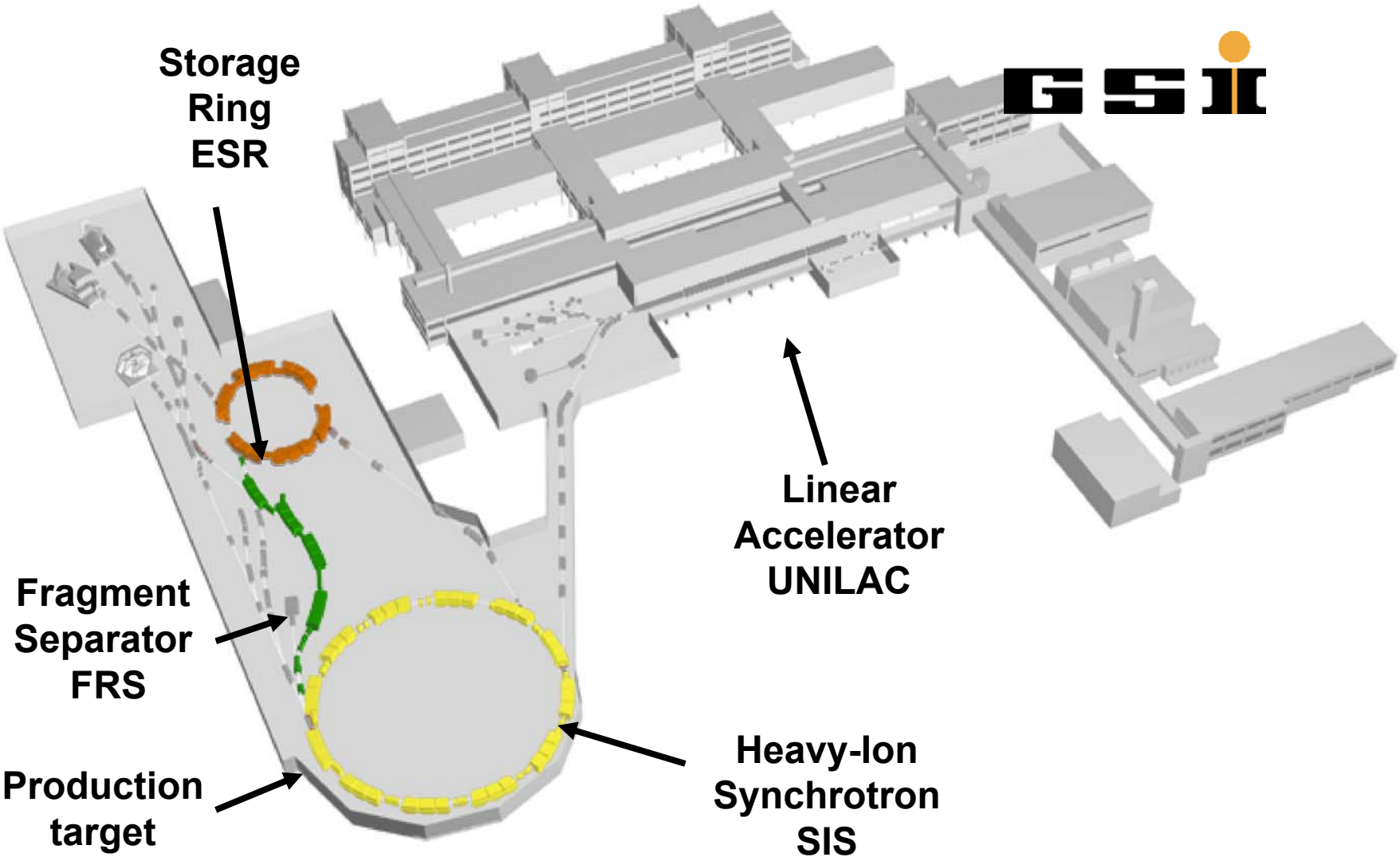
Orbital electron capture decay of stored highly-charged ions

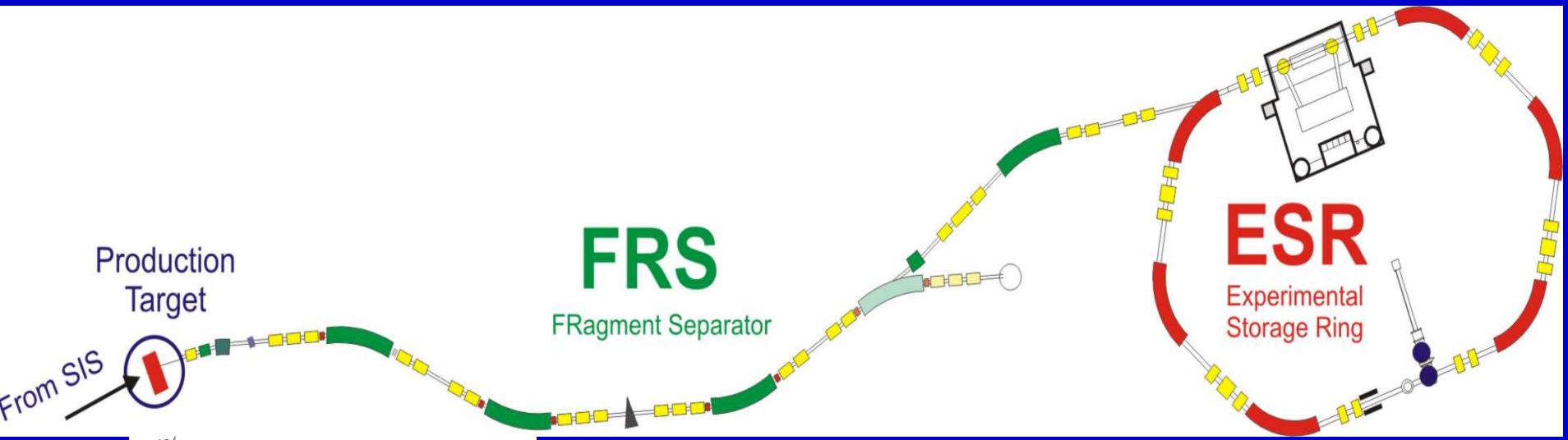
EMMI Workshop, 28. June 2010

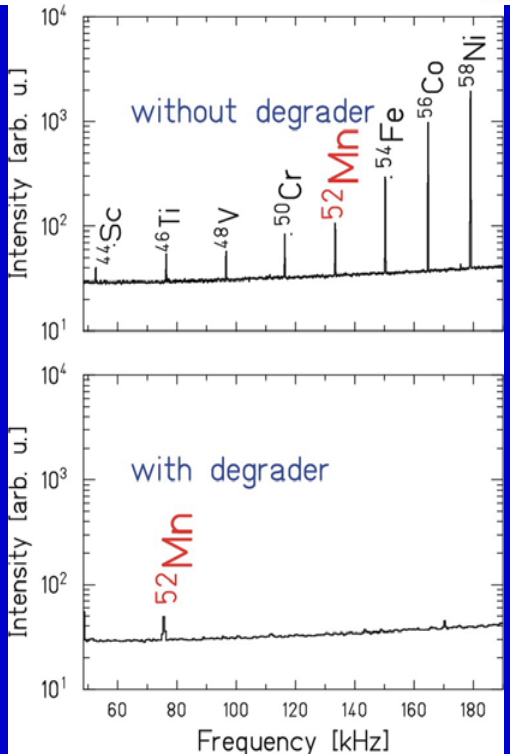
Nicolas Winckler, **MPI-K** Heidelberg

1. Experimental setup
2. Many-ion decay spectroscopy
3. Single-ion decay spectroscopy
4. Outlook


Storage
Ring
ESR
Linear
Accelerator
UNILAC
Fragment
Separator
FRS
Production
target
Heavy-Ion
Synchrotron
SIS

Production & Separation of Exotic Nuclei



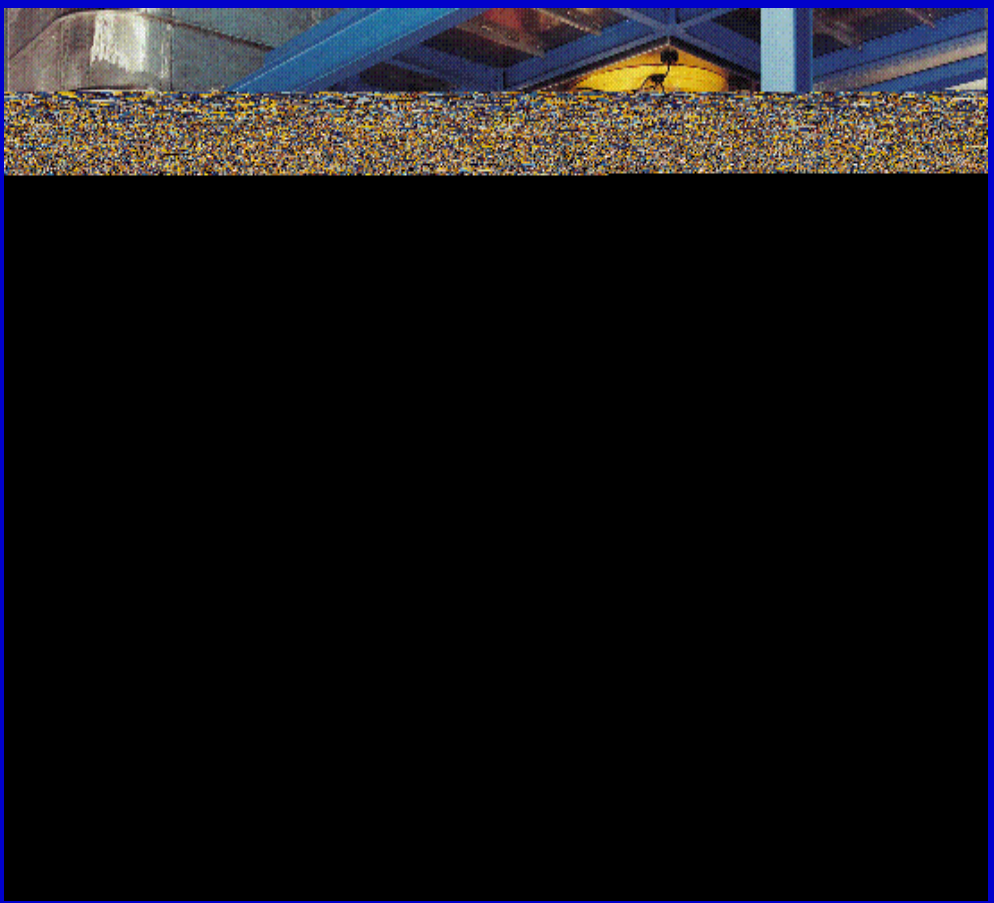


ESR: 108 m, 10^{-11} mbar, 2 MHz,
E= 400 MeV/u,
stochastic + electron cooling

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

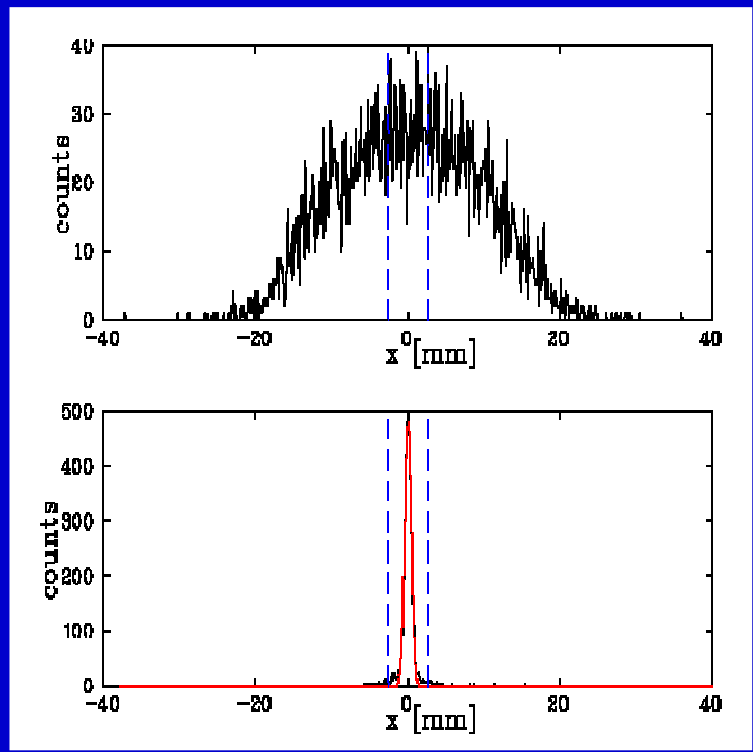
"Cooling": enhancing the phase space density

Electron cooling: G. Budker, 1967 Novosibirsk



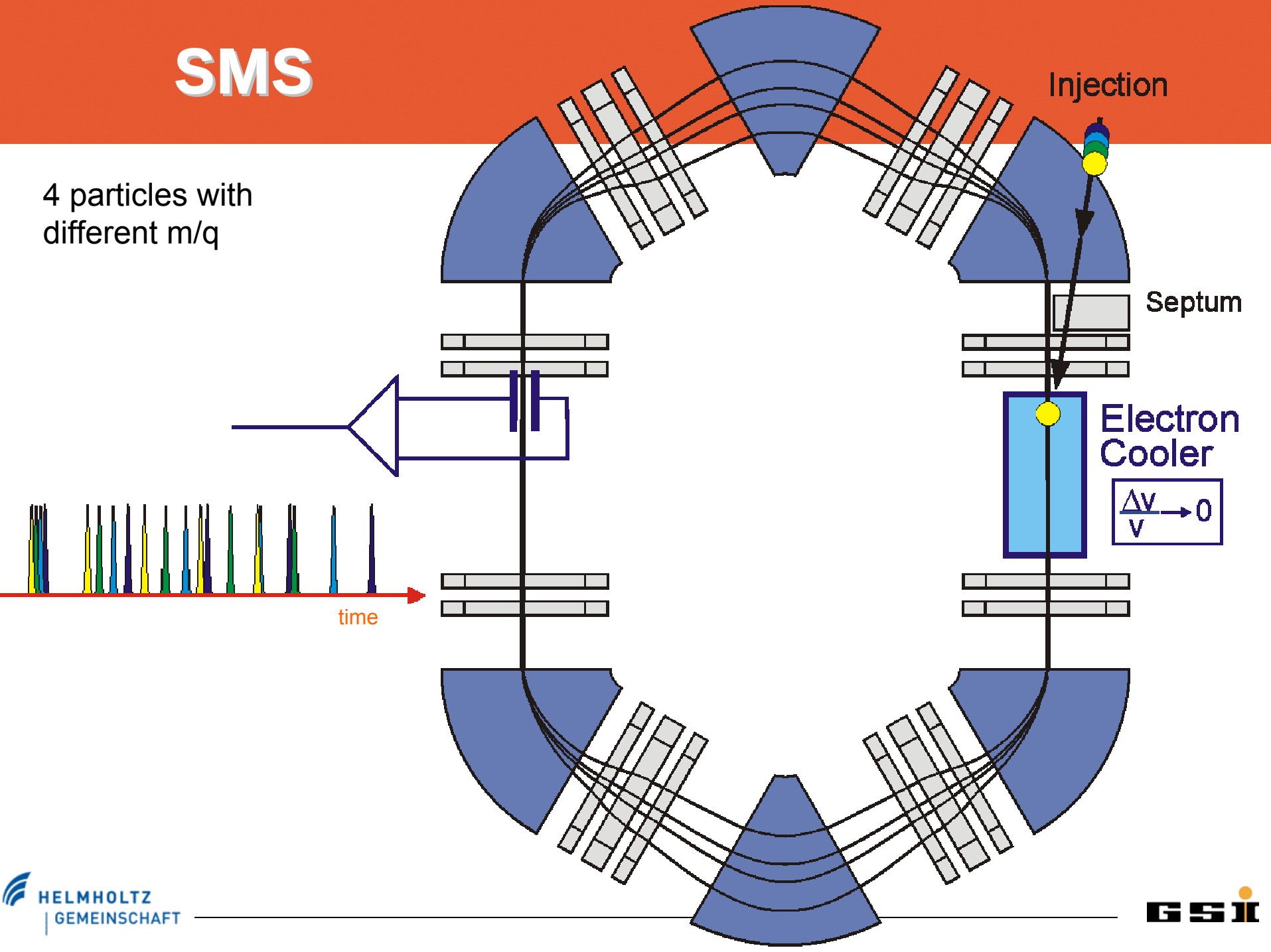
Momentum exchange

with a cold, collinear e^- beam. The ions get the **sharp velocity** of the electrons, small size and small angular divergence



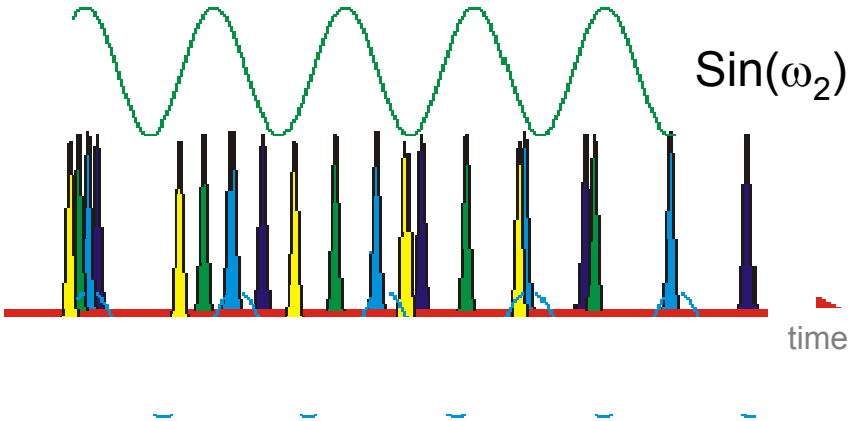
SMS

4 particles with
different m/q



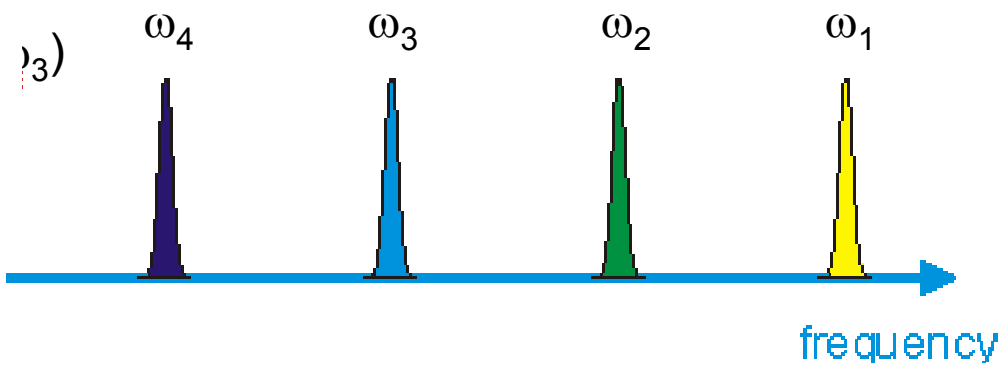
SMS

$\mathrm{Sin}(\omega_1)$

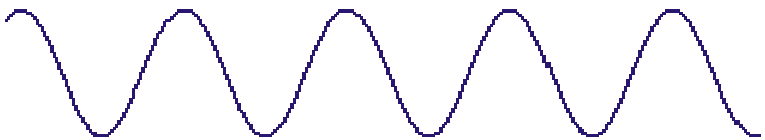


$\mathrm{Sin}(\omega_2)$

$\mathrm{Sin}(\omega_3)$

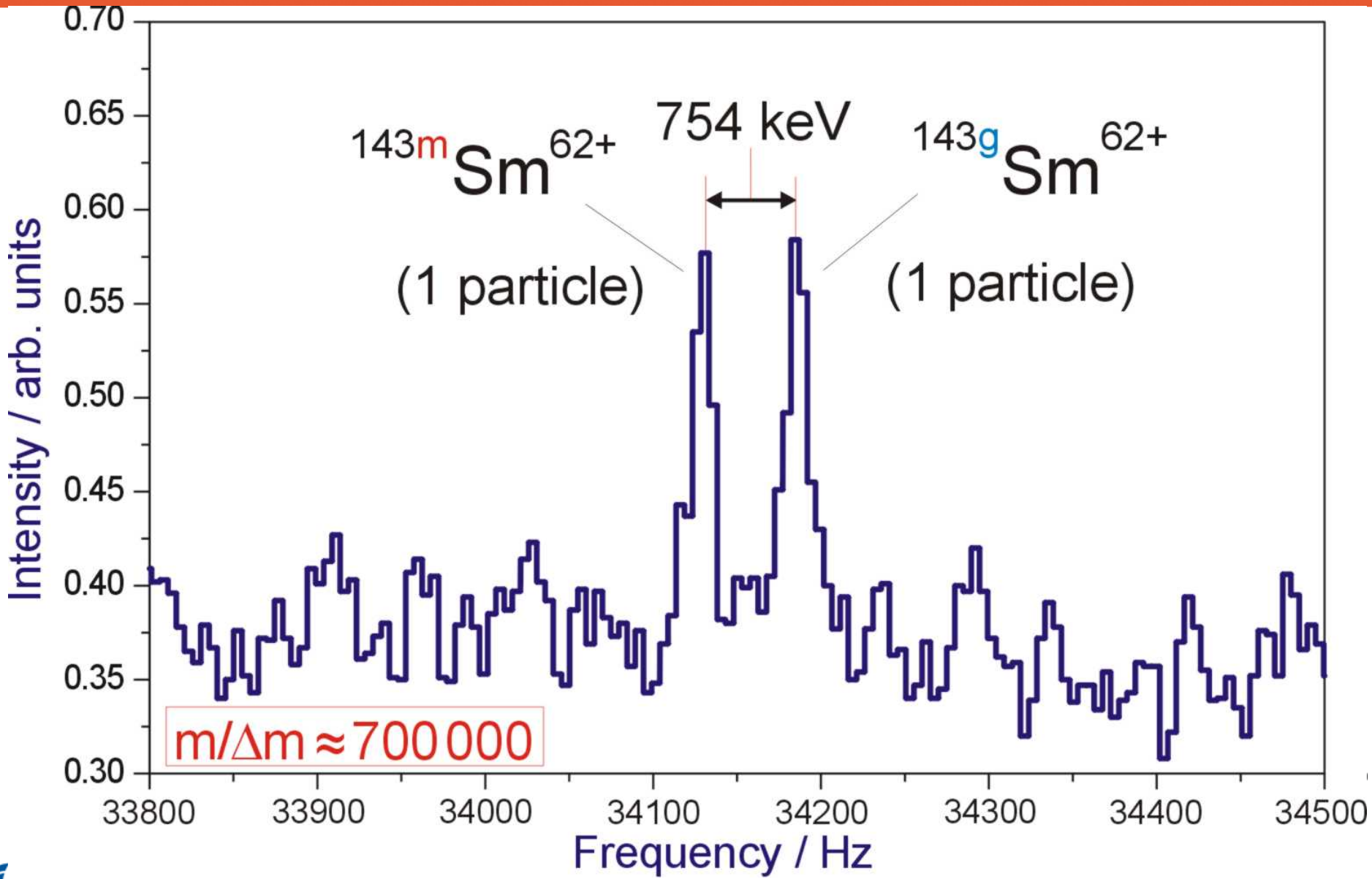


Fast Fourier Transform

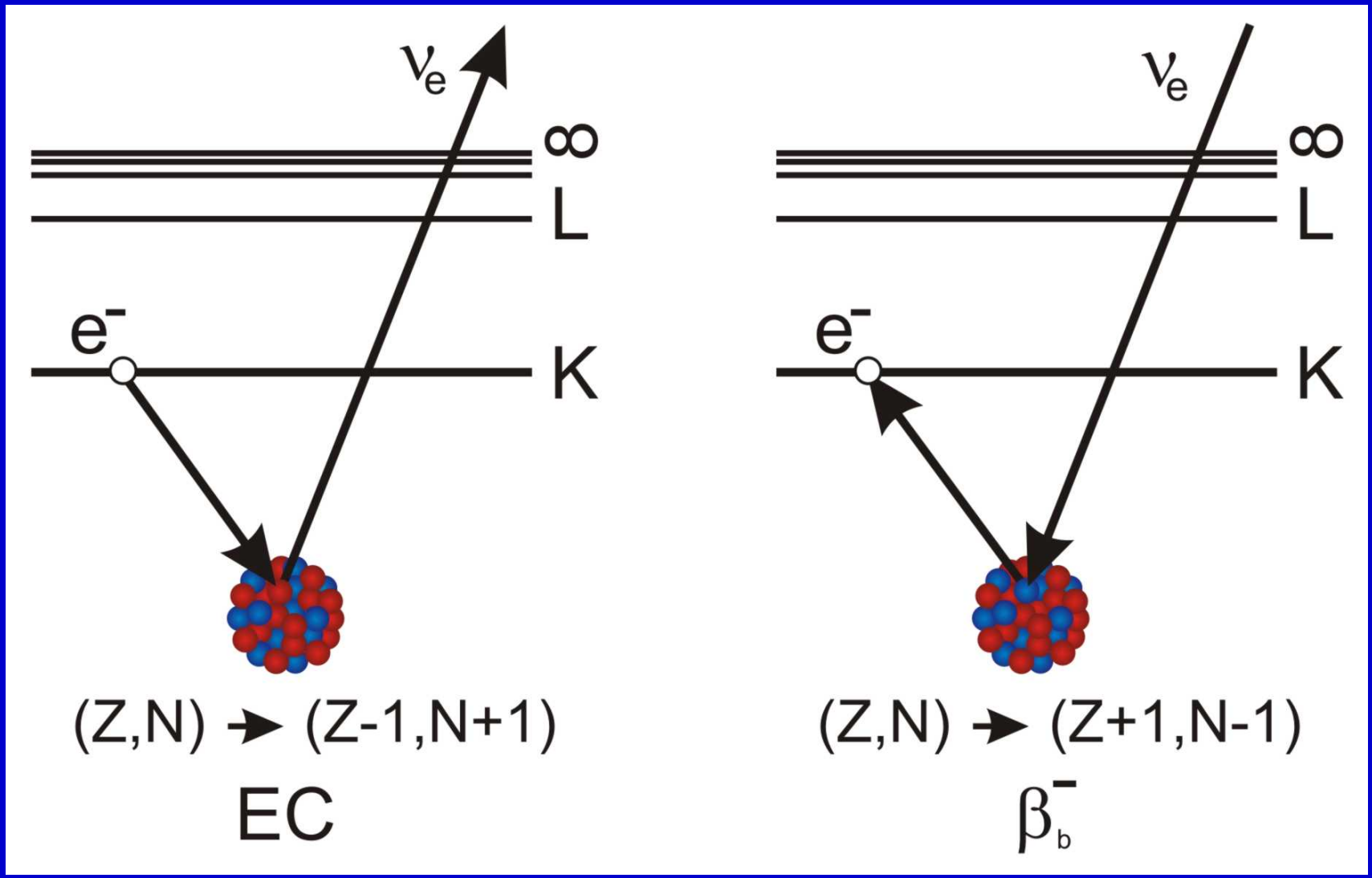


$\mathrm{Sin}(\omega_4)$

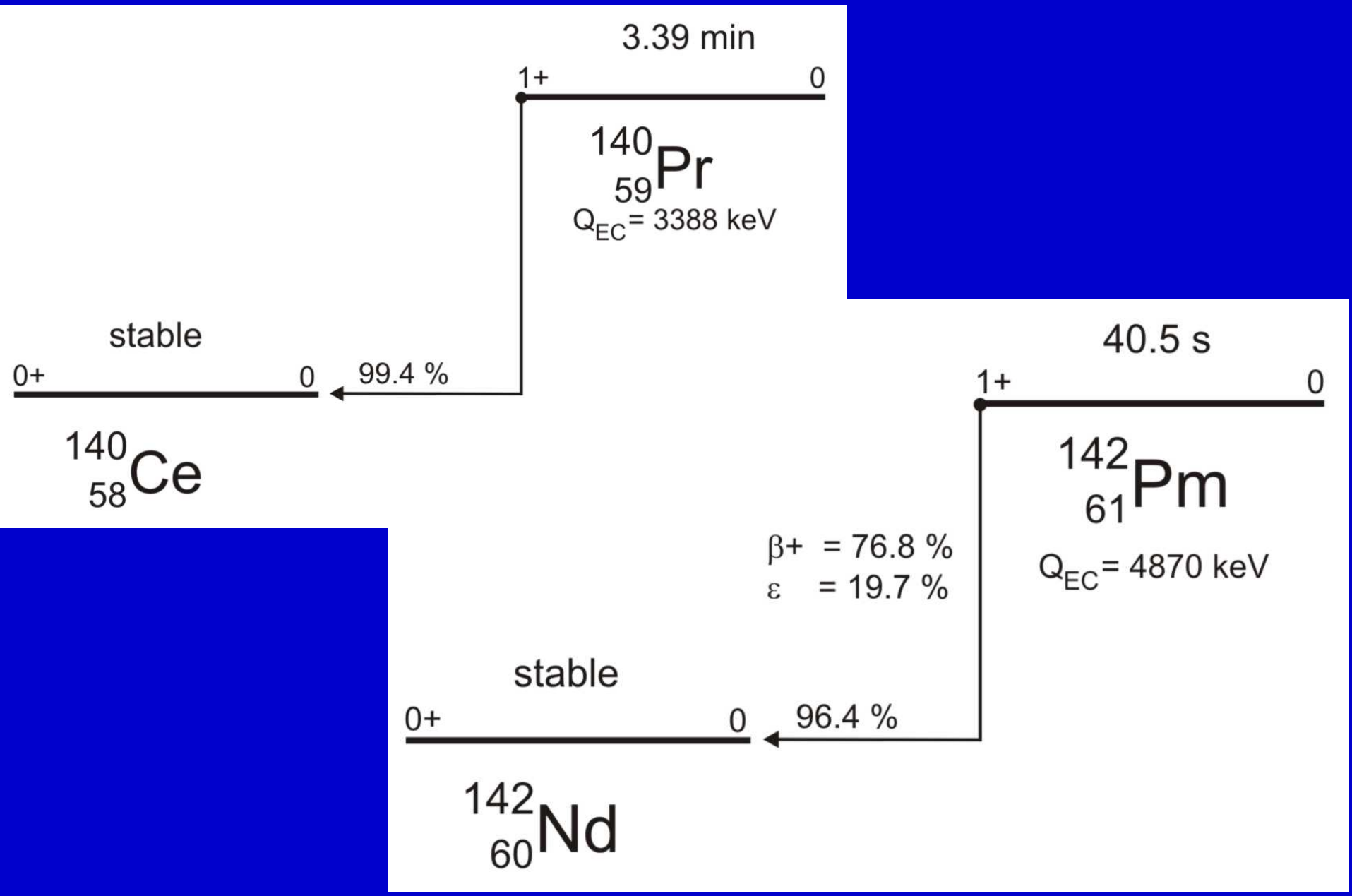
Broad-band Schottky frequency spectra



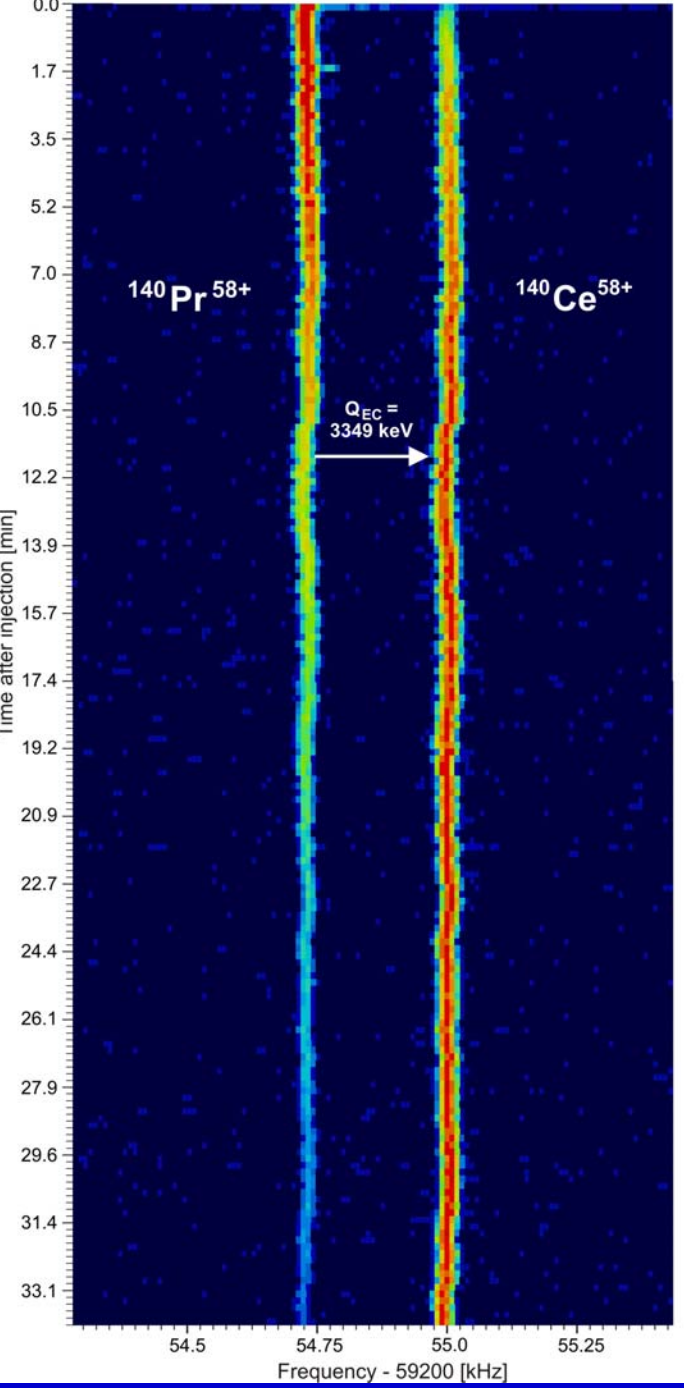
Two-body beta decay of stored and cooled highly-charged ions

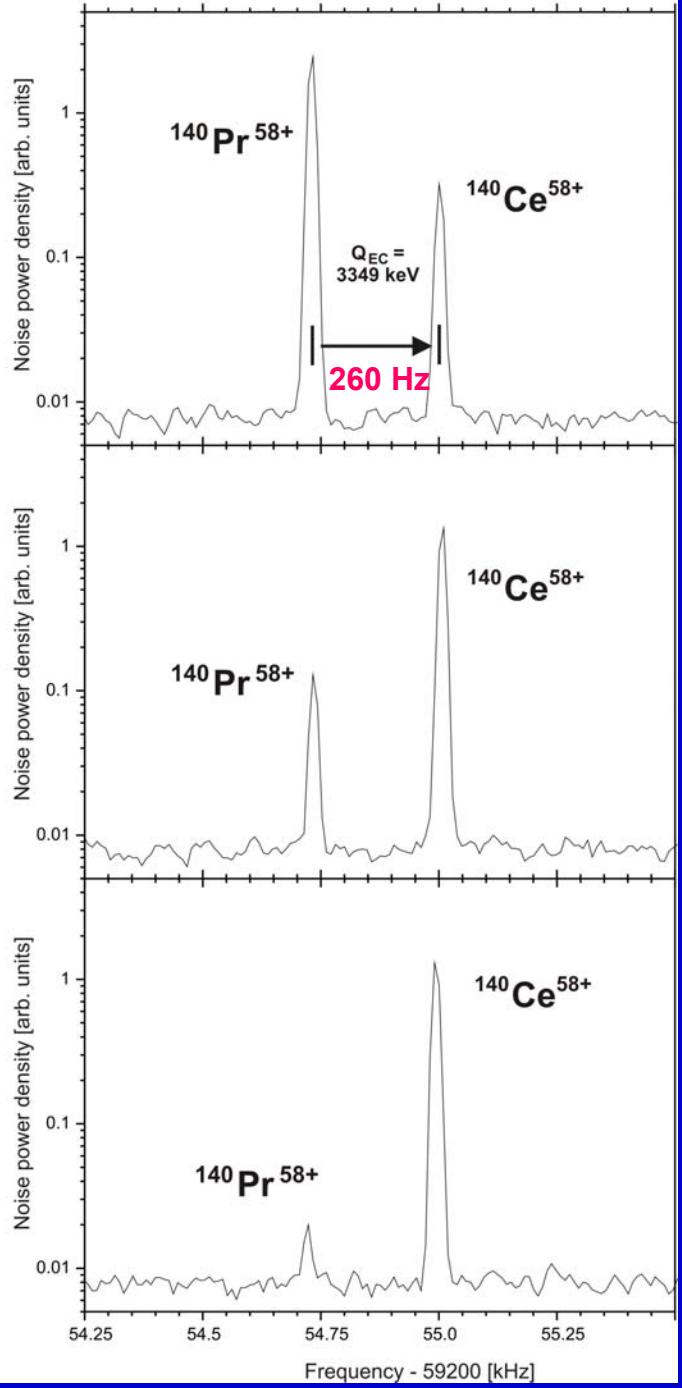


Decay Schemes



Two-body beta decay





f scales as ***m/q***

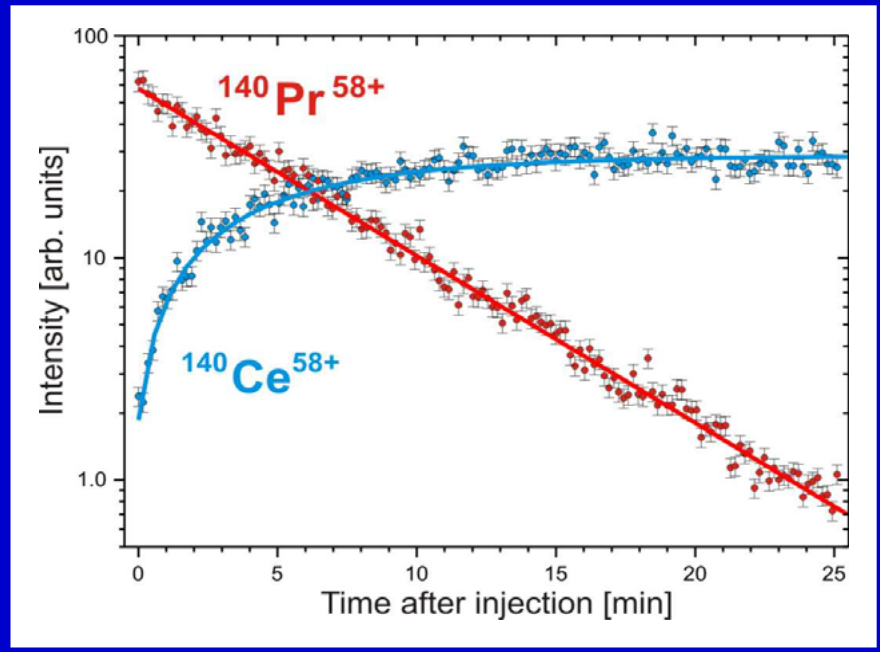
Two-body β decay:
q does **not** change

Change of ***f*** only due to **change of mass**

EC Decay Rates

^{140}Pr

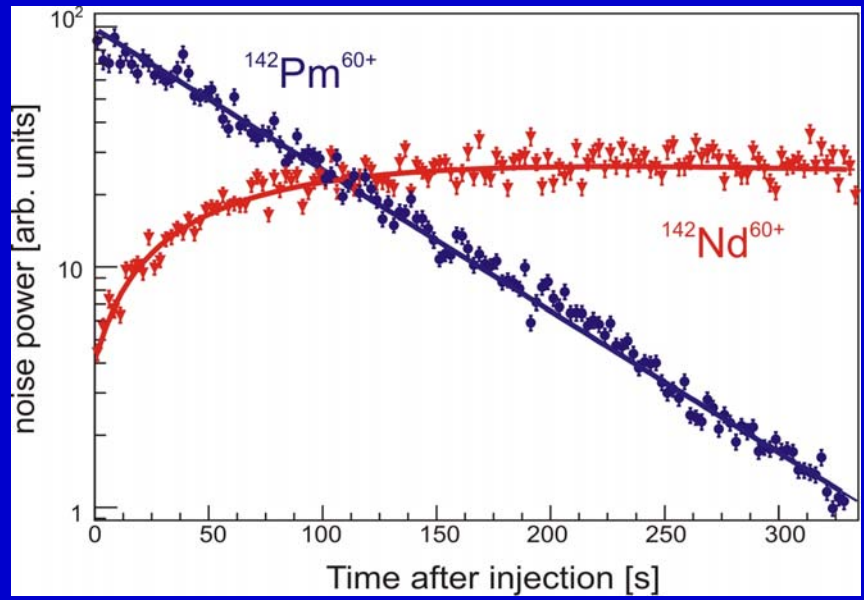
λ_{EC}(H-like)/λ_{EC}(He-like) = 1.49(8)



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

^{142}Pm

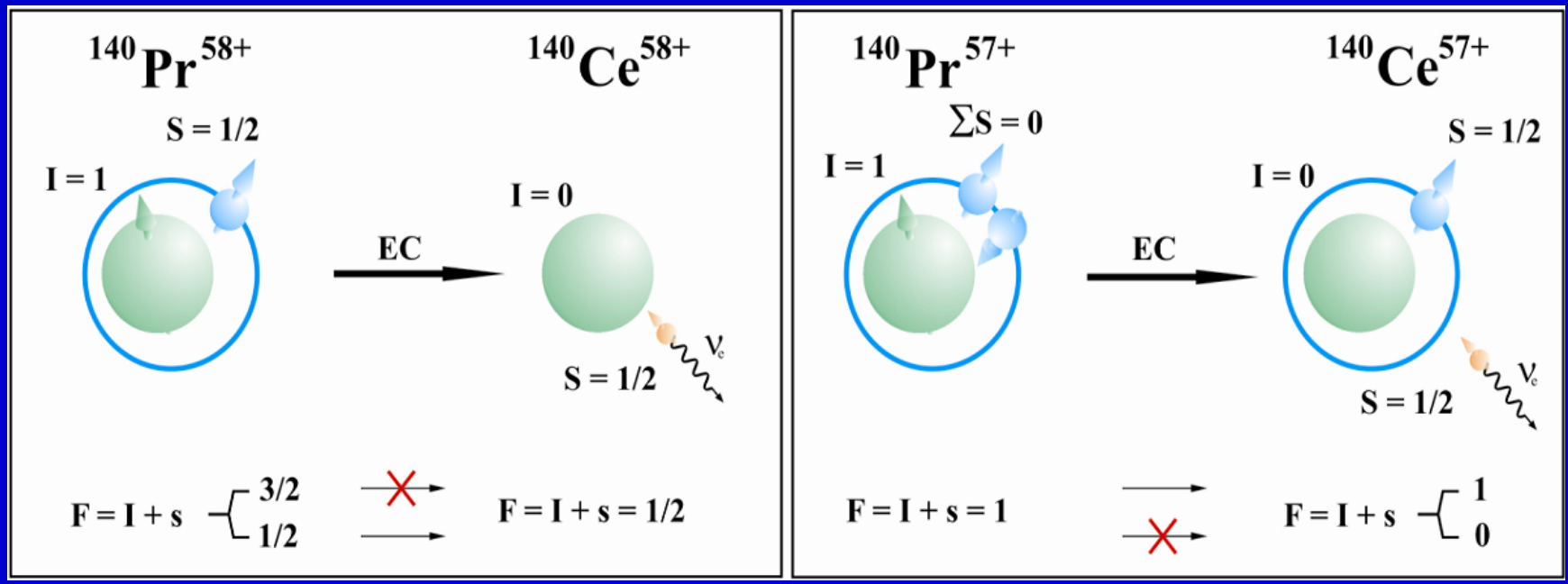
λ_{EC}(H-like)/λ_{EC}(He-like) = 1.44(6)



N. Winckler et al., Phys. Lett. B 679 (2009) 36-40

Electron Capture in Hydrogen-like Ions

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



$\mu = +2.7812\mu_N$

I. N. Borzov et al., Phys. Atomic nuclei

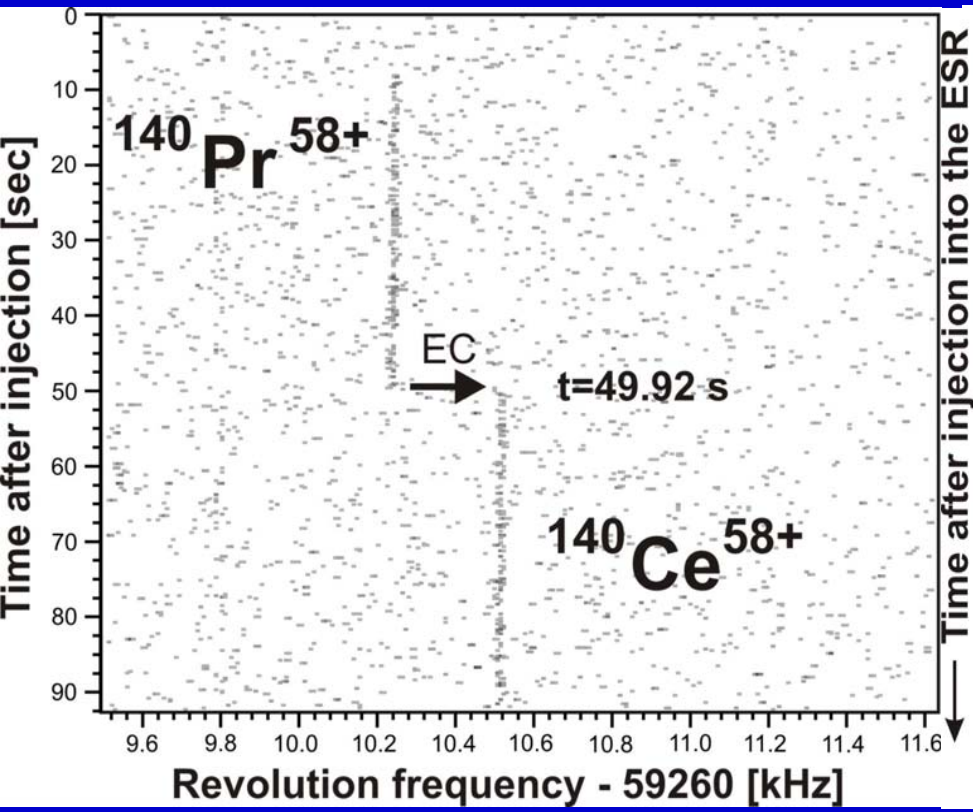
Theory: **λ(H)/λ(He) = (2I+1)/(2F+1)**

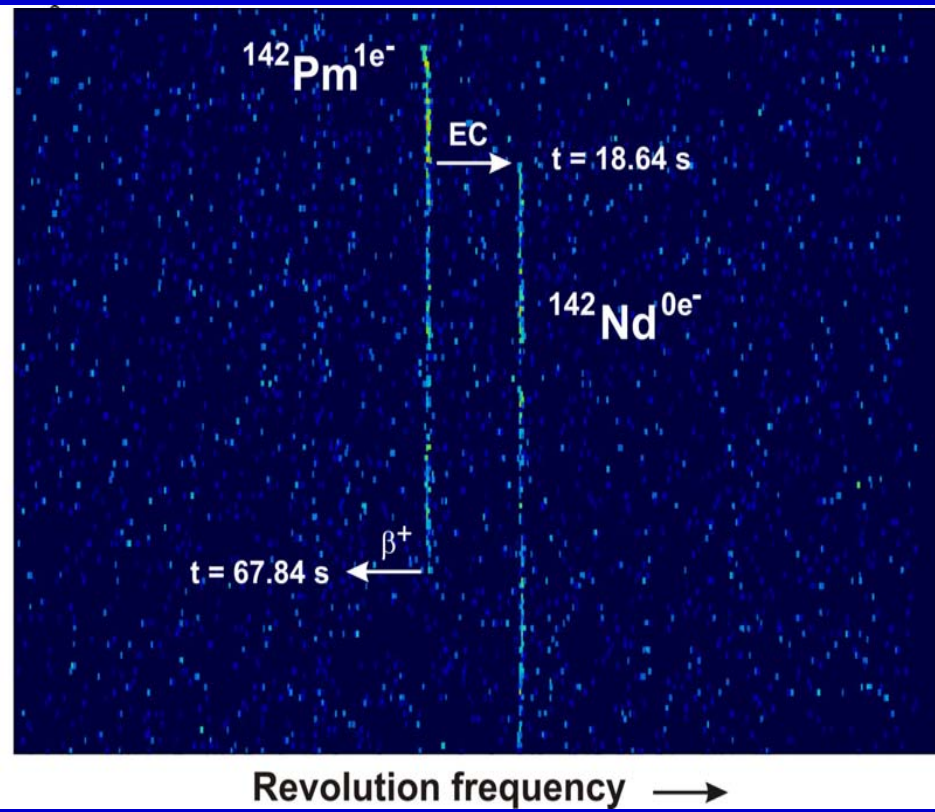
Z. Patyk et al., Phys. Rev. C 77 (2008) 014306

		Theory	Measurement
Ratio H/He:	^{140}Pr →	3/2	1.49 (9)
	^{142}Pm →	3/2	1.44 (6)

Single ion decay spectroscopy

Examples of Measured Time-Frequency Traces





Continuous observation

Parent/daughter correlation

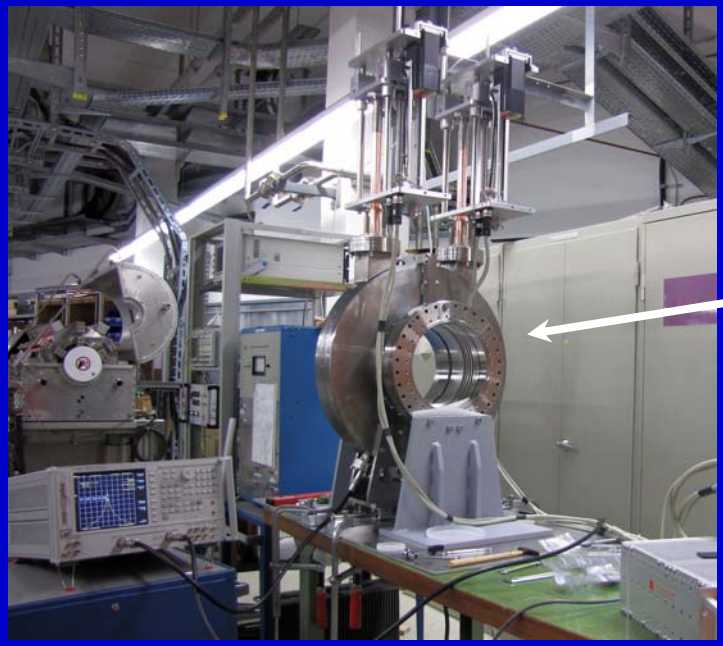
Well defined creation time

Detection of ALL EC decays

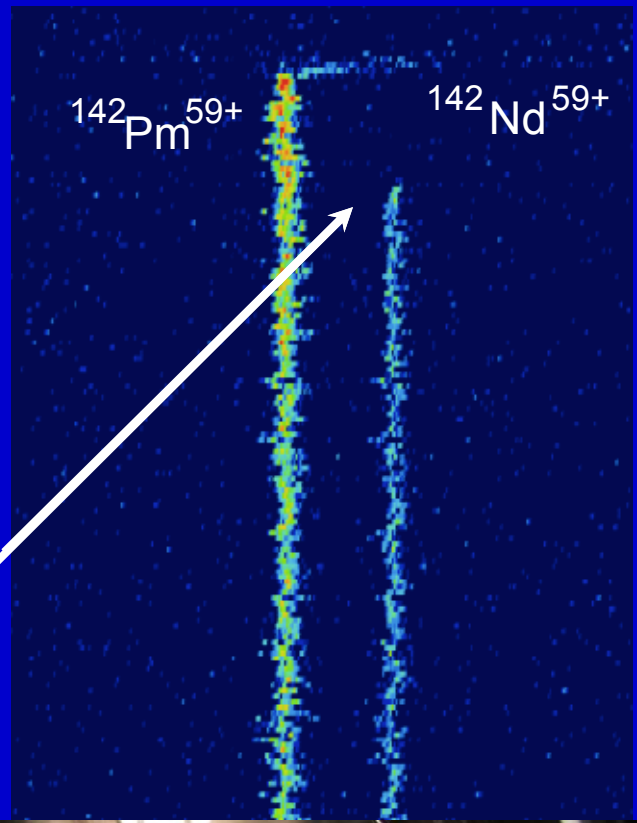
Delay between decay and "appearance" due to cooling

Restricted counting statistics

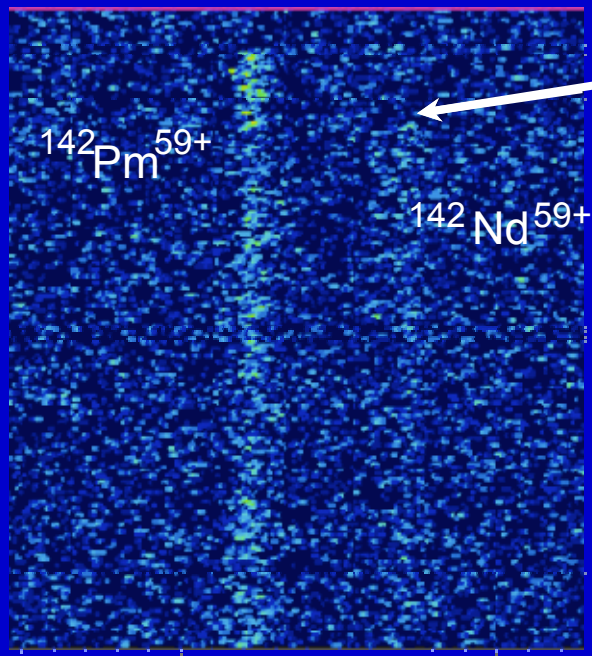
First EC-decay of He-like ^{142}Pm ions measured in E082 experiment



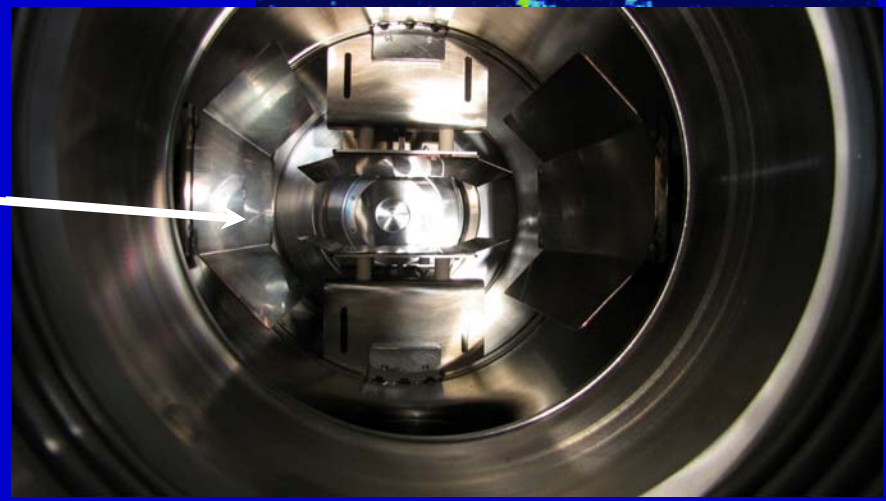
New resonator cavity (2010)
124th harmonic



the same decay: improvement by a factor of about 100



Old Schottky pickup (1992)
30th harmonic

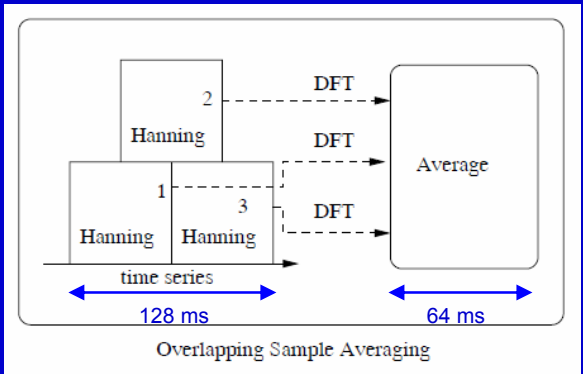


Folienquelle:
Y Litvinov – Email am 17.04.2010

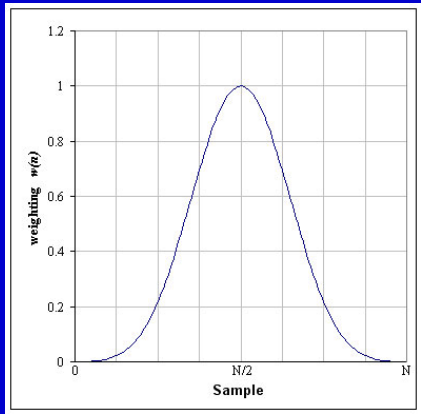
Old Schottky pick up

Data provided by the Sony real-time spectrum analyzer in frequency domain representation

Welch‘s overlapped segment averaging



Blackman–Harris window



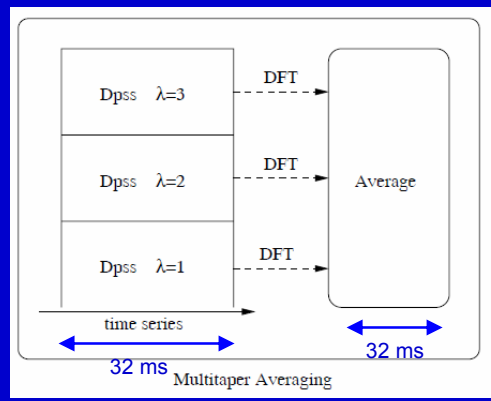
$$X_k(f) = \mathrm{DFT}(w_k(t)x(t))$$

New resonator cavity

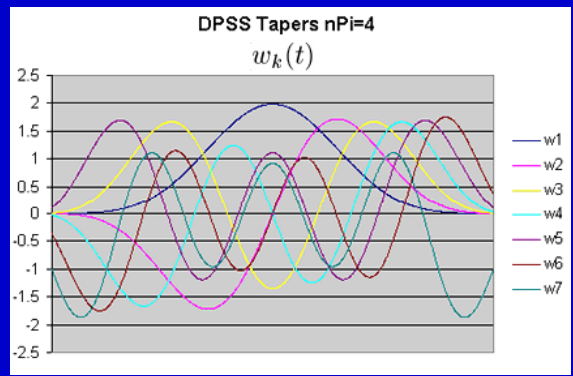
Data provided by the Tektronix real-time spectrum analyszer in time domain representation

Multitaper method

(F. Nolden, to be published)



discrete prolate spheroidal sequences (DPSS)



$$P_X(f) = \frac{\sum_{k=1}^{K} \mu_k |X_k(f)|^2}{\sum_{k=1}^{K} \mu_k}$$

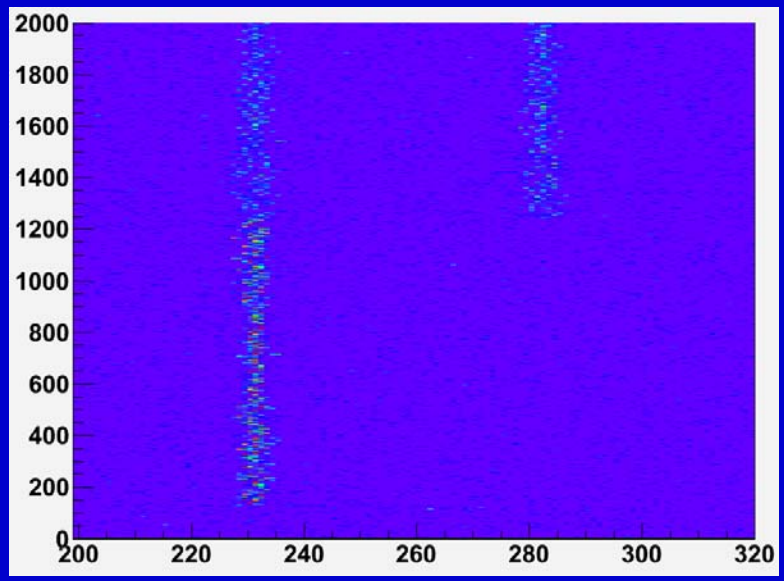
$$X_k(f) = \mathrm{DFT}(w_k(t)x(t))$$

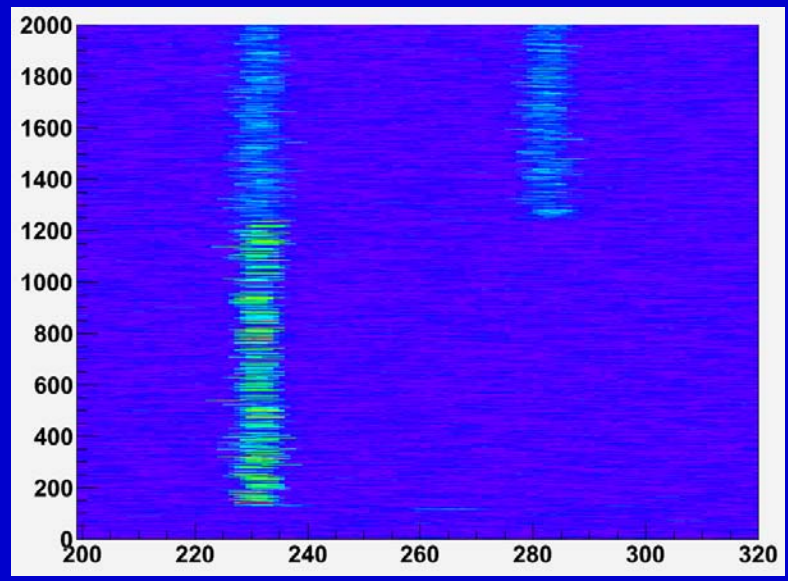
Comparison Wosa vs MTM for identical input

Welch‘s overlapped segment averaging (Wosa)

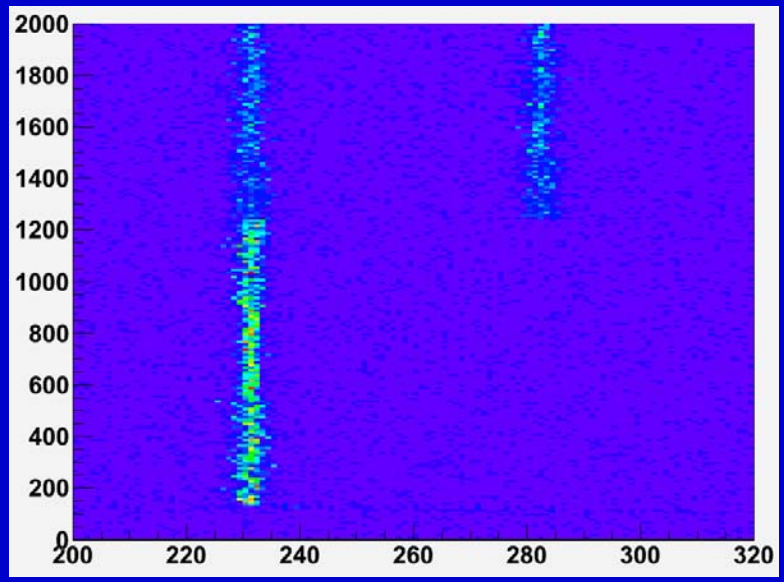
Multitaper Method (MTM)

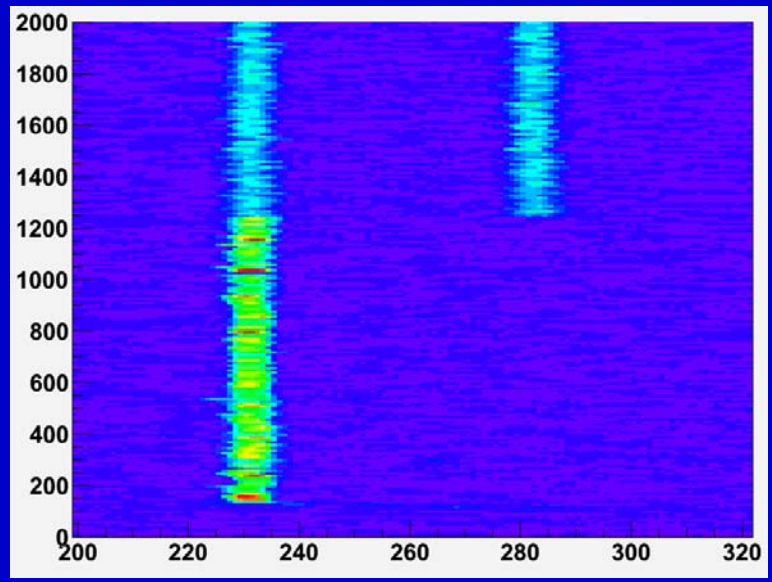
Binning: 1 frame (32 ms)



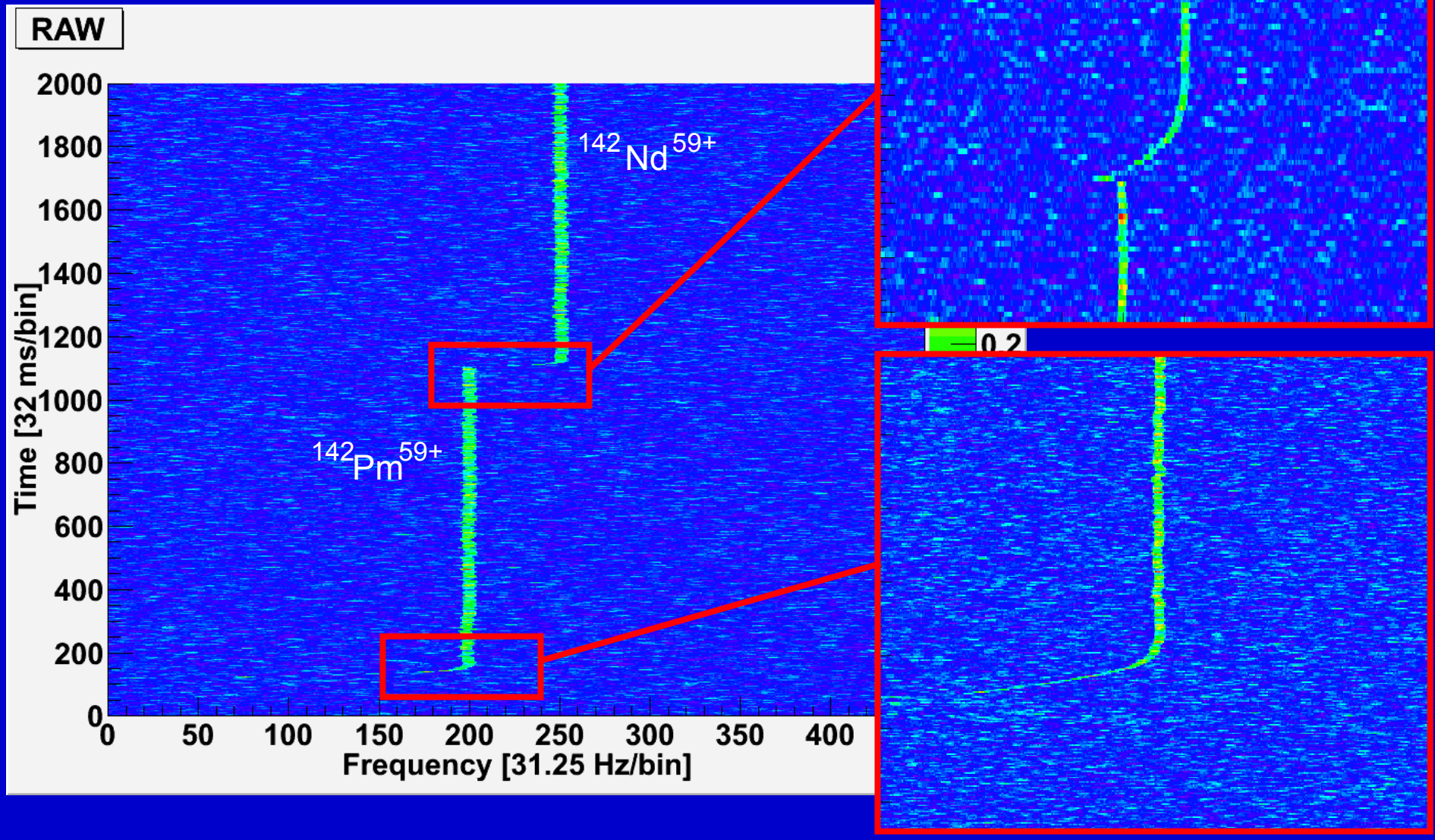


Binning: 10 frames (320 ms)

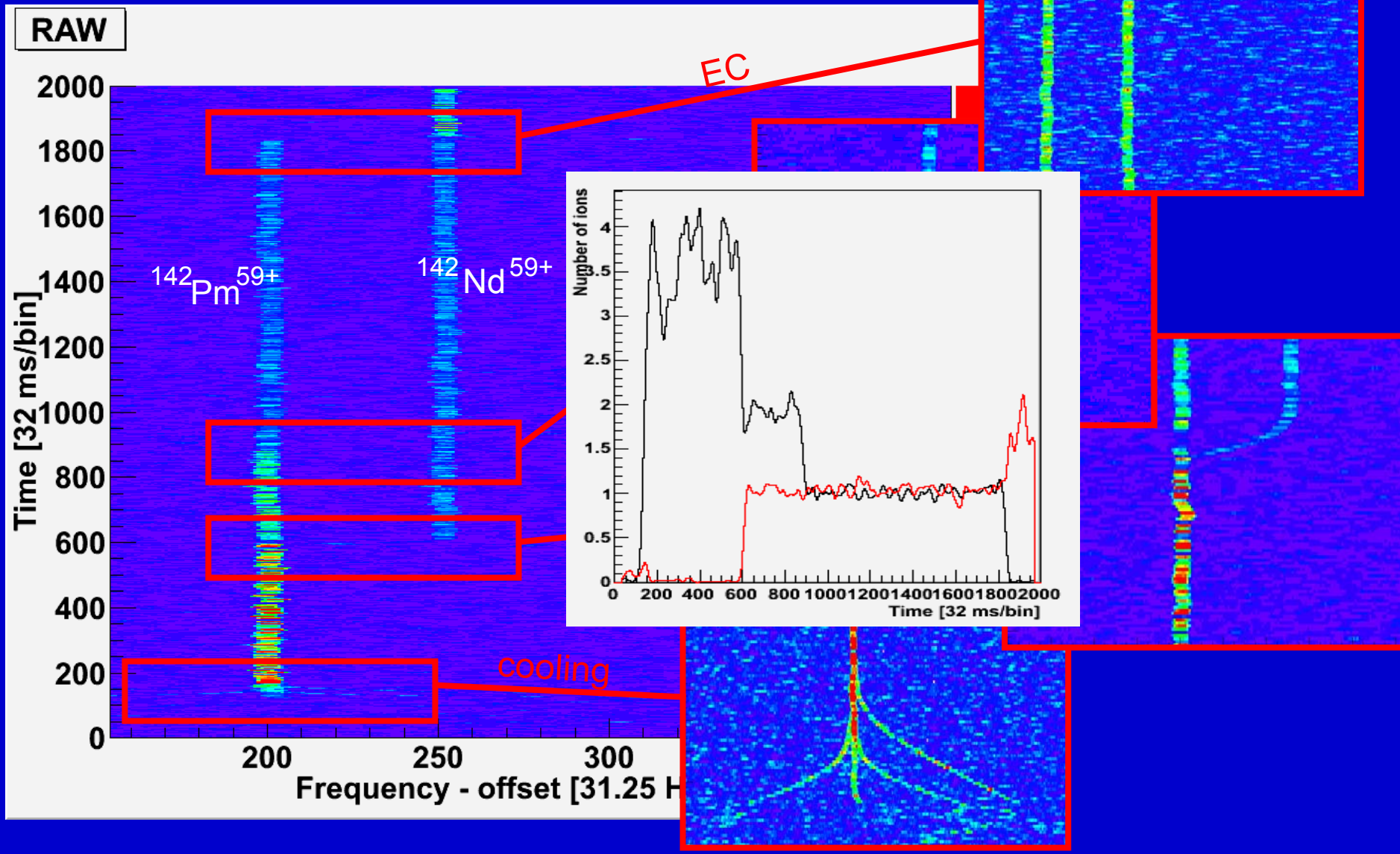




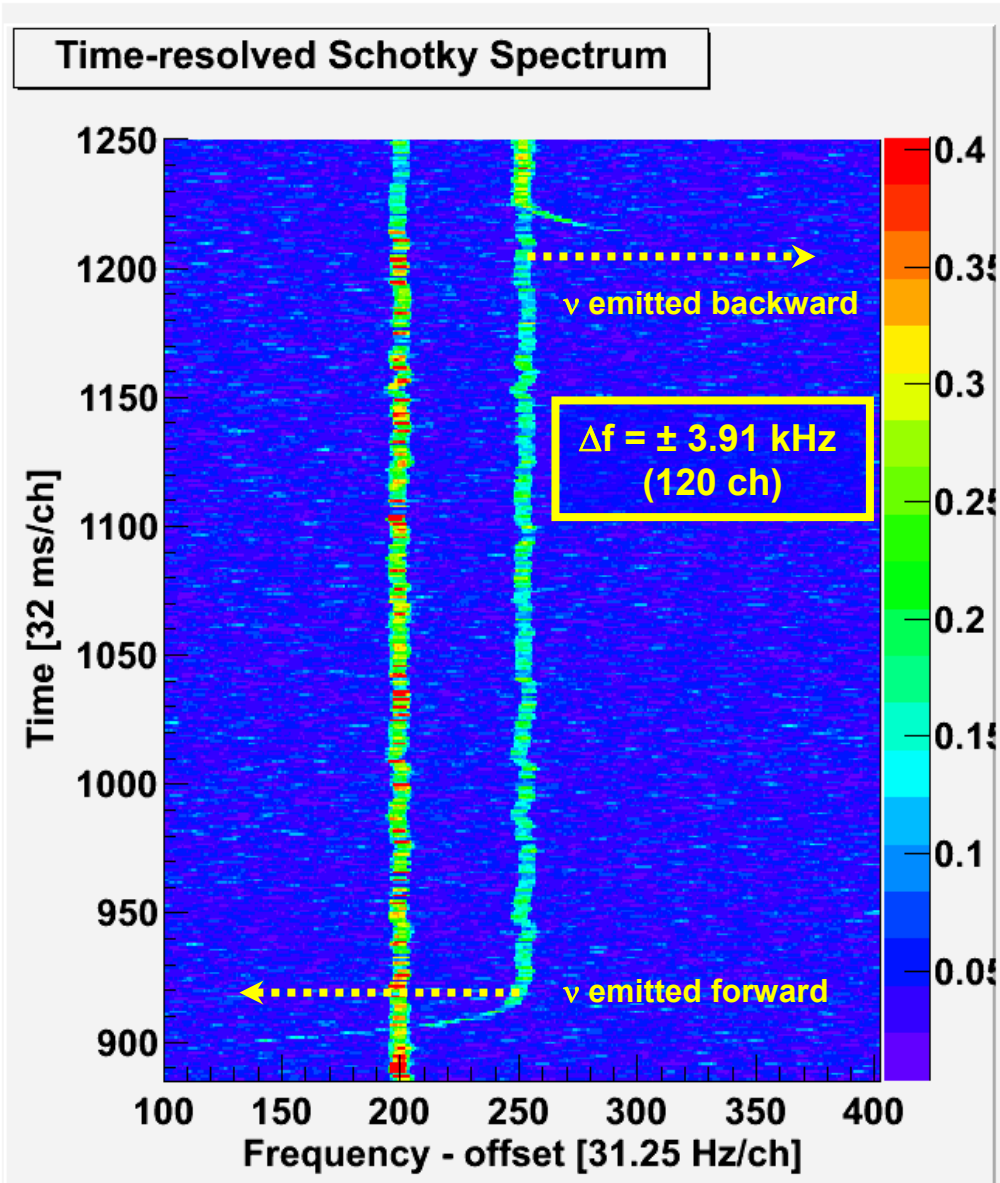
Example of one parent ion which decays to one EC-daughter ion

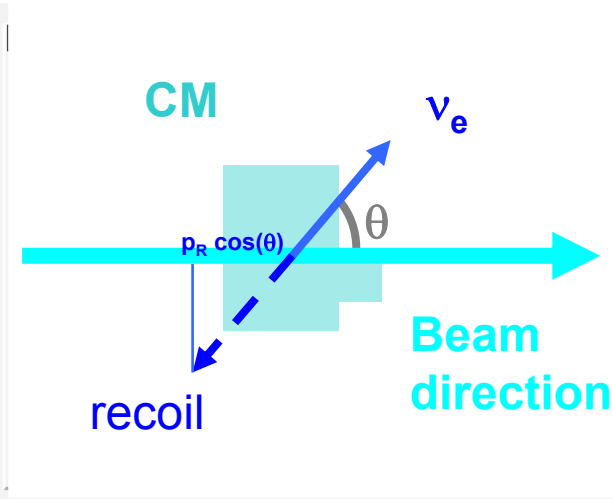


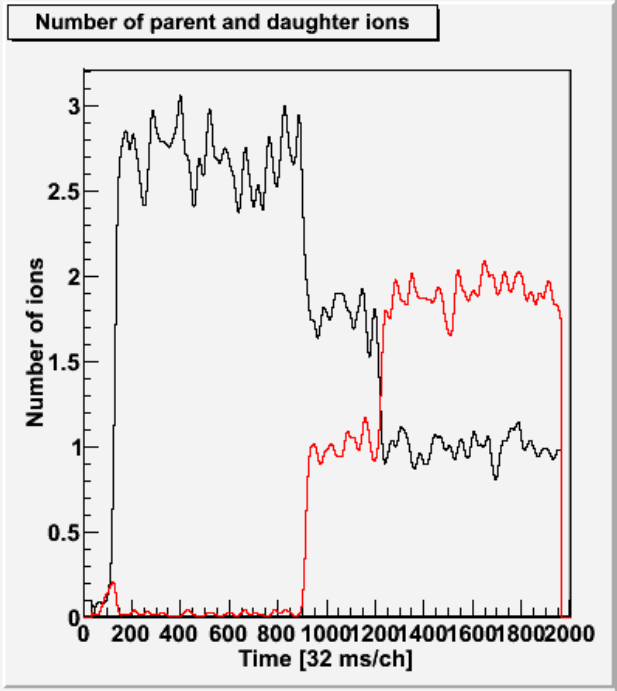
Example with 4 parent ions, 2 EC and 2 β^+ -decays

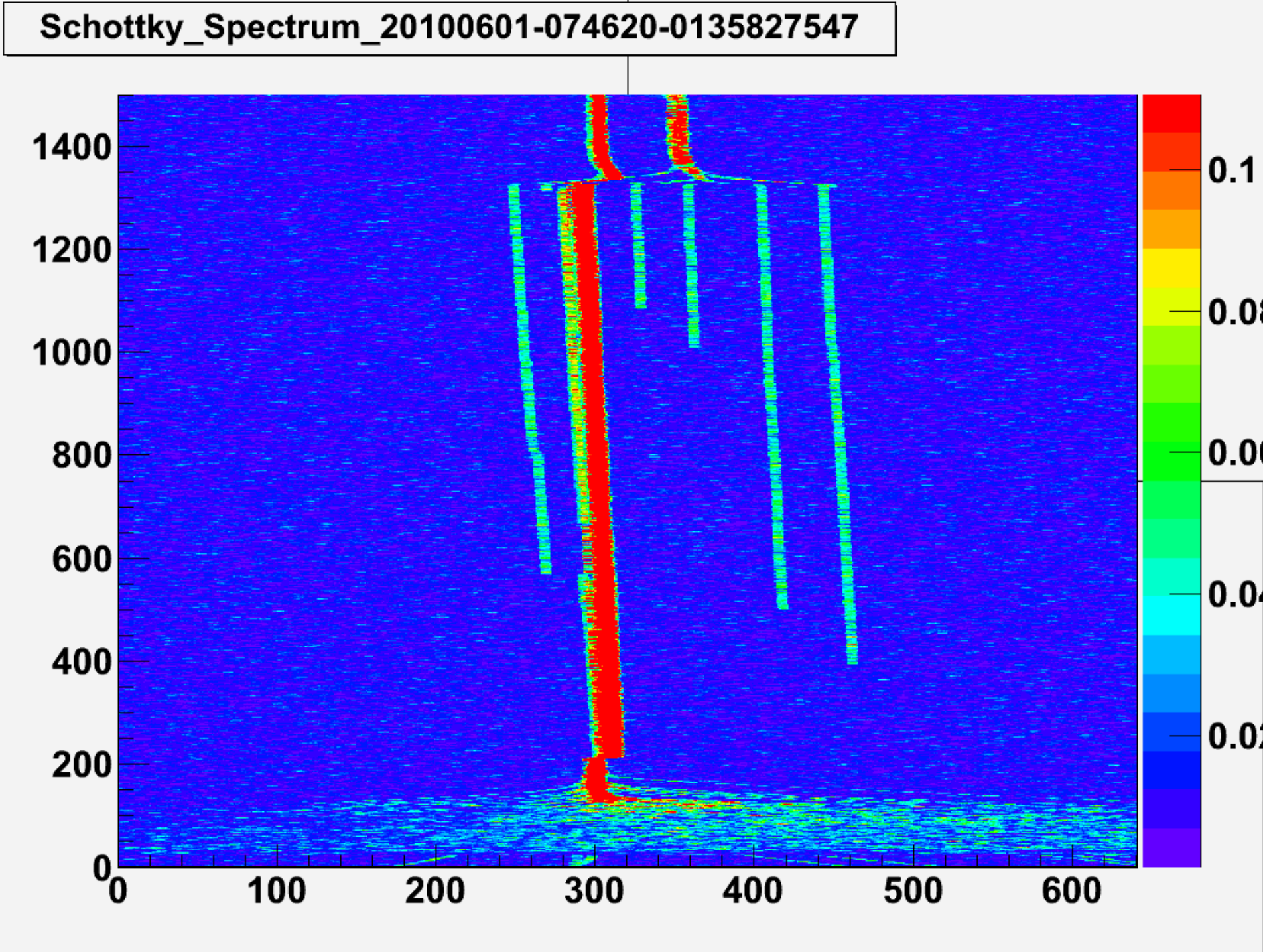


Another example with 3 parents and 2 EC-decays





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1000
800
600
400
200
0
0
100
200
300
400
500
600
0.1
0.08
0.06
0.04
0.02

FRS-ESR Mass - and Lifetime Collaboration

D. Atanasov, P. Beller†, K. Blaum, F. Bosch, D. Boutin, C. Brandau, L. Chen, I. Cullen, Ch. Dimopoulou, H. Essel, Th. Faestermann, B. Franczak, B. Franzke, H. Geissel, E. Haettner, M. Hausmann, S. Hess, P. Kienle, O. Klepper, H.-J. Kluge, Ch. Kozhuharov, R. Knöbel, R. Krücken, J. Kurcewicz, S.A. Litvinov, Yu.A. Litvinov, L. Maier, M. Mazzocco, F. Montes, A.Musumarra, G. Münzenberg, C. Nociforo, F. Nolden, T.Ohtsubo, A. Ozawa, Z. Patyk, W.R. Plass, A. Prochazka, R. Reuschl, S. Sanjari, Ch. Scheidenberger, D. Shubina, U. Spillmann, M. Steck, Th. Stöhlker, B. Sun, K. Suzuki, K. Takahashi, S. Torilov, M. Trassinelli, S. Trotsenko, P.M. Walker, H. Weick, S. Williams, M. Winkler, N. Winckler, D. Winters, T. Yamaguchi

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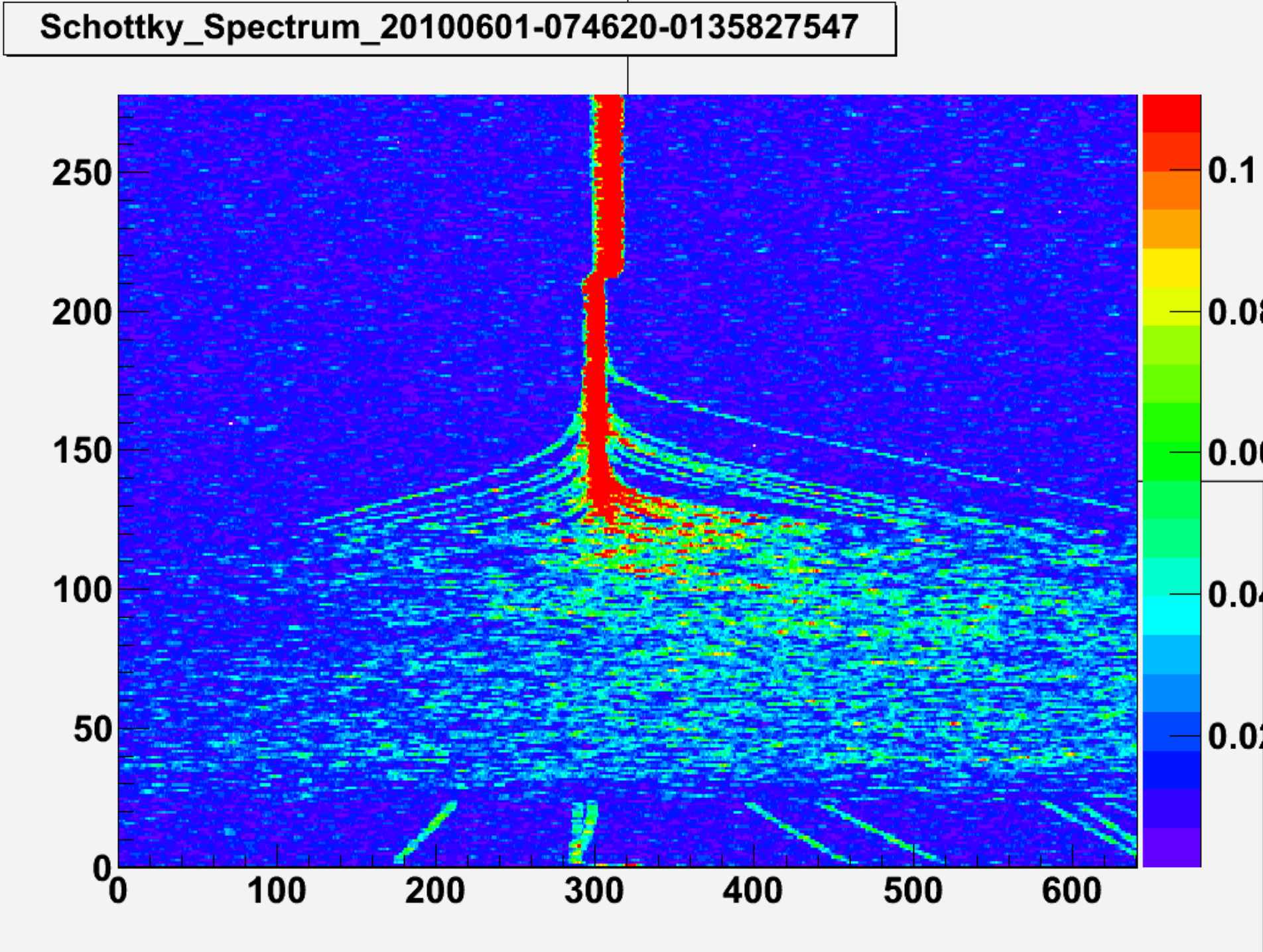
Niigata University

Max-Planck-Institut für Kernphysik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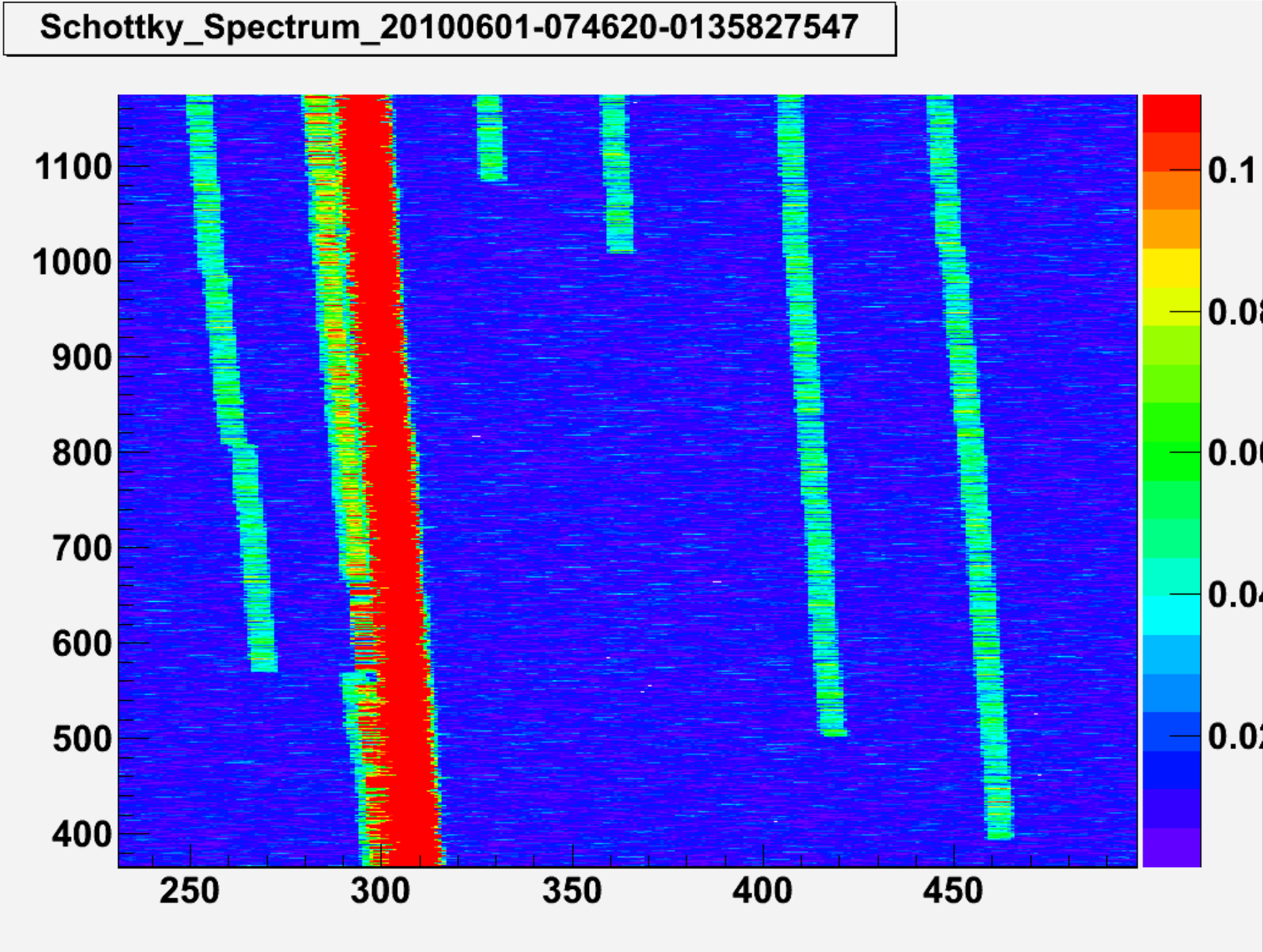
0.08
0.06
0.04
0.02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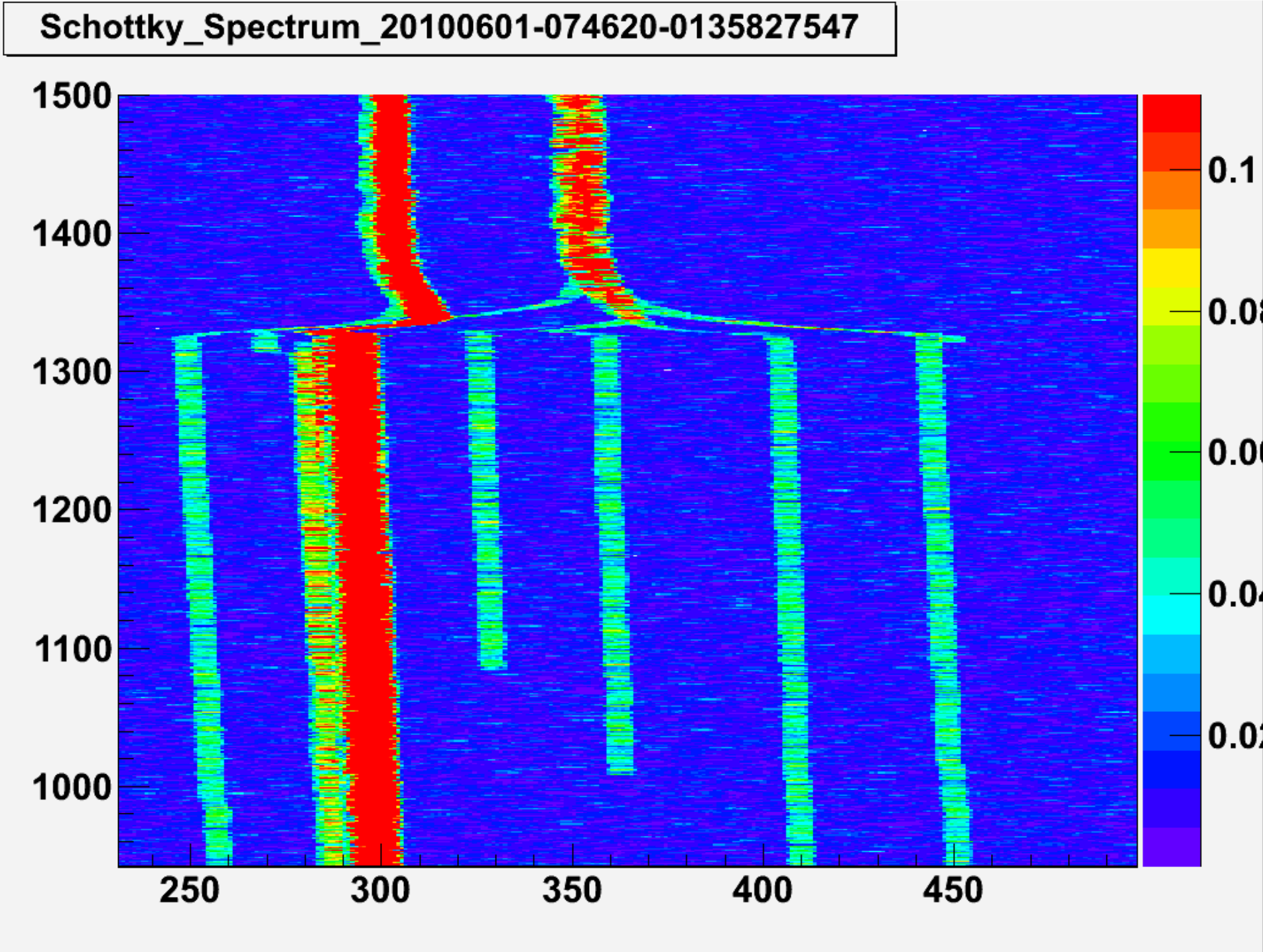
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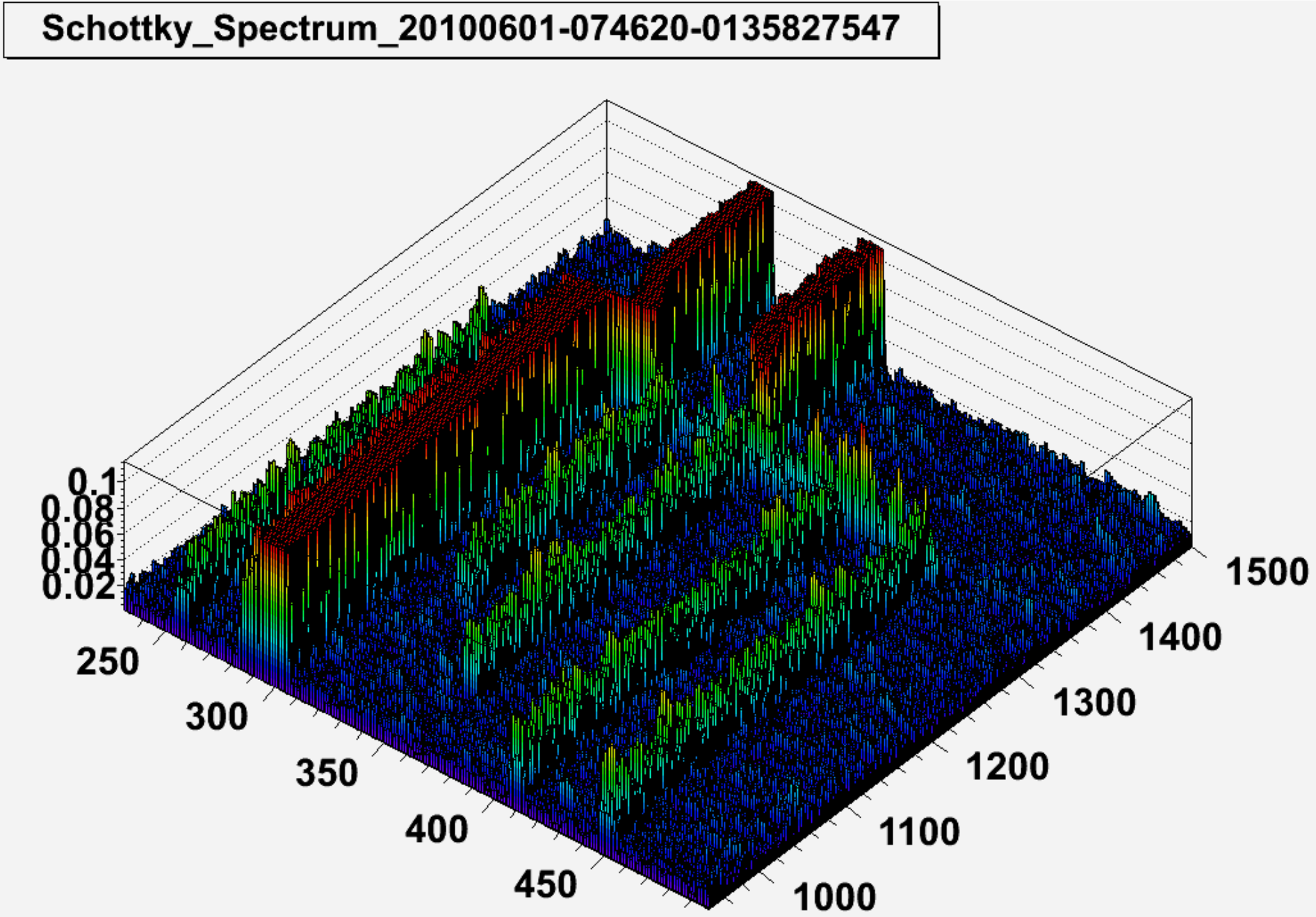
1500
1400
1300
1200
1100
1000
250
300
350
400
450
0.1
0.08
0.06
0.04
0.02


Schottky_Spectrum_20100601-074620-0135827547
0.1
0.08
0.06
0.04
0.02
250
300
350
400
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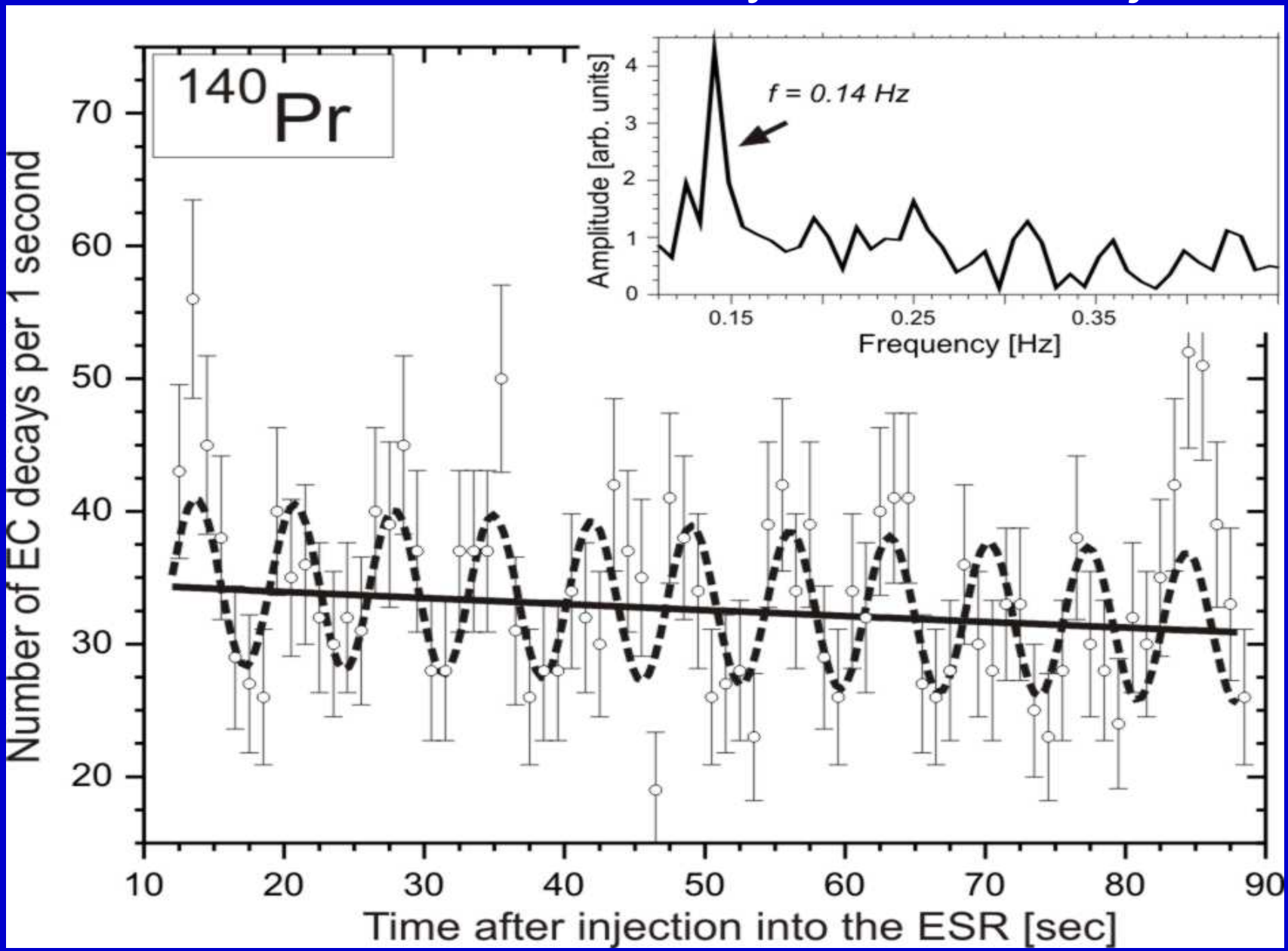
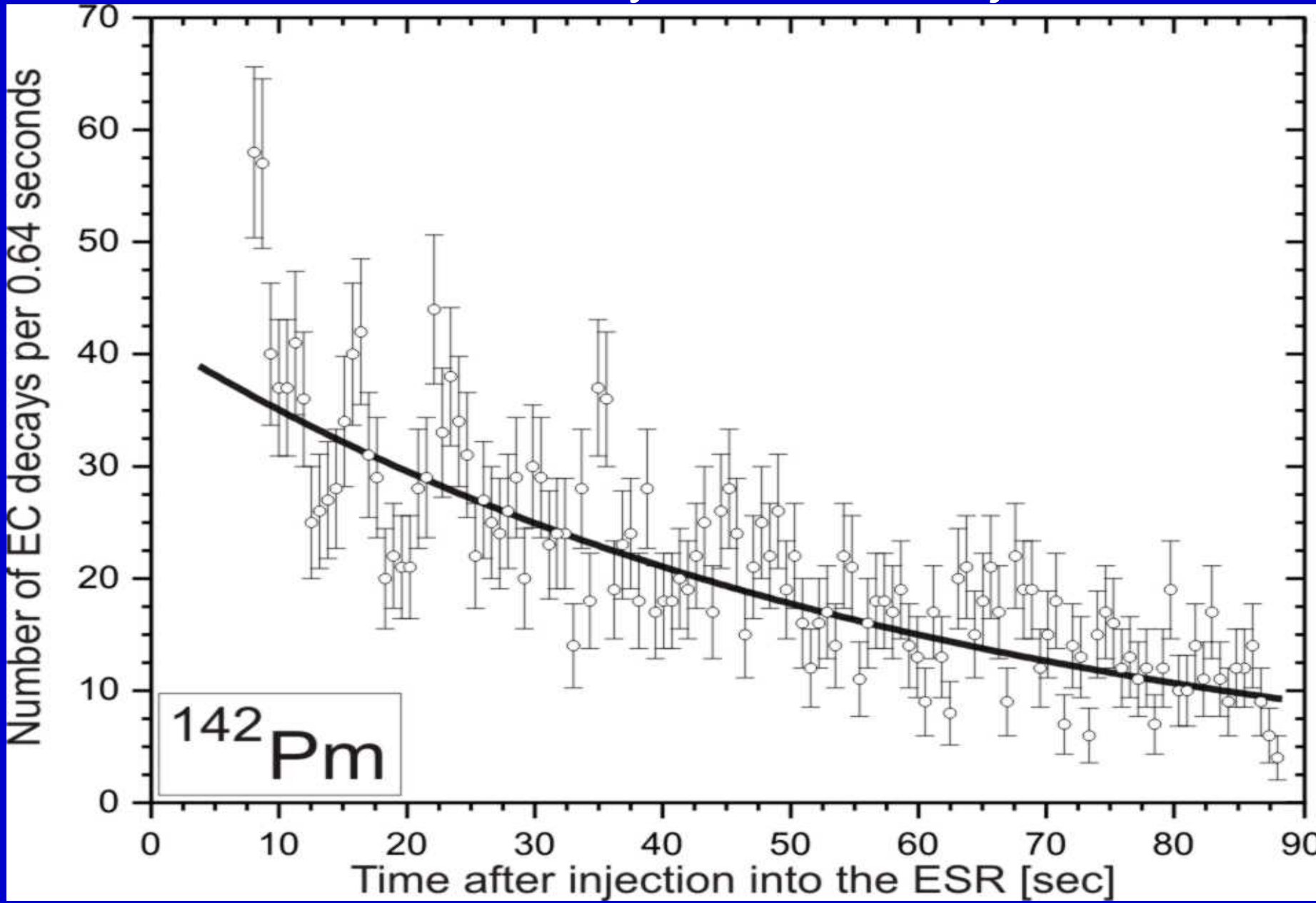
1000
1100
1200
1300
1400
1500

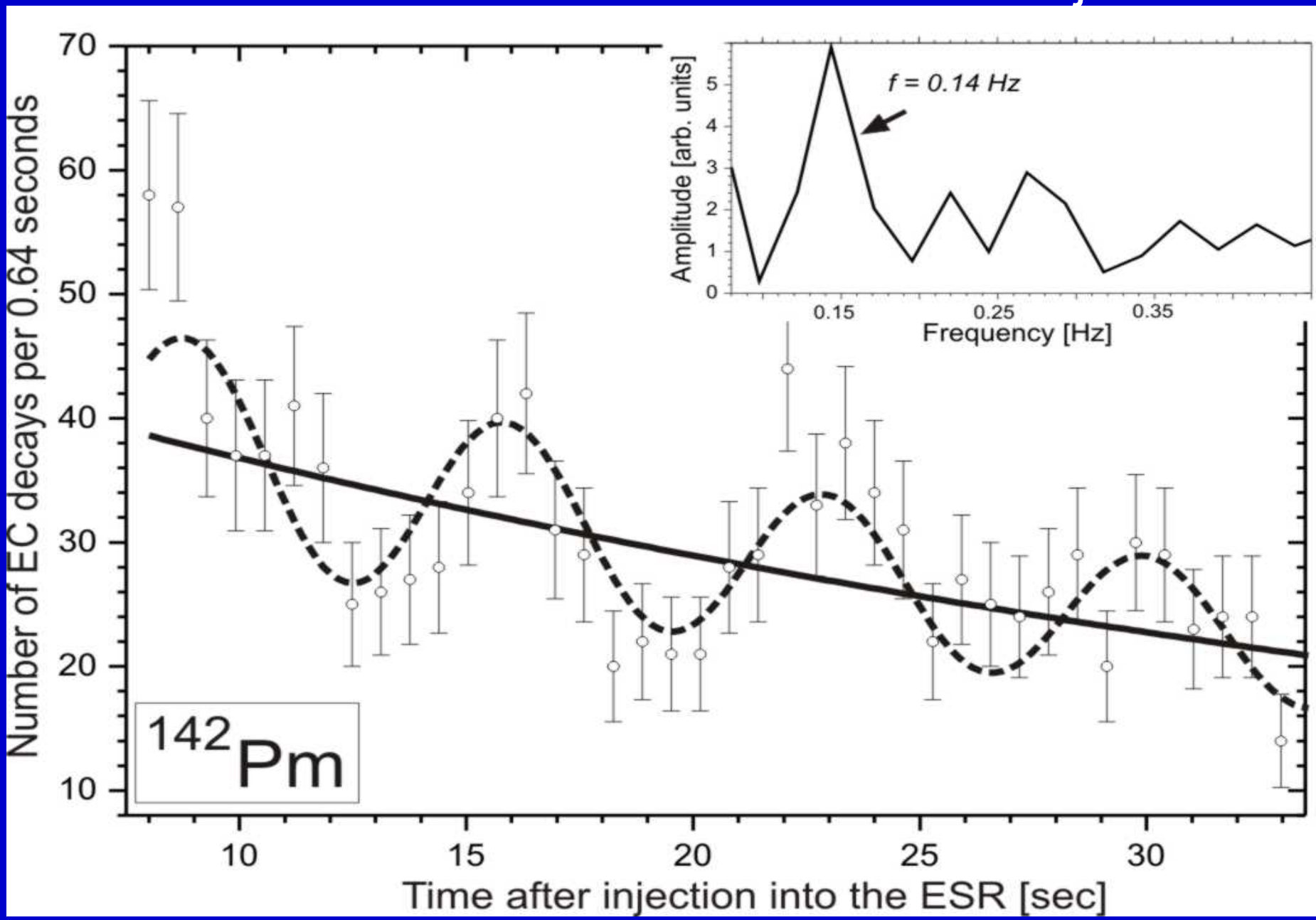
$^{140}Pr^{58+}$ all runs: 2650 EC decays from 7102 injections



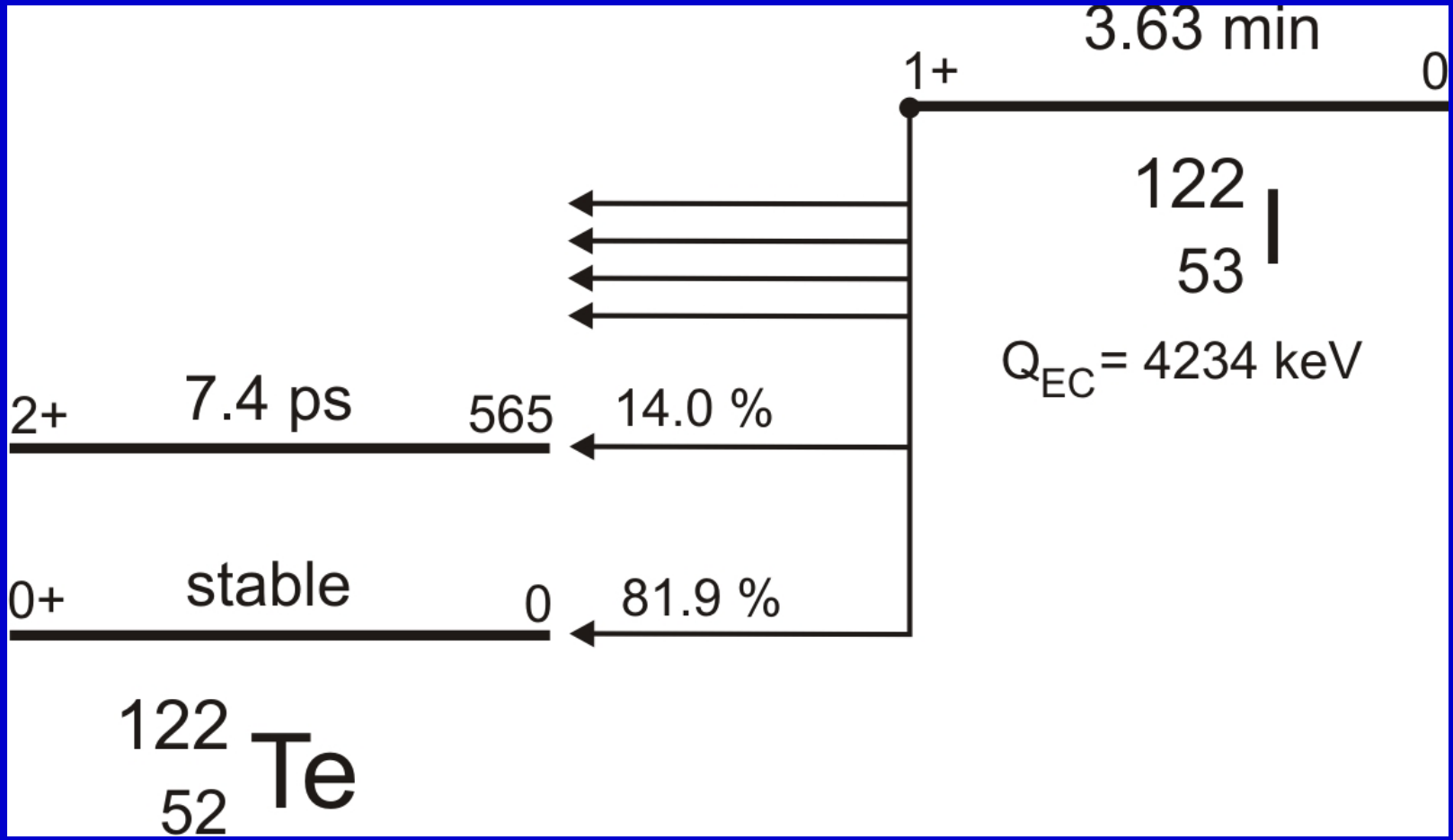
^{142}Pm: 2740 EC decays from 7011 injections



$^{142}Pm^{60+}$: zoom on the first 33 s after injection



Decay scheme of ^{122}I



Experiment: 31.07.2008-18.08.2008

Decay Statistics

Correlations: 10.808 injections ~1100 EC-decays
Many ions: 5718 injections ~4900 EC-decays