The GSI Anomaly

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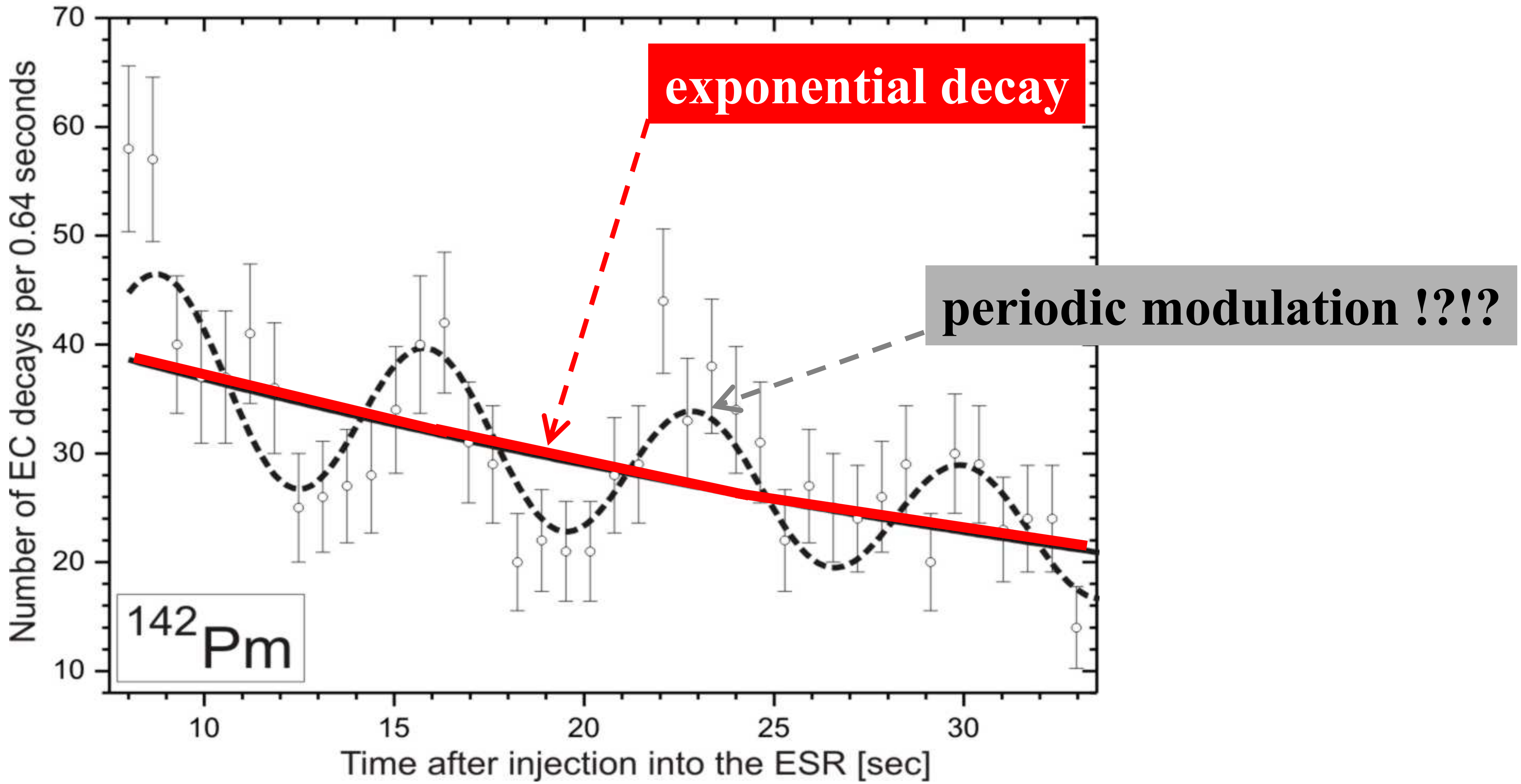
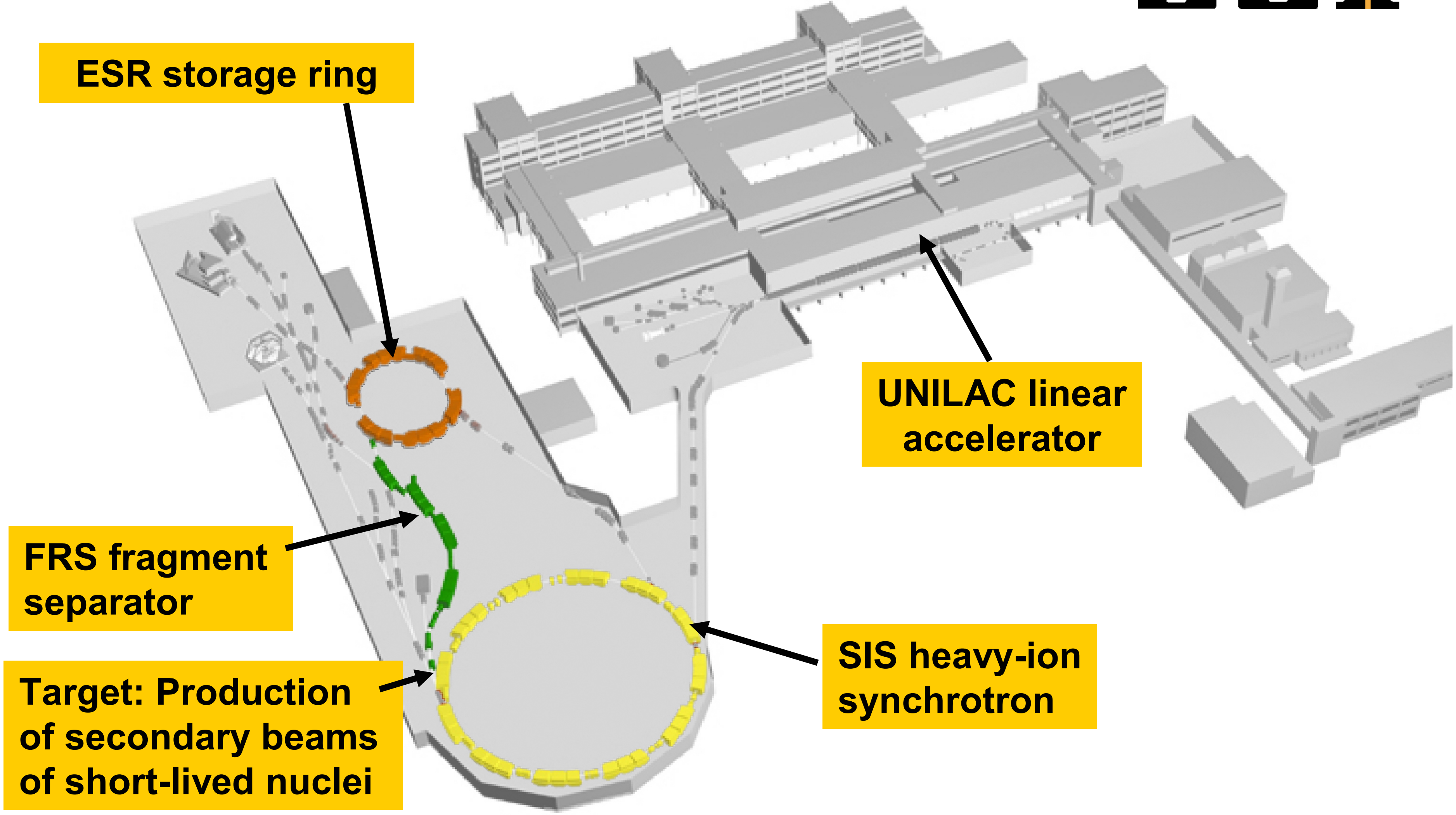
Sildes partially adopted from F. Bosch

What is the GSI Anomaly?

➔**Periodically modualted exponential β-decay law**
of highly charged, stored ions at GSI by the FRS/ESR Collaboration

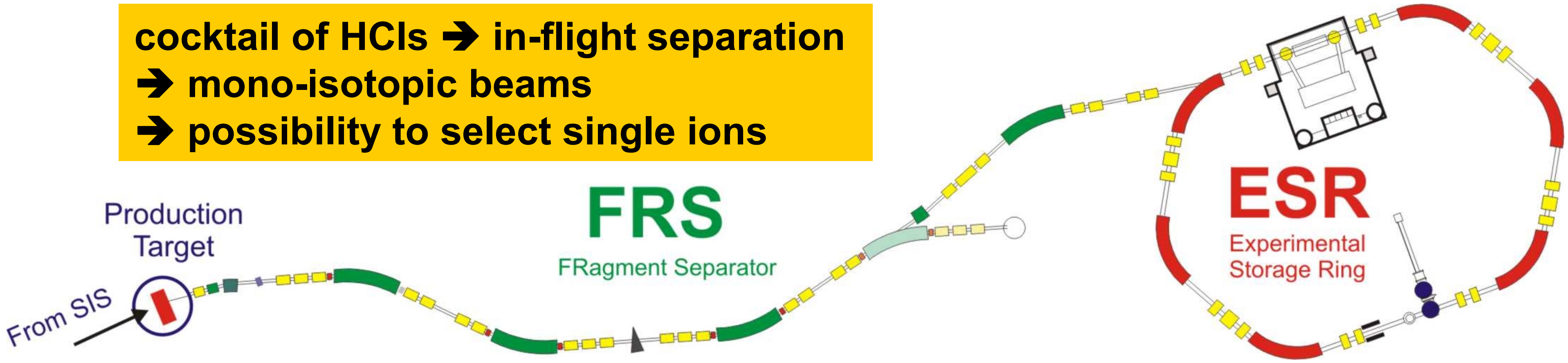


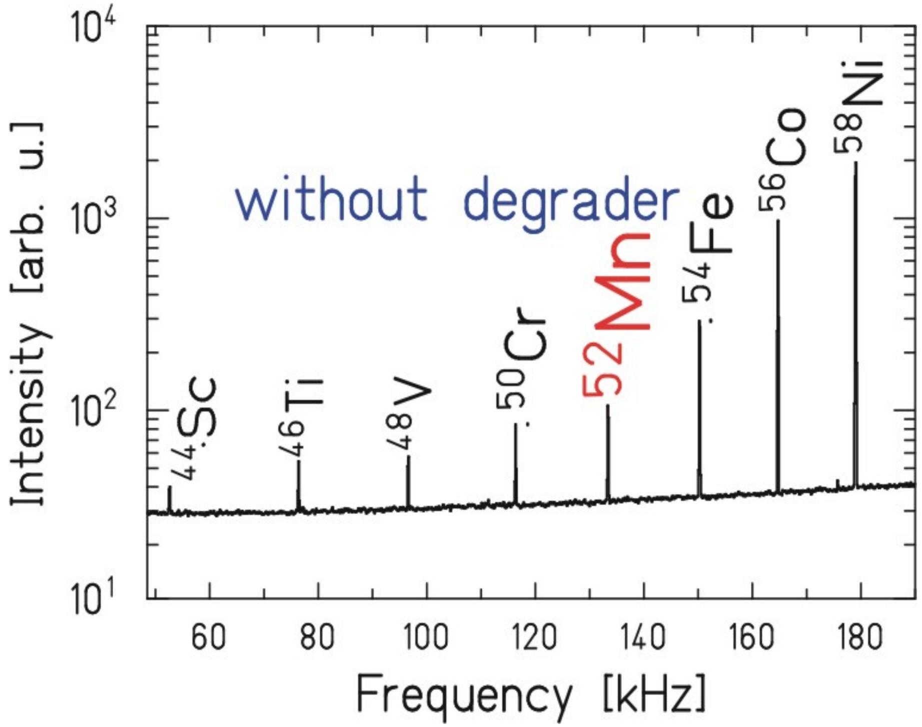
Production of HCI's

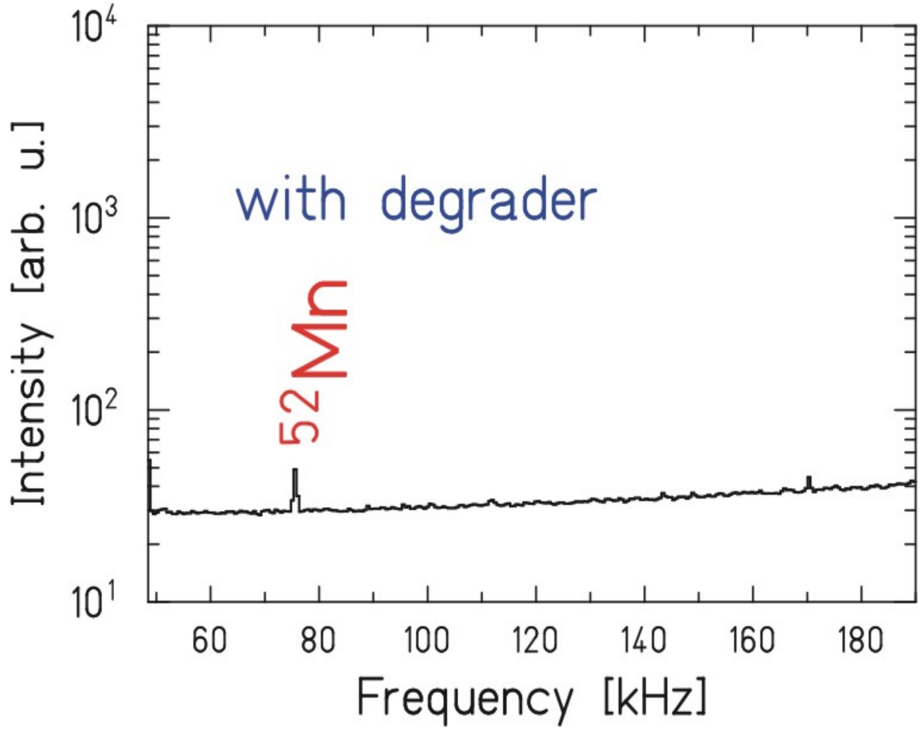


Production and Selection of exotic Nuclei

cocktail of HCIs ➔ in-flight separation
➔ mono-isotopic beams
➔ possibility to select single ions







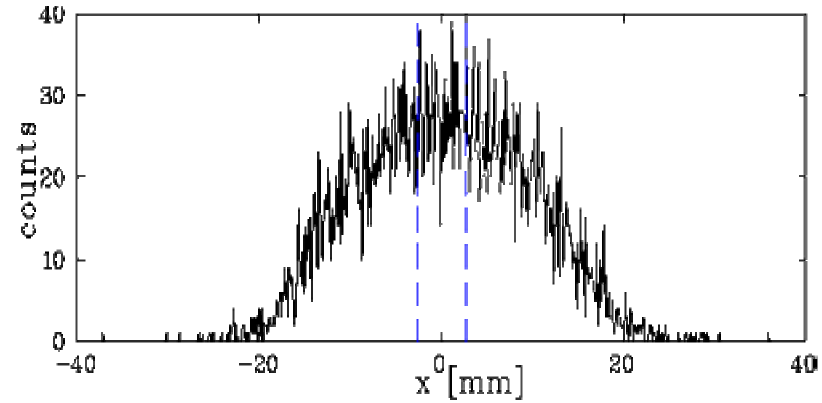
Beam Cooling

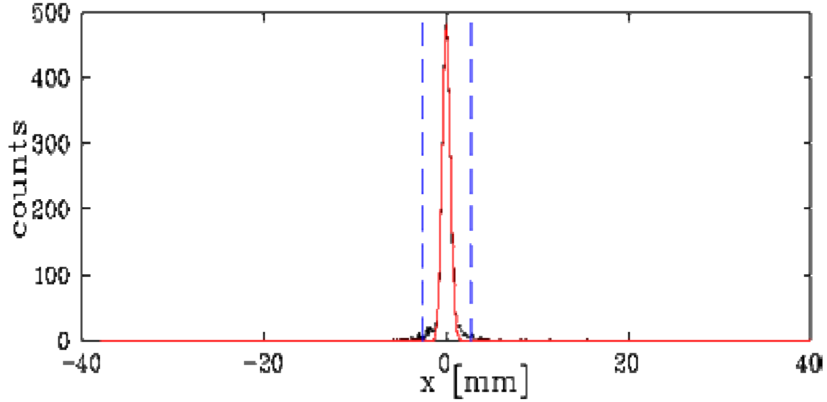
Initial momentum spread ➔ cooling:

- stochastic cooling for the first ~5 seconds

- electron cooling (permanently on)

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

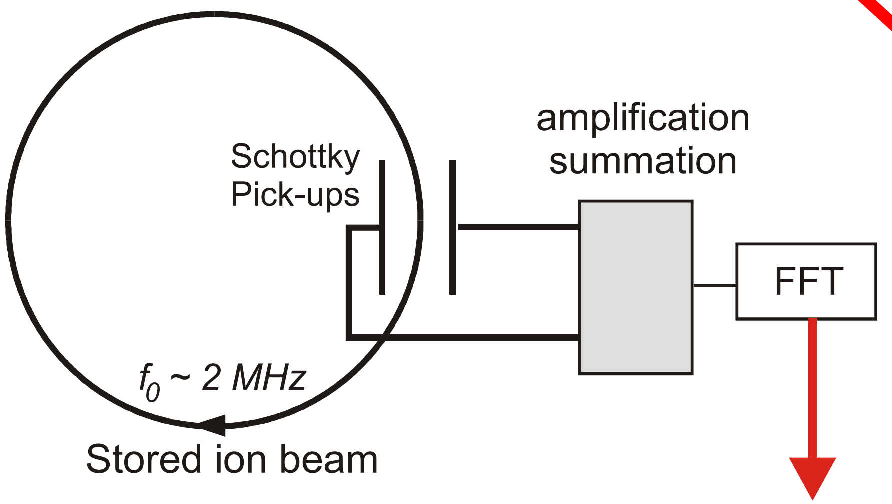


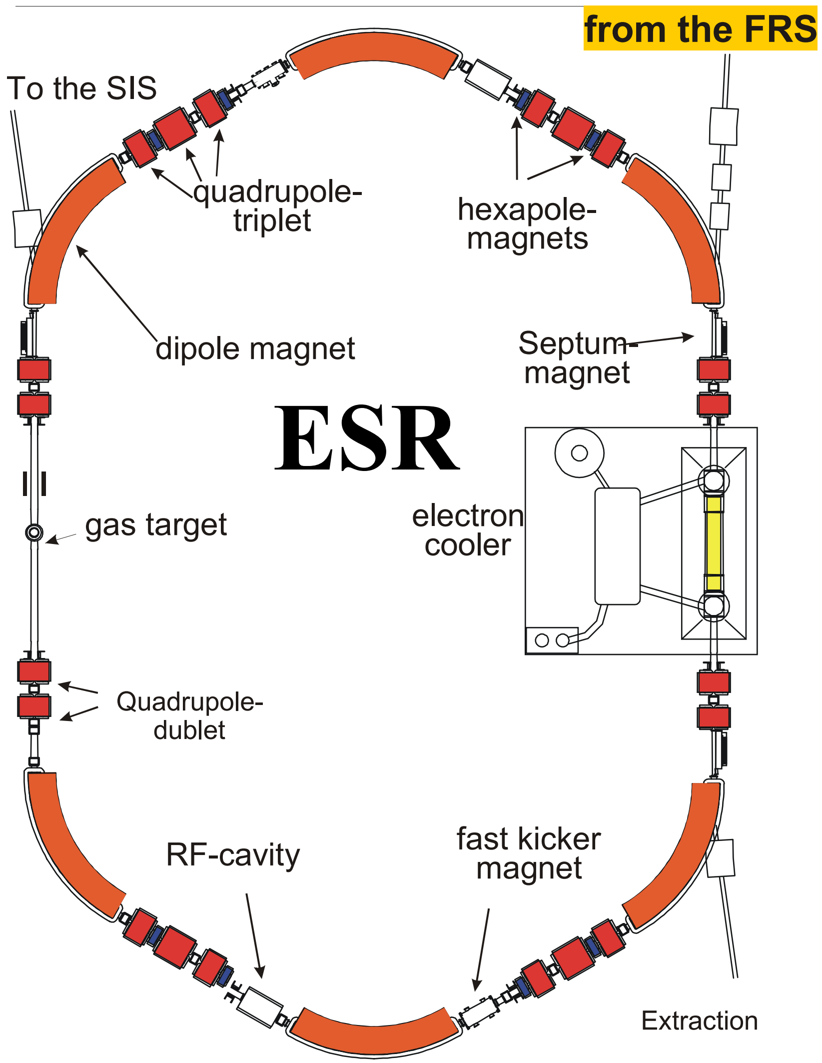


➔ narrows velocity, size and divergence of stored ions

Schottky-Noise Detection

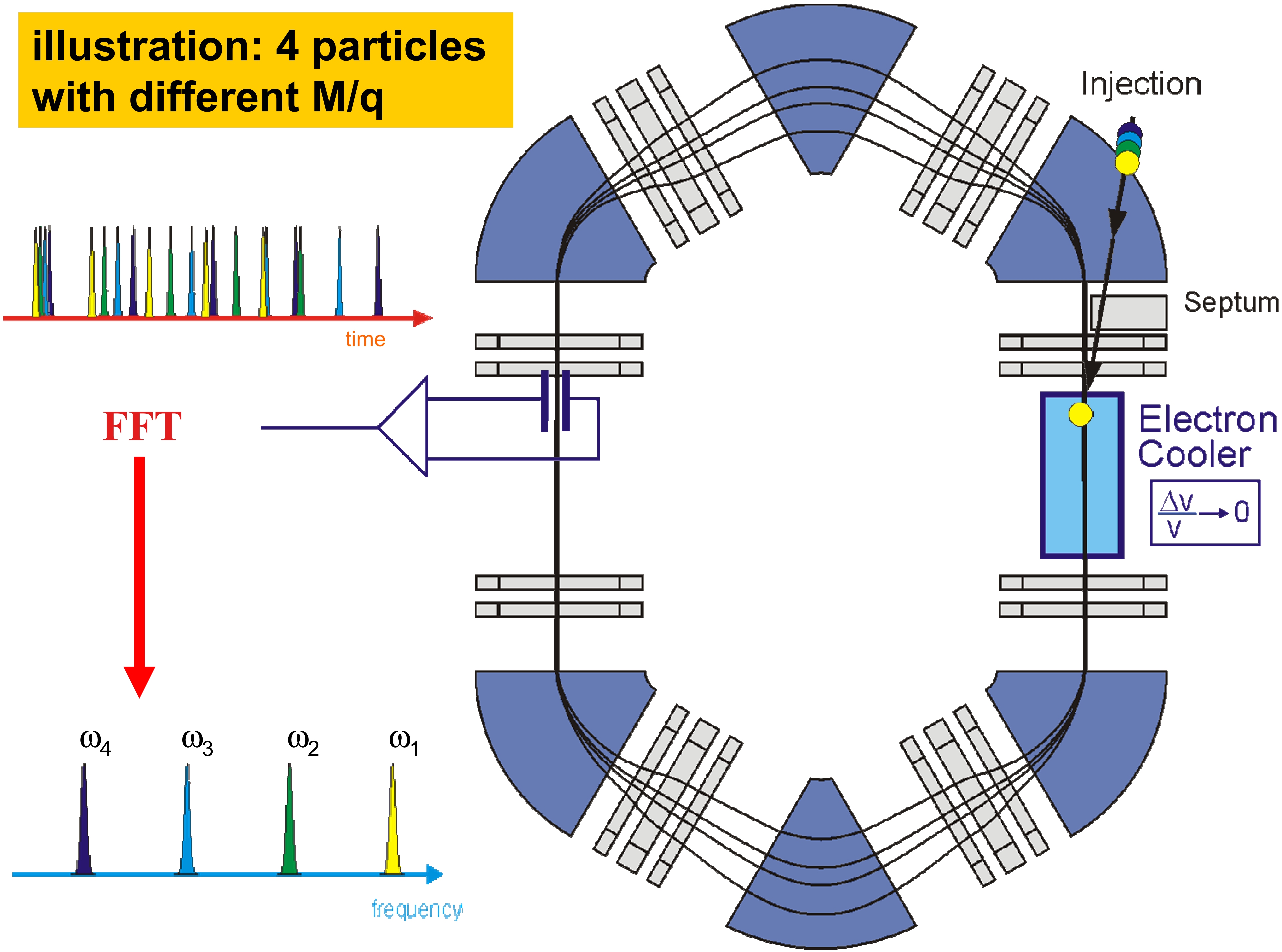
Schottky pick-ups





Continious digitizing and data storage for 1,2,3, … stored ions

illustration: 4 particles with different M/q

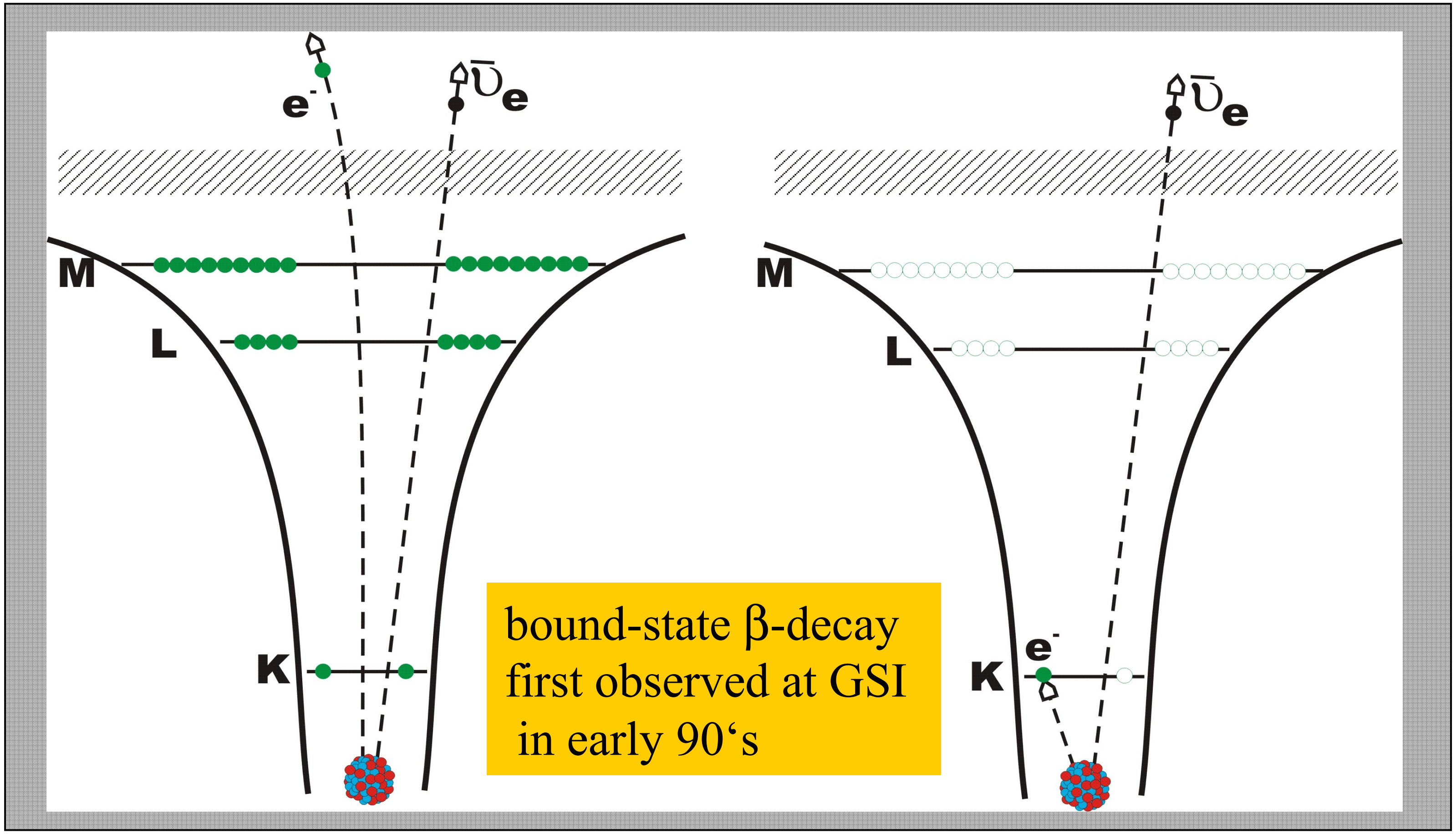


Observation of Decays of stored Ions

a) normal β-decay ➔ different charge ➔ different M/q

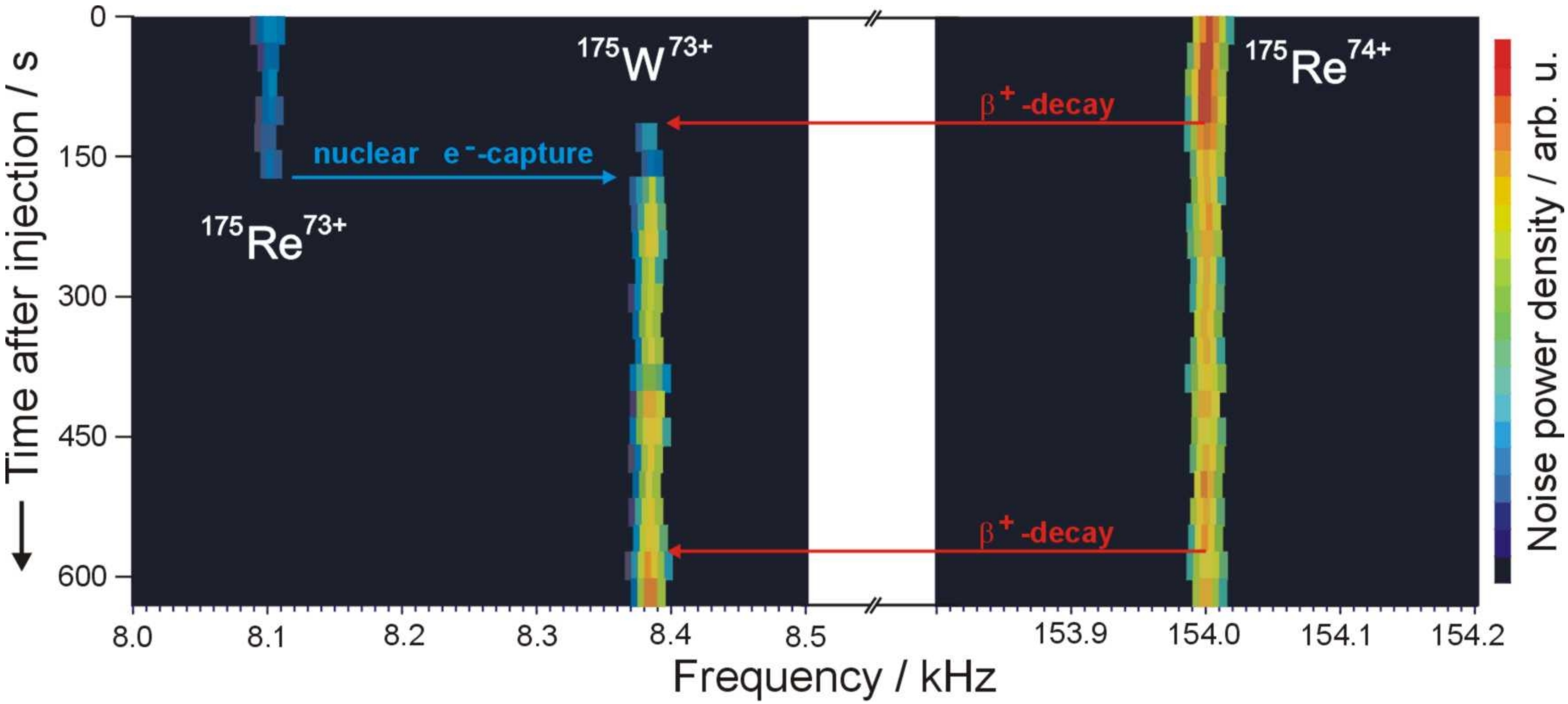
b) bound state β-decay by electon capture

➔ same q, slightly different M' (binding energy, ν-emission)



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

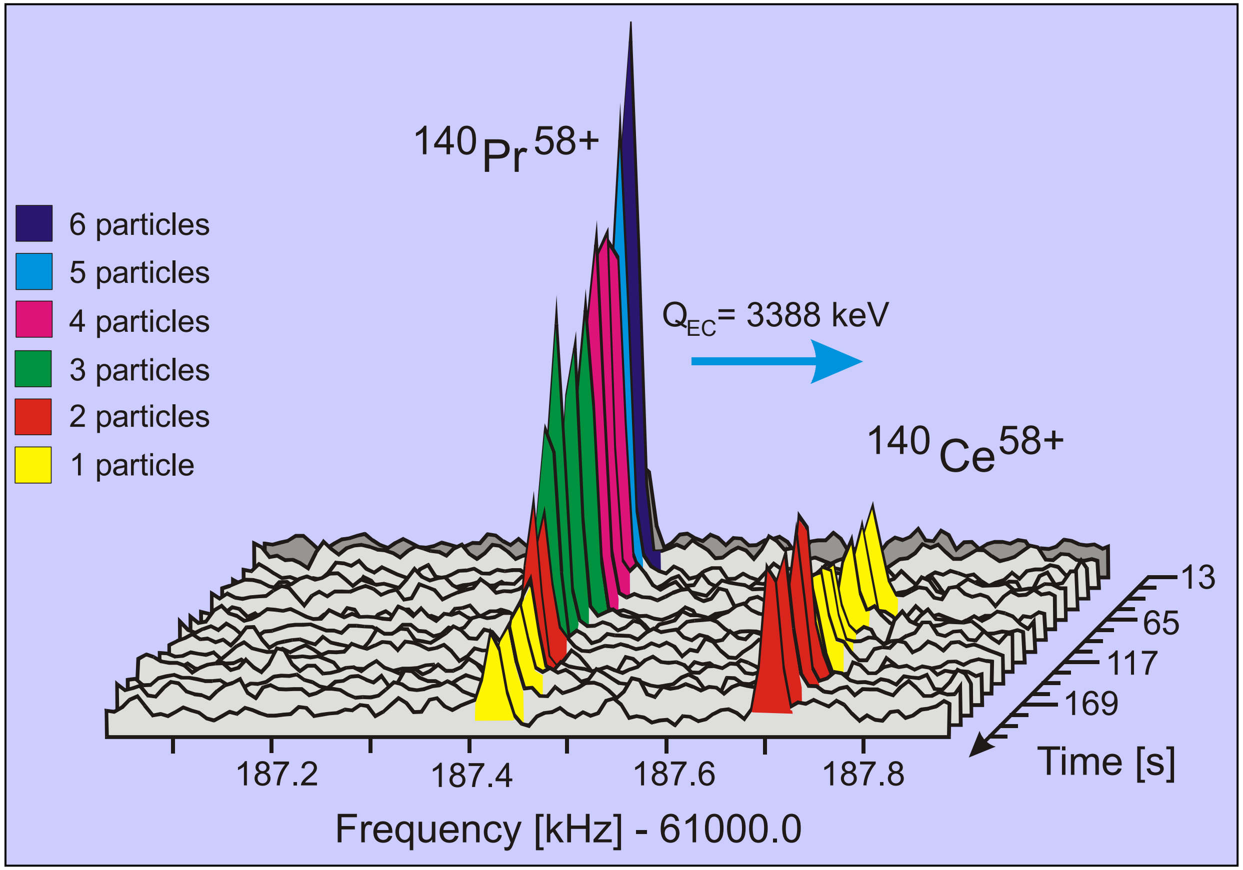
Examples for Decay of Single Ions



- ordinary β-decay and EC clearly separable
- for few ions: intensity allows to see individual decays

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

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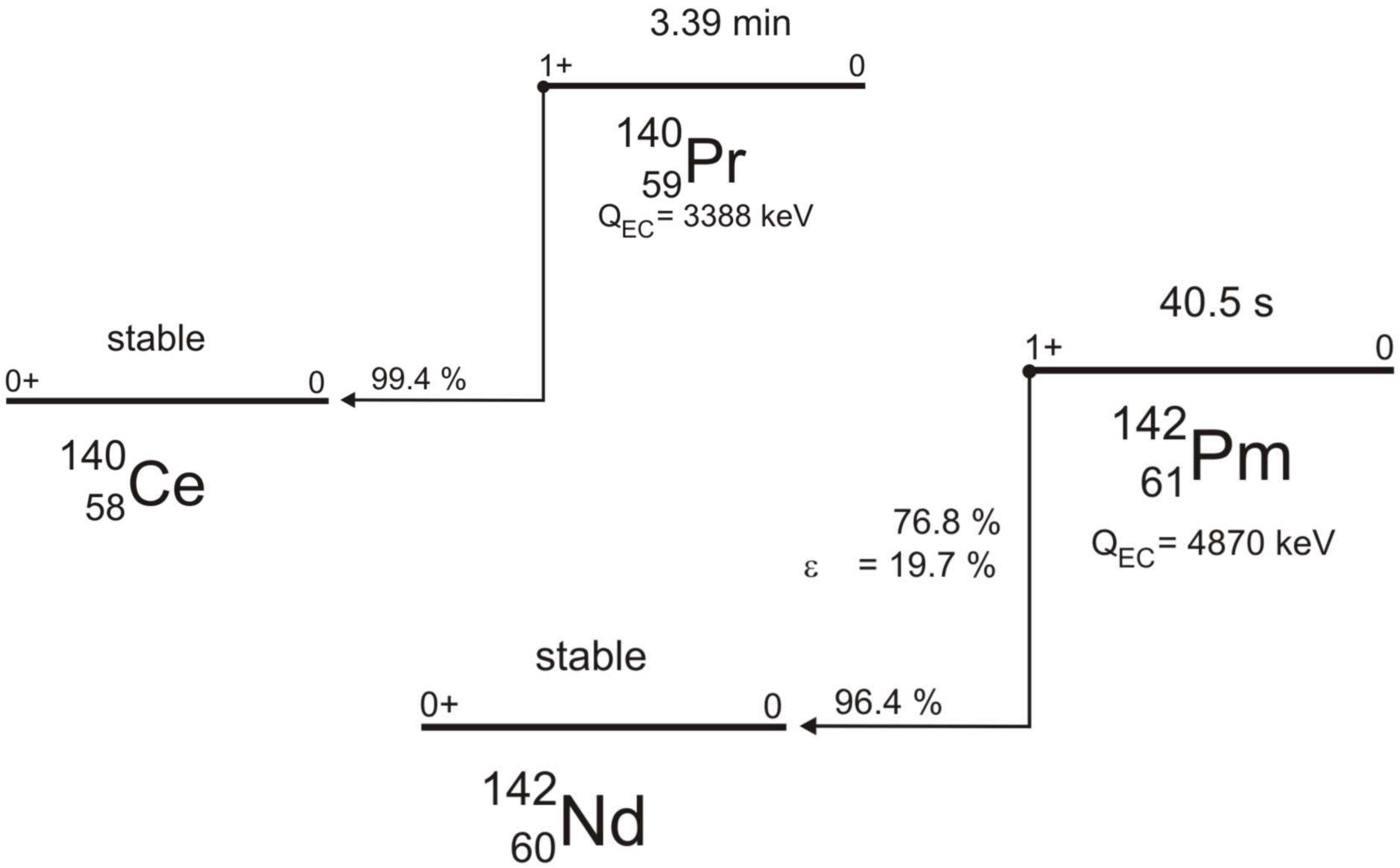
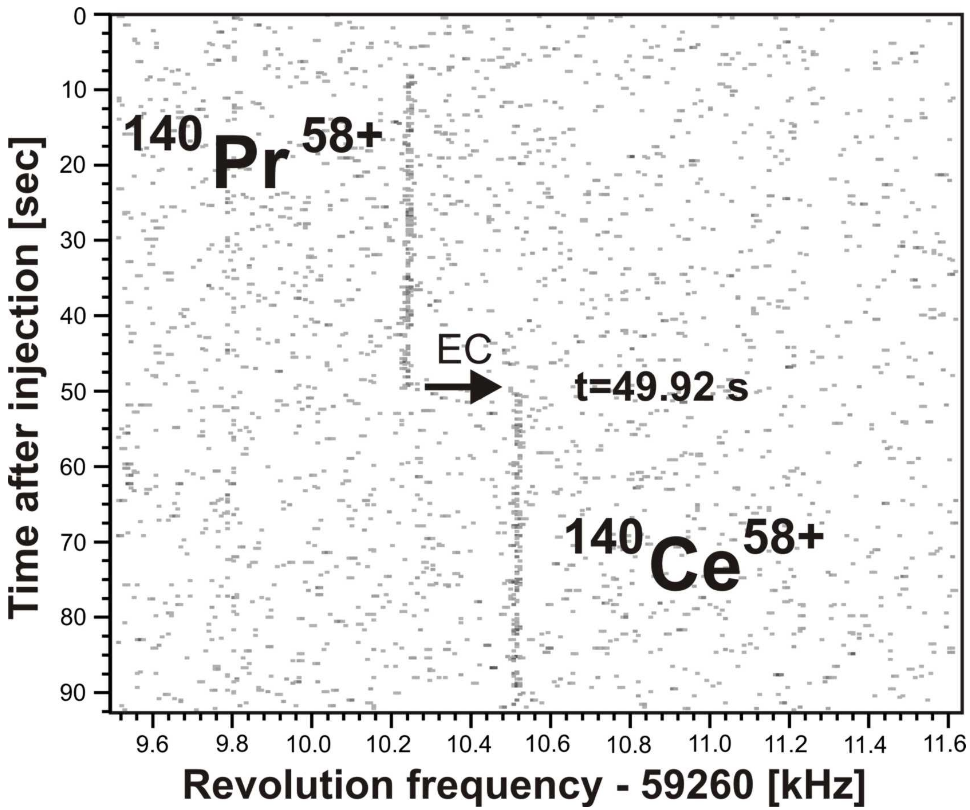
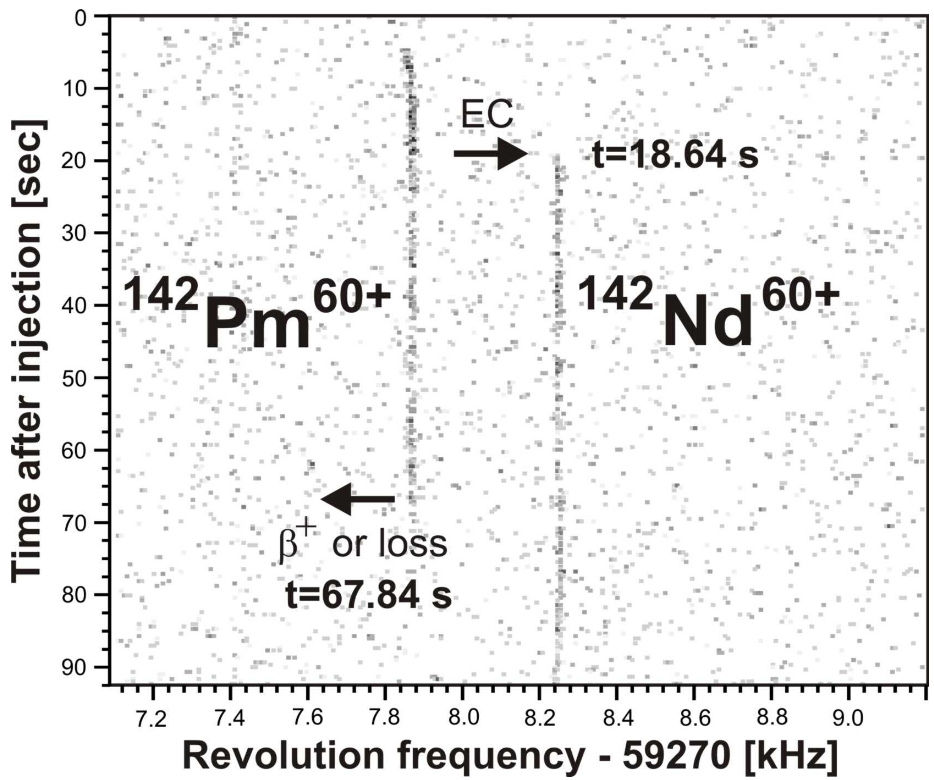
Relevant Decays: H-like ^{140}Pr and ^{142}Pm



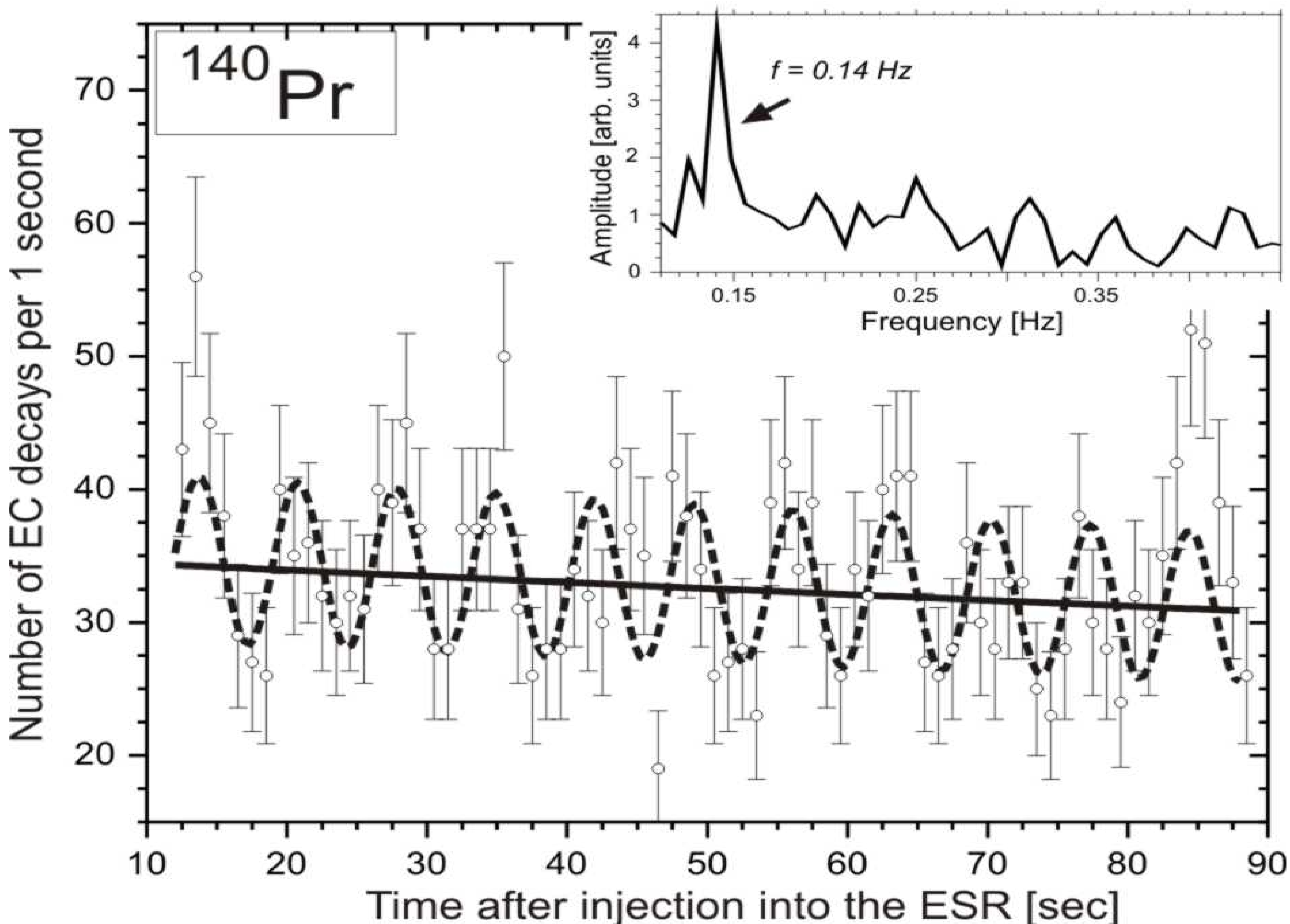
Examples of measured Time-Frequency Traces



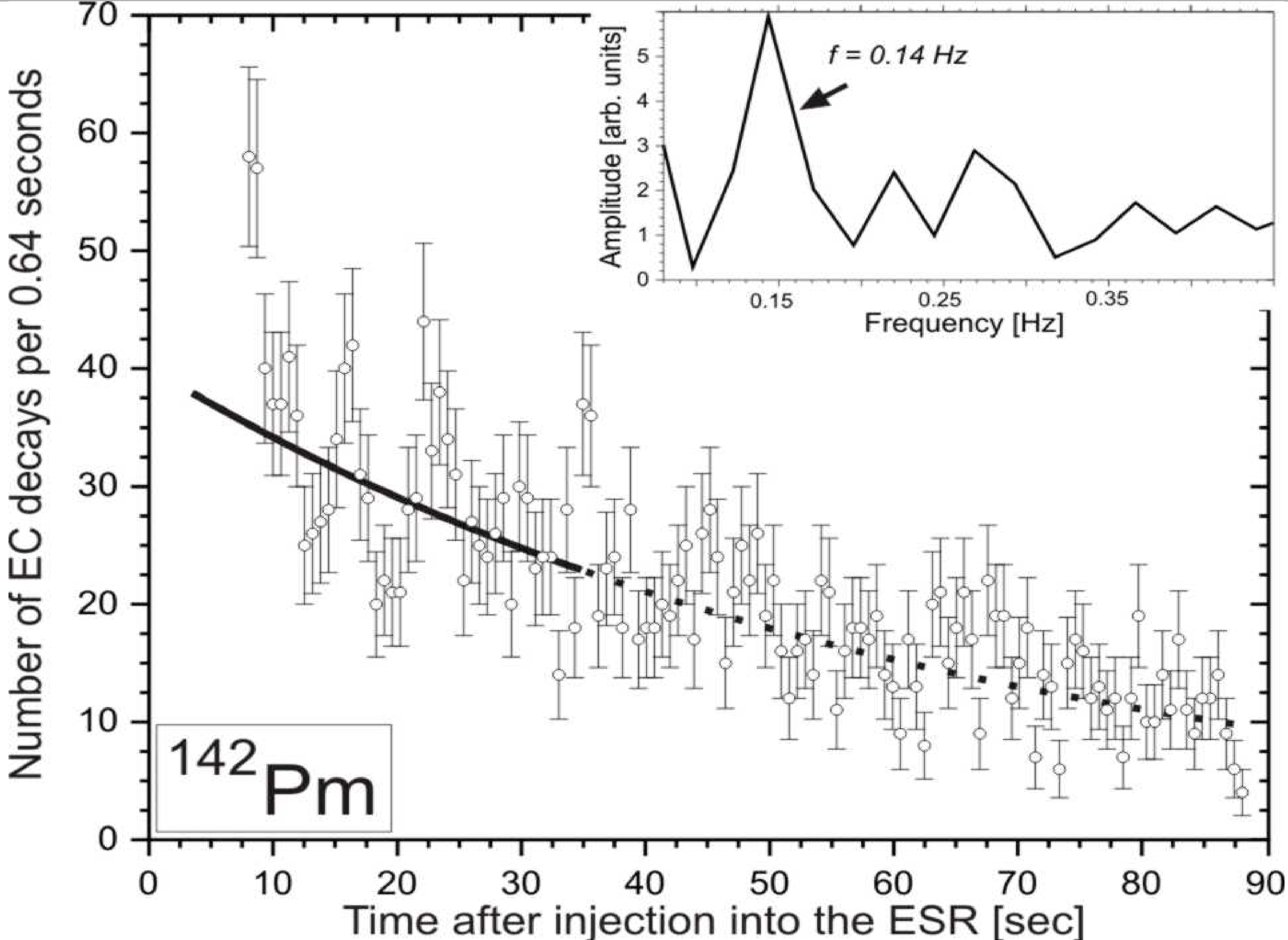


- ➔ determine lifetime of individual ions
- ➔ plot distribution of lifetimes
- ➔ expect exponential decay law

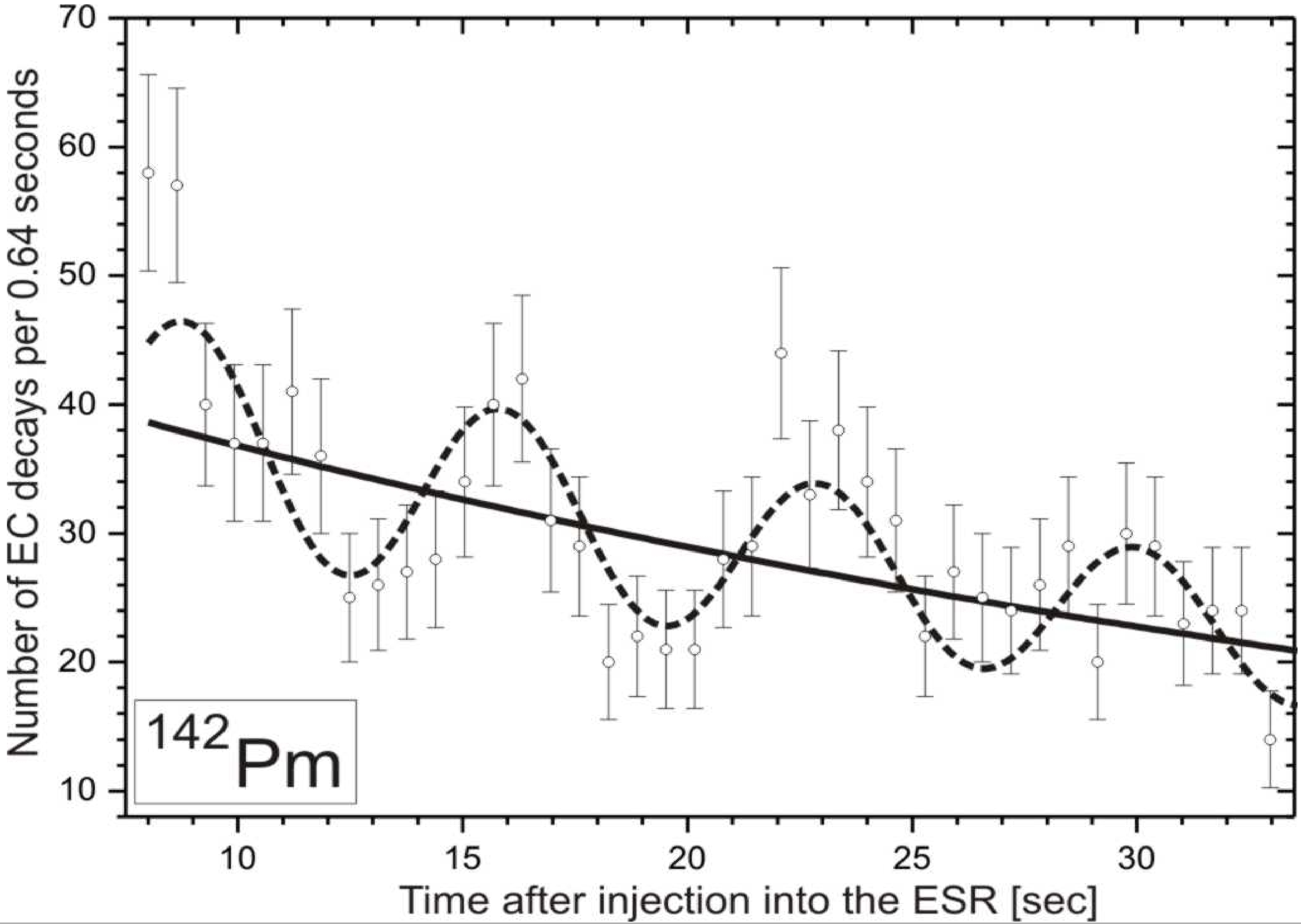
140Pr all Runs: 2650 EC Decays from 7102 Injections



142Pm: 2740 EC Decays from 7011 Injections



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 periodic 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

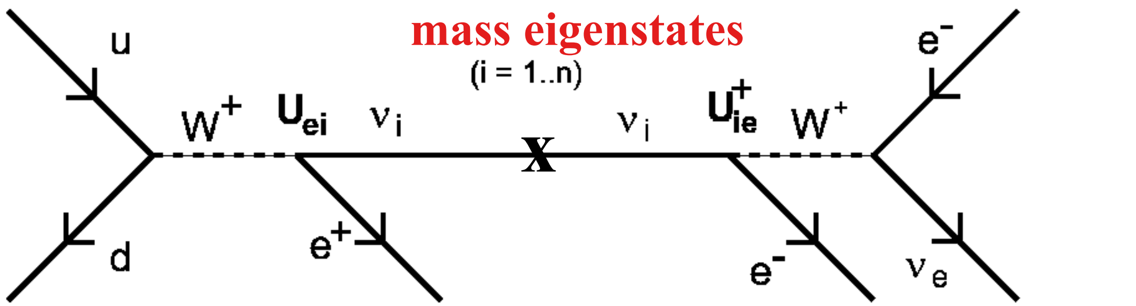
T = 7.06 (8) s
φ = - 0.3 (3)

T = 7.10 (22) s
φ = - 1.3 (4)

What causes the Oscillations?

- **explanations relating the effect to neutrino mixing**
  ➔ discussion of literature ➔ see poster
- **why this is <u>NOT</u> related to neutrino mixing**
  ➔ Feynman diagram of neutrino oscillation:
  - energy momentum properties, quantum numbers
  - e.g. observation of solar neutrinos in ν_e channel

Production
Propagation
Detection

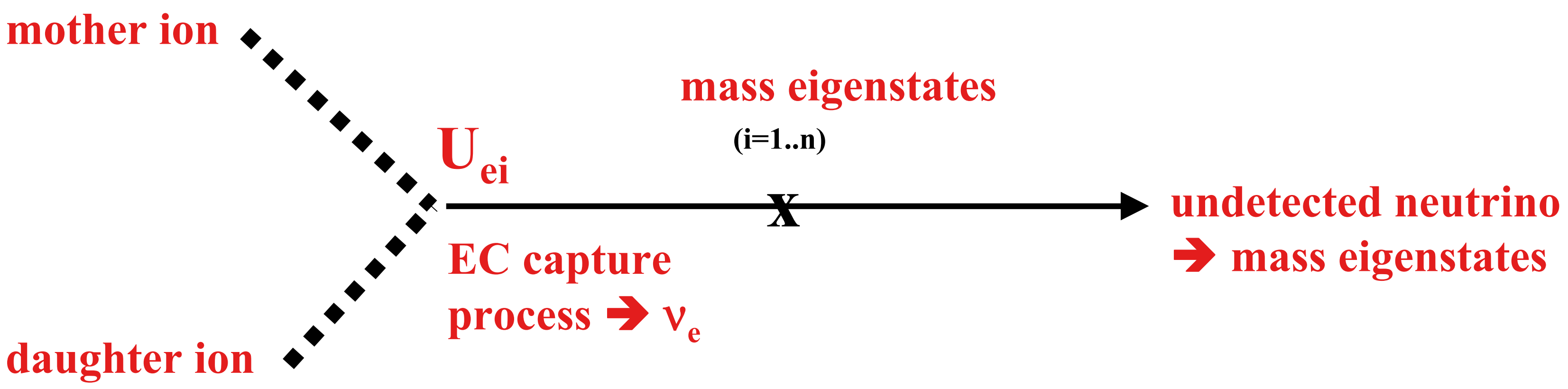


$p + p \rightarrow d + \nu_e + e^+$
solar fusion process ➔ ν_e

electron scattering
➔ projection on ν_e

$$➔ \quad A_{ee} = \sum |U_{ei}|^2 e^{ip_i x} = \ldots \qquad +\mathrm{MSW}$$

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

b) Finite kinematical resolution much smaller than neutrino masses ➔ all three mass eigenstates contribute <u>incoherently</u>

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

Checks / Questions / Problems

Carefully checks:

- 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 / problems?

- 3.5σ → could be a statistical fluctuation
- ? suppressed statistical bin-to-bin fluctuations →15
- ? scaling of amplitude of the Schottky-signal →9
- ! primary signal unobserved: noise >> individual ion signal →6
- ? relative phase Pr / Pm → 15+16

Summary and Outlook

- observation of an unexplained periodic modulation of the decay of H-like HCIs (3.5σ)
- *NOT* related to neutrino mixing
- conceivable: tiny splitting of a 2 level mother system
  - how to explain such a tiny split?
  - coherence length?
- many careful checks of all sort of systematics have been performed
- however: some unexplained statistical properties of data

➔ new run with different element approved ~fall