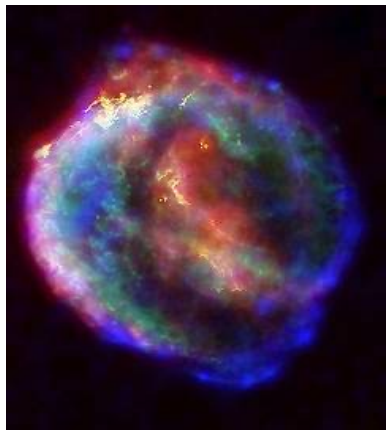
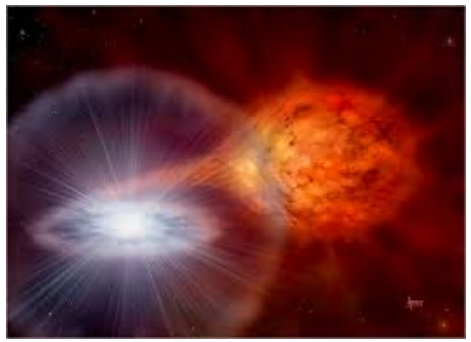
Highlights and future plans with the ISOLDE Solenoidal Spectrometer

Nuclear Physics Community Meeting 2023
D. K. Sharp and L. P. Gaffney

ISOL-SRS - reminder





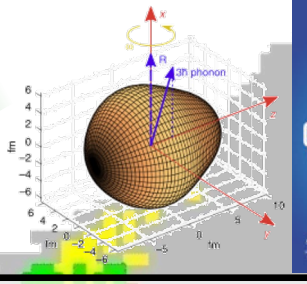
ISOLDE Solenoidal Spectrometer

EXTERNAL SPECTROMETER

CARME

INTERNAL SPECTROMETER

THE UNIVERSITY OF EDINBURGH

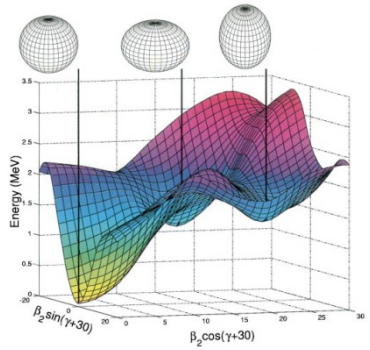


Pear shapes & EDM

Z=82 & N=126 shell evolution

Z=82

Pb-Po shape-coexistence



Z=50

p process

N=82 r-process, shell evolution

rp process

N=50 shell quenching and evolution

Z=28

Novae and cosmic γ emitters

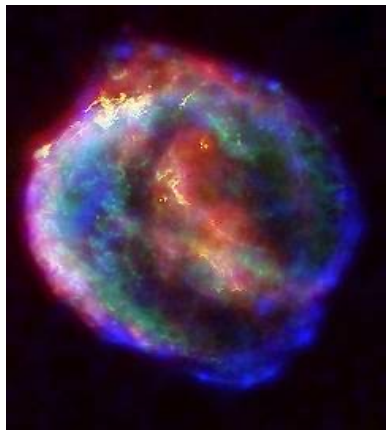
Breakout from CNO

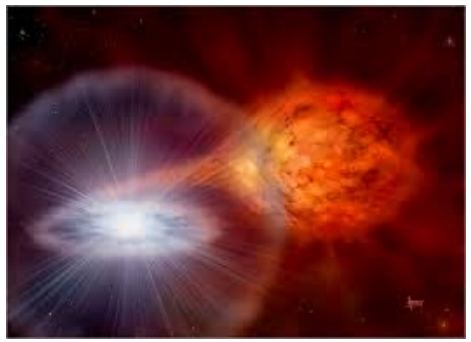
^{23}O Halo nuclei

N=20 N=28 N=40 N=50 N=82 N=126

LP Gaffney Community meeting 2021

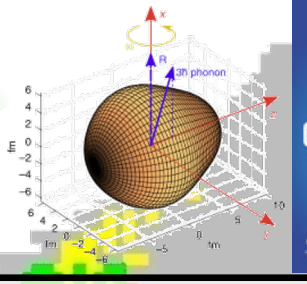
ISOL-SRS - reminder





ISOLDE Solenoidal Spectrometer

EXTERNAL SPECTROMETER



Pear shapes & EDM

Z=82 & N=126 shell evolution

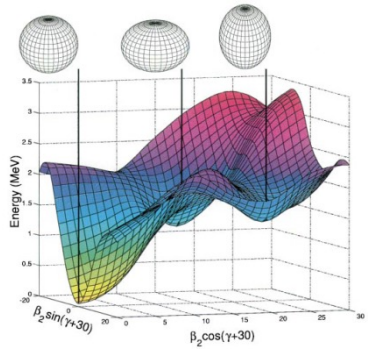
^{207}Hg

Z=82

Pb-Po shape-coexistence

CARME

INTERNAL SPECTROMETER



Z=50

p process

N=82 r-process, shell evolution

rp process

N=50 shell quenching and evolution

Z=28

Novae and cosmic γ emitters

N=40

N=50

N=126

Breakout from CNO

^{29}Mg

O Halo nuclei

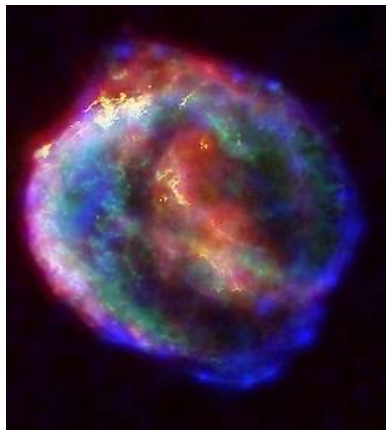
N=82

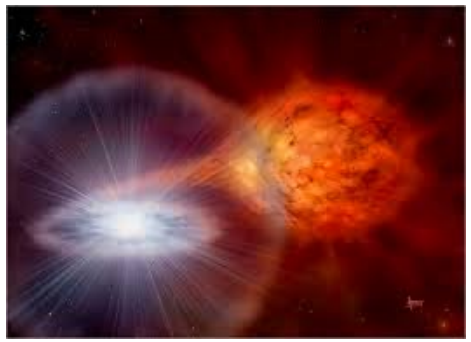
N=20

N=28

LP Gaffney Community meeting 2021

ISOL-SRS - reminder





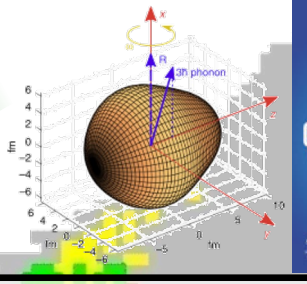
ISOLDE Solenoidal Spectrometer

EXTERNAL SPECTROMETER

CARME

INTERNAL SPECTROMETER

THE UNIVERSITY OF EDINBURGH



Pear shapes & EDM

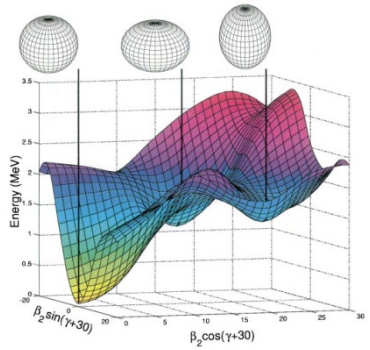
^{213}Rn

=82 & N=126 shell evolution

^{207}Hg

Z=82

Pb-Po shape-coexistence



Z=50

^{111}Sn

p process

^{95}Kr

N=82 r-process, shell evolution

rp proc

^{62}Zn

N=50 shell quenching and evolution

Z=28

^{69}Ni

N=50

Novae and cosmic γ emitters

N=126

Breakout from

Halo nuclei

^{31}Mg

^{12}Be

^{28}Na

N=82

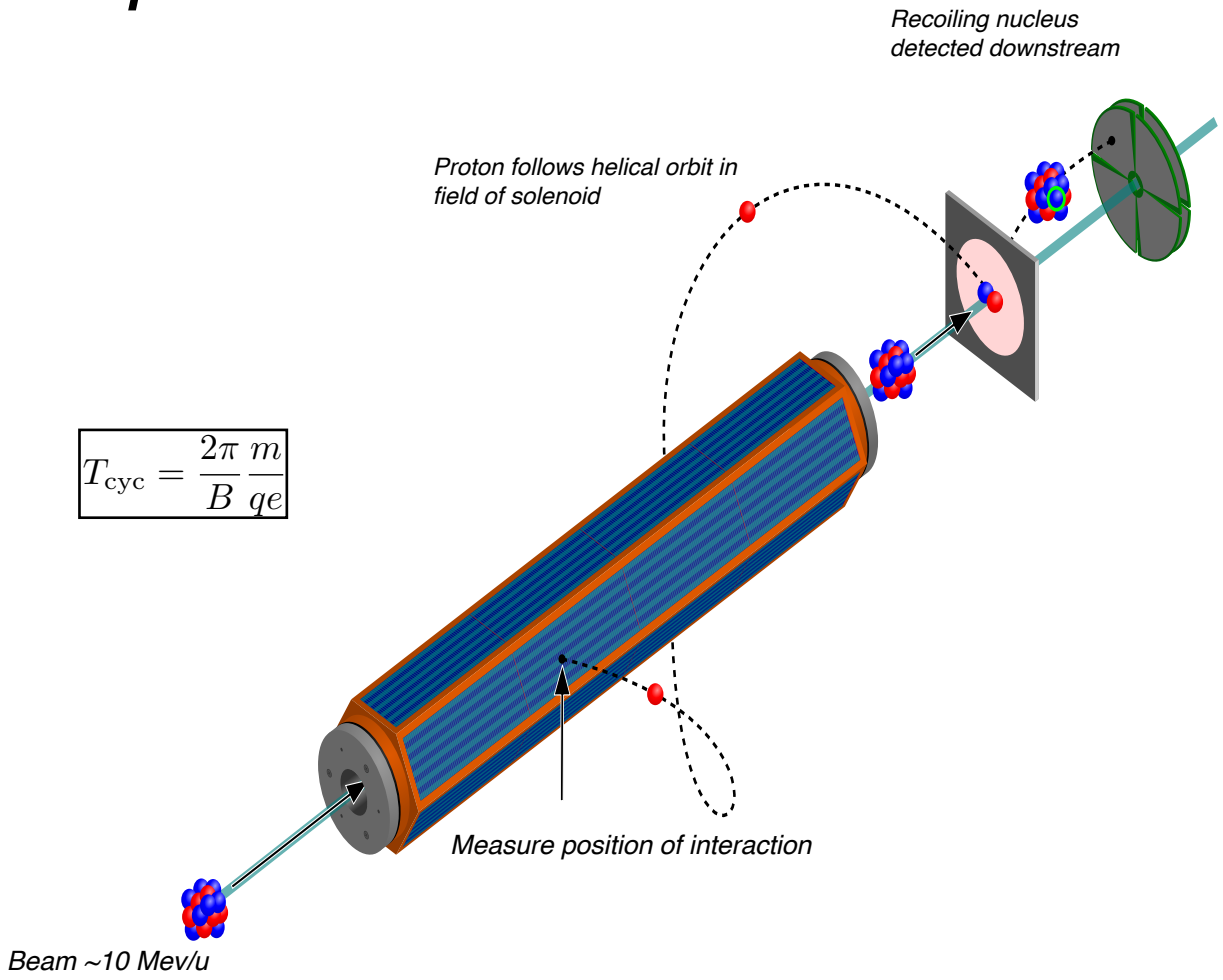
N=28

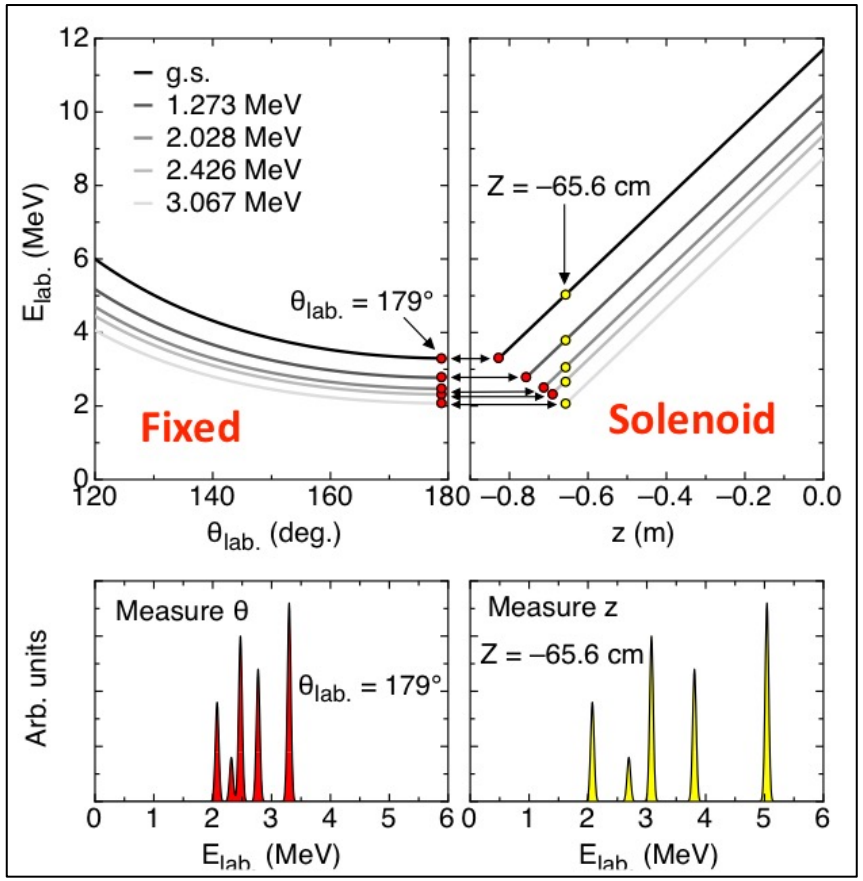
LP Gaffney Community meeting 2021

Community meeting 2023

ISS - concept

ISOLDE Solenoidal Spectrometer





MEASURED QUANTITIES: position z, cyclotron period T_{cyc} and lab particle energy $E_{p.}$

Suffers <u>no kinematic compression</u> of the Q-value spectrum.

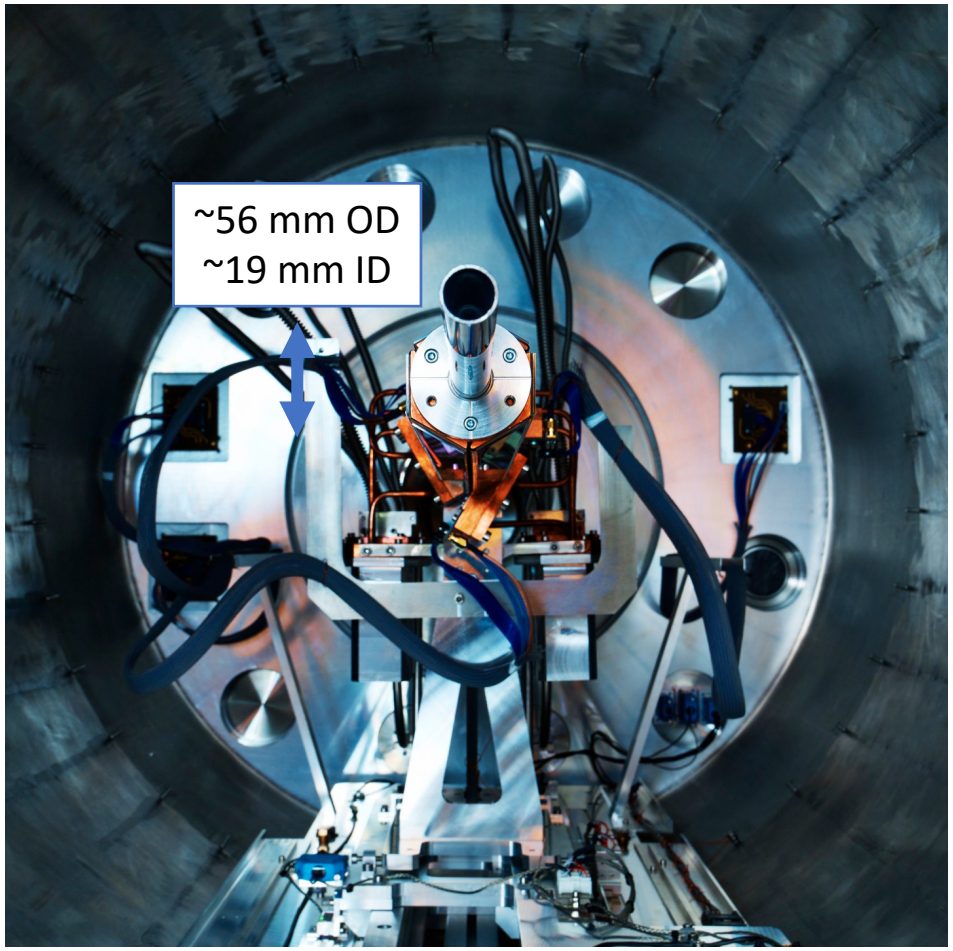
Linear relationship between E_{cm} and $E_{lab.}$

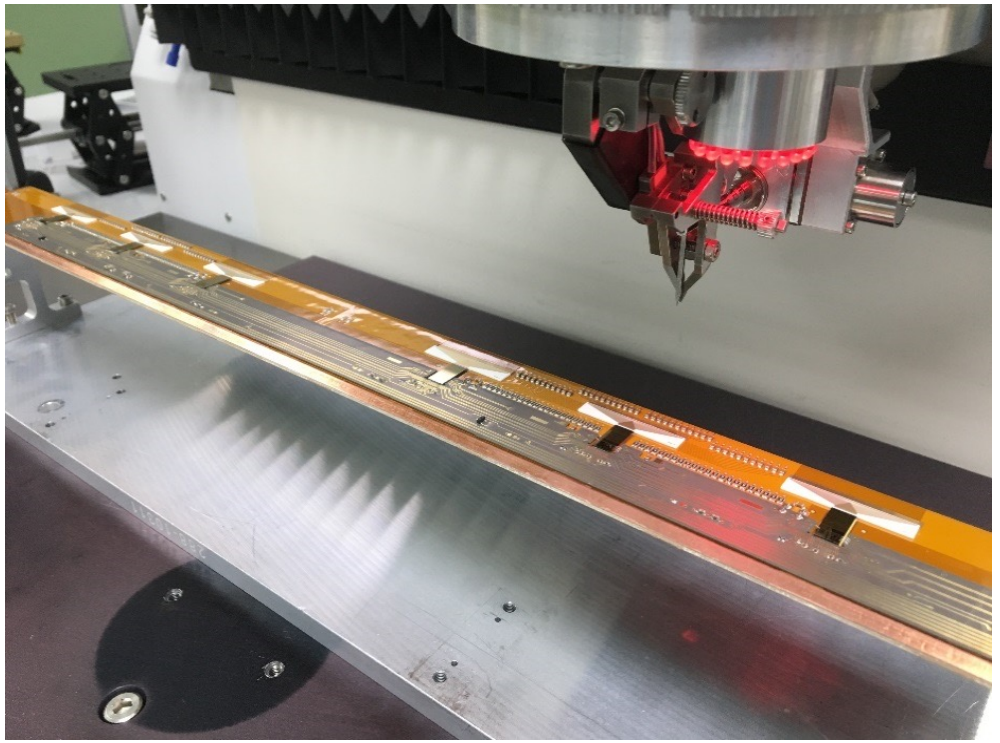
$$E_{\mathrm{cm}} = E_{\mathrm{lab}} + \frac{mV_{\mathrm{cm}}^2}{2} - \frac{mzV_{\mathrm{cm}}}{T_{\mathrm{cyc}}}$$

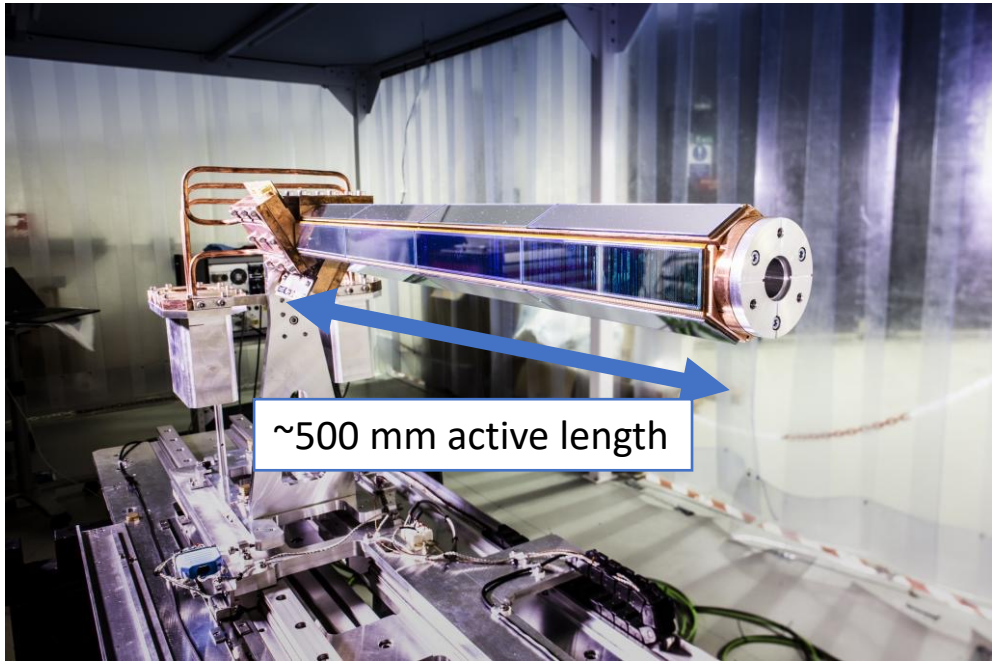
ISS – silicon array

Designed and constructed in Liverpool as part of ISOL-SRS project.

- *Hexagonal geometry with 4 DSSSDs on each side.*
- ***1668** channels of readout.*
- *ASIC readout, using chips designed for R^3B project.*
- *Future physics programme needs bespoke ASIC (see later)*







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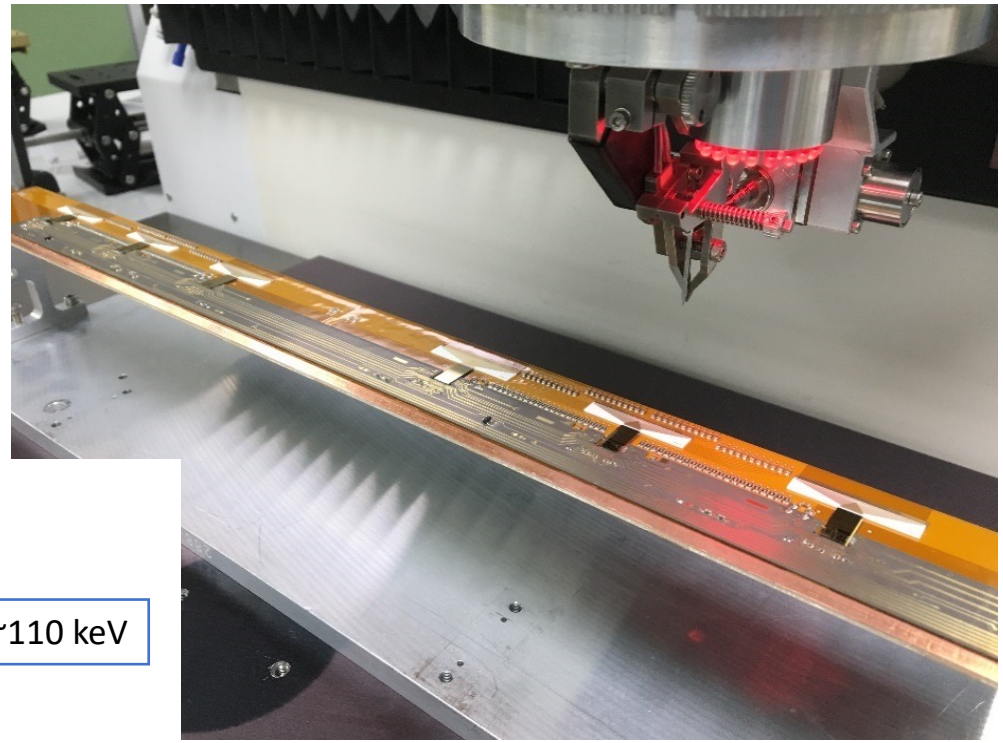
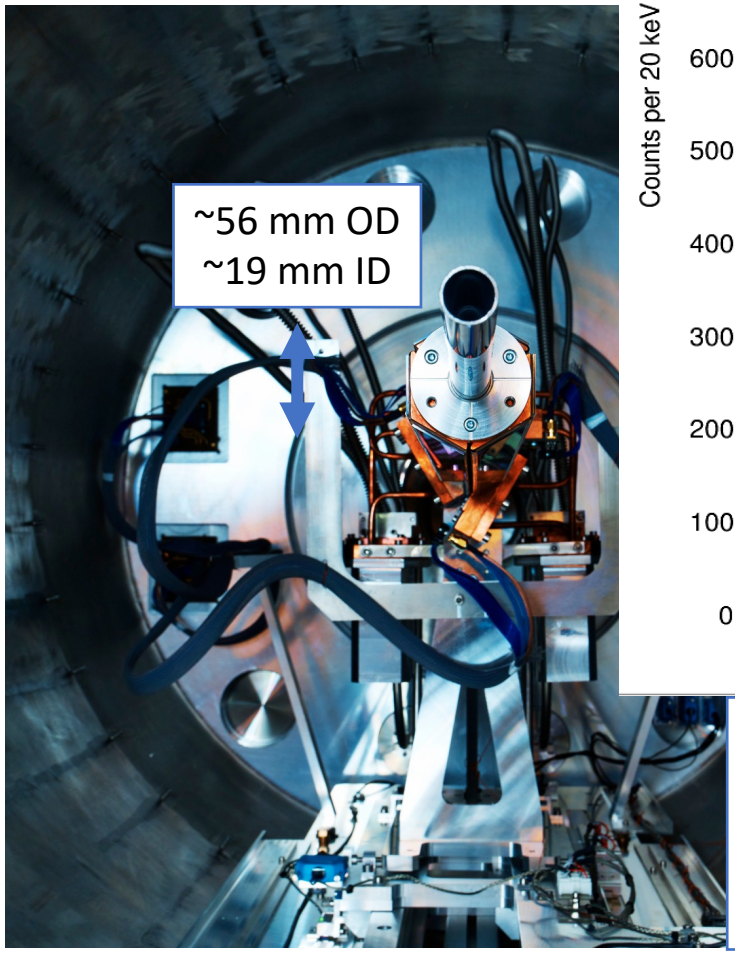
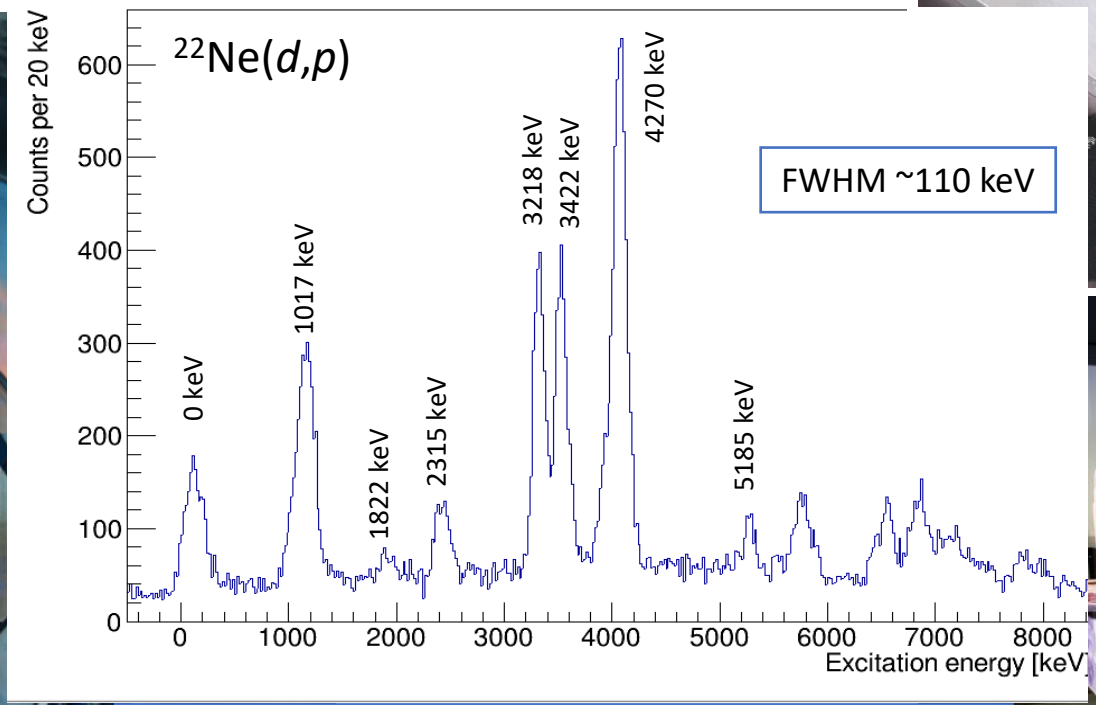
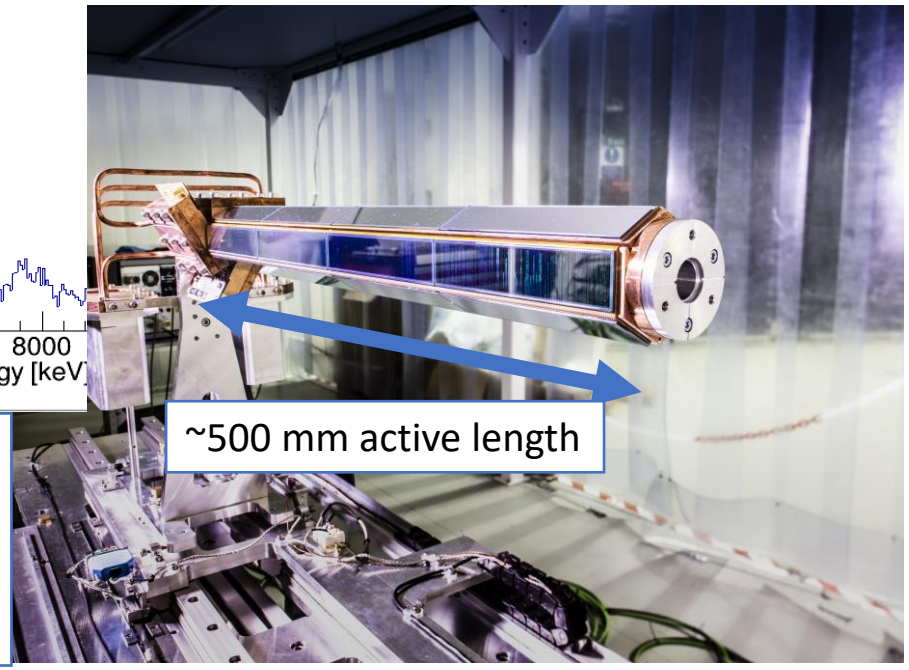








Installed at CERN February 2020

Then COVID limited commissioning…

Remote operation in place September 2020

Demonstration with first beams July 2021!

Physics highlights - Towards the N=20 island of inversion

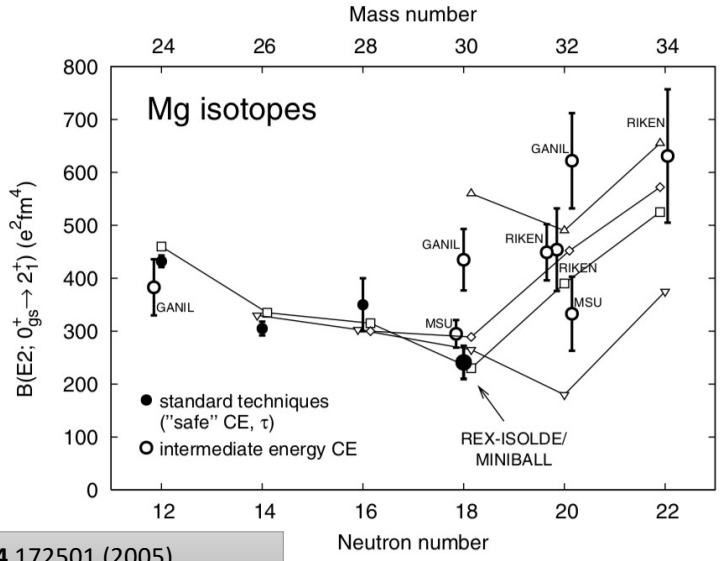
The University of Manchester

ISOLDE Solenoidal Spectrometer

*Island of inversion has been charaterized using numerous probes (mass measurements, beta-decay, **coulex**, multi-nucleon transfer, pair-transfer, knock-out).*
Details on SP properties are perhaps lacking. (knock-out)

*Measurements of the **single-particle properties** moving in to the island of inversion provide important data on the behaviour of the relevant orbitals and shell gaps.*

Mg isotopes exhibit rapid transition into this region. ^{30}Mg outside ^{31}Mg inside.

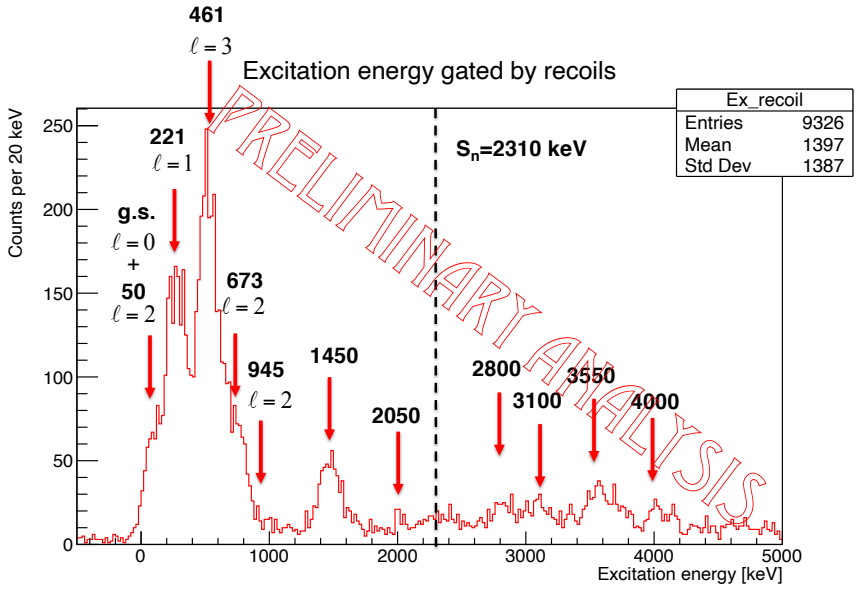


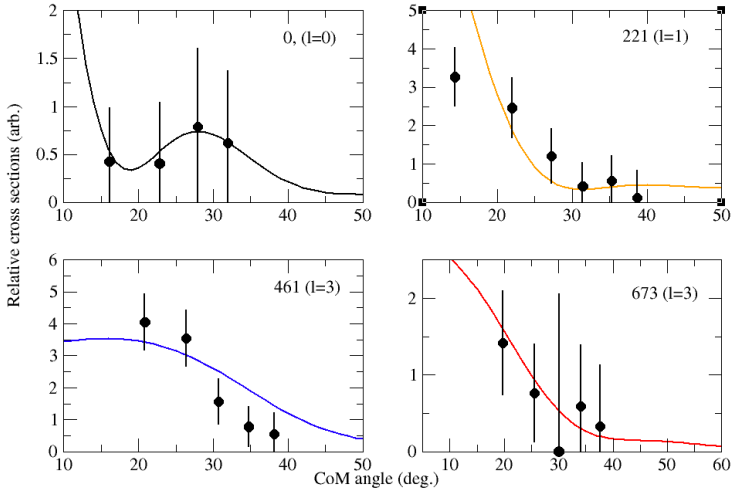
PRL, **94** 172501 (2005)

10^5 pps 8.2 MeV/u ^{30}Mg

150ug/cm^2 CD2 target
140 keV resolution

These data should provide a robust determination of the fragmentation of strength allowing determination of the behavior of SP centroids across the boundary of Island of Inversion

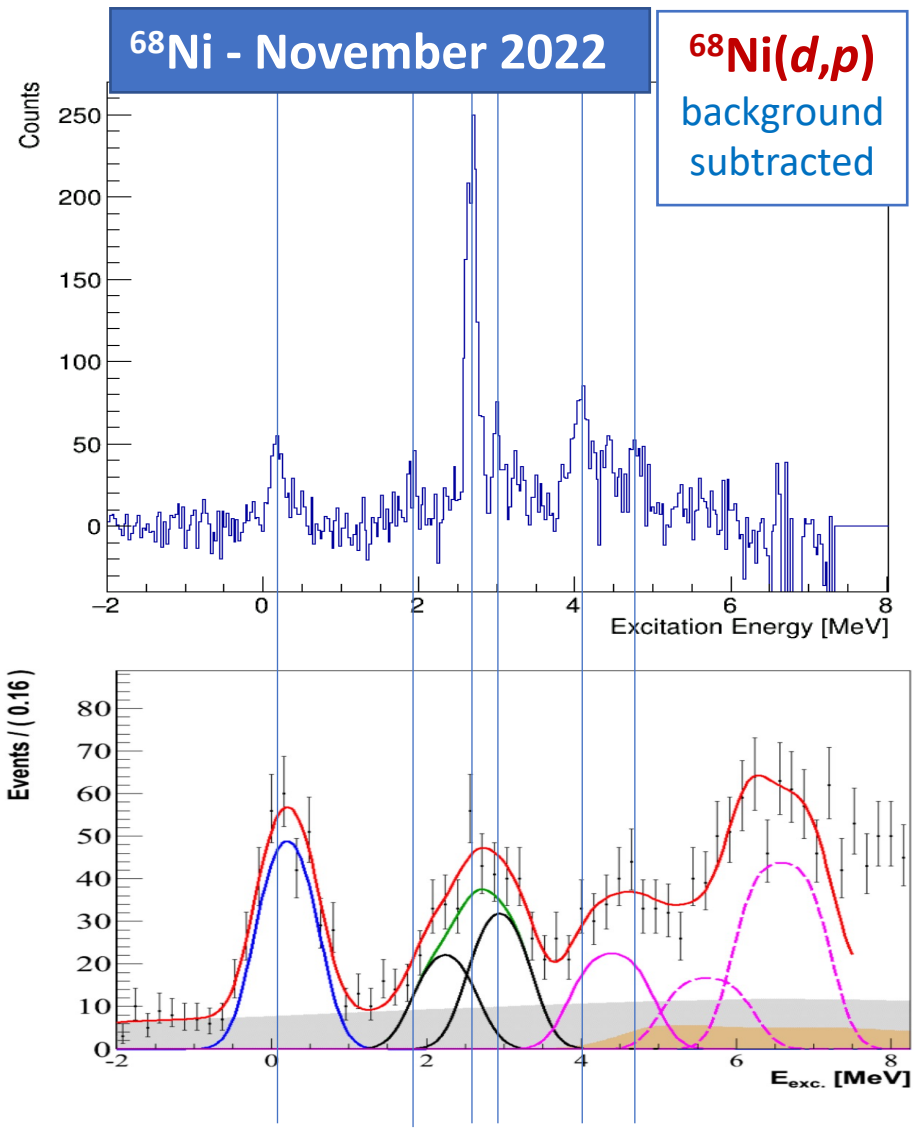


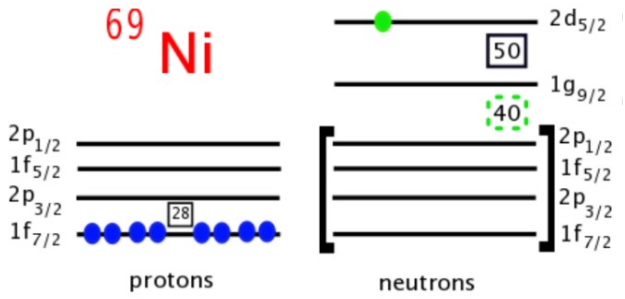


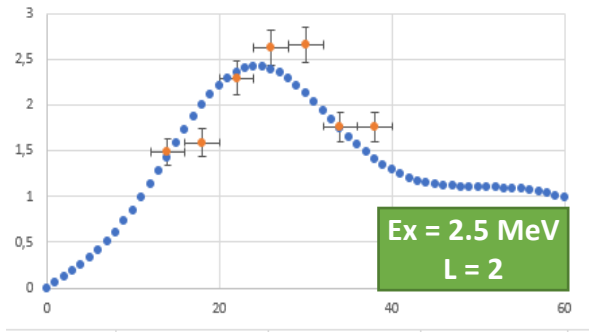
Physics highlights

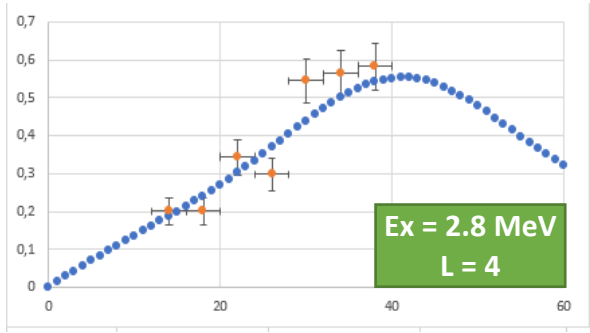
^{68}Ni - November 2022

KU LEUVEN









- ^{68}Ni ~2 x 10^4 pps @ 6.0 MeV/*u*
- *N* = 50 shell gap approaching ^{78}Ni
- Intruder configurations leading to shape coexistence

GANIL experiment

(2010, unpublished, M. Moukkamad et al.)

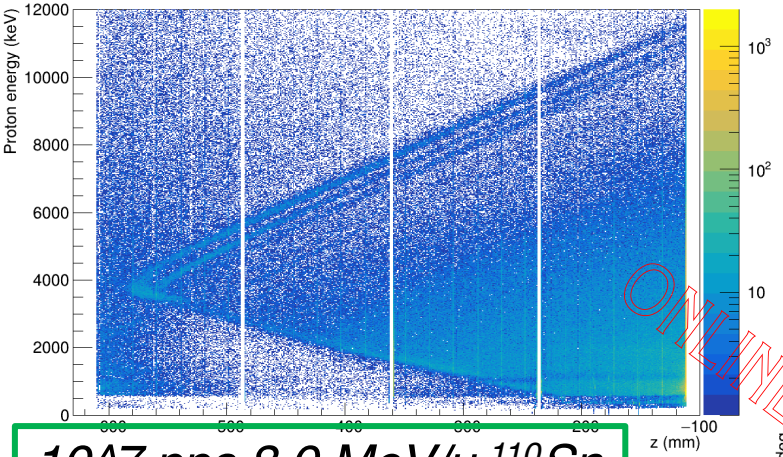
E_{beam} = 25.14 MeV/*u*; CD_2 Target : 2.6 mg/cm^2

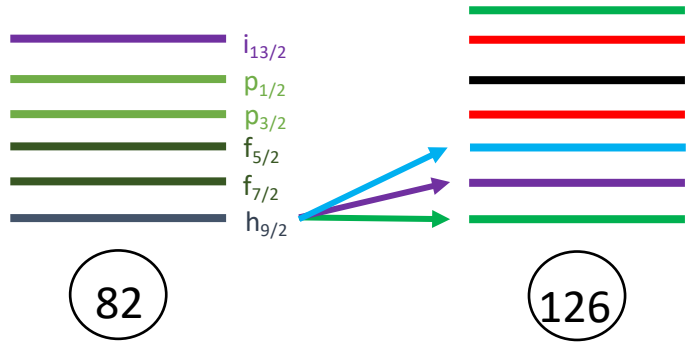
Investigating trends in single particle properties at shell closures - ^{110}Sn(d,p)^{111}Sn and ^{212}Rn(d,p)^{213}Rn

ISOLDE Solenoidal Spectrometer

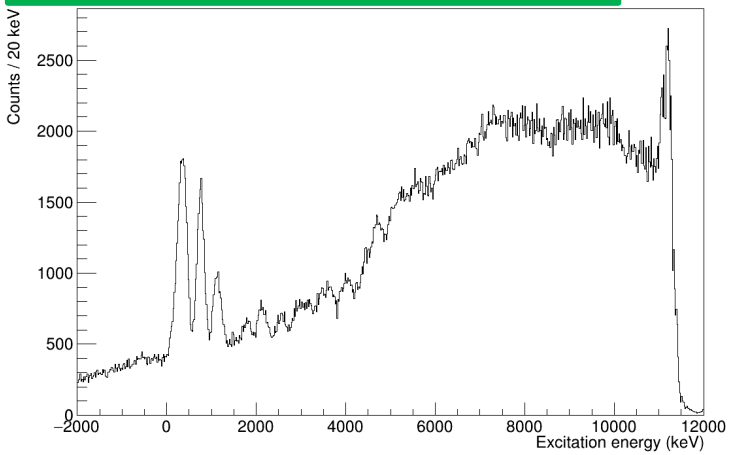
Systematic information on single-particle properties (ESPE's and occupancies). Provide details on relative strengths of np interactions.

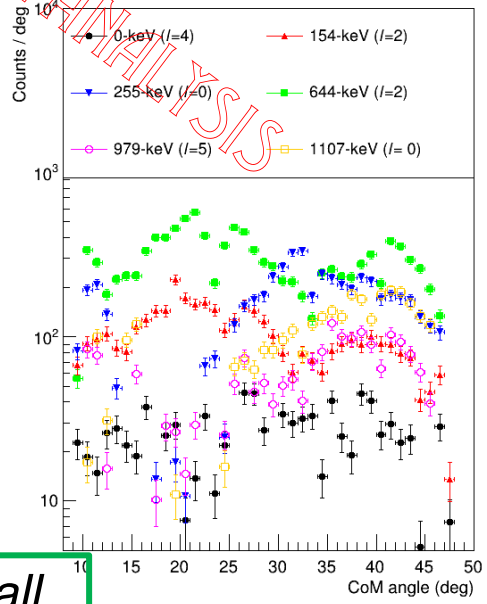
Beams at ISOLDE enabled studies of Sn isotopic chain and N=126





10^7 pps 8.0 MeV/u ^{110}Sn



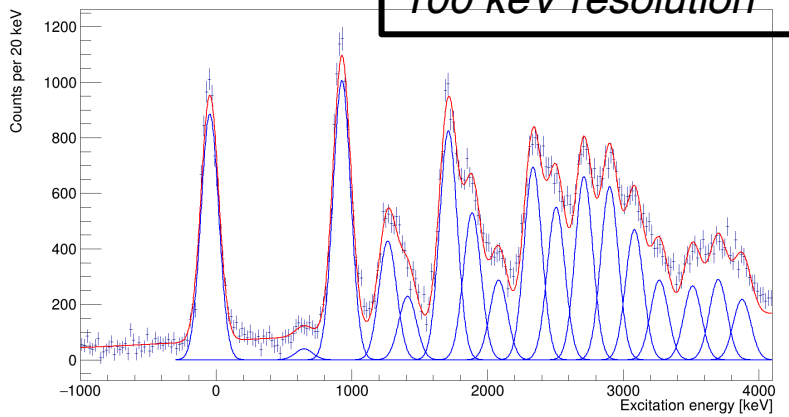


ONLINE ANALYSIS

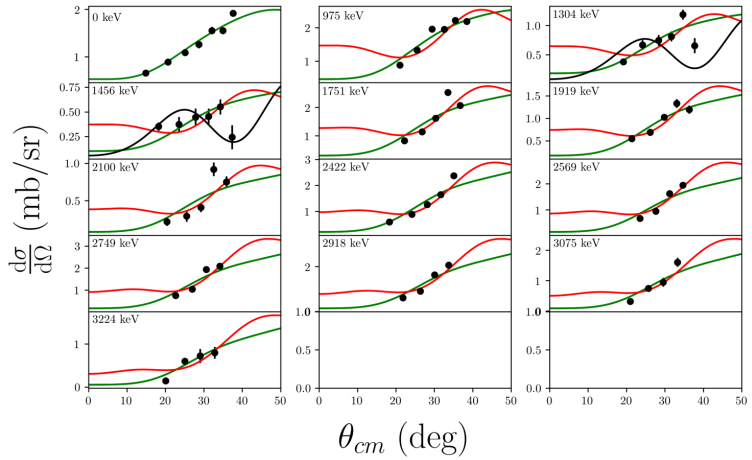
Courtesy of J Park and J Cederkall

MANCHESTER 1824
The University of Manchester

100 keV resolution



~5x10^6 pps 7.6 MeV/u ^{212}Rn



CENS

LUND UNIVERSITY

Collaboration

ISOLDE Solenoidal Spectrometer

- *68 collaborators, 25 institutions, 11 countries*
- *14 approved experiments, 2 LOI's, PI's from 13 institutions (UK leadership on 9/14).*
- *10 experiments completed to date.*
- *2022 63% of HIE-ISOLDE beam time allocated to ISS.*

ISS now operating under an MoU

- *5k CHF pa contribution to operating costs per institution.*
- *International signatories – ISOLDE, Leuven, Chalmers.*
- *Expression of interest – Santiago de Compostela, Padova*
- *UK contribution will be requested on Manchester CG*
  Manchester, Liverpool, Daresbury signed
  York and Surrey to sign

Current developments – recoil detector

MANCHESTER 1824
The University of Manchester

ISOLDE Solenoidal Spectrometer

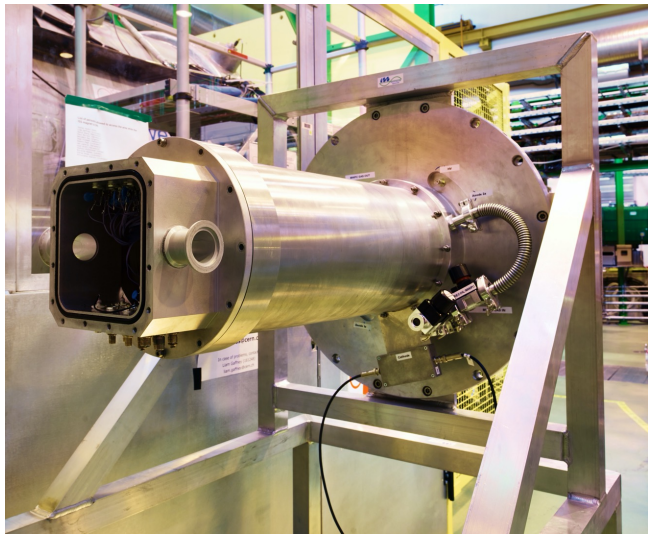
Used to determine beam composition.

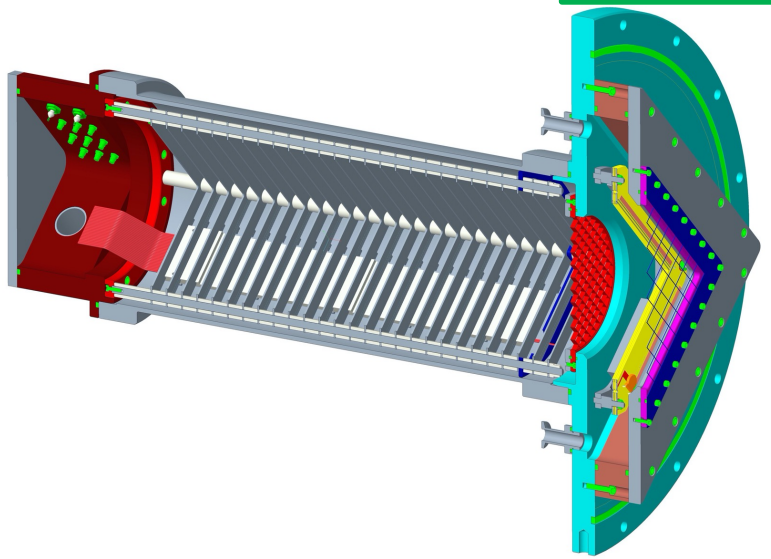
Based on modification of previous designs that operate up to 100 kHz.

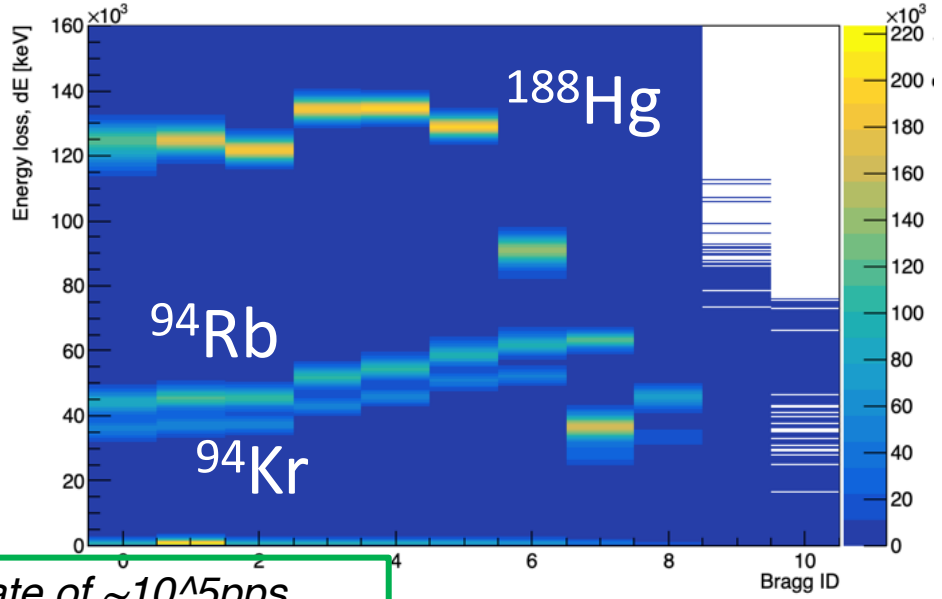
Essentially a stack of 13 PPAC's with short drift lengths to reduce pulse risetime.

Constructed and tested – identified improvements to preamplifiers and zero-degree blocker design.

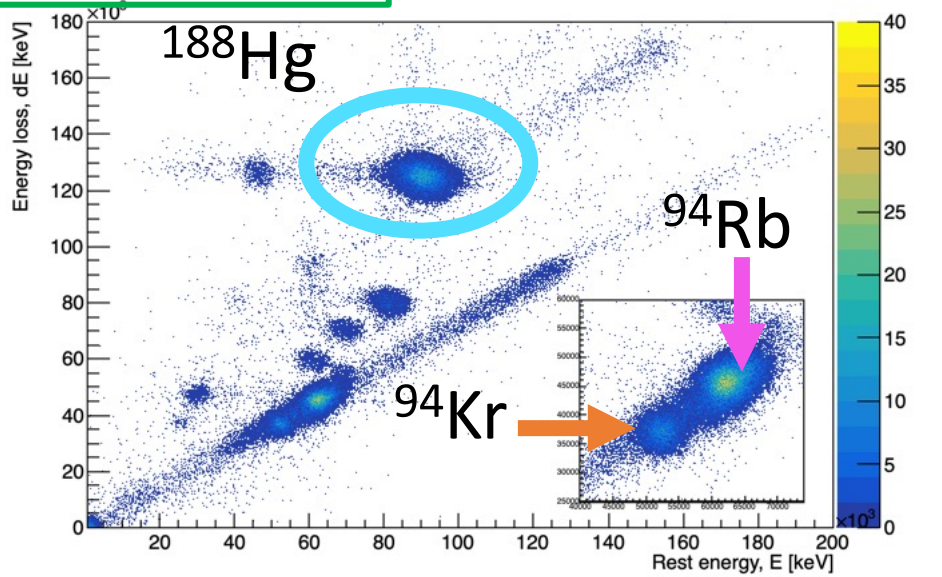
Funded on CG.







Total beam rate of ~10^5pps



Current developments – CRYogenic Pumped Target (CRYPT) for the ISS

ISOLDE Solenoidal Spectrometer

UNIVERSITY OF SURREY

An important tool to maximise the physics possibilities at the ISS

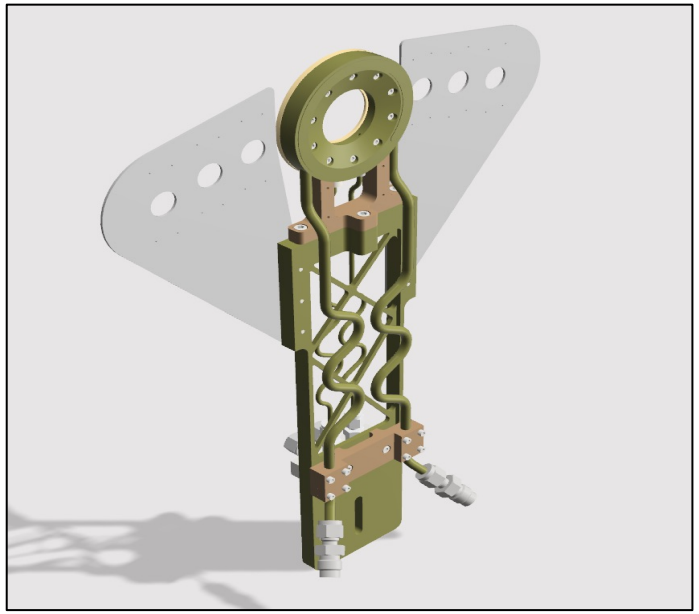
- **Direct measurement** of (α, p) reactions of astrophysical interest with RIBs, e.g., ^{34}Ar(α, p) for understanding astrophysical X-ray bursts
- Unique opportunity to study (^{3}He,d) reactions for **astrophysics and structure**

Gas at 90 K will have ~3 times the density compared to room temperature.
At 500 Torr -> 50-100 μg/cm^2 solid target.

Working on an improved design of the LSU targe previously used with HELIOS (larger windows and different material) **in collaboration with ANL**

Gas-handling to be based on Manchester IC design

Supported Capital item in last CG round



Current developments – Scintillator array

KU LEUVEN CHALMERS

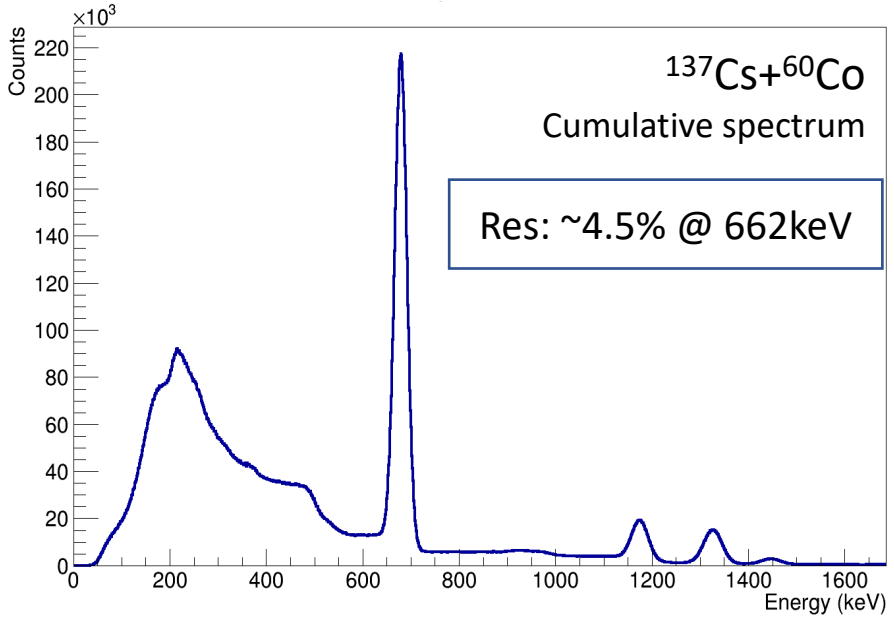
ISOLDE Solenoidal Spectrometer

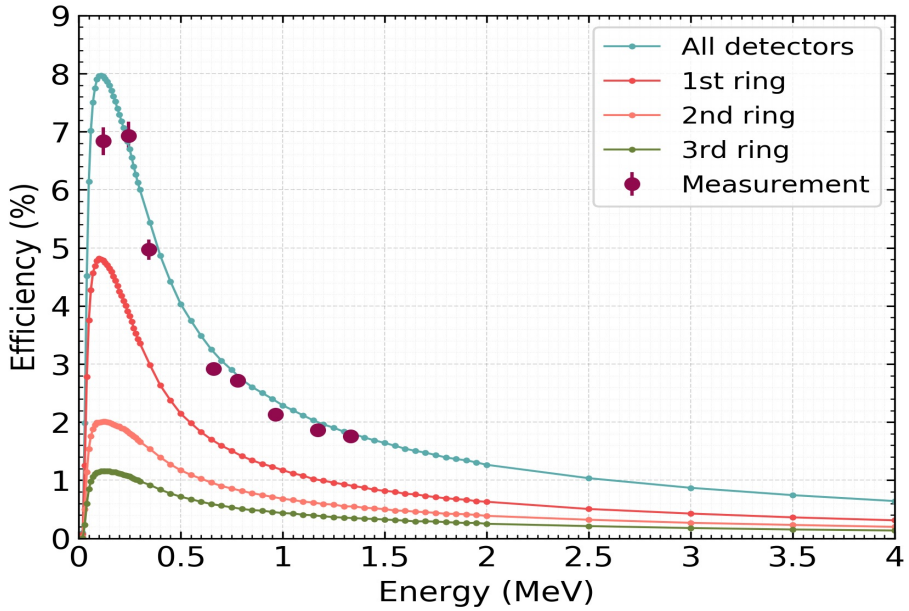
CeBr detectors from SpecMAT.

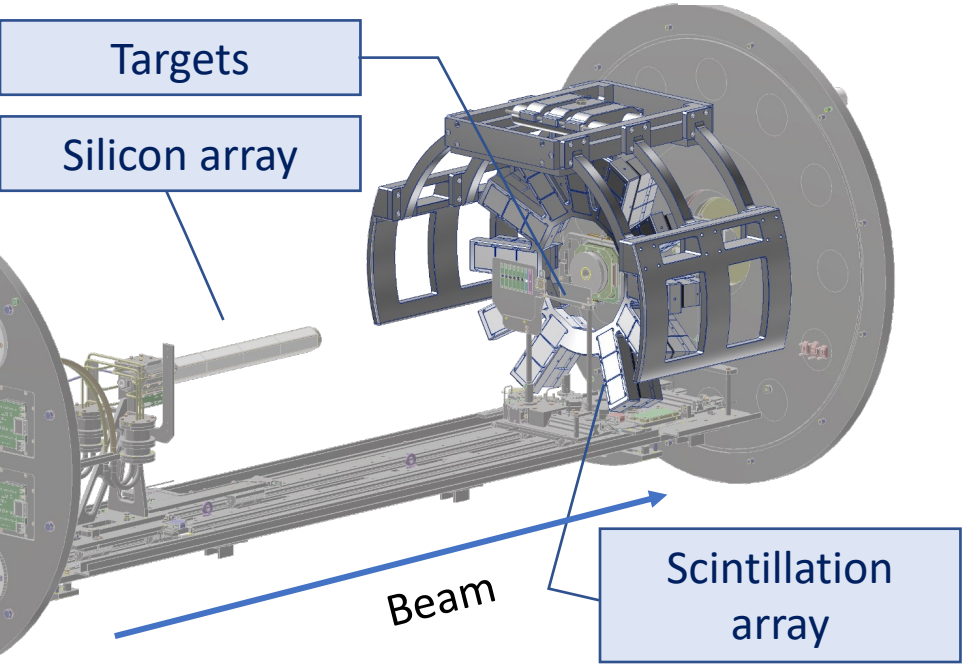
3 x rings of 11 detectors.

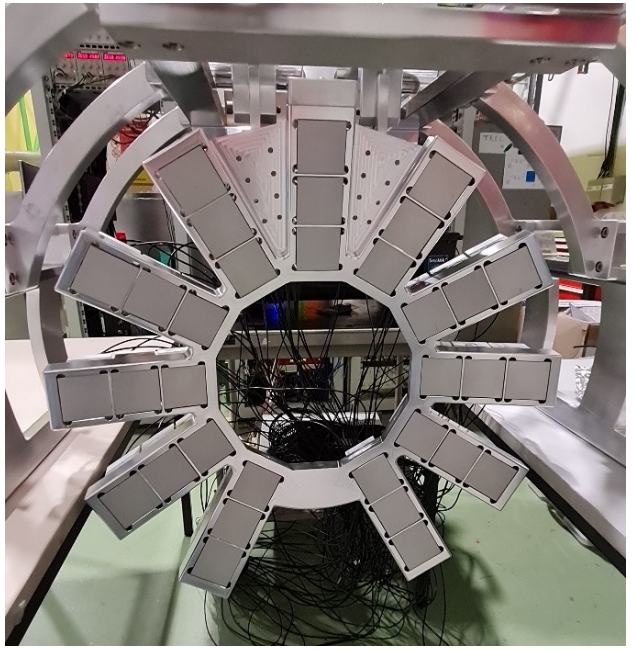
Mechanics, electronics, DAQ commissioned October 2022.

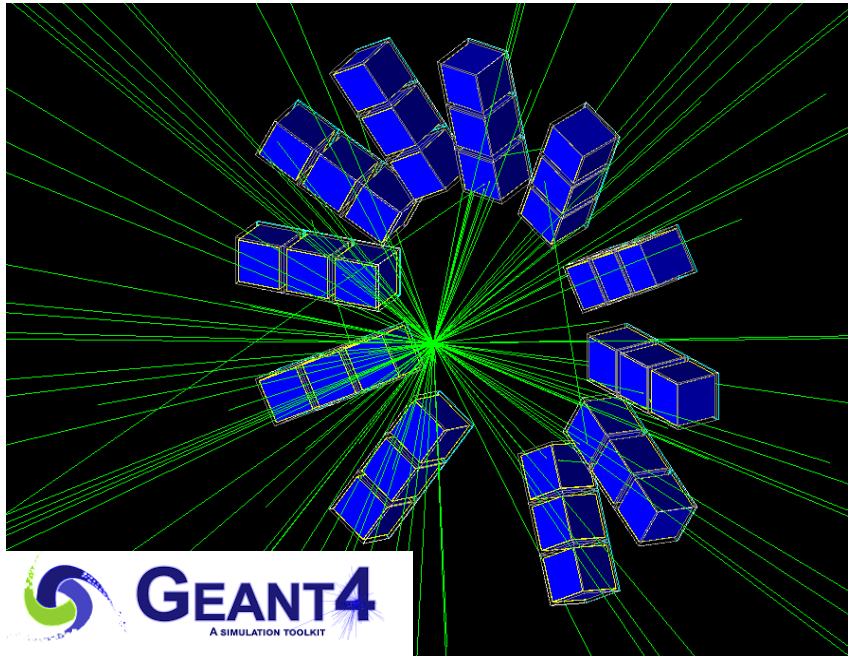
Ready for experiments, such as (d,pγ) for astrophysics.





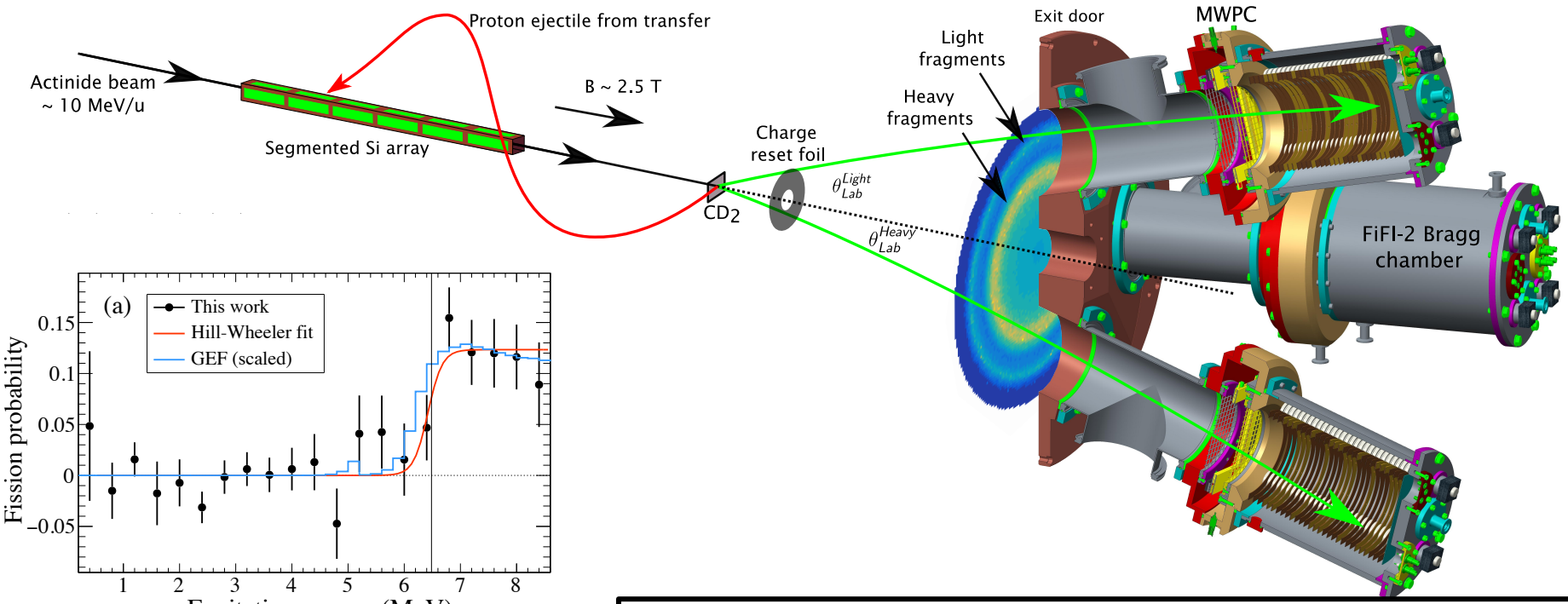


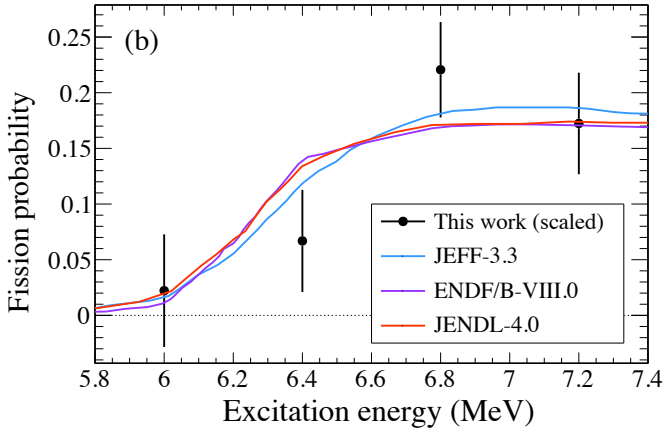




GEANT4 A SIMULATION TOOLKIT

Current developments - transfer-induced fission





SA. Bennett et al., Submitted PRL

Advantages of (d,pF) to probe fissioning systems

Direct measurement of fission barriers. Simultaneously probing above and below Sn.

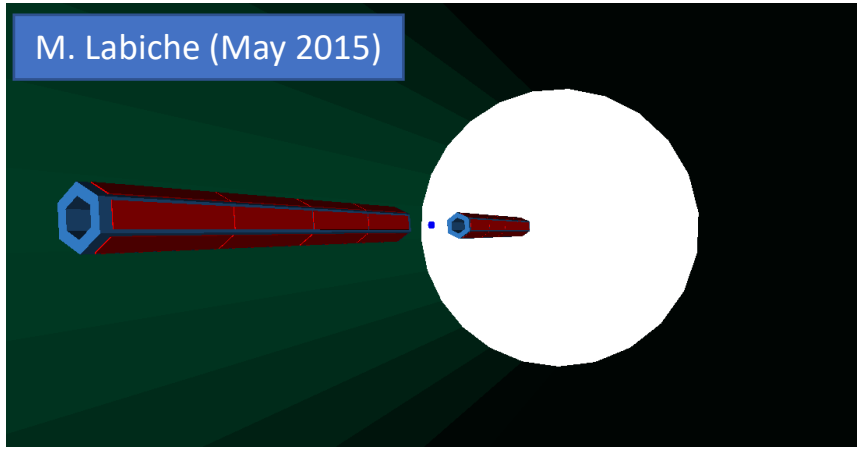
Fragments are boosted in to a small solid angle in inverse kinematics. Full Bragg peak spectroscopy possible due to energy of fragments.

Proof-of-principle performed using HELIOS at Argonne National Laboratory using 238U beam.

Access to short-lived actinides at ISOLDE.

Combine with scintillator array (n,γ)/(n,f)

Future developments – dual array



Sensitive reaction channel selection…

- Breakup following transfer, e.g. ^{7}Be(*d*,*p*)^{8}Be → 2*α* or 7Li+*p*
- Large angular coverage for 2*α* (forwards) and *p* (backwards)

Surrogate (*n*,*p*) and (*n*,*α*) reactions for astrophysics…

- Charge exchange with “extra” proton → (*d*,*pp*).
- Correlated protons in forward/backwards directions.

Proton-pair transfer reactions…

- Two-neutron transfer achieved with (*t*,*p*).
- Case of 2*p* transfer = (*n*,^{3}He) → (*d*,*p*^{3}He).

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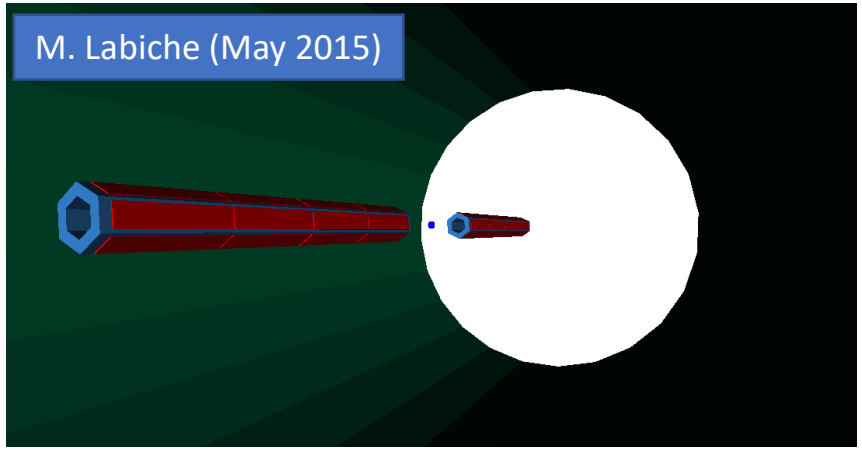
Sheffield Hallam University



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UNIVERSITY OF SURREY

UNIVERSITY of York

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UNIVERSITY OF LIVERPOOL

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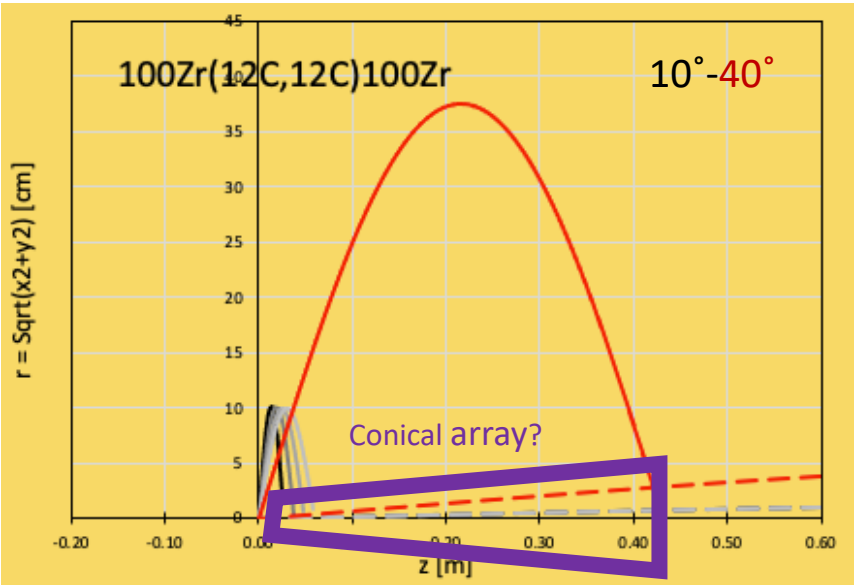

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- Modular design: 4/6/8 sides + plug-in boards
- Replaceable Si wafers reduces long-term cost
- Improved timing resolution for PID

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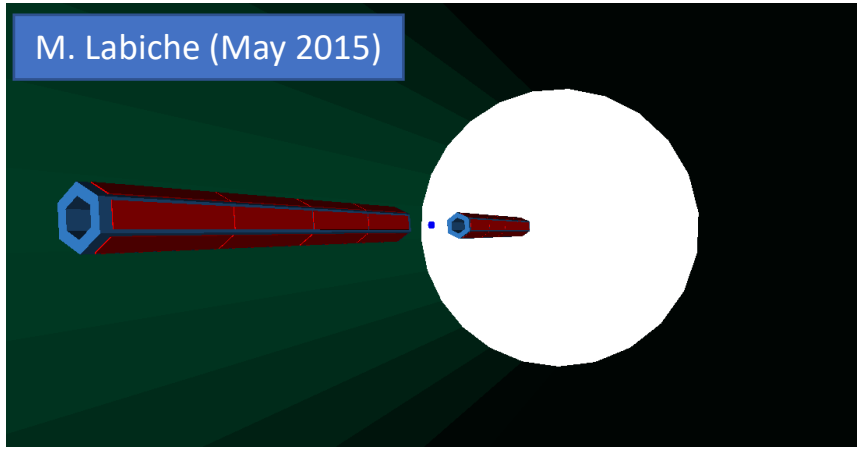

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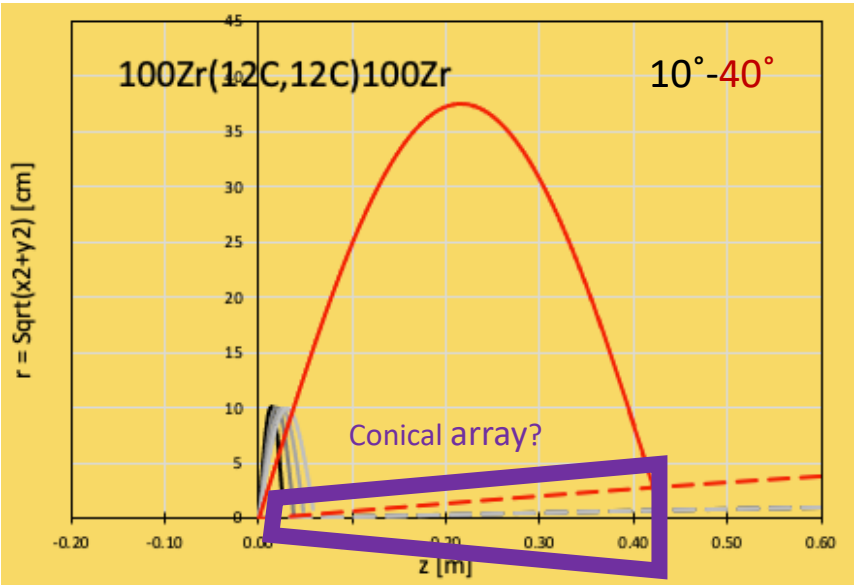

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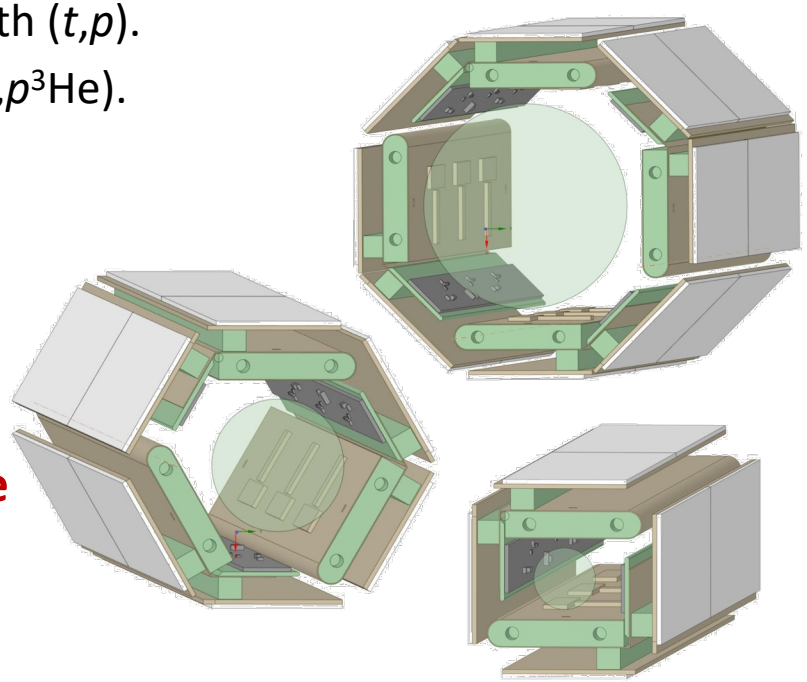


Demonstrator device to be built as proof-of-concept with stable beams during CERN's LS3 (2026).

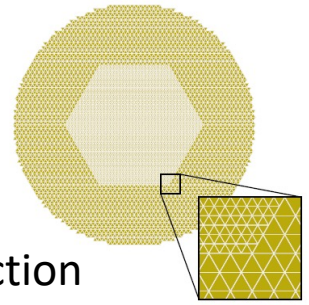
Expandable to full array in the future with modular design (project bid).

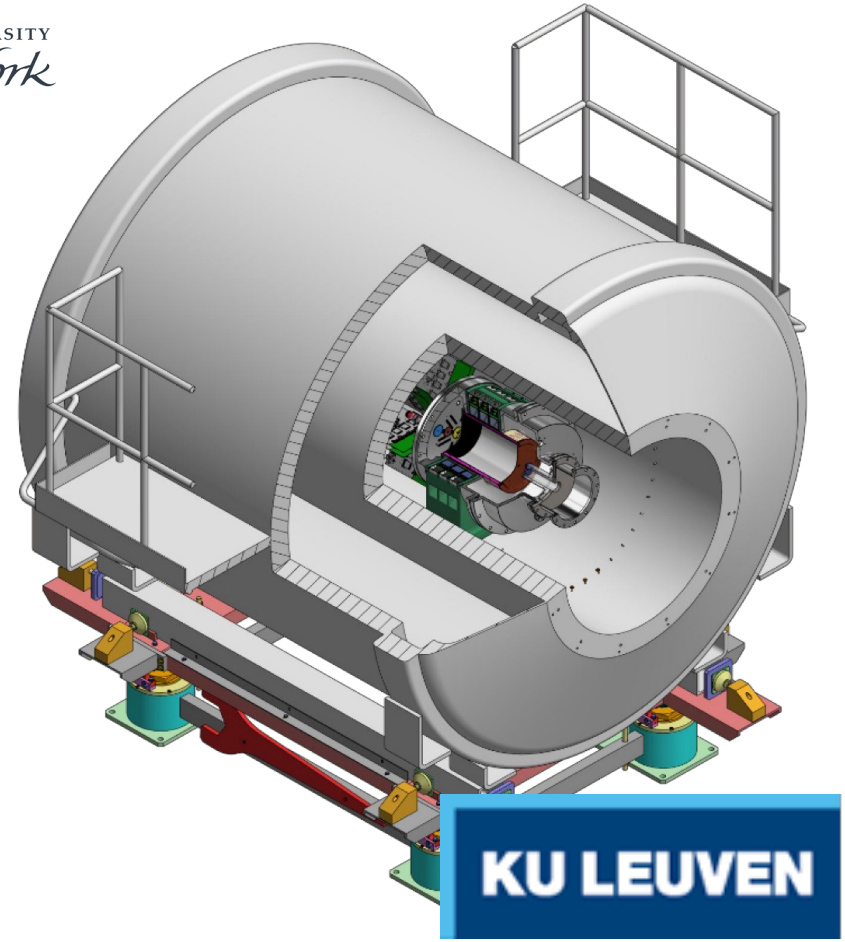
- Forward array requires geometric flexibility
- Modular design: 4/6/8 sides + plug-in boards
- Replaceable Si wafers reduces long-term cost
- Improved timing resolution for PID

Future developments – Hybrid Silicon-TPC

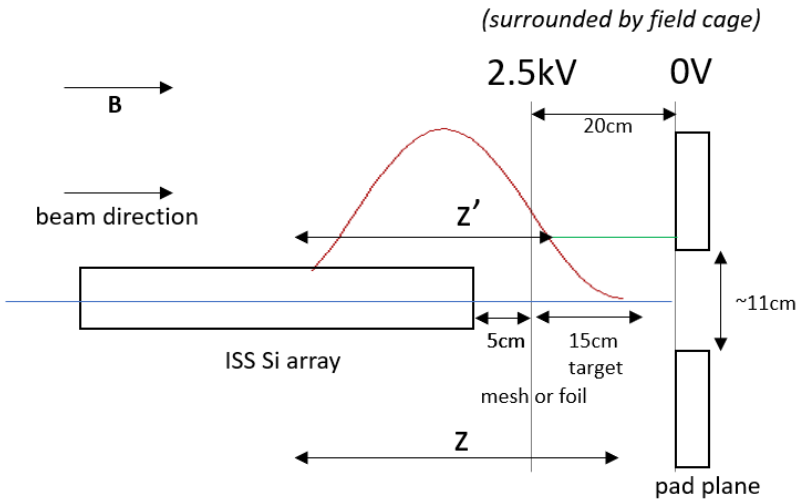
ISS currently has a TPC mode of operation – SpecMat

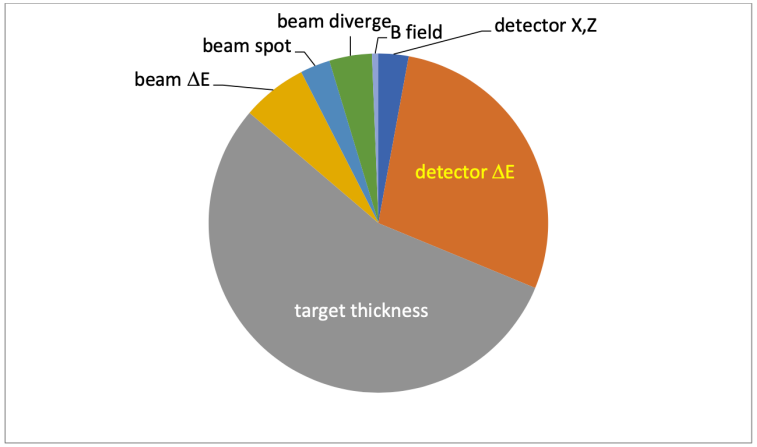
- Access to gaseous species
- Higher luminosity
- Windowless
- Reduced energy resolution – mitigated by gamma ray detection

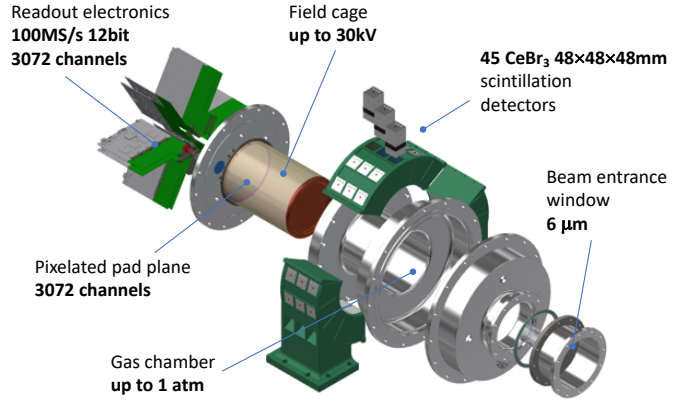




Hybrid-mode



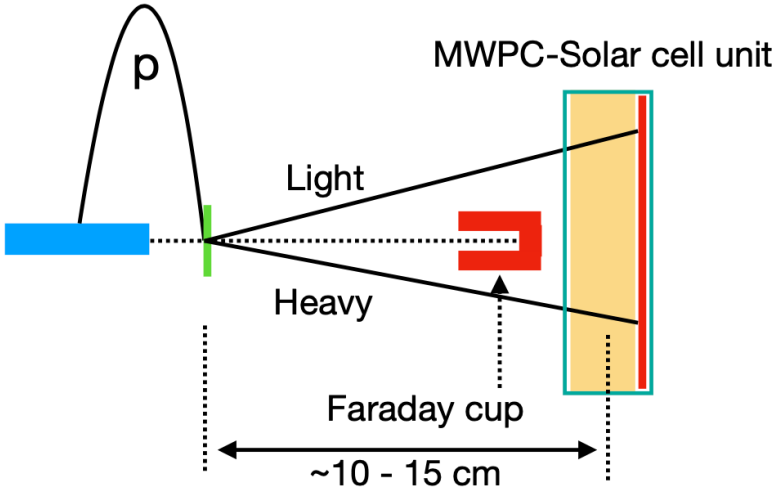


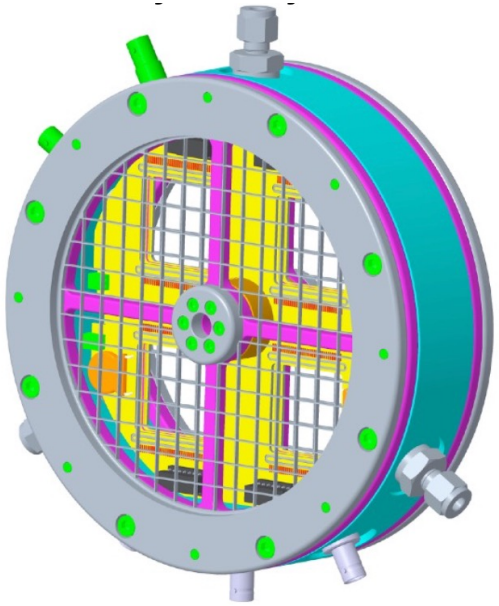


TPC designed to track initial path of trajectories

- **Maintain silicon resolution** – track initial trajectory and correct for reaction position in target which is dominant contribution to resolution in ISS array.

Future developments – Fission detector upgrade



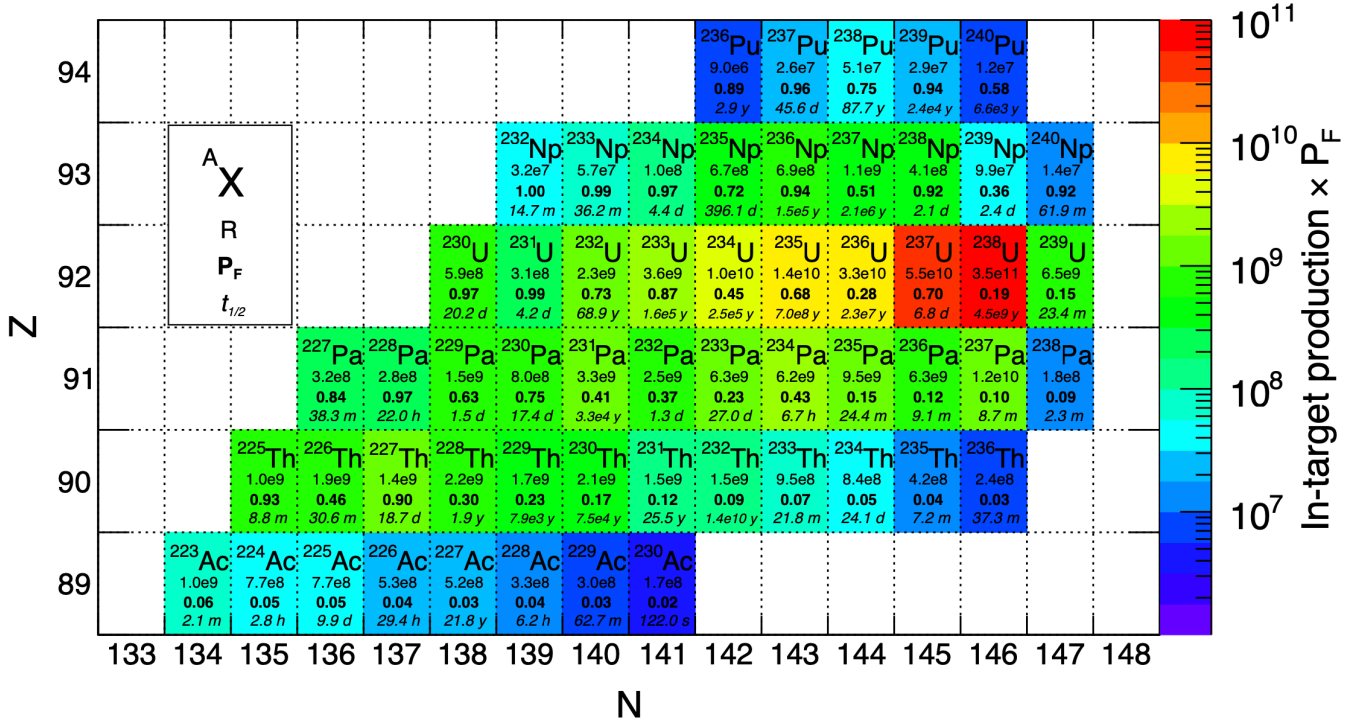


MWPC coupled to solar-cell array to study transfer-induced fission

Improved coverage compared to current set up.

Working in collaboration with Leuven and Chalmers.

ISOLDE – LISA initiative to develop actinide beams for study



Summary

ISS now fully commissioned and first two physics campaigns completed (8 measurements).

International interest in measurements with ISS.

Measurements have covered many physics cases.

Current developments.

- *Gas target.*
- *SpecMat.*
- *Scintillator array.*

Plans for technical developments that will increase capabilities of device.

- *Coincidence measurements giving access to surrogate reactions.*
- *TPC provide access to gaseous species, increased luminosity…*
- *Improved efficiency fission detection.*

Improved shielding to go to 4T

Campaign summary

Lots of physics from first 2 ISS campaigns.

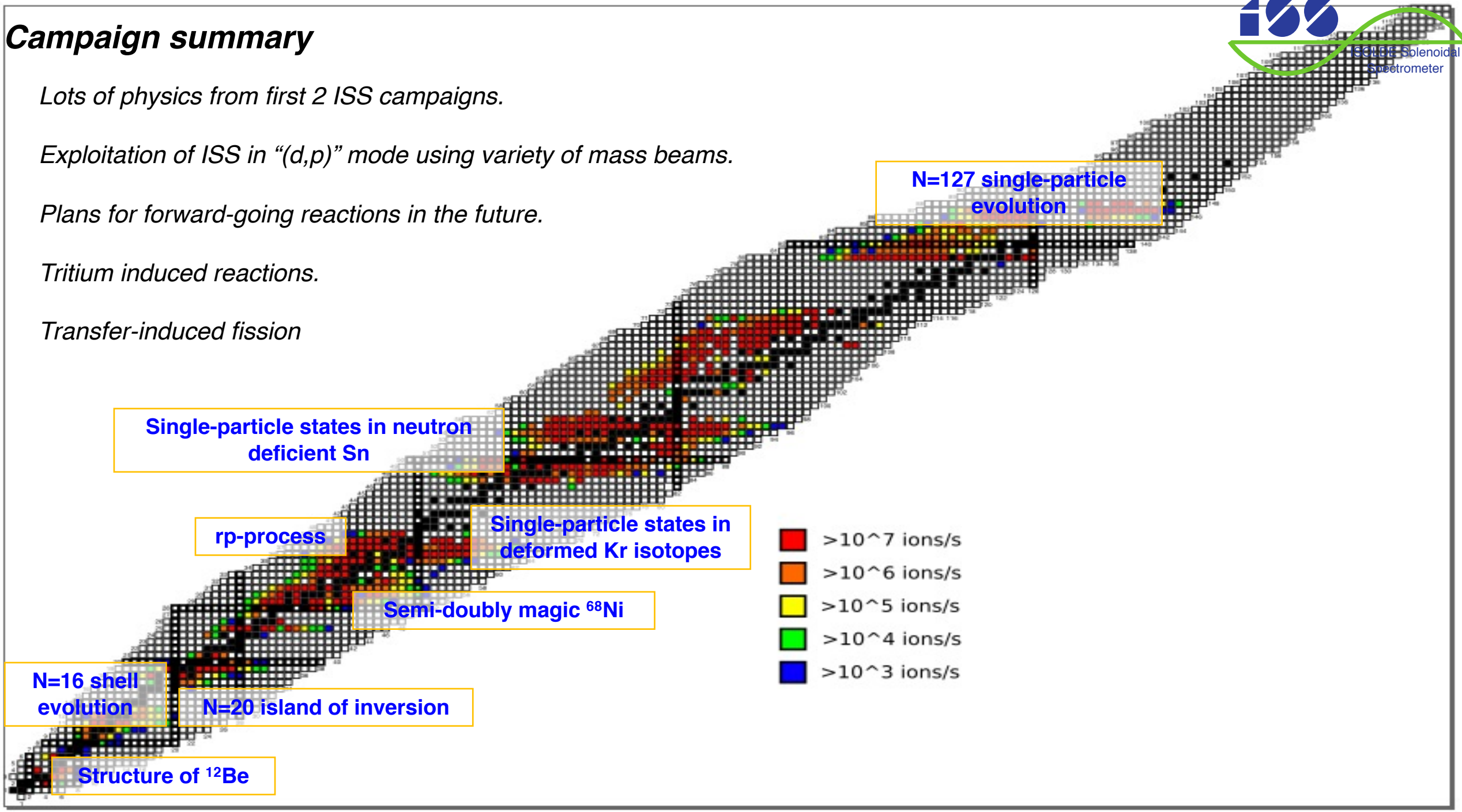
Exploitation of ISS in "(d,p)" mode using variety of mass beams.

Plans for forward-going reactions in the future.

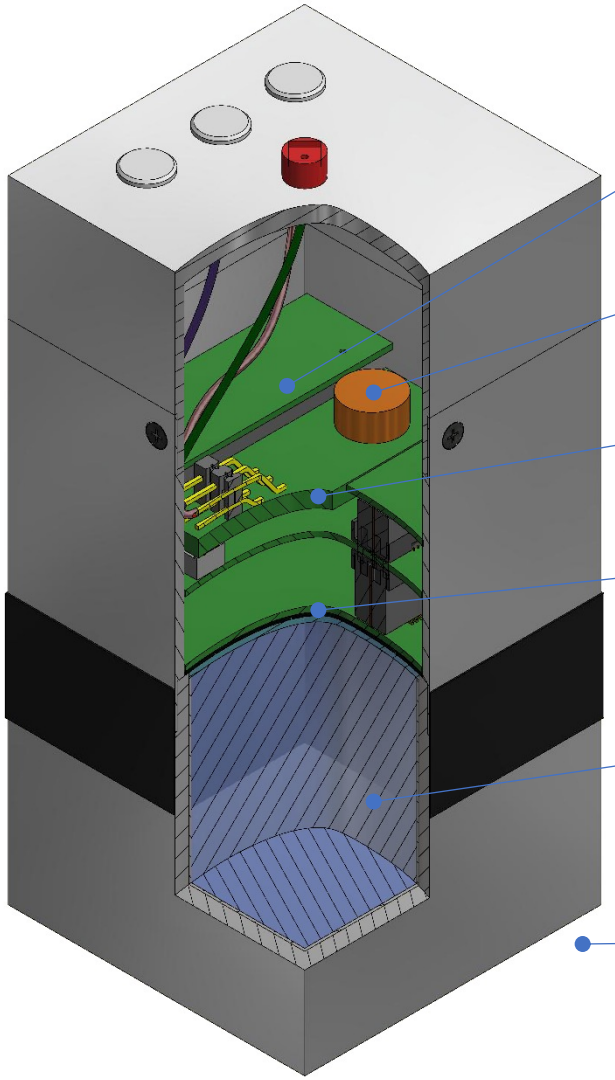
Tritium induced reactions.

Transfer-induced fission

ISOLDE Solenoidal Spectrometer



$CeBr_3$ detector for SpecMAT



Primary bias stabiliser

Temperature compensated secondary bias generator

Built-in preamplifier

8×8 6mm J-series SiPM array
(SiPM Silicone Photo Multiplier)

48×48×48mm cubic $CeBr_3$ scintillation crystal

All components can be used in a strong magnetic field