

TRIGA-TRAP:

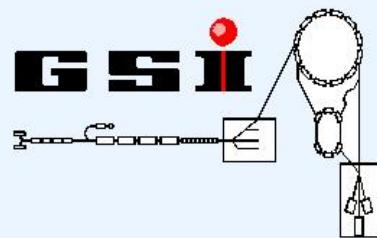
Mass measurements on exotic and heavy nuclides

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Outline:

- Motivation
- Measurement principle
- Experimental setup
- Summary and Outlook



Heavy ions from the Mainz TRIGA reactor



examples of

available elements

H																									He
Li	Be																								Ne
Na	Mg																								Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br								Kr	
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe								
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn								
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	112														

La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu										
Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	No	Lr											

Neutron flux for sample irradiation:

$$0.7 \cdot 10^{12} \text{ cm}^{-2} \text{ s}^{-1}$$

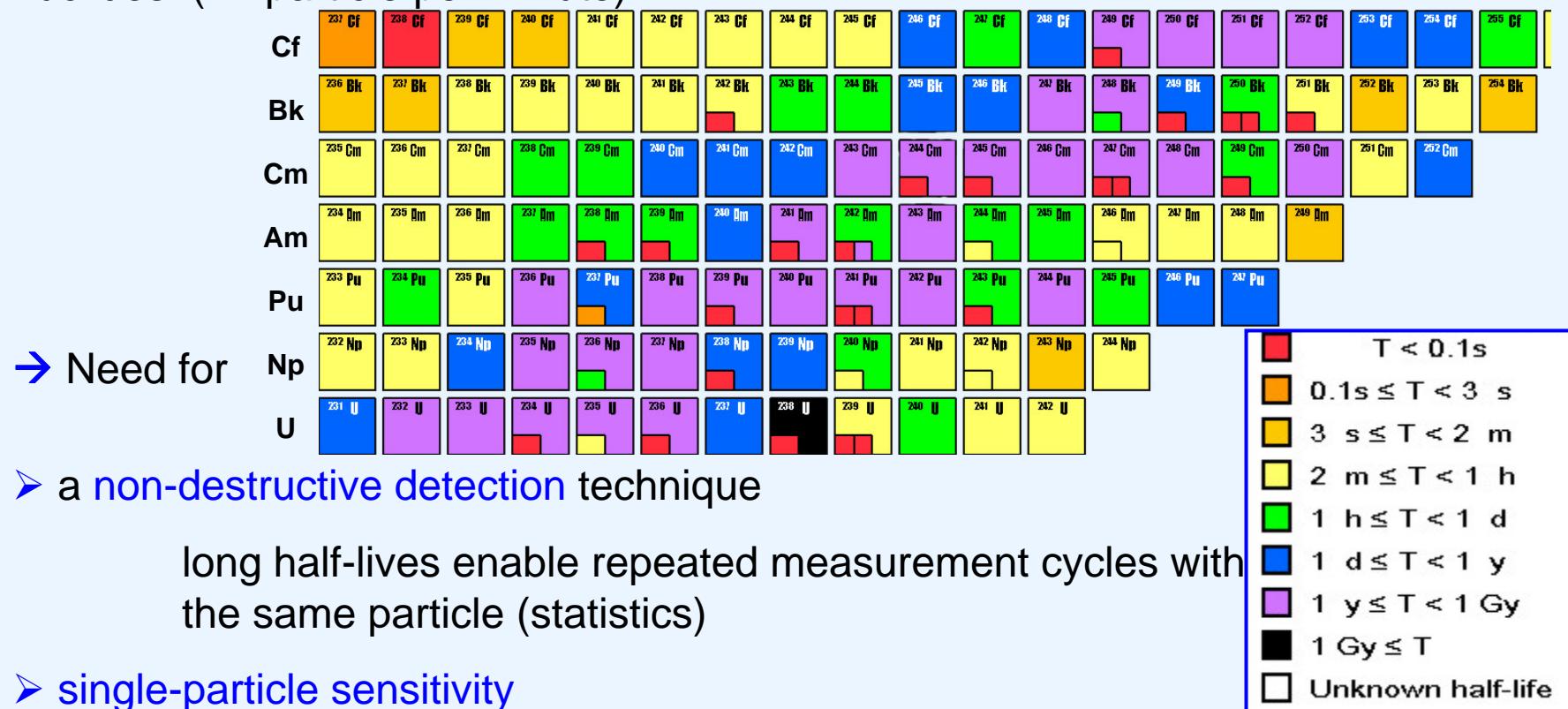
$$1.75 \cdot 10^{15} \text{ cm}^{-2} \text{ s}^{-1} \text{ (pulsed)}$$

Klaus Eberhardt, Gabriele Hampel, Norbert Trautmann



Challenges

We want to perform mass measurements on **rarely produced** heavy nuclides. (~1 particle per minute)



well-known non-destructive techniques in mass spectrometry are using several thousands of particles

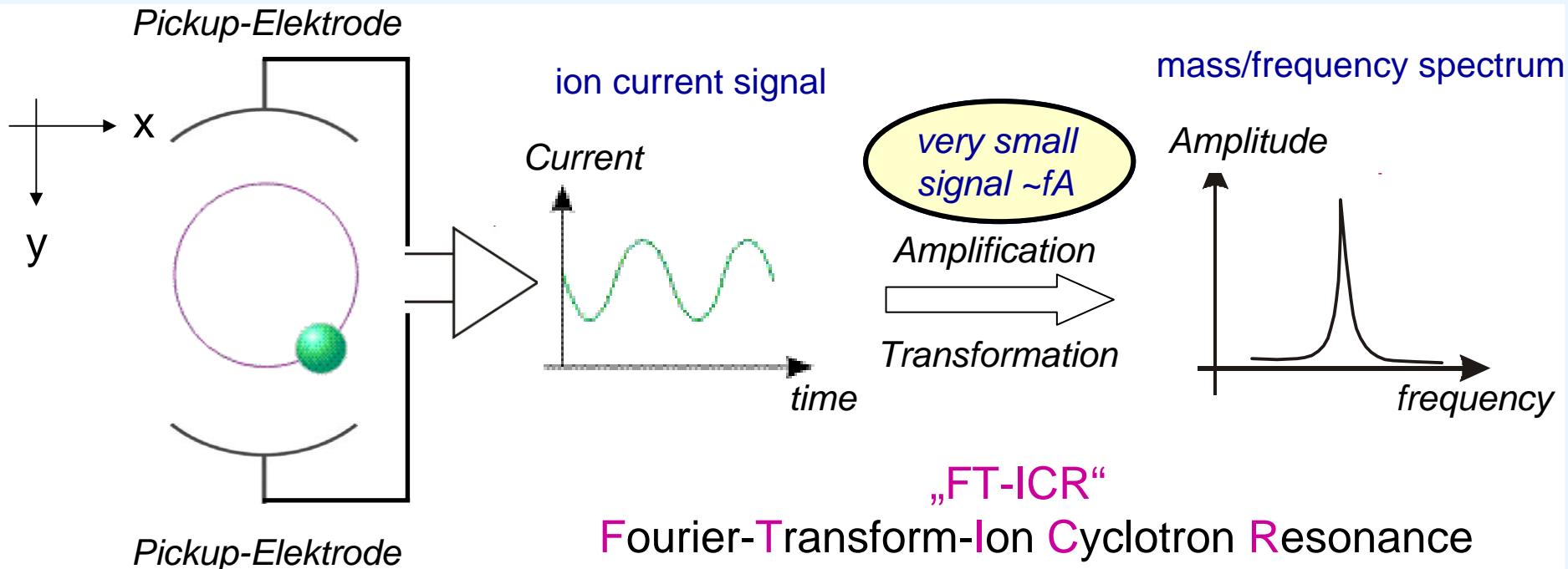
- a low-noise environment

single-particle signals are in the order of a few hundred fA

■	$T < 0.1\text{ s}$
■	$0.1\text{ s} \leq T < 3\text{ s}$
■	$3\text{ s} \leq T < 2\text{ m}$
■	$2\text{ m} \leq T < 1\text{ h}$
■	$1\text{ h} \leq T < 1\text{ d}$
■	$1\text{ d} \leq T < 1\text{ y}$
■	$1\text{ y} \leq T < 1\text{ Gy}$
■	$1\text{ Gy} \leq T$
■	Unknown half-life

Nucleus Win, NUBASE Data

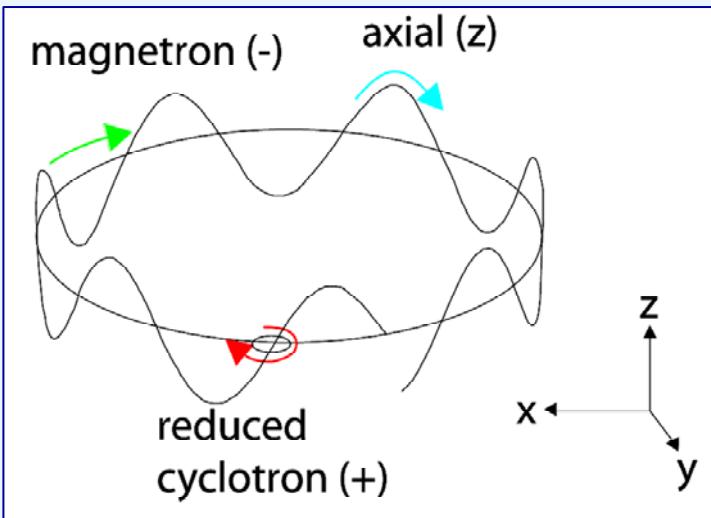
Non-Destructive Ion Detection



- ions induce an image current in two opposing trap electrodes (e.g. segments of the ring)
- Voltage drop across a resistor is Fourier transformed
- detection of an eigenfrequency

Mass determination

With FT-ICR it is possible to detect the three independent eigenmotions separately.



Cyclotron frequency:

$$\nu_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B$$

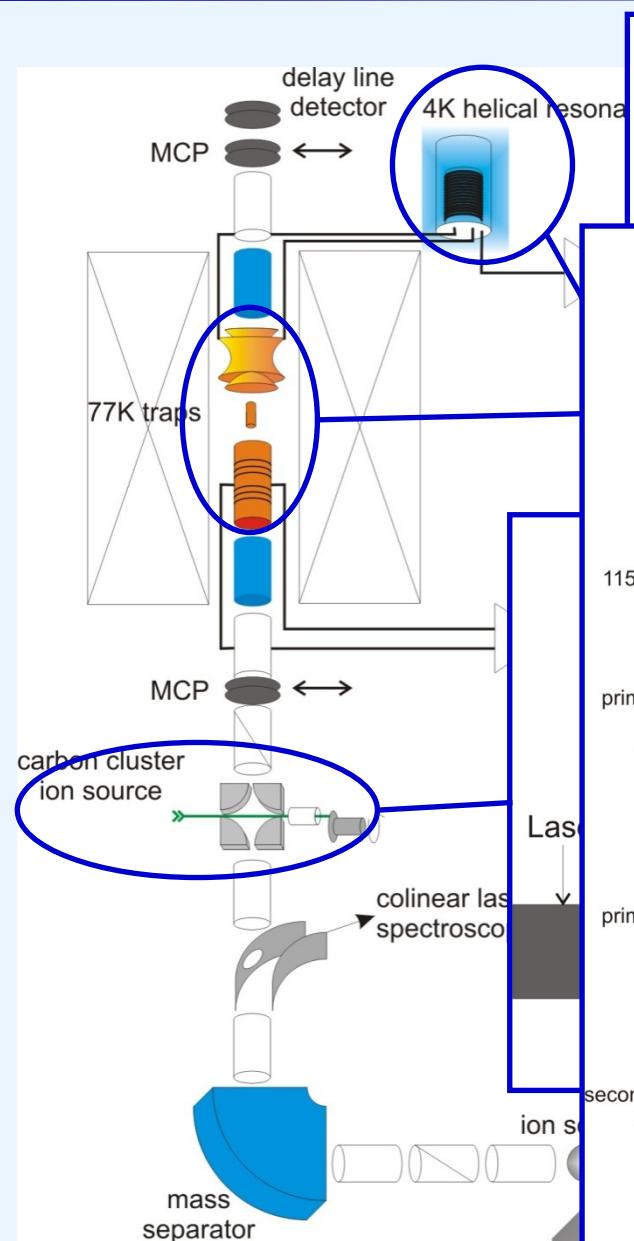
To obtain the charge to mass ratio, one needs to measure the masses of two different reference ions, e.g. a lighter and a heavier carbon cluster.

$$\frac{q}{m} = \frac{\nu_+^2}{\nu_+ a + b}$$

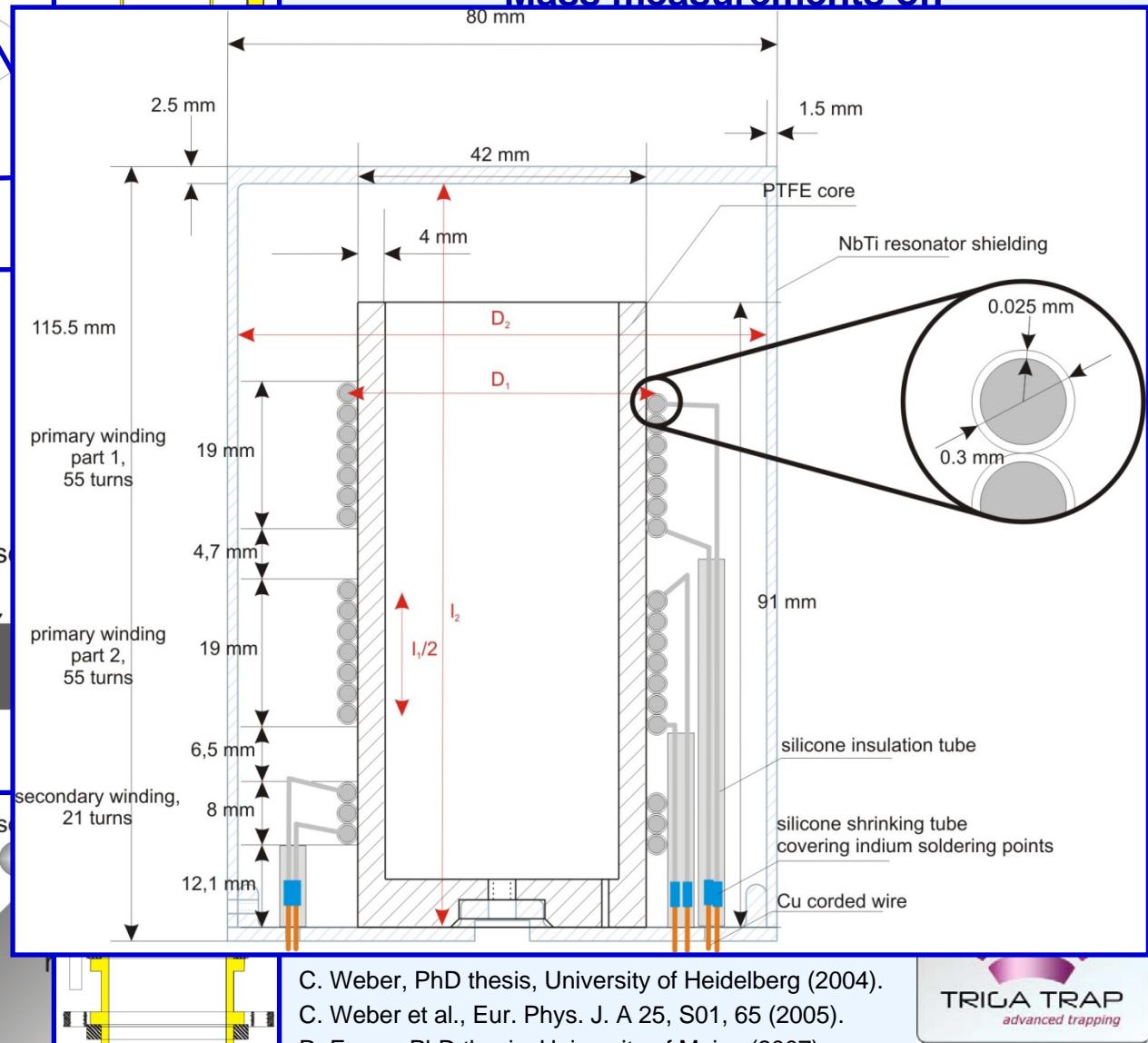
$$a = \frac{B}{2\pi}$$

$$b = \frac{V_0}{8\pi^2 d^2}$$

The TRIGA-TRAP facility



■ Mass measurements on



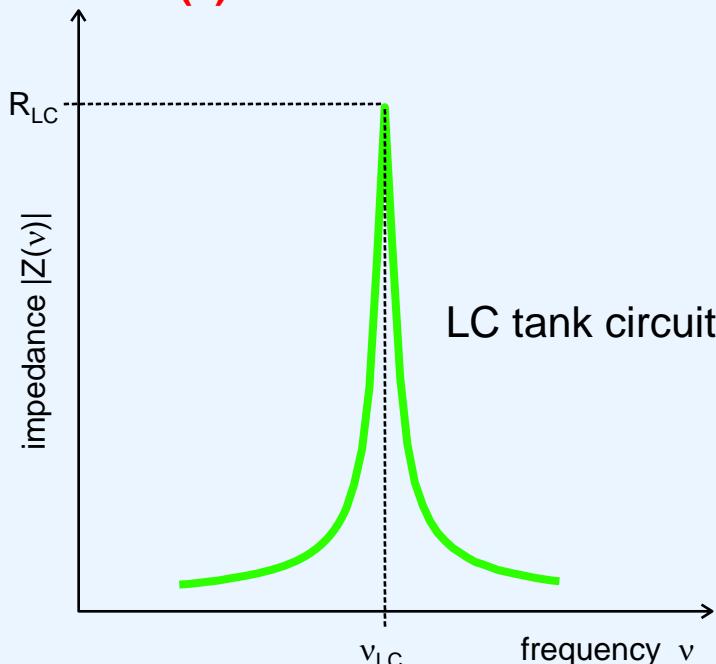
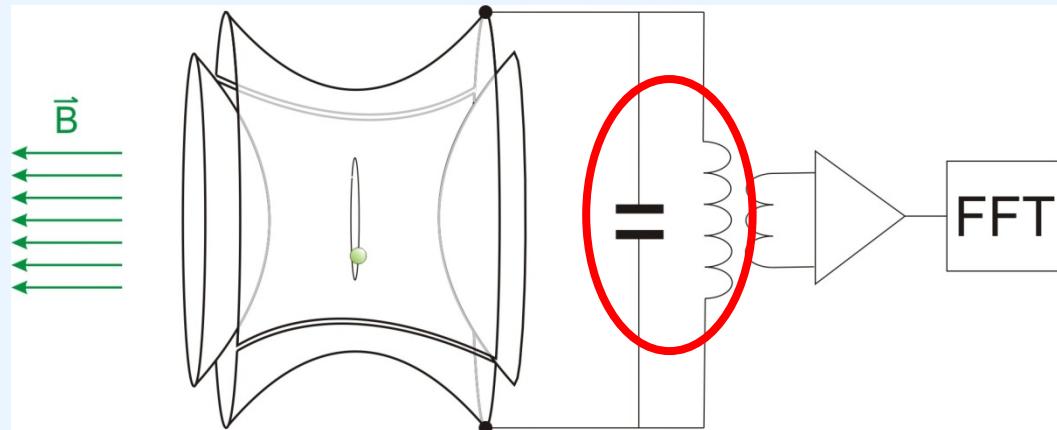
C. Weber, PhD thesis, University of Heidelberg (2004).
C. Weber et al., Eur. Phys. J. A 25, S01, 65 (2005).
R. Ferrer, PhD thesis, University of Mainz (2007).

Narrow-band FT-ICR detection

$$I(t) = 2\pi \frac{q v_{ion} r_{ion}(t)}{D} \approx 0.1 \text{ pA}$$

to improve signal-to-noise ratio, **detection bandwidth $\Delta\nu$** has to be reduced.

frequency-dependent impedance $Z(\nu)$



A measure for the bandwidth $\Delta\nu$ of a LC tank circuit is the quality factor Q .

$$Q = \frac{\nu_{LC}}{\Delta\nu} = 2\pi \frac{R_{LC}}{\nu_{LC} L}$$

Narrow-Band FT-ICR : signal-to-noise ratio

Problem: thermal noise (Johnson noise)

$$U_{noise} = \sqrt{4k_B T |Z| \Delta \nu}$$

Signal-to-Noise ratio

$$\frac{S}{N} = \frac{\sqrt{\pi}}{2} \frac{r_{ion}}{D} q \sqrt{\frac{\nu}{\Delta \nu}} \sqrt{\frac{Q}{k_B T C}}$$

To have a sufficient S/N ratio with single singly charged ions ($q=e$), the parameters T , Q have to be tuned.

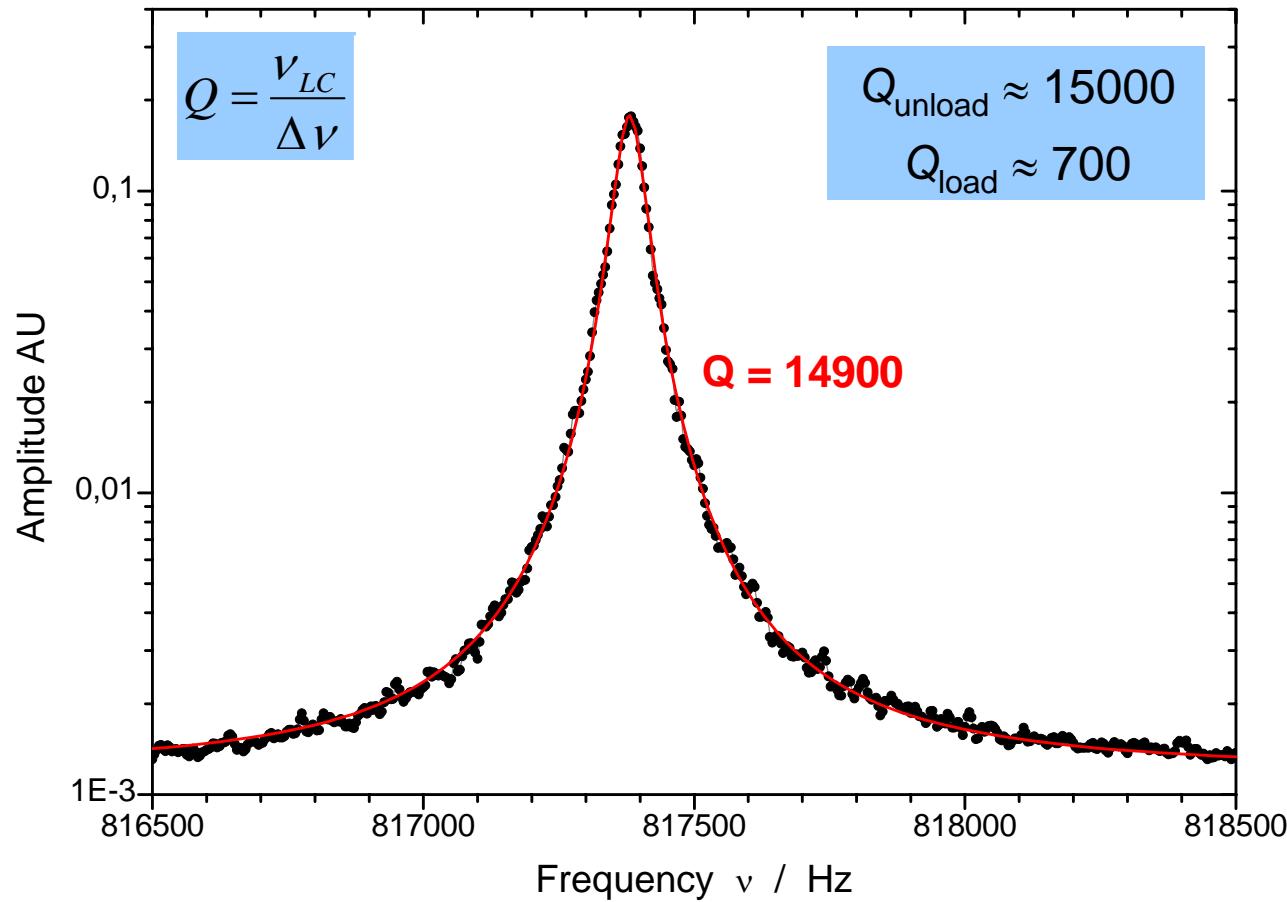
- cool down the system to **cryogenic temperatures**
(here: trap at **77 K** and first stage of electronics at **4 K.**)

Resonance of the superconducting tank circuit

Precision Trap

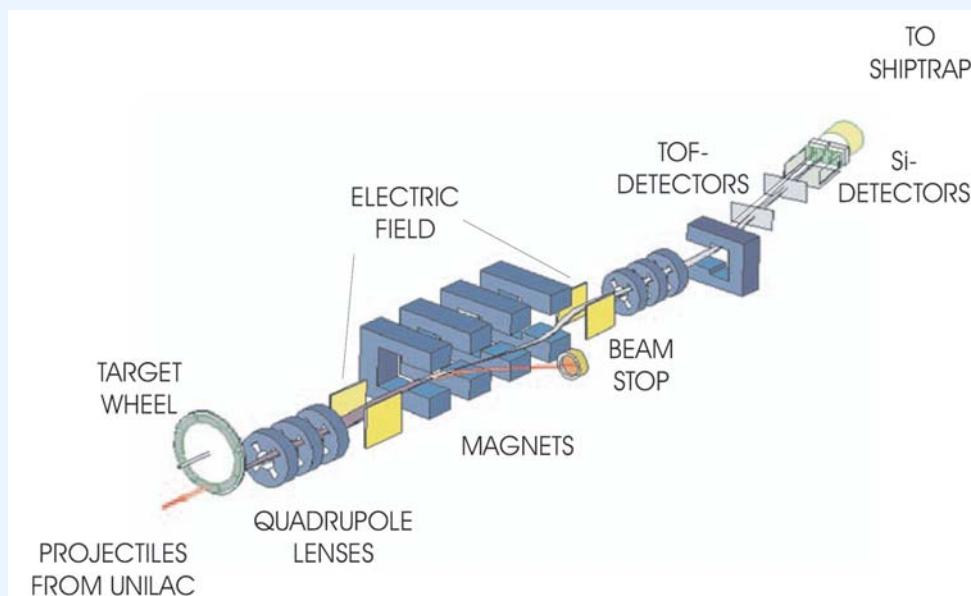


Resonance of the unloaded LC-circuit at $T=4\text{K}$

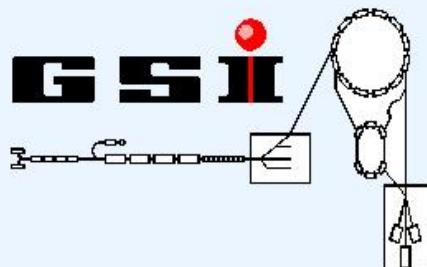
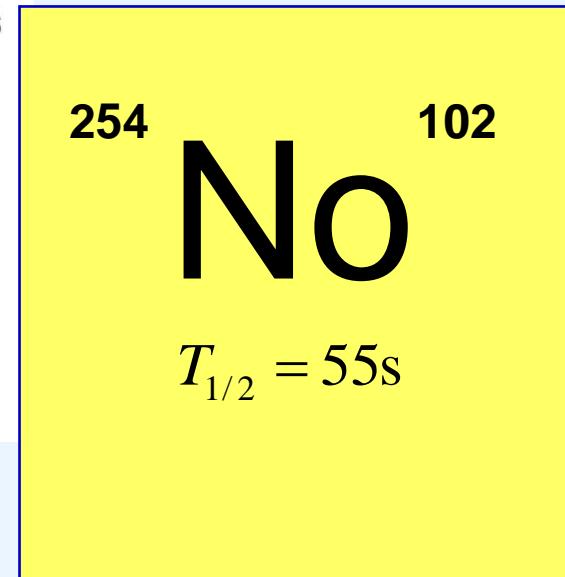


Single ion sensitivity (singly charged heavy ion)!

Heavy and superheavy ions from SHIP



example candidate



- comparably large production yield
(~ 2 ions per second)
- close to predicted “island of stability”

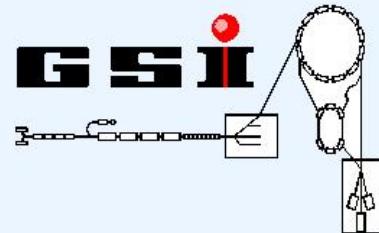
Summary and outlook

- At TRIGA-TRAP we will perform mass measurements on heavy transuranium elements up to ^{252}Cf , as well as on neutron rich nuclides around N=82
- The electronic is tested and the setup will be assembled at the TRIGA reactor in Mainz in the next months
- First measurements in the next year
- Later we will move the setup to the SHIPTRAP facility for the measurement of superheavy elements



Special Thanks to:

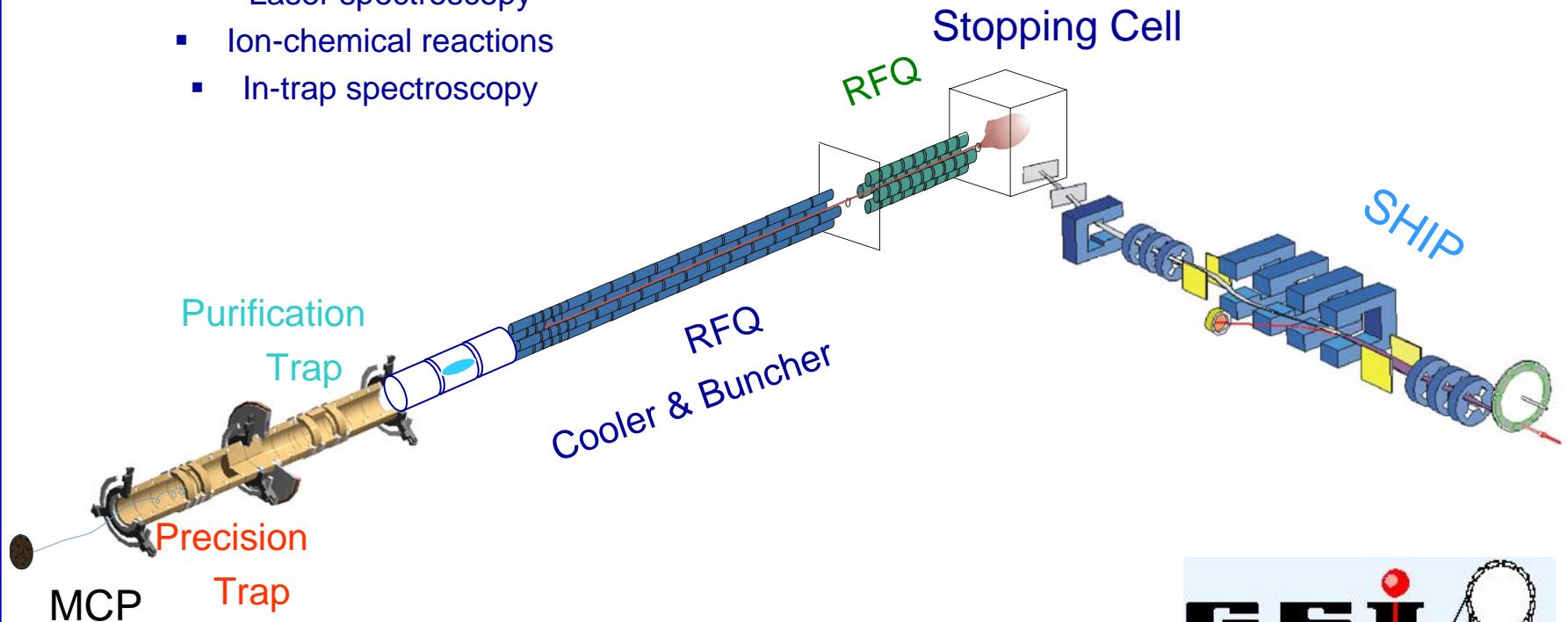
- MATS group within QUANTUM at the institute of physics, especially:
K. Blaum, G. Eitel, R. Ferrer, S. George, J. Ketelaer, Sz. Nagy, J. Repp, C. Smorra
- The SHIPTRAP-team with M. Block, F. Herfurth and H.-J. Kluge
- Our collaborators: K. Eberhardt, S. Stahl and C. Weber
- Funding:



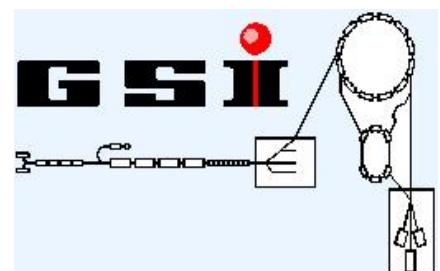
Thanks a lot for your attention!

The SHIPTRAP facility

- Mass measurements
 - Laser spectroscopy
 - Ion-chemical reactions
 - In-trap spectroscopy

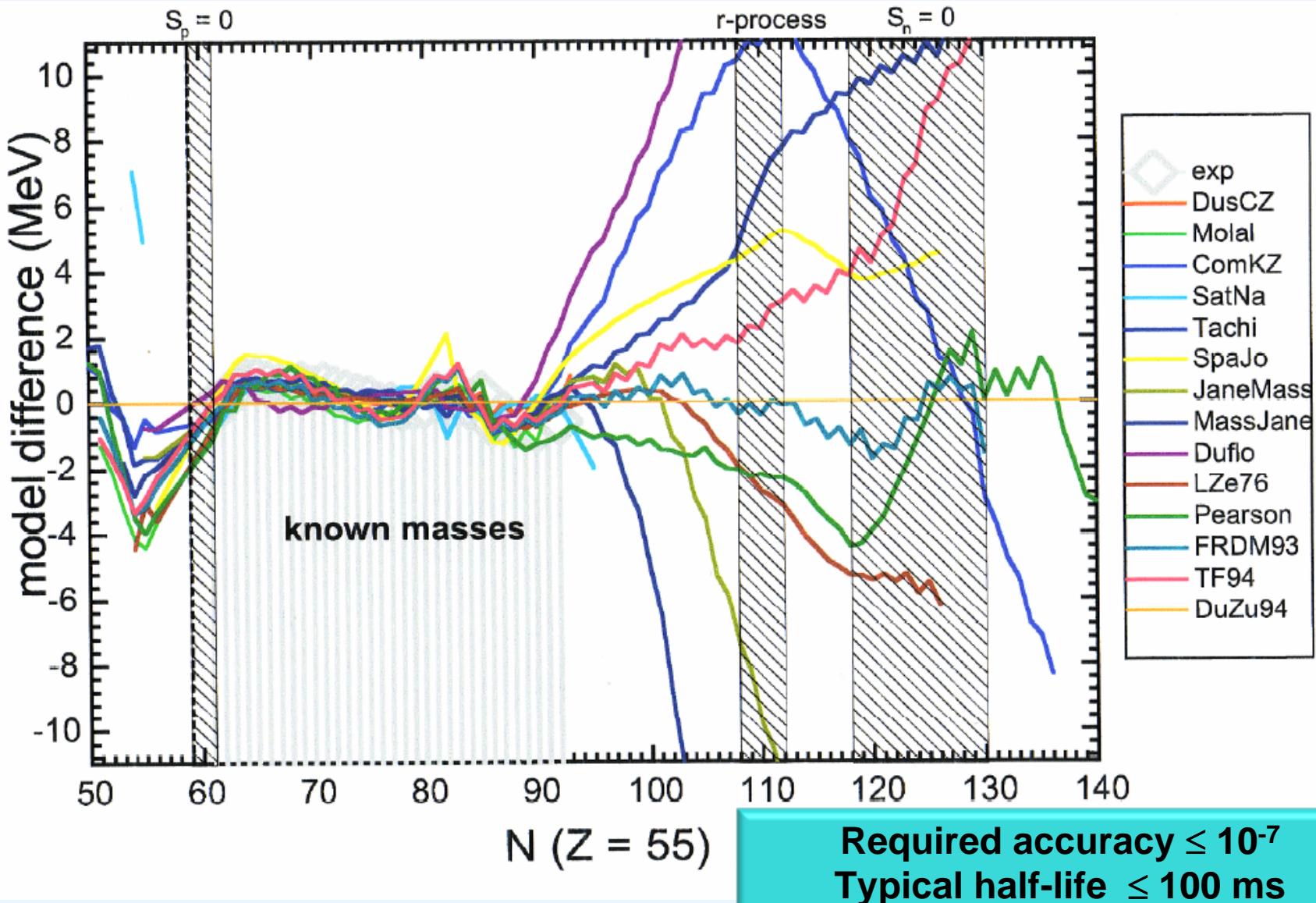


Penning trap mass spectrometer to perform high-precision mass measurements on rare species produced in fusion-evaporation reactions



Motivation: Test of mass models

M
A
T
S



Carbon clusters as absolute mass references (1)

MAT

