Penning-trap based mass and decay spectroscopy of exotic nuclei

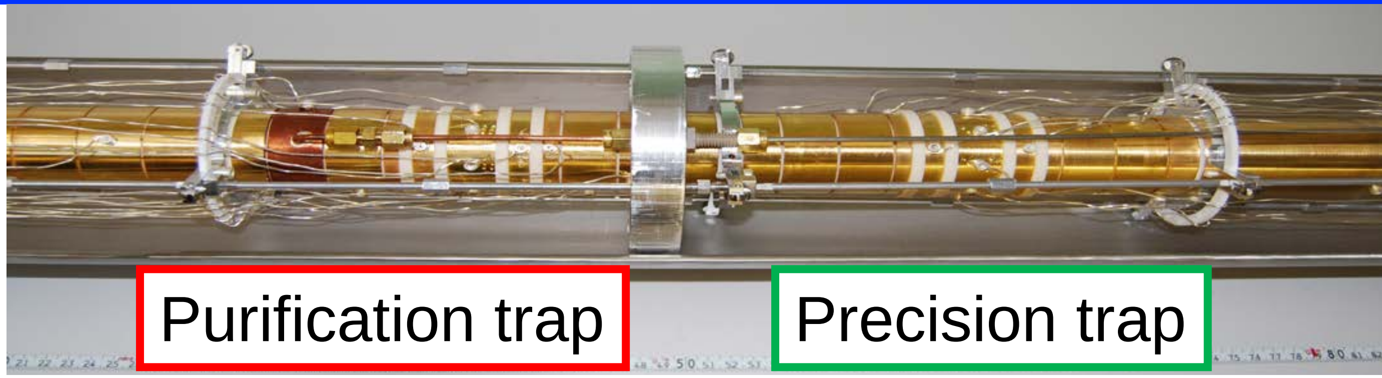
UNIVERSITY OF JYVÄSKYLÄ

Ari Jokinen

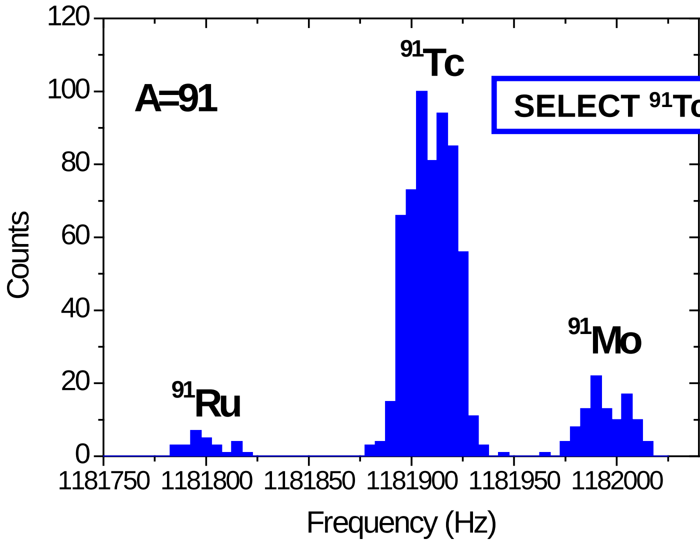
- Tandem trap (at JYFL)
- Mass measurements
- Trap-assisted spectroscopy

CPT, ISOLTRAP, **JYFLTRAP**, LEBIT
SHIPTRAP, TITAN, TRIGA-TRAP, ...

Purification & measurement

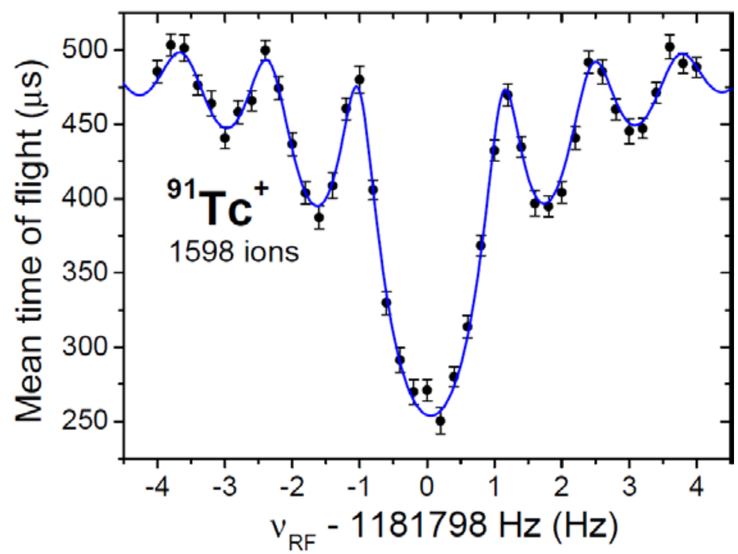


mass-selective buffer gas cooling



SELECT $^{91}Tc^{+}$

TOF-ICR method



Basic equations for mass determination

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

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

Routinely M/ΔM ~ 10^5
Space charge limit ~10^5
Good/Bad ~ 10000

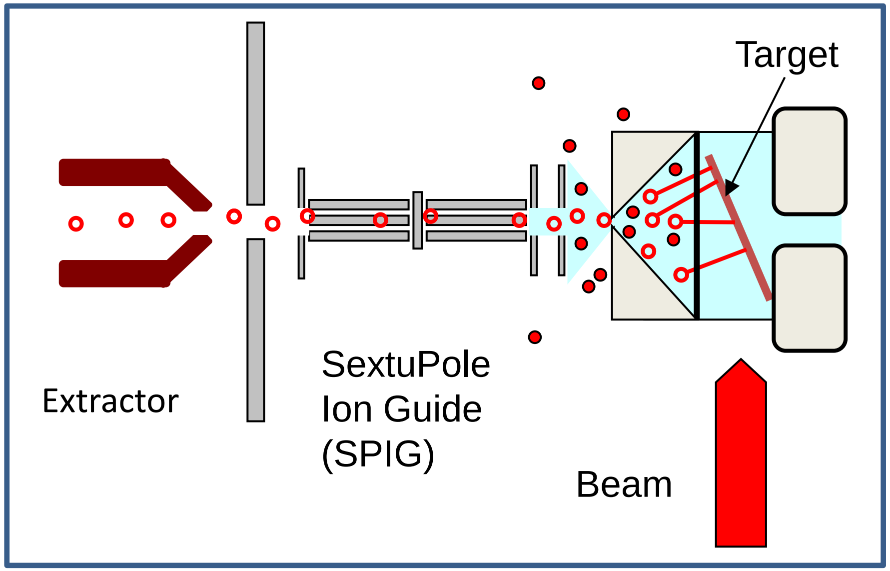
Routinely few keV
If required few tens of eV (***δm/m* < 1·10^{-8}**)

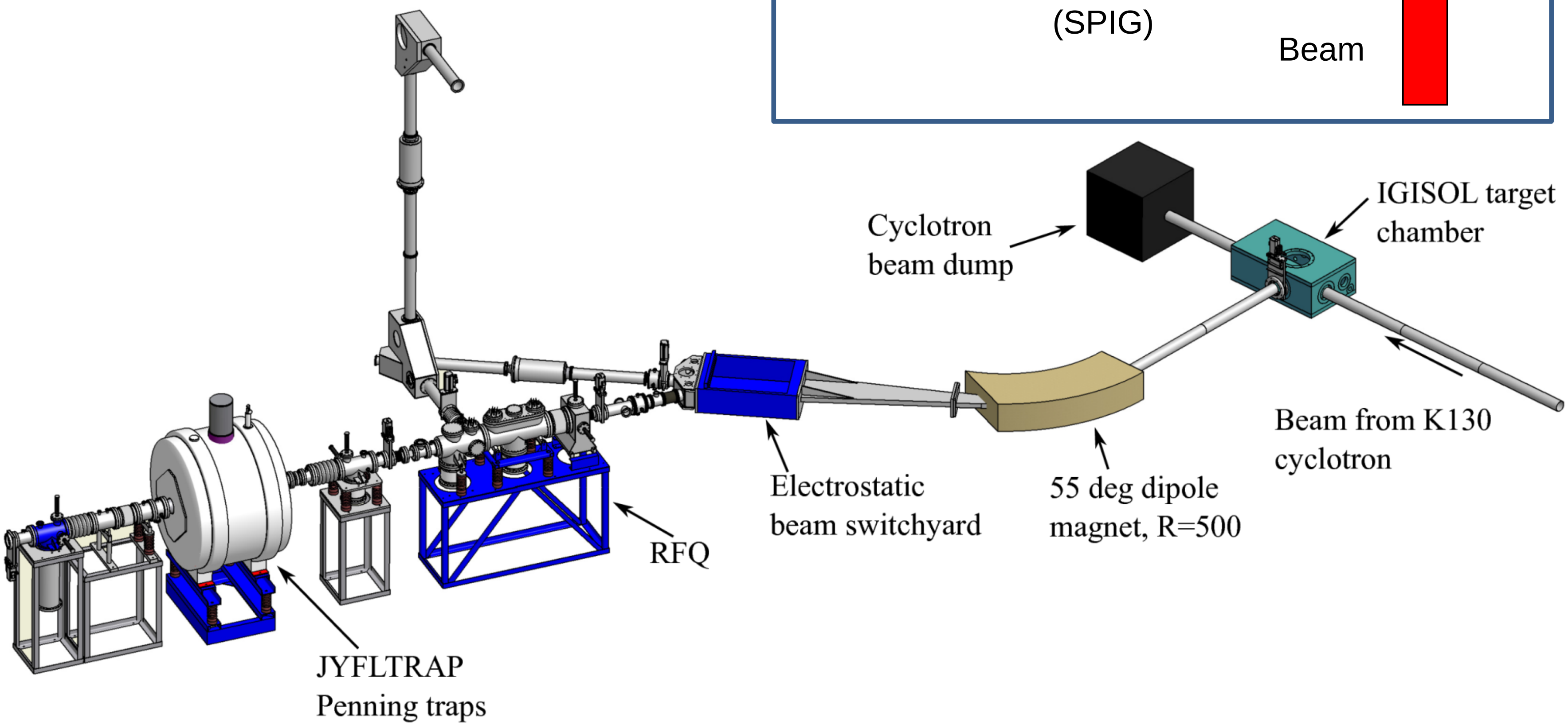
IGISOL3: Spectroscopy of exotic isotopes of all elements

Ion guide technique

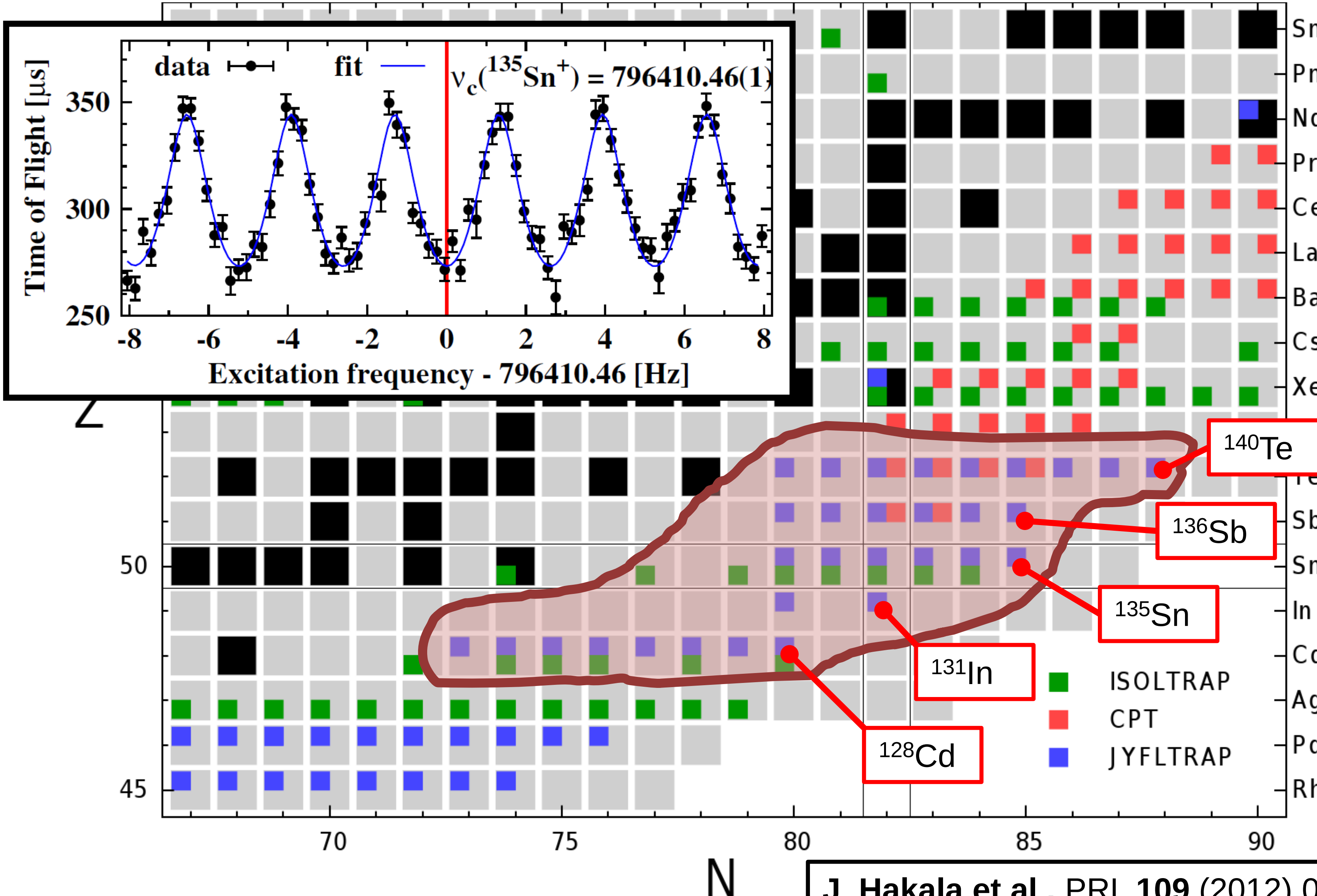
p + ^{238}U fission
Heavy and light ion fusion
Transfer reactions

Laser ionization





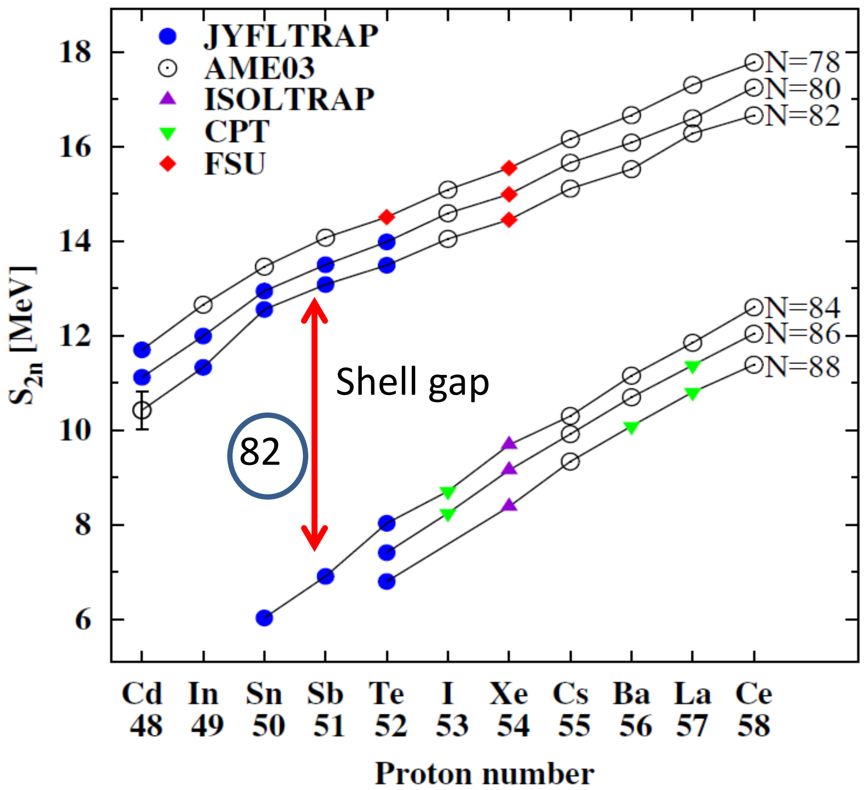
JYFLTRAP data in ^{132}Sn region



J. Hakala et al., PRL **109** (2012) 032501

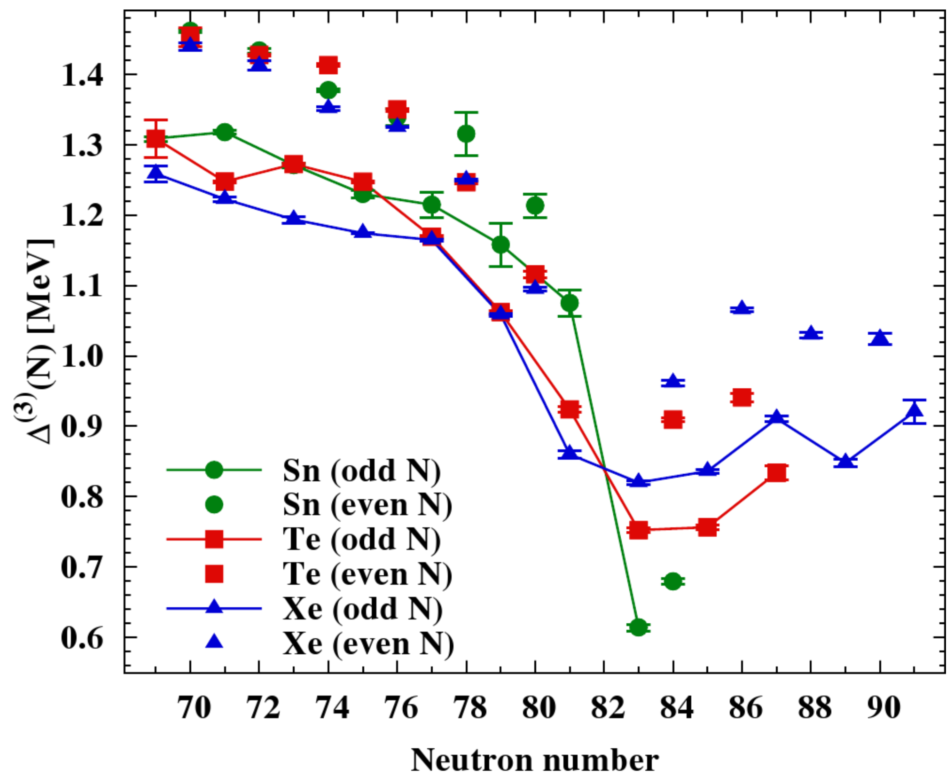
Mass differences

Two-neutron shell gap for N=82



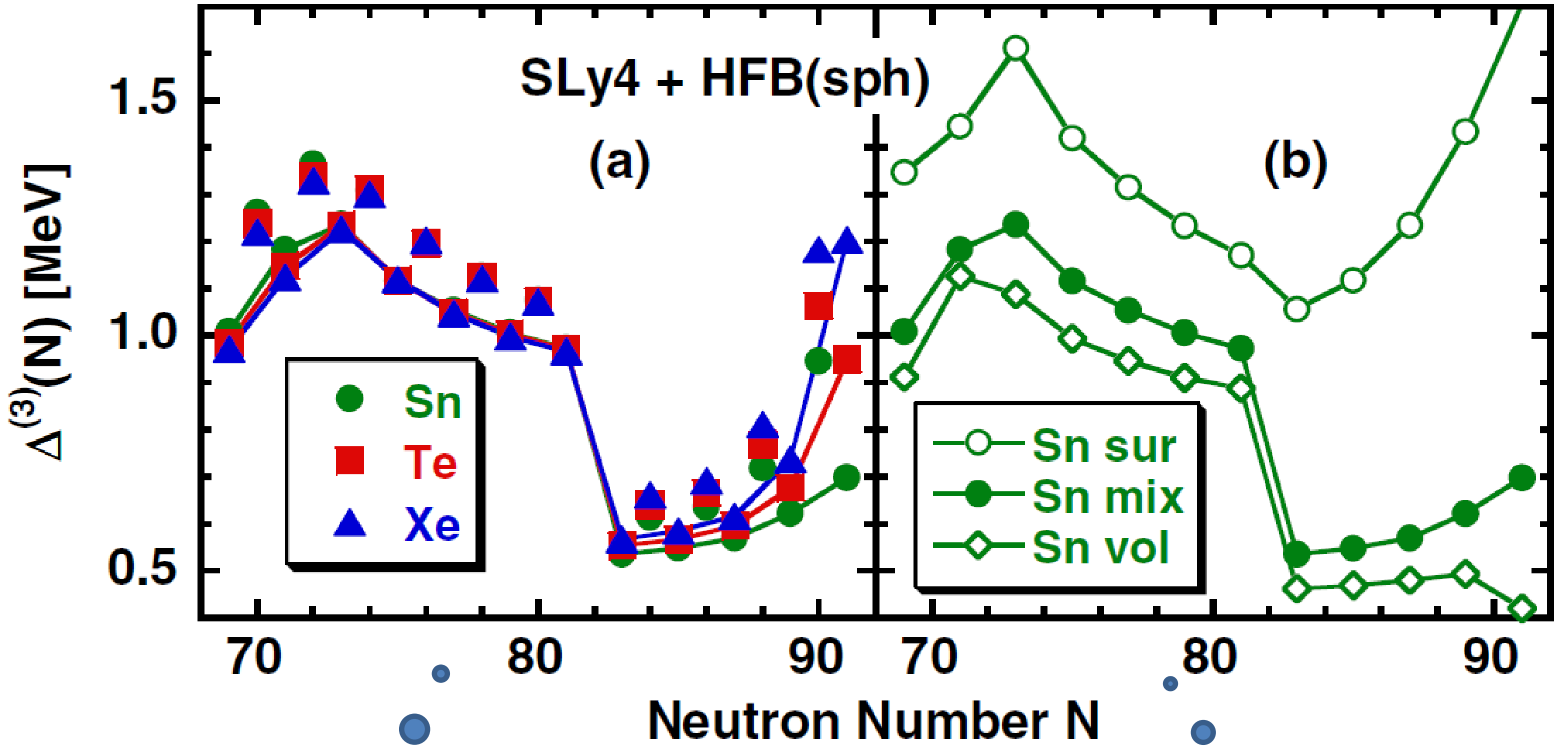
Odd-even mass staggering

$$\Delta^{(3)}(N) = (-1)^N [E(N+1) - 2E(N) + E(N-1)]/2$$



J. Hakala et al., PRL **109** (2012) 032501

Spherical EDF calculations around ^{132}Sn

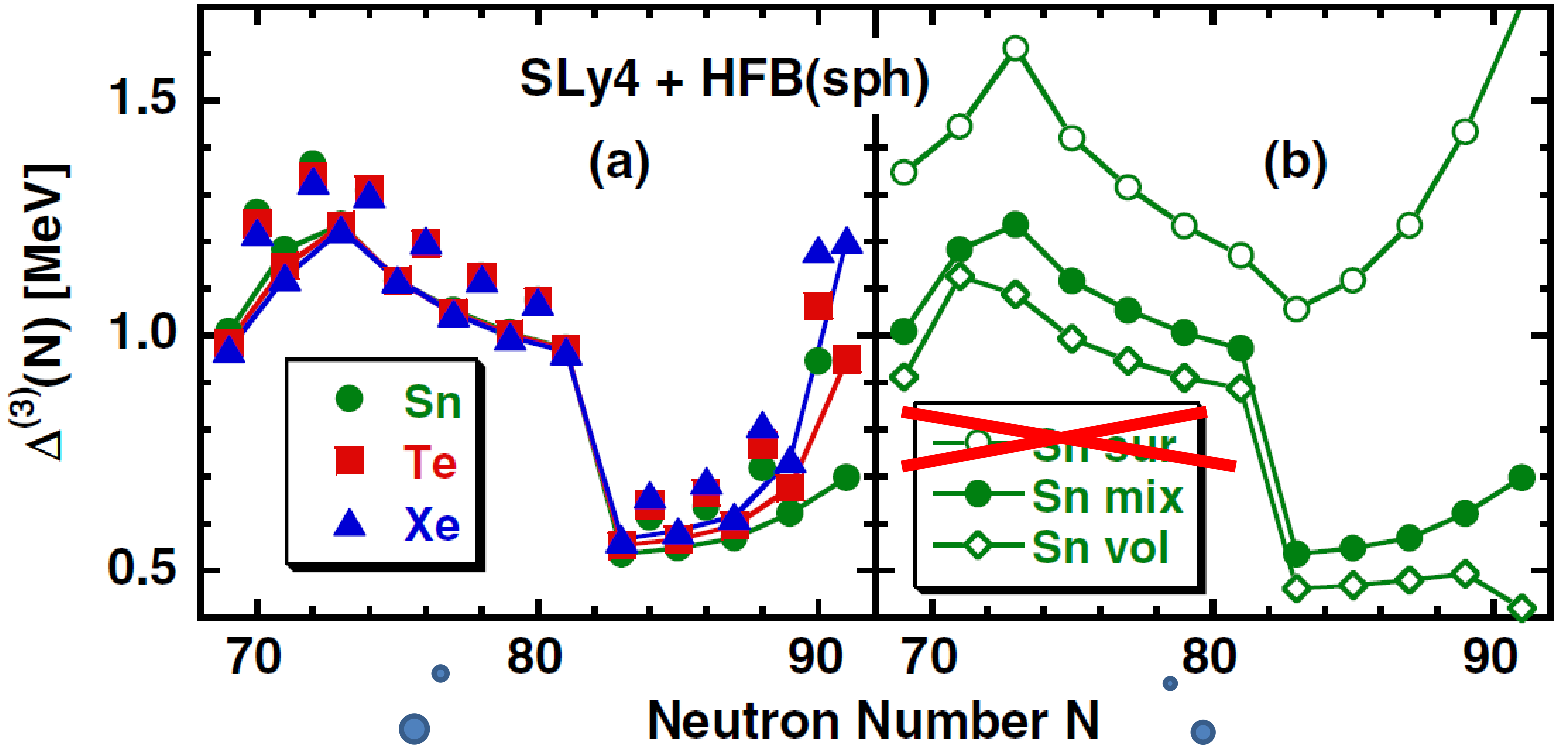


Spherical approach

Sn isotopes with different pairing options

J. Hakala et al., PRL **109** (2012) 032501

Spherical EDF calculations around ^{132}Sn

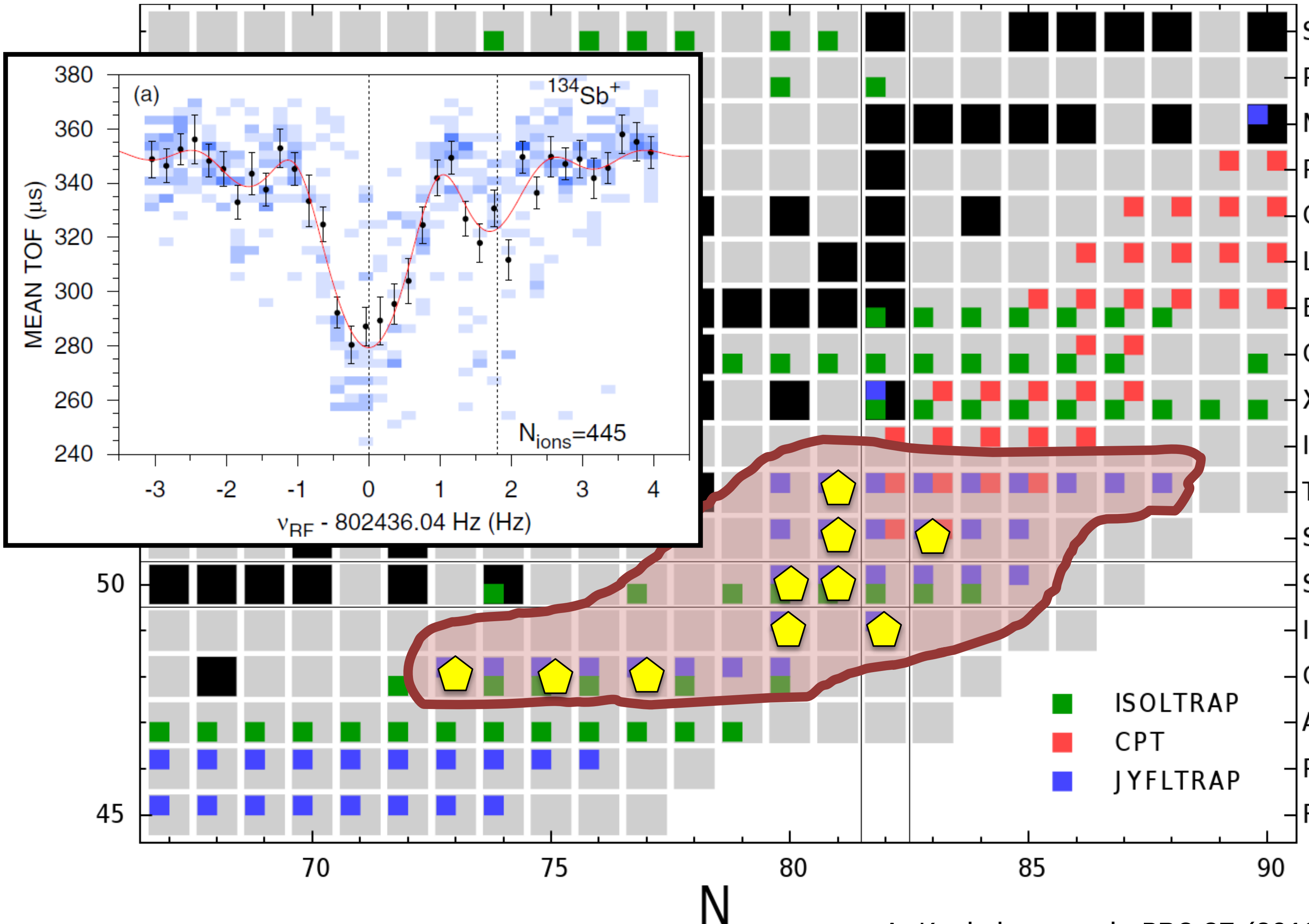


Spherical approach

Sn isotopes with different pairing options

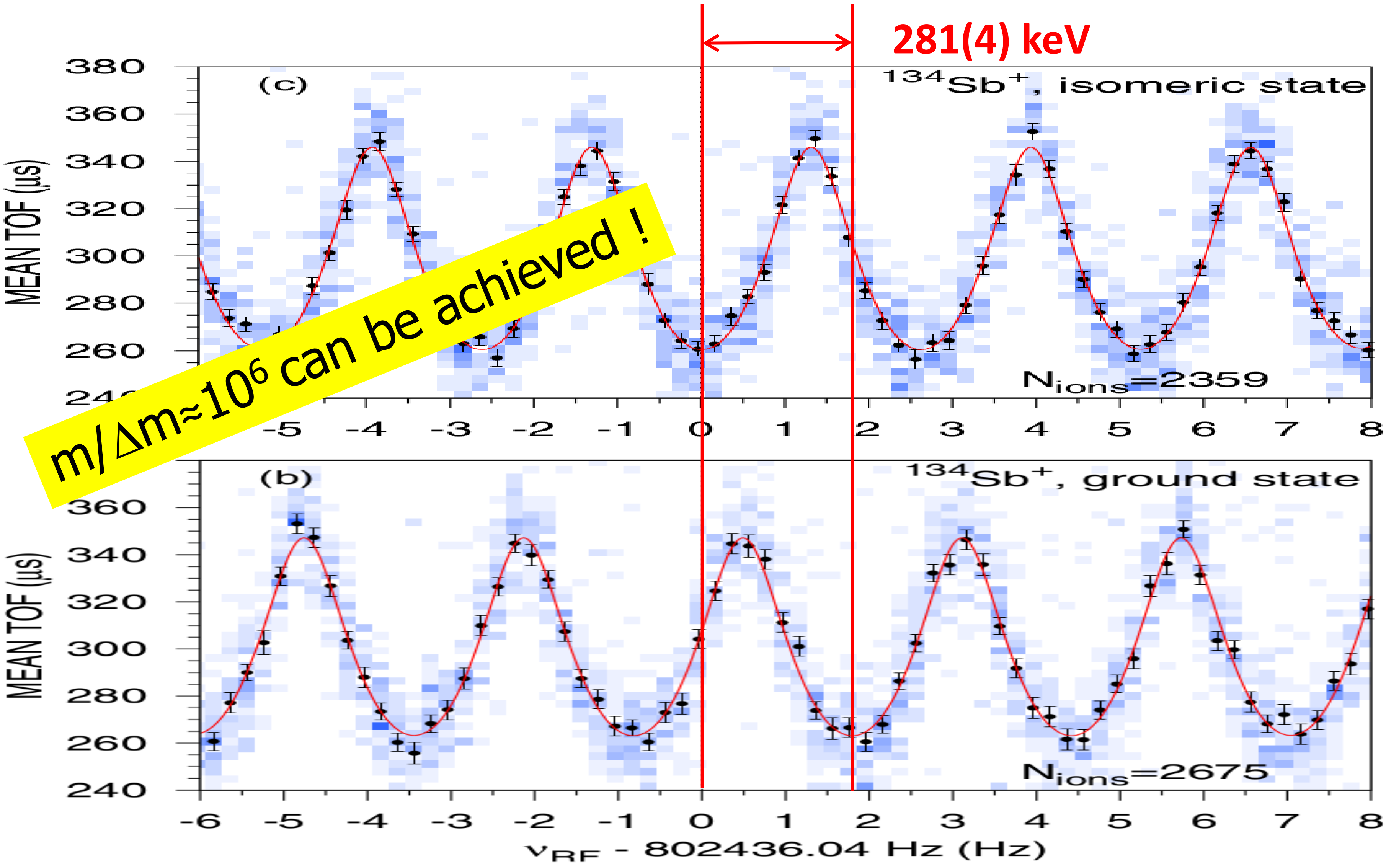
J. Hakala et al., PRL **109** (2012) 032501

Isomeric states, $T_{1/2}$ > 100 ms



A. Kankainen et al., PRC 87 (2013) 024307

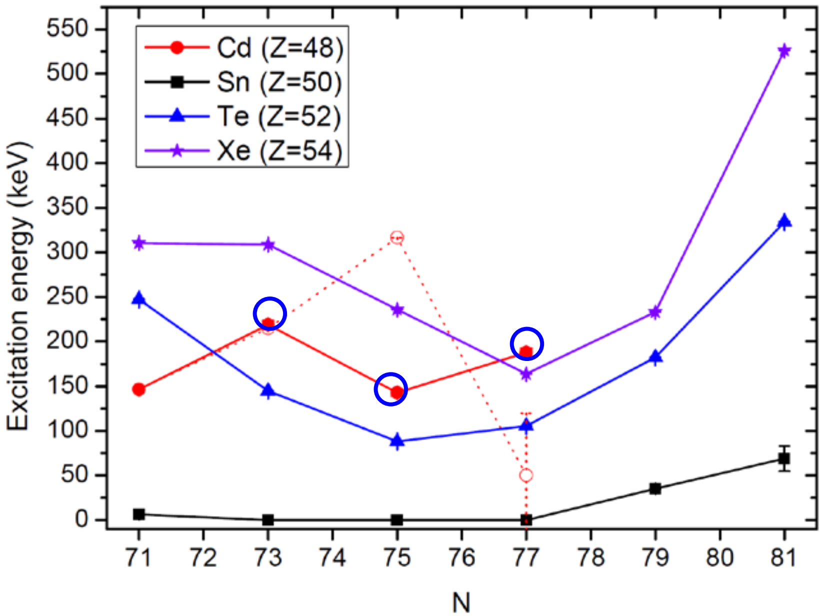
Dipole Ramsey cleaning for isomeric purification



T. Eronen et al., NIM. B 266 (2008) 4527

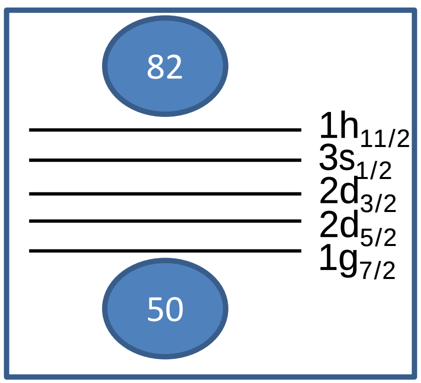
Single-particle states close to ^{132}Sn

SYSTEMATICS of the 11/2⁻ state

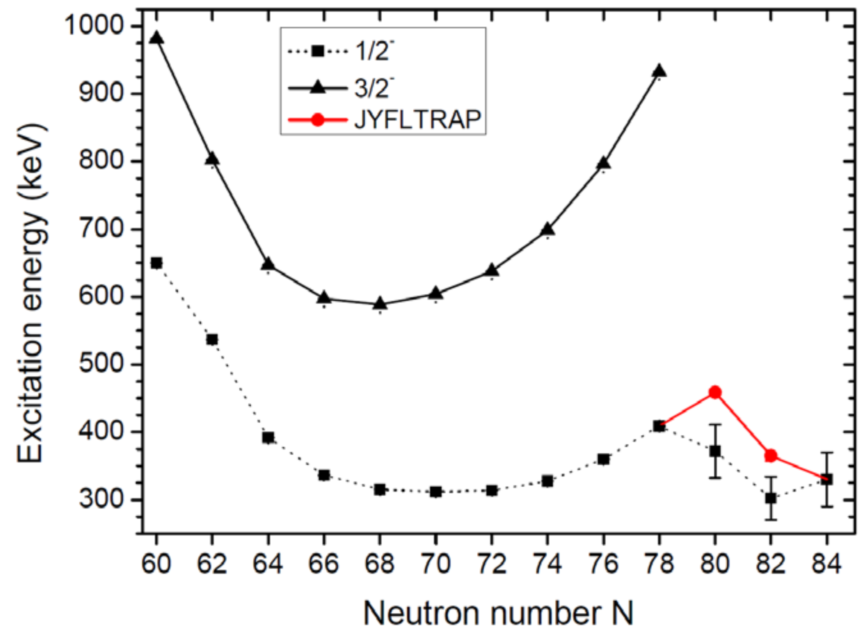


Odd neutron in the $1h_{11/2}$ shell

Cd isomers relocated → trend similar to Te isomers

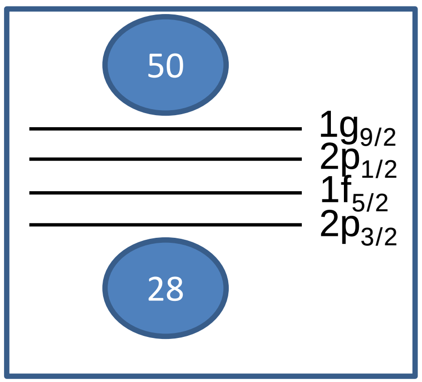


SYSTEMATICS of the 1/2⁻ state



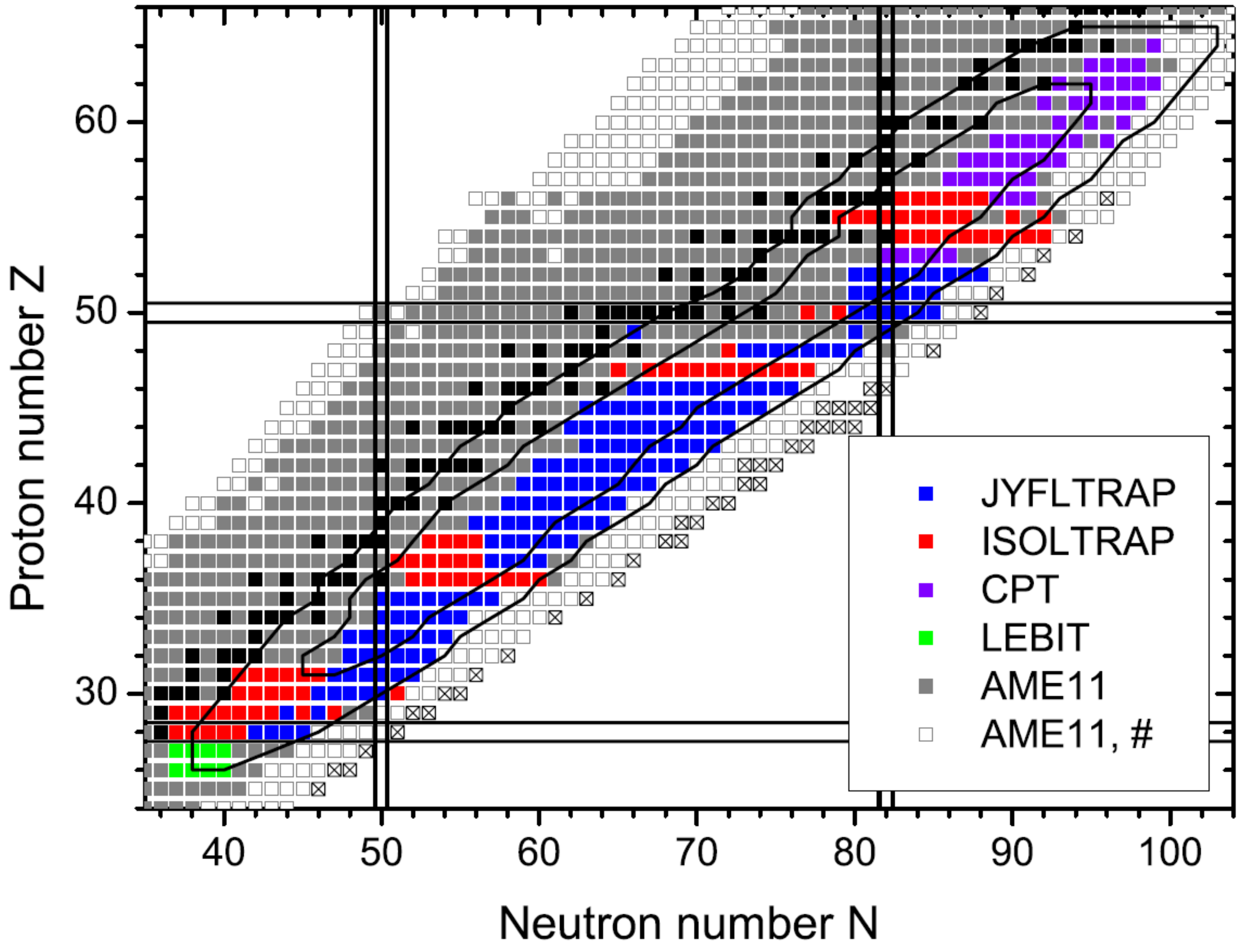
In (Z=49) proton-hole in the $2p_{1/2}$ shell

Old Q-value based energies corrected



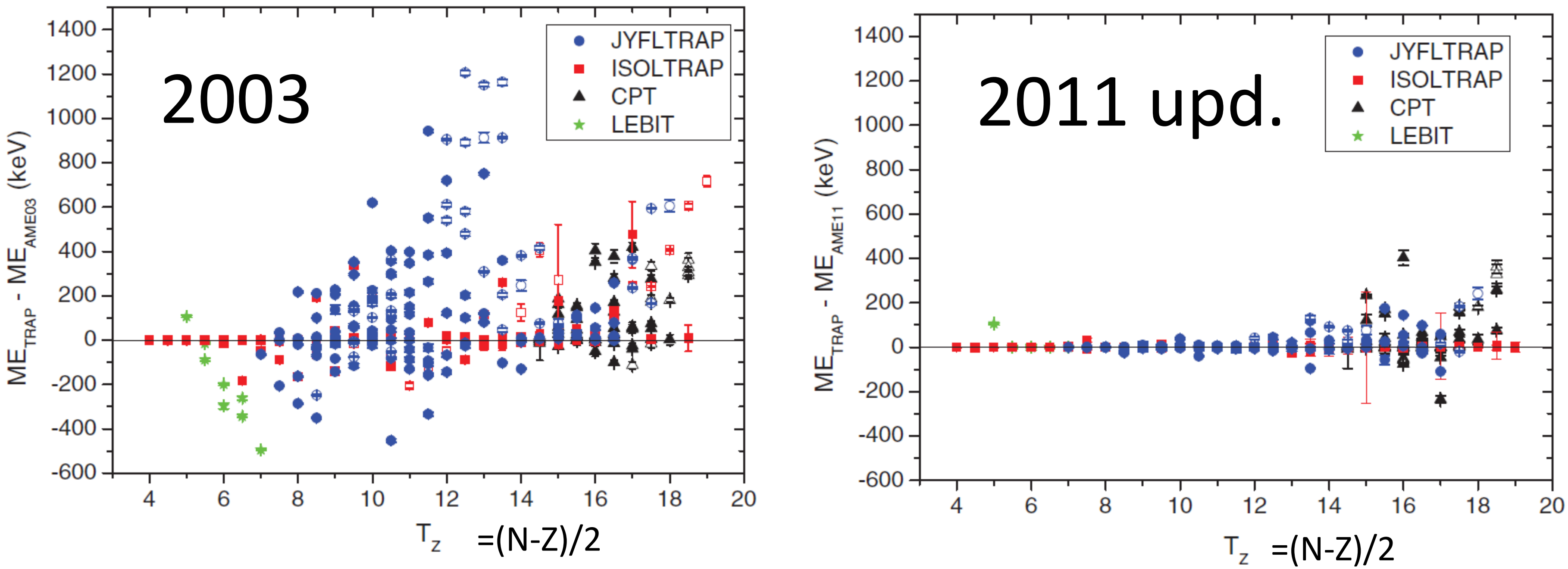
A. Kankainen et al., PRC 87 (2013) 024307

PT measurements of fission fragments



A. Kankainen, J. Äystö and A. Jokinen, J. Phys. G 39 (2012) 093101

AME vs. PT data (n-rich nuclei)

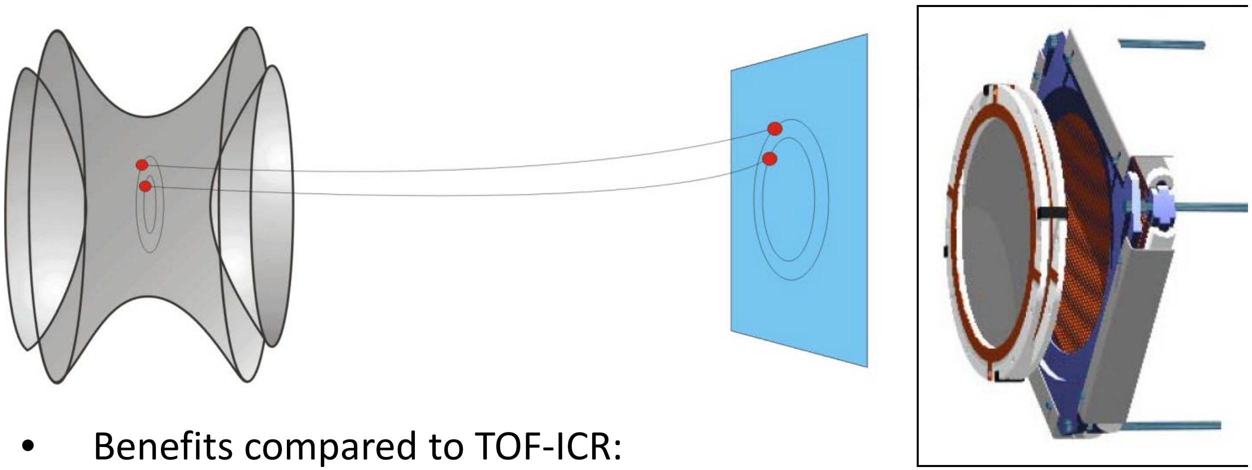


A. Kankainen, J. Äystö and A. Jokinen, J. Phys. G 39 (2012) 093101

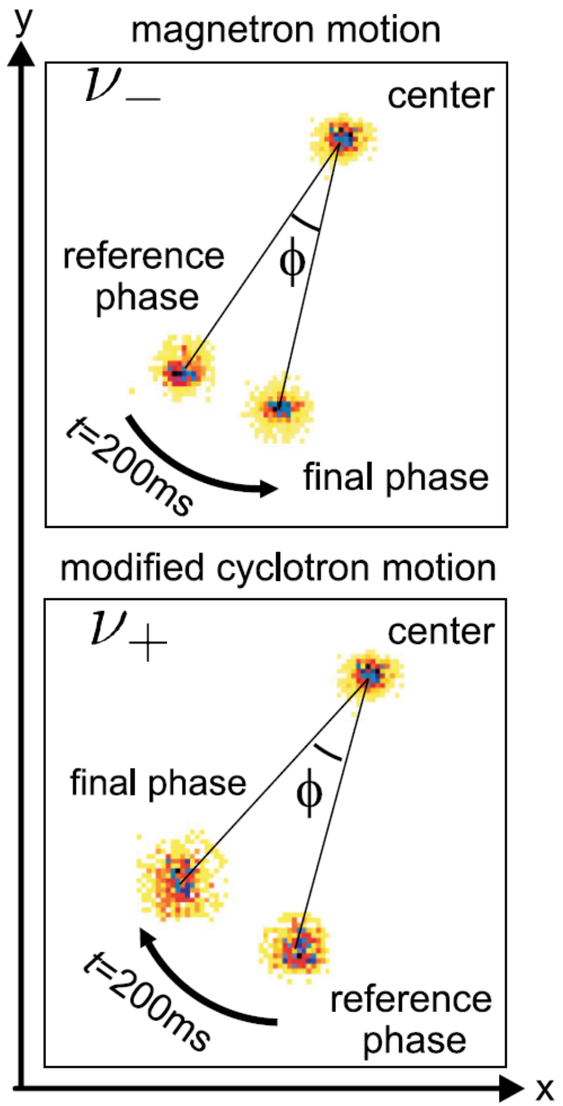
PI-ICR

Phase-Imaging Ion Cyclotron Resonance technique

- Count revolutions + final phase
- Spatially resolving MCP



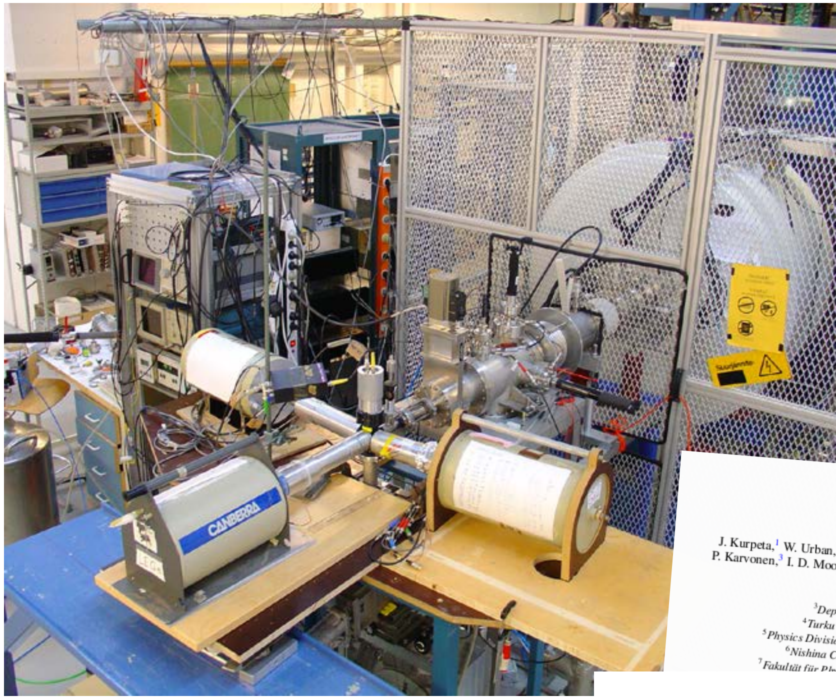
- Benefits compared to TOF-ICR:
  - 25x faster
  - 40x resolving power
- Well suited for short-lived ions
- Developed by S. Eliseev, MPIK Heidelberg and implemented at SHIPTRAP, GSI



S. Eliseev et al., PRL 110, 082501 (2013)

S. Eliseev et al., Appl. Phys. B 114, 107 (2014)

Trap-assisted spectroscopy



Eur. Phys. J. A **31**, 1–7 (2007)
DOI 10.1140/epja/i2006-10158-9
Regular Article – Nuclear Structure and Reactions
THE EUROPEAN PHYSICAL JOURNAL A

Decay study of ne… Penning trap as a…

S. Rinta-Antila, T. Eronen, V.-… T. Sonoda, A. Saastamoinen, and…
University of Jyväskylä, Departmen…

Received: 29 September … Published online: 18 Jan… Communicated by D. Gu…

Abstract. A new techniq…

Eur. Phys. J. A **31**, 263–266 (2007)
DOI 10.1140/epja/i2007-10009-3
Letter
THE EUROPEAN PHYSICAL JOURNAL A

Letter

Penning trap assisted decay spectroscopy of neutron-rich ^{115}Ru

J. Kurpeta[1,a], V.-V. Elomaa[2], T. Eronen[2], J. Hakala[2], A. Jokinen[2], P. Karvonen[2], I. Moore[2], H. Penttilä[2], … Saastamoinen[2], T. Sonoda[2], …

Eur. Phys. J. A (2011) **47**: 97
DOI 10.1140/epja/i2011-11097-0
Reply
THE EUROPEAN PHYSICAL JOURNAL A

Penning-trap–assisted study of ^{115}Ru beta decay

J. Rissanen[1,a], J. Kurpeta[2], … P. Karvonen[1], I.D. …
[1] Department of Phy…
[2] Faculty of Physics, …
[3] Institut Laue-Lange…

PHYSICAL REVIEW C **82**, 027306 (2010)

Excited states in ^{115}Pd populated in the β^- deca…

J. Kurpeta,[1] W. Urban,[1,2] A. Płochocki,[1] J. Rissanen,[3] V.-V. Elomaa,[4] T. Eronen,[3] J. H… P. Karvonen,[3] I. D. Moore,[3] H. Penttilä,[3] S. Rahaman,[5] A. Saastamoinen,[3] T. Sonoda,[6] …
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[3]Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40351, …
[4]Turku PET Centre, Accelerator Laboratory, Åbo Akademi University, FIN-…
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[6]Nishina Center for Accelerator Based Science, RIKEN …
[7]Fakultät für Physik …

RAPID COMMUNICATIONS
PHYSICAL REVIEW C **83**, 011301(R) (2011)

Decay study of ^{114}Tc with a Penning trap

J. Rissanen,[1,*] J. Kurpeta,[2] V.-V. Elomaa,[1,†] T. Eronen,[1] J. Hakala,[1] A. Jokinen,[1] I. D. Moore,[1] P. Karvonen,[1] A. Płochocki,[2] … H. Penttilä,[1] S. Rahaman,[1,‡] M. Reponen,[1] A. Saastamoinen,[1] J. Szerypo,[4] …

IOP PUBLISHING
JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS
J. Phys. G: Nucl. Part. Phys. **39** (2012) 015101 (6pp)
doi:10.1088/0954-3899/39/1/015101

Trap-assisted separation of nuclear states for gamma-ray spectroscopy: the example of ^{100}Nb

C Rodríguez Triguero[1], A M Bruce[1], T Eronen[2], I D Moore[2], M Bowry[3], A M Denis Bacelar[1], A Y Deo[3], V-V Elomaa[2], D Gorelov[2], J Hakala[2], A Jokinen[2], A Kankainen[2], P Karvonen[2], V S Kolhinen[2], J Kurpeta[4], T Malkiewicz[5], P J R Mason[3], H Penttilä[2], M Reponen[2], S Rinta-Antila[2], J Rissanen[2], A Saastamoinen[2], G S Simpson[5] and J Äystö[2]
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Received 9 May 2011
Published 24 November 2011

PHYSICAL REVIEW C **80**, 035502 (2009)

Half-life, branching-ratio, and Q-value measurement for the superallowed $0^+ \rightarrow 0^+ \beta^+$ emitter ^{42}Ti

…ouin,[1] T. Eronen,[2] L. Audirac,[1] J. Äystö,[2] B. Blank,[1] V.-V. Elomaa,[2] J. Giovinazzo,[1] U. Hager,[2,†] … Kankainen,[2] P. Karvonen,[2] T. Kessler,[2,‡] I. D. Moore,[2] H. Penttilä,[2] S. Rahaman,[2,§] M. Reponen,[2] …inta-Antila,[3] J. Rissanen,[2] A. Saastamoinen,[2] T. Sonoda,[2,‖] and C. Weber[2,¶]
…aires de Bordeaux Gradignan-Université Bordeaux 1-UMR 5797 CNRS/IN2P3, Chemin du Solarium, BP 120, F-33175 Gradignan, France
…tment of Physics, University of Jyväskylä, P. O. Box 35, FI-40014 Jyväskylä, Finland
…hysics, Oliver Lodge Laboratory, University of Liverpool, Liverpool L69 7ZE, United Kingdom
(Received 26 July 2009; published 8 September 2009)

…the branching ratio, and the decay Q value of the superallowed β emitter ^{42}Ti were measured in …rformed at the JYFLTRAP facility of the Accelerator Laboratory of the University of Jyväskylä. …st $T_z = -1$ nucleus for which high-precision measurements of these quantities have been tried. …$_{/2}$ = 208.14 ± 0.45 ms) and the Q value [Q_{EC} = 7016.83(25) keV] are close to or reach the …n of about 0.1%. The branching ratio for the superallowed decay branch [BR = 47.7(12)%], a …e half-life measurement, does not reach the necessary precision yet. Nonetheless, these results …ermine the experimental ft value and the corrected $\mathcal{F}t$ value to be 3114(79) and 3122(79) s, …

…ysRevC.80.035502 PACS number(s): 23.40.Bw, 21.10.Tg, 27.40.+z

…ODUCTION

…ved nuclear β decays provides …ing the standard model of particle …$^+ \rightarrow 0^+ \beta$ decay between $T = 1$ …ly on the vector part of the weak … to the conserved vector current …imental ft value is related to the …, a fundamental constant that is …

the statistical rate function, f, whereas the half-life and the branching ratio yield the partial half-life, t.

The aim of the present piece of work is to measure the half-life of ^{42}Ti and the decay Q value with a precision close to or better than 0.1%. In addition, the branching ratio for the superallowed decay is measured with less precision. ^{42}Ti decays by superallowed β^+ emission to its isobaric analog state ($J^\pi = 0^+$, $T = 1$), the ground state of ^{42}Sc. Before the measurement reported here, the accepted value for the half-life …

PRL **105**, 202501 (2010) Selected for a Viewpoint in *Physics* PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010

Reactor Decay Heat in ^{239}Pu: Solving the γ Discrepancy in the 4–3000-s Cooling Period

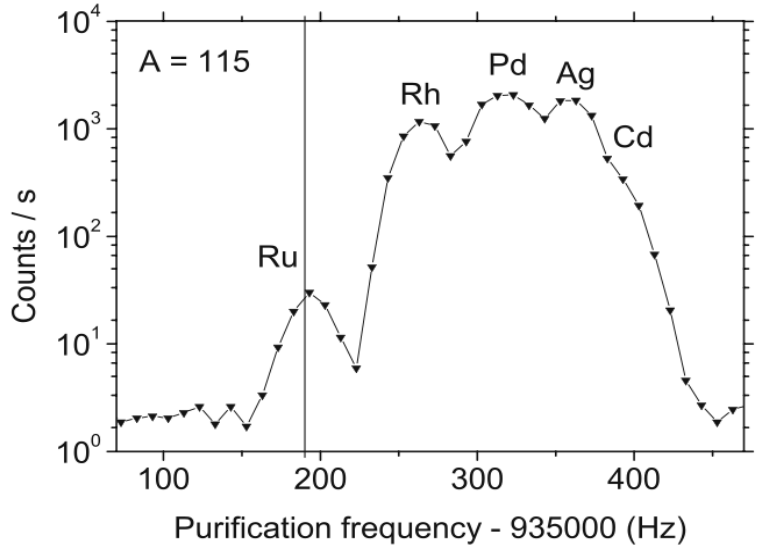
A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äysto,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] A. Nieminen,[3] J. Hakala,[3] P. Karvonen,[3] A. Kankainen,[3] A. Saastamoinen,[3] J. Rissanen,[3] T. Kessler,[3] C. Weber,[3] J. Ronkainen,[3] S. Rahaman,[3] V. Elomaa,[3] S. Rinta-Antila,[3] U. Hager,[3] T. Sonoda,[3] K. Burkard,[4] W. Hüller,[4] L. Batist,[5] W. Gelletly,[6] A.L. Nichols,[6] T. Yoshida,[7] A.A. Sonzogni,[8] and K. Peräjärvi[9]
[1]IFIC (CSIC-Univ. Valencia), Valencia, Spain
[2]Institute of Nuclear Research, Debrecen, Hungary
[3]University of Jyväskylä, Jyväskylä, Finland
[4]GSI, Darmstadt, Germany
[5]PNPI, Gatchina, Russia
[6]University of Surrey, Guildford, United Kingdom
[7]Tokyo City University, Setagaya-ku, Tokyo, Japan
[8]NNDC, Brookhaven National Laboratory, Upton, New York, USA
[9]STUK, Helsinki, Finland

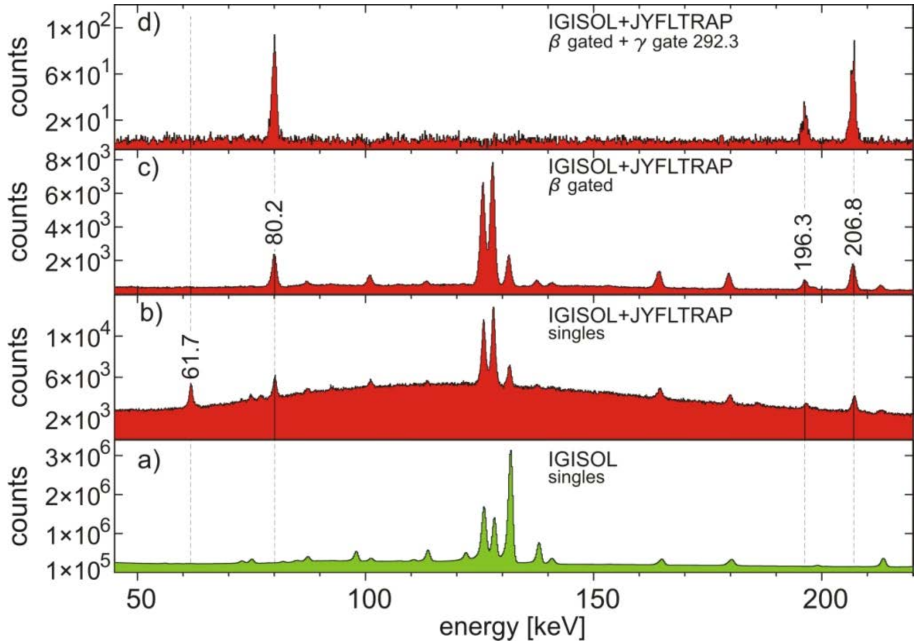
(Received 13 May 2010; published 8 November 2010)

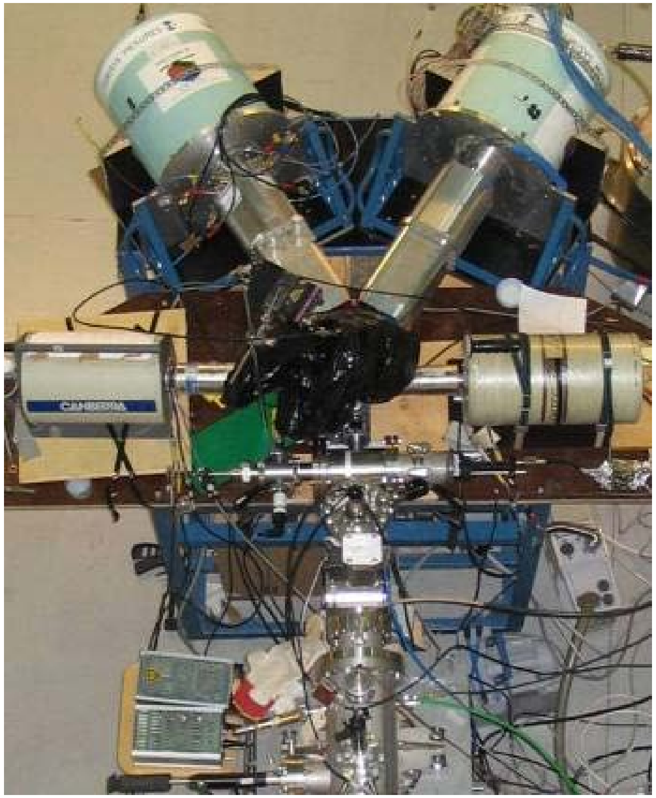
The β feeding probability of ^{102,104,105,106,107}Tc, ^{105}Mo, and ^{101}Nb nuclei, which are important contributors to the decay heat in nuclear reactors, has been measured using the total absorption technique. We have coupled for the first time a total absorption spectrometer to a Penning trap in order to obtain sources of very high isobaric purity. Our results solve a significant part of a long-standing discrepancy in the γ component of the decay heat for ^{239}Pu in the 4–3000 s range.

DOI: 10.1103/PhysRevLett.105.202501 PACS numbers: 23.40.−s, 27.60.+j, 28.41.Fr, 29.30.Kv

Example: Purification in A=115



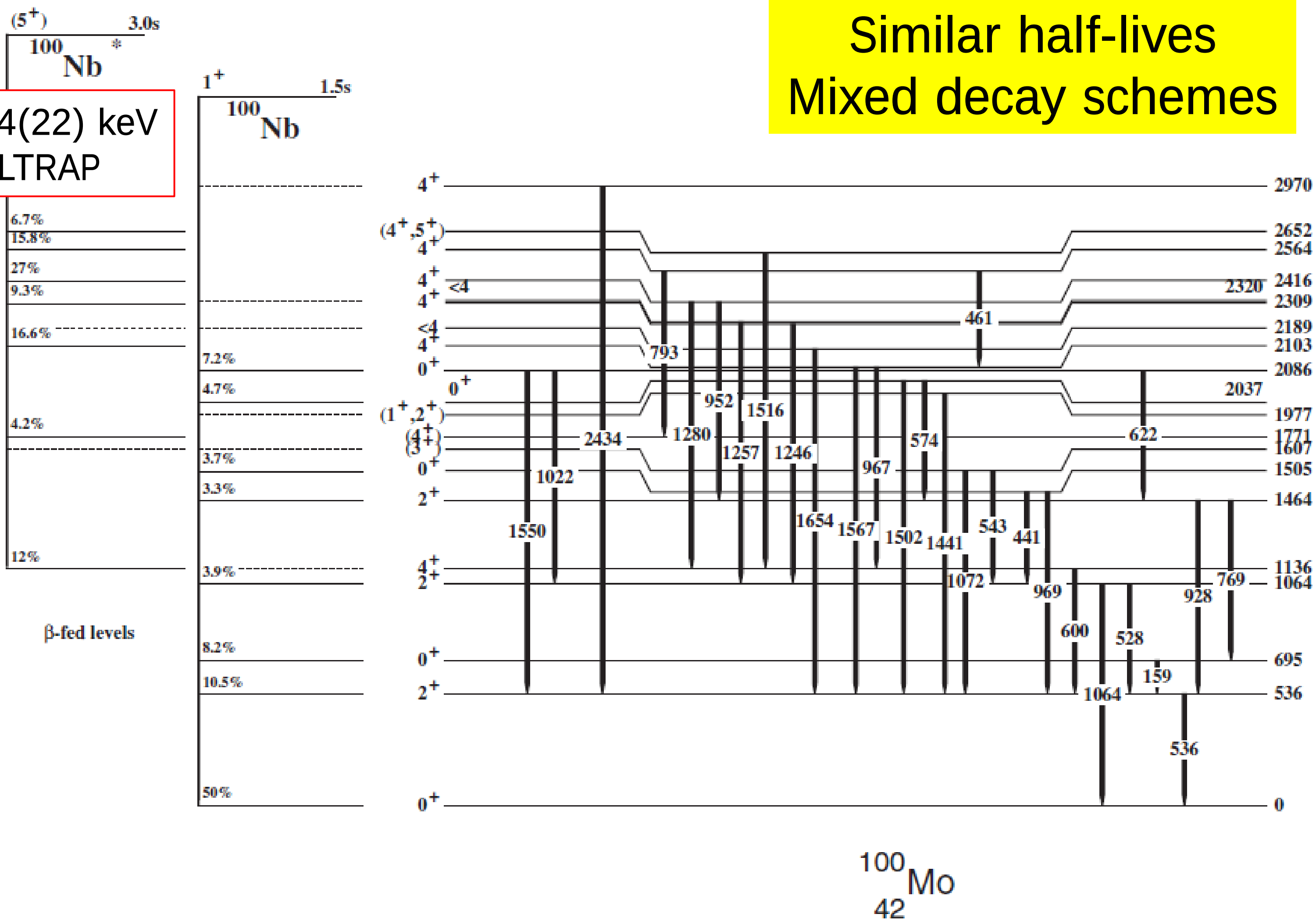




Isomer separation - Decay study of ^{100}Nb

Similar half-lives
Mixed decay schemes

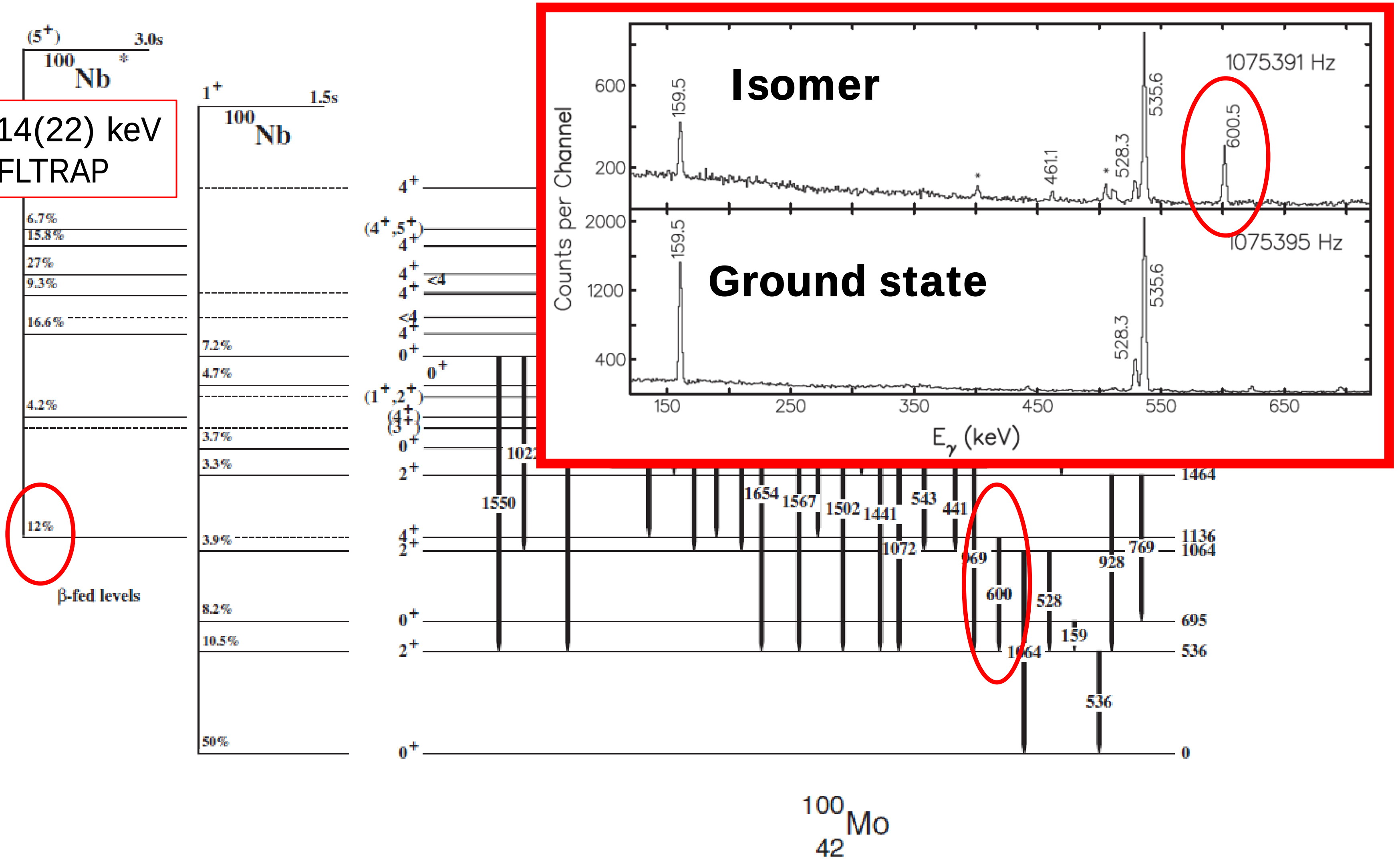
ΔE=314(22) keV
JYFLTRAP



C. Rodríguez Triguero et al., J. Phys. G: Nucl. Part. Phys. 39 (2012) 015101

Isomer separation - Decay study of ^{100}Nb

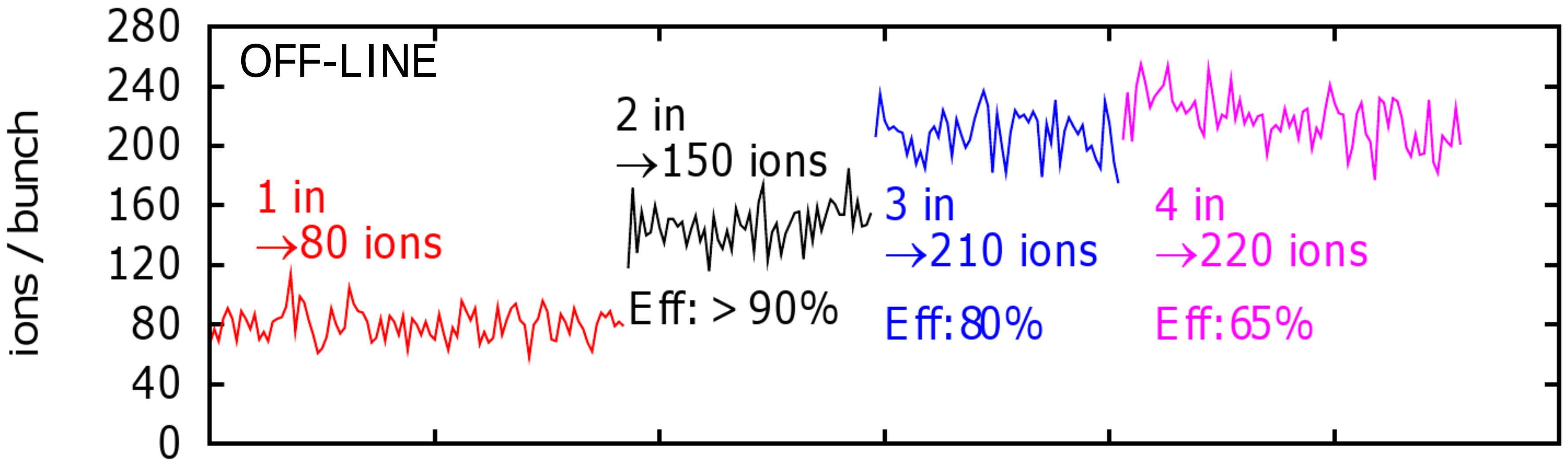
ΔE=314(22) keV
JYFLTRAP



C. Rodríguez Triguero et al., J. Phys. G: Nucl. Part. Phys. 39 (2012) 015101

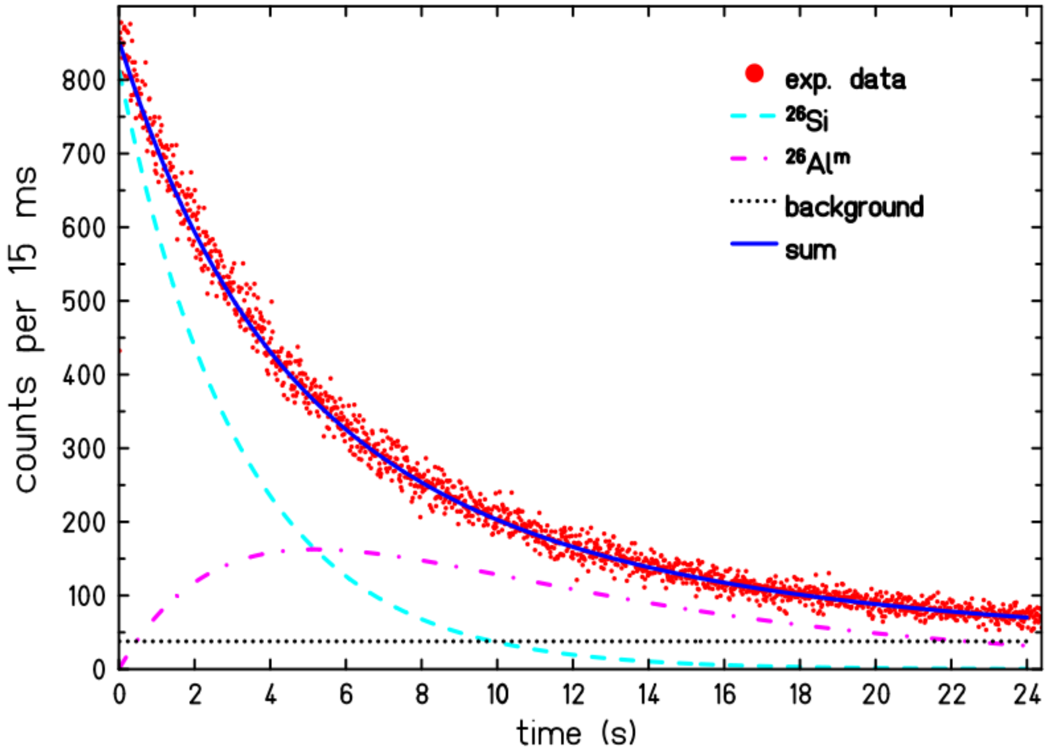
Multiple loading

Repeated cleaning and mixing with a new ion cloud
→ increase of ions of interest in each cycle



Multiple loading: Ex. $T_{1/2}(^{26}Si)$

- Beta counting -> requires a clean sample
- Measurement cycle requires 25 s decay period
- Accumulation in RFQ, bunches sent to purification trap
- Purification trap saturates in 300 ms -> use multiple loading
- In 25 s 8 cycles and 6-7 times more ^{26}Si than in single loading

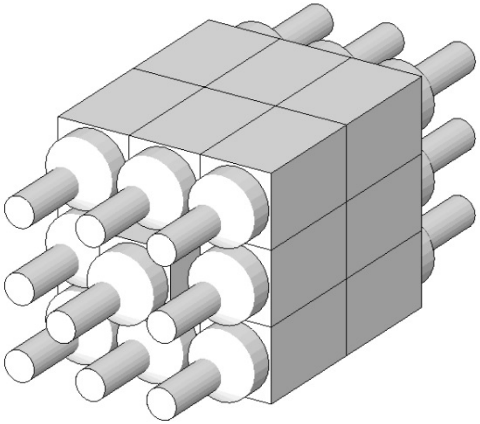


$t_{1/2} = 2228.3(27)$ ms

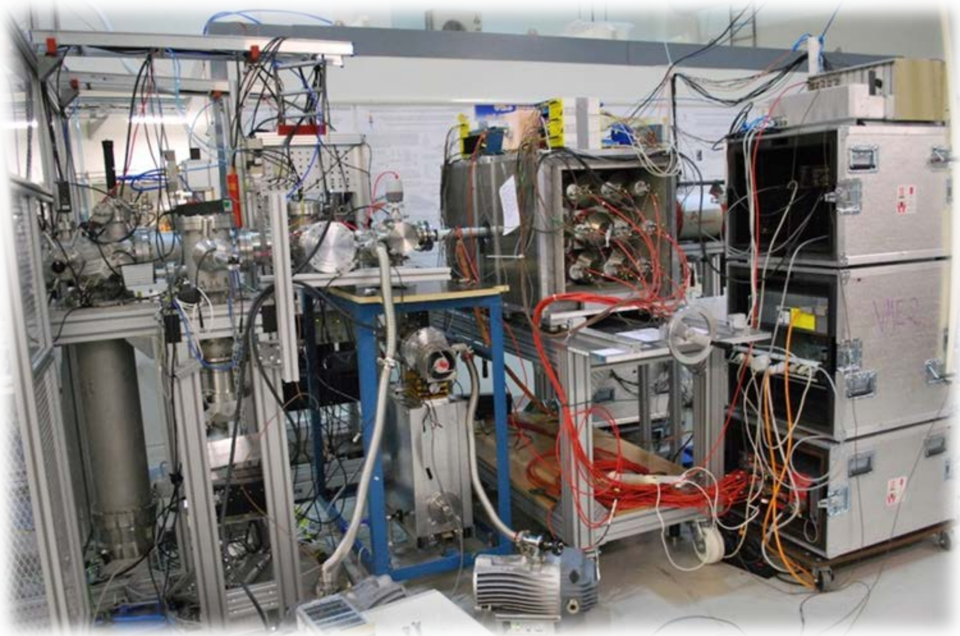
^{26}Si, EPJ A 37 (2008) 151
^{42}Ti, PRC 80 (2009) 035502
^{30}S, EPJ A 47 (2010) 40
^{31}S, EPJ A 48 (2012) 155

A new era of post-trap spectroscopy: DTAS detector for DESPEC at IGISOL-4

- **16 (+2) NaI(Tl) modules**
- **5” PMT (50% light collection)**
- **Commissioning Valencia (Jan/2014)**
- **IGISOL-4 run (Feb-Mar/2014)**



- JYFLTRAP provides high purity beams
- Measurements of beta decay strength of ^{100}Tc
- 18 nuclei relevant for precise predictions of neutrino spectra from reactors (8 days)



IGISOL - 4

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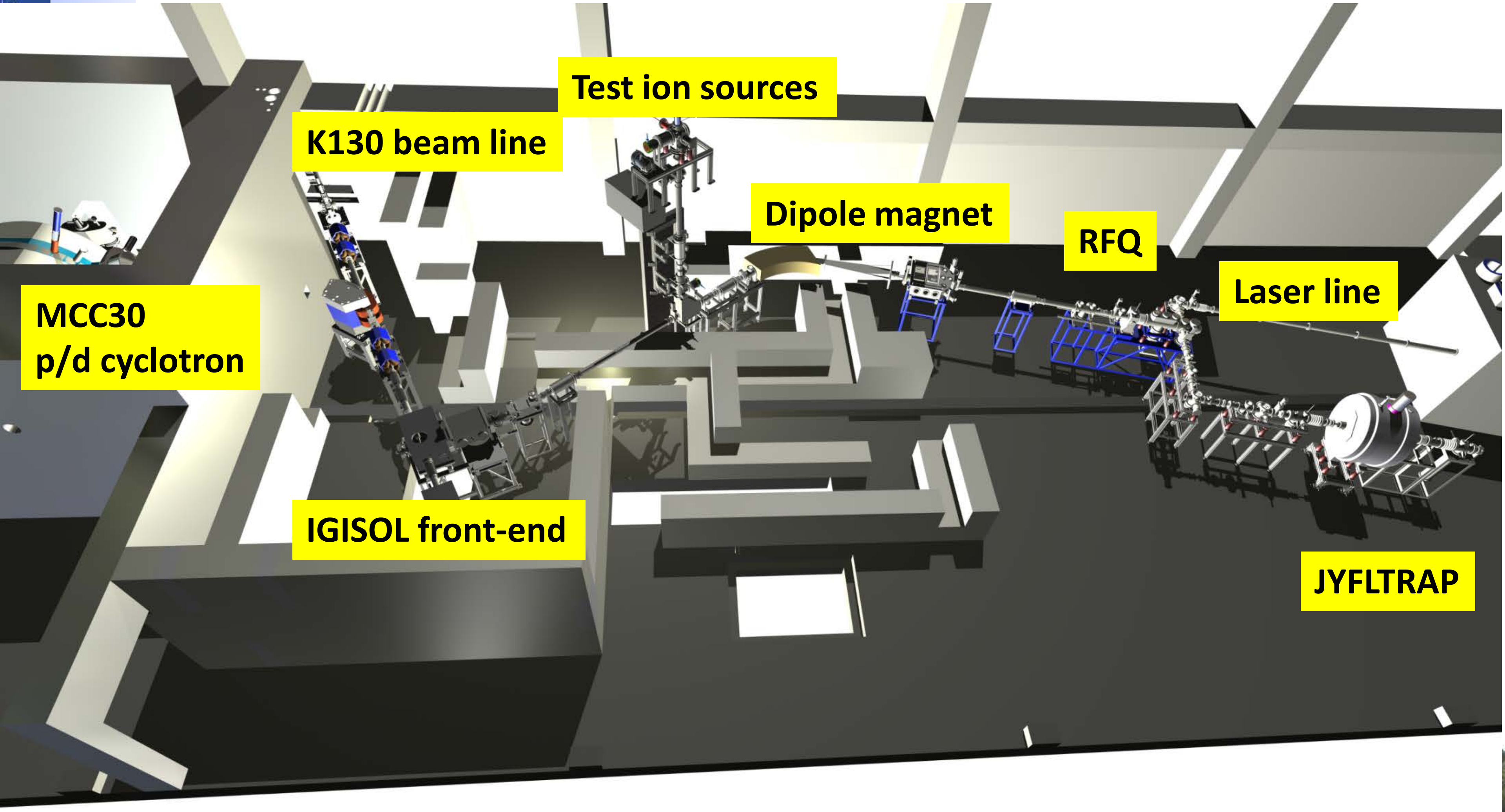


Summary

PT mass measurements have contributed to:

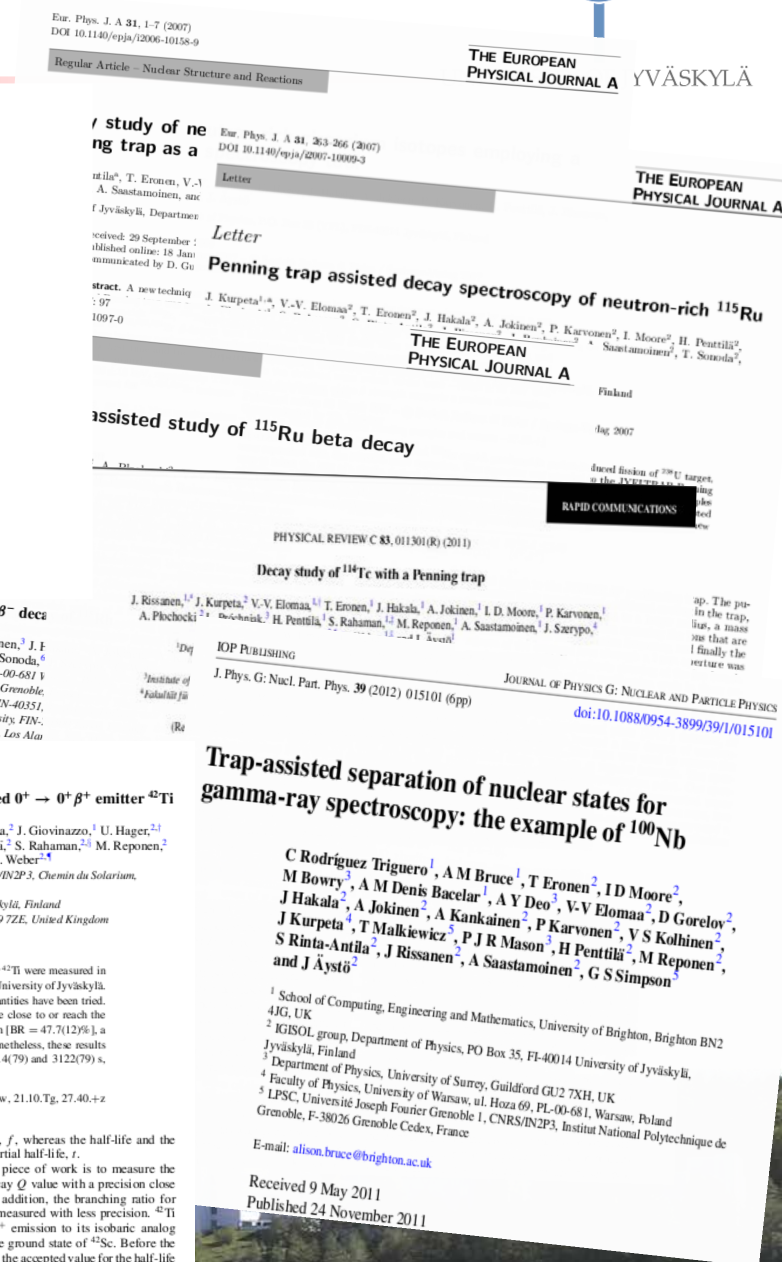
- Better understanding of the binding of exotic nuclei
- Nuclear structure information
  - Shell evolution, shape changes, new regions of deformation, pairing
  - Single-particle energies
- CVC hypothesis and the unitarity of CKM
- Rare decays (Xth-forbidden beta decays, ββ, ECEC,)
- Nuclear astrophysics
- Applications, etc

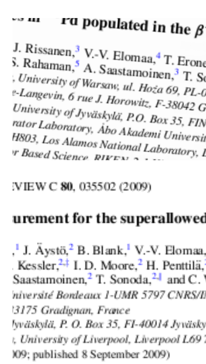
Trap-assisted spectroscopy

- has improved the spectroscopic sensitivity
- Improved the quality of the data

Outlook

- Complementary: rings, MR-TOF, ...
- Laser techniques
- Faciility upgrades





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THANK YOU FOR YOUR ATTENTION !