Investigations of the time-modulated orbital electron capture decays

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Capture Gamma-Ray Spectroscopy and Related Topics
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The Two-Body-Weak-Decay Collaboration

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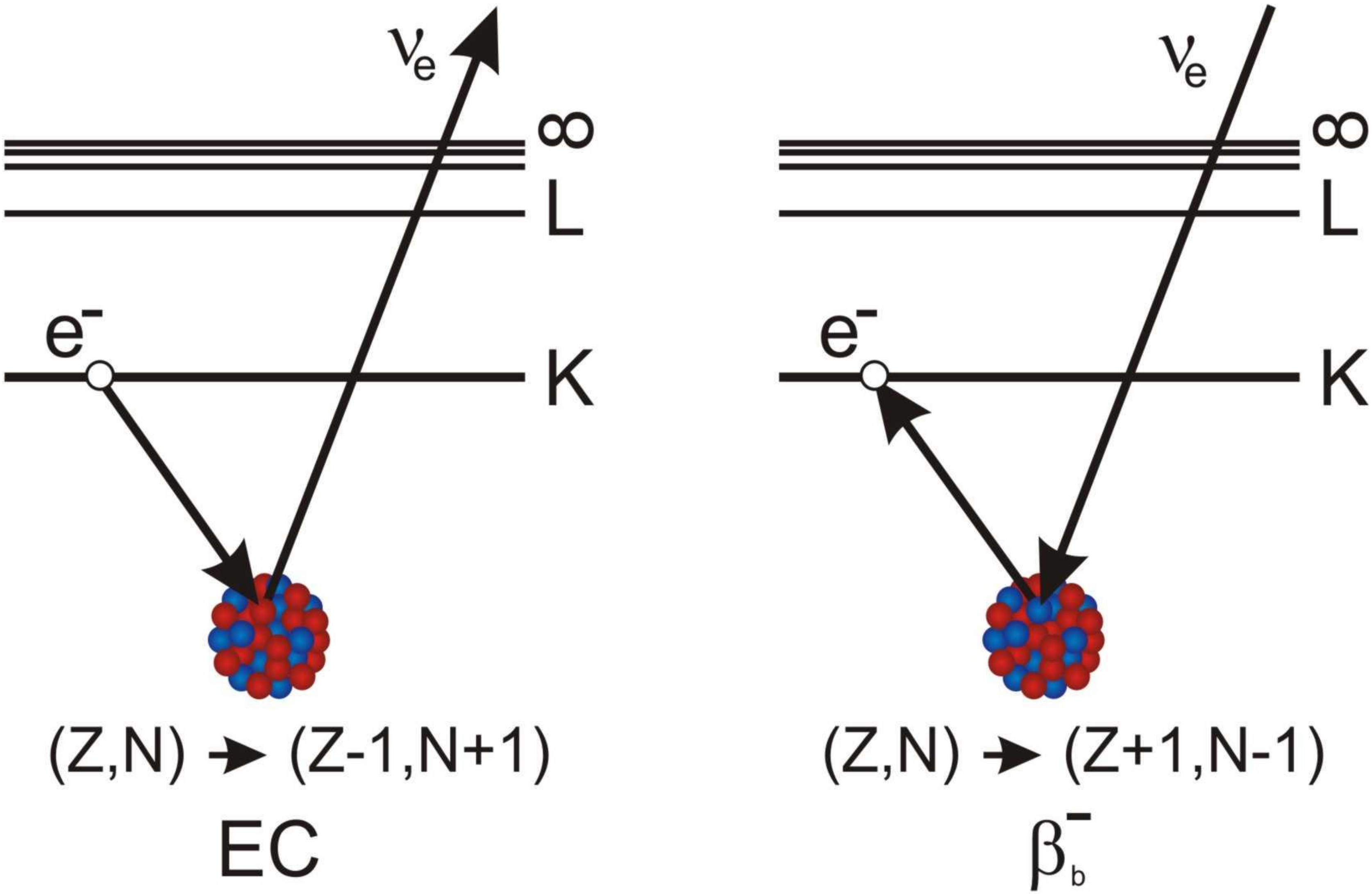
Two-Body Beta Decay



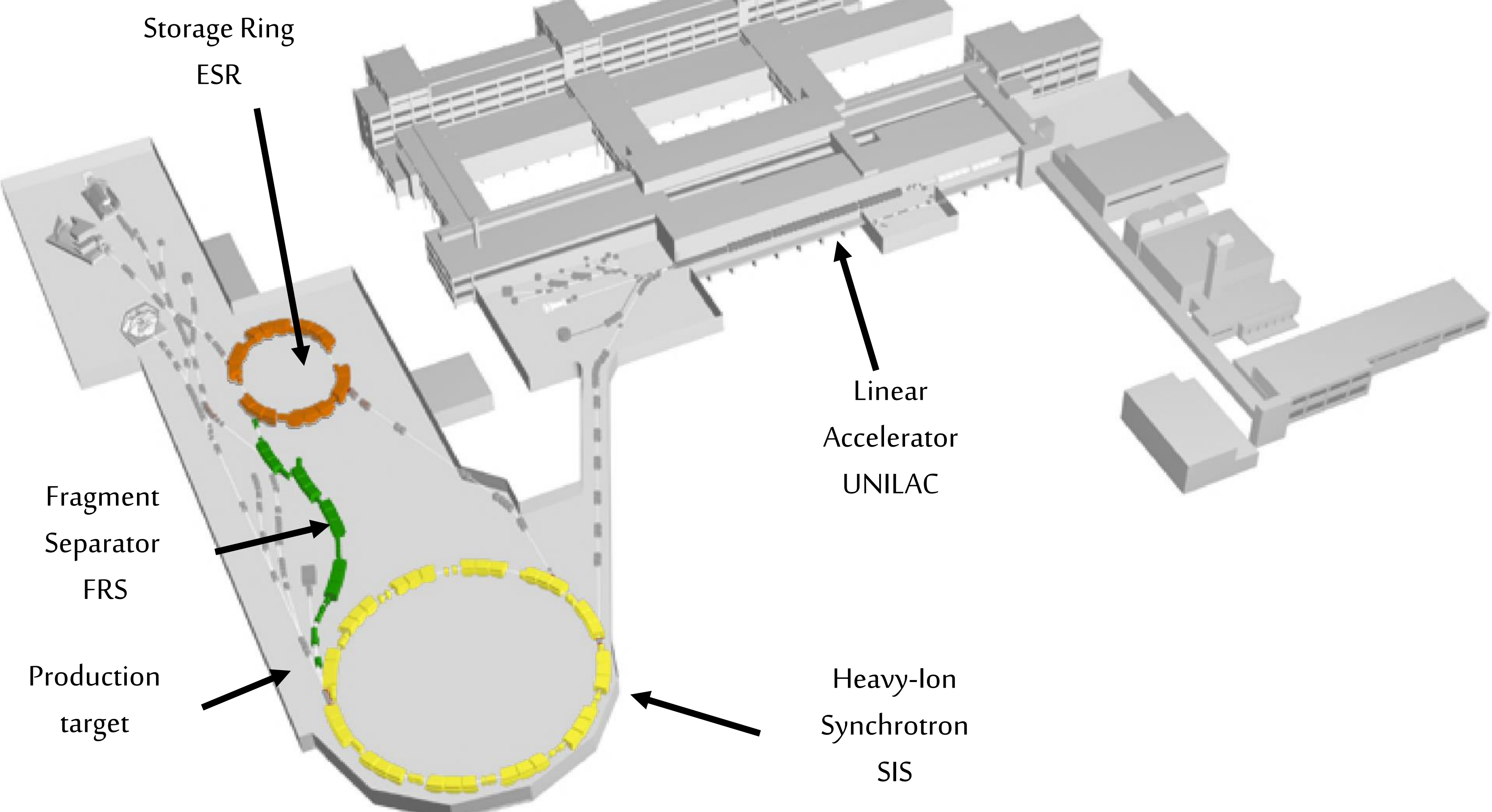
Exotic (radioactive) nuclides
in high atomic charge states
stored for an extended period of time

Radioactive ion beam facilities

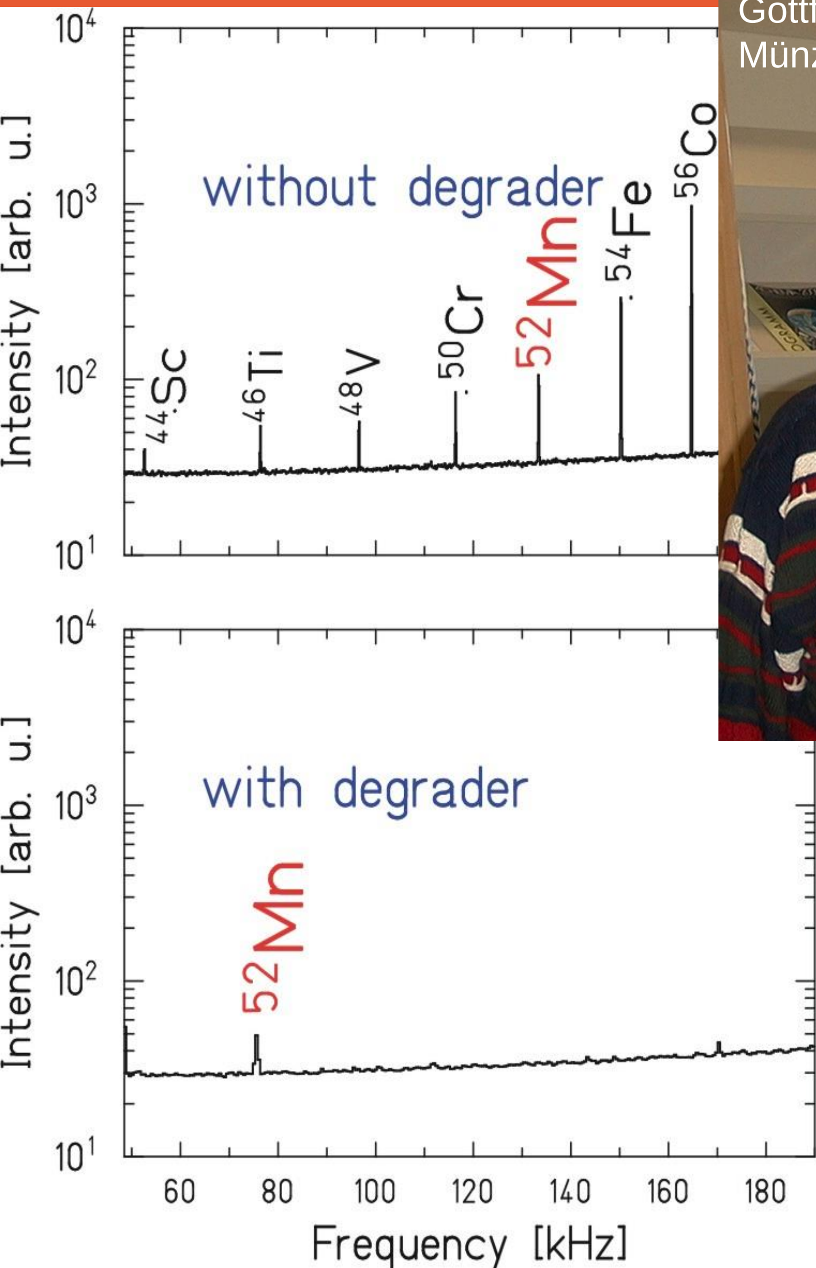
High kinetic energies

Ultra-high vacuum conditions

Production, storage and cooling of HCI at GSI



Production & Separation of Exotic Nuclides



Nuclear reactions in target → exotic nuclides

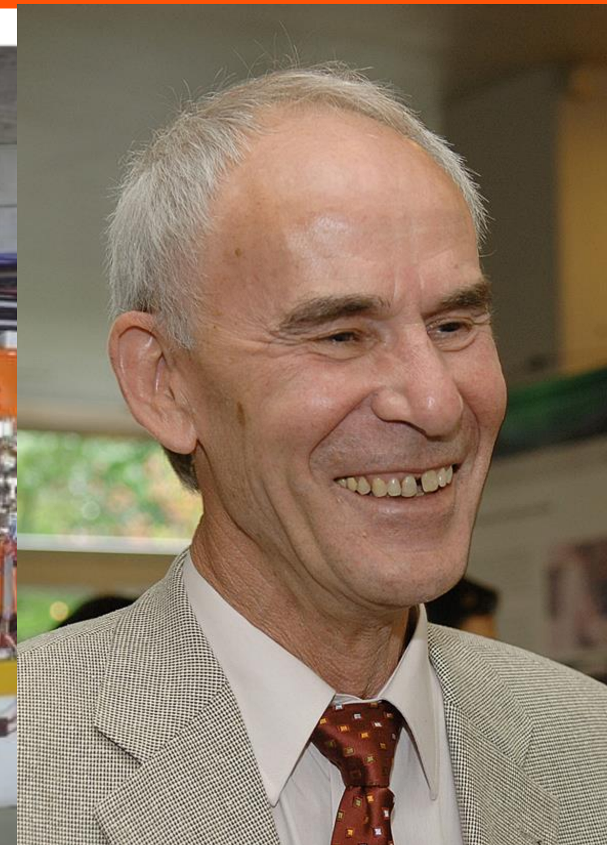
Separation in flight

Cocktail or monoisotopic beams

H. Geissel et al., Ann. Rev. Nucl. Part. Sci. **45** (1995) 163

The Physics of - and with - a High Energy Ion Storage Ring

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



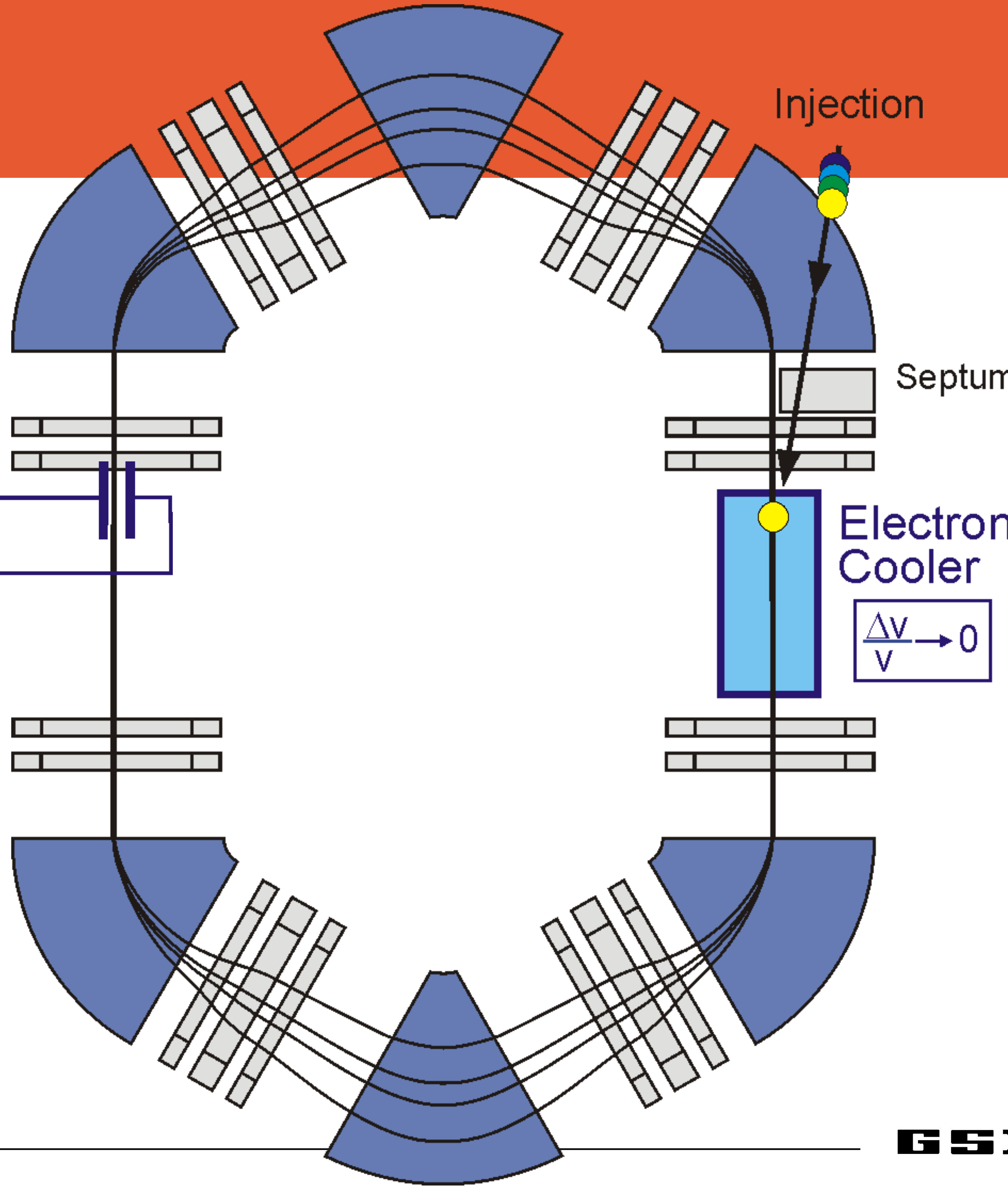
Bernhard Franzke

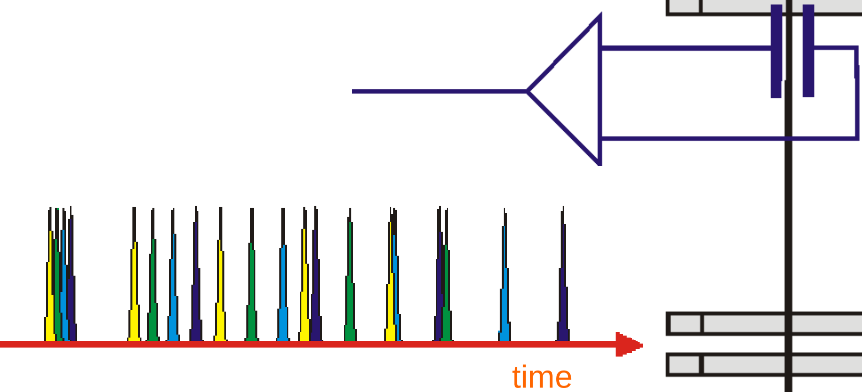
"Der GSI-Ring sollte der Erzeugung höchstmöglicher Phasenraumdichte von hochgeladenen schweren Ionen wie z.B. nacktem Uran und zur Speicherung, Akkumulation und Kühlung radioaktiver Strahlen dienen, der Präzisionsspektroskopie hochgeladener Ionen, der Untersuchung der Hyperfeinstruktur und der radioaktiven Zerfälle hochgeladener Ionen"

Paul Kienle

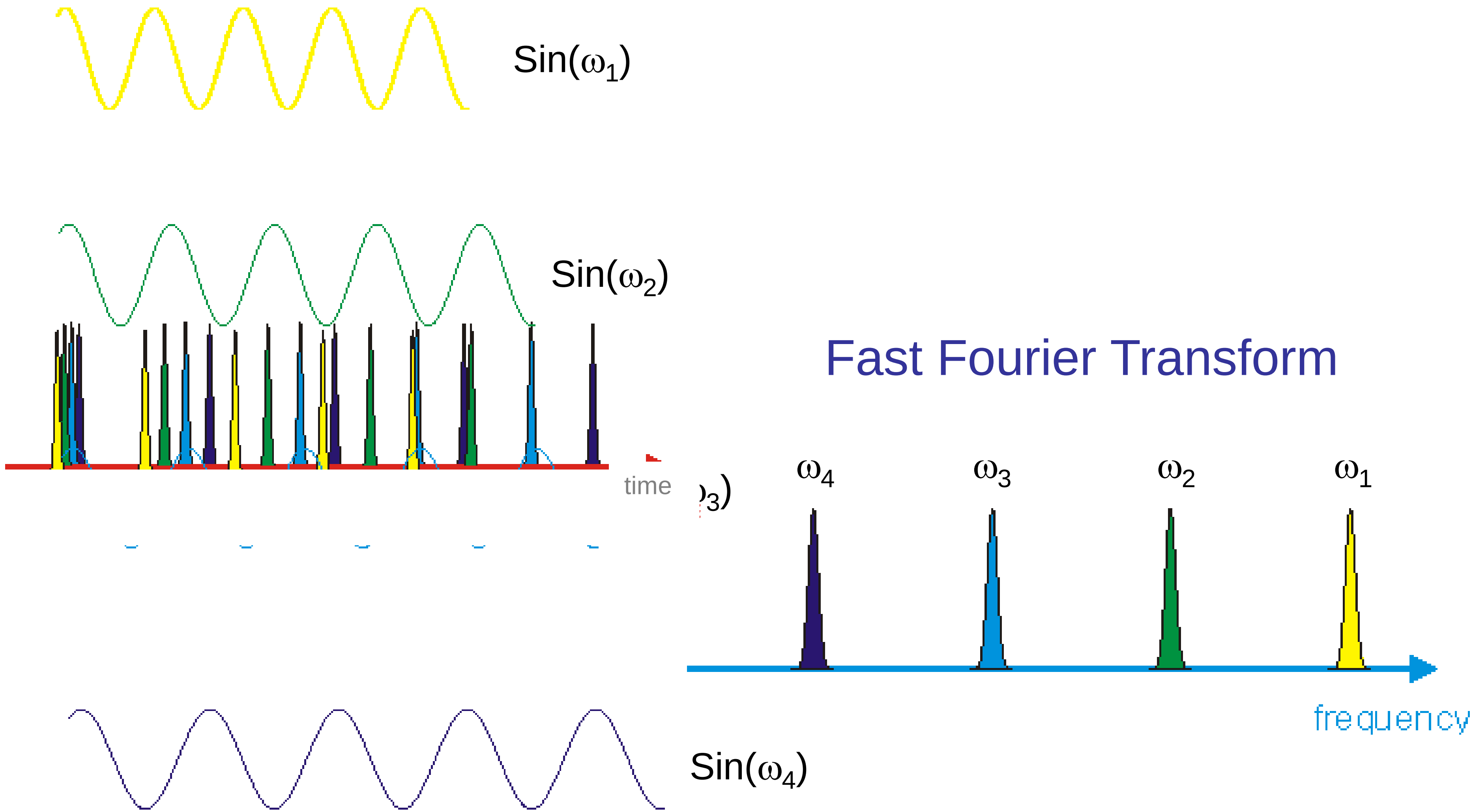
SMS

4 particles with
different m/q



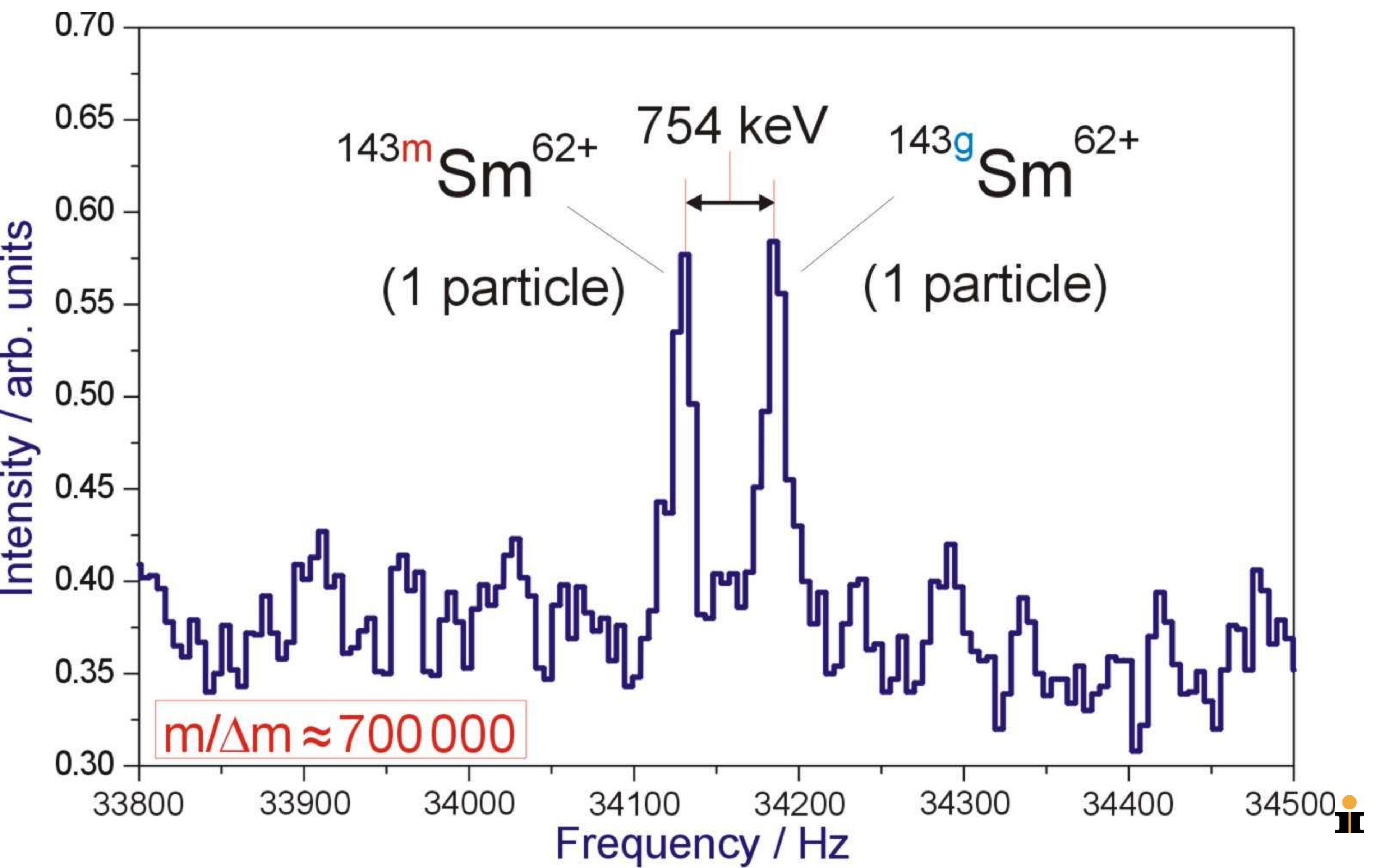


SMS



Sin(ω_1)
Sin(ω_2)
time
Fast Fourier Transform
ω_4
ω_3
ω_2
ω_1
frequency
Sin(ω_4)

SMS: Single-ion sensitivity



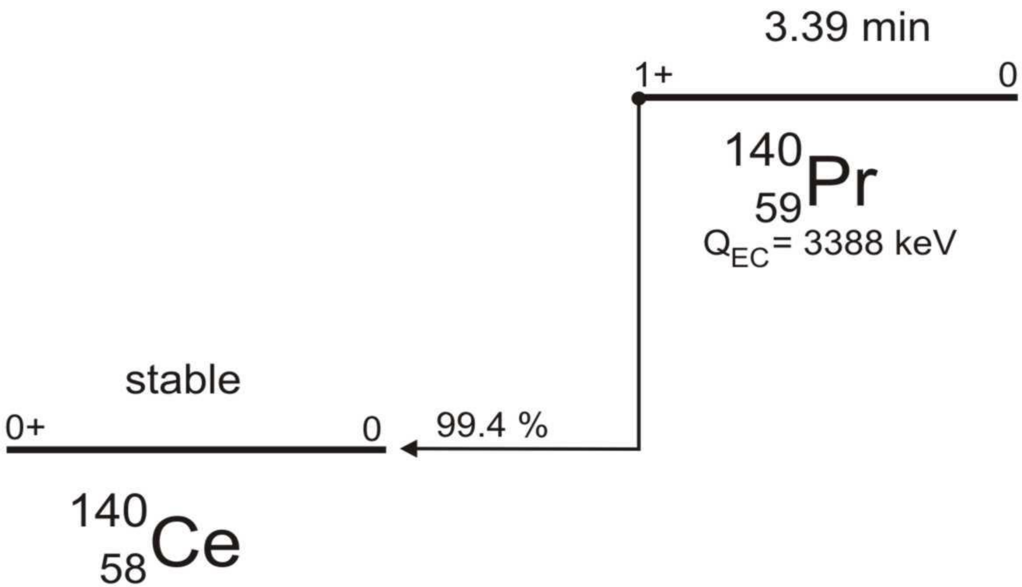
Two-body beta decay

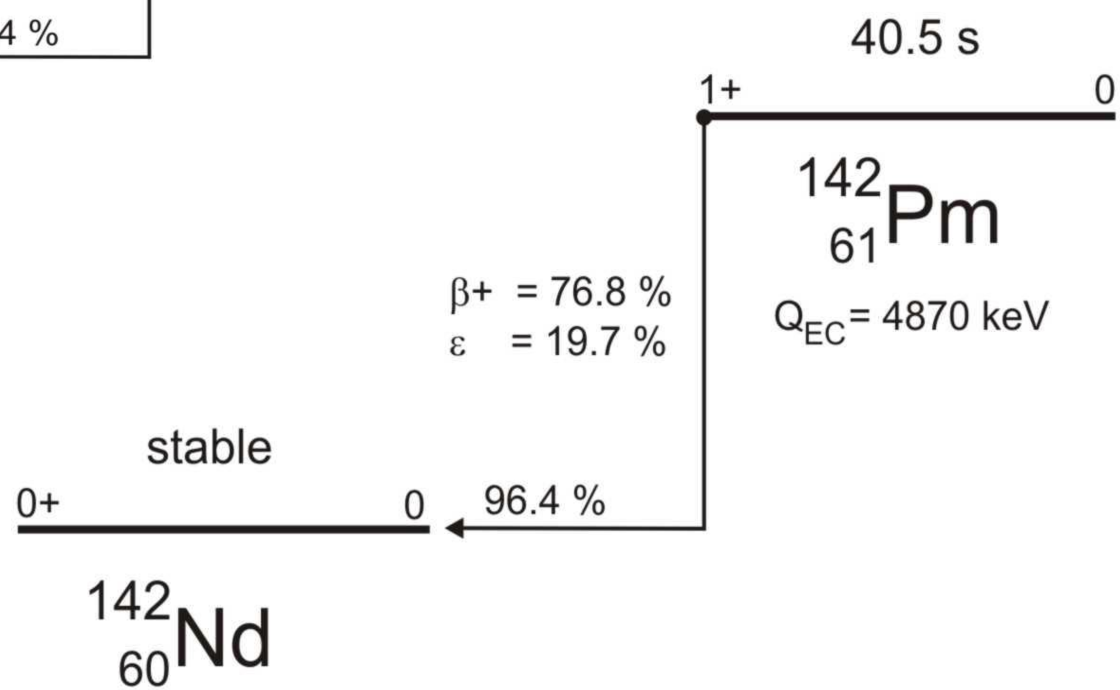
Gamow-Teller ($\Delta I = 1$) - Transition

$$\mathbf{p + e^-_b \rightarrow n + \nu_e}$$

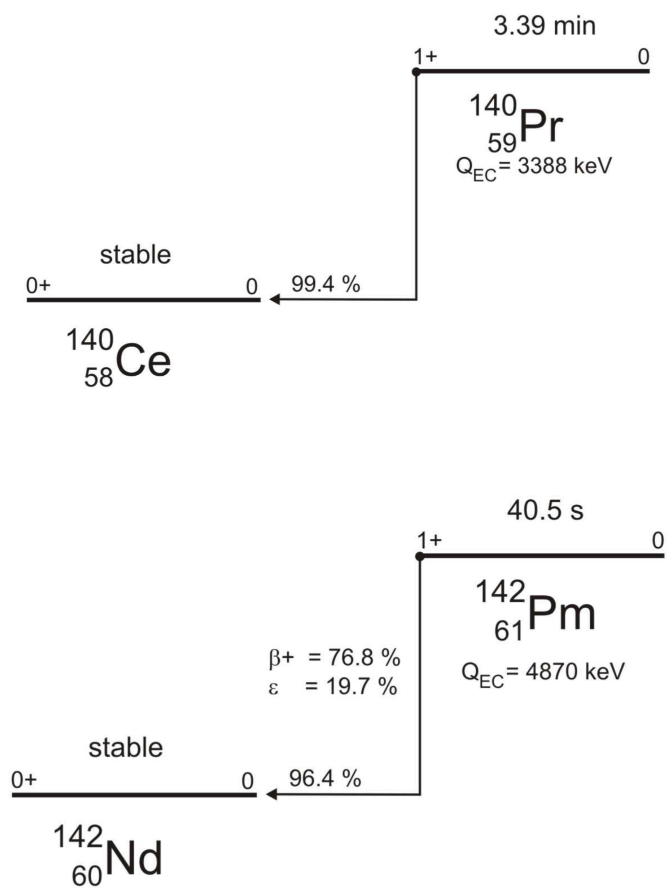
Final state EC: „mono-energetic“ electron-neutrino ν_e and daughter nucleus entangled via momentum conservation $\mathbf{p_t = p_{\nu e}}$ and energy conservation

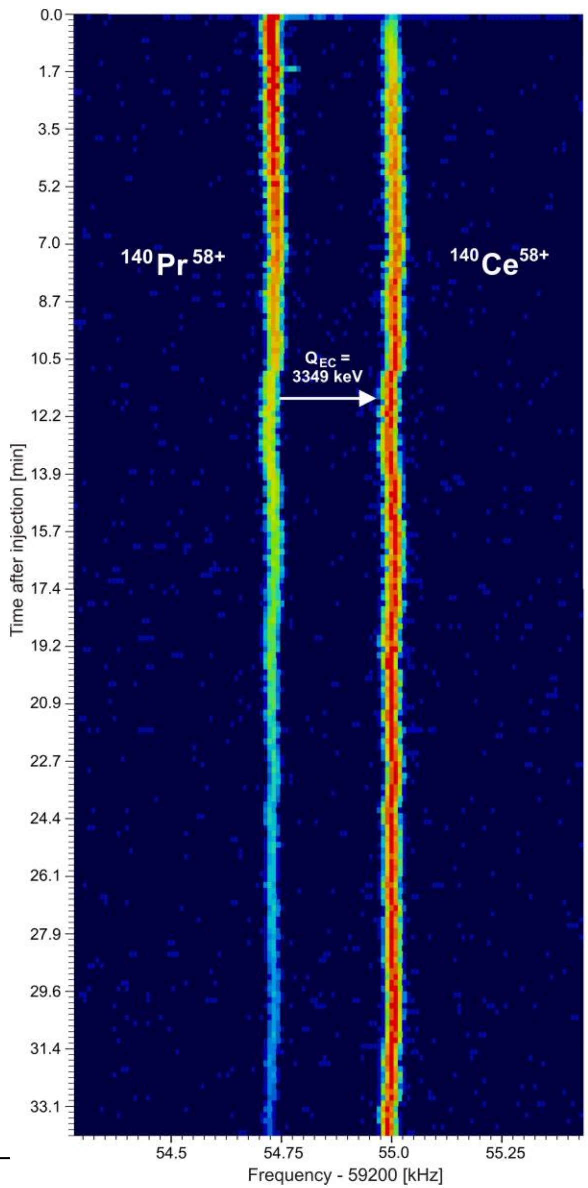
β^+: $e^+ + \nu_e$ continuous energy spectrum

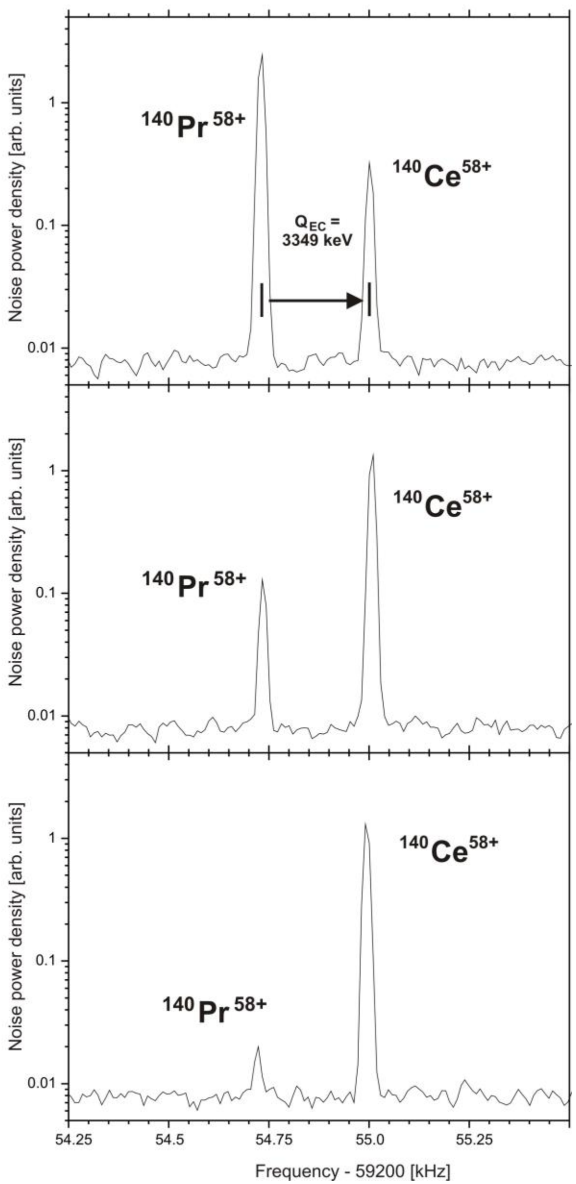




Orbital Electron Capture Decay of Few-Electron Ions







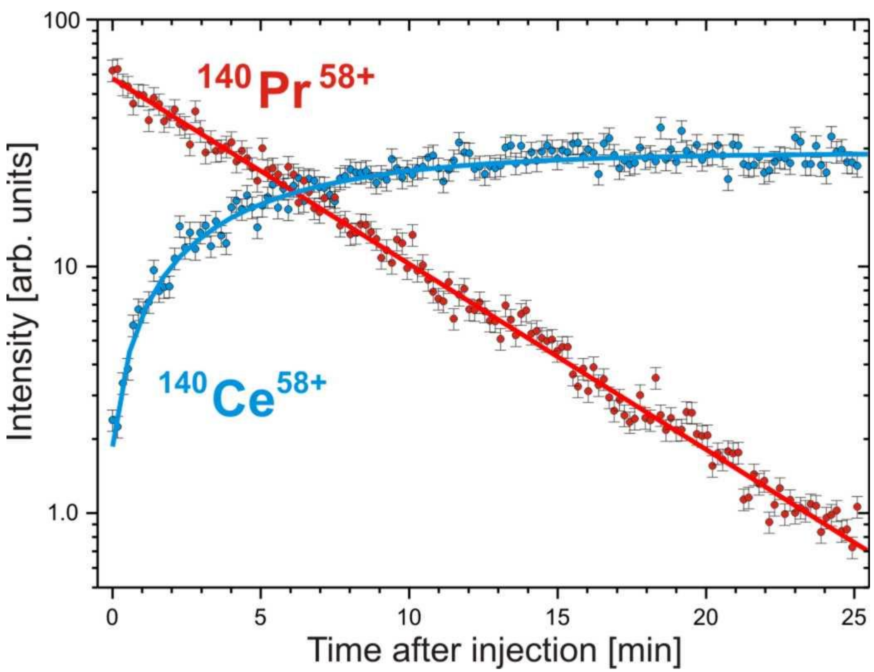
HELMHOLTZ GEMEINSCHAFT

Orbital Electron Capture Decay of Few-Electron Ions

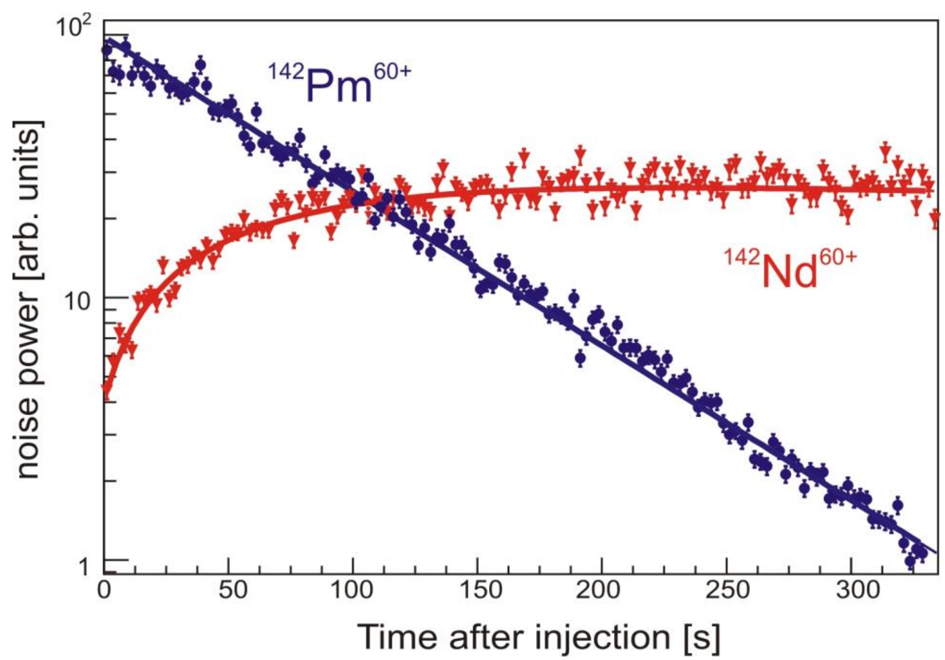
Expectations: $\lambda_{EC}(\text{H-like})/\lambda_{EC}(\text{He-like}) \approx 0.5$

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

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



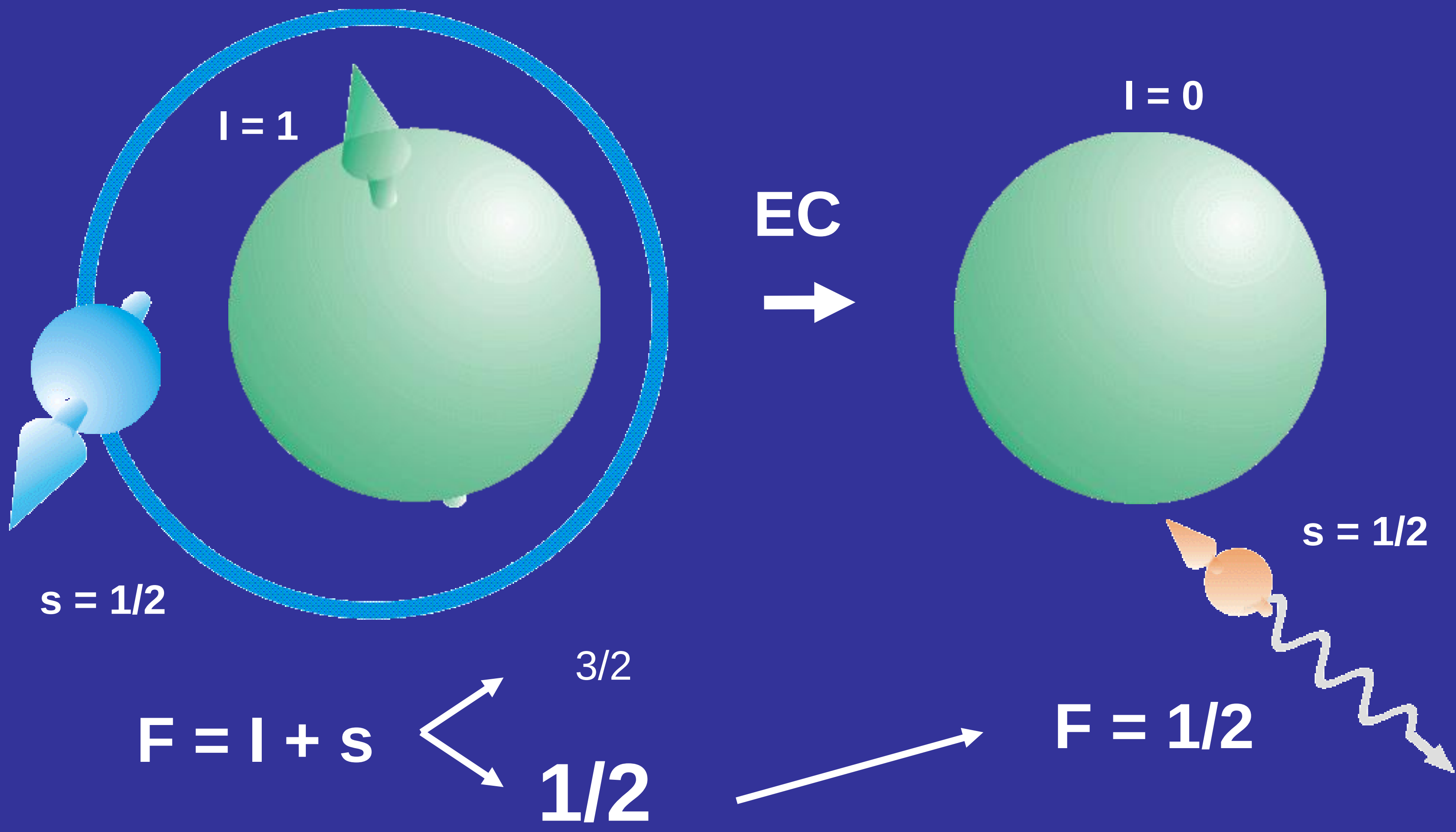
Yu.A. Litvinov et al., Phys. Rev. Lett. 99 (2007) 262501



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

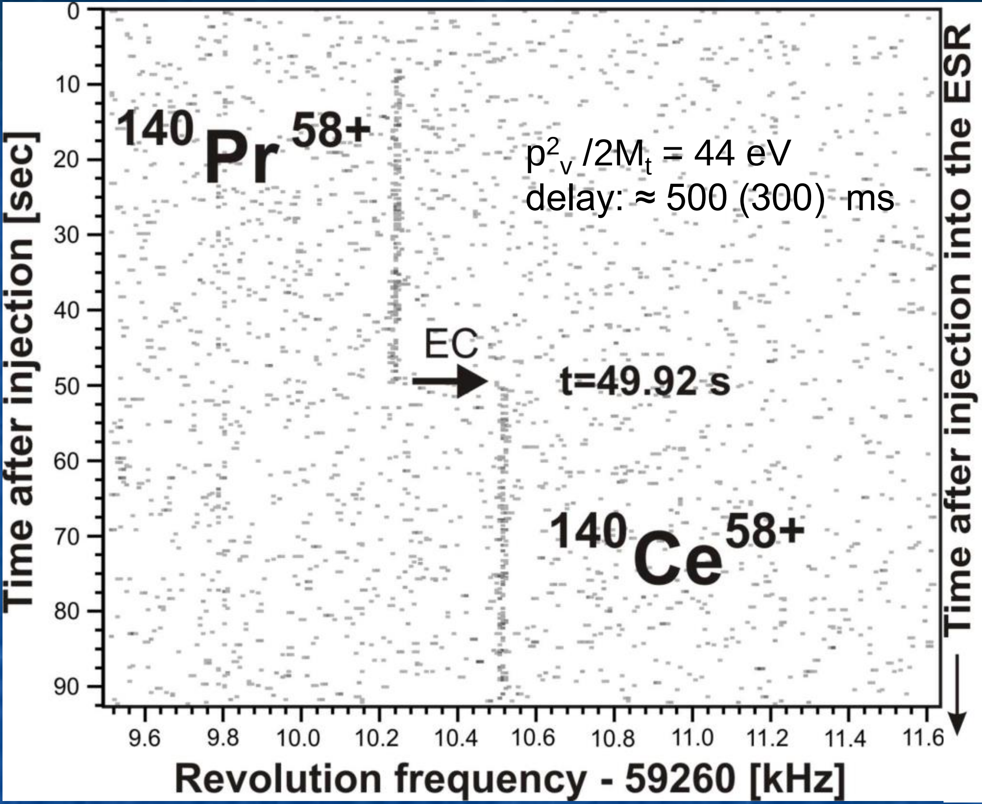
Electron Capture in Hydrogen-like Ions

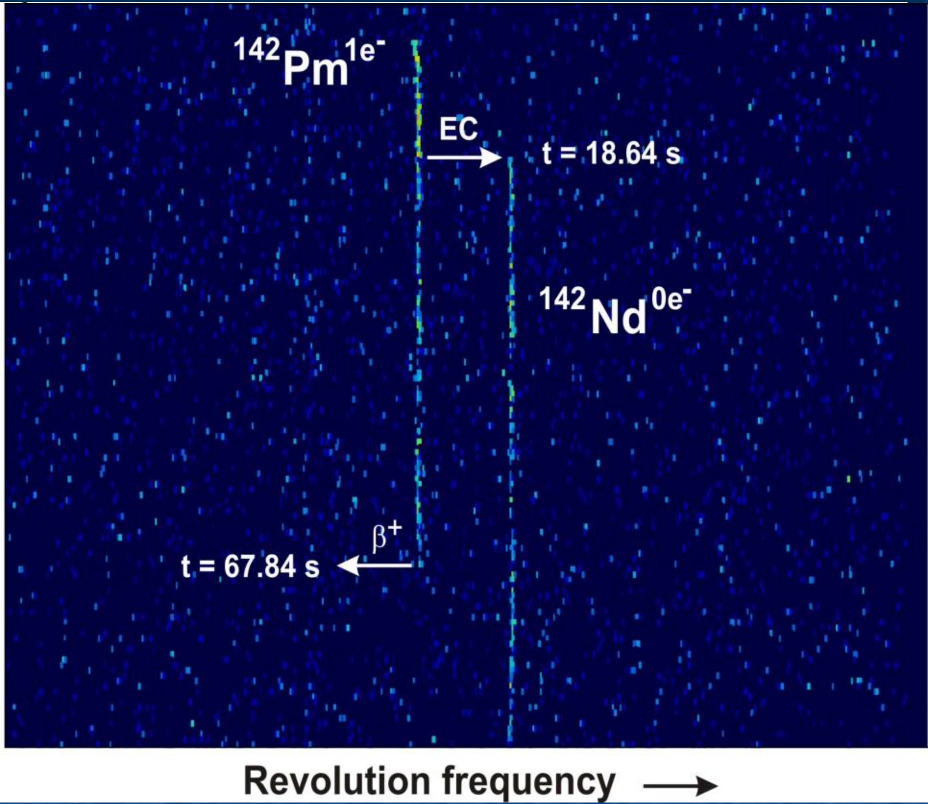
Gamow-Teller transition $1^+ \rightarrow 0^+$



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

Examples of Measured Time-Frequency Traces (2008)





From the observation of the decay we know:

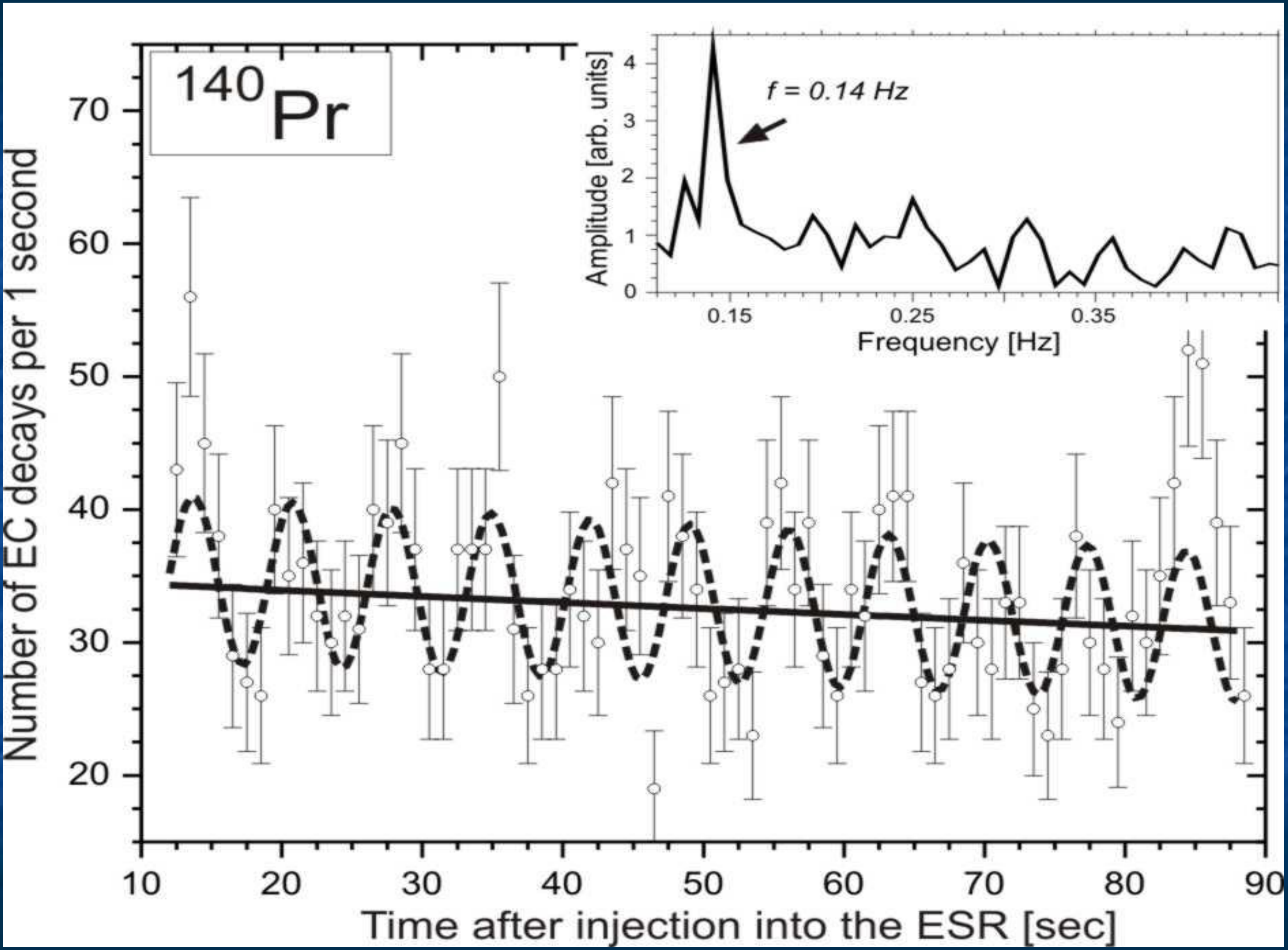
- p is transformed into n (hadron vertex)
- electron is absorbed (lepton vertex)
- electron neutrino $|\nu_e\rangle = a|\nu_1\rangle + b|\nu_2\rangle$ is emitted (if the lepton-number conservation holds)

Detection of ALL EC decays

Delay between decay and "appearance" due to cooling

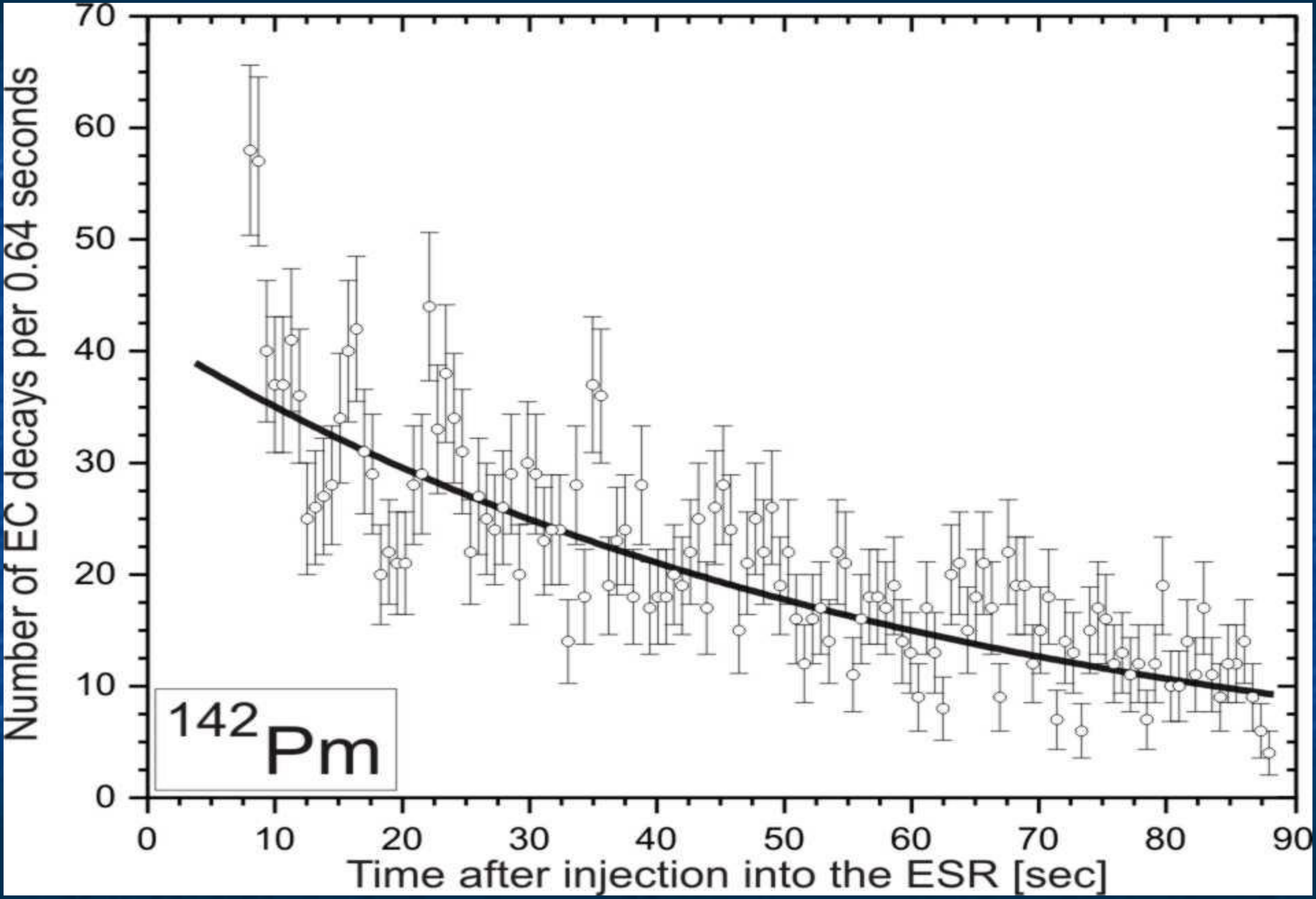
No third particle involved

^{140}Pr : 2650 EC decays from 7102 injections (2008)



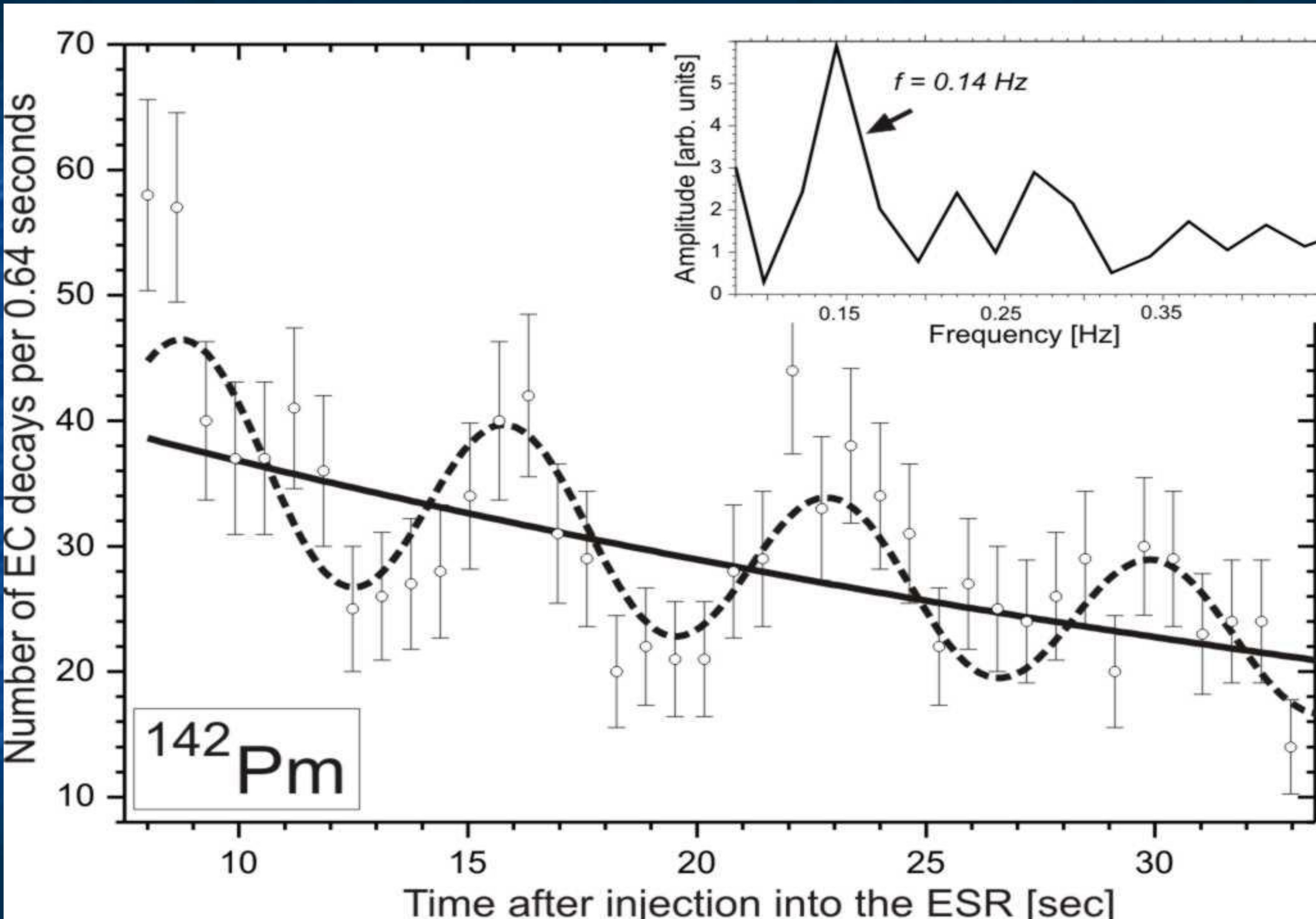
Yu.A. Litvinov et al., PL B 664 (2008) 162

^{142}Pm: 2740 EC decays from 7011 injections (2008)



Yu.A. Litvinov et al., PL B 664 (2008) 162

^{142}Pm: zoom on the first 33 s after injection (2008)



Yu.A. Litvinov et al., PL B 664 (2008) 162

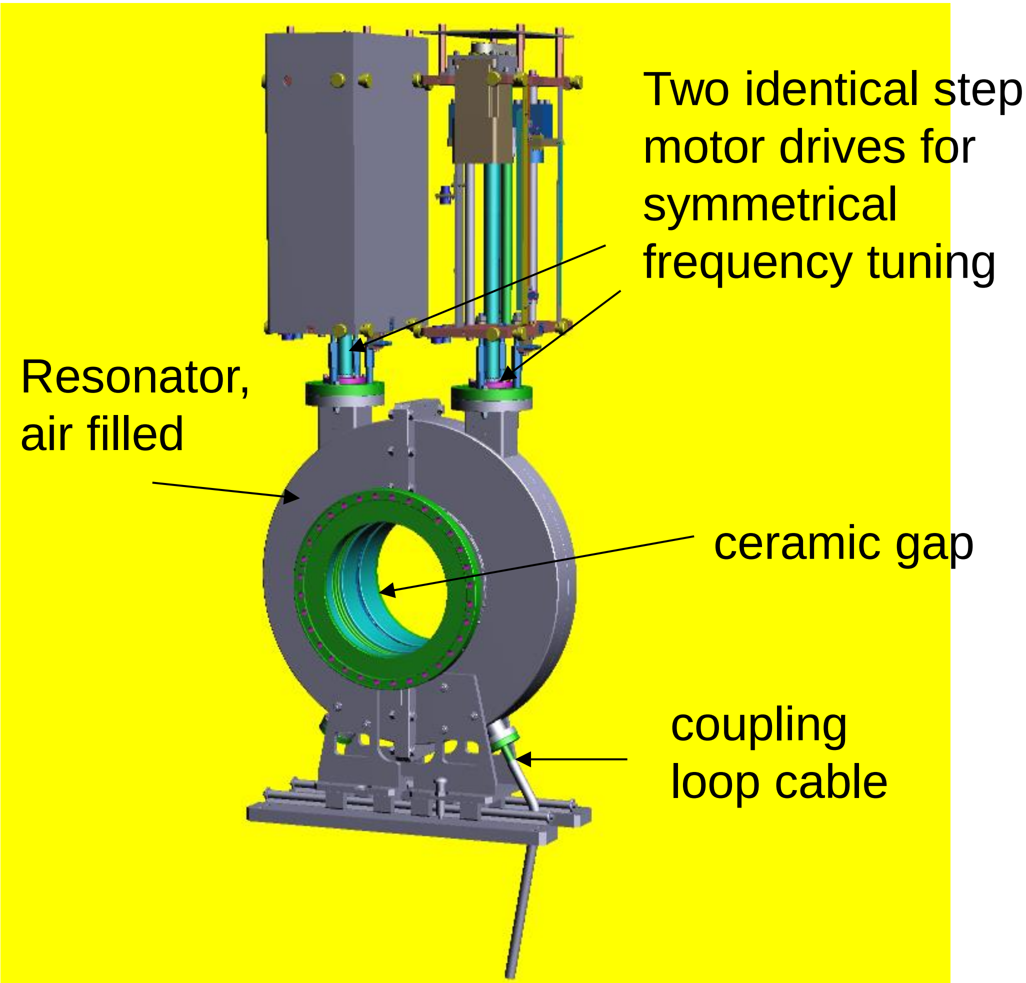
Synopsis (^{140}Pr & ^{142}Pm) (2008)

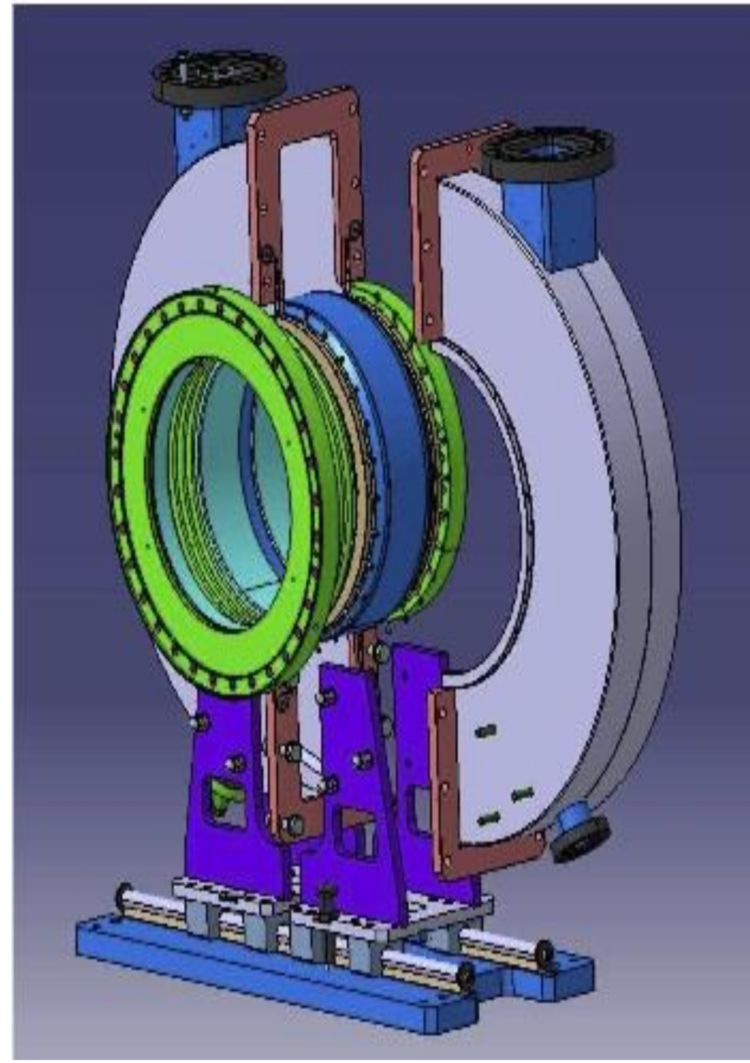
mass	ω(1/s)	Period (s)	Amplitude	φ(rad)
140	0.890(10)	7.06(8)	0.18(3)	0.4(4)
142	0.885(27)	7.10(22)	0.23(4)	- 1.6(4)

Are the modulations real or an artifact?

Yu.A. Litvinov et al., PL B 664 (2008) 162

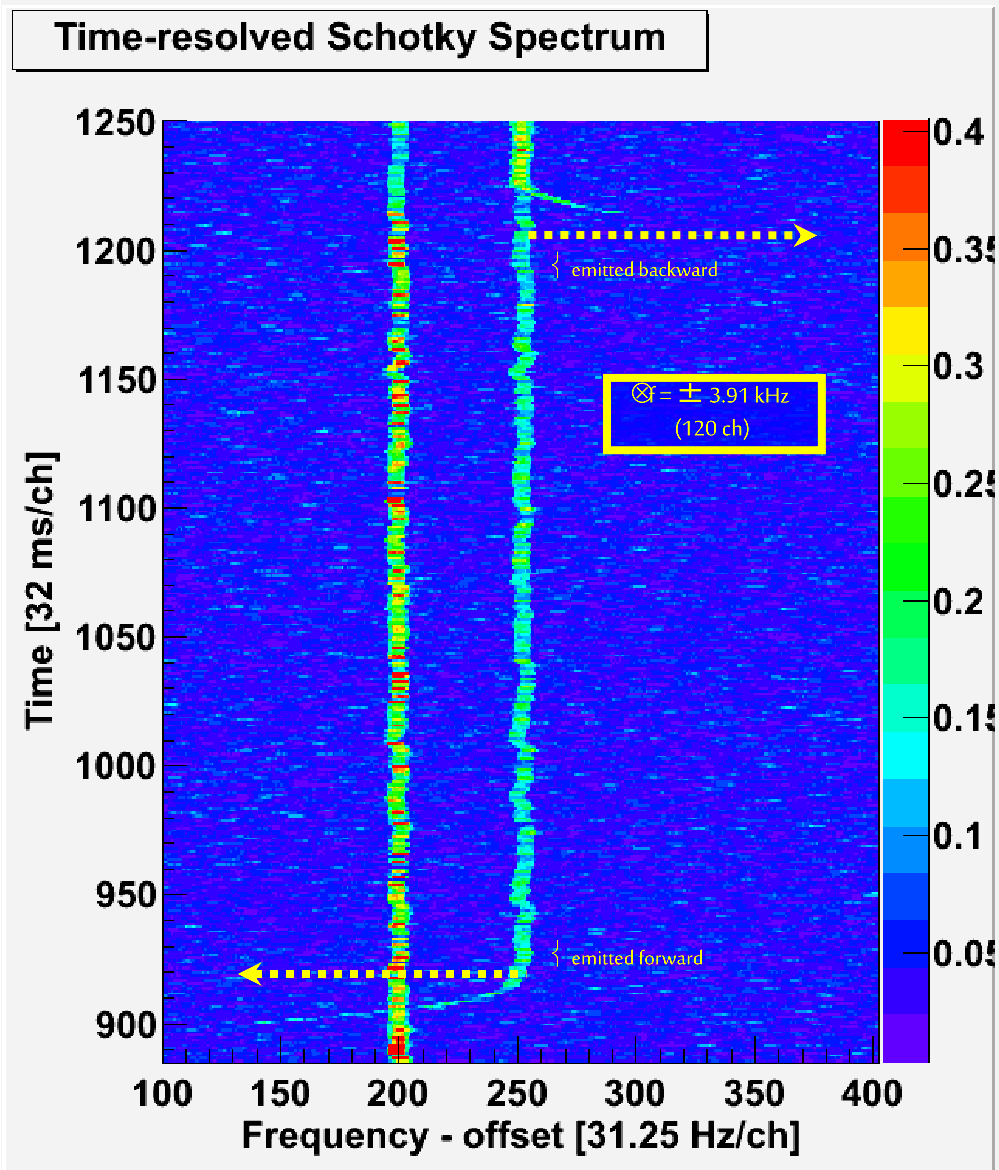
New Resonant Schottky Cavity

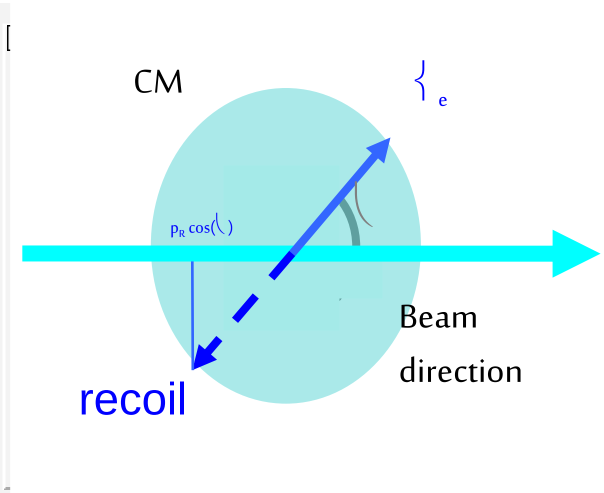


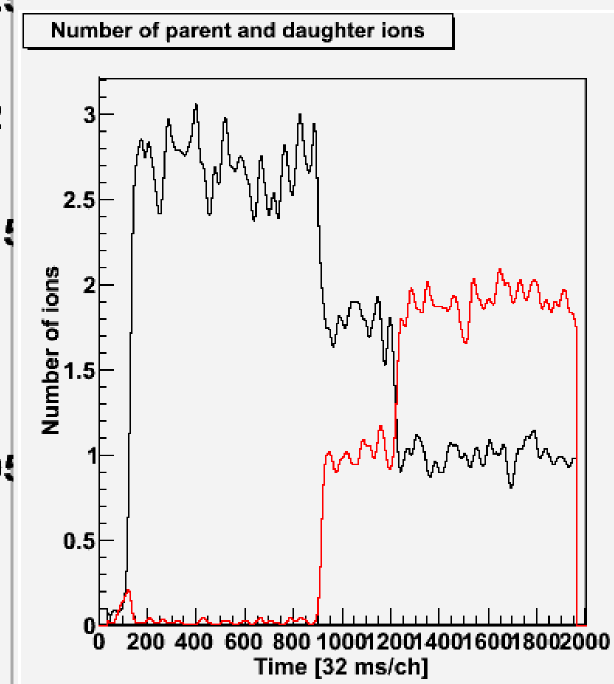


F. Nolden et a., Nucl. Instr. Meth. A659 (2011) 69--77

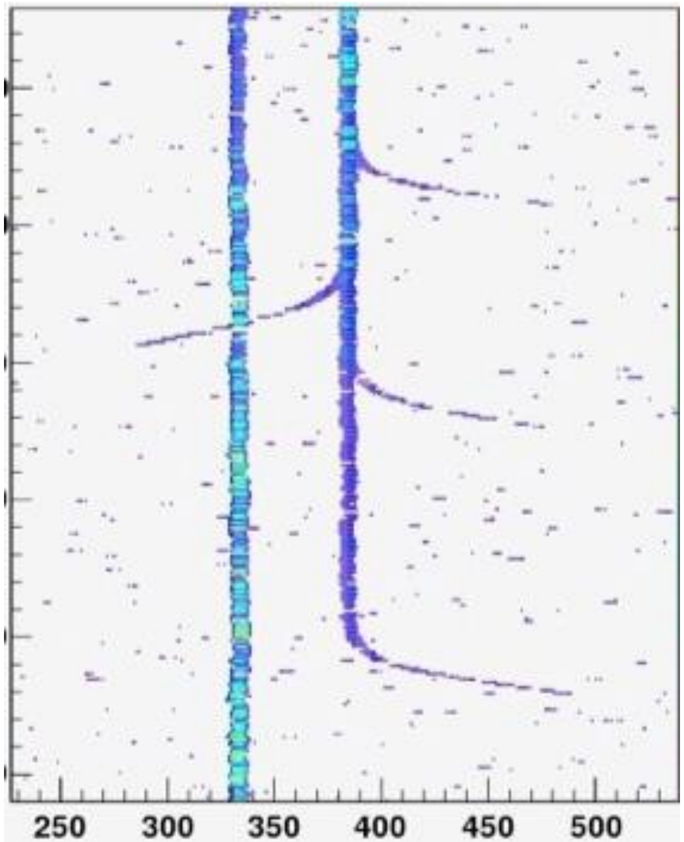
Three Parent He-Like ^{142}Pm Ions

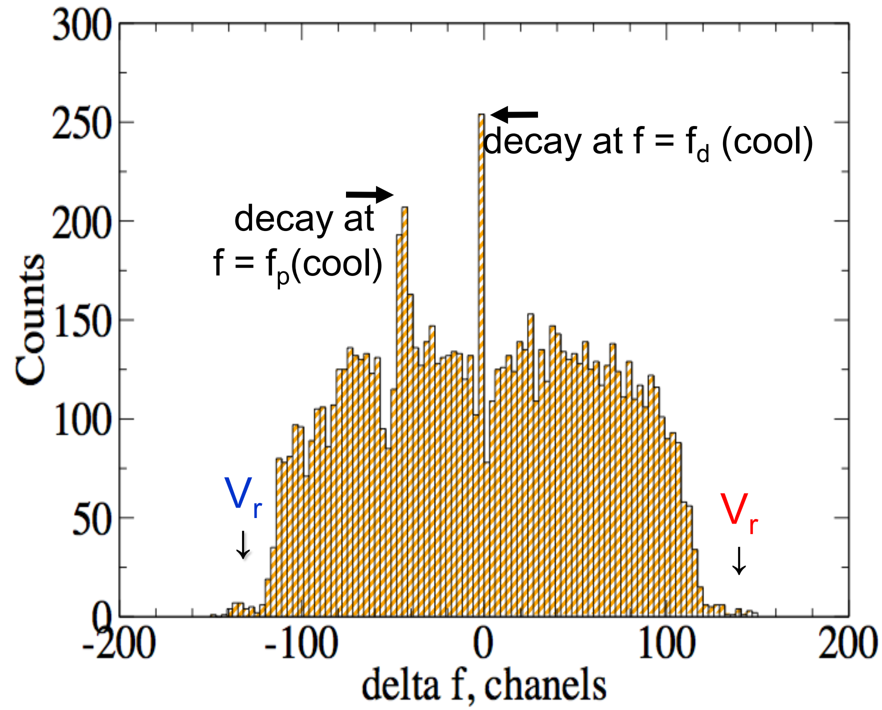






Revolution-frequency difference δf of the recoils just after decay: $\delta f = f_{dec} - f_{cool}$





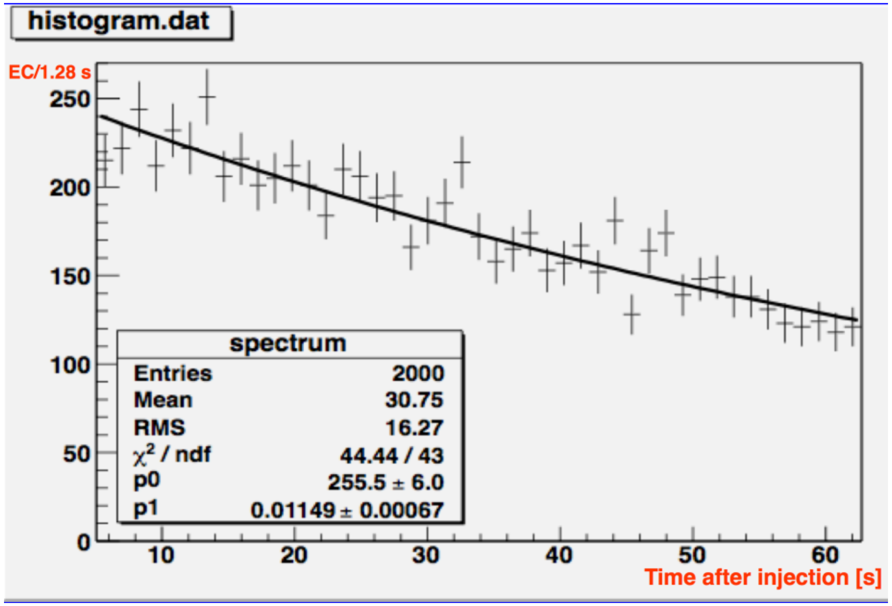
For a (longitudinally) unpolarized beam the distribution should have a rectangular shape

For a (steadily controlled) polarized beam the distribution would provide the helicity of the neutrino

From v_r and m_r one gets the momentum of the (monochromatic) neutrino: $(pc)_d = m_d cv_d = (pc)_\nu$

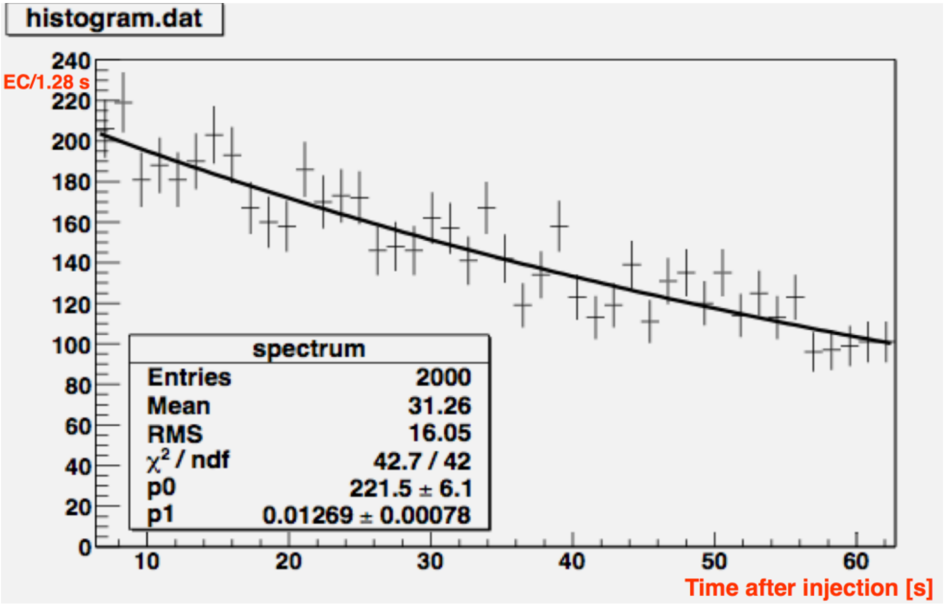
From m_p and m_d one gets its energy: $E_\nu = (m_p - m_d) c^2$ and then $\beta_\nu = E_\nu / (pc)_\nu$

Full statistics for H-like ^{142}Pm ions (9300 EC decays)



Older Schottky pick-up

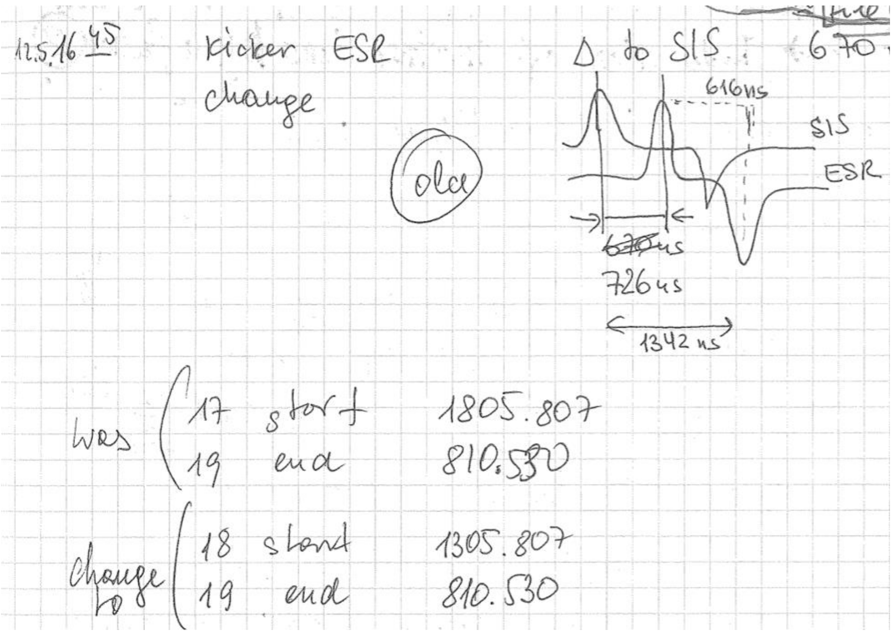
New Schottky pick-up

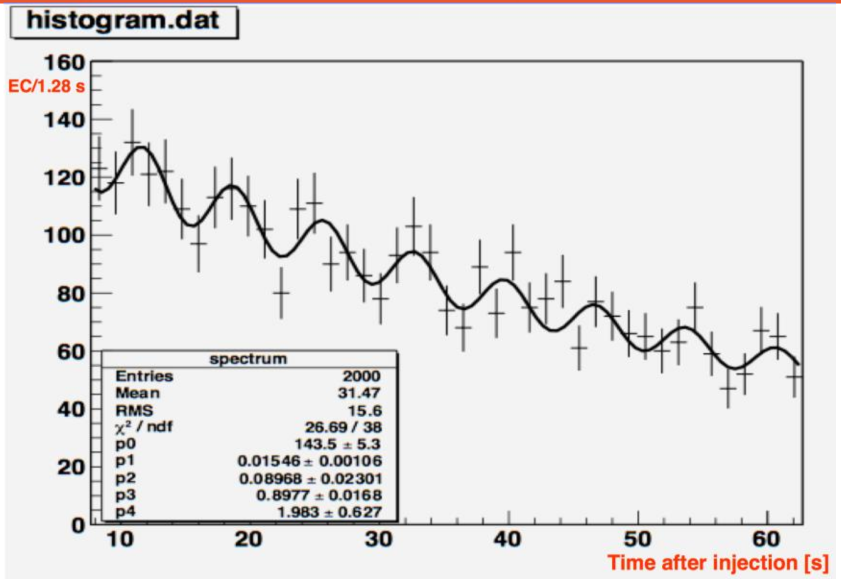


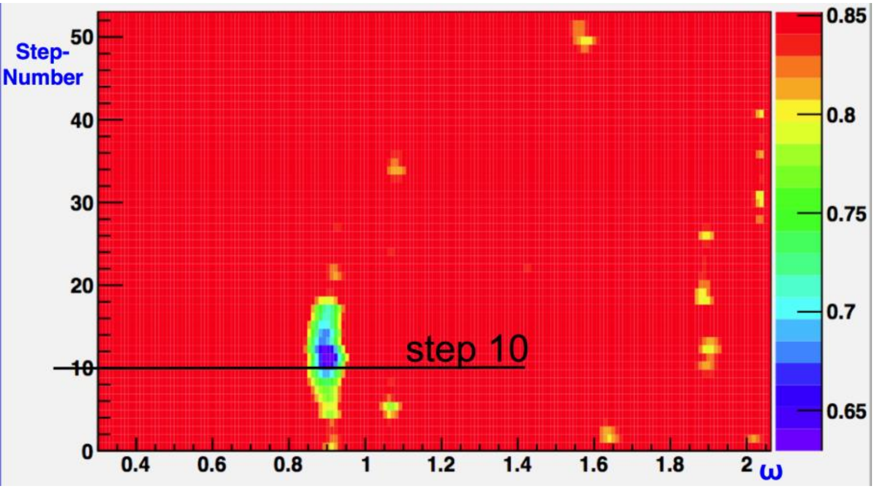
If the modulations are real - what could wash them out?

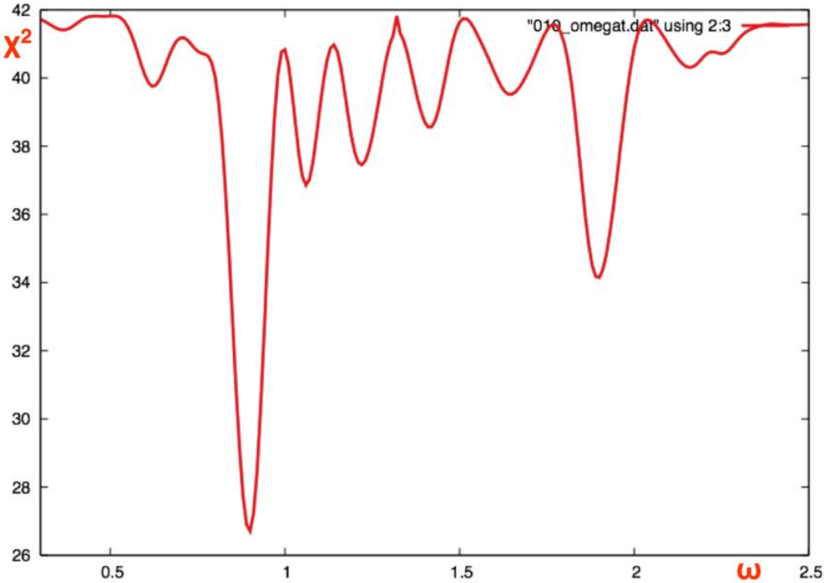
If the stored parent ions are **not** removed after a record of 64 s, The time $\mathbf{t_0}$ of generation of the parent ion is **not anymore well-defined.**

Testing the "kicker" hypothesis

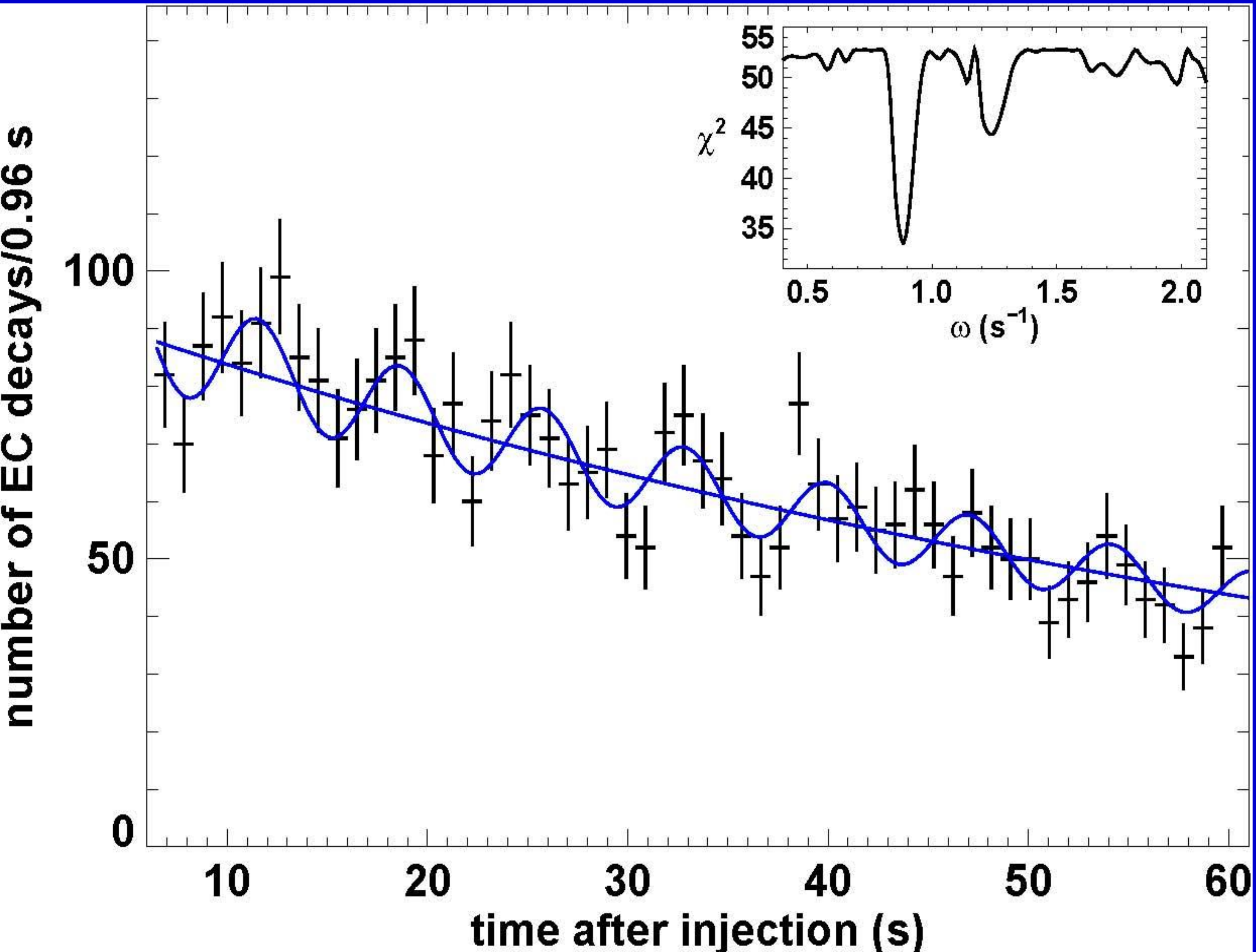




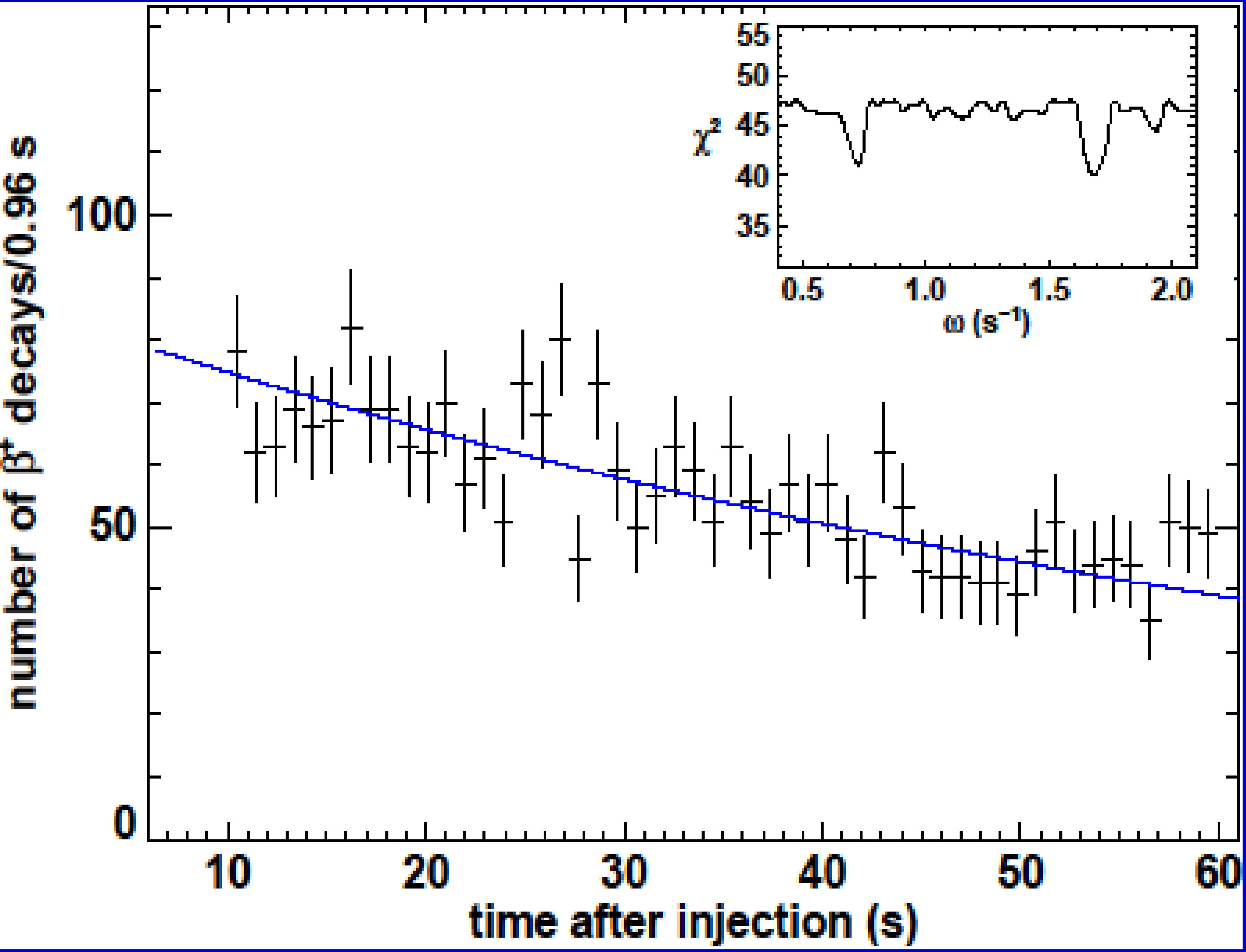




245 MHz Resonator: $\omega = 2\pi/T = 0.884(14)$/s, **T = 7.11(11) s**, a = 0.107(24)



245 MHz Resonator: bei ω = 0,907/s a = 0,03(3), **no** significant modulations



Summary

- New data measured with the capacitive and resonant detectors are consistent within 1 sigma.
- Measured period is <T>=7.11(11) s is consistent with the published in 2008 value of 7.10(25) s
- Amplitude <a>=0.12(2) is 2.8 sigma smaller than the 2008 value of 0.23(4)
- Data on continuum beta decay show for 6.56 s < T < 7.66 s (5 sigma) no modulations

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Physics Letters B

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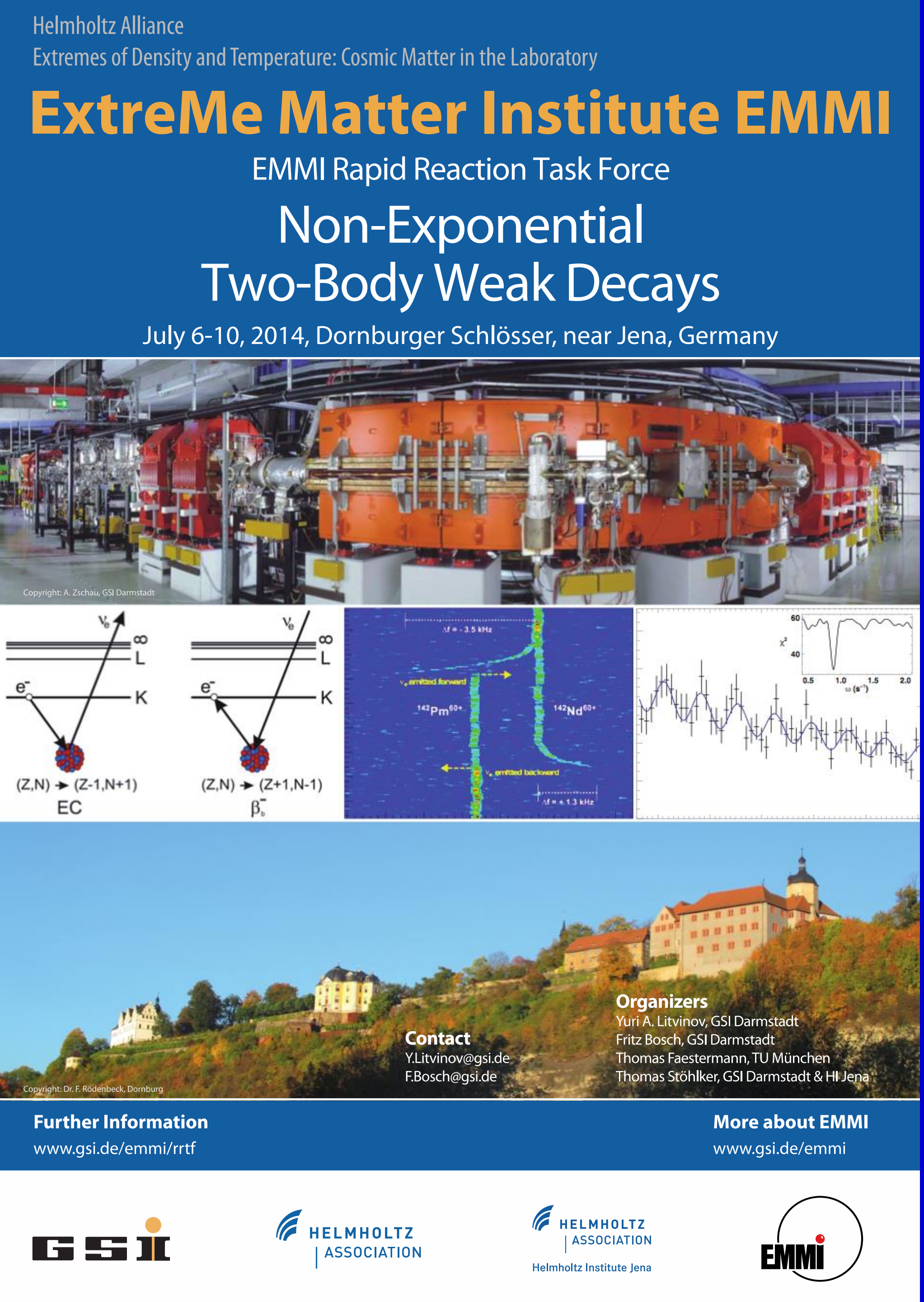
High-resolution measurement of the time-modulated orbital electron capture and of the β^+ decay of hydrogen-like $^{142}Pm^{60+}$ ions

Two-Body-Weak-Decays Collaboration

P. Kienle[a, 1], F. Bosch[b], P. Bühler[c], T. Faestermann[a], Yu.A. Litvinov[b, d, e], N.



Recommendation:

-- repeat experiment at GSI with highest priority with the same experimental conditions

(scheduled for 09-10.2014)

-- change the magnetic field/velocity of the stored beam

(probes atomic physics related effects)

-- measurements without e-cooler

-- measurements of beta-decay mode

-- measurements of different A-nuclei

Paul Kienle
1931-2013

In Memoriam

Our friend and colleague, Paul Kienle, passed away on January 29, 2013.

Besides many other outstanding achievements we owe him the construction and the successful operation of both, the fragment separator FRS and the storage ring ESR, for more than 20 years now!