# International Conference on Ion Sources 2025

Monday, 8 September 2025 - Friday, 12 September 2025

# Book of Abstracts

# Contents

Overview of the Heavy Ion Physics Programme at CERN –Current and Future Ion Source Requirements and Challenges . . . . 1

CW operation of high-current deuteron injector for the Linear IFMIF Prototype Accelerator (LIPAc) . . . . 1

The gasdynamic ECR ion source developed at IMP and its preliminary results . . . . 2

Beam extraction and transport for high current ribbon-beam ion implanters . . . . 2

Ion sources in medical isotope production - requirements, trends, and limitations . . . . 3

Ion source life and defect control for ion implanters used in semiconductor device manufacturing . . . . 3

Overview of ion sources for alternative fusion concepts . . . . 4

Role of NBI ion sources in achieving the world-record fusion power at JET . . . . 4

NBI for W7-X: A Four Operational Campaign Overview . . . . 5

Optimization of the large-area RF negative ion source for long-pulse and high-power operation on CRAFT NNBI test facility . . . . 6

Investigations on symmetrizing the plasma properties in the expansion region of large RF ion source via magnetic fields . . . . 6

Research on $He^-$ Ion Beam Generation Technology for Tandem Accelerators and Experimental Optimization . . . . 7

Design and Implementation of an Online Beam Current and Stability Monitor for the UMCG-PARTREC AECR Ion Source . . . . 7

Model Improvement for Isotope Effects in a Negative Ion Source Using KEIO-MARC and Rate Equation Model . . . . 8

First operational results of IRISC assessed via optical emission spectroscopy . . . . 8

Beam current characteristics of negative ion source on EVISS by C12A7 electride . . . . 9

Development of advanced electromagnetic PIC code for the study of RF negative ion sources . . . . 9

Investigating the Potential of an ECR Large-Area Plasma Source for Hydrogen Negative Ion Production in Fusion Applications . . . . 10

Overview of Cs evaporation control and monitoring in the ITER negative ion source prototype SPIDER . . . 10

Ion Source Characterization using Integrated Data Analysis . . . 11

Beam intensity prediction using machine learning and plasma images . . . 12

AI Tools for Plasma Diagnostics by X-ray Imaging and Spectroscopy in ECR plasmas . . 12

Simulation of the ALISES 3 Plasma Chamber . . . 13

Comparison of the RF power coupling efficiency for 1.0 and 1.7 MHz at BATMAN Upgrade . . . 13

Optical Emission Spectroscopy as non-invasive tool for beam stability monitoring at MedAustron Therapy Center . . . 14

A data driven Model of the Existing and Optimal Cs Delivery into the LANSCE $H^-$ Ion Source . . . 14

Recent advancements and hydrogen plasma experiments in RF based two driver negative ion source (Twin source) at IPR . . . 15

Positive Ion Source Technology Demonstration for DIII-D Neutral Beam Heating . . . . 15

Plasma characterization and technological application of a heater less hollow cathode plasma source with C-shape scanning device . . . 16

Towards NIO2, a 5 kW RF compact H- ion source . . . 17

Large scale discharge space for penning negative hydrogen ion source . . . 17

Modelling the spatial and temporal dynamics of Cs inside the BATMAN Upgrade source using the CsFlow3D code . . . 18

Production of negative helium ions via transmission through nano-foils . . . 19

Plasma parameter measurement during efficiently producing multicharged ions by selectively heating low-Z ions on Electron Cyclotron Resonance Ion Source in mixing low-Z gases . . . 19

Comparison of Performance Efficiency of Different Types of RF Antennas for Permanent Magnet-based Helicon Plasma Source via Finite Element Simulations . . . 20

Probing ECR Plasmas through Light: Spectroscopic Analysis of Hydrogen, Helium, and Neon Discharges . . . 20

Development of an Optical Diagnostics System for Arc Discharge Ion Sources . . . 21

Scintillating fiber and perovskite-based sensors for X-ray diagnostics on ECR plasmas . . 21

Vacuum Brazing Process for Large-Scale Grid Production for Negative Ion Source Application . . . 22

Development of a 120 kV high power ion source prototype for neutral beam injector . . 23

A compact 35 keV ECR proton ion source with advanced chopping for neutron source applications . . . 23

Diagnostics for characterization of neutral beams parameters at TCV . . . 24

Investigation of plasma transport through a neutral gas layer in a high-repetition-rate laser ion source. . . . 25

Emittance measurement of ion beam current in selectively heating low Z ions on electron cyclotron resonance ion source in mixing low Z gases . . . 25

Low-energy charged particle extraction from an RF-driven negative hydrogen ion source 26

On the pronounced increase of the co-extracted electron current during long pulses in H-/D- negative ion sources for fusion . . . 26

Development progress of negative beam source for the CRAFT NNBI . . . 27

Development and First Results from SupRISE: An RF-Driven Ion Source for Neutral Beam Injection . . . 28

Review of ion sources for charged particle radiotherapy - status, challenges and future trends . . . 28

Overview and performance of the MAST Upgrade Neutral Beam Injectors. . . . 29

Silvaco Exhibitor Talk . . . 29

Theoretical and numerical study of the ECRIPAC accelerator concept . . . 30

Space Charge Compensation in Negative Hydrogen Ion Beams: A Particle-In-Cell Study 30

Electron Cyclotron Resonance Supernanogan Ion Source Commissioning for the Sarajevo Ion Accelerator (SARAI) . . . 31

The role of ECR ion sources in superheavy element synthesis . . . 31

Development of key technologies for 4th generation ECR ion sources- microwave launching and innovative solutions for plasma chamber cooling . . . 32

FECR: A 28~45 GHz Next Generation Ion Source and Its First Results . . . 32

Prospects and challenges of the next generation highly-charged ECR ion source . . . 33

Diagnostic beam for ITER (INTF): Status and accompanying research . . . 33

Beam current performance in the ITER negative ion source prototype SPIDER . . . 34

Characterization of the properties of negative hydrogen ion beam of CRAFT NNBI test facility . . . 35

Investigating the origin of the pressure dependence on the beam divergence at an RF negative hydrogen ion source . . . 35

Overlap of Plasma and Beam Properties in ITER-Relevant Negative Ion Sources . . . 36

The effect of space-charge neutralization on charge breeding performance . . . 37

Advancements in the Antenna Based Miniaturized 2.45 GHz Permanent Magnet ECR Ion Source at Peking University . . . 37

Modeling and Operation of an Electromagnetic Isotope Separation System for Ytterbium-176 Production . . . 38

Developments towards autonomous optimisation and stabilisation of the CERN GTS-LHC ion source . . . 38

Basic Commissioning of the ELIMED Line: challenges in the selection and extraction of a laser-driven beam . . . 38

Development of HECRAL-C: A Cryogen-Free Hybrid Superconducting ECR Ion Source for Milliampere-Level $C^{4+}$ Ion Beam Production . . . 39

Current status of the cesiated RF-driven negative hydrogen ion source and its R&D activities for future facility projects at J-PARC . . . 39

Progress towards 28 GHz operations of ECR ion sources at the Facility for Rare Isotope Beams (FRIB) . . . 40

LAMP ion source commissioning and future plans . . . 40

Plasma Conditions for High-Intensity $He^{2+}$ Beams: A Semi-Empirical Modeling Approach . . . 41

Ion Sources for CRYRING@ESR . . . 41

Recent LANSCE efforts on improving H+ duoplasmatron capabilities . . . 42

Hot Liner for the Production of Metallic Ion Beams from an ECR at GSI . . . 42

Mixed carbon and helium ion beams for simultaneous heavy ion radiotherapy and radiography –recent advances and perspectives . . . 43

Solid state amplifier for a 2,45 GHz high intensity proton source . . . 43

Numerical Analysis of the Influence of Plasma Parameters on the 1+ Beam Capture in the ECR-based Charge Breeder . . . 44

Ion Beam Emittances of Intense Highly Charged Ion Production from the RIKEN 28GHz SC-ECRIS . . . 44

From ECR Ion Source to Electrostatic Thruster . . . 45

RF ion source of Hydrogen ions, . . . 45

Long-Lived Radioactive Beam Upgrade at TRIUMF-ISAC . . . 46

Magnetic field Investigations of the ATLAS ECR Ion Sources . . . 46

On the comprehensive characterization of the thermally optimized SPES Laser Ion Source 47

Intense Metallic Ion Production and Operation with Electron Cyclotron Resonance (ECR) Ion Sources at the Institute of Modern Physics . . . 47

Status and Development with CANREB at TRIUMF . . . 48

Progresses on compact carbon positive ion mass spectrometry (C-PIMS) at Peking University . . . 48

On-Line production of SnS radioactive ion beams with the ISOL technique . . . 49

ELIMAIA-ELIMED beamline –a new opportunity for radiobiological research with laser-driven protons . . . 50

First commissioning results of the MIST-2 ion source for the High-Current H2+ Cyclotron HCHC-XX . . . 50

Bremsstrahlung Heat load Scaling Measurements for Future ECRIS Cryostat . . . 51

Beams production optimisation on ECR4/4M ion sources at GANIL cyclotrons facility . . 51

The development of the ion source and target for BRISOL facility . . . 52

Proof-of-Principle Microwave Plasma Cathode Source toward Negative Ion Production . 52

Investigation of an Internal Antenna Design for an RF ion source . . . 53

Recent progress with Diagnostic Neutral Beam at TCV tokamak . . . 53

Thermal and plasma modeling of a hot cavity ion source for radioactive ion beam production at ISOL@MYRRHA . . . 54

Development of deuterium-deuterium compact neutron source . . . 55

The effect of gas mixing on the afterglow transient of beams extracted from an electron cyclotron resonance ion source . . . 55

The target-ion source system for the SPES facility commissioning: design, development and online testing . . . 56

Developments for Target-Ion-Sources at TRIUMF towards the ARIEL era . . . 57

Performance of the Brillouin Electron Gun at the TwinEBIS Test Bench . . . 57

Prodigy Exhibitor Talk . . . 58

Reimagining FEBIAD Ion Sources: From Design Innovation to Performance Optimization 58

Towards a high-throughput laser ion source for CERN-MEDICIS . . . 59

Plasma diagnostics of charge breeder ECR ion sources . . . 59

Closed Shell Charge Breeding of Radioactive Fission Products with an Electron Beam Ion Source . . . 60

Design of a hollow hexapole applicable to ECR charge breeder to mitigate the plasma contamination by sputtering . . . 60

Radioactive ion beam development at SPIRAL1-GANIL: recent progress and future developments . . . 61

Experimental investigation on ECR ion source plasma towards more intense highly charged ion beam production . . . 61

High Resolution Optical Emission Spectroscopic Study of the ECR Plasma in the GTS-LHC Ion Source . . . 62

Brightness Award Presentation . . . 62

Conversion of a positive ion into a negative ion and a neutral atom: formation processes from a few keV to MeV energies . . . 62

Implementation of a temperature and density monitoring diagnostic for the LANSCE negative ion source . . . 63

Beam optics analysis by visible cameras applied for the first time to a large-scale multi-beamlet configuration in the ITER prototype source . . . 64

ES-PIC simulation of volume- and surface-produced H- ion trajectories . . . 64

Influence of microwave parameters on the afterglow beam . . . 65

Broadband electron gun design for a 5T solenoid EBIS for cancer therapy accelerators . . . 65

Investigation into Transient Processes in Electron Cyclotron Resonance . . . 66

Extraction and emittance characterization of high-intensity ion beams from a laser ion source . . . 66

Directional Control of Ablation Plasma in a Laser Ion Source Using a Permanent Magnet 67

Operation and Optimization of a Negative Hydrogen Ion Source for BNCT Applications 67

A Penning Ion Source for Stable Isotope Beam Production at TRIUMF-OLIS . . . 68

Numerical Investigations of Coulomb Collisions and Energy Conservation in a Particle-in-Cell Model for Ion Source Applications . . . 68

Numerical Validation of a New Extraction System for the ECR Source LEGIS at INFN-Legnaro National Laboratories . . . 69

First experimental evaluation of the Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source for the RAON ISOL system . . . 70

Outcomes and Perspectives Arising from Particle-in-Cell Simulation of ECR Ion Sources 70

Integrated Design, Simulation, and Fabrication of a PIG Ion Source Accelerator for Functional Materials Research . . . 71

Beam dynamics calculations of the ADIGE injector for the SPES Project . . . 71

A Tunable Permanent Magnet Quadrupole with Openable Design for In-Situ Installation 72

Impedance Characteristics and Sputtering Behaviour of Two Pulsed DC Arc Discharge H-Sources . . . 73

Commissioning status of a combined RFQ Cooler with axial magnetic field in the Eltrap machine . . . 73

Overview of Ion Beam Delivery Program at Avalanche Energy . . . 74

Decelerating beamline design of an ECR ion source at Avalanche Energy . . . . . . . . . 74

Comparative Study of CW and Pulsed 13 MHz vs 27 MHz RF Plasma Ignition Systems for H- Ion Source Operation at SNS . . . . . . . . . . . . . . . . . . . . . . . . . . . . 75

Status of ECR ion source at RAON . . . . . . . . . . . . . . . . . . . . . . . . . . . . 75

Beam energy spread of a filament-type Penning Ionization Gauge Ion Source for a compact ion microbeam system . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 76

ASTERICS ion beam extraction : system optimization by simulation . . . . . . . . . . . . 76

The effect of the oscillation of plasma parameters on the beam extraction in RF negative ion source . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 77

Experimental Validation of a Double-Gridded Lens System for High-Frequency RFQ Injection . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 78

Space Charge Modeling for Negative Ion Beam Transport: A PIC Study . . . . . . . . . . 78

Modeling of 1D DC Discharges Using Various Particle-in-Cell Schemes . . . . . . . . . . 79

Design of a Permanent Magnet System for the Production of Closed Resonance Surfaces in Microwave Discharge Ion Sources . . . . . . . . . . . . . . . . . . . . . . . . . . . 79

Stationary Transverse Striations in Medium-Energy, High-Current Ion Beams . . . . . . 80

Ultra-low work function surfaces for $H^-/D^-$ ion sources . . . . . . . . . . . . . . . . . 80

Application and Effects of Introducing Low Frequency Electromagnetic Waves in Electron Cyclotron Resonance Ion Source . . . . . . . . . . . . . . . . . . . . . . . . . . . . 81

Numerical design and experimental characterization of an innovative, 3D-printed, 'plasma-shaped'cavity for ECR Ion Sources . . . . . . . . . . . . . . . . . . . . . . . . . . 82

The high-energy tail of the EEDF and its impact on $H^-$ volume ion sources . . . . . . . . 82

X-ray imaging and spectroscopy of space- and time-dependent phenomena in ECRISs to investigate fundamental plasma processes . . . . . . . . . . . . . . . . . . . . . . . . 83

Superconducting magnet structures and developments for 4th Generation ECR ion sources . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 84

BNCT ECR Discharge Chamber Low SWR Design and Beam Experiments . . . . . . . . 84

PIBHI 2025 workshop: open mind discussions on ECR ion sources . . . . . . . . . . . . . 85

Negative ion sources for accelerators - status and future prospects . . . . . . . . . . . . 86

Medium to high Z-ion beams from laser-plasma interactions . . . . . . . . . . . . . . . 86

The High Intensity Polarized Proton Source . . . . . . . . . . . . . . . . . . . . . . . . 87

Optimization for RF-driven H- source and low energy beam transport for CSNS-II . . . . 87

Advancing H- injector beam intensity frontier at high duty-factor for multi-megawatt proton accelerators . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88

Opening Remarks . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88

Wisman Exhibitor Talk . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 88

**Oral Session / 32**

## Overview of the Heavy Ion Physics Programme at CERN –Current and Future Ion Source Requirements and Challenges

**Author:** Detlef Küchler[1]

**Co-authors:** Reyes Alemany Fernández [1]; Giulia Bellodi [1]; Bichu Bhaskar [1]; Edgar Mahner [1]; Richard Scrivens [1]; Maciej Slupecki [1]

[1] *CERN*

**Corresponding Author:** detlef.kuchler@cern.ch

CERN has a long history of providing different types of ion beams for high-energy physics, both with fixed targets and in the LHC. Over the years, the user community was growing, and the range of requested beam types and species continued to expand. Especially in the last couple of years a Future Ions Working Group was established at CERN and tasked with collecting all the requests, identifying synergies and making proposals for future upgrades and operation plans of the CERN ion accelerator complex.

This paper provides a brief overview of the status of the present requirements, limitations and possible solutions for the CERN ion source and low-energy beam line including results from tests with magnesium, krypton and oxygen beams.

**Oral Session / 34**

## CW operation of high-current deuteron injector for the Linear IFMIF Prototype Accelerator (LIPAc)

**Author:** Tomoya Akagi[1]

**Co-authors:** Benoît Bolzon [2]; Fabio Cismondi [3]; Hervé Dzitko [3]; Kai Masuda [1]; Keitaro Kondo [1]; Nicolas Chauvin [2]; Pau González Caminal [4]; Tomonobu Itagaki [1]; Toshihiko Kitano [1]; Yann Carin [5]

[1] *QST*

[2] *CEA*

[3] *Fusion for Energy*

[4] *ATG Science & Engineering, S.L.*

[5] *IFMIF/EVEDA Project Team*

**Corresponding Author:** akagi.tomoya@qst.go.jp

The Linear IFMIF (International Fusion Materials Irradiation Facility) Prototype Accelerator (LIPAc) aims at validating the design of the low energy section of the 40 MeV/125 mA IFMIF deuteron accelerator up to 9 MeV in continuous-wave (CW) operation. For such a high-power deuteron accelerator, the LIPAc injector is required to provide a stable deuteron beam of 100 keV, 140 mA with low emittance ($\leq$0.25 $\pi$ mm mrad). The injector is composed of an ECR ion source based on the CEA-Saclay SILHI source and a Low Energy Beam Transport (LEBT) line. In June 2024, the commissioning of the LIPAc accelerator was completed with the acceleration and transport of a 5 MeV deuteron beam at 9% duty cycle up to the beam dump, marking the completion of Phase B+. During this phase, the injector delivered a beam that met the LIPAc requirements and achieved the acceleration of a 120-mA deuteron beam (corresponding to an extracted current from the source of 160 mA) with a RFQ transmission exceeding 90%. Afterwards, in preparation for future phases, the LIPAc team proceeded with the CW beam commissioning of the injector in stand-alone operation, achieving a long run of 24 hours of CW operation with a total extracted beam current of 150 mA. This paper presents the results of the most recent CW injector campaign and provides an update on the ongoing assessment of the ion source's critical components and their expected lifetimes.

**Oral Session / 137**

## The gasdynamic ECR ion source developed at IMP and its preliminary results

**Author:** Huanyu Zhao[1]

**Co-authors:** Hongwei Zhao [1]; Jindou Ma [1]; Liangting Sun [1]; Libin Li [1]; Luting Lu [1]; Peng Zhang [1]; Yuguo Liu [1]

[1] *The Institute of Modern Physics, Chinese Academy of Sciences*

**Corresponding Author:** zhaohy@impcas.ac.cn

Driven by the increasing demands on high-intensity heavy ion beams, next-generation acceleration facilities require unprecedented beam intensities from the front-ends, such as High Intensity Heavy-io Accelerator Facility (HIAF) constructed in China. The future upgrade of HIAF requires its injector to deliver over 50 pμA U beams with a charge state beyond 40, which is far beyond the capability of state-of-the-art ECR ion sources, the present pre-injectors of the HIAF. As an alternative solution, it was proposed to pre-accelerate tens of emA ion beams with low-to-medium charge states produced by a gasdynamic ECR ion source, and then to strip them to the higher charge states. As the first step to investigate this scheme, a 45 GHz gasdynamic ion source which operates in pulsed mode has been developed. Electron temperature diagnostic has been performed by measuring the energy distribution of the lost electrons and fitting it with the integral of the Maxwell electron energy distribution function. First beams have been extracted to demonstrate its potential of intensive beam formation.

**Oral Session / 127**

## Beam extraction and transport for high current ribbon-beam ion implanters

**Author:** Alexander Perel[1]

[1] *Applied Materials, Inc.*

**Corresponding Author:** alexander_perel@amat.com

High current ion implanters for semiconductor manufacturing are primarily used for doping and amorphization of source and drain regions of devices on silicon wafers. Most often this is done with a spot beam that is scanned across the wafer as the wafer moves up and down. Applied Materials does it with a ribbon beam that allows for greater dose rate on the wafer. With this architecture comes the added hurdle of meeting customer requirements of high dose uniformity across a 300 mm wafer.

This requires extracting tens of milliamps from a 4 cm2 slit and implanting the wafer with a parallel ribbon beam that is uniform in current across the wafer to better than 1%. The shape of the extracted and transported beam is associated with the meniscus at the plasma boundary. Tuning the shape is done with adjustments to the plasma conditions and extraction settings. We discuss some of the challenges and achievements with meeting these requirements.

The magnetized ion source can create fluctuations in the extracted beam current and affect the transmission of the beam through the implanter beamline. Plasma rotations in the ion source caused by an ExB force, affects the extracted beam current amplitude, resulting in an ion beam that pulsates with a frequency in the range of 100 kHz. The creation and transmission of this cyclic behavior is discussed.

Finally, we discuss the concept of a digital twin for ion implanters. Customer requirements for the beam characteristics at the wafer necessitate the tuning of multiple optical components along the beamline. Integrating all these components in a digital twin model enhances the user experience in understanding the multiple steps of an ion implanter.

**Oral Session / 170**

## Ion sources in medical isotope production - requirements, trends, and limitations

**Author:** Allan Jarvine[None]

**Corresponding Author:** allan.jarvine@kinectrics.com

Since the 1940s, when radioactive iodine was first used to treat hyperthyroidism and later thyroid cancer, the field of nuclear medicine has grown substantially, benefiting tremendously from technological advancements in physics, chemistry, and biology, as well as an increased understanding of disease mechanisms and immunology. From the early days of the cyclotron for radioisotope production and external beam radiation therapy to the discovery of the world's most commonly used radioisotope, metastable technetium-99m, for diagnostic imaging via gamma cameras, medical isotopes have played a significant role in disease diagnosis and treatment. This role became even more prominent with the development of Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET)—technologies that enhanced disease diagnosis and treatment, advanced knowledge of metabolic activity, and ultimately led to significant progress in the following decades with the introduction of targeted cancer therapies such as radioimmunotherapy and radiopharmaceutical therapy. Radiopharmaceutical therapy, in particular, is one of the most exciting and promising developments, offering the ability to administer highly tailored and localised radiation to specific cancer cells or tumour microenvironments while minimising damage to surrounding cells and organs-at-risk. While several key components make up a radiopharmaceutical and ultimately govern its success, the type of emitted radiation and the amount of energy transferred to surrounding material per unit distance are crucial to the treatment's efficacy. Radiopharmaceuticals labelled with the radioisotope lutetium-177—a beta (electron) emitter—have received widespread attention and obtained regulatory approval in the USA, Canada, and Europe for the treatment of neuroendocrine tumours and metastatic prostate cancer. Additionally, interest in expanding the application of lutetium-177-labelled radiopharmaceuticals to the treatment of other types of cancer continues to drive growing demand for this radioisotope. Among other beta emitters used in radiopharmaceutical therapy, terbium-161 is emerging as an attractive alternative to lutetium-177. Both lutetium-177 and terbium-161 are produced through neutron irradiation in a reactor, but their target materials and production pathways differ. A preferred pathway for lutetium-177 production involves the enrichment of stable ytterbium-176 isotope targets. These targets are subsequently neutron irradiated to produce ytterbium-177, which undergoes beta decay to form non-carrier-added lutetium-177. For terbium-161, enriched stable gadolinium-160 targets can be neutron irradiated to produce gadolinium-161, which subsequently decays to terbium-161. For both of these radioisotopes, enriched stable isotope targets can be produced via conventional electromagnetic isotope separation, provided a suitable ion source is paired with an appropriate electromagnet. Achieving the desired production, enrichment, and isotopic purity requirements is not trivial, however. This talk will discuss the experience at Kinectrics Canada in the production of highly enriched, chemically pure ytterbium-176 targets, with specific emphasis on ion beam generation, transport, and separation.

**Oral Session / 59**

## Ion source life and defect control for ion implanters used in semiconductor device manufacturing

**Author:** TSEH-JEN HSIEH[1]

[1] *APPLIED MATERIALS-VARIAN SEMICONDUCTOR EQUIPMENT(ION IMPLANTATION)*

**Corresponding Author:** tsehjen_hsieh@amat.com

Semiconductor device manufacturing involves a complex series of processes on silicon wafers. Implanting ions for transistor doping or surface modification is performed at ion energies from sub-keV to a few MeV and require ion currents ~ uA to 100 mA. This wide range requires a broad set of implanter tool types. Across that range are requirements that the ion source has 400 hours of life and

up-time is greater than 90%. The ion beam transport across analyzing magnets, parallelizing magnets, and quadrupoles assure high ion beam quality.
We review the ion sources that are utilized in wafer processing with ion implanters. The variety of implant species used on a single implanter demand that the ion source tolerate gaseous molecules of fluorides, hydrides, oxides, chlorides, and iodides [1-3]. Stable and uniform ion beam current, long source life, low beam arcing (<10/hr), and short species transition time are important and competitive metrics for implanters.
Though high mass resolution in analyzer magnets separate contaminant ions from the intended ion beam before impacting the wafer, sputtering, residual gas charge exchange with ions, and other harmful effects, can create particles that land on the wafer. Defects on wafer are detrimental on advanced nodes and imaging sensors directly impact the device yield as shown in Fig.1. The defects specification for 45nm node of was < 50 adders @45nm size to 5nm node < 9 adders @ 32nm to 2nm node of < 2 adders @ 26 nm size. Aggressive mitigation techniques are necessary to maximize wafer device yields.

Ref :
[1]: Tseh-Jen Hsieh, Et al, Enhanced Life Ion Source for Germanium & Carbon, Ion Implantation Tech (IIT) Conf, Nov.2012
[2]: Tseh-Jen Hsieh, Et al, Improved ion source stability using H2 co-gas for fluoride-based dopants, IIT Conf, Oct 2014
[3]: Tseh-Jen Hsieh, Et al, Exemplary Ion Source for the Implanting of Halogen and Oxygen Based Dopant Gases, IIT Conf, Sept. 2016

**Oral Session / 62**

## Overview of ion sources for alternative fusion concepts

**Authors:** Rob Welton[1]; Robin Langtry[2]; Samantha Valenteen[2]; Scott Schipmann[2]; Shadrach Hepner[2]; Siamak Rahmanian[2]

[1] *Oak Ridge National Laboratory*
[2] *Avalanche Energy*

**Corresponding Author:** shepner@avalanche.energy

Many common nuclear fusion concepts actively being investigated rely on particle injection from ion sources. While many of these sources have been developed in publicly funded laboratories, we have seen a rapidly growing interest from the private sector in recent years, with the number of private fusion companies more than doubling in the last 6 years alone. With this growing interest, a multitude of novel concepts have emerged to increase fusion rates, whether for neutron production or net energy generation. Several of these concepts rely on injecting ions into their systems.

Each company maintains their own requirements for ion beams. Their systems include differing ionization schemes, acceleration techniques, and pumping requirements. This work focuses on four different concepts. The first two, similar to more frequently discussed systems like ITER, implement neutral beam injection (NBI) to add energy to a plasma. In the magnetic mirror geometry of the Wisconsin HTS axisymmetric mirror, NBI thermally heats the plasma directly. In the field-reversed configuration plasmas generated by Helion, where rotated, pulsed magnetic field generates a high energy plasmoid, energy input from NBI is meant in part to nullify instabilities arising in the plasma.

Alternatively, beams are being used to fuse directly. The beam-target fusion of SHINE Technologies bombards a small tritium target with a high energy deuterium beam as a neutron generator. Finally, the inertial electrostatic confinement concept known as the Orbitron being developed at Avalanche Energy injects an ion beam into an azimuthally symmetric electrostatic well, where ions in stable orbits can collide at over 100 keV energies. This work presents an overview of these fusion concepts and discusses the ion beam generation architectures in each.

**Oral Session / 42**

# Role of NBI ion sources in achieving the world-record fusion power at JET

**Author:** damian king[1]

**Co-authors:** Alan Barth [1]; Alastair Shepherd [1]; Andrew Ash [1]; Ben Woods [1]; Chris Balshaw [1]; David Keeling [1]; Dragoslav Ciric [1]; Gavin Withenshaw [1]; Hana El-Haroun [1]; Ian Day [1]; Kieron Deakin [1]; Maria Nicassio [1]; Martyn Walsh [1]; Ridhima Sharma [1]; Robert King [1]; Roy McAdams [1]; Stephen Marsden [1]; TTC Jones [1]; Thomas Wilson [1]; Tim Robinson [1]

[1] *UKAEA*

**Corresponding Author:** damian.king@ukaea.uk

The Joint European Torus (JET) completed its extraordinary experimental lifetime in December 2023. JET had the unique capability to operate with tritium and exploited this to complete deuterium-tritium (D-T) experiments in both 2021 and 2023.
These experimental campaigns, known as DTE2 and DTE3, broke the world record fusion energy record, achieving 59MJ and 69MJ respectively. Further to the record, a large experimental programme in D-T provided a wealth of data in both physics and technology.
High input power to the tokamak plasma was required to reach the plasma temperatures relevant for D-T fusion reactions. The majority of this power was provided by the Neutral Beam Injection (NBI) system. NBI is a flexible auxiliary heating method for tokamak plasmas, capable of being efficiently coupled to the various plasma configurations. NBI was first used on JET in 1986 and is composed of 16 ion sources on two separate beamlines. Following a series of upgrades to the ion sources and beamlines it was possible to achieve >32MW of power to the plasma in either deuterium or tritium.
The development and operational experience of increasing the power delivered by the JET NBI ion sources to the level required to achieve this fusion record across the 2021 and 2023 JET D-T experiments are explored in this contribution.

**Oral Session / 43**

# NBI for W7-X: A Four Operational Campaign Overview

**Author:** Paul McNeely[1]

**Co-authors:** Dirk Hartmann [1]; Norbert Rust [1]

[1] *Max-Planck-Institut für Plasmaphysik*

**Corresponding Author:** paul.mcneely@ipp.mpg.de

The Stellarator Wendelstein 7-X (W7-X) used neutral beam injection (NBI) for plasma heating in the last four experimental campaigns (called OP1.2b, OP2.1, OP2.2, and OP2.3). In OP1.2b was the initial operation of the first injector box with two sources. In OP2.1 the second injector box with two sources was brought into operation. In OP2.2 and OP2.3 both boxes were used routinely for experiments. In OP2.3 the operation of one source in Helium for injection into W7-X was tested. The NBI system uses inductively coupled RF driven ion sources operating in Hydrogen. The sources operate for 5 seconds at 55 keV with a current of 90 A, and achieve ~2 MW of neutral beam power at the calorimeter. The paper will first focus on the ion sources and detail their operation over the four campaigns with their fixed frequency solid state RF amplifiers. The focus of the paper will then

shift to the topic of the un-expected. Over the campaigns there have been un-anticipated events or results that are worthy of note. These include: pulse length limitation due to ion dump overheating, a sudden change in the required capacitance for source ignition, damage to the source Faraday screens, W7-X magnetic field effects, an enhancement in neutralization efficiency, and observation of beam influence on the bending magnet. For each of these topics the reason, when known, will be given followed by what was done to mitigate the effect, if this was necessary.

**Oral Session / 44**

# Optimization of the large-area RF negative ion source for long-pulse and high-power operation on CRAFT NNBI test facility

**Authors:** Yuwen Yang[1]; Jianglong Wei[1]; Lizhen Liang[1]; yahong xie[1]; Chundong Hu[1]

[1] *ASIPP*

**Corresponding Author:** yuwen.yang@ipp.ac.cn

To explore the key technology of negative-ion-based neutral beam injection (NNBI), a NNBI test facility is under construction in the frameworks of the Comprehensive Research Facility for Fusion Technology (CRAFT). During the second experimental campaign of the CRAFT NNBI test facility, the 100 seconds and megawatt-class negative hydrogen beams have been repeatably achieved via a dual-driver RF negative ion source. The parameters of the best long-pulse shot were 135 keV, 10.6 A (~ 180 A/m2), 110 s. When pursuing a long-pulse shot with higher power (>2 MW), the leading-edge element of the neutralizer was damaged and lead to serious water leaking. In addition, during the disassembly and maintenance, some obvious heating erosions were found on the supporting frame of ground grid electrode. Hence, a multi-physics coupling model has been upgraded to study the acceleration of negative ions within the full-size extraction system, including the particle-gas and particle-solid interaction. The simulation results showed that, the over-focusing of multi-beamlet was the main reason of the damage on the downstream neutralizer, and the erosions on the supporting frame without cooling were consistent with the hot spots induced by the stray secondary electrons. Accordingly, the optimizations on the field shaping plate and the electron deflection magnetic field were proposed and estimated, which will be tested in the following experimental campaign.

**Oral Session / 124**

# Investigations on symmetrizing the plasma properties in the expansion region of large RF ion source via magnetic fields

**Author:** Dimitar Yordanov[None]

**Co-authors:** Christian Wimmer [1]; Dirk Wünderlich [1]; Ursel Fantz [1]

[1] *Max Planck Institute for Plasma Physics*

**Corresponding Author:** dimitar.yordanov@ipp.mpg.de

The ITER NBI system will rely on the neutralization of accelerated hydrogen/deuterium negative ion beams, extracted from a plasma ion. A radio-frequency (RF) current with 1 MHz excites cylindrical coils, which generate the discharge in eight quartz cylinders, called drivers, and it expands into a bigger metallic chamber equipped with an extraction system. The negative ions are extracted inevitably with electrons. A magnetic filter field applied for cooling down the plasma to ≈1 eV reduces the co-extracted electrons. Side-effect of the filter are ×B drifts, resulting in a vertical plasma inhomogeneity which can affect the co-extracted electrons and limit the source performance.
Inspired by the experimental investigations at the test Facility ROBIN [1] the influence of the magnetic field configuration on the vertical plasma uniformity is modelled by a fluid model on the similar

ion source BATMAN Upgrade. The model is fully time-dependent 2D with self-consistent coupling of the coil's RF electromagnetic fields with the plasma. The study aims to investigate the effect of different profiles of the magnetic filter field on the plasma parameters in the expansion and the collected currents on the first grid of the extraction system –the plasma grid (PG). Different topologies of the magnetic field are studied: profile similar to standard BUG operation, created by high current flowing through the PG (IPG), profiles with different configurations of permanent magnets attached to the ion source side walls and superposition of IPG with permanent magnets. The results show the plasma properties in vertical direction can be symmetrize as a superposition of IPG filter field with permanent magnets acting as weakening magnetic field in the region of the higher plasma density. In this case the collected electron current on the PG has the lowest value, which could benefit on lower co-extracted electrons.
[1] K. Pandya et al Rev. Sci. Instrum. 96, 043309 (2025)

**Poster Session / 60**

## Research on $He^-$ Ion Beam Generation Technology for Tandem Accelerators and Experimental Optimization

**Authors:** 兵唐[1]; 立华陈[1]; 荀王[1]

[1] 中国原子能科学研究院

**Corresponding Author:** 1392634454@qq.com

To address the negative ion injection requirements of tandem accelerators, this study proposes a $He^-$ ion beam generation technology based on a dual charge-exchange mechanism. Given the technical bottleneck caused by the negative electron affinity of ground-state helium atoms, which prevents direct $He^-$ ion production, an innovative cascade charge-exchange pathway ($He^+ \longrightarrow He^0 \longrightarrow He^-$) is adopted. A self-designed metallic cesium vapor charge-exchange cell is developed, incorporating a thermal equilibrium temperature field model to optimize the operational temperature range, thereby ensuring stable cesium vapor density and enabling long-term stable operation of the charge-exchange medium. Experimental validation was conducted at the Ion Source Experimental Platform of the China Institute of Atomic Energy. This research provides a reliable solution for generating MeV-level He ion beams in tandem accelerators, and the parameter optimization methodology holds universal reference value for heavy-element negative ion beam production.

**Poster Session / 37**

## Design and Implementation of an Online Beam Current and Stability Monitor for the UMCG-PARTREC AECR Ion Source

**Author:** Herman Kremers[1]

**Co-authors:** Alexander Gerbershagen [2]; Shariq Khan [1]

[1] *University of Groningen*

[2] *UMCG - PARTREC*

**Corresponding Author:** h.r.kremers@umcg.nl

At UMCG-PARTREC, formerly known as the KVI institute, a beam intensity and stability monitor has been developed for the AECR ion source setup. This monitor measures a small fraction of the analyzed beam current parasitically, utilizing inherent beam aberrations. The beam current and its stability are presented to the user via a LabVIEW Graphical User Interface (GUI), which also displays plasma and ion-optical variables. The GUI is designed to facilitate the easy correlation of beam fluctuations with plasma fluctuations or with beam optical changes in the analyzing section. Additionally, this GUI has been integrated into the main control system and is actively used by

operators of the superconducting cyclotron AGOR. This tool is particularly beneficial for operators, providing continuous online beam current monitoring throughout the beam development process. The present article details the construction of the monitor device, including its wiring, sampling, and analysis processes. Also, it covers the GUI and provides an outlook on potential applications of this tool.

**Poster Session / 46**

## Model Improvement for Isotope Effects in a Negative Ion Source Using KEIO-MARC and Rate Equation Model

**Author:** Hayato Soejima[1]

**Co-authors:** Takanori Shibata [2]; Haruhisa Nakano [3]; Katsuya Hayashi [4]; Kenji Miyamoto [5]; Kazuo Hoshino [4]

[1] *Keio-University*

[2] *KEK*

[3] *National Institute for Fusion Science, National Institutes of Natural Sciences*

[4] *Keio University*

[5] *Naruto University of Education*

**Corresponding Author:** hayato0614s@keio.jp

In the Research and Development Negative Ion Source (RNIS) at the National Institute for Fusion Science (NIFS), it has been reported that the electron density increases by approximately three times when changing the operation gas from hydrogen to deuterium [1].

In the previous studies, analyses were carried out using a three-dimensional kinetic electron transport code KEIO-MARC and a rate equation code 0D model to understand the hydrogen isotope effects [2]. The simulation showed that the electron density in the deuterium case was 1.61 times larger than in the hydrogen case, due to differences in vibrationally excited states of molecules and the sheath potential. However, the simulation results did not fully explain the discrepancy of electron density observed in the hydrogen and deuterium experiments.

In this study, to analyze the isotope effects in more detail, the numerical model has been improved in the following points: (1) the recombination process of protons is introduced into KEIO-MARC to solve the behavior of low energy electrons more precisely in the simulation. As the loss of low energy electrons is enhanced by the recombination process, the electron temperature is expected to increase. (2) The confinement time estimated in the KEIO-MARC is substituted into the 0D model to ensure consistency in the electron transport loss between the two codes. In addition, the 0D model is more closely coupled with KEIO-MARC for improved self-consistency.

In the presentation, impacts of these model improvements on results will be discussed in detail. In addition, the influence of arc current on hydrogen isotope effects will also be discussed. It is expected that increasing the arc current enhances the dissociation of molecules, resulting in a suppression of isotope effects in molecular processes.
[1]H. Nakano, et al., J. J. Appl. Phys. 59, SHHC09 (2020).
[2] K. Iwanaka, et al., 20th International Conference on Ion Source, Victoria Canada, 2023.

**Poster Session / 58**

## First operational results of IRISC assessed via optical emission spectroscopy

**Author:** Miguel León López[1]

**Co-authors:** Antonio Estévez Fornari [1]; Concepción Oliver Amorós [1]; Daniel Gavela Pérez [1]; Fernando Toral Fernández [1]; José Manuel Pérez Morales [1]; Pedro Calvo Portela [1]; Ángel Rodríguez Páramo [1]

[1] *CIEMAT*

**Corresponding Author:** miguel.leon@externos.ciemat.es

Internal Radio-frequency Ion Source for Cyclotrons (IRISC) is a 2.45 GHz internal $H^-$ ion source designed for compact cyclotron applications. During its initial operational campaign, optical emission spectroscopy (OES) was employed to investigate the influence of key operational parameters — specifically, RF power and gas flow rate —on the generated plasma. Spectral analysis focused on the Balmer series emission lines and the Fulcher-α molecular band. The experimental results exhibit a clear correlation between operational parameters and spectral emission characteristics, demonstrating the suitability of the OES system for obtaining preliminary estimates of plasma parameters in IRISC.

**Poster Session / 55**

## Beam current characteristics of negative ion source on EVISS by C12A7 electride

**Authors:** Haruhisa Nakano[1]; Kohki Hoshino[2]; Mamiko Sasao[3]; Motoi Wada[3]; Takaaki Ishikawa[2]

[1] *National Institute for Fusion Science, National Institutes of Natural Sciences*

[2] *Nagoya University*

[3] *Doshisha University*

**Corresponding Author:** nakano.haruhisa@nifs.ac.jp

C12A7 electride, a low work function material, is one of the candidate materials of the plasma grid for a cesium-free negative ion source. The enhancement of the negative ion current was demonstrated using a negative ion source with an ion source plasma discharge power of tens of watts [1]. Toward the fusion and accelerator applications, the C12A7 electrode was applied to a negative ion source with kW-class discharge power on Equipment with Versatility for Ion Source Study (EVISS). Comparing the ion beam using the plasma grid made of aluminum as reference material, the beam current increased by 70 % using the C12A7 electride where the discharge power of the induced coupling plasma was 1 kW in 0.5 Pa hydrogen gas pressure, the extraction voltage was 0.7 kV, and the acceleration voltage was 9.8 kV.

**Poster Session / 69**

## Development of advanced electromagnetic PIC code for the study of RF negative ion sources

**Author:** Kenji Miyamoto[1]

**Co-authors:** Haruhisa Nakano [2]; Kazuo Hoshino [3]; Takanori Shibata [4]

[1] *Naruto University of Education*

[2] *National Institute for Fusion Science, National Institutes of Natural Sciences*

[3] *Keio University*

[4] *KEK*

**Corresponding Author:** kmiyamot@naruto-u.ac.jp

In the operations of the Radio Frequency (RF) negative hydrogen ion sources, temporal oscillation of the H- ion beam has been a significant issue in the particle accelerator or the fusion applications from a viewpoint of the beam optics. Especially, it is pointed out that temporal oscillation of the plasma meniscus may degrade the beam optics. In order to clarify the underlying physics and settle the issue, we are developing the integrated model of RF inductively coupled H- source plasma, beam extraction, and acceleration with three-dimensional particle-in-cell (PIC) method. In this numerical model, not only electromagnetic field but also electrostatic field are obtained by solving Maxwell and Poisson equations. Thus, the plasma meniscus can be solved self-consistently in the simulation. The details will be shown in the conference.

**Poster Session / 79**

## Investigating the Potential of an ECR Large-Area Plasma Source for Hydrogen Negative Ion Production in Fusion Applications

**Author:** Bibekananda Naik[1]

**Co-authors:** Ramesh Narayanan [2]; Debaprasad Sahu [2]; Mainak Bandyopadhyay [3]; Ashish Ganguli [2]

[1] *Ph. D. Scholar, Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India*

[2] *Indian Institute of Technology Delhi, Hauz Khas, New Delhi, India*

[3] *INSTITUTE FOR PLASMA RESEARCH*

**Corresponding Author:** bibekanandanaik74@gmail.com

$H^-$ ions play a crucial role in hydrogen plasmas, with important applications in plasma-based material processing, accelerator technology, and, most notably, thermonuclear fusion. In fusion research, $H^-$ ions are indispensable for plasma heating and current drive in magnetically confined fusion devices. Currently, most $H^-$ ion sources employed in fusion rely on inductively coupled plasma (ICP) systems driven by radio frequency (RF) power at levels ~ 1 MW. Electron cyclotron resonance (ECR) presents a more efficient alternative, but its potential in large-area, high-current ion sources remains insufficiently explored. This study investigates an ECR-based, large-volume plasma system with a focus on enhancing the volume production of $H^-$ ions. Experiments were conducted in a cylindrical expansion chamber, called the ECR-based Large Negative Ion Beam Source (ELNIBS), measuring ~ 1 meter in height and diameter. Plasma was generated using a compact ECR plasma source (CEPS) mounted on the chamber's top dome. The source's magnetic field decayed exponentially into the expansion chamber, facilitating plasma spread. To further reduce plasma losses to the chamber walls, a set of three-dimensional magnetic fields was superimposed using permanent ring magnets placed around the periphery of the expansion region. Plasma characterization was performed under varying microwave power inputs (400–600 W) and gas pressures (1–3 mTorr). Axial and radial Langmuir probes were used to measure key plasma parameters, while both positive and negative ions were detected using a low-pressure plasma sampling (PSM) probe attached to a Hiden HPR-60 quadrupole molecular beam mass spectrometer (MBMS). The results demonstrated the formation of a uniform plasma with an electron density ne ~ 10^11 cm−3 and a low electron temperature Te ~ 1 eV. These plasma conditions are conducive to the volume production of $H^-$ ions, which were successfully identified through MBMS measurements.

**Poster Session / 84**

## Overview of Cs evaporation control and monitoring in the ITER negative ion source prototype SPIDER

**Author:** Basile Pouradier Duteil[1]

**Co-authors:** Alastair Shepherd [2]; Antonio Pimazzoni [3]; Barbara Zaniol [3]; Emanuele Sartori [4]; Fabio Veronese [3]; Gianluigi Serianni [5]; Isabella Mario [3]; Michele Fadone [5]; Riccardo Casagrande [3]

[1] *CEA, IRFM, F-13108 St. Paul lez Durance, France*

[2] *UKAEA (United Kingdom Atomic Energy Authority), Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, United Kingdom of Great Britain and Northern Ireland*

[3] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete S.p.A.), Corso Stati Uniti 4, 35127 Padova, Italy*

[4] *Department of Management and Engineering, Università degli Studi di Padova, Strad. S. Nicola 3, 36100 Vicenza, Italy*

[5] *Institute for Plasma Science and Technology of the Italian National Research Institute, Corso Stati Uniti, 4, 35127 Padova, Italy*

**Corresponding Author:** basile.pouradierduteil@cea.fr

SPIDER is the full-scale prototype of the ITER Heating Neutral Beam (HNB) ion source. In order to reach the current density requirements, the production of H-/D- ions is greatly enhanced by covering the source's converter surfaces with caesium, which lowers their work function. In particular, a sufficient and uniform Cs coating is required at the Plasma Grid (PG), the first electrode of the multi-grid accelerator facing the plasma. SPIDER is equipped with 3 Cs ovens located at the rear part of the source.

This contribution presents the control and monitoring of Cs evaporation in SPIDER during the 2024 and 2025 experimental campaigns during which only ¼ of the ion source was operated, resulting in unusual caesiation conditions. The use of Cs enabled the extracted negative-ion current density to reach values up to 210 A/m2 with extracted electron-to-ion ratios of the order of 1. The estimations of Cs consumption from simulations made with the AVOCADO code are compared to the consumption measured during the campaigns, and the data obtained from Laser Absorption Spectroscopy (LAS) and Optical Emission Spectroscopy (OES) are analyzed to obtain information on the uniformity of Cs flux at the PG and Cs dynamics.

*This work has been carried out within the framework of the ITER-RFX Neutral Beam Testing Facility (NBTF) Agreement and has received funding from the ITER Organization. The views and opinions expressed herein do not necessarily reflect those of the ITER Organization. This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 —EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.*

**Poster Session / 92**

# Ion Source Characterization using Integrated Data Analysis

**Authors:** Melissa Showers[None]; James Titus[None]; Connor Exton[None]

TAE's current experimental device, C-2W, utilizes edge-biasing, neutral beam injection, and plasma control to create and sustain a field-reversed configuration (FRC) plasma imbedded in a mirror plasma. The eight positive ion-source neutral beams, four static energy (15 keV) and four tunable energy (15-40 keV), also stabilize, fuel, and heat the FRC. Injected beam power correlates non-linearly to plasma performance, and therefore, it is crucial to understand beam propagation from the ion source into the plasma. Ion sources are generally characterized by divergence, focal length, and perveance. Knowing the most probable values of these parameters assists in designing efficient beam lines and understanding the power injected into the confinement vessel. On short-pulsed, low-energy neutral beam systems, these quantities are diagnosed throughout the beam line by wire calorimeters and shinethrough detectors. A model has been developed to comprehensively utilize the measurements and associated uncertainties with an integrated data analysis technique, based on Bayesian probability theory, to estimate the beam divergences and focal length at optimum perveance.

**Poster Session / 121**

## Beam intensity prediction using machine learning and plasma images

**Author:** Yasuyuki Morita[1]

**Co-authors:** Ayumi Kasagi [2]; Keita Kamakura [3]; Naoya Oka [4]; Osamu Kamigaito [5]; Takashi Nagatomo [1]

[1] *RIKEN Nishina Center*

[2] *Rikkyo University*

[3] *The University of Tokyo*

[4] *National Institute of Information and Communications Technology*

[5] *RIKEN Nishina Center for Accelerator-Based Science*

**Corresponding Author:** yasuyuki.morita@riken.jp

Monitoring beam intensity and emittance is crucial when supplying multicharged heavy ion beams from an ECR ion source. We are developing a method to predict beam intensity using machine learning based on plasma light images taken through the beam extraction port. Our previous studies have demonstrated the effectiveness of using plasma light images for this purpose[1]. However, when an oven is used, strong light emissions are observed during heating, which may significantly affect the quality of plasma light imaging. In this study, we investigated whether such oven light emissions influence the accuracy of beam intensity predictions by machine learning, using the 28 GHz ECR ion source at RIKEN. Furthermore, in order to operate this method as a non-destructive beam intensity monitoring system over extended periods, high prediction accuracy must be maintained throughout long-term beam operation. To this end, we collected data at multiple time points during the extended operation of the ECR ion source, including after vacuum breaks due to sample refilling. In this presentation, we will discuss the role of plasma light images in maintaining prediction accuracy under oven light emission conditions, as well as the challenges and future prospects for implementing this system in long-term ECR ion source operations.

[1] K. Kamakura et al., Proceedings of the 21st PASJ Meeting, THP085 (2024).

**Poster Session / 126**

## AI Tools for Plasma Diagnostics by X-ray Imaging and Spectroscopy in ECR plasmas

**Author:** Bianca Peri[1]

**Co-authors:** Angelo Pidatella [1]; Bharat Mishra [1]; David Mascali [1]; Domenico Santonocito [1]; Eugenia Naselli [1]; Giorgio Finocchiaro [1]

[1] *Istituto Nazionale di Fisica Nucleare*

**Corresponding Author:** eugenia.naselli@lns.infn.it

Magnetized ECR plasmas in compact traps are used in ion-source technology, accelerator physics, materials science, and beyond. At INFN-LNS the novel PANDORA facility is also thought as a powerful plasma-based infrastructure dedicated to fundamental research on nuclear decays in plasmas and for various applications. In this frame, an advanced diagnostic system has been developed, enabling non-invasive measurements of plasma properties. Indeed, plasma parameters critically influence the extracted beam's current, charge state, emittance, and stability, therefore their careful investigation is needed to address future development of ECRIS.

We have developed an innovative algorithm for soft X-ray imaging in Single-Photon Counting (SPhC) mode, enabling space-resolved soft-X-ray spectroscopy and magneto-plasma diagnostics (local thermodynamics, confinement dynamics, structure) via an X-ray pinhole CCD camera. This work presents its further development and optimization through an AI-based machine-learning model implemented in MATLAB.

Using datasets acquired under varied plasma conditions in two magnetic traps—the B-minimum ECR ion source at ATOMKI (Debrecen) and the simple-mirror Flexible Plasma Trap (FPT) at INFN-LNS—each photon event on the CCD was characterized by geometric and intensity-related features. A K-means clustering–based AI tool characterized similar events, revealing parameters that discriminate real from spurious signals. From these clusters, we built a labelled dataset in order to train a neural network that minimizes spurious pile-up events. This approach aims to accelerates plasma emission-spectrum retrieval with improved energy and spatial resolution, maximizes signal-to-noise ratio, and delivers significant speed and accuracy in characterizing soft-X-ray fluorescence and bremsstrahlung emissions from such plasmas.

**Poster Session / 148**

## Simulation of the ALISES 3 Plasma Chamber

**Author:** Mathias BARANT[None]

**Co-authors:** Augustin DUBOIS [1]; Guillaume FERRAND [2]; Juliette PLOUIN [2]; Olivier TUSKE [1]

[1] *CEA PARIS SACLAY*

[2] *CEA*

**Corresponding Authors:** mathias.barant@cea.fr, olivier.delferriere@cea.fr

As part of the development of ion sources, we have simulated the behaviour of particles within the ALISES 3 source, an ECR source ion operating at 2.45 GHz. Thanks to software CST Studio, we can study and evaluate the influence of electromagnetic fields (RF, magnetic and electric DC) and collisional processes on the plasma creation, as well as on the production of the beam. The simulation results show that the combination of the RF field, multipactor, and the presence of gas leads to the ignition of the plasma and can produce high current beams. Some limitations of the software are presented.

**Poster Session / 156**

## Comparison of the RF power coupling efficiency for 1.0 and 1.7 MHz at BATMAN Upgrade

**Author:** Anil Cherukulappurath Mana[1]

**Co-authors:** Christian Wimmer [2]; Dimitar Yordanov ; Dirk Wünderlich [3]; Ursel Fantz [4]

[1] *Max Planck Institute of Plasma Physics*

[2] *Max-Planck-Institut f. Plasmaphysik*

[3] *Max-Planck-Institut für Plasmaphysik*

[4] *IPP Garching - ITED division - NBI group*

**Corresponding Author:** anch@ipp.mpg.de

In the negative Ion-Based Neutral Beam Injector (NNBI) sources for ITER, hydrogen/deuterium plasma is generated by inductive coupling of RF power at 1 MHz. Experiments on the BATMAN upgrade (BUG) prototype source revealed a significant power loss (over 40%) within the RF network and driver assembly, prompting the necessity to seek source performance improvements to avoid increasing input power. Zielke et al. predicted that increasing the driving frequency could enhance plasma coupling using a self-consistent fluid model [1]. This prediction motivated the modification

of the RF generator at the BUG, an initiative by ITER IO in collaboration with Consorzio RFX under a bilateral framework agreement to experimentally investigate the effect on power coupling at higher RF frequency. The current RF generator allows for an increase in RF frequency to 1.7 MHz with slight modifications to the oscillator amplifier setup. However, modifications caused severe RF disturbances, which affected many sub-systems of BUG since the whole setup was previously optimized to 1.0 MHz.

After several optimization steps, an experimental study has been performed comparing power coupling at 1 MHz and 1.7 MHz. Losses in the RF network and power coupling efficiency are evaluated from measured input RF power and coil current [2]. Langmuir probe and Optical Emission Spectroscopy (OES) were used to diagnose the driver plasma. The experimental results showed a higher power coupling efficiency up to 15% at 1.7 MHz across all tested power levels. This increased efficiency was also reflected in higher plasma density values measured by the probe and OES. When comparing the same power coupled to the plasma, the density values at 1.0 and 1.7 MHz are comparable, pointing out that the different frequency impacts only the coupling efficiency.

1. S. Briefi et al., Rev. Sci. Instrum. 93 (2022) 023501.
2. Hopwood, J. PSST 3.4 (1994): 460.

**Poster Session / 142**

## Optical Emission Spectroscopy as non-invasive tool for beam stability monitoring at MedAustron Therapy Center

**Authors:** Piera Galeazzo[1]; Nadia Gambino[2]

**Co-authors:** Aleksandr Andreev [3]; Matthias Kausel [2]; Jan Mäder [3]; Valeria Rizzoglio [2]

[1] *TU Wien Austria*

[2] *MedAustron EBG*

[3] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

**Corresponding Author:** nadia.gambino@medaustron.at

MedAustron is a synchrotron-based cancer therapy center located in Austria, where patients are treated with clinical proton and carbon ion beams at energy ranges of 62- 252 MeV and of 120-400 MeV/u, respectively. The MedAustron injector features three identical Electron Cyclotron Resonance Ion Sources (ECRIS) operated at 14.5 GHz, two of which are used for clinical treatment. The third source, dedicated to non-clinical research, provides helium ion beams and serves as test bench for various experimental activities at the source level. Second generation ECRIS provide stable extracted currents within ±2.5% of the nominal beam current, which are essential for minimizing spill-to-spill intensity fluctuations and ensure stable dose delivery to the patient up to the treatment room. The extracted ion source current stability is generally monitored via ion collectors such as Faraday Cups (FCs), which, as invasive diagnostic technique, cannot be used during clinical treatment. Optical Emission Spectroscopy (OES) is a non-invasive diagnostic tool generally used to characterize the plasma and estimate parameters such as the electron density and the electron temperature. In this work, the extracted current stability generated by a medical ECRIS is investigated using OES. A Charged Coupled Device (CCD) camera equipped with a telephoto lens connected to an optical emission spectrometer operating from 450-830 nm has been used to perform time resolved measurements on three different ion species (proton, carbon and helium ions). The measurements show a clear correlation between intensity variation of characteristic neutrals and ionized atoms emission lines and extracted current instabilities measured at the FC. The results validate OES in the visible range as a potential non-invasive technique for current stability monitoring at the source level for a medical accelerator.

**Poster Session / 100**

## A data driven Model of the Existing and Optimal Cs Delivery into the LANSCE $H^-$ Ion Source

**Authors:** David Kleinjan[1]; Rob Welton[2]

[1] *Los Alamos National Laboratory*

[2] *Oak Ridge National Laboratory*

**Corresponding Author:** kleinjan@lanl.gov

The LANSCE $H^-$ Ion Source delivers a 120 Hz, 15 mA, 10% duty factor beam, which is created via a filament driven hydrogen plasma and cesiated surface-conversion. To induce cesiated surface conversion, the converter is coated in cesium via a basic Cs transfer tube port that is connected to a heated Cs reservoir, such that the amount of Cs flux induced on the converter is increased by increasing the Cs reservoir temperature. A COMSOL model of the Cs flux out of the existing transfer tube and into the LANSCE $H^-$ Ion Source will be utilized using data driven empirical variables: temperature measurements of the source walls and points along the Cs transfer tube, heating power of the filaments, background H2 pressure inside the source, and the Cs density out of the Cs transfer tube using Tunable Diode Laser Spectroscopy. Using these same parameters a study will be done using COMSOL to propose an optimal Cs transfer tube for the LANSCE $H^-$ Ion Source.

**Poster Session / 105**

## Recent advancements and hydrogen plasma experiments in RF based two driver negative ion source (Twin source) at IPR

**Author:** GOURAB BANSAL[1]

**Co-authors:** Ravi Pandey [1]; Manas Bhuyan [1]; Mahesh Vuppugalla [1]; Ratnakar Yadav [1]; Agrajit Gahlaut [1]; Hardik Shishangiya [1]; Hiren Mistri [1]; Deepak Parmar [1]; M.N. Vishnudev [1]; Jignesh Bhagora [1]; Mainak Bandyopadhyay [1]; Arun Chakraborty [1]

[1] *INSTITUTE FOR PLASMA RESEARCH, BHAT, GANDHINAGAR, GUJARAT, INDIA 382428*

**Corresponding Author:** bansal@ipr.res.in

TWo-driver Indigenous Negative ion source, popularly known as TWIN source, at IPR has been operational for the last few years. The TWIN source is ¼th of the ITER DNB source in size. It has been developed to support the Indian Test Facility, INTF operation (testing of ITER DNB source). Hydrogen plasma is generated in both the drivers (diameter ~ 280 mm, length 150 mm, each) of the TWIN source by coupling RF power (from 180 kW, 1 MHz RF generator) inductively and then allowed to expand into a rectangular expansion chamber of volume ~ 1000 (L) × 500 (B) × 200 (H) mm3. The RF power is fed into two water-cooled RF coils of 6.5 turns each simultaneously via a motorized variable capacitor-based matching network and a 3:1 ferrite-based isolation transformer. More design details of the Twin source can be found in [1-4].
The TWIN source is designed to be operated in both "air mode"and "vacuum immersed mode"(air mode: RF coils are in air; vacuum mode: RF coils are immersed in vacuum). Presently, the air mode operation of the TWIN source is ongoing. RF input power of 75 kW is coupled successfully, for the first time, with a power factor of more than 0.8 to generate hydrogen plasma. Langmuir probes and optical emission spectroscopy diagnostics are implemented to study TWIN plasma dynamics. In addition, for safe operation, H-alpha based interlocks, RF coil currents and voltage monitors, water calorimeter, etc., are also integrated with the TWIN data acquisition and control system (DACS). The hydrogen plasma density of the order of 10^17 m-3 has been achieved and is expected to be 10^18 m-3 at higher RF power in vacuum mode. TWIN source has also been successfully operated at a low pressure of 0.35 Pa, for the first time. The H-ion beam extractor-accelerator system is not yet coupled to the ion source. The paper will give an overview of the TWIN source progress, together with the recent experimental data and the challenges faced during plasma operation.

**Poster Session / 171**

## Positive Ion Source Technology Demonstration for DIII-D Neutral Beam Heating

**Author:** Florian M. Laggner[1]

**Co-authors:** Amanda Lietz [1]; Arthur G. Mazzeo [1]; Brendan J. Crowley [2]; Evan Kallenberg [2]; J. Timothy Scoville [2]; Keanu J. Ammons [1]; Kirtan M. Davda [1]; Md Sazzad Hossain [1]; Miral Shah [1]; Steven C. Shannon [1]

[1] *North Carolina State University*

[2] *General Atomics*

**Corresponding Author:** fmlaggner@ncsu.edu

Radio-frequency (RF) inductively coupled plasma (ICP) positive ion sources are under development for the DIII-D neutral beam injection (NBI) system. The project targets 25% higher extracted ion current compared to existing arc-discharge ion sources, while increasing operational reliability.
This research program focuses on understanding physical mechanisms behind ion production and optimizing engineering of the RF ICP ion sources. The approach integrates three experimental devices (described below) at different scales with advanced modeling. Hybrid kinetic-fluid plasma simulations validate performance across spatial scales to project achievable ion currents, while finite element electromagnetic modeling informs prototype designs.
LUPIN, a reduced-scale cylindrical setup (20 cm diameter), demonstrates novel multi-strap RF antenna concepts and validates hybrid kinetic-fluid plasma simulations under NBI-relevant power densities. LUPIN operates with up to 20 kW RF power at 2 MHz and features an internal, inertially cooled Faraday screen with comprehensive plasma diagnostics. The SupRISE device investigates power coupling to plasma as a function of RF frequency and chamber dimensions. SupRISE features a full-scale racetrack-shaped quartz vessel with 50 kW RF power available at 4-8 MHz. AMAROK will be a full-scale, full-power pre-prototype that demonstrates homogeneous plasma density across a 48×12 cm ion extraction area, translating to 85 A positive ion beam. The system provides 200 kW installed RF power (2-4 MHz) and gas flow rates of 15 Torr-L/s at 1-10 Pa, replicating the DIII-D NBI conditions.
Recent accomplishments include successful experimental scans on LUPIN to validate comprehensive ion flux modeling, which reveals enhanced dissociation and ionization above 10 kW operation. SupRISE achieved its first plasma with successful power sweeps up to 1 kW at various frequencies. AMAROK facility preparations near completion, and hardware installation is imminent.

This work is supported by US DOE under DE-SC0024523 and DE-FC02-04ER54698.

**Poster Session / 5**

## Plasma characterization and technological application of a heater less hollow cathode plasma source with C-shape scanning device

**Author:** Zhao Shengfu[1]

[1] *Nanyang university SINGAPORE*

**Corresponding Author:** shengfu.zhao620@gmail.com

An efficient large volume plasma source with large substrate area coverage has been established by arranging a multi-pole line Cusp Magnetic Field (MMF) and two C-Shape scanning devices in front of a heatless hot hollow cathode electron emission source, allowing for higher ionization efficiency and large area surface treatment for industry use. Substrate collected ion current topographic plot shows both higher solenoid coil generated axial magnetic field and reduction of feed gas flow (Argon) could effectively increase plasma source ionization efficiency. Diamond-like coating (DLC) deposition method has been used to access the C-shape scanning device effectiveness for large area coverage with good uniformity. Generally, with solenoid coil generated magnetic field and MMF, a strongly increased ability for the reactive process dissociation and ionization was observed. The effectiveness of scanning device has been approved by the deposited DLC film color as well as thickness distribution measurement, the effective coverage can be up to 600mm with less than 10% uniformity. Two applications related to the coating applied onto the tools and components are discussed: the anti-static discharge coating on the wafer contact surface of tools and components used in semiconductor industry to provide protective properties against Electrostatic Discharge (ESD) and DLC coating for 2D material encapsulation. The first mentioned ASD coating could be an excellent solution to raise production yield due to their provision of ESD protection and their good tribological properties. The second coating acts like a Permeation Barrier or Moisture Barrier against gases (e.g. oxygen) and moisture for 2D material such as Perovskite coating for Solar application.

**Poster Session / 11**

# Towards NIO2, a 5 kW RF compact H- ion source

**Author:** marco cavenago[1]

**Co-authors:** Marco Barbisan [2]; Rita Delogu [2]; Carlo Baltador [1]; Denis Martini [1]; Andrea Muraro [3]; Diego Ravarotto [2]; Francesco Taccogna [4]; Gabriele Croci [5]; Giuseppe Castro [6]; Grazia D'Agostino [6]; Lorenzo Neri [6]; Vanni Antoni [7]; Vincenzo Variale [8]; Alberto Ruzzon [1]; Luigi Celona [9]

[1] *INFN-LNL div. Acceleratori*

[2] *Consorzio RFX*

[3] *CNR-ISTP e INFN-MIB*

[4] *CNR-ISTP e INFN-BA*

[5] *Dip. Fisica, Univ. Milano e INFN-MIB*

[6] *INFN-LNS div. Acceleratori*

[7] *CNR-ISTP*

[8] *INFN-BA*

[9] *INFN-LNS*

**Corresponding Author:** giuseppe.castro@lns.infn.it

The negative ion sources operation of neutral beam injectors (NBI) for tokamak must be carefully optimized for low beam divergence, minimal Cs use, and related HV stability. The long term operation (LTO) is challenging, especially because not only plasma but also evolving surface wall conditions are involved in H- or D- production; moreover, in a full-size source (as SPIDER) installed RF (radio frequency) power may reach 800 kW and H gas consumption 16 mg/s with consequential pumping, so that reduced size or compact ion sources are very convenient for studying the underlying physics and for flexibility in testing innovations. The NIO1 (negative ion optimization phase 1) source was indeed operated since 2014 (in close collaboration between Consorzio RFX and INFN) as a convenient benchmark, but it is limited to 9 beamlets and about 2 kW RF power; evidence of both of fast transients and slow evolution in LTO was demonstrated. Based on these experiences, design of a companion source NIO2 is proposed, with a larger expansion chamber and at least 25 beamlet extraction, for better beam uniformity studies. Generalization of the seamless match of magnetic filter and multipole confinement introduced in NIO1 is discussed, considering optimization of expansion backplate magnets also. The spacing between source rear plate and RF coil and the large aspect ratio length/radius of this coil (which were introduced as design rules in NIO1 and in following studies for the Divertor Test Tokamak) are maintained. Results and issues with Langmuir probe RF compensation measured in MetAlice LNL test-stand are also summarized. Improved gas and Cs injection are also proposed. The application of additive manufacturing at least to Faraday Shields (as recently build) and to the extraction grid is fostered.

**Poster Session / 36**

# Large scale discharge space for penning negative hydrogen ion source

**Author:** LIU Shengjin[1]

**Co-author:** Huafu OUYANG [1]

[1] *IHEP-CAS*

**Corresponding Author:** liusj@ihep.ac.cn

For a high-current negative hydrogen ion source, the discharge power deposited on the electrode surface increases rapidly under high duty factor. At a discharge voltage of 150 V and a discharge current of 50 A, approximately two-thirds of the pulsed discharge power acts on the cathode surface, while about one-third acts on the anode and slit plate surfaces. Such high power density deposition can cause significant sputtering damage and potentially leading to arcing short in the discharge chamber and reducing its lifetime.
Additionally, SRIM calculations reveal that continuous surface sputtering damage makes it difficult to maintain optimal cesium deposition on electrode surface. In later stages of operation, the extracted negative hydrogen beam exhibits a noticeable drop in the pulse flat-top, particularly under high duty factor, where this phenomenon becomes more significant.
To address these issues, the designed discharge chamber features an 8-fold increase in the discharge region volume compared to the original design. By expanding the cathode's discharge surface area while maintaining the same discharge power, the spatial discharge power density is reduced.
The enlarged discharge area minimizes sputtering damage on electrodes and improves cesium deposition. This new discharge chamber has undergone thermal analysis, discharge parameters testing, emittance measurements, and discharge emission spectroscopy to validate its performance.

**Poster Session / 68**

# Modelling the spatial and temporal dynamics of Cs inside the BATMAN Upgrade source using the CsFlow3D code

**Author:** Daniele Mussini[1]

**Co-authors:** Christian Wimmer [2]; Dirk Wünderlich [1]; Ursel Fantz [1]

[1] *Max-Planck-Institut für Plasmaphysik*

[2] *Max-Planck-Institut f. Plasmaphysik*

**Corresponding Author:** daniele.mussini@ipp.mpg.de

The production of negative hydrogen ions inside the ion sources for ITER's neutral beam injectors (NBI) takes place on a low work function large-area converter surface (plasma grid, PG). Cs is continuously evaporated into the ion-source forming a layer on the PG aiming at reducing its work function (< 2eV) in order to make the production of negative ions more efficient. However, the interaction of the plasma with the surface and the subsequent redistribution of Cs inside the source lead to a temporally unstable and inhomogeneous Cs layer. This aspect must be investigated and comprehended in order to perform long extraction pulses at ITER's requirements (several hundred s in H, 3600s in D). The Monte-Carlo Test-Particle code CsFlow3D, developed at IPP Garching, is exploited to comply with this task. CsFlow3D simulates the dynamics of Cs particles inside the pulsed plasma operating source using different input parameters such as electromagnetic fields, sticking coefficients, Cs evaporation rate, plasma-induced Cs removal rate from the surfaces, plasma density and temperature. Moreover, to interpret the results of the experimental absorption diagnostic (TDLAS), through which only the neutral Cs density along different lines of sight can be measured, a synthetic diagnostic estimating both neutral and ionized Cs densities, the latter not accessible experimentally, has already been introduced into the code. For the first time, input plasma parameters obtained from a 2D fluid code, realistic oven nozzle geometries and time/space-dependent surface parameters (e.g. sticking coefficients and plasma-induced removal rate of Cs from the surface) are adopted for the code. This contribution presents results investigating the influence of the new input

parameters on the Cs redistribution and the respective validation against the experimental results for the BATMAN Upgrade source in hydrogen.

**Poster Session / 94**

## Production of negative helium ions via transmission through nano-foils

**Author:** Philip Jackle[1]

**Co-authors:** Hyunmin Kim [1]; Karen Kavanagh [1]; Melissa Radford [1]; Morgan Dehnel [2]

[1] *Simon Fraser University*

[2] *Selkirk Ion Source Centre*

**Corresponding Author:** pjackle@sfu.ca

The production rate of negative helium ions ($He^-$) was measured for the case of passing positive helium ions ($He^+$) through a nano-foil, used as a charge exchange medium. Ratios of the amount of transmitted positive, neutral, and negative helium particles to total transmitted particles were measured when using different nanometer-thick foils including carbon, Formvar, silicon nitride, and gold with an incident $He^+$ beam energy of 25 keV and sub-pico-amp beam currents. Results have given $He^-$ production ratios of 0.01% to 0.05% consistent with previous reports.

Experiments were performed using a helium ion microscope (HIM) with the foil mounted at the beam-limiting aperture, and transmitted ions detected by an added CMOS camera mounted below the sample stage. Transmitted particles were initially separated by charge with the HIM's internal electrostatic deflectors into distinct beams, and the intensity of each beam measured by the CMOS sensor. Current experiments with previous foils, as well as titanium oxide, platinum, and palladium, are using a new custom-designed sample holder mounted on the HIM sample stage that contains the nano-foil and a magnetic deflector. These experiments are performed at incident beam energies from 10 to 30 keV.

This work endeavours to find an alternate method of producing $He^-$ ions from $He^+$ with non-metallic materials at a comparable rate to the existing method of using vapour charge exchange with alkali or metallic atomic vapours. A non-metallic, foil-based method could greatly reduce or eliminate the problems associated with containing vapours within vacuum systems, and for semiconductors manufactured with $He^-$ and metallic vapours, the problem of contamination in the implantation process.

**Poster Session / 71**

## Plasma parameter measurement during efficiently producing multicharged ions by selectively heating low-Z ions on Electron Cyclotron Resonance Ion Source in mixing low-Z gases

**Author:** Shinji Tokuno[1]

**Co-authors:** Yushi Fujimura [1]; Akinobu Ide [1]; Daichi Inoue [1]; Toyohisa Asaji [2]; Masayuki Muramatsu [3]; Atsushi Kitagawa [4]; Yushi Kato [1]

[1] *The University of Osaka*

[2] *The University of Shiga Prefecture*

[3] *QST*

[4] *National Institutes for Quantum Science and Technology (QST)*

**Corresponding Author:** tokuno@nf.eie.eng.osaka-u.ac.jp

Electron Cyclotron Resonance Ion Sources (ECRIS) have been widely applied in various fields, including particle accelerators, superheavy element research, cancer therapy, and ion implantation. We are conducting research on the efficient production of multicharged ion beams on 2.45 GHz ECRIS. Gas mixing with low-Z gases is known as an effective method for enhancing the production of multicharged ions, and one of its possible mechanisms is the ion cooling effect. Focusing on this effect, we attempt to amplify its effect by selectively heating low-Z gases using ion cyclotron resonance (ICR). In this experiment, we used Xe as the operating gas and introduced low-Z gases that is He or Ar. Low-frequency RF power was applied through an ICR antenna which six turn antenna made of Cu covered by Al2O3. The frequencies of ion cyclotron resonance is 400 kHz for He+ and 40 kHz for Ar+ . The charge state distribution (CSD) based on ion beam current showed an increase in the yield of multicharged ions, with a more significant enhancement when $He^+$ ions were heated than that of $Ar^+$ case. We measured the plasma parameter of mixing gas by using a Langmuir probe, both with and without low-frequency RF. Electron temperatures and electron densities increase in both Xe/He and Xe/Ar plasmas. Xe/He case exhibited a more significant increase. These trends are in good agreement with enhancement of ion beam currents.In this paper, we will present details of these experimental results, and also plan to measure ion energy inside the ion source by using ion-sensitive probe method.

**Poster Session / 75**

## Comparison of Performance Efficiency of Different Types of RF Antennas for Permanent Magnet-based Helicon Plasma Source via Finite Element Simulations

**Author:** AMARDAS ALLI[1]

**Co-authors:** Mainak Bandyopadhyay [1]; Piyush Patel [2]; Rajsingh - [1]

[1] *INSTITUTE FOR PLASMA RESEARCH*

[2] *Silver Oak University*

**Corresponding Author:** amar@ipr.res.in

This work investigates the performance efficiency of three different RF antenna configurations: Half-Helix, Nagoya-III, and simple helical (coil type) in a permanent magnet-based Helicon Plasma Source (HPS) through finite element-based simulations. These simulation studies on argon and hydrogen plasmas focus on the wave coupling efficiency and power absorption to evaluate antenna effectiveness by analyzing key parameters such as plasma density and temperature. The simulations integrate electromagnetic wave propagation, plasma-fluid interactions, and the influence of the permanent ring magnet array on plasma production and its dynamics. Results reveal distinct differences in plasma generation and wave excitation characteristics, with the Nagoya-III antenna demonstrating superior power coupling in specific operational regimes compared to the other designs. These findings offer crucial insights for optimizing RF antenna structures in Helicon plasma sources, which are essential for the applications in ion beam generation, space propulsion, and plasma processing technologies. The study serves as a valuable reference for designing high-efficiency RF-driven ion sources.

**Poster Session / 86**

## Probing ECR Plasmas through Light: Spectroscopic Analysis of Hydrogen, Helium, and Neon Discharges

**Authors:** Giuseppe Castro[1]; Riccardo Reitano[2]; Luigi Celona[3]; Ornella Leonardi[4]; Grazia D'Agostino[4]; Giacomo Costanzo[3]; Davide Siliato[3]; Santo Gammino[3]

[1] *Istituto Nazionale di Fisica Nucleare - LNS*

[2] *Catania University Physics department*

[3] *INFN - LNS*

[4] *INFN-LNS*

**Corresponding Author:** castrog@lns.infn.it

In this work, electron temperature and density have been estimated for hydrogen, helium and neon plasmas generated in a plasma trap known as the plasma reactor, operating at INFN - Laboratori Nazionali del Sud. Plasma is generated by means of Electron Cyclotron Resonance (ECR) between microwaves at 3.8 GHz frequency and a solenoidal magnetic field. Optical emission spectroscopy has been used to analyze the spectral lines emitted from the plasma for various conditions of microwave power and pressure in the optical domain 300-1100 nm, enabling non-invasive determination of plasma parameters. This methodology provided detailed insights into plasma conditions, contributing to the characterization and development of ion sources and enhancing the understanding of fundamental plasma processes occurring in ECR-generated plasmas.

**Poster Session / 98**

## Development of an Optical Diagnostics System for Arc Discharge Ion Sources

**Authors:** Alejandro Garcia Sosa[1]; Claire Talbott[2]; Darren Mitchard[2]; Dean Morris[2]; Erin L. Flannigan[2]; Moenir Sakieldien[3]; Olli Tarvainen[2]; Rob Abel[2]

[1] *STFC - Rutherford Appleton Laboratory*

[2] *STFC*

[3] *iThemba LABS*

**Corresponding Author:** m.sakieldien@ilabs.nrf.ac.za

The UK Science and Technology Facilities Council (STFC) and iThemba Laboratory for Accelerator Based Sciences (LABS) are currently collaborating on the development of an optical diagnostic system for monitoring ion sources. The proposed work builds on the pioneering development of optical diagnostics at ISIS. A particular interest with this work is for monitoring the Penning ion sources at both facilities under operational conditions. At iThemba LABS the Penning source is used to produce a proton beam whereas it produces negative hydrogen ions at ISIS. At iThemba LABS the protons are produced by electron impact ionization of hydrogen atoms producing a 500 - 700 μA beam at the centre of the 8 MeV cyclotron. At ISIS the $H^-$ ions forming a 55-60 mA beam are produced on the caesiated molybdenum cathode surfaces of the ion source and injected into an RFQ and linac. A common mode of failure of both ion sources seems to be intricately linked to erosion and subsequent poisoning of the plasma surfaces. By monitoring the optical emission spectrum emitted from the plasma, the results can be analysed and used to guide operational decisions e.g. caesium feed rate at ISIS or filament heating current at iThemba LABS. With this contribution we will report on prototyping results of various optical detectors (CCD spectrometer, Avalanche PhotoDetectors, Single-Photon Avalanche Detectors and PhotoMultiplier Tubes) viewing the slit and extraction electrode of the ISIS source and using bandpass filters for wavelength selection. Detection techniques, first results of time-resolved hydrogen and caesium optical emissions and their dependencies on the ion source operational parameters, and prototyping status in general will be reported on. Additionally, we will discuss the challenges foreseen when deploying the optical emission monitoring technique developed for the ISIS ion source to monitoring the internal ion source at iThemba LABS.

**Poster Session / 144**

## Scintillating fiber and perovskite-based sensors for X-ray diagnostics on ECR plasmas

**Authors:** Alessandra Alberti[1]; Angelo Pidatella[2]; Antonino La Magna[1]; Bharat Mishra[2]; Bianca Peri[3]; David Mascali[2]; Domenico Santonocito[3]; Eugenia Naselli[4]; Gaetano Calogero[1]; Giorgio Finocchiaro[5]; Giorgio Sebastiano Mauro[2]; Giuseppe Torrisi[2]; Richard Ràcz[6]; Salvatore Valastro[1]; Sàndor Biri[6]

[1] *CNR-IMM, Catania, Italy*

[2] *INFN - LNS*

[3] *Istituto Nazionale di Fisica Nucleare*

[4] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS)*

[5] *INFN-LNS*

[6] *HUN-REN Institute for Nuclear Research (ATOMKI), Debrecen, Hungary*

**Corresponding Author:** mauro@lns.infn.it

Within the SAMOTHRACE ecosystem, funded by the EU Next Gen Program, and synergically with the INFN PANDORA project, we here present the development and application of two novel and versatile X-ray sensors, particularly suitable to monitor high X-ray fluxes from ECR plasmas.
Such systems, based on organic scintillating fibers (Sci-Fi) coupled to Si-photomultipliers and X-ray sensitive perovskite polycrystals, feature low intrinsic efficiency and high radiation hardness, and are cheap and durable if compared to common Si detectors. Their rapid response, versatility and stability make them very interesting tools for ion source plasma diagnostics.
Sci-Fi have been developed and tested at INFN-LNS to check for the first time its sensitivity at soft X-ray domain (< 50keV). Further measurements have been performed on the B-minimum ECRIS at ATOMKI. The system is flexible (7 m long fibers with 1 mm diameter) and fully suitable to the high voltage of the extraction systems, so it was coupled externally to the plasma chamber. The X-ray emission from ECR plasma has been measured at different RF power (100 –400W) and plasma regimes, by tuning the B-field configurations, well resolving the emission variations in the time scale of 100 ms and distinguishing stable from unstable plasma regimes.
Perovskite-based X-ray sensors, developed at CNR-IMM, were irradiated by a mechanically shuttered X-ray tube to test the time-response in the ms range. It has been tested at zero bias voltage in the X-ray energy range of 5 –50keV, producing signals of the order of few nA at the lowest photon flux. A Si-PIN detector was used to benchmark the X-ray emission.
Fast-responding self-powered perovskites and flexible scintillating fibers can open the route to new generation of X-ray sensitive detectors for studying plasma instability phenomena not only in ECR sources. Moreover, their use could be of wide and interdisciplinary interest on any fields requiring the detection of high radiation fluxes.

**Poster Session / 31**

## Vacuum Brazing Process for Large-Scale Grid Production for Negative Ion Source Application

**Author:** Ravi Pandey[1]

[1] *Institute for plasma research*

**Corresponding Author:** rpandey@ipr.res.in

Large grids used in ion beam generation from an ion source are exposed to high heat flux and therefore require active cooling. To address this, cooling channels are embedded within the grids. Traditionally, these embedded channels have been fabricated through electroforming, as implemented in systems like JET-PINI, BATMAN and ITER-DNB. Recently, efforts have been made to manufacture a full-scale grid set for TWIN source—a two-driver, RF-based negative ion source using vacuum brazing as an alternative technique. Due to its ability to produce millimeter-scale embedded cooling channels, the vacuum brazing method has demonstrated potential applications for other plasma-facing components as well.

Vacuum brazing offers several advantages over conventional copper electroforming. It is more economical and environmentally friendly, provides better repeatability, induces lower residual stresses, allows for improved distortion control, and is generally less time-consuming. Due to restricted information, the electroforming technique in a few countries or companies maintains a monopoly. Vacuum brazing can be considered as an alternative technique for manufacturing large-size grid segments more economically.

The cooling geometry of the grids has been optimized through a combination of finite element analysis (FEA), prototype fabrication, and experimental validation. A critical aspect of this development is the characterization of the brazed joint, which must withstand operational water pressures at temperatures ranging from 100℃ to 150℃. Fixtures are selected to maintain a precise gap clearance of 50–100 microns throughout the brazing cycle. Post-brazing, the grid segments achieve a flatness within the range of 200–400 microns. The process also incorporates various inspections and testing methods, including cold and hot helium leak testing, infrared thermography, and radiographic testing (RT), ensuring the integrity and performance of the final grid segments.

**Poster Session / 104**

## Development of a 120 kV high power ion source prototype for neutral beam injector

**Authors:** yahong xie[1]; Yuming Gu[1]; Longbin Liu[2]; Wen Deng[1]; Lixin Yang[1]; Yongjian Xu[1]; Jianglong Wei[1]; Sheng Liu[1]; Chundong Hu[1]

[1] *ASIPP*

[2] *East China University of Technology*

**Corresponding Author:** xieyh@ipp.ac.cn

Neutral beam injection (NBI) is one of the most effective tools for the plasma heating and current driver. The high power ion source is the key part of NBI system. In order to increase the performance of high power source on the Experimental Advanced Superconducting Tokamak (EAST), a new ion source with 120 keV was proposed.
The accelerator of ion source is the key parts. The accelerator gird was designed with hole type. The beam optics was simulated with tetrode and triode type, respectively. The results shown that, the tetrode accelerator can extract the deuterium beam with the lowest divergeance angle of 0.65 degree and optimum extracted ion current density of 0.17 A/cm2. When change to the triode type, the accelerator can get the lowest divergeance angle of 0.7 degree with optimum extracted ion current density of 0.22 A/cm2. The transparency of grid was designed as 0.5, which can extract more ions to form high current ion beam. The cooling channels inside the grids was analyzed with Cu and Mo materials, respectively. The results shown that, the grids with Mo can got good performance with active cooling during long pulse operation.
An ion source prototype was developed and tested on the testbed. High energy of 120 keV was achieved with beam current of 15 A. Long pulse of 100 s was tested with lower energy of 80-95 keV due to the limitation of testbed. The hydrogen beam with 80 keV and 12.7A was extracted with 102 s. The beam divergence angle was measured with calorimeter around 1 degree, which larger than the simulation value of 0.7. The results are good for the R&D of a high power ion source with 120 keV.

**Poster Session / 101**

## A compact 35 keV ECR proton ion source with advanced chopping for neutron source applications

**Author:** Gábor Anda[1]

**Co-authors:** andrás zsákai [1]; Miklós Merse [1]; Domonkos Czémán [1]

[1] *Centre for Energy Research*

**Corresponding Author:** anda.gabor@ek.hun-ren.hu

A novel medium-current (up to 20 mA) and low normalized beam emittance (<1 π mm·mrad) ECR microwave $H^+$ ion source has been developed at the Centre for Energy Research in Budapest, Hungary, to work as the serve as the core of a compact neutron source. Designed for high stability, the system aims for an energy ripple below 1%, delivering continuous or pulsed proton beams (20 mA) with adjustable pulse durations (0.1–10 ms) and modulation frequencies (0.01–40 Hz) at 35 keV. The configuration includes a microwave generator, four-stub tuner, E-bends, DC-break, vacuum window, and a four-section matching transformer, all connected to a 90 mm diameter, 100 mm length cylindrical plasma ionizing chamber. Magnetic fields are generated by six axially arranged permanent magnet bars. Magnetic simulations guided the placement of magnets and ferromagnetic components to achieve the desired field within the chamber. Beam simulations confirm effective proton beam focusing. High-voltage insulators are radially installed, minimizing the distance between the extraction slit and ion optic entrance. The extracted beam is diagnosed using a water-cooled Faraday cup. An infrared camera enables measurement of both beam current and its distribution.

Beam chopping is implemented via electrostatic deflection plates driven at ~3 kV, directing the beam to a Faraday cup acting as a beam dump. This approach avoids the challenges of high-voltage (35 kV) switching.

Measurement results are presented for both continuous and chopped beam modes.

**Poster Session / 10**

# Diagnostics for characterization of neutral beams parameters at TCV

**Author:** Alexander N. Karpushov[1]

**Co-authors:** Aleksandr Listopad [1]; Dmytry Mykytchuk [1]; Holger Reimerdes [1]; Matthieu Toussaint [1]; Remy Jacquier [1]; Yanis Andrebe [1]

[1] *SPC-EPFL*

**Corresponding Author:** alexander.karpushov@epfl.ch

The TCV tokamak is equipped with three neutral beams injectors. The low power 50keV, 80kW DNBI together with the CXRS system is used for measurements of plasma ion temperature, velocity, and carbon impurity density since 2000. The 1.3MW/28keV NBI-1 has been operated on TCV from 2015 providing the direct ion heating. The second 1MW/52keV high-energy NBI-2 was installed on TCV in July 2021 and extended the TCV capability for ion heating and fast ion studies.
TCV heating beams are equipped with a similar set of standard diagnostic tools: beam acceleration voltage, ion current, voltage and current of suppression grid, current of bending magnet, power of RF plasma sources are measured in power supplies; neutral beam profile on calorimeter and distribution of ions on the ion dump are monitored by thermocouples as well as the temperature of beam duct elements; the temperature of the beam dump (shine-through) is monitored by pyrometers and TCs, etc. The Doppler shift spectroscopy looking along a single view-line intersecting beam axis used for measurement of the beam energy composition.
A new multichord beam spectroscopy diagnostic has been developed and implemented in 2024. The measurement of Hα (Dα) emission spectra along several view lines aligned either along or across beam allow to evaluate density profiles across beam, as well as to estimate parallel and perpendicular velocity spread for each energy fraction.
Minimization of the beam size and power losses in the beam transmission line from injector to tokamak is essential for TCV with relatively narrow ports. The in-house built device, to assess the 3D NB power density distribution, was implemented for TCV NBIs. This device featured an actively cooled tungsten tile inclined at 45° with respect to the beam. An IR camera records the surface temperature rise, which is near proportional to the 2D beam power distribution. The device can be moved along the beam axis for evaluation of beam divergences and focal lengths.

**Poster Session / 39**

## Investigation of plasma transport through a neutral gas layer in a high-repetition-rate laser ion source.

**Author:** Jun Hasegawa[1]

**Co-authors:** Koki Yokoi [1]; Ziyu Wang [1]

[1] *Institute of Science Tokyo*

**Corresponding Author:** jhasegawa@zc.iir.isct.ac.jp

In the laser ion source, it is known that the amount of plasma supplied to the ion extraction gap decreases with increasing laser repetition frequency due to the interference of neutral gas released by laser ablation and remaining in the surrounding space. In particular, charge exchange reactions with neutral gas molecules have a significant impact on the amount of highly charged ions, so suppressing the effects of neutral gas is a critical issue for high-repetition-rate laser ion sources.
To investigate the plasma transport through the neutral gas layer near the laser target, plasma ion fluxes were measured under various laser repetition rates up to 10 Hz using a laser ion source with a rotating cylindrical target. Highly charged ions are produced from a solid target or a solidified gas target formed on a liquid-nitrogen-cooled cold head. The pressure increase during repetitive operation was compared between these two targets. The ion charge state distributions in the supplied plasma were also measured and the dependence of the amount of highly charged ions on the repetition rate was examined.
In addition to the experimental investigation, numerical investigations were performed using a 2D PIC-MCC simulation and a fluid simulation using a rarefied gas model. The former was used for plasma ion tracking in background neutral gas, the latter for neutral gas dynamics after each laser ablation.
The effectiveness of introducing a differential pumping system in high-repetition-rate laser ion sources is discussed on the basis of the experimental and numerical results.

**Poster Session / 65**

## Emittance measurement of ion beam current in selectively heating low Z ions on electron cyclotron resonance ion source in mixing low Z gases

**Author:** Akinobu Ide[1]

**Co-authors:** Yushi Fujimura [1]; Shinji Tokuno [1]; Daichi Inoue [1]; Toyohisa Asaji [2]; Masayuki Muramatsu [3]; Atsushi Kitagawa [4]; Yushi Kato [1]

[1] *The University of Osaka*

[2] *The University of Shiga Prefecture*

[3] *QST*

[4] *National Institutes for Quantum Science and Technology (QST)*

**Corresponding Author:** u492084e@ecs.osaka-u.ac.jp

We have been studying efficient production of multicharged ions in electron cyclotron resonance (ECR) ion source (ECRIS) based on experimental facts and theoretical considerations. We are conducting experiments in mixing low Z gases, which is widely known empirically as a method for efficient production of multicharged ions. Furthermore, low-frequency electromagnetic waves have been introduced to the experiment to enhance effect of the low Z gas mixing.
Specifically, we conduct experiments in which Ar and He gases are introduced into Xe operation gases and then selectively heat low Z ions (Ar+ and He+) by ion cyclotron resonance (ICR) to actively promote the cooling effect of multicharged Xe ions. Experiments of ICR selectively heating are conducted by using electromagnetic waves with frequencies of 40kHz for Ar and 400kHz for He.

Multicharged Xe ion beam currents extracted from ECRIS are increased by introducing low-frequency electromagnetic waves. When He was introduced, the multicharged Xe ion currents increased significantly compared to Ar case. Next, the emittance of each ion beam was measured in both of Xe/Ar and Xe/He cases. Since the effect of the magnetic field strength on emittance in our ECRIS is considered to be comparable to ion temperature's one, we conduct under constant magnetic field strength. We confirmed the effect of ICR selectively heating He+ and Ar+ from rms emittance values derived from multislit method and corresponding primary profiles of beam current. Rms emittances of ion species heated by ICR is tending to be higher than those without ICR. Therefore, low Z ions are heated by introducing low-frequency electromagnetic waves. We consider these results cause the increase of multicharged Xe ion beam currents due to enhance ion cooling effect. We conduct the same measurements for multicharged Xe ions in progress. We also obtain the corresponding plasma parameters. In this report, we describe the details of these experimental results.

**Poster Session / 66**

## Low-energy charged particle extraction from an RF-driven negative hydrogen ion source

**Author:** Katsuhiro Shinto[1]

**Co-authors:** Takanori Shibata [2]; Kiyonori Ohkoshi [3]; Kesao Nanmo [4]; Kentaro Tobita [5]; Motoi Wada [6]

[1] *J-PARC center/Japan Atmic Energy Agency*

[2] *KEK*

[3] *JAEA*

[4] *J-PARC/KEK*

[5] *NECO*

[6] *Doshisha University*

**Corresponding Author:** kshinto@post.j-parc.jp

We have been investigating the optical emission spectra of hydrogen plasma in a cesiated RF-driven negative hydrogen ion source [1] and the time dependent behavior of the extracted $H^-$ beam from the ion source [2-6] for utilization in particle accelerators. A new diagnostic method that measures electrical current flowing from the ion source to the extraction electrode was tested. The ion/electron current characteristics in both with and without cesium cases were measured by scanning the bias voltage between the plasma electrode and the extraction electrode of the ion source. The measured I-V characteristics for cesiated operation conditions exhibited substantially lower negative charge current compared with those for operations of the source prior to the Cs introduction. When an adequate quantity of cesium is introduced for the purpose of high $H^-$ beam current extraction, the I-V characteristics manifest formation of an ionic plasma [7]. Dynamic change of the extraction current measured by the method may suggest outflow of high energy electrons in the ignition phase of ion source discharge.

References
[1] T. Shibata et al., AIP Conf. Proc., Vol. 2011, 020008 (2018).
[2] K. Shinto et al., AIP Conf. Proc., Vol. 2011, 080016 (2018).
[3] M. Wada et al., Rev. Sci. Instrum., Vol. 91, 013330 (2020).
[4] T. Shibata et al., AIP Conf. Proc. Vol. 2373, 050002 (2021).
[5] M. Wada et al., J. Inst., Vol. 19, C02019 (2024).
[6] M. Wada et al., J. Phys.: Conf. Ser., Vol. 2743 012031 (2024).
[7] Y. Takeiri et al., AIP Conf. Proc., Vol. 1655, 060004 (2015).

**Poster Session / 82**

# On the pronounced increase of the co-extracted electron current during long pulses in H-/D- negative ion sources for fusion

**Author:** Joey Rubin[1]

**Co-authors:** Dirk Wünderlich [1]; Ursel Fantz [1]

[1] *IPP Garching - ITED division - NBI group*

**Corresponding Author:** joey.rubin@ipp.mpg.de

The negative ion sources for ITER's NBI must provide 47 A of negative ion current in hydrogen ($H^-$) and 40 A in deuterium ($D^-$). Particles must be accelerated to 870 keV for 1000 s in H and to 1 MeV for 3600 s in D. Inherently, the extracted negative ions are accompanied by co-extracted electrons, which must be removed from the beam. Magnets are embedded in the extraction system to deflect electrons onto one of the grids. The resulting heat load on the grid is a critical limitation : under full-performance conditions, ITER's grid design requires the co-extracted electron current $I_e$ to stay below the extracted negative ion current $I_{ext}$. The ELISE test facility hosts a negative ion source at half the scale of ITER's and supports its development. Since 2021, ELISE has been capable of performing long pulses (> 100 s) with continuous extraction. The present work provides an overview of these campaigns. The main outcome is that $I_e$ remains difficult to keep low, stable, and vertically symmetric –particularly in deuterium. Notably, $I_e$ rises significantly during long pulses, although this rise is not monotonic. A range of diagnostic data has been analyzed to investigate the origin and time dependence of this behavior. The evolution of $I_e$ is found to correlate with several parameters, including caesium concentration, negative ion and electron densities, plasma potential and sheath potential drop. Based on these observations, a mechanism is proposed to explain the temporal evolution of the co-extracted electron current, outlining a sequence of contributing effects. Particular attention is given to the differences between hydrogen and deuterium.

**Poster Session / 112**

# Development progress of negative beam source for the CRAFT NNBI

**Author:** Chundong Hu[1]

**Co-authors:** Jianglong Wei [1]; Lizhen Liang [1]; Wei Liu [2]; Yongjian Xu [2]; Yuming Gu [1]; yahong xie [1]

[1] *ASIPP*

[2] *Insititute of Plasma Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences*

**Corresponding Author:** cdhu@ipp.ac.cn

Neutral beam injection (NBI) is one of the most effective ways for the plasma heating and current driver. The negative based NBI was proposed for the fusion device, especially for the fusion reactor. In order to support the development of fusion energy, a large scientific device, the Comprehensive Research Facility for Fusion Technology (CRAFT) was under-development in China. A negative beam source based neutral beam injector (NNBI) with beam energy of 200-400 keV, beam power of 2 MW and beam duration of 100 s is one of the sub-system. The radio frequency (RF) based negative beam source was employed for the CRAFT NNBI system. There have several different sizes of negative beam sources, such as single driver, double drivers and four drivers.

The double drivers negative beam source was half size of the CRAFT NNBI source. It contains two RF drivers, an expansion chamber and a negative ion accelerator with three electrodes, which is plasma grid (PG), extraction grid (EG) and ground grid (GG). The extracted beam size around 320 mm × 800 mm. A complete negative beam test facility was developed at the same time. The half-size beam source was tested and achieved the long pulse of 50s with beam energy of 200 keV. The RF power is 75 kW with two drivers, the extracted voltage is 7 kV and the extracted negative hydrogen current is 10.5 A. The ratio of electrons to negative ions is around 0.5 and the extracted ion current density is 178 A/m2. The temperature of accelerator almost got the equilibrium state, which shows long pulse operation ability. During higher power and long pulse is still under conditioning and exploration.

The results and lessons lays good foundation for the R&D of full size negative ion source for CRAFT NNBI system.

**Poster Session / 172**

## Development and First Results from SupRISE: An RF-Driven Ion Source for Neutral Beam Injection

**Author:** Brendan Crowley[1]

**Co-authors:** Evan Kallenberg [2]; Kurt Van Lakwijk [3]; Kirtan. M Davda [4]; Md Sazzad Hossain [4]; Arthur. G Mazzeo [4]; Miral Shah [4]; Keanu J Ammons [4]; Amanda Lietz [4]; Steven C Shannon [4]; Florian Laggner [4]; J. Timothy Scoville [1]

[1] *General Atomics*

[2] *General Atomics/NCSU*

[3] *Eindhoven University of Technology*

[4] *North Carolina State University*

**Corresponding Author:** crowleyb@fusion.gat.com

Neutral Beam Injection (NBI) is widely used for non-inductive heating, current drive, fueling, and diagnostics in most major magnetic confinement fusion devices. The DIII-D tokamak operates with eight NBI ion sources based on the U.S. Common Long Pulse Source (CLPS) design, delivering a total output power of up to 20 MW. Over the years, the DIII-D NBI system has undergone significant evolution, incorporating various enhancements that have endowed it with unique features and capabilities. These include beamlines capable of both on- and off-axis injection, co- and counter-current injection, as well as pre-programmed and feedback-controlled variable power and energy injection. In recent years, however, system reliability has declined due to aging ion source components and fatigued power supplies. In response, the DIII-D NBI team has launched a program to renew and modernize key NBI technologies. Central to this effort is the development of a radiofrequency (RF)-driven, inductively coupled plasma (ICP) ion source that is compatible with the existing DIII-D infrastructure. The objective is to develop a large-area ion source with high plasma uniformity and a favorable species mix, suitable for extraction of up to 70 A of ion current with a target divergence of less than 20 mRad vertically and 5 mRad horizontally.
To this end, a full-scale test device—**the Superior Radiofrequency Ion Source Experiment (SupRISE)**—has been constructed. The primary aim is to investigate how power coupling to the plasma is influenced by drive frequency, antenna design, and chamber geometry. SupRISE uses a four-turn copper antenna to couple up to 50 kW of RF power into a racetrack-shaped (~70 × 30 × 30 cm) quartz vessel, operating at frequencies between 4–8 MHz. Also central to the study are the properties and performance of the RF power supply and impedance-matching unit.
Presented is an overview of the SupRISE source engineering and design, along with initial experimental results. Systematic scans of power, frequency, pressure, and matching conditions are performed to explore the plasma response using Langmuir probe and optical emission spectroscopy diagnostics. Results are compared to both analytical and computational models.

This work is supported by US DOE under DE-SC0024523 and DE-FC02-04ER54698

**Oral Session / 77**

## Review of ion sources for charged particle radiotherapy - status, challenges and future trends

**Author:** Atsushi Kitagawa[1]

[1] *National Institutes for Quantum Science and Technology (QST)*

**Corresponding Author:** kitagawa.atsushi@qst.go.jp

In order to treat a deep-seated tumor in a body by radiations, it is important to decrease the damage to normal organs surrounding the tumor. The high energy ion beam gives the good localized dose distribution on such tumors. This advantage was proposed by R. Wilson in 1946. First, proton beams have been utilized since 1954, after that, heavier ion beams have been utilized since 1970s at LBNL. Several institutes followed LBNL as pioneers in the dawn of the charged particle radiotherapy from 1950s to 1990s. Almost of them converted accelerators from physics research to medicine. Their ion sources were various due to their primary purposes and ages. The medical specified facilities have been constructed in 1990 at Loma Linda Univ. for proton and in 1994 at QST for heavy ion. The follower was only one hospital in the 20th century, however the commercial based facilities has become widespread now. This review summarizes the status of their ion sources.

The performances of an ion source are classified into some categories, such as power, efficiency, reliability and cost effectiveness. The optimizing of parameters frequently shows a conflict between them. For example, in the case of the production of carbon ions, the carbon deposition affects the condition of the surface of the chamber wall. This phenomenon causes the decreasing of the intensity and the short-term stability together. The lower microwave power improves the short-term stability, however decreases the intensity simultaneously. The two-frequency heating technique improves both the short-term stability and the intensity, though it is expensive. The technology becomes established during over 30 years of experiences. The optimizing for the existing facilities has been continued. In addition, new ideas have been proposed for a future facility. It seems there is still room for further developments to improve an ion source. This review also introduces past, present and future challenges and its trends.

**Oral Session / 12**

## Overview and performance of the MAST Upgrade Neutral Beam Injectors.

**Author:** Maria Nicassio[1]

**Co-authors:** Andrew Ash [1]; Christopher Tame [1]; Dean Payne [1]; Hana El-Haroun [1]; Ian Day [1]; Jake Ashton [1]; James Edmond [1]; James Goatley [1]; Jamie Smith [1]; Martyn Walsh [1]; Matthew Lees [1]; Paul Jepson [1]; Ridhima Sharma [1]; Robert King [1]; Robert Proudfoot [1]; Robert Seath [1]; Roy McAdams [1]; Stephen Marsden [1]; Thomas Wilson [1]; damian king [1]

[1] *UKAEA*

**Corresponding Author:** maria.nicassio@ukaea.uk

The MAST Upgrade machine is equipped with two Neutral Beam Injectors, which deliver on- and off-axis deuterium neutral beam power to the tokamak plasma. The injectors are based on filament driven arc discharge ion sources (Positive Ion Neutral Injectors, PINIs) in "supercusp"filter field configuration with a maximum design deuterium beam voltage and current of 75 kV and 65 A, respectively. The injectors have been operating since 2020 after undergoing major upgrades to the beamlines and power supplies to fulfil the operational requirements of pulse lengths up to 5 s and off-axis injection. In this contribution an overview of the beamlines and ion sources is presented and the performance and operational experience with pulse lengths of up to 1 s and total average power of 3 MW discussed. Future improvements to the system, with emphasis on the ion source power supplies, for reliable operations at higher power and longer pulse lengths are outlined.

**Oral Session / 174**

## Silvaco Exhibitor Talk

**Corresponding Authors:** andrew.patterson@silvaco.com, david.green@silvaco.com

**Oral Session / 17**

## Theoretical and numerical study of the ECRIPAC accelerator concept

**Author:** Andrea Cernuschi[1]

**Co-authors:** Laurent Garrigues [2]; Thomas Thuillier [3]

[1] *CNRS-LPSC, Université Grenoble Alpes*

[2] *LAPLACE, Université de Toulouse, CNRS*

[3] *CNRS-LPSC*

**Corresponding Author:** andrea.cernuschi@lpsc.in2p3.fr

This work presents a comprehensive study of the Electron Cyclotron Resonance Ion Plasma Accelerator (ECRIPAC) concept, an idea developed in the nineties for a compact, plasma-based accelerator capable of producing high-energy pulsed ion beams using robust and well-established technologies. The limited literature and absence of experimental prototypes motivate further studies on the topic.

The ECRIPAC concept is strongly intertwined with Electron Cyclotron Resonance Ion Source (ECRIS), exploiting similar physical principles for their operation and including an ECRIS as injector in its original design. The physical and technological similarities between ECRIPAC and ECRIS will be explored and discussed, reviewing the physical theory behind ECRIPAC with novel corrections to the existing literature.

Afterwards, a detailed theoretical analysis of the ion acceleration stability condition is conducted, revealing more stringent limitations than previously anticipated and examining the influence of various physical parameters on the accelerator's performance. Based on this analysis, a compact accelerator design is proposed, capable of accelerating $He^{2+}$ ions to 9.5 MeV per nucleon within a 1.8-meter-long cavity. Finally, a Monte Carlo particle-tracking code is used to study the electron population behaviour within the proposed accelerator design. The simulation results validate the theoretical treatment of ECRIPAC and provide insights into the effects of important physical parameters on electron dynamics during operation.

**Oral Session / 138**

## Space Charge Compensation in Negative Hydrogen Ion Beams: A Particle-In-Cell Study

**Authors:** Alejandro Garcia Sosa[1]; Benzi John[2]; Dan Faircloth[2]; David Emerson[2]; Dean Morris[2]; Erin L. Flannigan[2]; Kiran Jonathan[2]; Olli Tarvainen[2]

[1] *STFC - Rutherford Appleton Laboratory*

[2] *STFC*

**Corresponding Author:** kiran.jonathan@stfc.ac.uk

Negative hydrogen ion sources have applications across many fields, from particle accelerators (e.g., for high-energy applications in facilities such as CERN, or in spallation neutron source facilities such as ISIS) to magnetic fusion experiments (e.g., those utilising neutral beam injection for plasma heating and diagnosis). In the case of particle accelerators, a common cause of transport losses is the beam divergence due to space charge effects in the low energy beam transport (LEBT) region.

As such, space charge compensation (SCC) [1] is crucial to counteract the repulsive space charge forces and maintain efficient transport. In the case of the ISIS H- ion beamline source, the SCC process is mainly derived from interactions between the beam and a neutral background gas, which can produce positive compensating ions that help to reduce the local charge density and electric field.

The present work is a collaborative effort which aims to combine high-fidelity simulations and experimental diagnostics to explore the SCC process, with ultimate goals of supporting ISIS operations and informing designs for upgrades to the ISIS facility. The particle-in-cell (PIC) code PICLas [2] has been used to perform multi-reaction framework simulations of the SCC process in negative hydrogen ion beams, allowing for the exploration of how key parameters such as external magnetic fields, secondary electron emission, and boundary conditions can impact the SCC time and degree. Simulation results will be compared to diagnostic data from ISIS and the Front-End Test Stand (FETS), where experiments have been conducted to correlate the beam transport and light emissions with the SCC process.

REFERENCES

[1] C. A. Valerio-Lizarraga et al., Phys. Rev. Accel. Beams 18, 080101 (2015).
[2] S. Fasoulas, et al., Physics of Fluids, 2019, 31(7): 072006 (2019).

**Oral Session** / **154**

## Electron Cyclotron Resonance Supernanogan Ion Source Commissioning for the Sarajevo Ion Accelerator (SARAI)

**Authors:** Amer Ajanovic[1]; Oleksandra Khrul[2]

**Co-authors:** Alessandra Lombardi [2]; Alexander Pikin [3]; Aristeidis Mamaras [4]; Azra Gazibegovic-Busuladzic [5]; Danis Bradaric [5]; Eleonora Pasino [2]; Elvedin Hasovic [5]; Francesco Di Lorenzo [2]; Jean-Baptiste Lallement [2]; Marten Koopmans [6]; Maurizio Vretenar [2]; Naida Ustavdic [5]; Tomaz Meglic [7]; Tomaz Tratnik [7]; Urban Bobek [7]

[1] *CERN / UNSA*

[2] *CERN*

[3] *CIEMAT*

[4] *Aristotle University of Thessaloniki | CERN*

[5] *University of Sarajevo*

[6] *ESS*

[7] *COSYLAB*

**Corresponding Author:** amer.ajanovic@cern.ch

The Sarajevo ion accelerator (SARAI) comes as a result of a successful transfer of the CERN's 750 MHz radiofrequency quadrupole (RFQ) technology, adapted for societal and medical applications. Designed to generate alpha particles and ions with a charge-to-mass ratio of 1/2 for ion beam analysis research, SARAI incorporates an industrial electron cyclotron resonance supernanogan ion source operating at 14.5 GHz. The system is equipped with a pentode extraction system capable of extracting and focusing multiple ion species at voltages up to 30 kV. The source has been optimized at CERN for injection into an existing 750 MHz, 2.5 MeV/u RFQ with an overall acceptance of 0.25 mm mrad normalised, initially with protons, followed by helium and carbon ions. This paper focuses on comparing the experimental results obtained during source commissioning to beam dynamics simulation of the source extraction system.

**Oral Session** / **125**

## The role of ECR ion sources in superheavy element synthesis

**Author:** Janilee Benitez[1]

[1] *Lawrence Berkeley National Lab*

**Corresponding Author:** jybenitez@lbl.gov

Superheavy element (SHE) research focuses on understanding the structure of the heaviest nuclei at the edges of the proposed Island of Stability as well as the synthesis of new elements. Electron Cyclotron Resonance (ECR) ion sources are an important part of this endeavor since superheavy elements (z>104) can be created by bombarding a target with an ion beam that is often produced by an ECR at many facilities. The synthesis of these elements through reactions that have low cross-sections requires intense ion beams of 48Ca, 50Ti, 51V, 54Cr, and 55Mn, for example, in addition to beam delivery for weeks or more. The need for high intensities, coupled with the low isotopic abundance of some of these metals, and thus low availability, requires efficient production methods and careful tuning. These beams are produced by an ECR using various methods that include low temperature ovens, resistively heated high temperature ovens, inductive ovens, sputter probes, and MIVOC. I will summarize the production techniques and the results achieved by ECR ion sources around the world.

**Oral Session / 130**

## Development of key technologies for 4th generation ECR ion sources-microwave launching and innovative solutions for plasma chamber cooling

**Author:** Junwei Guo[1]

**Co-author:** Guillaume Machicoane [1]

[1] *Facility for Rare Isotope Beams, Michigan State University*

**Corresponding Author:** guoju@frib.msu.edu

Highly efficient microwave coupling and plasma chamber that can handle high power are key technologies for the existing third-generation ECR ion source operating at 24~28 GHz/10 kW and as well for the new fourth-generation ECR ion source operating at 45 GHz/25 kW. The use of a small-diameter waveguide antenna was first demonstrated that changing the microwave power distribution on the ECR surface could enhance the performance of the 24 GHz ion source, and the later proposed a removable Vlasov launcher further improved the source performance. An innovative plasma chamber with micro-channel cooling structure was developed and validated to be durable up to a total power of 11 kW. A plasma chamber for the 4th generation ECR source expected to operate reliably at 25 kW has been developed and is currently being commissioned. This talk will review the details of these two key technologies.

**Oral Session / 90**

## FECR: A 28~45 GHz Next Generation Ion Source and Its First Results

**Author:** Liangting Sun[1]

**Co-authors:** Beimin Wu [1]; Bin Li [1]; Canjie Xin [1]; Enmin Mei [1]; Hongwei Zhao [2]; Jindou Ma [1]; Libin Li [3]; Lixuan Li [2]; Mingzhi Guan [1]; Peng Zhang [1]; Shijun Zheng [1]; Wang Lu [2]; Xianjin Ou [1]; Xudong Wang [1]; Xuezhen Zhang [2]; Yao Yang [4]; Yucheng Feng [1]; Yuquan Chen [1]

[1] *Institute of Modern Physics, CAS*

[2] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

[3] *Institute of Modern Physics, Chinese Academy of Sciences*

[4] *nstitute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

**Corresponding Author:** sunlt@impcas.ac.cn

Driven by the fast development of heavy ion linacs and next generation heavy ion accelerators, higher performance high intensity highly-charged heavy ion beams are strongly needed. The next generation ECR ion sources operated at 45~56 GHz have the potential to produce highly charged ion beams with the intensities by several folds of those for the 3rd generation ECR ion sources. A 4th generation ECR (Electron Cyclotron Resonance) ion source FECR (First 4th generation ECR ion source) has been developed at IMP recently. Aiming to be operated with the microwave power of 20 kW at 28~45 GHz, FECR is expected to be equipped with a fully superconducting Nb3Sn magnet and conventional parts durable for high power ECR plasma heating and optimum for intense beam production and extraction. For the complexity of strong stresses during the Nb3Sn coils assembly, a hybrid superconducting ECR ion source FECR whose magnet is composed by Nb3Sn solenoids and NbTi sextupole coils as a prototype of the next generation ECR ion source has been developed. The preliminary test of FECR at 28 + 45 GHz has enabled the production of 360 eμA Bi35+ and >600 eμA Bi31+. This paper will present the development of FECR ion source and its first plasma with 45 GHz microwave power heating.

**Oral Session / 110**

## Prospects and challenges of the next generation highly-charged ECR ion source

**Authors:** Hongwei Zhao[1]; Liangting Sun[1]; Zuqi Xie[2]

[1] *Institute of Modern Physics, Chinese Academy of Sciences*

[2] *Retiree of Nuclear Science Division, Lawrence Berkeley National Lab, Berkeley, USA*

**Corresponding Author:** zhaohw@impcas.ac.cn

High performance highly-charged ECR ion sources have been operated for more than 40 years to deliver highly-charged heavy ion beams for worldwide cyclotron and linac heavy ion accelerators. Successful operations of the 3rd generation highly-charged ECR ion sources operating at 24-35 GHz microwave frequency such as LBNL 28GHz VENUS, IMP 24-28 GHz SECRAL&SECRAL-II, RIKEN 28 GHz SCECRIS and FRIB 28GHz SCECRIS, have demonstrated amazing performance in terms of beam intensity and charge state typically 5-10 pμA 238U35+ - 238U40+, which have boosted dramatically the performances of cyclotrons and linacs from the point of view of beam intensity and energy. Demands for higher intensity and higher charge state of heavy ion beams keep increasing particularly for high intensity heavy ion superconducting linacs. The 4th generation ECR ion source operating at 45-56 GHz microwave frequency is being developed worldwide to produce higher charge state heavy ion beams with higher intensity targeting 5-10 pμA 238U45+ - 238U50+. This paper will present an overview of developments and technical challenges of the 4th generation ECR ion source focusing on high power microwave coupling and high field minimum-B superconducting magnet. Concept of the 5th generation highly-charged ECR source will be proposed operating at 65-84 GHz microwave frequency targeting 5-10 pμA 238U60+ - 238U65+. Innovative structure of minimum-B superconducting magnet and performance prospects for the 5th generation ECR source will be presented and discussed in this paper.

**Oral Session / 167**

## Diagnostic beam for ITER (INTF): Status and accompanying research

**Author:** Mahendrajit J. Singh[1]

[1] *ITER India, Institute for Plasma Research, Bhat, 382428, Gandhinagar, India.*

**Corresponding Author:** mahendrajit.singh@iterindia.in

The Diagnostic Neural Beam (DNB) for ITER is a part of India's in-kind commitment to ITER. The 100 keV 20 A Ho beam shall be used to monitor He ash fraction using the CXRS diagnostic technique. Realizing DNB to meet the operational goals is challenging both from the engineering and operational perspectives.
The engineering perspective of first of kind large sized components includes various aspects of materials, precision machining over sizeable areas, jointing of similar and dis-similar materials, assembly, alignment and testing to ensure the strict quality and safety norms. Compliance is necessary to enable components to survive the life time of ITER with minimal maintenance requirements. From the point of view of operations, 100 keV 60 A H- beams are required from 1280 beamlets extracted and accelerated from the 2 m x 1 m ceisated RF source with a beamlet divergence between 5-7 mrad. At ITER India both these perspectives have been addressed in parallel.
On the engineering front, DNB beam line components like the neutralizer, electrostatic residual ion dump and the calorimeter with a vacuum sealed insitu movement mechanism have been manufactured, tested and accepted. Most of the components of the RF beam source and the 3-grid extractor and accelerator system have been realized. During the course of manufacturing several design changes emerging from the experimental learnings from the SPIDER beam source development facility at RFX Padua have been incorporated to ensure better source performance. While the beam source is in its assembly stage, the accepted beam line components have been installed in the 9 m long 4.5 m diameter vacuum vessel with a top openable lid on the Indian test facility (INTF). The INTF is a voluntary activity with the beam source, neutralizer and ERID loaned from ITER. Such an arrangement enables DNB like beam studies over a path length of 21 m and is expected to create a database of use for diagnosticians responsible for ITER CXRS diagnostics.
In order to pursue working experience and learnings with H- beams, two test beds, single driver RF source "ROBIN"and dual driver RF source "TWIN"are currently under operation at ITER India. ITER relevant H- beams in terms of current densities > 30 mA/cm2 and electron/ion ratios < 1 have at source filling pressures of 0.3 –0.4 Pa have been realized on ROBIN. The TWIN has been used to couple powers upto 60 kW to the two drivers connected to a single RF generator in DNB like configuration. ROBIN has also been used to study the effect of confinement magnets on the plasma and beam uniformity. Recently it has been upgraded to a neutral beam line where 30 keV ~1 A neutral beams have been produced and transported to understand aspects related to neutralization, reionisation and also to establish the functionality of the first of a kind electrostatic residual ion dump concept in neutral beam lines.
The talk will cover both, the engineering and operational aspects of DNB related neutral beam activities at ITER India, IPR, with a special emphasis on learnings, results obtained and future plans.

**Oral Session / 50**

## Beam current performance in the ITER negative ion source prototype SPIDER

**Author:** Alastair Shepherd[1]

**Co-authors:** Antonio Pimazzoni [2]; Basile Pouradier-Duteil [3]; Emanuele Sartori [4]; Gianluigi Serianni [5]; Giulia Emma [4]; Isabella Mario [2]; Riccardo Casagrande [2]; Valeria Candeloro [2]

[1] *UKAEA*

[2] *Consorzio RFX*

[3] *CEA*

[4] *Università degli Studi di Padova*

[5] *Institute for Plasma Science and Technology of the Italian National Research Institute*

**Corresponding Author:** alastair.shepherd@ukaea.uk

SPIDER is the full-sized ion source prototype for the ITER Heating Neutral Beams (HNB). Hosted by Consorzio RFX in Padova, Italy, it forms part of the ITER Neutral Beam Test Facility (NBTF). SPIDER has for the first time operated with fully opened beam segments, up to ¼ of the designed beam

extraction area. With an increase in the maximum achieved RF power and acceleration voltage, this has enabled SPIDER to take a substantial step towards the ITER HNB requirements of 60 A extracted current at 100 keV.
As the first negative ion beam source fully enclosed in a single vacuum, SPIDER has presented some unique challenges for high power operation. RF induced breakdowns at the rear of the source drove the initial decision to reduce the number of open beam apertures, so to reduce the pressure at the back of the source while keeping the same filling pressure in the plasma chamber. The recent increase in the number of open apertures from 28 to 300 has resulted in an increase in the beam-generated plasma downstream of the accelerator. Due to the enclosed nature of the vacuum and the electromagnetic field generated by the source, the high voltage power supplies collect some of these additional charges, complicating the measurement of the beam current.
This contribution describes the assessment of the SPIDER beam current for three different source configurations, and the impact of steps taken to remediate the issue. Source parameter dependences are discussed, for both the beam and the additional current.

**Oral Session / 54**

## Characterization of the properties of negative hydrogen ion beam of CRAFT NNBI test facility

**Author:** Yongjian Xu[1]

**Co-authors:** Chundong Hu [2]; Jianglong Wei [2]; Lizhen Liang [1]; Wei Liu [2]; Yahong Xie [2]

[1] *Institute of Plasma Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences*

[2] *Insititute of Plasma Physics, Hefei Institutes of Physical Science, Chinese Academy of Sciences*

**Corresponding Author:** yjxu@ipp.ac.cn

The Comprehensive Research Facility for Fusion Technology (CRAFT) serves as an integration of diverse testing and demonstrating facilities. Its primary aim is to develop crucial technologies and key prototype systems for the magnetic confinement fusion reactor.Neutral beam injection (NBI) system, as an effective means of plasma heating, has been widely adopted in magnetic-confinement nuclear fusion devices. In the pursuit of delving into the physical and engineering aspects of Negative Ion Source Neutral Beam Injection (NNBI) and accumulating operational experience with RF-driven negative ion sources, several diagnostic techniques are employed to characterize the beam properties of the CRAFT negative ion source. These techniques include One-Dimension Carbon Fibre Composite (1D-CFC) calorimeters, Tungsten Wire Calorimeters (TWC), Beam Emission Spectroscopy (BES), Secondary Electron Detector (SED), and Water Flow Calorimetry (WFC).The main beam parameters, such as beam divergence, homogeneity, and asymmetries, are examined under different operational scenarios, which involve different magnetic filter field setups and source settings. The impact of the magnetic field configuration on the beam homogeneity and asymmetries, as well as the evolution of the beam features, is investigated thoroughly. Meanwhile, the relationship between the beam divergence and source settings is also explored.

**Oral Session / 106**

## Investigating the origin of the pressure dependence on the beam divergence at an RF negative hydrogen ion source

**Author:** Christian Wimmer[1]

**Co-authors:** Dimitar Yordanov [1]; Dirk Wünderlich [1]; Jasper Knaack [1]; Julian Hörsch [1]; Ursel Fantz [1]

[1] *Max-Planck-Institut f. Plasmaphysik*

**Corresponding Author:** christian.wimmer@ipp.mpg.de

Negative hydrogen ion sources for fusion rely on the surface conversion of hydrogen atoms and/or positive ions to $H^-$ on low-work function (caesiated) surfaces. A low source filling pressure of 0.3 Pa is required to minimize stripping losses in the accelerator at ITER. Particularly in RF sources, the beam divergence depends strongly on the pressure –between 0.4 Pa and 0.3 Pa the divergence increases by 20%. The higher divergence is attributed to a higher temperature of negative ions, possibly originating from more energetic precursors. This opens up the question whether the energy distribution of the precursors and/or the relative relevance between the $H^-$ production channels from H atoms and $H_x^+$ changes with the filling pressure.
BATMAN Upgrade is a test facility equipped with a single-driver RF source with unique diagnostic capabilities. Beside beam tools such as CFC tile calorimetry and Beam Emission Spectroscopy to determine the beam divergence, a manifold of plasma diagnostics are available to characterize $H^-$ and its precursors: Cavity Ring-Down Spectroscopy for $n_{H^-}$, Two-photon Absorption Laser Induced Fluorescence for $n_H$ and $T_H$, Langmuir probes for $n_{H_x^+}$ and the plasma potential distribution, and a Mach probe for determining net fluxes of positive ions. In addition, a LED-based diagnostic gives access to the work function of the convertor surface and thus to the conversion probability and energy loss of precursors during $H^-$ production. Exemplarily, at 0.3 Pa a higher plasma potential drop from the plasma generation region to the $H^-$ production region is observed –possibly causing, in combination with the reduced collision rate at lower pressure, a more energetic flux of positive ions onto the convertor surface.
This contribution summarizes the present insight into the physics of the source filling pressure dependence on the precursor properties, the relevance of the production channels and the beam divergence.

**Oral Session / 157**

## Overlap of Plasma and Beam Properties in ITER-Relevant Negative Ion Sources

**Author:** Dirk Wünderlich[1]

**Co-authors:** Jasper Knaack [2]; Daniele Mussini [1]; Araceli Navarro [1]; Rudi Riedl [2]; Dimitar Yordanov [2]; Andreas Döring [2]; Ursel Fantz [1]; Isabella Mario [3]; Emanuele Sartori [4]; Barbara Zaniol [5]; Carlo Poggi [6]; Pierluigi Veltri [6]

[1] *Max-Planck-Institut für Plasmaphysik*

[2] *Max-Planck-Institut f. Plasmaphysik*

[3] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127 - Padova, Italy*

[4] *Università degli Studi di Padova*

[5] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete S.p.A.), Corso Stati Uniti 4, 35127 Padova, Italy*

[6] *ITER Organization*

**Corresponding Author:** dirk.wuenderlich@ipp.mpg.de

The ITER neutral beam injection (NBI) system will deliver a large negative deuterium or hydrogen beam (≈2 m×1 m) with an accelerated current of 40 A negative deuterium ions (46 A in hydrogen). The ion beam is extracted from an ion source where a plasma is generated in eight cylindrical RF drivers by inductive coupling ($P_{RF}$<100 kW/driver, f=1 MHz). Four horizontal pairs of drivers are powered in series by one RF generator each. The plasma expansion and overlap into a rectangular vessel is strongly affected by vertical plasma drifts. The resulting plasma homogeneity close to the extraction system is of high relevance for the properties of the extracted negative ion beam and in particular for the co-extracted electrons.

Investigations on the plasma overlap have been conducted at the half-size (four RF drivers) test facility ELISE at IPP Garching by request of the ITER Organization to support the interpretation of similar experiments done at the full-size SPIDER test facility at Consorzio RFX, Padova. Systematic parameter variations have been done using either all the four RF drivers at the same time or only

the upper or lower pair of drivers. The plasma parameters from a comprehensive set of diagnostics as well as the properties of the beam are compared for these three operational modes.

While the results confirm the effect of drifts on the plasma expansion, the sum of the extracted negative ion current for individual operation of the top and bottom RF generators is higher than the current achieved when operating both generators. This demonstrates that at least one step in the process chain connecting the production of precursor particles (hydrogen atoms and positive ions), their transport and the production and extraction of negative ions shows a non-linear behavior. The contribution presents and discusses the results of the different investigations and their implications on the operation of large-area sources for negative hydrogen ions.

**Poster Session / 16**

## The effect of space-charge neutralization on charge breeding performance

**Author:** Fredrik Wenander[1]

**Co-authors:** Jone Etxebarria Erdoiza [2]; Anton Gunnarsson [1]; Concepcion Oliver [2]; alexander Pikin [2]

[1] *CERN*

[2] *CIEMAT*

**Corresponding Author:** fredrik.wenander@cern.ch

The recently introduced non-adiabatic electron gun at the REXEBIS has shown excellent charge breeding results for a very low number of injected stable and radioactive ions. When increasing the number of ions, the effective electron current density is immediately affected. We have studied these effects and tried to mitigate the performance loss by the use of ion-ion cooling evaporation, although with limited success. The measurements from this semi-immersed electron gun have been correlated with similar tests performed with a Brillouin gun at the TwinEBIS setup. In this paper, both experimental results and simulations will be presented, with a discussion about the observed discrepancies and possible reasons.

**Poster Session / 27**

## Advancements in the Antenna Based Miniaturized 2.45 GHz Permanent Magnet ECR Ion Source at Peking University

**Authors:** Bujian Cui[1]; Shixiang Peng[1]; Tenghao Ma[None]; Jianbin Zhu[None]; Yicheng Dong[None]; Zhiyu Guo[None]; Jiaer Chen[None]

[1] *Peking University*

**Corresponding Author:** 2101110316@pku.edu.cn

The 2.45 GHz electron cyclotron resonance (ECR) ion source offers several advantages, including high ion current intensity, low ion beam emittance, excellent stability, a relatively simple structure, cost-efficient, and an extended operational lifespan. Consequently, it is the preferred choice for generating high-intensity ion beams in various ion beam facilities. Nowadays numerous compact devices such as neutron tubes, ion thrusters, EUV lithography cleaners, and medical accelerators require the miniaturized plasma sources. Therefore, promoting the miniaturization of the 2.45 GHz ECR ion sources is crucial for their broad range of applications. However, the miniaturization of ECR ion sources faces limitations due to challenges associated with RF transmission and microwave coupling. Therefore, innovative methods for microwave coupling beyond ridge waveguide or microwave window are urgently needed. Recently, an antenna based microminiature 2.45 GHz ECR ion source was designed and tested at Peking University (PKU). This source features a discharge chamber diameter of only 13 mm and has a body weight of 1.5 kg. Numerical models were developed to optimize the antenna structure and characterize plasma properties effectively. Initial tests were carried out on PKU ion source test bench and 2.2 mA hydrogen current load can be achieved with 10 W RF power in DC mode. When microwave power increased to 40 W, the current went up to 11.2 mA with a $H^+$ ratio of 47.1%. Furthermore, long-term operation confirmed the stability of this novel source design.

**Poster Session / 63**

## Modeling and Operation of an Electromagnetic Isotope Separation System for Ytterbium-176 Production

**Author:** Allan Jarvine[None]

**Corresponding Author:** allan.jarvine@kinectrics.com

As radiopharmaceutical therapy gains prominence in the targeted treatment of certain cancers, global demand for radionuclides—particularly the beta-emitting lutetium-177—is rapidly increasing. Lutetium-177 is widely used in treating advanced neuroendocrine tumors and prostate cancer, and it is also well-suited for theranostic applications. Traditionally, production of lutetium-177 has relied primarily on direct neutron irradiation of the long-lived radioisotope lutetium-176, and to a lesser extent on neutron irradiation of the stable isotope ytterbium-176. For the latter route, several enrichment techniques have been developed, with laser-based isotope selectivity emerging as a novel approach. Nevertheless, the most established method for enriching ytterbium-176 remains electromagnetic isotope separation (EMIS), in which ions are extracted from a suitable source and directed through a bending electromagnet. This paper provides a high-level overview of Kinectrics' efforts in commissioning a first-generation EMIS system for the commercial production of highly enriched, chemically pure ytterbium-176. Particular attention is given to the advantages and limitations encountered when using the IBSimu particle tracking code to model ion beam extraction and transmission.

**Poster Session / 33**

## Developments towards autonomous optimisation and stabilisation of the CERN GTS-LHC ion source

**Authors:** Verena Kain[1]; Detlef Küchler[1]; Michael Schenk[1]

**Co-authors:** Levente Foldesi [1]; Adrian Menor de Oñate [1]; Borja Rodriguez Mateos [1]

[1] *CERN*

**Corresponding Author:** detlef.kuchler@cern.ch

Building on first experience with state-of-the-art model-based adaptive stabilisation algorithms, this contribution presents the results obtained at the LINAC3 ion source after introducing a hierarchical control architecture to better deal with the different response times after control parameter changes. Tailor-made algorithms were necessary to limit exploration during periods of change of the overall system. The obtained performance will be shown and the remaining challenges and steps towards operational deployment will be summarised.

**Poster Session / 35**

## Basic Commissioning of the ELIMED Line: challenges in the selection and extraction of a laser-driven beam

**Author:** Francesco Schillaci[1]

**Co-authors:** Andriy Velyhan [1]; Daniele Margarone [1]; Filip Grepl [1]; G.A. Pablo Cirrone [2]; Helena Lefabvre [1]; Lorenzo Giuffrida [1]; Maksym Tryus [1]; Nina Gamaiunova [1]; Pavel Blaha [1]; Valeriia Istokskaia [1]

[1] *ELI Beamlines*

[2] *INFN - LNS*

**Corresponding Author:** francesco.schillaci@eli-beams.eu

ELIMED is the ion transport and dosimetry section of the ELIMAIA laser-plasma accelerator [1].
In this contribution, we present the main characteristics and capabilities of the ELIMED ion beam transport system. We also describe the initial phases of the experimental testing, highlighting key results, challenges encountered, and the solutions adopted.
In particular, we report on the successful extraction of a selected ion beam with a central energy of 20 MeV with a 30% energy spread at FWHM, i.e. a spread ranging from 17 to 23 MeV, conresponding to a 7nsec bunch length at the sample location (7.5m downstream the interaction point). The achieved peak dose was of about 40mGy per laser shot which, with a 7nsec long bunch delivered to the irradiation point and successfully used for irradiation experiments of biological samples [2], both cells and embryos, as part of the ELI User Program.
These preliminary steps were crucial for enhancing the beam diagnostics along the line, improving control over beam transport, energy selection, and final beam shaping, with the goal to offer a more reliable machine to the users from different communities.

[1] The ELIMAIA Laser–Plasma Ion Accelerator: Technological Commissioning and Perspectives, F. Schillaci et al., Quantum Beam Sci. 2022, 6(4), 30; https://doi.org/10.3390/qubs6040030

[2] ELIMAIA-ELIMED: A new user platform for radiobiological research utilizing laser-driven protons, P. Blaha et al., Front. Phys. Sec. Accelerator Physics Volume 13 –2025, doi: 10.3389/fphy.2025.1567622

**Poster Session / 56**

## Development of HECRAL-C: A Cryogen-Free Hybrid Superconducting ECR Ion Source for Milliampere-Level $C^{4+}$ Ion Beam Production

**Authors:** Cheng Qian[1]; Jibo Li[2]; Liangting Sun[2]; Yao Yang[1]; Zehua Jia[1]

**Co-authors:** Jiaqing Li [1]; Libin Li [1]; Lixuan Li [2]; Pengpeng Wang [1]; Wang Lu [2]; Xing Fang [1]; Yun Cao [1]

[1] *nstitute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

[2] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

**Corresponding Author:** qianc@impcas.ac.cn

A novel hybrid superconducting Electron Cyclotron Resonance (ECR) ion source named HECRAL-C has been developed to produce milliampere-level $C^{4+}$ ion beams. It features a conduction-cooled superconducting axial magnet for 18 GHz operation and a Halbach-array radial hexapole made of high-coercivity and high- remanence NdFeB magnets. The development of HECRAL-C builds on the previous HECRAL ion source with a liquid-helium bath-cooled axial superconducting magnet designed for 24 GHz operation. HECRAL-C has been successfully commissioned and stably producing over 1 emA of $C^{4+}$ beams. Integrated with a newly designed Low Energy Beam Transport line (LEBT), it delivers a 1.2 emA $C^{4+}$ beam to the Radio Frequency Quadrupole (RFQ) accelerator with a normalized transverse emittance of 0.23 π·mm·mrad. This paper details the design and performance of HECRAL-C and the LEBT system.

**Poster Session / 64**

## Current status of the cesiated RF-driven negative hydrogen ion source and its R&D activities for future facility projects at J-PARC

**Author:** Katsuhiro Shinto[1]

**Co-authors:** Kiyonori Ohkoshi [2]; Takanori Shibata [3]; Kesao Nanmo [4]; Kentaro Tobita [5]; Kiyoshi Ikegami [4]; Akira UENO [6]

[1] *J-PARC center/Japan Atmic Energy Agency*

[2] *JAEA*

[3] *KEK*

[4] *J-PARC/KEK*

[5] *NECO*

[6] *J-PARC*

**Corresponding Author:** kshinto@post.j-parc.jp

More than a decade has elapsed since the radiofrequency (RF)-driven negative hydrogen ($H^-$) ion source initiated operation in the autumn of 2014 at J-PARC. Since the 2022/2023 campaign, $H^-$ beams with a beam current of 60 mA have been generated by a single RF-driven $H^-$ ion source in a campaign. The continuous operation time of the ion source reached 4,962 hours in the 2023/2024 campaign. In the 2024/2025 campaign, as of the end of April 2025, a single RF-driven $H^-$ ion source extracts the $H^-$ beams with a beam current of 62.5 mA for the J-PARC users and 75 mA for the accelerator beam studies aiming at the future delivery of the proton beam with a beam power of 1.5 MW to the Materials and Life Science Experimental Facility (MLF), which is currently delivered with a maximum of 1 MW. Concurrently, we are engaged in R&D activities of the ion source for the future J-PARC projects.

**Poster Session / 160**

## Progress towards 28 GHz operations of ECR ion sources at the Facility for Rare Isotope Beams (FRIB)

**Author:** Guillaume Machicoane[1]

**Co-authors:** Haoyu Cheng [1]; Junwei Guo

[1] *Michigan State University*

**Corresponding Author:** machicoane@frib.msu.edu

This paper review progress being made with FRIB superconducting ion source and the first results at 28 GHz operation. FRIB has now been in operations for over 3 years and deliver beam to the nuclear physics users with up to 20kW beam power on target. This beam power was achieved for many primary beams including Uranium and has been used routinely for experiments over the past year. In preparation to the next step at 50kW, over 100euA of U35+ has been obtained when coupling 2.5kW at 28GHz. This presentation goes over the operation of the ECR ion sources at FRIB with emphasis on the 28 GHz ECR ion source including solid beam and new beam development.
Work supported by the U.S. Department of Energy Office of Science under Cooperative Agreement DE-SC0023633, the State of Michigan, and Michigan State University.

**Poster Session / 83**

# LAMP ion source commissioning and future plans

**Authors:** Anna Alexander[None]; Evan Loftin[1]; Greg Dale[1]; Haoran Xu[1]; Isaac Wiens[1]; John Lewellen[1]; John Lyles[1]; Kip Bishofberger[1]; Maria Sanchez Barrueta[1]; Muhammed Zuboraj[1]; Remington Thornton[1]; Salvador Sosa[1]

[1] *LANL*

**Corresponding Author:** aalexander@lanl.gov

The LANSCE Modernization project (LAMP) is planning to replace the first 100 MeV of the LANSCE linac, from the ion sources through the end of the drift-tube linac. In addition to replacing the drift-tube linac and switching from dual Cockcroft-Walton injectors to a single RFQ, the existing filament based H- ion source will be replaced by RF-driven, SNS style ion source. This poster will describe our progress in commissioning the new H- ion source at our RFQ Test Stand, and in building a 35kV beamline for the existing H+ duoplasmatron to test dual-beam species through an RFQ for technical maturation. It will also describe future efforts planned as part of the LAMP project.

**Poster Session / 85**

# Plasma Conditions for High-Intensity $He^{2+}$ Beams: A Semi-Empirical Modeling Approach

**Authors:** Giuseppe Castro[1]; Grazia D'Agostino[2]; Luigi Celona[3]; Ornella Leonardi[4]; Santo Gammino[3]

[1] *Istituto Nazionale di Fisica Nucleare - LNS*

[2] *INFN-LNS div. Acceleratori*

[3] *INFN - LNS*

[4] *INFN-LNS*

**Corresponding Author:** castrog@lns.infn.it

The demand for high-intensity $He^{2+}$ ion beams is rapidly increasing, driven by applications in ad-vanced medical therapies and groundbreaking scientific research. The stringent requirements for these beams require a deep understanding of the interplay between plasma parameters and beam properties. Establishing this connection would enable strategic R&D advancements for next-generation ion sources.

This work presents a semi-empirical strategy to estimate the plasma conditions required to produce high-intensity $He^{2+}$. The approach is based on solving a non-linear system of balance equations for helium plasmas, incorporating the critical cross-sections of key reactions. The method accounts for the generation of helium ions, providing a comprehensive framework for optimizing ion sources' per-formances.

We will also discuss the theoretical methodology and explore the plasma parameter regimes necessary to enhance the production of high-intensity ion beams. These findings provide critical insights into the development of advanced ion sources tailored to the needs of the medical and scientific communities.

**Poster Session / 102**

# Ion Sources for CRYRING@ESR

**Author:** Gleb Vorobyev[1]

**Co-authors:** Aleksandr Andreev [1]; Claude Krantz [1]; Frank Herfurth [1]; Michael Lestinsky [1]; Sergiy Trotsenko [1]; Svetlana Fedotova [1]; Wolfgang Geithner [1]; Zoran Andelkovic [1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

**Corresponding Author:** g.vorobjev@gsi.de

CRYRING is a heavy-ion storage ring originally designed and operated at the Manne Siegbahn Laboratory (MSL), Stockholm. Recommissioned within the CRYRING@ESR project, it serves as low-energy storage ring for a wide range of research areas, from precision spectroscopy in strong field systems, dynamics in slow atomic collisions, nuclear reactions, materials research and beyond. The ring is able to store highly charged heavy ions (HCI) produced at the GSI accelerator complex after deceleration in the Experimental Storage Ring (ESR).
To maximize beam time usage, the local ion source allows the ring to operate quasi-independently of the GSI-complex, serving as test bench under real beam conditions for multiple systems: vacuum, detectors and controls. It also address operation stability issues and operators training.
The local ion source can provide a range of soft, low-charged ions from gaseous and easily vaporized solid materials. Over time, its potential for stand-alone experiments has been revised. A scientific advisory committee now evaluates and approves a growing number of beam time applications using local injector. Efforts are being made to meet the experiment's needs and to provide ion species with the required intensities, beam quality and stability. We started by using a hot cathode Nielson type ion source. A 10 GHz ECR ion source based on a permanent magnets arrangement, a rebuild of a source developed at the University of Giessen, is our workhorse now. Another ECR ion source with a frequency of 14.5 GHz, which has been in operation at IAP Frankfurt for many years, is currently being refurbished before recommissioning to serve as second source for the local injector. It will expand the range of ion species giving access to Ne8+, S10+, Ar12+ and similar A/q combinations.
This contribution will present the achievements, plans, performance and limitations of the local ion sources at CRYRING@ESR.

**Poster Session / 107**

## Recent LANSCE efforts on improving H+ duoplasmatron capabilities

**Authors:** Adler Weismantel[1]; Anna Alexander[None]; Cole Cochran[1]; Etienne Vermeulen[1]; Evan Loftin[1]; Gary Rouleau[1]

[1] *LANL*

**Corresponding Author:** aalexander@lanl.gov

LANSCE uses a duoplasmatron ion source to produce H+ ion beams for the Isotope Production Facility, which uses 100 MeV proton beams to produce a variety of therapeutic and diagnostic isotopes for research purposes and also supports a variety of other experiments for materials and nuclear physics. We have recently begun work to improve the reliability, peak current, and lifetime of the ion source, while restoring existing capabilities to build new ion sources and filaments. This poster will cover these efforts, with a particular focus on the work to re-establish and improve the filament production capability and production of higher peak current beams.

**Poster Session / 116**

## Hot Liner for the Production of Metallic Ion Beams from an ECR at GSI

**Author:** Fabio Maimone[1]

**Co-authors:** Aleksandr Andreev [1]; Jan Mäder [1]; Michael Galonska [1]; Ralf Lang [1]; Ralph Hollinger [1]

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

**Corresponding Author:** f.maimone@gsi.de

At GSI, the CAPRICE ECR Ion Source (ECRIS), installed at the High Charge State Injector (HLI), delivers continuous-wave (cw) metallic ion beams for studies and experiments, carried out by nuclear physics, materials research, and superheavy elements groups. To meet the demand for ions from metals and solid compounds, thermal evaporation via resistively heated ovens is employed.
The use of a hot tantalum liner, inserted into the plasma chamber, has been validated for the efficient production of high charge state ion beams from rare isotopes, such as 48Ca10+ with high intensity and low material consumption. Recent results from the latest beam run demonstrate increased beam intensity, stability and reduced material consumption.
Furthermore, the hot liner helps mitigate metallic buildup on ceramic surfaces, enabling stable operation at high intensities with minimal disruptions. Results from operations with 54Cr and 55Mn confirm the effectiveness of the hot liner in enhancing operational stability.

**Poster Session / 153**

## Mixed carbon and helium ion beams for simultaneous heavy ion radiotherapy and radiography –recent advances and perspectives

**Author:** Michael Galonska[1]

**Co-authors:** Aleksandr Andreev [1]; Christian Graeff [1]; Fabio Maimone [1]; Jan Mäder [1]; Lennart Volz [1]; Ralf Lang [1]; Ralph Hollinger

[1] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

**Corresponding Author:** m.galonska@gsi.de

A mixed carbon/helium ion beam with a variable He percentage for heavy ion radiotherapy and radiography has been provided and investigated at GSI for a second time in order to continue the studies on this new mode of image guidance for carbon ion beam therapy.
The mixed 12C3+/4He+ ion beam out of CH4 and 4He was provided by the 14.5 GHz CAPRICE ECR ion source for the subsequent linac-synchrotron accelerator systems at GSI. During the beam times and prior checks at the ion source test bench, different ion source settings were compared in terms of ion beam currents, stability, C-to-He-fraction, and O4+-contamination quantified by optical spectral lines, mass spectra, and current measurements with a current transformer.
Finally, both ions were simultaneously accelerated to different energies above 200 MeV/u, extracted, and characterised in the biophysics cave.
This paper outlines some of the measurements obtained and some of the perspectives for future work on this topic.

**Poster Session / 151**

## Solid state amplifier for a 2,45 GHz high intensity proton source

**Author:** Olivier TUSKE[1]

**Co-authors:** Augustin DUBOIS [1]; Damien Minenna [1]; Guillaume FERRAND [1]; Mathias BARANT [1]; Olivier DELFERRIERE [1]; Robin Penavaire [1]; Vallerio Calvelli [1]; Vincent Trauchessec [1]; Yannick GAUTHIER [1]; Yannick SAUCE [1]

[1] *CEA PARIS SACLAY*

**Corresponding Author:** otuske@cea.fr

The ALISES3 Ion source has demonstrated very good reliability for 30mA extracted current on a long term opreration at 50kV extraction energy with a single magnetic coil at ground potential. ALISES3 source is originally equipped with a 2.45GHz magnetron. Several RF measurements of the

magnetron, installed on a stand alone test bench showed a frequency modulation which can lead to detune the ECR heating process. In order to increase even more the reliability, we removed of the whole RF chain (Magnetron + ATU) and installed at its place a solid amplifier that can deliver with up to 1kW µwave power between 2.4 and 2.5 GHz. The measurement of the ALISES ion source with this new µwave generator is presented in this paper.

**Poster Session / 146**

## Numerical Analysis of the Influence of Plasma Parameters on the 1+ Beam Capture in the ECR-based Charge Breeder

**Author:** Alessio Galatà[1]

**Co-authors:** Olli Tarvainen [2]; Julien ANGOT [3]; Angelo Pidatella [4]; Bharat Mishra [4]; Carmelo Sebastiano Gallo [5]; Giuseppe Torrisi [4]; David Mascali [4]

[1] *INFN-Legnaro National Laboratories*

[2] *STFC*

[3] *LPSC-CNRS*

[4] *INFN - LNS*

[5] *INFN - LNL*

**Corresponding Author:** alessio.galata@lnl.infn.it

Electron Cyclotron Resonance-based charge breeding is a reliable and well-established technique to boost the charge states of radioactive ions produced in Isotope Separation Online (ISOL) Facilities. While its first applications relied on a pure experimental approach, the optimization of charge breeding has recently benefitted from numerical simulations guiding the experiments and providing insights into various steps of the process. Both approaches have proven very useful in pointing out the main physical mechanisms behind the process. Due to the complexity of the charge breeding process involving several steps such as the 1+ beam capture, step-wise ionization to high charge states and extraction of the high charge state ions, the experiments and simulations often deviate from each other. This contribution describes the latest results of numerical simulations with the aim of focussing on the role of the different plasma parameters on the overall capture efficiency, thus trying to merge in a unified description of both experimental and numerical evidences in qualitative terms. We describe the numerical approach, show that parameters like ion temperature, plasma density and potential (absolute value and profile) affect the simulated capture of the injected 1+ ions, discuss the experimental evidence corroborating the simulation results, and highlight discrepancies between experiments and simulations.

**Poster Session / 133**

## Ion Beam Emittances of Intense Highly Charged Ion Production from the RIKEN 28GHz SC-ECRIS

**Author:** Glynnis Mae Saquilayan[1]

**Co-authors:** Yoshihide Higurashi [1]; Takashi Nagatomo [1]; Yasuyuki Morita [1]; Jun-ichi Ohnishi [1]; Osamu Kamigaito [2]

[1] *RIKEN Nishina Center*

[2] *RIKEN Nishina Center for Accelerator-Based Science*

**Corresponding Author:** glynnismae.saquilayan@riken.jp

The production of high intensity multiple charged heavy ions is one of the main objectives of the 28GHz superconducting electron cyclotron resonance ion source (SC-ECRIS) at RIKEN. As the SC-ECRIS gradually move towards high power operation, it is important to confirm that the extracted ion beam properties are within the acceptable range of the low energy beam transport system. Investigating the beam quality through the beam emittance and the possible growth factors are currently in progress. Beam emittances were measured using a slit-wire-type emittance monitor and the normalized rms emittances were calculated in a systematic study under different beam conditions. From the experimental results, a proportional relation between the beam emittance and extraction current was observed and an approximation for finding an initial value of the beam emittance ε<sub>0</sub> was tested. For the case of uranium <sup>238</sup>U<sup>35+</sup> ion beam, the approximation of the initial beam emittance was found to be at ~0.09 π mm mrad. However, considering the expected beam conditions of the required output beam current, this initial beam emittance is predicted to increase up to 0.22 π mm mrad based on growth factors from space charge effects in the extraction region. Although conditions with low total beam current result in smaller beam emittance sizes, achieving such conditions will be challenging while optimizing for high beam intensities. As a next step, space charge compensation methods are currently being considered to further lower the emittance sizes. Fundamental studies to understand the beam dynamics in the extraction region are being planned and this will be used to properly formulate strategies for space charge beam compensation.

**Poster Session / 51**

## From ECR Ion Source to Electrostatic Thruster

**Author:** Romain Bellet[None]

**Co-authors:** Matthieu Cavellier ; Sarah Naimi ; Serge Della-Negra ; Vincent Bertrand

**Corresponding Author:** romain.bellet@ijclab.in2p3.fr

An electrostatic thruster is an Electric Propulsion [0] technology that ionizes its propellant to accelerate it using electric force. Its performance is measured by the thrust $T = \dot{m}v$ it develops and its specific impulse $I_{sp} = \frac{v}{g}$, the fuel combustion efficiency, with $\dot{m}$ and $v$ the mass flow rate and the velocity of exhaust, and $g$ the standard gravity. The Electron Cyclotron Resonance Ion Sources have demonstrated their ability to produce highly charged ions and powerful currents. Integrated to a propulsion system, the high ejection speeds of these multicharged ions allow to reach high specific impulses thus decreasing its gas consumption. Furthermore, it is necessary to increase simultaneously the puller and plasma electrodes'hole diameters to extract a maximum of ion current intensity without destabilizing the plasma. This extra expelled mass can develop greater thrust.

The study and the results presented here are obtained on a 10 GHz Microgan ECR ion source supplied by the company Pantechnik, and mounted on the Tancrede test bench of the Mosaic platform. The goal of this work is to study the influence of electrodes diameters change in the Ar ions charge distribution and their intensities. The measurements are performed with and without magnetic deviation, to obtain the charge distribution and the transmission. The different diameters studied are $_{plasma}$={6,8} mm, and $_{puller}$={8,12} mm.

Increasing the diameter of the puller electrode increases intensity, but this gain is offset by an increase in divergence, which reduces efficiency of an electric propulsion application. The aim of this study is to find a configuration by adjusting the puller and plasma electrodes diameters, extraction voltage and acceleration distance.

[0]: S Mazouffre, "Electric propulsion for satellites and spacecraft,"Plasma Sources Sci. & Tech., 25(3), 033002. (2016)

**Poster Session / 4**

## RF ion source of Hydrogen ions,

**Author:** vadim Dudnikov[1]

**Co-author:** vadim Dudnikov

[1] *Muons, Inc*

**Corresponding Author:** vadim@muonsinc.com

V. Dudnikov, R. Johnson, S. Murrey, M. Popovic, R. Abrams, MaryAnne Cummings, T. Roberts, D. M. Kaplan, T. Phillips, T. Smick
Muons, Inc, Batavia, IL 60510, USA.
RF ion source of Hydrogen ions with energy 30 keV and current up to 100 mA is described.
AlN discharge chamber is water-cooled. A multiaperture 4 electrode extraction system is used for ion beam formation. RF discharge is supported by current in the antenna with a frequency 13.56 MHz.
A longitudinal magnetic field is used for increase the current density of emitted ions.

**Poster Session / 7**

# Long-Lived Radioactive Beam Upgrade at TRIUMF-ISAC

**Author:** Christopher Charles[1]

**Co-authors:** Friedhelm Ames [1]; Brad Schultz [1]; Oliver Kester [1]

[1] *TRIUMF*

**Corresponding Author:** ccharles@triumf.ca

TRIUMF's Isotope Separator and Accelerator (ISAC) complex produces rare radioactive ion beams for experiments by bombarding targets with a primary $H^{+}$ driver beam from the 500 MeV cyclotron. A dedicated electron cyclotron resonance (ECR) ion source at ISAC –the so-called "charge-state booster"(CSB), is used to charge-breed those radioactive ions for post-accelerated experiments. Here we consider a future upgrade to the existing CSB facility where a second small ion source positioned upstream would deliver low charge-state ion beams from solid or gaseous samples into the injection-side of the CSB for charge-state boosting. Adding a second ion source, perhaps a small permanent magnet ECR, would significantly improve beam delivery capabilities and availability at TRIUMF-ISAC for heavy long-lived radioactive elements from prepared materials. Here we study various ion / ECR source designs, characteristics, and optics from different manufacturers together with all required matching and transport optics, to determine the best possible integration of a new ion source to the existing ISAC-CSB system.

**Poster Session / 20**

# Magnetic field Investigations of the ATLAS ECR Ion Sources

**Author:** Jake McLain[1]

**Co-authors:** Richard Vondrasek [1]; Robert Scott [1]

[1] *Argonne National Laboratory*

**Corresponding Author:** jmclain@anl.gov

A complete redesign of the ATLAS ECR2 ion source permanent magnet hexapole was completed to support 18 GHz operation, allowing for increased intensities and beam energies. This permanent magnet hexapole has since been manufactured and received. A magnetic field mapping of the hexapole was completed and compared against simulation results. Additionally, the ATLAS ECR3

has struggled with instabilities without a known cause. These beam instabilities can be tuned out but often require significant effort. A recent plasma chamber cooling water leak has given rise to an opportunity for deeper investigation of the fully permanent magnet ion source. A magnetic field mapping of the ECR3 axial and radial magnetic fields was also completed, leading to further understanding of the ion source's cause for instabilities. Updated plans for the ECR2 upgrade and the ECR3 stability improvement are described following their respective magnetic field mappings.
This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DEAC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility

**Poster Session / 22**

## On the comprehensive characterization of the thermally optimized SPES Laser Ion Source

**Author:** Omorjit Singh Khwairakpam[1]

**Co-authors:** Lisa Centofante [1]; Alberto Andrighetto [1]; Alberto Monetti [1]; Bernard Crepieux [2]; Cyril Bernerd [2]; Daniele Scarpa [1]; Emilio Mariotti [3]; Katerina Chrysalidis [2]; Maximilian Schuett [2]; Mia Au [2]; Piergiorgio Nicolosi [4]; Ralitsa Mancheva [2]; Reinhard Heinke [2]; Sebastian Rothe [2]; Thierry Stora [2]; Tommaso Marchi [1]; Valentin Fedosseev [2]; Mattia Manzolaro [1]

[1] *INFN-LNL*

[2] *CERN*

[3] *University of Siena, Italy*

[4] *University of Padova, Italy*

**Corresponding Author:** khwairakpam@lnl.infn.it

The SPES (Selective Production of Exotic Species), located in INFN-LNL, Italy, is an ISOL (Isotope Separator On-Line) facility dedicated to the production of radioactive ion beams (RIBs). One of the main ion sources SPES employs is the Hot Cavity Resonant Ionization Laser Ion Source (HC-RILIS). The RILIS method employs stepwise photo-ionization schemes that are element-specific, thereby offering high elemental selectivity. When combined with mass separation, it enables the production of high-purity isotopic beams with minimal isobaric contamination.
The geometry of the SPES-Laser Ion Source (SPES-LIS) has been realized as a result of the thermal optimization of the ISOLDE MK1 ion source. The SPES-LIS is made of tantalum, and is composed of a hot cavity, a transfer line, and an alignment system.
Laser enhancement ratio of the ion yield and time structure of the ion beam has been measured in relation to the production of Sm and Ga ions. The time structure of the laser ion beams from the SPES-LIS reveals that roughly 50% of the total ions are produced in the transfer line which was not observed for the ISOLDE MK1 source. This effect is attributed to the actively heated transfer line system in the SPES-LIS which provides an ion guide along the whole length of the ion source.
The measurements were performed under various ion source temperatures and ion load conditions, primarily influenced by surface ion contaminants. Through this study, it was also observed that the radial ion confinement in the transfer line could be further optimized for high ion load conditions, which is particularly critical for the production of medical radionuclides with inherently low in-target yields.
Furthermore, laser resonance ionization efficiency measurements for the production of Ga were performed, with a reported value of 27.2%. This measurement sets a crucial reference as it was the first completed set of laser ionization efficiency in ISOLDE Offline 2, performed using the SPES-LIS.

**Poster Session / 103**

## Intense Metallic Ion Production and Operation with Electron Cyclotron Resonance (ECR) Ion Sources at the Institute of Modern

# Physics

**Authors:** Cheng QIAN[1]; Jibo Li[2]; Ke Deng[3]; Liangting Sun[4]; Lixuan Li[2]; Ma Hongyi[3]; Ma Jindou[3]; Pengxia Cao[5]; Wang Lu[3]; Ye Zhao[3]; Yucheng Feng[4]; Zhang Wenhui[3]

[1] 中国科学院近代物理研究所

[2] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

[3] *Institute of Modern Physics*

[4] *Institute of Modern Physics, CAS*

[5] *Northwest Normal University*

**Corresponding Author:** luwang@impcas.ac.cn

Production of intense highly charged heavy ion beams is of high challenge with an ECR ion source. To meet the strong requirements from the nuclear physics experiments various methods have been developed to produce metallic ion beams with ECR ion sources at the Institute of Modern Physics (IMP). In the recent 5 years, more than 14 different species of metallic ions have been produced with the intensity typically of hundreds of eμA at IMP. According to the specific properties of materials, several methods have been successfully developed and applied for routine operation. Low temperature oven with resistance heating and maximum working temperature around 700 degree C was used to heat material like Ca, Bi, CsI, and ZrF4. High temperature inductive heating oven with maximum service temperature about 2000 degree C was applied to produce metallic ions like Ca, Al, Cr, Mn, Fe, Ni, Sr, Gd, U, etc. For extremely refractory metals, such as Ta, U, and Th, sputtering technique with special design was developed. The technical advancement enables the production of >600 eμA of U35+, Bi31+, and reliable routine operation with intense U46+, Ta38+. In this paper, typical ion yields for various elements are presented, comparisons are shown, and the challenges to produce more intense highly charged metallic ion beams for the next generation heavy ion accelerators are also discussed.

**Poster Session / 115**

# Status and Development with CANREB at TRIUMF

**Author:** Brad Schultz[1]

**Co-authors:** Friedhelm Ames [1]; Marco Hartmann [1]; Mathieu Cavenaile [1]; Oliver Kester [1]

[1] *TRIUMF*

**Corresponding Author:** bschultz@triumf.ca

The Canadian Rare isotope facility with Electron Beam ion source (CANREB) is part of the Advanced Rare Isotope Laboratory (ARIEL) at TRIUMF. CANREB will be used for charge state breeding of rare isotope beams for post-acceleration to experiments in ISAC. Beams injected into CANREB are first bunched using an RFQ cooler buncher and energy matched into an electron beam ion source (EBIS). The EBIS was designed for a maximum electron beam current of 500 mA at a maximum magnetic field of 6 Tesla. Ions are charge bred to A/q < 6 within 10 ms and extracted at energies up to 12 keV x q. The highly charged ions are mass separated using a Nier spectrometer before being injected into the ISAC linear accelerator chain. Recent development efforts will be discussed, as well as an update on EBIS technical limitations.

**Poster Session / 29**

# Progresses on compact carbon positive ion mass spectrometry (C-PIMS) at Peking University

**Authors:** Jianbin Zhu[None]; Shi PENG[1]; Bujian Cui[None]; Yicheng Dong[None]; Zhiyu Guo[None]; Jiaer Chen[None]

[1] 物理学院

**Corresponding Author:** 2406392567@pku.edu.cn

Positive ion mass spectrometry (PIMS) represents an advanced methodology for radiocarbon dating, that operates on principles differ from those of traditional. Current research mainly focuses on the miniaturization and automation of equipment. The Electron Cyclotron Resonance (ECR) ion source is designed to utilize gas sample supply, facilitating automated measurement processes. A compact 2.45 GHz ECR ion source developed by Peking University (PKU) with full permanent magnet structure demonstrates the ability to produce more than 1 mA of $C^{2+}$ ions. Recently memory effect test results prove that this ion source exhibits exceptionally low background levels and possesses a robust capacity for producing highly charged carbon ions, thereby fulfilling the requirements necessary for PIMS applications. Several PIMS related experiments have yielded promising outcomes recently. Using a nonmetallic gas charge exchange target, a charge exchange efficiency of 6.1% from $C^{2+}$ to $C^-$ was achieved, and a $C^-$ beam current of 19 $\mu$A was obtained. The configuration of the beamline was meticulously designed through beam dynamics simulations to ensure precise ion focusing and enhanced transmission efficiency for $^{14}C$ ions. This beamline incorporates two sets of "electrostatic analyzer-magnetic analyzer" to reduce the influence of scattered particles on the background noise, thus improving the measurement accuracy of the system. Consequently, the compact PIMS occupies an area of about 3.6 m × 2.2 m while significantly reducing associated costs.

**Poster Session / 91**

# On-Line production of SnS radioactive ion beams with the ISOL technique

**Author:** Maher CHEIKH MHAMED[1]

**Co-authors:** Alberto Monetti [2]; Annie Ringvall Moberg ; Brigitte Roussiere ; Clement Delafosse [1]; David Leimbach ; David Verney [1]; Fadi Ibrahim [1]; Fatih Yagan ; Joao Pedro Ramos [3]; Jochen Ballof ; Lisa Centofante [2]; Matthieu Lebois [1]; Mattia Manzolaro [2]; Michele Ballan [2]; Pierre Delahaye [4]; Sebastian Rothe [5]; Stefano Corradetti [2]; Thierry Stora [5]

[1] *CNRS-IJCLAB, Université Paris-Saclay*

[2] *INFN-LNL*

[3] *SCK CEN*

[4] *GANIL*

[5] *CERN*

**Corresponding Author:** maher.cheikh-mhamed@ijclab.in2p3.fr

Selectivity is a major parameter of the ISOL process. In order to avoid overloading downstream processes, purity control should be implemented as early as possible in the process chain from target material to the beam user delivery point 1. In this work we present a novel approach for the development and production of SnS radioactive ion beams using the photofission production mode. The successful developments of the sulfur delivery system at ISOLDE and SPES, in the frame work of the BEAMLAB task of the ENSAR2 program, have triggered the beam time request for molecular tin (SnS) beams at the ALTO facility.
The On-line radioactive SnS Beam has already taken place and SnS molecules are well formed and released from the UCx target volume. The major observation is the purification of the tin beams by sulfurization. We note the antimony, main isobaric contaminant of tin isotopes, was fully suppressed and we got very pure SnS beams. Radioactive exotic isotopes 133Sn and 134Sn have well identified and released. Technical developments of the target-ion source production setup and selected results of these on-line measurements will be presented. The overall molecular production efficiency which was 75% will be discussed.

1 U. Köster, ISOLDE target and ion source chemistry, Radiochimica Acta 89 (2001)

**Poster Session / 73**

## ELIMAIA-ELIMED beamline –a new opportunity for radiobiological research with laser-driven protons

**Author:** Pavel Bláha[1]

**Co-authors:** Pankaj Chaudhary [2]; Pavol Lukáč [3]; Marco Borghesi [4]; G.A.P. Cirrone [5]; Roberto Catalano [5]; Filip Grepl [1]; Valeria Istokskaia [1]; Alfio Pappalardo [5]; Giada Petringa [5]; Kevin Prise [4]; Giuseppe Schettino [2]; Francesco Schillaci [1]; Maksym Tryus [3]; Luca Vannucci [3]; Daniele Margarone [1]; Lorenzo Giuffrida [1]

[1] *ELI Beamlines Facility, The Extreme Light Infrastructure ERIC, Dolní Břežany, Czech Republic*

[2] *National Physical Laboratory, Teddington, United Kingdom*

[3] *Institute of Microbiology of the Czech Academy of Sciences, Prague, Czech Republic*

[4] *Queen's University Belfast, Belfast, Northern Ireland*

[5] *National Institute for Nuclear Physics –Laboratori Nazionali del Sud, Catania, Italy*

**Corresponding Author:** pavel.blaha@eli-beams.eu

With the growing number of cancer patients requiring radiation treatment, advancements in accelerator technologies, proton-based in particular, are essential. The ELI Beamlines user facility is exploring laser-driven accelerators as an alternative type. The laser-driven proton beams (LDP) are produced with specific temporal and dose-rate characteristics that may potentially offer treatment benefits. The acceleration system is powered by the L3 HAPLS petawatt laser, integrated with the ELIMAIA (ELI Multidisciplinary Applications of laser-Ion Acceleration) laser-plasma accelerator and the ELIMED (ELI MEDical application) beam transport and dosimetry line, enabling multi-shot LDP irradiation.
During the first LDP biological experiment, human skin fibroblasts AG01522 were irradiated by protons with a mean energy ~23.5 MeV, fixed about 30 min post-irradiation, and assayed for DNA DSB assessment in the form of 53BP1 foci. The results suggest that the samples irradiated with multi-shot LDP exhibit a similar biological response to samples exposed to single-shot LDP assessed between 1- and 2-hours post-exposure. Considering the extended irradiation duration, cells likely initiated repair processes already during irradiation. Results for conventionally accelerated protons agree well with the corresponding single-shot LDP samples.
Another experiment focused on the irradiation of two cancer cell lines as 3D spheroids with LDP. This unique conformation is considered an intermediate step between in vitro and in vivo research, and in combination with LDP, provides rarely tested setup. LLC1 and HT-29 cell cultures are investigated for several biological endpoints, including survival, heat shock proteins 70 & 90 analysis, or RNA sequencing. Preliminary results will be discussed. These experiments provide an initial look at this user platform's potential for advanced research in the field of ultrafast radiation biology and open new opportunities for further experimental work.

**Poster Session / 161**

## First commissioning results of the MIST-2 ion source for the High-Current H2+ Cyclotron HCHC-XX

**Author:** Daniel Winklehner[1]

**Co-authors:** Eleanor Winkler [1]; Jarrett Moon [1]; Joshua Villarreal [1]; Parker Landon [2]; Philip Weigel [1]; Samuel Engebretson [1]

[1] *MIT*

[2] *Boston University*

**Corresponding Author:** winklehn@mit.edu

Abstract: In the HCHC-XX cyclotron design, an H<sub>2</sub><sup>+</sup> ion source is feeding a high-current beam through an RFQ buncher, axially embedded in the cyclotron yoke, into the central region of the cyclotron where the beam is guided onto the median plane and accelerated. The 60 MeV/amu version, the HCHC-60 will be the driver for the particle physics experiment IsoDAR, an underground search for new physics (e.g., sterile neutrinos, axion dark matter, and light X particles). Other applications of the HCHC-XX at various output energies are in fusion research, nuclear waste transmutation, and medical isotope production. For the HCHC-1.5 prototype, we initially built the MIST-1, a filament-driven, multicusp ion source tuned for H<sub>2</sub><sup>+</sup> production. Recently, we built a new ion source, the MIST-2, incorporating lessons-learned from MIST-1. Here we report the results of a study using the MIST-1 and different permanent magnet configurations to determine the optimal magnet material for the MIST-2. Further, we show the design of the MIST-2, highlight the improvements we made, and present the first commissioning results, which, so far, approximately doubled the total beam current extracted from the MIST-1.

**Poster Session / 128**

## Bremsstrahlung Heat load Scaling Measurements for Future ECRIS Cryostat

**Author:** Miles Chen[1]

**Co-authors:** Damon Todd [1]; Janilee Benitez [2]

[1] *Lawrence Berkeley National Laboratory*

[2] *Lawrence Berkeley National Lab*

**Corresponding Author:** mlchen2@lbl.gov

In order to push the intensities of beam production capabilities, 3rd generation ECR ion sources such as VENUS have implemented the use of superconducting radial and axial confinement magnets that allow for higher fields and higher frequency heating. VENUS'NbTi superconducting magnets are enclosed in a 4.2K liquid helium reservoir to maintain their temperature and prevent quenching. During operation, electron losses to the plasma chamber produce a significant amount of bremsstrahlung radiation, and these x-rays can deposit several watts of heating to the cold mass and cryostat. The amount of heat load these x-rays deliver is dependent on the total microwave power and the source' s minimum B-field ($B_{min}$). The 4th generation MARS-D Ion Source is currently being developed at LBNL to meet the beam intensity needs of future heavy ion research. MARS-D uses NbTi magnets in a novel configuration, and will operate with 45 GHz heating and higher $B_{min}$, which are expected to produce higher energy electrons than VENUS. In order to anticipate and design MARS-D for this increased load, we have undertaken a series of cryostat heat load experiments with VENUS where we vary $B_{min}$, microwave power, and different heating frequencies. Measured results will be presented, as will heat load projections for expected MARS-D operating conditions.

**Poster Session / 159**

## Beams production optimisation on ECR4/4M ion sources at GANIL cyclotrons facility

**Author:** Mickael DUBOIS[1]

**Co-authors:** Benoit Osmond [1]; Bertrand Jacquot [1]; Frédéric Lemagnen [1]; Laurent Gouleuf [1]; Vincent Metayer [2]

[1] *GANIL - CNRS*

[2] *GANIL - CEA*

**Corresponding Author:** dubois@ganil.fr

The GANIL (Grand Accélérateur National d'Ions Lourds) in Caen has been producing and accelerating stable and radioactive ion beams for nuclear physics, atomic physics, radiobiology and materials irradiation since 1982.

Since 2019, the beam time available on the cyclotron accelerators has been reduced in favour of the commissioning of the SPIRAL2 linear accelerator. This LINAC already delivers proton and deuteron beams for neutron physics and a second step was taken in 2024 with the acceleration and delivery of heavy ion beam to the S3 (Super Spectrometer Separator) facility.

The next objective is to increase the beam times in both facilities to meet the demand from physicists. This is accompanied by a renovation program aimed at increasing the availability of cyclotron accelerators. With this in mind, a number of studies have been carried out over the last two years on the ECR4/4M ion sources feeding the cyclotrons. The aims were to identify ways of optimising the sources to produce more stable beams with higher intensities, but also to reduce the on-call work for the ion source experts, who will have to operate up to four ECR ion sources in parallel.

In 2025, the first optimisations have been implemented online and the first results will be presented.

**Poster Session / 6**

## The development of the ion source and target for BRISOL facility

**Author:** Bing T[None]

**Corresponding Author:** tangb364@126.com

The Beijing Radioactive ion beam facility Isotope Separator On-Line（BRISOL）is a radioactive ion beam facility based on a 100MeV cyclotron providing 200μA proton beam bombarding the thick target to produce radioactive nuclei, which are transferred into an ion source to produce singly charged ion beams. A surface ion source had been developed for BRISOL, and the first radioactive beams (37K+, 38K+, 42K+, etc.) were produced by bombarding a CaO target with a 100MeV proton beam from the cyclotron in 2015. A FEBIAD ion source with MgO target are successful used to the first physics experiments, including the decay study of 20Na with the energy of 110keV and the elastic scattering study of 21Na and 22Na beams, post-accelerated by a 13MV tandem. The refractory carbide targets such as SiC, LaC2 and UC2 are also developing for more radioactive beams. The first online test of SiC target has been completed recently, and radioactivity beams of 25Al, 26Al, and 28Al were produced. The details of the development of BRISOL facility and the online experimental results will be presented in this paper.

**Poster Session / 61**

## Proof-of-Principle Microwave Plasma Cathode Source toward Negative Ion Production

**Author:** Yuji Shimabukuro[1]

[1] *University of California Irvine, TAE Technologies*

**Corresponding Author:** shimabuy@uci.edu

The technology for the continuous operation of neutral beam injectors (NBI) for thermonuclear fusion with high-power output based on negative ion sources has not yet been realized. One of the major challenges is the development of, long-pulse, high-power ion sources with limited maintenance requirements.

To meet the diverse requirements of next-generation fusion reactors, plasma sources with high scalability and high controllability for uniform plasma production are needed.
At TAE Technologies, a project has been launched to develop negative ion sources for applications in next-generation field-reversed configuration (FRC) fusion devices 1 and boron neutron capture therapy (BNCT) 2.
As one candidate for such plasma sources, the use of a microwave plasma cathode (MPC) [3] instead of conventional filaments has been proposed. The MPC aims to provide sufficient fast electron density to achieve the scalability and plasma uniformity of arc-driven plasma sources, while requiring less maintenance.
In this paper, initial results from a proof-of-principle experiment are presented, in which a commercially available electron cyclotron resonance (ECR) antenna [4] was biased to modify the electron energy distribution function of the ECR plasma. The influence of the applied bias on plasma parameters is discussed.

1 T. Roche et al., Nature Commun. 16, 3487 (2025).
2 A. Dunaevsky et al., UCANS11, Vancouver, Canada (2025).
[3] Y. Matsubara et al., Rev. Sci. Instrum. 63, 2595 (1992).
[4] F. Zoubian et al., Plasma Res. Express 3, 025010 (2021).

**Poster Session / 117**

## Investigation of an Internal Antenna Design for an RF ion source

**Author:** Anand George[1]

**Co-authors:** Morgan Dehnel [1]; Robert Welton [2]

[1] *D-Pace*

[2] *Oak Ridge National Laboratory*

**Corresponding Author:** anand@d-pace.com

D-Pace is developing a 13.56 MHz cesium-free RF ion source capable of generating negative ion beams ($H^-$, $D^-$) with energies around 25 keV. The current design employs an external flat spiral antenna to couple RF energy into the plasma through a dielectric window 1. Efforts are now underway to evaluate the performance of the RF ion source using a solenoid-type internal antenna inspired by the SNS ion source. The SNS internal antenna has demonstrated reliable operation for over four months operational period, sustaining plasma with approximately 4 kW of average RF power and achieving nearly 100% availability 2. The implementation of an SNS-type internal antenna is expected to enhance the beam current and reliability of D-Pace's RF ion source. This article presents preliminary results of the internal antenna design and compares the performance of the internal and external antenna configurations in D-Pace's RF ion source.

1 T Kalvas et al. "Recent negative ion source activity at JYFL". In: AIP Conference Proceedings. Vol. 1515. 1. American Institute of Physics. 2013, pp. 349–358.
2 Robert Welton et al. "Negative hydrogen ion sources for particle accelerators: Sustainability issues and recent improvements in long-term operations". In: Journal of Physics: Conference Series. Vol. 2244. 1. IOP Publishing. 2022,p. 012045.

**Poster Session / 3**

## Recent progress with Diagnostic Neutral Beam at TCV tokamak

**Author:** ALEKSANDR LISTOPAD[1]

**Co-authors:** Yanis Andrebe [1]; Stefano Coda [1]; Frederic Dolizy [1]; Jeremie Dubray [1]; Damien Fasel [1]; Vincent Giannattasio [1]; Remy Jacquier [1]; Alexander Karpushov [1]; Yves Martin [1]; Marc Noel [1]; Ugo Siravo [1]; Tibor Tersztyanszky [1]; Matthieu Toussaint [1]; David Velasco [1]; TCV Team [1]

[1] *Ecole Polytechnique Federale de Lausanne (EPFL), Swiss Plasma Center (SPC), CH-1015 Lausanne, Switzerland*

**Corresponding Author:** aleksandr.listopad@epfl.ch

The present status of the 50keV / 3A Diagnostic Neutral Beam Injector (DNBI) at TCV tokamak is described.
In 2024, optical and mechanical inspections of the Ion Optical System (IOS) were performed. A significant deformation of the first (plasma) grid was revealed of the order of ~ 1 mm at the central area. The plasma grid was replaced by a new re-manufactured one with its existing design. The technology and production were performed within SPC-EPFL, and there was the first experience of precise ion optics parts manufacturability.
The further re-design of the plasma grid was performed to improve its stability, accounting for the results of deformation measurements and considering IBSimu beam simulations results. The attempt to reduce radial stresses was taken by enlargement of the grid thickness in combination with a compensation of thermal expansion. The possible options for the grid manufacturing technologies and materials, were considered.
Basing on the visual inspection of the plasma source parts after long period of operations, and on the EM analysis of magnetic field distribution between cathode and anode, the most impacted elements of the arc-discharge channel were re-shaped to increase the DNBI beam pulse duration, as well as the plasma source lifetime.
After over 20 years of use, most of the DNBI Power Supply (PS) elements worked at their limit. A new Power Supply set for DNBI was proposed after the analysis of a beam current up to 3-3.5A and extended beam shot duration up to 2-2.5s. The PS set is built using standard industrial components, with some further customization, especially for modulated beam regime, increasing the frequency of rectangular pulses up to 300-500Hz.
The new multichannel beam optical diagnostics was recently implemented for spectral profiles scanning, as well as providing the evaluation of the beam species composition. The non-invasive tool is used either for the beam conditioning tests or during its normal operation with TCV CXRS.

**Poster Session / 38**

## Thermal and plasma modeling of a hot cavity ion source for radioactive ion beam production at ISOL@MYRRHA

**Author:** Lennert Quanjel[1]

**Co-authors:** Kim Rijpstra [2]; Agi Koszorus [1]; Ralitsa Mancheva [3]; Lucia Popescu [2]; Katerina Chrysalidis [4]; Thomas Elias Cocolios [5]; João Pedro Ramos [2]

[1] *Belgian Nuclear Research Centre, SCK CEN & KU Leuven, Institute for Nuclear and Radiation Physics (IKS)*

[2] *Belgian Nuclear Research Centre, SCK CEN*

[3] *CERN & KU Leuven, Institute for Nuclear and Radiation Physics (IKS)*

[4] *CERN*

[5] *KU Leuven, Institute for Nuclear and Radiation Physics (IKS)*

**Corresponding Author:** lennert.quanjel@sckcen.be

ISOL@MYRRHA, under construction at the Belgian Nuclear Research Centre, SCK CEN 1, will be an isotope separation facility producing radioactive ion beams (RIBs) using 100-MeV protons at beam intensities of up to 500 μA. These RIBs support applications in fundamental research, medical science, and materials science. A key component is the 'hot cavity' ion source, which relies on surface and/or resonant laser ionization to ionize radioactive isotopes. Our work aims to optimize the current ion source design by integrating experimental studies with computational modeling to achieve higher efficiencies at increased ion loads.

During operation, the ion source is resistively heated above 2000 ℃. Thermionic electrons from the cavity walls form a confining plasma potential that enhances ion survival. However, the accumulation of positive ions can generate a counteracting potential that overrides this confinement, causing significant ion losses and reduced extraction efficiency. To characterize this environment, thermal-electrical simulations using Ansys 2 provide the temperature profile and voltage drop along the length of the ion source, which serve as input for Particle-In-Cell (PIC) plasma simulations in Starfish [3]. These simulations provide insights into ionization behavior, plasma dynamics, beam shape, and the time that laser/surface ions spend in the system. Additionally, molecular flow simulations using MolFlow+ [4] evaluate collision rates, pressure, and the sticking times of neutrals in the system.

In parallel, using a fabricated prototype, experimental measurements reveal the temperature distribution, ionization efficiency, and the extraction time of laser ions leaving the hot cavity, all of which serve as validation for the computational models [5,6]. Using this experimental and computational approach, the geometry and operating conditions of the ion source design can be optimized to find the best configuration for ISOL@MYRRHA's operating requirements.

**Poster Session / 72**

## Development of deuterium-deuterium compact neutron source

**Author:** Andoni Pérez Segura[None]

**Co-authors:** Andrés Roldán Aranda [1]; Iñigo Arredondo [2]; Javier Praena Rodríguez [1]; Joaquín Portilla [2]; Jorge Feuchtwanger Morales [3]; Víctor Etxebarria

[1] *University of Granada*

[2] *University of the Basque Country*

[3] *Ikerbasque*

**Corresponding Author:** andoni.perezs@ehu.eus

In the present work, we will present the status of the deuterium-deuterium (D-D) neutron source that is being developed in collaboration between the University of Granada and the University of the Basque Country (Spain).

Our neutron source consists of an ECR ion source, which accelerates a deuteron beam towards a deuterated target. The deuterium plasma ionization is achieved by radiating the cylindrical ECR plasma chamber with a magnetron 2.45 GHz signal and an 875 G magnetic field generated by 6 NdFeB magnets around the plasma chamber. Moreover, a cylindrical alumina RF window is used to keep the vacuum status from the ambient pressure condition inside the WR340 and help the plasma to ignite.
Once the plasma is generated, the deuterons are extracted from the plasma chamber using a Pierce electrode geometry and a system of electrostatic lenses, fixed to different negative potentials. The beam is accelerated towards a copper target disk with a deuterated titanium mesh fixed to -100 kV, which generates the desired neutron radiation.
There are several applications of D-D neutron sources across scientific and industrial domains. In case of the University of Granada and its deep relation with IFMIF-DONES neutron source, it is worth mentioning that we plan to carry out experiments for determining the cross-sections of relevant isotopes in the studies of IFMIF-DONES to a better simulation of the behaviour of such material under high neutron flux irradiation.

**Poster Session / 76**

## The effect of gas mixing on the afterglow transient of beams extracted from an electron cyclotron resonance ion source

**Author:** Ville Toivanen[1]

**Co-authors:** Hannu Koivisto [1]; Oskari Timonen [1]; Olli Tarvainen [2]

[1] *University of Jyväskylä, Department of Physics*

[2] *STFC*

**Corresponding Author:** ville.a.toivanen@jyu.fi

Gas mixing and afterglow operation are common methods to improve high charge state ion beam performance with Electron Cyclotron Resonance (ECR) ion sources. In gas mixing a light gas species is introduced into the ion source plasma to enhance the ion currents of a heavier main element. The benefits of this technique are commonly attributed to the "cooling"of the heavier element ions through collisions with the lighter element particles, leading to longer ion confinement times and enhanced high charge state ion production. In afterglow operation the plasma heating microwaves are pulsed, and as a result, an intense short burst of high charge state ions is observed following the microwave switch-off, with a current that can be several times higher than the steady-state ion current. This effect is also attributed to ion confinement in plasma, namely the change of confinement scheme from ambipolar potential dip confinement to diffusive losses.
This work studies the influence of gas mixing on the properties of high charge state ion beams extracted from an ECR ion source operated in afterglow mode. The focus is on the temporal structure and magnitude of the extracted ion currents during the steady-state phase of the beam pulse and the afterglow current transient. The experimental results with different combinations of main and mixing gas species provide new insight into the mechanisms related to the gas mixing effect and the formation of the afterglow current transient, especially on the role of ion confinement in pulsed ECR ion source operation.

**Poster Session / 173**

## The target-ion source system for the SPES facility commissioning: design, development and online testing

**Author:** Michele Ballan[1]

**Co-authors:** Alberto Andrighetto [1]; Alberto Monetti [1]; Carlo Roncolato [1]; Damiano Bortolato [1]; Daniela Benini [1]; Daniele Scarpa [1]; Enrico Fagotti [1]; Faiçal Azaiez [1]; Francesco Grespan [1]; Gaia Pupillo [1]; Giacomo Voltan [1]; Giordano Lilli [1]; Giorgio Keppel [1]; Liliana Mou [1]; Lisa Centofante [1]; Loris Antoniazzi [1]; Luca Bellan [1]; Luca De Ruvo [1]; Lucia Sarchiapone [1]; Maria Luisa Allegrini [1]; Mario Maggiore [1]; Massimo Rossignoli [1]; Mattia Manzolaro [1]; Maurizio Montis [1]; Omorjit Singh Khwairakpam [1]; Piergiorgio Antonini [1]; Stefano Corradetti [1]; Tommaso Marchi [1]

[1] *INFN-LNL*

**Corresponding Author:** michele.ballan@lnl.infn.it

SPES, acronym for Selective Production of Exotic Species, is an Isotope-Separation On-Line (ISOL) facility at INFN-LNL that was commissioned in November 2024 with the production of the first Radioactive Ion Beam (RIB). In such kind of facilities the RIB production is achieved with the following steps: firstly a production target is typically impinged by a high energy and high intensity primary beam, generating radioactive isotopes. The target is coupled to an ion source, towards where the produced species migrate by diffusive and effusive phenomena and are then ionized, allowing their electrostatic extraction and acceleration as a RIB, useful for several multidisciplinary experimental activities. With the aim of an efficient RIB production, both target and ion source work in the 1600-2200℃ temperature range at high vacuum.
The Target-Ion Source (TIS) system represents the core of the RIB production process, and its reliable and efficient operation is of fundamental importance. For such reason, for the first RIB at SPES, the chosen TIS was constituted by a silicon carbide target, that was carefully designed and studied with an extensive use of thermomechanical simulations, and a Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source, that included the most recent technological advancements. In particular, the tantalum ion source cathode, its most critical component, was produced by AM technologies, given the outstanding stability and reliability achieved in the context of HISOL (High performance ISOL systems for the production of RIBs) a structured INFN program of research activities on targets,

ion sources and molecular beams.
The activities related to the design, development, test and online operation of the firs SPES TIS system will be presented in detail.

**Oral Session / 111**

## Developments for Target-Ion-Sources at TRIUMF towards the ARIEL era

**Author:** Friedhelm Ames[1]

**Co-authors:** Alexander Gottberg [1]; Carla Babcock [1]; Fernando Maldonado Millan [1]; Jens Lassen [1]; Luca Egority [1]; Navid Noori [1]; Oliver Kester [1]

[1] *TRIUMF*

**Corresponding Author:** ames@triumf.ca

Rare isotope beams are produced at the ISAC facility at TRIUMF by bombarding solid targets with 480 MeV protons at a current up to 100 µA. With target material at high temperature products will diffuse out and are guided into an ion source. Extracted ions are mass analyzed and either be send directly to experiments at an energy of several 10 keV or further accelerated to study nuclear reaction processes at high energy. Additionally, to one more target station using high energy protons, the newly to be installed ARIEL facility will use a high power (up to 100 kW) 30 MeV electron beam. The electrons will impact on a converter target to produce high energy photons via Bremsstrahlung to induce photo-fission in the isotope production target.The main challenge for the design and operation of the ion sources is the close vicinity to the target at high temperature and within high radiation fields. This requires remote handling of the assembly and minimizes any maintenance after the target ion source combination has been installed. Depending on the desired isotope different combinations of target materials and ion sources can be used. The average time of operation for one target ion source combination is about 3-4 weeks, after which the entire combination has to be disposed.
The ion sources used so far start with a simple surface ionizer for mainly alkaline elements to, a FEBIAD plasma ion source for gaseous elements with high ionization energy and several types of resonant laser ion sources for element selective ionization.
A similar set of ion sources is foreseen for the ARIEL target station. The design of the target stations has been modified as compared to ISAC to overcome problems with high voltage stability, as well as implementing improvements like simpler remote handling to increase the target station up-time.
The presentation will cover recent results from the ISAC operation and discuss the new ARIEL design features and first results on off-line prototype testing.

**Oral Session / 21**

## Performance of the Brillouin Electron Gun at the TwinEBIS Test Bench

**Author:** Anton Gunnarsson[1]

**Co-authors:** Jone Etxebarria Erdoiza [2]; Concepcion Oliver [2]; Alexander Pikin [1]; Fredrik Wenander [1]; Cristina Battaglia [3]; José Miguel Carmona [3]

[1] *CERN*

[2] *CIEMAT*

[3] *AVS*

**Corresponding Author:** anton.sebastian.gunnarsson@cern.ch

At the TwinEBIS test bench an electron gun of Brillouin-type has been operated since a few years. It is expected that this type of gun should yield the highest electron beam compression, therefore

allowing for rapid production of bunched C6+ ions, as required by the "all-linac accelerator"used for cancer therapy. Significant performance improvements have been achieved at the test bench following the realignment of the Brillouin electron gun and the installation of a redesigned collector. These upgrades have resulted in excellent electron beam transmission and a reduction in ion losses. Charge breeding measurements using $CH_4$ and Xe gas injection have demonstrated that the system now achieves a high degree of space-charge neutralisation. We present simulations investigating previously reported poor performance and provide guidelines for how to achieve improved operational conditions for attaining high space-charge neutralization and high charge states. The potential for using the device as a source of C6+ ions is also reevaluated.

**Oral Session / 175**

## Prodigy Exhibitor Talk

**Corresponding Authors:** jjing@prodigy.net.cn, wangxu@prodigy.net.cn, lizhiqi@prodigy.net.cn

Beijing Feifan Langtian Tech. Co., Ltd. (also known as "Prodigy"), founded in 2004, specializes in the R&D, manufacturing and sales of microwave products. Our comprehensive product portfolio covers 50-3000W full-band spatial combining power amplifiers, microwave power sources, up-converters, microwave components etc. We also provide customized M&C software and integration services related. Our clients span a wide range including satellite communication stations, scientific research institutions, medical facilities, and EMC testing labs.

Prodigy, rooted in China with a global vision, is dedicated to delivering cutting-edge, high-performance products and services to customers worldwide. As your trusted partner for innovative and reliable technology solutions, we stand ready to collaborate hand in hand, exploring new horizons, embracing global opportunities, and co-creating a brilliant future together.

**Oral Session / 123**

## Reimagining FEBIAD Ion Sources: From Design Innovation to Performance Optimization

**Author:** Fernando Maldonado Millan[1]

**Co-authors:** Alexander Gottberg [1]; Carla Babcock [1]

[1] *TRIUMF*

**Corresponding Author:** maldonado@triumf.ca

Radioactive ion beam production at Isotope Separation On-Line (ISOL) facilities depends on ion sources that offer high selectivity, stability, and efficiency. At TRIUMF, recent developments in FEBIAD ion source technology have focused on two complementary avenues: operational optimization and component redesign enabled by modern manufacturing. Systematic tuning of source parameters, combined with mass spectrometric diagnostics, led to a significant enhancement in the selectivity of the uranium fluoride molecular ion ($UF^+$), increasing its ratio relative to the isobaric contaminant $WOF_3^+$ from 4% to over 97% without reducing overall ion yield. In parallel, the electron accelerator grid—a critical element influencing electron transport and ionization efficiency—was redesigned using generative design techniques. The resulting geometry, not manufacturable by conventional methods, was successfully produced in collaboration with ISOLDE using additive manufacturing with tantalum. Upcoming tests will evaluate the predicted gains in electron transport efficiency and thermal management with the redesigned grid. These advances support the implementation of more robust and selective FEBIAD ion sources for future ISOL facilities, including TRIUMF' s Advance Rare IsotopE Laboratory (ARIEL).

**Oral Session / 108**

## Towards a high-throughput laser ion source for CERN-MEDICIS

**Author:** Ralitsa Ivaylova Mancheva[1]

**Co-authors:** Katerina Chrysalidis [2]; Thomas Elias Cocolios [3]

[1] *CERN, KU Leuven*

[2] *CERN*

[3] *KU Leuven, Institute for Nuclear and Radiation Physics (IKS)*

**Corresponding Author:** ramanche@cern.ch

Resonant laser ionization is an efficient and highly selective method for producing radioisotopes. In the laser ion source of ISOLDE –RILIS (Resonance Ionization Laser Ion Source), the laser interaction region is inside a metal tube which is heated to temperatures of up to 2200 degrees Celsius. This heating induces surface ionization from the walls of this so-called "hot cavity". If the overall ion load of laser and surface ionized species reaches a certain threshold, the efficient extraction of these ions is compromised. This effect is especially prevalent in facilities like CERN-MEDICIS which demand a high ion throughput and fast extraction. This work aims to present the limits of the current laser ion source at MEDICIS and introduce recent developments towards a new high throughput ion source. Parameters used to describe the ion confinement potential inside the ion source are presented (such as temperature distribution, neutrals density, electron density, ion survival, ion extraction etc). Experimental results as well as ion beam simulations are discussed, and the coupling of the ion source parameters is explored.

**Oral Session / 14**

## Plasma diagnostics of charge breeder ECR ion sources

**Authors:** Julien ANGOT[1]; Olli Tarvainen[2]; Thomas Thuillier[3]

[1] *LPSC-CNRS*

[2] *STFC*

[3] *CNRS-LPSC*

**Corresponding Author:** julien.angot@lpsc.in2p3.fr

Electron Cyclotron Resonance (ECR) ion source charge breeding (CB) technique was invented in the 1990s in the context of Isotope Separation On Line facilities development for the study of atomic nuclei far from stability. ECR CB allows the 1+ beam injection on the source axis at the higher magnetic mirror side. After the capture of the injected ions into the support plasma, they are multi-ionised and extracted in the same way as the support gas atoms and ions. Therefore, the plasma must simultaneously favour the 1+ capture, multi-ionisation and release of the injected ion species in order to enhance the CB efficiency while keeping the process time short and impurity contamination of the extracted beams low. In the 2010s, the "Enhanced Multi-Ionization of Short-Lived Isotopes at Eurisol"project funded by the European Research Activities NETwork for Nuclear Physics Infrastructures initiated a collaboration between several laboratories to improve the CB performances in view of the large-scale EURISOL nuclear physics project. Here we present a comprehensive description of the plasma diagnostics studies conducted by the collaboration with the LPSC ECR CB in parallel to its development towards improved CB efficiencies. Analysing the uncaptured fraction of the injected beam passing through the CB allowed estimating the limits of the electron density and ion-ion collision frequencies in the ion source plasma. Experiments in pulsed mode 1+ injection were conducted to study the CB time, estimate plasma parameters and timescales, e.g. plasma electron density and temperature, ionization, charge exchange and ion confinement times. Finally, to refine the capture model, comparative measurements with different injected species into the CB demonstrated that the plasma potential plays a key role for 1+ ions slowing down. These studies

together with the source improvements resulted in a significant enhancement of the performances and a better understanding of the CB process.

**Oral Session / 23**

## Closed Shell Charge Breeding of Radioactive Fission Products with an Electron Beam Ion Source

**Authors:** Clayton Dickerson[1]; Guy Savard[1]; Jake McLain[1]; RICHARD VONDRASEK[1]; Robert Scott[1]

[1] *Argonne National Laboratory*

**Corresponding Author:** vondrasek@anl.gov

The closed shell breeding technique has been used to significantly improve the charge breeding efficiency of the Argonne National Laboratory electron beam ion source. The source serves as a charge breeder for the Californium Rare Isotope Breeder Upgrade (nuCARIBU), accepting radioactive beams of 1+ or 2+ ions and raising their charge state for efficient post-acceleration in the ATLAS linac. The 100 ms breeding window and flexible drift tube voltage scheme affords the appropriate time and electron beam energy required to achieve a closed shell configuration for many of the mid-mass species typical of nuCARIBU. Initial tests with stable cesium reached an absolute charge breeding efficiency of 72% for Cs27+ and a total efficiency of 93%. The nuCARIBU system is undergoing commissioning, and results with radioactive species will be presented.

This work was supported by the U.S. Department of Energy, Office of Nuclear Physics, under Contract No. DE-AC02-06CH11357. This research used resources of ANL's ATLAS facility, which is a DOE Office of Science User Facility.

**Oral Session / 113**

## Design of a hollow hexapole applicable to ECR charge breeder to mitigate the plasma contamination by sputtering

**Authors:** Andrea Cernuschi[1]; Julien ANGOT[2]; Thomas Thuillier[3]

[1] *CNRS-LPSC, Université Grenoble Alpes*

[2] *LPSC-CNRS*

[3] *CNRS-LPSC*

**Corresponding Author:** thomas.thuillier@lpsc.in2p3.fr

ECR charge breeders are used to increase the charge state of radioactive ion beams (RIB) from 1+ to N+ in facilities using the isotope online production scheme (ISOL). ECR charge breeders can accept incoming 1+ RIB as high as a few μA, the method reaches ion charge conversion efficiency up to 20% with a characteristic time of the order of 15 ms per charge state. A drawback of ECR charge breeder comes with the minimum-B magnetic confinement of the plasma which forces the plasma to hit the plasma chamber wall both axially and radially. In this work, the classical hexapole used to confine the plasma radially is replaced by a hollow permanent magnet hexapole which forces the plasma to leak on surfaces defined by θ=const rather than r=const in cylindrical coordinated. The alternative magnetic structure proposed, applicable to a 14 GHz booster operation, is presented in detail. The topology of the magnetic field in the plasma chamber and its consequence on the plasma shape and loss surface locations is also assessed and compared to the classical Hallbach permanent hexapole shape. The mitigation of the atom sputtering from the chamber wall with the hollow hexapole is finally discussed, underlying its potential application in an ECR charge breeder to reduce the RIB background contamination.

**Oral Session / 139**

## Radioactive ion beam development at SPIRAL1-GANIL: recent progress and future developments

**Author:** Pierre Chauveau[1]

**Co-authors:** Samuel Damoy [1]; Pierre Delahaye [1]; Mickaël Dubois [1]; Romain Frigot [1]; Hugo Guérin [1]; Stéphane Hormigos [1]; Sophie Hurier [1]; Pascal Jardin [1]; Mathieu Lalande [1]; Erwan Le Villain [1]; Alexis Ribet [1]; Bernadette M. Rebeiro [1]; Jean-Charles Thomas [1]

[1] *GANIL*

**Corresponding Author:** pierre.chauveau@ganil.fr

SPIRAL1 is a unique radioactive ion beam (RIB) production facility as it can operate with several primary beams and target materials for isotope production. The upgrade of the last decade also allowed ionizing isotopes of non-gaseous elements, considerably extending the number of possible RIBs.
We will review recent progress supported with experimental results and discuss on-going and planned future developments. We will focus of three key aspects:

- Three production test runs were performed with a FEBIAD source between 2023 and 2024. During these runs many metallic isotopes from K to Cs were ionized and measured, including $^{48}$Cr, $^{56,57}$Ni, $^{55}$Co and $^{52,53}$Fe. Furthermore, we will discuss studies that are currently being carried out for a new version of the FEBIAD assembly with a hotter target cavity to speed-up the extraction of refractory elements.
- A unique target ion-source (TIS) assembly, TULIP, was developed for high efficiency extraction of short-lived neutron-deficient isotopes. A surface-ionization version of the TULIP TIS was successfully tested in 2024 and a second test is planned for 2025. A FEBIAD version is currently being tested on the SPIRAL1 test bench.
- SPIRAL1 has only ever been operated with graphite targets, although target materials up to Nb are authorized by safety regulations. New target materials are being studied, with the goal to increase the production rate and beam intensity of many isotopes from various elements, ranging from Zn to Rb.

**Oral Session / 9**

## Experimental investigation on ECR ion source plasma towards more intense highly charged ion beam production

**Authors:** Jibo Li[1]; Lixuan Li[1]; Xinyu Wang[1]; Wang Lu[1]; Xuezhen Zhang[1]; Olli Tarvainen[2]; Vladimir Mironov[3]; Liangting Sun[1]; Hongwei Zhao[1]

[1] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

[2] *STFC*

[3] *Joint Institute for Nuclear Research (JINR)*

**Corresponding Author:** jiboli@impcas.ac.cn

ECR ion source development is generally following the scaling laws and now is stepping into the 4th generation era. Nevertheless, the fundamental issues that determine the performance of a high performance ECR ion source remain the same, i.e. the magnetic field, microwave heating and ion confinement and extraction. Unfortunately, as most of the high performance ECR ion sources are busy with routine operation, there are not many new studies on the issues as aforementioned. With the high performance 18~28 GHz ECR ion sources at IMP, we have made numerous interesting investigations towards better understanding of ECR ion source plasma of high power high frequency so as to make more intense beam extraction of highly charged ions. We devised a novel movable Vlasov launcher and gave the first experimental demonstration of this technique to improve the microwave heating efficiency in superconducting ECR ion sources. With new microwave operating scheme and plasma manipulation techniques, the capability to produce intense pulsed beams of highly charged ions with a long peak duration of 5~10 ms in afterglow mode has been demonstrated, which provides a viable option of high intensity pulsed beam injection for the next generation heavy ion synchrotrons such as HIAF. This paper will summarize the recent progresses of experimental research with high performance ECR ion sources at IMP. The new recorded high intensity ion beam production as well as our interpretation on the experimental studies will be given.

**Oral Session / 15**

## High Resolution Optical Emission Spectroscopic Study of the ECR Plasma in the GTS-LHC Ion Source

**Author:** Bichu Bhaskar[1]

**Co-author:** Detlef Küchler [1]

[1] *CERN*

**Corresponding Author:** bichu.bhaskar@cern.ch

A high-resolution optical emission spectrometer has been implemented as a non-invasive diagnostic tool to investigate plasma behaviour in the GTS-LHC Electron Cyclotron Resonance Ion Source (ECRIS). This approach aims to establish correlations between spectral features and neutral particle densities, thereby contributing to the development of real-time optical feedback mechanisms for the automation of ECRIS operations. Measurements are conducted in afterglow mode, with the ion source operating in pulsed mode at 14.5 GHz (10 Hz, 50% duty cycle). Optical spectral data from oxygen, neon, and lead plasmas are analysed to examine the relationship between optical emission intensities and source parameters. The practical use of optical diagnostics as a tool for monitoring and controlling the source performance is discussed.

**Oral Session / 177**

## Brightness Award Presentation

**Oral Session / 26**

## Conversion of a positive ion into a negative ion and a neutral atom: formation processes from a few keV to MeV energies

**Author:** Sargis Ter-Avetisyan[1]

**Co-authors:** Matthias Schnuerer [2]; Vladimir Tikhonchuk [3]

[1] *Extreme Light Infrastructure-Nuclear Physics (ELI-NP), Horia Hulubei National R&D Institute for Physics and Nuclear Engineering, 077125 Magurele, Romania*

[2] *Max Born Institute, Nonlinear Optics and Short Pulse Spectroscopy, Berlin 12489, Germany*

[3] *CELIA, Université de Bordeaux-CNRS-CEA, 33405 Talence cedex, France*

**Corresponding Author:** sargis.ter-avetisyan@eli-np.ro

High-power lasers are routinely used to generate energetic positively charged ions. In laser-plasma ion acceleration experiments negative ions and neutral atoms have been observed when energetic positive ions were passing through the spray of nanometer-sized water droplets. Beams of negative ions and neutral atoms have the same properties as beams of positive ions: energy, direction, and divergence of positive ions are preserved in the converted beam.
In the experiments conversion of hydrogen and carbon positive ions into their neutral atoms and negative ions with energies up to 140keV and 1.2MeV, respectively, is confirmed. However, the physics of charge exchange at high ion energies is not well understood. It is suggested that electrification of spray droplets plays a decisive role in these processes. We developed a multistage ion beam manipulation method to isolate the mechanism of charge exchange associated with the droplets electrification 1. If the hypothesis of the role of electrically charged droplets in the production of negative ions confirmed, it opens new possibilities for controlling the electron capture process.
This paper also investigates the feasibility of using a liquid spray in a Neutral Beam Injection (NBI) system. We have shown that high neutralisation efficiencies can be achieved in the energy range 100keV to 1000keV. The requirements that NBI has to fulfil for different NBI functions on a DEMO or fusion power plant can be different 2. E.g., the NBI to drive toroidal plasma rotation requires energies <100keV, but a pulsed tokamak [3] does not require high-energy NBI. A study-state current drive requires beam energies in the 1MeV range, for which for spray-based NBI further research is needed.
1. S. Ter-Avetisyan, M. Schnürer, V. Tikhonchuk. J. Appl. Phys. 134, 063302 (2023)
3. D. R. Mikkelsen, et al., , Nucl. Fusion 58, 036014 (2018).
4. G. Federici, et al., Nucl. Fusion 59, 066013 (2019).

**Oral Session / 57**

## Implementation of a temperature and density monitoring diagnostic for the LANSCE negative ion source

**Author:** Charles Rohde[1]

**Co-authors:** David Kleinjan [2]; Jonathan Quemuel [1]; Jinlin Zhang [1]; Anna Alexander [1]

[1] *Los Alamos National Lab*

[2] *Los Alamos National Laboratory*

**Corresponding Author:** crohde@lanl.gov

We report on adding a mutiwavelength emission and absorption diagnostic to the Los Alamos Neutron Science Center (LANSCE) $H^-$ ion source. The LANSCE $H^-$ ion source is a filament/arc driven, multi-cusp, surface conversion based system. Historical trends for setting runtime parameters and user "know-how" are the primary tools for tuning and running the ion source. In this work we are better quantifying our runtime and source recycle processes. The LANSCE source is used in repeated four-week run cycles during the annual six-month run period. Here, we test the hypothesis that real-time monitoring of the plasma temperature and cesium density will provide feedback information to increase run cycle time, optimize $H^-$ current, and monitor the source's health. To this end, we have installed a dual wavelength tunable laser diode absorption spectroscopy (TLDS) system with fiber transport for monitoring the $H_\alpha$ Balmer line absorption strength of excited state hydrogen ($H_{n=2} \rightarrow H_{n=3}$ transition) at 656.3 nm and the $D_2$ absorption line of cesium at 852.3 nm. Our optical measurement and fiber transport to/from the active source provides a non-intrusive method for extracting data from the source's 750 kV high voltage environment. Simultaneous collection of TLDS absorption, and emission lines from the $H_\beta$ and $H_\gamma$ excited states are incorporated into the data collection scheme with a series of narrow-band dichroic mirrors. Our design of a sweeping TLDS allows for collection of emission and absorption data within the same sub-millisecond plasma arc pulse, and the combination of these measurements allows us to monitor the generating hydrogen plasma temperature and cesium density during ion source conditioning and operations. In addition to the system design, we will present our initial data on monitoring production run sources, and we will evaluate the future impact of these measurements on overall system efficiency.

**Oral Session / 67**

## Beam optics analysis by visible cameras applied for the first time to a large-scale multi-beamlet configuration in the ITER prototype source

**Author:** Giulia Emma[1]

**Co-authors:** Margherita Ugoletti [2]; Matteo Agostini [3]; Riccardo Casagrande [4]; Isabella Mario [4]; Antonio Pimazzoni [4]; Basile Pouradier-Duteil [5]; Alastair Shepherd [6]; Emanuele Sartori [7]

[1] *Università degli studi di Padova*

[2] *ISTP-CNR, Institute for Plasma Science and Technology, C.so Stati Uniti 4, 35127 - Padova, Italy*

[3] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127 - Padova, Italy/ISTP-CNR, Institute for Plasma Science and Technology, C.so Stati Uniti 4, 35127 - Padova, Italy*

[4] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127 - Padova, Italy*

[5] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127 - Padova, Italy/CEA, IRFM, F-13108 St. Paul lez Durance, France*

[6] *Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA), C.so Stati Uniti 4, 35127 - Padova, Italy/UKAEA (United Kingdom Atomic Energy Authority), Culham Science Centre, Abingdon, Oxfordshire, OX14 3DB, United Kingdom of Great Britain and Northern Ireland*

[7] *Università degli Studi di Padova, via VIII Febbraio 2, 35122 Padova, Italy*

**Corresponding Author:** giulia.emma@studenti.unipd.it

The production of high energy neutral hydrogen/deuterium beams (0.87MeV/1MeV) with more than 90% homogeneity and extremely low divergence (<7mrad) is one of the biggest challenges for the realization of the ITER Neutral Beam Injector system.
To reach this goal, the ITER-like radio-frequency negative ion source, SPIDER, is in operation at the Neutral Beam Test Facility in Padua since 2018.
For the first time since the beginning of the operation, experiments are now carried out by simultaneously extracting up to 312 beamlets from a single beam segment (out of the total 1280 beamlets of the entire area).
Among the various diagnostics available to investigate beam features, SPIDER visible tomography, composed of 15 2D visible cameras surrounding the vacuum vessel, has already proven to be a powerful non-invasive diagnostic tool for the characterization of the beam in configurations with isolated extracted beamlets.
In the present work, beam optics is investigated by means of visible cameras positioned on the top of the SPIDER vessel, looking vertically through the beam. Even with an entire segment open, these cameras are capable of distinguishing columns of superimposed beamlets within the same beamlet group.
In this way, the width of the beamlets aligned with the camera line of sight is accurately estimated at different positions along the beam propagation direction through a Gaussian fitting procedure. The width is then used to evaluate the beamlet divergence.
The analysis method is here presented and the dependence of divergence on source parameters, such as radio-frequency power, gas pressure, and the magnetic filter field, is explored through dedicated perveance scans in different beam source configurations.
Results by visible cameras are compared with the data obtained from other beam diagnostics.

**Poster Session / 47**

## ES-PIC simulation of volume- and surface-produced H- ion trajectories

**Author:** Takanori Shibata[1]

**Co-authors:** Haruhisa Nakano [2]; Hayato Soejima [3]; Hidetomo Oguri [4]; Katsuhiro Shinto [5]; Katsuya Hayashi [6]; Kazuo Hoshino [6]; Kenji Miyamoto [7]; Kiyonori Ohkoshi [4]; Motoi Wada [8]

[1] *KEK*

[2] *National Institute for Fusion Science, National Institutes of Natural Sciences*

[3] *Keio-University*

[4] *JAEA*

[5] *J-PARC center/Japan Atmic Energy Agency*

[6] *Keio University*

[7] *Naruto University of Education*

[8] *Doshisha University*

**Corresponding Author:** takanori.shibata@kek.jp

Recent beam phase space measurement of the J-PARC negative hydrogen ion ($H^-$ ion) source shows that the extracted beam involves several components: beam core, diverging halo, converging halo, and asymmetric components 1. As the beam components except the core lead to beam losses after accelerating in the linac cavities, understanding of the halo formation is an important task. A 3D electrostatic Particle-In-Cell (ES-PIC) simulation 2 is applied to the J-PARC ion source to clarify the relation between the beam components and the $H^-$ production processes in the plasma. The $H^-$ ions in the model are produced in three different processes: (1) volume production, (2) surface production by $H^0$ atoms, and (3) surface production by protons. The transport of the $H^-$ ions is calculated and associated with the beam components after being extracted from the ion source.
1 T. Shibata, *et al.*, AIP Conf. Proc. **2373**, 050002 (2021).
2 T. Shibata, *et al.*, J. Phys.: Conf. Ser. **2743**, 012007 (2024).

**Poster Session / 19**

## Influence of microwave parameters on the afterglow beam

**Authors:** Hongwei Zhao[1]; Jibo Li[1]; Liangting Sun[1]; Olli Tarvainen[2]; Wang Lu[1]; Xinyu Wang[1]; 立轩李[None]

[1] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

[2] *STFC*

**Corresponding Author:** lilixuan@impcas.ac.cn

Heavy ion synchrotron accelerators rely on intense pulsed beams of highly charged ions. The production of these pulsed beams from an electron cyclotron resonance (ECR) ion source is predominantly achieved through the afterglow mode. However, the influence of microwave parameters on the characteristics of afterglow beams in high-frequency, high-power and large plasma-volume ion sources remains underexplored. Recently, a series of experiments were conducted with a third-generation superconducting ECR ion source. The effects of key microwave parameters, including the power level and pulse length of the secondary microwave source, as well as the RF-off time of the primary microwave radiation, on xenon afterglow beam currents are systematically examined. The experimental results and conclusions derived from the data are presented in this article.

**Poster Session / 18**

## Broadband electron gun design for a 5T solenoid EBIS for cancer therapy accelerators

**Author:** Jone Etxebarria Erdoiza[1]

**Co-authors:** Anton Gunnarsson [2]; Concepcion Oliver [1]; Fredrik Wenander [2]; alexander Pikin [1]

[1] *CIEMAT*

[2] *CERN*

**Corresponding Author:** jone.etxebarria@ciemat.es

We present an adaptation of the broadband electron gun concept 1 for use within a 5 T solenoid, optimised for an Electron Beam Ion Source (EBIS) designed for medical accelerators in cancer therapy. Building upon previous developments utilizing non-adiabatic magnetic field shaping with coils and iron rings, this approach provides a laminar electron beam across a wide range of current densities by reduction of the amplitude of the cyclotron motion 2. We explore the impact of the axial position of the cathode on beam quality, identifying optimal configurations for minimizing electron beam angles in the operational range 0-3 A. The system is further optimized for a target working point of 2 A and 1000 A/cm² current density. A schematic overview of the cryogenic 5 T EBIS layout is also showcased. This work contributes to the development of high-performance, tuneable EBIS sources for the next-generation of cancer therapy accelerators.

1 High perveance electron gun with controllable current density. A. Pikin et al. (2025)
2 Effect of a nonadiabatic magnetic field on the amplitude of cyclotron motion. J. Etxebarria et al. (2025)

**Poster Session / 28**

## Investigation into Transient Processes in Electron Cyclotron Resonance

**Authors:** Yicheng Dong[None]; Shi PENG[1]; Bujian Cui[None]; JIANBIN ZHU[None]; Zhiyu Guo[None]

[1] 物理学院

**Corresponding Author:** dongyc@stu.pku.edu.cn

Electron cyclotron resonance (ECR) hydrogen ion source has advantages of producing high beam intensity with low emittance and long life, has been wildly used in high energy physics, medical and archaeology, etc. They are among the few efficient devices capable of generating high-intensity H+, H2+, or H3+ ion beams. To better understand the mechanisms underlying the hydrogen plasma discharges, a transient global model was developed at Peking University (PKU). This model is based on the mass and energy conservation equations of electron, H2, H, H+, H2+ and H3+, to describe the variety of number density and energy of these particles at each time-step. Simulation results illustrate the distributions of the key reactions affecting both number density and energy. Additionally, ion fractions are also calculated once the model reaches equilibrium, revealing their dependence on gas pressure and absorbed power. To validate this model, an experiment was carried out with a compact PKU type 2.45 GHz ECR ion source in continuous wave mode. The measured results of ion fractions align closely with those predicted by simulation. This transient global model will provide more precise guidance for design and operation of ECR hydrogen ion sources.

**Poster Session / 45**

## Extraction and emittance characterization of high-intensity ion beams from a laser ion source

**Authors:** Junjie Zhang[1]; Huanyu Zhao[1]; Libin Li[1]; Xing Fang[1]; Liangting Sun[1]; Hongwei Zhao[1]

[1] *Institute of Modern Physics, Chinese Academy of Sciences*

**Corresponding Author:** zhangjj@impcas.ac.cn

To enhance the matching efficiency between the laser ion source and the subsequent RFQ accelerator with the direct plasma injection scheme or other schemes, the characteristics of the ion beams extracted from the laser ion source was investigated. For this purpose, a three-electrode extraction

system and a Pepperpot emittance meter equipped with an intensified imaging system were developed. Comprehensive investigations were conducted on the beam extraction performance and the corresponding beam quality. Stable extraction of carbon and nickel ion beams with peak currents exceeding 100 emA was demonstrated at an extraction voltage of 55 kV. With the help of the dedicated intensified imaging system of the Pepperpot, the emittance of the extracted beam can be measured for only one beam pulse. By optimizing the extraction voltage and electrode gap, a normalized RMS emittance of approximately 0.17 $\pi$·mm·mrad was achieved for the carbon ion beam with a peak current of 8 emA.

**Poster Session / 80**

## Directional Control of Ablation Plasma in a Laser Ion Source Using a Permanent Magnet

**Author:** Kazumasa Takahashi[1]

**Co-authors:** Yuto Kondo [1]; Kakeru Watanabe [1]; Toru Sasaki [1]; Takashi Kikuchi [1]

[1] *Nagaoka University of Technology*

**Corresponding Author:** kazumasa@vos.nagaokaut.ac.jp

In laser ion sources, it has been shown that the maximum ion charge state increases as the laser irradiation angle relative to the target surface approaches normal incidence. However, in practical systems, a plasma transport line for extracting ion beams is typically aligned along the vertical axis of the target, making it difficult to irradiate the target at normal incidence. To solve this issue, we propose a method that controls the directionality of the ablation plasma using a magnetic field, enabling the vertical laser irradiation of the target. Since plasma density decreases with distance from the laser target, we installed a ring-shaped permanent magnet close to the target, slightly offset from the vertical axis, to deflect the plasma while maintaining high density. As a result, plasma deflection caused by the installed magnet was successfully observed. In this presentation, we discuss how the plasma deflection varies with magnetic field conditions.

**Poster Session / 95**

## Operation and Optimization of a Negative Hydrogen Ion Source for BNCT Applications

**Author:** Vladislav Vekselman[1]

**Co-authors:** Mark Harrison [1]; Kirill Martianov [2]; Aleksandr Makarov [2]; Ken Franzen [1]; Alexander Dunaevsky [1]

[1] *TAE Technologies Inc., Foothill Ranch, CA, USA*

[2] *TAE Life Sciences, Irvine, CA, USA*

**Corresponding Author:** vvekselman@tae.com

A compact, cesium-free negative hydrogen ion source has been deployed as part of a boron neutron capture therapy (BNCT) accelerator system. The source, based on D-Pace hardware, is supported by ancillary systems developed by TAE Life Sciences and delivers a stable beam with currents up to 15 mA. It supports reliable and efficient operation across a range of beam currents, making it suitable for both routine clinical operation and experimental use. The source operates in both DC and pulsed modes, providing flexibility that is particularly valuable during system commissioning, tuning, and troubleshooting.

A fully automated control system enables hands-free operation. The system includes extensive logging of operational parameters and diagnostics, supporting fast interlocking, real-time monitoring,

trend analysis, and consistent long-term performance. This work illustrates the successful adaptation of a commercial ion source into a medical accelerator system with enhanced control, reliability, and operational flexibility.

**Poster Session / 93**

## A Penning Ion Source for Stable Isotope Beam Production at TRIUMF-OLIS

**Author:** Ben Warfield[1]

**Co-authors:** Chris Kent [2]; Christopher Charles [3]; Cory Drew [2]; Gwenael Fubiani [4]; Jacob Cramton [2]; Jason Taylor [2]; Morgan Dehnel [5]; Nicolas Savard [6]; Oliver Kester [3]; Tobias Junginger [1]

[1] *University of Victoria*

[2] *Selkirk Technology Access Center*

[3] *TRIUMF*

[4] *LAPLACE, Université de Toulouse, CNRS, Toulouse, France*

[5] *Selkirk Ion-source Research Centre*

[6] *D-Pace*

**Corresponding Author:** bwarfield@uvic.ca

Ben Warfield<sup>1</sup>, Oliver Kester<sup>3</sup>, Christopher Charles<sup>3</sup>, Jason Taylor<sup>4</sup>, Cory Drew<sup>4</sup>, Jacob Cramton<sup>4</sup>, Chris Kent<sup>4</sup>, Nicolas Savard<sup>5</sup>, Tobias Junginger<sup>1</sup>, Gwenael Fubiani<sup>6</sup>, Morgan Dehnel<sup>1,2,5</sup>

<sup>1</sup> University of Victoria Dept. of Physics and Astronomy, <sup>2</sup> Selkirk Ion-source Research Center, <sup>3</sup> TRIUMF, <sup>4</sup> Selkirk Technology Access Center, <sup>5</sup> D-Pace, <sup>6</sup> LAPLACE Université de Toulouse CNRS Toulouse, France

Abstract submitted to ICIS 2025, Oxford, UK, September 8 to 12, 2025.

The Off-Line Ion Sources (OLIS) facility at TRIUMF is considering replacement of its existing microwave ion source to increase the breadth of available beams for experiments at the Isotope Separator and ACcelerator (ISAC) complex. A Penning ion source is one potential new candidate source, with requirements for beams having A/q < 7 for masses under 30 AMU. Additionally, the Penning source lifetime, beam currents, and beam quality must achieve equal or better performance than the existing microwave source. A new Penning source is being collaboratively developed between SIRC and TRIUMF, utilizing a stand-alone Penning ion source test stand with an adjustable magnetic field up to 1 Tesla. The candidate ions chosen to assess the efficacy and utility of the Penning source are: <sup>6</sup>Li 1+, <sup>12</sup>C 2+, <sup>18</sup>O 3+, <sup>24</sup>Mg 4+, and <sup>30</sup>Si 5+. Here we describe the initial set-up of the Penning test stand and commissioning status. In addition, a study utilizing IBSimu is reported where the magnetic field is varied to maximize separation between the desired isotope and charge state, and others also extracted from the source. For example, for the case of a high purity Oxygen feed-gas, good separation between <sup>18</sup>O 3+ and (<sup>18</sup>O 2+, 4+) , and (<sup>16</sup>O 2+, 3+, 4+) is necessary.

**Poster Session / 132**

## Numerical Investigations of Coulomb Collisions and Energy Conservation in a Particle-in-Cell Model for Ion Source Applications

**Author:** Jasmin Deguire[1]

**Co-authors:** Gwenael Fubiani [2]; Nicolas Savard [3]

[1] *D-Pace, University of Victoria*

[2] *LAPLACE, Université de Toulouse, CNRS, Toulouse, France*

[3] *D-Pace*

**Corresponding Author:** jasmindeguire@hotmail.com

LEPIC is a Particle-In-Cell (PIC) code developed at the LAPLACE Laboratory in Toulouse, originally designed to simulate the dynamics of charged particles in negative ion sources for the ITER collaboration. In this work, we present recent developments that extend the code's capabilities to better model the physical processes relevant to high-density, low-temperature plasmas such as those found in inductively coupled ion sources. Specifically, Coulomb collisions have been implemented using Nanbu's binary collision algorithm, allowing for a more accurate representation of collisional energy and momentum exchange between charged particles. Additionally, we investigate the implementation of energy-conserving time integration schemes within LEPIC. While the code currently conserves momentum, the lack of exact energy conservation imposes a mesh cell size of about the electron Debye length to limit the development of the so-called Finite Grid Instability (FGI), leading to numerical heating. The planned energy-conserving scheme aims to relax this constraint.
We apply the upgraded LEPIC algorithm to simulate plasma behavior in conditions representative of an ion source operated at D-Pace. The objective is to assess how different numerical schemes and collisional models influence quantities such as energy distribution functions, plasma density profiles, and ion fluxes. Although experimental validation is beyond the scope of this current work, the numerical results serve as a foundation for future comparisons with measured data.

**Poster Session / 147**

## Numerical Validation of a New Extraction System for the ECR Source LEGIS at INFN-Legnaro National Laboratories

**Author:** Carmelo Sebastiano Gallo[1]

**Co-authors:** Giada Rachele Mascali [2]; Alessio Galatà [3]; Taneli kalvas [4]; Marco Miglioranza [3]; Massimo Rossignoli [3]; Paolo Francescon [3]; Francesco Giraldo [3]; Denis Martini [5]; Osvaldo Carletto [3]

[1] *INFN - LNL*

[2] *INFN Legnaro National Laboratories - Sapienza University of Rome*

[3] *INFN-Legnaro National Laboratories*

[4] *Accelerator Laboratory, Department of Physics, University of Jyvaskyla (JYFL)*

[5] *INFN-LNL div. Acceleratori*

**Corresponding Author:** carmelo.gallo@lnl.infn.it

The extraction system of the Electron Cyclotron Resonance Ion Source LEGIS (LEGnaro ecrIS), installed at INFN - Legnaro National Laboratories, and the following Low Energy Beamline (LEBT) have been recently characterized by numerical simulations, whose results showed a very good agreement with experimental evidences. The study correctly reproduced the beam transmission downstream the ion source, as well as some criticalities emerged during the beam transport for the scheduled nuclear physics experiments. Even if the beam properties (quality and intensity) are still suitable for the injection into the PIAVE-ALPI accelerator complex, their optimization would be desirable in view of the upcoming production and extraction of U beams, whose intensity in the desired mass-over-charge ratio could be lower than usual. This contribution describes a possible optimization, validated by numerical simulations, of the extraction system of the LEGIS source. The results revealed an improved extracted beam quality, thus foreseeing a higher transmission and an easier setting of the downstream LEBT. Starting from the conceptual design used in the numerical simulations, a possible mechanical implementation in the beamline has been studied and will be also presented.

**Poster Session / 40**

## First experimental evaluation of the Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source for the RAON ISOL system

**Author:** Je Hwan Han[1]

**Co-authors:** Dong-Joon Park [2]; Hee-Joong Yim [2]; Hyung Joo Woo [2]; Jinho Lee [2]; Kyounghun Yoo [2]; Moses Chung [3]; Wonjoo Hwang [2]; Yeong-Heum Yeon [2]

[1] *Institute for Basic Science, Ulsan National Institute of Science and Technology*

[2] *Institute for Basic Science*

[3] *Pohang University of Science and Technology*

**Corresponding Author:** jwksmin@ibs.re.kr

The Isotope Separation On-Line (ISOL) facility at the Rare Isotope Accelerator complex for ON-line experiments (RAON) produces rare isotope (RI) beams using various ion sources to support a wide range of research applications. Following the successful commissioning of RI beams using a Surface Ion Source and a Resonant Ionization Laser Ion Source (RILIS), a new Forced Electron Beam Induced Arc Discharge (FEBIAD) ion source was developed to extend the range of RI beams available at the facility. To evaluate the FEBIAD ion source, an ISOL Offline Test Facility (OLTF) was established. The OLTF consists of a target/ion source system, ion beam optics, beam diagnostics, a dipole magnet, a vacuum system, and a control system.

In the initial experiments, key operational parameters such as beam stability and thermal behavior under high-temperature conditions were measured. Additional tests, including emittance measurements, beam current analysis, and reliability assessments of the ion source, were also performed. In particular, the successful extraction of an argon (Ar) isotope beam was achieved, clearly demonstrating the feasibility of RI beam production using the FEBIAD ion source. Long-term operation tests further verified the stable performance of the conventional FEBIAD source under high-temperature conditions. This study presents and discusses the operational characteristics and emittance measurement results of the FEBIAD ion source at the RAON ISOL facility.

Future studies will involve systematic investigations using various noble gases to assess the ionization efficiency, thermal stability, and beam quality of the FEBIAD ion source. These efforts aim to validate its performance across a broader mass spectrum. Based on the findings of this study, stable and rare isotope beam experiments under online conditions are being planned to ensure reliable beam production at the RAON ISOL facility.

**Poster Session / 74**

## Outcomes and Perspectives Arising from Particle-in-Cell Simulation of ECR Ion Sources

**Authors:** Andrea Miraglia[1]; Annarita Laricchiuta[2]; Armando Coco[3]; Giampiero Colonna[2]; Giovanni Russo[3]; Giuseppe Bilotta[4]; Giuseppe Castro[5]; Lorenzo Neri[1]; Ornella Leonardi[1]; Sebastiano Boscarino[3]

[1] *INFN-LNS*

[2] *CNR ISTP*

[3] *UNICT-DMI*

[4] *INGV*

[5] *INFN-LNS div. Acceleratori*

**Corresponding Author:** neri@lns.infn.it

After several years of Particle-in-Cell (PIC) development to study Electron Cyclotron Resonance Ion Sources (ECRIS), we are close to reproducing the experimental behavior with high fidelity. We present some cases where the simulations disclose the reasons for observed behaviors. First, we observed the differences between the HSMDIS** magnetic configuration and the conventional magnetic configuration of 2.45GHz ECRIS. We revealed that these two magnetic configurations use different electromagnetic resonance conditions to ignite the plasma. The different electromagnetic configurations achieved in the steady state explain the different stability and beam intensity performances. An impacting problem of the standard magnetic configuration is the intense erosion of the boron nitride disk in correspondence with the microwave injection side of the plasma chamber. The simulations show the reason for the erosion and how the HSMDIS magnetic configuration produces a limited erosion rate. In perspective, a three-dimensional version of the PIC simulation tool is under development to investigate the electromagnetic configuration of high-charge state ECRIS operating at high frequencies. Different experimental evidence was identified to be studied with the new branch of the simulation tool development.

** L. Neri, L. Celona, "High Stability Microwave Discharge Ion Sources", Nature Scientific Reports 12, 3064 (2022) https://doi.org/10.1038/s41598-022-06937-7

**Poster Session / 155**

## Integrated Design, Simulation, and Fabrication of a PIG Ion Source Accelerator for Functional Materials Research

**Author:** Manjeet Mor[1]

**Co-author:** Puneet Jain [2]

[1] *IIT ROORKEE*

[2] *IIT Roorkee*

**Corresponding Author:** manjeet@ph.iitr.ac.in

Ion irradiation has emerged as a vital tool for engineering the structural and electronic properties of materials, particularly thin films used in advanced functional applications. Its precision and tunability make it highly effective for defect modulation at the nanoscale, driving innovations in materials research. In this work, we present the design, simulation, and fabrication of a compact ion accelerator system, centred around a Penning Ion Generator (PIG) ion source, developed entirely in-house to enable controlled and localized ion irradiation. The accelerator delivers ions up to 50 keV and comprises four components: a Penning Ion Source for stable production, an Electrostatic Quadrupole Triplet (EQT) for focusing, a Wien Velocity Filter (WVF) for mass-to-charge separation, and a high-vacuum Target Chamber for uniform delivery. The design and optimization of each subsystem were guided by computational simulations. The plasma extraction region was optimized using IBSimu to enhance ion yield and minimize divergence. COMSOL Multiphysics simulated the electric and magnetic fields in the EQT and WVF, enabling ion trajectory tuning and efficient transport. Following the simulation, each subsystem was fabricated and assembled in-house, resulting in a compact, efficient, and cost-effective platform for laboratory-scale irradiation. The accelerator supports $H_2$, $N_2$, $O_2$, and He gases and delivers beam currents up to 1 μA. High-voltage supplies drive the EQT and WVF, with Neodymium magnets generating the WVF magnetic field. A mu-metal shield minimizes fringe fields and maintains beam quality. The final beam spot (~1.5 cm × 1.0 cm) ensures localized irradiation. The system operates under high vacuum (~$10^{-6}$ mbar) to maintain purity.
In summary, the developed PIG ion source-based accelerator offers a versatile, cost-effective platform for ion irradiation research, with high flexibility and control for nanoscale materials engineering.

**Poster Session / 150**

# Beam dynamics calculations of the ADIGE injector for the SPES Project

**Author:** Giada Rachele Mascali[1]

**Co-authors:** Luca Bellan [2]; Osvaldo Carletto [3]; Michele Comunian [4]; Paolo Francescon [3]; Carmelo Sebastiano Gallo [5]; Francesco Giraldo [3]; Taneli Kalvas [6]; Denis Martini [4]; Alessio Galatà [3]; Julien ANGOT [7]

[1] *INFN Legnaro National Laboratories - Department of Physics, Sapienza University of Rome (Italy)*

[2] *INFN Legnaro National Laboratories*

[3] *INFN-Legnaro National Laboratories*

[4] *INFN-LNL div. Acceleratori*

[5] *INFN - LNL*

[6] *Accelerator Laboratory, Department of Physics, University of Jyvaskyla (JYFL)*

[7] *LPSC-CNRS*

**Corresponding Authors:** alessio.galata@lnl.infn.it, giada.mascali@lnl.infn.it

The ADIGE injector will be the first part of the post-acceleration of radioactive ions produced in the framework of the SPES project at INFN - Legnaro National Laboratories. The beam extracted from an ECR-based Charge Breeder (CB) will be transported toward a medium-resolution mass spectrometer (MRMS, resolving power 1/1000), installed on a negatively polarized high-voltage platform, and then injected into an RFQ through a magnetic beamline. Aim of the MRMS is to purify the extracted beam from the contaminants induced by the breeding process. The commissioning of the injector will start in Autumn 2025, using stable beams of increasing mass produced by turning the charge breeder into a conventional ion source. This contribution presents a numerical characterization of the CB extraction system and its downstream transport line, starting from the case study of a 132Sn19+ beam, being the most representative radioactive ion for the SPES project. The study revealed important information on the transport line's sensitivity to the initial beam parameters and proved to be very useful in estimating to which extent they can be scaled, following the mass-over-charge ratio of the transported ion. Preliminary considerations on the MRMS operation during an ion scan will be also reported.

**Poster Session / 169**

# A Tunable Permanent Magnet Quadrupole with Openable Design for In-Situ Installation

**Author:** Gábor Anda[1]

**Co-author:** Daniel Barna [2]

[1] *HUN-REN Centre for Energy Research*

[2] *HUN-REN Wigner Research Centre*

**Corresponding Author:** anda.gabor@ek.hun-ren.hu

We present a novel tunable permanent magnet quadrupole specifically suited for low-energy beam transport lines in ion source systems. These front-end sections often operate under tight spatial constraints and limited access, making conventional electromagnets or complex cooling systems impractical. Our design addresses these challenges by combining wide field tunability, mechanical openness, and zero power consumption.

The magnet consists of two concentric, independently rotatable Halbach rings made of NdFeB permanent magnets. Their relative rotation enables continuous tuning of the field gradient—including polarity reversal—allowing precise matching of ion beams to downstream optics without active power or cooling. Simulations predict a tunable integrated gradient of 0.8 to 4.5 T (depending on aperture size), corresponding to field gradients of ~10 to 70 T/m—well-suited for focusing and matching in the low-energy sections following an ion source. A prototype with a 54 mm aperture was constructed

and tested, demonstrating a measured tuning range of 7.75–17.75 T/m and an estimated integrated gradient of 0.36–1.01 T.
A key innovation is the openable, split-yoke mechanical design, enabling installation directly around existing beamlines without disassembly—ideal for integration into operational ion source facilities, especially where frequent maintenance, diagnostics, or vacuum bake-outs are required. The design also ensures low hysteresis (<1%) and suppresses unwanted multipole components by more than three orders of magnitude.

This scalable, modular quadrupole concept supports high-performance, maintenance-free ion optics in beamlines where power availability, space, and accessibility are constrained—making it a compelling tool for modern ion source front ends.

**Poster Session** / **2**

## Impedance Characteristics and Sputtering Behaviour of Two Pulsed DC Arc Discharge H- Sources

**Authors:** Alejandro Garcia Sosa[1]; Claire Talbott[2]; Dan Faircloth[2]; Daniel Bollinger[3]; Daniel Jones[3]; Erin Flannigan[2]; Olli Tarvainen[2]; Pat Karns[3]; Rob Abel[2]

[1] *STFC - Rutherford Appleton Laboratory*

[2] *STFC*

[3] *FNAL*

**Corresponding Author:** olli.tarvainen@stfc.ac.uk

Caesiated surface plasma sources are commonly used for high current H- production. These are pulsed DC arc discharge sources with varying geometries. The DC arc discharge is typically current-controlled, i.e. the discharge voltage is a free parameter adjusting over time and within the pulse. The longevity and performance of ion sources are critical factors in particle accelerators, especially for applications requiring high-intensity beams. One failure mechanism of these ion sources is electrode deformation by sputtering. The development of sputtering models that account for the physical interactions between ionized particles and material surfaces can help in the understanding and optimisation of ion source lifetimes. This paper presents a sputtering model developed for the pulsed DC discharges and investigates its potential utility in evaluating and comparing the lifetimes of two distinct ion source technologies: the ISIS H- Penning source and Fermilab's H- Magnetron source. By analysing the sputtering behaviour under operational conditions, the model can estimate the relative sputtering rate within the discharge pulse and the dependence of the sputtering on ion source control parameters and discharge properties . The study highlights how the model can be adapted to different source architectures, offering insights into source design improvements and lifetime predictions, ultimately aiding in the optimization of ion source technologies for high-energy physics applications.

**Poster Session** / **13**

## Commissioning status of a combined RFQ Cooler with axial magnetic field in the Eltrap machine

**Author:** marco cavenago[1]

**Co-authors:** Enea Boria [2]; Francesco Cavaliere [2]; Michele Comunian [1]; Giancarlo Maero [2]; Mario Maggiore [2]; Massimiliano Romè [2]; Alberto Ruzzon [1]; Alessio Galatà [3]

[1] *INFN-LNL div. Acceleratori*

[2] *Dip. Fisica, Univ. Milano e INFN-MI*

[3] *INFN-Legnaro National Laboratories*

**Corresponding Author:** alessio.galata@lnl.infn.it

In nuclear physics accelerators, as the SPES (Selective Production of Exotic Species) complex at LNL, radiofrequency quadrupole coolers (RFQC) are often necessary to cool the beam from exotic ion sources both in energy spread $\sigma_E$ and normalized transverse emittance $\epsilon_N$, in order to match the acceptance of high resolution mass spectrometers for exotic nuclei selection (rms roughly $\sigma_E = 0.5$ eV and $\epsilon_N < 3$ nm). Since cooling is due to ion-gas collisions with collision energy in the order of 10 eV, the ion beam energy ($K_s = 40$ keV in SPES) has to be reduced before RFQC iniection. Beam transport inside RFQC may be facilitated by an axial magnetic field as in Eltrap machine, where an RFQC prototype is now installed and being commissioned; in principle the RFQC extraction behaves as a virtual ion source, with a challenging beam optics; results from several computational codes are reported. In Eltrap RFQC, we limit $K_s \leq 5$ keV and ion kind to $Cs^{1+}$, to use a commercial ion source (installed on a suitable voltage platform) as injector. Beam diagnostics include a Faraday cup FC1 before RFQC injection, and, after extraction, another Faraday cup FC2 and a pepperpot emittance meter EMI1 (also on a suitable platform). Commissioning status is reported, including the elaborate final wiring of RFQC electrodes and the differential pumping system, the tuning of extraction optic and the communication between different hardware, especially with EMI1. Beam dynamics and energy analysis capabilities of FC2 (and/or its necessary updates to an energy spread analizer) are discussed.

**Poster Session / 87**

# Overview of Ion Beam Delivery Program at Avalanche Energy

**Authors:** Samantha Valenteen[1]; Scott Schipmann[1]; Shadrach Hepner[1]; Siamak Rahmanian[1]

**Co-author:** Robin Langtry [1]

[1] *Avalanche Energy*

**Corresponding Author:** shepner@avalanche.energy

Avalanche Energy's fusion systems require the transport of low-energy ion beams into extremely low-pressure environments, often within the constraints of compact packages. Traditional vacuum pumping methods used on accelerator beamlines are infeasible at this scale, necessitating innovative designs. This work presents an overview of the beam transport solutions developed at Avalanche, including the implementation of a multiple-stage differential pumping section that minimizes gas load downstream. To reconcile the need for low final beam energy with the advantages of high-energy extraction, we have adopted a decelerated beam approach—extracting and transporting at higher voltages, then reducing energy at the entrance to the Orbitron. Additionally, we employ electrostatic focusing and steering techniques, including Sikler lenses, to finely tune the beam trajectory and spot size within tight spatial constraints. This poster outlines the design rationale, simulation results, and performance metrics of our current beamline systems, highlighting their relevance for compact fusion.

**Poster Session / 129**

# Decelerating beamline design of an ECR ion source at Avalanche Energy

**Author:** Shadrach Hepner[1]

**Co-authors:** Robin Langtry [1]; Samantha Valenteen [1]; Scott Schipmann [1]

[1] *Avalanche Energy*

**Corresponding Author:** shepner@avalanche.energy

Avalanche Energy's fusion system, the Orbitron, requires the transport of low-energy, positive ion beams into extremely low-pressure environments. As the fusion systems mature, the need for beam current increases rapidly. To match development pace of the Orbitron system, we have acquired a D-Pace ECR ion source that can produce 30 mA of D+ beam current at 50 keV of energy. While this source produces sufficient beam current for the next generation of Orbitron machines, the energy at which this beam is produced is too high. To accommodate a 10 keV ion beam requirement, a deceleration scheme has been designed and tested. First, a series of IBSimu simulations were conducted to design a lensing and deceleration system to convert the higher energy beam into an adjustable, 10 keV beam as required by the Orbitron. Surrogate optimization is employed to optimize the geometry and biasing based on beam current and spot size. Next, the system was designed mechanically to support the voltage and cooling requirements inherent to the system. Finally, tests were conducted on this design, and emittance measurements were taken to ensure that the beam is matched to the Orbitron's requirements. This work presents each step of this process and discusses its relevance to Orbitron fusion.

**Poster Session / 165**

## Comparative Study of CW and Pulsed 13 MHz vs 27 MHz RF Plasma Ignition Systems for $H^-$ Ion Source Operation at SNS

**Author:** Amith Hulikal Narayan[1]

**Co-authors:** Baoxi Han [1]; Robert Welton [2]; Chris Stinson [1]; Dale Heidenreich [1]; Vic Andzulis [1]; Chip Piller [1]

[1] *Oak Ridge National Laboratory*

[2] *ORNL-SNS*

**Corresponding Authors:** hanb@ornl.gov, welton@ornl.gov, narayana@ornl.gov, piller@ornl.gov

This paper presents a planned comparative study of RF plasma ignition systems operating at 13 MHz and 27 MHz in both continuous wave (CW) and pulsed modes for $H^-$ ion sources at the Spallation Neutron Source (SNS). The objective is to evaluate how RF frequency and mode influence plasma ignition characteristics and system performance. Key parameters to be characterized include RF power requirements, $H_2$ gas flow rates, antenna current, pulse duration, and timing overlap between the RF ignition pulse and the main 2 MHz high-power pulse. Experiments will be carried out on the Ion Source Test Stand (ISTS) to assess performance under both CW and pulsed conditions.
A secondary focus is the characterization of dark current—residual $H^-$ beam current observed during 13 MHz CW operation when the main beam pulse is off. This current is presently directed into the first drift tube linac (DTL1) during maintenance operations. The study will investigate whether pulsed RF operation at either frequency reduces or eliminates this effect.
Findings from this study are expected to guide improvements in plasma ignition reliability, reduction of unintended beam current during standby periods, and optimization of RF system configurations for ion source applications at SNS.

**Poster Session / 48**

## Status of ECR ion source at RAON

**Author:** Jeongil Heo[1]

**Co-authors:** Inseok Hong [1]; Seokjin Choi [1]

[1] *Institute for Basic Science*

**Corresponding Author:** jiheo@ibs.re.kr

RAON (Rare isotope Accelerator complex for ON-line experiments) is a particle accelerator constructed in South Korea for research in nuclear physics, materials science, medicine, and related fields.
To stably produce and accelerate ion beams, three types of ECR ion sources are planned for operation: a 28 GHz ECR ion source, a 14.5 GHz ECR ion source, and a spare ECR ion source.
The 28 GHz ECR ion source, currently under development, is designed to generate heavy ion beams such as $U^{33+}$ and $U^{34+}$, and is composed of a fully superconducting magnet system.
The 14.5 GHz ECR ion source was manufactured by PANTECHNIK and installed in our beamline in September 2020. Initial beam conditioning of the RAON accelerator is being carried out using the 14.5 GHz ECRIS.
The spare ECR ion source, currently under development, is a hybrid type consisting of permanent magnets and superconducting magnets. At present, only the magnet assembly has been completed, and the design process is ongoing.

In this paper, we summarize the various issues encountered during the research, development, and operation of the three types of ion sources and discuss the future directions for further research and development.

**Poster Session / 30**

## Beam energy spread of a filament-type Penning Ionization Gauge Ion Source for a compact ion microbeam system

**Author:** Yasuyuki Ishii[1]

**Co-author:** Takeru Ohkubo [1]

[1] *National Institutes for Quantum Science and Technology*

**Corresponding Author:** ishii.yasuyuki@qst.go.jp

A filament-type penning ionization gauge ion source with small power consumption and low energy spread (FPIG) has been developed for a compact ion microbeam. In this microbeam system, a duoplasmatron-type ion source with a filament (DpIS) has, so far, been used to produce submicron beams. The DpIS can generate low energy ion beam with a low beam energy spread. However, the DpIS consumes electric power over 1 kW to heat a Thoriated Tungsten filament and cool electrodes heated by the filament. This power consumption is a barrier for the compact ion microbeam system to be used in many research and industrial fields. In general, typical PIGs have large beam energy spread over several ten electron-volts that are large to form ion microbeams although they have small electric power consume. One of the reasons to generate the beam energy spread is considered to supply electrons for plasma by impacting the ions to the cathodes. In this study, FPIG has been developing using a thin tungsten wire for small power consumption as electron supply. In the preliminary study, the tendency of the low energy spread of hydrogen ion beams generated by FPIG was obtained using a beam energy analyzer of a parallel electroplate type. In this presentation, the property of FPIG will be represented based on the beam energy spread.

**Poster Session / 49**

## ASTERICS ion beam extraction : system optimization by simulation

**Authors:** Quentin Hars[1]; Thomas Thuillier[2]

[1] *CNRS LPSC*

[2] *CNRS-LPSC*

**Corresponding Author:** quentin.hars@lpsc.in2p3.fr

As part of the NEWGAIN project 1, the ECR ion source ASTERICS aiming at delivering a continuous beam of 10 pμA U34+ is under development 2. This work reports the parametric simulation study of ASTERIC's ion extraction triode system using the IBSimu C++ library [3], focusing on an argon (Ar) beam.
The simulations assessed the impact of hot electron temperature escaping the plasma on the space charge compensation factor and its subsequent effect on beam emittance. A detailed exploration of the electrodes potential parameter space was carried out by varying the electrode gaps to optimize the Ar12+ beam quality. The optimal conditions minimizing the beam emittance were found for a 50 mm gap, with a source potential of 20 kV and the electron repeller electrode set to -4 kV.
Furthermore, parametric studies were performed to investigate the influence of geometric parameters, such as the plasma electrode angle, width and radius of curvature. These studies, detailed in this work, indicate that variations in geometry significantly affect beam focusing and emittance.

1 M. Moscatello et al., "NEWGAIN project at GANIL SPIRAL2:design of the new heavy ion injector for the superconducting LINAC", in Proc. 14th Int. Part. Accel. Conf. (IPAC'23), Venice, Italy, pp. 1747–1749, 2023. doi:doi/jacoW-ipac2023-tupa193/index.html
2 T. Thuillier et al, 2024 J. Phys.: Conf. Ser. 2743 012059. doi:10.1088/1742-6596/2743/1/012059
[3] T. Kalvas, et al., "IBSIMU: A three-dimensional simulation software for charged particle optics", Rev. Sci. Instrum. 81, 02B703, (2010). Doi:10.1063/1.3258608

**Poster Session / 52**

## The effect of the oscillation of plasma parameters on the beam extraction in RF negative ion source

**Author:** Katsuya Hayashi[1]

**Co-authors:** Keitaro Nomi [1]; Kenji Miyamoto [2]; Takanori Shibata [3]; Kazuo Hoshino [1]

[1] *Keio University*

[2] *Naruto University of Education*

[3] *KEK*

**Corresponding Author:** phy-kh@keio.jp

In RF negative ion sources, the extracted beam involves AC component oscillating with the RF frequency 1. The oscillation component causes the beam loss and damage the device. Therefore, the beam oscillation should be suppressed, but its physical mechanism is still unclear.

In this study, the numerical analysis was conducted using a 3D PIC model to understand the time evolution of the beam extraction mechanism in RF negative ion sources. In particular, variation of the plasma meniscus, which is beam emitting surface, is calculated. In the previous studies 2, dependence of the meniscus shape on the plasma density has been analyzed in steady-state simulation. The simulation model is modified to take into account the oscillation of particle and energy fluxes incoming to the extraction region, which are assumed to be results of the RF heating.

In the modified simulation, the meniscus shape and the beam current shows time variation with the same frequency as the plasma density oscillation. On the other hand, no significant time variation was observed on the meniscus profile in the case where only plasma temperature oscillates. These results show that upstream plasma density oscillation by RF heating affects the temporal beam profile.

In the presentation, difference of the meniscus behavior between the two cases: plasma density and temperature oscillation are discussed with detailed information: dependence of amplitude of source oscillation, the phase difference between the source oscillation and the beam oscillation, etc.
1 T. Shibata, et al., AIP Conference Proceedings 2373, 050002 (2021)
2 K. Hayashi, et al., 20th International Conference on Ion Source, Victoria Canada, 2023

**Poster Session / 78**

## Experimental Validation of a Double-Gridded Lens System for High-Frequency RFQ Injection

**Author:** Aristeidis Mamaras[1]

**Co-authors:** Alessandra Lombardi [2]; Alexander Pikin [3]; Amer Ajanovic [4]; Eleonora Pasino [2]; Francesco Di Lorenzo [2]; Julien Thiboud [2]; Oleksandra Khrul [2]; Sebastian Bertolo [2]

[1] *Aristotle University of Thessaloniki | CERN*

[2] *CERN*

[3] *CIEMAT / CERN*

[4] *UNSA / CERN*

**Corresponding Author:** amamaras@physics.auth.gr

As part of CERN's Medical and Societal Applications program, a system composed of an extractor and two-gridded lens has been experimentally validated as a compact Low-Energy Beam Transport (LEBT) solution, critical for integrating pre-injectors into compact medical accelerators. The system is under 90 cm long and it is designed to extract transport and transversely match ion beams at an energy of 15 keV/u into a 750 MHz Radio Frequency Quadrupole (RFQ) (q/m = ½ to 1). A novel ion extractor electrode has been integrated into a NEC ion source, yielding proton currents of the order of 0.1 mA, for injection into the high-frequency RFQ. The lens system delivers the stringent transverse focusing required by the RFQ. This work presents the design and implementation of the novel lens system, evaluates its experimental performance, and compares it to beam optics simulations. In parallel, its performance is assessed against a more compact, direct extraction scheme designed for immediate RFQ matching.

**Poster Session / 96**

## Space Charge Modeling for Negative Ion Beam Transport: A PIC Study

**Author:** Sidharth Dash[1]

**Co-author:** Mainak Bandyopadhyay [1]

[1] *Homi Bhabha National Institute (CI- Institute for Plasma Research)*

**Corresponding Author:** sidharth.dash@ipr.res.in

Large-size, Multi-beam group negative ion-based neutral beam injectors (NBI) are an effective heating and current drive system for fusion reactors such as ITER. Improving understanding of ion beam transport is critical for optimizing the performance and efficiency of such multi-beam group NBI systems. Primary studies on a $1/8^{th}$ size, 2-beam group-based negative ion source (ROBIN: RF-Operated Beam source in India for Negative ions), through comparison of numerical modeling and experimental studies, have shown the impact of space charge (SC) interaction (Coulomb repulsion) on the beam group separation during transport1. The IBSimu2 package is used to design a three-dimensional kinetic model (PIC: Particle In Cell) of two tilted charged beam groups to explore the impact of SC interaction on beam group dynamics downstream of the beam line. Two charged particle beams, characterized by Gaussian transverse profiles and uniform longitudinal distributions, are continuously injected into the simulation domain. The beam current and energy are used as two crucial input parameters for tracking these interactions in the simulation. The spatiotemporal evolution of the transverse particle distribution, both for individual beam groups and the resulting merged beam, is tracked to quantify the effects of the SC interaction field. Integrating secondary particle generation and SC compensation into the simulation code is in progress. This study aids the understanding of SC interactions between partially compensated ion beam groups in a negative ion source and their impact on beam transport.

1. Dash, Sidharth, et al. ``Probing into Space Charge Interactions of Negative Ion Beams through Ima
2. Kalvas, Taneli, et al. ``IBSIMU: A three-dimensional simulation software for charged particle opt

**Poster Session / 118**

## Modeling of 1D DC Discharges Using Various Particle-in-Cell Schemes

**Author:** Nicolas Savard[None]

**Co-authors:** Gwenael Fubiani [1]; Morgan Dehnel [2]

[1] *LAPLACE, Université de Toulouse, CNRS, Toulouse, France*

[2] *D-Pace*

**Corresponding Author:** nicolas@d-pace.com

A common approach for modeling plasma dynamics in ion sources is the Particle-in-Cell (PIC) method. However, in the high-density, low-temperature, low-pressure plasmas typically found in ion sources, PIC simulations face significant challenges. Accurately resolving the Debye length and plasma frequency requires fine spatial and temporal resolution, along with sufficient particles per cell, leading to high computational cost. To alleviate these constraints, explicit and implicit energy-conserving PIC schemes, particularly those using non-uniform grids, have been proposed to enable lower-resolution simulations and achieve significant speedups in two- and three-dimensional models. While these approaches can reduce numerical demands, previous studies have shown that, for electrostatic cases, reductions in execution time may be offset by decreased accuracy due to larger cell sizes and lower particle counts, even when resolution is selectively relaxed in the quasi-neutral region while retaining fine resolution in the high-voltage sheath. Importantly, this trade-off has not yet been examined in the context of discharges sustained by electron emission from cathodes commonly used in ion sources. In this work, we apply energy-conserving explicit and implicit PIC schemes to a one-dimensional, low-pressure direct-current plasma discharge with a thermionic electron emission. We compare a standard momentum-conserving explicit scheme with lower-resolution variants of energy-conserving explicit and implicit approaches. Our results quantify the impact of reduced spatial and particle resolution on simulation accuracy and assess the viability of these schemes for predictive modeling in ion sources.

**Poster Session / 162**

## Design of a Permanent Magnet System for the Production of Closed Resonance Surfaces in Microwave Discharge Ion Sources

**Authors:** Alex Hinton[1]; Ben Shepherd[1]; Dan Faircloth[1]; Kareem Elahee Doomun[1]; Olli Tarvainen[1]

[1] *STFC*

**Corresponding Author:** alex.hinton@stfc.ac.uk

The production of high current beams of multiply charged ions has many applications, such as accelerator-based medical isotope production and optimisation of the atomic to molecular ion ratio in high-current proton sources relevant for major accelerator facilities. Microwave discharge ion sources are one option for production of ion beams. These sources require a system to generate a magnetic field which is resonant with a coupled microwave input to generate the plasma.
In simple designs using solenoid magnet coils, the resonant field surface that is produced is open ended and leads to poor plasma confinement and these ion sources producing only singly charged ions. Other designs require complex magnet arrays which combine solenoid and multipole fields to form a closed resonant surface, at the expense of lower beam currents but can achieve multiple charge states.

We present here the design of a novel method for generating a closed resonant field surface from a simplified permanent magnet array without a solenoid. The magnet system consists of an array of permanent magnets rods and steel pole pieces whose arrangement can produce the closed surface without the requirements for any electrical power. A mechanical tuning system allows adjustment of the shape and size of the closed resonant surface.
A prototype proof of principle device has been designed for application to a 2.45 GHz microwave source. The prototype has been built to measure the magnetic field distribution created by this magnetic array and to test the generation and tuning of the closed resonant field surface.
Future work will aim to test this magnet device on an operational plasma chamber to measure how the plasma density can be adjusted through tuning of the closed resonant field surface.

**Poster Session / 168**

## Stationary Transverse Striations in Medium-Energy, High-Current Ion Beams

**Author:** Elijah Wilson[1]

**Co-authors:** Adrian Lopez [2]; John Foster [1]; Ronald Moore [2]

[1] *University of Michigan*

[2] *Oak Ridge National Laboratory*

**Corresponding Author:** willlson@umich.edu

Standing plasma striations are characterized by alternating regions of high and low luminosity observed in various plasma environments, including positive columns of DC discharges and microwave-generated plasma. In each case, the cause of said striations and the parameter space in which they exist vary. In recent tests at Oak Ridge National Laboratory (ORNL), stationary striations have been observed in medium-energy, high-current (i.e., 20-50 keV, >10 mA) ribbon ion beams produced in ORNL's ion source test stand 1. These striations are aligned parallel to the beam direction—a phenomenon that, to our knowledge, has not been previously reported in literature.

To investigate the source and characteristics of these striations, a comprehensive study is conducted using argon and xenon plasma under a range of operating conditions. Spectroscopy and emittance diagnostic methods are employed to analyze the optical emission properties and phase space distributions of the generated ion beams. The results, including the sensitivity of striations to changing operating conditions, will be presented.

**Acknowledgement**
This research is supported by the U.S. Department of Energy Isotope Program, managed by the Office of Science for Isotope R&D and Production.

**References**
1 Wilson, E.J., Lopez, A., Clay, P., Stevenson, A., and Egle, B.J. (2023, October). "A 100 mA Metal Ion Source Test Stand."[Poster]. In the 76th Annual Gaseous Electronics Conference, Ann Arbor, MI.

**Oral Session / 81**

## Ultra-low work function surfaces for $H^-/D^-$ ion sources

**Author:** Nikolas Klose[None]

**Co-authors:** Christian Wimmer [1]; Roland Friedl ; Ursel Fantz [2]

[1] *Max-Planck-Institut f. Plasmaphysik*

[2] *Max-Planck-Institut für Plasmaphysik*

**Corresponding Author:** nikolas.klose@ipp.mpg.de

The efficient and reliable production of negative ions is a key challenge for all $H^-/D^-$ ion sources. The method with the highest production rate of $H^-/D^-$ relies on the surface conversion of atomic and positively charged hydrogen/deuterium particles at a low work function (WF) surface. The state-of-the-art to obtain the low WF is by evaporating Cs, the element with the lowest WF (1.9-2.1 eV as bulk material), onto a substrate surface. Under ultra-high vacuum conditions (UHV, $<10^{-8}$ mbar), sub-monolayer sheaths of pure Cs show WFs as low as 1.5 eV.
Neutral beam injection systems based on negative ions for fusion are, however, typically operated under non-UHV conditions. In such non-baked systems, water is the most abundant residual gas, which will react with the Cs in the ion source. During operation, the conversion surface of the ion source undergoes alternating vacuum, gas and plasma phases.
Measurements in vacuum under different background pressures and after short plasma pulses reveal WFs as low as 1.2 eV, attributable to the formation of Cs oxides, which indicates that the interplay of Cs with residual water may lead to the optimal converter surface for $H^-/D^-$ sources. The ultra-low WF-layers are not stable over long plasma pulses. Hence, procedures to reliable obtain these layers at the ITER background pressures and maintain them during long pulses, needs to be developed.
Therefore, the required layer characteristics in terms of thickness and chemical composition and to its reliable synthesis and persistence during ions source operation needs to be identified. To this end, campaigns under different conditions ranging from UHV to water-rich environments are performed using a comprehensive set of diagnostics. Besides the absolute photoelectric WF determination, tuneable diode laser absorption spectroscopy (TDLAS) is used for the absolute quantification of neutral Cs. A quartz micro balance (QMB) measures the adsorbed thickness of the Cs layer.

**Oral Session / 24**

## Application and Effects of Introducing Low Frequency Electromagnetic Waves in Electron Cyclotron Resonance Ion Source

**Author:** Yushi Kato[1]

**Co-authors:** Yushi Fujimura [1]; Akinobu Ide [1]; Shinji Tokuno [1]; Daichi Inoue [1]; Masayuki Muramatsu [2]; Atsushi Kitagawa [2]; Toyohisa Asaji [3]

[1] *The University of Osaka*

[2] *QST*

[3] *The University of Shiga Prefecture*

**Corresponding Author:** kato@eei.eng.osaka-u.ac.jp

We have been experimentally measuring the charge state distribution of the multiply-charged ion current generated and extracted from an electron cyclotron resonance (ECR) ion source (ECRIS), and plasma parameters in the ECRIS, and then investigating the correspondence between them. According to the accessibility conditions of wave propagation in the magnetized ECRIS plasma, it is speculated that the essential factor that determines the limitations in the multiply charged ion current in the current ECRIS is not simply the ordinary wave cutoff, nor the right-hand polarization wave cutoff density, but rather the higher density limit one, i.e., the left-hand polarization wave cutoff density where electromagnetic waves no longer can exist. In addition to the conventional method of simply increasing the frequency to establish the magnetic field strength, it is necessary to overcome this limit and to stabilize instabilities that appears in them. As a new strategy, we applied electromagnetic waves with much lower frequency than ECR's ones, which essentially has no density limit. Typical examples include the introduction of ion cyclotron resonance (ICR) and lower hybrid resonance (LHR). In this paper, we will mainly report on the former, and will report the results obtained by improving the efficiency of multiply charged ion generation based on selective heating by ICR of low mass number element ions during low mass number element gas mixing. In particular, it was found that the effect of low-frequency electromagnetic waves was large when introducing light Z gases such as Ar and He into the Xe operating gas, and the corresponding changes in various parameters were measured. We will also discuss the preparation status of the LHR experiment, as well as strategies for applying low-frequency electromagnetic waves to relieve and stabilize possible instabilities caused by the peaking phenomenon of spatial parameters due to the already mentioned density limit.

**Oral Session / 122**

## Numerical design and experimental characterization of an innovative, 3D-printed, 'plasma-shaped'cavity for ECR Ion Sources

**Authors:** David Mascali[1]; Giorgio Sebastiano Mauro[1]; Dora Bianconi[1]; Giuseppe Torrisi[1]; Ornella Leonardi[2]; Alessio Galatà[3]; Carmelo Sebastiano Gallo[4]; Angelo Pidatella[1]; Bharat Mishra[1]; Eugenia Naselli[5]; Filippo Russo[1]; Eduard Chyhyrynets[4]; Cristian Pira[4]; Davide Cester[6]; Leonardo Salvò[6]; Pietro Rebesan[6]; Adriano Pepato[6]; Angelica Gallo[6]; Razvan Dima[6]

[1] *INFN - LNS*

[2] *INFN-LNS*

[3] *INFN-Legnaro National Laboratories*

[4] *INFN - LNL*

[5] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS)*

[6] *INFN - PD*

**Corresponding Author:** mauro@lns.infn.it

To improve the performances of ECR In Sources, several approaches are possible. One proposed by INFN consists in the re-design of the plasma chamber and of its microwave injection system. In this work we propose innovative plasma chamber named IRIS (Innovative Resonator Ion Source), whose shape is derived from the electrons last iso-density surface as the electrons move under the influence of the confining minimum-B magnetic field. Moreover, a new microwave launching system, based on a slotted waveguide that smoothly matches the cavity wall profile, is proposed. The simultaneous adoption of these two approaches increases the source performances by: a) the excitation of electromagnetic modes with a predominance of electric field along the cavity axis, unlike the standard cylindrical plasma chambers and b) a more uniform power deposition into the plasma core due to the injection waveguide radiating slot positions.
The plasma chamber and its microwave injection system have been designed by using CST Studio Suite with the objective to maximize the waveguide-to-cavity microwave coupling for the modes excited inside the operational frequency interval. Particle-In-Cell simulations have confirmed the higher in-plasma energy deposition expected for IRIS compared to a conventional cylindrical cavity. By employing COMSOL Multiphysics, a combination of RF, thermal and structural simulations have also been carried out to assess the correct behaviour of the water cooling system.
A full-scale structure prototype has been realized in Additive Manufacturing (AM) technique via Selective Laser Melting (SLM) technology, post-processed via Plasma Electropolishing (PEP). It has been then experimentally characterized in terms of S-parameters (modal distribution) and on-axis electric field measurement for selected modes through the bead-pull technique. Experimental results are coherent with numerical simulations, confirming the correctness of the design and of the fabrication process.

**Oral Session / 134**

## The high-energy tail of the EEDF and its impact on $H^-$ volume ion sources

**Author:** Roland Friedl[1]

**Co-authors:** Olli Tarvainen [2]; Ursel Fantz [3]; Anand George [4]

[1] *University of Augsburg, AG EPP*

[2] *STFC*

[3] *Max-Planck-Institut für Plasmaphysik*

[4] *D-Pace*

**Corresponding Author:** roland.friedl@uni-a.de

Volume production of negative hydrogen ions relies on the dissociative attachment process by which low-energy electrons attach to highly vibrationally excited molecules ($H_2(v^*)$), the latter being produced predominantly by high-energy electrons. Understanding the processes leading to high $H_2(v^*)$ populations gives the opportunity to optimize $H^-$ volume sources. This contribution focusses on a modelling approach to relate the electron energy distribution function (EEDF) to the obtainable vibrational populations and the subsequent $H^-$ density in the source. The high energy-tail of the EEDF is of particular interest and its importance is highlighted in filament sources where primary electrons of high energy are present due to the arc voltage that drives the arc discharge [e.g. Terasaki et al., RSI 81 (2010) 02A703].

The modelling is based on the flexible Yacora solver: collisional-radiative models for the electronic $H_2$ states [Wünderlich et al., J. Phys. D 54 (2021) 115201] and the vibrational states of the molecular ground state (including redistribution via the singlet states $^1$B and $^1$C) [Bergmayr et al. Eur. Phys. J. D 77 (2023) 136] are used together with a balance model for the production and destruction channels of $H^-$ [Rauner at al., AIP CP 1655 (2015) 020017]. The Yacora solver accepts arbitrary EEDFs, which gives the opportunity to analyse the impact of variations of the high-energy tail of the filament sources and compare it to a Maxwellian distribution that is more representative for RF driven discharges. Overall, the analysis suggests that the impact of the EEDF on the $H^-$ density can be significant, i.e. a factor of two or more. The anticipated influence of varying the arc voltage on the EEDF is studied and compared to $H^-$ beam current measurements done on the D-Pace filament ion source test stand. An outlook is given, showing the capabilities of using VUV spectroscopy to obtain empirical insights into the variation of the EEDF.

**Oral Session / 145**

# X-ray imaging and spectroscopy of space- and time-dependent phenomena in ECRISs to investigate fundamental plasma processes

**Author:** Eugenia Naselli[1]

**Co-authors:** Sándor Biri [2]; Giorgio Finocchiaro [3]; Giorgio Sebastiano Mauro [4]; Bharat Mishra [4]; Bianca Peri [5]; Angelo Pidatella [4]; Richard Rácz [2]; Domenico Santonocito [5]; Giuseppe Torrisi [4]; David Mascali [4]

[1] *Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali del Sud (INFN-LNS)*

[2] *HUN-REN Institute for Nuclear Research (ATOMKI), Debrecen, Hungary*

[3] *INFN-LNS*

[4] *INFN - LNS*

[5] *Istituto Nazionale di Fisica Nucleare*

**Corresponding Author:** eugenia.naselli@lns.infn.it

Within the INFN PANDORA project, a fully superconductive ECR plasma trap-based research facility is being developed to measure β-decays in magnetized plasmas. This infrastructure also enables fundamental and applied plasma physics studies through non-invasive multi-diagnostics systems, with implications for ion source R&D. X-ray diagnostics emerge a very powerful tool for monitoring plasma parameters, confinement dynamics, and stability in B-minimum ECR traps. While the full-scale PANDORA trap is under construction (expected completion by August 2026), several studies were conducted using the ATOMKI ECRIS.
In a recent experiment, a novel diagnostic setup –combining a 400 µm Pb pinhole, a 4 MP X-ray CCD camera (0.6-30 keV range), and a millisecond-resolution X-ray shutter - was deployed. Coupled with single photon counting algorithm and advanced trigger systems, this enabled energy-, space-, and time-resolved X-ray spectroscopy to study plasma transients, including ignition, afterglow decay,

and turbulence.
The first relevant results include space-resolved gas mixing studies to investigate changes in plasma confinement structure (combining Ne, Kr, Ar, Xe) when compared to single-gas mode, shedding light on debated gas mixing effect. Further results concern time- and space-resolved plasma dynamics studies, where transient phenomena (plasma ignition and afterglow phases) were resolved for the first time with 100 µs temporal, 400 µm spatial, and 260 eV (@ 8 keV) energy resolution. Structural and temporal evolution of the plasma on ms timescales between different configurations were reveled using various trigger delays, and elucidated electron/ion deconfinement dynamics during afterglow decay. These evidences were also correlated with the main properties (intensity and ion charge state) of the extracted beam.
The obtained results highlight the broad potential of X-ray diagnostic techniques for applications in ECRIS operation and plasma physics research.

**Oral Session / 99**

## Superconducting magnet structures and developments for 4th Generation ECR ion sources

**Author:** Paolo Ferracin[1]

[1] *LBNL*

**Corresponding Author:** pferracin@lbl.gov

In an Electron Cyclotron Resonance (ECR) ion source for heavy-ion accelerators, the plasma is confined by a magnet system composed by a combination of sextupole and solenoid coils which generate a magnetic field characterized by closed iso-surfaces. Third generation sources operate at RF frequencies in the 20 to 30 GHz range and implement coils made with Nb-Ti superconductor producing magnetic fields of 6 to 7 T. Fourth generation sources aim at RF frequencies at the 50 GHz level. For these sources, the magnet system relies either on Nb-Ti superconducting coils with innovative and more efficient designs, like the MARS magnet currently under development at Lawrence Berkeley National Laboratory (LBNL), USA, or on the use of advanced superconducting materials, like Nb3Sn, which can achieve magnetic fields of up to 15 T. The latter option is being investigated both at the Institute of Modern Physics (IMP), China, and at LBNL. In this presentation, we provide an overview on the development of magnet systems for 4th generation ECR ion Sources, focusing on the description of their magnetic and mechanical designs, and on the status of their fabrication and qualification tests.

**Oral Session / 53**

## BNCT ECR Discharge Chamber Low SWR Design and Beam Experiments

**Author:** 乐瑶黄[1]

**Co-authors:** 永川肖 [1]; 华甫欧阳 [1]; 秀霞曹 [1]; 康佳薛 [1]

[1] 中国科学院高能物理研究所

**Corresponding Author:** huangly@ihep.ac.cn

Boron Neutron Capture Therapy (BNCT) is an emerging treatment in nuclear medicine and radiation therapy, offering precise cancer cell targeting while sparing healthy tissue. The discharge chamber, a critical component of the BNCT ECR ion source, significantly impacts ion source performance and beam quality. This article details the design of the second BNCT accelerator ECR ion source (BNCT02 ECR) at the Institute of High Energy Physics, Chinese Academy of Sciences. It explores two design schemes for the discharge chamber：a cylindrical discharge chamber and a square discharge chamber on geometric structure, magnetic field configuration, and ridge waveguide design to achieve a low standing wave ratio (SWR). These improvements address discharge instability caused by sensitive ceramic block positioning, enhancing beam intensity, stability, and arc ignition success. Beam experiments validated the design. The BNCT system at Dongguan People's Hospital has operated efficiently since 2024, achieving a target beam power of ~28 kW, an operational rate >95%, and cumulative runtimes of 6,694 hours for the ion source and 7,073 hours for the power source. A single neutron target has accumulated 5,160 milliampere-hours, with a peak daily target time exceeding 110 milliampere-hours. BNCT02's neutron flux density meets IAEA clinical standards.

**Oral Session / 140**

## PIBHI 2025 workshop: open mind discussions on ECR ion sources

**Author:** Luigi Celona[1]

**Co-authors:** Aleksandr Andreev [2]; Benoit Gall [3]; Damon Todd [4]; Guillaume Machicoane [5]; Hongwei Zhao [6]; Janilee Benitez [7]; Liangting Sun [6]; Olivier Tuske [8]; Olli Tarvainen [9]; Paolo Ferracin [10]; RICHARD VONDRASEK [11]; Ralph Hollinger ; Santo Gammino [12]; Sergey Kondrashev [13]; Takashi Nagatomo [14]; Thomas Thuillier [15]; Vadim Skalyga [16]; Xinyu Wang [17]

[1] *INFN-LNS*

[2] *GSI Helmholtzzentrum für Schwerionenforschung GmbH*

[3] *IPHC-CNRS*

[4] *Lawrence Berkeley National Laboratory*

[5] *Facility for Rare Isotope Beams, Michigan State University*

[6] *The Institute of Modern Physics, Chinese Academy of Sciences*

[7] *Lawrence Berkeley National Lab*

[8] *CEA-IRFU*

[9] *STFC*

[10] *LBNL*

[11] *Argonne National Laboratory*

[12] *INFN - LNS*

[13] *BNL*

[14] *RIKEN Nishina Center*

[15] *CNRS-LPSC*

[16] *IAP-RAS*

[17] *Institute of Modern Physics (IMP), Chinese Academy of Sciences (CAS)*

**Corresponding Author:** celona@lns.infn.it

This article summarizes the discussions during the PIBHI 2025 workshop highlighting the most crucial points emerged. The workshop's main purpose was to stimulate debate among participants on various topics of interest to the community in dedicated round tables.
The discussions covered several key arguments with a huge impact on daily ECRIS operations and in perspective on the development of the new generation sources. In fact, an adequate understanding of the fundamental processes may provide crucial information for optimizations facilitating the production and transport of stable high-intensity ion beams.
Plasma studies, factors contributing to the emittances measured and solutions that can be envisioned for transporting such intense beams were discussed in depth. It is traditionally thought that the magnetic field is the dominating contribution while recent works show that the extraction design has a huge impact on the source.
Moreover: availability, reproducibility and stability of HCI beams for various elements up to uranium are required from several facilities worldwide. Requests are usually accompanied by an increasing value of beam intensity creating serious beam quality problems of match with downstream

accelerator. Only an appropriate plasma and beam diagnostics would permit the correlation between beam and plasma parameters optimizing the operating conditions for each specific experimental context.
Finally, the discussion moved to the challenges for the development of new generation ECRIS. Two factors look to be the most critical: the magnetic system and a new coupling scheme.
The magnetic system of future ECRIS envisages the need to operate daily and reliably with high magnetic fields. Limiting factors, technologies, and new magnet solutions are analyzed. The development of new coupling schemes for high-frequency ECRIS belongs to a launching-dominated scenario instead of the classical modal-dominated scenario of second-generation ECRIS.

**Oral Session / 131**

## Negative ion sources for accelerators - status and future prospects

**Authors:** Robert Welton[1]; Baoxi Han[2]; Olli Tarvainen[3]; Vasiliy Morozov[4]

[1] *ORNL-SNS*

[2] *Oak Ridge National Laboratory*

[3] *STFC*

[4] *ONRL*

**Corresponding Author:** welton@ornl.gov

Abstract. Today, negative ion sources, particularly those producing H- ions are used extensively in many large, accelerator-based, user facilities operating worldwide. Beams of H- ions have become the preferred means of filling circular accelerators and storage rings as well as enabling efficient extraction from cyclotrons. Such facilities include the US Spallation Neutron Source (SNS), Japan Proton Accelerator Research Complex (J-PARC), Rutherford Appleton Laboratory (RAL-ISIS), Los Alamos Neutron Science Center (LANSCE), Fermi National Accelerator Laboratory (FNAL), Brookhaven National Laboratory (BNL), the CERN LHC injector, the Chinese Spallation Neutron Source (CSNS) as well as numerous installations of D-Pace (licenced by TRIUMF) ion sources used mainly with cyclotrons. In addition, several future facilities as well as upgrades to existing facilities are being envisioned which will generally require higher performing H- ion sources, Low Energy Beam Transports (LEBTs) and Radio frequency Quadrupoles (RFQs). This report will first define the current state-of-the-art by specifying the beam parameters routinely injected into the accelerators of existing facilities as well as provide a simple description of their injector systems. Next, the parametric upgrade goals of existing and envisioned facilities will be discussed as well as research efforts at the SNS and world-wide and to meet these goals.

**Oral Session / 149**

## Medium to high Z-ion beams from laser-plasma interactions

**Author:** Marco Borghesi[1]

[1] *Queen's University Belfast*

**Corresponding Author:** m.borghesi@qub.ac.uk

Laser-driven approaches to ion acceleration are the focus of significant scientific attention in light of the beams'unique temporal properties as well as the compactness and versatility of the acceleration process.
Most of the experimental activity has focused so far on the acceleration of protons, through sheath acceleration processes acting at the rear of laser-irradiated foils, where ultra-high, spatially localized fields (>TV/m) accelerates protons present on the surface, e.g. in contaminant layers. Accelerating

higher-Z ions from the target surface requires in-situ removal of contaminants which is a complex and often inefficient process.

Alternative acceleration mechanisms have recently emerged which act directly on ions located in the bulk of laser-irradiated targets, and have been employed for efficient acceleration of medium to high-Z ions. These include Radiation Pressure Acceleration, where the very large light pressure carried by an ultraintense laser pulse transfers momentum to the ions of a dense, opaque target plasma. Exploiting this process for efficient acceleration requires precise control of the parameters of the driving laser, as well as of the dynamics of the ionized target.
The talk will review results obtained so far with these techniques using the GEMINI and VULCAN lasers of the Central Laser Facility of the Rutherford Appleton Laboratory, with particular focus on the acceleration of carbon and gold ions. We will also discuss perspectives for further progress on the next generation of multi-Petawatt facilities, and for the applications that will be enabled by these developments.

**Oral Session / 8**

## The High Intensity Polarized Proton Source

**Author:** Grigor Atoian[1]

**Co-authors:** Anatoli Zelenski ; Antonino Cannavo [1]; Brian Snyder [1]; Deepak Raparia [1]; John Ritter [1]; Timothy Lehn [1]

[1] *Brookhaven National Laboratory*

**Corresponding Author:** atoian@bnl.gov

The High Intensity Polarized Proton Source and Siberian Snakes enabled RHIC's high-luminosity polarized proton beams to study proton spin structure, conduct fundamental tests of QCD, and conduct electroweak interactions. For 25 years, the polarized proton source based on OPPIS (Optically Pumped Polarized H- Ion Source) reliably delivered the high-intensity polarized proton beam for the RHIC spin physics program. The first OPPIS system, based on the ECR (Electron Cyclotron Resonance) primary proton source, operated successfully in the Runs 2000–2012. In 2012 it was then replaced by an OPPIS system based on the Fast Atomic Ion Source (FABS) with a hydrogen atomic beam injector and a helium ionizer 1. FABS produces a significantly brighter primary proton beam, resulting in increased beam intensity and polarization. Since 2012 FABS-based OPPIS has been operating successfully for RHIC. Since its implementation FABS has undergone numerous upgrades to optimize beam parameters, ensuring high polarization and intensity while effectively suppressing unpolarized beam components and maintaining small beam emittance. As a result, we have achieved a peak polarization of over 86%, an intensity exceeding 1000 μA, and a beam pulse duration of over 400 μs out of the Linac. The average volume of polarization is approximately 80% and an intensity of 350 μA. After the successful operation in Runs-2013-24, OPPIS is in good shape to deliver up to 1012 polarized H- ions/linac pulse with 82-85% polarization for future Electron Ion Collider (EIC) operation 2.

1. A. Zelenski et al., "The RHIC polarized source upgrade"19th International Spin Physics Symposium (SPIN2010)

2. D. Raparia* et al., "Polarized ion sources at BNL", 25th International Spin Physics Symposium (SPIN 2023) 24-29 September 2023 Durham, NC, USA

**Oral Session / 25**

## Optimization for RF-driven H- source and low energy beam transport for CSNS-II

**Author:** Weidong Chen[1]

[1] *Institute of high energy physics, Chinese academy of sciences (CAS)*

**Corresponding Author:** chenwd@ihep.ac.cn

The RF-driven $H^-$ ion source has demonstrated a maintenance interval exceeding 7500 hours with nearly 100% availability. To achieve the goal of delivering 500 kW beam power to the spallation target, as required by CSNS-II, the beam current from the ion source must be increased while minimizing the beam emittance. Research on beam intensity, space charge compensation, and stripped proton beam elimination has been conducted on the test bench with a new LEBT. This report presents the latest experimental results from these studies, along with the issues encountered during commissioning. A key focus of this work is the elimination of the stripped proton beam in the LEBT section, achieving a proton-to-$H^-$ ratio below 0.01%. This reduction minimizes the heat load and radioactivity induced by stripped proton losses in the superconducting linac section planned for CSNS-II.

**Oral Session / 97**

## Advancing H- injector beam intensity frontier at high duty-factor for multi-megawatt proton accelerators

**Author:** Baoxi Han[1]

**Co-authors:** Amith Narayan [1]; Chip Piller [1]; Chris Stinson [1]; Greg Terszakowec [1]; Jordan Thomas [1]; Rob Welton [1]; Sang-Ho Kim [1]; Vic Andzulis [1]

[1] *Oak Ridge National Laboratory*

**Corresponding Author:** hanb@ornl.gov

The SNS accelerator complex features a front-end H- injector equipped with an RF-driven H- ion source and an electrostatic low energy beam transport (LEBT) system. Recent advancements in the beam extraction system have successfully increased the H- ion source beam output capability from ~60 mA to ~120 mA, while operating reliably at the routine RF power level of roughly 50 kW and a duty-factor of 6% (1.0 ms at 60 Hz). This enhancement plays a crucial role in the ongoing SNS beam power upgrade from 1.4 MW to 2.8 MW, providing a substantial margin for beam current. Furthermore, a maximum beam current of approximately 150 mA has been achieved by increasing the RF power to about 80 kW.

Current efforts are focused on optimizing the ion source plasma filter field and cesium system to improve H- ion formation efficiency relative to RF power, ultimately further enhancing both beam current output and reliability. Additionally, the development of LEBT systems - both electrostatic and magnetic - aims to ensure robust beam transport and beam chopping even at very high currents. These advancements are expected to yield promising solutions for H- injectors for future upgrades or new developments of multi-megawatt high power proton accelerators.

**Opening Remarks / 1**

## Opening Remarks

**Oral Session / 176**

# Wisman Exhibitor Talk

**Corresponding Authors:** flora@wismanhv.com, anna@wismanhv.com, susie@wismanhv.com