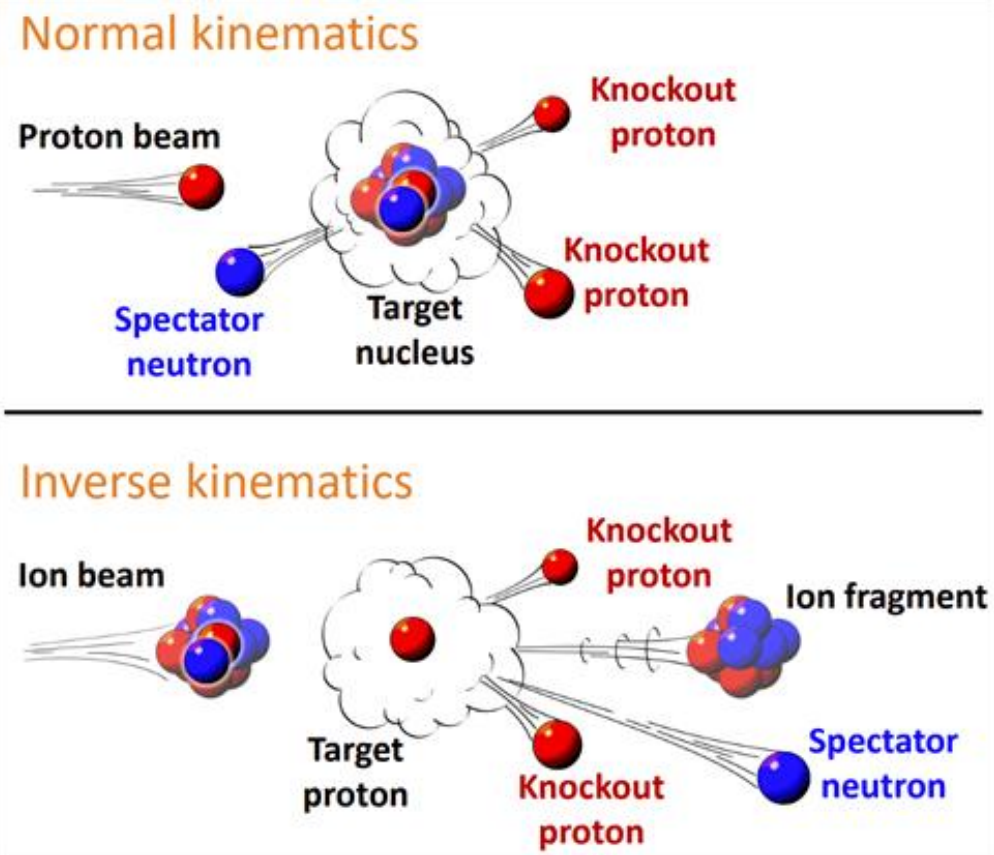
The ISOLDE Solenoidal Spectrometer

Bruno Olaizola
for the ISS collaboration
EuNPC 2022 – Santiago de Compostela

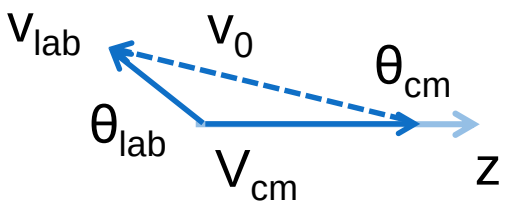
Inverse kinematic



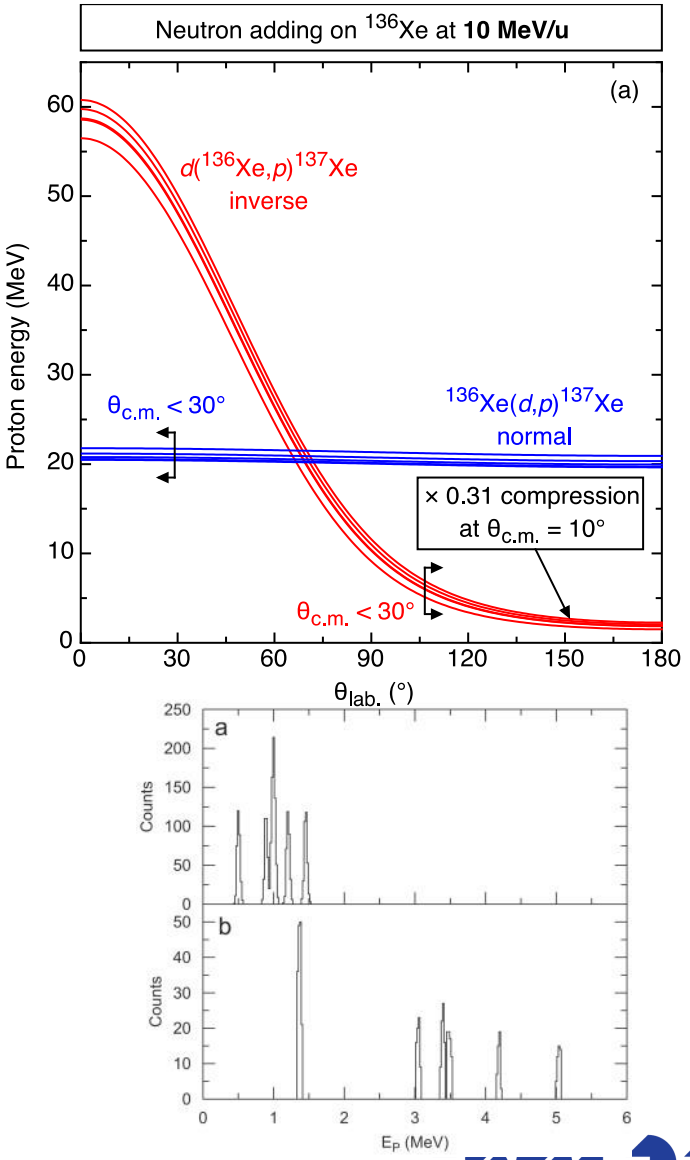
- Exotic nuclei have short lifetimes → target not possible
- With advent of radioactive beams, they can be studied
- Only feasible in inverse kinematics

Kahlbow Journal of Modern Physics, 13, 761-767 (2022)

Kinematic compression

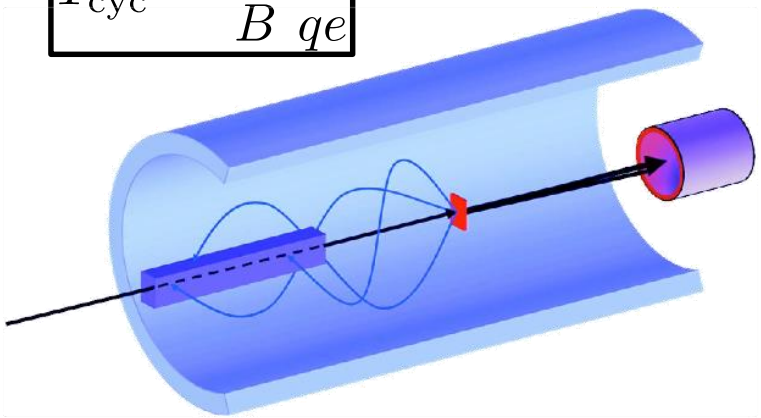


- Now the CM has a high velocity
- The speed v_0 of the small fragment, measured in the LAB, will be compressed by v_{CM}
- This effects is speed (energy) dependent
- Compresses the energy spectrum, lowering resolving power



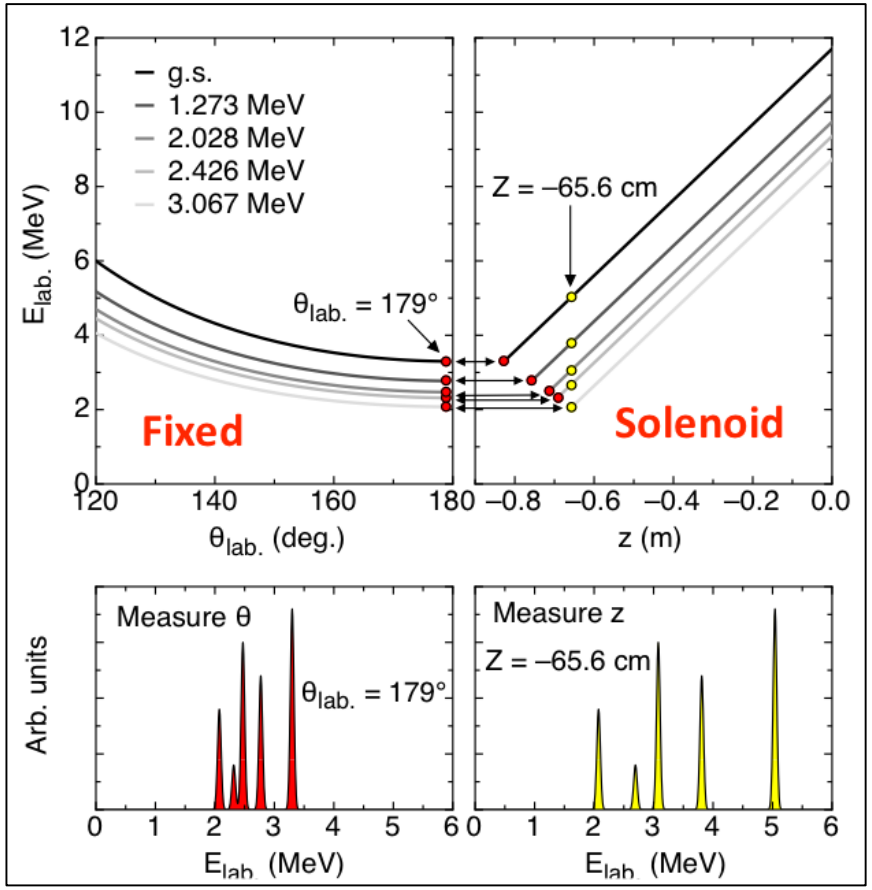
Reactions in a magnetic field

$$T_{\mathrm{cyc}} = \frac{2\pi}{B}\frac{m}{qe}$$



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

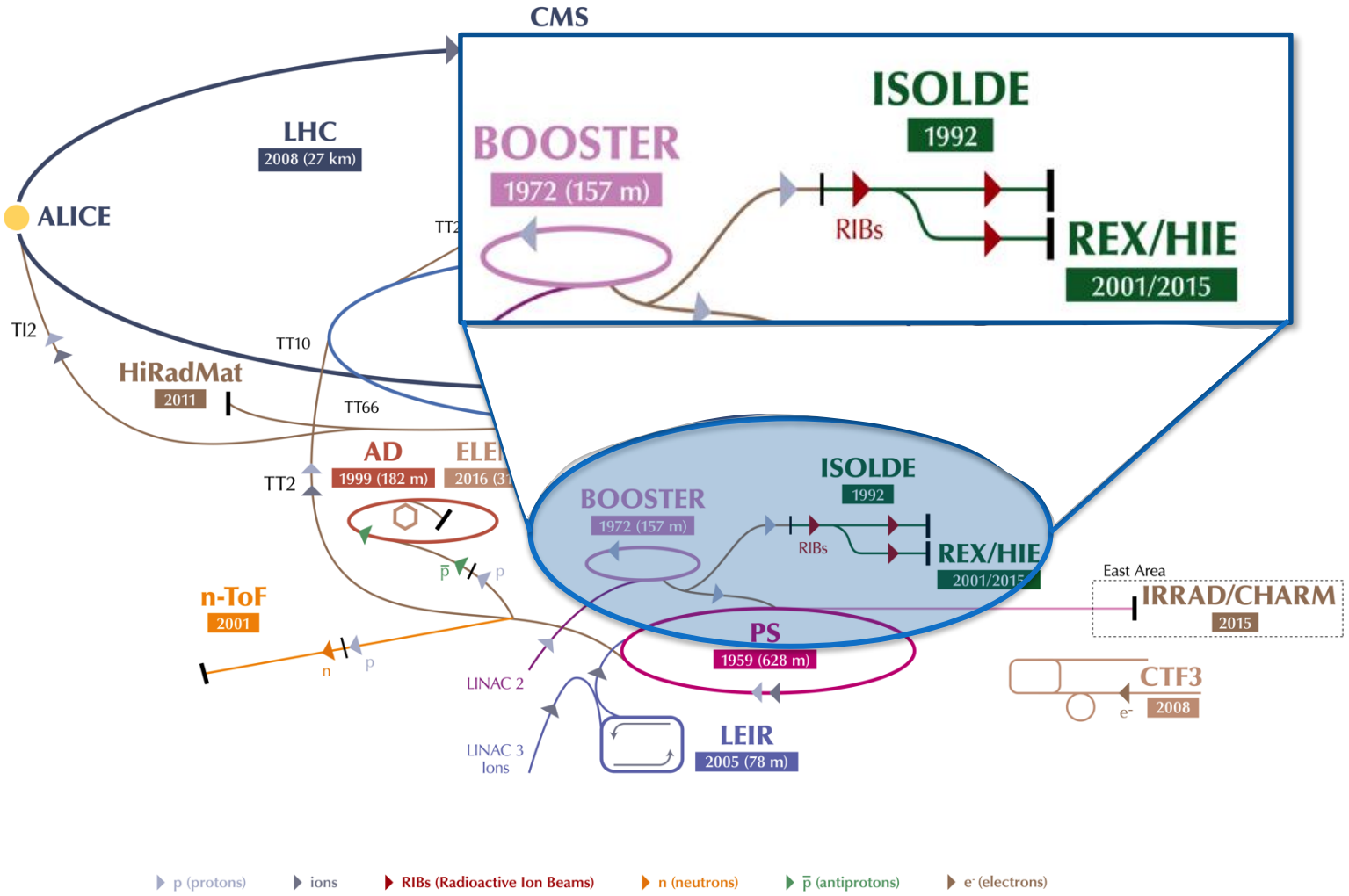
- Magnetic field along the beam axis
- MEASURED QUANTITIES: position z, cyclotron period T_{cyc} and LAB particle energy E_p.
- Suffers no kinematic compression



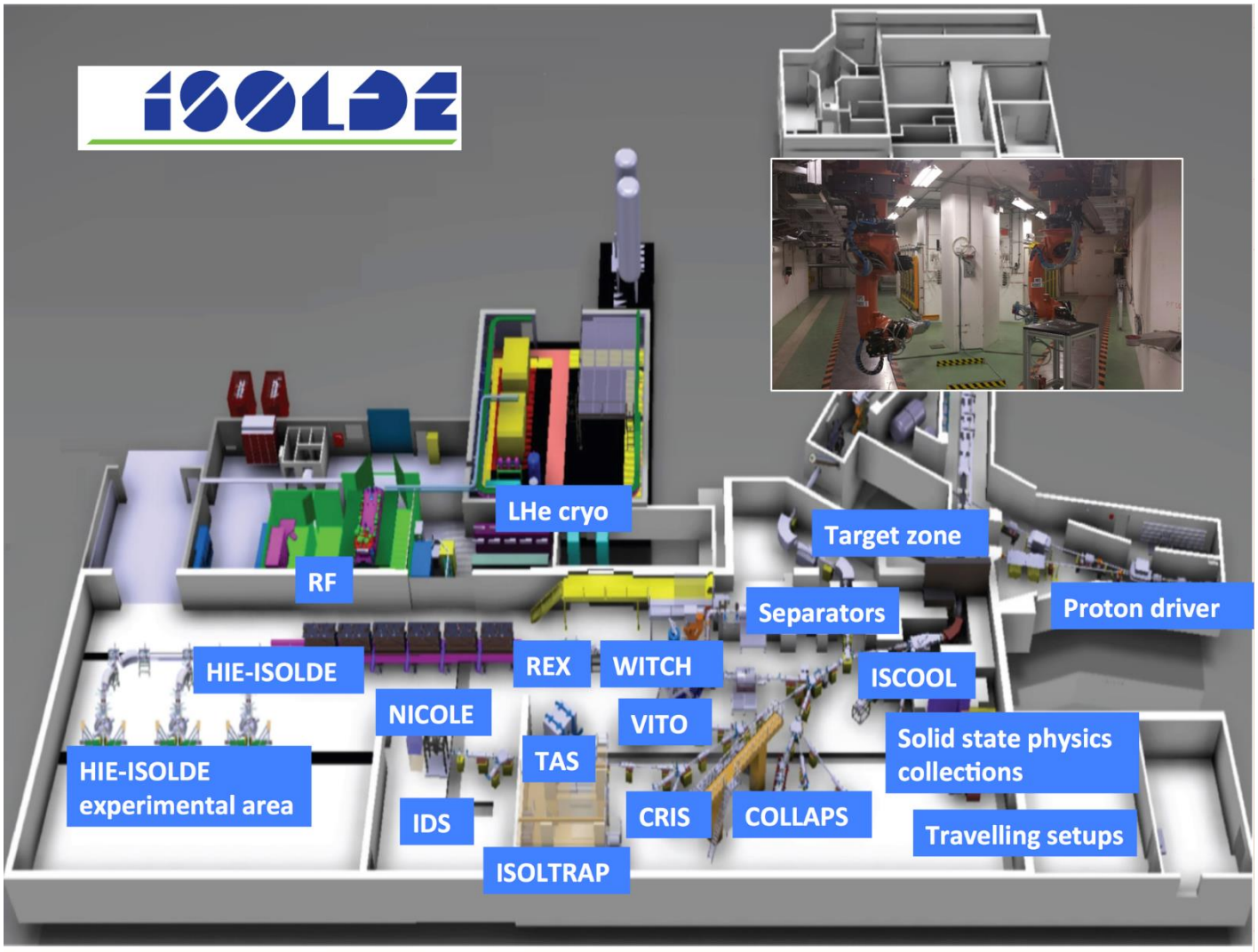
Recycling an MRI magnet

Pictures courtesy of L. Gaffney

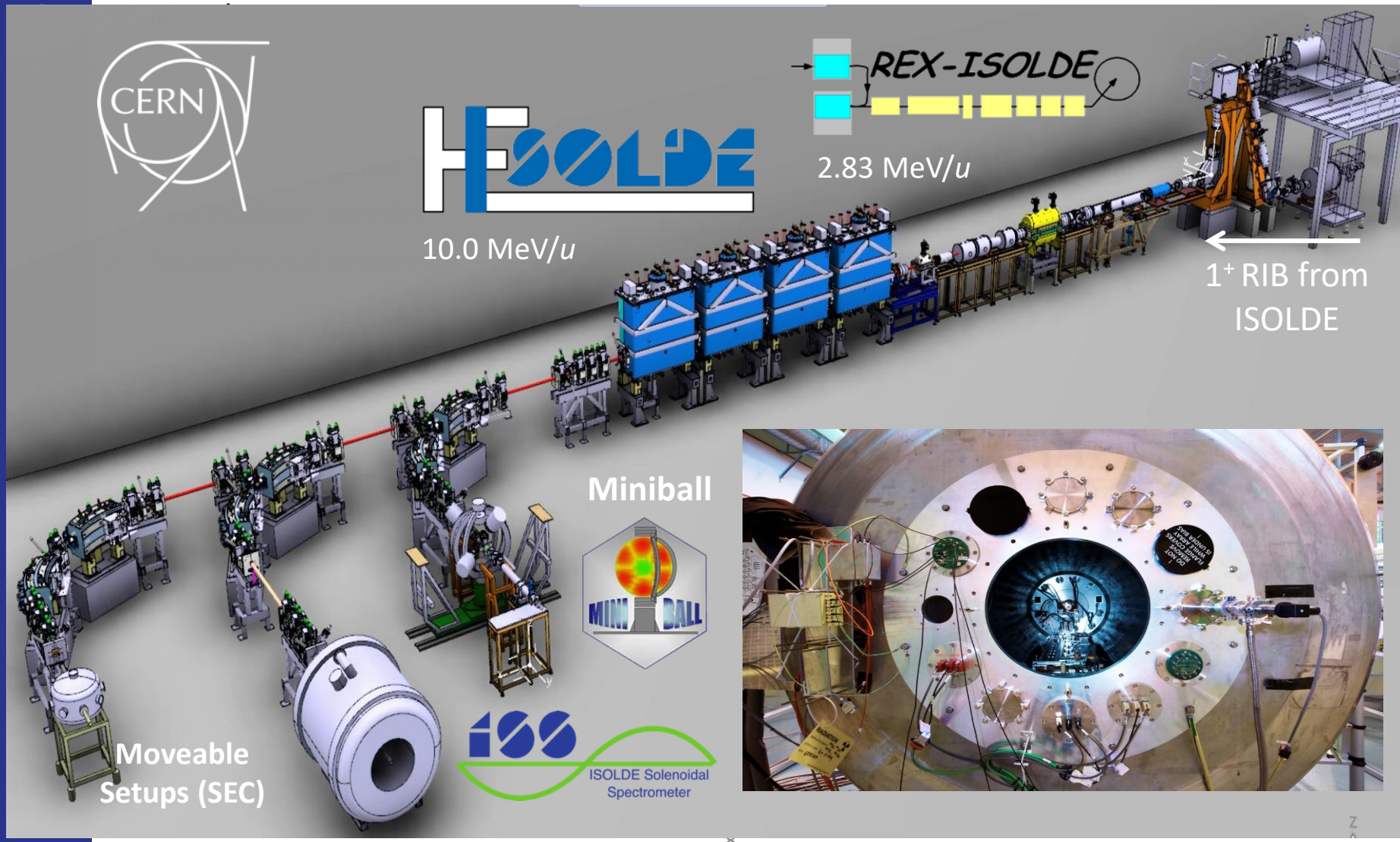
CERN accelarators



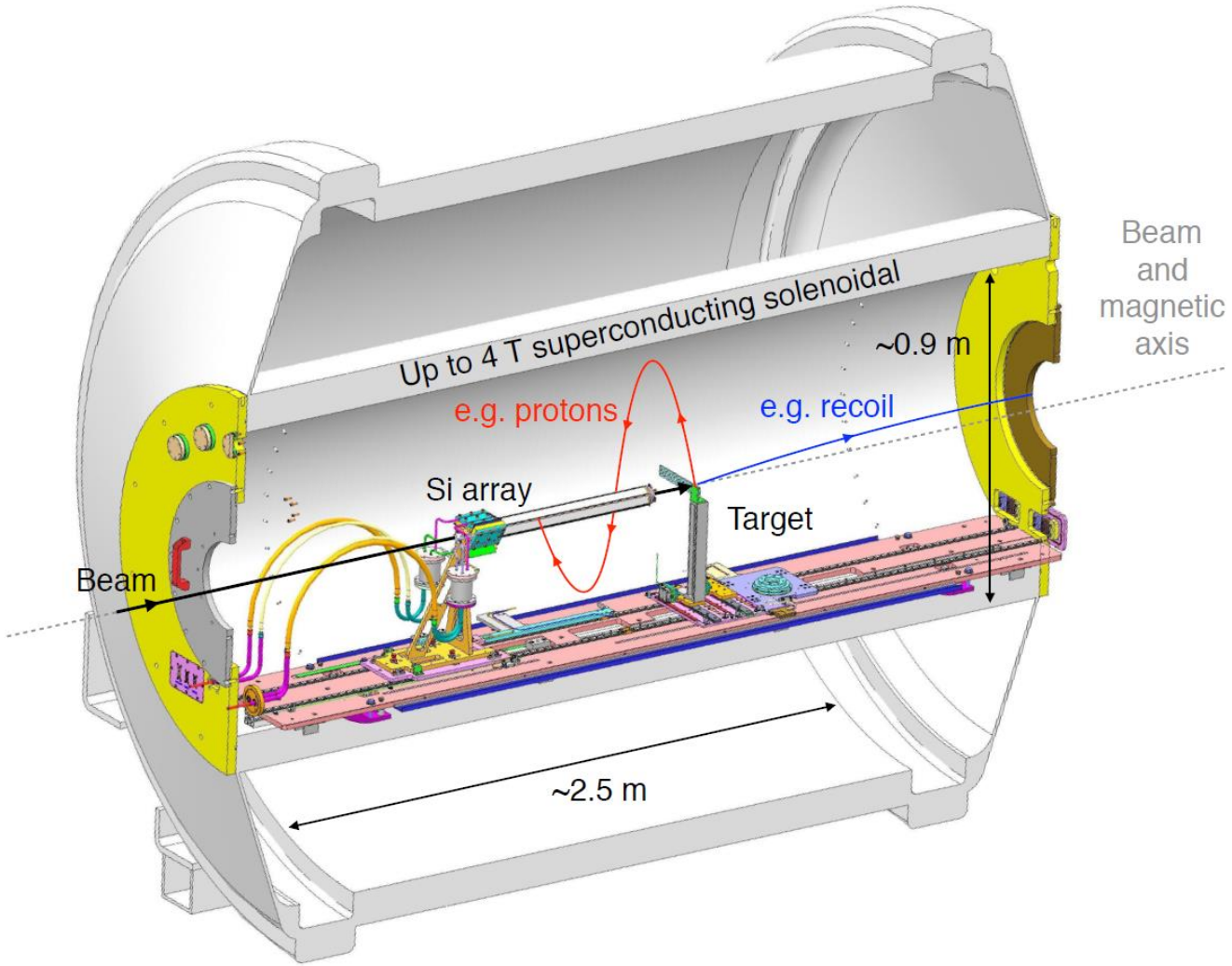
ISOLDE facility



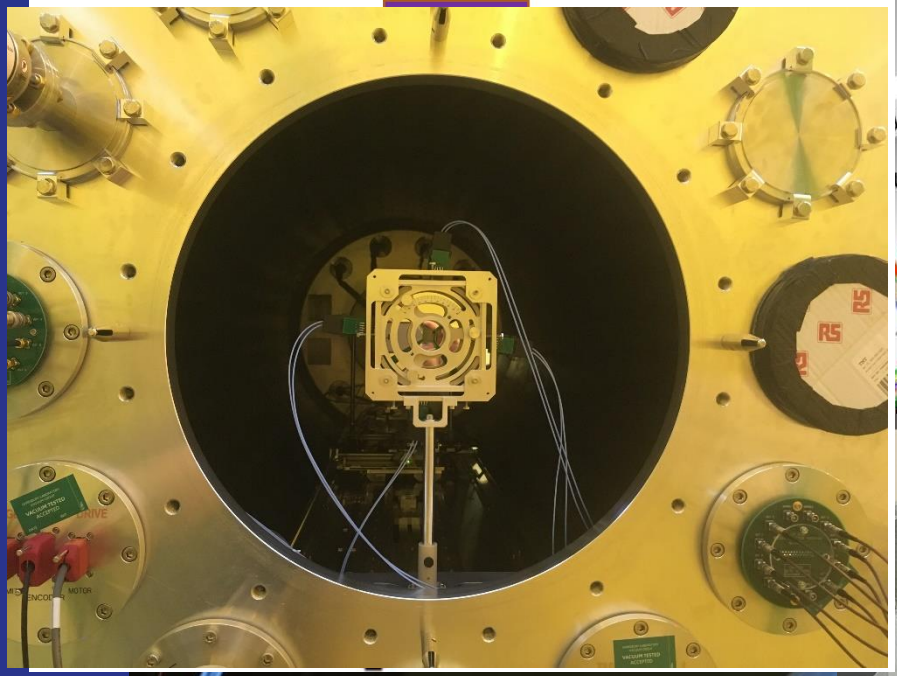
HIE-ISOLDE

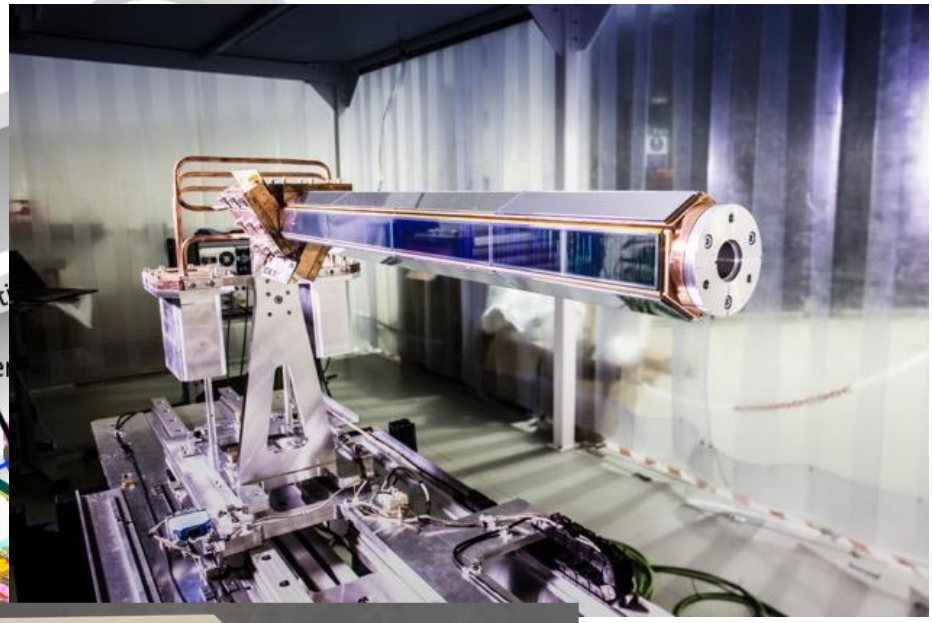

CERN
HIE-ISOLDE
10.0 MeV/u
REX-ISOLDE
2.83 MeV/u
1⁺ RIB from ISOLDE
Miniball
MINIBALL
Moveable Setups (SEC)
ISOLDE Solenoidal Spectrometer

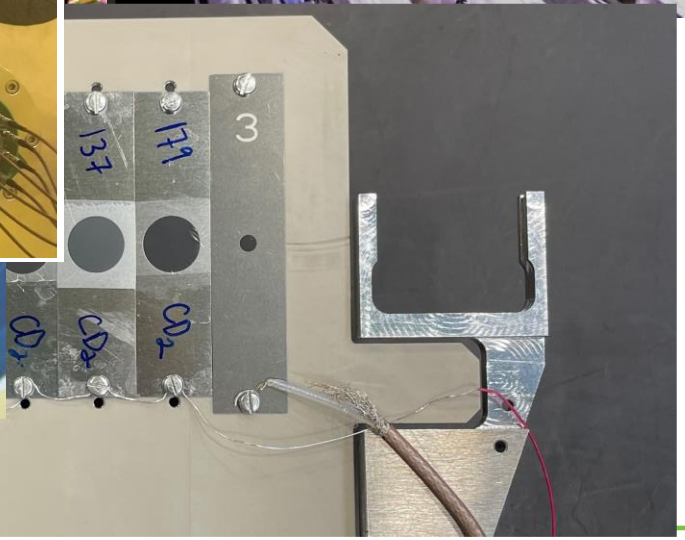
ISOLDE Solenoidal Spectrometer



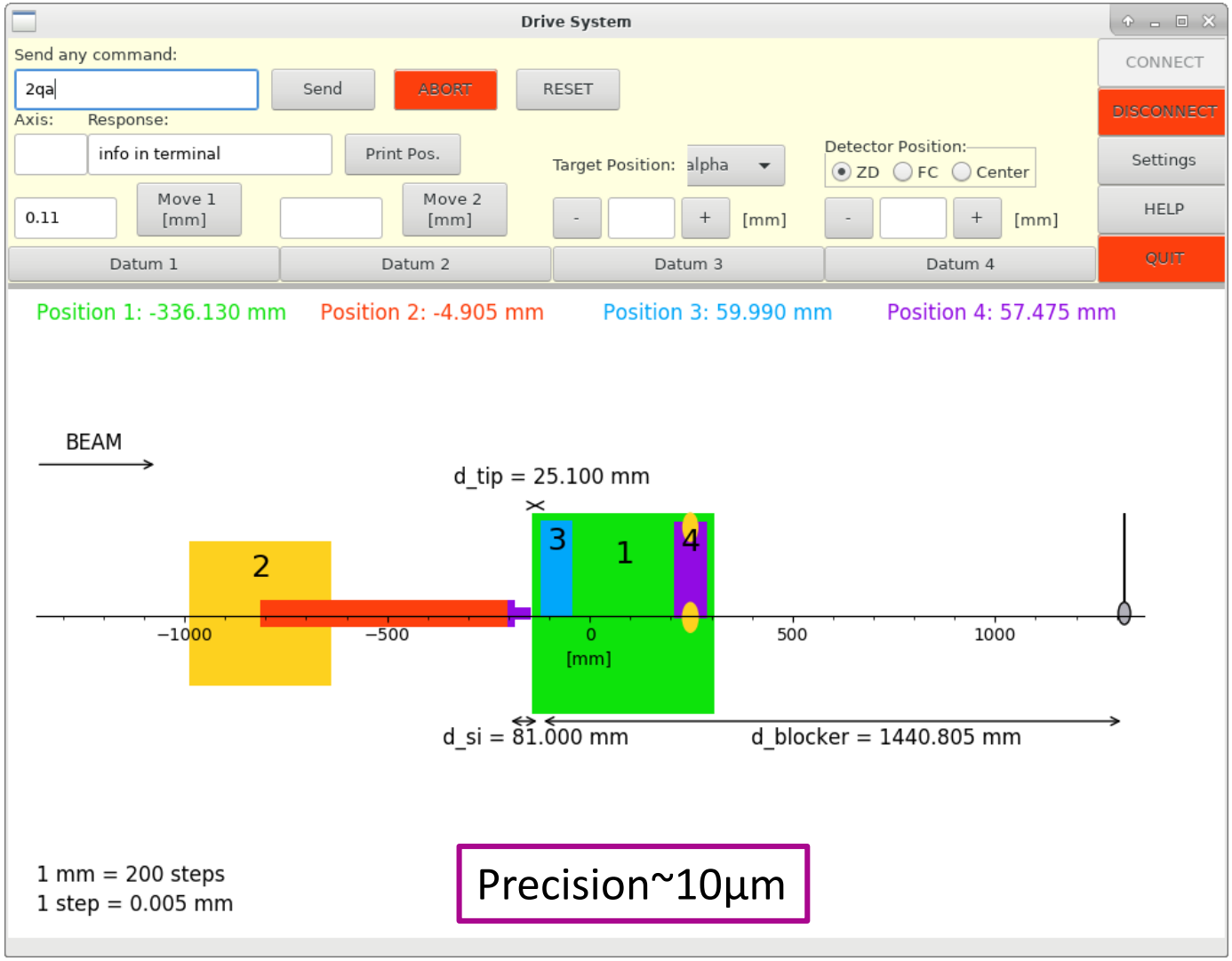
ISS





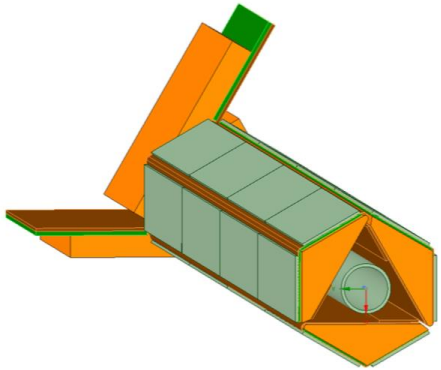


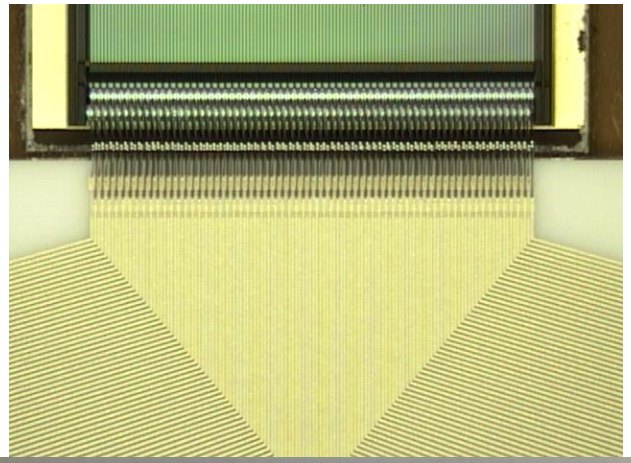
Moving axis

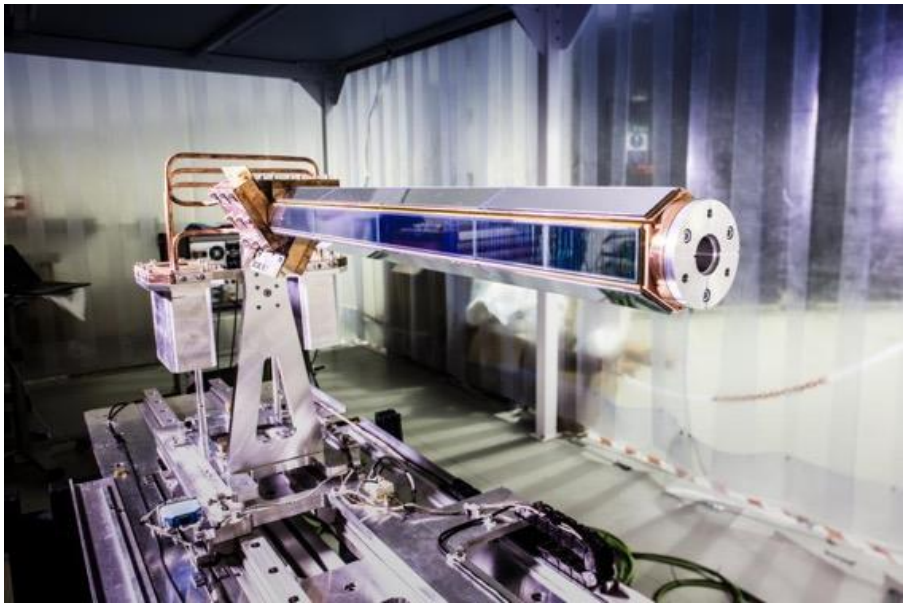

Drive System
Send any command:
2qa
Send
ABORT
RESET
CONNECT
DISCONNECT
Settings
HELP
QUIT
Axis:
Response:
info in terminal
Print Pos.
Target Position:
alpha
Detector Position:
ZD
FC
Center
0.11
Move 1 [mm]
Move 2 [mm]
[mm]
[mm]
Datum 1
Datum 2
Datum 3
Datum 4
Position 1: -336.130 mm
Position 2: -4.905 mm
Position 3: 59.990 mm
Position 4: 57.475 mm
BEAM
d_tip = 25.100 mm
2
3
1
4
−1000
−500
0
500
1000
[mm]
d_si = 81.000 mm
d_blocker = 1440.805 mm
1 mm = 200 steps
1 step = 0.005 mm
Precision~10µm

Advanced Liverpool Array

- 6-sided 4 DSSDs + ASIC readout.
- Each detector consists of strips:
  - x: 128 x 0.95mm.
  - y: 11 x 2mm.
- 1668 channels readout
- Total length of silicon is 510.4mm (486.4mm active)



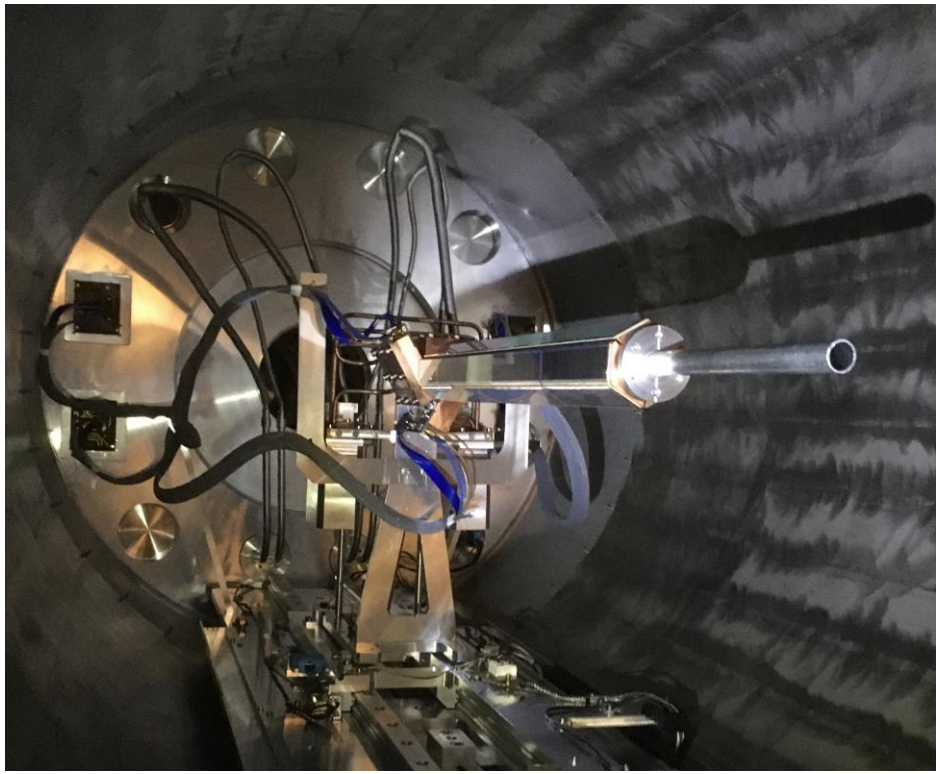




“The Silencer”

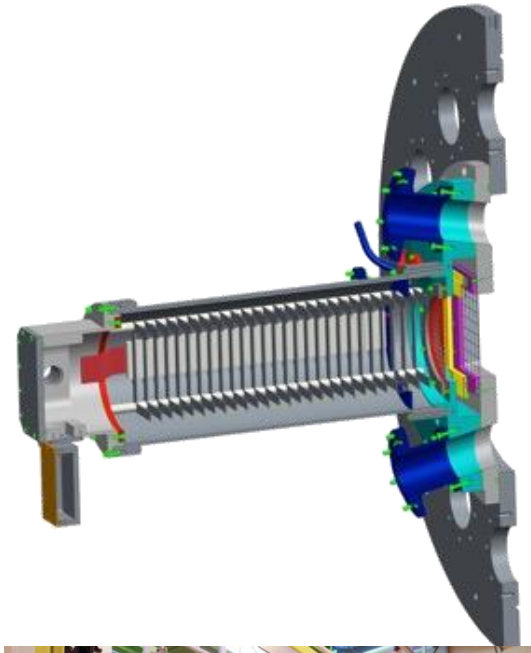
$$T_{\mathrm{cyc}} = \frac{2\pi}{B}\frac{m}{qe}$$

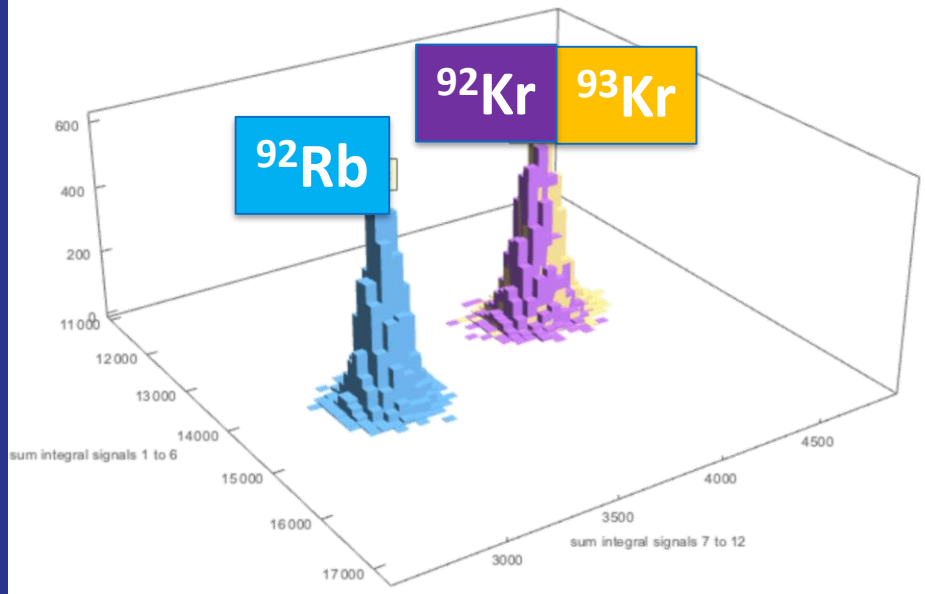
- Not enough time resolution
- Can’t measure cyclotron period
- No particle identification
- Cannot distinguish between one orbit or 2 or more
- Pipe blocks multiple orbit trajectories

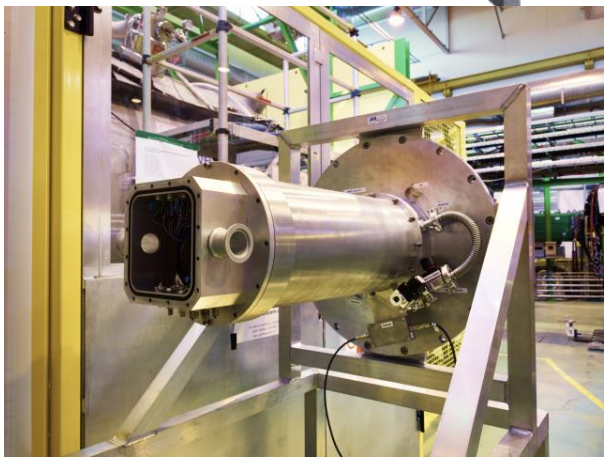


Gas ionization chamber

- Up to 100 kHz counting.
- Segmented with digital readout
- Sample dE/dx along track of recoils
- Beam composition identification
- MWPC for position sensitivity and time reference

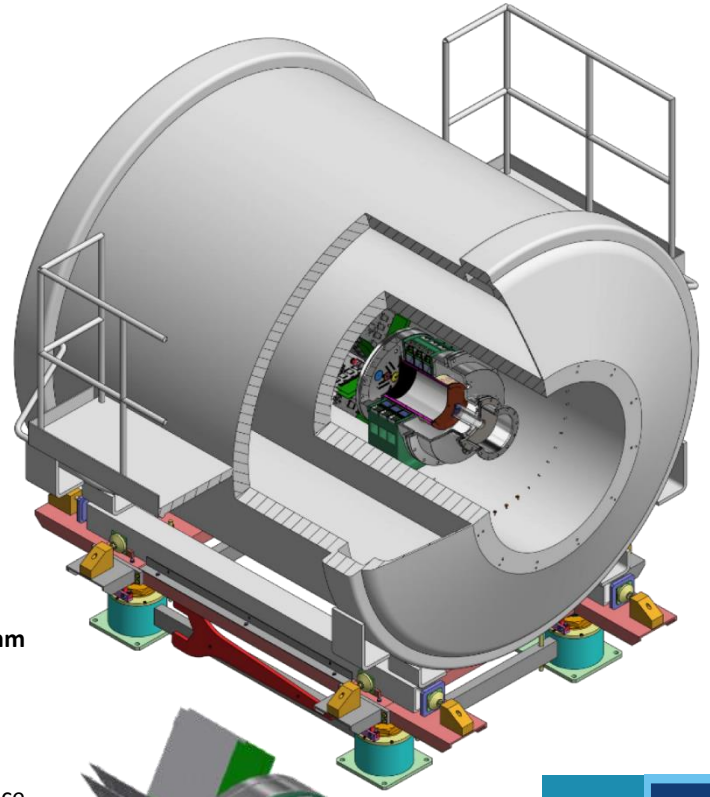


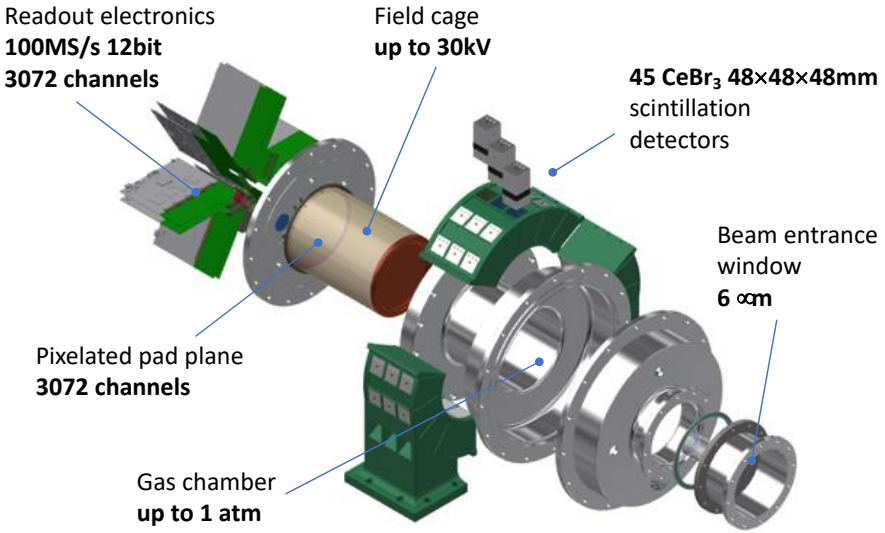


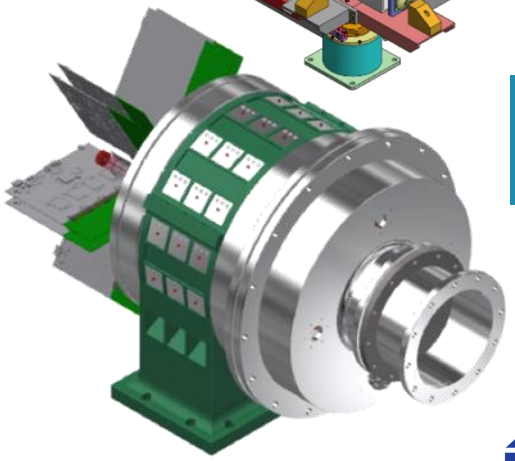


SpecMat

- SpecMat – R. Raabe
- Time-projection chamber
- Active target
- Helium or hydrogen species as gas
- $CeBr_3$ detectors array for gamma-ray detection

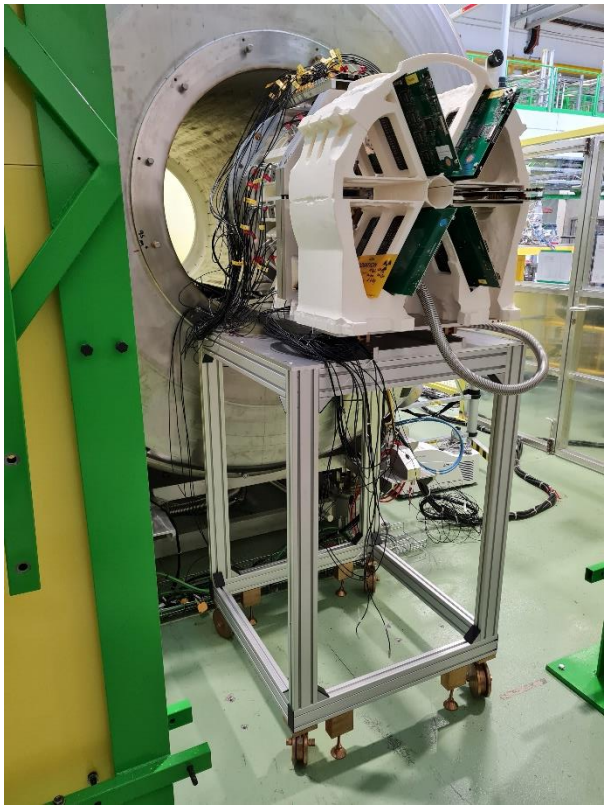




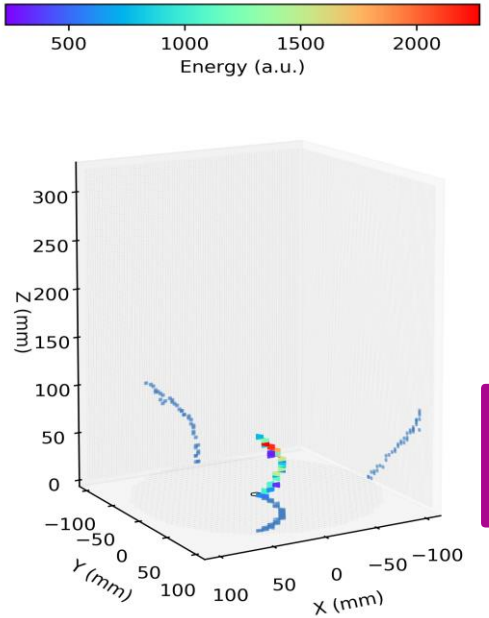


Figures made by Oleksii Poleschchuk

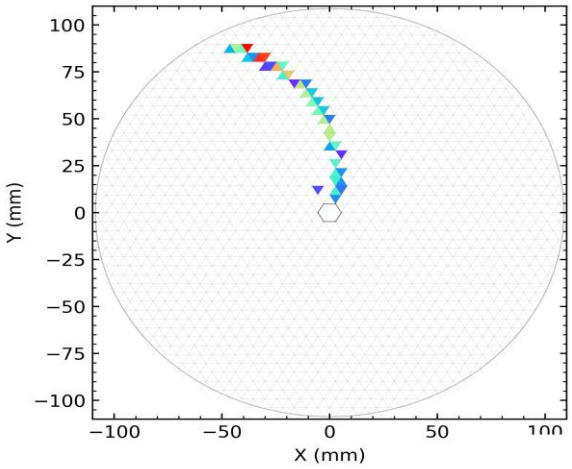
Tests of the SpecMAT active target in ISS



SpecMAT installation in the superconducting magnet



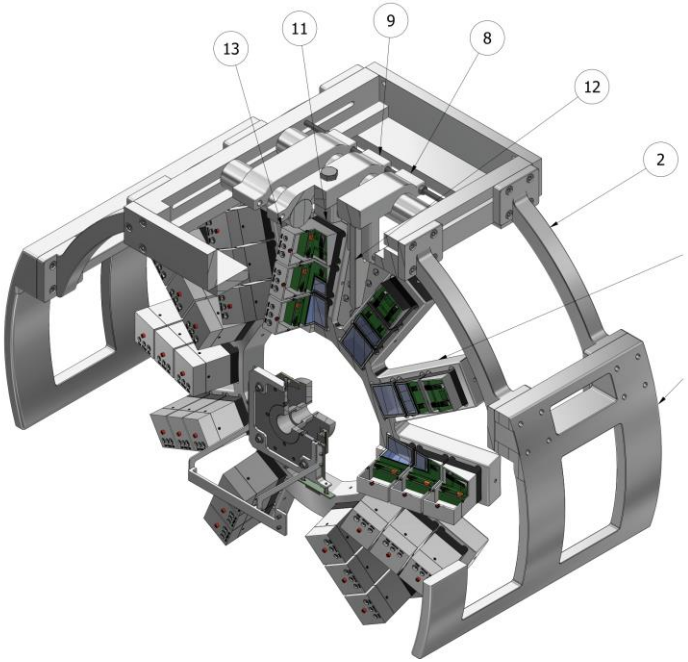
Measured α-particle track in B=2.5T

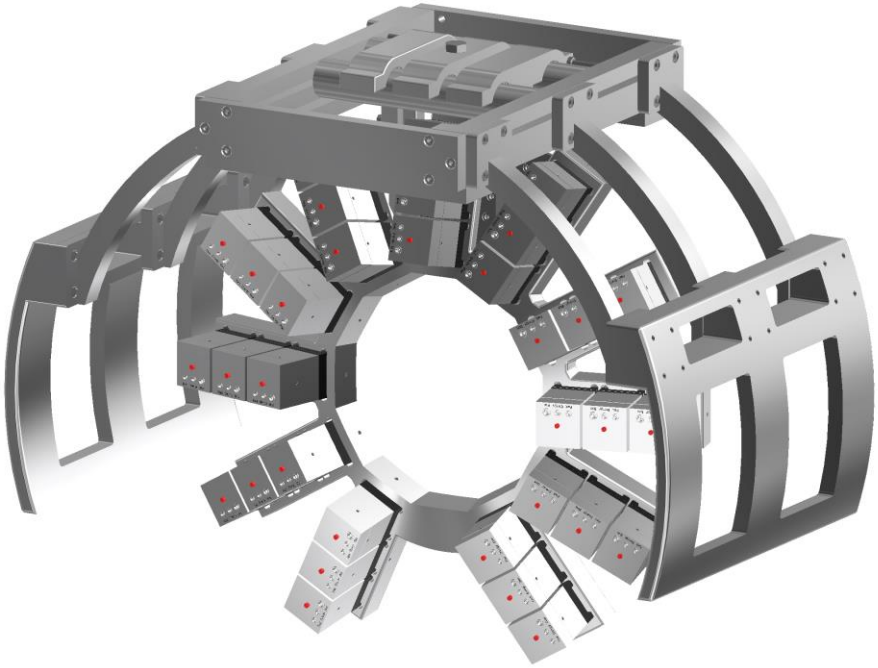


Images provided by O. Poleshchuk

(d,p) reactions with a gamma array

- In November we plan to run (d,p) reactions with the SpecMAT $CeBr_3$ array

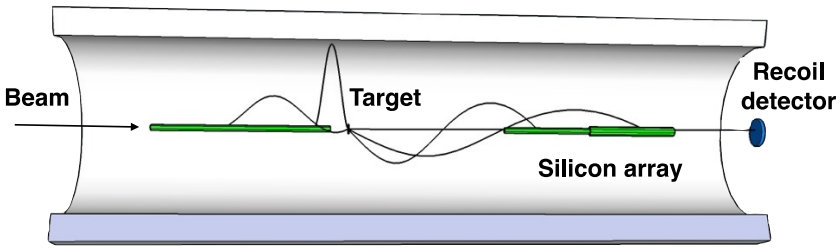


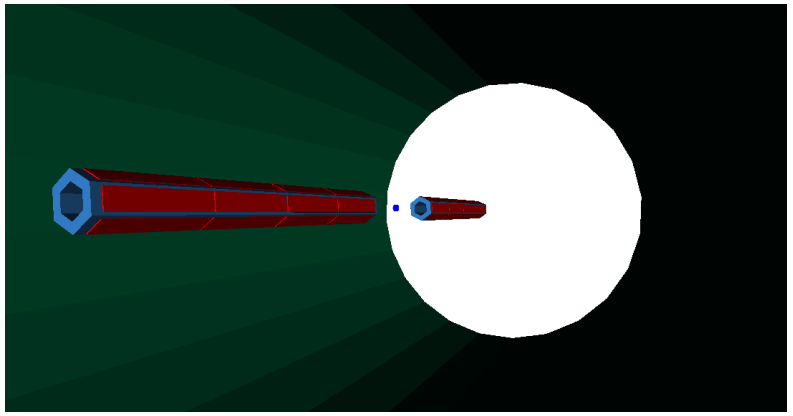


Images provided by O. Poleshchuk

Future

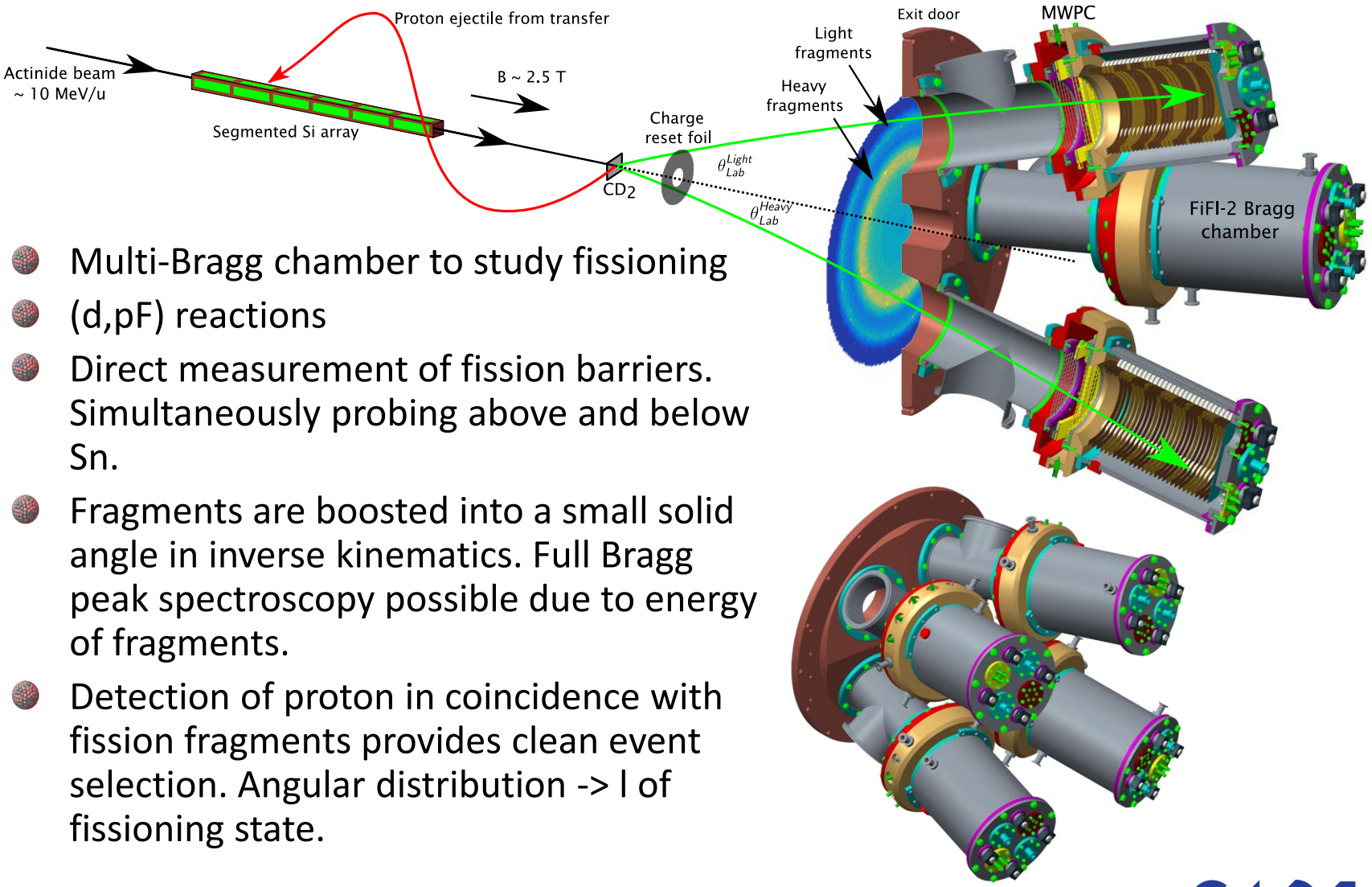
- Many reaction channels **forward-going** in lab. frame:
  - Interest shown already in e.g. (d,d'), (d,^{3}He)
  - Foreseen to **rotate geometry** for these measurements.
  - Limit for recoil angles passing through (A>120) or around array (A<30) + beam diagnostics, etc.
- Physics for free in dual-array mode ← **Increasing output**
- **New possibilities** e.g. coincidences between arrays.





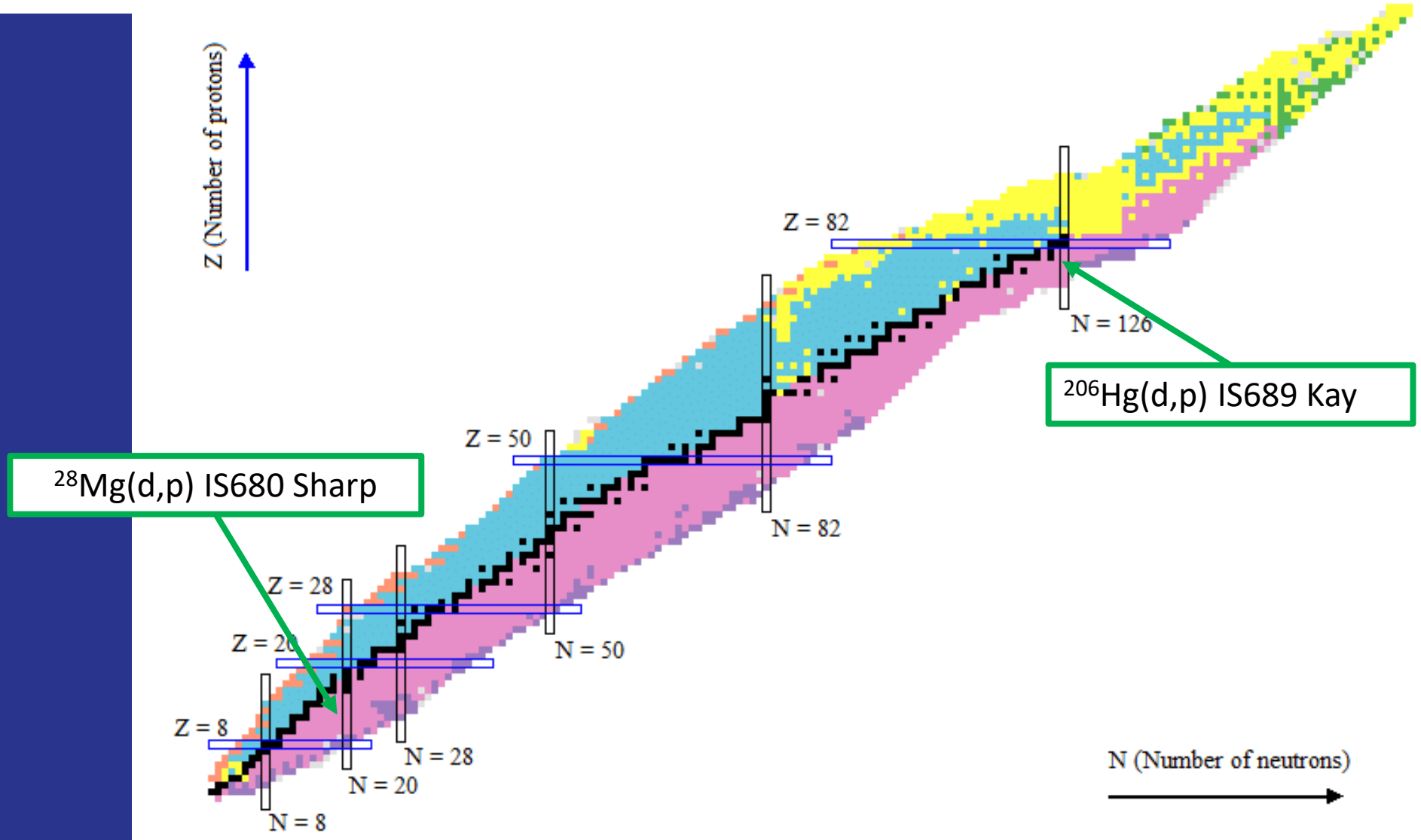
Courtesy of L. Gaffney U. Liverpool

Future



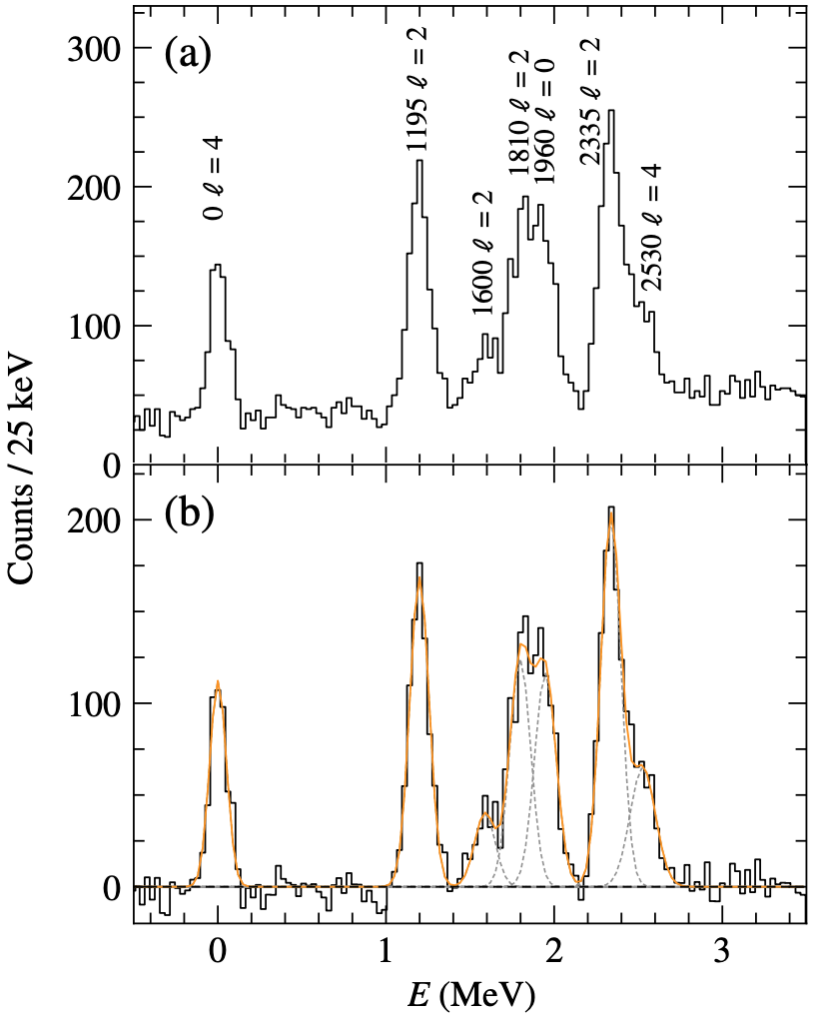
- Multi-Bragg chamber to study fissioning
- (d,pF) reactions
- Direct measurement of fission barriers. Simultaneously probing above and below Sn.
- Fragments are boosted into a small solid angle in inverse kinematics. Full Bragg peak spectroscopy possible due to energy of fragments.
- Detection of proton in coincidence with fission fragments provides clean event selection. Angular distribution -> l of fissioning state.

Experiments pre-2020



ISS first results – ^{207}Hg

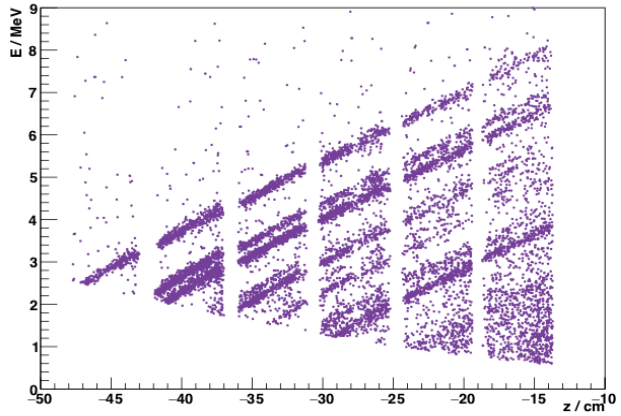
- Measurements in 2018 with HELIOS array and DAQ - Argonne
- ^{206}Hg(*d*,*p*) – first step into region south-east of ^{208}Pb
- First ^{207}Hg level scheme

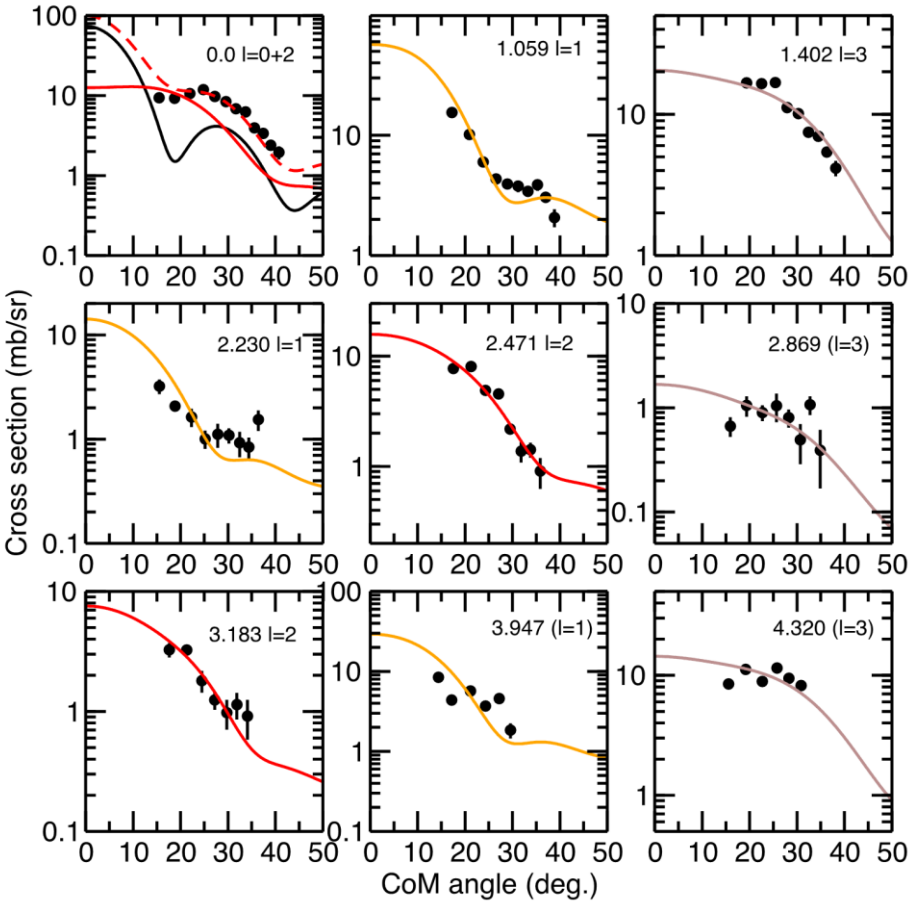


T. L. Tang et al., Phys. Rev. Lett **124**, 062502 (2020)

ISS first results – ^{29}Mg

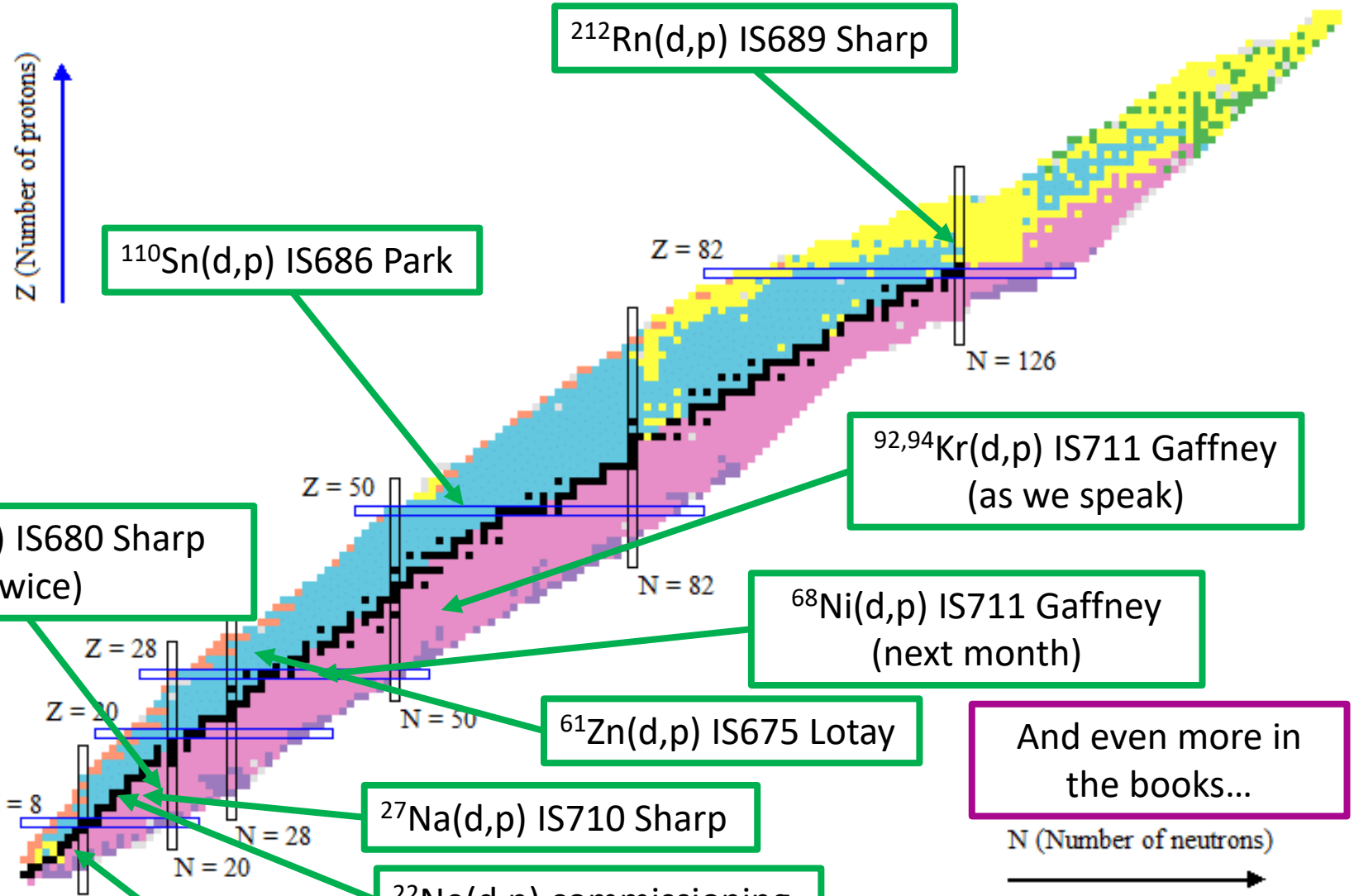
- Excitation energy resolution of ~140 keV.
- Compared to DWBA calculations to make ℓ assignments.





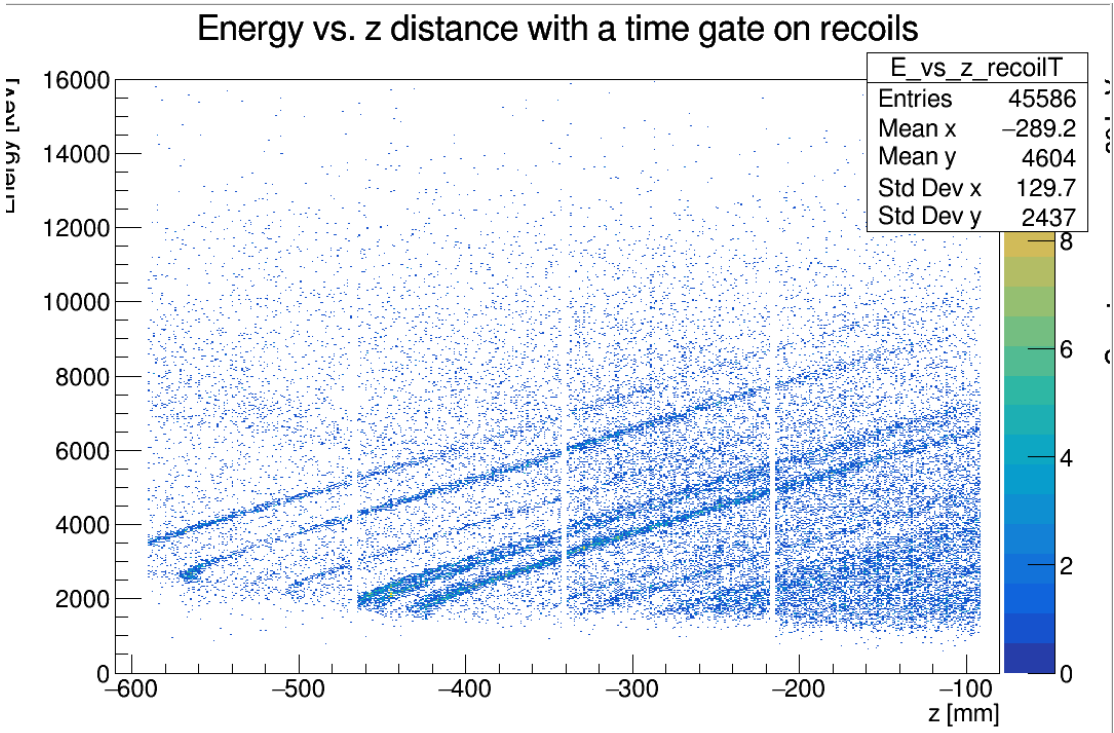
MacGregor PHYSICAL REVIEW C 104, L051301 (2021)

Experiments 2021-2022



Test with stable ^{22}Ne

- Array commissioned with stable ^{22}Ne
- 120 µg/cm^2 target
- Kinematic lines correspond to excited states
- “Bend” at the end of lines due to finite size of Si array
- Can be corrected
- Projection is excitation energy
- Energy resolution~140 keV



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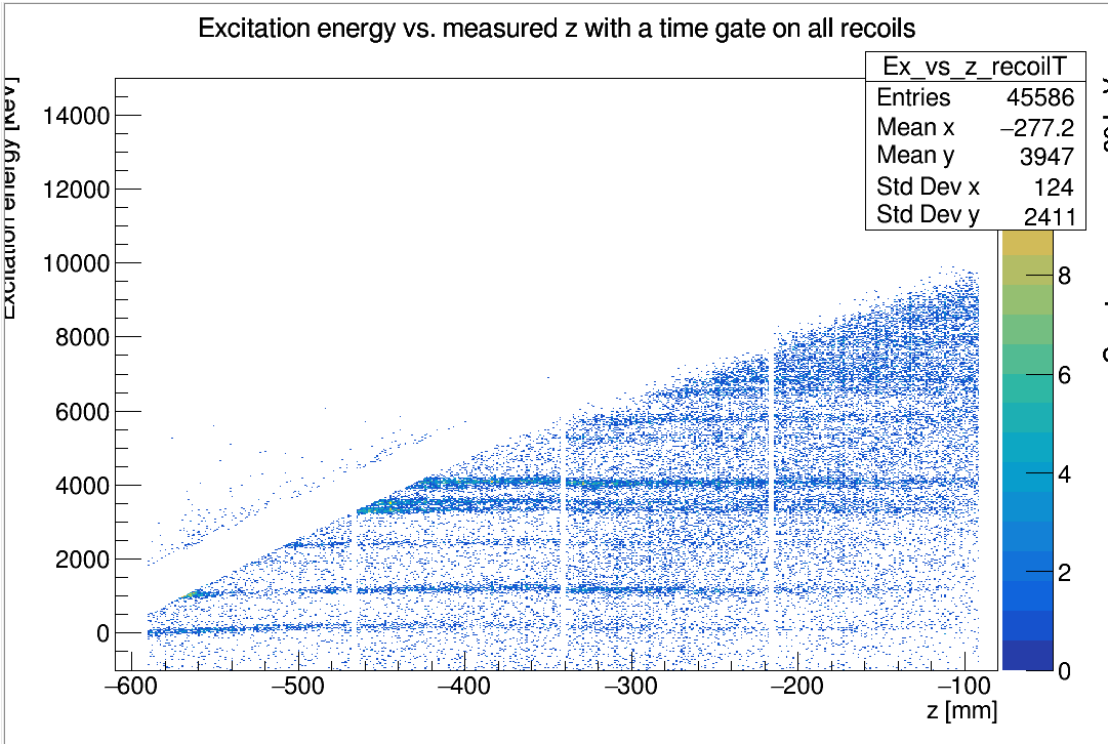

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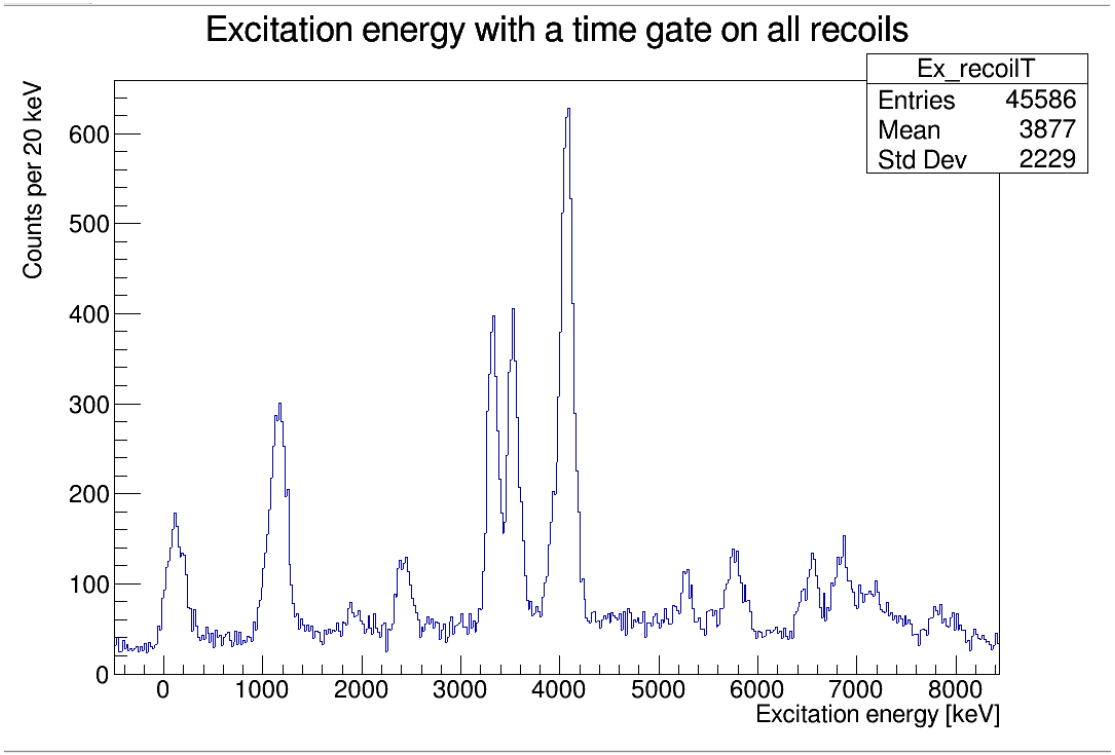
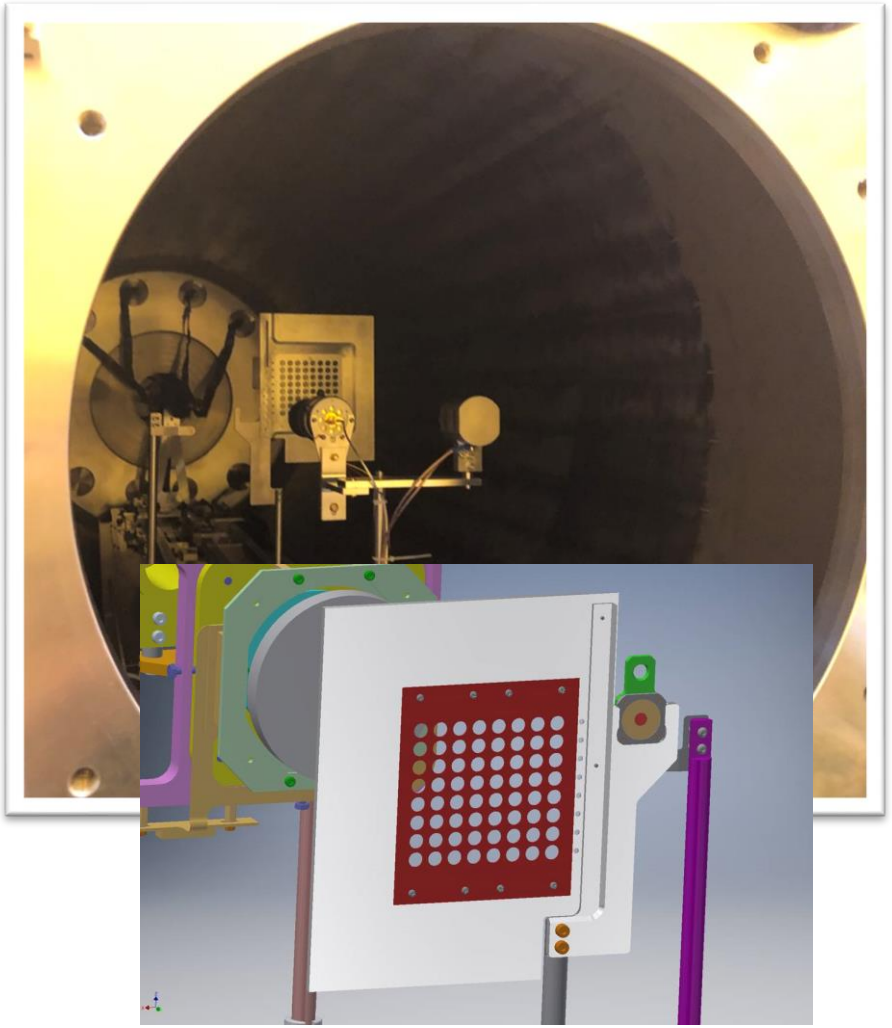


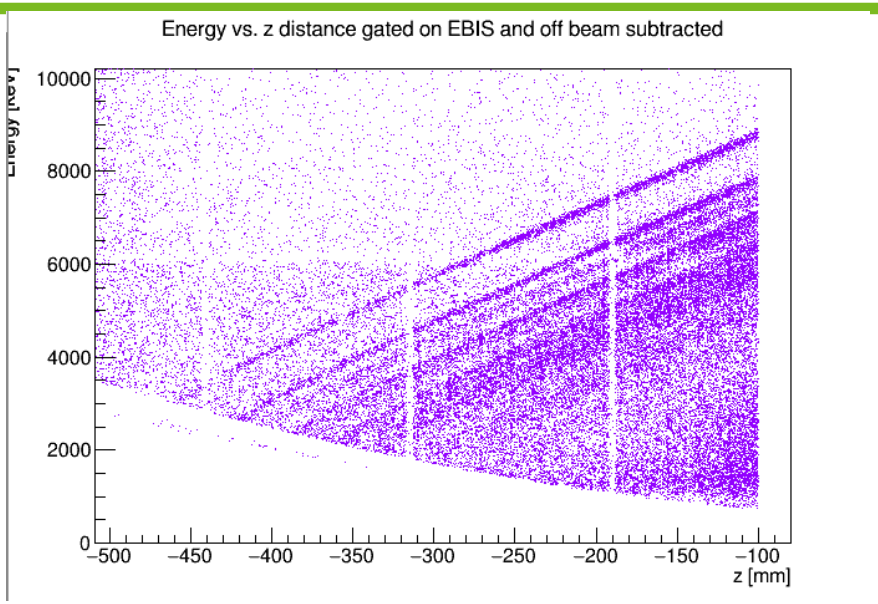
$^{212}Rn(d,p)^{213}Rn$ – SP structure outside N=126

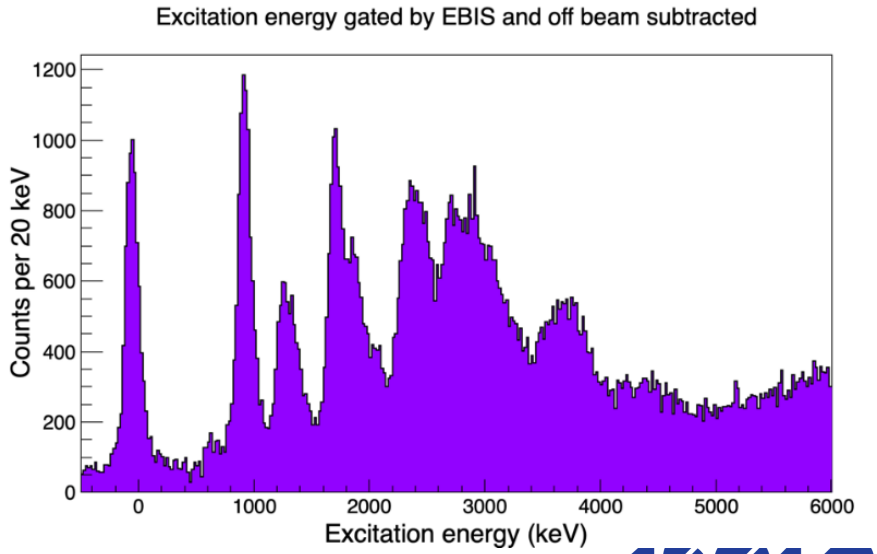
- Beam: ~5x10^6 pps of ^{212}Rn.
- Produced using cold transfer line from the target – contaminants condense out of beam
- A 7.63 MeV/u – highest total HIE-ISOLDE beam >1.6 GeV
- Measured in singles mode
- Beam purity >99%.
- Using >20 deuterated polyethylene targets of ~125µg/cm2
- ISS set to B-field of 2.5 T



$^{212}Rn(d,p)^{213}Rn$ – SP structure outside N=126

- Best case resolution ~100 keV.
- Background from alpha decay of beam and fusion-evaporation.
- 24 states identified up to 5 MeV – predominantly l=2 and 4 strength.
  - Hints of $i_{11/2}$ population above $g_{9/2}$





Slide courtesy of D. Sharp U. Manchester

$^{212}Rn(d,p)^{213}Rn$ – SP structure outside N=126

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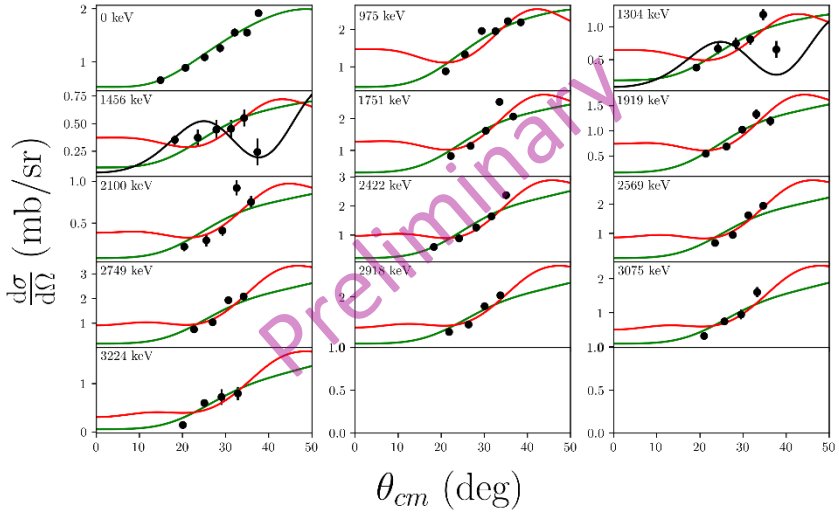

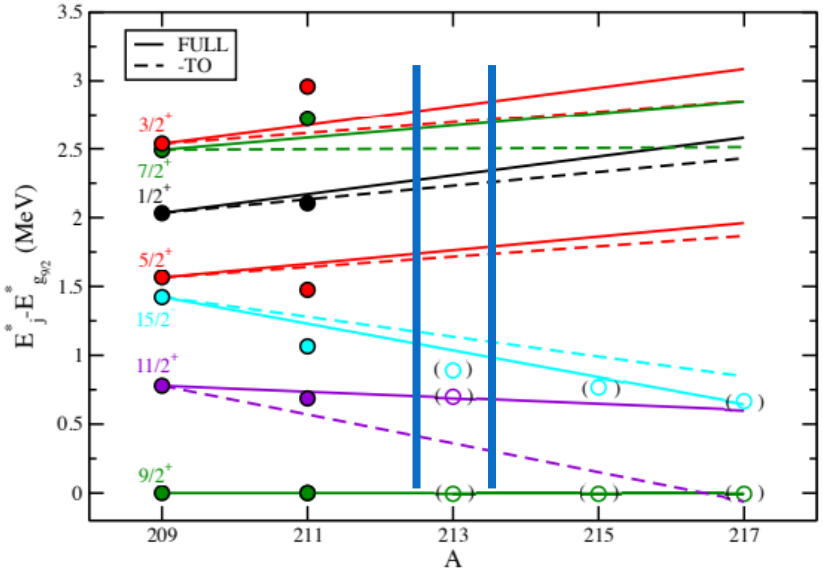

Slide courtesy of D. Sharp U. Manchester

Summary

- Reaction in a magnetic field suffer no kinematic compression
- High position sensitivity → good angular resolution
- Improved energy resolution
- Versatile ancillary detectors
- Several upgrades planned

Thanks to collaborators

PT MacGregor, **DK Sharp**, SJ Freeman,
SA Bennett, D Clarke,BD Cropper, K Garrett, *University of Manchester, UK*
CR Hoffman, BP Kay, JP Schiffer, TL Tang, J Chen, MD Gott, *Argonne National Laboratory, USA*
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RS Lubna, *Florida State University, USA*
I Martel, *Universidad de Huelva, Spain*
DG McNeel, *University of Connecticut, USA*
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F Recchia, *Universita degli Studi di Padova and INFN Padova*
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F Flavigny, *Orsay and LPC Caen, France*
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Future

- **HPGe spectrometer** for γ-ray detection.
  - Tests in the solenoid field with Padova group.
  - Possibility for **plunger** measurements *(Manchester)*