The Electron Cloud Instability Studies in BEPC

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Outline

I. Introduction

II. Experimental Studies in BEPC

III. Simulation Studies for BEPCII

IV. Summary

I. Introduction

- **Studies started from 1996 under the collaboration with KEK**
- **Coupled bunch oscillation observation and parameters dependence investigation**
- **Electron cloud measurement using detectors**
- **Observation on coupled bunch oscillation and beam size to survey the different cure methods**
- **Simulation study by developing codes**

II. Experimental Studies

1. **Vertical sidebands observation**
2. **Electron cloud measurement**
3. **Various effects on ECI:**
   - **a) solenoid**
   - **b) clearing electrode**
   - **c) chromaticity**
   - **d) octupole**

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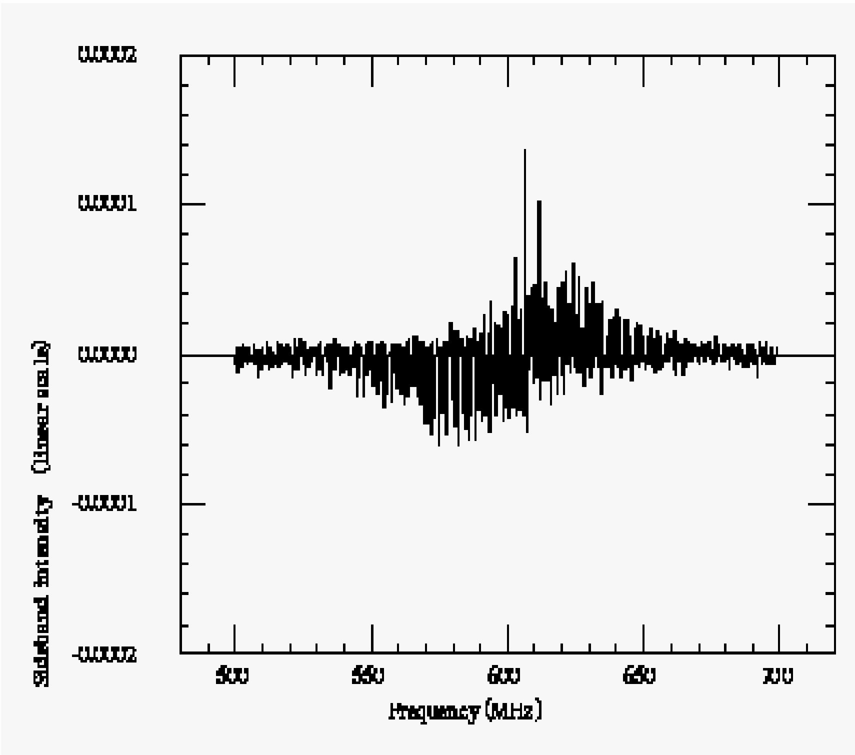
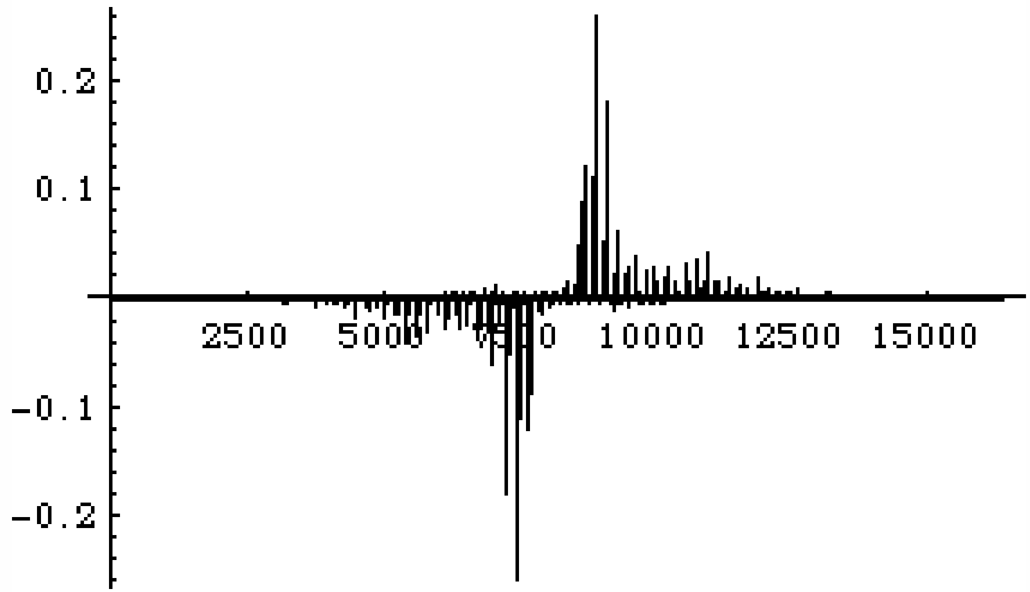
1. Vertical sidebands observation



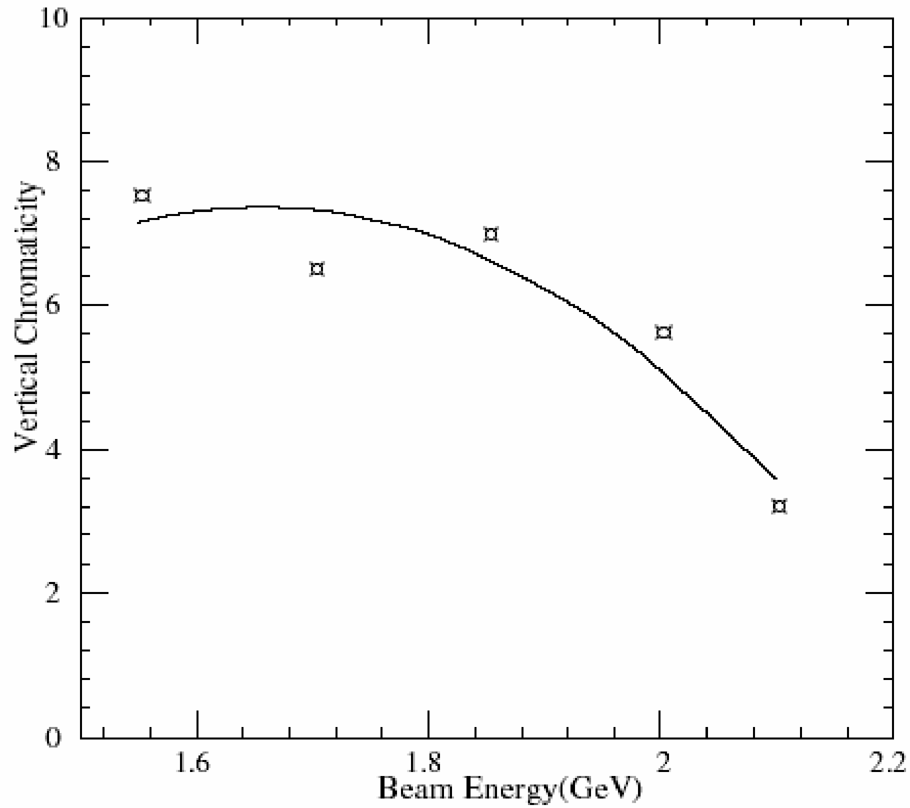
Experiment



simulation

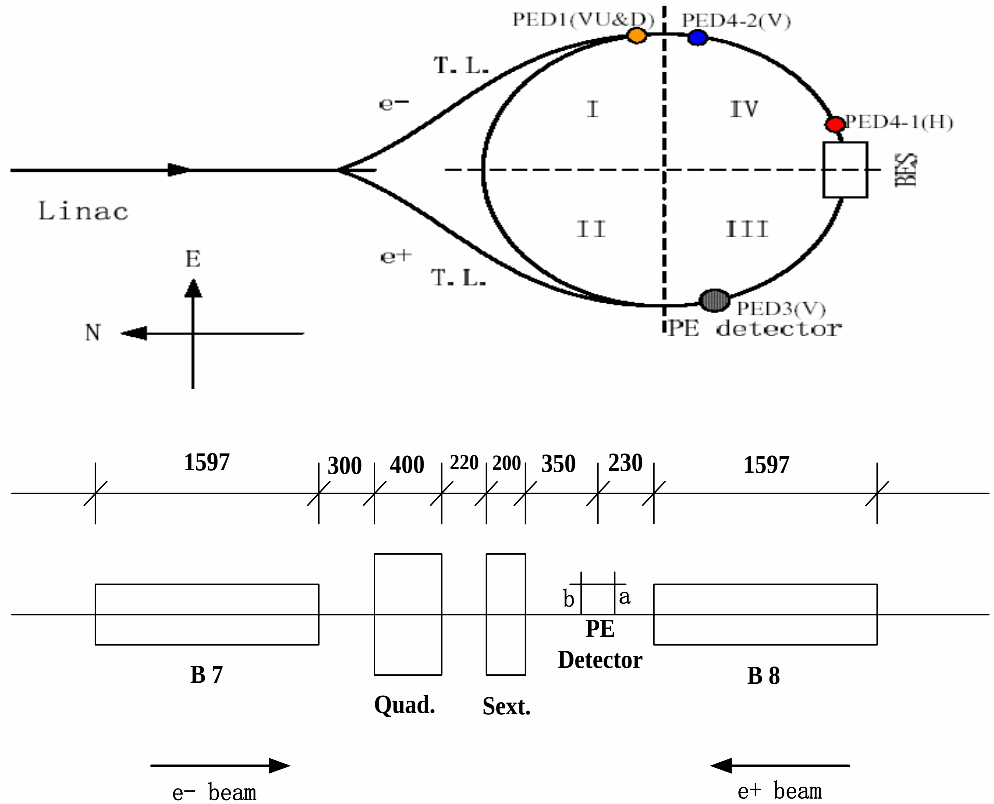
Parameter dependence

- Bunch spacing
- Bunch train
- Chromaticity
- Beam energy
- Beam emittance
- Other parameters

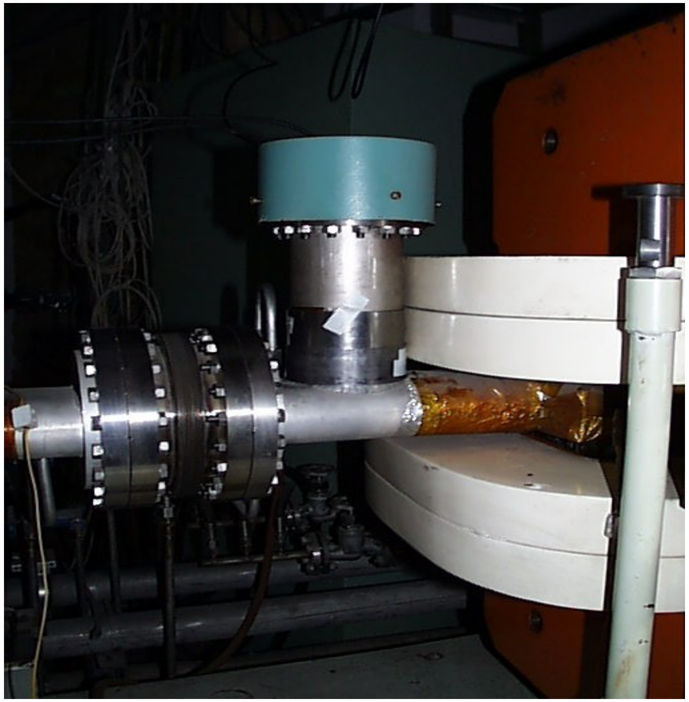
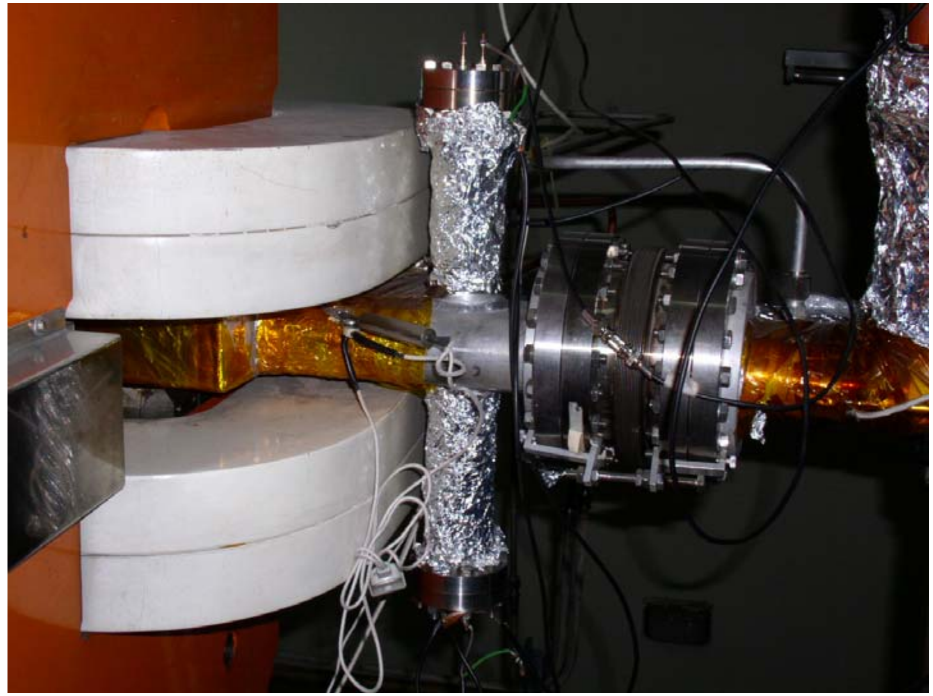


The energy dependence on chromaticity at the threshold of the instability.

2. Electron cloud measurement

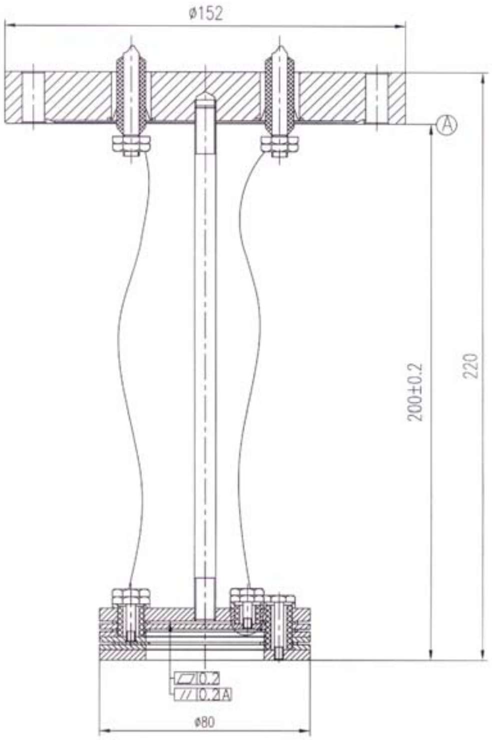


Detector location

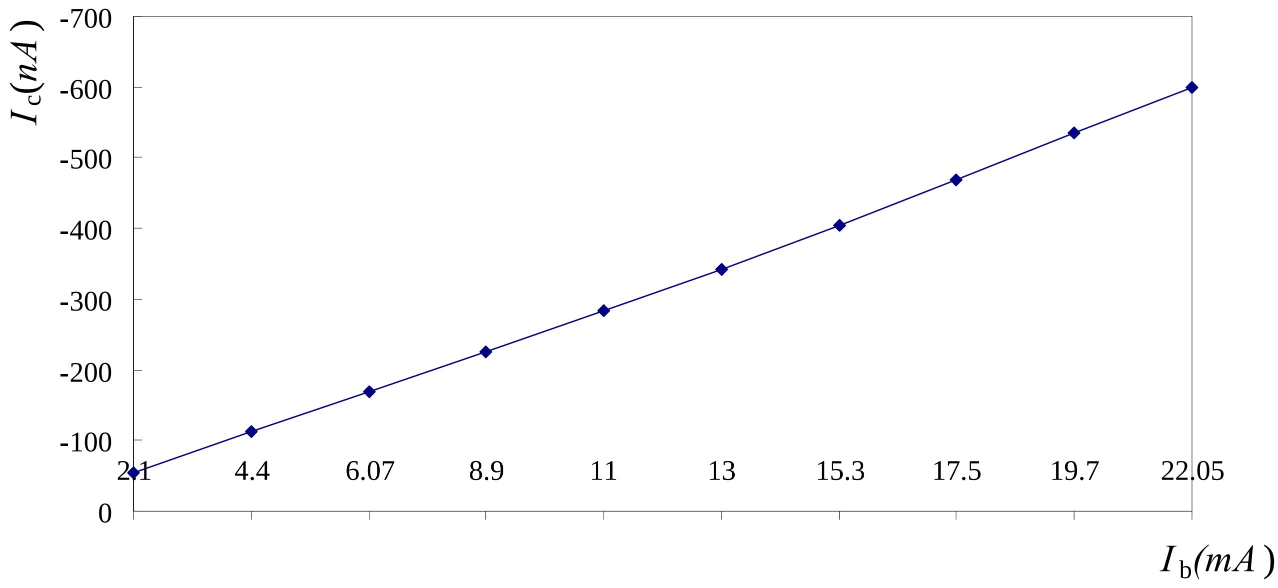
 

Detectors on BEPC

Inner structure of detector

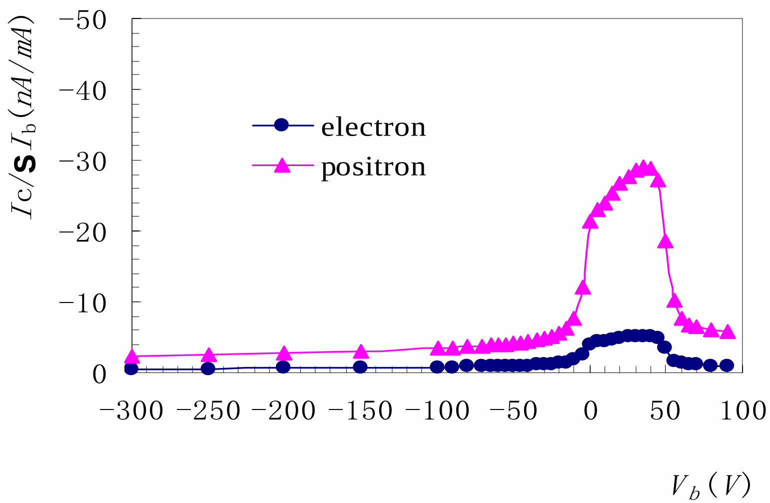


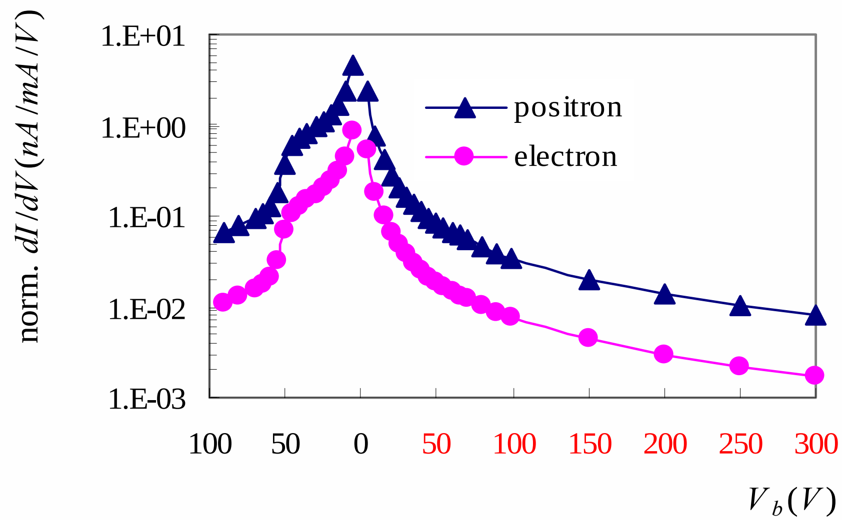
2. Electron cloud measurement (cont.)



EC measured vs. beam current

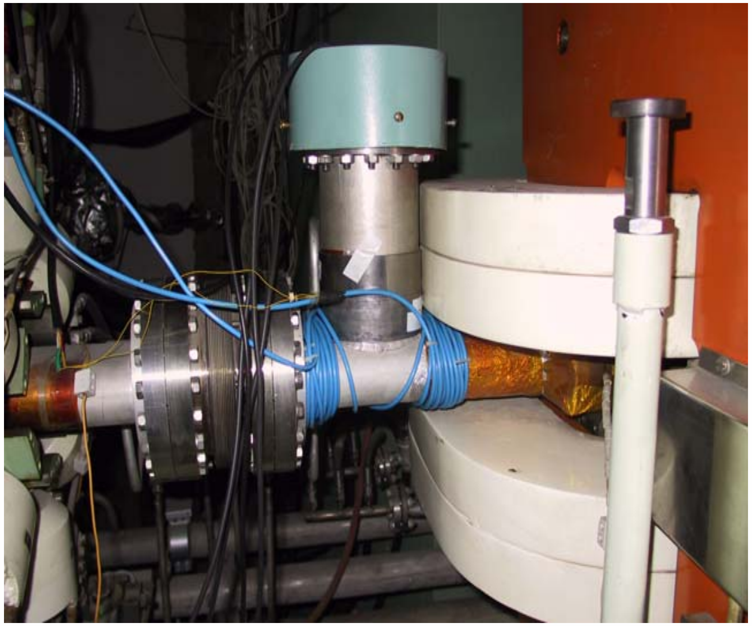
2. Electron cloud measurement (cont.)





Electron energy distribution using e^+ and e^- beam

3a. Solenoid effect on EC collection



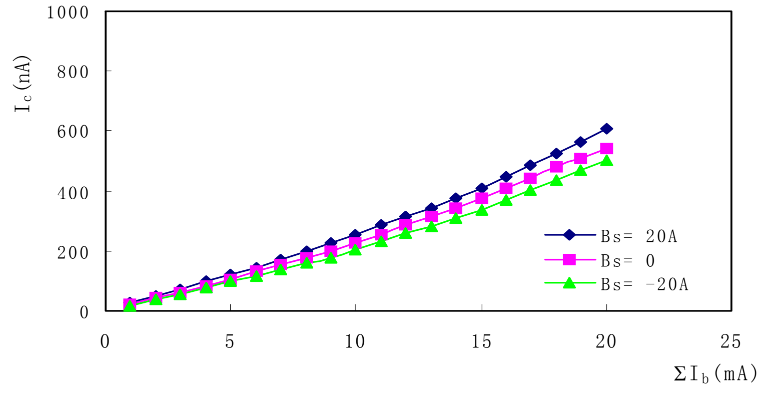


Fig 5.1 Solenoide field effect(before more shielding)

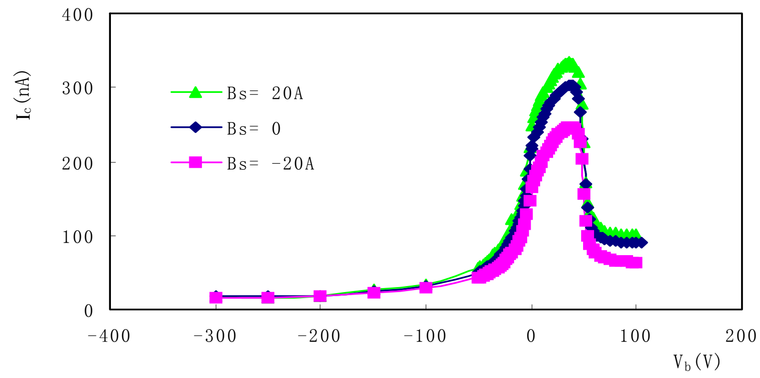
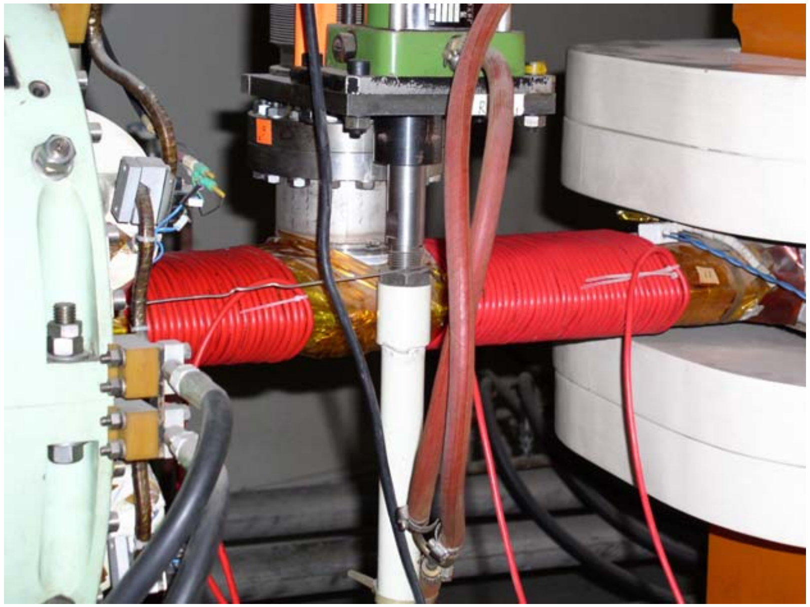
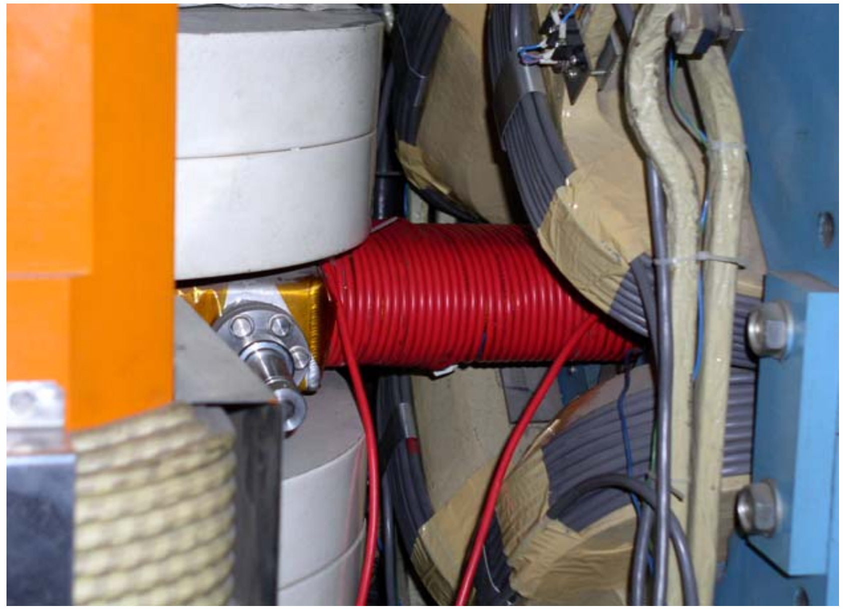


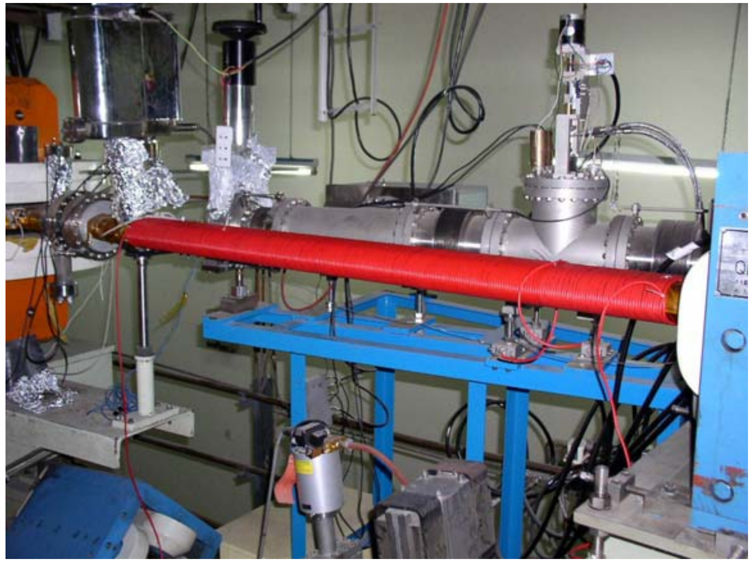
Fig 5.2 Solenoide field effect (after more shielding)
single bunch I_b=9.7mA

Solenoid winding on BEPC

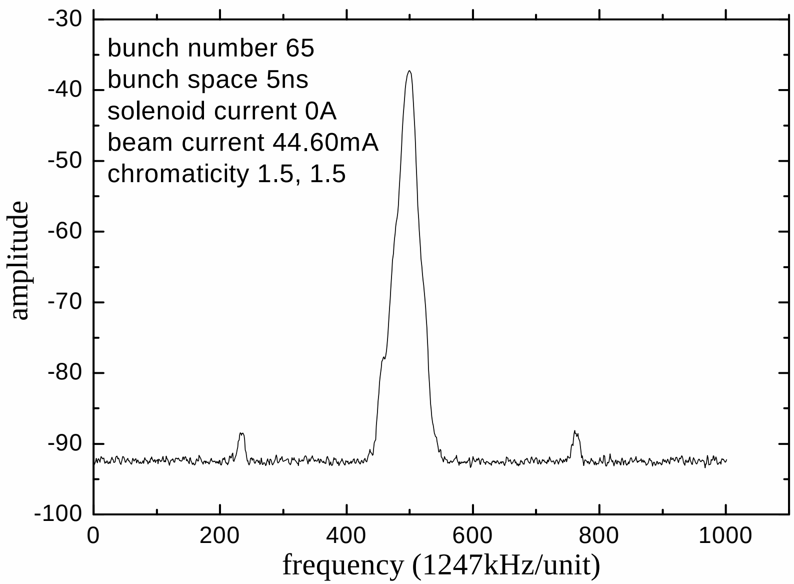


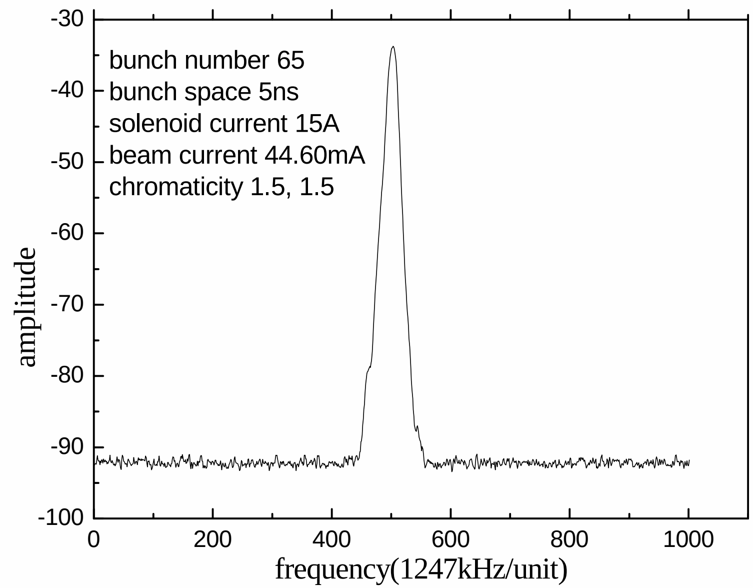


Solenoid winding on BEPC



3a. Experiment of solenoid effect (cont.)



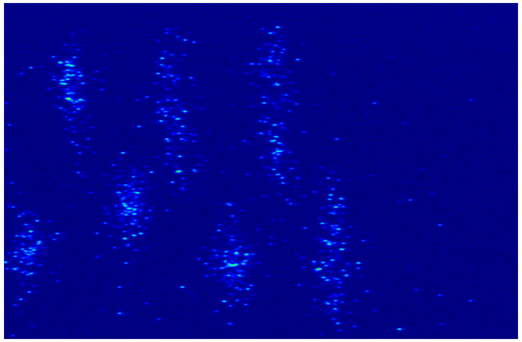


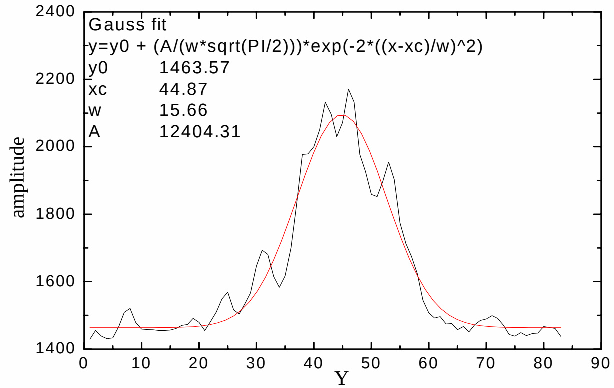
Betatron sideband

with solenoid off (left) and on (right)

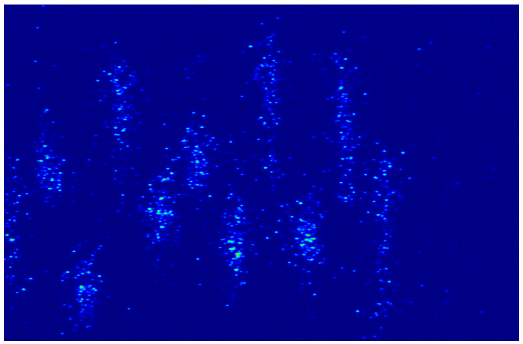
3a. Experiment of solenoid effect (cont.)

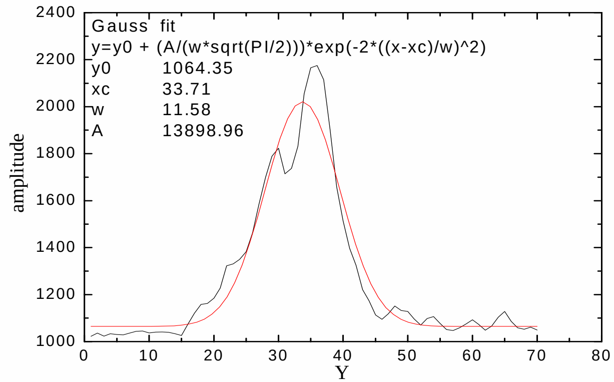
$B_s = 0$





$B_s = 15$

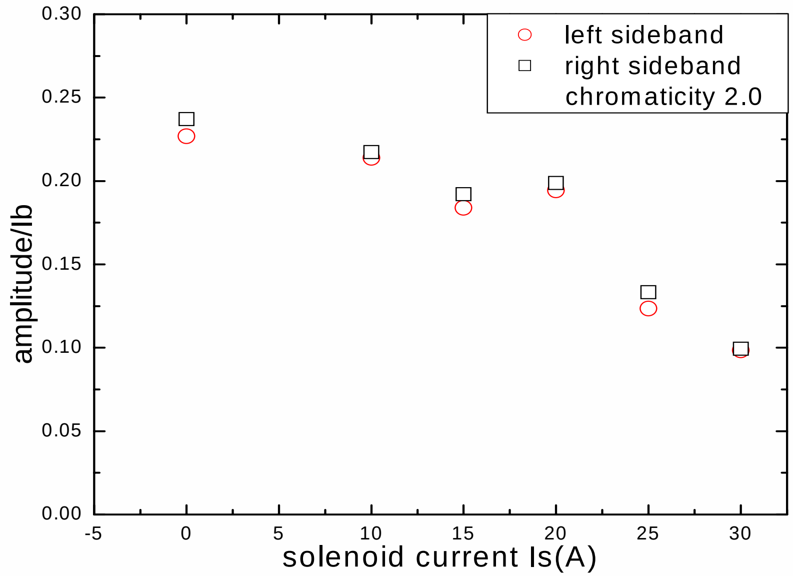


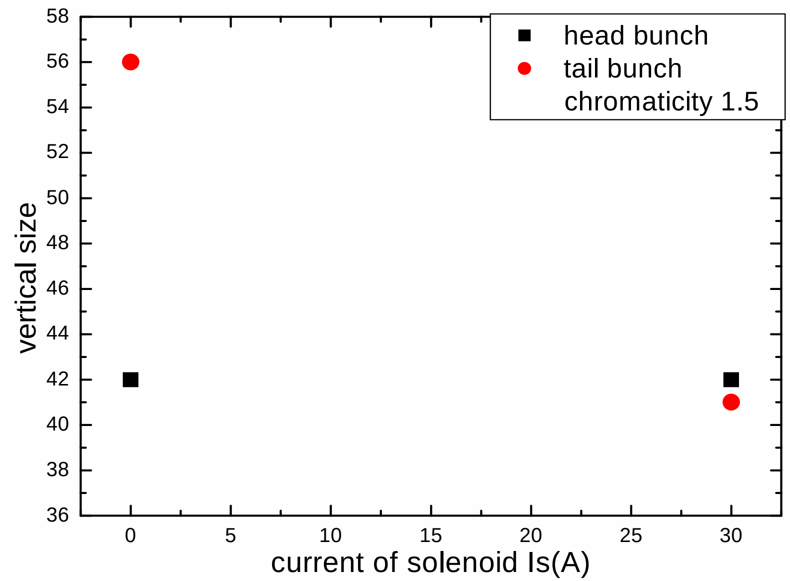


Vertical beam size

with solenoid off (up) and on (down)

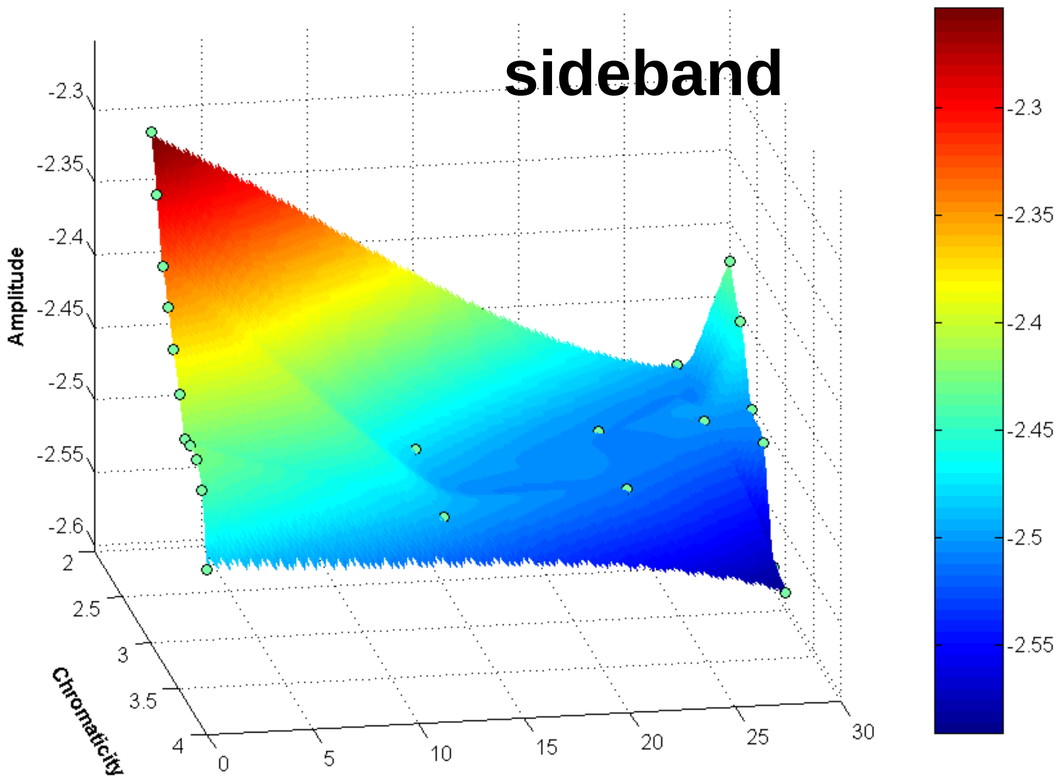
3a. Experiment of solenoid effect (cont.)





Amplitude of sideband (left) and bunch size (right) vs. solenoid strength

3a. Experiment of solenoid effect (cont.)



Solenoid current

3b. Experiment on electrode effect

- **Electron detector as one electrode**
- **BPM buttons as electrodes**
  32 BPM with 128 buttons
  A DC voltage supplied on the buttons
  from -600V to 600V

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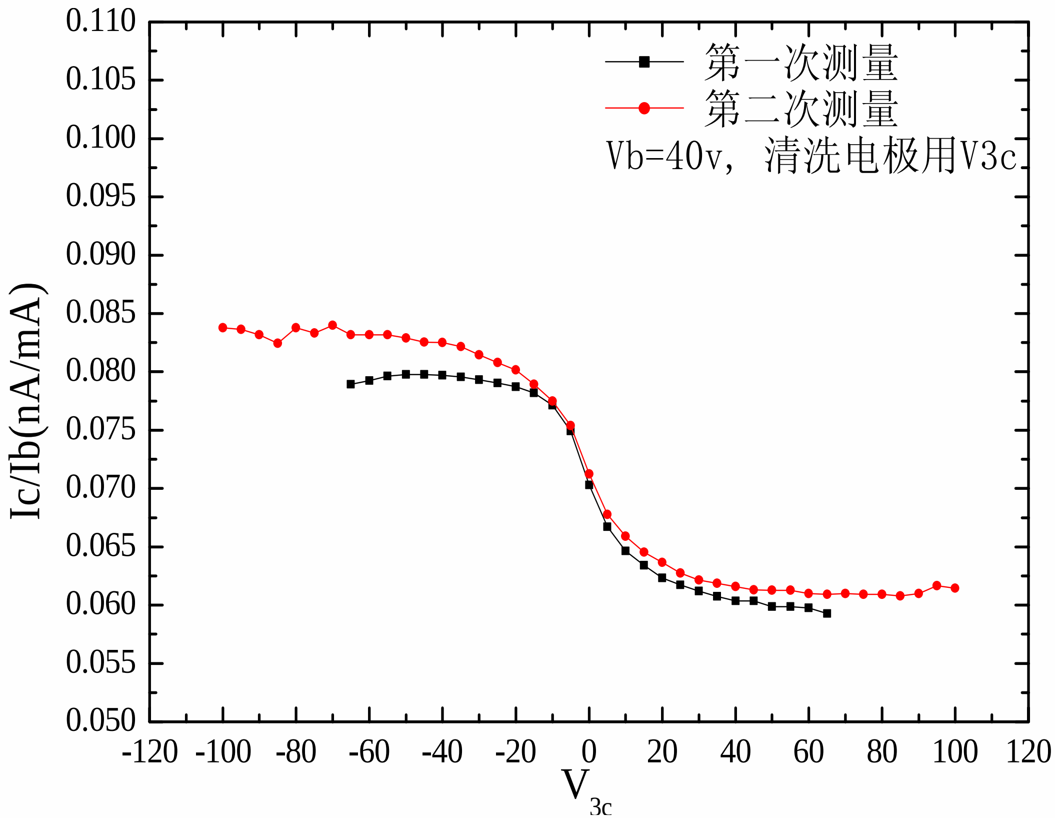
3b. Experiment on electrode effect (cont.)



EC vs electrode voltage using detector

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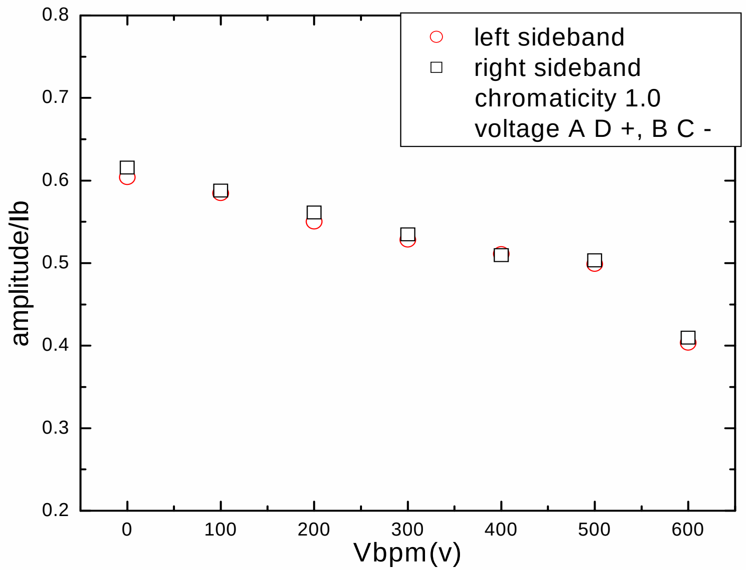
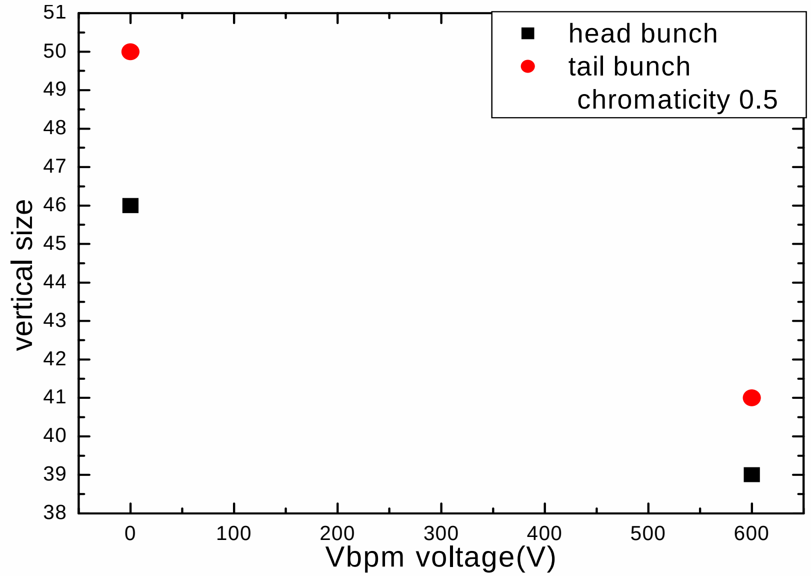
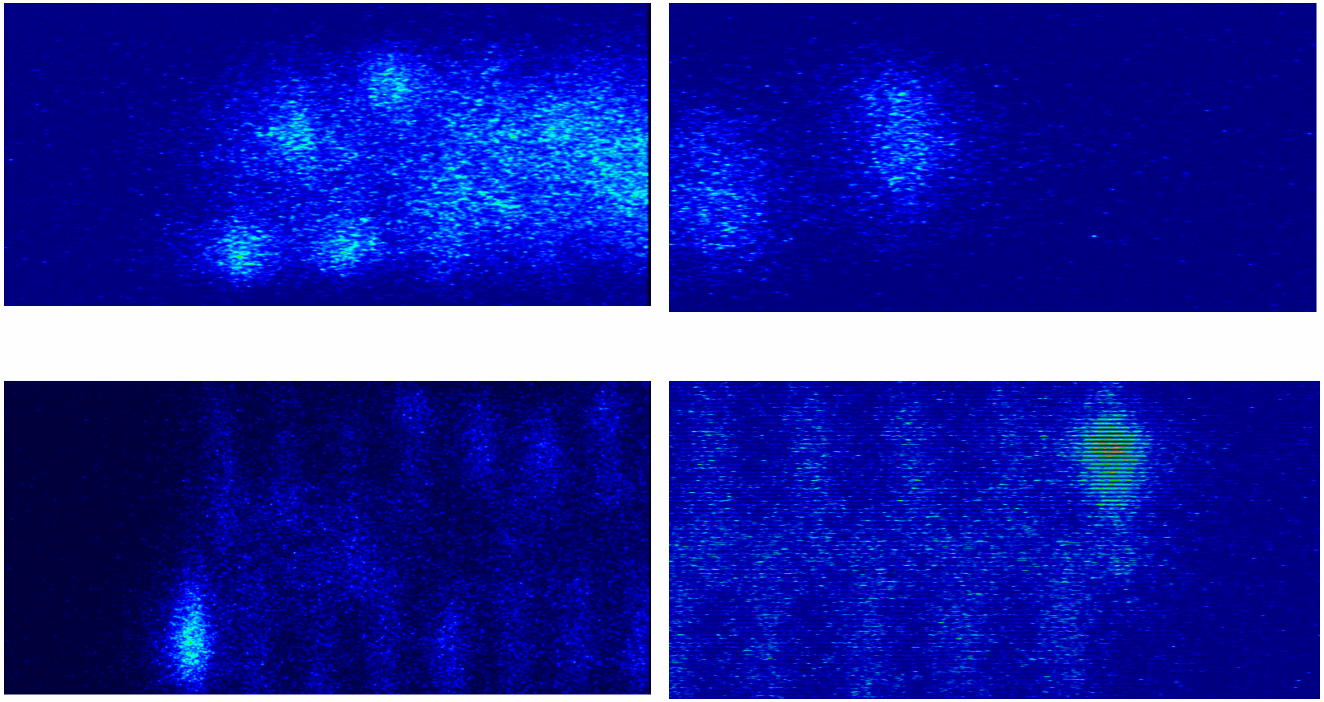
3b. Experiment on electrode effect (cont.)





Amplitude of sideband (left) and bunch size (right) vs. voltage on BPM buttons

3b. Experiment on electrode effect (cont.)



Beam size vs. voltage on buttons off (up) and on (down)
head of bunches (left) and tail of bunches (right)

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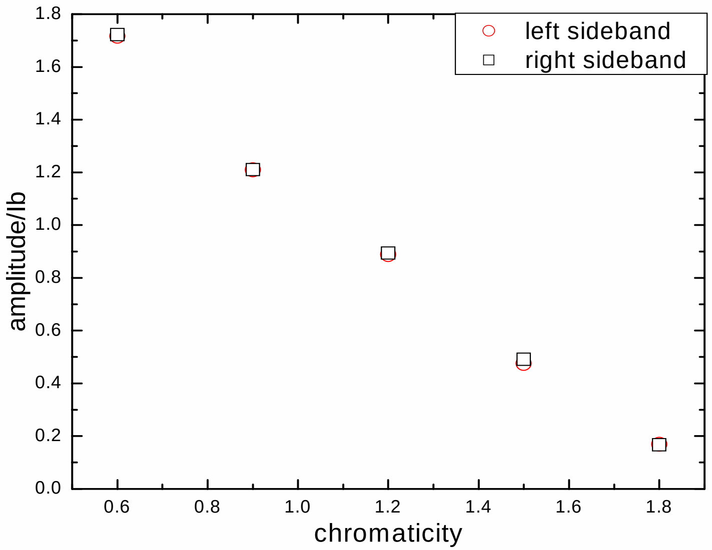
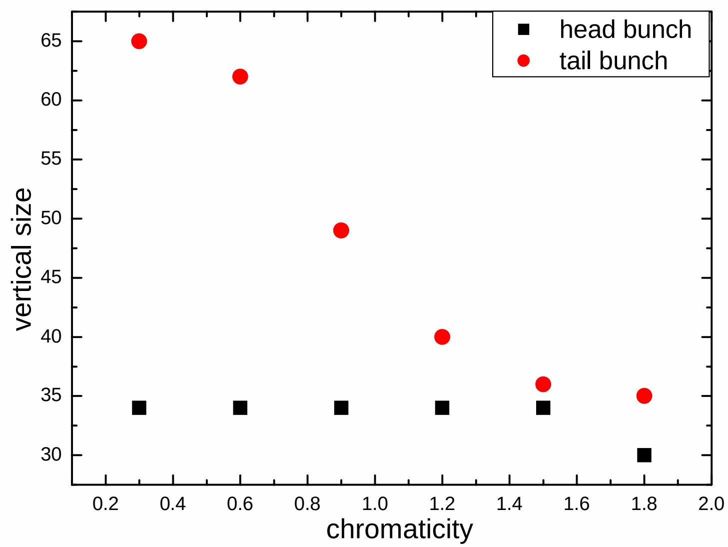
3c. Experiment on Chromaticity effect

The chromaticity can be changed from 0/0 to 8/8 in horizontal and vertical direction respectively, without change on the linear lattice and with no beam loss

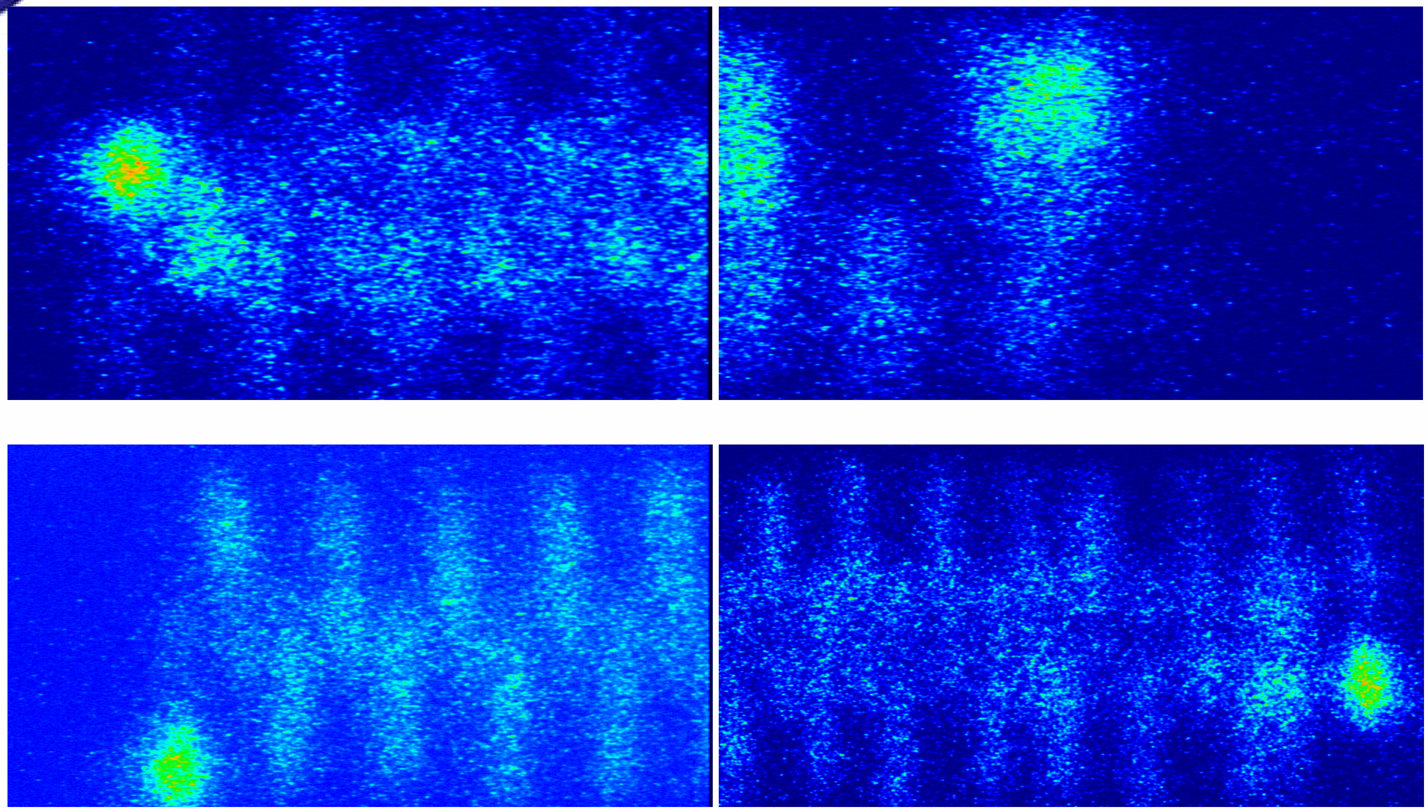
3c. Chromaticity effect experiment (cont.)





Amplitude of sideband (left) and bunch size (right) vs. chromaticity

3c. Chromaticity effect experiment (cont.)

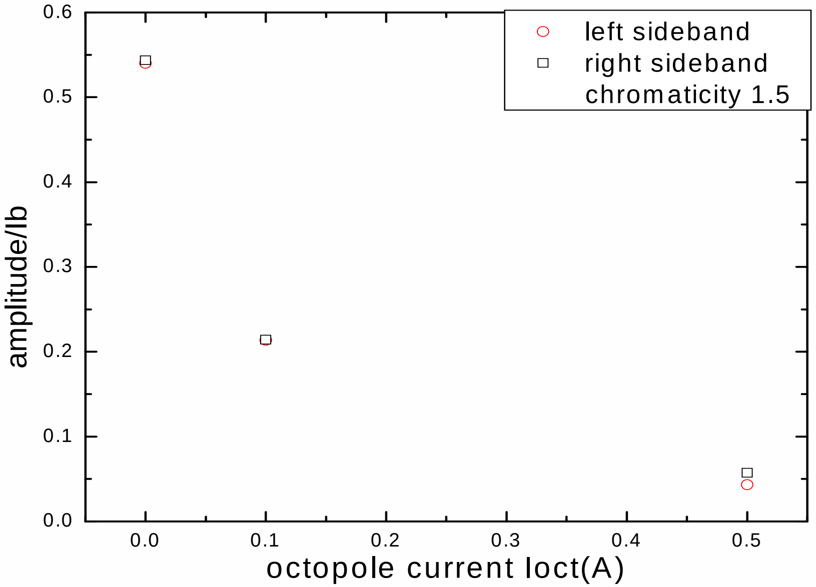


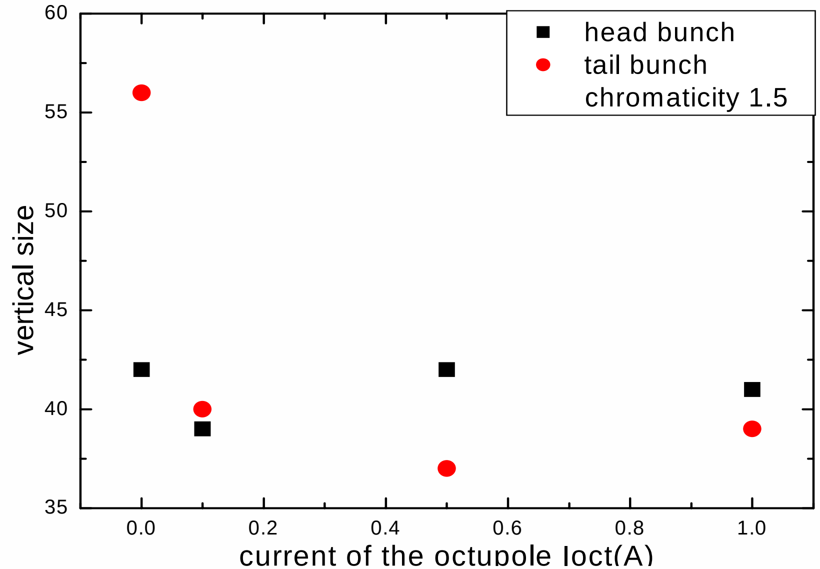
Beam size observation vs. chromaticity of 0.3 (up) and 1.8 (down)
head of bunches (left) and tail of bunches (right)

3d. Octupole effect experiment

An octupole was installed in the dispersion free straight section of the ring. The current can be reached to 1.0A by a DC power supply corresponding to K'''=30m^{-3} in the experiment.

3d. Octupole effect experiment (cont.)





Amplitude of sideband (left) and bunch size (right) vs. octupole strength

Summary of effects

	Amplitude of side band	Beam size of head	Beam size of tail
Solenoid 0A to 30A	**-58%**	**-**	**-27%**
Solenoid in straight section	**-25%***	**-**	**-**
Electrode 0V to 600V	**-18%**	**-15%**	**-18%**
Octupole 0A to 1A	**-89%**	**-2%**	**-34%**
Chromaticity 1.8 to 0.3	**-90%**	**-2%**	**-46%**

***35% solenoid reduced in straight sections**

Suggested methods from experiment to cure ECI

- **Winding solenoid in the straight section nearby magnet as much as possible;**
- **Electrode inside the chamber is a very effective way: Installing clearing electrode in beam tube;**
- **Chromaticity as larger as possible;**
- **Octupole is quite helpful;**
- **Feedback system to cure coupled bunch oscillation;**

III. Electron cloud instability simulation for BEPCII

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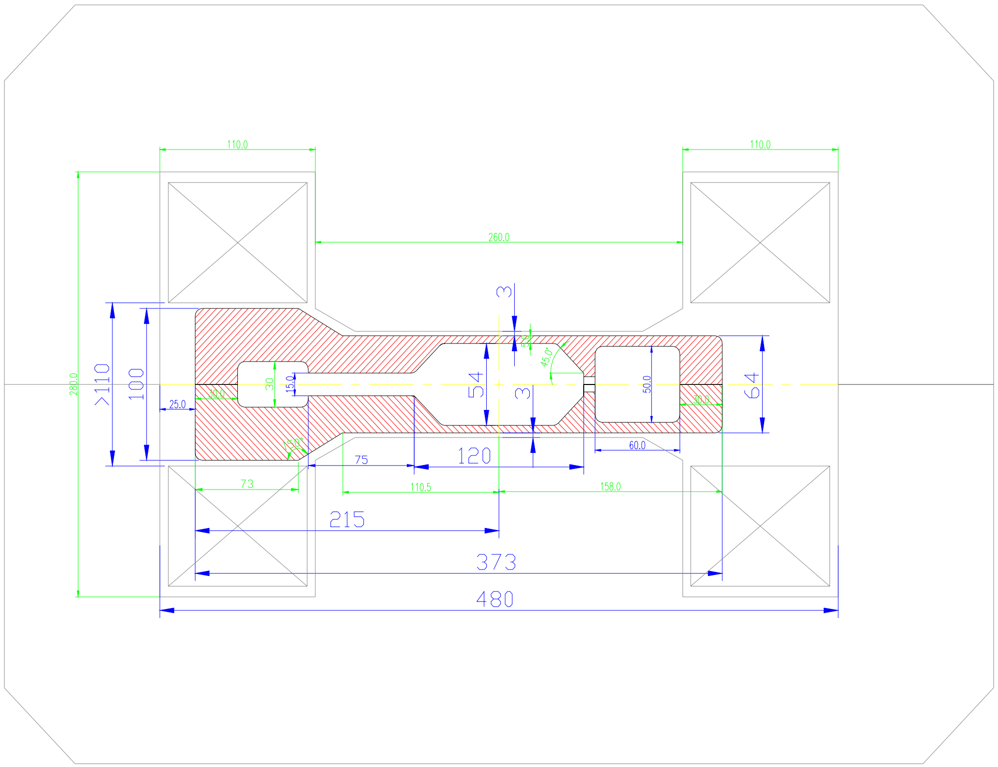
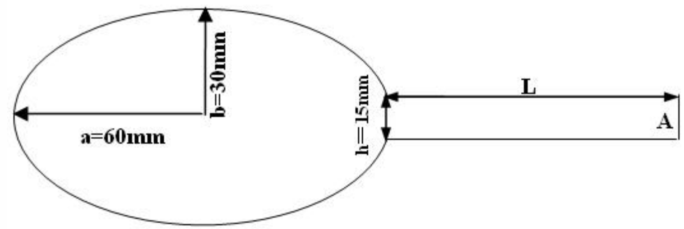
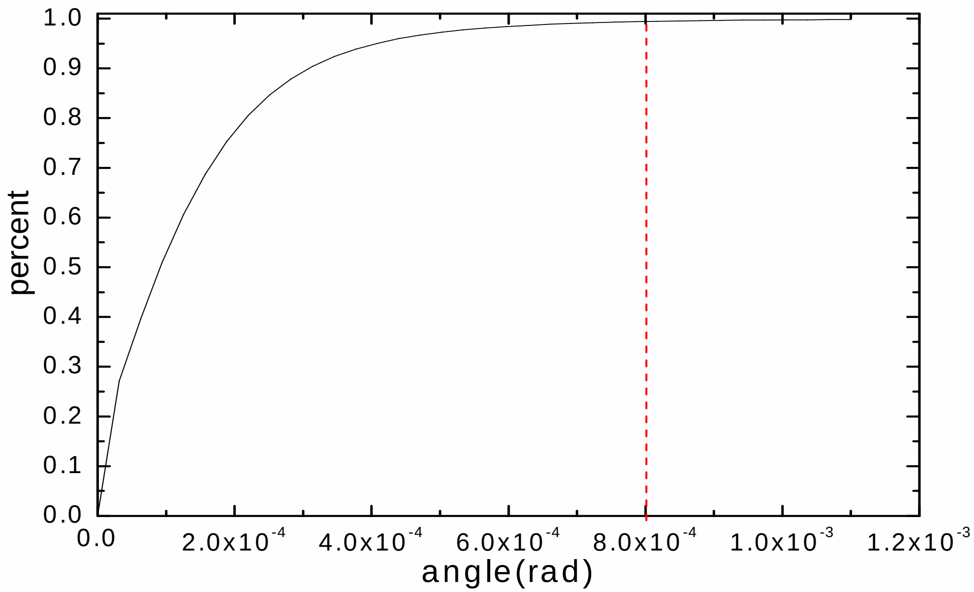
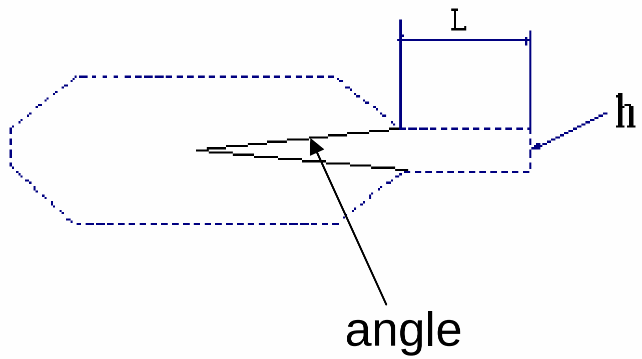
Antechamber of BEPCII





Ratio of photon into antechamber

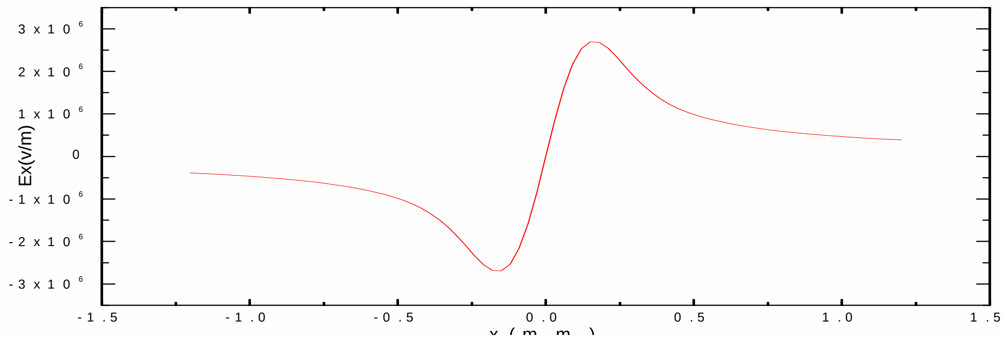




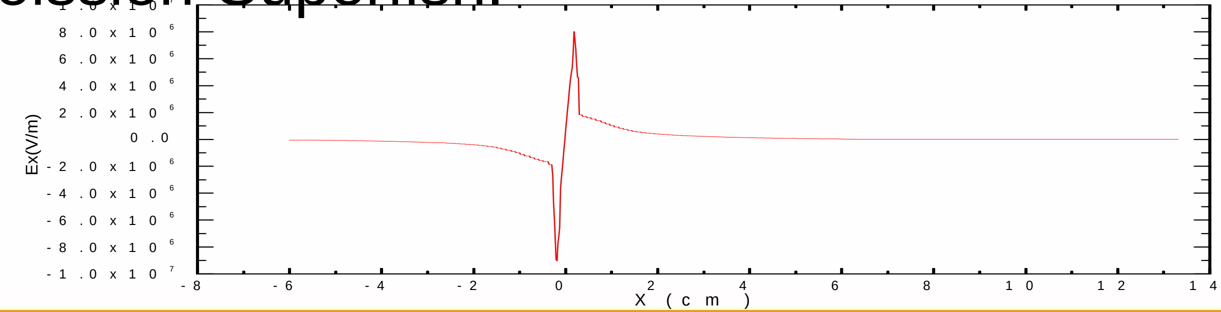
99.5% photons into the antechamber

The beam field in the antechamber

- In central region of beam $(10\sigma_x, 10\sigma_y)$,the beam field is presented by Basseti-Erskine formula.



- Out of the central region, the beam field is the solver of Poission-Superfish.



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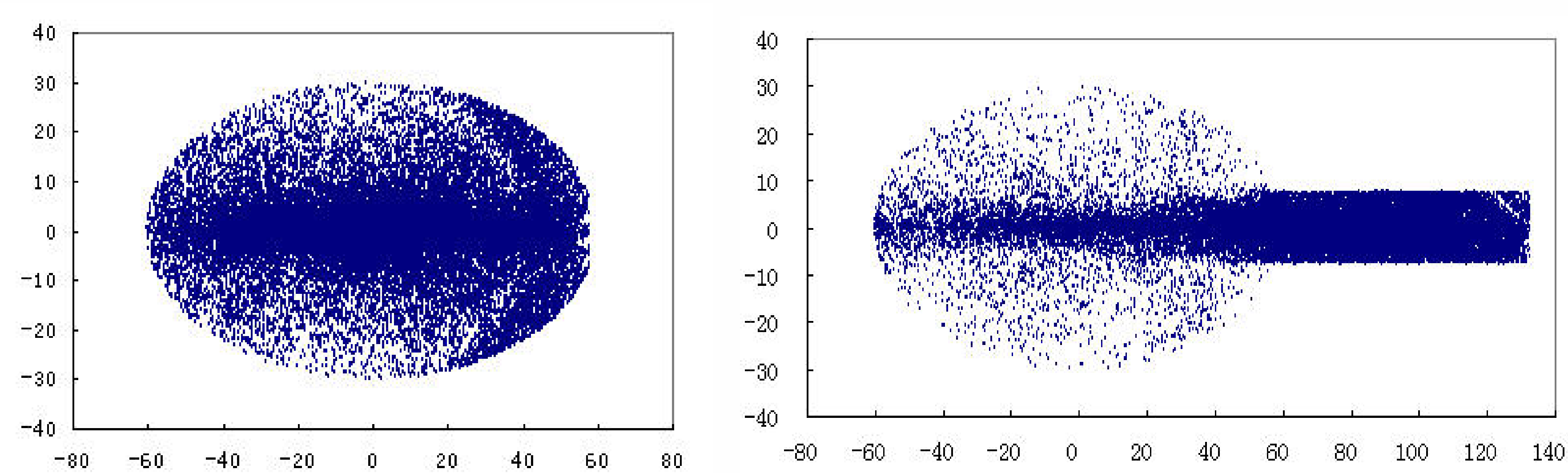
Simulation recipe for the ecloud build up

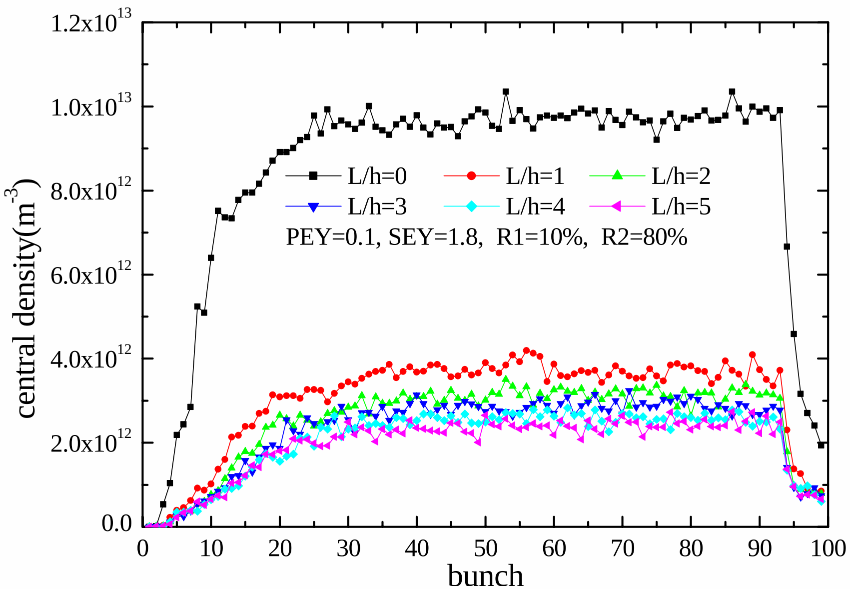
- Represent e- with macro-particles(10^4 e- for a bunch passing)
- For every bunch, e- will be produced in the pipe and antechamber
- e- will be accelerated in the beam field
- If e- hit the boundary of the pipe, secondary electron will be produced.
- e- will move between the bunches in the field of the ecloud space force and clearing electrode field
- If there is a photon absorber in the antechamer, the yield Y and reflectivity R will be much smaller.

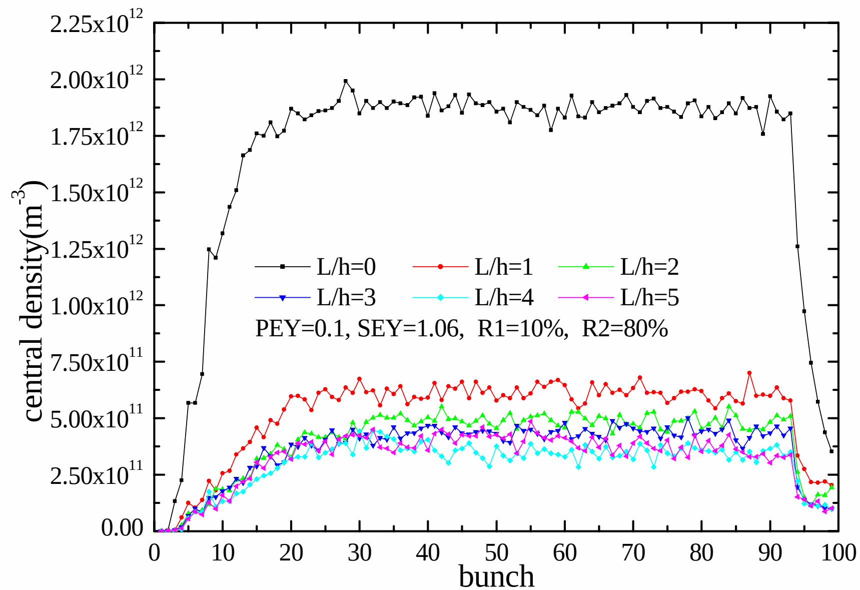
Simulation on electron cloud



Electron distribution, L/h＝0 left and L/h=5 right

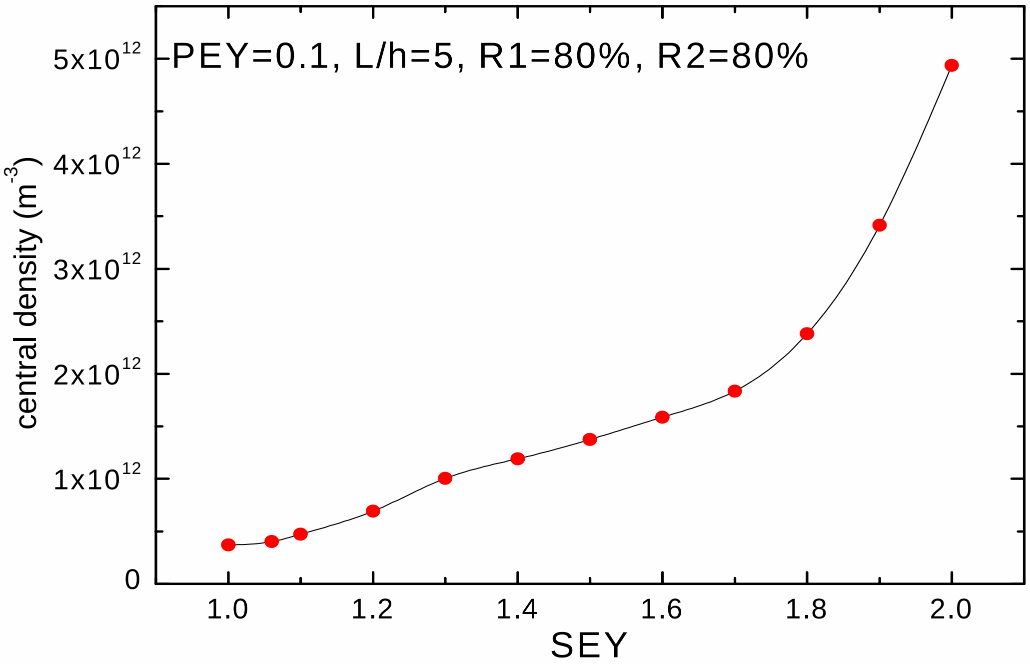
- Ecloud density in different width of antechamber





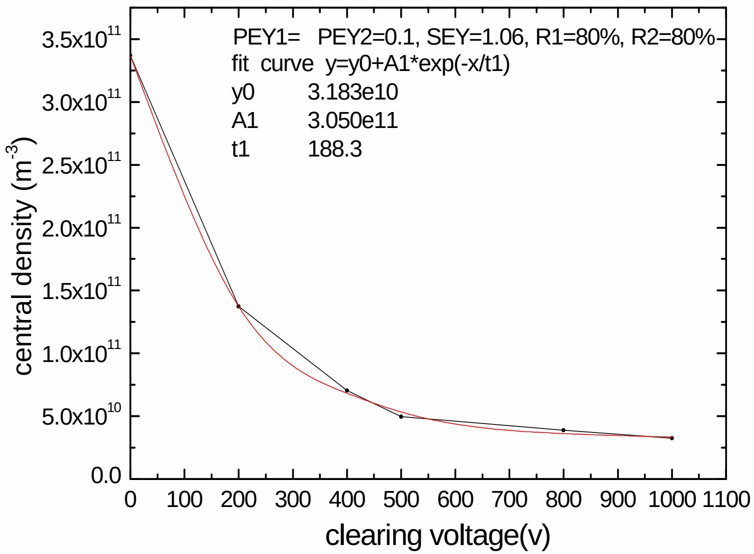
With the antechamber, the central density can be reduced about 5 times.

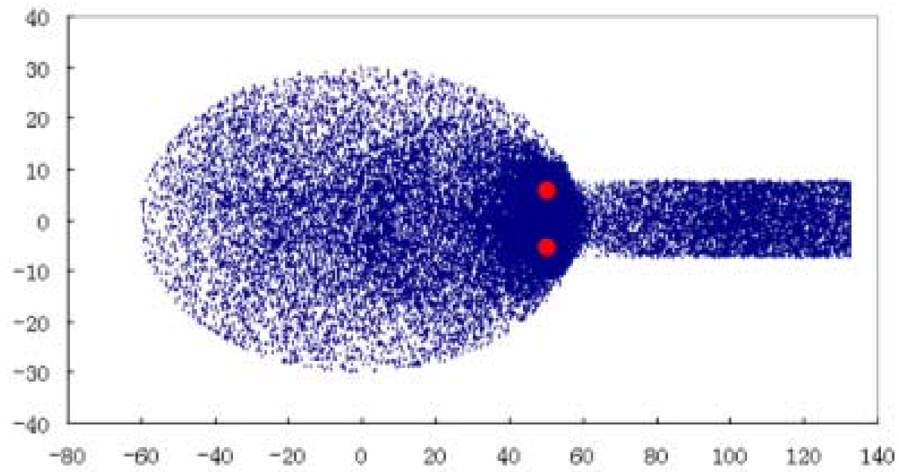
Ecloud density with different secondary yield



After SEY>1.6, ecloud density increased quickly.

Electron distribution with electrode





Much of the electrons will surround the electrodes, the central density decrease.

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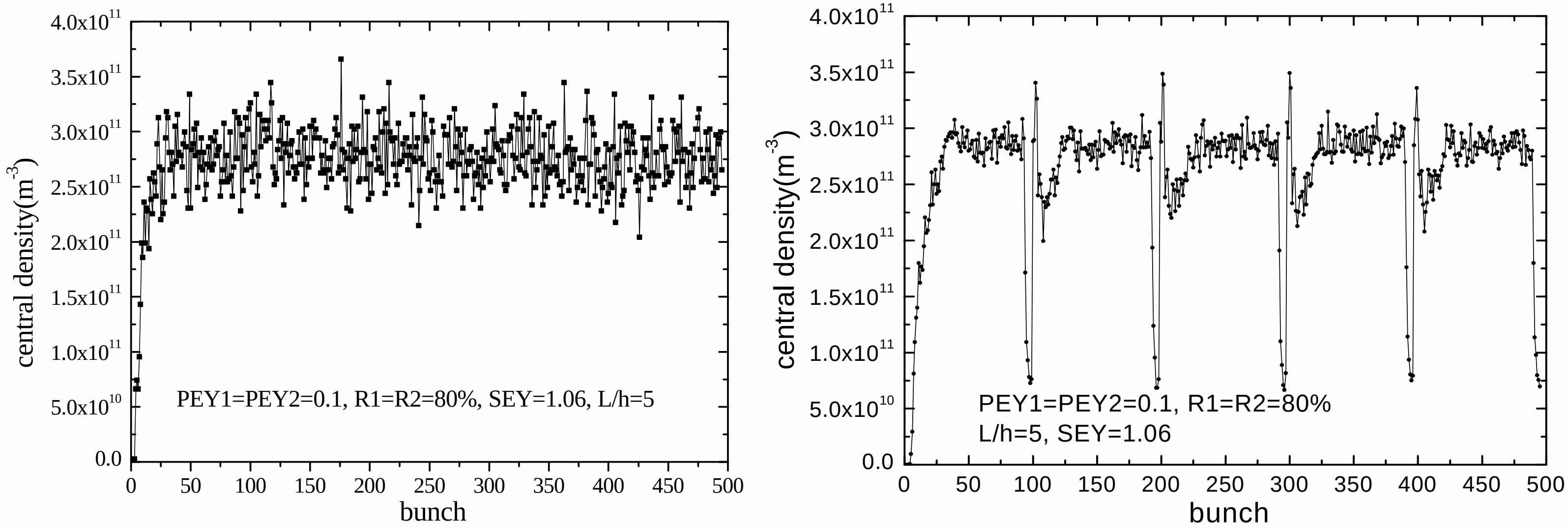
Simulation on electron cloud



Multi-turn effect on electron density without gap (left) and with gap (right)

Summary of the EC vs restraining methods

Restraining methods	Width of antechamber L/h	Photo electron yields PEY	Secondary electron yields SEY	Average linear density λ (m^{-1})	Central density ρ (m^{-3})
none	0	0.1	1.8	3.478×10^{10}	1.035×10^{13}
Only antechamber	5	0.1	1.8	1.973×10^{10}	2.22×10^{12}
only coating TiN	0	0.1	1.06	7.413×10^{9}	1.856×10^{12}
antechamber and coatingTiN	5	0.1	1.06	3.588×10^{9}	3.261×10^{11}
antechamber and photon absorber	5	0.02	1.8	5.567×10^{9}	7.188×10^{11}
antechamber, photon absorber and TiN	5	0.02	1.06	7.299×10^{8}	1.355×10^{11}
antechamber and clearing electrodes	5	0.1	1.8	2.846×10^{9}	3.748×10^{11}
antechamber, clearing electrodes and TiN	5	0.1	1.06	6.021×10^{8}	3.334×10^{10}

Electron density can be reduced

- by about 5 times if the antechamber is adopted
- by about 6 times if the TiN is coated
- by about 3 times if the photon absorber is made in the wall of the chamber
- by about 5 times if the electrode is installed in beam tube
- by about two orders if the first three above technologies adopted=> BEPCII: **$1.355 \times 10^{11} (m^{-3})$**

Suggested methods from simulation to cure ECI

- **Using antechamber in arc sections, adopting absorber inside the antechamber;**
- **Coating material with lower SEY rate, such as TiN, on inner surface of vacuum chamber;**
- **Installing clearing electrode in beam tube.**

Electron cloud instability simulation for BEPCII

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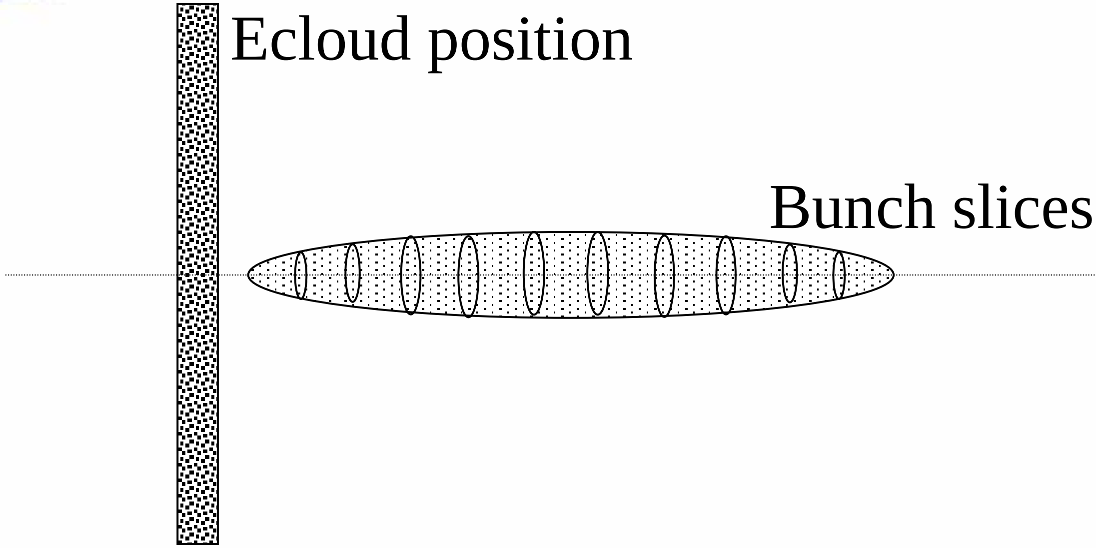
Single bunch instability

- Electron cloud described as macro-particles transversely.
- Bunch divided into a few slices longitudinally, macro-particles in each slice interacts with EC. Macro-particles of the bunch move between slices by synchrotron motion.
- If there is a displacement between head and tail particles, the tail experiences a ‘wake’ force. Then bunch size blow-up recorded.
- Strong head tail theory can be use to estimate the threshold of the blow up.

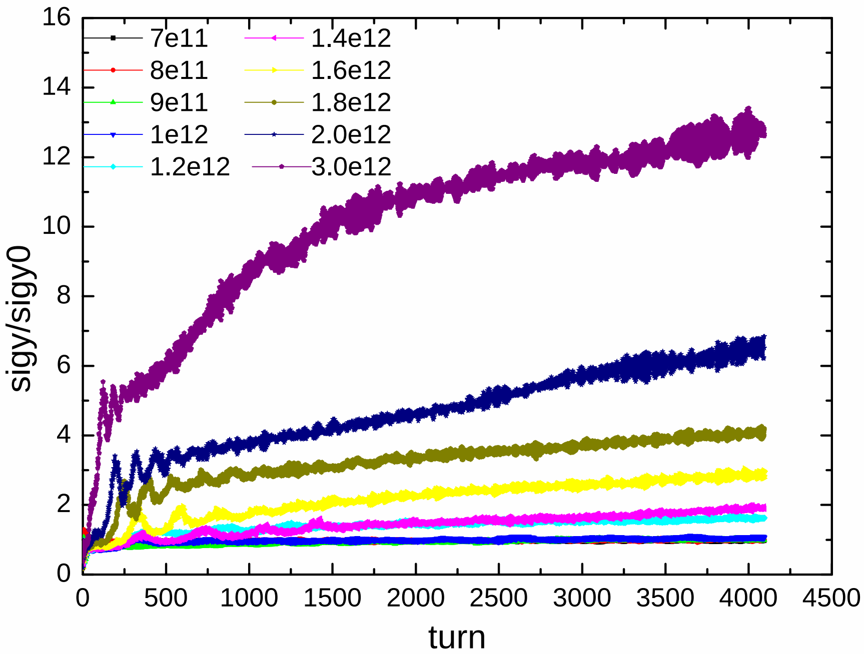
Simulation approaches for single bunch instability

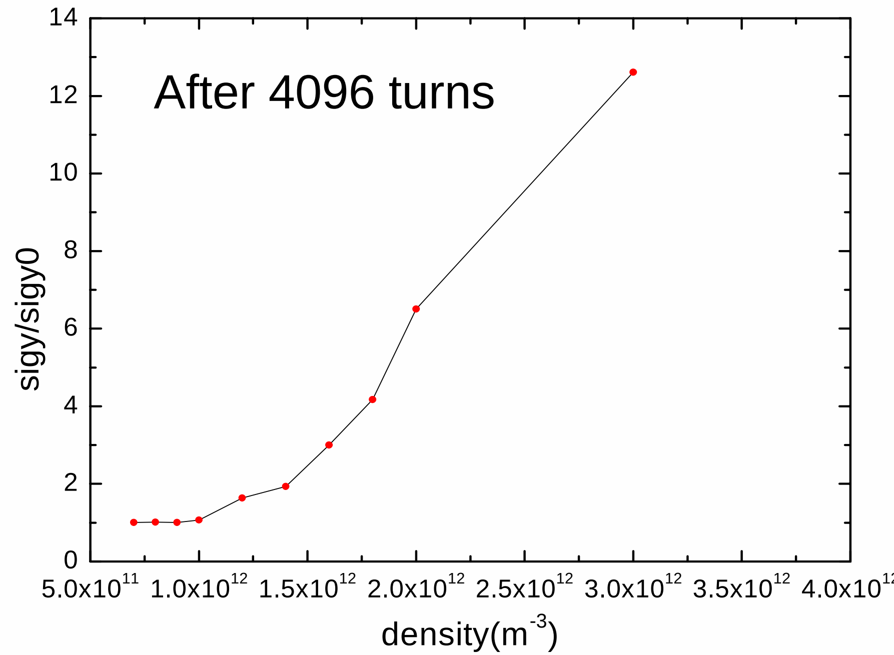


- Concentrate e− cloud at one location of the ring
- Represent bunch and e- with macro-particles

Single bunch instability

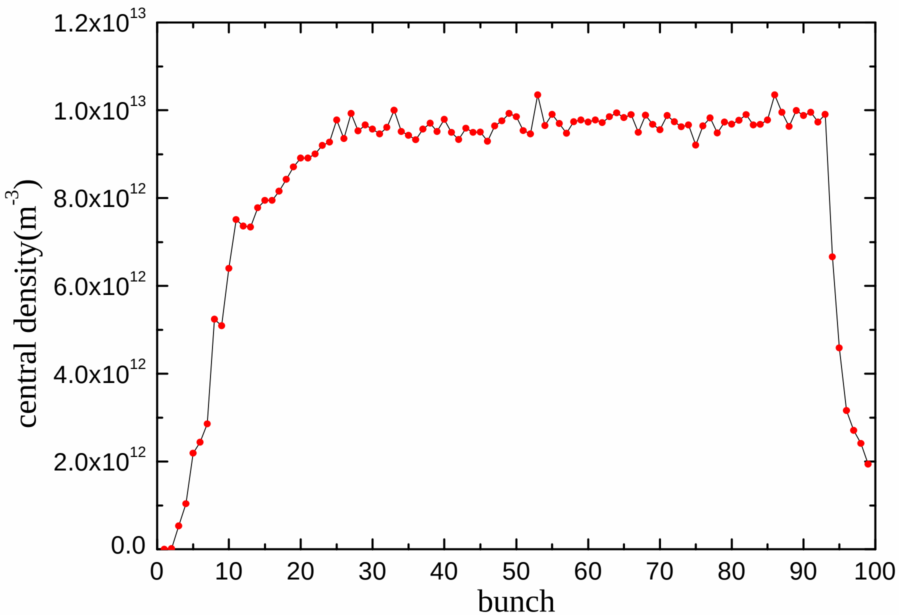
- Increase of bunch size in different ecloud density
  (considering the synchrotron motion ,chromaticity (0,0))



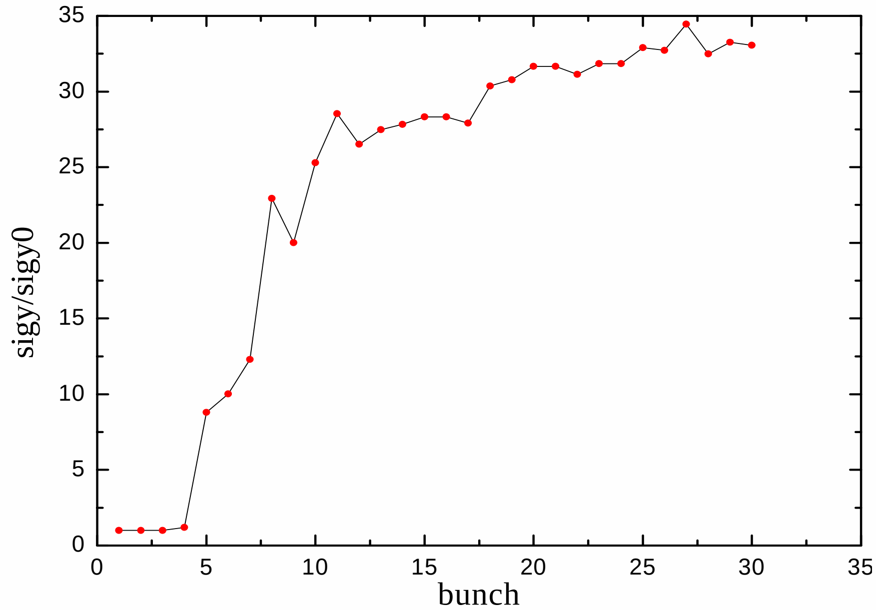


blow-up in bunch train

According to the ecloud density, the bunches size change in the train can be simulated.



The ecloud density in BEPCII (without any restrain methods)



The bunches size in a train

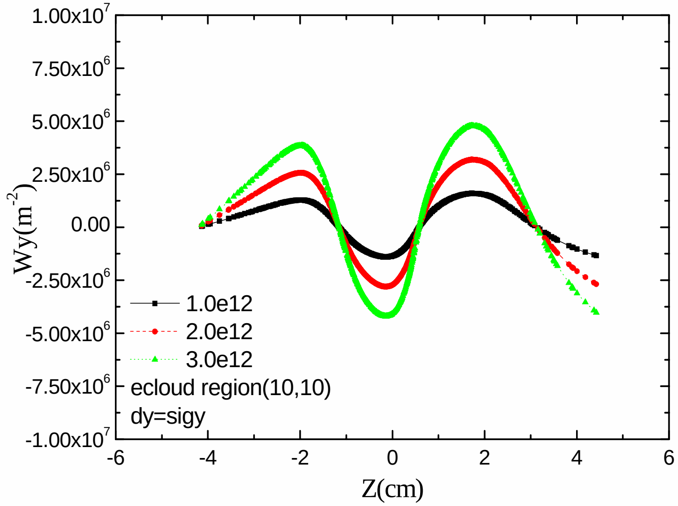
Single bunch instability

- Ecloud short-wake field

  Head particles distance $\Delta y = \sigma_y$,

  the short wake expressed as:

$$W(z_j, z_i) = \frac{N_p \gamma}{N_b r_e} \frac{\delta y'_{p,j}}{\Delta y_{p,i}}$$



wake increases vs EC

Strong head-tail instability threshold

$$\Gamma = \frac{N_b r_e |W_y| \bar{\beta}_y}{16 \gamma \nu_s}$$

=>EC threshold: 1.0×10^{12}m^{-3}.

For BEPCII, EC lower than the threshold

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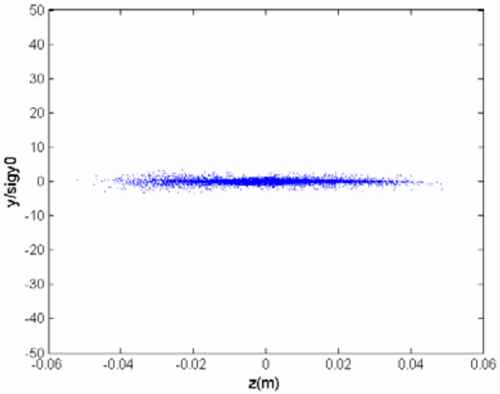
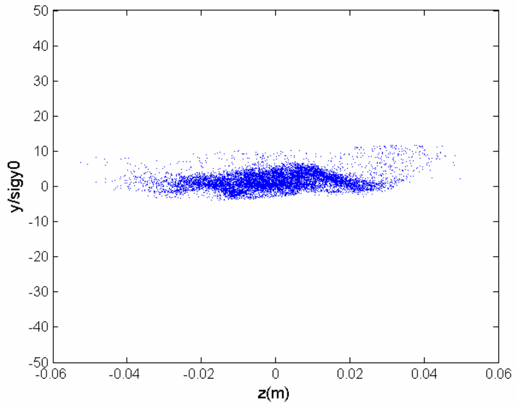
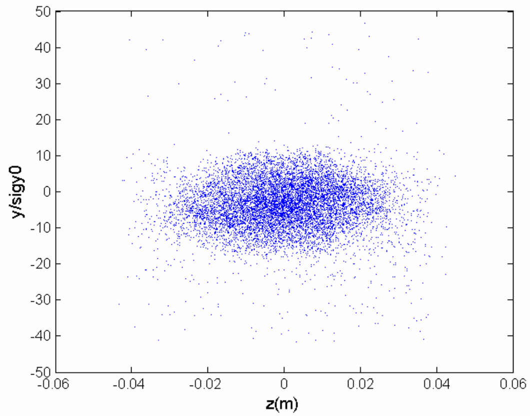
Single bunch instability





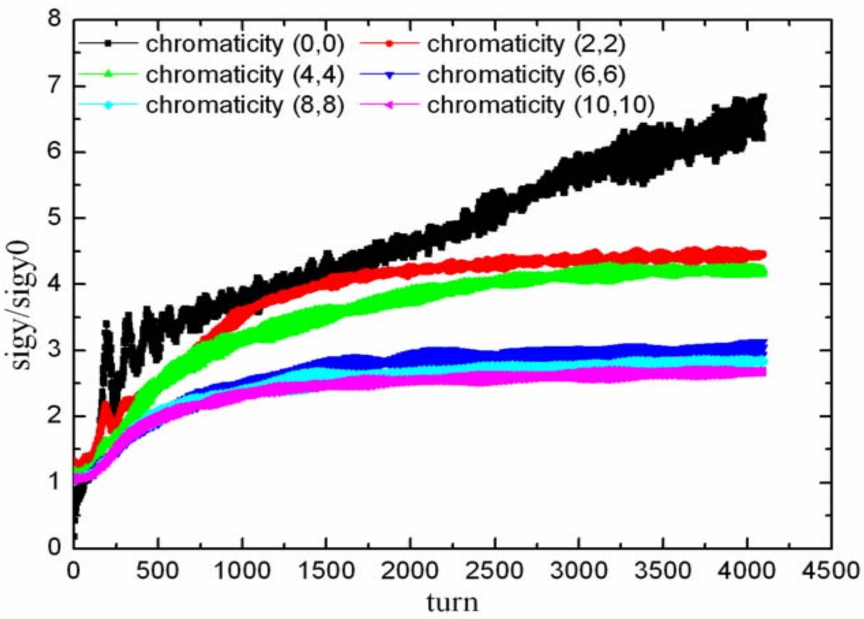


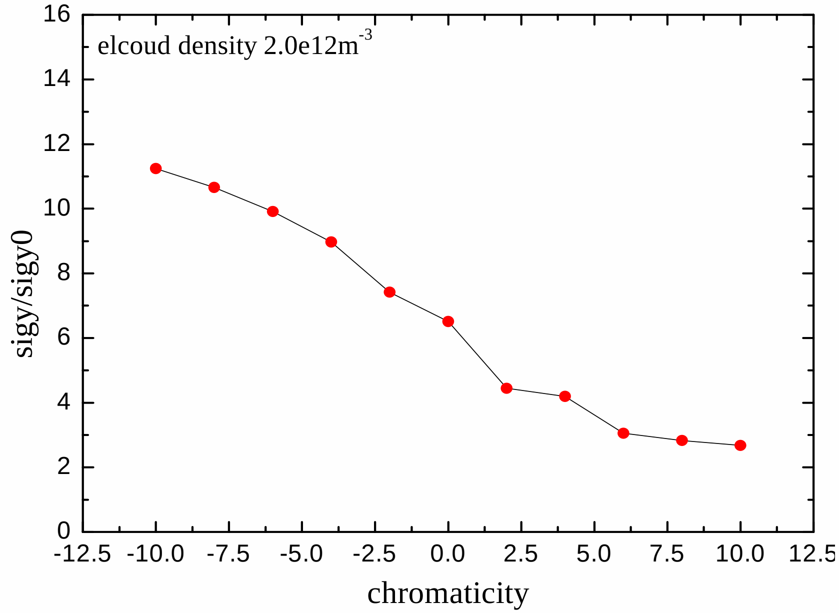
Start 500 turns 1000 turns

Head tail oscillation in a bunch
EC density is 1.0×10^{12} around the threshold

Single bunch instability

- Results for different chromaticity

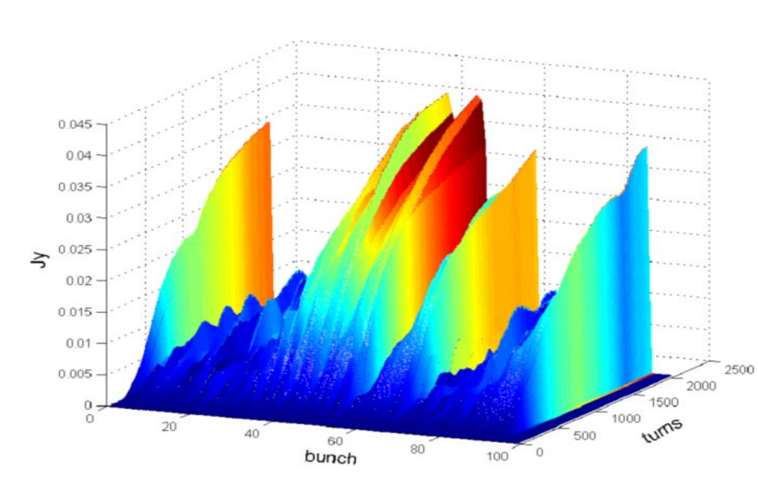


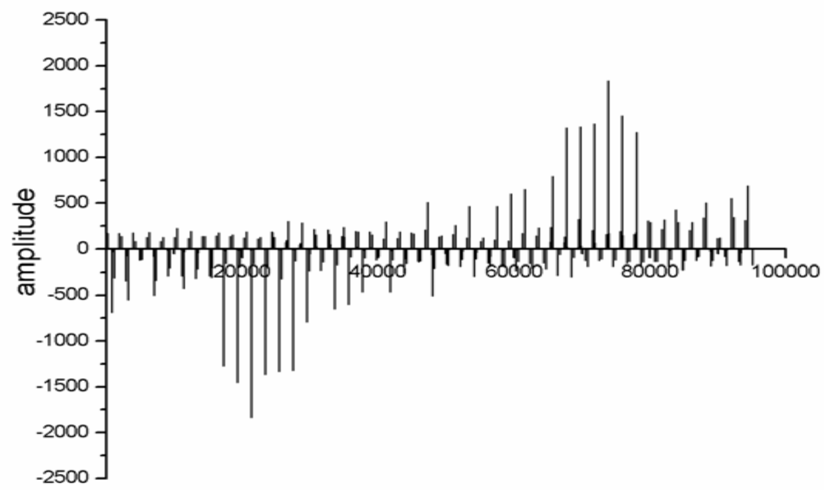


Coupled bunch instability

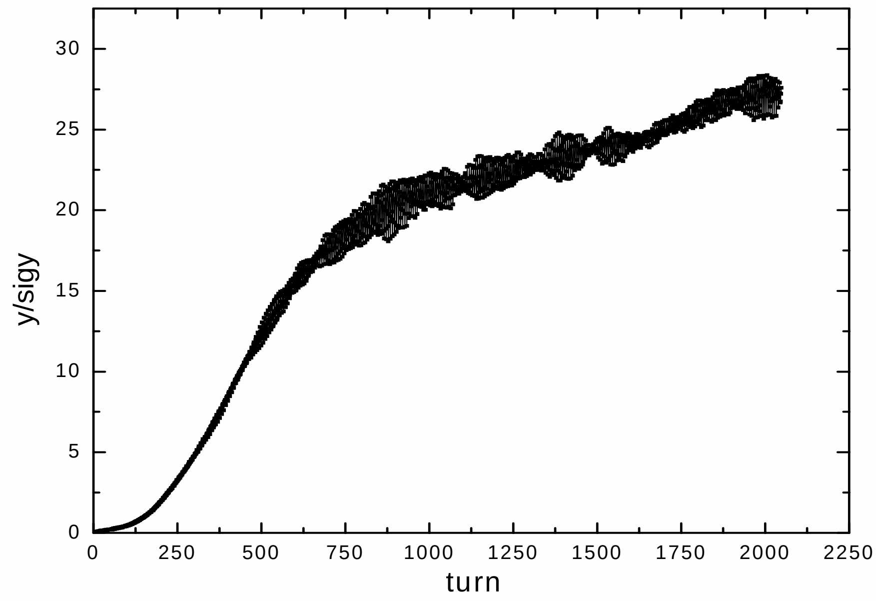
- **The turn by turn method was used to track the motion of 93 bunches in a train.**
- **The EC build up process along the bunch train is simulated each turn. The EC dissipates in the bunch gap between turns.**
- **In every turn the positions of 93 bunches will be recorded.**
- **The oscillation can be transferred to the spectrum by FFT.**

Coupled bunch oscillation





The growth process
of coupled bunch oscillation and mode spectrum.



Growth time @ 1×10^{12} m^{-3} $\tau_y \approx 0.08ms$

Growth time estimation

EC density (m^{-3})	CBI raising time (ms)
$1.0x10^{13}$	0.08
$1.0x10^{11}$ (BEPCII)	8.0

Damping time of radiation = 25 ms
Damping time of transverse feedback = 0.5 ms
=> Possible to damp the CBI

Summary

- From the experiment => the way to suppress ECI well investigated: Winding solenoid ; Clearing electrode ; Large chromaticity; Octupole.
- From simulation for BEPCII => with restraining methods as antechamber+TiN etc, EC controlled below the threshold of Head-tail instability.
- From experiment & simulation => the way to cure ECI in BEPCII.

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The way to cure ECI in BEPCII

To guarantee the beam performance against ECI, from our experiment and simulation results, and reference to the methods adopted in PEPII and KEKB, it is decided in BEPCII design:

- **Antechamber**
- **TiN coating of the inner surface, and photon absorber**
- **Larger chromaticity, and octupole**
- **Transverse feedback system**
- **Solenoid winding (as backup)**
- **Clearing electrode and BPM (R&D)**

Acknowledgement

- ECI experiments has been collaborated between IHEP and KEK since 1996.
- Many thanks to the BEPC operation group for their effective work to offer the beam conditions in the experiment.
- The model used in simulation refers to previous theoretic work.

Thank You for Attention