# Development of a radiation resistant magnetometer

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## Motivation

Operation of accelerators requires knowledge of the magnetic field strength on the order of $\Delta B/B=10^{-4}$

### Challenges

- NMR or Hall probes are used to monitor magnetic fields
- High radiation fields damage active components in the probe heads
- Lifetime is on the order of months at GSI beam intensities

→ FAIR and FRIB intensities require a radiation-hard solution with competitive stability and precision

→ Example: Fragment Separators (Super FRS)

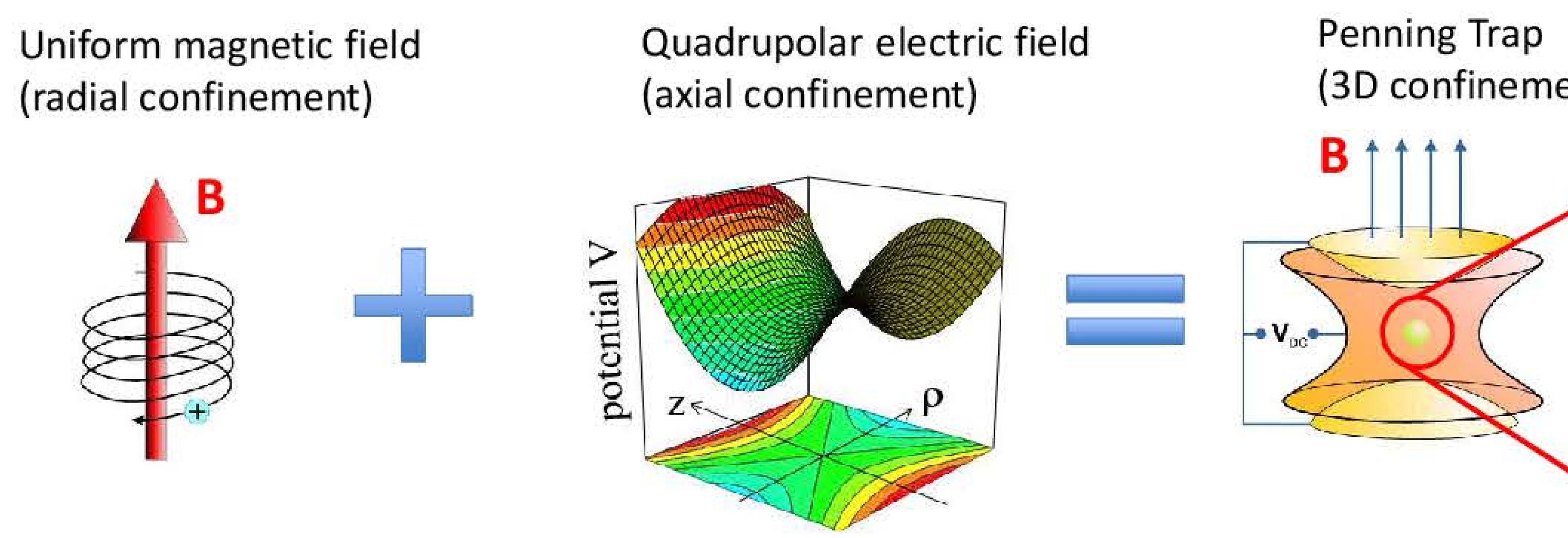
### Modern Rare-Isotope Facilities need robust Precision Magnetometers for the use in high-radiation environments

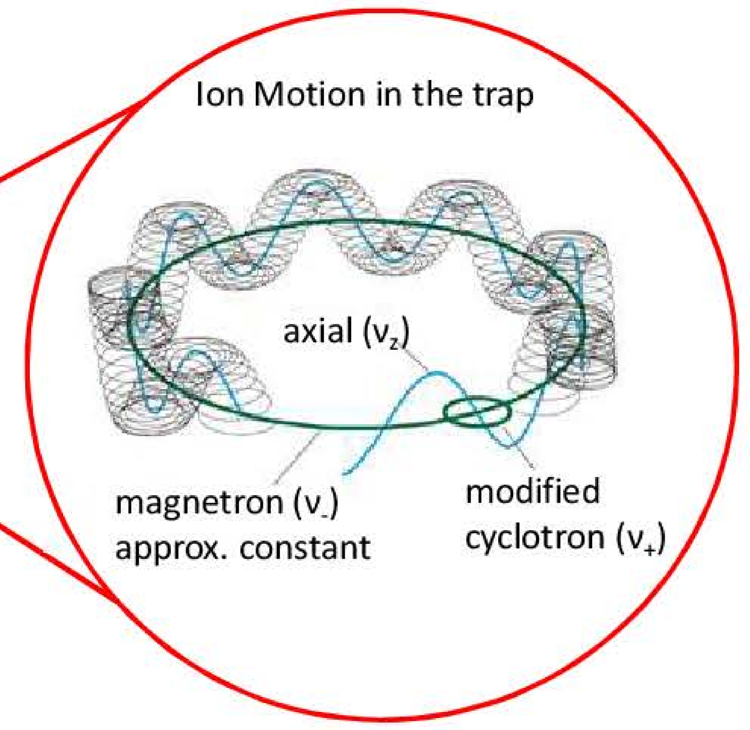
### Approach

- Move all radiation-sensitive parts away from radiation
- Produce ion-trap based, radiation-hard magnetometer Ideal: Detection electronics can be placed behind shielding, no active electronics remains in high-radiation area
- Leverage FRIB ion trap expertise in high-precision mass measurements with ion traps

### Adapt FRIB's miniature Penning Trap for FAIR

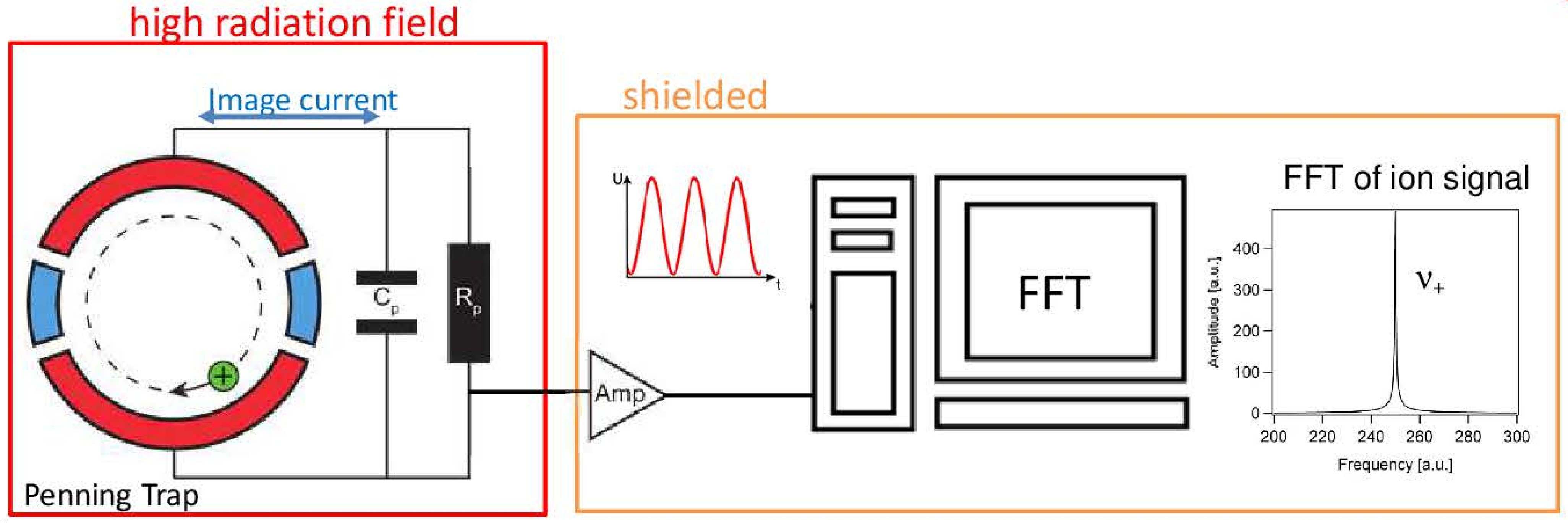
## How to measure the Magnetic Field Strength with a Penning trap




**Measure $\nu_+$ or $\nu_c$ to monitor magnetic field strength B**
**Technique: Broadband FT-ICR[1] detection**

- Motion is characterized by three eigenfrequencies:
  Axial – $\nu_z$
  Magnetron – $\nu_-$
  Modified Cyclotron – $\nu_+$
- Direct connection to free cyclotron frequency:
  $\nu_- + \nu_+ \approx \nu_c = q/m \cdot B$

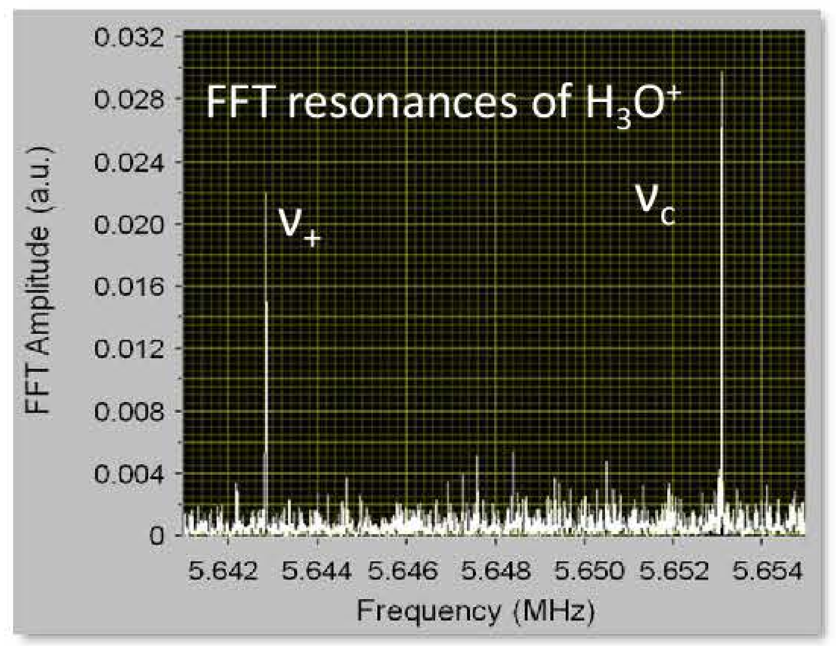


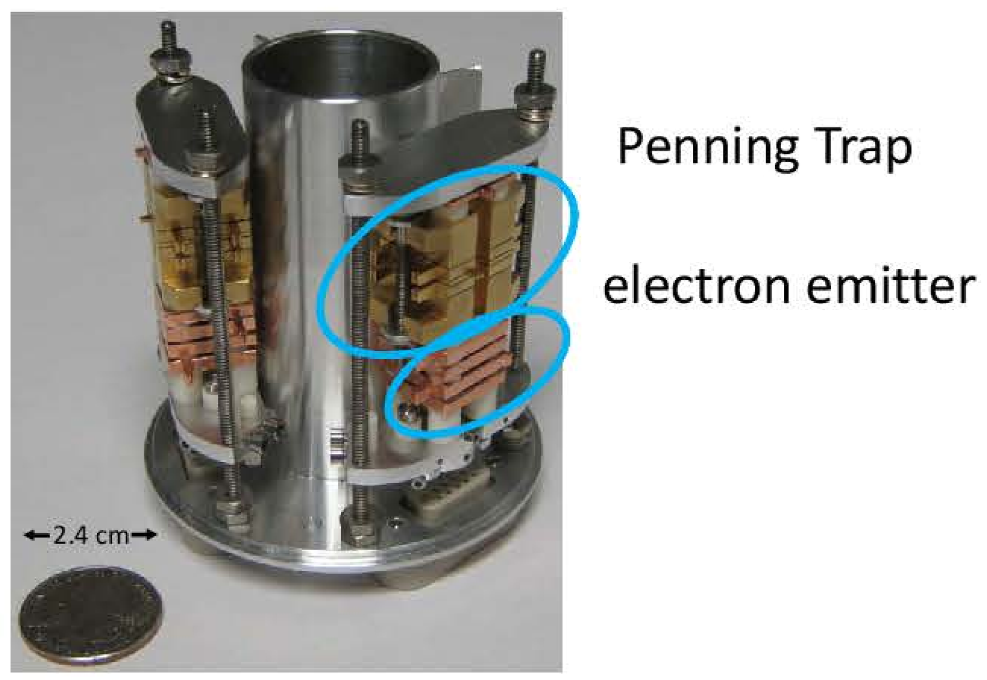

- An oscillating cloud of particles with known charge-to-mass ratio (q/m) in the trap induces an image current.
- The signal is processed in a shielded region to protect the electronics from radiation-damages.
- An FFT analysis of the time-dependent signal reveals the eigenfrequencies of the ion cloud and thereby the magnetic field strength B.

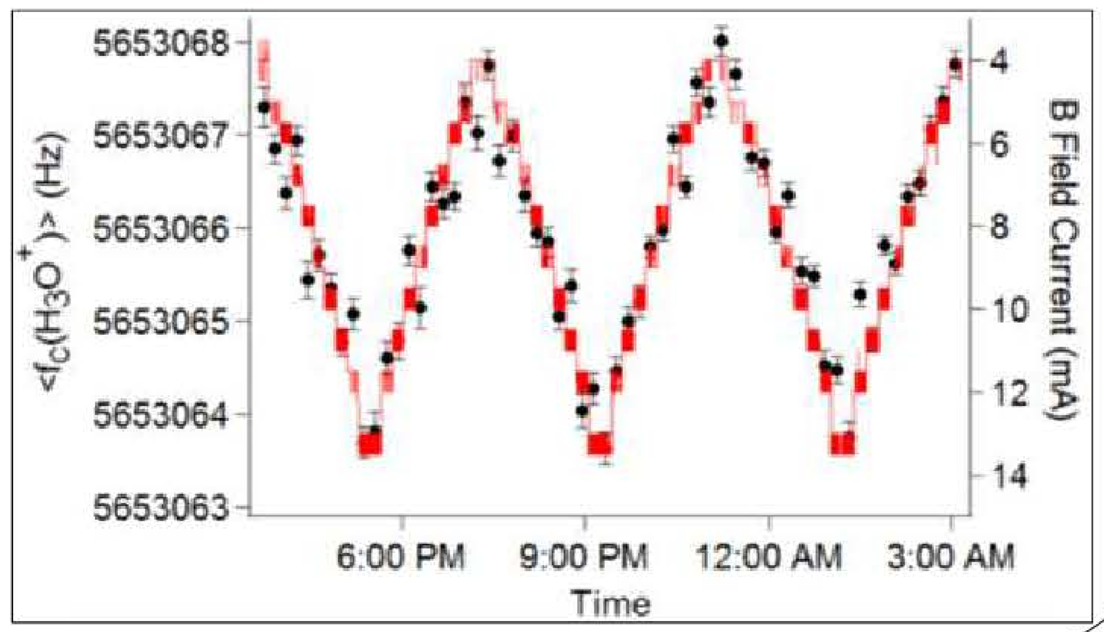
## Proof of principle: LEBIT minitrap magnetometer[2]

### Systematic studies

- Penning Trap was built and installed in a 7T solenoid
- Electrons emitted by a $LaB_6$ crystal produced $H_3O^+$ ions **in trap** from residual gas
- Both, $\nu_+$ and $\nu_c$ were observed, $\nu_c(H_3O^+)$ was continuously monitored while the magnetic field was changed using an external coil
- Multiple measurements averaged

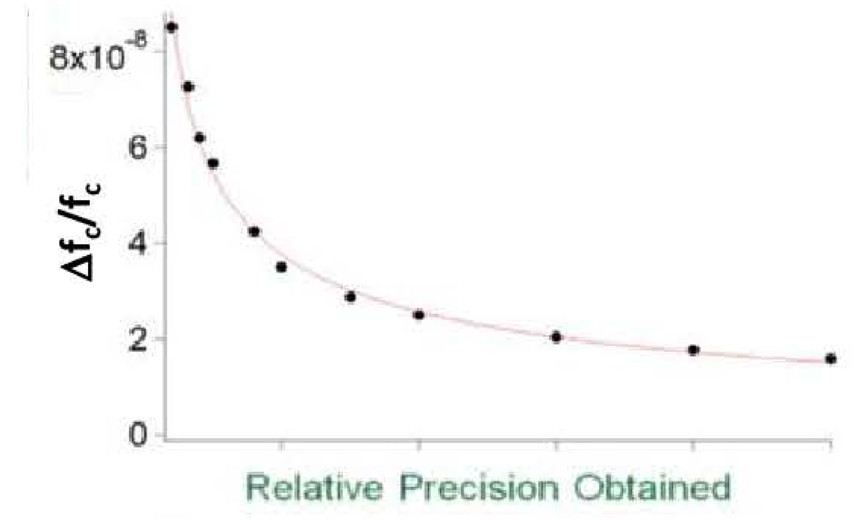



## Outlook

- Build/Purchase Equipment for Test-Setup
- Move test setup to an existing Magnet → $\Delta B/B=10^{-5}$ within reach as better precision has been demonstrated (with higher field/fewer ions):




- Operate in high radiation areas to observe possible degeneration of trap electrodes
- Ultimately install in beam line

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[1] A. G. Marshall and C. L. Hendrickson, Int. J. Mass Spectrom. **215**, 59 (2002).
[2] D. L. Lincoln, *et. al.*, Int. J. Mass Spectrom. **379**, 1 (2015).