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Independent fission yield studies at the JYFL accelerator laboratory

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and the IGISOL group

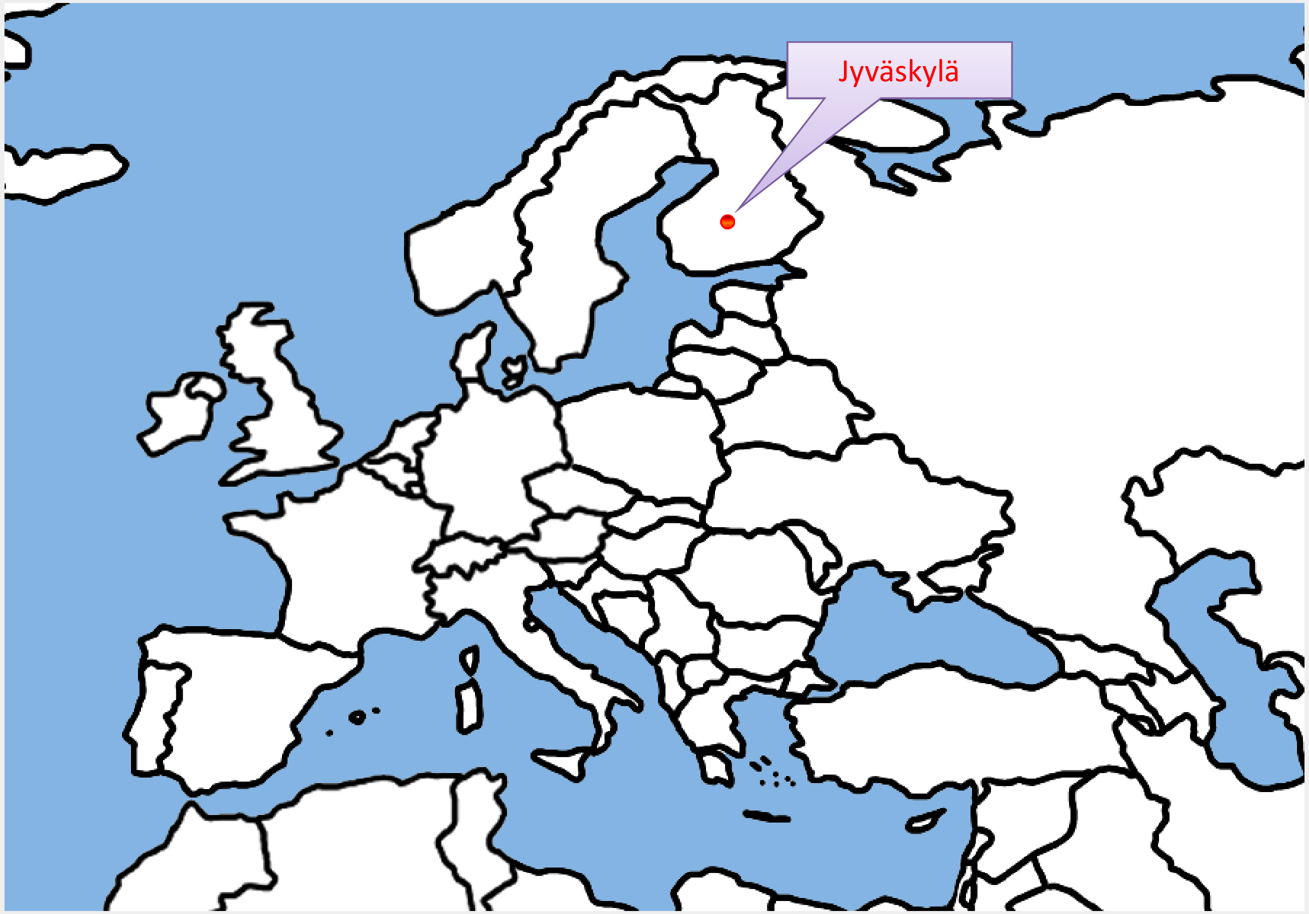
University of Jyvaskyla, Finland

European Commission

ACADEMY OF FINLAND

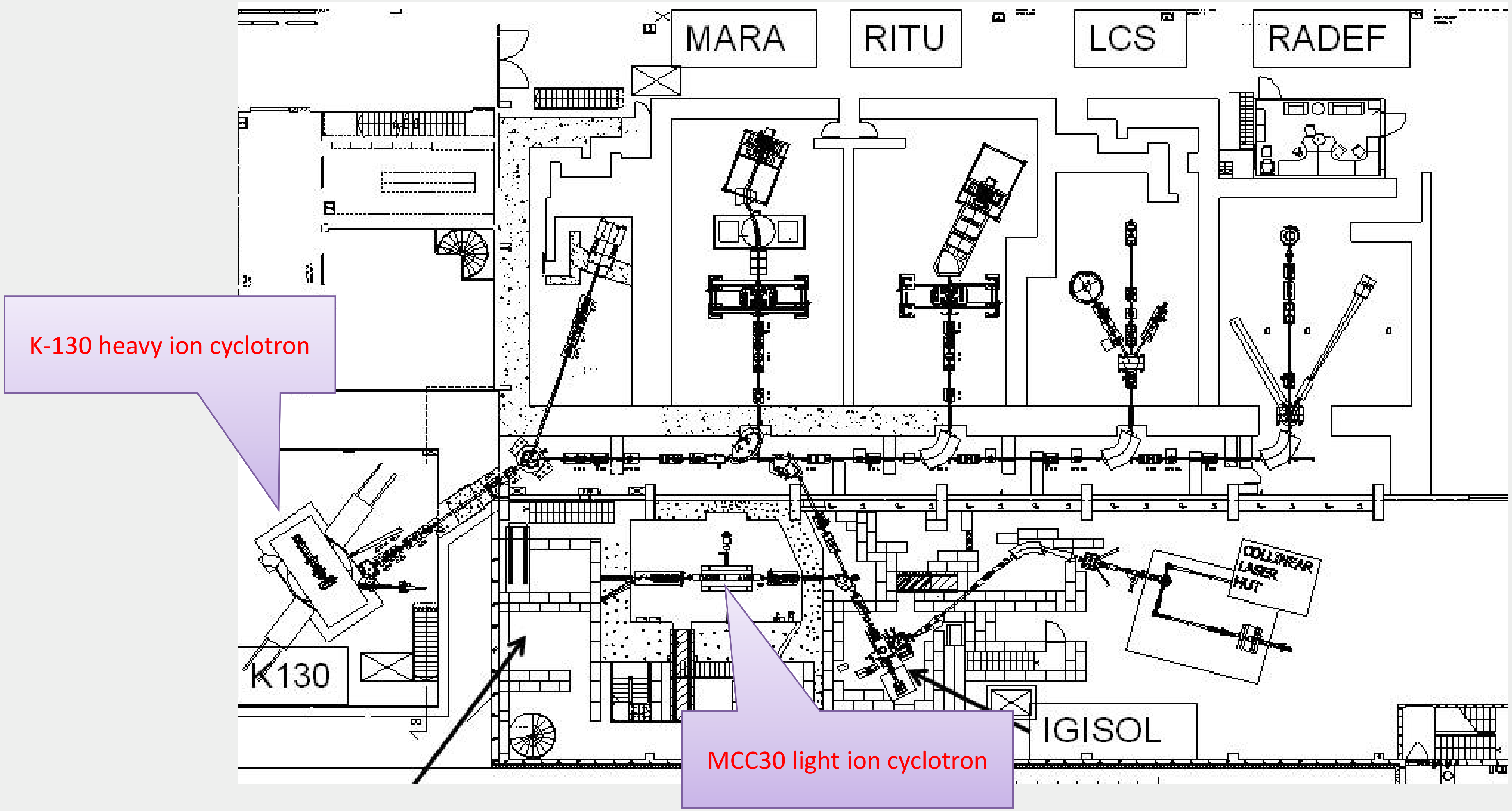
UPPSALA UNIVERSITET

Fast orientation: (i) Jyväskylä

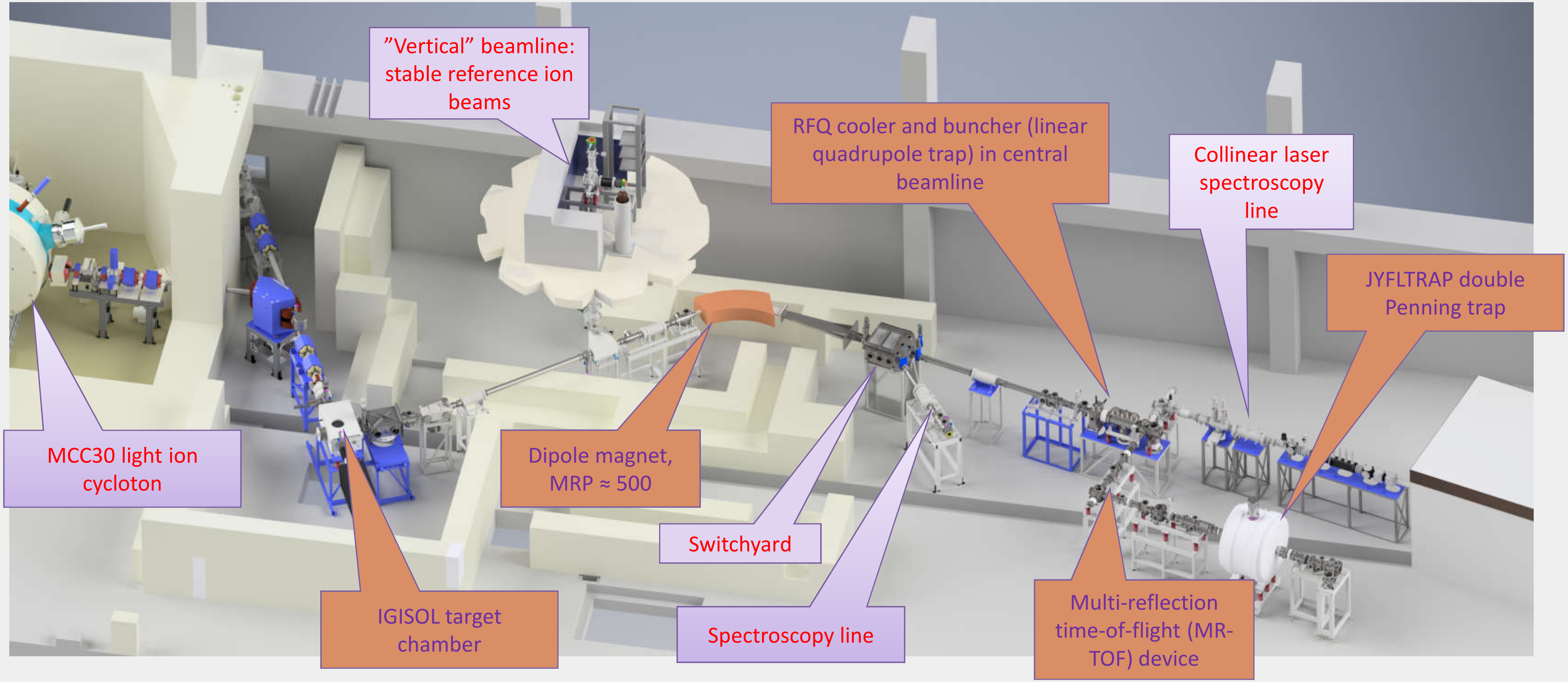


Fast orientation: (ii) JYFL

Fast orientation: (iii) JYFL-ACCLAB



Fast orientation: (iv) IGISOL



Ion guide technique

- Based on survival of primary ions from nuclear reaction in helium buffer gas
- Fast extraction of ions is required to prevent neutralisation
- Charge state concentration: (0), +1, (+2)
- **Ion production independent of chemistry**
  - Produces ions of any element
  - Millisecond time scale
  - Very small decay losses

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Submillisecond On-Line Mass Separation of Nonvolatile Radioactive Elements: An Application of Charge Exchange and Thermalization Processes of Primary Recoil Ions in Helium

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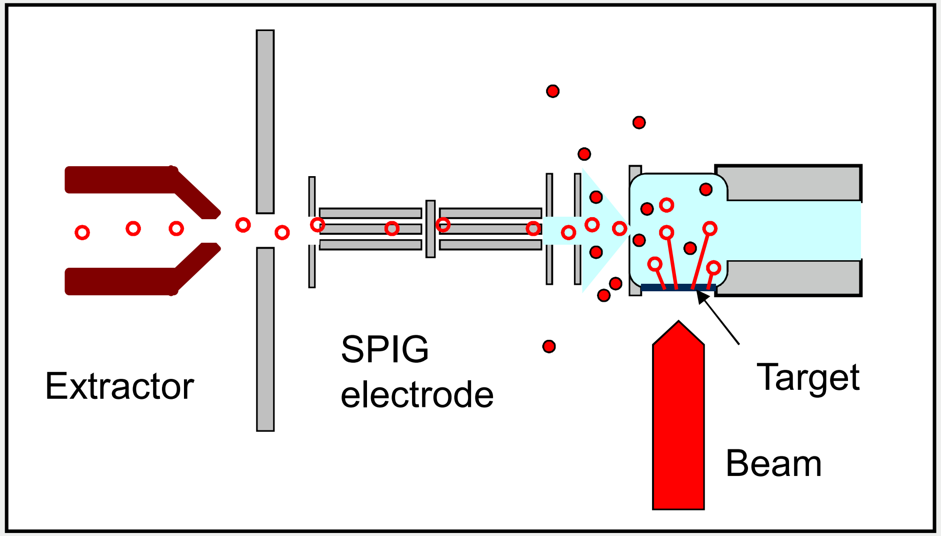
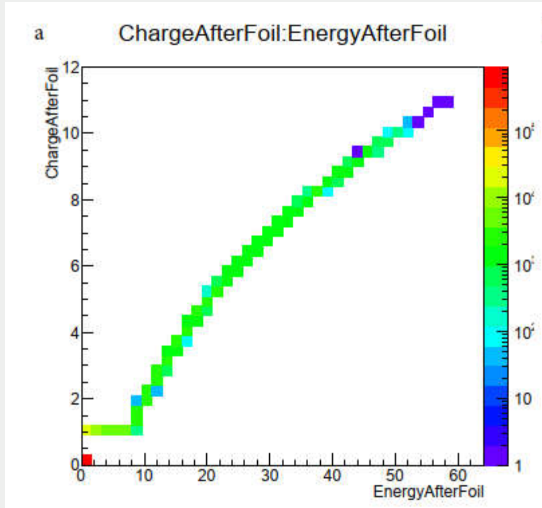
(Received 17 September 1984)

Transportation of thermalized primary recoil ions from nuclear reactions by helium flow has been investigated as a means of injecting short-lived radioactive nuclides into an on-line isotope separator. Several short-lived radioactive isotopes of highly nonvolatile elements such as B, Sc, Nb, and W have been separated. The efficiency for heavy nuclides with half-lives above 1 ms is between 1 and 10%. The shortest-lived activity identified in an on-line separation is the 182-μs isomeric state in ^{207}Bi.



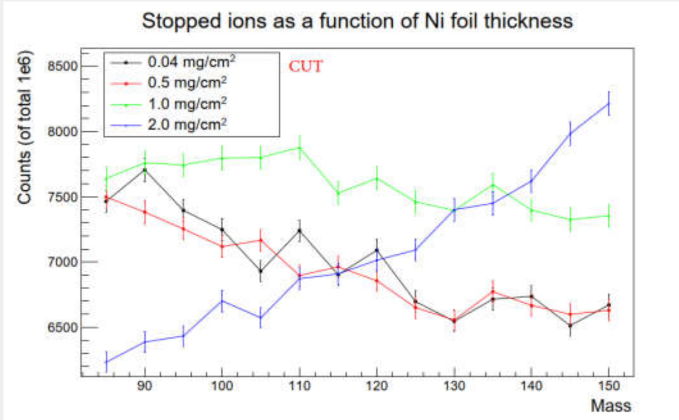


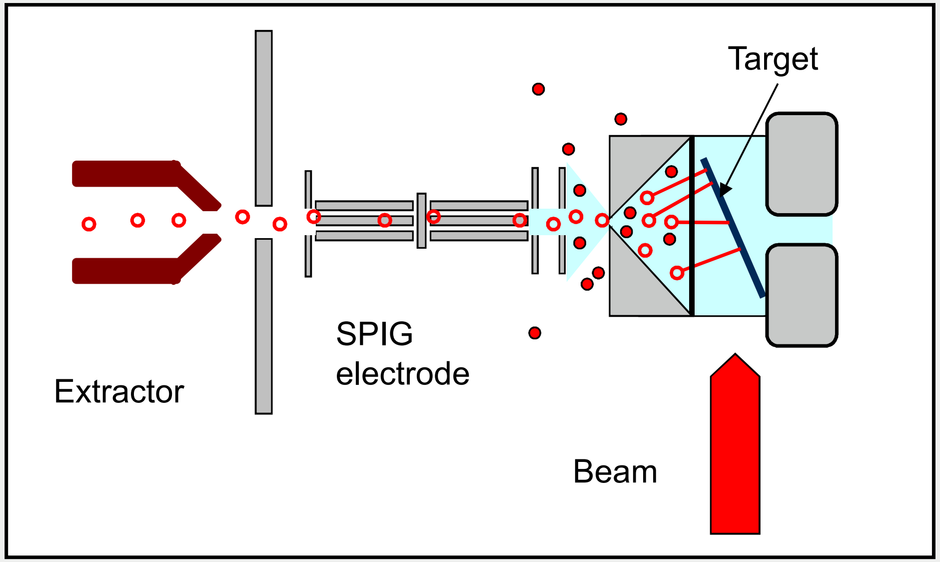
Fission ion guide technique

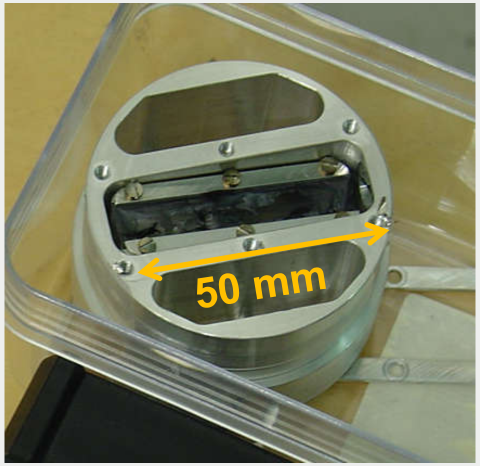
Based on survival of primary ions from nuclear reaction in helium buffer gas
Fast extraction of ions is required to prevent neutralisation
Charge state concentration: (0), +1, (+2)
Produces ions of any element
All elements can be studied

Ions come directly from fission

Ion rate in the formed beam corresponds to the independent fission yield

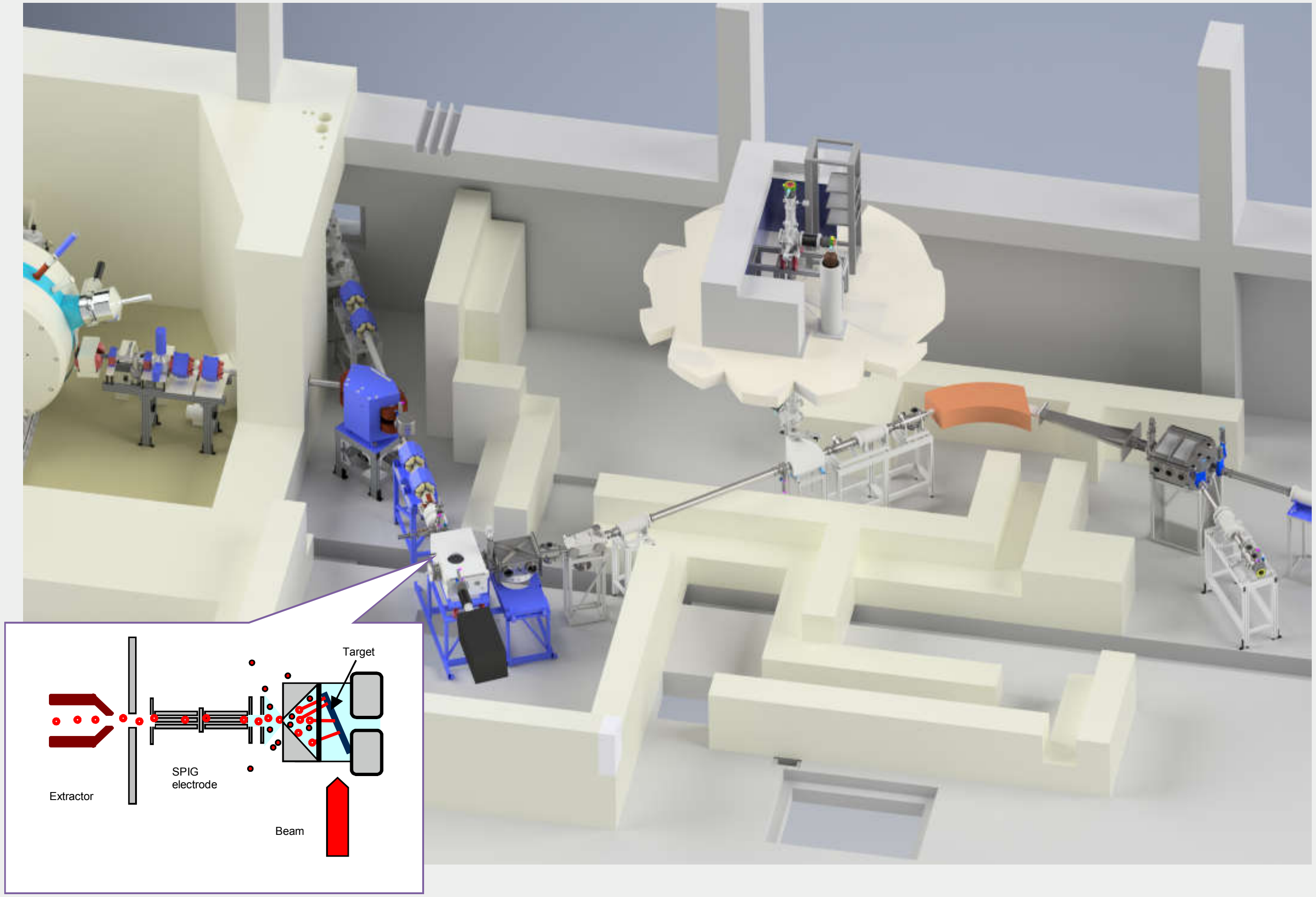


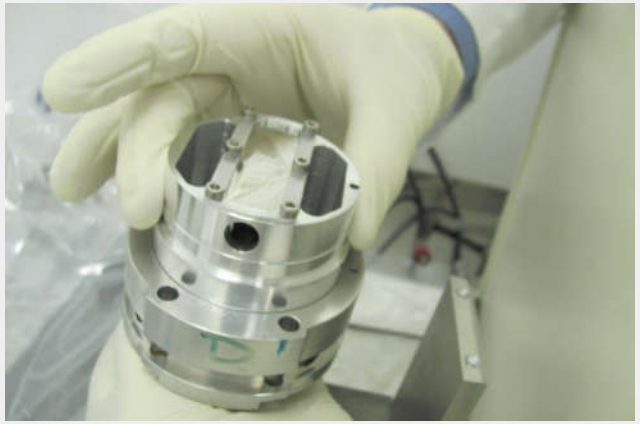




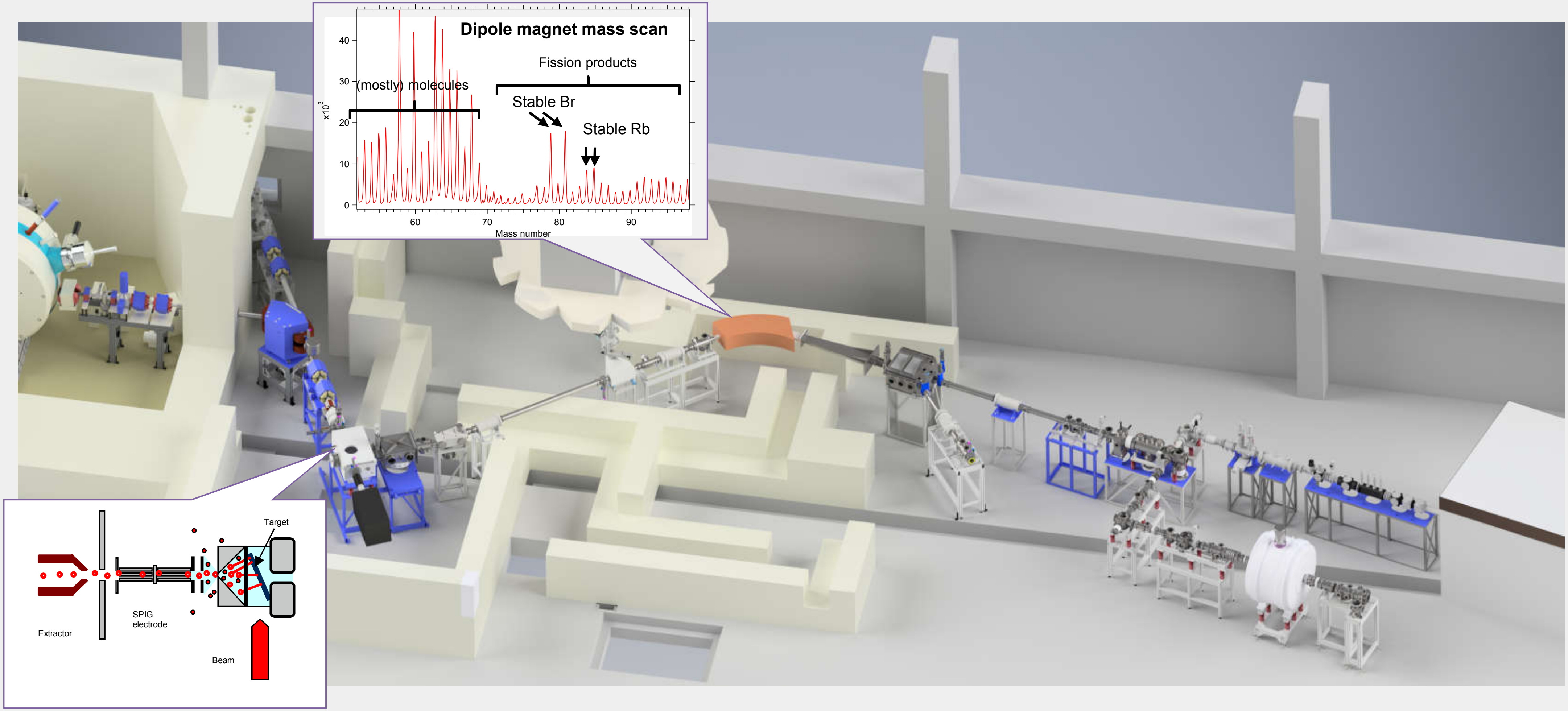
Simulations show that the fission product distribution of the beam is not biased due to the mass of the fission products

The fission ion guide preparation

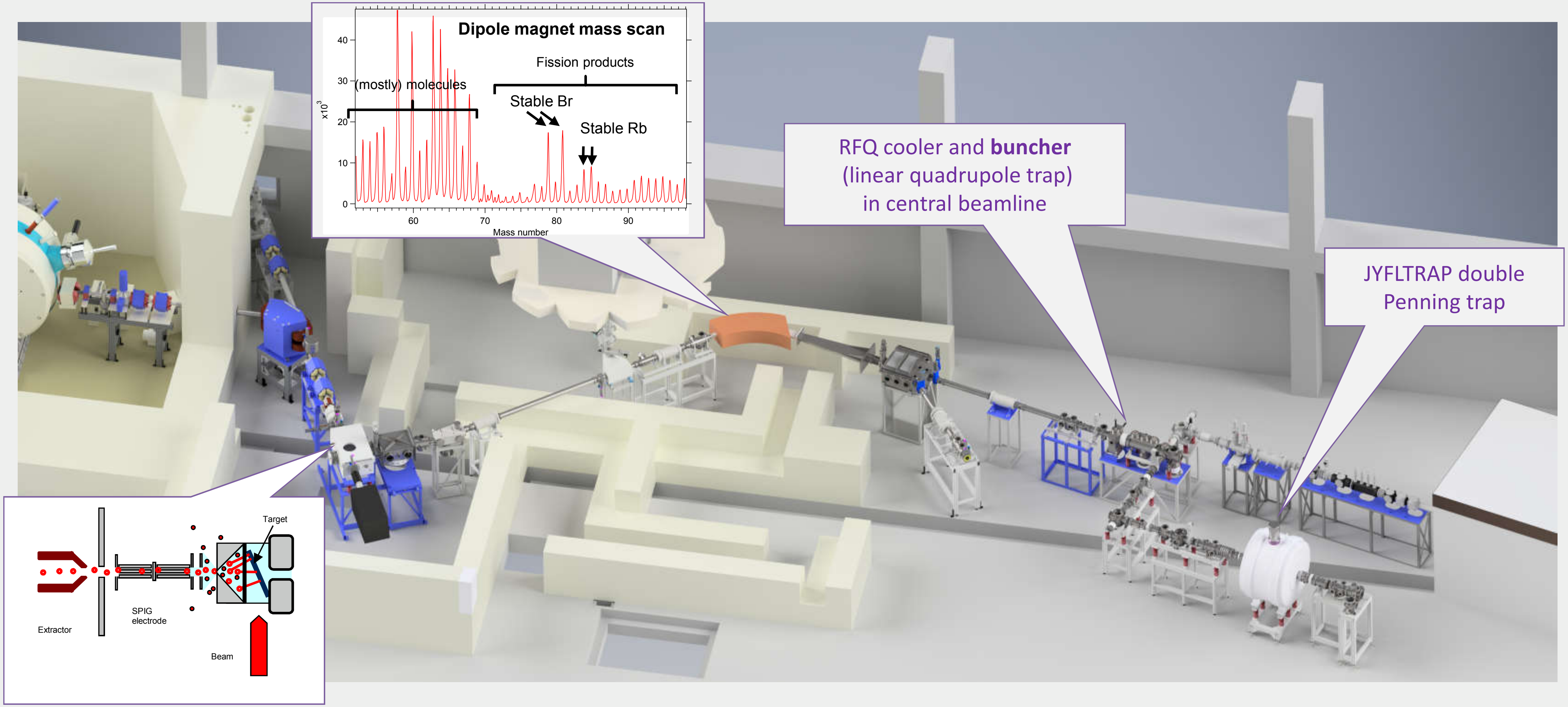




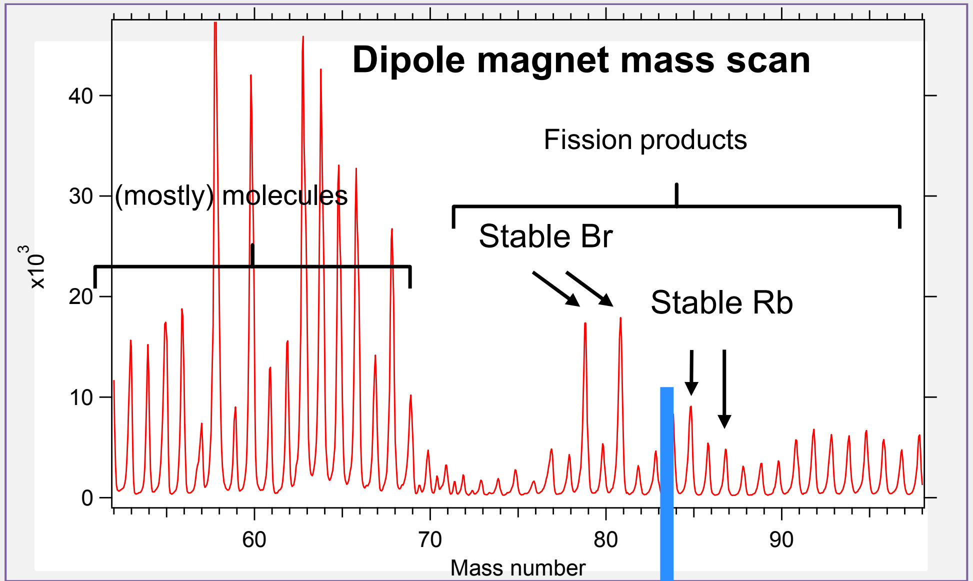
Dipole magnet allows resolving the mass numbers…

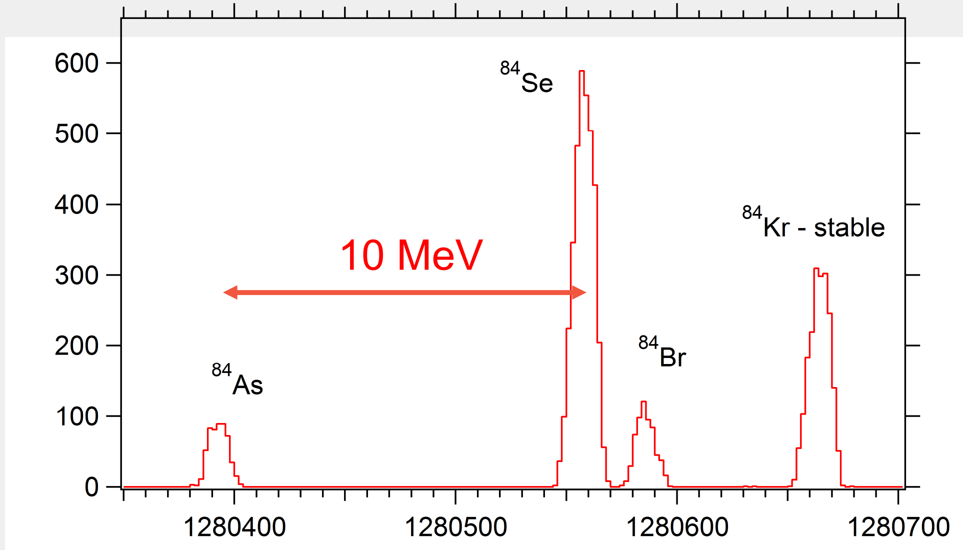


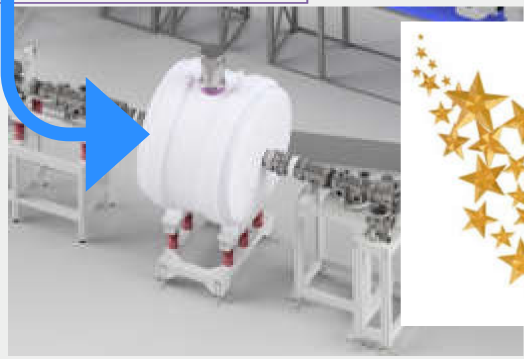
…for finer resolution with the JYFLTRAP



Resolving the isobars with a Penning trap





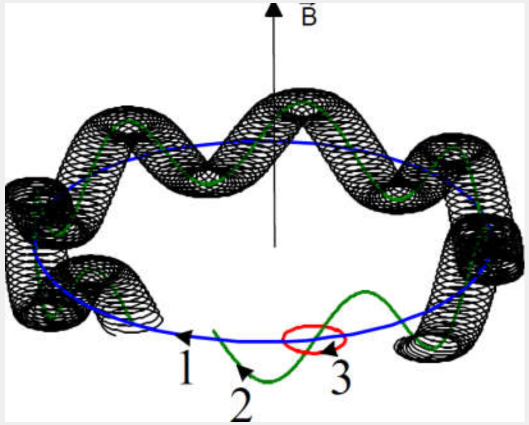


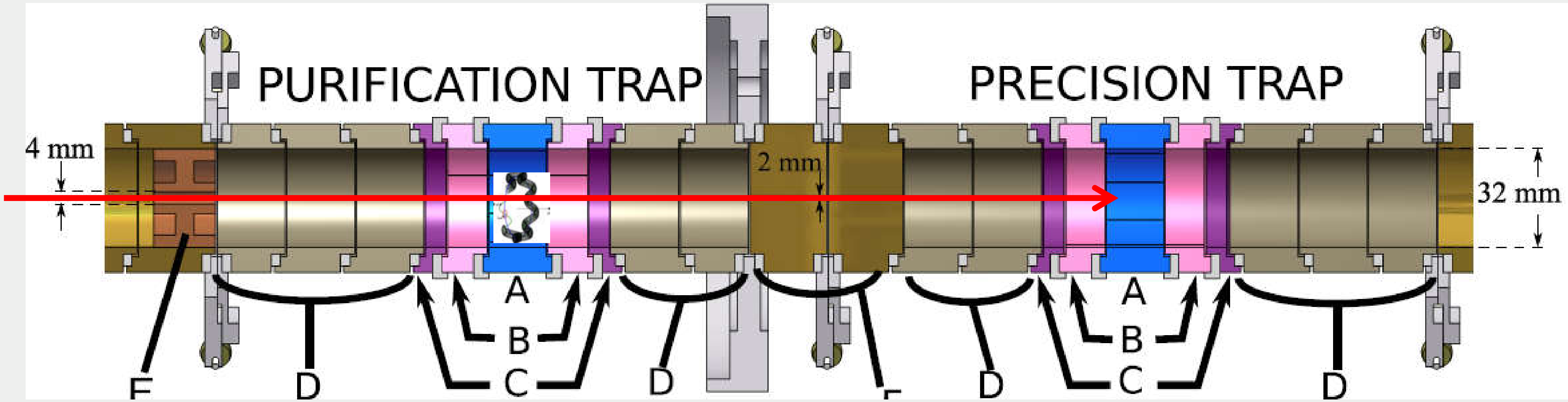
Operation of the purification trap

Charged particle in elecctric fipole magnetic field: three eigenmotions

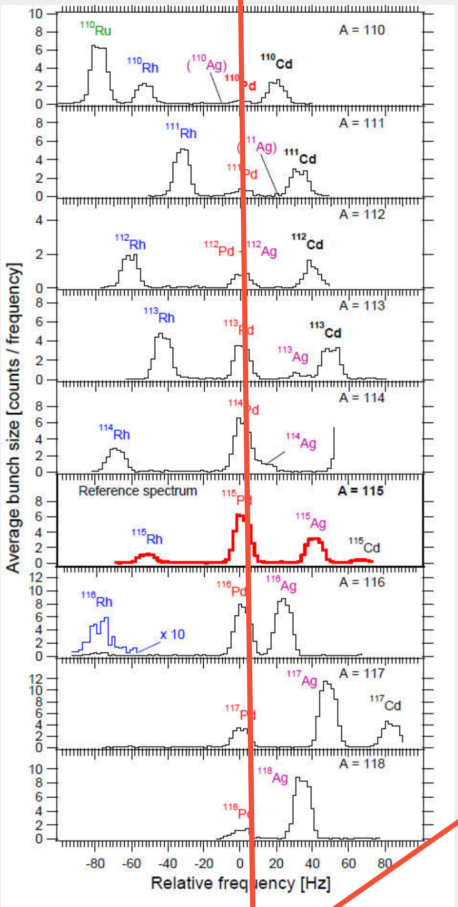
1. Modified cyclotron motion (large loop in the figure)
3. Magnetron motion (tiny loop in the figure)
2. Transversal motion

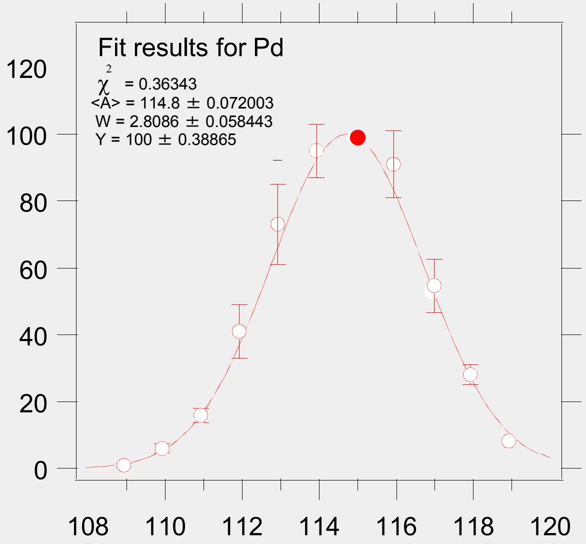
1 and 3 can be changed to each other; the change is mass selective





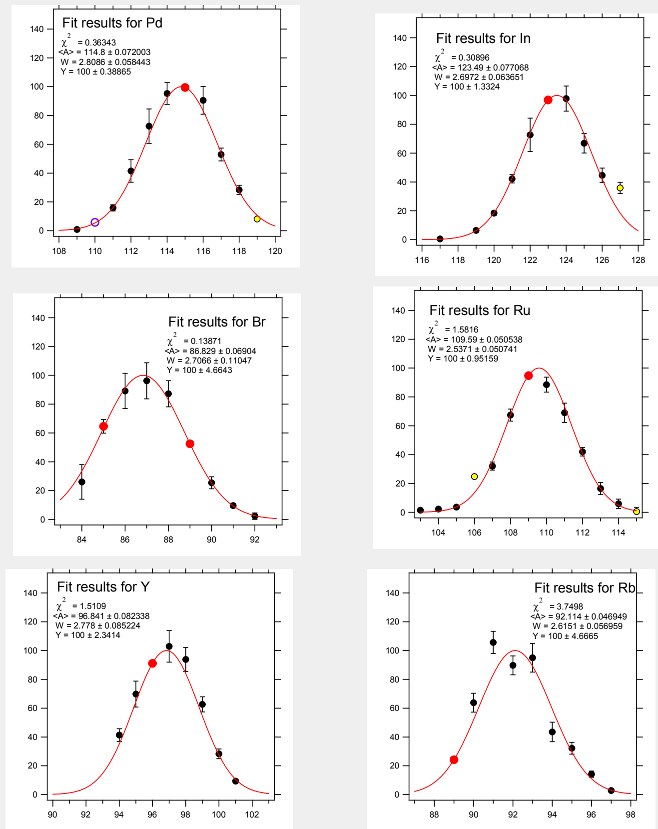
How to properly extract your yields?



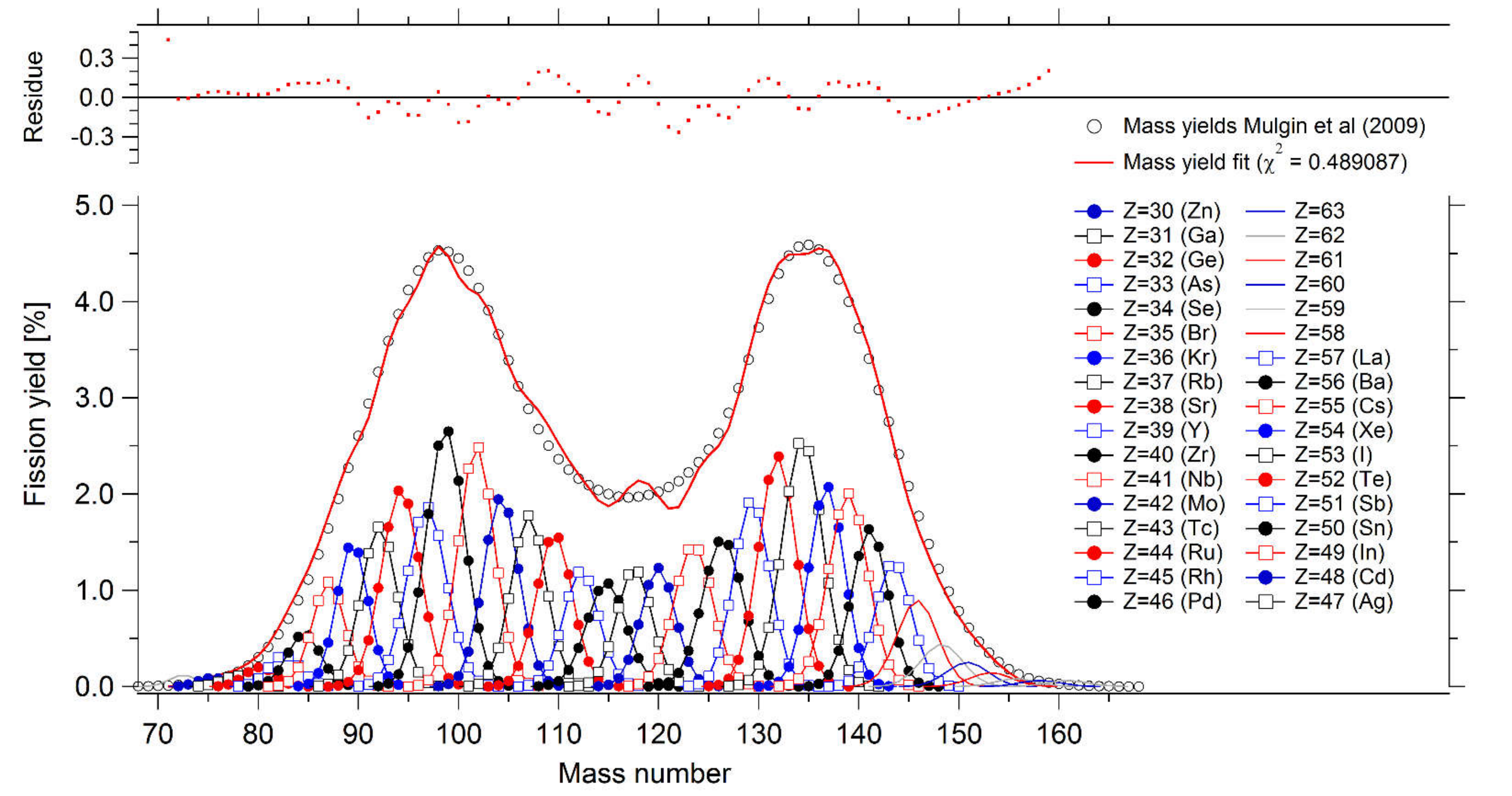


Element-dependent (chemical) effects in transmission same for all isotopes of the same element

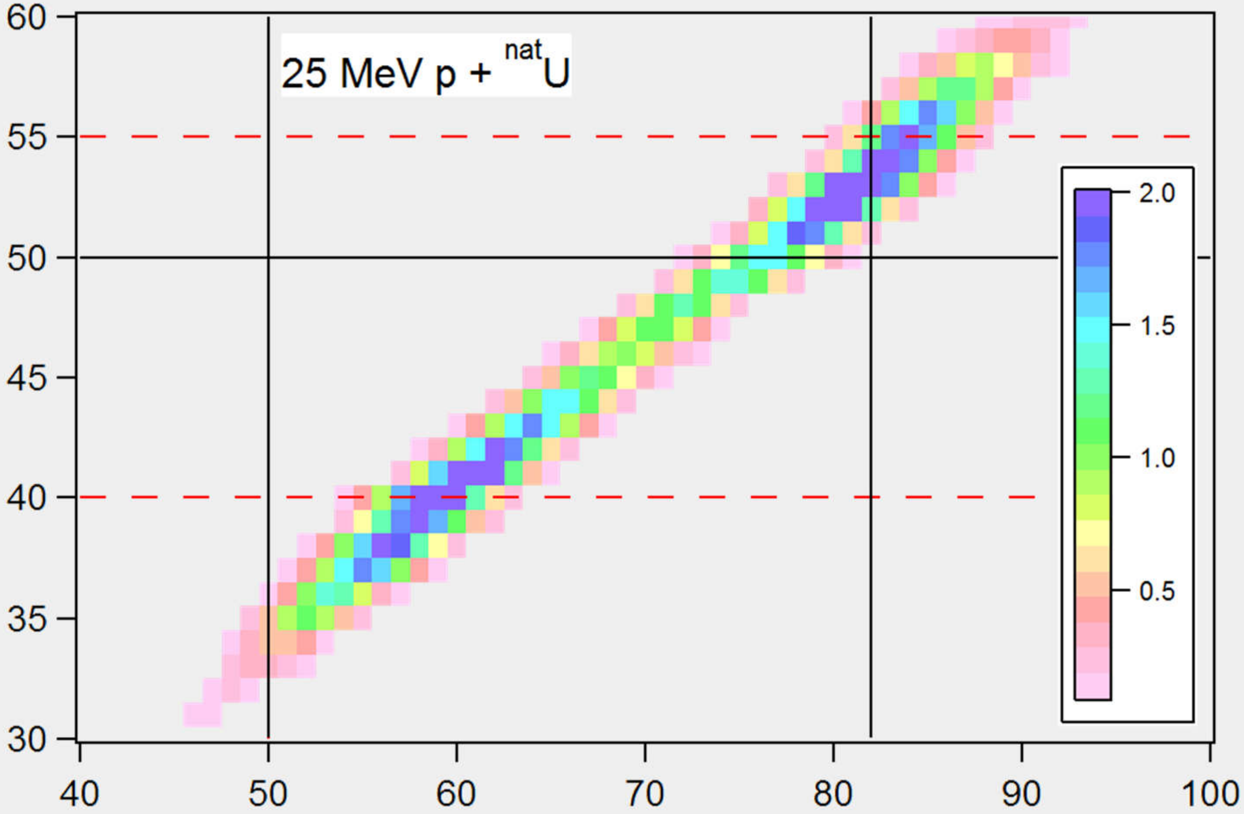
Independent isotopic FY measured



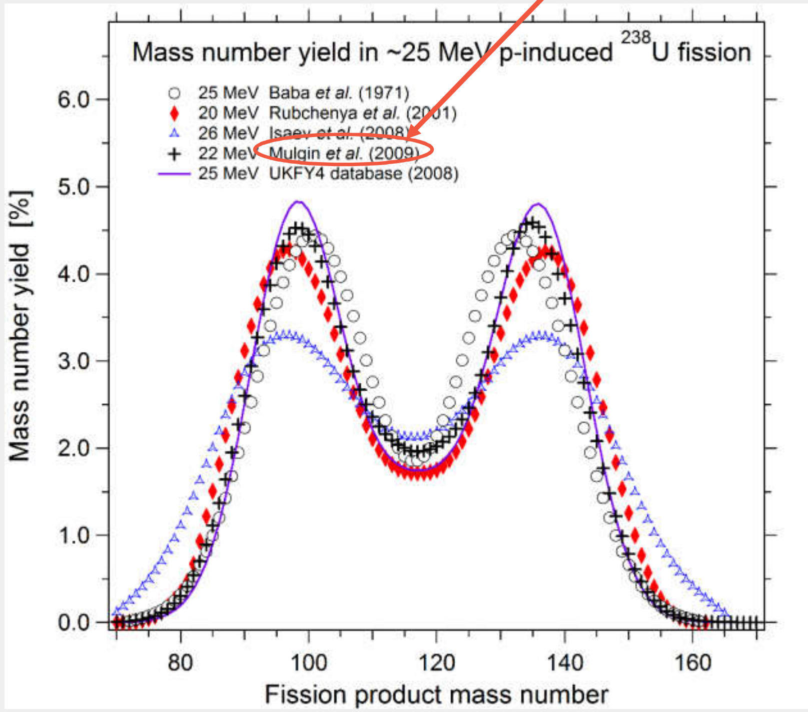
From independent isotopic yields to independent FY



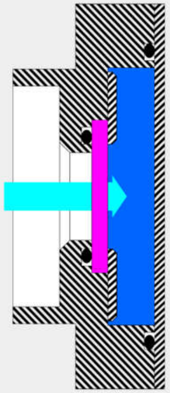
Independent fission yields and mass yield market

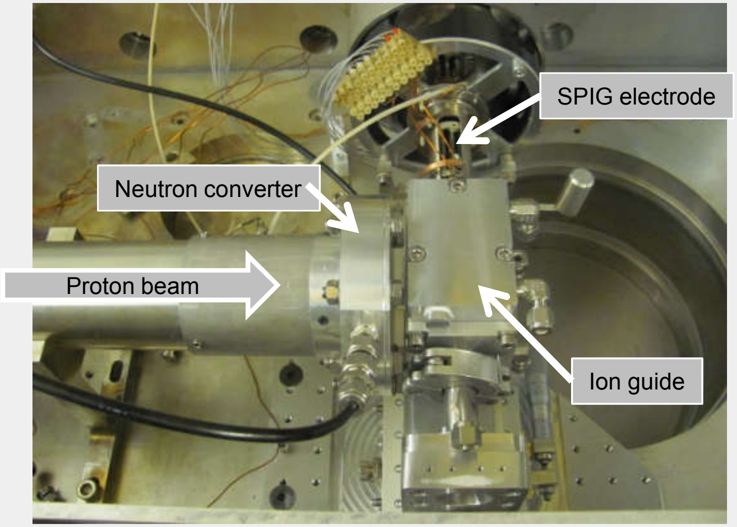


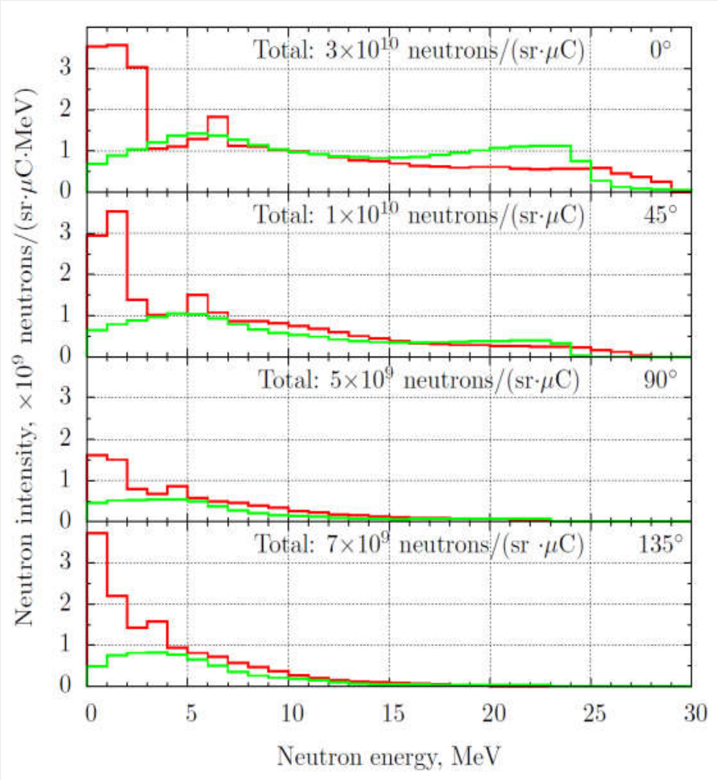
The Institute of Nuclear Physics
Ministry of Energy of the Republic of Kazakhstan



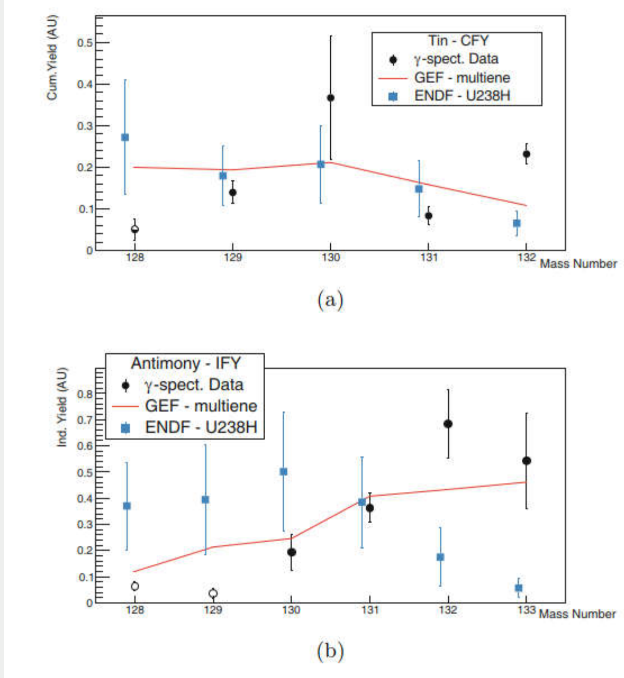
Neutron induced fission







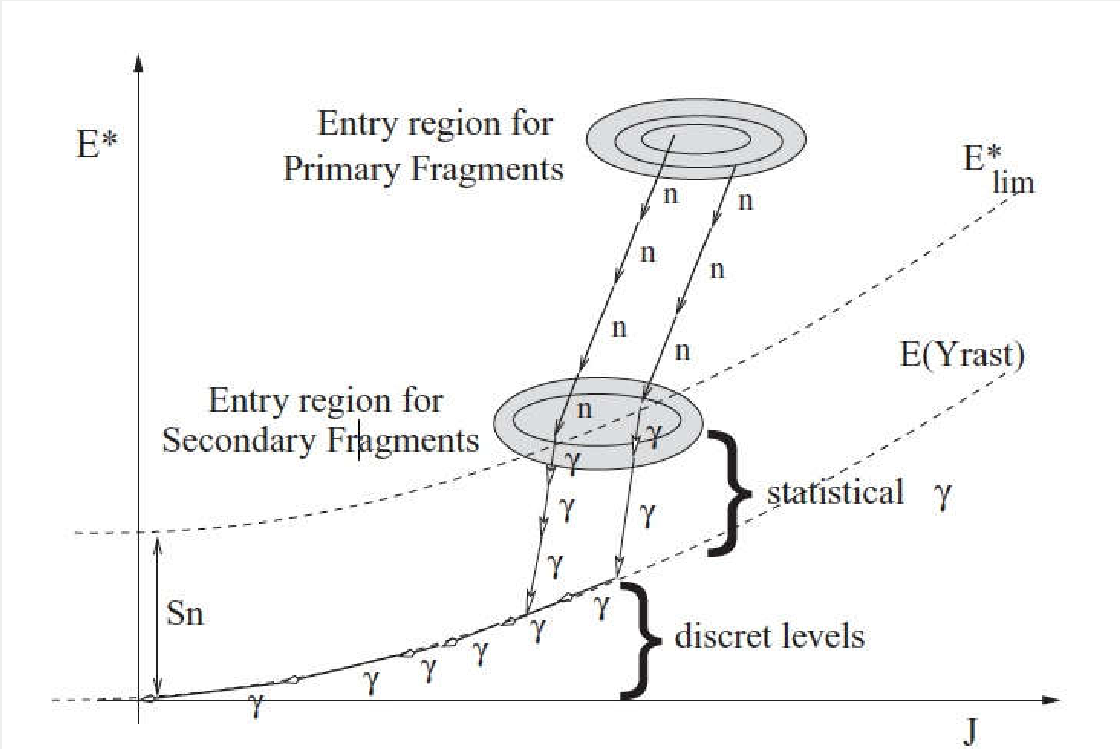
Eur. Phys. J. A (2018) **54**: 33
DOI 10.1140/epja/i2018-12462-1



A design of a large gas cell is in progress is in progress with the support of European Commission (SANDA project)

Isomeric yield ratios and separation of isomers

Isomeric yield ratio measurements give a handle on the initial spin of fission fragments

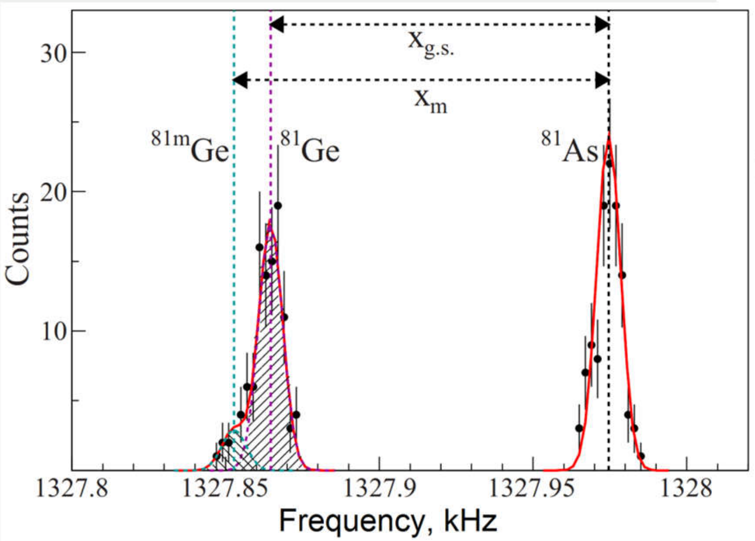


O. Litaize and O. Serot,
PRC 82, (2010)

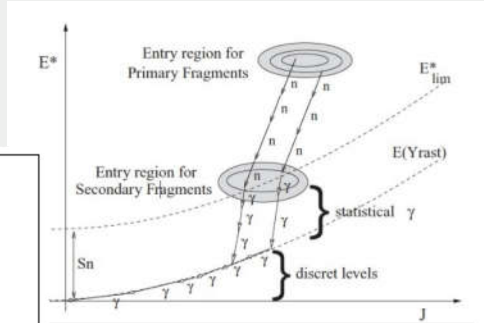
Isomeric yield ratios and separation of isomers

Isomeric yield ratio measurements give a handle on the initial spin of fission fragments

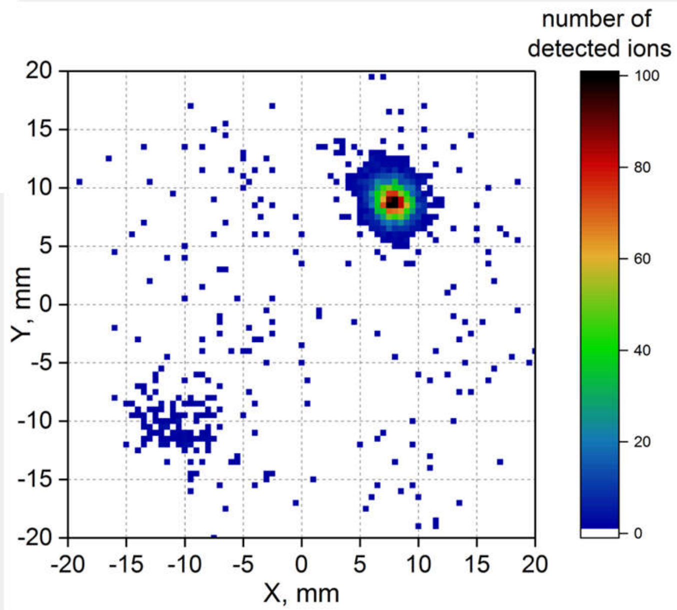
JYFLTRAP:
Buffer-gas cooling technique



V. Rakopoulos et al., PRC 98, 024612 (2018)

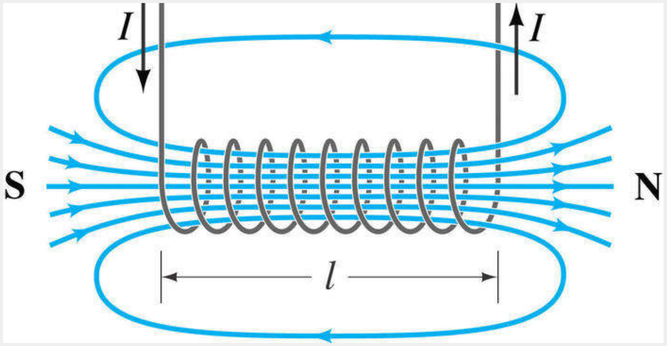


JYFLTRAP: PI-ICR, t_{acc} = 42 ms



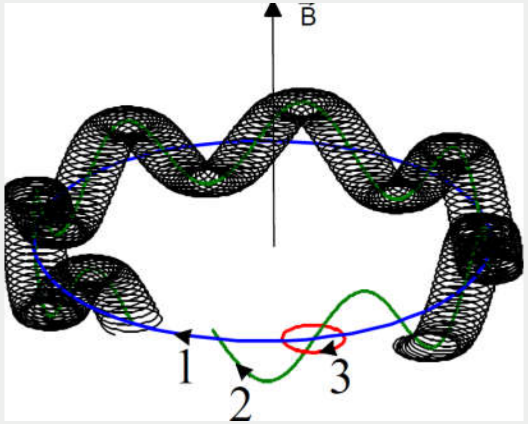
Results (YIR) from both techniques are in a good agreement!

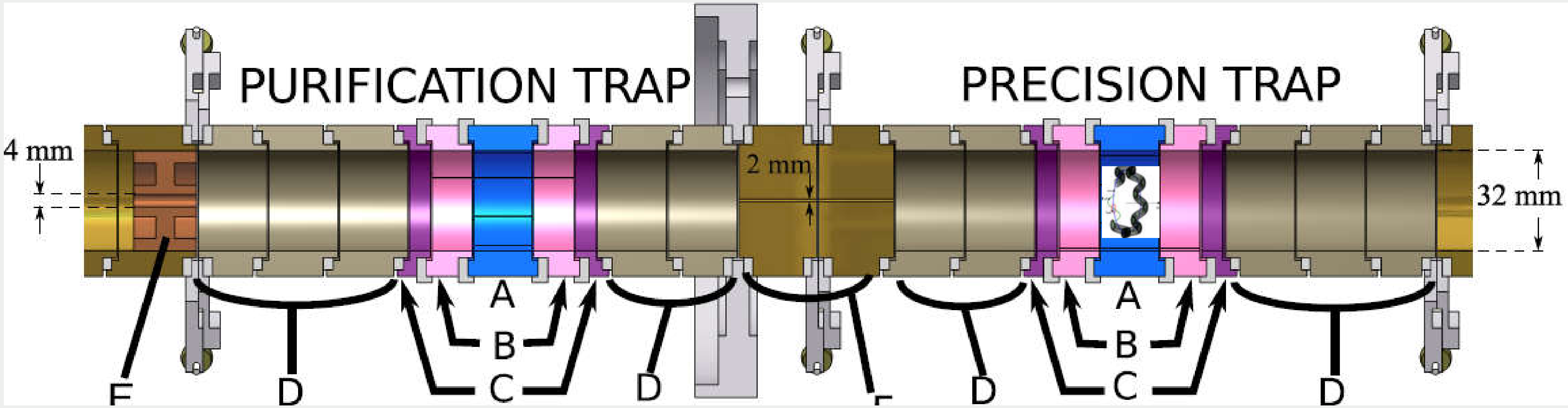
Principle of position imaging spectrometry



Charged particles follow the field lines – the field magnifies the distance or a released particle from trap center

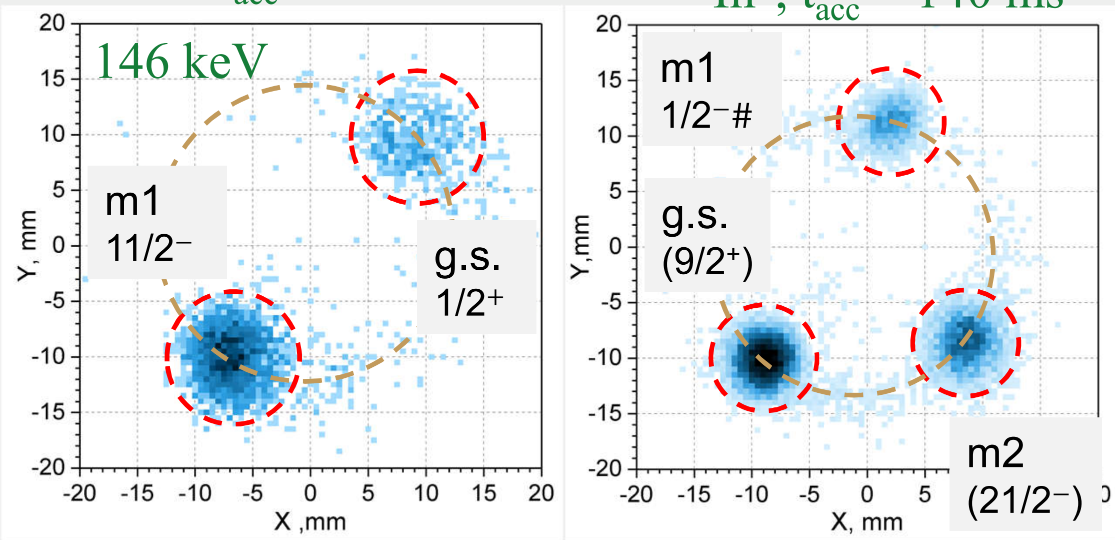
Magnetron motion velocity depends on ion mass





Separation of isomers

$^{119}Cd^{+}$, $t_{acc} = 416$ ms $^{127}In^{+}$, $t_{acc} = 140$ ms



→ Isomeric yield ratios

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Conclusions

A technique to determine **independent fission yields** with a Penning trap has been developed in JYFL accelerator laboratory in the University of Jyvaskyla.

The method determines relative independent isotopic fission yields. If the mass yields and total fission cross section are known, the absolute independent fission yields can be extracted.

Method has been commissioned by proton induced fission of ^{nat}U. It has been utilised to proton induced fission of natural thorium, deuterium induced fission of natural uranium, and fast neutron induced fission of natural uranium.

In addition, method has been applied to determine the isomeric yield ratios in fission. The recent PI-ICR (position imaging ion cyclotron resonance) technique that allows separating isomers with mass difference as low as 50 keV has allowed systematic precision studies in this field.

Preparations to improve the yield of neutron induced fission products to study the neutron induced fission yields are underway, partly supported by European Commission.

Acknowledgement and other praises

JYFL-IGISOL: H. Penttilä, A. Jokinen, I.D.Moore, J. Äystö, V.A. Rubchenya, S. Rinta-Antila, V. Kolhinen, T. Eronen, A. Kankainen, A. Voss, D. Gorelov, J. Hakala, V. Simutkin, V. Sonnenschein, I. Pohjalainen, J. Koponen, J. Reinikainen, O. Beliuskina, L. Canete, A. de Roubin, M. Hukkanen, D. Nesterenko, I. Pohjalainen, M. Vilén, V.Virtanen

Uppsala University: A. Al-Adili, K. Jansson, M. Lantz, A. Solders, C. Gustavsson, **A.Mattera**, A. V. Prokofiev, **V. Rakopoulos**, D.Tarrío, S. Wiberg, M.Österlund, S. Pomp

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In addition, a really marvellous proof of the true meaning of life was discovered during these studies, which this margin is too narrow to contain