Status update on the MARA-LEB facility

Philippos Papadakis

LA^{3}NET Workshop
25.10.2016

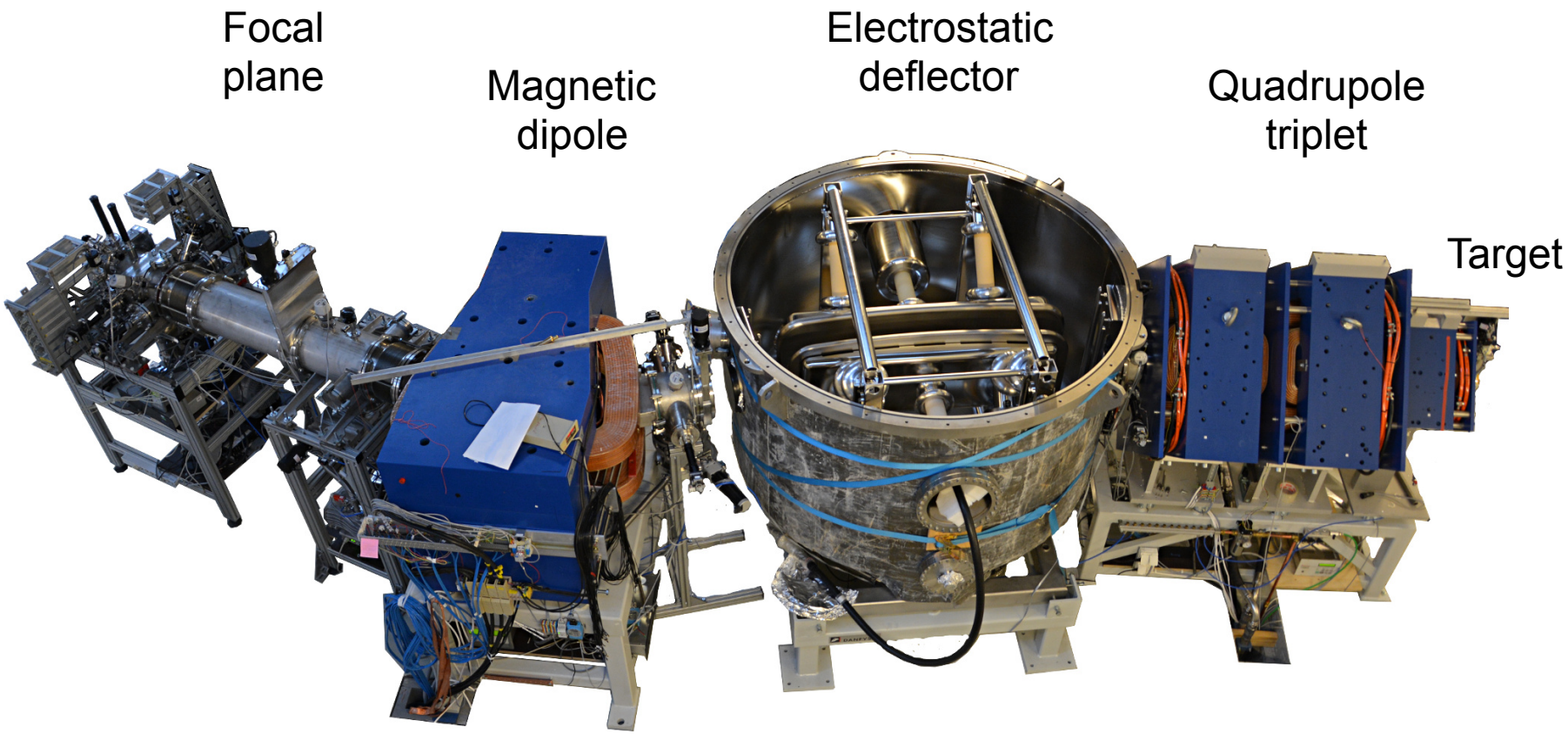
Outline

- The MARA vacuum-mode recoil-mass separator
  - Overview of separator
  - In-beam tests / first experiment
- The MARA-Low Energy Branch (MARA-LEB)
  - Scientific motivation
  - Components of MARA-LEB
  - Detector systems
  - Current status

The MARA vacuum-mode recoil-mass separator

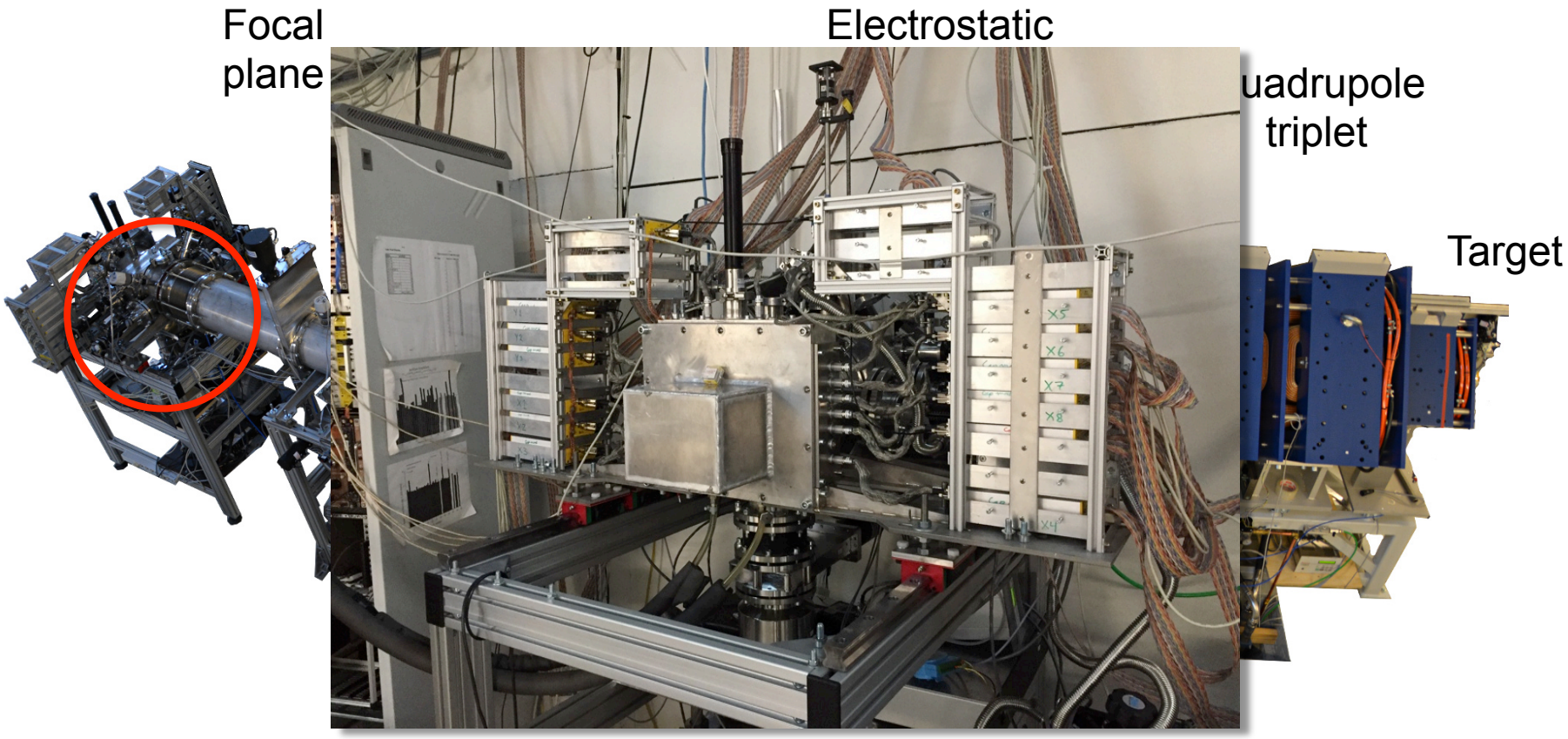
Mass Analyzing Recoil Apparatus
Massa Analysoiva Rekyyli Aparaatti

The MARA vacuum-mode recoil-mass separator



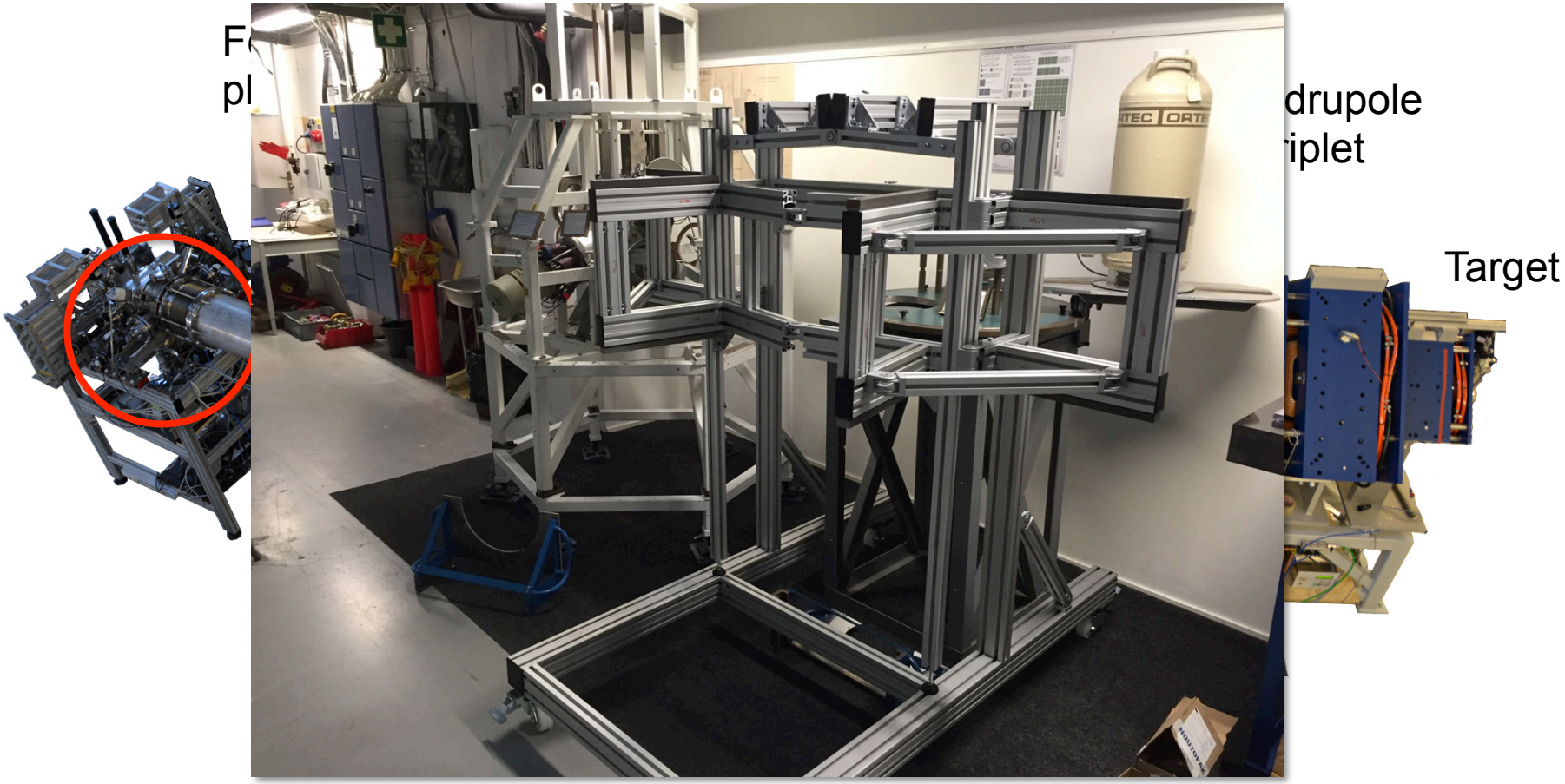
- 1st order mass resolving power: ~250
- Angular acceptance: 10msr

The MARA vacuum-mode recoil-mass separator



- DSSD (MICRON BB20)
- Punch-through detector
- Silicon box for escaped particles
- Germanium-detector array

The MARA vacuum-mode recoil-mass separator



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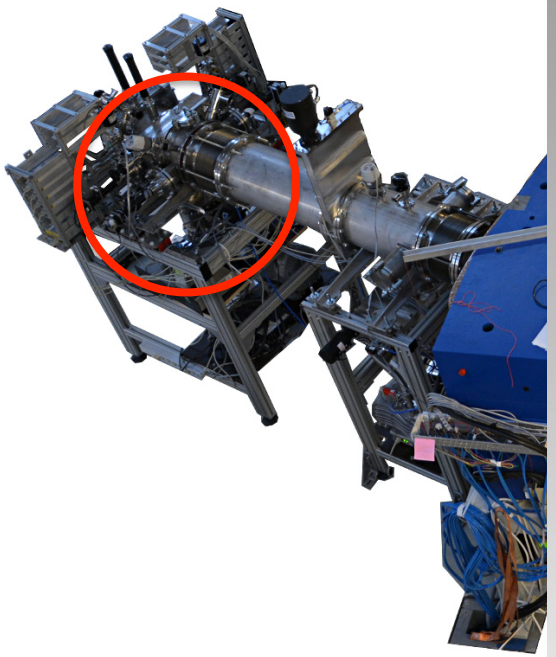
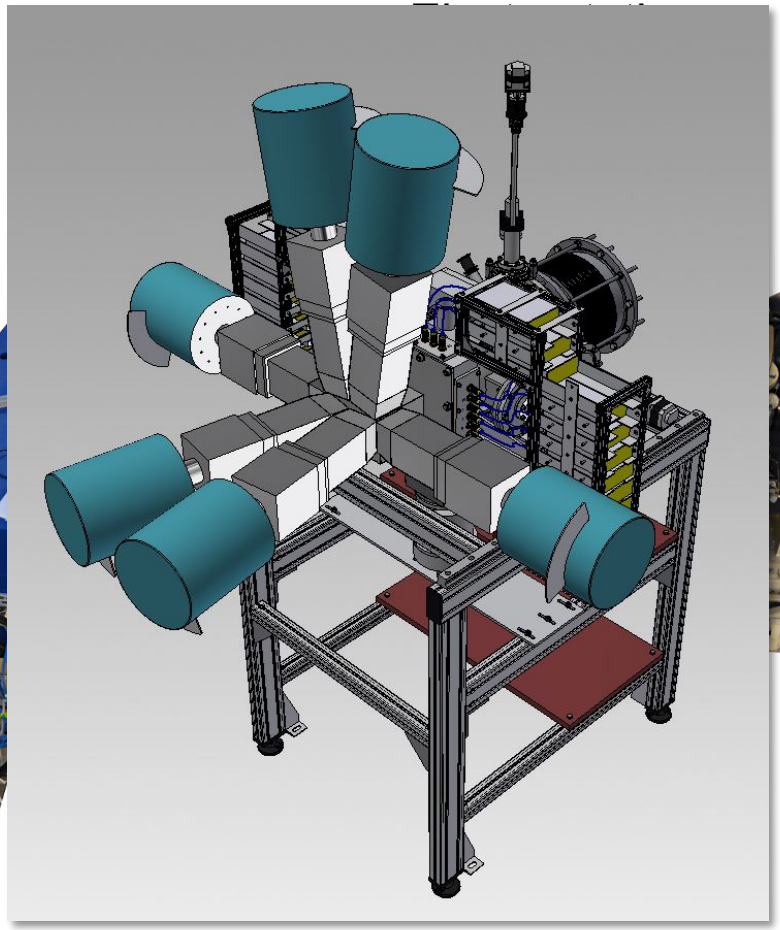
The MARA vacuum-mode recoil-mass separator

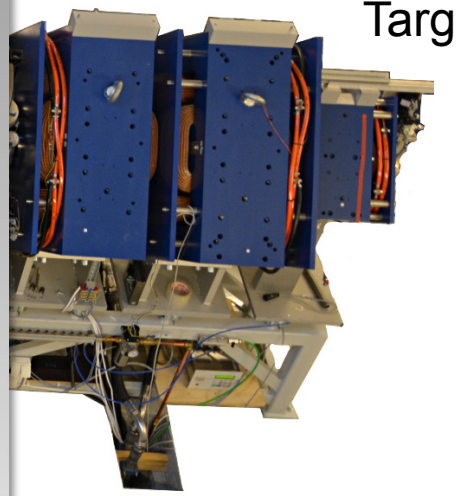
Focal plane





Quadrupole triplet

Target



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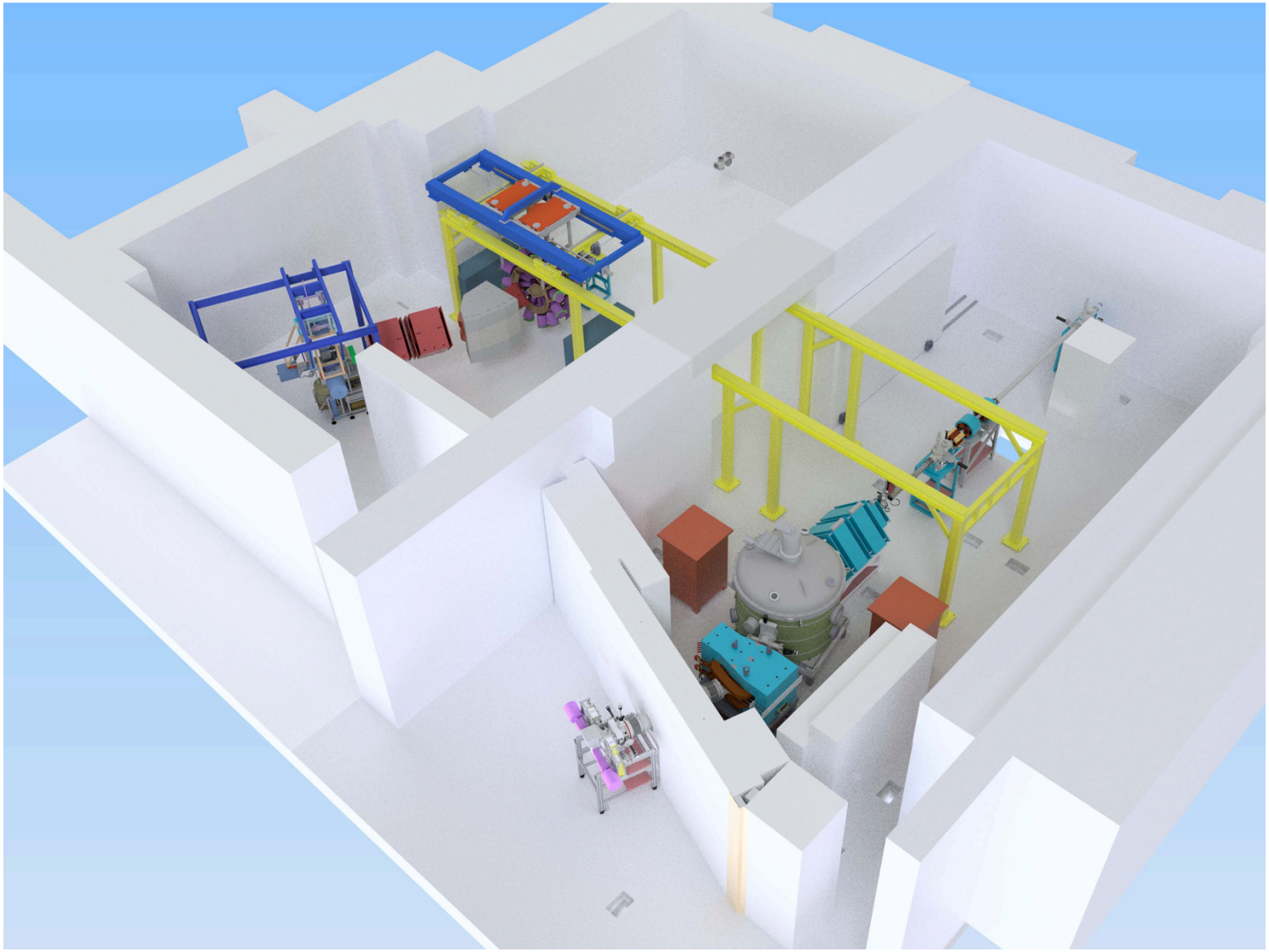
The MARA vacuum-mode recoil-mass separator

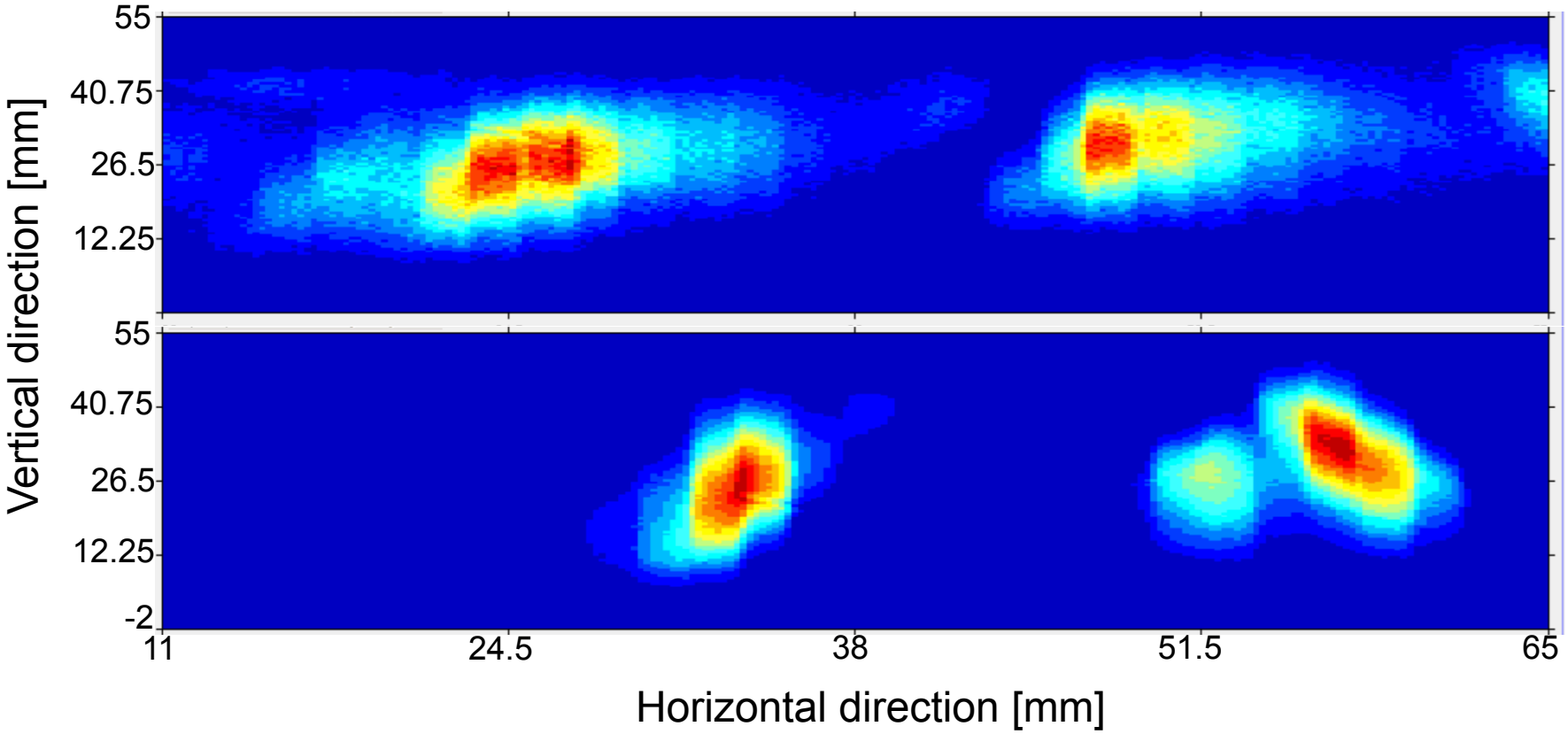


The MARA vacuum-mode recoil-mass separator

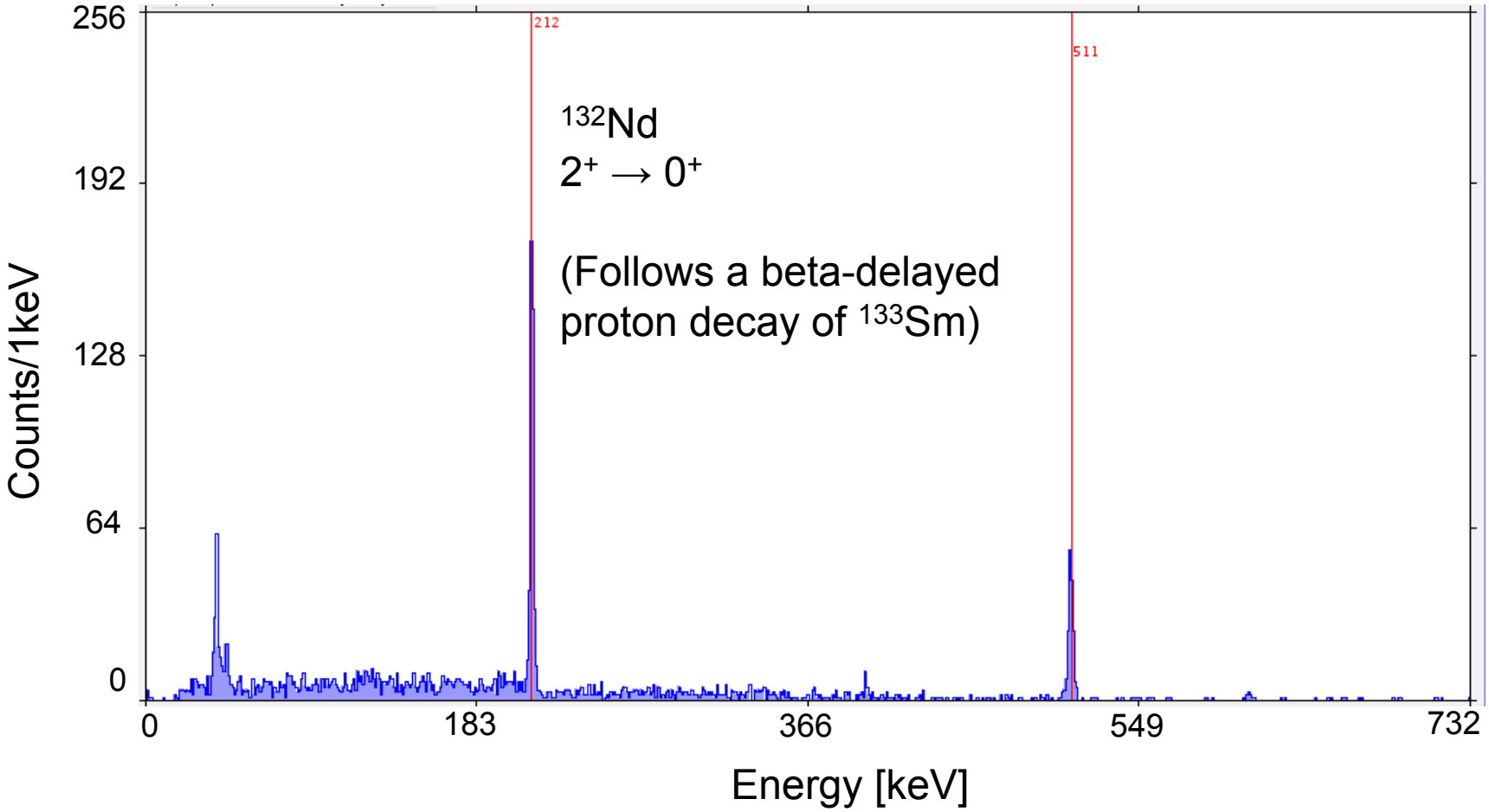
Commissioning runs (M01) this far

- Part 1: Slightly asymmetric
  - $^{78}Kr + {}^{98}Mo \rightarrow {}^{176}Pt^*$
- Part 2: Symmetric
  - $^{40}Ar + {}^{45}Sc \rightarrow {}^{85}Nb^*$
  - $^{40}Ar + {}^{nat}Ca \rightarrow {\sim}^{80}sr^*$
- Part 3: Inverse kinematics
  - $^{78}Kr + {}^{58}Ni \rightarrow {}^{136}Gd^*$
  - 2 BGO crystals around the target for normalization,
  - 2 Clover germanium detectors at the focal plane,
  - Punch through detector behind the DSSD
- Part 4: Asymmetric
  - $^{40}Ar + {}^{124}Sn \rightarrow {}^{164}Er^*$
  - 2 single crystal germanium detectors around the target,
  - Punch through detector behind the DSSD

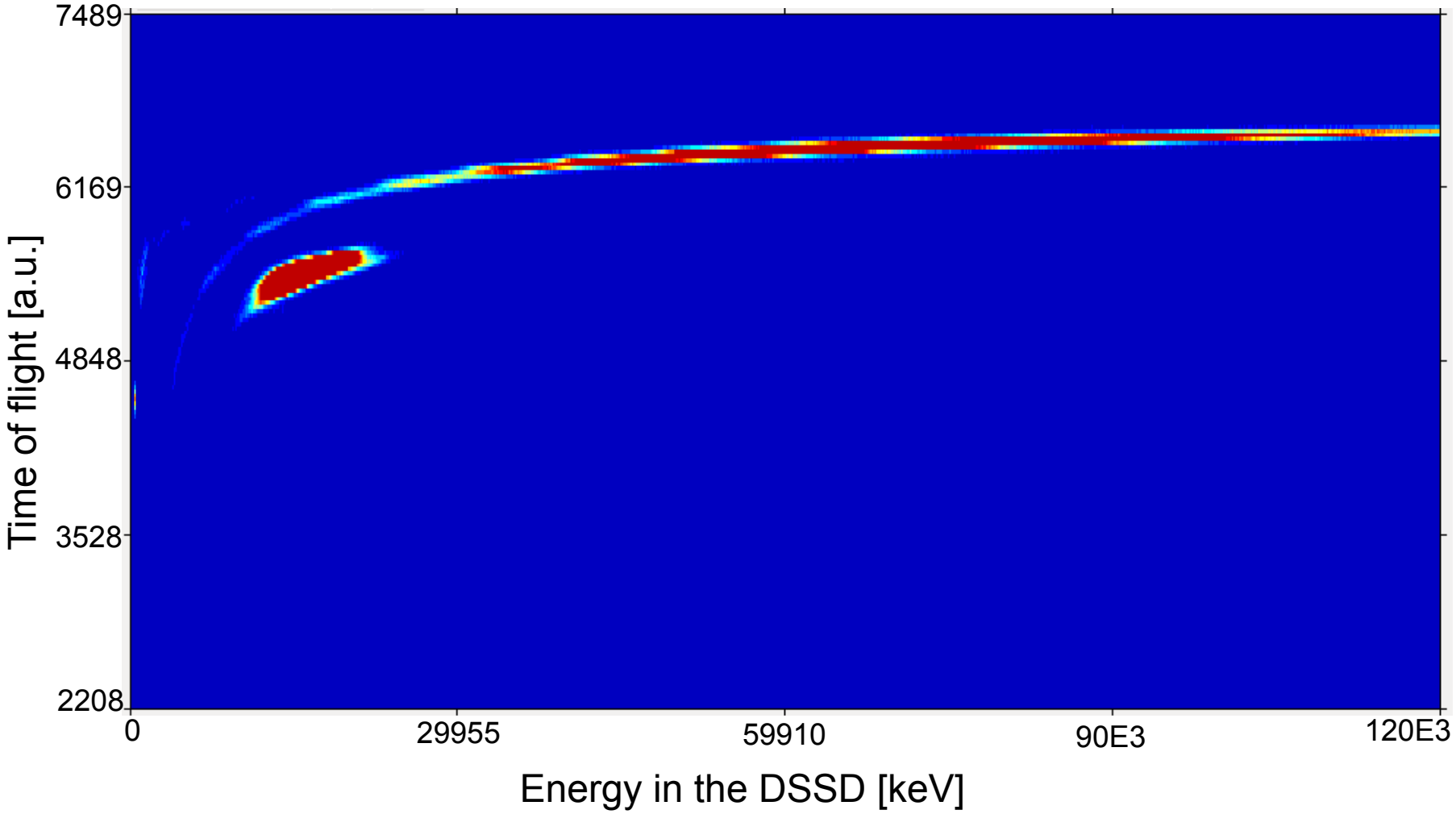
Part 3: $^{78}Kr + ^{58}Ni \rightarrow ^{136}Gd^*$



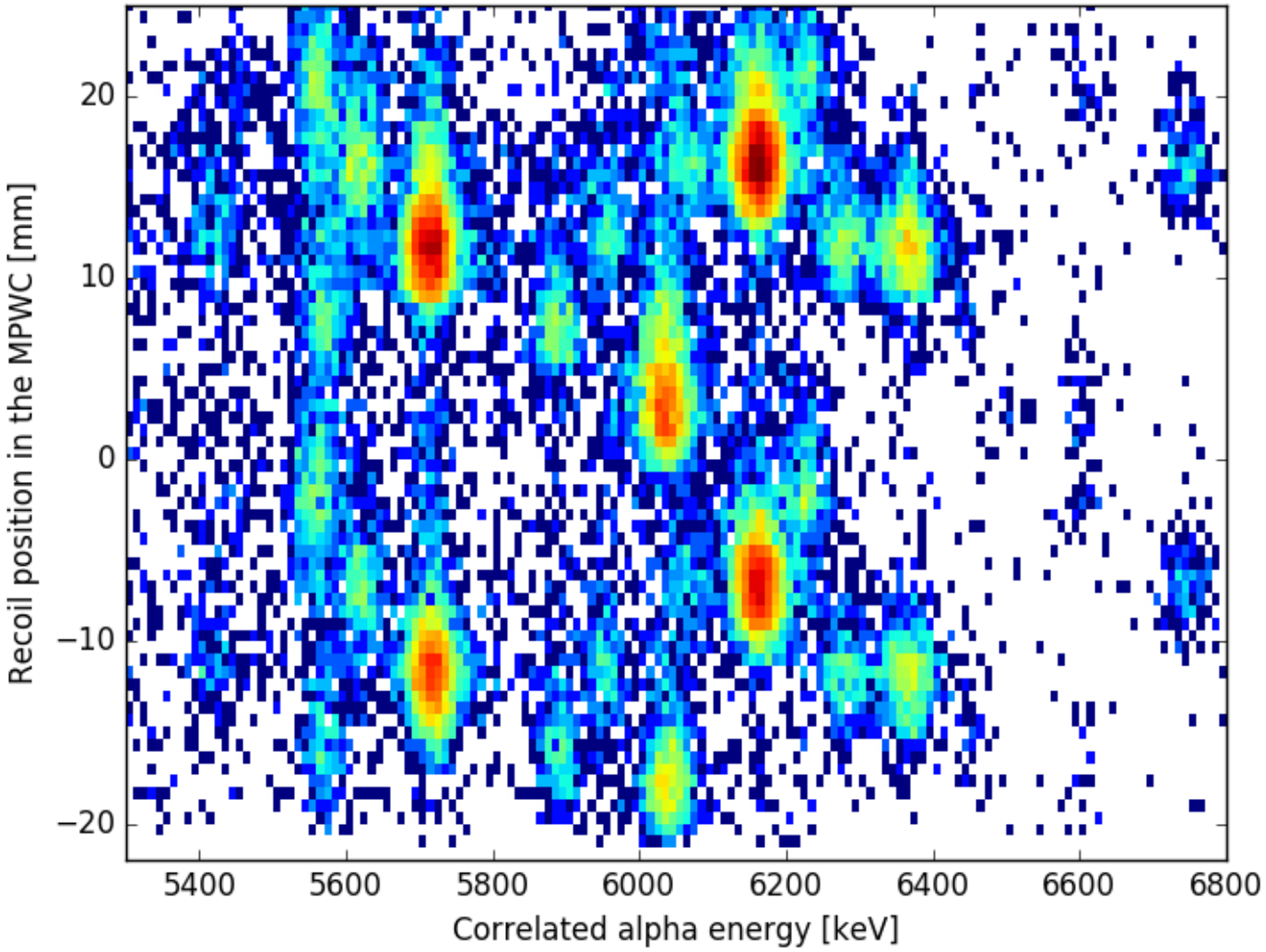
Part 3: $^{78}Kr + ^{58}Ni \rightarrow ^{136}Gd^*$



Part 4: $^{40}Ar + ^{124}Sn \rightarrow ^{164}Er^*$



1st experiment: $^{78}Kr + ^{96}Ru \rightarrow ^{174}Hg^{*} \rightarrow ^{169}Au$



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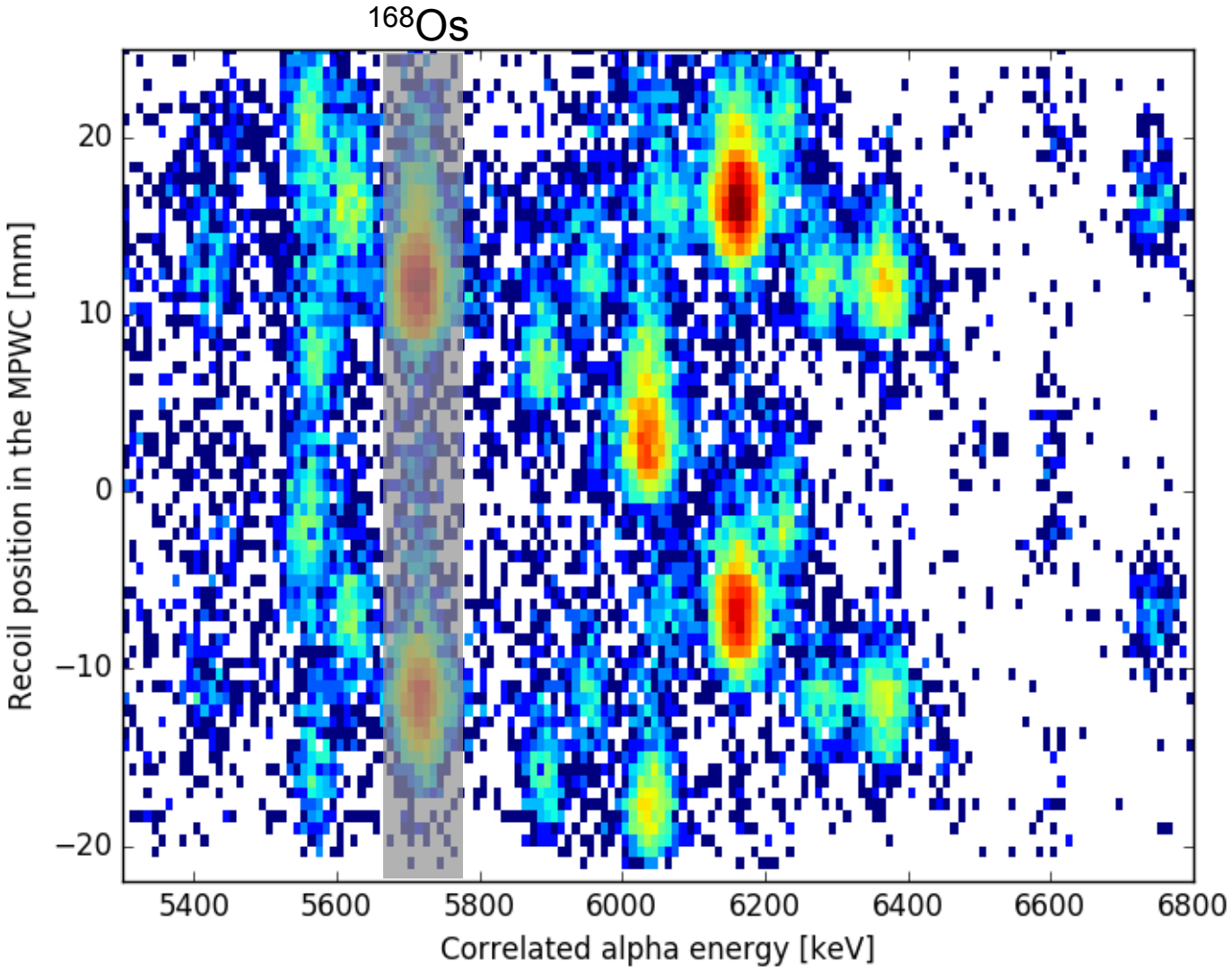

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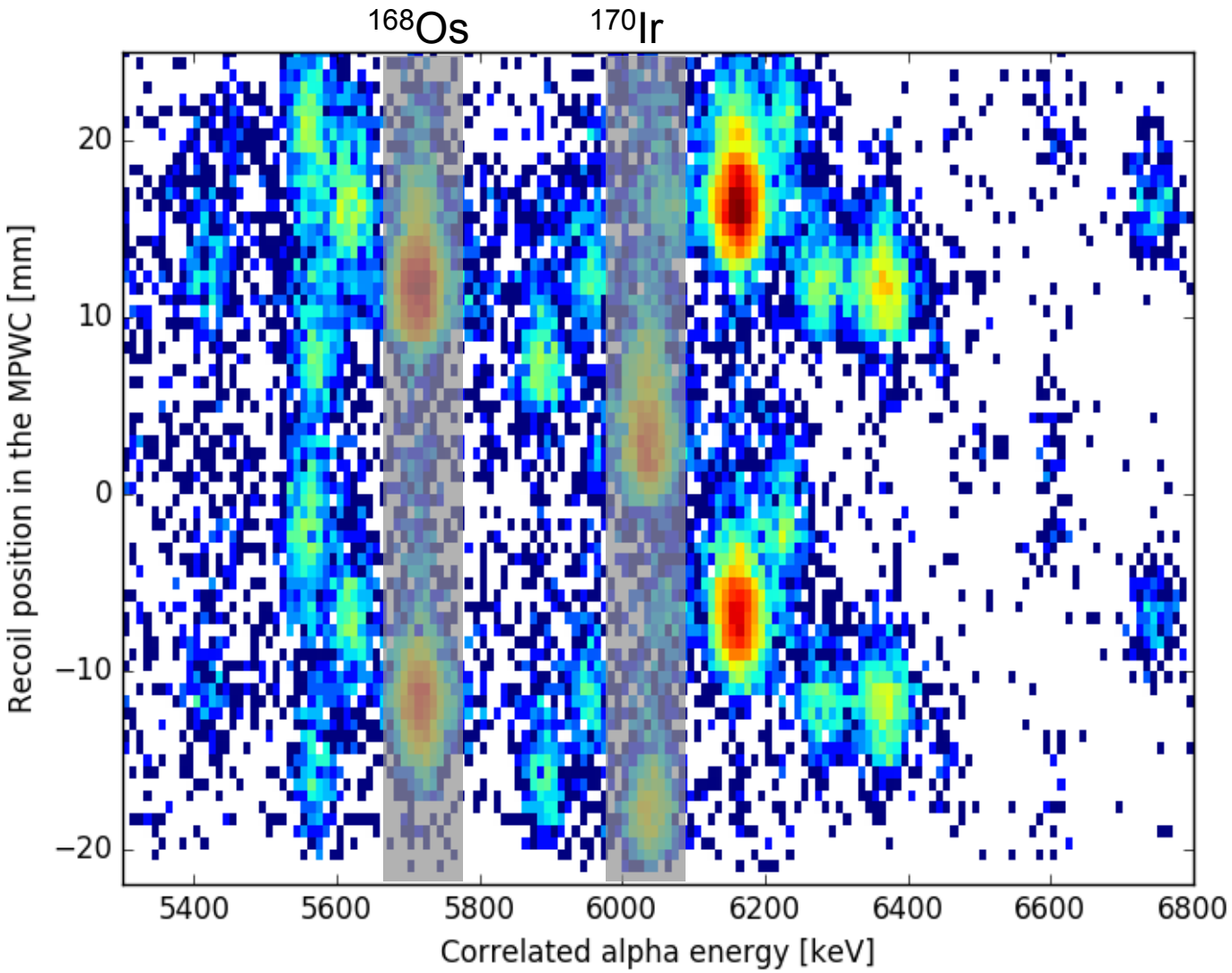

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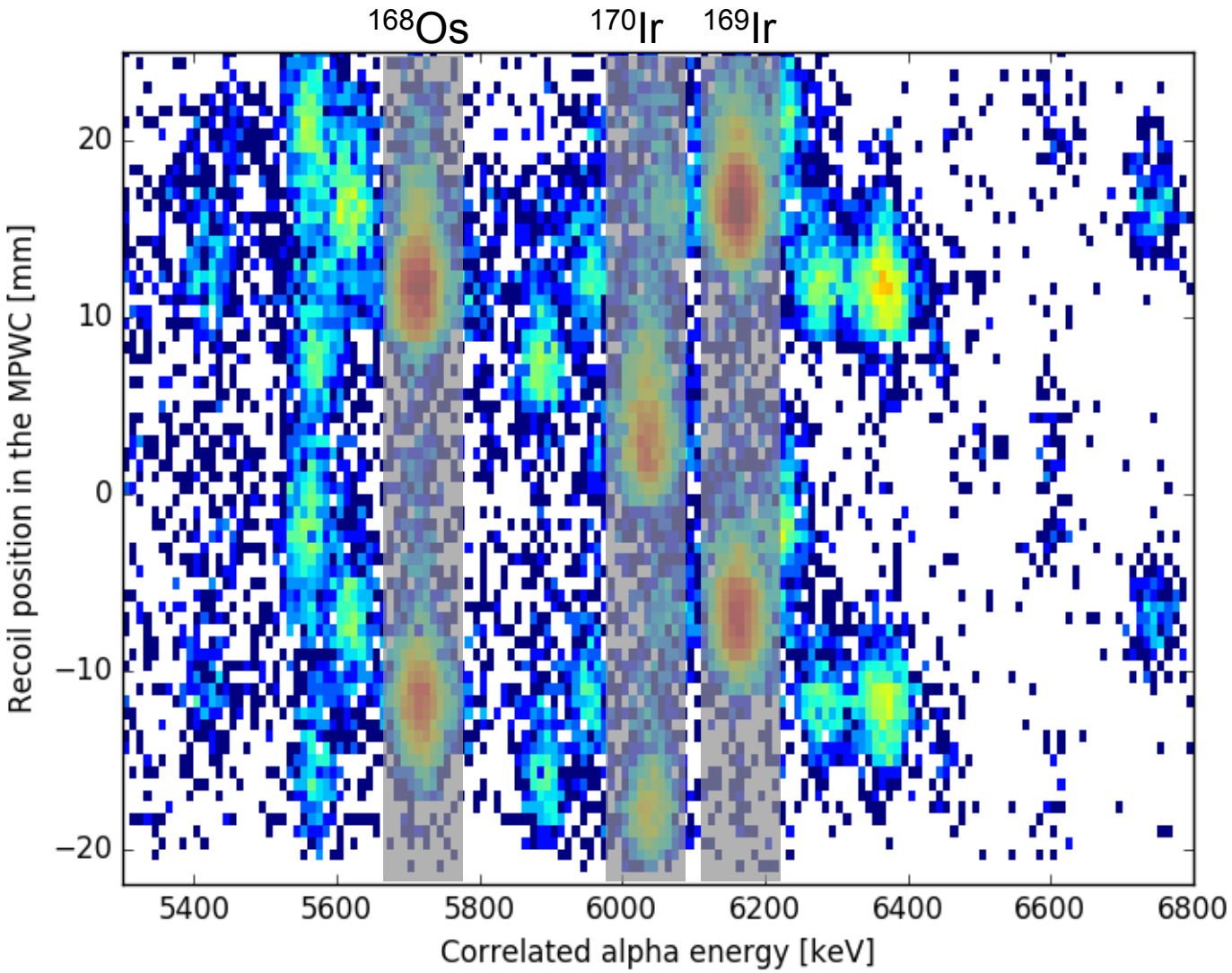

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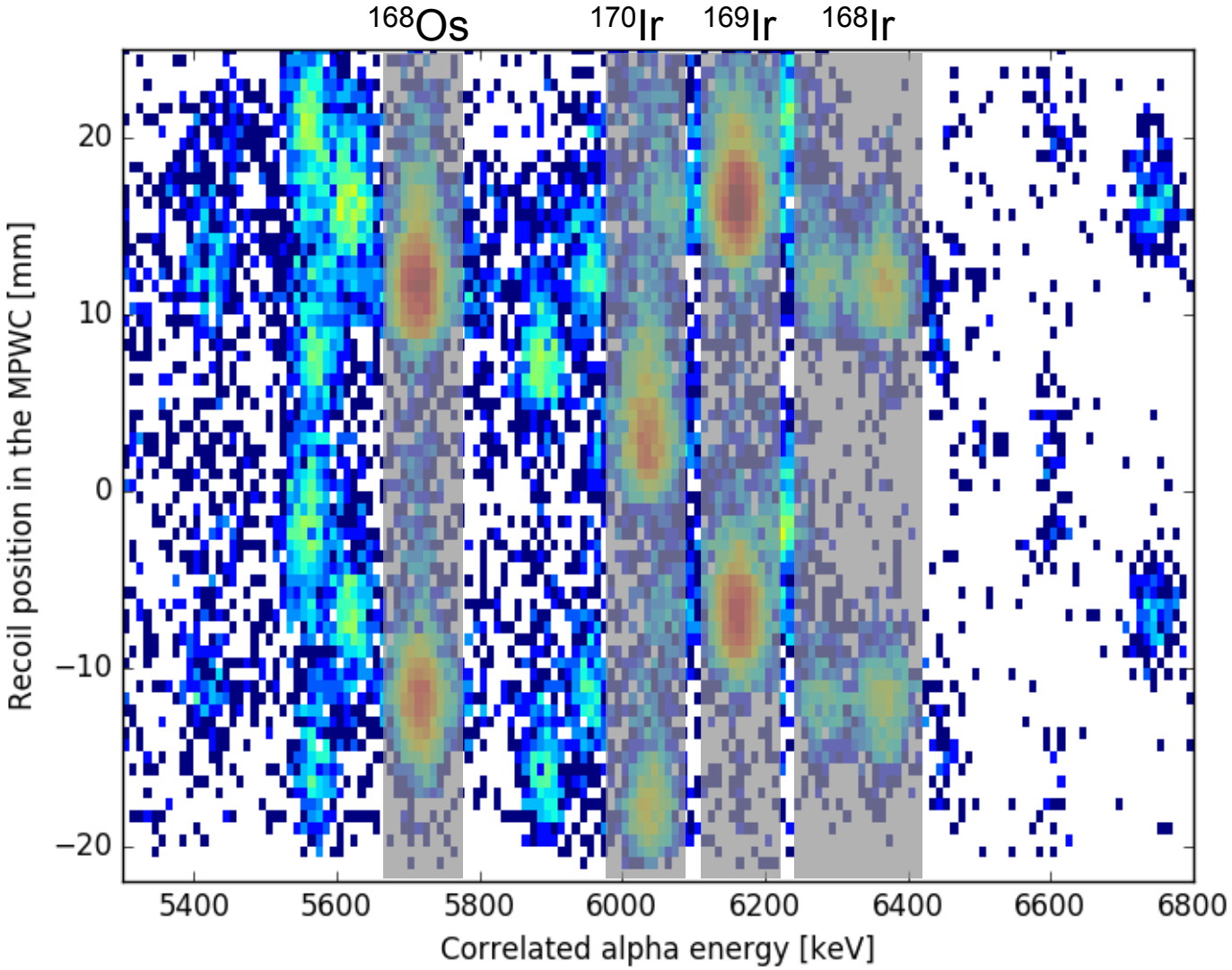

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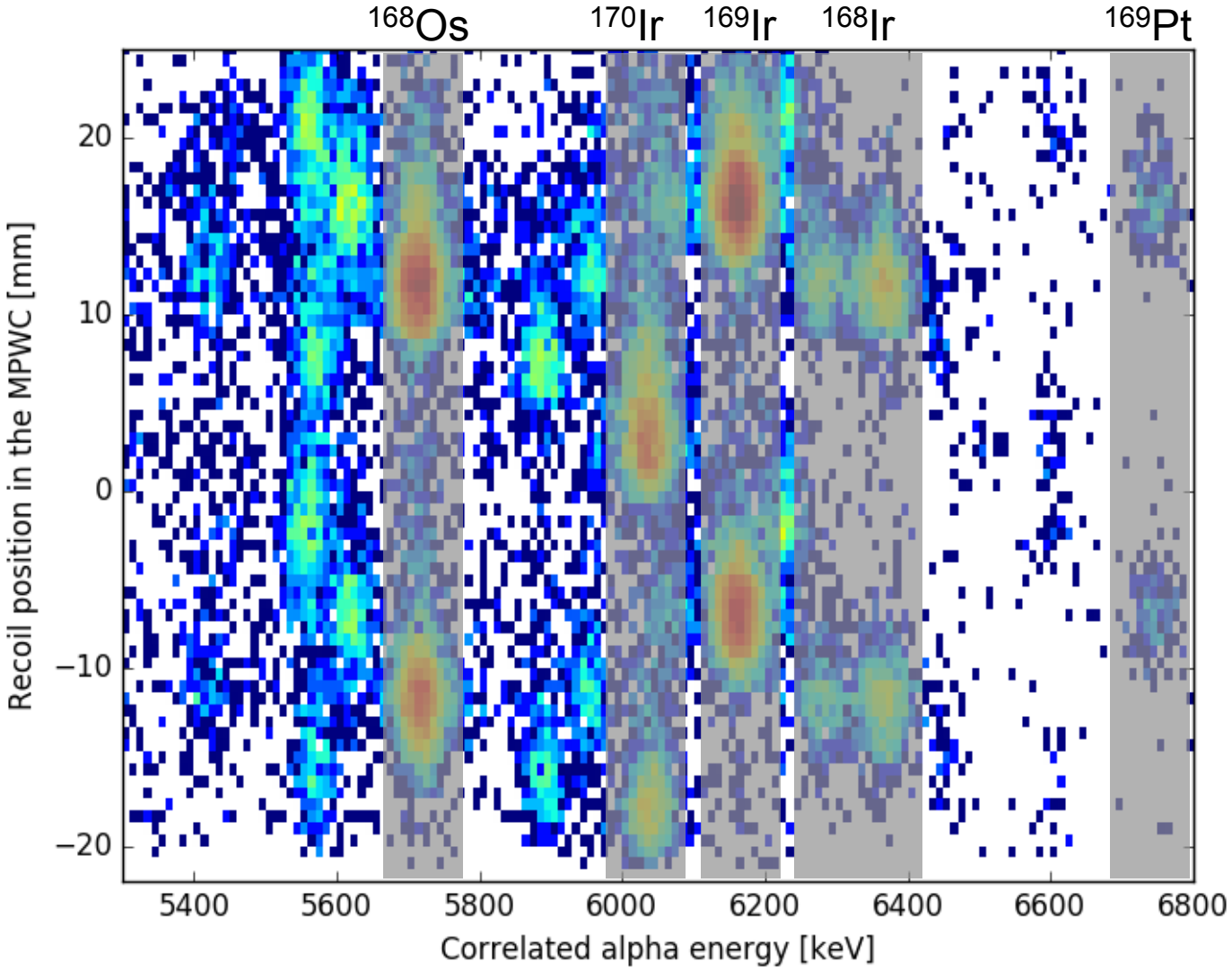
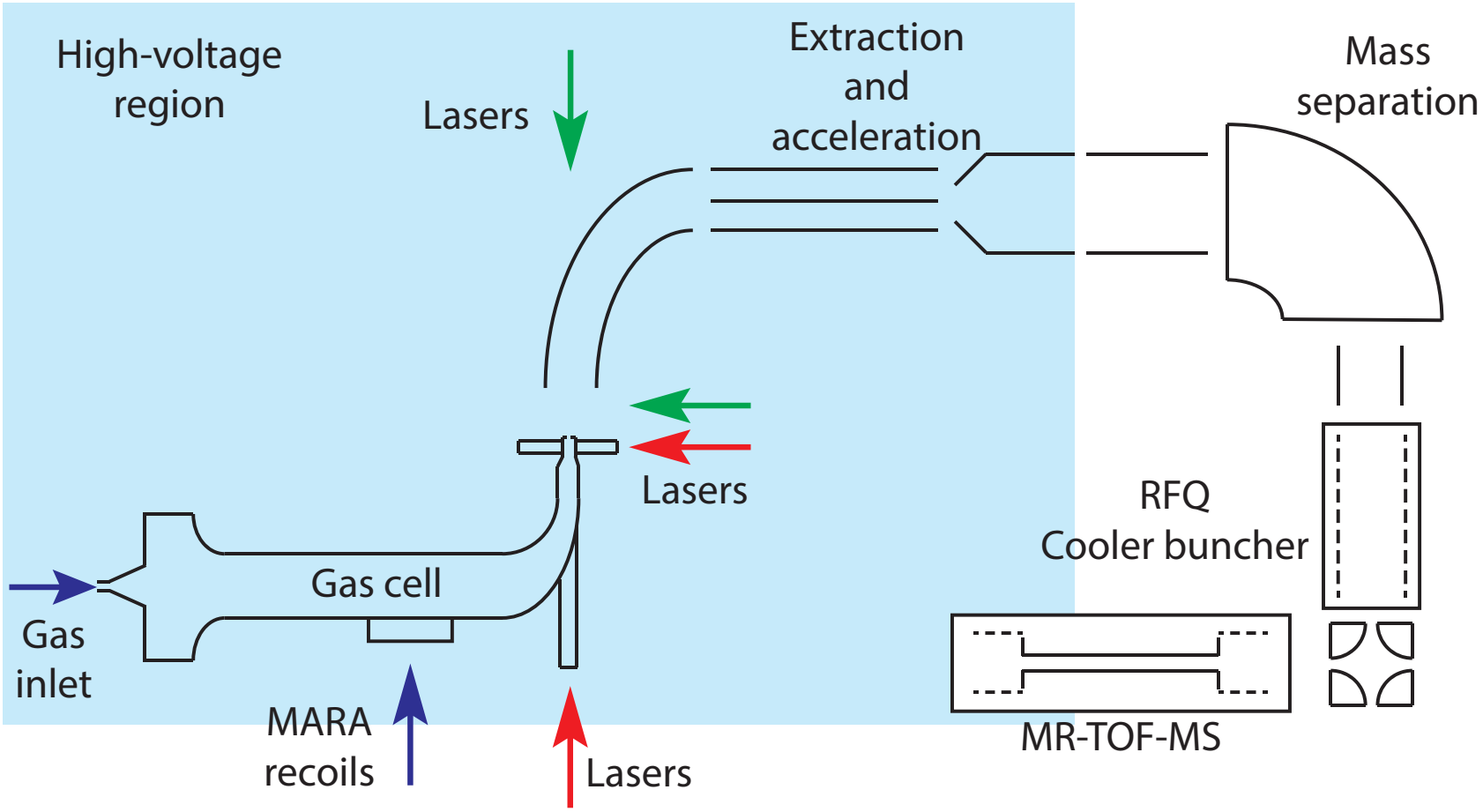


The MARA Low-Energy Branch

The concept of MARA-LEB

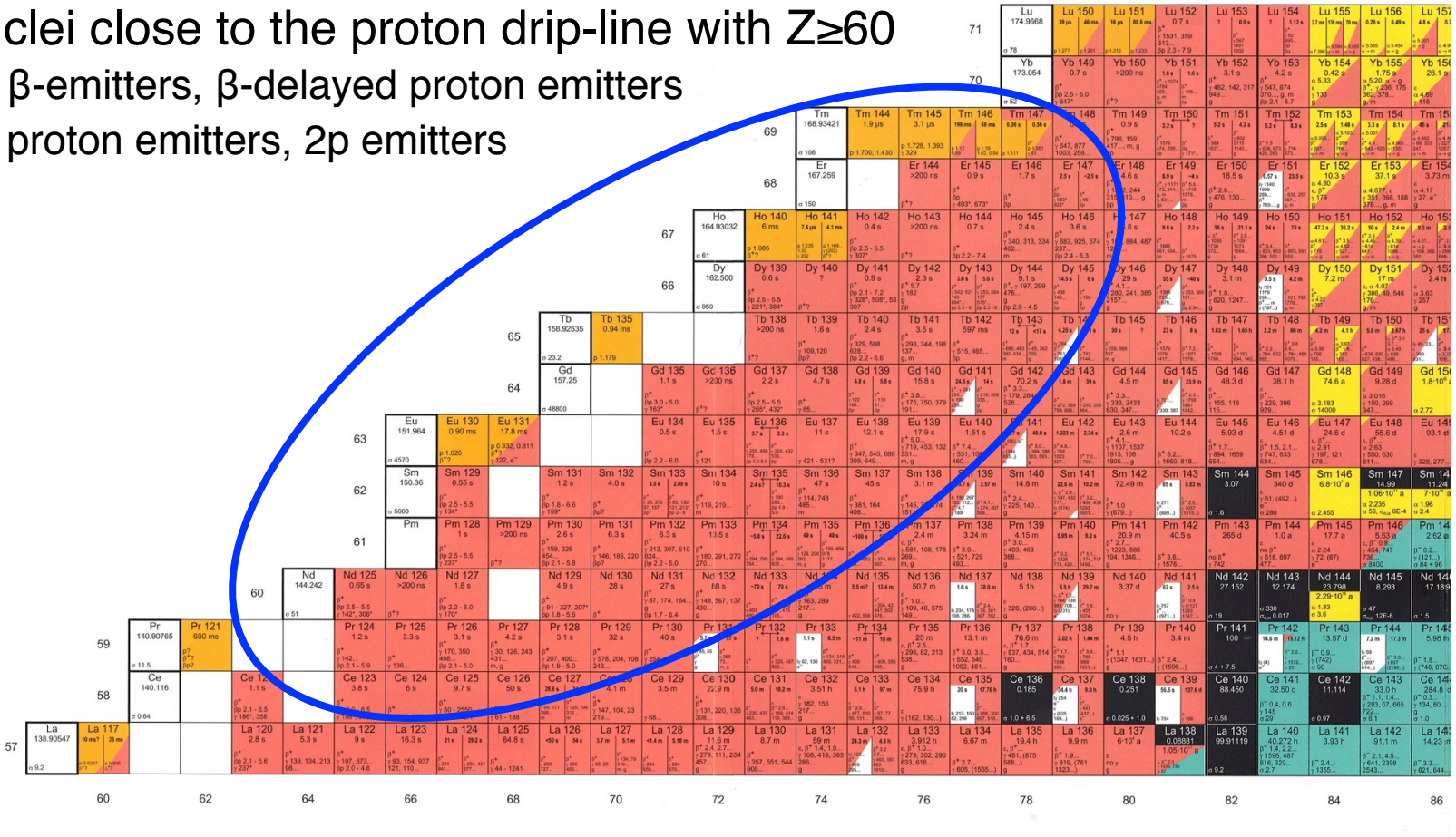


P. Papadakis *et al.*, Hyperfine Interact. DOI: 10.1007/s10751-016-1364-8

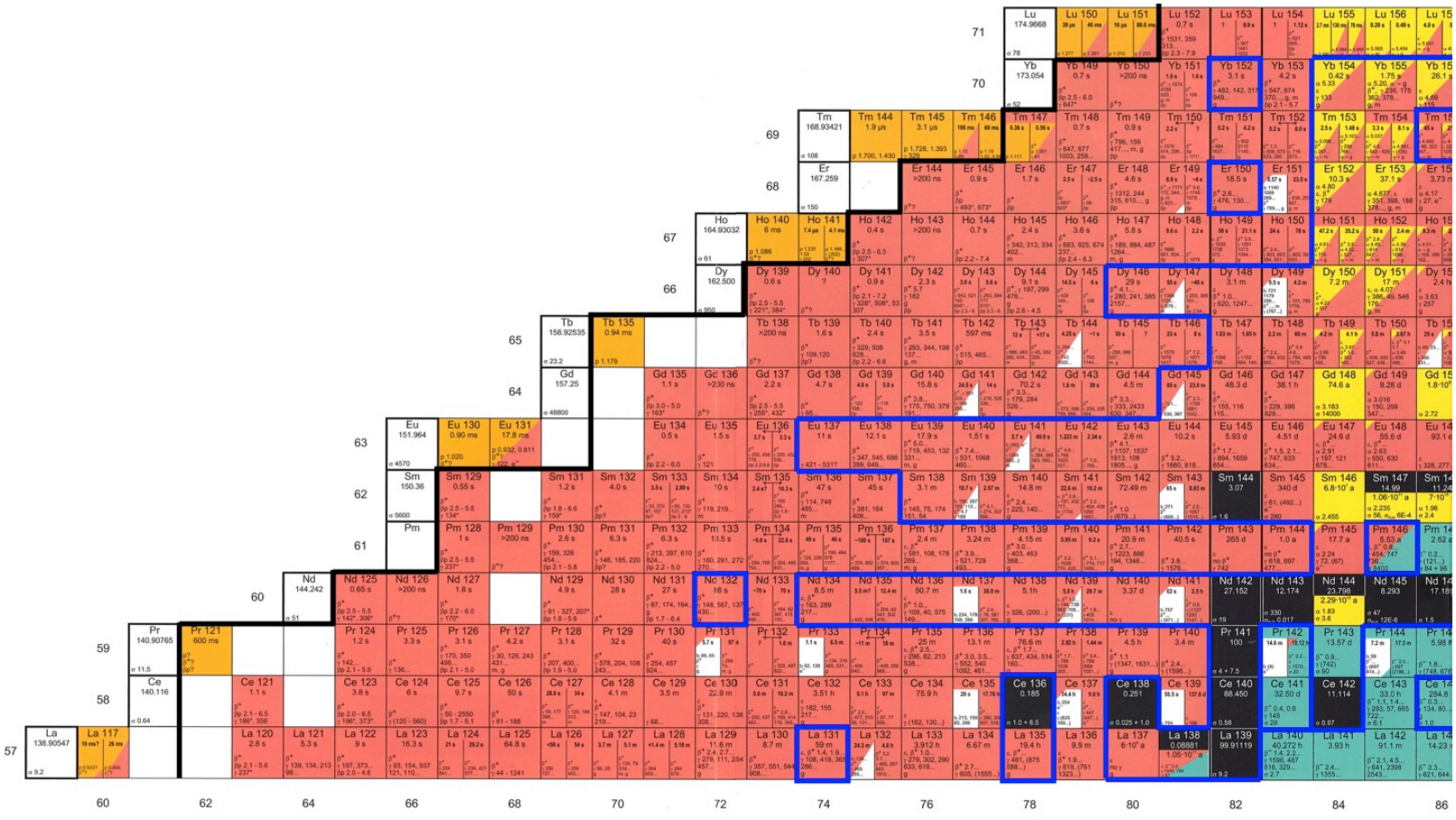
Motivation – A few examples

Nuclei close to the proton drip-line with Z≥60

- β-emitters, β-delayed proton emitters
- proton emitters, 2p emitters



Motivation – A few examples

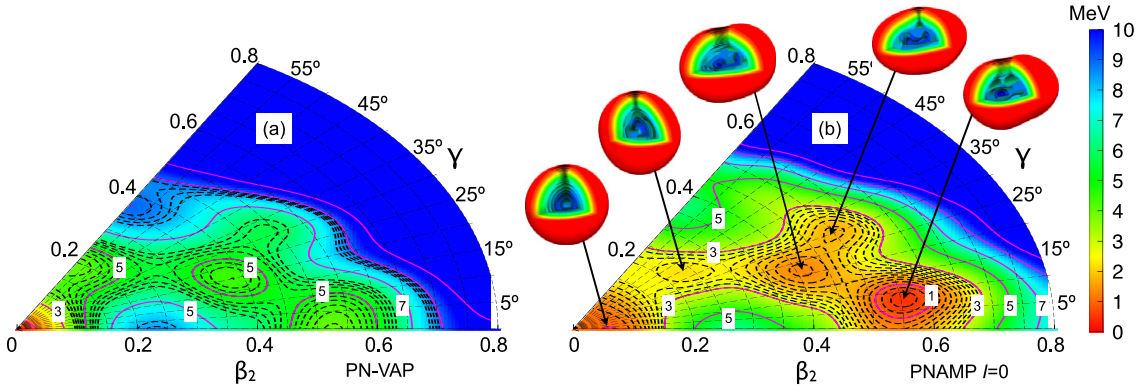


Data from :P. Campbell, I.D. Moore and M.R. Pearson, Progress in PPNP **86**, 127 (2016)

Motivation – A few examples

^{80}Zr

- Highly deformed
- Theoretical predictions indicate coexistence of 5 shapes
- Waiting point of astrophysical rp-process



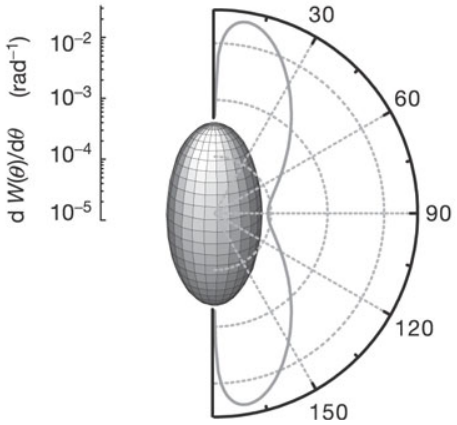
PN-VAP: Particle number symmetry restored
PNAMP: Rotational symmetry also restored

T. Rodriguez and J. Luis Egido, Phys. Lett. B **705**, 255 (2011)

Motivation – A few examples

^{94}Ag 21^{+} Isomer

- I. Mukha *et al.*, Nature **439** (2006) 298
  - 1st nucleus to exhibit 1p and 2p radioactivity
  - Very large prolate deformation



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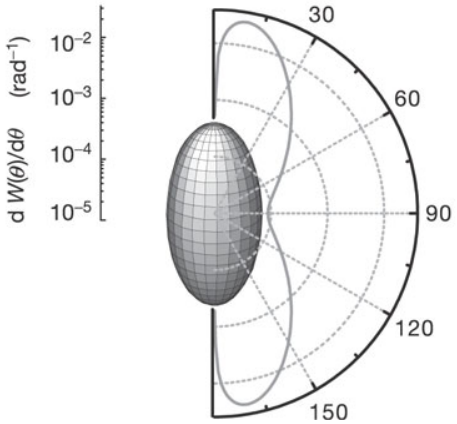


- O. L. Pechenaya *et al.*, Phys. Rev. C **76** (2007) 011304(R)
  - No indication of 2p decay to ^{92}Rh
- J. Cerny *et al.*, Phys. Rev. Lett. **103** (2009) 152502
  - Confirmation of 1, 1p decay branch
  - No sign of the 2p decay
- A. Kankainen *et al.*, Phys. Rev. Lett. **101** (2008) 142503
  - Measurement of ^{92}Rh, ^{94}Pd mass with JYFLTRAP at IGISOL
  - Contradicting masses for ^{94}Ag 21^{+} isomer

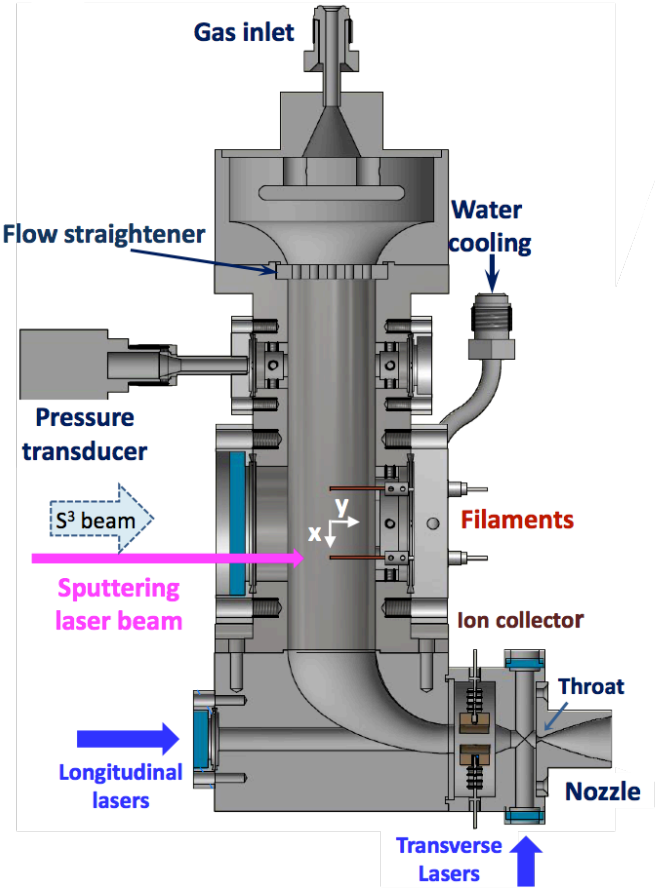
Motivation – A few examples

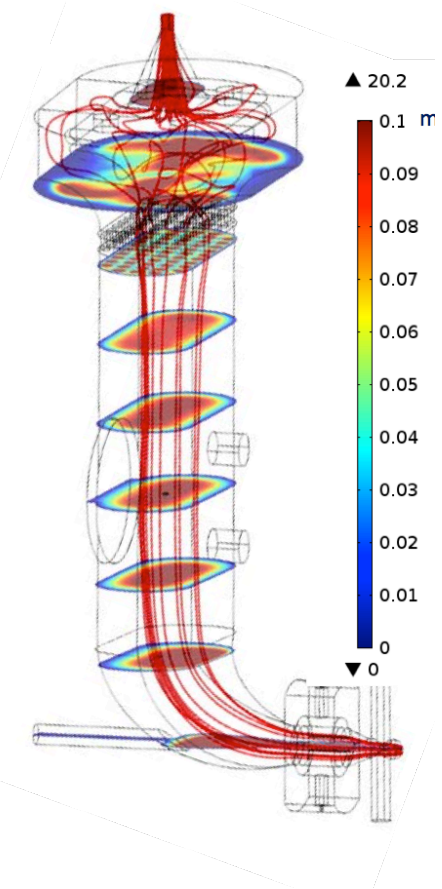
Medical applications

- Development of laser ionisation schemes
- Comparison of ionisation efficiencies

The gas cell

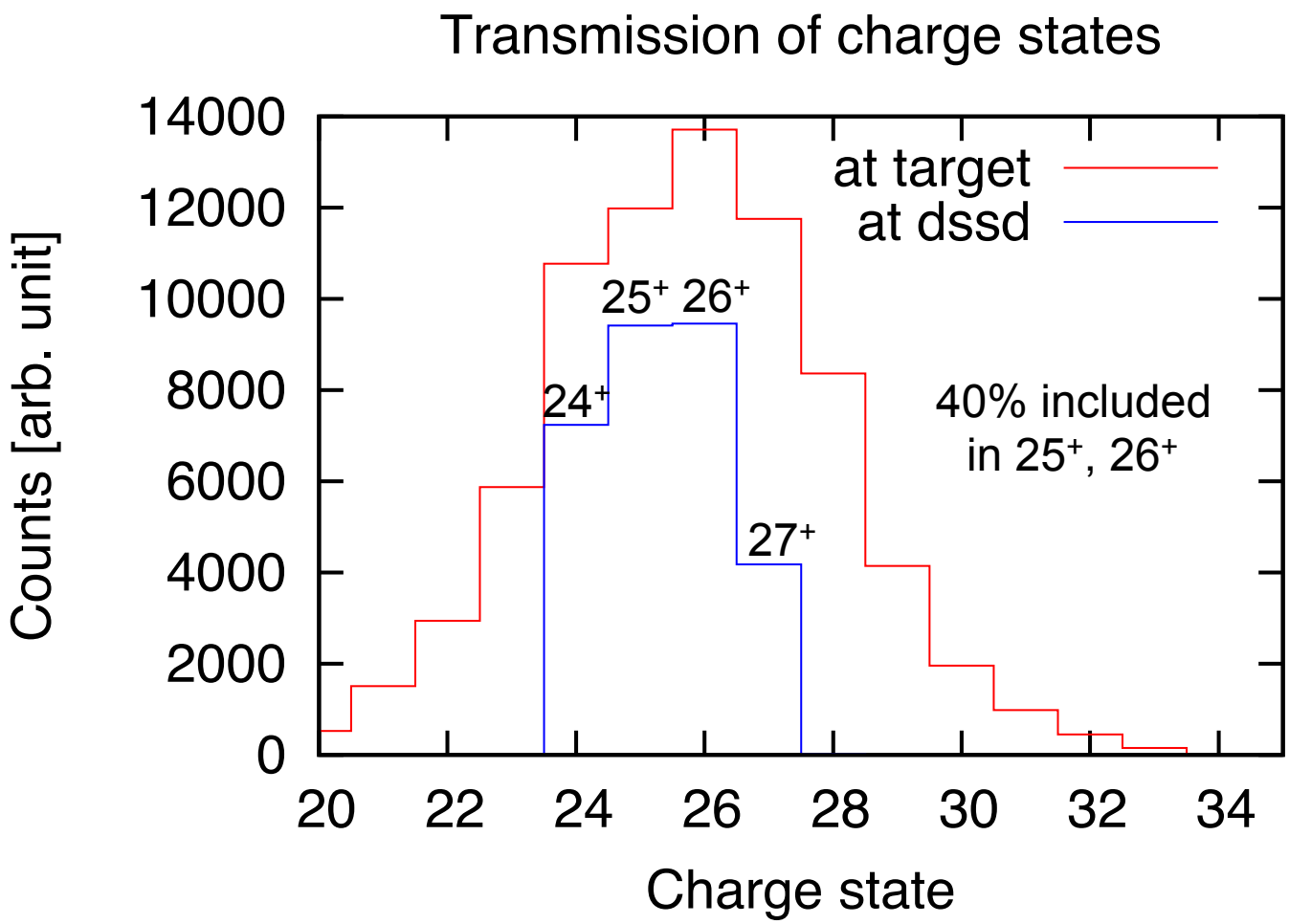
Designed by KU Leuven to be used for the rare element in-gas laser ion source (REGLIS) at S^3, GANIL.





Yu. Kudryavtsev *et al.*, Nucl. Instr. and Meth. B **376**, 345 (2016)

Recoil distributions at the focal plane



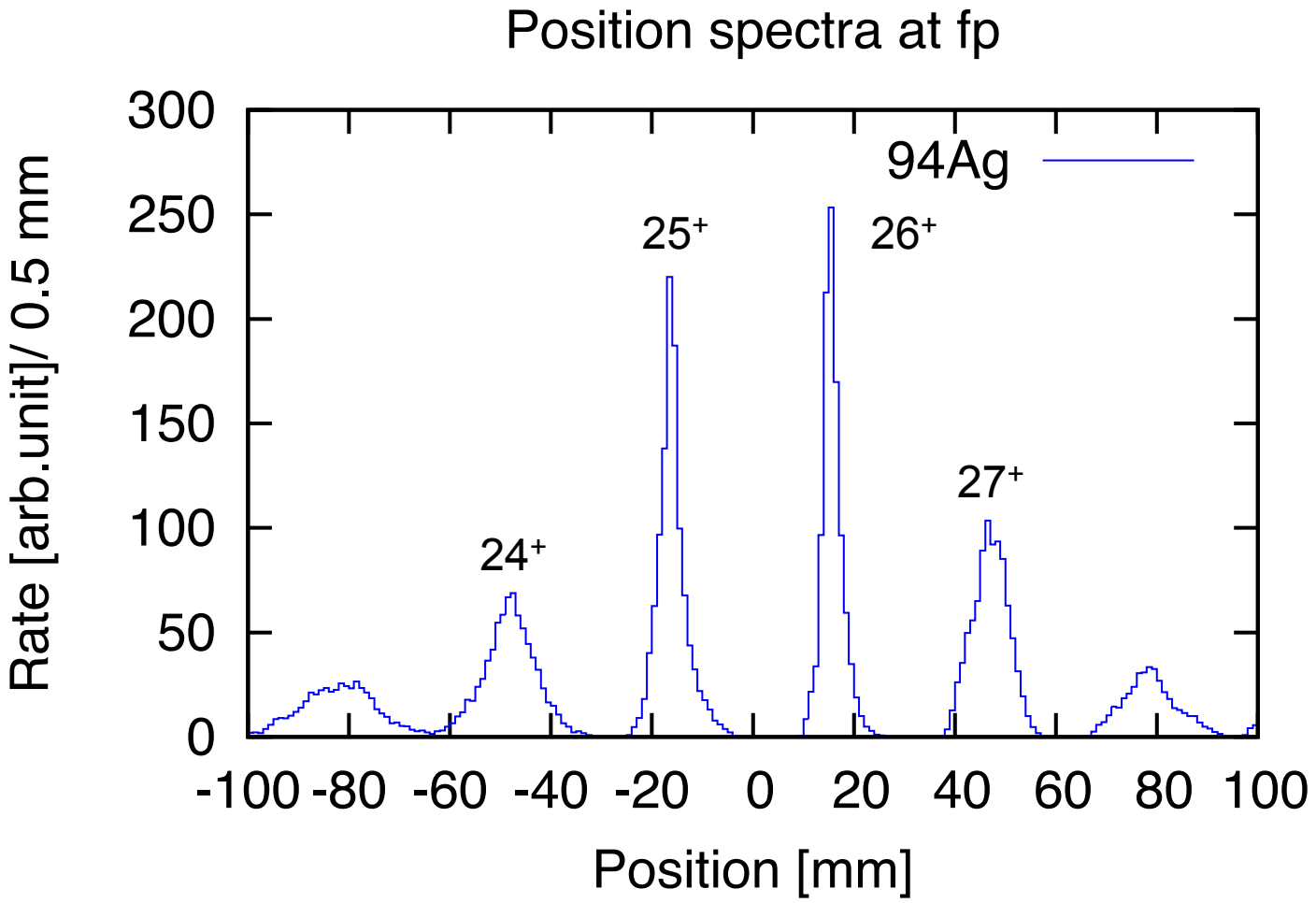
^{58}Ni(^{40}Ca,p3n)^{94}Ag @ 192MeV

Calculations by J. Sarén

Production of ^{94}Ag

- ^{58}Ni(^{40}Ca,p3n)^{94}Ag, 200pnA, 240MeV, 500µg/cm^2
- ^{94}Ag cross section ~500nbarn
- MARA transmission efficiency for the 2 most abundant charge states in inverse kinematics: ε=0.4x0.8
- ^{94}Ag at the MARA focal plane: ~1.5 ions/s
- Efficiency for resonance ionisation spectroscopy: ~12%
  - 50% thermalisation, transport efficiency, 50% neutralisation, 50% in-gas-jet laser ionisation
  - Yield of ^{94}Ag: ~0.2 ions/s
- Efficiency to the MR-TOF-MS: ~27%
  - 50% thermalisation, transport efficiency, 90% to the cooler and buncher, 60% efficiency through the buncher
  - Yield of ^{94}Ag: ~0.4 ions/s

Recoil distributions at the focal plane



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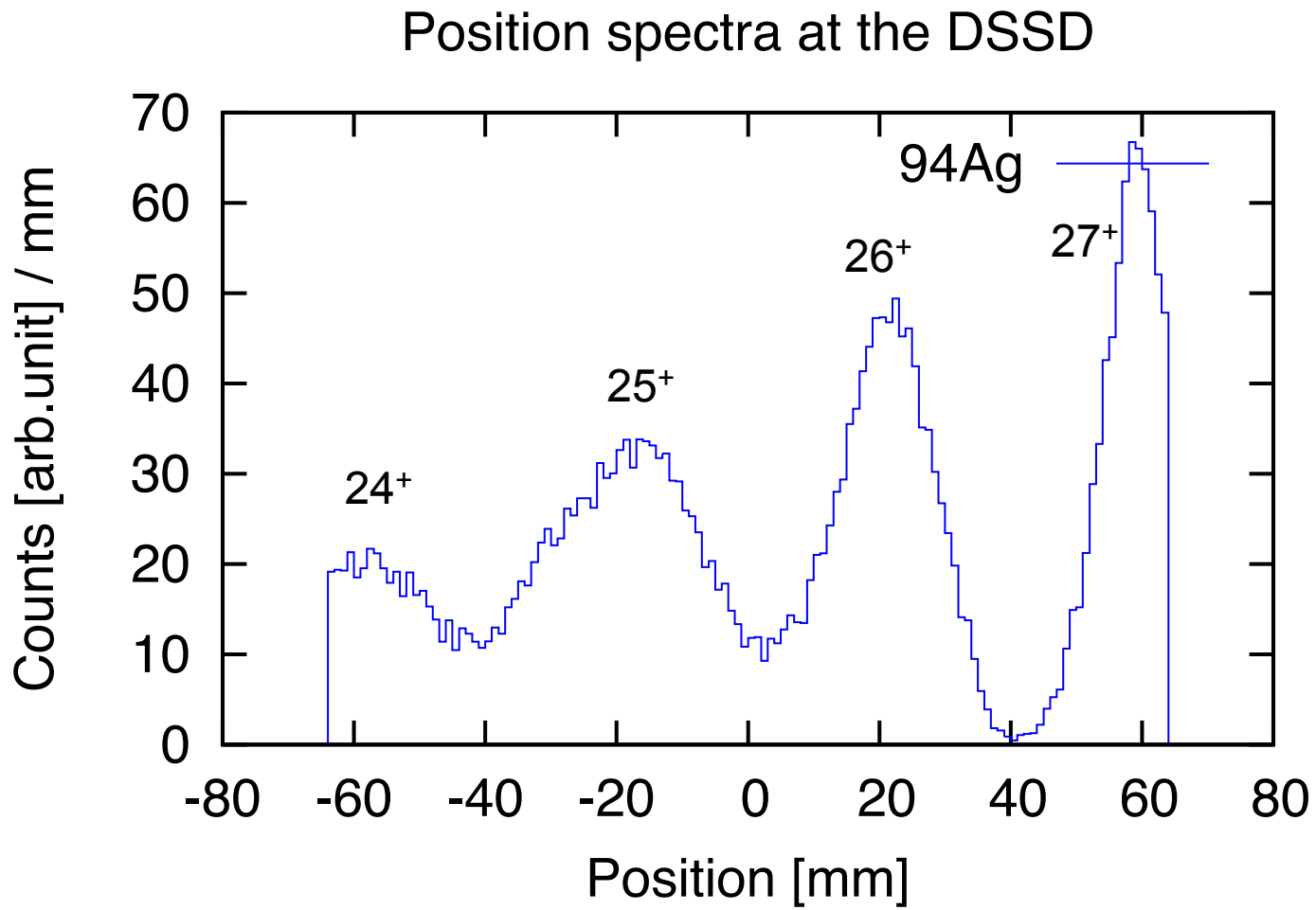

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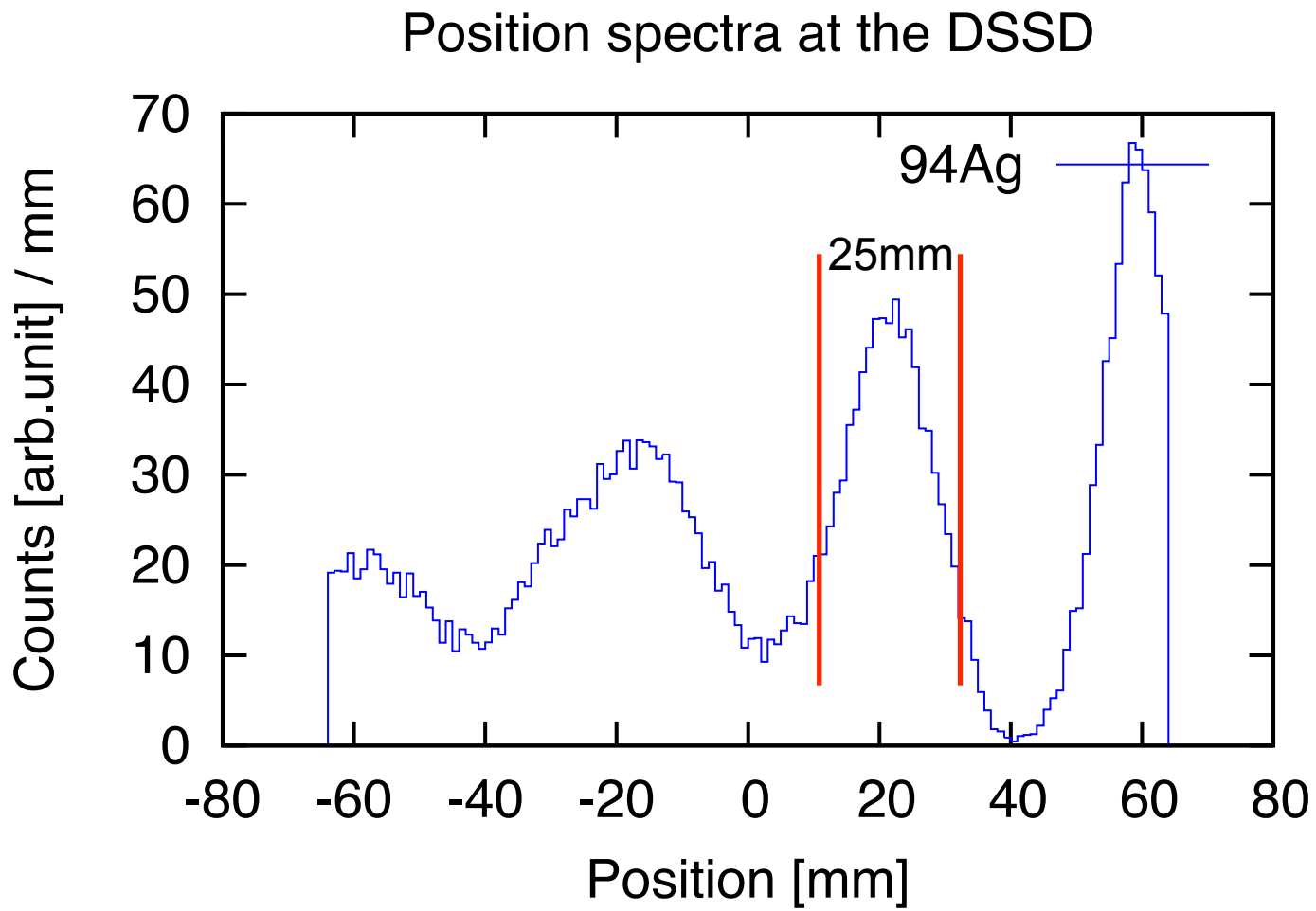

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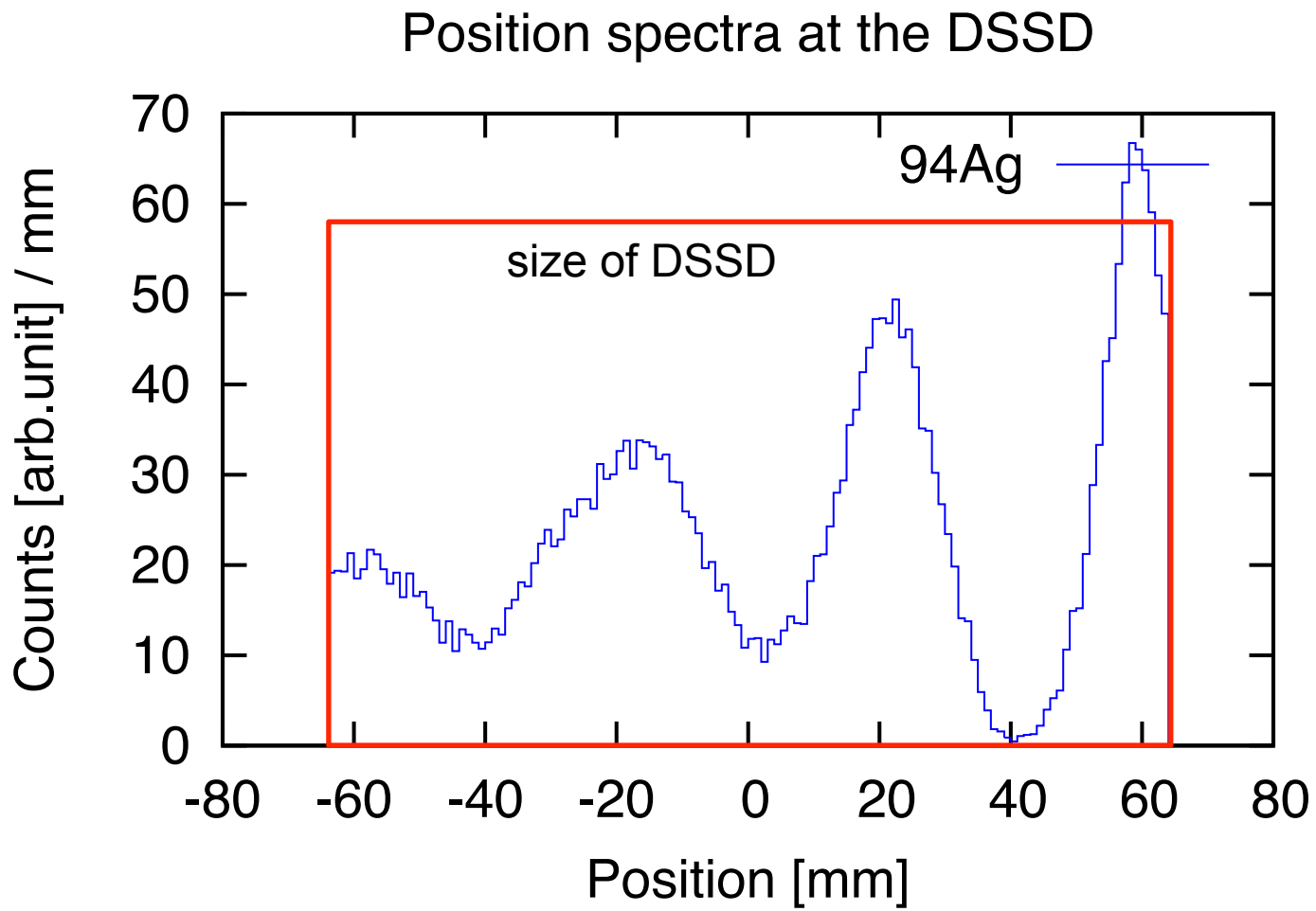

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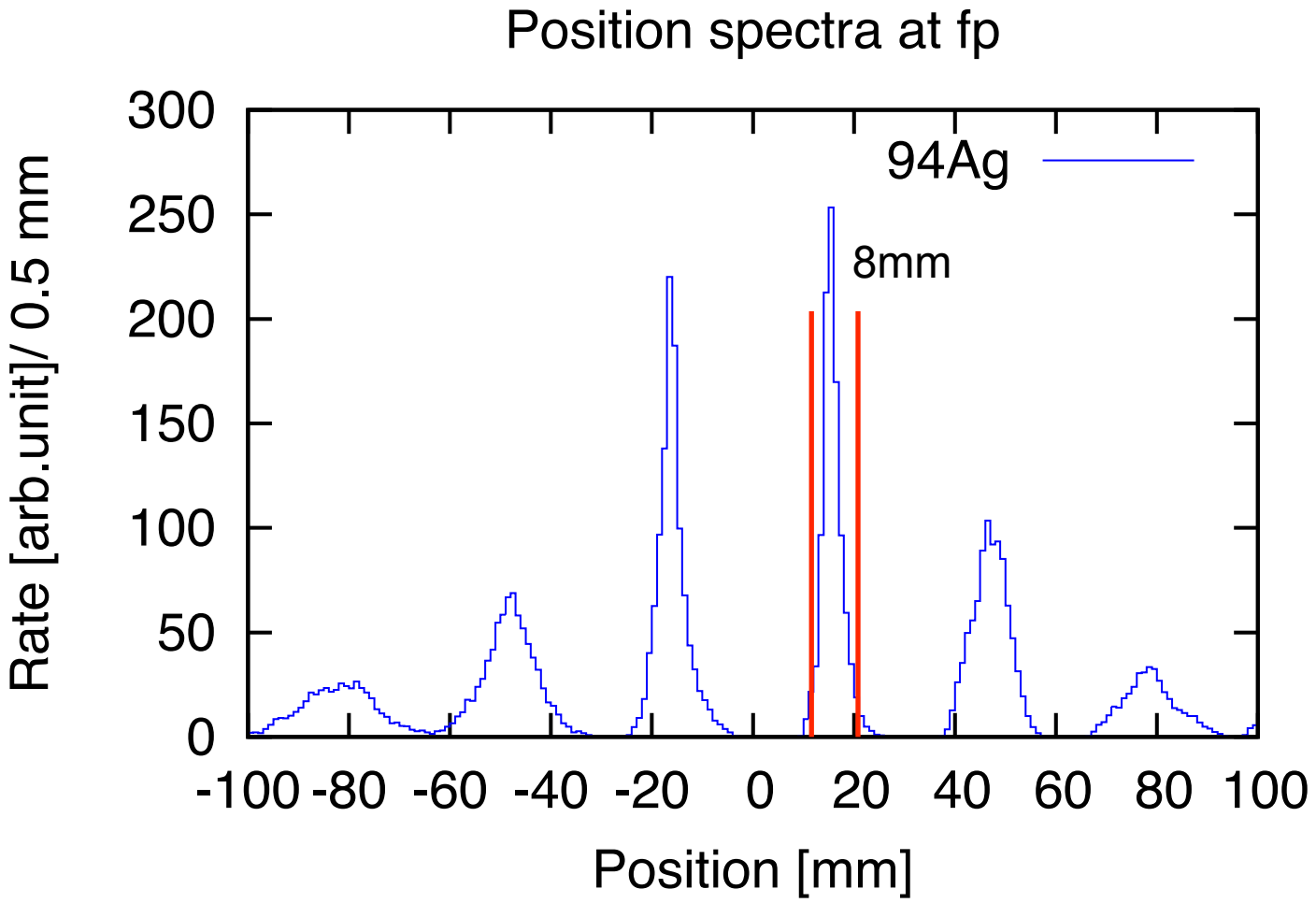

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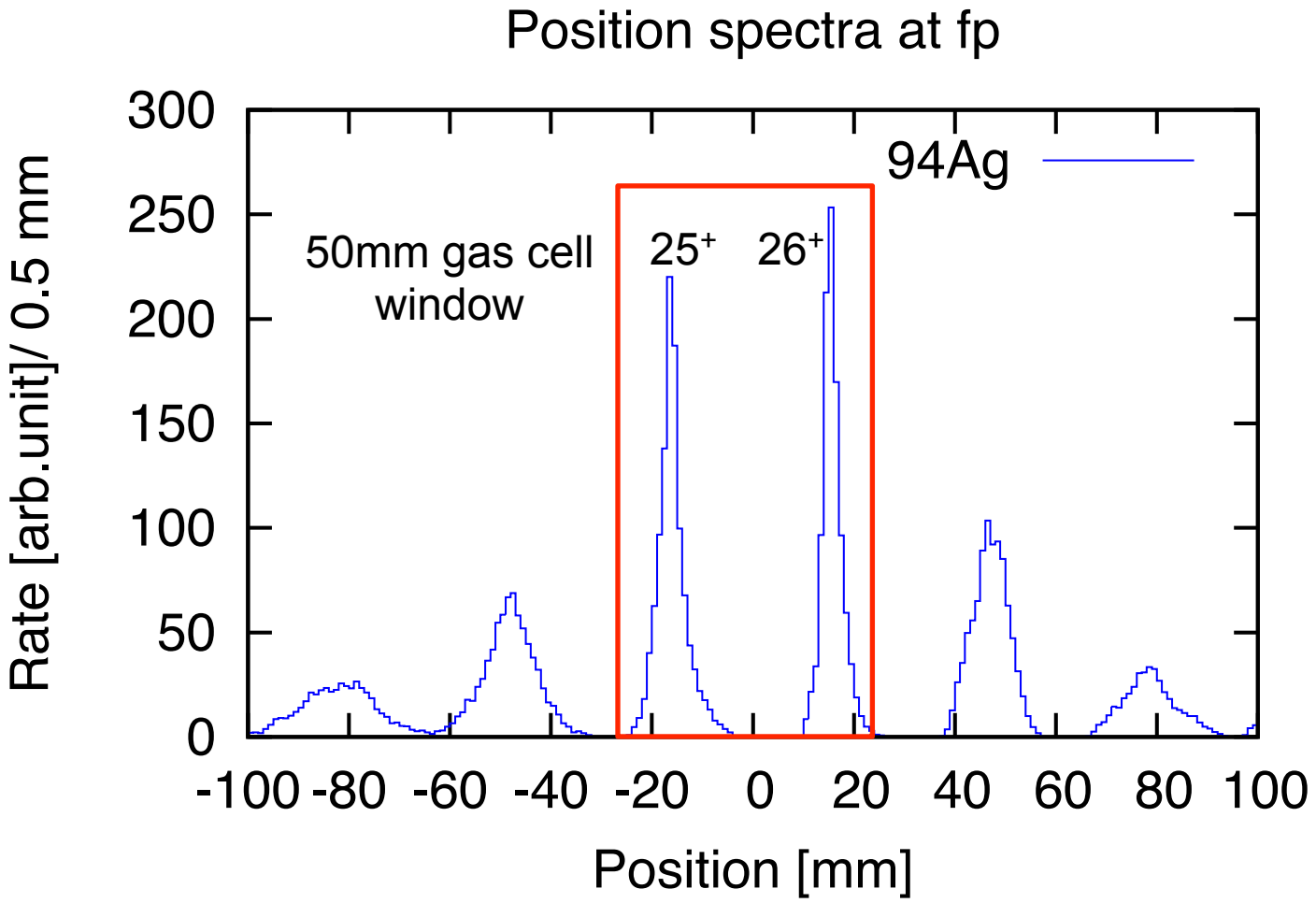

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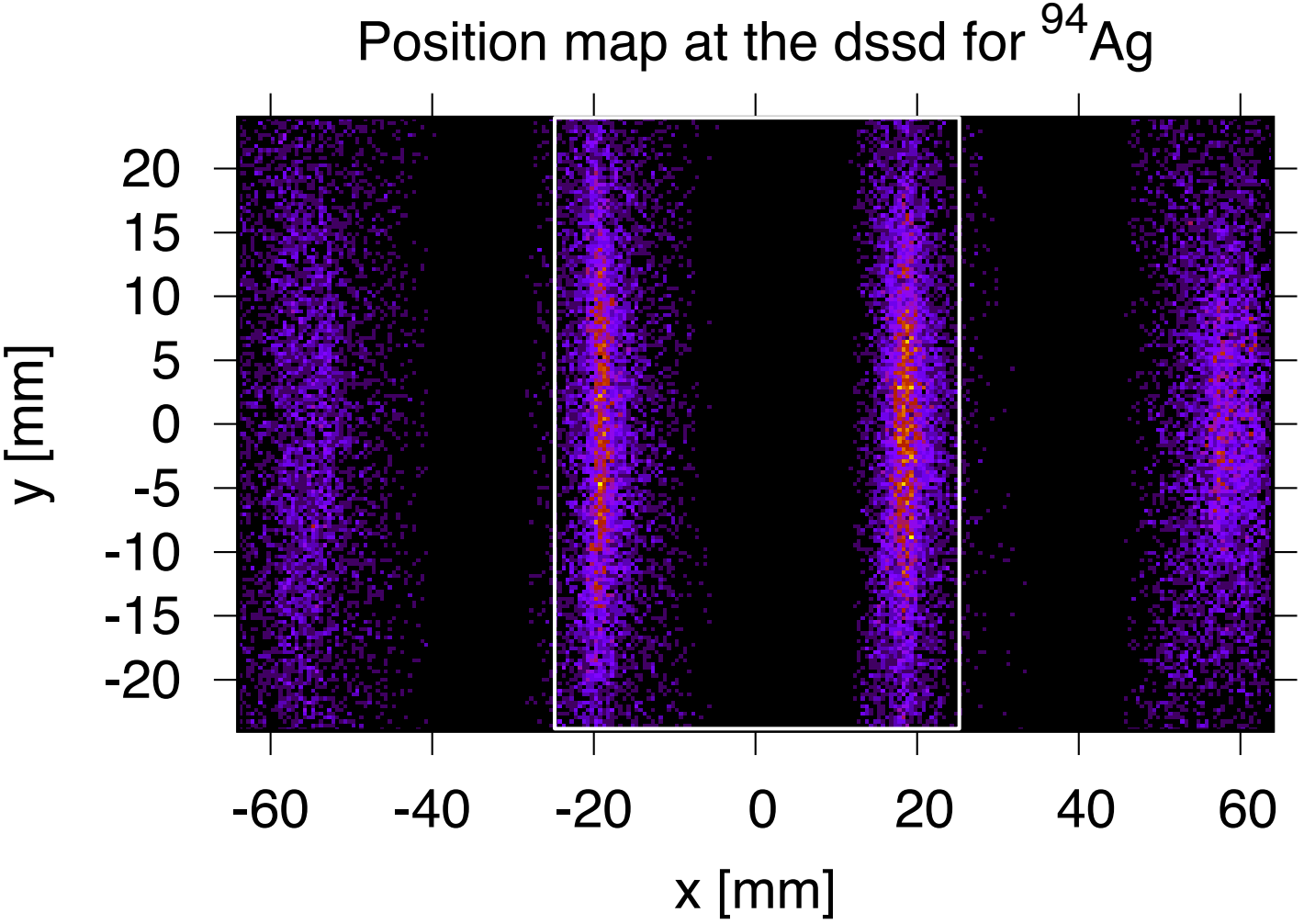

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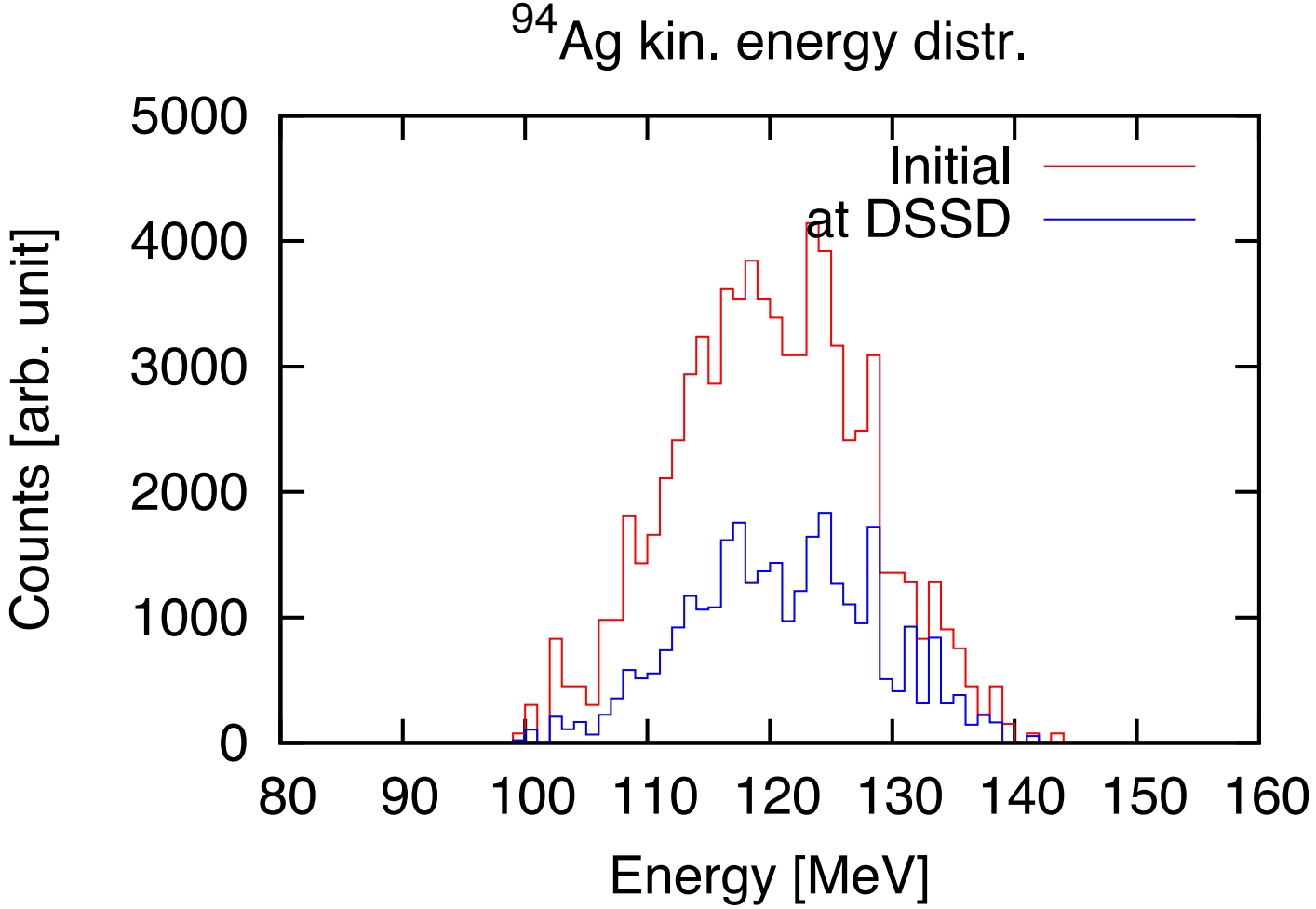
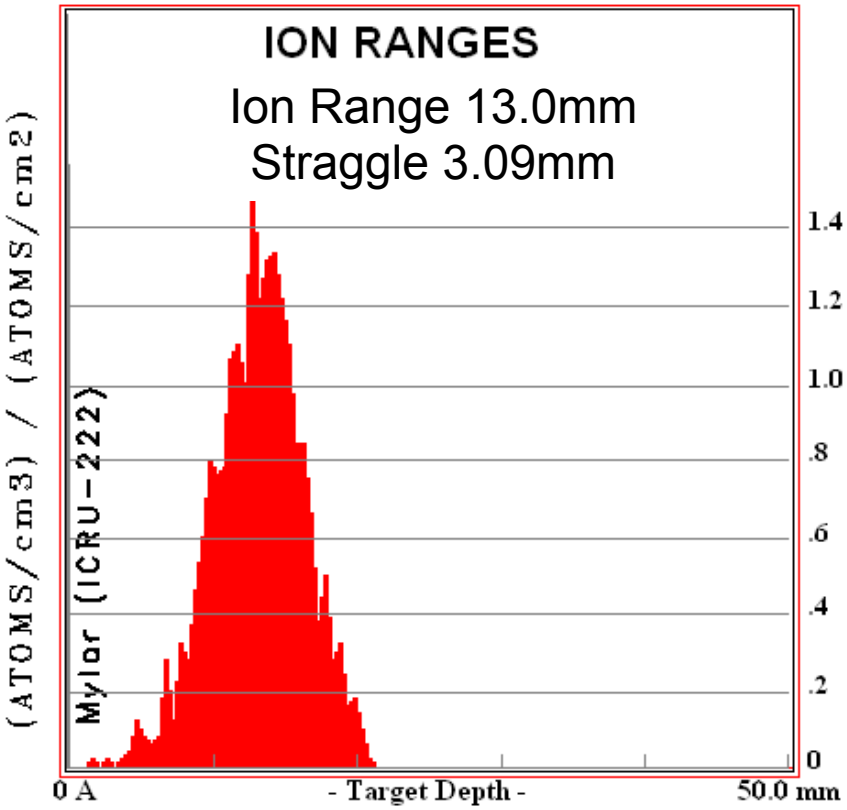


^{58}Ni(^{40}Ca,p3n)^{94}Ag @ 192MeV

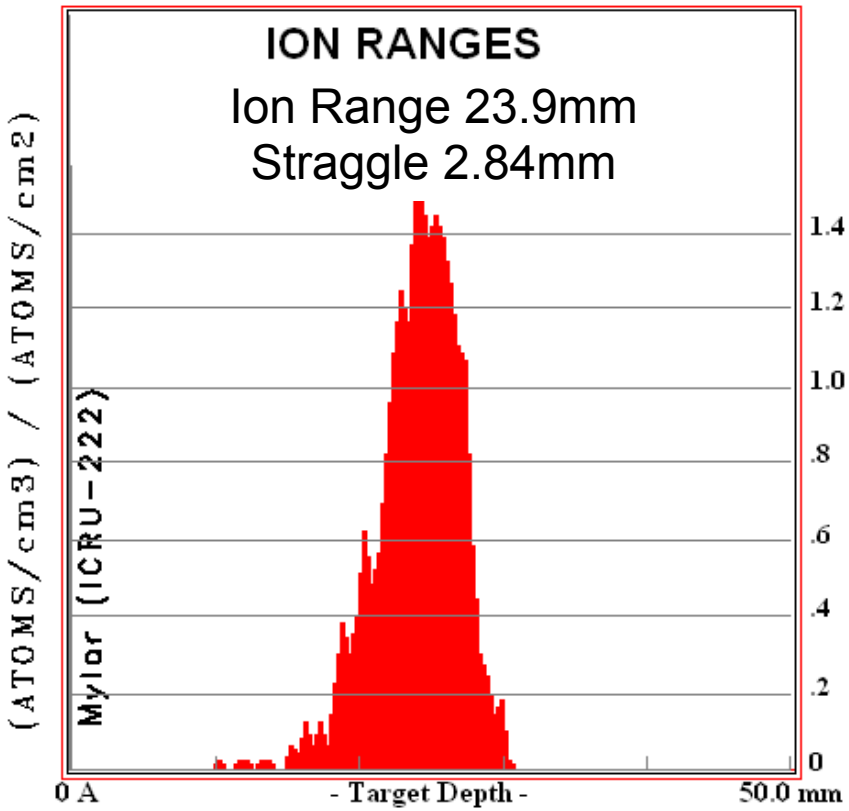
Calculations by J. Sarén

Stopping ranges

$^{58}Ni(^{40}Ca,p3n)^{94}Ag$
192MeV, 500µg/cm^2
10+1µm Mylar foils, 500mbar **Ar**



$^{40}Ca(^{58}Ni,p3n)^{94}Ag$
240MeV, 500µg/cm^2
10+1µm Mylar foils, 500mbar **Ar**



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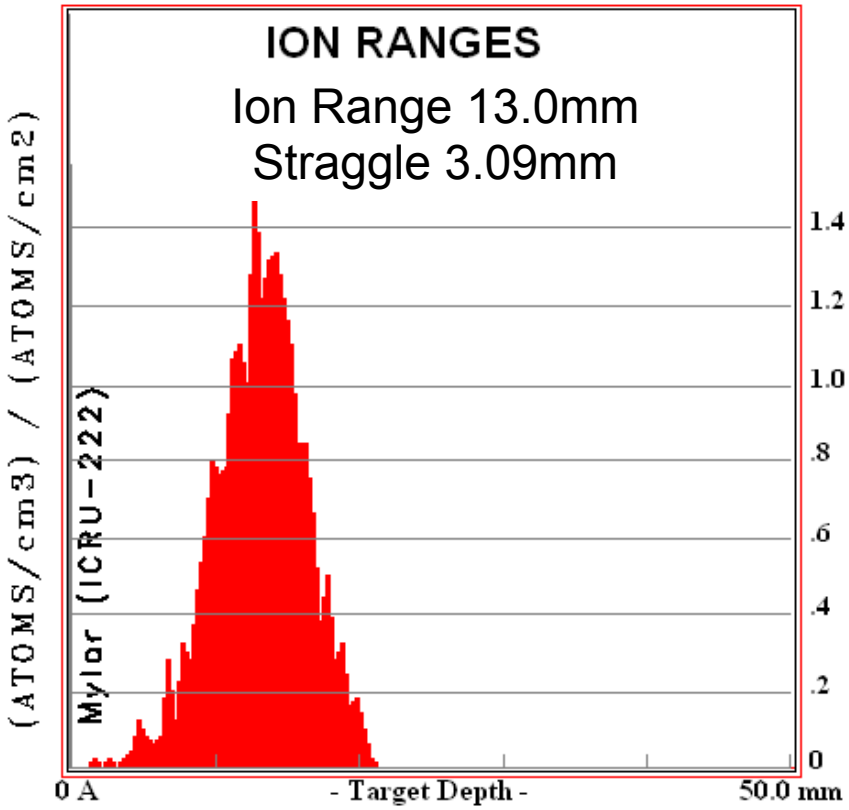
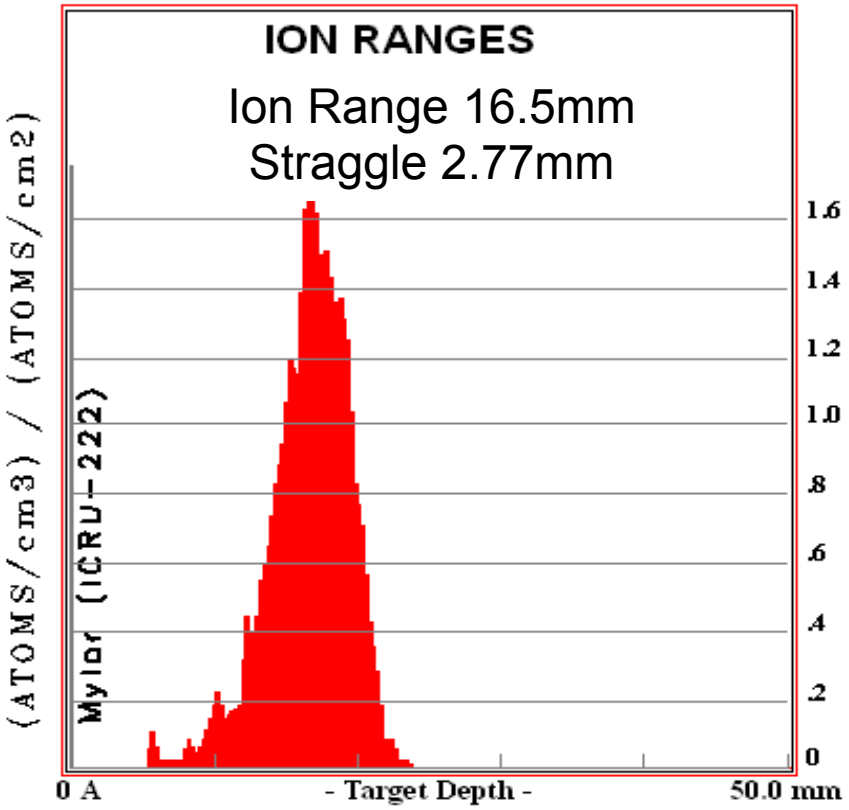
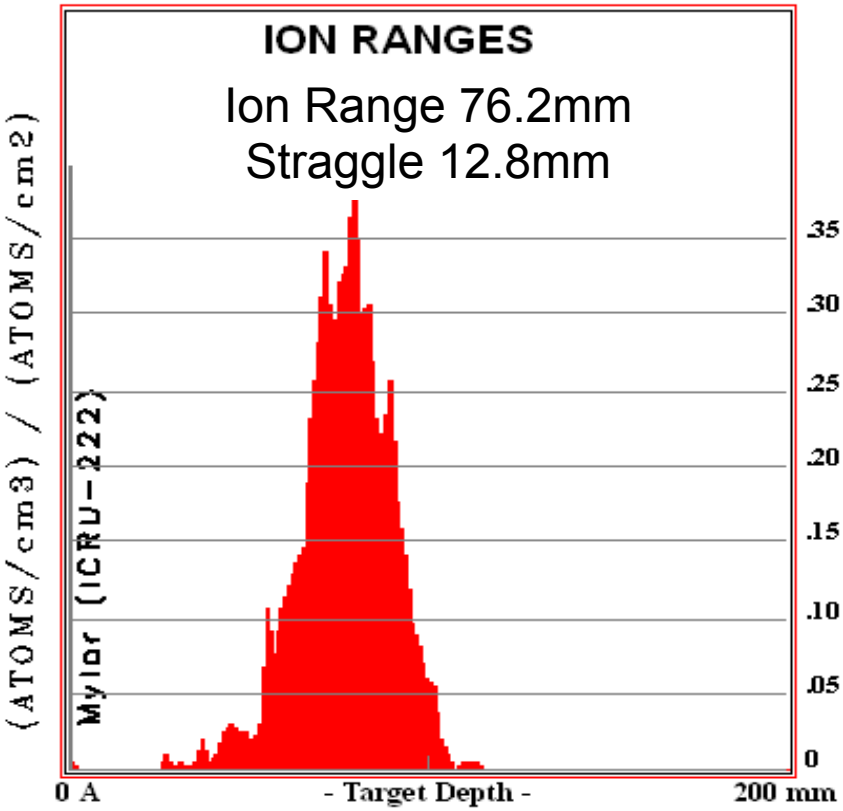


$^{40}Ca(^{58}Ni,p3n)^{94}Ag$
240MeV, 500µg/cm^2
13+1µm Mylar foils, 500mbar **Ar**

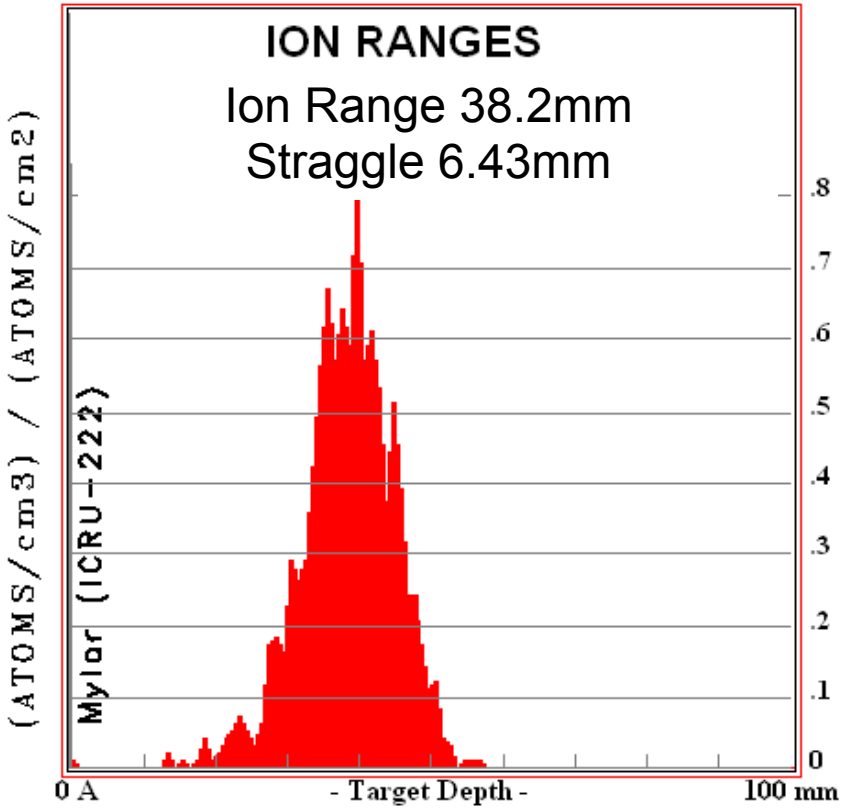


Stopping ranges

$^{58}Ni(^{40}Ca,p3n)^{94}Ag$
192MeV, 500µg/cm^2
10+1µm Mylar foils, 500mbar **He**

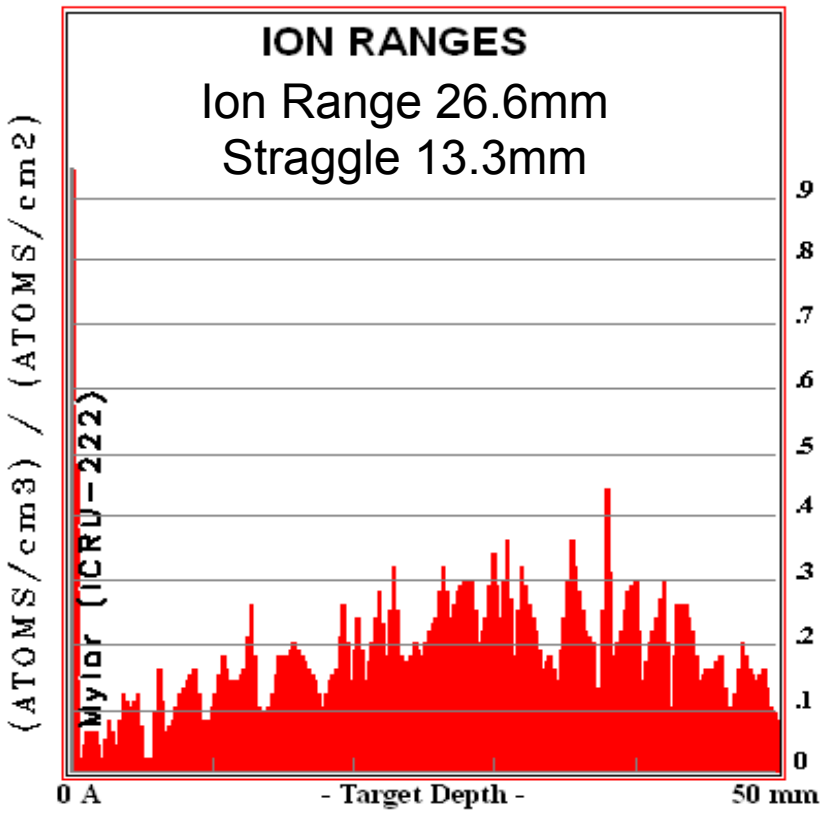


$^{58}Ni(^{40}Ca,p3n)^{94}Ag$
192MeV, 500µg/cm^2
10+1µm Mylar foil, 1000mbar **He**



Stopping ranges

$^{58}Ni(^{40}Ca,p3n)^{94}Ag$
192MeV, 500µg/cm^2
14µm Mylar foils, 500mbar **He**



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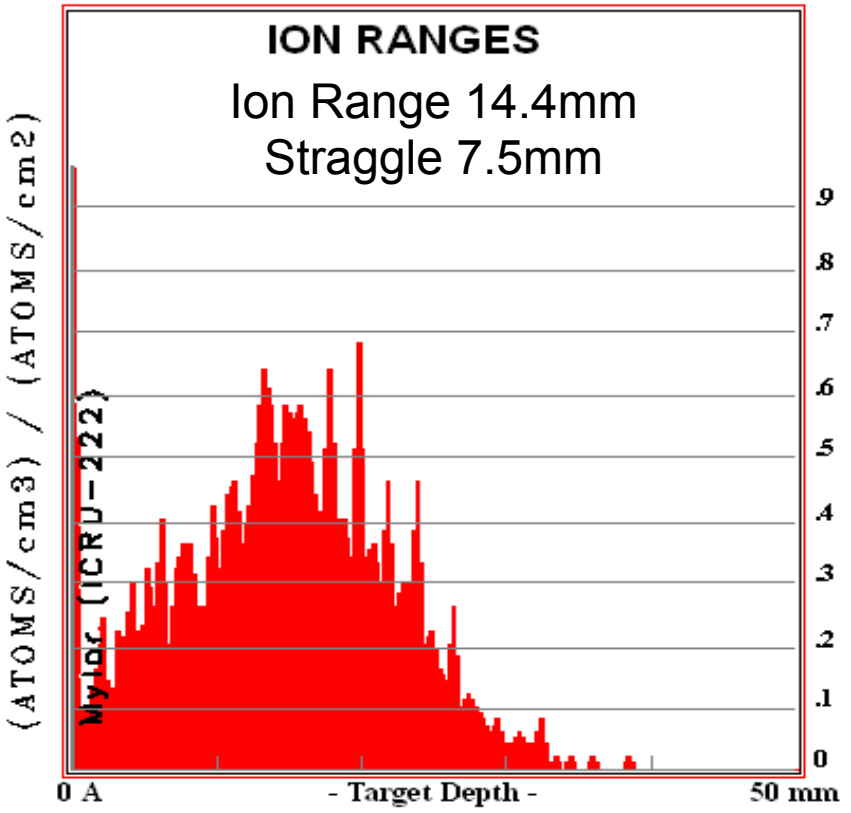
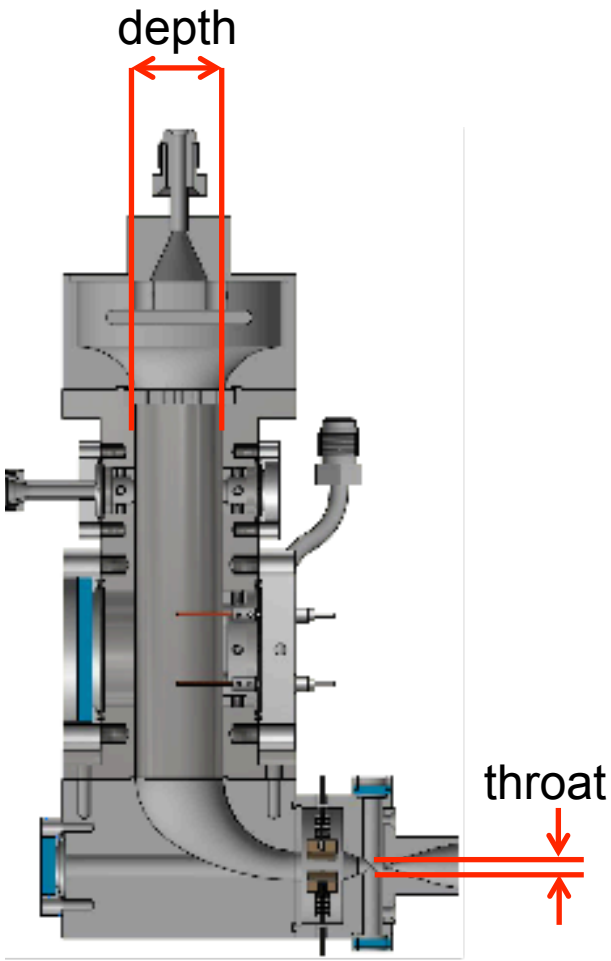
192MeV, 500µg/cm^2
14µm Mylar foil, 1000mbar **He**



Evacuation times

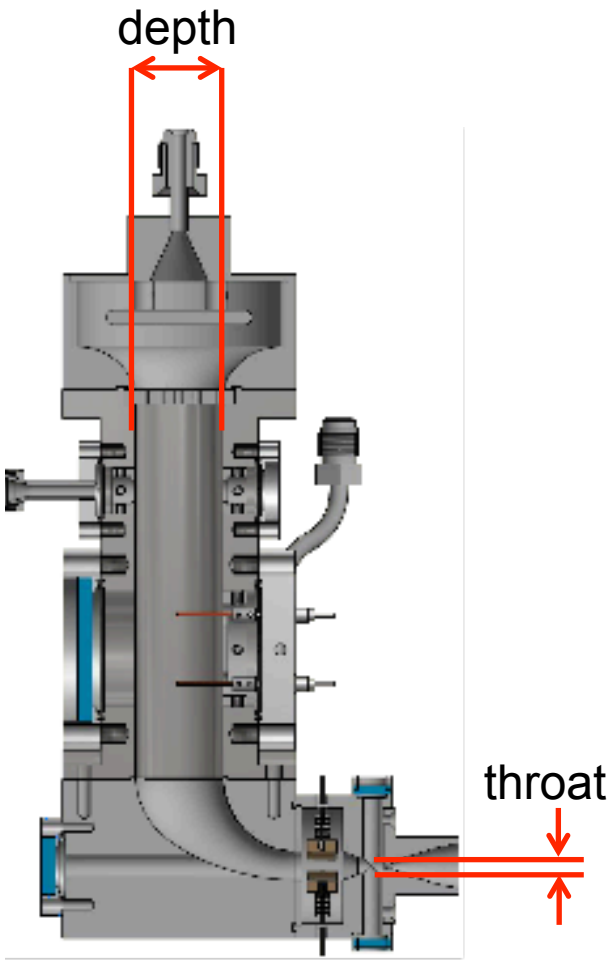


For Ar:

- Depth: 30mm. Throat: 1mm (1.5mm)
  - By detailed calculation of the gas velocity profile in the cell: 630ms *
  - By estimating the evacuation time: ~600ms (~260ms)
- Depth: 20mm. Throat: 1.5mm
  - By detailed calculation of the gas velocity profile in the cell: 190ms *
  - By estimating the evacuation time: ~180ms

*Yu. Kudryavtsev *et al.*, Nucl. Instr. and Meth. B **376,** 345 (2016)

Evacuation times



For Ar:

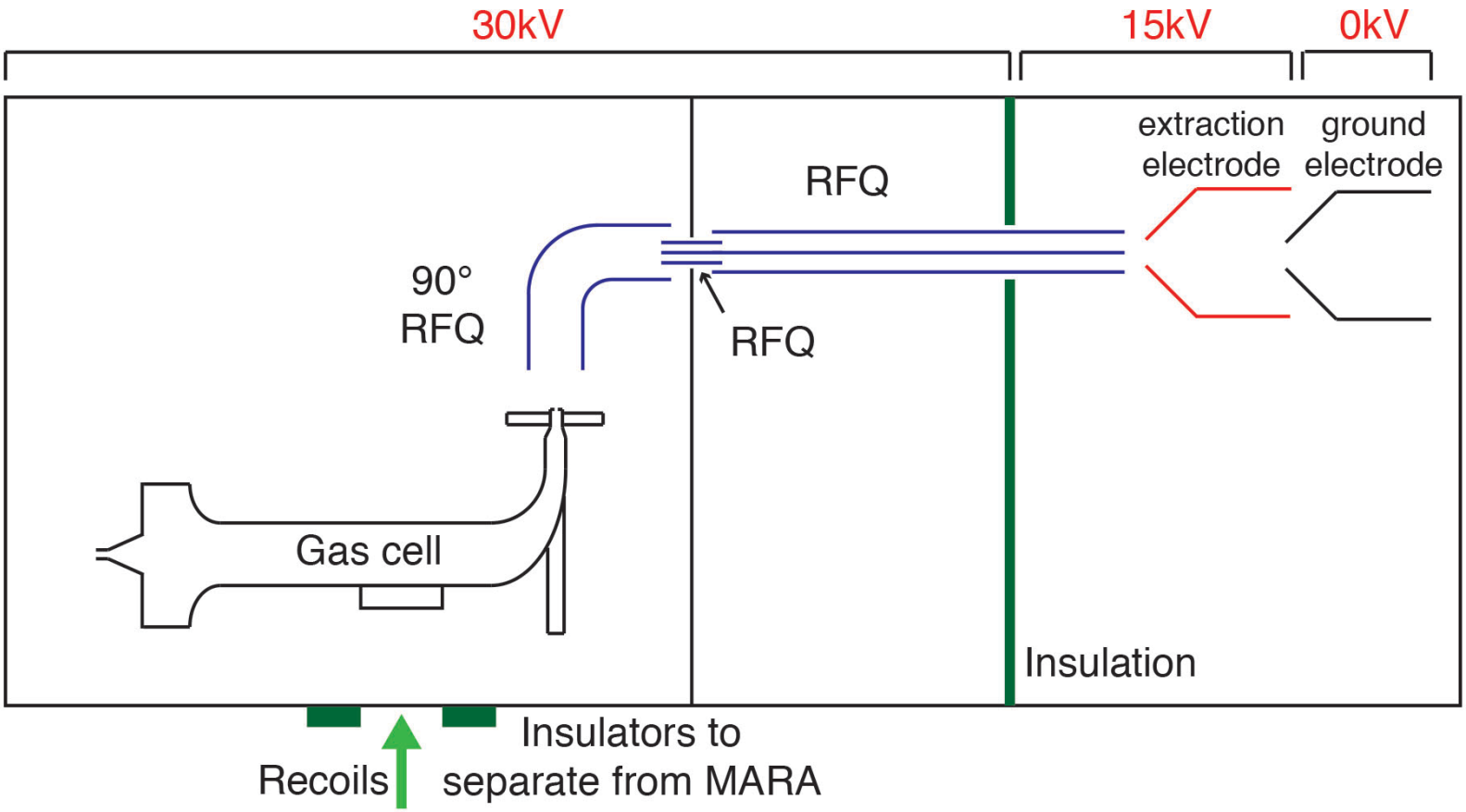
- Depth: 30mm. Throat: 1mm (1.5mm)
  - By detailed calculation of the gas velocity profile in the cell: 630ms *
  - By estimating the evacuation time: ~600ms (~260ms)
- Depth: 20mm. Throat: 1.5mm
  - By detailed calculation of the gas velocity profile in the cell: 190ms *
  - By estimating the evacuation time: ~180ms

For He:

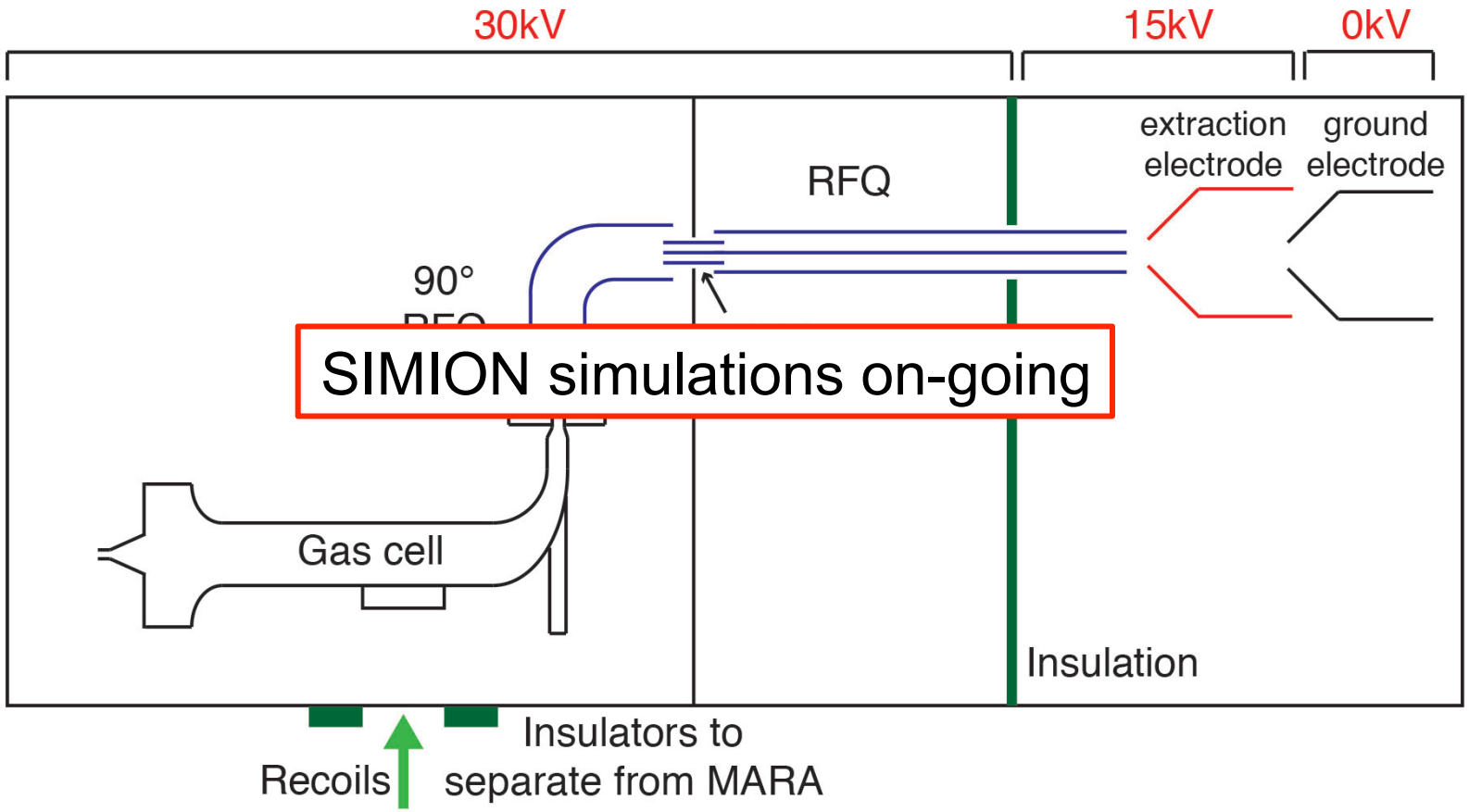
- Depth: 30mm. Throat: 1mm
  - By estimating the evacuation time: ~180ms
- Depth: 20mm. Throat: 1.5mm
  - By estimating the evacuation time: ~60ms

*Yu. Kudryavtsev *et al.*, Nucl. Instr. and Meth. B **376,** 345 (2016)

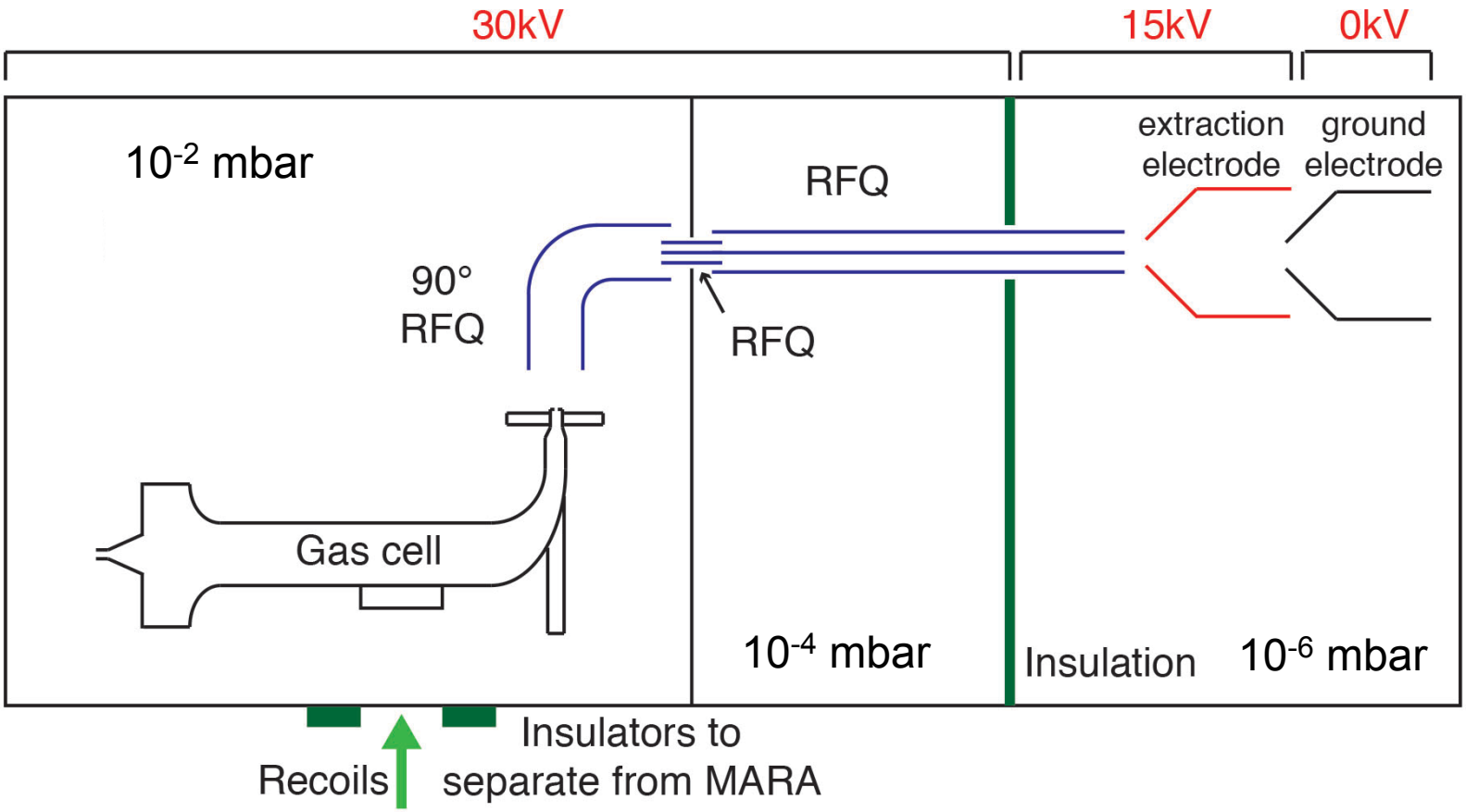
Ion Extraction



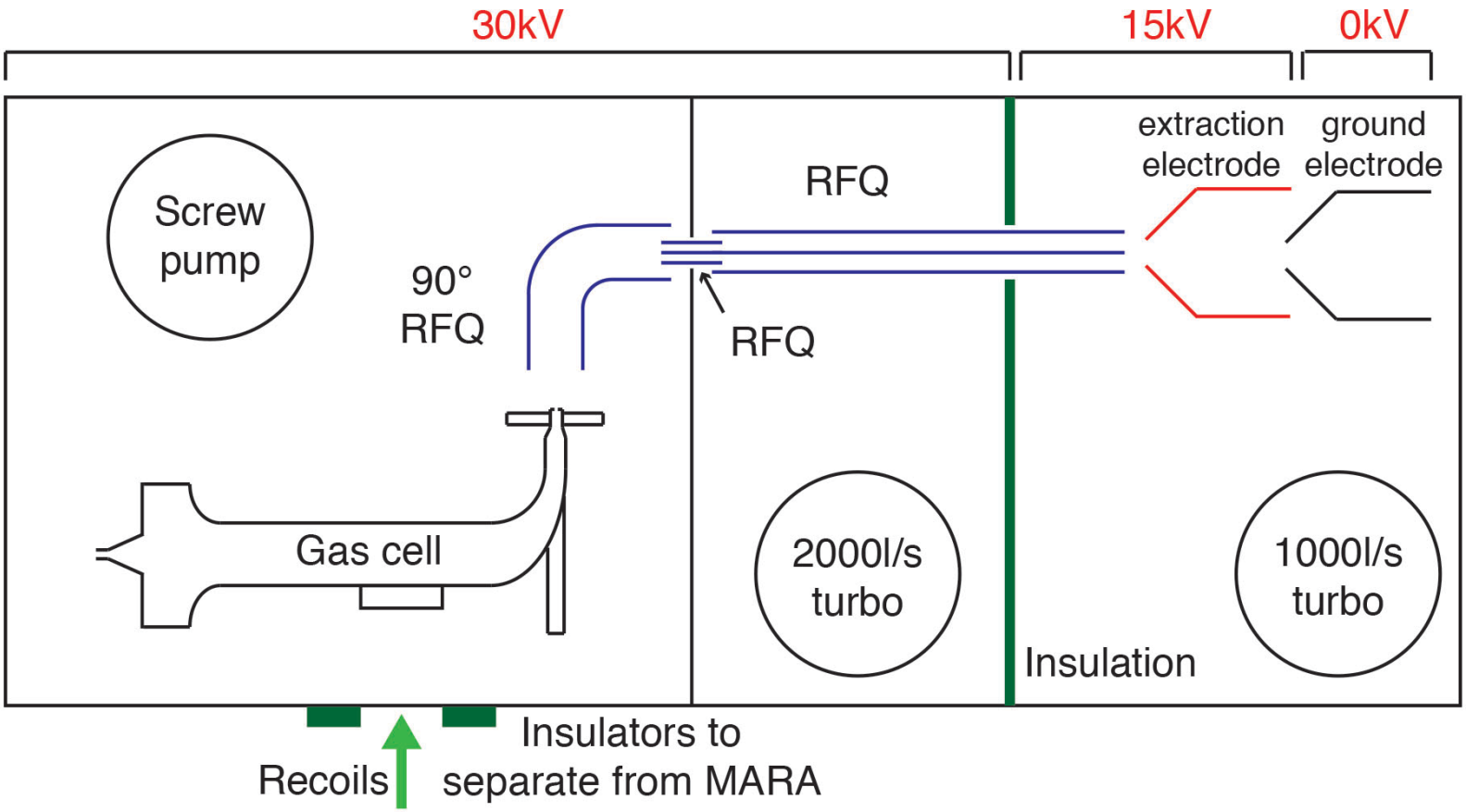
Ion Extraction



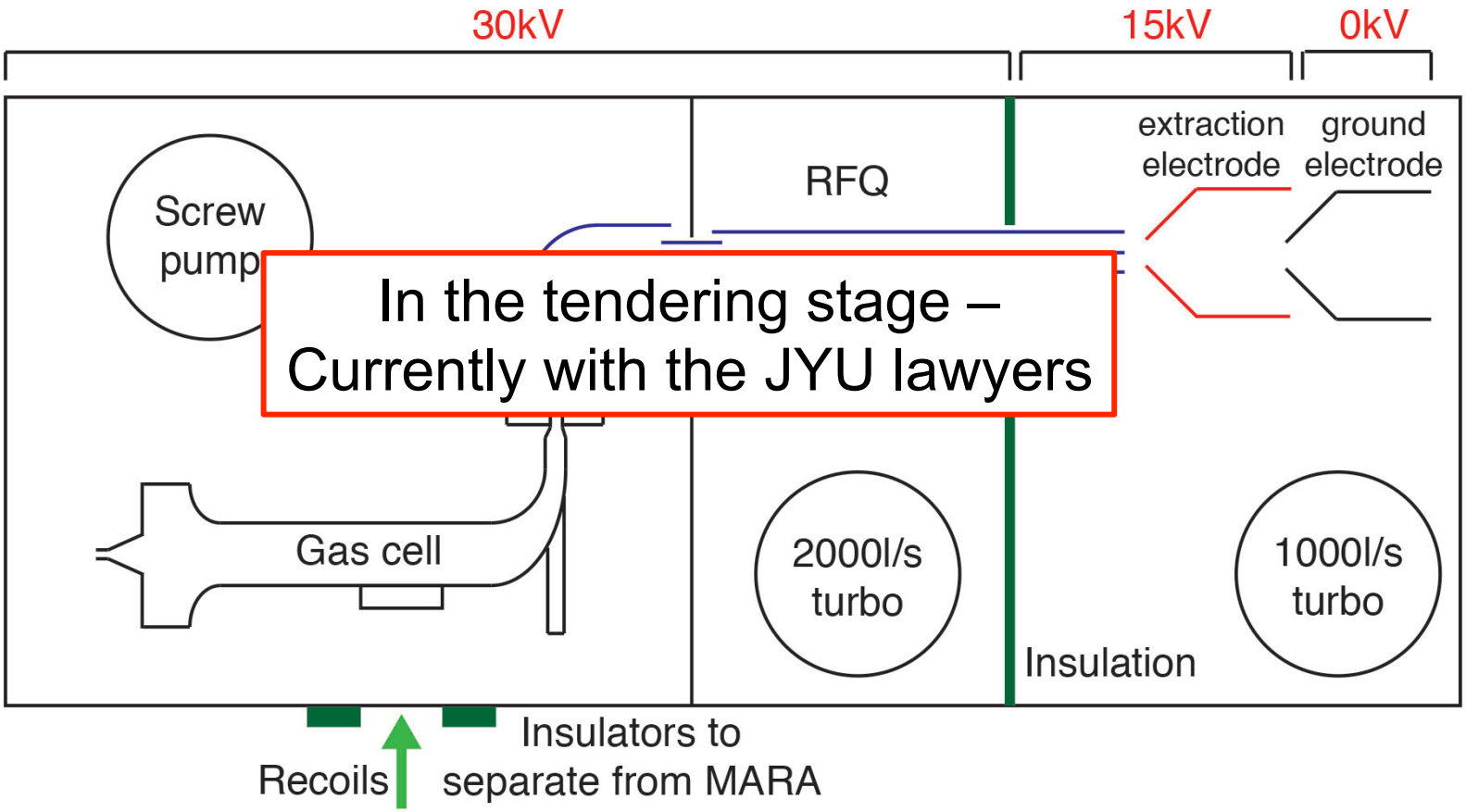
Differential pumping



Differential pumping

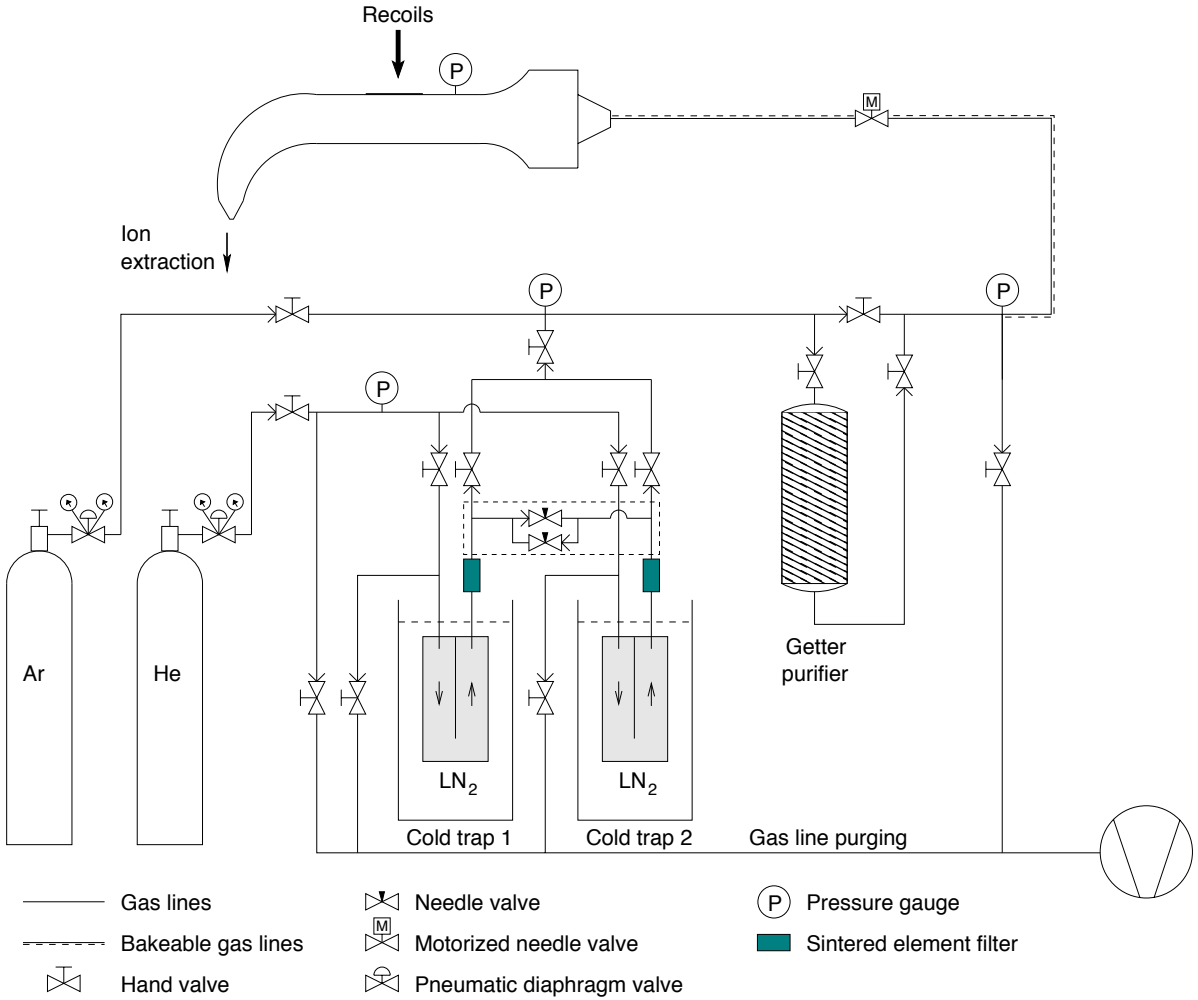


Differential pumping



Gas handling system

Based on the system build for IGISOL-4 by I. Pohjalainen



Gas handling system

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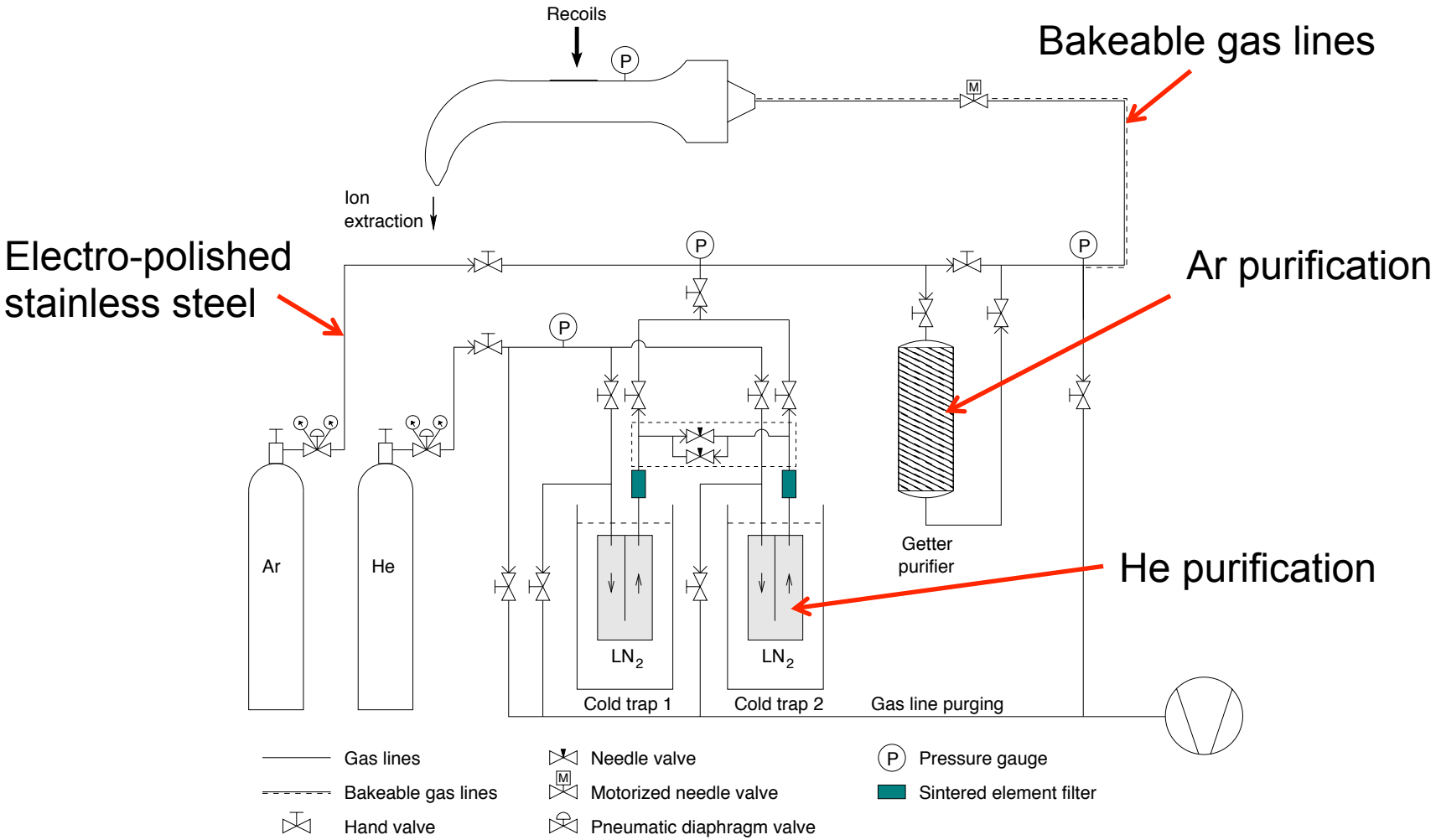
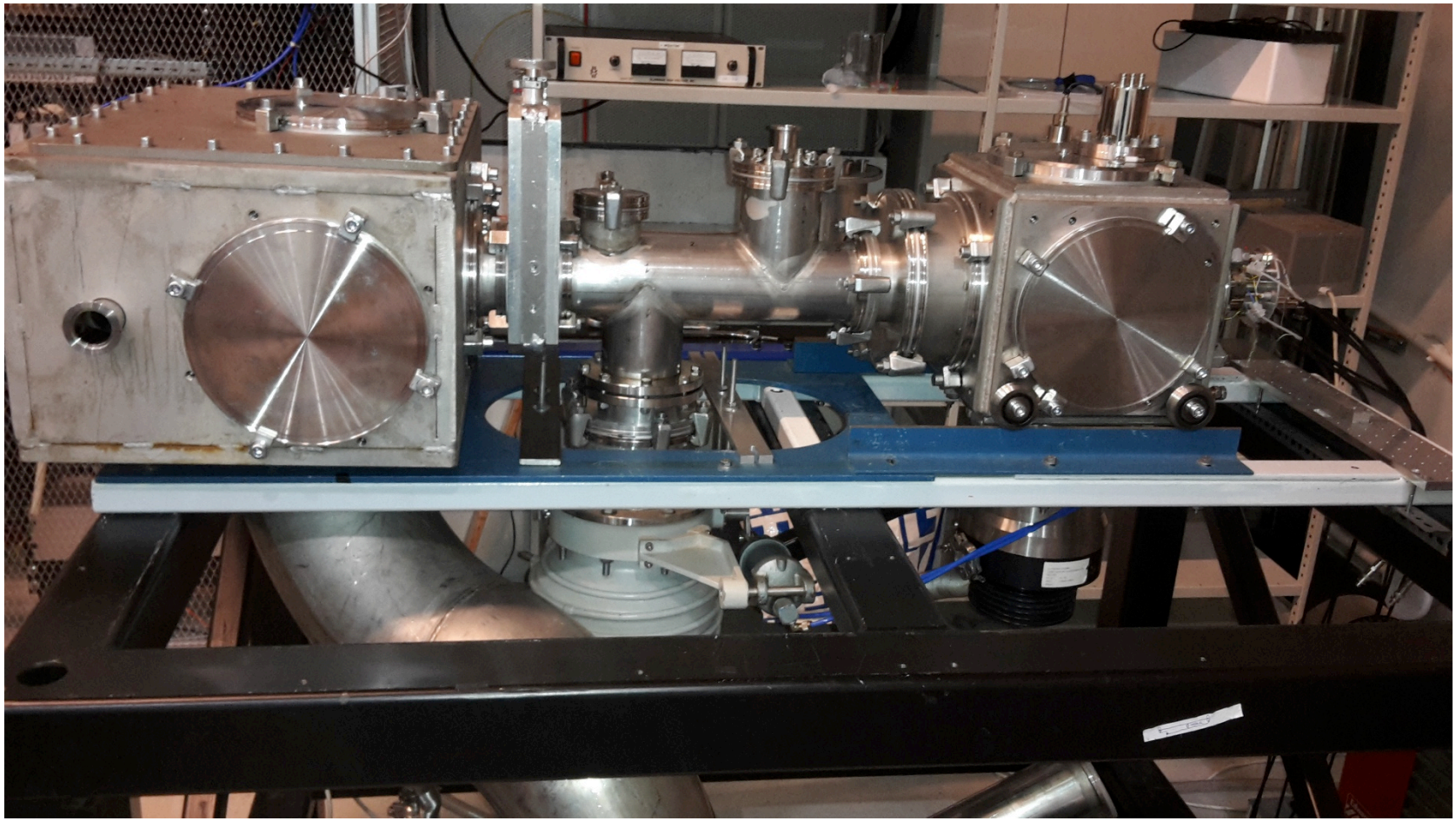


Gas handling system

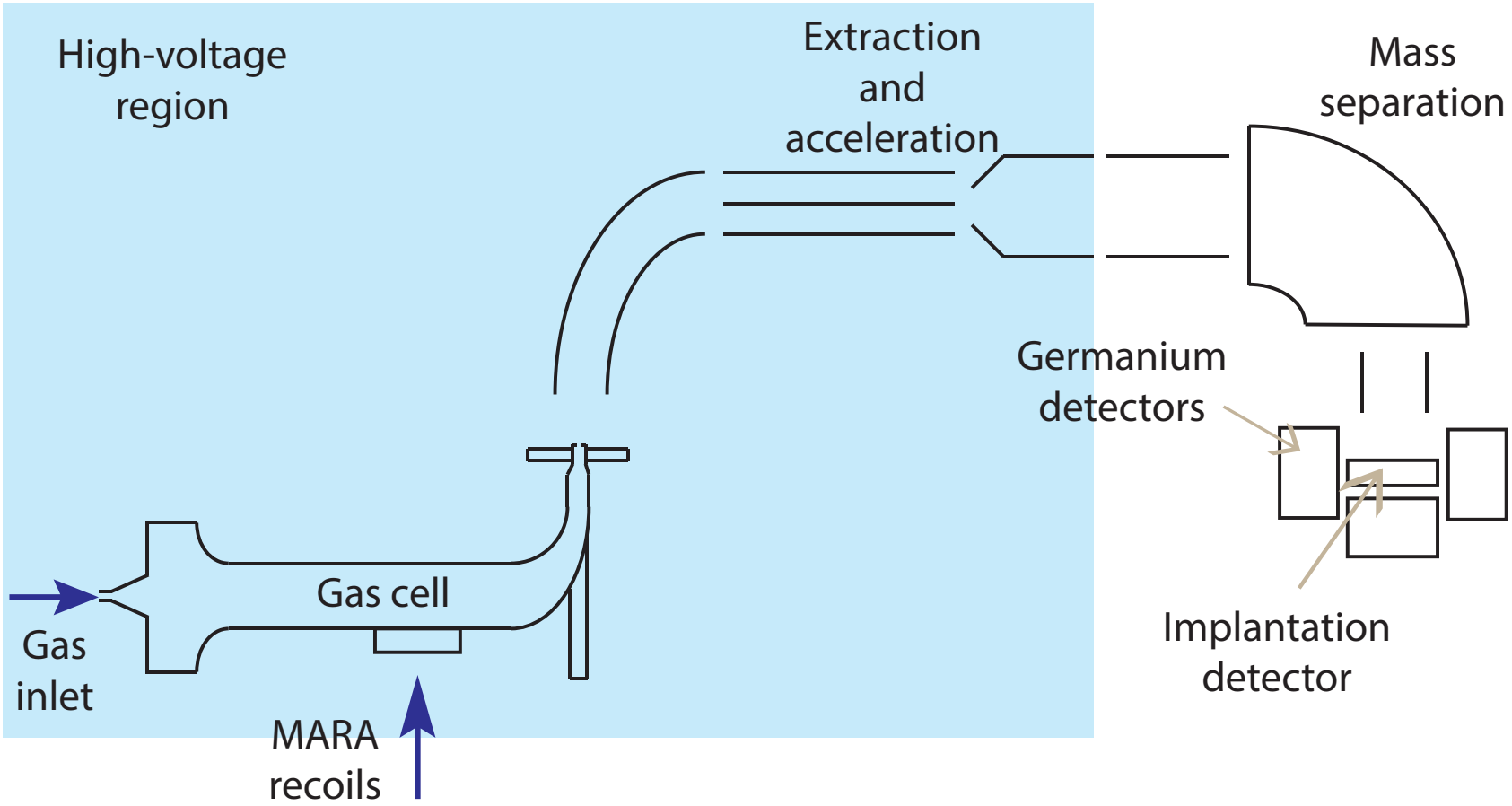
MonoTorr PS4-MT3-R2
Heated getter purifier

IGISOL off-line rig – Equipment testing



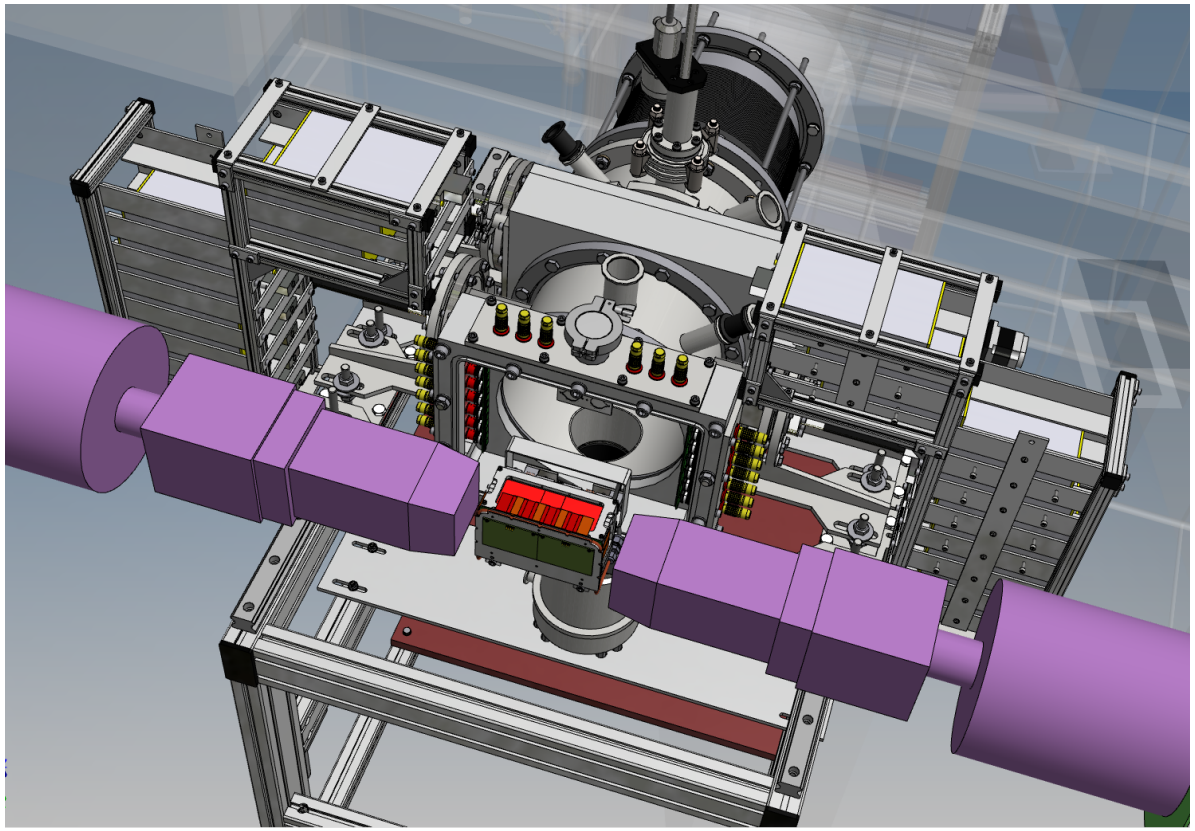
Detector stations

- 1st phase



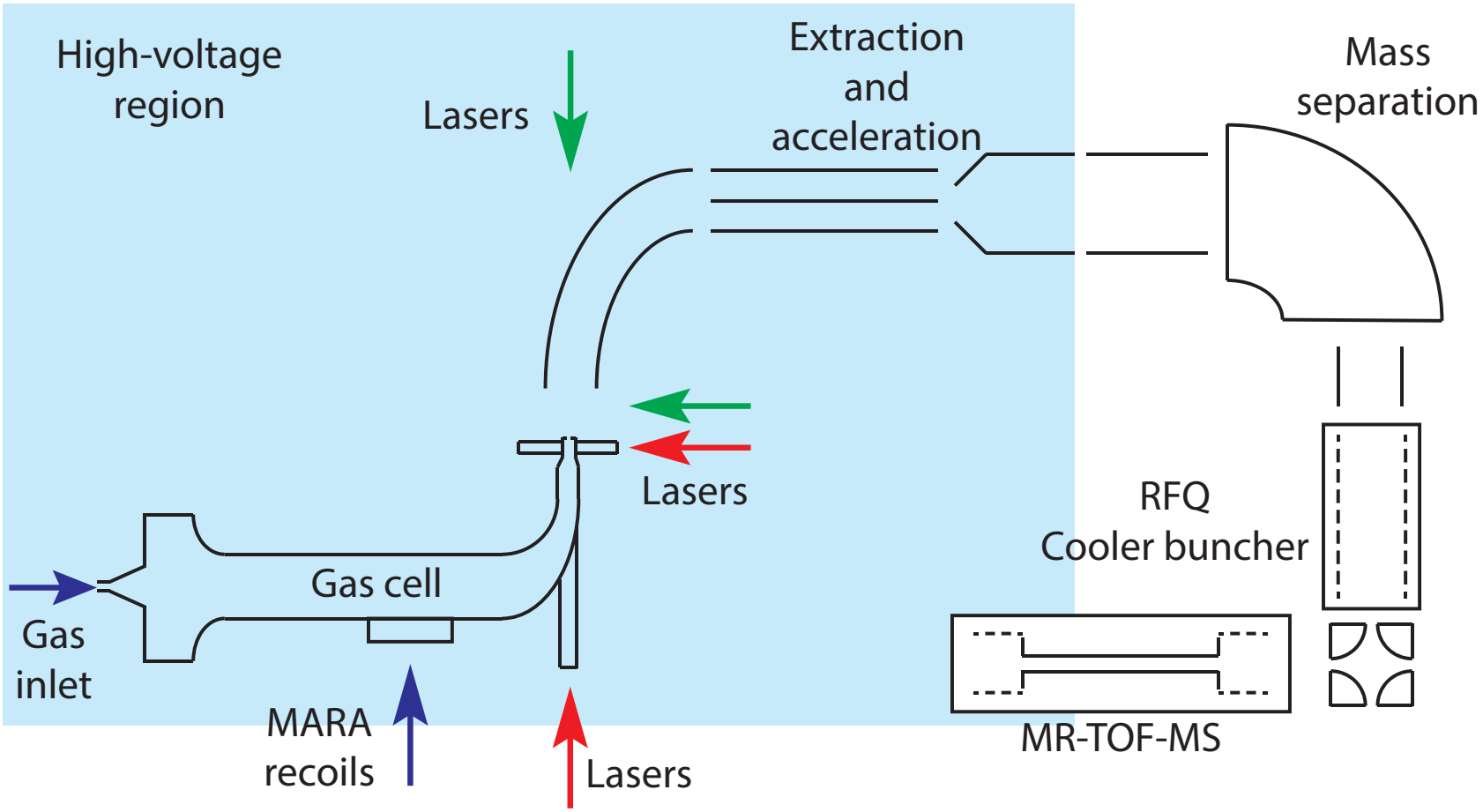
Detector stations

- 1st phase



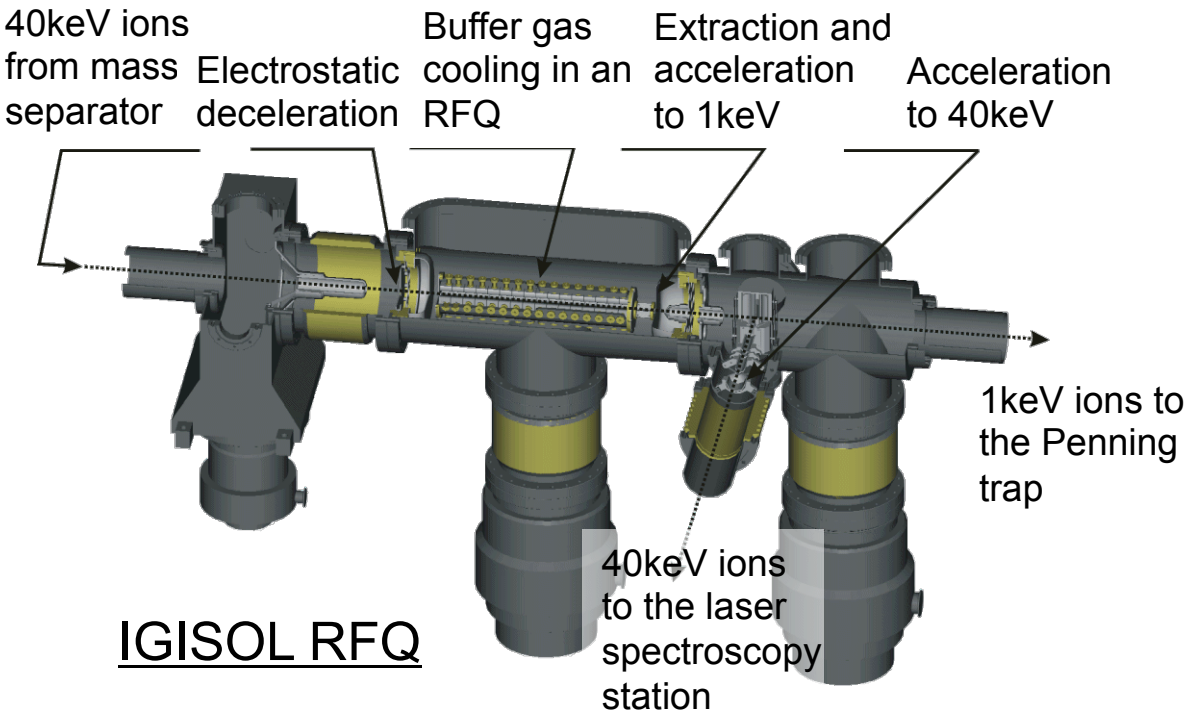
Detector stations

- 2nd phase



Radiofrequency quadrupole cooler and buncher

To be used for decelerating, cooling and bunching of the ion beam to make it suitable for the MR-TOF mass spectrometer.

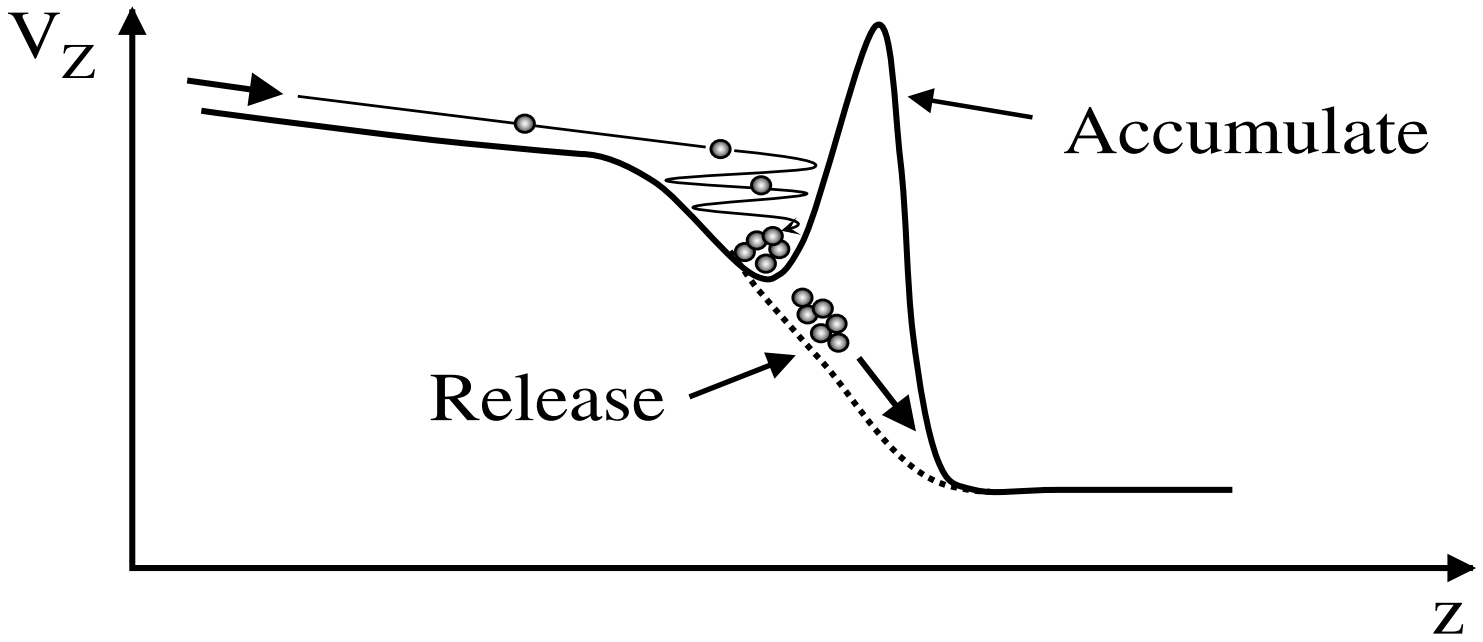


IGISOL RFQ

A. Nieminen *et al*., Phys. Rev. Lett. 88 (2002) 9

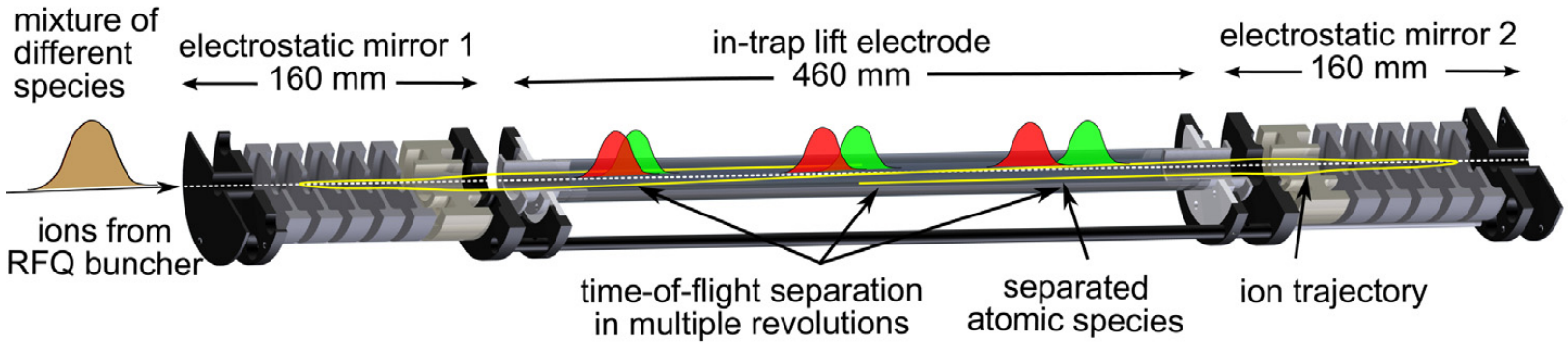
Radiofrequency quadrupole cooler and buncher

To be used for decelerating, cooling and bunching of the beam to make it suitable for the MR-TOF mass spectrometer.



A. Nieminen *et al*., Phys. Rev. Lett. 88 (2002) 9

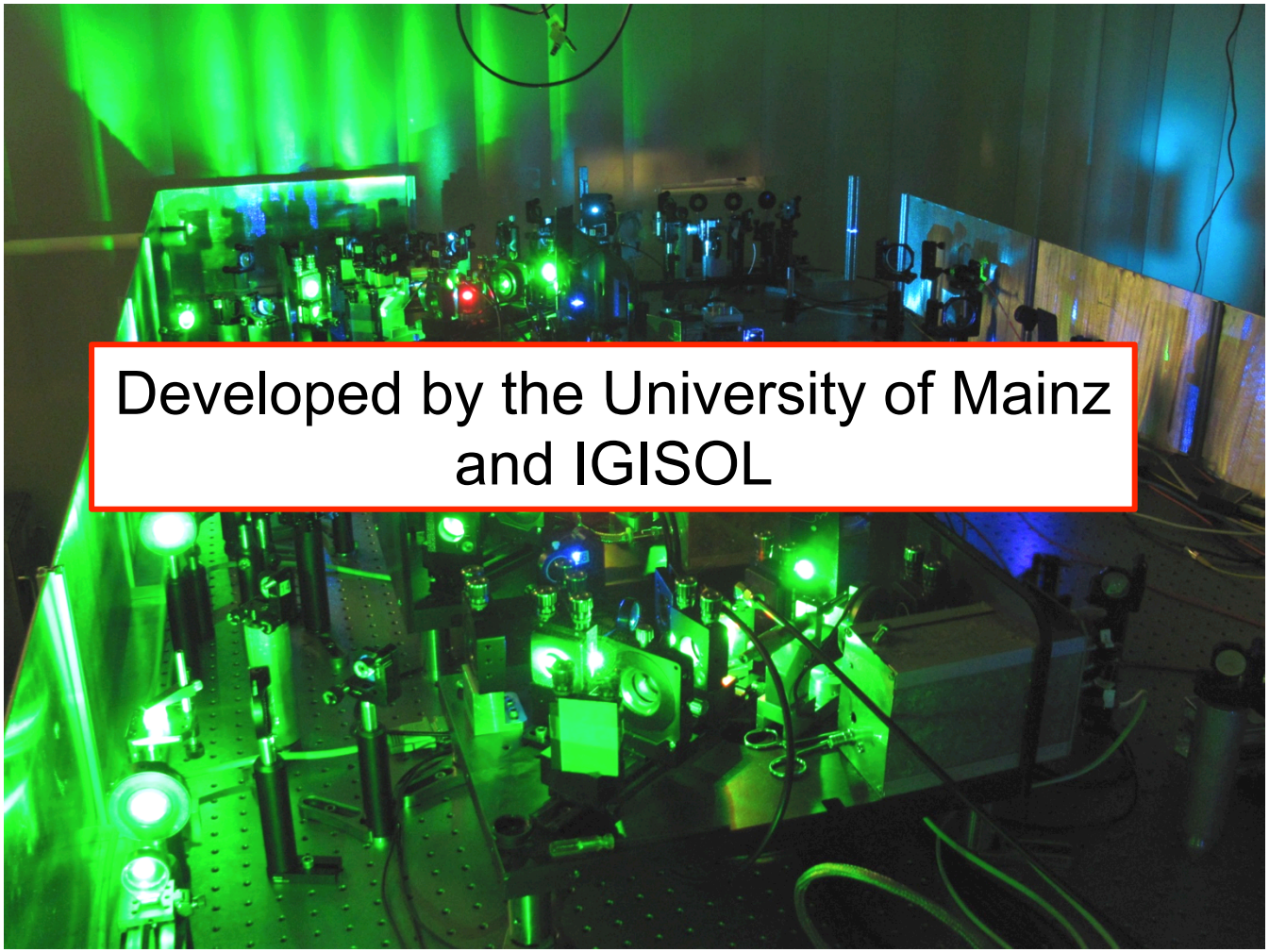
Multi-reflection time-of-flight mass analyser



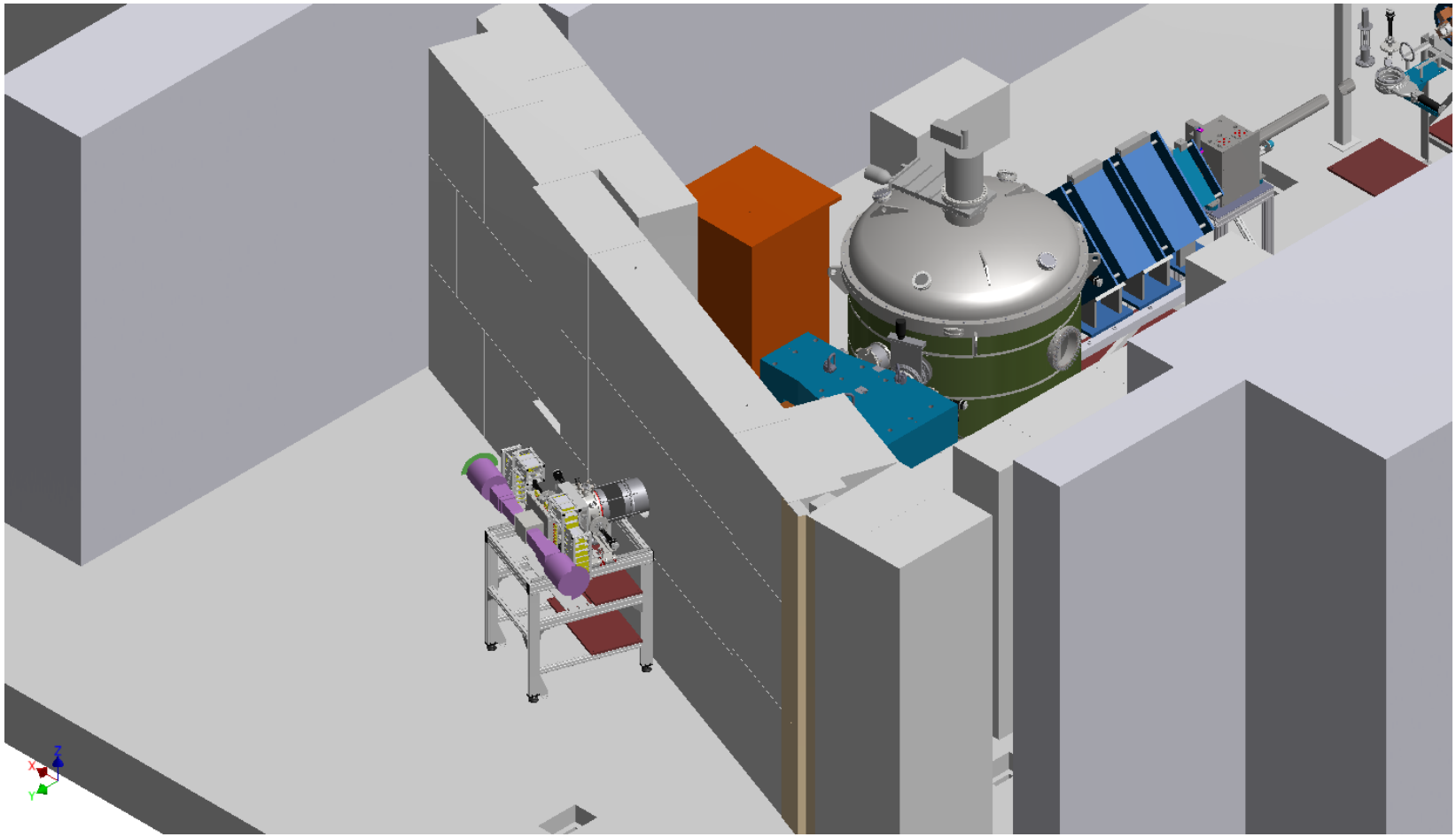
R.N. Wolf *et al.*, Int. Journal of Mass Spectrometry **349–350** (2013) 213

Lasers system

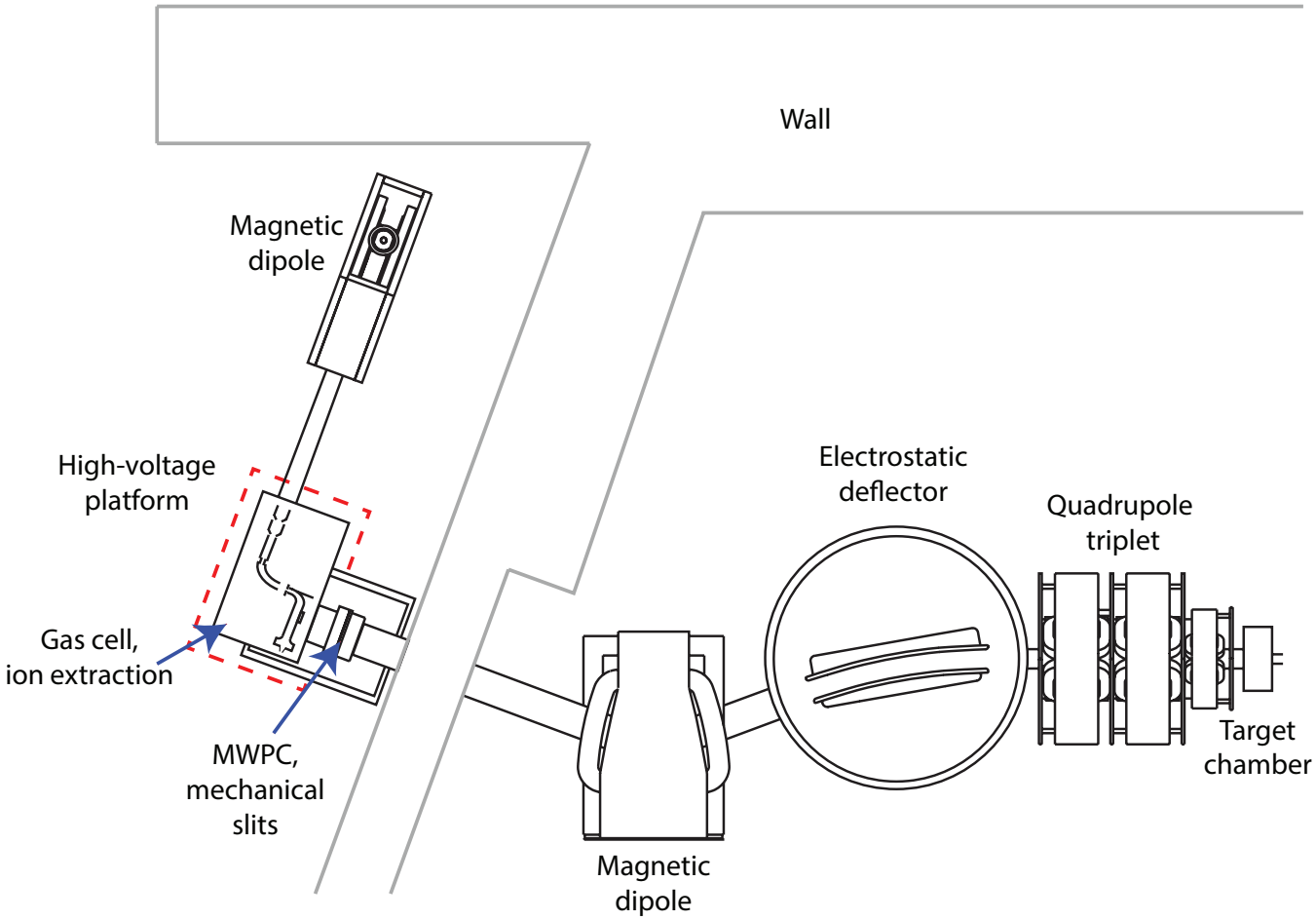
Lasers system



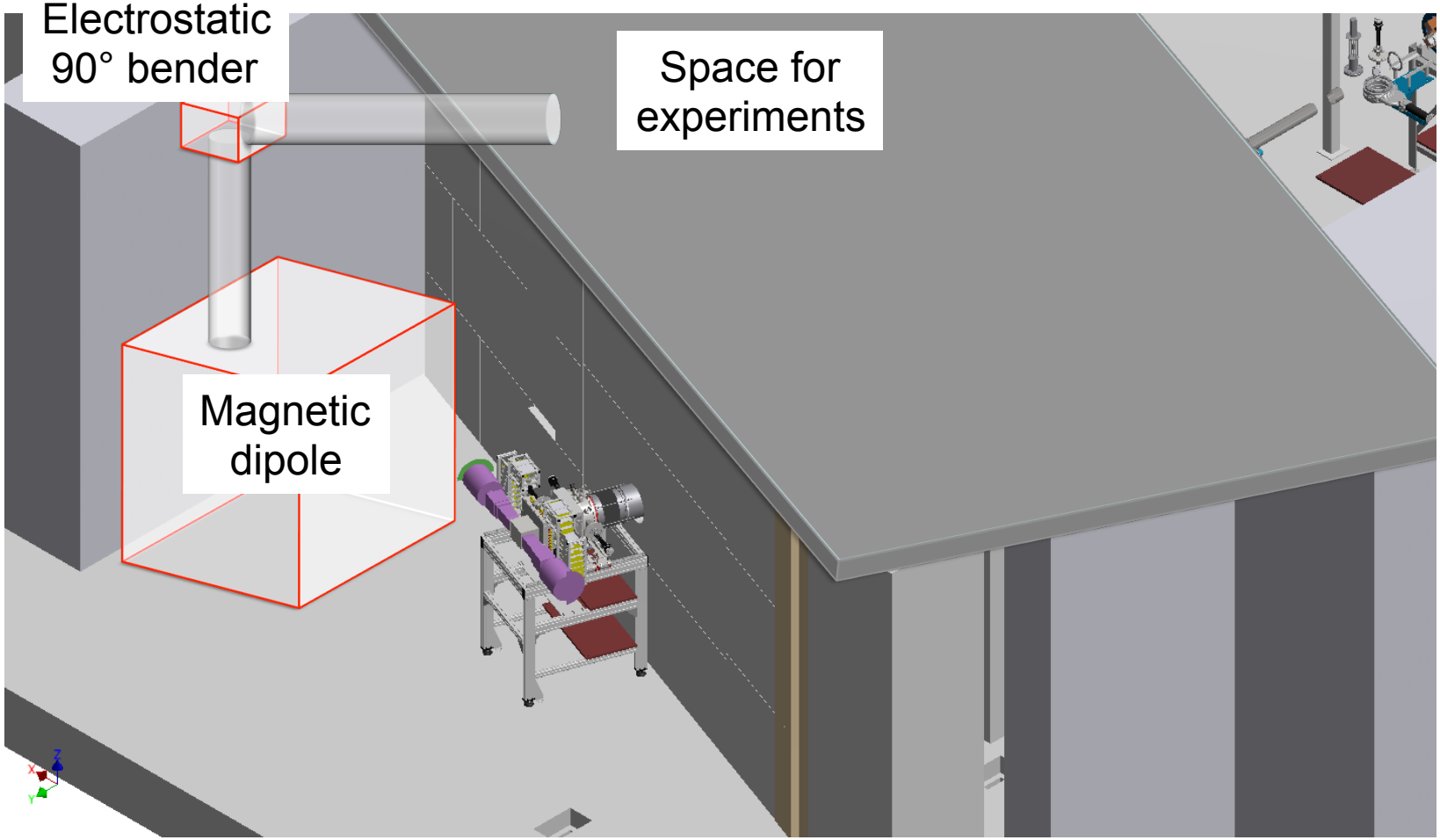
Space requirements



Space requirements



Space requirements



Current Status

Funding:

- Received infrastructure funding from the Academy of Finland, 2016-2018 FIRI
  - 432k€
- MR-TOF-MS for IGISOL funded from Academy of Finland 2014-2016 FIRI
  - 150k€
  - Tommi Eronen
  - Duplicate device to be build for MARA-LEB

Current Status

Equipment

- Tendering for vacuum pumps on-going
- Simulations for the dipole magnet in progress
- Gas cell order by the end of the year
- Ion optics design decided, simulations on-going

People

- MSc student working on the design of the ion guides
- Submitted a number of funding applications for personnel costs

Collaboration

Iain Moore
Philippos Papadakis
Jari Partanen
Ilkka Pohjalainen
Sami Rinta-Antila
Jan Sarén
Juha Uusitalo

Piet Van Duppen
Rafael Ferrer
Yuri Kudryavtsev
Alexandra Zadvornaya