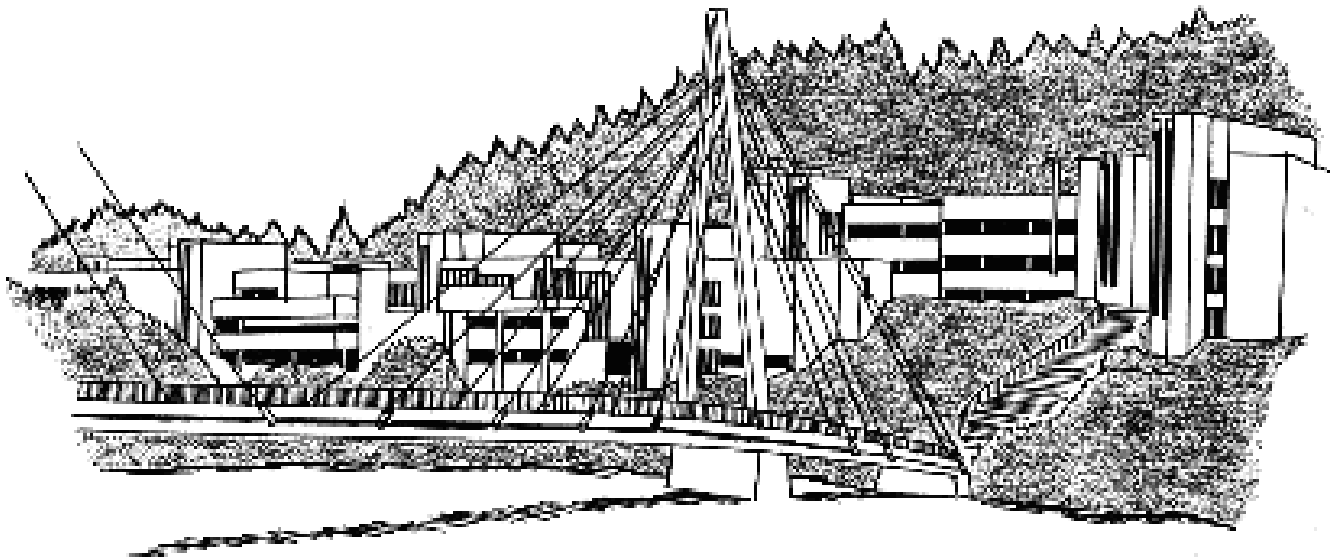
Trap-assisted (nuclear) spectroscopy

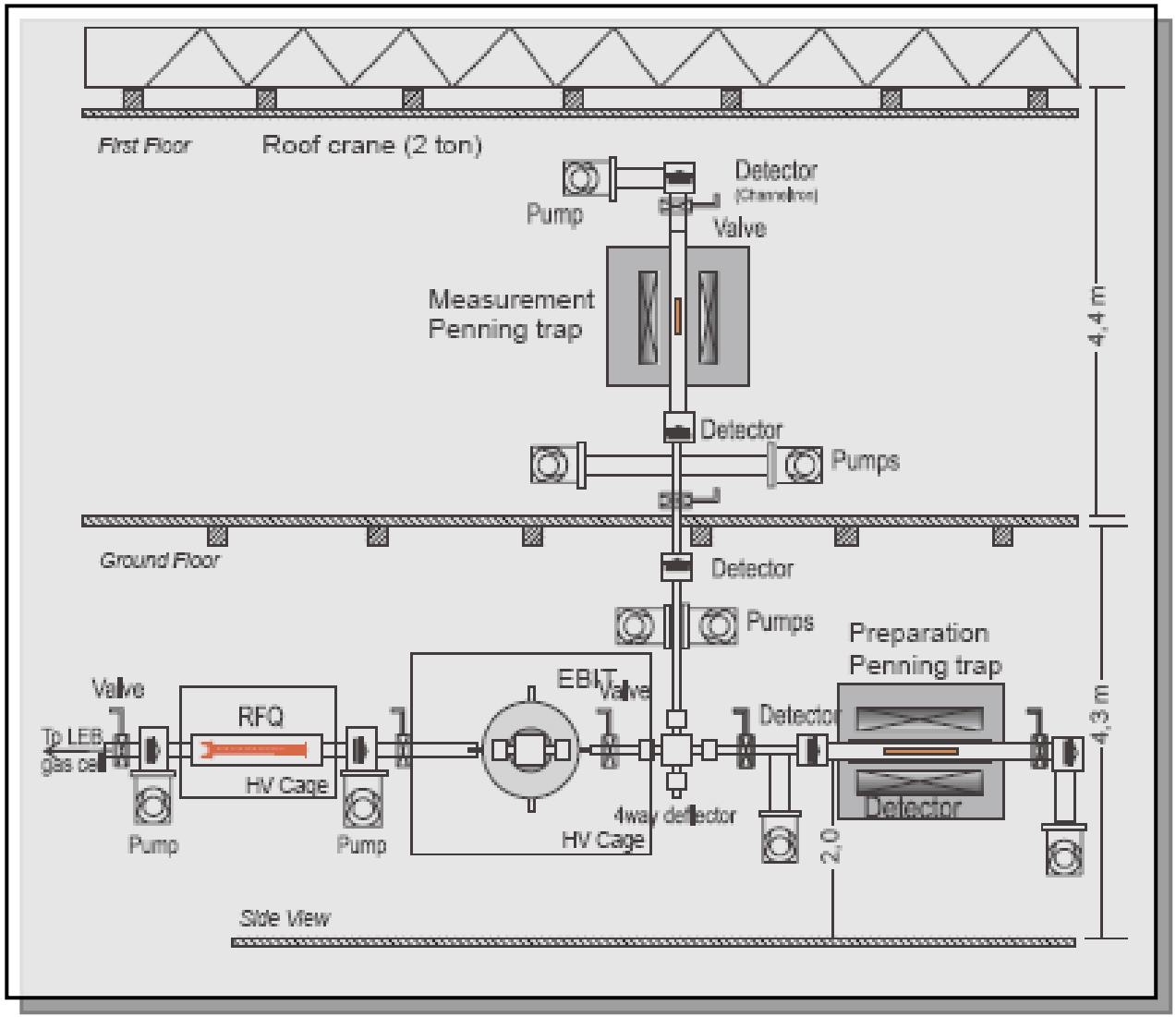


Plan of the MATS setup

Exotic nuclei from SuperFRS at low energy

Complex decays
Isomers
Low rates
$T_{1/2}$ (β) > 10 ms

Observables:
Mass
Moments, spin
Decay properties



Trap- assisted spectroscopy is a broad concept !!!

RFQ or Paul traps

- Cooled and bunched sources → <mm^2 & <eV
- Collinear laser spectroscopy with few ions/s !
- Implantations for high-precision experiments

Penning traps

- Confined sources coupled with very high mass resolution
- Ultra-high mass resolving power

Optical traps

- Confined & pure sources for fundamental studies

In-trap spectroscopy of stored and purified ion samples

- electron/positron spectroscopy (CE, β^+, β^-, e^+/e^-)
- recoil ion spectroscopy (α, β, βn, β2n,...)
- CP and photon spectroscopy

Post-trap "low-background" spectroscopy

- β, p, α, γ and βn decay spectroscopy of pure isotope sources
- decay spectroscopy of isomers
- spectroscopy with ion tagging
- ion counting for cross sections

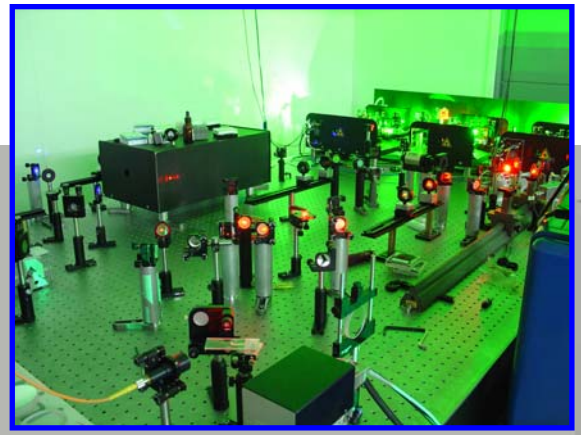
Examples from recent experiments employing

IGISOL
&
JYFLTRAP

&
ISOLTRAP

IGISOL is universal and fast production method and provides a good reference for opportunities at the FAIR MATS experiment.

The IGISOL Beamline at JYFL



FURIOS laser cabin

Collinear laser spectroscopy

Mass & decay spectroscopy

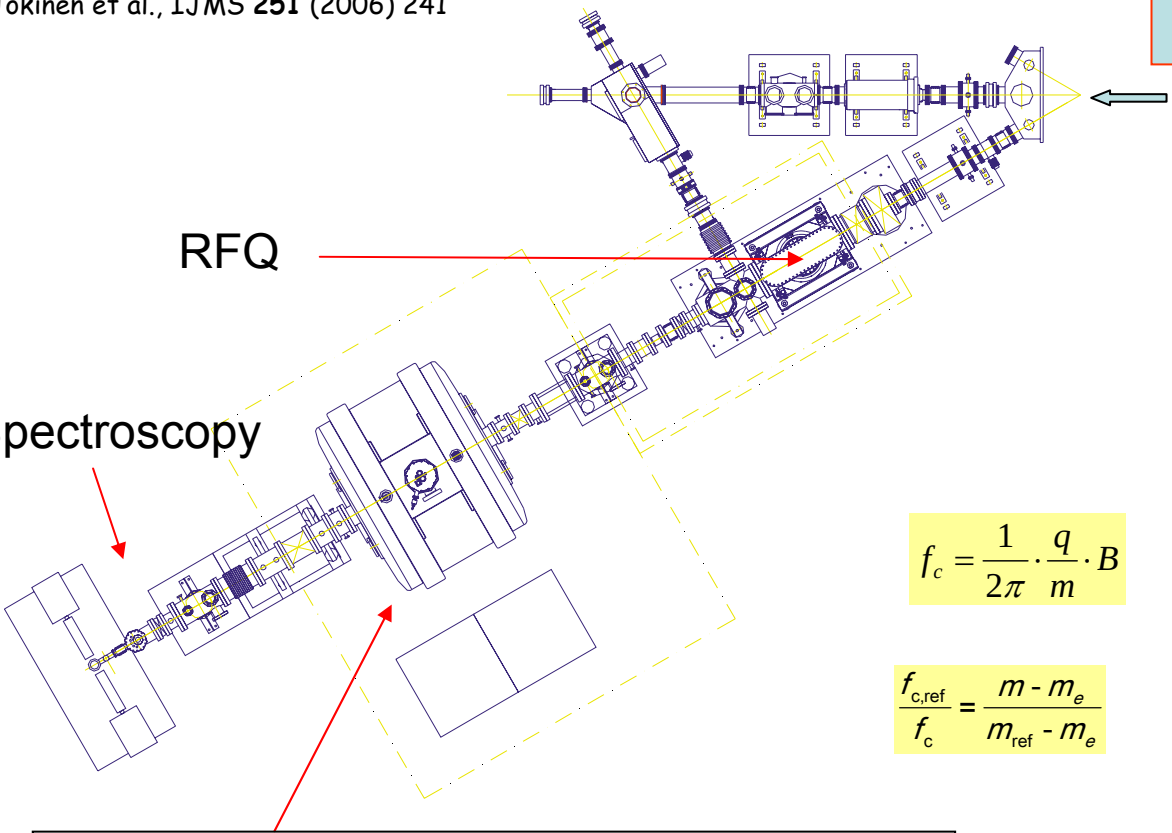
Ion guide & laser ion source (trap)

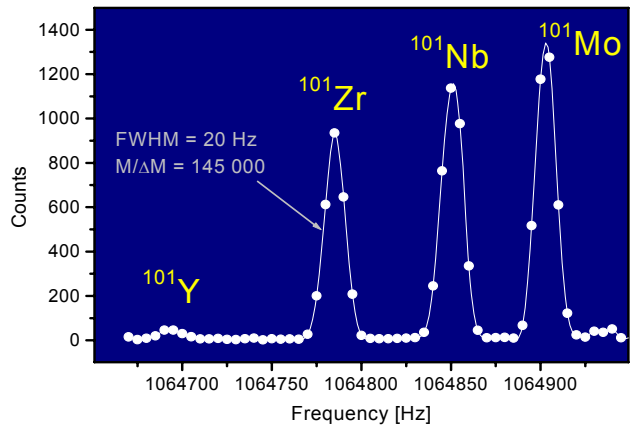
RFQ cooler & buncher – optical manipulation

Double Penning trap, JYFLTRAP

V. Kolhinen et al., NIM A **528** (2004) 776
S. Rinta-Antila et al., PRC **70** (2004) 011301(R)
A. Jokinen et al., IJMS **251** (2006) 241

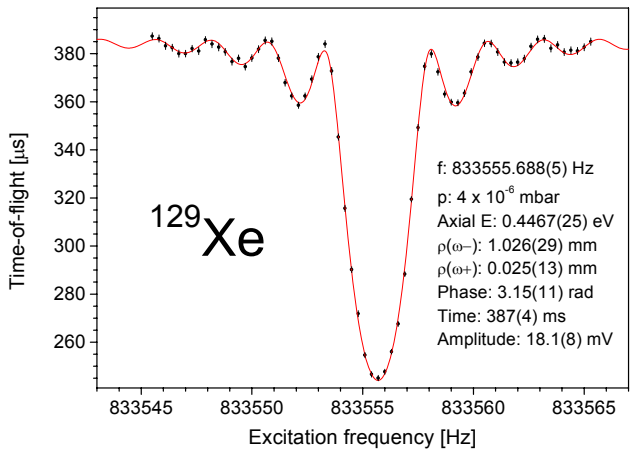
K130-accelerator + IGISOL:
✓ Mass-separated 1+ DC ion beam at 30 keV of all elements.





$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

$$\frac{f_{c,ref}}{f_c} = \frac{m - m_e}{m_{ref} - m_e}$$

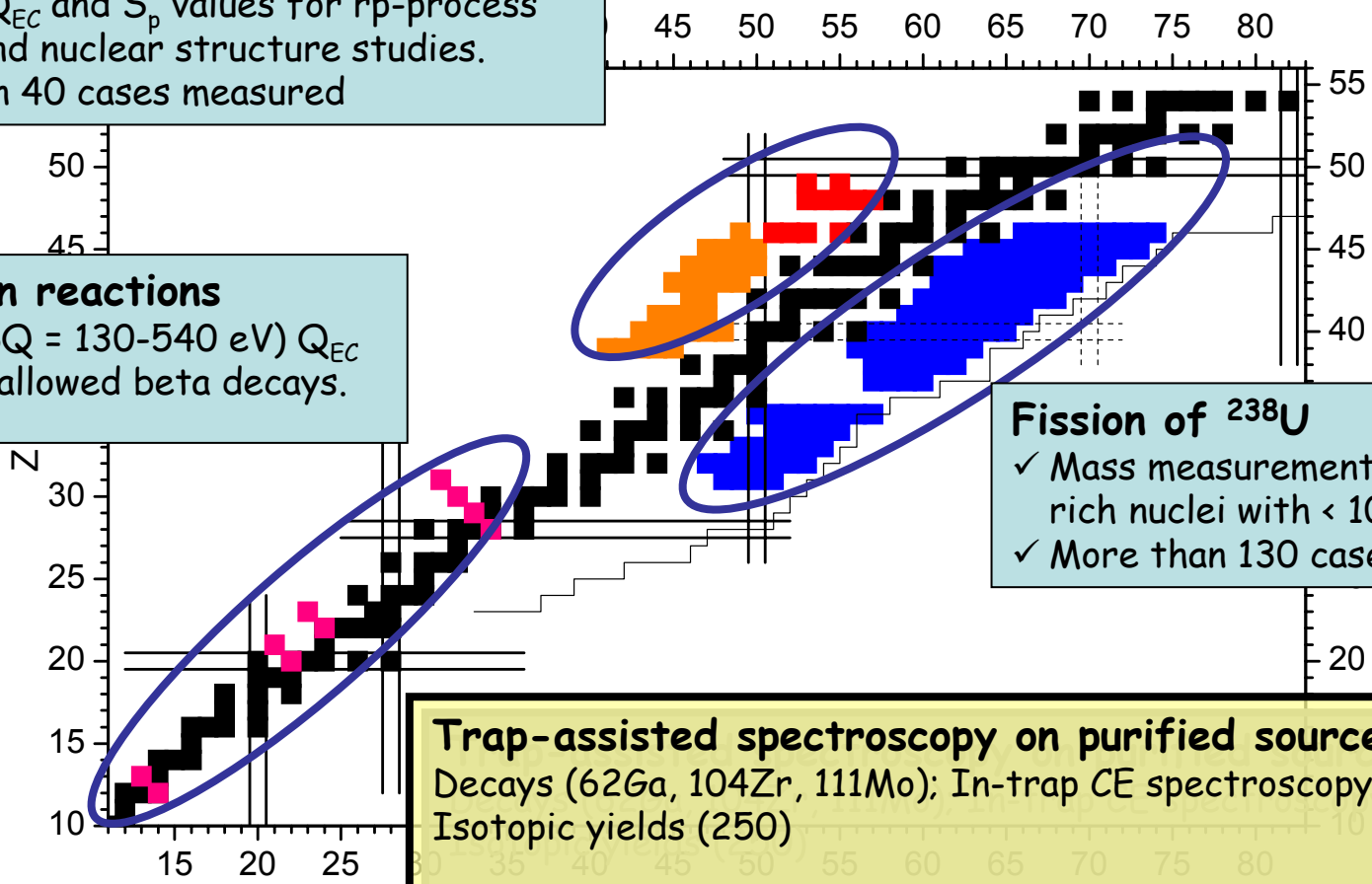


7 T superconducting solenoid @ 30 kV:
Purification trap ($\Delta M/M < 10^{-5}$):
Precision trap ($\Delta M/M < 10^{-6}$):

Program running @ JYFLTRAP

HI, p- and ^{3}He-induced reactions
Masses, Q_{EC} and S_p values for rp-process physics and nuclear structure studies.
More than 40 cases measured

Light-ion reactions
Precise (δQ = 130-540 eV) Q_{EC} for superallowed beta decays.



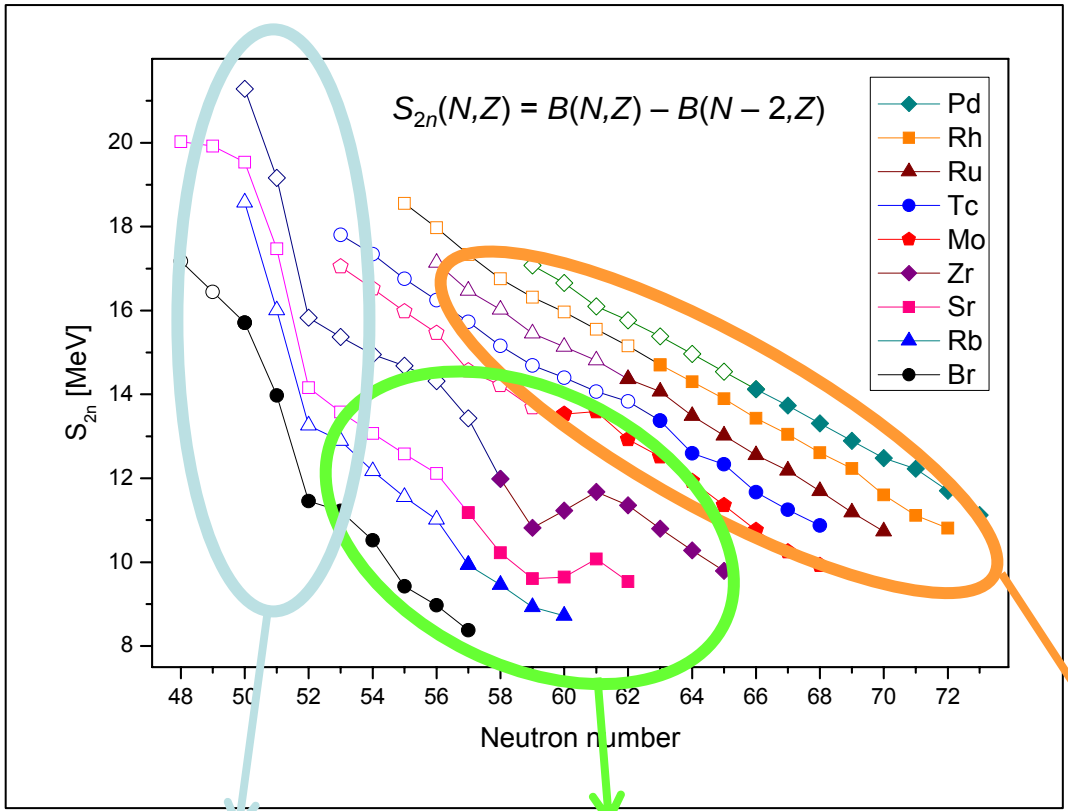
Fission of ^{238}U
- ✓ Mass measurements for neutron-rich nuclei with < 10 keV precision
- ✓ More than 130 cases measured!

Trap-assisted spectroscopy on purified sources
Decays (62Ga, 104Zr, 111Mo); In-trap CE spectroscopy
Isotopic yields (250)

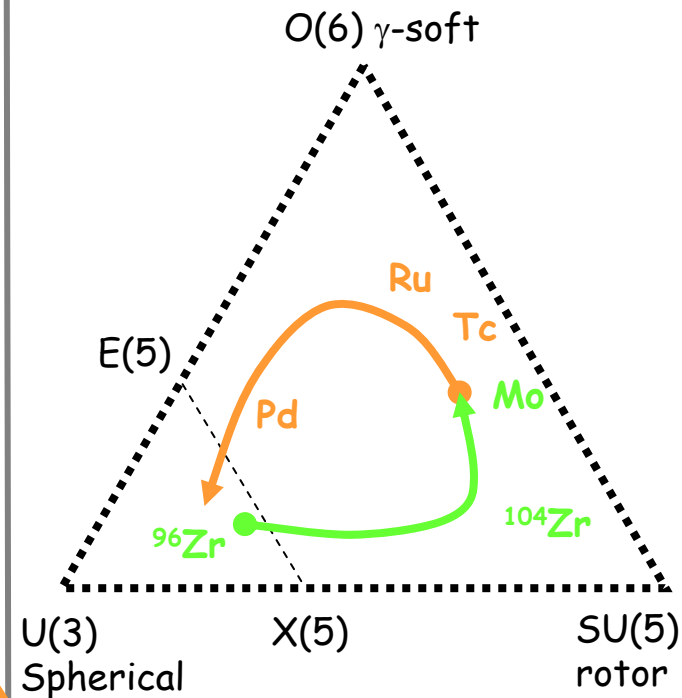
Collinear laser spectroscopy of cooled and bunched refractory isotopes (using RFQ trap only)

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

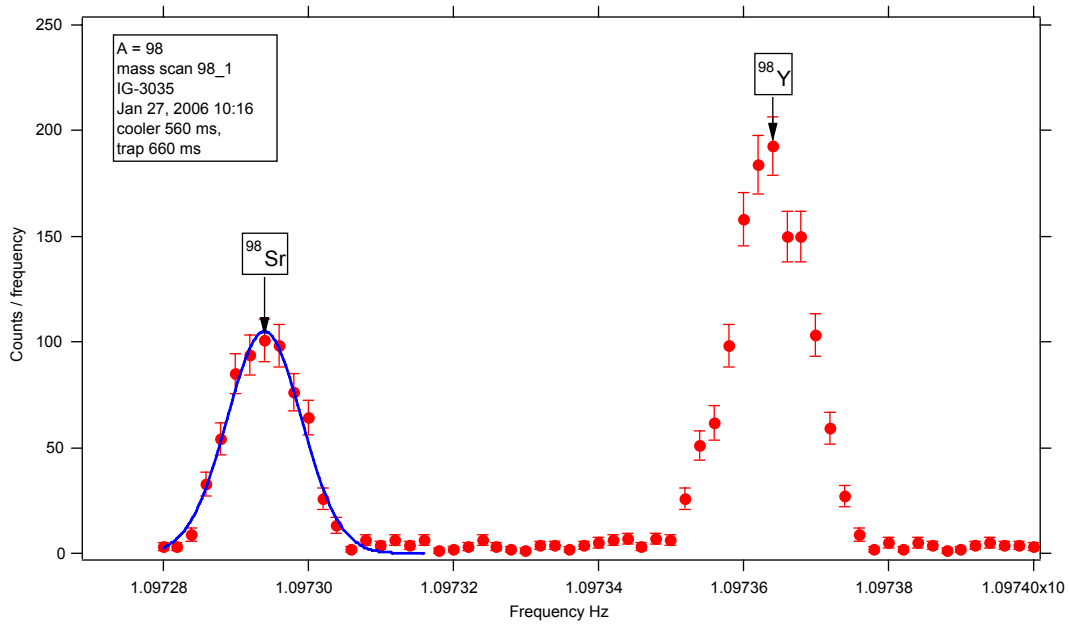
U. Hager et al., PRL 96 (2006) 042504

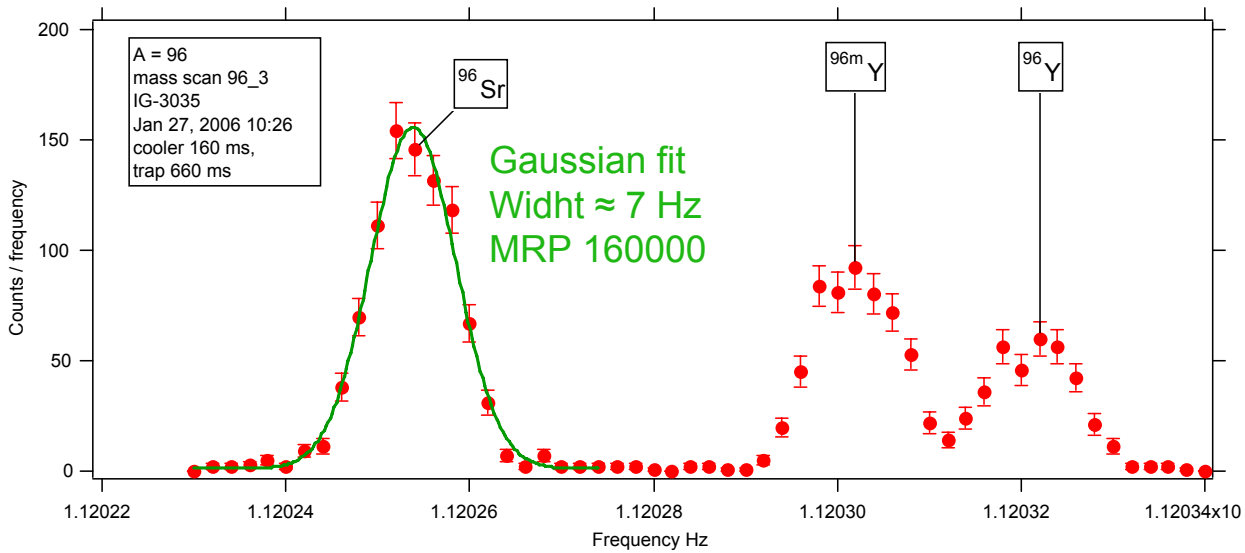
- ✓ Changes from gamma-soft/triaxial nuclei to almost perfect vibrator
- ✓ A smooth trend dominated by the asymmetry term in LD-presentation.

U. Hager et al. (2006) to be publ.

Ion manipulation
&
Post-trap spectroscopy

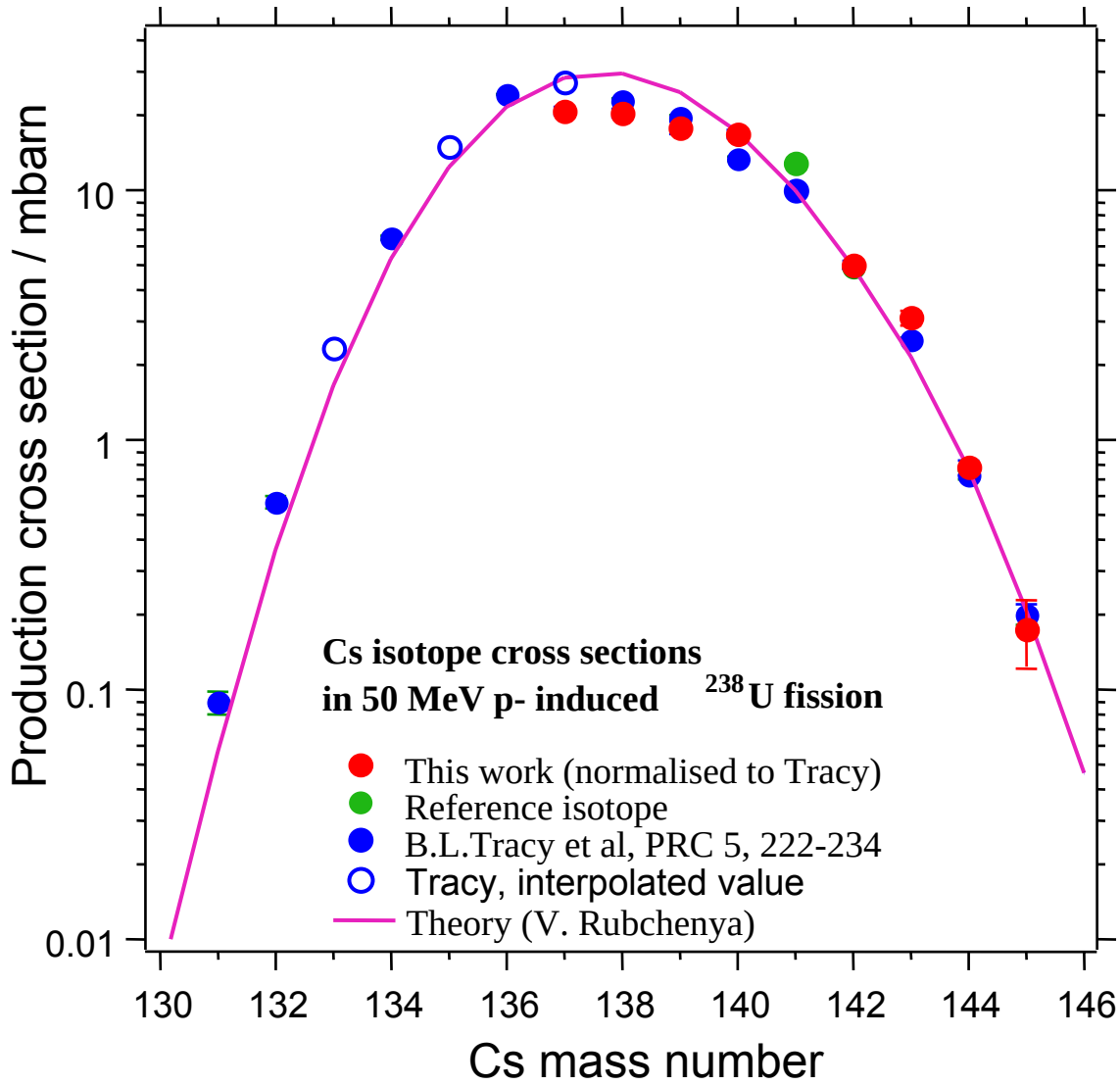
Independent yields of fission products





Comparison to previous data

- Comparison to 50 MeV p induced fission
- Yield normalised to the Tracy data
- Measured distribution shape seems to agree more closely to the old experimental values than to the theory
- Low mass side not measured because of difficult background from stable Xe isotopes



EUROPHYSICS LETTERS 15 August 2004

Europhys. Lett., **67** (4), pp. 586–592 (2004)
DOI: 10.1209/epl/i2004-10089-5

Population inversion of nuclear states by a Penning trap mass spectrometer

K. Blaum[1,2], D. Beck[2], G. Bollen[3], P. Delahaye[1], C. Guénaut[4], F. Herfurth[2], A. Kellerbauer[1], H.-J. Kluge[2], D. Lunney[4], S. Schwarz[3], L. Schweikhard[5] and C. Yazidjian[2]

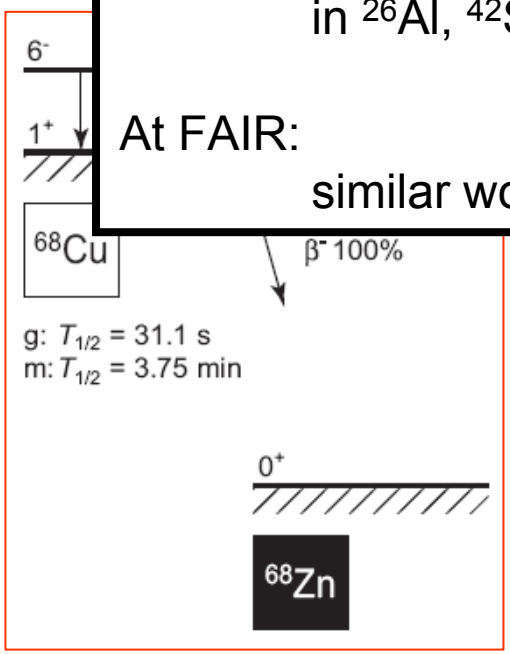
[1] *CERN, Physi*
[2] *GSI - Plancks*
[3] *NSCL, Michig*
[4] *CSNSM-IN2P*
[5] *Institute of P*

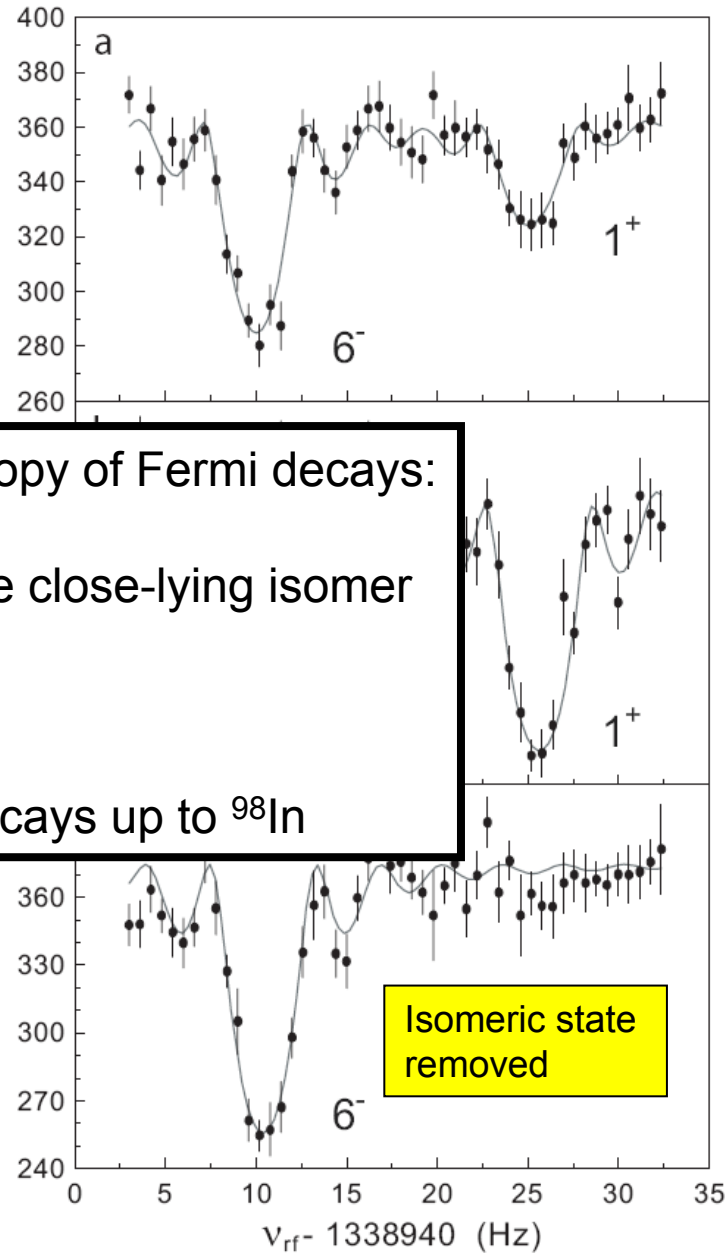
Application at JYFLTRAP in spectroscopy of Fermi decays:

separation of $0^+(T=1)$ from the close-lying isomer in ^{26}Al, ^{42}Sc, ^{50}Mn and ^{54}Co

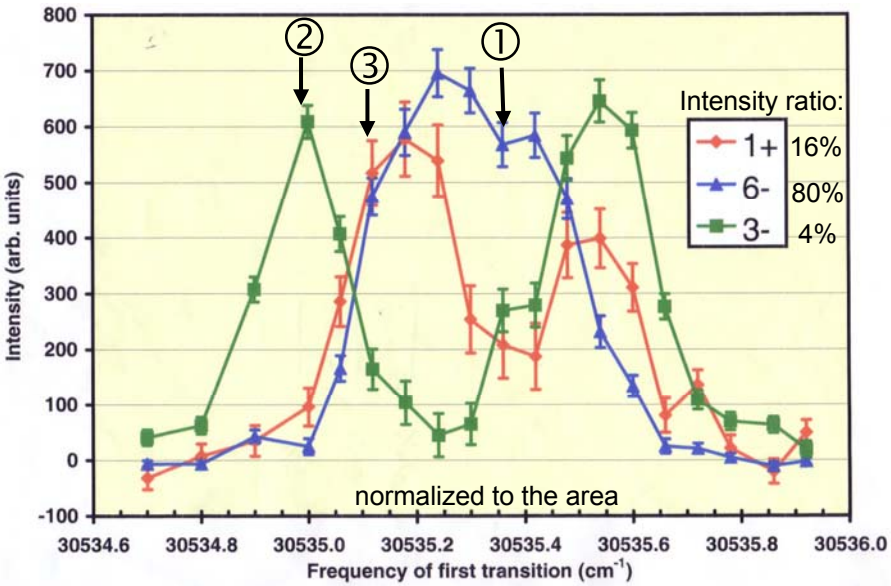
At FAIR:

similar work on heavier 0+ decays up to ^{98}In





Identification of Triple Isomerism in 70Cu

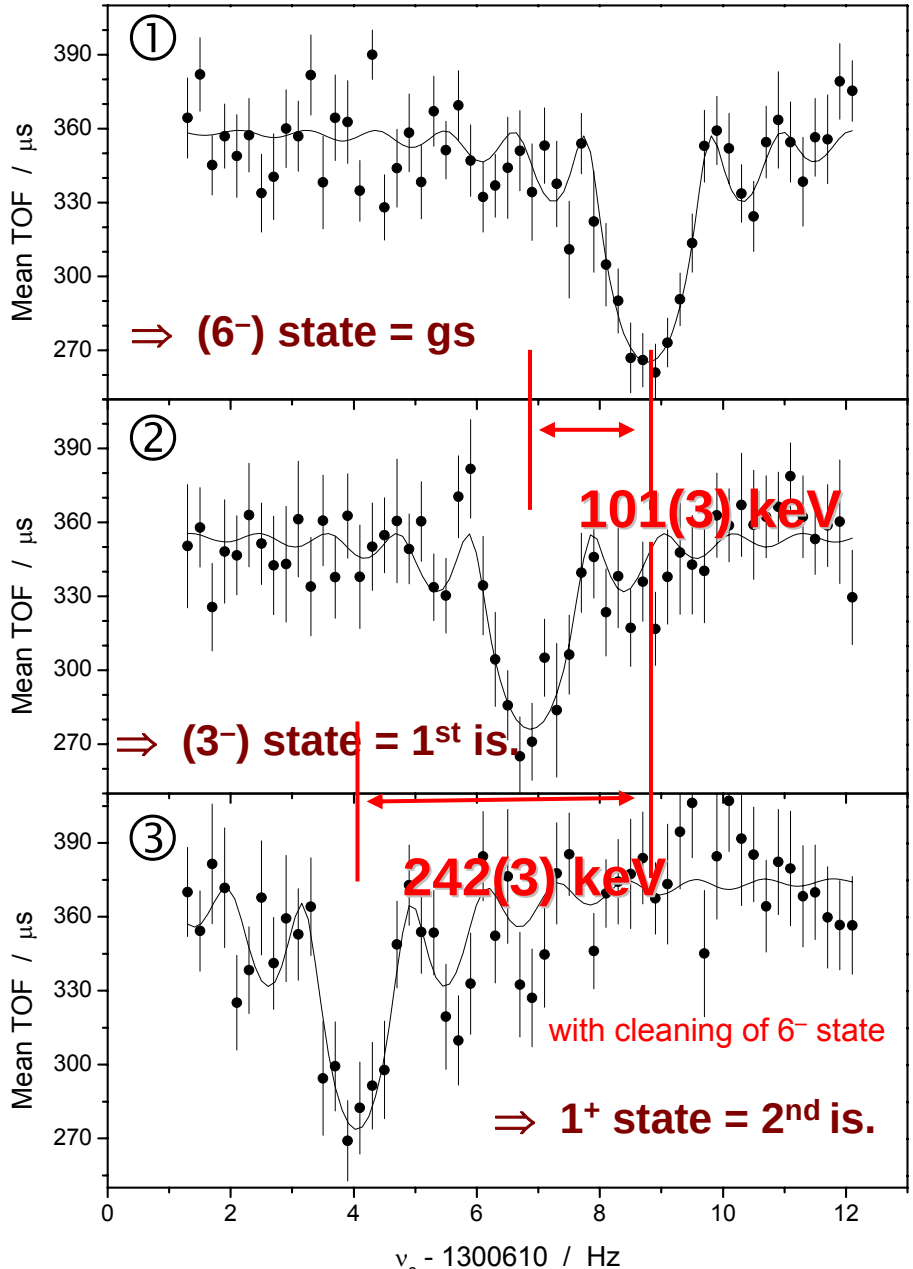


$$\omega_c = \frac{q}{m} \cdot B$$

Unambiguous state assignment!

ME of ground state is 240 keV higher than literature value!

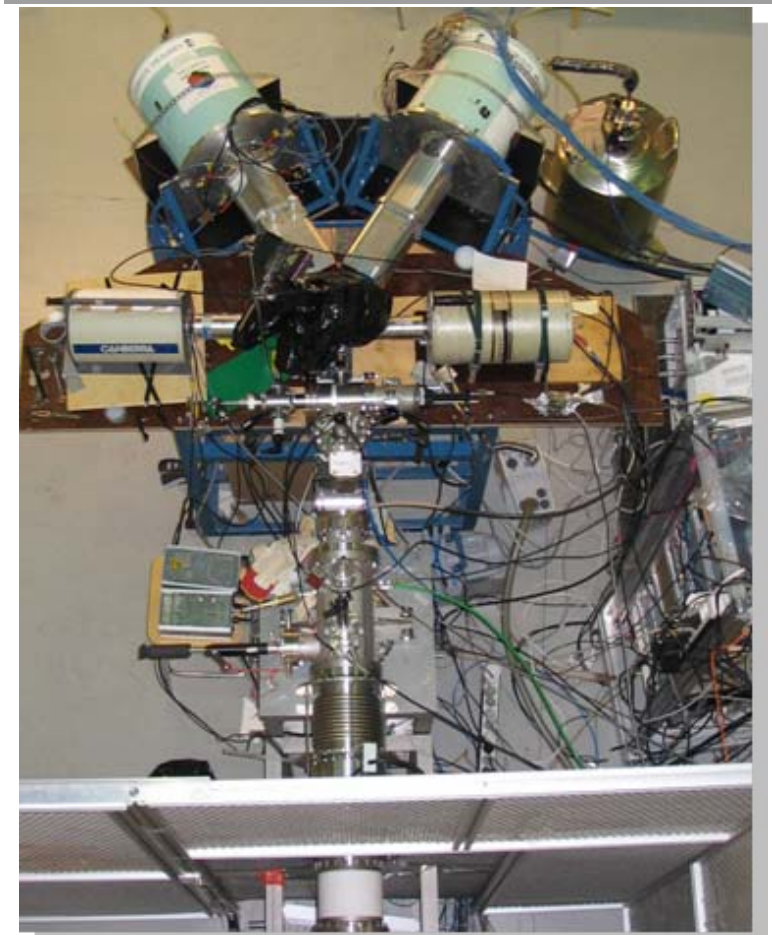
$R \approx 1 \cdot 10^7, \delta m/m \approx 4 \cdot 10^{-8}$



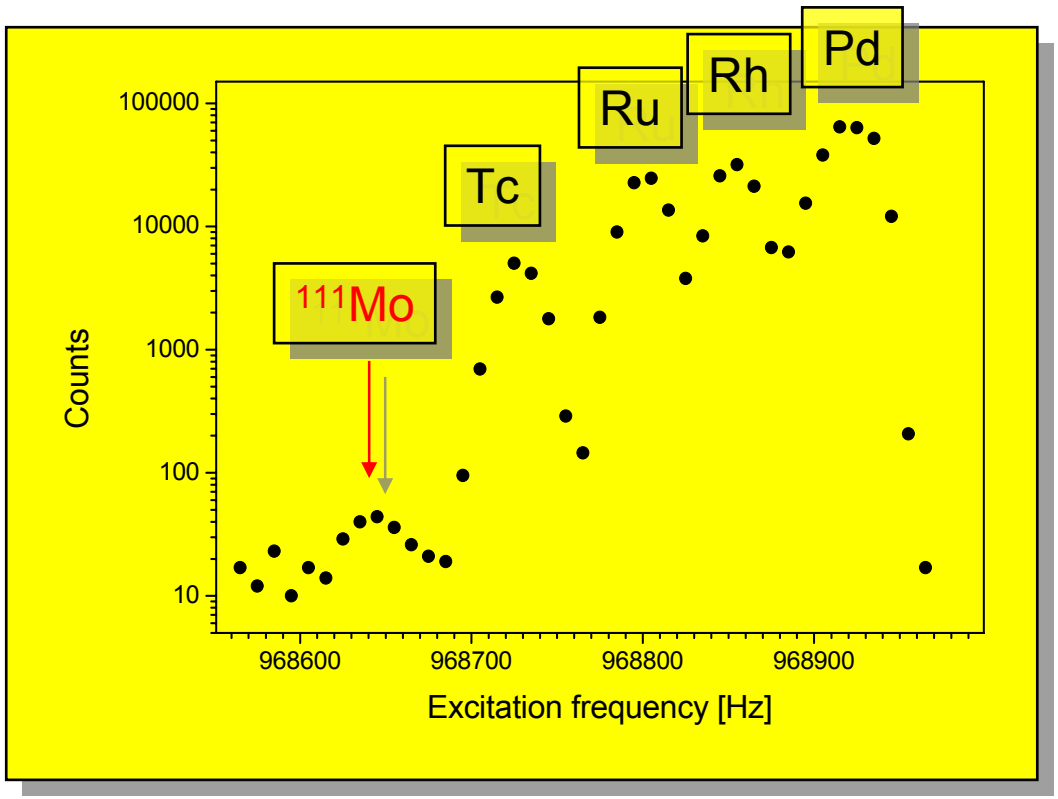
J. Van Roosbroeck et al., Phys. Rev. Lett. 92, 112501 (2004).

Post-trap nuclear spectroscopy

Spectroscopy with mass-purified samples:
Decay spectroscopy of ^{100,102,104}Zr
Decay studies ^{111}Mo, ^{113}Tc and ^{115}Ru



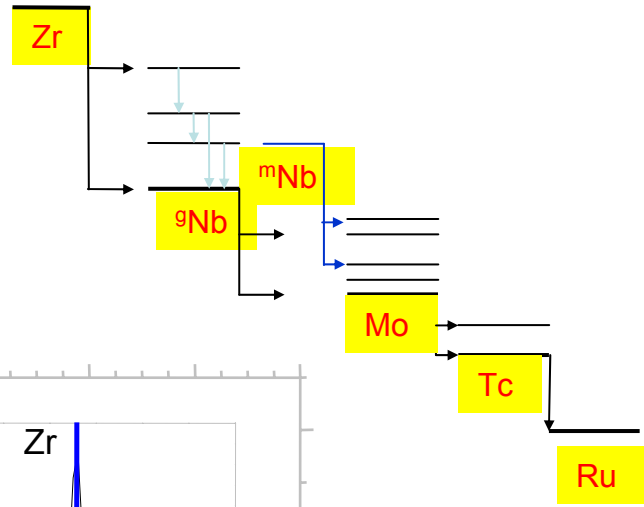
Search for new isotopes & β half lives



S. Rinta-Antila, PhD thesis
Jan Kurpeta

J. Rissanen et al. (2006)

Decay studies of ^{100,102,104}Zr

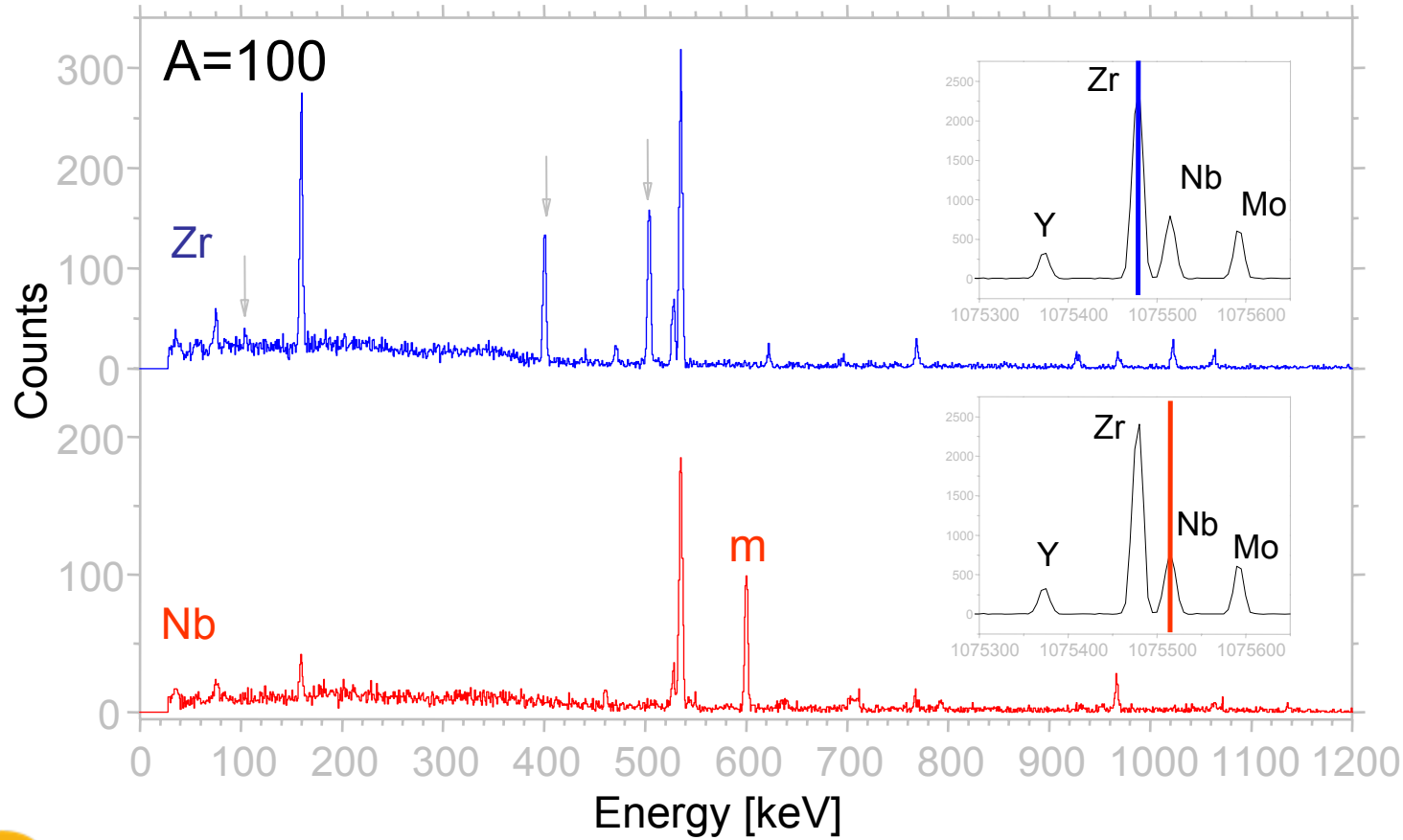


Transmission 40 %

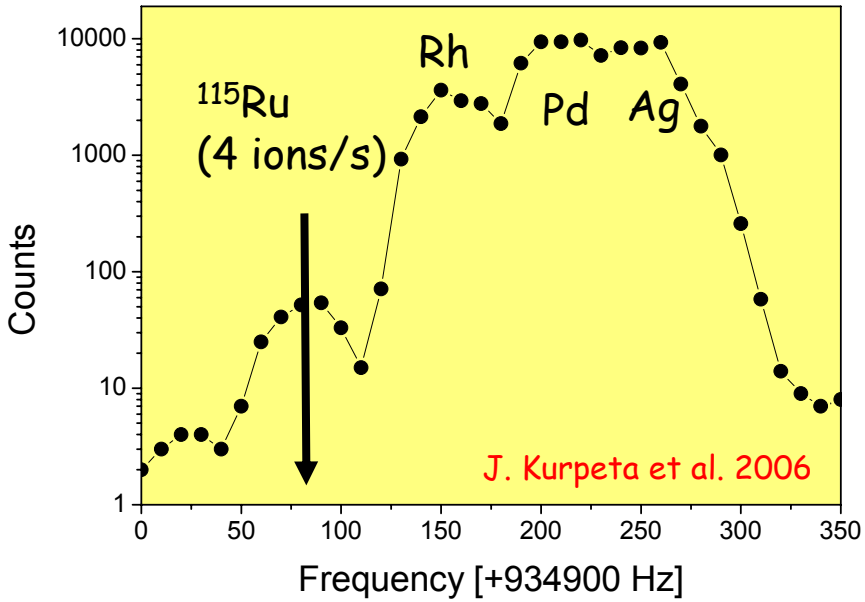
Excellent ion optics after the trap

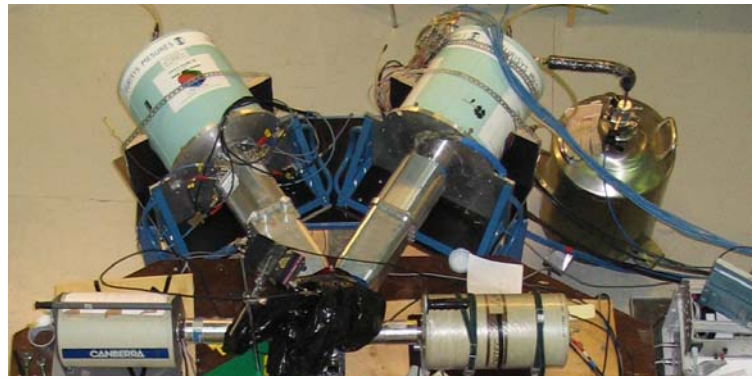
Spectroscopic results after the analysis of the data

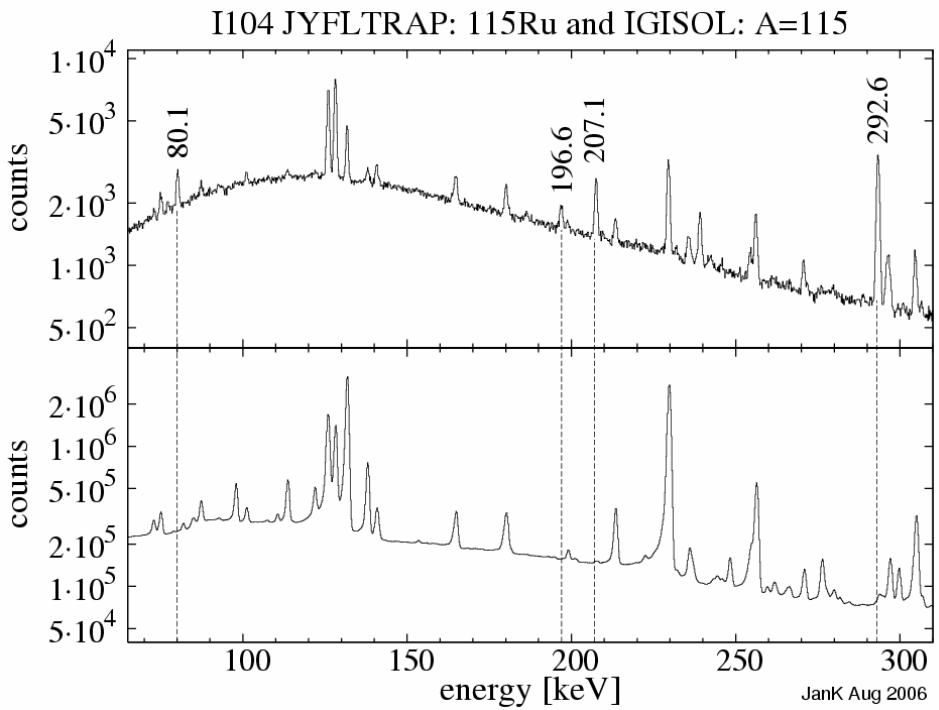
S. Rinta-Antila et al., submitted to Eur. Phys. J. A

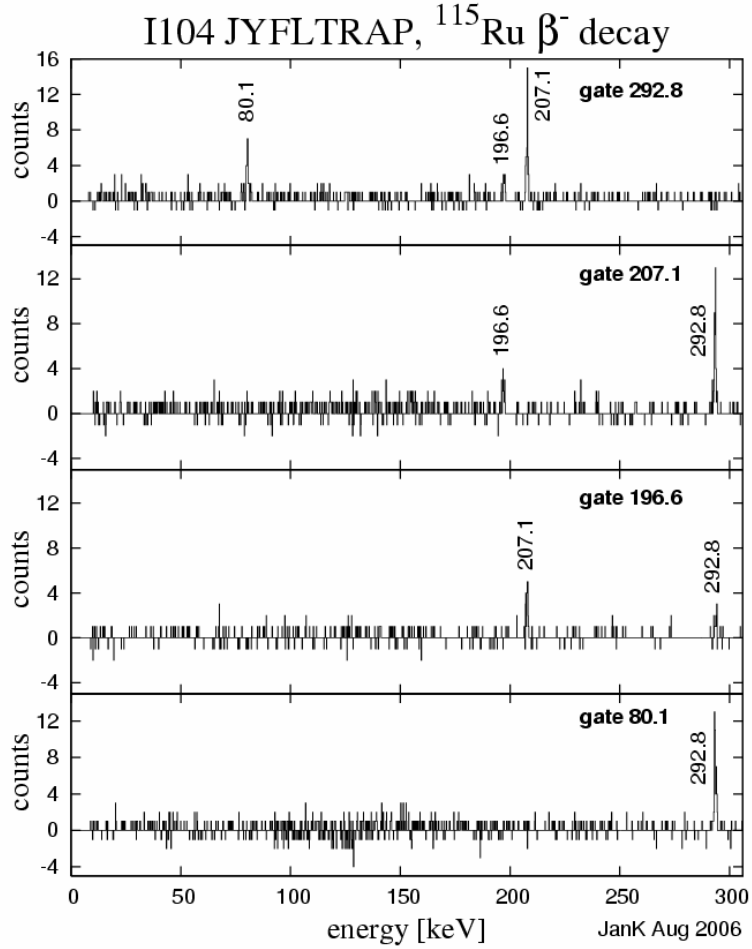


The first decay study of ^{115}Ru









Precision experiments

Q_{EC}-values for superallowed beta decay

CVC: *Ft* should be constant !

$$Ft \equiv ft(1+\delta_R)(1-\delta_C) = \frac{K}{2G_V^2(1+\Delta_R^V)}$$

δ_R – radiative correction
δ_C – isospin symmetry breaking correction
Δ^V_R – nucleus-independent radiative correction

Ft→G_v→V_{ud}→Unitarity of CKM: $V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1$

Exp. parameters Q_{EC}, $T_{1/2}$ and I_b

"World data 2005":
J. Hardy and I. Towner, PRC71 (2005) 055501
Nine best known cases: ^{10}C, ^{14}O, ^{34}Cl, ^{26m}Al, ^{42}Sc, ^{46}V, ^{50}Mn and ^{54}Co

Request:
to expand the set.
to improve accuracy in some cases.
to check some of the old values (^{3}He,t).

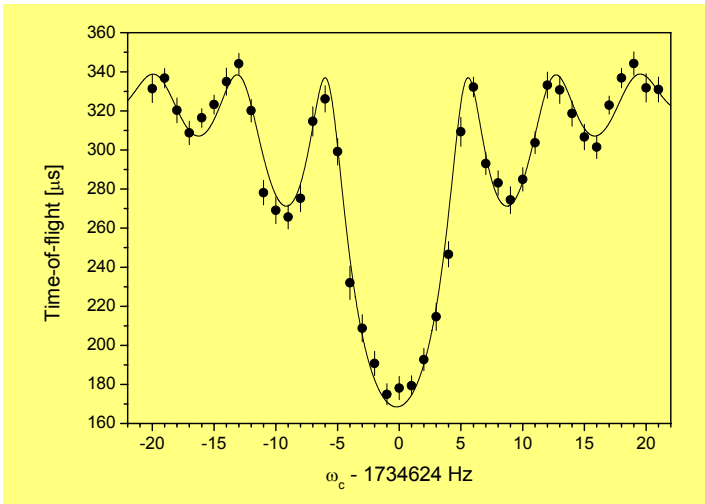
JYFLTRAP:
✓ 48 MeV p-beam on ^{64}Zn-target
✓ 600 ions/s ^{62}Ga, 7x10^5 ions/s ^{62}Zn

$$Q_{EC} = M_p - M_d = \underbrace{\left(\frac{f_d}{f_p} - 1\right)}_{\leq 10^{-3}} M_d$$

→ ΔM_d negligible !

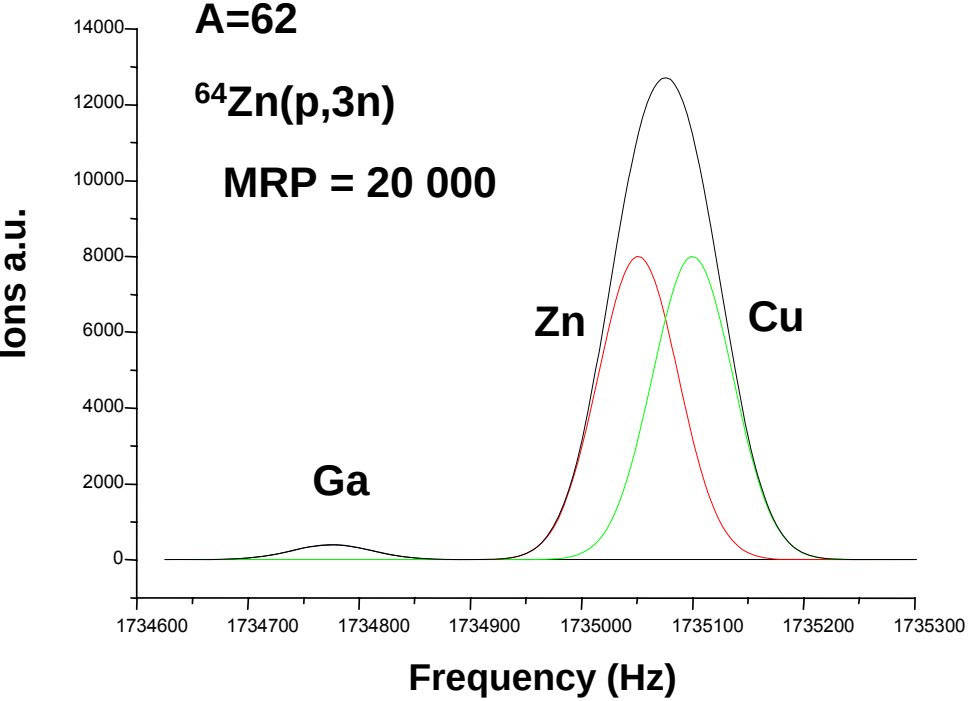
Q_{EC} = 9181.07(54) keV
$T_{1/2}$ = 116.175(38) ms
I_b = 99.861(11) %
Uncertainty of (δ_{NS}-δ_C) dominates !!!

T. Eronen et al., Phys. Lett. B 636 (2006) 191



Superallowed beta decay of ^{62}Ga

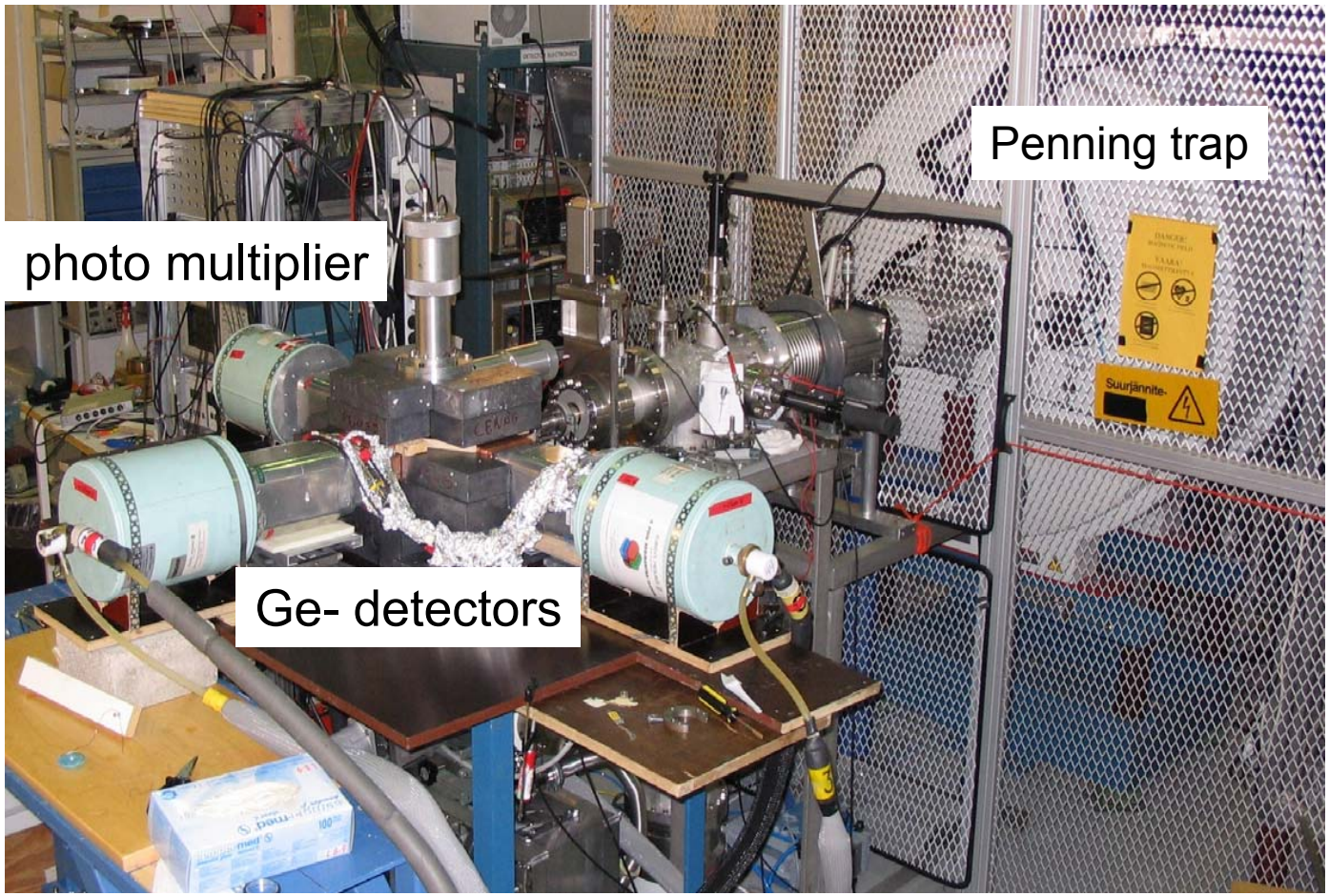
Precise $T_{1/2}$, I_b and Q_b requested



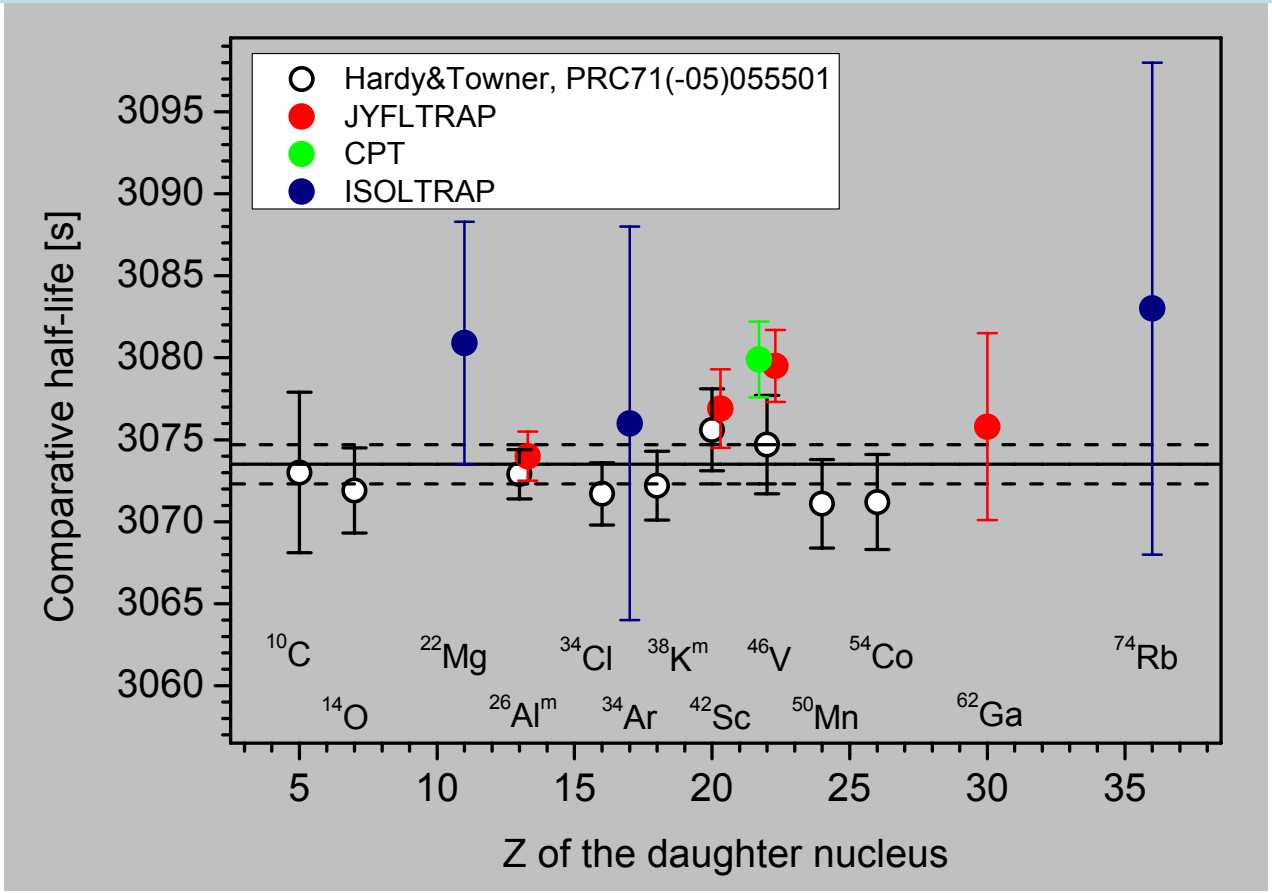
- ^{62}Ga lifetime ~ 116 ms
- Trap cycle time 71 ms
- 25 ms cooling
- 5 ms magnetron excitation
- 40 ms cyclotron excitation
- 40% cooler & trap transmission
- 150 ions/s detected after trap
- Branching ratio study: 4π β + 3 EXOGAM clovers around implantation point

BR & $T_{1/2}$ of 0^+-0^+ decay

4π β detector and three clover germanium detectors.



FT-systematics + new PT-data and unitarity of CKM



Z>37: FAIR

New Q-value determinations (PT):

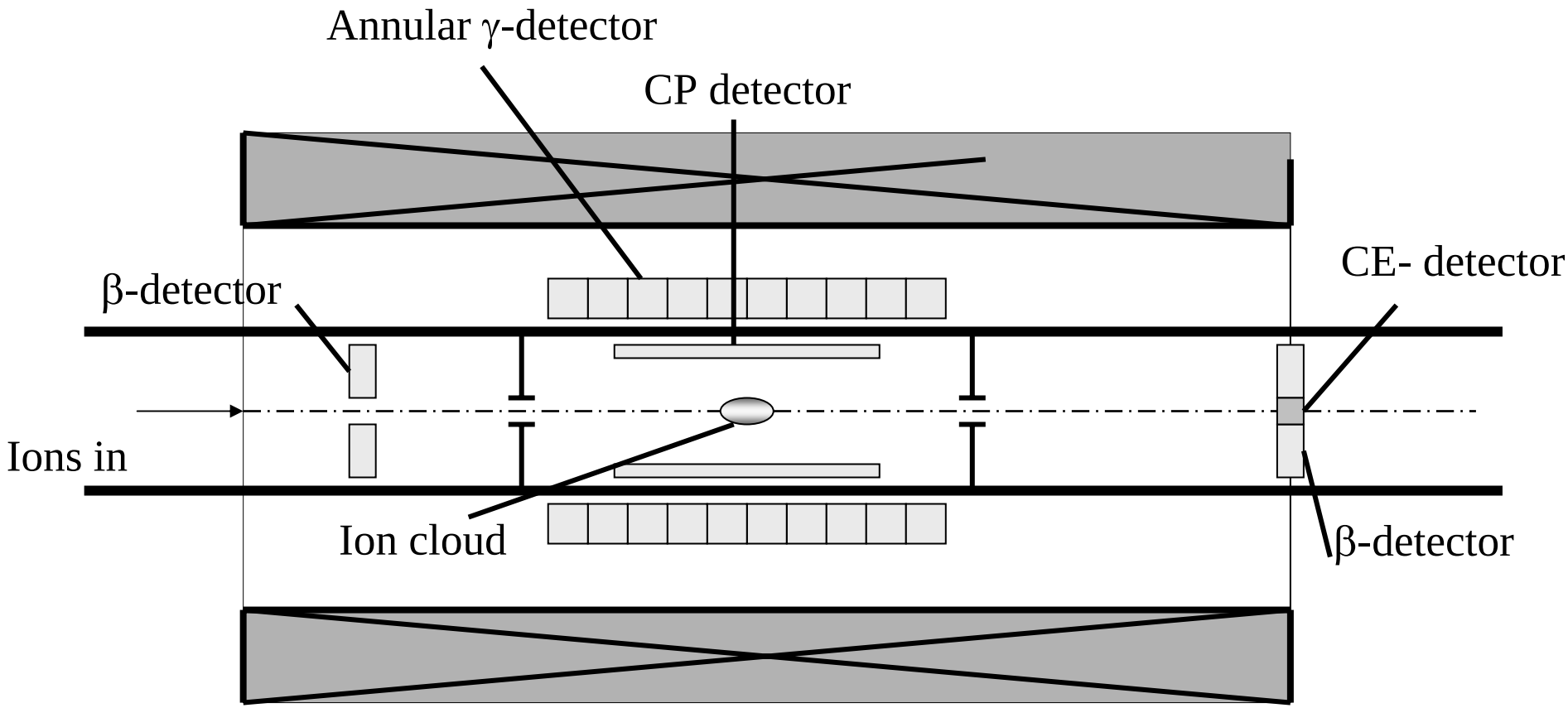
^{22}Mg	M. Mukherjee *et al.*, Phys. Rev. Lett. 93 (2004) 150801
^{26}Al^{m},^{42}Sc, ^{46}V	T. Eronen *et al.*, Phys. Rev. Lett. (2006) submitted, arXiv nucl-ex/0606035
^{34}Ar	F. Herfurth *et al.*, Eur. Phys. J. A 15 (2002) 17
^{38}Ca	G. Bollen *et al.*, Phys. Rev. Lett. 96 (2006) 152501
^{46}V	G. Savard *et al,*, Phys. Rev. Lett. 95 (2005) 102501
^{62}Ga	T. Eronen *et al.*, Phys. Lett. B 636 (2006) 191; B. Hyland et al., Phys. Rev. Lett. 97(2006) 102501
^{74}Rb	A. Kellerbauer *et al.*, Phys. Rev. Lett. 93 (2004) 072502

In-trap spectroscopy

In-trap spectroscopy

free of source effects
high efficiency

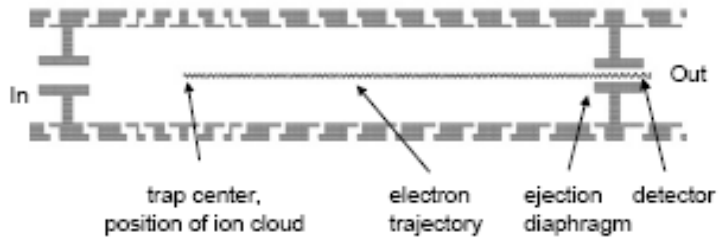
Ion beam coolers in nuclear physics,
J. Äystö and A. Jokinen
J. Phys. B 36 (2003) 573



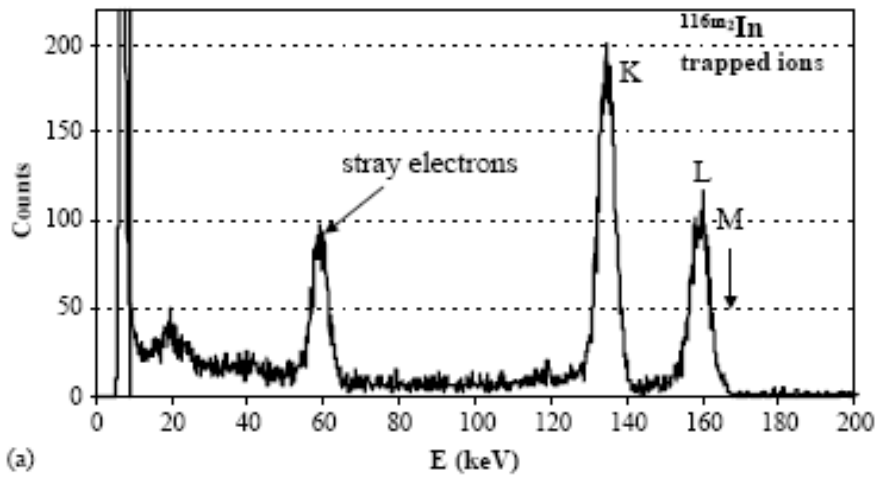
Nuclear Instruments and Methods in Physics Research A 492 (2002) 451–463

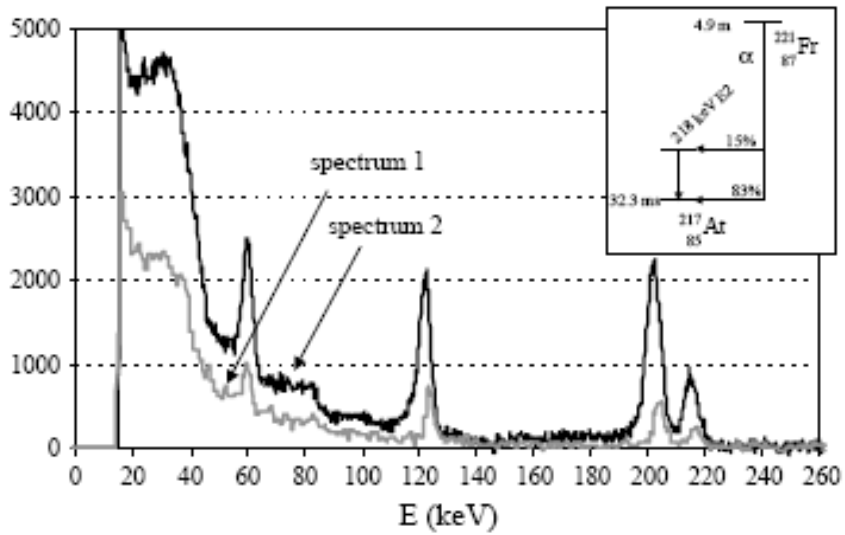
In-trap conversion electron spectroscopy

L. Weissman[a,*], F. Ames[a,b], J. Äystö[a,c], O. Forstner[a], K. Reisinger[a,b], S. Rinta-Antila[d]

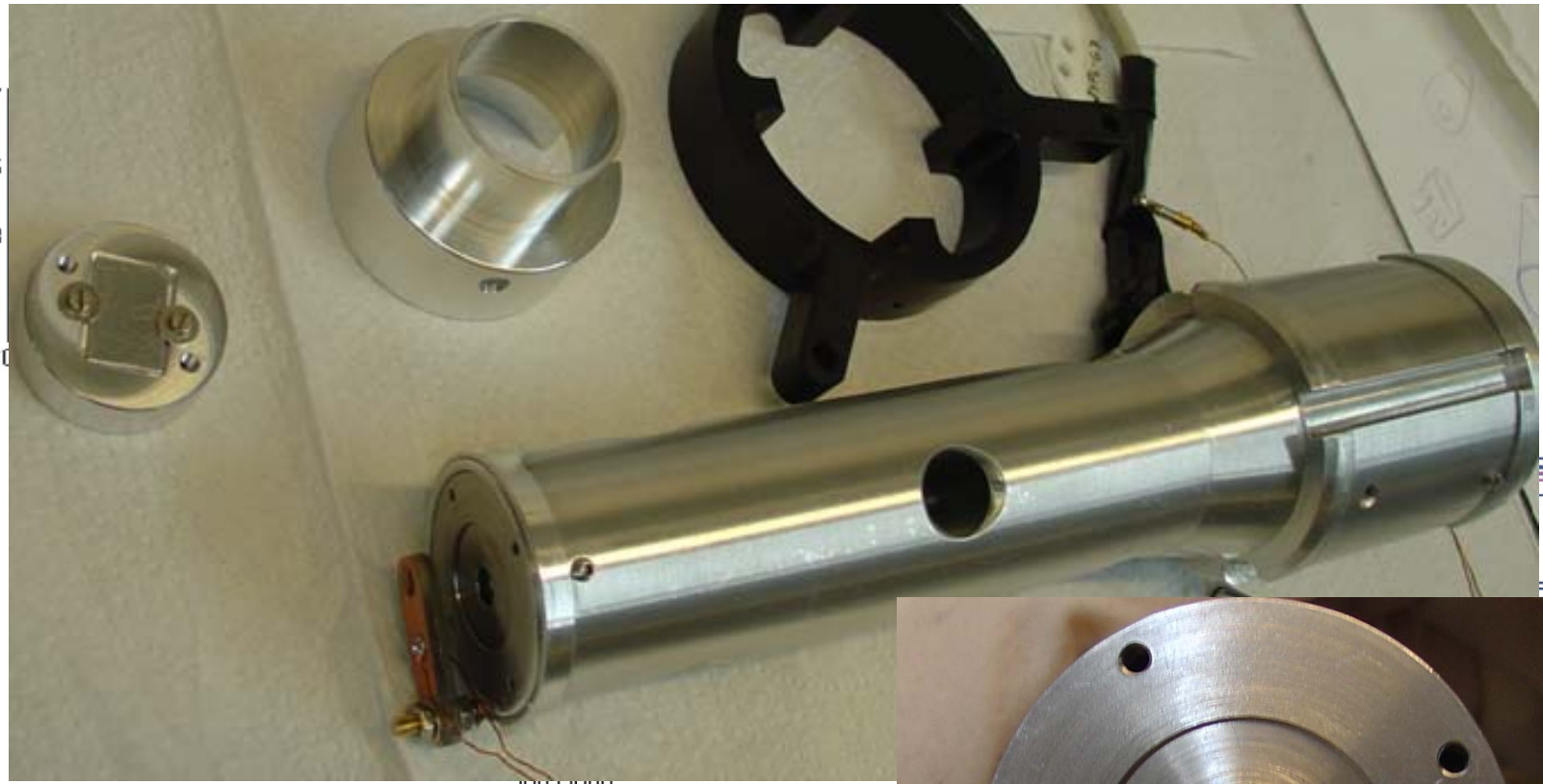


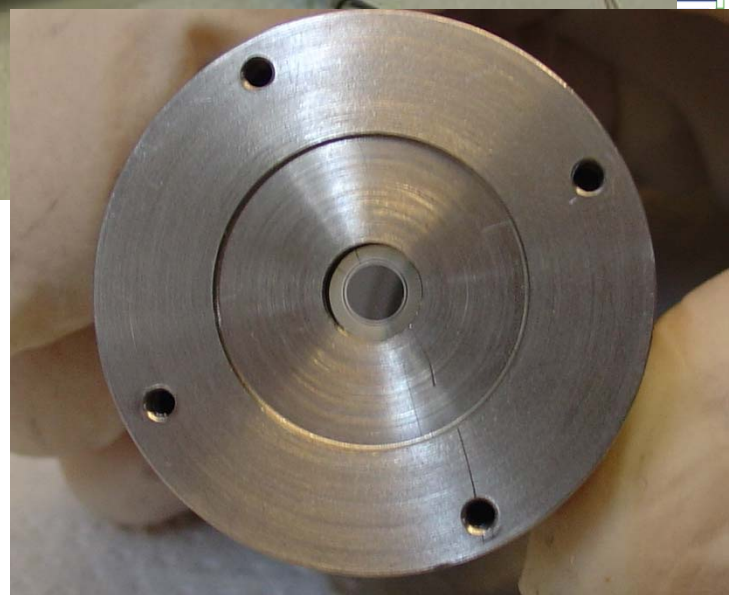
(α,e$^-$) position information
→ τ(E2) transition





JYFLTRAP in conversion electron spectroscopy

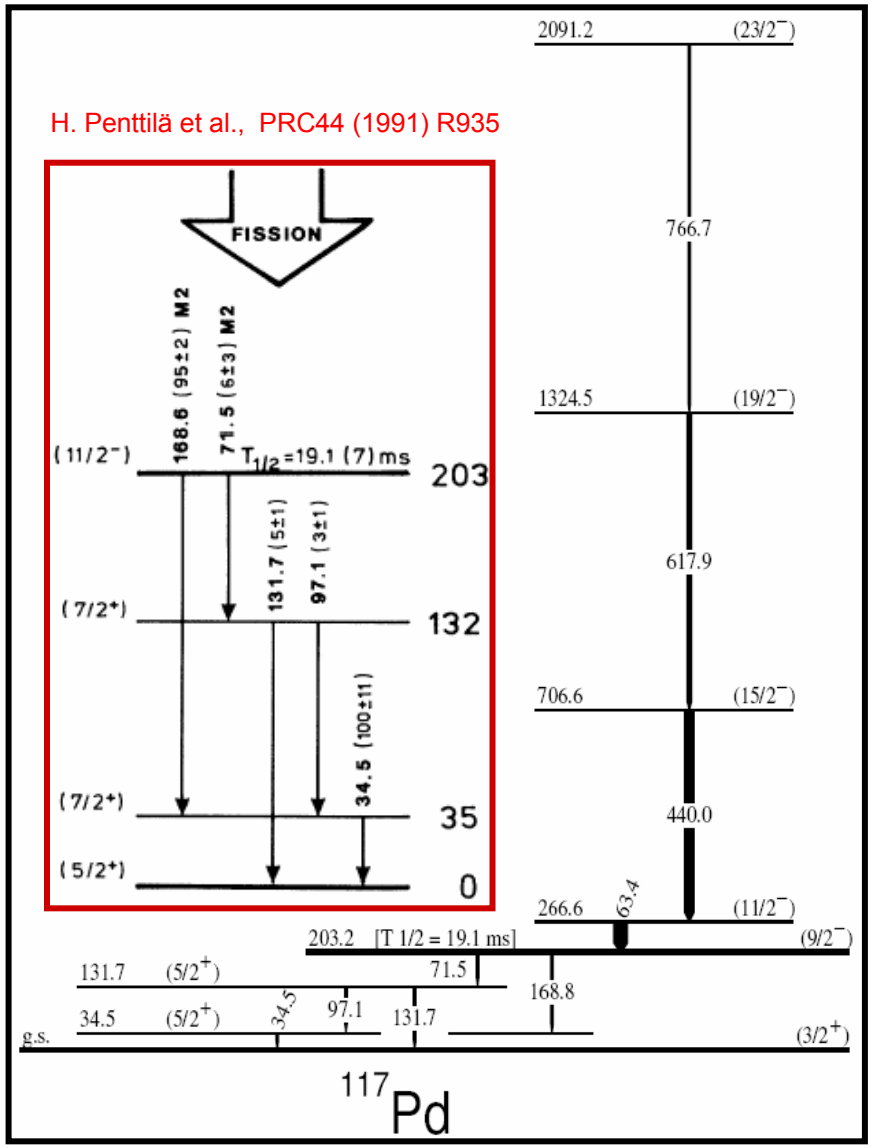




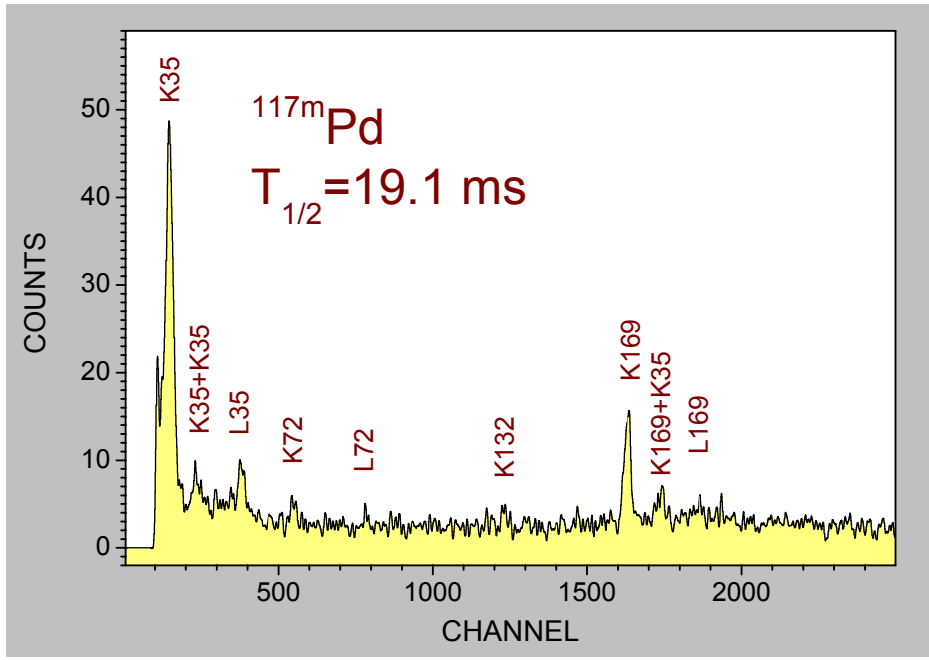
Canberra RD EB 10GC-500P
Thickness 500 μm
Active area 10 mm² (r = 1.78 mm)
Dead layer 250 Å
PA 1201 Pre amp
Resolution less than 1 keV for 59.5 Xray ^{241}Am

J. Rissanen Diploma thesis 2005

In-trap spectroscopy; commissioning run for ^{117m}Pd



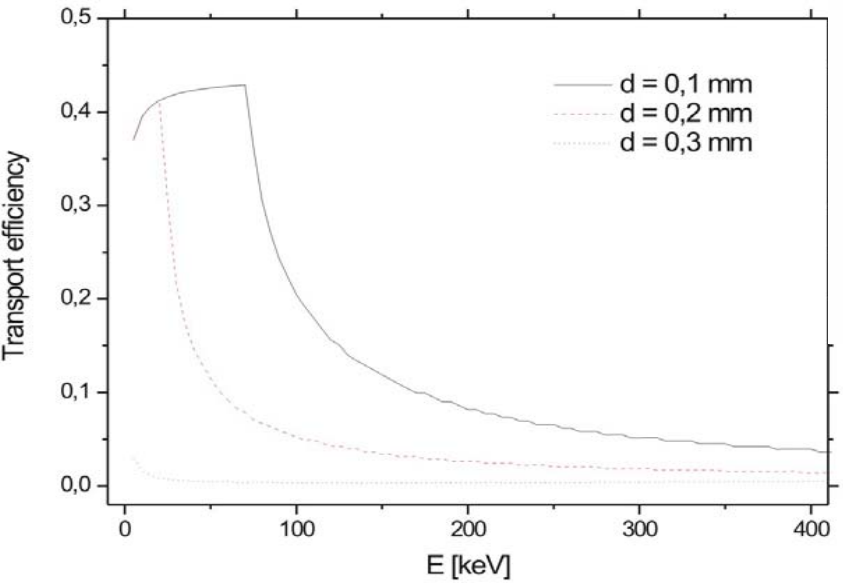
W. Urban et al., EPJA 22 (2004) 157

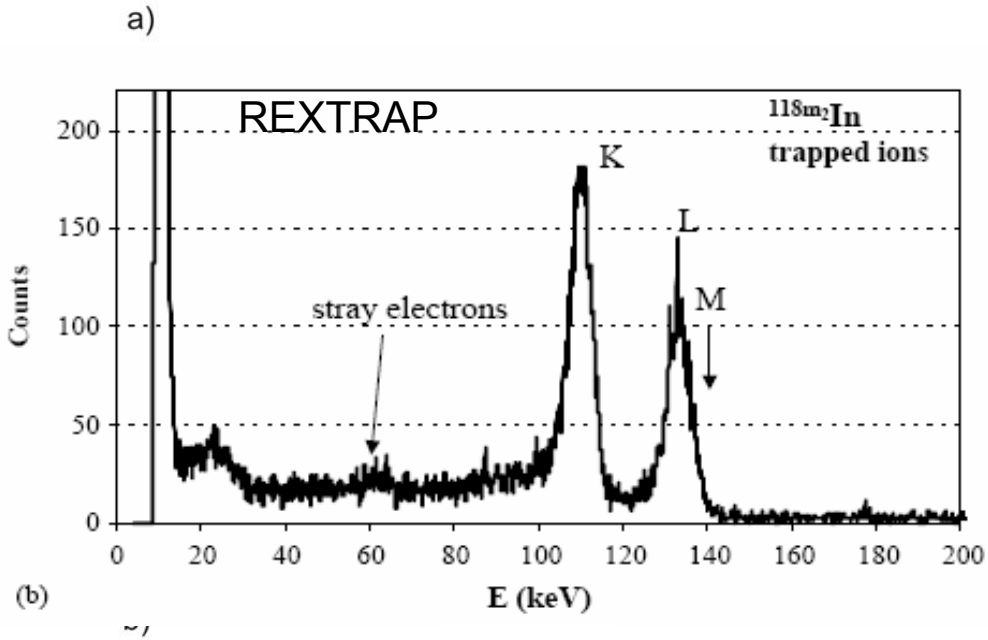


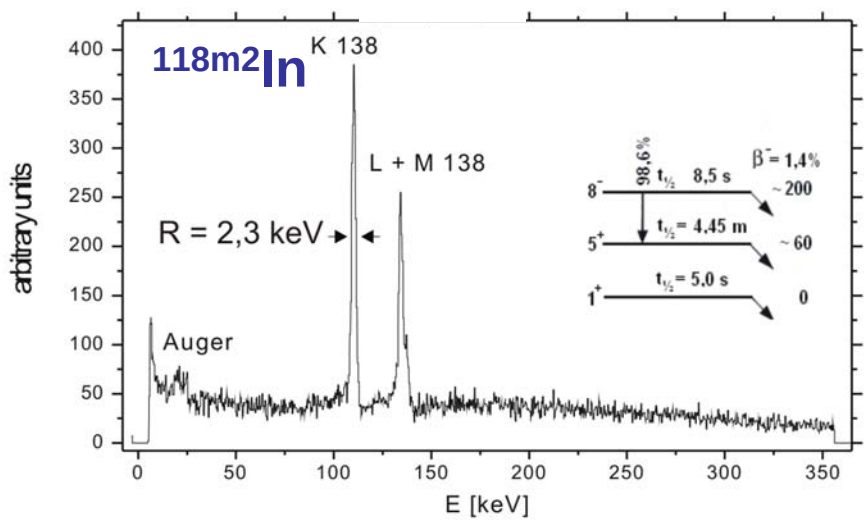
- ✓ ^{238}U(p,f) @ 25 MeV
- ✓ 10 mm^2 Si-detector @ B=0.7 T
- ✓ Excellent lineshape
- ✓ Efficient collection of electrons
- ✓ Background-free spectra
- ✓ Extends to very low energies
- ✓ No X-rays !
- ✓ Applicable to rather short-lived states

Online Results: ^{117m}Pd and ^{118m2}In

Transport efficiency







J. Rissanen et al. to be published

Outlook for FAIR

In-trap spectroscopy:

$T_{1/2}$ reach 10 ms
Rates of few ions /min possible

Need for multidetector array for
γ- & X -rays, electron, CP and recoil ion detection
➔ significant R&D required

Very high energy resolution measurements (bolometers?)

Post-trap spectroscopy:

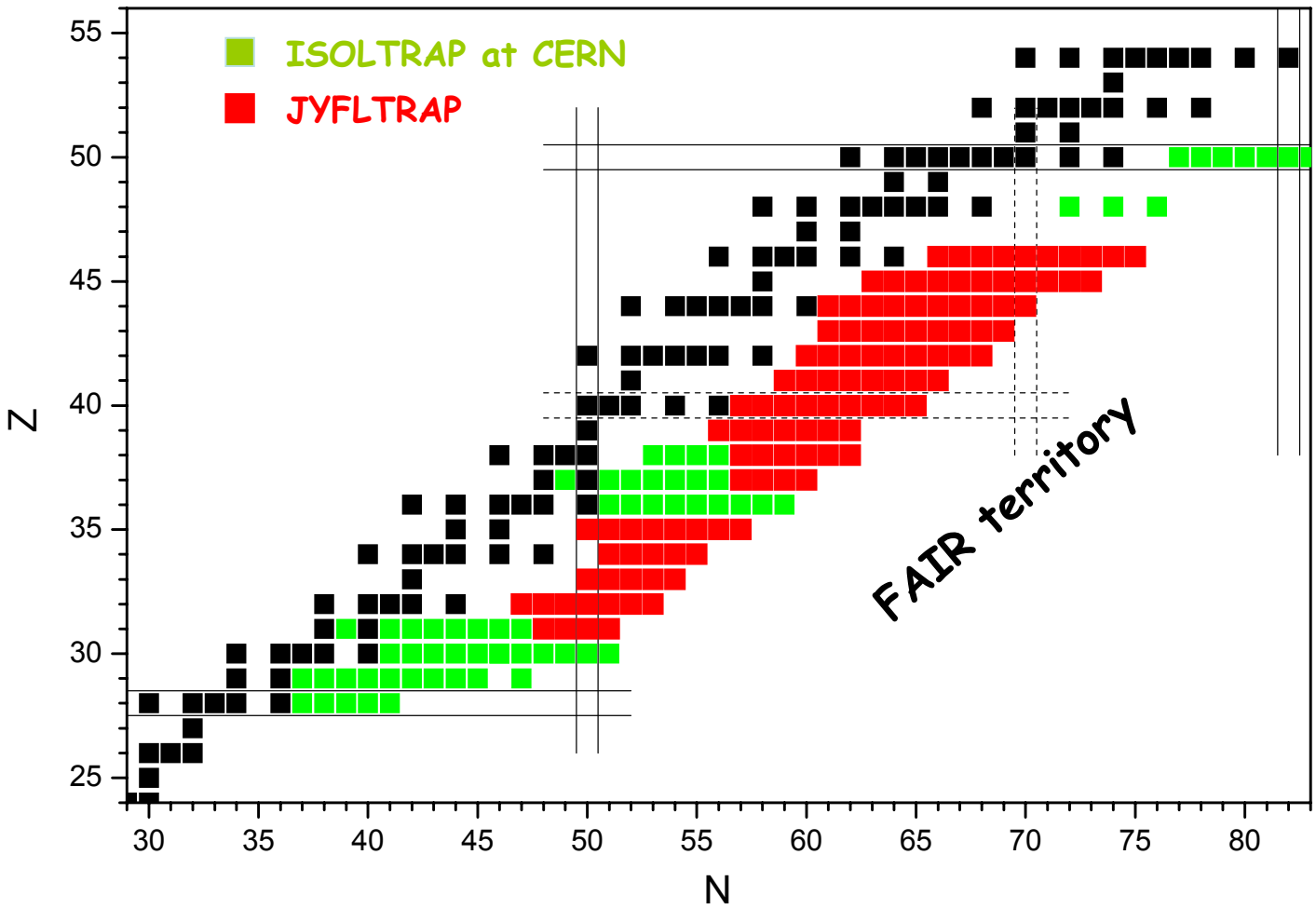
Precision measurements ($T_{1/2}$, br)
Isomer tagging (for mass measurement)
Ion tagging for sensitivity improvement
Delayed neutron measurements

Need a special multipurpose setup

Post RFQ-spectroscopy:

cooled & bunched sub-mm beams → applications

Overview of the recent studies (PT)



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