Pursuing mass resolving power of 10^6: Commissioning of IGISOL 4

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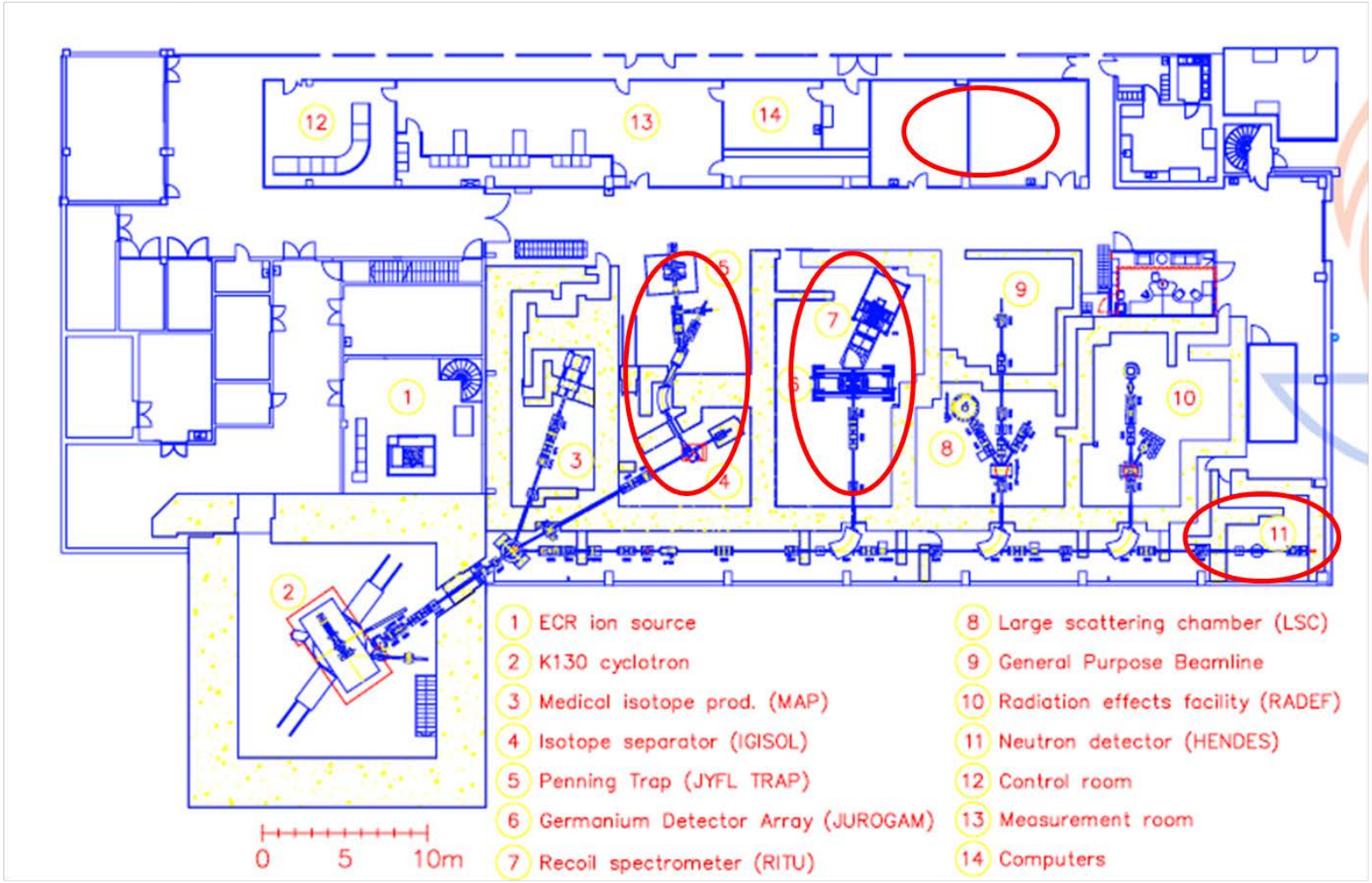
Special thanks to I.D. Moore and D.Gorelov

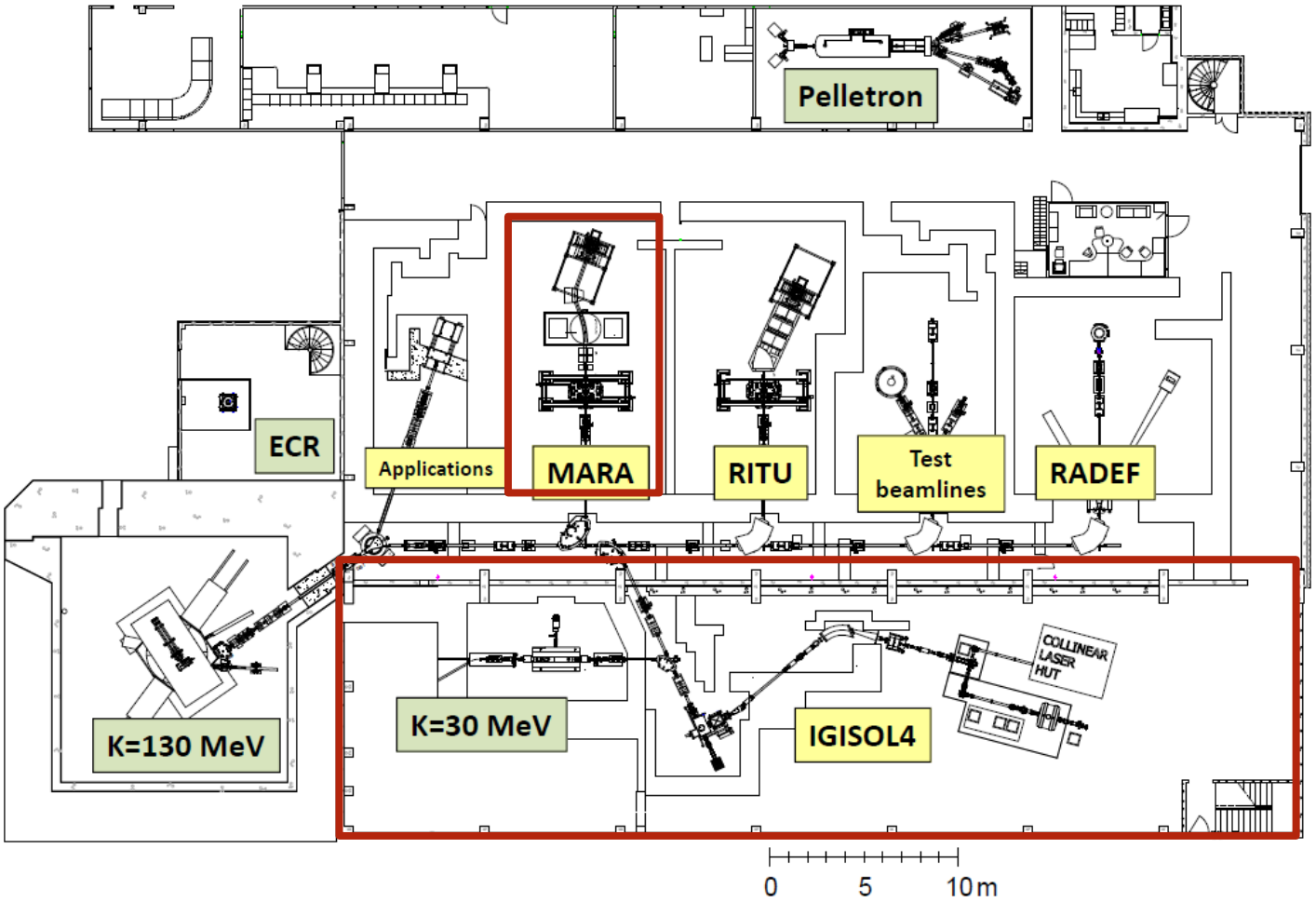
JYFL


JYFL = Jyväskylän Yliopiston Fysiikan laitos
= Department of Physics, University of Jyväskylä

JYFL laboratory layout



JYFL ACCLAB, ca. 2014



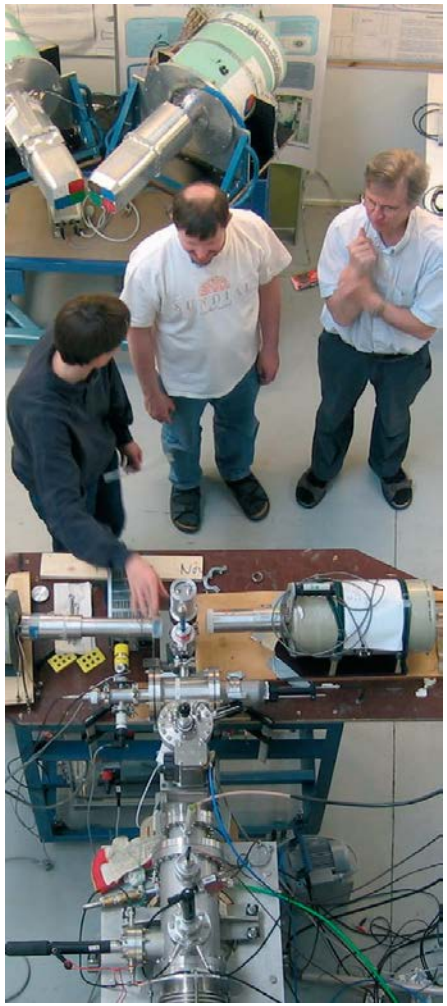
The new MCC30/15 aka K-30 cyclotron

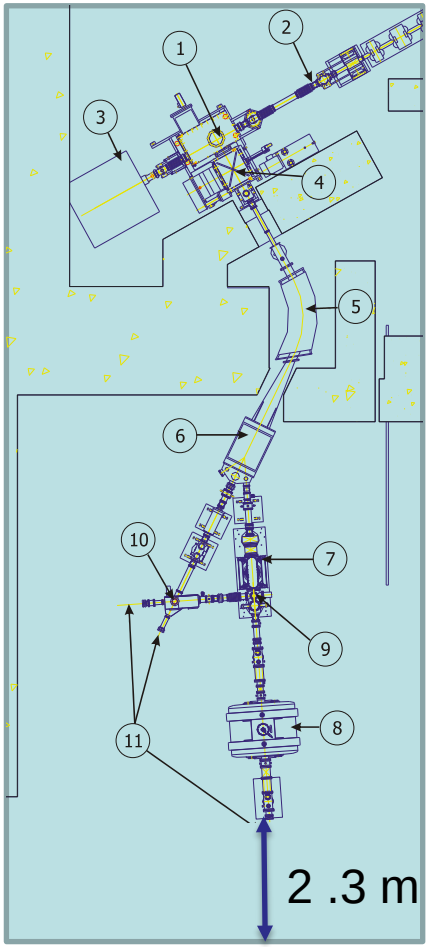
- From D.V. Efremov Scientific Research Institute of Electrophysical Apparatus
- Delivery based on the Intergovernmental Agreement between Finland and Russia regarding compensation of part of the former Soviet Union debt to Finland
- Decision signed June 19, 2007
- Delivery August 10, 2009
- Inauguration November 15, 2010

Photo: Wladek Trzaska

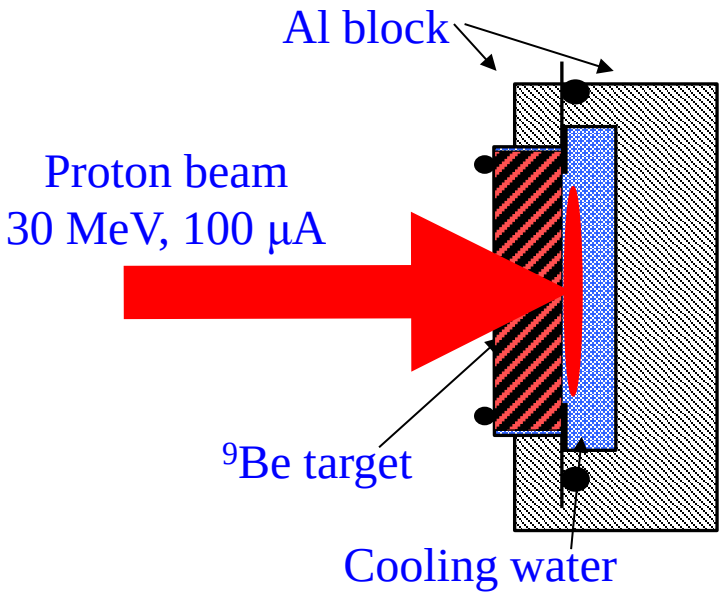
Beam	H− d− Beam current	18 – 30 MeV 9 – 15 MeV 100/50 uA
Power consumption	Stand by Beam on	< 15 kW < 120 kW
Magnetic structure	Magnet diameter Pole diameter sectors weight	2500 mm 1400 mm 4 45 tons
RF−system	Frequency	40.68 MHz
	Number of dees	2
	Dee voltage	35 – 40 kV
	RF−gen. power	25 kW
Ion source	external CUSP	

IGISOL-3 growing out of its craddle

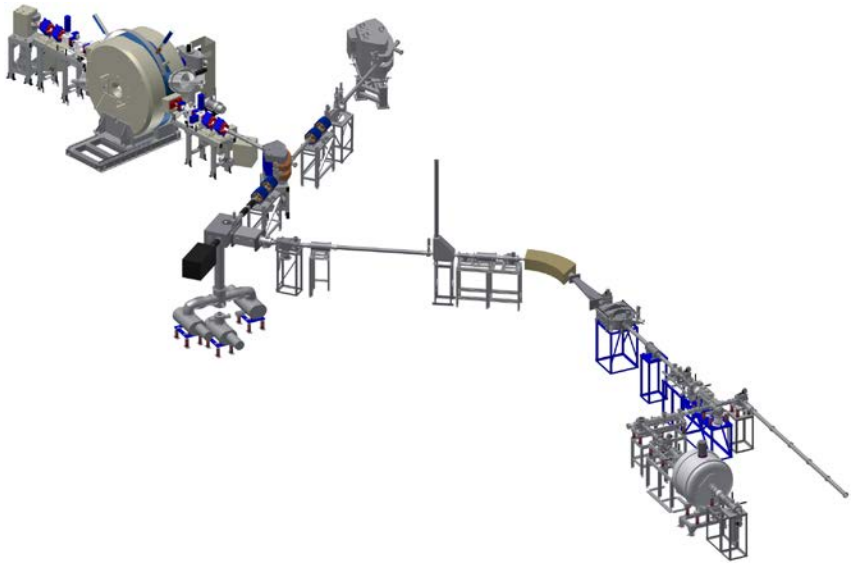




Reasons to move IGISOL



- IGISOL is the main user of proton beams
- high intensity p and d beams available from the new MCC30/15 cyclotron
- possibility to gain from neutron induced fission
- better access with laser beams to the target area and the RFQ
- new test ion source allowing continious operation of JYFLTRAP (offline during front end cooling)
- more effective beam transportation to the beam yard
- more space for experimental setups



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)
- 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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Department of Physics, University of Jyväskylä, SF-40100 Jyväskylä, Finland

and

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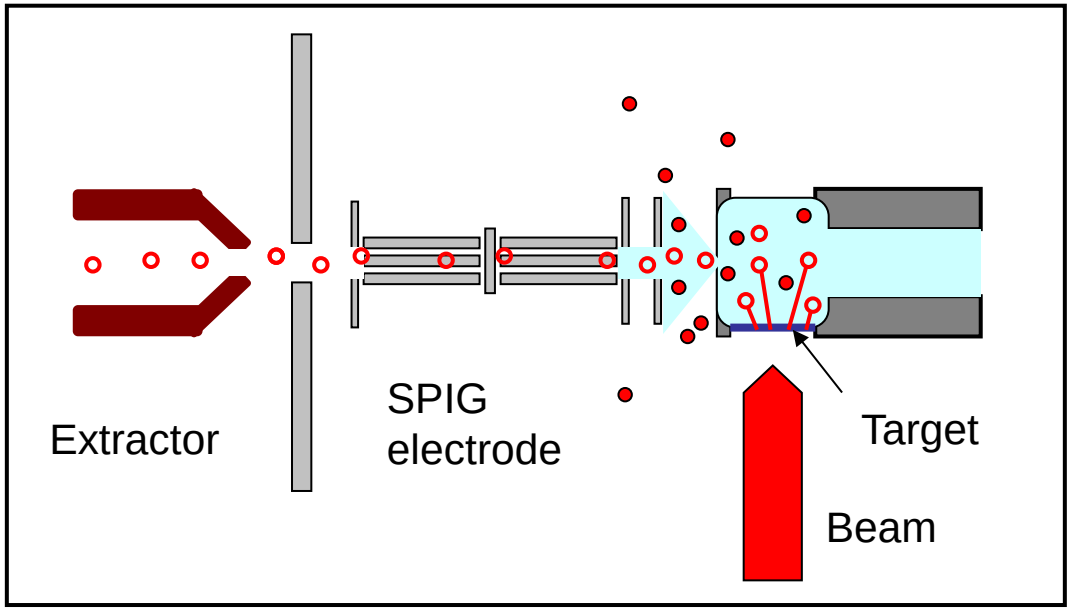
Department of Physics, University of Helsinki, SF-00170 Helsinki, Finland
(Received 17 September 1984)

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 ^{197}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)

Independent of chemistry

Produces ions of any element

Millisecond time scale

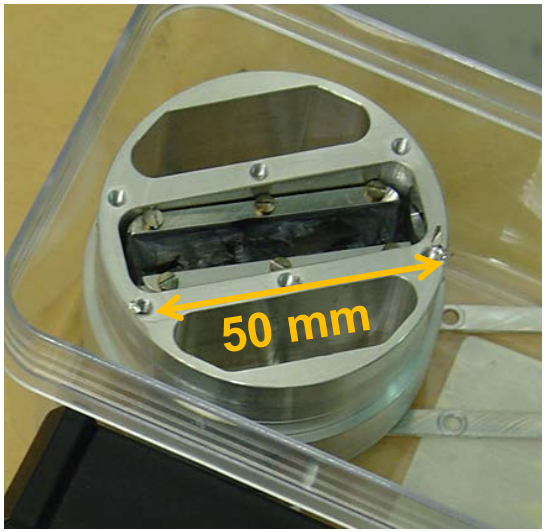
Very small decay losses

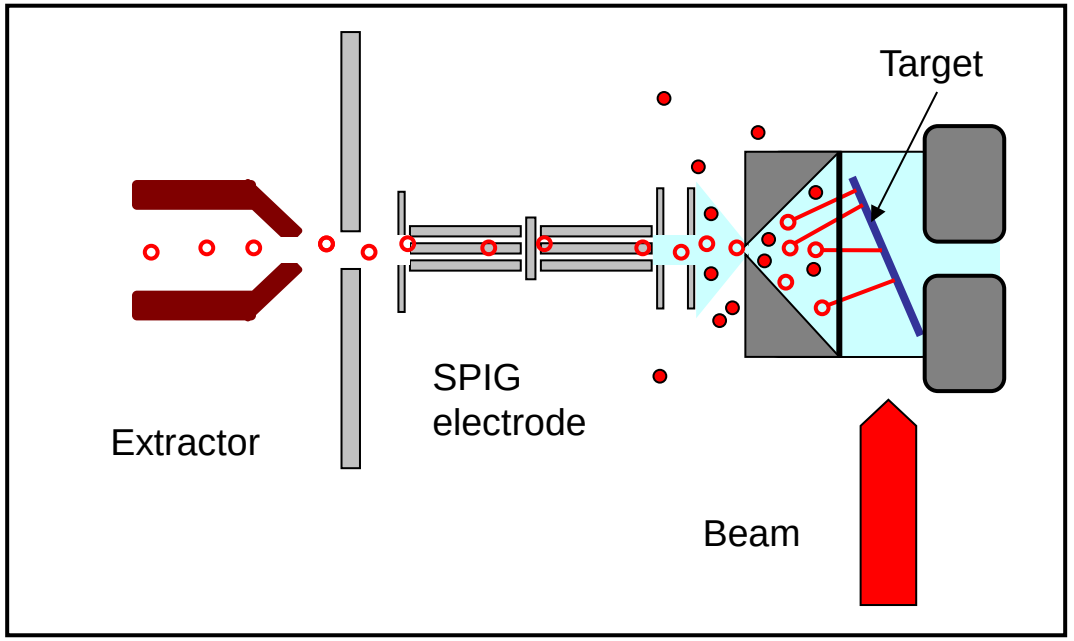
All ions come **directly from fission**

Ion rate corresponds to the independent fission yield -

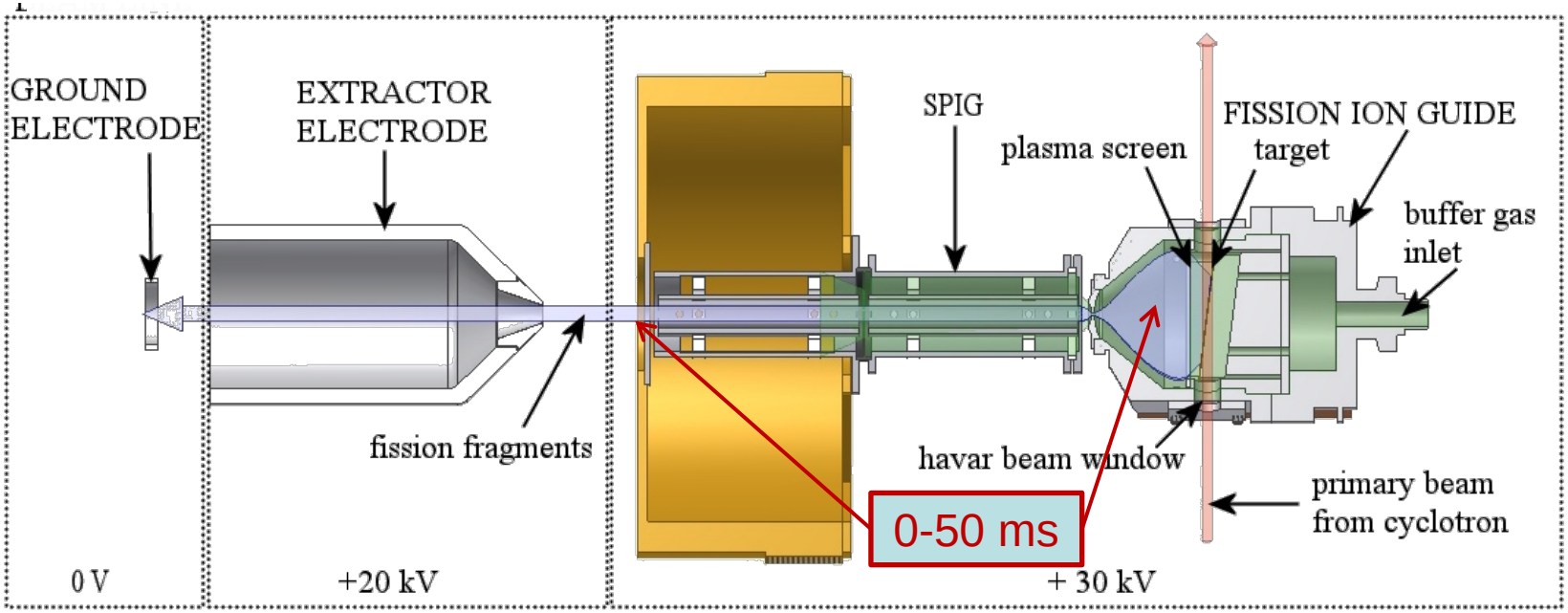
No gaps in the systematic studies

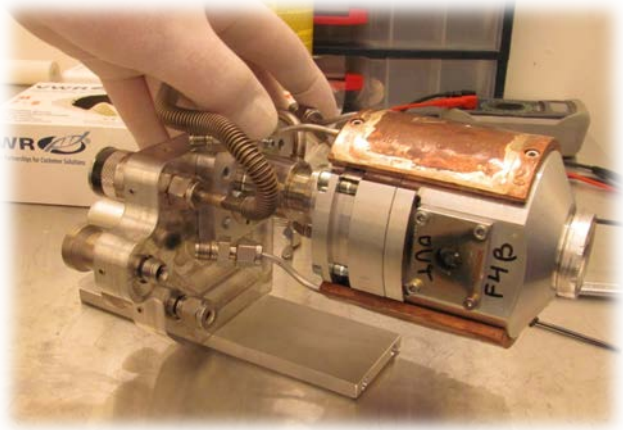
Study the most neutron rich nuclei produced in the fission (isobaric background usually sets the limit)

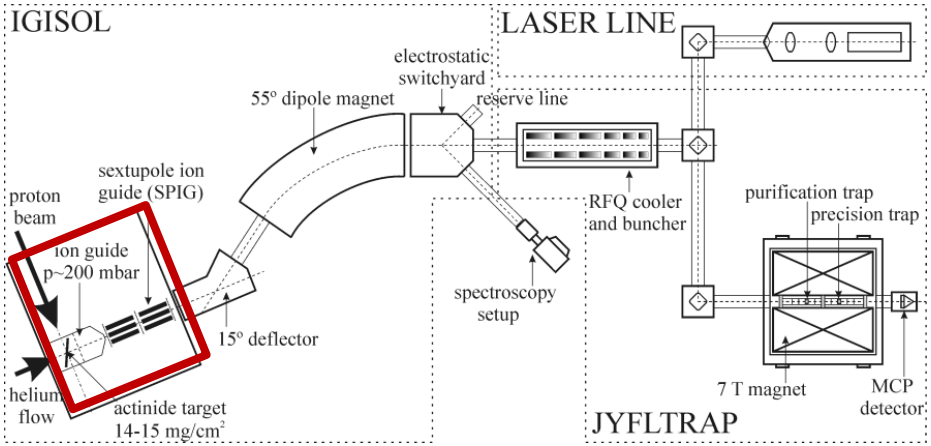




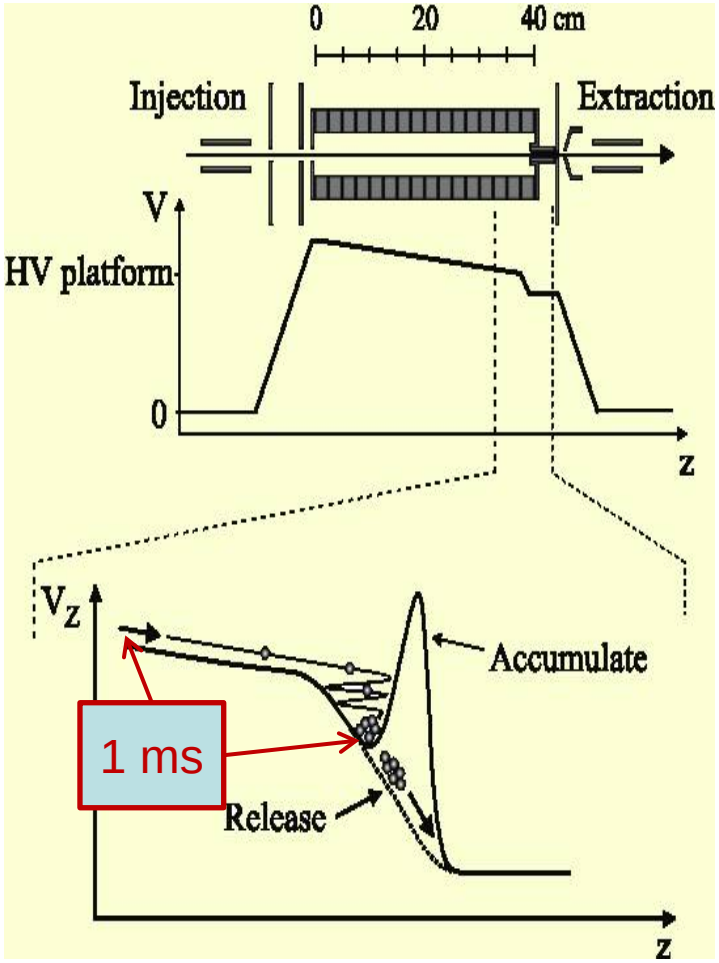
Isotopical purification with JYFLTRAP



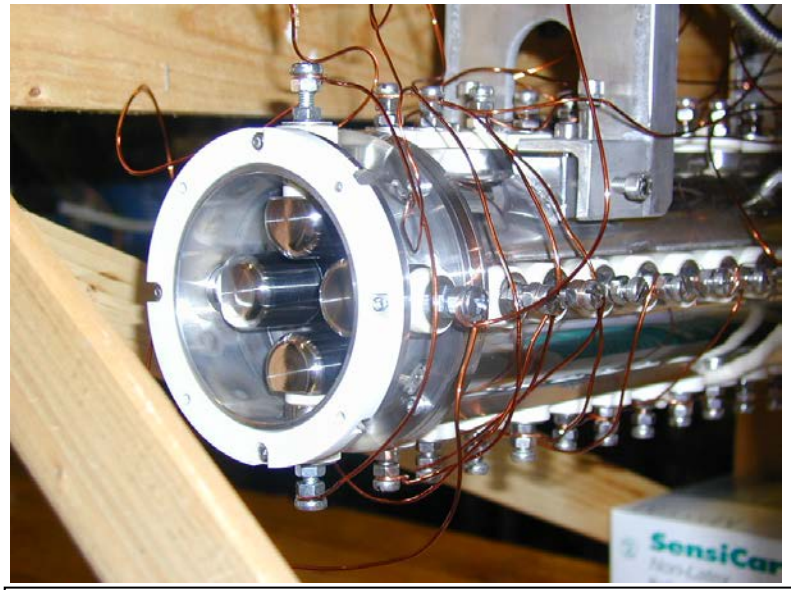




RFQ: get your ions cool and bunched

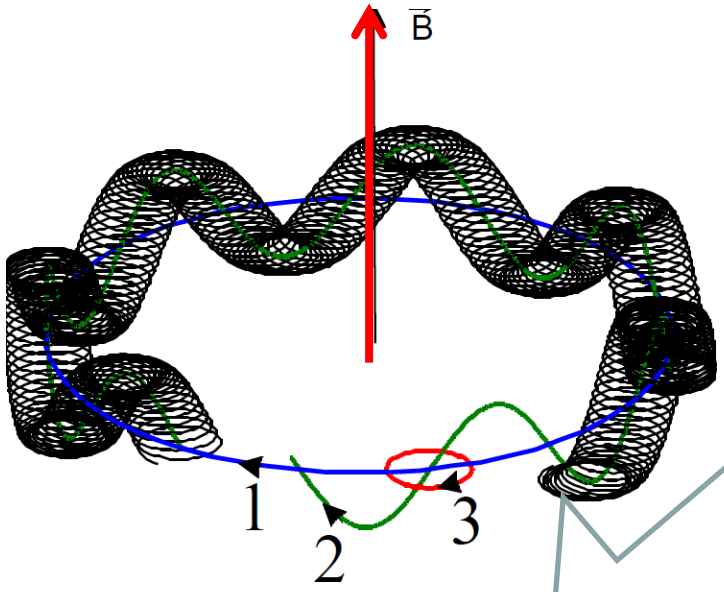


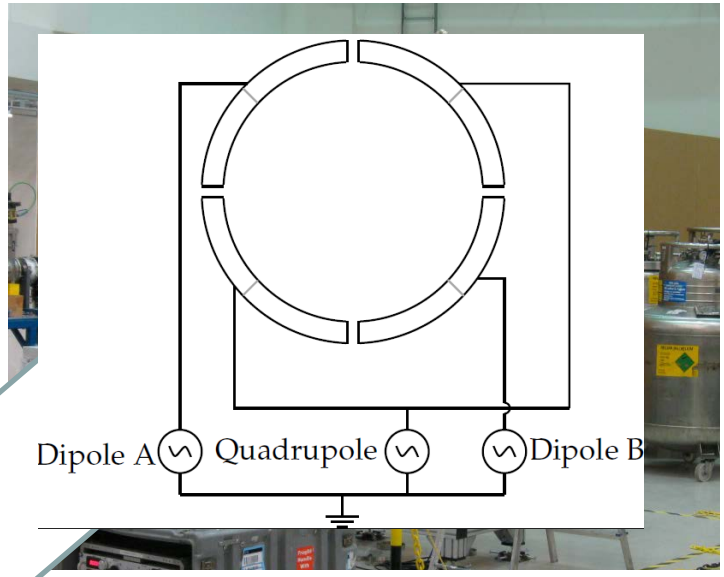
A. Nieminen *et al.*, Nucl .Instr. Meth. A 481 (2001) 244
P. Campbell *et al.*, Phys. Rev. Lett. 89 (2002) 082501

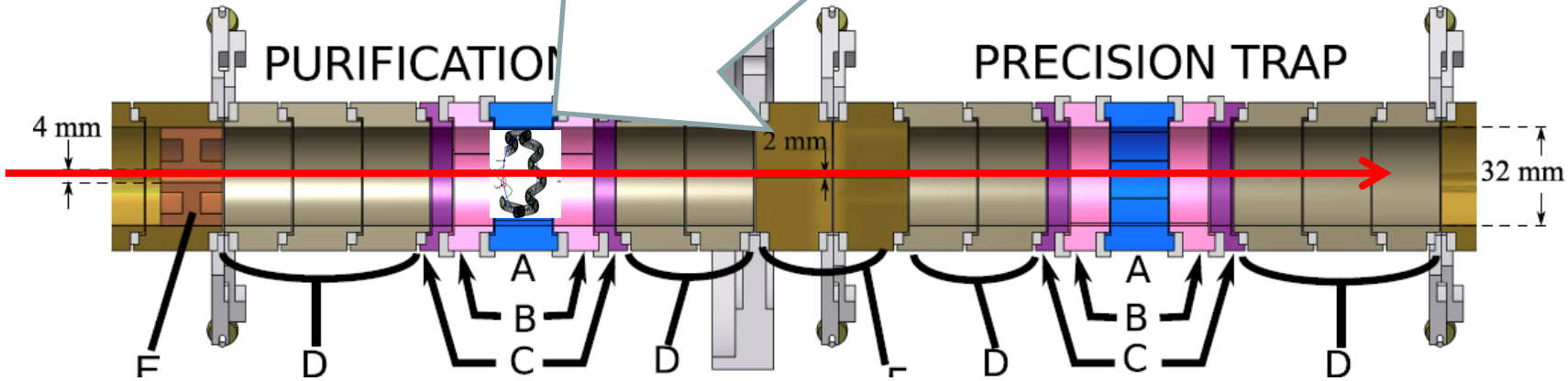


- Energy loss in ion-atom collisions
- Confinement of ions by RF field
- Injector for Penning trap
- Cooler & buncher for collinear laser spectroscopy
- Bunch length < 15 ms
- Energy spread < 1 eV

Isotopic purification with JYFLTRAP

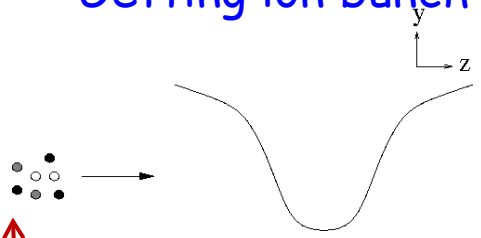




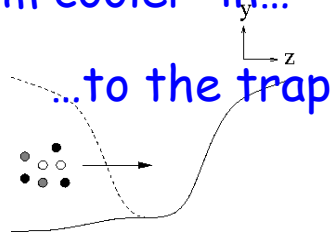


Isotopic purification with JYFLTRAP

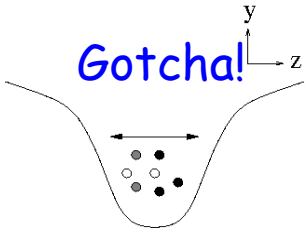
Getting ion bunch from cooler in…



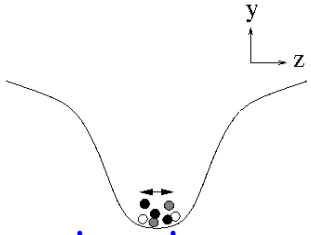
…to the trap



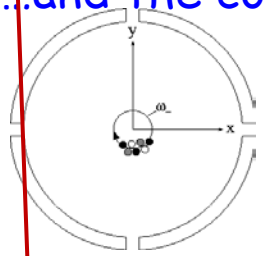
Gotcha!

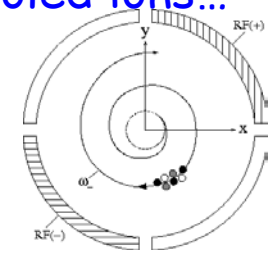


Ions are cooled…

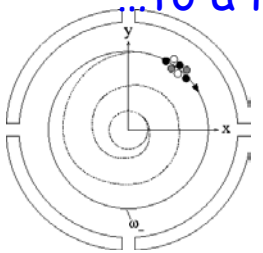


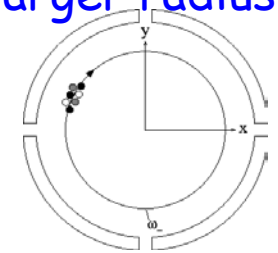
…and the cooled ions…



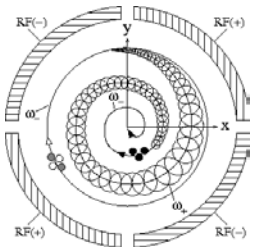


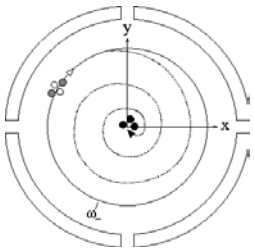
…to a larger radius





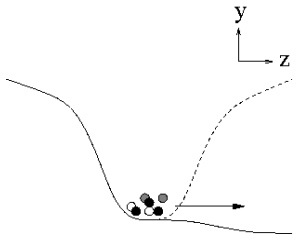
…centers the chosen ones





… are dipole excited first…

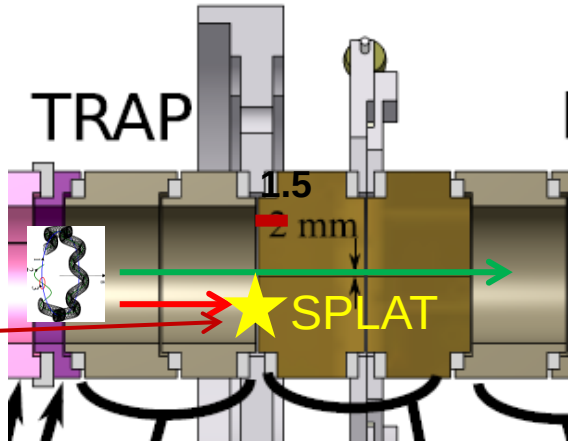
Mass selective quadrupole excitation…



Finally,
out of the trap they go

> 70 ms, typical 600 ms

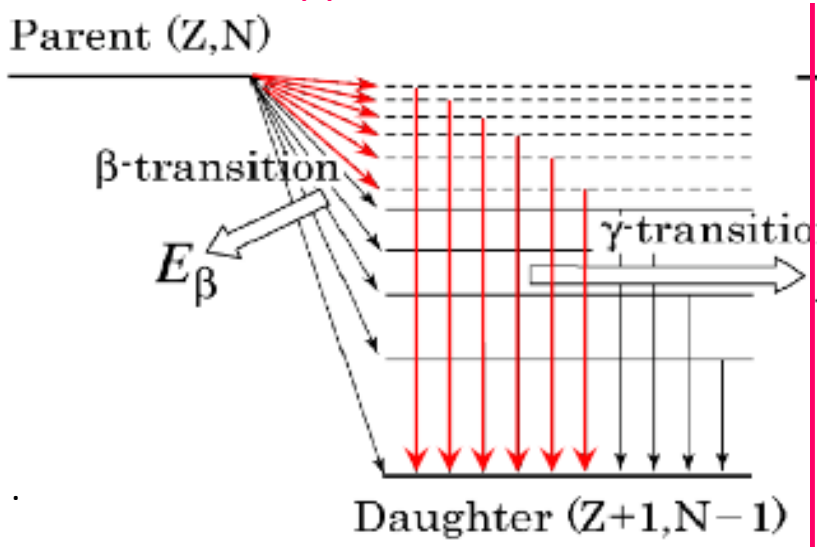
namely,
those that go



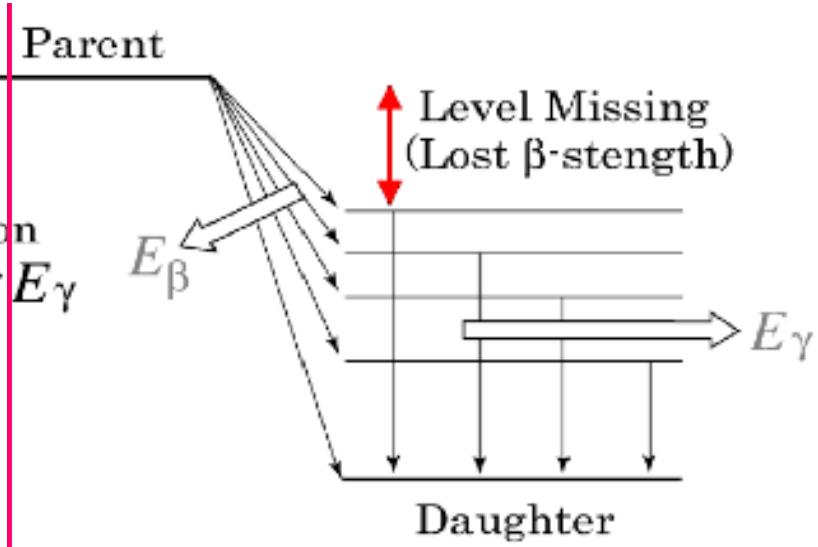
Beta decay heat and city of devils

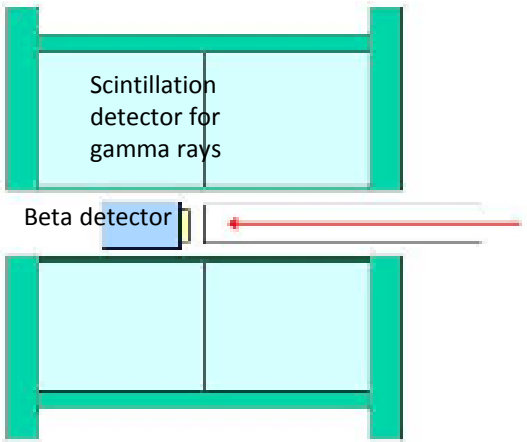
Pandemonium Effect

This is what happens

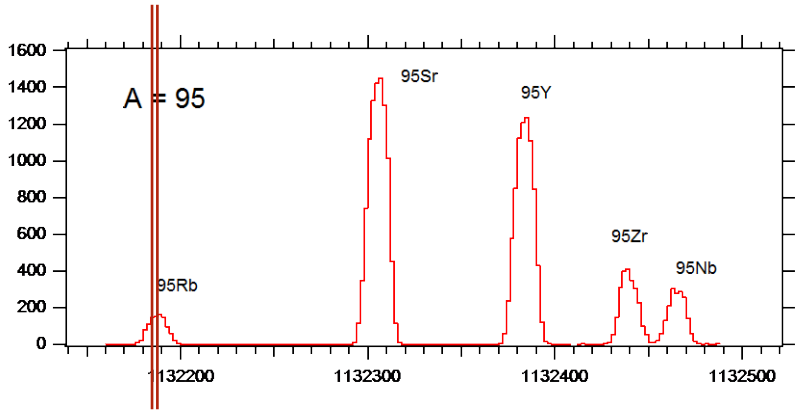


This is how it looks like

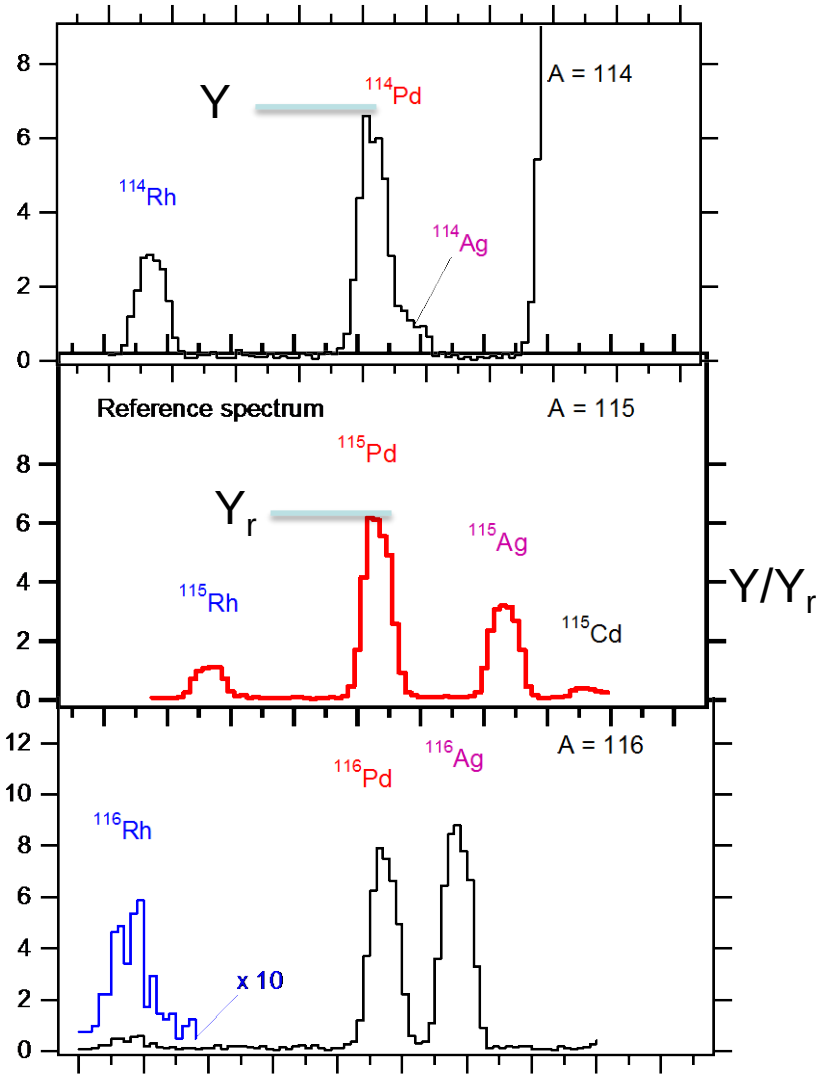


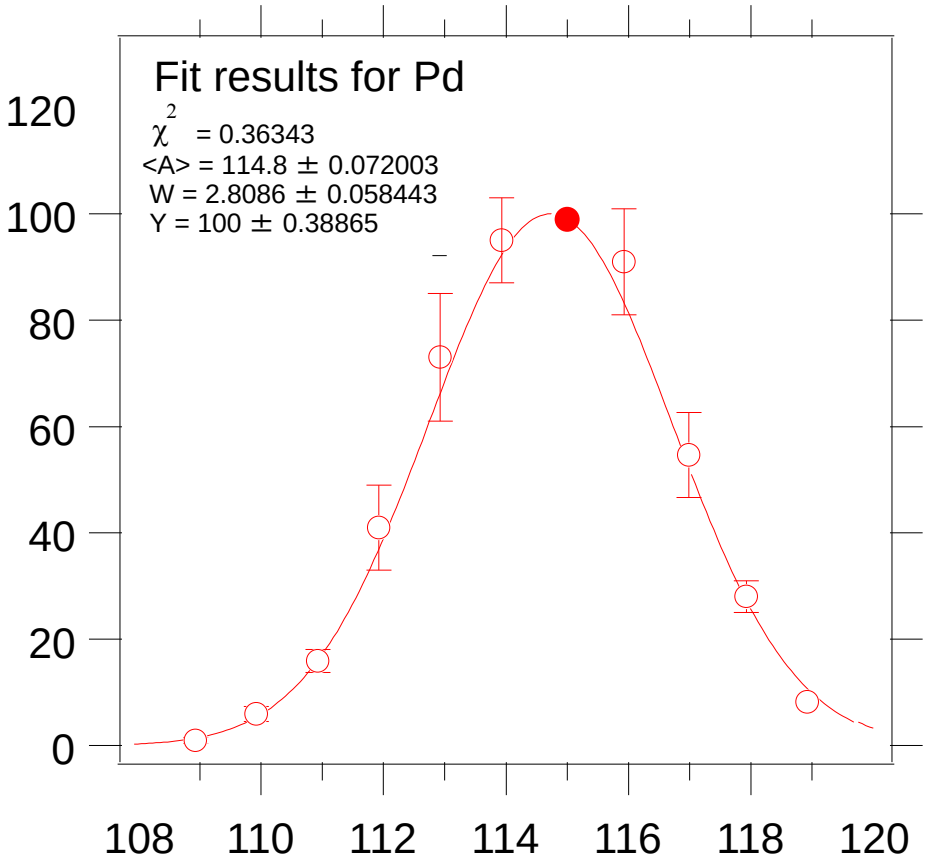


Mass separated ion beam of fission products

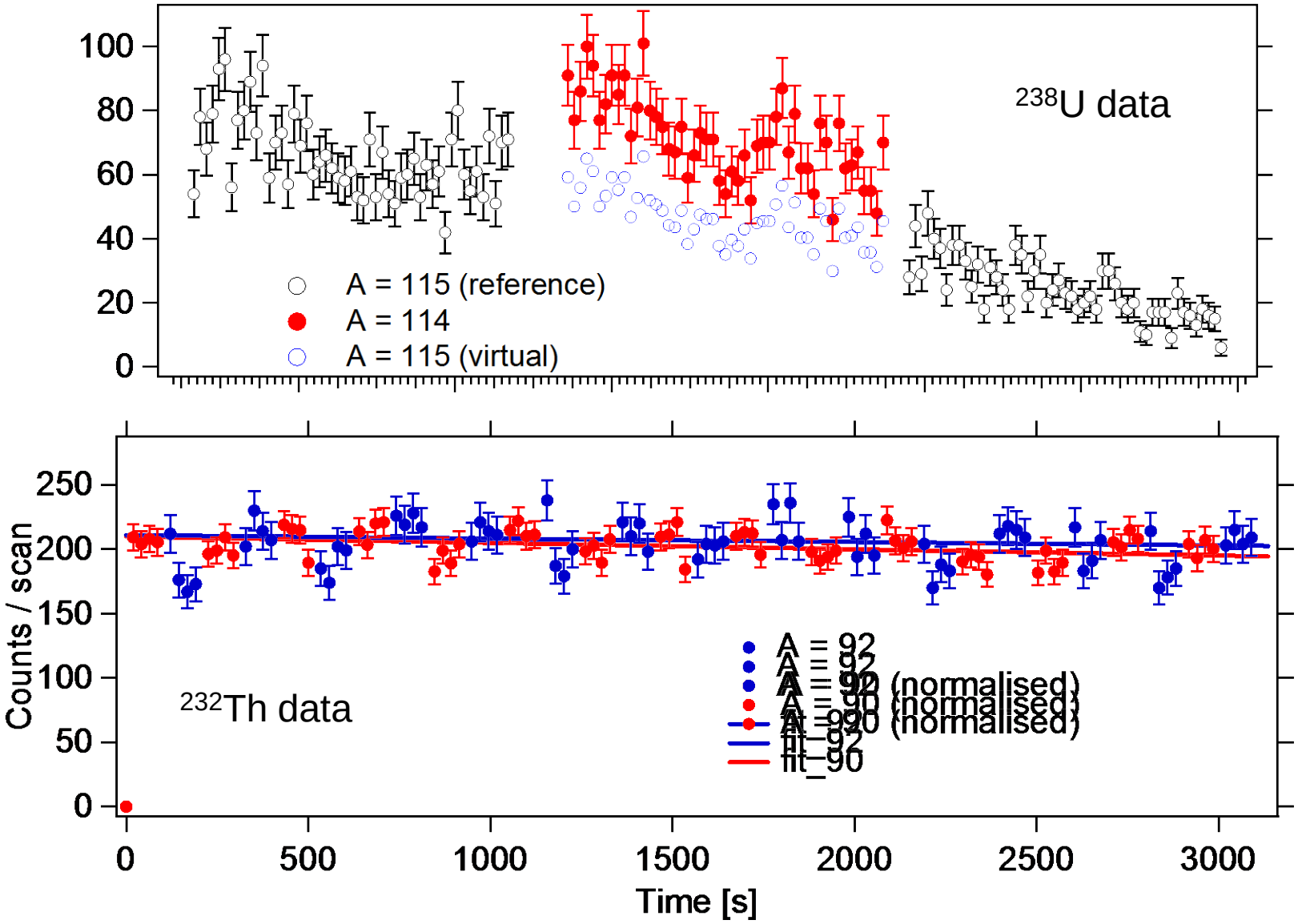


Independent isotopic fission yield studies

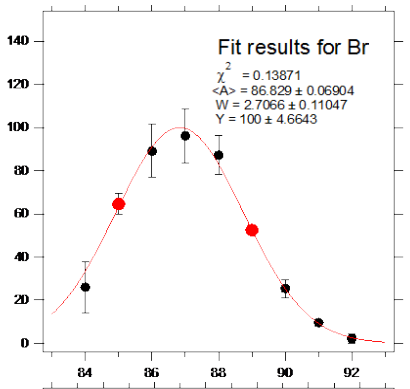


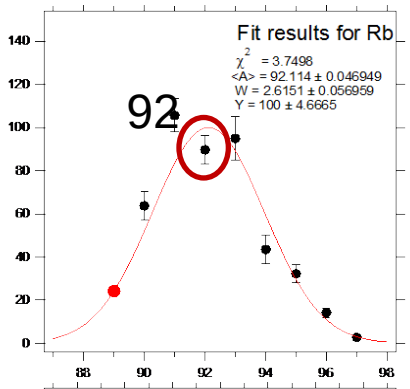


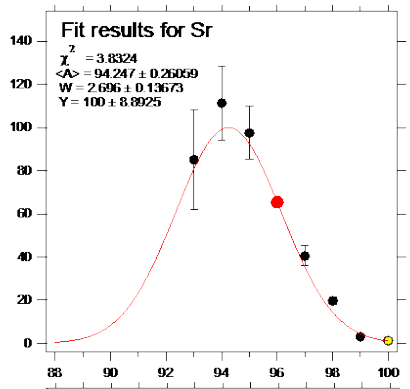
Uncertainty due to yield fluctuations

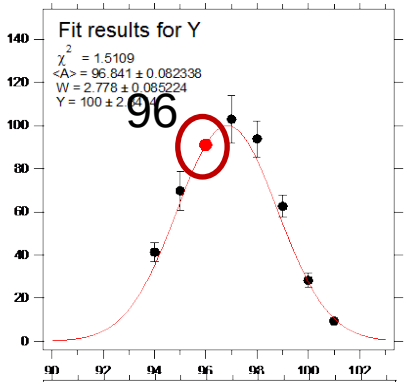


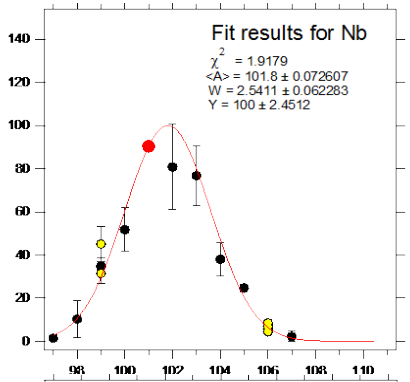
Independent isotopic 25 MeV p fission yields

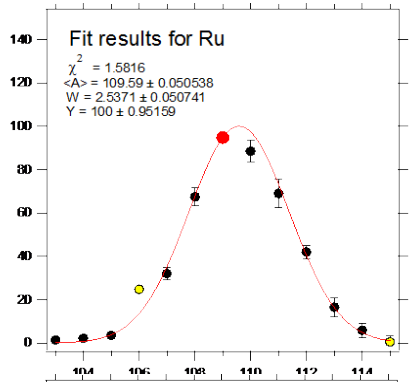


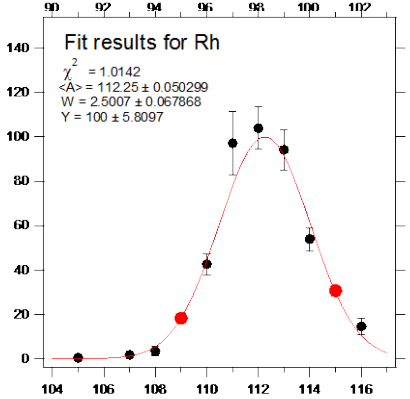


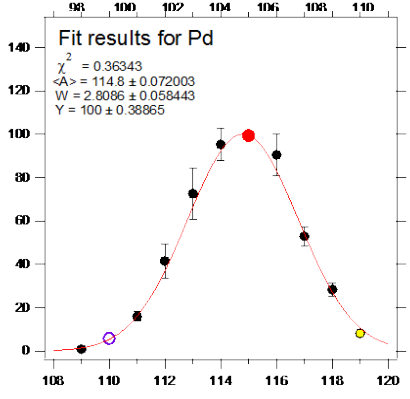


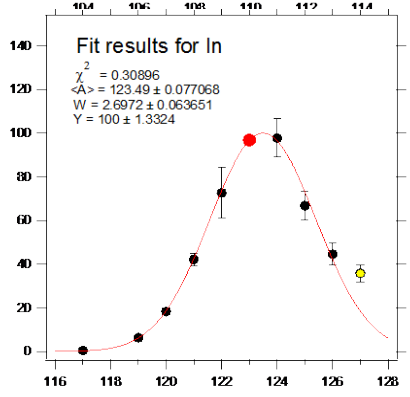




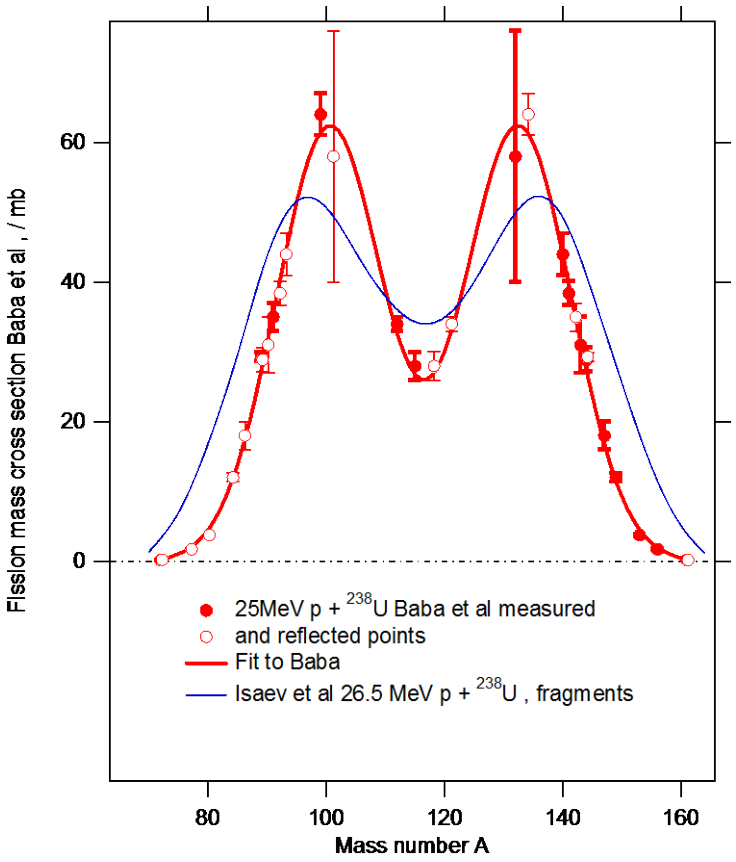


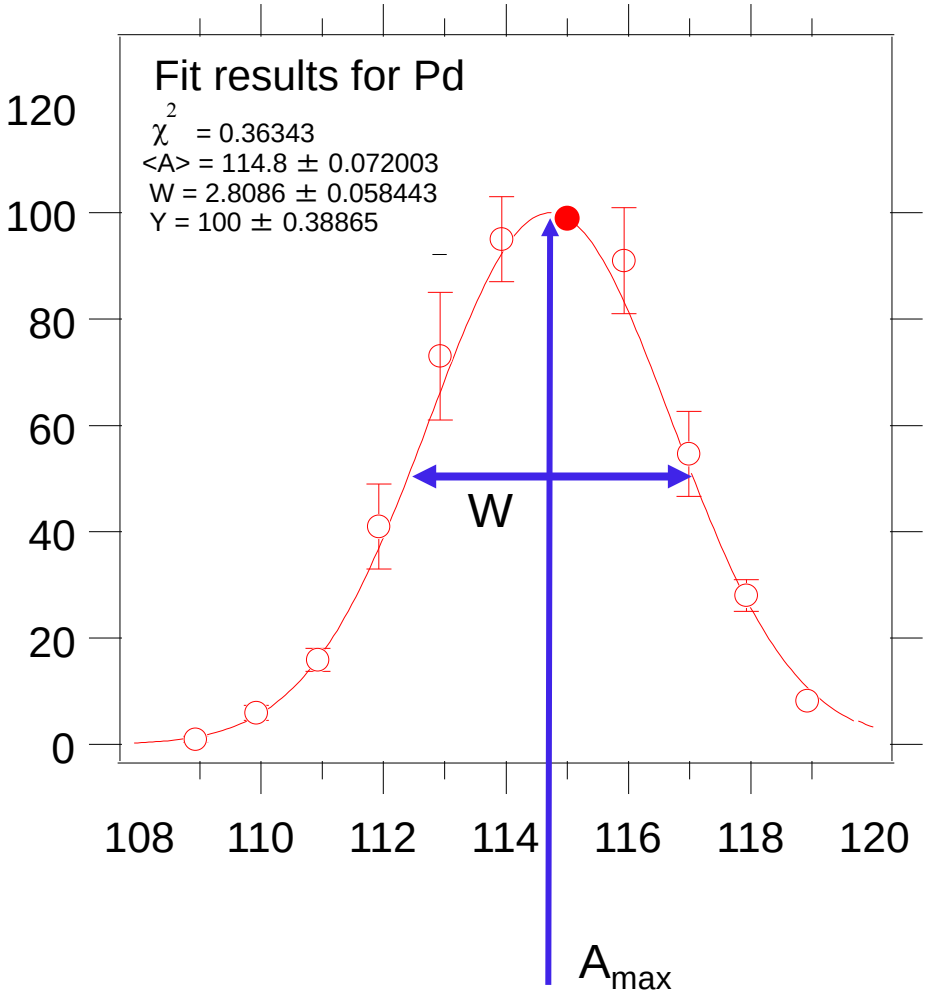




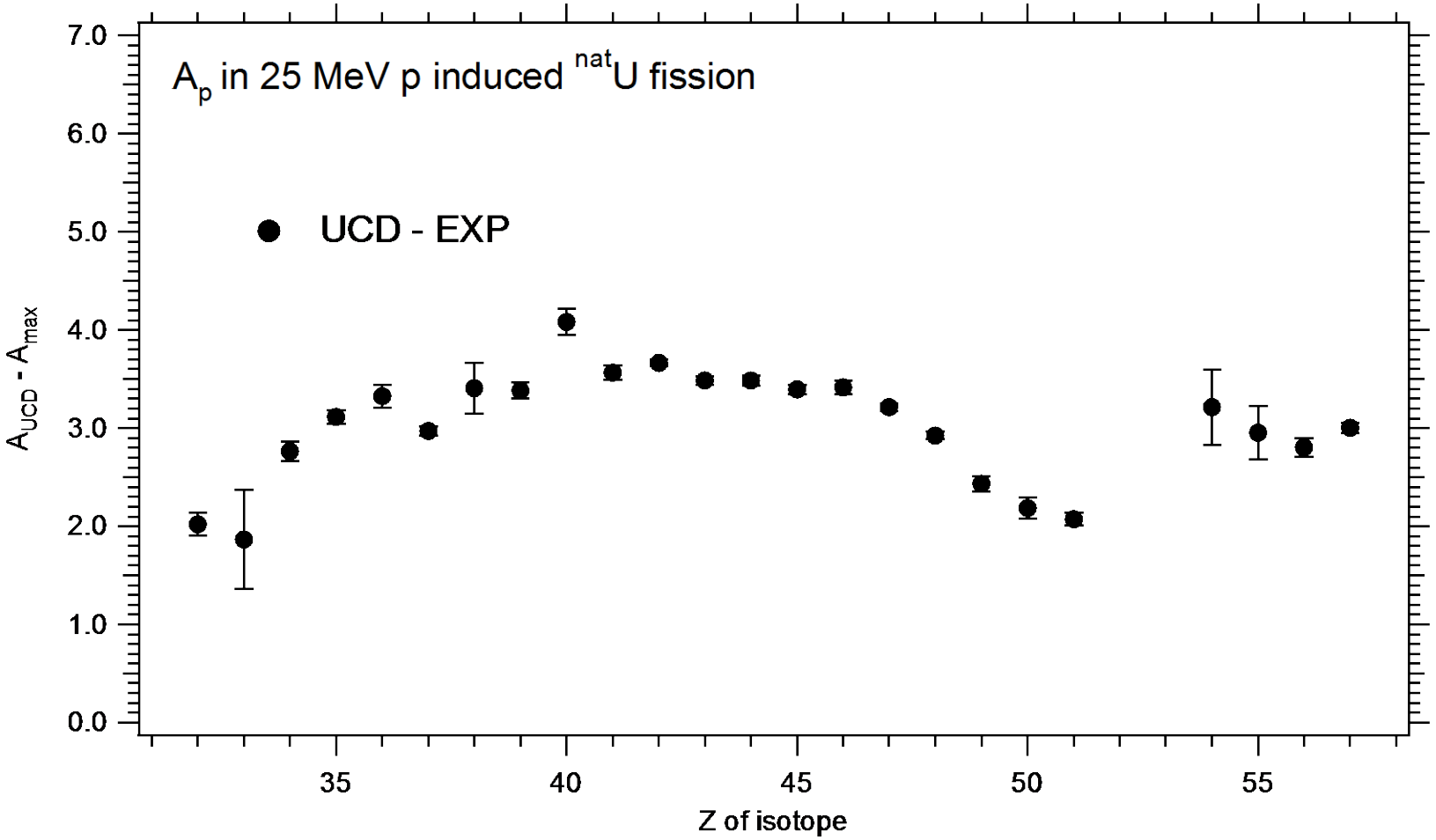


Absolute yields?

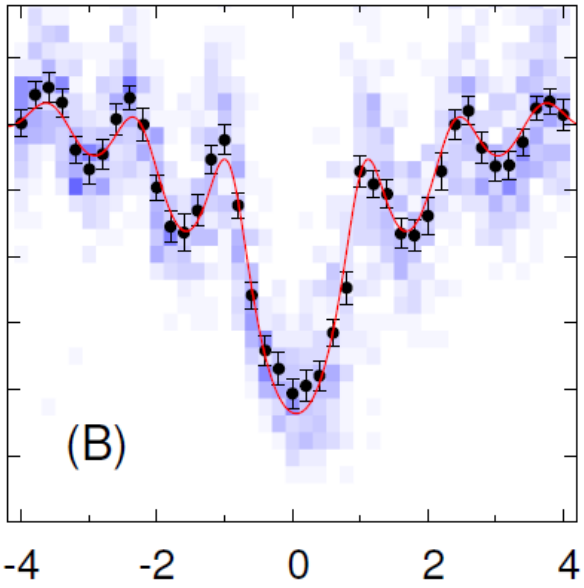


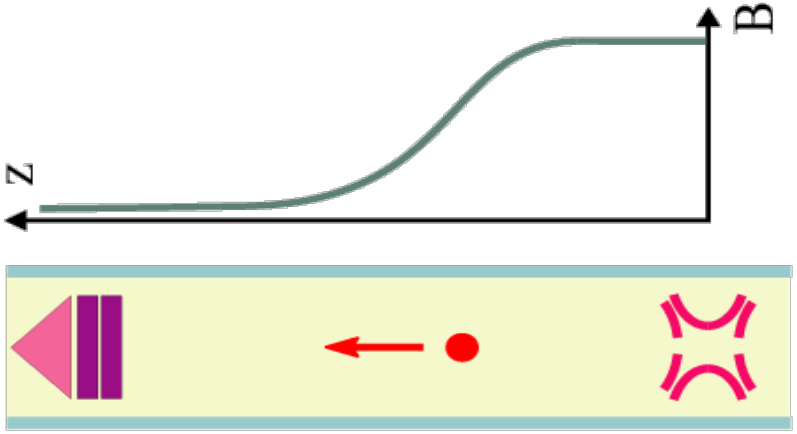


Distribution locations

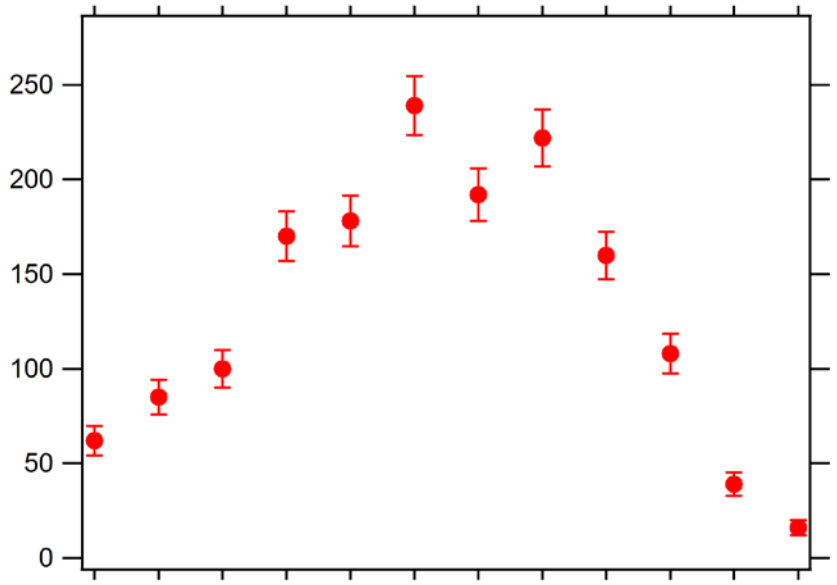


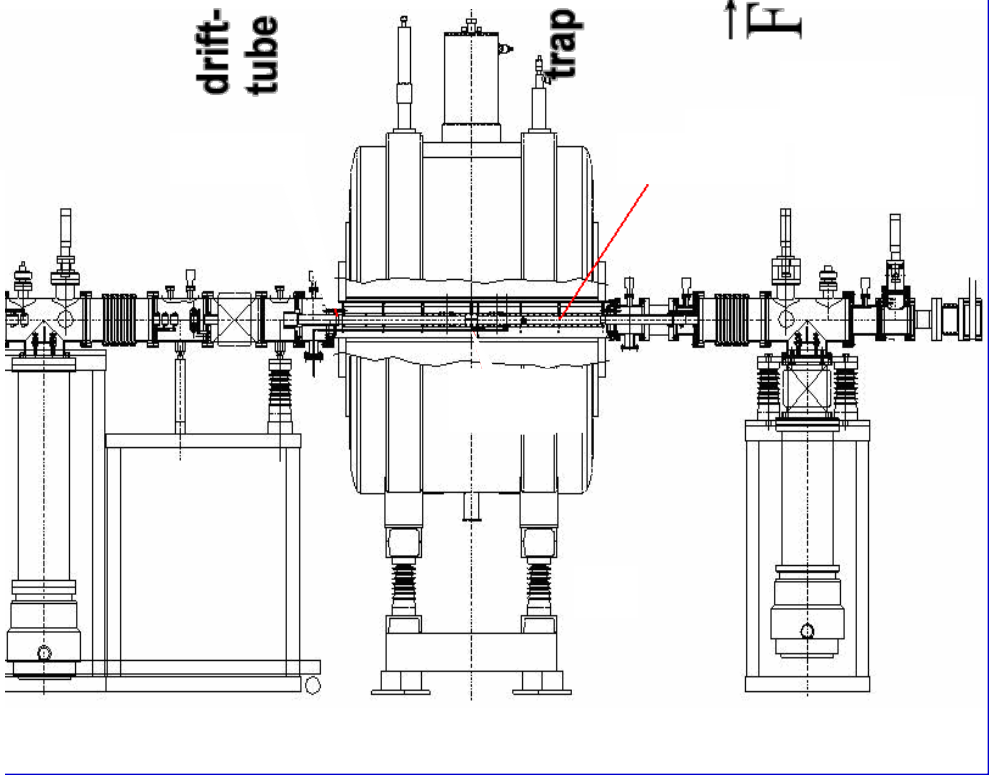
Mass measurements with JYFLTRAP



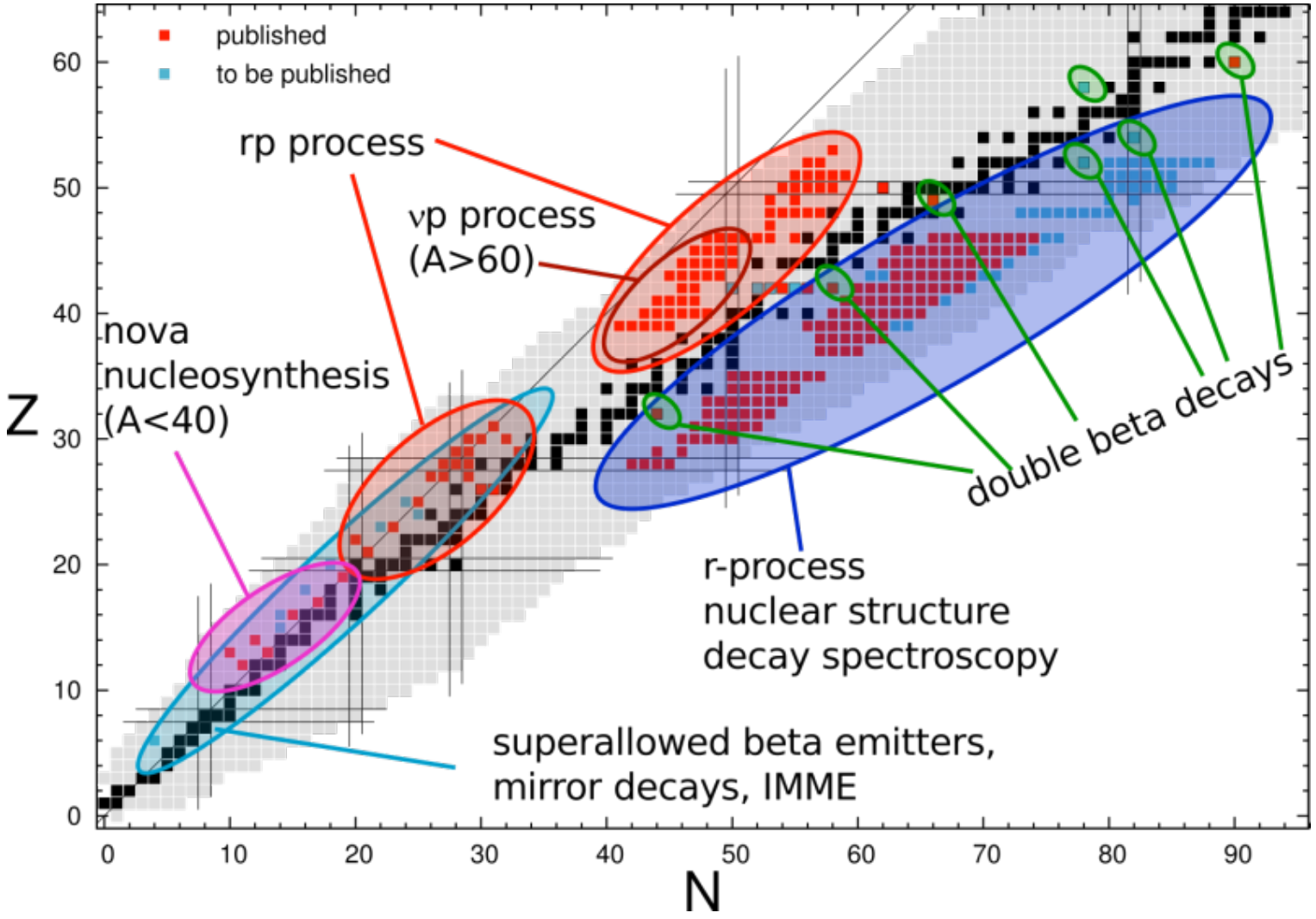


$$\vec{F} = \vec{\mu} \vec{\nabla} B$$

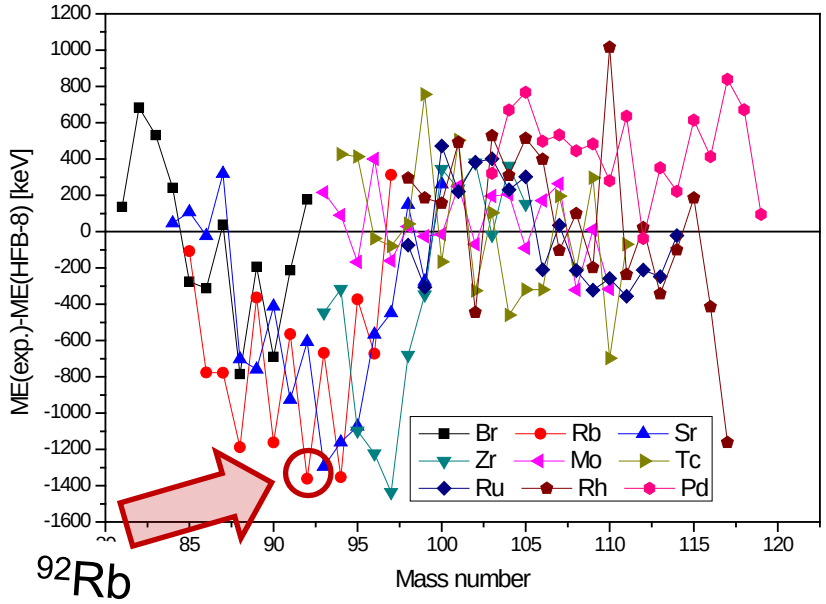


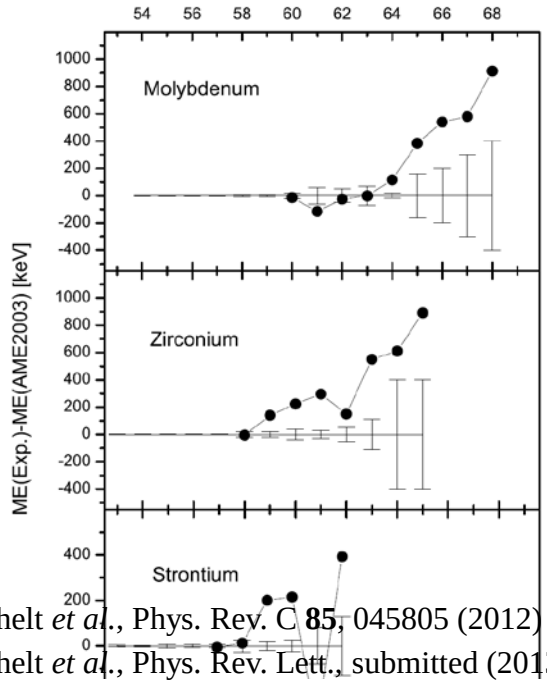


Mass measurement program with JYFLTRAP

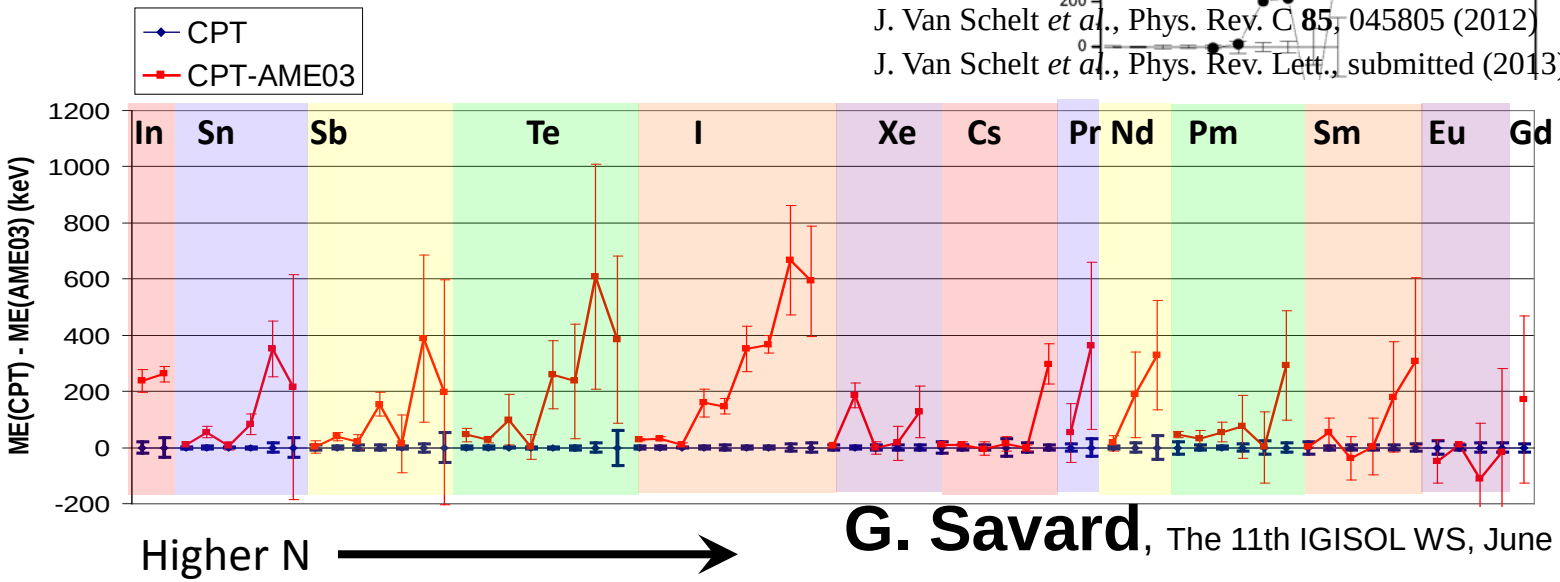


Mass measurements: old sins revealed

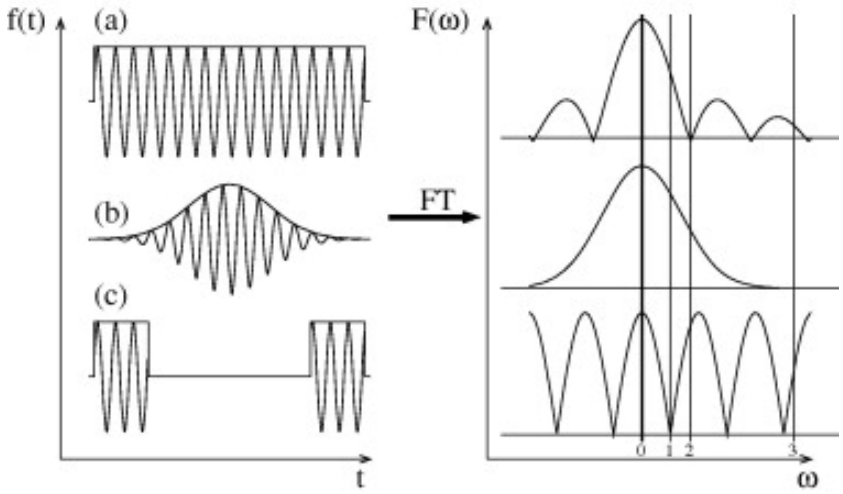


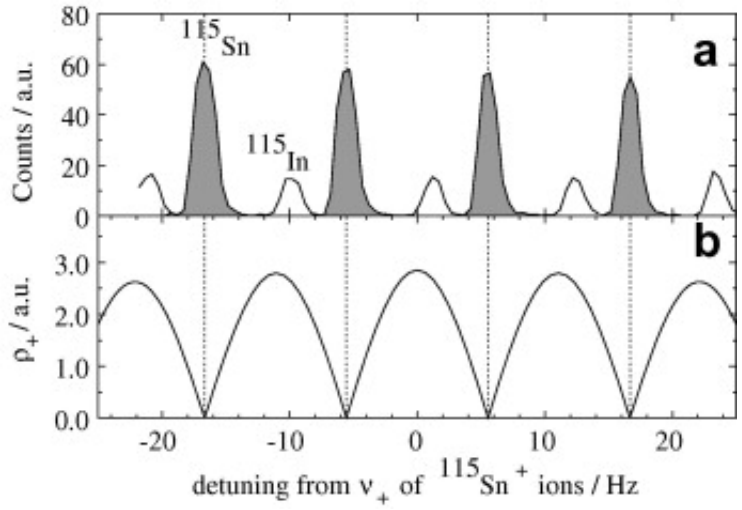


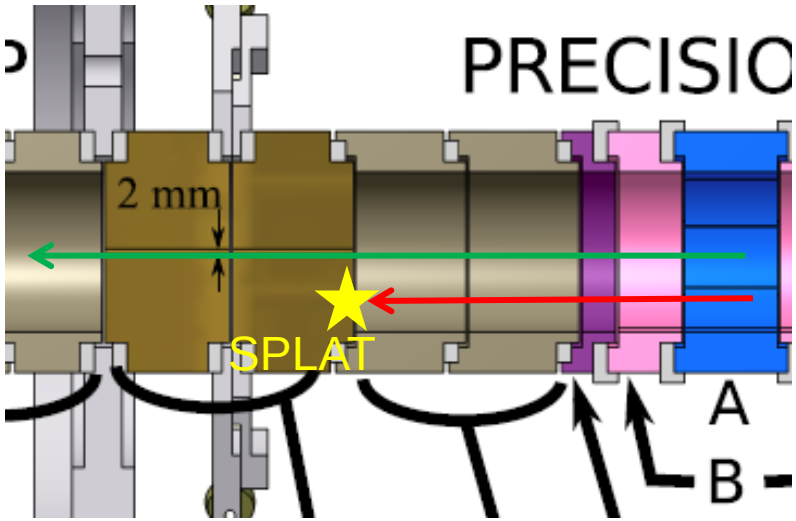
J. Van Schelt *et al.*, Phys. Rev. C **85**, 045805 (2012)
J. Van Schelt *et al.*, Phys. Rev. Lett., submitted (2013)

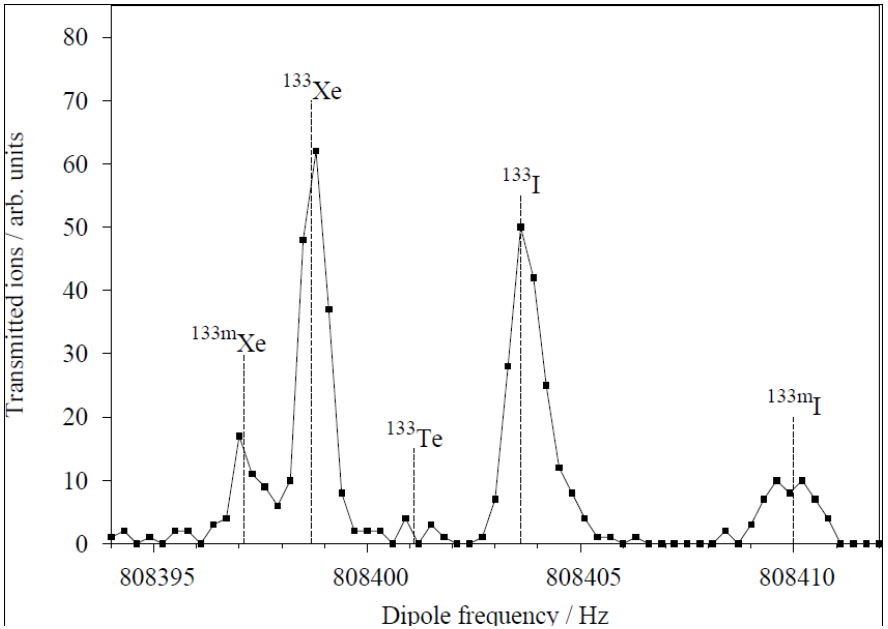


Ramsey cleaning with JYFLTRAP

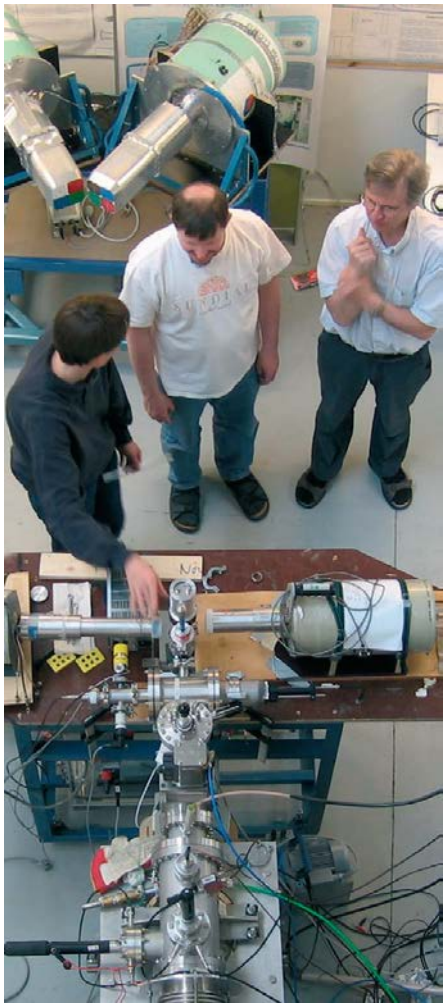


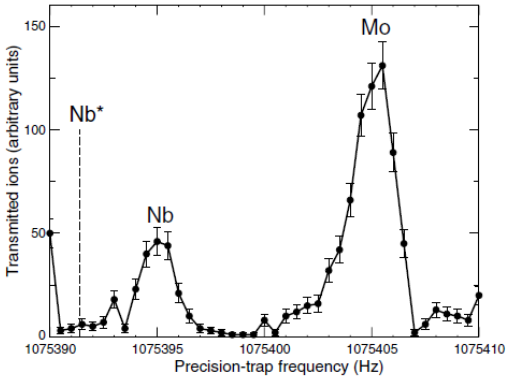






Trap assisted gamma ray spectroscopy





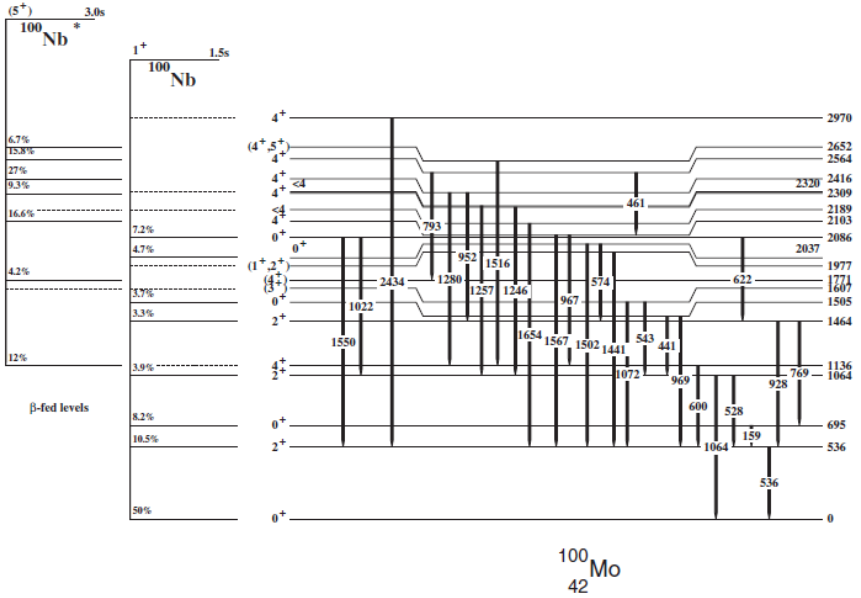
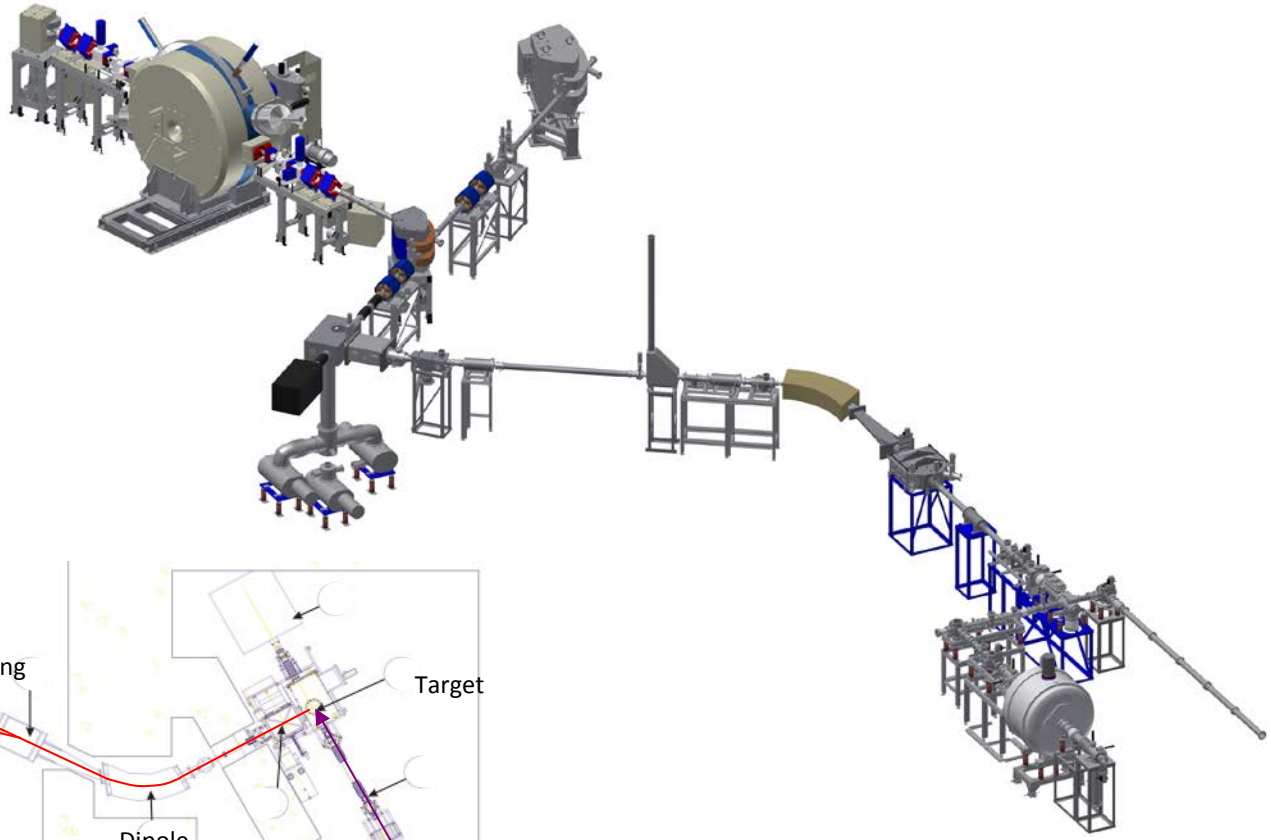
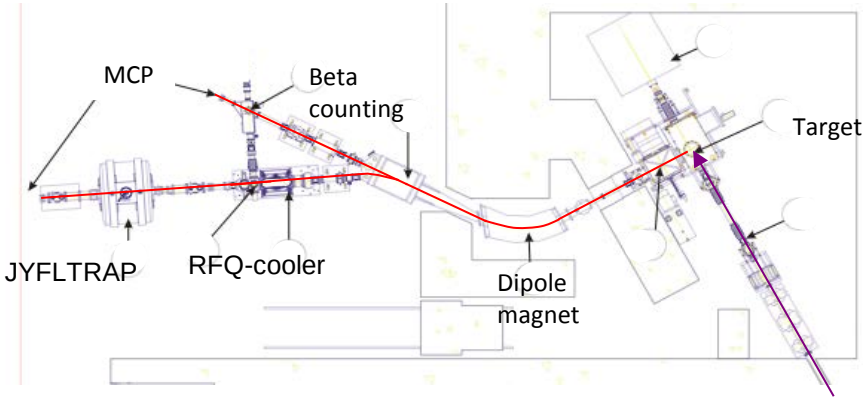


Figure 1. A schematic of the beta decay of the isomeric and ground states in ^{100}Nb into ^{100}Mo. Beta-decay intensities are from [9]; dashed levels indicate feeding intensities <3%.

From IGISOL-3 * Dec 3, 2003 † June 29, 2010 to IGISOL-4

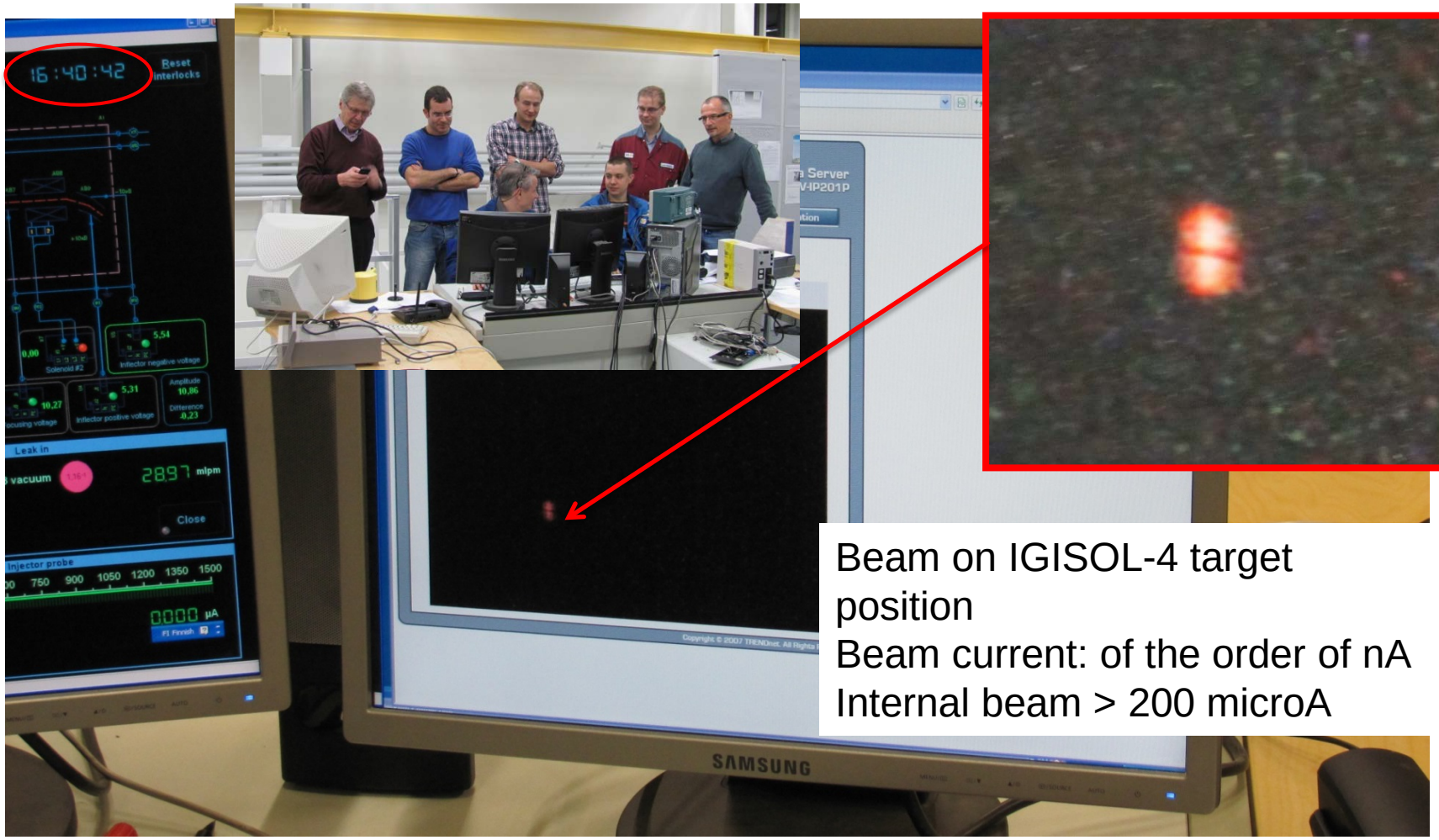




I. Moore et al, EMIS-2012

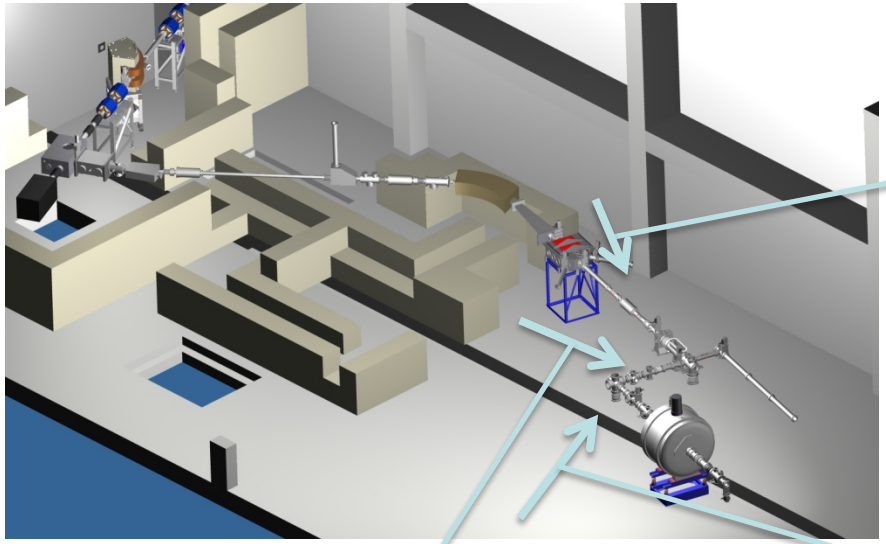
Digging up IGISOL-4

Beam from MCC30 to IGISOL-4 (23 Nov 2011)

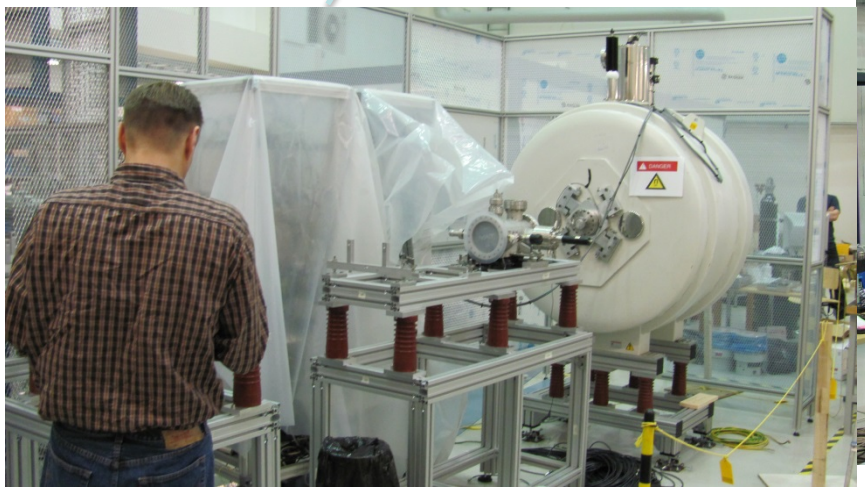


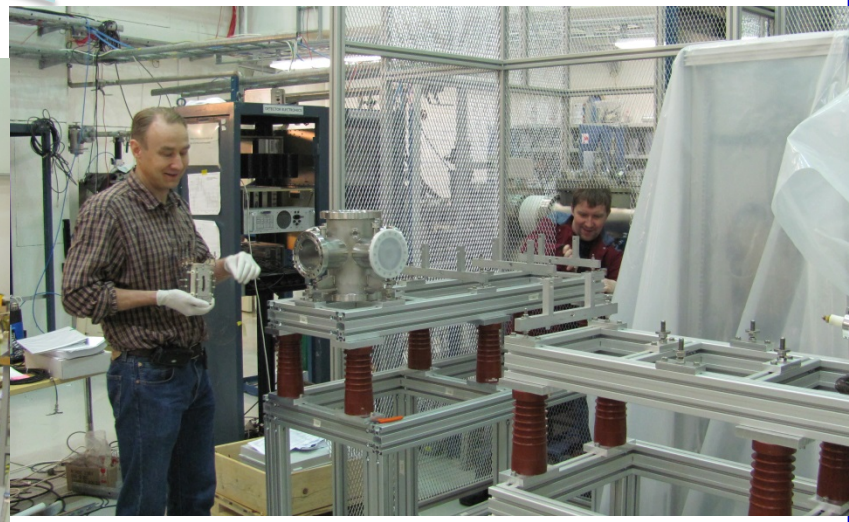
Beam on IGISOL-4 target position
Beam current: of the order of nA
Internal beam > 200 microA

Laboratory in the state of construction

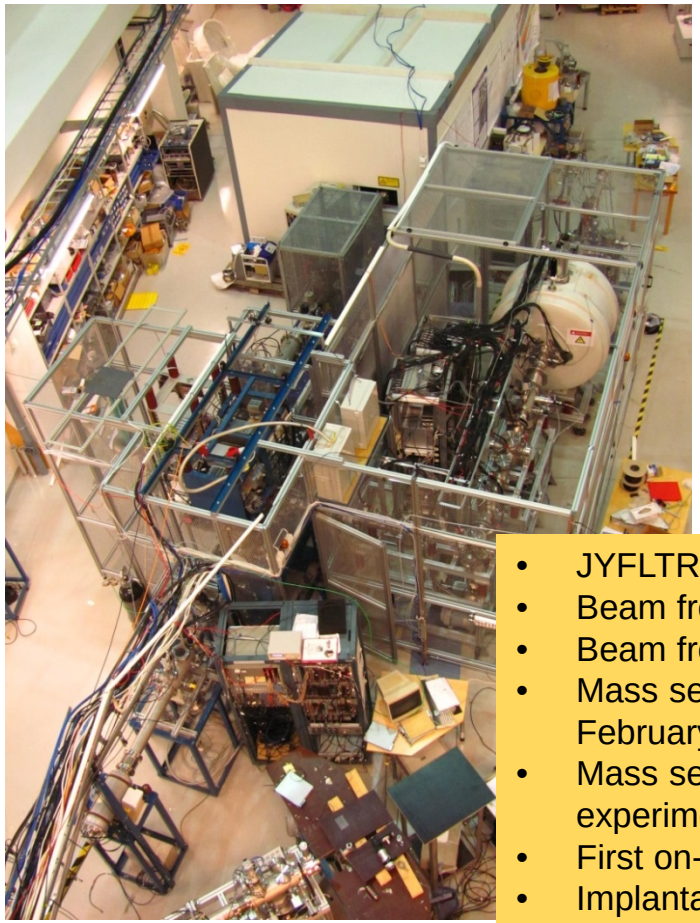


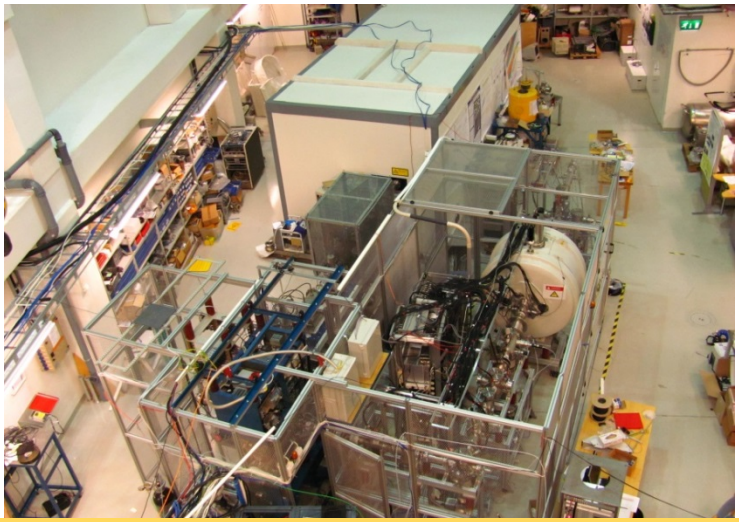
April 18, 2012





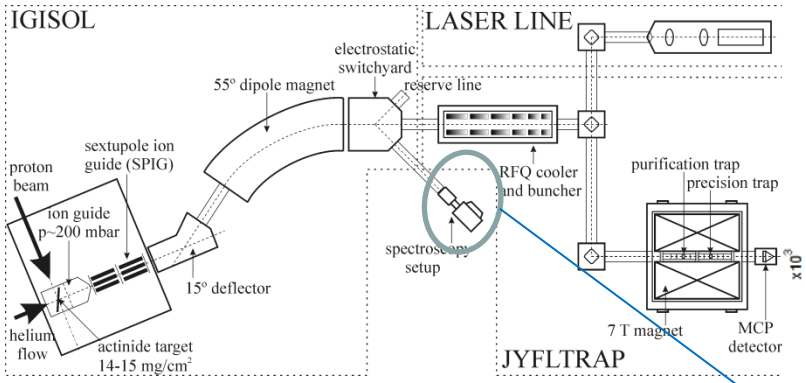
Laboratory in the state of commissioning

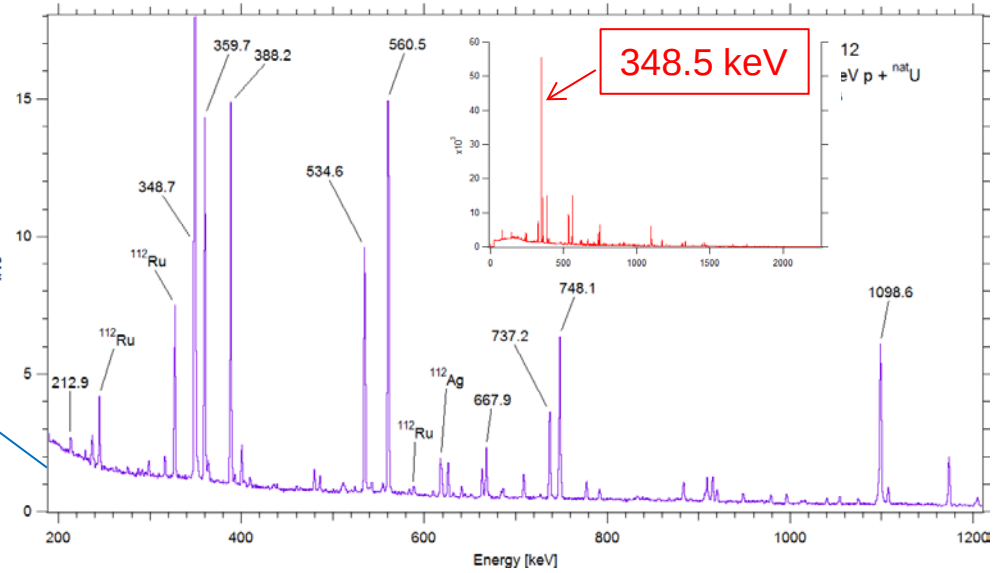




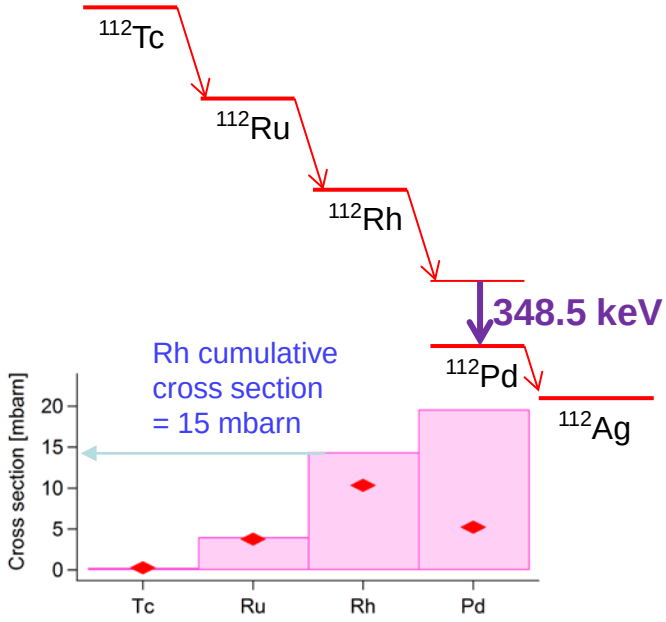
- JYFLTRAP Penning trap energised in July 2011
- Beam from K-130 to IGISOL target position in October 2011
- Beam from K-30 (MCC30) to IGISOL target position in November 2011
- Mass separated beam from a spark ion source to experimental area in February 2012
- Mass separated radioactive beam from a nuclear reaction (p,n)^{58}Cu to experimental area in March 2012
- First on-line experiment (yield test of ^{103}Rh(p,4n)^{100}Pd) November 2012
- Implantation experiment January 2013 ^{103}Rh(p,n)^{103}Pd (first physics!)
- First fission experiment February 2013
- First collinear laser spectroscopy experiment (^{107}Nb) in May 2013
- First Penning trap experiment (isomeric ratios, ERINDA) June 2013
- First Ramsey cleaning (off-line source) September 2013
- First decay spectroscopy experiment in October 2013 (^{204m}Bi M4-decay)
- First TAS decay spectroscopy experiments scheduled in February 2014

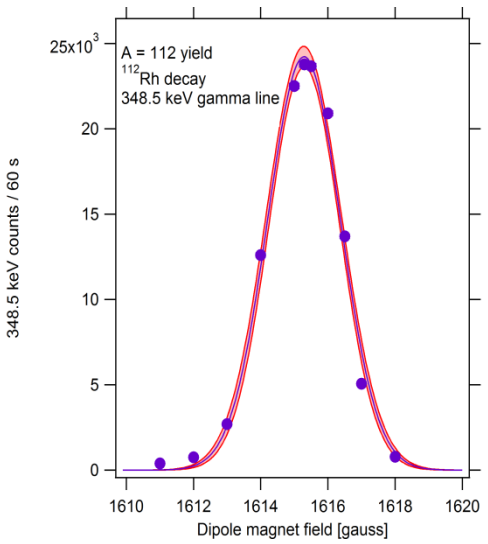
Fission yield at IGISOL 4

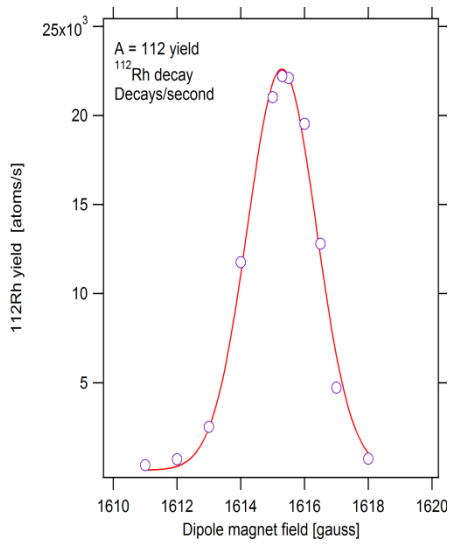




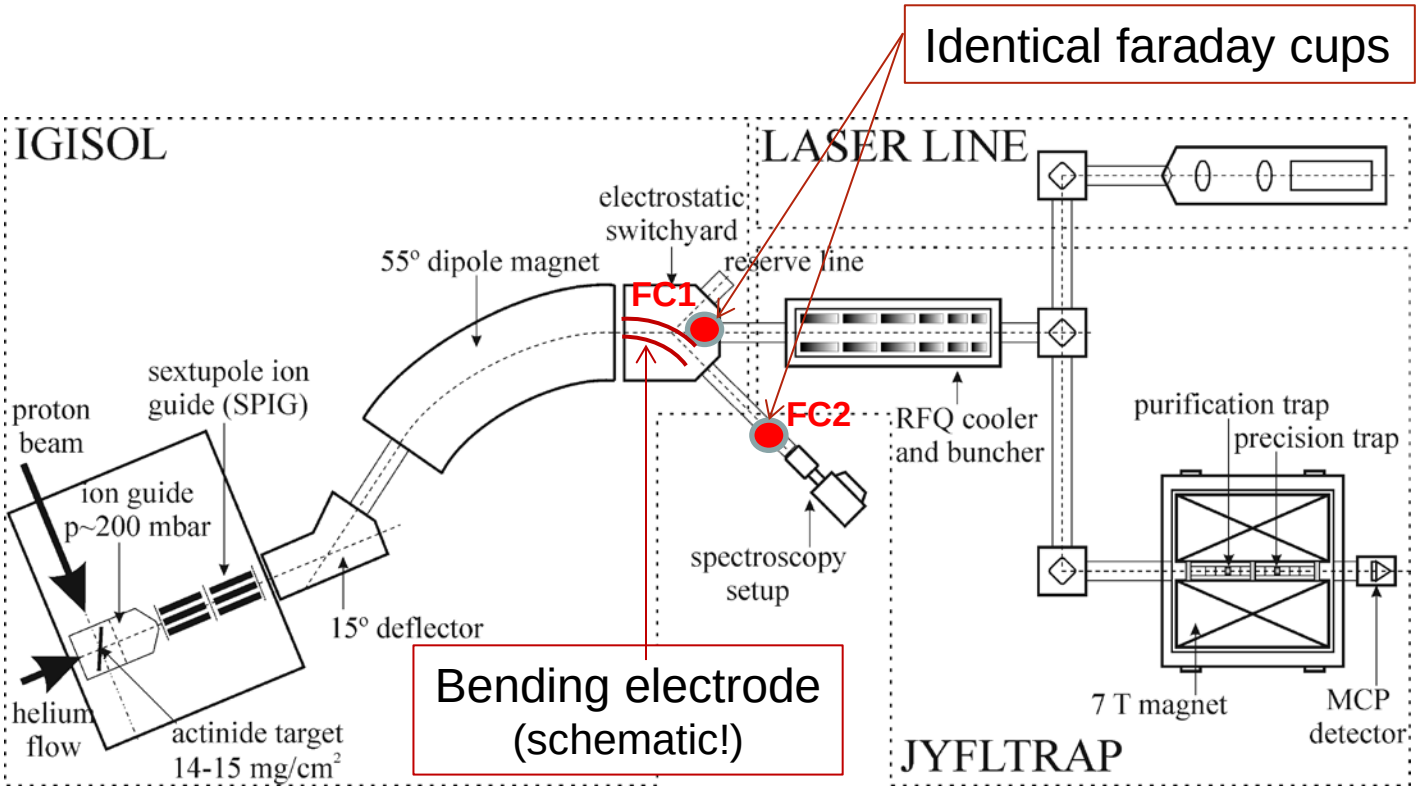
Fission yield:
1400 atoms/(μC * mbarn)







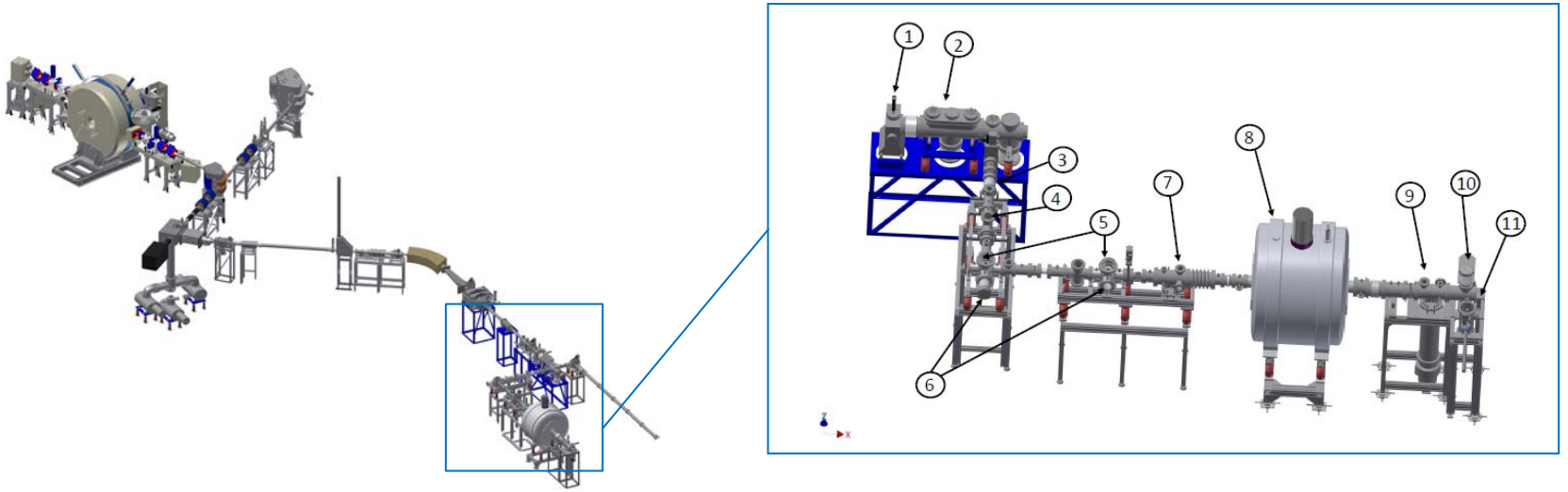
Note on fission yield at IGISOL 4:



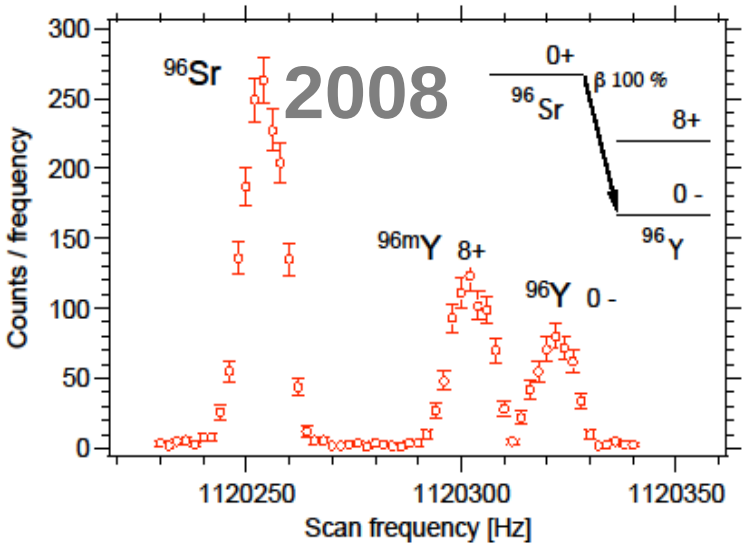
Transmission to FC2 in spectroscopy line ≈ 50 %

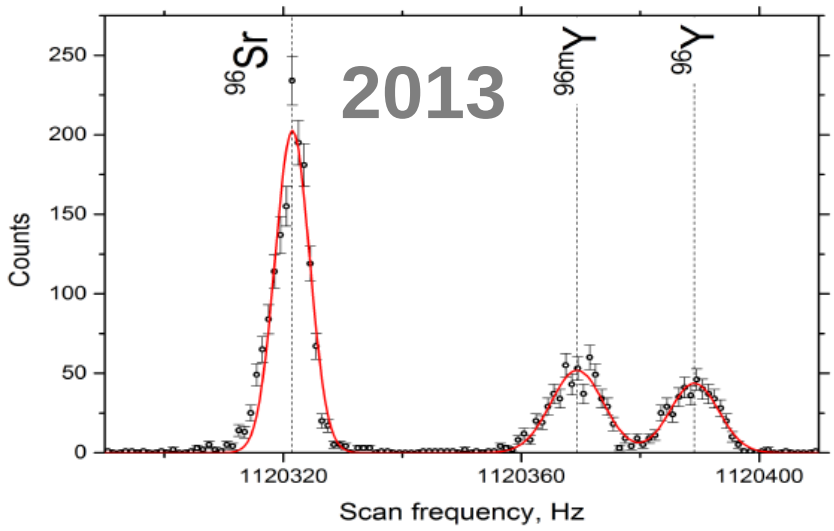
Fission yield to the central line 2800 atoms/(μC * mbarn) ?

JYFLTRAP performance

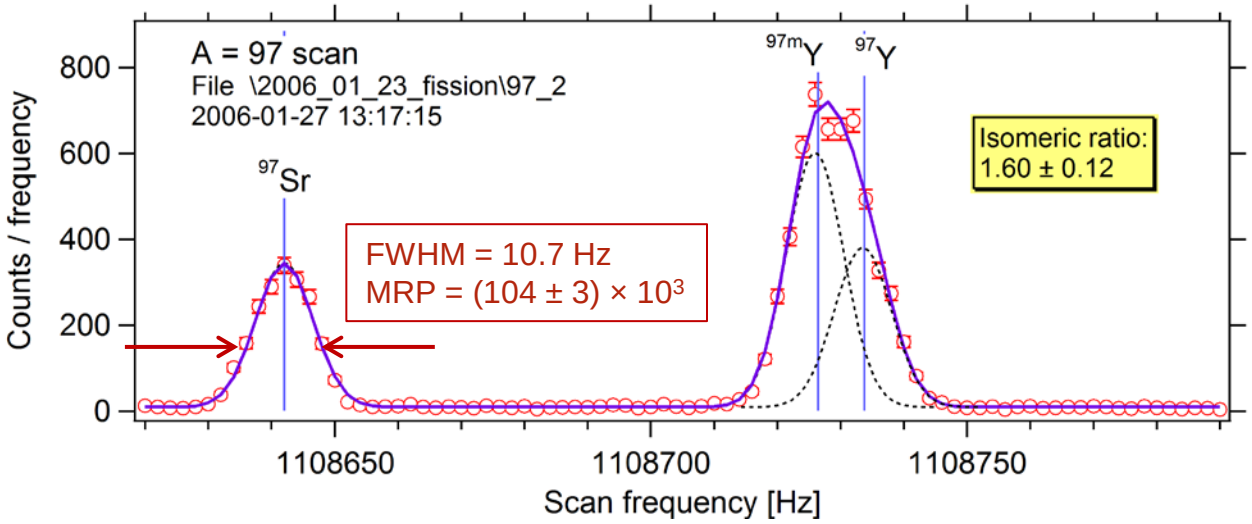


Purification trap mass resolving power → 200,000

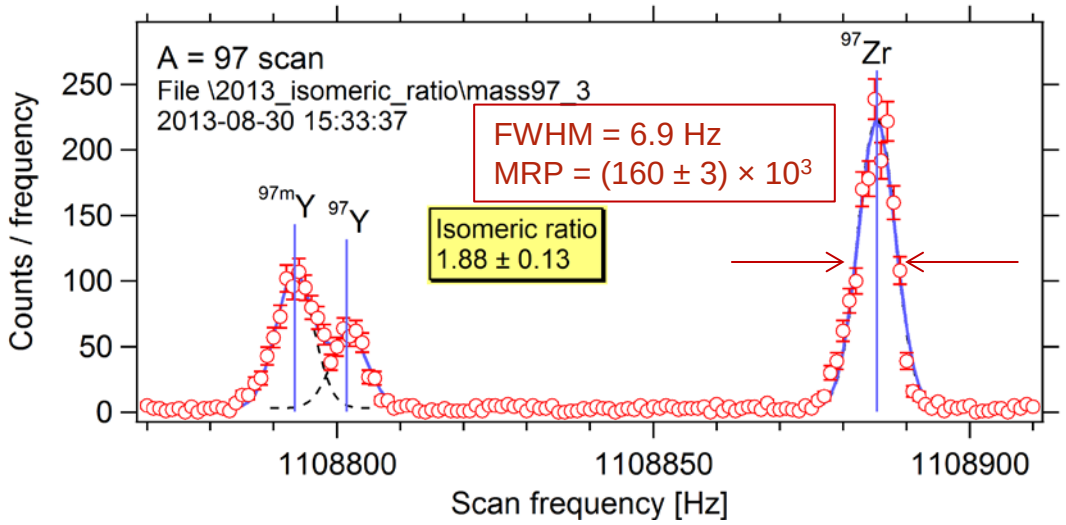




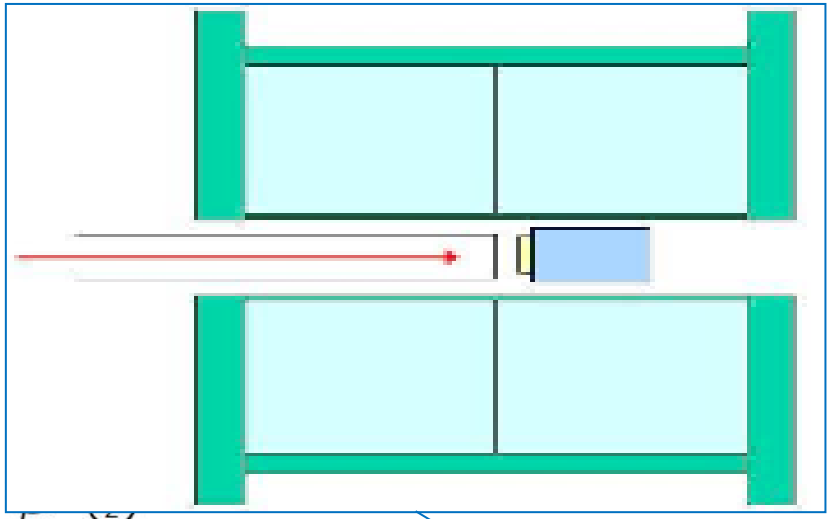
Isomeric ratio of ^{97}Y

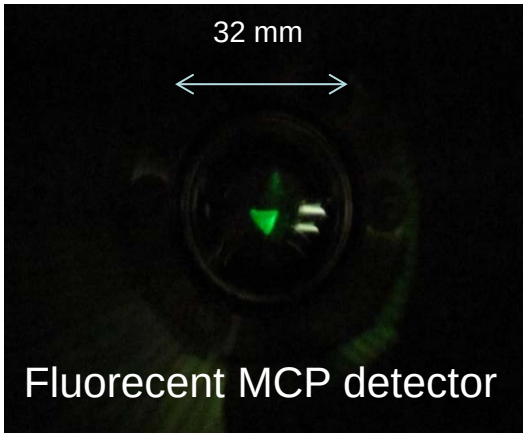


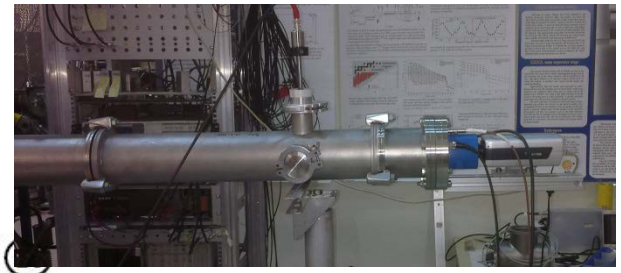
Litterature value
2.39 ± 0.36
{M. Tanikawa et al,
Z.Phys.A347, 53, (1993)}

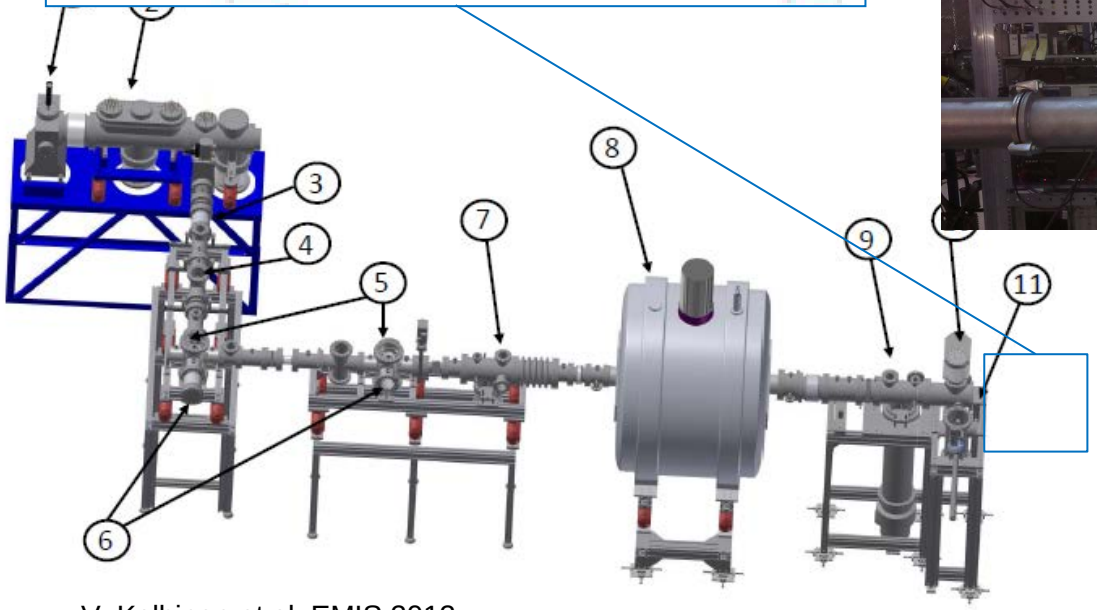


Post-trap implantation







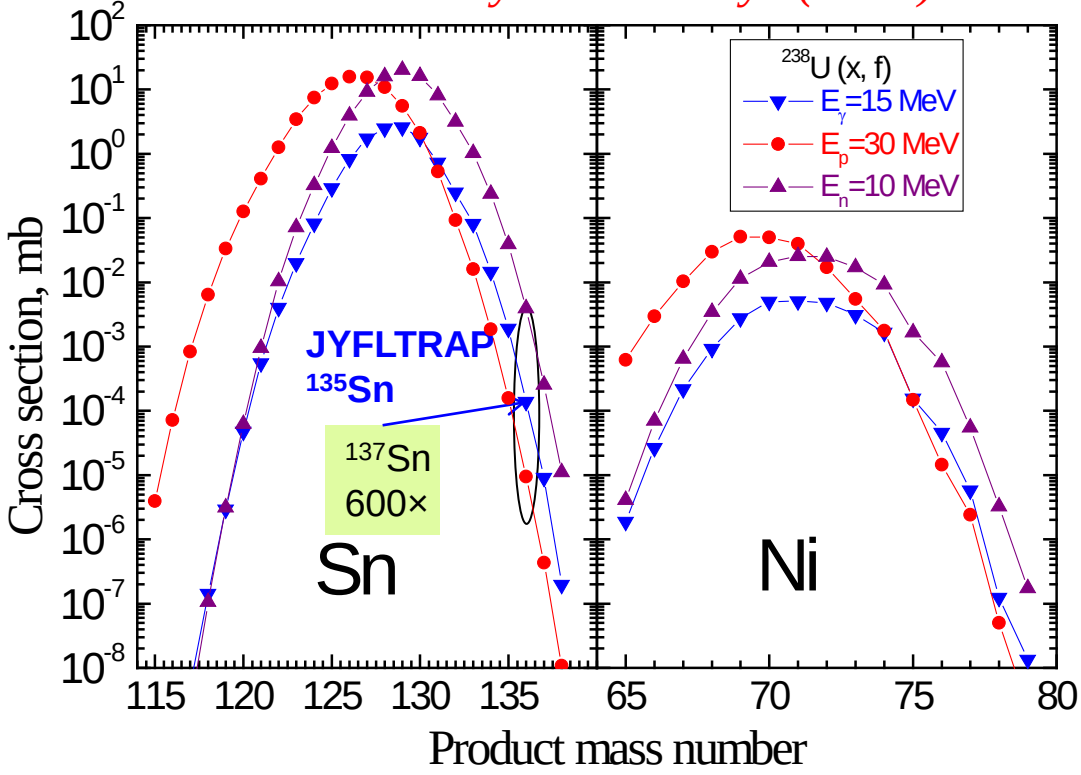


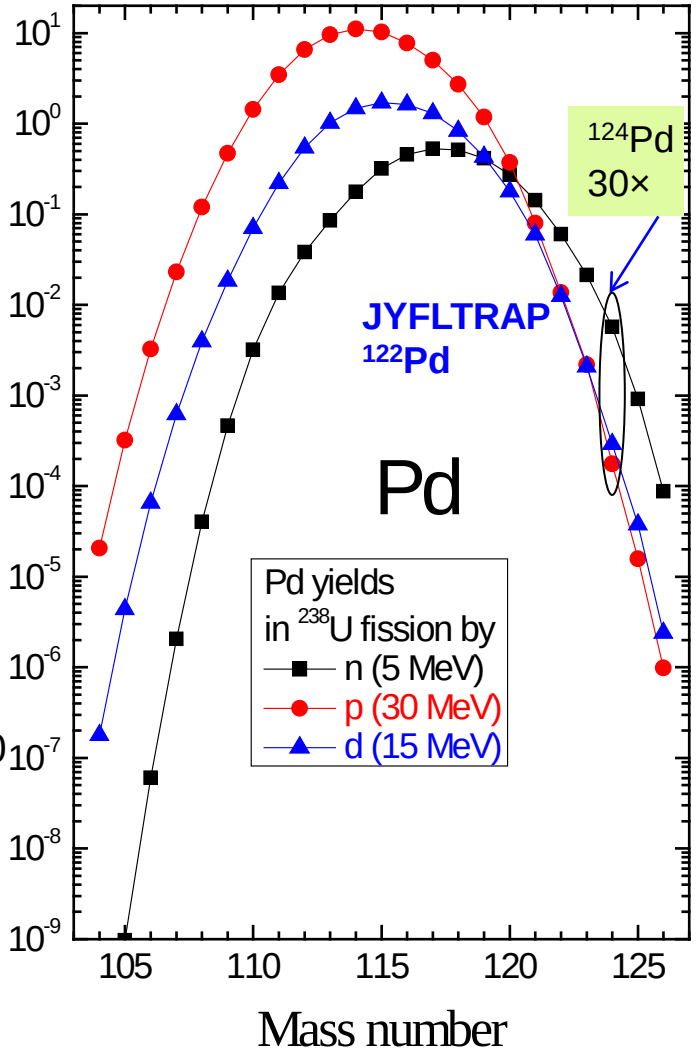
V. Kolhinen et al, EMIS 2012

Towards more neutron rich

Independent isotope production cross sections for fission of ^{238}U

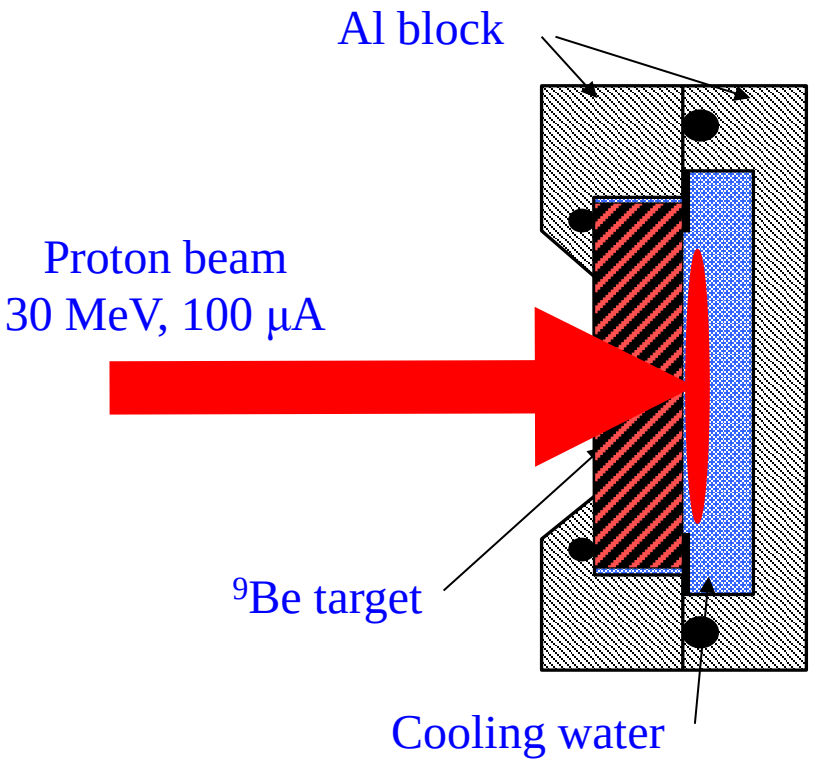
Calculations by V. Rubchenya (JYFL)

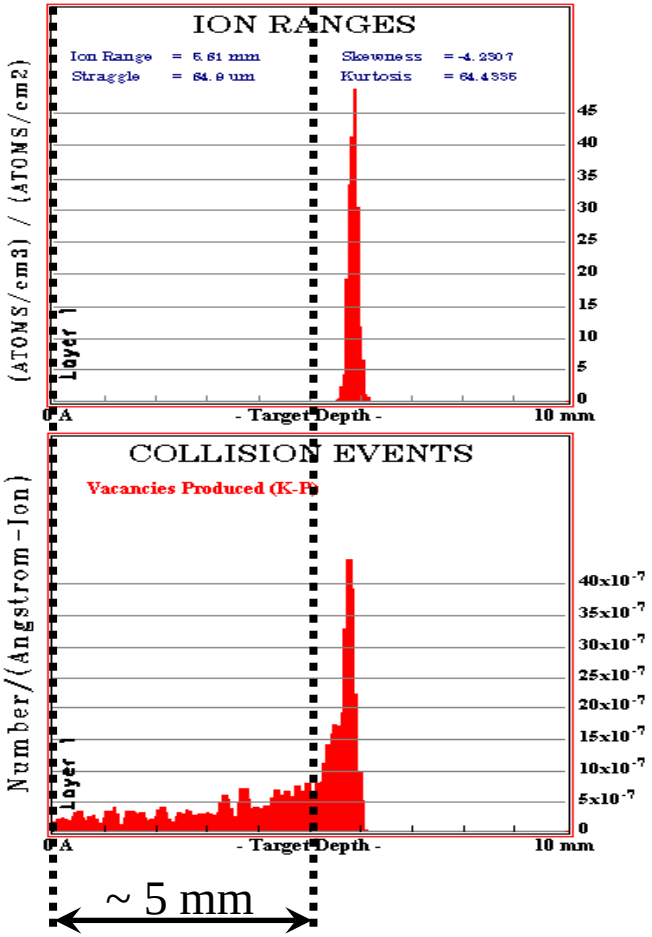




Yields of neutron-rich isotope for neutron entrance channel substantially higher than other channels

Beryllium converter target

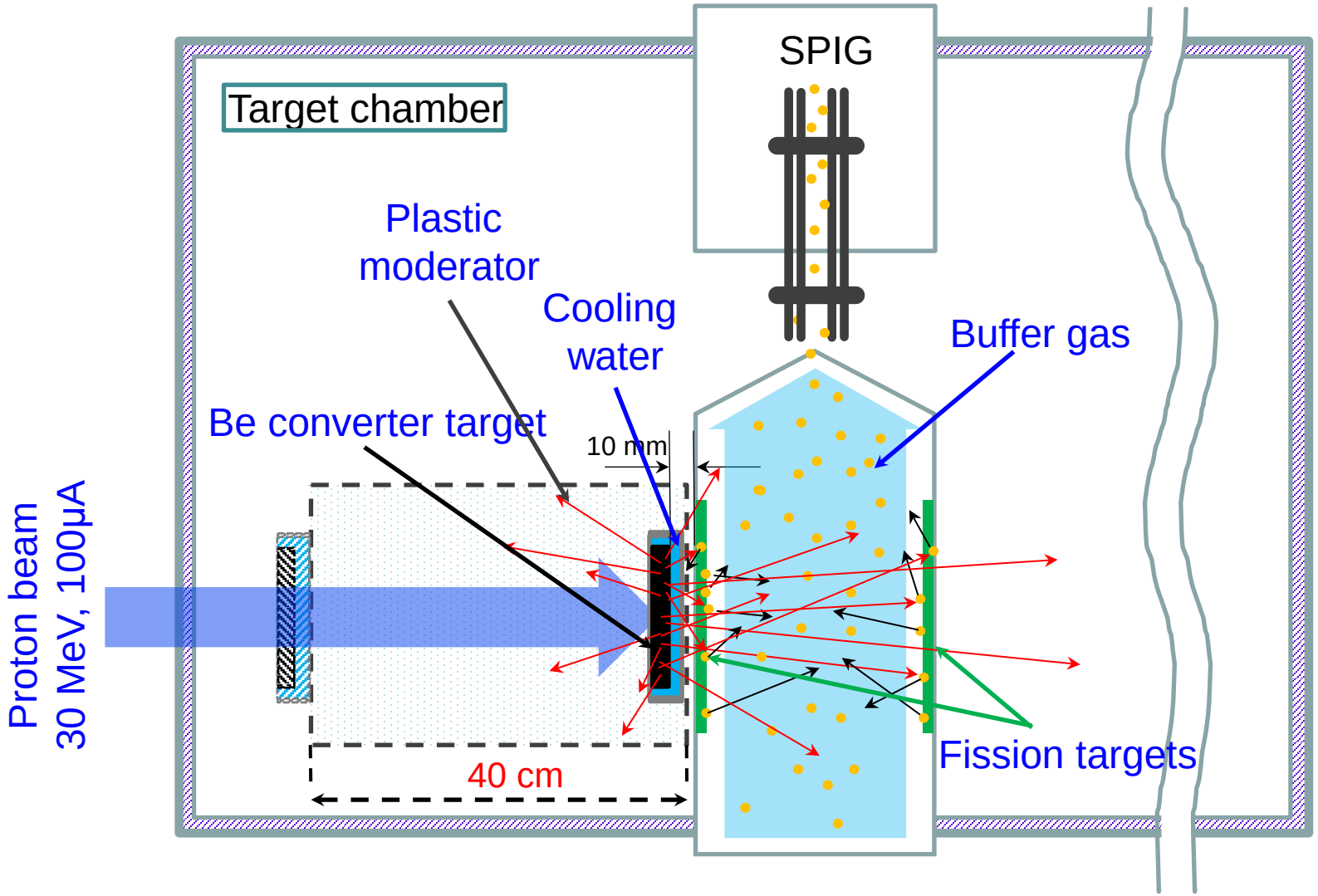




- Fast and thermal neutron spectra
- 30 MeV protons on Be
- 100μA protons yield 10^{12} fast neutrons/sr/s
- Monte-Carlo simulations with MCNPX and Fluka for neutron target design*
- Calibration measurement at TSL (2012); energy, angular spread

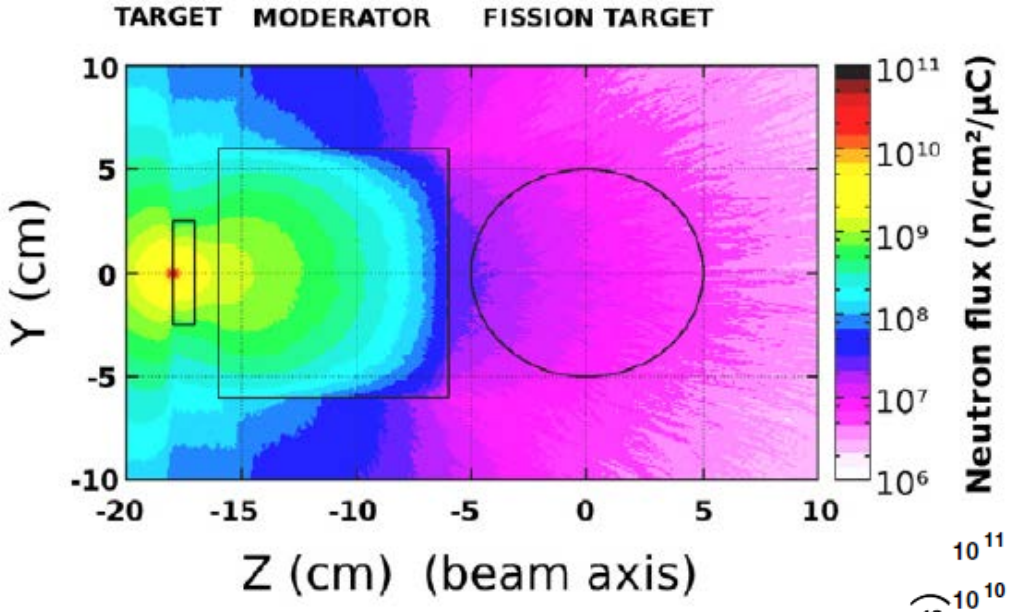
**M. Lantz, D. Gorelov et al., Phys. Scr. T150 (2012) 014020*

Neutron converter, fission target & moderator



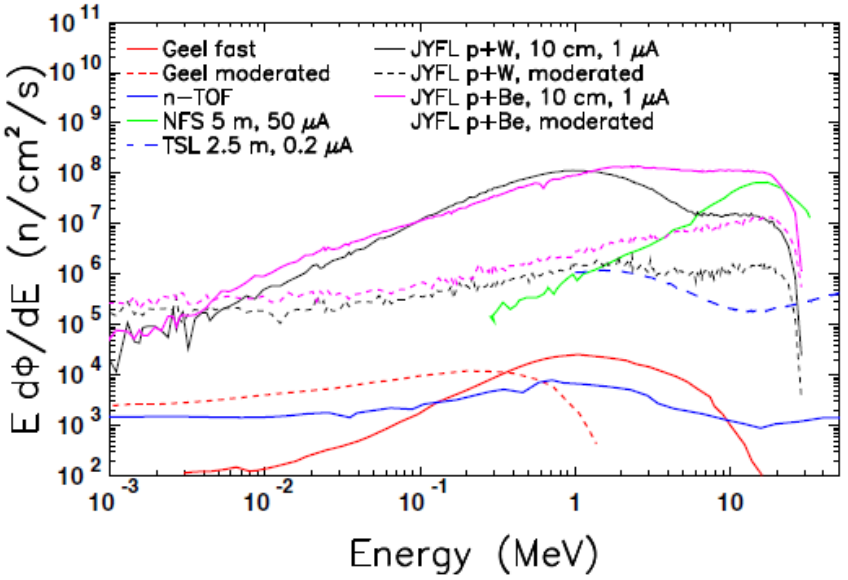
Courtesy of D. Gorelov

FLUKA calculation



- 30 MeV p on W target
- 10 cm-thick CH_2 moderator
- Fission target, cylindrical foil, 10 cm φ, 10 cm width

- Fast and thermal neutron spectra
- 30 MeV protons on W or Be
- 100μA protons yield 10^{12} fast neutrons/sr/s
- Calibration measurement at TSL 2012; energy, angular spread



M. Lantz, D. Gorelov et al., Phys. Scr. T150 (2012) 014020

Thank you for your attention