Electron-Ion Recombination with HITRAP

Andreas Wolf
Max-Planck-Institut für Kernphysik, Heidelberg

HITRAP workshop
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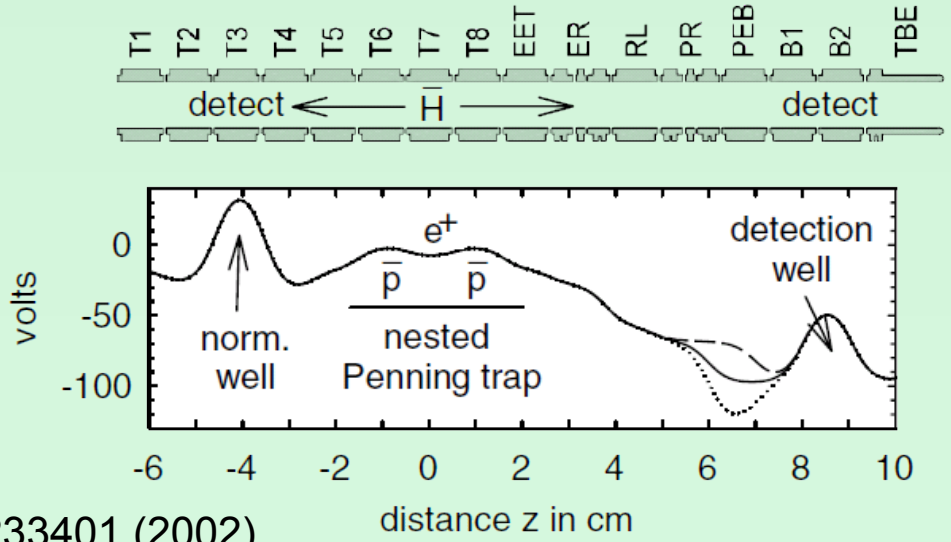
Electron-ion recombination in Penning traps

Product-counting recombination measurements at HITRAP

Instrumental steps

- Electron loading scheme
- Detectors

Penning trap formation of antihydrogen



Gabrielse et al., PRL 89, 233401 (2002)

Observations on antihydrogen from a nested Penning trap

High energy spread (~ 0.1 - 1 eV)

Gabrielse et al., PRL 93, 073401 (2004)
Madsen et al., PRL 94, 033403 (2005)

Highly excited final states, in high magnetic field (~ 5 T)

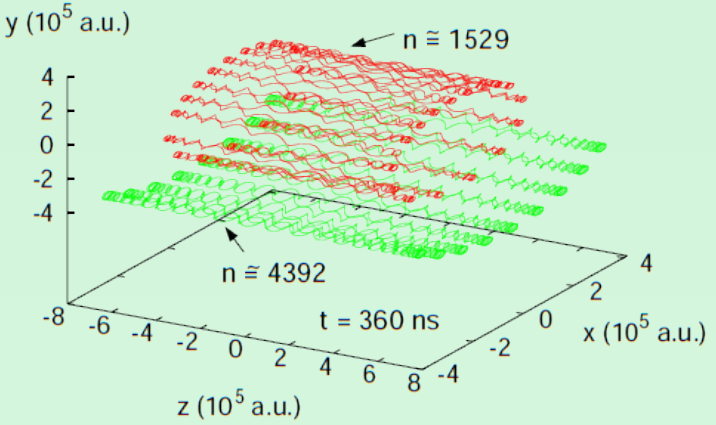
Charge exchange $H_{slow} + p_{fast} \rightarrow H_{fast} + p_{slow}$?

Pohl et al., PRL 97, 1434071 (2006)

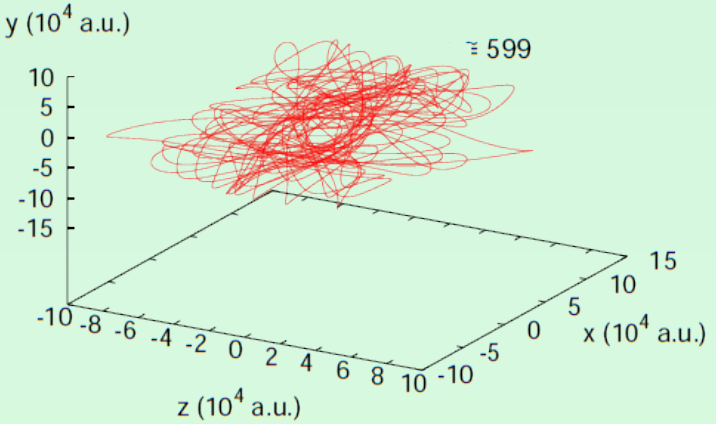
Highly excited states

Guiding center drift

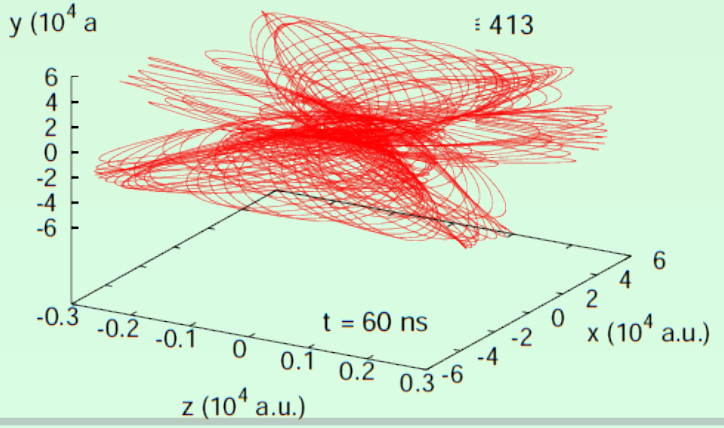
B = 0.04 T
(ion storage rings)



Chaotic

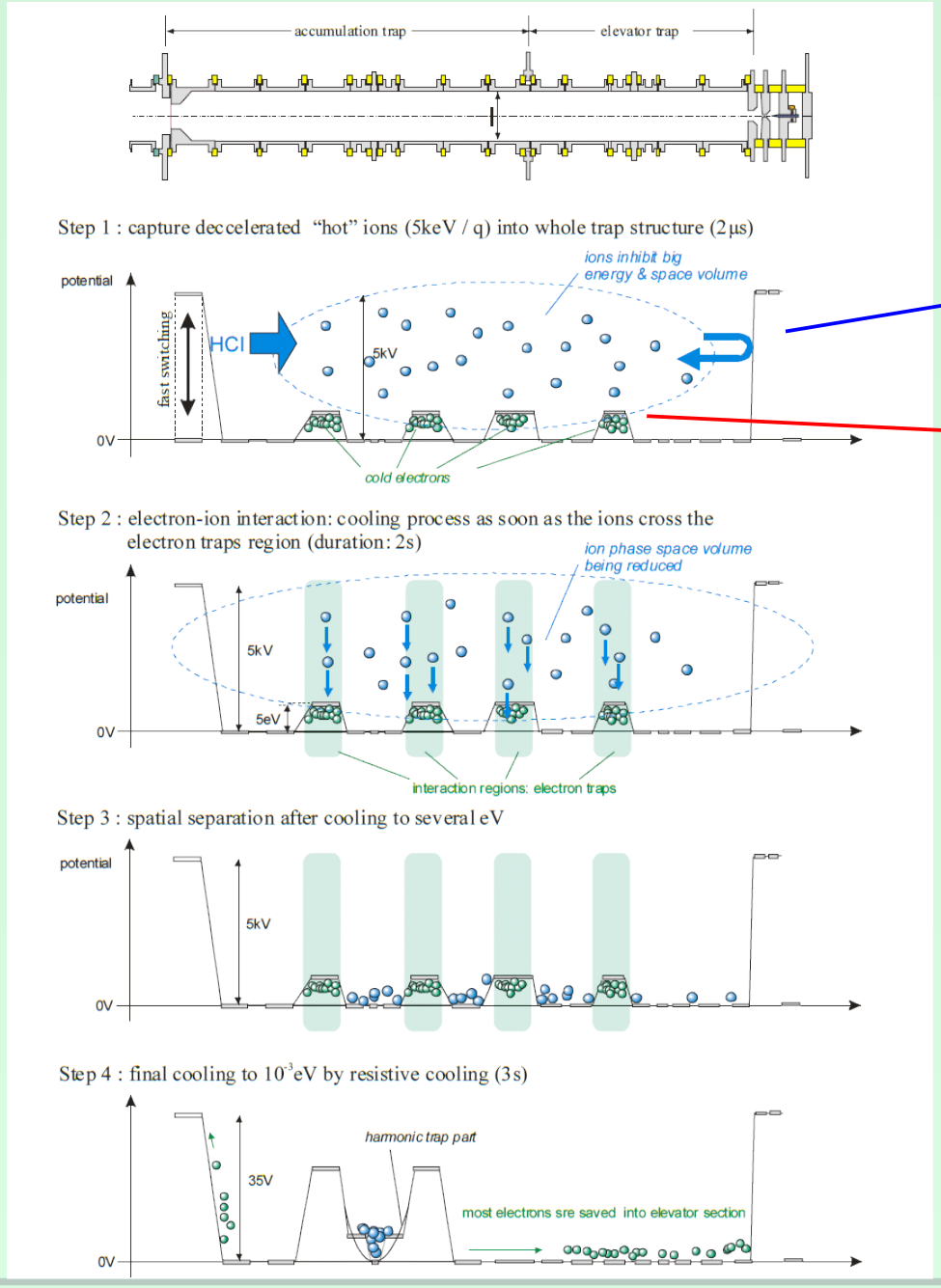


Perturbed Kepler orbit



M. Hörndl et al, PRL 95, 243201 (2005)
and PRA, in print

HITRAP ion cooling and loading cycle



Ions

Electrons

Electron cooling

Separation and resistive cooling

HITRAP design report 2003

Questions in multicharged ion recombination at HITRAP

Three-body vs. radiative recombination

Collision energy dependence of the cross section

Final state distribution

Control of recombination in nested trap

Ion charge dependence

Basic relations

Relative rates of *radiative* recombination and electron cooling

$$\frac{\lambda_r}{\lambda_c} \sim \underbrace{2\sqrt{\frac{2\pi}{3}}\,\alpha\,\frac{Am_u}{m_e}}_{2.9\frac{A\cdot 1822}{137}\;\sim\;39\cdot A}\;\underbrace{\left(\frac{\bar{v}_r}{c}\right)^2}_{\frac{3kT_e}{m_e c^2}\sim 2\times 10^{-9}}\;\frac{L_r}{L_c}$$

~ 0.35 meV (4 K)

$\lambda_r \ll \lambda_c$ at low electron temperature

Basic relations

Electron collision energy

~ 0.35 meV (4 K)

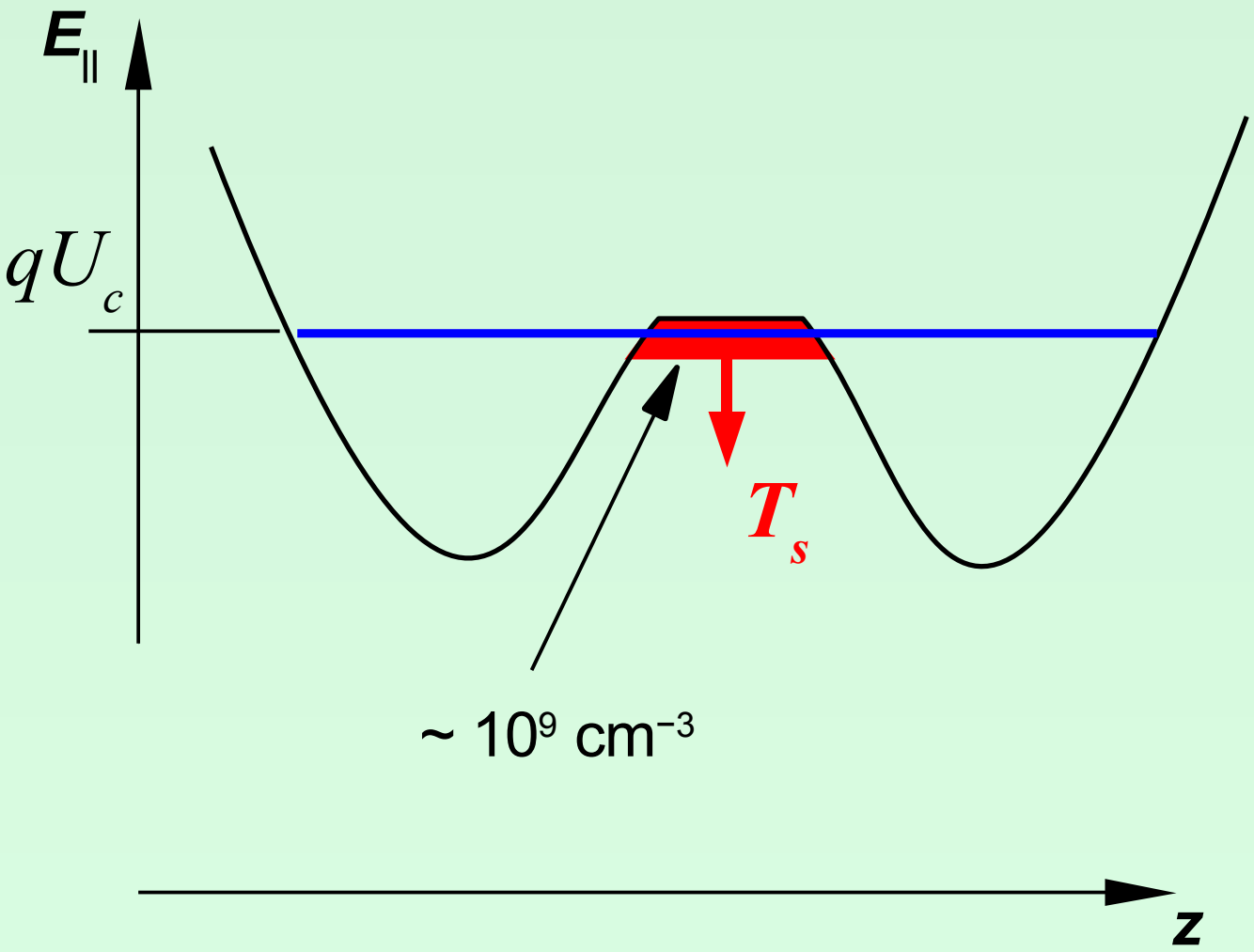
$$E_i = \frac{3}{2}\frac{M}{m} kT_e$$

~ 4 eV $(A = 4)$

$$v_i < \bar{v}_e : \quad E \sim kT_e$$

$$v_i > \bar{v}_e : \quad E \sim \frac{m}{M} E_i$$

Recombination product counting in HITRAP



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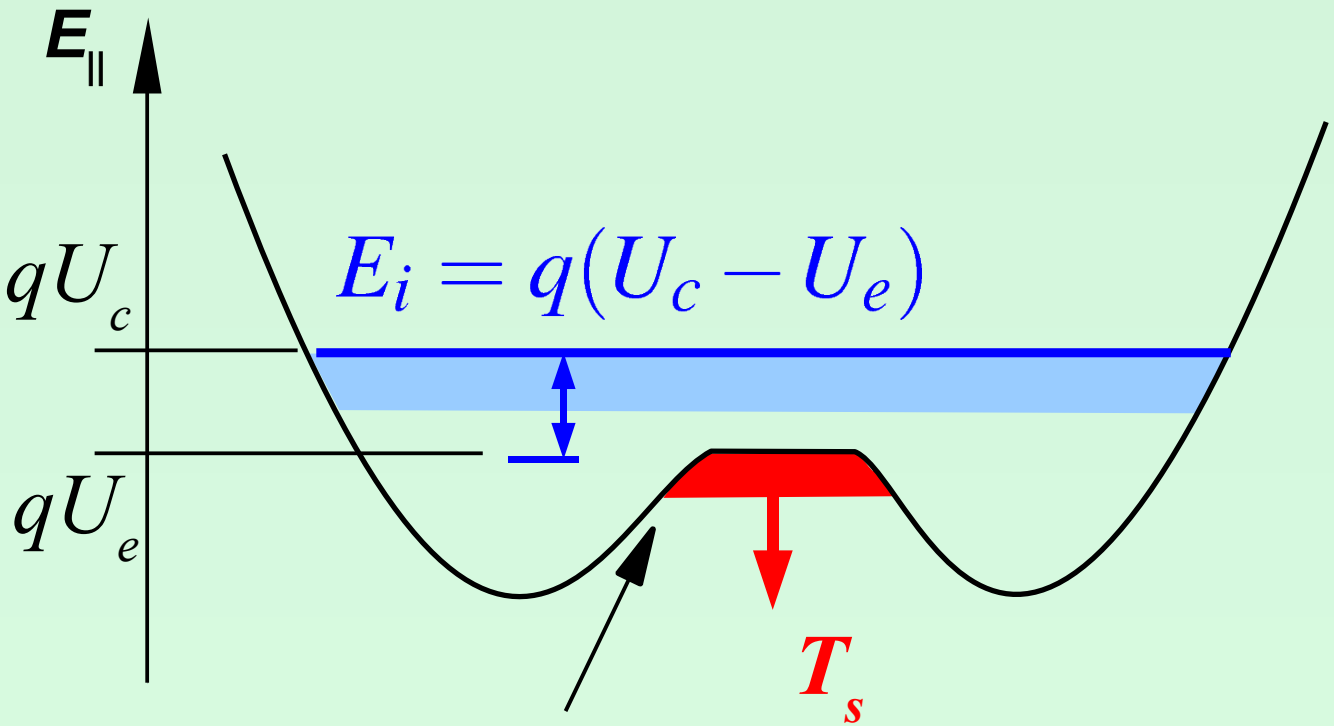
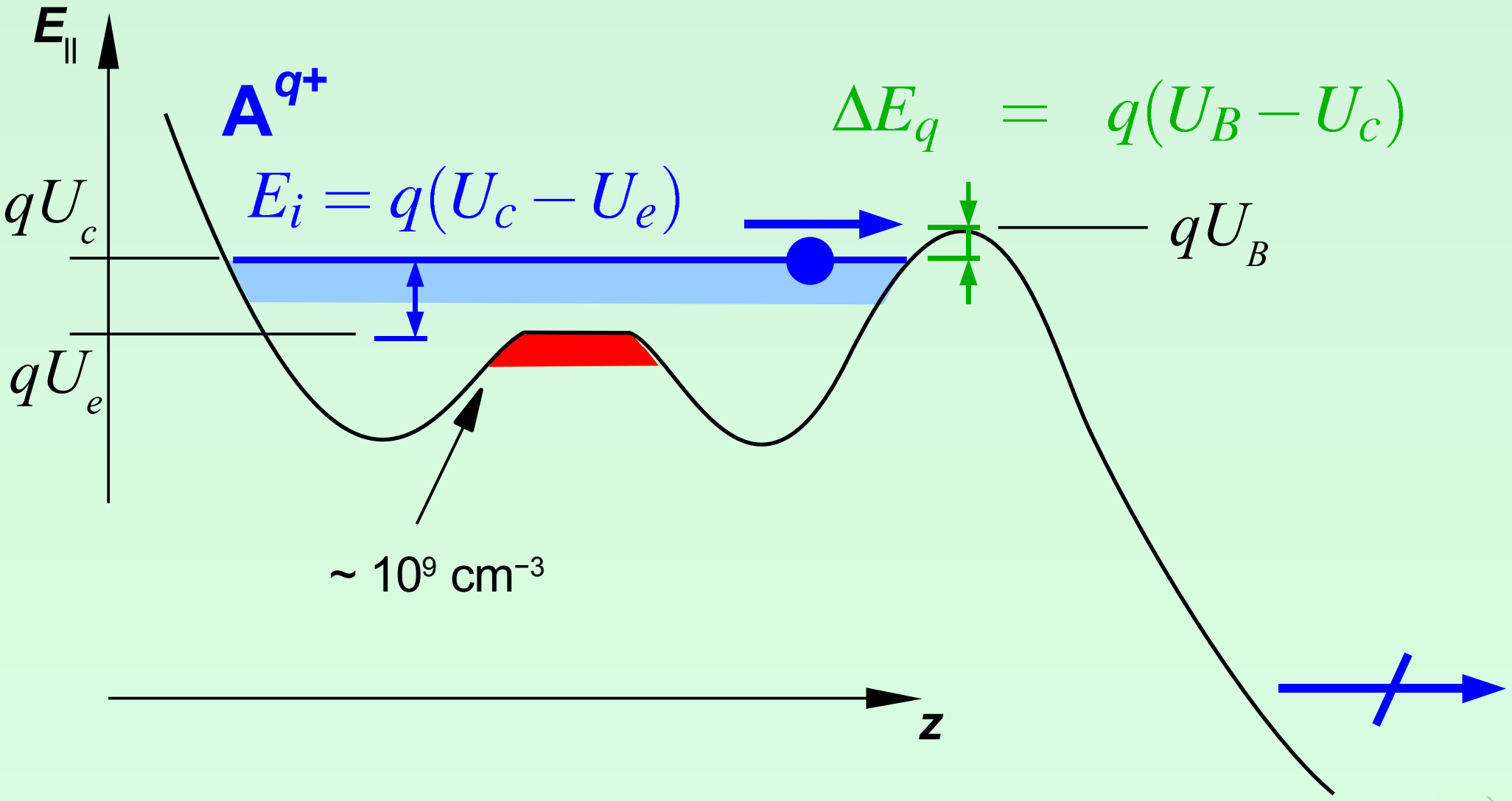


$$\omega_{ze}^{-1} < T_s < \omega_{zi}^{-1}$$

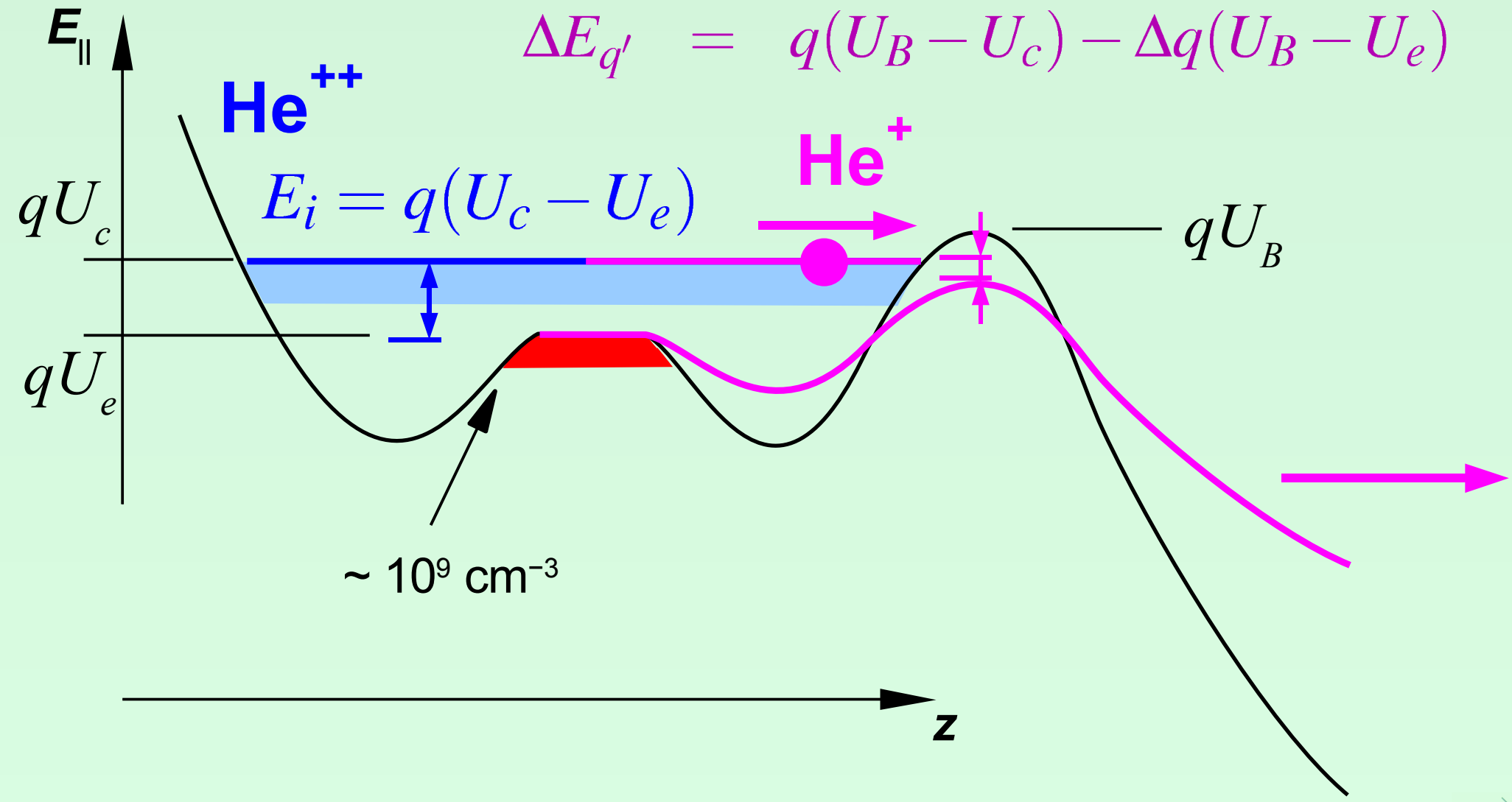
Recombination product counting in HITRAP



Recombination product counting in HITRAP

$$\Delta E_q = q(U_B - U_c)$$

$$\Delta E_{q'} = q(U_B - U_c) - \Delta q(U_B - U_e)$$



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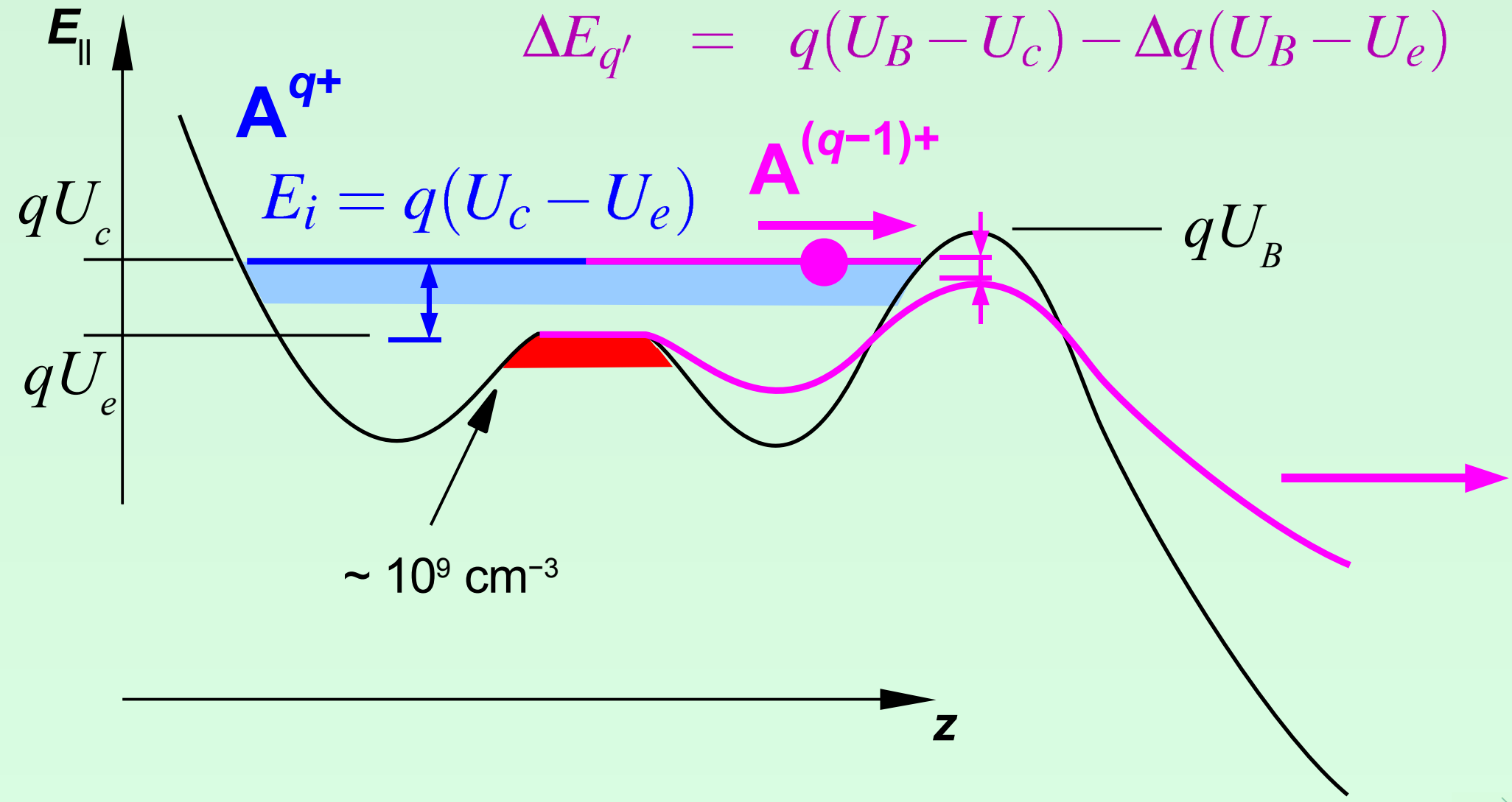
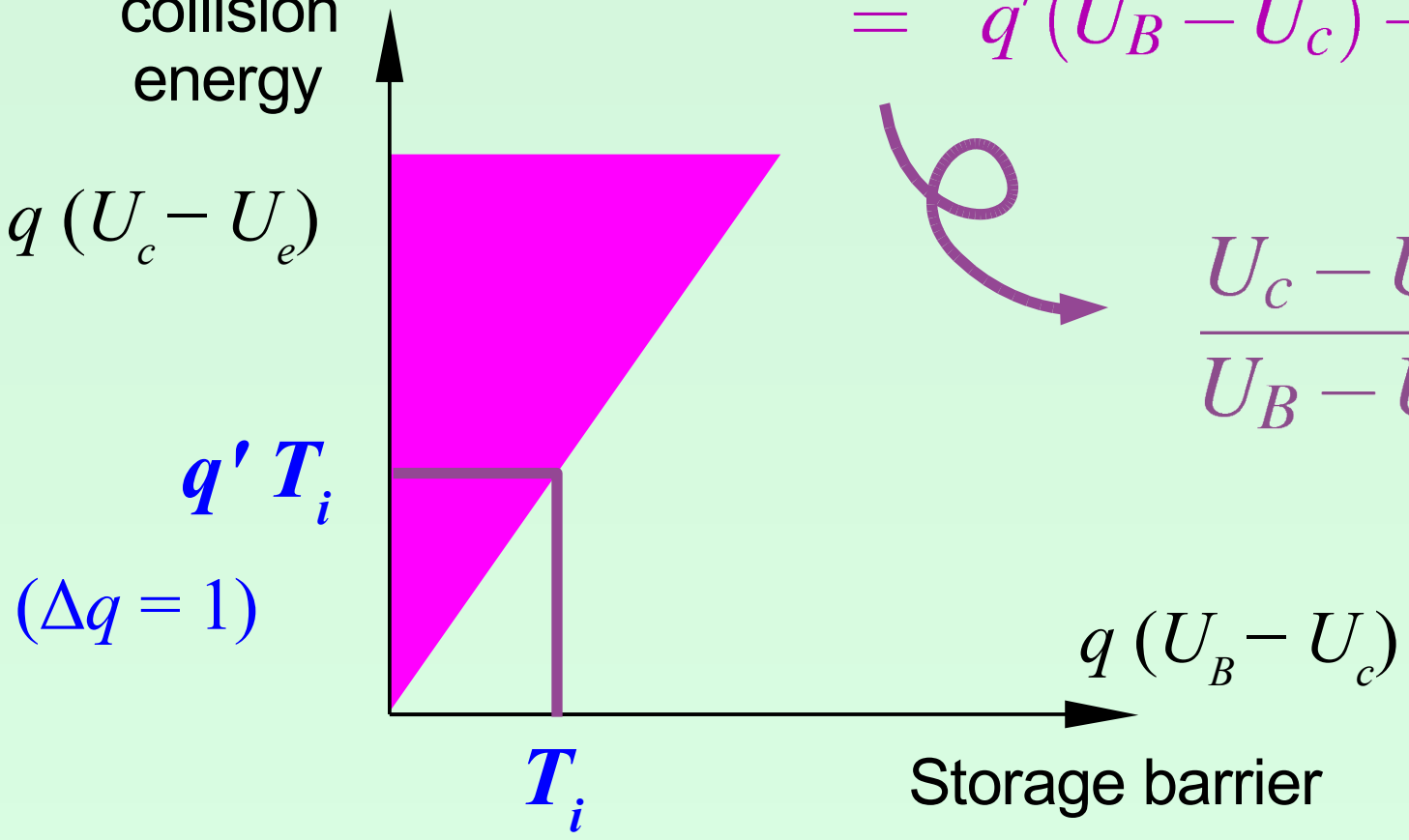


Recombination product counting in HITRAP

$$\Delta E_{q'} = q(U_B - U_c) - \Delta q(U_B - U_e) \quad \underbrace{-U_c + U_c}$$

$$= q'(U_B - U_c) - \Delta q(U_c - U_e)$$

$$\frac{U_c - U_e}{U_B - U_e} > \frac{q'}{\Delta q}$$

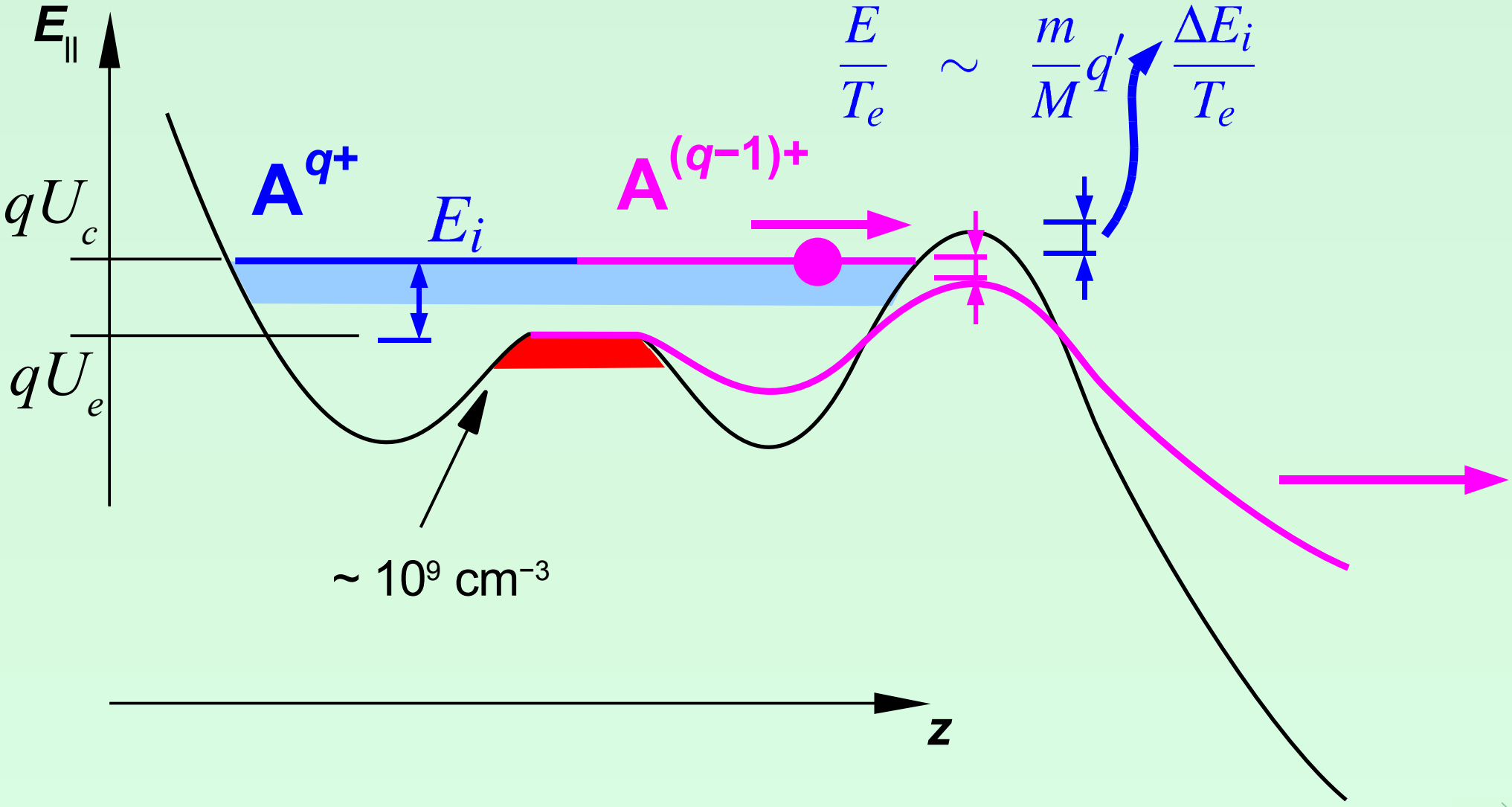


Recombination product counting in HITRAP

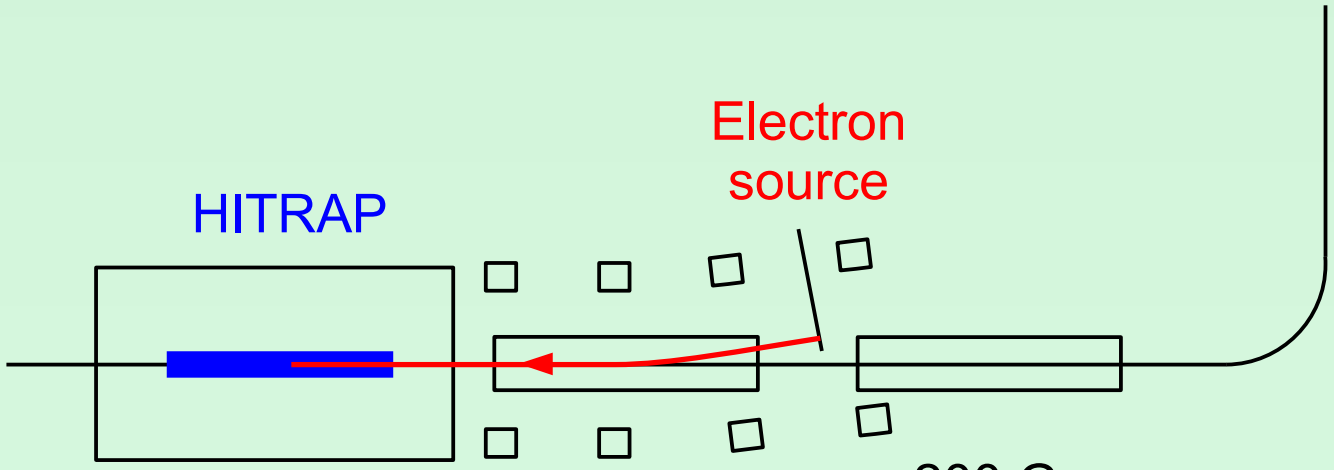
Minimum collision energy

$$E = \frac{m}{M} E_i \sim \frac{m}{M} q' \Delta E_i$$

$$\frac{E}{T_e} \sim \frac{m}{M} q' \frac{\Delta E_i}{T_e}$$



Electron loading

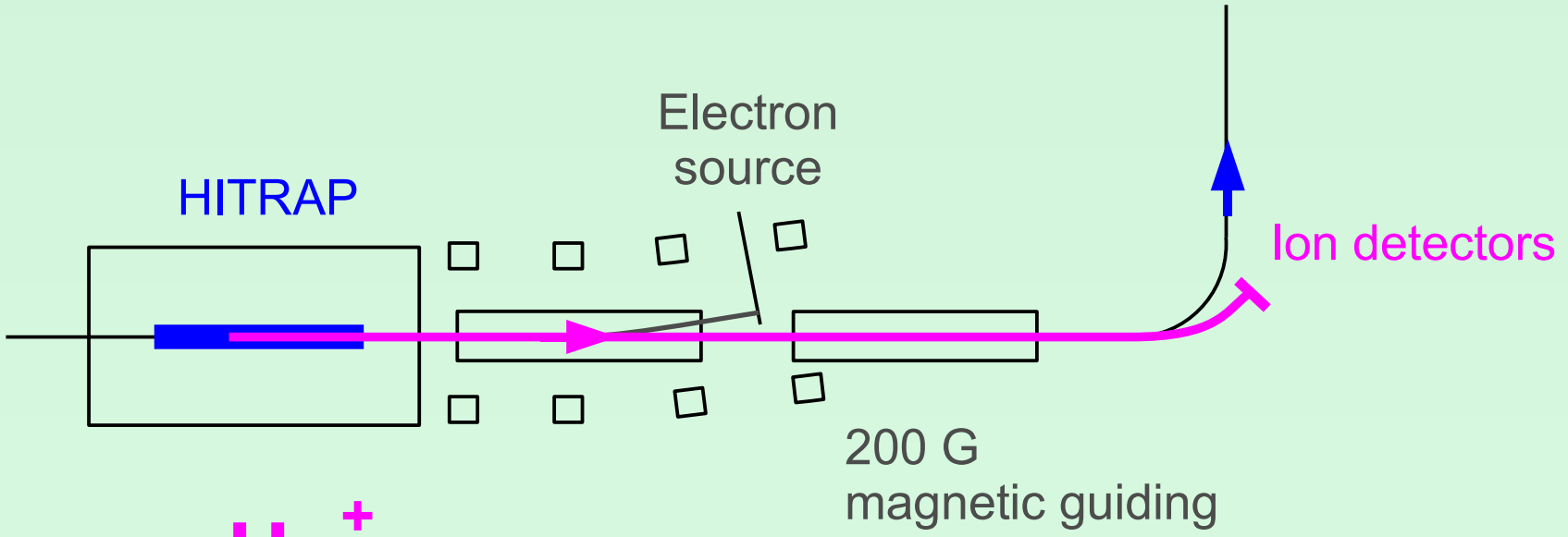


1 m trap length

5 mm diam.
electron beam

Stored electrons	Current	Pulse length	Transport energy
10^{10}	20 mA	80 ns	480 eV
10^{9}	0.7 mA	240 ns	48 eV

Counting of recombination products



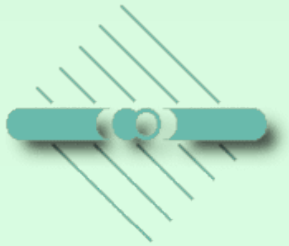
$$He^{++} + e \rightarrow He^{+}$$

- Find recombination energy dependence for $E_i > \Delta E_i$
- Measure density, temperature dependences
- Measure charge exchange rates
  on auxiliary trapped ion clouds

A sensitive tool for low-energy recombination in high-density, cold, magnetically trapped plasma

Cold, intense photocathode electron beams

Max-Planck-Institut für Kernphysik
Heidelberg, Germany



D. Orlov
H. Fadil
C. Krantz
A. Jaroshevich
(visitor)
M. Grieser
A. W.