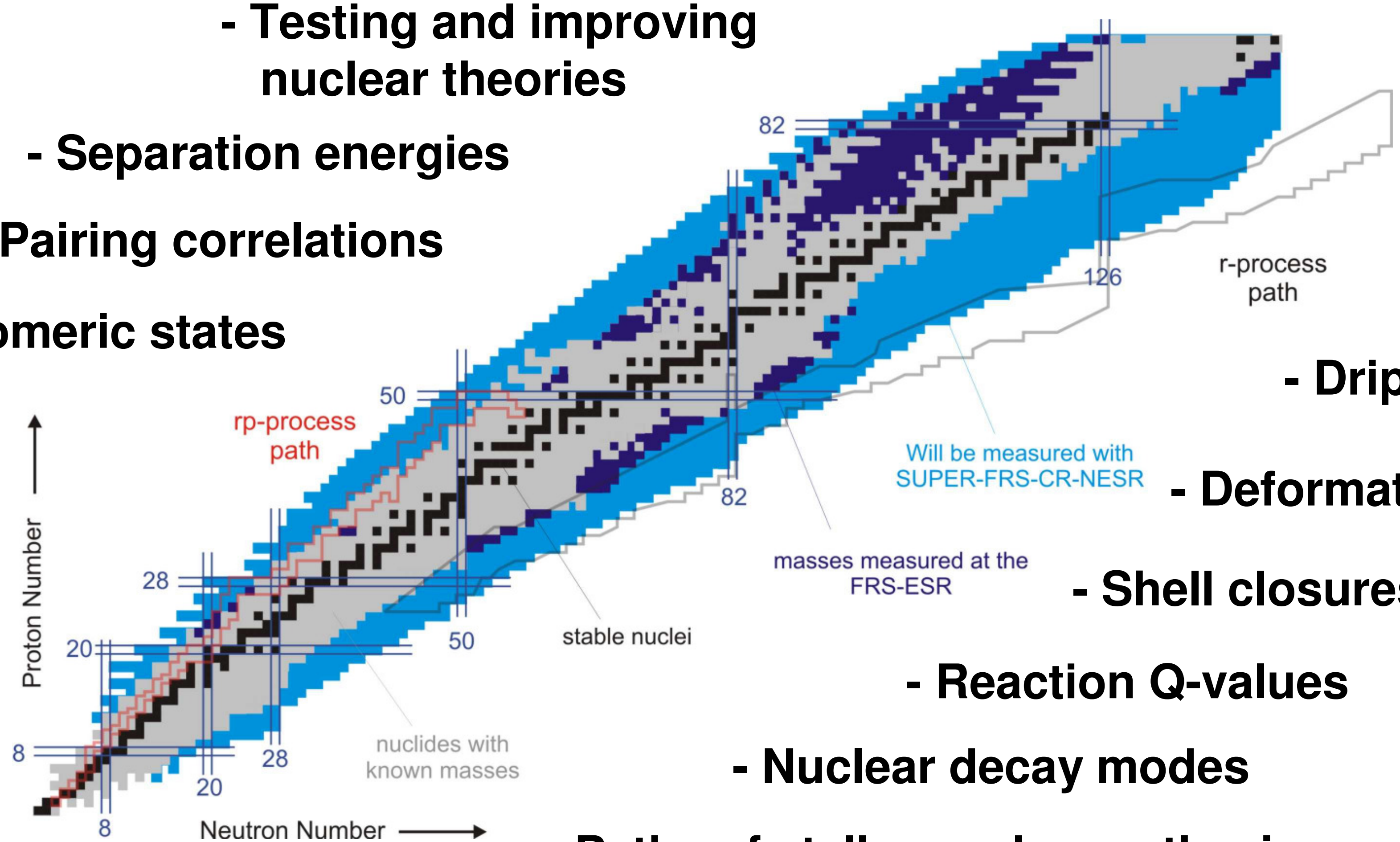
Direct mass measurements of n-rich nuclei and developments for ILIMA@FAIR

Ronja Knöbel

- **The FRS – ESR – Facility**
- **Schottky – Mass – Spectrometry**
- **Isochronous – Mass – Spectrometry**
- **Developments for ILIMA@FAIR**

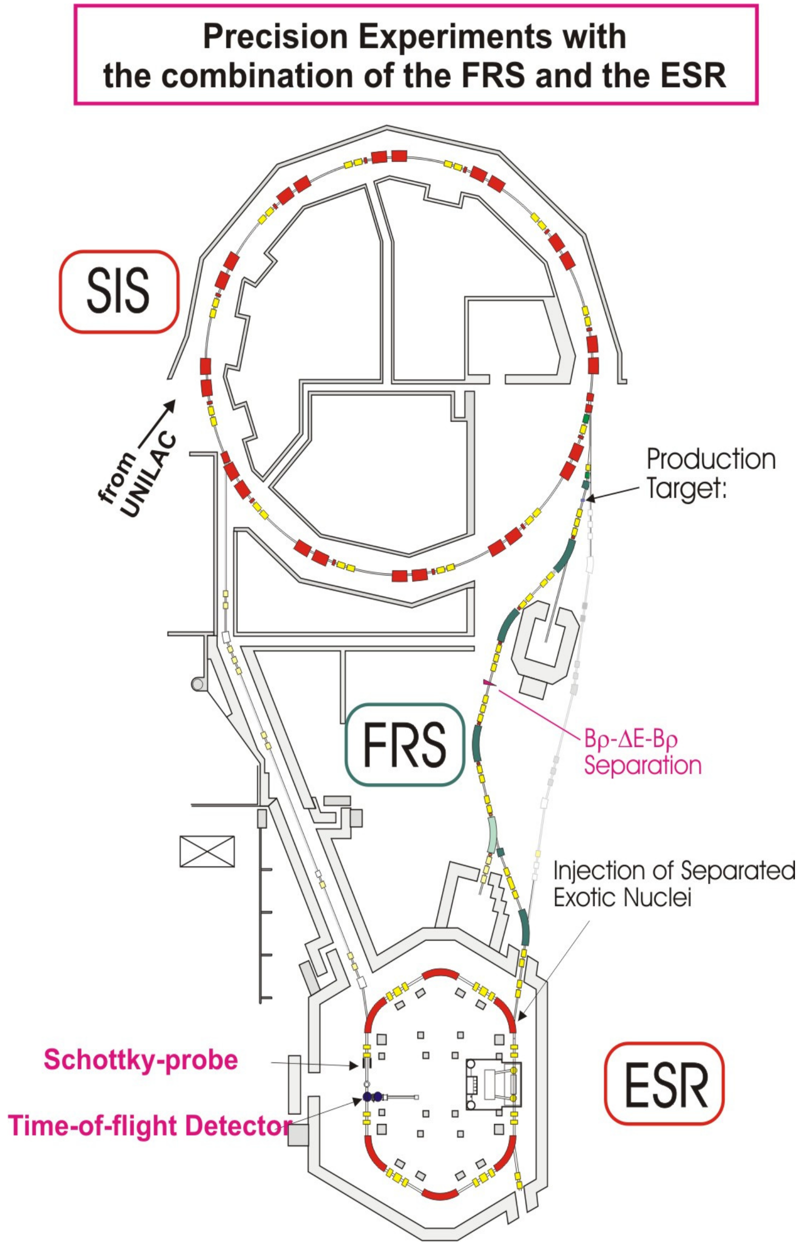
Motivation

- Total binding energies
- Testing and improving nuclear theories
- Separation energies
- Pairing correlations
- Isomeric states

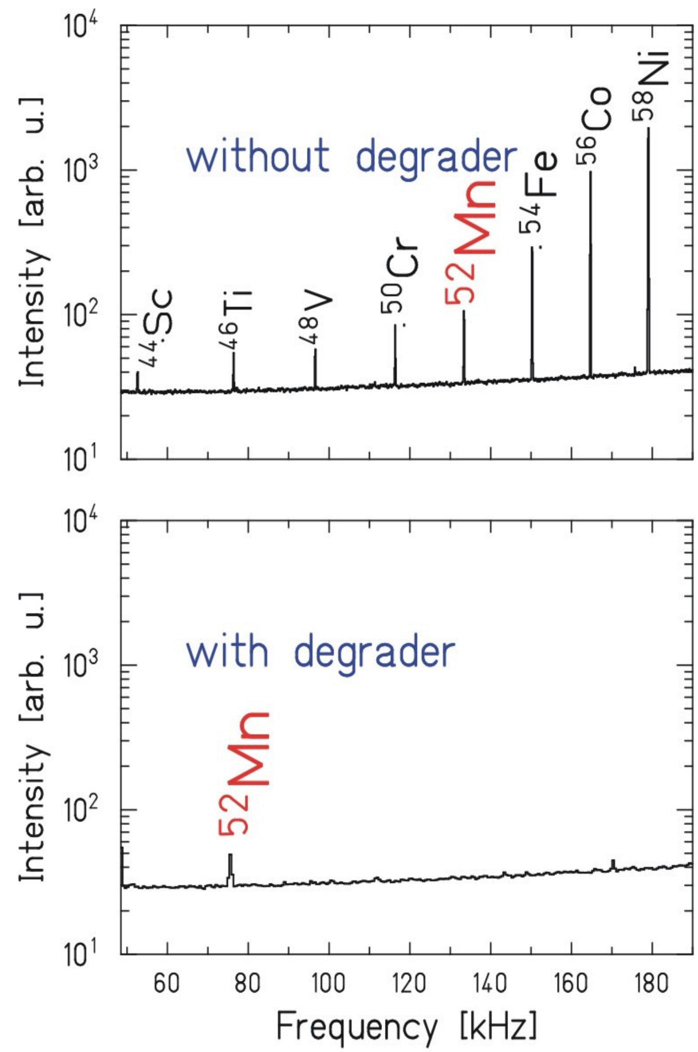


- Driplines
- Deformations
- Shell closures
- Reaction Q-values
- Nuclear decay modes
- Paths of stellar nucleosynthesis

Experimental Facilities

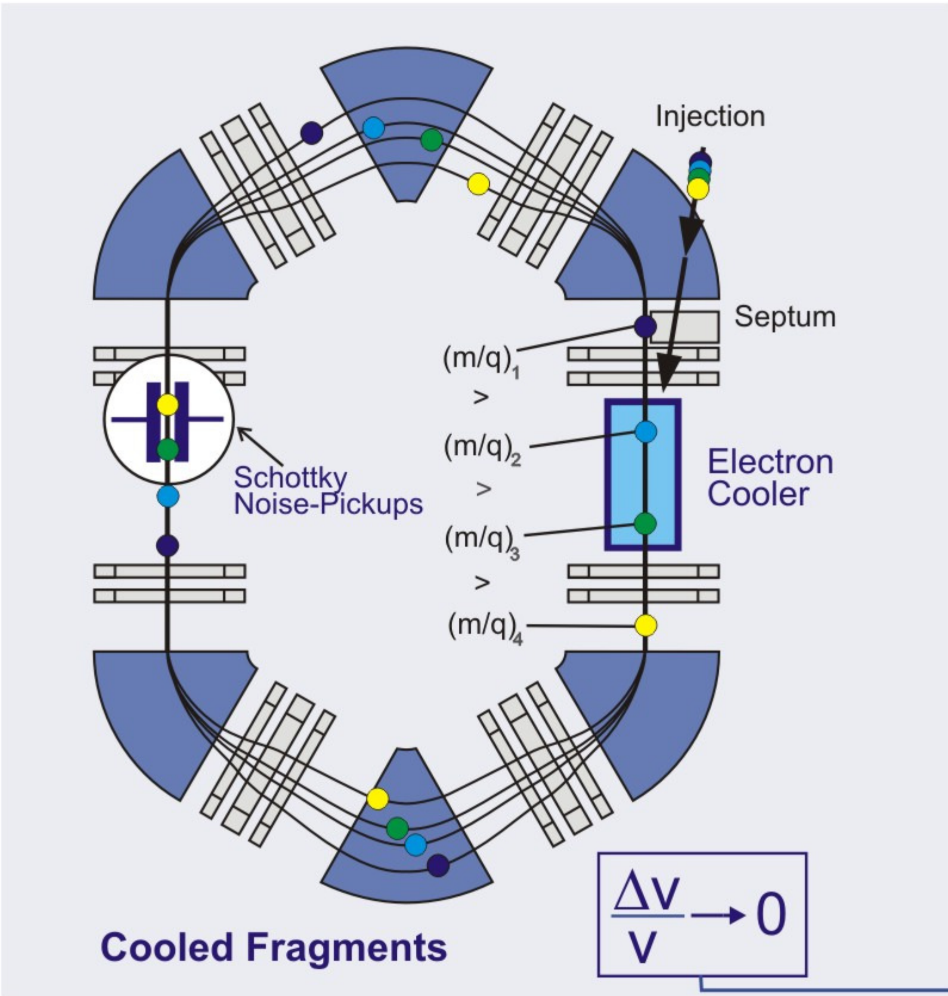


Mono-isotopic fragment beams stored in the ESR

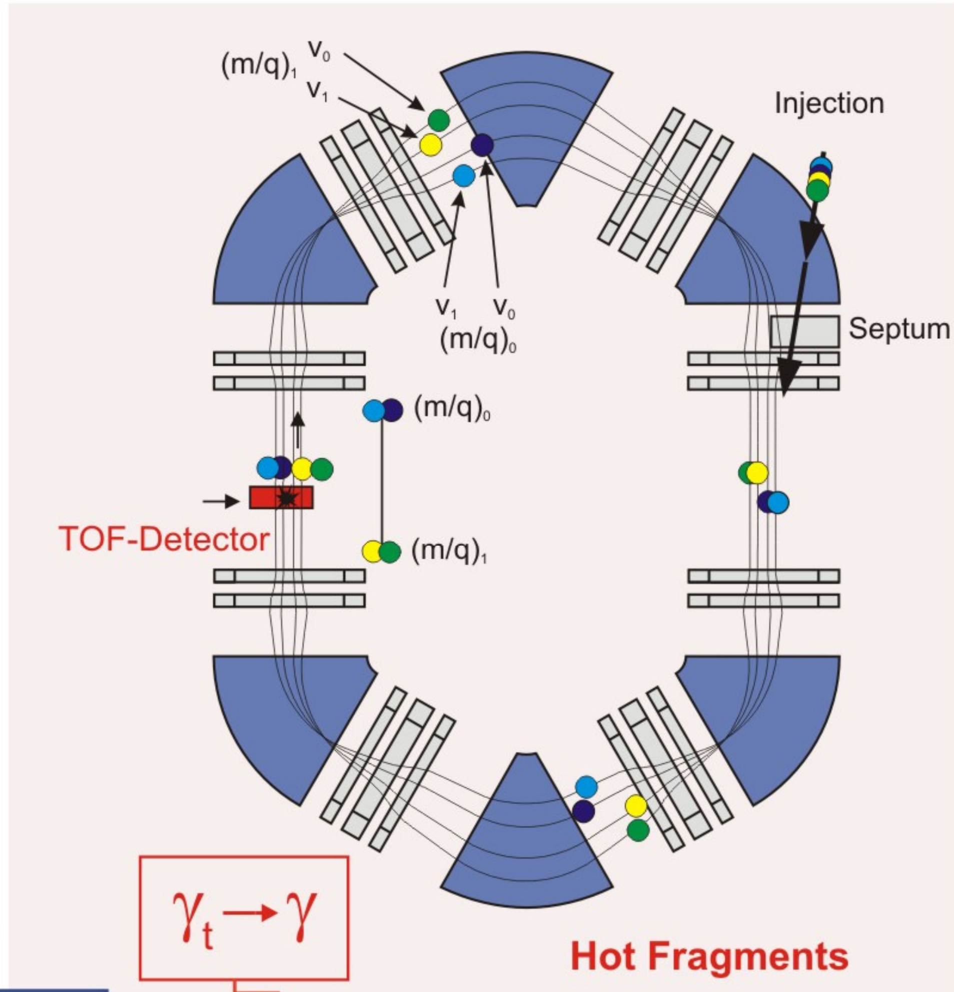


Mass Measurements at the ESR

SCHOTTKY MASS SPECTROMETRY



ISOCHRONOUS MASS SPECTROMETRY

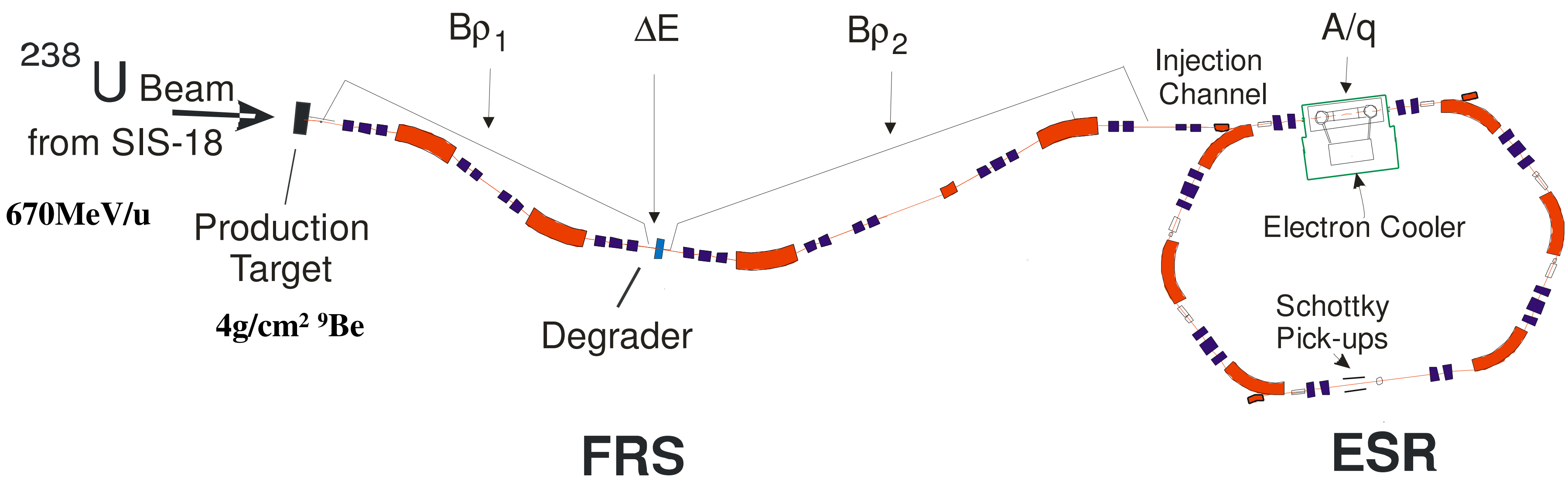


$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1 - \frac{\gamma^2}{\gamma_t^2}\right)$$

B. Franzke, H. Geissel, G. Münzenberg, H. Wollnik

Schottky Mass Spectrometry (SMS)

Intensity: $2{\cdot}10^9$/spill

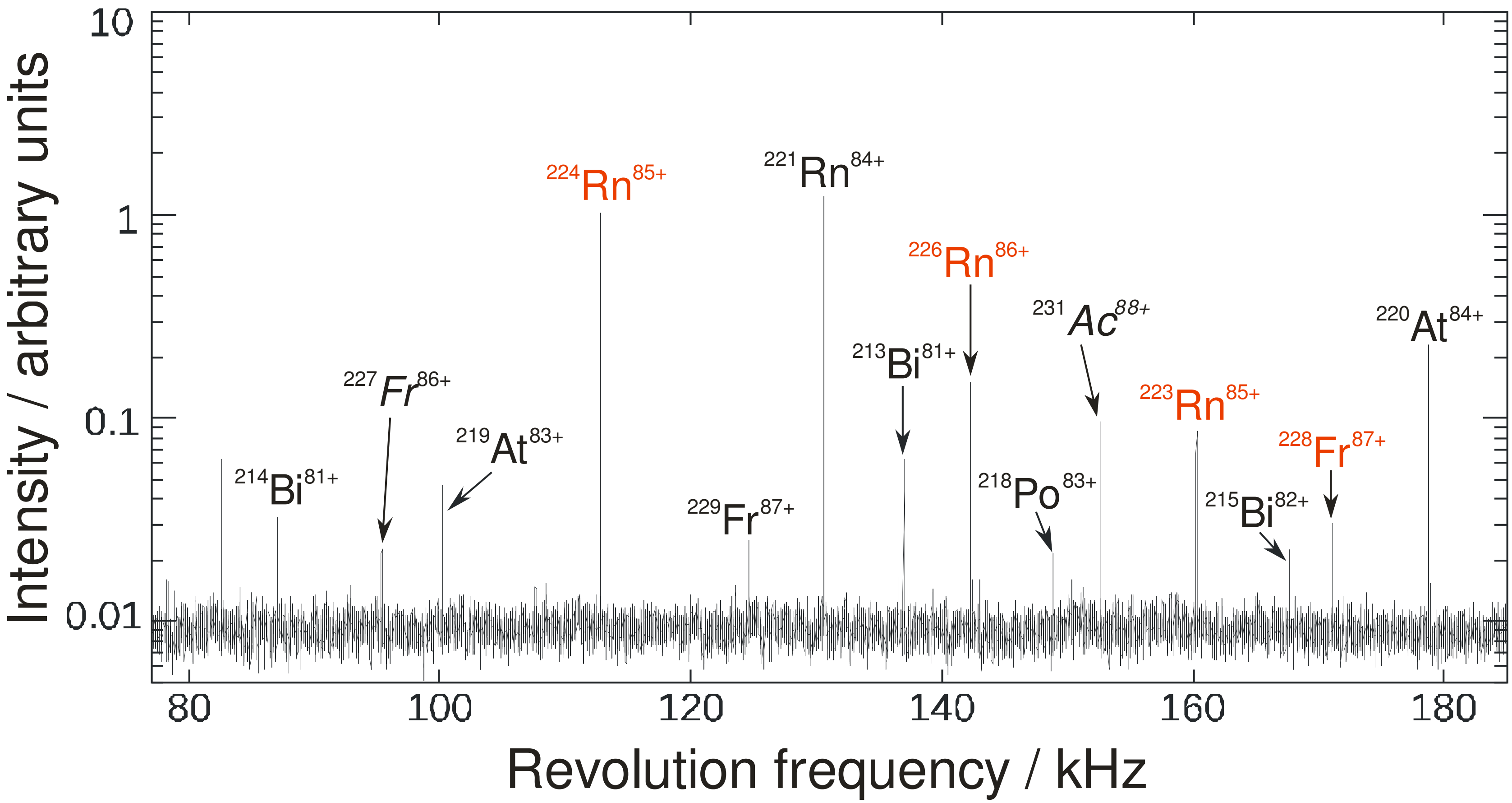


Bρ=7.9Tm

E_{ESR}= (360-400) MeV/u

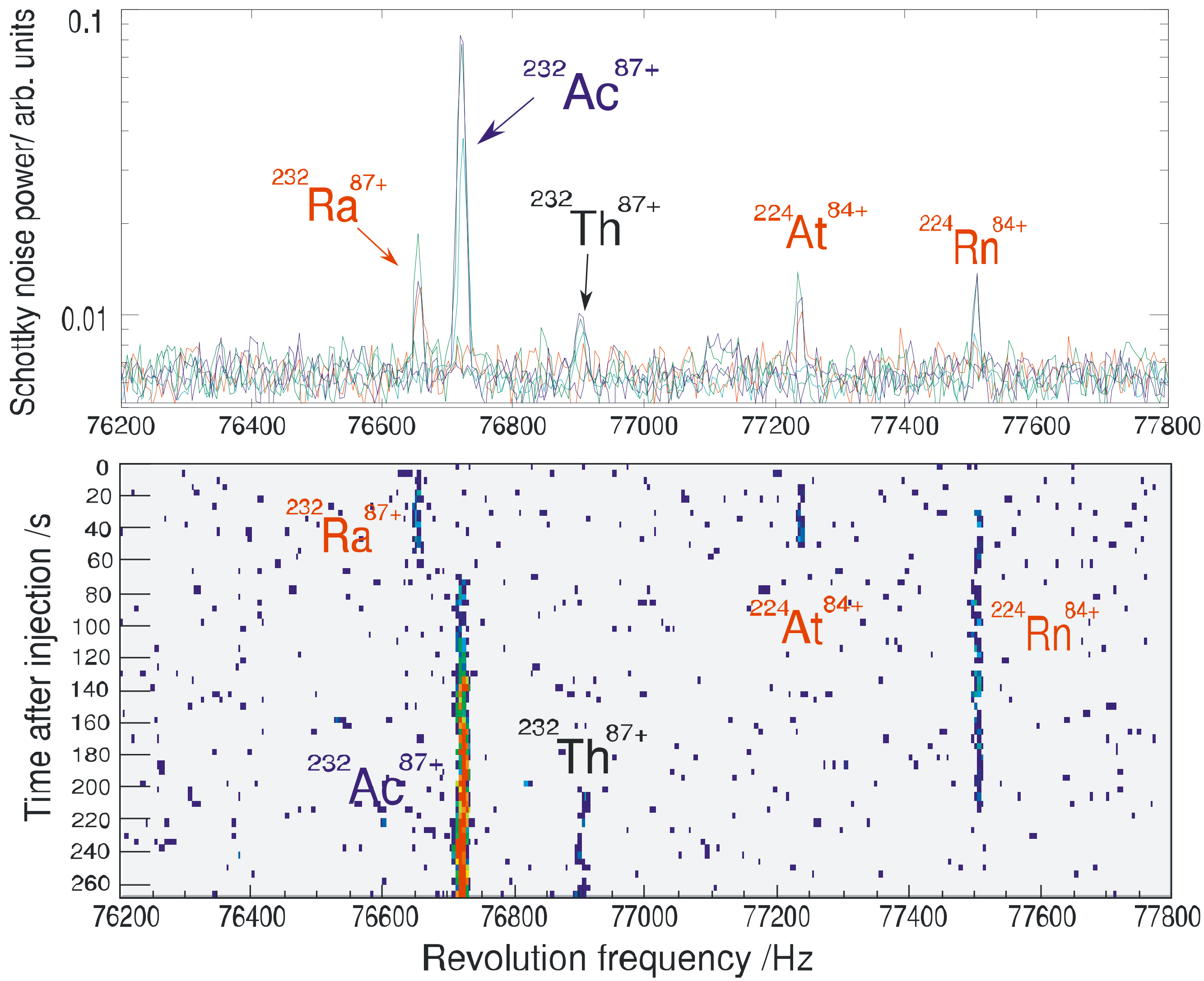
L. Chen et al., NPA 882 (2012) 71.

Schottky Mass Spectrometry (SMS)



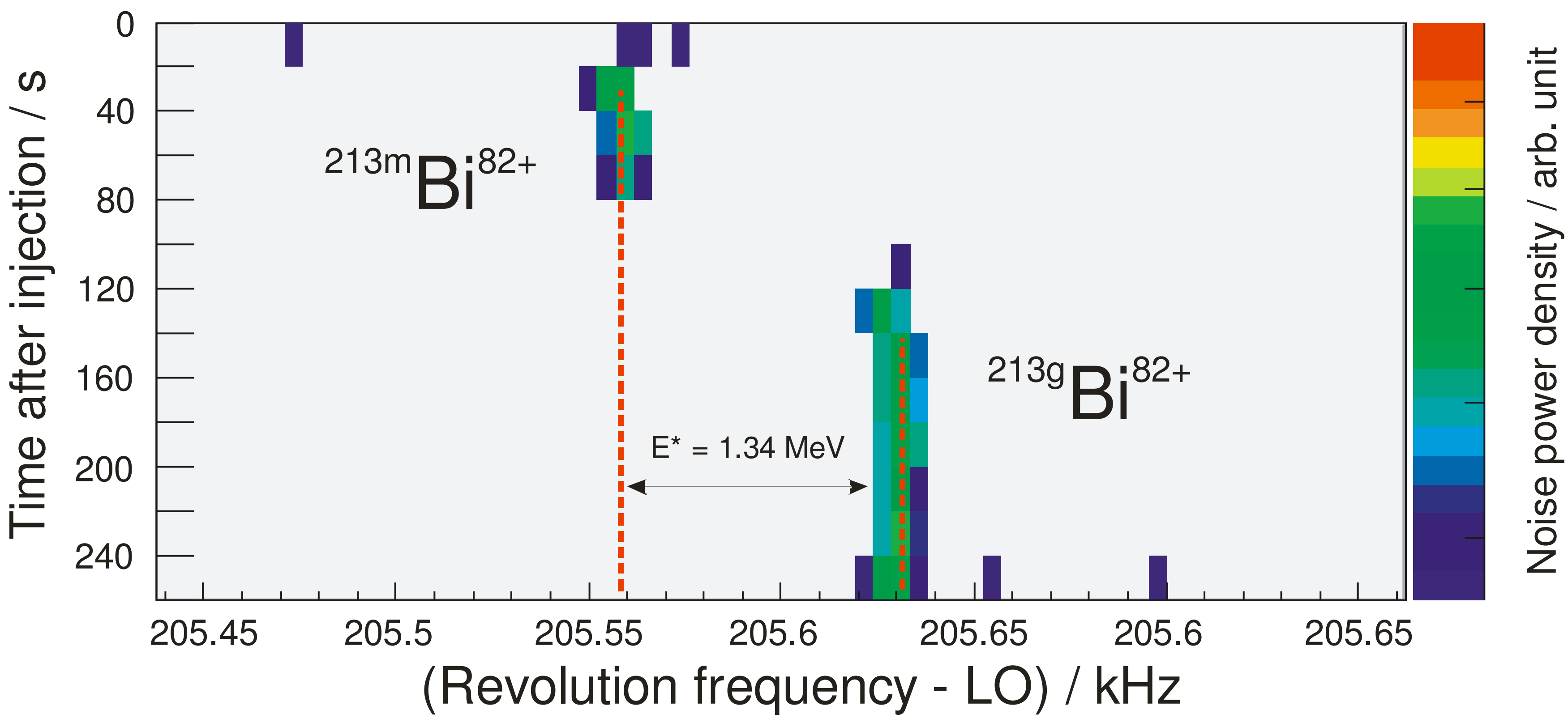
L. Chen et al., NPA 882 (2012) 71.

Schottky Mass Spectrometry (SMS)



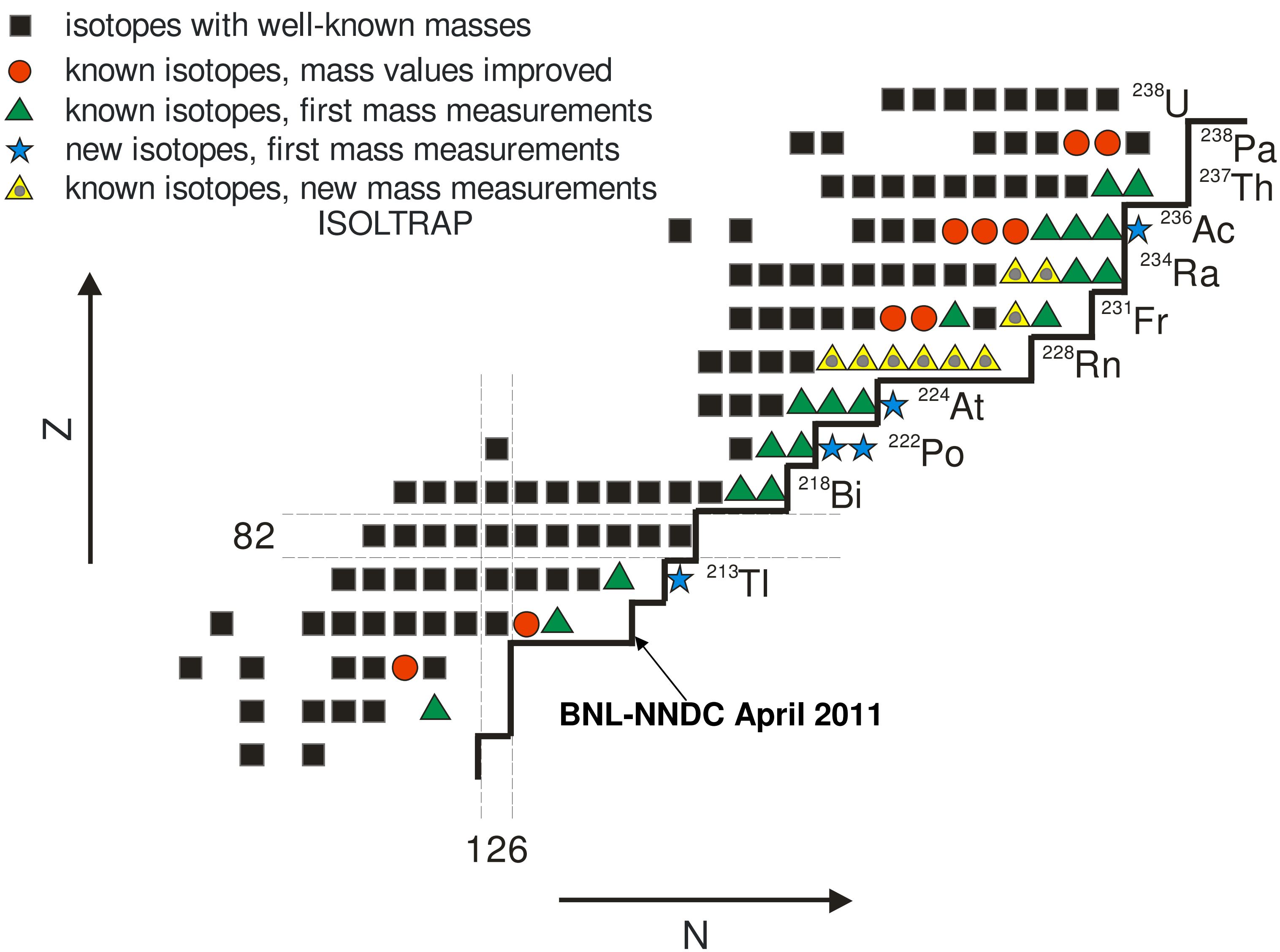
L. Chen et al., Phys. Lett. B 691 (2011) 234.

Schottky Mass Spectrometry (SMS)



L. Chen et al., NPA 882 (2012) 71.

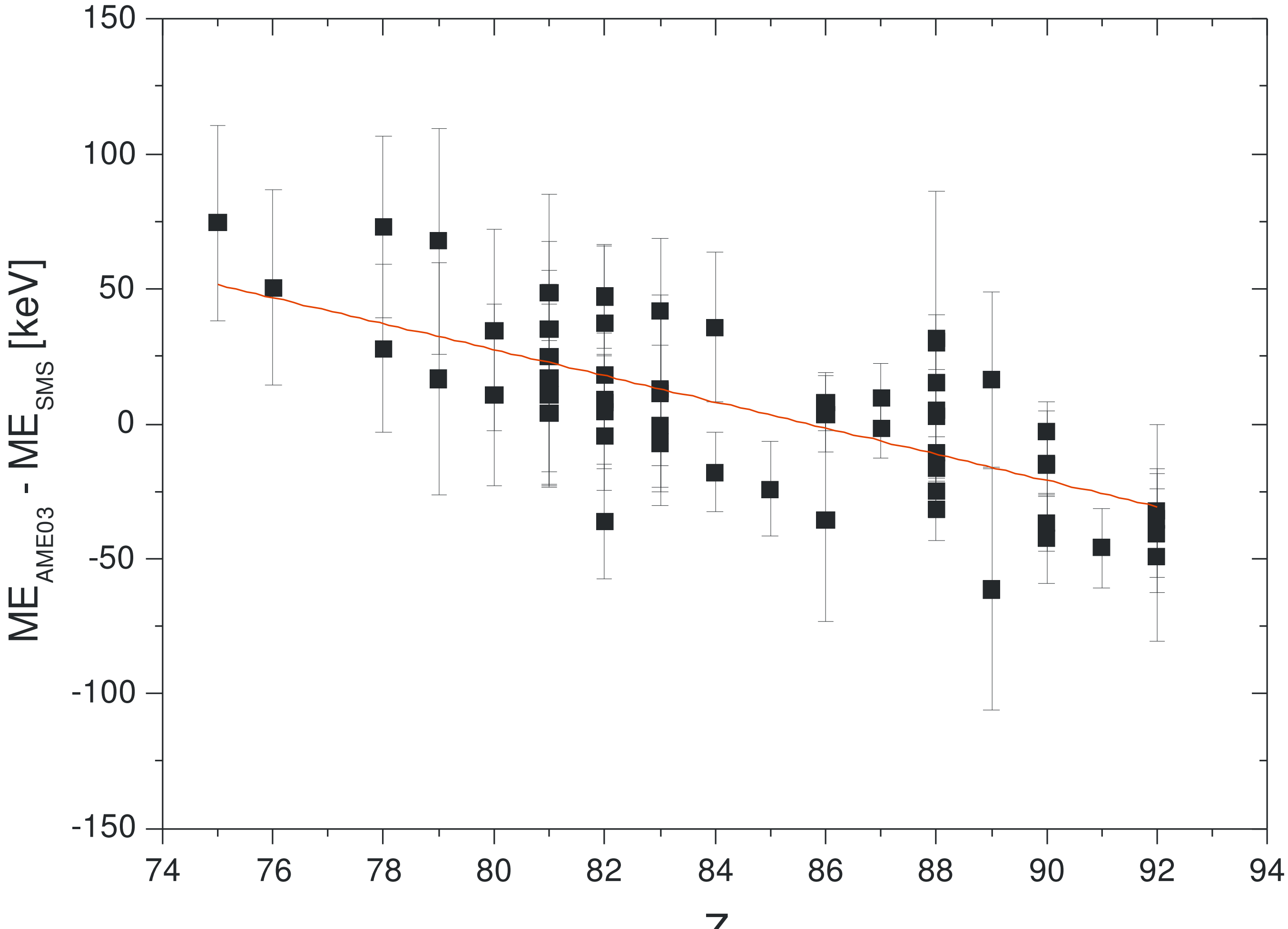
Schottky Mass Spectrometry (SMS)



L. Chen et al., NPA 882 (2012) 71.

Analysis

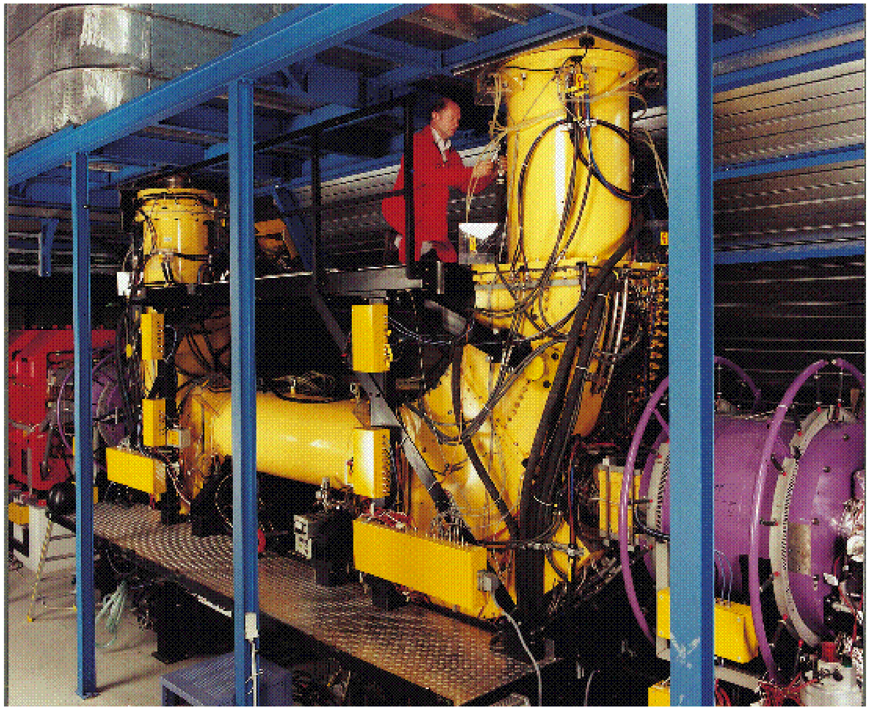
SYSTEMATIC DEVIATIONS FOR REFERENCE MASSES

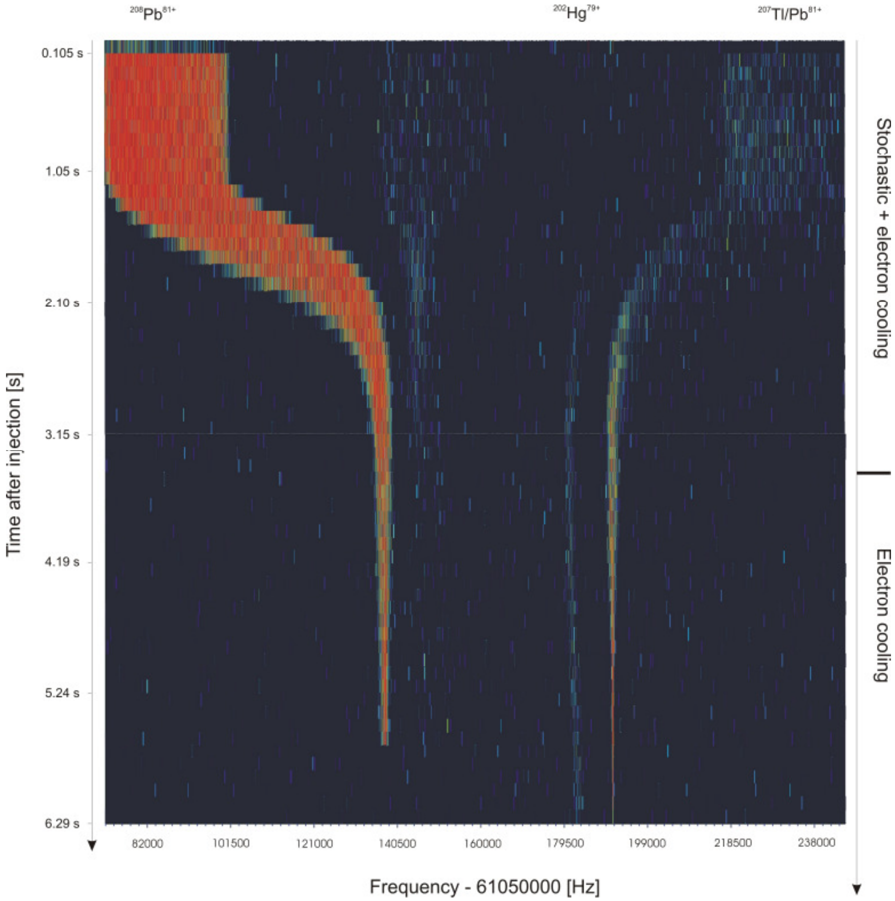


AME03: G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A 729 (2003) 337.

Electron Cooling

$$\frac{\Delta v}{v} \approx 5 \cdot 10^{-7}$$



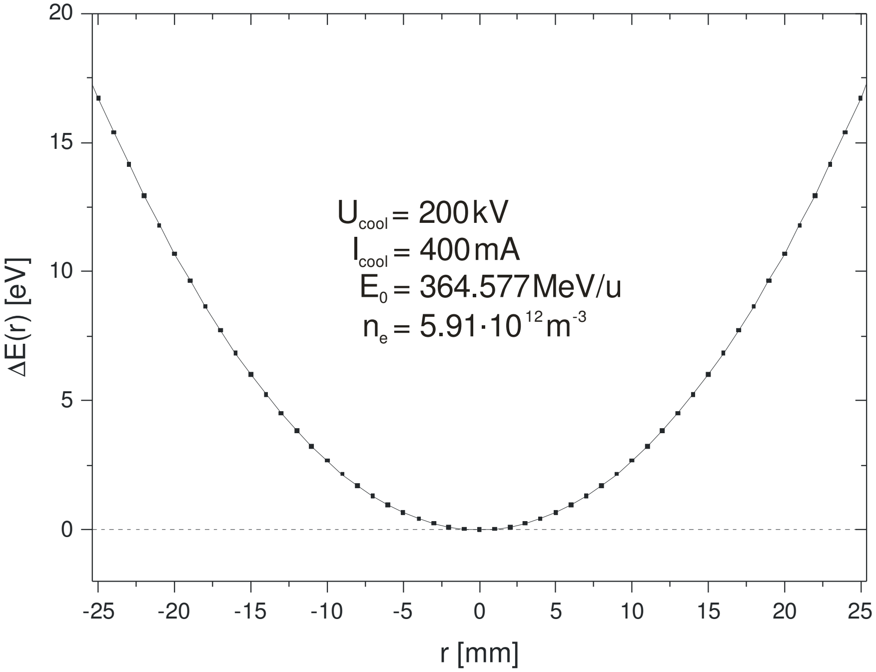


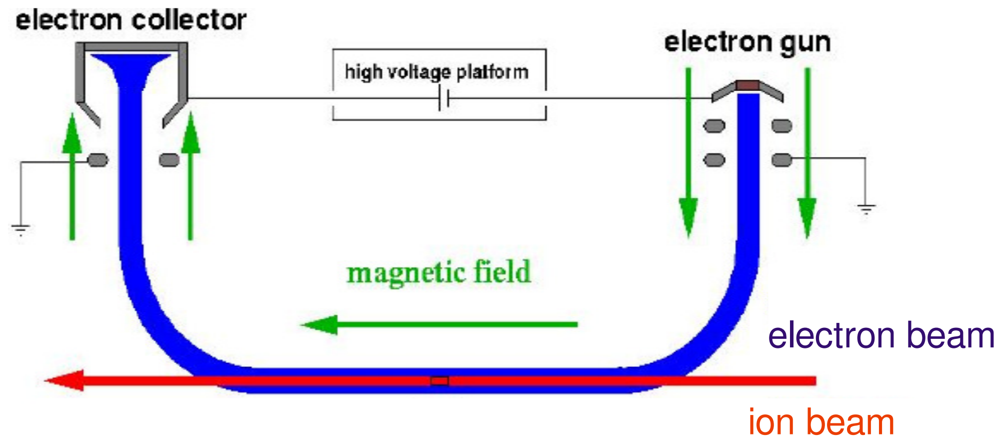
B. Franzke, M. Steck, F. Nolden, K. Beckert, P. Beller

Electron Cooling

H. Poth, Phys. Rep. 196 (1990) 135.
M. Steck, Beam Cooling, Talk at the CERN Accelerator School Darmstadt, 28.09.2009-09.10.2009
C. Brandau, Dissertation, Justus-Liebig-Universität Gießen, 2000.

$$\Delta E(r) = n_e \pi r_e m_e c^2 r^2$$





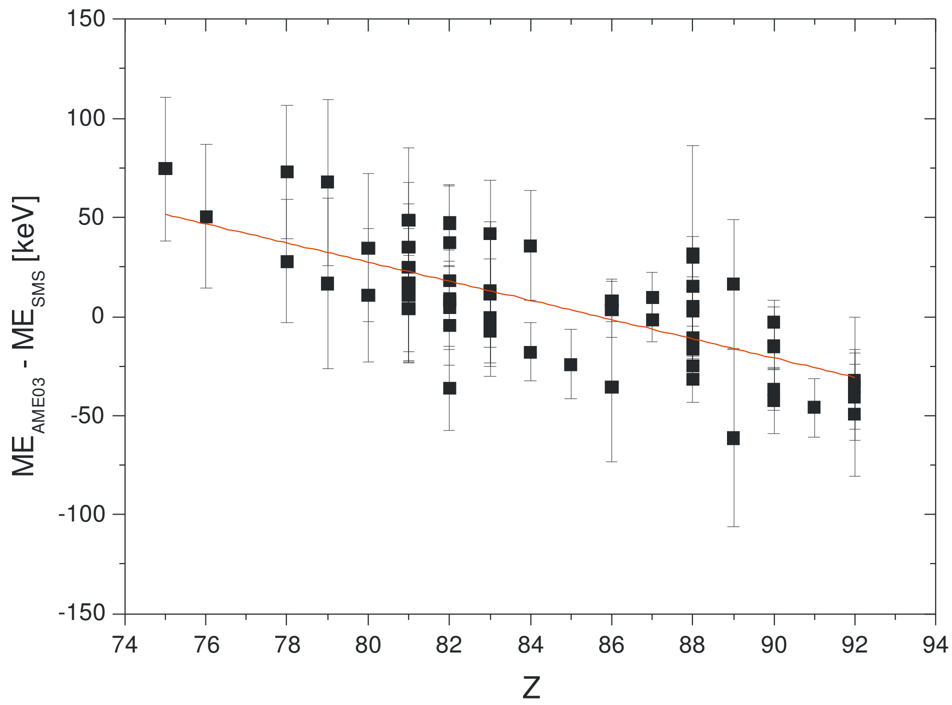
radial profile of the longitudinal velocity of the cooler electrons

$$\frac{f_i - f_j}{f_i} = -\alpha_p \left[\frac{(m/q)_i - (m/q)_j}{(m/q)_i}\right] + \left(1 - \frac{\gamma^2}{\gamma_t^2}\right)\left(\frac{v_i - v_j}{v_i}\right)$$

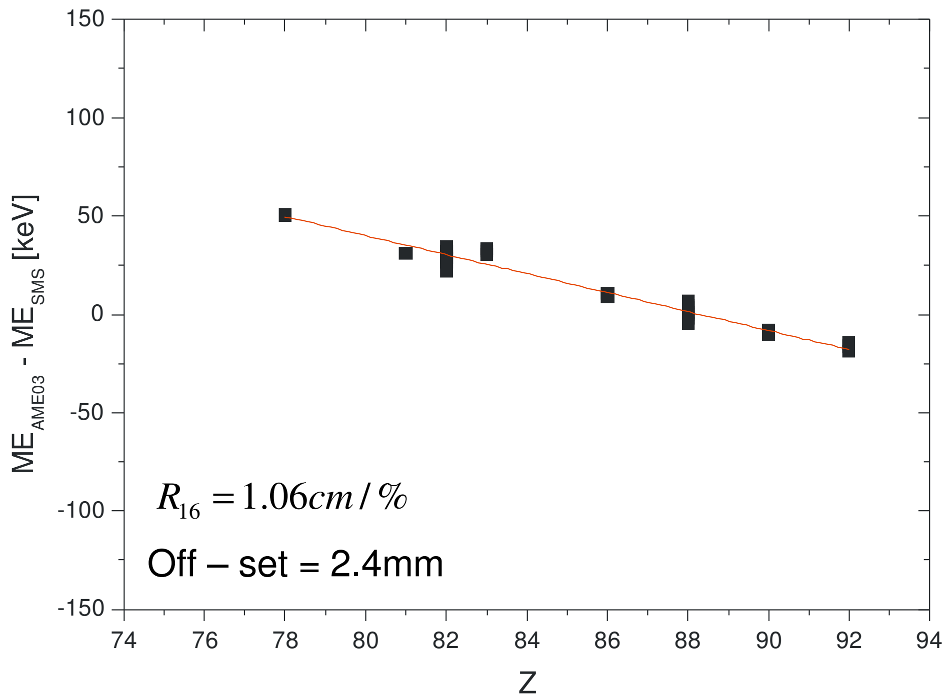
L. Chen et al., NPA 882 (2012) 71.

Recent Developments in the Analysis

Observed



Calculated



Observed dependence can be reproduced by taking into account the radial profile of the longitudinal velocity of the cooler electrons

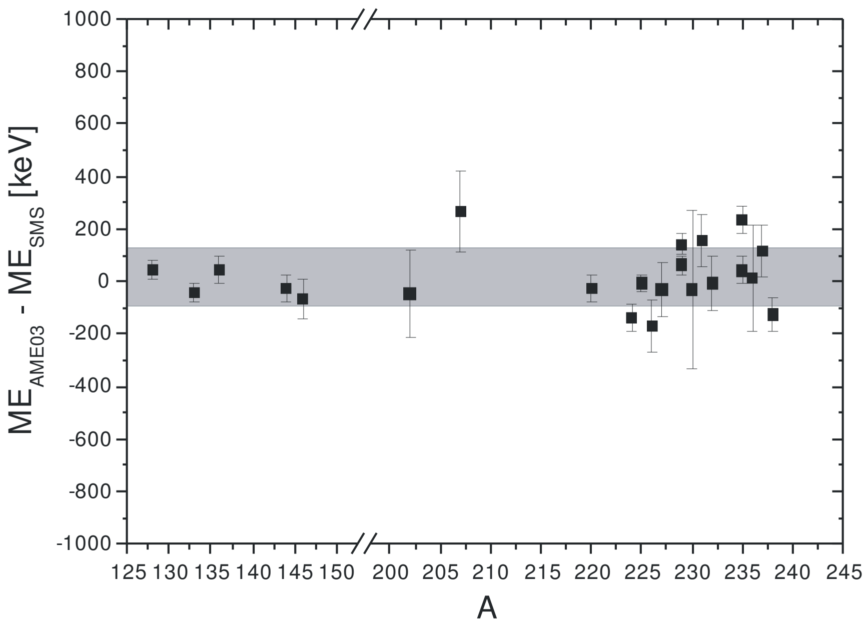
AME03: G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A 729 (2003) 337.

L. Chen et al., NPA 882 (2012) 71.

Comparison with AME03

AME03: G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A 729 (2003) 337.

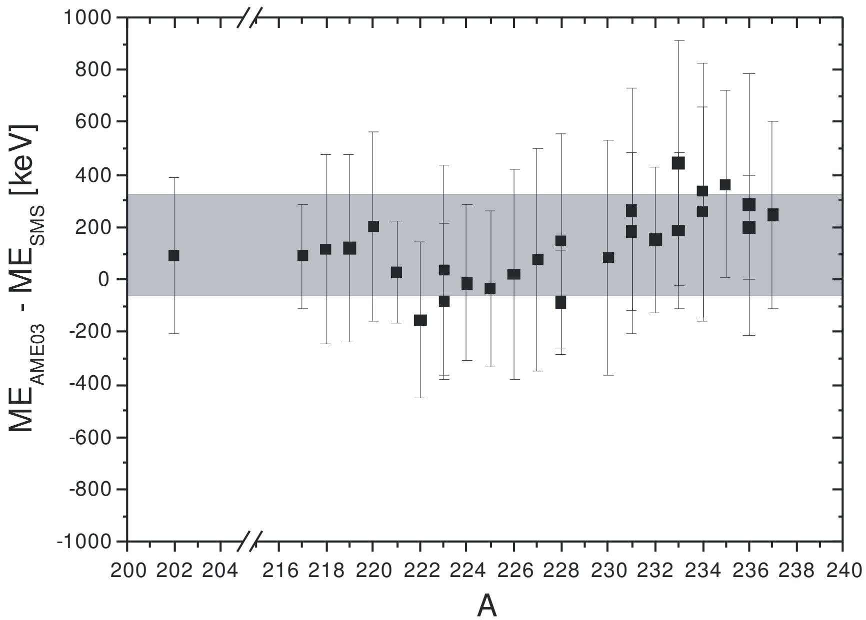
Comparison to
improved mass values



$$\overline{\Delta ME} = 19keV$$

$$\sigma_{rms} = 111keV$$

Comparison to
extrapolated mass values



$$\overline{\Delta ME} = 133keV$$

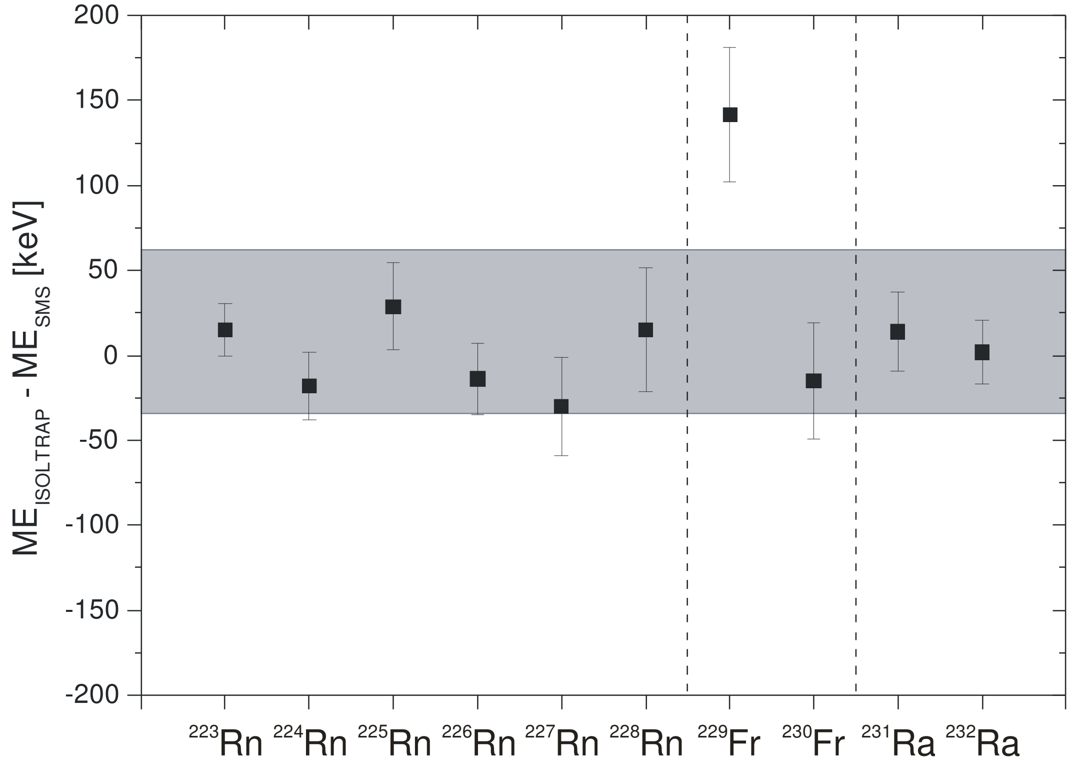
$$\sigma_{rms} = 195keV$$

L. Chen et al., NPA 882 (2012) 71.

Comparison with ISOLTRAP

<u>ISOLTRAP – data:</u>

F. Herfurth et al., Eur. Phys. J. A 25 (2005) 17-21.
D. Neidherr et al., Phys. Rev. Lett. 102 (2009) 112501.
C. Weber et al., Nucl. Phys. A 803 (2008) 1.

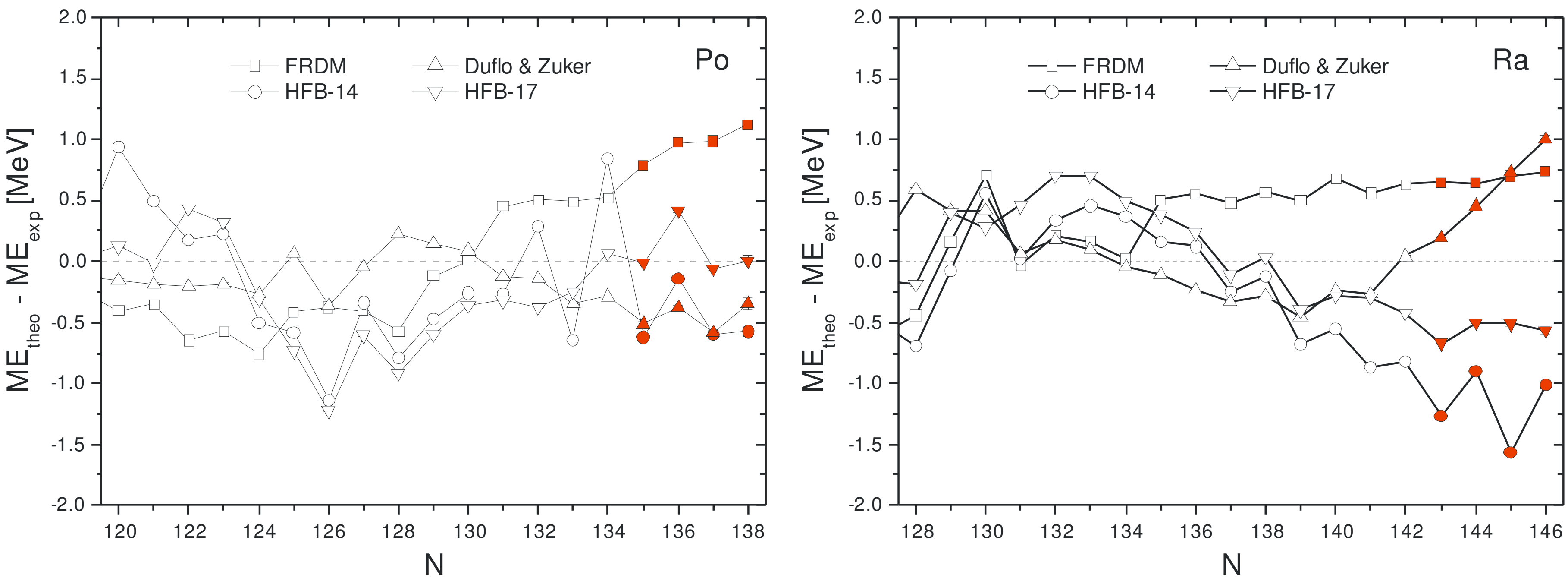


$$\overline{\Delta ME} = 14keV$$

$$\sigma_{rms} = 48keV$$

L. Chen et al., NPA 882 (2012) 71.

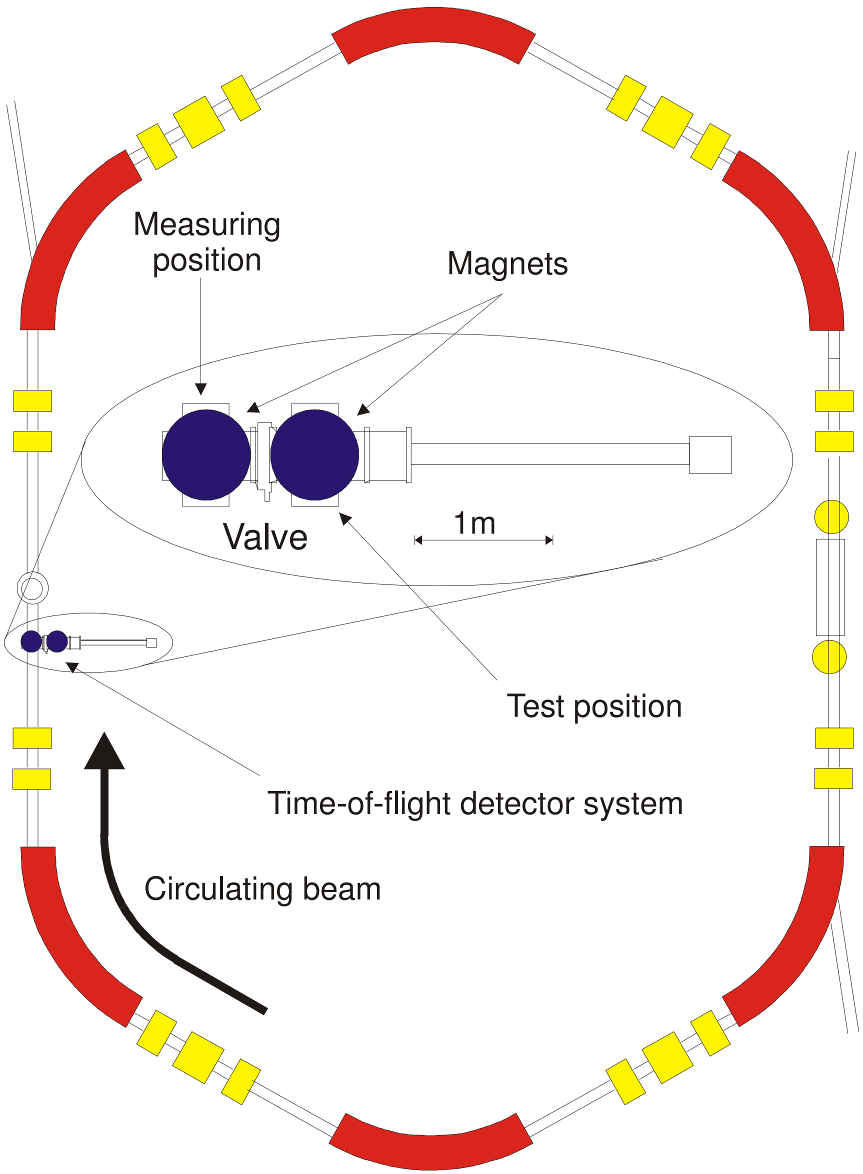
Comparison with Mass Models

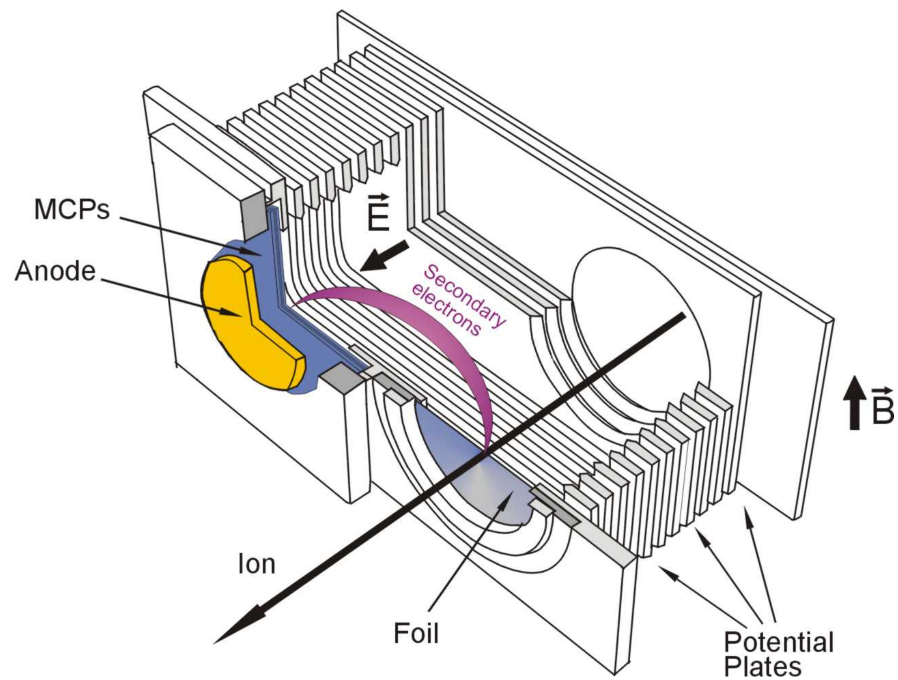


FRDM: P. Möller et al., At. Data Nucl. Data Tables 59 (1995) 185.
HFB – 14: http://www-astro.ulb.ac.be/Nucdata/Masses/hfb14-plain,
S. Goriely, M. Samyn, and J.M. Pearson, Phys. Rev. C 75 (2007) 064312 and references therein.
HFB – 17: S. Goriely, N. Chamel, and J.M. Pearson, Eur. Phys. J. A 42 (2009) 547-552.
Duflo & Zuker: J. Duflo, A.P. Zuker, Phys. Rev. C 52 (1995) R23.
Experimental data not marked in red: G. Audi, A. H. Wapstra, C. Thibault, Nucl. Phys. A 729 (2003) 337.

L. Chen et al., NPA 882 (2012) 71.

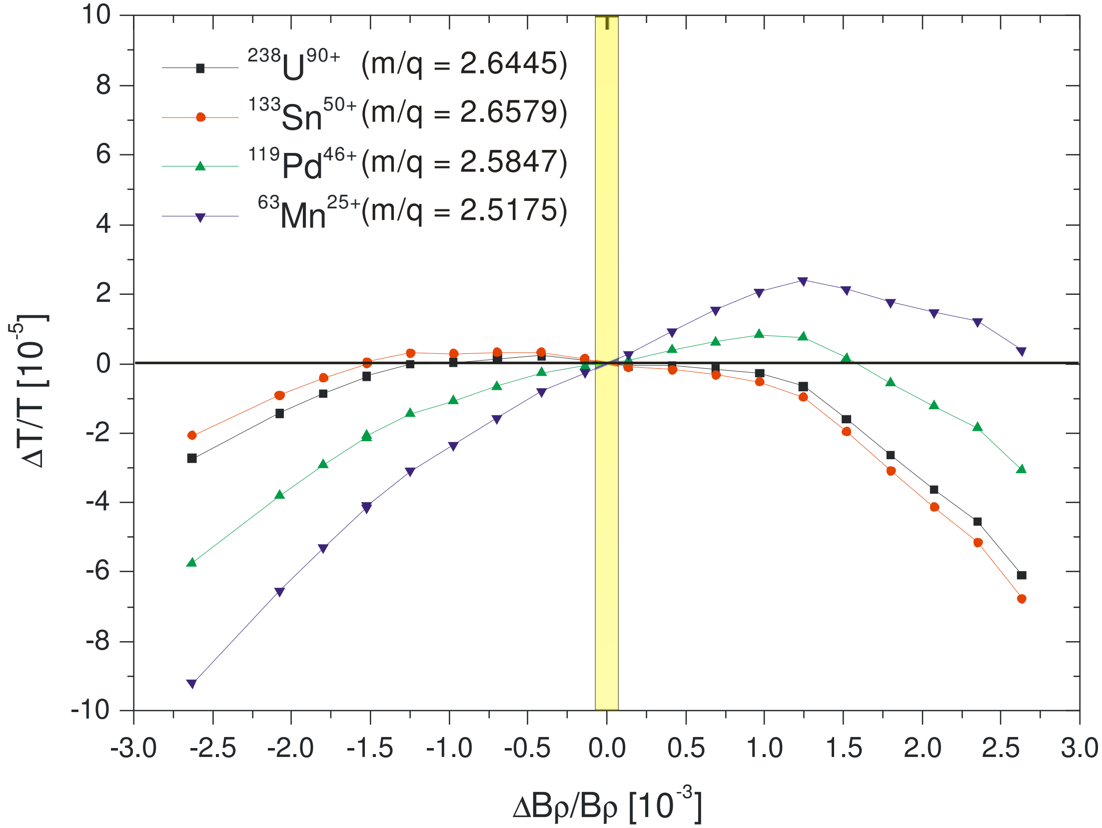
Isochronous Mass Spectrometry (IMS)

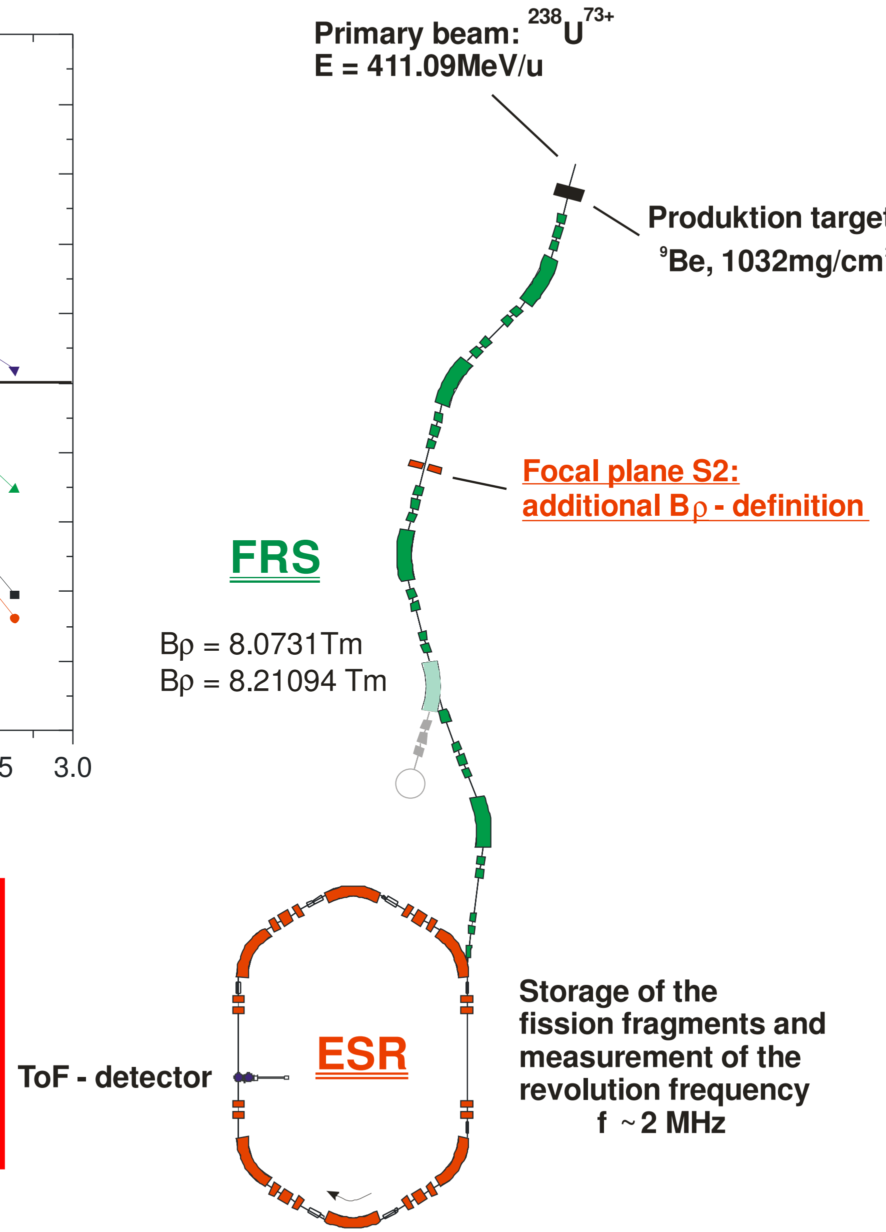




J. Troetscher, B. Fabian, N. Kuzminchuk, M. Diwisch

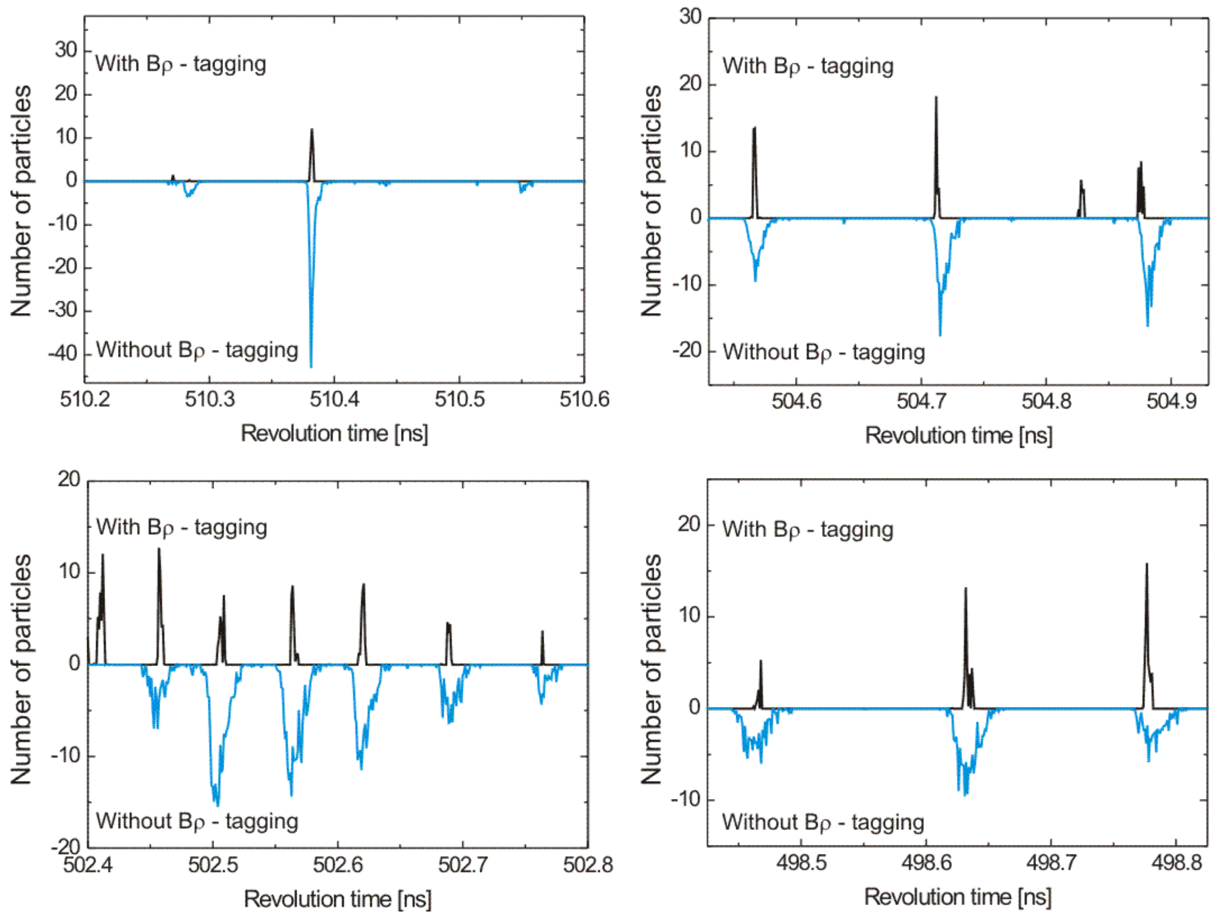
New Experimental Approach for IMS





The isochronous condition can be fulfilled only for a small area
⇒ Solution: additional Bρ – definition (Bρ – Tagging)

New Experimental and New Data-Analysis Approach for IMS

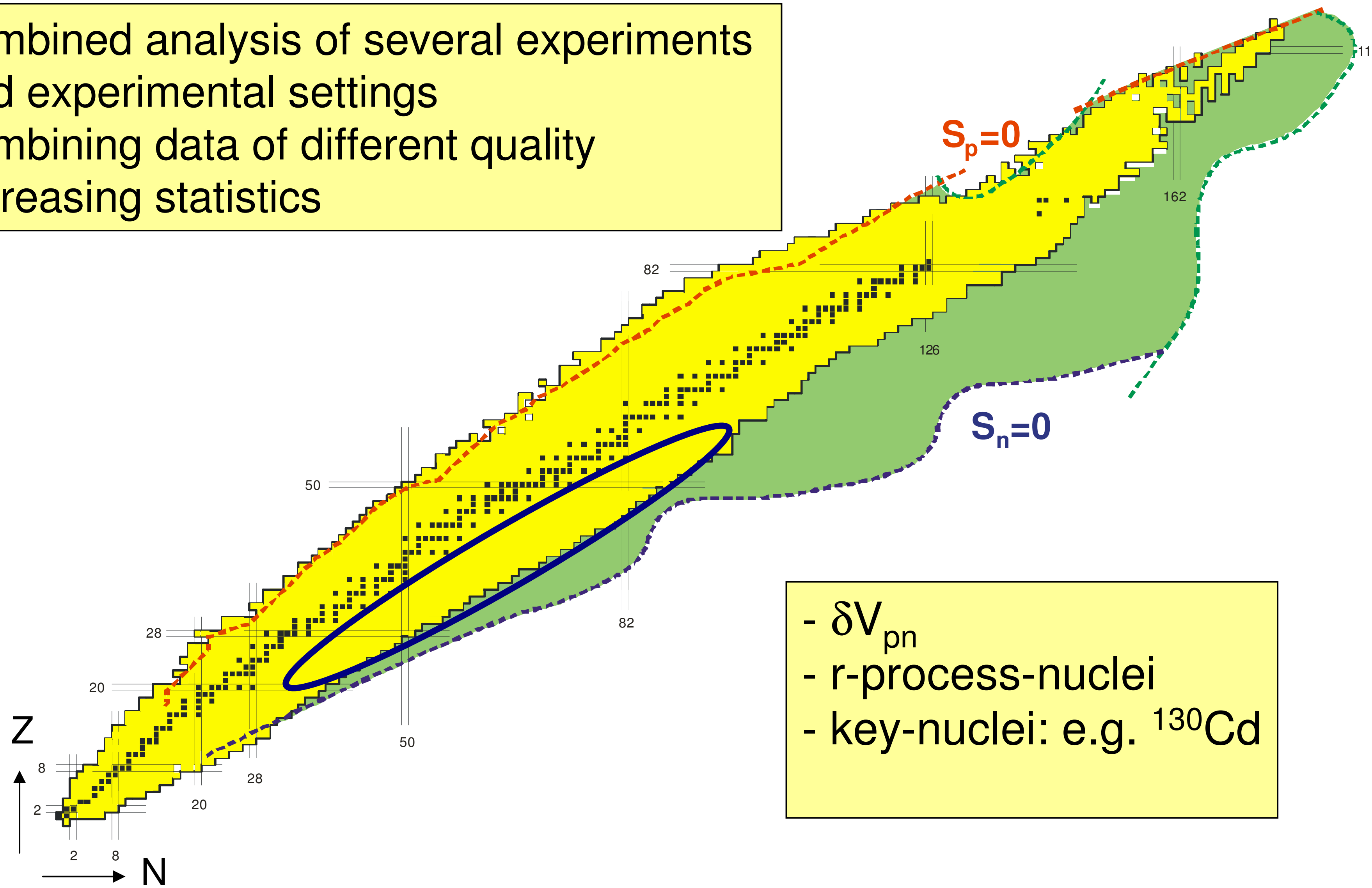


Results of additional Bρ-determination with the FRS

Experimental data without Bρ-tagging: M. Matos, PhD
Experimental data with Bρ-tagging: B. Sun, R. Knöbel, PhDs

New Experimental and New Data-Analysis Approach for IMS

- combined analysis of several experiments and experimental settings
- combining data of different quality
- increasing statistics



- δV_{pn}
- r-process-nuclei
- key-nuclei: e.g. ^{130}Cd

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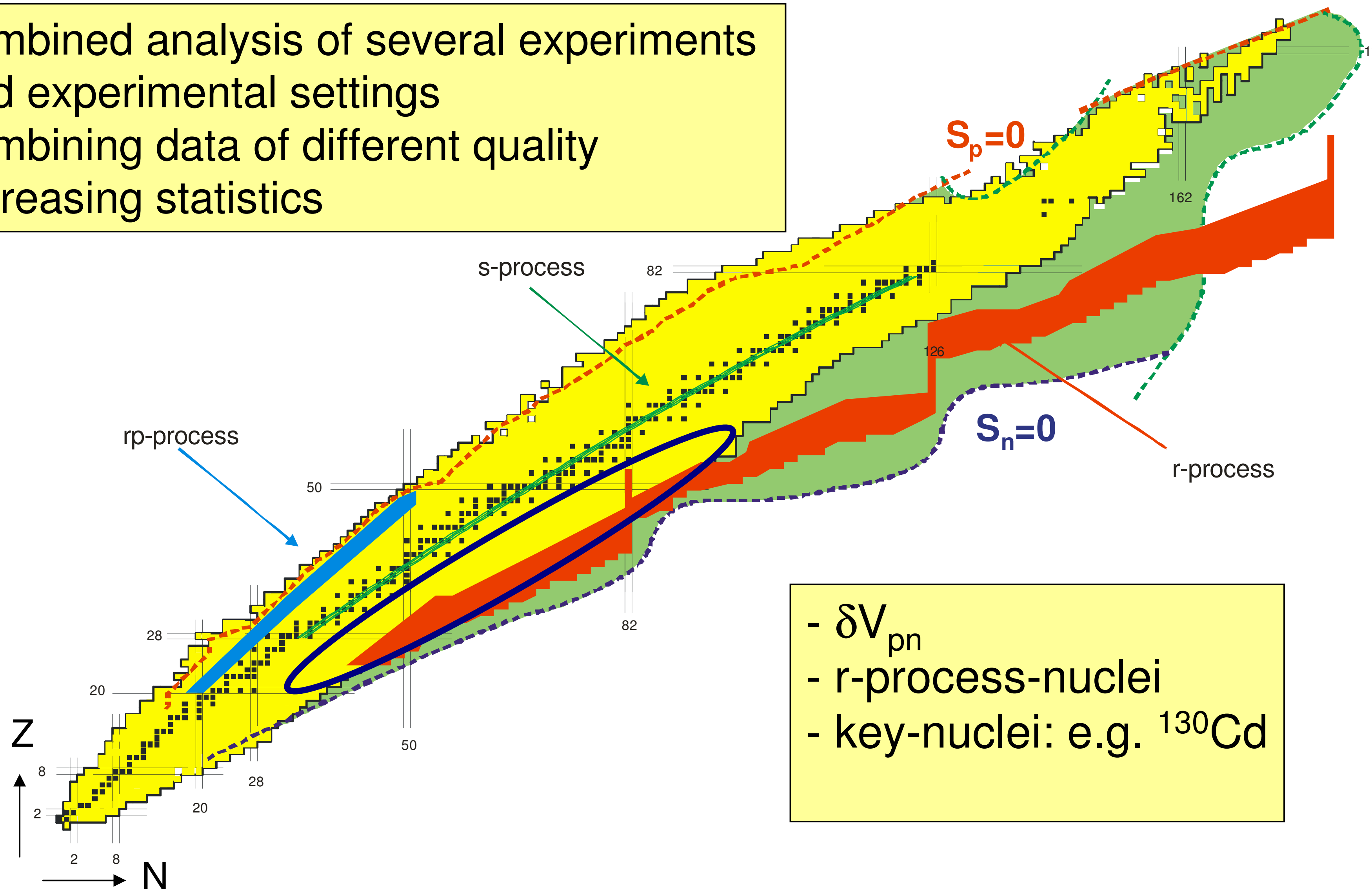

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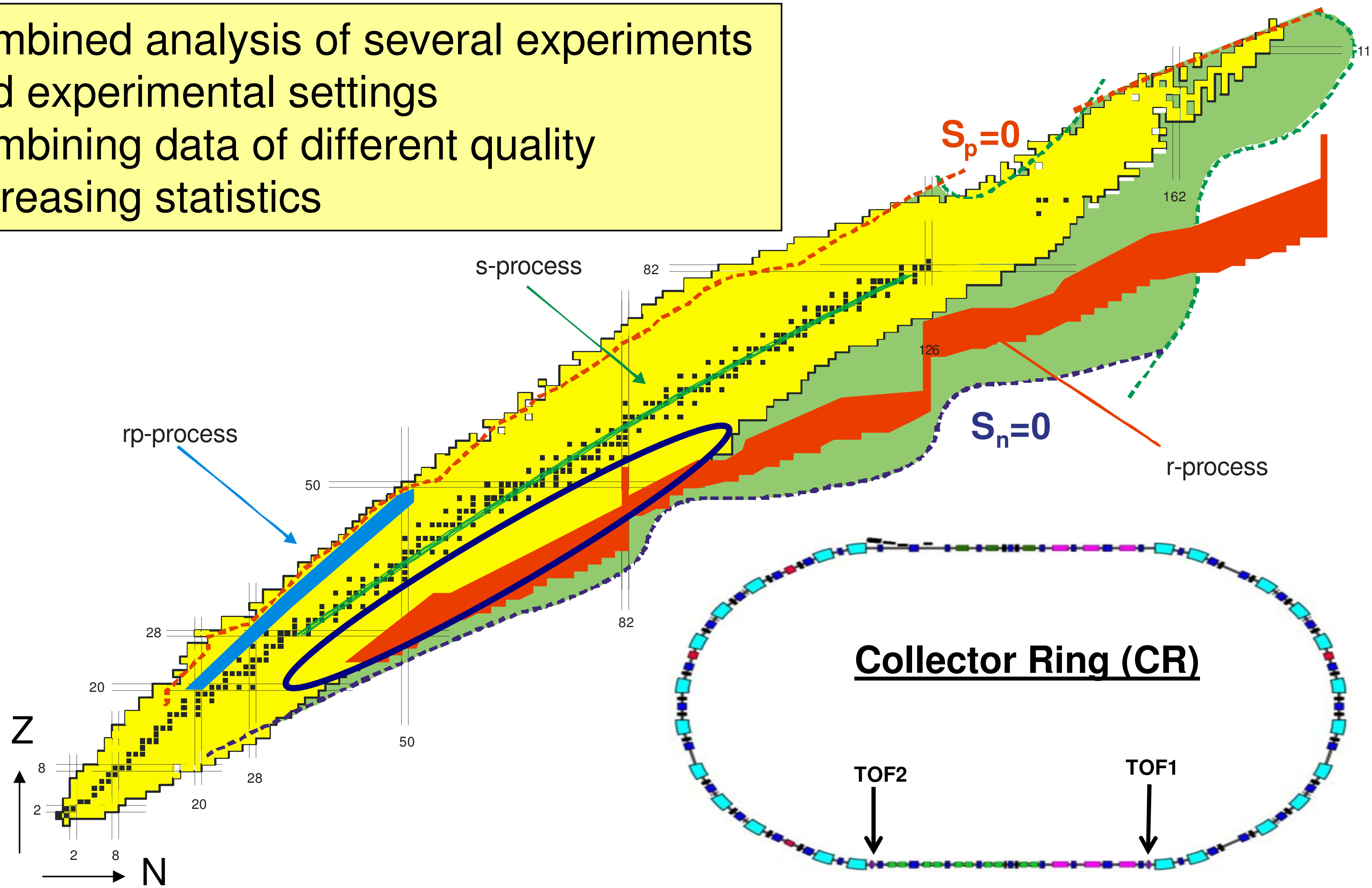
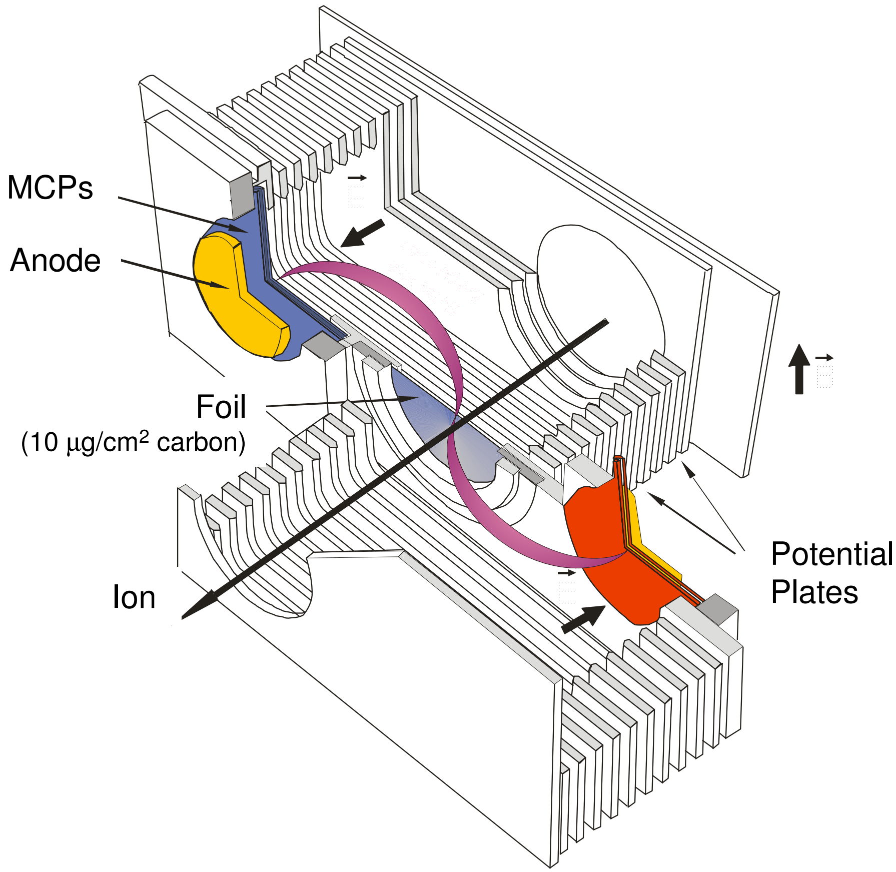


Timing Limitations

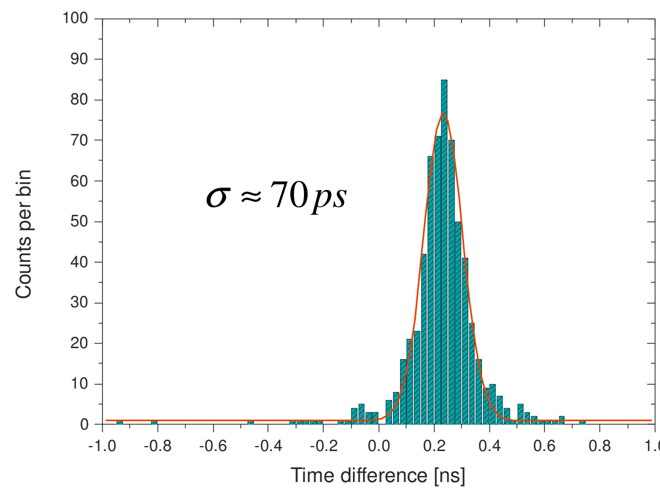
Isochronicity of the Storage Ring



Signal Acquisition and Processing

Electron Transport

- Acceleration fields
- Electrode design, fringe fields
- Initial electron velocities
- Mechanical tolerances



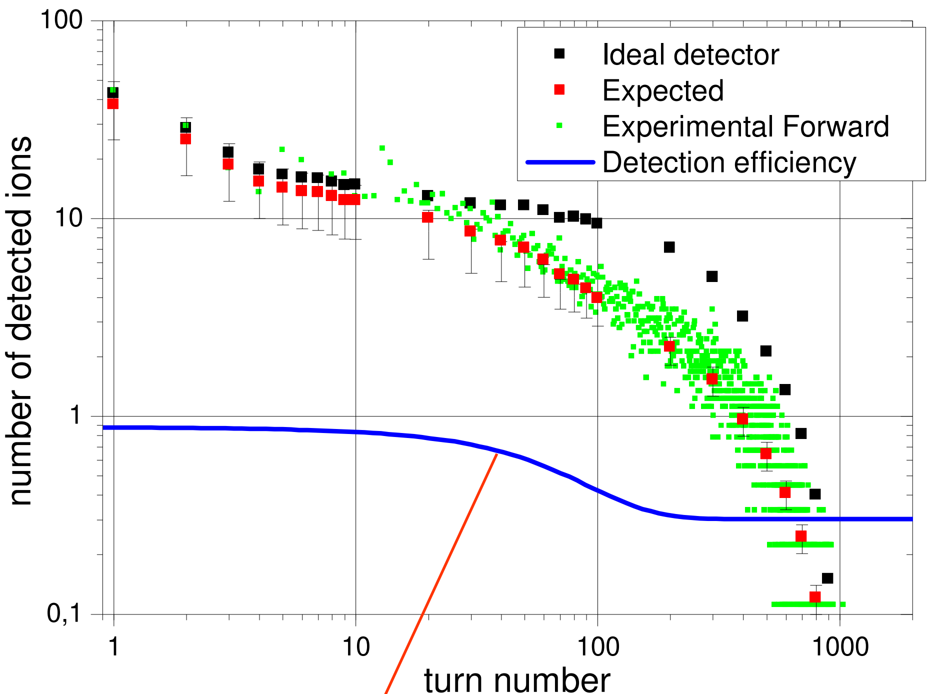
Electron Detection

- Rate and number of impinging electrons
- MCP pore size
- Detector voltages
- Anode design and spacing
- Transmission line matching

Offline - and Online - Tests

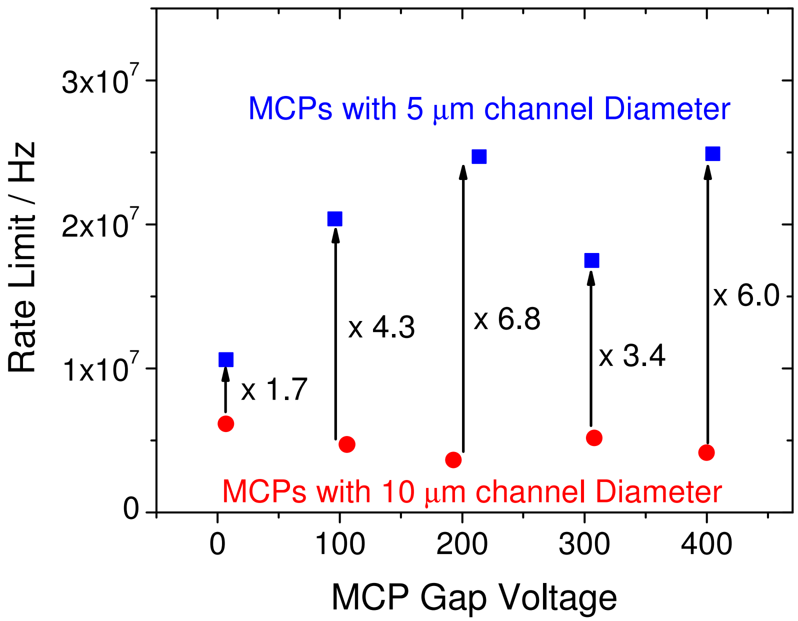
Revolution time detectors in the ESR and in the CR need high rate capability

Revolution frequency: ~ 2 MHz
→ 50 particles generate 10^8 hits / s



High rate limits detection efficiency

Recent Development Results:



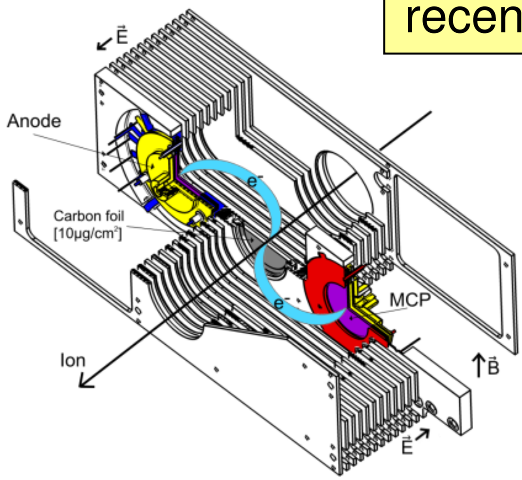
MCPs with smaller pore size
→ rate capability increased
by a factor of 4

B. Fabian, H. Weick

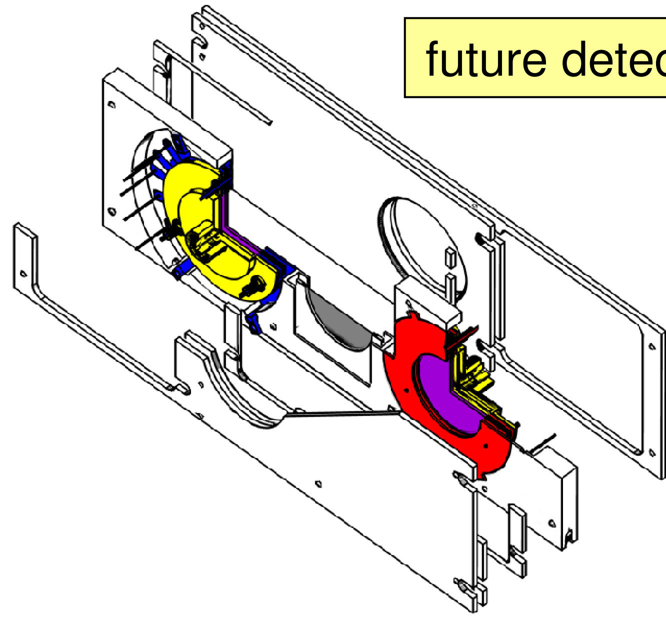
N. Kuzminchuk, M. Diwisch

Design of the ToF – Detector

recent detector



future detector

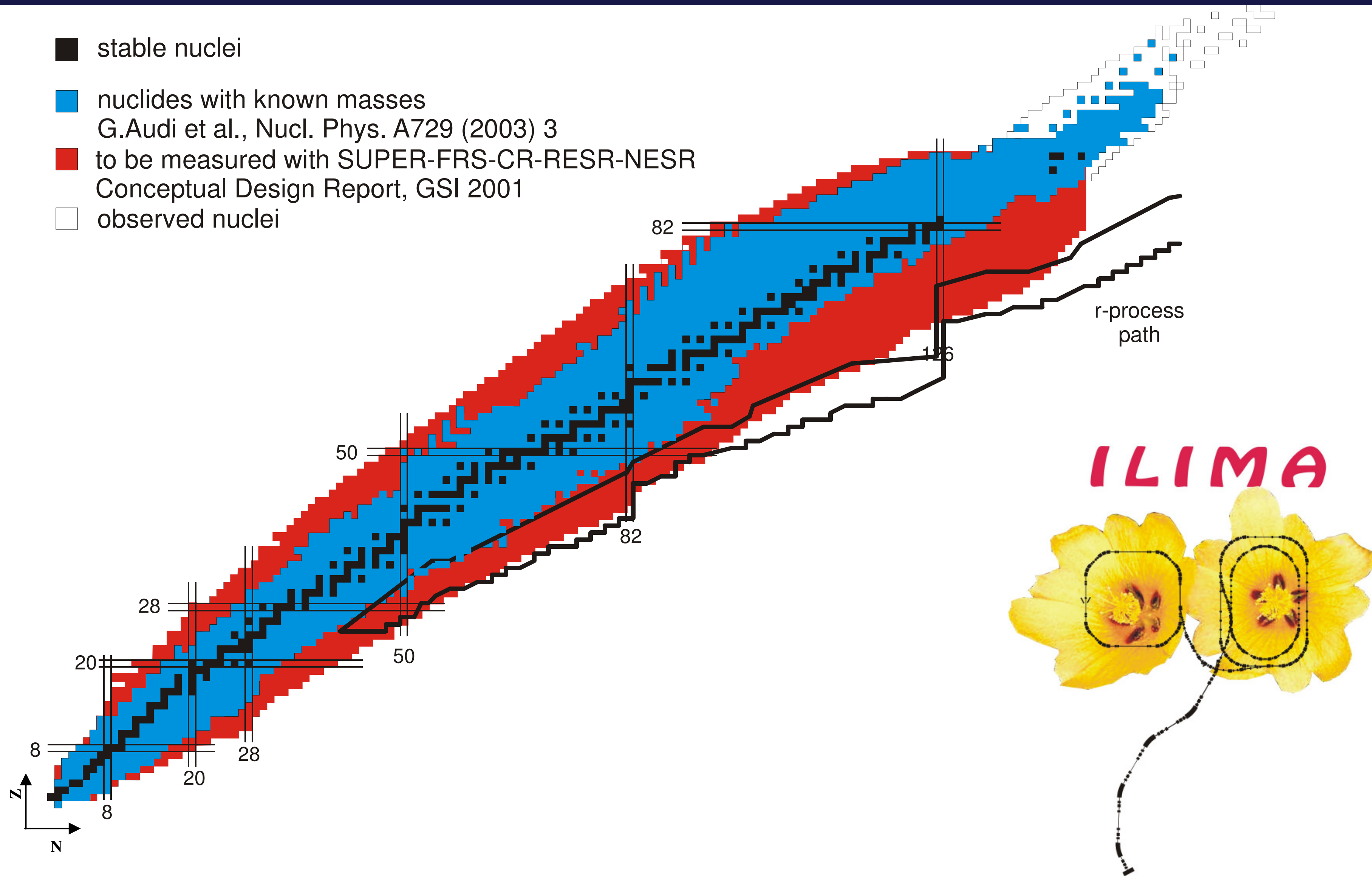


Main challenge:
larger foil diameter since larger beam-spot
→ larger total detector geometry
→ longer flightpath from foil to MCPs
→ larger absolute time of flight
→ time uncertainty increases

Possible solution:
→ higher electrical field strength
→ better homogeneity of (electrical) fields due to electrode shape and position
→ displacement of MCP detector

M. Diwisch, PhD-thesis, JLU Gießen, in preparation

Mass Measurements of Stored Exotic Nuclei at Relativistic Energies



The Collaboration

**F. Bosch, D. Boutin, C. Brandau, L. Chen, I. Cullen, C. Dimopoulou,
M. Diwisch, B. Fabian, H. Geissel, M. Hausmann, R. Knöbel, C. Kozhuharov,
J. Kurcewicz, N. Kuzminchuk, S.A. Litvinov, Yu.A. Litvinov, A. Musumarra,
S. Nakajima, C. Nociforo, F. Nolden, T. Ohtsubo, A. Ozawa, Z. Patyk,
W.R. Plaß, C. Scheidenberger, M. Steck, B. Sun, T. Suzuki,
P.M. Walker, H. Weick, N. Winckler, M. Winkler, T. Yamaguchi**

Thank you for your attention!