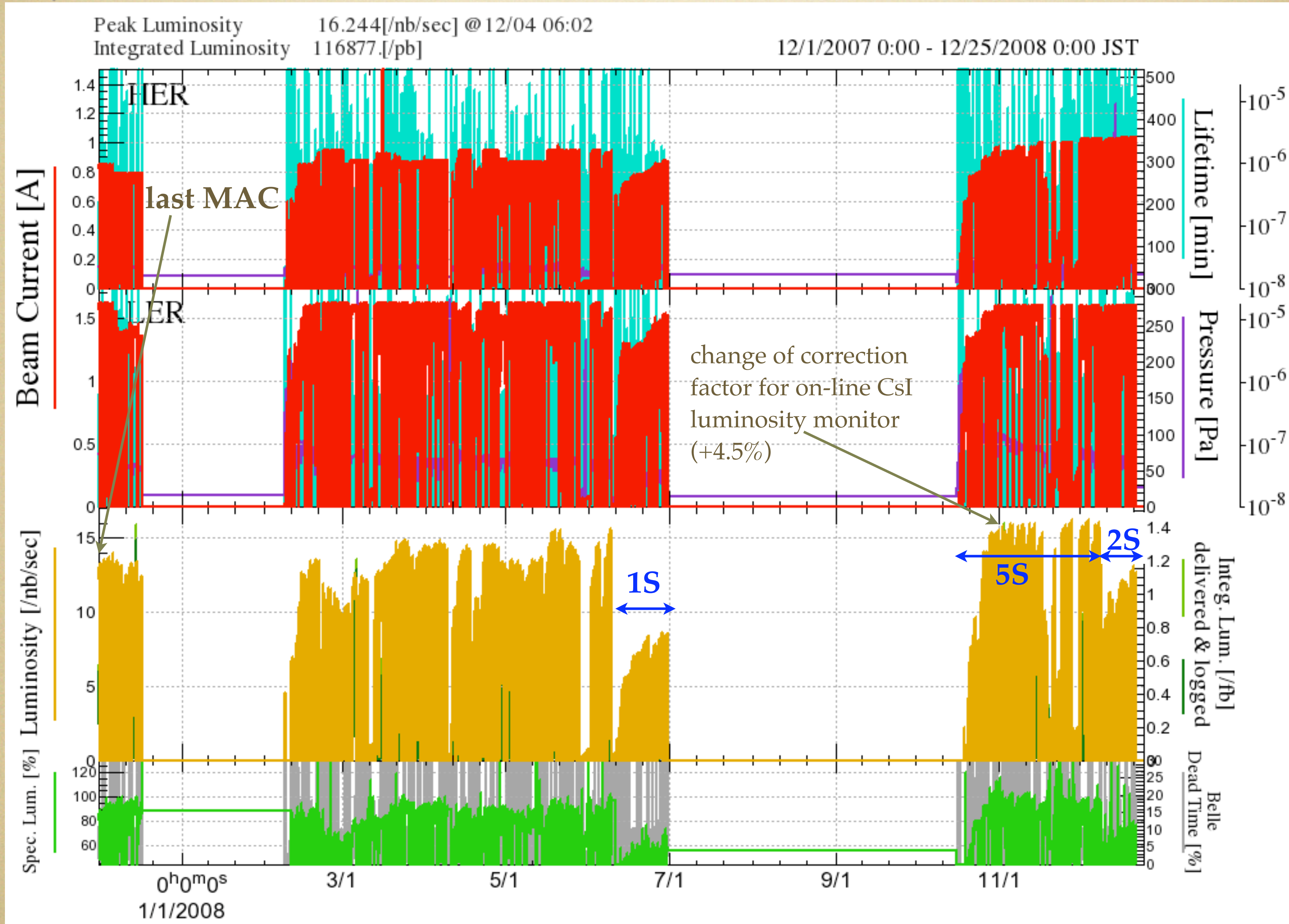
Progress in crab crossing

Mac 2009 Feb. 09

Y. Funakoshi



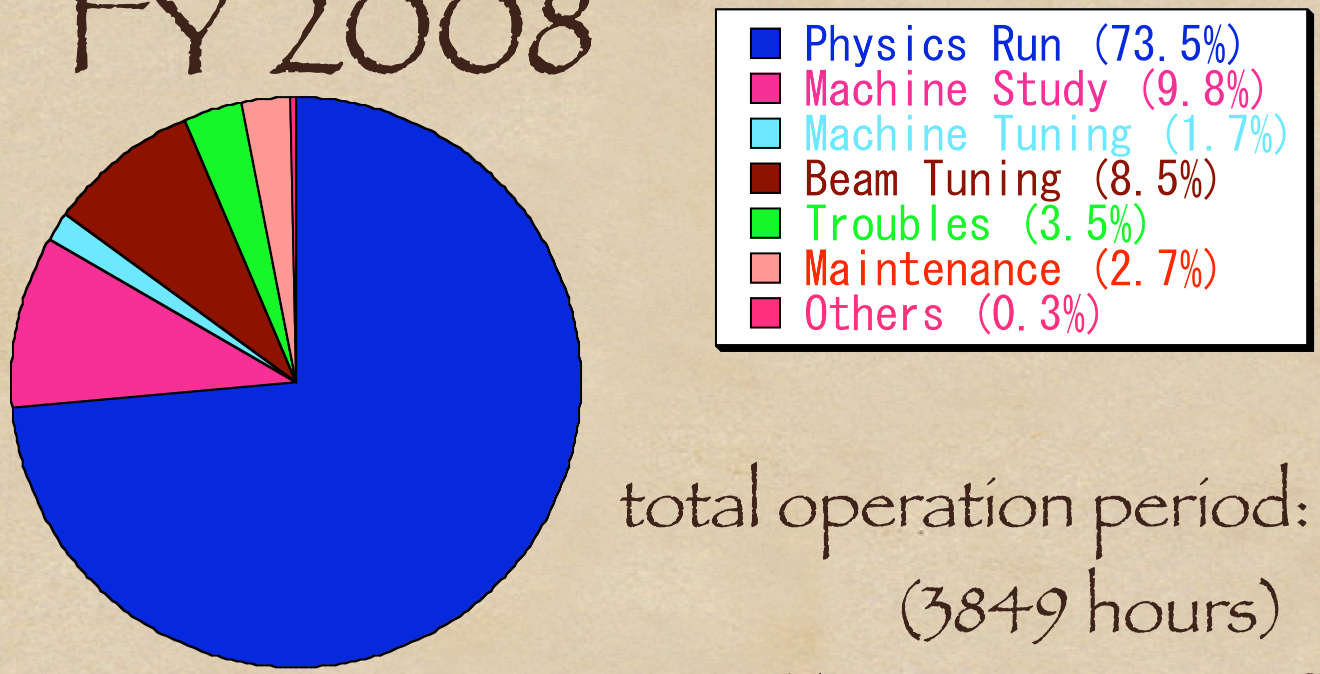
Peak Luminosity 16.244[/nb/sec] @12/04 06:02
Integrated Luminosity 116877.[/pb]
12/1/2007 0:00 - 12/25/2008 0:00 JST
HER
LER
last MAC
change of correction factor for on-line CsI luminosity monitor (+4.5%)
1S
5S
2S
Beam Current [A]
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
0h0m0s 1/1/2008
3/1
5/1
7/1
9/1
11/1

Conclusion.

- Run to run stability of the Online Luminosity is about 0.3% if injection is OK.
- Due to slow drift of the Luminosity Monitor parameters the correction factor $(+4.5 \pm 0.5)\%$ for Online Luminosity arises.
- The CM energy change cause an increase of Bhabha rate. There Online Luminosity correction for $\Upsilon(5S)$ is $(0.6 \pm 0.5)\%$.
- The preliminary results for begging of the Exp 67 shows $[D]L/L = 2.5 \pm 0.5\%$ with expectation $(3.9 \pm 0.7)\%$.
- The conservative estimation of KEKB Luminosity can be $L(true) = L(Onl) * (1 - .02) * (W/5.29)^2$.
- Corrected results for some previous KEKB records
  - Record peak luminosity without crab.
    Nov. 15 2006 at Y4S : Peak = 17.12 /nb/s → 17.60.
  - Record peak luminosity with crab.
    May 19 2008 at Y4S: Lpeak = 16.10 /nb/s → 16.8
  - Maximum peak luminosity in this term.
    Oct. 30 2008 at Y5S : Lpeak = 15.91 /nb/s → 16.3

V. Zhilich

Machine operation in FY 2008



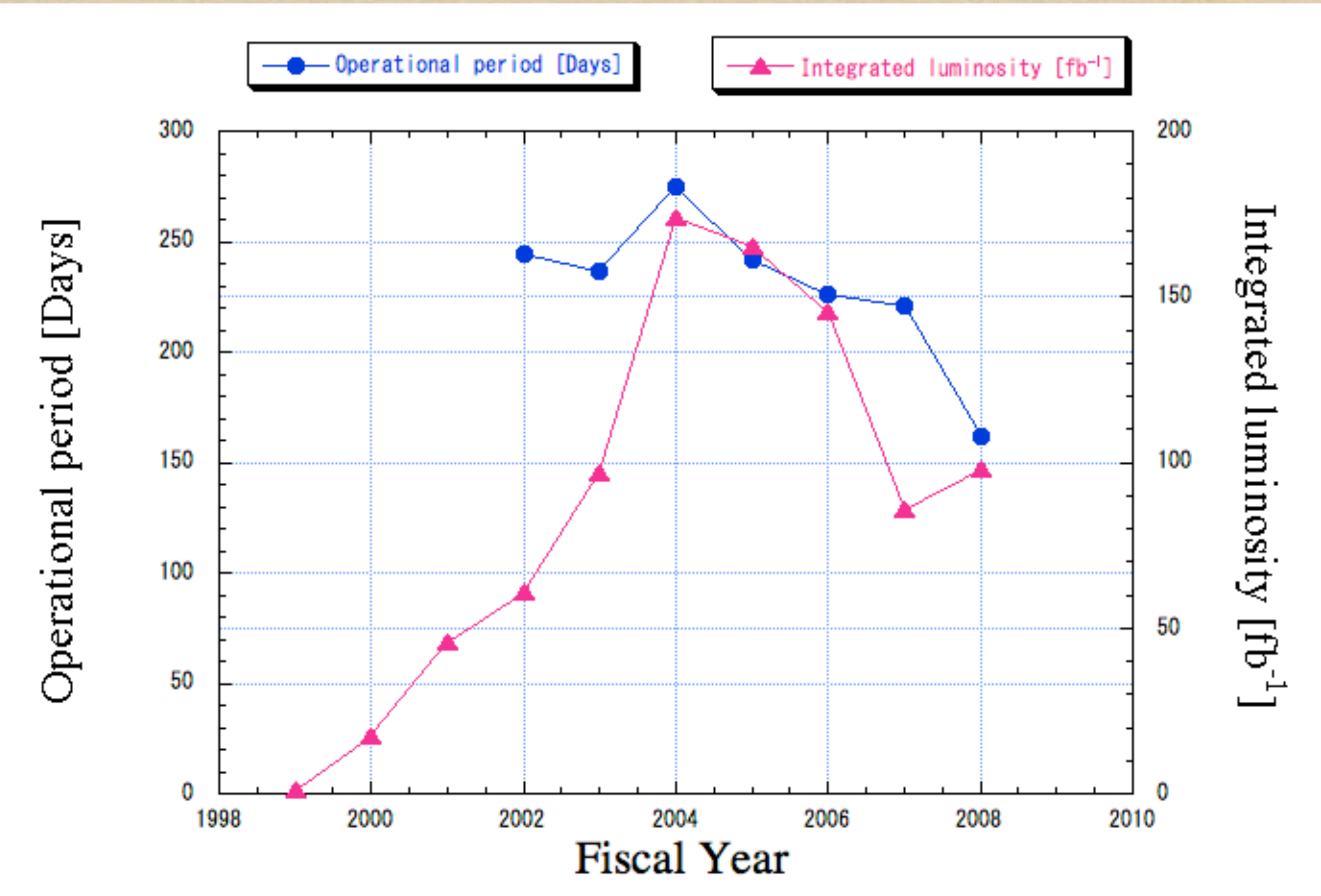
total operation period: 161 days (3849 hours)

Integrated luminosity: 98.5 fb^{-1} (FY2008)

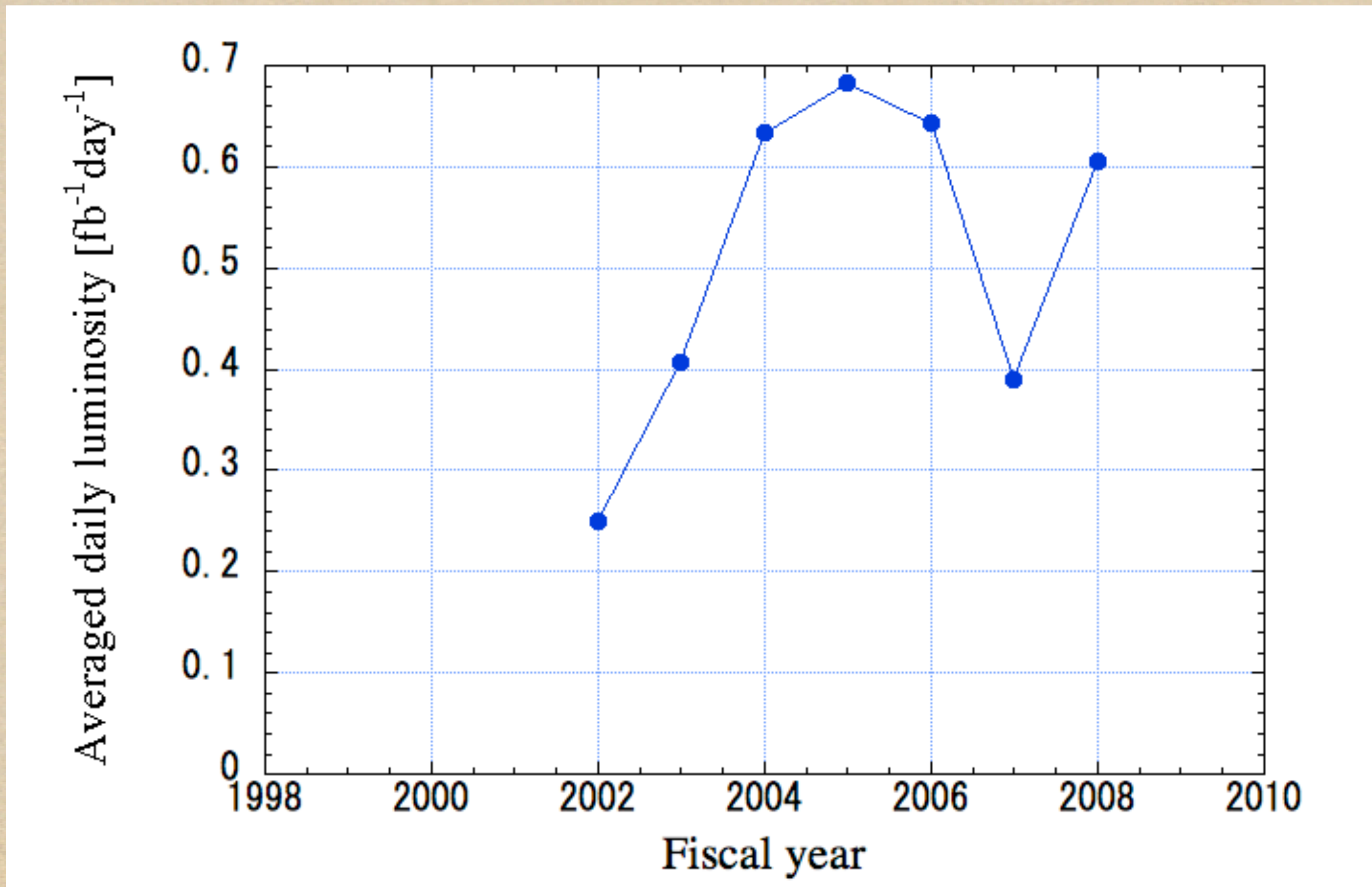
Total Integrated luminosity: 894.8 fb^{-1}

needed to be updated

Annual integrated luminosity



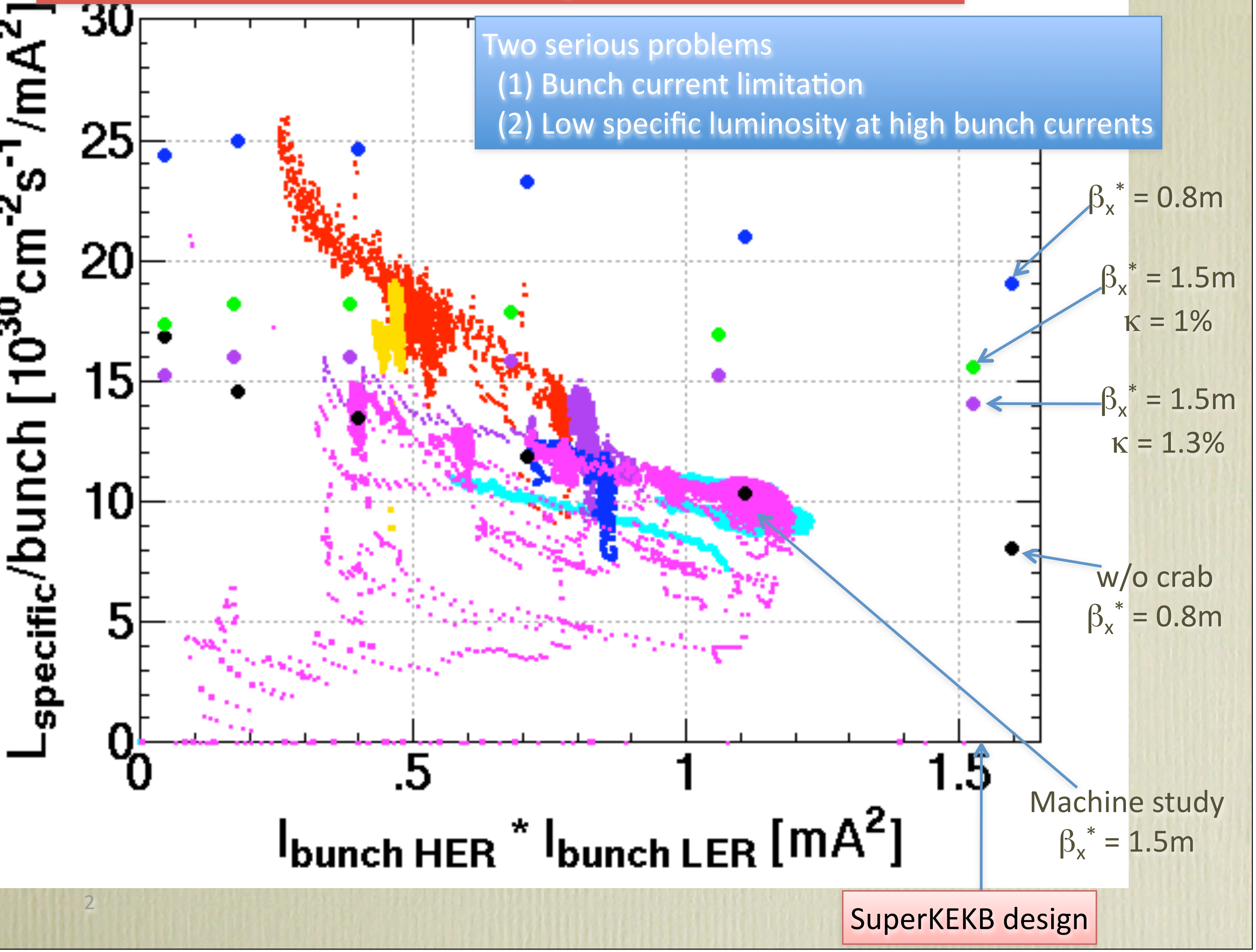
Averaged Daily Luminosity



Machine parameters

Date	Nov.15 2006 before crab		Nov. 28 2007 with crab (Last MAC)		May 19 2008 with crab		
	LER	HER	LER	HER	LER	HER	
Current	1.65	1.33	1.58	0.839	1.60	0.933	A
Bunches	1389		1584		1584		
Bunch current	1.19	0.96	0.998	0.530	1.01	0.590	mA
spacing	2.10		1.84		1.84		mA
emittance ε_x	18	24	18	24	15	24	nm
β_x^*	59	56	90	90	90	90	cm
β_y^*	6.5	5.9	5.9	5.9	5.9	5.9	mm
σ_x @IP	103	107	127	147	116	147	μm
σ_y @IP	1.8	1.8	1.1	1.1	1.1	1.1	μm
ν_x	45.505	43.534	45.506	44.511	45.505	44.509	
ν_y	44.509	41.565	43.570	41.590	43.567	41.596	
ν_s	-0.0246	-0.0226	-0.0246	-0.0204	-0.0240	-0.0204	
beam-beam ξ_x	0.117	0.070	0.089	0.098	0.099	0.119	
beam-beam ξ_y	0.108	0.058	0.096	0.089	0.101	0.096	
Luminosity	17.6		15.1		16.8		$10^{33}cm^{-2}s^{-1}$

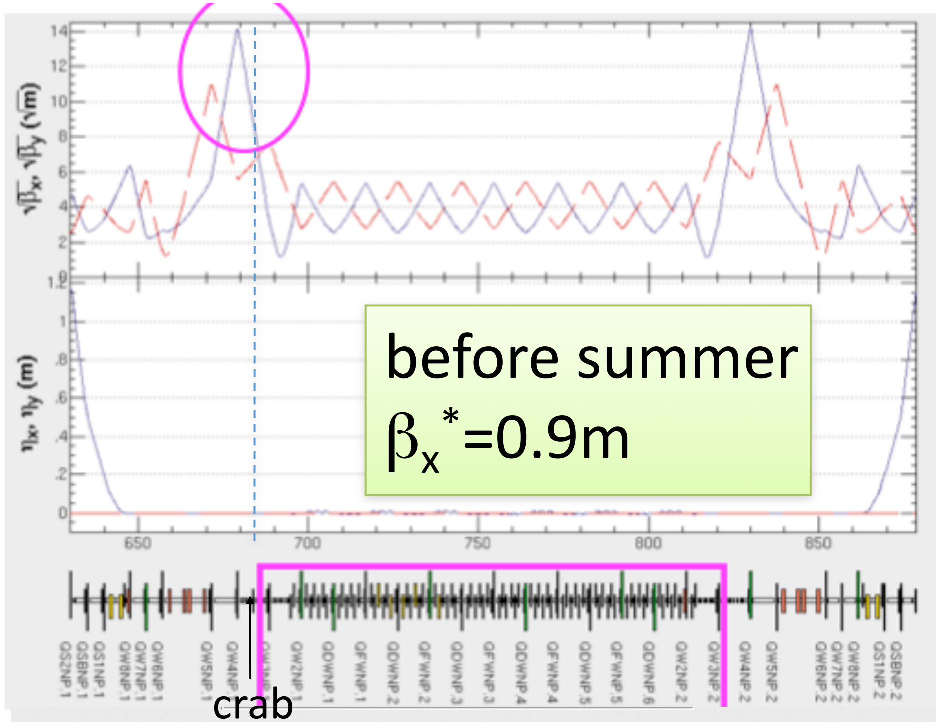
What are the problems?

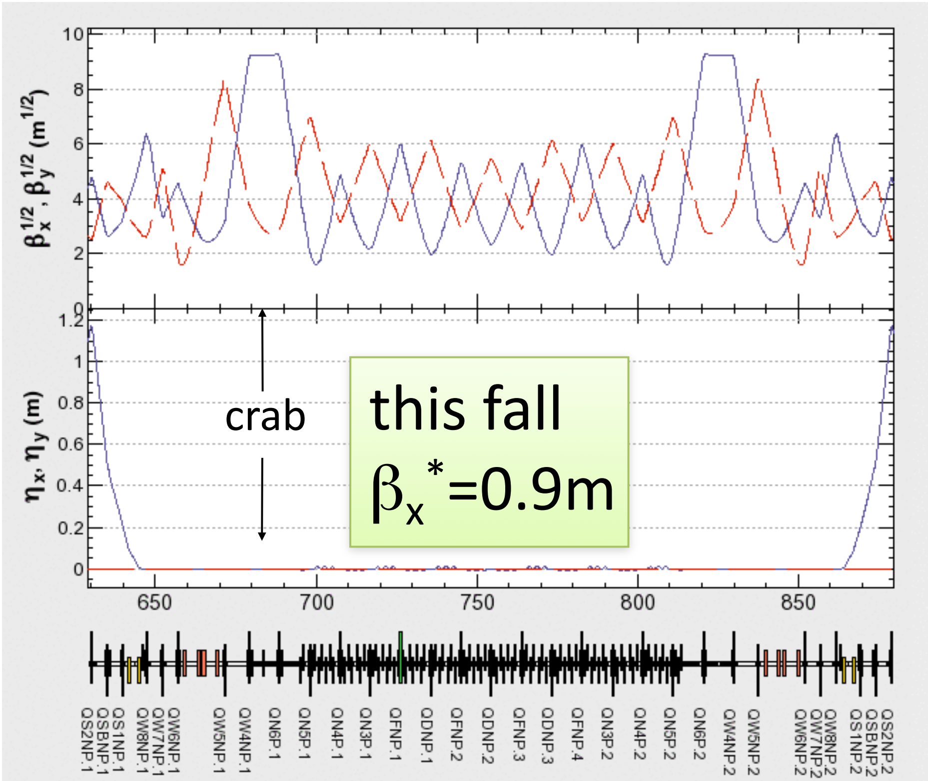


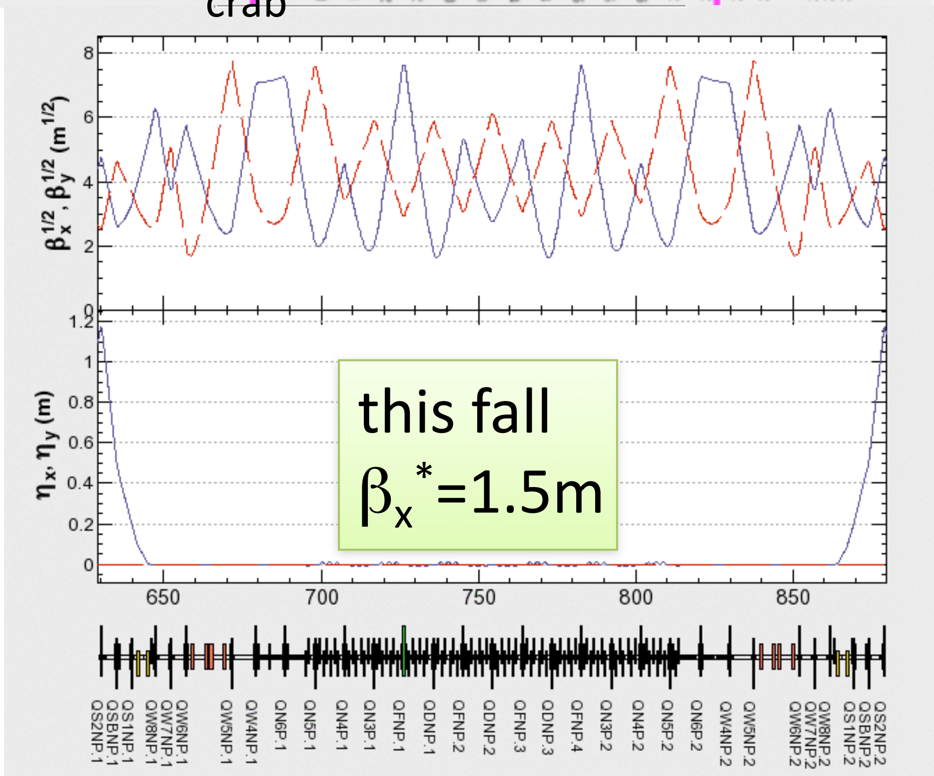
Cause of bunch current limitation

- Physical aperture at the crab cavities?
  - Dynamic beam-beam effects in the horizontal direction
- Possible cures
  - LER:
    - Reduce the β_x around the crab by changing wiring of quadrupole magnets (actually done in summer break)
  - Both rings
    - Raise the crab Vc by lowering crab cooling temperature
      - We gave up the trial in the autumn run for some technical reasons (-> Nakai's Talk).
      - Raised the HER crab Vc w/o changing temperature (1.343 -> 1.5MV)
    - Increase at β_x at IP
    - Realize the e+/e- simultaneous injection (-> Iida's Talk)
      - enables us to operate the machine with shorter beam lifetime

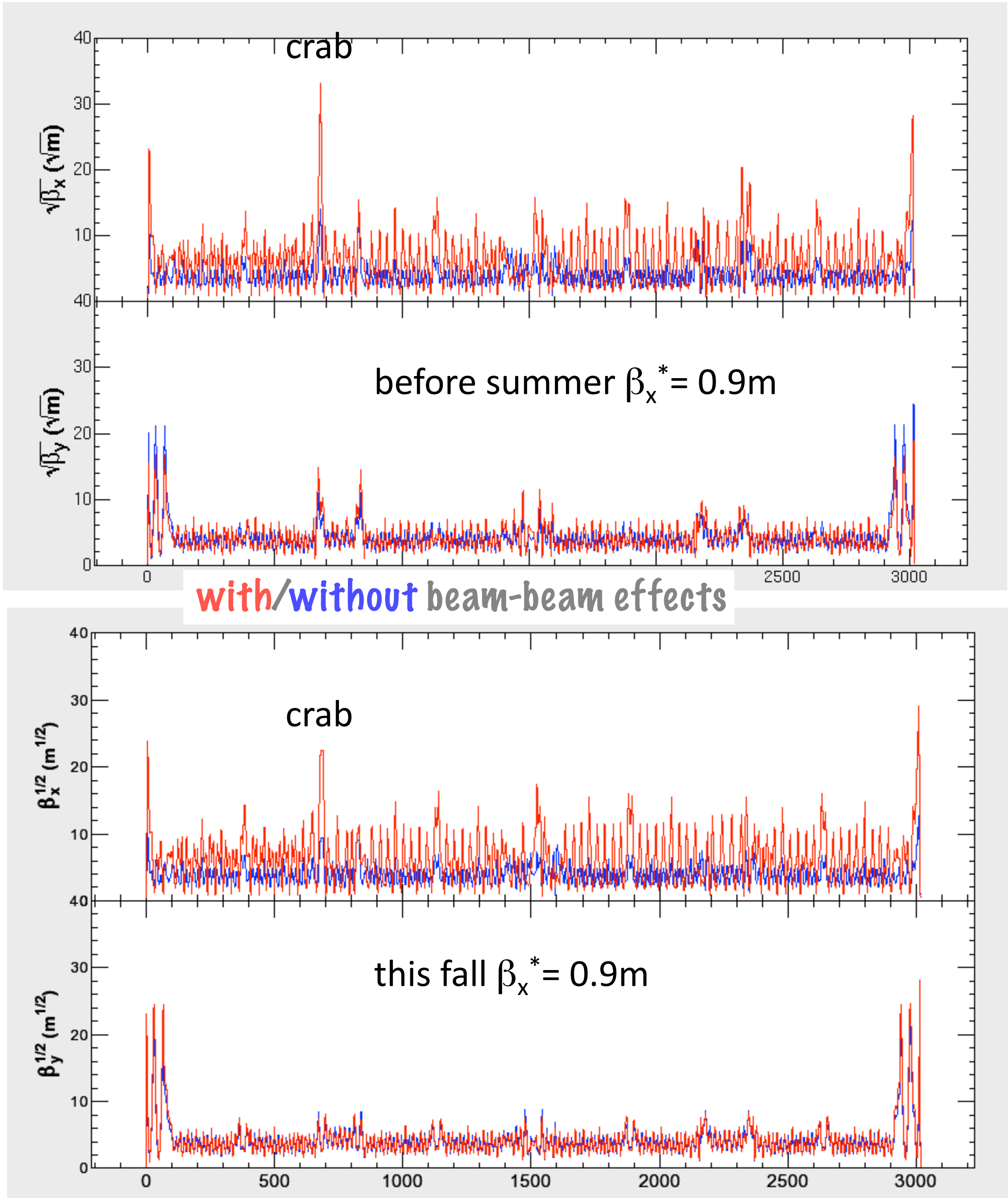
Beta's at LER crab cavity (w/o beam-beam)







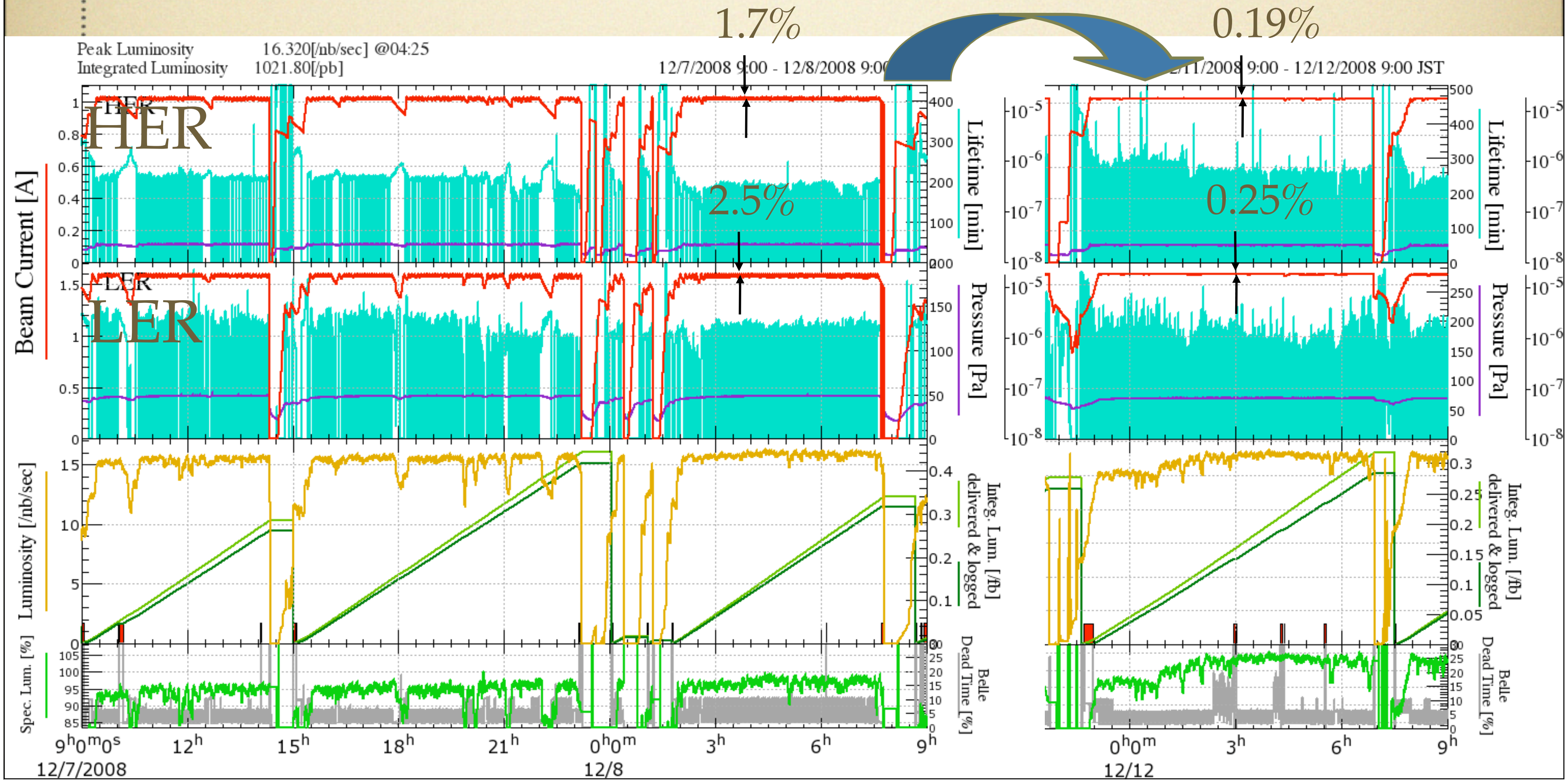
Beta's with dynamic beam-beam effect



N. Iida

HER/LER Fast Alternating Beam Injection

- On Dec. 12 2008, HER/LER injection could be successfully switched in 2 sec.
- The injection rates were as good as usual.
- The beam current variations were by one order decreased in both rings.

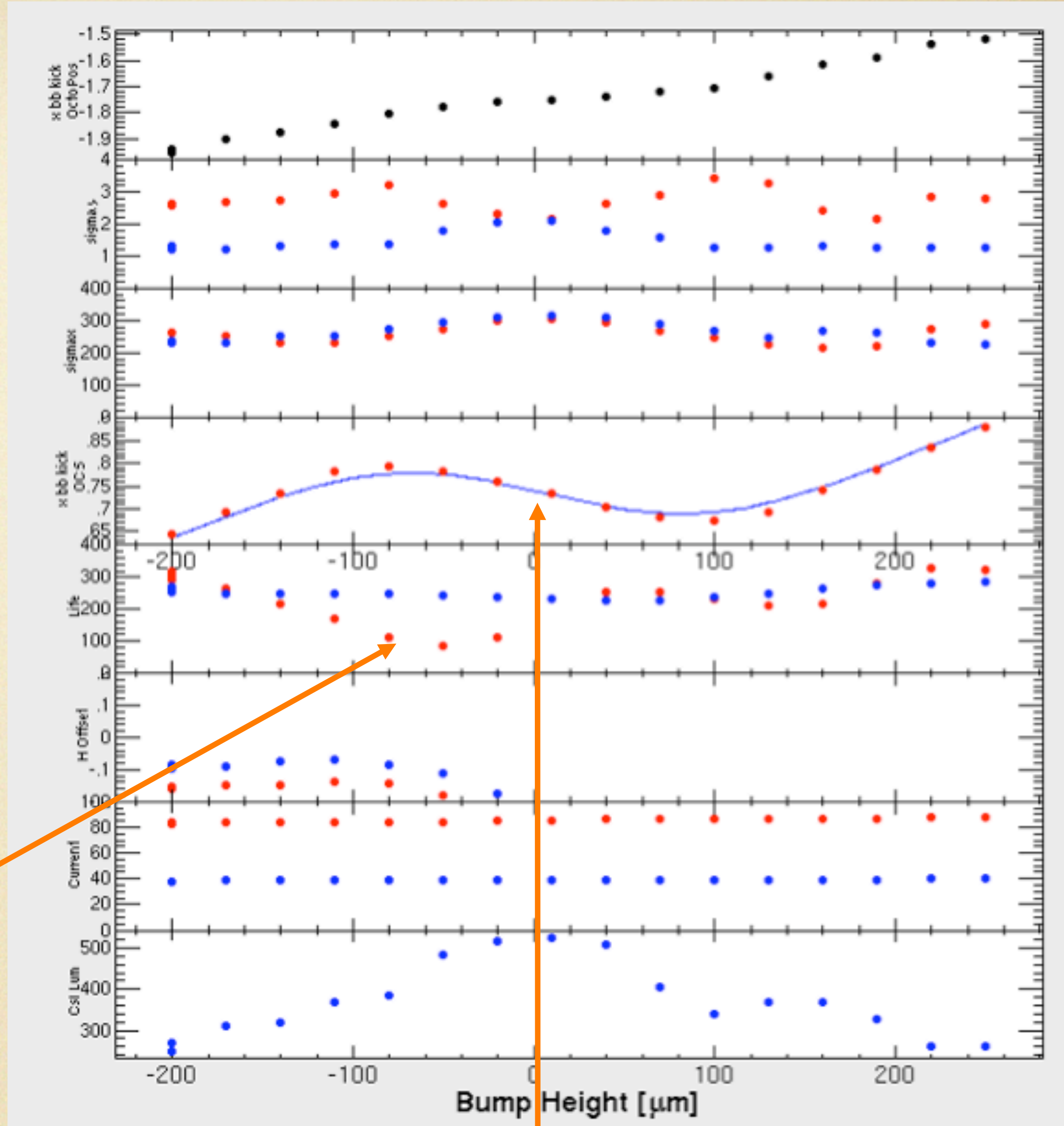


What is the origin of steep slope of specific luminosity?

- Short beam lifetime
  - Horizontal offset at IP
- Beam current dependent emittance growth in a single beam mode?
- Machine errors
  - Usual knob tuning is not enough to compensate the machine errors?
    - Too many knobs?
  - Side effects of large knobs?
- Beam-beam simulation misses something?
  - Cross-check the beam-beam simulation code
  - Wakefield effect + beam-beam?
  - Off-momentum optics play some role to decrease the luminosity?

Horizontal offset scan

- The (HER) beam current seems to be limited by the short life time of the LER beam.



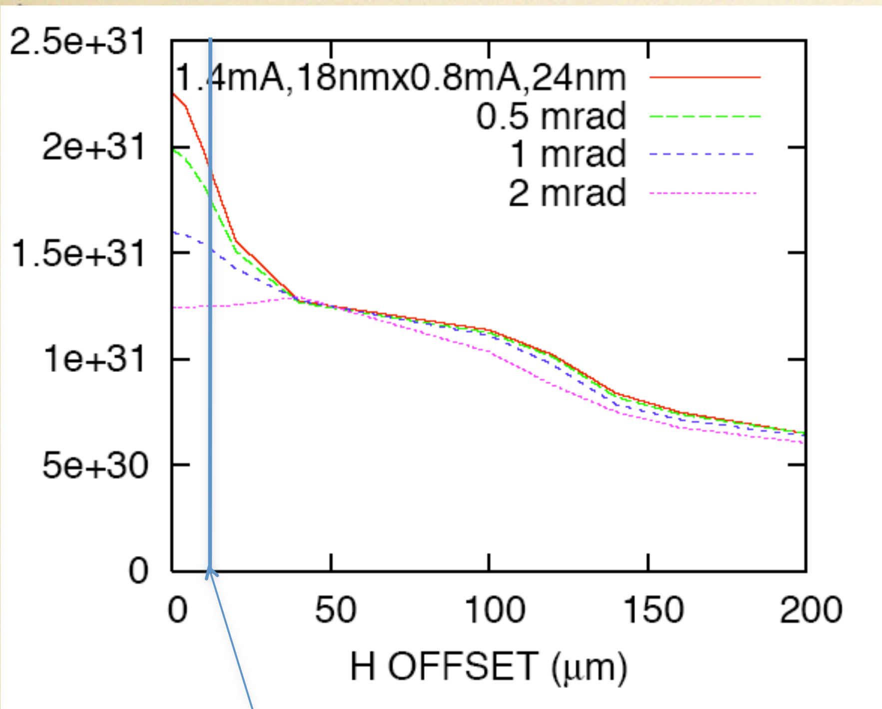
LER lifetime

Collision center given by the beam-beam kick

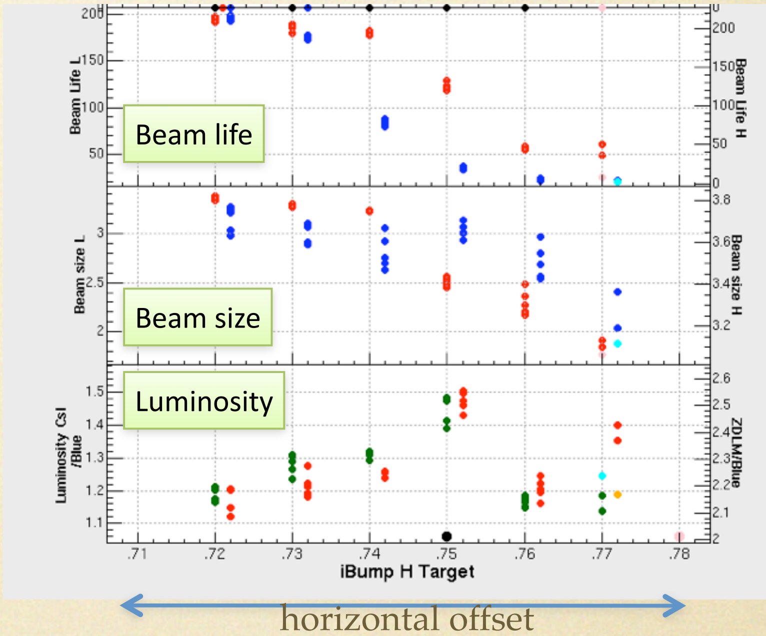
- The (LER) beam lifetime is very asymmetric with respect to H offset.

Horizontal offset at IP and crossing angle

Beam-beam simulation

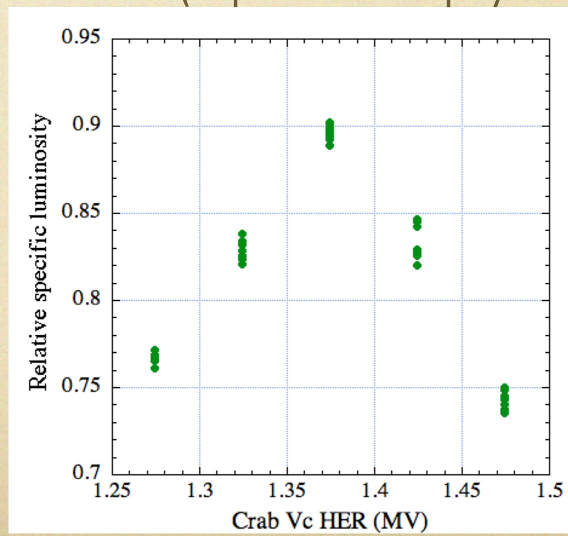


Horizontal offset scan:
experiment with relatively small beam current

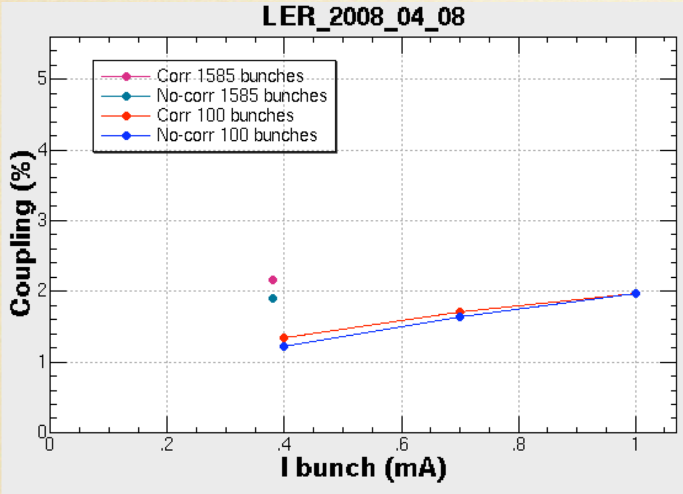


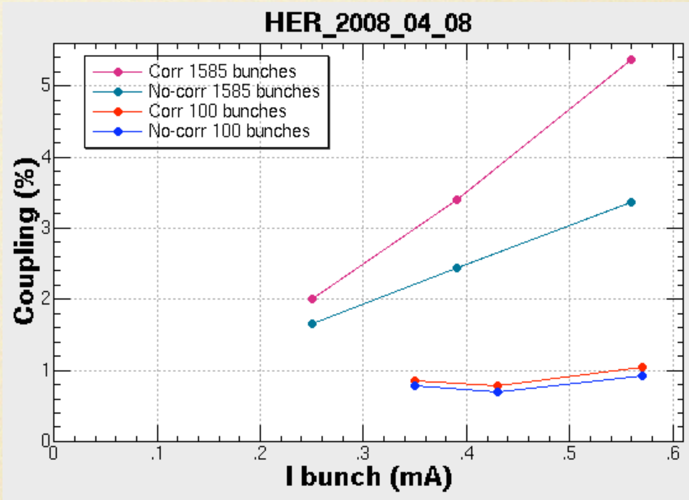
- Luminosity boost by crab crossing disappears with 2 mrad crossing angle.
- Luminosity boost by crab crossing disappears with ~40 μm horizontal offset.
- Typical value of horizontal offset in physics experiment is **~15 μm**, which is obtained by offset scan.
- **This kind of offset depending on beam current can degrade the specific luminosity.**
- Some luminosity boost by the crab crossing is actually observed by crab Vc scan.

Crab Vc scan (experiment in physics run)



Bunch current dependence of vertical beam sizes





- Bunch current dependence of vertical beam size was observed in LER in Apr. 2008.
- This can explain the bunch current dependence of the specific luminosity?
- More studies were conducted in autumn 2008.

Lifetime issue

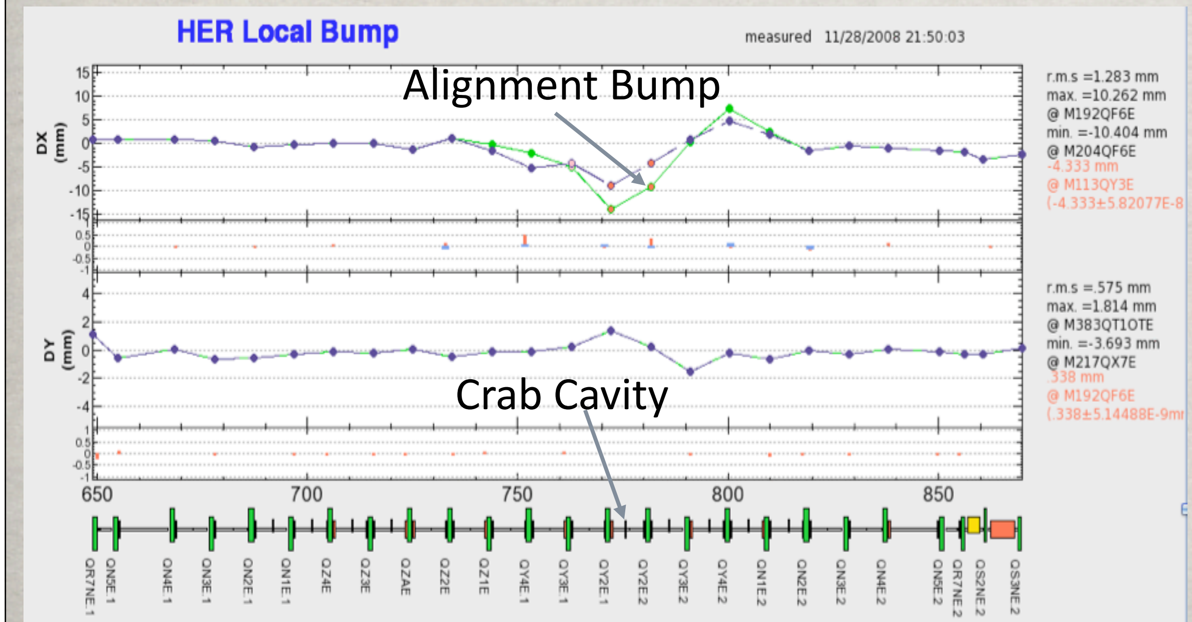
- Can we store more bunch currents and increase the luminosity by enlarging physical aperture around the crab cavities?
- β_x^*=0.9m
  - The LER beam lifetime seemed to be longer than before summer.
  - The HER beam lifetime was short and the beam loss monitor near crab had a response to the HER beam life.
  - At nominal operation currents, both LER and HER beam lifetime became short depending on IP horizontal offset.
    - We decided to go to β_x^*=1.5m.
  - Trial of larger β_y^*
    - β_y^*=5.9mm -> 7mm: No significant difference was observed.

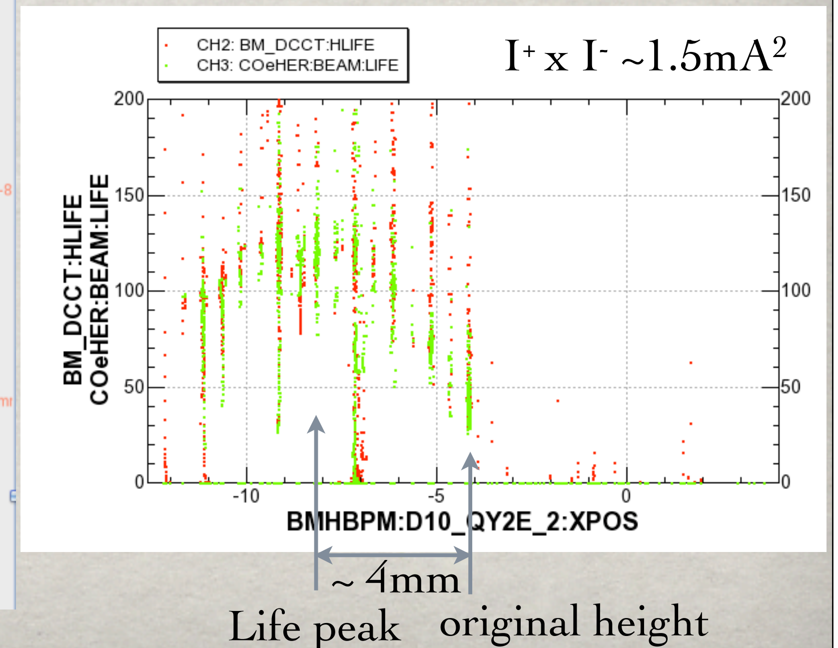
Lifetime issue [cont'd]

- β_x^*=1.5m
  - –We could successfully store the high bunch currents corresponding to the SuperKEKB design.
  - –At $I^+ \times I^-$ ~1.1mA^2, no beam lifetime decrease was observed. However, the achieved luminosity was much lower than the simulation.
  - –At $I^+ \times I^-$ ~1.5mA^2, beam lifetime decrease in HER was observed depending on IP horizontal offset.

Aperture survey around HER crab

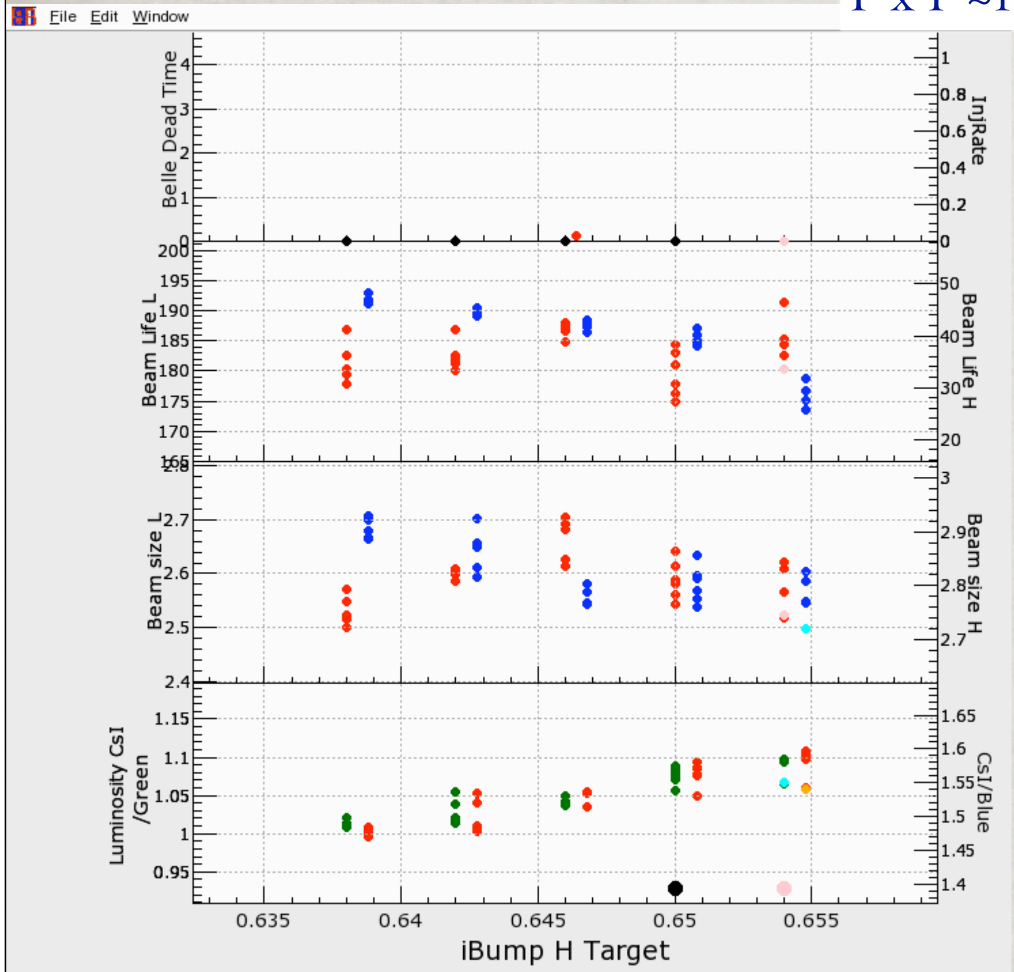
- Scan of HER Crab Alignment Bump
  - Original bump height: ~-6.5 mm necessary to minimize the beam loading
  - Higher bumps made the lifetime longer (peak at a bump with Δx = ~ -4mm).
- Mis-alignment of HER crab cavity?
  - After the machine was shutdown, we actually found a mis-alignment of the HER crab cavity which is consistent with the original bump height.
  - Necessity of the additional 4mm bump is still a mystery.



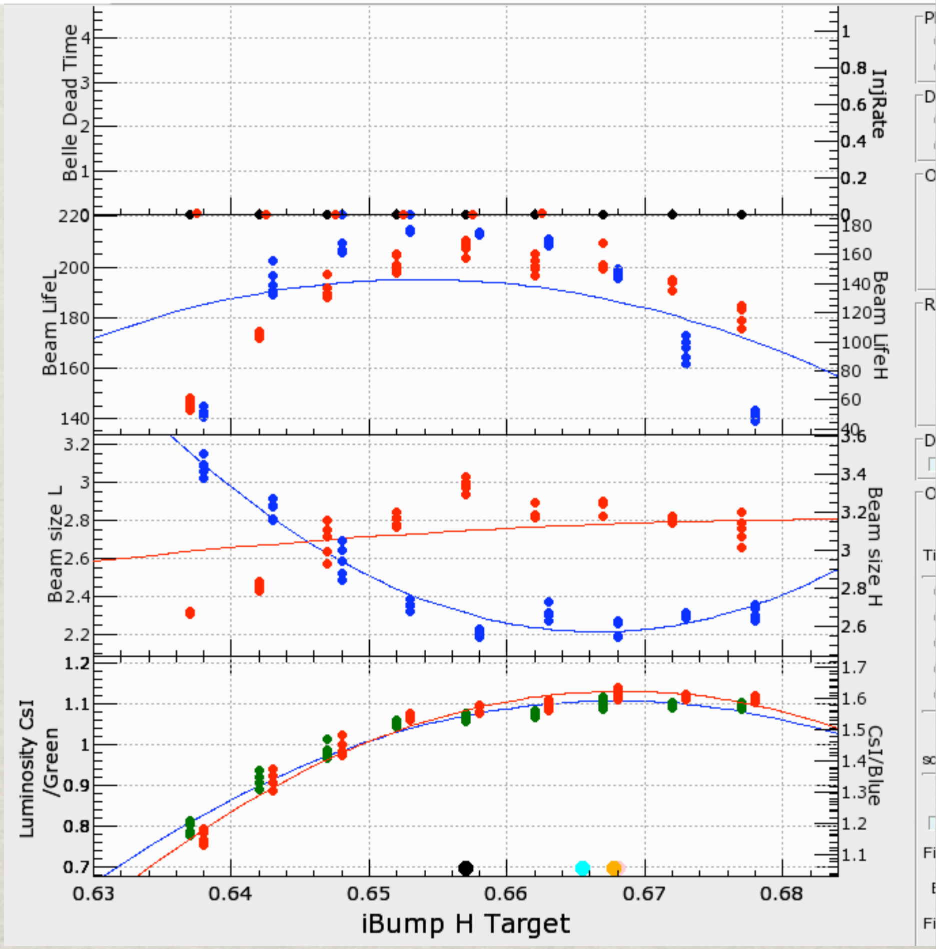


Horizontal offset target scan

$I^{+} \times I^{-} \sim 1.5 mA^2$

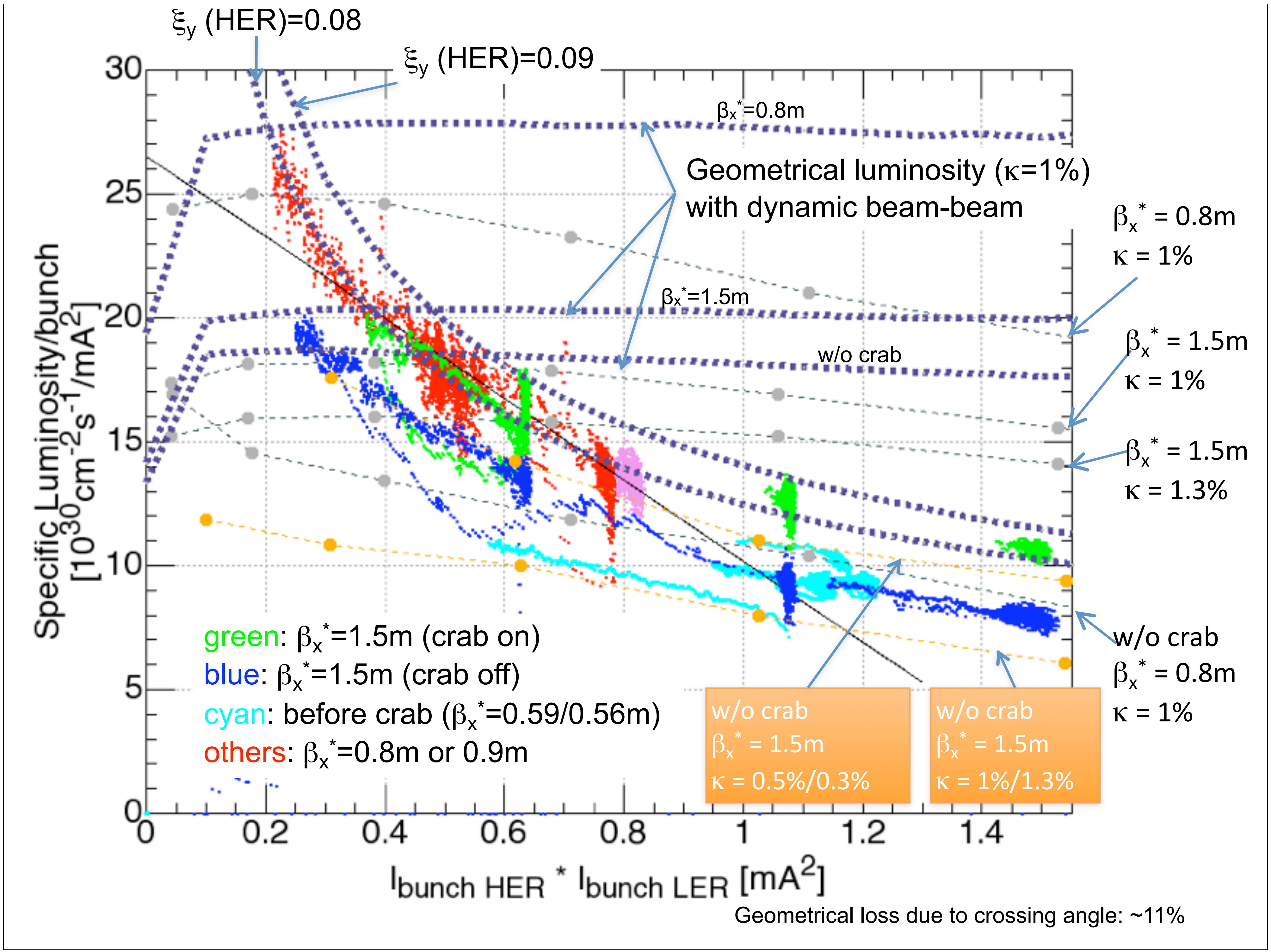


Original crab bump
Could not go to the right direction.



crab bump -5mm
in addition to original crab bump

Physical aperture around the crab is responsible to the short beam lifetime and restricted the luminosity.



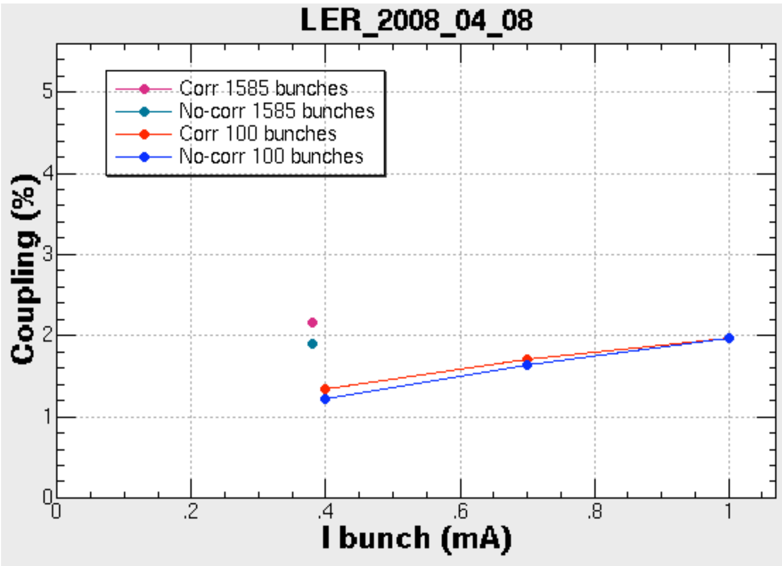
ξy (HER)=0.08
ξy (HER)=0.09
βx*=0.8m
Geometrical luminosity (κ=1%)
with dynamic beam-beam
βx* = 0.8m
κ = 1%
βx*=1.5m
βx* = 1.5m
κ = 1%
w/o crab
βx* = 1.5m
κ = 1.3%
Specific Luminosity/bunch
[10^30 cm^-2 s^-1/mA^2]
green: βx*=1.5m (crab on)
blue: βx*=1.5m (crab off)
cyan: before crab (βx*=0.59/0.56m)
others: βx*=0.8m or 0.9m
w/o crab
βx* = 1.5m
κ = 0.5%/0.3%
w/o crab
βx* = 1.5m
κ = 1%/1.3%
w/o crab
βx* = 0.8m
κ = 1%
I bunch HER * I bunch LER [mA^2]
Geometrical loss due to crossing angle: ~11%

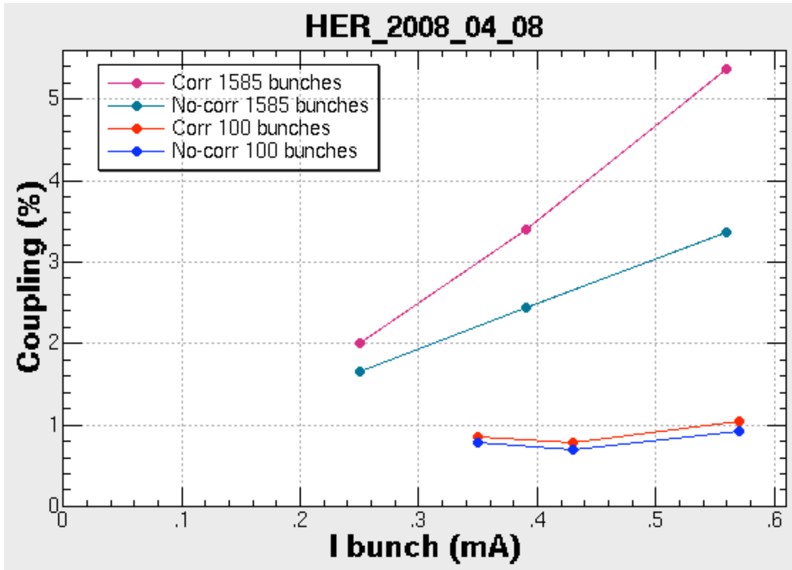
Vertical beam size issues

- Direct measurement
  - LER: κ=1.3~2.0%, HER: κ=1.0% (2008/4/8)
  - LER: κ=0.9~1.0%, HER: κ=1.3% (2008/11/28)
- The achieved luminosity with crab off is by far higher than the simulation with κ=1.0%, 1.3%(LER,HER).
  - Consistent with κ=0.5%, 0.3% (LER, HER)
- Recalculated beam sizes from the luminosity
  - ~60% of direct measurement (Y. Ohnishi)
  - Consistent with κ=<0.5%

Vertical beam size measurement (2008/4/8)

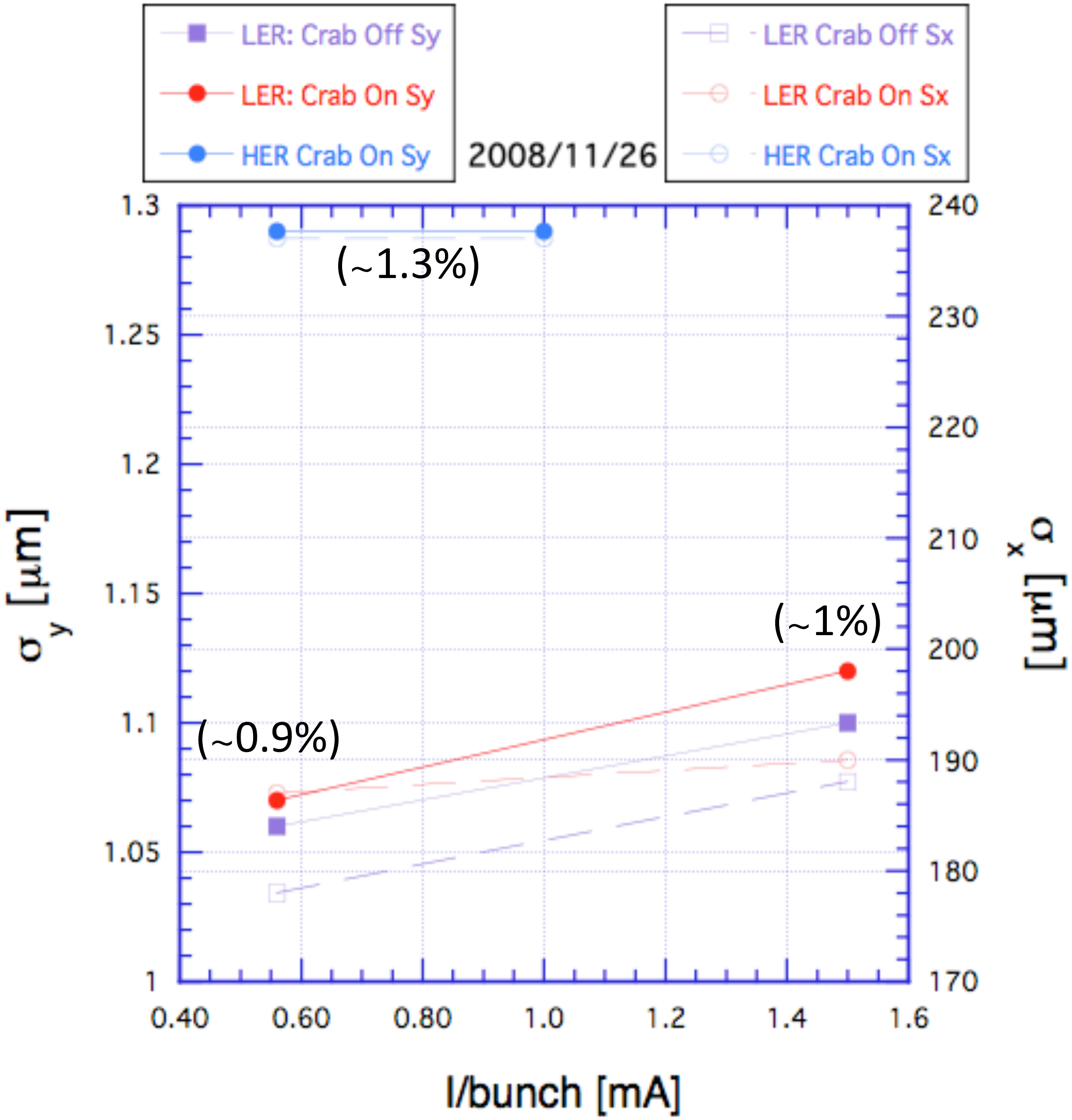
- The beam size seems to depend on the bunch current in LER.





N. Iida

Vertical beam size measurement



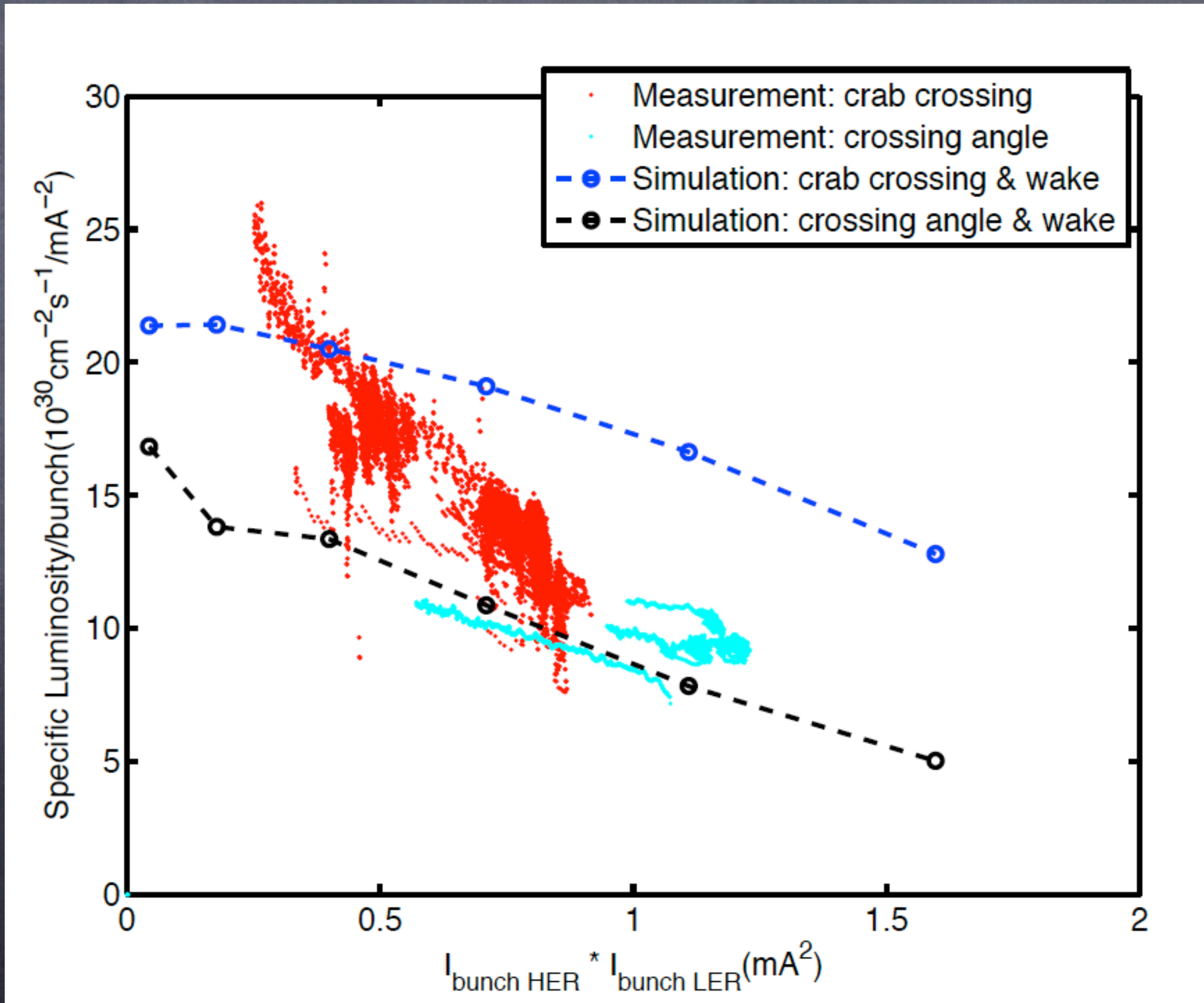
The bunch current dependence of the vertical beam size is very weak.

N. Iida

Beam-beam simulations

- Cross-check the beam-beam simulation code
  - We invited Prof. Yunhai Cai from SLAC who is the head of beam physics department.
  - He made a beam-beam simulation with a different code from Ohmi's. The result was consistent with Ohmi's.
- Y. Cai studied the wake field effect on the beam-beam performance.
  - No remarkable effects were found.
  - As a byproduct of the study, he showed a possibility that the microwave instability already occurs in the present LER.
- M. Tawada simulated the knob tuning method in the computer by using Ohmi's code. The result is very interesting.
- K. Ohmi and his student (Y. Seimiya) are studying effects of momentum dependent optics.
  - Chromaticity of R parameters at IP may induce the degradation of specific luminosity.

beam-beam simulation with wakefield (Y. Cai)



LRC Broadband Impedance Model

For q<0, wakefield is given by

$$W(q) = -w_0[\cos(Aq) + B\sin(Aq)]\exp(xq/2Q)$$

where $$A = x\sqrt{1-\frac{1}{4Q^2}}, B = \frac{1}{\sqrt{4Q^2-1}}, x = \frac{\sigma_z\omega_R}{c}$$

It's integral:

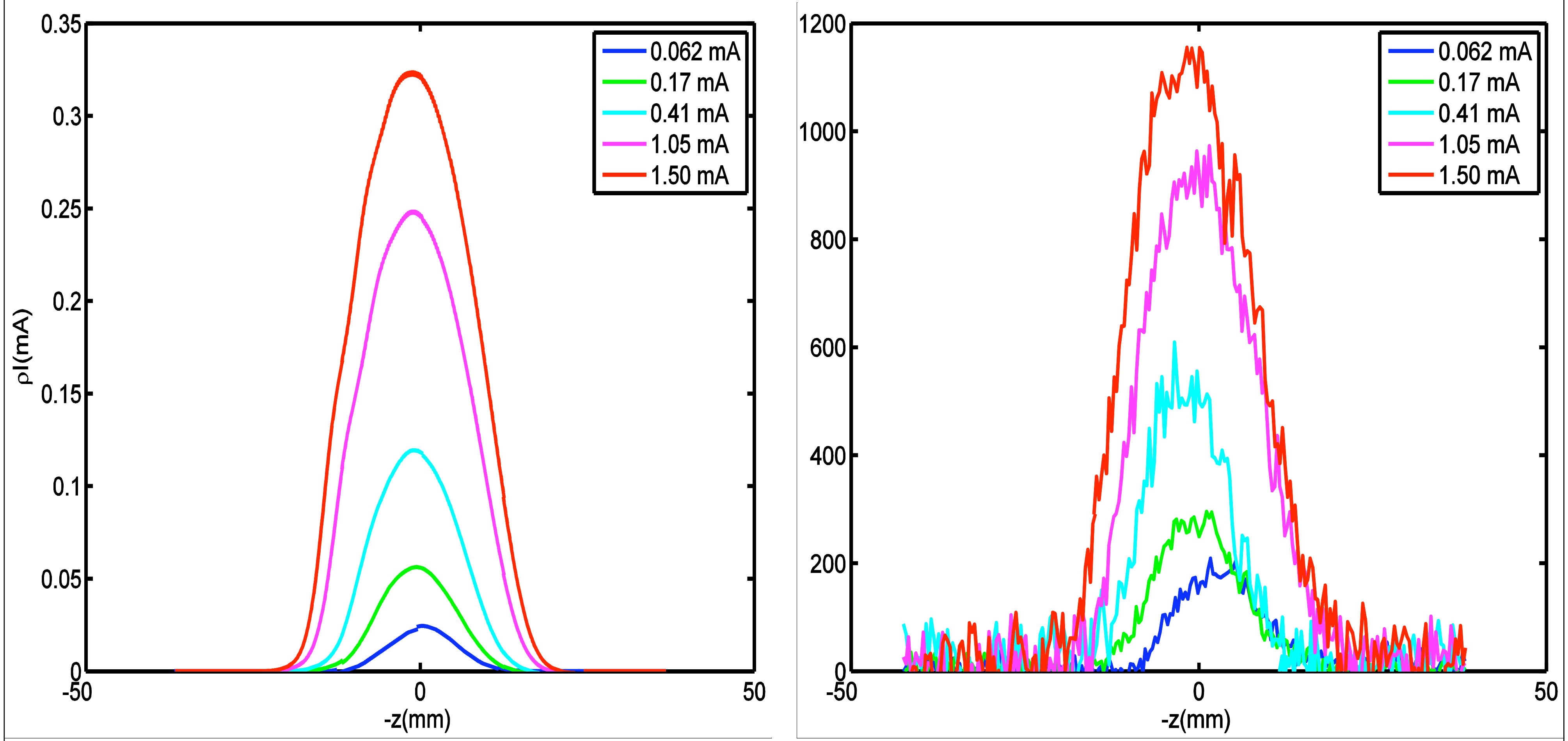
$$S(q) = \int_{-\infty}^{q} W(q')dq' = -\frac{w_0}{A}\sin(Aq)\exp(xq/2Q)$$

Conversion of LRC parameters:

$$C = \frac{1}{w_0}, L = w_0(\frac{\sigma_z}{xc})^2, R = Qw_0(\frac{\sigma_z}{xc})$$

Impedance Model and Measurement

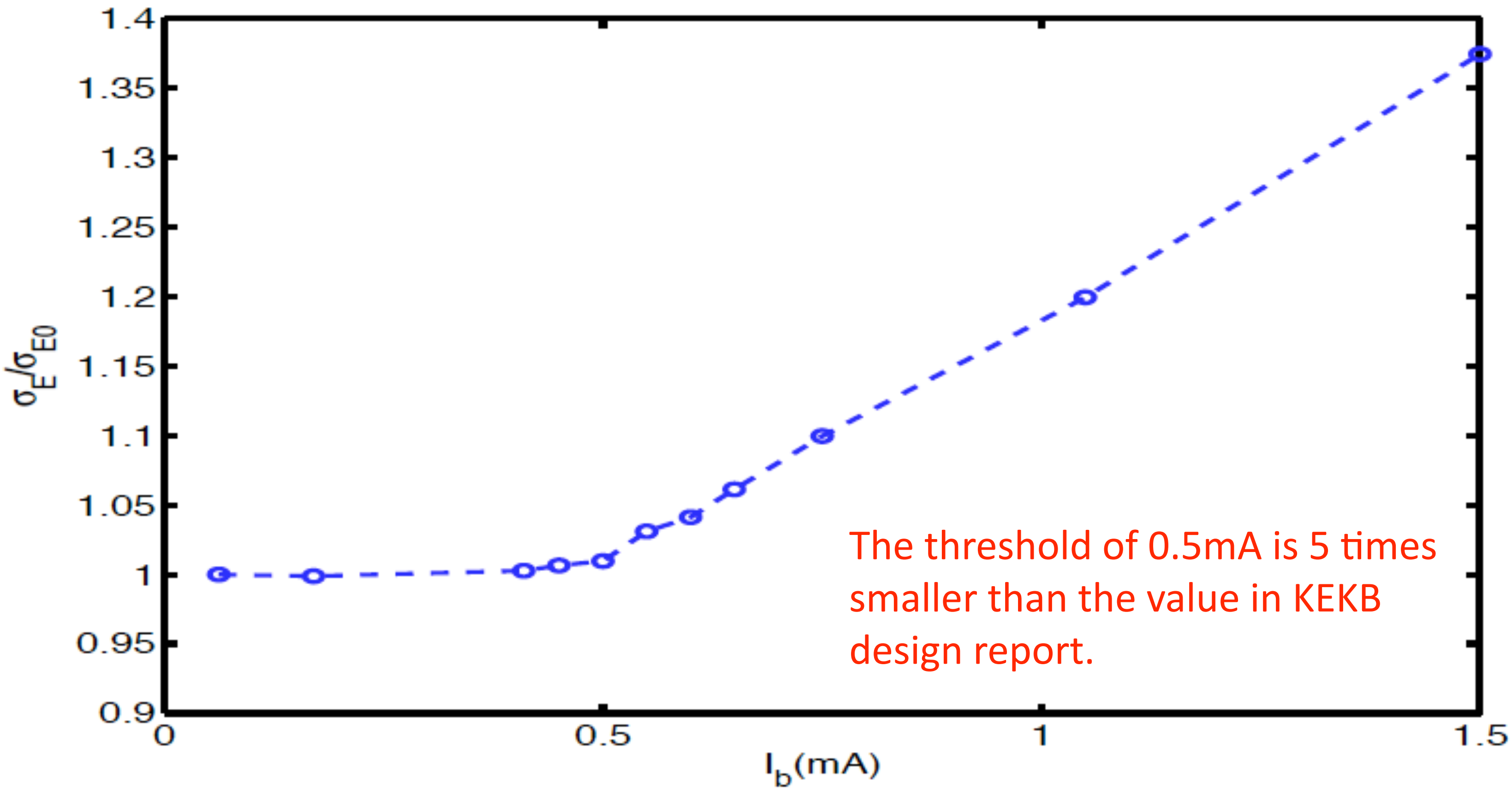
Q=1, $x(\omega_R\sigma_z/c)=3$, $w_0=5\times10^5(m^{-1})$



For the LER, we have L=116.8 nH, R=22.94 KΩ, C=22.1 fF

Yunhai Cai

Threshold of Microwave Instability in the Low Energy Ring of KEKB

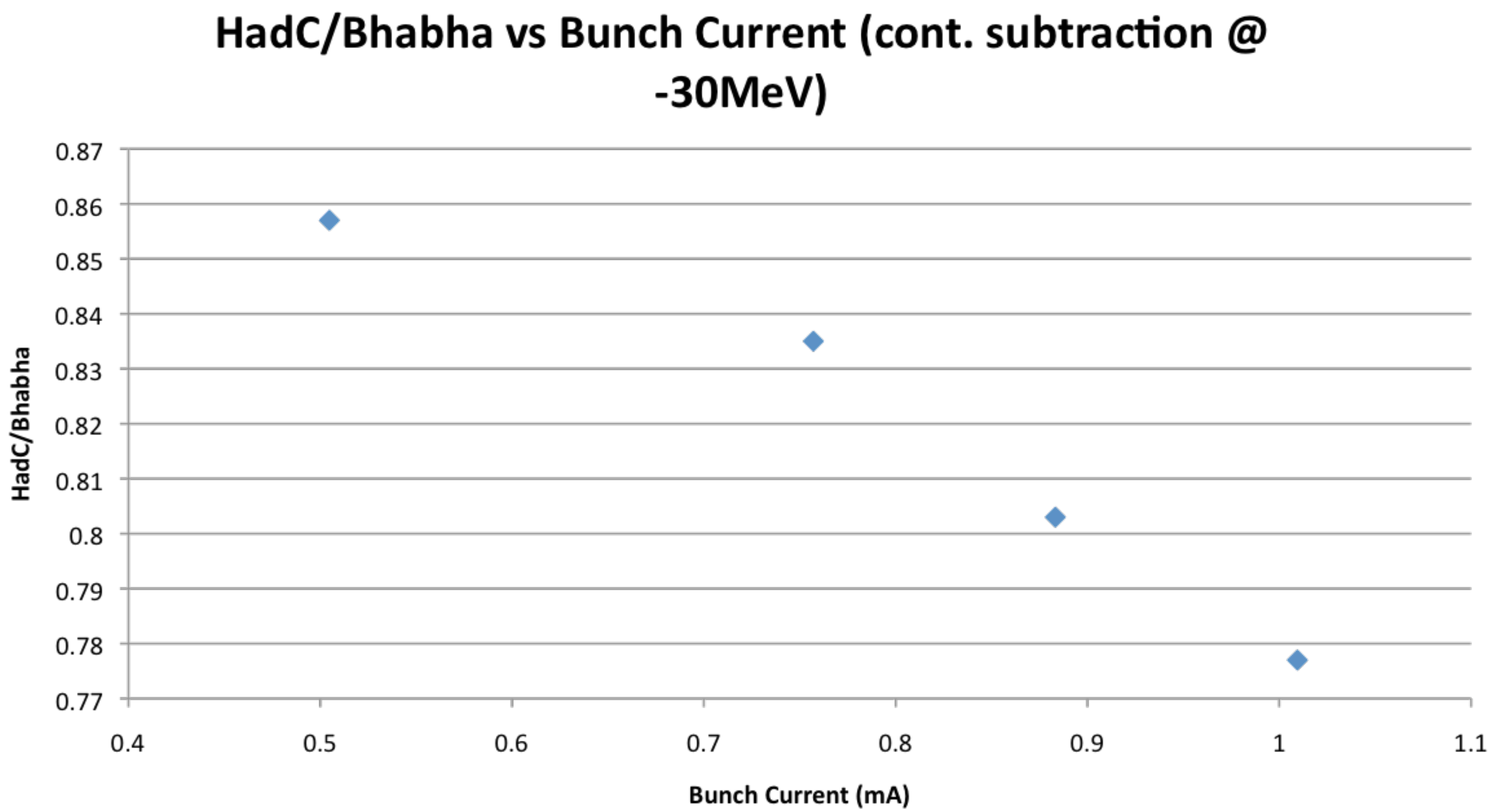


Threshold is about 0.5 mA. There is a 20% increase of energy spread at 1.0 mA.

Yunhai Cai

Y(2S) Run Summary

J. Rorie



	800mA	1600mA	
-30MeV	0.857	0.777	9.3%
+30MeV	0.810	0.739	9.8%

Beam-beam simulations to investigate effectiveness of knob tuning

- Computer simulations have been done on knob tuning (Downhill Simplex Method plus Manual Scan) by M. Tawada.
- Start with 4 or 5 units of machine errors on 12 coupling and dispersion parameters at IP, with which the luminosity was about 35% of that w/o the errors.
- With the Downhill Simplex method in the computer, the luminosity we achieved was only around 60% of that w/o the errors.
- We could not increase the luminosity with the manual scan after this.
- We tried with another set of initial errors having a similar size. But the resultant luminosity was almost the same.
- These simulations indicate a possibility that we can not reach as the high luminosity as the beam-beam simulation predicts with the usual tuning methods, if the machine errors have some sizes.

	LER (1unit)	HER (1unit)
r1 (mrad)	15.71 (3.17)	-3.16 (0.53)
r2 (mm)	-1.34 (0.22)	-1.97 (0.43)
r3 (/km)	-341 (59.38)	374 (48.72)
r4 (mrad)	-149 (25.02)	215 (36.85)
ey (mm)	-1.91 (0.36)	2.17 (0.59)
eyp (mrad)	-62.6 (18.98)	94.4 (21.65)

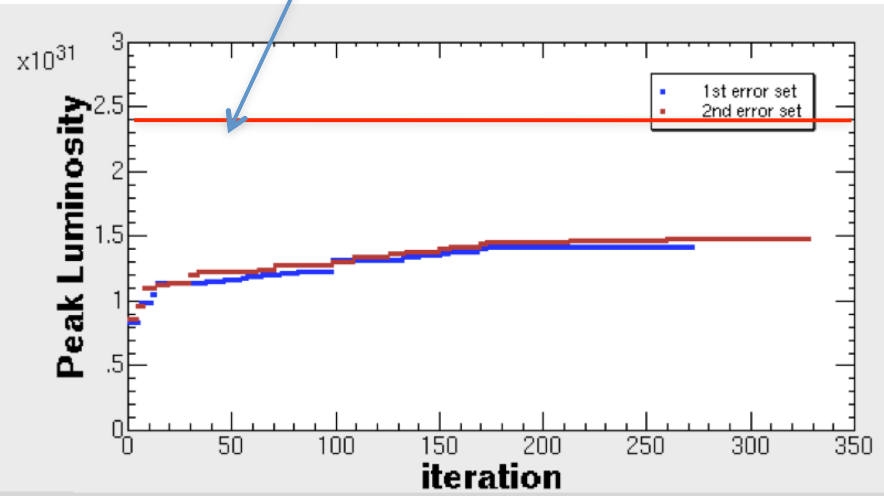
Initial errors

Downhill simplex method

	LER (1unit)	HER (1unit)
r1 (mrad)	-24.94 (3.17)	-22.377 (0.53)
r2 (mm)	-1.51 (0.22)	-1.73 (0.43)
r3 (/km)	-651 (59.38)	1176 (48.72)
r4 (mrad)	-21.3 (25.02)	-20.9 (36.85)
ey (mm)	-0.314 (0.36)	-0.114 (0.59)
eyp (mrad)	-25.3 (18.98)	-1.455 (21.65)

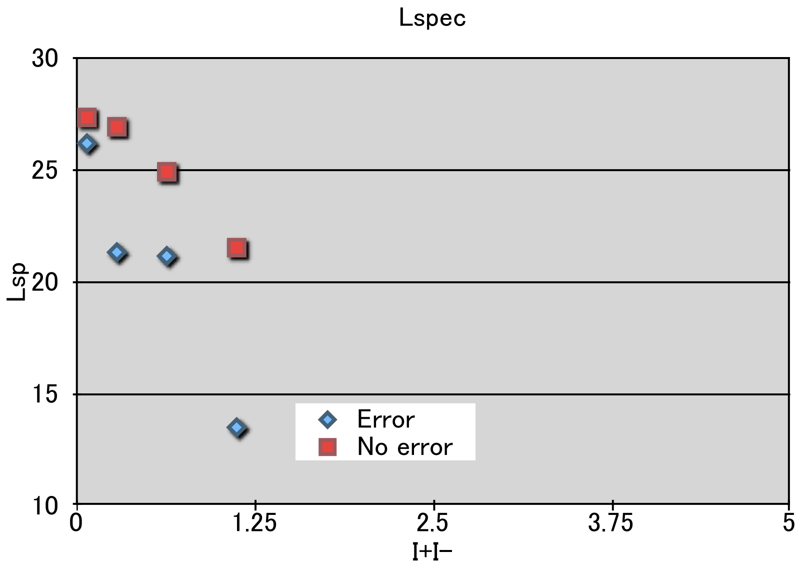
DSM fell into a local maximum.

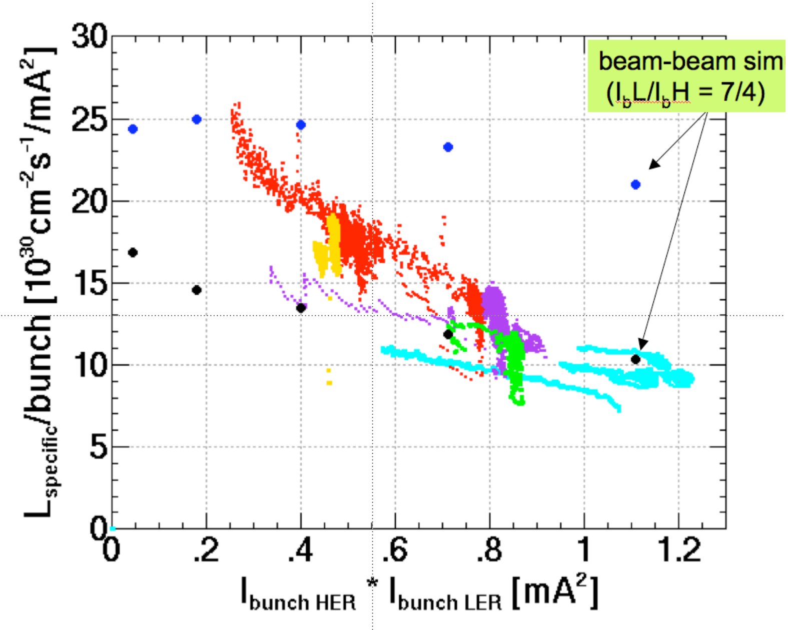
Luminosity without errors



Beam-beam simulation with the resultant errors after the tuning in the computer

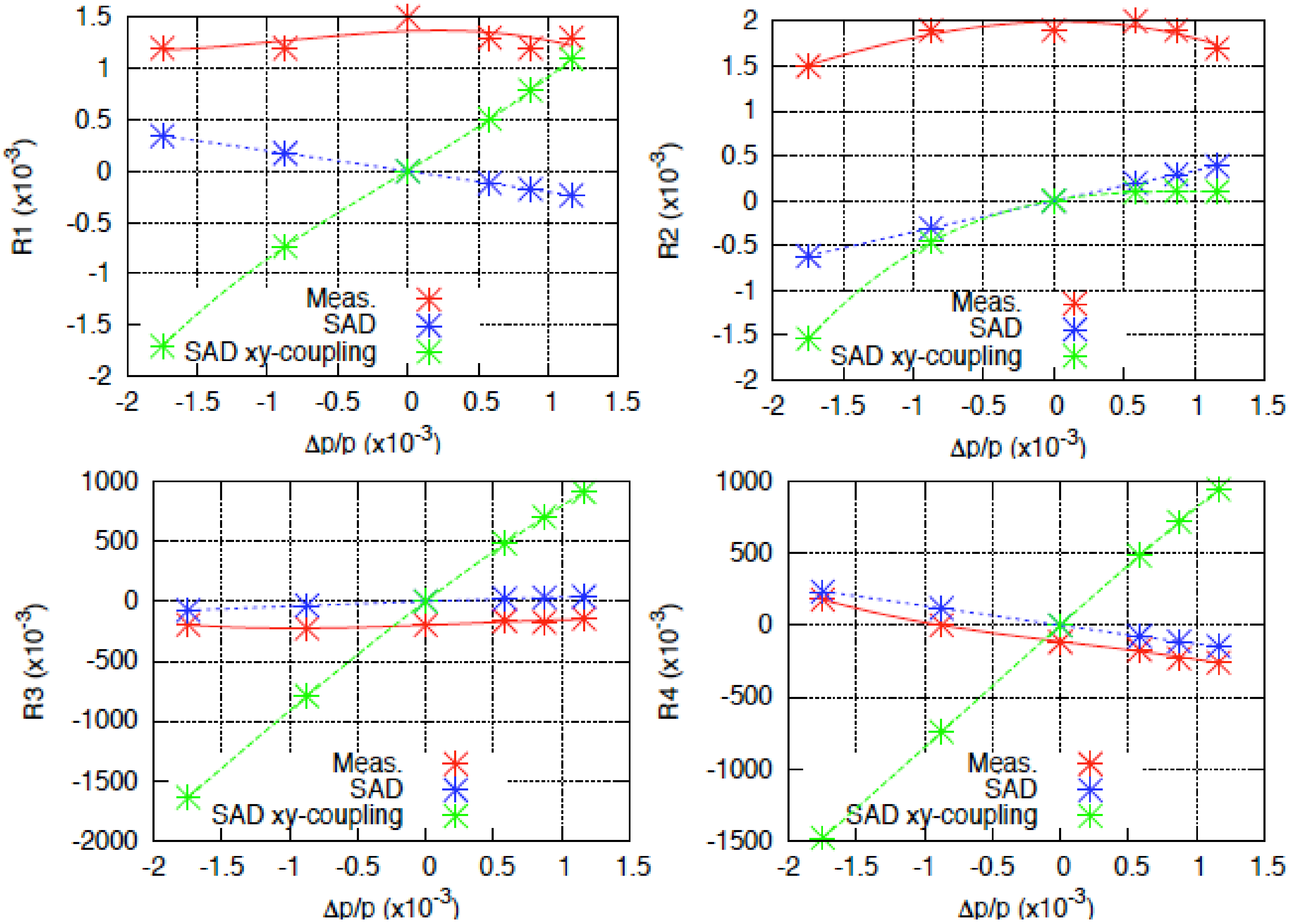
- With the errors, the steep slope of the specific luminosity is reproduced.





K. Ohmi, Y. Seimiya

How to calculate Hamiltonian



Beam size and luminosity simulation with BB

K. Ohmi, Y. Seimiya

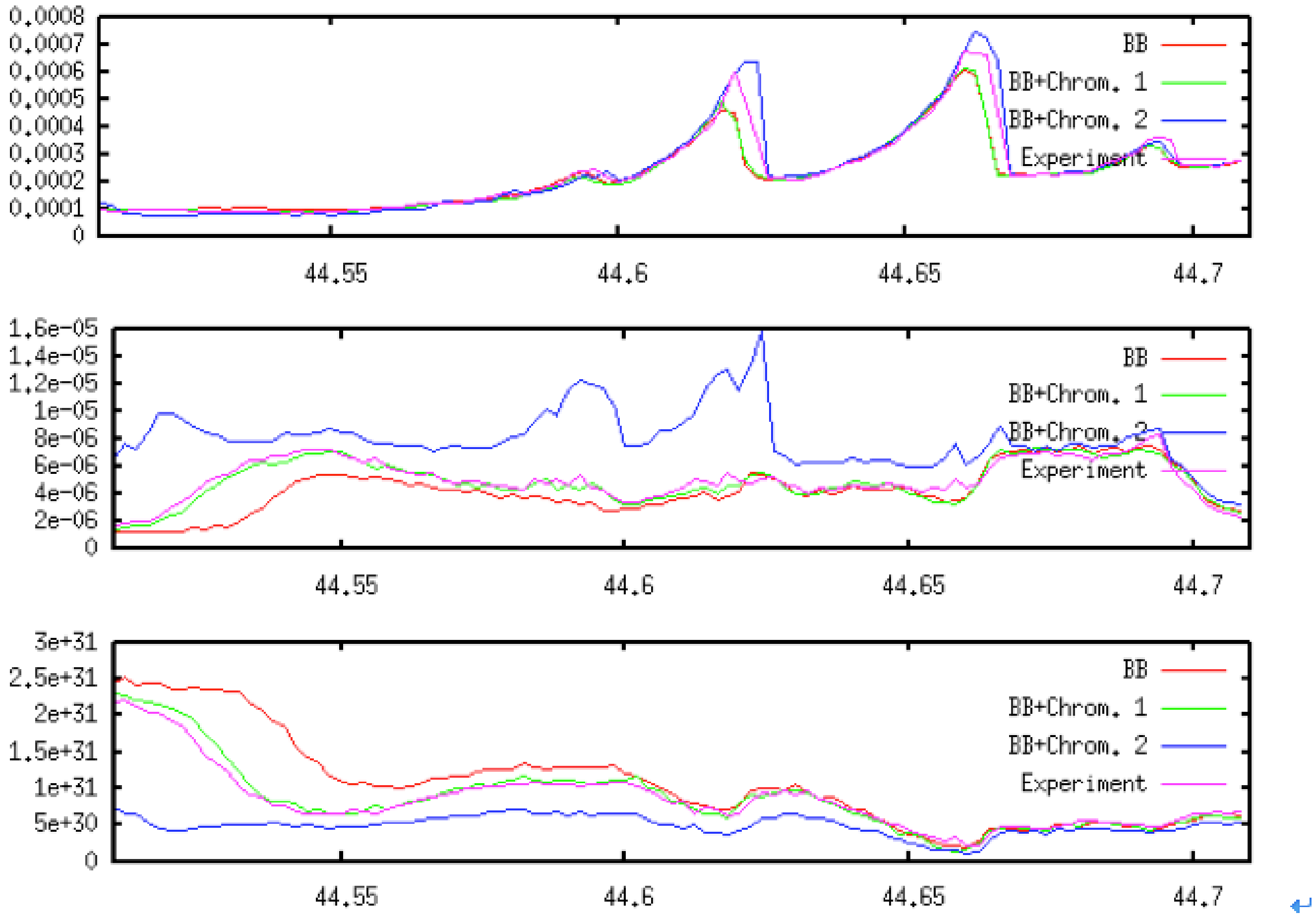
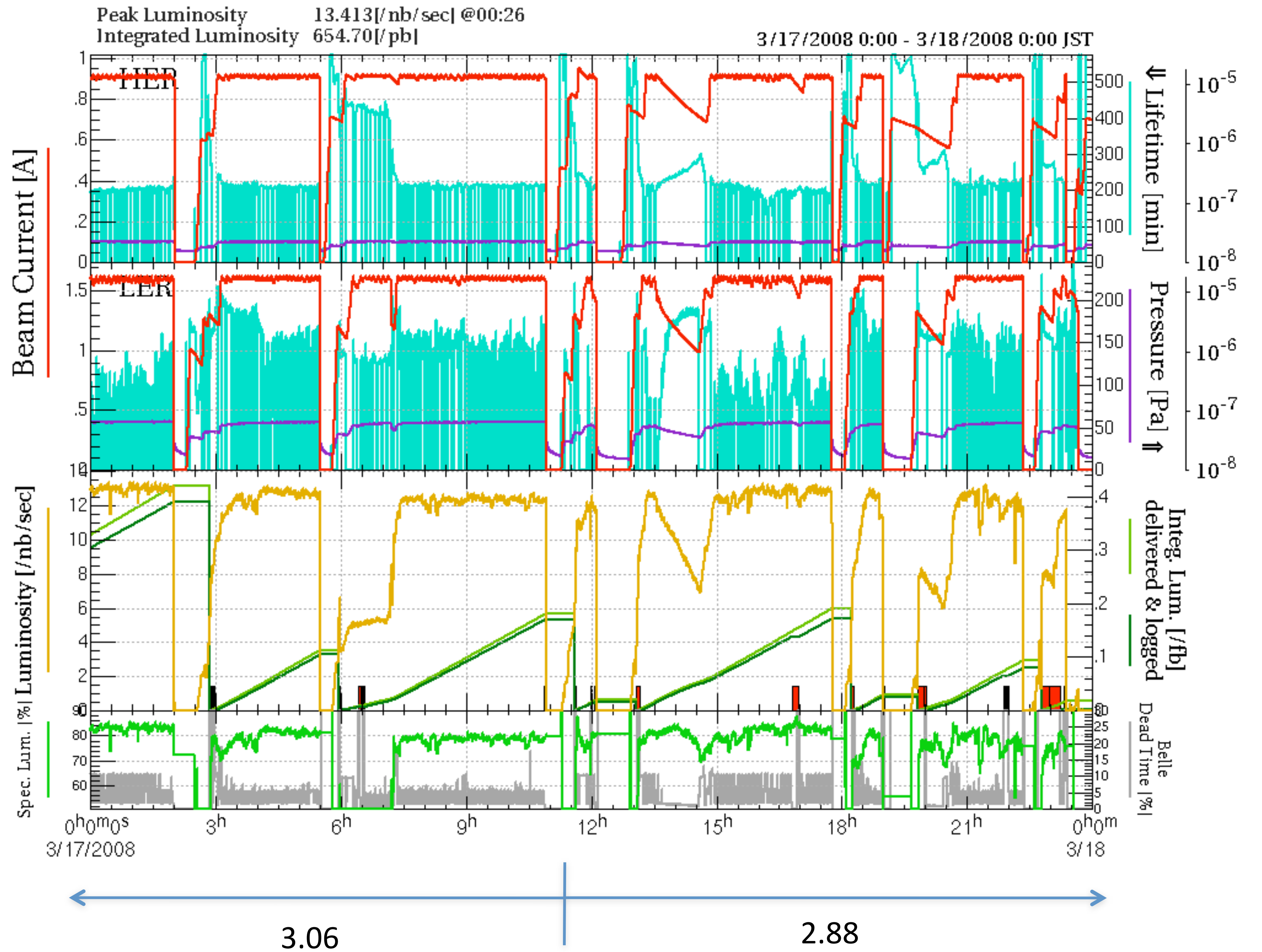


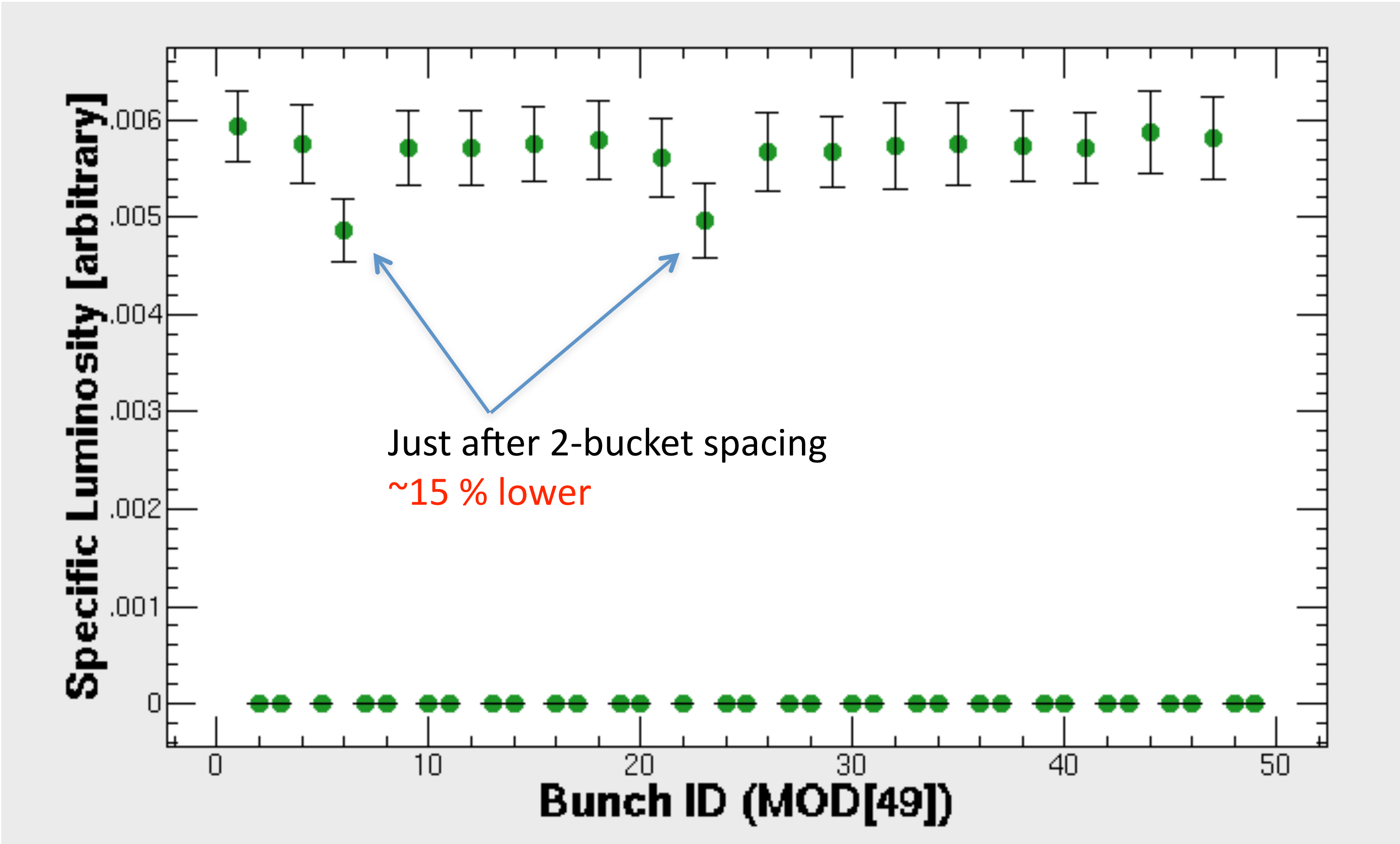
Fig. 13 Hor. Beam size (up), Vertical Beam size (middle), and Luminosity (down) at different settings of chromaticities with vertical tune Nuy=41.58 (BB: only beam-beam added, BB+Chrom. 1: 2008-10-27-sad file, BB+Chrom. 2: 2008-10-27-SAD_xy file, Experiment: measured chromaticities)

Other trials

- Horizontal emittance
  - LER 15, 18, 24 nm HER 18, 24 nm
  - The highest luminosity with crab (16.8 /nb/s) was achieved with 15nm(LER) and 24nm(HER).
- Negative α (May 2008)
  - 49 spacing
  - LER -6.7e-4, HER +3.4e-4
    - The microwave instability was successfully suppressed but the beam condition was not very stable.
  - LER 3.3e-4, HER -3.4e-4
    - We couldn't lower the horizontal tune below the SB resonance line this time.
- Fill pattern
  - Almost all cases: 3.06 spacing
  - We once tried 2.88 spacing : V size blowup just after the 2-bucket spacing in LER.


Peak Luminosity 13.413[/nb/sec] @00:26
Integrated Luminosity 654.70[/pb]
3/17/2008 0:00 - 3/18/2008 0:00 JST
HER
LER
Beam Current [A]
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
0h0m0s 3/17/2008
3h
6h
9h
12h
15h
18h
21h
0h0m 3/18
3.06
2.88

2.88 spacing specific luminosity



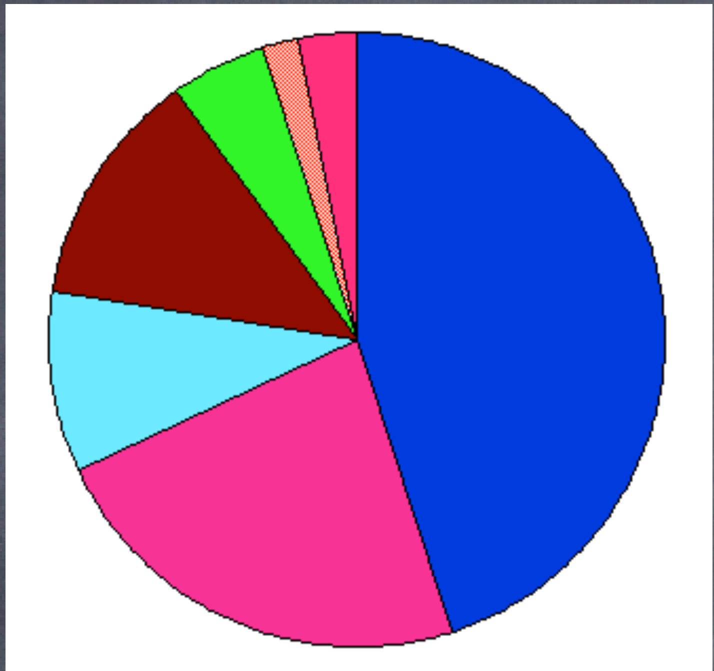
2008/3/21

Other resonances

	Υ(1S)	Υ(2S)	Υ(4S)	Υ(5S)
Mass [GeV]	9.4603	10.0233	10.5794	10.865
Radiation damping rate (relative)	0.715	0.850	1	1.083
Achieved specifc luminosity	~70%	~80%	~105%	~105%

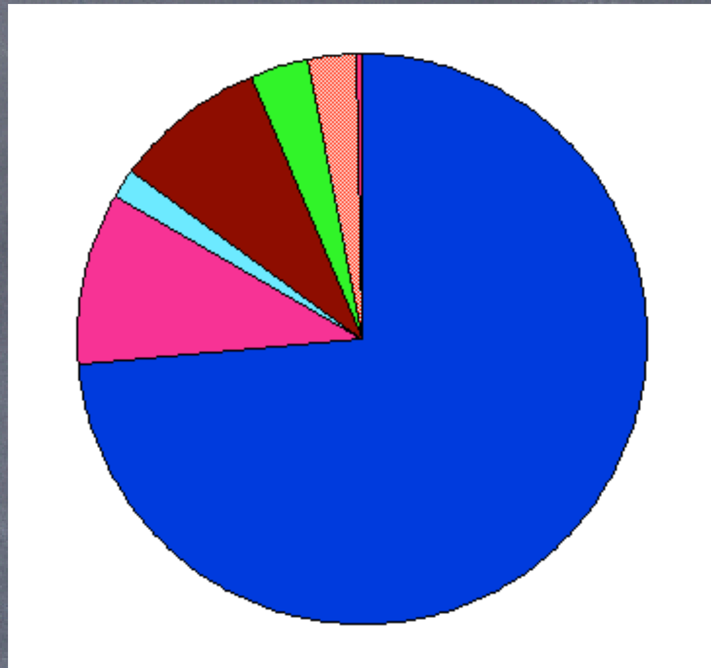
- Difference in damping rate is not nought to explain difference in luminosity (K. Ohmi)
- Residual x-y coupling at IP in the optics model is not zero at the energy other than Υ(4S) (A. Morita)

Operation statistics



- Physics Run (45.1%)
- Machine Study (22.9%)
- Machine Tuning (9.7%)
- Beam Tuning (12.3%)
- Troubles (4.9%)
- Maintenance (2.1%)
- Others (3.0%)

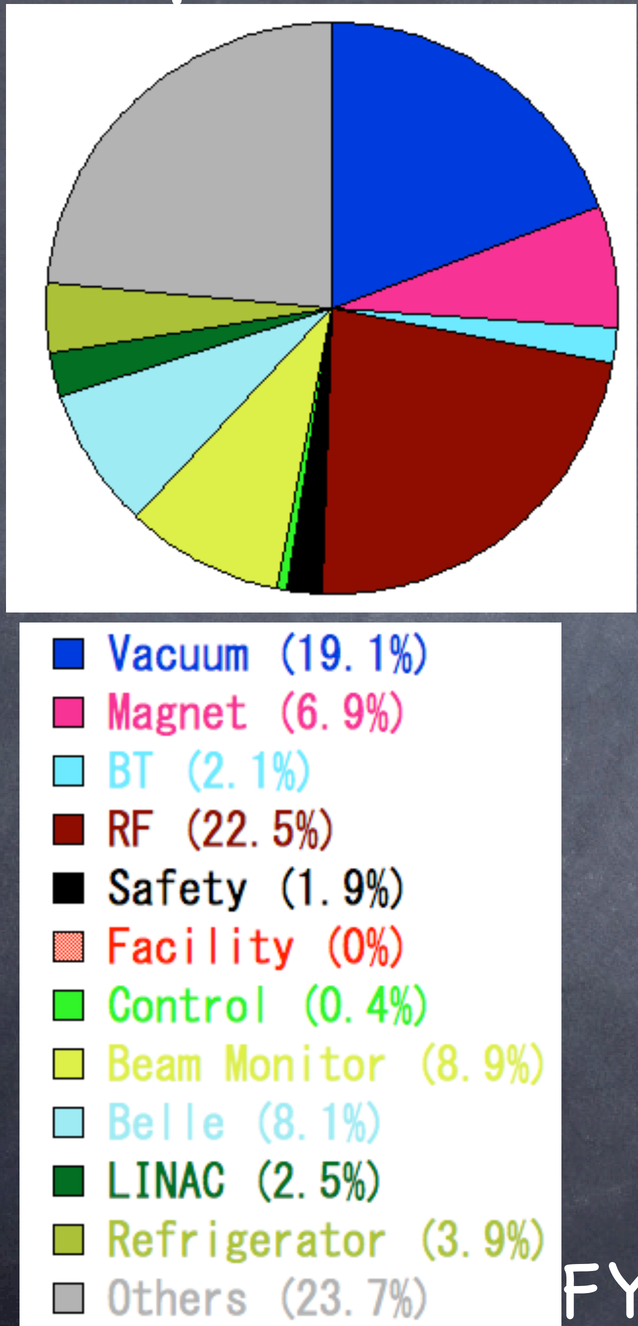
FY2007 (5256 hours)



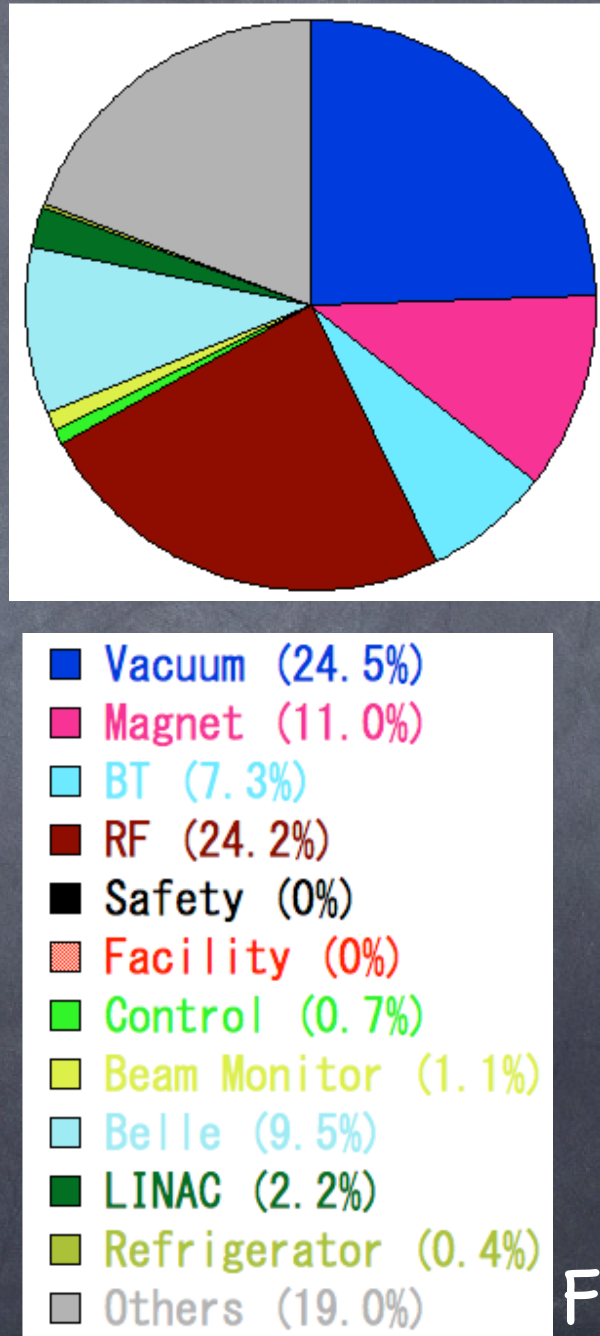
- Physics Run (73.5%)
- Machine Study (9.8%)
- Machine Tuning (1.7%)
- Beam Tuning (8.5%)
- Troubles (3.5%)
- Maintenance (2.7%)
- Others (0.3%)

FY2008 (3849 hours)

Operation statistics (troubles)

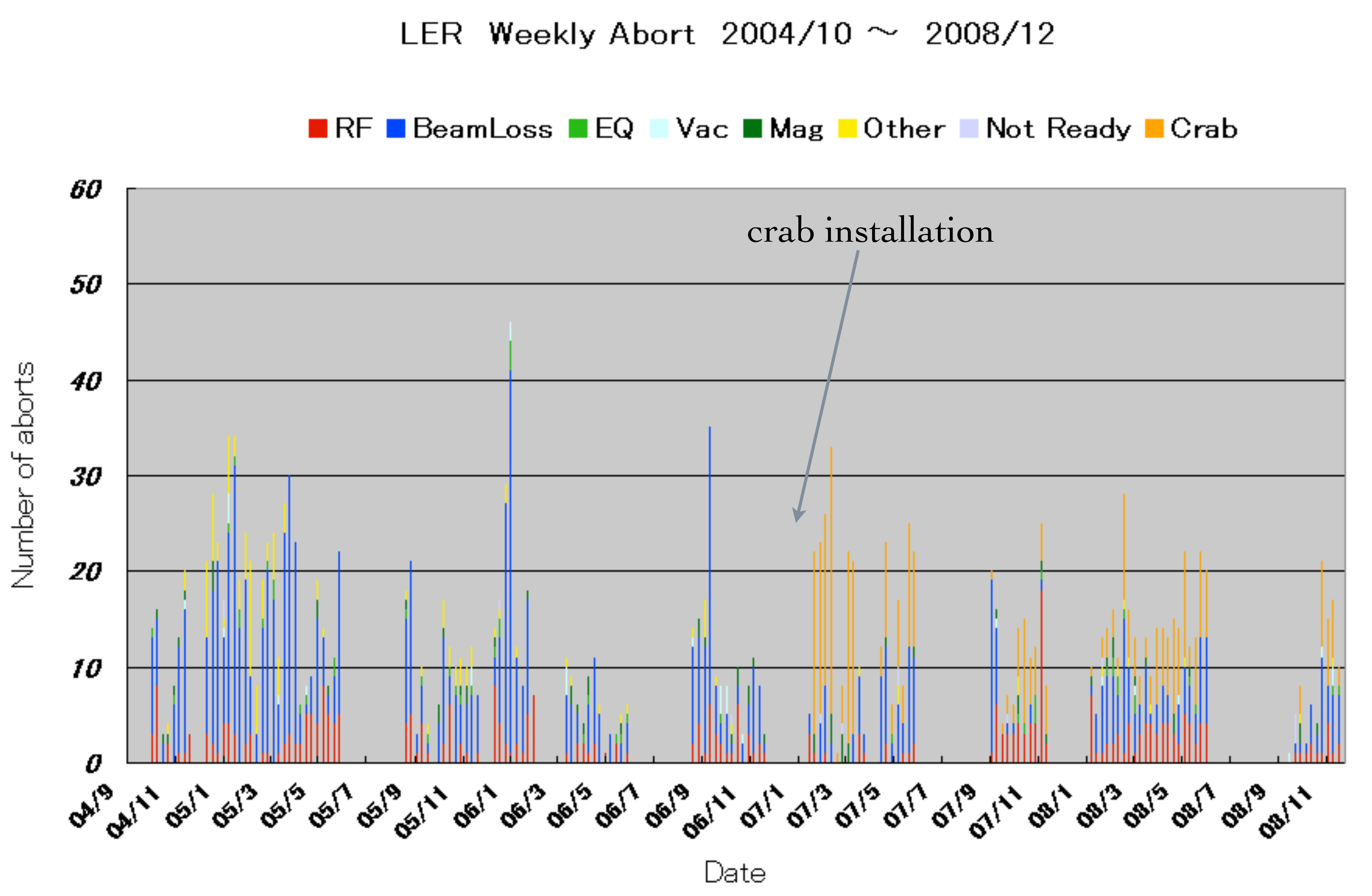


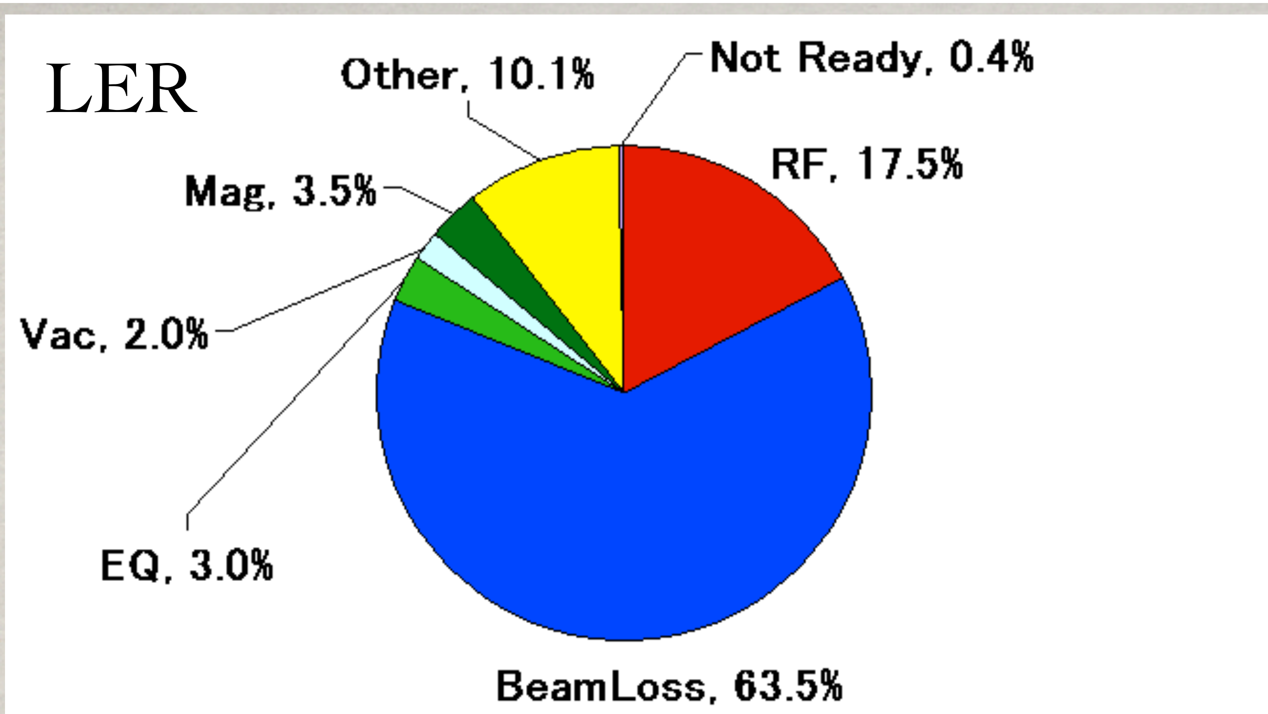
FY2007



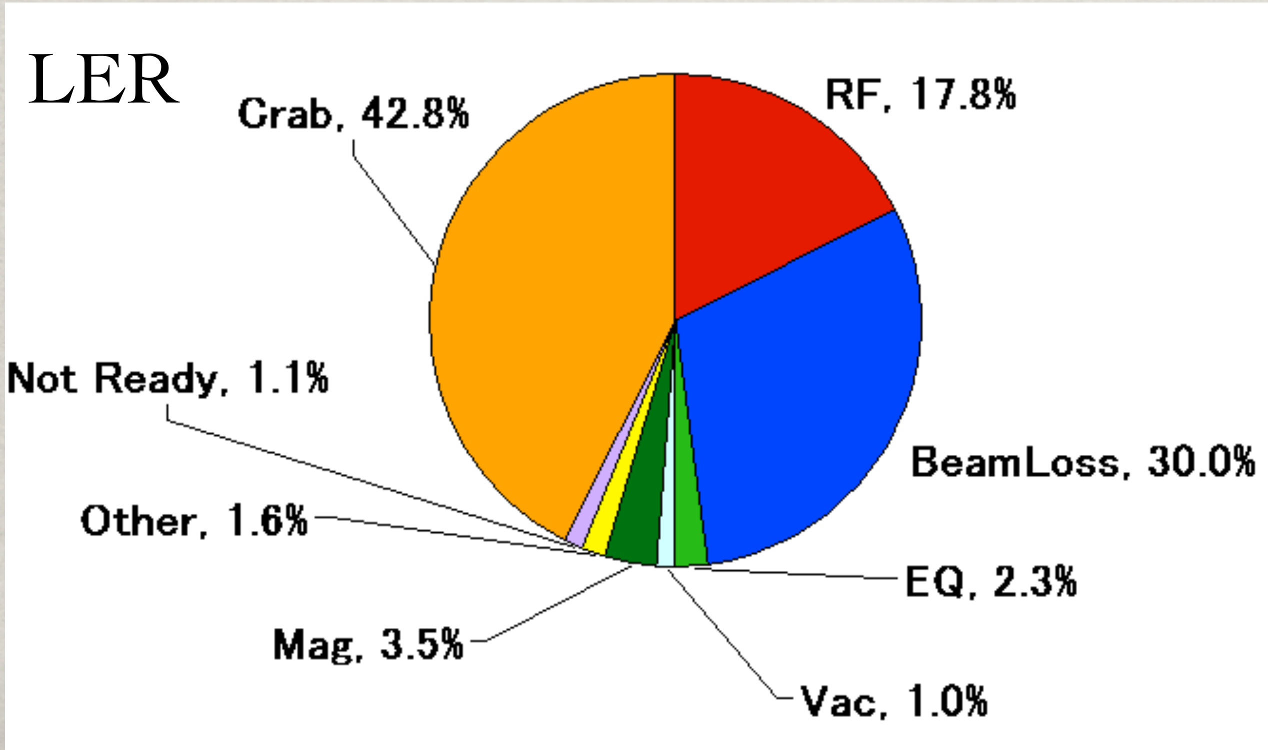
FY2008

LER weekly aborts



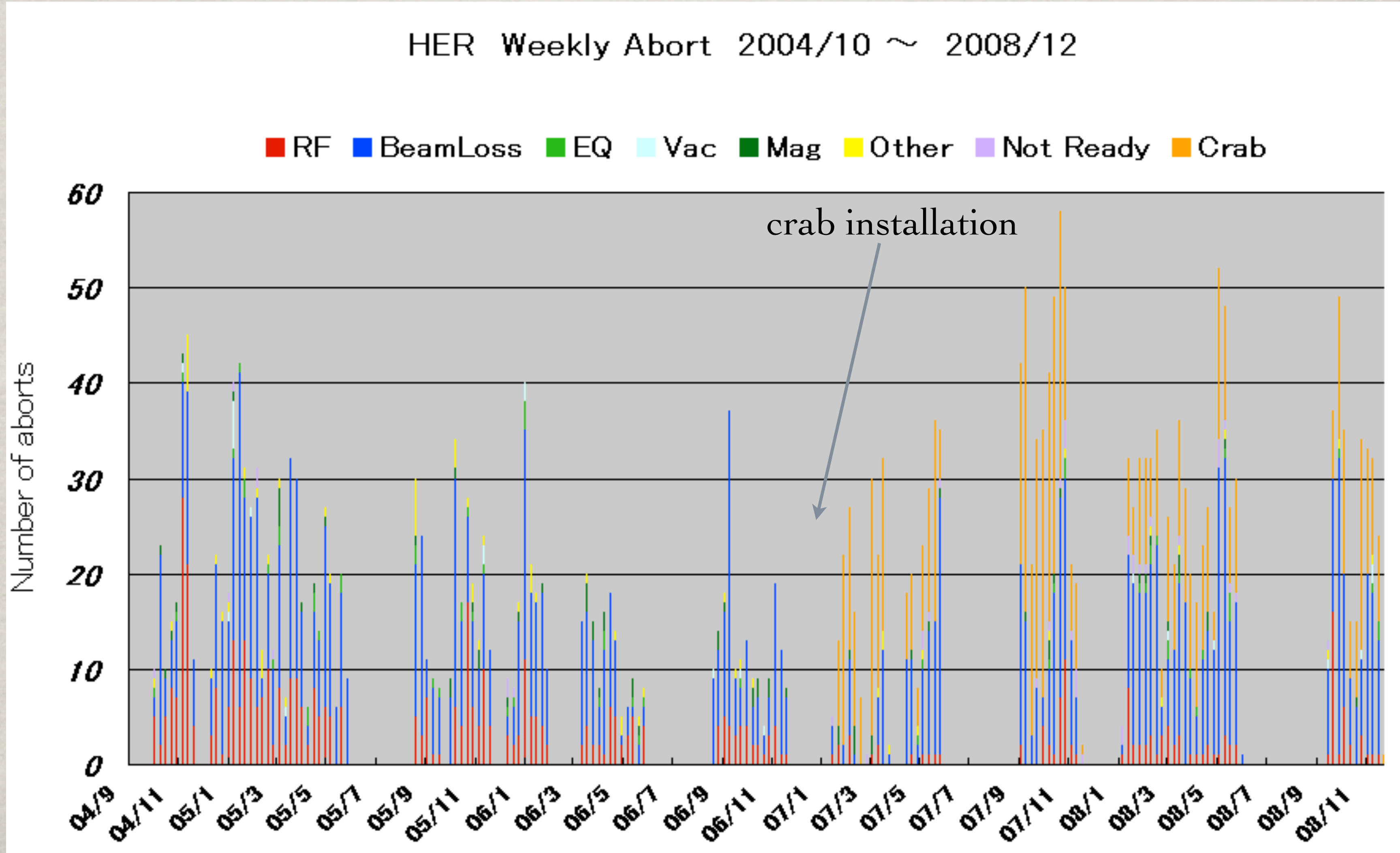


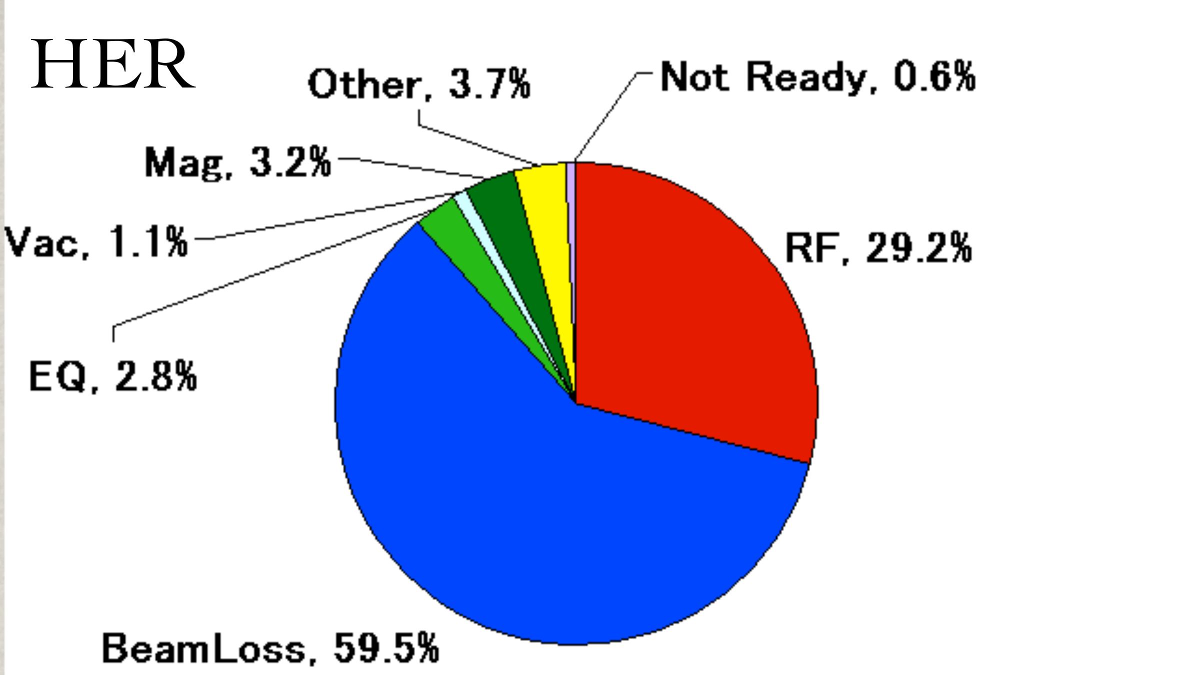
before crab



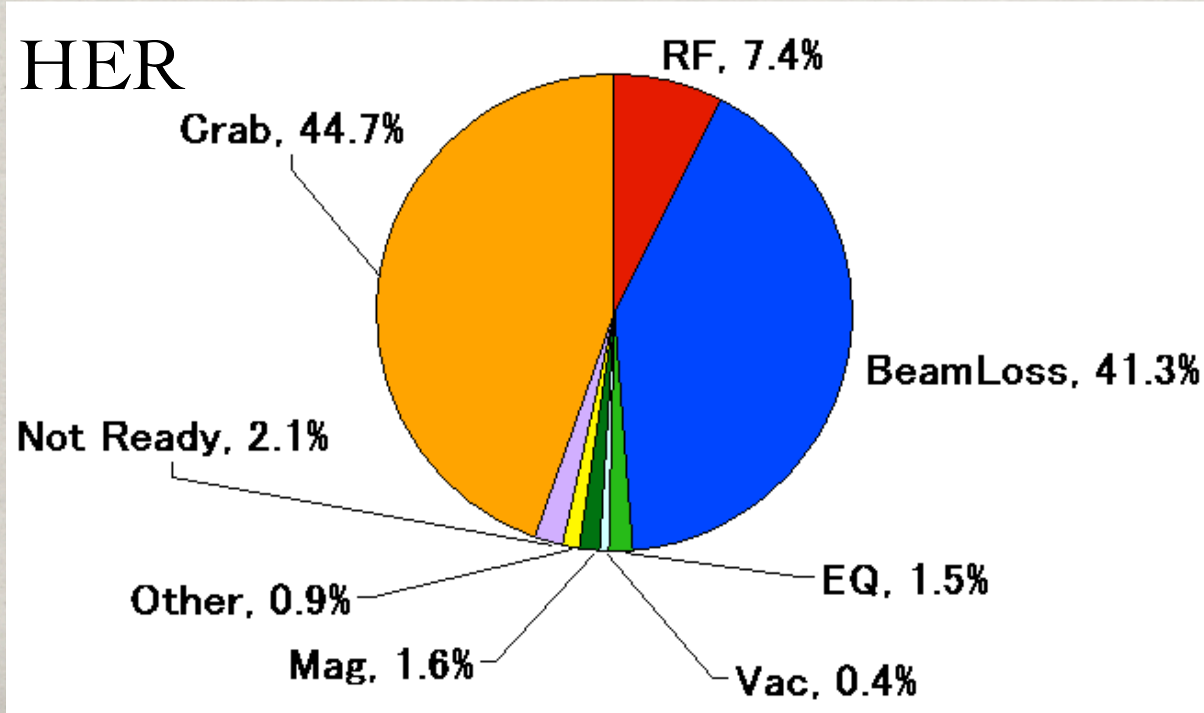
after crab

HER weekly aborts





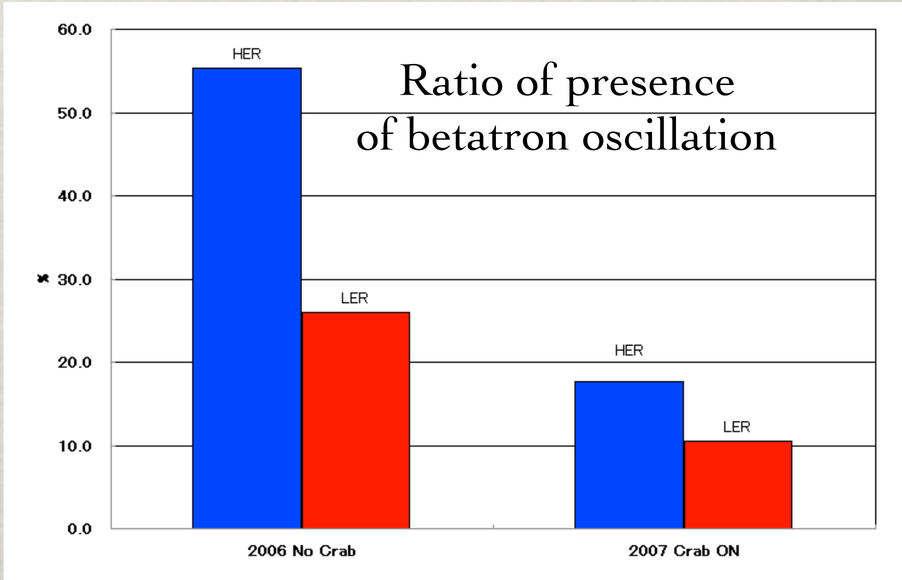
before crab



after crab

Causes of beam loss aborts

- Instability
  - coupled bunch oscillation
- Malfunction of tune control
- Vacuum trouble
  - X-aborts
- Dust trapping?



Summary

- We finally confirmed that physical aperture around crab cavities is responsible to the beam lifetime decrease at high bunch currents (LER, HER).
    - We could successfully store the design bunch currents of SuperKEKB.
- This lifetime decrease brings some loss in the luminosity. But its effect does not seem as large as initial expectations, although we need further confirmation with β_x^*=0.9m optics.
- The luminosity with crab off was unexpectedly high. The difference between crab on and off is about 20%. There is a possibility that the actual vertical beam sizes (w/o beam-beam) are much smaller than the measurements.
- If this is the case, the luminosity predicted by the simulation with crab on becomes much higher the present one.

Summary [cont'd]

- The achieved specific luminosity seems to be on the line of a constant beam-beam parameter (ξ_y (HER)) of 0.08 or 0.09.
- There is 10% ~ 20% difference in the specific luminosity between a fewer number collision (24.5 bucket spacing) and the usual multibunch collision (3.06 or 3.5 bucket spacing).
- The beam current dependence of vertical beam size in LER, which we once believed, was maybe fake by the vertical oscillation.
- Efforts to explain the steep slope of the specific luminosity by the beam-beam simulation are still going on.
- Some realistic machine errors seem to explain why we can not reach the high luminosity predicted by the beam-beam simulation.

What is the origin of steep slope of specific luminosity?

- Short beam lifetime
  - Horizontal offset at IP
- Beam current dependent emittance growth in a single beam mode?
- Machine errors
  - Usual knob tuning is not enough to compensate the machine errors?
    - Too many knobs?
  - Side effects of large knobs?
- Beam-beam simulation misses something?
  - Cross-check the beam-beam simulation code
  - Wakefield effect + beam-beam?
  - Off-momentum optics play some role to decrease the luminosity?

Remaining problems

- Method for knob search
  - Can we measure x-y coupling at IP with independent methods?
    - Artificial noise to crab? (-> Y. Morita’s talk)
  - Tuning with the simultaneous injection scheme
- Chromaticity of R parameters at IP
  - We are preparing tuning knobs for R chromaticity. (-> Koiso’s talk)
- Vertical beam size problem
  - Estimation of vertical beam size by the beam-beam scan?
- Can we get higher luminosity with a higher HER beam current (for exceeding the luminosity record before crab)?

SPARE SLIDES

2008/12/12

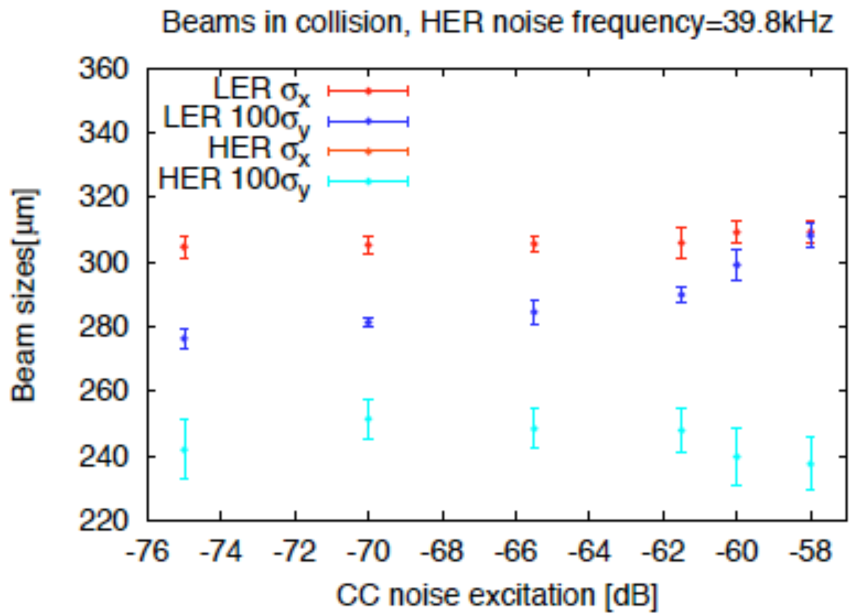
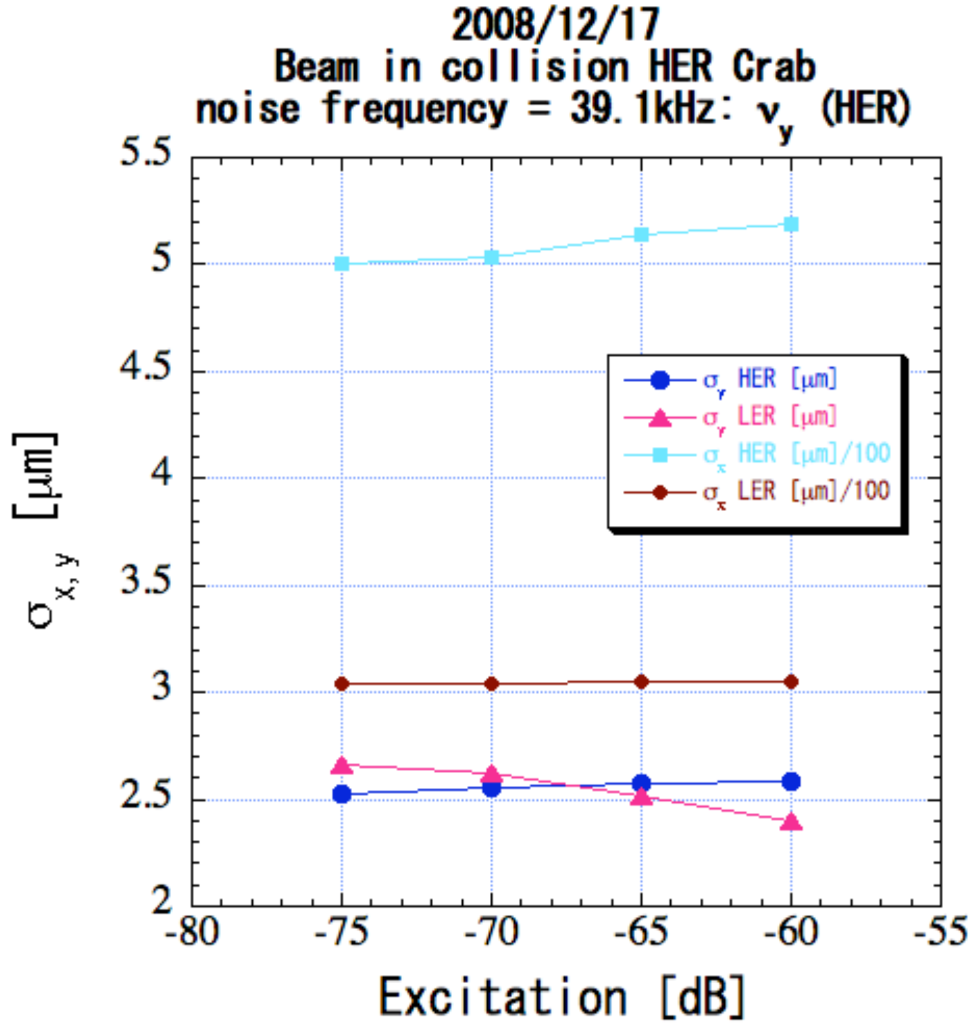
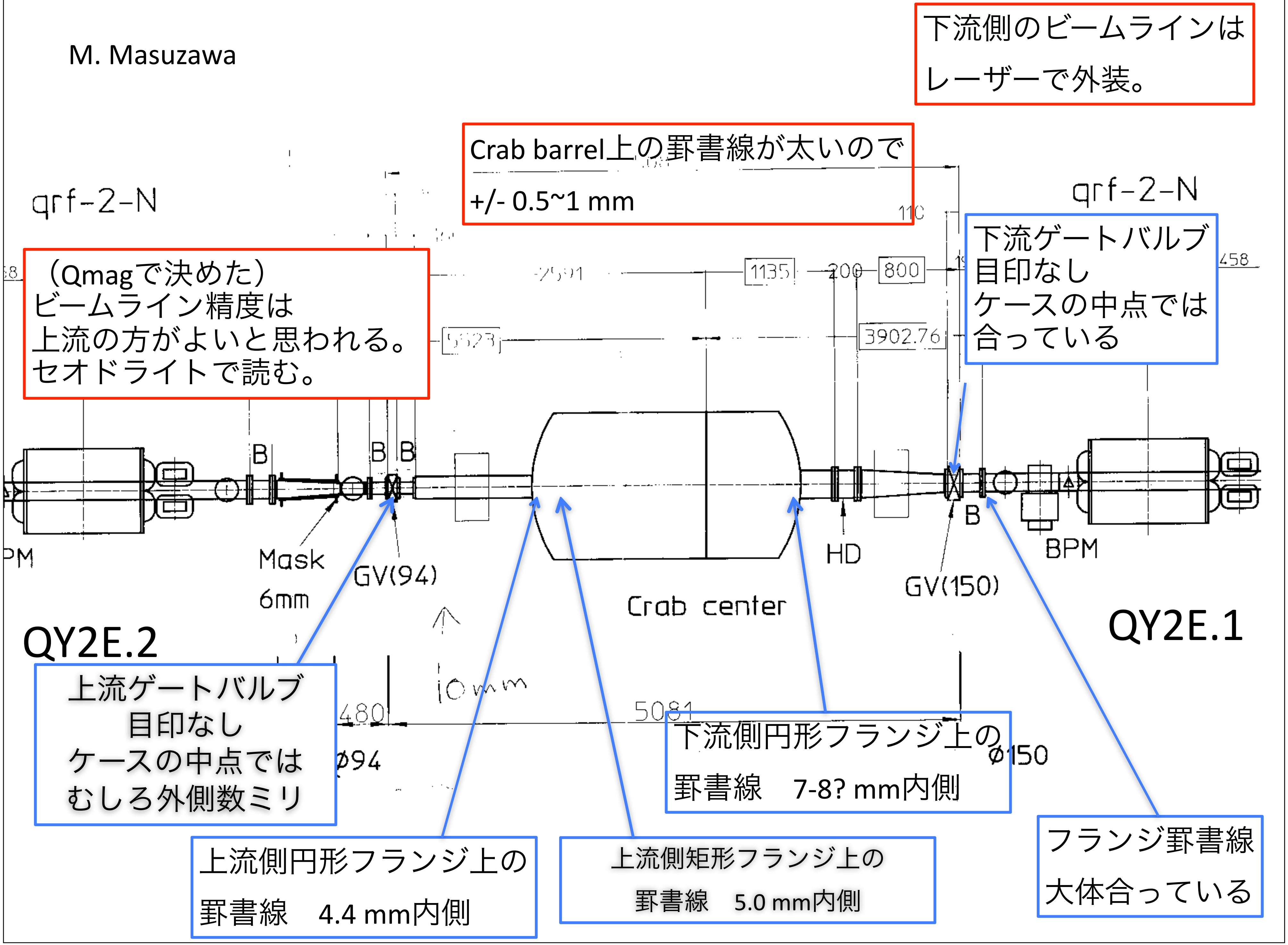
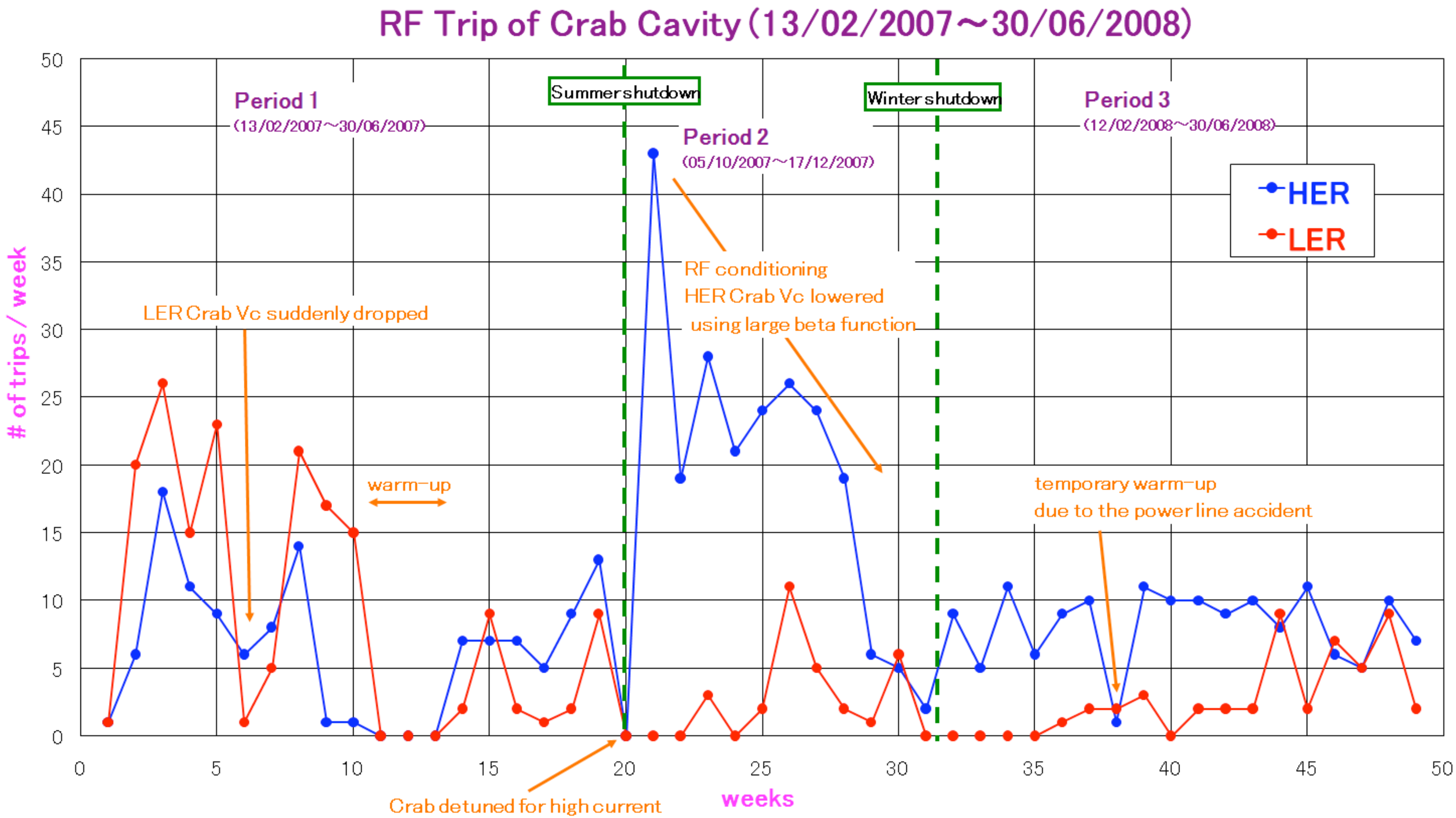


Figure 19: HER and LER IP beam sizes in collision versus HER CC noise excitation at 39



M. Masuzawa


下流側のビームラインは
レーザーで外装。
Crab barrel上の罫書線が太いので
+/- 0.5~1 mm
qrf-2-N
qrf-2-N
（Qmagで決めた）
ビームライン精度は
上流の方がよいと思われる。
セオドライトで読む。
下流ゲートバルブ
目印なし
ケースの中点では
合っている
1135
200
800
3902.76
110
458
B
B
B
B
PM
Mask
6mm
GV(94)
HD
GV(150)
BPM
Crab center
QY2E.2
QY2E.1
上流ゲートバルブ
目印なし
ケースの中点では
むしろ外側数ミリ
480
5081
ø94
ø150
10mm
下流側円形フランジ上の
罫書線 7-8? mm内側
上流側円形フランジ上の
罫書線 4.4 mm内側
上流側矩形フランジ上の
罫書線 5.0 mm内側
フランジ罫書線
大体合っている


RF Trip of Crab Cavity (13/02/2007～30/06/2008)
Period 1
(13/02/2007～30/06/2007)
Summer shutdown
Period 2
(05/10/2007～17/12/2007)
Winter shutdown
Period 3
(12/02/2008～30/06/2008)
HER
LER
LER Crab Vc suddenly dropped
RF conditioning
HER Crab Vc lowered
using large beta function
warm-up
temporary warm-up
due to the power line accident
Crab detuned for high current
# of trips / week
weeks
0
5
10
15
20
25
30
35
40
45
50

Y. Yamamoto