

# Nuclear Structure Studies with Penning Traps



**Michael Block**

# Unique Combination for SHE Studies



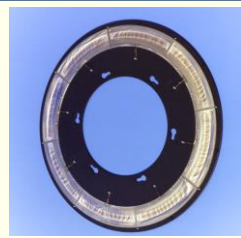
ECR/PIG + UNILAC



TRIGA-

-LASER

-TRAP



Stable targets



Actinide targets



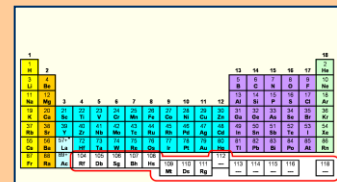
Radiochem . labs



SHIP



TASCA



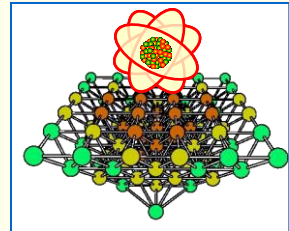
Chemistry



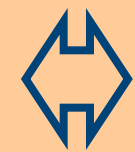
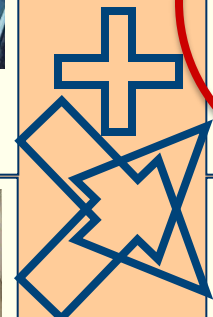
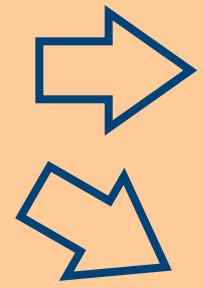
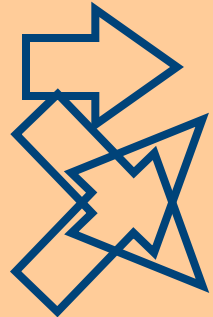
SHIPTRAP



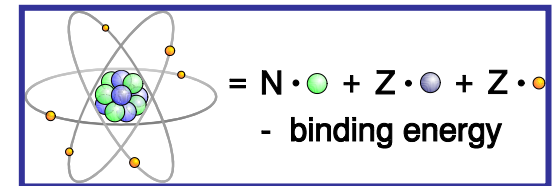
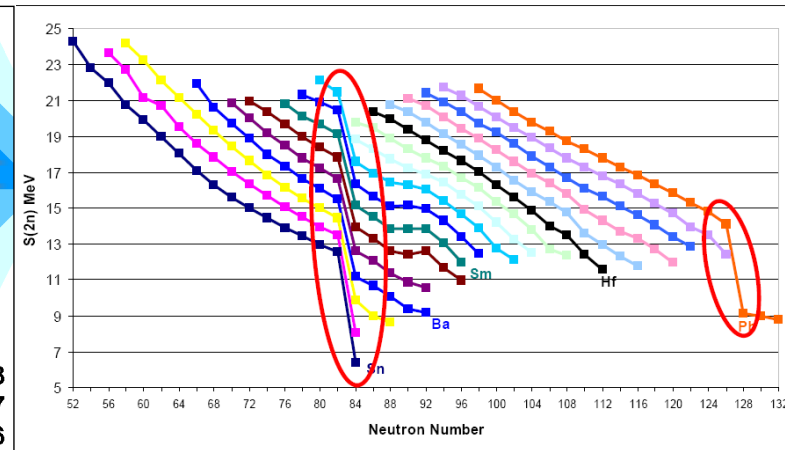
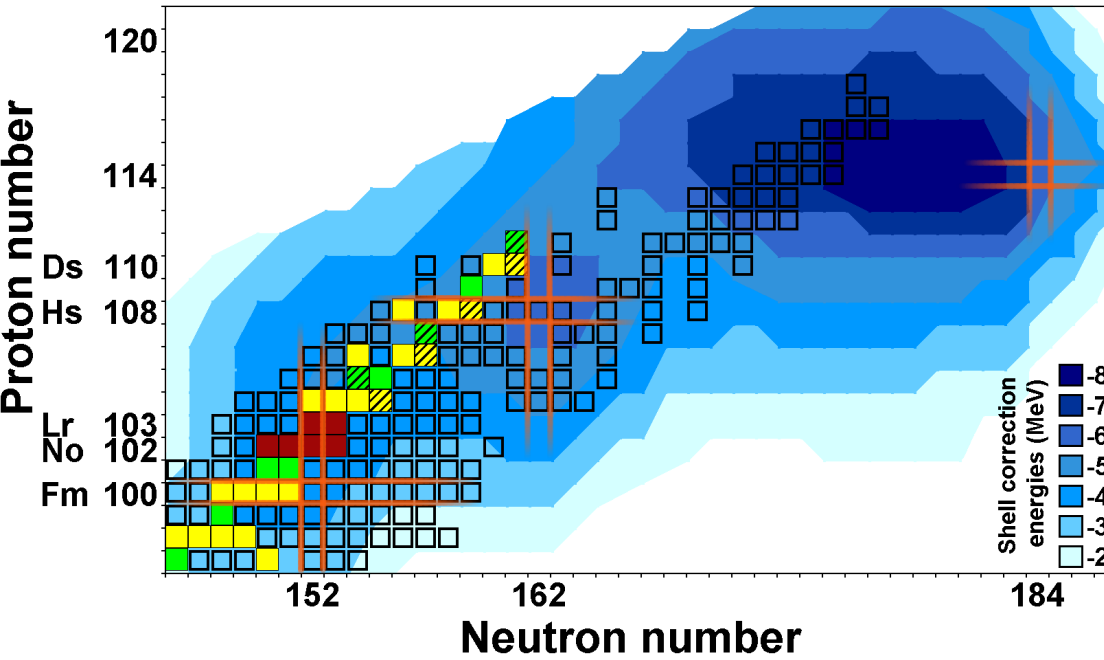
TASISpec



Chemical theory



# Importance of Masses for $Z > 100$



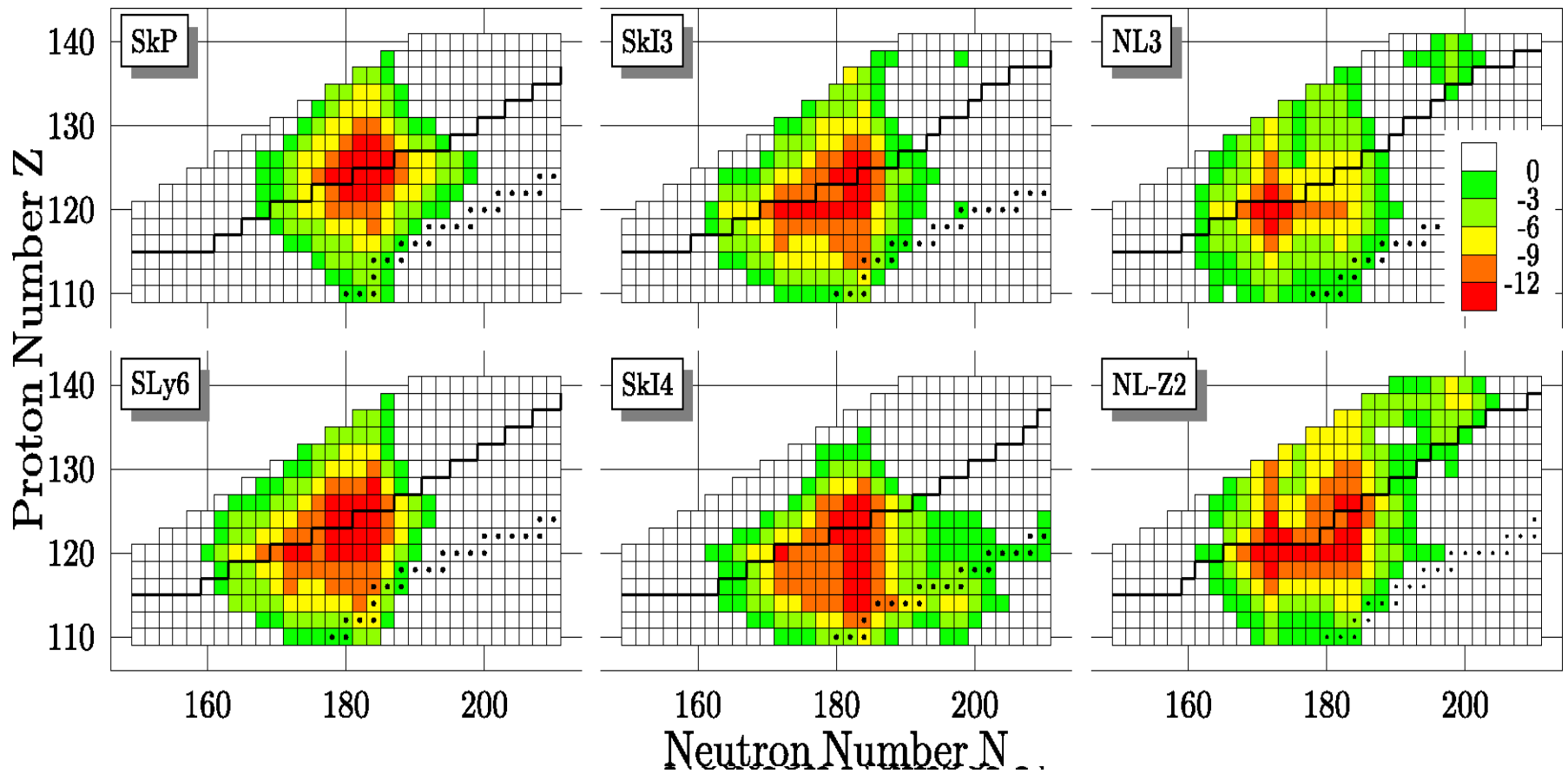
high-precision mass measurements provide

- accurate absolute nuclear binding energies
- anchor points to fix decay chains

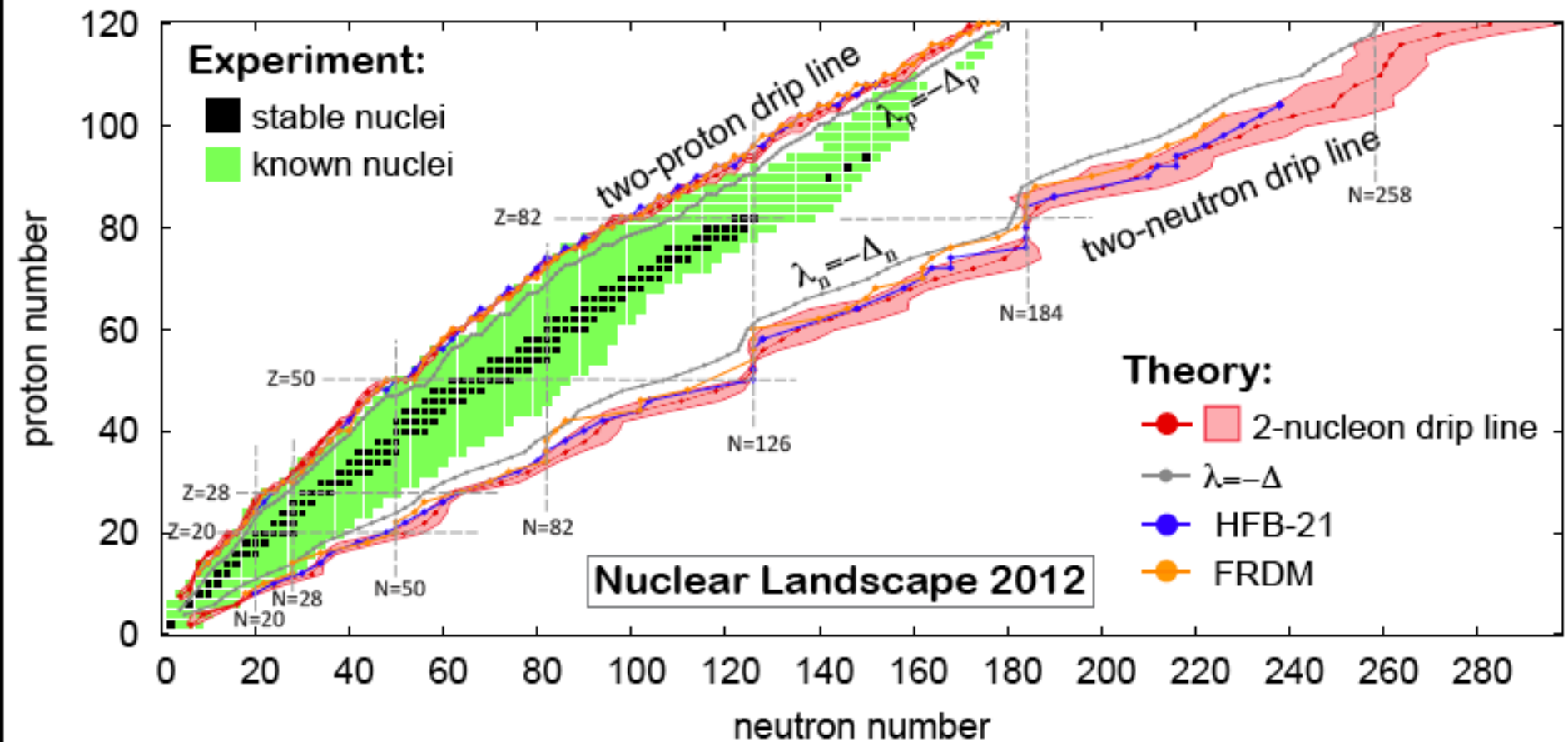
➔ Studies the nuclear structure evolution

➔ Benchmark theoretical nuclear models

# Nuclear Shells: No Magic Numbers in SHE?



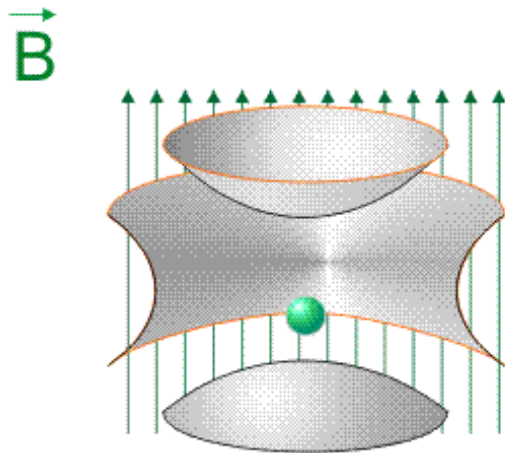
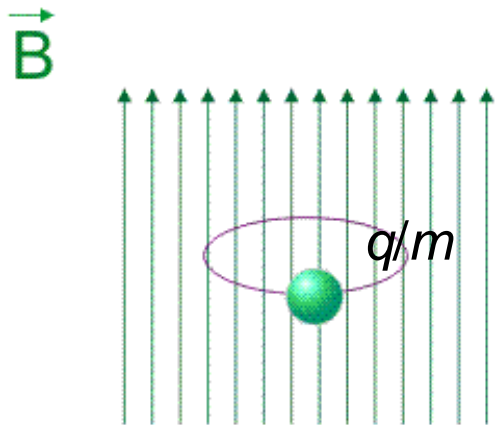
# Exploring the Limits of Nuclear Chart



Prediction: about 7000 nuclides exist

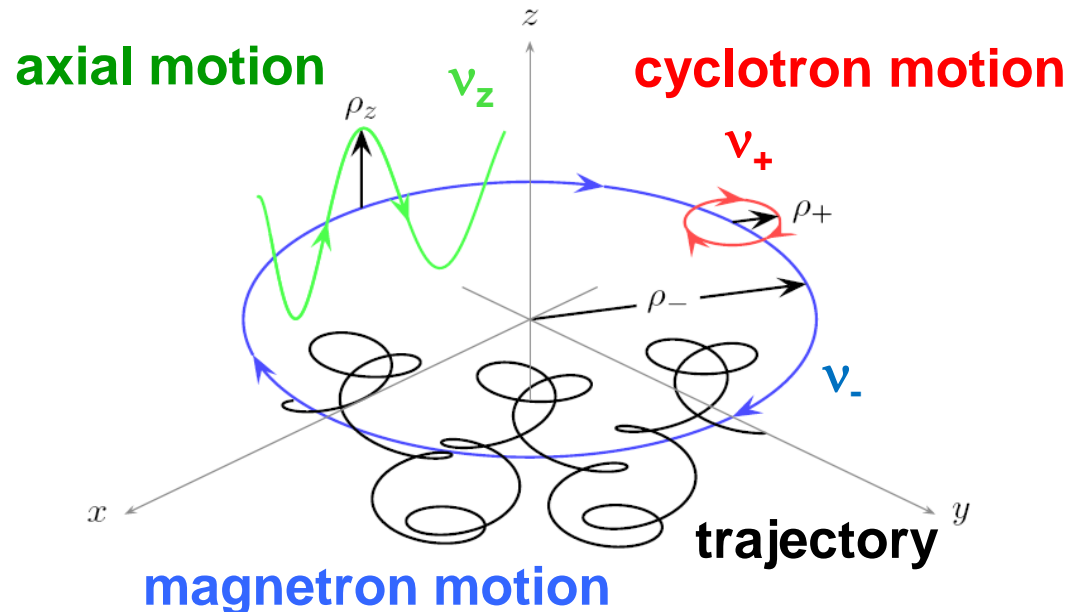
# Principle of Penning Traps

## PENNING trap



- Strong homogeneous magnetic field
- Weak electric 3D quadrupole field

**Cyclotron frequency:** 
$$f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$



# Complementarity of Penning Traps

Type of Reacion	ISOL TRAP	CPT	SHIP TRAP	JYFL TRAP	LEBIT	TITAN	TRIGA TRAP	CARIBU	MLL TRAP	MATS @FAIR
ISOL	X					X			X	
Fusion		X	X						↑	
IGISOL				X						
Fragm.					X					
Neutron induced fission							X		X	
Spontaneous fission								X		X
HCI						X				X

# Present Performance of PTMS for RIBs

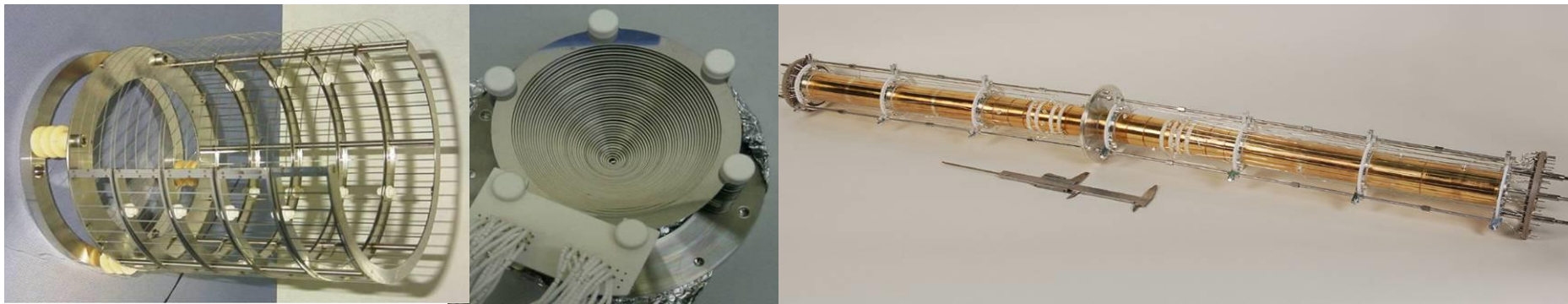
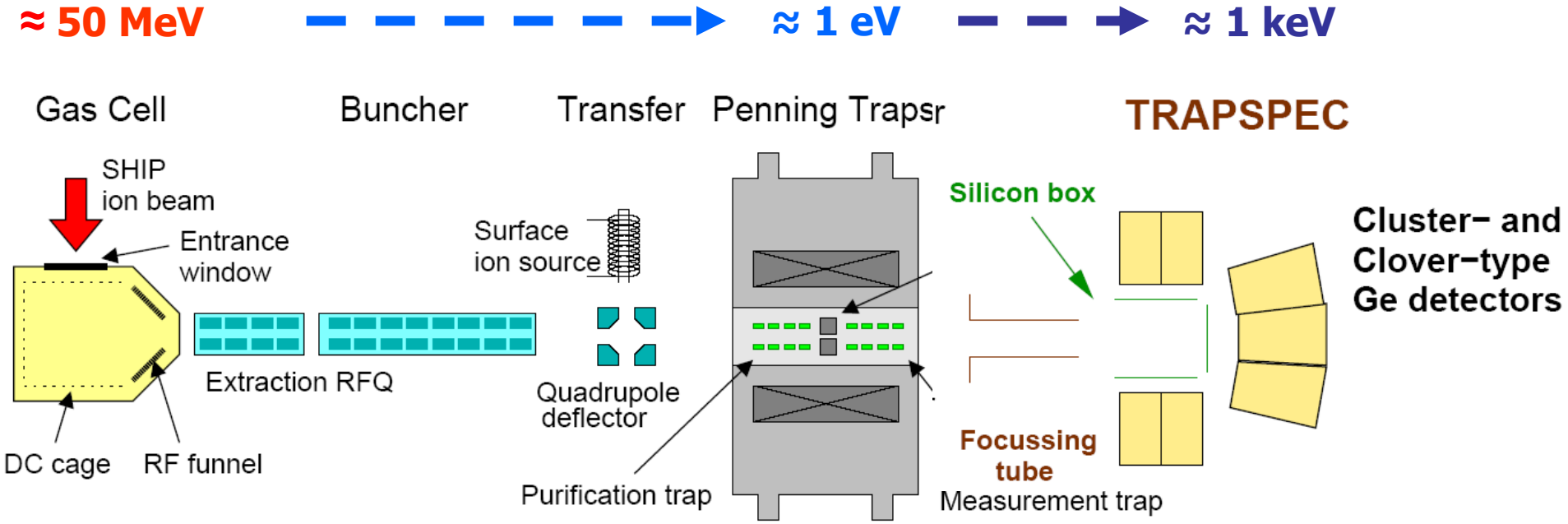
- required yield: at present  $\approx 1$  particle per minute
- accessible half-life  $\approx 10$  ms
- relative mass uncertainty  $\approx 10^{-8}$  (for mass doublets  $10^{-9}$ )
- required number of ions for a mass measurement  $\approx 30$

**Yield often still not the limiting factor but contaminants**

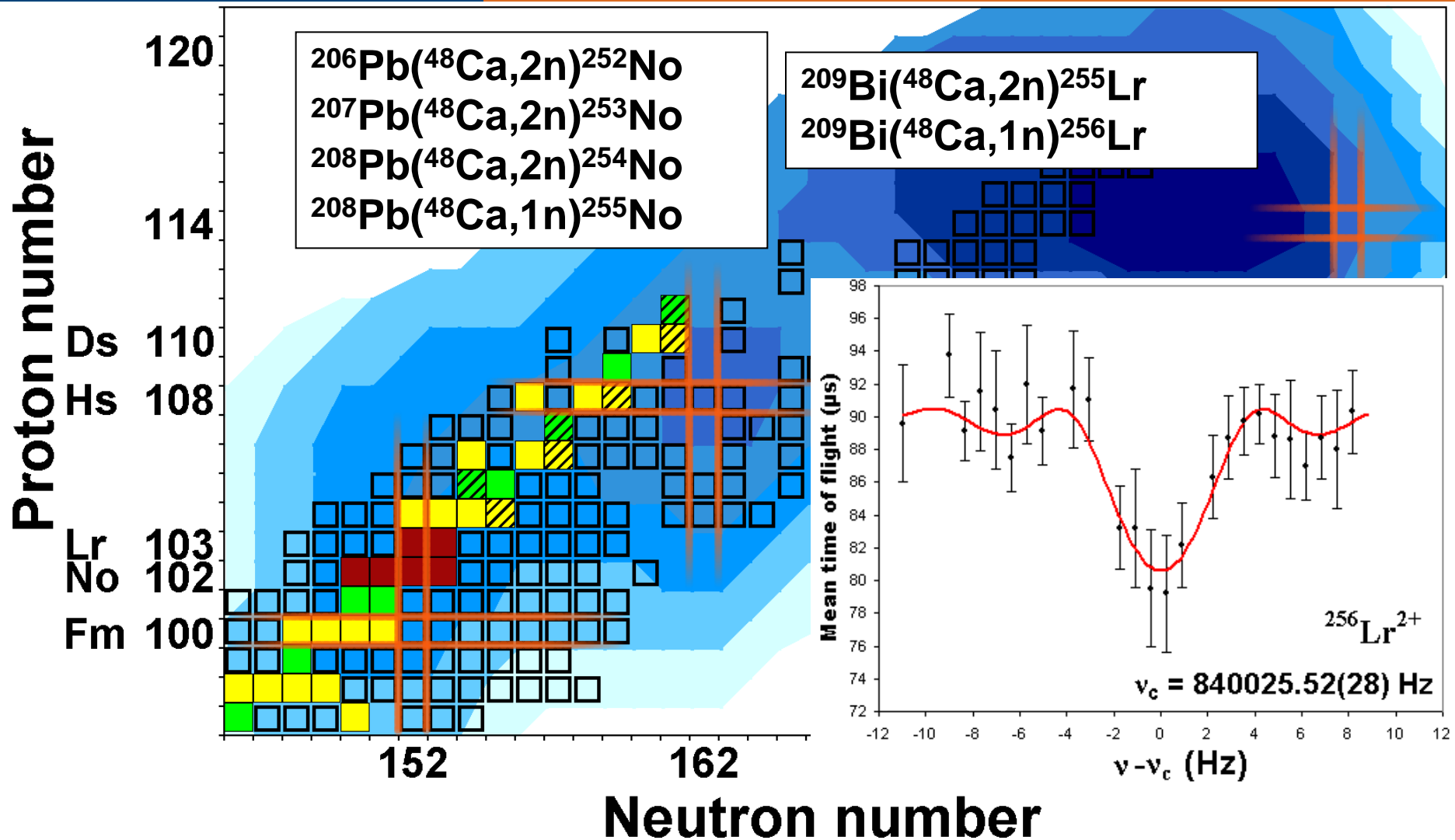




# SHIPTRAP Setup

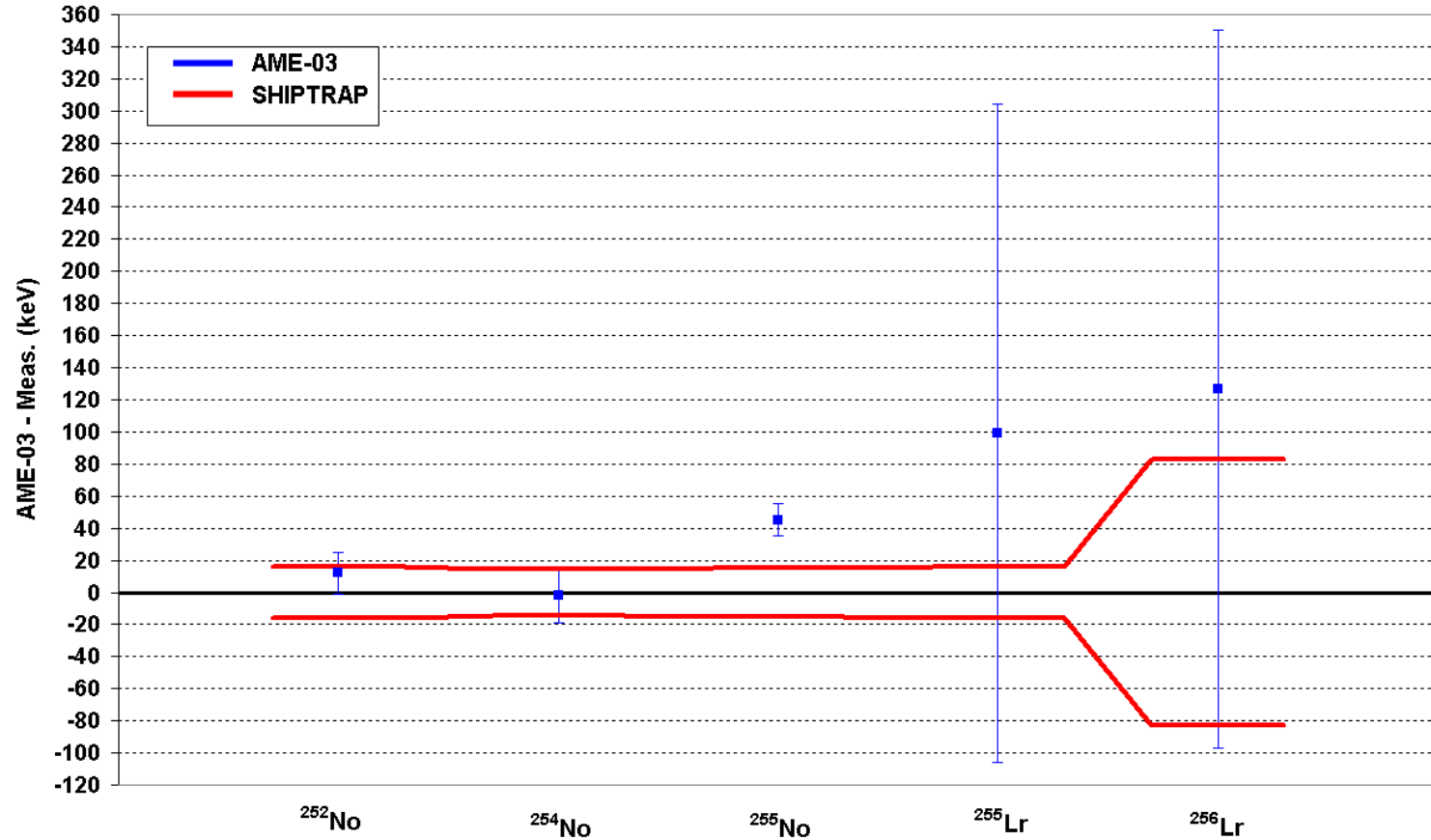


# Direct mass measurements with SHIPTRAP

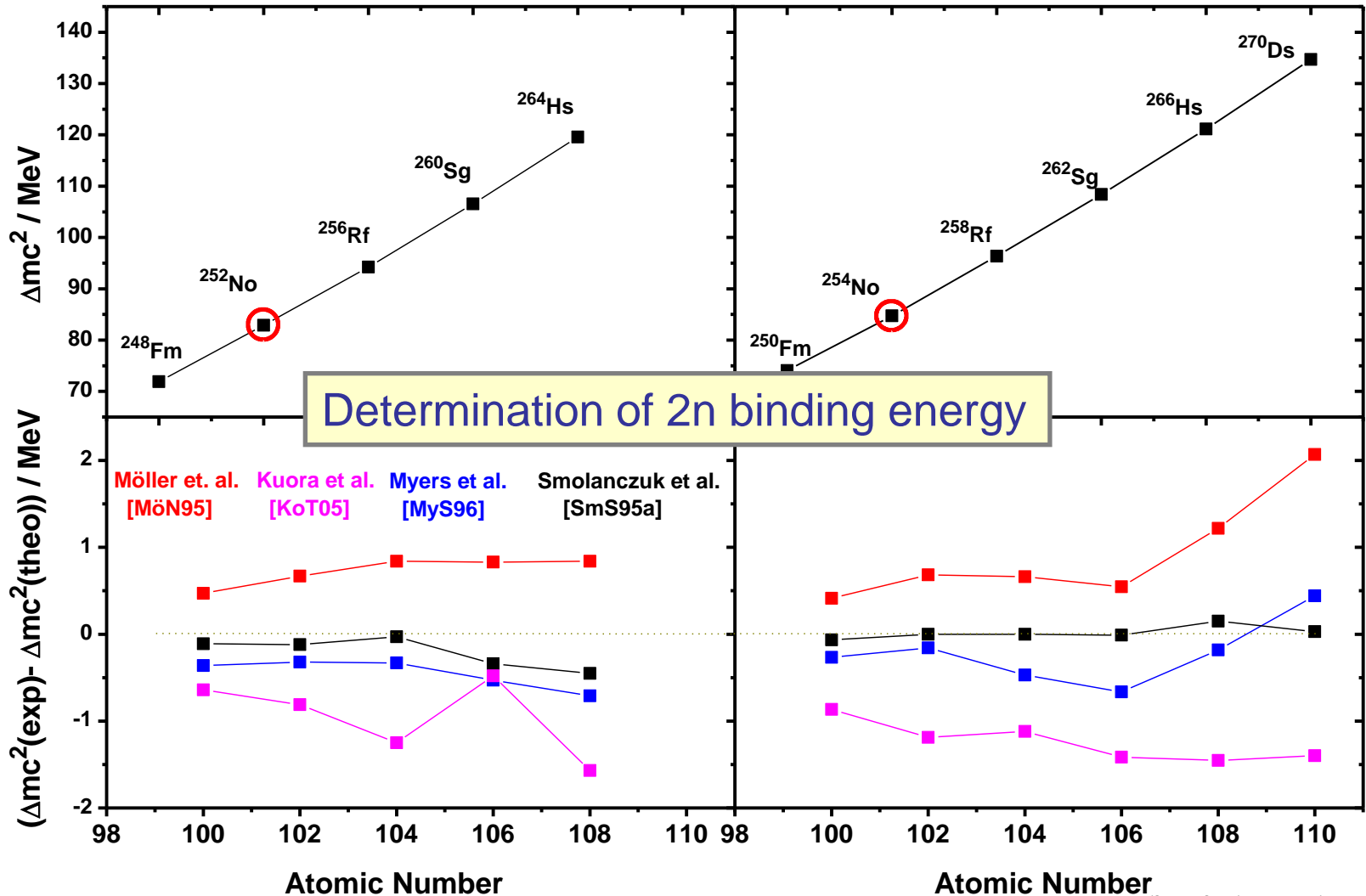


*M. Block et al., Nature 463, 785 (2010), M. Dworschak et al., Phys. Rev. C 81, 064312 (2010)*  
*E. Minaya Ramirez et al., Science 337, 1183 (2012)*

# Comparison of SHIPTRAP results to the AME



# Masses of even-even $N-Z = 48$ and $N-Z = 50$ Nuclei



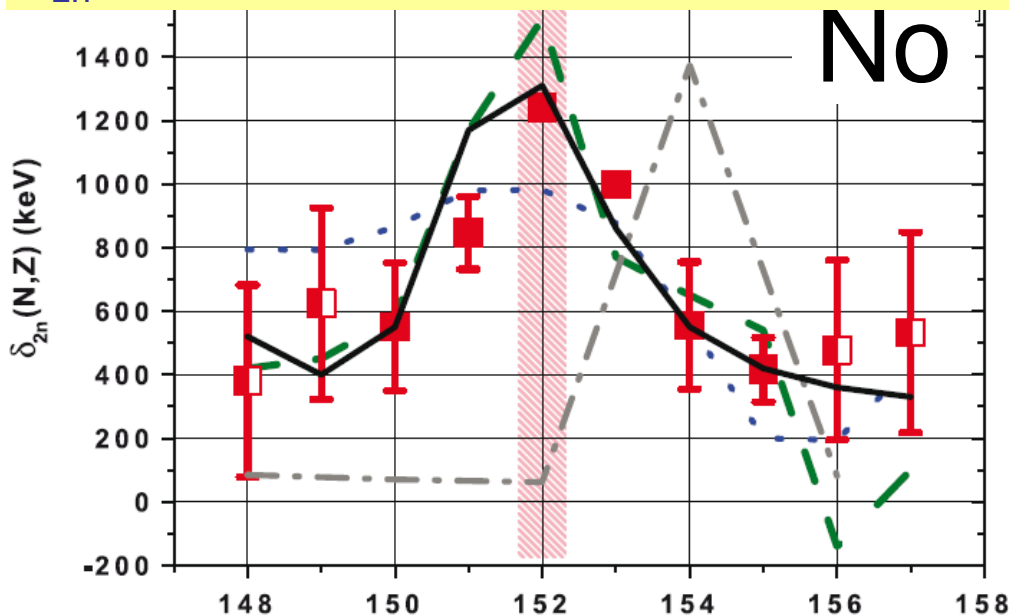
/StrukturSWK/Abbildungen/Massen,  
F.P. Heßberger, 3.9.2013

# SHIPTRAP: Probing the Strength of Shell Effects

## Direct Mapping of Nuclear Shell Effects in the Heaviest Elements

E. Minaya Ramirez,<sup>1,2</sup> D. Ackermann,<sup>2</sup> K. Blaum,<sup>3,4</sup> M. Block,<sup>2\*</sup> C. Droese,<sup>5</sup> Ch. E. Düllmann,<sup>6,2,1</sup>  
M. Dworschak,<sup>2</sup> M. Eibach,<sup>4,6</sup> S. Eliseev,<sup>3</sup> E. Haettner,<sup>2,7</sup> F. Herfurth,<sup>2</sup> F. P. Heßberger,<sup>2,1</sup>  
S. Hofmann,<sup>2</sup> J. Ketelaer,<sup>3</sup> G. Marx,<sup>5</sup> M. Mazzocco,<sup>8</sup> D. Nesterenko,<sup>9</sup> Yu. N. Novikov,<sup>9</sup> W. R. Plaß,<sup>2,7</sup>  
D. Rodríguez,<sup>10</sup> C. Scheidenberger,<sup>2,7</sup> L. Schweikhard,<sup>5</sup> P. G. Thirolf,<sup>11</sup> C. Weber<sup>11</sup>

$$\delta_{2n}(N,Z) = 2B(N,Z) - B(N-2,Z) - B(N+2,Z)$$



Experimental

Muntian (mic-mac)  
Z=114 N=184

Möller FRDM  
Z=114 N=184

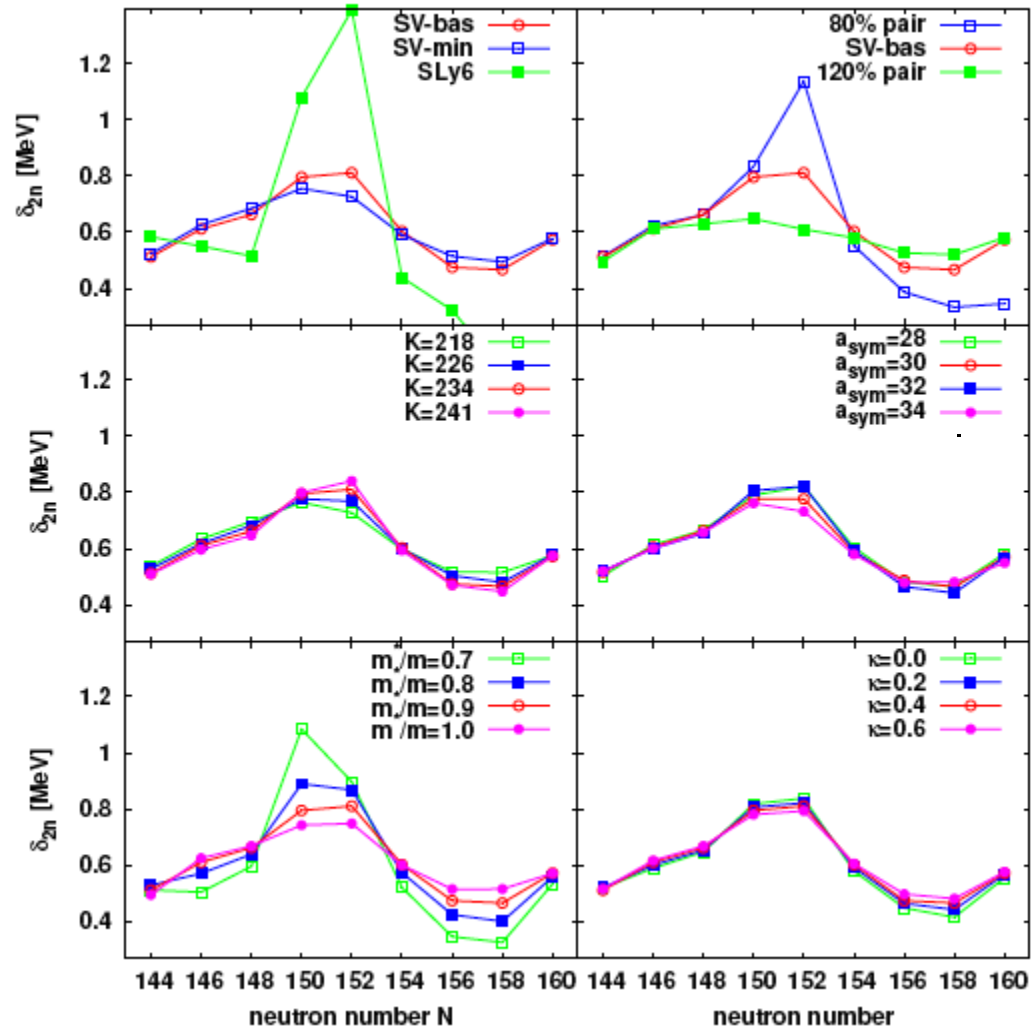
TW-99  
Z=120 N=172

SkM\*  
Z=126 N=184

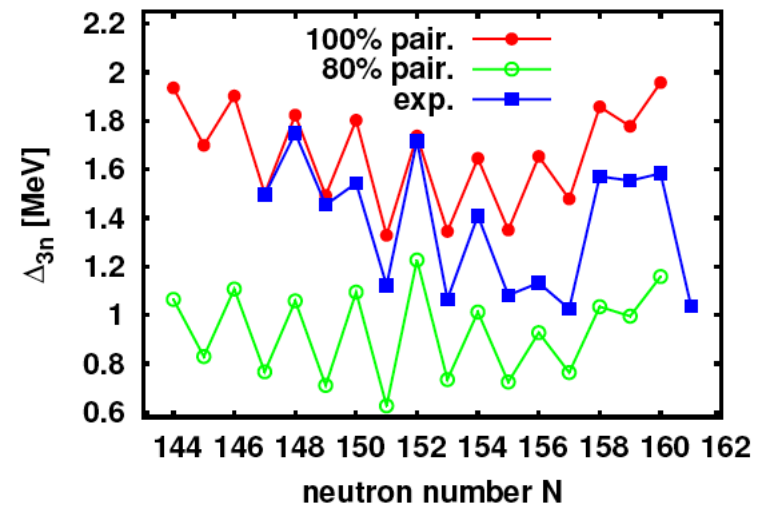
**Science** 337 (2012) 1207

# Calculations with Skyrme Forces

No isotopes

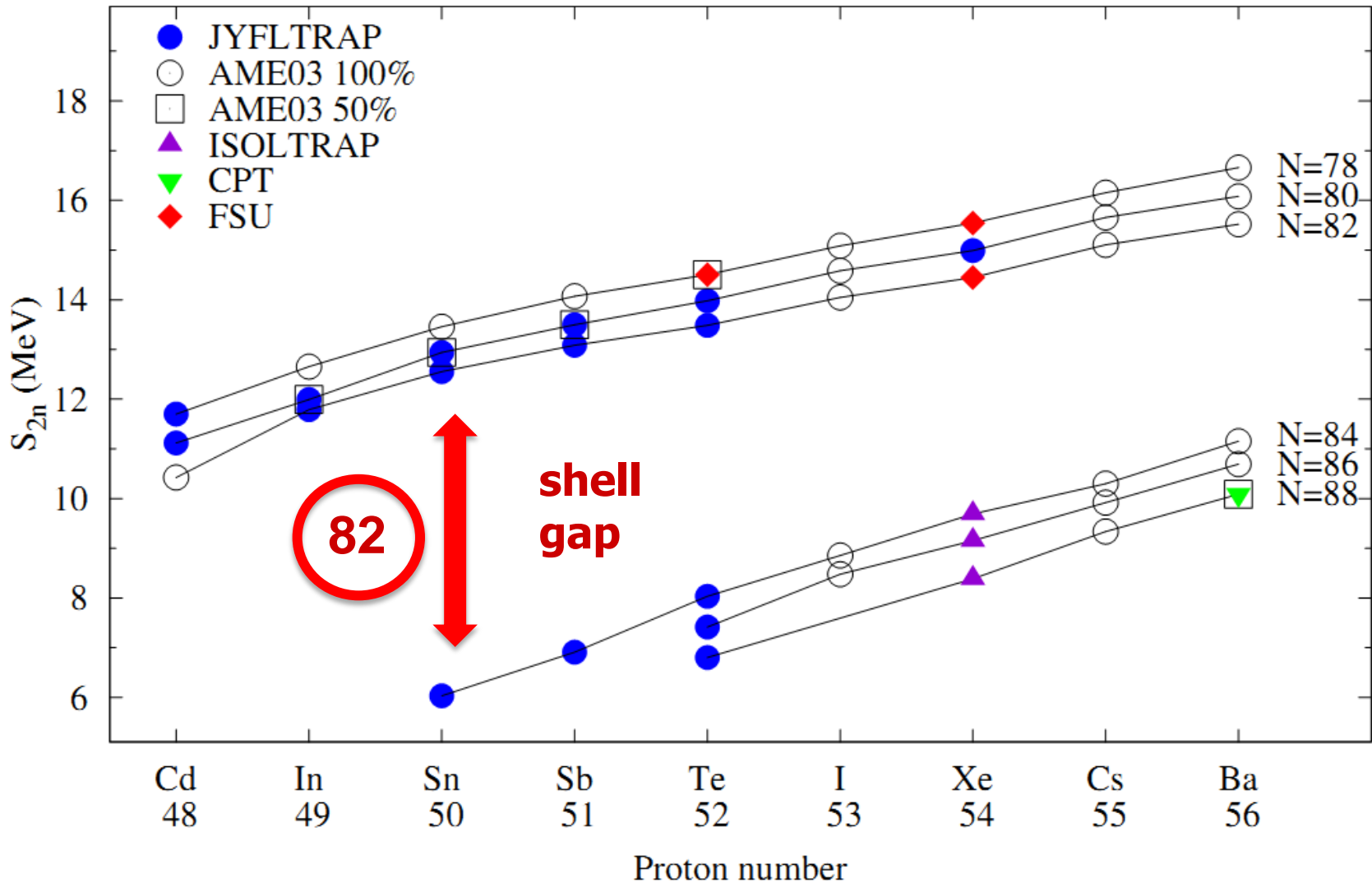


3-point difference (pairing gap), No isotopes

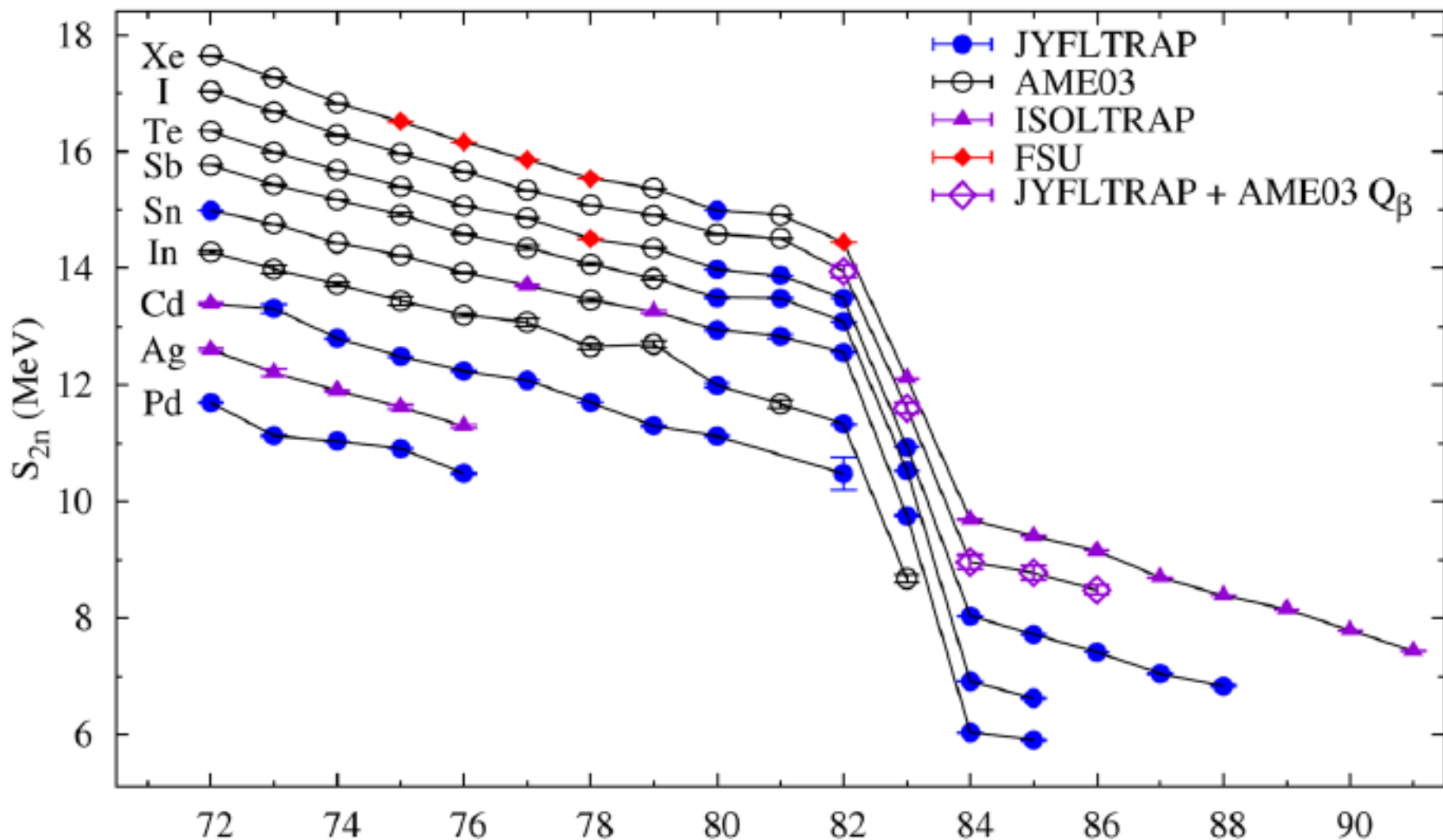


P. G. Reinhard

# Shell Gap at $N = 82$ via $S_{2n}$

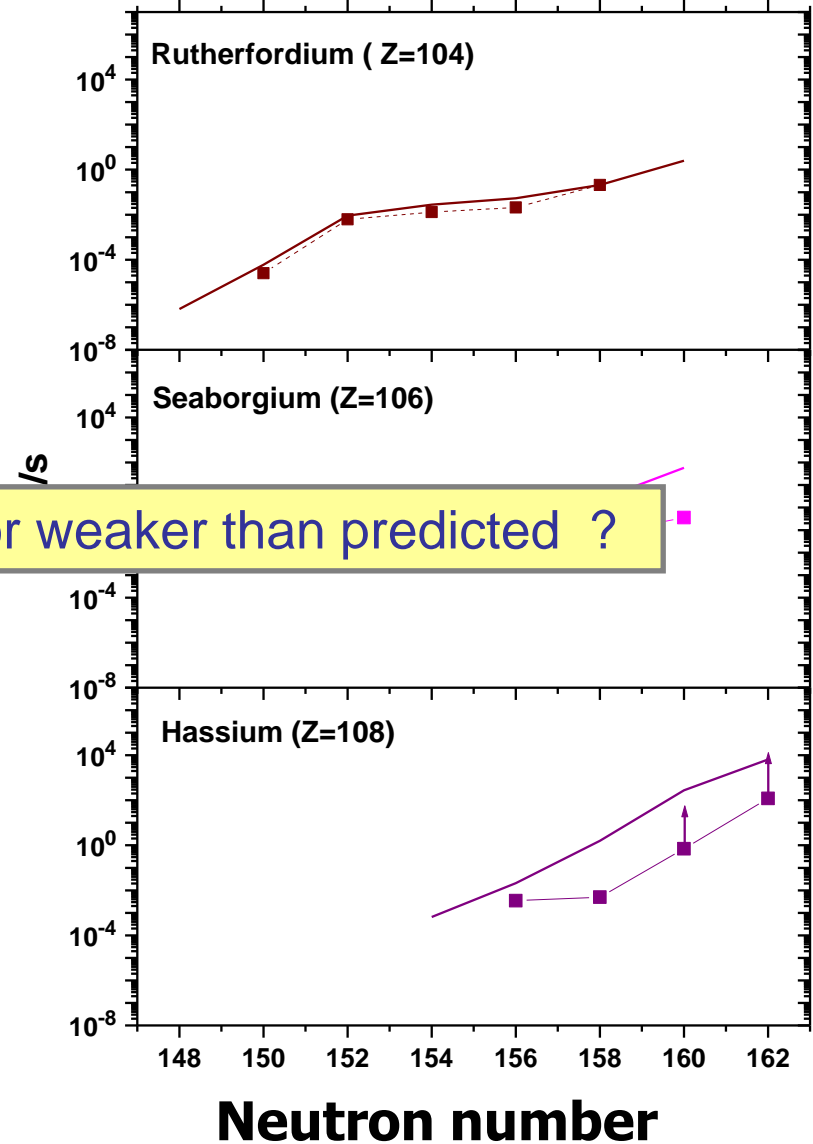
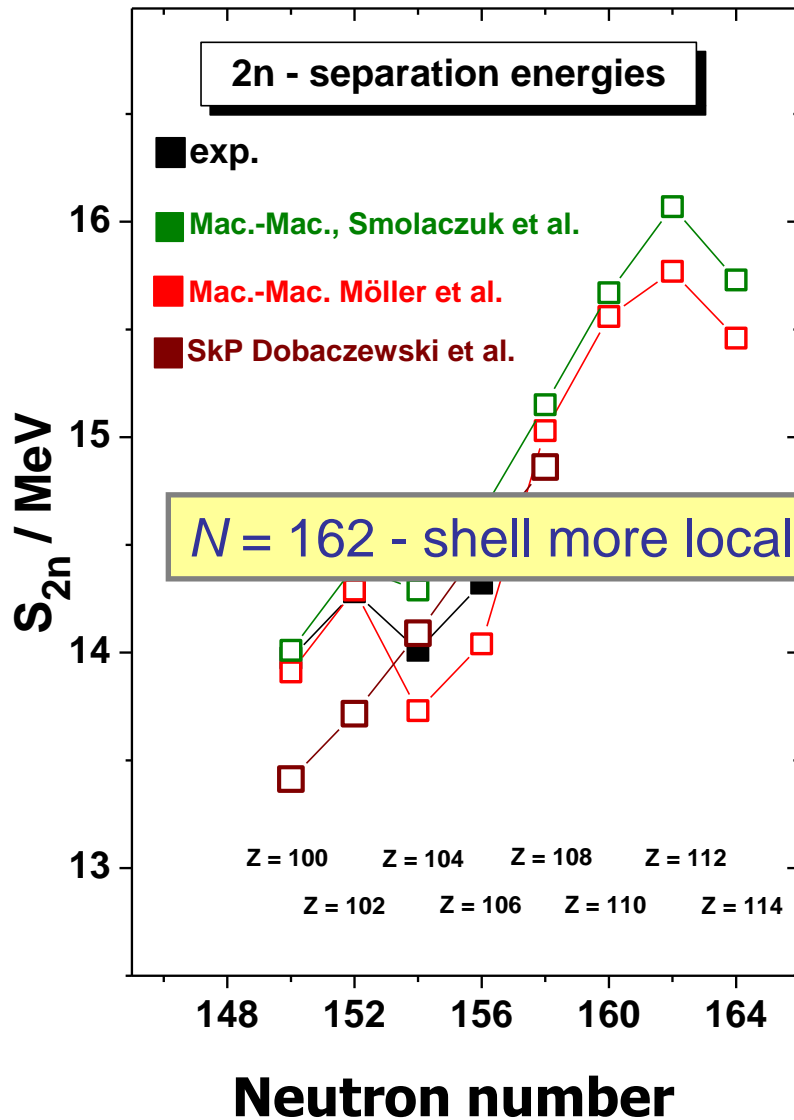


# Shell Gap at $N = 82$ via $S_{2n}$

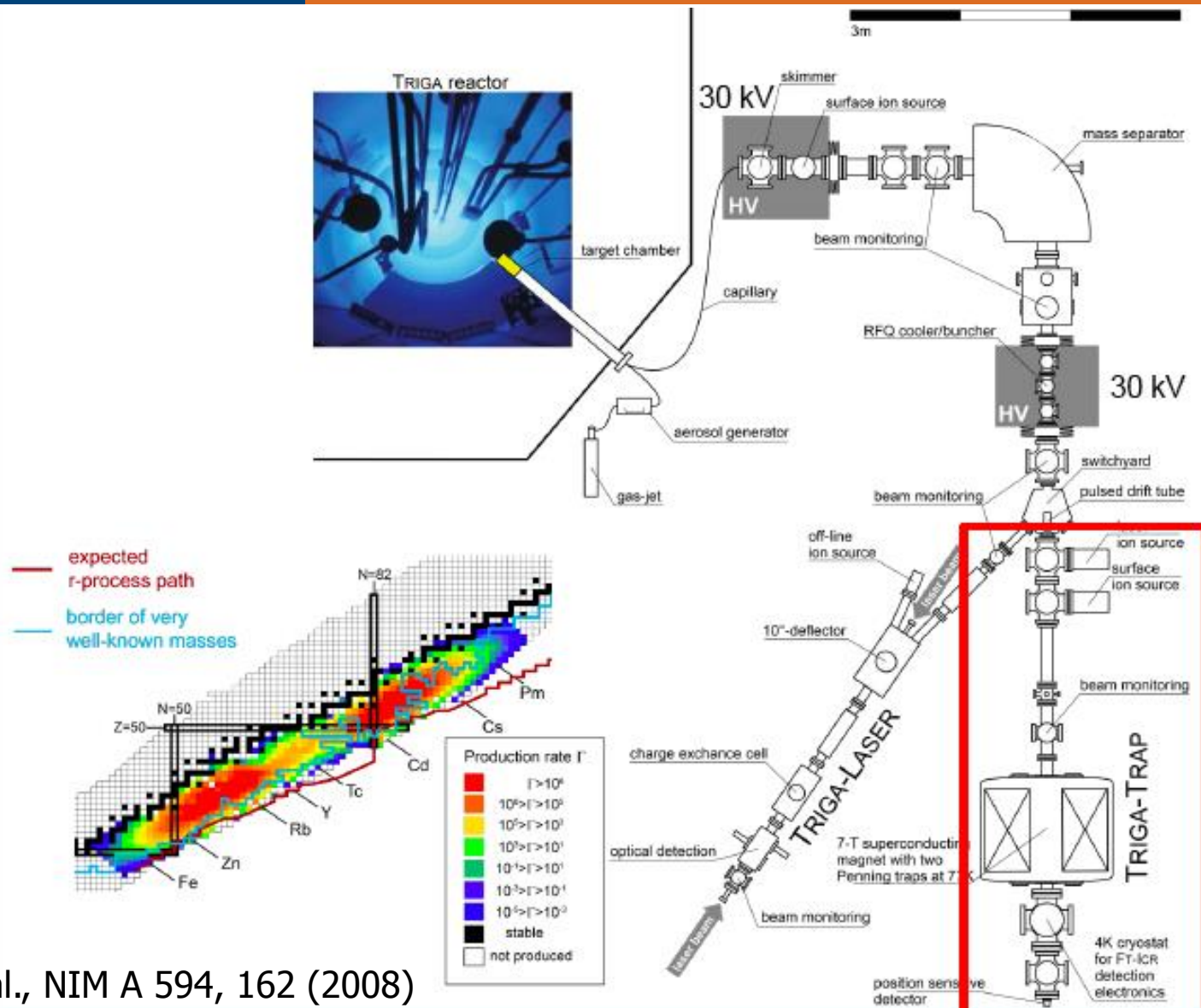




# Shell strength towards $N = 162$

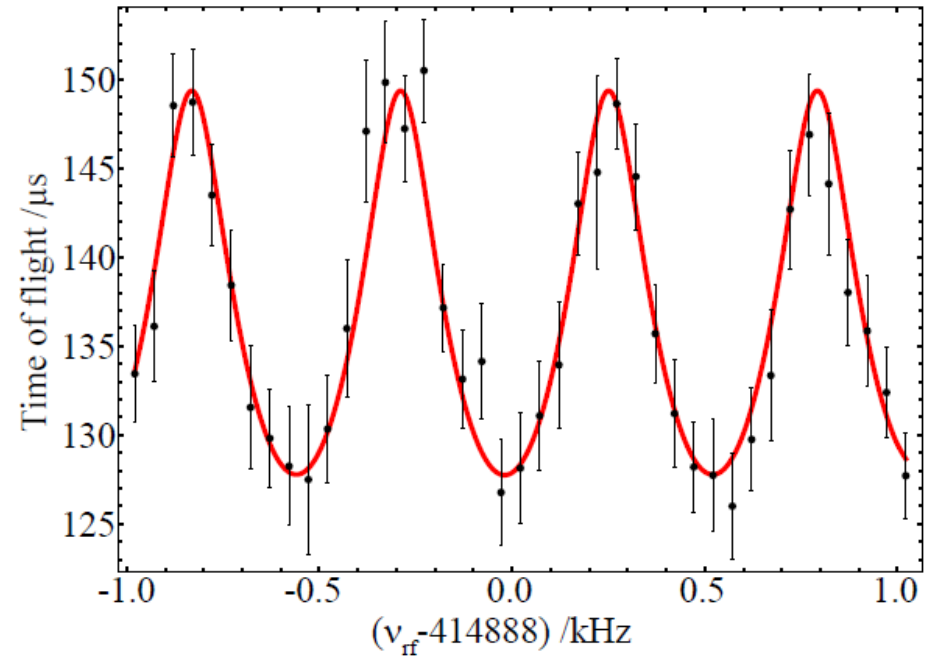
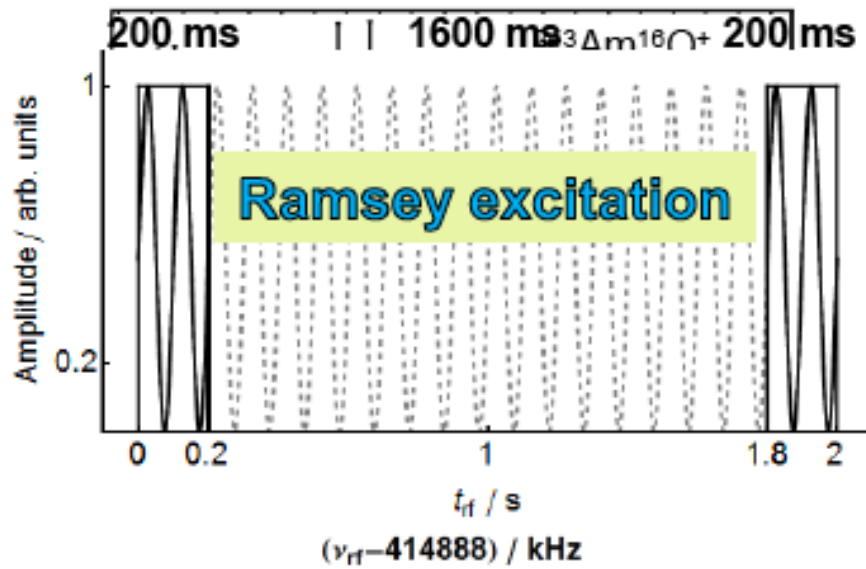


# TRIGA-SPEC Setup in Mainz



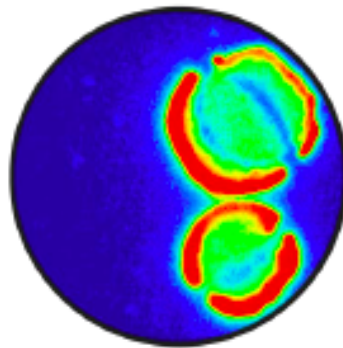
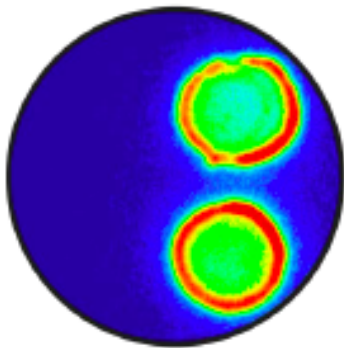


# TRIGA-TRAP Results 2013



target

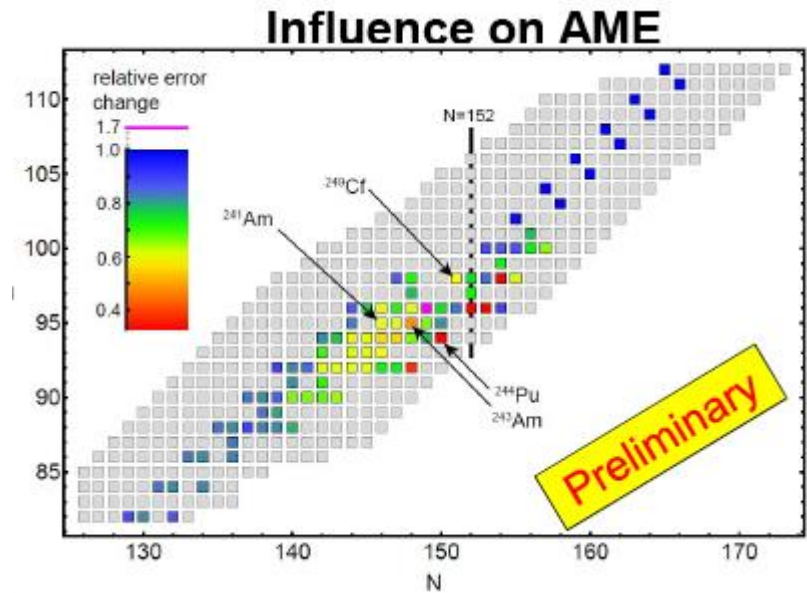
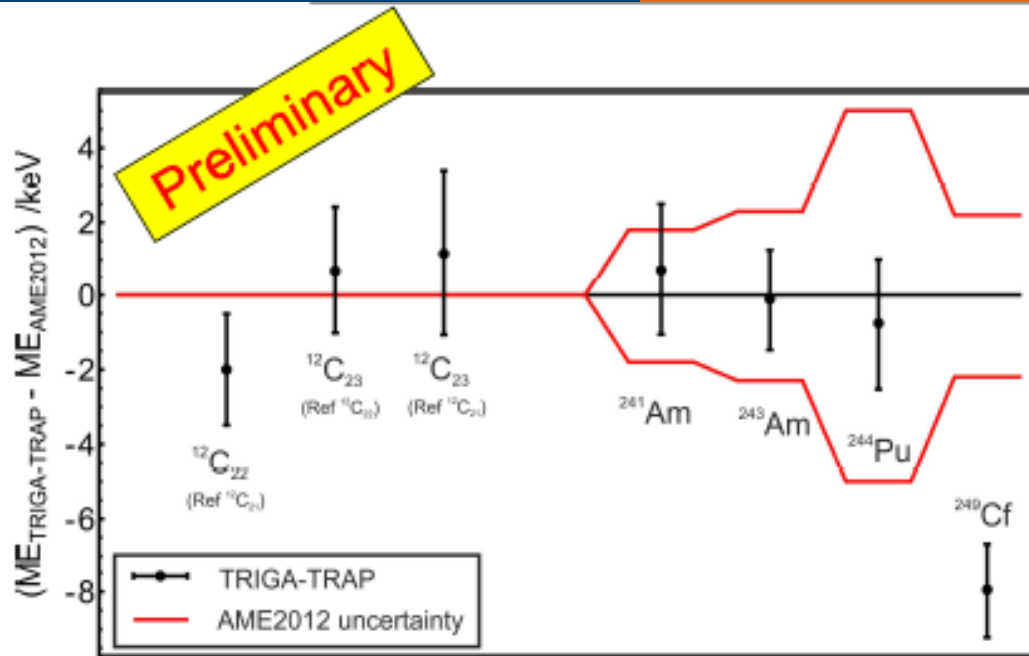
used target



5 mm

Mass measurement with only  $10^{15}$  atoms target material.

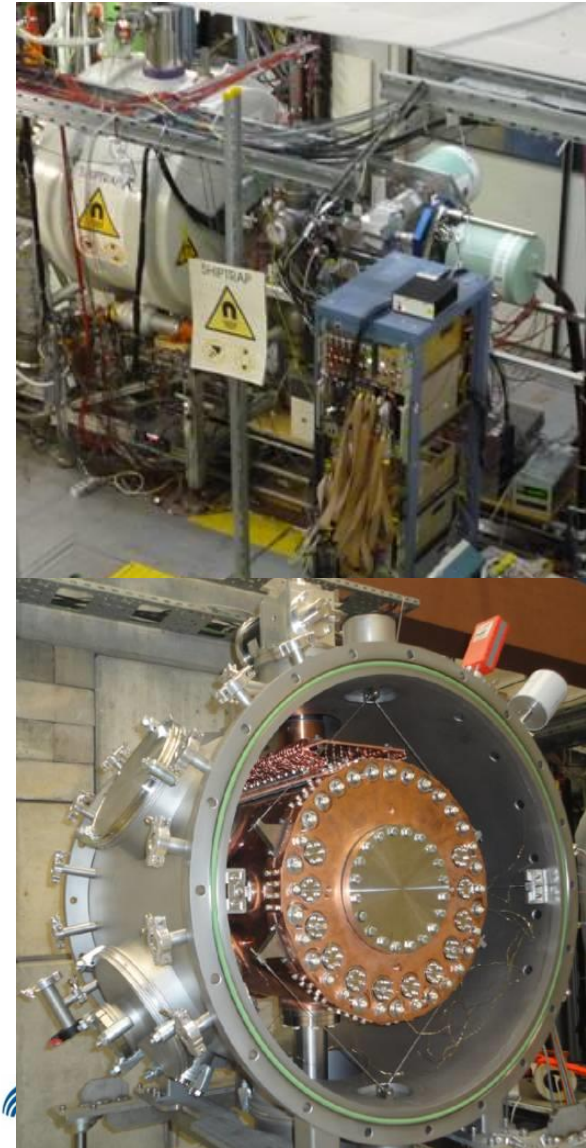
# Probing the Evolution of Shell Effects @ $N=152$



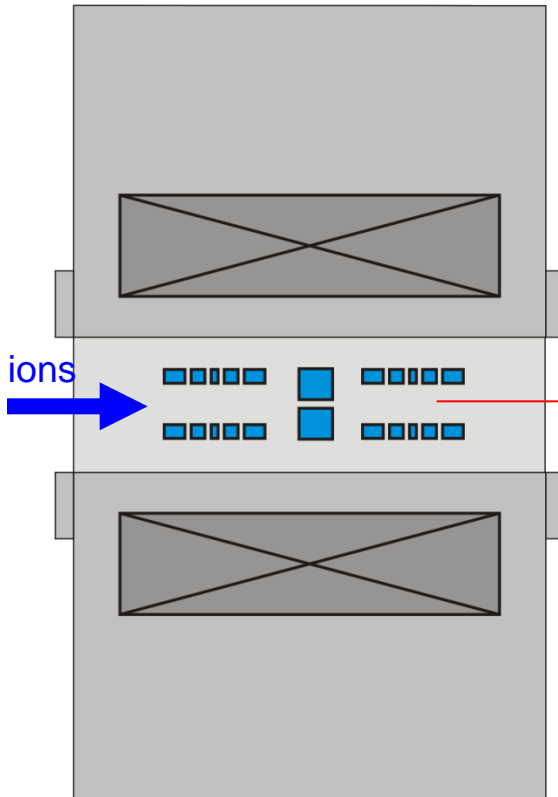
Accurate mass measurements with keV precision on long-lived actinides can be performed to provide anchor points and cross check masses obtained by other techniques

# Improvements and Extensions

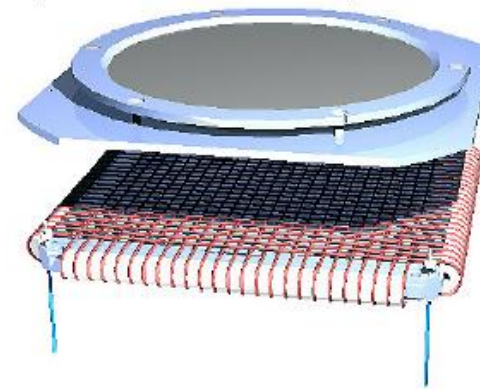
- **novel experiments**
  - trap-assisted decay spectroscopy
  - in-trap decay spectroscopy
  - in-trap and in-gas cell ion chemistry
- **increasing efficiency, sensitivity, and resolving power**
  - cryogenic gas stopper
  - single-ion mass measurement scheme
  - new measurement techniques



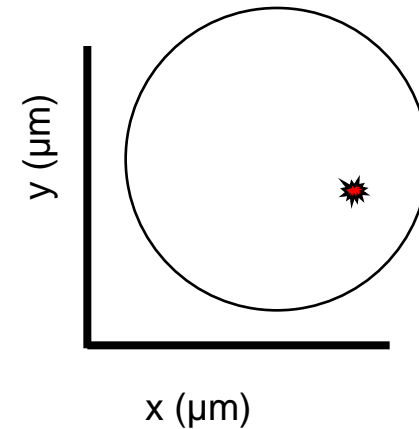
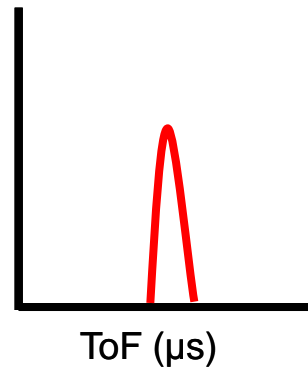
# Phase Imaging Ion Cyclotron Resonance (PI-ICR)



Delay-Line Detector by Roentdek GmbH

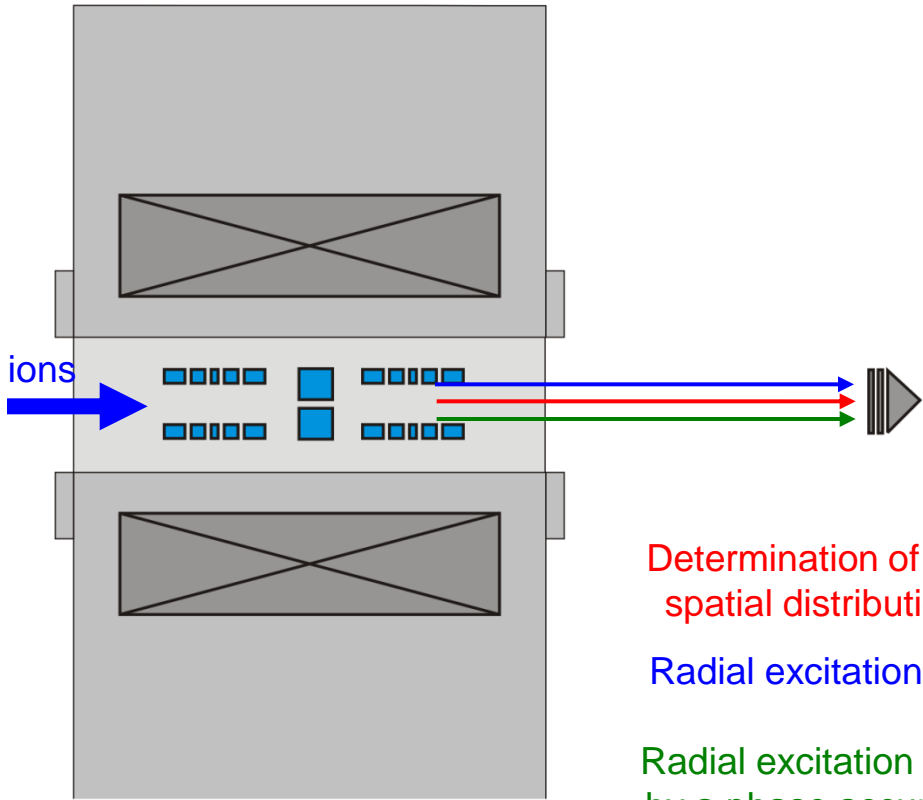


Position sensitive detector



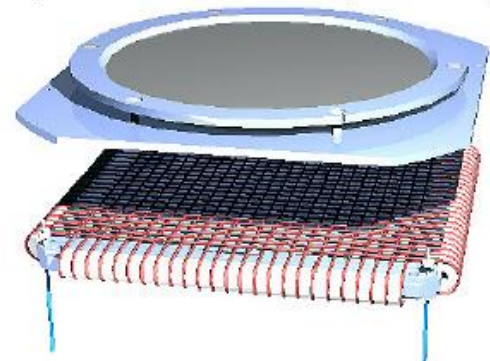
- **position resolution : 70  $\mu\text{m}$**
- **active diameter : 42 mm**

# Phase Imaging Ion Cyclotron Resonance (PI-ICR)

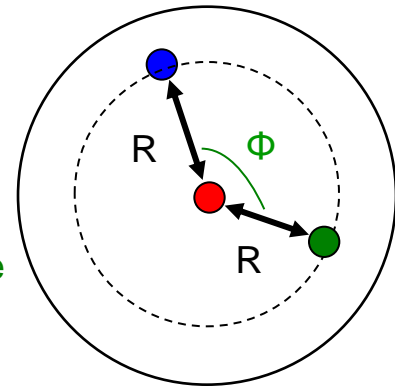


Determination of the spatial distribution  
 Radial excitation  
 Radial excitation followed by a phase accumulation time

Delay-Line Detector by Roentdek



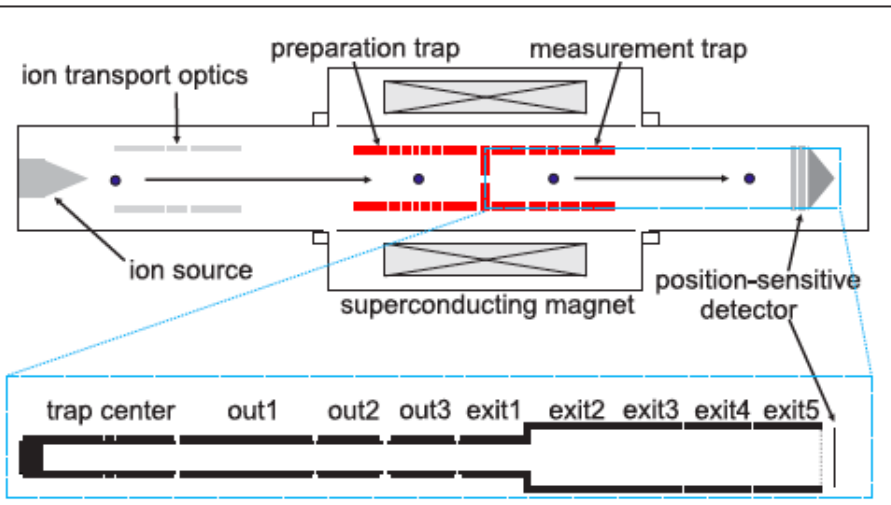
Independent Measurements of Eigenfrequencies  $\nu_+$  and  $\nu_-$



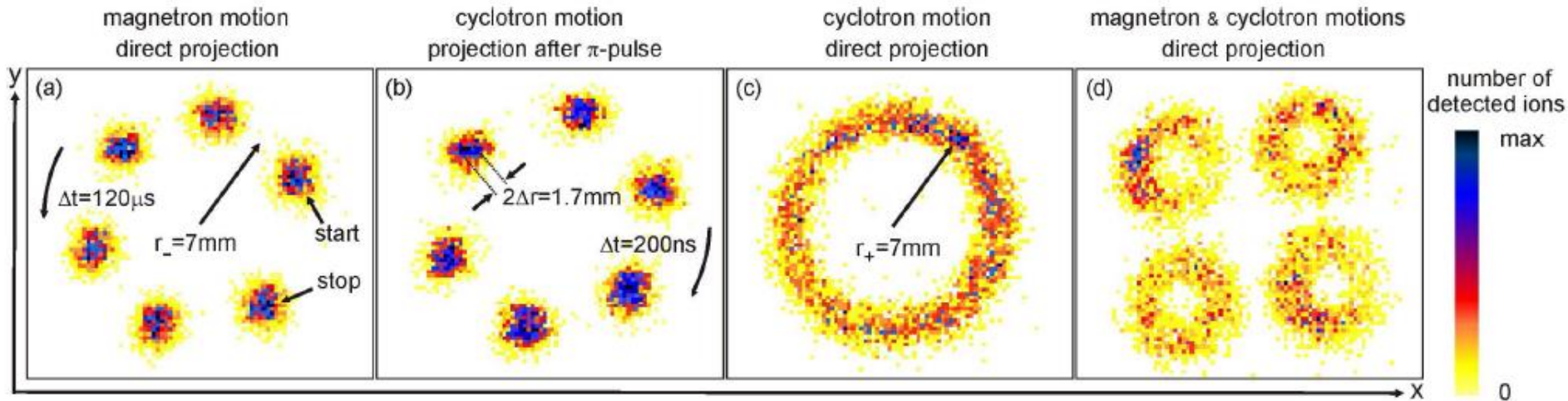
$$\phi + 2\pi n = 2\pi \nu t \quad \Delta \nu = \frac{\Delta \phi}{2\pi t} = \frac{\Delta R}{\pi t R}$$



# Phase Imaging-Ion Cyclotron Resonance Method

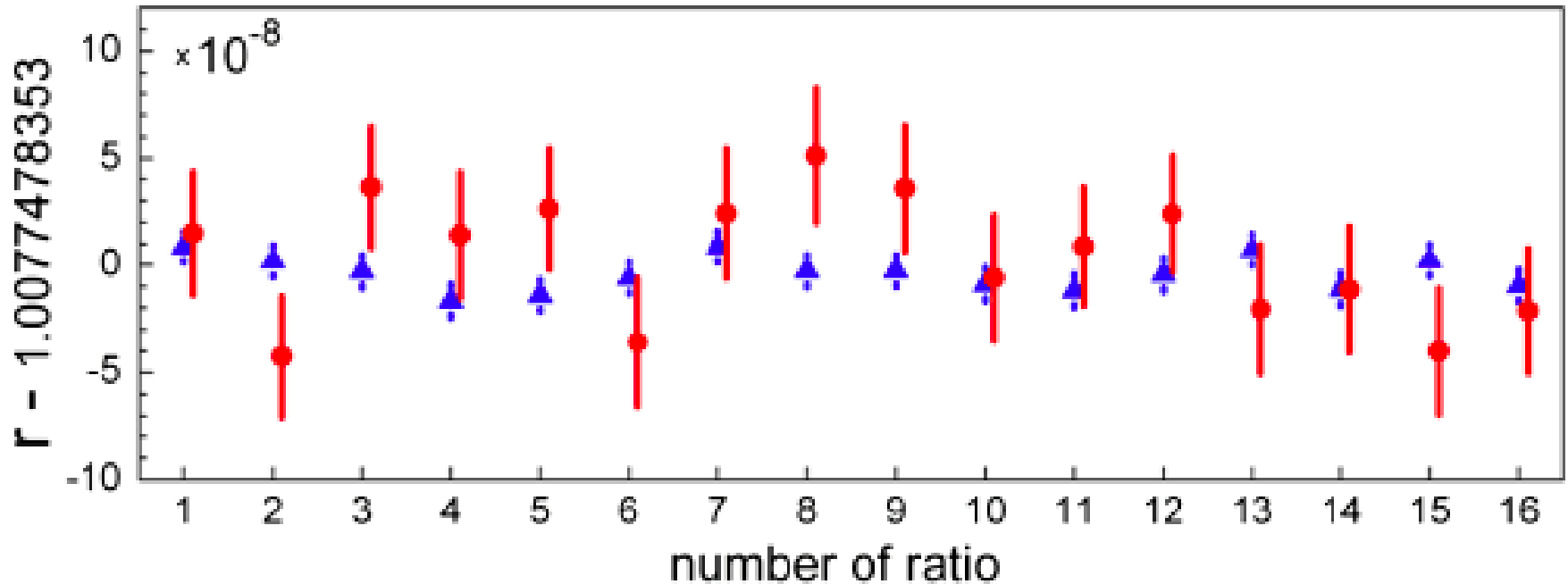


- Image ion motion
- Determine phase of ion motion
- Excite ions
- Determine phase after evolution time



S. Eliseev et al., Phys. Rev. Lett. 110, 082501 (2013)  
 S. Eliseev et al., Appl. Phys. B (2013) in press

# Phase Imaging-Ion Cyclotron Resonance



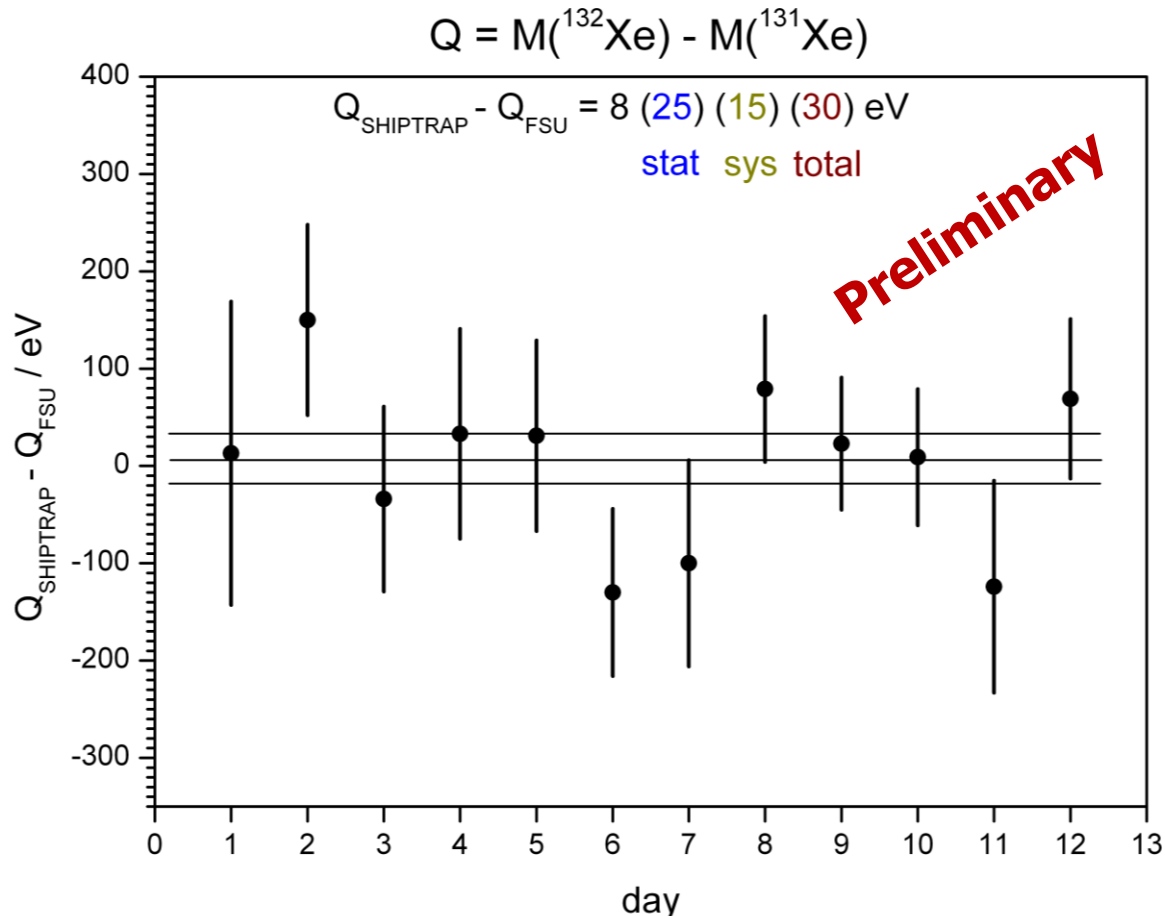
$^{129}\text{Xe}-^{130}\text{Xe}$  mass difference  $\Delta m_{\text{SHIPTRAP-FSU}} = 180(240) \text{ eV}$

Improved performance compared to conventional method:

- **40x gain in resolving power**
- **5x gain in precision**

# Phase Imaging-Ion Cyclotron Resonance

Outstanding performance of PI-ICR technique  
 $\delta m \approx 10^{-9}$  for stable xenon isotopes demonstrated



Next step:  $^{187}\text{Re}/^{187}\text{Os}$  Q value measurement (ongoing)

# Future at FAIR: MATS

## TDR approved by FAIR STI in May 2010

Dipole magnet  
(Jyväskylä)

RFQ buncher  
(Jyväskylä)

MR-TOF-MS  
(Giessen)

LaSpec facility  
(talk by W. Nörtershäuser)

MATS Penning traps  
(LMU, Granada, GSI, Mainz,  
MPIK, Sweden, VECC)

EBIT  
(MPIK)

Spectroscopy setup  
(IFIC, UPC)

Gas catcher  
(Giessen, GSI, Jyväskylä, KVI)

Beam line, ion sources,  
identification  
(Greifswald, PNPI)  
In-trap decay  
(LMU, PNPI)

Eur. Phys. J. Special Topics 183, 1–123 (2010)  
© EDP Sciences, Springer-Verlag 2010  
DOI: 10.1140/epjst/e2010-01231-2

THE EUROPEAN  
PHYSICAL JOURNAL  
SPECIAL TOPICS

Review

### MATS and LaSpec: High-precision experiments using ion traps and lasers at FAIR

D. Rodríguez<sup>1,a</sup>, K. Blaum<sup>2,b</sup>, W. Nörtershäuser<sup>3,c</sup>, M. Ahammed<sup>4</sup>, A. Algora<sup>5</sup>, G. Audi<sup>6</sup>, J. Äystö<sup>7</sup>, D. Beck<sup>8</sup>, M. Bender<sup>9</sup>, J. Billowes<sup>10</sup>, M. Block<sup>8</sup>, C. Böhm<sup>2</sup>, G. Bollen<sup>11</sup>, M. Brodeur<sup>12</sup>, T. Brunner<sup>12</sup>, B.A. Bushaw<sup>13</sup>, R.B. Cakirli<sup>2</sup>, P. Campbell<sup>10</sup>, D. Cano-Ott<sup>14</sup>, G. Cortés<sup>15</sup>, J.R. Crespo López-Urrutia<sup>2</sup>, P. Das<sup>1</sup>, A. Dax<sup>16</sup>, A. De<sup>17</sup>, P. Delheij<sup>12</sup>, T. Dickel<sup>18</sup>, J. Dilling<sup>12</sup>, K. Eberhardt<sup>3</sup>, S. Eliseev<sup>2</sup>, S. Ettenauer<sup>12</sup>, K.T. Flanagan<sup>10</sup>, R. Ferrer<sup>11</sup>, J.-E. García-Ramos<sup>19</sup>, E. Gartzke<sup>20</sup>, H. Geissel<sup>8,18</sup>, S. George<sup>11</sup>, C. Geppert<sup>3</sup>, M.B. Gómez-Hornillos<sup>15</sup>, Y. Gusev<sup>21</sup>, D. Habs<sup>20</sup>, P.-H. Heenen<sup>22</sup>, S. Heinz<sup>8</sup>, F. Herfurth<sup>8</sup>, A. Herlert<sup>16</sup>, M. Hobein<sup>24</sup>, G. Huber<sup>25</sup>, M. Huysse<sup>26</sup>, C. Jesch<sup>18</sup>, A. Jokinen<sup>7</sup>, O. Kester<sup>11</sup>, J. Ketelaer<sup>2</sup>, V. Kolhinen<sup>7</sup>, I. Koudriavtsev<sup>26</sup>, M. Kowalska<sup>2</sup>, J. Krämer<sup>3</sup>, S. Kreim<sup>2</sup>, A. Krieger<sup>3</sup>, T. Kühl<sup>8</sup>, A.M. Lallena<sup>1</sup>, A. Lapiere<sup>12</sup>, F. Le Blanc<sup>27</sup>, Y.A. Litvinov<sup>2,8</sup>, D. Lunney<sup>6</sup>, T. Martínez<sup>14</sup>, G. Marx<sup>23</sup>, M. Matos<sup>28</sup>, E. Minaya-Ramírez<sup>3</sup>, I. Moore<sup>7</sup>, S. Nagy<sup>2</sup>, S. Naimi<sup>6</sup>, D. Neidherr<sup>2</sup>, D. Nesterenko<sup>21</sup>, G. Neyens<sup>26</sup>, Y.N. Novikov<sup>21</sup>, M. Petrick<sup>18</sup>, W.R. Plaß<sup>8,18</sup>, A. Popov<sup>21</sup>, W. Quint<sup>8</sup>, A. Ray<sup>4</sup>, P.-G. Reinhard<sup>29</sup>, J. Repp<sup>2</sup>, C. Roux<sup>2</sup>, B. Rubio<sup>5</sup>, R. Sánchez<sup>3</sup>, B. Schabinger<sup>2</sup>, C. Scheidenberger<sup>8,18</sup>, D. Schneider<sup>30</sup>, R. Schuch<sup>24</sup>, S. Schwarz<sup>10</sup>, L. Schweikhard<sup>23</sup>, M. Seliverstov<sup>21</sup>, A. Solders<sup>24</sup>, M. Suhonen<sup>24</sup>, J. Szerypo<sup>20</sup>, J.L. Taín<sup>5</sup>, P.G. Thirol<sup>20</sup>, J. Ullrich<sup>2</sup>, P. Van Duppen<sup>26</sup>, A. Vasiliev<sup>21</sup>, G. Vorobjev<sup>21</sup>, C. Weber<sup>20</sup>, K. Wendt<sup>25</sup>, M. Winkler<sup>8</sup>, D. Yordanov<sup>16</sup>, and F. Ziegler<sup>23</sup>

# Conclusions

## **Ion traps are powerful tools for nuclear structure studies**

- mass measurements for yields of  $\approx 1$  / min demonstrated
- novel techniques increase sensitivity, resolving power, and accuracy
- Powerful tool to track shell structure evolution
- precise Manipulation and purification of samples for trap-assisted decay spectroscopy (state-selected beams) possible
- push towards more exotic (short-lived) nuclides at next-generation RIB facilities

**Thank you for your attention !**

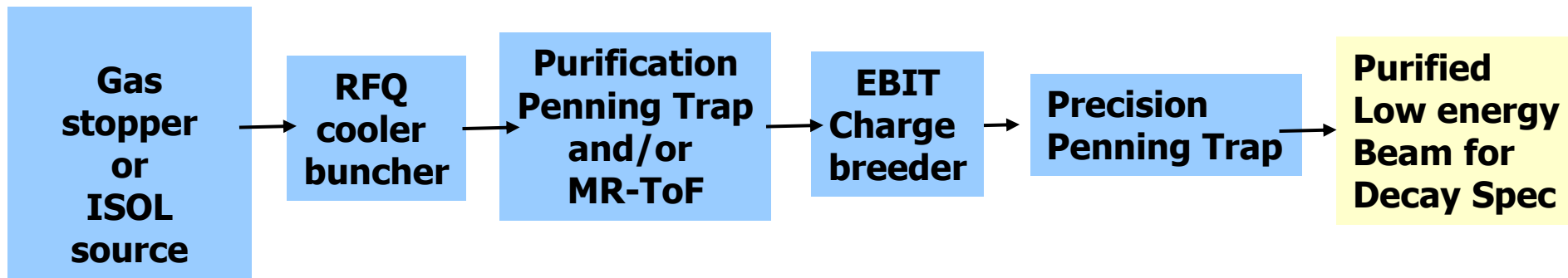
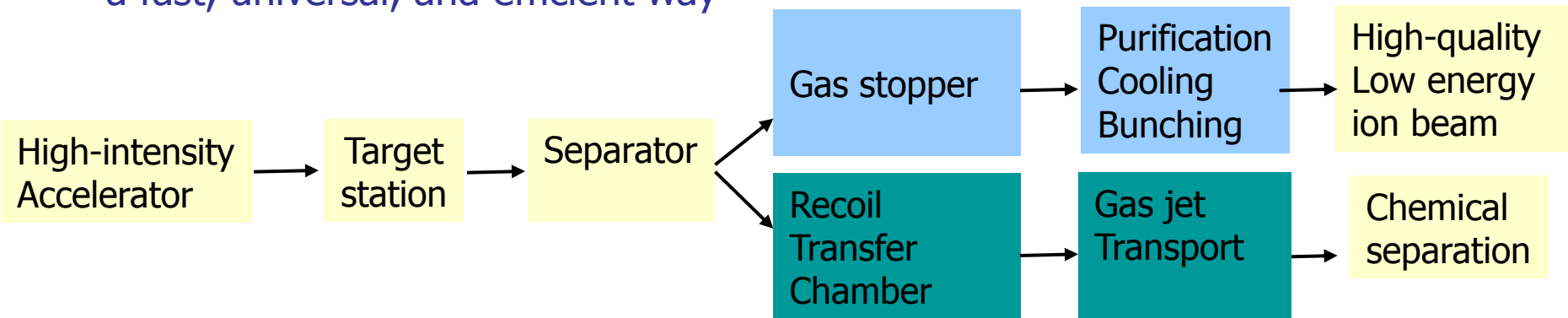
# The SHIPTRAP collaboration 2010



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# Preparing Rare Isotopes for Precision Experiments

Task: prepare rare isotopes of all elements for experiments at low-energy in a fast, universal, and efficient way



Gas cells successfully employed at Cern/Aargonne, SHIP TRAP/GSI, IGISOL/JYFL, LISOL/Louvain-la-Neuve, and for fragment beams at NSCL/MSU, RIKEN, FRS/GSI

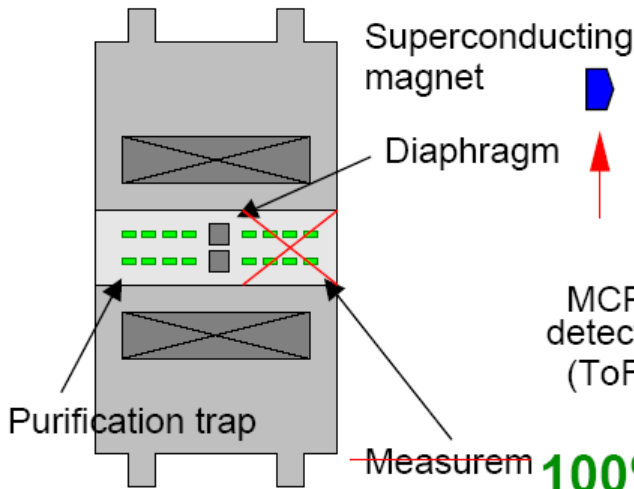


# TRAPSPEC: Trap-assisted Spectroscopy

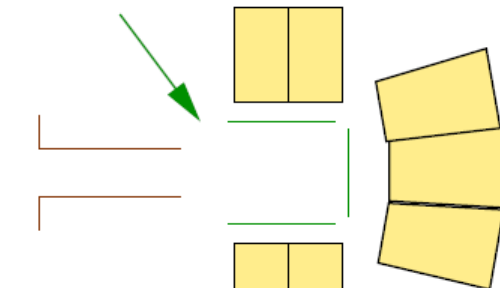
Penning Traps

Detector

TRAPSPEC

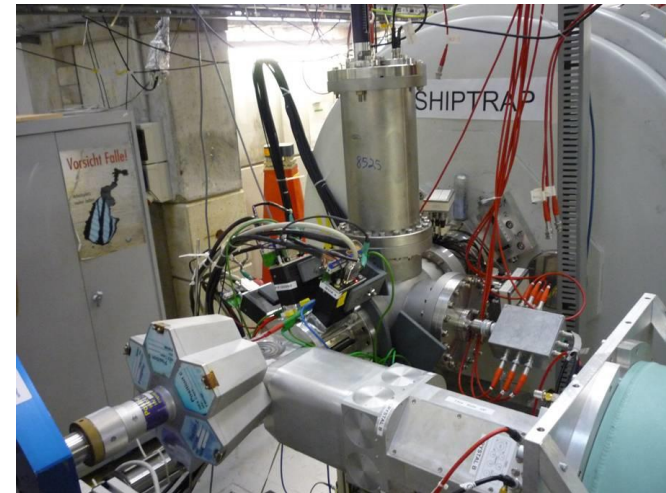
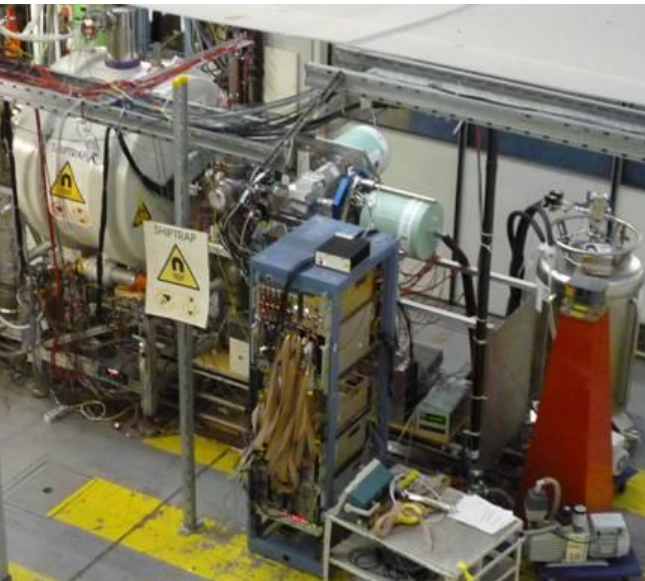


Silicon box



Cluster- and Clover-type Ge detectors

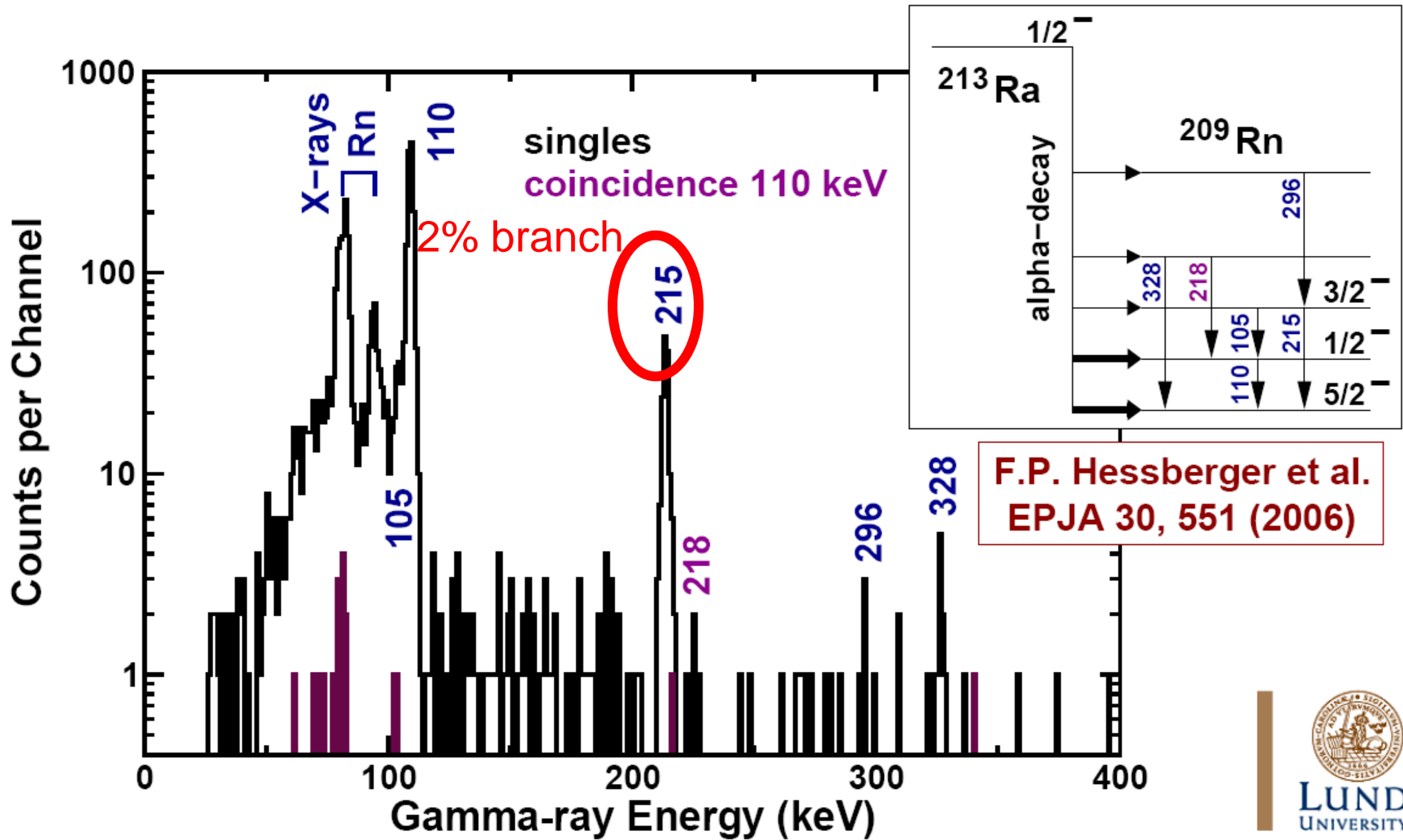
100% transmission!



Penning trap as high-resolution mass separator to prepare state-selected pure sample

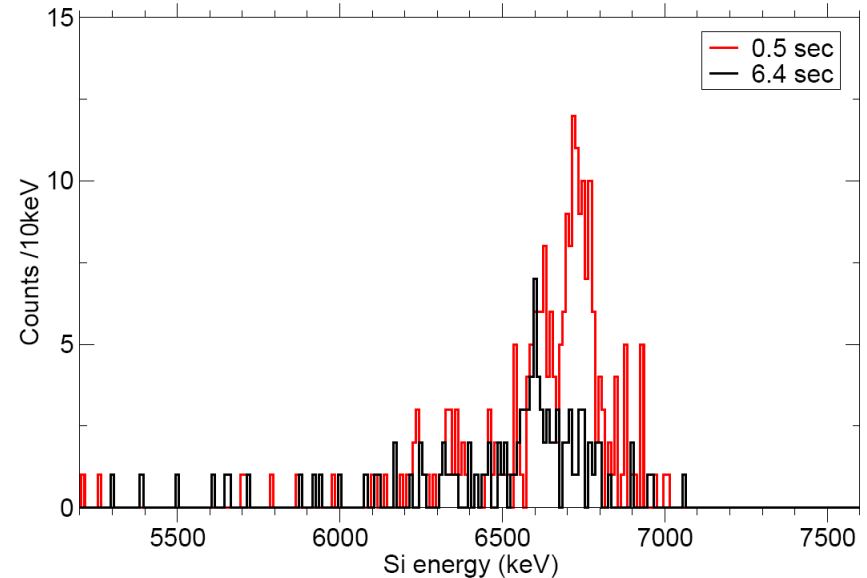
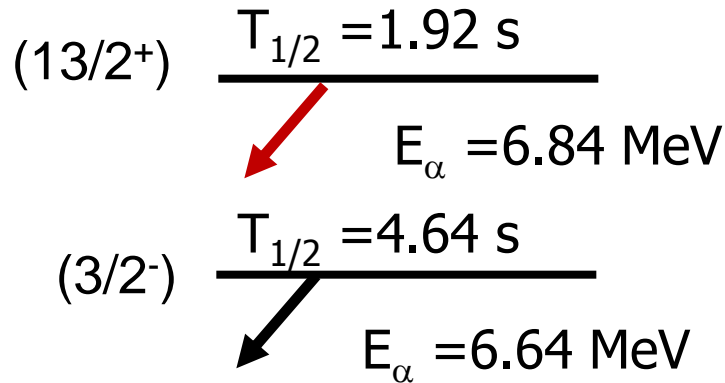
*M. B., D. Rudolph et al.*

# TRAPSPEC – Decay studies $^{213}\text{Ra}$



# TRAPSPEC – State selection by half-life

$^{195}\text{Po}$

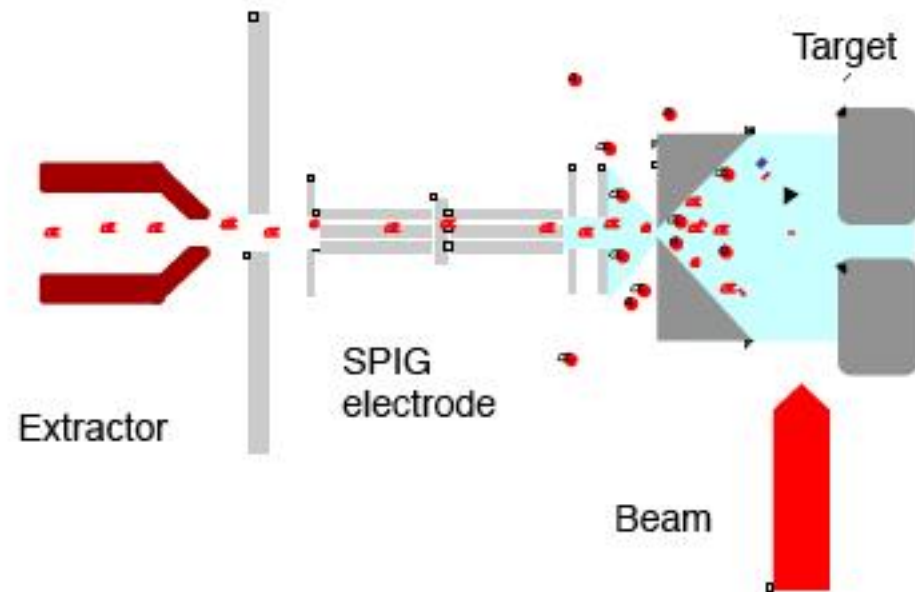
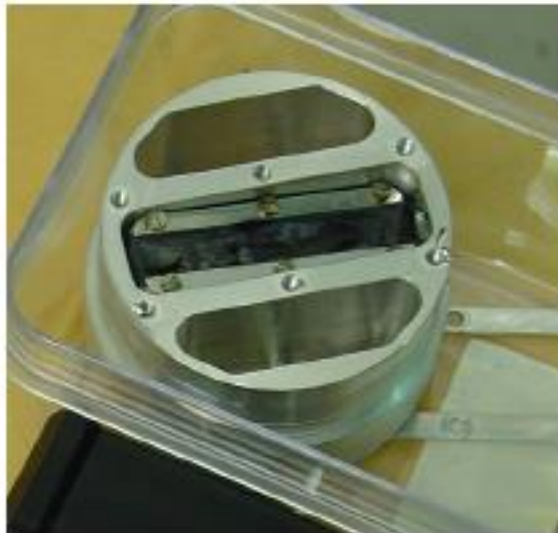


$\alpha$ -spectrum for different storage time in the Penning trap:

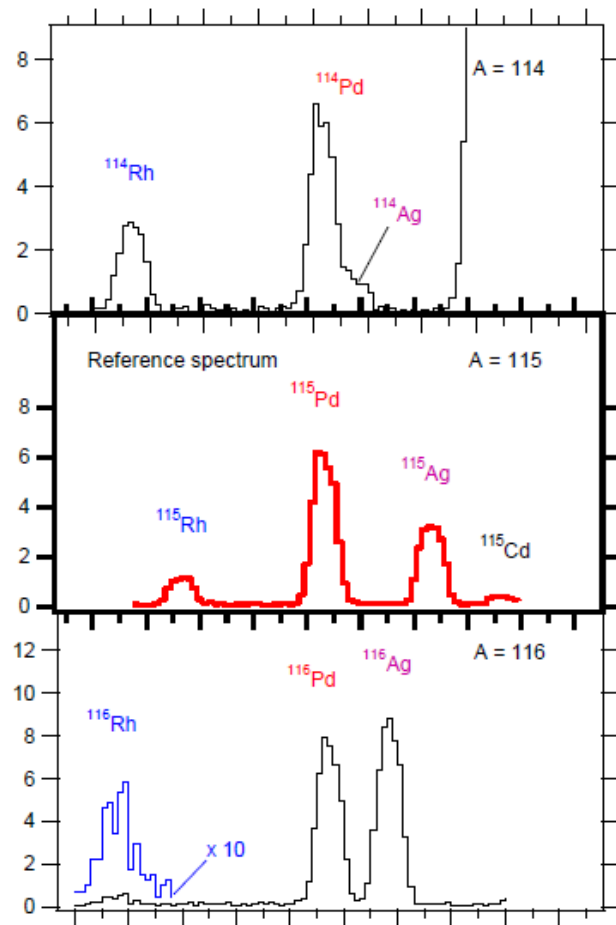
- short-lived state decays
- $\alpha$ -daughter not captured due to high recoil
- preparation of a single state
- in addition: mass spectrometric cleaning possible

# JYFL: 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)
  - Ion formation 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<sup>\*</sup>) accumulation effects
  - No gaps in the systematic studies
  - Study the most neutron rich nuclei produced in the fission (isobaric background usually sets the limit)

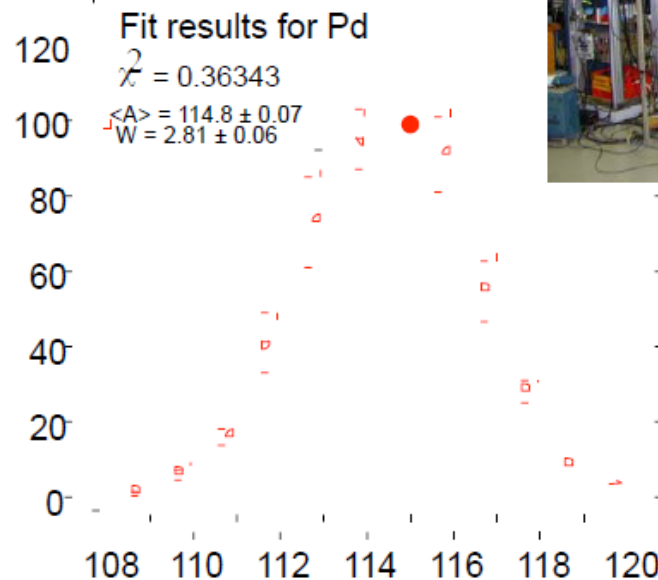


# JYFL: Fission Yields with Penning Traps



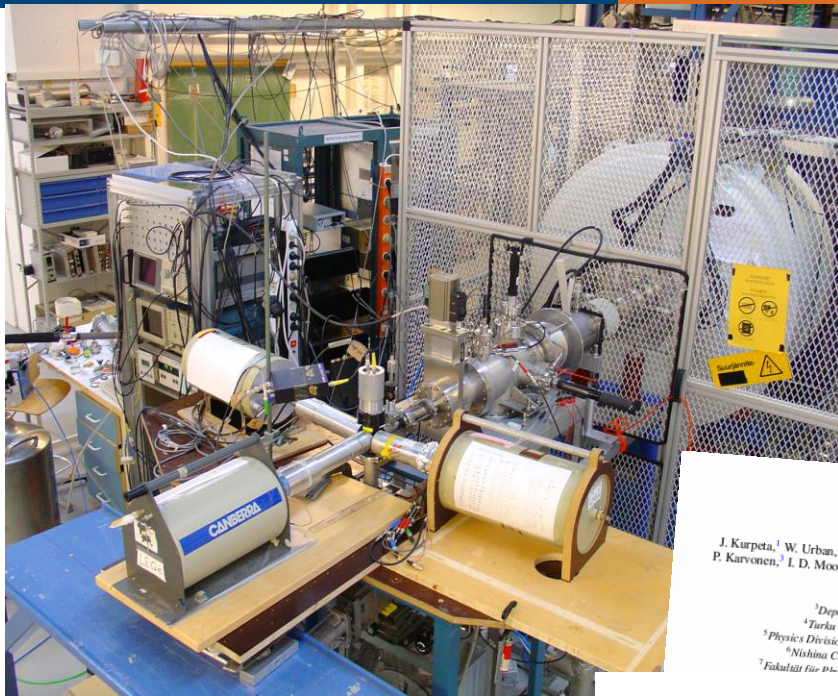
Based on **unambiguous identification** of isotopes by their **mass only**.

- No further knowledge on e.g. decay is needed
- Fast
- Yield of long-lived and stable isotopes can be determined



Eur. Phys. J. Special Topics 150 (2007) 317  
 Nucl. Instr. and Meth. A 576 (2007) 371  
 Eur. Phys. J. A 44 (2010) 140  
 Eur. Phys. J. A 48 (2012) 43

# Trap-assisted spectroscopy at JYFL



Eur. Phys. J. A 31, 1-7 (2007)  
DOI 10.1140/epja/i2006-10158-9

**THE EUROPEAN PHYSICAL JOURNAL A**

Regular Article – Nuclear Structure and Reactions

**Decay study of ne Penning trap as a**

Eur. Phys. J. A 31, 363-366 (2007)  
DOI 10.1140/epja/i2007-10009-3

Letter

S. Rinta-Anttila<sup>1</sup>, T. Eronen<sup>2</sup>, V.-I. T. Sonoda, A. Saastamoinen, and University of Jyväskylä, Department

Received: 29 September / Published online: 18 Jan / Communicated by D. Greife

**Abstract:** A new technique for the decay spectroscopy of neutron-rich nuclei is presented. The technique is based on the Penning trap assisted decay spectroscopy of neutron-rich nuclei.

Eur. Phys. J. A (2011) 47: 97  
DOI 10.1140/epja/i2011-11097-0

Reply

**THE EUROPEAN PHYSICAL JOURNAL A**

Finland  
Aug 2007

Involvement of <sup>200</sup>Pu target, ...

**RAPID COMMUNICATIONS**

**Penning-trap-assisted study of <sup>115</sup>Ru beta decay**

J. Kurpeta<sup>1,2</sup>, J. Karvonen<sup>2</sup>, P. Karvonen<sup>1</sup>, I. D. Moore<sup>3</sup>, H. Penttilä<sup>2</sup>, S. Rahaman<sup>4</sup>, A. Saastamoinen<sup>2</sup>, T. Sonoda<sup>2</sup>, and C. Weber<sup>5</sup>

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Received: 8 February 2010

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

**Excited states in <sup>115</sup>Pd populated in the  $\beta^-$  decay**

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Received: 12 November 2009 / Accepted: 12 November 2009

**PHYSICAL REVIEW C 83, 011301 (2011)**

**Decay study of <sup>114</sup>Te with a Penning trap**

J. Kurpeta<sup>1,2</sup>, V.-V. Elomaa<sup>3</sup>, T. Eronen<sup>3</sup>, J. Hakala<sup>4</sup>, A. Jokinen<sup>4</sup>, I. D. Moore<sup>5</sup>, P. Karvonen<sup>1</sup>, A. Plochocki<sup>2</sup>, H. Penttilä<sup>2</sup>, S. Rahaman<sup>6</sup>, A. Saastamoinen<sup>2</sup>, J. Szerypo<sup>7</sup>, and C. Weber<sup>8</sup>

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Received: 12 November 2010 / Accepted: 12 November 2010

**PHYSICAL REVIEW C 83, 015101 (2011)**

**Decay study of <sup>114</sup>Te with a Penning trap**

J. Kurpeta<sup>1,2</sup>, V.-V. Elomaa<sup>3</sup>, T. Eronen<sup>3</sup>, J. Hakala<sup>4</sup>, A. Jokinen<sup>4</sup>, I. D. Moore<sup>5</sup>, P. Karvonen<sup>1</sup>, A. Plochocki<sup>2</sup>, H. Penttilä<sup>2</sup>, S. Rahaman<sup>6</sup>, A. Saastamoinen<sup>2</sup>, J. Szerypo<sup>7</sup>, and C. Weber<sup>8</sup>

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**PHYSICAL REVIEW C 83, 015101 (2011)**

**Decay study of <sup>114</sup>Te with a Penning trap**

J. Kurpeta<sup>1,2</sup>, V.-V. Elomaa<sup>3</sup>, T. Eronen<sup>3</sup>, J. Hakala<sup>4</sup>, A. Jokinen<sup>4</sup>, I. D. Moore<sup>5</sup>, P. Karvonen<sup>1</sup>, A. Plochocki<sup>2</sup>, H. Penttilä<sup>2</sup>, S. Rahaman<sup>6</sup>, A. Saastamoinen<sup>2</sup>, J. Szerypo<sup>7</sup>, and C. Weber<sup>8</sup>

<sup>1</sup>Department of Physics, <sup>2</sup>Faculty of Physics, <sup>3</sup>Institut Lule-Langevin, <sup>4</sup>Turku PET Centre, Accelerator Laboratory, Abo Akademi University, FIN-20520 Turku, Finland, <sup>5</sup>Physics Division, P-23, Mail Stop HB03, Los Alamos National Laboratory, Los Alamos, NM 87545, USA, <sup>6</sup>Nishina Center for Accelerator Based Science, RIKEN, 351-0199 Wako, Japan, <sup>7</sup>Fakultät für Physik, Universität Wien, A-1040 Wien, Austria, <sup>8</sup>Physikalisches Institut, Universität Bayreuth, D-95834 Bayreuth, Germany

Received: 12 November 2010 / Accepted: 12 November 2010

## Half-life, branching-ratio, and $Q$ -value measurement for the superallowed $0^+ \rightarrow 0^+$ $\beta^+$ emitter <sup>42</sup>Ti

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The branching ratio, and the decay  $Q$  value of the superallowed  $\beta^+$  emitter <sup>42</sup>Ti were measured in a Penning trap at the JYFLTRAP facility of the Accelerator Laboratory of the University of Jyväskylä. The  $T_{1/2}$  of <sup>42</sup>Ti was measured to be  $208.14 \pm 0.45$  ms and the  $Q$  value  $[Q_{EC} = 7016.83(25) \text{ keV}]$  are close to or reach the  $\alpha$  of about 0.1%. The branching ratio for the superallowed decay branch  $[BR = 47.7(12)\%]$ , a  $\beta$  half-life measurement, does not reach the necessary precision yet. Nonetheless, these results confirm the experimental  $f$  value and the corrected  $F$  value to be 3114(79) and 3122(79), respectively.

15RevC.80.035502 PACS number(s): 23.40.Bw, 21.10.Tg, 27.40.+z

**INTRODUCTION**

Superallowed  $\beta^+$  decays provide the standard model of particle physics. The  $0^+ \rightarrow 0^+$   $\beta^+$  decay between  $T = 1$  on the vector part of the weak interaction is related to the conserved vector current (CVC) hypothesis, a fundamental constant that is the statistical rate function,  $f$ , whereas the half-life and the branching ratio yield the partial half-life,  $t_{1/2}$ .

The aim of the present piece of work is to measure the half-life of <sup>42</sup>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. <sup>42</sup>Ti decays by superallowed  $\beta^+$  emission to its isobaric analog state ( $J^\pi = 0^+, T = 1$ ), the ground state of <sup>42</sup>Sc. Before the measurement reported here, the accepted value for the half-life

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

## Reactor Decay Heat in <sup>239</sup>Pu: Solving the $\gamma$ Discrepancy in the 4–3000-s Cooling Period

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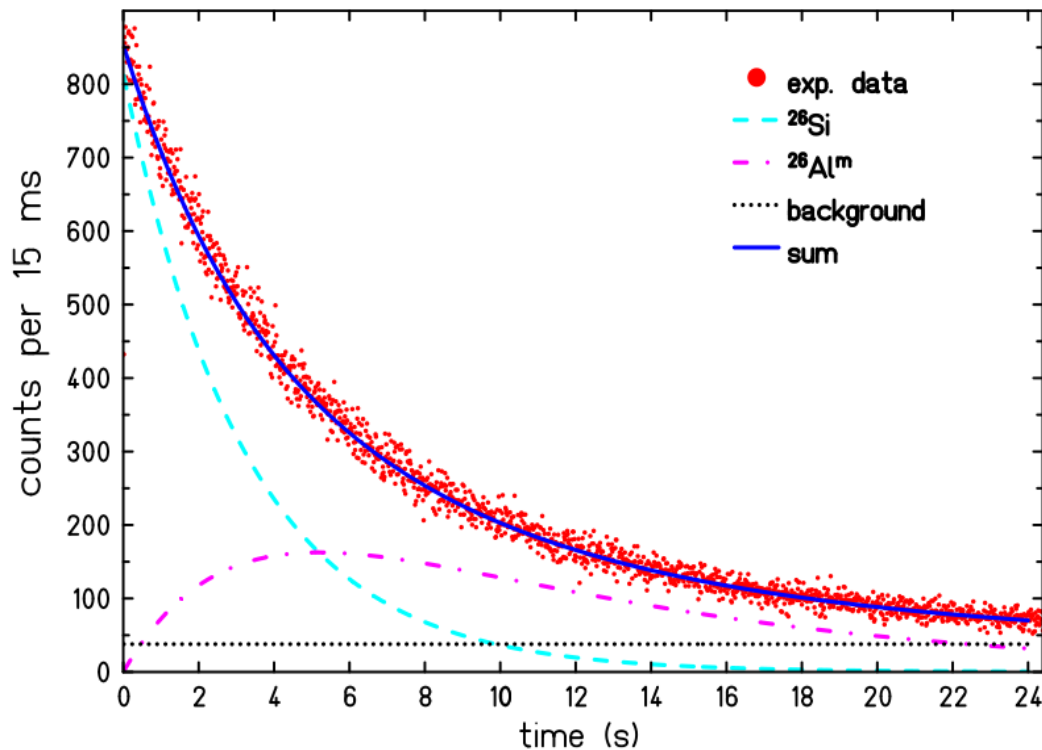
(Received 13 May 2010; published 8 November 2010)

The  $\beta$  feeding probability of <sup>102,104,105,106,107</sup>Tc, <sup>105</sup>Mo, and <sup>108</sup>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 isotopic purity. Our results solve a significant part of a long-standing discrepancy in the  $\gamma$  component of the decay heat for <sup>239</sup>Pu in the 4–3000 s range.

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

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

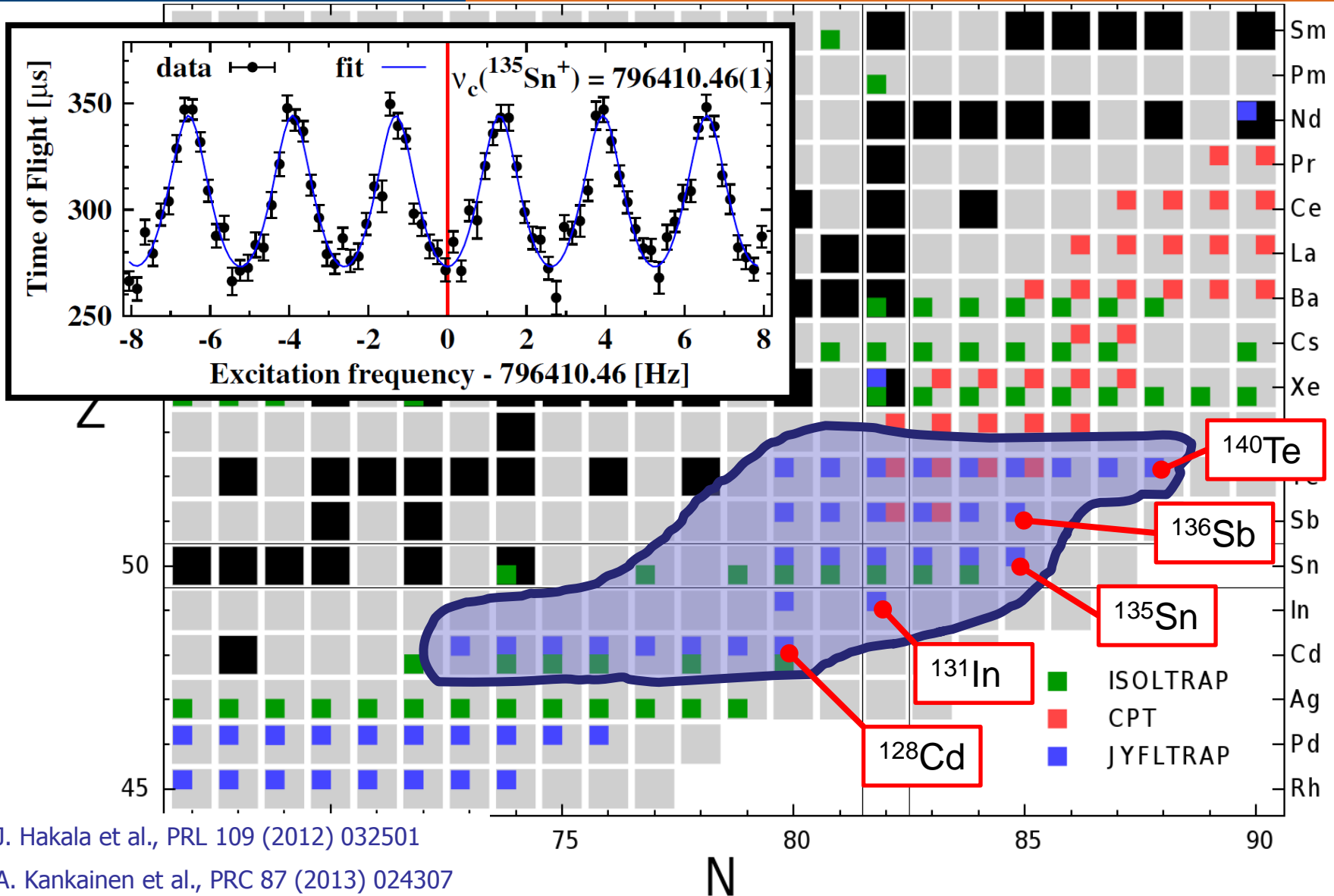
- Bbeta counting -> requires a clean sample
- Measurement cycle requires 25 s decay period
- Accumulation in RFQ, bunches sent to purification trap
- Purification trap saturates in 300 ms -> use multiple loading
- In 25 s 8 cycles and 6-7 times more  $^{26}\text{Si}$  than in single loading



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

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

# JYFLTRAP data in $^{132}\text{Sn}$ region

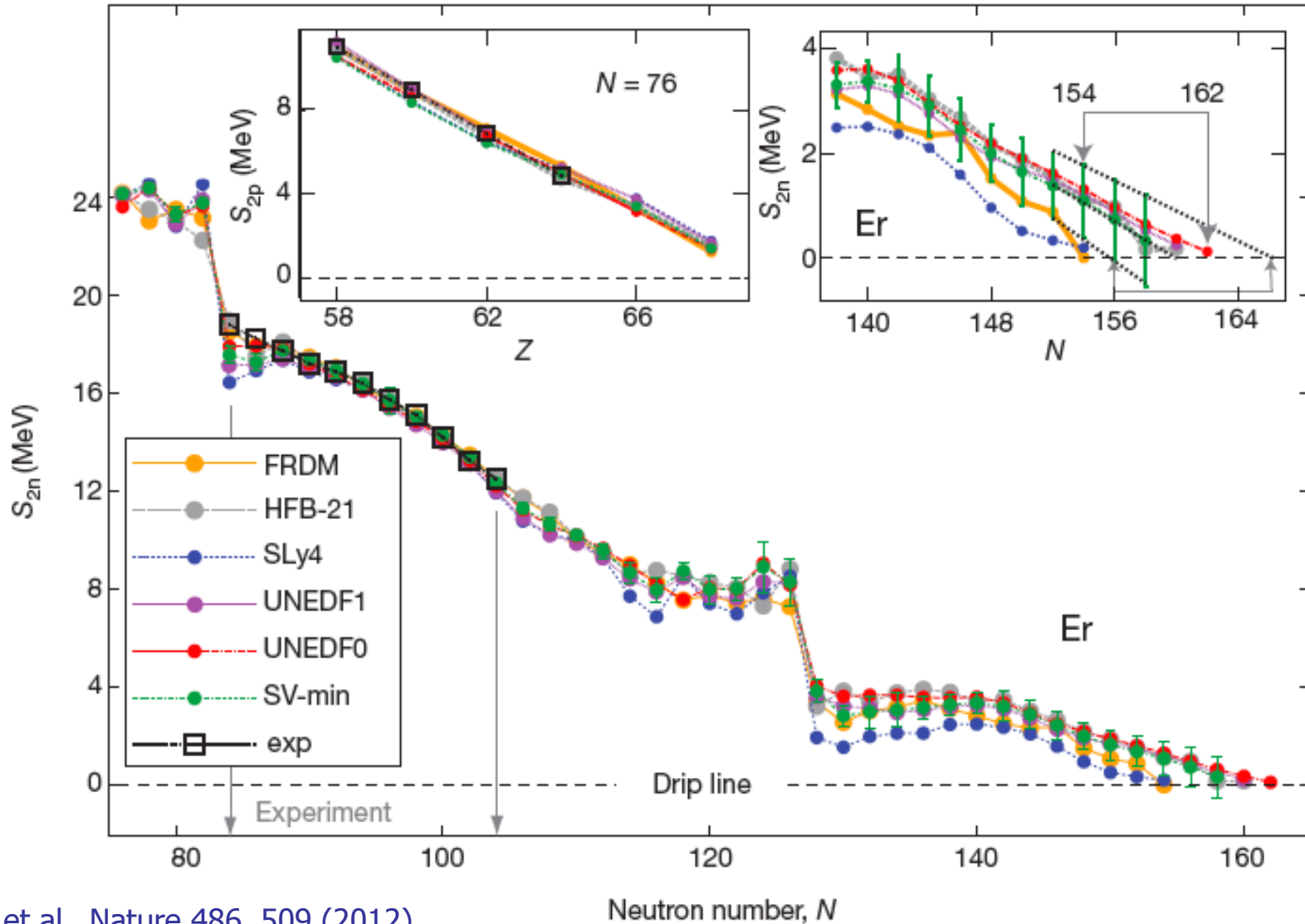


J. Hakala et al., PRL 109 (2012) 032501

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

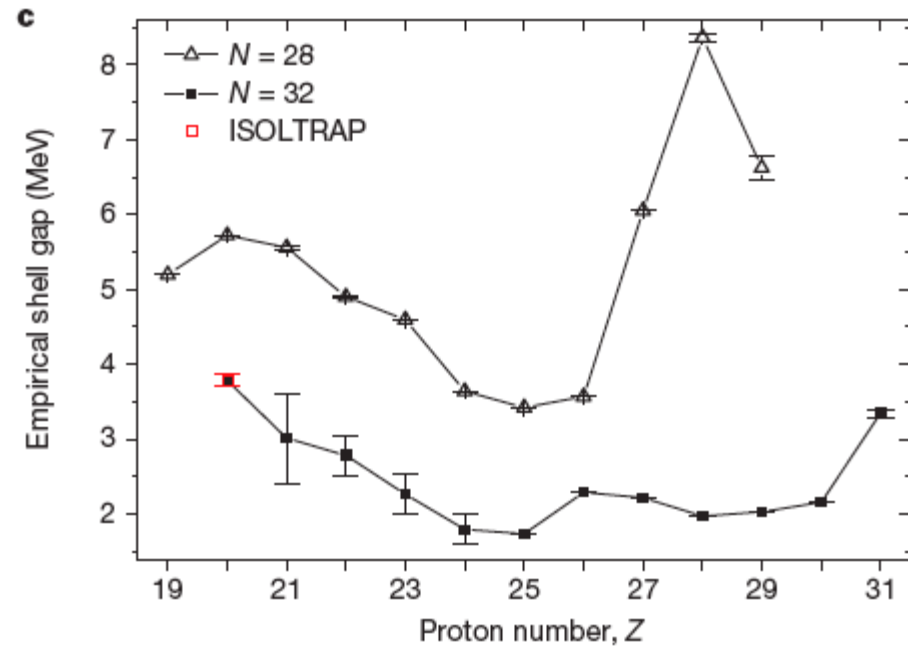
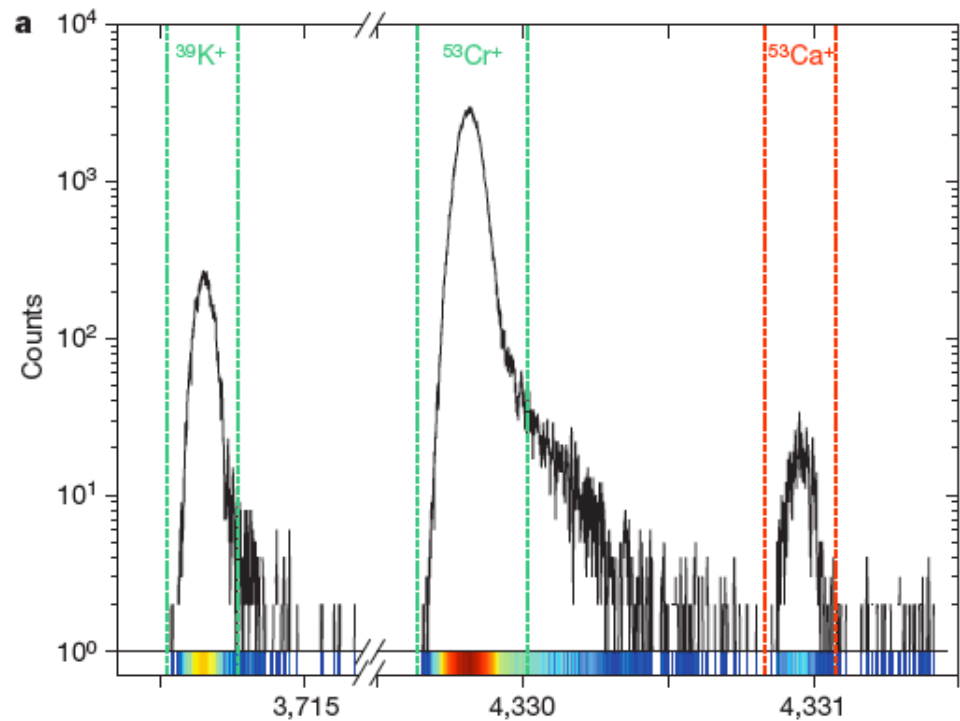


# Indicators of Nuclear Structure Evolution



# Nuclear Structure in Neutron-rich Nuclides

Masses of neutron-rich calcium isotopes measured by ISOLTRAP



# Nuclear Structure in Neutron-rich Nuclides

## Mass measurements by ISOLTRAP

