Solenoid effects on electron cloud

L. Wang (BNL, Upton, New York, USA)

S. Kurokawa, S.S. Win (KEK, Tsukuba, Japan)

A. Chao (SLAC, Menlo Park, California,USA)

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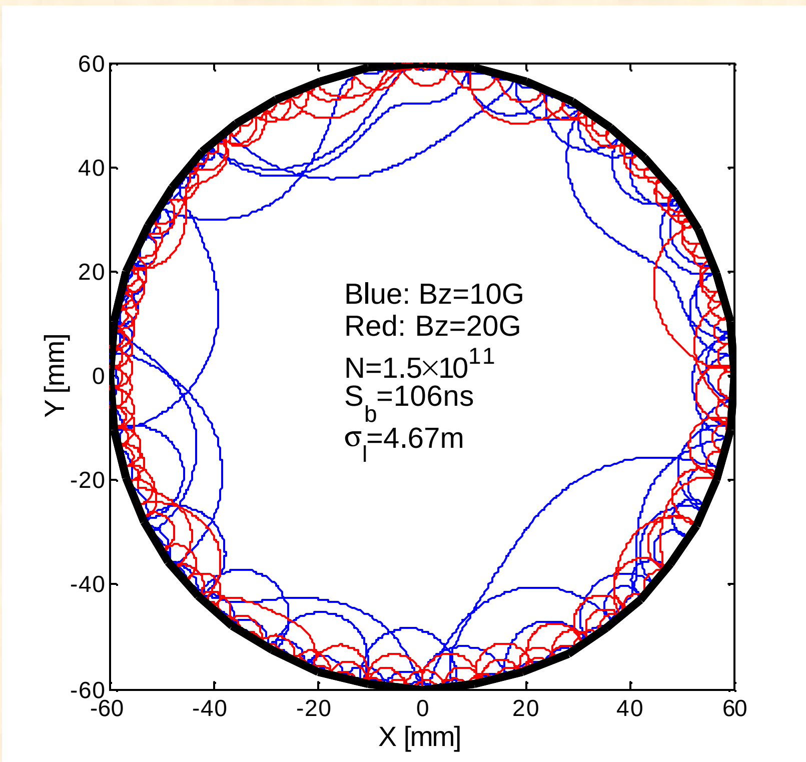
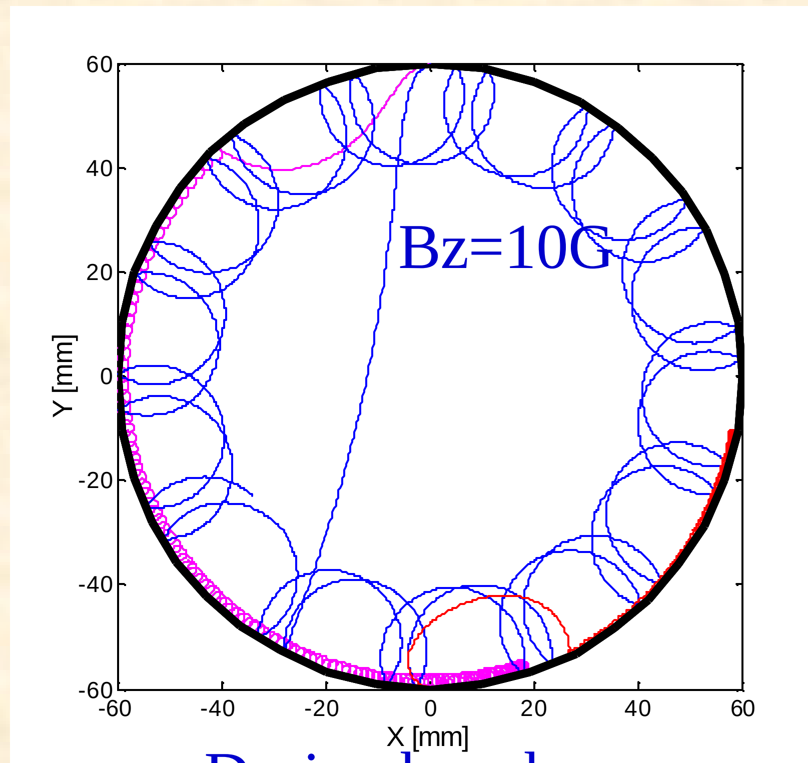
- ***Mechanism of electron clearing with solenoid***
- ***Solenoid configuration***
- ***Wake field and instability***
- ***Resonance with solenoid***

Electron orbit with solenoid -short bunch case

- Electron is confined near the chamber surface by the solenoid fields
- The energy and orbit of electron vary due to the interaction with beam.
- More low energy electrons survive from the bunch gap (reflected electrons are very important for e-cloud in bunch gap!)



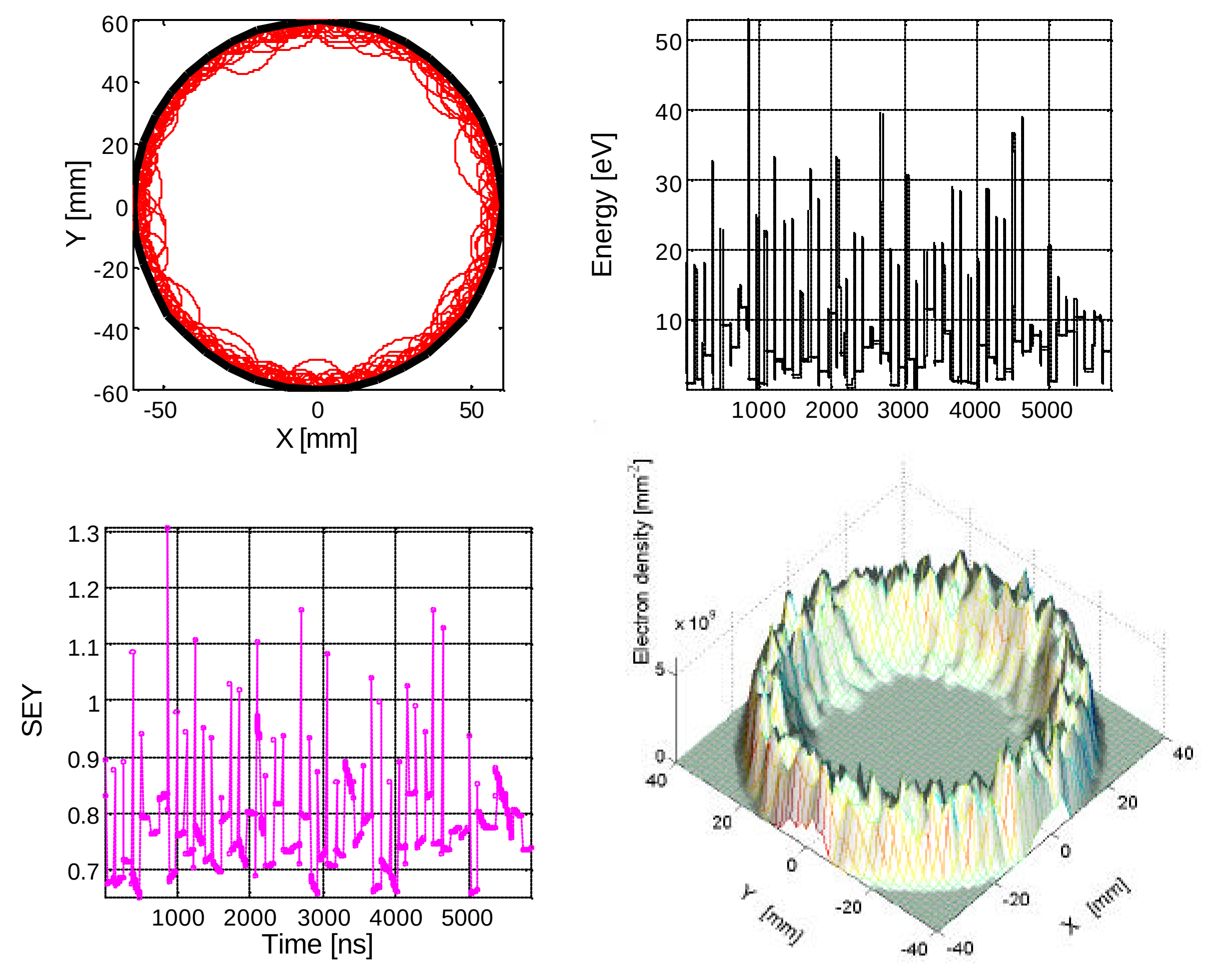
Within bunch train

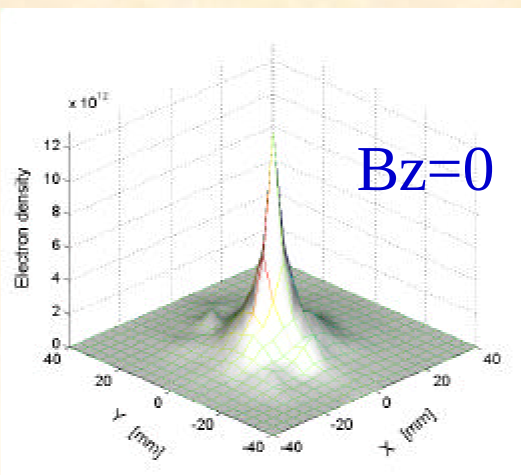


During bunch gap

Clearing mechanism—*short bunch case*

Solenoid confines electrons near the chamber surface and limits the electrons' energy at wall.

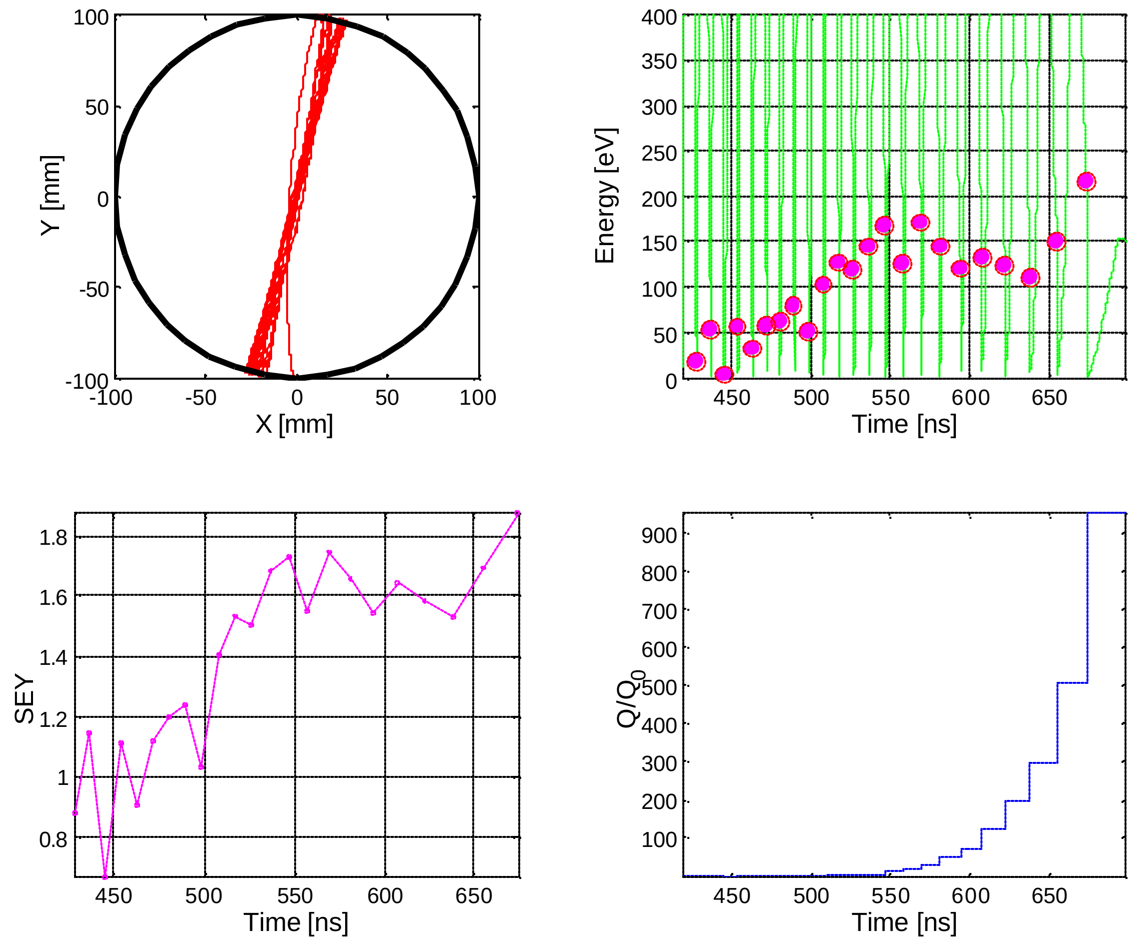




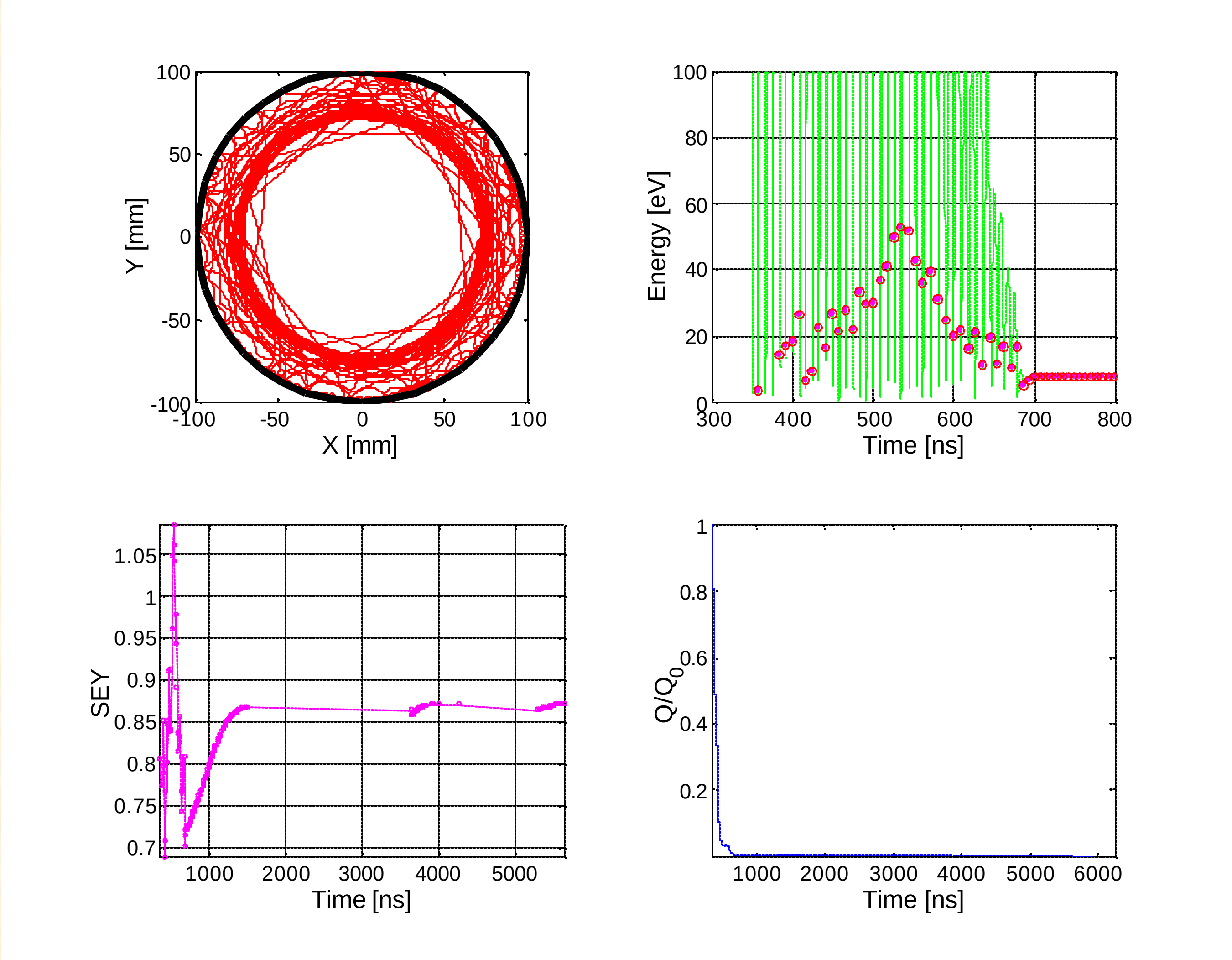
Bz=20G, RHIC

Multipacting—*long bunch case*

Traveling edge multipacting--- high energy gain around the bunch tail



Clearing mechanism—*long bunch case (I)*

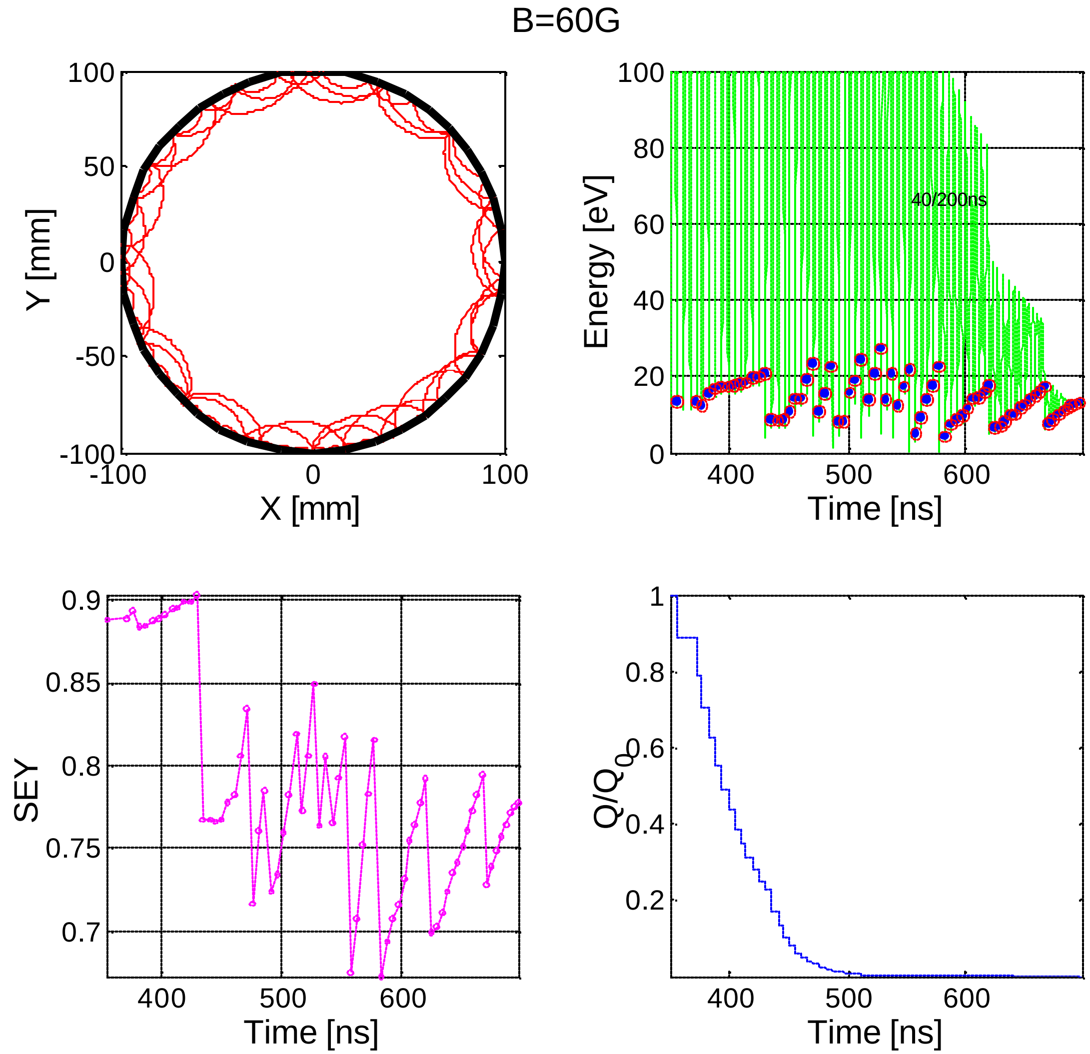


Bz=30G, f_c=90MHz

Clearing mechanism—*long bunch case (II)*

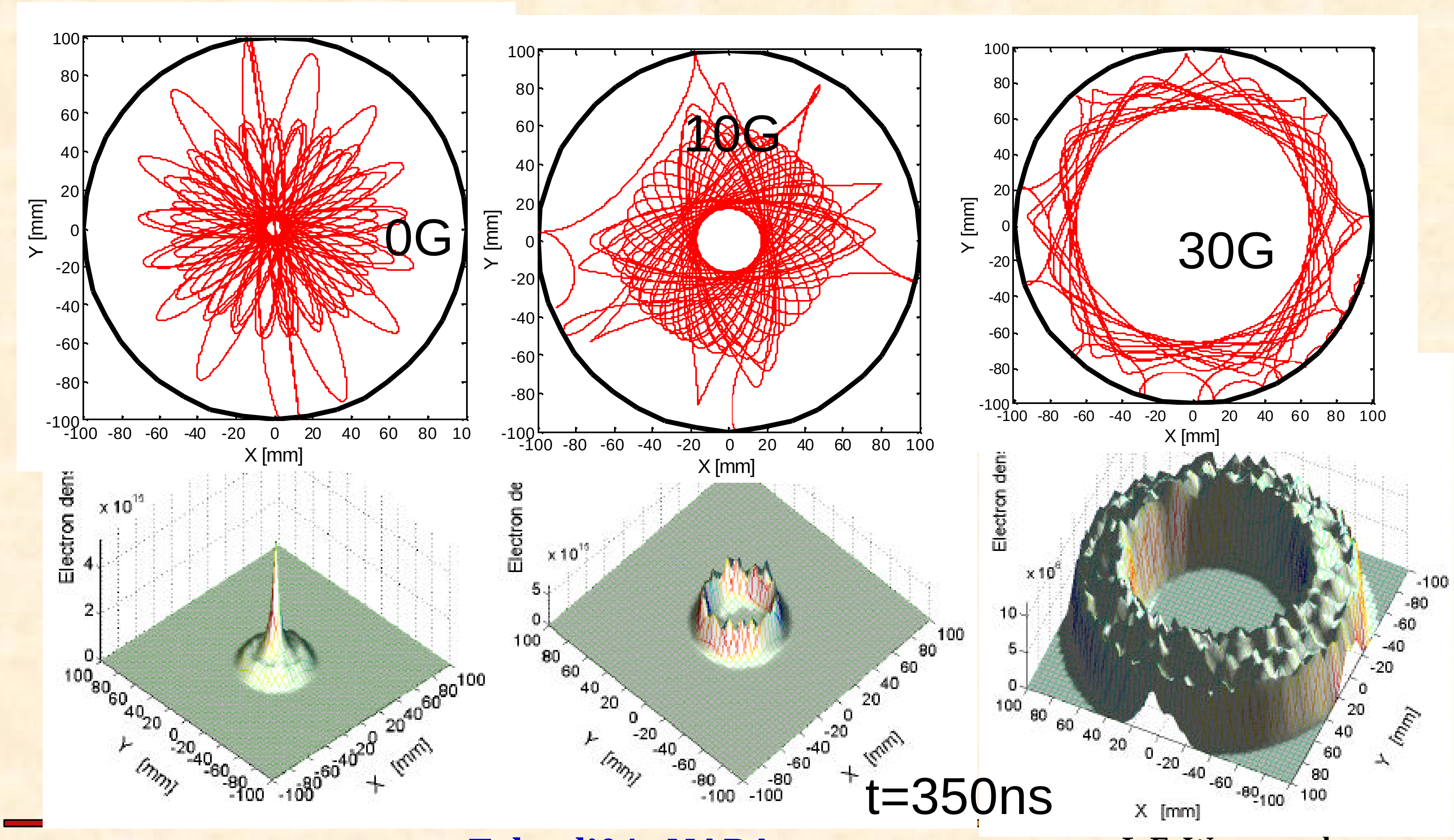
With enough strong solenoid field

- ➢ electron is confined near the chamber surface.
- ➢ The electron hits the wall more frequently with lower energy gain



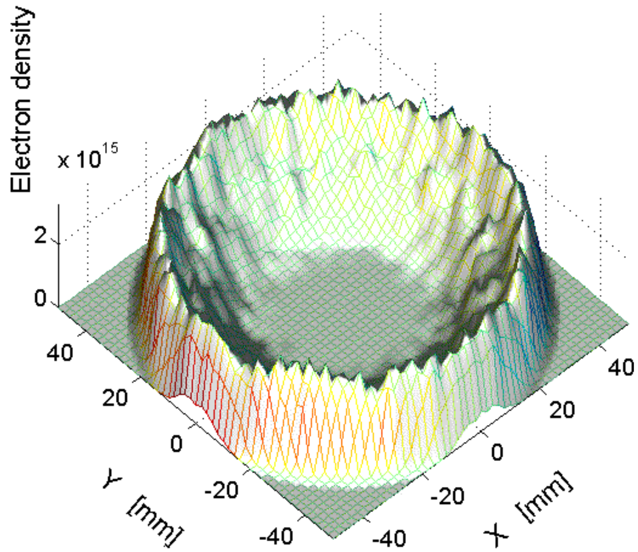
Solenoid effects for long bunch case---SNS (sigz=700ns)

- **30G Solenoid field can reduce the e-cloud density with a factor 2000 !**
- **Zero density within beam**

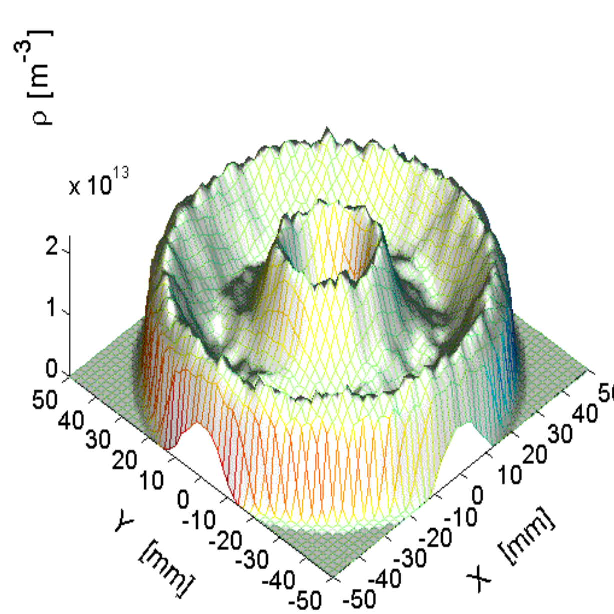


Beam intensity effect with solenoid B=10G

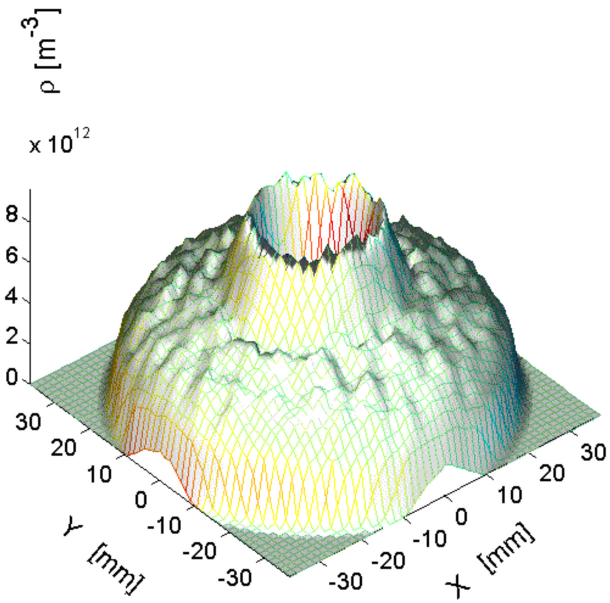
- **Required clearing solenoid field strongly depends on beam (beam pattern, bunch current, chamber size…). Higher beam current usually need stronger clearing field. Strong beam force may attract the electron to the chamber center if solenoid field is weak.**



$N_p=3.3\times10^{10}$, 8ns spacing

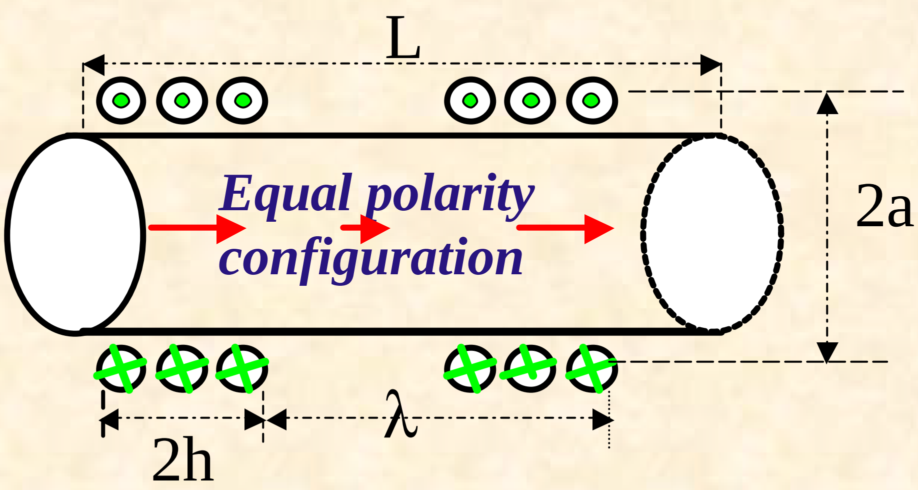


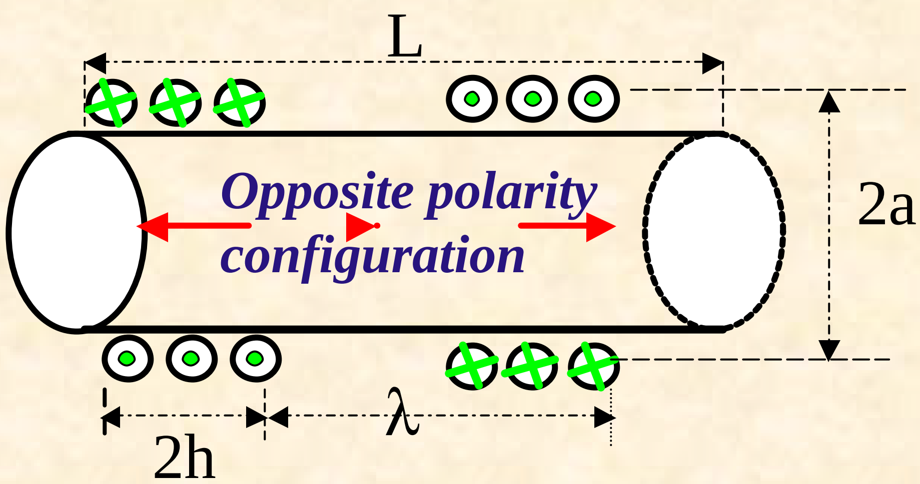
$N_p=8\times10^{10}$, 4ns spacing



SuperKEKB, $N_p=5.2\times10^{10}$
2ns spacing

Solenoid - - - Configuration





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

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

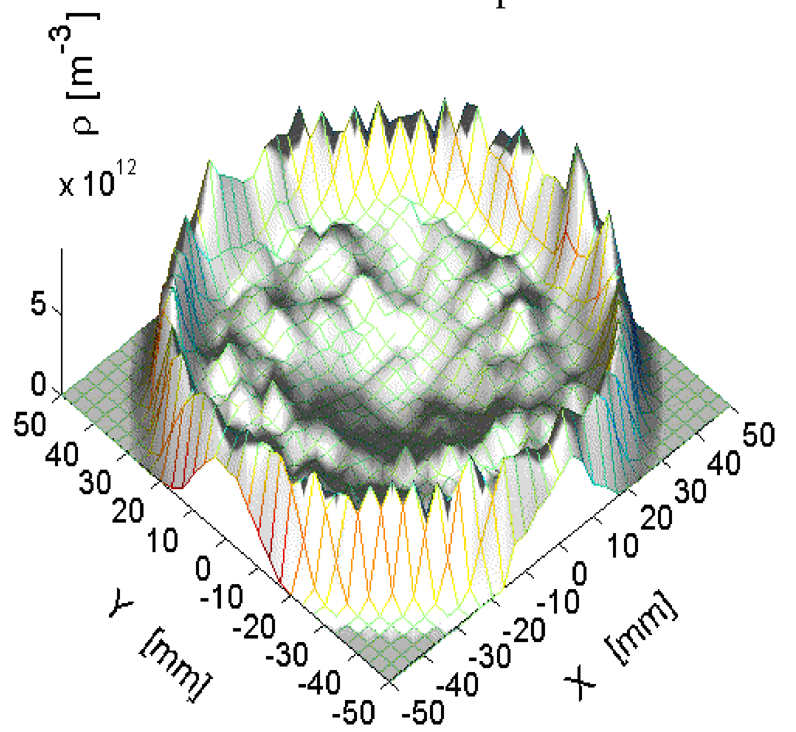
$$B_z = B_0 \left(\frac{2h}{l} + \frac{2ka}{p} \sum_{n=1}^{\infty} \sin nhk K_1(nka) I_0(nkr) \cos nkz \right)$$

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

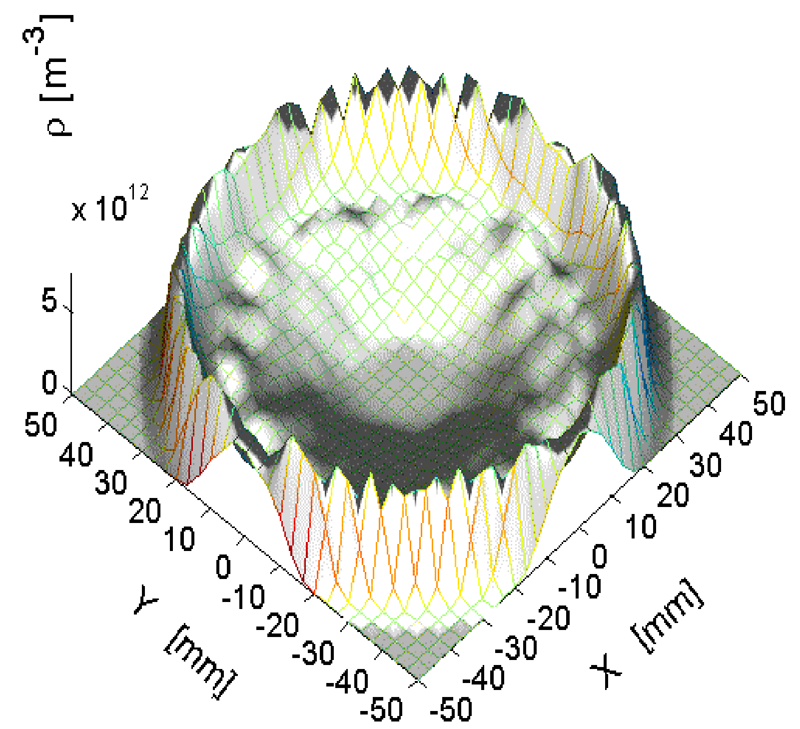
By E. Perevedentsev

B_0=50 Gauss, h=0.4 m, a=120 mm, l =1 m and 2 m

$N_p = 8\times 10^{10}$, 8ns spacing, KEKB



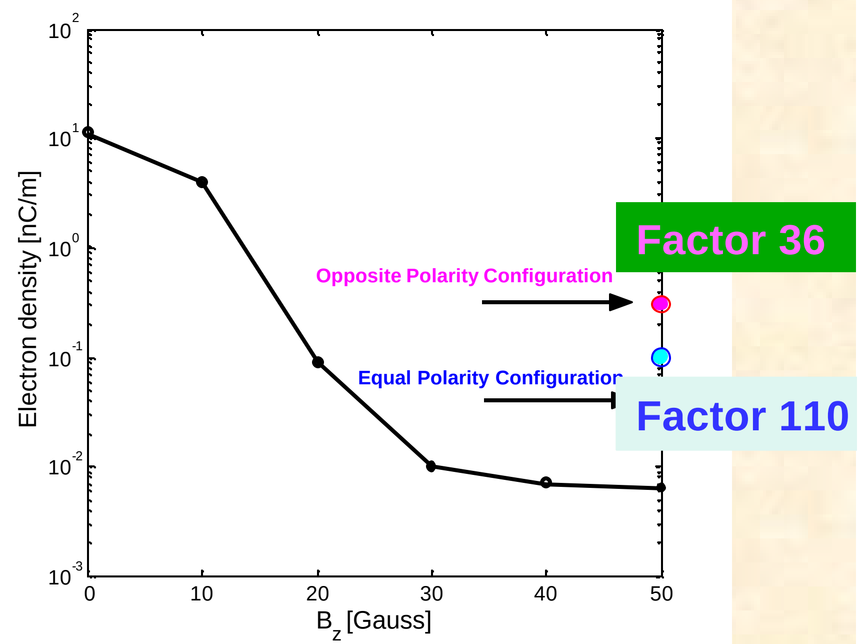
Opposite polarity

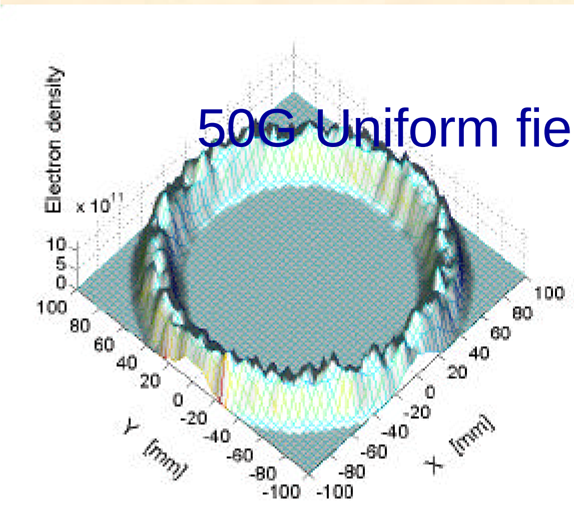


Equal polarity

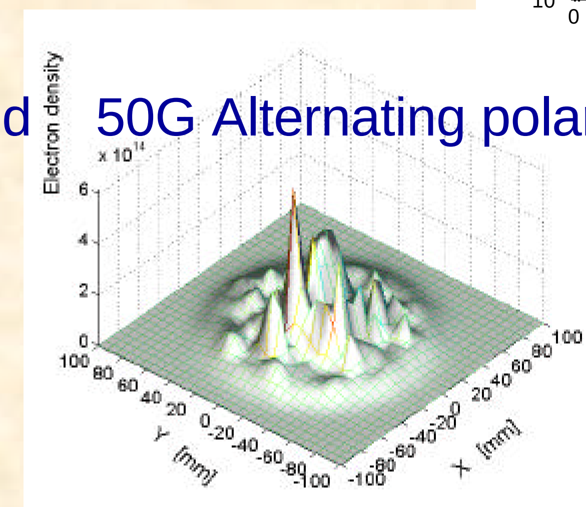
The effect of Solenoid configuration effect--- (SNS)

- The more uniform the solenoid field, the more effective the confinement.
- No Multipacting+zero central density+low level heating

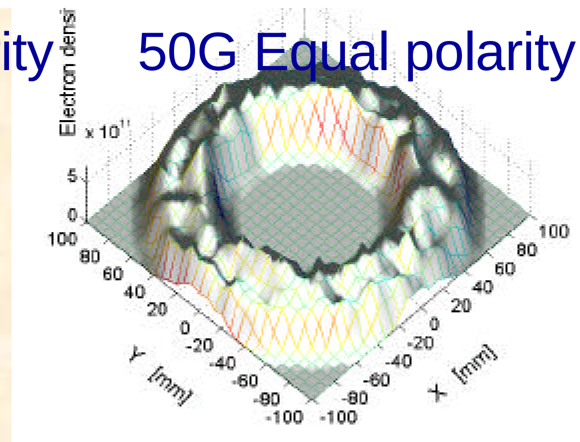




50G Uniform field



50G Alternating polarity

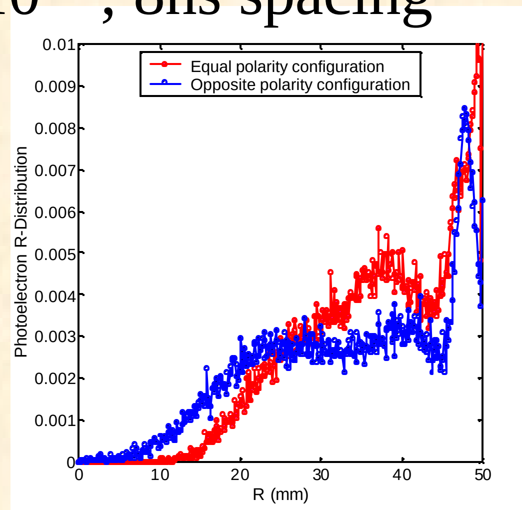


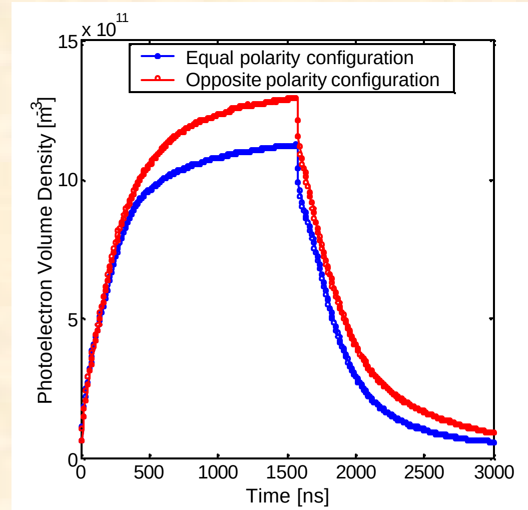
50G Equal polarity

Distribution of E-cloud with solenoid (KEKB)

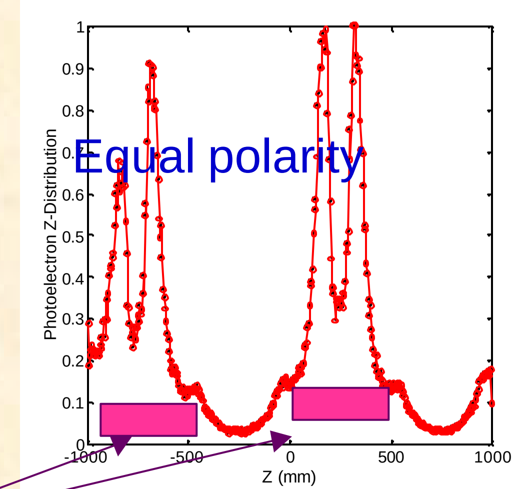
$N_p = 3.3 \times 10^{10}$, 8ns spacing

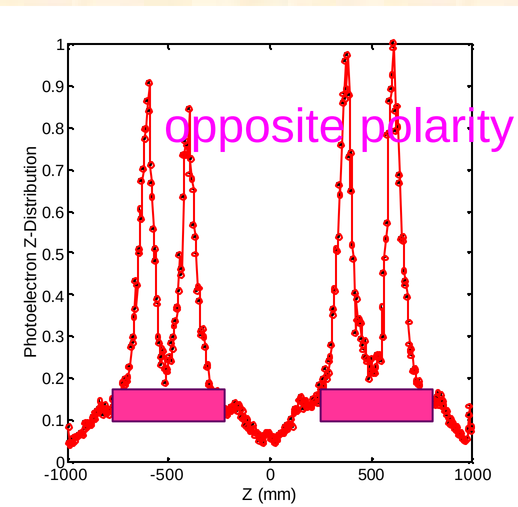
- **Equal polarity is better than opposite polarity (on both r-distribution and density)**
- **E-cloud are trapped in solenoid instead of the gap!**
- **Slower saturation and long decay time!**





Radial distribution



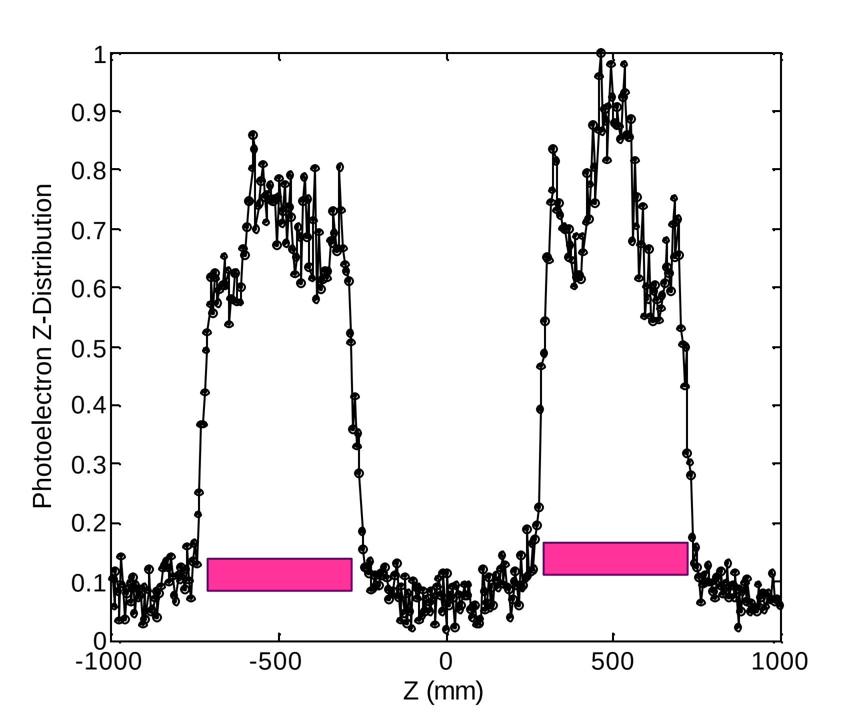


solenoid

Longitudinal distribution

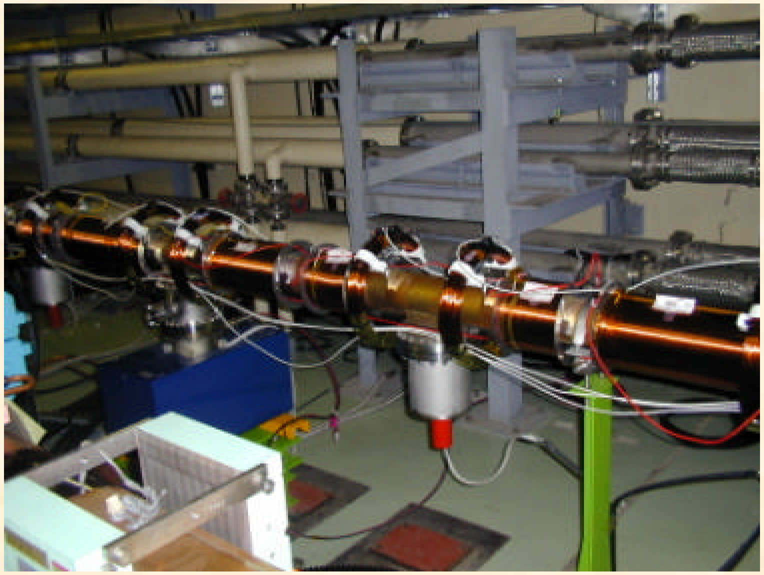
Longitudinal E-cloud distribution in SNS

- E-cloud are trapped in solenoid with opposite configuration.
- Longitudinal distribution of E-cloud with equal solenoid configuration is close to uniform.

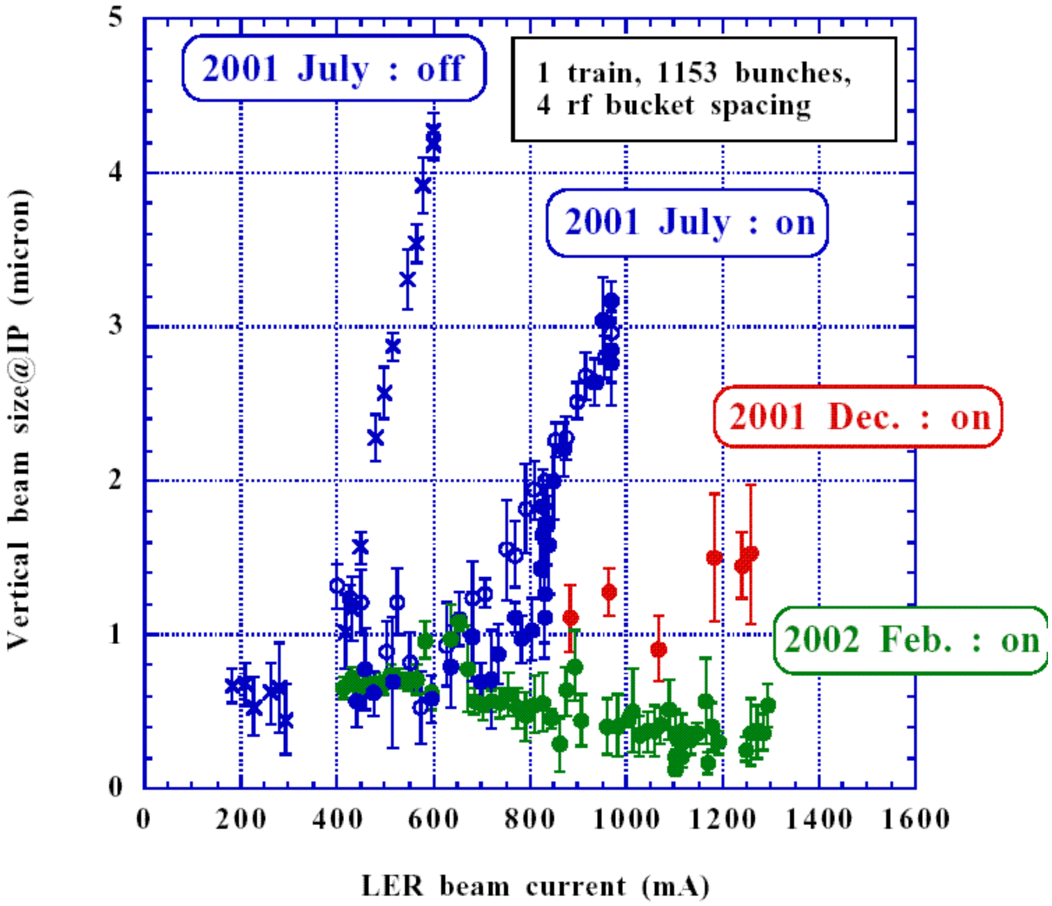


Electron Z-distribution with opposite configuration

Solenoid effect on beam size in KEKB LER



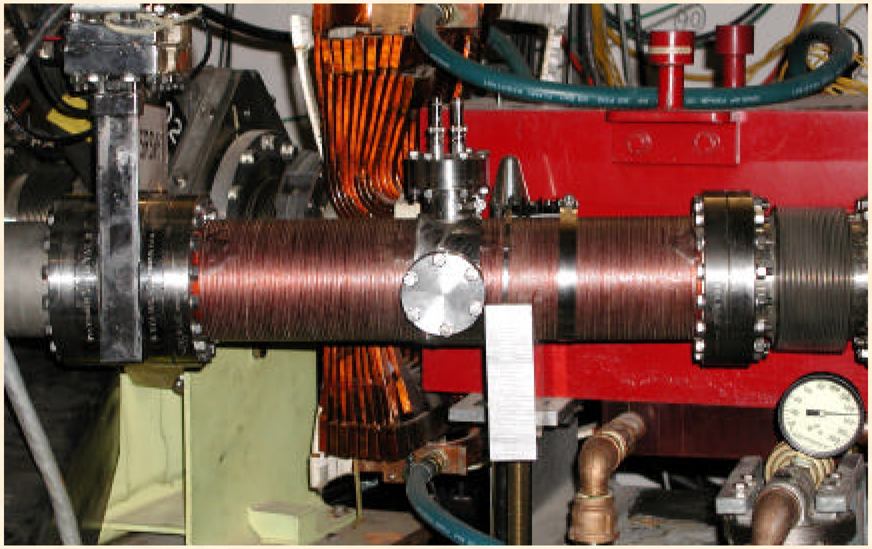
H. Fukuma, e-cloud'02



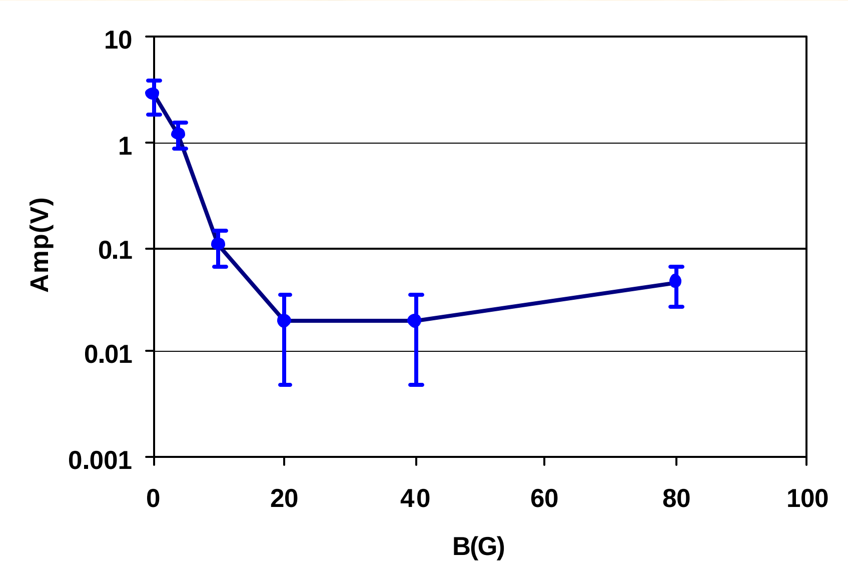
After last installation of solenoid, blowup was disappea up to 1300mA.

Solenoid effect ------PSR experiment

- **20G Solenoid field can reduce the e-cloud signal with a factor > 50 !**
- **10% of the ring is covered by solenoid, but solenoid has no effect no the instability threshold !**



Picture of RFA (ED92Y) in a short solenoid in section 9 of PSR



Effect of weak solenoid on prompt electron peak (ED92Y)

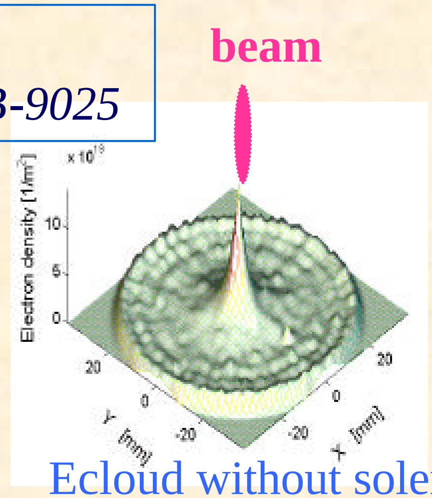
Physics model for wake of e-cloud

Ref: K. Ohmi, F. Zimmermann E. Perevedentsev, Phys.Rev.E65:016502, 2002. & S. Heifets, SLAC-PUB-9025

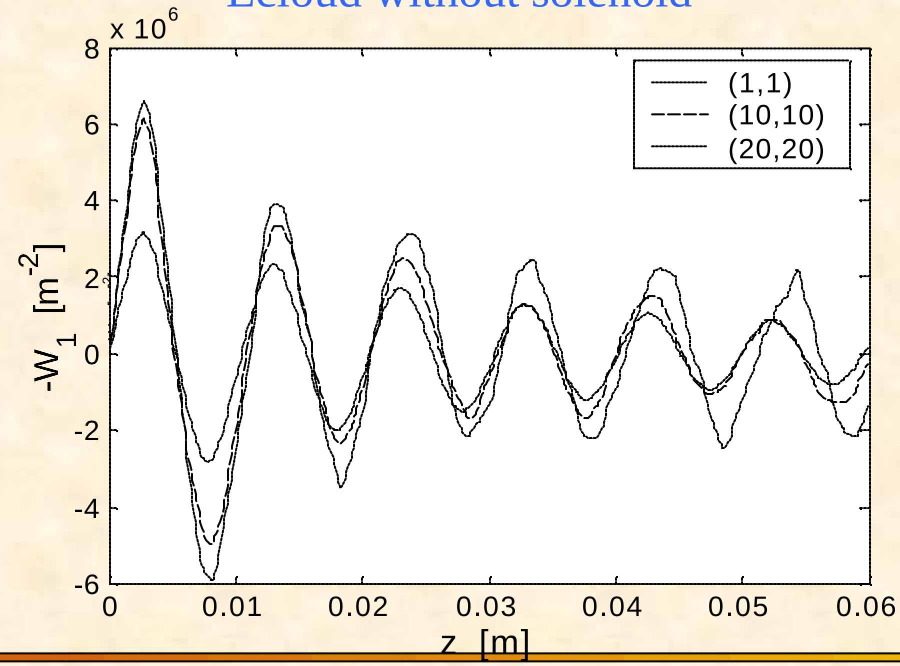
$$\frac{d^2\mathbf{x}_{e,a}}{dt^2} = -\frac{2N_+ r_e c}{N_b}\sum_{i=1}^{N_p}\mathbf{F}_G(\mathbf{x}_{e,a}-\bar{\mathbf{x}}_{p,i}; s)\, d(t-t(s_b))$$

$$\Delta\bar{x}'_{p,j} = -\frac{2r_e}{g}\sum_{i=1}^{N_e}\mathbf{F}_G(\bar{\mathbf{x}}(s)_{p,i}-\mathbf{x}_{e,a}; s)$$

$$W_1(z_i - z_j) = \frac{g}{N_b r_e}\frac{\Delta\bar{x}'_{p,i}}{\bar{x}_{p,i}}$$

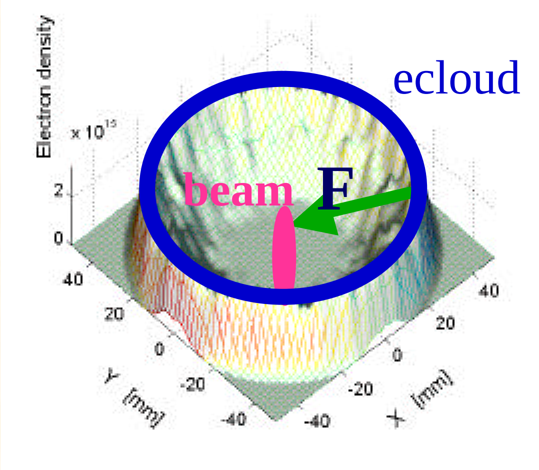


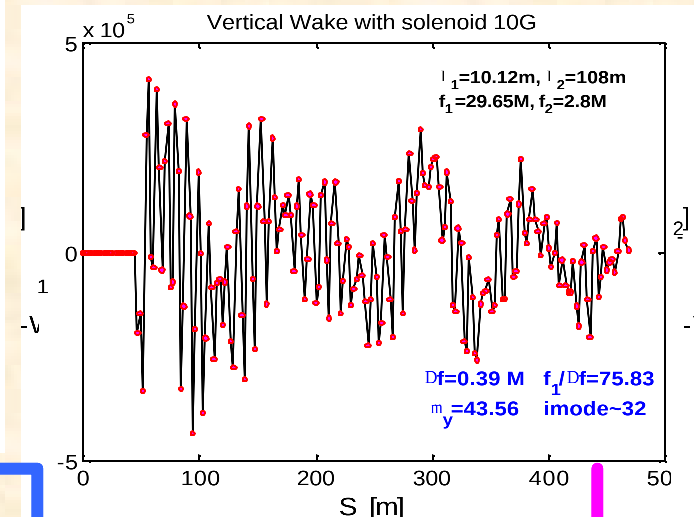
Ecloud without solenoid

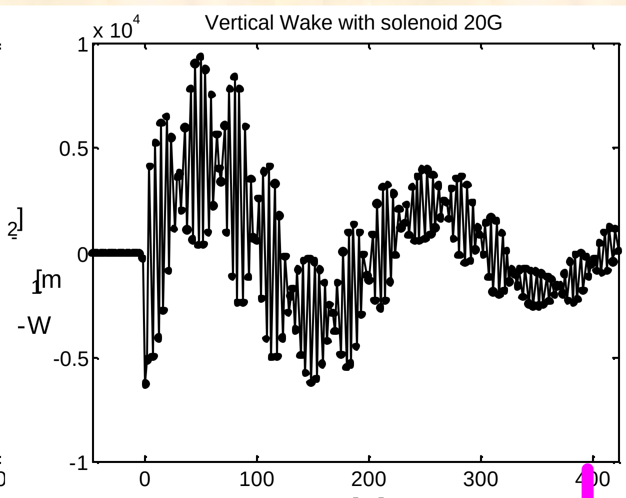


- **Wake strongly depends on the electron density near the beam**
- **Wake depends on the electron cloud distribution.**

Long range wake of electron cloud with solenoid (KEKB)





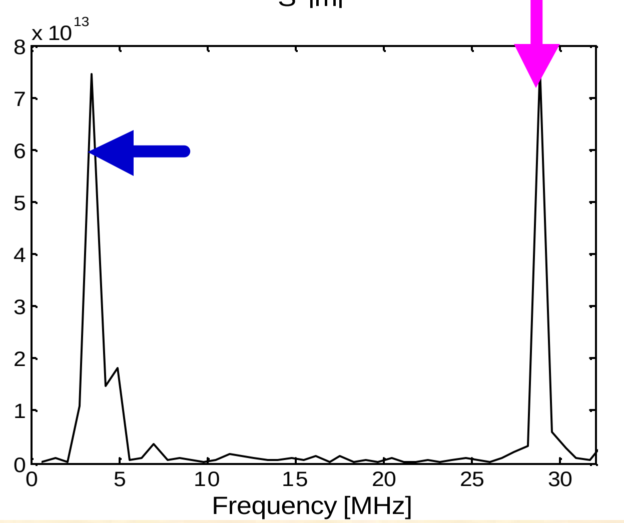


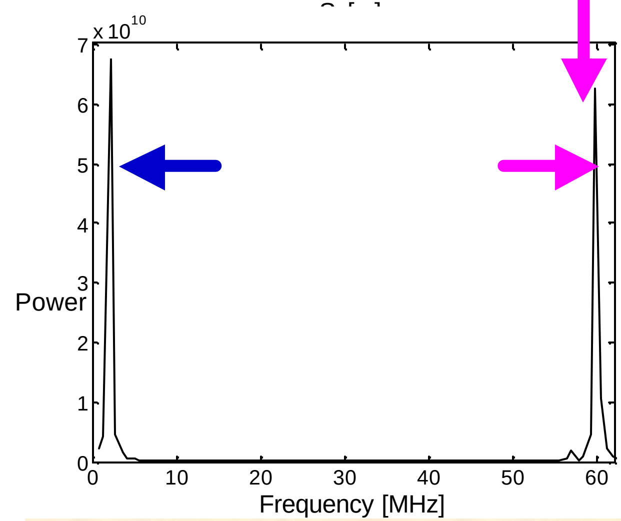
Wake has two Modes:

One depends on the electron bounce frequency. The frequency of this mode usually decreases when solenoid fields increase.

Another one comes from the gyration motion of electrons

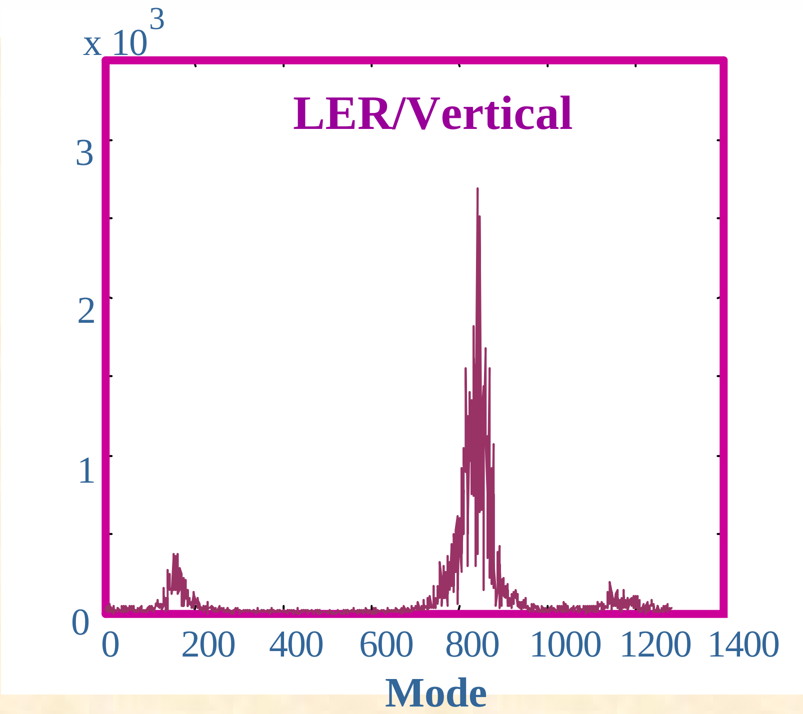
$$f_c = \frac{eB}{2pm_e}$$

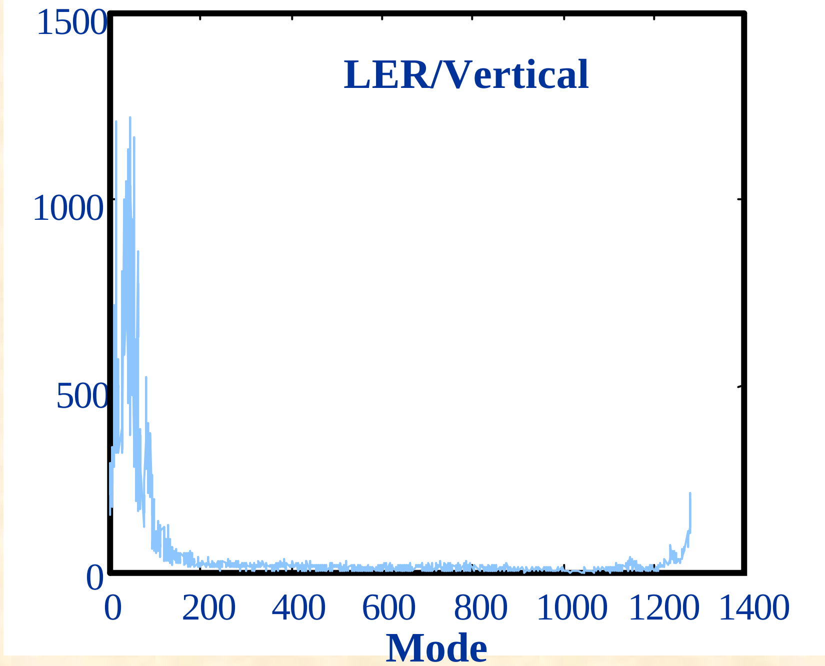




B=10G $N_p=3.3\times10^{10}$, 8ns spacing B=20G

Coupled bunch instability in KEKB LER (Experiment)





Solenoid off

Solenoid on

- **The growth rate of CBI reduces about 20~30%(2002 data) when solenoid is on**

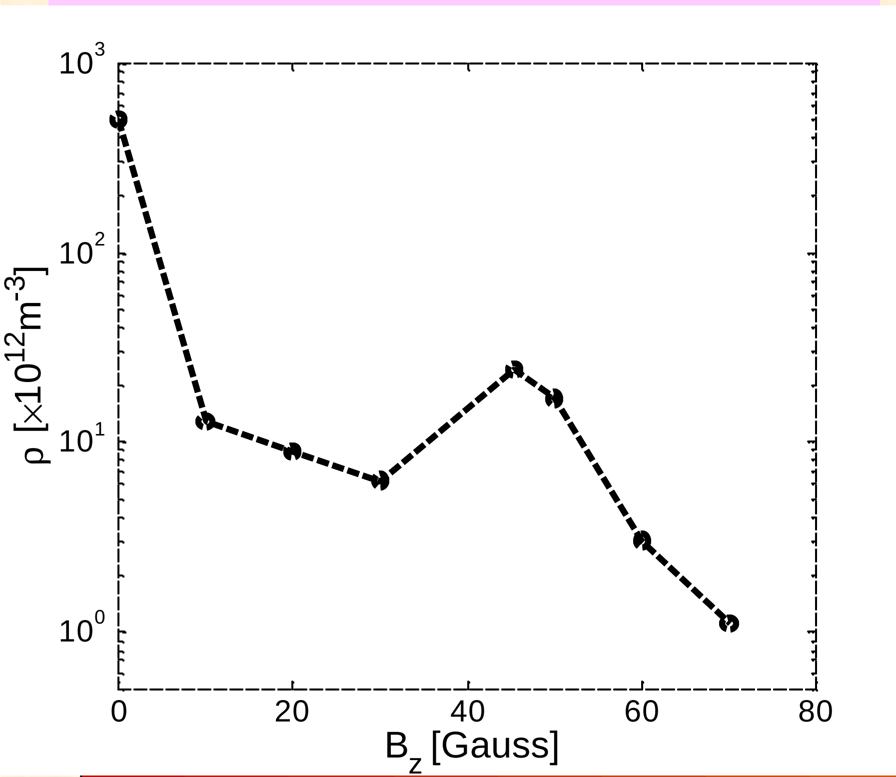
Resonance of e-cloud build-up

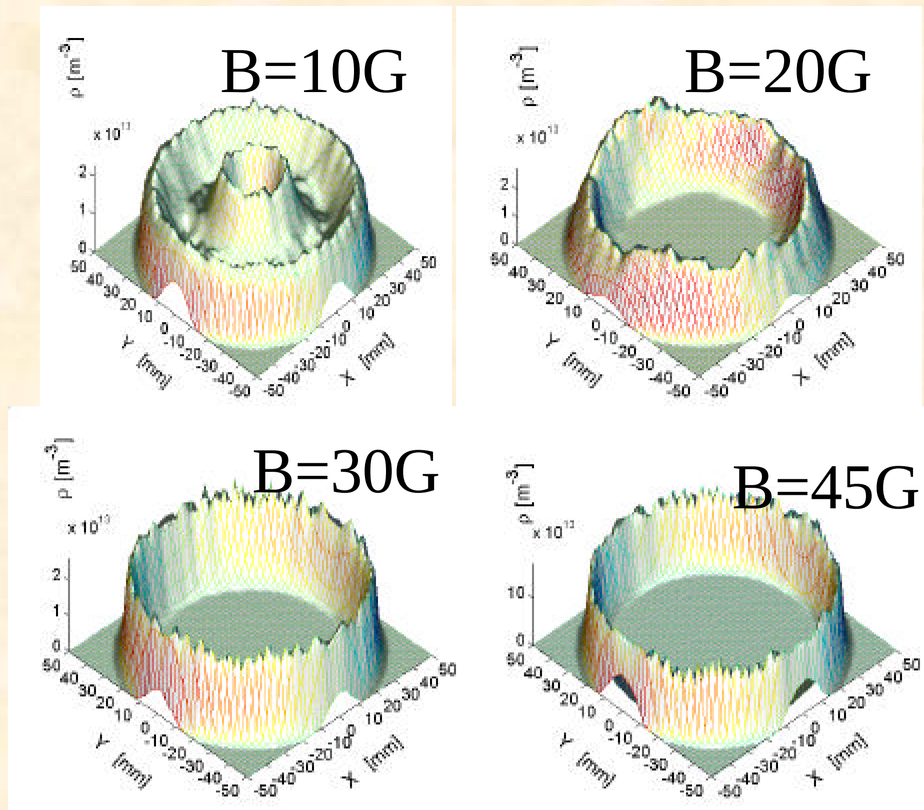
Strong multipacting occurs when $T/2 = S_b/c$

There is a resonance at 22G and 45G for 8ns and 4ns spacing

There is no such kind of resonance for SuperB (2ns sp) if Bz<90G.

Y. Cai, M. Pivi, M. Furman, PRSTAB, 7:024402,2004
A. Novokhatski, J. Seeman, SLAC-PUB-9950

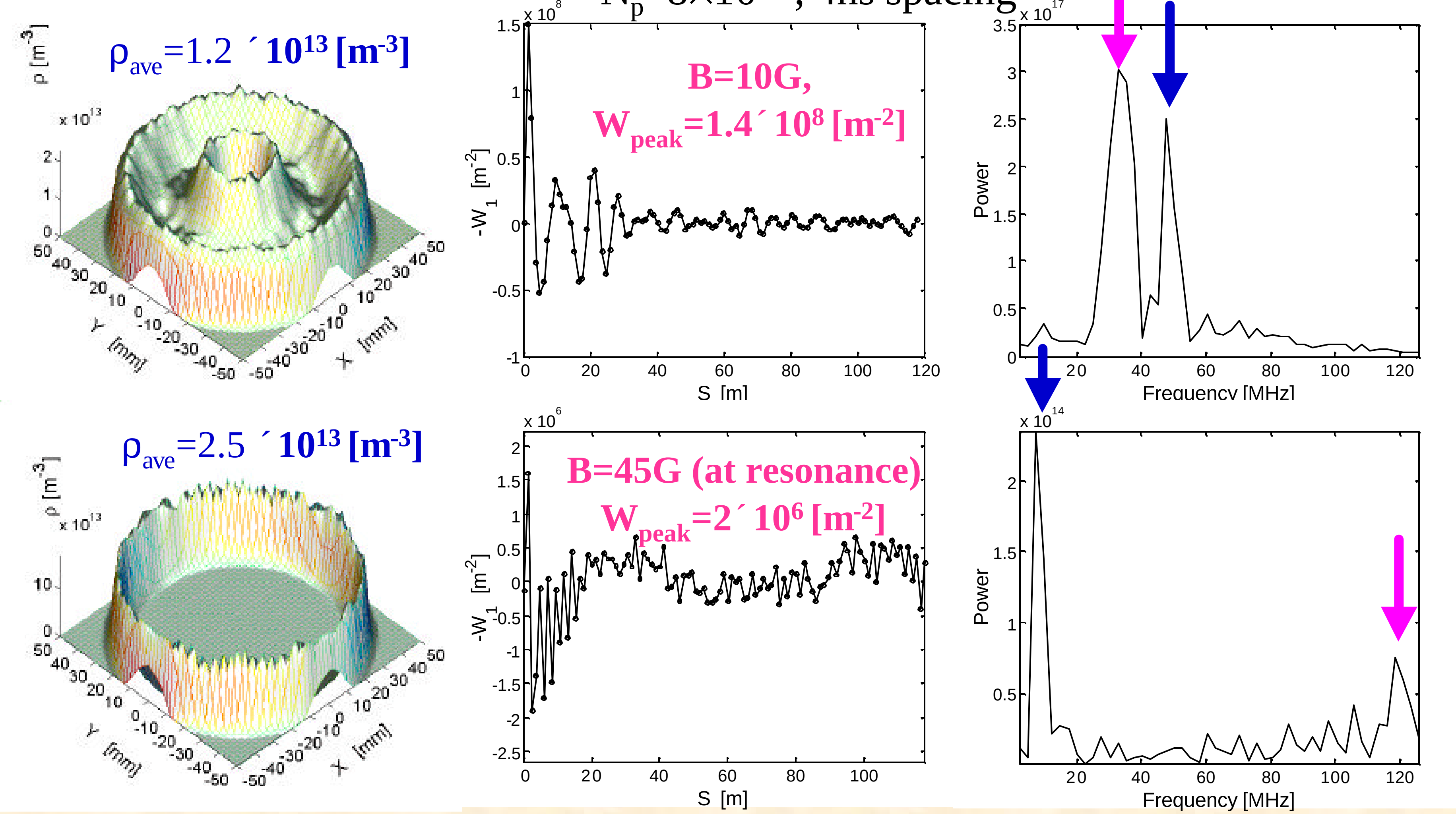




$N_p=8\times10^{10}$, 4ns spacing

Wake with different solenoid field

$N_p = 8\times10^{10}$, 4ns spacing

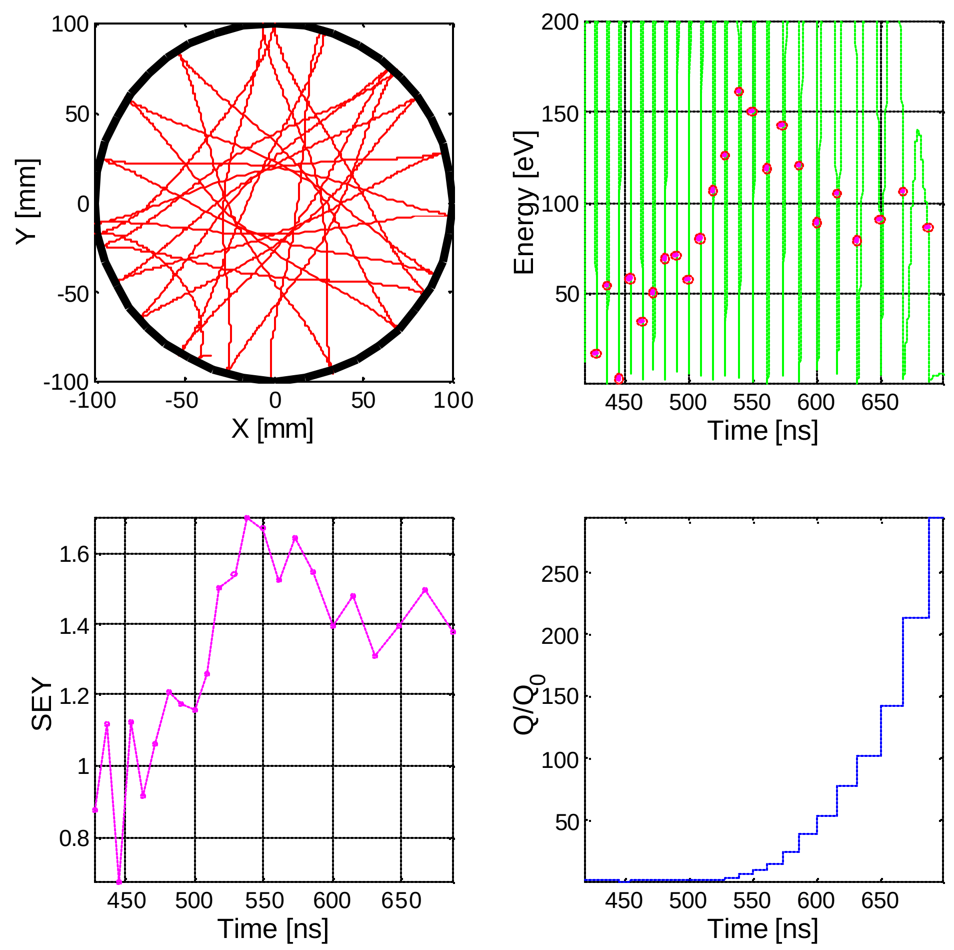


Wake strongly depends on the electron distribution!

Conclusion

- A weak solenoid field (up to 50-Gauss) can confine all electrons near the wall surface and suppress electron multipacting by reducing the electron's energy at the chamber surface. It works for both long and short bunch, but only in drift region. (Work in quadrupole? F. Zimmermann).
- Required clearing solenoid field strongly depends on beam (beam pattern, bunch current, chamber size…). Higher beam current usually need stronger solenoid fields
- Equal polarity configuration is better with zero density at chamber center, especially for long bunch case. Electrons are longitudinally trapped inside solenoid except long bunch with equal polarity case. Uniform solenoid field is more effective.
- The wake of electron cloud has two modes. One is cyclotron mode.
- Solenoid can suppress beam size blow-up, CBI for short bunch case.
- The electron cloud at resonance contributes high heat-load at the wall but it may be not a problem for beam dynamics if electrons stay close to chamber. There is no resonance for SuperB if Bz<90G.

Clearing mechanism—*long bunch case*

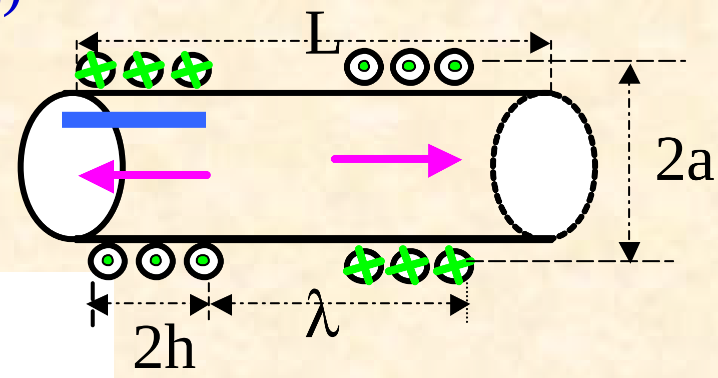


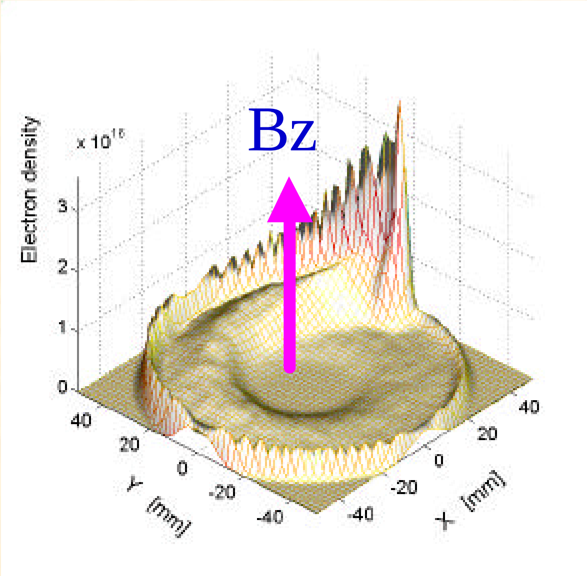
Bz=10G

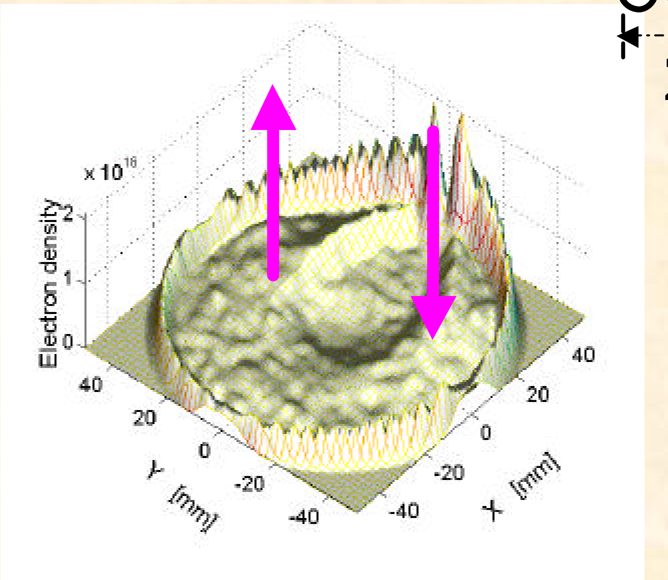
The effects of Solenoid configuration (short bunch case)

The distribution depends on the initial electron distribution & solenoid field direction (Bz)

$N_p=3.3\times10^{10}$, 8ns spacing, KEKB







B_{max}=50 Gauss, l =1 m equal polarity *B_{max}=50 Gauss, l =2 m opposite polarity*