Trapping of Electron Cloud in CESRTA/ILC Quadrupole and Sextupole Magnets

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Acknowledgements

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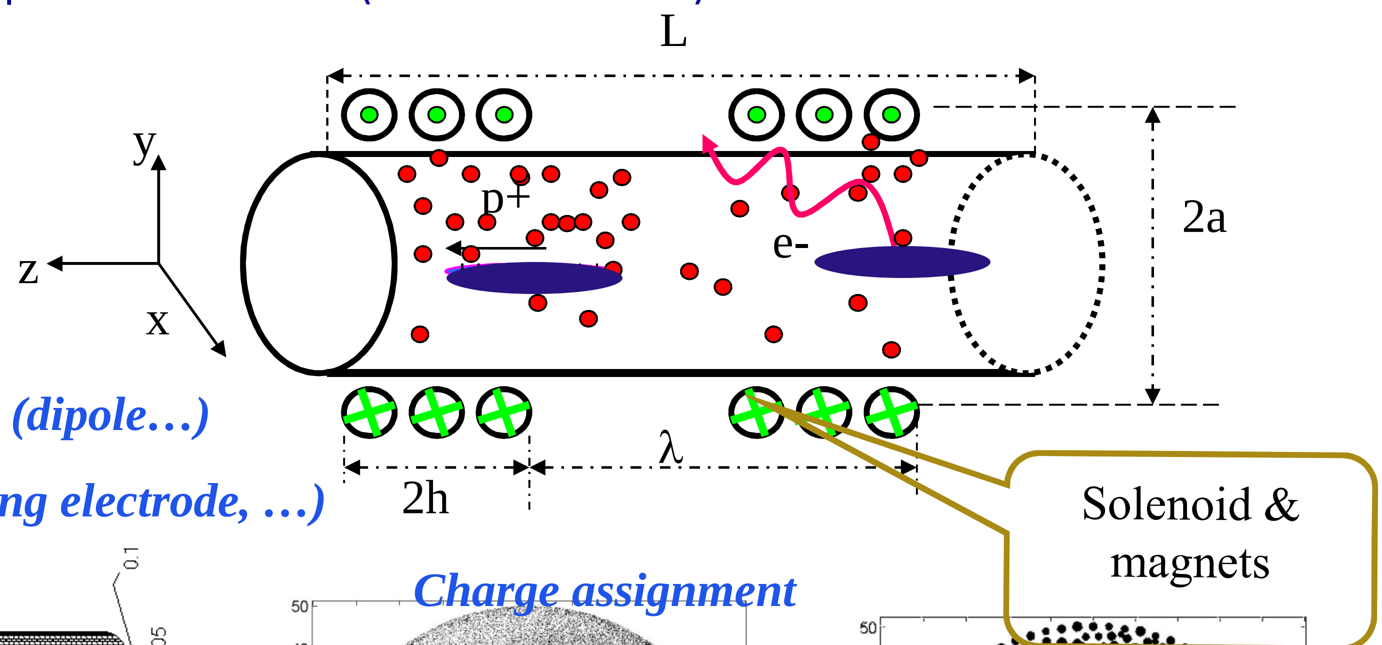
Outline

- Introduction
- Mechanism of electron trapping in a Quadrupole and Sextupole
- Electron cloud in CESRTA Quadrupole
- Electron Cloud in ILC Quadpole and Sextupole
- Summary

3D PIC Program--- CLOUDLAND

CLOUDLAND is a complete 3D PIC code (*PRST-AB 124402*)

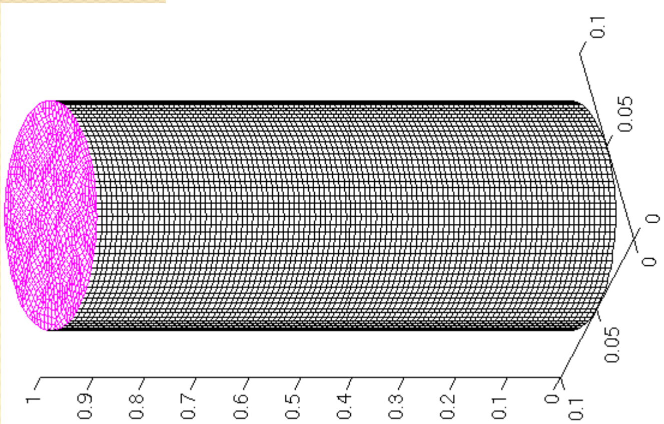
Program model



- PIC methods

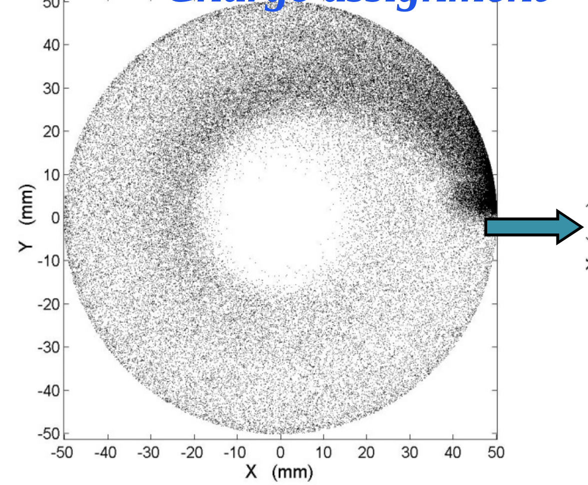
Various magnetic field (dipole…)

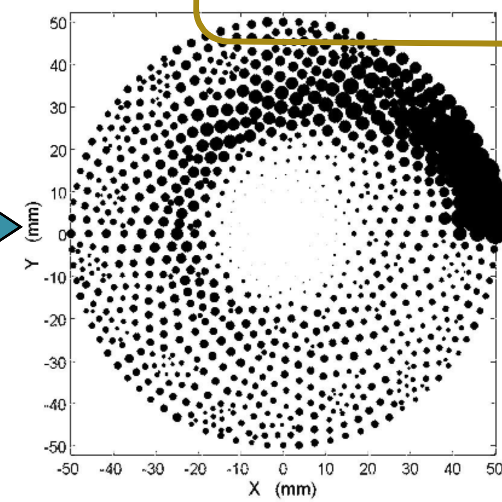
& Electric field (clearing electrode, …)



Mesh of chamber

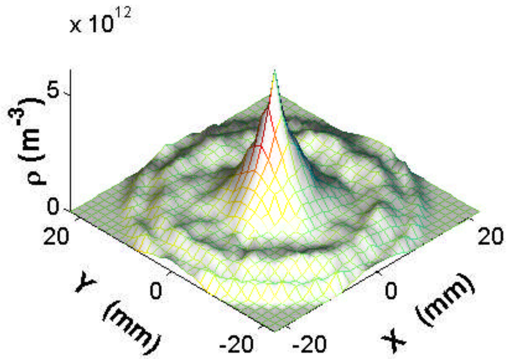
Charge assignment

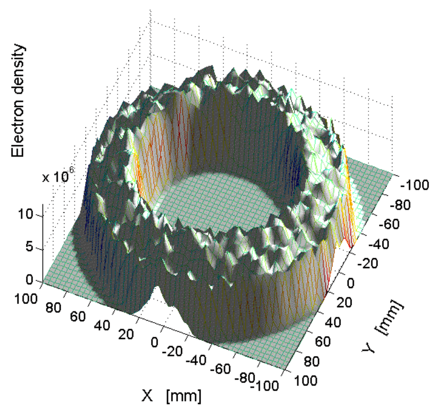


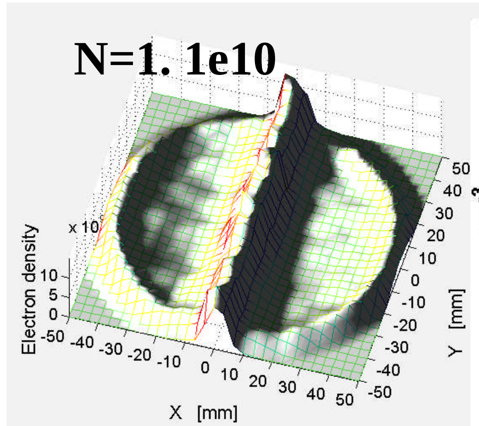


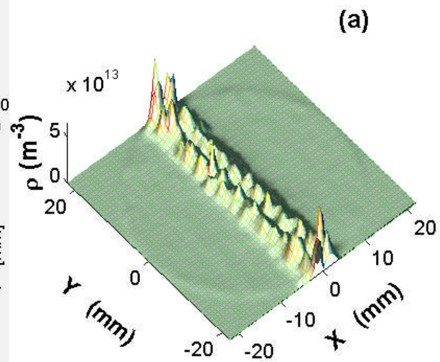
Real charge distribution ***Meshed Charge distribution***

Examples of e-cloud distribution in different magnets

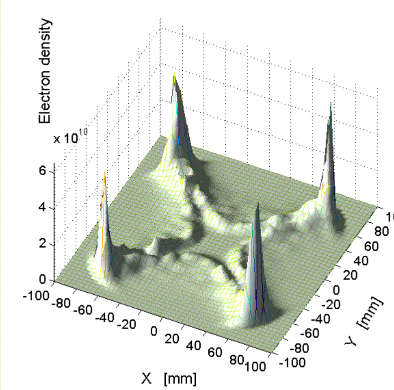




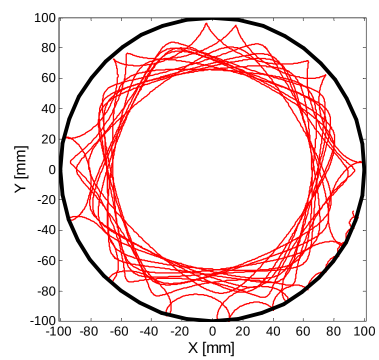




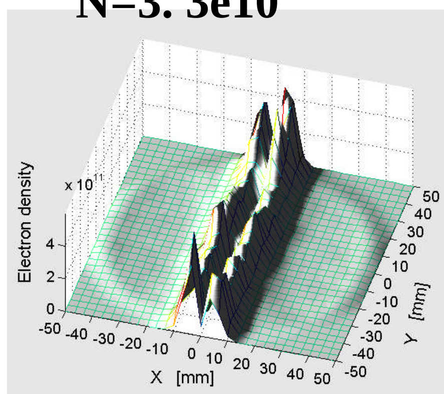
Field free region



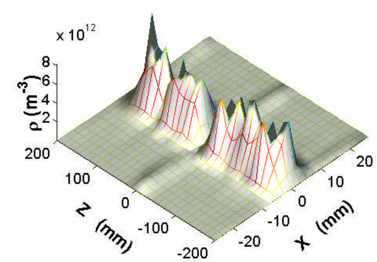
Quadrupole



Drift+Solenoid



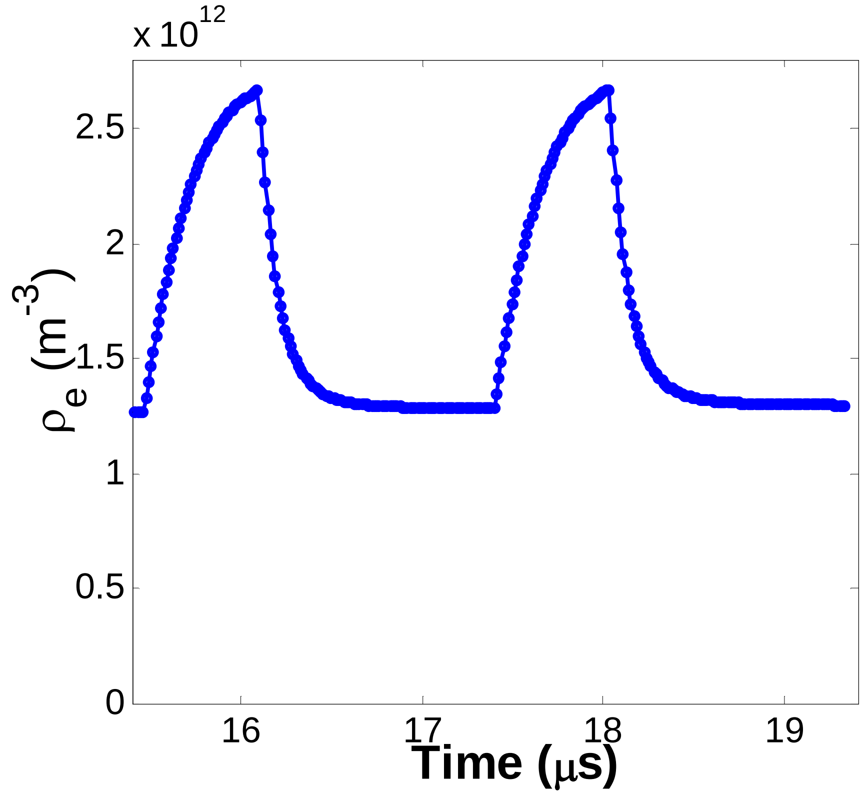
Dipole magnet



Wiggler magnet

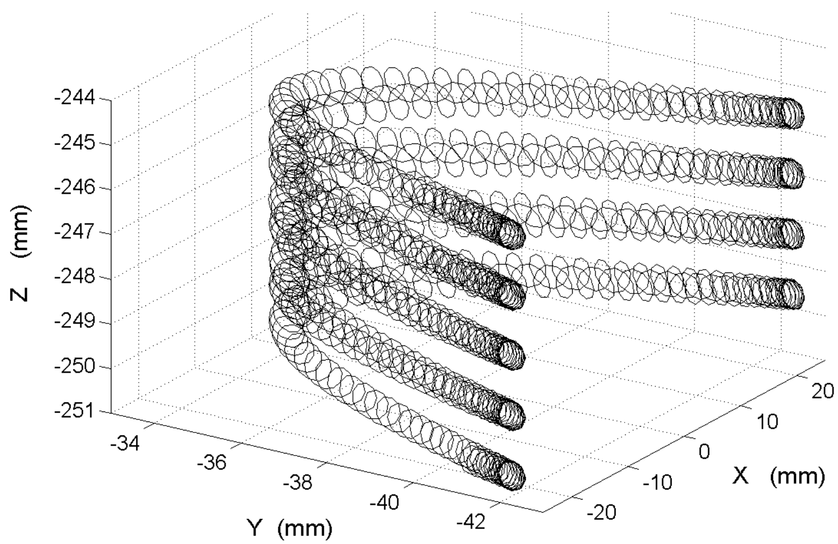
Electron in CESRTA Quadrupole (simulation)

- It happens in quadrupole, sextupole, octutpole… magnets
- The electrons has long decay time and can survive a long bunch train gap

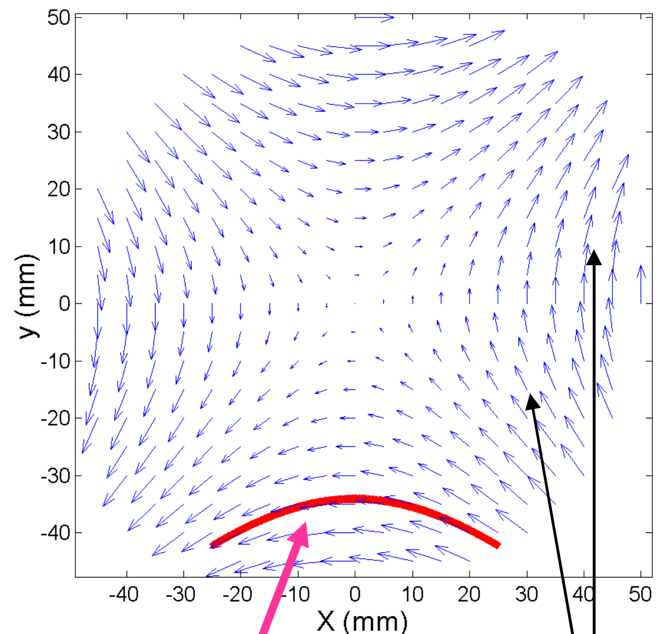


Electron cloud density evolution in CESRTA Quadrupole

Trapping phenomenon---in quadrupole magnet



3D orbit



2D orbit

Field lines

Orbit of a trapped photoelectron in normal quadrupole magnet during the train gap (field gradient=0.5T/m)

Trapping mechanism (I) – Mirror field trap

- The motion of the electron in magnetic field can be regarded as the superposition of the gyration motion around the guide center and the motion of the guide center.

Adiabatic invariant

For periodic motion

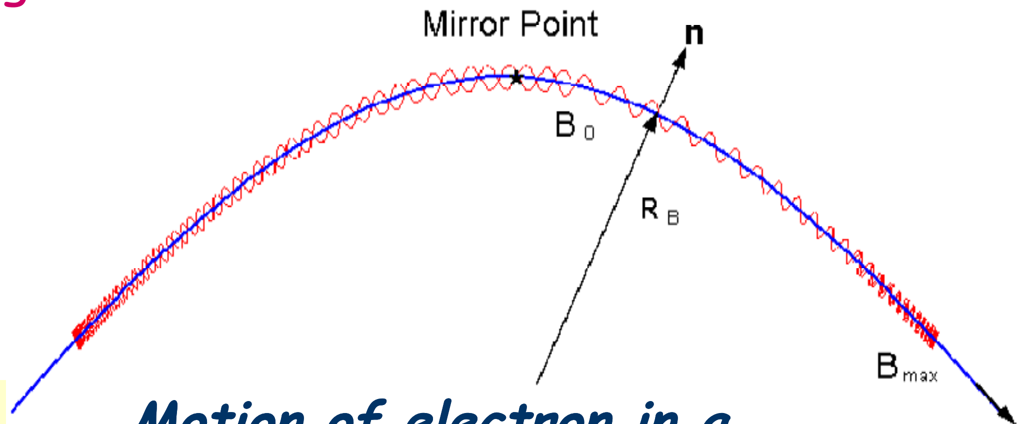
$$J = \oint pdq = cons\tan t$$

Field changes slowly

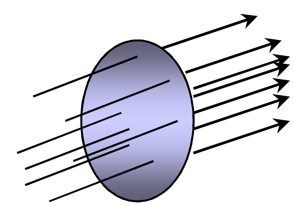
$$J_{\perp} = \oint m\upsilon_{\perp}\rho_s d\varphi = \frac{4\pi m}{e}\mu_m$$

$$J_{\parallel} = \oint m\upsilon_{\parallel} dl$$

$$\mu_m = \frac{m\upsilon_{\perp}^2}{2B}$$ is the magnetic moment



Motion of electron in a mirror magnetic field



$\upsilon_{\perp}$ $\upsilon_{\parallel}$ the gyration and parallel velocity

ρ_s the Larmor radius

Trapping mechanism (II) – Beam induced trapping

Invariant value of motion

$$W = \frac{m\upsilon^2}{2} = \frac{m\upsilon_{\parallel}^2}{2} + \frac{m\upsilon_{\perp}^2}{2} = constant$$

$$\frac{1}{2} m\upsilon_{\parallel}^2 + \mu_m B = const$$

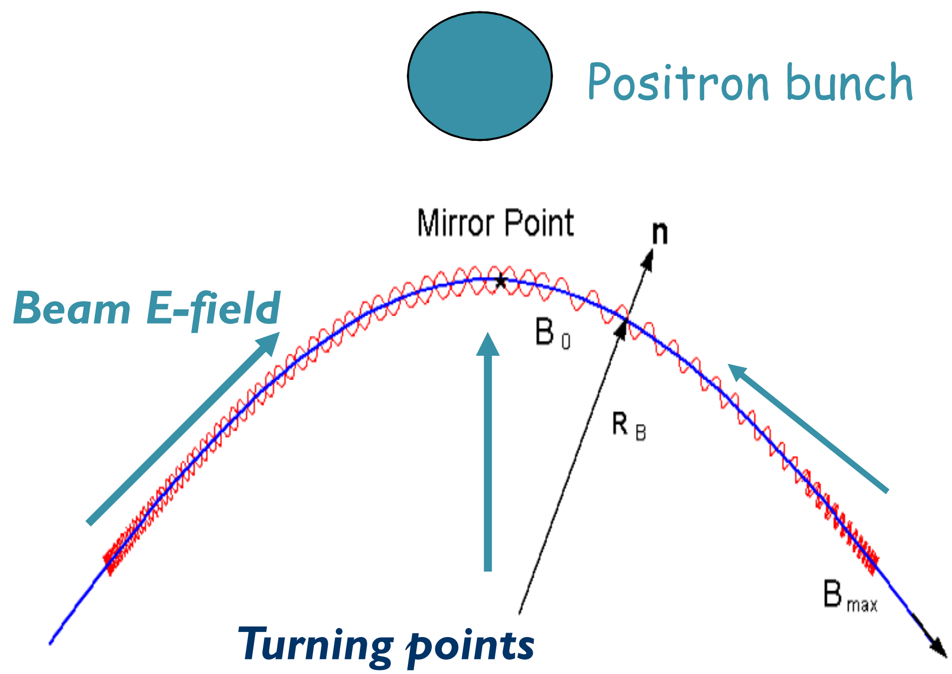
⇒ Reflective Points: $\nu_{\parallel}=0$

Trapping condition

$$\Gamma_{trap} > 1$$

$$\Gamma_{trap} = \frac{F_{\upsilon}}{F_B} = \frac{\upsilon_{\perp 0}^2}{\upsilon_{\perp 0}^2 + \upsilon_{\parallel 0}^2} \frac{B_{max}}{B_0}$$

Trap factor is constant if no other force (except B force) disturbs the electron and smaller than 1.0, no trapping



mirror field trapping

$$\Gamma_{trap} = \left.\frac{\upsilon_{\perp 0}^2}{\upsilon_{\perp 0}^2 + \upsilon_{\parallel 0}^2}\right|_{at\ the\ emission\ point} = constant \le 1$$

Orbit of the Guiding Center---Longitudinal Motion

- **Longitudinal Velocity of the Guiding Center (Beam direction)**

  - **Magnetic gradient drift**

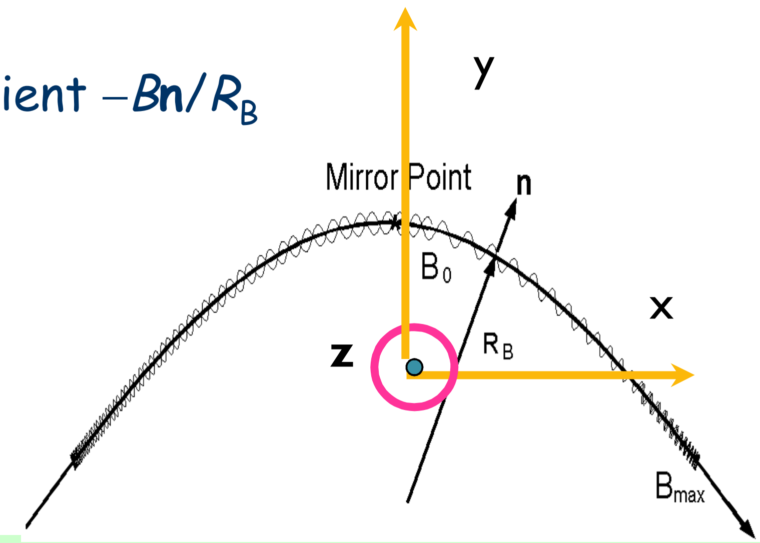
$$\bar{\mathbf{v}}_{grad} = \frac{m v_\perp^2}{2eB^3} \mathbf{B} \times \nabla \mathbf{B}$$ With normal gradient $-B\mathbf{n}/R_B$

  - **Centrifugal force drift**

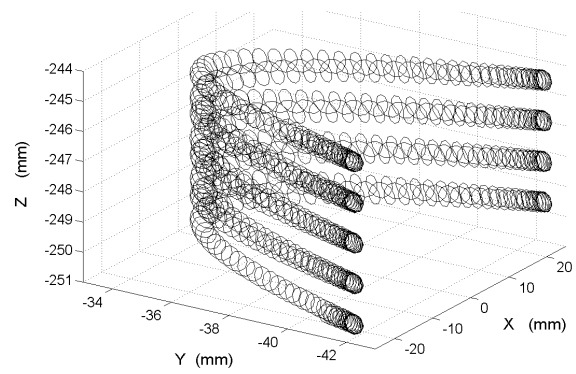
$$\mathbf{F}_c = \frac{m v_\parallel^2 \mathbf{R_B}}{R_B^2} = \frac{m v_\parallel^2}{R_B} \mathbf{n}$$

$$\bar{\mathbf{v}}_F = \frac{\mathbf{F} \times \mathbf{B}}{eB^2} = \frac{\mathbf{n}}{B\Omega_s} \times \frac{\mathbf{B}}{R_B} v_\parallel^2$$

  - **Beam Effect (EXB drift)**



Example: one electron in Quadrupole:

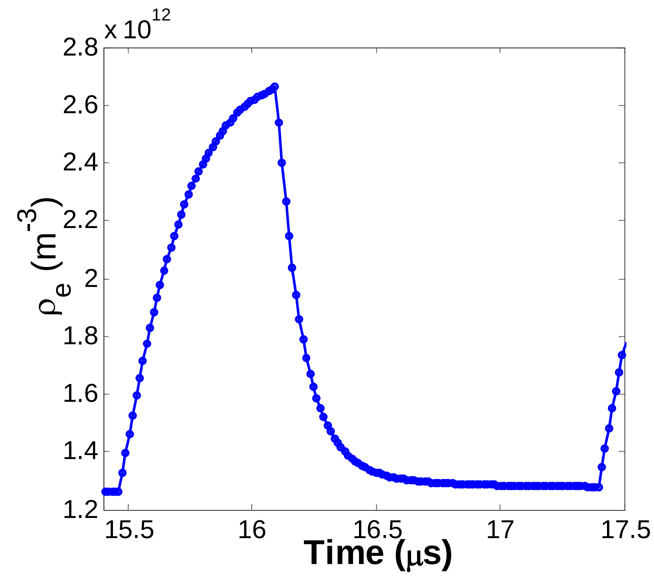


E-cloud in the Quadrupole of **CESRTA**

Slow Build-up

- ➢**Slow build-up:**

  up to 10 turns to reach saturation
- ➢**Slow decay during the long train gap**
- ➢ **Trapped electrons (~50%) survive from the long gap (1.9μs)**



Parameters used for simulation:

Bunch length 15 mm

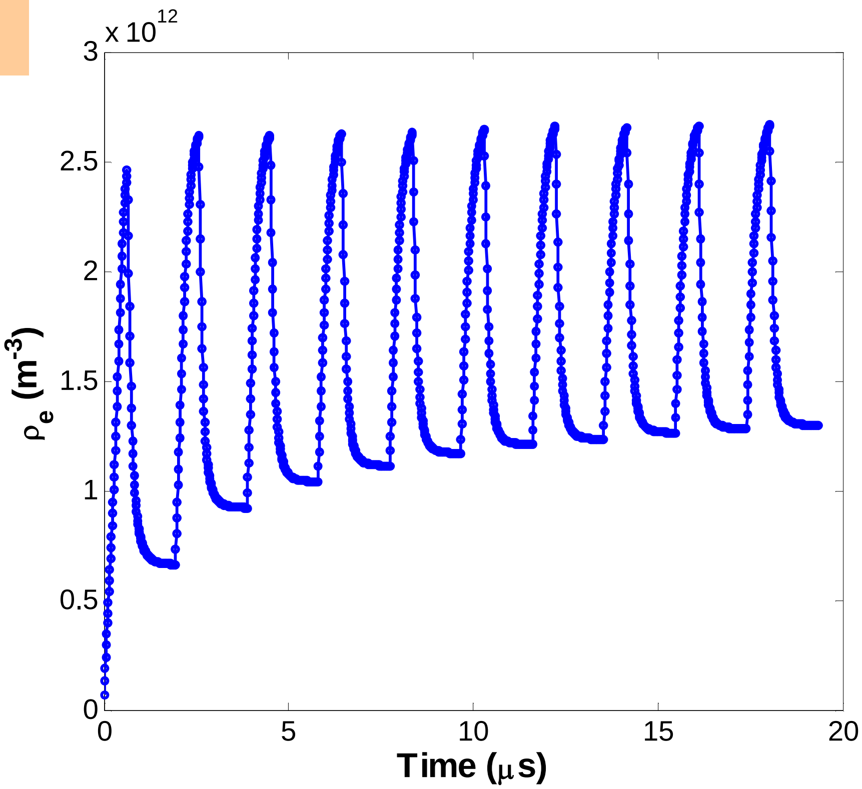
Bunch current 1.3 *mA*

Bunch spacing 14 *ns*

Field gradient 0.517 *T/m*

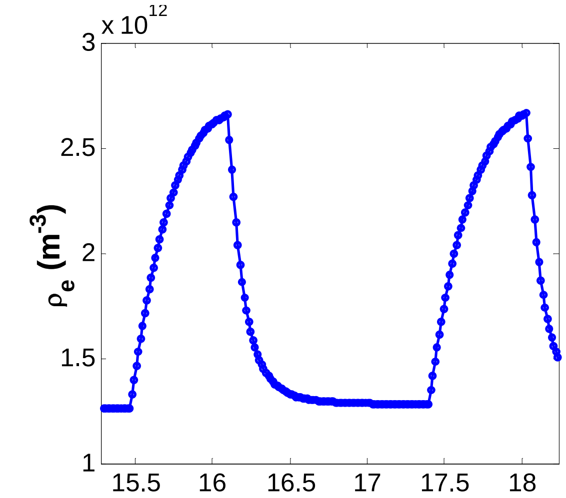
Peak SEY 2.0

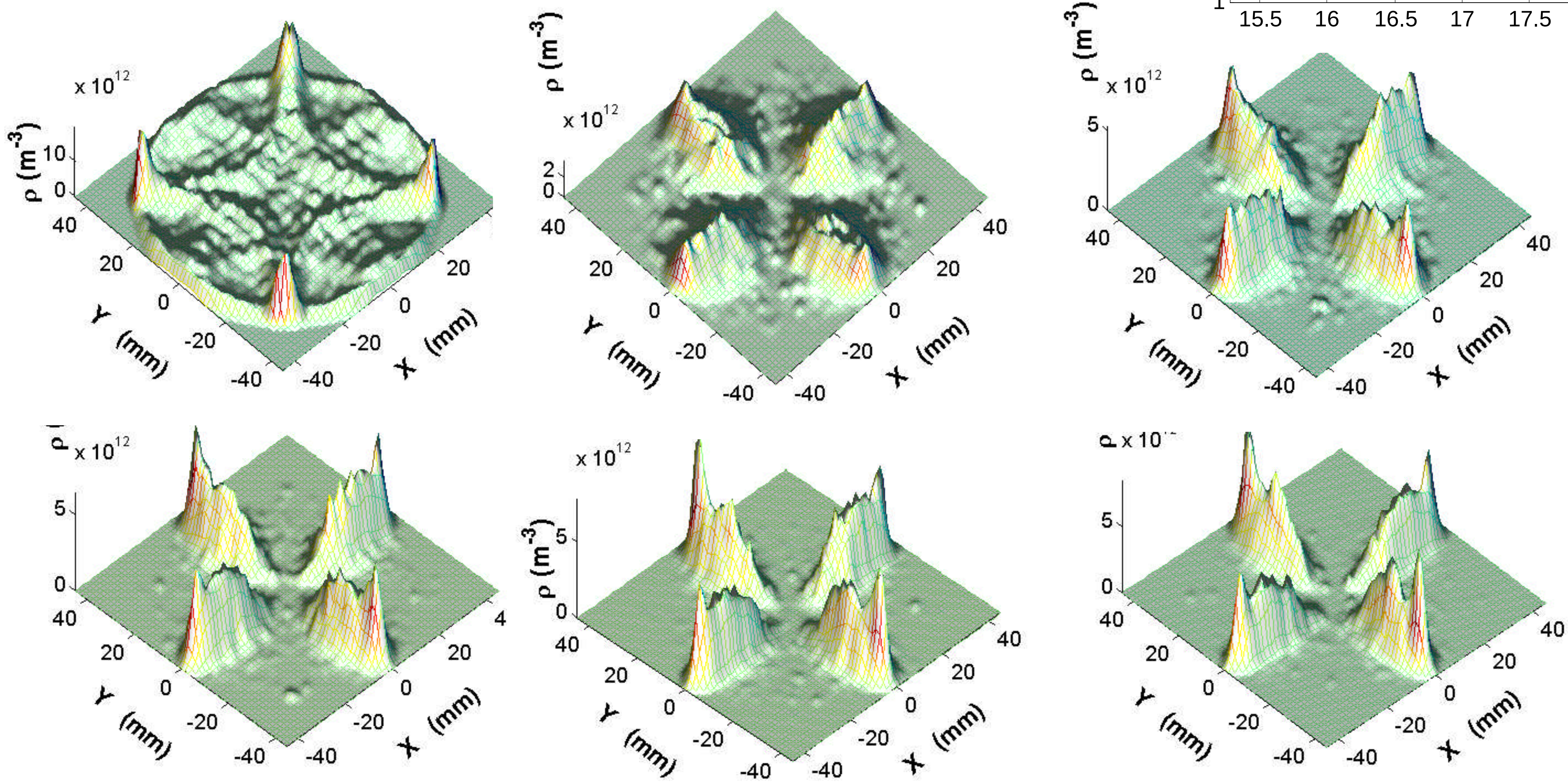
Energy at peak SEY 276 *eV*



Ecloud build-up in CESRTA Quadrupole

Evolution of electron cloud during the train gap, frames separated by Δt=70 *ns*

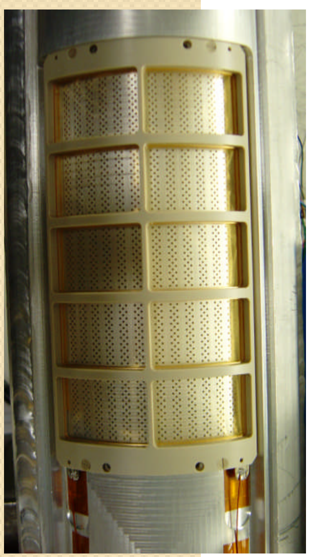


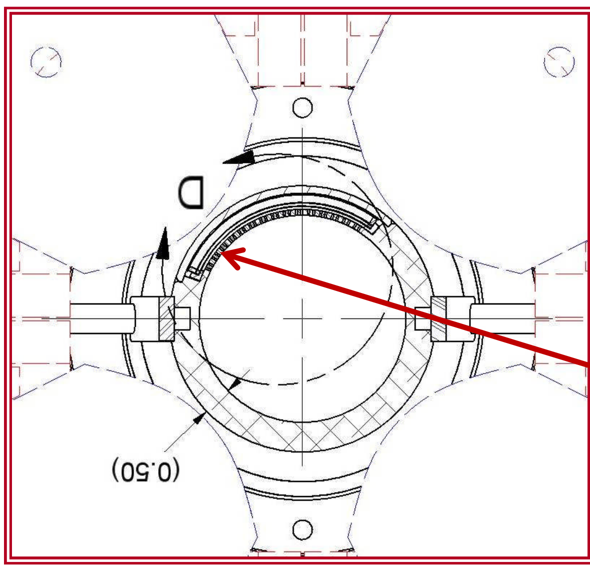


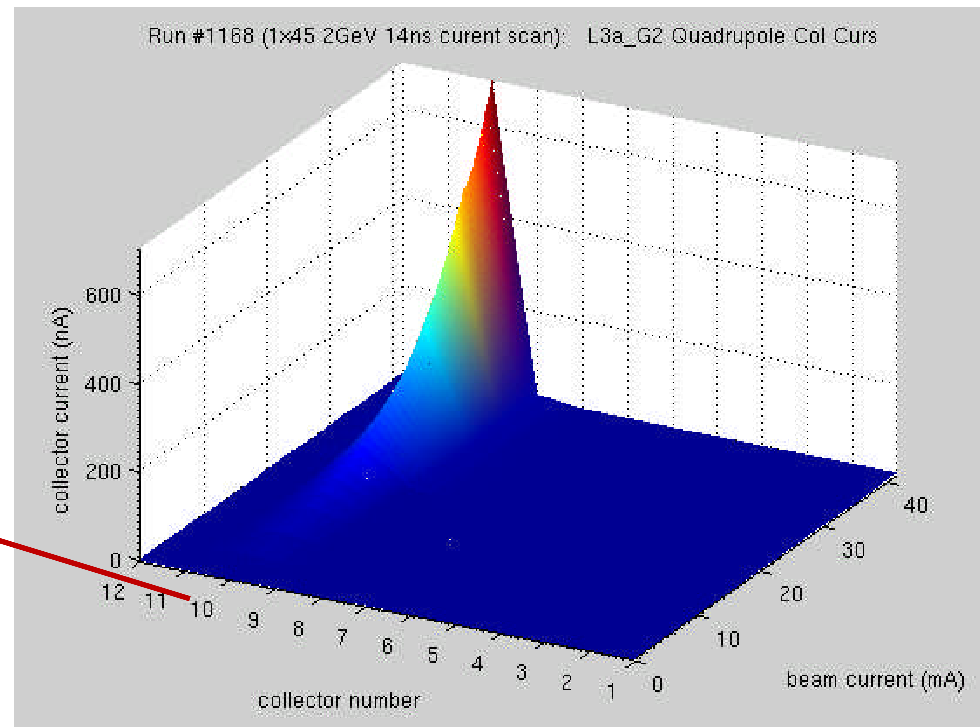
Evolution of e-cloud during the train gap, Δt=70ns

RFA in CESRTA Quadrupole

- **(see de tail @Joseph Calvey's talk,** 8/9/2010**)**

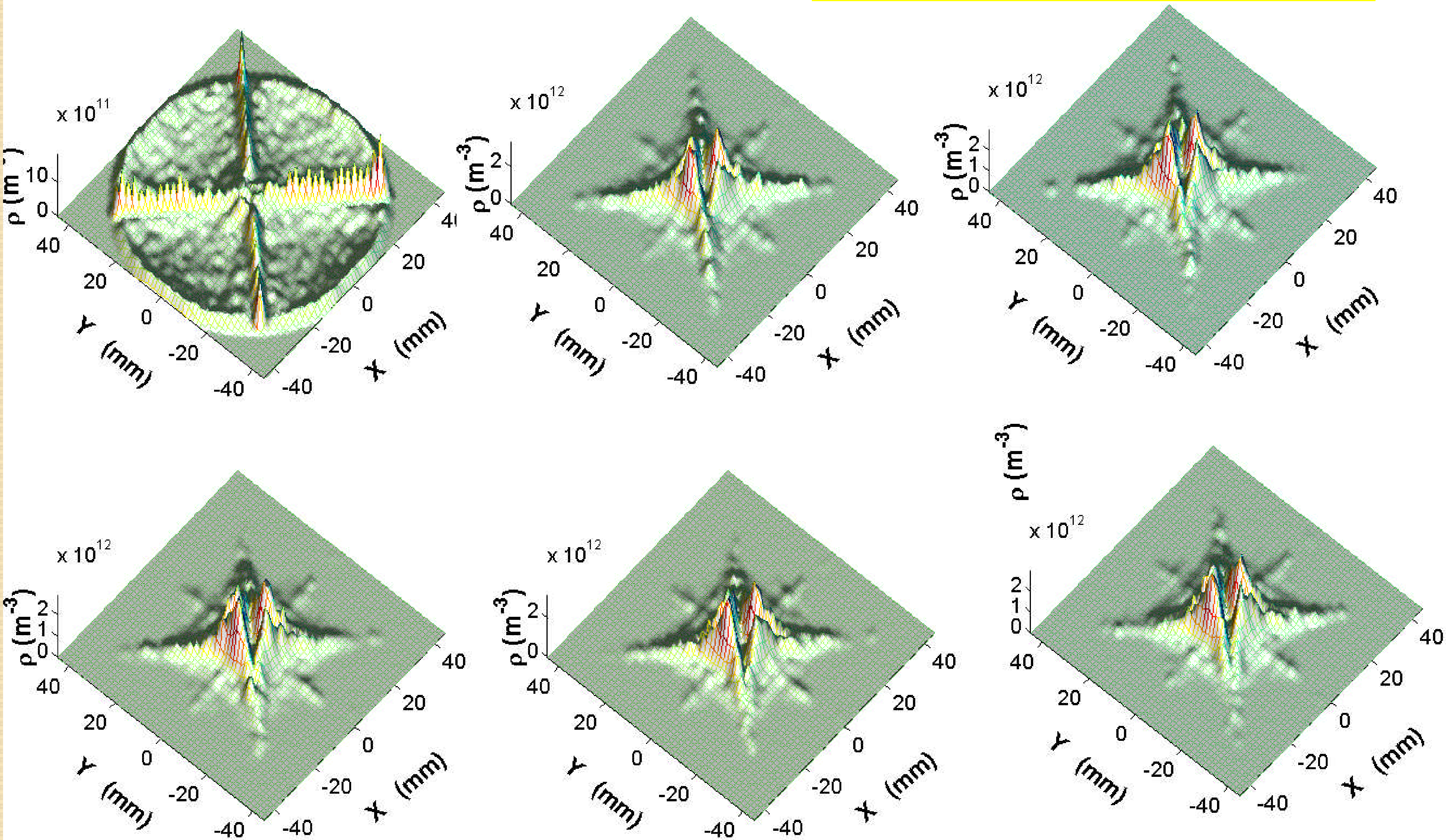






Evolution of electron cloud (example II)

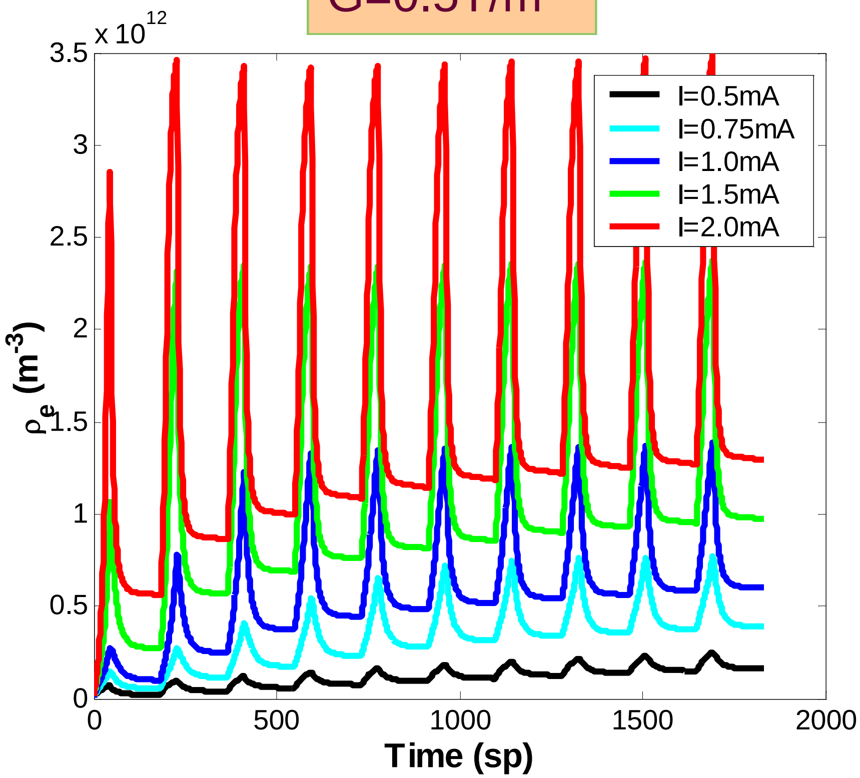
Parameters
Bunch length 17.24 *mm*
Bunch current 1.0 *mA*
Bunch spacing 14 *ns*



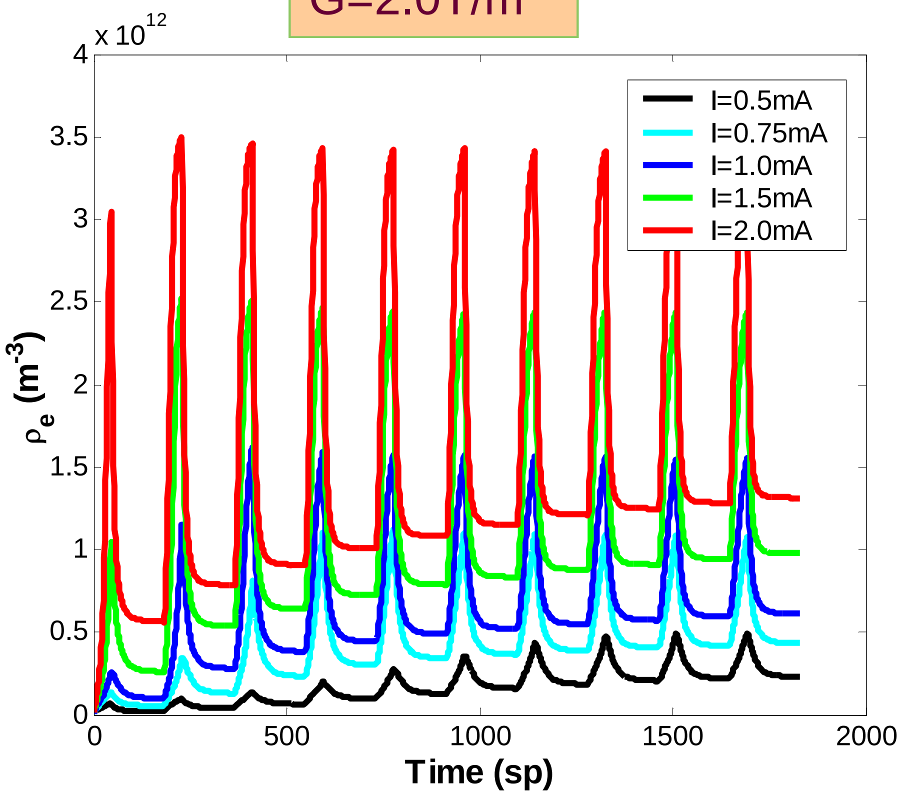
Beam current dependence

- ❑ There is a larger electron density for high bunch current (strong dependence)
- ❑ About 30~60% electrons can survive the long gap (1.9 μs)
- ❑ There is a larger electron density for a higher magnetic field (weak dependence)

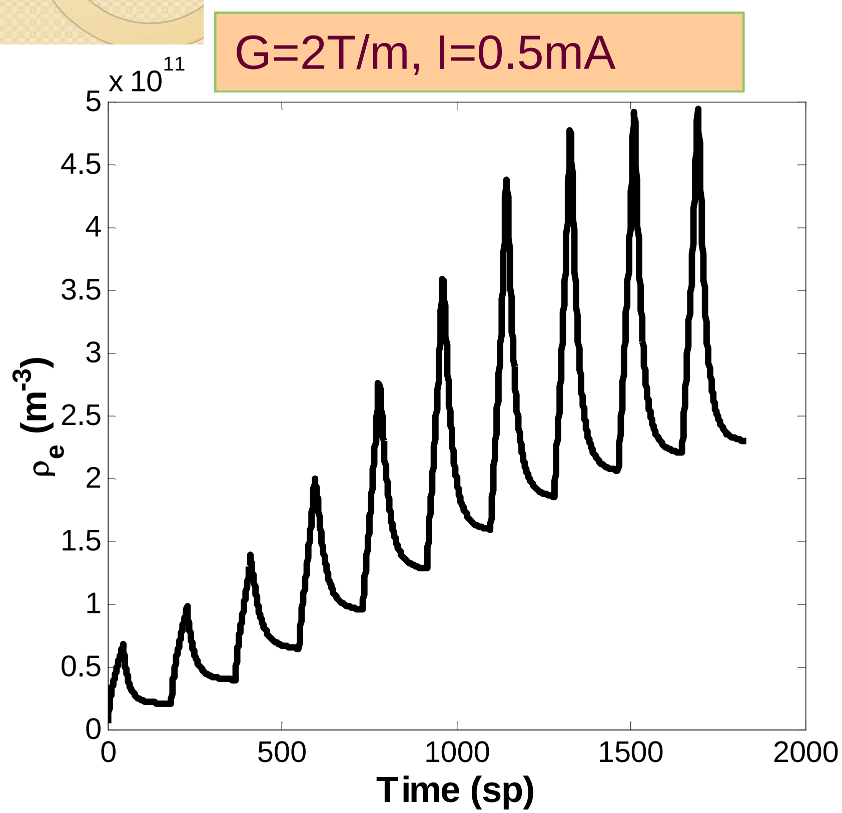
G=0.5T/m

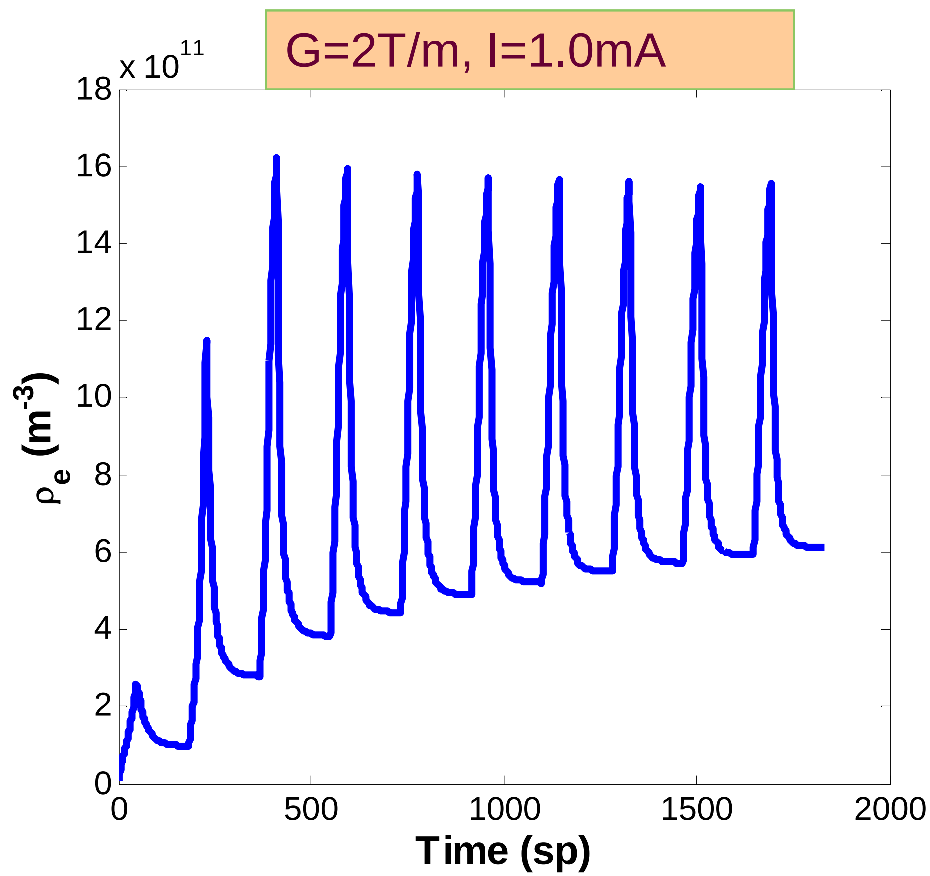


G=2.0T/m



Slow build-up

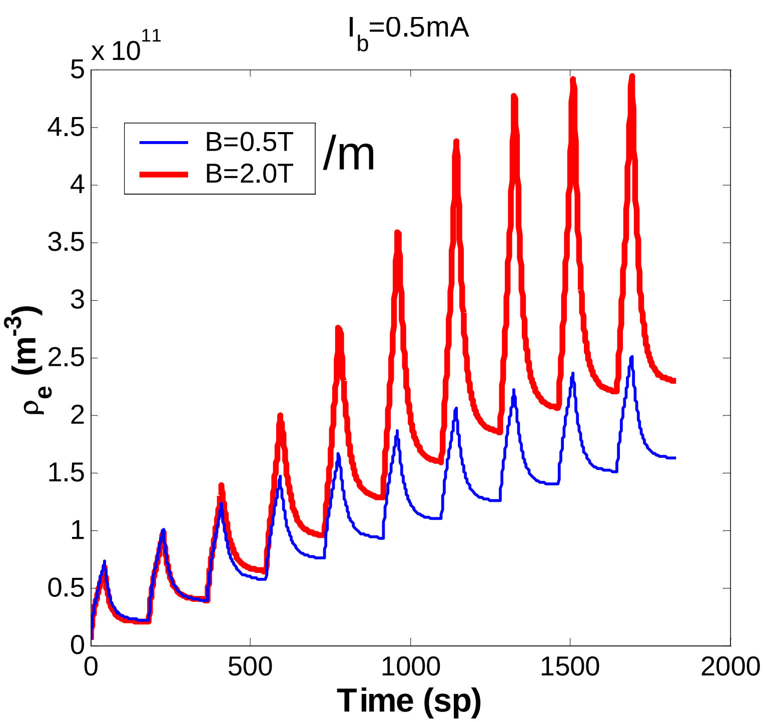


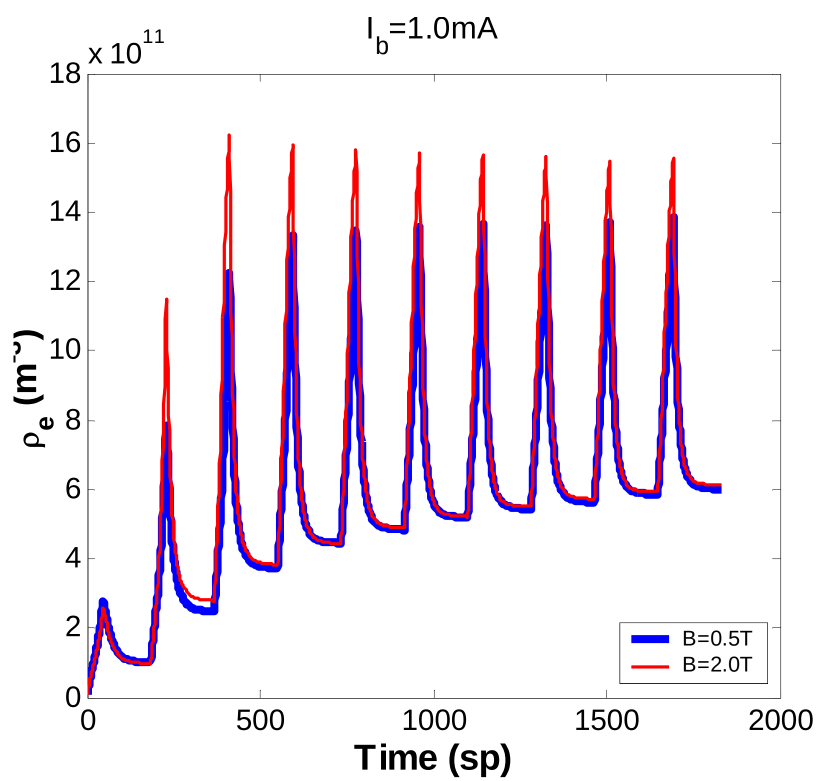


Ecloud build-up with different bunch current (left: 0.5mA),(right:1.0mA)

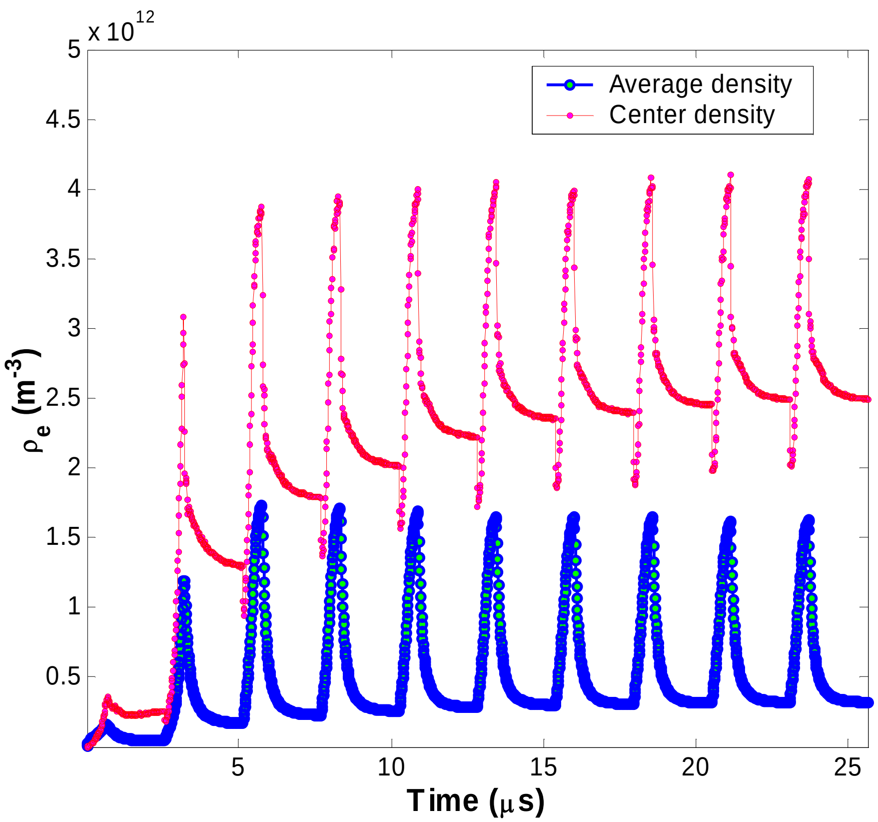
a larger electron density for a high magnetic field (sensitive to beam current)

- ❑**More electrons (in percentage) can be trapped in a weak field**

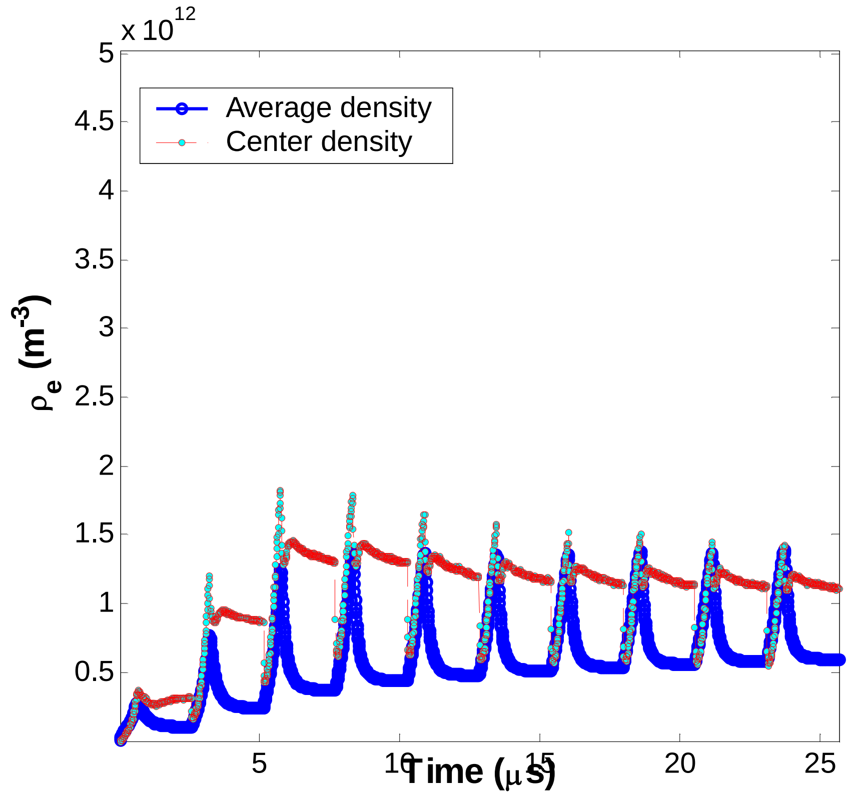




Magnetic field effect



large field gradient g=9.2T/m



Lower field gradient g=0.5T/m

ECLOUD IN THE ILC QUADRUPOLE & SEXTUPOLE

Photon parameters

- Average number of photons emitted per unit length per beam particle in the ARCS are:
  - 0.47 photons/meter/e+ in the ARCS of 3.2 km ring
- Photoelectric yield: 0.1

Build Up Input Parameters for CLOUDLAND

ilc-DR 3.2 Km, 3/6 ns bunch spacing*.

Bunch population	N_b	2.1×10^{10}
Number of bunches	N_b	45 per train
Bunch gap	$Ngap$	15 bunches
Bunch spacing	$L_{sep} [m]$	0.9
Bunch length	$\sigma_z \, [mm]$	6
Bunch horizontal size	$\sigma_x \, [mm]$	0.270
Bunch vertical size	$\sigma_y \, [mm]$	0.005
Photoelectron Yield	Y	0.1
Photon rate (e^-/e^+/m)	dn_γ/ds	0. 47
Antechamber protection	η	0%, 90%, 98%
Photon Reflectivity	R	20%
Max. Secondary Emission Yeld	δ_{max}	0.9~1.4
Energy at Max. SEY	$E_m \, [eV]$	300
SEY model	Cimino-Collins $(\delta(0)=0.5)$	

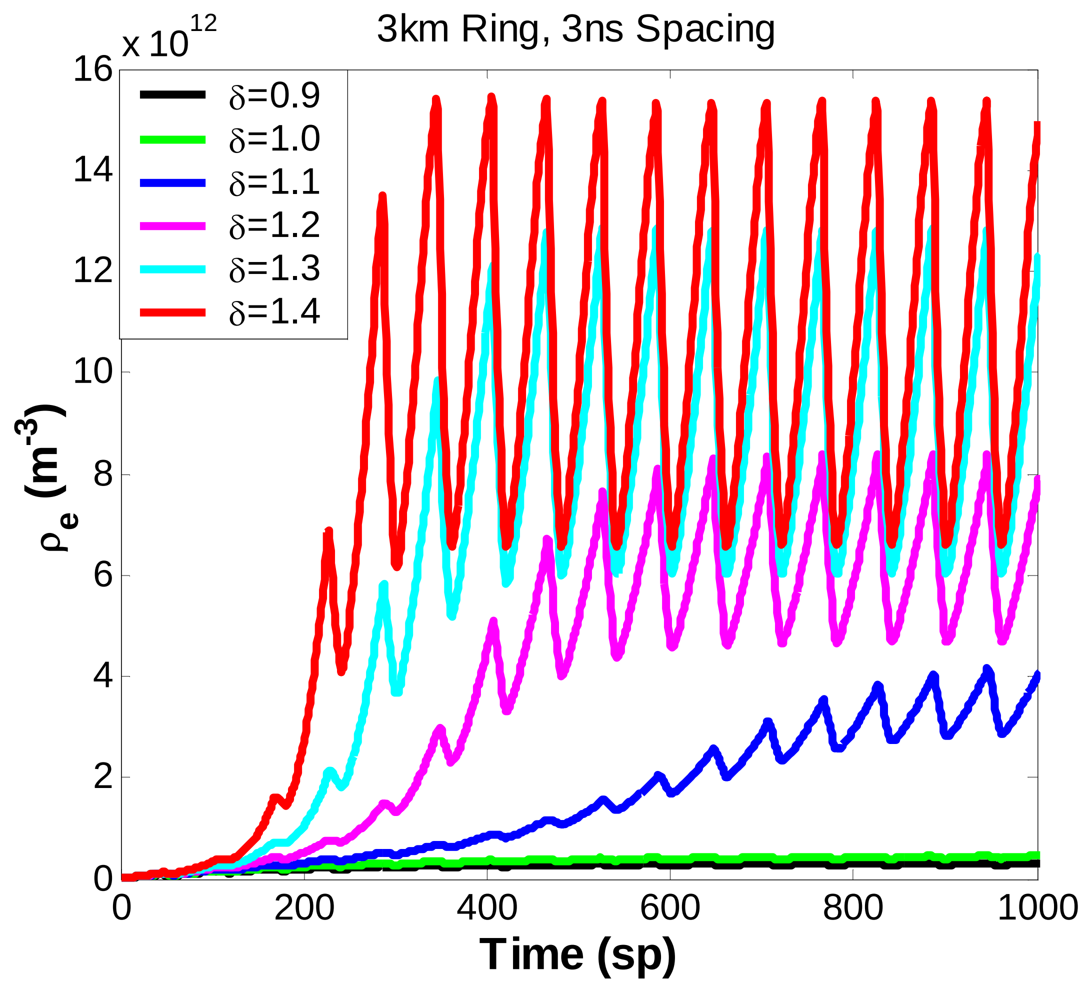
*https://wiki.lepp.cornell.edu/ilc/pub/Public/DampingRings/WebHome/DampingRingsFillPatterns.xls

Example:

ILC Quadrupole

Antechamber protection =98%

Average density

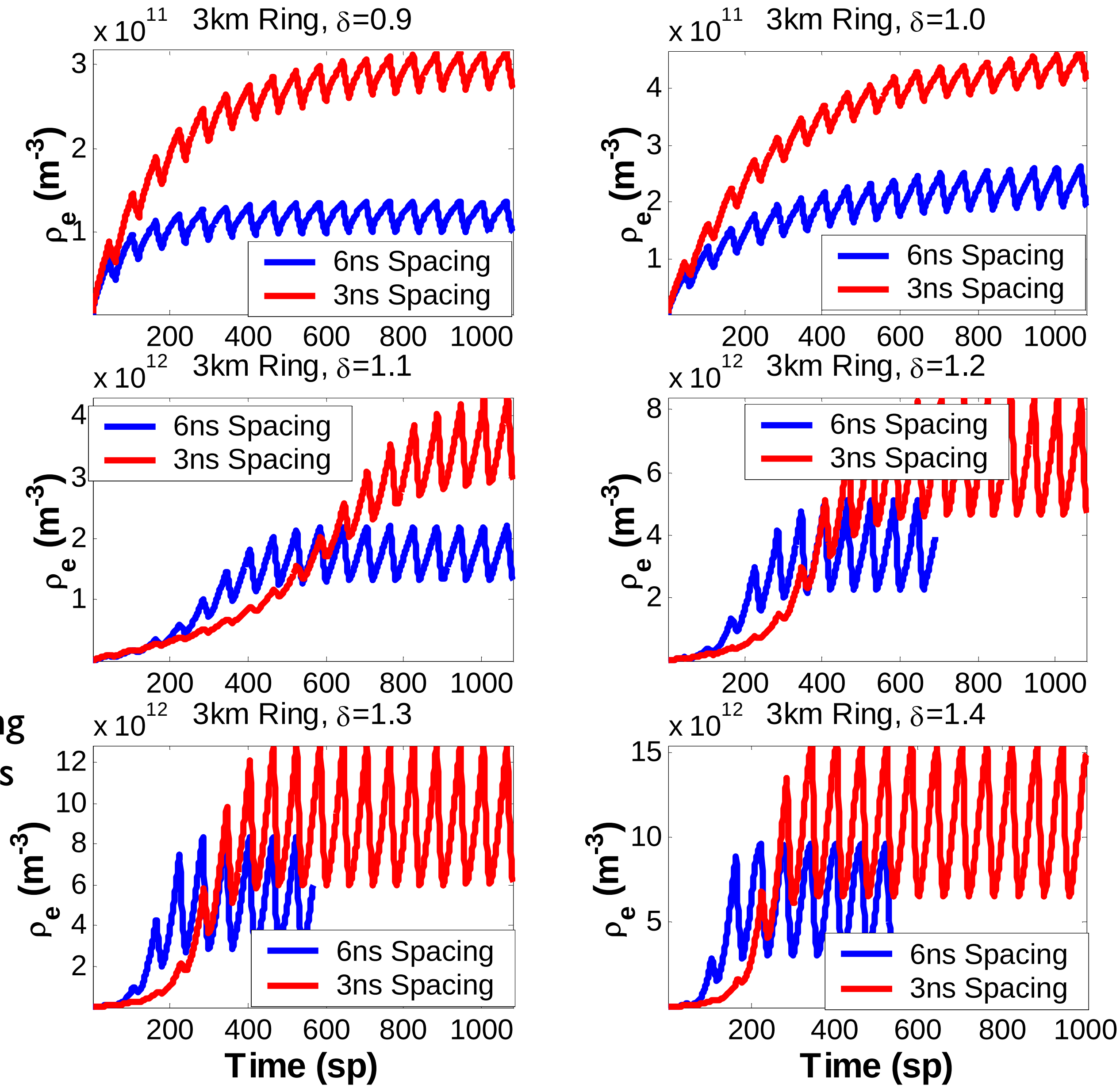


3 ns spacing

Bunch Spacing effect

Quadrupole: Photon Reflectivity =20%
Antechamber protection =98%

Average density build-up



- slow saturation for 3ns spacing
- a larger ecloud density for 3ns spacing :
  130%(σ=0.9) ~60%(σ=1.4)

Summary of ecloud in ILC Quadropole

Peak average density in ILC quadrupole ($\times 10^{12} m^{-3}$)

SEY	Antechamber protection =0%		Antechamber protection =90%		Antechamber protection =98%	
	3ns spacing	6ns spacing	3ns spacing	6ns spacing	3ns spacing	6ns spacing
0.9	12.0	8.04	1.64	0.70	0.315	0.136
1.0	12.8	8.70	2.20	1.0	0.466	0.260
1.1	13.85	9.41	4.82	2.38	4.30	2.20
1.2	15.74	10.44	8.70	5.25	8.40	5.13
1.3	17.50	11.45	13.2	8.58	12.8	8.35
1.4	19.20	12.35	15.8	9.97	15.37	9.7

Peak ecloud density near the beam in ILC quadrupole ($\times 10^{12} m^{-3}$)

SEY	Antechamber protection =0%		Antechamber protection =90%		Antechamber protection =98%	
	3ns spacing	6ns spacing	3ns spacing	6ns spacing	3ns spacing	6ns spacing
0.9	1.0	0.67	0.18	0.11	0.035	0.020
1.0	1.6	0.9	0.55	0.35	0.135	0.14
1.1	2.2	1.5	3.25	2.2	4.0	2.75
1.2	4.4	2.6	7.5	6.0	8.7	6.55
1.3	6.7	3.8	11.5	8.5	12.4	9.2
1.4	7.5	4.9	13.0	9.5	13.6	9.9

Summary of ecloud in ILC Sextupole

Peak average density in ILC Sextupole ($\times 10^{12}m^{-3}$)

SEY	Antechamber protection =0%		Antechamber protection =90%		Antechamber protection =98%	
	3ns spacing	6ns spacing	3ns spacing	6ns spacing	3ns spacing	6ns spacing
0.9	11.3	6.4	1.07	0.52	0.2	0.10
1.0	>11.8	7.05	1.2	0.605	0.22	0.116
1.1	>12.4	7.75	>1.35	0.73	0.248	0.135
1.2	>13.2	>8.46	>1.55	0.94	0.290	0.174
1.3	>13.8	>9.3	1.95	1.56	0.354	0.303
1.4	14.8	10.2	3.03	3.25	0.65	>2.0

Peak ecloud density near the beam in ILC Sextupole ($\times 10^{12}m^{-3}$)

SEY	Antechamber protection =0%		Antechamber protection =90%		Antechamber protection =98%	
	3ns spacing	6ns spacing	3ns spacing	6ns spacing	3ns spacing	6ns spacing
0.9	0.55	0.40	0.06	0.05	0.01	0.008
1.0	0.60	0.50	0.08	0.07	0.014	0.012
1.1	0.70	0.55	0.1	0.085	0.018	0.016
1.2	0.90	0.75	0.145	0.150	0.026	0.025
1.3	1.3	0.9	0.24	0.370	0.05	0.075
1.4	1.4	1.1	0.76	1.14	0.18	>1.0

Summary and future work

- A larger number of electrons (30%~70%) can be trapped and survive a long train gap; there is slow build-up and slow decay. (can explination of the obersevation?see Gerry's talk)
- We sysmatically studied the effects of Bunch current, Magnetic field, and bunch spacing

- Antechamber is effective in reduction of the ecloud density when SEY is small (<=1.0); For High SEY, its mitigation effect becomes small becauses the seconaries are dominant.
- For ILC Quadrupole, there is a larger (a factor 2.3~1.6) average electron density in 3ns spacing case comapring with 6ns spacing;

- Benchmark with RFA : need a better model
- Simulation of one section of the ring(multi-magnets effect)

Acknowledgements

Thanks Joseph Calvey, Gerry Dugan, Bob Macek, Mark Palmer, Pivi Mauro for fruitful discussions and information

Backup slides