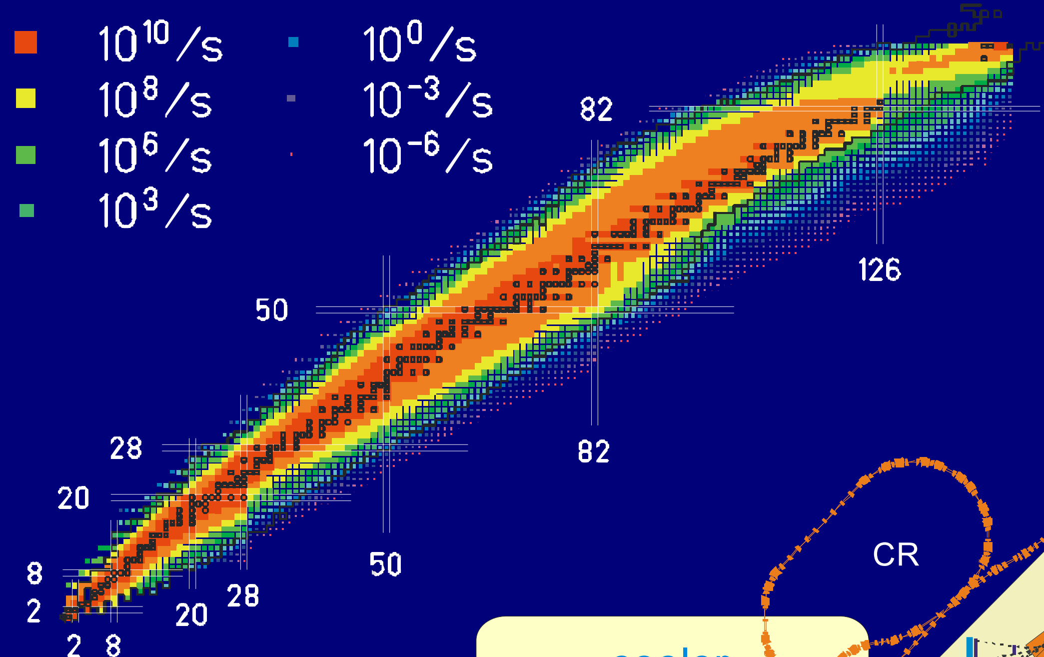
Symbiosis of DAQ, Accelerator Settings, Diagnostics, and Slow Controls

Illustrative Examples:

- Particle Detection by Means of Schottky-Noise Frequency Measurements
- Revolution Frequencies at the Transition Setting of the Experimental Storage Ring
- Photon-free Precise Spectroscopy by Means of Dielectronic Recombination

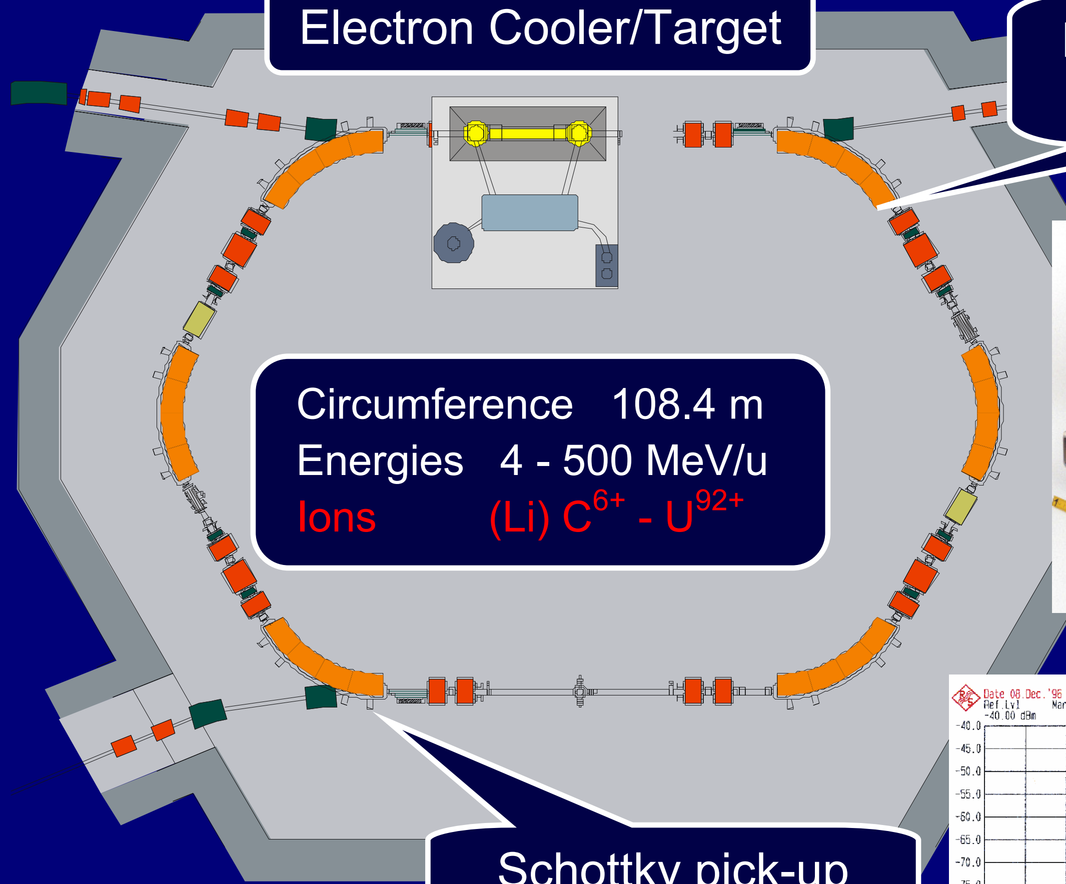
New exprimental possibilities at Super-FRS/NESR

Large production rates of radioactive nuclei



- Separate Ring, CR, with stochastic cooling
- NESR with a cooler and with a separate ultracold e-target

Experimental Storage Ring, ESR



Injection from SIS/FRS

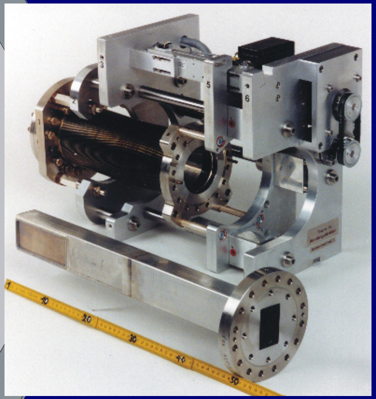
Electron Cooler/Target

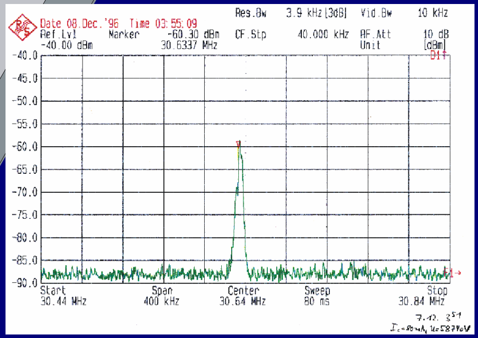
Recombination Detector

Circumference 108.4 m
Energies 4 - 500 MeV/u
Ions (Li) C^{6+} - U^{92+}

Reinjection to SIS

Schottky pick-up

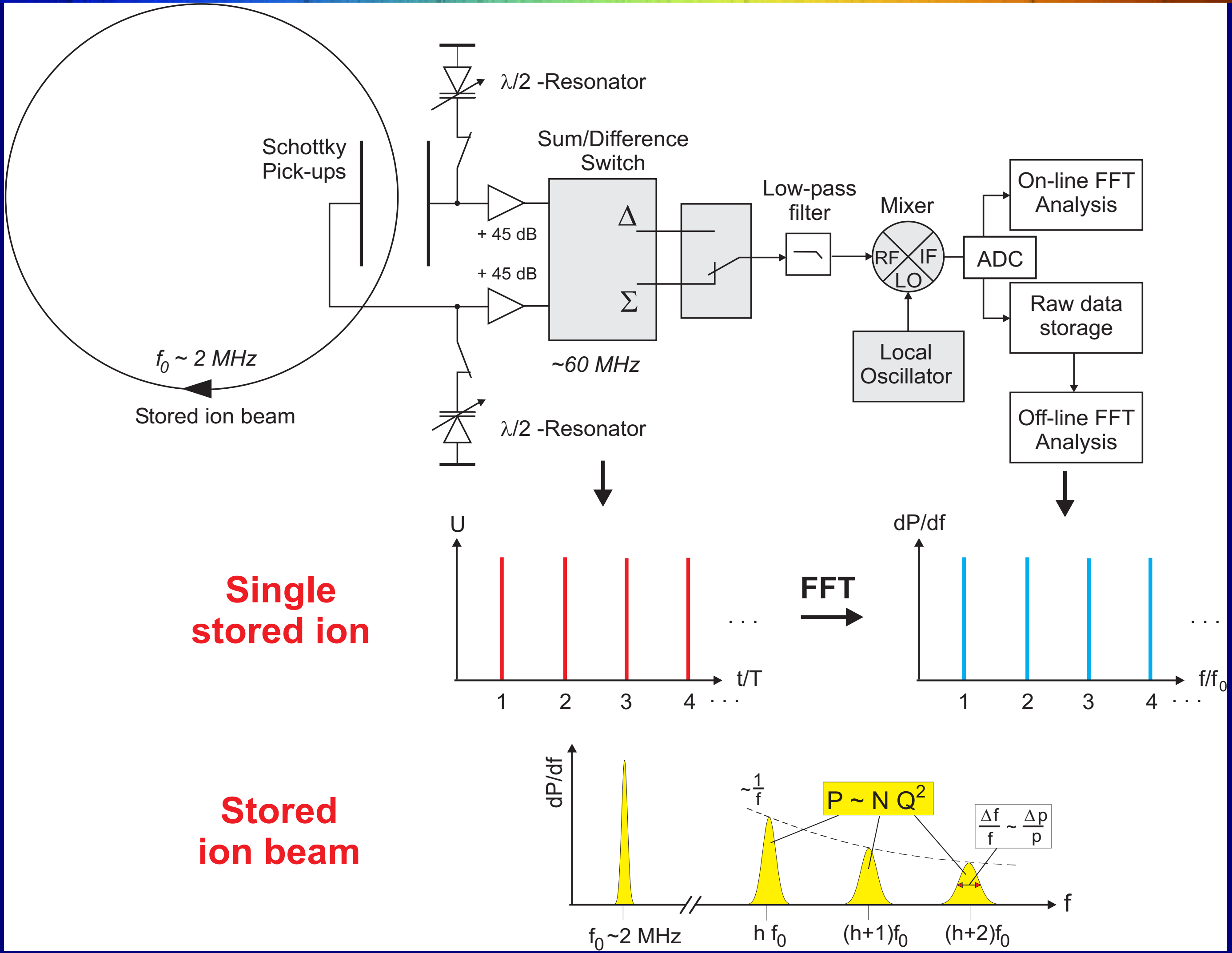




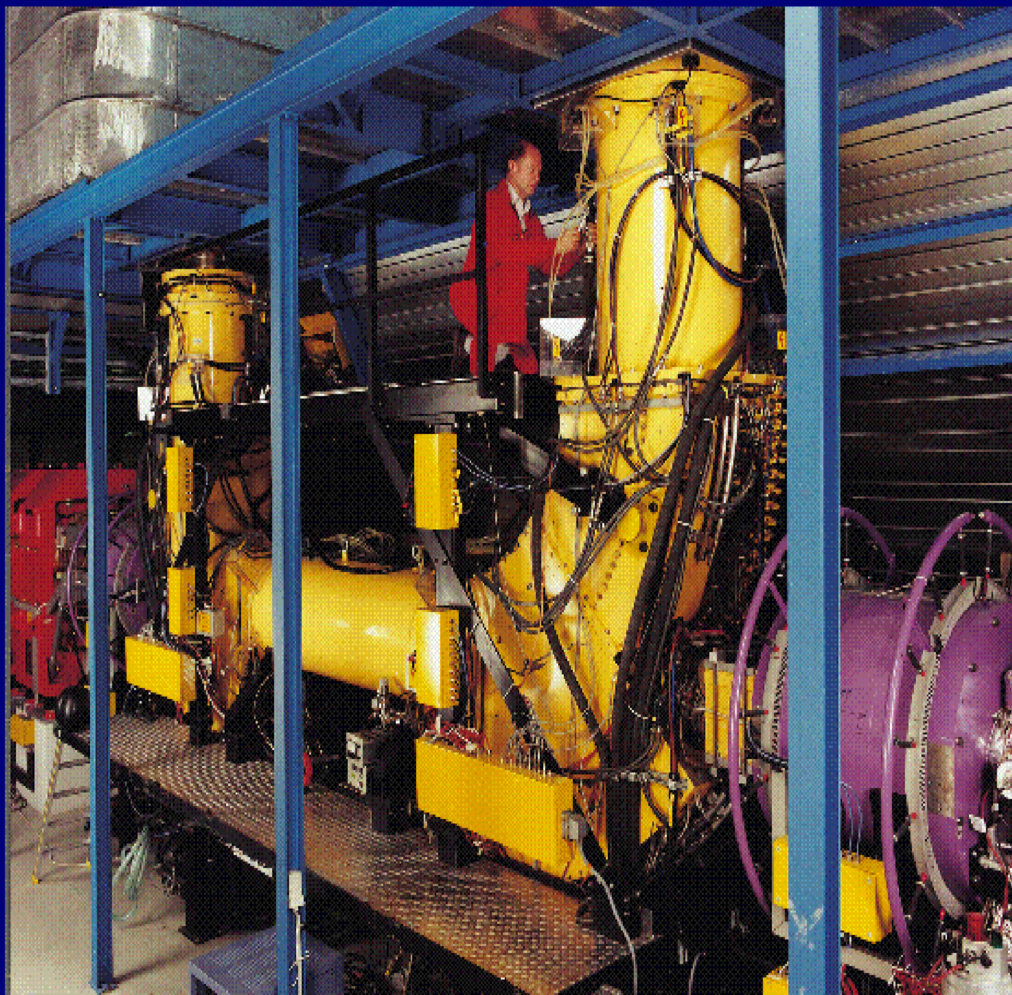
Particle Detection in Storage Rings by Means of Schottky-Noise Frequency Measurements

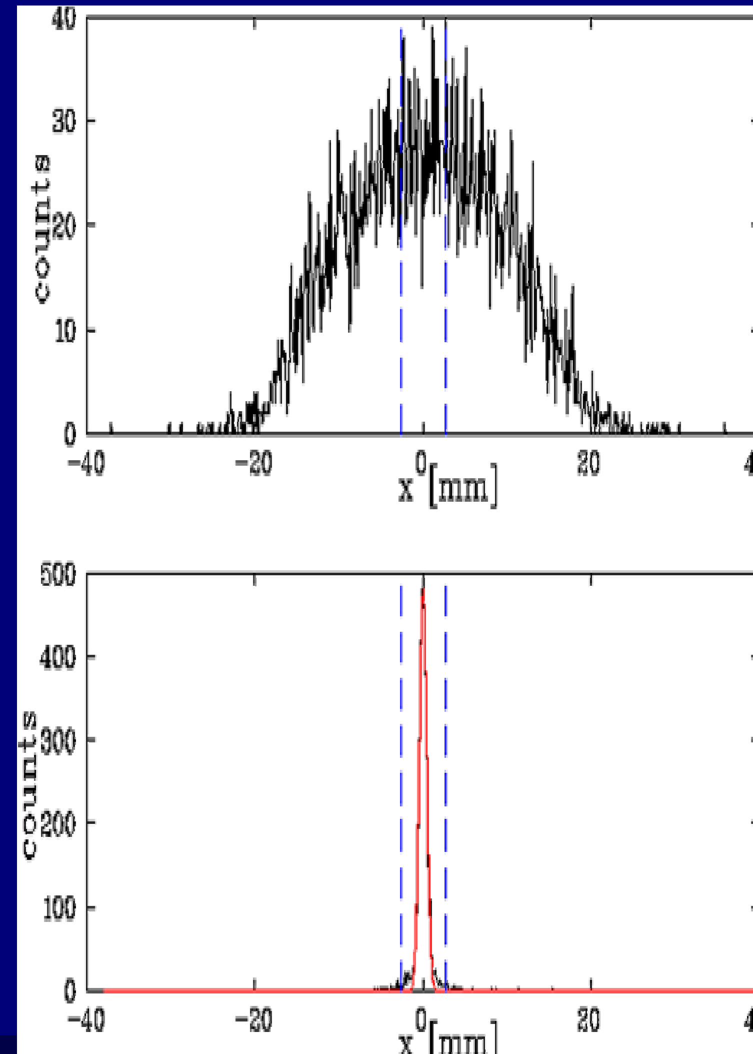
- Basic features of the Schottky noise method.
- ESR-Experiments as Examples for:
  - Non-destructive non-instantaneous particle detection.
  - Broad band detection of a multitude of masses (momenta).
  - Frequency (momentum, mass) resolving power.
  - Count rate: dynamics; number of particles.
  - Sensitivity, single particle detection.
- Schottky–noise equipment for the ESR experiments:
  - Schottky-noise sampling.
  - Time Capture Data Acquisition, TCAP-DAQ.
- Outlook:
  - Electron cooling force spectrometer.
  - R&D topics, developments, and improvements

Frequency Measurements by Schottky Noise

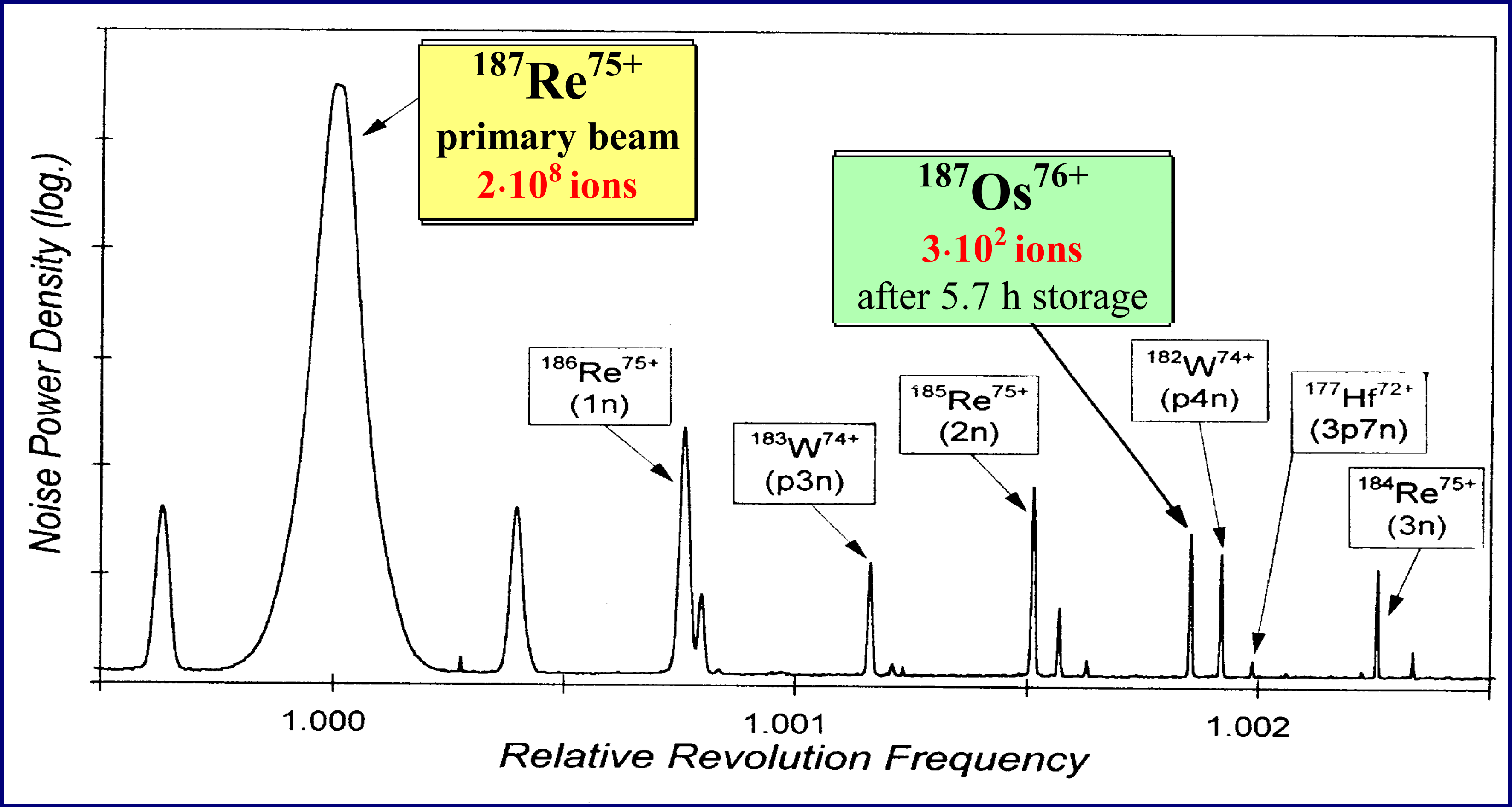


Cooling: narrowing velocity, size and divergence of the stored ions





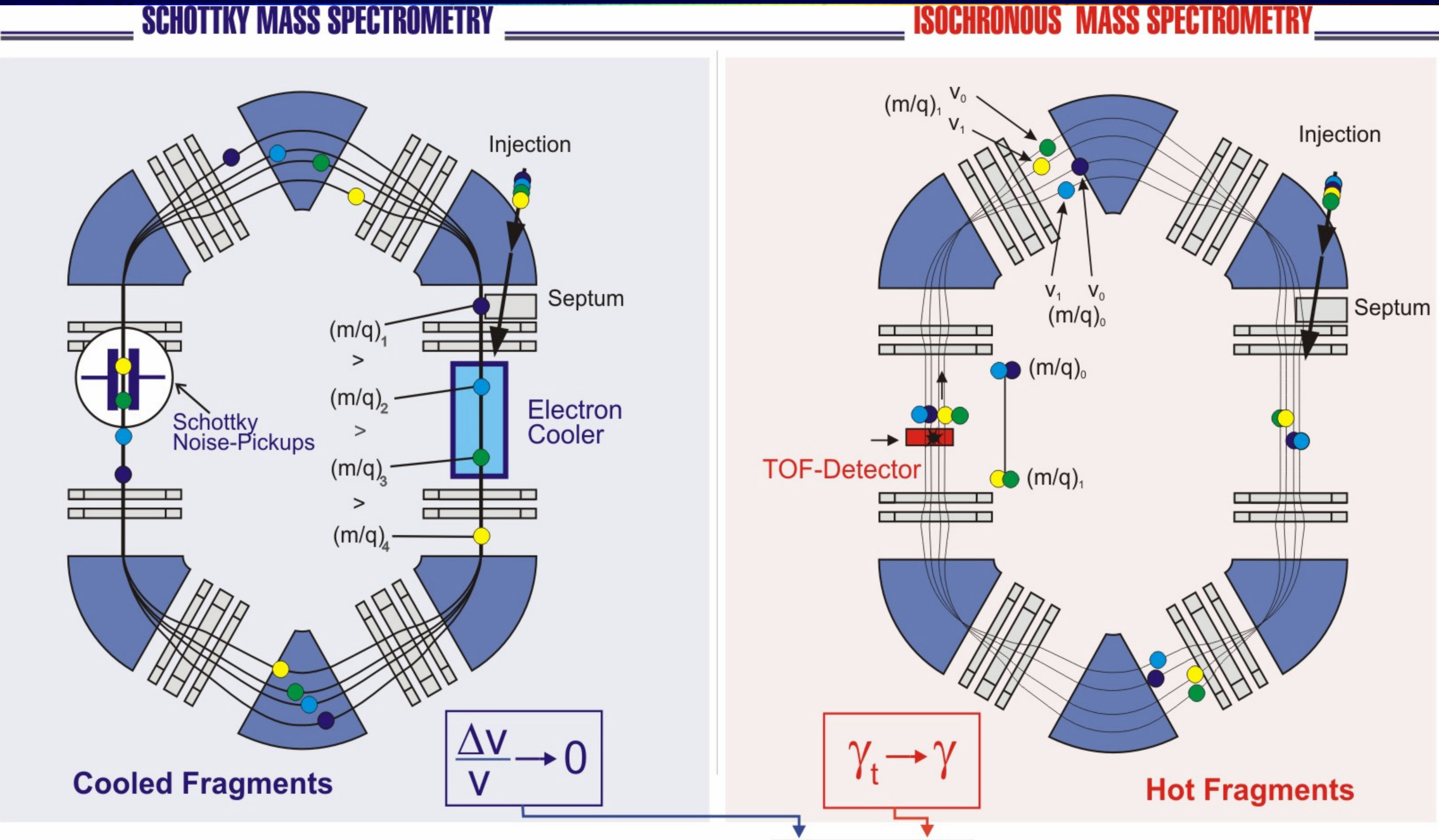
Schottky Signal of the Bound-State β-Decay
$^{187}Re^{75+} \rightarrow {}^{187}Os^{75+}$



$T_{1/2}$ ($^{187}Re^{75+}$) = 33(2) y

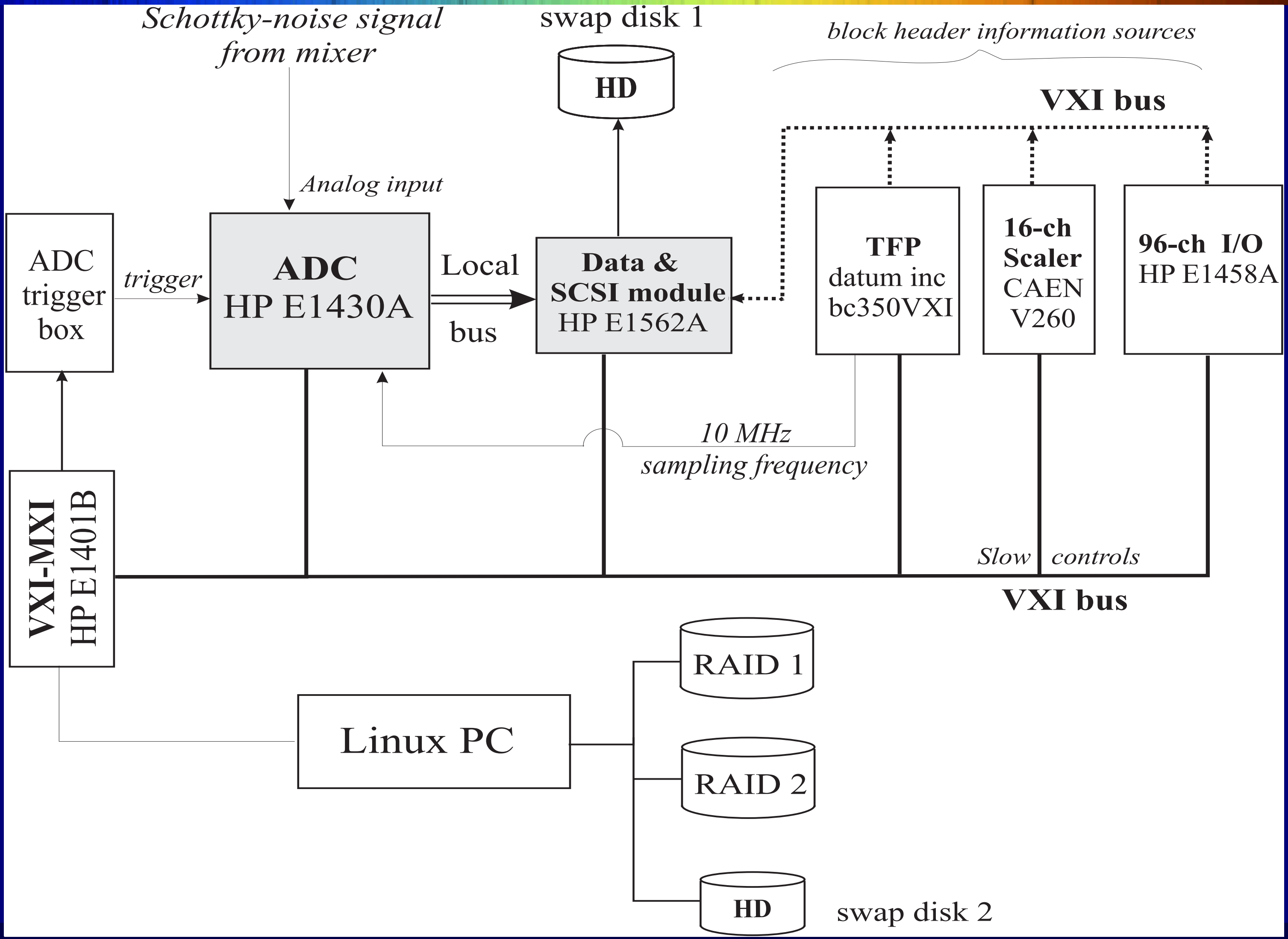
Ions in super nova explosions are highly ionized.

Mass Measurements at ESR

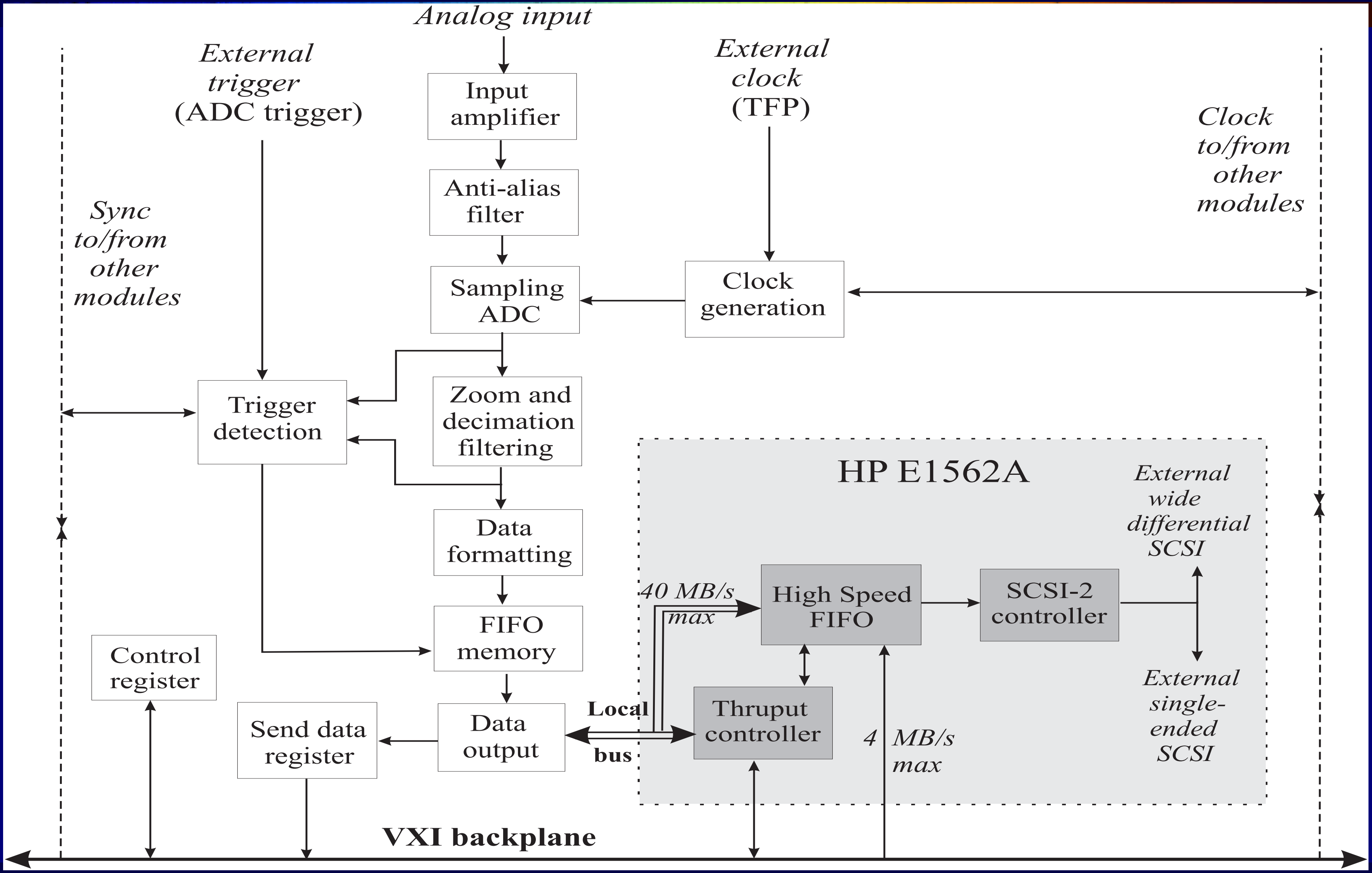


$$\frac{\Delta f}{f} = -\frac{1}{\gamma_t^2}\frac{\Delta(m/q)}{m/q} + \frac{\Delta v}{v}\left(1-\frac{\gamma^2}{\gamma_t^2}\right)$$

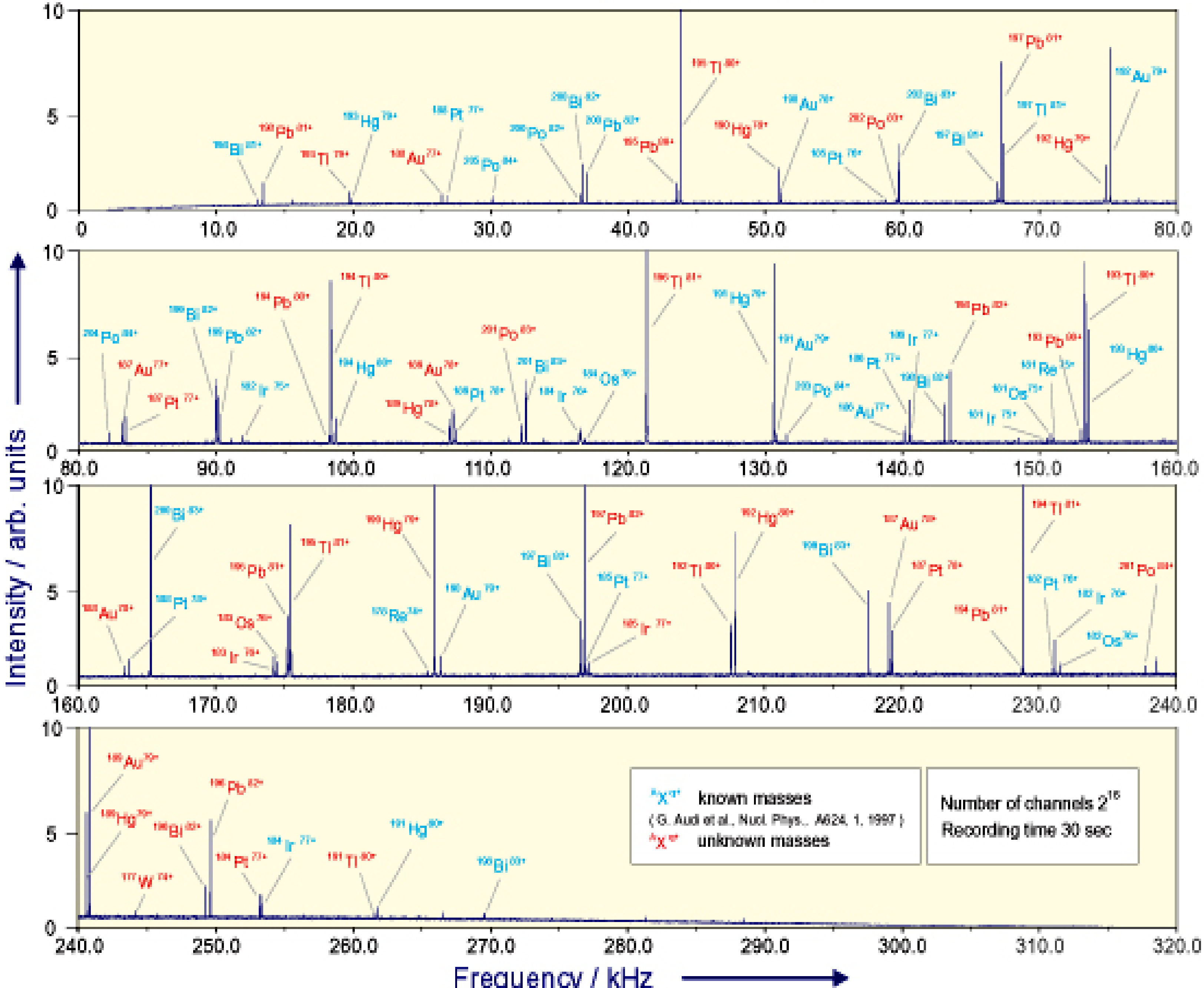
Time Capture Data Acquisition (TCAP DAQ)



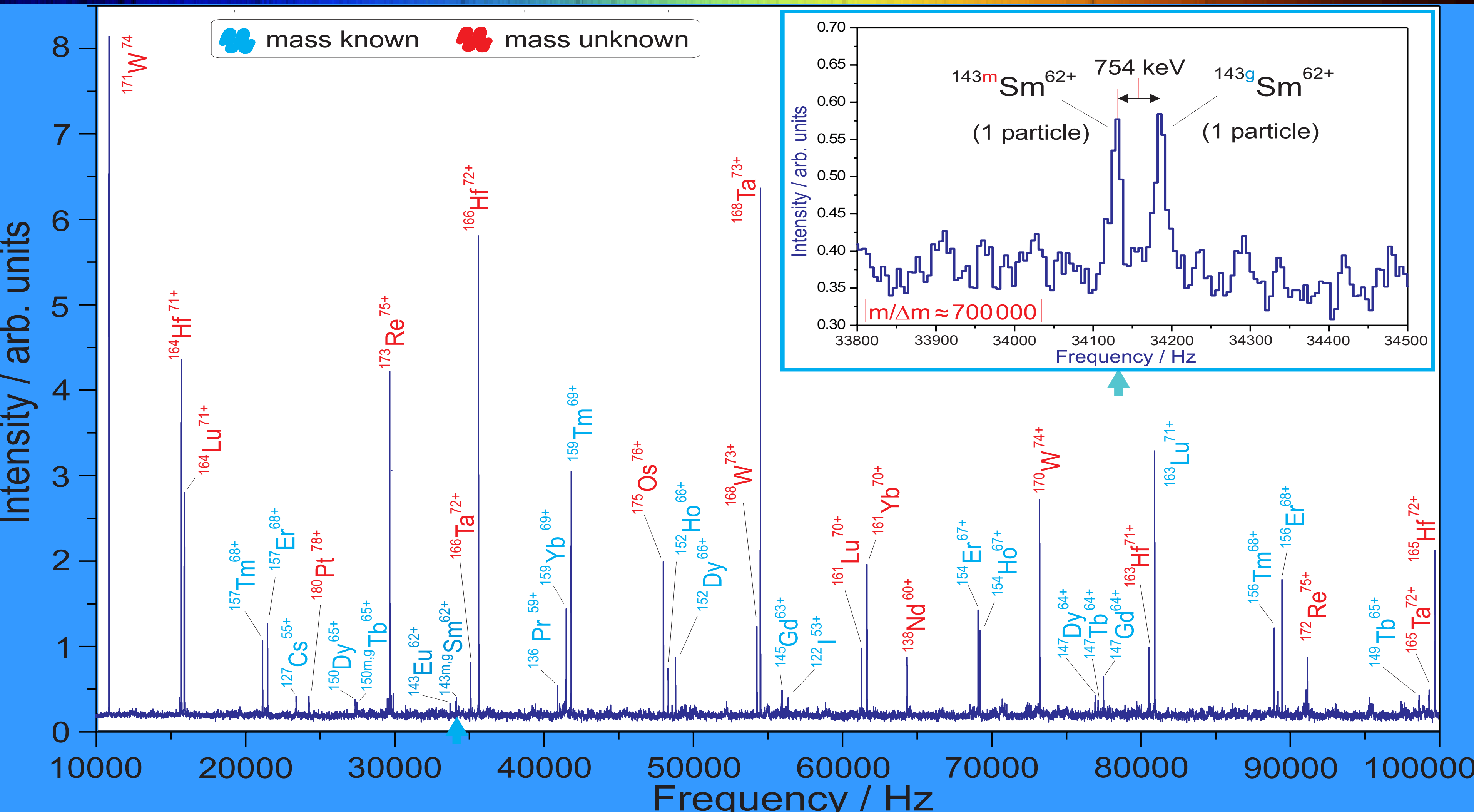
Schottky Noise Sampling



Broad band Schottky frequency spectrum



Schottky Mass Measurements

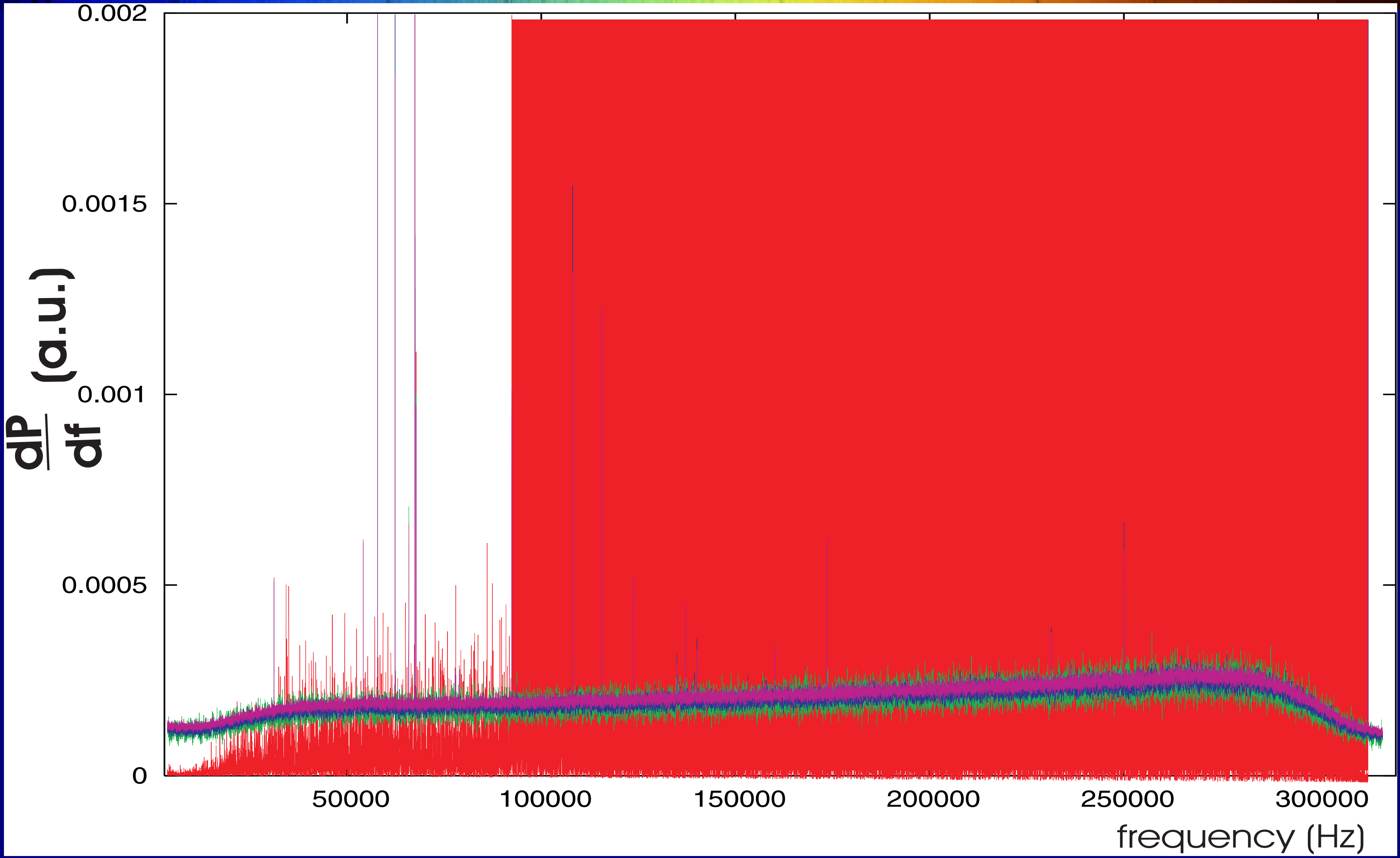


Resolving power 2x10^6
Sensitivity 1 ion (Z > 40)

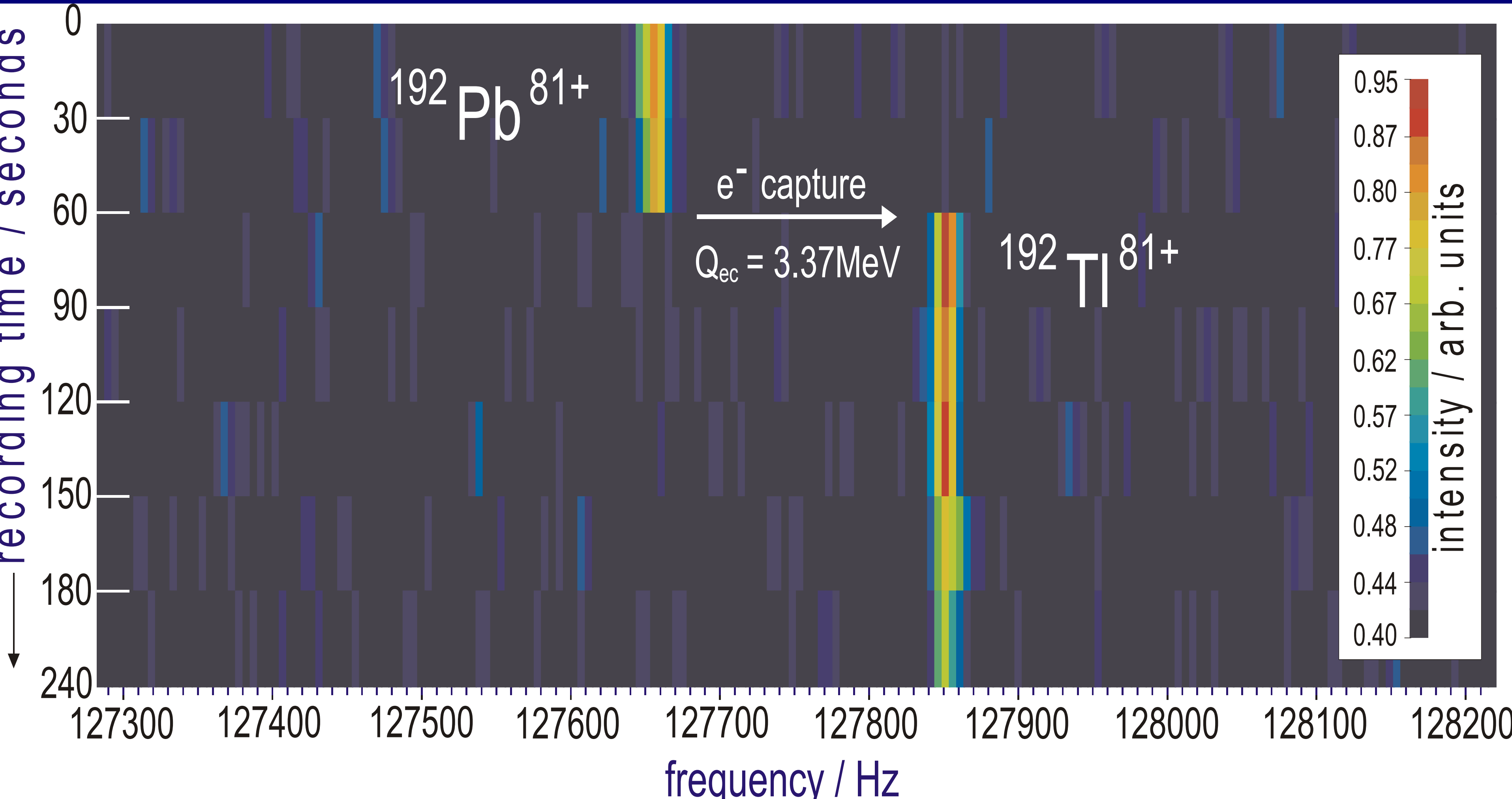
T½ > 1s

Accuracy 30 keV
285 new masses

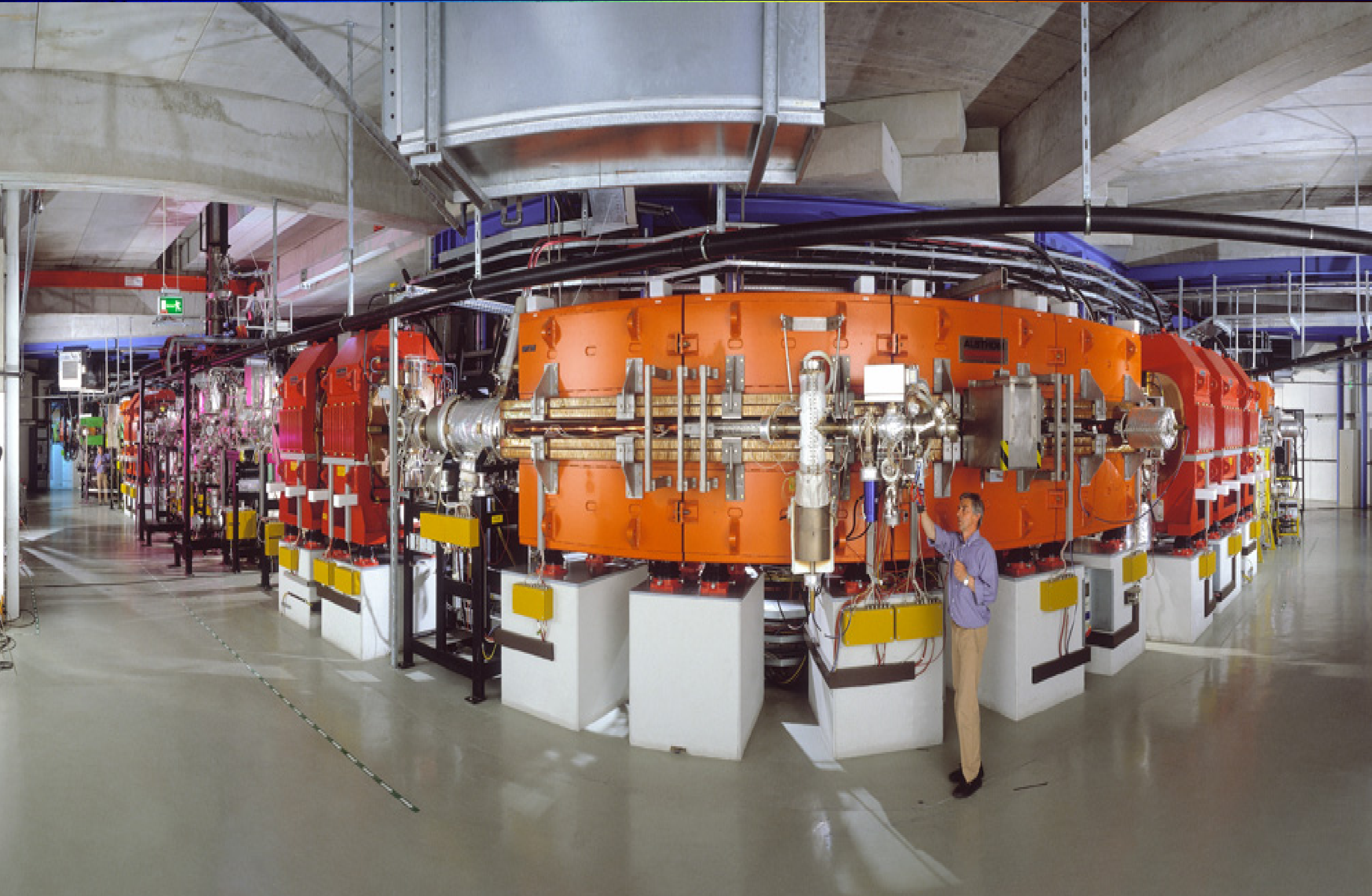
Integration Time



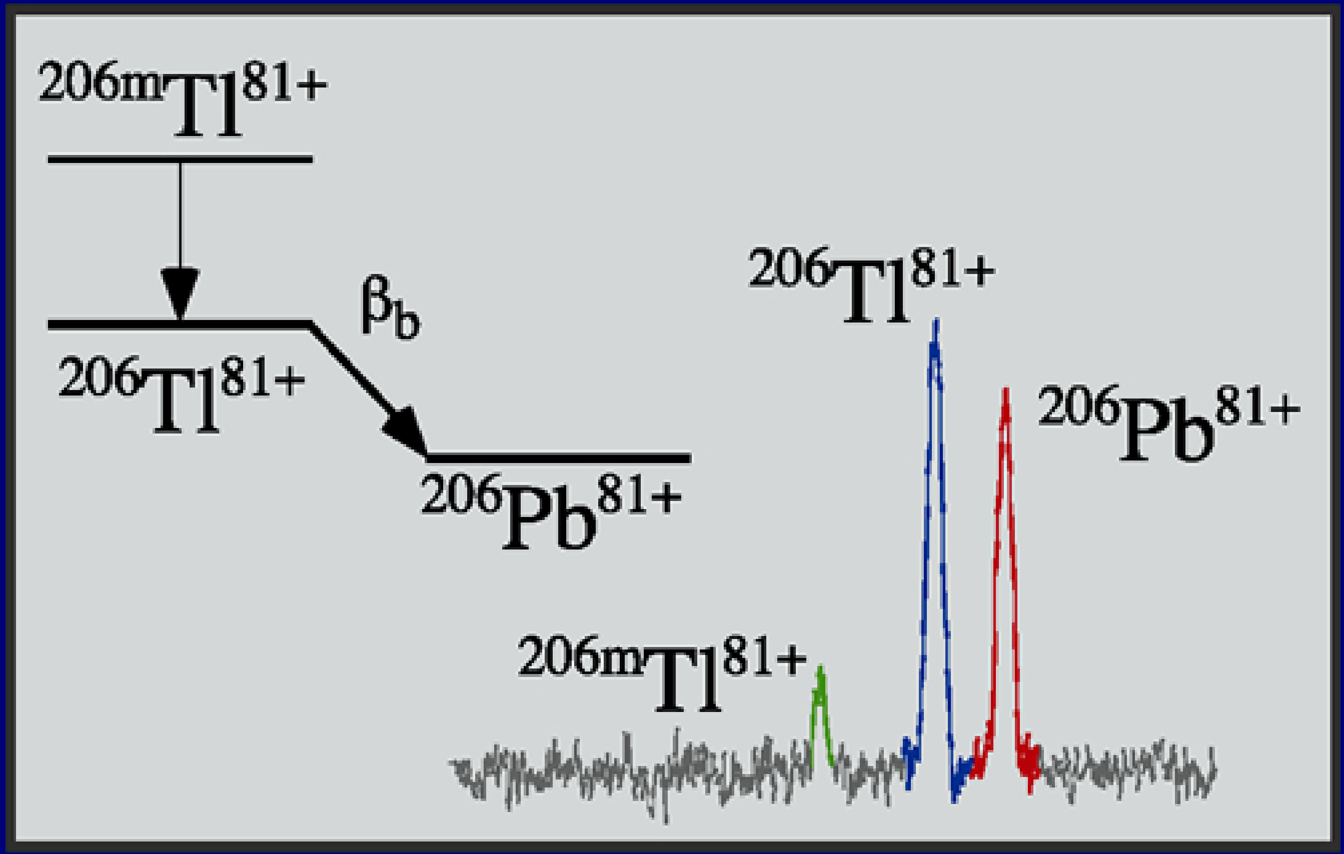
Decay of a Single Stored Ion



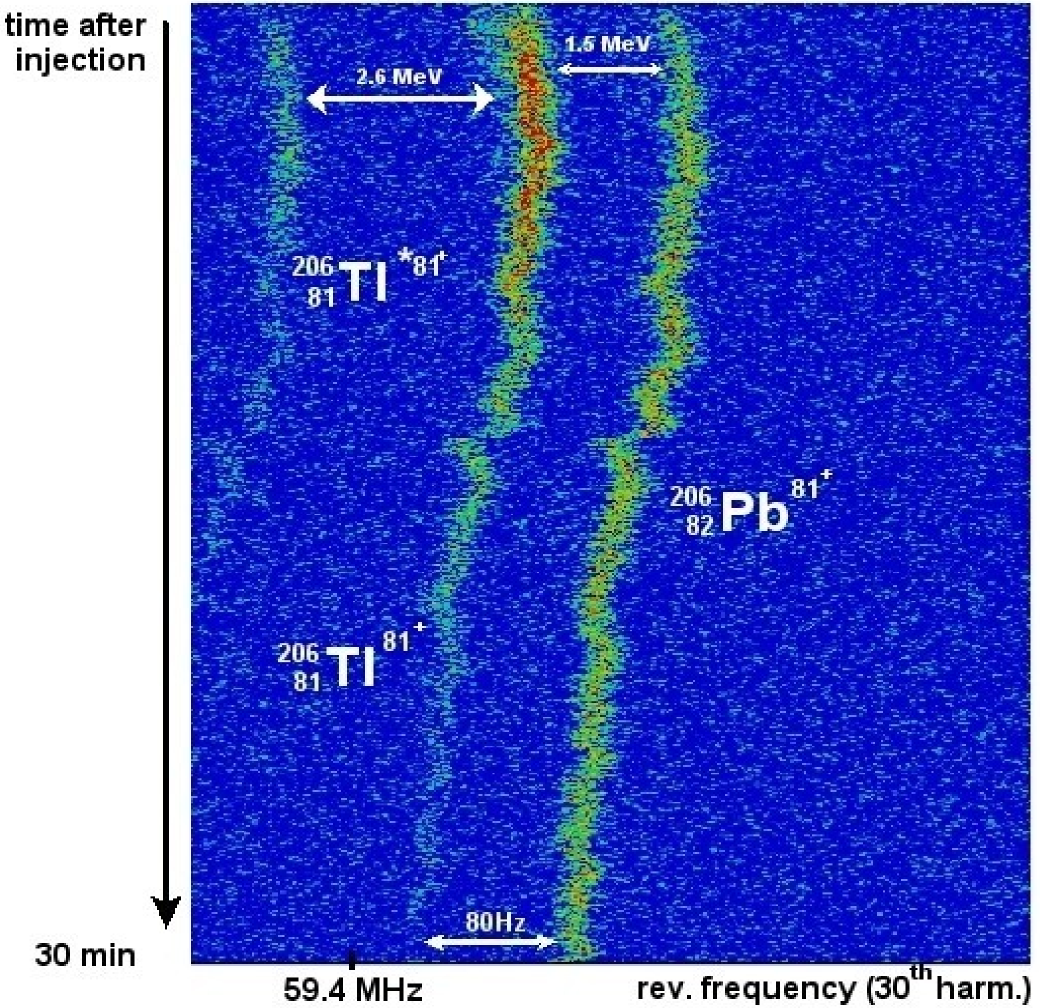
The Experimental Storage Ring, ESR



First Direct Observation of Bound-State β-Decay

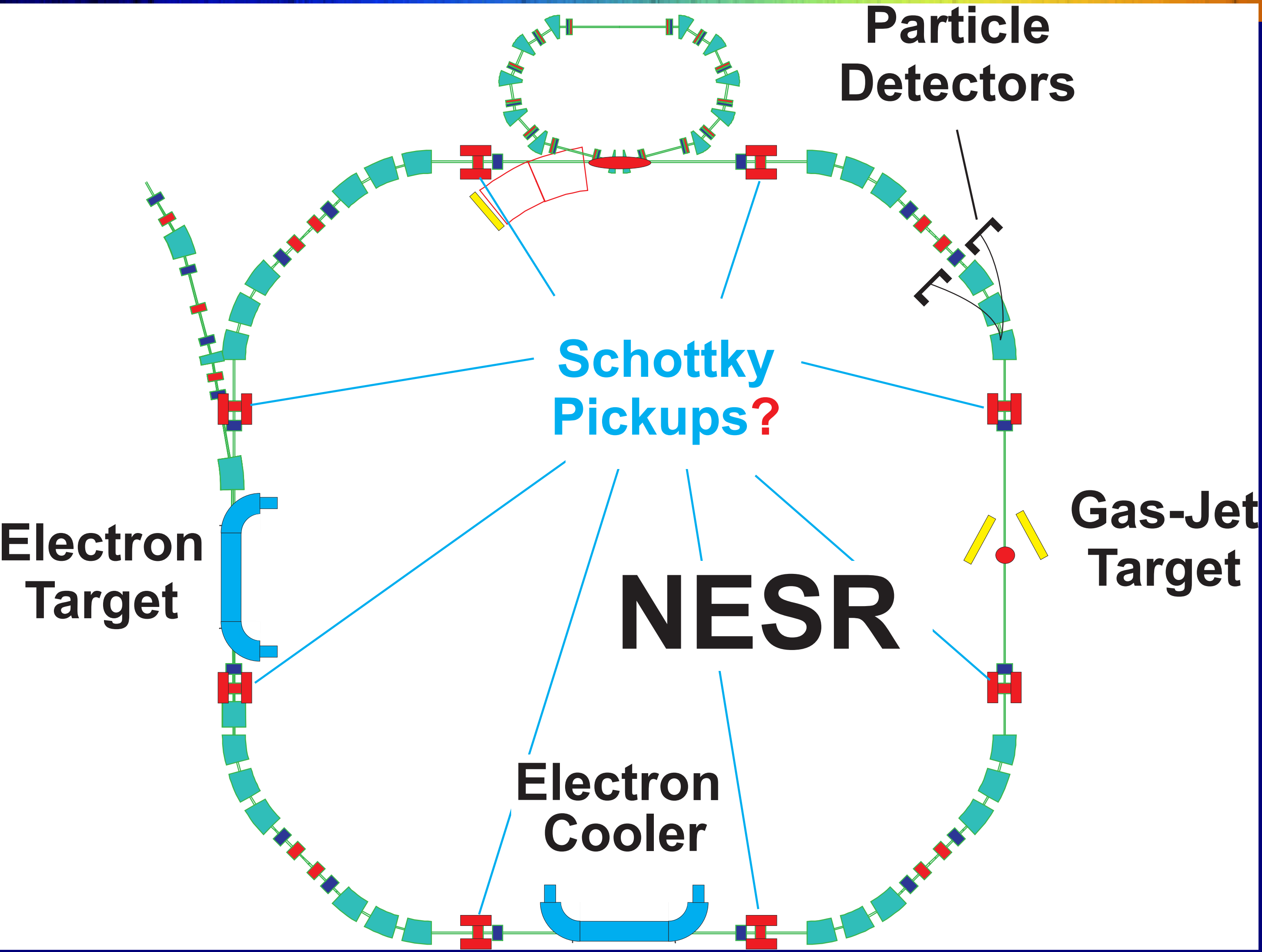


Time traces of bound beta decay



- **Left: isomeric nuclear state**
- **Middle: bare Tl-206 g.s.**
- **Right: β(b) daughter = = H-like Pb-206**

R&D Topic: Multiple Schottky Pickups and FFT

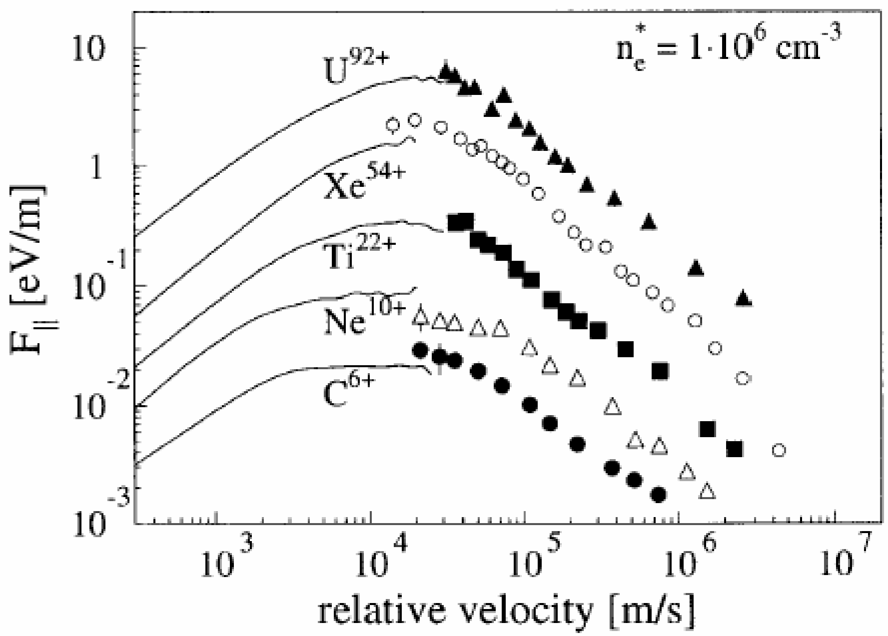


- Signal/Noise and/or time gain = √ n
- 'Coincidence technique with replay capabilities'
- Multi-dimensional Fourier expansion of amplitudes and phases.
- Position information?

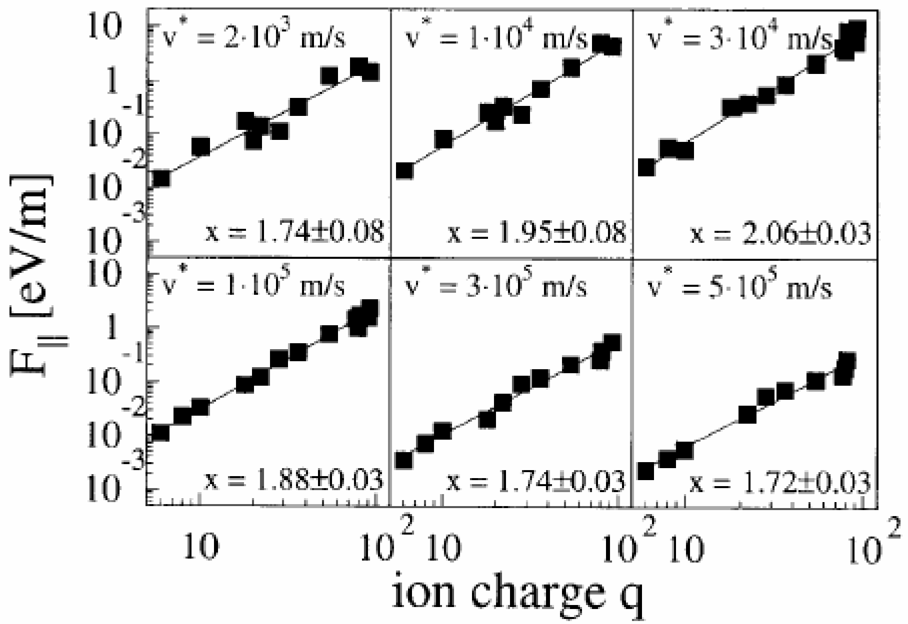
Cooling Force

Measured Longitudinal Cooling Force at ESR (Th. Winkler et al.)

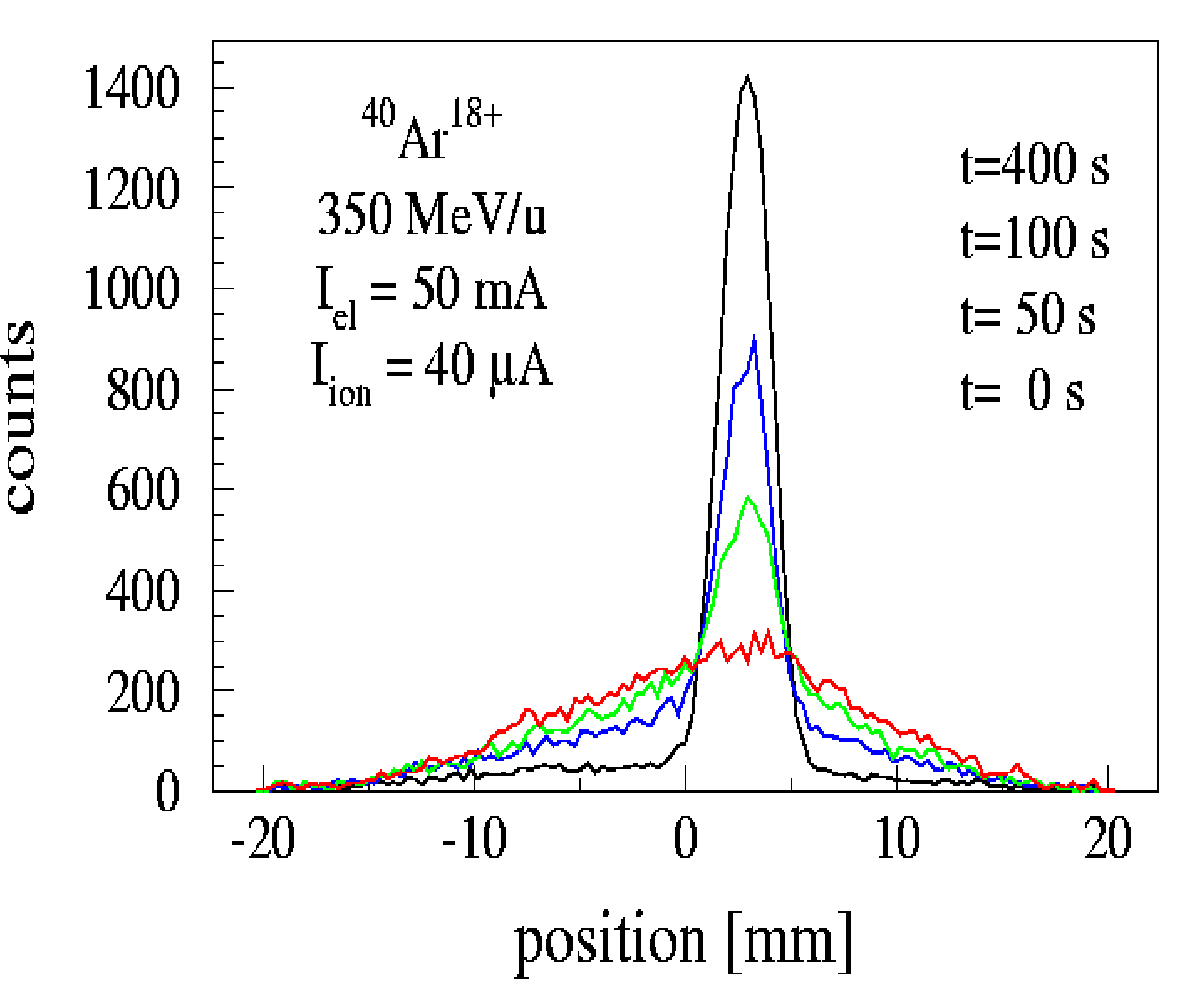
as a function of the relative velocity between the ions and the electrons



as a function of the ion charge



Basic Idea of the Cooling Force Spectrometer



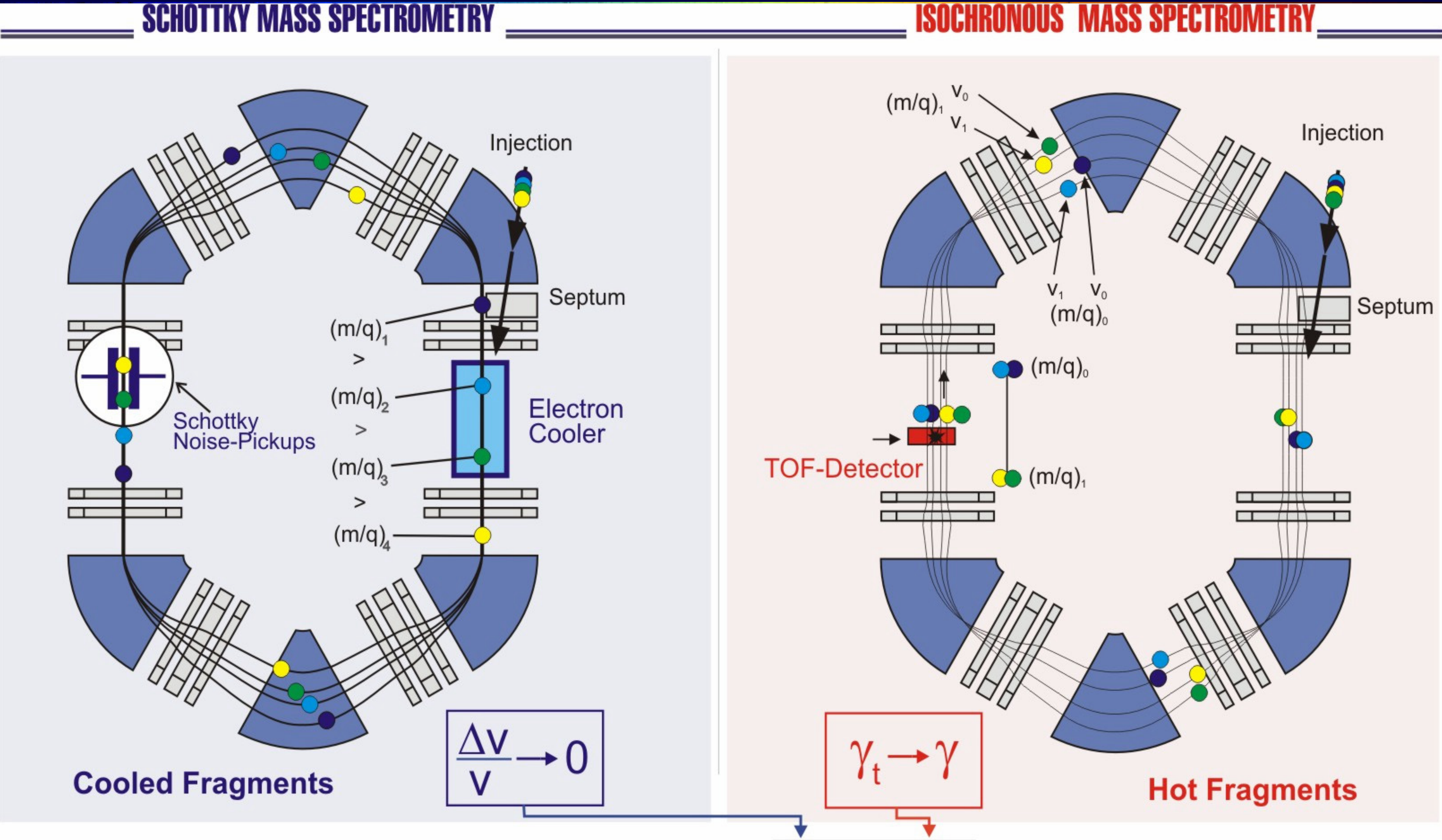
bservable:
Time dependent increase of the ion intensity in the cooled peak.

uning Parameters:
Cooler voltage
Electron current

esult:
Velocity (Momentum) distribution

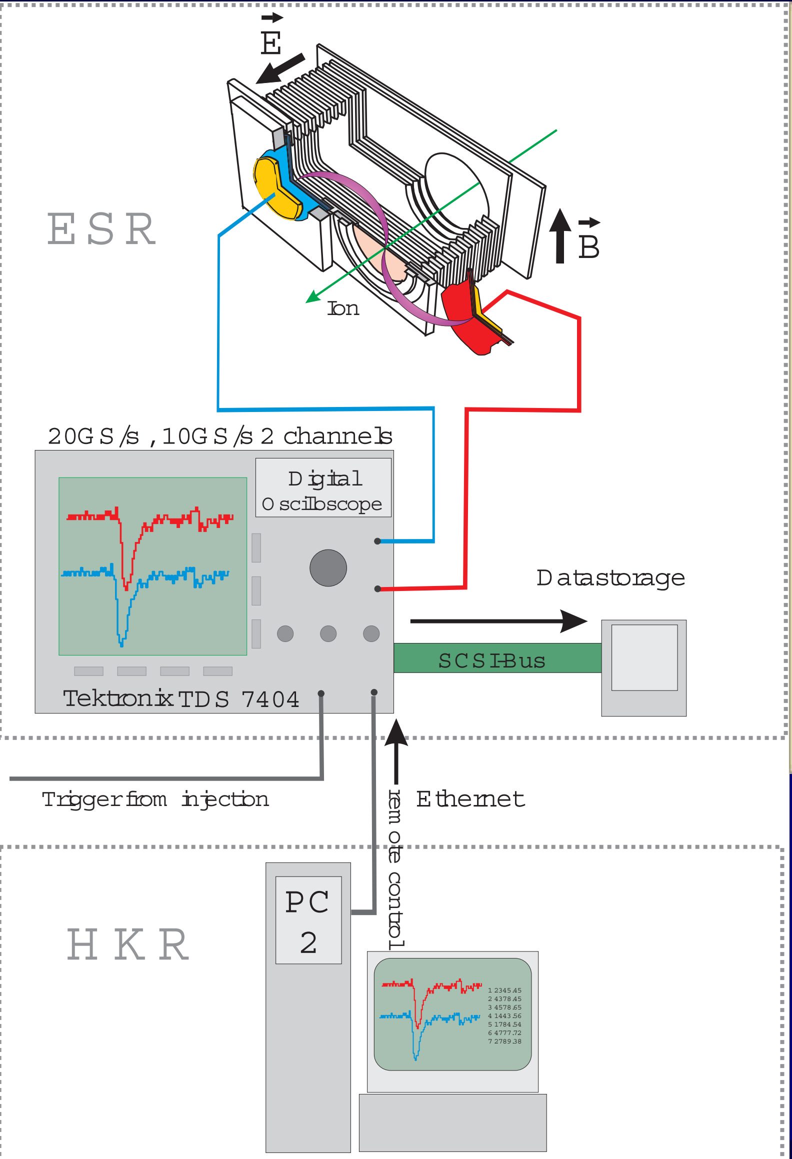
AIC-proposal)

Mass Measurements at ESR



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

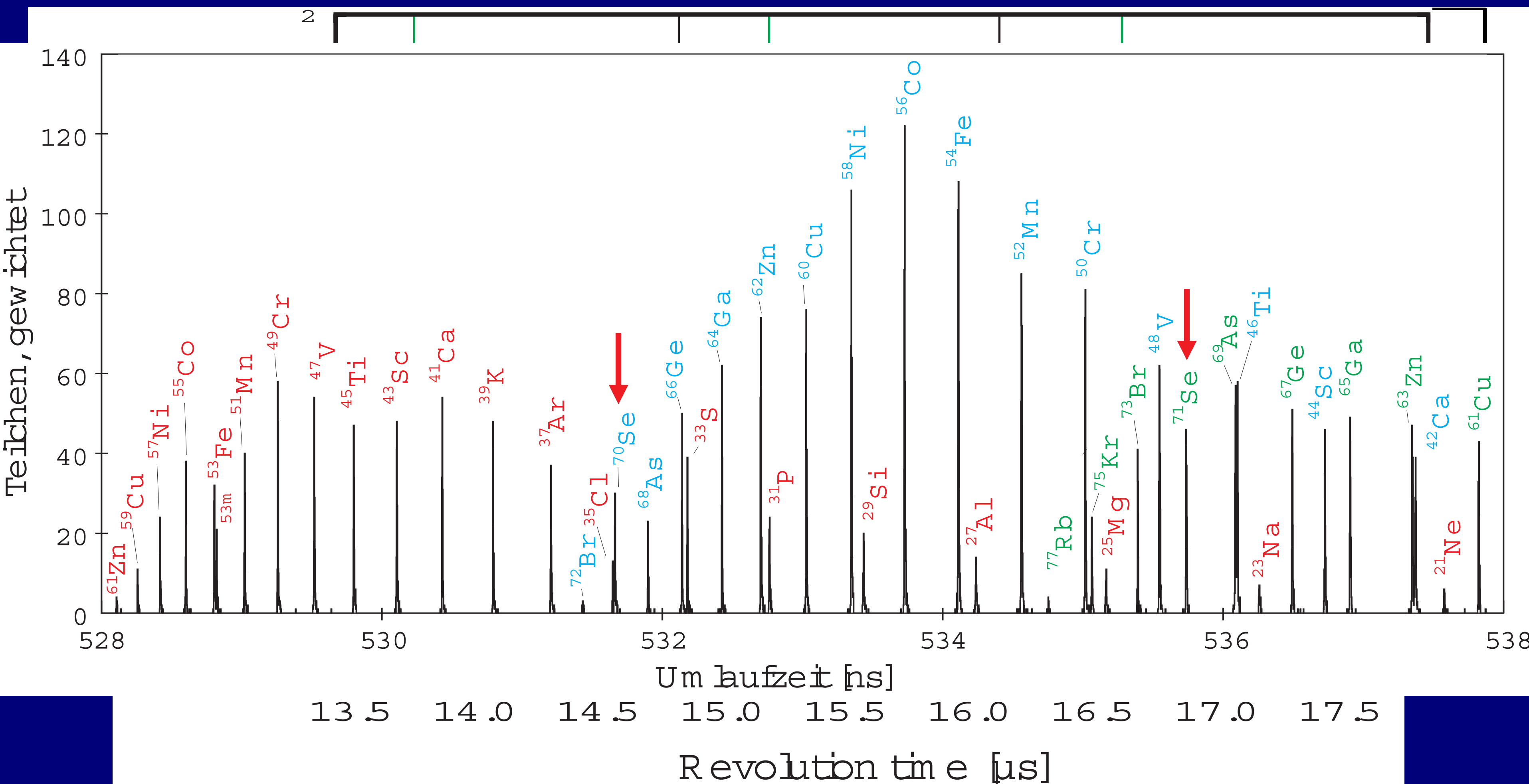
Isochronous Mass Measurements at ESR



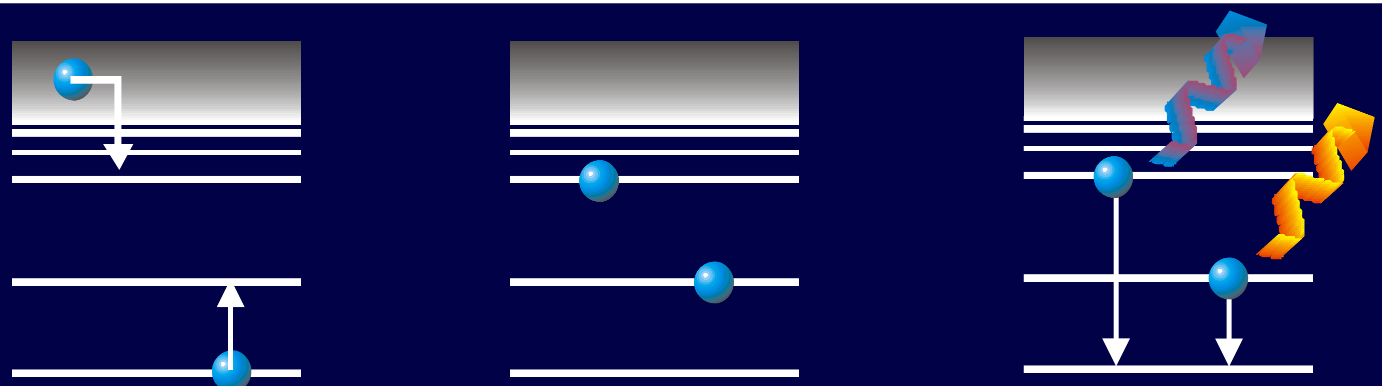
5 GHz bandwidth, 10 GHz sampling rate
2 channels with 64 MB fast memory

new: 15 GHz, 40 GHz sampling rate (2 ch.)
64 MB fast memory per channel

Data Analysis



Dielectronic Recombination



$$A^{q+} + e^{-} \rightarrow [A^{(q-1)+}]^{**} \rightarrow A^{(q-1)+} + n \cdot h\nu$$

Dielectronic Capture (DC)
(time-reverse to autoionization)

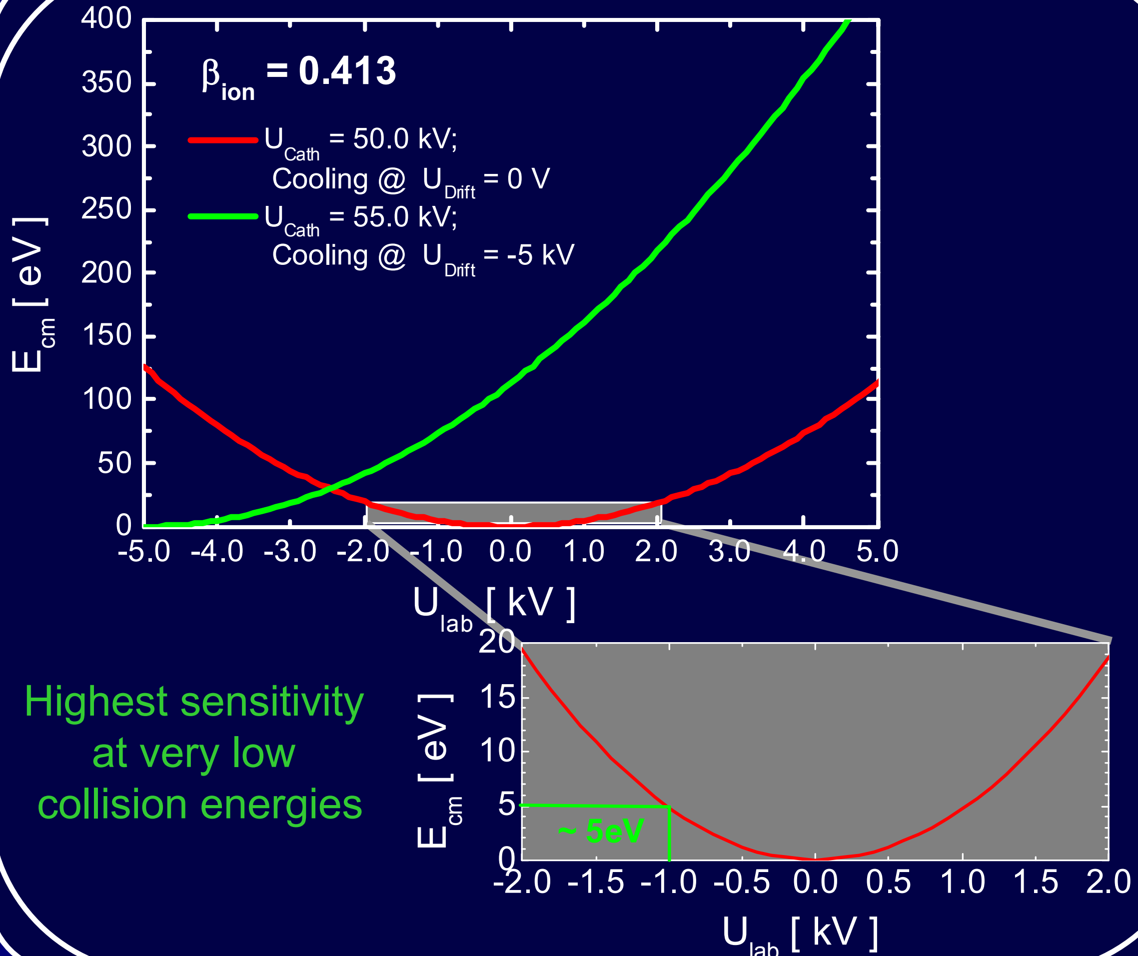
$$\Rightarrow \quad \sigma_{DC} \propto A_a$$

Radiative Stabilization
(in competition to autoionization)

$$\Rightarrow \quad \sigma_{DR} = \sigma_{DC} \cdot \left[\frac{\Sigma A_r}{\Sigma A_a + \Sigma A_r} \right]$$

Two observables: recombined ion or photons (e.g. EBIT, RTE @ Gasjet)

Experimental Setup



Highest sensitivity at very low collision energies

Merged circulating Ion beam and cooler electron beam

Variation of E_{rel}: fast energy scan (approx. 1500 pts. à 40 ms with intermediate cooling)

Detection of the recombined ions **A** $^{(q-1)+}$ with single particle detector

$\Rightarrow$ Rate coeffizient $\alpha(E_{rel})$ on an absolute scale

Co-propagating beams

$\Rightarrow \quad 0 \leq E_{rel} \leq 400$ eV

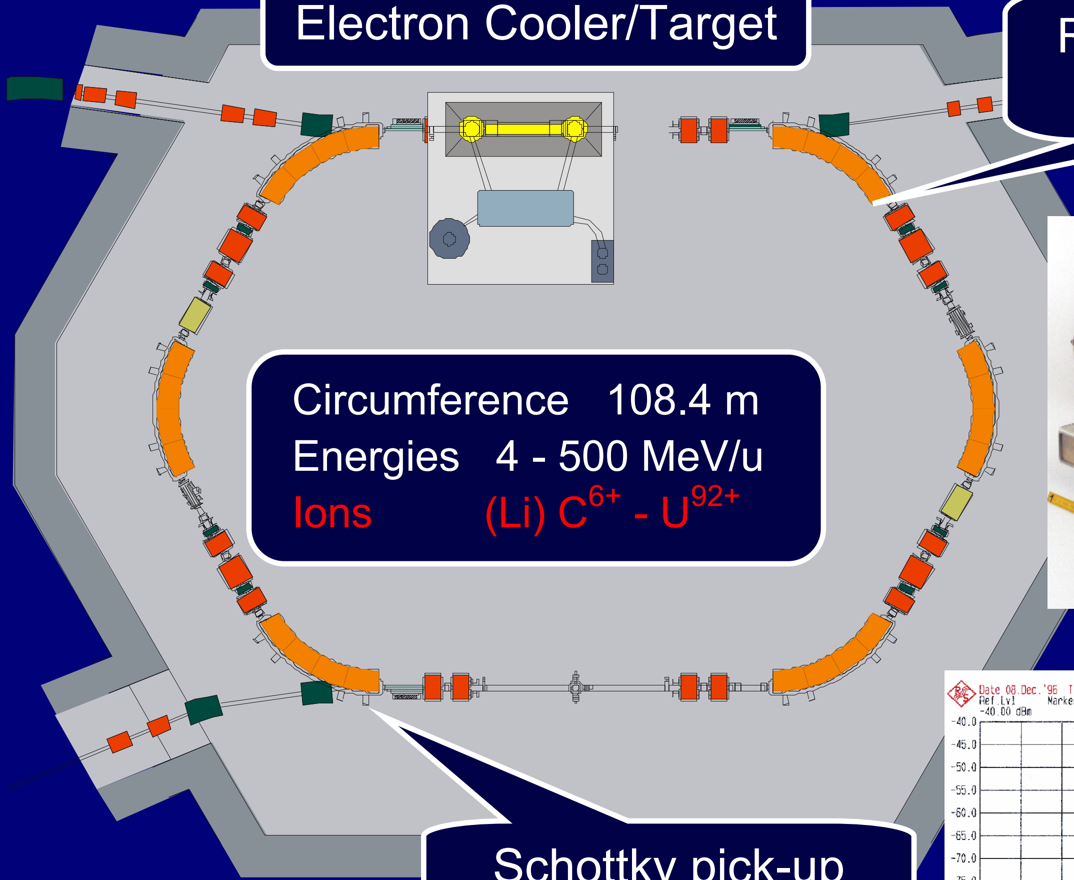
@ $\quad 0 \leq \Delta U_{lab} \leq 10000$ V

Experimental Storage Ring, ESR

Injection from SIS/FRS

Electron Cooler/Target

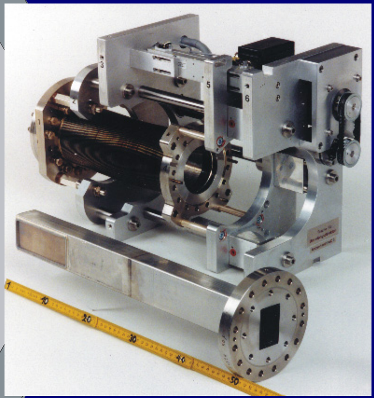
Recombination Detector



Circumference 108.4 m

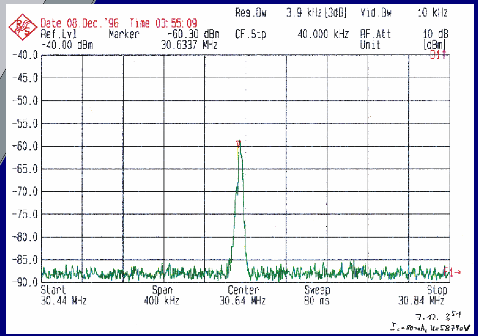
Energies 4 - 500 MeV/u

Ions (Li) C^{6+} - U^{92+}

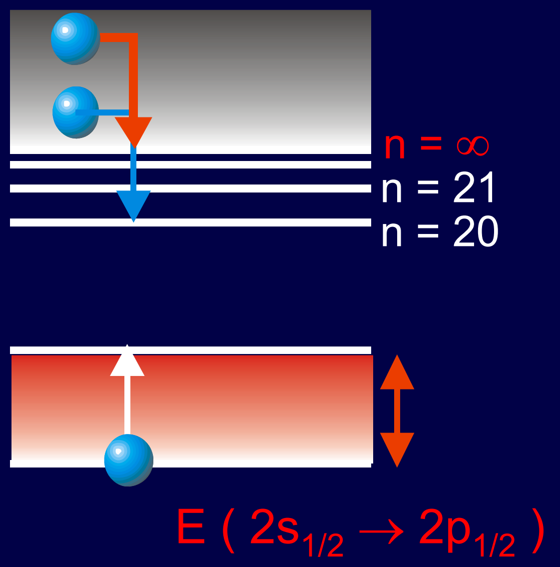


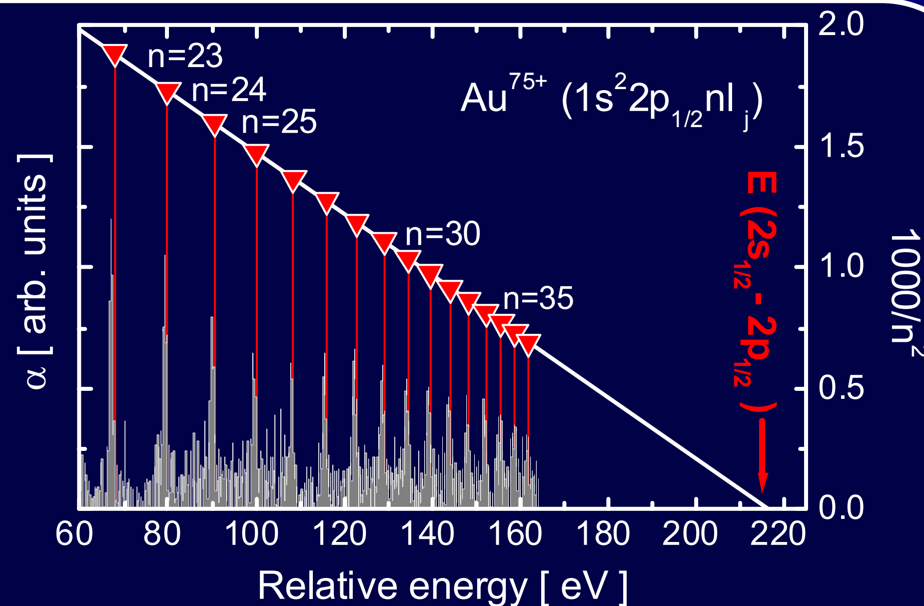
Reinjection to SIS

Schottky pick-up



Determination of the $2s_{1/2}$ - $2p_{1/2}$ Splitting



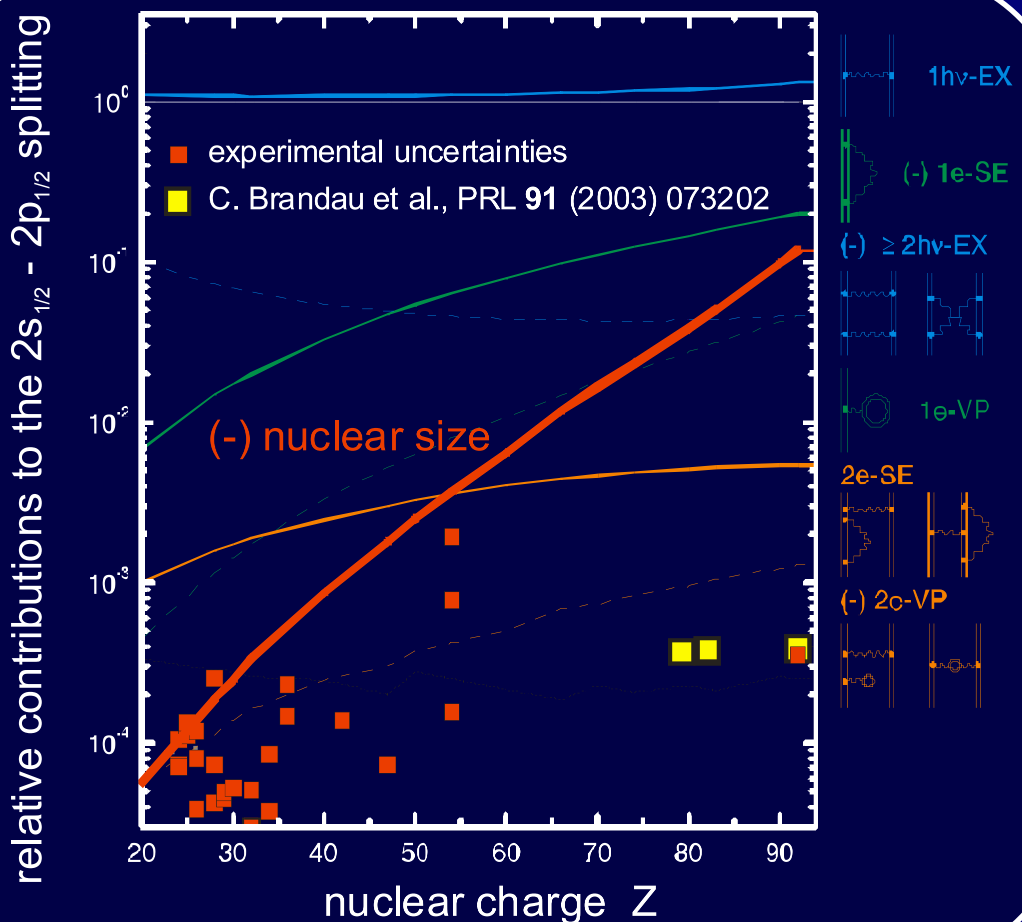


Main Idea:
Extrapolate to the
series limit!

Additionally taken into account:

- fine structure of peaks
- distribution of individual resonance strengths
- apparaus function (velocity spread of electrons)

Relative Contributions to the $2s_{1/2}$ -$2p_{1/2}$ Energy Splitting (Li-like Ions)



Sensitivity :

0,5 % of „QED“

< 7 % of QED in order α^2

< 3 % of nuclear size contributions (on an absolute scale)

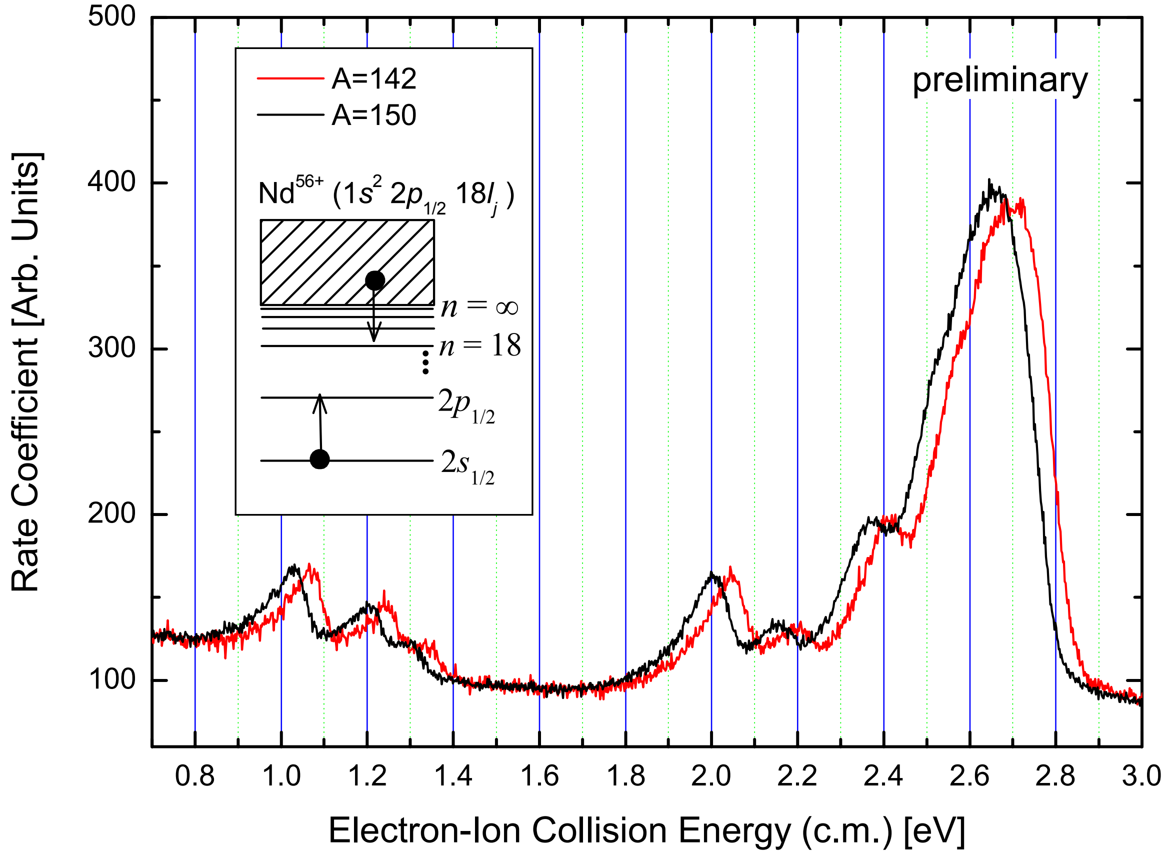
QED or nuclear pyhsics ?

^{208}Pb remains an ideal candidate for QED tests

QED: Yerokhin et al. (2001,2002)

Experimental uncertainties from:
Bosselmann et al. (1999)
Feili et al. (2000)

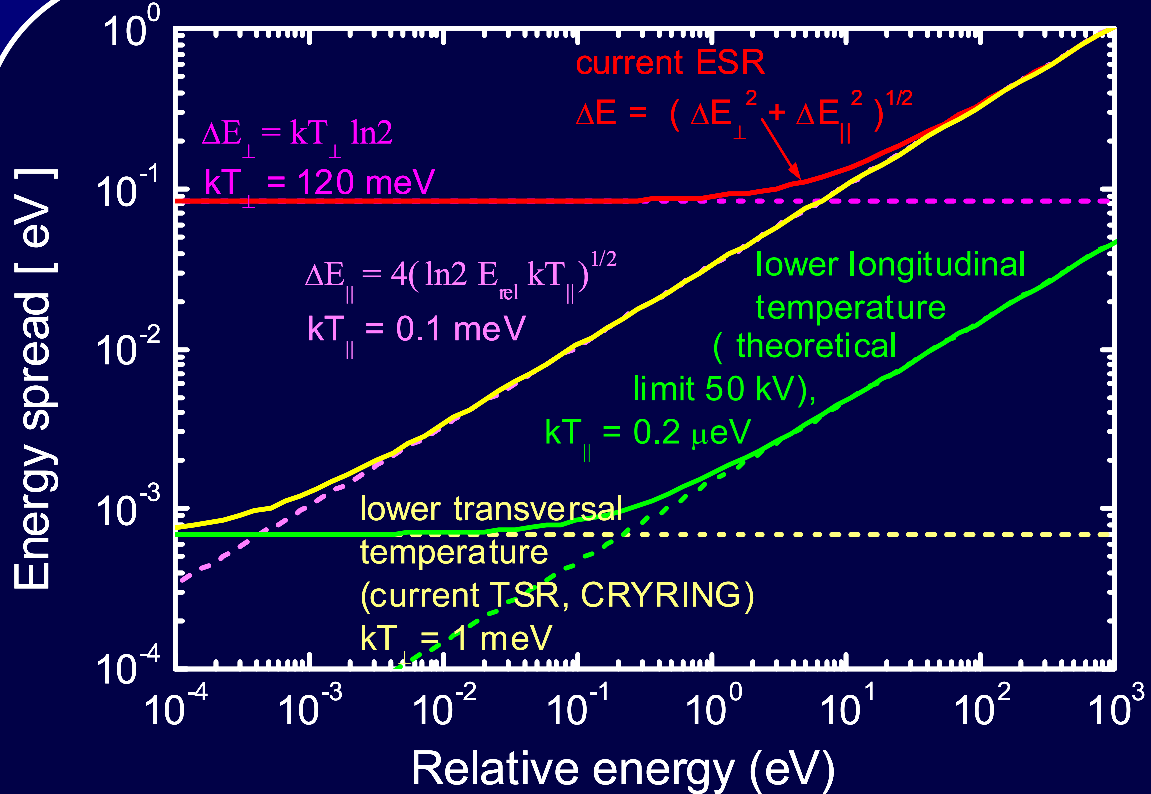
Isotopic Shift of Li-like $^{142}Nd^{57+}$ vs. $^{150}Nd^{57+}$ by Means of Dielectronic Recombination at ESR



C. Brandau,
C. Kozhuharov,
A. Müller et al.

First preliminary results of a pilot experiment performed at ESR in August 2005

Ultracold Electron Beam



<u>Present ESR:</u>
kT given by cathode heating and fast accelaeration

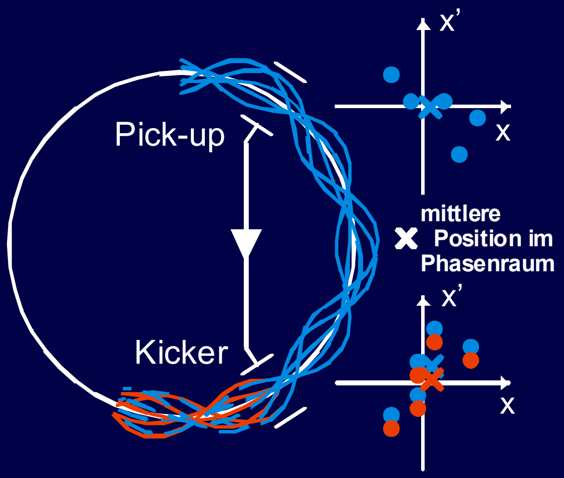
Adiabatic expansion of the electron beam
⇨ <u>lower transversal kT:</u>

Adiabatic acceleration of electron beam
⇨ <u>lower longitudinal kT:</u>

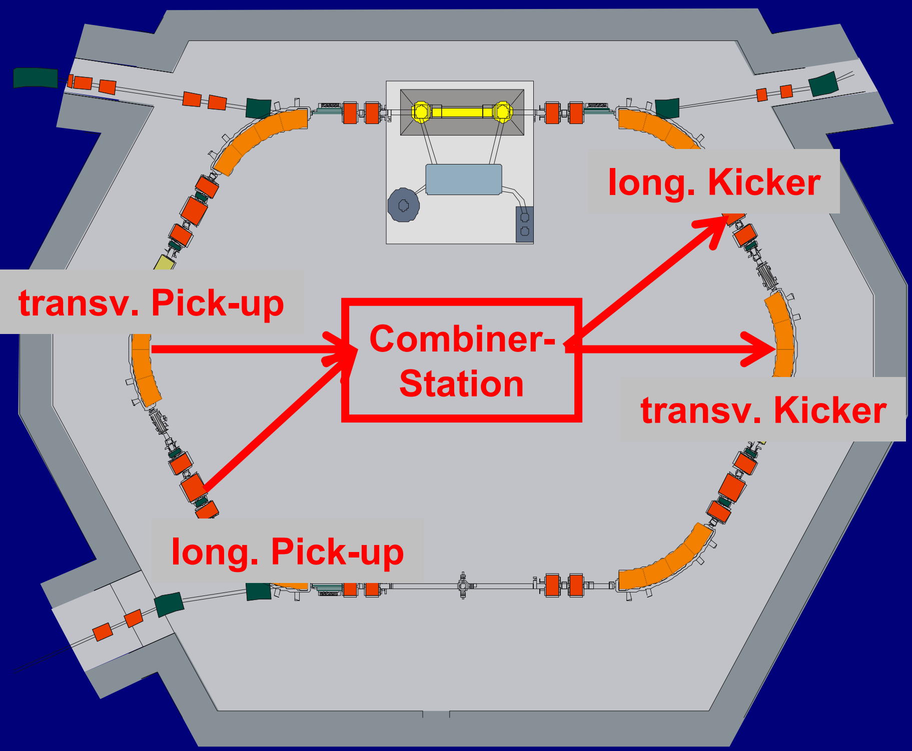
Further reduction of kT with cold (80 K) photo cathode
Has been demonstrated at MPI-K in Heidelberg.

KLL-DR-Experiments at ESR

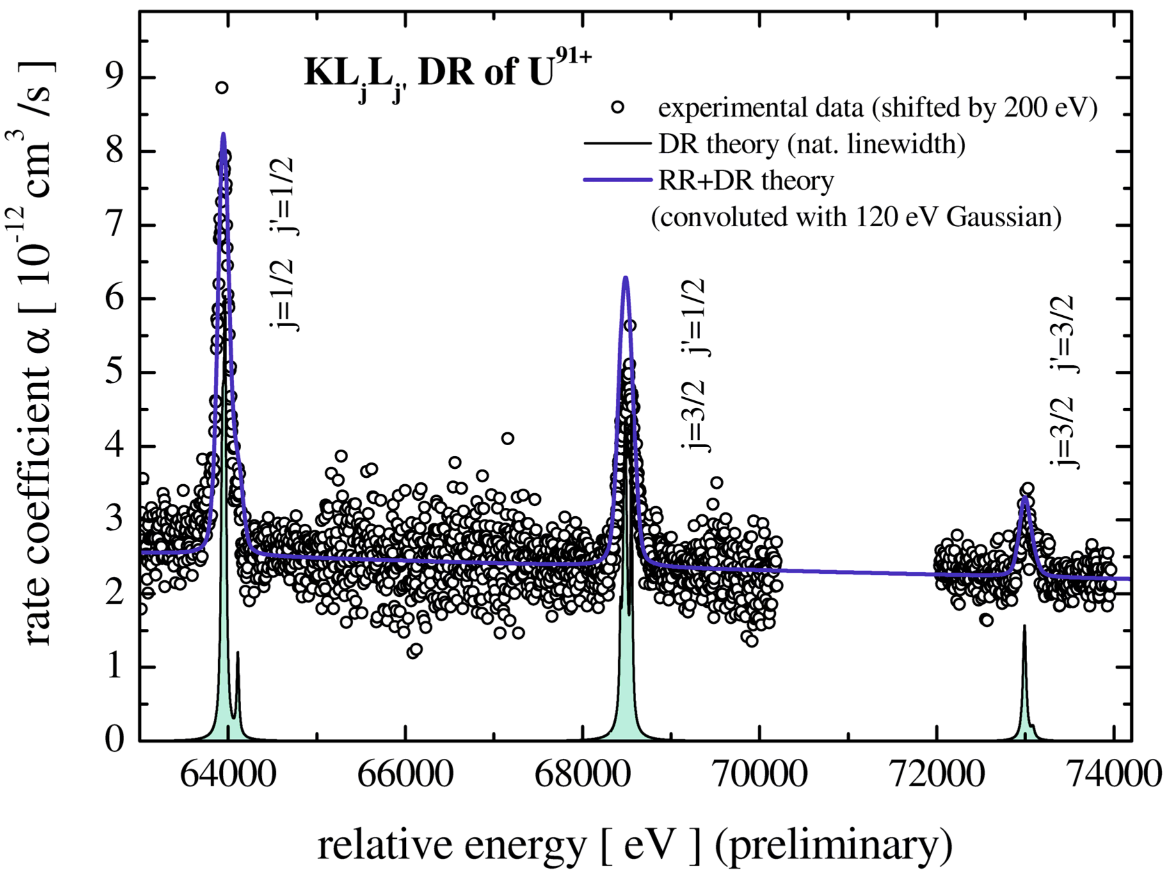
Basic Idea: The ion beam is cooled stochastically.
The electron cooler serves solely as an electron target.



Stochastic Cooling : The average position of a sample in the phase space is detected. This defines the correction of the kicker.



First Measurement of KLL-DR-Resonances in U^{91+}



Conclusions

- The symbiosis of experimental FEE with special accelerator settings, with the slow controls, and with the diagnostics has been the base of several successful experiments.
- Opportunity knocks but once—the present planning of the future accelerators, of their diagnostics and slow controls ought to ensure a large bandwidth of networking and interfacing between the experiments and storage rings.

Conclusions

- Particle detection in storage rings by means of Schottky-noise fast Fourier transform frequency measurements is a versatile tool for non-destructive non-instantaneous measurements.
- A broad band of masses or of momenta can be detected.
- The mass and/or momentum resolving power is excellent.
- Intensities and lifetimes can be measured as well.
- The count rate dynamics is up to eight orders of magnitude.
- One single highly-charged heavy-ion can be detected.
- The data—taken continuously—can be handled and stored.
- There is room for improvement, research and development:
  - multiple Schottky pickups and correlated FFT.
  - electron cooling force spectrometer