First commissioning results of the MIST-2 ion source for the High-Current H_2^+ Cyclotron HCHC-XX

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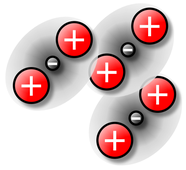
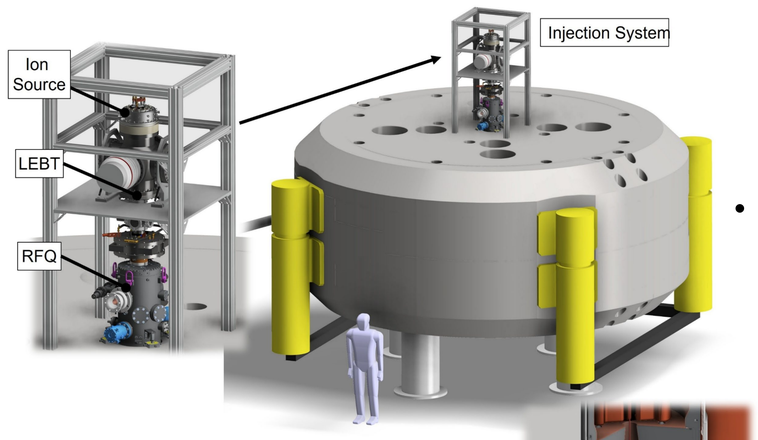
Abstract. In the HCHC-XX cyclotron design, an H_2^+ ion source is feeding a high-current beam through an RFQ buncher, axially embedded in the cyclotron yoke, into the central region of the cyclotron where the beam is guided onto the median plane and accelerated. The 60 MeV/amu version, the HCHC-60 will 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_2^+ production. Recently, we built a new ion source, the MIST-2, incorporating lessons-learned from MIST-1. Here we report the design of the MIST-2, highlight improvements we made, and present the first commissioning results, which, so far, approximately doubled the total beam current extracted from the MIST-1.

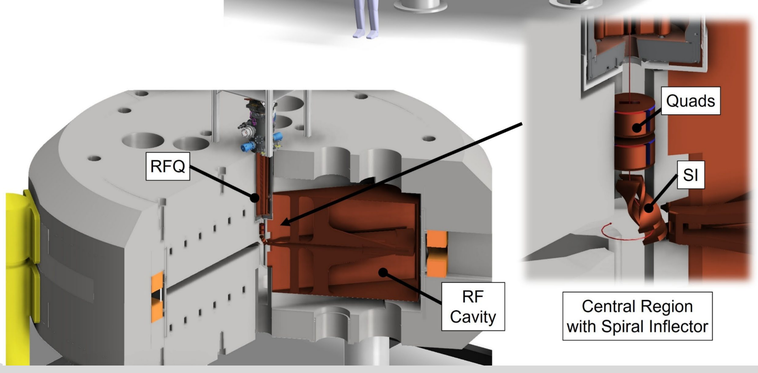
The HCHC-XX

High-Current H_2^+ Cyclotron – XX MeV/amu

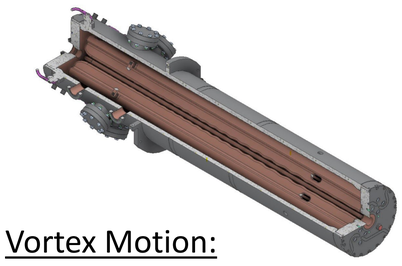
- Room-temperature compact isochronous cyclotron
- Core features:
  - Four double gap RF cavities – high energy gain per turn
  - Accelerate H_2^+
  - Inject directly through RFQ
  - Utilize “vortex motion”
  - Resonant extraction







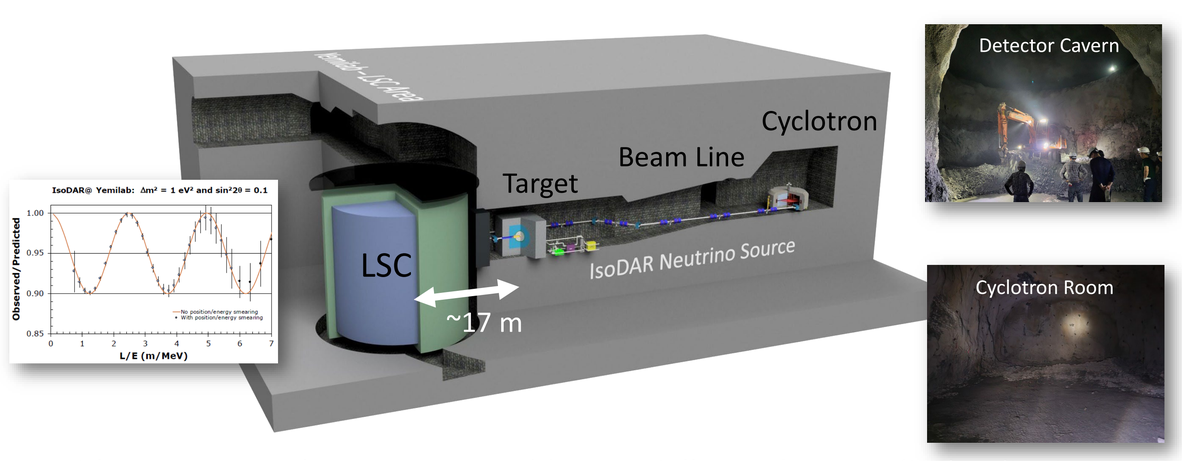
- RFQ:
  - Split-coaxial for low frequency
  - Accelerate from 15 to 70 keV



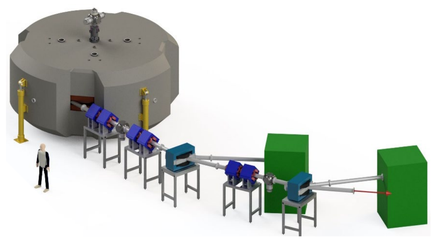
- Vortex Motion:
  - Accidentally discovered at PSI Injector II
  - The radial-longitudinal coupling due to space-charge causes a curling up of the bunch that contains the particles radially, allowing clean extraction
  - Simulated with OPAL.
  - Beam matching in the center using collimators (~40% loss, but at low E)
  - < 150 W loss during extraction

Applications

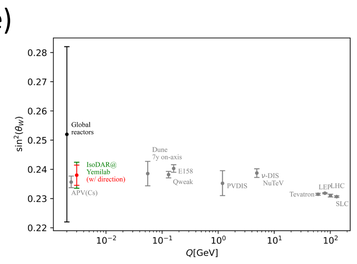
- An HCHC-60 is planned for beyond standard model searches with IsoDAR@Yemilab



- With HCHC-XX cyclotrons, one could potentially produce medical radio- isotopes in large quantities close to where needed
  - Current isotope targets are not equipped for 600 kW, but we can split (see image) → remove the electron from a portion of the beam with a foil → bend protons to target, let H2+ continue to next splitter



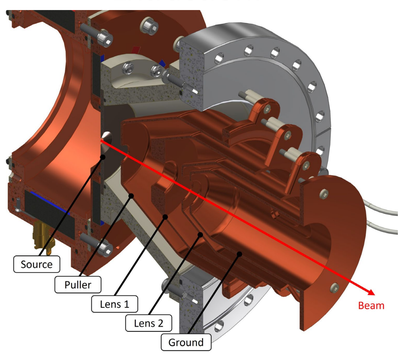
- Many other applications:
  - Material research (tests of plasma facing material in short time)
  - Specialized Z’ and Axion-Like Particle (ALP) searches
  - Decay-At-Rest (DAR) flux for coherent scattering
  - Test stands for detectors in high neutron environments
  - Weak mixing angle

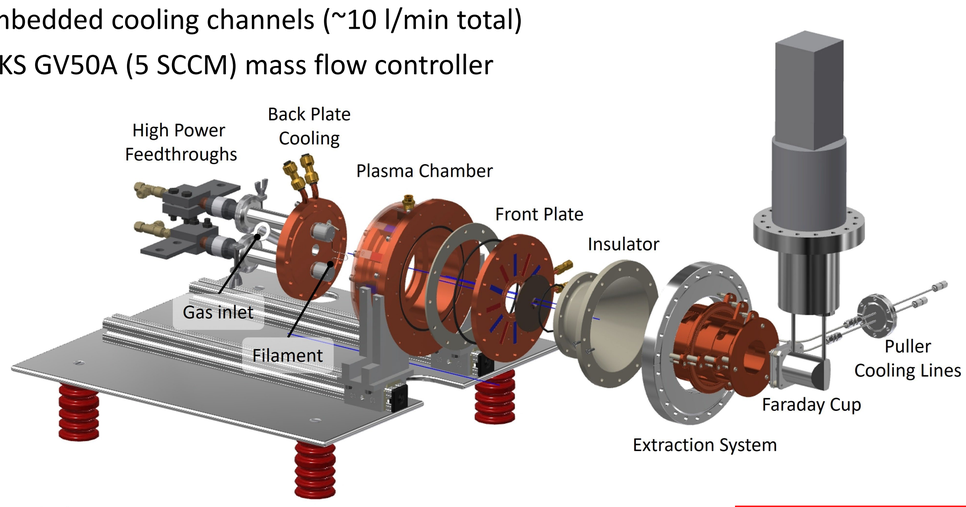


MIST-2 Ion Source

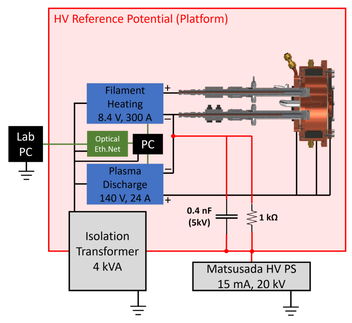
- Requirements:
  - 10 mA DC bam current @ 15 kV source voltage
  - 80% H_2^+ fraction
  - Emittance < 0.079 π-mm-mrad (RMS, normalized)
  - Low energy spread
- Design:
  - Filament driven multicusp ion source
  - Short chamber – Copper 101
  - Nd2Fe14B permanent magnets
  - Embedded cooling channels (~10 l/min total)
  - MKS GV50A (5 SCCM) mass flow controller

Extraction:



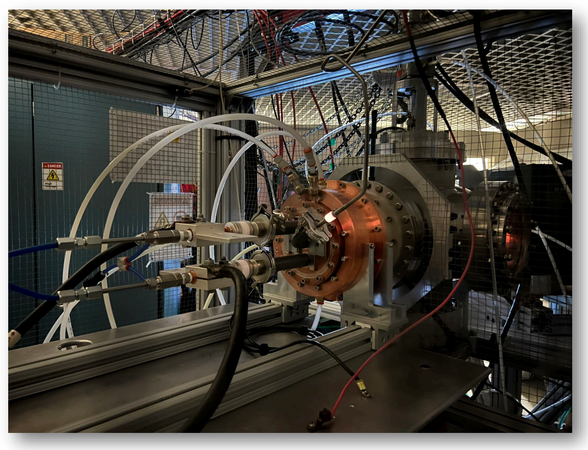


- Electrical design:
  - Filament heating: TDK 8.4V/300A (max)
  - Plasma discharge: Matsusada REK 150 V/24 A (max)
  - Control system: Optical Ethernet to local PC
- Extraction system:
  - Pentode arrangement
  - Source: 15 kV, Puller: -8 kV, Lens 1: 12 kV, Lens 2: -3 kV

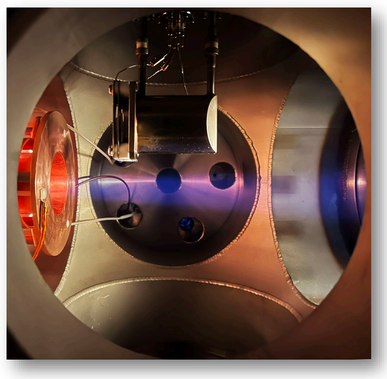


Results

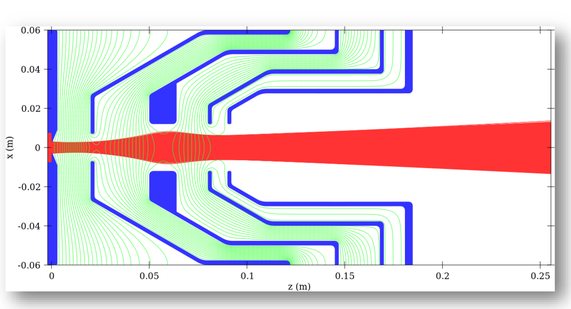
- Installation and high voltage conditioning:
  - First commissioning run without analysis beam line (FC1 @ 255 mm from plasma)
  - HV conditioning without issues
  - Vacuum in extraction region: 2.2e-7 Torr

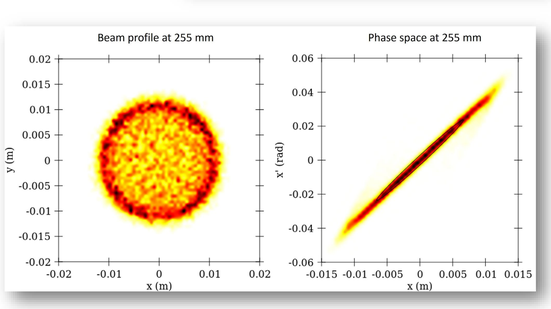


- Test run:
  - Stable operation at 6 mA for 1 hour
    - 20 A/140 V discharge
    - 75 A filament heating
  - Maximum current: 7 mA
  - At the limit of the discharge power supply
  - All temperatures nominal



- Simulated Emittance:
  - Parameters of test run simulated with IBSimu (3D)
  - 0.079 π-mm-mrad (RMS, normalized)
  - Diameter 13.7 mm (RMS) – agrees with image analysis





Conclusion:

- The HCHC-XX is a flexible high-current cyclotron design with many applications in physics and industry, like particle physics,, fusion material research and medical isotope production.
- We developed the MIST series of ion sources to fulfil the requirements of the cyclotron injection (10 mA beam @ 80% H_2^+ fraction with low emittance and energy spread)
- The MIST-2 performed nominally during the first commissioning run, but the discharge power supply proved insufficient. A PS upgrade and a detailed analysis of the beam quality are next.

References:

- IBSimu: https://aip.scitation.org/doi/full/10.1063/1.3258608
- IsoDAR@Yemilab PDR Vol I: https://arxiv.org/abs/2404.06281
- IsoDAR@Yemilab PDR Vol II: https://arxiv.org/abs/2508.11774
- MIST-1 Original Paper: https://aip.scitation.org/doi/10.1063/5.0063301
- MIST-1 & MIST-2 Paper (under review): https://arxiv.org/abs/2507.03155

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