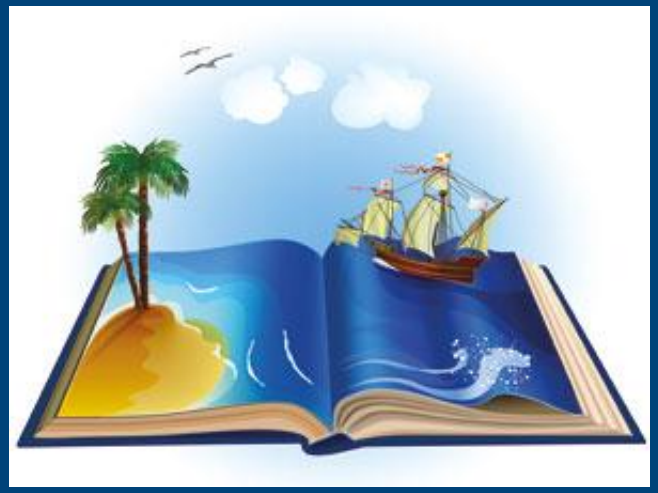
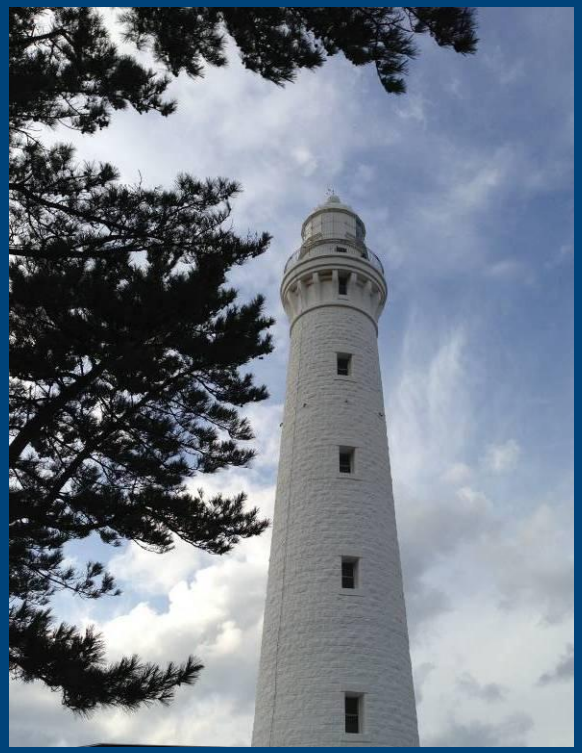
EMIS 2012

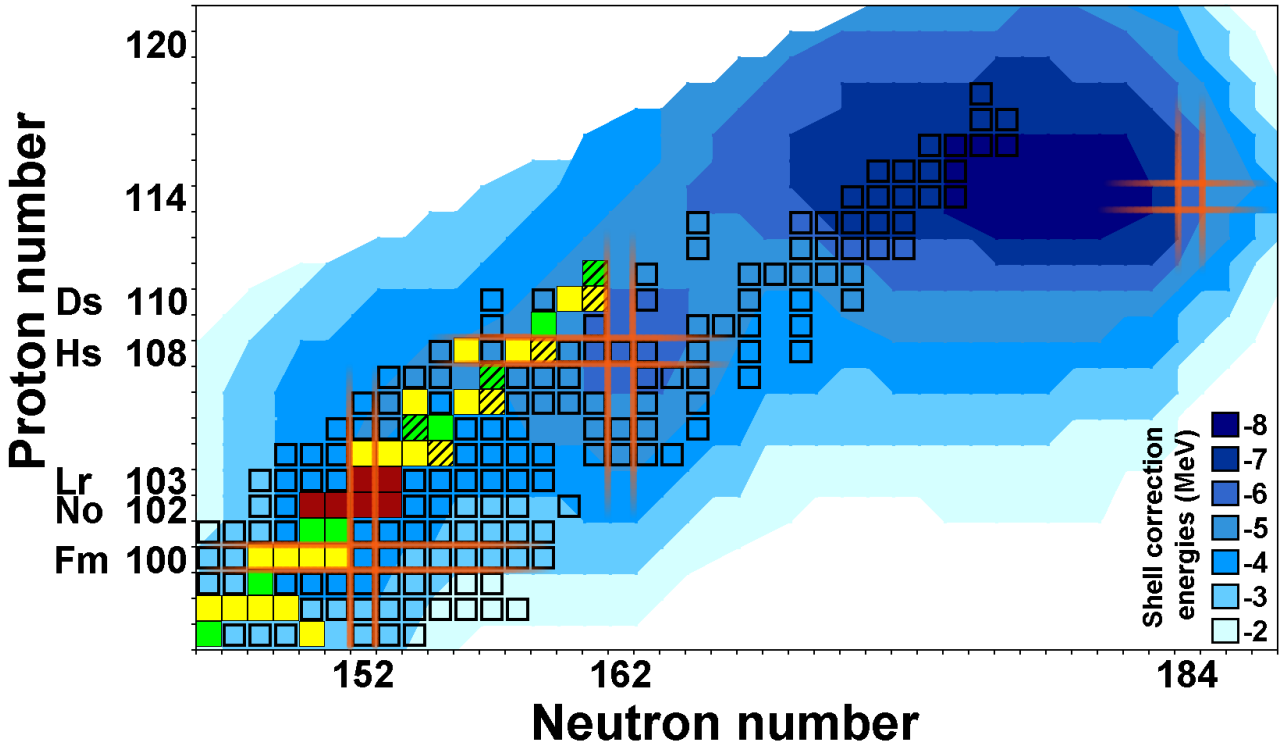
Recent Developments for High-Precision Measurements of the Heaviest Elements with SHIPTRAP

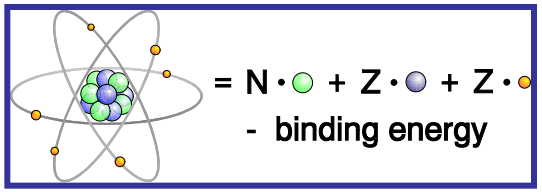




Michael Block, GSI

Importance of Masses for Z > 100





- masses provide absolute nuclear binding energies and allow studies of the shell structure evolution
- high-precision mass measurements provide anchor points to fix decay chains
- benchmark nuclear models

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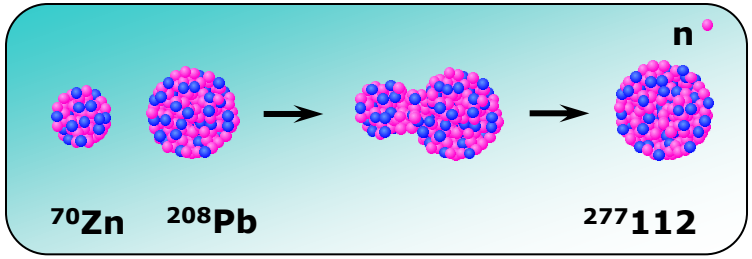
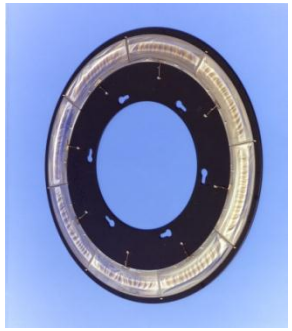
Synthesis and Identification of SHE at SHIP





kinematic separation in flight by velocity filter

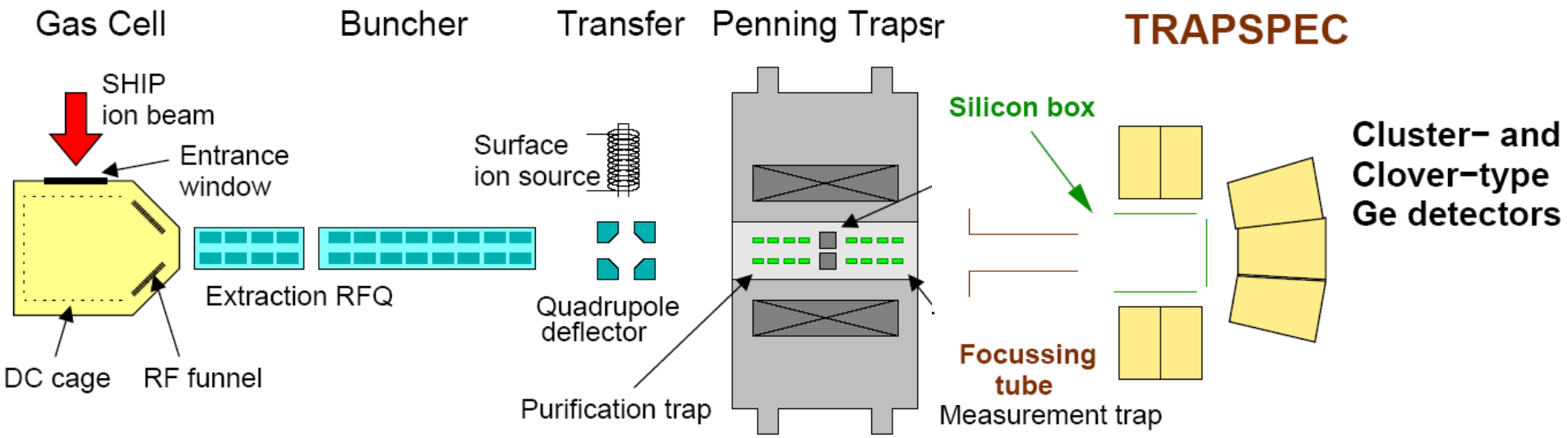
Typical yield for primary beam intensity of ≈ 6 x 10^{12} / s

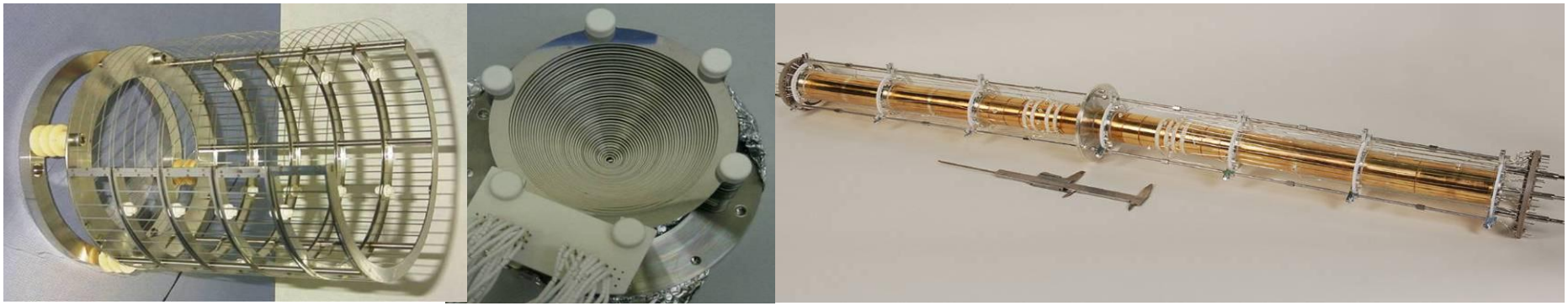
- 1 atom/s @ Z ≈ 102 ($\sigma \approx 1$ μb)
- 1 atom/week @ Z= 112 ($\sigma \approx 1$ pb)

ASSOCIATION

SHIPTRAP Setup

≈ 50 MeV → ≈ 1 eV → ≈ 1 keV





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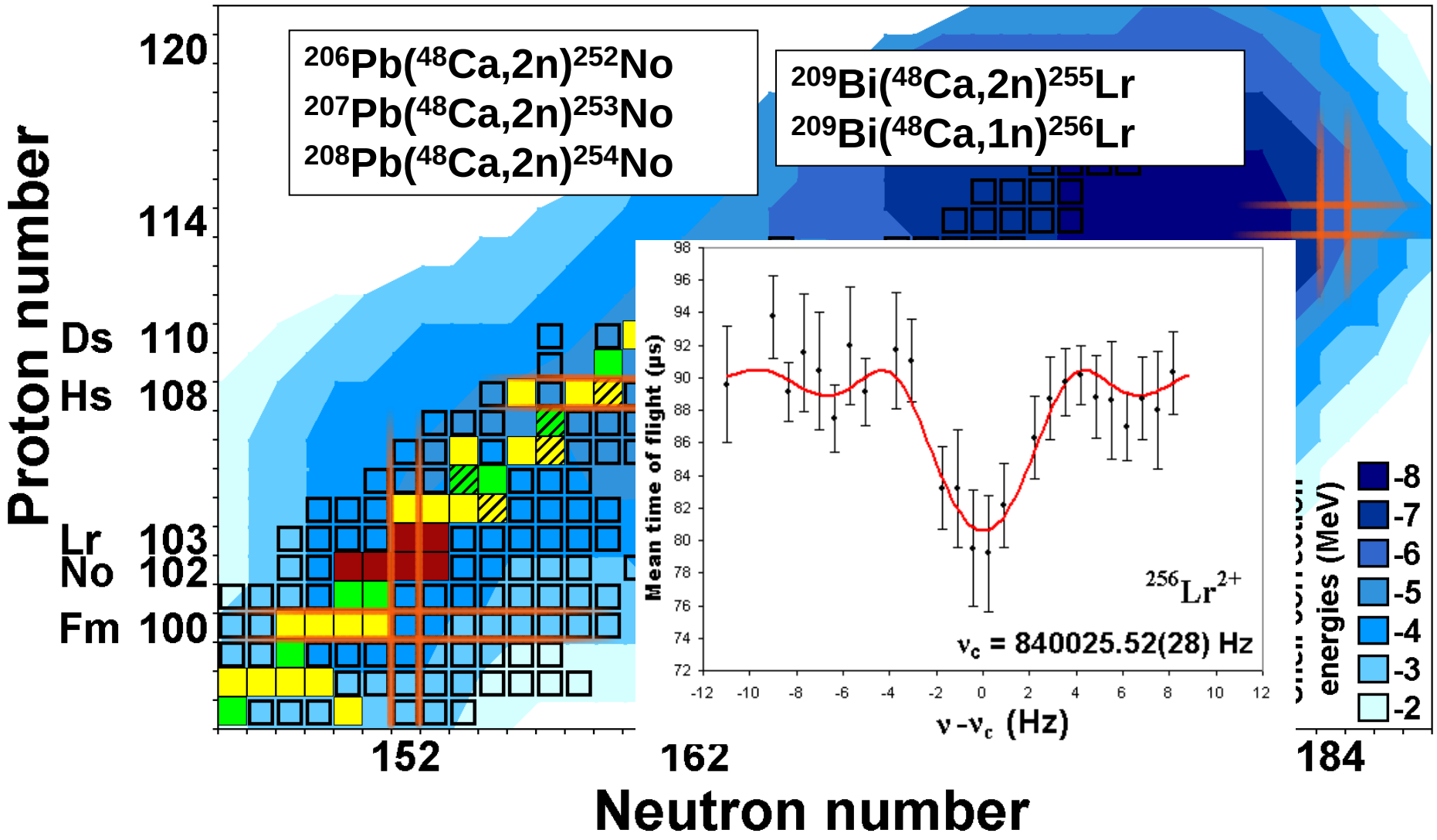
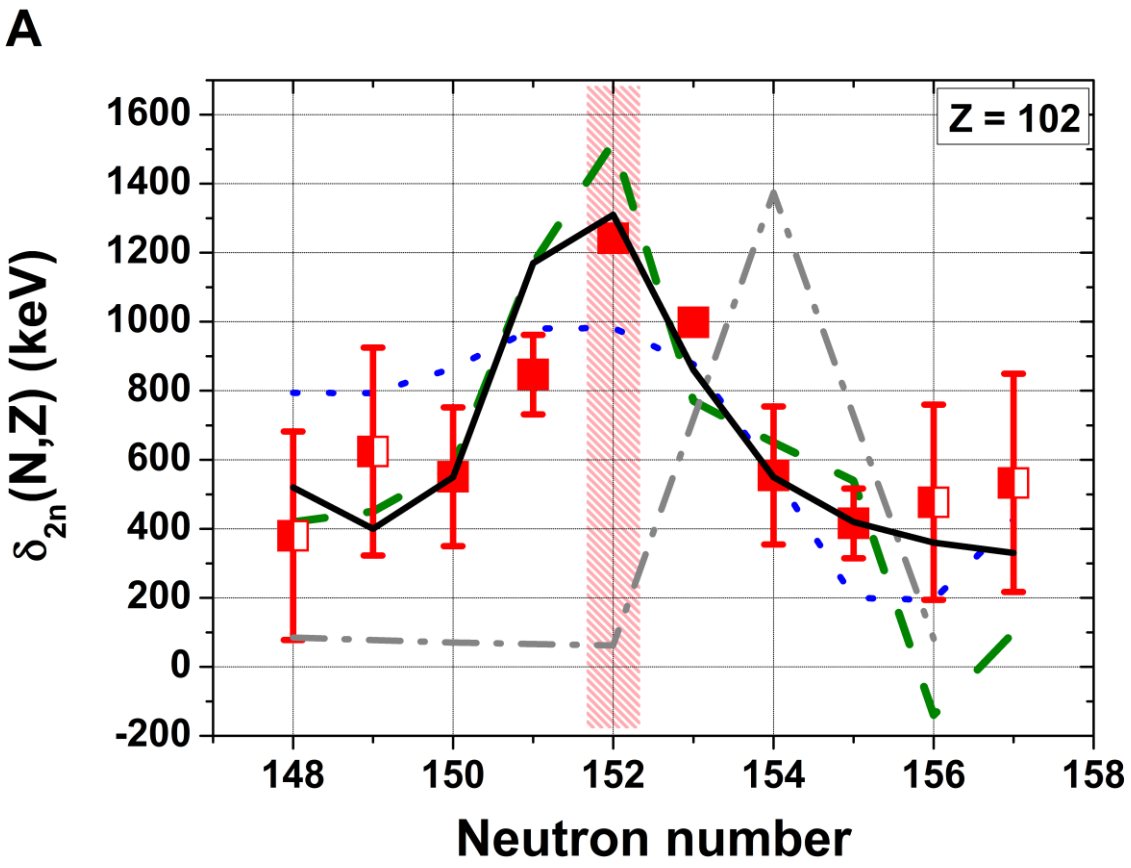
Direct mass measurements with SHIPTRAP



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)

Mapping the shell gap at $N = 152$

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



Experiment

Moeller et al.

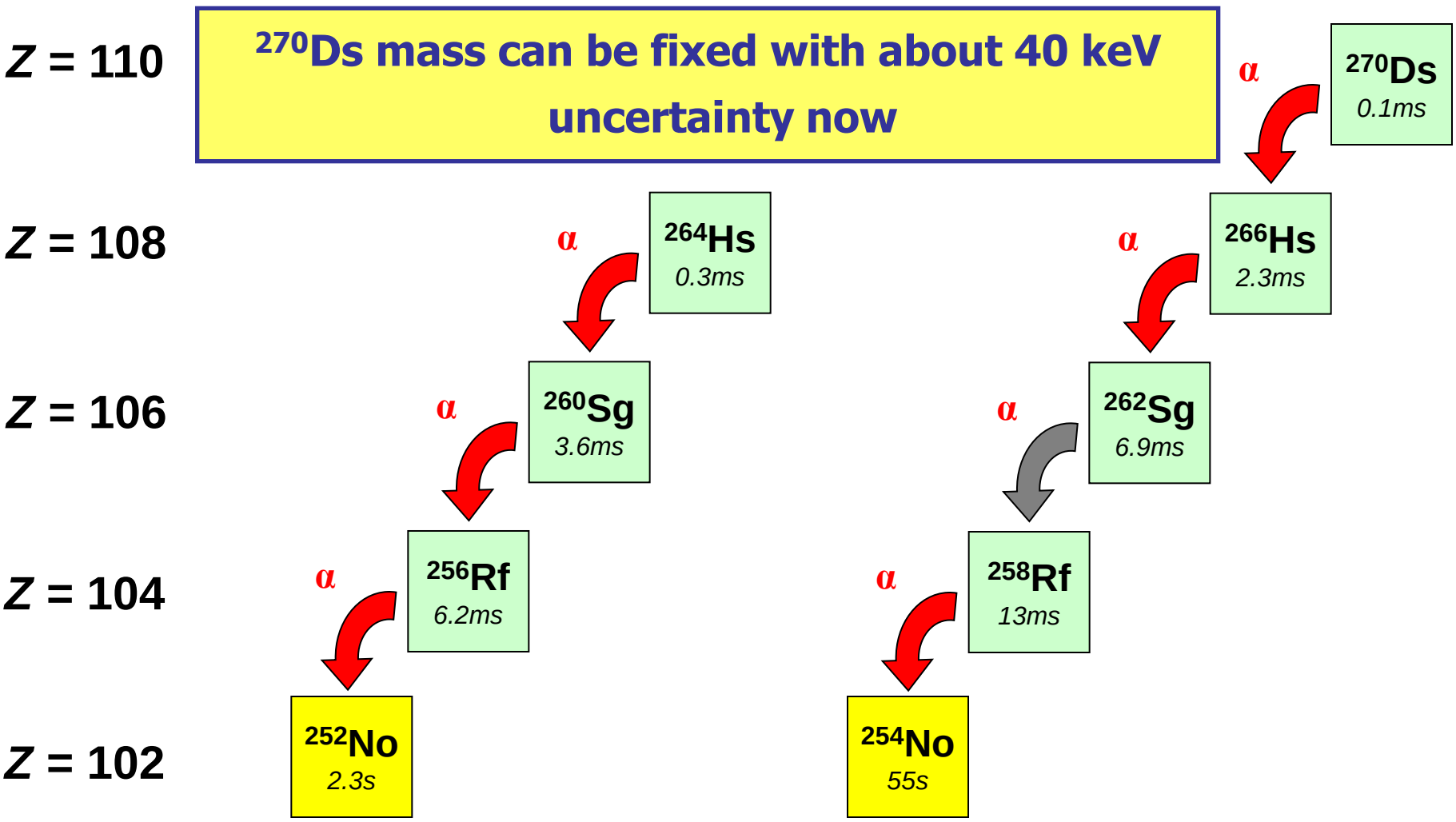
Sobiczewski et al.

SkM*

Typel et al.

Enrique Minaya Ramirez et al., Science 337, 1183 (2012)

Follow up α-decay chains



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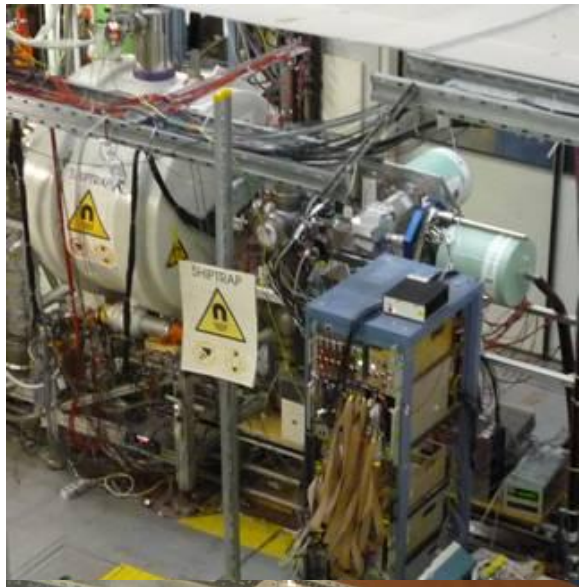
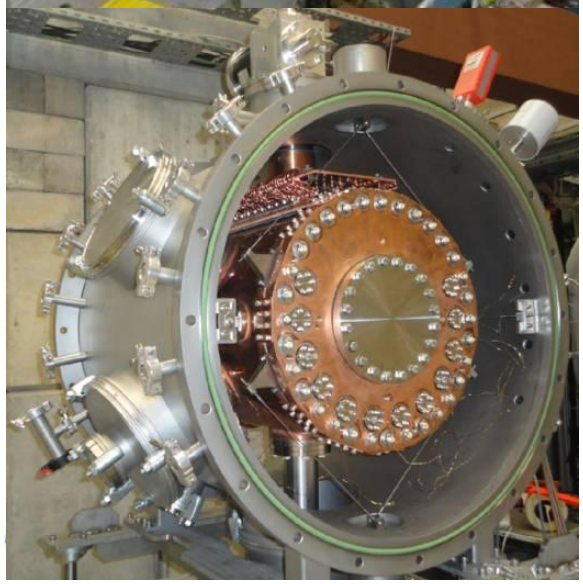
Improvements and Extensions

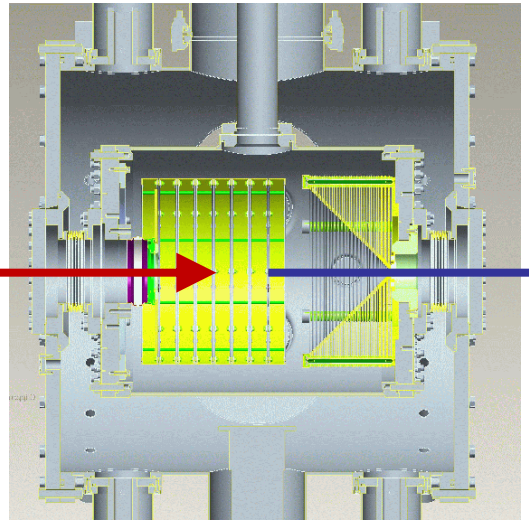
- **Novel Experiments**
  - trap-assisted decay spectroscopy
  - laser spectroscopy
  - chemistry in the buffer gas cell
- **increasing efficiency, sensitivity, and resolving power**
  - electronic image current detection
  - cryogenic gas stopper
  - new excitation schemes





Future: SHIPTRAP cryogenic gas stopper

Cryo cooler (40 K)

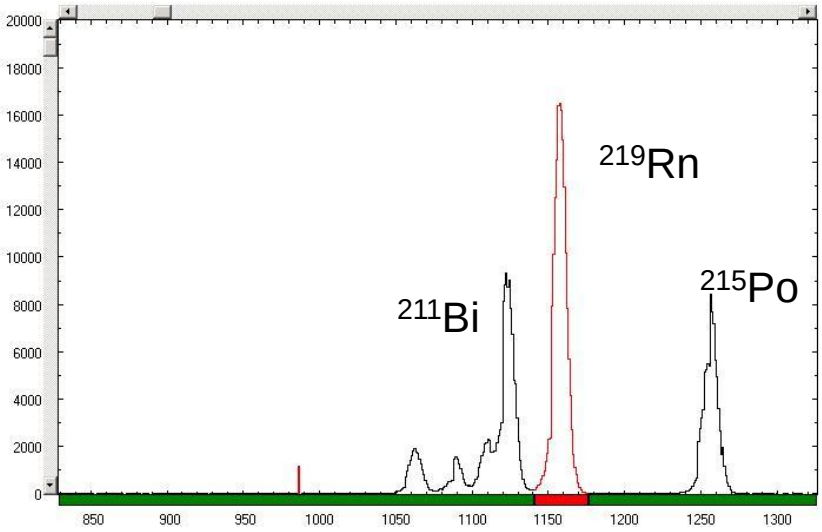


Ion beam

Low-energy beam

outer chamber ≈ 650 mm long,
500 mm in diameter

Gain in overall efficiency factor: ≥5



S. Eliseev et al., Nucl. Instr. and Meth. B 266 (2008) 4475–4477

Max-Planck-Institut für Kernphysik

LMU

S. Eliseev, C Droese,
M. Laatiaoui, E. Minaya et al.

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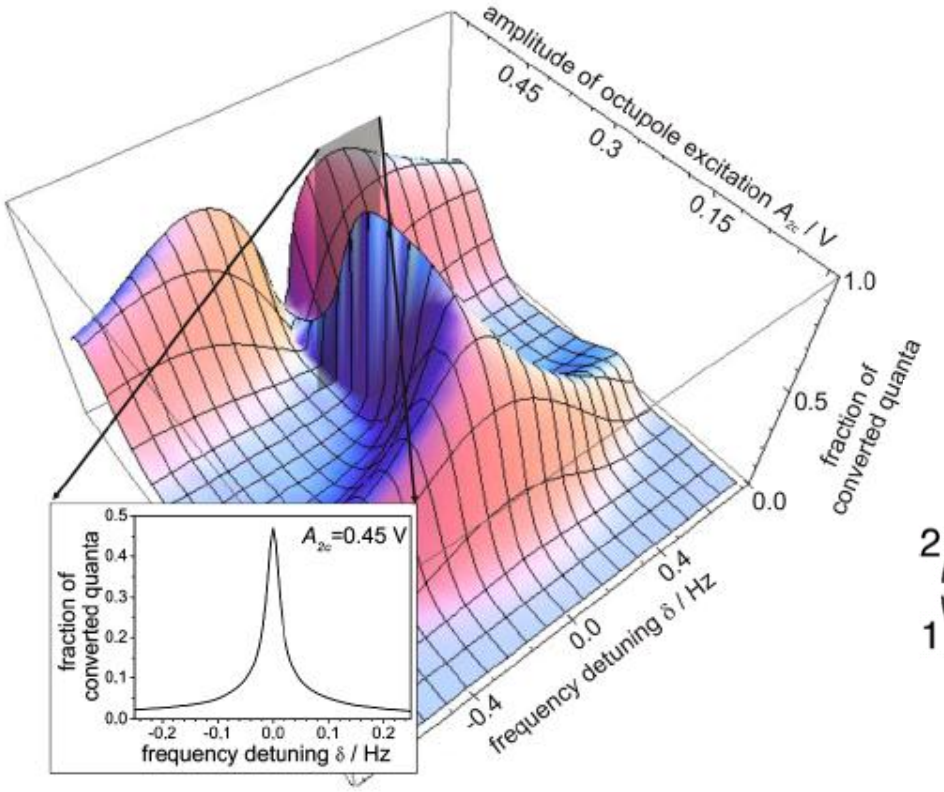
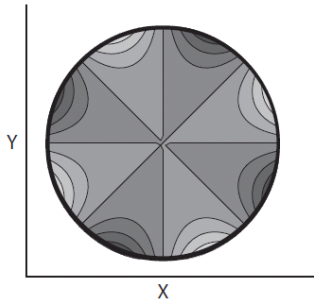
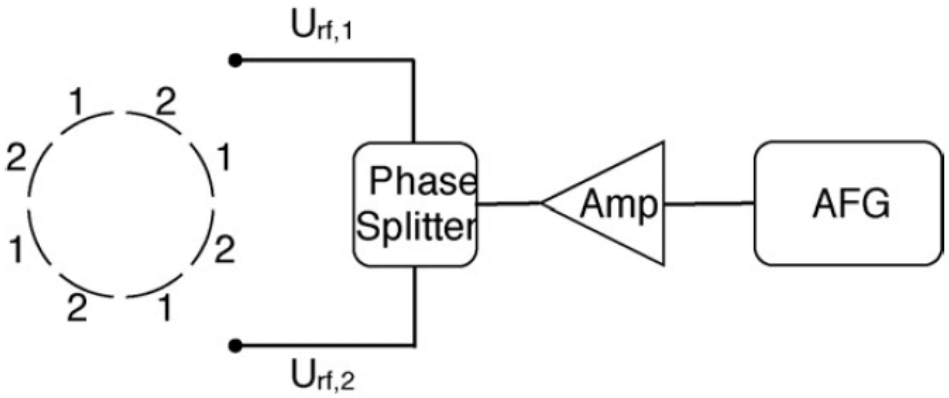
Octuploar Excitation







SHIPTRAP: S. Eliseev et al., Int. J. Mass Spectrom. 262, 45 (2007)
S. Eliseev et al., Phys. Rev. Lett. 107, 152501 (2011)
LEBIT: R. Ringle et al., Int. J. Mass Spectrom. 262, 33 (2007)

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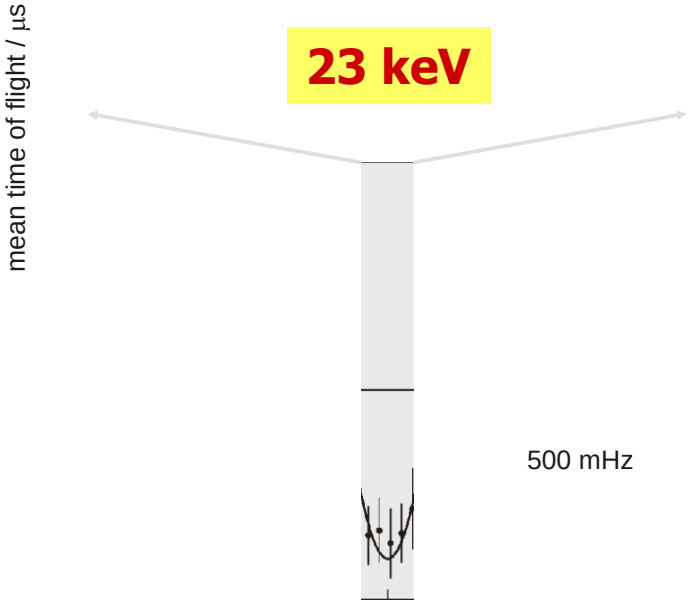
Improving the Resolving Power

Octupolar

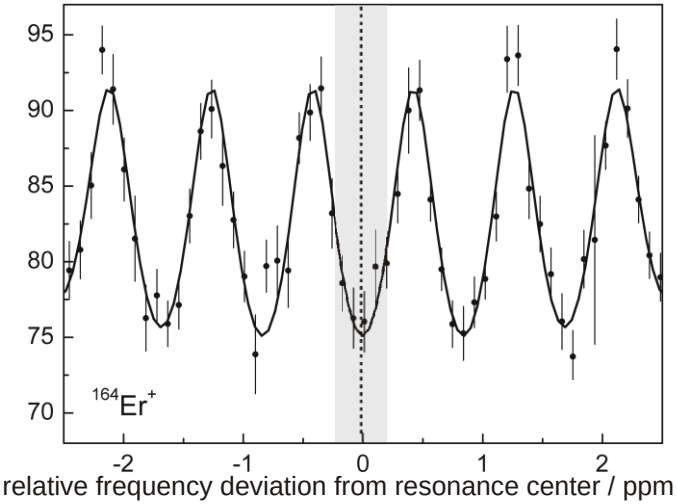
Octupolar excitation scheme leads to gain in resolving power R by a factor of 10

R≈20,000,000 for T_{RF}=2 s



Quadrupolar

Quadrupolar Ramsey



S. Eliseev et al., Phys. Rev. Lett. 107, 152501 (2011)

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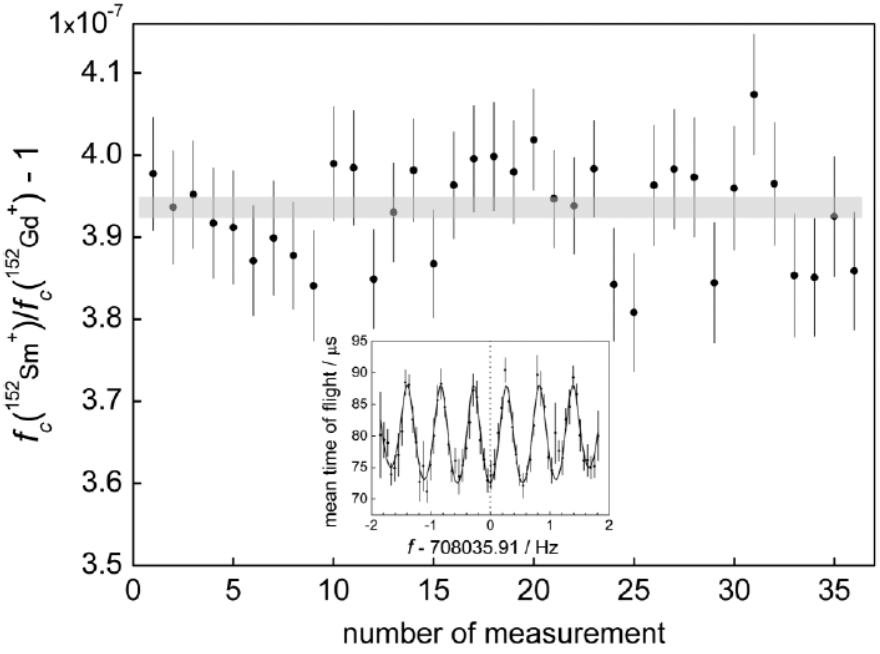
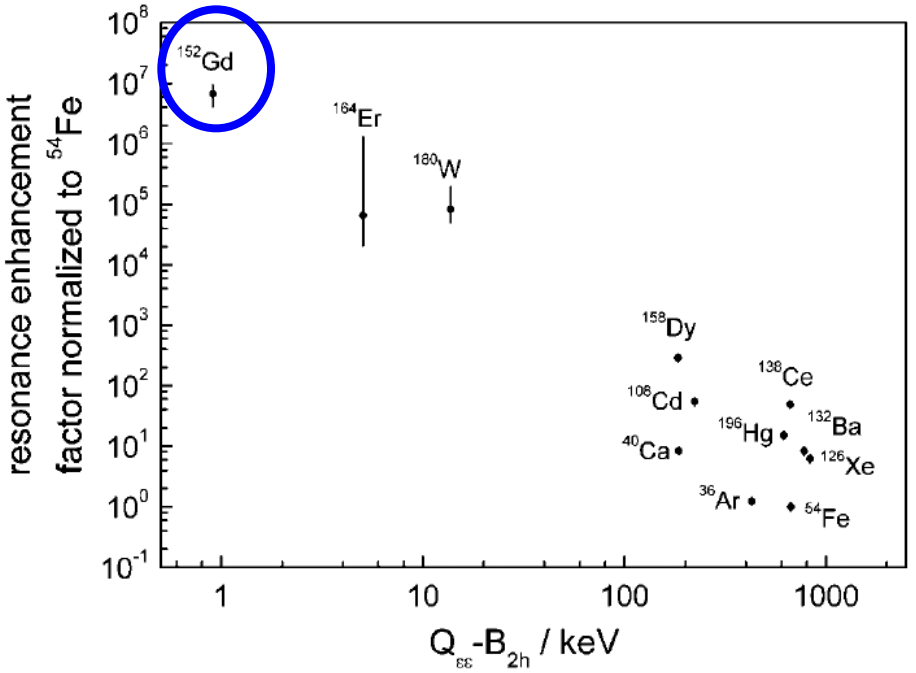
Mass Measurements for Neutrino Physics

PRL **106,** 052504 (2011) PHYSICAL REVIEW LETTERS week ending 4 FEBRUARY 2011

Resonant Enhancement of Neutrinoless Double-Electron Capture in ^{152}Gd

S. Eliseev,[1] C. Roux,[1] K. Blaum,[1,2] M. Block,[3] C. Droese,[4] F. Herfurth,[3] H.-J. Kluge,[2,3] M. I. Krivoruchenko,[5] Yu. N. Novikov,[6] E. Minaya Ramirez,[3,7] L. Schweikhard,[4] V. M. Shabaev,[8] F. Šimkovic,[9,10] I. I. Tupitsyn,[8] K. Zuber,[11] and N. A. Zubova[8]





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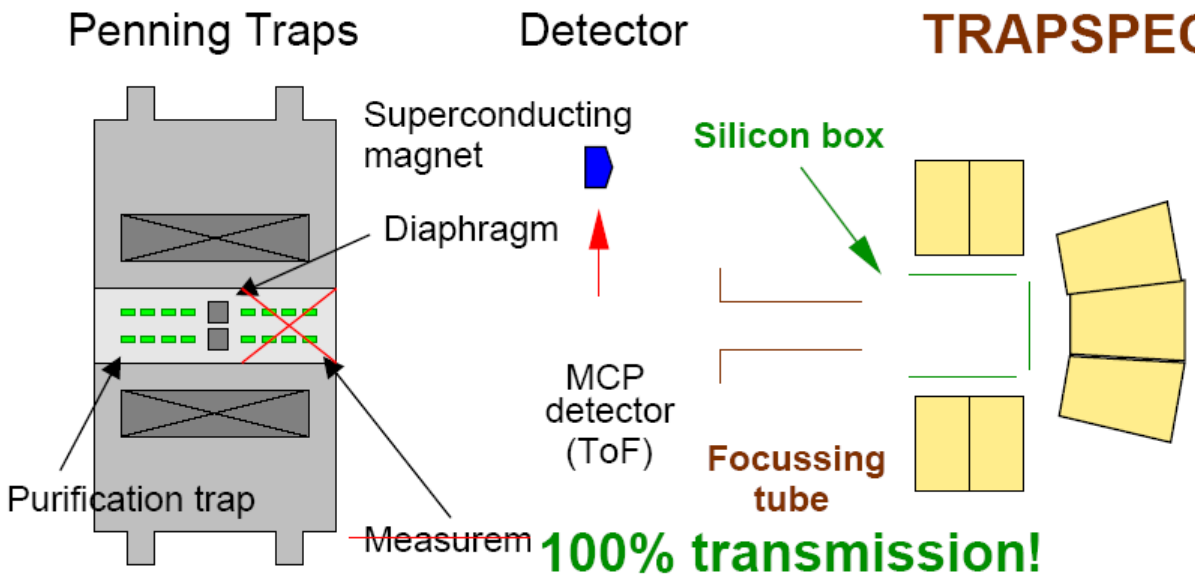
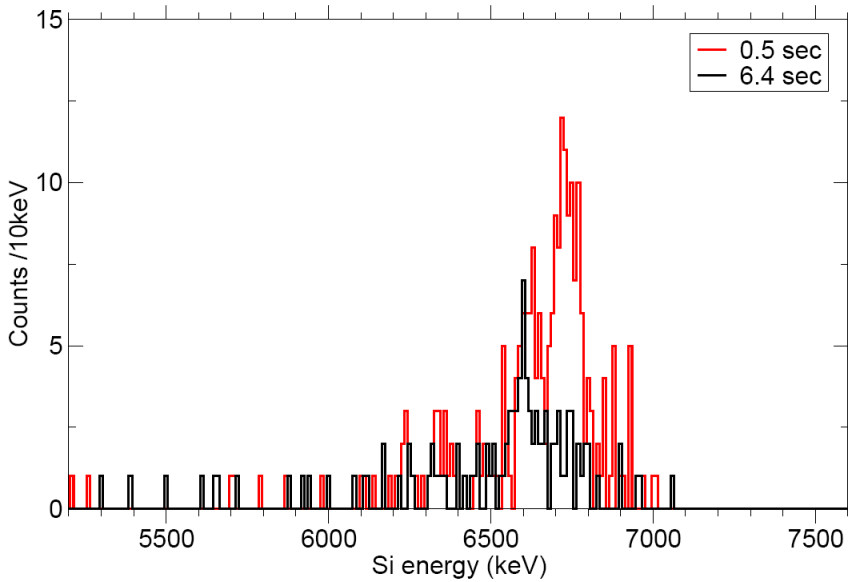
TRAPSPEC: Trap-assisted Spectroscopy



M. B., D. Rudolph et al.

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



^{195}Po

$(13/2^+)$ $T_{1/2}$ =1.92 s

E_α =6.84 MeV

$(3/2^-)$ $T_{1/2}$ =4.64 s

E_α =6.64 MeV

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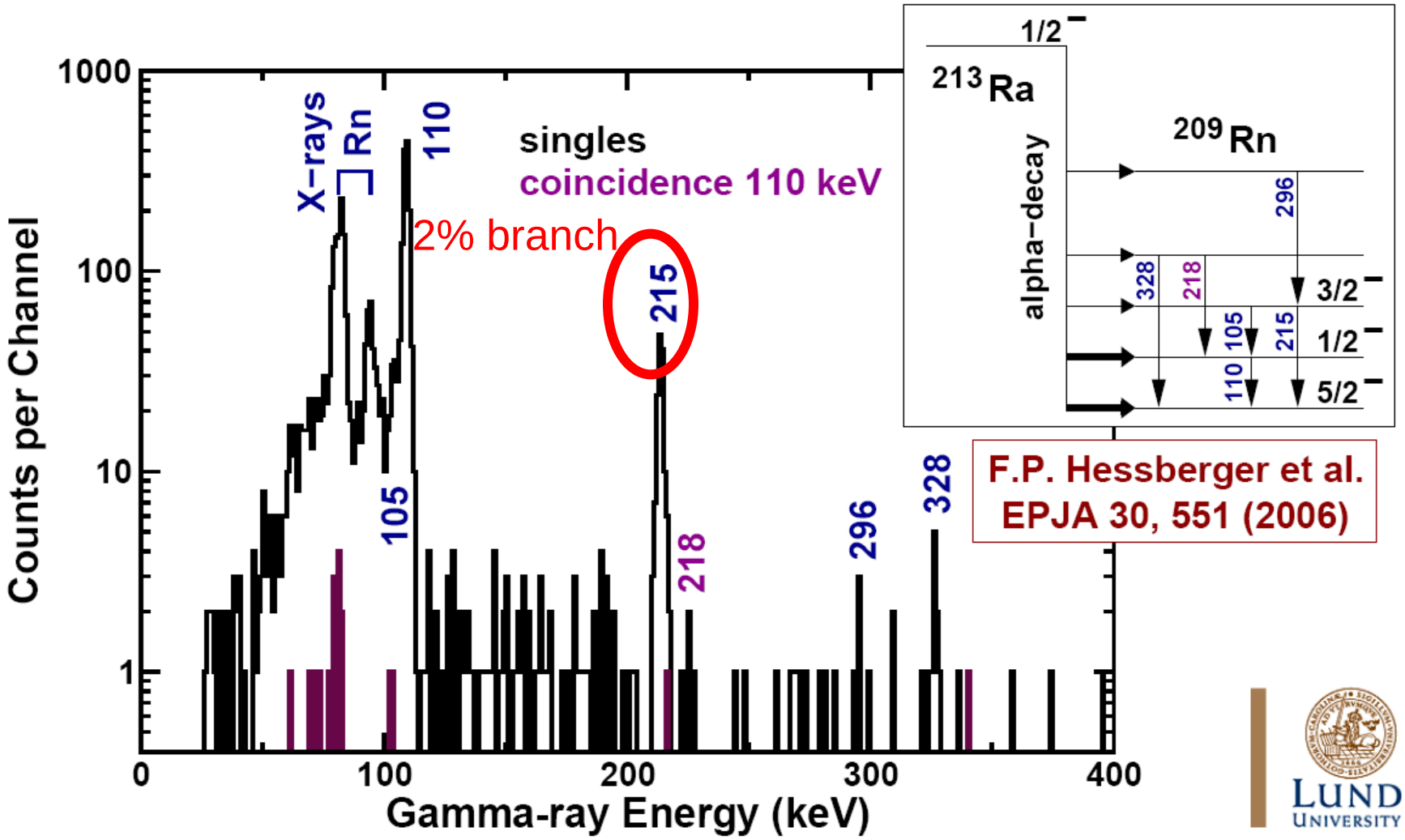
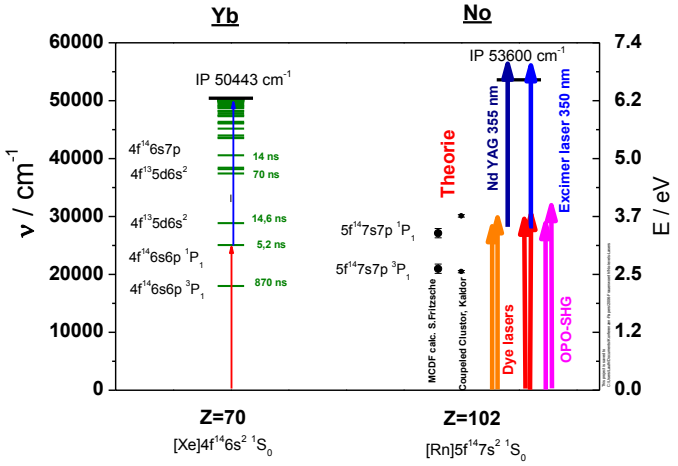
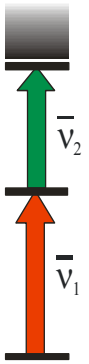
TRAPSPEC – Decay studies ^{213}Ra



D. Rudolph al., GSI Scientific Report, NUSTAR-SHE-08, 177 (2009)

Radioactive Detected Resonance Ionization





Buffer Gas

Recoil Beam

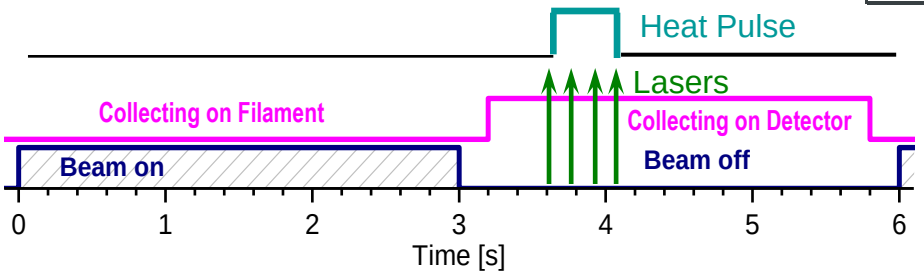
Laser Beams

Pulsed Filament (Tantal)

10 cm

Electrodes

α Detector



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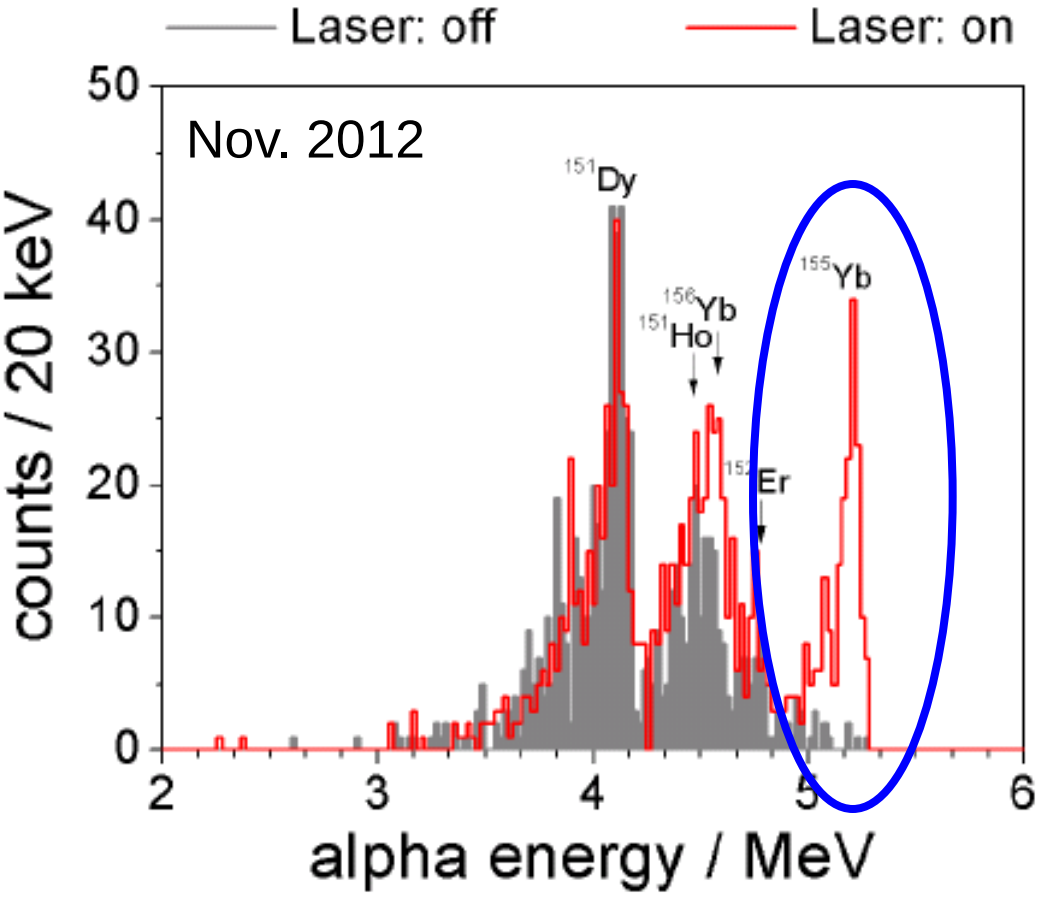
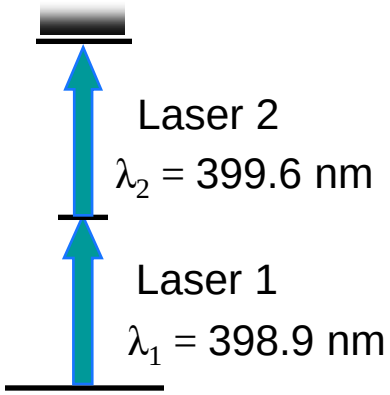
On-line Experiment on ^{155}Yb at GSI

On-line experiment ^{112}Sn(^{48}Ca,5n)^{155}Yb ($T_{1/2}$=1.75 s, α) $\sigma \approx 8$ mbarn





Preliminary
Evaporation and
RIS efficiency ≈12 %

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Summary and Outlook

- high-precision mass measurements of nuclides with rates of trapped ions down to about 1 per hour demonstrated
- Strength of nuclear shell effects mapped at A ≈ 252
- New excitation schemes boost mass resolving power
- Cryogenic gas cell provides higher efficiency paving the way to higher *Z*
- Novel experiments possible: e.g. laser-assisted decay spectroscopy
- Laser resonance ionization spectroscopy of heaviest elements
  - will provide data on atomic structure (relativistic effects)
  - data about nuclear spins, moments and charge radii

Thank you for your attention !

HELMHOLTZ ASSOCIATION GSI

The SHIPTRAP collaboration

GSI

HELMHOLTZ Institut Mainz

LUND UNIVERSITY

LMU

Max-Planck-Institut für Kernphysik

ugr Universidad de Granada

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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