# *Simulation study of e-cloud in KEK-B LER*

*L. WANG*

1) **Three dimensional PIC program**
2) **Photoelectron cloud in various magnetic fields**
3) **Remedies to clear the e-cloud**
4) **Summary**

*In collaboration with H. Fukuma, K. Ohmi, S. Kurokawa, K. Oide, F. Zimmermann,...*

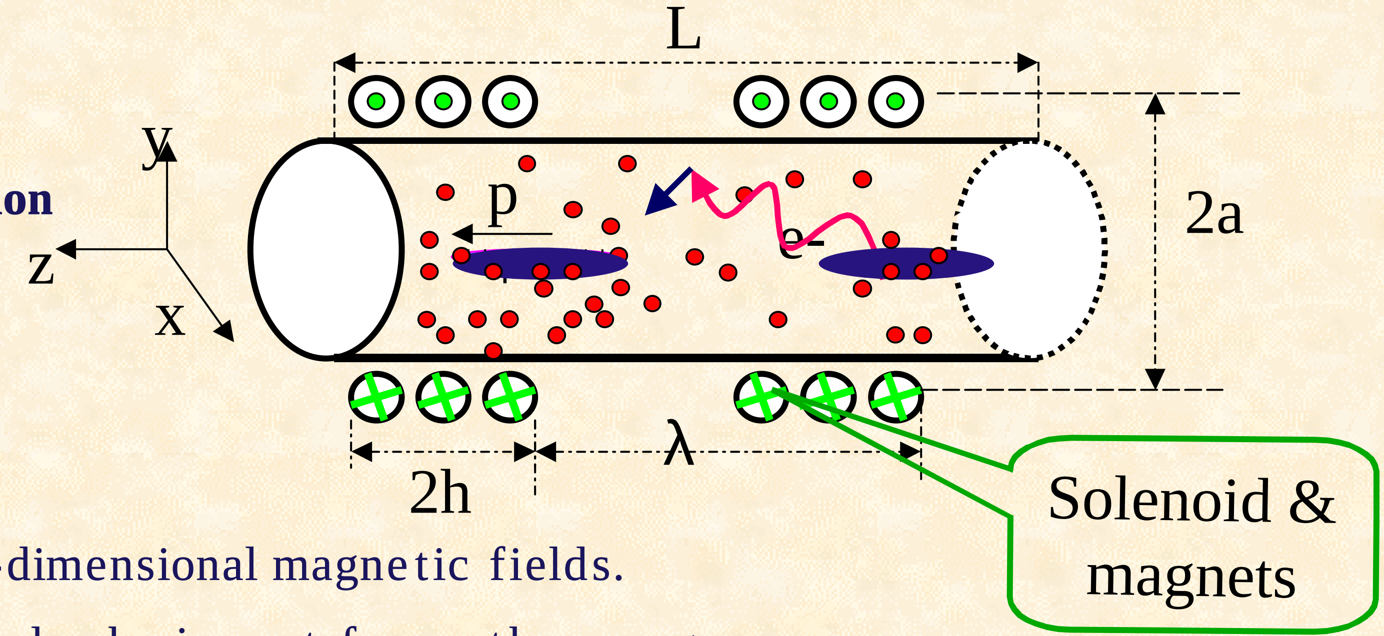
# Study methods for E-cloud

- Analysis method (*E. Perevedentsev, S. Heifets, E. Metral,…)*
- Numerical Method
  - **Photoelectron cloud build-up, distribution, heat loading ……**
  - ***(M.A. Furman, Mauro Pivi, K. Ohmi, F. Zimmermann and G. Rumolo, L. Wang …*** )
  - Transverse single bunch instability simulation (Gaussian/Uniform Cloud) (*K.Ohmi, F. Zimmermann, G. Rumolo,Y. Cai, …*)
  - Extracting wakefield from simulation program, then analysis the transverse mode coupling, get the electron cloud threshold density (*F. zimmermann, K. Ohmi, L. Wang…*)
  - Coupled bunch instability (S. S.Win)
- Experimental method (*CERN-SPS and PS, KEK-KEKB, SLAC-PEPII, LANL-PSR, LBNL-APS, BNL-AGS and RHIC, IHEP-BEPC, ALS,CESR,…)*

# 3D PIC Program--- CLOUDLAND

***Program model***

- **Three dimension PIC methods**




***Magnetic field***

- General 3-dimensional magnetic fields.
- Fields can also be import from other program

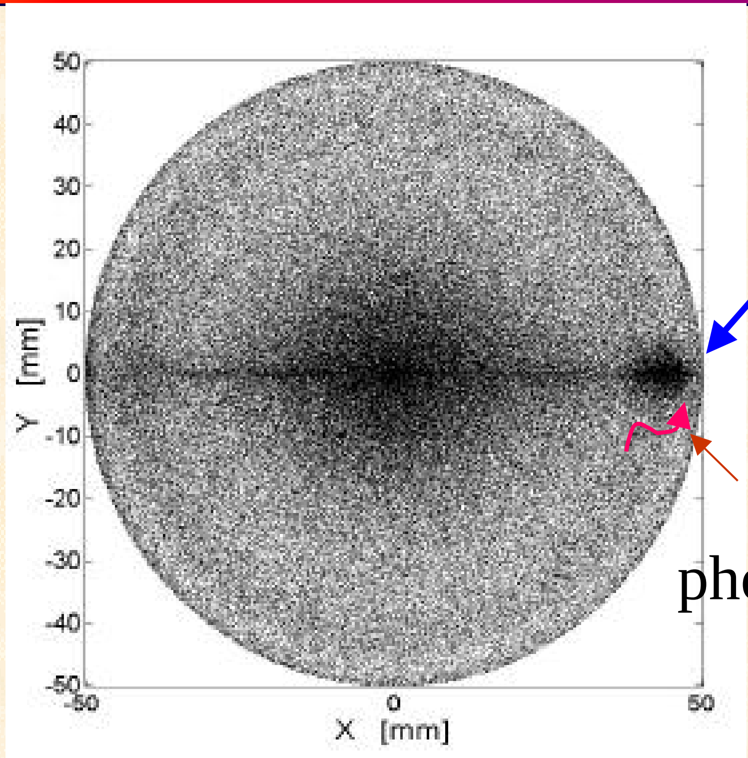
***Beam potential***

- Gaussian bunch in round chamber ( image charge is included)
- PIC method for general geometry

***Secondary emission and reflective electron are included***

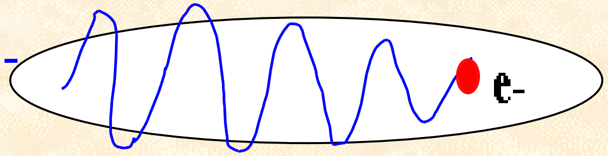
***Irregular mesh & high order element are applied***

# Field free region




*Live Cloud Distribution in Transverse Plane*

Preliminary e-




***Proton/Positron bunch***

Electron trapping near beam

(a)

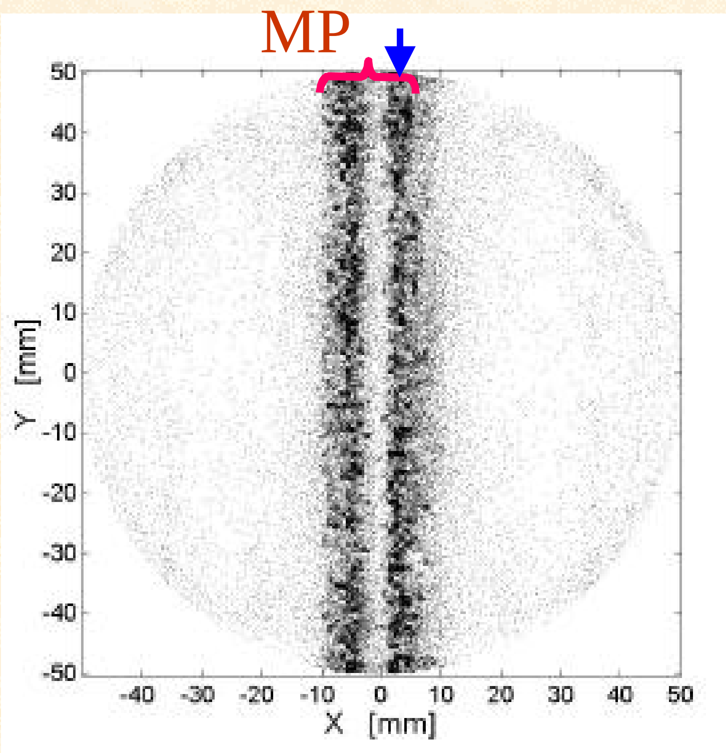
(b)

Orbit of tapped electron with larger amplitude.

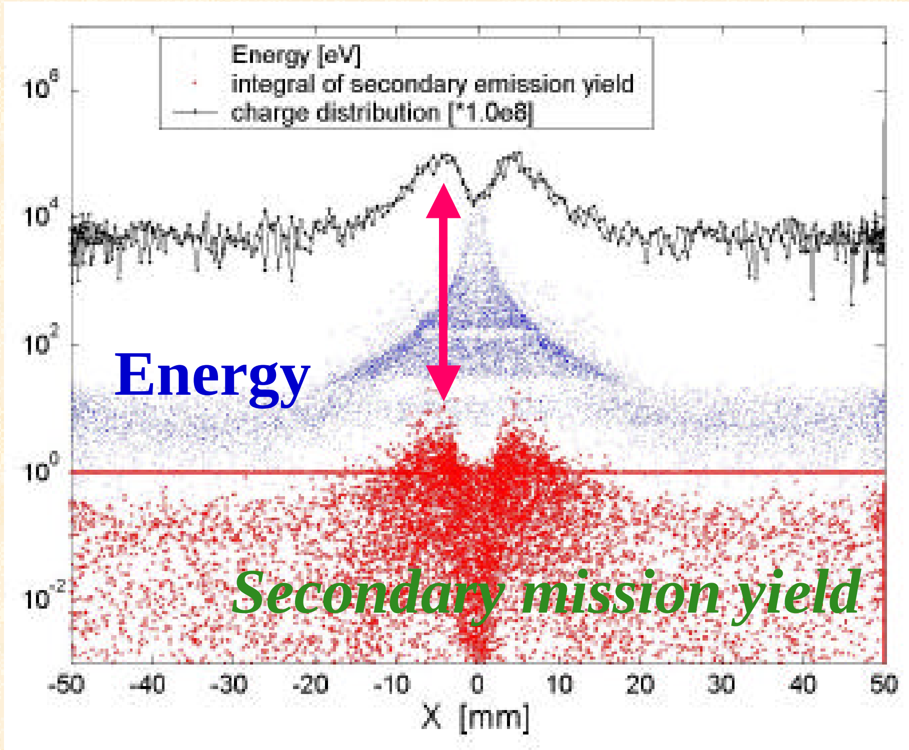
➢***Large central density due to the confinement of positron beam***

➢***Multi-pacting and heating-load effect are important***

# *Normal Dipole*



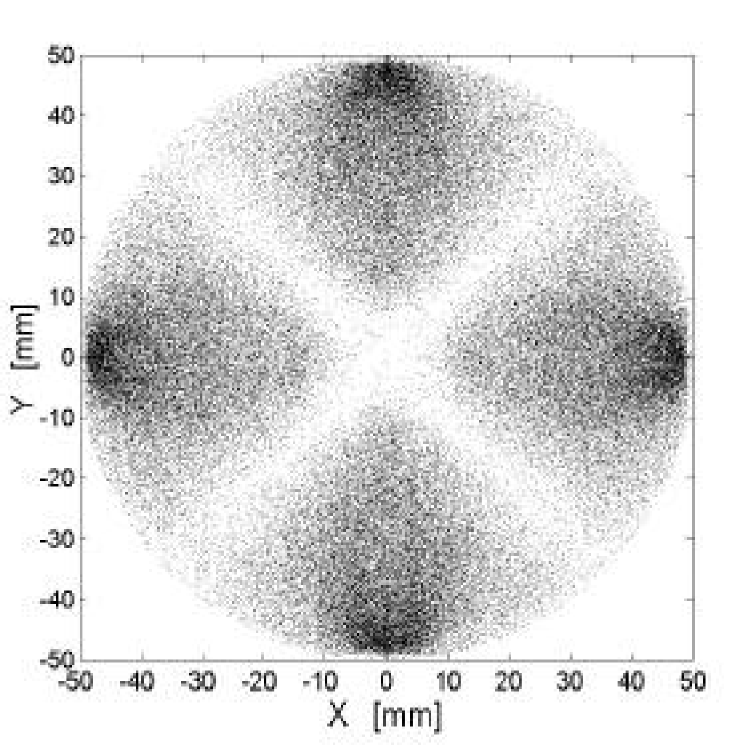

*Live Cloud Distribution*



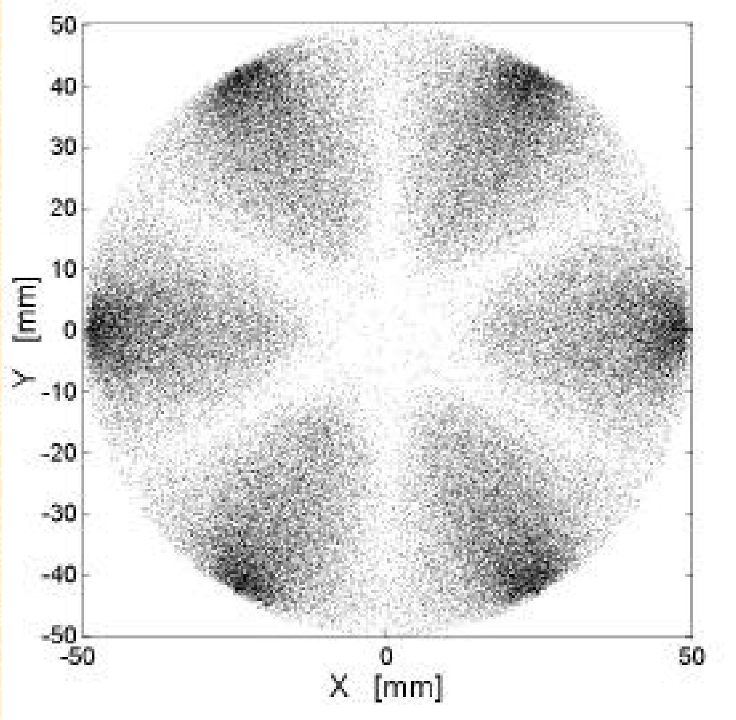

*Multipacting mechanism*

***Central density +local multipacting+local heating***

# Normal Quadrupole & Sextupole




*quadrupole*

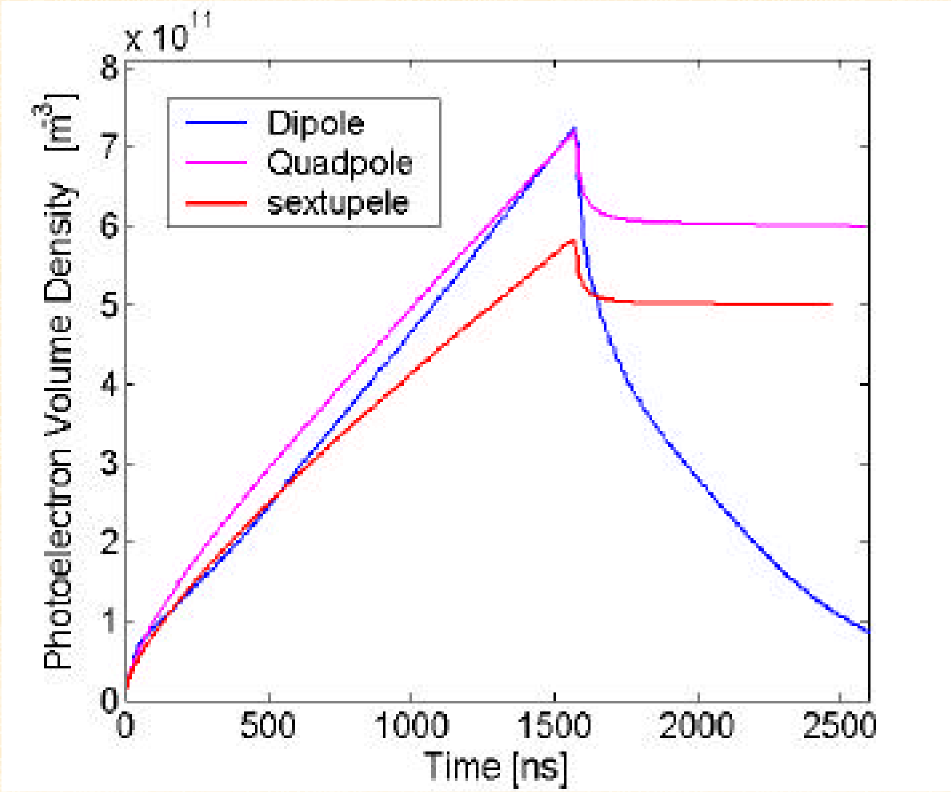



*sextupole*

***Weak multipacting+low central density+weak heating+trapping***

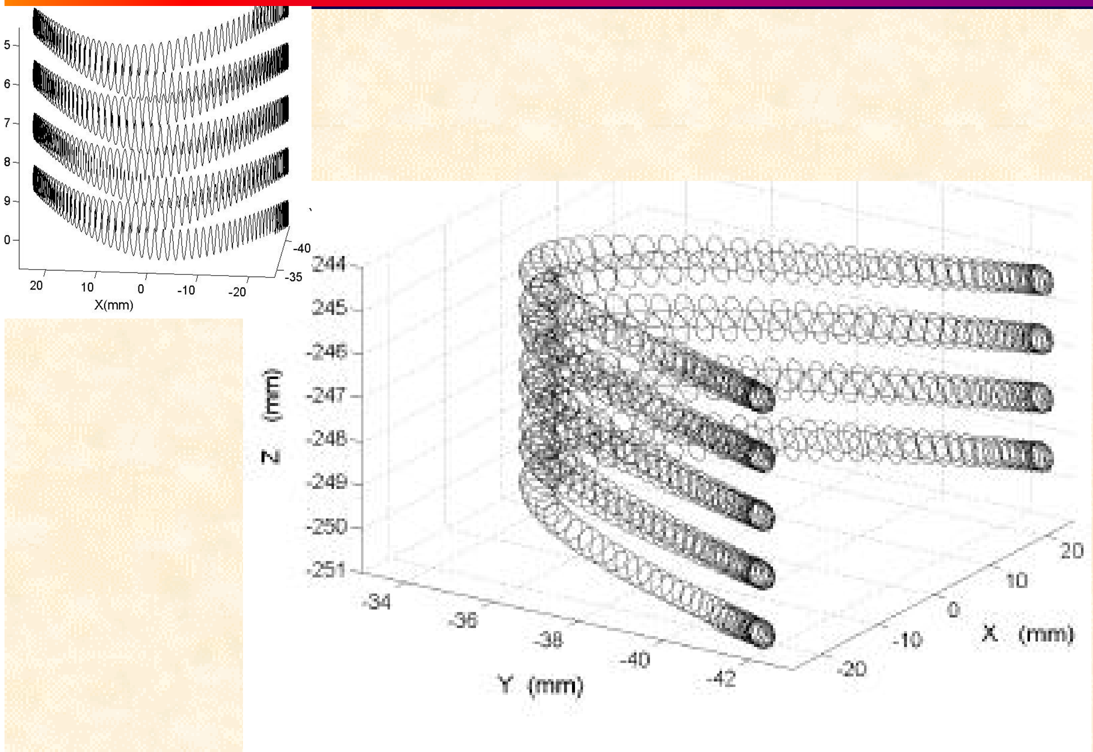
# *Trapping phenomenon*

- It happens in quadrupole and sextupole magnets
- The photoelectron can be trapped in quadrupole and sextupole magnets for very long time until it longitudinally drift out of the magnets.($v_z$~0.004 mm/ns)
- The trapping phenomenon is strongly beam-dependent. There is no such kind of trapping when the positron beam force is not included

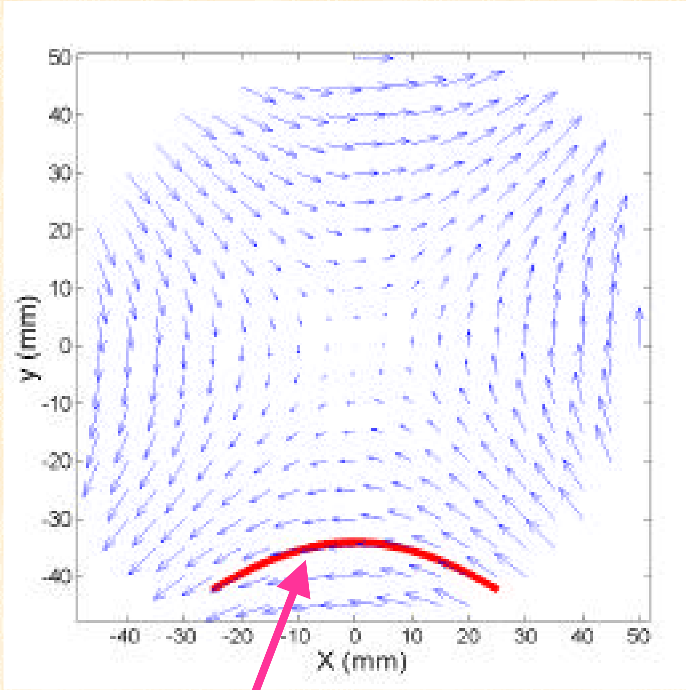



***Average cloud density evolution in different magnetic fields***

# *Trapping phenomenon---in quadrupole magnet*




*3D orbit*

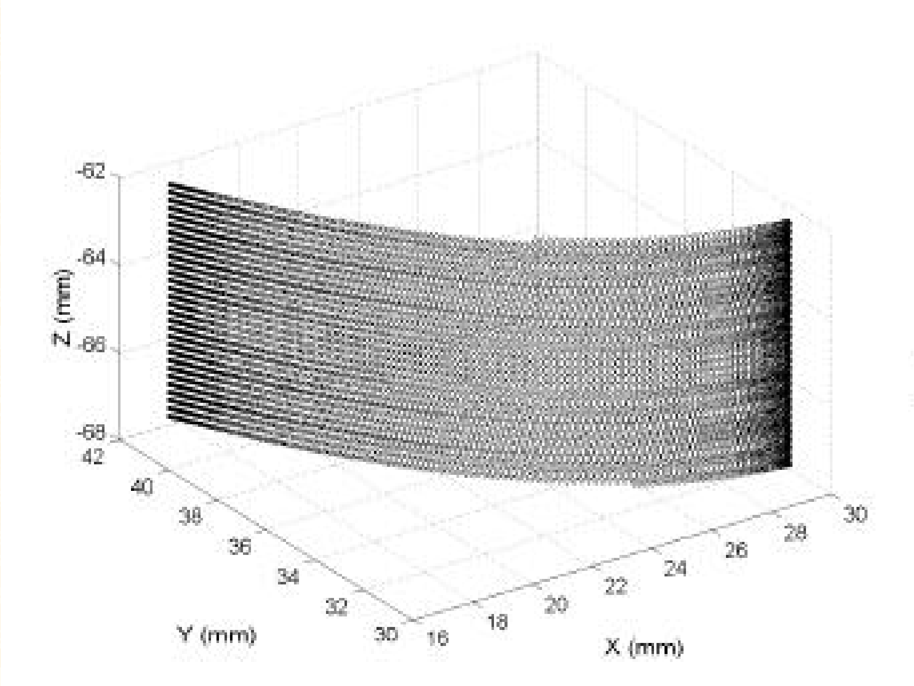


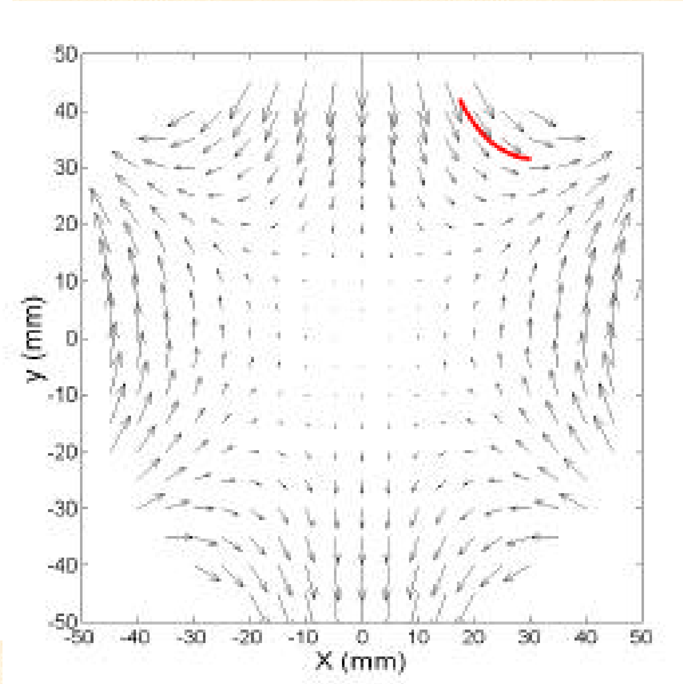

*2D orbit*

Field lines

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

# *Trapping phenomenon---in sextupole magnet*




***Orbit of a trapped photoelectron in normal sextupole magnet during the train gap***

# *Trapping mechanism – Mirror field trap*

## *Invariation value of motion*

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

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

Reflective Points: $\upsilon_{\|}=0$

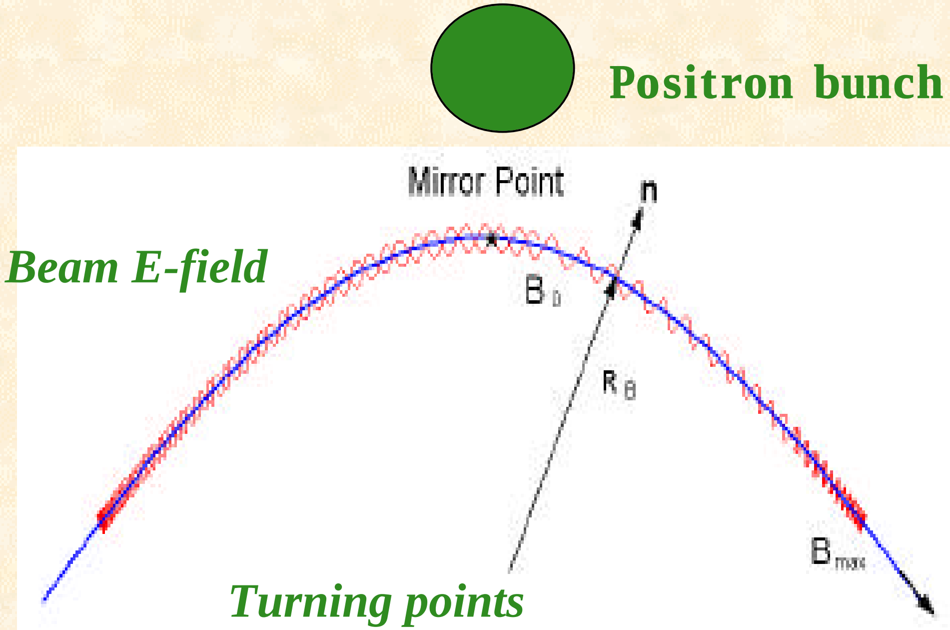
## *Trapping condition*

$$\Gamma_{trap} > 1$$

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

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

**Positron bunch**




***mirror field trapping***

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

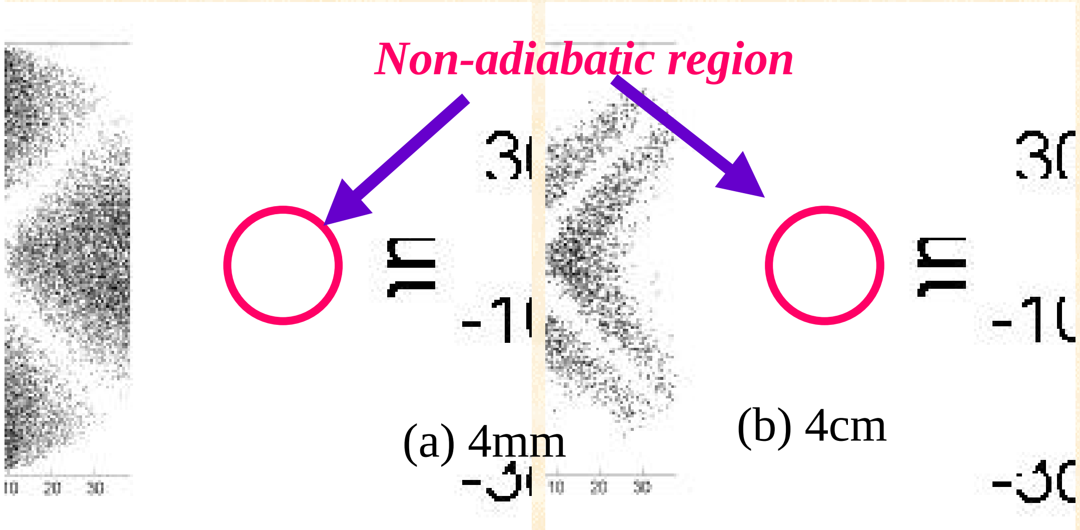
# *Trapping mechanism ---Beam potential effect on* $F_{\upsilon}$ & $\Gamma_{trap}$

## *Trap requirement for positron bunch*

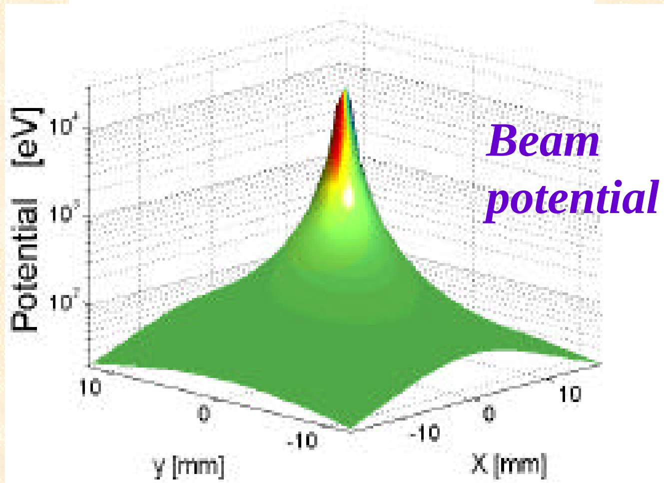
**Bunch length should be shorter than period of gyration motion**

$$\sigma_l < \frac{2\pi cm}{e}\frac{1}{B} \Longrightarrow \sigma_l(mm) < 10.7 / B(T)$$

**Particle motion in non-adiabatic region**




**Trapped photoelectron distribution in quadrupole magnet with field gradient 10.3 T/m during the train gap for different bunch length**



# Orbit of the Guiding Center (Contd.)

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

**•Magnetic gradient drift**

$$\tilde{\mathbf{o}}_{grad} = \frac{m\upsilon^2}{2eB^3}\mathbf{B}\times\ \mathbf{B}$$ With normal gradient $-B\,\mathbf{n}/R_B$

**•Centrifugal force drift**

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

$$\tilde{\mathbf{o}}_F = \frac{\mathbf{F}\times\mathbf{B}}{eB^2} = \frac{\mathbf{n}}{B\Omega_s}\times\frac{\mathbf{B}}{R_B}\upsilon_\parallel^2$$

$$\tilde{\mathbf{o}}_{gz} = \frac{\mathbf{n}}{B\Omega_s}\times\frac{\mathbf{B}}{R_B}\left(\upsilon_\parallel^2 + \upsilon^2/2\right)$$

$$\tau = \oint\frac{dl}{\upsilon_\parallel} \qquad \bar{\bar{\upsilon}}_{gz} = \frac{1}{\tau}\oint\frac{\bar{\upsilon}_{gz}}{\upsilon_\parallel}dl$$

Example: one electron in Quadrupole:

Simulation: 236 ns and 0.0066 mm/ns

Analysis: 228 ns and 0.0063 mm/ns

Magnets length=0.4m

Very slow drift velocity $v_{gz}$ (**$1.5\sim3.5\times10^{-3}$ mm/ns**)

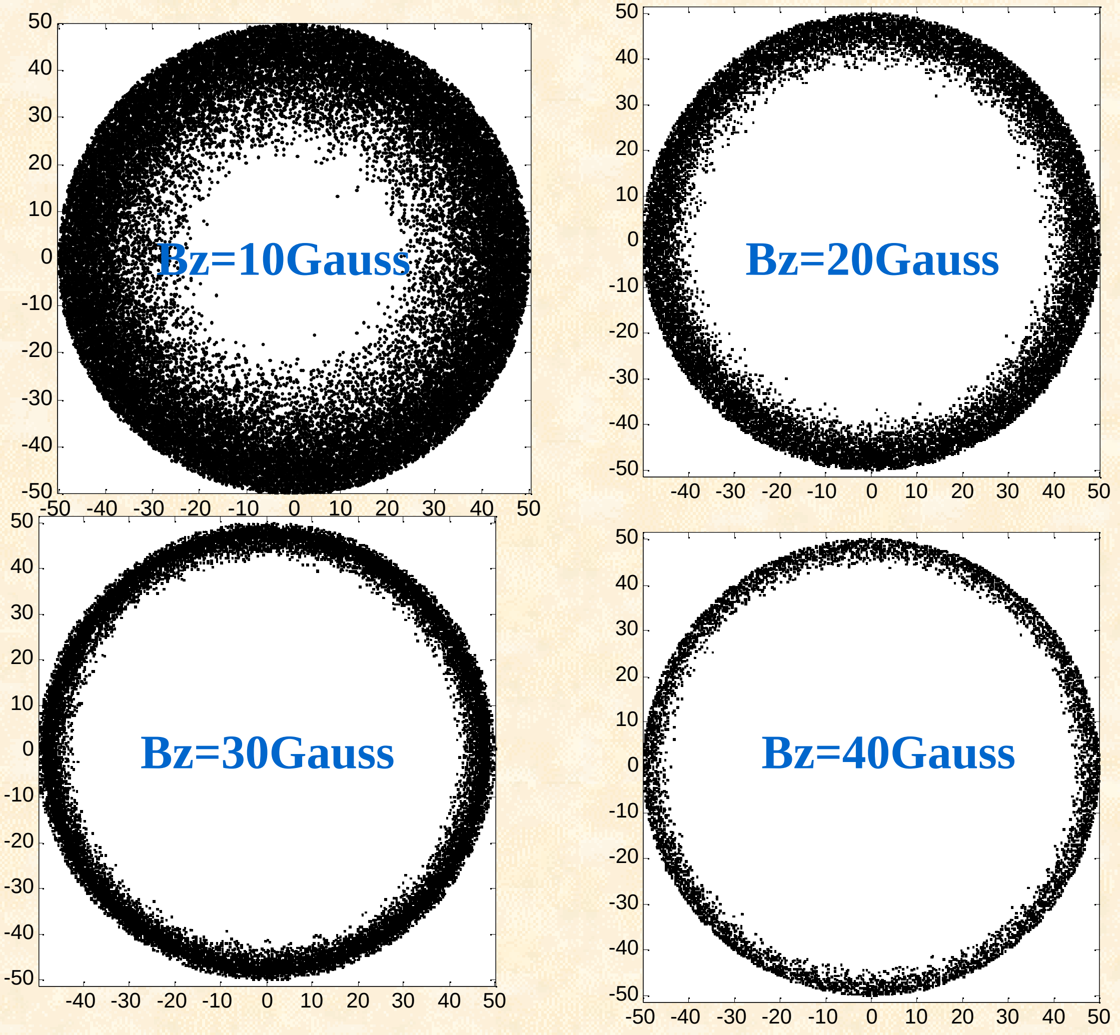
Long trapping time(~$10^5$ ns)

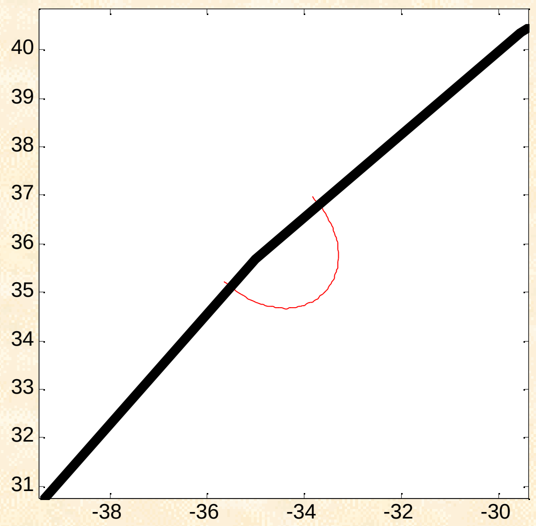
**Coupled-bunch effects!!**

# *III Cures of e-cloud*

- Weak Solenoid (work well in drift region, but not in magnets)
- Chamber surface preparation (Vacuum chamber coatings, ribbed structures, Beam scrubbing)
- BPM serve as clearing electrode?

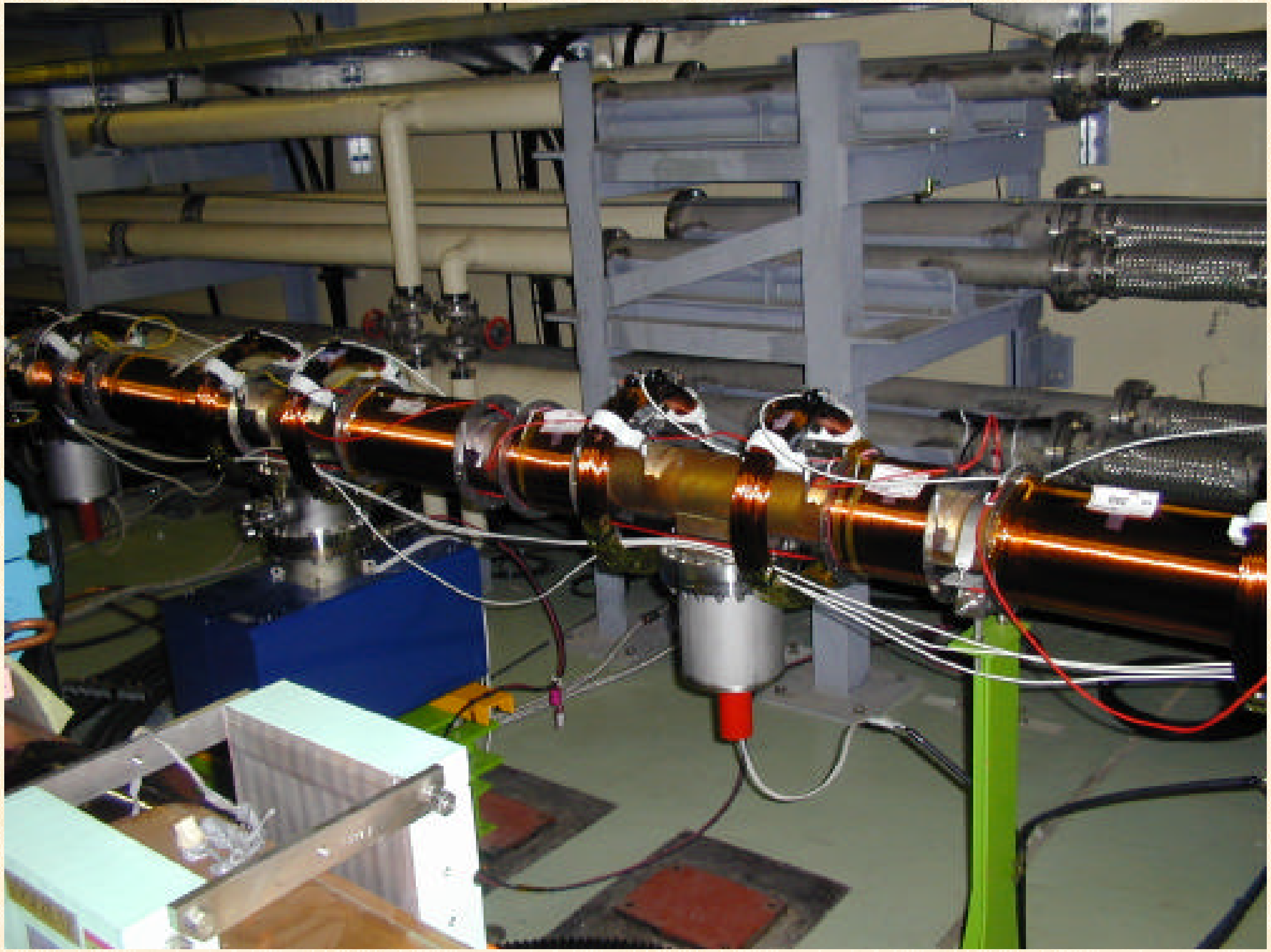
# Uniform Solenoid effect in drift region



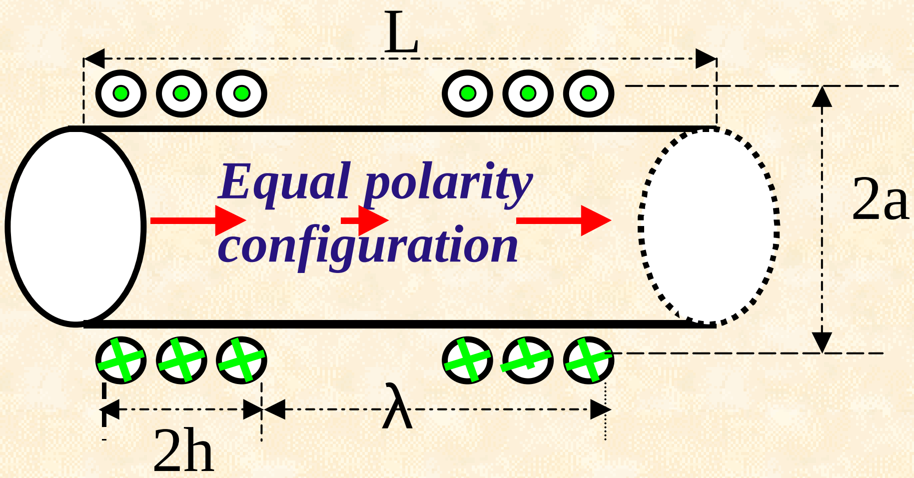



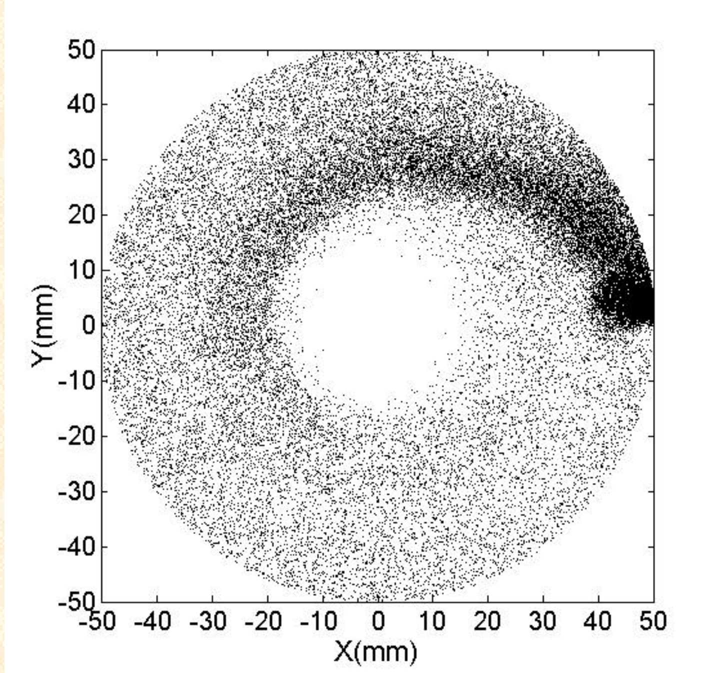
Clearing mechanism

# Solenoid



# Periodic Solenoid




*$B_0$=50 Gauss, h=0.4 m, a=70 mm, λ =1 m*

$$B_r = B_0 \frac{2ka}{\pi} \sum_{n=1}^{\infty} \sin nhk K_1(nka) I_1(nkr) \sin nkz$$

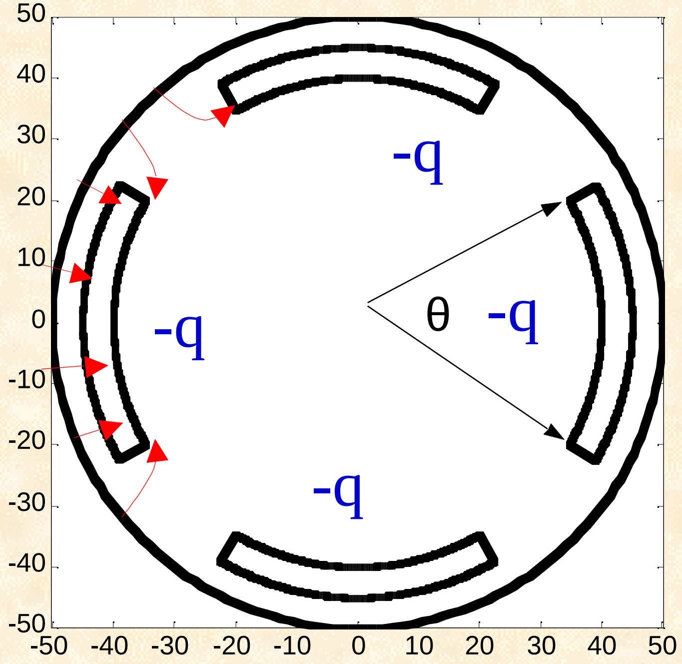
$$B_r = B_0 \frac{4ka}{\pi} \sum_{n=1,3,5}^{\infty} \sin nhk K_1(nka) I_1(nkr) \sin nkz$$

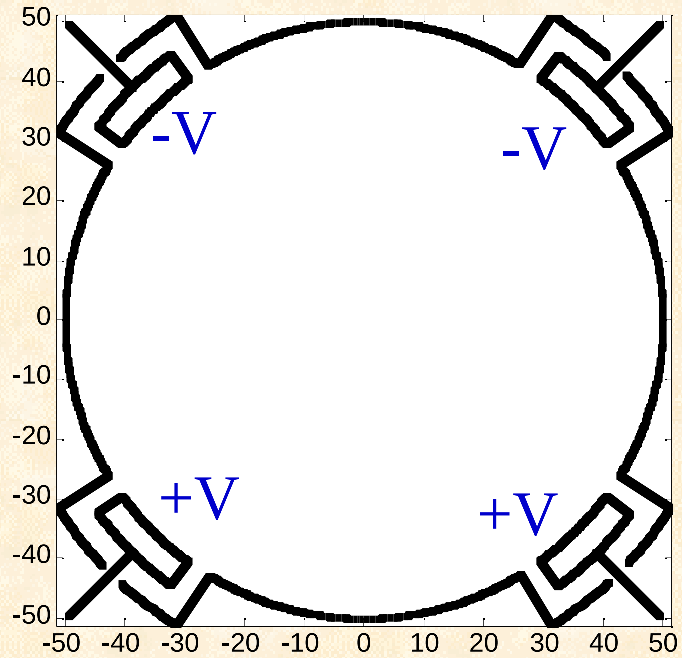
$$B_z = B_0 \left( \frac{2h}{\lambda} + \frac{2ka}{\pi} \sum_{n=1}^{\infty} \sin nhk K_1(nka) I_0(nkr) \cos nkz \right)$$

$$B_z = B_0 \frac{4ka}{\pi} \sum_{n=1,3,5}^{\infty} \sin nhk K_1(nka) I_0(nkr) \cos nkz$$

*By E. Perevedentsev*

# BPM serves as clearing system?




Stripline-type BPM

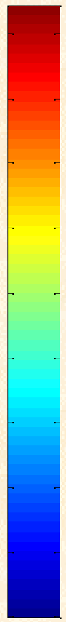
(wire-type)

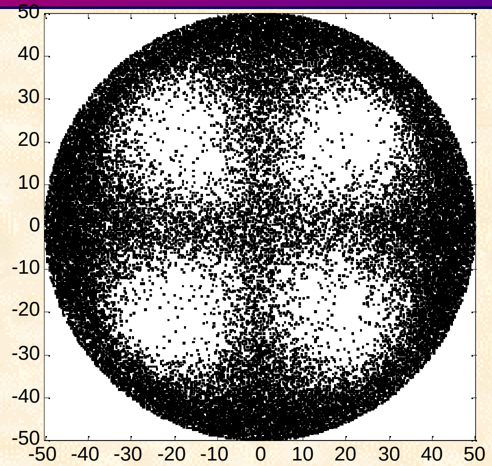
Button-type BPM

(ion clearing system type)

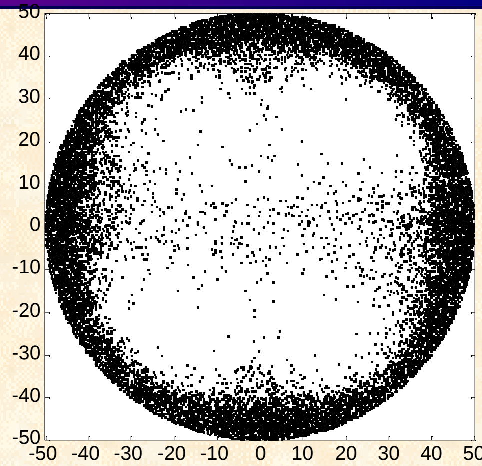
**Replace the electrodes with wires to reduce the impedance!**

# Clearing effects for Drift region

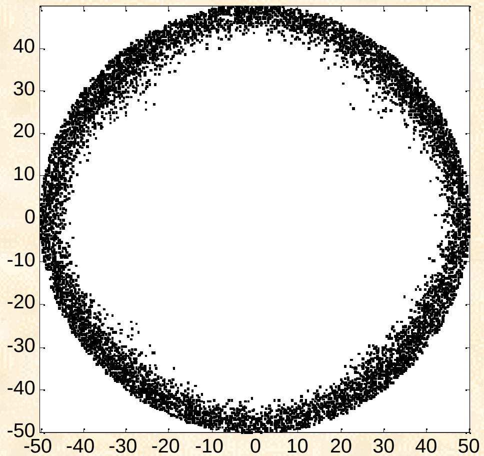




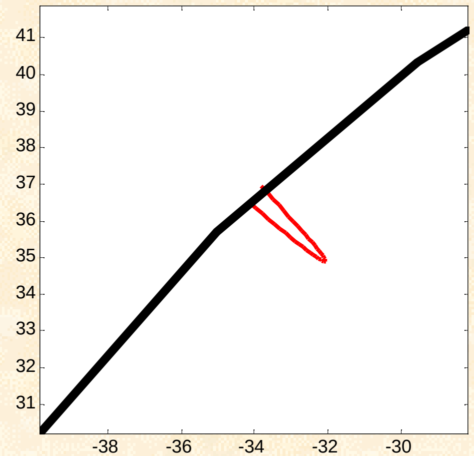

-100V




-150V




-200V 4 electrodes



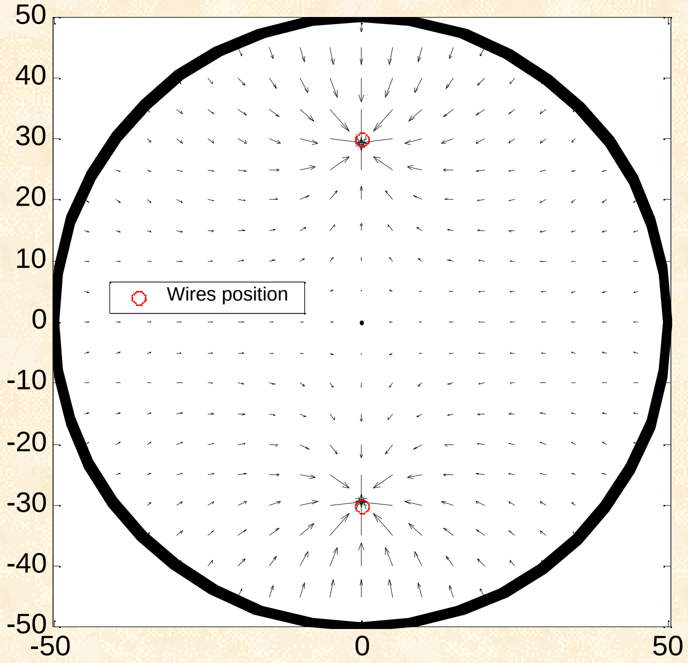

**Requirement:**

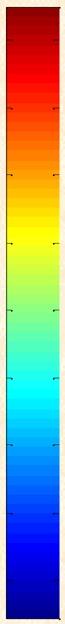
**-200V for 4 electrodes system**

**-400 V for 2 electrodes system**

# Clearing electrodes for Dipole Magnet

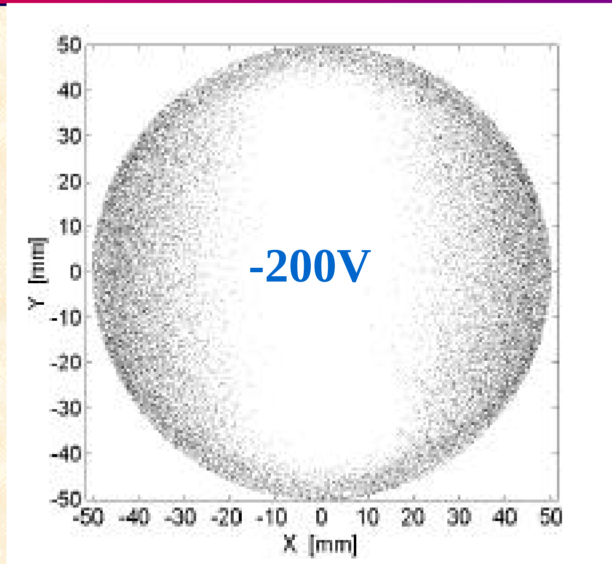
- *Inside the strong dipole magnets, crossed-field and gradient drifts couldn't eliminate the electrons. Therefore, the electric field must be along the magnetic field line in order to effectively repel the electron. This conclusion holds for other strong magnetic fields*
- *The wire electrodes must have negative potential relative to the grounded chamber!!!*
- *The field is perfect!!! (very weak field at chamber center, strong vertical field around both the top and bottom of the chamber, where multipacting could happen.*

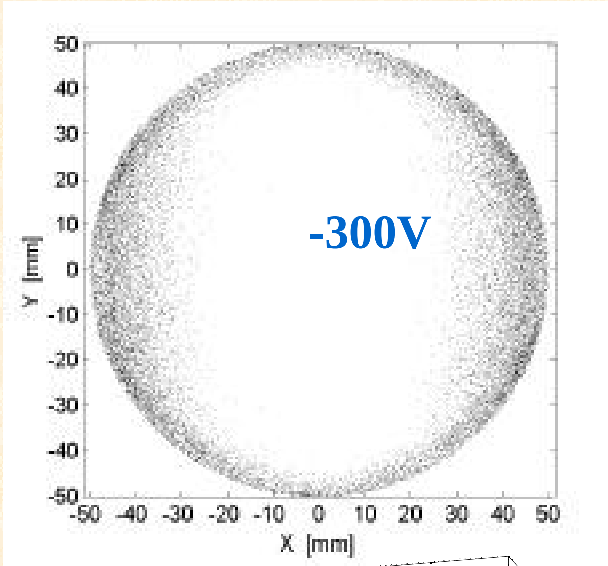


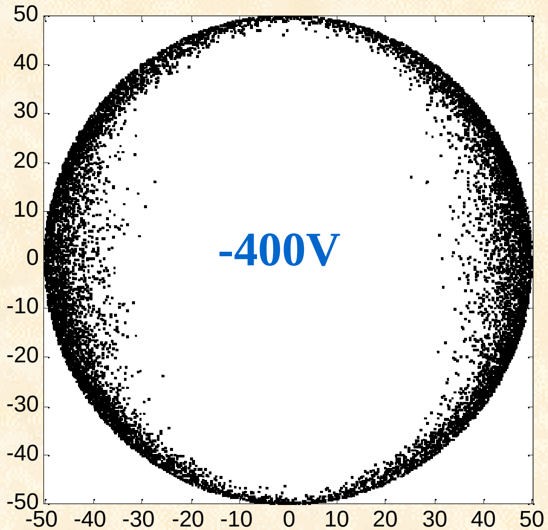



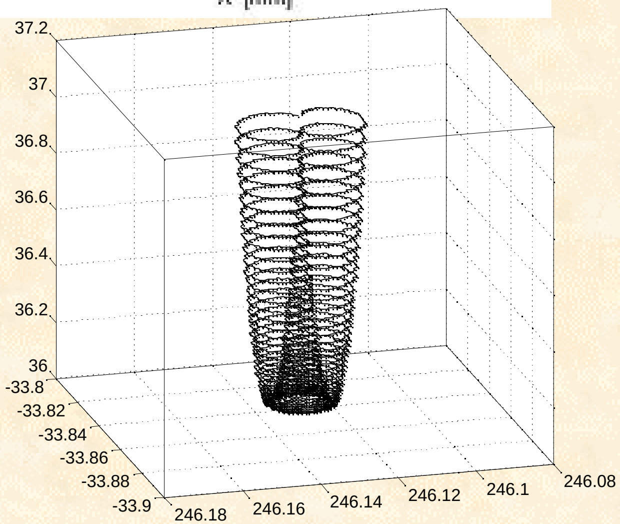
# Clearing effects in dipole magnet

-200~400V ok

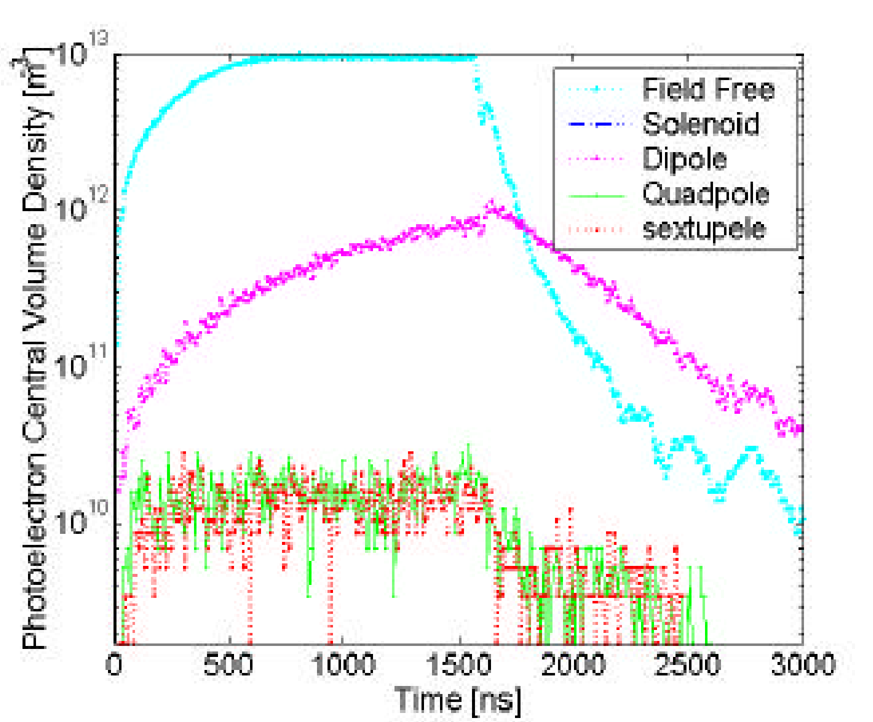


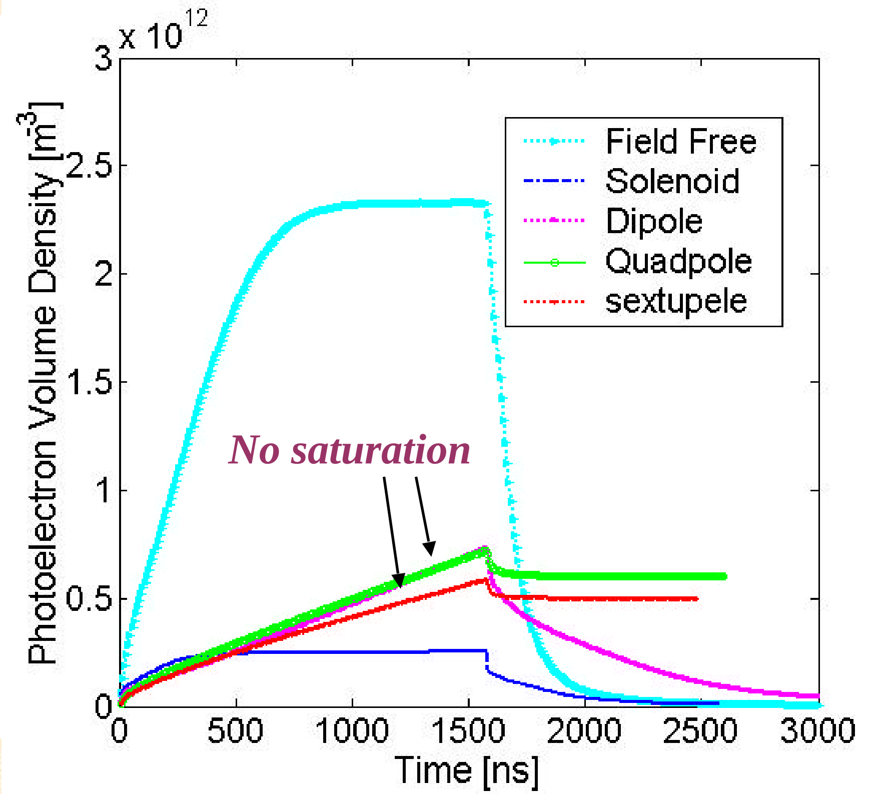



# Cloud Density in Different Fields




*Central density*




*Average density*

***Electron volume density as a function of time for a train with 200 bunches spaced by 7.86 ns and followed by a gap***

# Summary: *e*-Cloud in various fields

- **Drift region**
  - *Large central density*
  - *Multipacting & heating*
  - *Trapping by beam field*
- **Dipole magnet**
  - *Strong local multipacting & heating*
  - *Important central density*
  - *Multipacting mechanism*
- **Quadrupole and sextupole magnets**
  - *Low central density*
  - *Low heating load*
  - *Deep trap*
- **Solenoid**
  - *Uniform solenoid is preferred*
  - *Solenoid work well (No multipacting, no heating-load problem)*
- **Multi-wire clearing system**
  - Work in both drift region and magnet
  - Small impedance
  - *Easy* mechanical design,…..
  - Realistic study?
- **BPM & ion clearing system**
  - *Stripline-type works well but impedance…*
  - *Button-type doesn't apply*
  - *Ion-clearing system work, but its effect is not perfect, long bunch…*

# Thanks!!