Study on Beam Instability

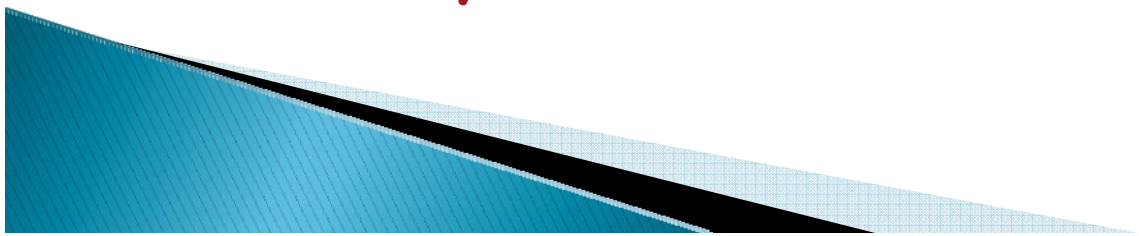
Qing Qin (秦庆)

Institute of High Energy Physics

April 8, 2009

Outlines

- Overview
- Electron cloud instability
- Impedance-based beam collective effects
- Beam-beam interaction
- Beam instrumentation & beam commissioning
- Wake and impedance in proton rings
- Summary



Overview

- Starting collaboration from 1999.
- Strengthening the collaboration between KEK and IHEP in the field of beam instability
- Main topics on beam instability:

  ECI, dust effect, impedance-based instabilities, instability observation and cure, wake field and impedance calculation, simulation, etc.
- Expanded to beam-beam interaction, commissioning, beam instrumentation, etc.
- Achievements: theoretical and experimental results, papers, Ph. D thesis, etc.

- No. of participants from IHEP side: 21
- Coordinator of the beam instability group:

  Zhiyuan Guo, 1999 – 2006

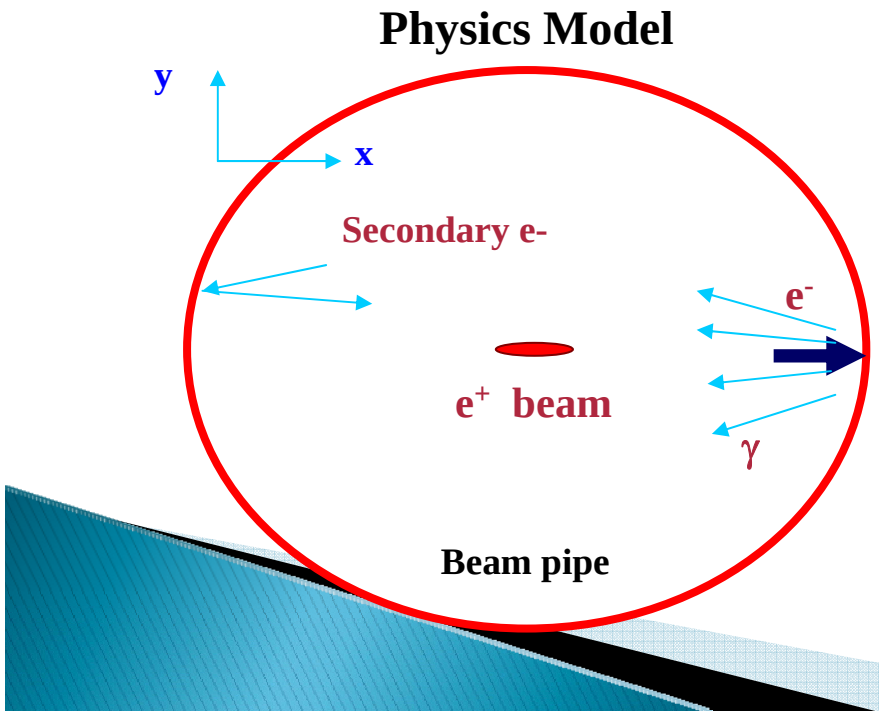
  Qing Qin, 2007 – 2009

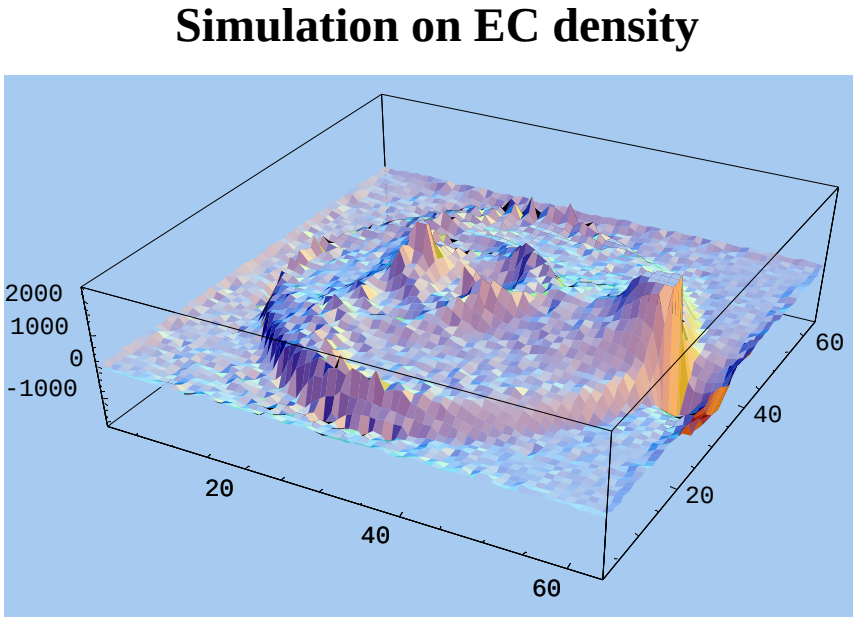
- Covering beam physics and beam instrumentation in both IHEP-BEPCII and KEK-KEKB

- Aiming at understanding and analyzing beam instabilities, observing and curing the instabilities, simulating and guiding in new machines.

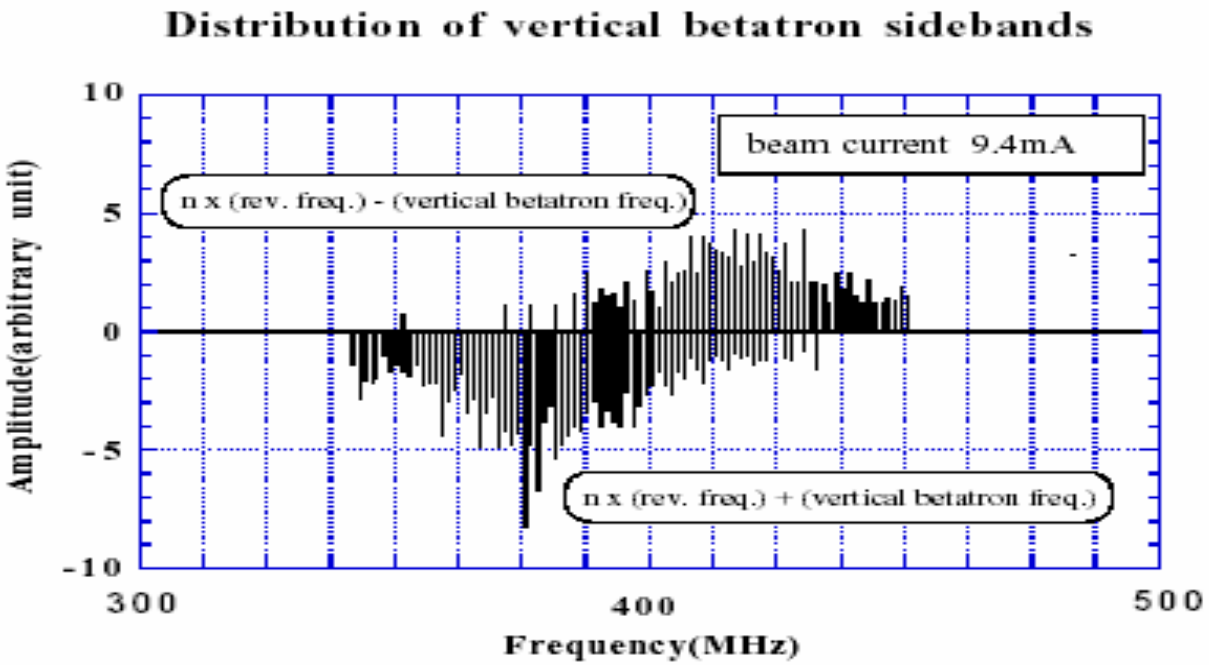
Electron cloud instability

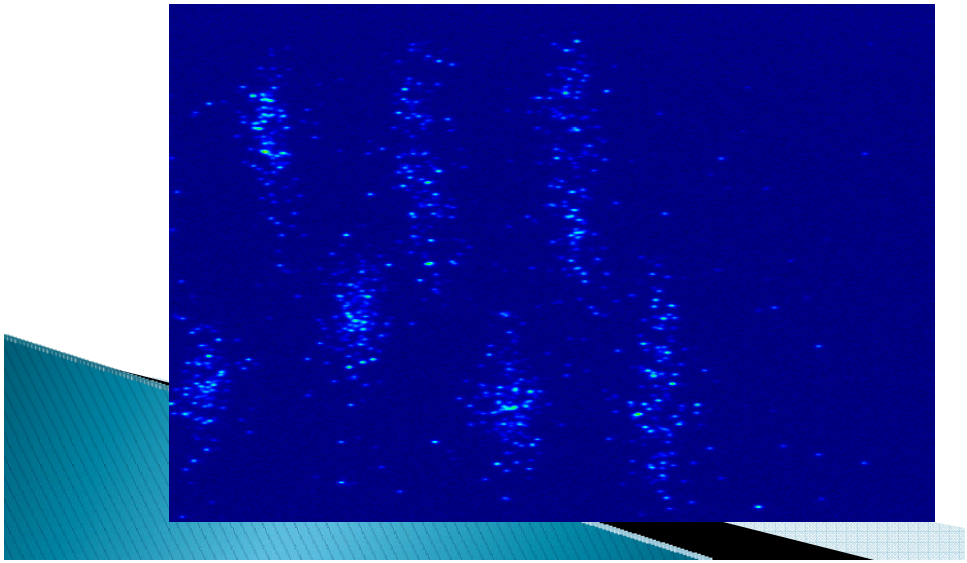
- Observation and confirmation at BEPC
- Measuring and curing ECI
- Modeling and simulation

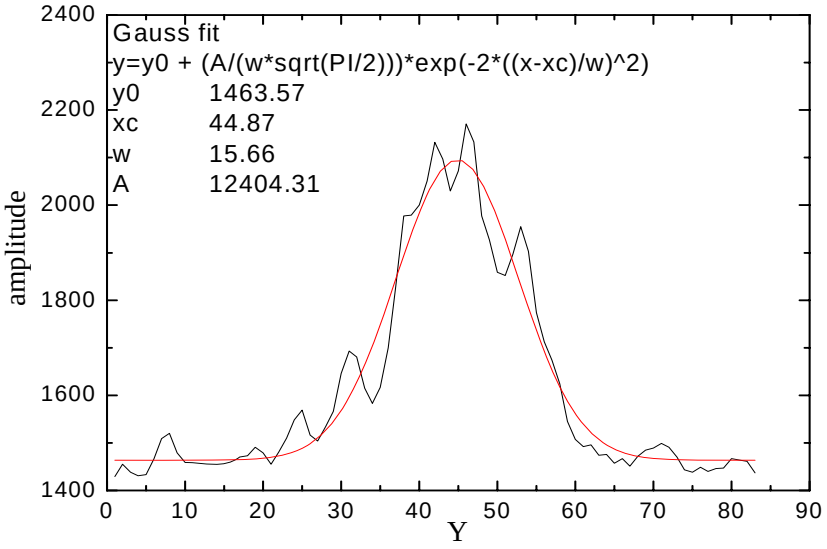




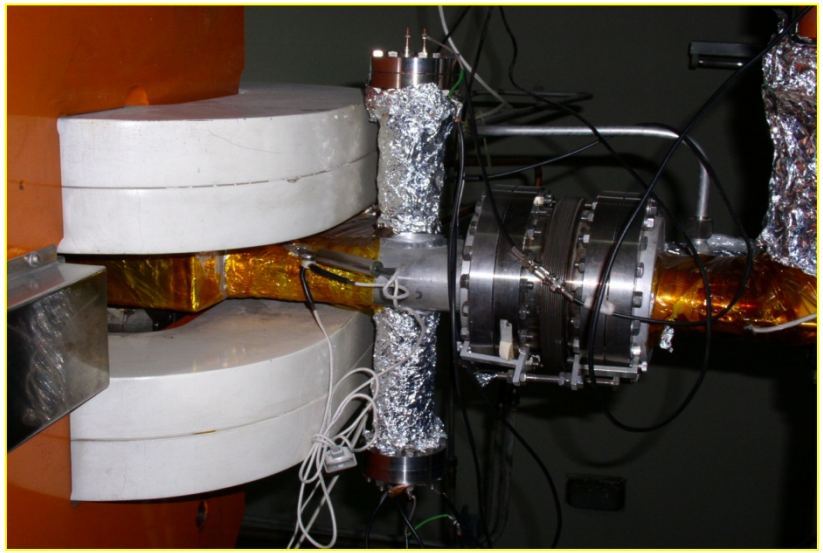
Observations of ECI on BEPC

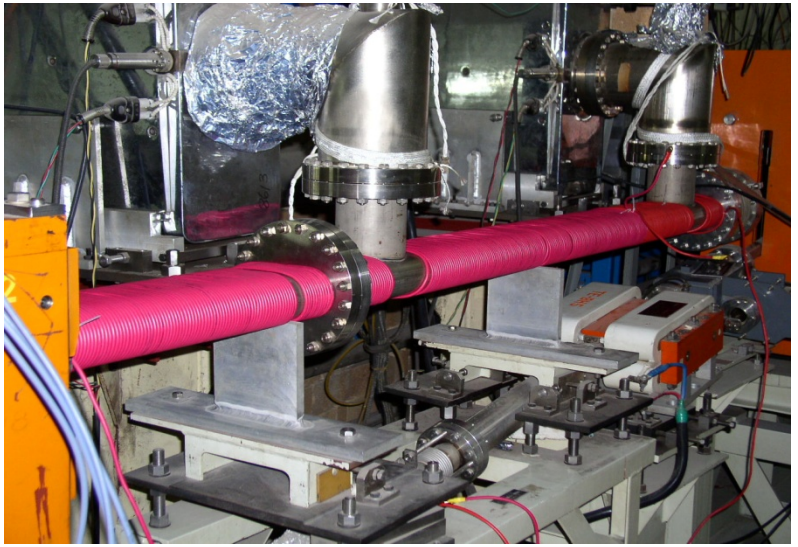


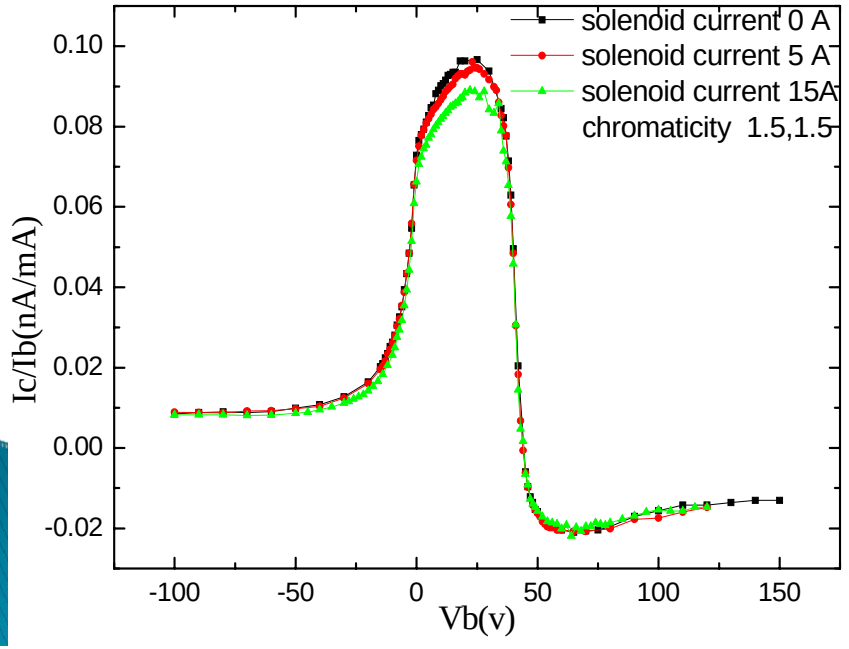


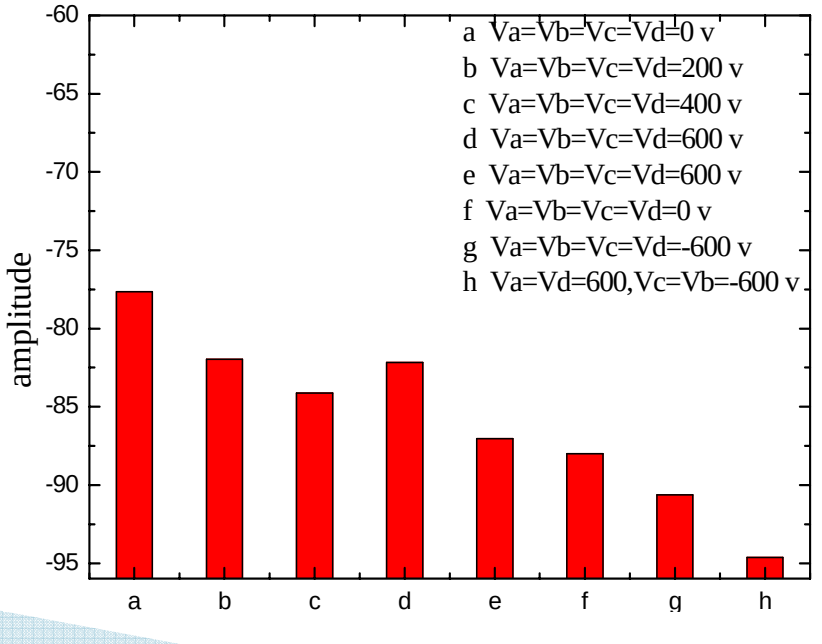


Measurement and cure of EC on BEPC

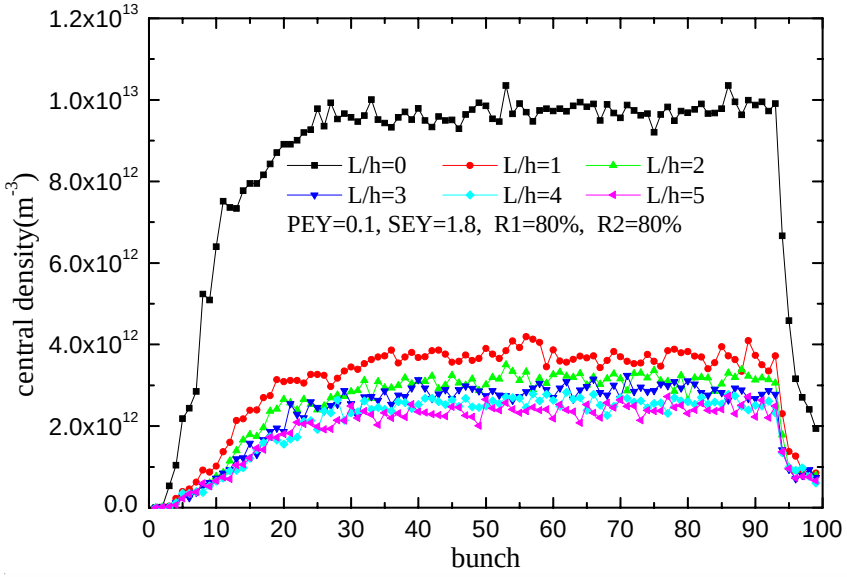


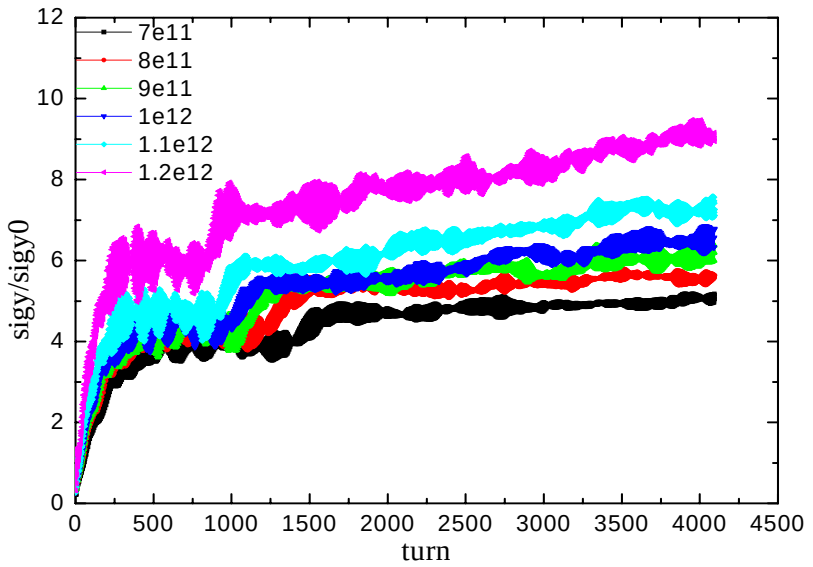


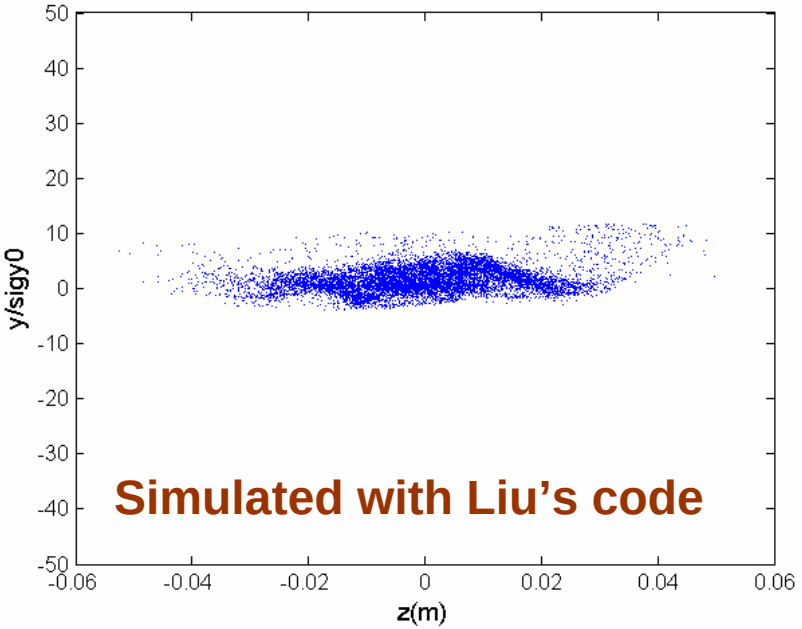


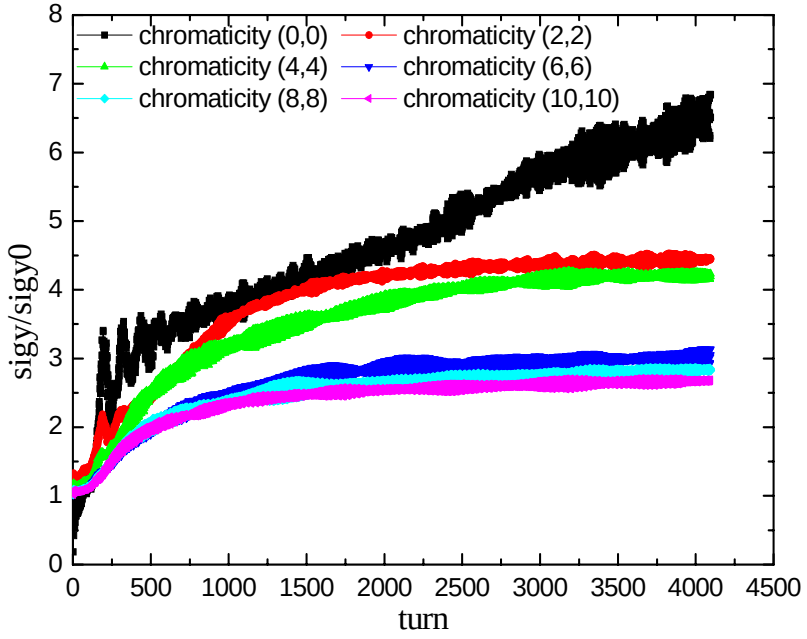


Simulation of ECI for BEPCII



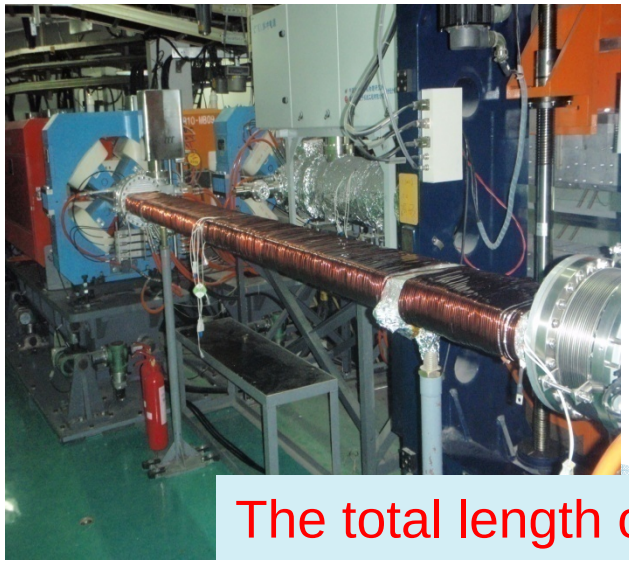


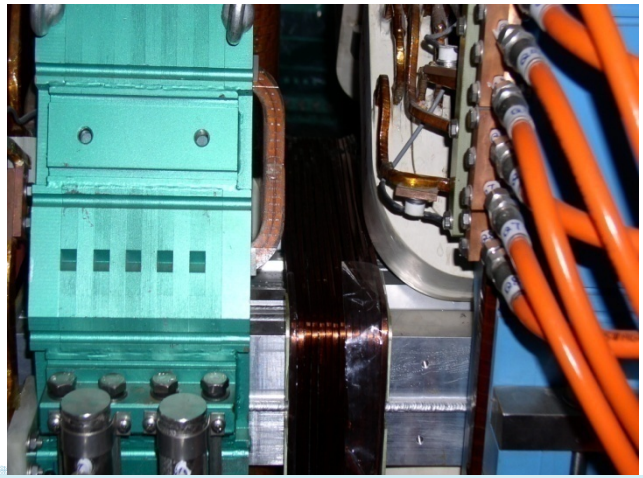


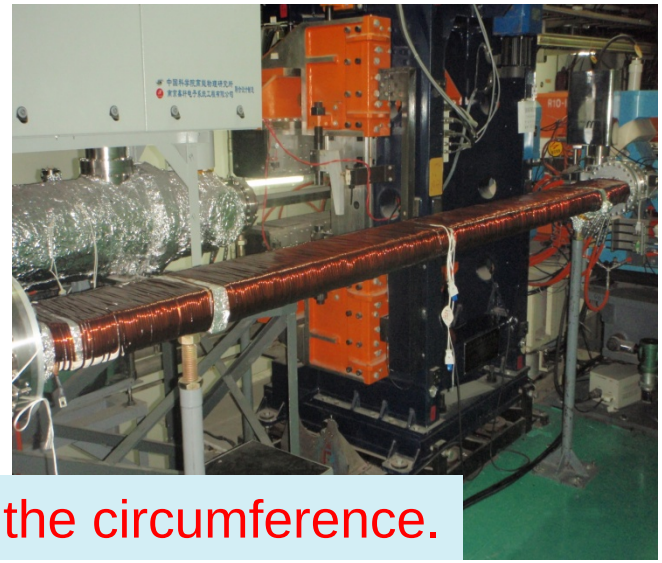


Cures of ECI on BEPCII

- Ante-chamber
- TiN coating of the inner surface, and photon absorbers in arcs
- An Octupole installed in positron ring
- Transverse feedback system
- Solenoid winding along the straight sections of the positron ring

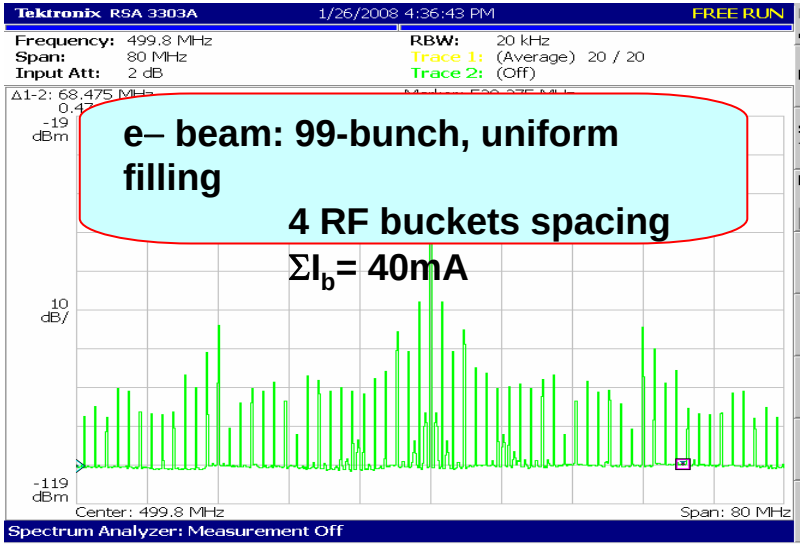


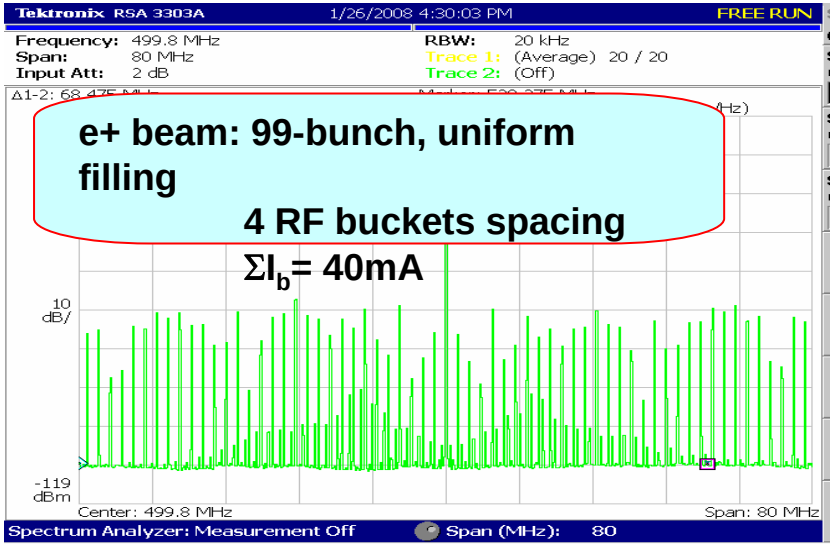


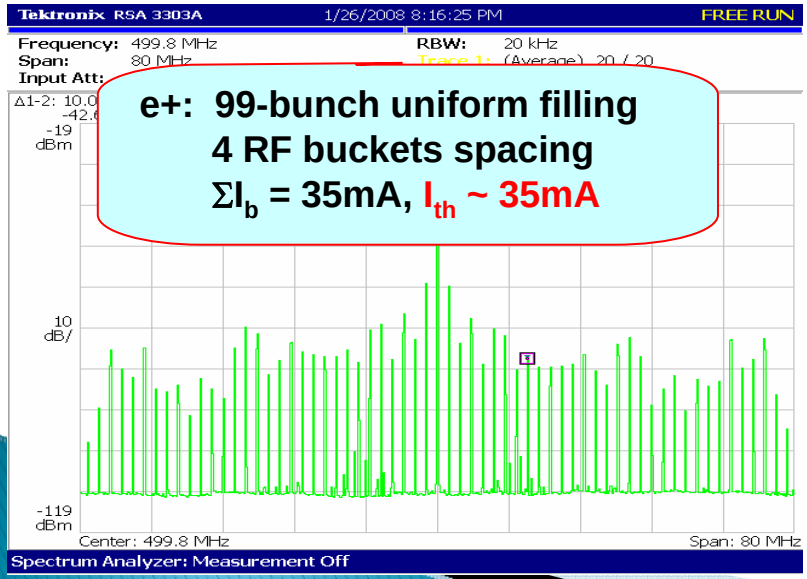


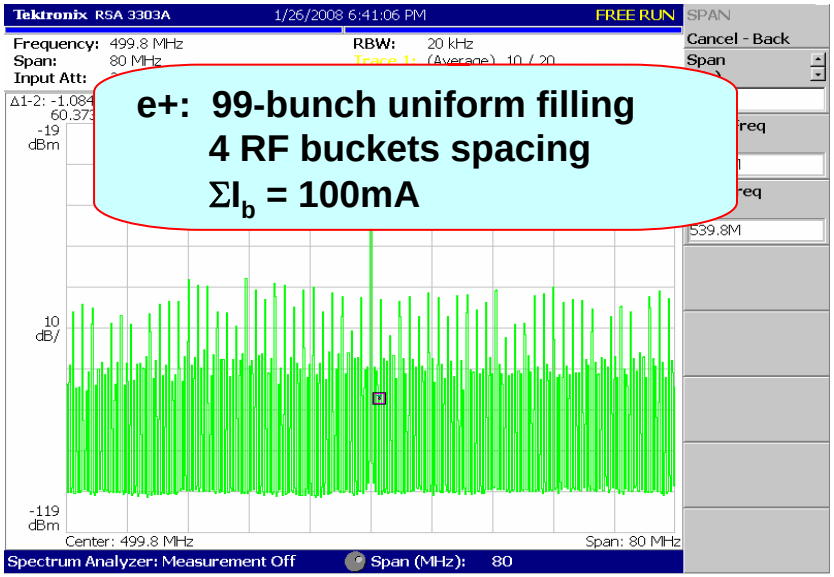
The total length of solenoid is about 15% of the circumference.

Observations of ECI at BEPCII



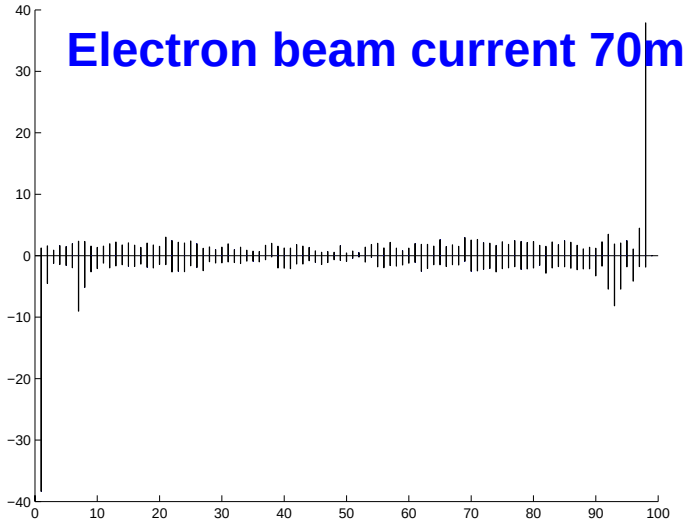


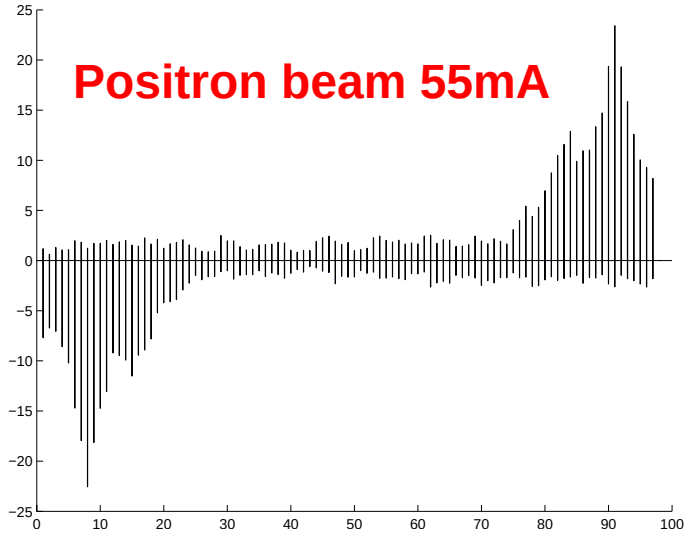




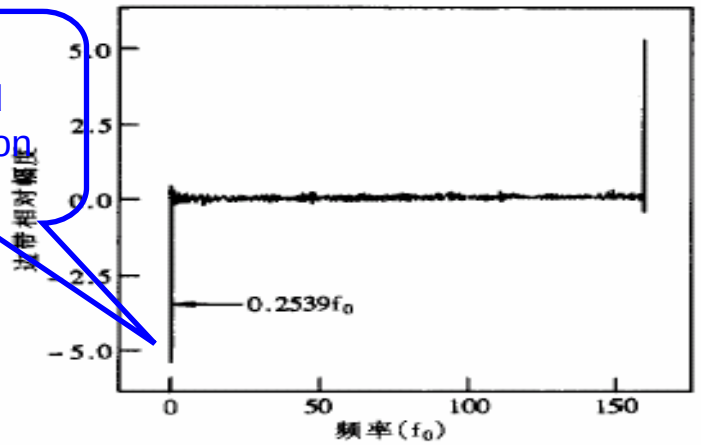
Mode distribution of electron and positron beam

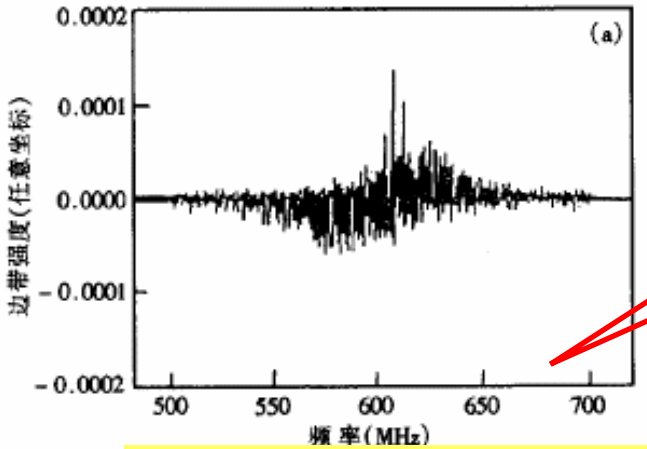
Electron and positron beam with the same filling pattern: 99 bunches bunch spacing 8ns





Electron sideband distribution in BEPC



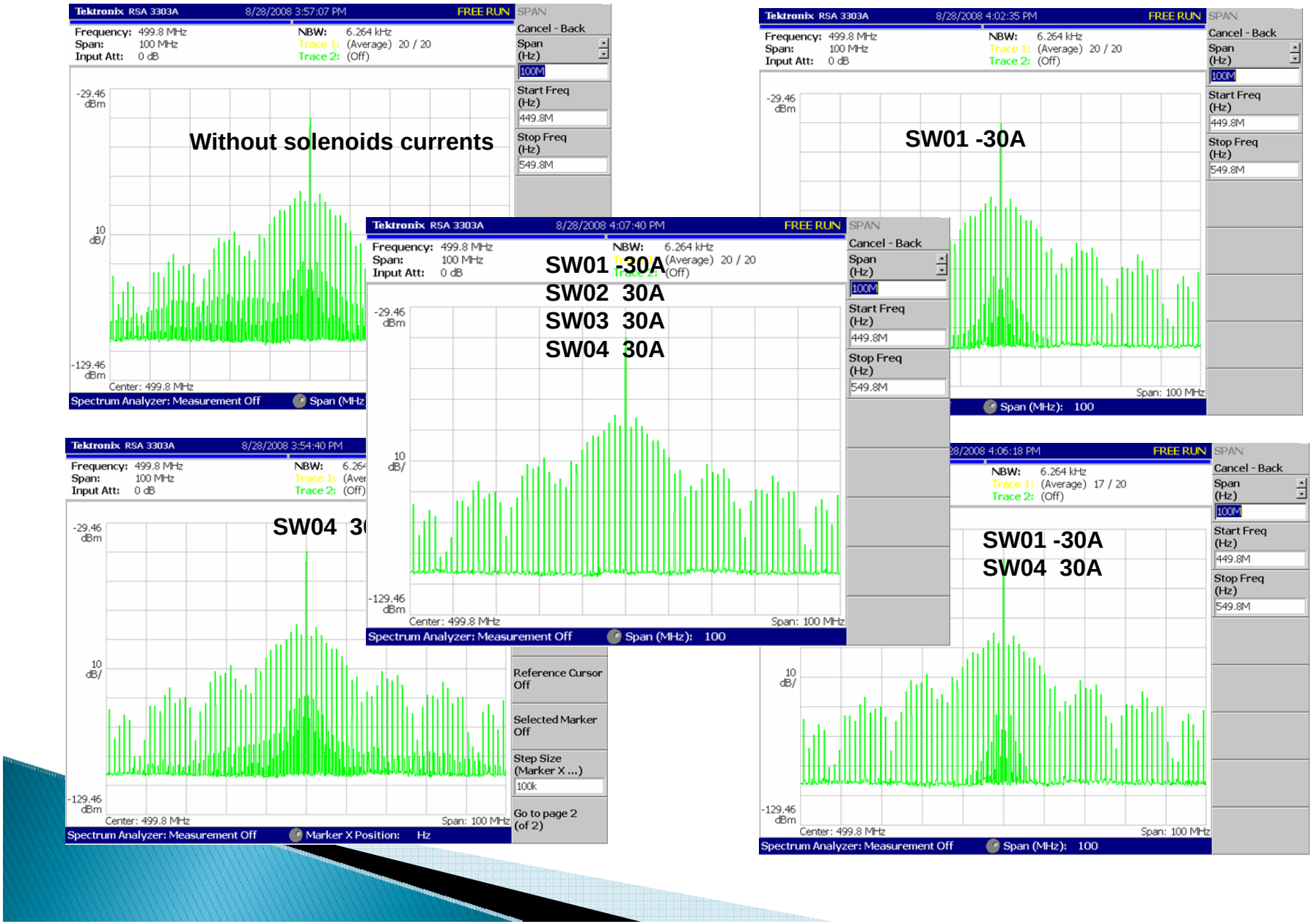


Positron sideband distribution in BEPC

Y. Luo, et al, HEP&NP, Vol. 25.No 3.,258-263,2001

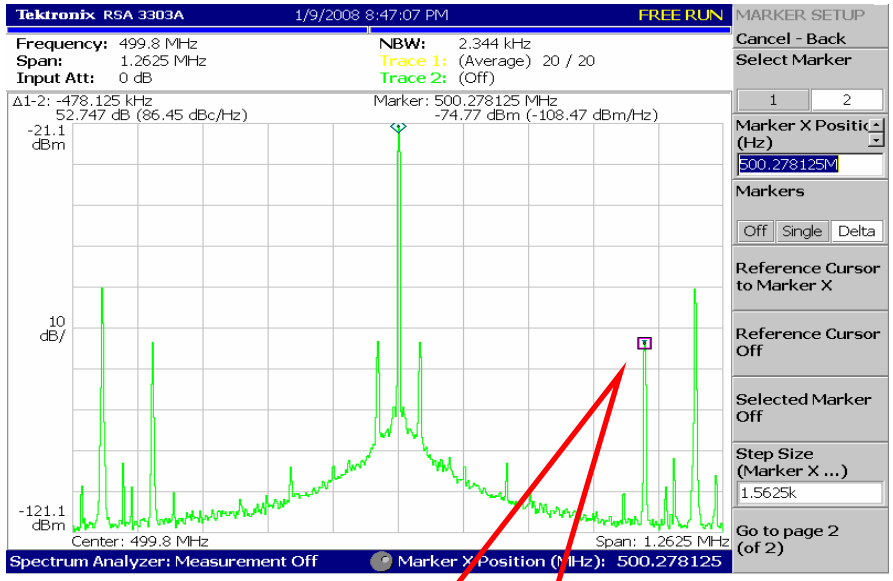
Z.Y. Guo, et al, HEP&NP, Vol. 25.No 3.,251-257, 2001

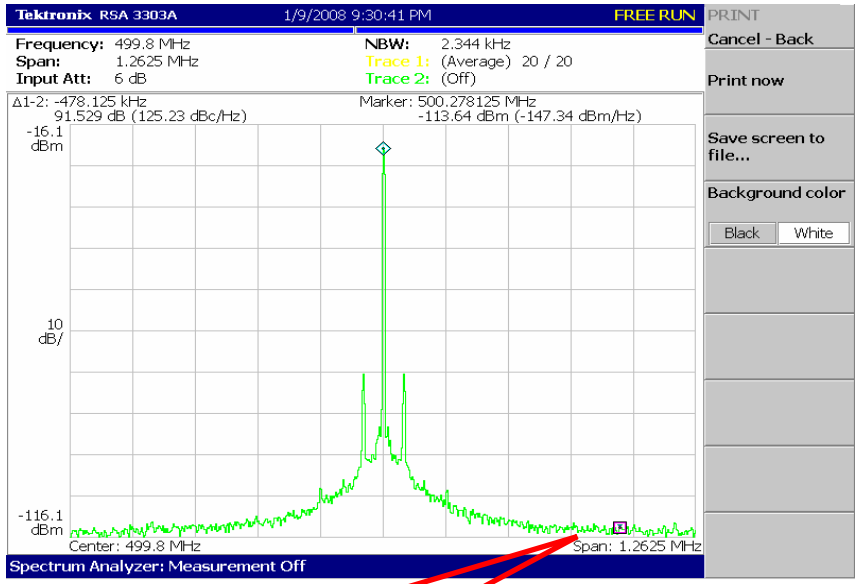
Suppression on sidebands of Coupled bunch instability with Solenoids



Octupole for suppression the sidebands

The octupole magnet has been installed in BEPCII. The Landau damping caused by the octupole is strong to restrain the coupled bunch instability caused by the electron cloud.



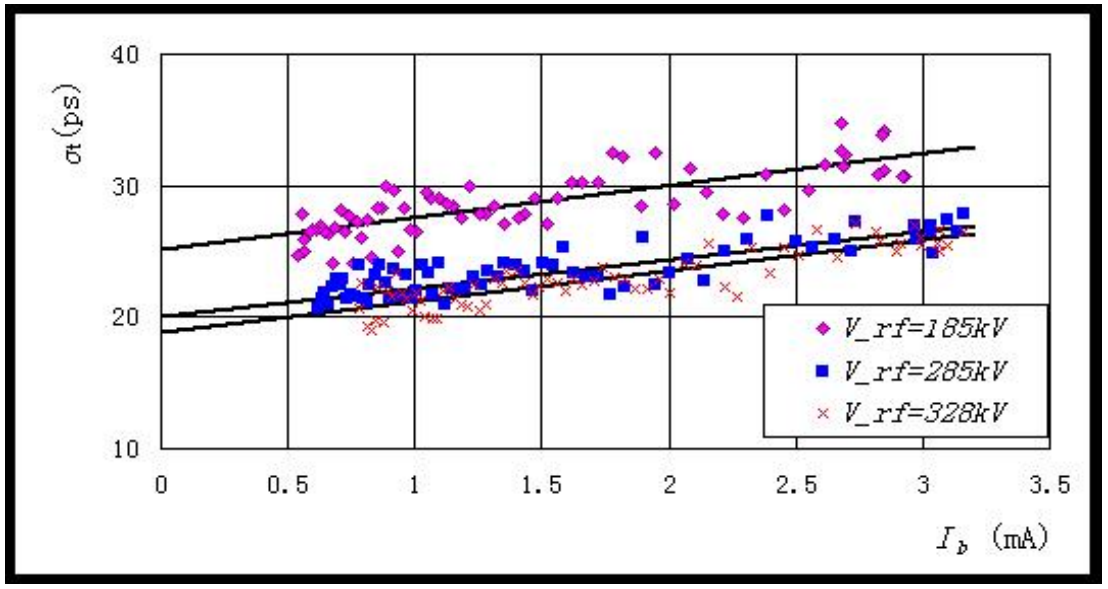


Sideband when octupole off

Sideband disappear octupole current 0.7A

Impedance-based beam collective effect

- Bunch lengthening due to broad band impedance
- ✓ Measured bunch lengthening at KEK-ATF damping ring
- ✓ Got inductance, resistance of ATF

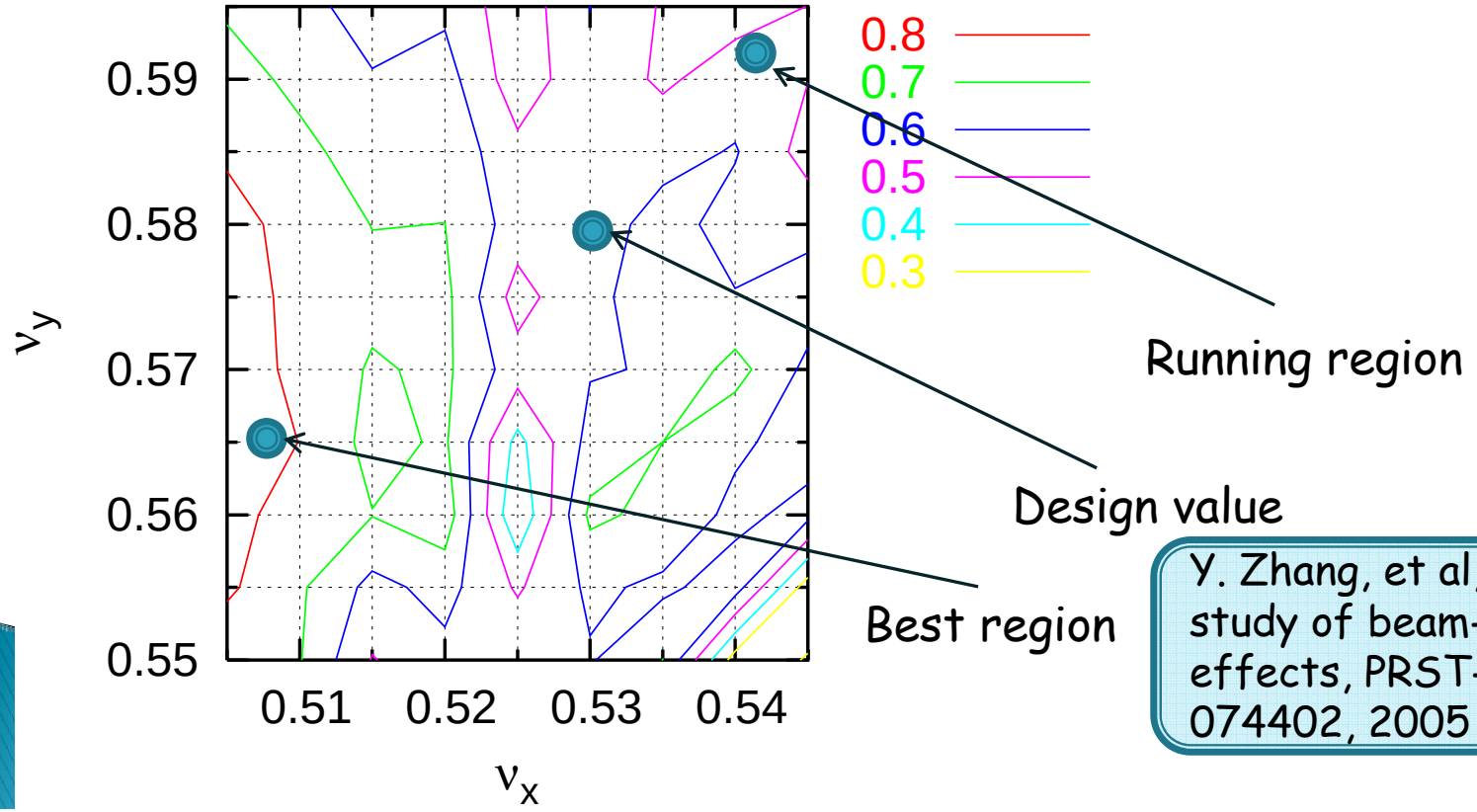


L = 32.43±1.00 (nH)
R = 1651.60±187.93 (Ω)

Q. Qin, et al, Bunch length measurement in the ATF damping ring, KEK-ATF Internal Report, ATF-01-01, 2001.

Beam-beam interaction

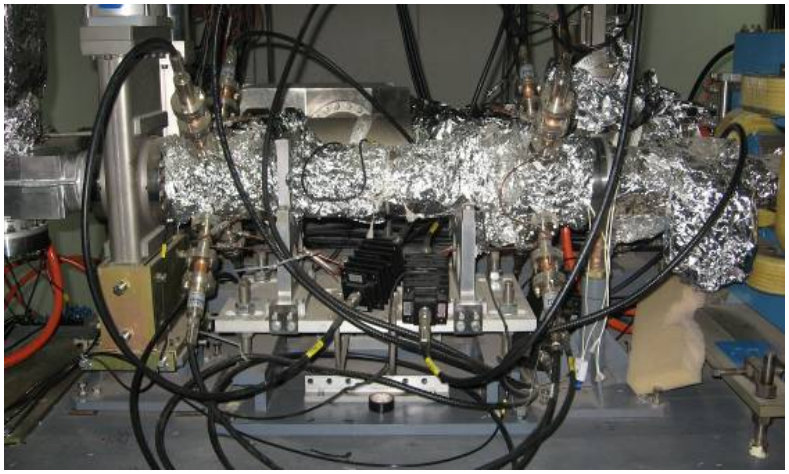
- Main topics in both KEKB and BEPCII
- A simulation code developed by Y. Zhang, and bench marked with Ohmi and Cai's codes.
- Results of BEPCII rings:

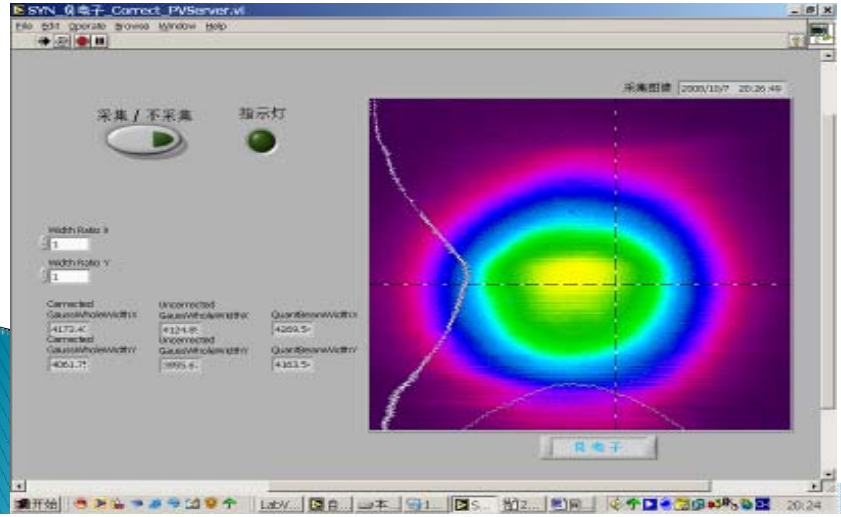


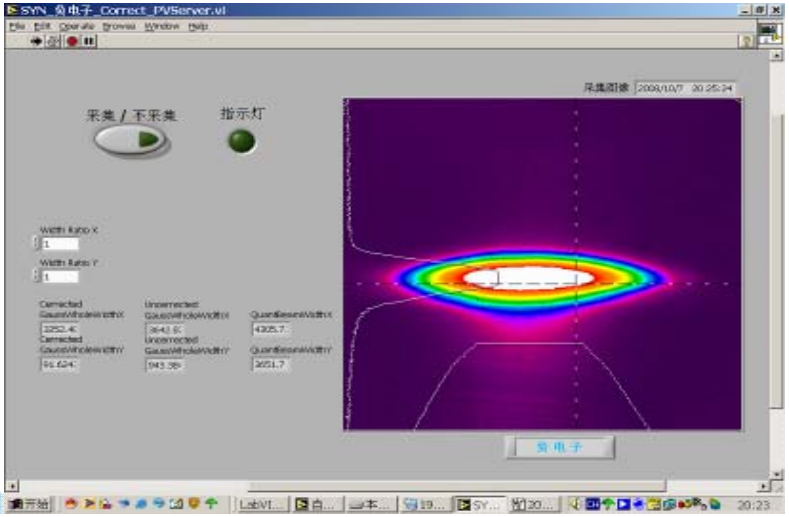
Y. Zhang, et al, Simulation study of beam-beam effects, PRST-AB 8, 074402, 2005

Beam instrumentation and beam commissioning

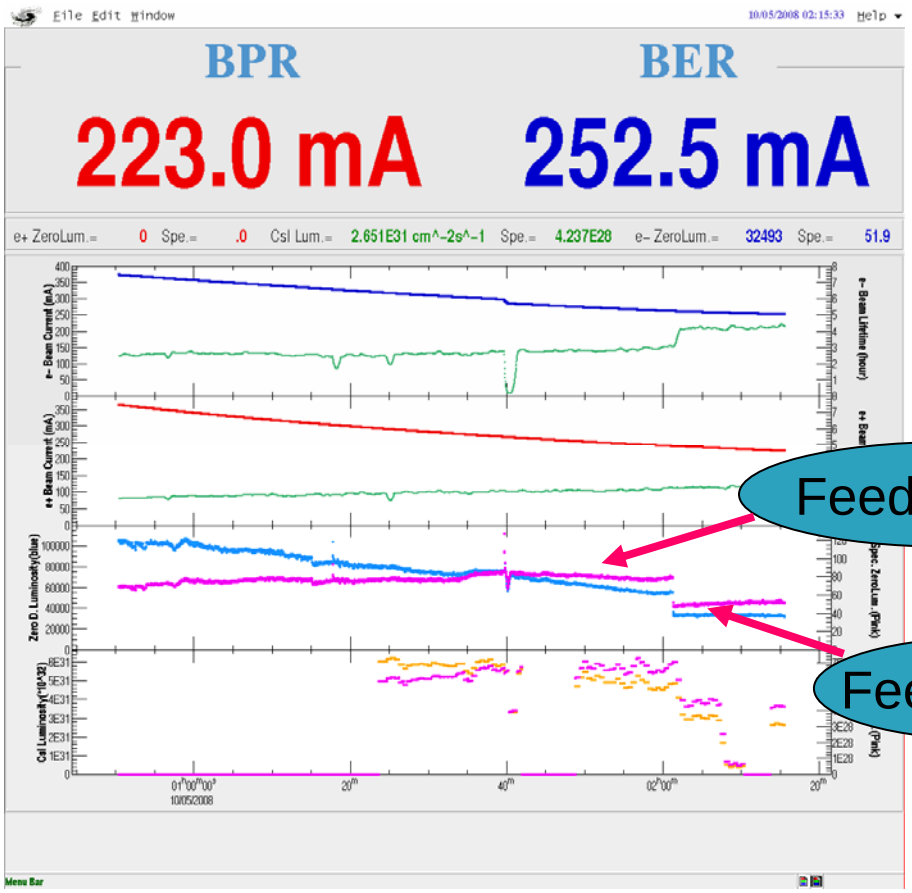
- Transverse feedback system

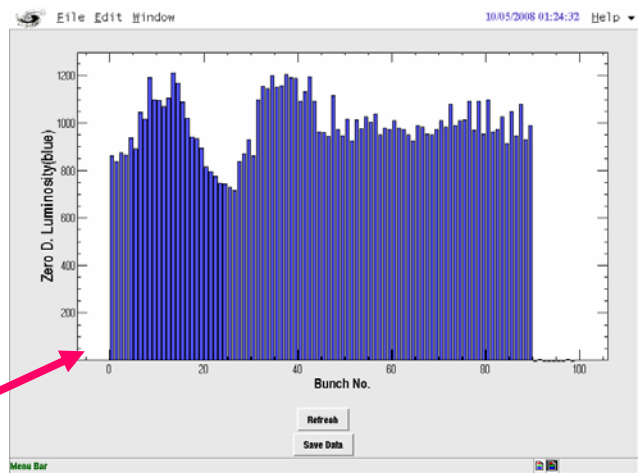






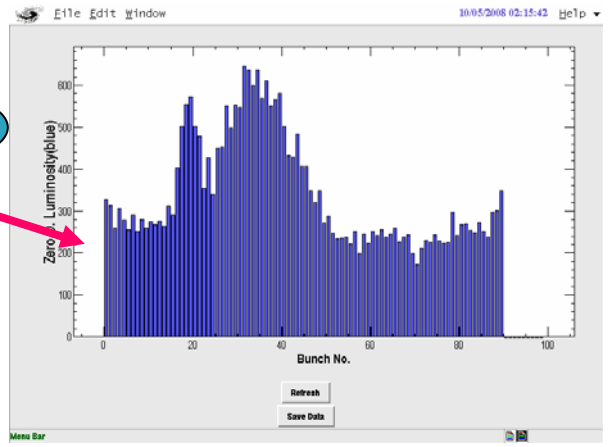
- Luminosity w/ and w/o feedback system



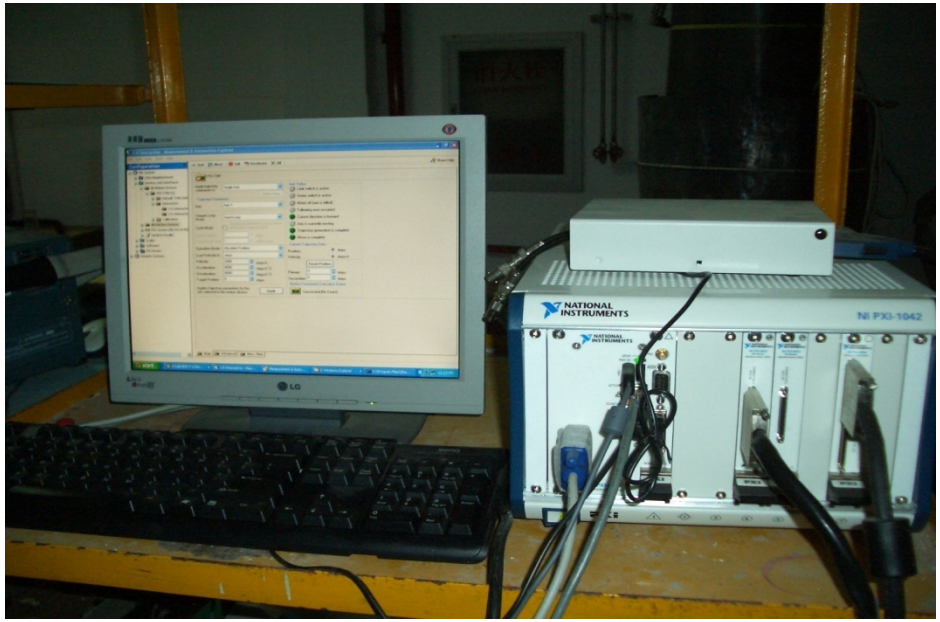


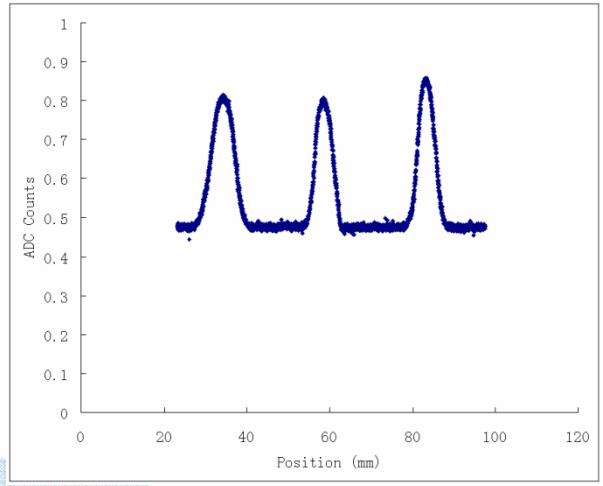
Feedback on

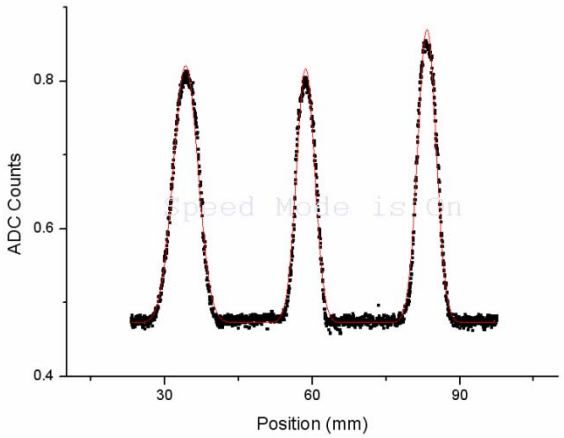
Feedback off



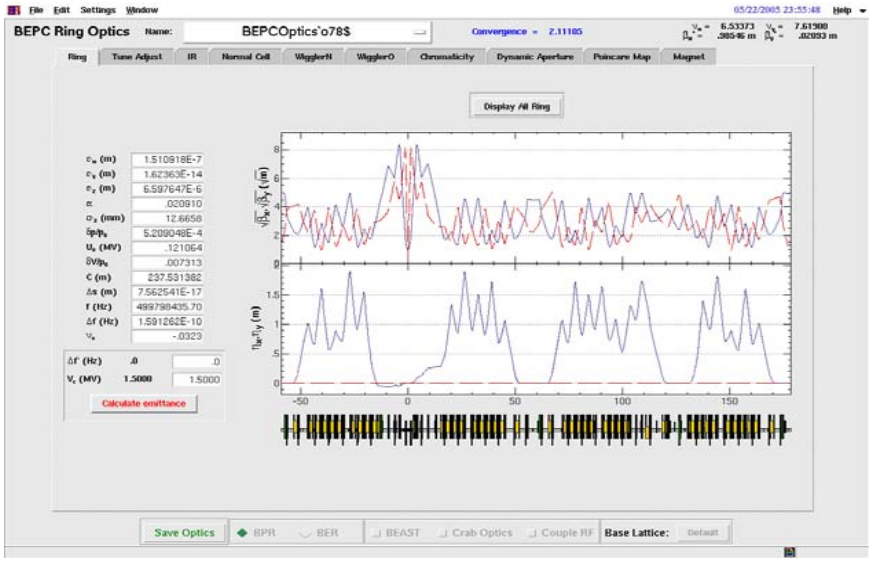
- Wire scanner for bunch size measurement

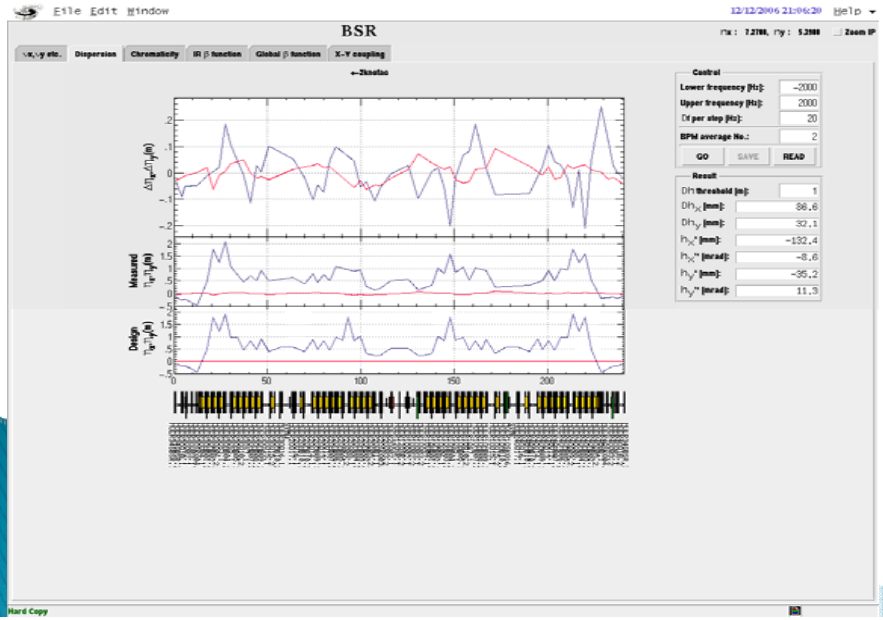


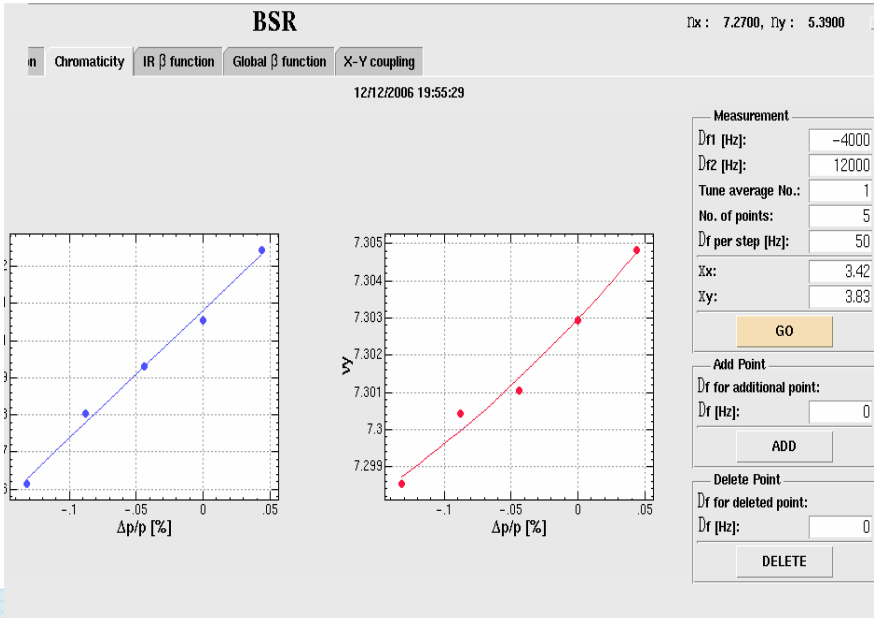




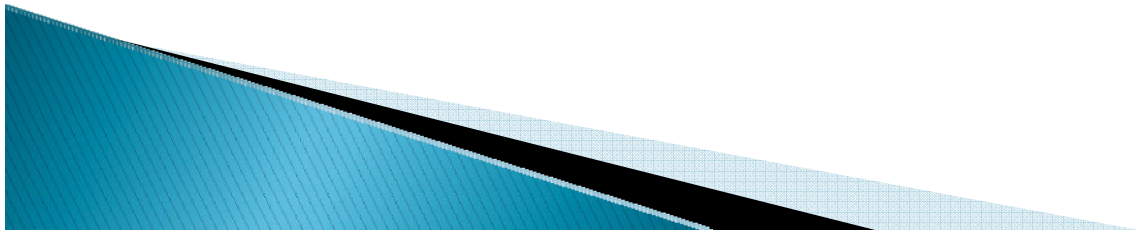
BEPCII commissioning





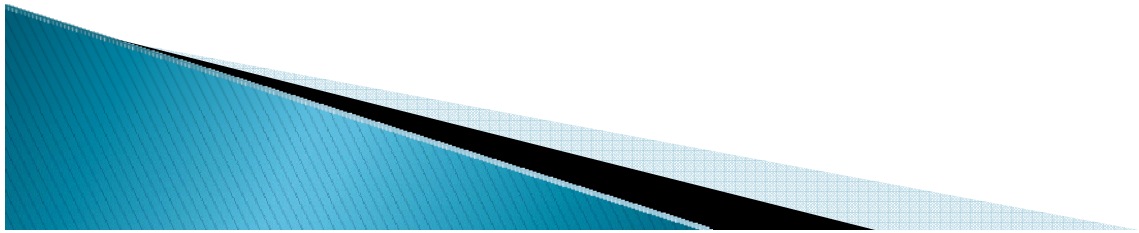


- H. Fukuma, Y. Funakoshi, N. Iida, K. Ohmi, M. Tobiyama, etc, joined the BEPCII storage ring commissioning in different periods of BEPCII running
- Z.Y. Guo, Q. Qin, Y.Y. Wei, G. Xu, C.H. Yu, Y. Zhang, D.M. Zhou, etc, joined the KEKB commissioning in different periods of KEKB running



Wake and impedance in proton rings

- Low beam energy — proton ring (<10 GeV)
- Non-ultrarelativity will affect the wake field and impedance
- Existing formulae of wake and impedance should be corrected
- Applied to small and low energy proton/heavy ion ring



Impedance of two-layer resistive wall

- **Longitudinal impedance:**

$$Z_{//}(\omega)=\frac{Z_0}{2\pi c}\left[-\frac{ic^2k_r^2}{\omega}\ln\left(\frac{r}{a_2}\right)-\frac{\delta_2\mu_2\omega\left[\mathrm{sgn}(\omega)-i\right]}{2a_2\mu_0}\left(1-\frac{k_r^2(2a_2^2-r^2-a_1^2)}{4}\right)M\right]$$

$$M=-\frac{\varepsilon_0\lambda_3\left(\alpha\tanh(x_1)+\tanh(x_2)\right)K_1(k_ra_4)+\varepsilon_3'k_r\left(\alpha\tanh(x_1)\tanh(x_2)+1\right)K_0(k_ra_4)}{\varepsilon_0\lambda_3\left(\alpha+\tanh(x_1)\tanh(x_2)\right)K_1(k_ra_4)+\varepsilon_3'k_r\left(\alpha\tanh(x_2)+\tanh(x_1)\right)K_0(k_ra_4)}$$

Non-relativity correction：space charge　resistive wall

- **Transverse impedance:**

$$Z_{//}^{(1)}(\omega)=-i\frac{Z_0}{c}\left(\frac{c^2k_r^{\,2}(r^2-a_2^2)}{2\pi a_2^2\omega r^2}+\delta_2\frac{1+i\,\mathrm{sgn}(\omega)}{2}\frac{\omega\mu_2}{4\pi a_2^3\mu_0}(4-k_r^2a_2^2+\frac{1}{2}k_r^2r^2+\frac{1}{2}k_r^2a_1^2)\frac{1+\alpha\tanh(x_1)\tanh(x_2)}{\alpha\tanh(x_2)+\tanh(x_1)}\right)$$

$x_1=\lambda_2(a_3-a_2)$,　$x_2=\lambda_3(a_4-a_3)$.

- Multi-layer resistive wall

- Longitudinal impedance

N. Wang and Q. Qin, "Resistive-wall impedance of two-layer tube", PRST- AB 10, 11103 (2007)

$$Z_{//}(\omega)=\frac{iZ_0ck_r^2}{2\pi\omega}I_0(k_ra_1)\left[K_0(k_rr)+I_0(k_rr)\frac{\kappa MK_1(k_ra_2)-K_0(k_ra_2)}{\kappa MI_1(k_ra_2)+I_0(k_ra_2)}\right]$$

- Transverse impedance

$$\kappa=-\frac{b_1c_2}{c_1b_2}\qquad M=\frac{\begin{pmatrix}S_{1,3} & S_{1,4}\end{pmatrix}\prod_{i=2}^{n-1}\begin{pmatrix}S_{i,1} & S_{i,2}\\ S_{i,3} & S_{i,4}\end{pmatrix}\begin{pmatrix}K_1(\lambda a)\\ -K_0(\lambda a)\end{pmatrix}_n}{\begin{pmatrix}S_{1,1} & S_{1,2}\end{pmatrix}\prod_{i=2}^{n-1}\begin{pmatrix}S_{i,1} & S_{i,2}\\ S_{i,3} & S_{i,4}\end{pmatrix}\begin{pmatrix}K_1(\lambda a)\\ -K_0(\lambda a)\end{pmatrix}_n}$$

$$Z_{\perp}(\omega)=\frac{ic\mu_0}{\pi a_1r\beta\gamma^2}I_1(k_ra_1)\left(\frac{p_{s1}}{q_{s1}}I_1(k_rr)+K_1(k_rr)\right)$$

$$\begin{pmatrix}p_+\\ p_s\end{pmatrix}_1=\left(\xi_1B^*(k_ra_2)N_1+\zeta_1D^*(k_ra_2)N_2\right)\left(\xi_1A^*(k_ra_2)N_1+\zeta_1C^*(k_ra_2)N_2\right)^{-1}\begin{pmatrix}0\\ q_s\end{pmatrix}_1$$

$$N_1=\begin{pmatrix}L_{11}^{(1)} & L_{12}^{(1)}\end{pmatrix}\prod_{i=2}^{n-1}\begin{pmatrix}L_{11}^{(i)} & L_{12}^{(i)}\\ L_{21}^{(i)} & L_{22}^{(i)}\end{pmatrix}\begin{pmatrix}B(\lambda_na_n)\\ D(\lambda_na_n)\end{pmatrix}\qquad N_2=\begin{pmatrix}L_{21}^{(1)} & L_{22}^{(1)}\end{pmatrix}\prod_{i=2}^{n-1}\begin{pmatrix}L_{11}^{(i)} & L_{12}^{(i)}\\ L_{21}^{(i)} & L_{22}^{(i)}\end{pmatrix}\begin{pmatrix}B(\lambda_na_n)\\ D(\lambda_na_n)\end{pmatrix}$$

Bi-lateral communication

- Visitors from KEK and IHEP

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total
KEK	3	3	1	6	1	4	4	9	8	39
IHEP	2	4	4	3	3	8	10	4	8	46

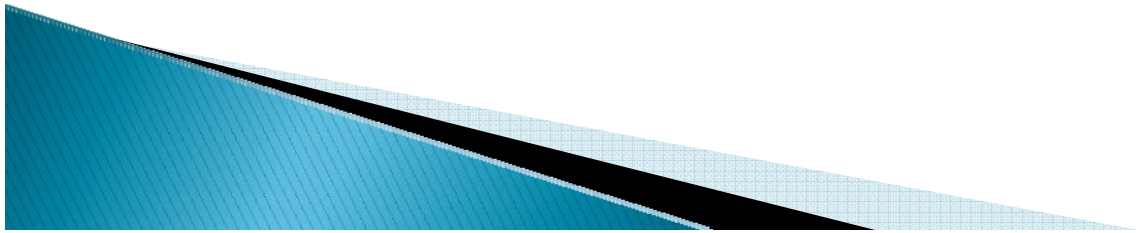
- Seminars held in KEK and IHEP

Seminar name	Place	Period	Participants
Beam physics seminar	IHEP	2001.09.21 – 09.22	Japan: 9, China: 5, Other: 3
Seminar on Beam Instability in Electron Accelerators	IHEP	2005.10.13 – 10.14	Japan: 4, China: 24, Korea: 6, Other: 2
Accelerator beam instability seminar	KEK	2008.12.01 – 12.02	Japan: 11, China: 2, Korea: 3, Other: 1

Publications

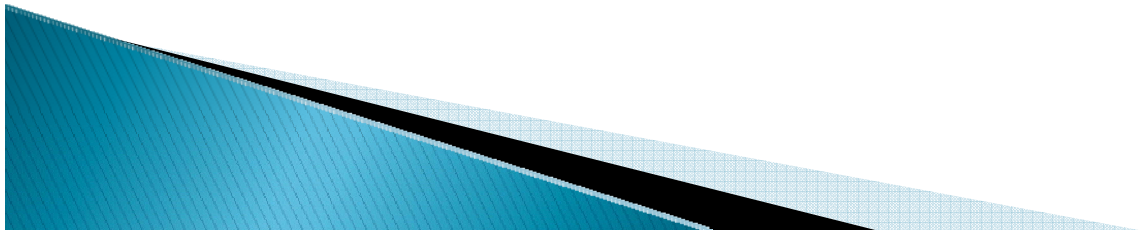
- 86 papers and talks related partially to JSPS core university program
- 9 Ph. D students benefited to the program with their theses:

- ✓ LUO Yun, Two stream instability studies in BEPC and BTCF, 2000.
- ✓ HUANG Gang, The study of longitudinal coupling impedance measurement and beam feedback system, 2002.
- ✓ GE Jun, The study of longitudinal microwave instability including synchrotron radiation effect, 2003.
- ✓ LIU Yudong, The study of electron cloud instability in BEPC and BEPCII, 2004.
- ✓ ZHANG Yuan, Study of beam-beam effects in e+e- storage ring collider, 2005.



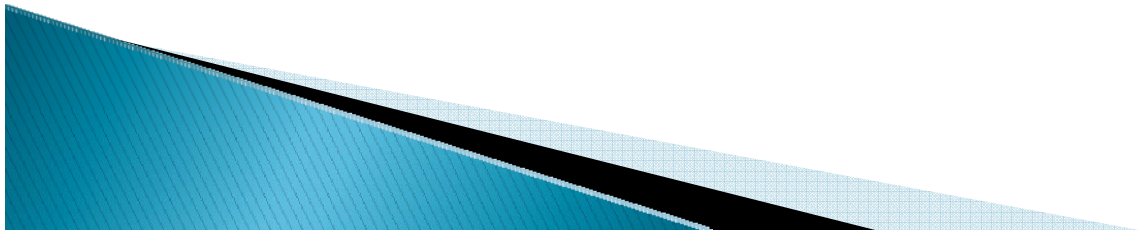
(Continued)

- YUE Junhui, Study of the transverse feedback system for the BEPCII storage ring, 2005.
- WEI Yuanyuan, Beam parameter correction based on the response matrix in the BEPCII storage ring, 2007.
- JIAO Yi, Application of the frequency map analysis to analyze beam dynamics in the ring accelerator, 2008.
- ZHANG Lei, Study and manufacture of the bunch current monitor system of the BEPCII storage ring, 2008.



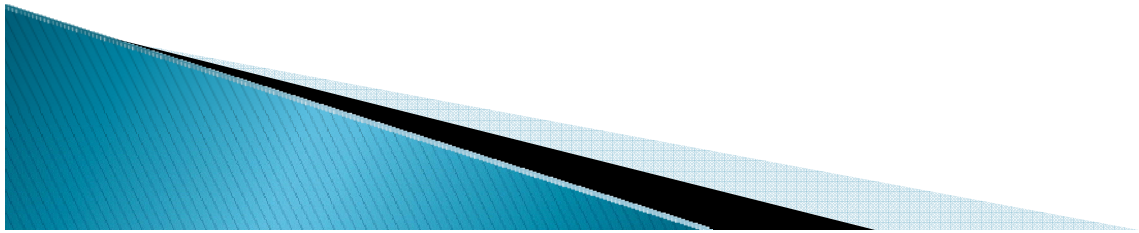
Summary

- JSPS Core University Program executed fruitfully in last 9 years for both KEK and IHEP.
- Focused on the beam instabilities (ECI, general instabilities, etc.), beam-beam interaction, beam commissioning, beam instrumentation, etc.
- Promoted collaborations between KEK and IHEP, including people's exchanging, bi-lateral understanding, studying, friendship, etc.
- Benefited to both KEK/KEKB and IHEP/BEPCII.



Acknowledgement

- Drs. J.H. Yue, Y.D. Liu, Y. Zhang, Y.F. Sui, N. Wang and Y.Y. Wei from IHEP.
- Prof. H. Fukuma from KEK.
- Mr. L.J. Guo from IHEP foreign affair office.



Thanks for your attentions!