The Second Phase Commissioning of BEPCII

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Outline

- Introduction
- BER & BPR Commissioning
- Beam Performance
- Luminosity Tuning
- High Current Issues
- Summary

Design Goals of BEPCII

Upgrade of BEPC: continues to serve the purposes of both high energy physics experiments and synchrotron radiation applications.

Beam energy range	1–2.1 GeV
Optimized beam energy region	1.89GeV
Luminosity @ 1.89 GeV	1×10^{33} cm^{-2}s^{-1}
Injection from linac	Full energy injection: E_{inj}=1.55–1.89GeV
Dedicated SR operation	250 mA @ 2.5 GeV

Main Parameters

Parameters		Unit	BEPCII	BEPC
Operation energy (E)		GeV	1.0–2.1	1.0–2.5
Injection energy (E_{inj})		GeV	1.55–1.89	1.3
Circumference (C)		m	237.5	240.4
β^*-function at IP (β_x^*/β_y^*)		cm	100/1.5	120/5
Tunes ($\nu_x/\nu_y/\nu_s$)			6.57/7.61/0.034	5.8/6.7/0.02
Hor. natural emittance (ε_{x0})		mm·mr	0.14 @1.89 GeV	0.39 @1.89 GeV
Damping time ($\tau_x/\tau_y/\tau_e$)			25/25/12.5 @1.89 GeV	28/28/14@1.89 GeV
RF frequency (f_{rf})		MHz	499.8	199.533
RF voltage per ring (V_{rf})		MV	1.5	0.6–1.6
Bunch number (N_b)			93	2×1
Bunch spacing		m	2.4	240.4
Beam current	Colliding	mA	910 @1.89 GeV	~2×35 @1.89 GeV
	SR		250 @ 2.5GeV	130
Bunch length (cm) σ_l		cm	~1.5	~5
Impedance $\|Z/n\|_0$		Ω	~ 0.2	~4
Crossing angle		mrad	±11	0
Vert. beam-beam param. ξ_y			0.04	0.04
Beam lifetime		hrs.	2.7	6–8
luminosity@1.89 GeV		$10^{31}cm^{-2}s^{-1}$	100	1

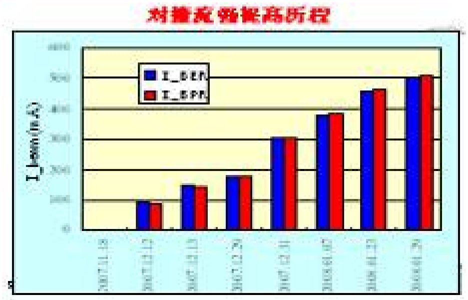
The Milestones



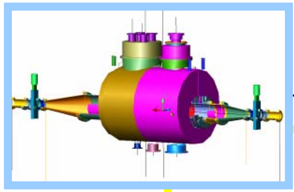


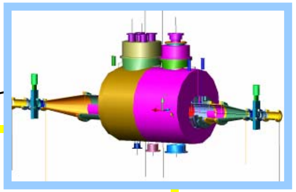

January 2004	Construction started
May. 4, 2004	Dismount of 8 linac sections started
Dec. 1, 2004	Linac delivered e$^-$ beams for BEPC
July 4, 2005	BEPC ring dismount started
Mar. 2, 2006	BEPCII ring installation started
Nov. 13, 2006	Phase 1 commissioning started
Aug. 3, 2007	Shutdown for installation of IR-SCQ's
Oct. 24, 2007	Phase 2 commissioning started
Mar.28, 2008	Shutdown for installation of detector






Commissioning





Collission: e^- ring (BER) + e^+ ring (BPR)

SR Operation: Outer ring (BSR)

Phase 1 ：IR with Conventional magnets

Phase 2 ：IR With SCQ's

Phsse 3 ：BEPCII + BESIII

Beam commissioning Phase 1
(Nov. 12, 2006-Aug. 3, 2007)

- Synchrotron Radiation Mode (BSR) commissioning and user experiment operation

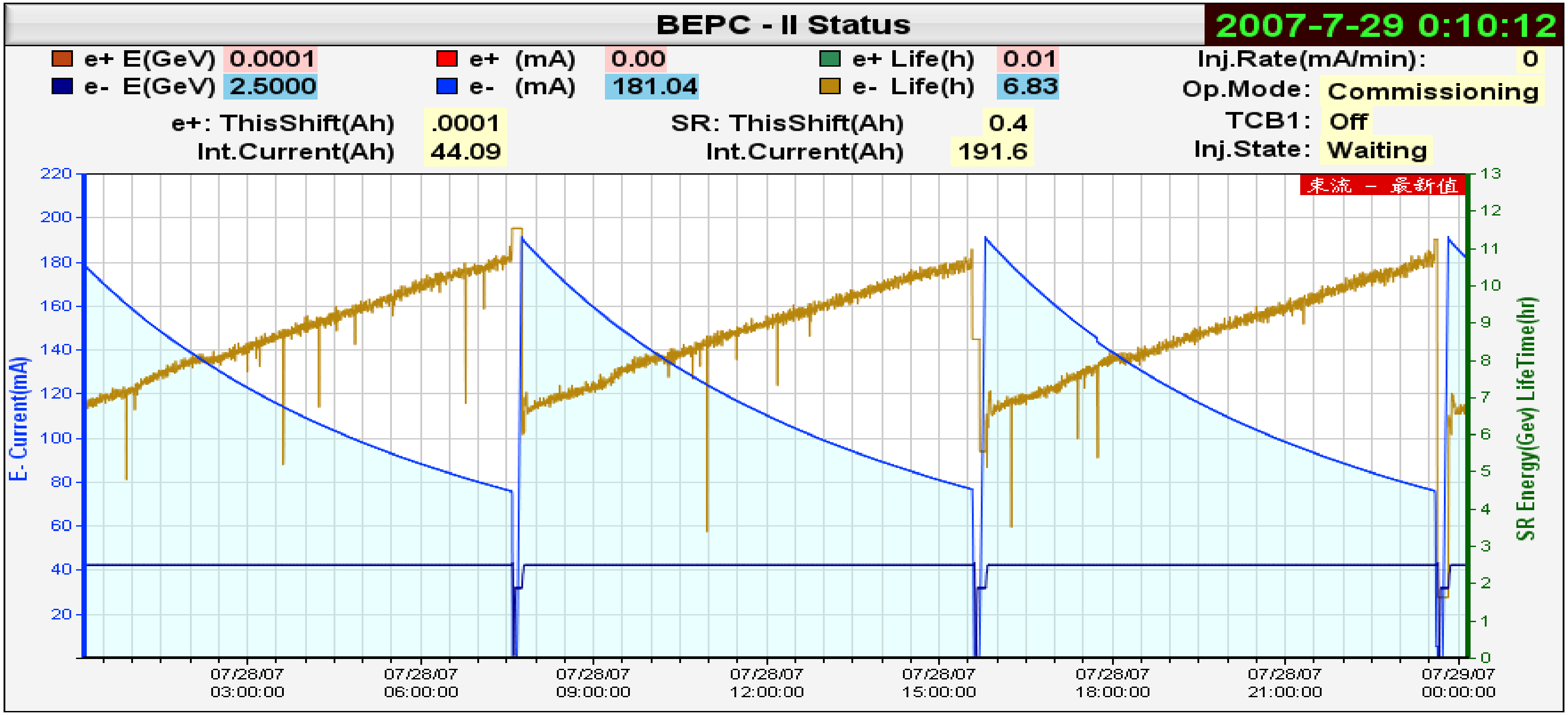
  (2006/11.13-2007/02.02)

  (2007/05.25-2007/07.31)

- Collision mode commissioning (2007/02.02-2007/05.25)
  - Electron Ring (BER) commissioning
  - Positron Ring (BPR) commissioning
  - Collision
- Large beam current experiment (07/07.31-07/08.03)

--Reported on APAC07, PAC07

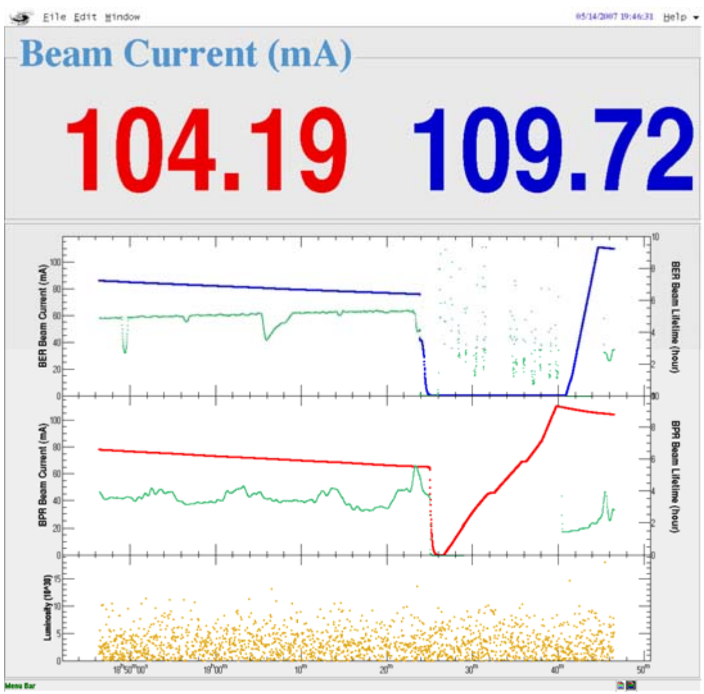
BSR user operation in phase 1



- All 5 wigglers put into operation
- Beam current 180－70mA, three injections a day
- Beam lifetime ~7.5 hrs@150mA

Collision achieved in phase 1

100mA×100mA beam collision has been achieved with multi-bunches (20, 50 bunches for each beam).



100mA×100mA on May 14

□For single bunch

Estimate from tune shift:

Lum ~5-10×10^{29} $cm^{-2}s^{-1}$ @ I_b=5mA

Estimated from beam size:

$\sigma_x = 489\mu m$, $\sigma_y = 16\mu m$,

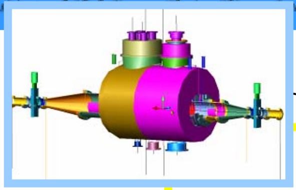
Lum~ 7.8×10^{29} $cm^{-2}s^{-1}$ @ I_b=5mA

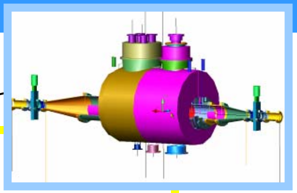
□For multi-bunch 100mA×100mA

K_b=20, I_b=5mA,

Lum. > 1.0×$10^{31}$$cm^{-2}s^{-1}$, which is the record of BEPC

Phase 2 Commissioning





Collission: e^- ring (BER) + e^+ ring (BPR)

SR Operation: Outer ring (BSR)

Phase 1 ：IR with Conventional magnets

Phase 2 ：IR With SCQ's

Phsse 3 ：BEPCII + BESIII

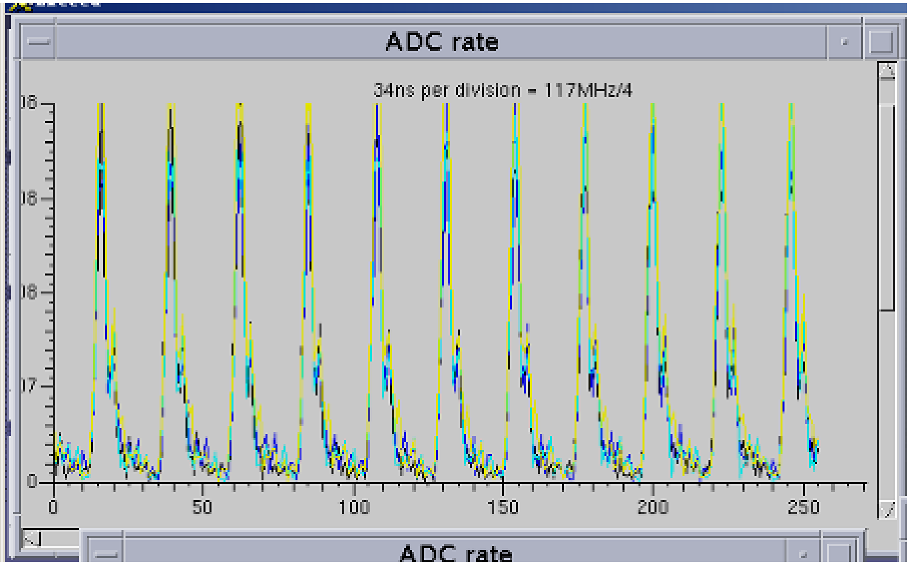
Beam commissioning Phase 2

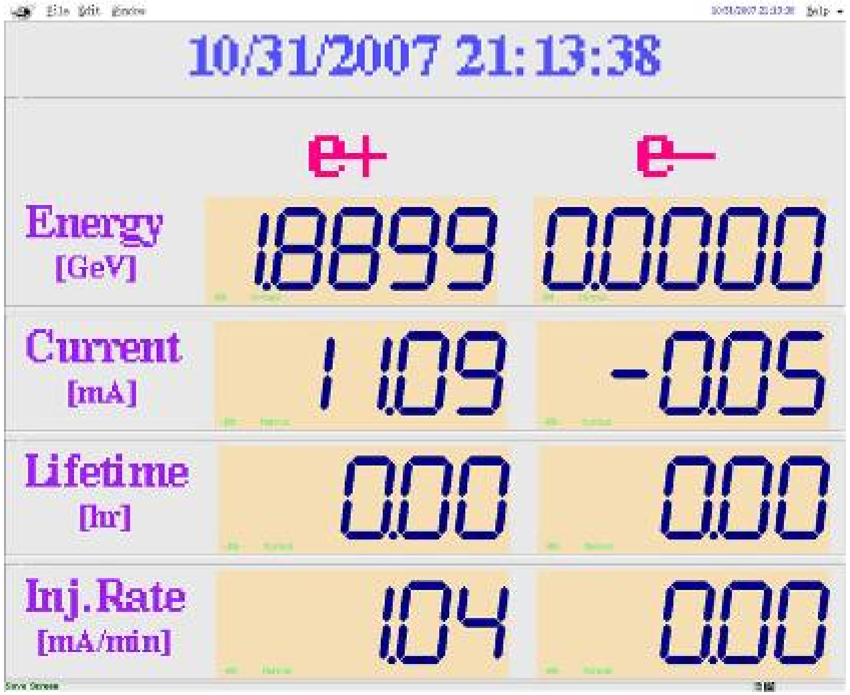
- Collision mode commissioning (Oct. 24, 07--Feb. 1, 08)
  - Electron Ring (BER) commissioning
  - Positron Ring (BPR) commissioning
  - Collision
- Synchrotron Radiation Mode (BSR) commissioning and user experiment operation

  (Feb. 1, 08- Mar. 28, 08)

e+ stored on Oct.31

e- stored on Oct. 25





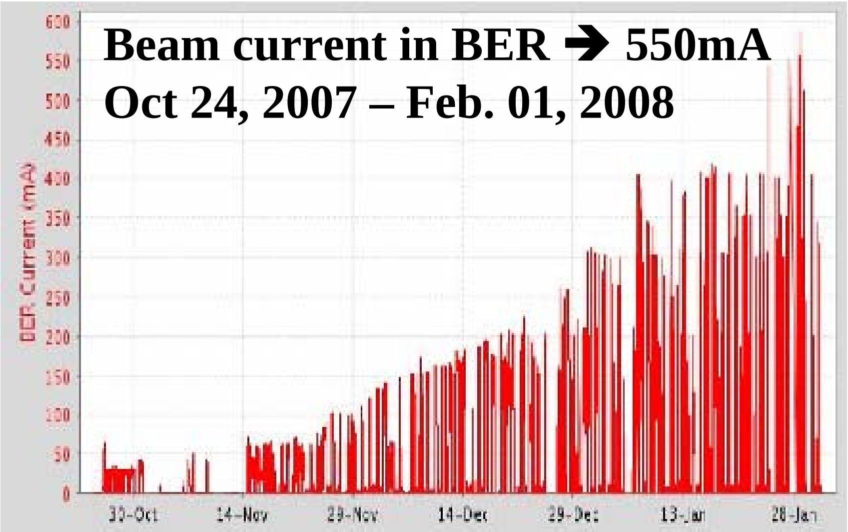
The road to high beam current

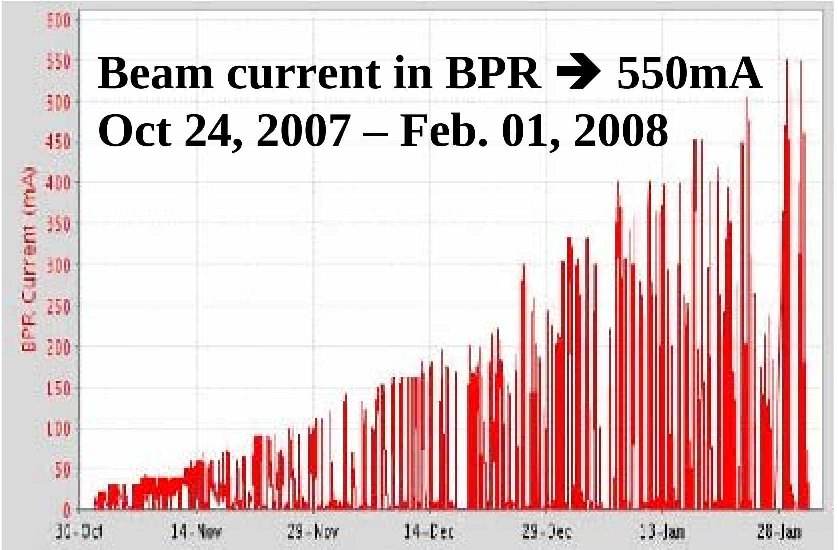
- Optics optimization：Twiss parameter corrected to design values, orbit correction, etc.
- High beam current: Beam dose cleaning vacuum, RF conditioning, bunch-by-bunch feedback, cooling in beam ducts, etc.
- High luminosity：tune scan, collision optimization, single bunch current, more bunches, etc.

As the result:

Beam current > 500mA,

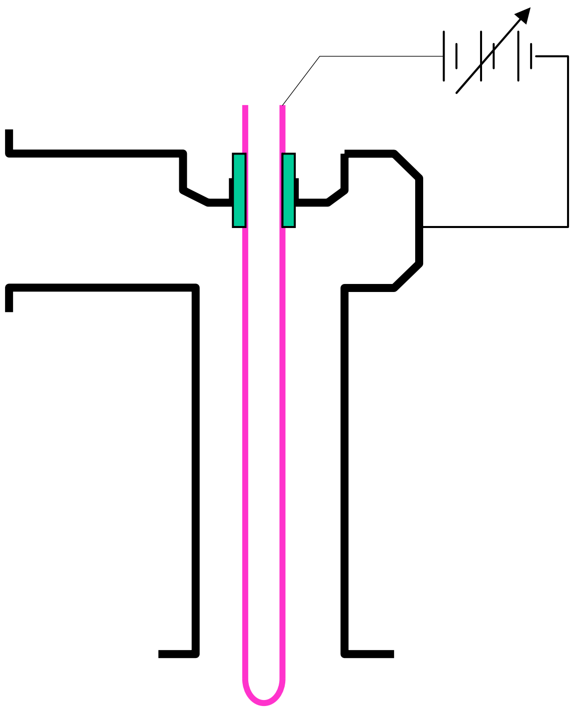
Lum. $>1\times10^{32}cm^{-2}s^{-1}$





RF tuning to increase the beam current

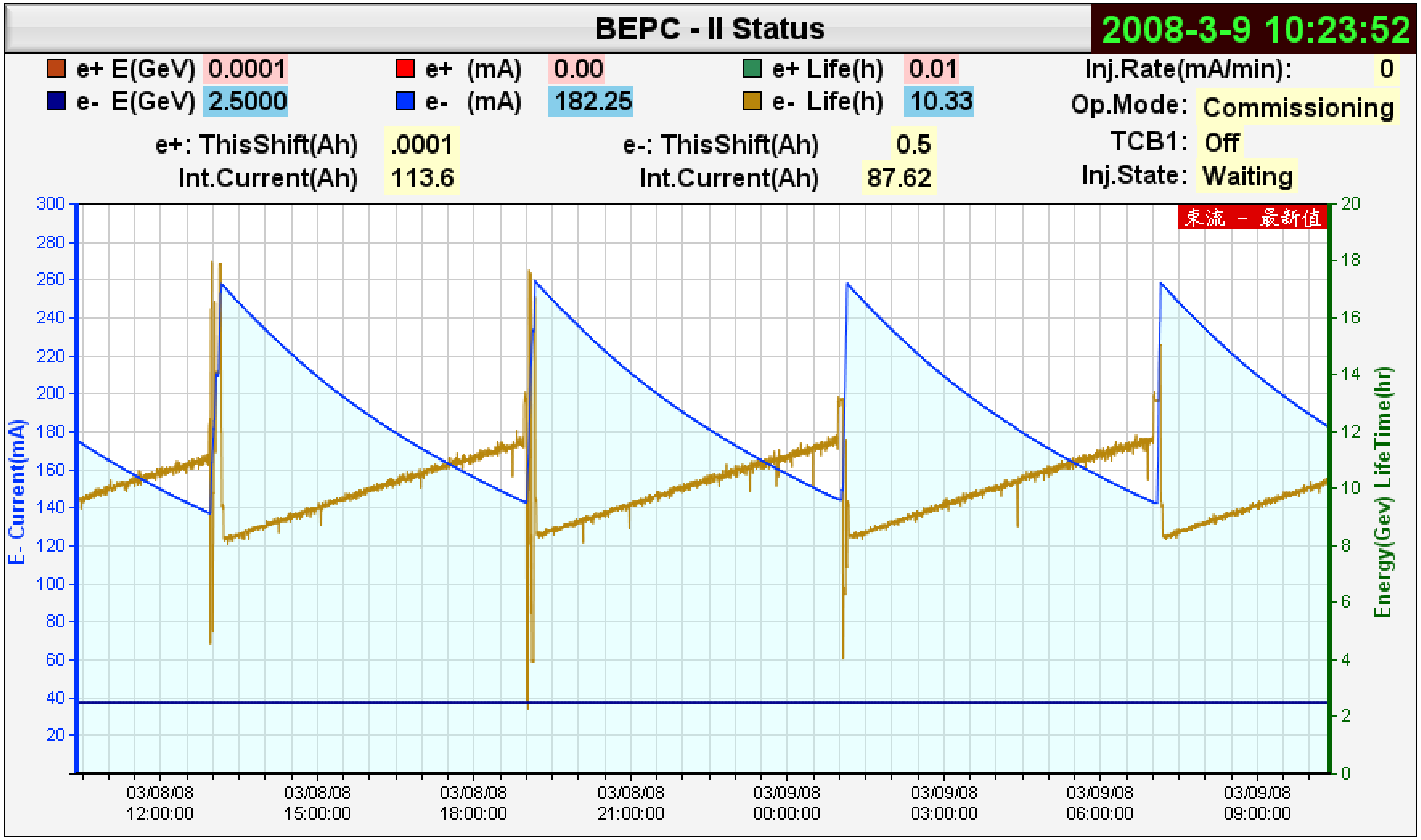
- **Initially, increase rate restrained to 10mA per day.**
- **When the beam current in BER &BPR exceeded 100mA, the SC cavity (SCC) tripped often due to its vacuum pressure raised quickly.**
- **To overcome the problem, a DC bias voltage was used on the power coupler of the SC cavity to suppress the multi-pacting effect.**
- **For longitudinal stable: LLRF tuning when with current.**



Lum.> $1\times10^{32}cm^{-2}s^{-1}$ with 500mA×500mA Collision

SR operation in phase 2

(Feb.25 - March 28)



(Imax=250mA, 2.5GeV top-off injection)

Beam Performance of Collision Mode

1. **Optics Correction**
2. **Injection**
3. **Instabilities & feedback**
4. **Beam lifetime**

…

More and details will be in the following talks:

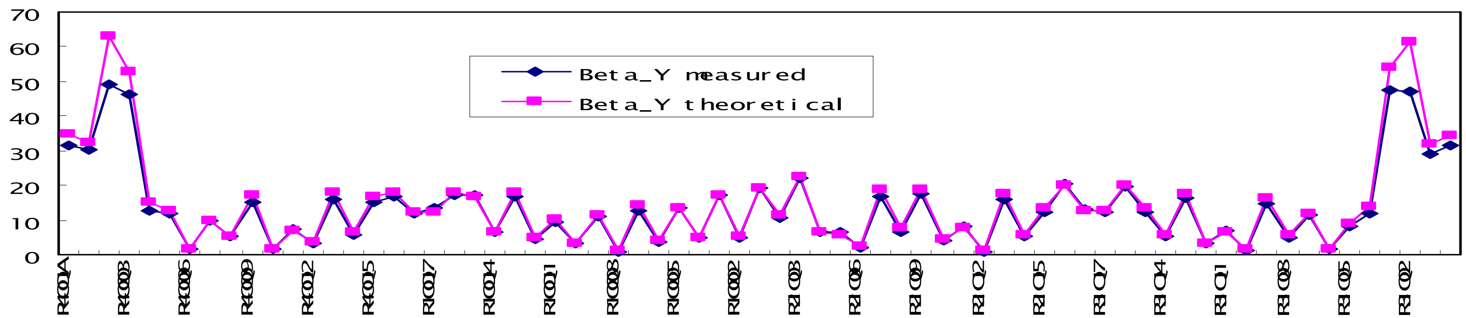
Beam Dynamics Studies in the BEPC-II Storage Rings—Q. Qin

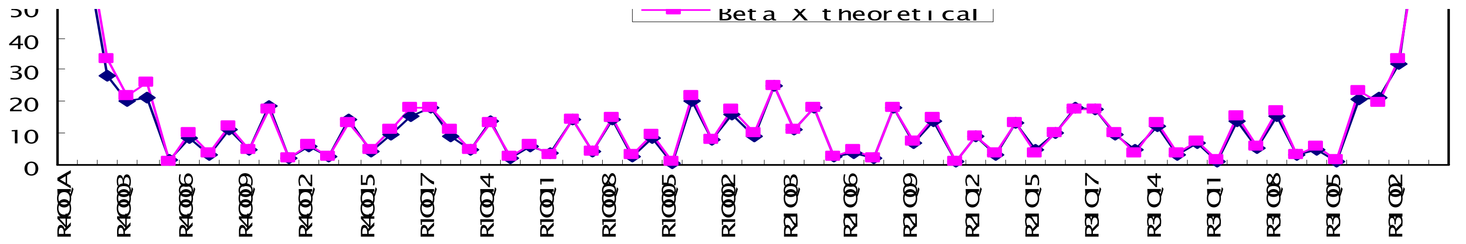
Analysis of BEPCII Optics using Orbit Response Matrix—Q. Qin

Performance of the transverse coupled-bunch feedback system in BEPCII storage ring—J.H. Yue

Optics Correction

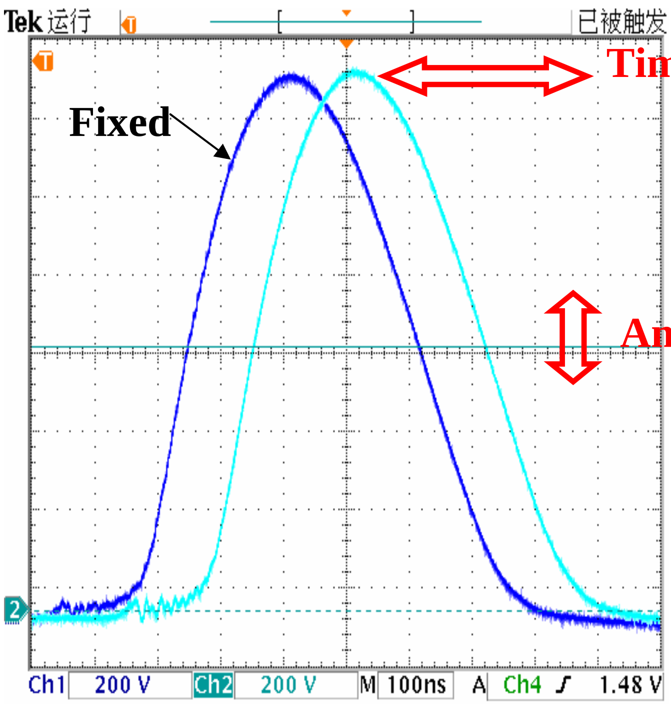
- ✓ **Measured beam optics functions are in good agreement with theoretical prediction with discrepancy within ±10% at most quadrupoles,**
- ✓ **Design nx/ny= 6.54, 5.59, measured nx/ny= 6.544, 5.599**
- ✓ **Quadrupole strengths systematically 1~2% lower than design set:**
  1) **Quadrupole and sextupole near to each other**
  2) **fringe filed effect.**
  3) **Other origin of these errors is still pursued.**

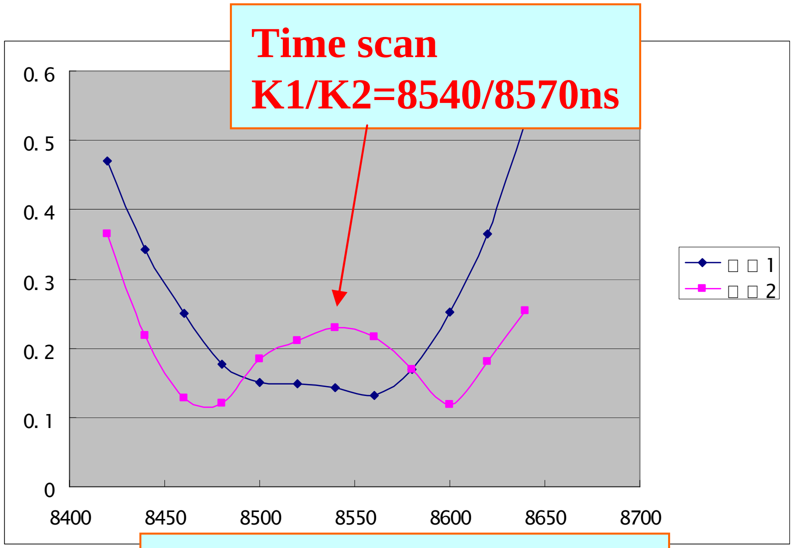


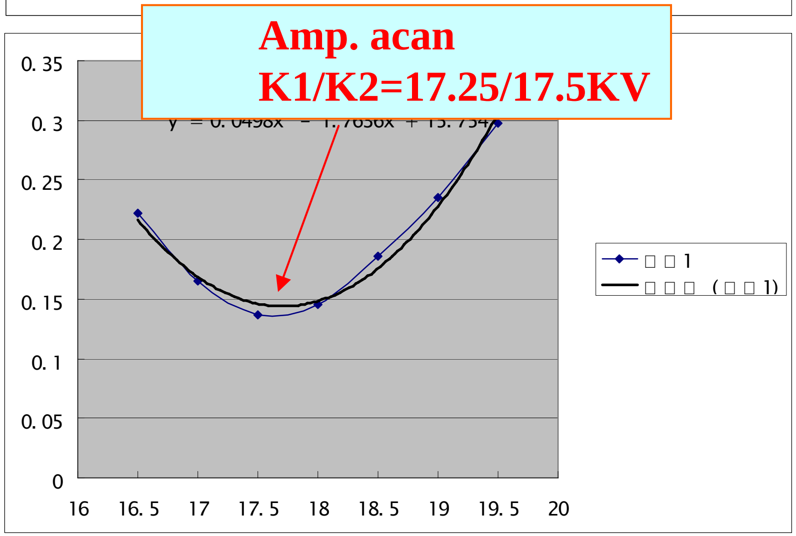


Injection

To reduce the residual orbit oscillation of the stored beam during injection =>set the right timing and amplitude of the two kickers.





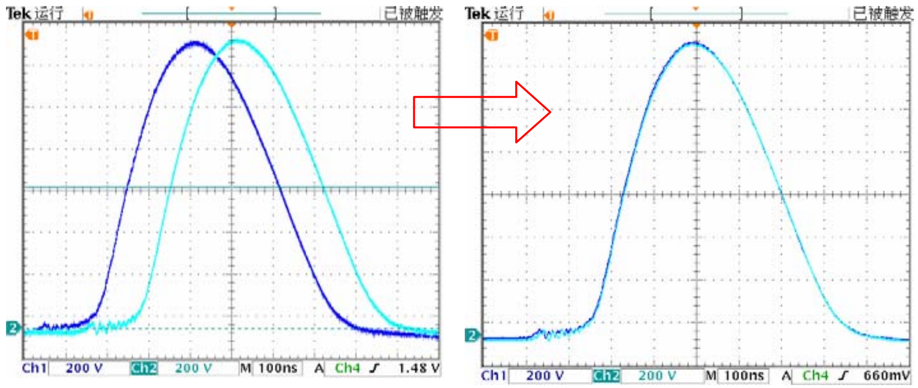


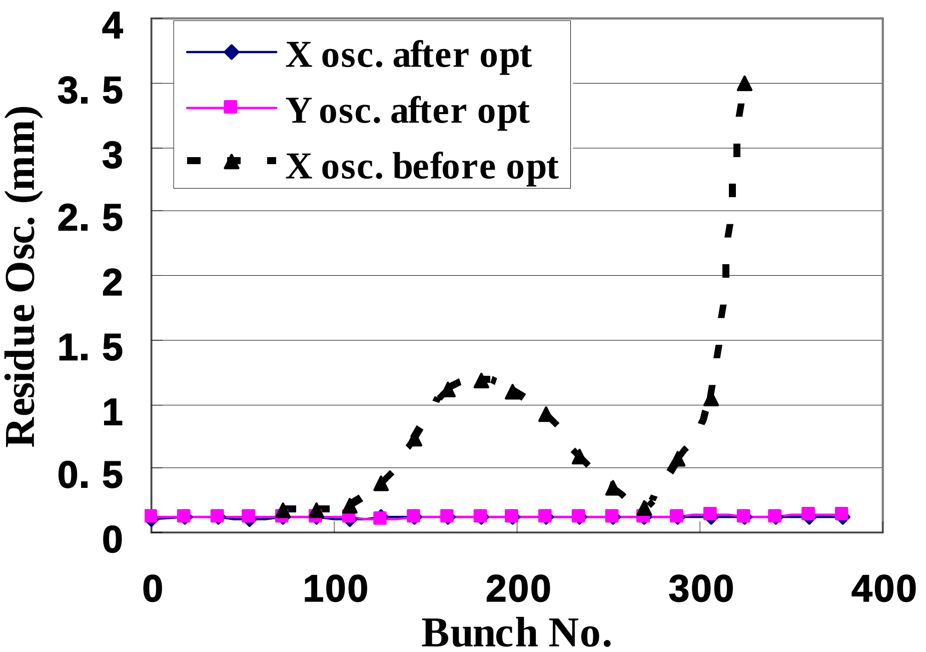
Injection (cont')

- The waveforms of the two kickers consistent with each other.

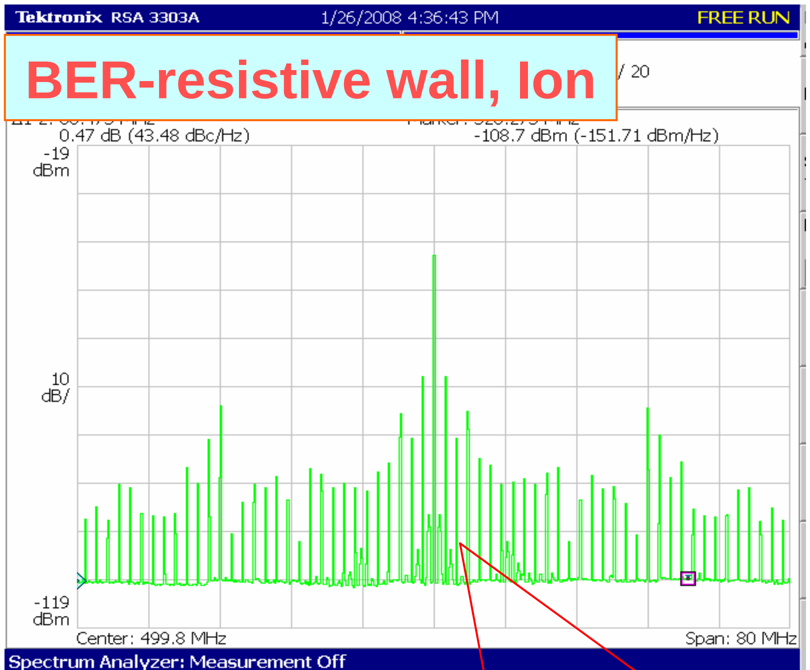
⇒ After time delay and amplitude of the two kickers optimized, the residual orbit oscillation of all the other bunches during injection can be reduced to around 0.1mm, corresponding to about $0.1\sigma_{x}$.

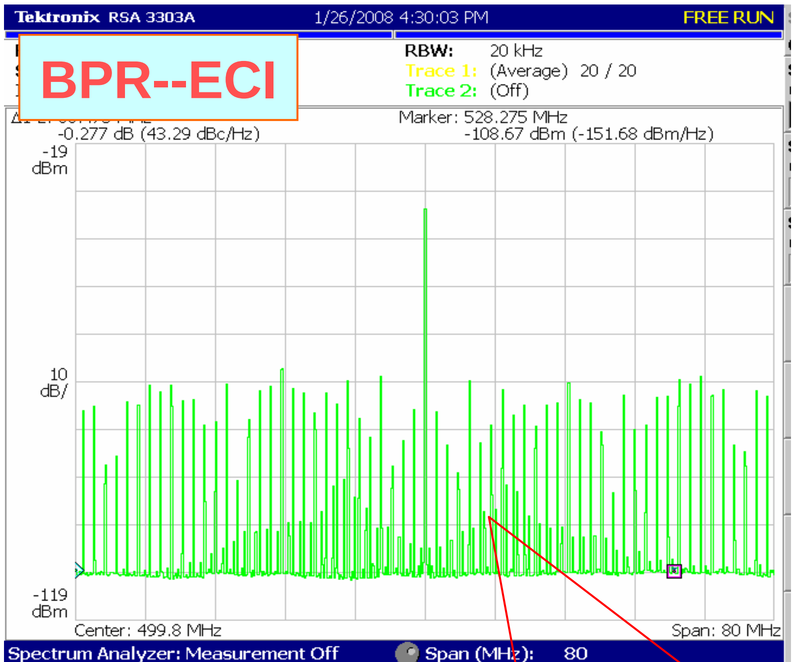
⇒ Injection on collision possible





Coupled bunch instability
(transverse)





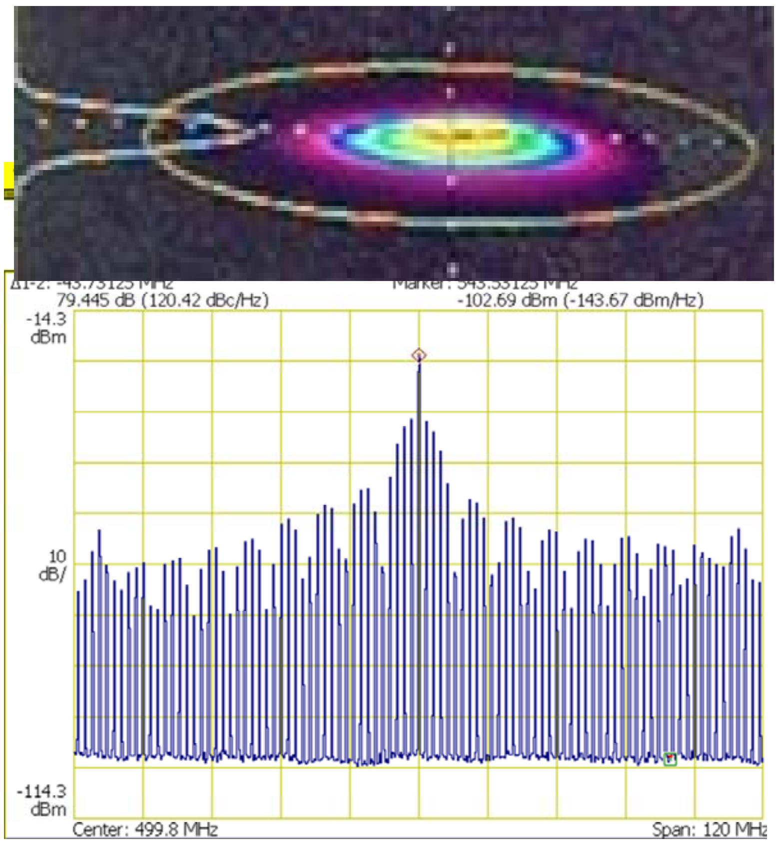
Sidebands of the electron beam with 99 bunch uniform filling, spacing 4 buckets, beam current 40mA.

Sidebands of the positron beam with 99 bunch uniform filling, spacing 4 buckets, beam current 40mA.

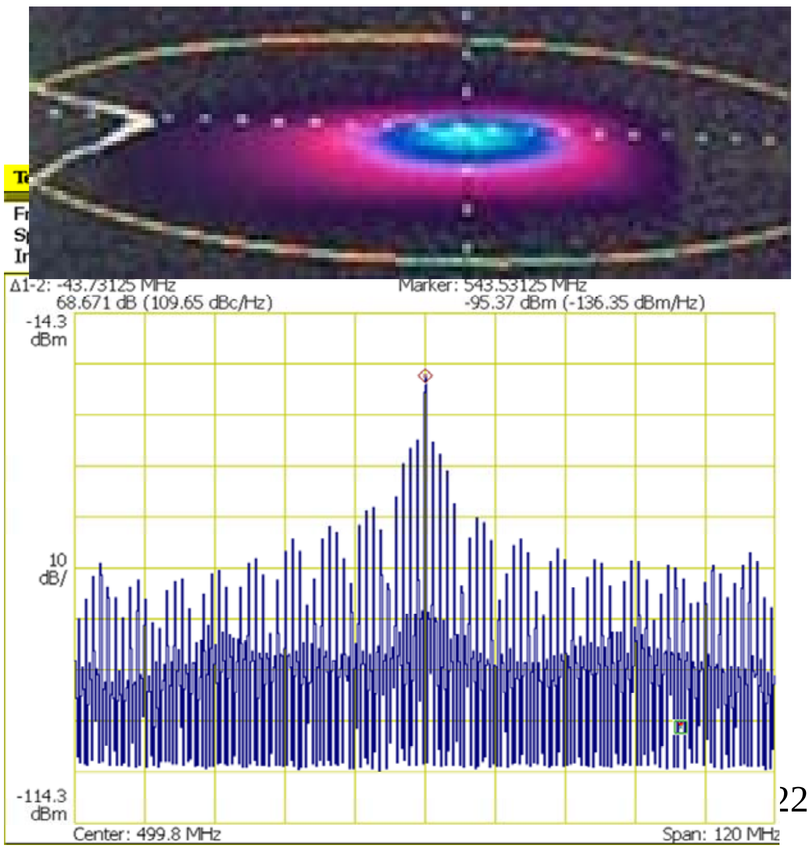
Transverse FeadBack System

Couple bunch instabilities can be cured with the analog TFB system, the sidebands of in both BER and BPR can be well suppressed

Feedback ON



Feedback OFF

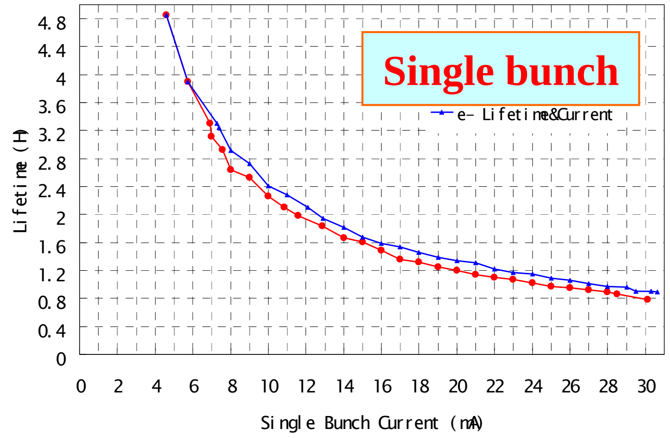


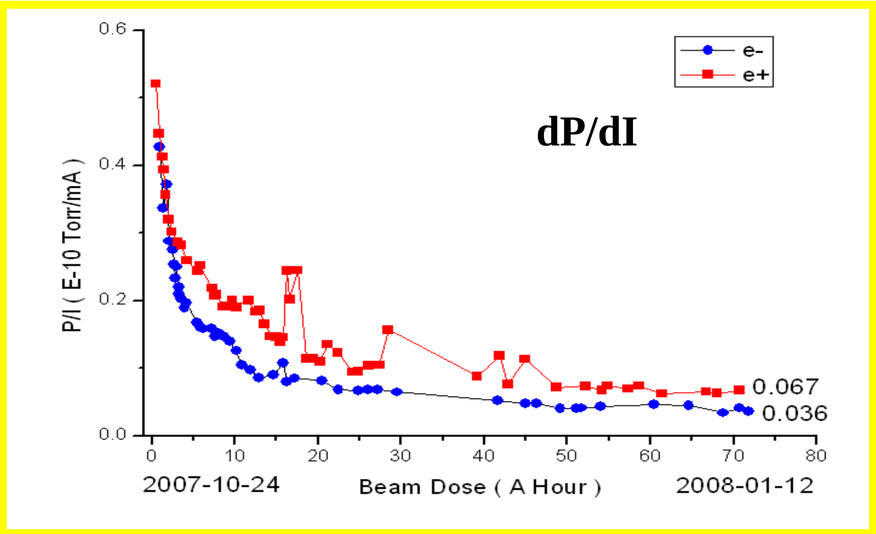
Beam life time

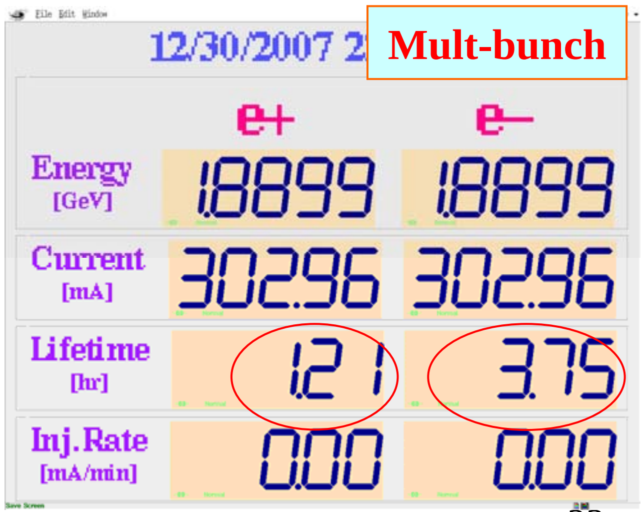
- Single bunch: $\tau_{BER} \sim \tau_{BPR}$
- Muli-bunch @high current: $\tau_{BER} > \tau_{BPR}$
- Possible cause: vacuum, $P_{BPR} > P_{BER}$

? Both τ_{BER} and τ_{BPR} <calculation

=>Systematic studies in future.







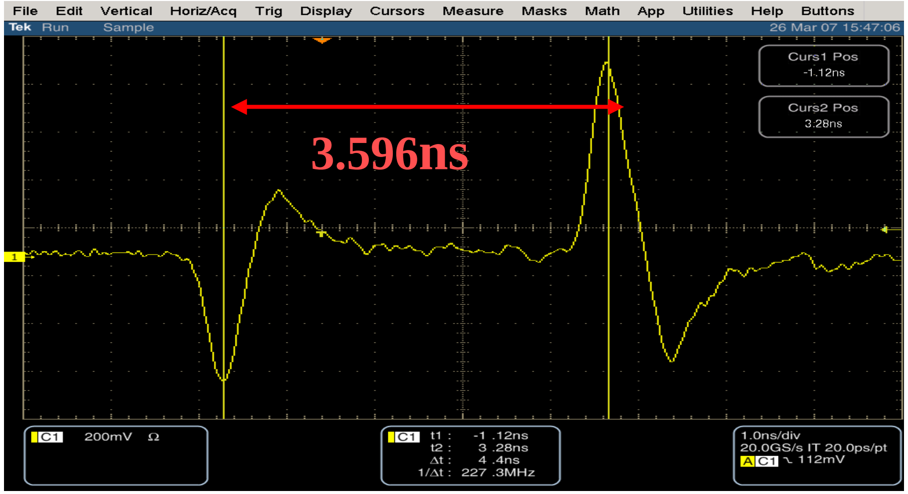
Luminosity Tuning

Collision with BBS

IP bunch size： σ_z=1.5cm (50ps)
transverse： σ_x=0.5mm, σ_y=5μm

Collision in long.

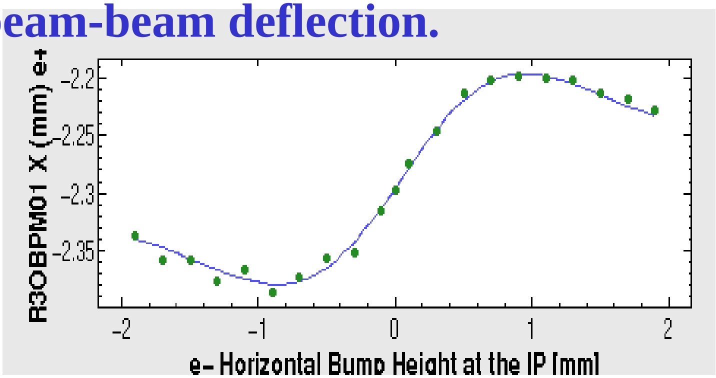
Adjust RF phase=> Two bunch reach IP at same time (deviation <10ps)

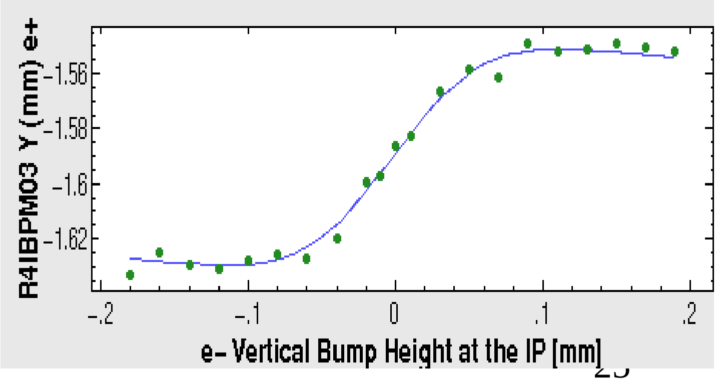


e+ and e- signals on R4CBPM00 (0.539m to IP)

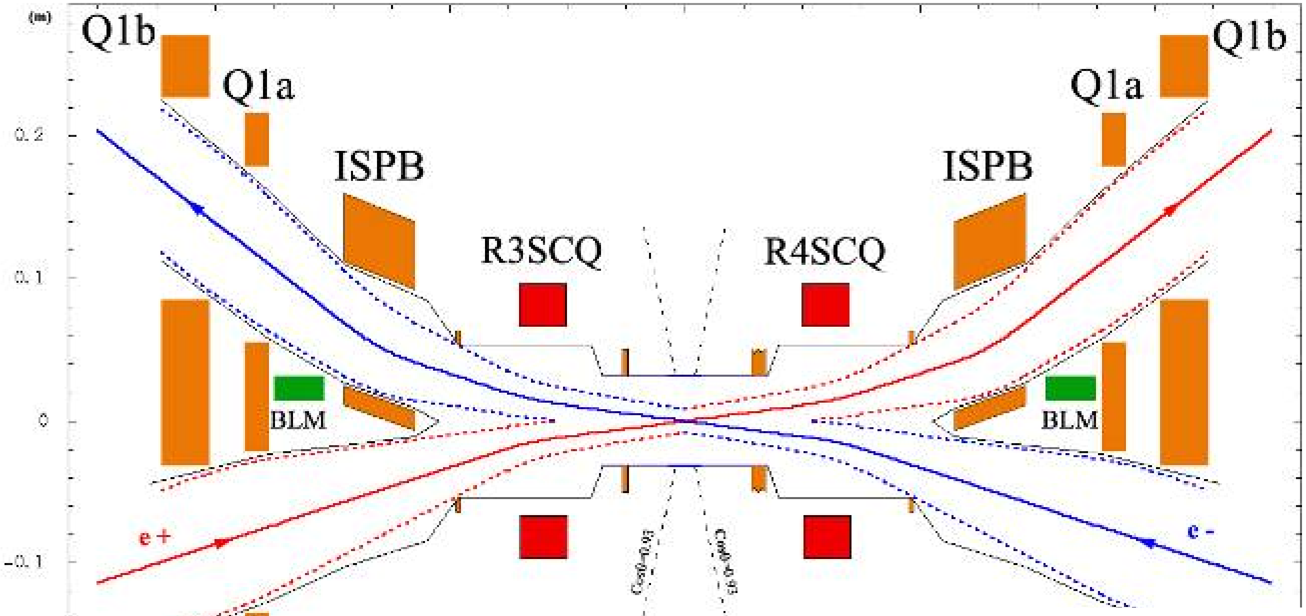
Transverse Scan

Adjust an orbit bump (step in 10/1.0 μm) around the IP in one ring, while observing the beam orbit variation in the other ring due to the beam-beam deflection.





Luminosity monitor

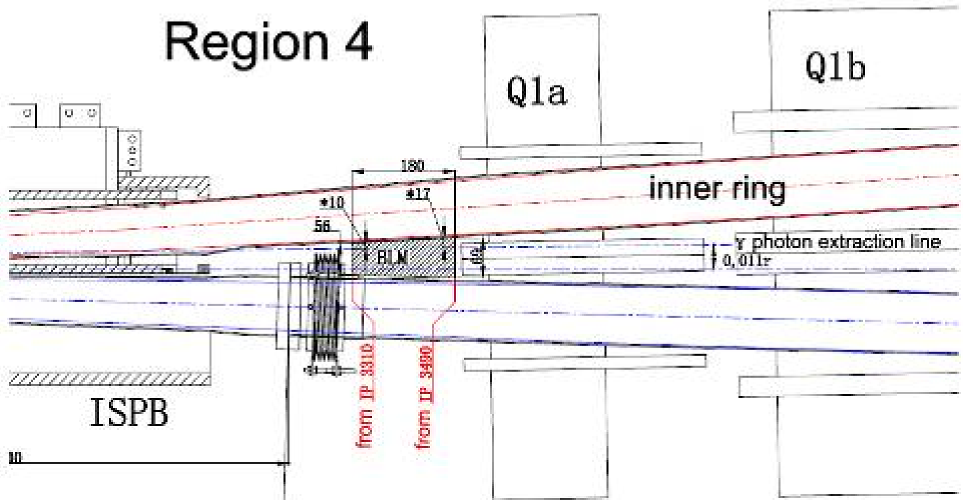


Zero degree Radiative bhabha process

$$e^+ + e^- \rightarrow e^+ + e^- + \gamma$$

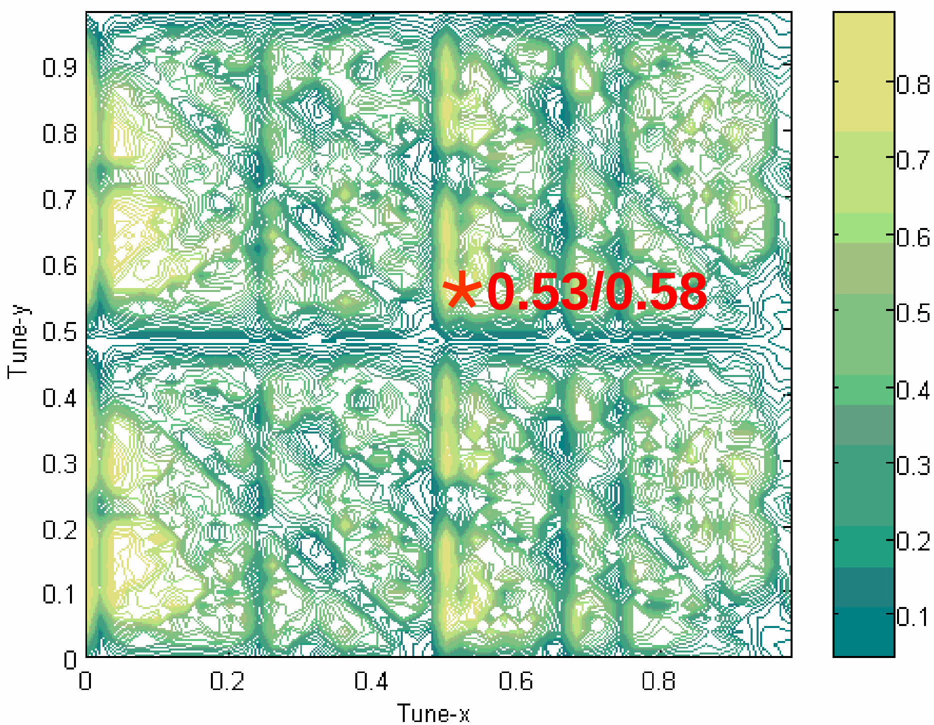
- **R=3mm aperture**
- **Time res. 0.21ns**

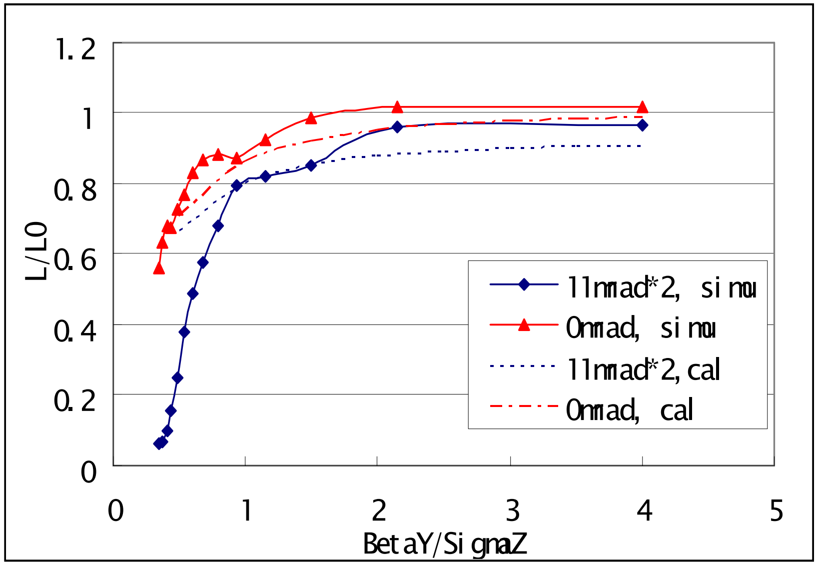
=> Bunch lum.



Choice of Working Point

- **Beam-beam simulation with BBC code has shown that the beam-beam parameters of 0.04 and crossing angle of 11mrad×2 are acceptable.**





Tune Scan to find the best working point for high specific luminosity L/(I+×I-)

BPR	5.55	5.56	5.57	5.58	5.59	5.6	5.61	5.62	5.63	5.64	5.65
6.52	t 差	t 差	t 差	t 差	76.92		丢束	t 差	127.3	139.2	166.0
6.53	108.6	119.3	98.8	105.4	89.7	198.6	164.9	139	99.2	84.3	81.1
6.54	105.7	160.8	164.8	182.4	118.5	168.7	172.5	129.9	137.8	131.8	142.8
6.55	82.1	101.6	109.4	96.7	125.6	150.3	117.3	164.4	157.9	149.2	155.7
6.56	74.2	79.0	139.4	147.0	118.5	139.7	161.7	134.1	139.3	141.6	146.2
6.57	112.9	96.1	77.1	87.2	132.5	133.4	151.2	148.4	143.4	131.8	164.8
6.58	93.5	e+ blow up			185.2	102.4	114.3	128.5	171.0	136.0	146
6.59	113.1	101.9	158.9	75.2		110.5	113.7		140.4	t 差	

BER	5.55	5.56	5.57	5.58	5.59	5.6	5.61	5.62	5.63	5.64	5.65
6.52											
6.53	131.8	167.2	141.9	111.7	139.1	146.2	145.6			207.1	214.1
6.54	t差 119	109	139.5	164.5	156.5 145.2					218.5	224.2
6.55	60.1	106.3	93.1	99.2	123	143.4	142.7			205.6	215.2
6.56		丢束	丢束	132.1	165.5				205.8	198.6	丢束
6.57	75.2	143.3	134	116.2	94.1	111.1	122.5	104.4	166.9	170.7	t 差
6.58											
6.59	131.9	171.8	163.2	93.0	118.2	丢束	90.1				

Design： 6.54/5.59 6.54/5.59

Scan result: BER: 6.540/5.640 BPR: 6.545/5.636

Single bunch collision

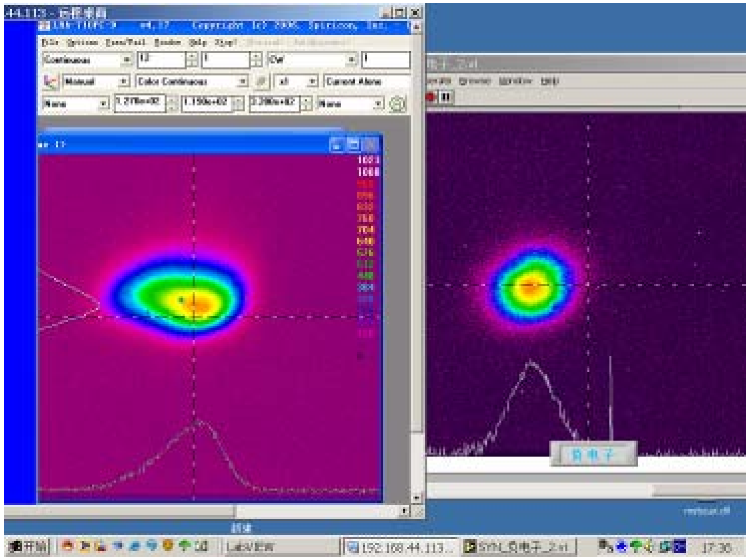
Global optimization

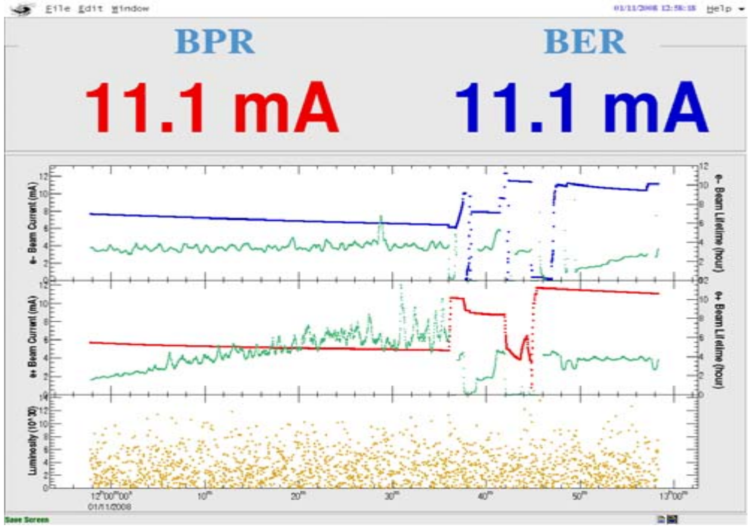
- ✓ x-y coupling: adjusting the local vertical orbit in one sextupole in the arc

=>1% coupling gives the best specific luminosity.

- ✓ Dy* < 10mm

=>contribution to the beam size at IP can be neglected.





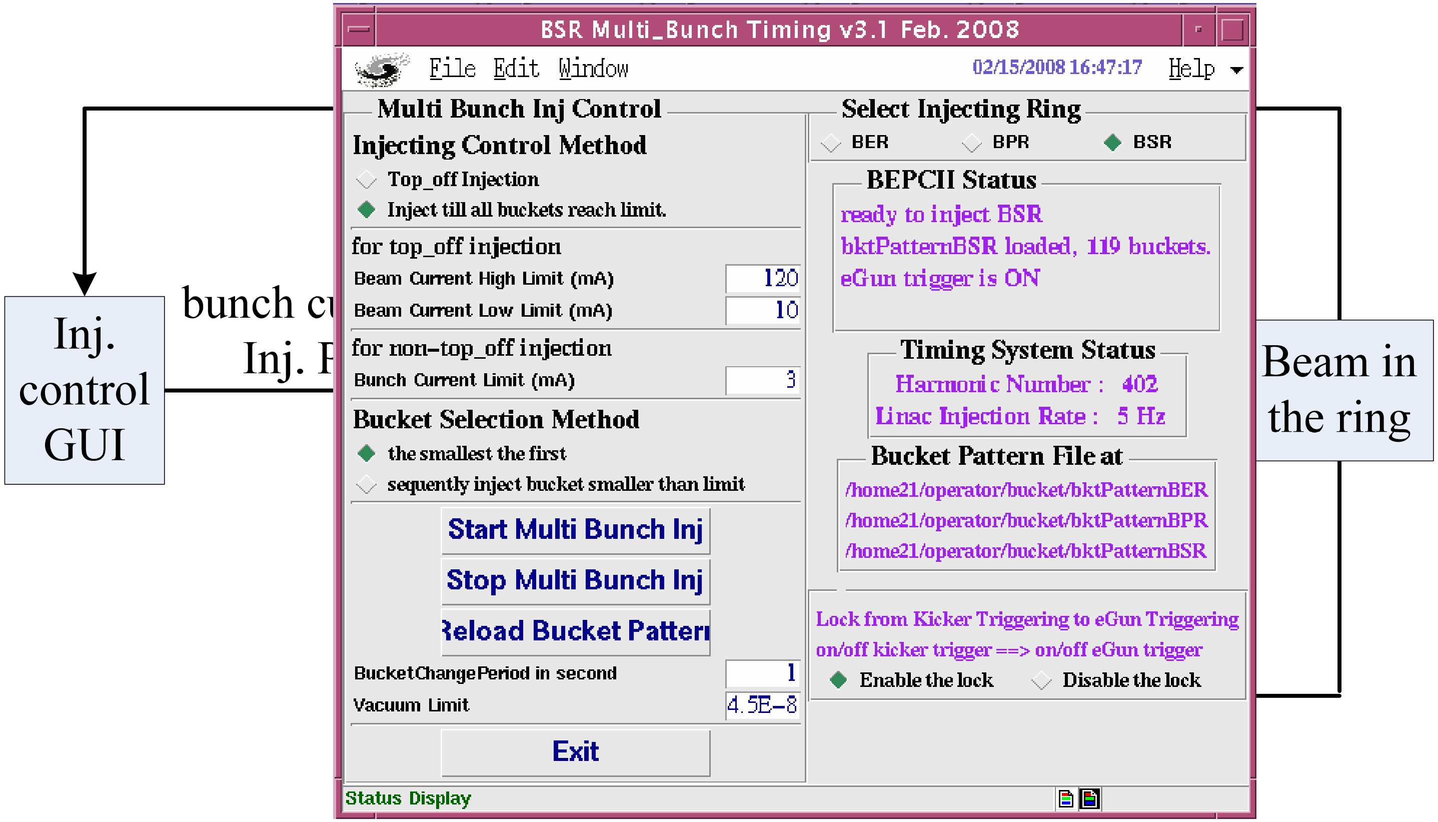
Local optics at the IP

Coupling and βy* waist were also adjusted to optimize the luminosity.

11mA×11mA was reached.

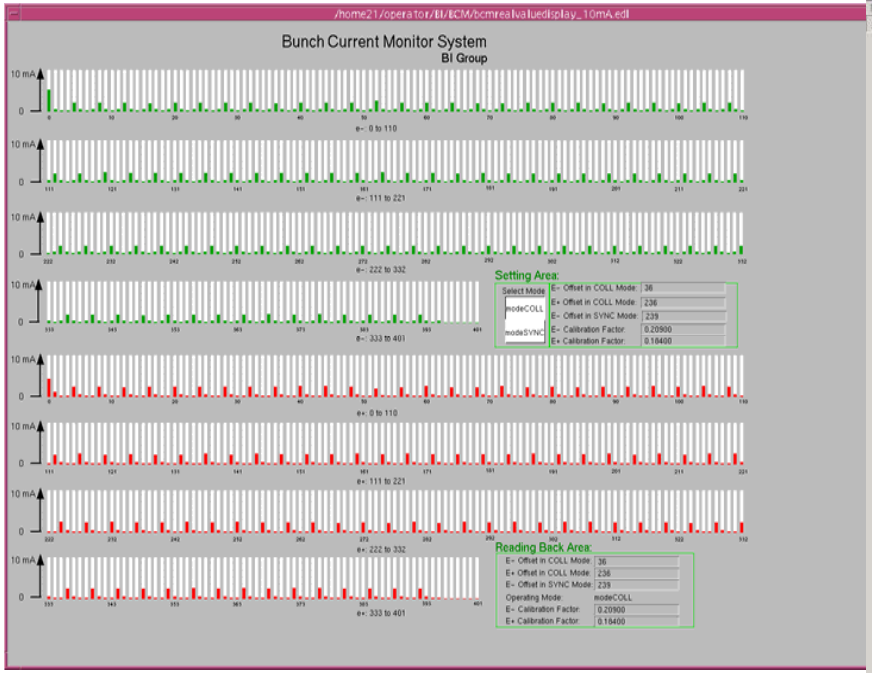
Multi-bunch collision

To get uniform filling of each bucket: Fast bucket selection programm event timing + Beam Current Monitor

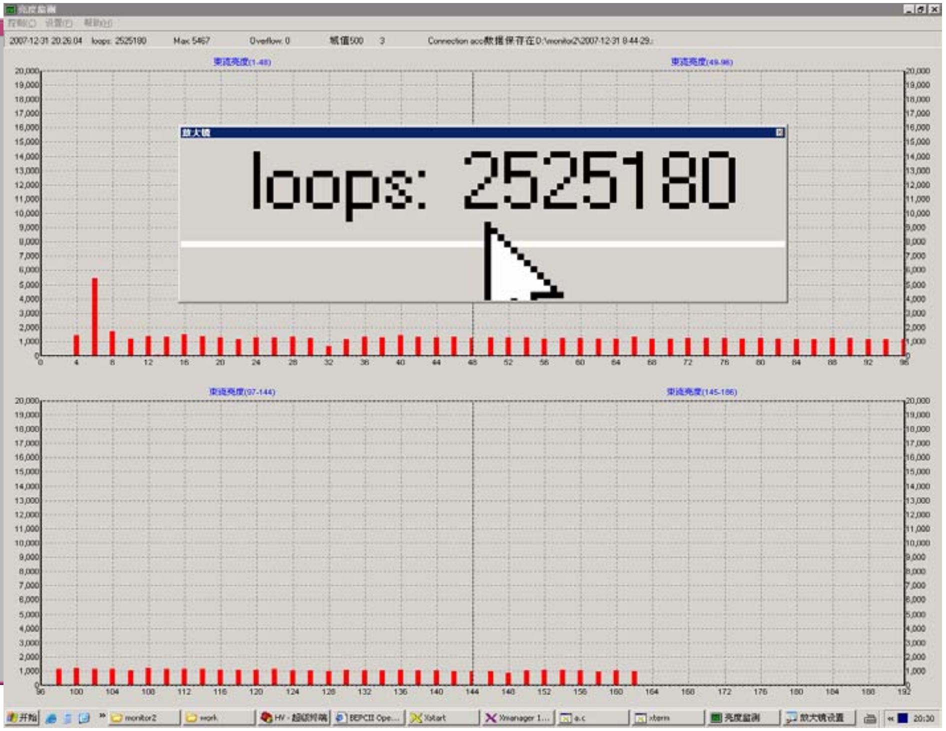


Uniform filling with BCM in mutil-bunch collision

300*300mA on BCM (Bunch current monitor)

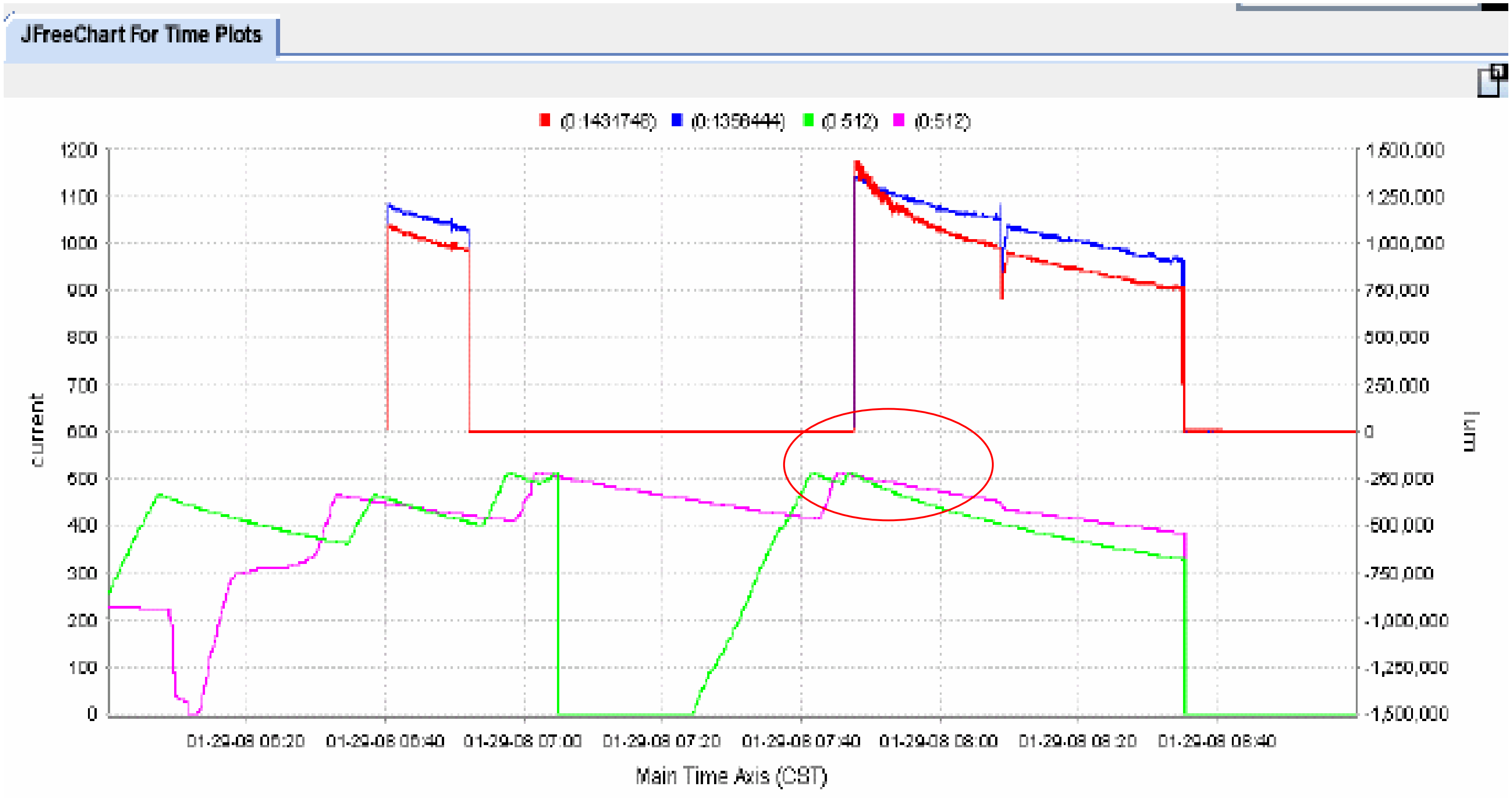


300*300mA luminosity with 99 bunches



On Jan. 29, 2008, 500mA*500mA

$L_{+} = 1.43M$, $L_{-} = 1.35M$ => $L > 1 \times 10^{32} cm^{-2}s^{-1}$.



Main parameters achieved in collision mode

parameters	design	Achieved	
		BER	BPR
Energy (GeV)	1.89	1.89	1.89
Beam curr. (mA)	910	550	550
Bunch curr. (mA)	9.8	>10	>10
Bunch number	93	93	93
RF voltage	1.5	1.5	1.5
Tunes (ν_x/ν_y)	6.54/5.59	6.540/5.599	6.540/5.596
* ν_s @1.5MV	0.033	0.032	0.032
β_x^*/β_y^* (m)	1.0/0.015	~1.0/0.016	~1.0/0.016
Inj. Rate (mA/min)	200 e^-/ 50 e^+	>200	>50
Lum. ($\times 10^{33} cm^{-2}s^{-1}$)	1	0.1	

Further studies on collision

1) Injection improvement: above 7mA/bunch, the injection of the second beam in collision becomes difficult with slow injection rate

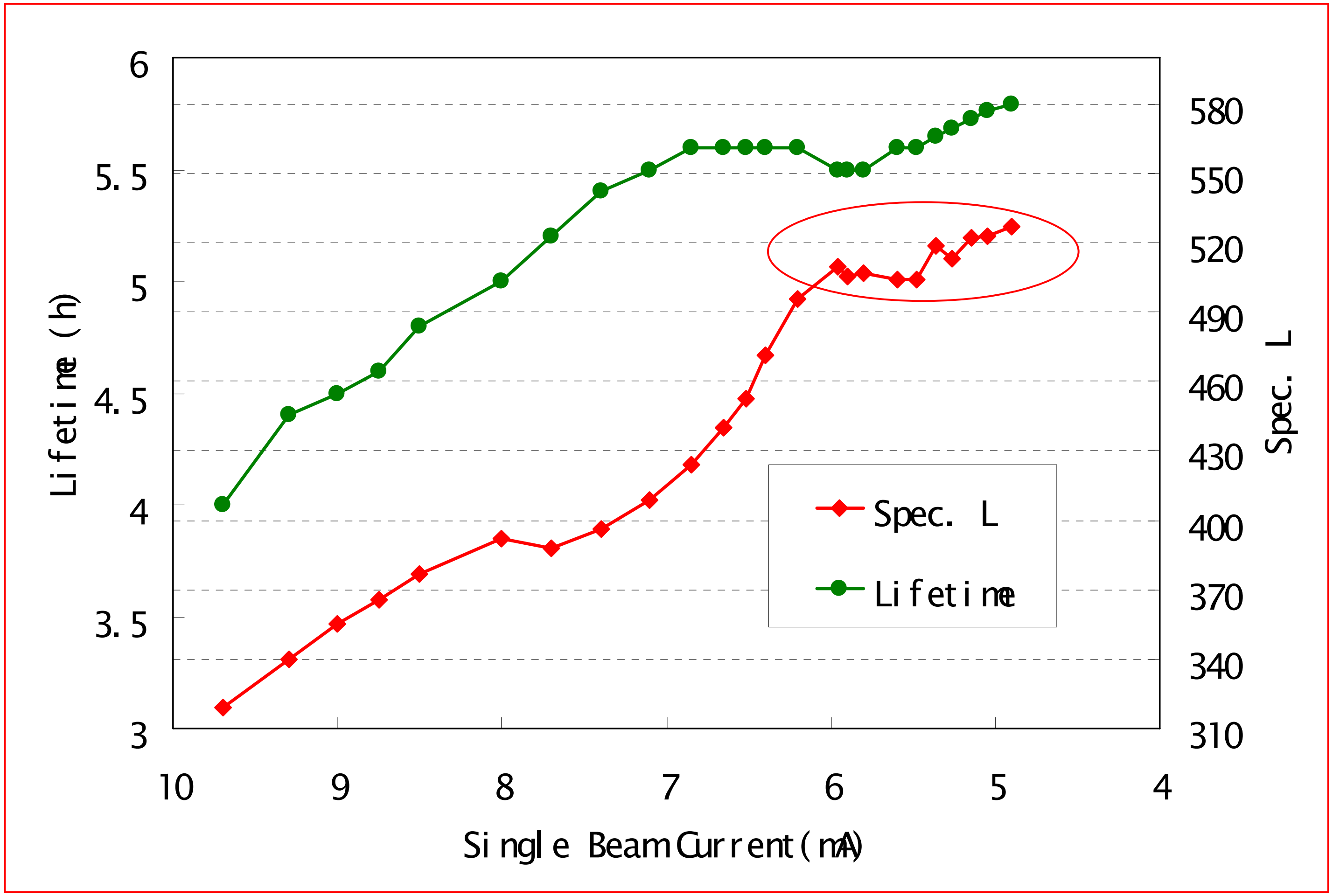
   =>To investigate better ways for smooth injection and stable collision at high bunch current: injection on collision or injection with hor./vert. separation at IP

2) Improve the specific luminosity of single bunch at high current

   =>Optimization of collision parameters, as tunes, orbits, beam sizes, etc

3) Improve the specific luminosity in multi-bunch case with high current

   =>Better tuning of TFB on Y-direction



Specific Lum. Vs bunch current:
The curve is flat below 6mA=>beam size not blow up,
Potential to improve specific luminosity at high bunch current.

Beam size at IP designed:

$\beta_x^* / \beta_y^* = 1.0m / 1.5cm$

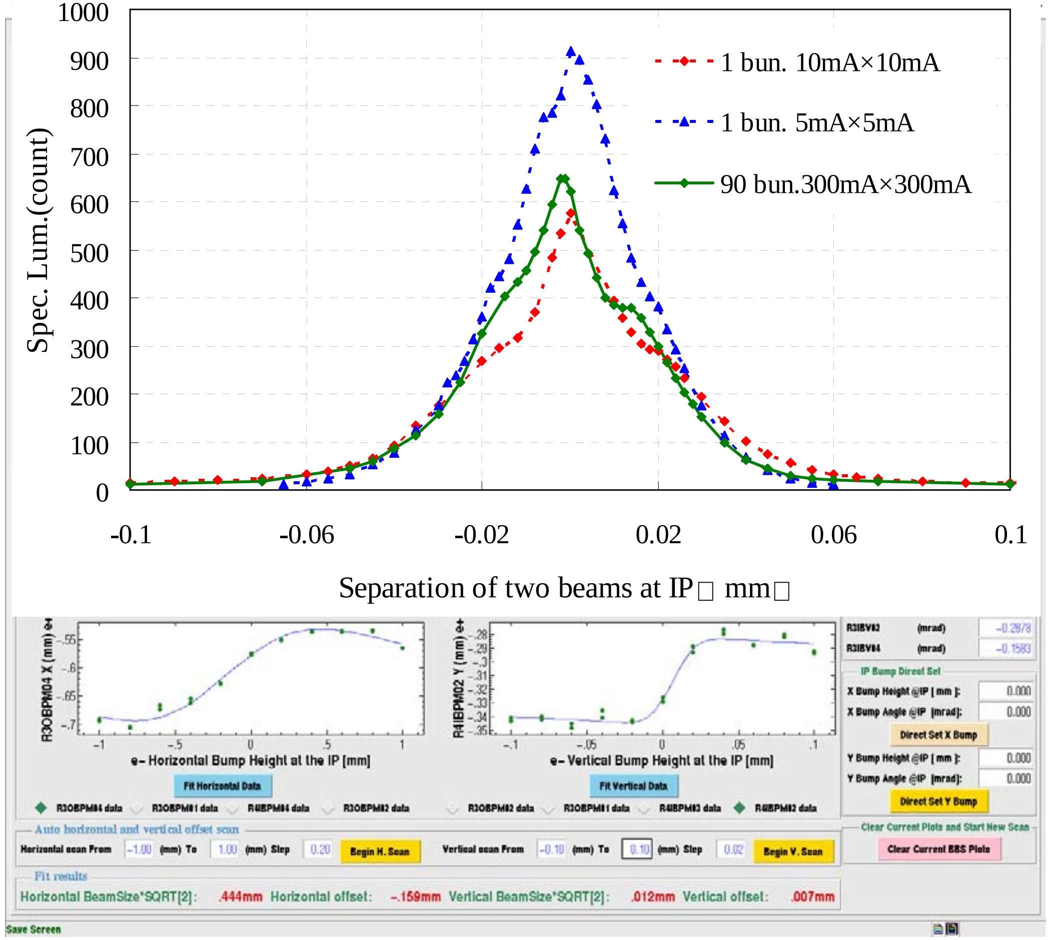
$\sigma_x^* / \sigma_y^* = 0.4mm / 5.5\mu m$

Scan Spec. lum. of single (dashed) and mult- bunch (solid) vs the vertical separation of two beams at IP:

1) Single bunch higher

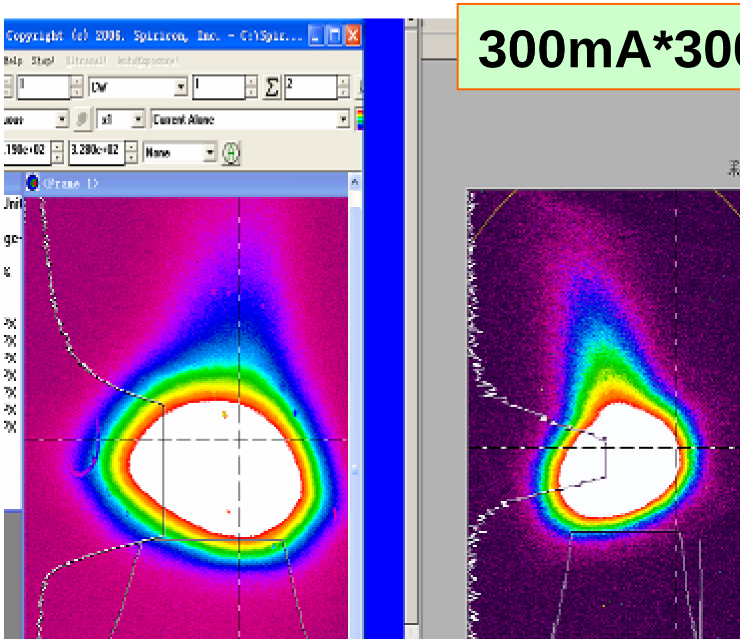
2) $\sigma_x^* / \sigma_y^* = 0.35mm / 8\mu m$

=> **TFB to suppress σ_y for higher lum.**

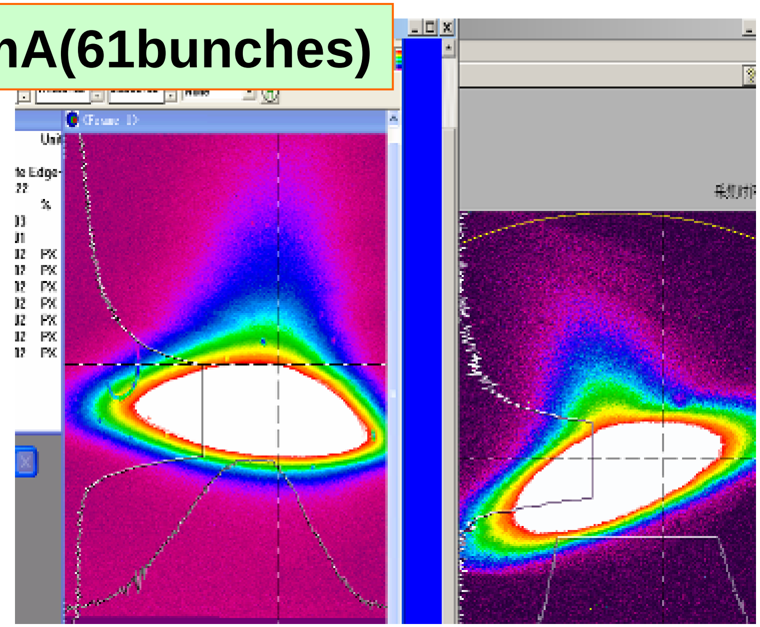


With TFB better tuned, particularly on Y-direction, luminosity can be improved

300mA*300mA(61bunches)



Feedback off



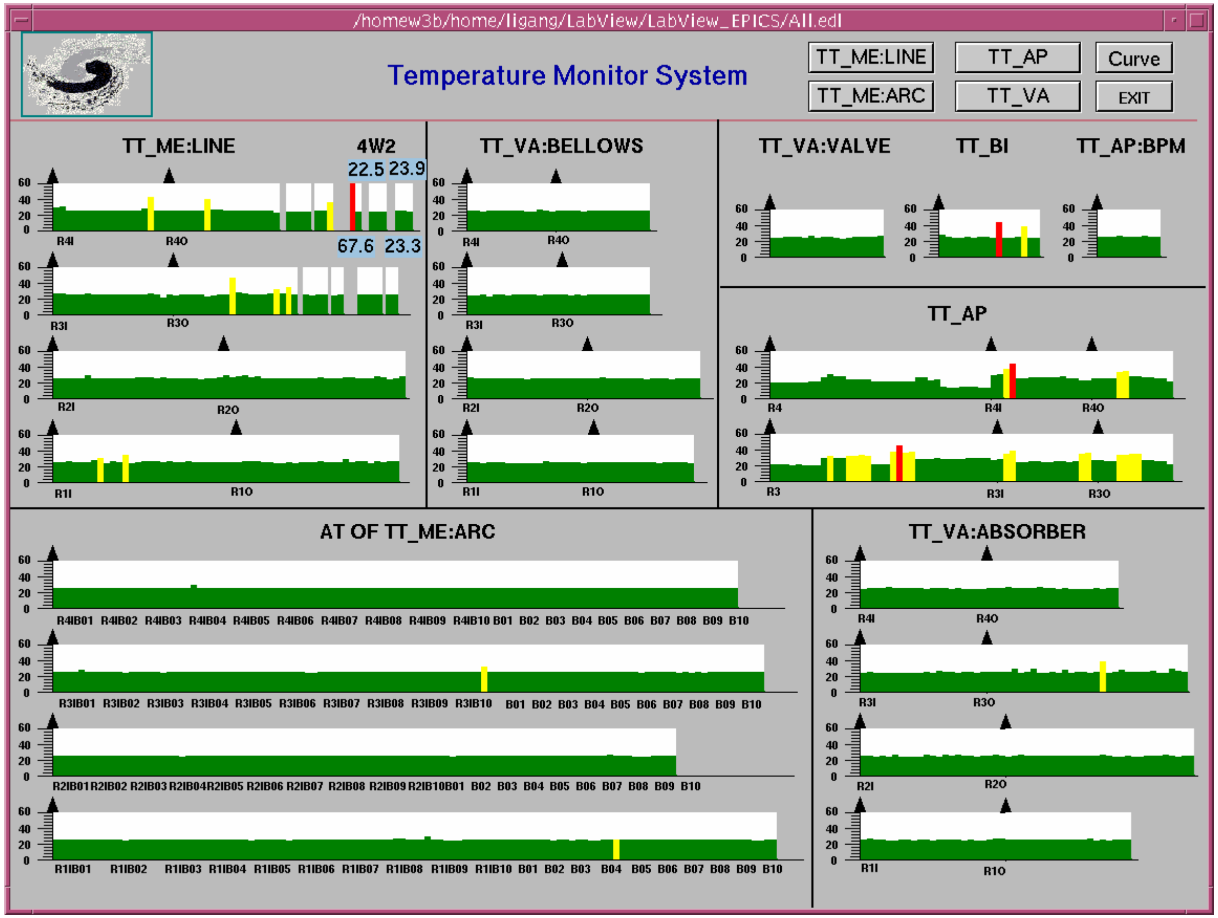
Feedback on

HIGH CURRENT ISSUES

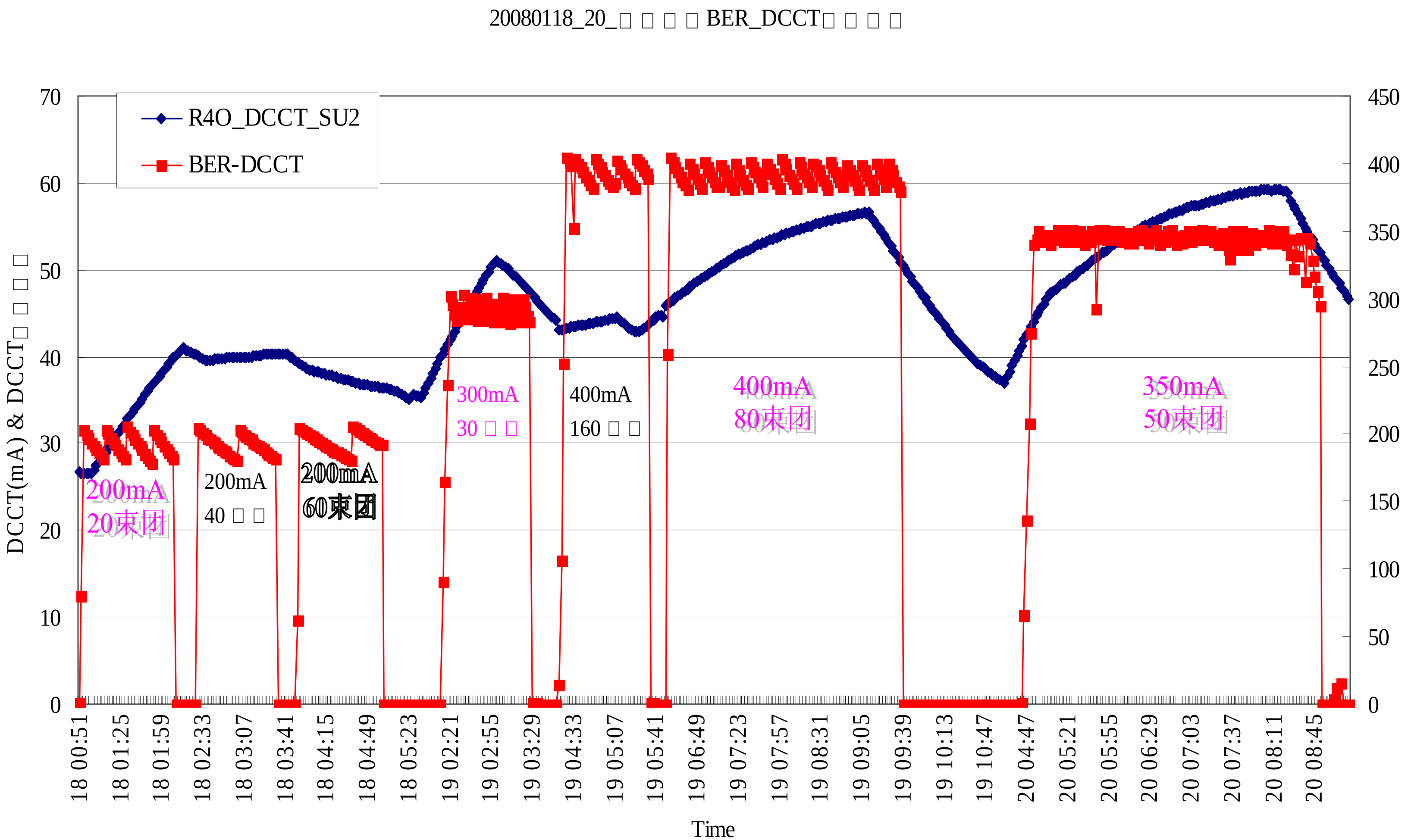
1) More than 1000 thermal couplers used

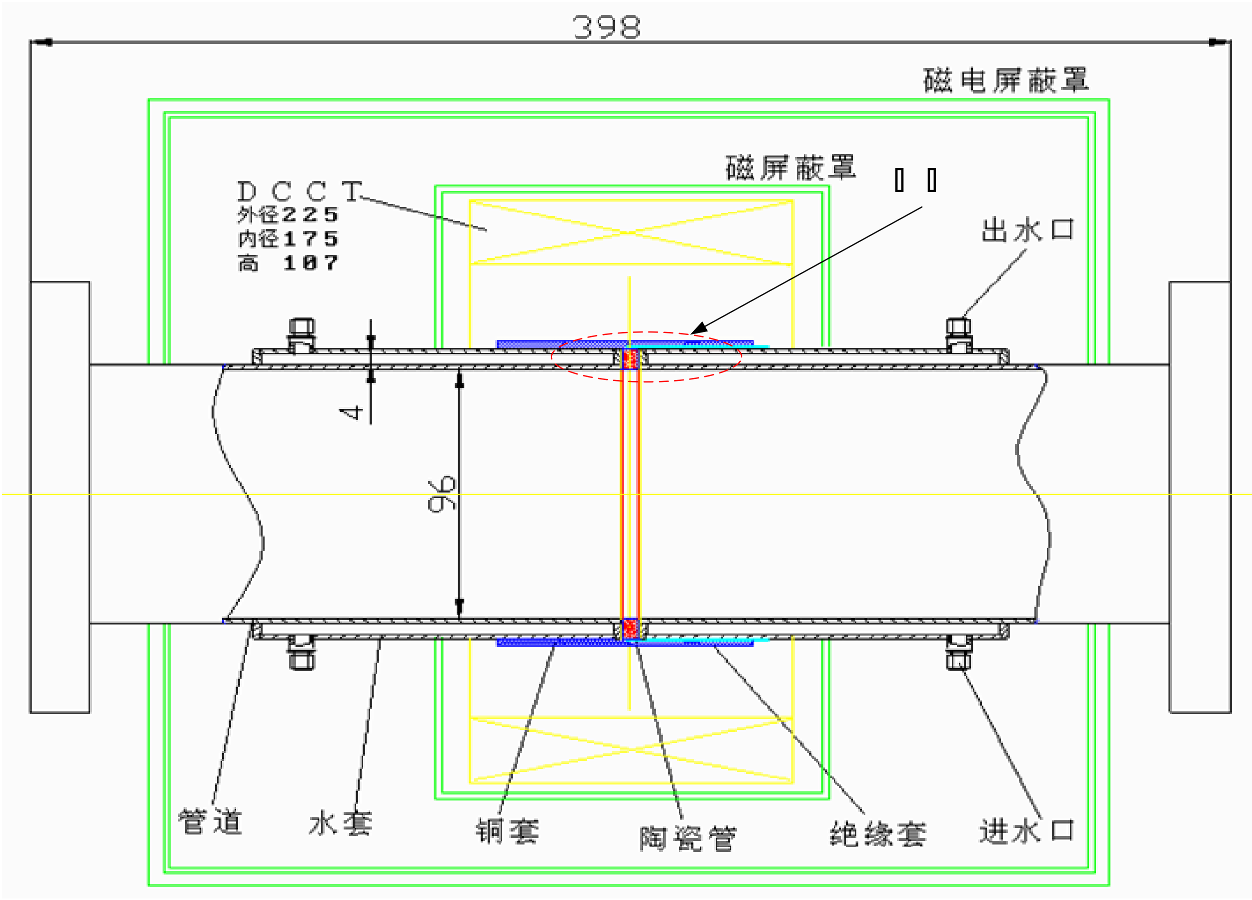
2) Display in colour according dangerousness: green, yellow and red.

3) In most case, the temperature rise (SR) => flux of cooling water adjusted



HOM heating of DCCT

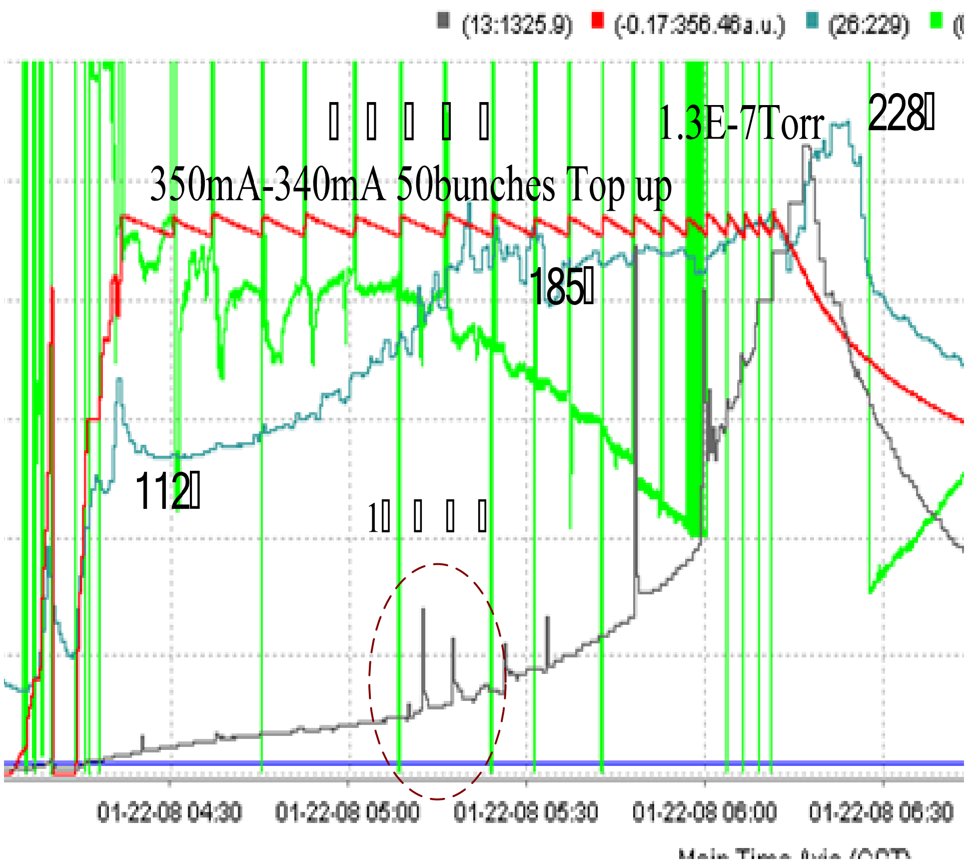


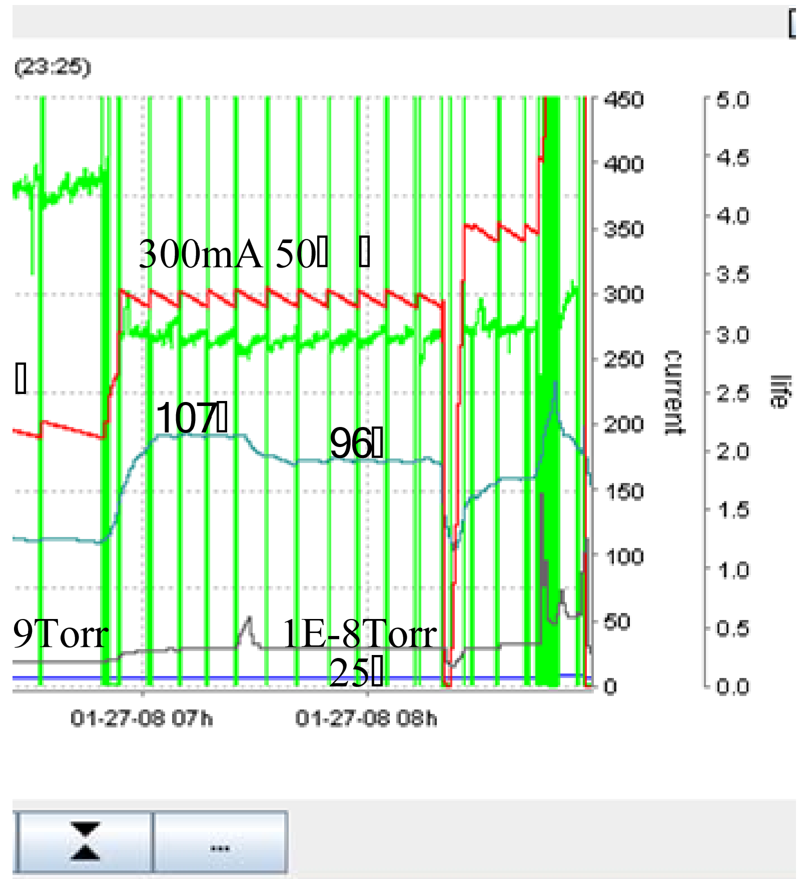


1) Some capacitors will be connected in parallel to improve the RF shield.

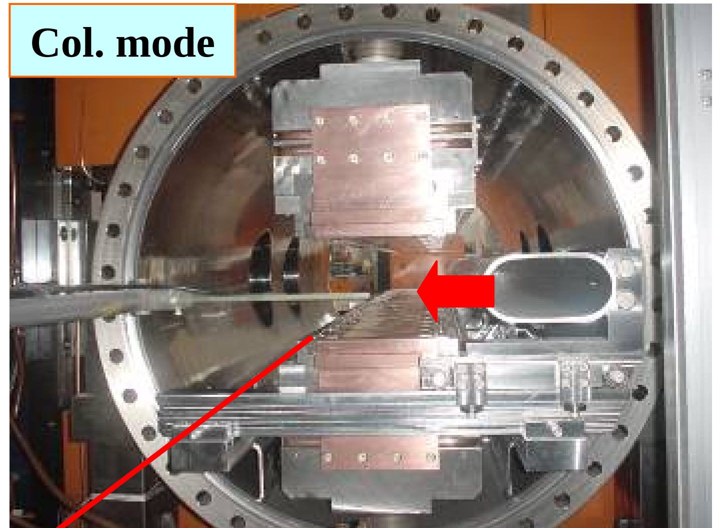
2) Improve the local cooling capacity

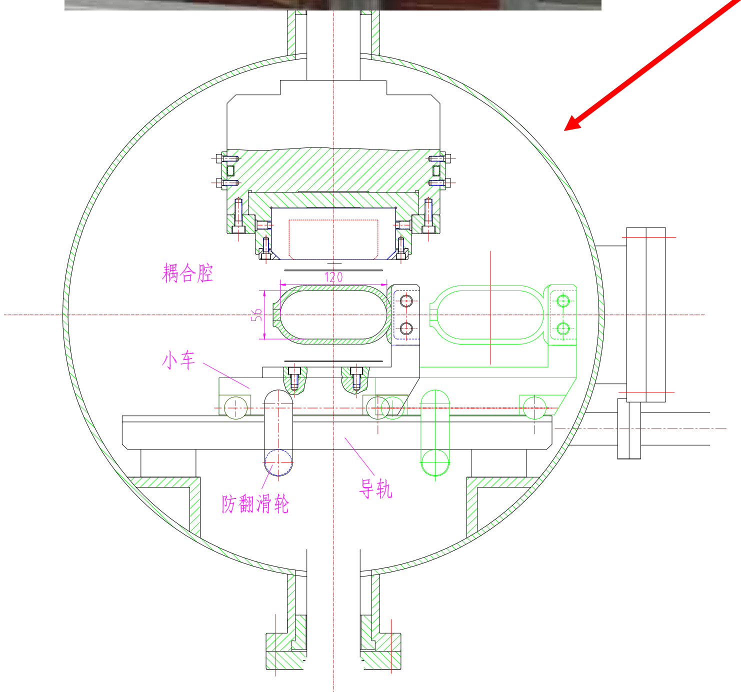
HOM heating of in vacuum wiggler

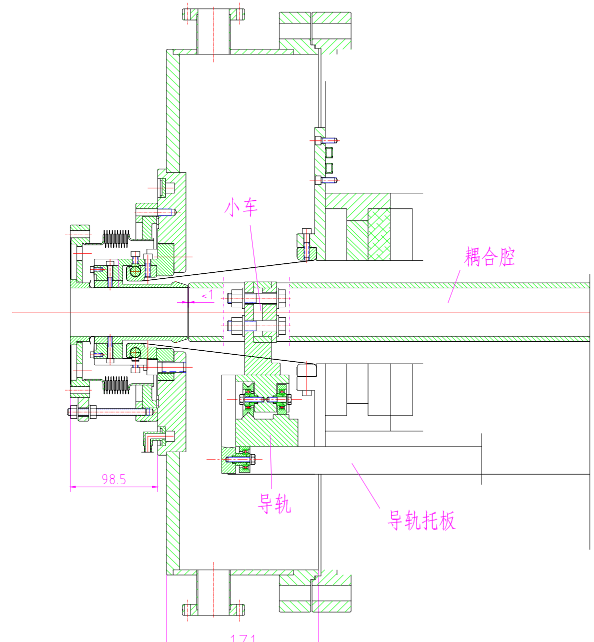




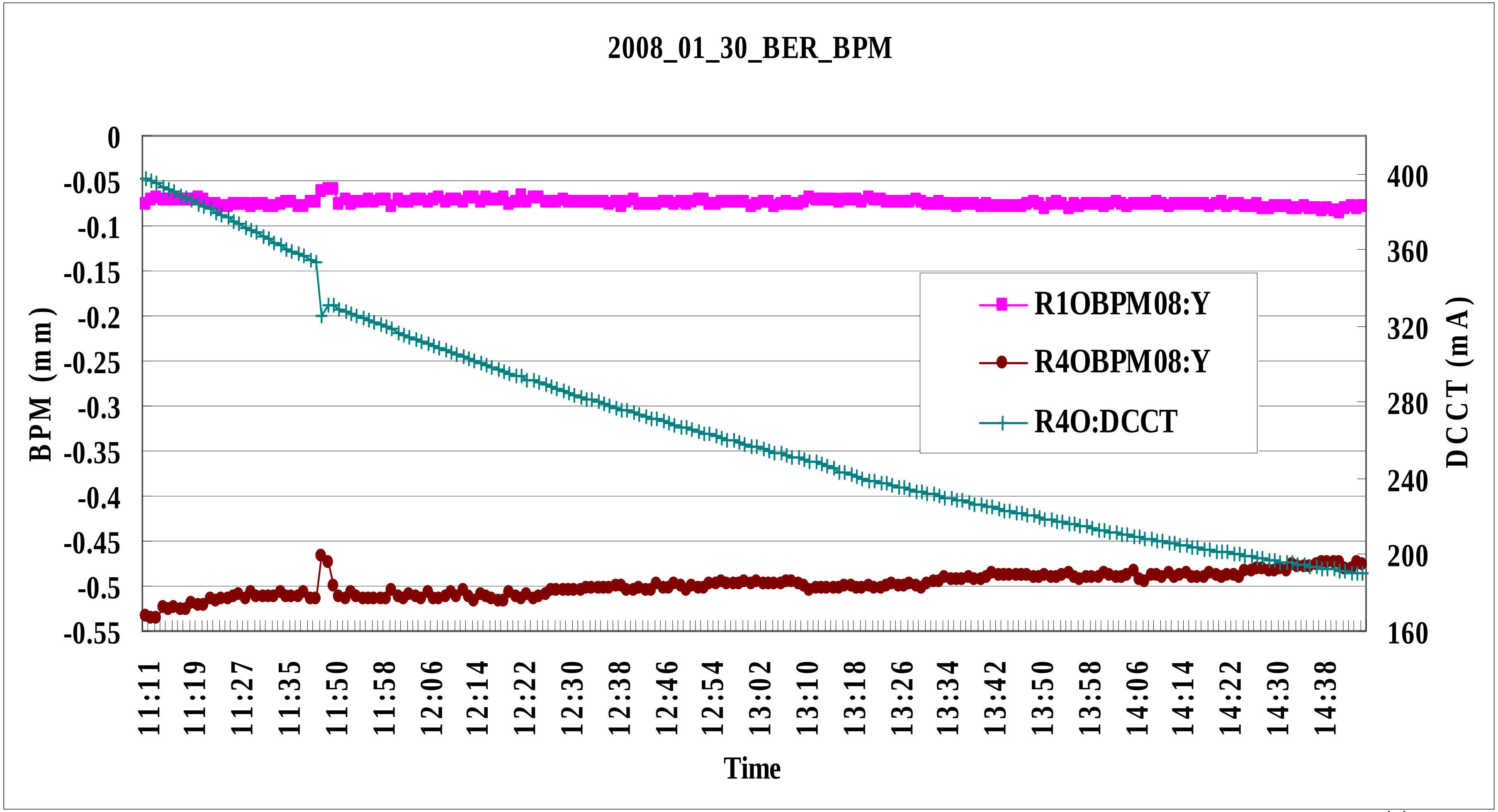

SR mode


Col. mode

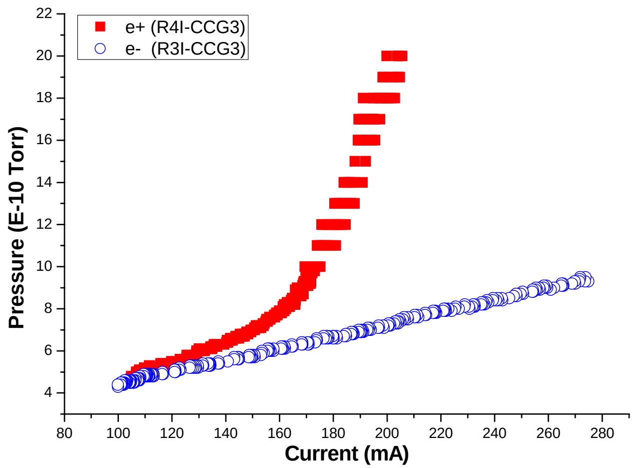

耦合腔
120
50
小车
防翻滑轮
导轨

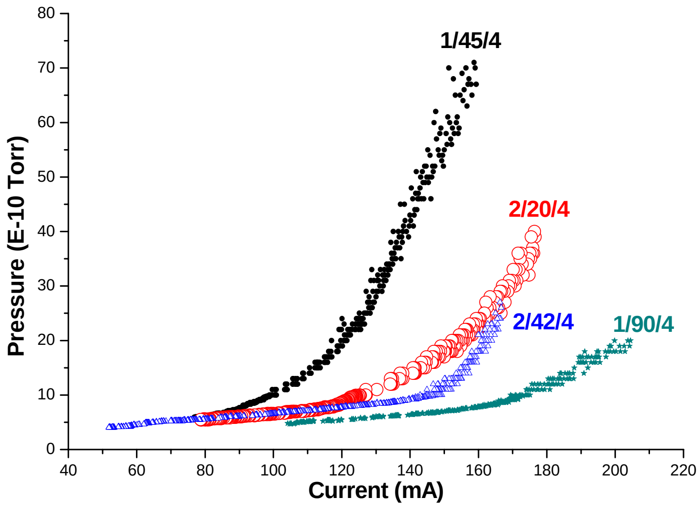

小车
耦合腔
98.5
导轨
导轨托板
171

Beam position measured by some BPM appeared sensitive to the beam current=> transverse wake field, as TE_{10} mode?



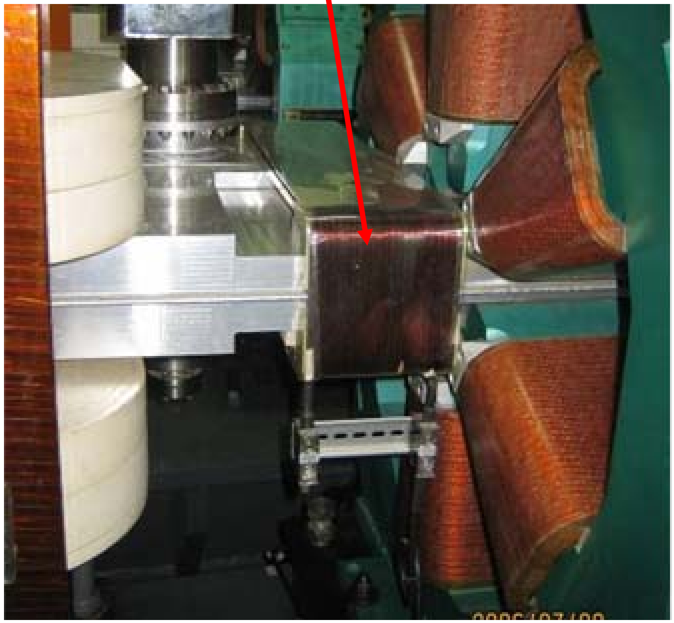
Nonlinear increase of vacuum pressure in BPR





- The threshold depends on the filling pattern.
- This may due to beam induced multipacting inside the beam pipe and can be one cause of the higher vacuum pressure in BPR.
- Solenoid winding may be helpful to ease the problem.

Solenoid



BACKGROUND

- Experimental studies have been carried out to study the radiation dose around IP as well as the way to reduce the background (D. P. Jin, C. Zhang)
- The main conclusion:
  - With the injection optimization the dose rate in the IR gets acceptable for the BESIII detector
  - With collimators and masks, the background in the detector during its data acquiring could be well controlled

SUMMARY

- The optimization methods to achieve high current as well as high luminosity have been practice systematically.
- The beam current has reached more than 1/2 of design with no disastrous instabilities, and most devices performed stably as expected.
- However, there are still lot of issues for further studies such as to improve the specific luminosity at high beam current, to understand the beam loss mechanism, and so on.
- The detector is being moved into the IR this spring, and the third phase commissioning is scheduled in early June. To improve the luminosity while control the background acceptable for data taking is still challenging.

Thank you for your attention