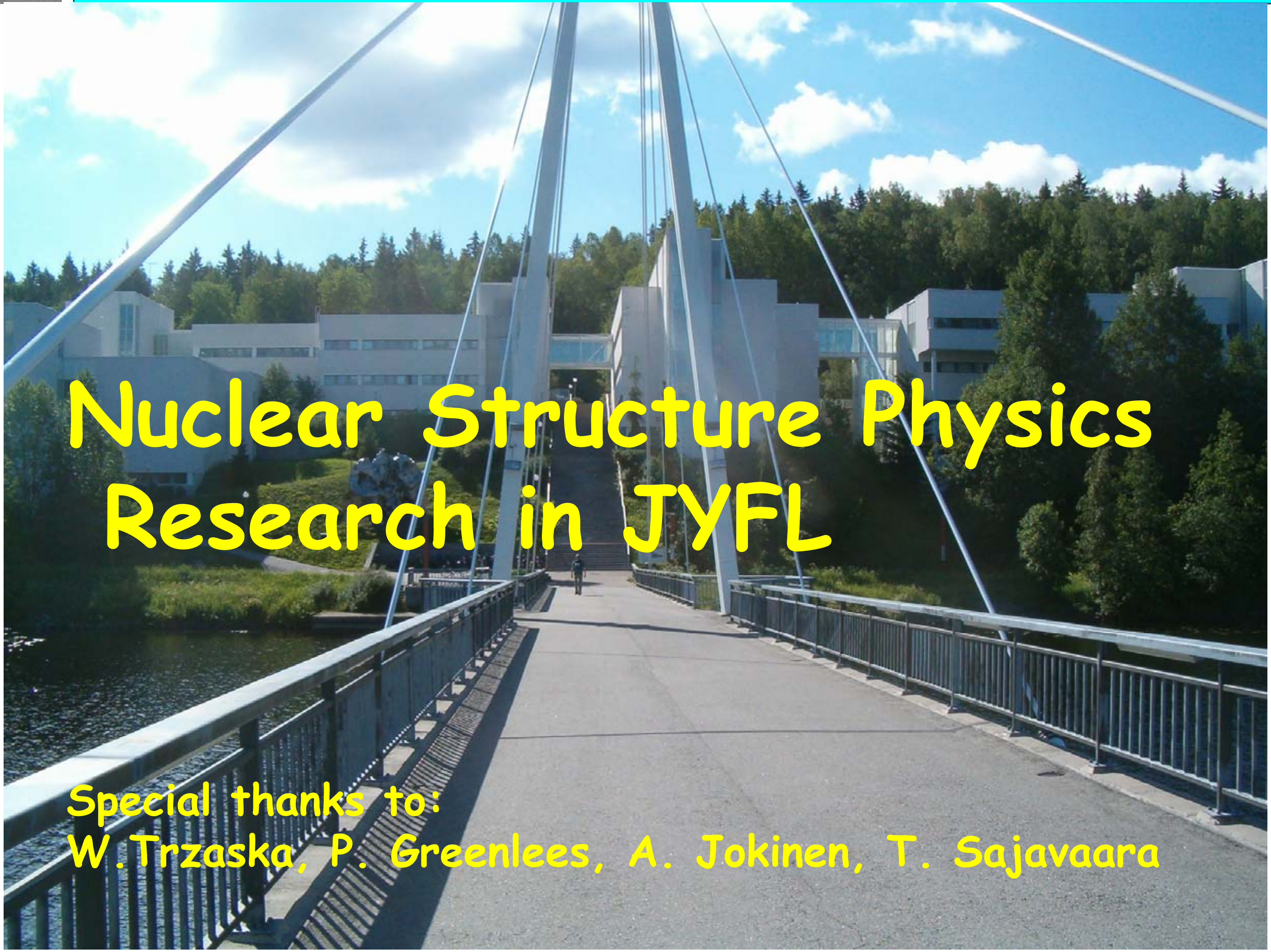
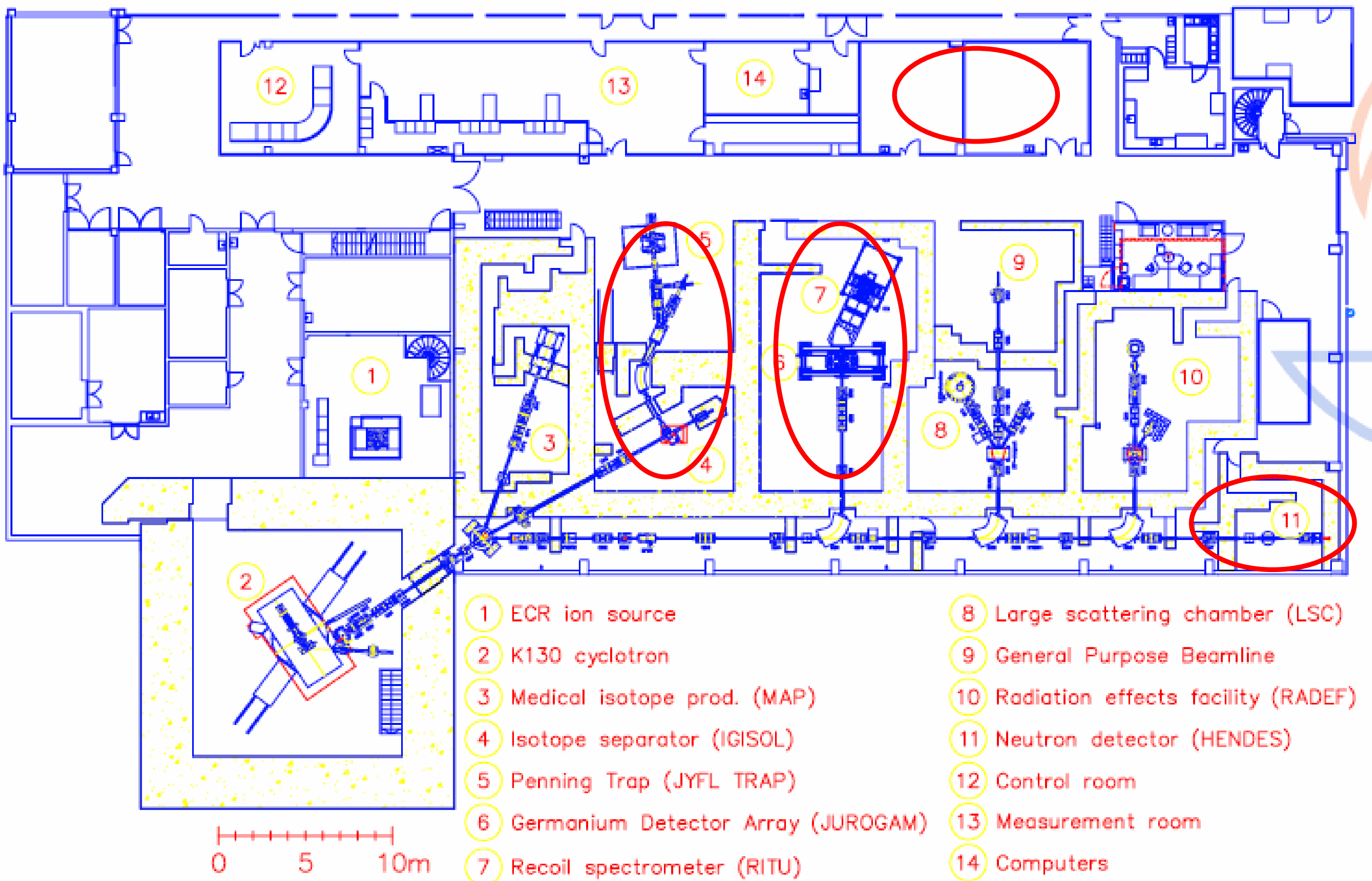


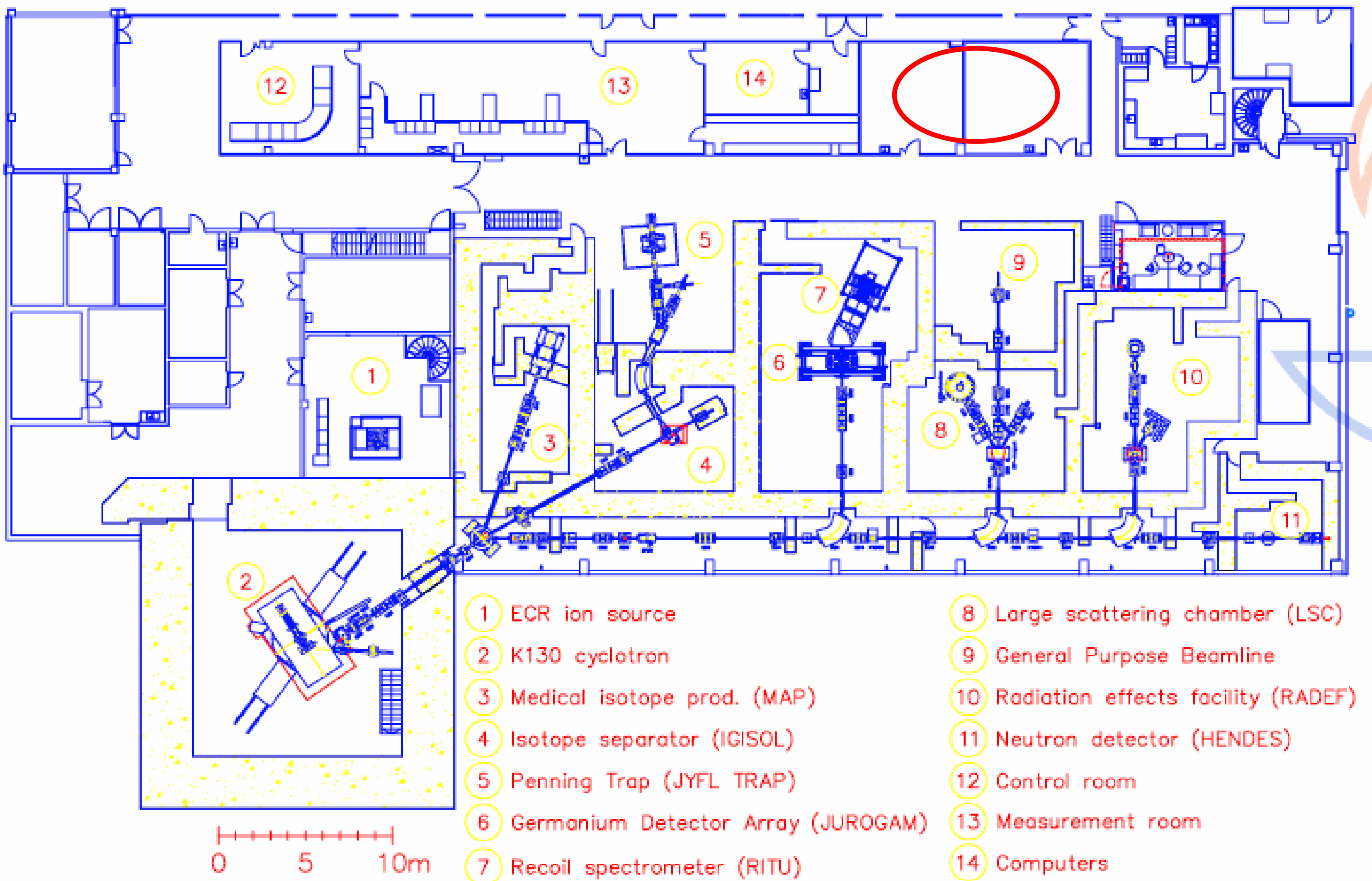
Nuclear Structure Physics Research in JYFL

Special thanks to:
W.Trzaska, P. Greenlees, A. Jokinen, T. Sajavaara

JYFL laboratory layout



Ion beam applications



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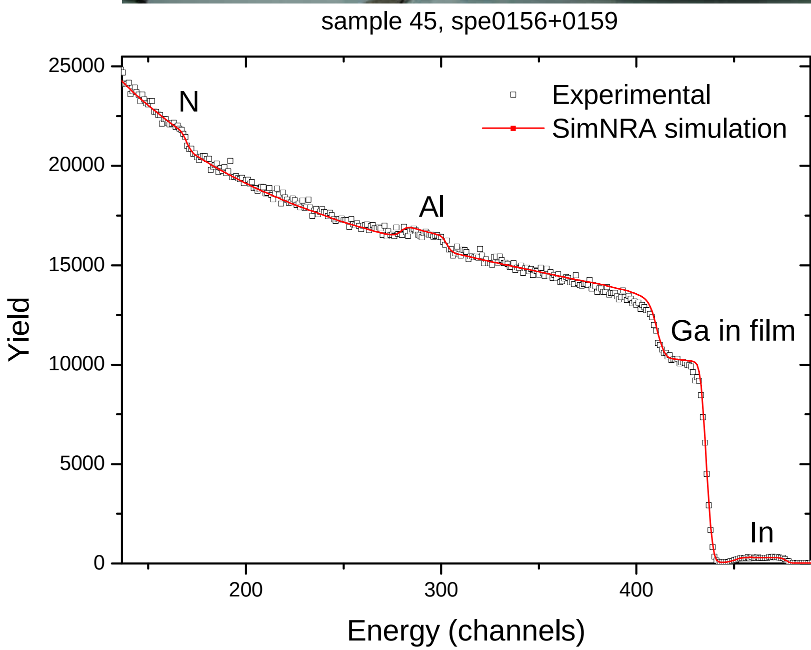
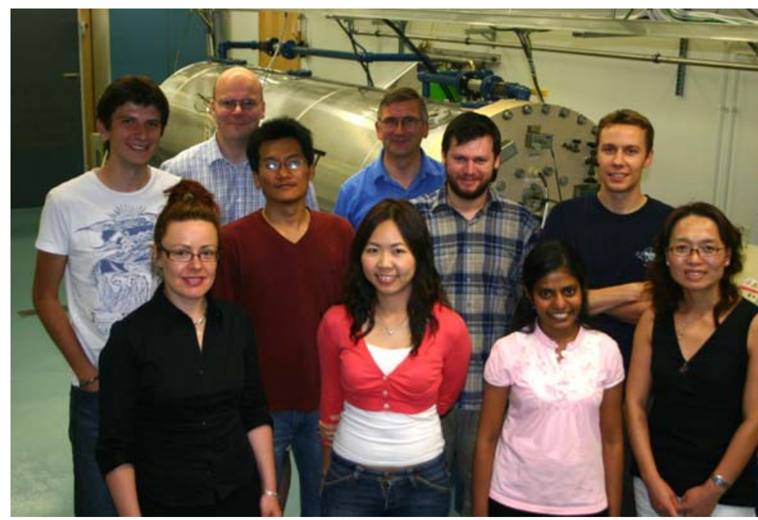
Ion beam analysis using Pelletron-accelerator

Can give answers to many material or thin film related questions, mostly used for determining elemental depth profiles in quantitative manner

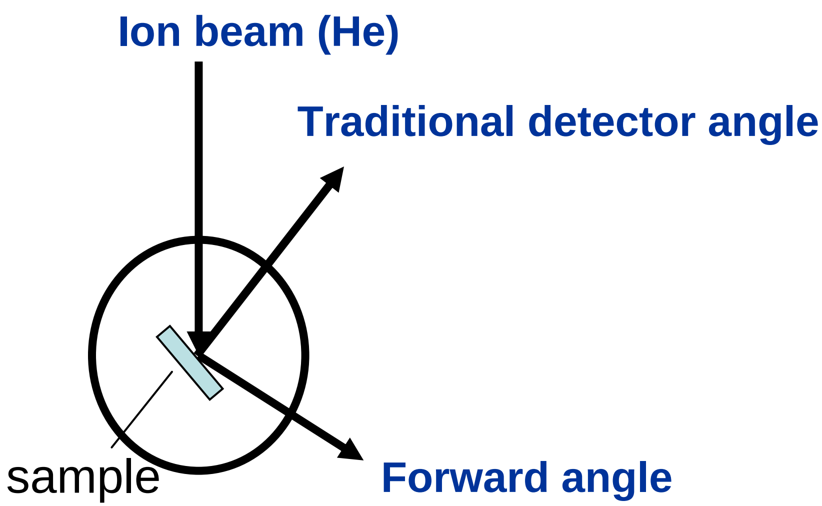




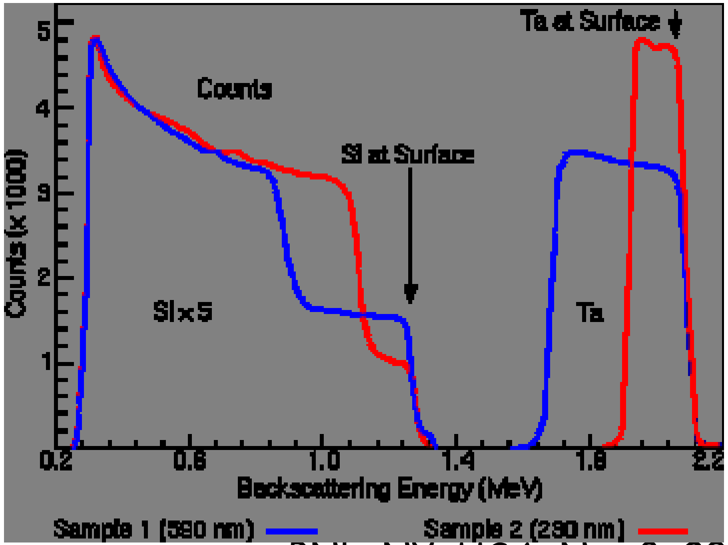
Contact person: docent Timo Sajavaara (timo.sajavaara@jyu.fi)

Measurements that can be done at the moment

- Rutherford Backscattering Spectrometry (RBS)
  - Elemental depth profiles in the sample or thin film
  - Film thickness
  - Depth resolution 5-20 nm (FWHM) at the surface, maximum analysis depth several micrometers
  - For heavy elements concentrations even down to ppm-level can be measured
  - Fast and quantitative
  - Main limitation: detection of light elements on a heavy substrate
  - Also to some degree sensitive to surface roughness



Example: Ta_xSi_{1-x} film on silicon



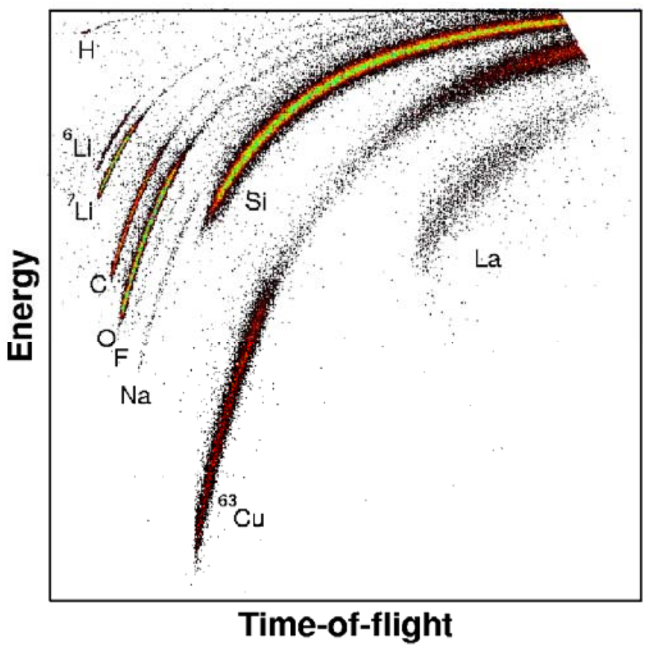
- Elastic recoil detection analysis (ERDA) using forward scattering angles
  - Hydrogen concentration
  - Depth resolution about 50-100 nm at the surface

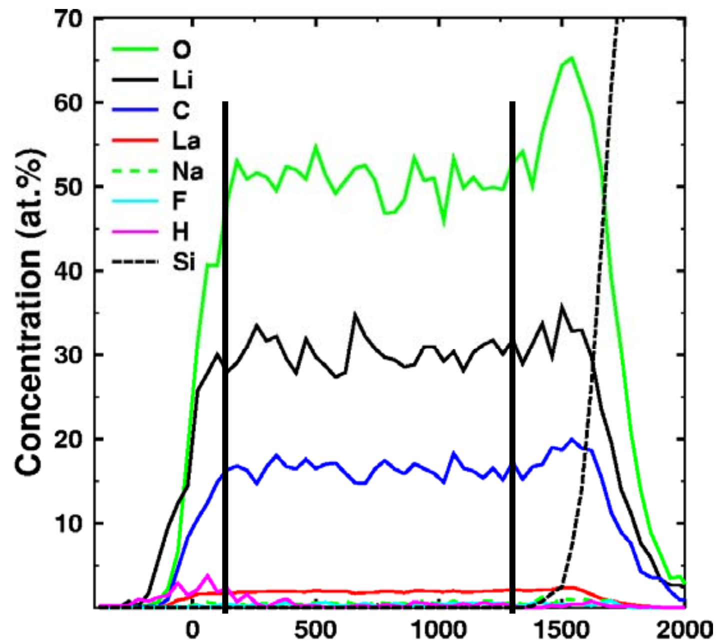
Contact person: timo.sajavaara@jyu.fi

Plans for the near future

- We have applied fund from EU to build up a detector system which is capable of depth profiling all sample elements (including hydrogen) with a depth resolution better than 1 nm.

An analysis example of the performance of this type of detector system, which was build by Timo Sajavaara at IMEC, Belgium. Sample is 140 nm thick Li-La-O film on Si substrate and it contained plenty oh impurities which could be quantified.





Sample composition (in atomic %):
O: 51 ± 4, **Li**: 30 ± 3, **C**: 16± 2, **La**: 1.9 ± 0.2,
Na: 0.48 ± 0.05, **F**: 0.34 ± 0.04, **H**: 0.4 ± 0.1
Integrated between $200 \le x \le 1400\times10^{15}$ at. cm^{-2}

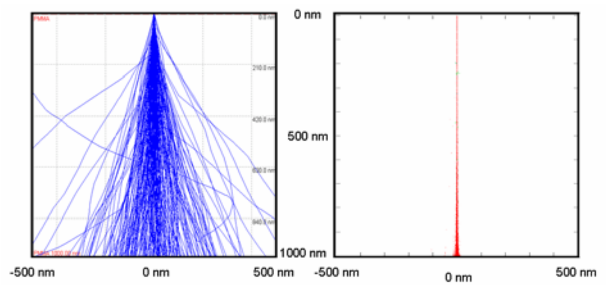
Contact person: timo.sajavaara@jyu.fi

MeV ion beam litography

Why?

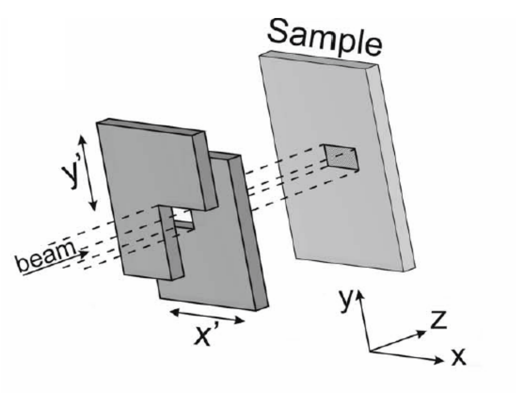
MeV ions can write sharp patterns in thick polymers.

20 keV electrons 1 MeV protons



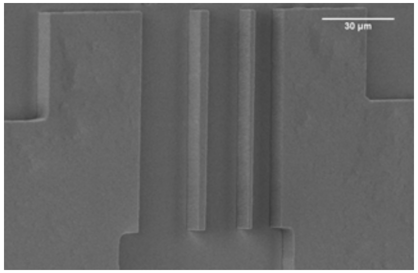
How?

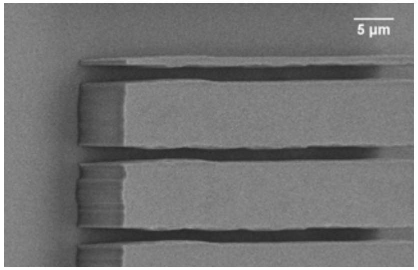
Shaped beam using computer controlled aperture and target movement



What we do?

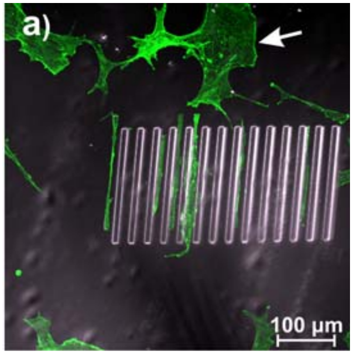
Structures made with MeV ion beam lithography in 7 μm PMMA





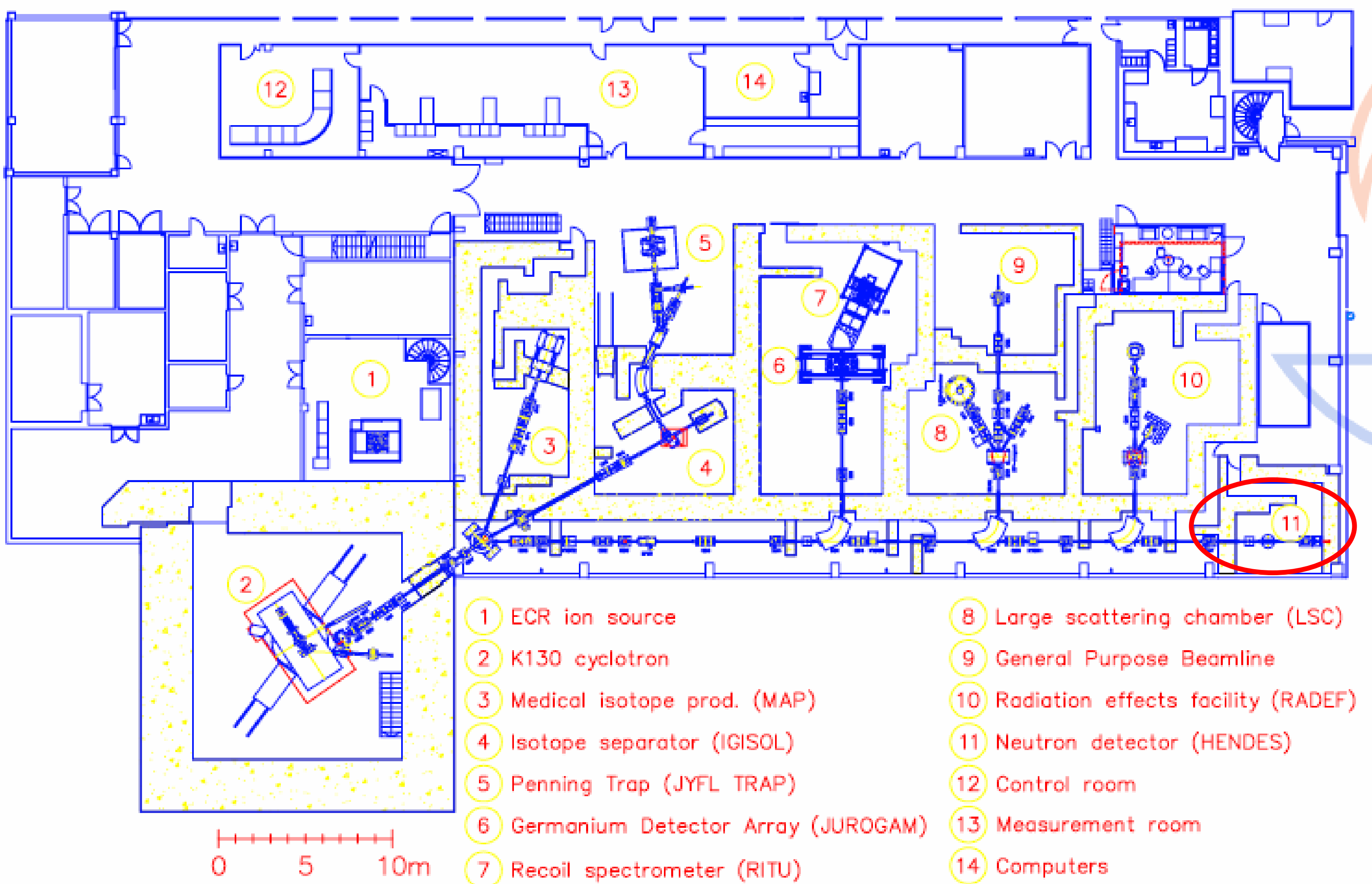
What is this used for?

Cell growth substrates for bone-cell research, fast prototyping of microfluidics lab-on-a-chip, micromachining, master stamps for hot embossing.



Organisation of mouse pre-osteoblast cell cytoskeleton by MeV ion beam machined channels

HENDES



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0 5 10m

Nuclear reaction studies at HENDES

$^{238}U(d,pf)$ measurements

At JYFL and Catania

<u>The aim:</u> to investigate super asymmetric fission mode connected with influence of the nuclear shells N=50 and Z=28 (^{78}Ni fission mode)

The collaboration

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W.H.Trzaska
J.Äystö

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E.V. Chernysheva
D.A.Gorelov
G.N.Knyazheva
E.M. Kozulin
L.Krupa
S.Krupko
S.V. Smirnov

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Khlopin Radium Institute, St. Petersburg, Russia

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TEXAS A&M Univercity, Cyclotron Institute, College Station, USA

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C.Maiolino
F.Mammoliti
A.Di Pietro
V.Scuderi

E.Vardacci
V.Rizzi
M.Cinausero
G.Prete
N.Gelli

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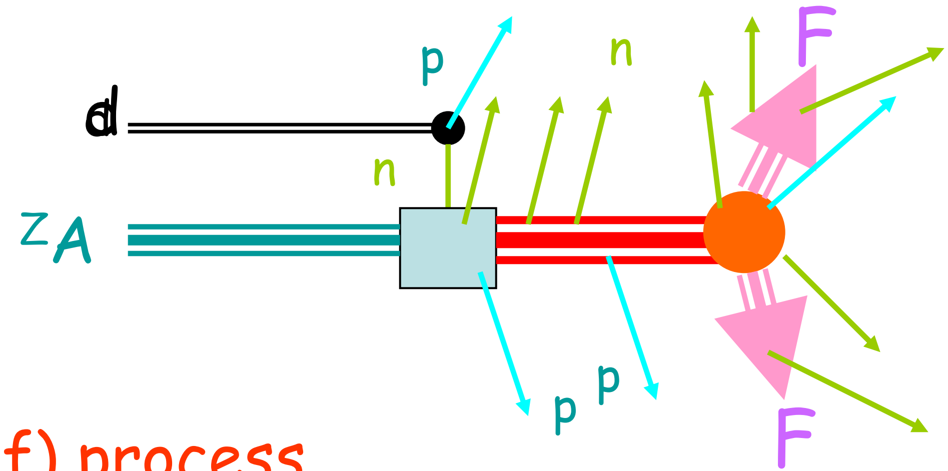
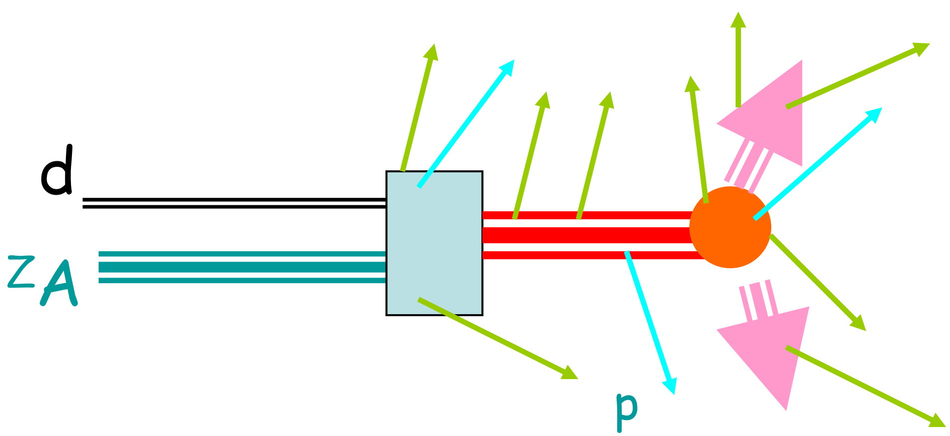
IReS, Strasbourg, France
F.Hanappe
Universite Libre de Bruxelles, Belgium
D.Ridikas, D.Dore
CEA Saclay, France

Fission reaction modes

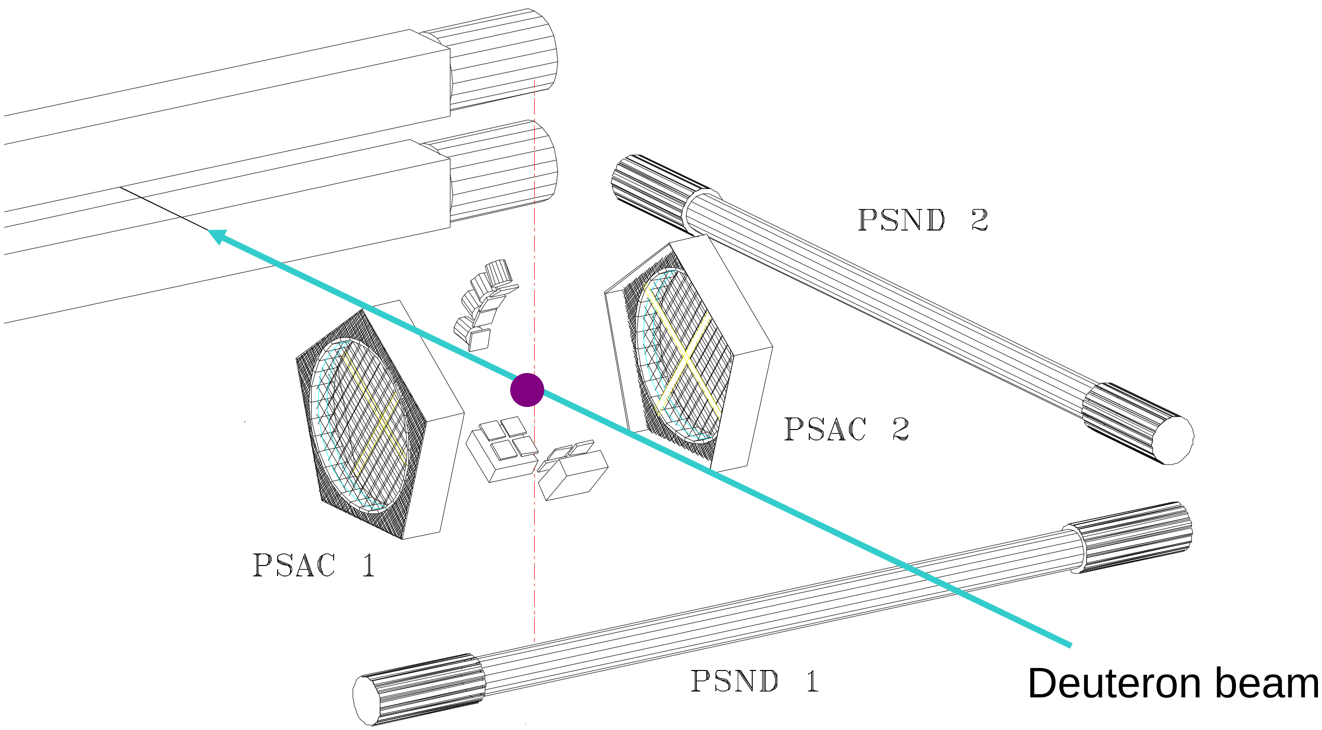
Direct (d, pf) process



Pre-equilibrium (d, pf) process



Detection setup

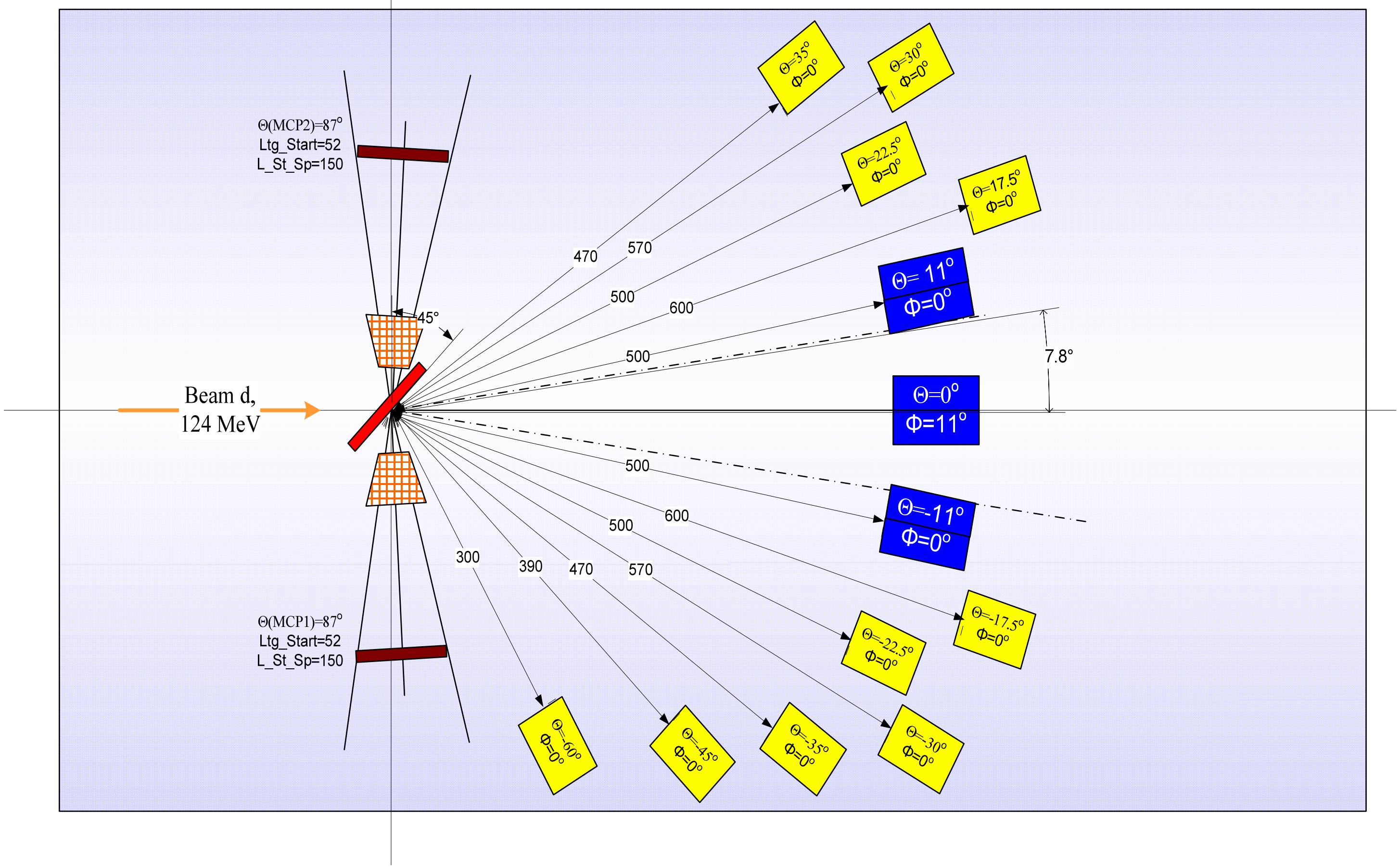


Lay-out of HENDES for the $^{238}U(d, p(n) f)$ at $E_d = 65$ MeV

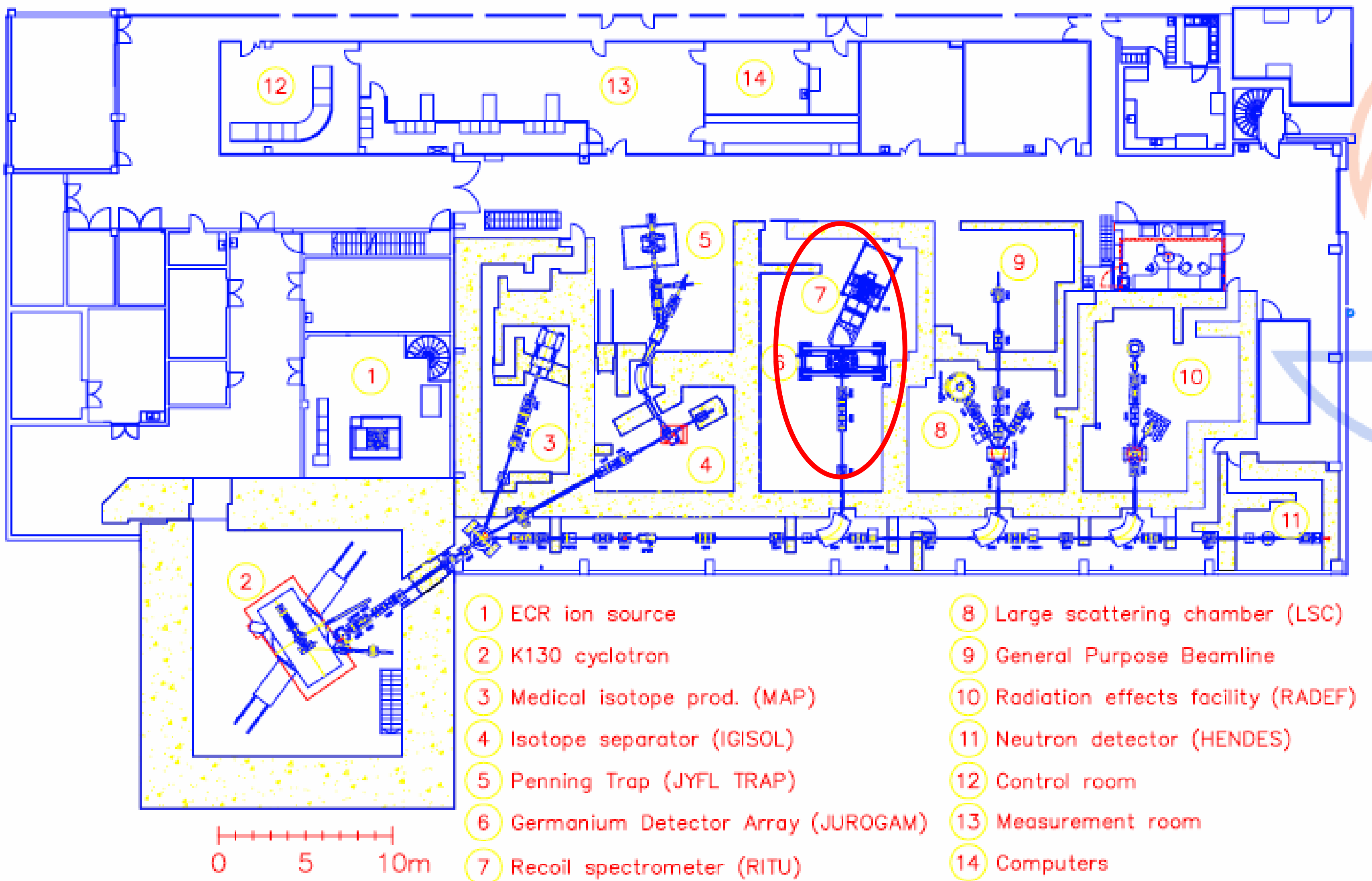
Higher deuterium energies

^{238}U(d,pf), E_d = 124 MeV

Catania, March 2007

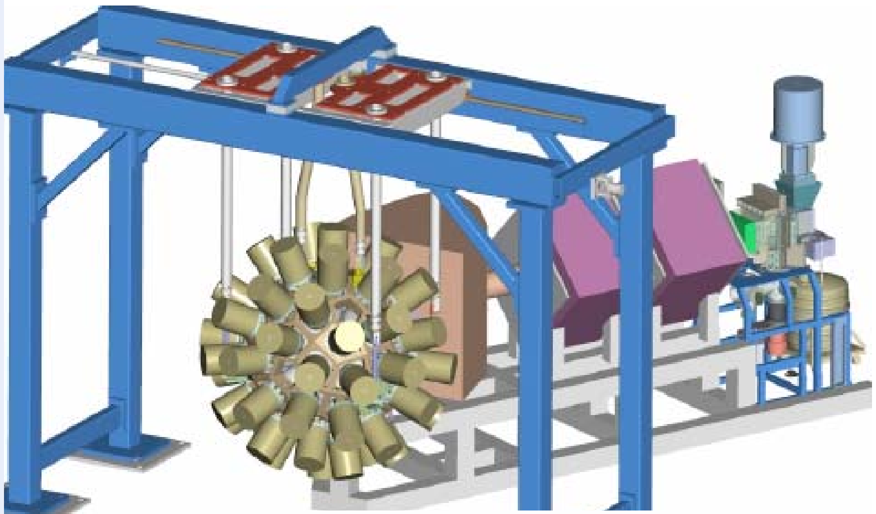


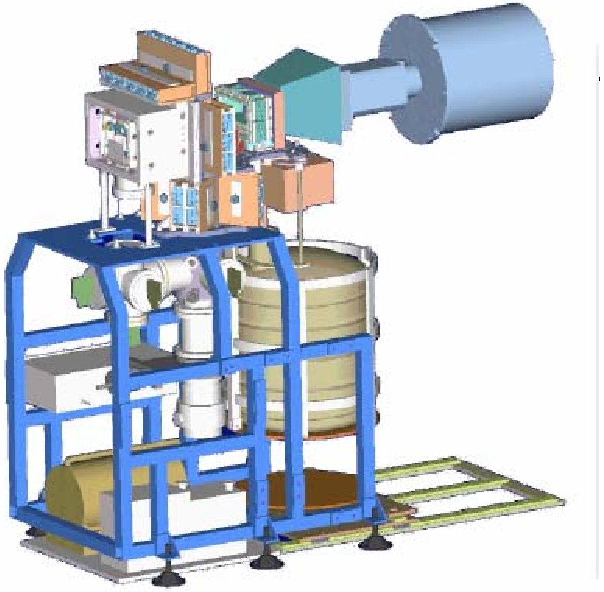
RITU & JUROGAM



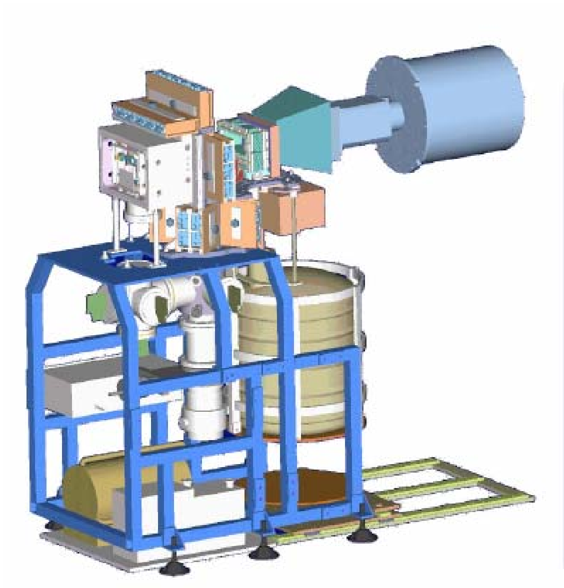
RITU & JUROGAM

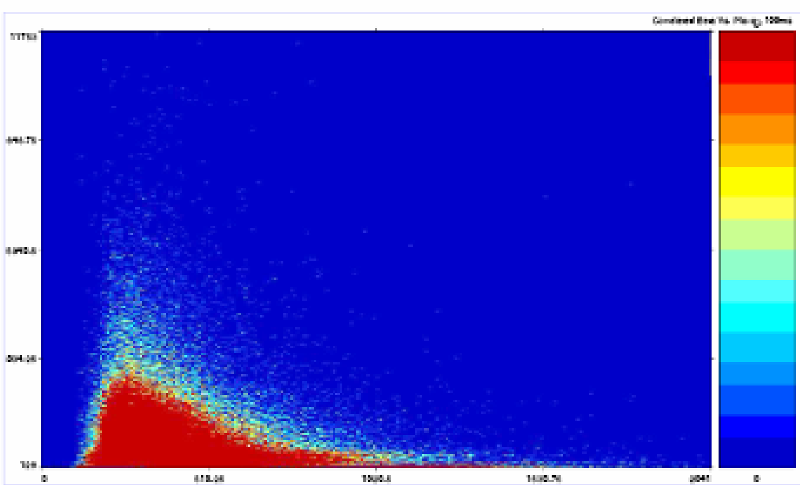
- 43 Phase I and GASP-type Ge detectors - EUROBALL and U.K.-France loan pool
- Total Photopeak Efficiency 4.2% @ 1.3 MeV
- Much improved (x10) γ-γ efficiency
- Software Compton suppression
- Autofill system built by University of York, part of GREAT
- Target chamber built by IReS Strasbourg, allows use of rotating target wheel
- Modified EUROGAM support structure

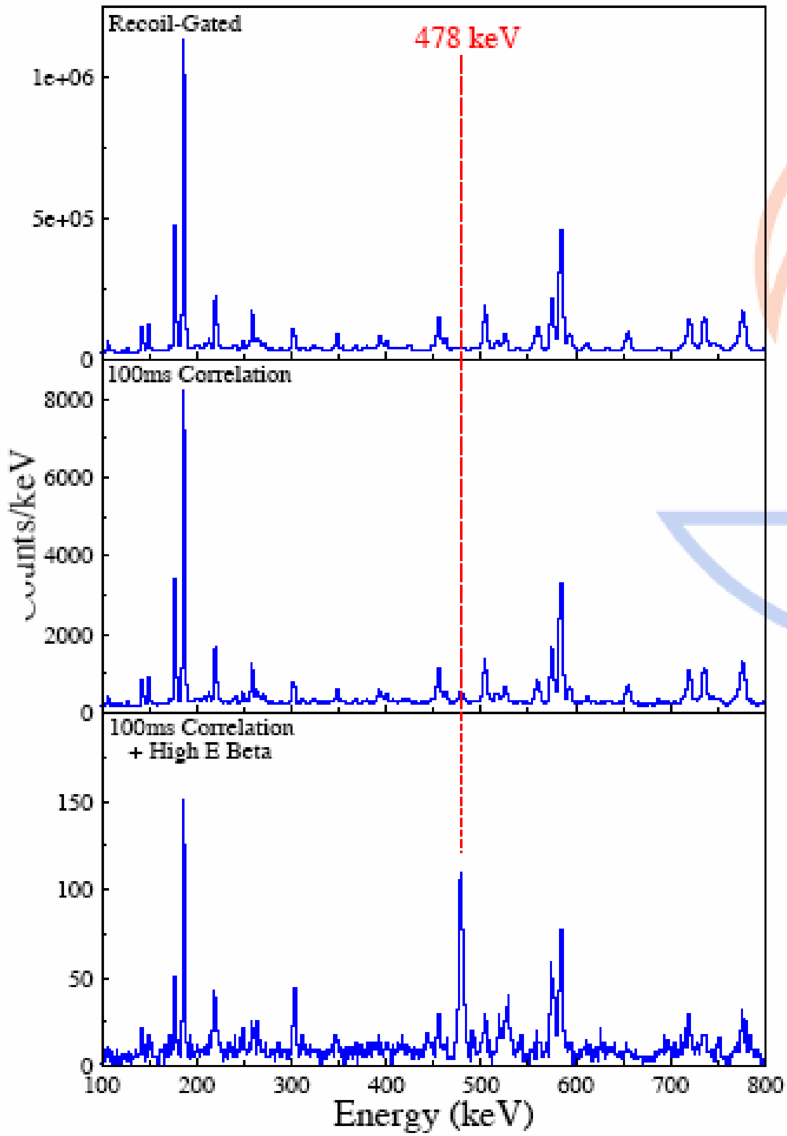




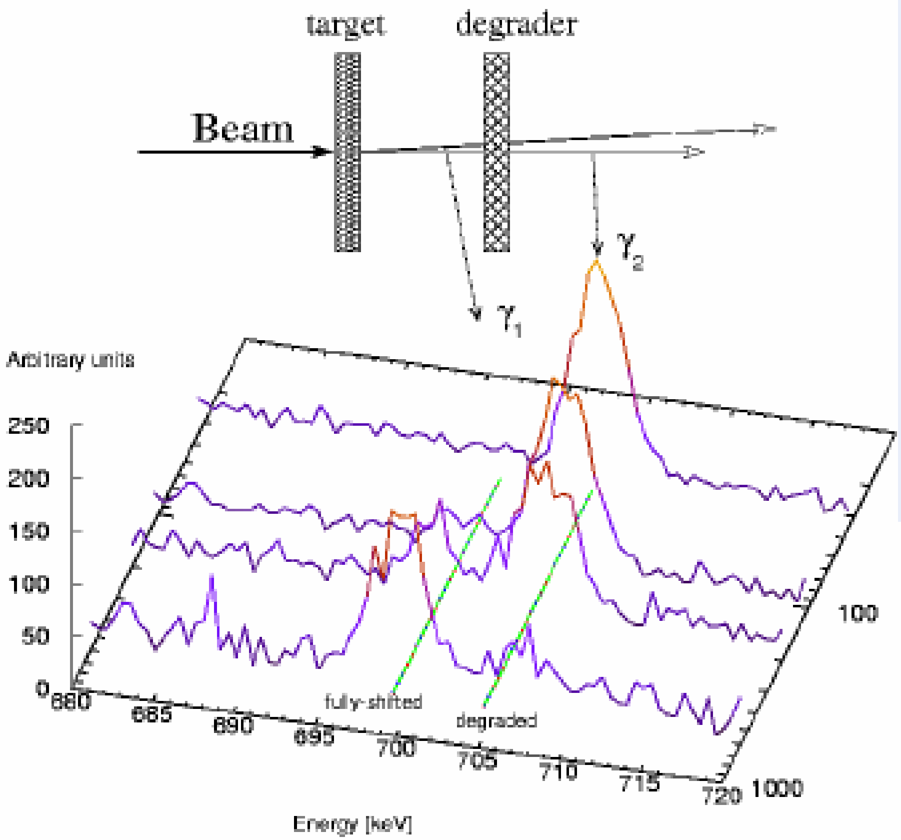
Beta recoil tagging







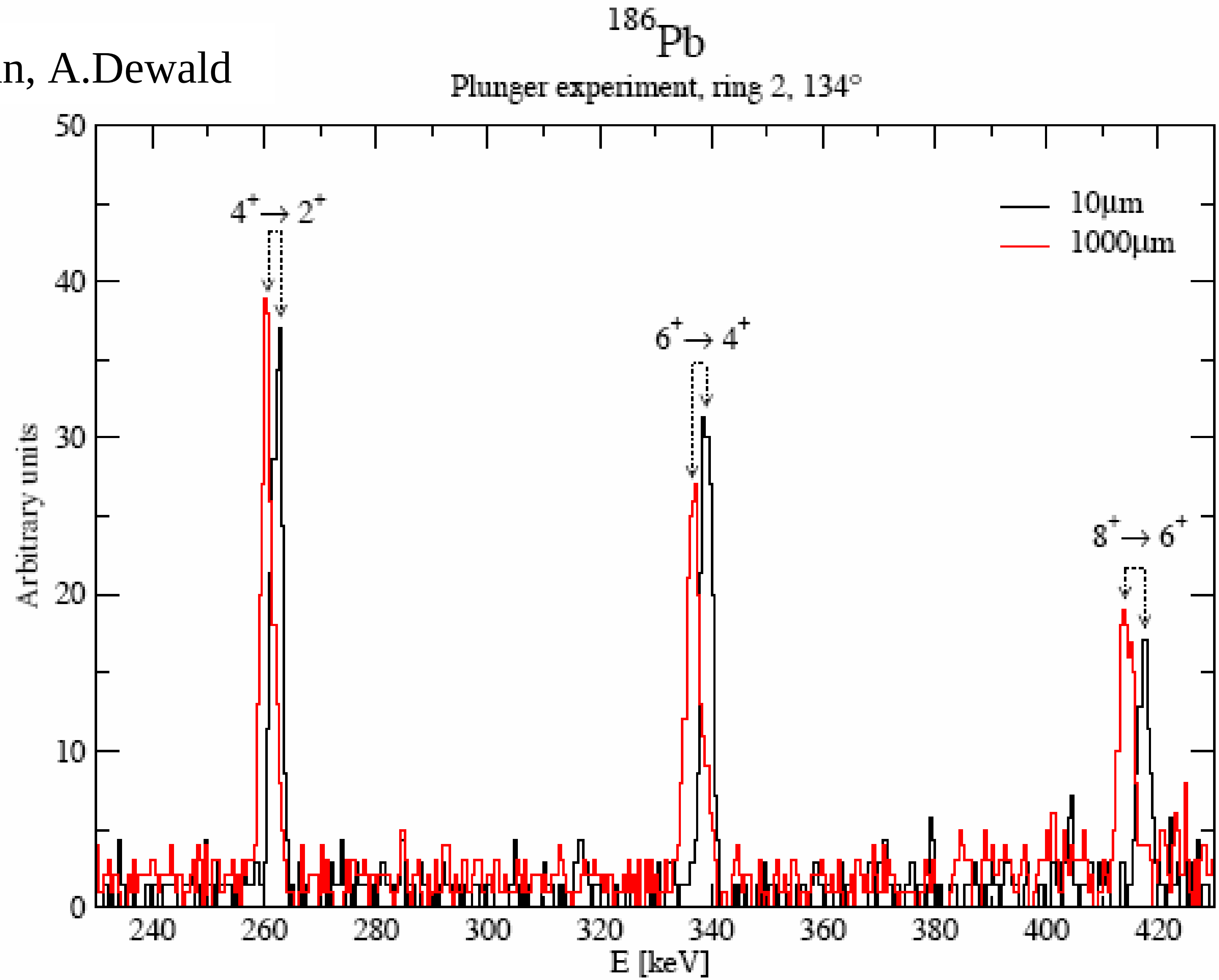
RDDS lifetime measurements



- $E(\theta) = E_0(1 - \frac{v}{c}\cos\theta)$
- Need high initial recoil velocity
- Degrader - 1 mg/cm^2 Mg,Al or 2 mg/cm^2 Au
- Typical velocity change 4% to 3%
- Loss of separator transmission efficiency

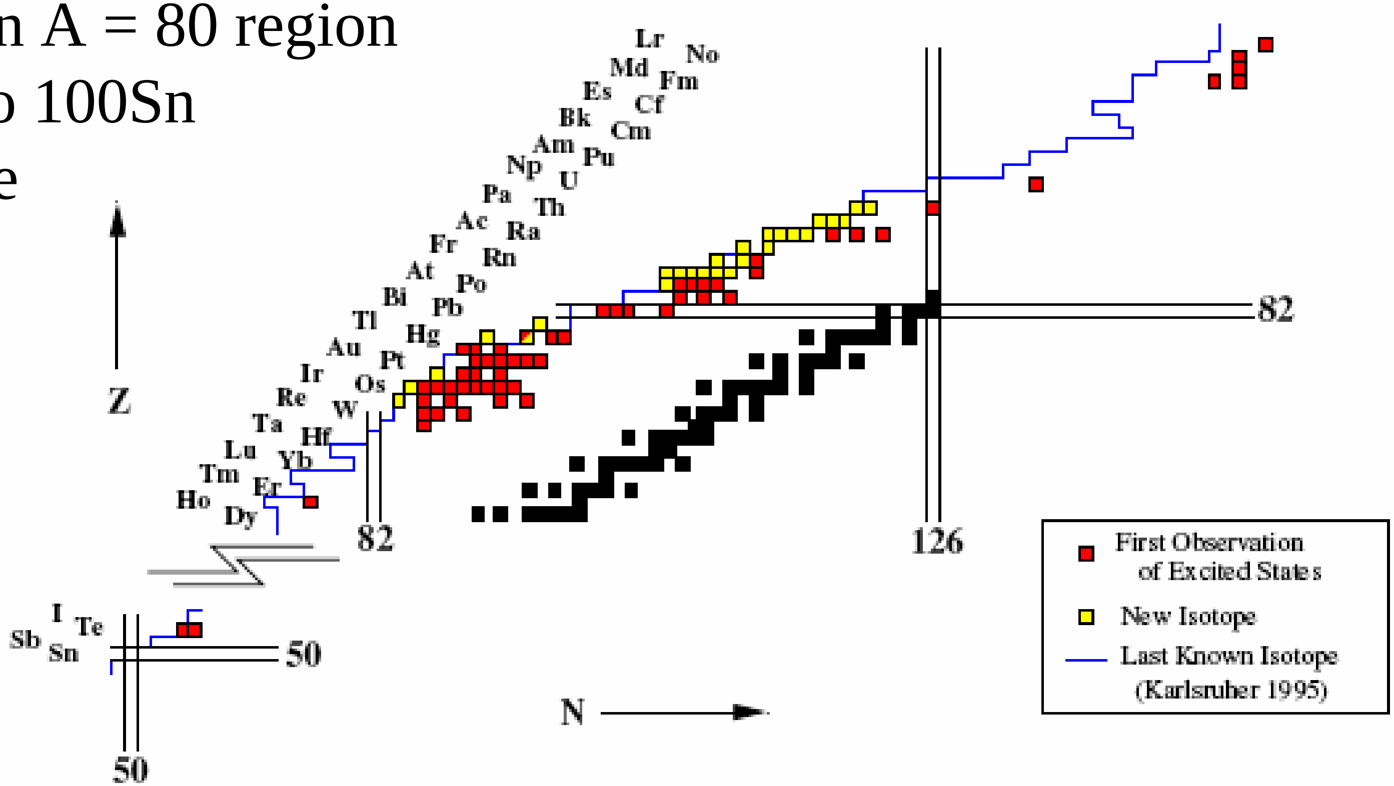
Combined RDT and RDDS

T.Grahn, A.Dewald

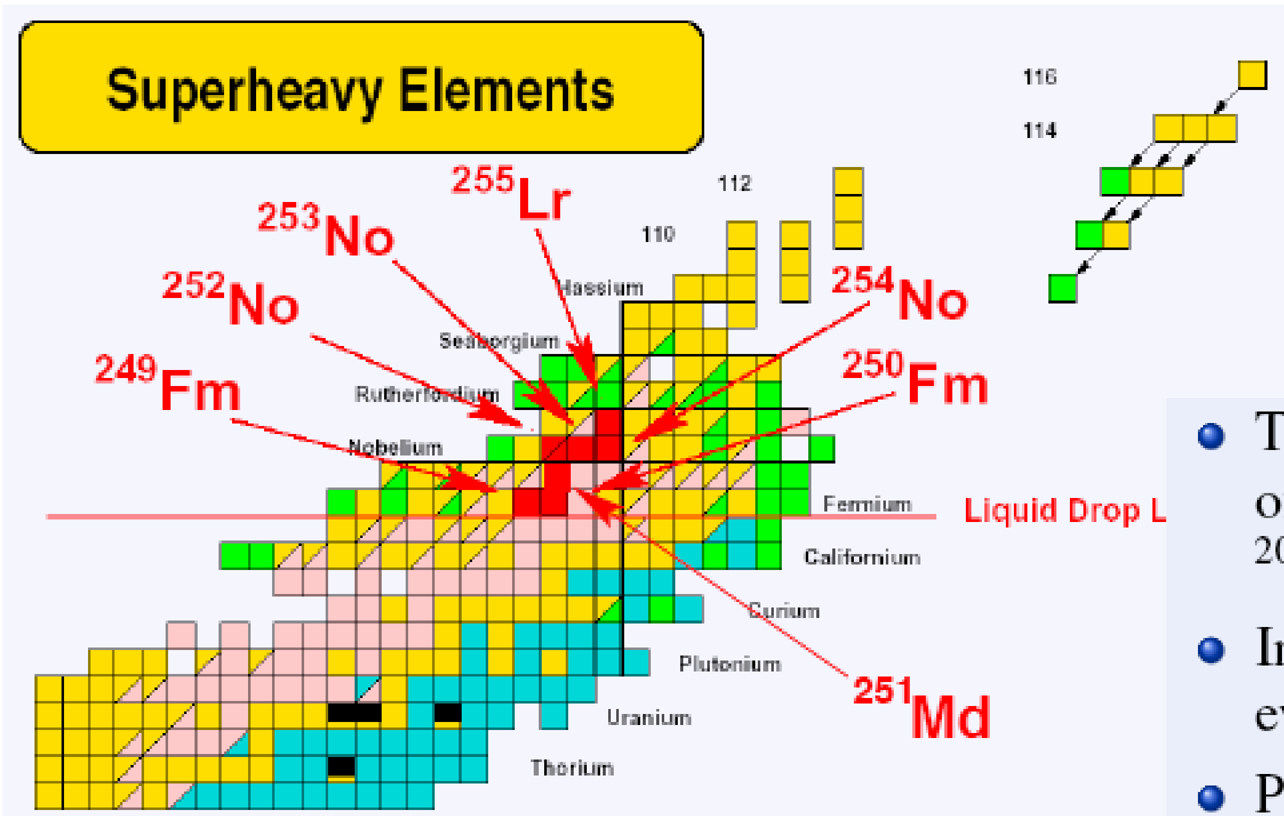


Studied nuclei

- Shell stabilised transfermium nuclei
- Shape coexistence in light Pb and Po
- K-isomerism in A=240 nuclei
- N = Z nuclei in A = 80 region
- Nuclei close to 100Sn
- Proton dripline

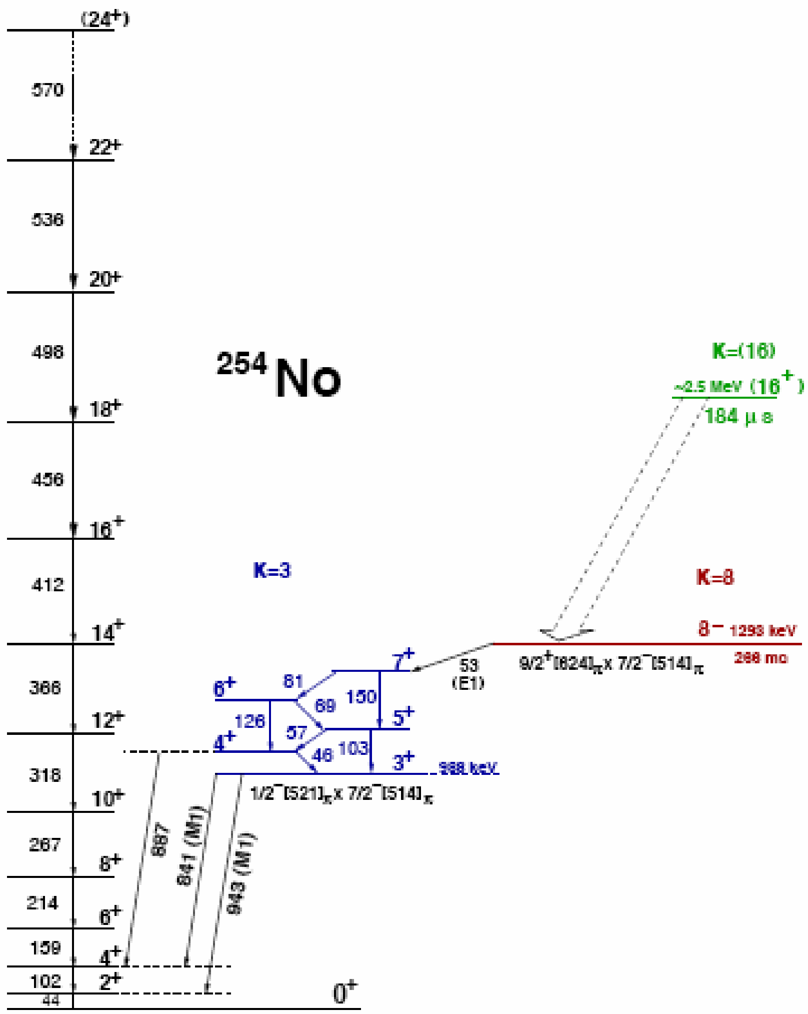


Transfermium nuclei



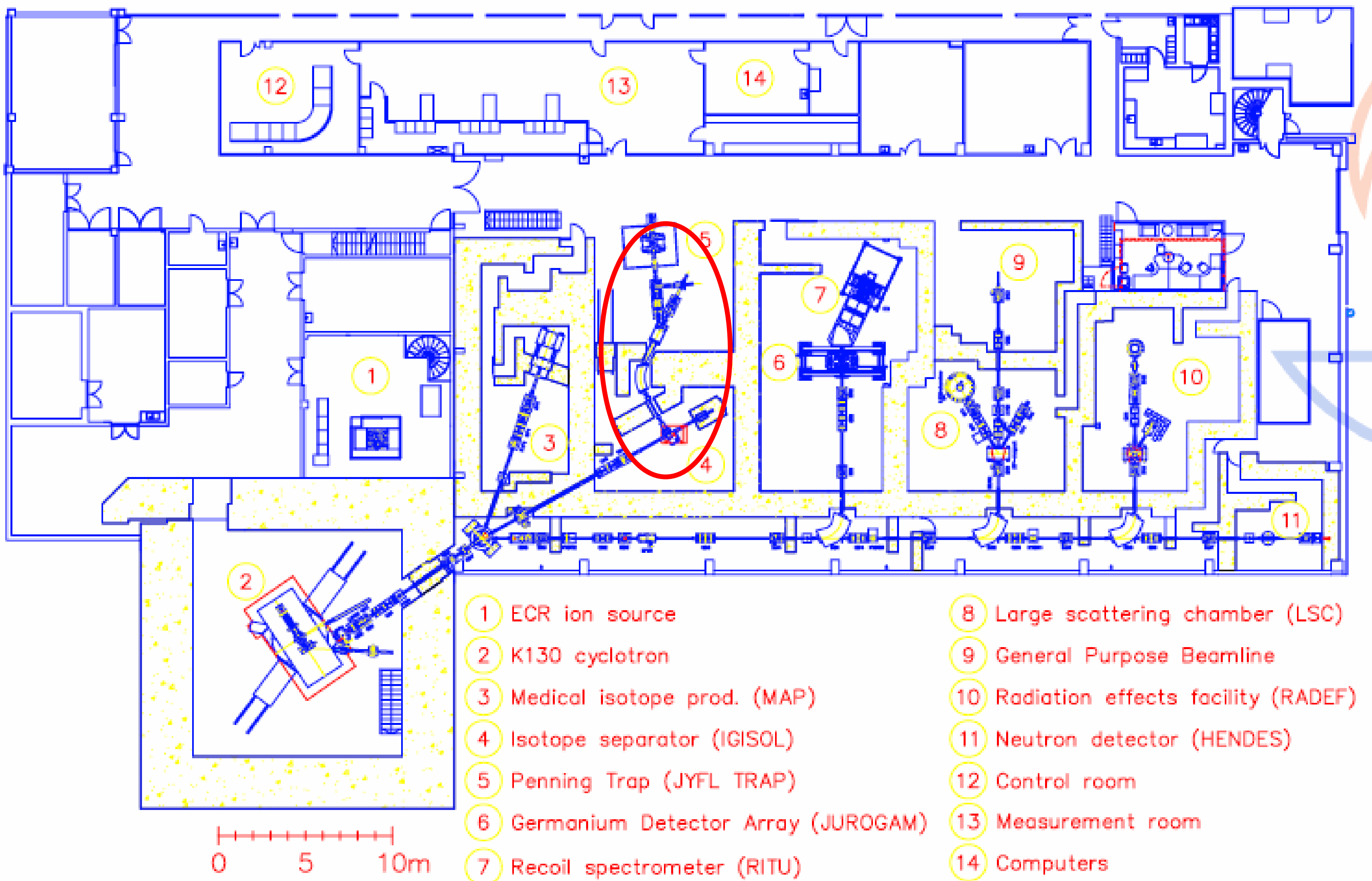
- Theory disagrees on location of next closed shells above ^{208}Pb
- Initial studies focussed on even-even nuclei
- Progressed to studies of odd-A nuclei
- Studies of high-K states

K-isomerism



R.-D. Herzberg, P.T. Greenlees et al., Nature **442**, 896-899 (2006)

IGISOL



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0
5
10m

IGISOL group

Heikki Penttilä, Viki-Veikko Elomaa, Tommi Eronen, Ulrike Hager, Jani Hakala, Ari Jokinen, Anu Kankainen, Pasi Karvonen, Thomas Kessler, Bruce Marsh*, Iain Moore, Kari Peräjärvi, Saidur Rahaman, Sami Rinta-Antila, Juho Rissanen, Janne Ronkainen, Perttu Ronkanen, Valery Rubchenya, Antti Saastamoinen, Tetsu Sonoda, Benjamin Tordoff*, Juha Äystö

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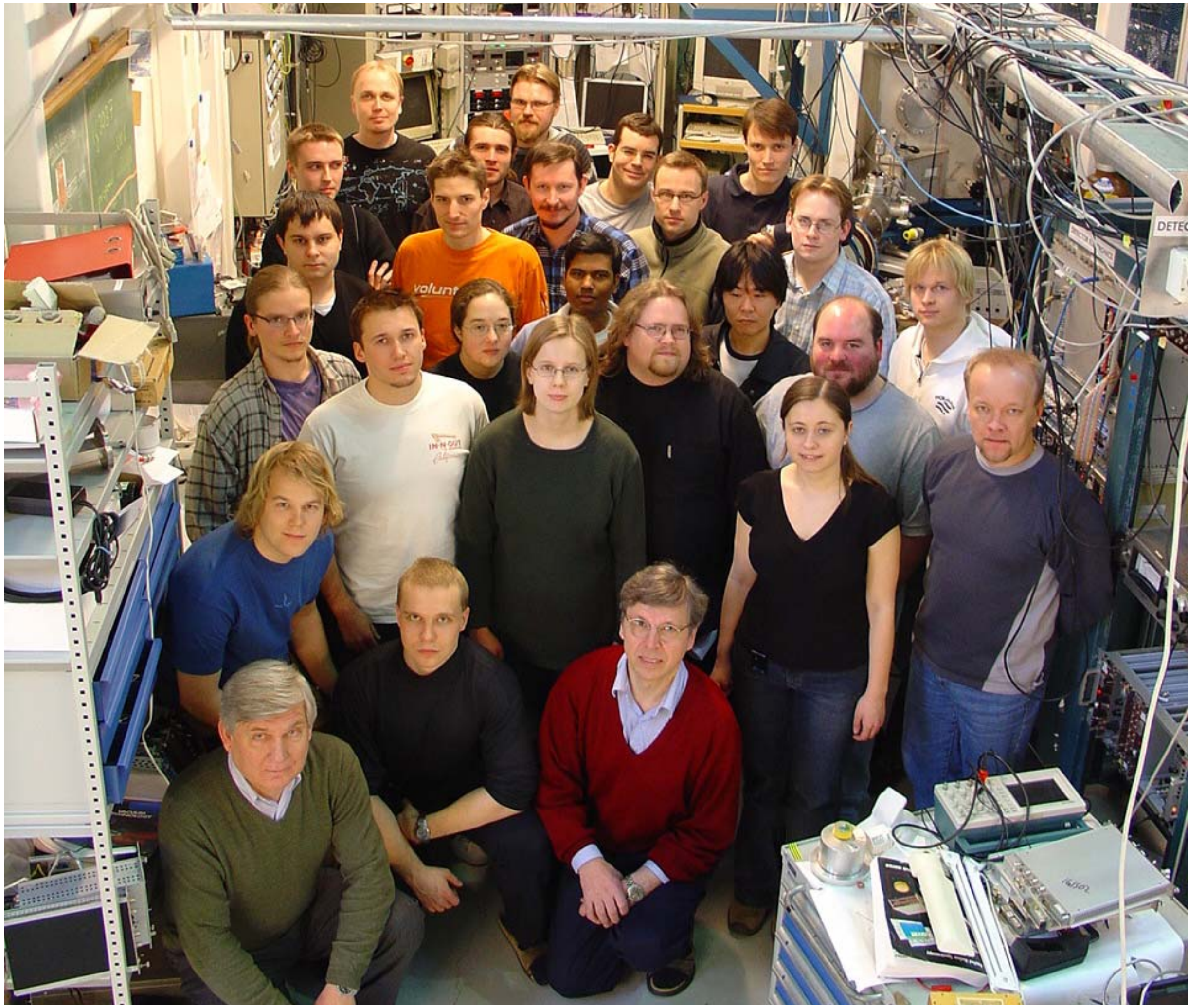
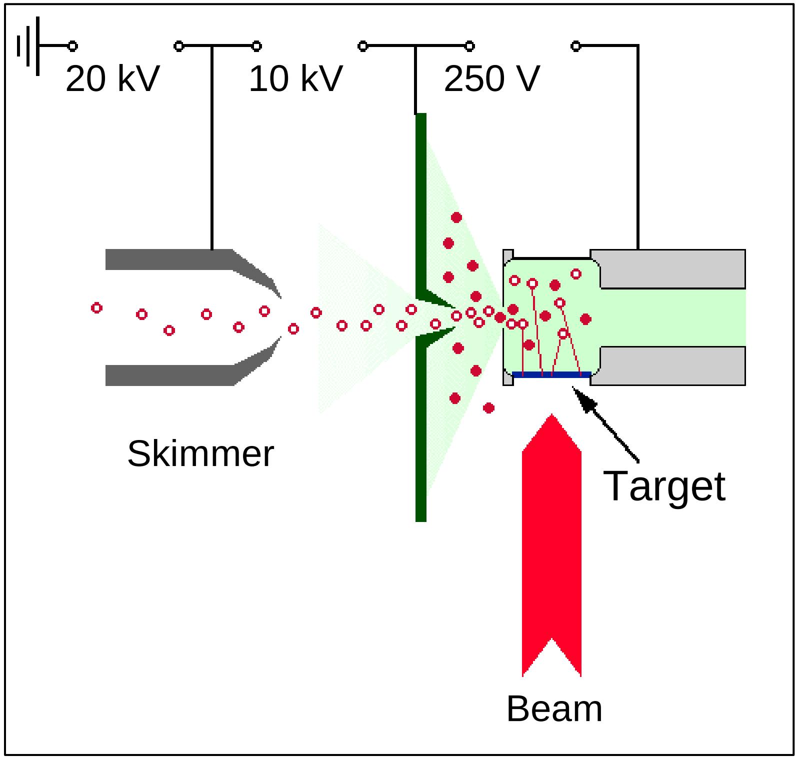
* University of Manchester



Ion guide principle



Classical consept:

Based on survival of primary ions in helium buffer gas

Charge state concentration: (0), +1, (+2)

Fast gas flow required to prevent neutralisation

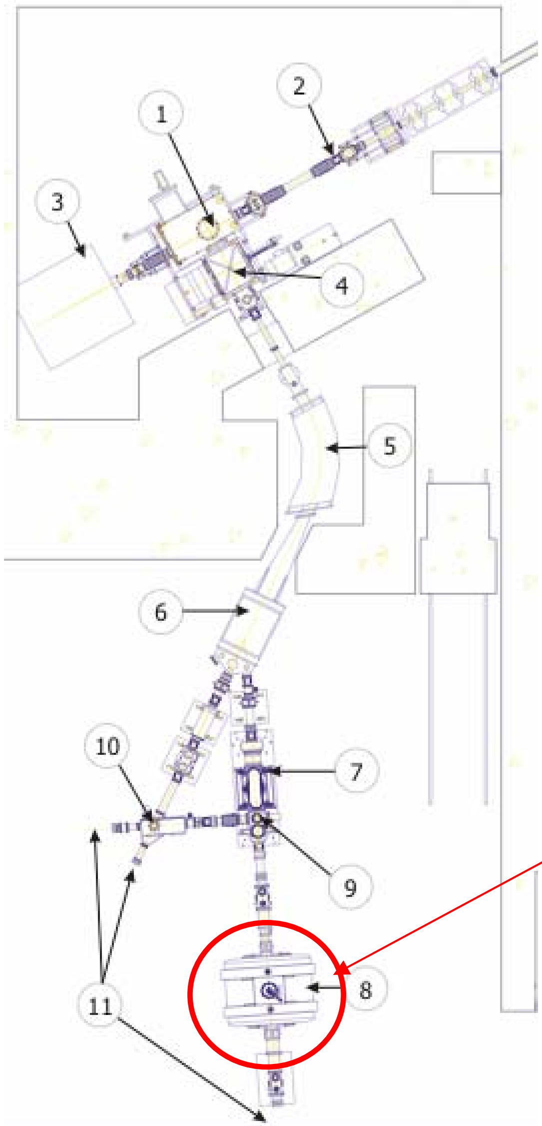
No electrodes or rf-carpets inside the gas cell

Produces ions of any element

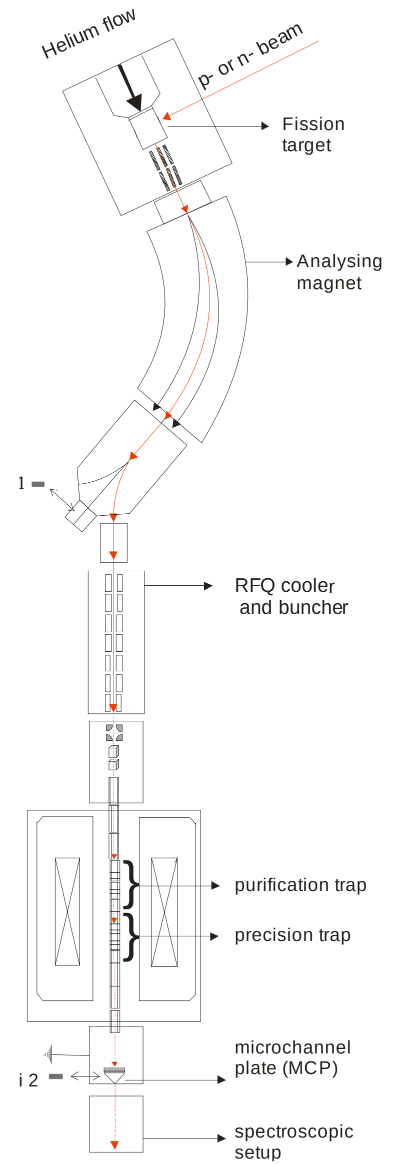
All ions are primary ions from reaction

Delay time (a) few milliseconds

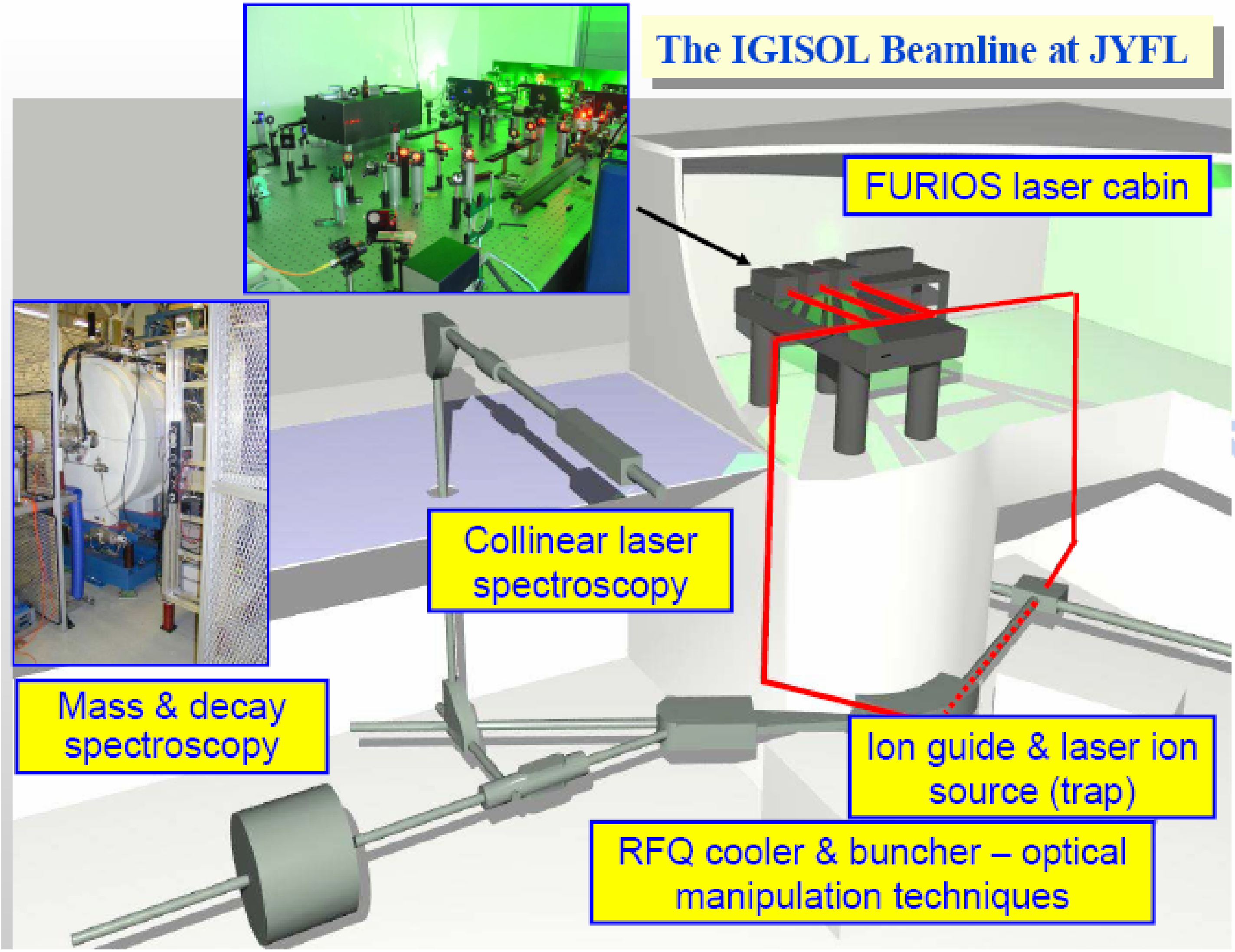
Current IGISOL facility



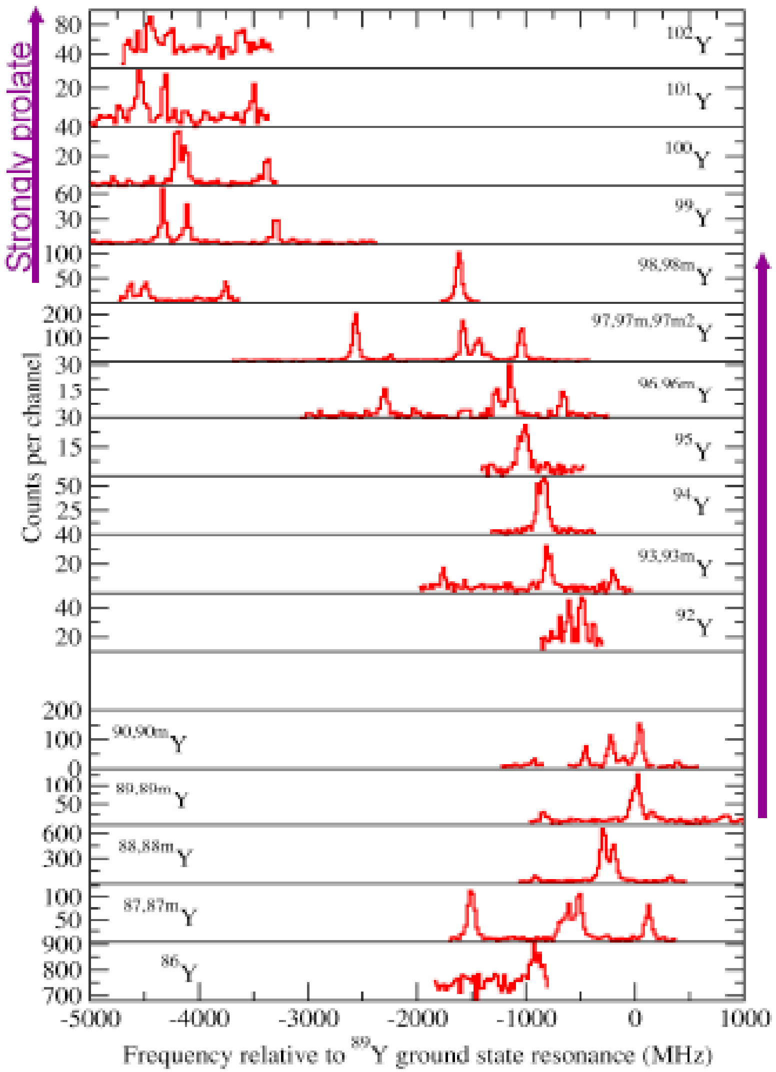
1. Target chamber
2. K-130 cyclotron beam line
3. Beam dump
4. Extraction chamber
5. Dipole magnet (55°)
6. Switchyard
7. Radiofrequency (RFQ) cooler
8. Double Penning trap
9. Miniquadrupole
10. 90° bend to upstairs, collinear laser setup
11. End of beam line for spectroscopy setups

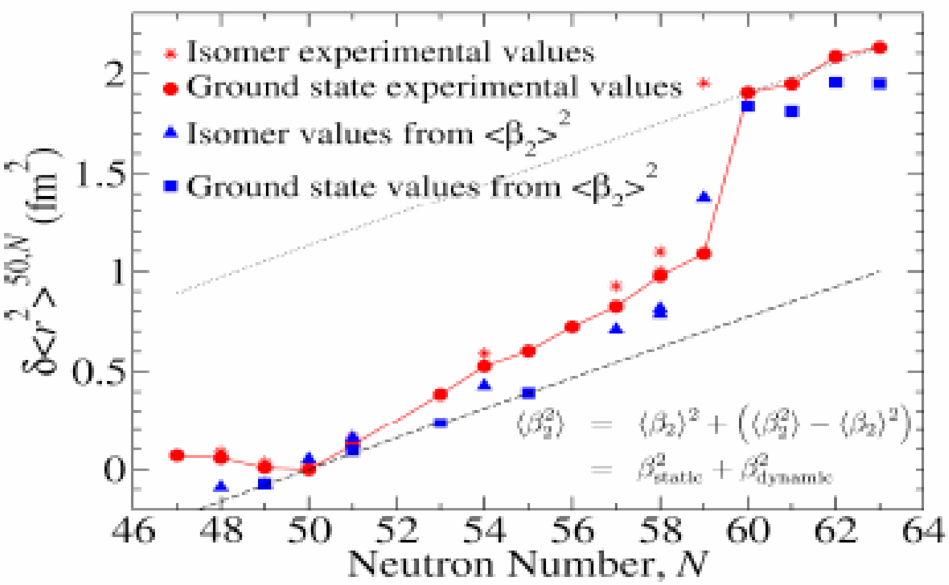


Lasers at IGISOL



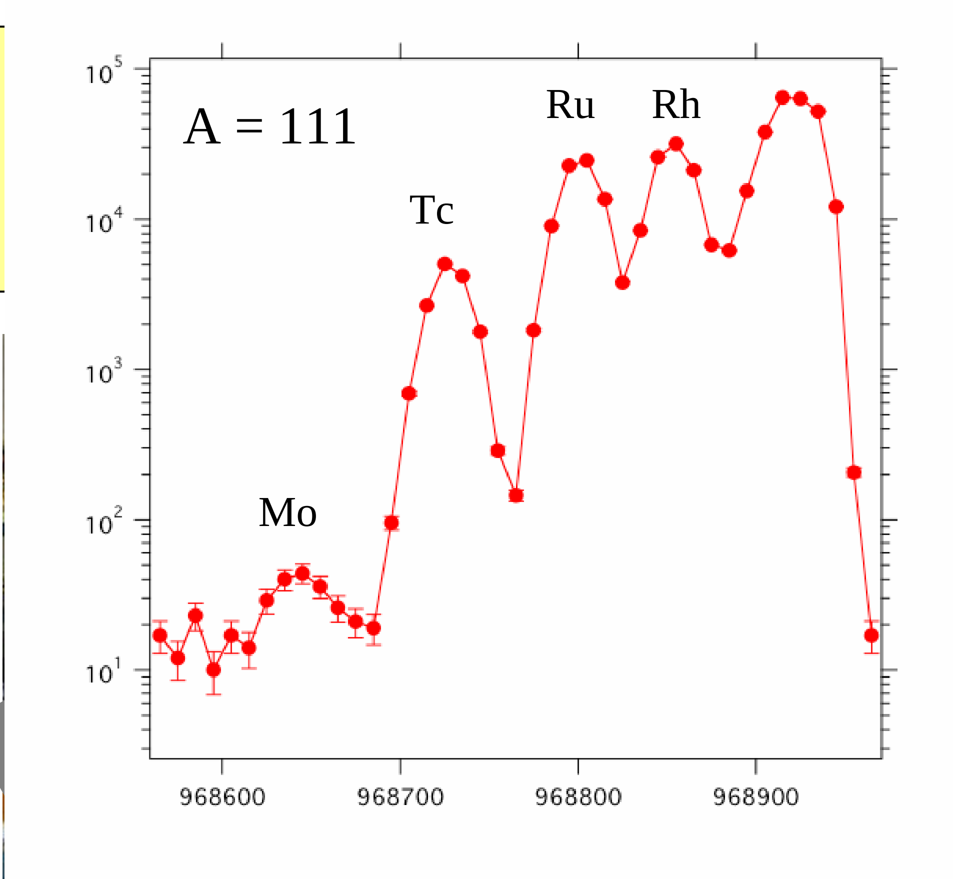
Nuclear shapes by collinear laser spectroscopy

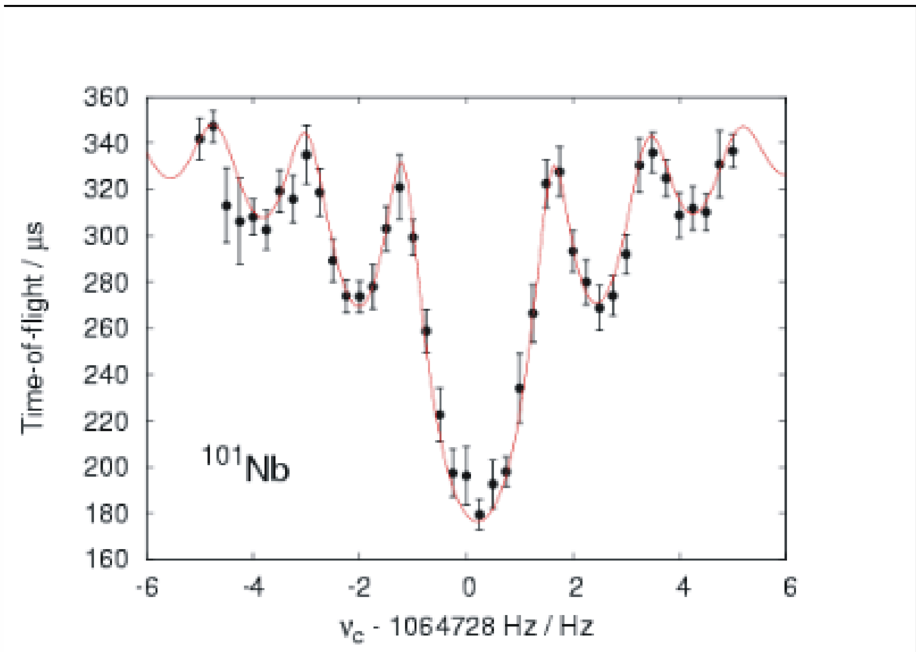


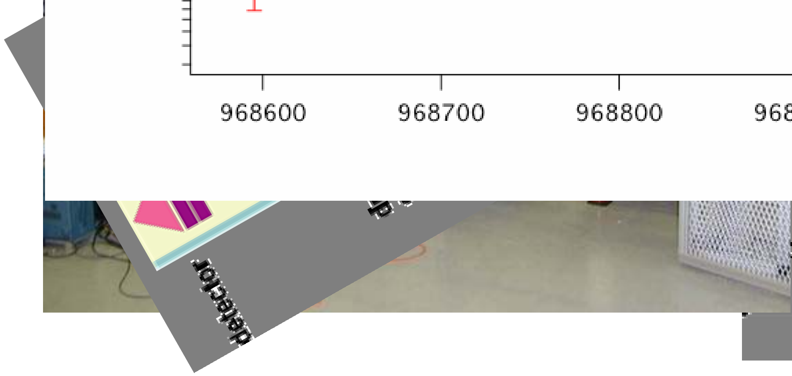


USNDP Meeting BNL, NY, USA Nov 8, 2007

JYFLTRAP

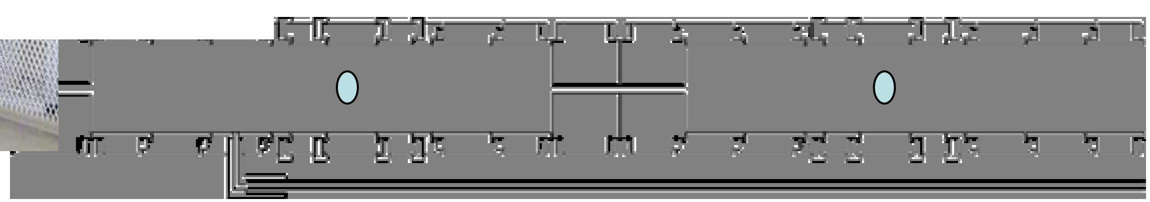




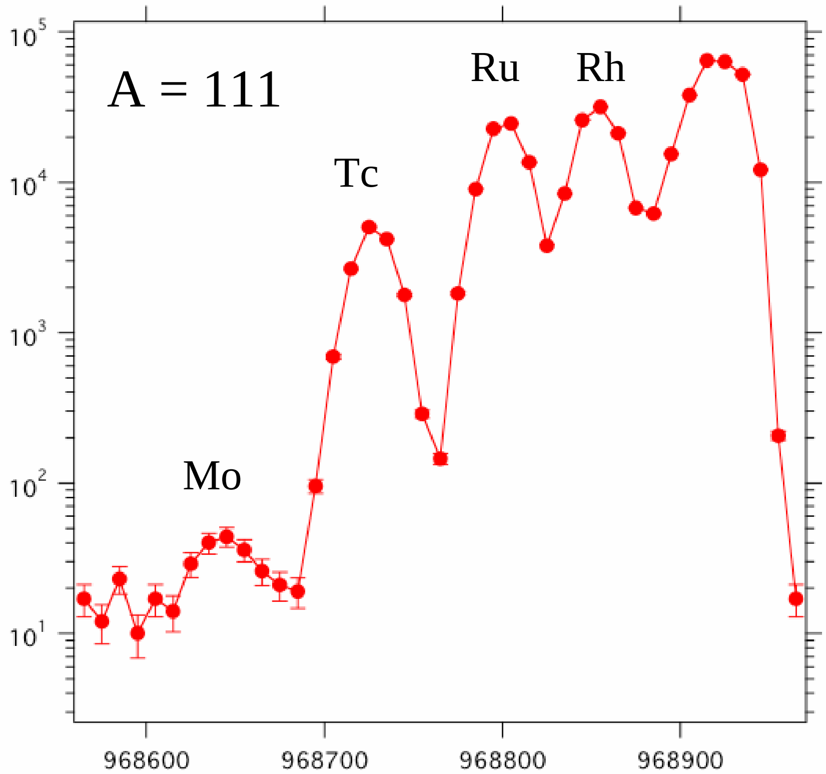


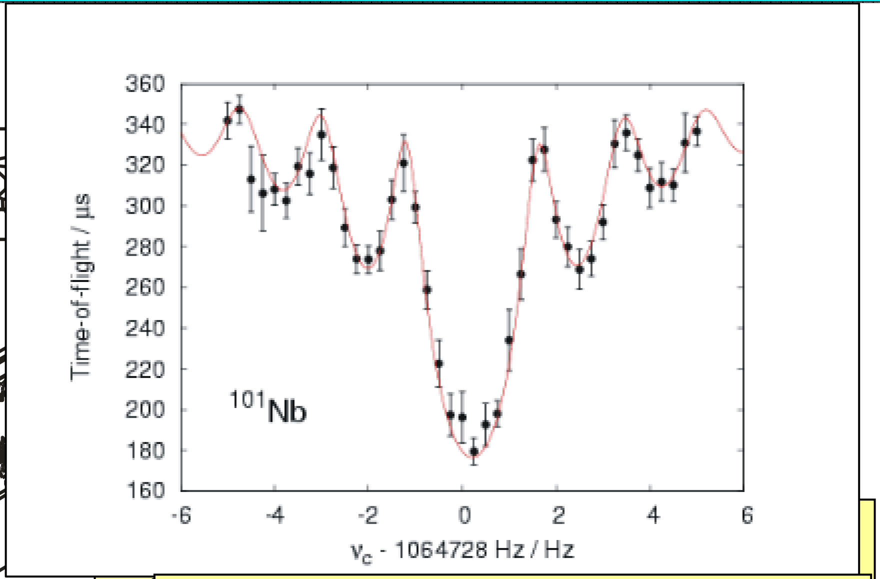
purification trap

precision trap



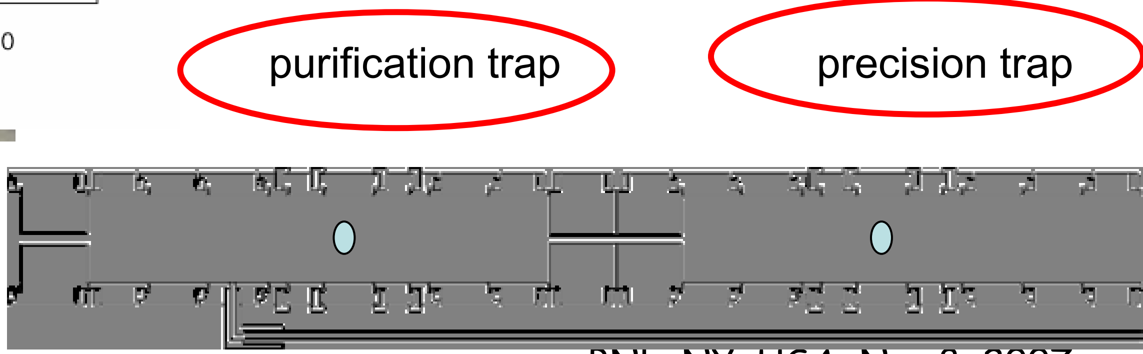
JYFLTRAP





The most precise mass measurements are made with Penning traps.

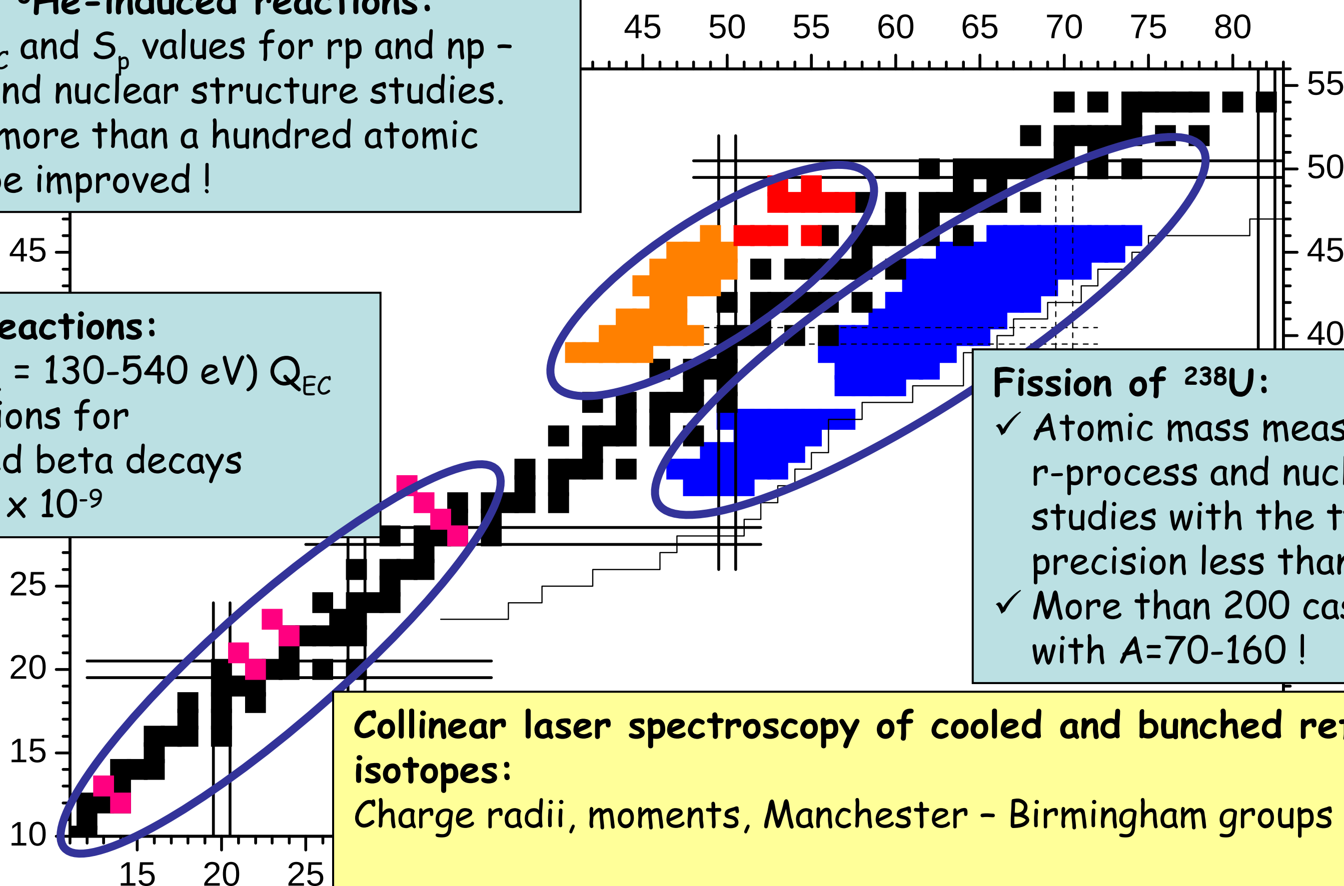
- D. Morrissey -



The recent results from IGISOL

HI, p- and ³He-induced reactions:
Masses, Q_{EC} and S_p values for rp and np – processes and nuclear structure studies. Potentially more than a hundred atomic masses to be improved !

Light-ion reactions:
Precise (δQ = 130-540 eV) Q_{EC} determinations for superallowed beta decays
Rel. prec. 8 x 10^{-9}



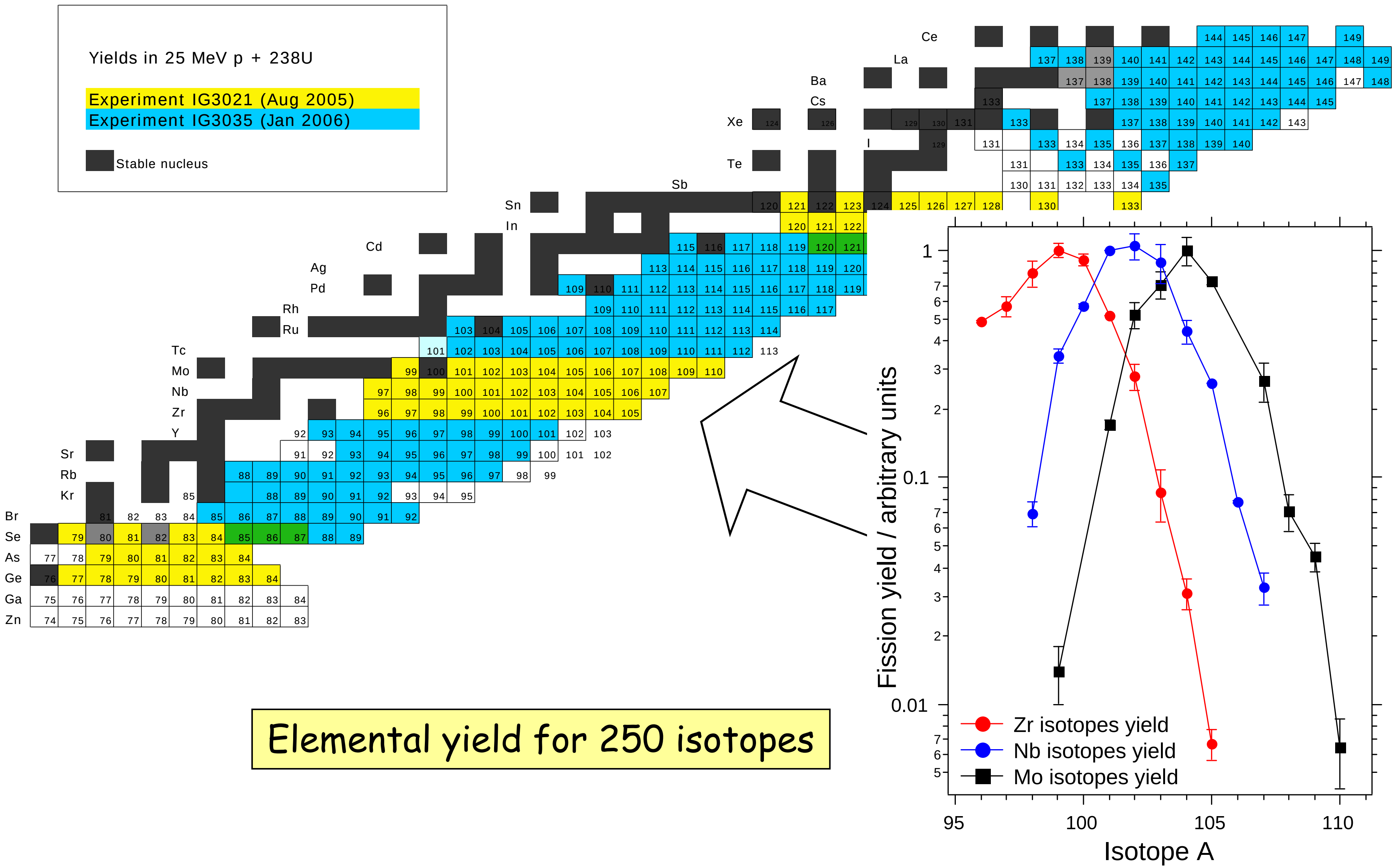
Fission of ²³⁸U:
- ✓ Atomic mass measurements for r-process and nuclear structure studies with the typical precision less than 10 keV
- ✓ More than 200 cases reachable with A=70-160 !

Collinear laser spectroscopy of cooled and bunched refractory isotopes:
Charge radii, moments, Manchester – Birmingham groups

Decay spectroscopy: half-lives, decay schemes, branching ratios, isotopic yield measurements, … more and more often with purification in the Penning trap (trap-assisted spectroscopy)

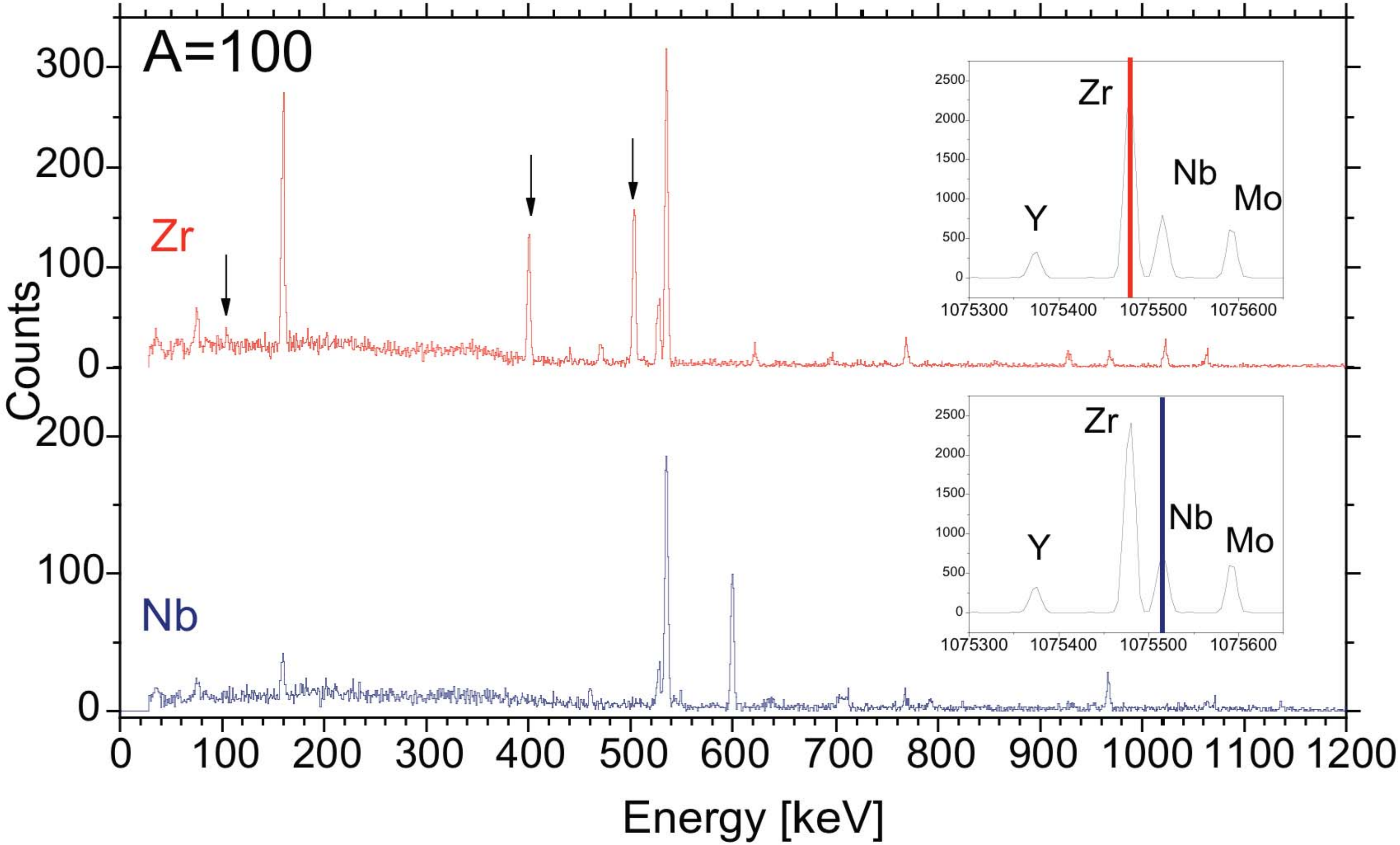
R&D on instrumentation related to production of exotic nuclei and spectroscopic techniques

Measured yields: 25 MeV proton induced fission



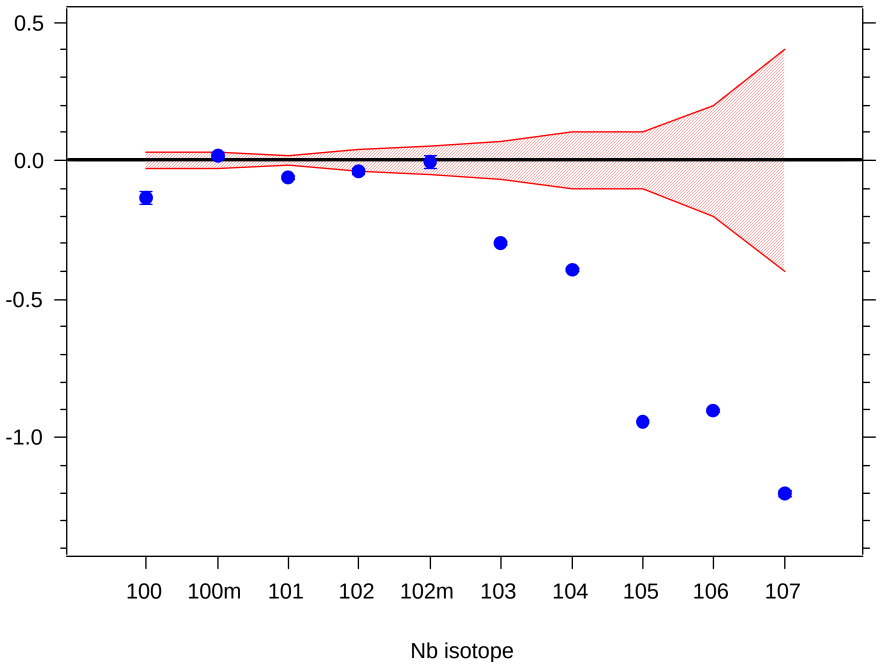
Elemental yield for 250 isotopes

Spectroscopy with trap purified beam



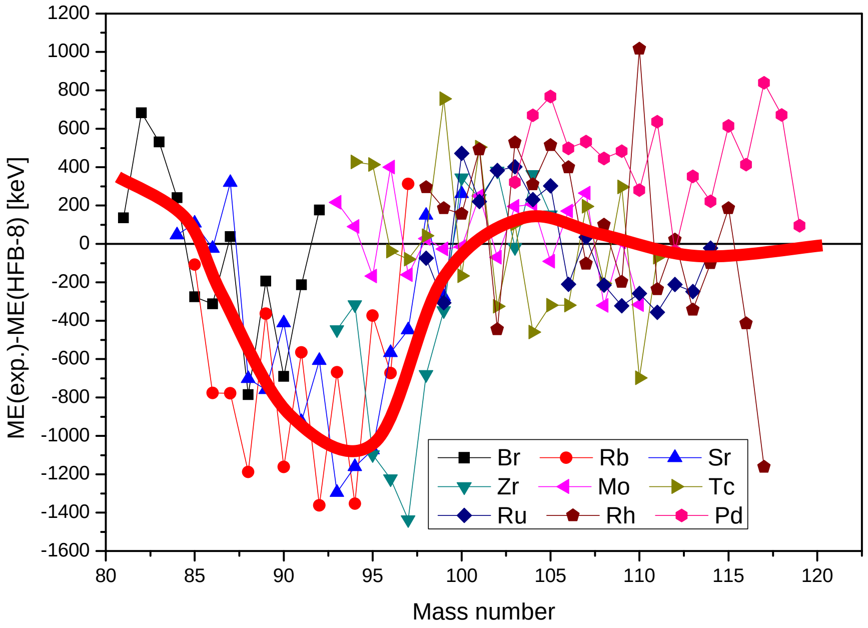
Precision atomic mass values

Comparison of results to compiled data (earlier experiments)



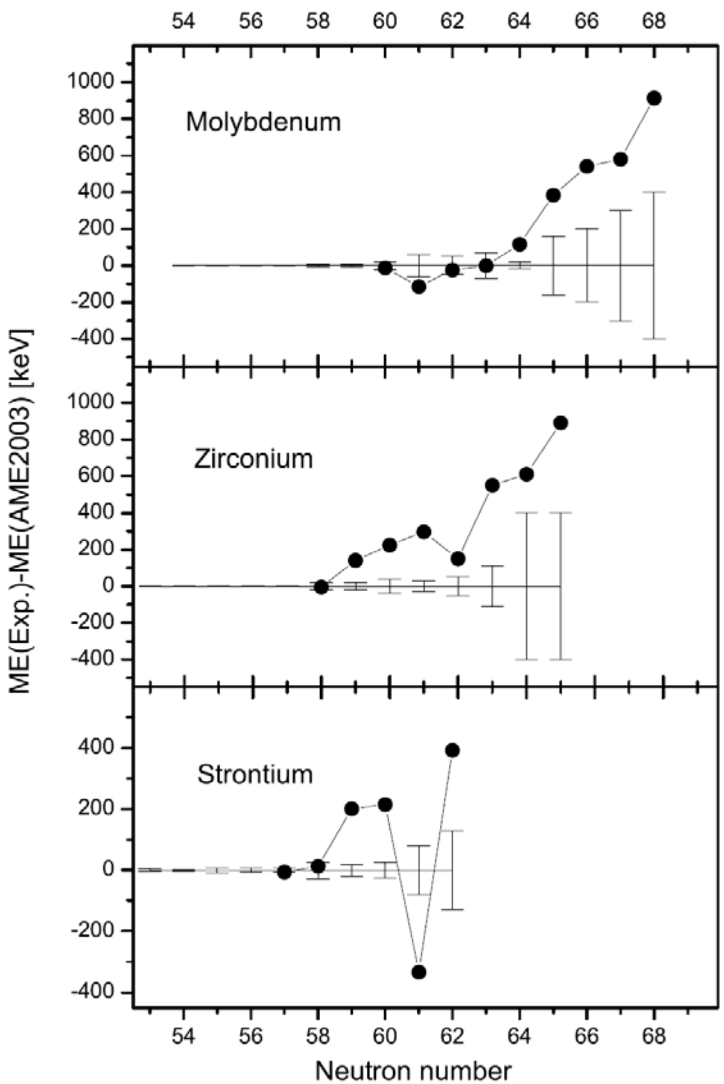
Large deviations from compiled values

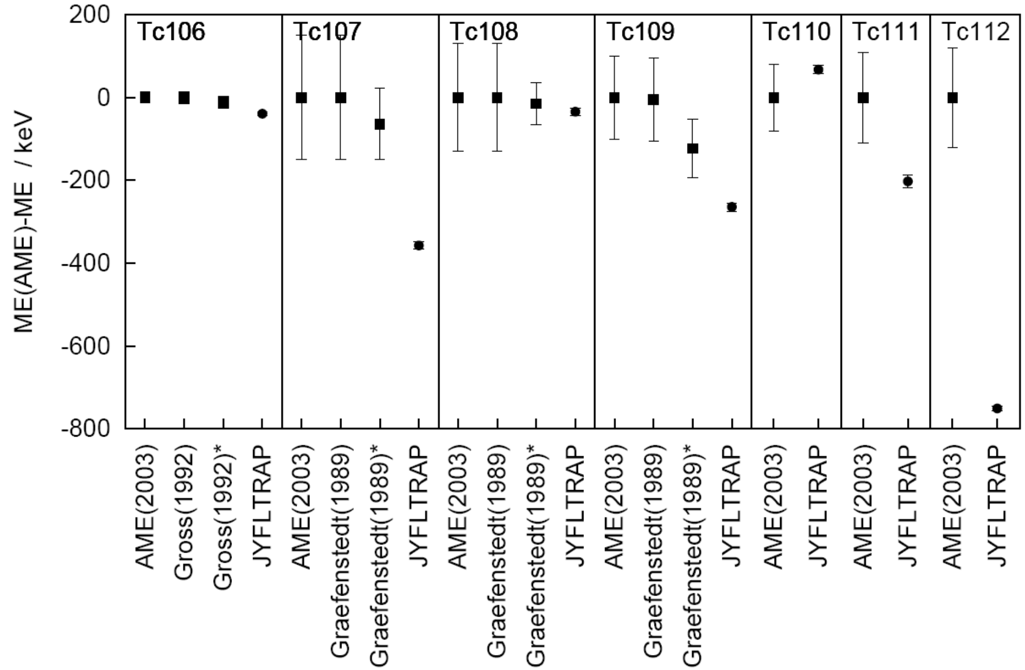
Comparison of results to theoretical mass values



Large systematic deviations from calculated values - hidden physics?

New data vs. previous measurements (+AME); ex. Sr, Zr, Mo, Tc



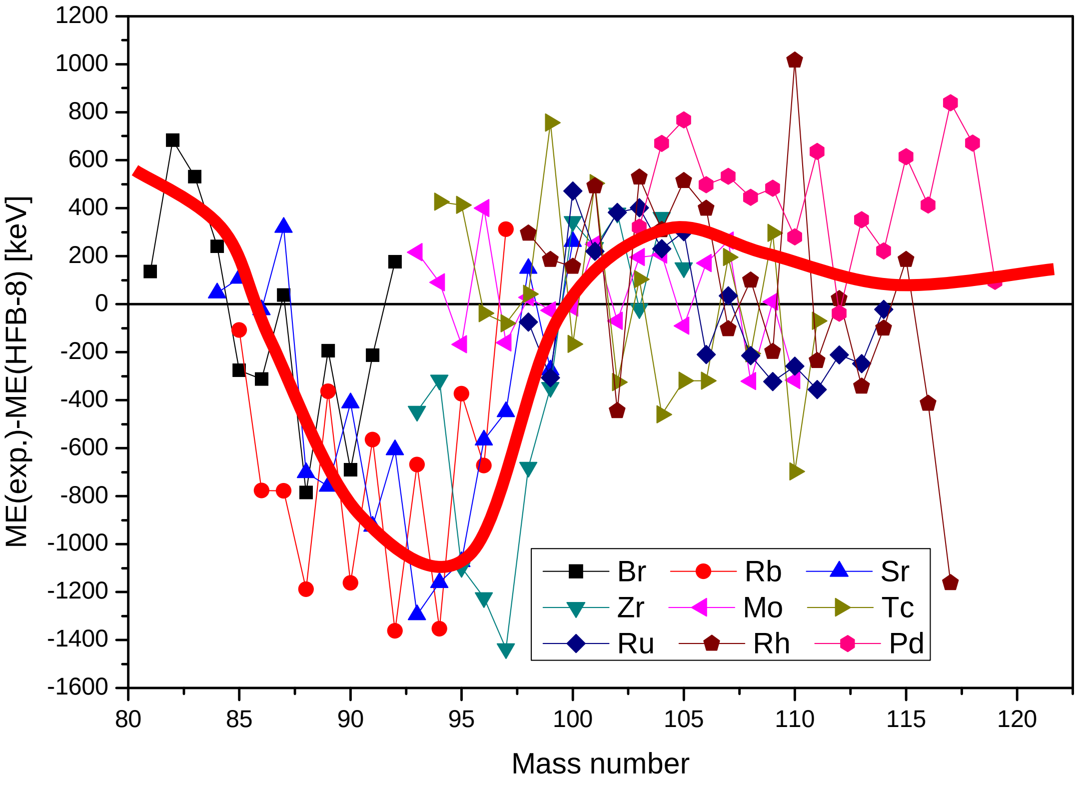


Our measured neutron-rich nuclei are found significantly less bound than the AME03

Mass predictions are usually tuned to reproduce AME values !

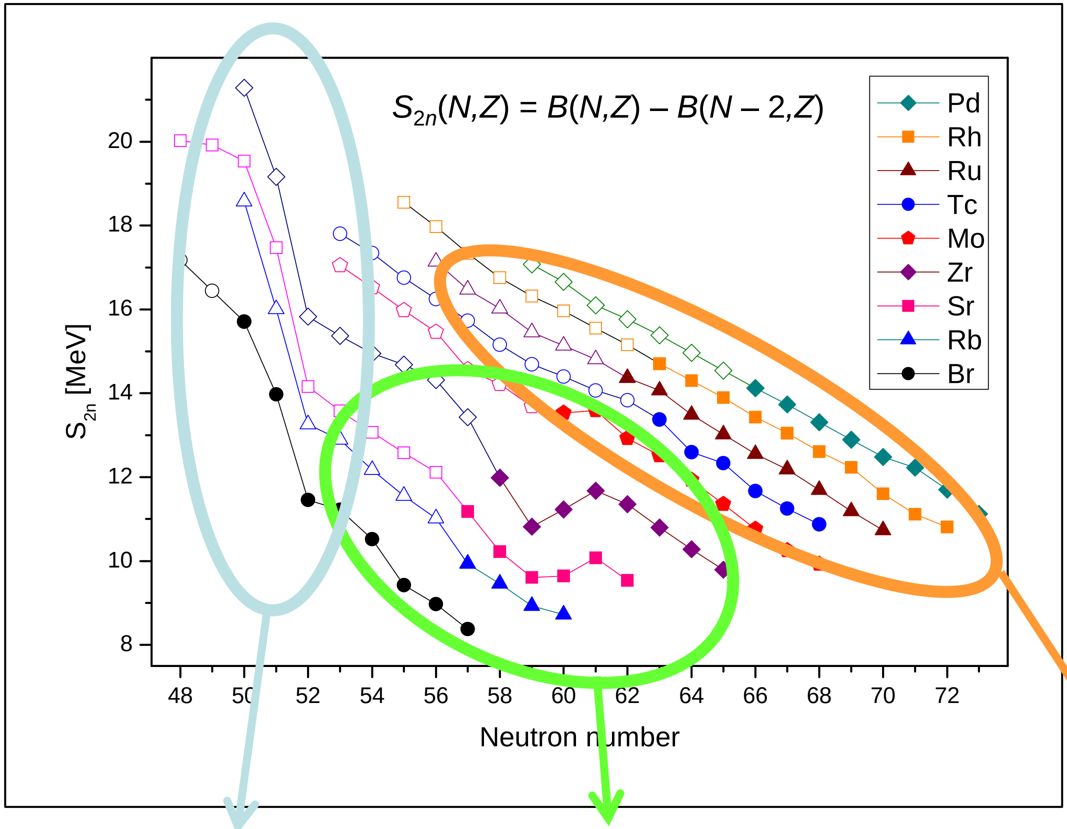
Mass predictions vs. experiments

Mass measurements
→ Benchamarking and improvement of mass predictions
Plenty of new precise data is needed !
- statistical evaluation
- hidden correlations Ex. HFB-8; S. Goriely et al., vs JYFLTRAP data

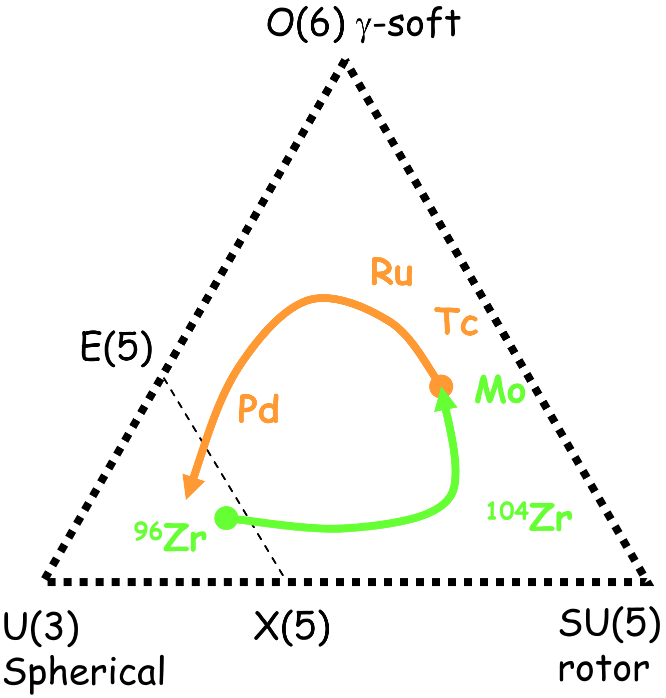


Two-neutron separation energies, S_{2n}

S_{2n} sensitive for structure effects



"Casten triangle"



Sudden drop in S_{2n} due to shell closure at N=50.

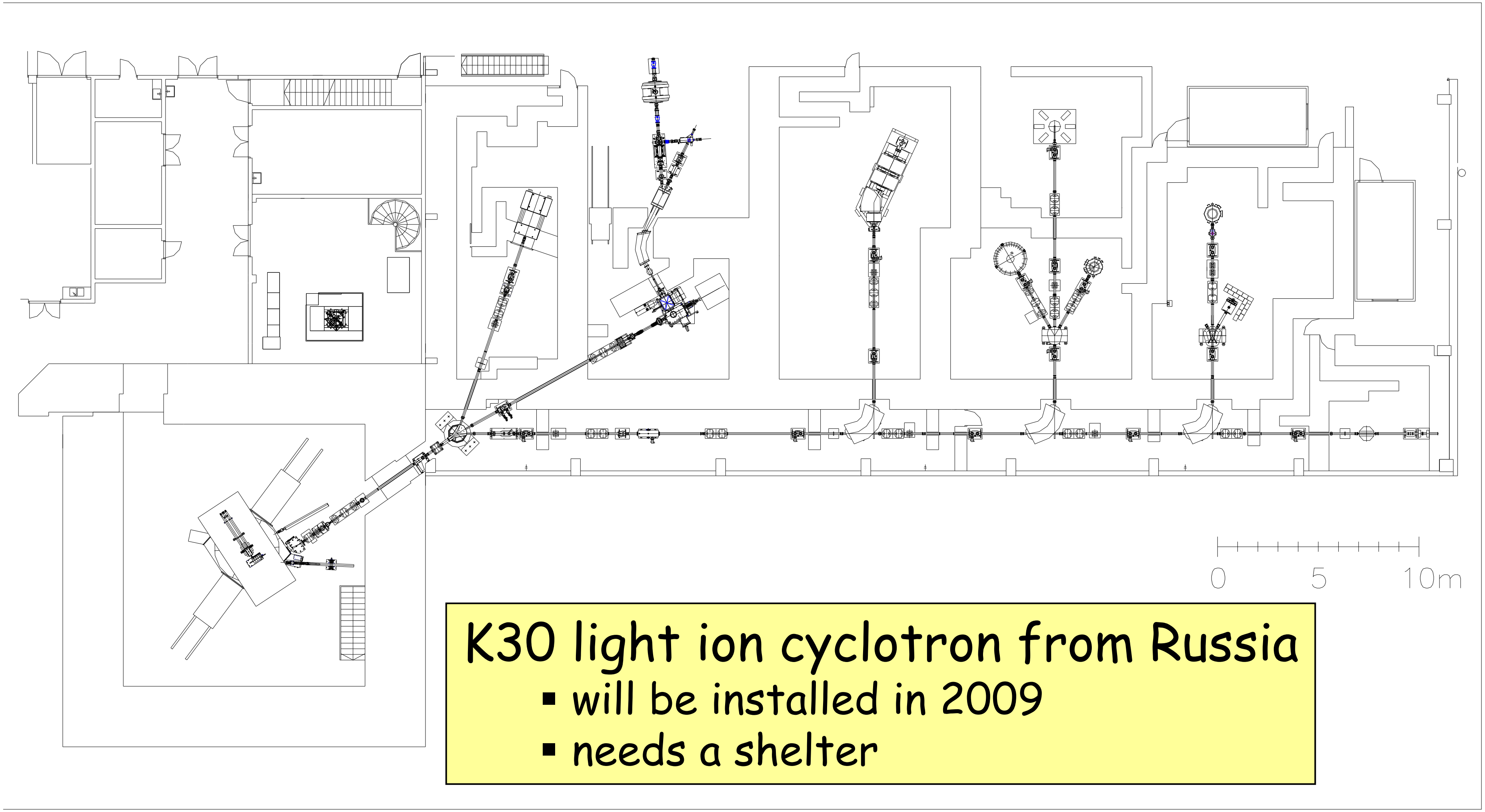
- ✓ Change of the deformation
- ✓ Coincides with observed shape changes for Zr and Y isotopes (coll. laser sp.).

U. Hager et al., PRL 96 (2006) 042504

- ✓ Changes from gamma-soft/triaxial nuclei to almost perfect vibrator
- ✓ A smooth trend dominated by the asymmetry term in LD-presentation.

U. Hager et al. (2007) PRC, in press

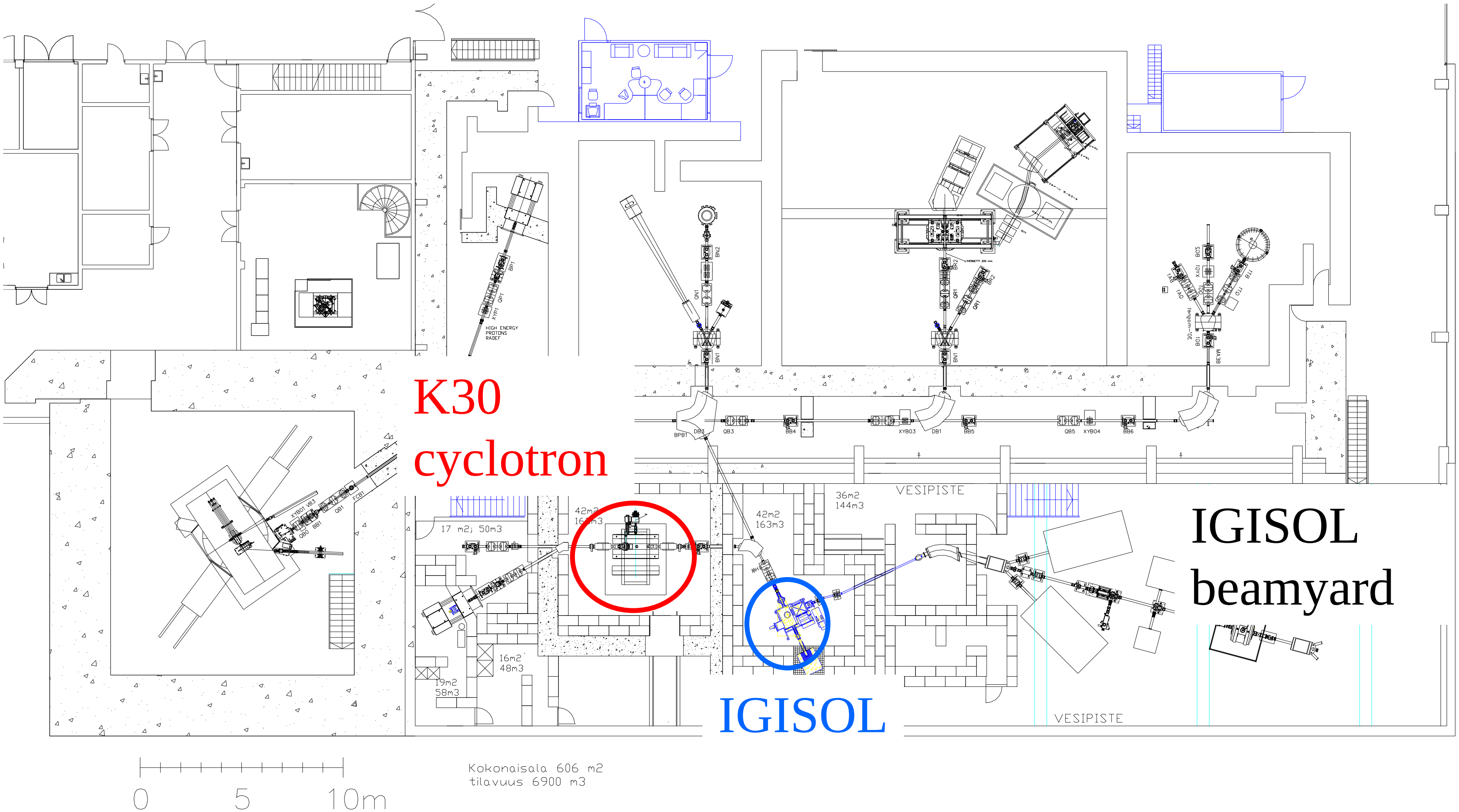
K30 cyclotron and laboratory extension



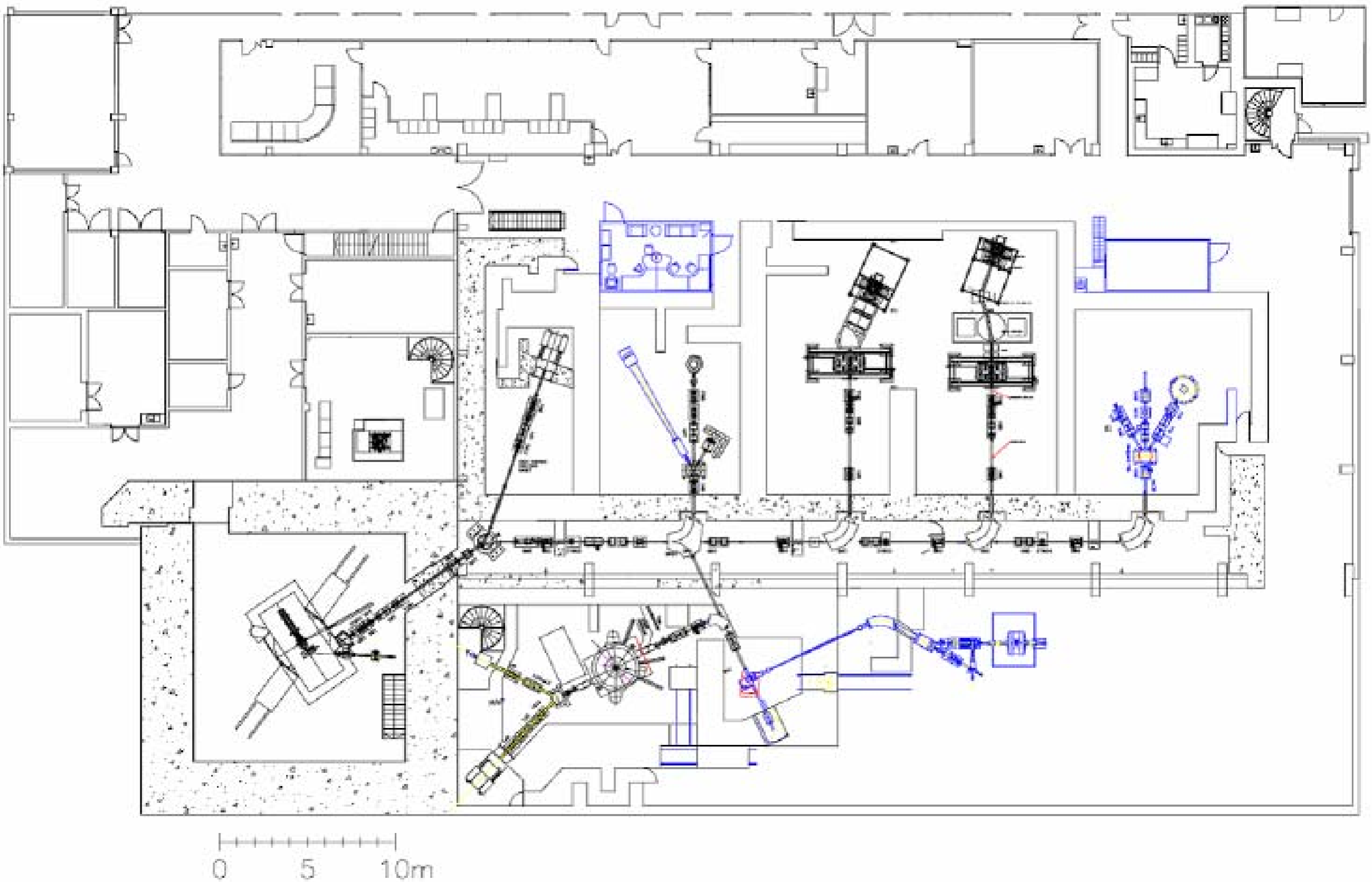
K30 light ion cyclotron from Russia

- will be installed in 2009
- needs a shelter

Laboratory extension: K30 and "BIGISOL"

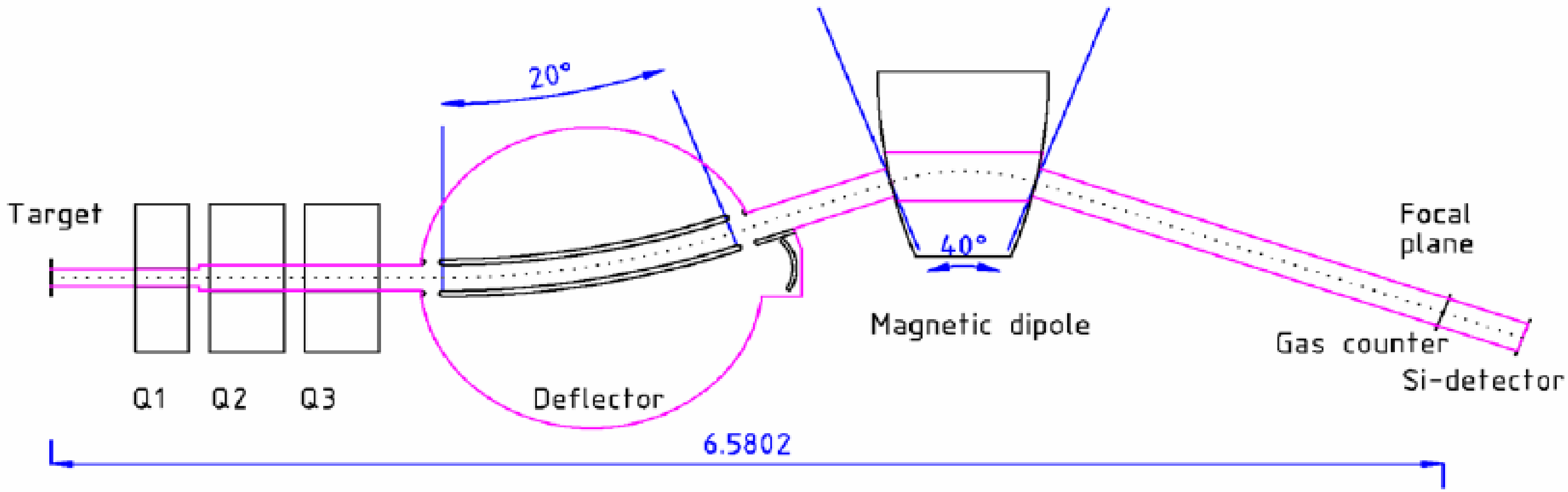


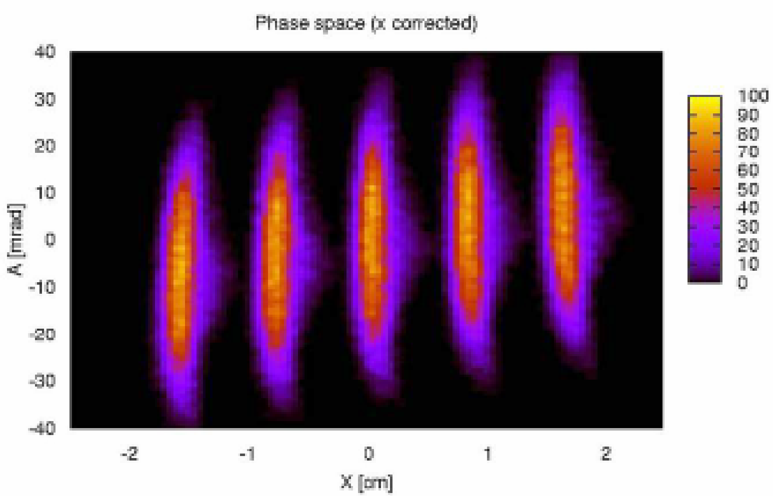
K30 cyclotron and laboratory extension

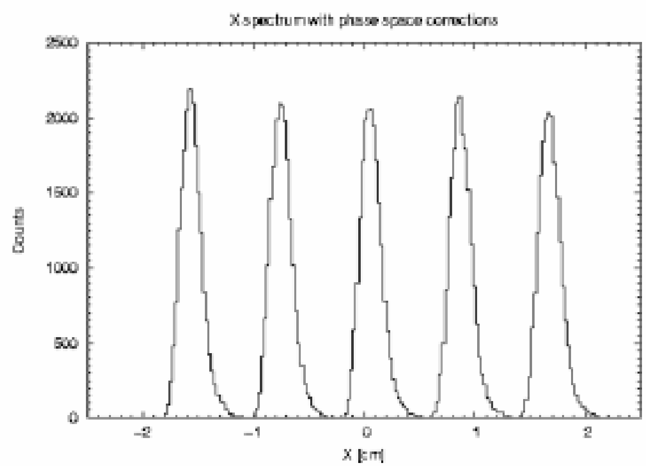


Vacuum mode recoil separator MARA

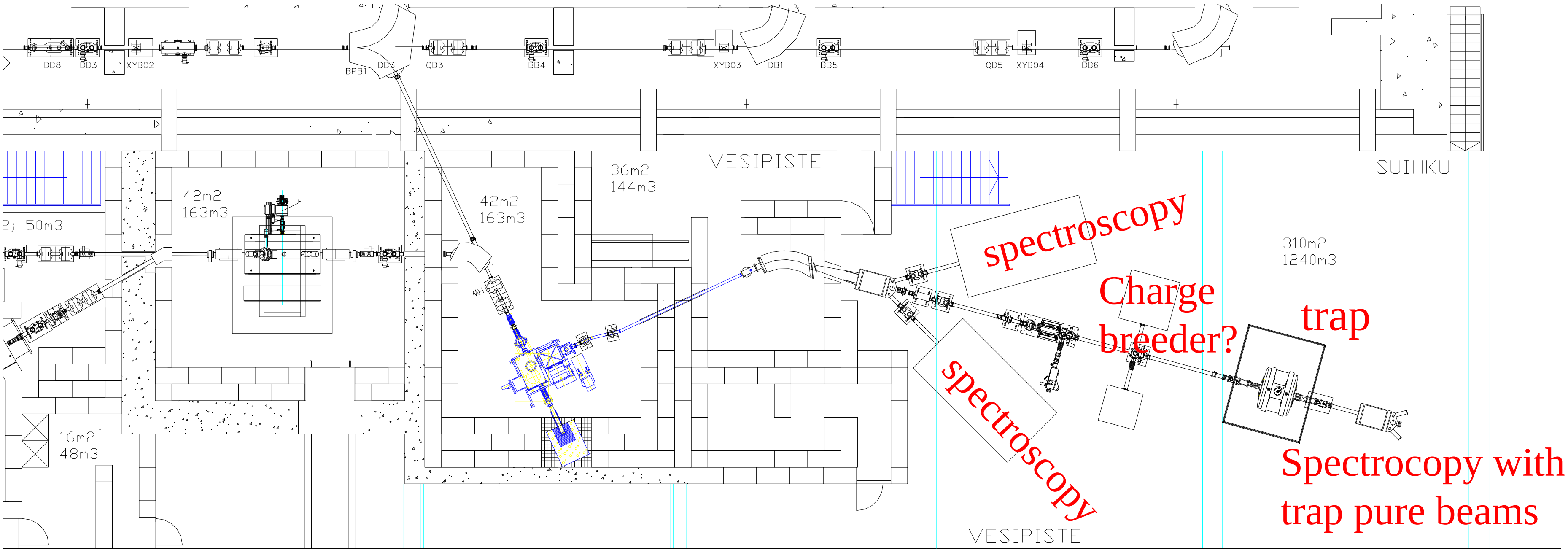
J. Uusitalo, J. Sarén, M. Leino, C. Scholey







Laboratory extension: K30 and "BIGISOL"



Kokonaisala 606 m2
tilavuus 6900 m3

IDEAS AND INSTRUMENTS WELCOMED!

REQUESTS to NNDC

by some (non-JYFL) theorists:

- Horisontal evaluations!
  - Quotation: "Mass chains are usually coherent but adjanged isotopes with different mass number often disagree"
- "Best eduacated guess" data bases.
  - Quotation: "Data should of course be confirmed but sometimes you need nuclear data without gaps (for simulation). There you are inventing data without having any clue which values were likely…"
- Computer friendly data bases
  - Quotation: "How do you read a database of half-lives in a computer when half-lives are given in six different units: year, day, hour, minute, second and MeV"