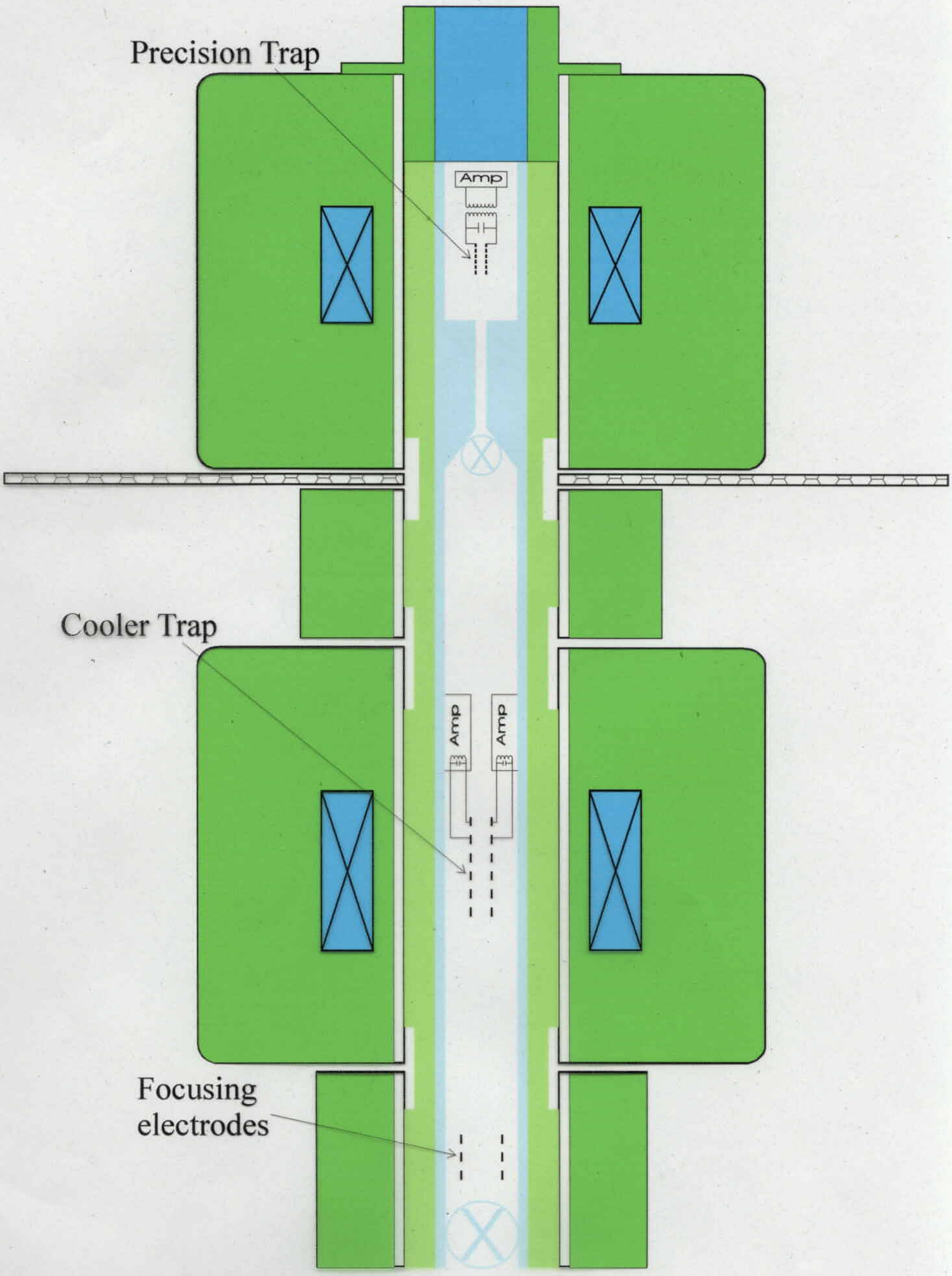
Accumulation and Cooling of HCI

Mainz HITRAP Team:

Manuel Vogel
Joseba Alonso
Slobodan Djekic
Tristan Valenzuela
José Verdu
G.W.

Stefan Stahl

Cooperation with GSI and London Team


Precision Trap
Amp
Cooler Trap
Amp
Amp
Focusing
electrodes

Vacuum requirements:

Time constant for electron capture (U^{92+}):

ca. 10 s at 10^{-10} mbar

Presently achieved (closed system): 10^{-16} mbar

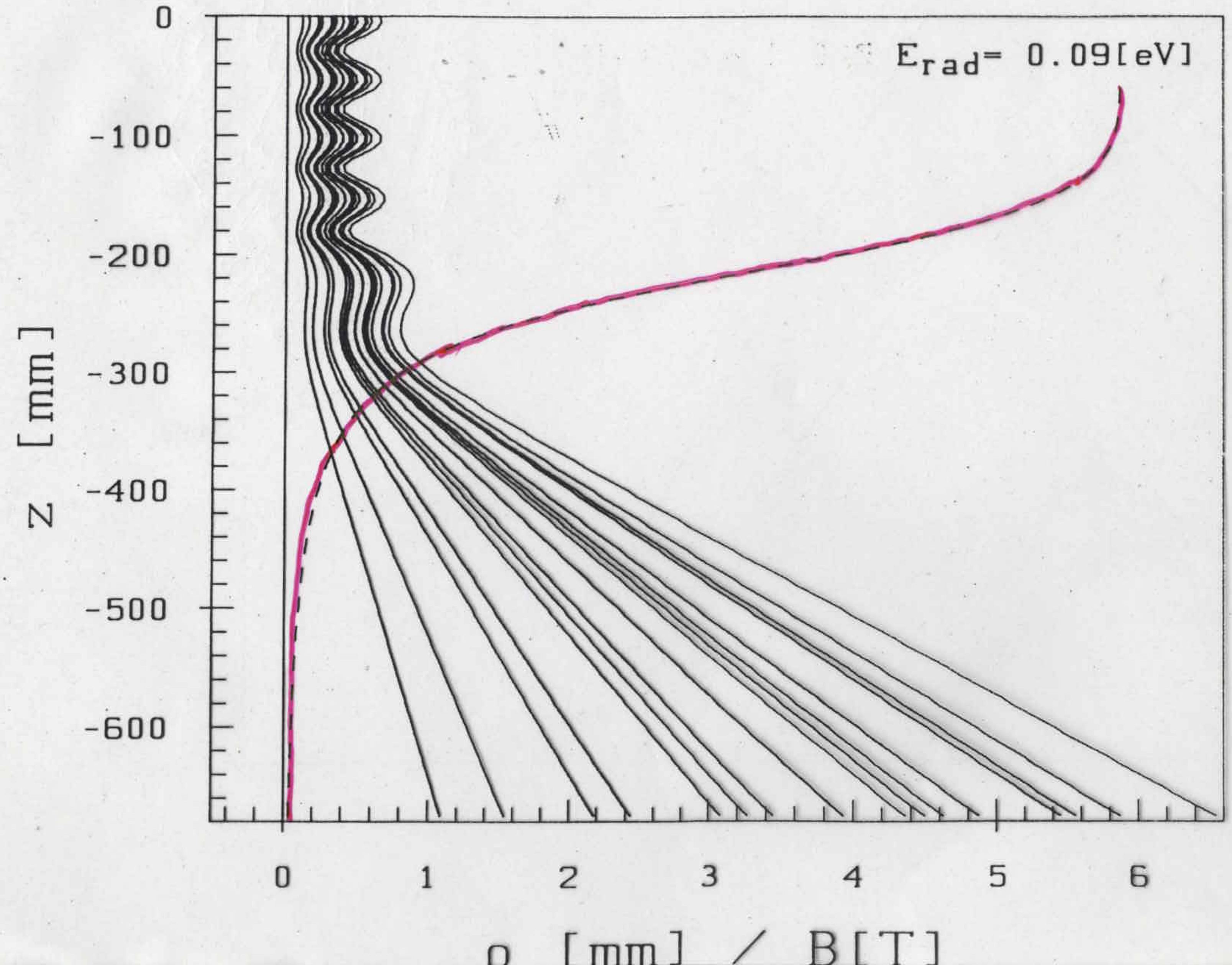
Goal (semiclosed system): 10^{-13} mbar

HITRAP cooler trap: parameters of decelerated ion beam

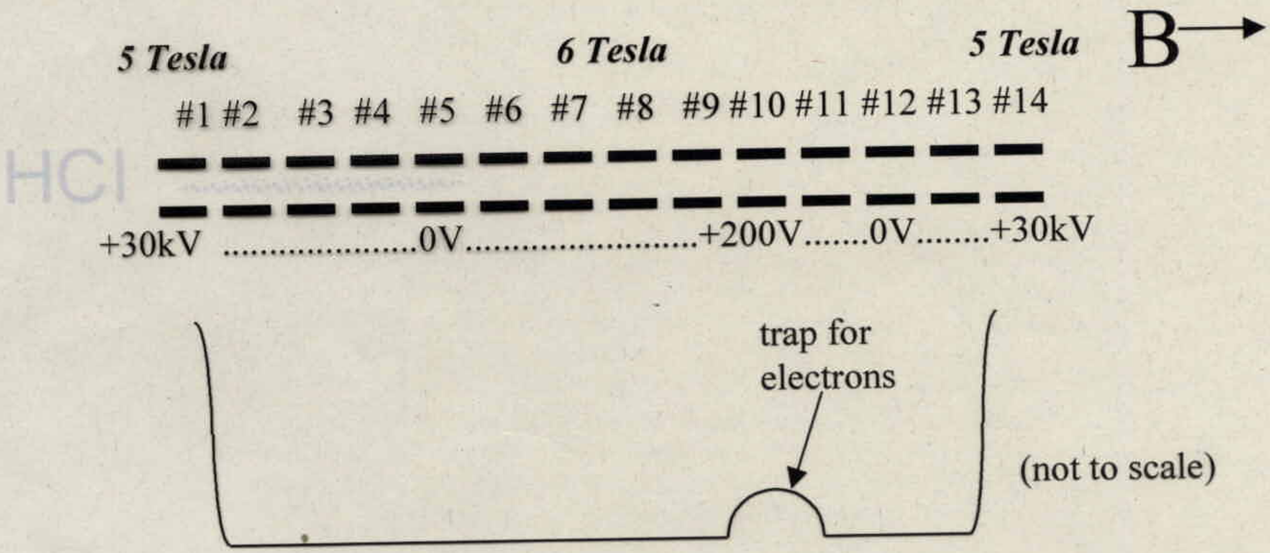
Ion energy:	4 keV /qu
Ion bunch length:	1 μs
Repetition time:	10 s
Intensity:	10^6 ions/bunch
Beam diameter:	10 mm
Beam emittance:	200 π mm rad
Time of flight for one round trip: (for U^{92+} at E_{kin} = 4 keV/q)	2.3 μs

Ion injection into B-field

A = 100
E = 1.0[k

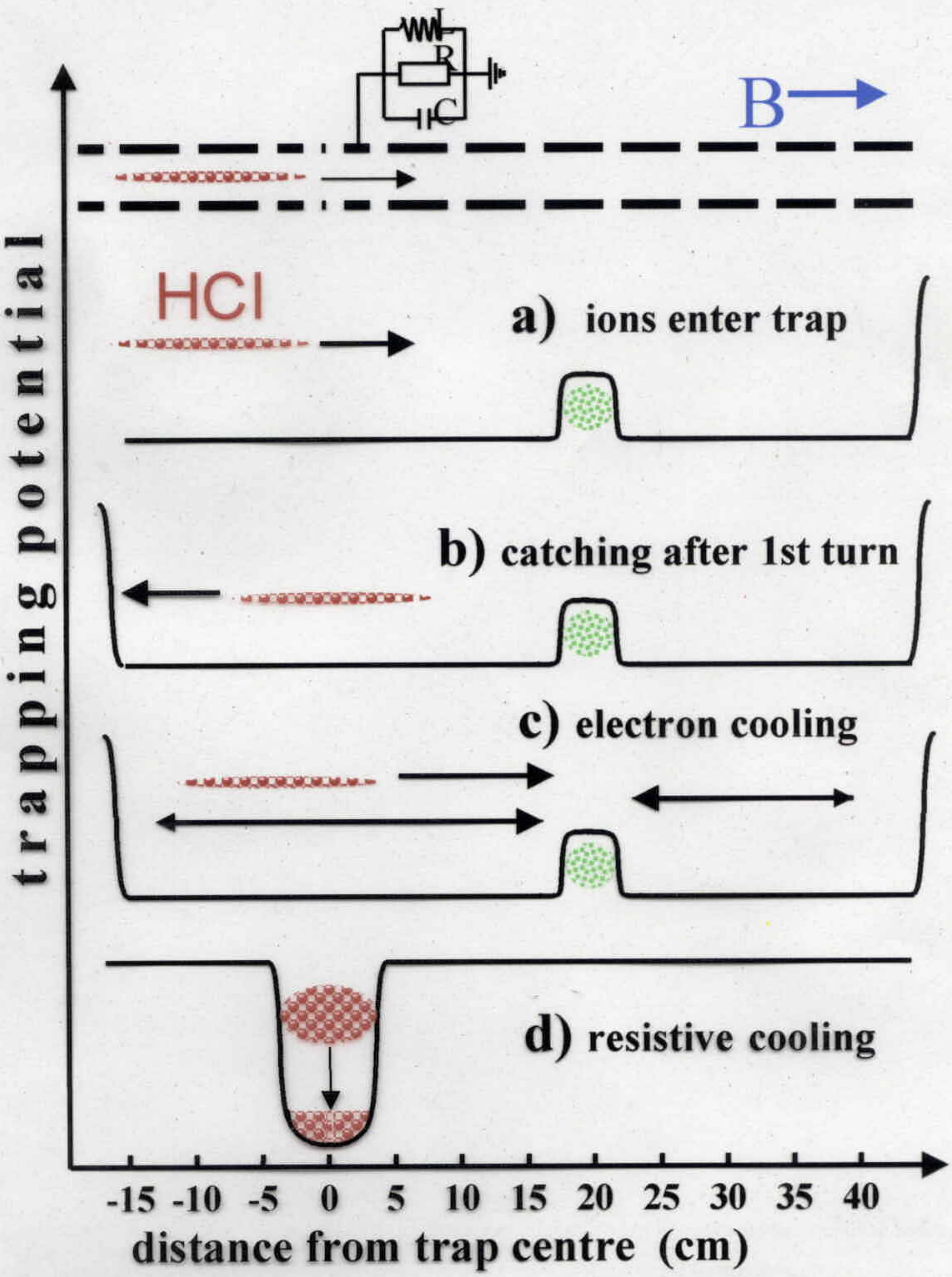


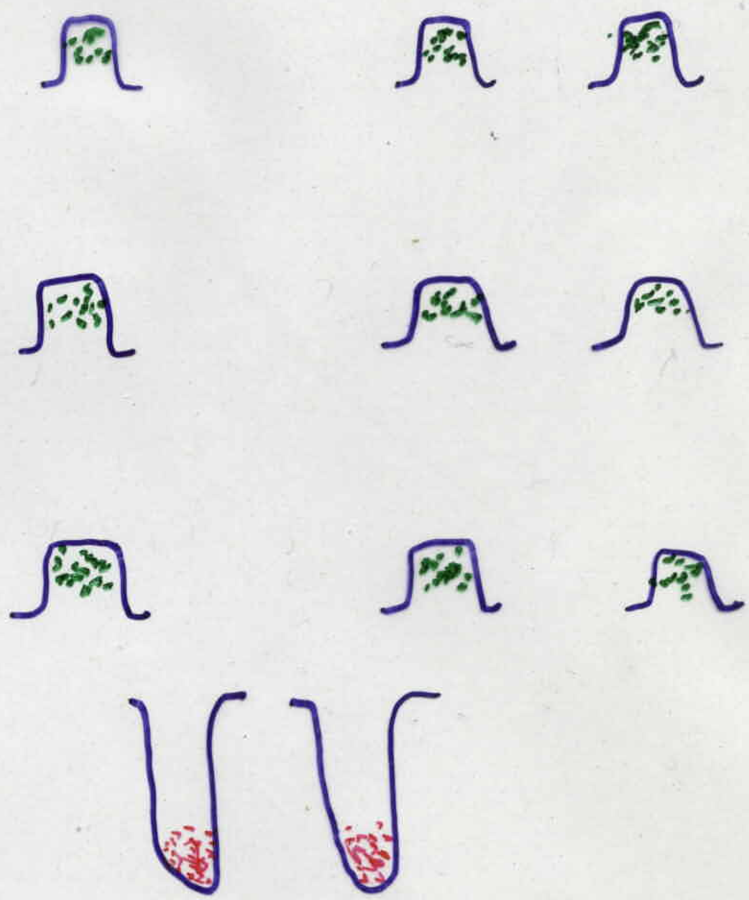
HITRAP: parameters of the Penning cooler trap used for SIMION simulations



Total length of trap:	about 56 cm
inner diameter:	5 cm
14 electrodes with a length of	4 cm
spacing between electrodes #2 to #13:	0.05 cm
spacing to HV electrodes #1 and #14:	0.5 cm
<u>potentials:</u>	
electrode #1 and #14:	+30 kV
electrode #10:	+200 V
electrodes #2 - #9 and #11 - #13:	0 V
magnetic field at center:	B = 6 Tesla
magnetic field at z = ± 25 cm:	B = 5 Tesla
cyclotron frequency:	$\nu_c (U^{92+}) = 35$ MHz

Experimental scheme for electron cooling in a Penning Tap





Equations for thermalization of a 2-component plasma

Cooling time constant :

$$\tau_c = \frac{3\, m_i\, m_c\, C^3}{8\sqrt{2\pi}\, n_e\, \mathbf{Z}^2 e^4 \ln(\Lambda)} \left(\frac{kT_i}{m_i C^2} + \frac{kT_e}{m_e C^2} \right)^{3/2}$$

Coulomb logarithm :

$$\ln(\Lambda) = \int_{b_{\min}}^{b_{\max}} \frac{db}{b} = \ln\left(\frac{b_{\max}}{b_{\min}} \right)$$

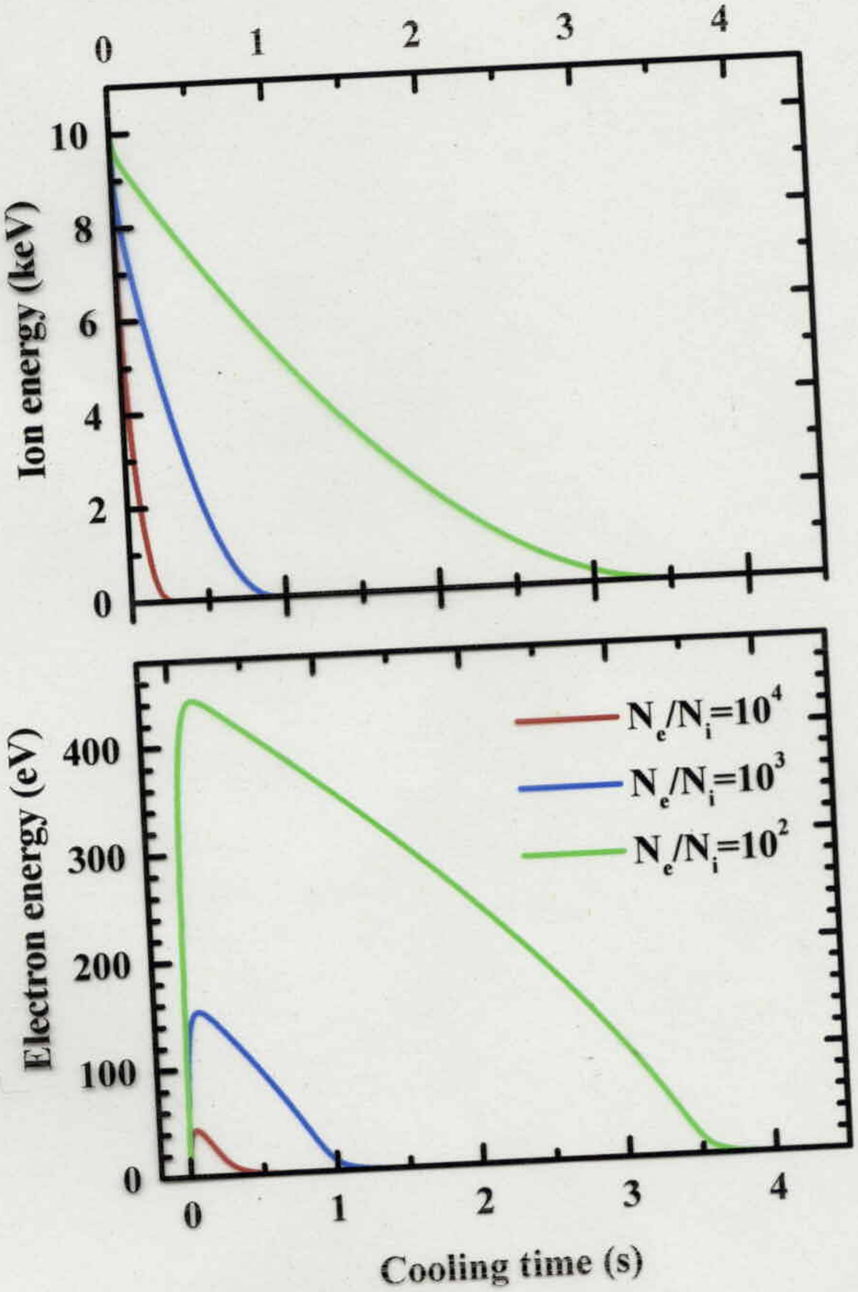
$$\Lambda = \left(4\pi \left(\frac{\varepsilon_0 k}{e^2} \right)^{3/2} \right) \frac{1}{Z} \sqrt{\frac{T_e}{n_e}} \left(T_e + \frac{m_e}{m_i} T_i + 2\sqrt{\frac{m_e}{m_i}} \sqrt{T_e T}_i \right)$$

Decay rate equations :

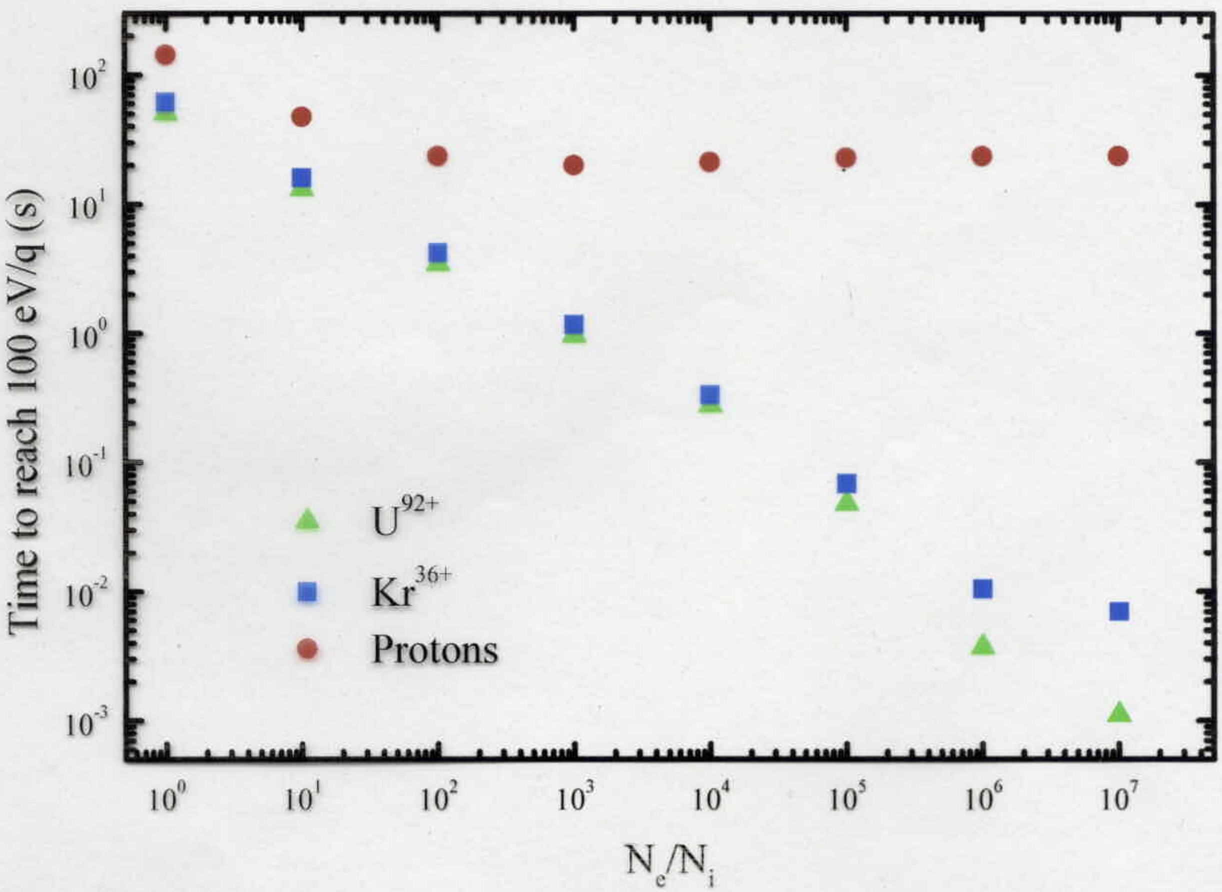
$$\begin{cases} \dfrac{d}{dt} T_i = -\dfrac{1}{\tau_c}(T_i - T_e) \\ \dfrac{d}{dt} T_e = \dfrac{1}{\tau_c}\left(\dfrac{N_e}{N_i} \right)(T_i - T_e) - \dfrac{1}{\tau_e}(T_e - 4.2) \end{cases}$$

S.L. Rolston and G. Gabrielse, Hyperfine Interaction 44 (1988) 233-2246
H. Poth, Physics Reports 196, (1990) 135-297

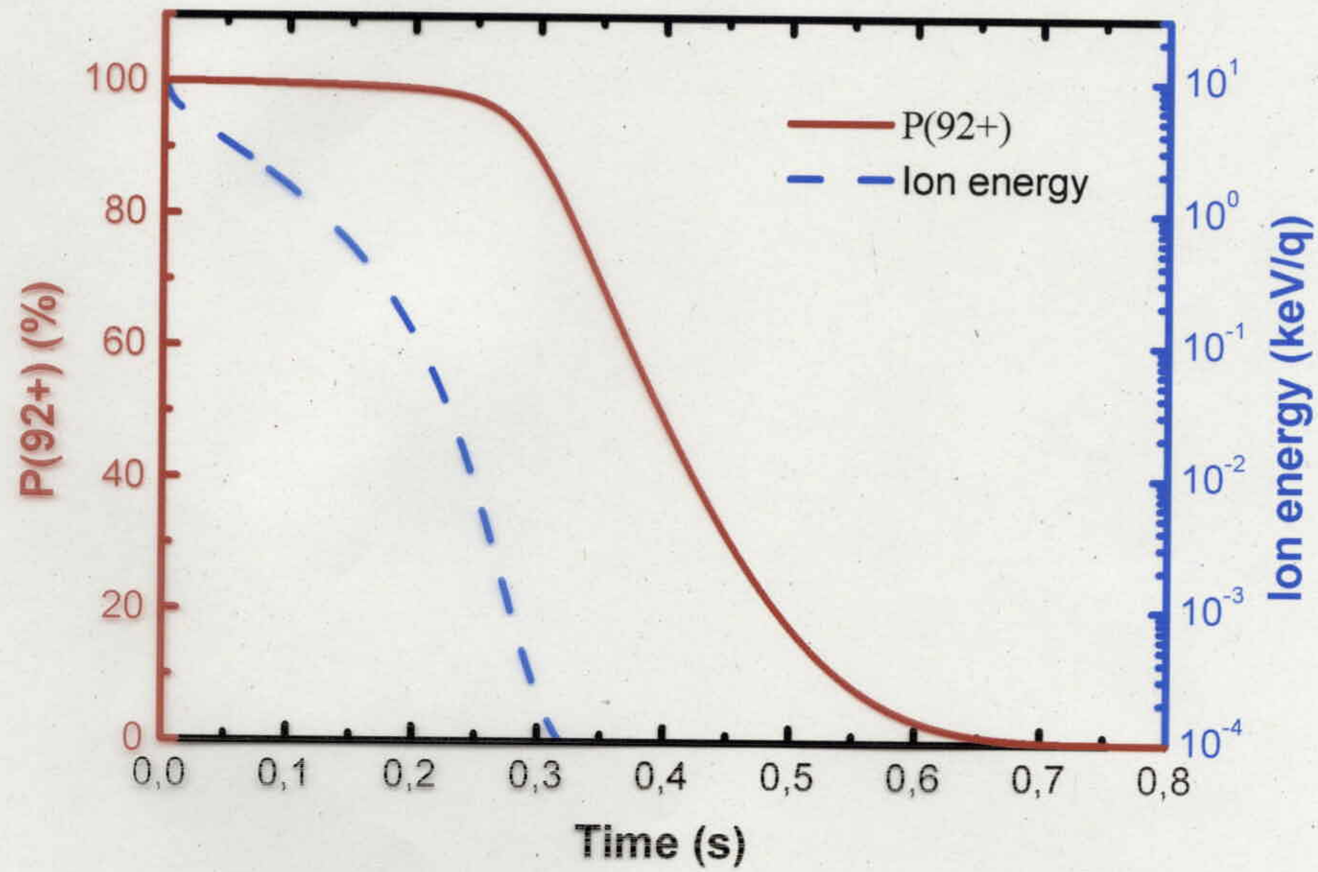
RESULTS :
Electron cooling of U^{92+}



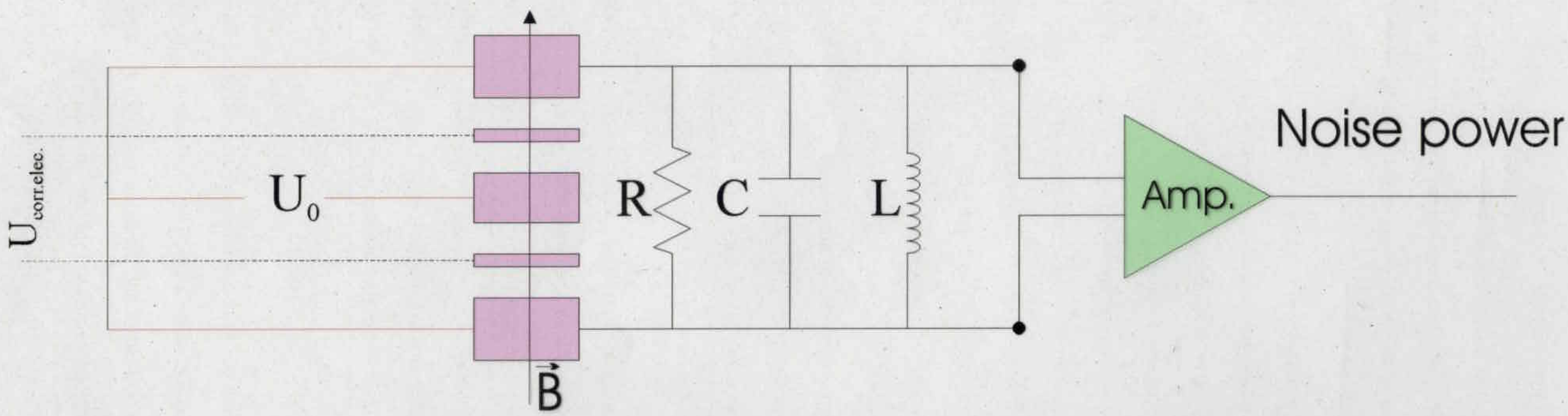
Varying the number of ions



Electron Cooling in Penning Trap: Surviving Probability of U^{92+} Ions



Axial Detection and Cooling

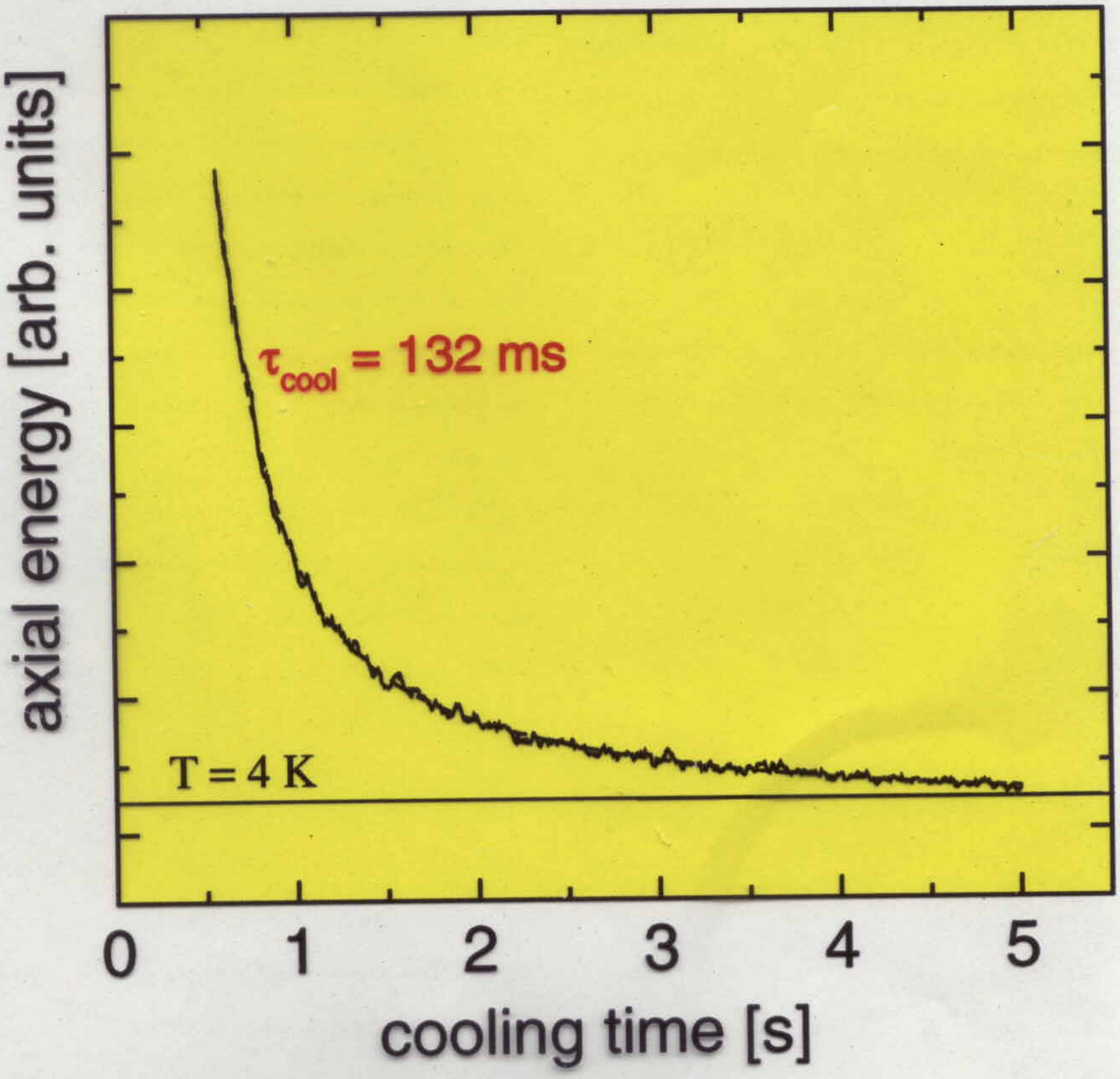


At resonance: $\omega_z = \sqrt{\dfrac{qU_0}{md^2}} = \dfrac{1}{\sqrt{LC}} = \omega_{LC}$

Cooling time constant: $\tau = \left(\dfrac{2d}{q}\right)^2 \dfrac{m}{R} = \left(\dfrac{2d}{q}\right)^2 \dfrac{m}{\omega_z LC^2} \dfrac{1}{Q}$

Resistive Cooling of C^{5+}-ions in a Penning Trap

- final temperature: T = 4 Kelvin



Conclusion

Accumulation of about 10^5 ions cooled to near 4 K by electron- and resistive coling every 10 s is feasible. They can be extracted from the cooler trap and delivered to different experiments.