Interaction of stored ions with electron target in low energy electrostatic ring

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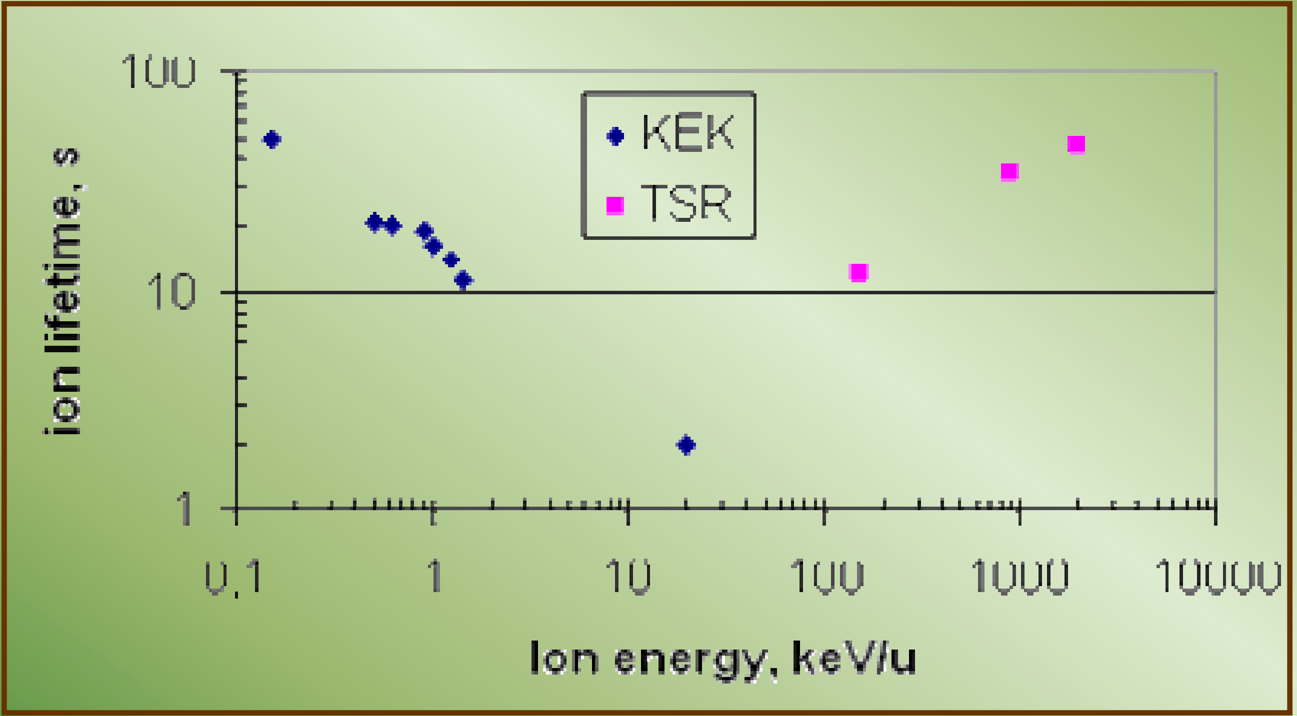
Advantages of electrostatic ring

- **Independence rigidity on the ion mass**

Magnetic rigidity **Electrostatic rigidity**

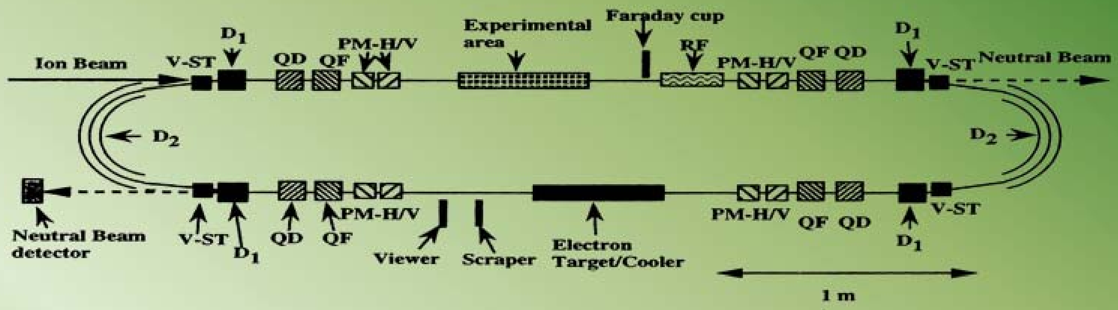
$$B\rho = \sqrt{2E_i M} / q_i \qquad E\rho = 2E_i / q_i$$

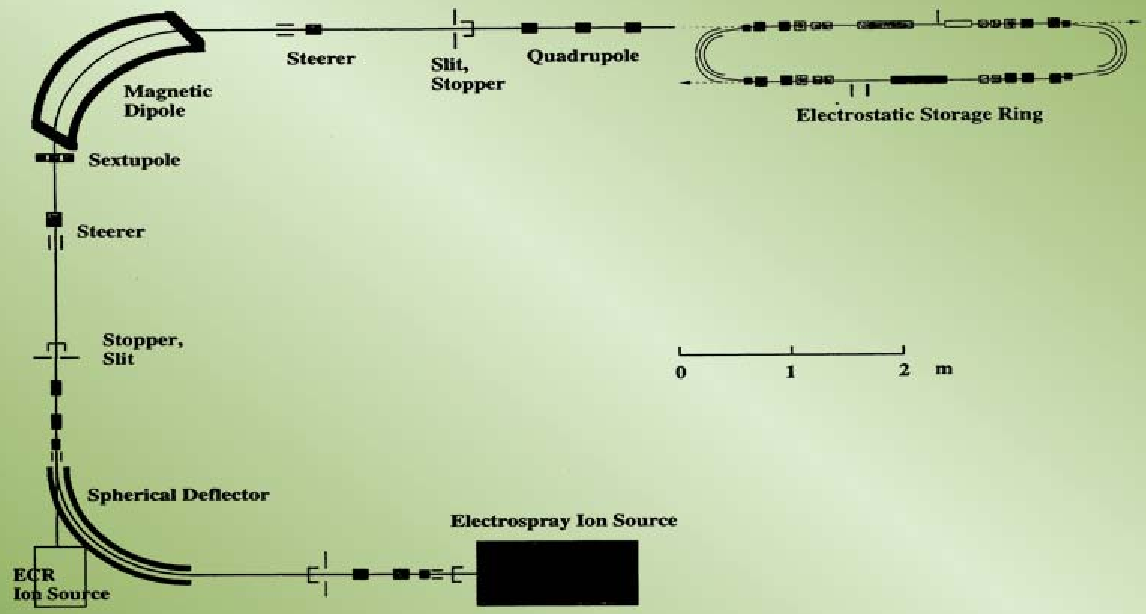
- **Lifetime of partially stripped ions of 10-50 s at a vacuum pressure of $5 \cdot 10^{-11}$ Torr**



The KEK Electrostatic ring parameters

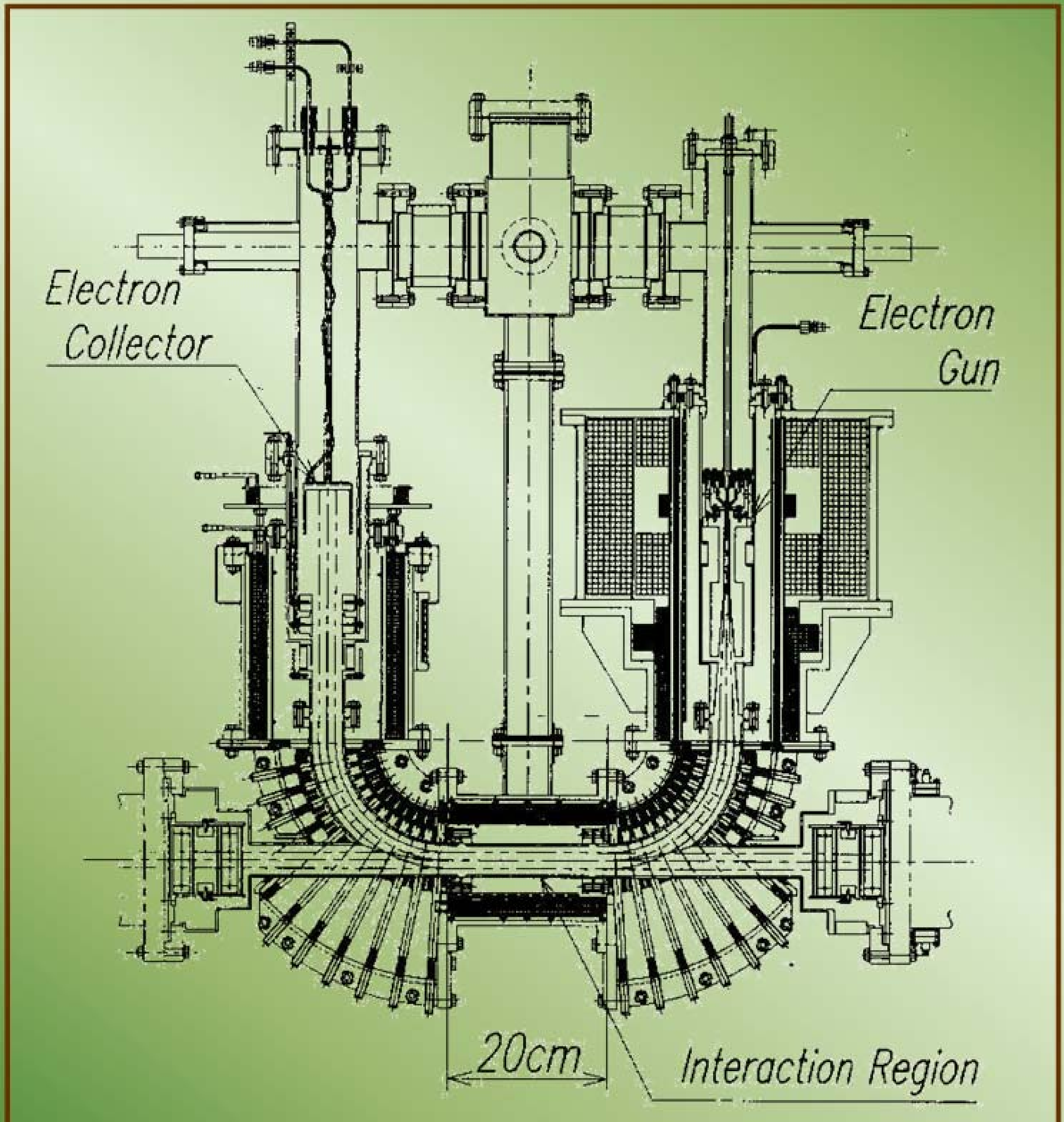
Parameters	Electrostatic ring	
Circumference, m	8.136	
Pressure, mbar	$3 \cdot 10^{-11}$	
Ion energy, keV/Z	20	
Atomic mass	1-1000	
Lifetime, s	10-50	
Injection current, nA	50-500	
Injection emittance, $\varepsilon_v / \varepsilon_h$, $\pi \cdot$mm$\cdot$mrad	15	
Initial momentum spread	10^{-3}	
	Electron cooler	Electron target
Electron target length, cm	20	
Gun magnetic field, kG	1	
Cooler magnetic field, G	10-100	
Electron beam radius in the cooler, cm	0.5-1	
Electron energy, eV	0.1-10	1-100
Electron beam current, μA	0.1-200	1-2000

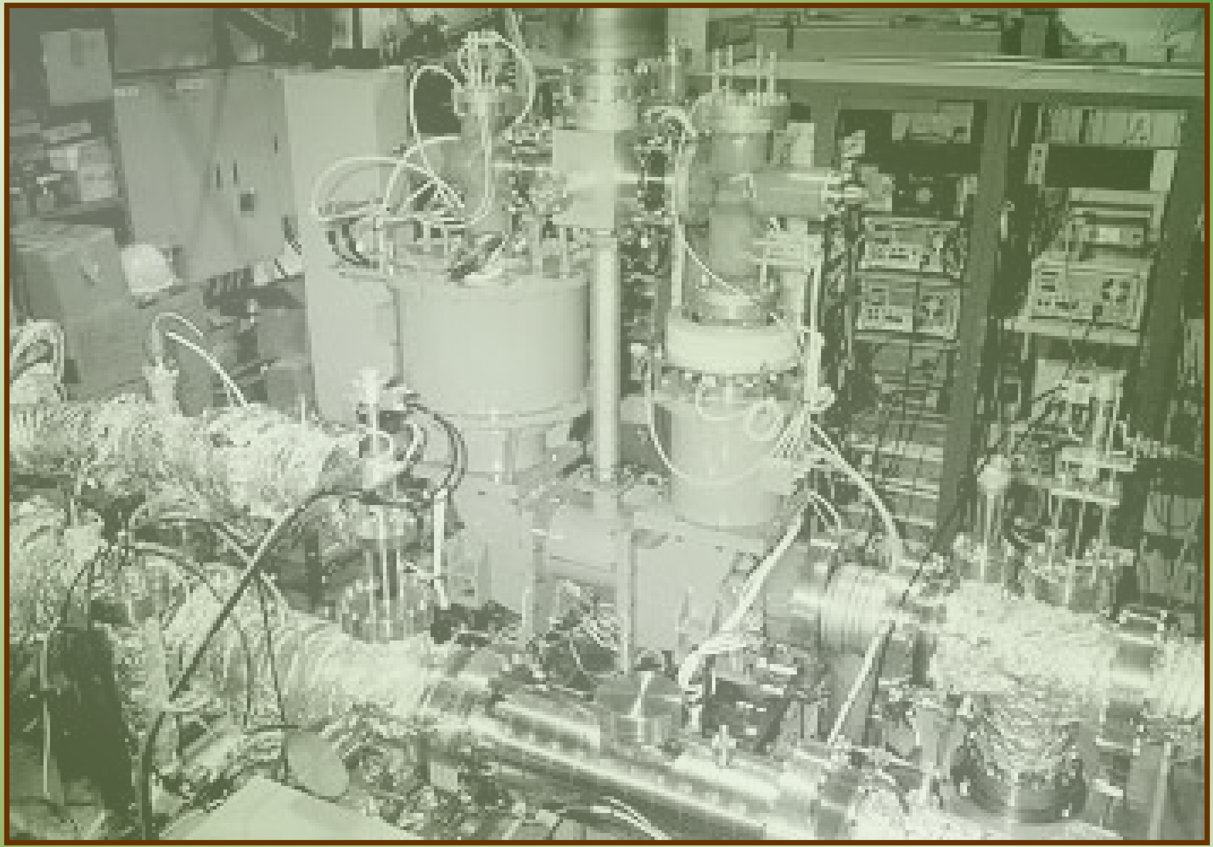




Layout of the ion sources, the mass-analyzer and the electrostatic storage ring. D_1 and D_2 are 10°and 160°deflectors, QF and QD the horizontally focusing and defocusing electrostatic quadrupoles, PM-H and PM-V the horizontal and vertical position monitors, RF system and V-ST the vertical steerer.

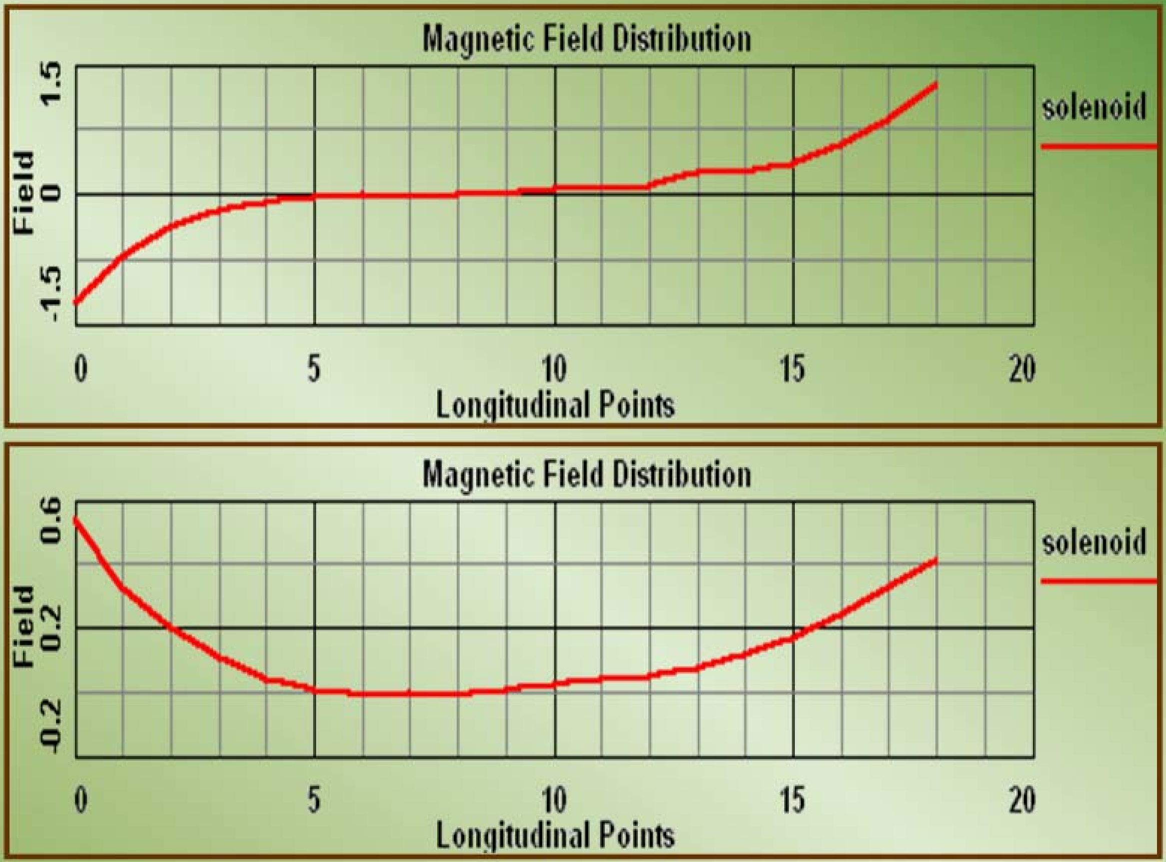
Layout of the KEK electron target/cooler





Photograph of the electron target installed in the KEK electrostatic ring.

KEK cooler magnetic field

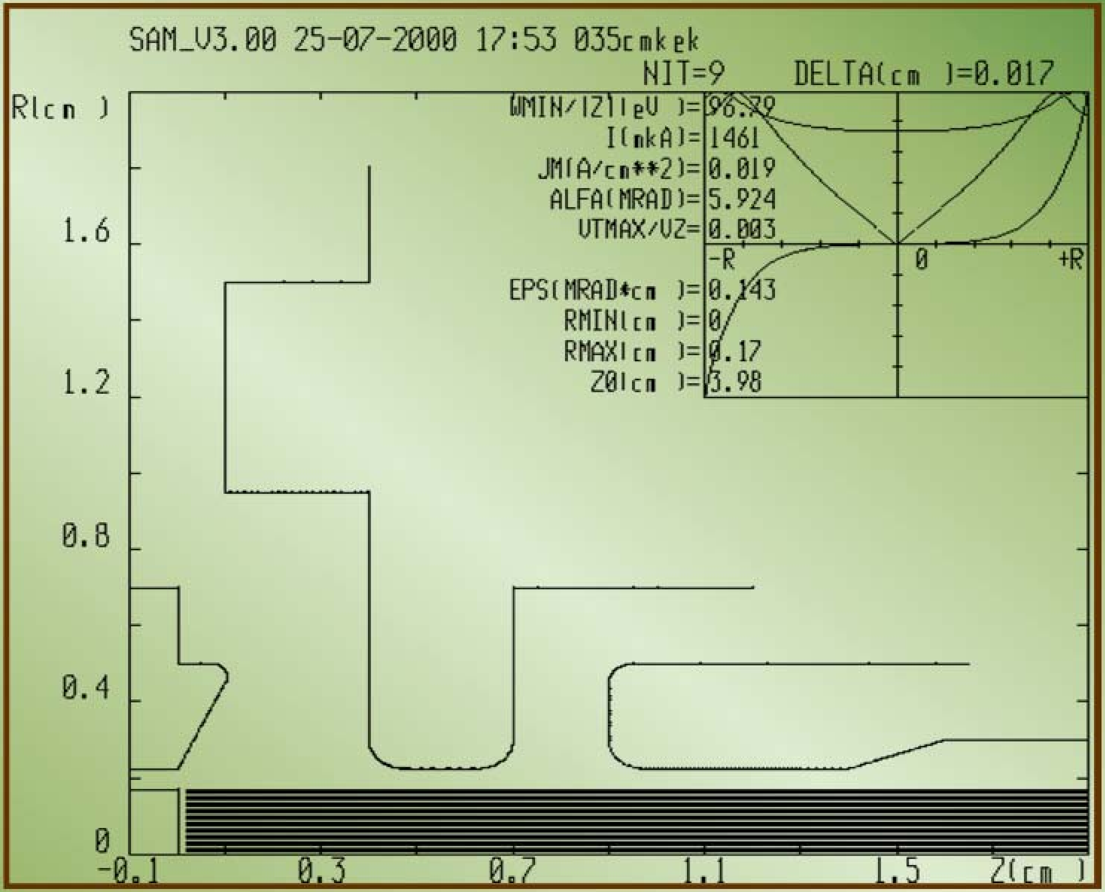


The vertical and horizontal magnetic field for B=30 G.

The central region with a length of 10 cm corresponds to a high quality of the magnetic field

at E=10 eV

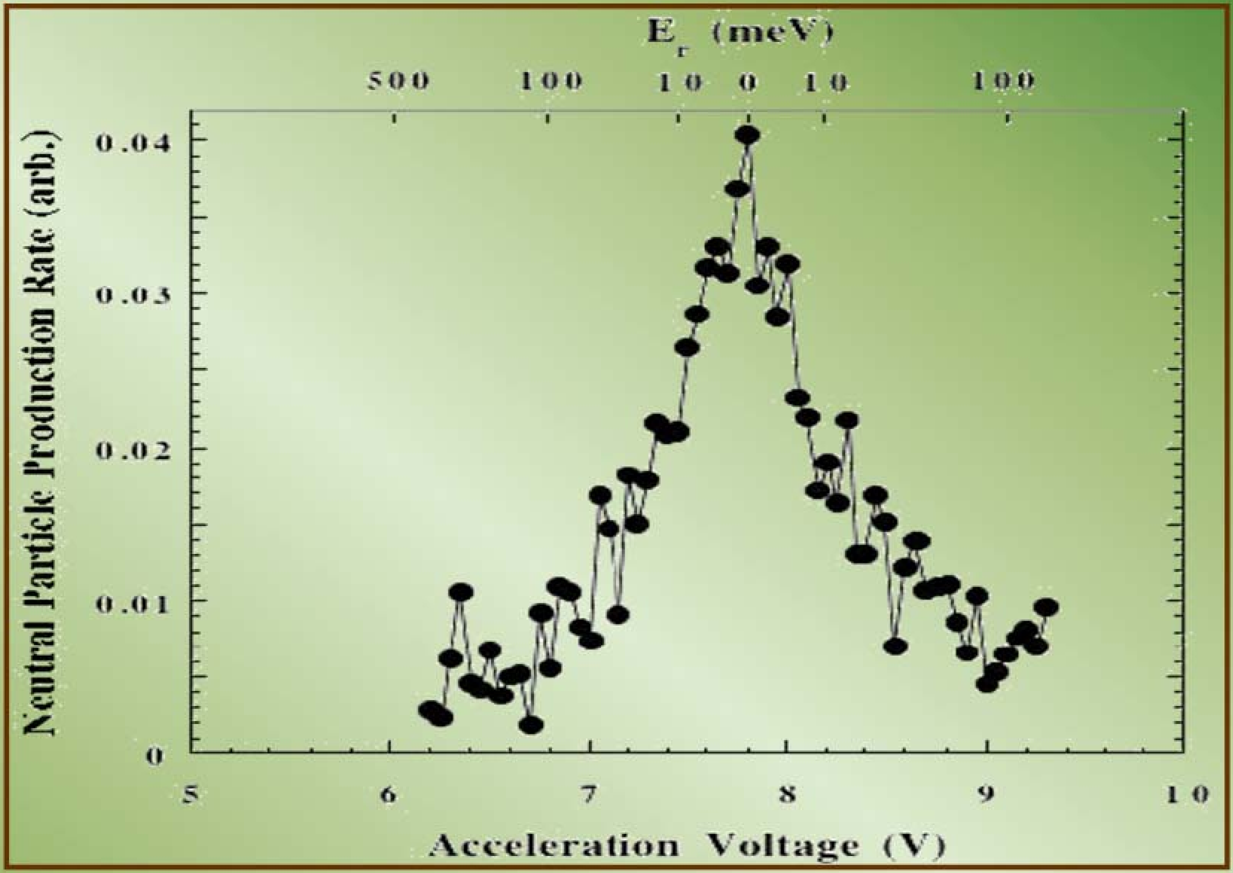
Electron gun with variable beam spot diameter of 2-3.5 mm



Maximum beam perveance corresponds to a vacuum chamber perveance of 10 μA/V$^{3/2}$

$$I = \frac{8\pi\varepsilon_0}{3\sqrt{3}} \frac{Ev}{1 + 2\ln b/a}$$

Electron energy calibration

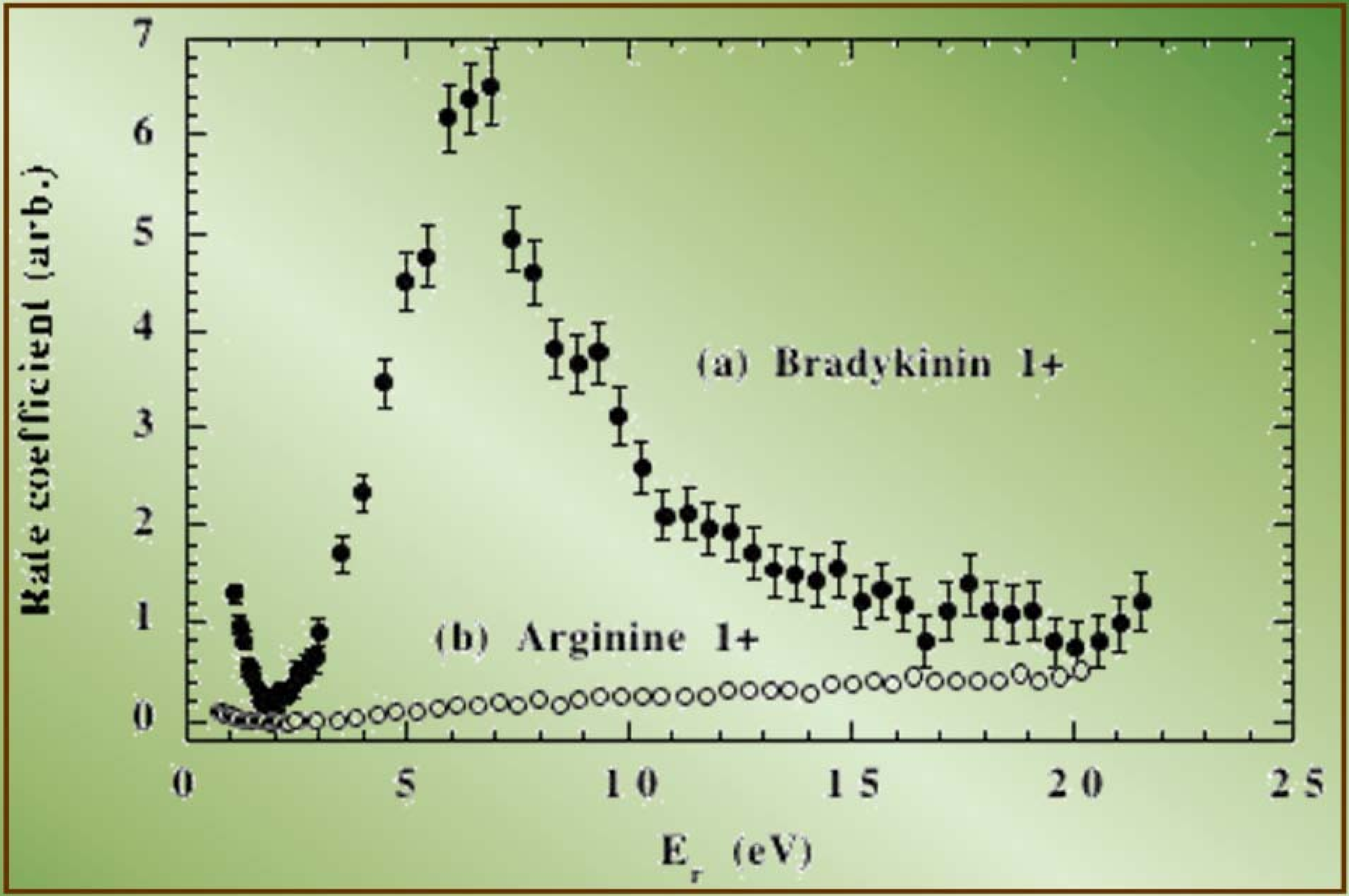


Dissociative recombination rate for H_2^+ with an energy of 20 keV as a function of the electron acceleration voltage at I_e = 60 μA and B= 30 G.

$$E_e = eV_{cath} - eV_0 - kI_e/E_e^{1/2},$$

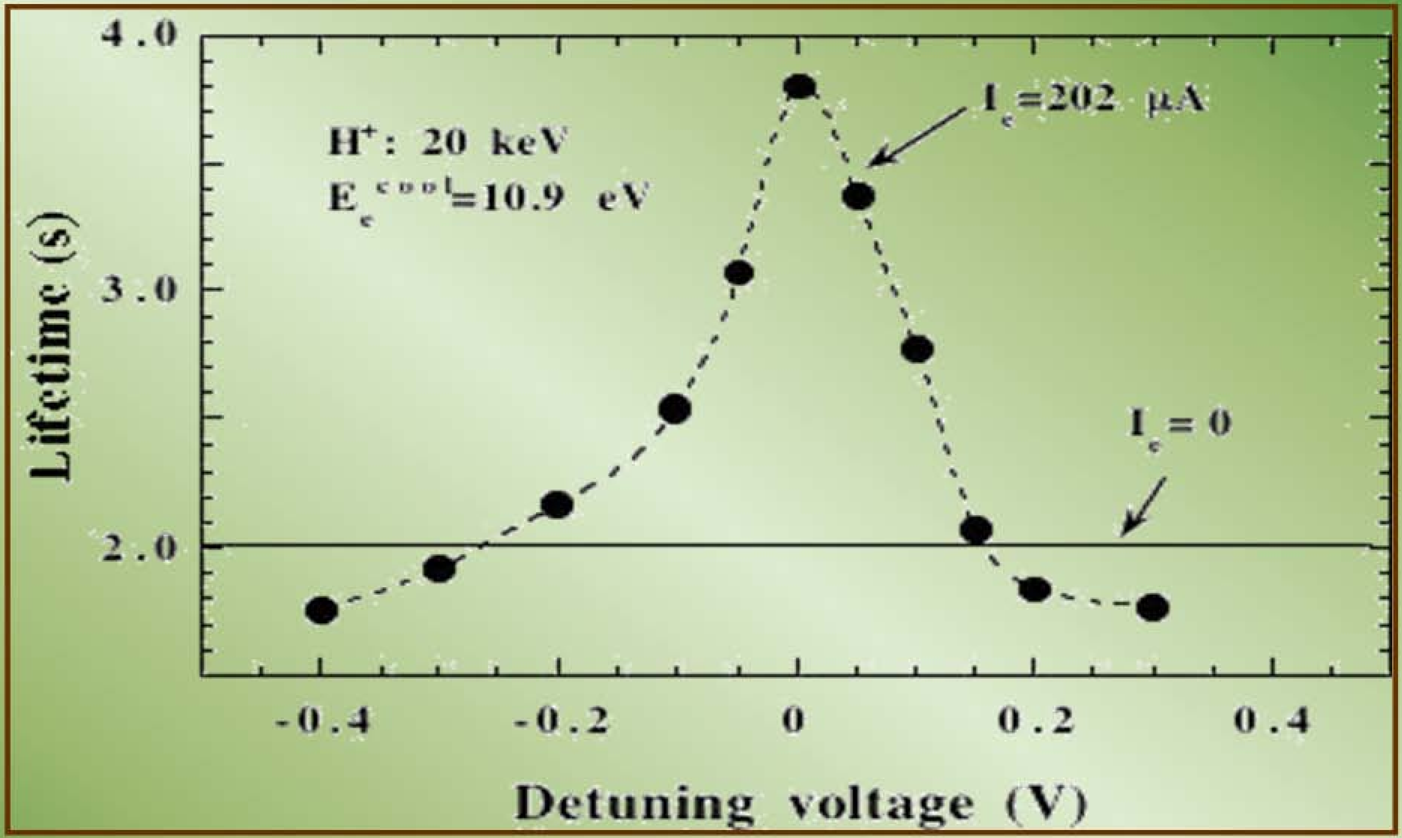
E_e=5,45 eV, V_{cath}=7,8 V, V_0=1,5 V, V_{sp}=0,85 V

Ion-electron collisions



Neutral-particle production rate as a function of the relative energy for singly protonated arginine and bradykinin

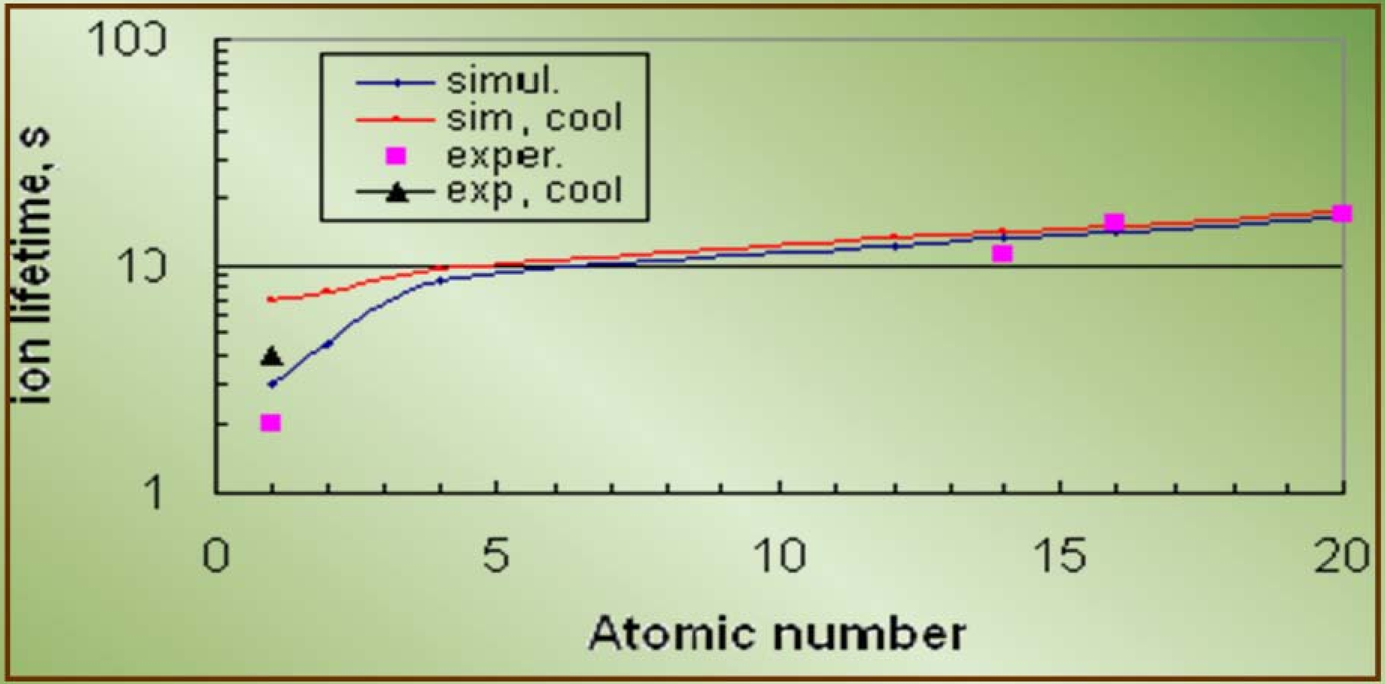
Electron cooling



Lifetimes of 20-keV H^+ beam with and without electron beam as a function of detuning acceleration voltage of electrons. The tuned voltage is 14.5 V.

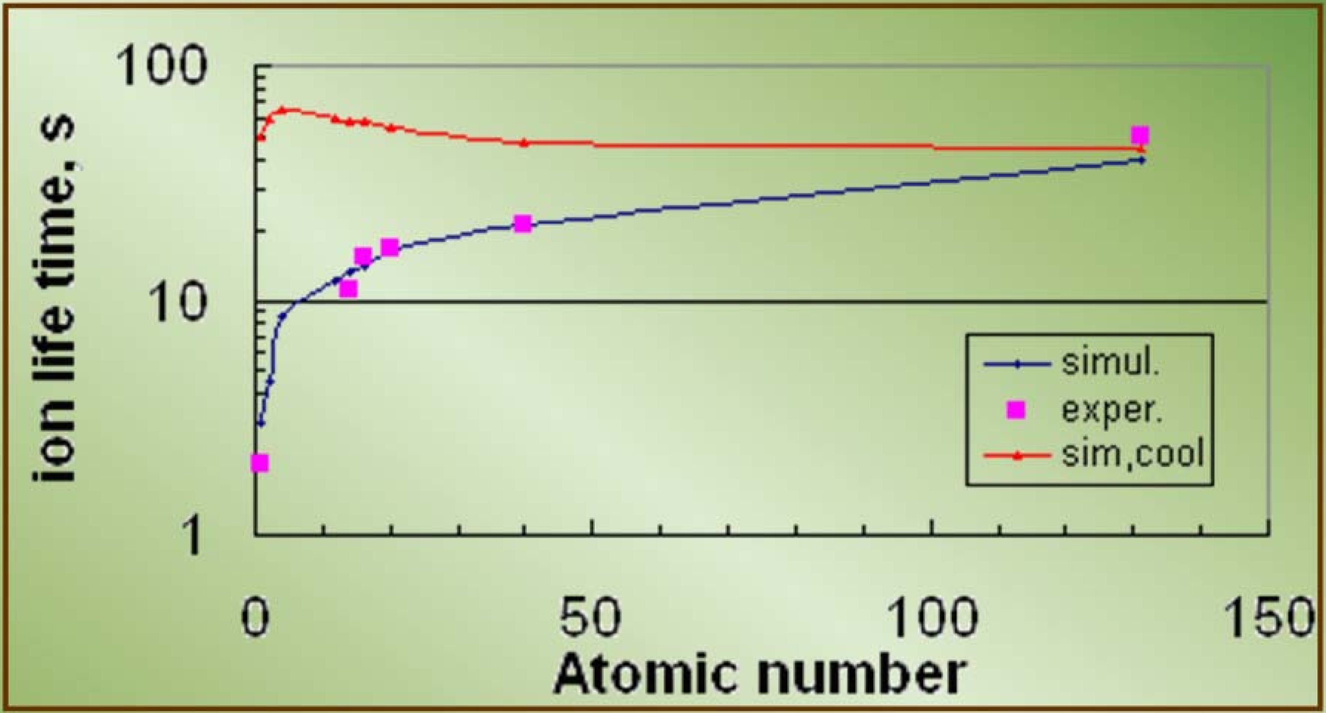
Numerical simulation of electron cooling

Electron gun with cathode diameter of 3.5 mm



Dependence of the ion lifetime on the ion atomic number at $P = 4\cdot10^{-11}$ Torr, E_i=20 keV, $\varepsilon_h/\varepsilon_v$=50/50 π·mm·mrad, L_{ef}=10 cm, R=33, $T_\perp$=3 meV, $T_{//}$=10 meV, r_{cath}=1.75 mm, μP= 5 $\mu A/V^{3/2}$.

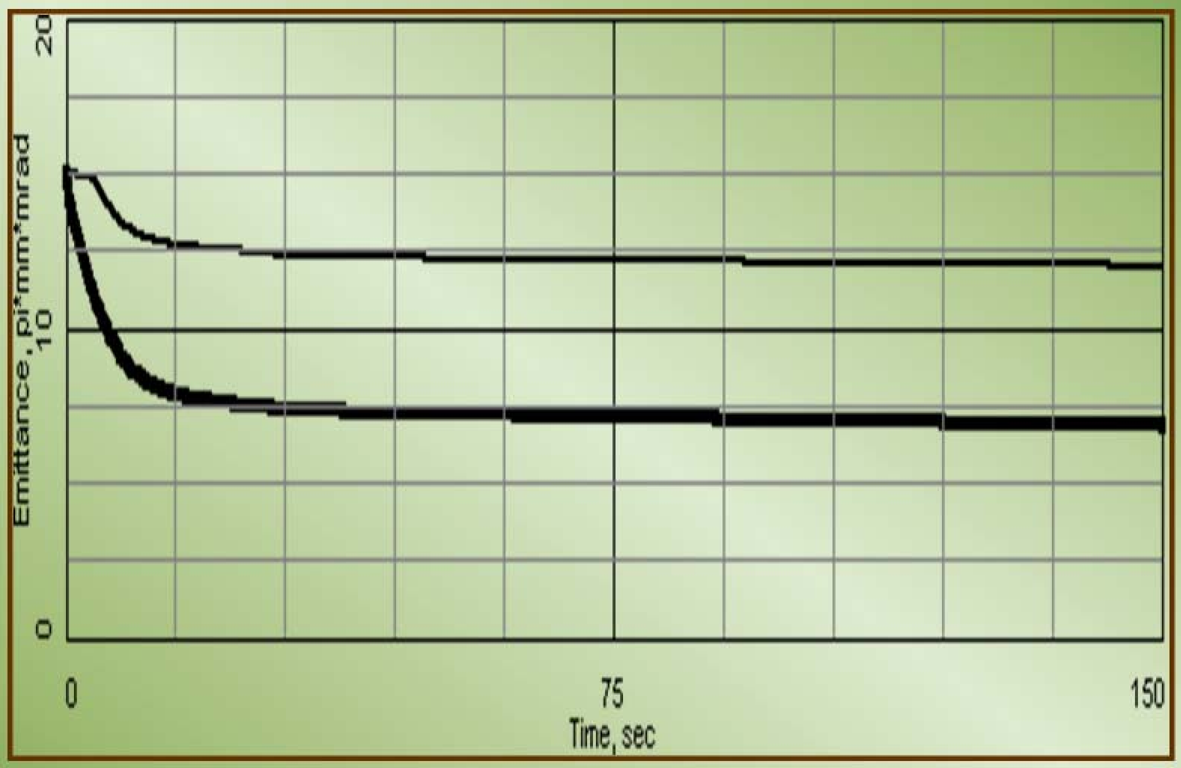
Electron gun with cathode diameter of 1mm



Dependence of the ion lifetime on the ion atomic number at $P = 4 \cdot 10^{-11}$ Torr, E_i=20 keV, $\varepsilon_h/\varepsilon_v$=50/50 π·mm·mrad, L_{ef}=20 cm, R=100, $T_\perp$=1 meV, r_{cath}=0.5 mm, μP= 5 $\mu A/V^{3/2}$.

Compensation of ion multiple scattering on residual gas atoms at electron cooling.

Electron gun with photo emission cathode



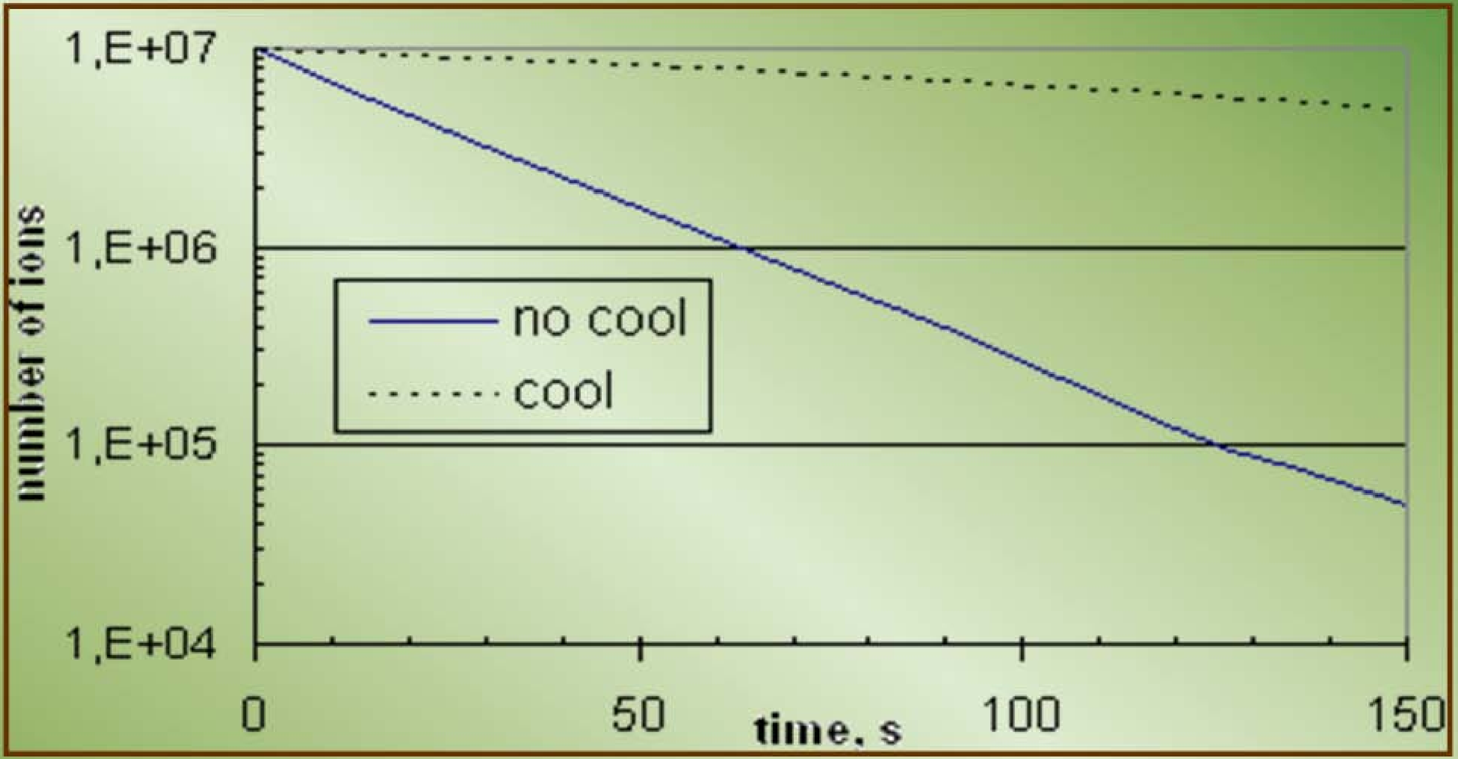
Dependence of ion (A=300, Z=-2) emittance on the time at the cooler parameters:

l_{cool} = 0.2 m, I_e = 100 nA, E_e= 72 meV,

$T_{//}$ = 30 meV, $T_{\perp}$ = 0.1 meV,

r_{cath}=1.5 mm, r_b= 0.5 cm, B_{gun}= 300 G, B_{cool}=30 G.

Simulation of ion lifetime for biomolecular ions



Dependence of the number of ions (A=300, Z= -2) on the time for E =20 keV, P=$5\cdot10^{-11}$ Torr.

Dipole transverse coherent oscillations of cooled ion beam

Electron heating

D. Reistad, ECOOL, 1993

V. Parkhomchuk, D. Pestrikov, ECOOL, 1993

Coherent ion and electron center gravity motion

$$\ddot{z} + i\omega_c \dot{z} + \omega_i^2 z = \omega_i^2 z_e \quad ; \quad \dot{z}_e + i\omega_d z_e = i\omega_d z$$

t=0: $z(0)=z_0,$ $\quad \dot{z}(0) = \dot{z}_0 \;, \quad z_e(0) = \dot{z}_e(0) = 0$

$$X = M_{ring} X_0$$

4×4 transfer matrix

$$M_{ring} = L_{dr} \cdot RT_{wiss} \cdot L_{dr} \cdot M_{sol}^{-1} \cdot M_{cool} \cdot M_{sol}$$

Determinant of cooler matrix

$$|\mathrm{Mcool}| \neq 1$$

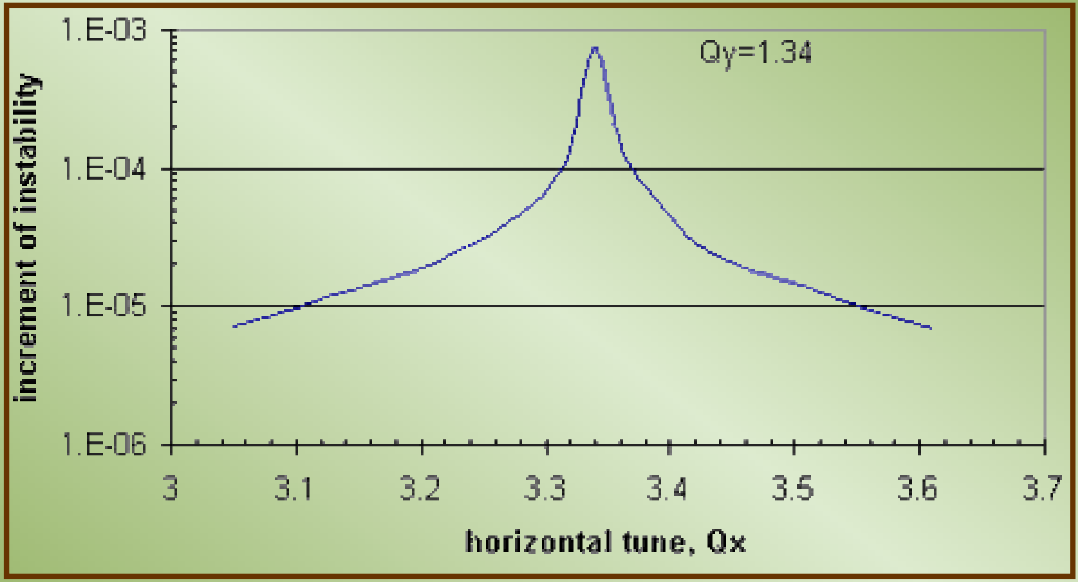
$$\Delta\lambda_{1,2,3,4} \equiv \left|\lambda_{1,2,3,4}\right| - 1 \neq 0$$

Simulations of transverse coherent oscillations

V. Parkhomchuk, V. Reva, 2000

$$Q_x - Q_y = n$$

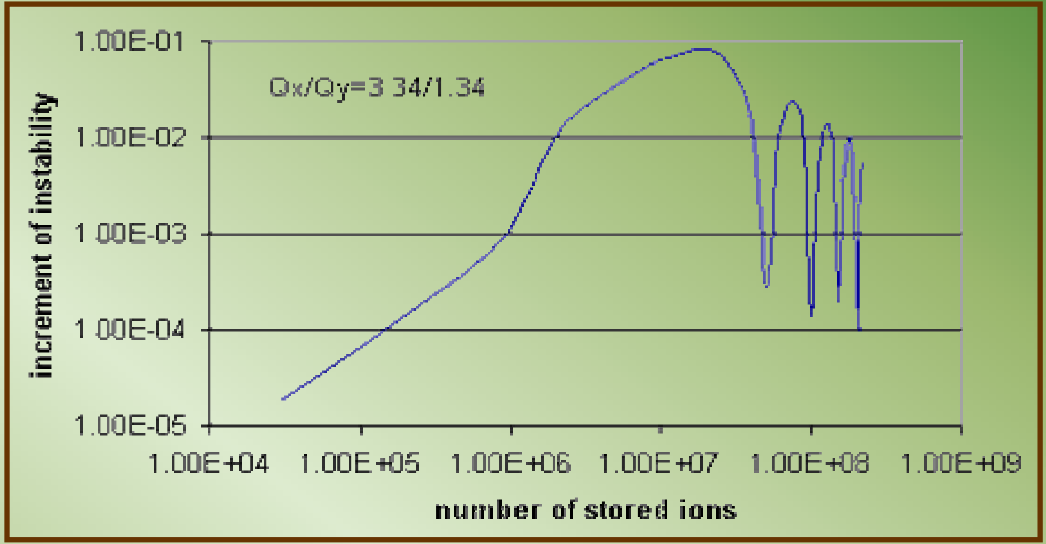
$$\gamma_{ins} = \frac{2\pi^2 n_e n_i \beta_{x,y} r_e r_i \ L^2}{\beta^3} \frac{c}{\omega_{ci}}$$



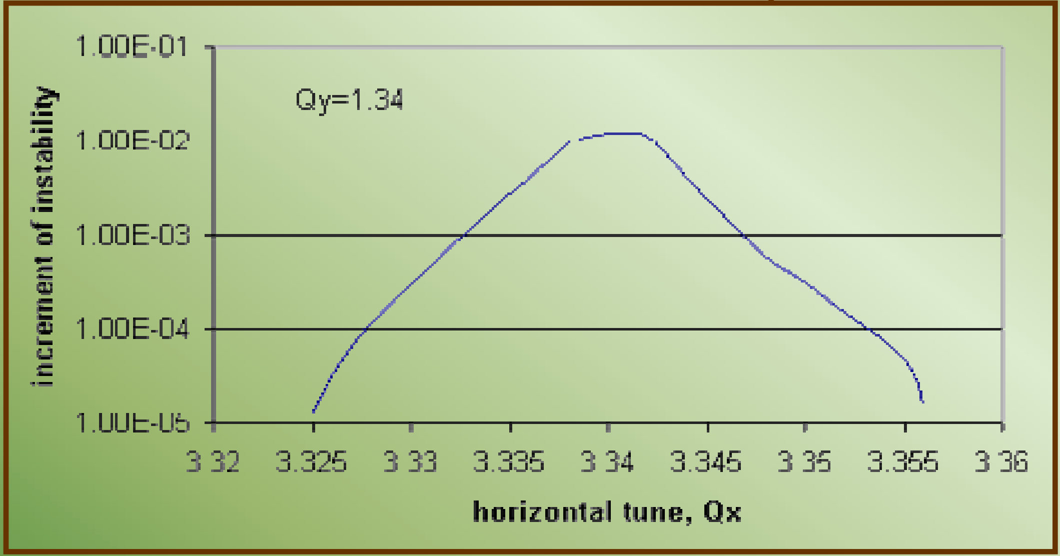
Dependence of the increment on the horizontal tune at Qy=1.34, I=0.1 mA, B=30 G, H_2^+ - ion, N_i =10^7ppp and FWHM = 6 mm.

Ion lifetime reduction during KEK cooling experiments at detuning of acceleration voltage.

Simulation of transverse coherent oscillations



Dependence of increment of instability on number of stored ions.
I_e=0.5 mA, E_e =40 eV, B=30 G, Z=4, A=1200, $N_i=10^7$ ppp, FWHM=6 mm.



Dependence of the increment of instability on the horizontal tune at Q_y=1.34, I_e=0.1 mA, E_e =40 eV, B=30 G, Z=4, A=1200, $N_i=10^7$ ppp, FWHM=6 mm.

Conclusion

- The KEK electrostatic storage ring with merging electron beam is effectively used for studying atomic collisions.
- Electron cooling compensates multiple scattering of ions on residual gas atoms.
- Dipole transverse coherent oscillations of high intensive cooled ion beam produce an ion lifetime reduction at an ion interaction with electron target.