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Workshop Towards Neutrino Technologies

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The GSI anomaly

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The GSI Anomaly

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Based on collaboration with: H. Kienert, J. Kopp and A. Merle
+ close contact with experiment

Workshop Towards Neutrino Technologies
International Center for Theoretical Physics
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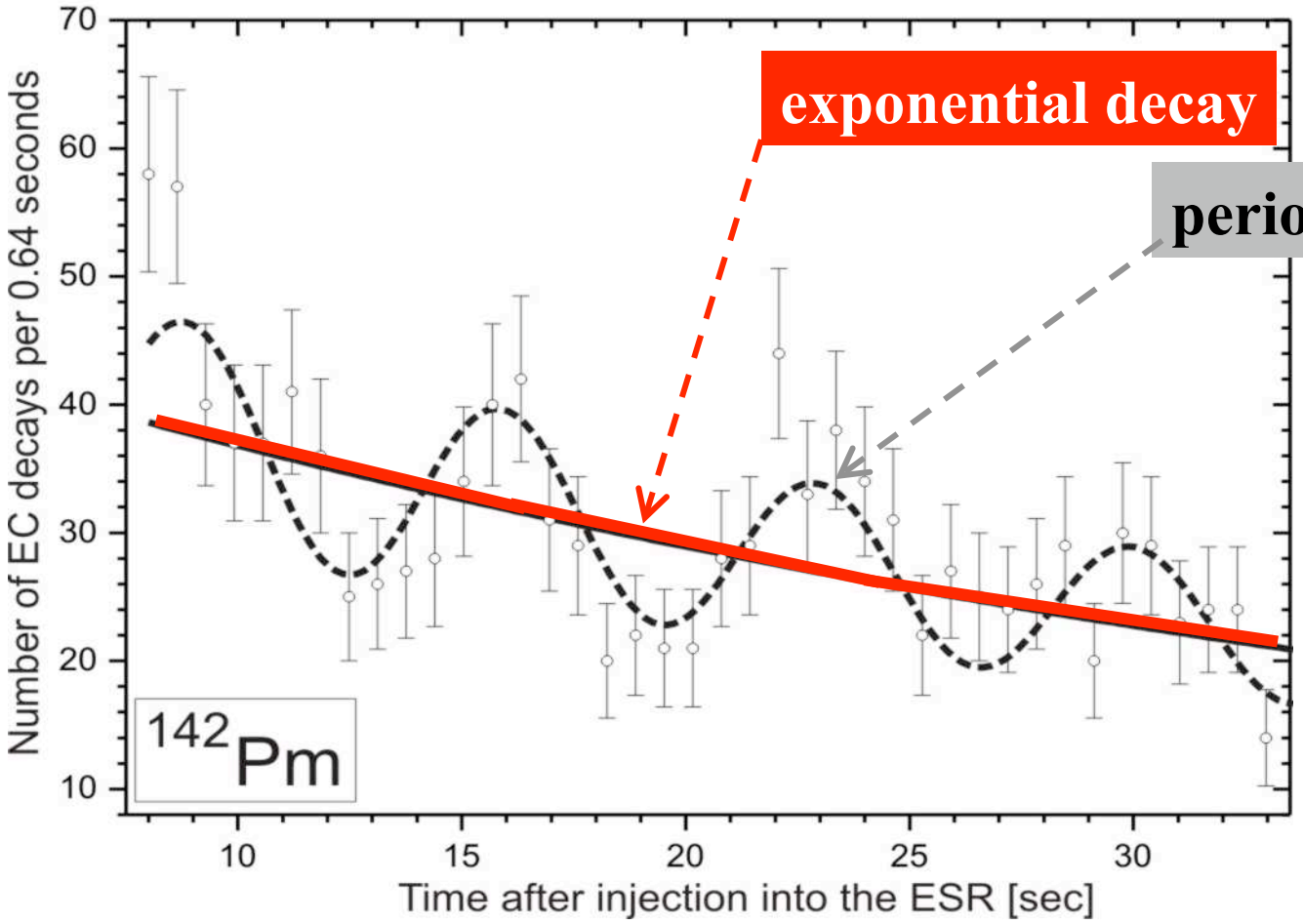
What is the GSI Anomaly?

➔**Periodically modualted exponential β-decay law**

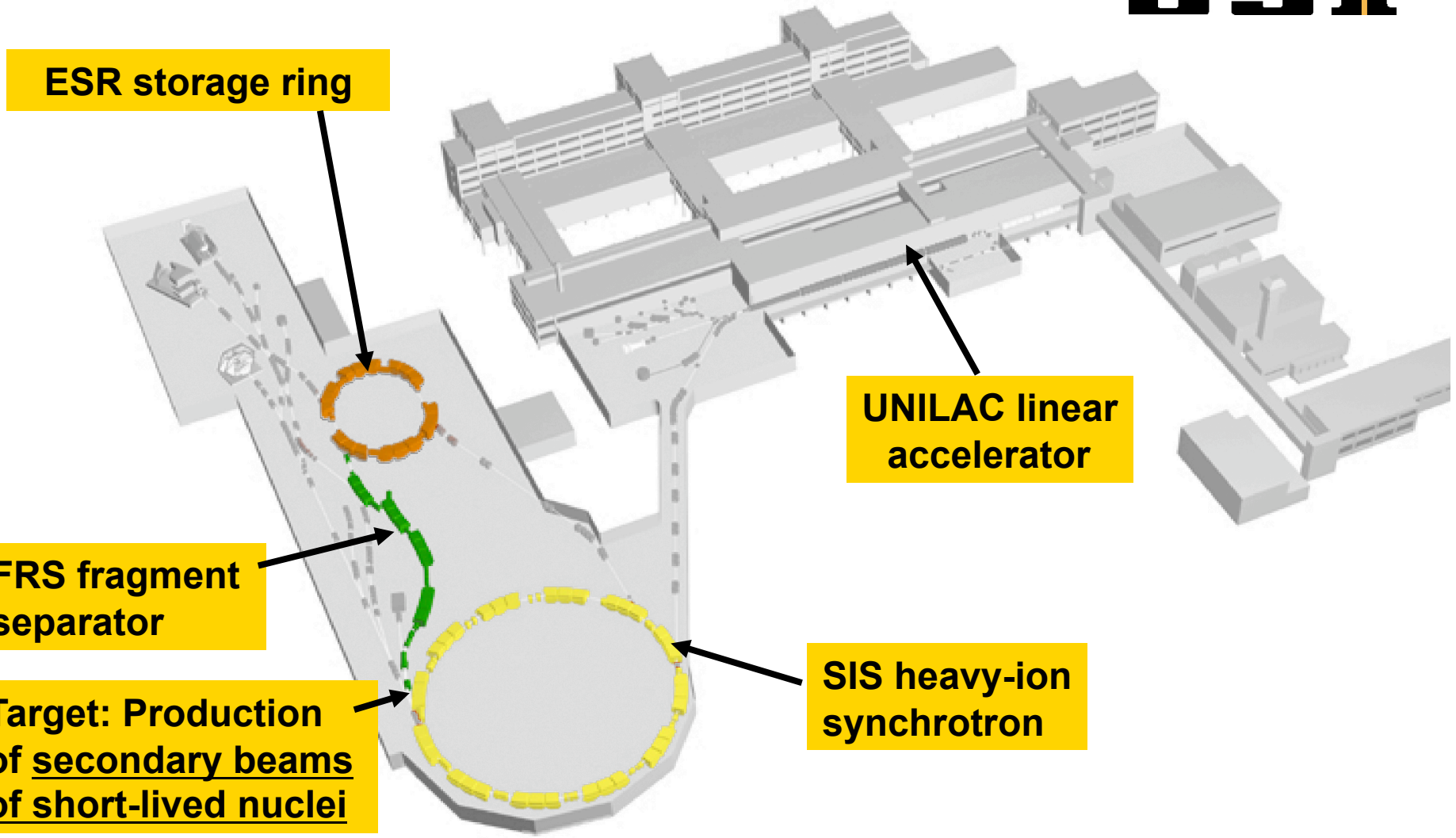
of highly charged, stored ions at GSI by the FRS/ESR Collaboration



Outline:

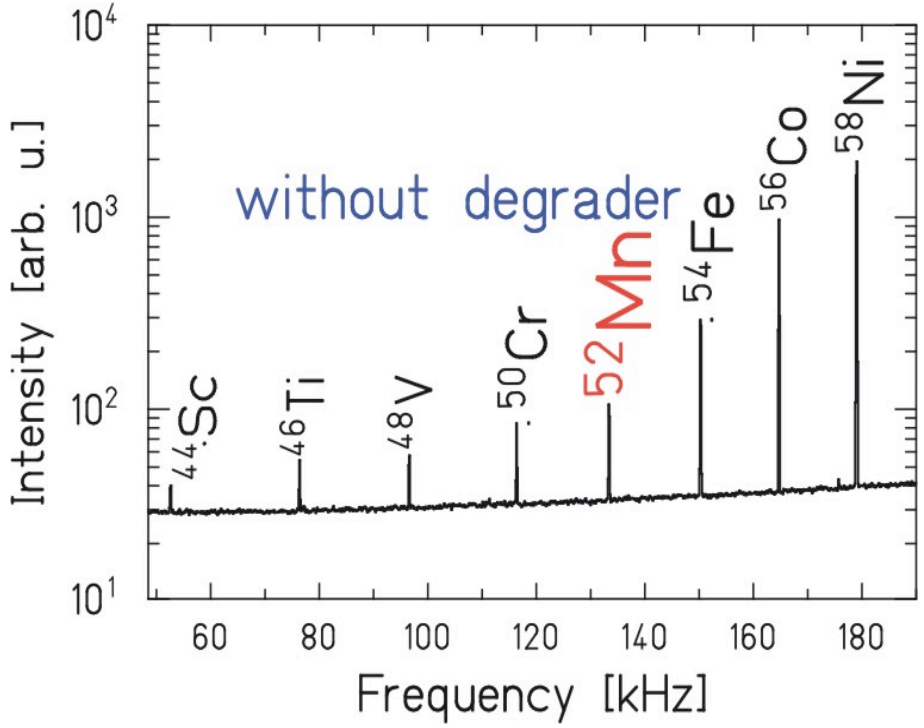
- **Is there an effect?**
- **The observation**
- **Explanations**
- **Conclusions**

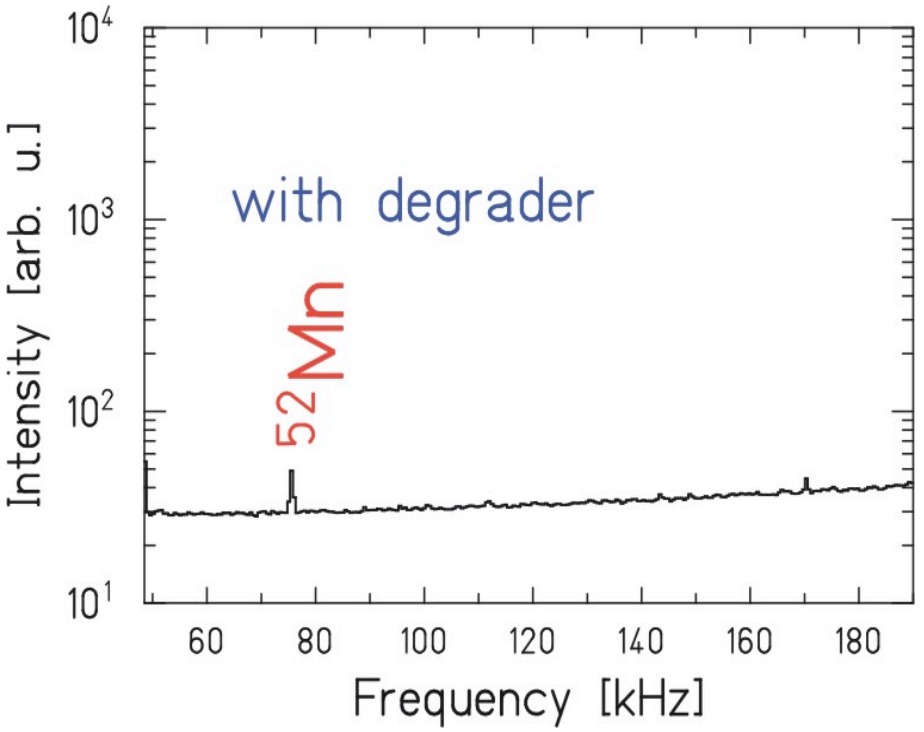
Production of HCI's



Production and Selection of exotic Nuclei

cocktail of HCIs ➔ in-flight separation
➔ mono-isotopic beams
➔ possibility to select 1,2,3,… ions



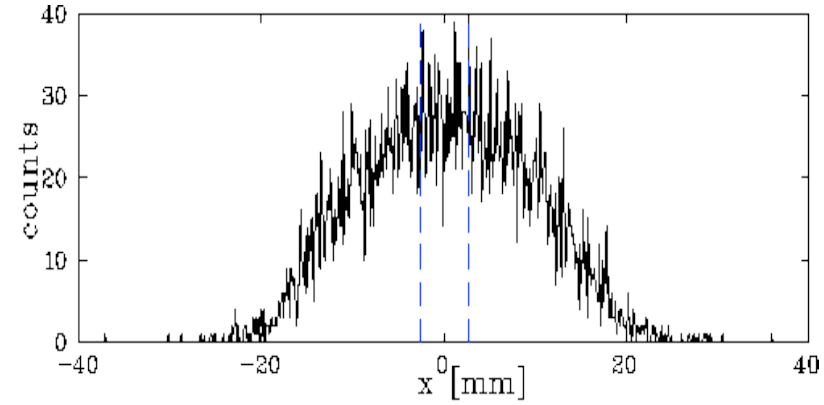


Beam Cooling

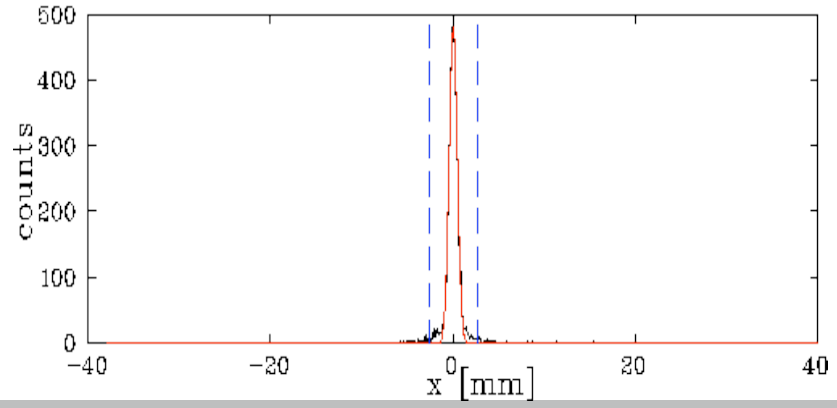
Initial momentum spread ➔ cooling required:

- **stochastic cooling for the first few seconds**
- **electron cooling (permanently on)**

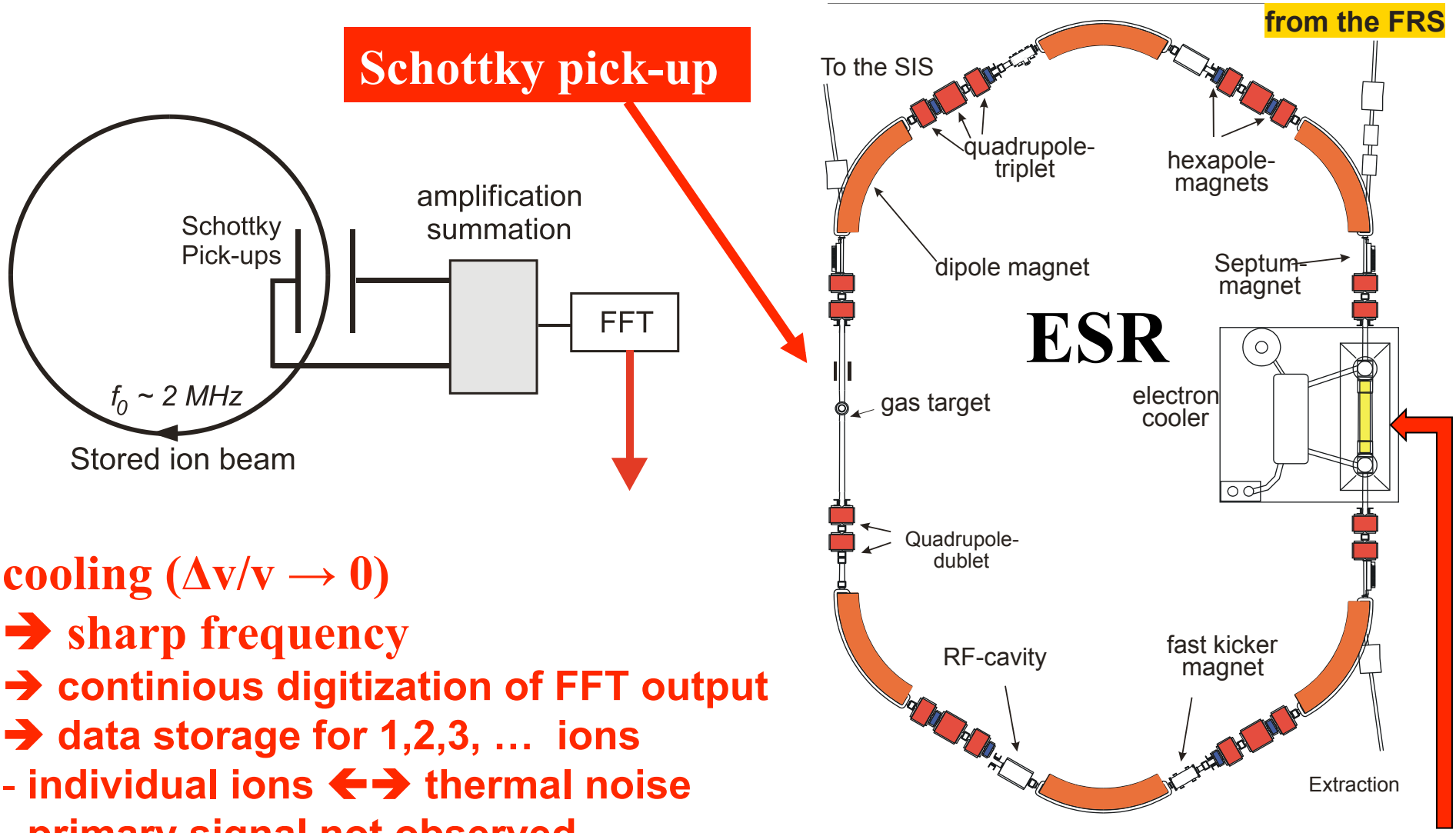
➔momentum exchange with 'cold' electron beam ➔ cooling ~ seconds ➔ ions get the **sharp velocity** of the electrons, small size and divergence



➔ **sharp rotation frequency**



Schottky-Pickup Detection



cooling ($\Delta v/v \rightarrow 0$)

➔ sharp frequency

➔ continious digitization of FFT output

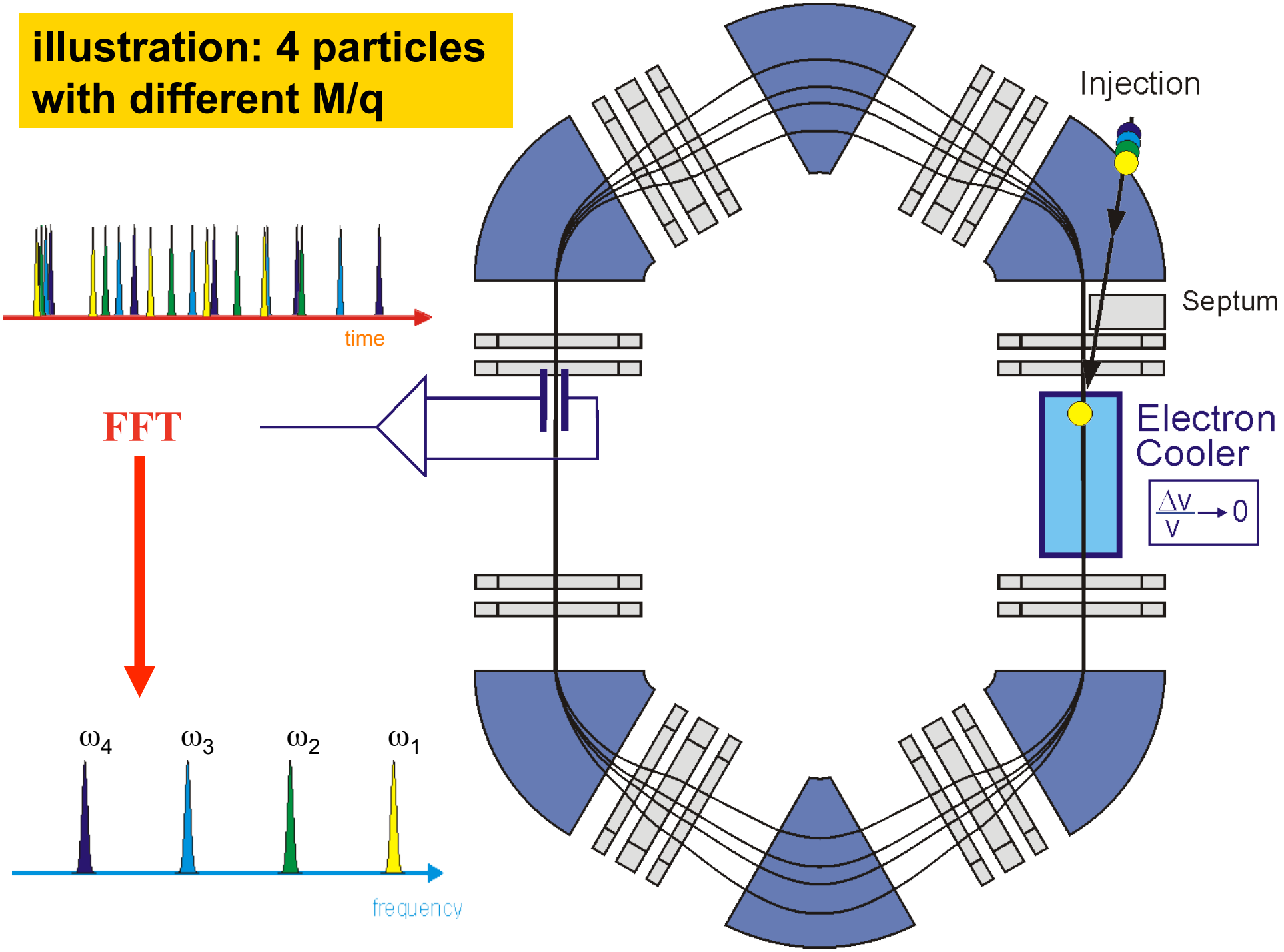
➔ data storage for 1,2,3, … ions

- individual ions ←➔ thermal noise

- primary signal not observed

Cooling (stochastic & electron)

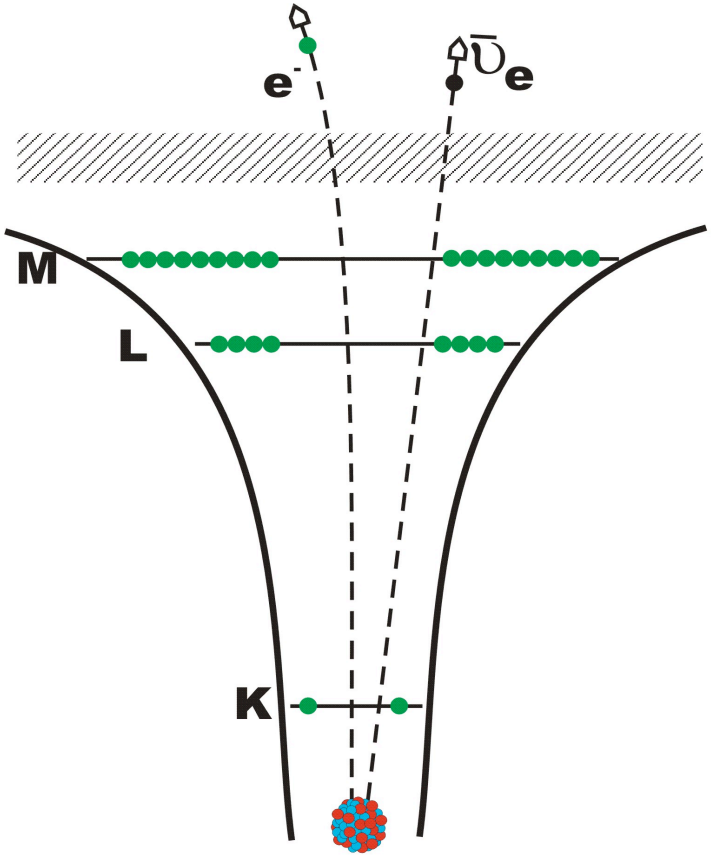
illustration: 4 particles with different M/q

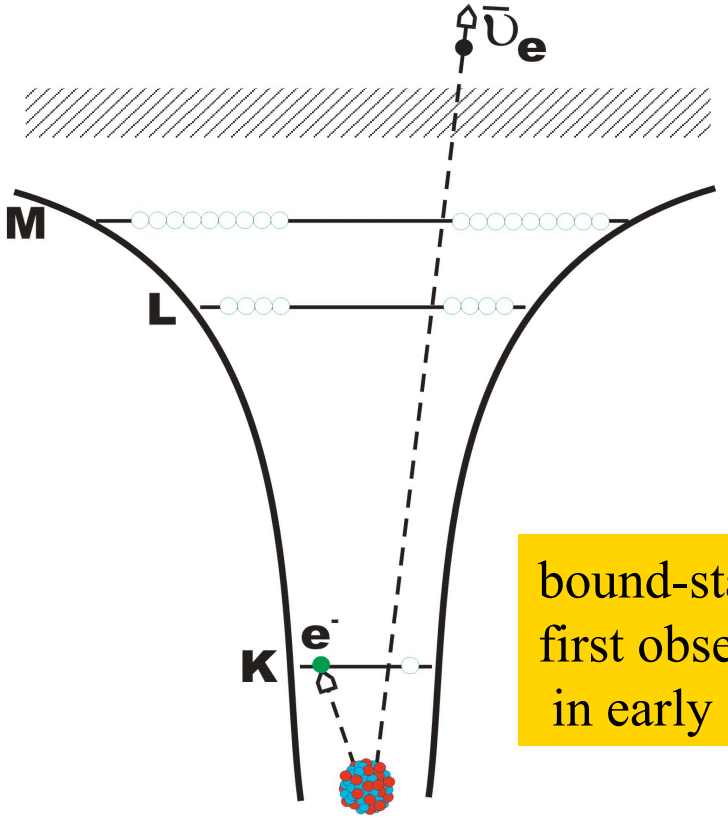


Observation of Decays of stored Ions

a) Normal β-decays
➔ different charge
➔ different M/q ➔ Δf

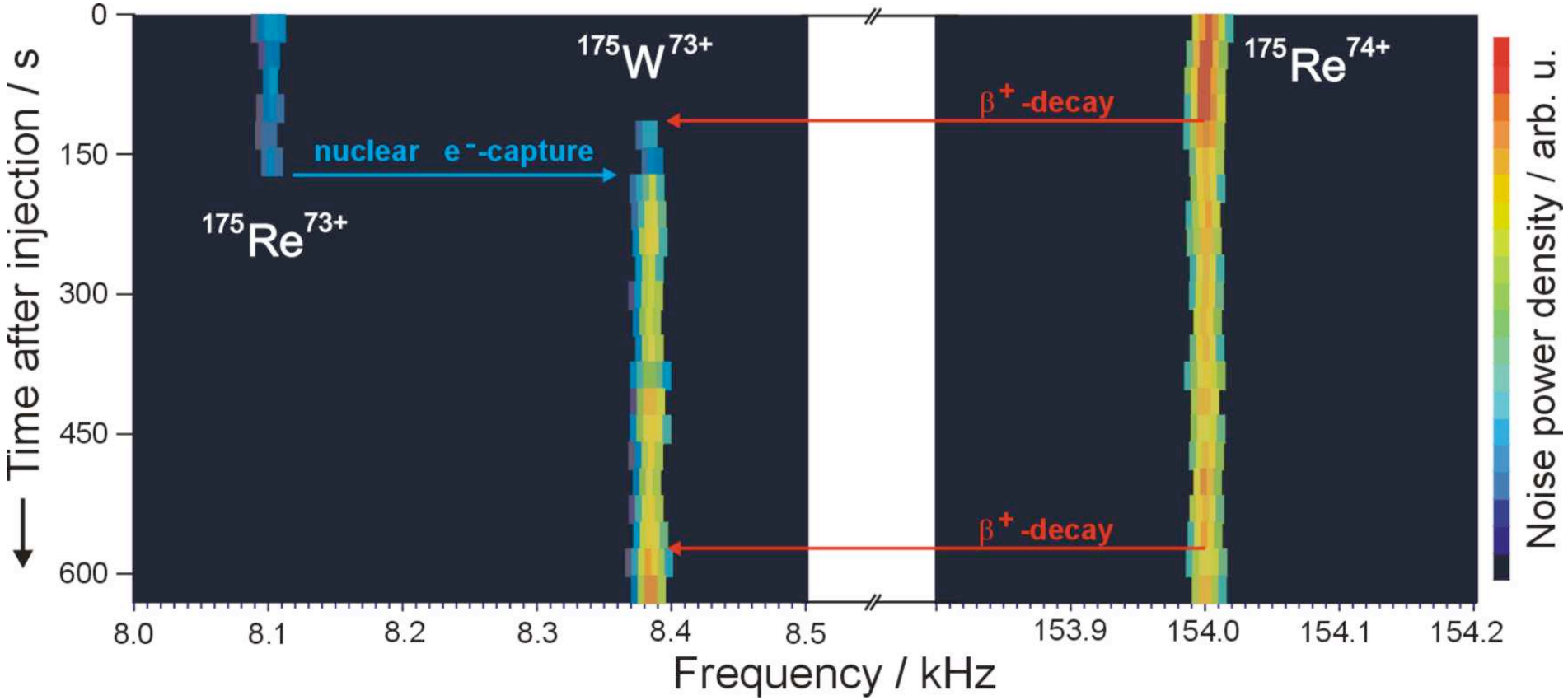
b) Bound state β-decay by e- capture
➔ same q, slightly different M'
(binding energy) ➔ tiny Δf





bound-state β-decay
first observed at GSI
in early 90's

Examples for Decay of Single Ions



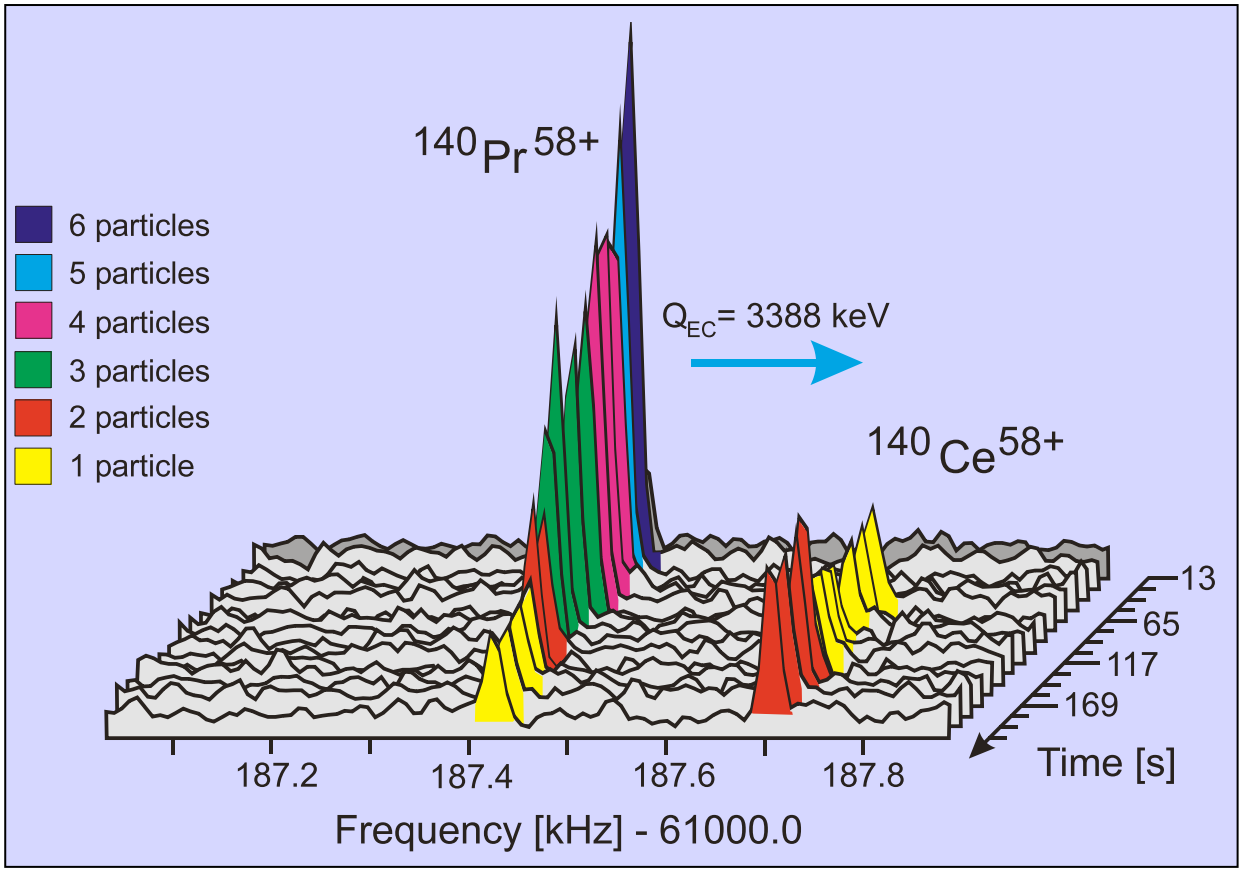
- ordinary β-decay and EC clearly separable (magnitude of Δf)
- for few ions: intensity allows to see individual decays
- mother *AND* daughter seen

Spectroscopy of individual Particles

- sensitive to single ions
- well-defined
  - creation time t_0
  - charge states
- two-body β-decay

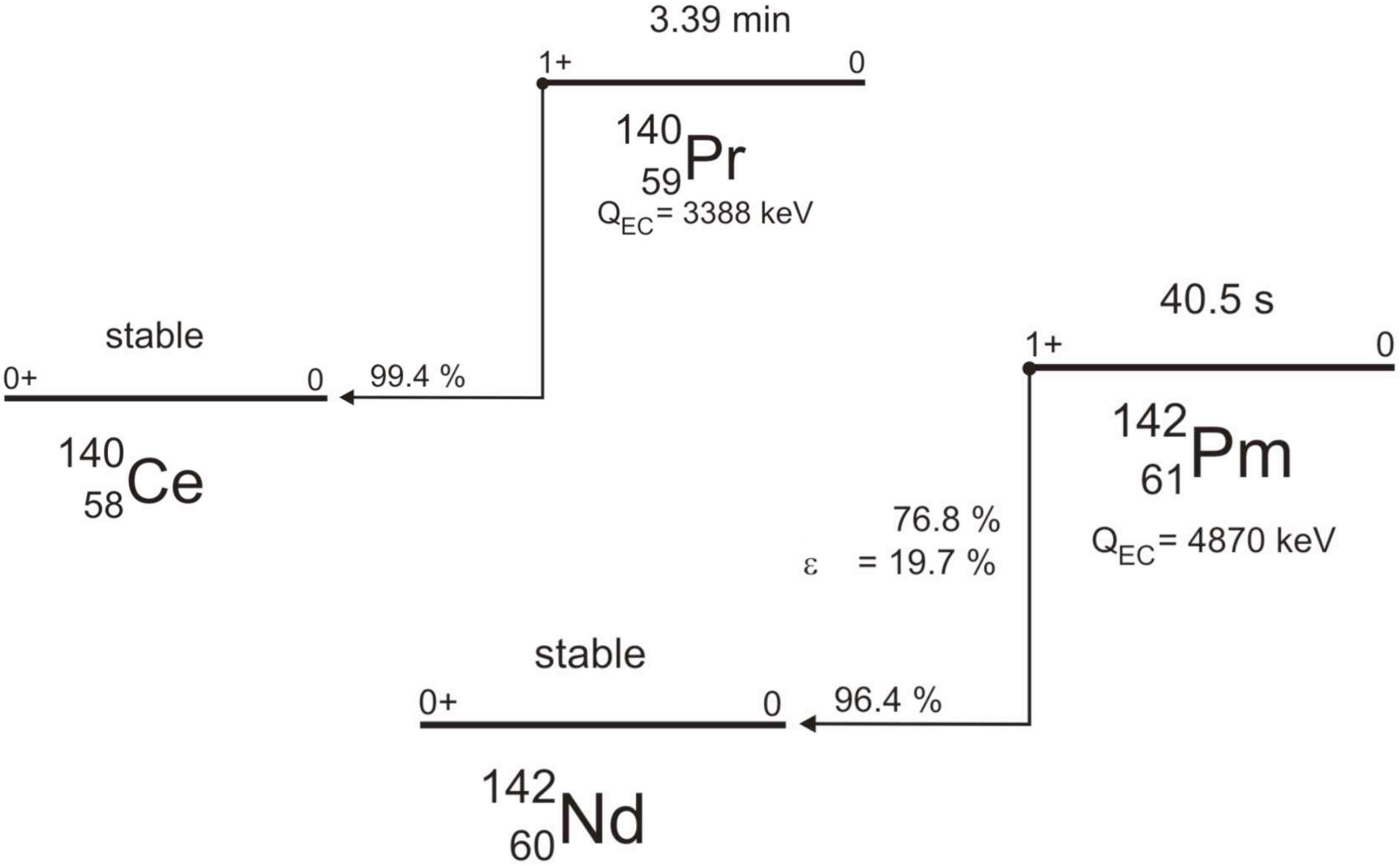
➔ monochromatic ν_e

- observation of changes in peak intensities of mother and daughter ions

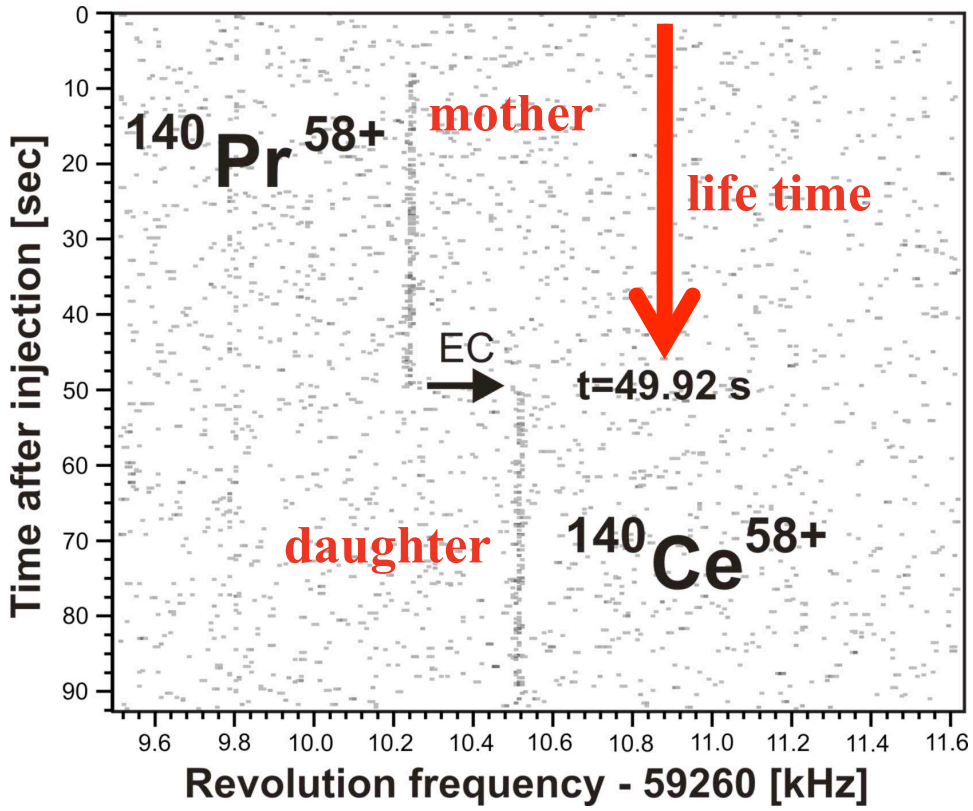


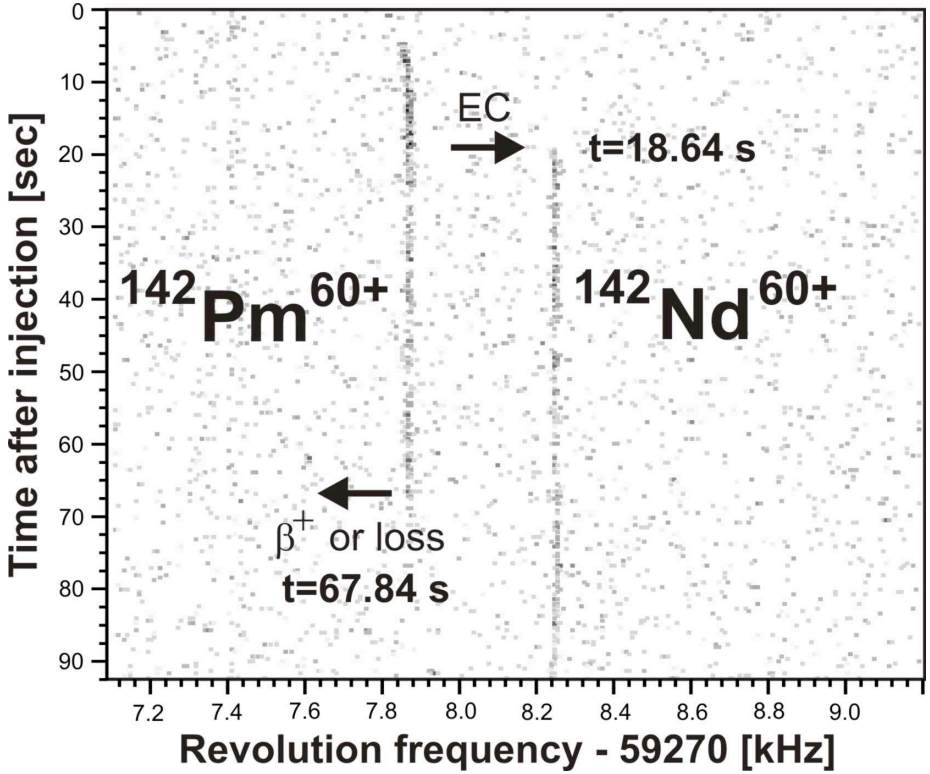
- investigation of a selected decay branch, e.g. pure EC decay
- time-dependence of the detection efficiency is excluded

Relevant Decays: H-like ^{140}Pr and ^{142}Pm



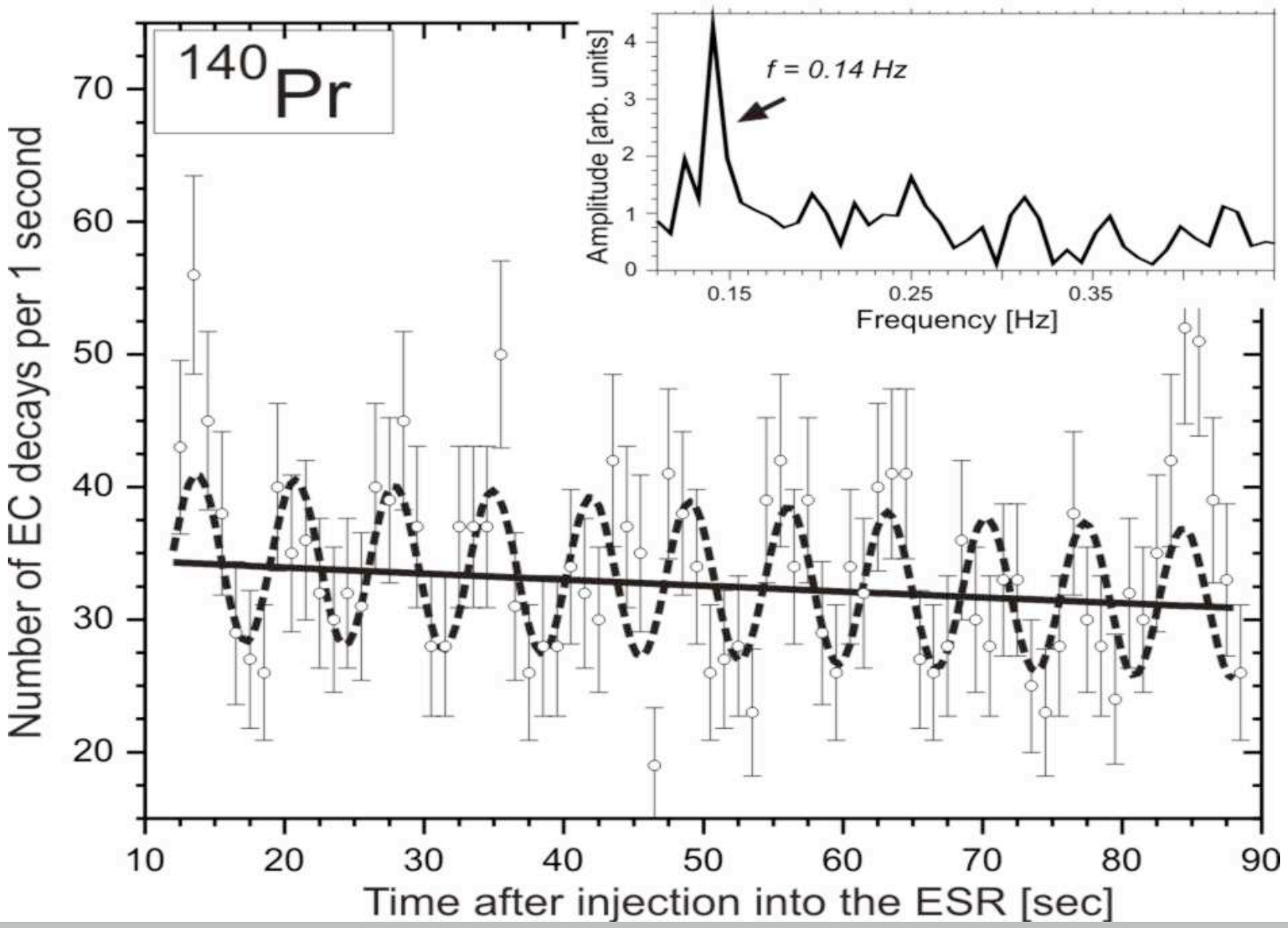
Examples of measured Time-Frequency Traces



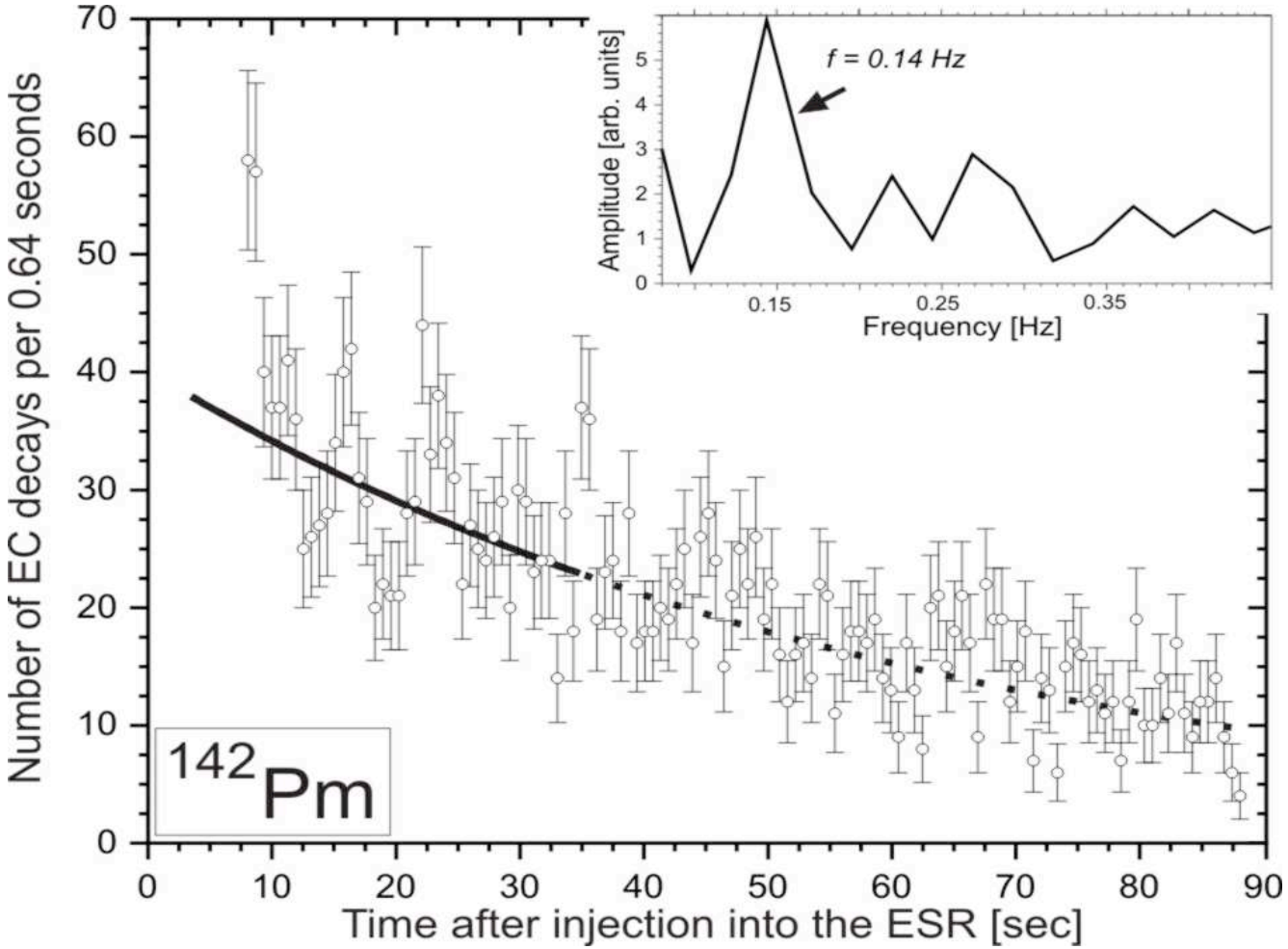


➔ determine lifetime of individual ions
➔ plot distribution of lifetimes
➔ expect exponential decay law

140Pr all runs: 2650 EC decays from 7102 injections

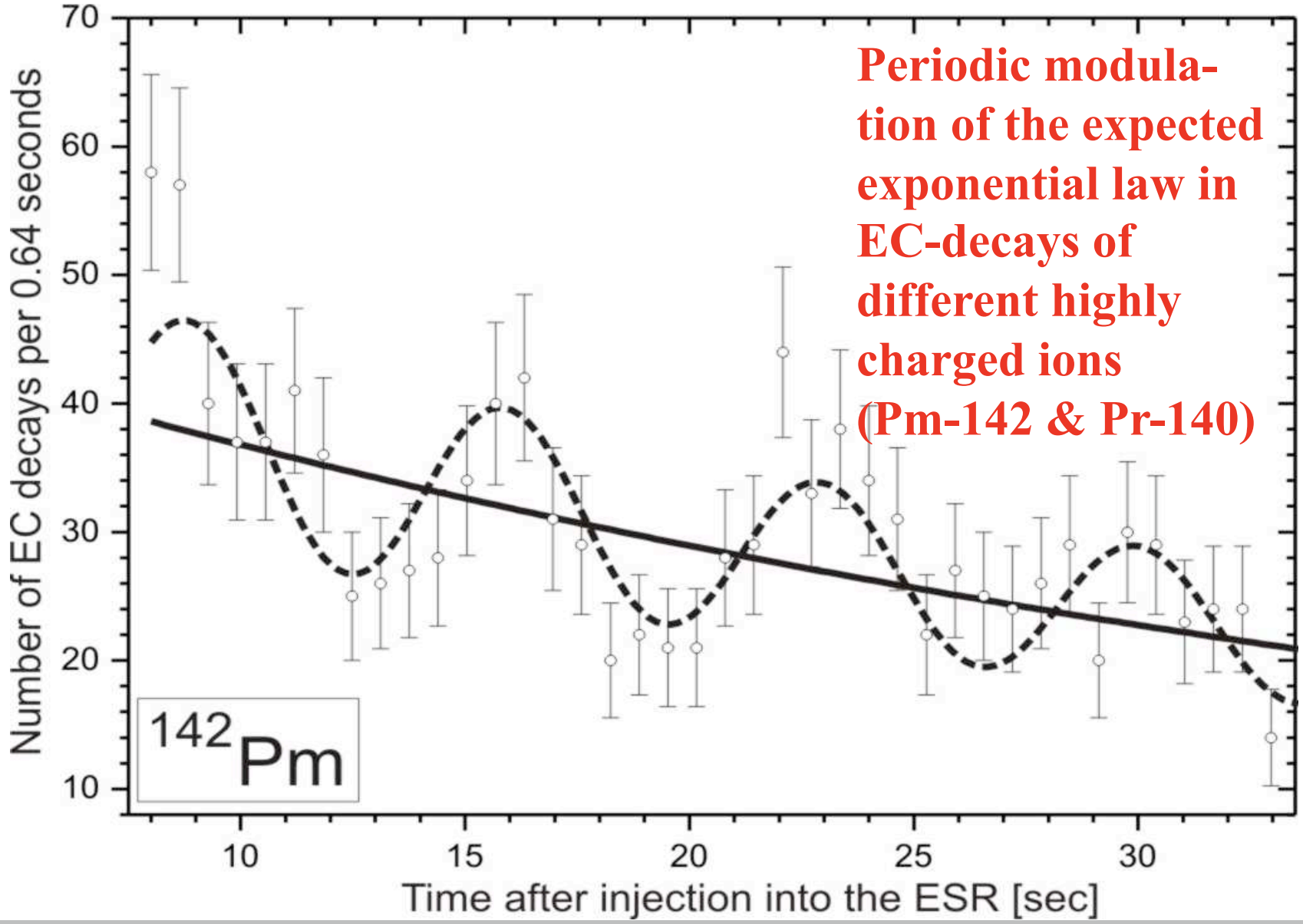


142Pm: 2740 EC decays from 7011 injections



Periodic modulation of exponential decay?

142Pm: zoom on the first 35s after injection



Fits

1) exponential

$$dN_{EC}(t)/dt = N_0 \exp\{-\lambda t\}\,\lambda_{EC}\ ;\ \ \lambda = \lambda_{\beta+} + \lambda_{EC} + \lambda_{loss}$$

2) exponential plus oscillation

$$dN_{EC}(t)/dt = N_0 \exp\{-\lambda t\}\,\lambda_{EC}(t)$$

$$\lambda_{EC}(t) = \lambda_{EC}\,[1 + a\cos(\omega t + \varphi)]$$

Fit parameters of ^{140}Pr data					
Eq.	$N_0\lambda_{EC}$	λ	a	ω	χ^2/DoF
1	34.9(18)	0.00138(10)	-	-	107.2/73
2	35.4(18)	0.00147(10)	0.18(3)	0.89(1)	67.18/70
Fit parameters of ^{142}Pm data					
Eq.	$N_0\lambda_{EC}$	λ	a	ω	χ^2/DoF
1	46.8(40)	0.0240(42)	-	-	63.77/38
2	46.0(39)	0.0224(41)	0.23(4)	0.89(3)	31.82/35

T = 7.06 (8) s
φ = - 0.3 (3)

T = 7.10 (22) s
φ = - 1.3 (4)

➔ T agrees for Pr and Pm
➔ what about the phase (relative, absolute)?

Recent Developments

New run with Iodium:

3.5σ effect in Pr/Pm data ➔ could be a statistical fluctuation

➔ new Iodium data: so far only partial information public (talks, GSI annual report)

➔analysis & publication rather slow… talks…

➔confirm oscillations ➔ 8σ … , M scaling seen

➔ understanding / explanation required!

Carefully checks of the experiment by the colaboration:

- artefacts such as periodic coupling of the Schottky-noise to all sort of backgrounds excluded
- all EC decays are recorded; continuous information on the status of mother- and daughter ion during the whole observation time

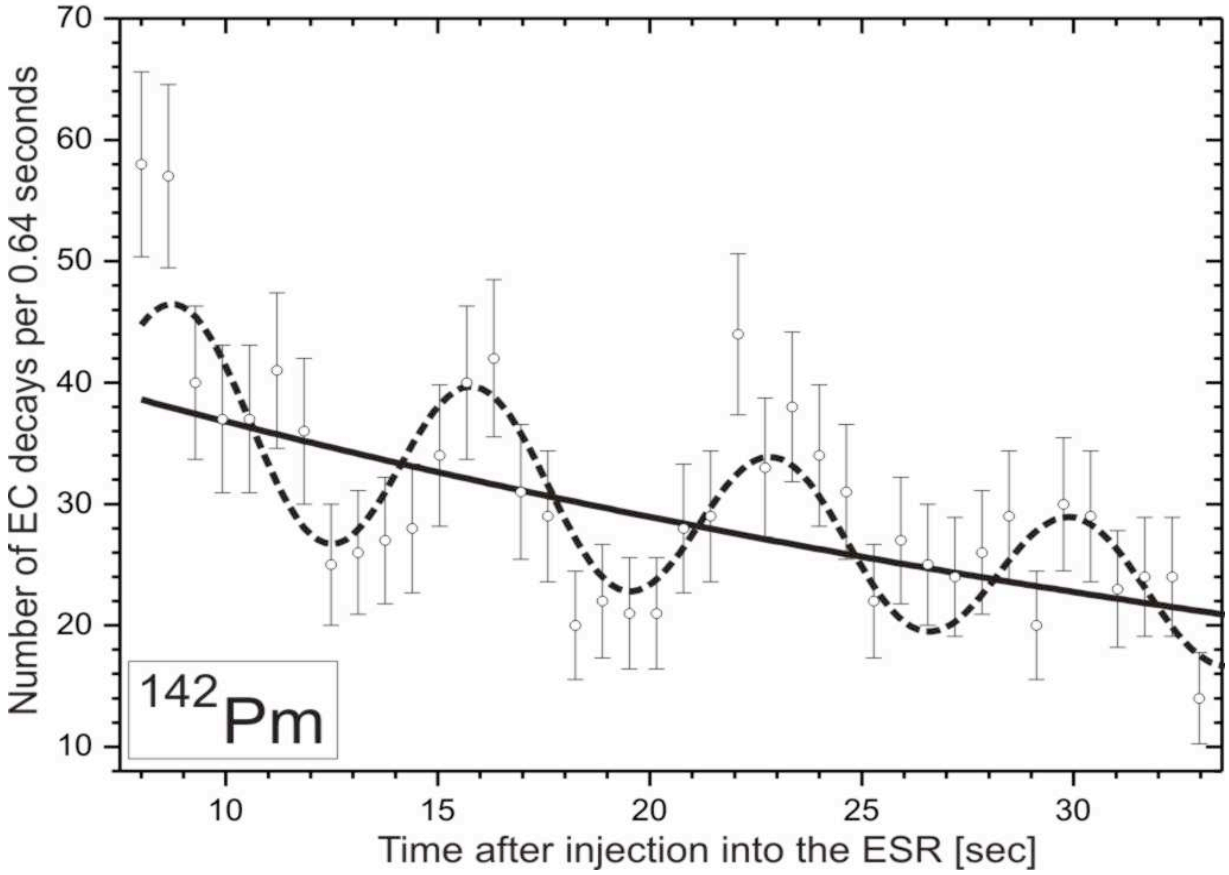
Questions and potential Issues

- Neutrino explanation?
  - wrong masses/mixings compared to KamLAND
  - ideas to change KamLAND analysis ←→ solar parameters
  - …
  - ➔ will show that cannot be neutrinos
- Scaling of amplitude of the Schottky-signal ➔ 9, 10
  ➔ no plausible model fits scaling of the growing fluctuations
  ➔ fluctuations limit to few ions (N or N+1 ions?)
- Primary signal unobserved + 30th harmonic + hardware FFT
  noise >> individual ion signal ➔ 6,7
- Relative phase Pr / Pm
- Precision ←→ complex system
  - interaction ions with other ions, eöectron-cooler, ring, …

Statistical Issues

Visible even by eye: Central values follow the curve to nicely!

- **➔ unexplained statistical feature**
- **➔ statistical fluctuations on top of oscillation must exist!**



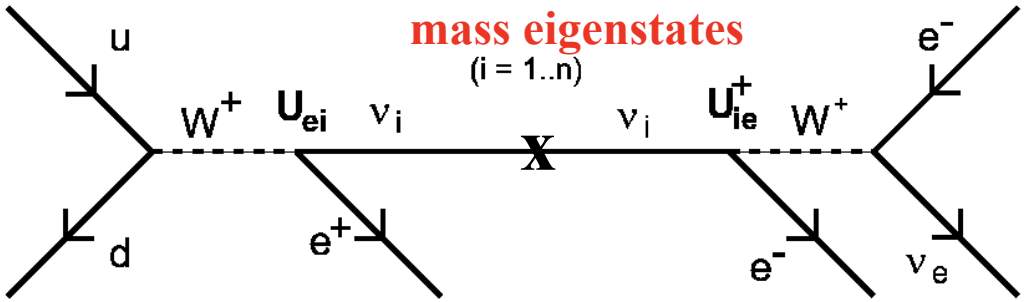
Mann-Whitney-test: The probability that the remaining fluctuations are random is about 5%

➔new Iodium data are supposedly OK

Neutrino Mixings?

- **Why this is NOT explained by neutrino mixing**
  - ➔ H. Kienert, J. Kopp, ML, A. Merle, arXiv: 0808.2389, J.Phys.Conf.Ser.136:022049,2008 (proceedings of Neutrino 2008)
  - ➔ **Feynman diagram of neutrino oscillation:**
    - energy momentum properties, quantum numbers, coherence, …
    - e.g. observation of solar neutrinos in ν_e channel

Production
Propagation
Detection



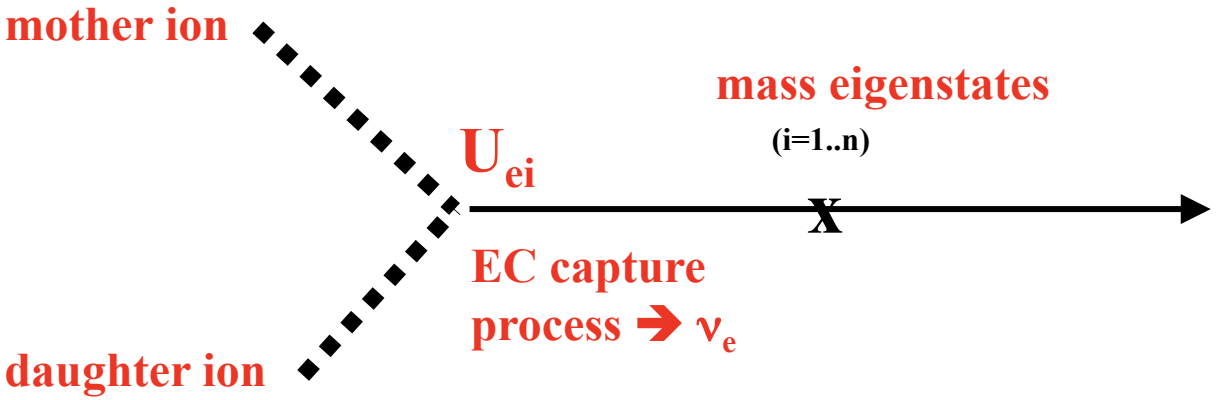
$p + p \rightarrow d + \nu_e + e^+$
solar fusion process ➔ ν_e

electron scattering
➔ projection on ν_e

➔ $$P_{ee} = \sum |U_{ei}|^2 e^{ip_i x} = \ldots$$

+MSW

The EC Process



Kinematics:

a) **precise measurement of mother and daughter energies and momenta ➔ emitted mass eigenstate known ➔ one contribution ➔ no oscillation, but rate ~ $|U_{ei}|^2$ ➔ not realized here (& no oscillation)**

b) **finite kinematical resolution much less than neutrino masses**

➔ **all three mass eigenstates contribute incoherently**

➔ $\propto \sum |U_{ei}|^2 = 1$ ➔ **independent of flavour mixing**

➔ **no periodic modulation of decays due to netrino mixing**

➔ **same result in detailed QM calculation ➔ see our paper**

Explanations

So far two categories of explanations:

- **simply wrong**
- **in principle OK ➔ but order of magnitude…**

- **systematic issues in the experiment …**
- **QM oscillations ➔➔ interfering paths**

  ➔ c.f. neutrino oscillations

  - the mother ion is a two level system

  ➔➔ not seen in β^+ decays ➔ … nucleus or e-shell?

  - quantum beats ?

  β-decay + unobserved neutrino (only ν_e) + kinematics

  ➔ unresolved kinematical states of the daugther ion

  ➔ quantum beat due to neutrino masses...

  ➔ no – do incoherent sum!

Conclusions

- observation of an unexplained periodic modulation of the decay of H-like HCIs (3.5σ → ~ 8σ)
- M scaling confirmed ←→ necessary but not sufficient for a physics effect
- *NOT* related to neutrino masses and mixing
- conceivable: tiny splitting of a 2 level mother system

  - how to explain such a tiny split?
  - coherence length?

- careful checks of all sort of systematics were performed
- however: some unexplained issues

  → release of full information from Iodium run
  → new ideas?