Mass and Lifetime Measurements of Stored Exotic Nuclei

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Max Planck Institute for Nuclear Physics

Max-Planck-Institut für Kernphysik

Masses: Fundamental Properties of Atomic Nuclei

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- ➢ **Binding energies**
- • **Mass models**
- • **Shell structure**

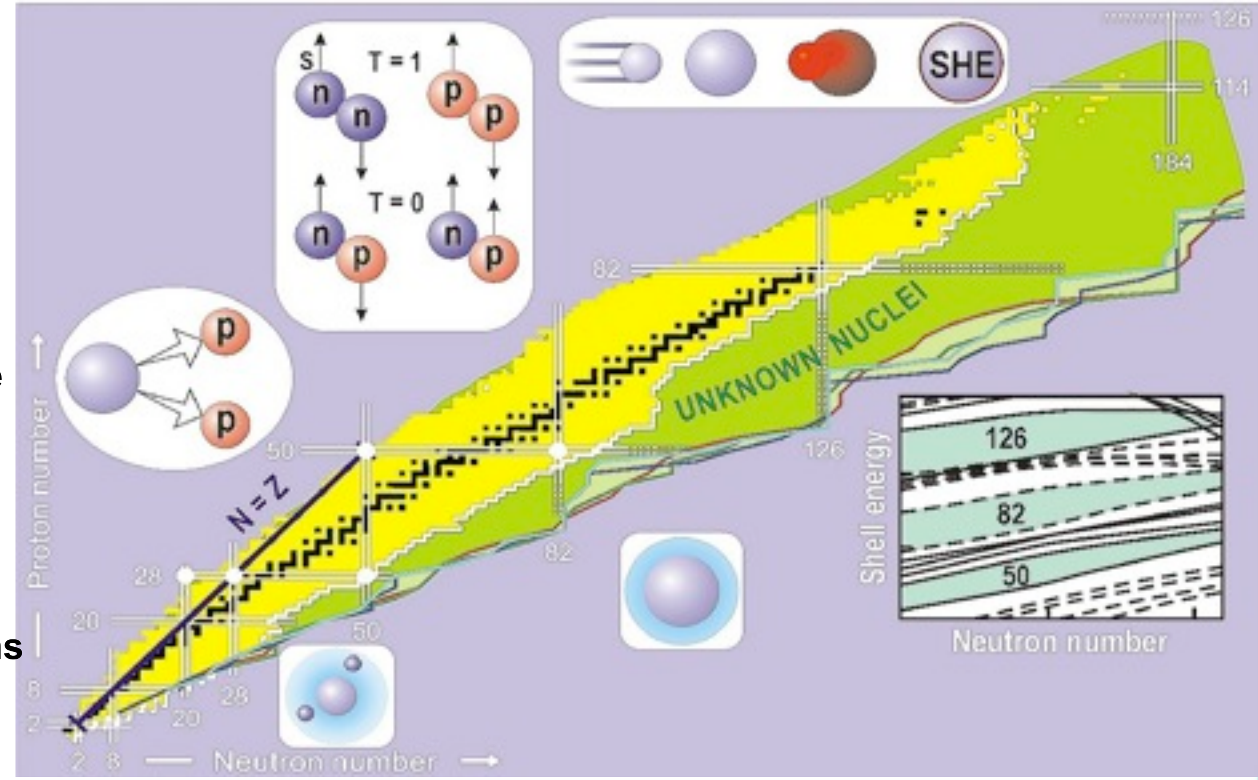
- ➢ **Correlations**
- • **pairing**

- ➢ **Reaction phase space**
- • **Q-values**
- • **Reaction probabilities**

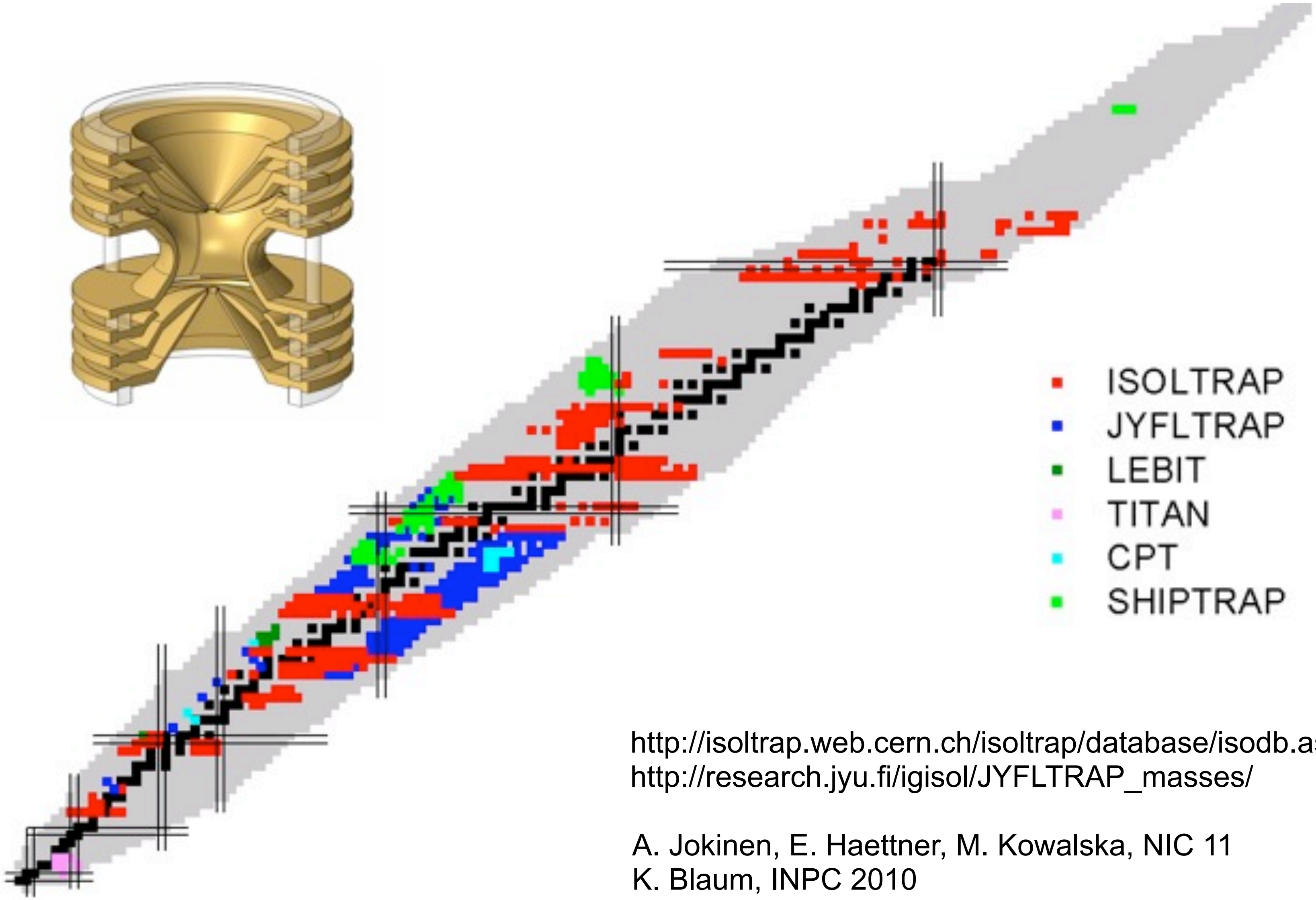
- ➢ **The reach of nuclei**
- • **Drip lines**
- • **Specific configurations and topologies**

- ➢ **Nuclear astrophysics**
- • **Paths of nucleosynthesis**

- ➢ **Fundamental symmetries**
- ➢ **Metrology**
- ➢ **…..**



Penning Trap Mass Measurements



http://isoltrap.web.cern.ch/isoltrap/database/isodb.asp
http://research.jyu.fi/igisol/JYFLTRAP_masses/

A. Jokinen, E. Haettner, M. Kowalska, NIC 11
K. Blaum, INPC 2010

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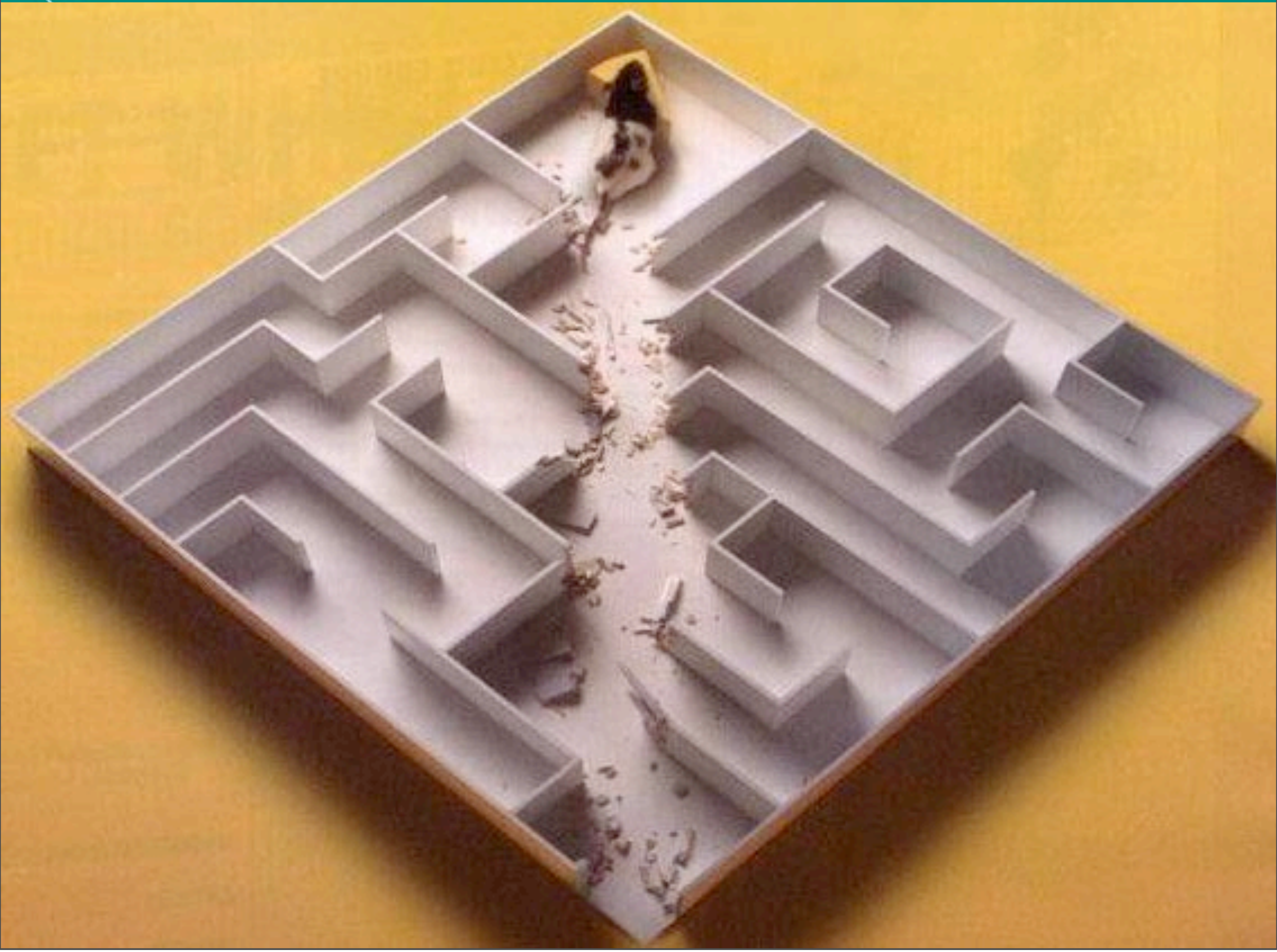
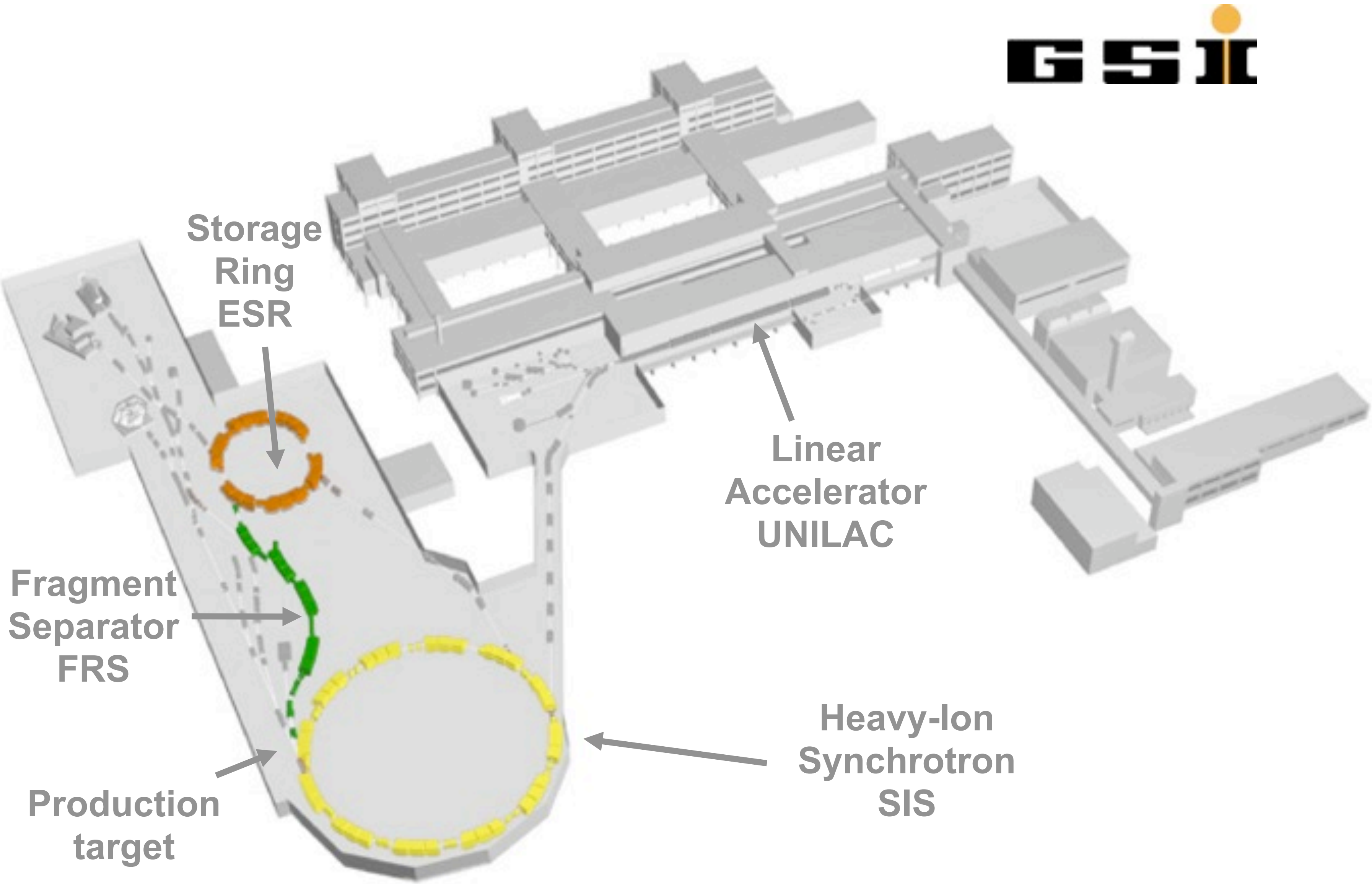


Secondary beam facility at GSI



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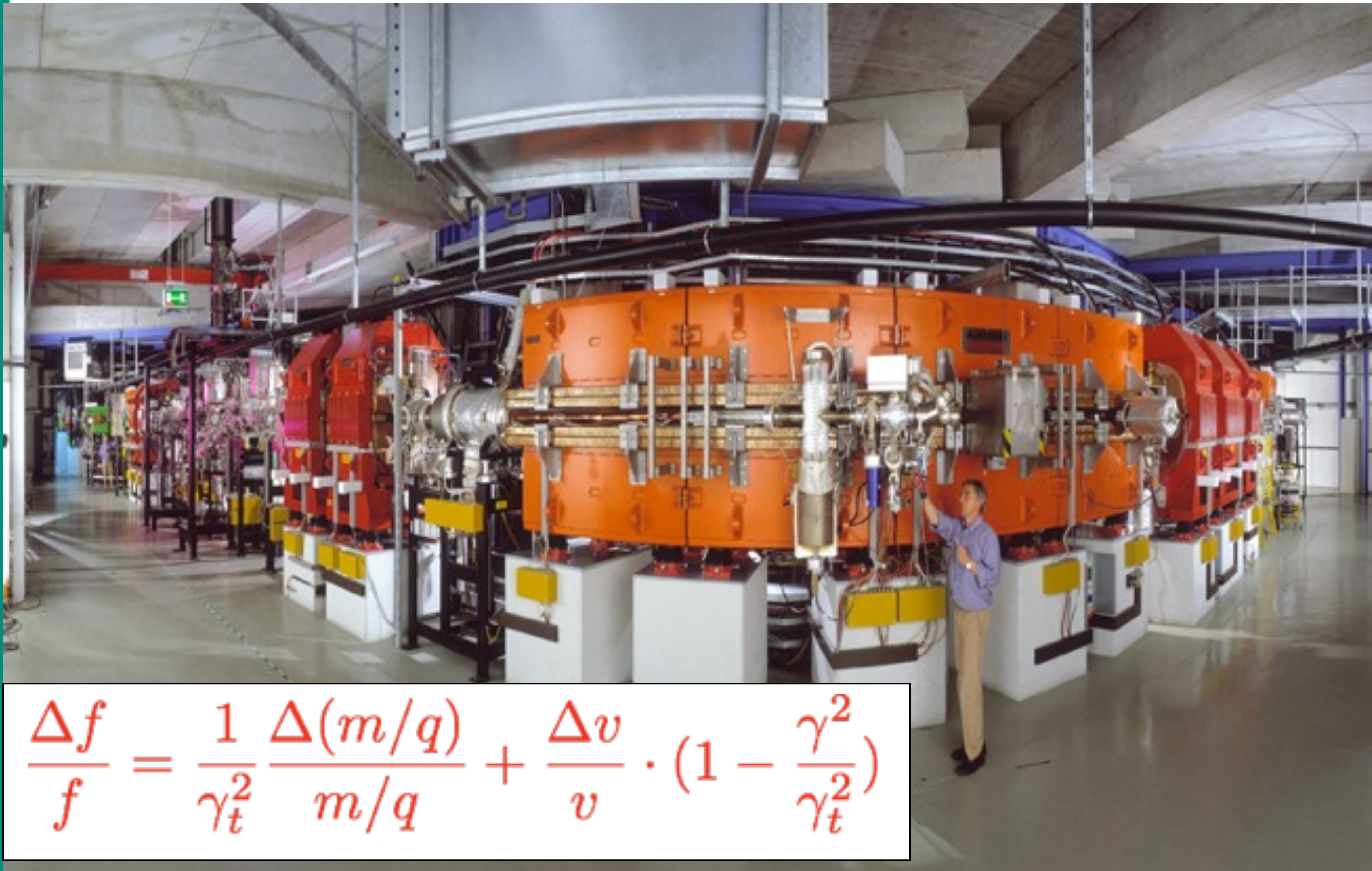
Experimental Storage Ring at GSI



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

ESR: B. Franzke, NIM B 24/25 (1987) 18

Stochastic cooling: F. Nolden et al., NIM B 532 (2004) 329
Electron cooling: M. Steck et al., NIM B 532 (2004) 357

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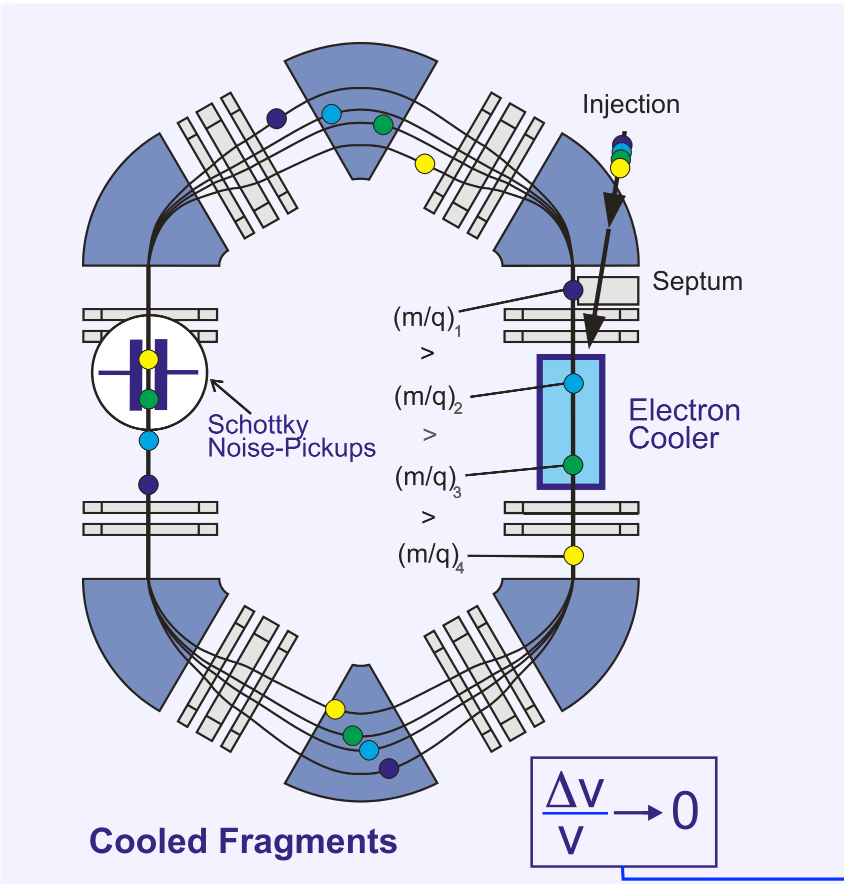
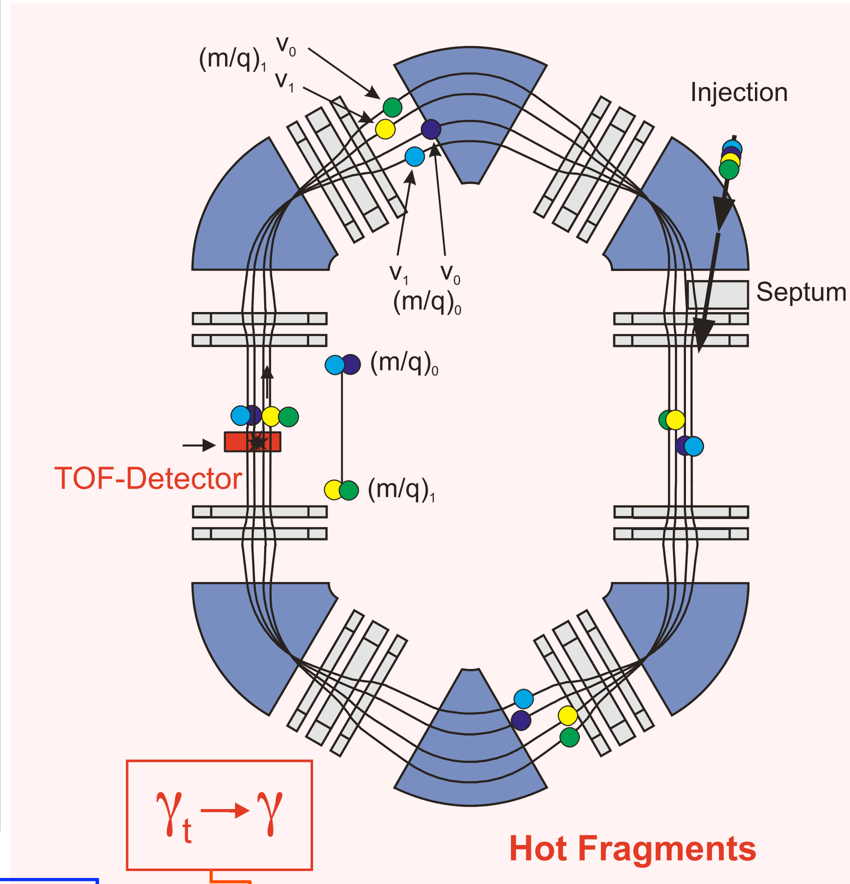
Two Methods

SCHOTTKY MASS SPECTROMETRY



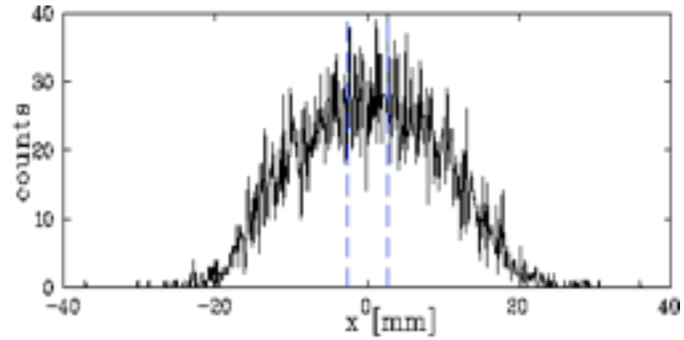
ISOCHRONOUS MASS SPECTROMETRY

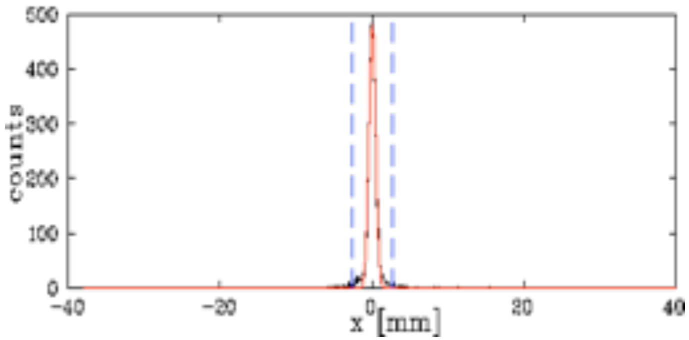


$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

Electron Cooling

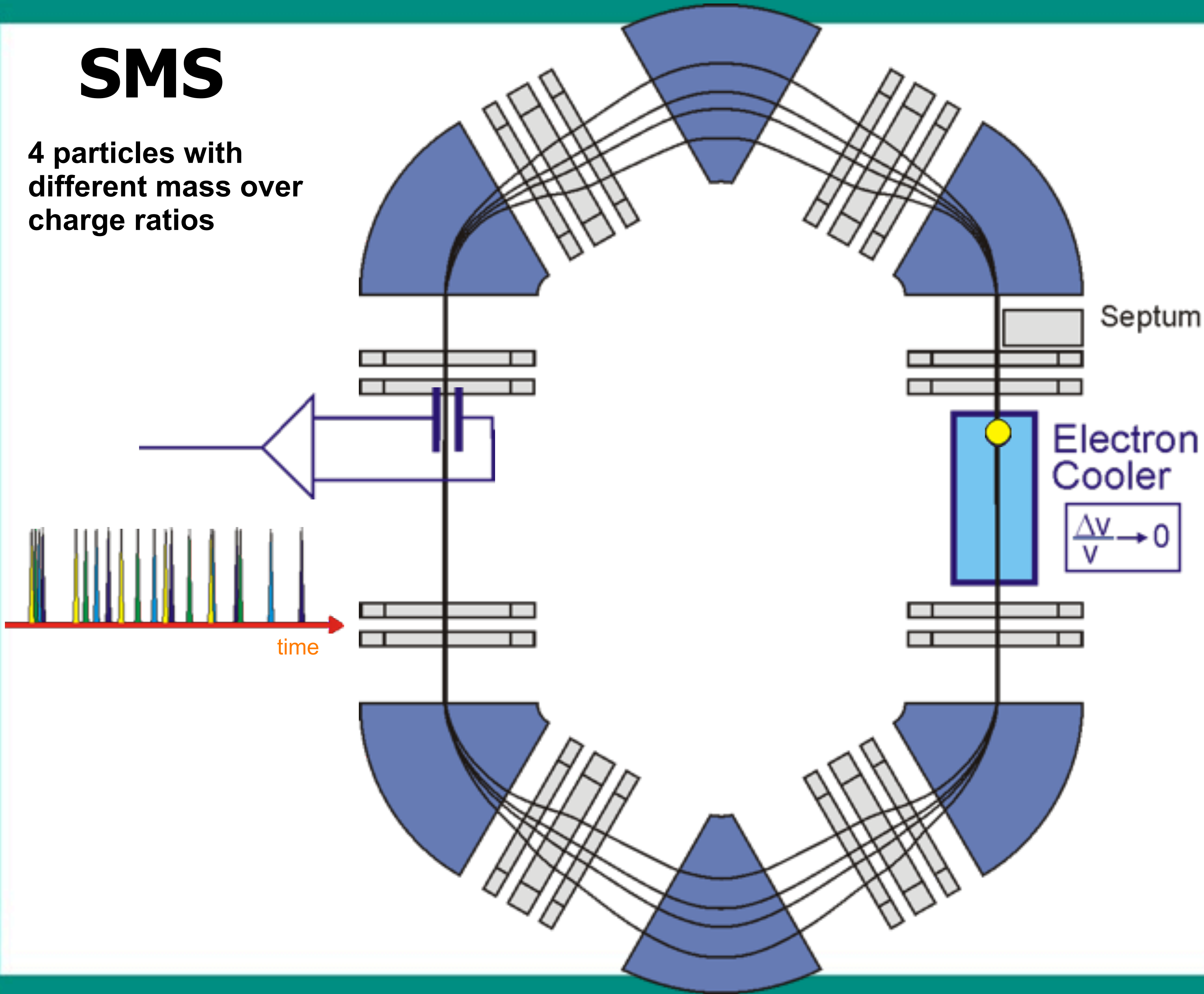
momentum exchange with 'cold', collinear e- beam. The ions get the **sharp velocity** of the electrons, small size and divergence



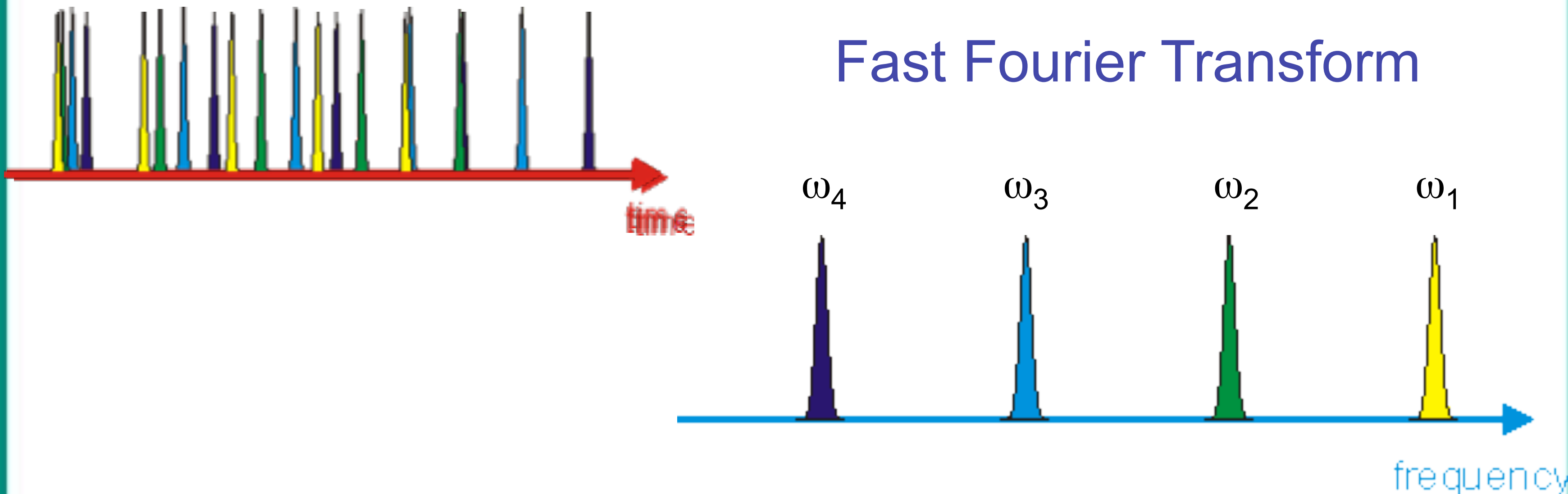


SMS

4 particles with different mass over charge ratios



Schottky Mass Spectrometry



Broad-band Schottky Frequency Spectrum

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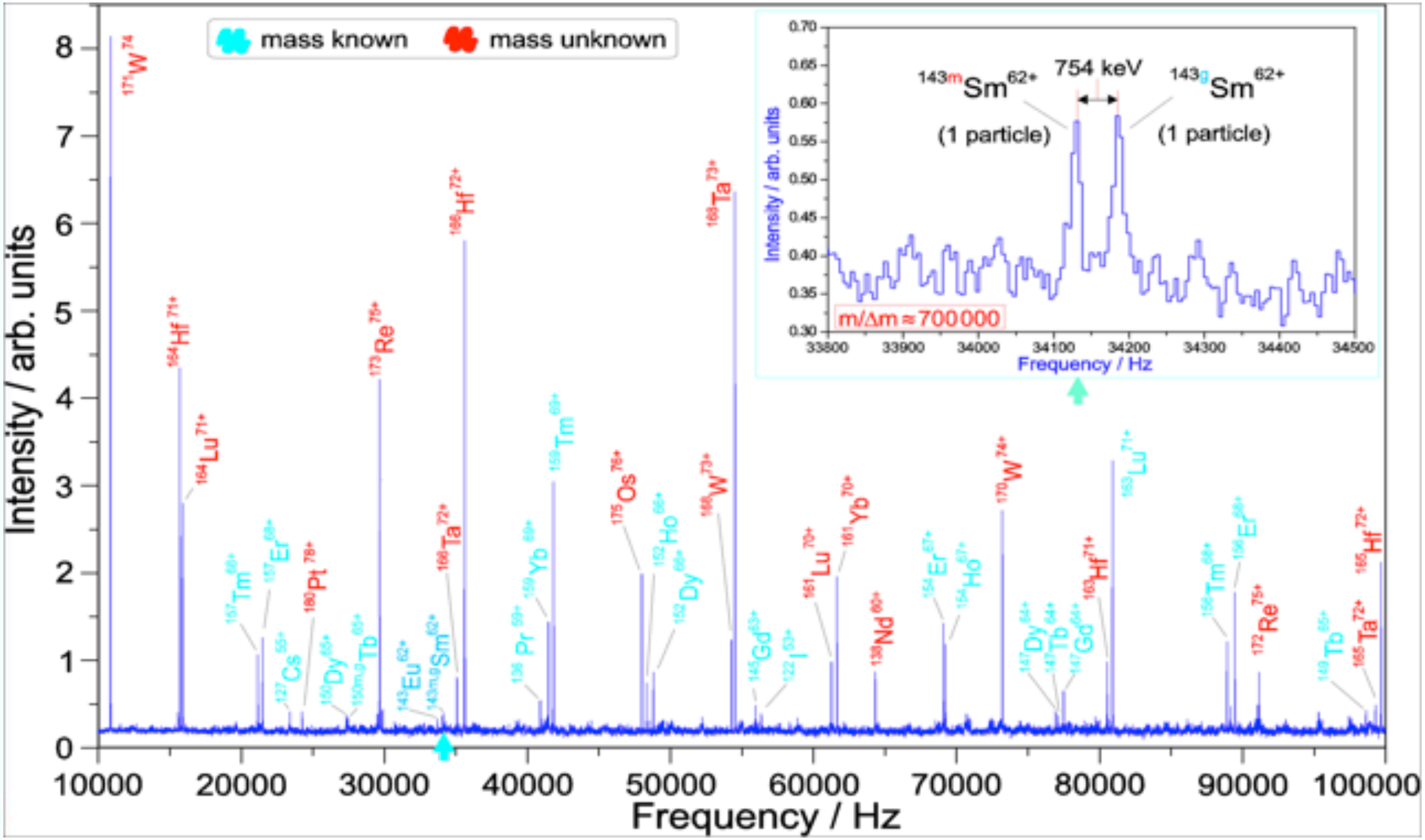
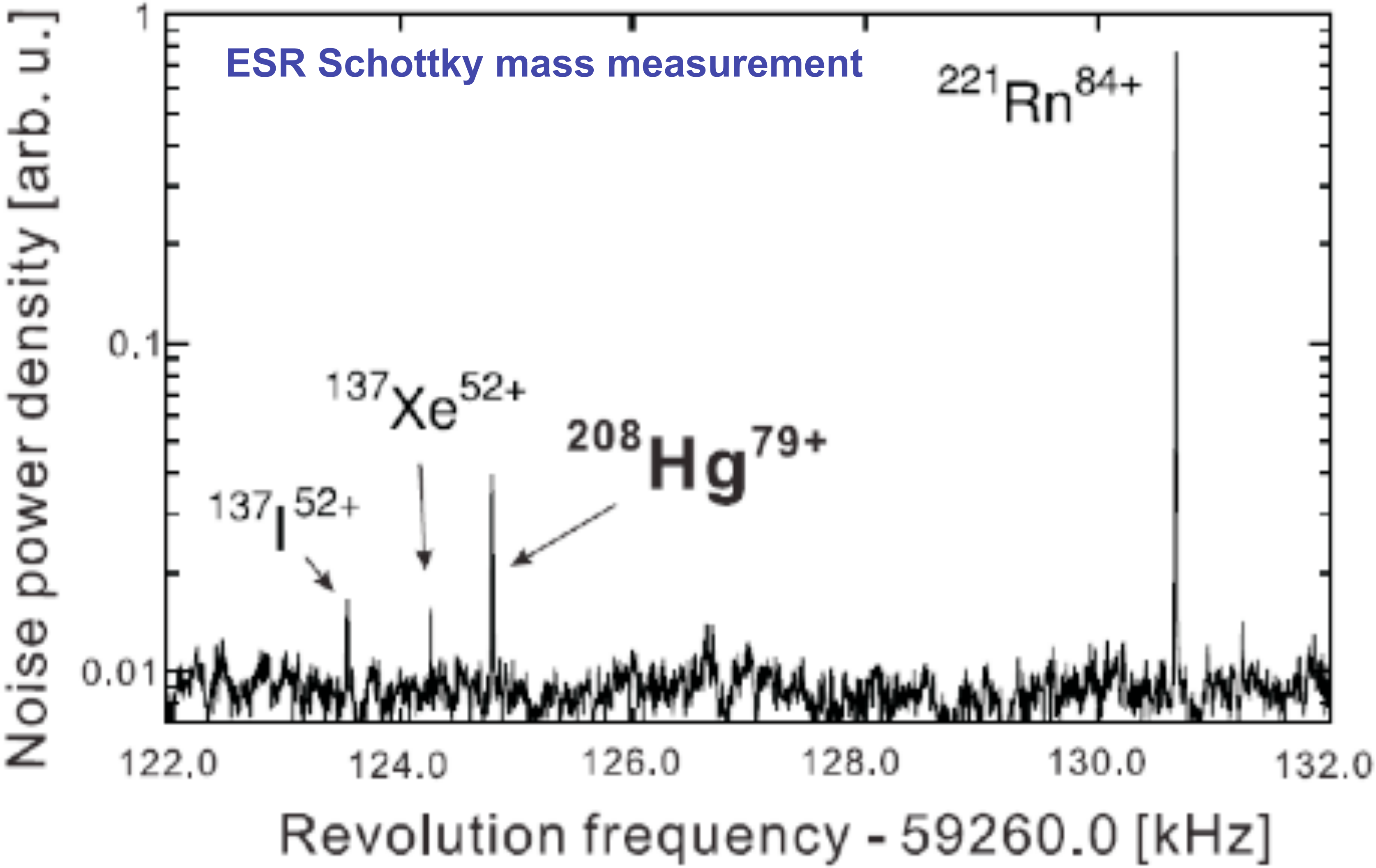
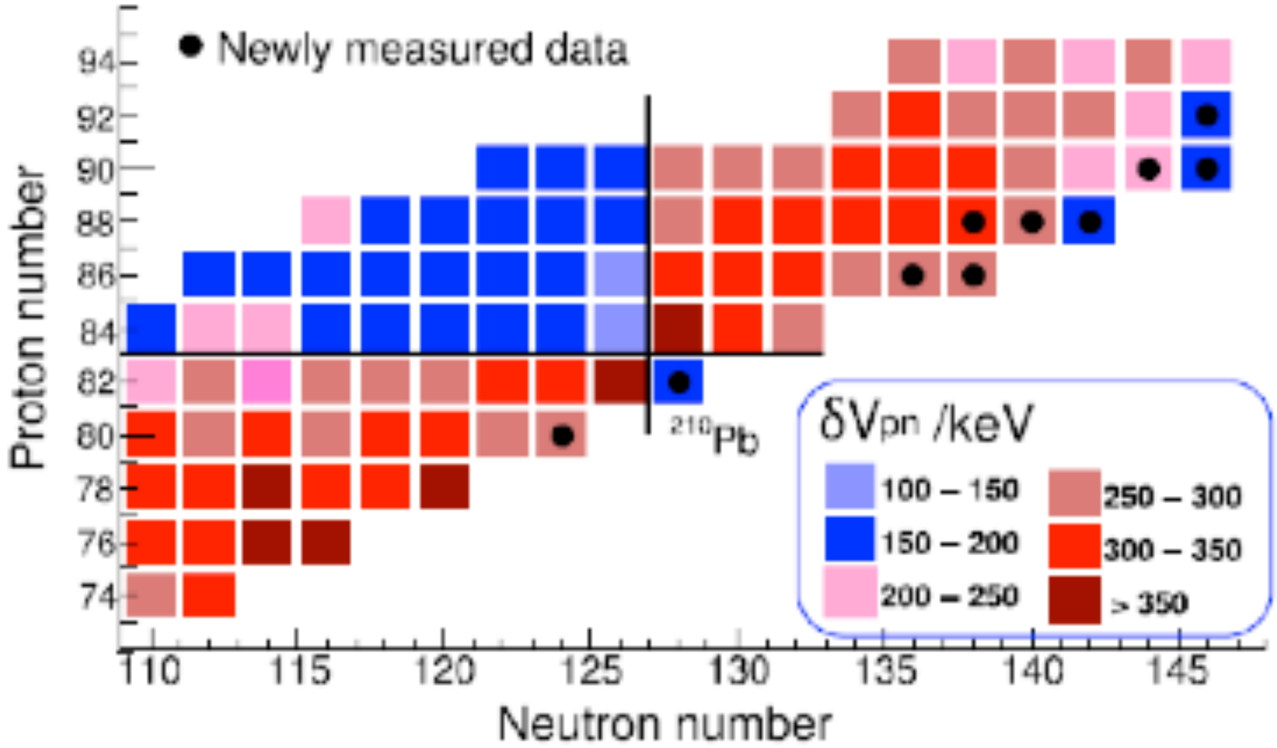


Direct Mass Measurement of ^{208}Hg Nuclide



Experimental proton-neutron interaction



For even-even nuclei

$$\delta V_{pn}(Z,N) = \frac{1}{4}[\{B(Z,N) - B(Z,N-2)\} - \{B(Z-2,N) - B(Z-2,N-2)\}]$$

L. Chen *et al.*, Phys. Rev. Lett. 102, 122503 (2009)

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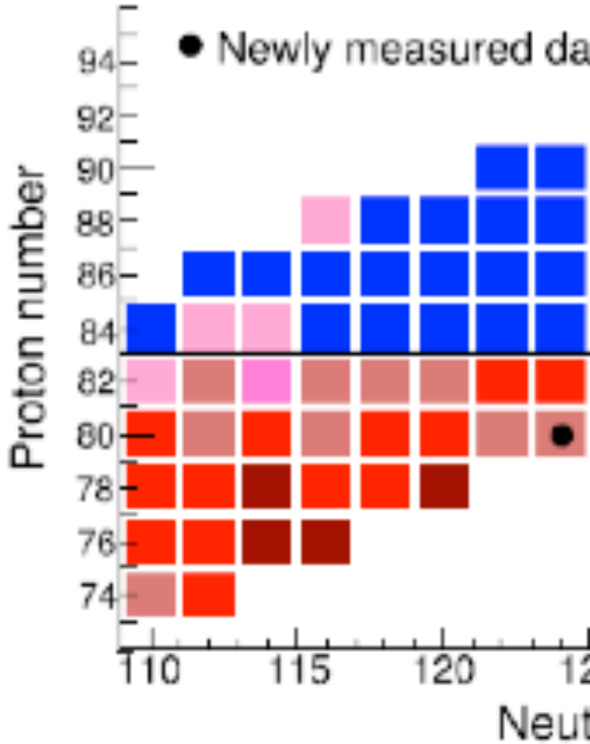
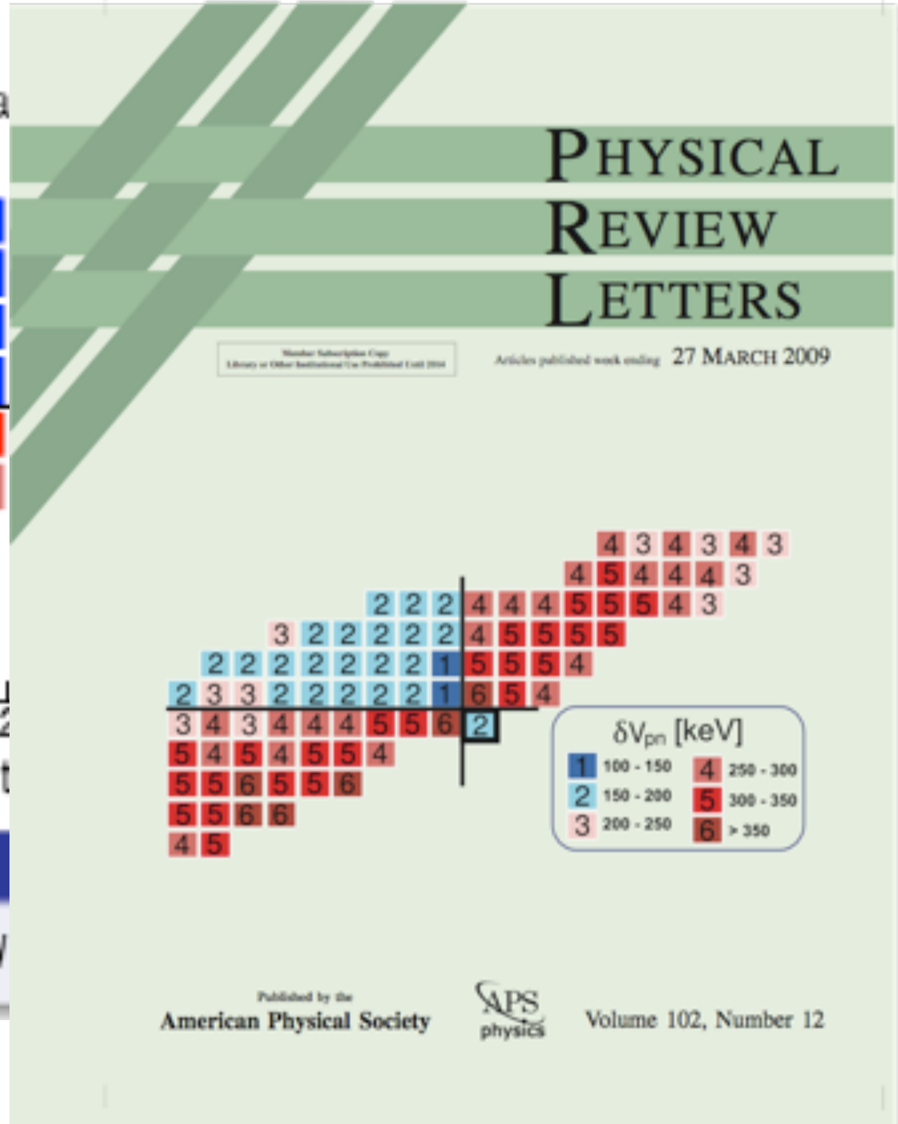
Experimental proton-neutron interaction





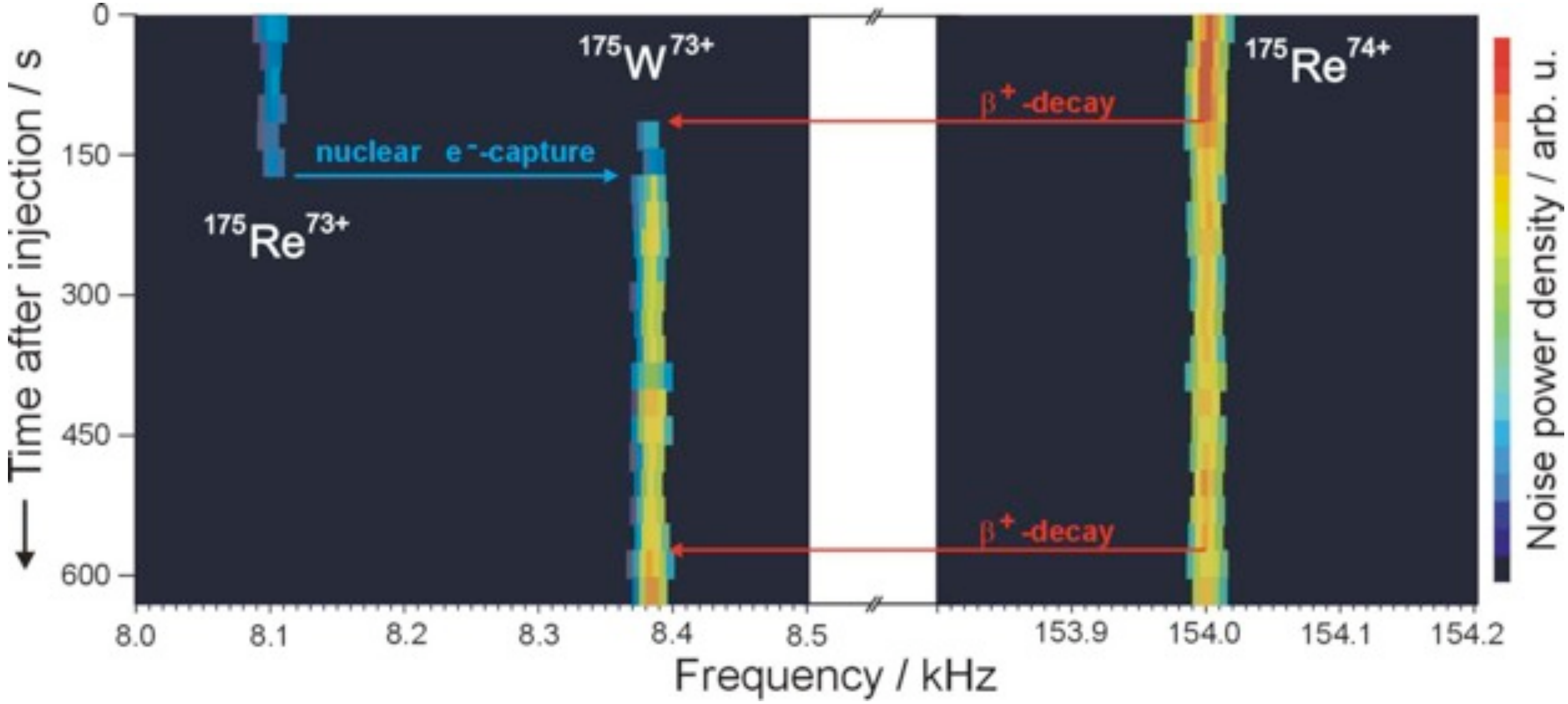
For even-even nuclei

$\delta V_{pn}(Z,N) = \frac{1}{4}[\{B(Z,N) - B(Z,N$

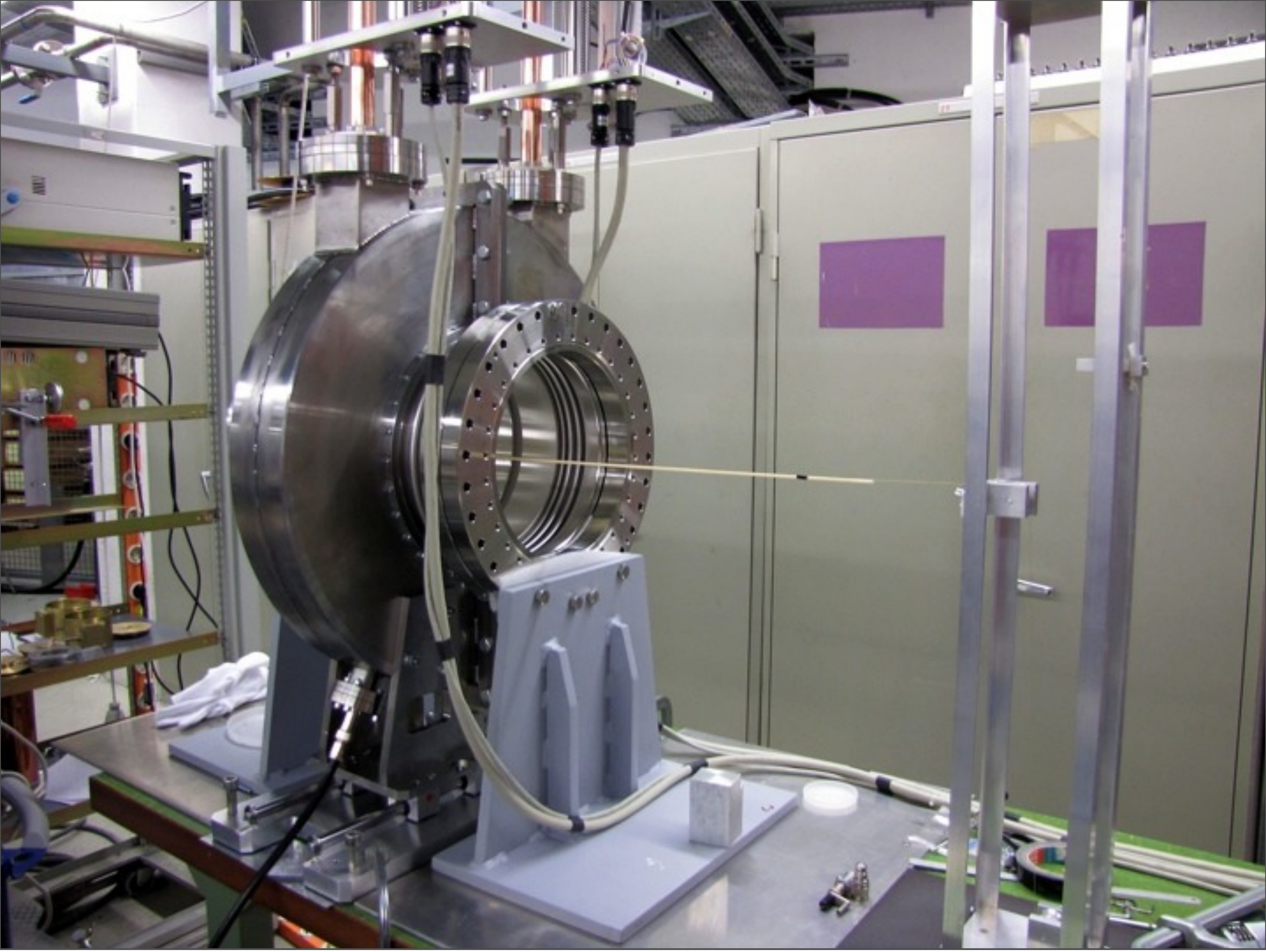
L. Chen *et al.*, Phys. Rev.

Nuclear Decays of Stored Single Ions

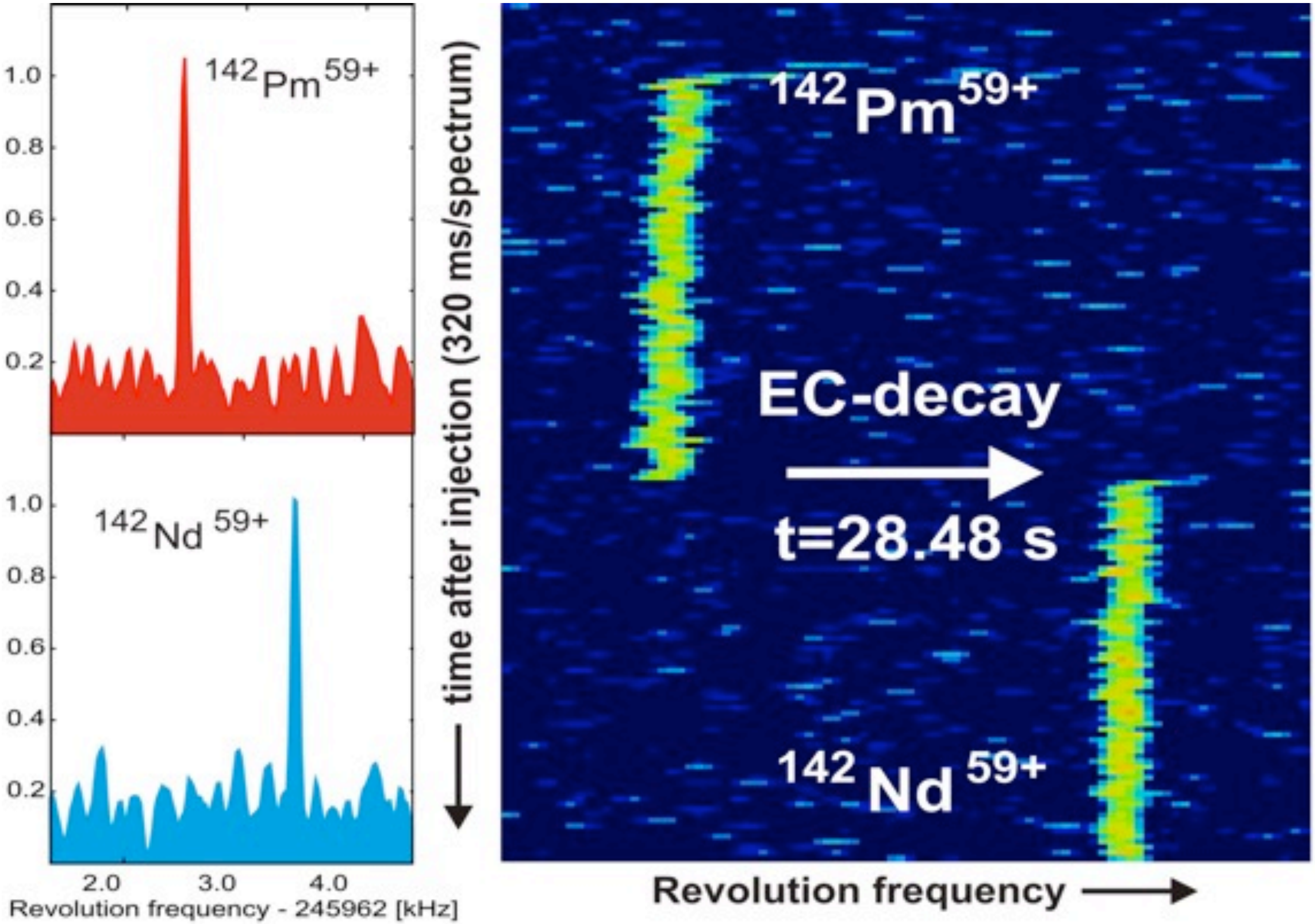
Time-resolved SMS is a perfect tool to study decays in the ESR



EC, β+,β-, bound-state β, and IT decays were observed



Single ion sensitivity



Measured Mass Surface

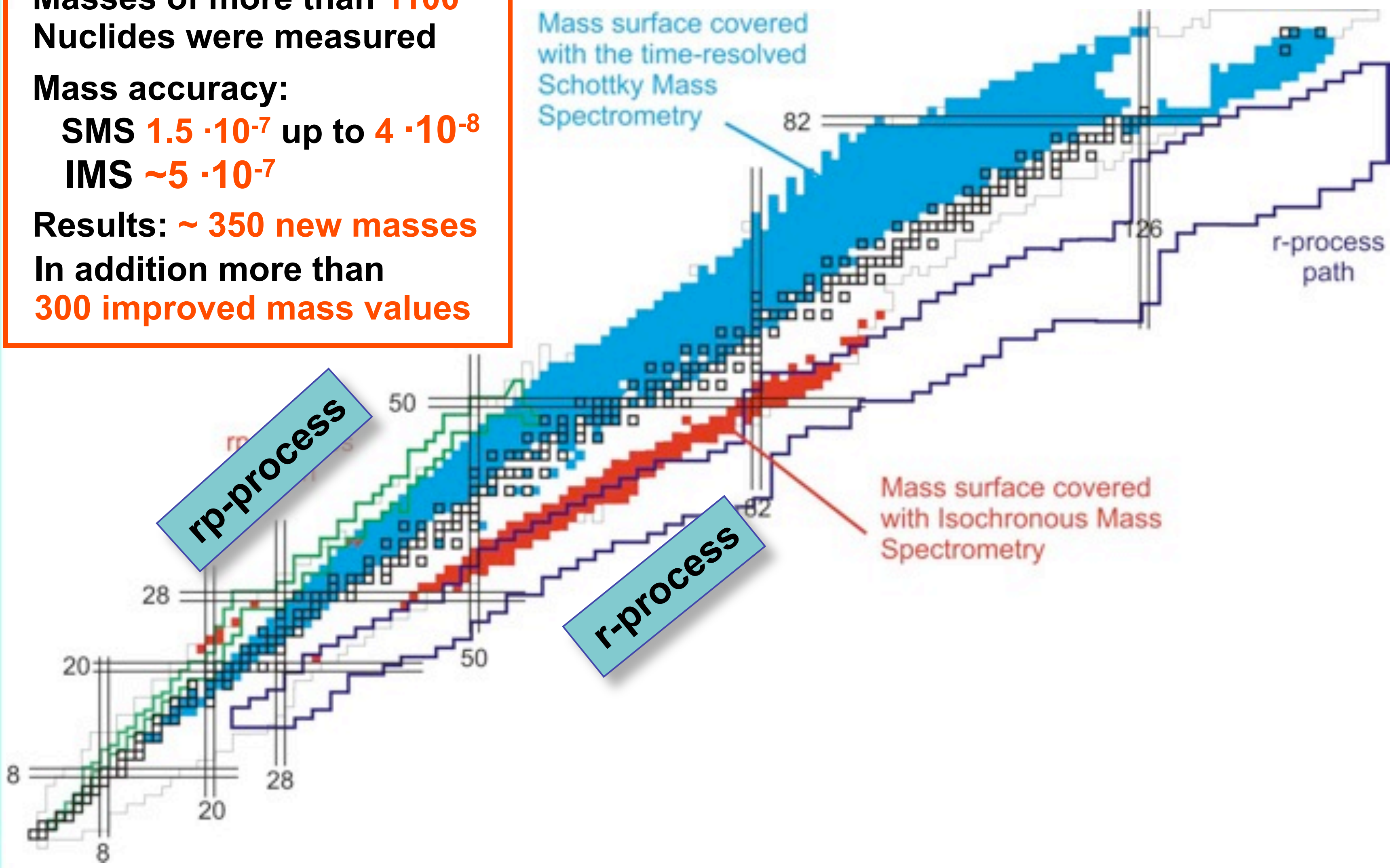
Masses of more than 1100 Nuclides were measured

Mass accuracy:

- SMS $1.5 \cdot 10^{-7}$ up to $4 \cdot 10^{-8}$
- IMS $\sim 5 \cdot 10^{-7}$

Results: ~ 350 new masses

In addition more than 300 improved mass values



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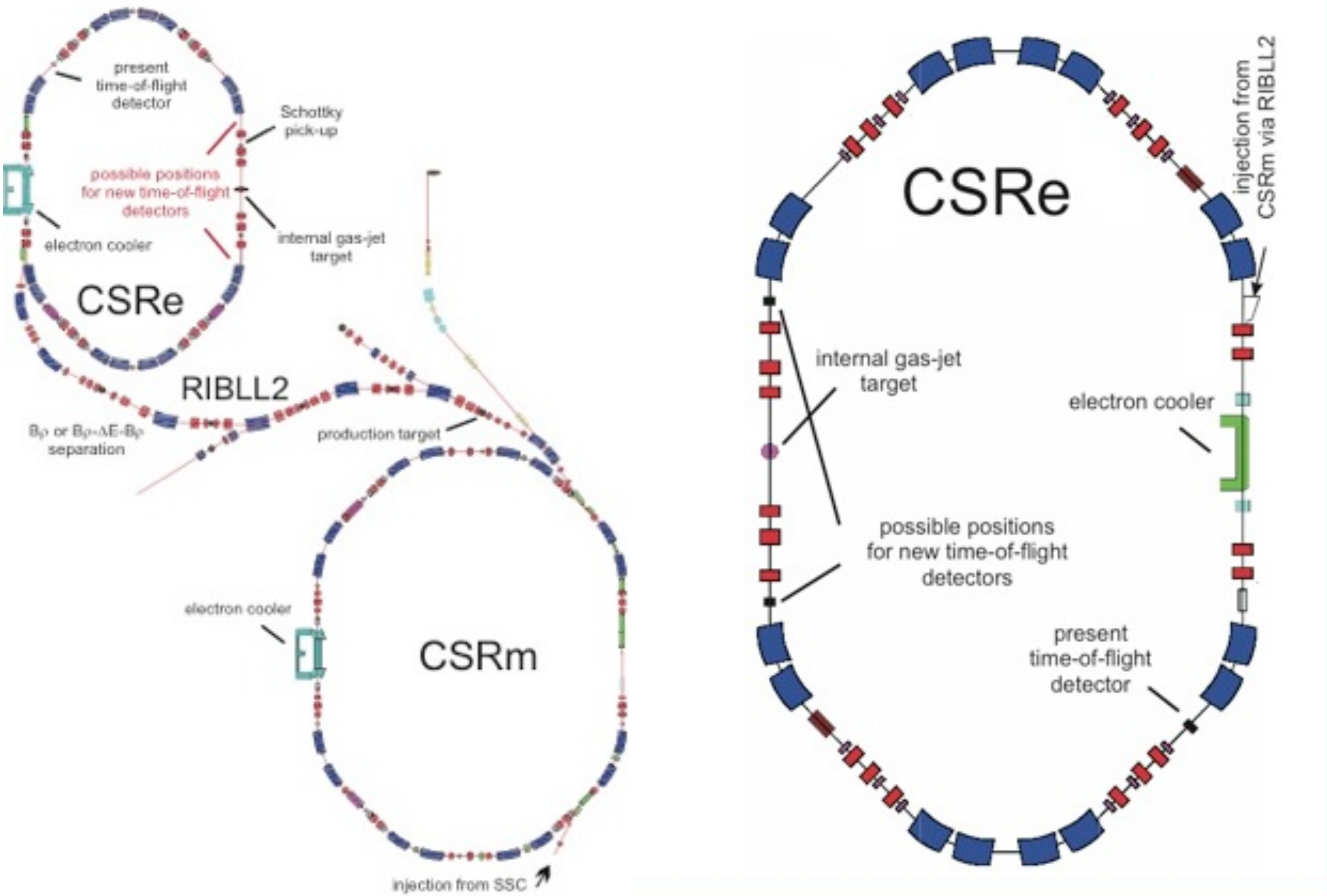
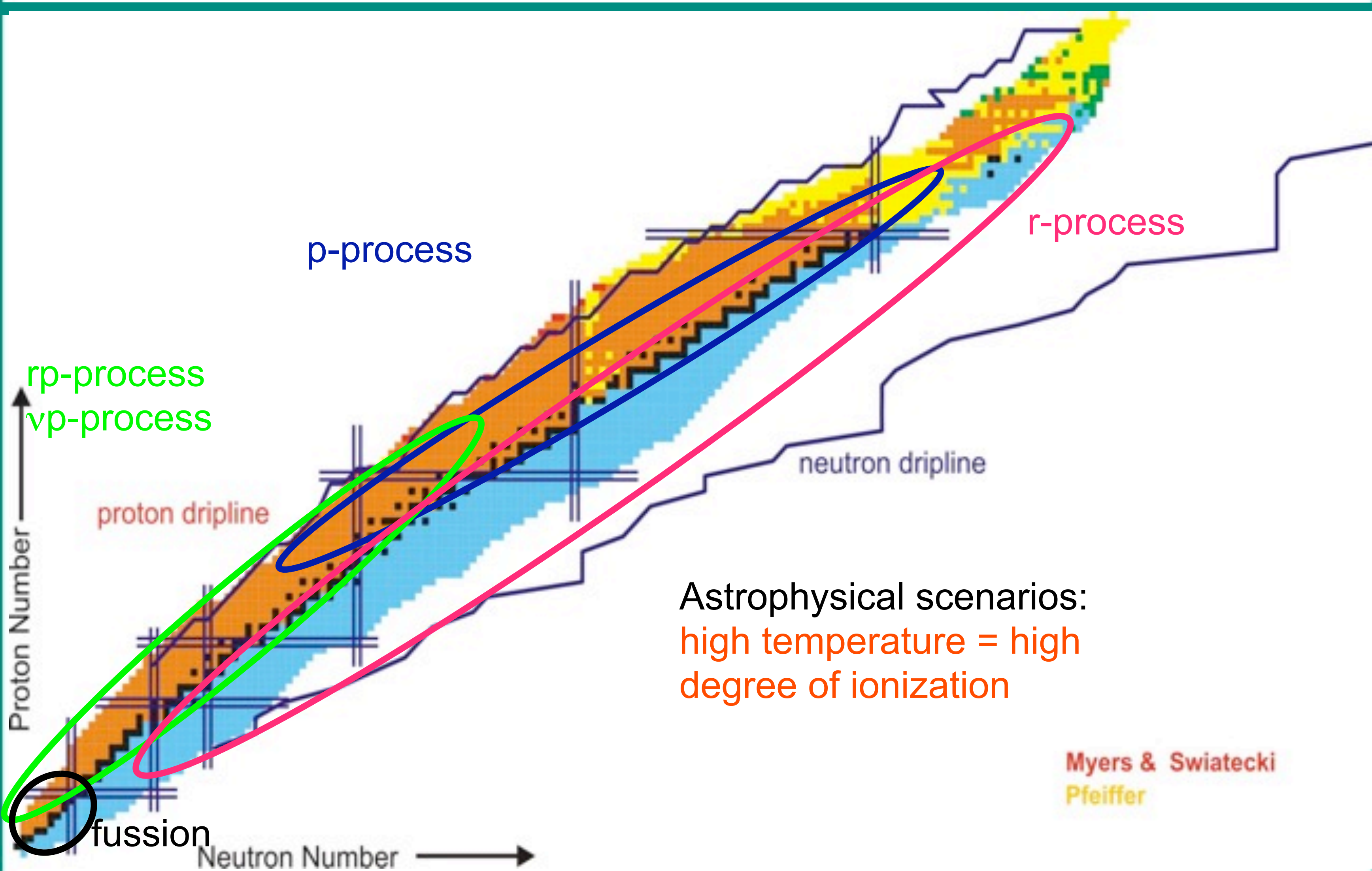
CSRm-CSRe Complex at IMP in Lanzhou

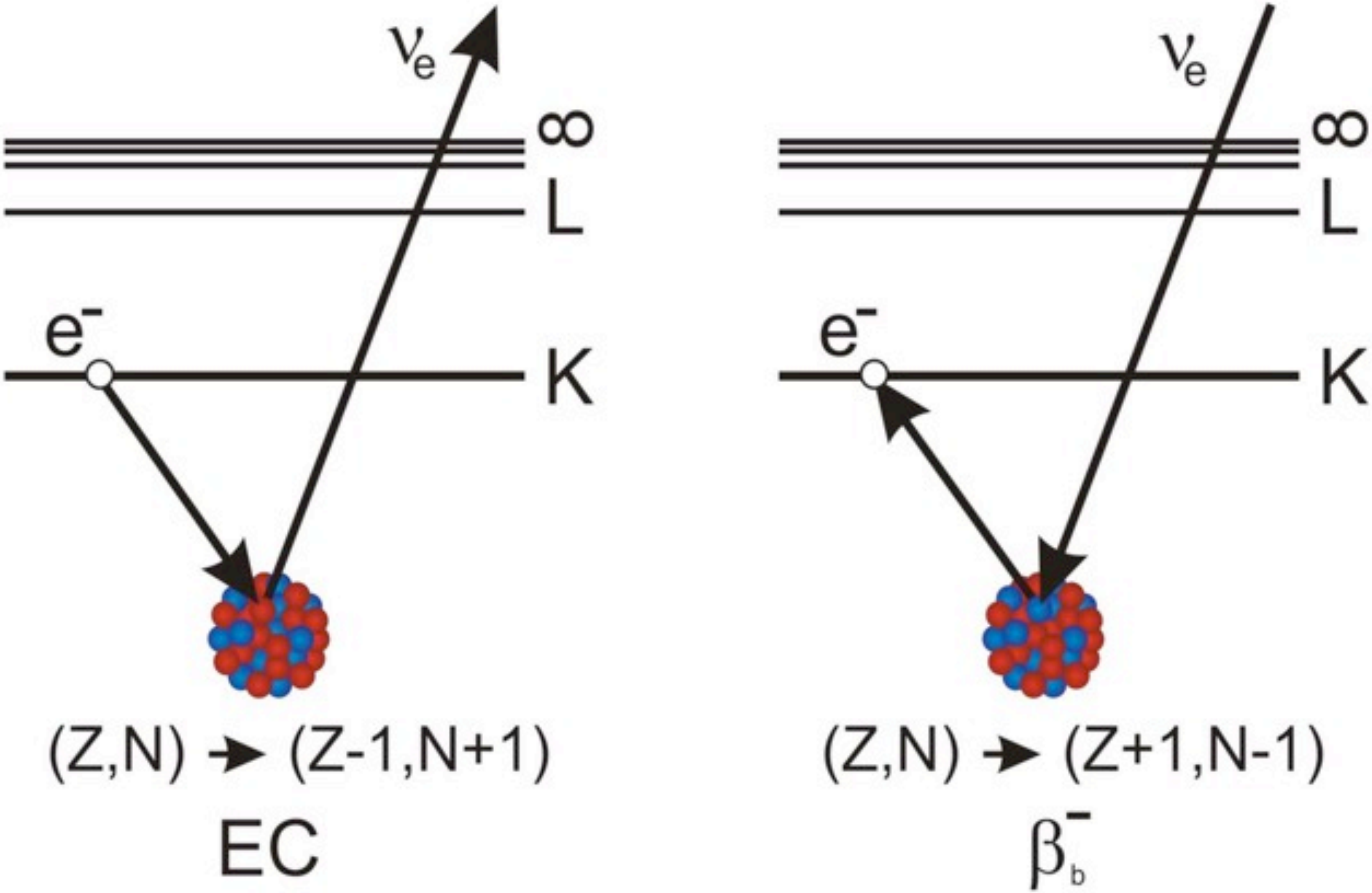


Beta-decay on the Chart of Nuclides



Astrophysical scenarios:
high temperature = high degree of ionization

Two-body beta decay



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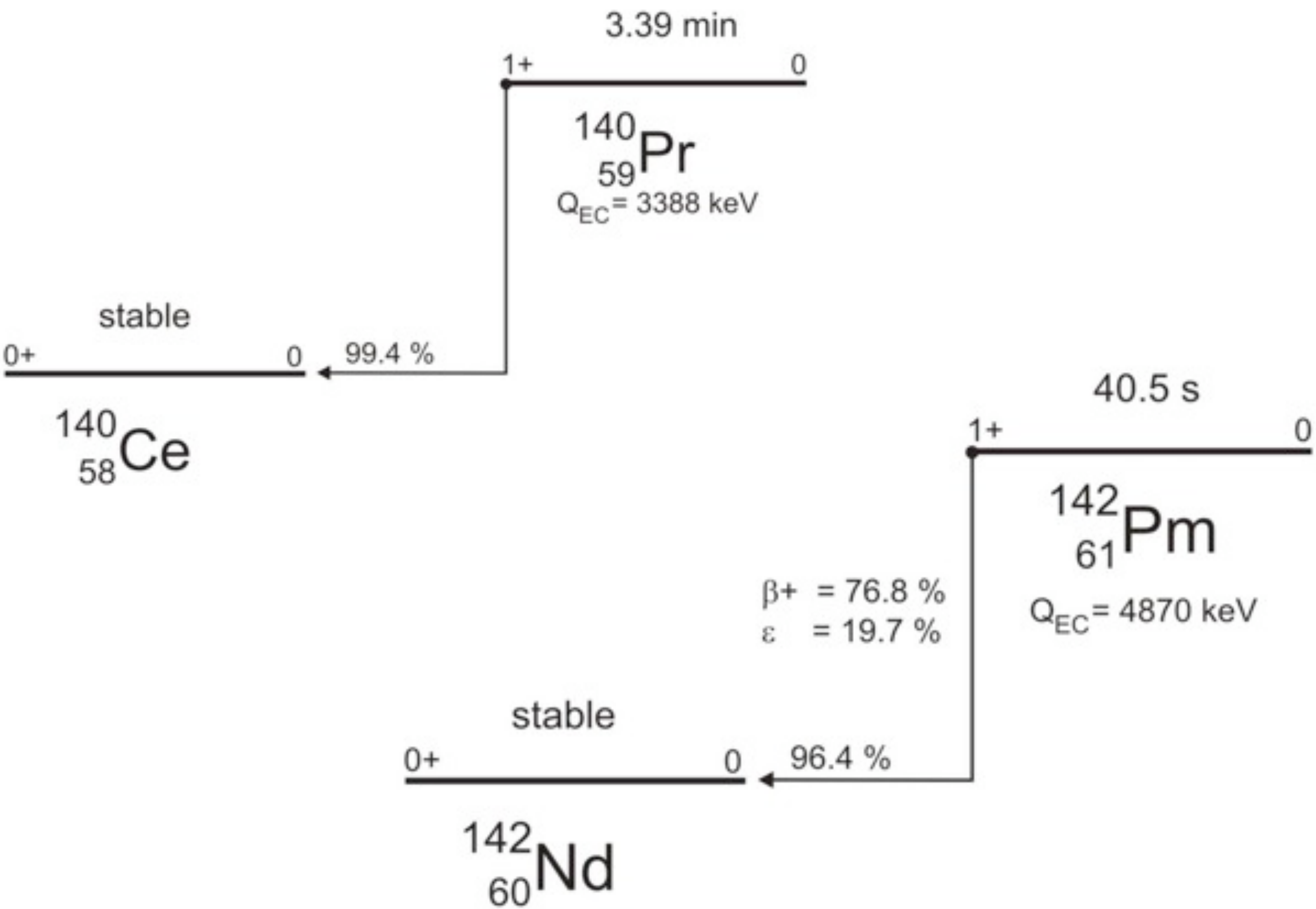
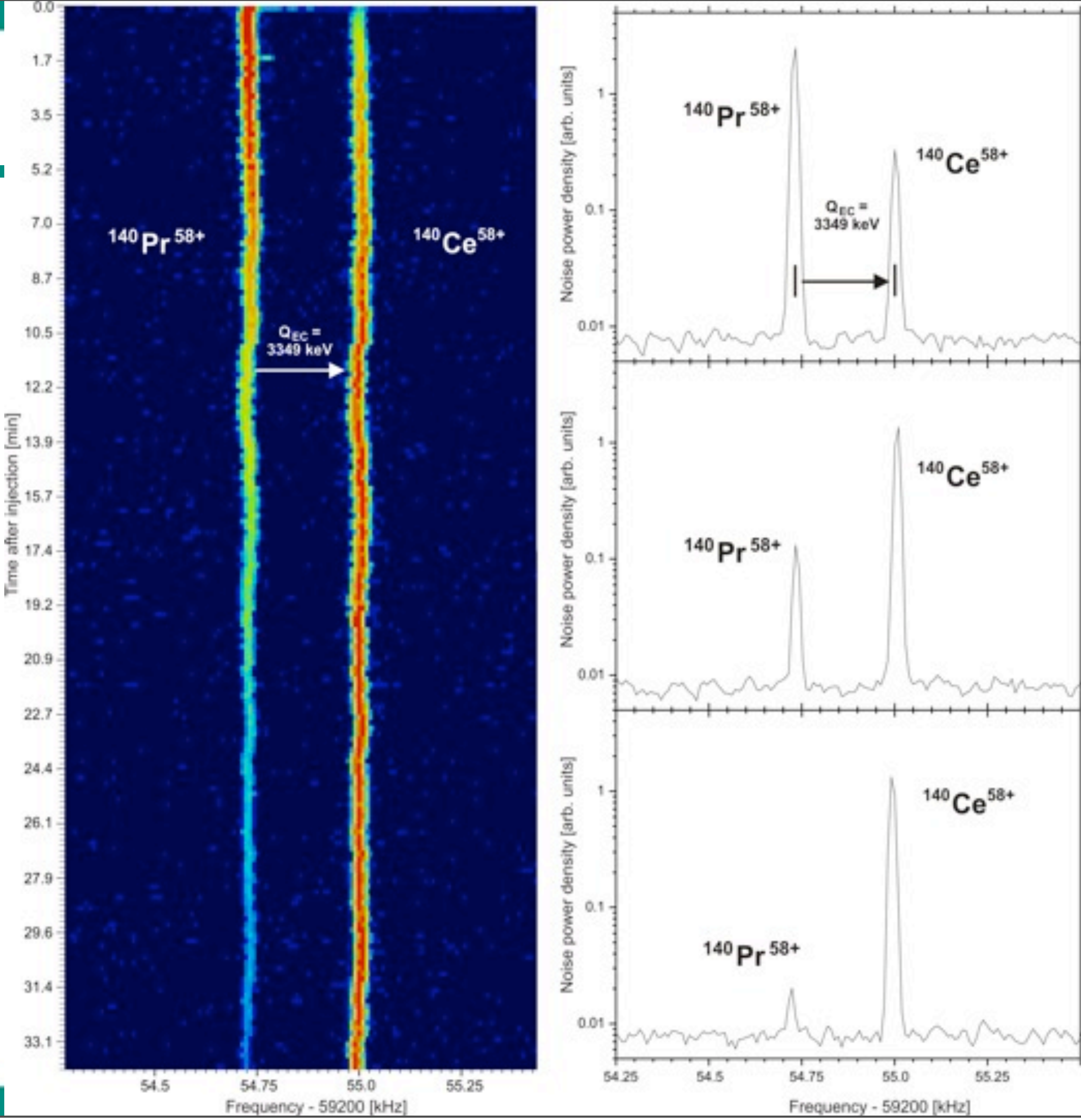
Orbital Electron Capture in H-Like Ions





140Pr58+
140Ce58+
QEC = 3349 keV
Time after injection [min]
Frequency - 59200 [kHz]
Noise power density [arb. units]

EC in Hydrogen-like Ions

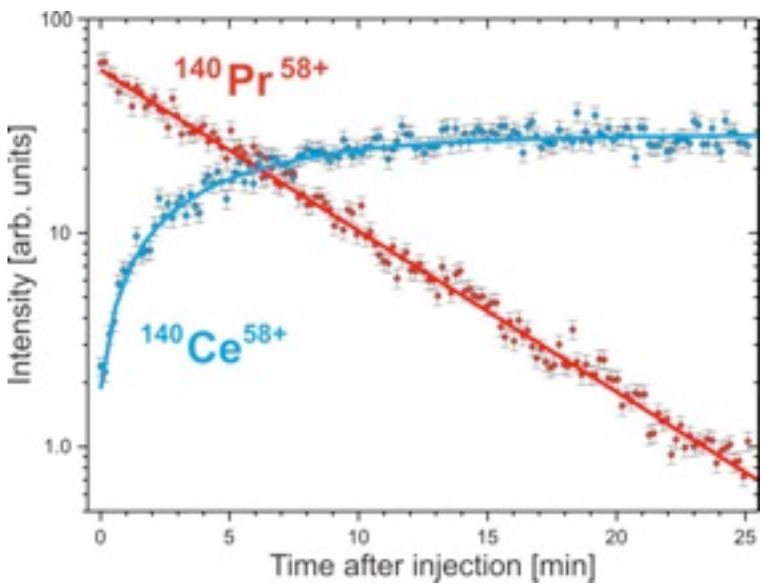
Expectation: $\lambda_{EC}(\text{H-like})/\lambda_{EC}(\text{He-like}) \approx 0.5$

^{140}Pr

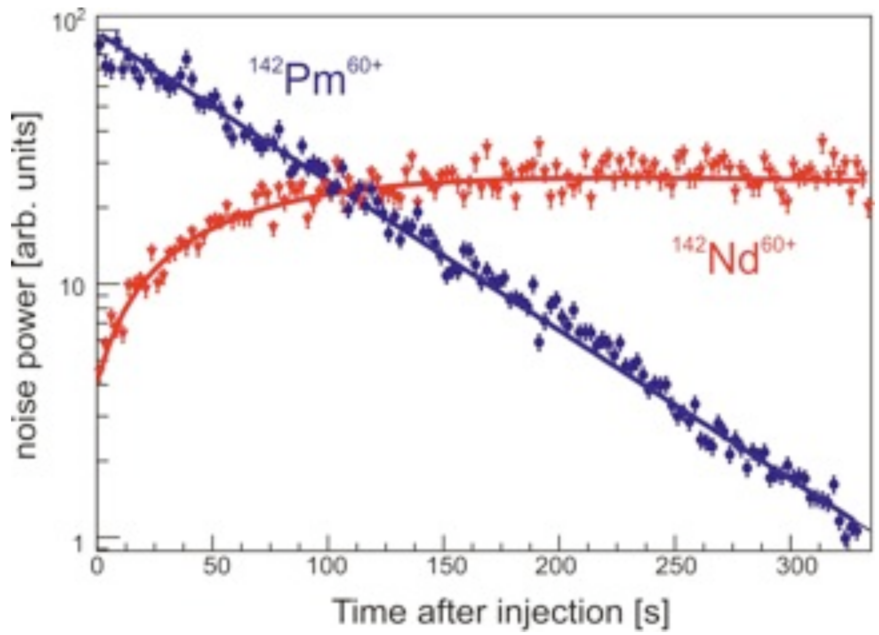
$\lambda_{EC}(\text{H-like})/\lambda_{EC}(\text{He-like}) = 1.49(8)$

^{142}Pm

$\lambda_{EC}(\text{H-like})/\lambda_{EC}(\text{He-like}) = 1.44(6)$



Yu.Litvinov et al., Phys. Rev. Lett. 99 (2007) 262501



N. Winckler et al., Phys. Lett. B579 (2009) 36

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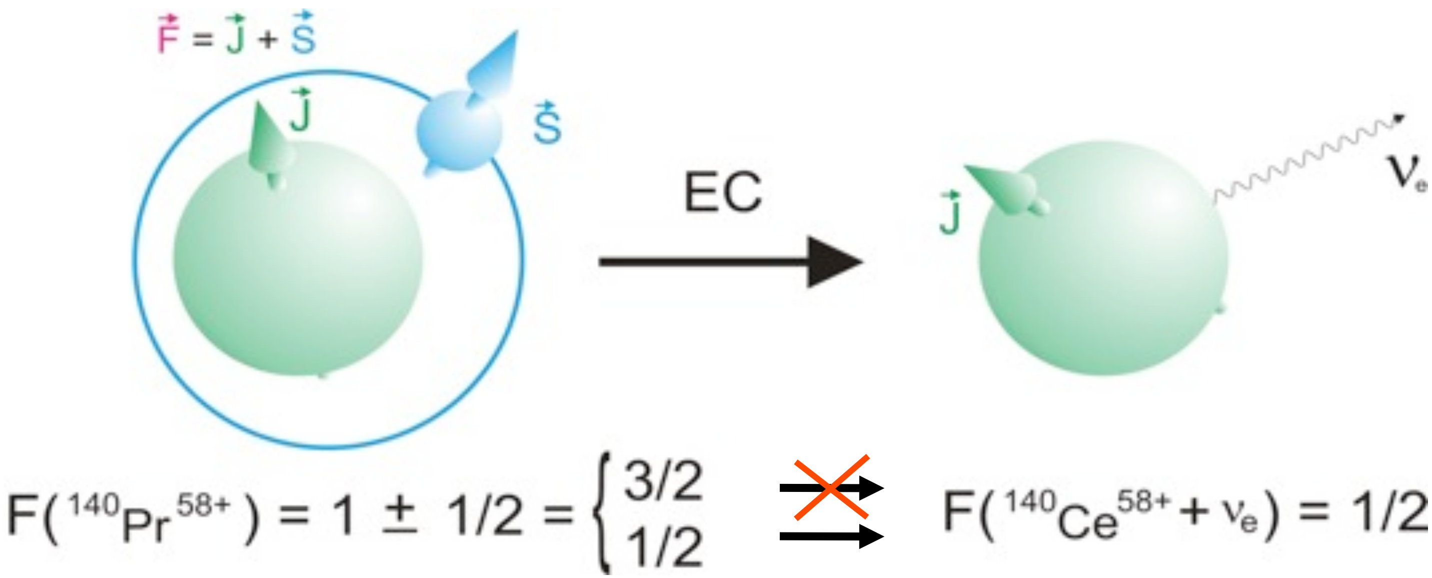
Electron Capture in Hydrogen-like Ions

Gamow-Teller transition $1^+ \rightarrow 0^+$



Theory:
The H-Like ion should really decay 20% faster than neutral atom!

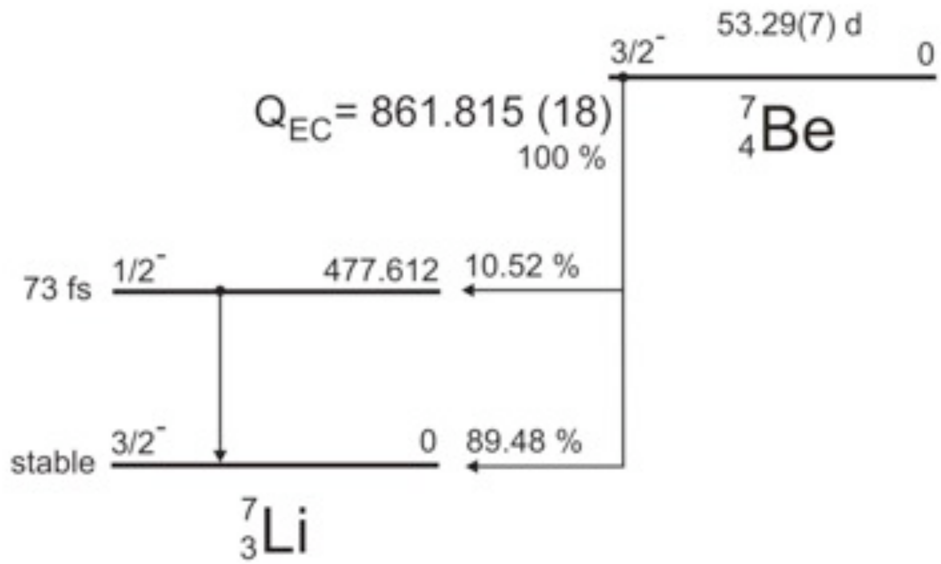
(2I+1)/(2F+1)

Z. Patyk et al., Phys. Rev. C 77 (2008) 014306

Some speculations on the EC-decay of ^{7}Be

A.V. Gruzinov, J.N. Bahcall, Astroph. J. 490 (1997) 437

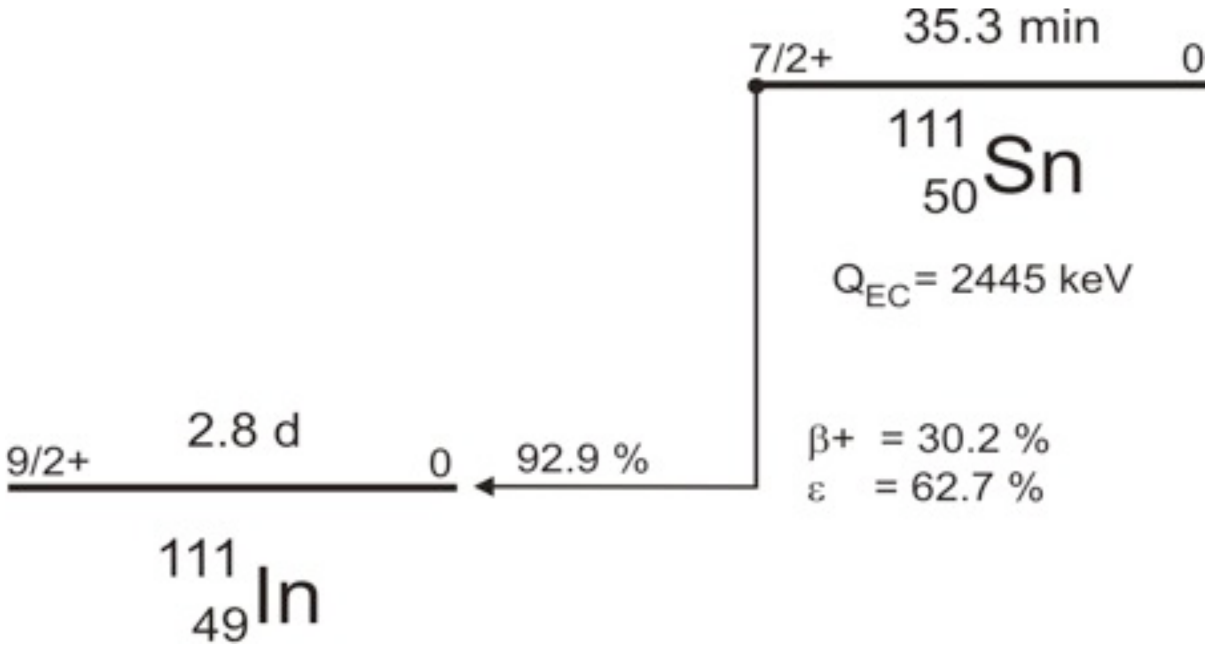
Ionization of ^{7}Be in the Sun can be ~ 20-30 %



Transition (F=1→F=1) is accelerated by **$(2I+1)/(2F_1+1)$** i.e. by 8/3

However, there are only **$(2F_1+1)/((2F_1+1)+(2F_2+1)) = 3/8$** of ^{7}Be in this state

Electron Capture in Hydrogen-like Ions



F = I + s → 4, 3 ⟶ F = I + s → 5, 4

Possibility to address the electron screening in beta decay under very clean conditions !

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Conclusion

1. Broad band mass measurements
2. Beta decay of highly-charged ions
3. Nuclear magnetic moments
4. Nuclear reactions on thin targets
5. Capture reactions at low energies [(p,γ),(α,γ)…]
6. Experiments with isomeric beams
7. Experiments with polarized beams
8. ….

Experimental Collaboration

D. Atanasov, D. Balabanski, K. Blaum, F. Bosch, D. Boutin, C. Brandau, L. Chen, Ch. Dimopoulou, H. Essel, Th. Faestermann, H. Geissel, E. Haettner, M. Hausmann, S. Hess, V. Ivanova, P. Kienle, Ch. Kozhuharov, R. Knöbel, R. Krücken, J. Kurcewicz, S.A. Litvinov, Yu.A. Litvinov, X. Ma, L. Maier, M. Mazzocco, W. Meng, F. Montes, A. Musumarra, G. Münzenberg, C. Nociforo, F. Nolden, T. Ohtsubo, A. Ozawa, W.R. Plass, A. Prochazka, R. Reuschl, S. Sanjari, Ch. Scheidenberger, D. Shubina, U. Spillmann, M. Steck, Th. Stöhlker, B. Sun, T. Suzuki, S. Torilov, X. Tu, H. Weick, M. Winkler, N. Winckler, D. Winters, N. Winters, T. Yamaguchi, G. Zhang