A Penning trap
for precision laser spectroscopy
of highly charged ions

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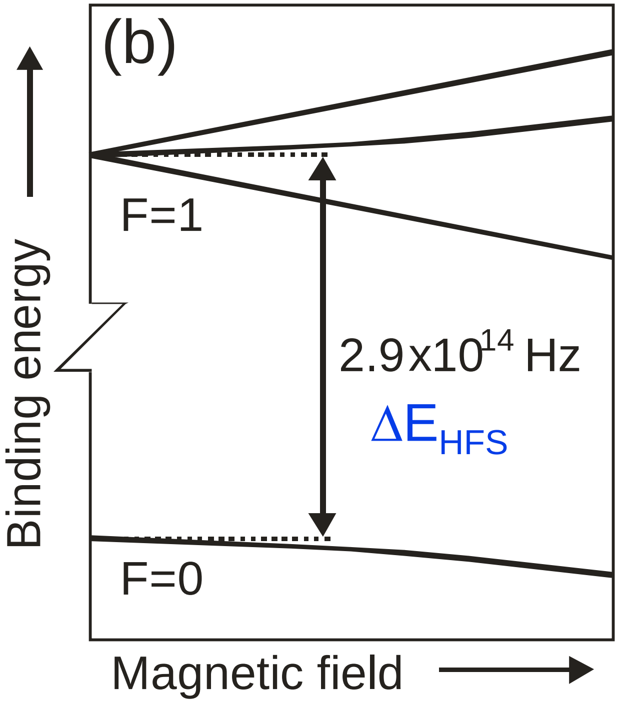
What do we want to measure?

Energy of the ground state hyperfine transition in highly charged ions with an accuracy of 10^{-7}



nuclear spin

e.g. $^{207}Pb^{81+}$

$\vec{F}=\vec{I}+\vec{J}$

e^- angular momentum

For heavy H- and Li-like ions this transition is in or near the visible ($\Delta E \sim Z^3$, $\tau \sim Z^{-9}$) -> laser spectroscopy

Why do it in a cryogenic trap?

natural linewidth ~ 3 Hz
Doppler-broadened 30 MHz
transition frequency ~ 10^{14} Hz
Excitation lifetime ~ ms
-> relative accuracy ~ 10^{-7}

Ions can be cooled nearly to rest
-> small Doppler shift and broadening

Ions are well-localized
-> laser irradiation is easy

Many ions in a dense ion cloud can be investigated at the same time
-> high fluorescense signal

Extended time for measurement
-> makes life easier, allows slow transitions

Wanted trap properties

High harmonicity

-> well-defined and calculable trap frequencies

Optically accessible („transparent“)

-> efficient laser excitation and detection

Designed for in-flight capture and storage of a HITRAP ion bunch

-> effective loading

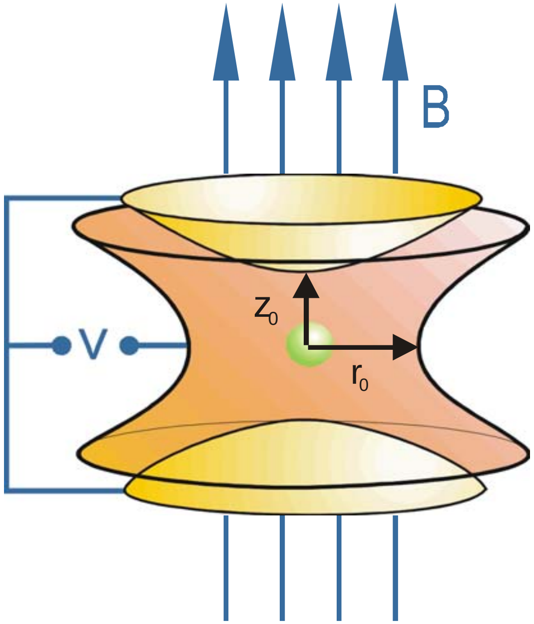
Designed for cooling and compression of an ion cloud

(resistive cooling, „rotating wall“)

-> localisation, dense ion cloud

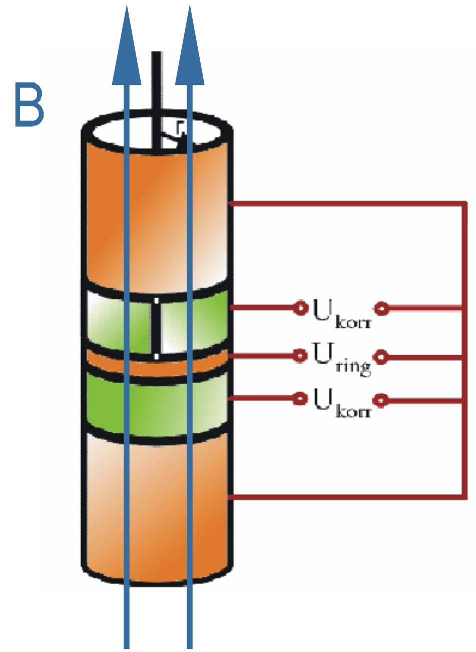
What kind of trap to use?

hyperbolic trap



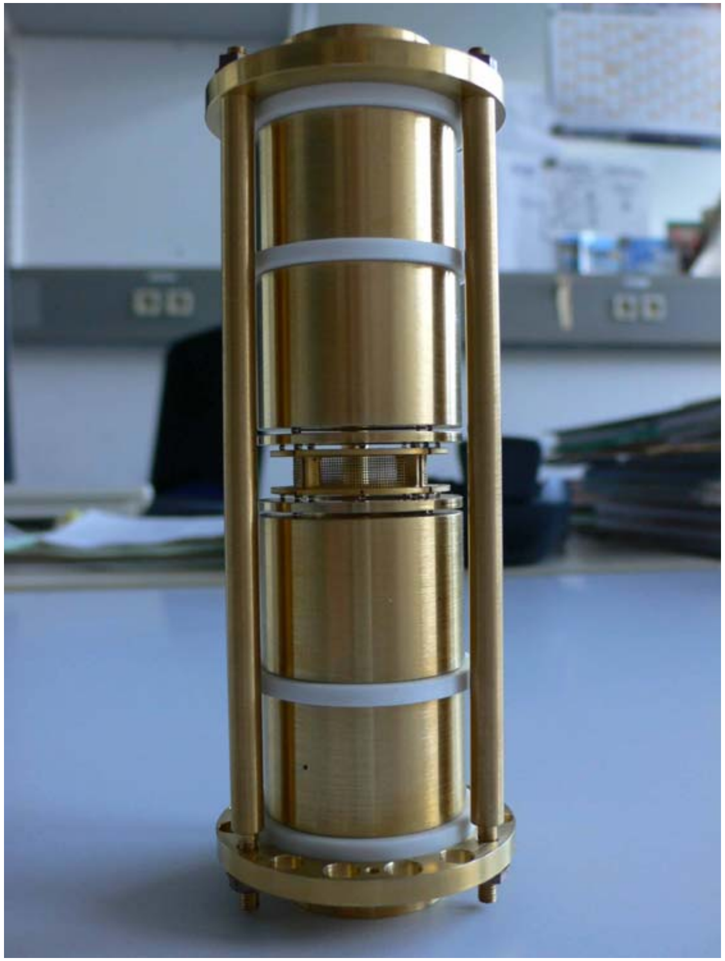
high harmonicity
optically closed
not easy to build

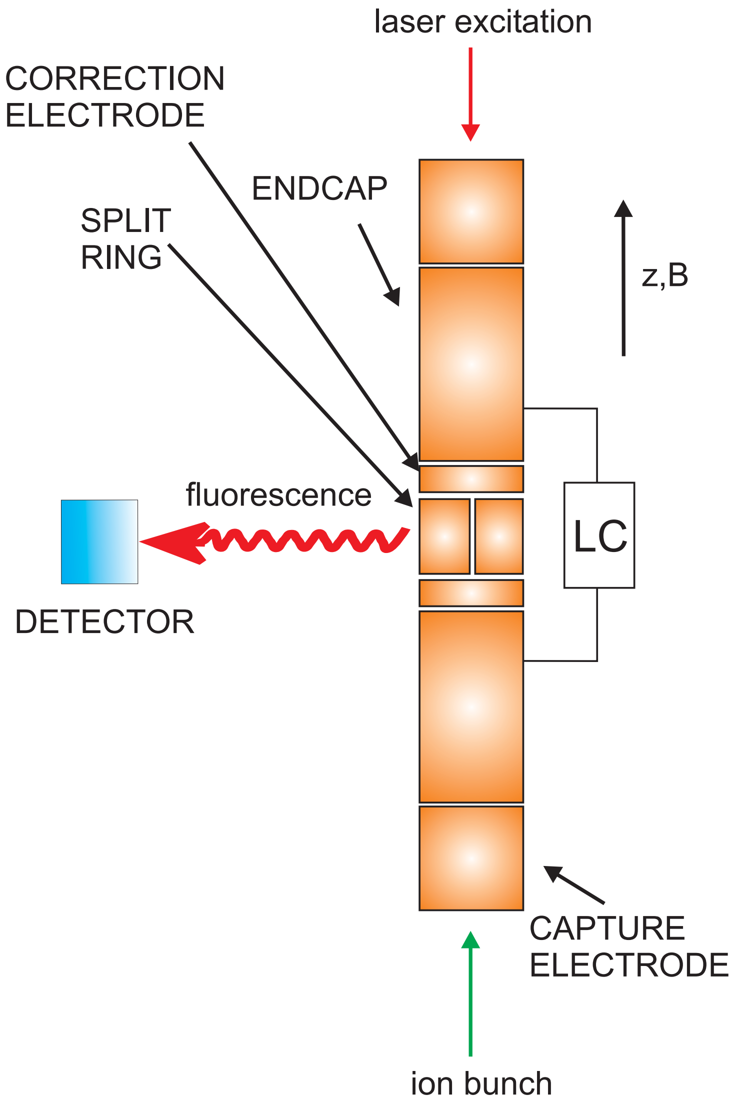
cylindrical trap



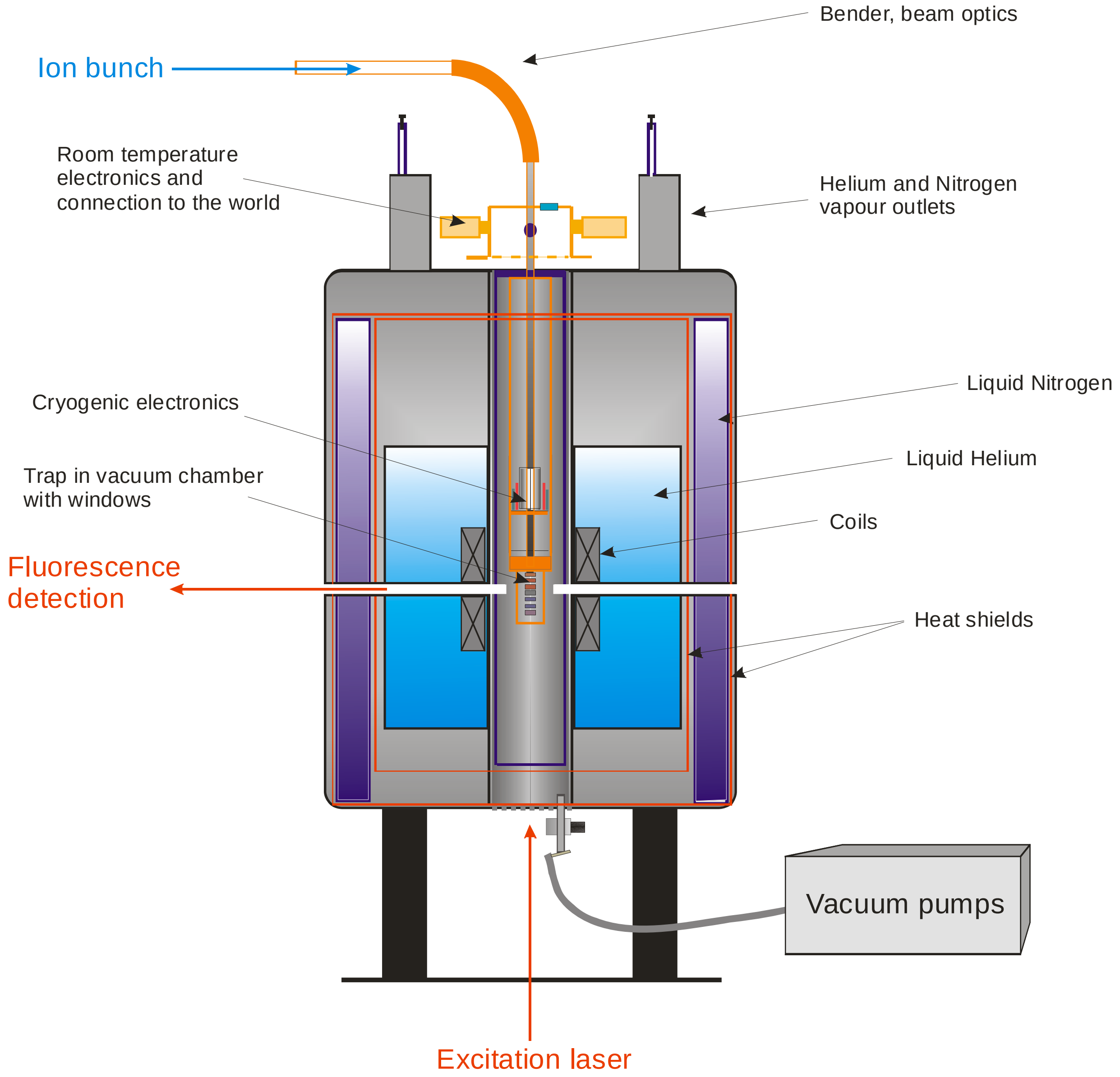
low harmonicity can be corrected for
optically accessible
comparatively easy to build

Reality looks like this:

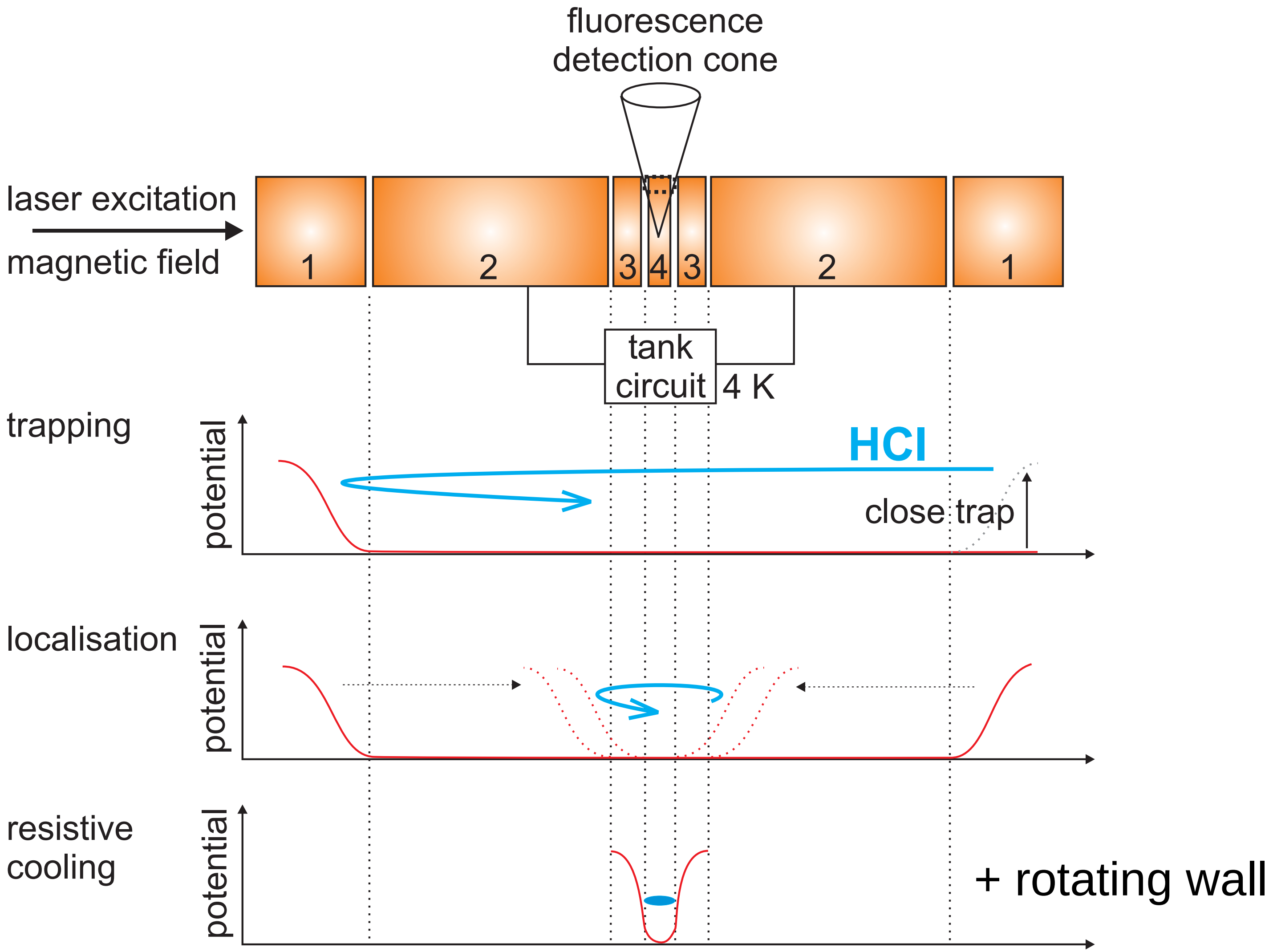




Scheme of the envisaged setup

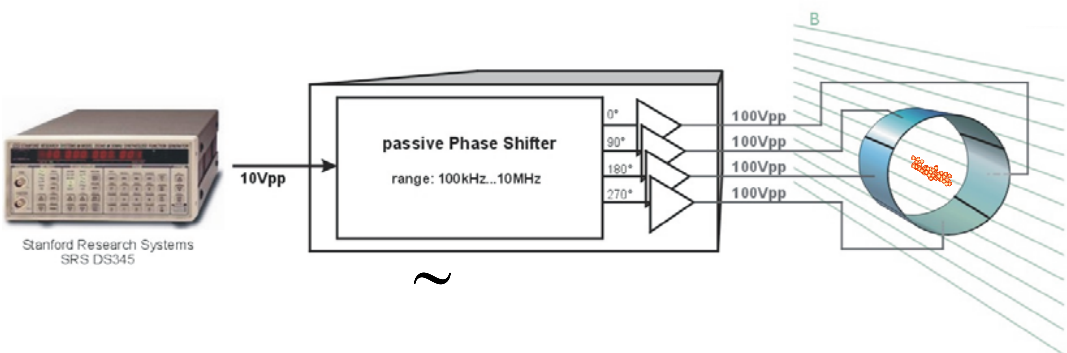


Capture and trapping sequence

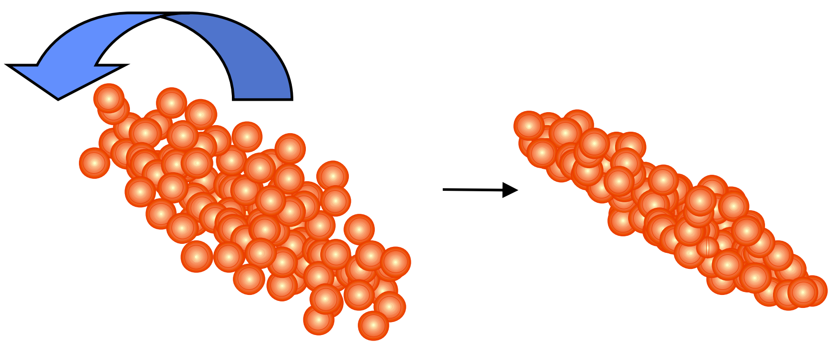


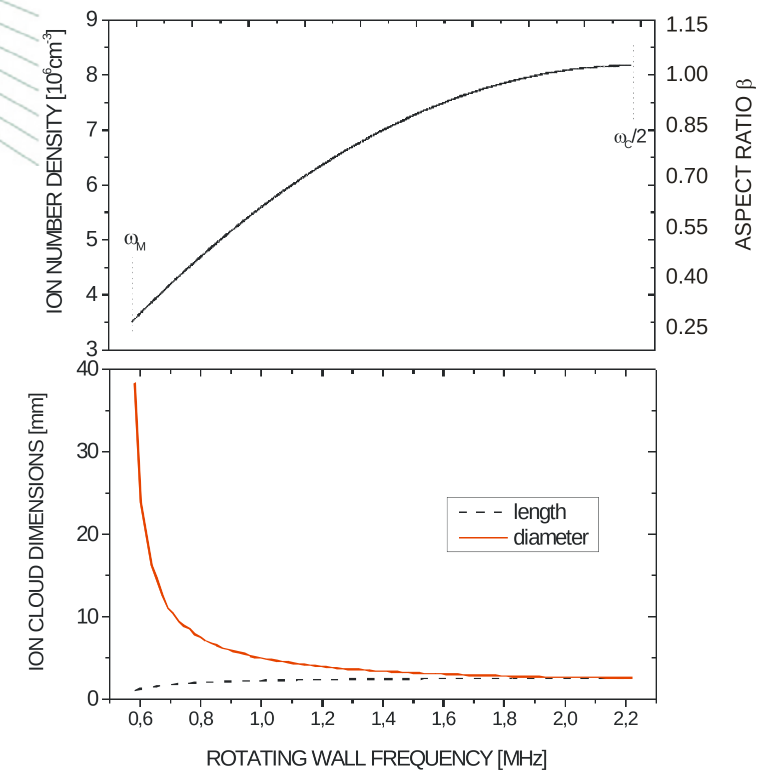
Rotating wall technique

Use segmented ring electrode to create a rotating dipole field



cloud rotation around z induces Lorentz force which compresses the cloud



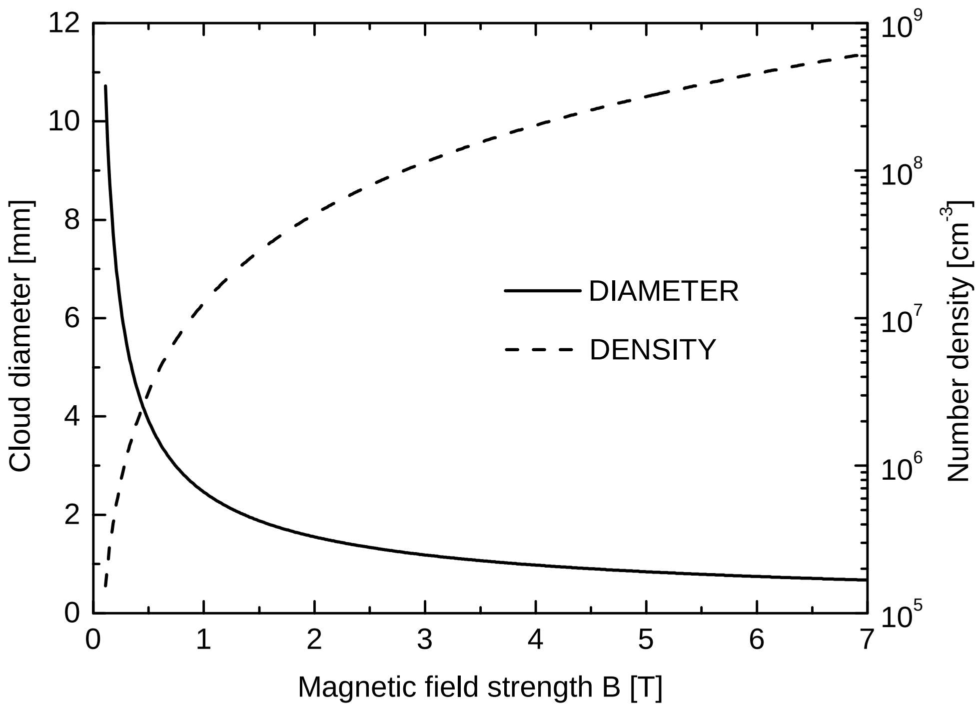


torque ~ A $\Delta\omega^{-1}$ $T^{-1/2}$

density ~ m $\omega(\omega_c - \omega)$ q^{-2}

Choice of the magnetic field strength

Cloud dimensions and ion number density as a function of B



Already for B=1 T expected S/N is 50

Overall status

trap – built, being tested offline (J.Krämer)
vacuum housing – built
rotating wall drive – designed, ordered
trap electronics – being designed
excitation lasers and fluorescence detection – being designed

A proposed precision laser spectrometer for trapped highly charged ions
M. Vogel, D.F.A. Winters, D. Segal and R.C. Thompson
Rev. Sci. Instr. **76** (2005) 103102

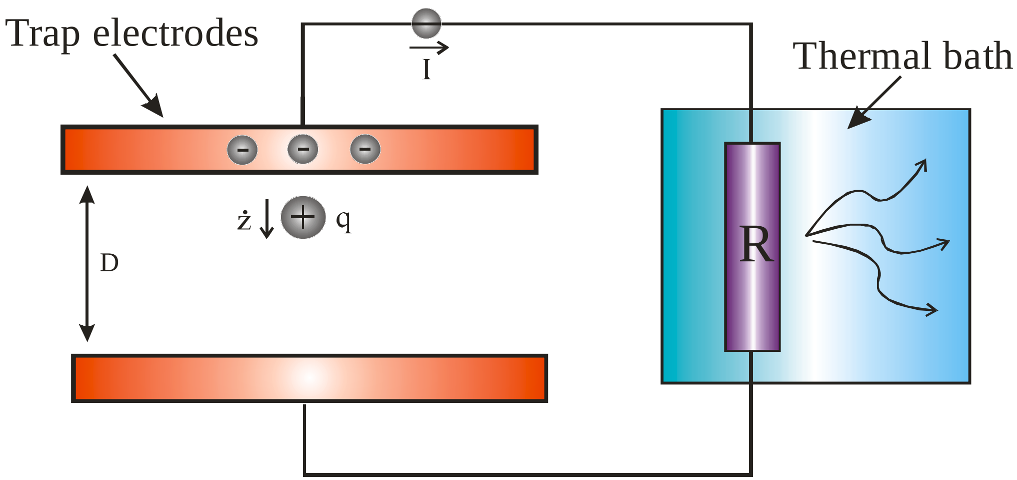
Plans for laser spectroscopy of trapped cold hydrogen-like HCI
D.F.A. Winters, A.M. Abdulla, J.R. Castrjon Pita, A. deLange, D.M. Segal, R.C. Thompson
Nucl. Instr. Meth. B **235** (2005) 201

Hyperfeinstruktur-Spektroskopie
M. Vogel, D.F.A. Winters, R.C. Thompson
Physik in unserer Zeit, 36. Jahrgang (2005), **Nr.4**, Seite 156

Electronic detection of charged particle effects in a Penning trap
D.F.A. Winters, M. Vogel D. Segal and R.C. Thompson
J. Phys. B **39** (2006) 3131

Laser spectroscopy of hyperfine structure in highly-charged ions: a test of QED at high fields
D.F.A. Winters, M. Vogel, D.M. Segal, R.C. Thompson and W. Nörtershäuser
accepted for Can. J. Phys. (2006)

Resistive cooling: single particle



Axial motion

Time constant for energy dissipation

$$\tau = \frac{4md^2}{q} \frac{1}{\underbrace{2\pi\nu_{res} LQ}_{1/R}}$$

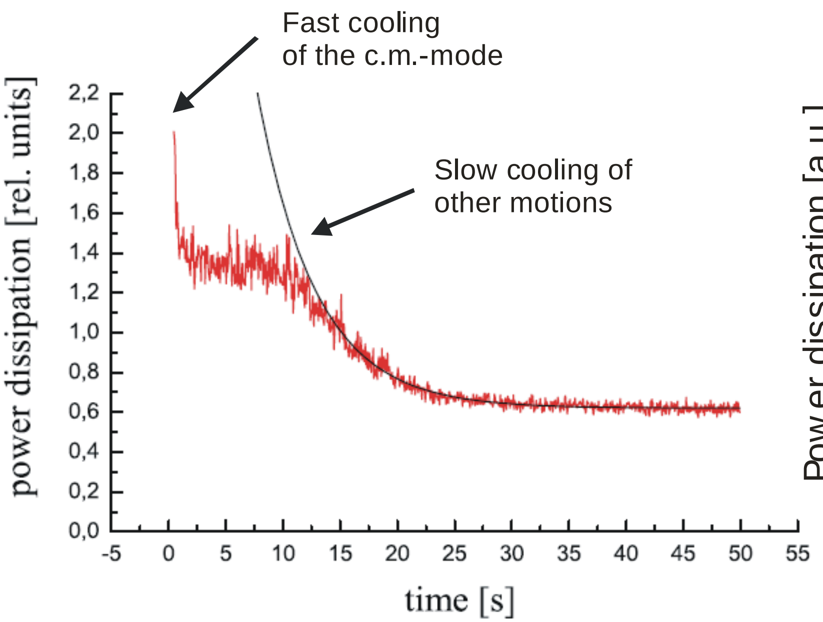
Exponential energy loss of the moving particle with time constant τ

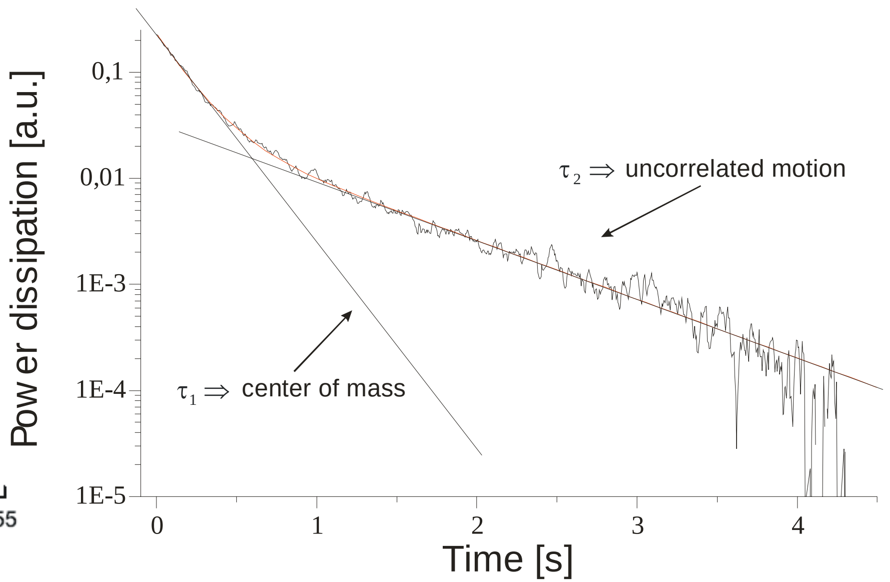
Typical τ of order milliseconds

Resistive cooling of an ion cloud

measurement: cloud of about 20 $^{12}C^{5+}$ ions in a Penning trap

(H. Häffner et al.)





Effective cooling of c.m. motion only,
Trap imperfections cool other motions (much less effectively)

-> Large clouds: cooling times of several s