Time-Resolved Schottky Mass Spectrometry in the ESR

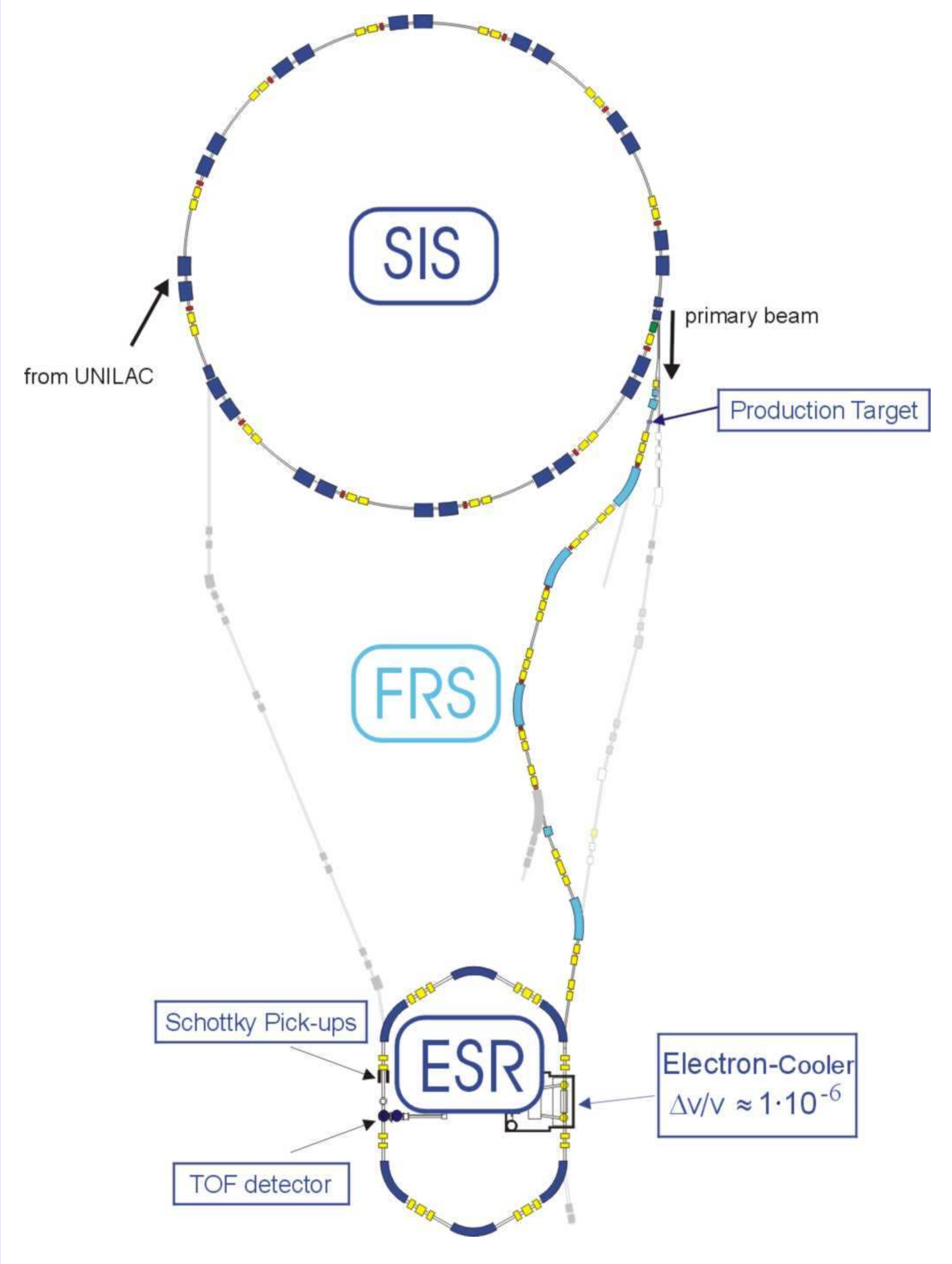
Decay Studies in the ESR

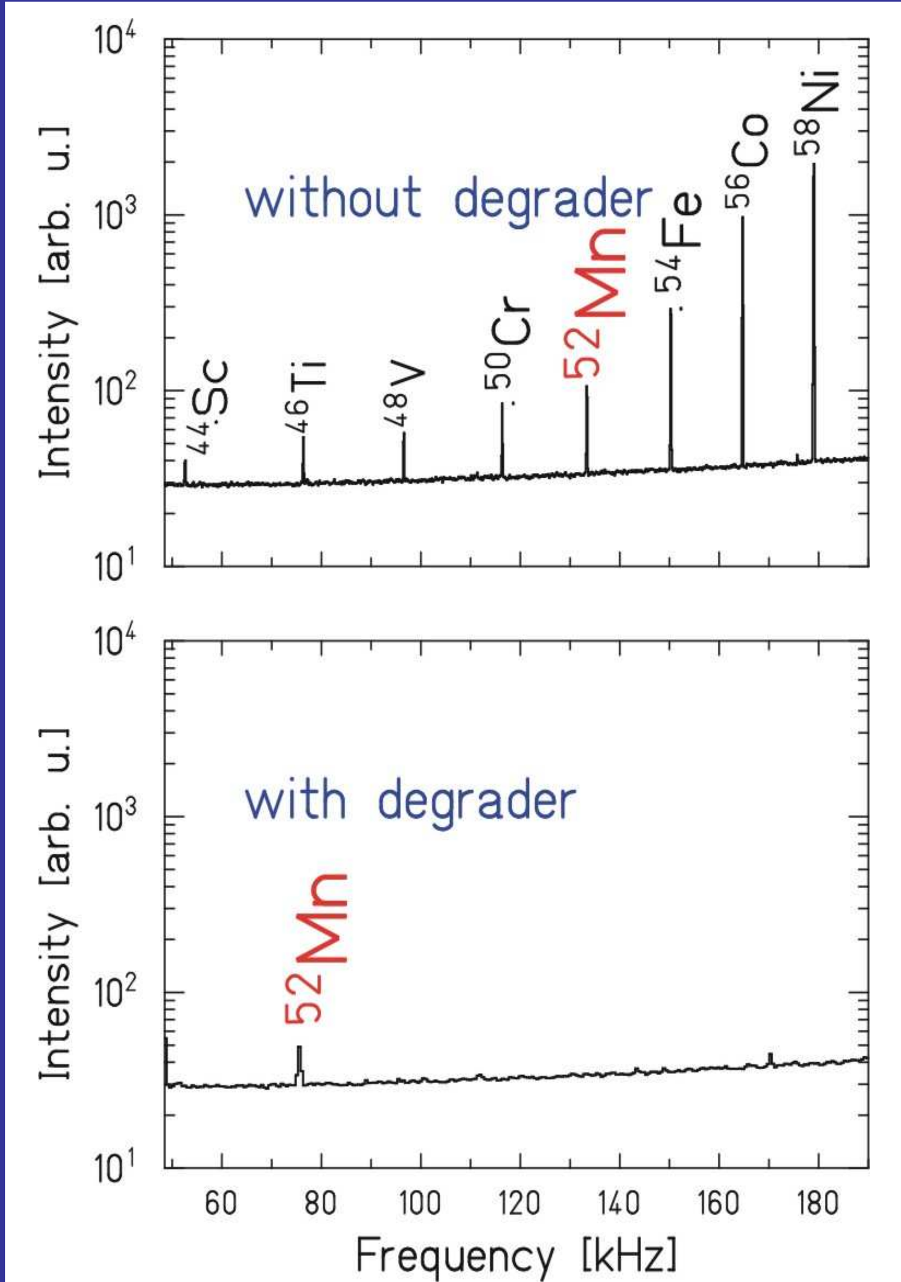
Yuri A. Litvinov

20 October 2006

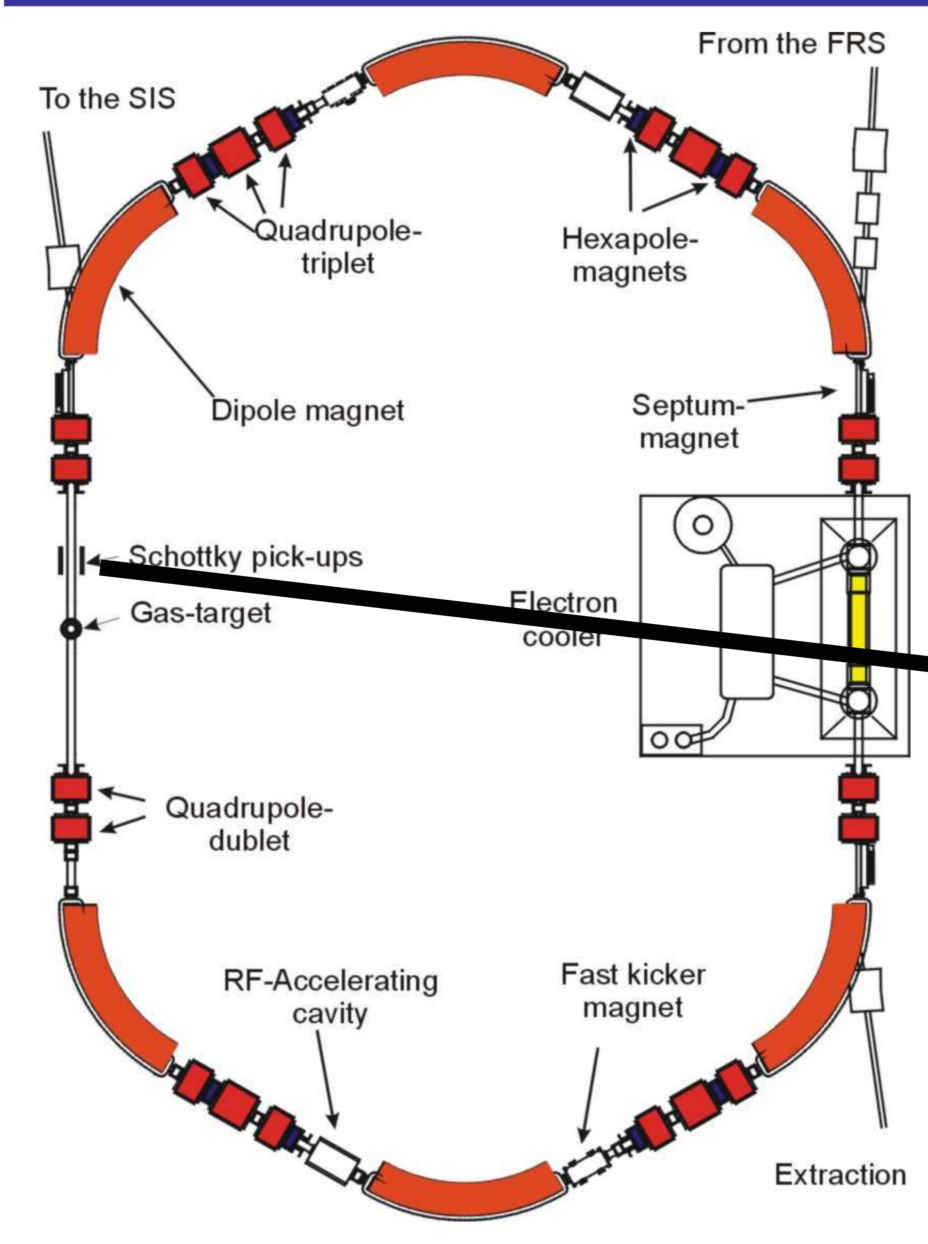
- **Introduction**
- **Time-Resolved Schottky Mass Spectrometry**
- **Present Results on Half-Lives**
- **Future Perspectives**

Production & Separation of Exotic Nuclei



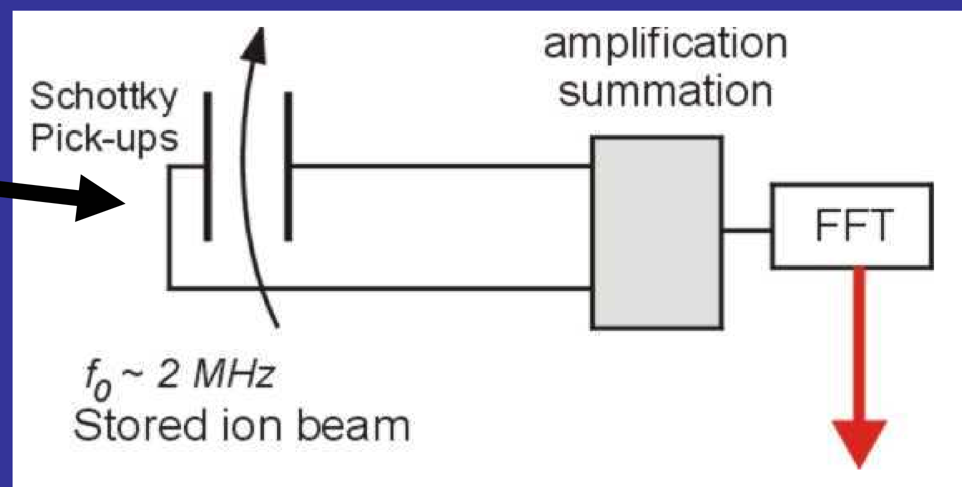


Schottky Mass Spectrometry (SMS)



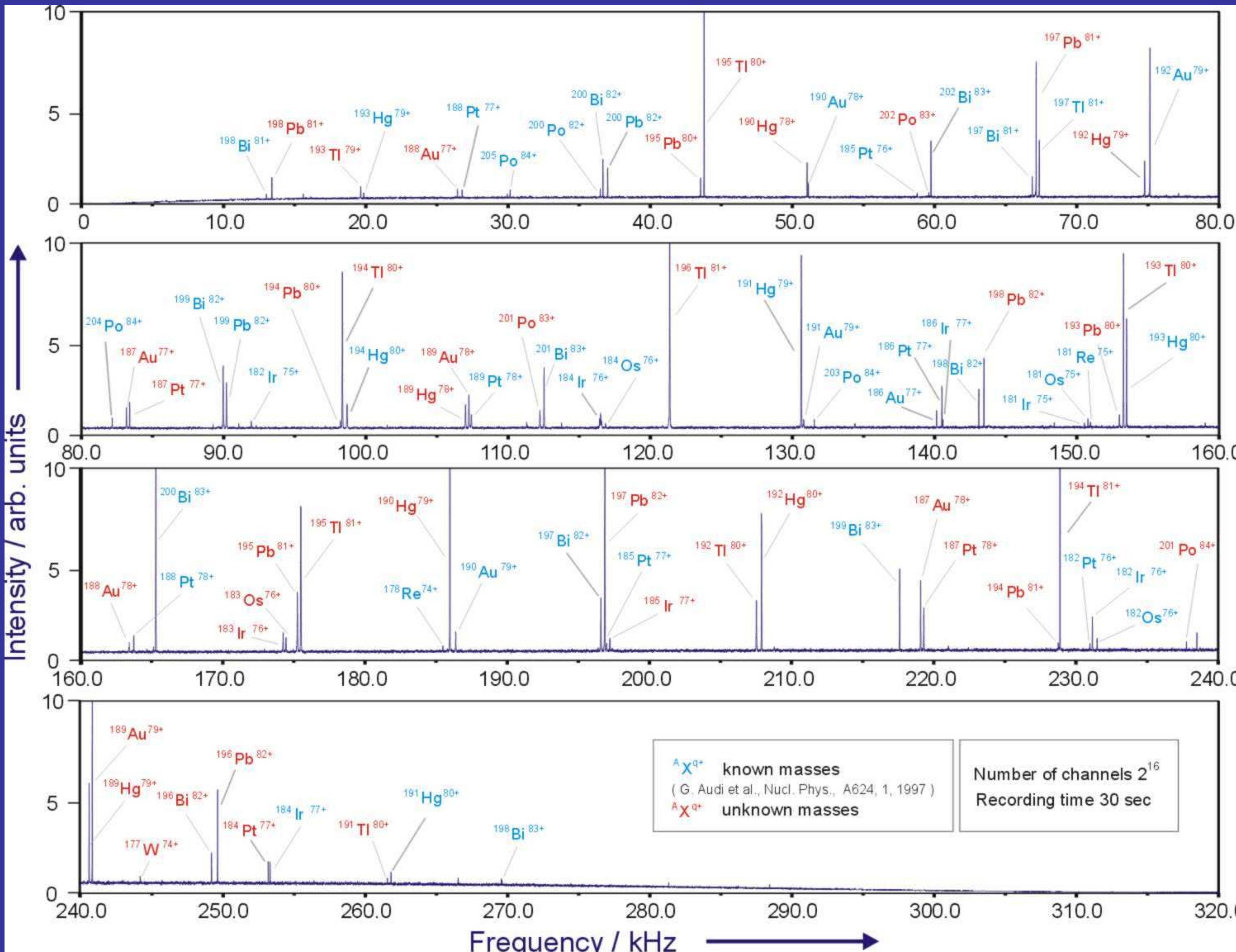
$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

$$\frac{\Delta v}{v} \longrightarrow 0$$

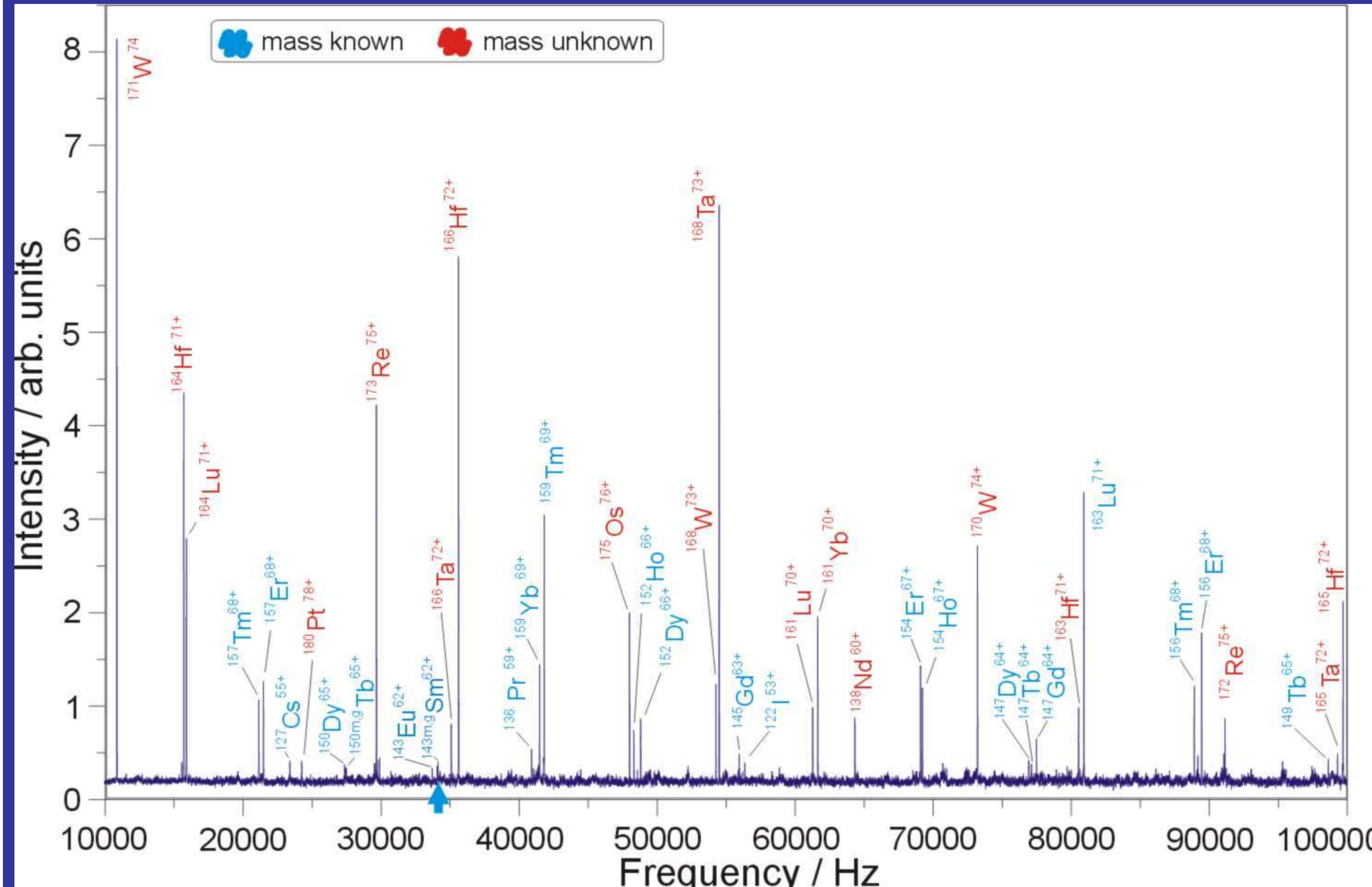


Continuous digitizing and storage of raw data

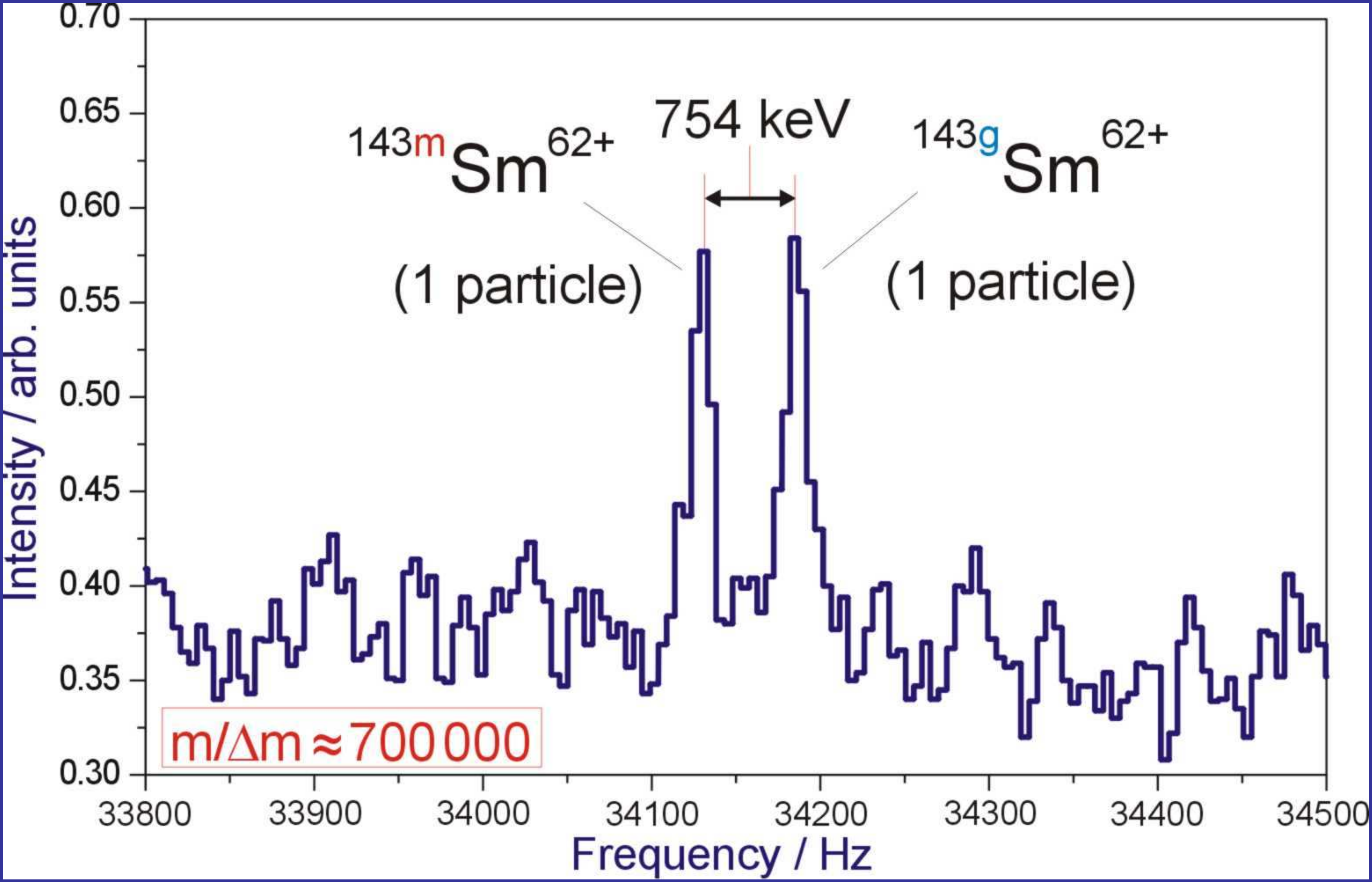
Broad-Band Schottky Frequency Spectra



Broad-Band Schottky Frequency Spectra

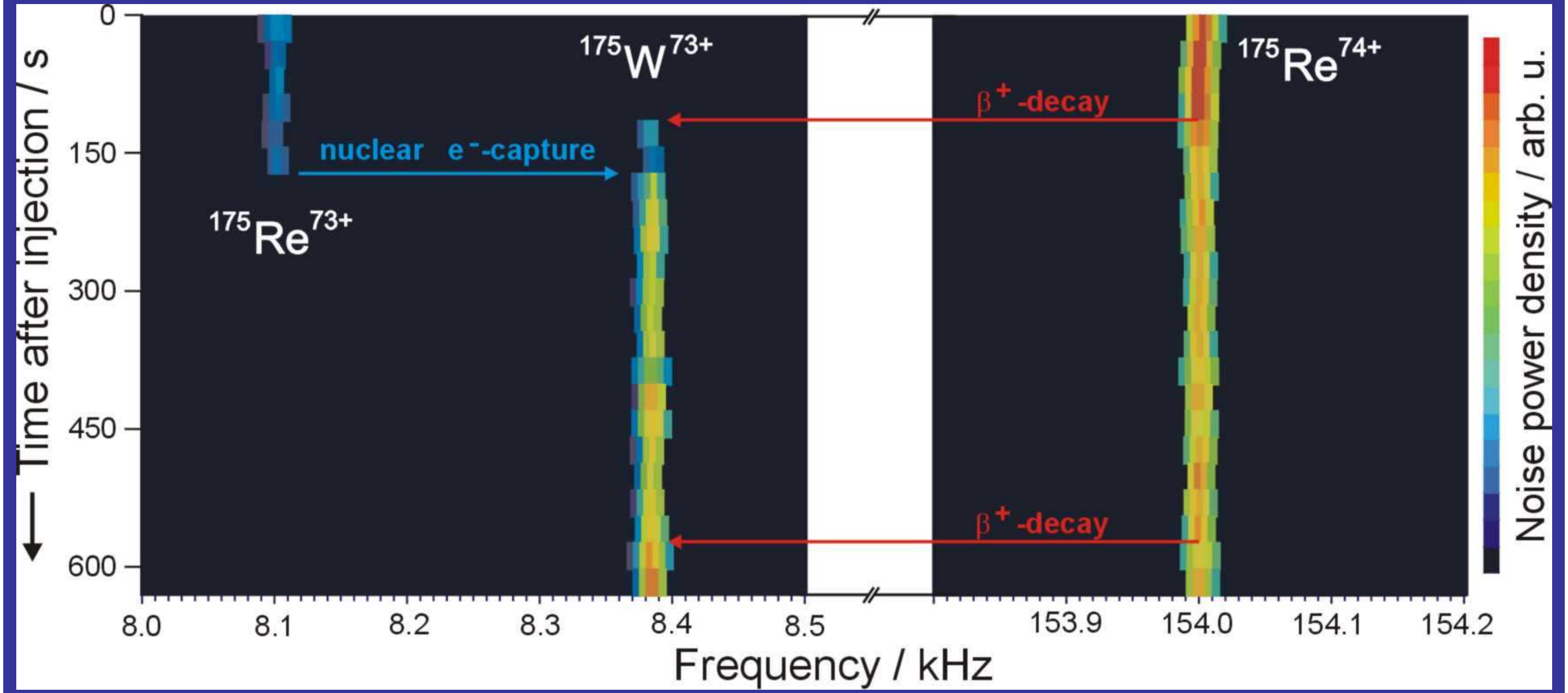


Broad-Band Schottky Frequency Spectra



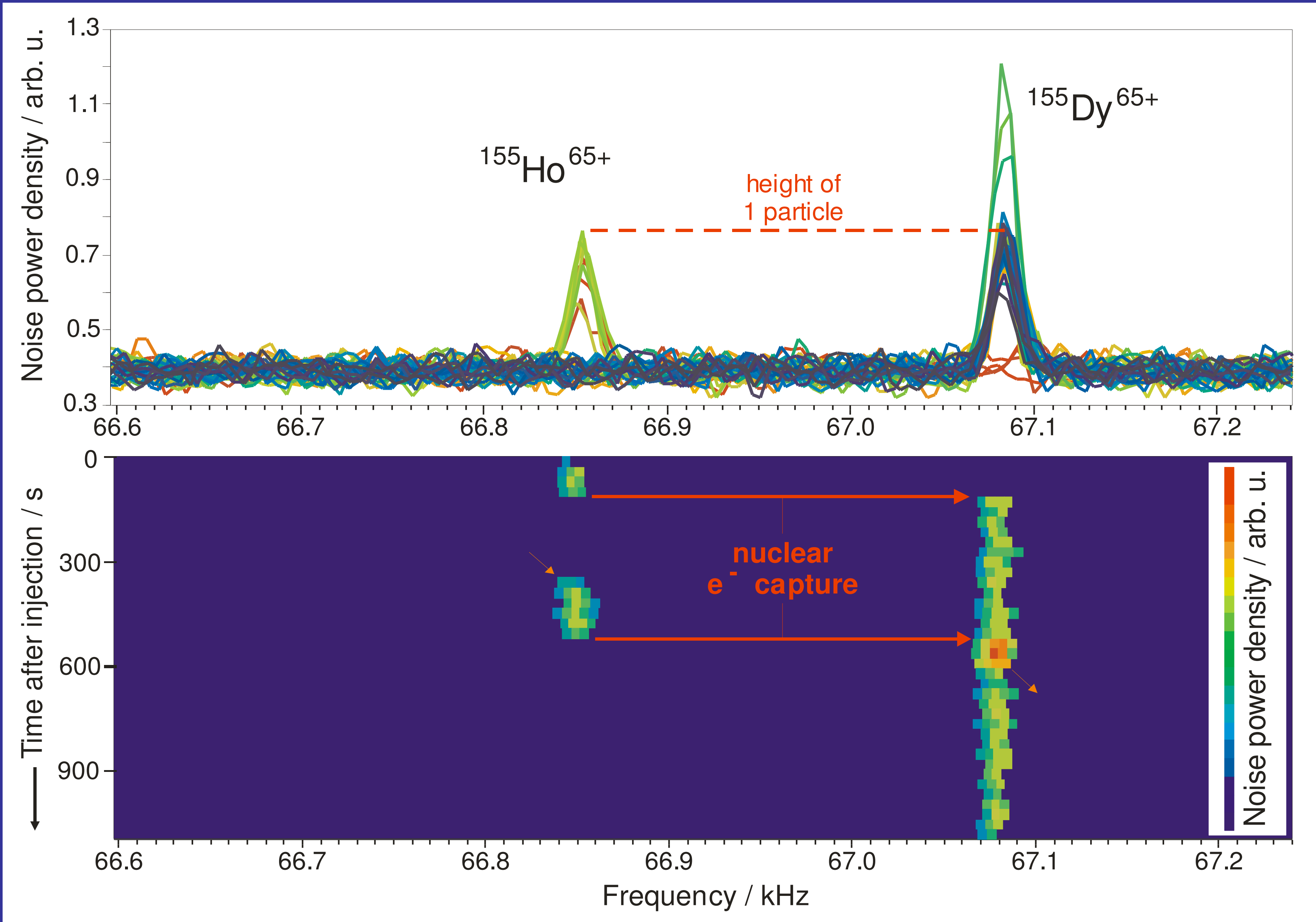
Nuclear Decays of Stored Single Atoms

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

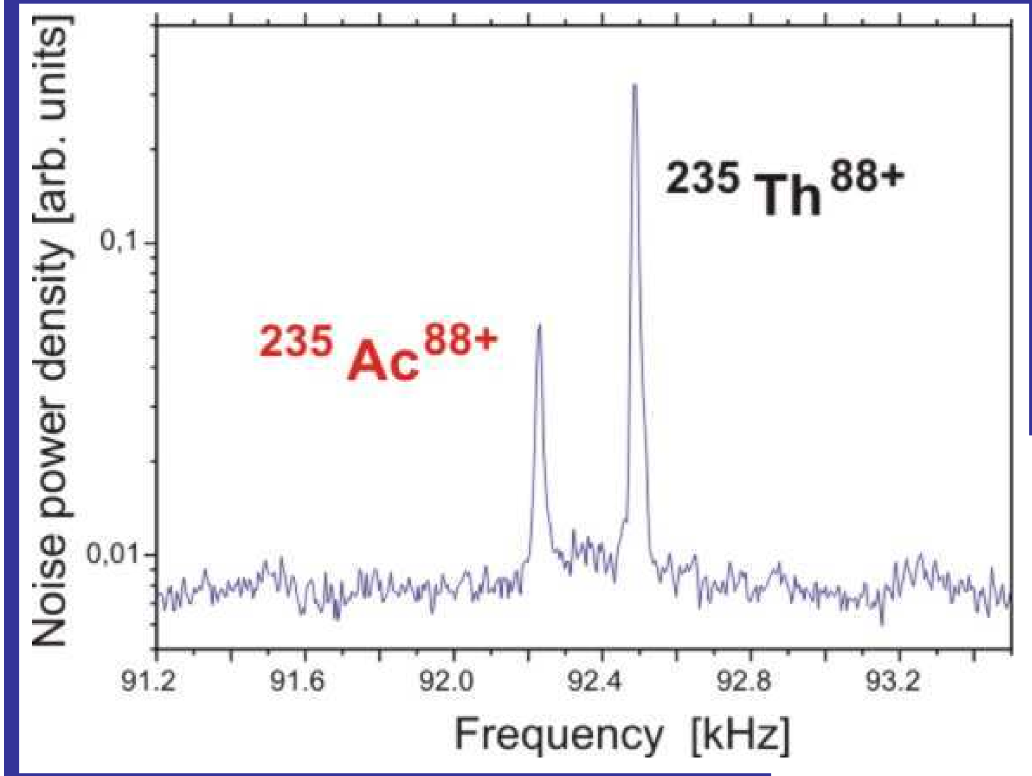


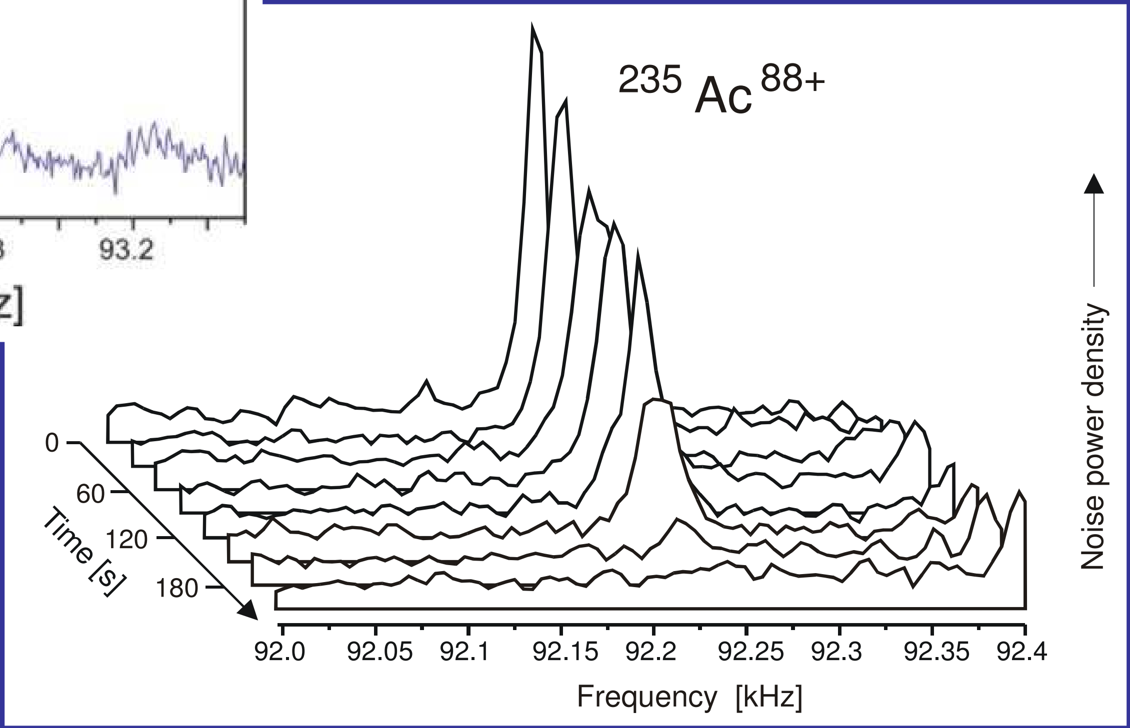
Nuclear electron capture, β+,β- and bound-β decays were observed

Nuclear Decays of Stored Single Atoms



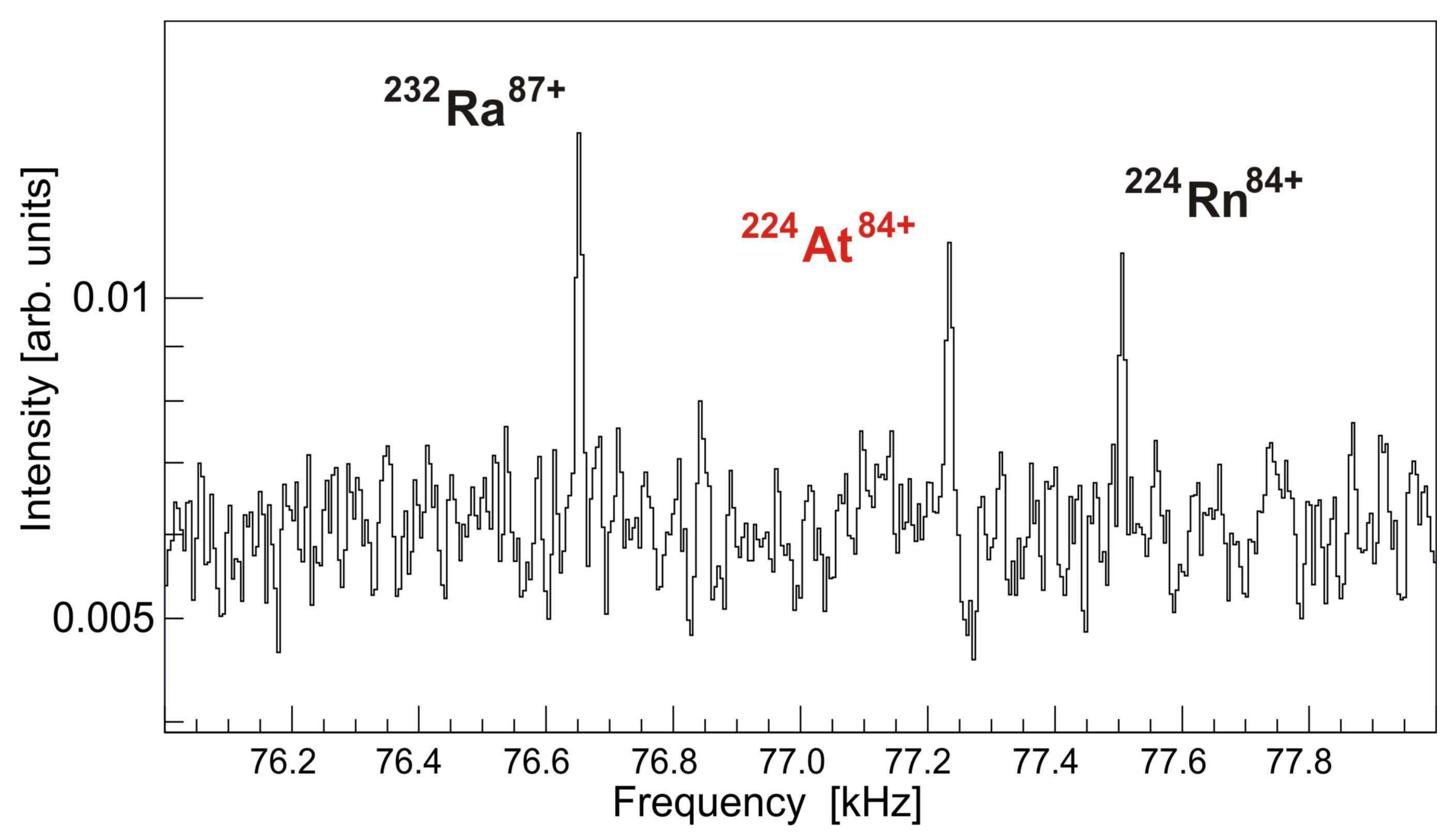
Identification of New Isotopes





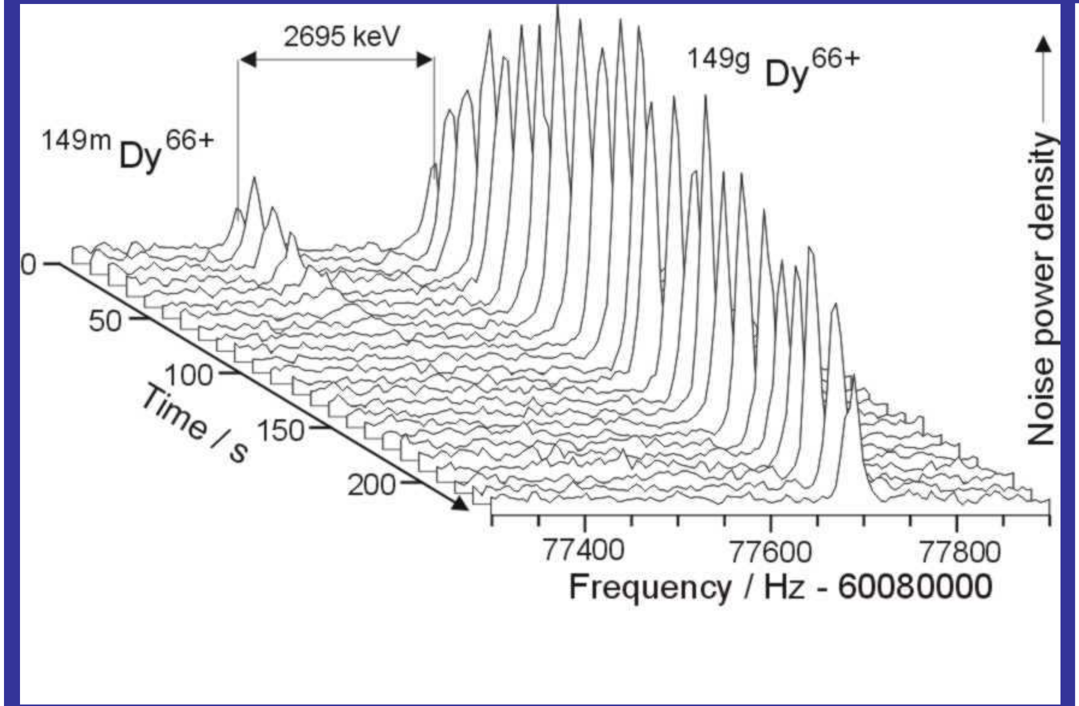
F. Bosch, et al., Int. J. Mass Spectr. 251 (2006) 212-219

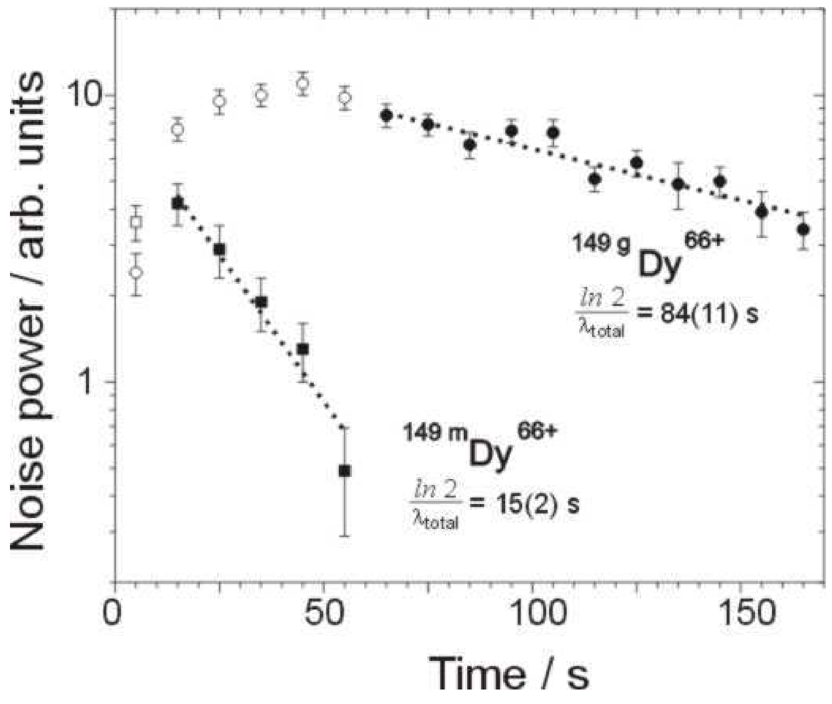
Identification of New Isotopes



F. Bosch, et al., Int. J. Mass Spectr. 251 (2006) 212-219

Half-Lives of Nuclear Isomers





Neutral atom is 0.49(2) s
Fully ionized atom is 11(1) s

$$\frac{T_{1/2}\ \text{(fully ionized)}}{T_{1/2}\ \text{(neutral)}} = 22(2)$$

Isomer	$T_{1/2}$ bare, s	$T_{1/2}$ neutral, s	Hindrance factor
^{151m}Er	19(3)	0.58(2)	33(5)
^{149m}Dy	11(1)	0.49(2)	22(2)
^{144m}Tb	12(2)	4.25(15)	2.8(5)

Yu.A. Litvinov, et al., PLB 573 (2003) 80-85

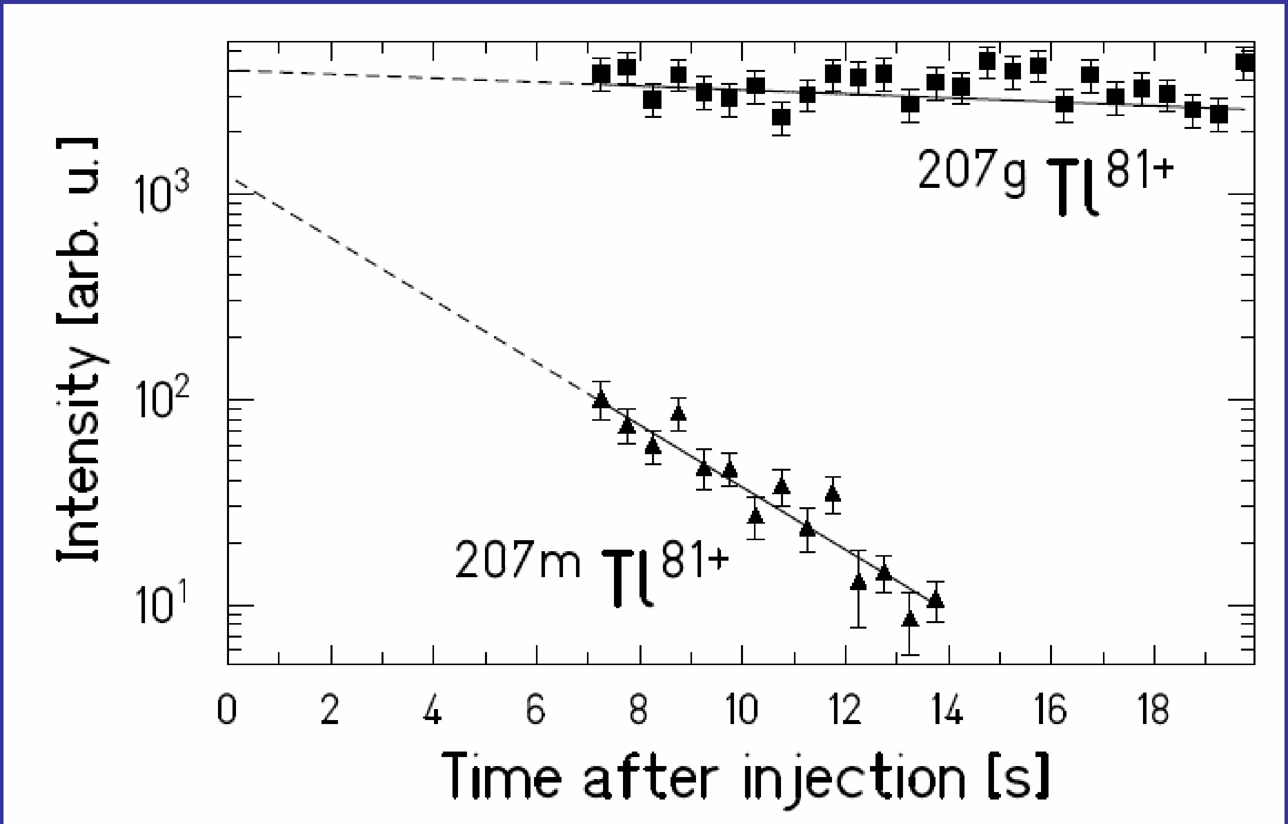
Half-life of Fully-Ionized $^{207m}Tl^{81+}$

^{207m}Tl (E^* = 1348 keV)

$T_{1/2}$(neutral) = 1.33(11) s

$T_{1/2}$(bare) = 1.47(32) s

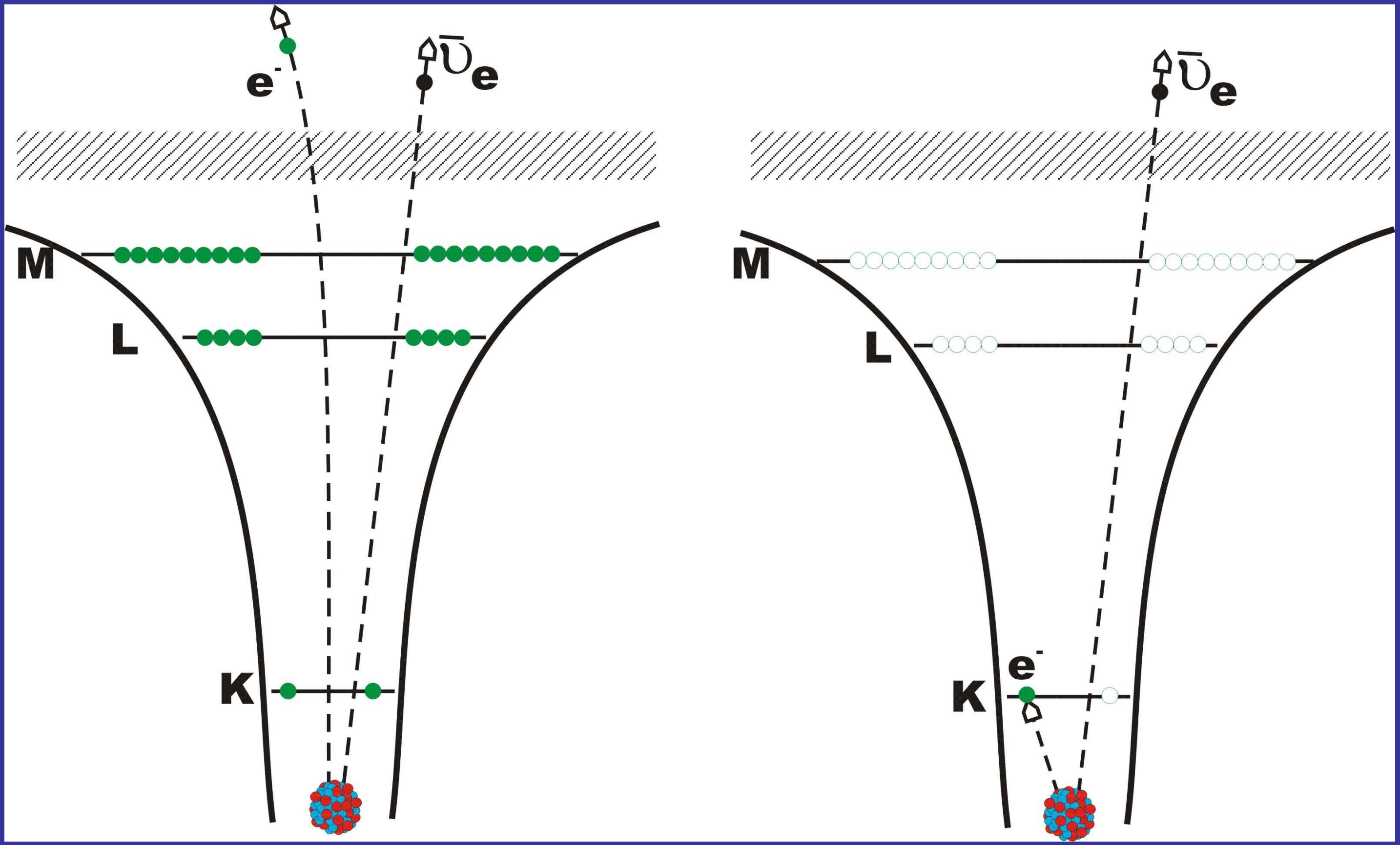
$T_{1/2}$(theory) = 1.52(12) s



D. Boutin, PhD Thesis, JLU Giessen, 2005

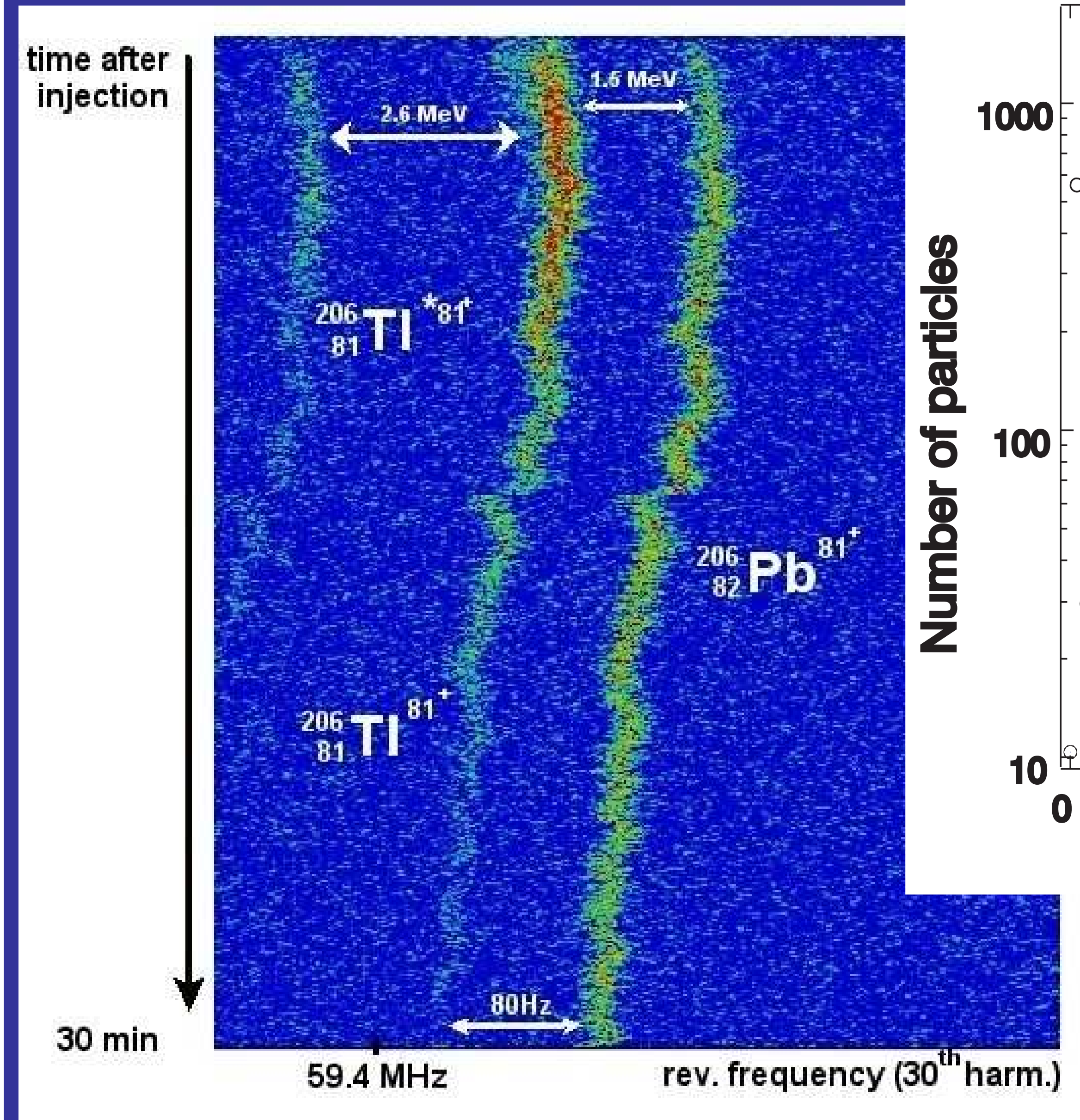
T. Ohtsubo et al., Phys. Rev. Lett. 95 (2005) 052501

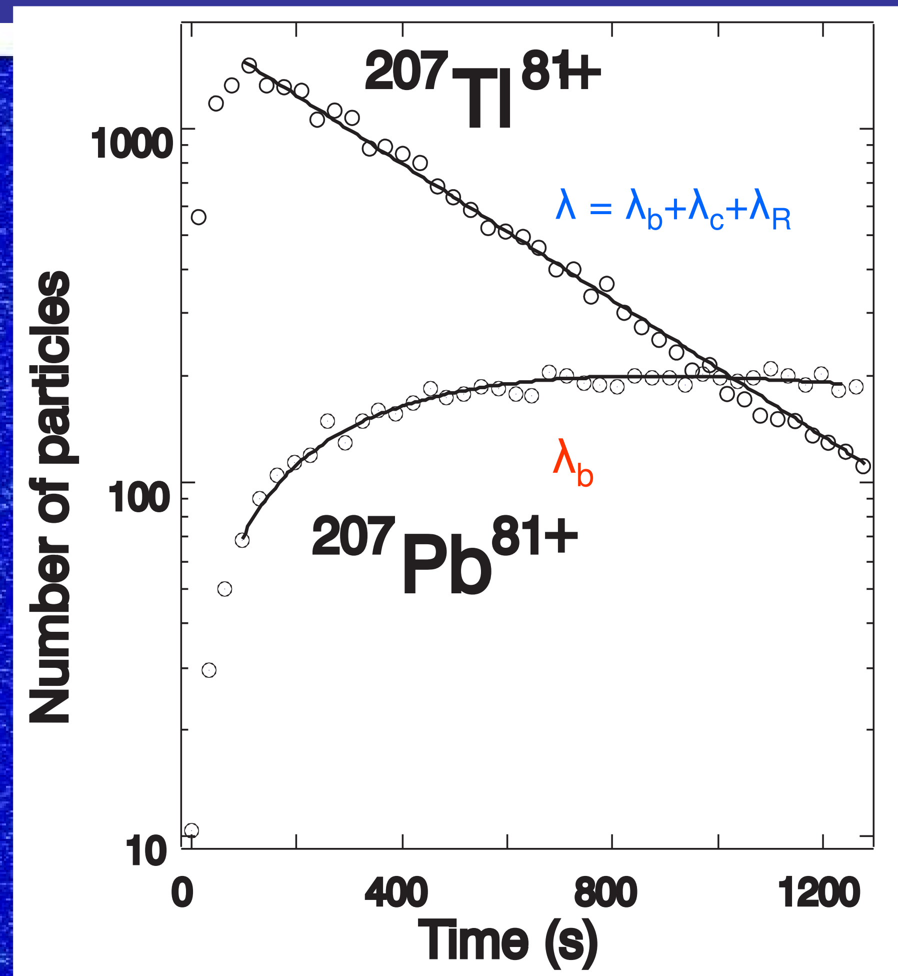
Bound-State β-decay



providing larger Q values
enhancing stellar β decay rates
altering β chronometers
modifying s-process branching points

Bound-State β-decay in ^{206,207}Tl

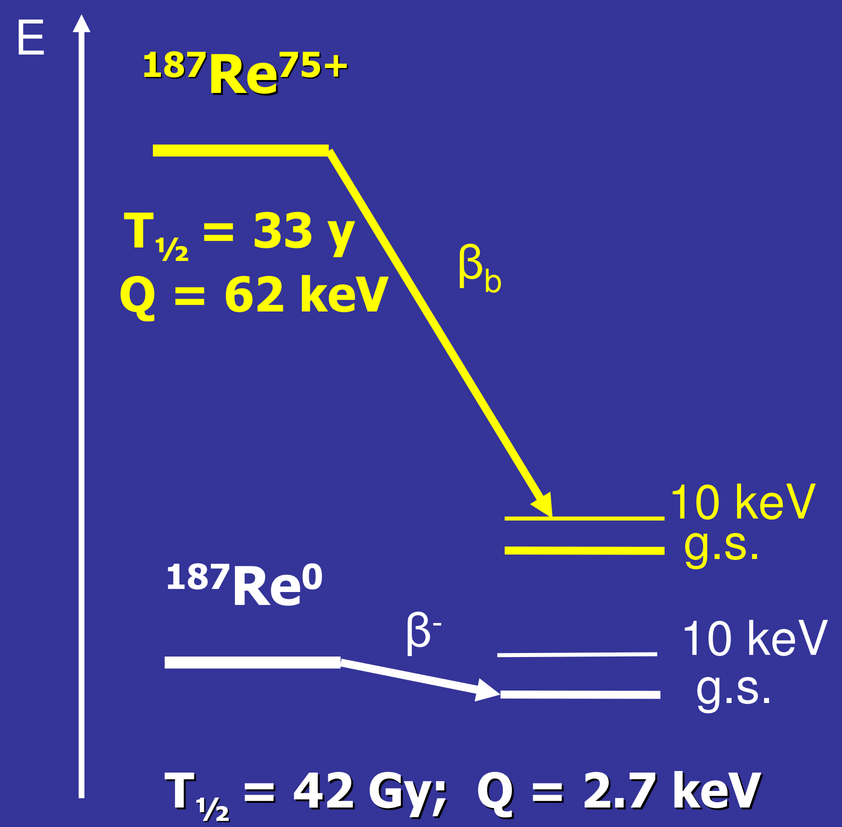


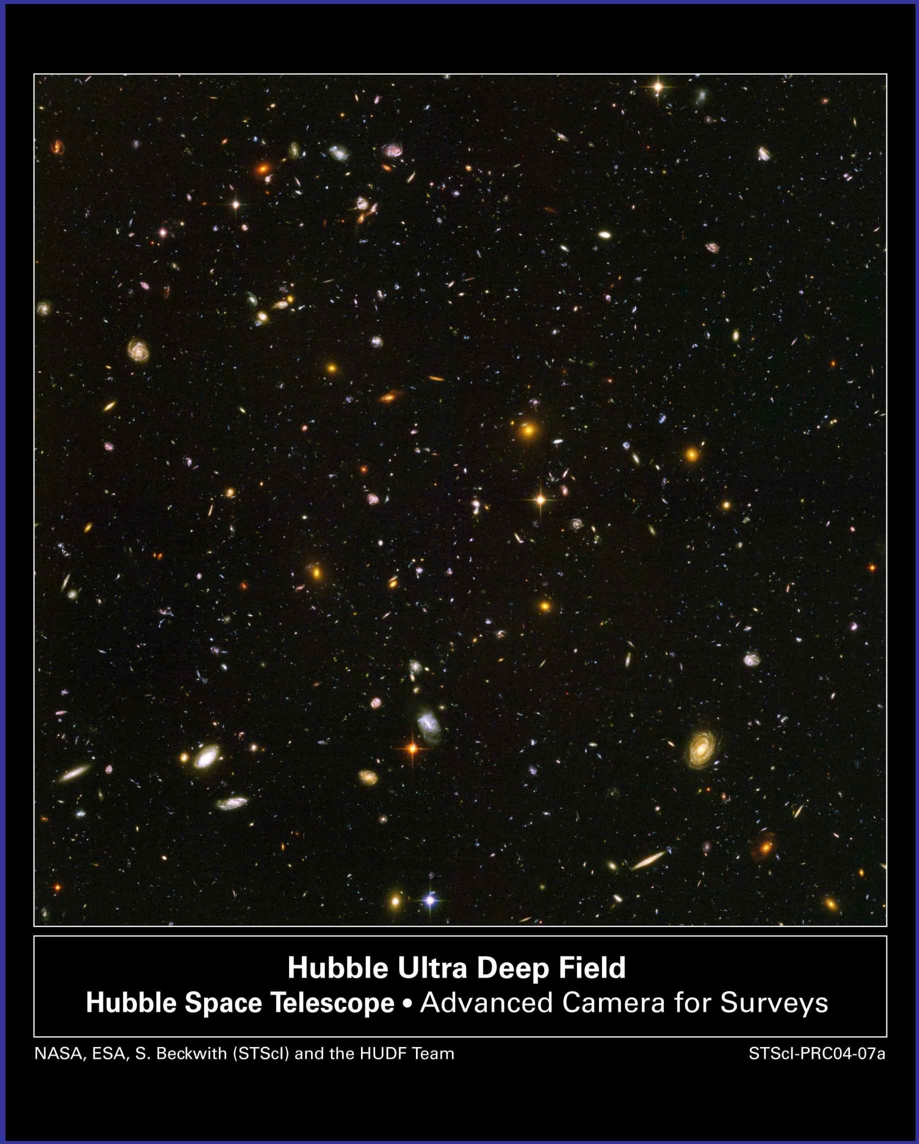


bound/continuum branching ratio

→ Fermi function f(Z) of β^- decay

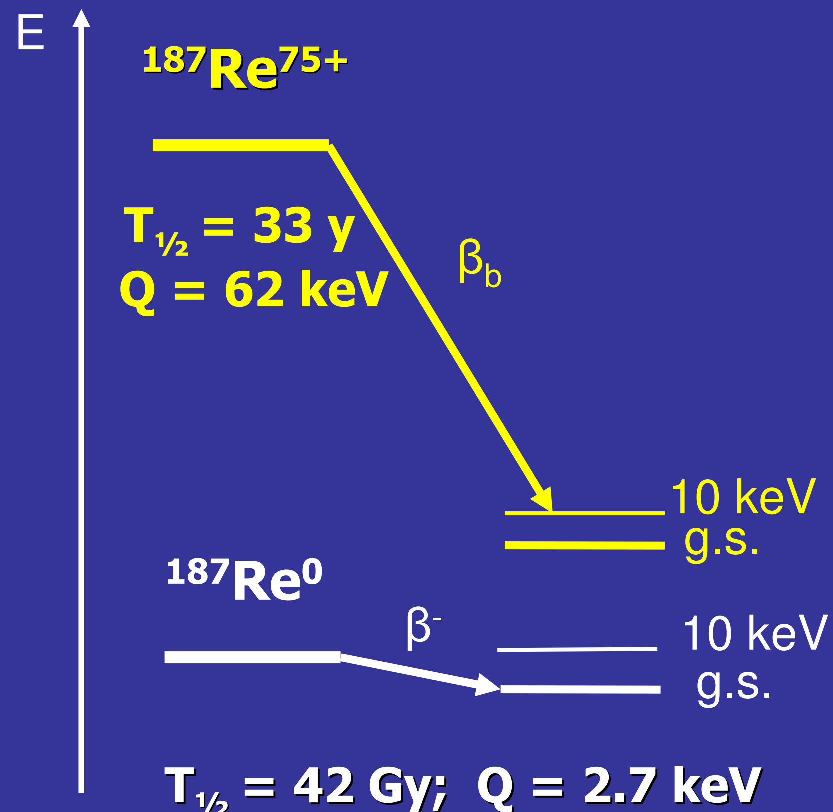
Bound-State β-decay of ^{187}Re





F. Bosch et al., Phys. Rev. Lett. 77 (1996) 5190

Bound-State β-decay of ^{187}Re



The 7 Nuclear Clocks for the Age of the Earth, the Solar System, the Galaxy, and the Universe

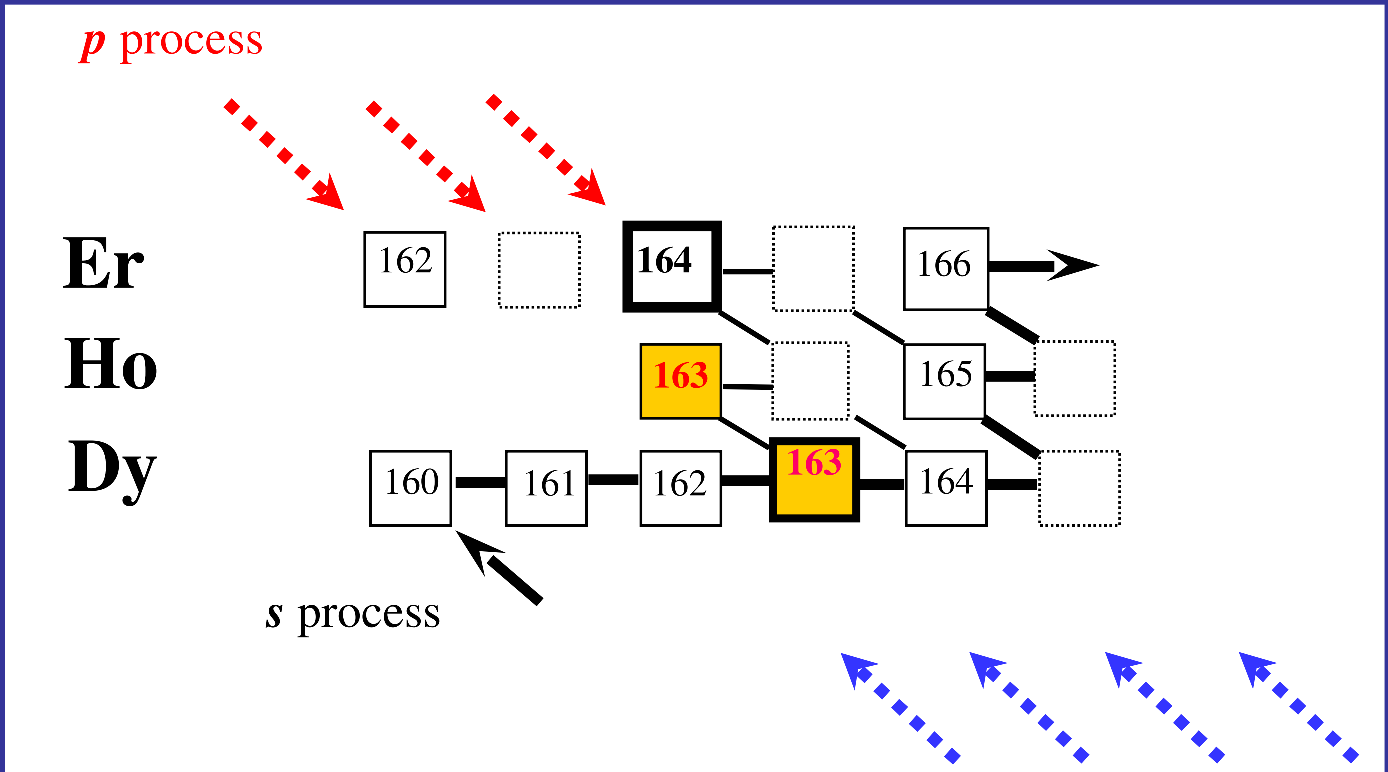
clock	$T_{1/2}[10^9$ y]
$^{40}K/^{40}Ar$ (β)	1.3
^{238}U…Th…^{206}Pb (α,β)	4.5
^{232}Th…Ra…^{208}Pb (α,β)	14
$^{176}Lu/^{176}Hf$ (β)	30
$^{187}Re/^{187}Os$ (β)	42
$^{87}Rb/^{87}Sr$ (β)	50
$^{147}Sm/^{143}Nd$ (α)	100

Clayton (1964): *a mother-daughter couple ($^{187}Re/^{187}Os$) is the "best" radioactive clock*

F. Bosch et al., Phys. Rev. Lett. 77 (1996) 5190

Bound-State β-decay of ^{163}Dy

s process: slow neutron capture and β- decay near valley of β stability at
kT = 30 keV; → high atomic charge state → bound-state β decay

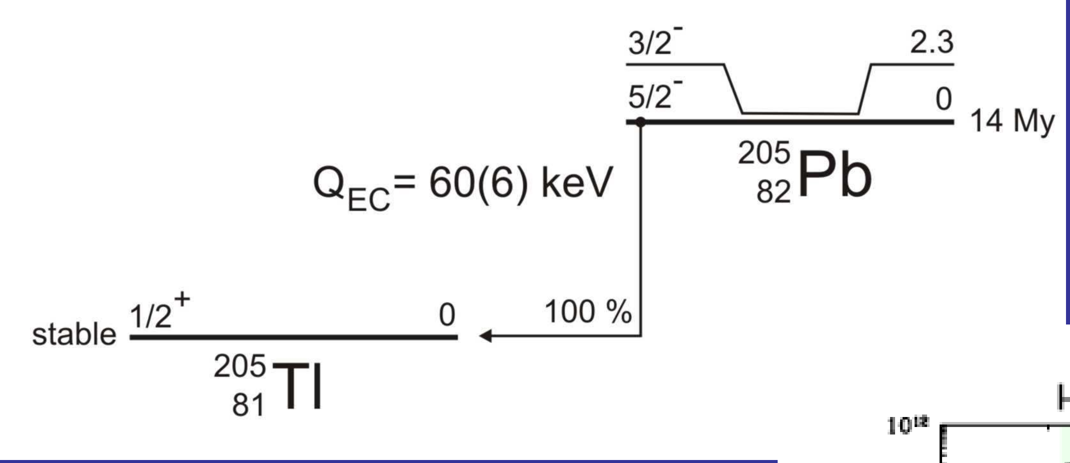


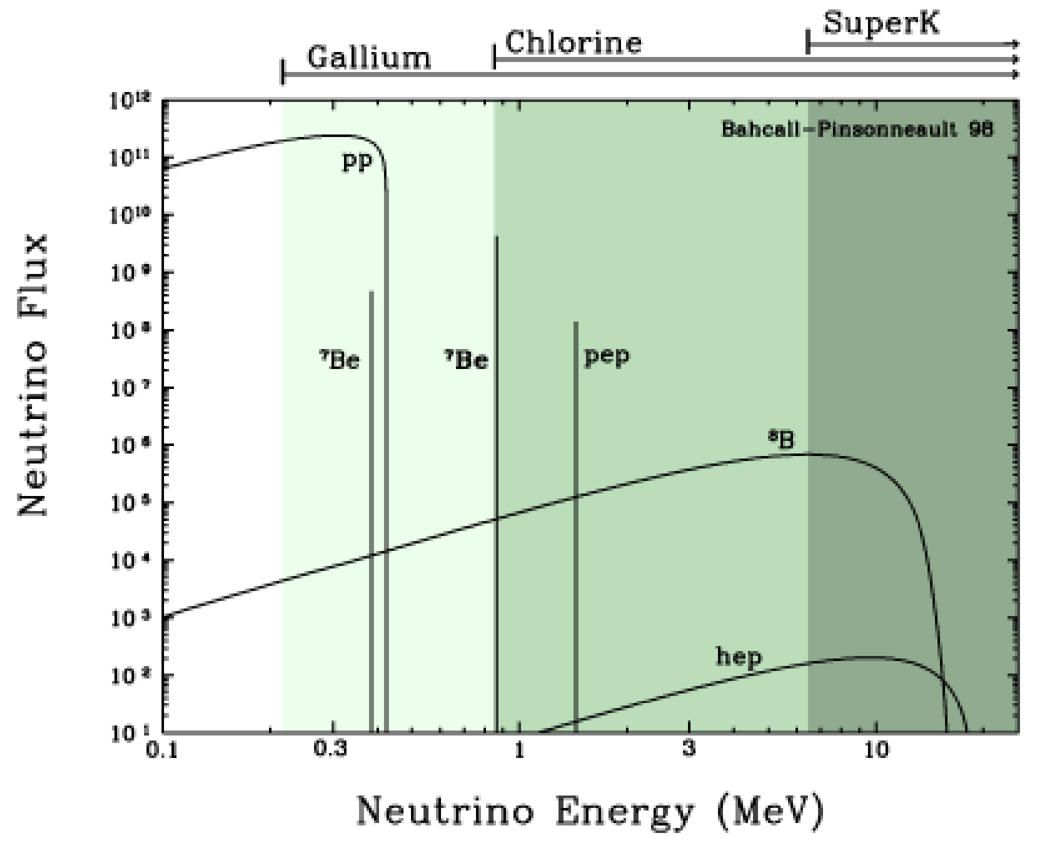
$T_{1/2}$ = 48 days

branchings caused by bound-state β decay

M. Jung et al., Phys. Rev. Lett. 69 (1992) 2164

Next Step: Bound-State β-decay of ^{205}Tl





F. Bosch et al., GSI Proposal

Electron Capture in Hydrogen-like Ions

Simple theoretical estimation:

R.B. Firestone, Table of Isotopes, 1996

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

β+ to EC branching ratio:

$\lambda_{\beta+}/\lambda_{EC}$ **(neutral atom) ≈ 1**

W.Bambynek et al., Rev. Mod. Phys 49, 1977

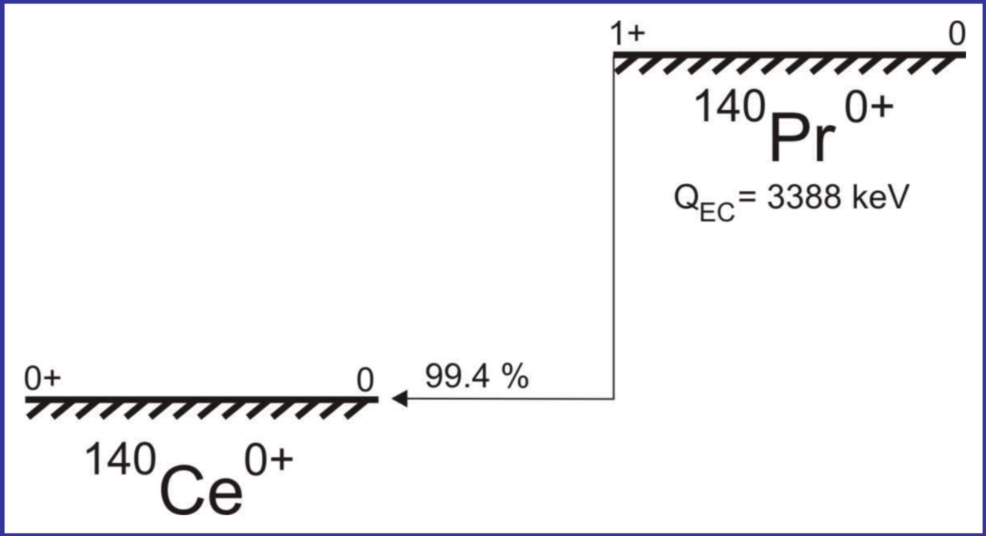
S-electron density at the nucleus:

$|f_S(0)|^2 \propto 1/n^3$

P_{EC} **(neutral atom)** $\propto 2 \sum 1/n^3 = 2.4$

P_K **(H-like)** $\propto 1 * 1/1^3 = 1$

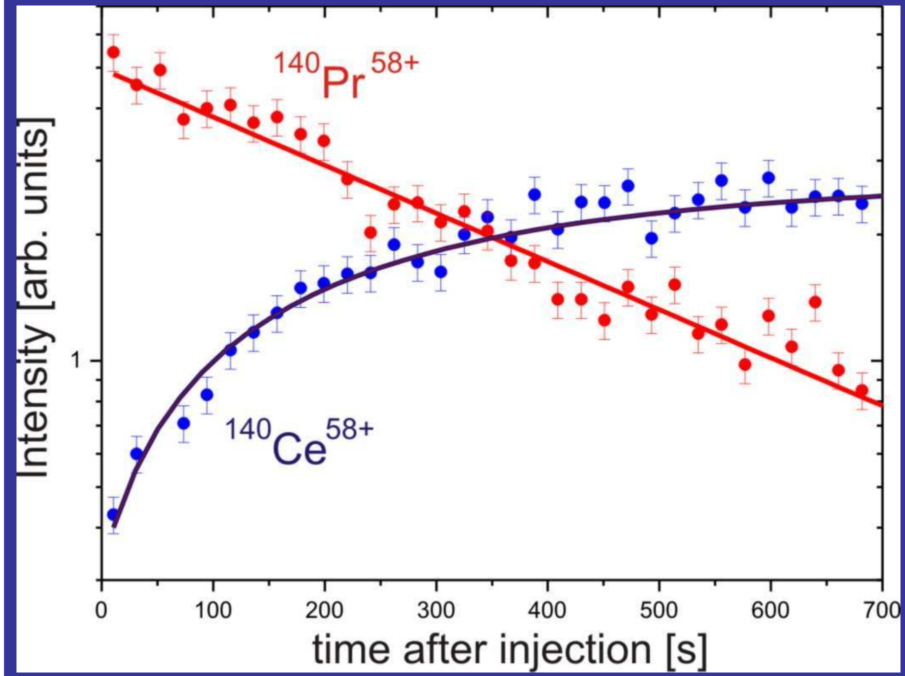
$\lambda_{\beta+}/\lambda_K$ **(H-like) ≈ 2.4**

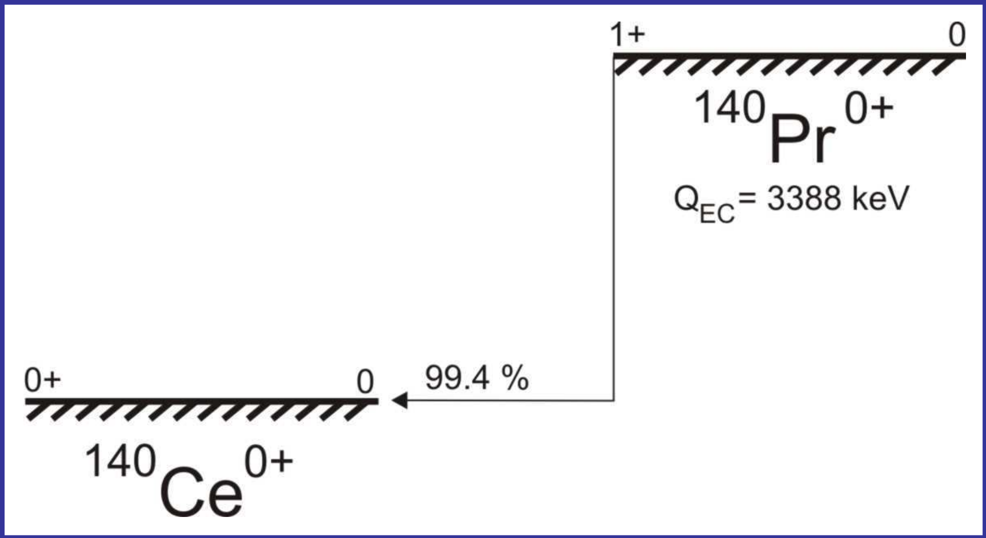


Conclusion:

H-Like ion should have 41% longer half-life

Electron Capture in Hydrogen-like Ions





G.Audi et al., NPA729 (2003) 3

λ(neutral) = 0.00341(1) s^{-1}

Decay of fully-ionized ^{140}Pr:

$\lambda_{\beta+}$ = 0.00172(7) s^{-1}

Decay of H-like ^{140}Pr:

λ_K = 0.00213(19) s^{-1}

J. Kurcewicz, N. Winckler et al., in preparation

Expectation:

$\lambda_{\beta+}/\lambda_K$ (H-like) ≈ 2.4

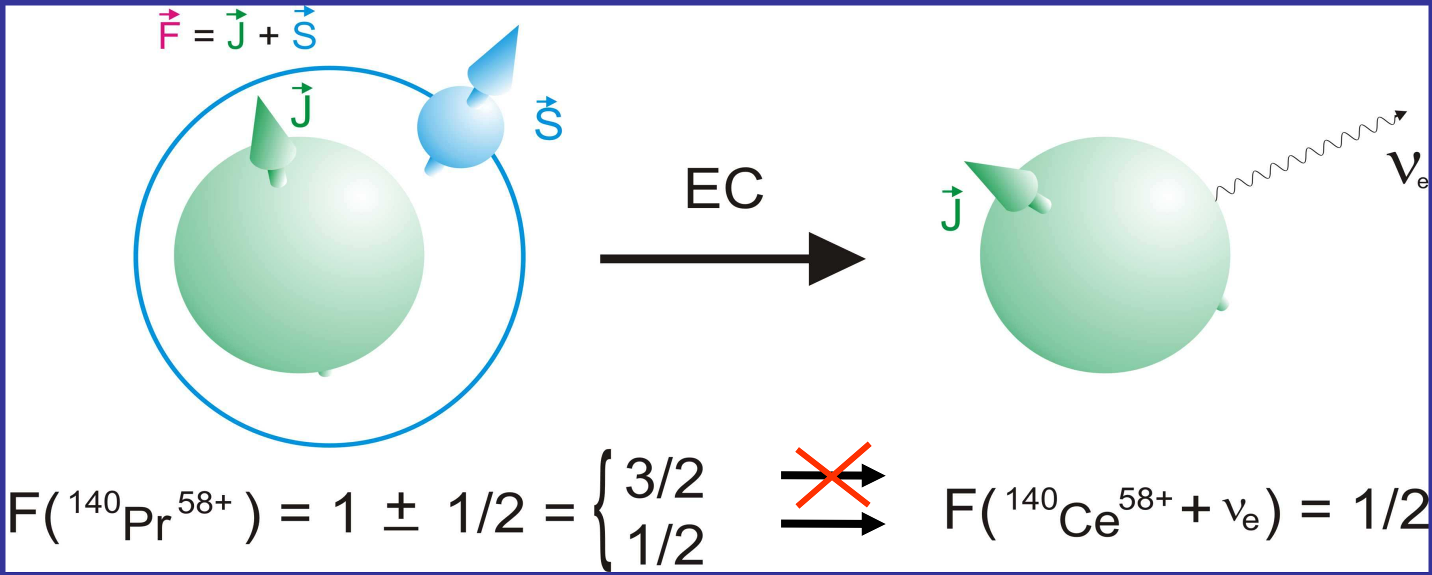
Experiment:

$\lambda_{\beta+}/\lambda_K$ (H-like) = 0.81(8)

H-Like ion decays ~20% faster than neutral atom !!!

Electron Capture in Hydrogen-like Ions

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



S. Typel and L. Grigorenko

$\mu = +2.7812\mu_N$

Z. Patyk

Probability of EC Decay

Neutral ^{140}Pr: **P = 2.381**

He-like ^{140}Pr: **P = 2**

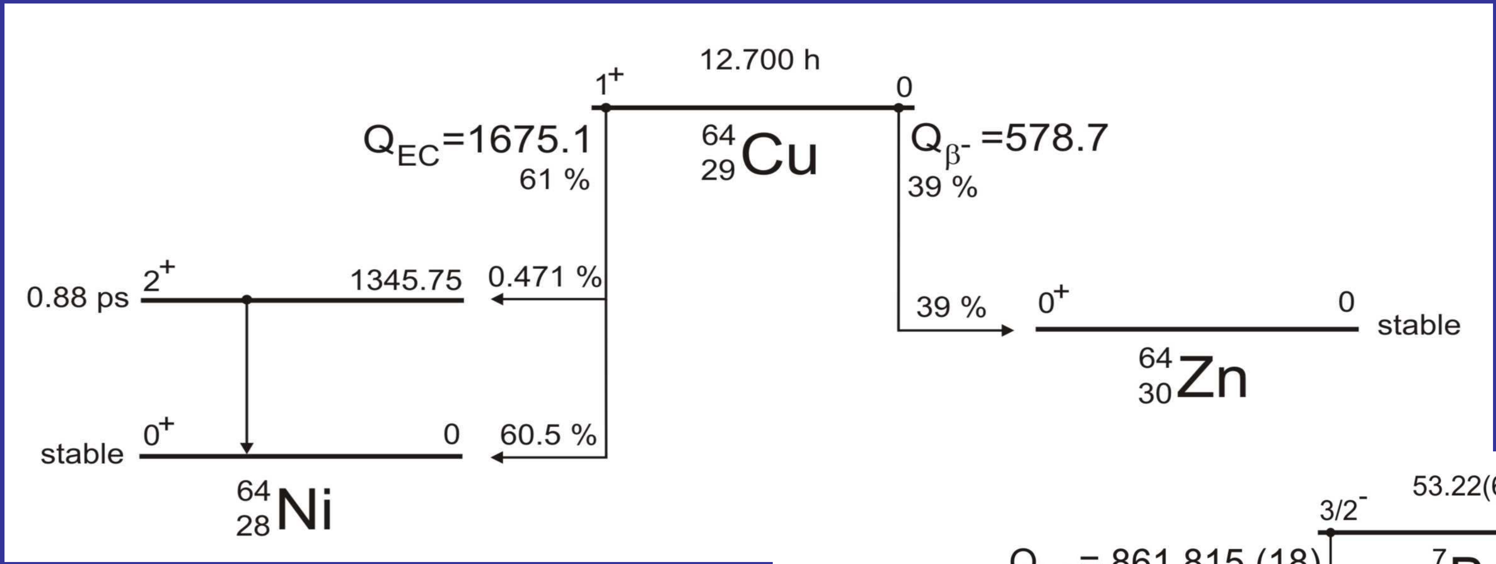
H-like ^{140}Pr: **P = 3**

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

Electron Capture in Hydrogen-like Ions

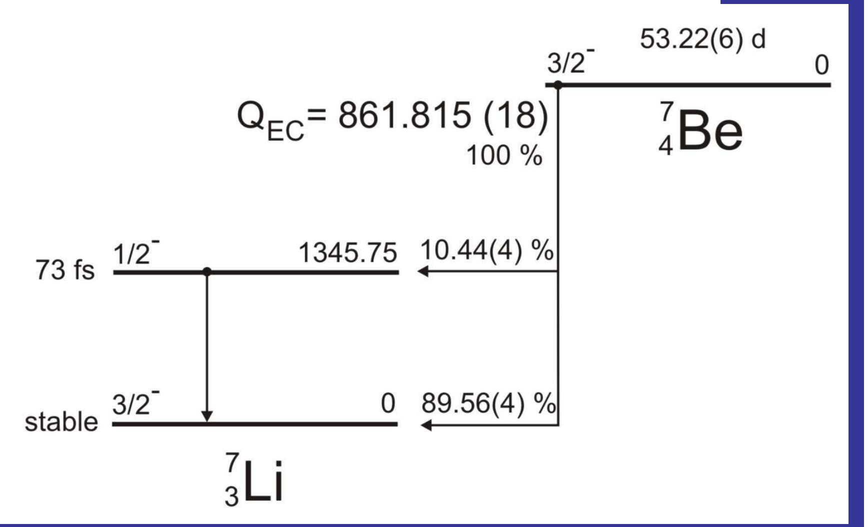
B.M. Dodsworth et al., Phys. Rev. 142 (1966) 638.

μ (^{64}Cu) = –0.217(2) nm



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

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



Single-Particle Decay Spectroscopy

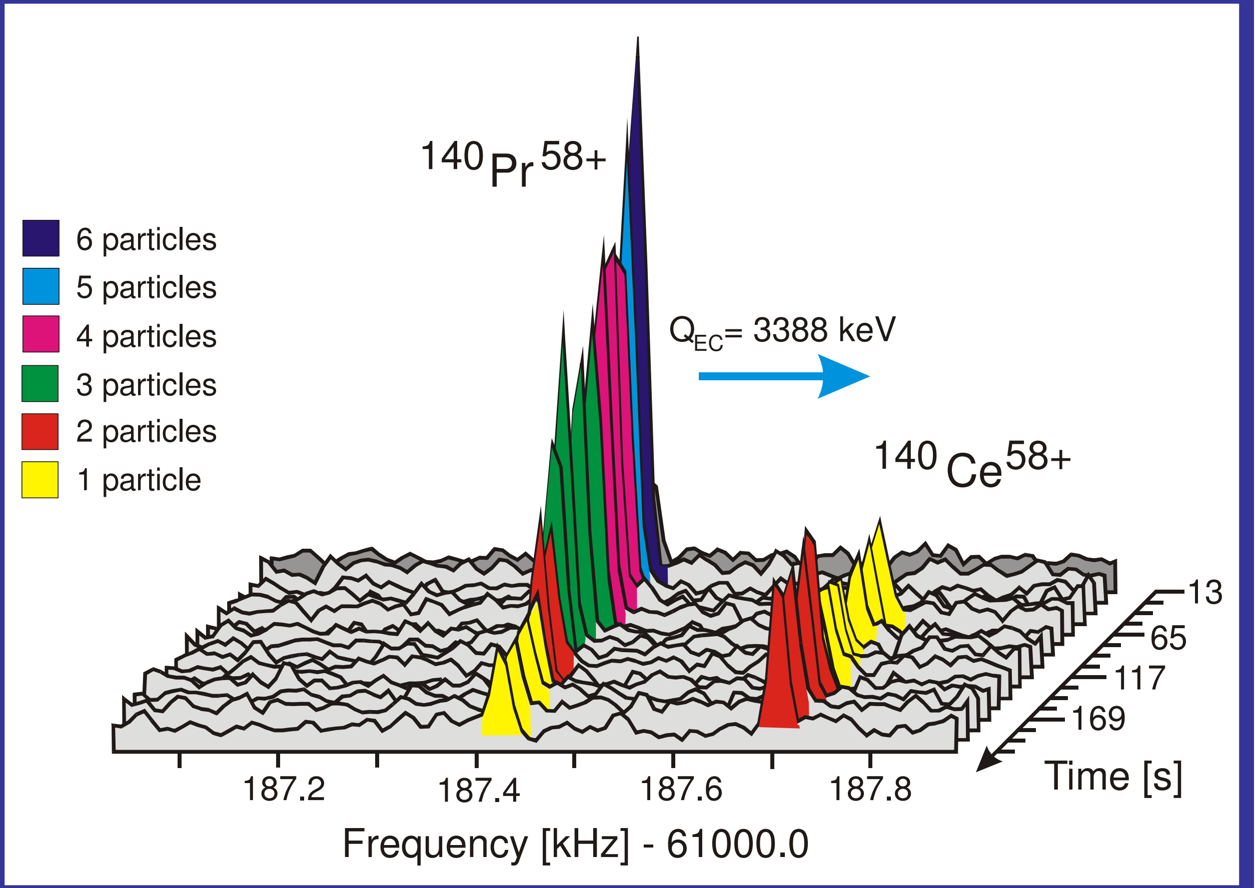
Sensitivity to single stored ions

Recording the correlated changes of peak intensities corresponding to mother and daughter ions

Reliable determination of the number of a few stored particles

Investigation of a selected decay branch, e.g. pure electron capture decay

Systematical effects such as late cooling or feeding via atomic or nuclear decays can be disentangled



F. Bosch et al., Int. J. Mass Spectr. 251 (2006) 212

Summary and Future Plans

- β^+ decay of bare nuclei

  H.Irnich et al., Physical Review Letters 75 (1995) 4182-4185
- Half-lives of highly-converted isomeric states in bare nuclei

  Yu.A. Litvinov et al., Physics Letters B573 (2003) 80-85
- First Direct Observation of Bound-State β decay

  T. Ohtsubo et al., Physical Review Letters 95 (2005) 052501
- EC and β^+ decay of hydrogen-like ^{140}Pr ions

  J. Kurcewicz, N. Winckler et al., in preparation

- Half-life measurements of exotic nuclides

  C. Scheidenberger et al., GSI Proposal E055
- α decay of bare nuclei

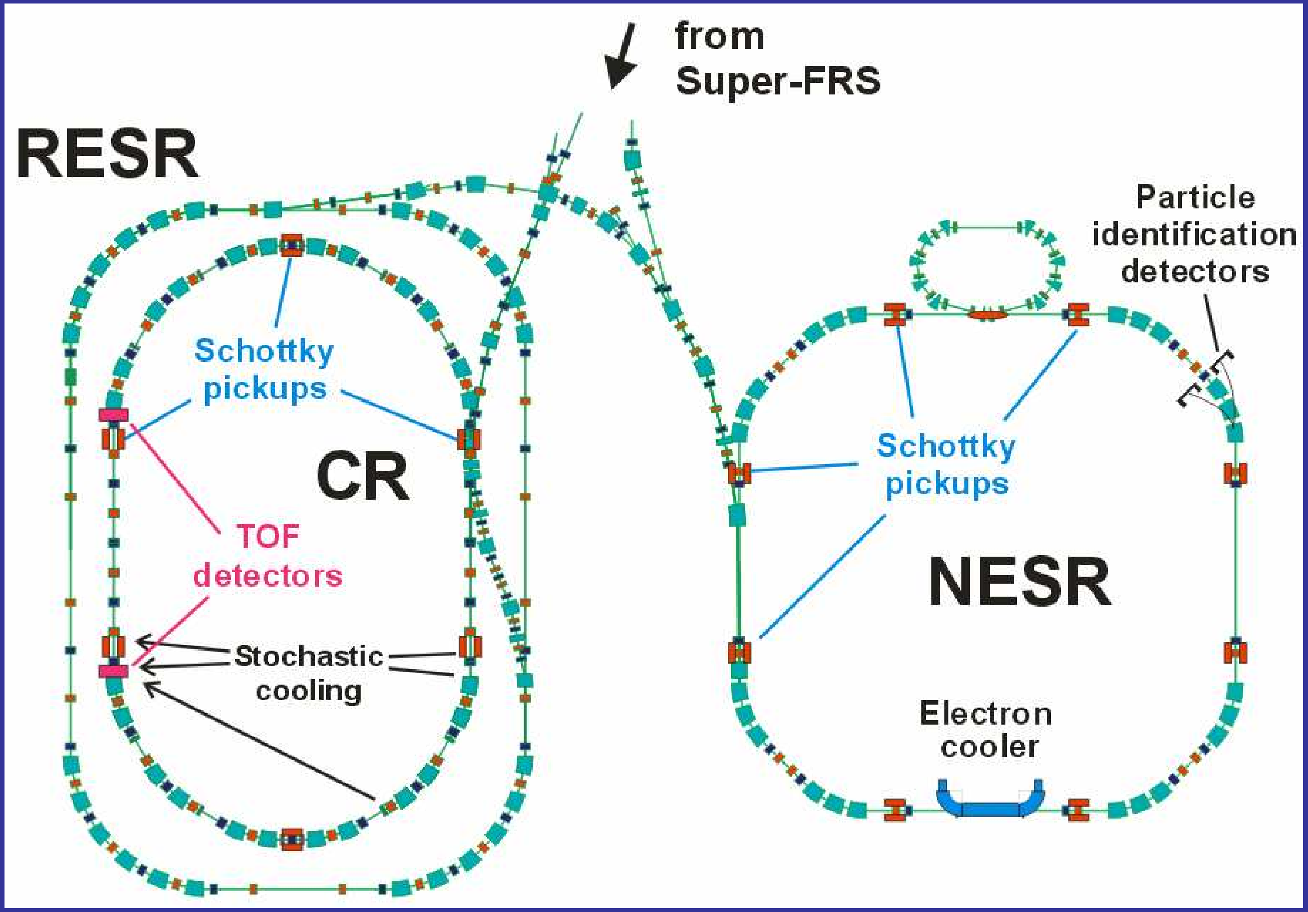
  A. Musumarra et al., GSI Proposal 2006
- Bound-state β decay in ^{205}Tl

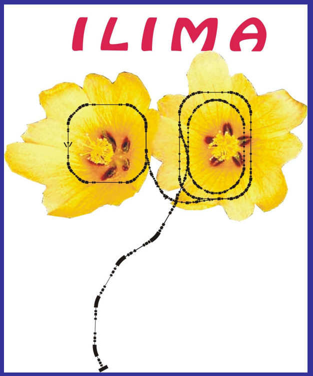
  F. Bosch et al., GSI Proposal E069
- EC and β^+ decay in ^{64}Cu

  Yu.A. Litvinov et al., GSI Proposal, in preparation
- Single Particle Decay Spectroscopy of ^{140}Pr and ^{142}Pm

  Yu.A. Litvinov, F. Bosch et al., GSI Proposal, submitted

ILIMA: Isomeric beams, Lifetimes, and Masses





Decay Studies in the ESR

G.Audi, L.Batist, K.Beckert, F.Bosch, D.Boutin, C.Brandau, Th.Buervenich, L.Chen, I.Cullen, C.Dimopoulou, H.Essel, B.Fabian, T.Faestermann, B.Franczak, B.Franzke, H.Geissel, M.Hausmann, P.Kienle, O.Klepper, R.Knöbel, C.Kozhuharov, K.-L.Kratz, R.Krücken, J.Kurcewicz, S.A.Litvinov, Yu.A.Litvinov, Z.Liu, M.Mazzocco, L.Maier, F.Montes, I.Mukha, G.Münzenberg, A.Musumarra, C.Nociforo, F.Nolden, T.Ohtsubo, A.Ozawa, Z.Patyk, B.Pfeiffer, M.Pfützner, W.R.Plass, C.Scheidenberger, M.Shindo, J.Stadlmann, M.Steck, Th.Stöhlker, K.Sümmerer, B.Sun, T.Suzuki, S.Typel, P.M.Walker, H.Weick, N.Winckler, M.Winkler, T.Yamaguchi

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