TRIUMF

Canada's national laboratory for particle and nuclear physics
Laboratoire national canadien pour la recherche en physique nucléaire
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Trapping and cooling of highly charged ions for precision mass spectrometry at TITAN

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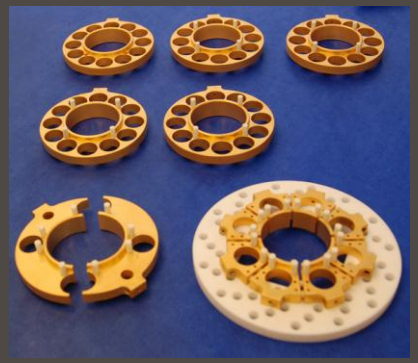
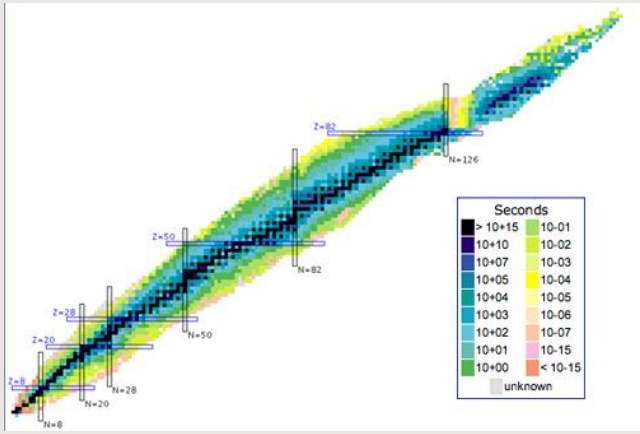
WNPPC 2012



Motivation for precision mass measurements

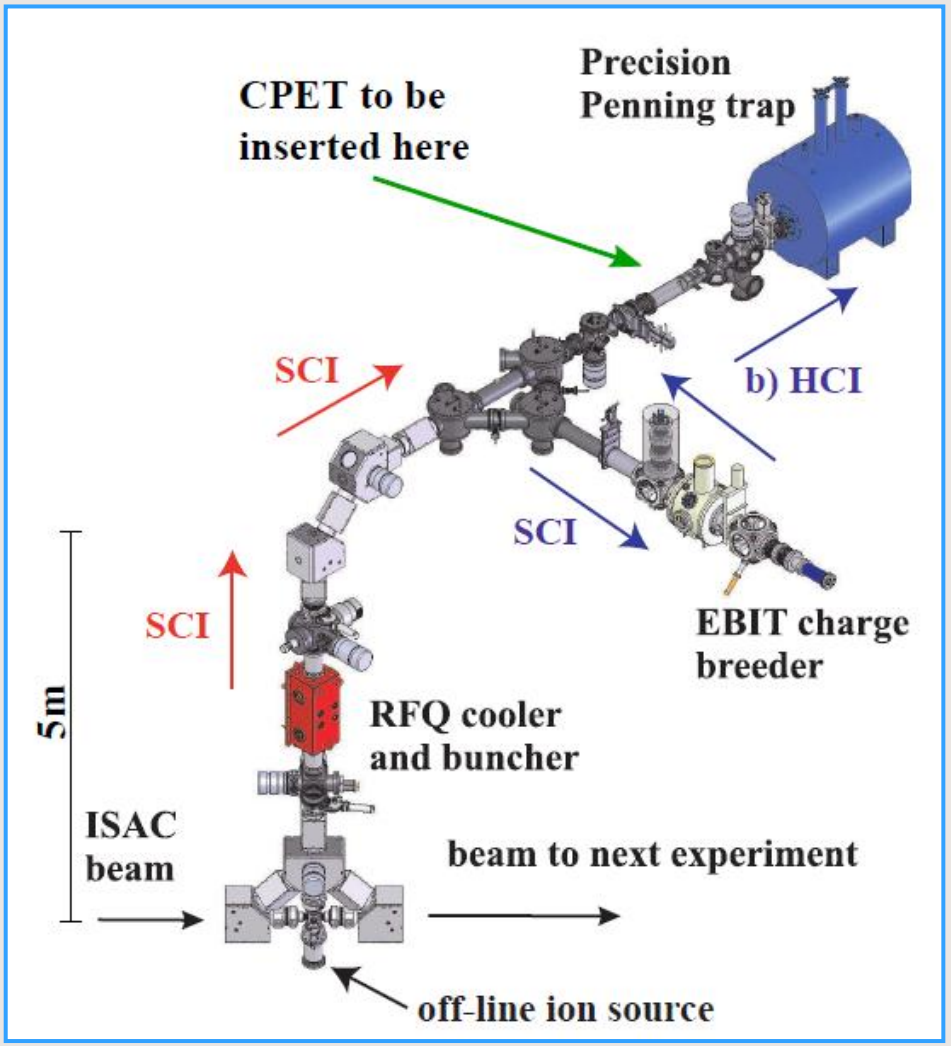
- Nuclear physics: modification of shell model far from the valley of stability in neutron-rich matter (magic numbers), halo nuclei ($\delta m/m \sim 10^{-7}$-10^{-8})
- Particle physics: unitarity of CKM matrix, CVC hypothesis ($\delta m/m \sim 10^{-9}$)
- Astrophysics: nucleosynthesis (r-, rp-process) ($\delta m/m \sim 10^{-7}$-10^{-8})

$$\begin{pmatrix} V_{ub} & V_{cb} & V_{tb} \\ V_{ud} & V_{cd} & V_{td} \\ V_{us} & V_{cs} & V_{ts} \end{pmatrix}$$

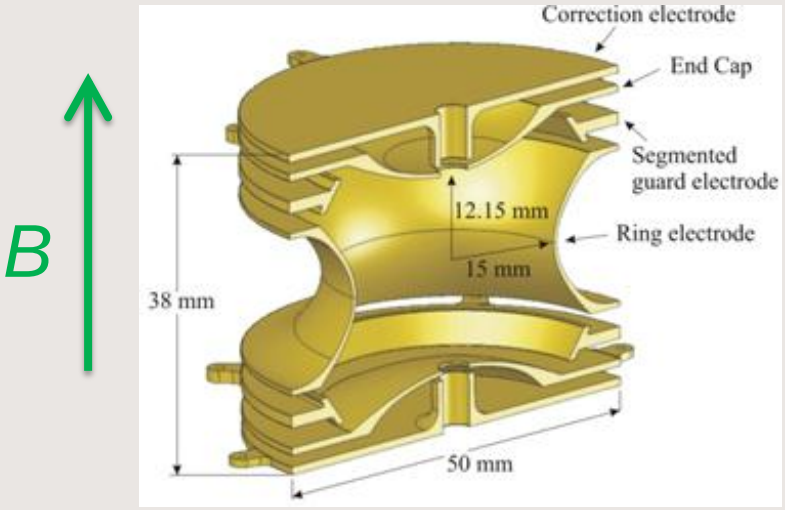


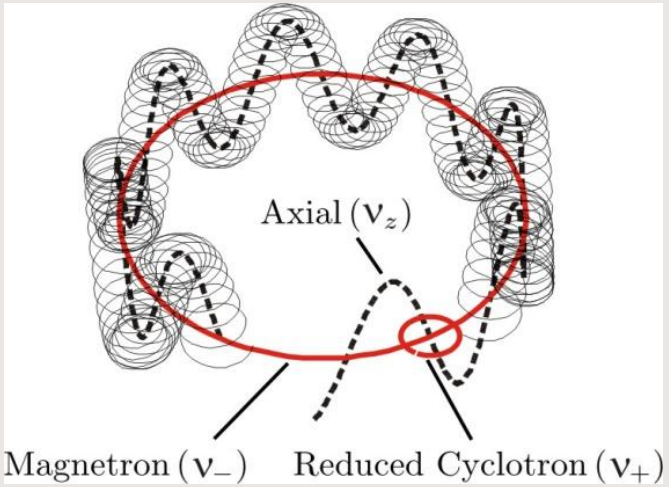
TITAN

- Radio frequency quadrupole (RFQ)
- Electron beam ion trap (EBIT)
- Cooler Penning trap (CPET)
- Measurement Penning trap (MPET)

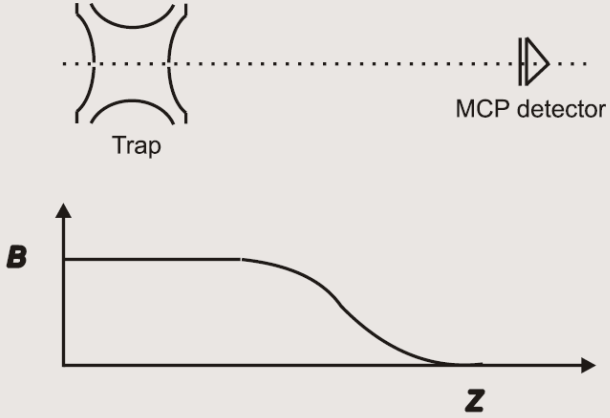


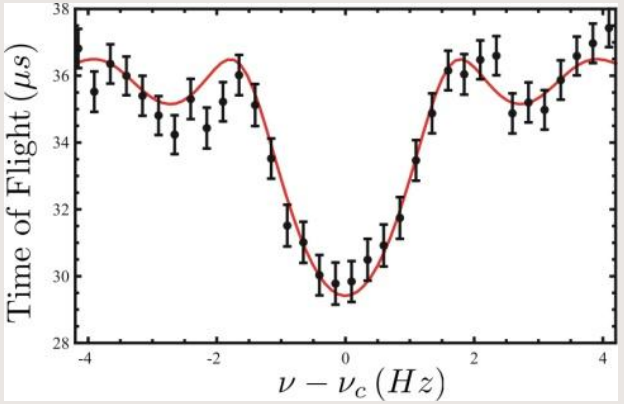
Penning trap mass spectrometry





$$\nu_c = \nu_+ + \nu_- = \frac{1}{2\pi}\frac{q}{m}B$$

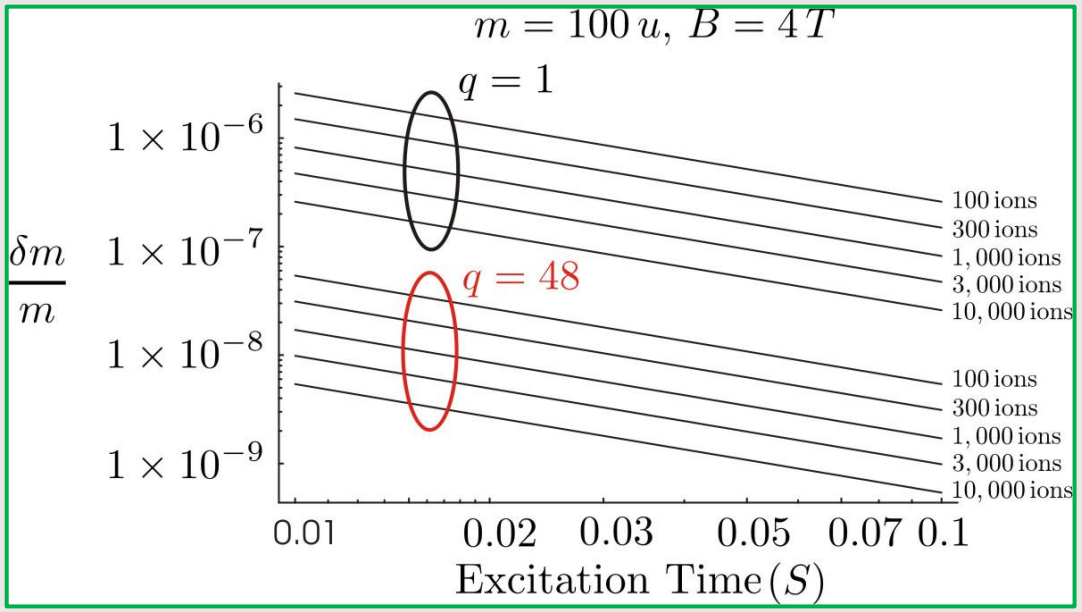




Measurement uncertainty

- Uncertainty given by

$$\frac{\delta m}{m} \propto \frac{m}{q} \frac{1}{BT_{ex}\sqrt{N}}$$



B = magnetic field

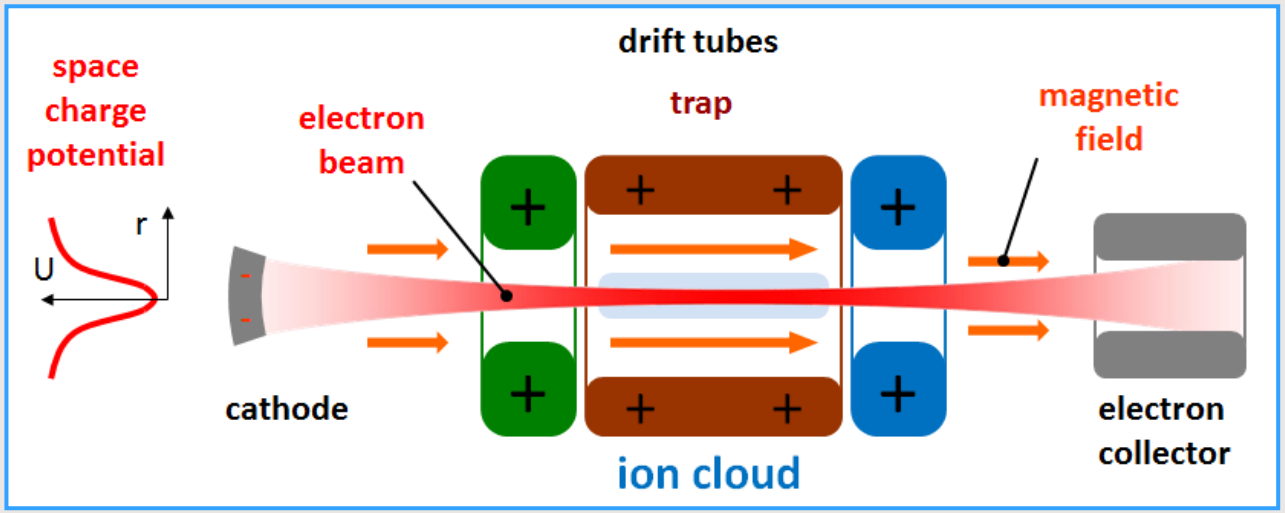
T_{ex} = excitation time

N = number of ions

q = charge state

→ Increase q !

Charge breeding



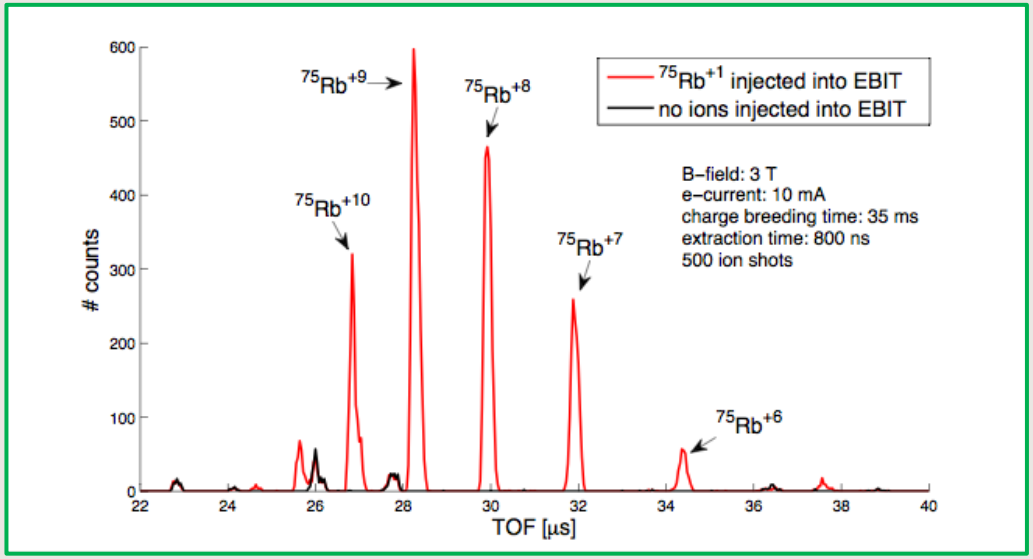
max EBIT current
500 mA

e-beam = 10 mA

breeding time = 35 ms

Extraction time = 800 ns

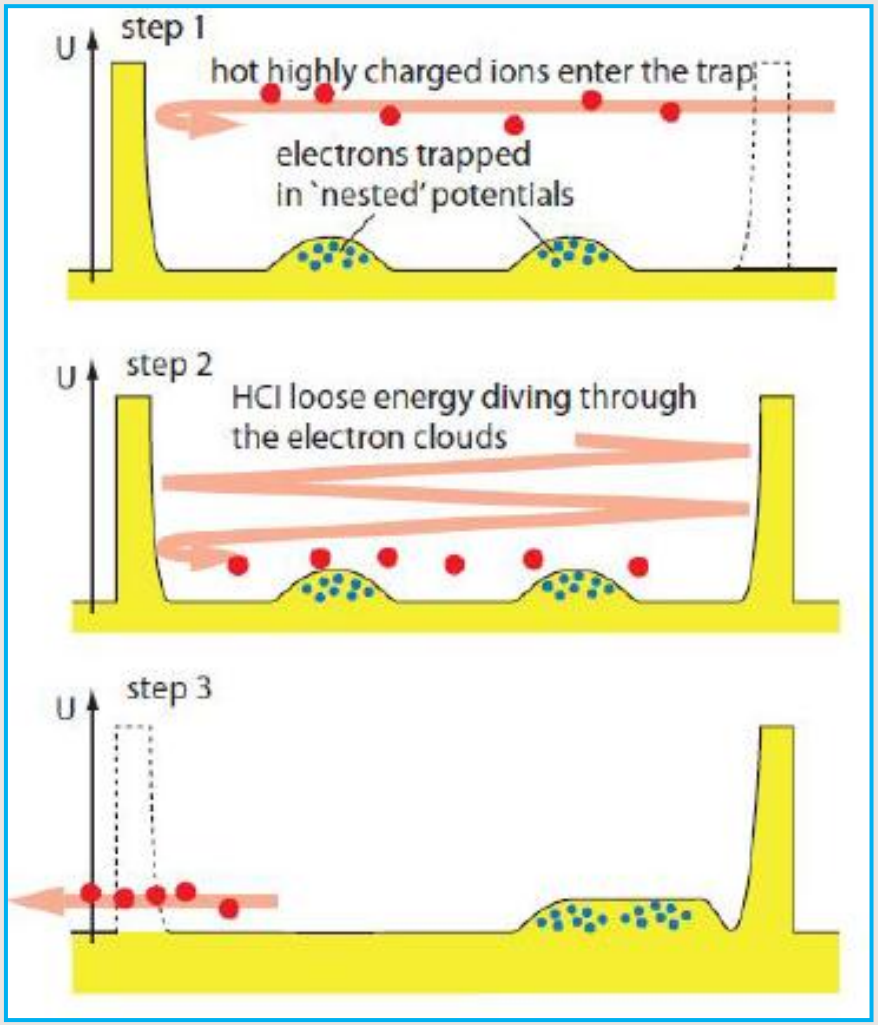
Figures: M. C. Simon



CPET motivation

- Charge breeding increases energy spread of ions
- Ions sample a larger volume in MPET and see a larger field distribution
- CPET will cool ions prior to injection, reducing emittance and measurement uncertainty

Electron cooling



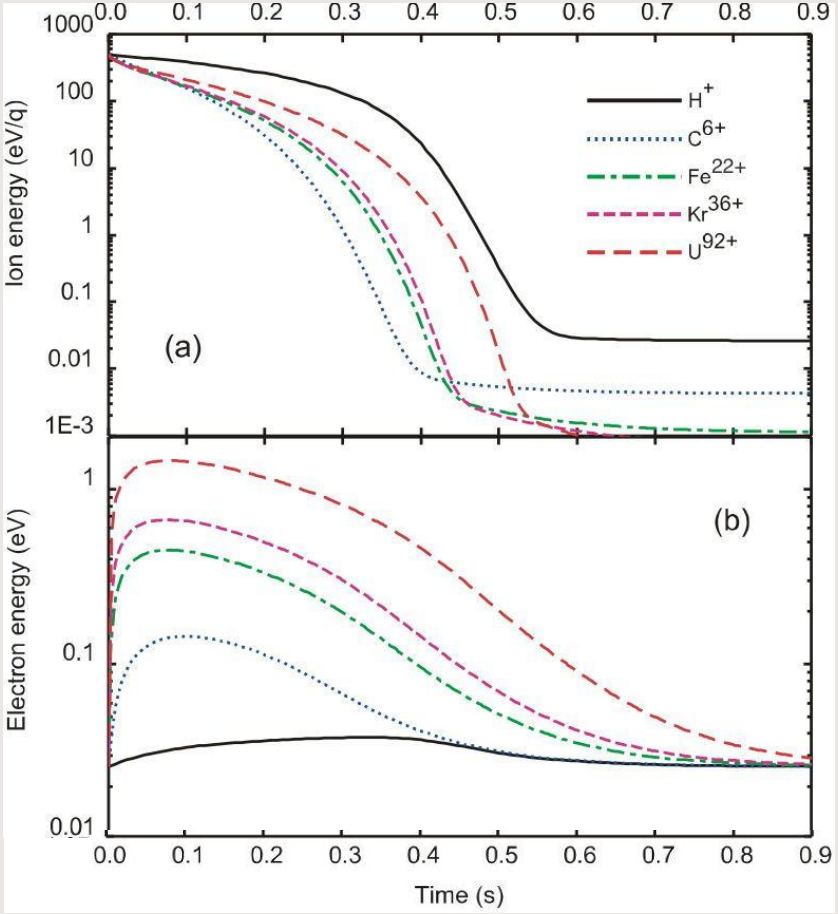
- Electrons trapped in “nested” potentials
- Electrons self-cool through synchrotron radiation (~0.1 sec in 7 T field)

Electron cooling – theory

- Ions give up energy to cold electrons
- Electrons gain energy, but re-cool through synchrotron radiation

$$\frac{dT_i}{dt} = -\frac{1}{\tau_i}(T_i - T_e)$$

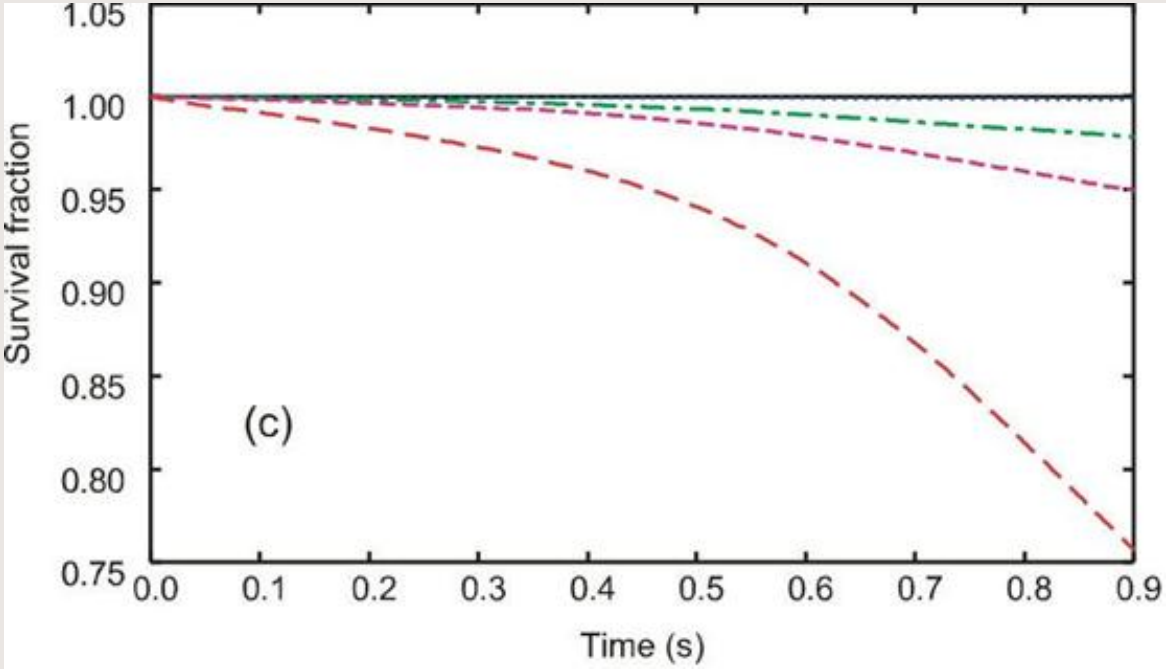
$$\frac{dT_e}{dt} = \frac{1}{\tau_i}\frac{N_i}{N_e}(T_i - T_e) - \frac{1}{\tau_e}(T_e - T_{res})$$



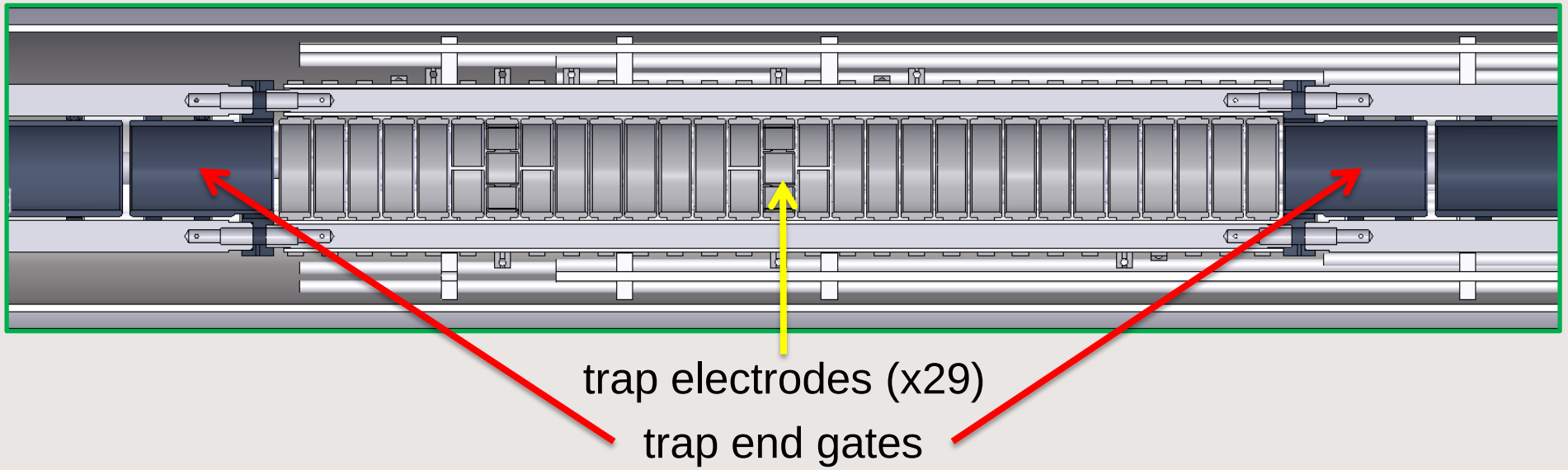
[1] Z. Ke *et al.*, Hyperfine Interactions **173,** 103 (2007)

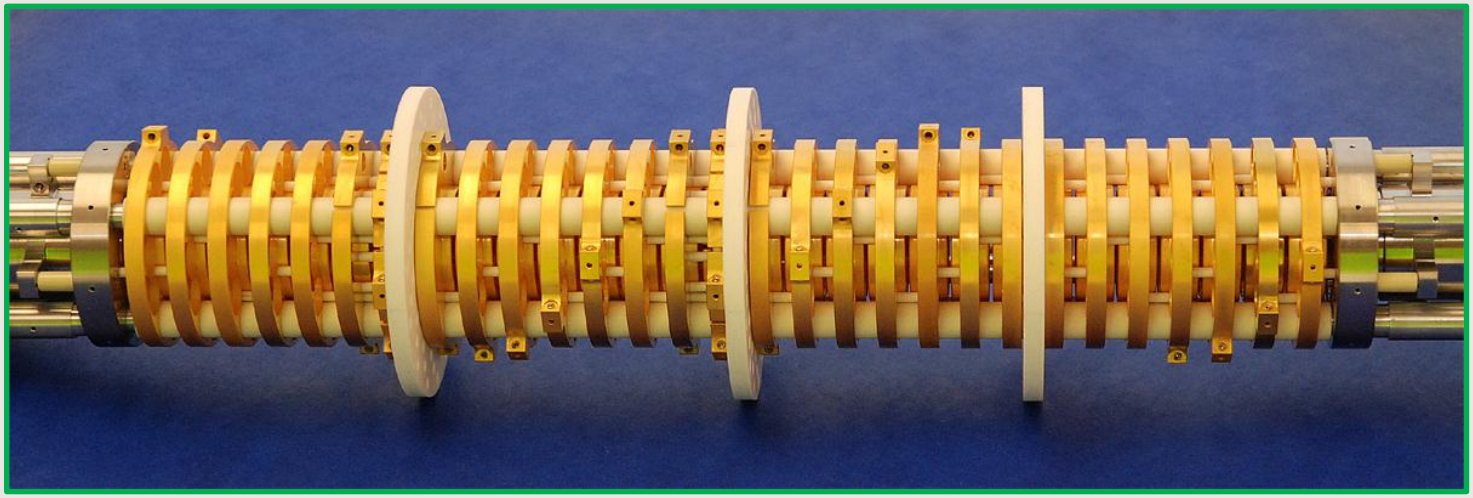
Electron cooling – theory

- Electron-ion recombination increases as ion energy decreases → contamination of charge state
- Ions must be separated from electrons



CPET structure

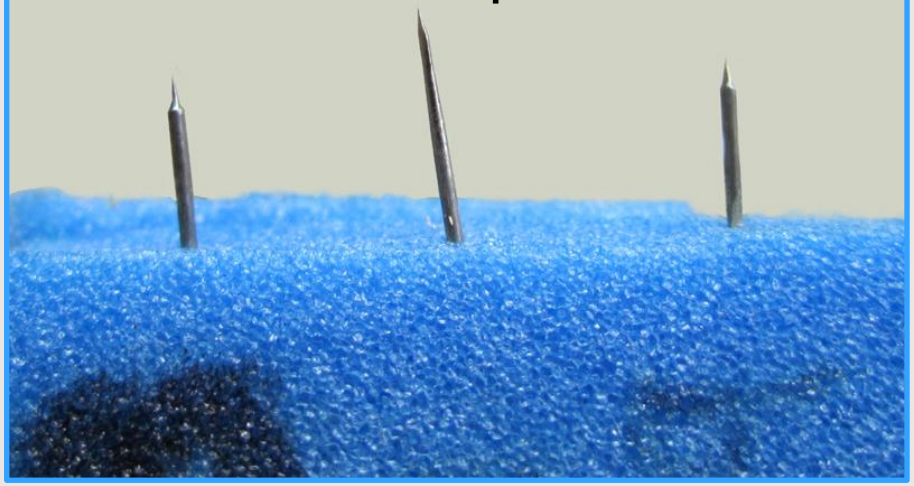




CPET status

- Trap is assembled
- Remaining beamline components are being cleaned & assembled, including electron source
- First offline testing begins in Summer 2012

Field emission tips



Conclusion

- Precision mass measurements at TITAN provide important information for nuclear physics, particle physics, and astrophysics
- Highly charged ions can be used to decrease the uncertainty, but must be cooled prior to the measurement
- CPET is a unique trap, which will cool ions before injection into MPET

CPET team: Vanessa Simon, Usman Chowdhury, Gerald Gwinner

Acknowledgements

TITAN Team: Jens Dilling, Corina Andreoiu, Paul Delheij, Gerald Gwinner, Dieter Frekers, Melvin Good, David Lunney, Mathew Pearson, Ankur Chaudhuri, Alexander Grossheim , Ania Kwiatkowski, Ernesto Mané, Martin Simon, Brad Schultz, Thomas Brunner, Usman Chowdhury, Stephan Ettenauer, Aaron Gallant, Annika Lennarz, Tegan Macdonald, Vanessa Simon

Special thanks to: ISAC operations, the yield measurement team, and J. Lassen and the TRILIS group for their experimental support

Thank you!
Merci

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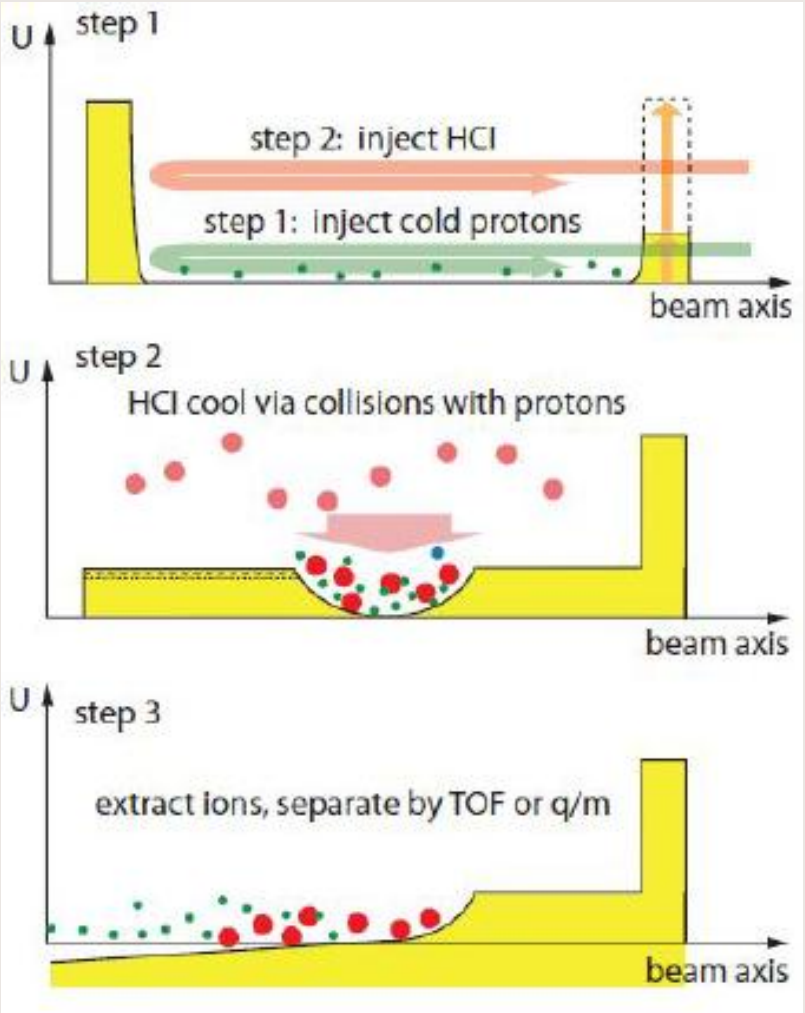
Proton cooling



- Recombination a non-issue
- *Phase space overlap*?
- Protons must be cooled first → electrons, resistive cooling
- Will not self-cool after HCI injection
- Requires initially high densities of protons