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MATS

A novel four-trap mass spectrometer for high-accuracy mass measurements on highly-charged ions

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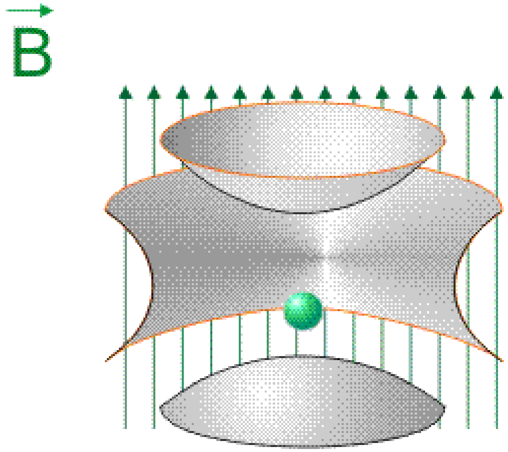
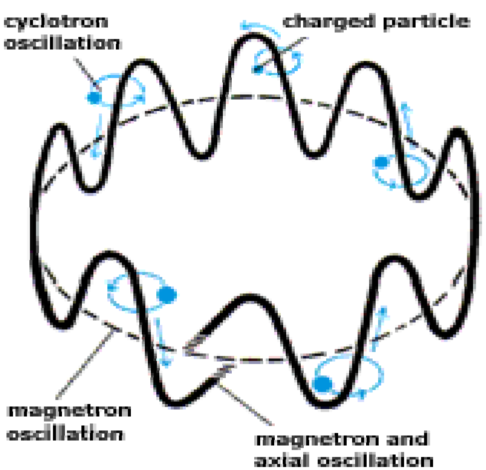
Outline:

- Penning traps as mass spectrometers
- Related physics and recent results using HCI
- Features of the novel apparatus
- Present status
- Outlook

Penning traps as mass spectrometers

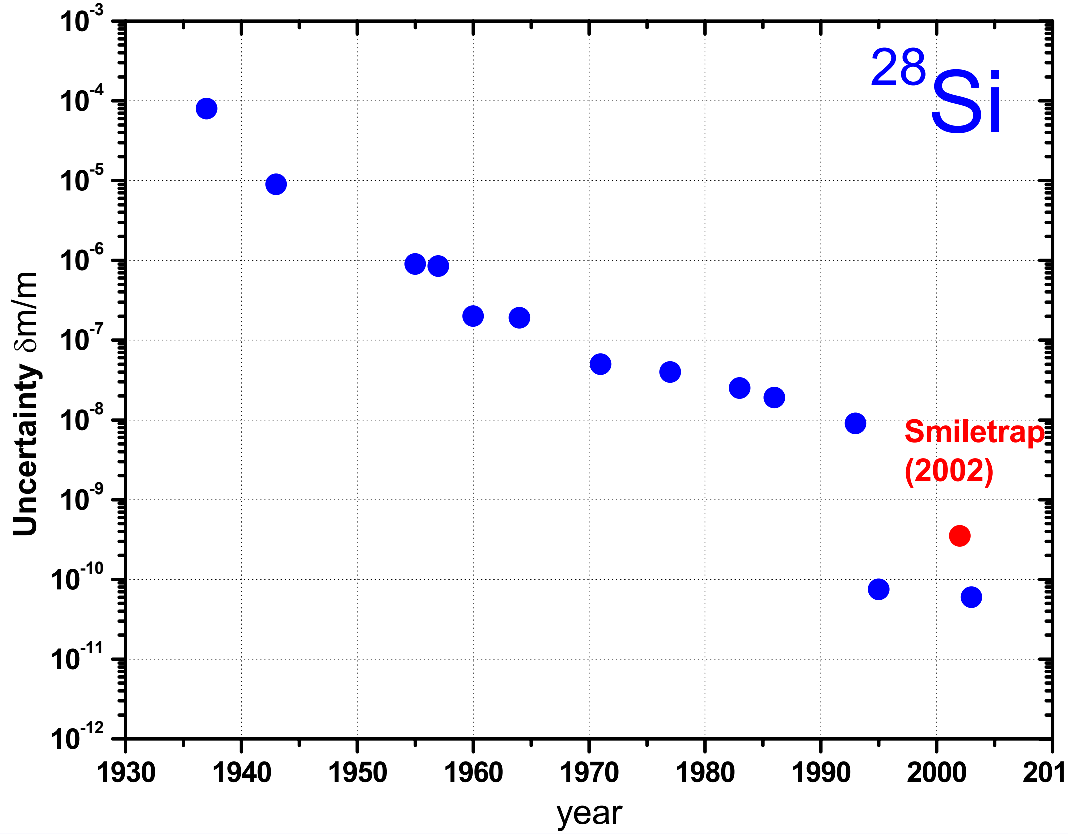




$$\nu_c = \frac{1}{2\pi}\frac{qeB}{m}$$

$$\nu_c = \nu_+ + \nu_-$$

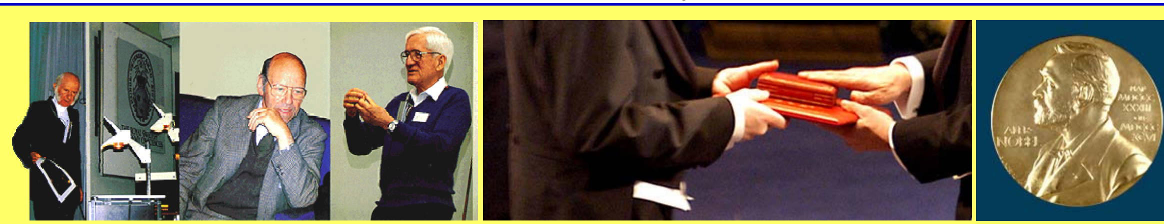
$$\nu_c = \sqrt{\nu_+^2 + \nu_-^2 + \nu_z^2}$$



1979 VanDyck, Dehmelt e^- / e^+ 100ppb

P.B. Schwinberg, R.S. vanDyck, H.G Dehmelt, Phys. Lett 81A, 119 1981

1989 Nobel Prize in Physics:
Dehmelt, Paul, Ramsey

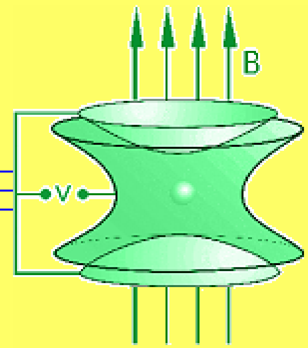


What can be done using high accuracy mass spectrometry

Direct test of atomic structure calculations,

´´weigh´´ QED effects directly, (200u 0.1ppb)

measure in a Penning trap the first superheavy element



determine fundamental constants, e.g. α, m_e, m_p

better direct test of E=mc², if: E=hν

test BS-QED in strong fields, *g*-factor

accurate *Q*-values to find *0ν2β*-decay e.g. ^{76}Ge-^{76}Se

help the search for electron antineutrino rest mass

measure directly atomic electron binding energies ($A^{(q-1)} - A^{q+} - m_e$)

and all these (and many more) can be done using highly charged ions...

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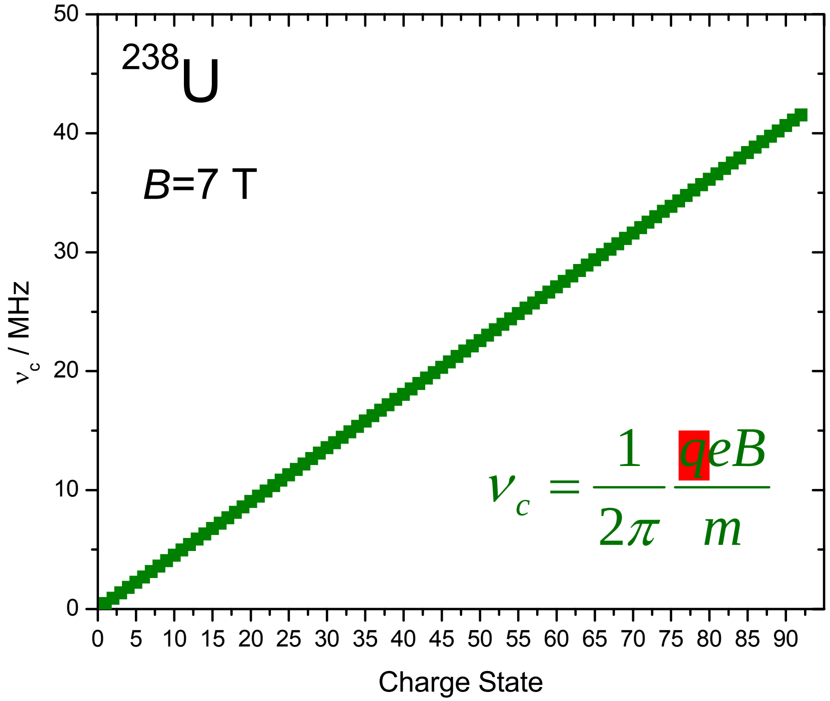
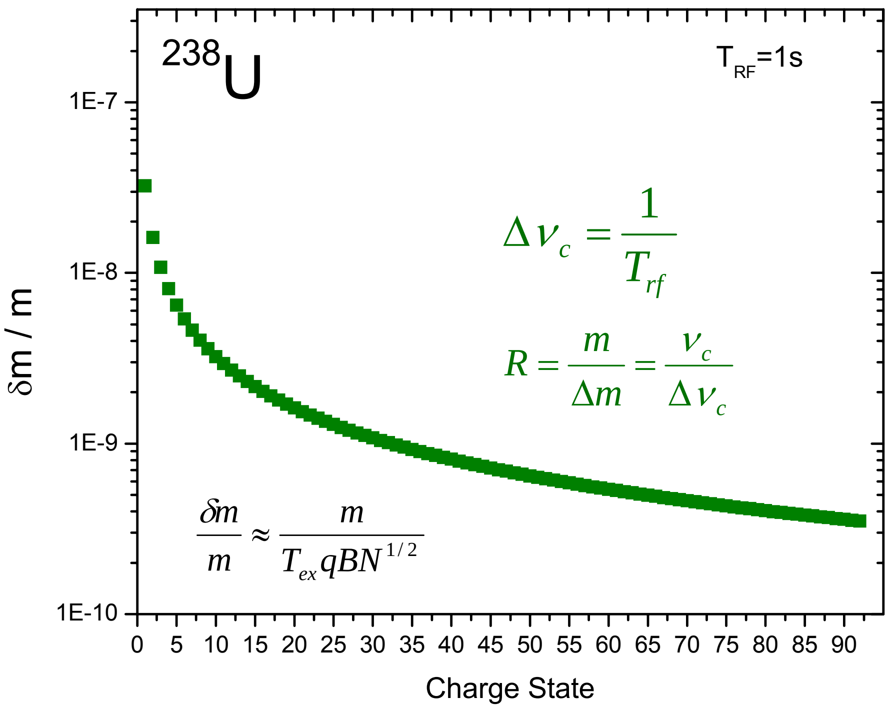
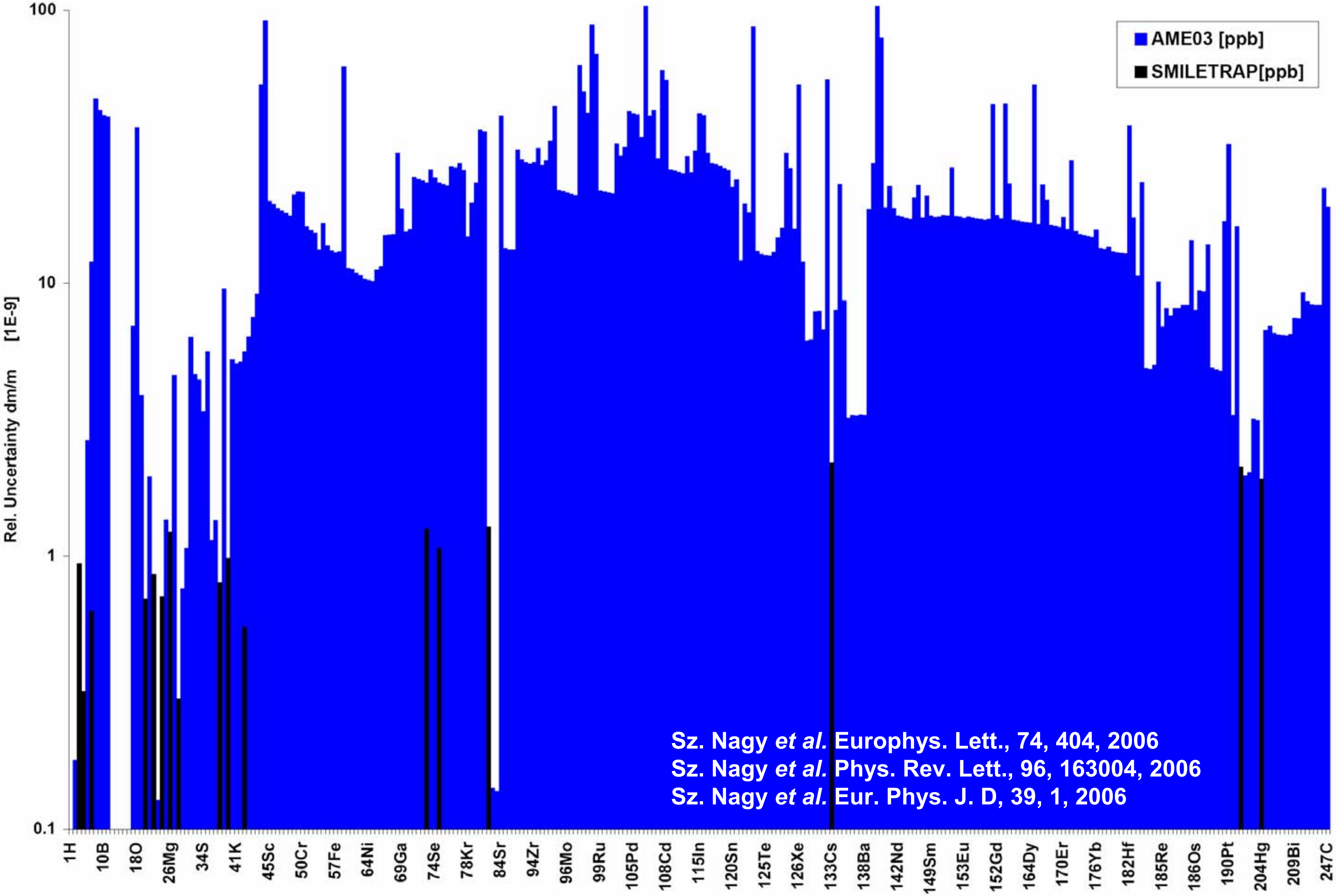
Why highly-charged ions -is there a benefit?





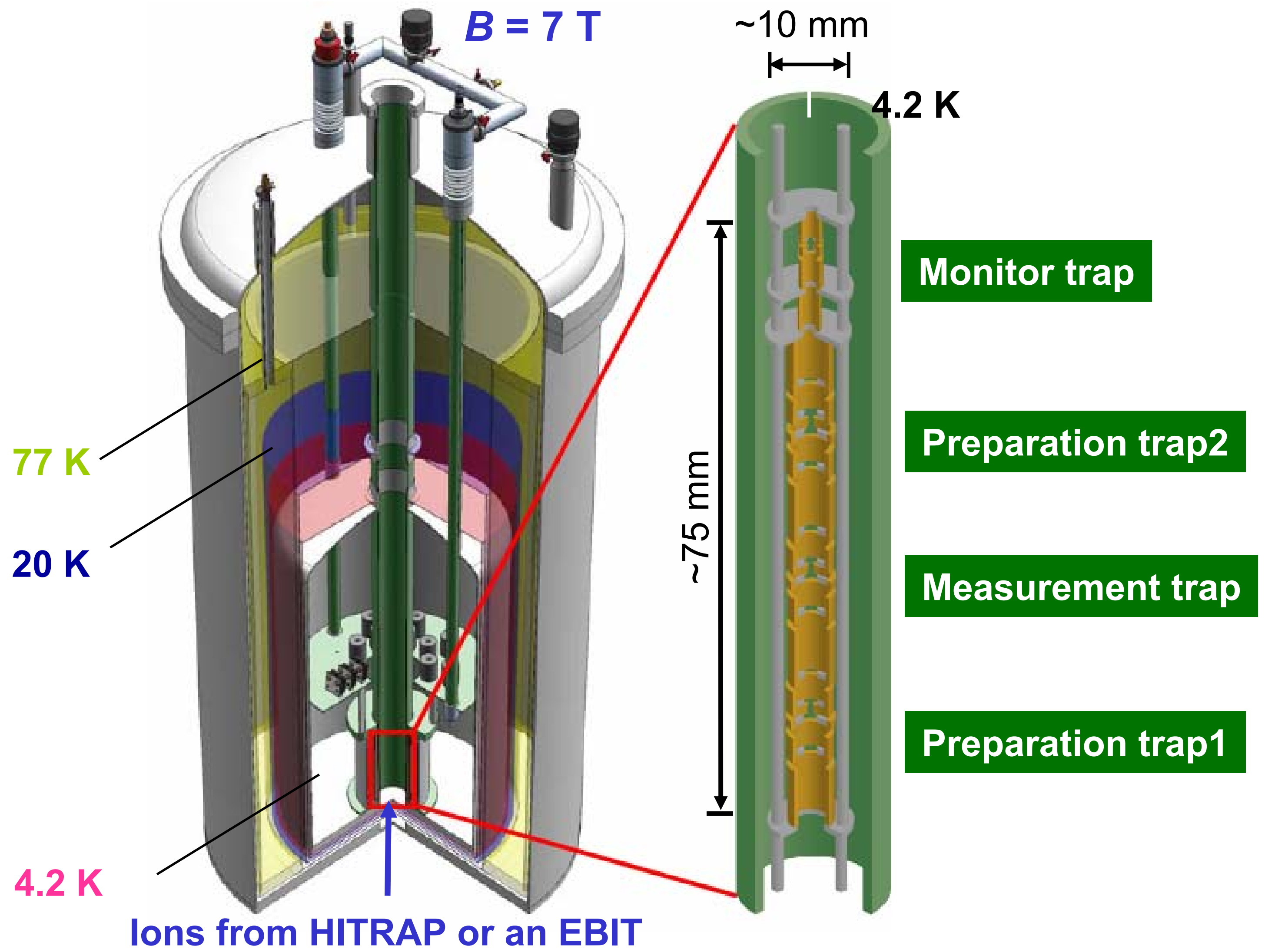
In the case of ^{238}U max. 92X higher resolving power can be achieved by using q=92+ ions.

Recent results using HCl at SMILETRAP

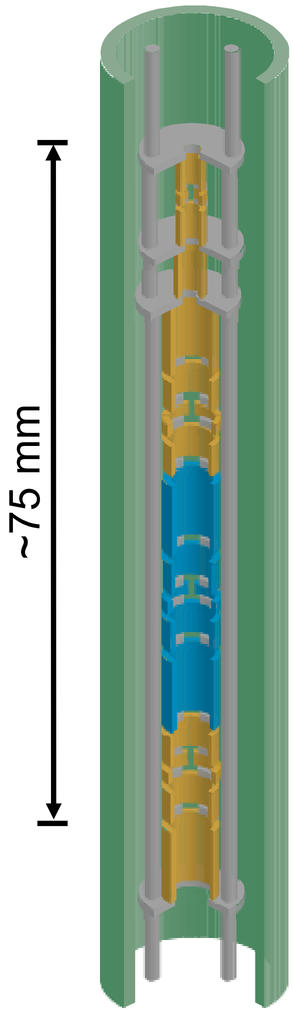


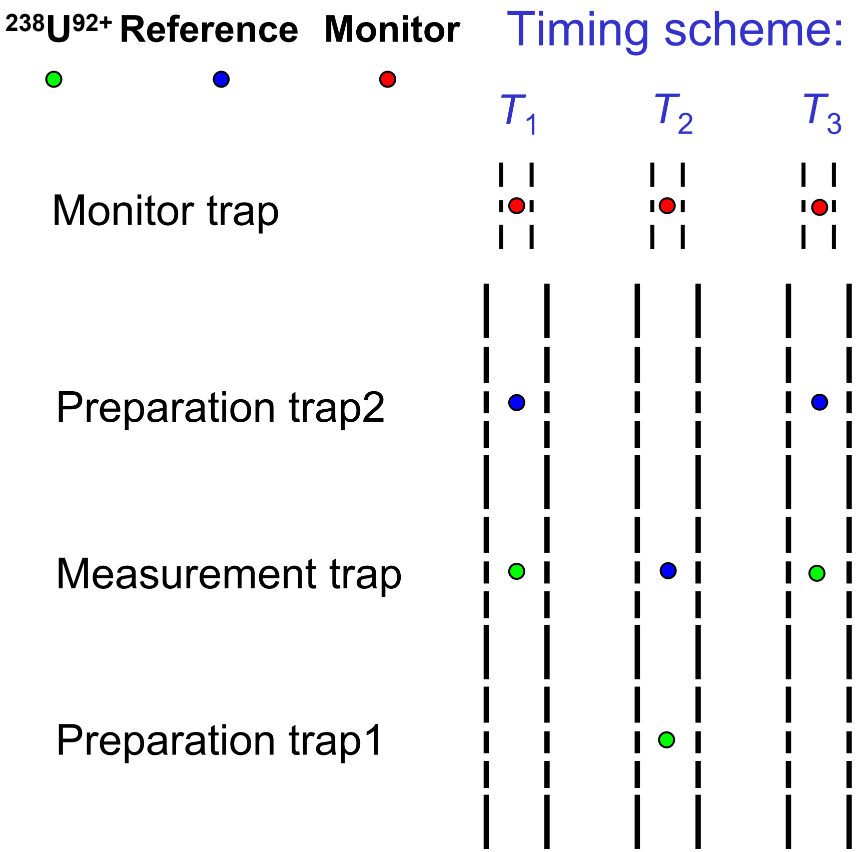
Sz. Nagy *et al.* Europhys. Lett., 74, 404, 2006
Sz. Nagy *et al.* Phys. Rev. Lett., 96, 163004, 2006
Sz. Nagy *et al.* Eur. Phys. J. D, 39, 1, 2006

The layout of the cryogenic four trap-mass spectrometer



What´s new? Features





Advantages:

- Cryogenic temperatures
- Highly-charged ions
- Non-destructive ion detection
- Direct electron binding energy measurement
- No ion-ion interaction
- Short measurement cycle
- Continuous *B*-field monitoring/ calibration

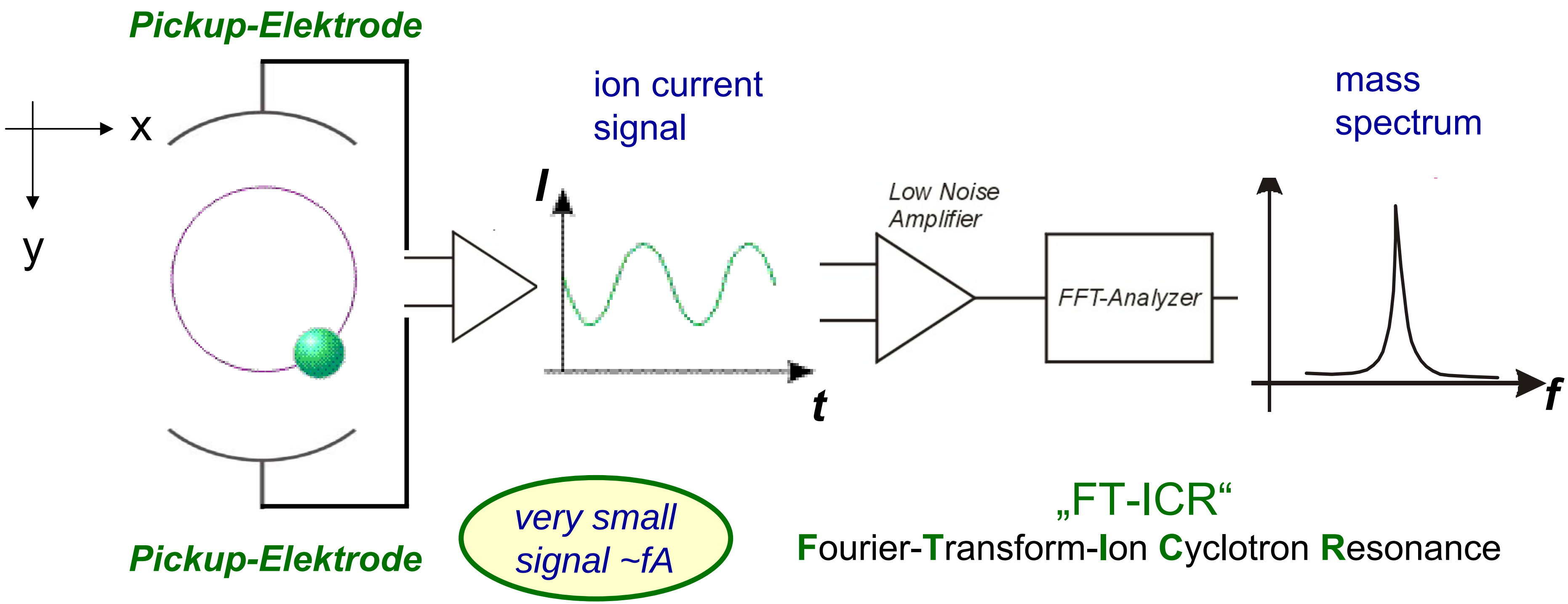
$T = 4.2$ K

$\delta B/B < 10^{-7}/\text{cm}^3$,
$(\delta B/dt)\cdot(1/B) < 10^{-10}$/h

Goal: $\delta m/m \leq 1\cdot10^{-11}$

$\delta m(^{238}U^{92+}) = 2$ eV

Cryogenic FT-ICR detection with single ion sensitivity



„FT-ICR“

Fourier-**T**ransform-**I**on **C**yclotron **R**esonance

Signal-to-noise ratio: $$\frac{S}{N} = \frac{\sqrt{\pi}}{2} \cdot \frac{r_{ion}}{D} \cdot q \cdot \sqrt{\frac{\nu}{\Delta\nu}} \cdot \sqrt{\frac{Q}{kT \cdot C}}$$

r_{ion}: ion motion radius **D: trap dimension** **q: charge state**

Q: quality factor **T: temperature** **C: capacity**

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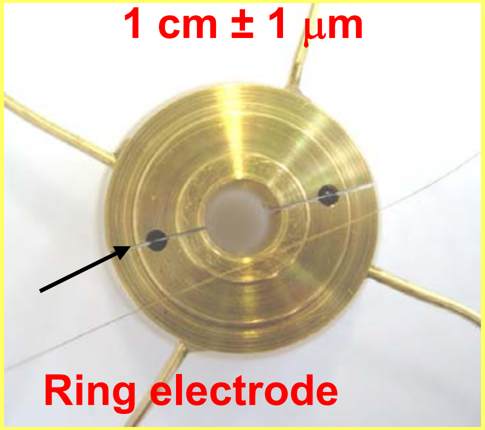
Already available in Mainz

Precision trap

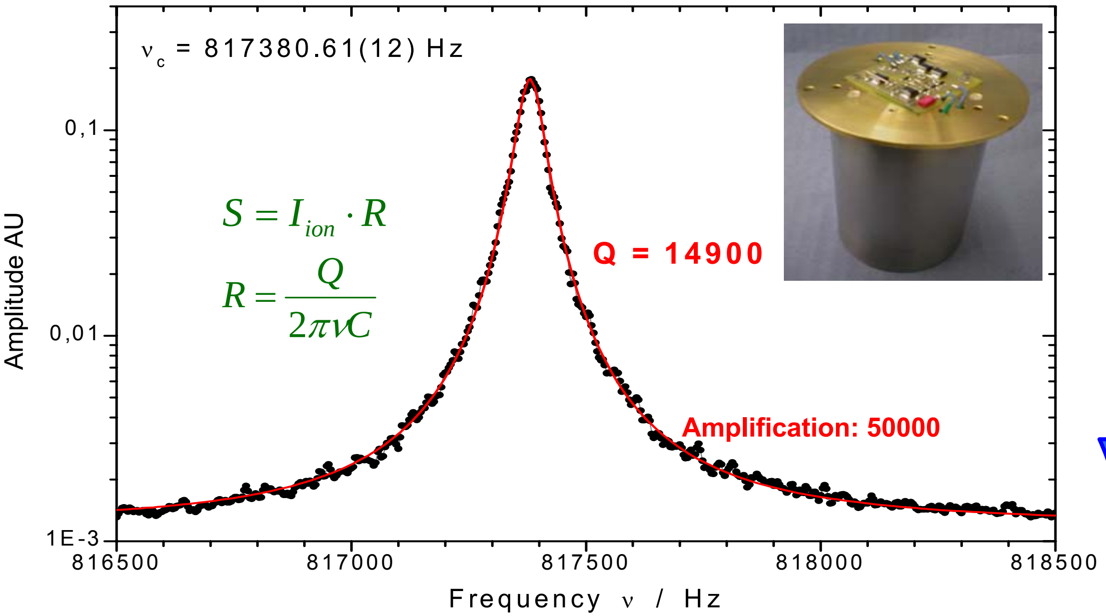
C. Weber *et al.*, Eur. Phys. J A 25, 65 (2005)



Machined at the **I**nstitute for **M**icrotechnique **M**ainz

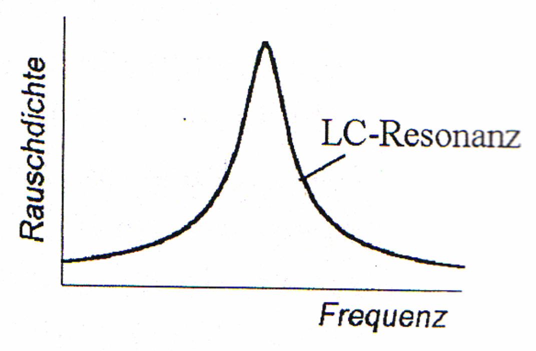
Single-ion sensitivity!

Resonance of the unloaded *LC*-circuit at *T* = 4K

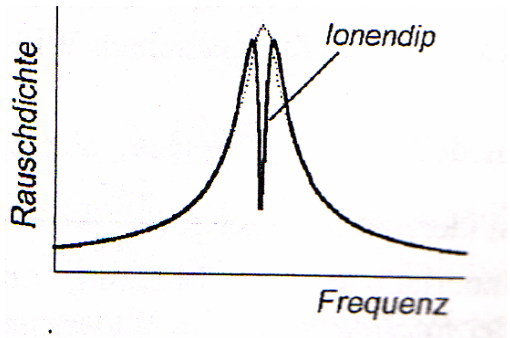


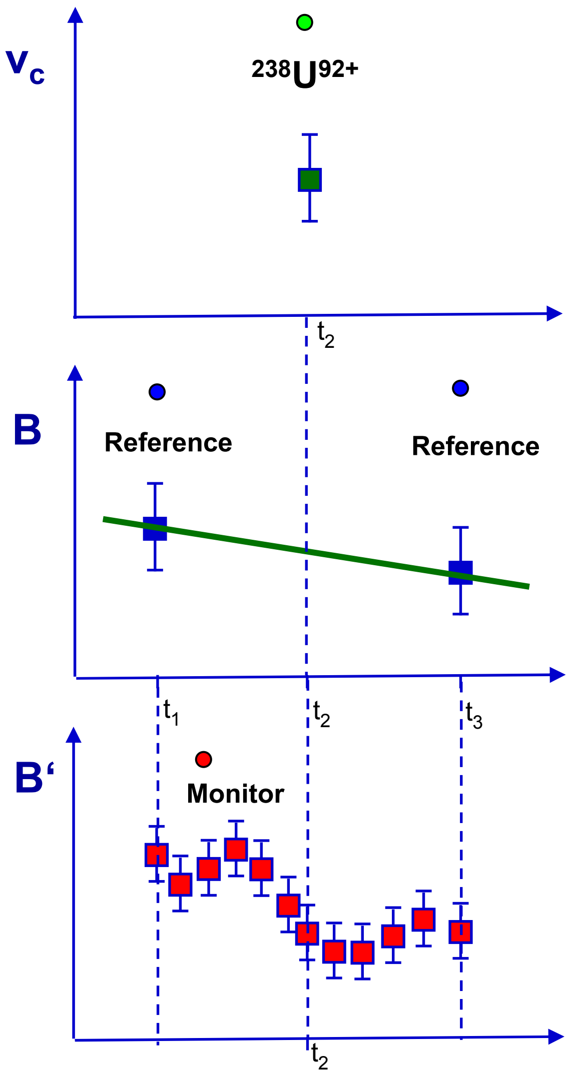
Monitoring Trap

Technique 1



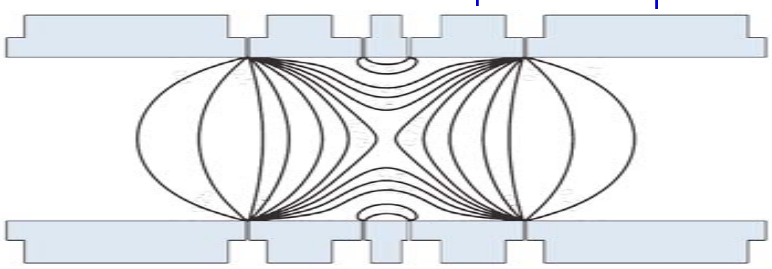
Technique 2



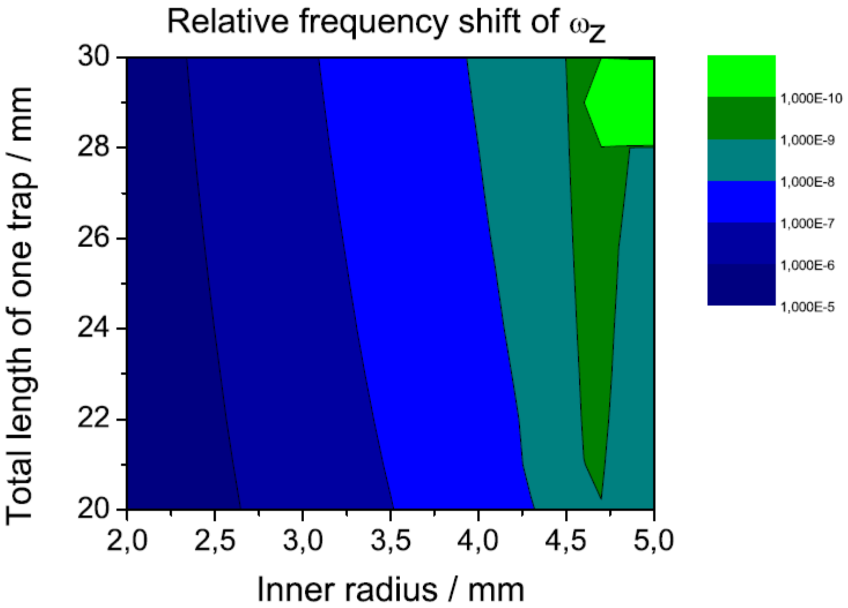


$$\nu_c = \frac{1}{2\pi}\frac{qeB}{m}$$

Status



$$U(r,d) = \frac{1}{2} V_0 \sum_{k_{even}=0}^{\infty} C_k \left[\frac{r}{d}\right]^k P_k(\cos\Theta)$$



Ideal trap: C_2=1, $C_{k(even)>2}$=0

$C_4 \neq 0$, gives ω_z shift

$$\frac{\Delta\omega_z}{\omega_z} = \frac{3}{2}\left(\frac{C_4}{C_2}\right)\frac{E_z}{qU_0C_2} \ ,$$

Simulations, field calculations *-done.*
Estimated S/N ratio, Cooling times τ , *-available.*
Trap dimensions, *-calculated,*
Magnet is specified, price quotation, *-available.*

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Summary & Outlook

´´The road´´ to high precision & accuracy with the new 4-trap spectrometer

- Precision electrodes, *1cm±5µm*
- Compensation electrodes, *C4, C6, D2* <<
- Stable voltage source, *eg.* standard cell, *100 nV in 10 V*
- Strong, homogeneous and stable *B*-field, $B=7\ T$, $\delta B/B<10^{-7}/cm^3$, $(\delta B/dt)\cdot(1/B)<10^{-10}/h$
- Cooling, $T=4.2\ K$
- High Q-value circuit, $Q>15000$
- UHV- vacuum, $P<10^{-12} mbar$
- single HCI,

Working programe and time table

2006	Design study; numerical simulations; field calculations; magnet specifications, CAD drawings of Penning traps
2007	Magnet ordering; cryostat specifications and drawings; trapmachining; final design for resonance circuits, beam transport in SIMION, off line ion source construction
2008	Magnet comissioning; cryostat alignement, experimental chamber alignment versus B, tests at 4.2 K
2009	Control and data acquisition system; comissioning the full setup, first test with real ions from offline source; single ion detection tests
2010	Test measurements with singly charged ions, determination of systematic uncertainties, preparation for HCI
20XX	Spectrometer is ready to take HCI beam

Acknowledgements

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