Commissioning of BEPCII

J.Q. Wang for BEPCII Commissioning Team,
Institute of High Energy Physics, CAS

June 24, 2008,
11th European Particle Accelerator Conference, Genoa, Italy

Outline

- Introduction of BEPCII
- 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


May 2004


July 2005

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
June 24, 2008	Phase 3 commissioning started


Sep. 2004

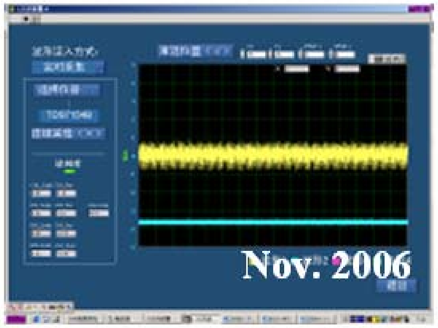

July 2005


Oct. 2005


May 2006


Oct. 2006


Oct. 2006


Nov. 2006


Nov. 2006.


Oct. 2007


May 2008

Commissioning in 3 Phases

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

SR Operation: Outer ring (BSR)

Phase 1：IR with Conventional magnets

Commissioning in 3 Phases

Commissioning in 3 Phases

Commissioning of BEPCII

2006 Oct. Installation completed with NCQ-IR

2006 Nov 18 SR beam first stored
2007 Feb 9 BER beam first stored
2007 Mar 4 BPR beam first stored
2007 Mar 26 First collisions
2007 May 14 Luminosity (as BEPC)
2007 July 31 SR mode 250mA

Phase 1

reports on APAC07, PAC07

2007 Oct. Installation completed with SCQ-IR

2007 Oct. 24 BER beam first stored
2007 Oct. 31 BPR beam first stored
2007 Nov. 18 First collision
2008 Jan. 29 Luminosity $>1\times10^{32}cm^{-2}s^{-1}$
2008 Feb. 25-Mar. 28 SR operation

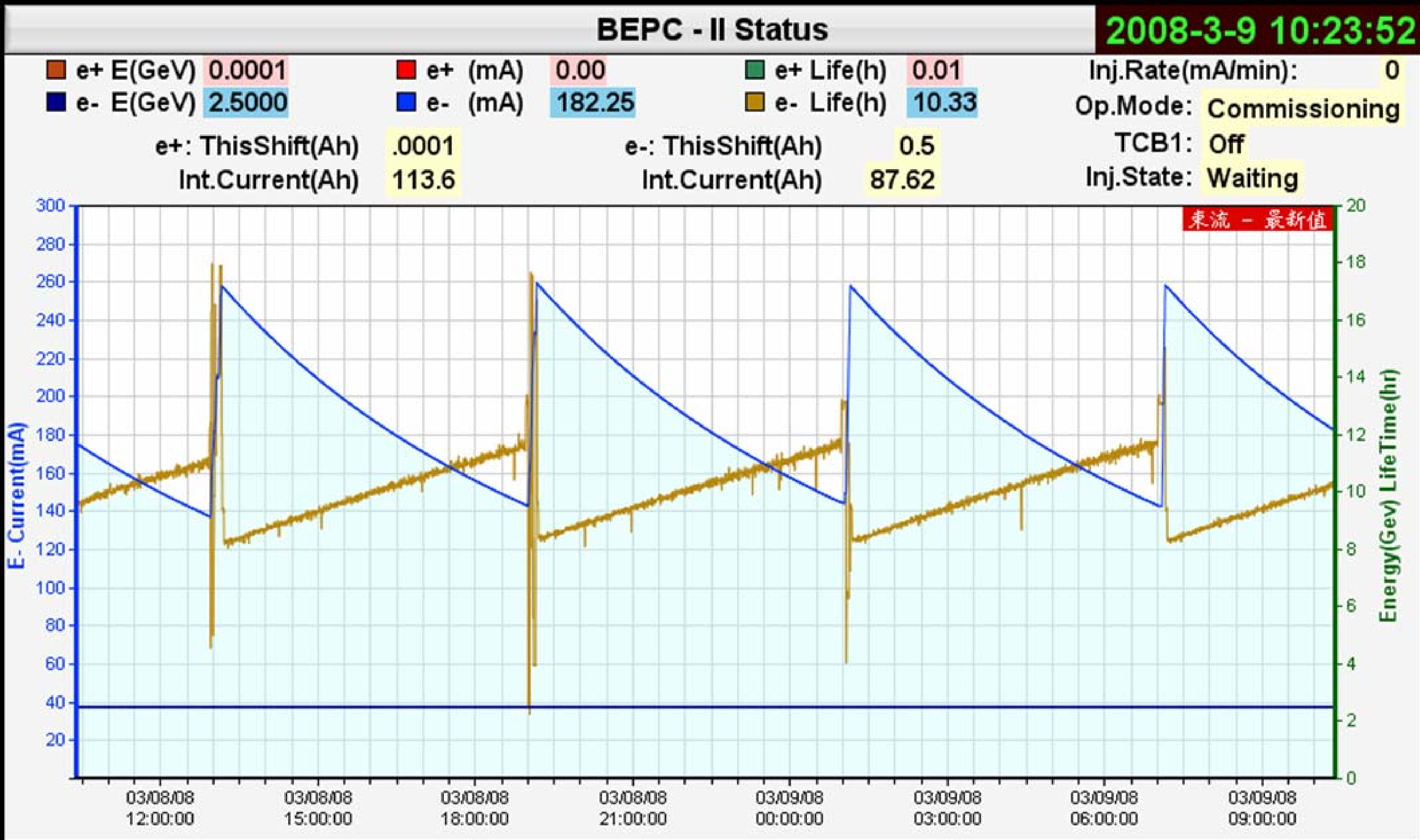
Phase 2

2008 June. Installation completed with SCQ-IR

…Phase 3

SR operation in phase 2

(Feb.25 - March 28)



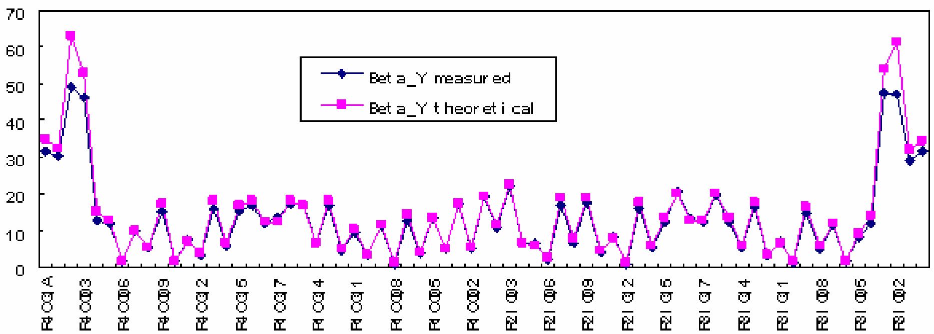
(Imax=250mA, 2.5GeV top-off injection)

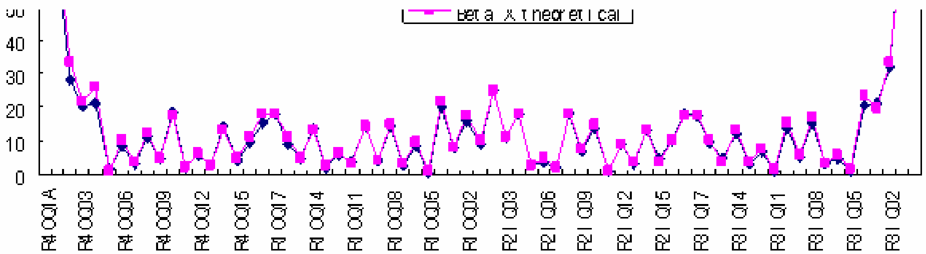
Beam Performance of BER & BPR

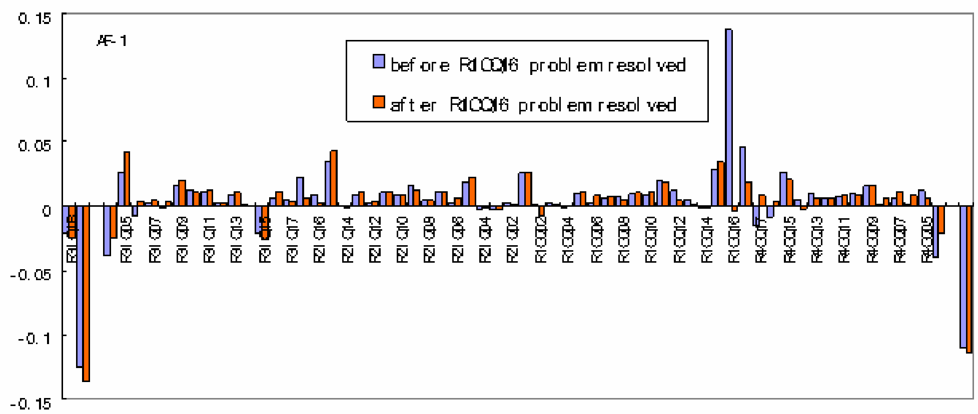
- Optics Correction
- Injection
- Instabilities & feedback

Optics Correction

- ✓ Measured beam optics functions are in good agreement with theoretical prediction with discrepancy within ±10% at most quadrupoles,
- ✓ Design ν_x/ν_y= 6.54, 5.59 , measured ν_x/ν_y= 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.

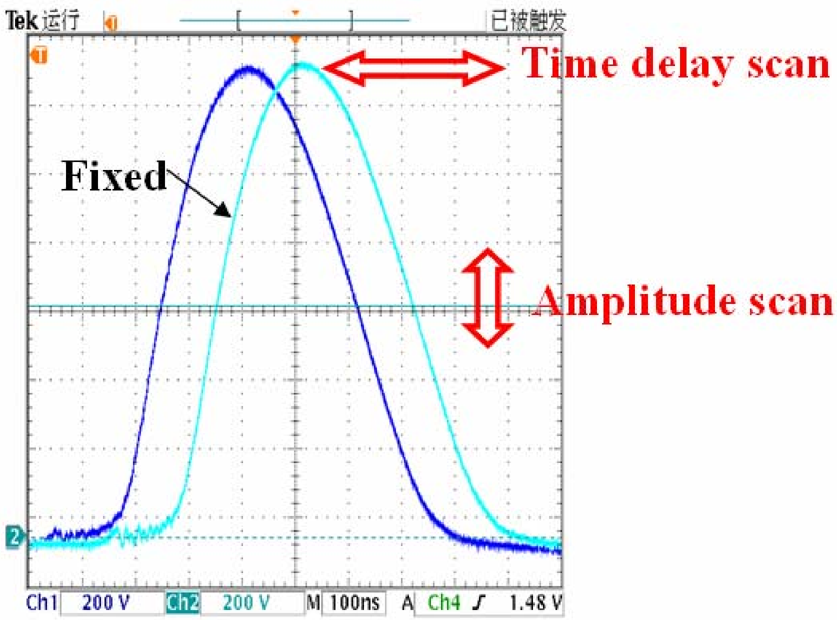


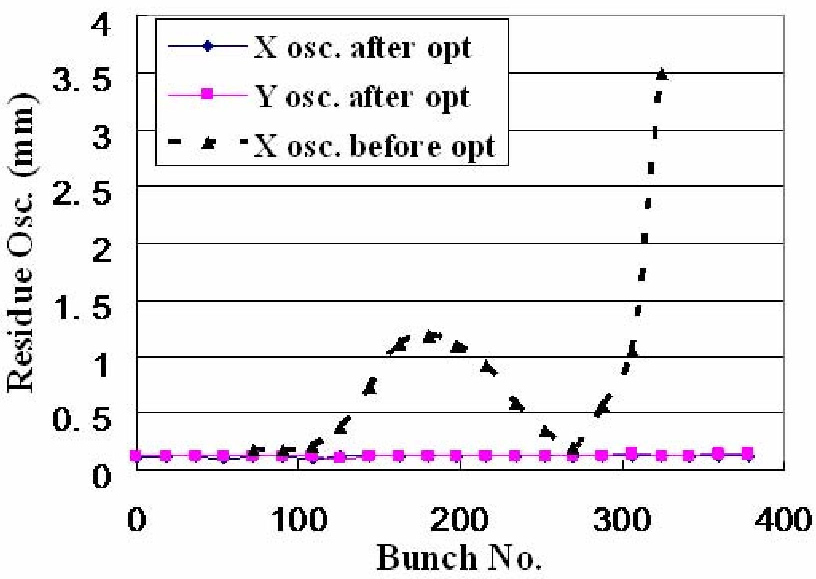




Injection

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





=>For timing: fix k1, scan k2 ; do in turn for k2

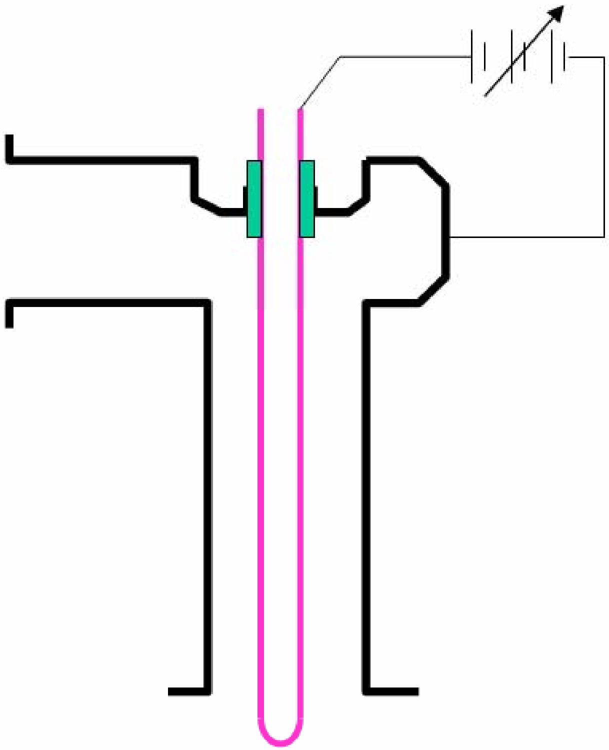
=>For amp: fix k1 or k2 amp, scan the other

⇒ After optimization with on bunch, the residual orbit oscillation of all the other bunches during injection reduced to around 0.1mm/0.1σ_x.

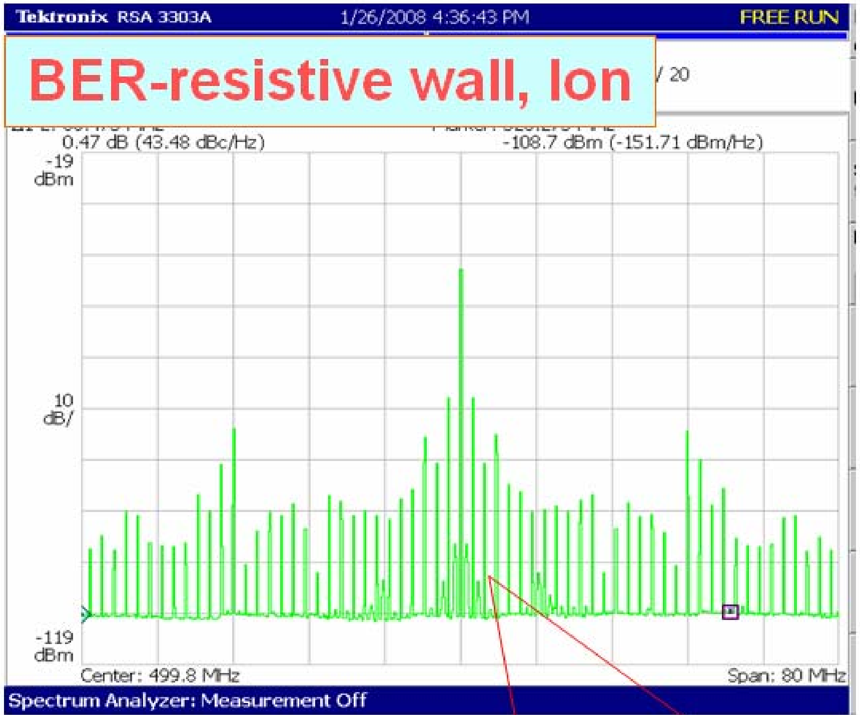
⇒ Injection on collision possible

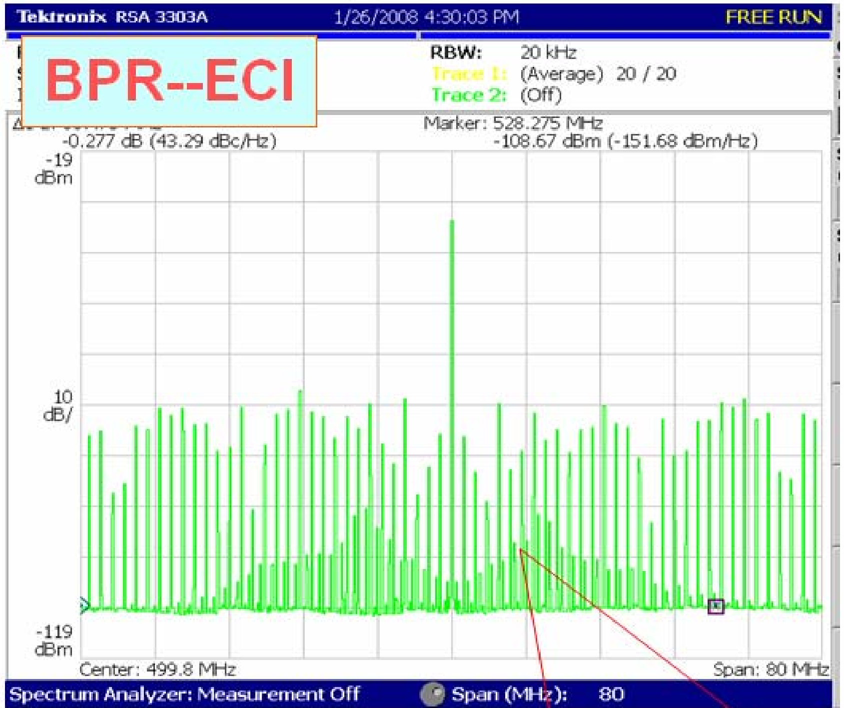
RF tuning to increase the beam current

- When the beam current in BER exceeded 100mA, the SC cavity (SCC) tripped often due to its arc interlock of window and following 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.



Coupled Bunch Instability
(transverse)





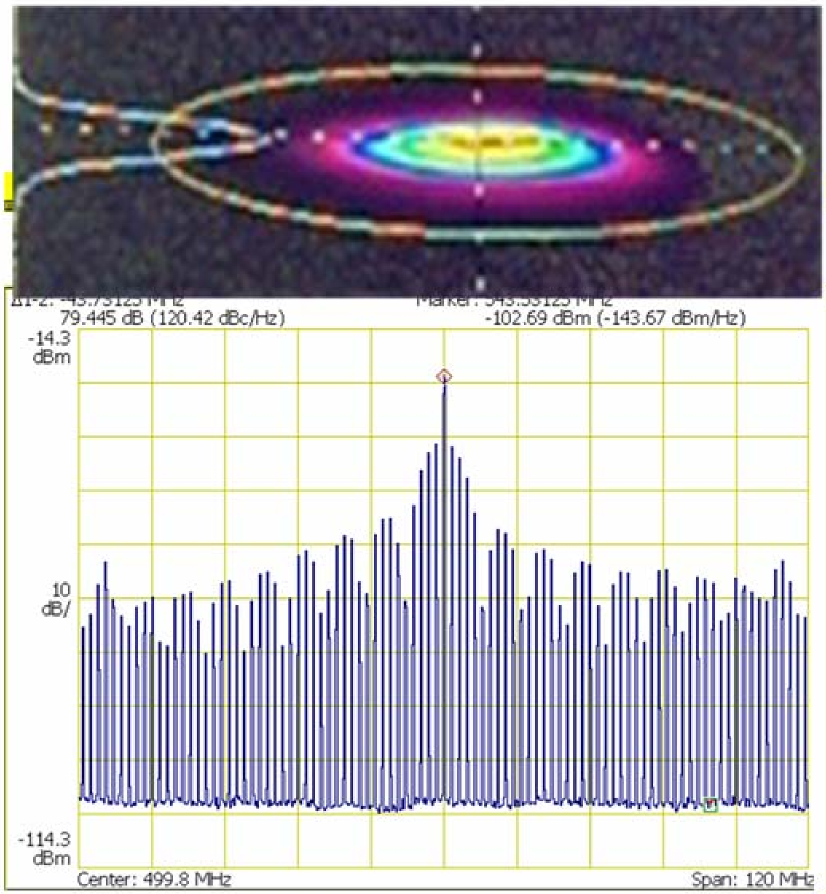
Sidebands of the electron beam with 99 bunch uniform filling, spacing 4 buckets, beam current 40mA.

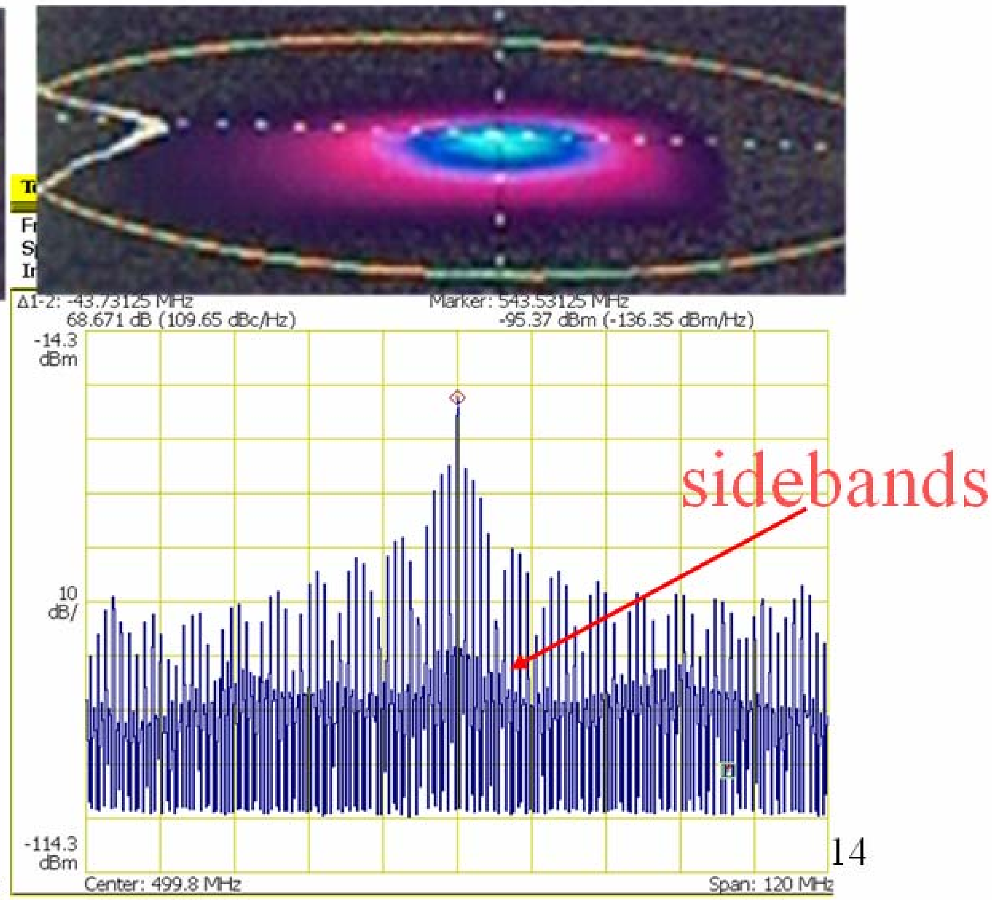
Sidebands of the positron beam with 99 bunch uniform filling, spacing 4 buckets, beam current 40mA.

Transverse FeedBack System

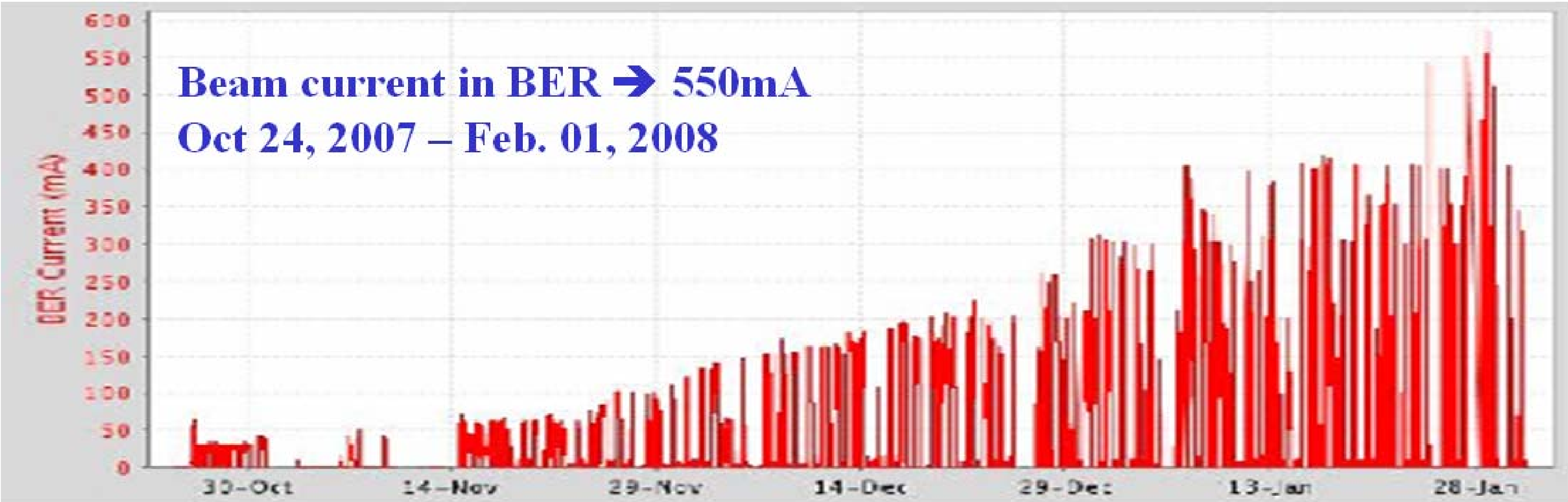
Couple bunch instabilities can be cured with the analog TFB system, the sidebands of in both BER and BPR can be well suppressed

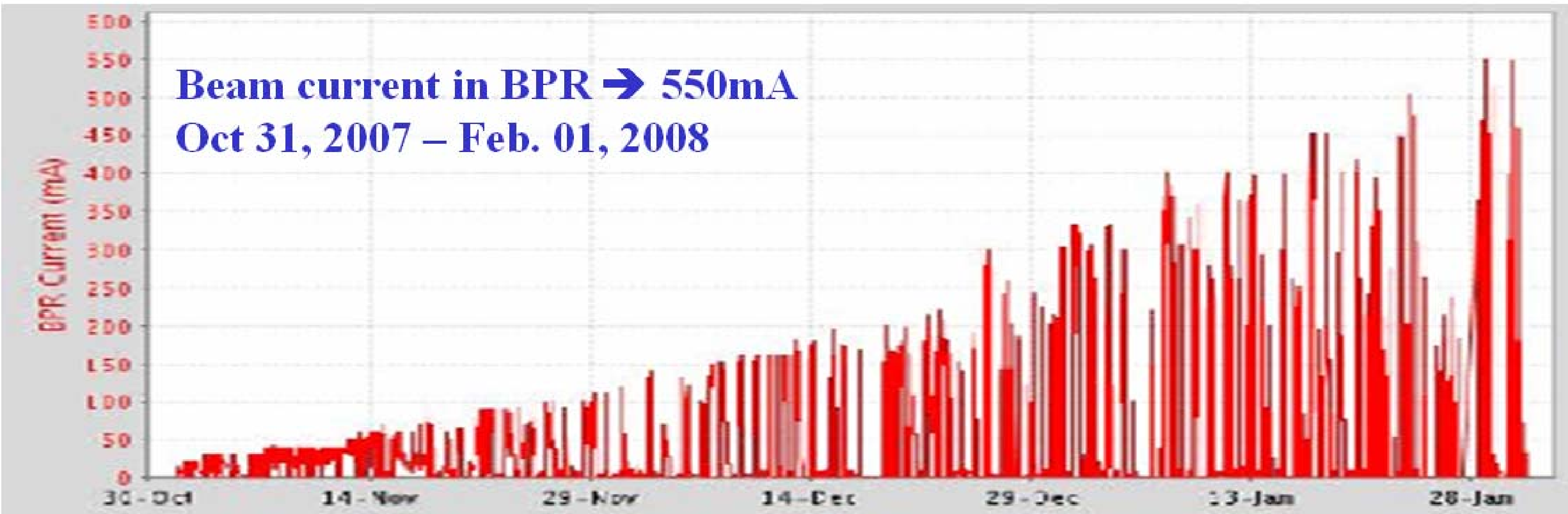
Feedback ON | **Feedback OFF**





History of beam current growth





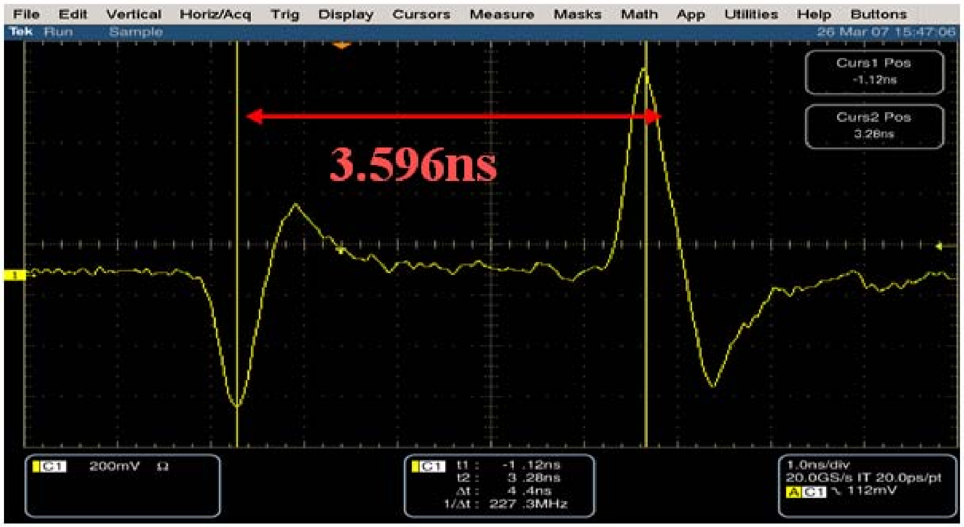
Luminosity Tuning

Collision with Beam-Beam Scan

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

Collision in long.

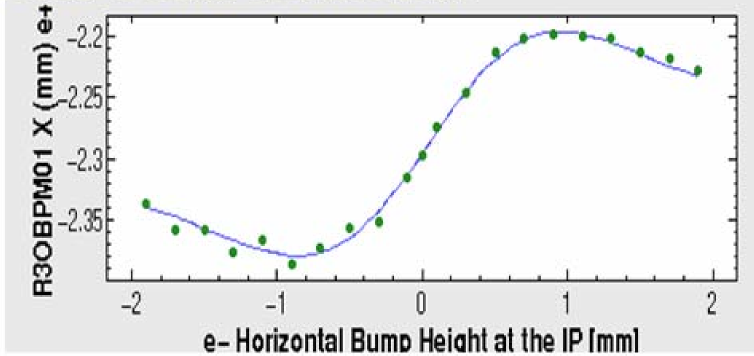
Adjust RF phase=> Two bunch reach IP at same time (deviation <10ps)

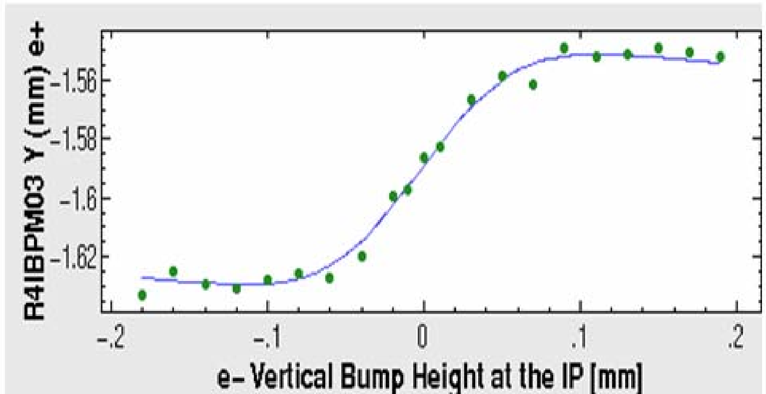


e+ and e- signals on R4CBPM00 (0.539m to IP)

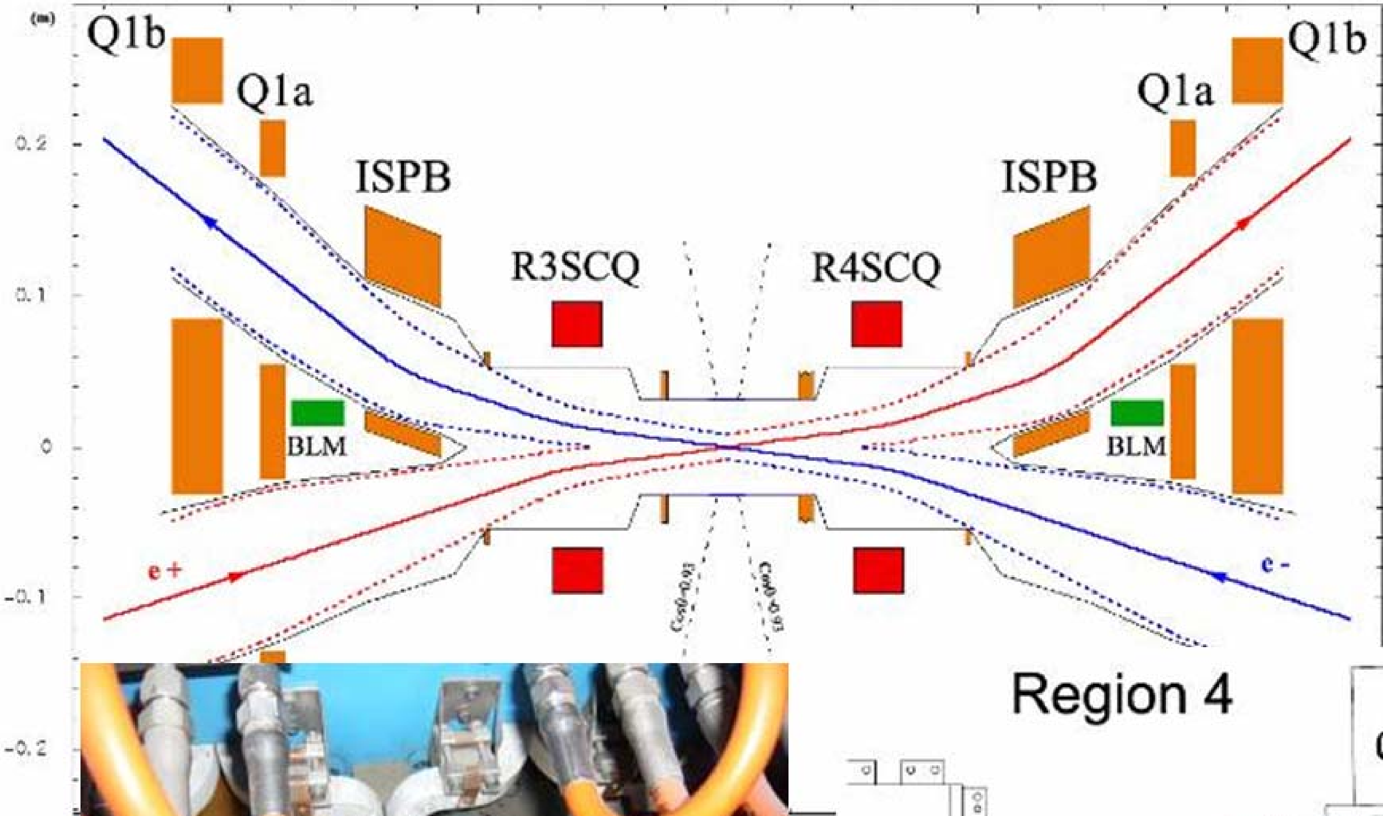
Transverse Scan

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

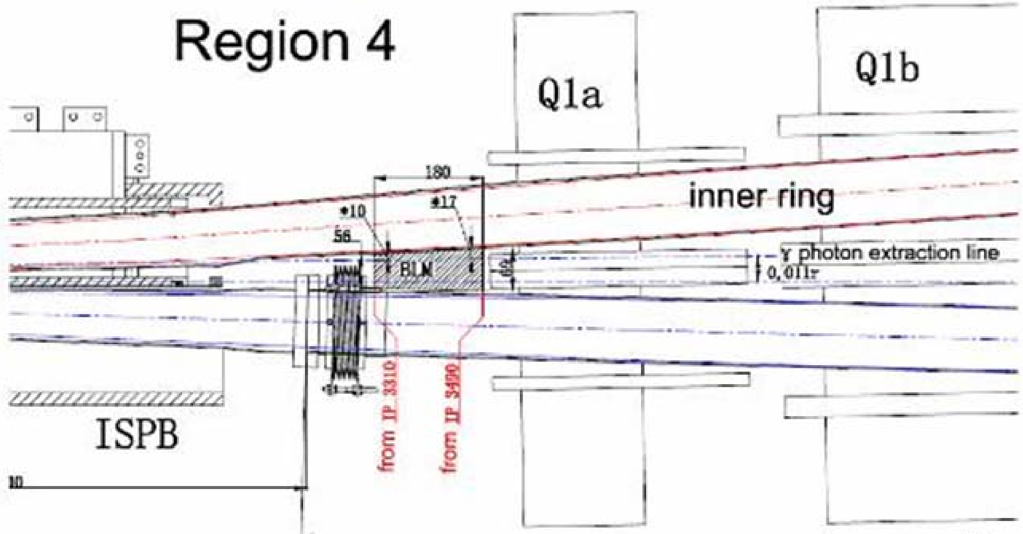


Zero degree Radiative bhabha process

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

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

=> Bunch lum.



Choice of Working Point --Tune Scan to find the best working point for high specific luminosity L/(I+×I-) around the designed one by beam-beam simulation.

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 up	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	164.4	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.

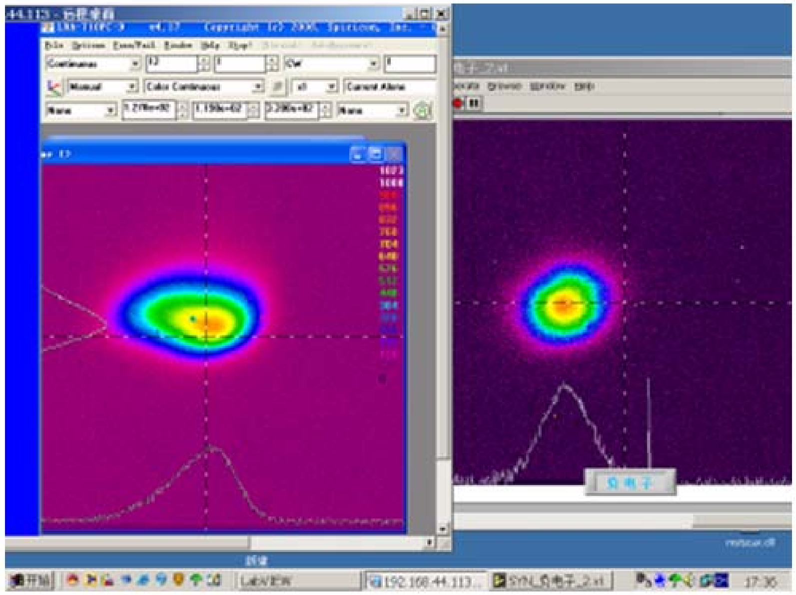
✓ Dy* < 10mm

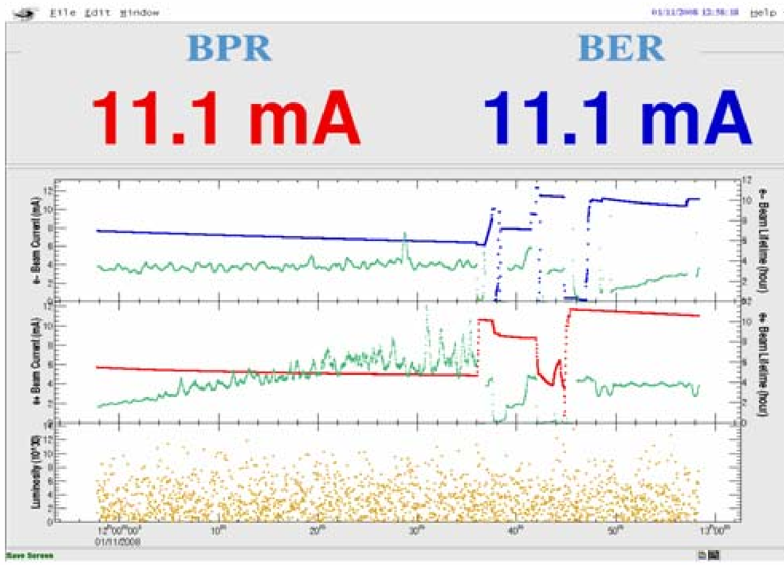
=>contribution to the beam size at IP can be neglected.

□Local optics at the IP

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

11mA×11mA was reached, more than the design of 9.8mA.

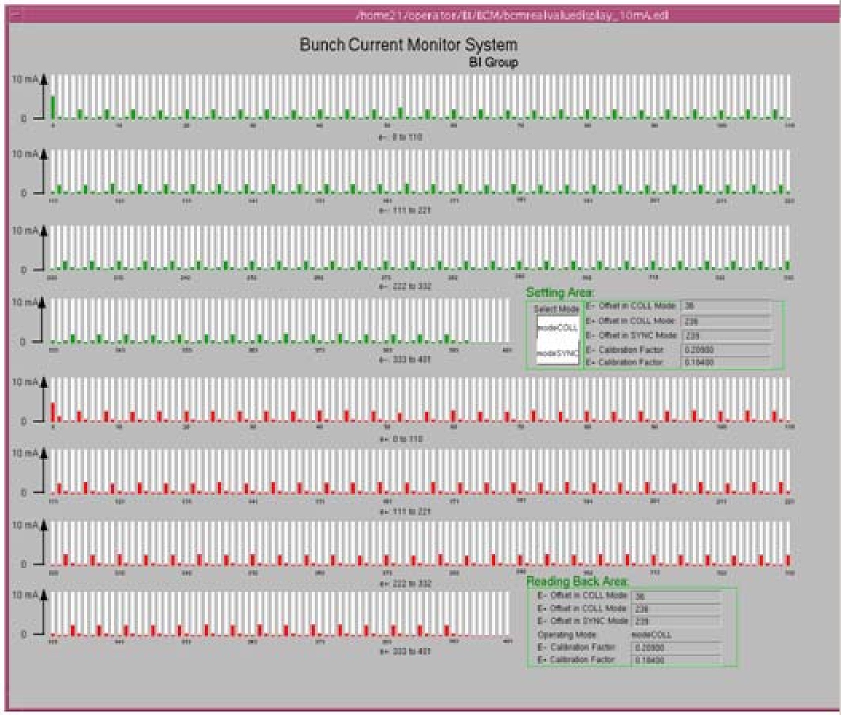




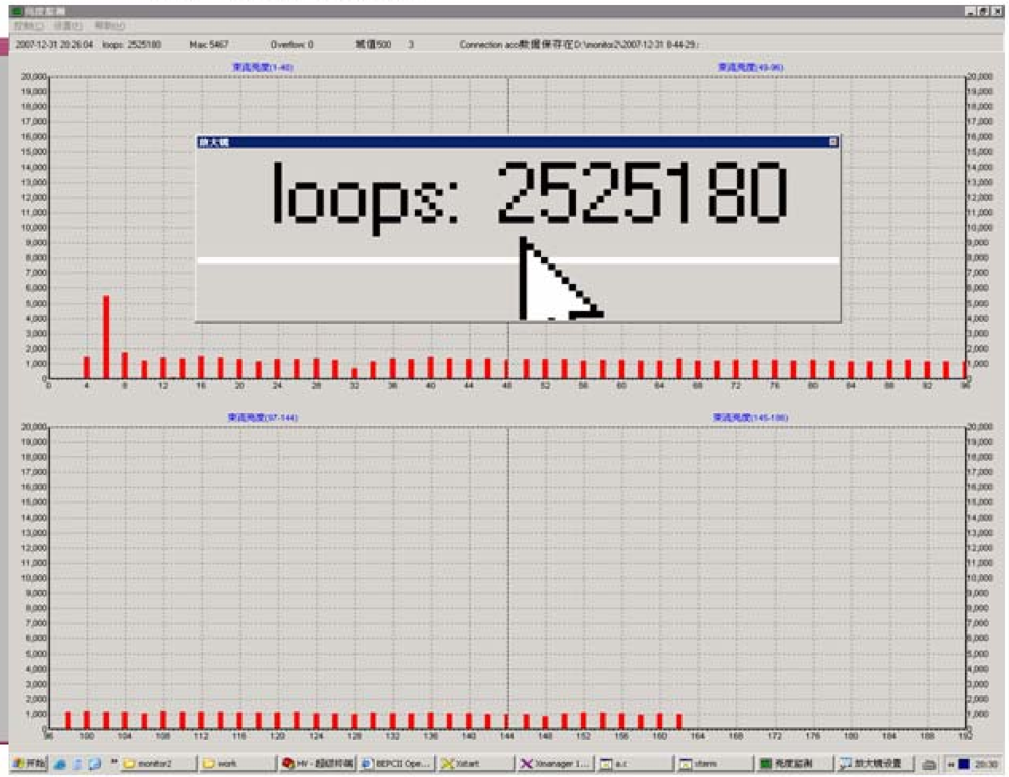
Multi-bunch collision

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

- **300*300mA on BCM (Bunch current monitor)**

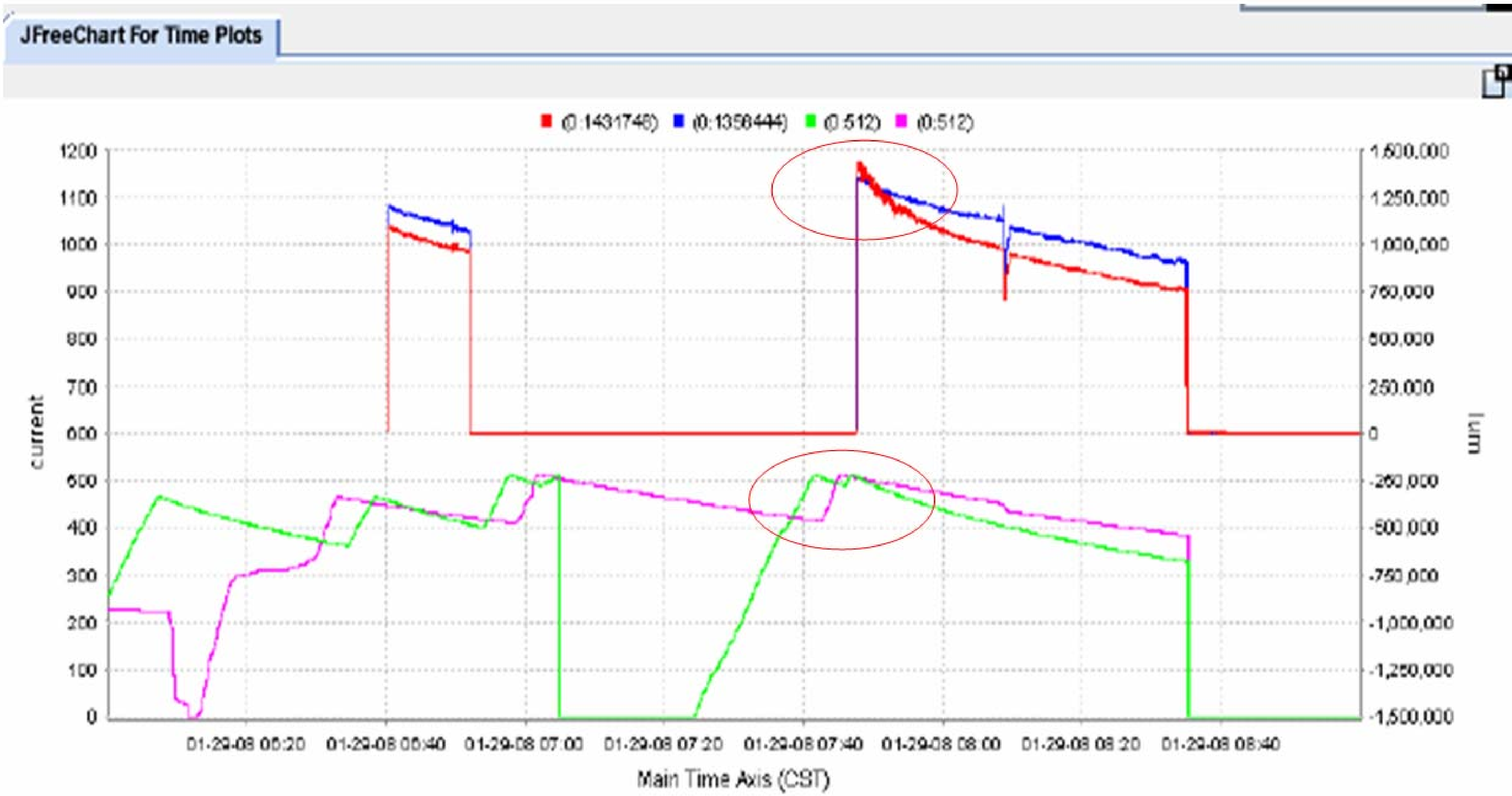


- **300*300mA luminosity with 99 bunches**



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

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



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

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

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	

Issue to be further studied

1) Injection: 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

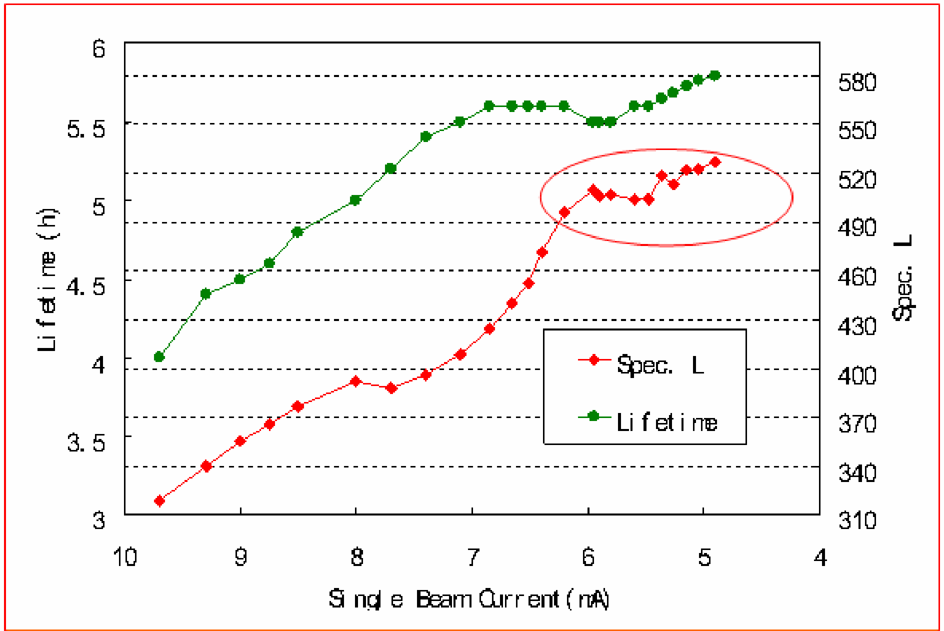
2) Improve the specific luminosity of single bunch at high current

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

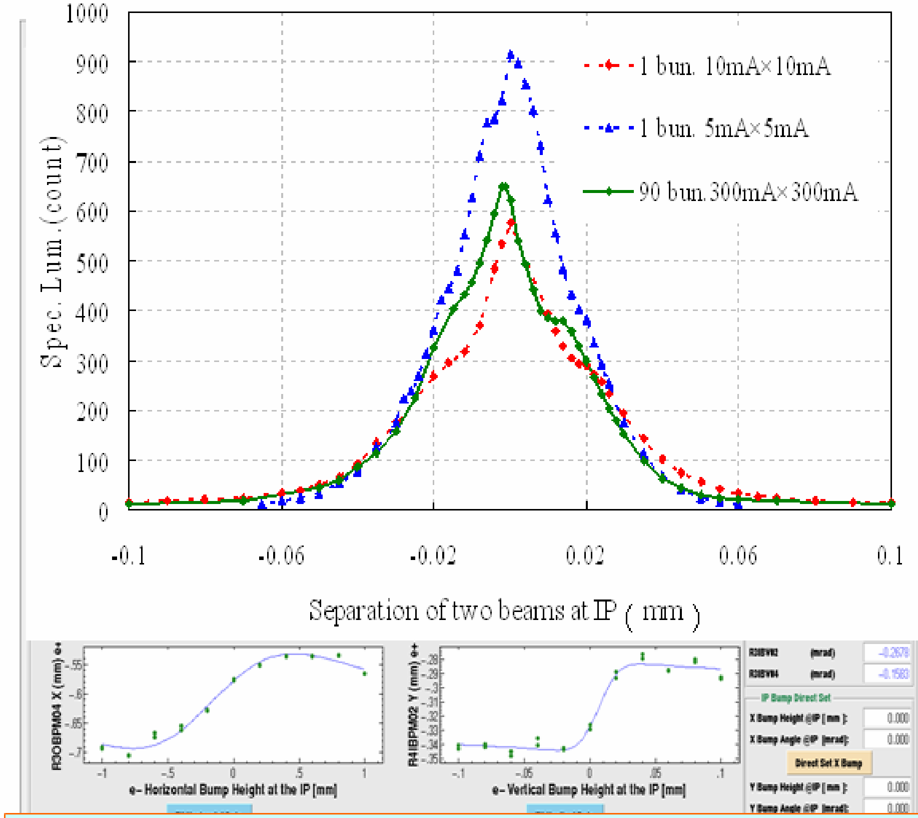
3) Improve the specific luminosity in multi-bunch case with high current

   =>Better tuning of TFB on Y-direction

4) Beam lifetime, high current effects, background, etc



- Specific Lum. [$L/(n^*I_b{}^*I_b)$] vs I_b
- The curve is flat below 6mA=>beam size not blow up,
- Potential to improve specific luminosity at high bunch current.



Scan of spec. lum. for single(dashed) and multi-bunch (solid) vs. the vertical offset at IP.:

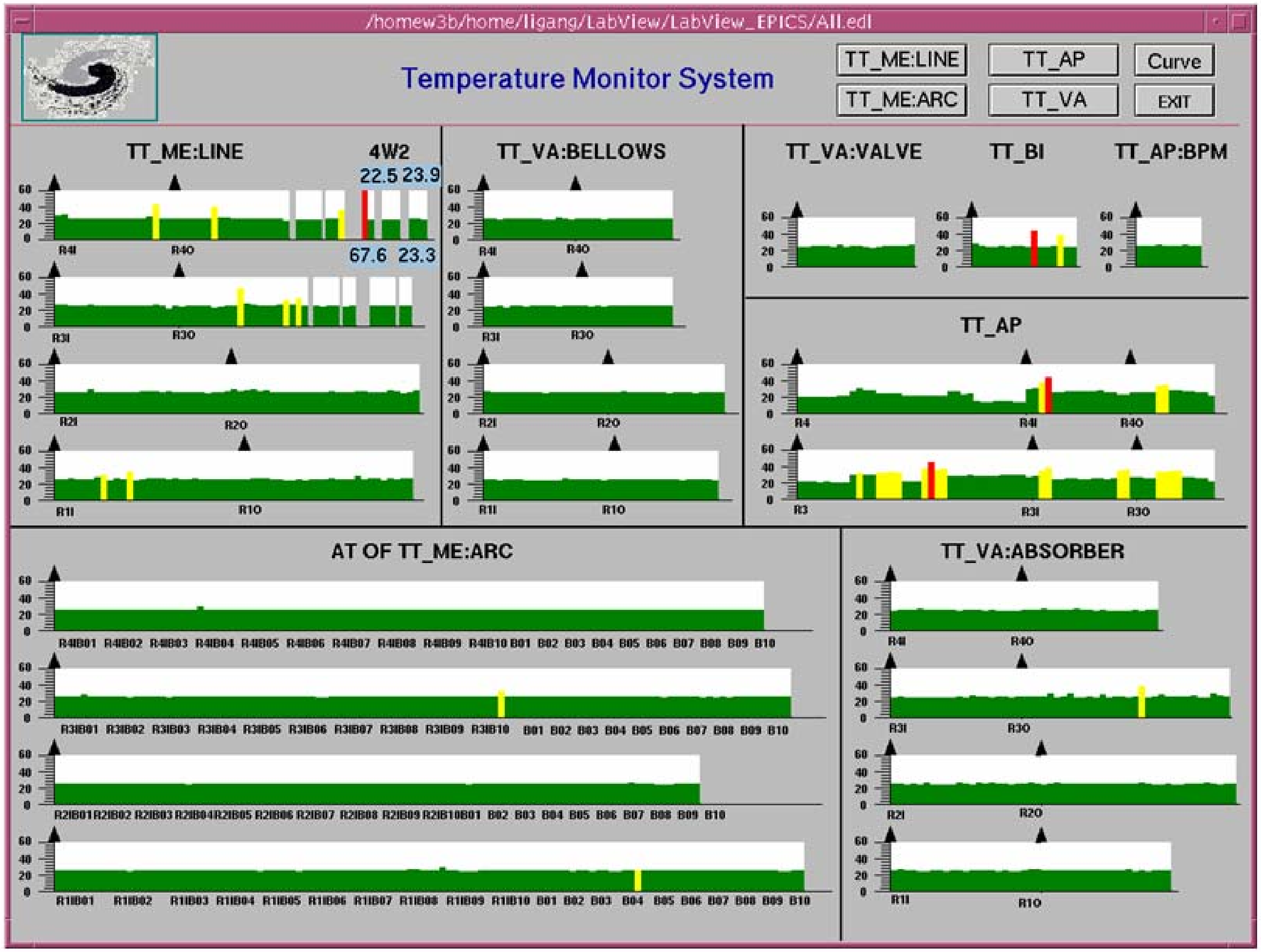
1) $\sigma_y{}^*$ smaller for single bunch

2) Spec. L higher for single bunch

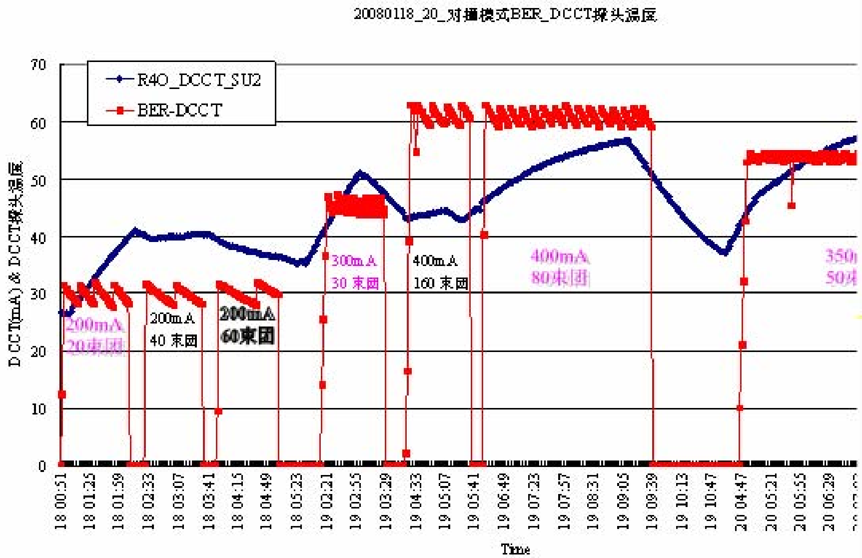
=> TFB to suppress σy for higher lum. In multi-bunch at higher current

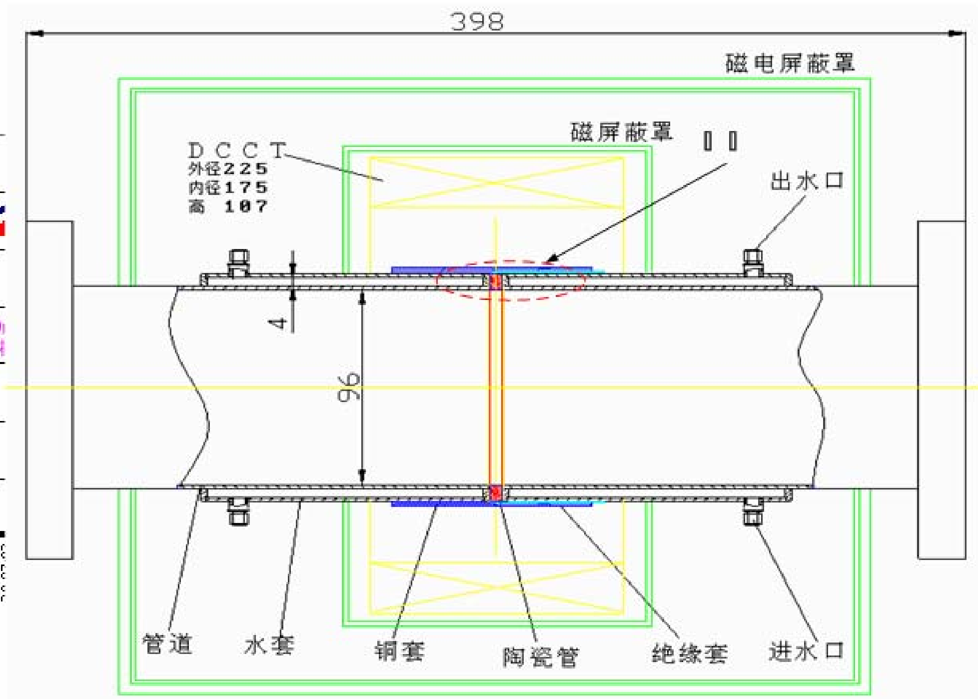
Heating effects at High Current

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

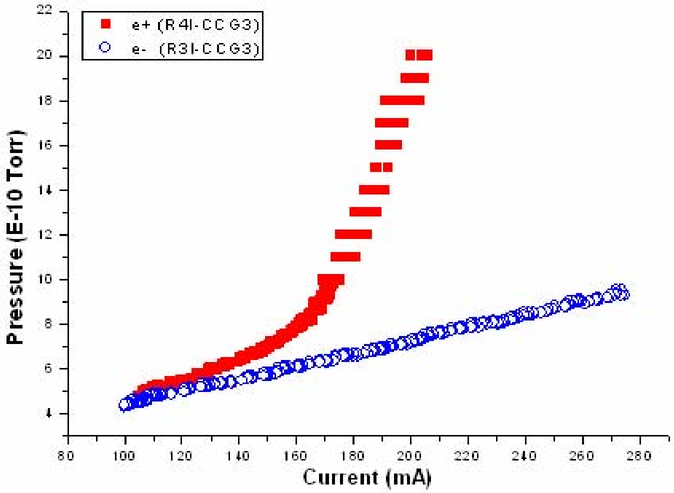


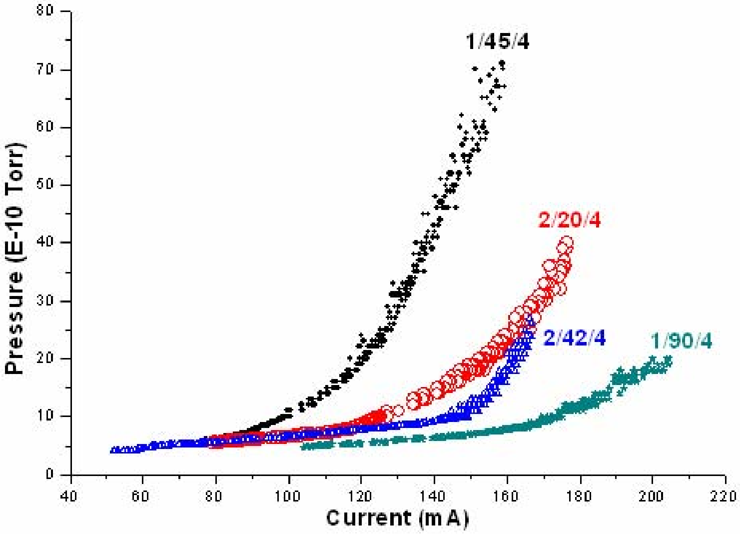


1) Some capacitors will be connected in parallel to improve the RF shield.

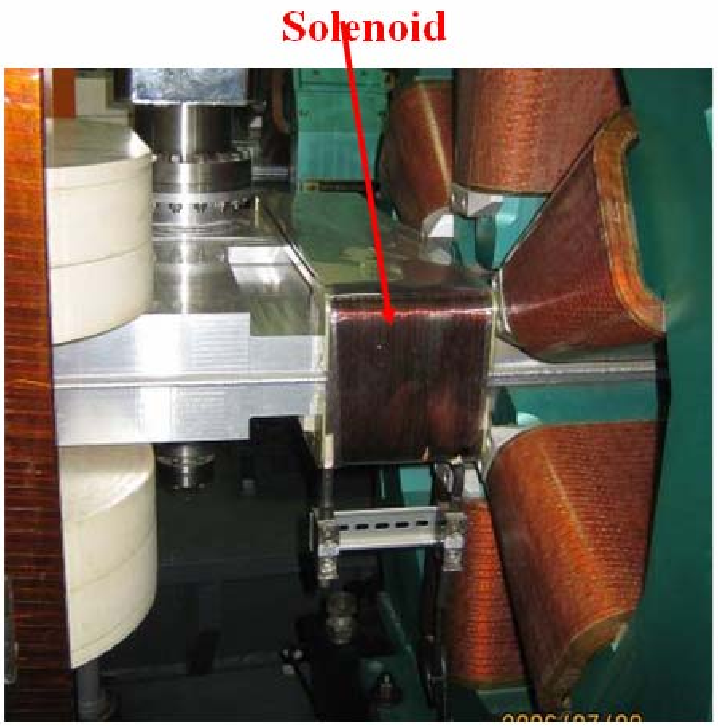
2) Improve the local cooling capacity

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.

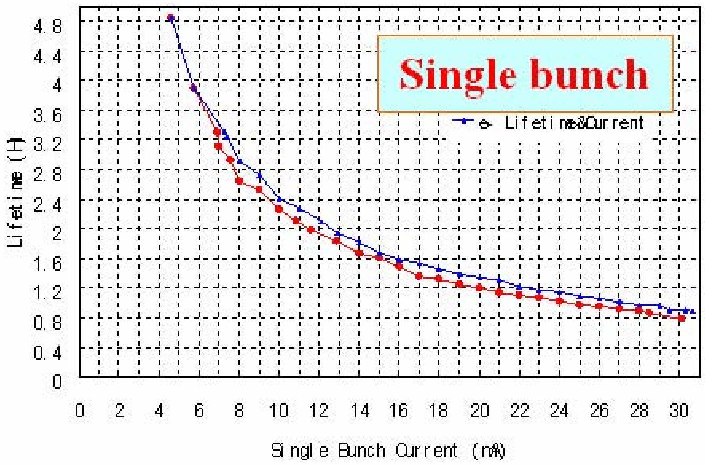


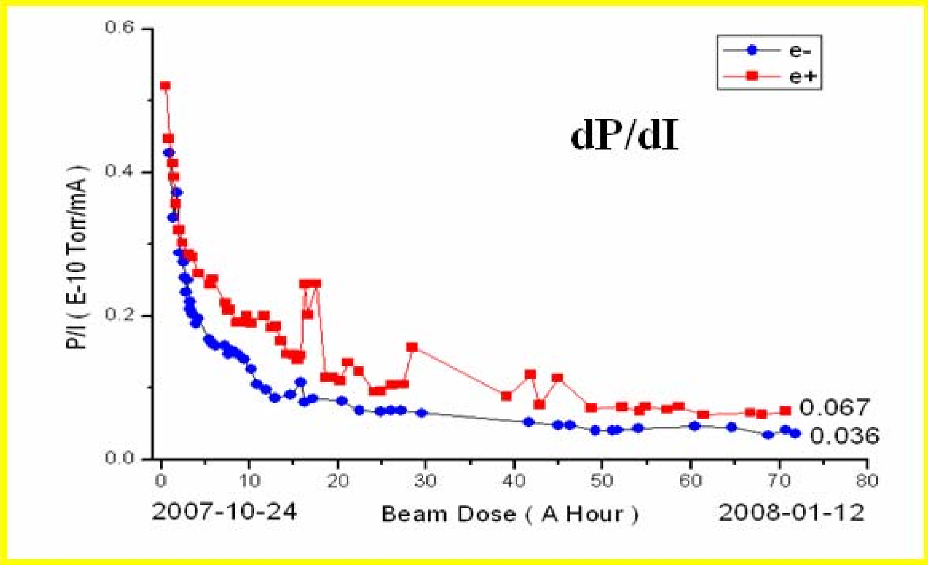
Beam life time

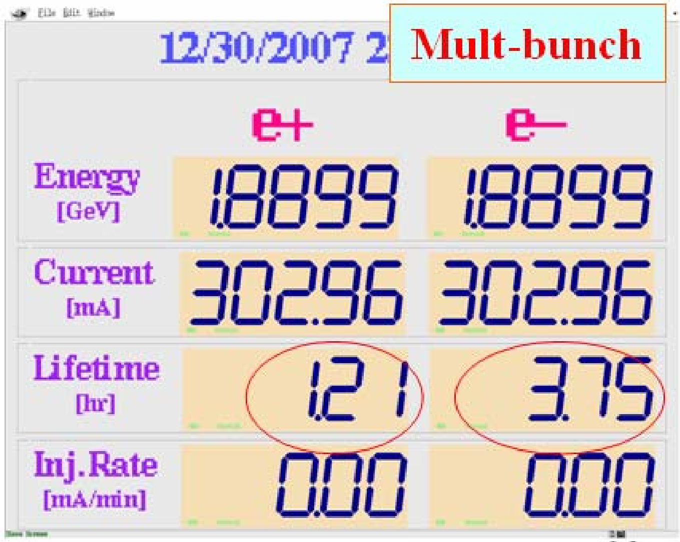
- Single bunch: $\tau_{BER} \sim \tau_{BPR}$
- Muli-bunch @high current: $\tau_{BER} > \tau_{BPR}$
- Possible cause: vacuum, $P_{BPR} > P_{BER}$

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

=>Systematic studies in future.



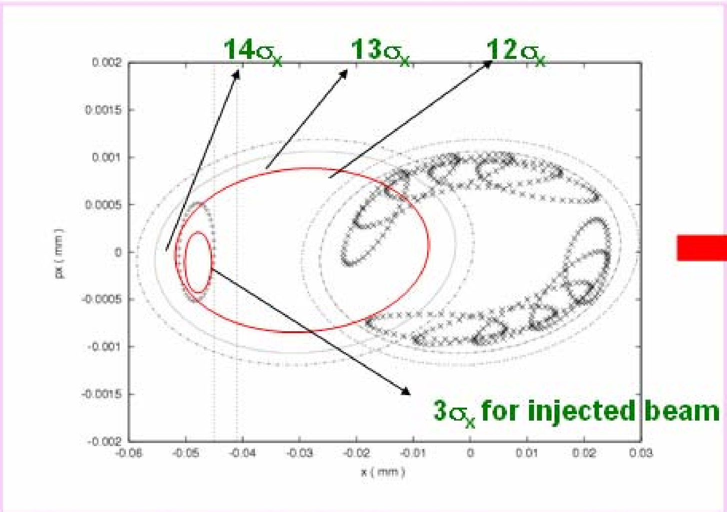


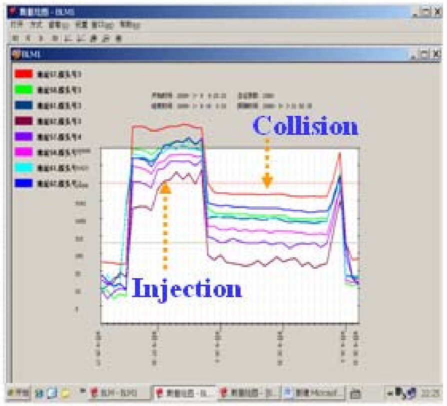


BACKGROUND

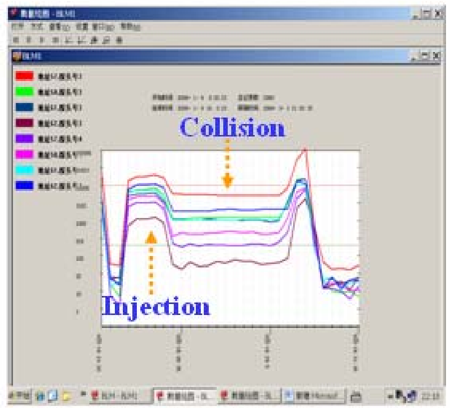
- Various experiments are done to study the behavior of the backgrounds and means to reduce them are found:
  - With the injection optimization and fast beam abort the dose rate in the IR gets acceptable for the BESIII detector which is being pulled into the IR.
  - The backgrounds due to steady runs and ways to reduce them should be studied thoroughly in the near BEPCII/BESIII joint experiment

Collimation during Injection





Aperture $8\sigma_x$
Energy spread ± 0.8%

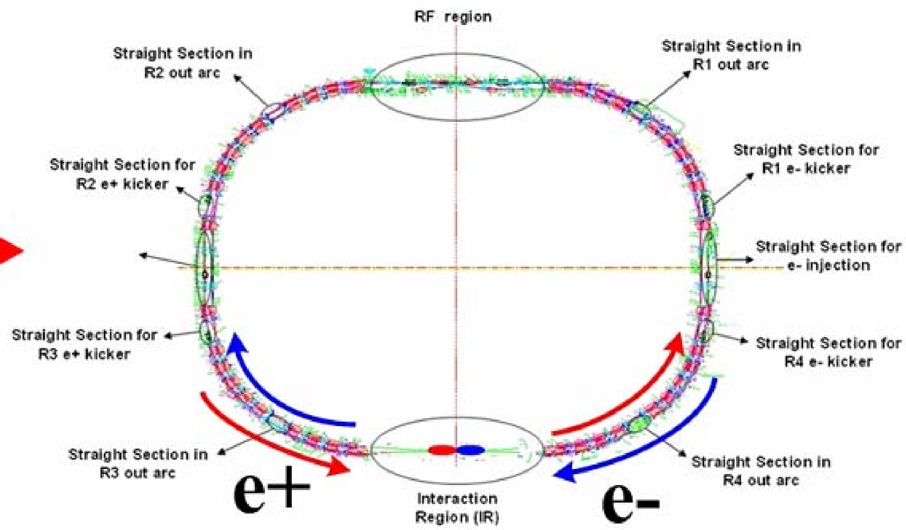


Aperture $3\sigma_x$
Energy spread ± 0.3%

The collimators in the electron transport line were used to limit the energy spread(± 3‰) and the emittance(aperture $3\sigma_x$) of the injected beam.

- Simulation of background due to SR, Beam-gas interactions, Touschek effect:

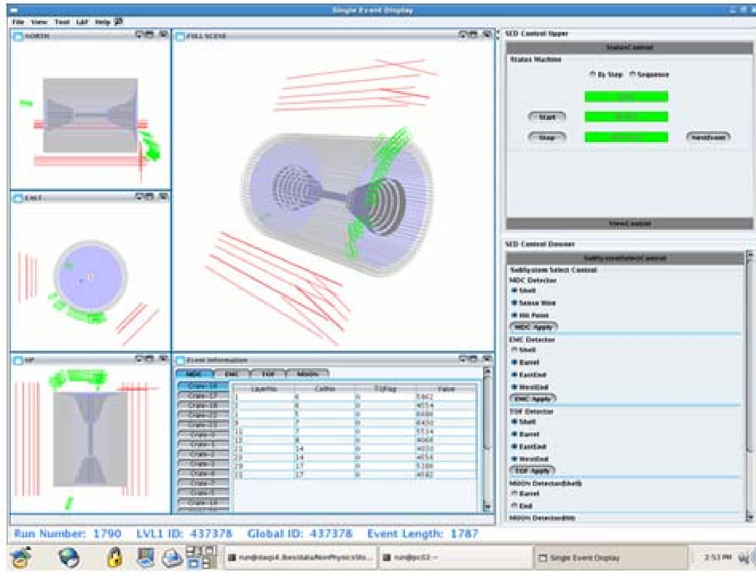
  With collimators and masks, the background in the detector during its data acquiring could be well controlled.



PLAN AND SCHEDULE

- The detector was moved into the IR in May
- The third phase commissioning is scheduled in mid of June.
- It is expected that the luminosity would be high enough for the BESIII detector to start experiment by the end of 2008.

Detector and accelerator in IR in June



BESIII realized cosmic ray data acquisition offline on Feb. 14

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 third phase commissioning with detector is just started. To improve the luminosity while control the background acceptable for data taking is still challenging.

Thank you for your attention