Ion trap program at IGISOL

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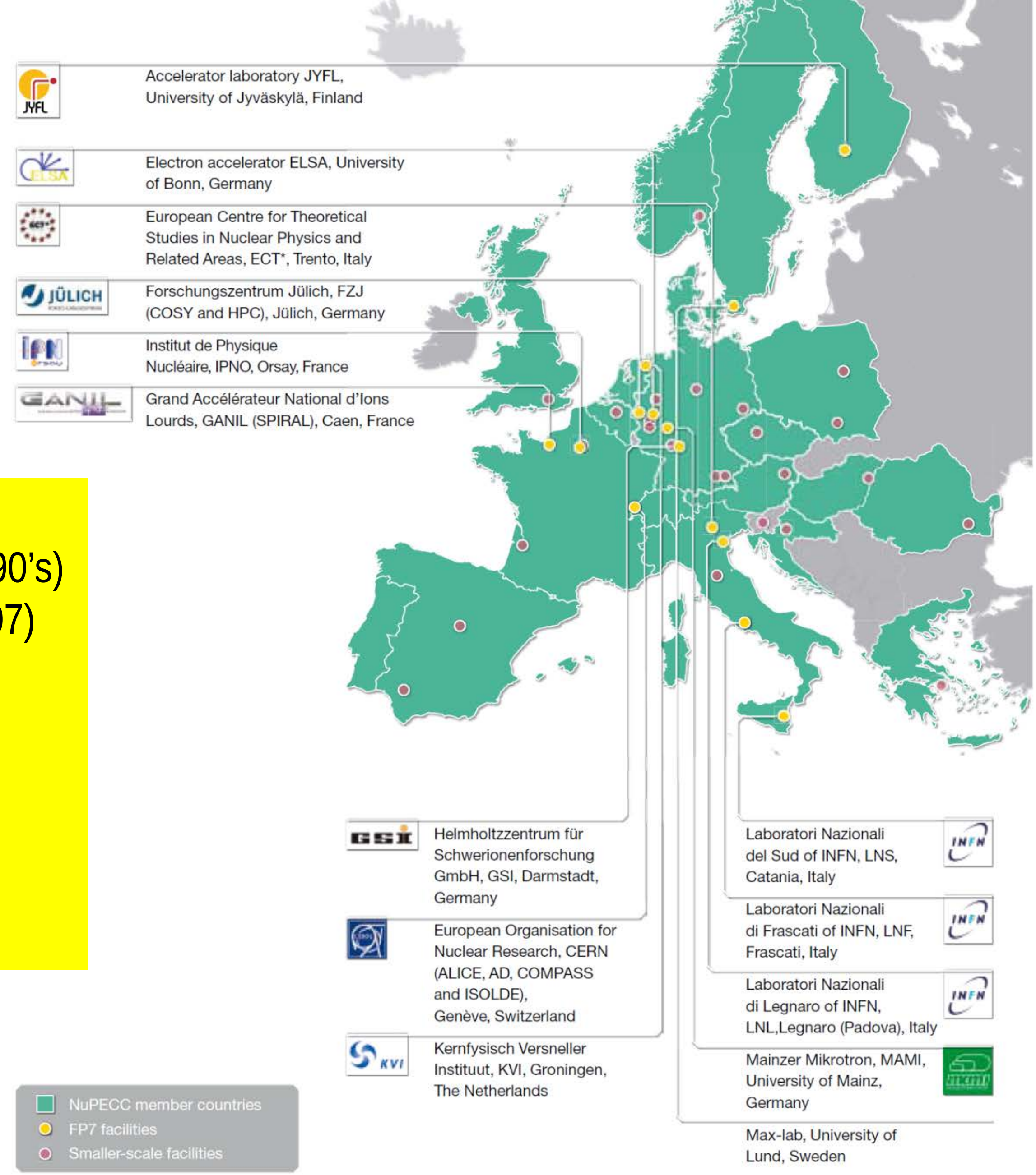
Department of Physics

UNIVERSITY OF JYVÄSKYLÄ

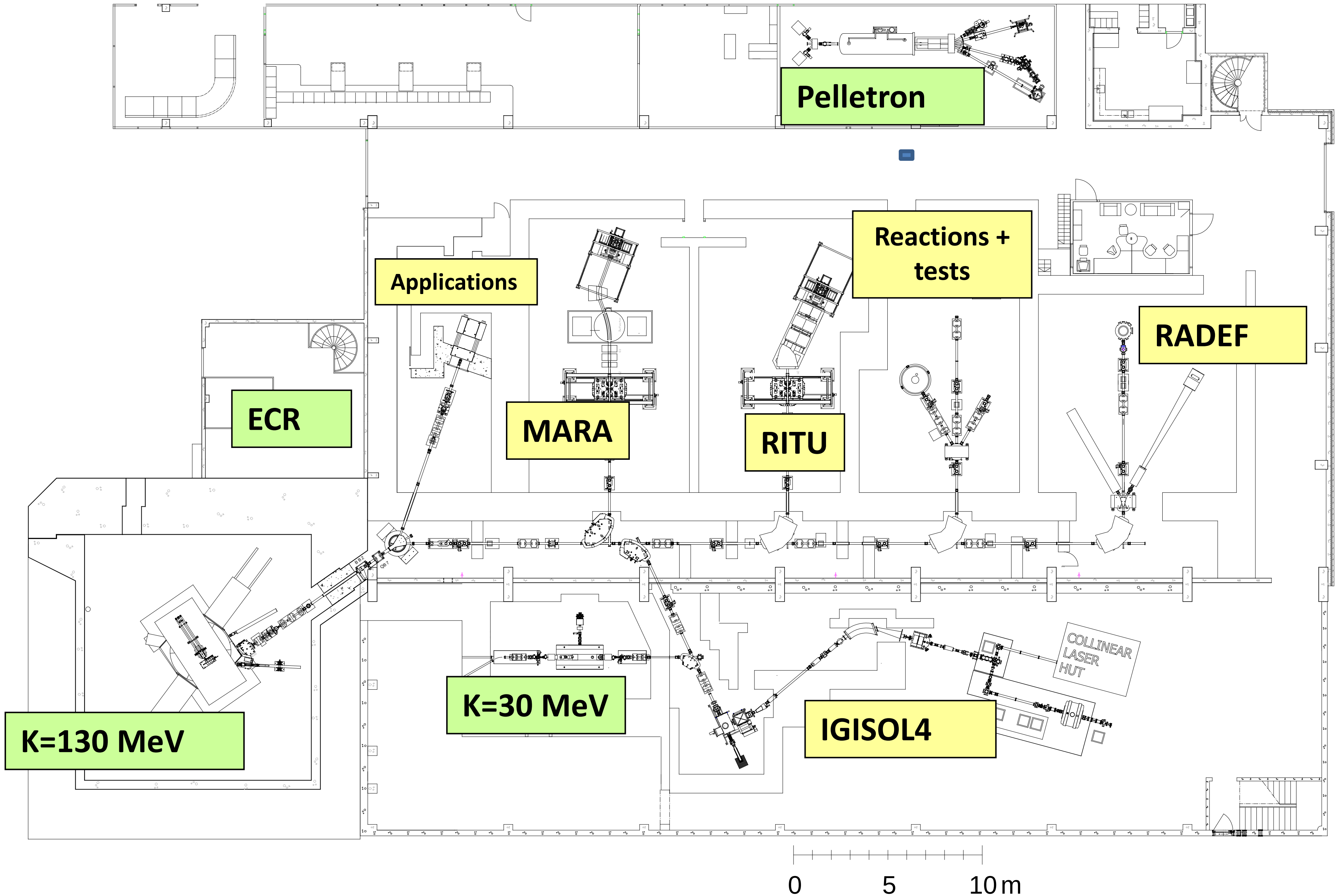
Accelerator Laboratory

NuPECC Long Range plan 2010

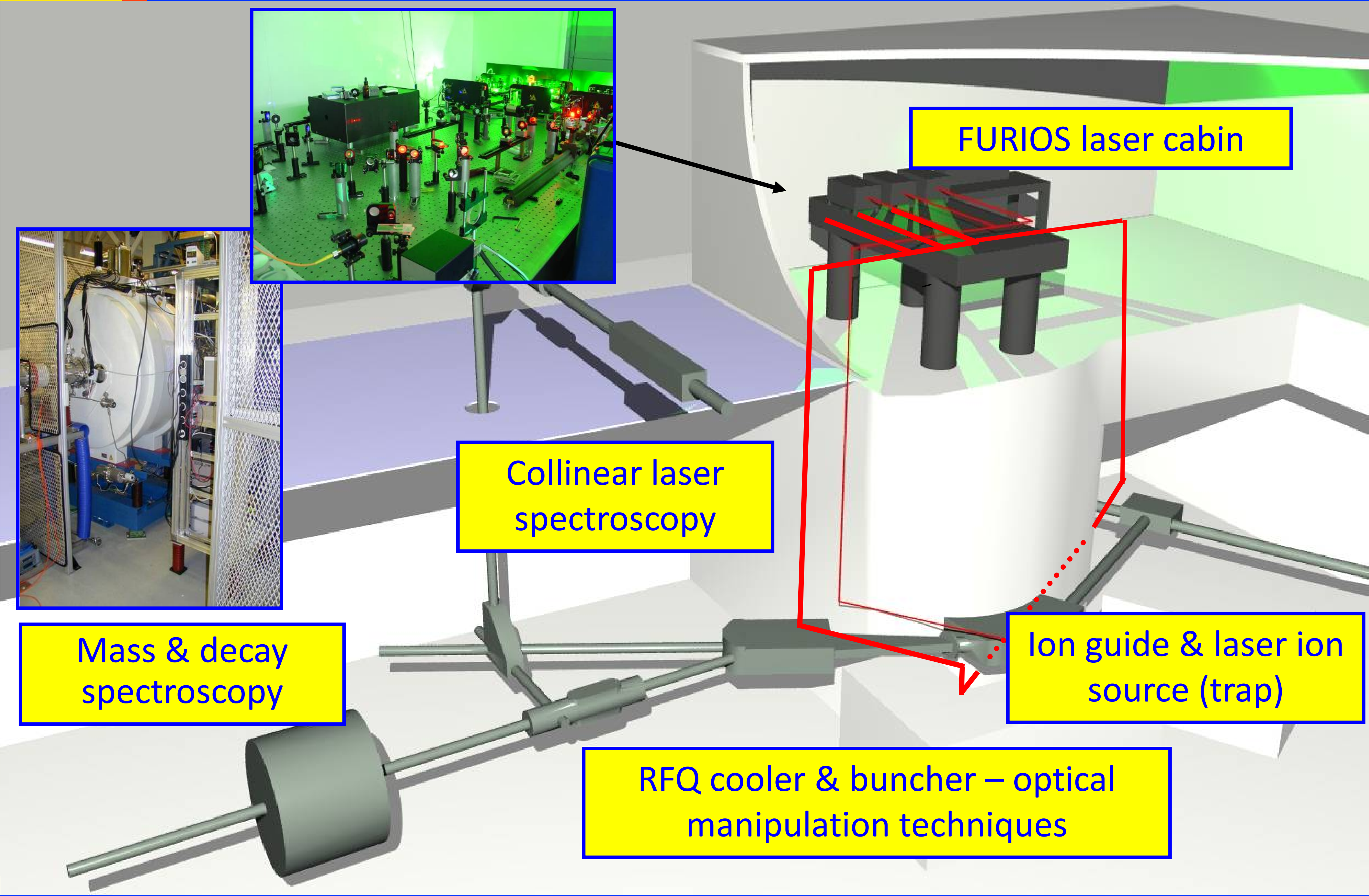


- Three accelerators:
  - K130: 6.4 &14 GHz ECR, H- source (early 90's)
  - 1.7 MV Pelletron with three ion sources (2007)
  - MCC30 p/d cyclotron (2009)
- Over 6000 beam time hours per year (K130)
- Over 200 users a year,
- EU- Access Laboratory
- One of the three ESA accredited test facilities
- Part of the Department of Physics

JYFL Accelerator Laboratory



IGISOL3: Spectroscopy of exotic isotopes of all elements

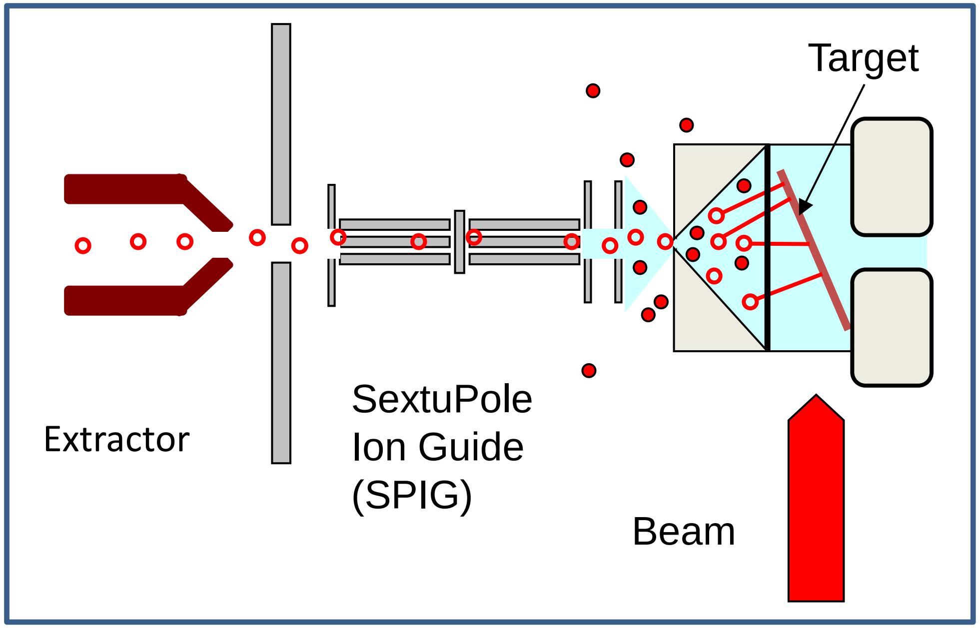


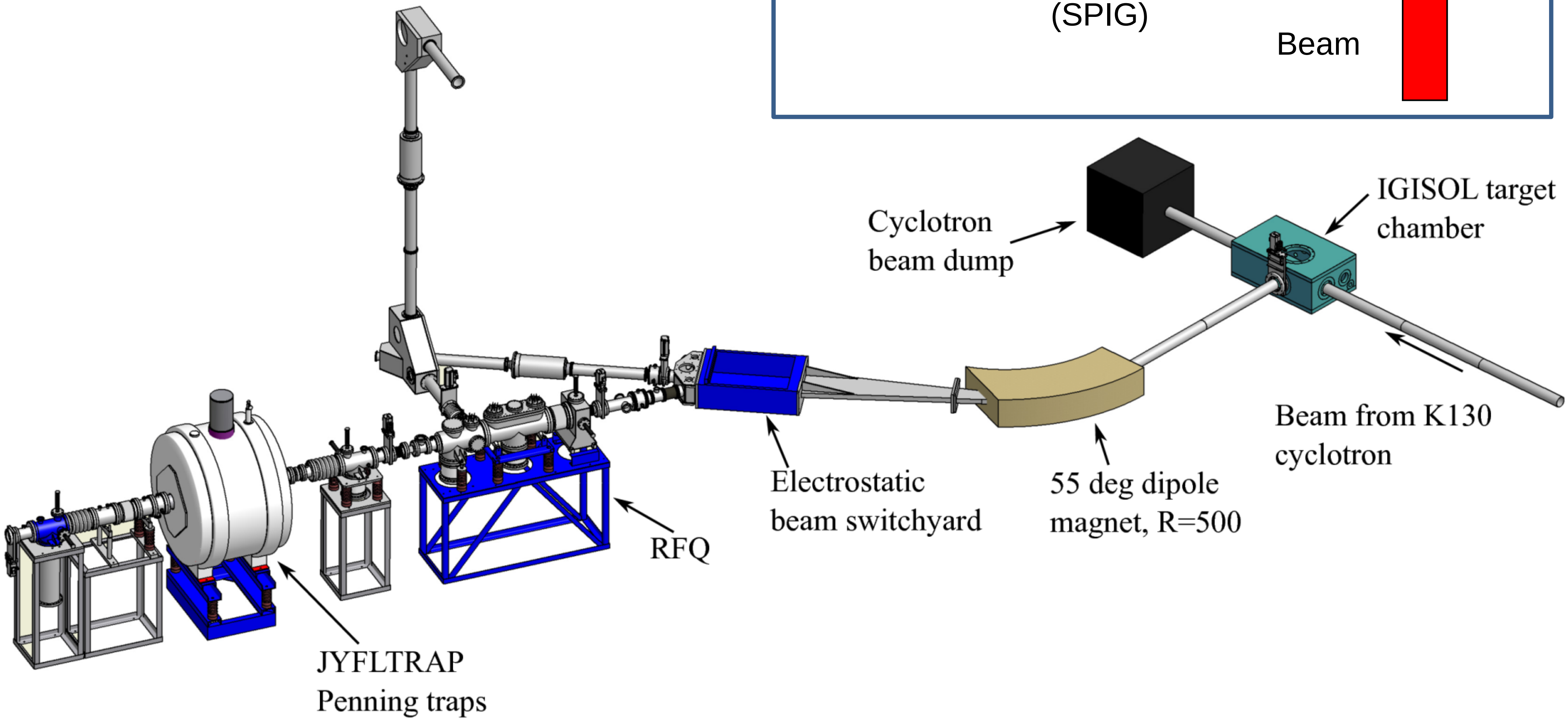
IGISOL technique

Ion guide technique

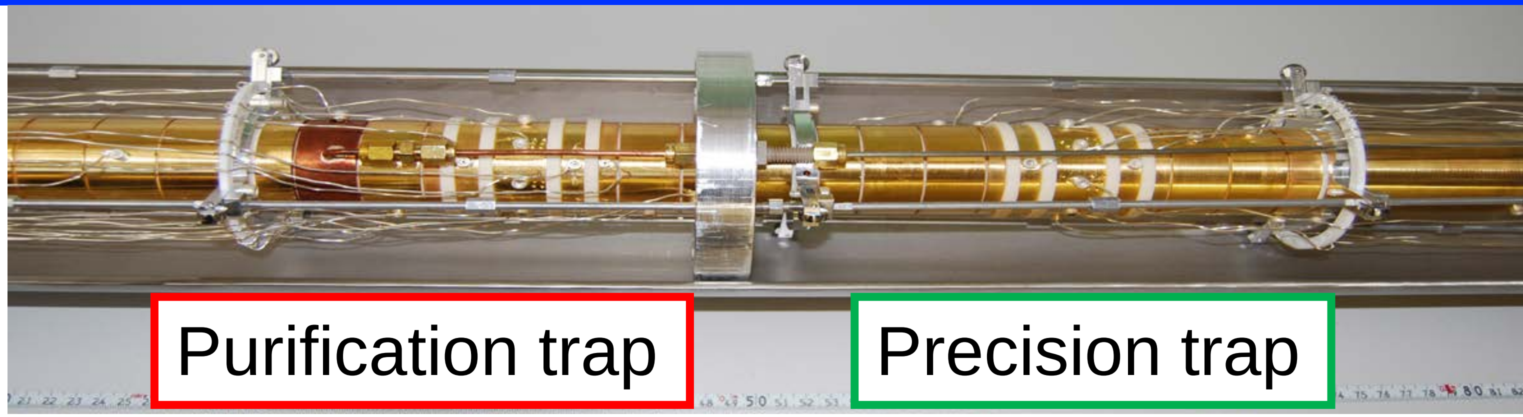
p + ^{238}U fission
Heavy and light ion fusion
Transfer reactions

Laser ionization



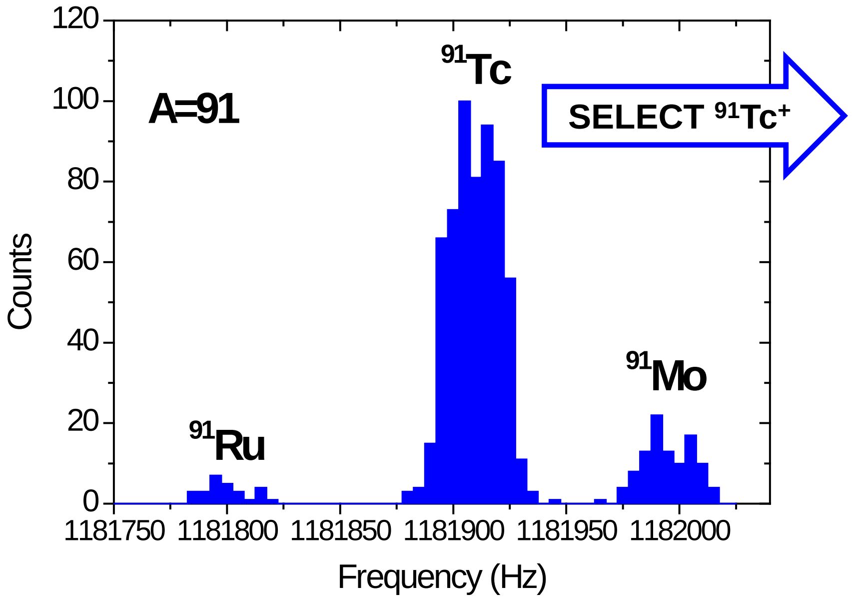


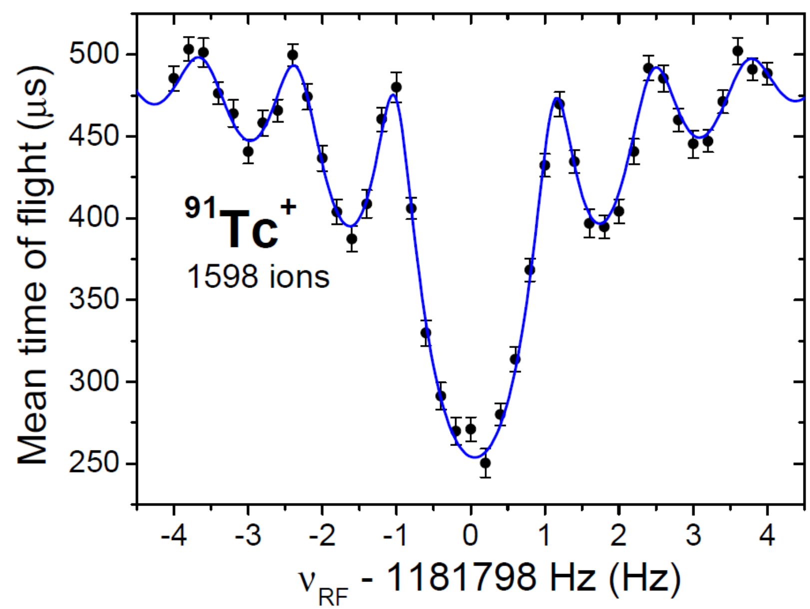
JYFLTRAP - tandem trap



mass-selective
buffer gas cooling

TOF-ICR method





Basic equations for mass determination

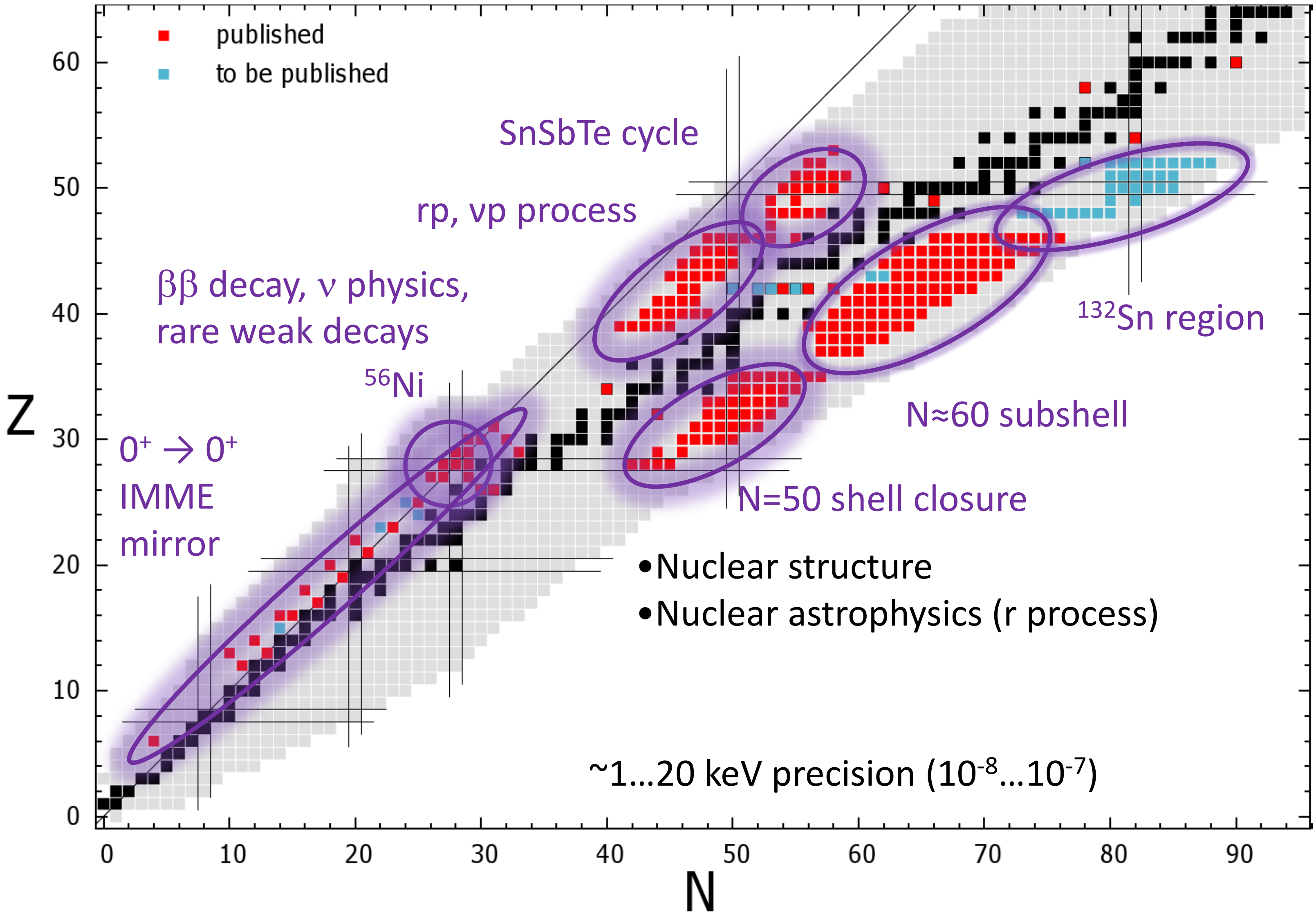
$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

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

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

Routinely few keV
If required few tens of eV (**$\delta m/m < 1\cdot 10^{-8}$**)

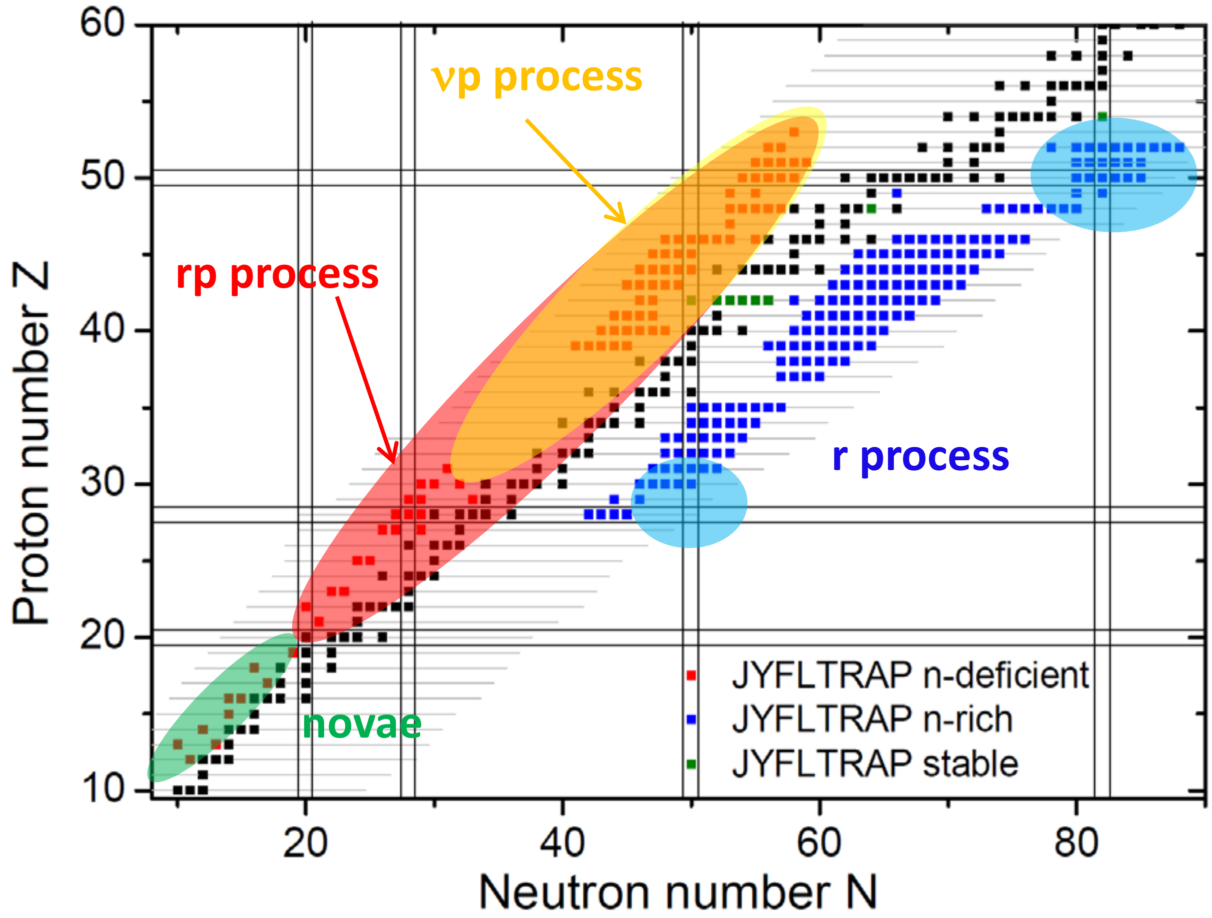
JYFLTRAP summary



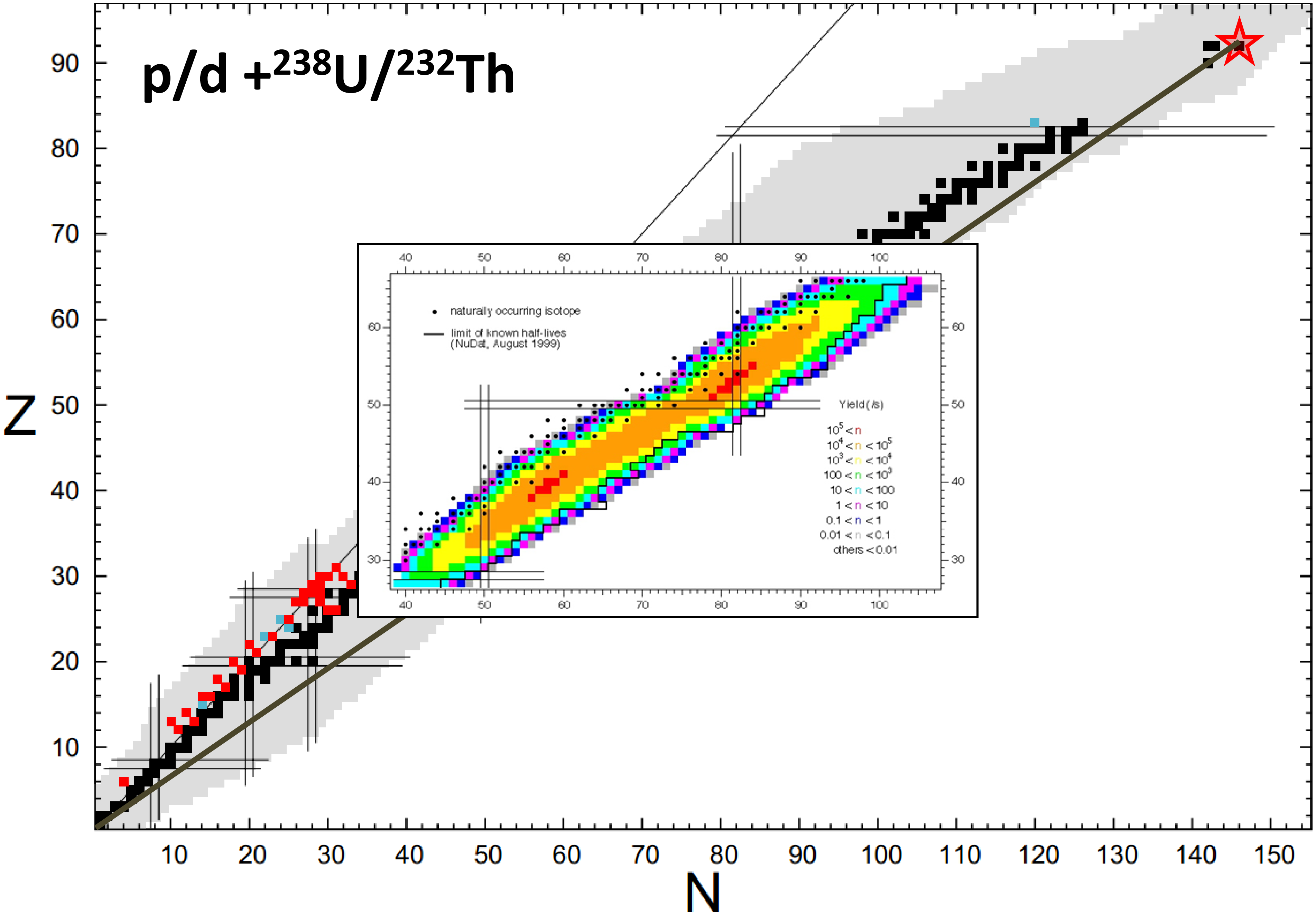
http://research.jyu.fi/igisol/JYFLTRAP_masses/

Nuclear astrophysics

Capture rates depend exponentially on Q-values → Need **accurate** masses → Reaction paths, Abundances, …



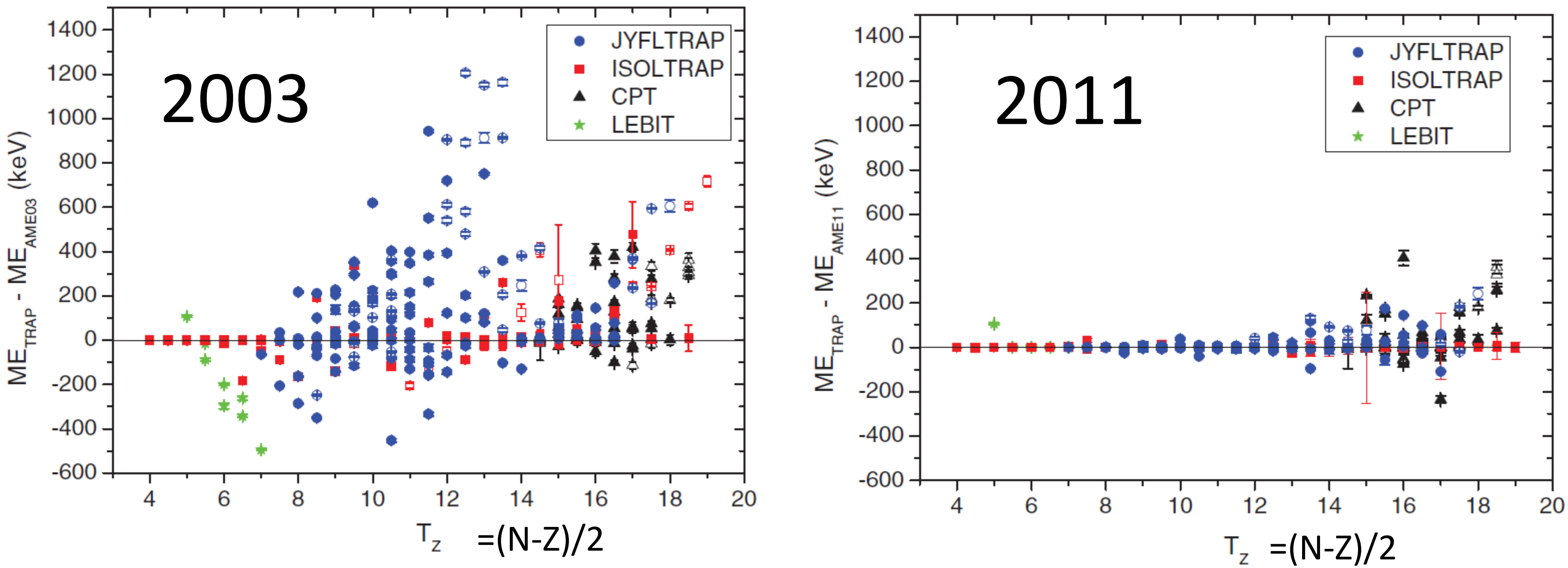
Production



p/d +^{238}U/^{232}Th
Z
N
naturally occurring isotope
limit of known half-lives (NuDat, August 1999)
Yield (/s)
$10^5 < n$
$10^4 < n < 10^5$
$10^3 < n < 10^4$
$100 < n < 10^3$
$10 < n < 100$
$1 < n < 10$
$0.1 < n < 1$
$0.01 < n < 0.1$
others < 0.01

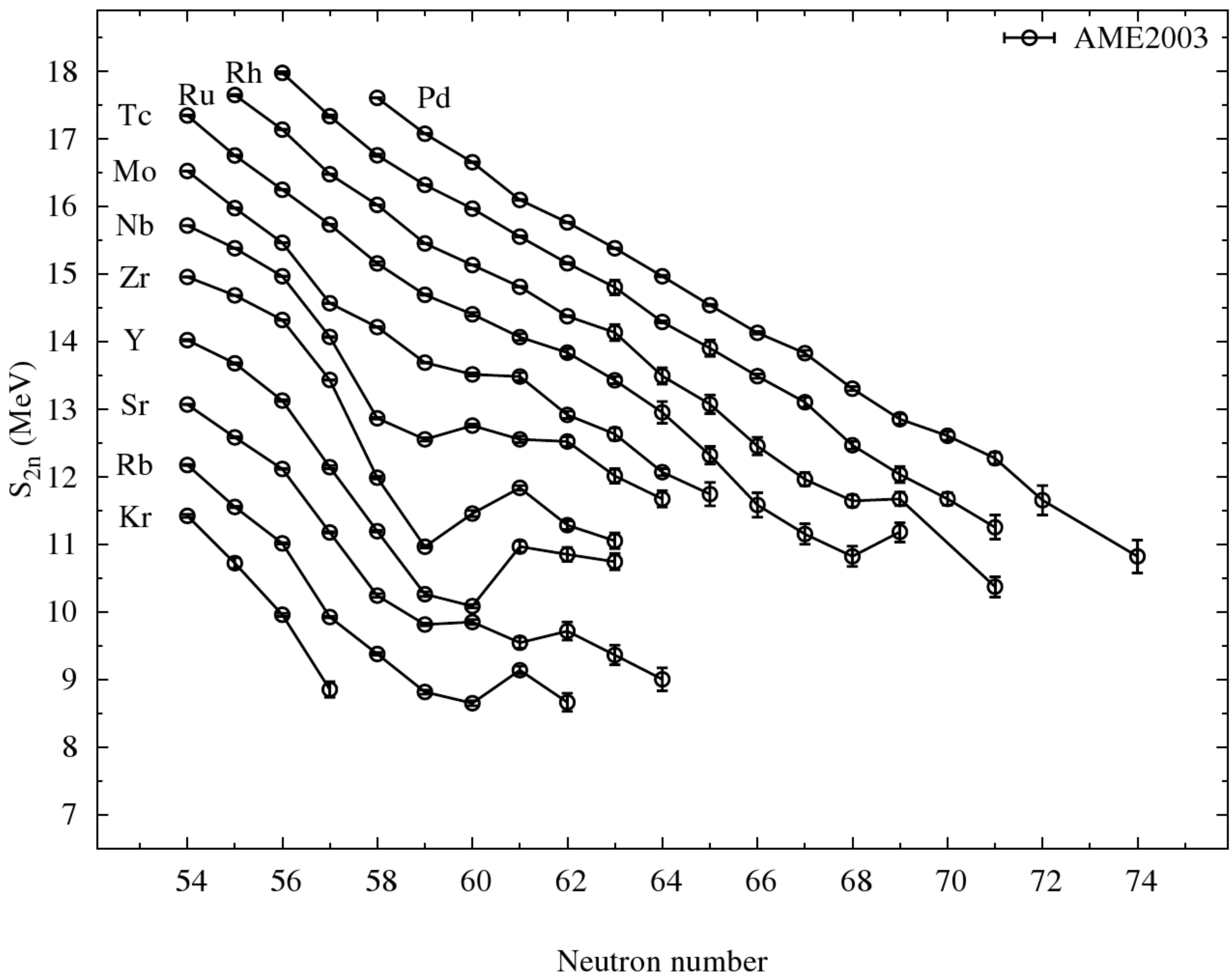
AME vs. PT data (n-rich nuclei)

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

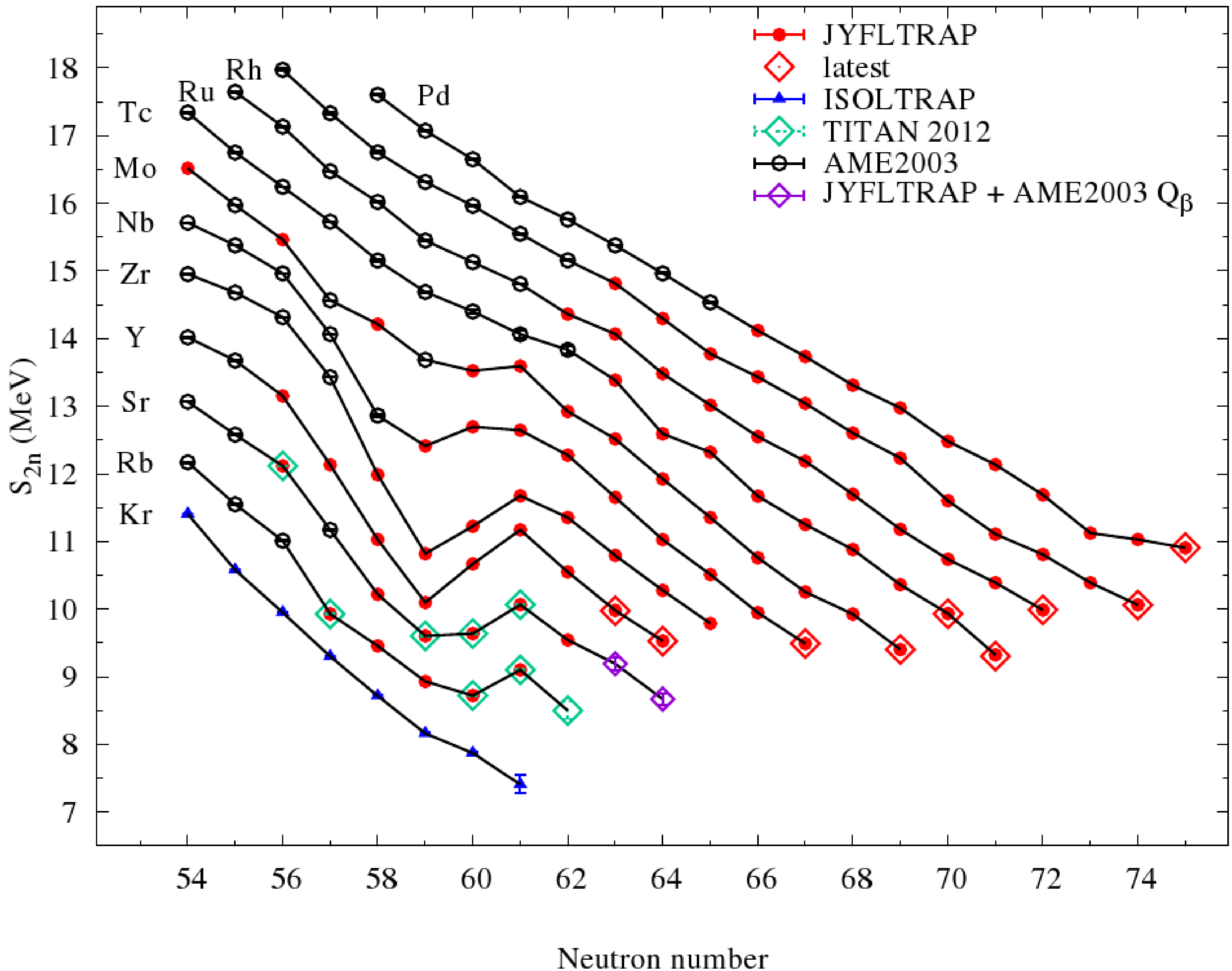


http://research.jyu.fi/igisol/JYFLTRAP_masses/

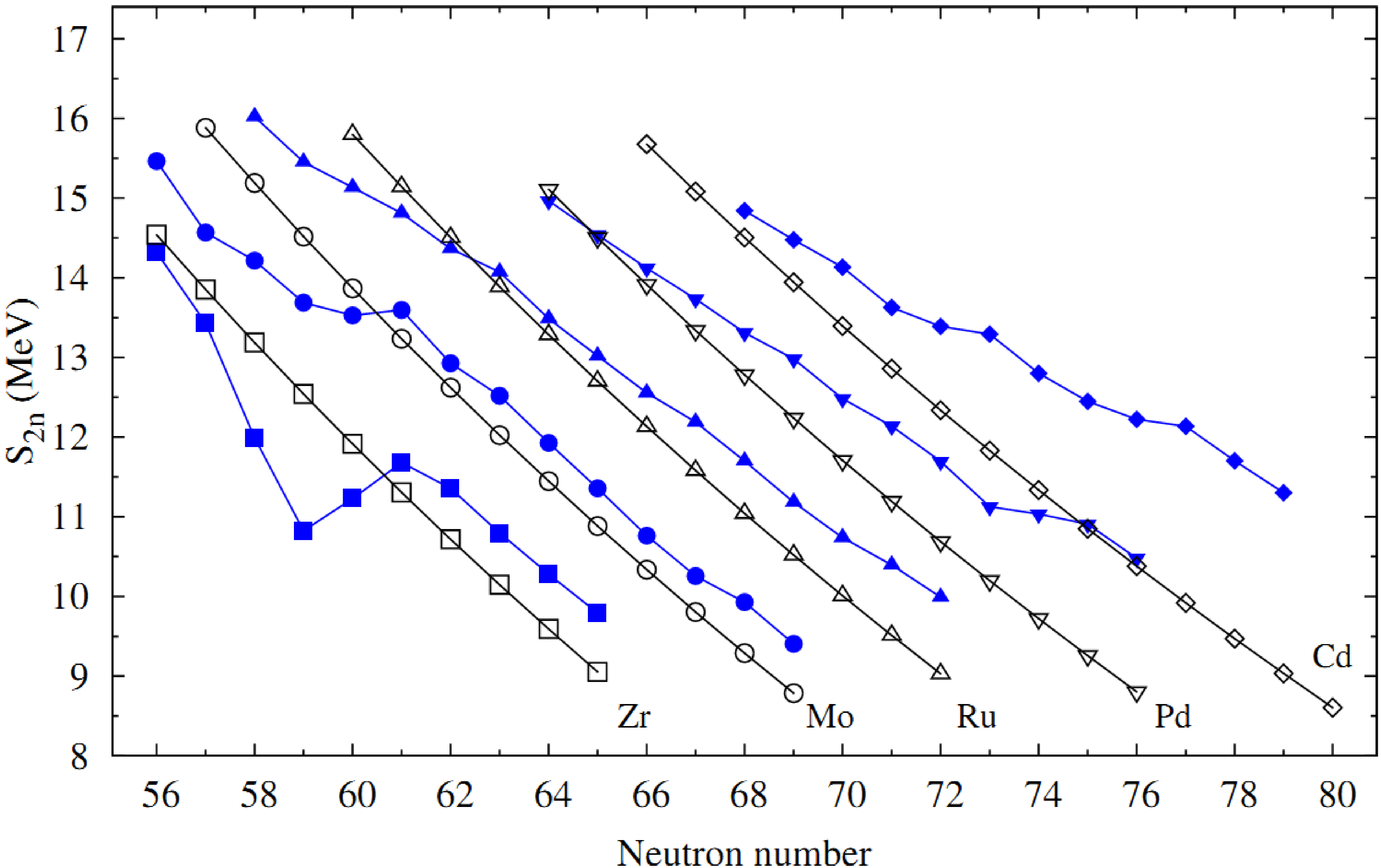
Two-neutron separation energies



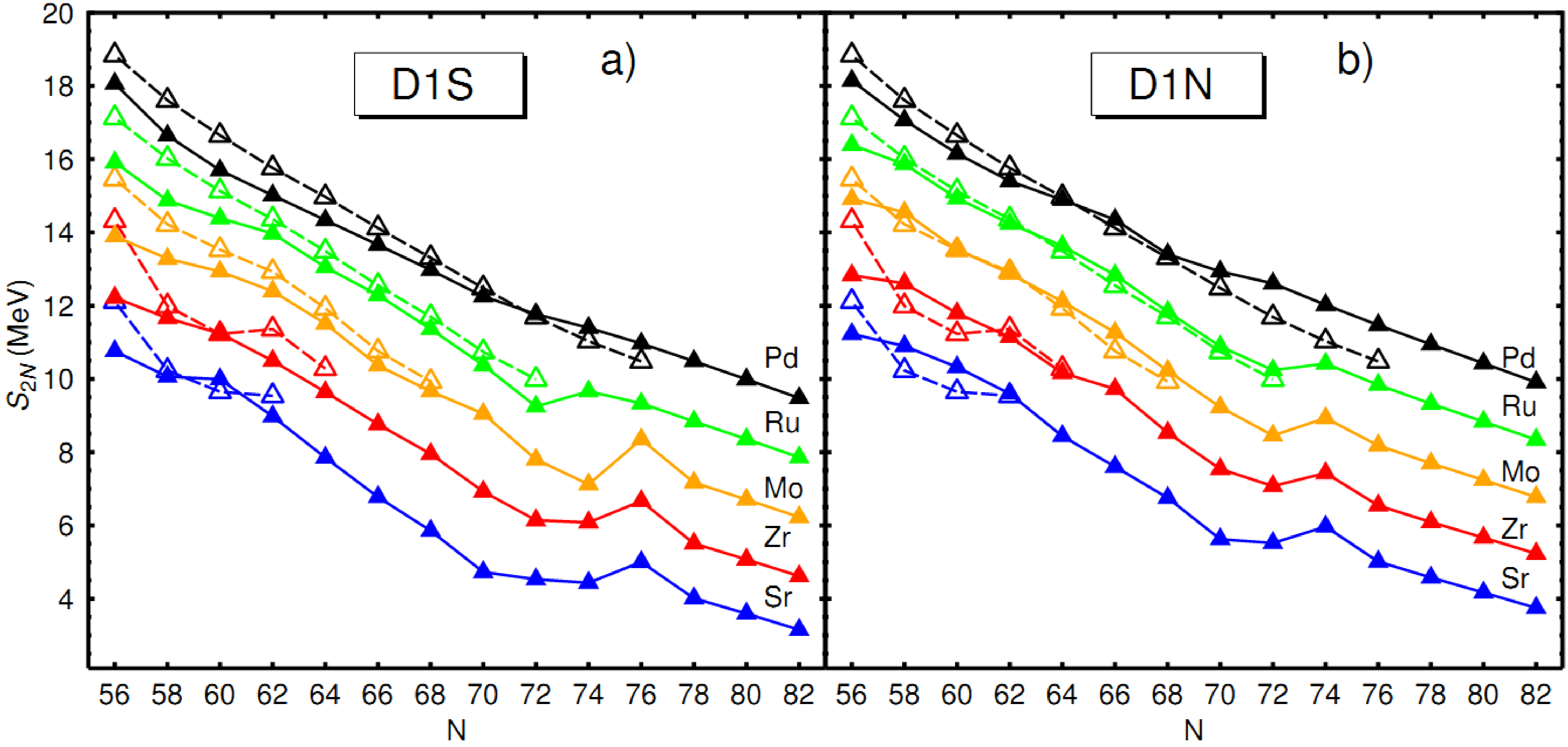
Two-neutron separation energies



Comparison to liquid drop model

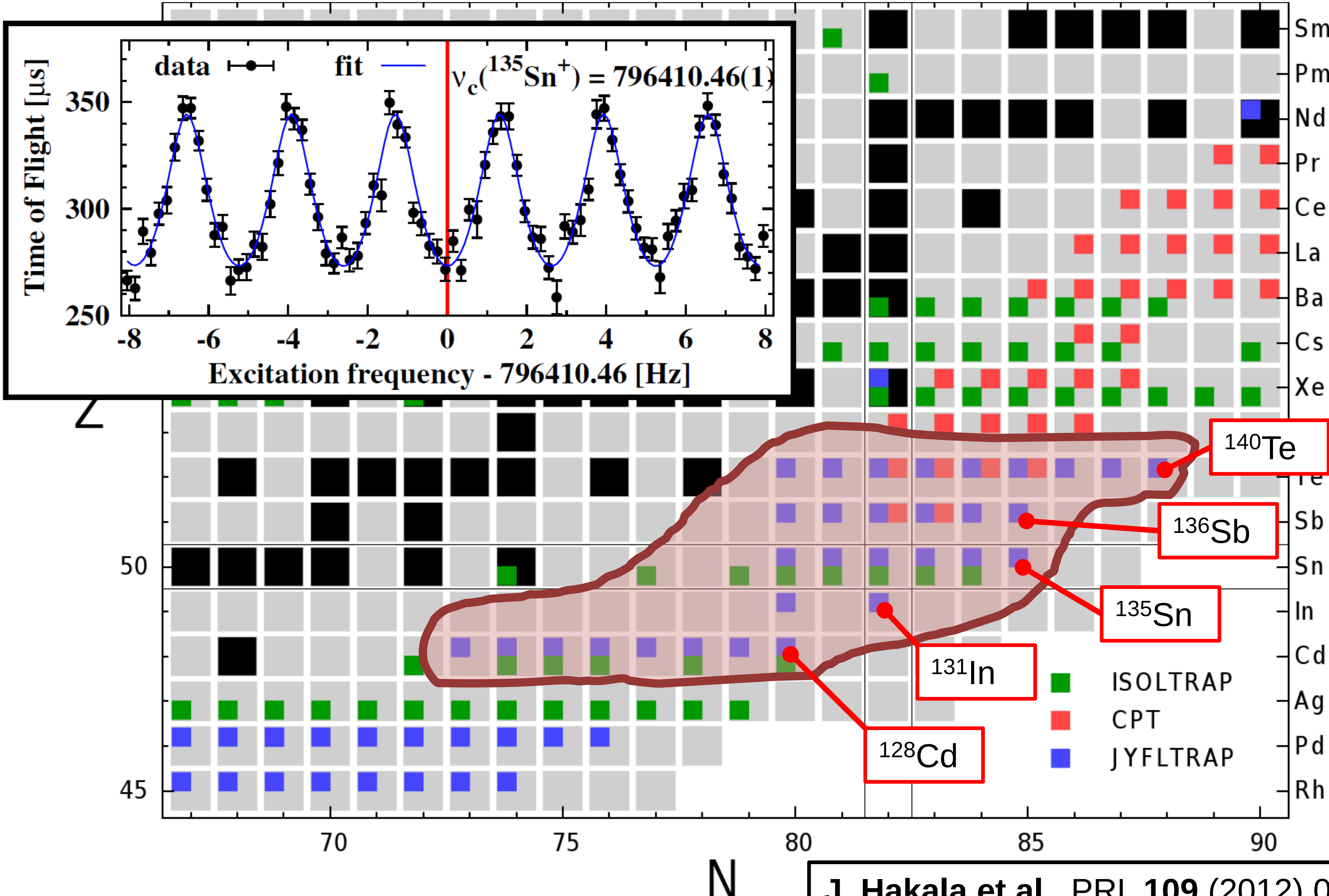


Cogny EDFs



J. Hakala, R. Rodriguez-Guzman et al., EPJA 47 (2011) 129

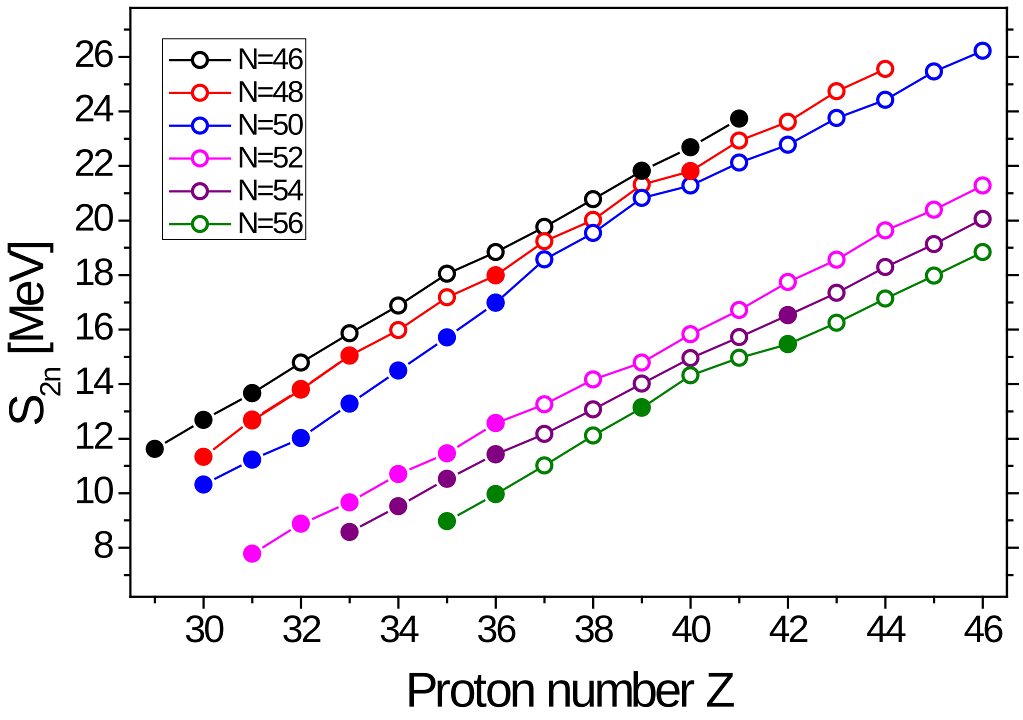
JYFLTRAP data in ^{132}Sn region



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

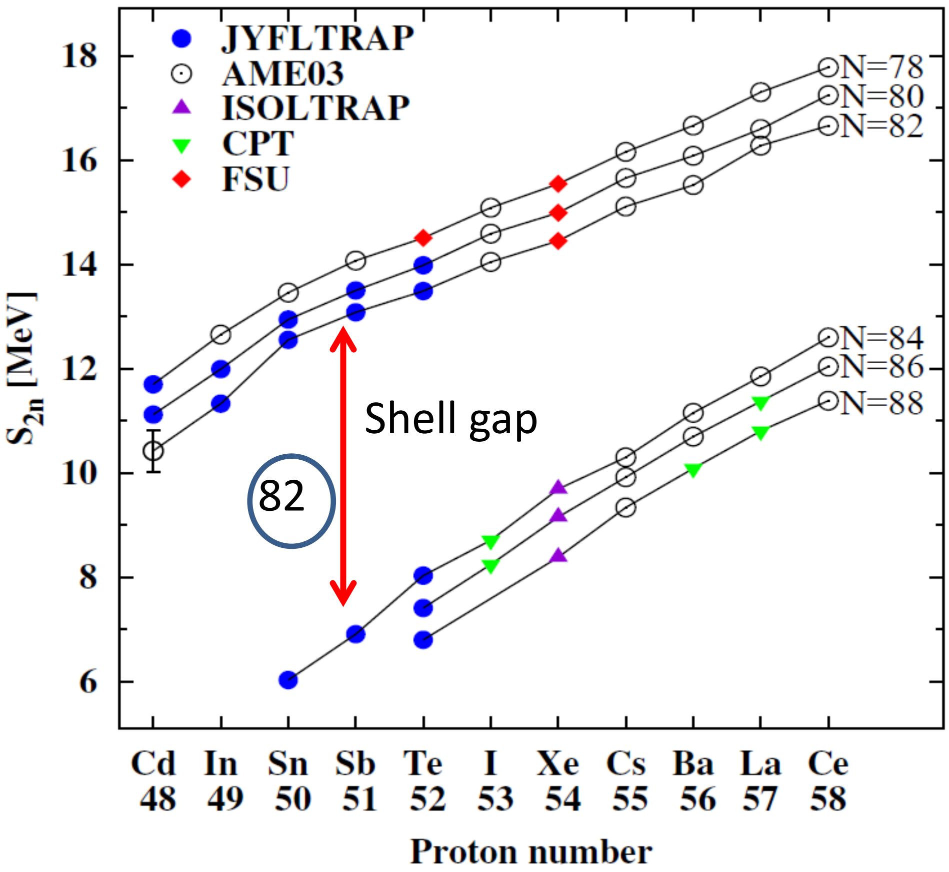
Shell gaps at N=50 and N=82

Two-neutron shell gap for N=50



J. Hakala et al., PRL **101** (2008) 052502

Two-neutron shell gap for N=82

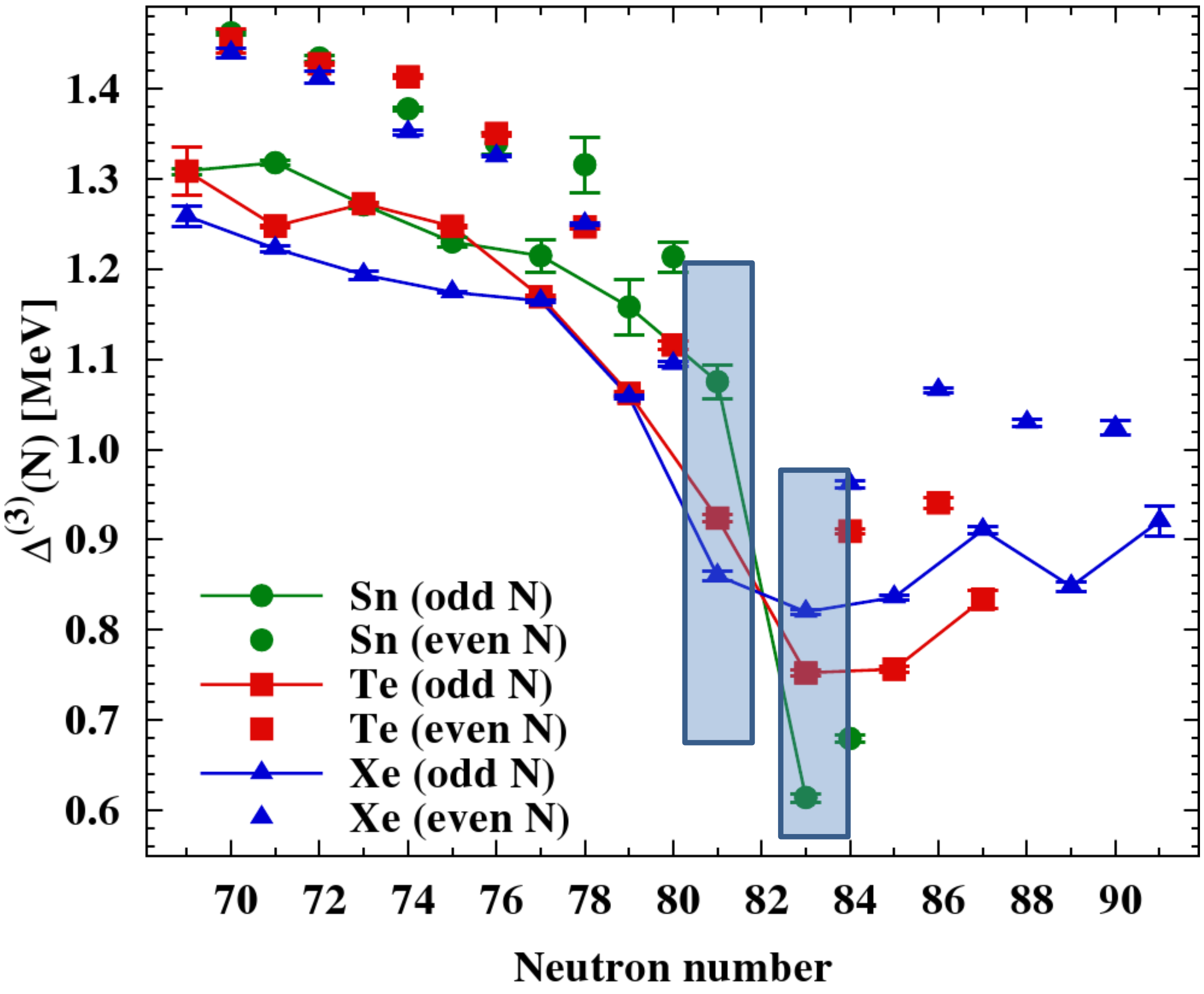


J. Hakala et al., PRL **109** (2012) 032501

Odd-even mass staggering;

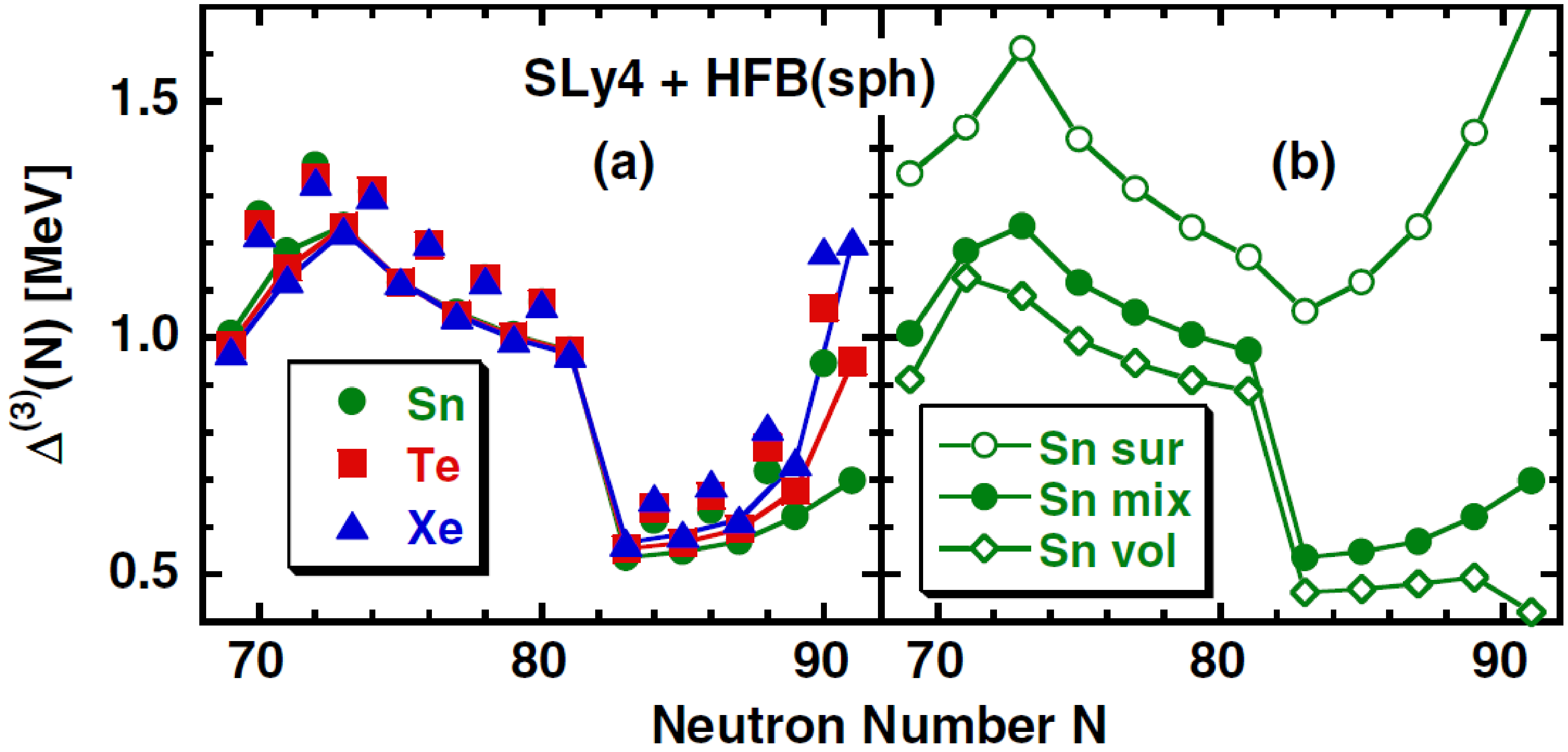
a measure of empirical pairing gap

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



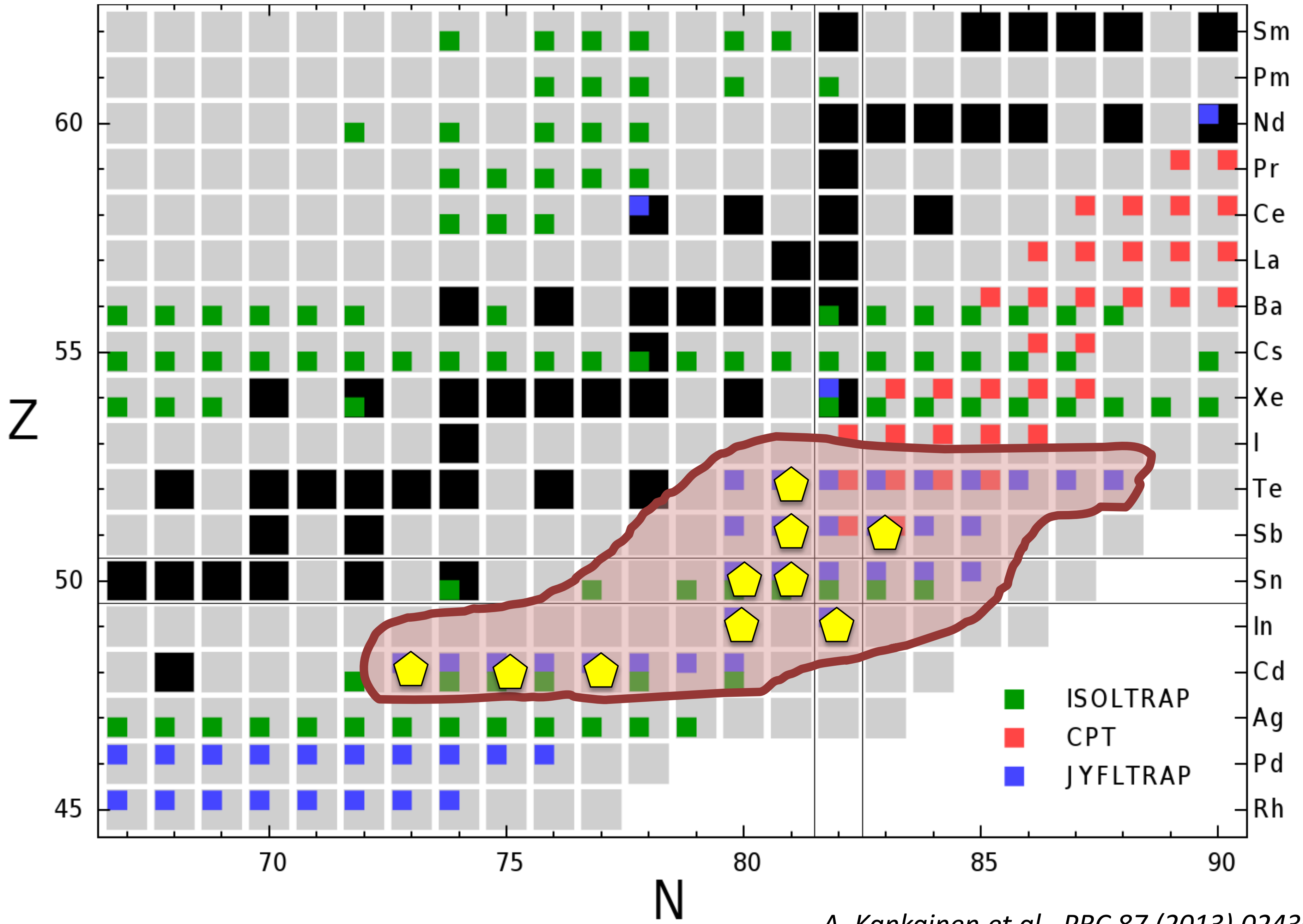
J. Hakala et al., PRL **109** (2012) 032501

Spherical EDF calculations around ^{132}Sn



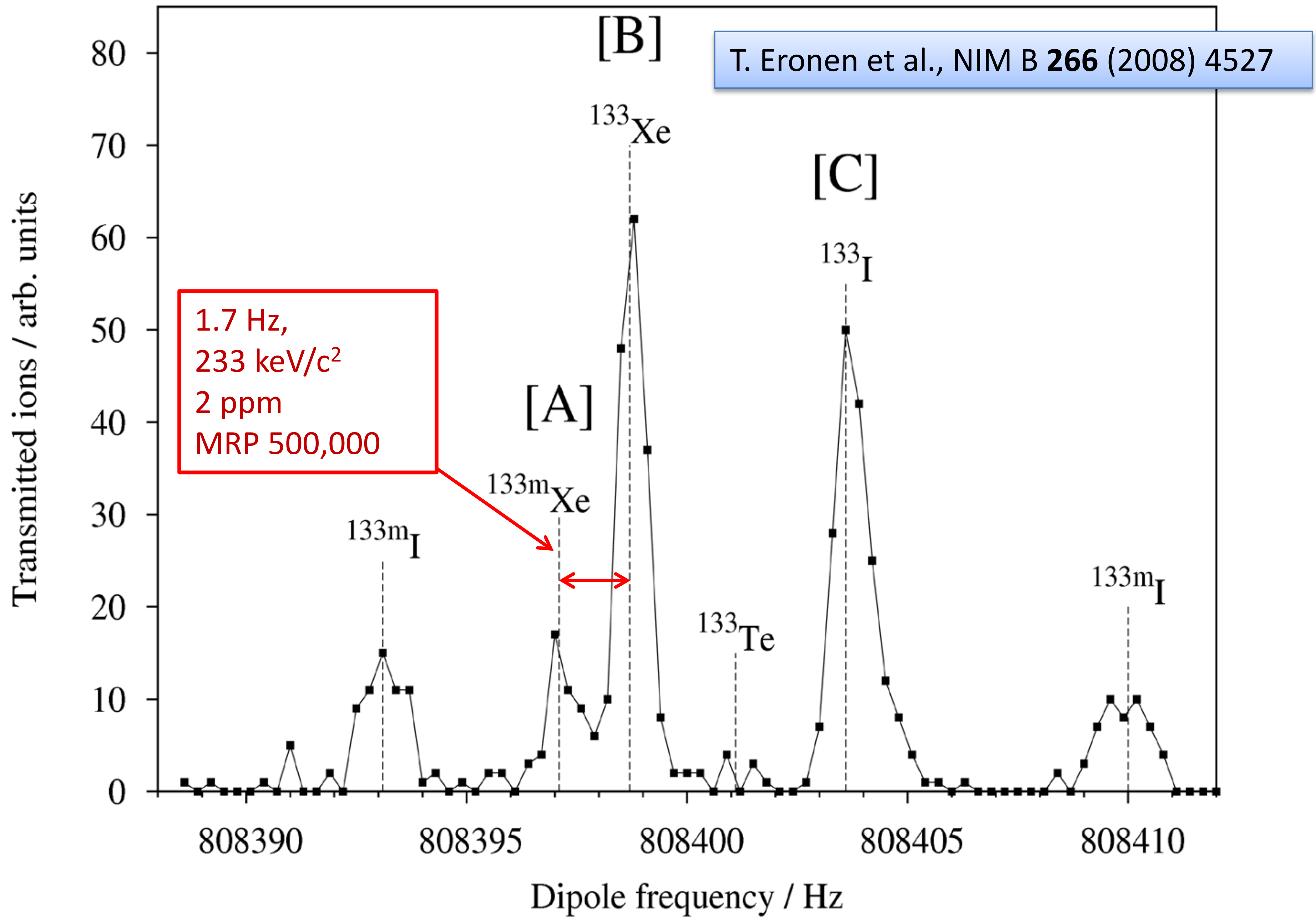
J. Hakala et al., PRL 109 (2012) 032501

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



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

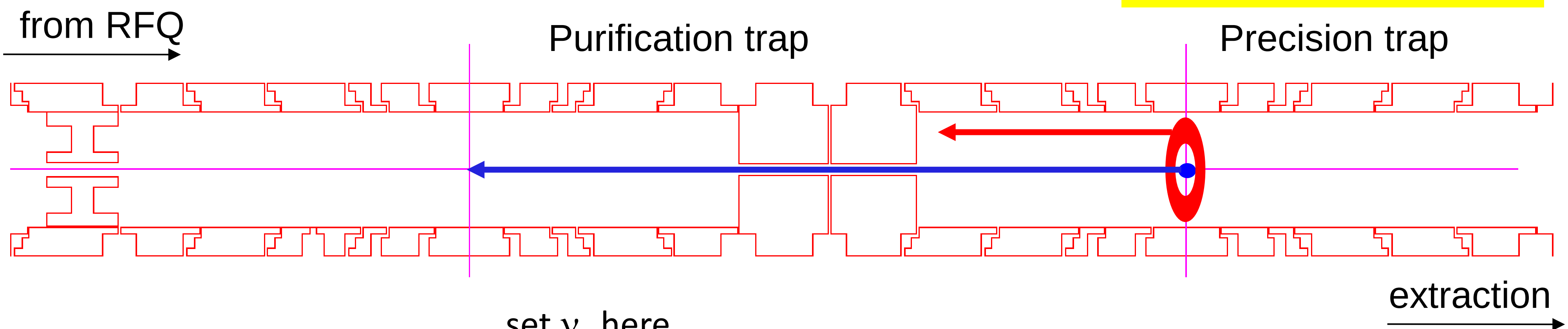
Isomers can be separated (500 ms)



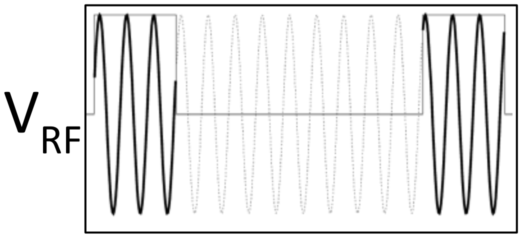
New technique at JYFL

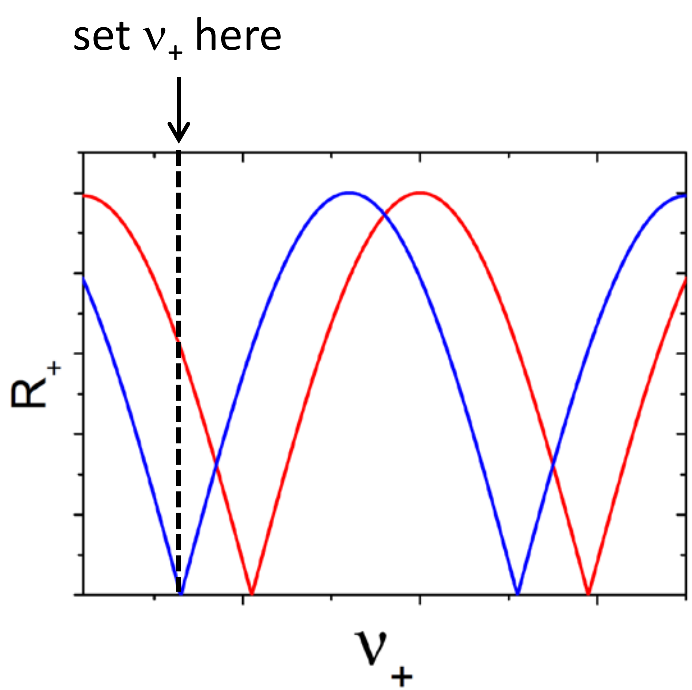
DIPOLE RAMSEY CLEANING FOR ISOMERIC PURIFICATION
T. Eronen et al., NIM. B 266 (2008) 4527

$m/\Delta m \approx 10^6$ can be achieved !



For example
10 ms – 40 ms – 10 ms
(On - Off - On)

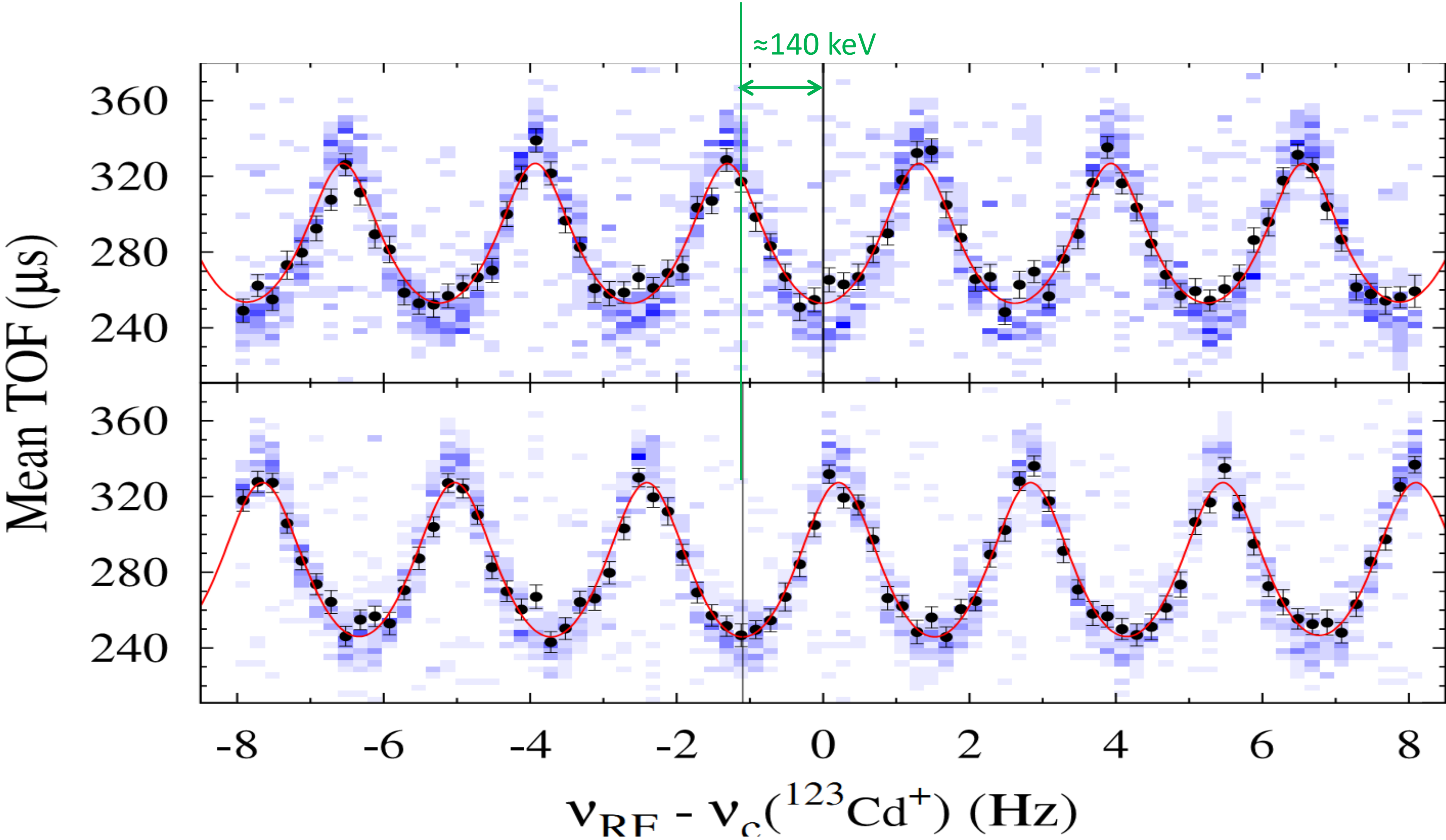




Recipe:

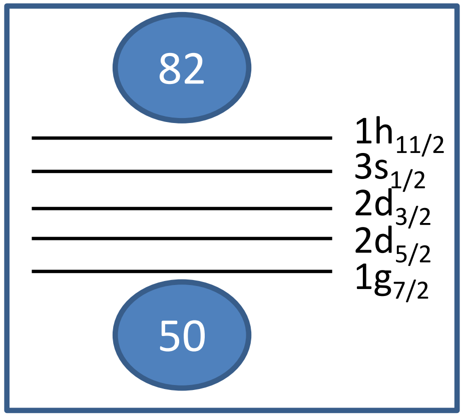
- Small increase of radius
- Time-separated oscillatory field → reduced linewidth
- Additional cooling and centering in the purification trap
- Back to precision trap

Example: ^{123}Cd and ^{123m}Cd



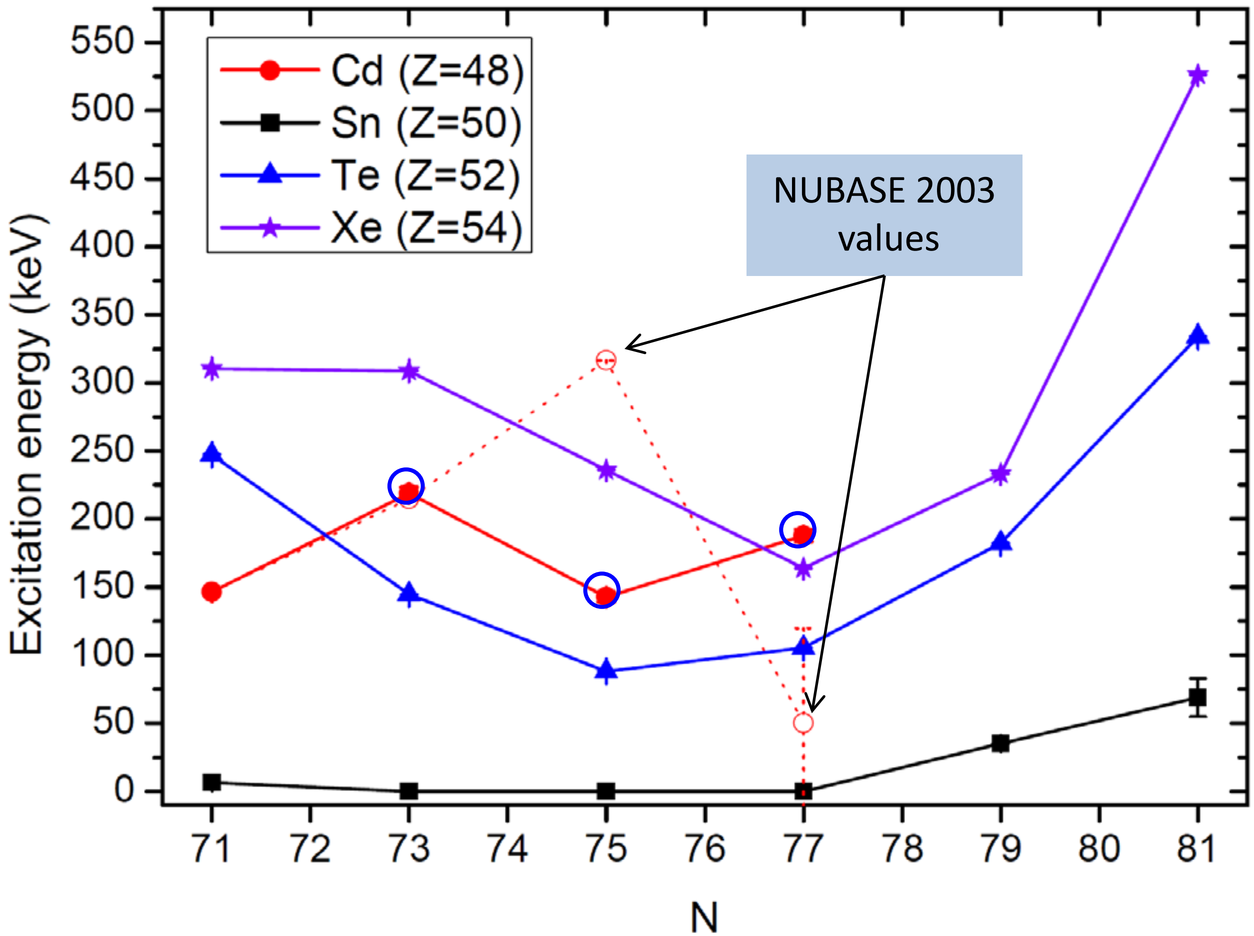
$11/2^-$ isomers in odd-N isotopes

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



JYFLTRAP agrees with the literature values of the well-known isomers in ^{121}Cd, ^{130}Sn and ^{134}Sb.

SYSTEMATICS of the $11/2^-$ state



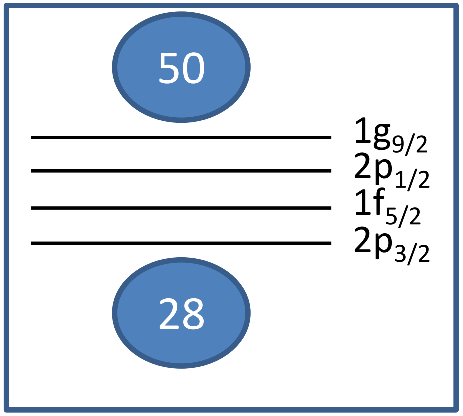
JYFLTRAP values→ similar trend as for Te isotopes

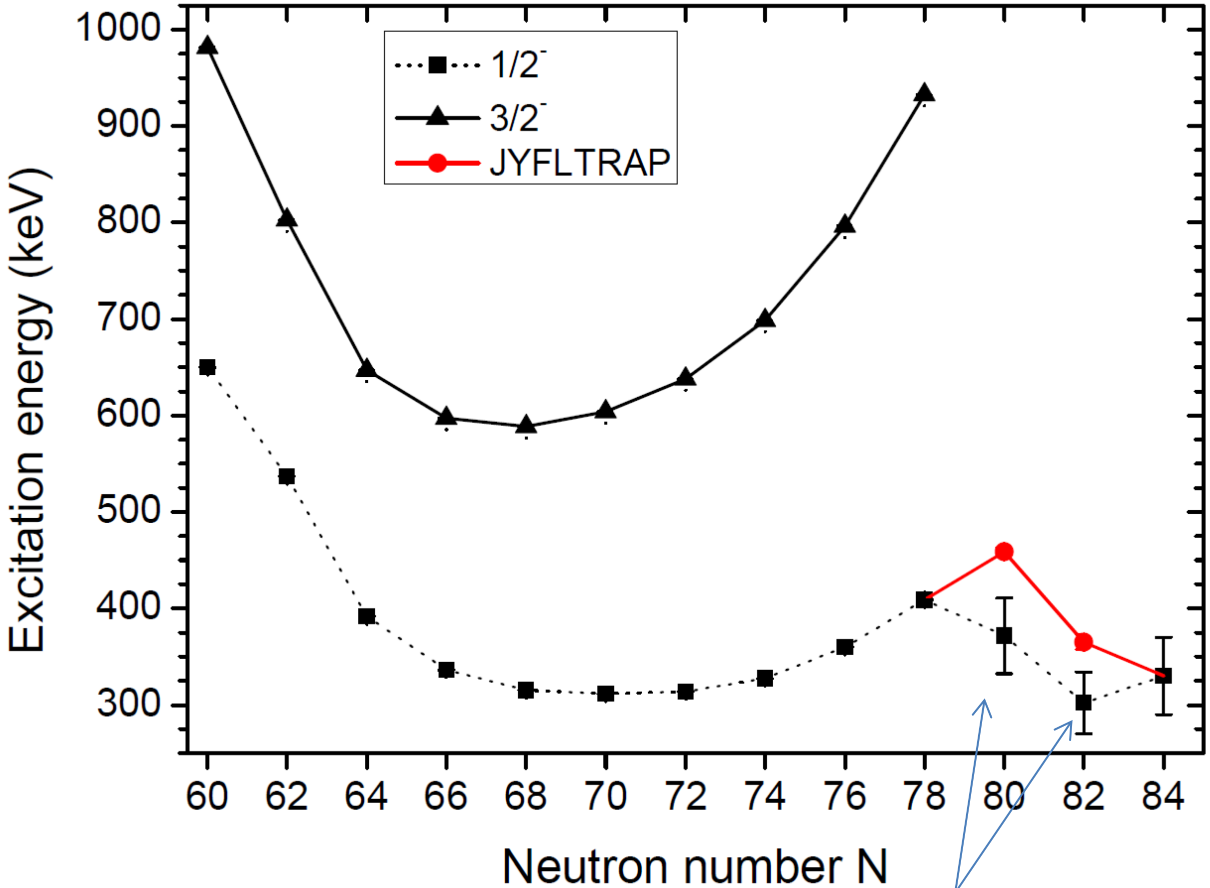
A. Kankainen et al., PRC 87 (2013) 024307

$1/2^-$ isomers in In isotopes

Excitation energy increases from N=78 to N=80

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

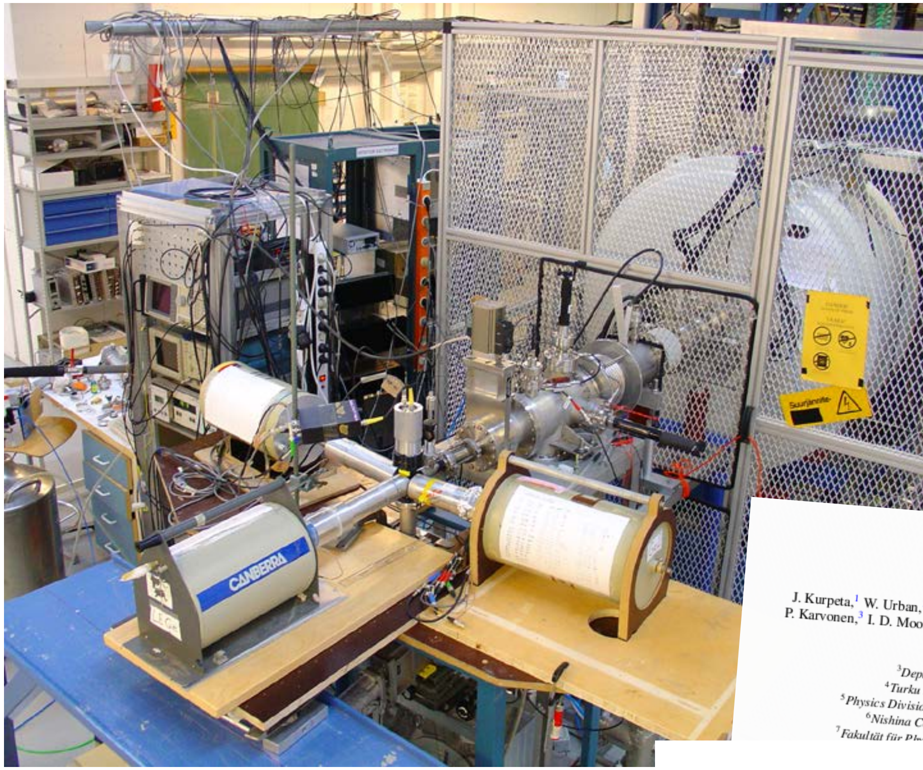




Old values based on beta-decay energy differences

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

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[a], 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], ...
Finland

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...

Received: 8 ...

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] ... J. Äystö[1]

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. ... P. Karvonen,[3] I. D. Moore,[3] H. Penttilä,[3] S. Rahaman,[5] A. Saastamoinen,[3] T. Sonoda,[6] ...
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[4] Turku PET Centre, Accelerator Laboratory, Åbo Akademi University, FIN-...
[5] Physics Division, P-23, Mail Stop H803, Los Alamos National Laboratory, Los Ala...
[6] Nishina Center for Accelerator Based Science, RIKEN ...
[7] Fakultät für Physik ...

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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[3] Department of Physics, University of Surrey, Guildford GU2 7XH, UK
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E-mail: alison.bruce@brighton.ac.uk

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) PHYSICAL REVIEW LETTERS week ending 12 NOVEMBER 2010
Selected for a Viewpoint in Physics

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

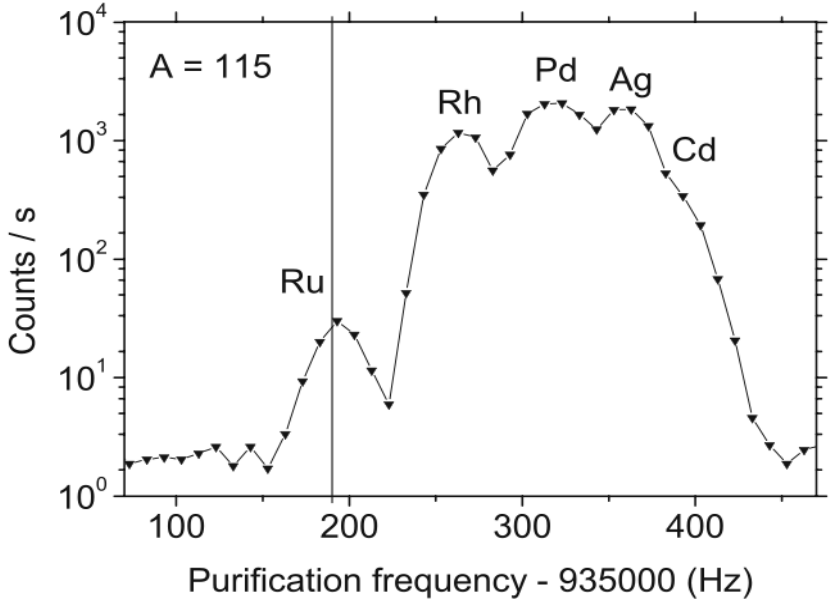
A. Algora,[1,2,*] D. Jordan,[1] J. L. Taín,[1] B. Rubio,[1] J. Agramunt,[1] A. B. Perez-Cerdan,[1] F. Molina,[1] L. Caballero,[1] E. Nácher,[1] A. Krasznahorkay,[2] M. D. Hunyadi,[2] J. Gulyás,[2] A. Vitéz,[2] M. Csatlós,[2] L. Csige,[2] J. Äystö,[3] H. Penttilä,[3] I. D. Moore,[3] T. Eronen,[3] A. Jokinen,[3] 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

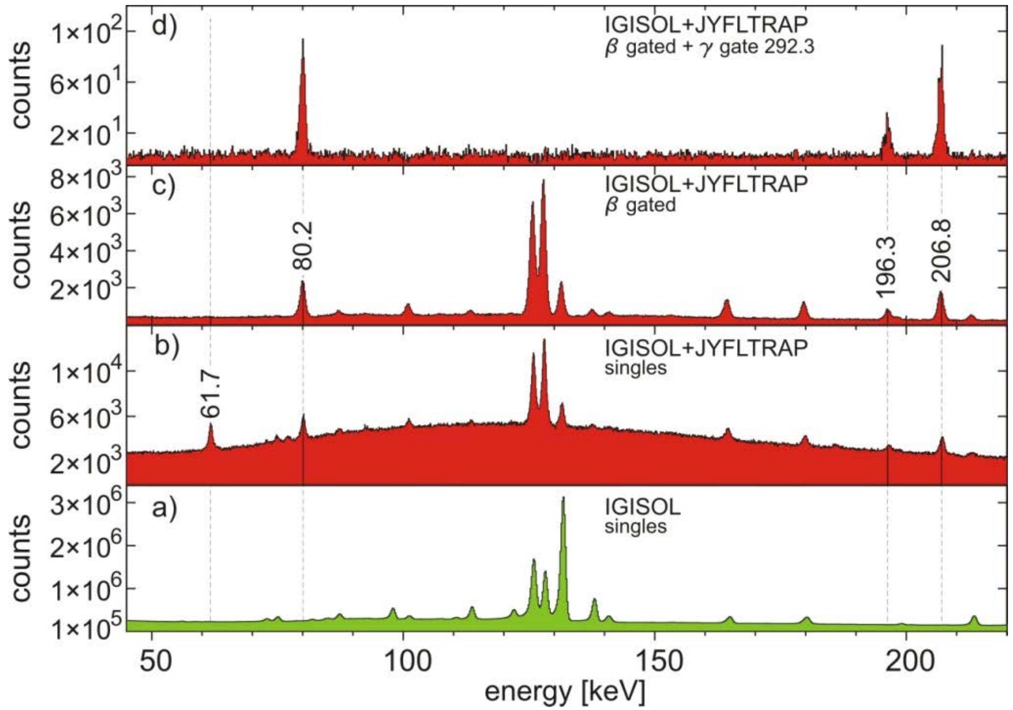
(Received 13 May 2010; published 8 November 2010)

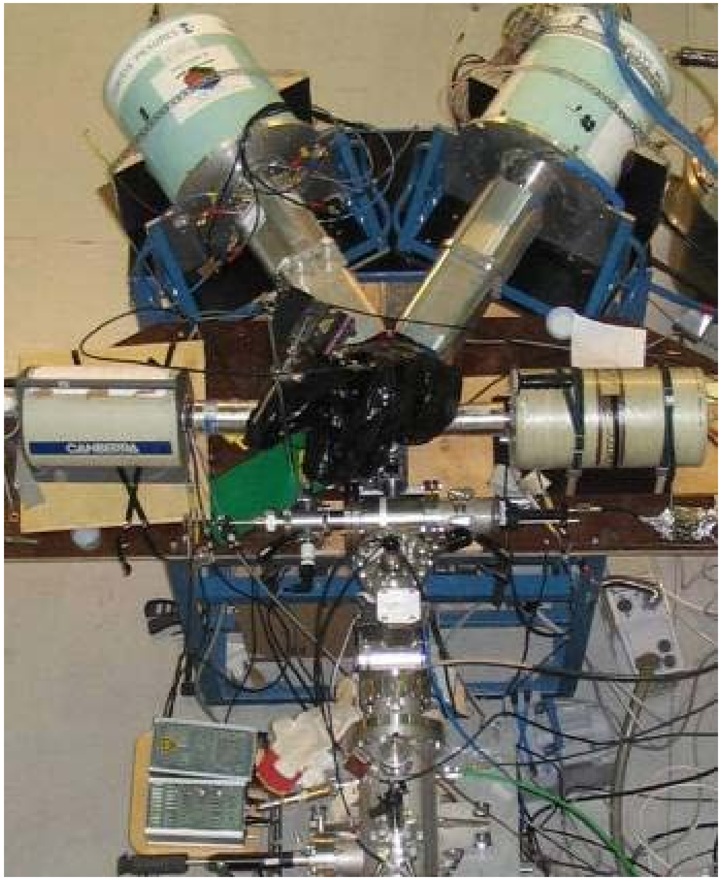
The β feeding probability of ^{102,104,105,106,107}Tc, ^{105}Mo, and ^{101}Nb nuclei, which are important contributors to the decay heat in nuclear reactors, has been measured using the total absorption technique. We have coupled for the first time a total absorption spectrometer to a Penning trap in 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

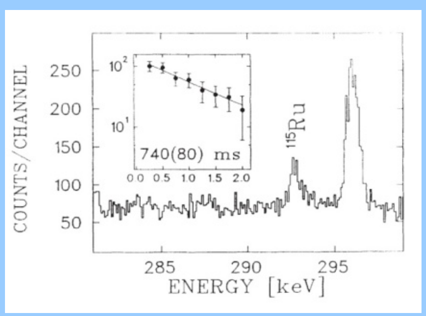




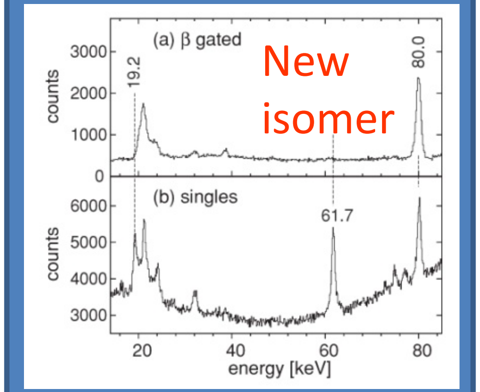


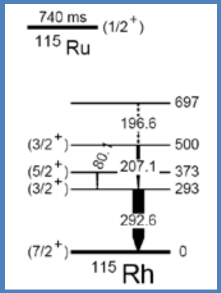
Impact of the trap: ^{115}Ru

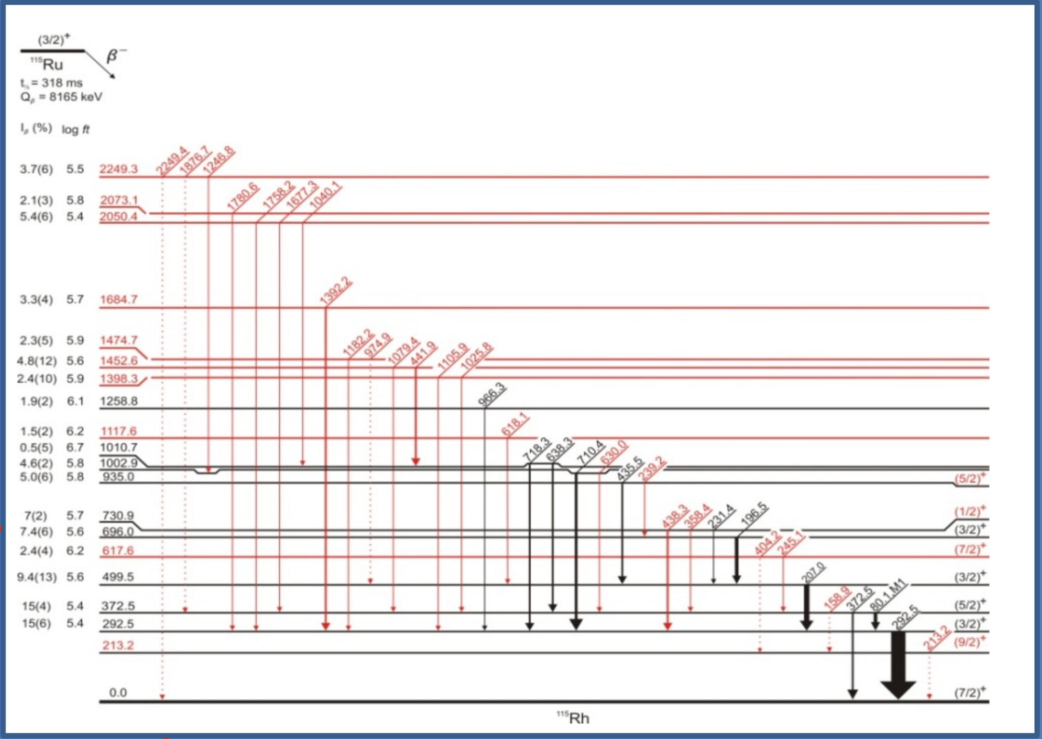
IGISOL only



IGISOL+JYFLTRAP



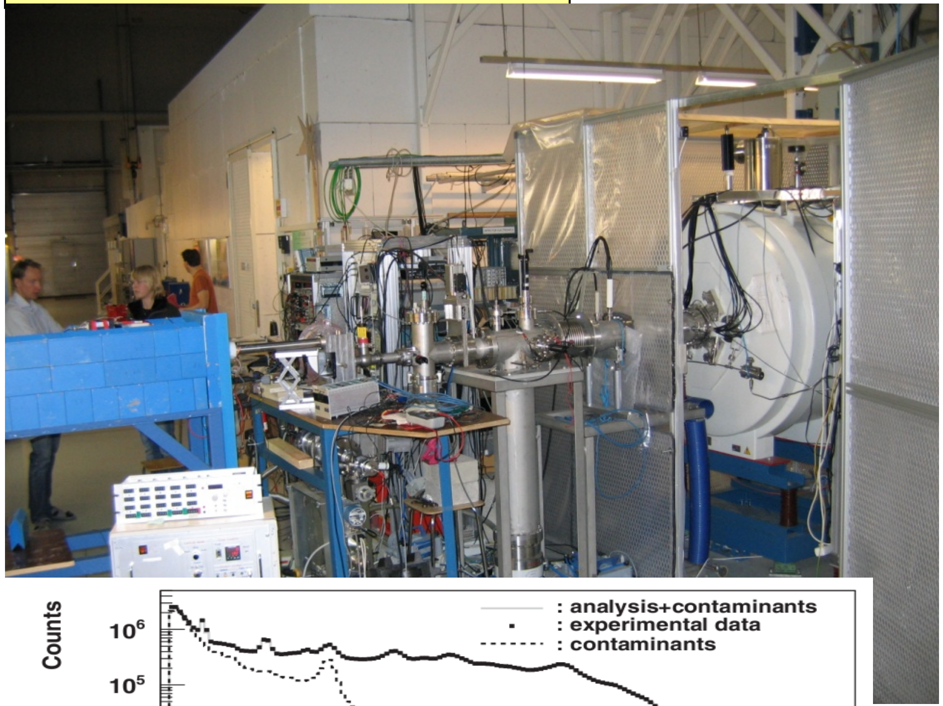


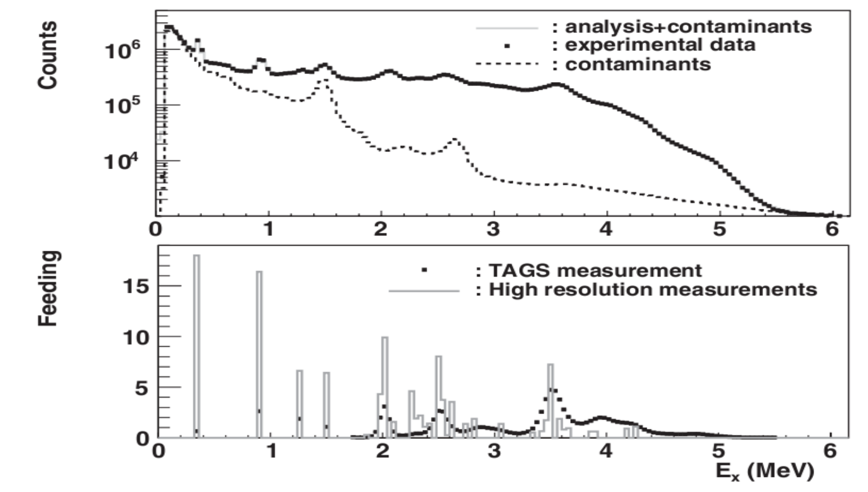


1992	2007	2010	2011
IGISOL experiment 292.8 keV gamma line $t_{1/2}$=740(80) ms ??	Trap-assisted test experiment First simple beta-decay scheme	Trap-assisted half-life measurement -$t_{1/2}$(g.s)=318(19) ms -$t_{1/2}$(i.s)=76(6) ms	Trap-assisted beta-decay experiment Extended beta-decay scheme
J. Äystö et al., PRL 69, 1167 (1992)	J. Kurpeta et al., EPJ A 31, 263 (2007)	J. Kurpeta et al., PRC 82, 064318 (2010)	J. Rissanen et al., EPJ A 47, 97 (2011)

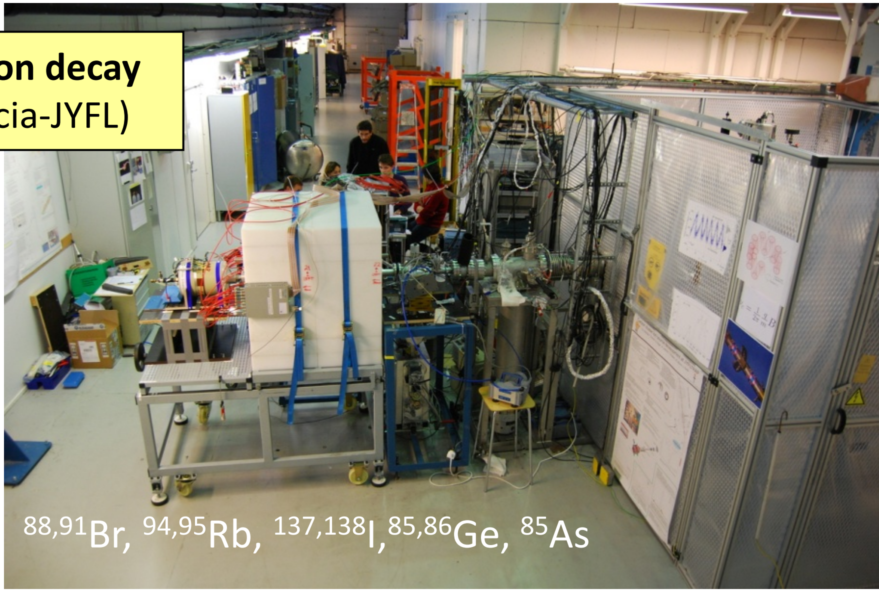
Trap combined with other setups …

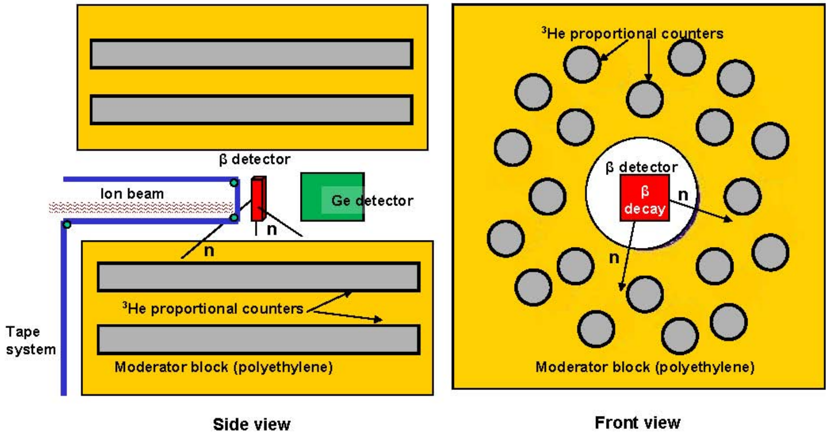
Total absorption spectroscopy
"Reactor decay heat studies"
PRL 105 (2010) 202501





Beta-delayed neutron decay
Nuclear data (Valencia-JYFL)

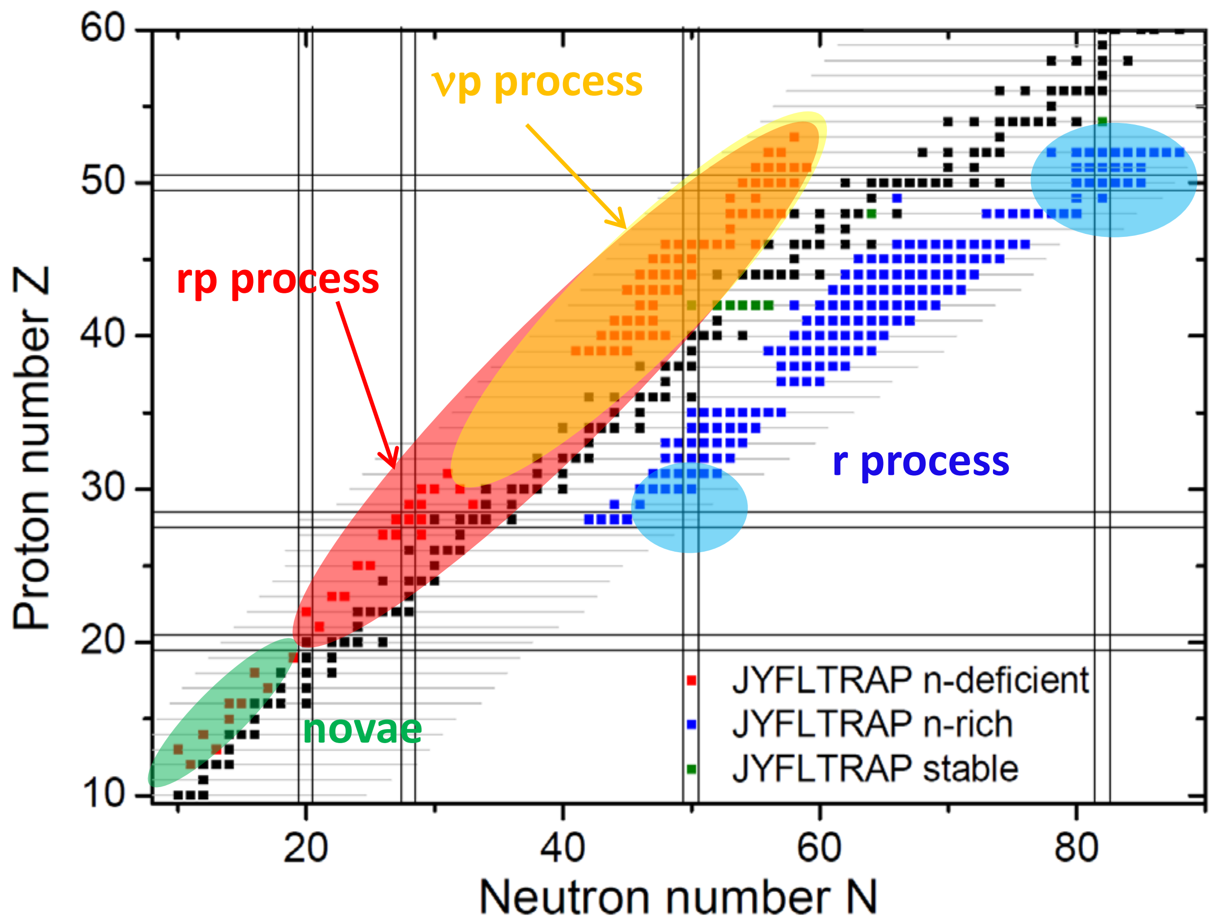




Collaboration:
CIEMAT (Madrid) – IFIC (Valencia) – Inst. Nucl. Res. (Debrecen) – LPC (Caen) – PNPI (St. Petersburg) – Univ. Jyväskylä (Jyvaskyla) – UPC (Barcelona) – Univ. Surrey (Surrey)

Nuclear astrophysics

Capture rates depend exponentially on Q-values → Need **accurate** masses → Reaction paths, Abundances, …



Reaction rate of $^{25}Al(p,\gamma)^{26}Si$

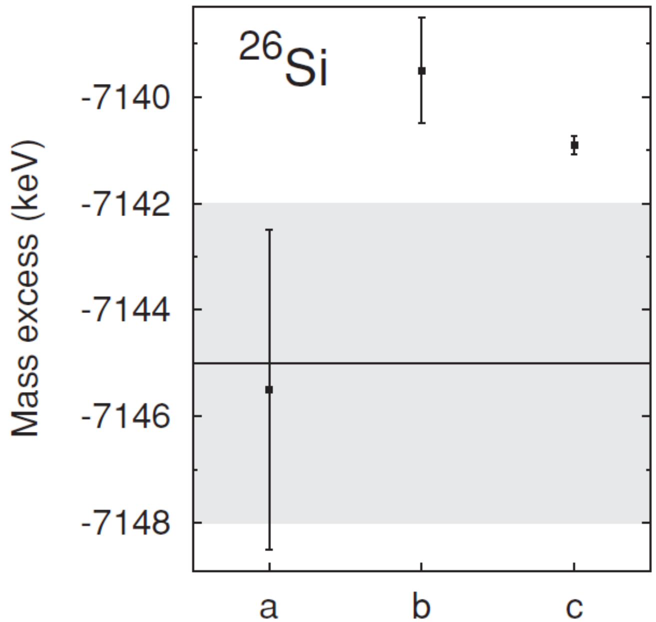
Important reaction to bypass ^{26}Al production in MgAl cycle. Resonant proton captures to excites states above proton threshold

$$N_A \langle \sigma v \rangle_r = N_A \left(\frac{2\pi}{\mu kT} \right)^{3/2} \hbar^2 \sum_i (\omega\gamma)_i \exp\left[-E_{r,i}/(kT)\right]$$

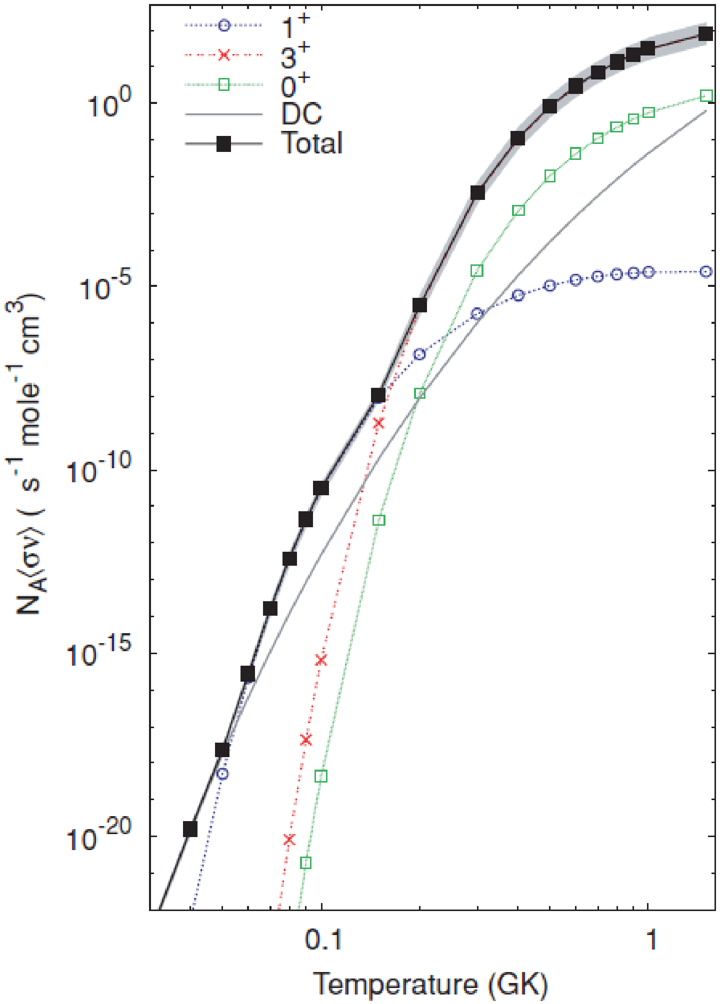
$E_r = E_x - S_p$

Need to know:

- Energies of the final states
- Width of the initial and final state
- **Proton separation energy S_p=5513.7(5) keV**



(a) J. C. Hardy et al., Phys. Rev. C 9, 252 (1974)
(b) A. Parikh et al., Phys. Rev. C 71, 055804 (2005)
(c) JYFLTRAP



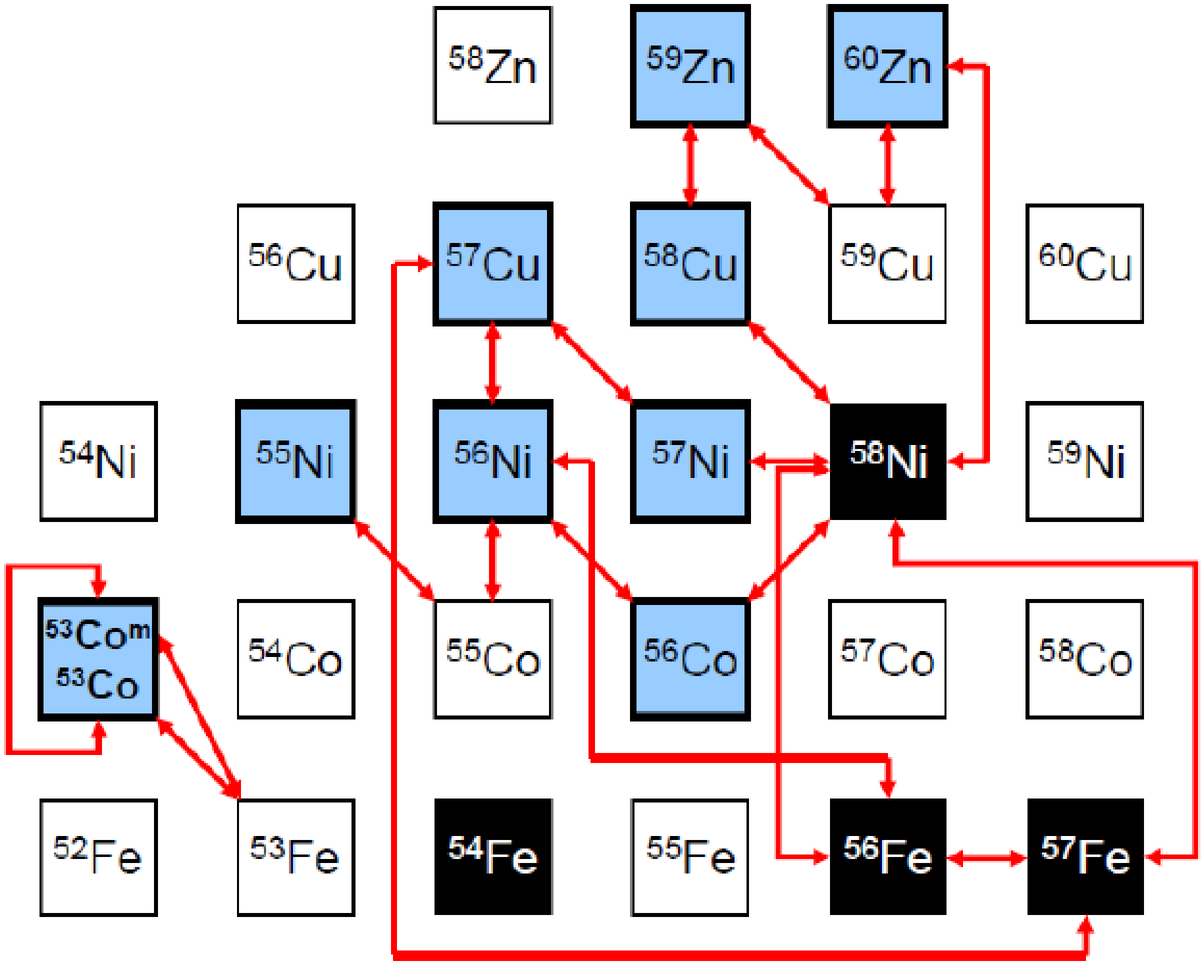
T. Eronen et al., PRC 79, 032802(R) (2009)

Network of mass measurements at A~56

Production:
^{3}He/p on ^{54}Fe/^{58}Ni
^{20}Ne on Ca

Analysis network:
13 nuclides
17 links

Results:
S_p of ^{57}Cu directly !
JYFLTRAP: 689.7(5) keV
AME03: 695(19) keV



rp-process waiting point ^{56}Ni

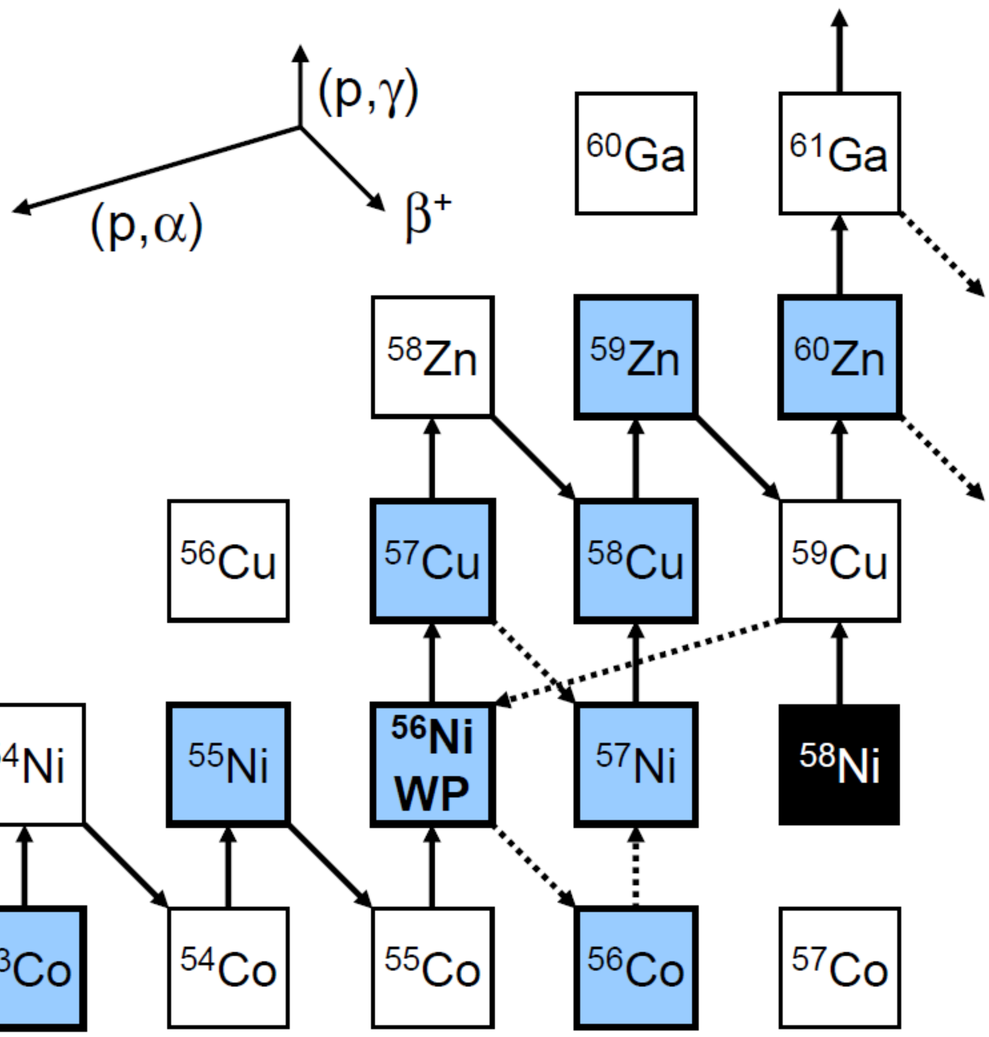
x-ray burst timescales: 10-100 s

$T_{1/2}$ (^{56}Ni)= 6.075 d !

rp process must proceed via proton captures on ^{56}Ni

rate of $^{56}Ni(p,\gamma)^{57}Cu$ important!

A. Kankainen et al., PRC 82 (2010) 034311



rp-process path for steady-state burning

Reaction rate of $^{56}Ni(p,\gamma)^{57}Cu$

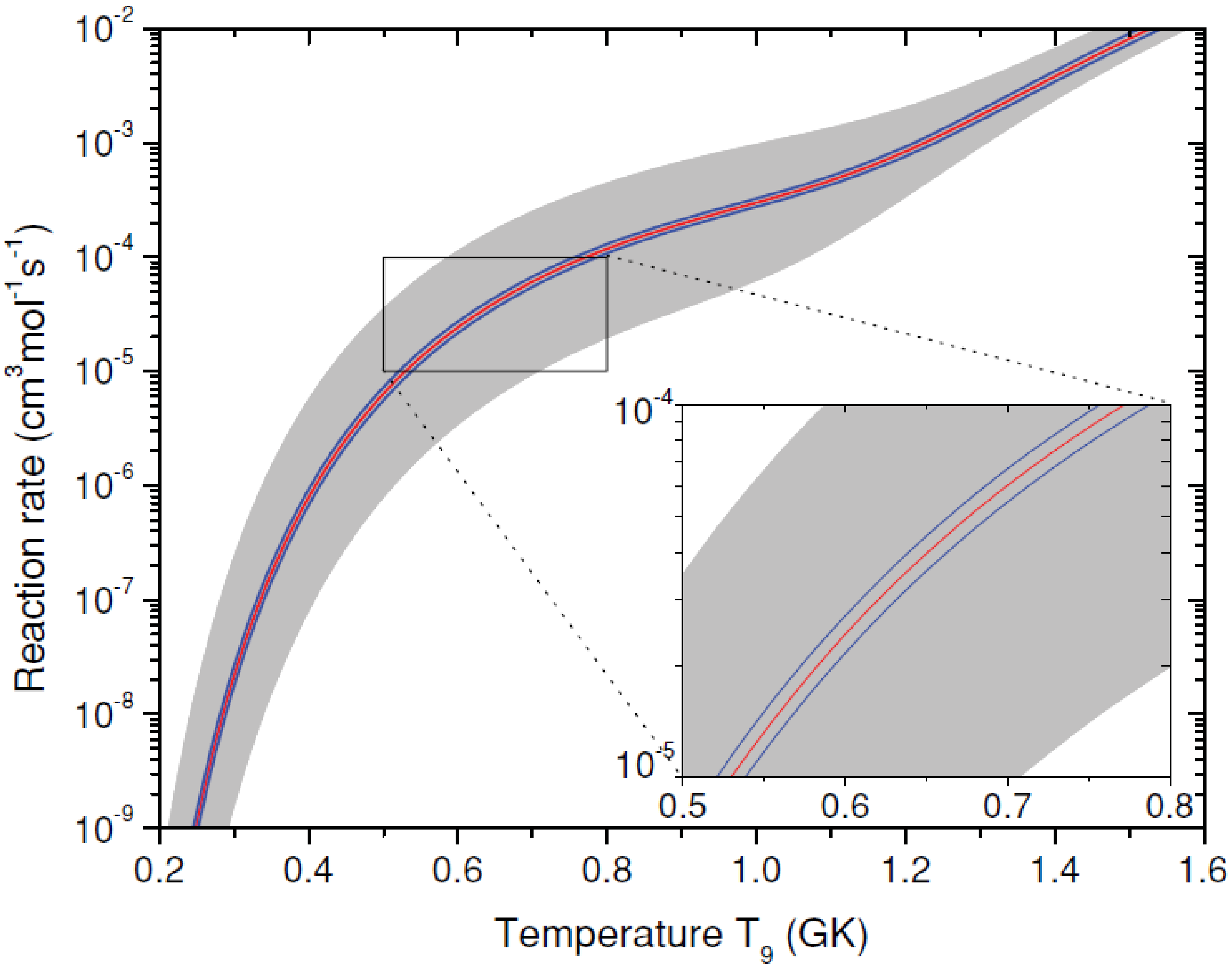
A. Kankainen et al., PRC 82 (2010) 034311

JYFLTRAP:
$Q_{(p,\gamma)}$=689.7(5) keV

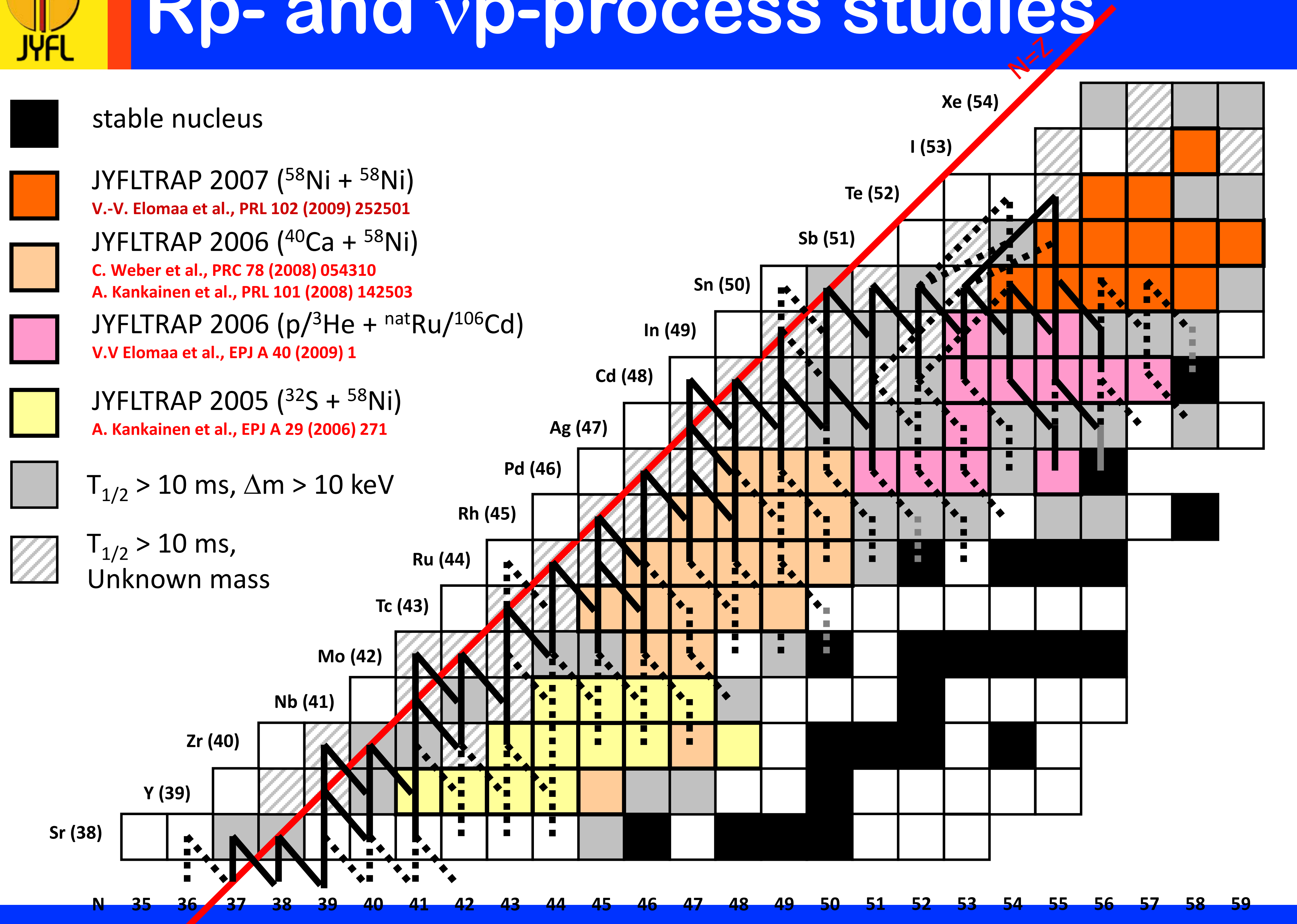
vs

AME03:
$Q_{(p,\gamma)}$= 695(19) keV

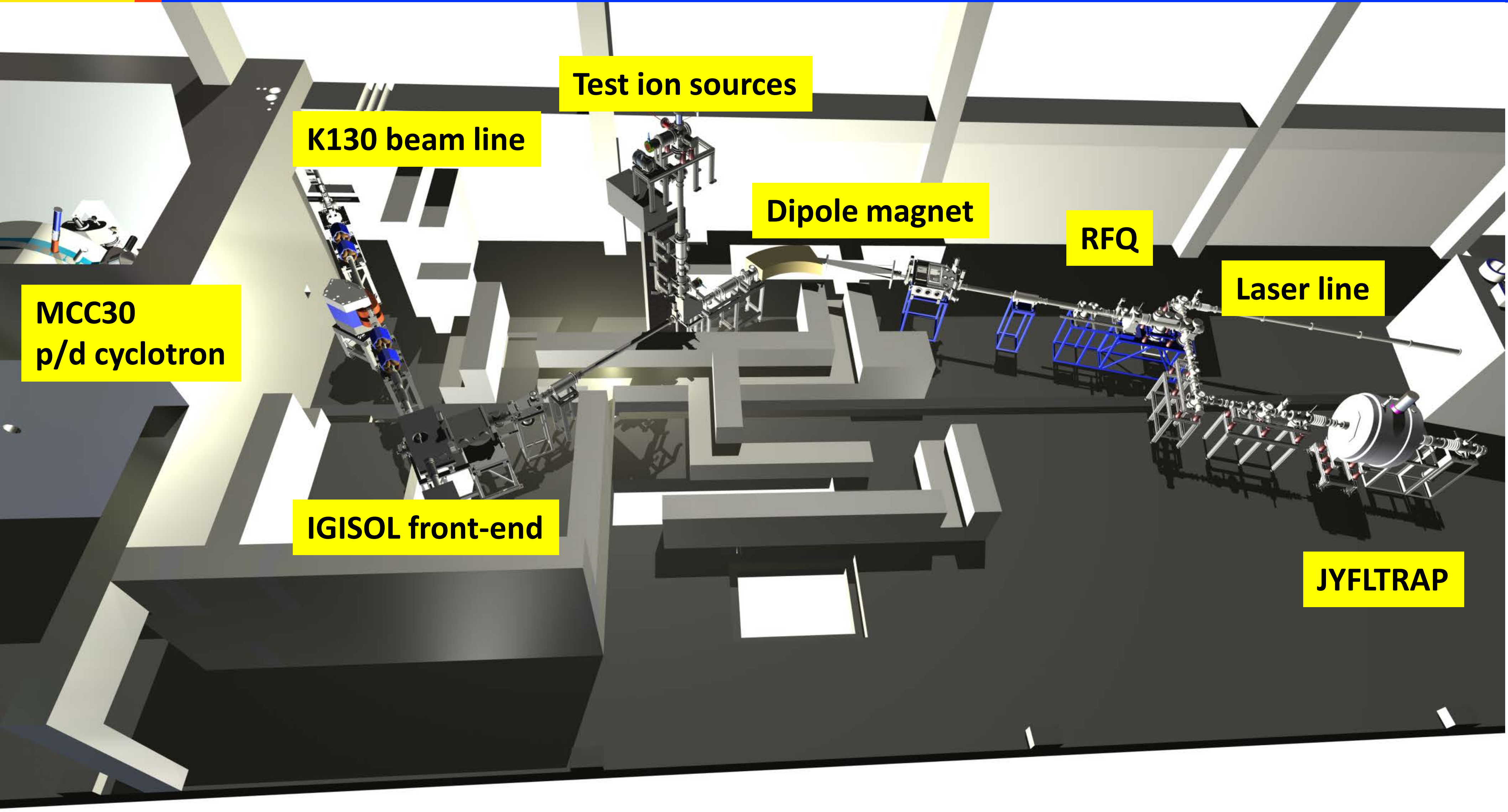
Rates slightly higher but uncertainties much smaller



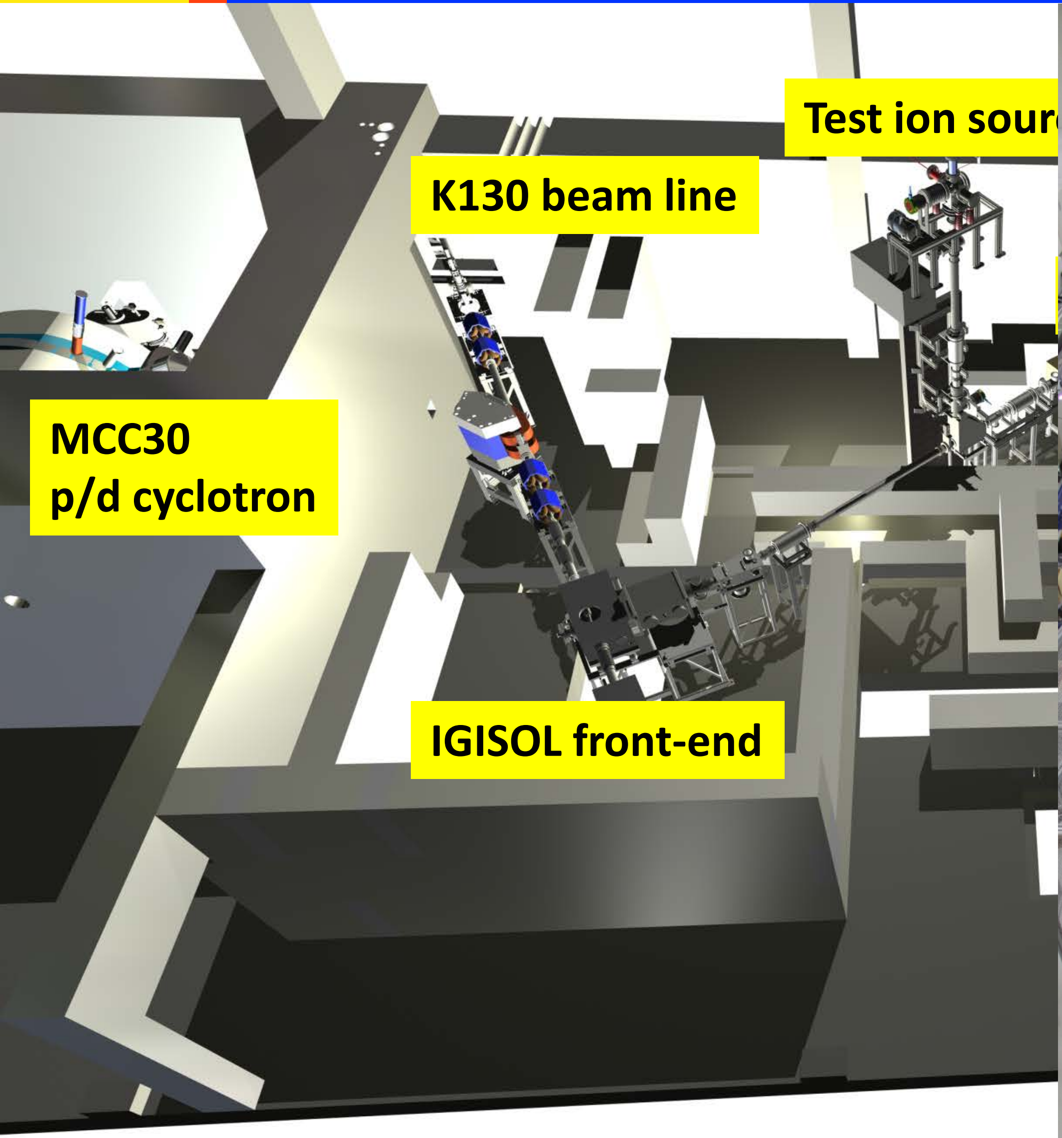
Rp- and νp-process studies

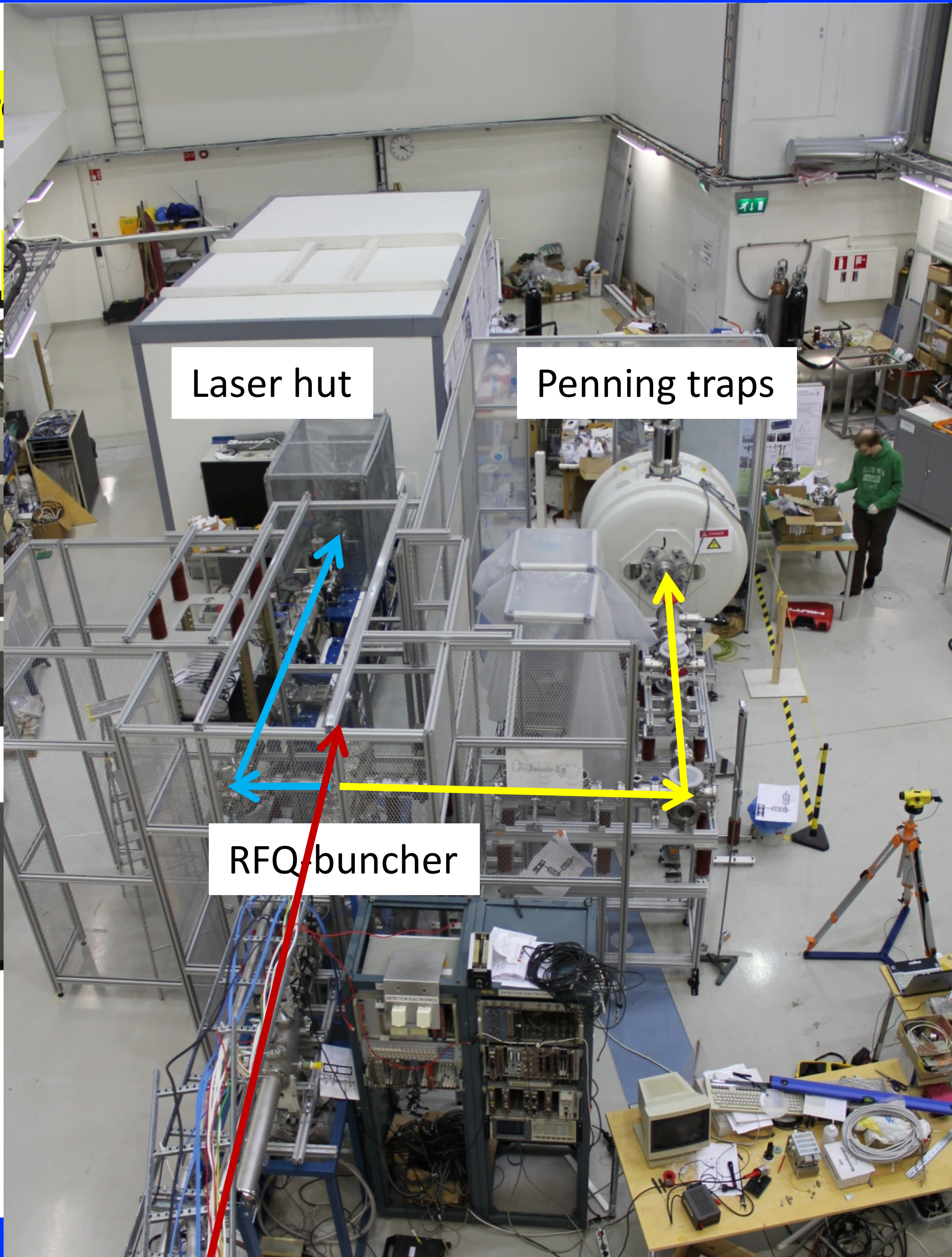


New era: IGISOL 4

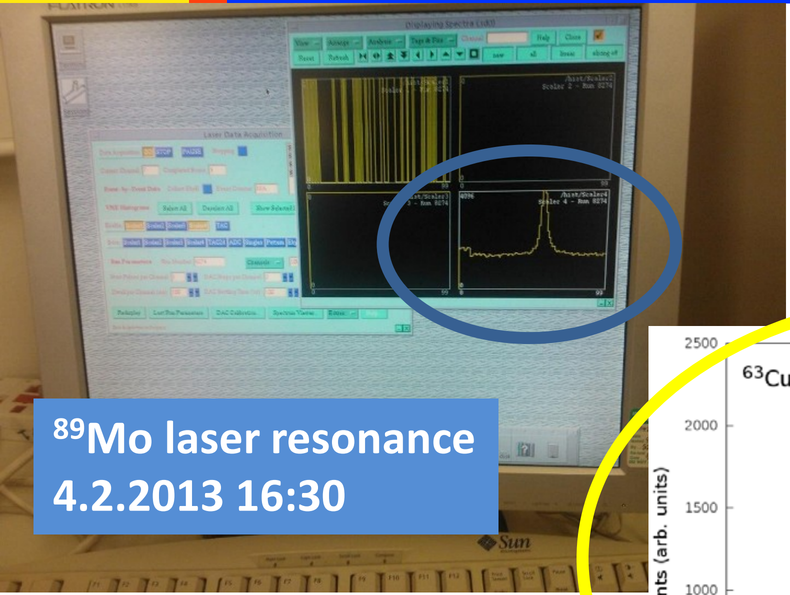


New era: IGISOL 4



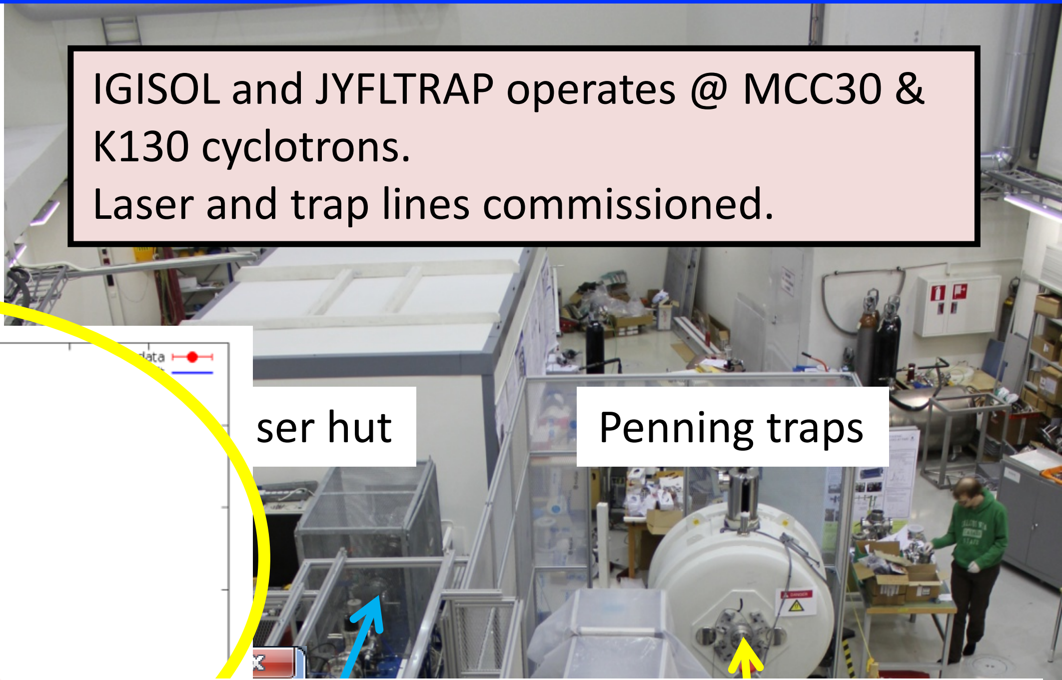


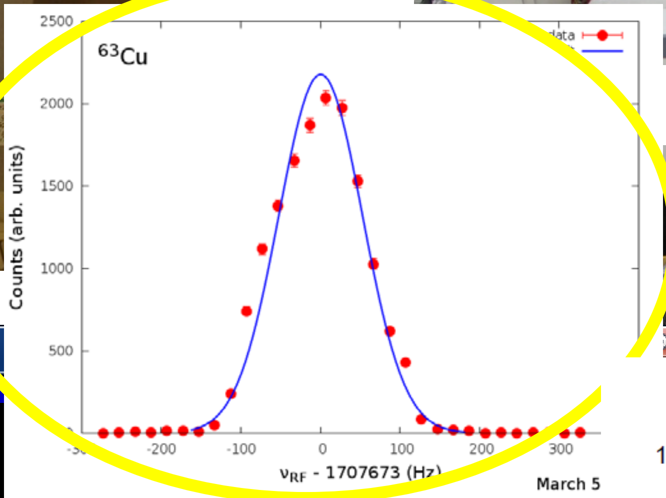
Status



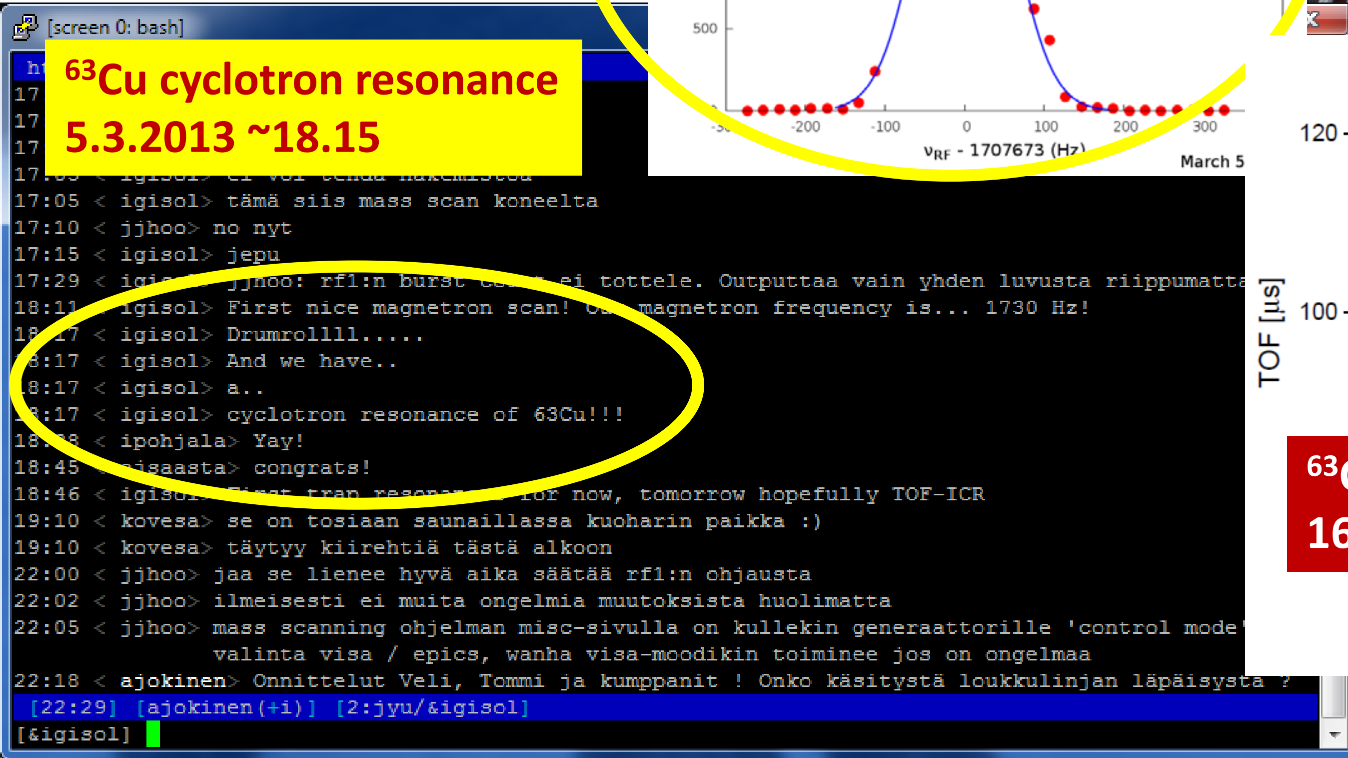
^{89}Mo laser resonance
4.2.2013 16:30

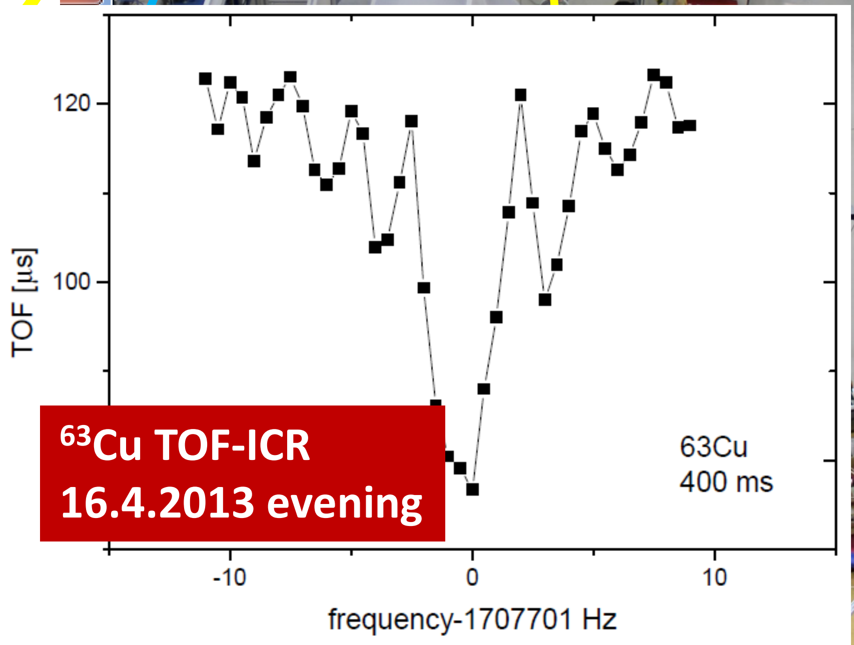
IGISOL and JYFLTRAP operates @ MCC30 & K130 cyclotrons.
Laser and trap lines commissioned.





^{63}Cu cyclotron resonance
5.3.2013 ~18.15





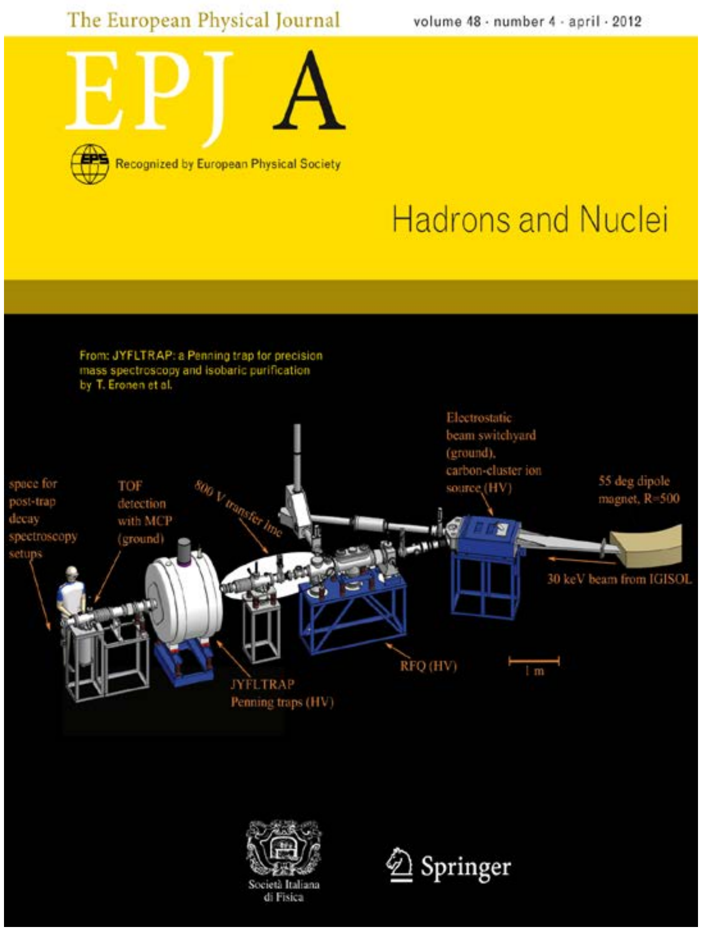
^{63}Cu TOF-ICR
16.4.2013 evening

Summary

- Successful JYFLTRAP & IGISOL 3 period

- A rich program of decay studies and measurements of ground state properties (JYFLTRAP and lasers)
    - Shell evolution
    - Shape changes, new regions of deformation
    - Pairing
    - CVC hypothesis and the unitarity of CKM
    - Rare decays (Xth-forbidden beta decays, ββ, ECEC,)
    - Nuclear astrophysics
    - Applications

- Next phase (IGISOL-IV):
    - Intensity and instrumentation upgrade
    - Flexible scheduling
    - Development and testing time
    - New production methods, …



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J. Rissanen (LBNL)
A. Saastamoinen (TAMU)
J. Äystö (Helsinki Inst. of Physics)

Searching for students, graduate students and post docs (traps, spectroscopy, lasers)
Contact ari.jokinen@jyu.fi

http://research.jyu.fi/igisol/JYFLTRAP_masses/