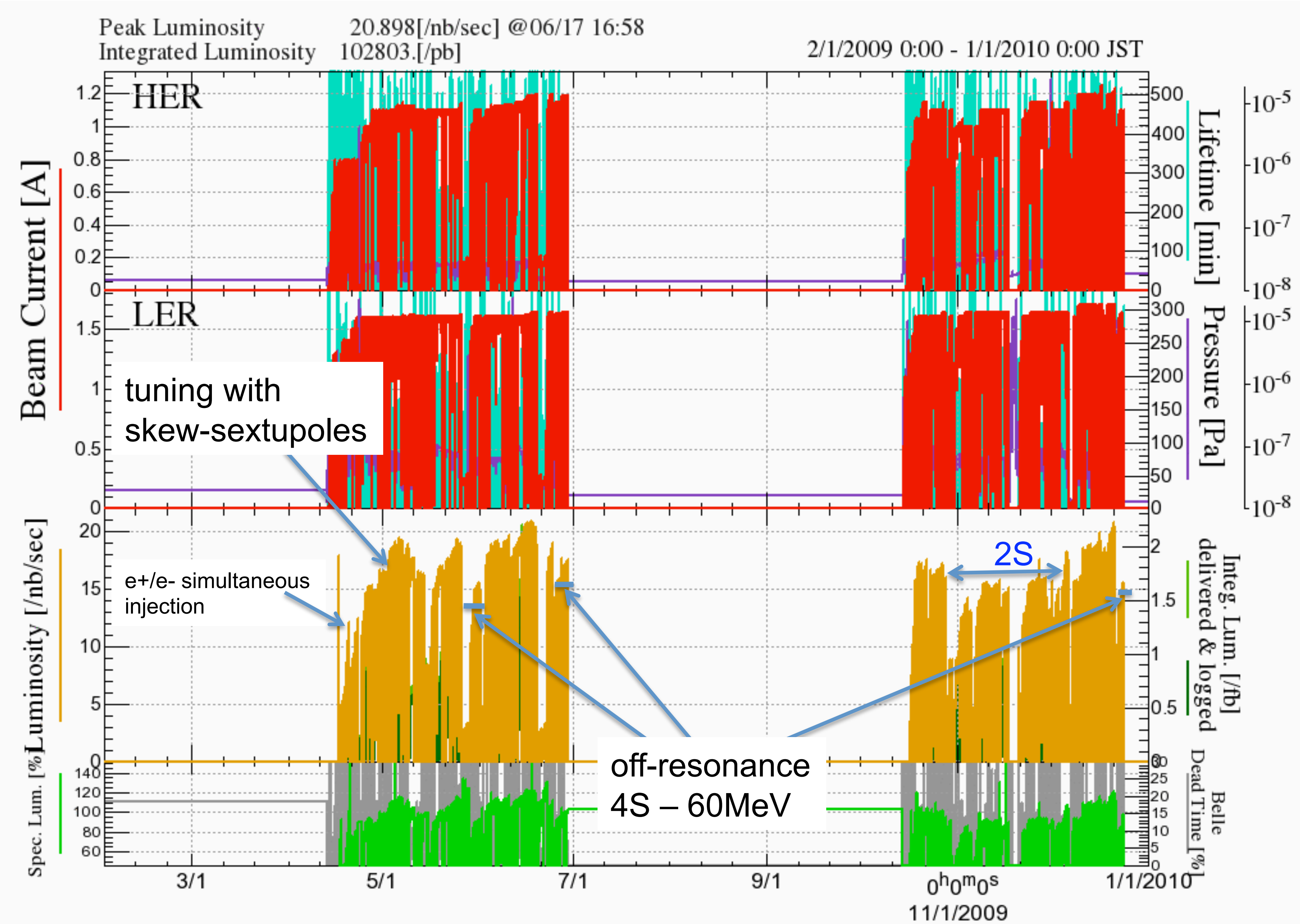
KEKB Status

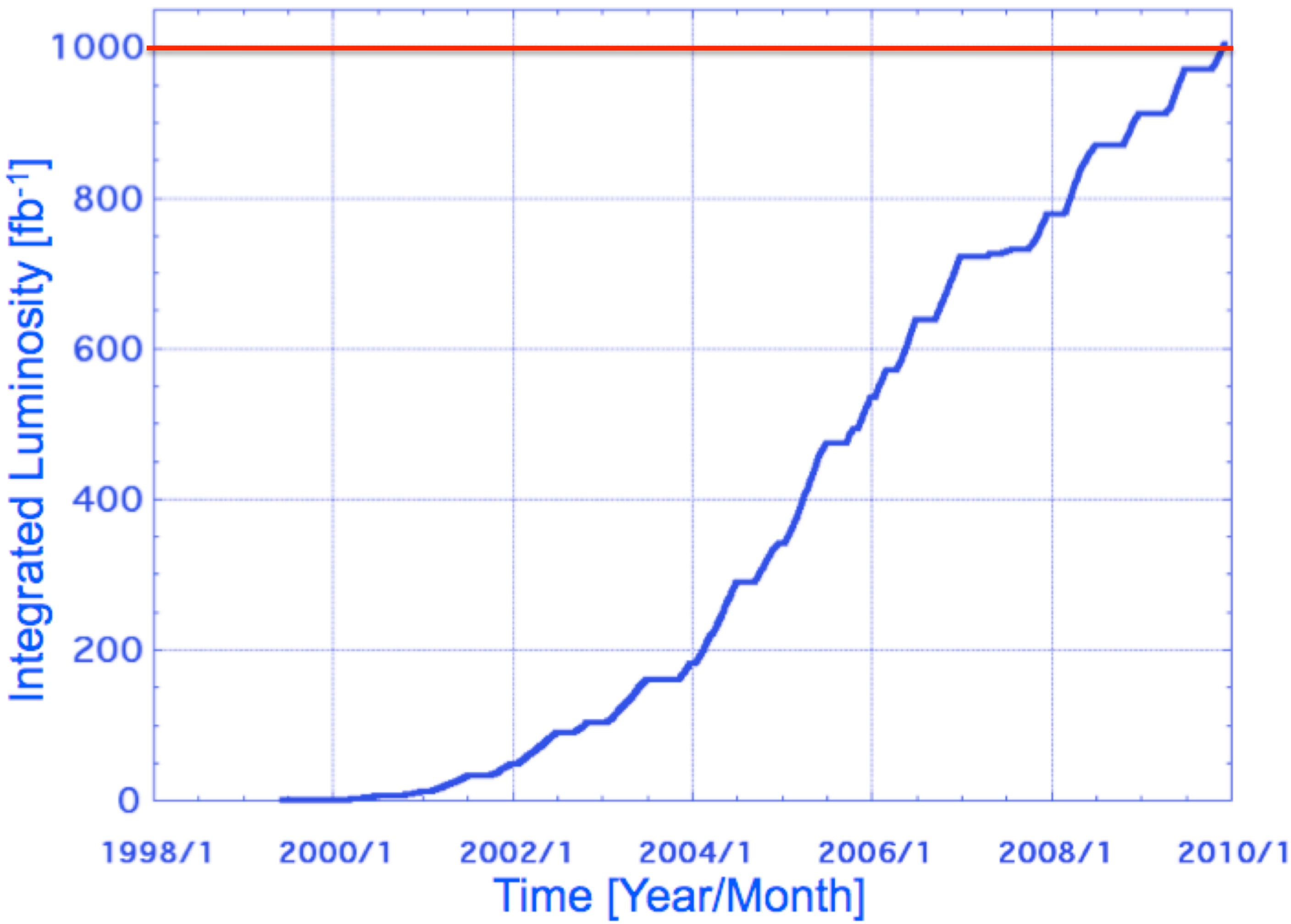
MAC 2010 Feb. 15

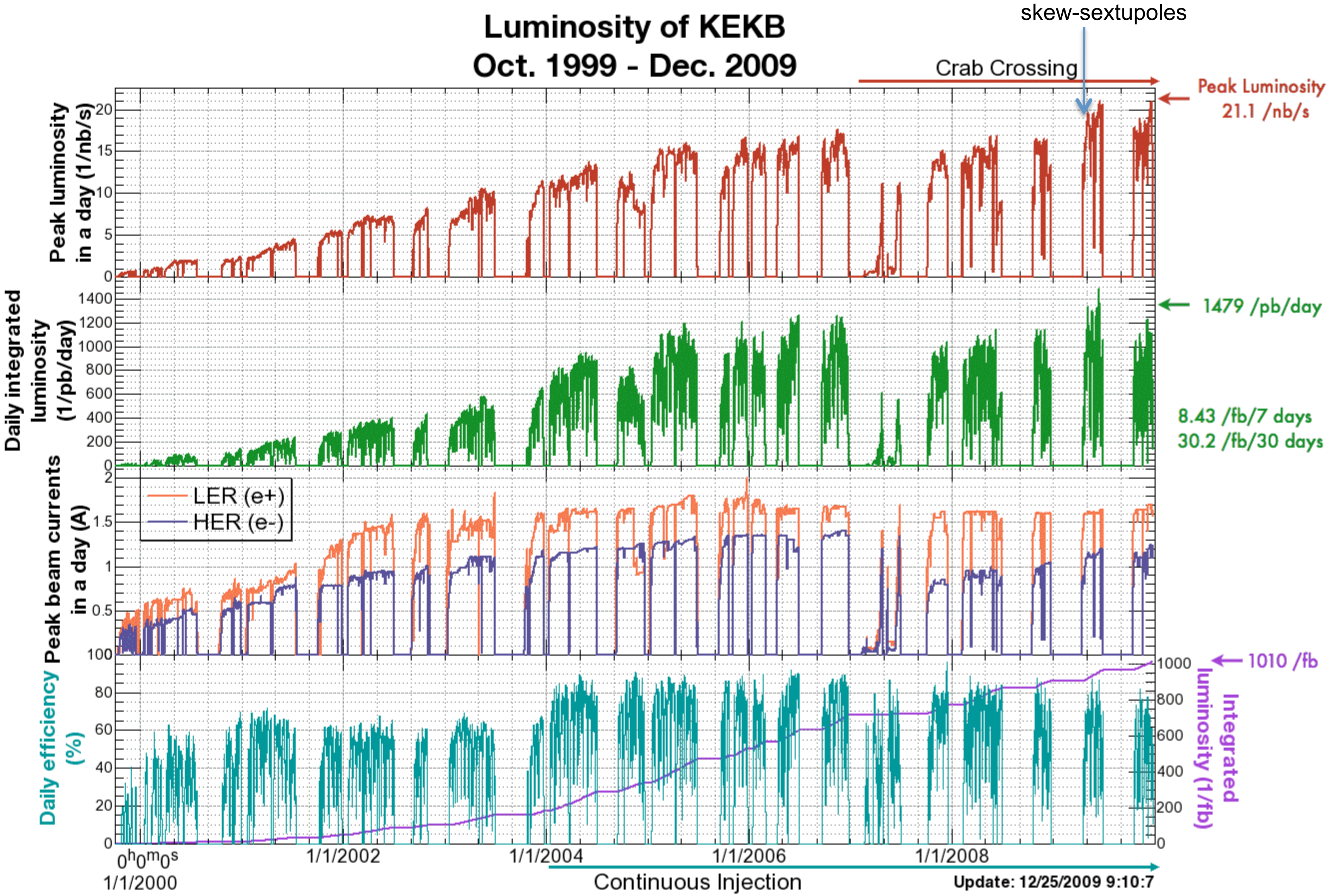
Y. Funakoshi



KEKB was operated at Y(5S), Y(2S) and off-resonance(4S-60MeV).

KEKB/Belle total integrated luminosity surpassed 1000 fb^{-1} !!!




Luminosity of KEKB
Oct. 1999 - Dec. 2009
skew-sextupoles
Crab Crossing
Peak Luminosity
21.1 /nb/s
1479 /pb/day
8.43 /fb/7 days
30.2 /fb/30 days
1010 /fb
Peak luminosity in a day (1/nb/s)
Daily integrated luminosity (1/pb/day)
Peak beam currents in a day (A)
LER (e+)
HER (e-)
Daily efficiency (%)
Integrated luminosity (1/fb)
0h0m0s 1/1/2000
1/1/2002
1/1/2004
1/1/2006
1/1/2008
Continuous Injection
Update: 12/25/2009 9:10:7

Machine parameters

Date	Nov.15 2006 before crab		May 19 2008 with crab (Last MAC)		Jun. 17 2009 with crab		
	LER	HER	LER	HER	LER	HER	
Current	1.65	1.33	1.60	0.933	1.64	1.19	A
Bunches	1389		1584		1584		
Bunch current	1.19	0.96	1.01	0.590	1.03	0.750	mA
spacing	2.10		1.84		1.84		mA
emittance ε_x	18	24	15	24	18	24	nm
β_x^*	59	56	90	90	120	120	cm
β_y^*	6.5	5.9	5.9	5.9	5.9	5.9	mm
σ_x @IP	103	107	116	147	147	170	μm
σ_y @IP	1.8	1.8	1.1	1.1	0.94	0.94	μm
ν_x	45.505	43.534	45.505	44.509	45.506	44.511	
ν_y	44.509	41.565	43.567	41.596	43.561	41.585	
ν_s	-0.0246	-0.0226	-0.0240	-0.0204	-0.0246	-0.0209	
beam-beam ξ_x	0.117	0.070	0.099	0.119	0.127	0.102	
beam-beam ξ_y	0.108	0.058	0.101	0.096	0.129	0.090	
Luminosity	17.6		16.8		21.08		$10^{33}cm^{-2}s^{-1}$

KEKB operation in FY2009

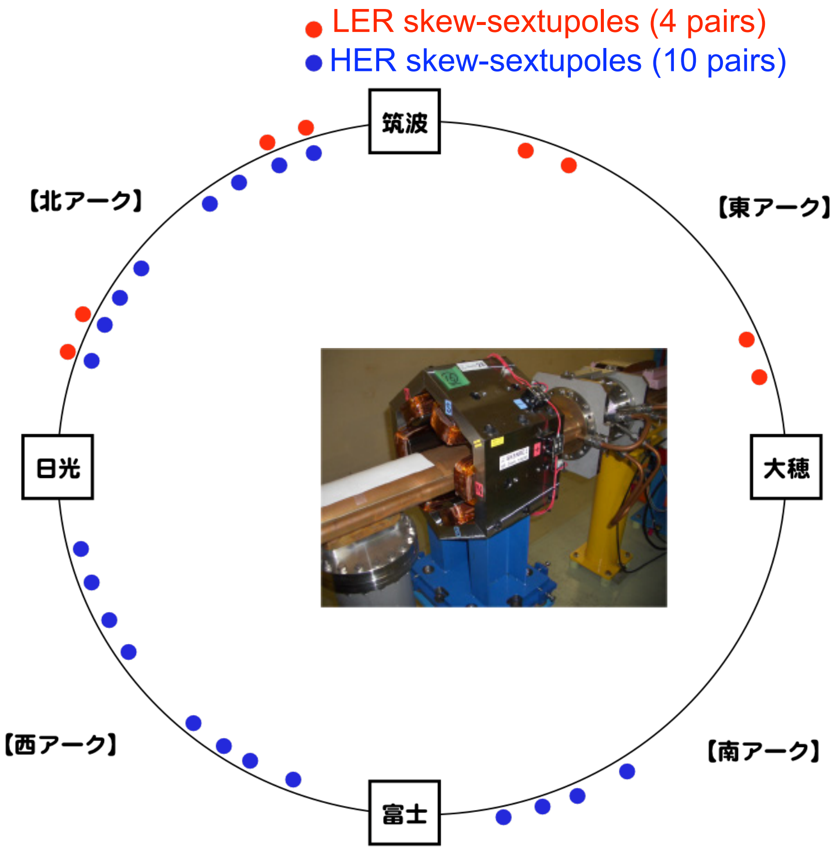
- The machine time was rather limited.
- Outcomes
  - The total integrated luminosity accumulated by Belle detector reached 1000 fb^{-1} on Nov. 29th .
  - We have continued efforts to increase the luminosity with crab crossing.
    - The peak luminosity exceeded 2×10^{34} cm^{-2} s^{-1} by using skew-sextupole magnets.
    - e+/e- simultaneous injection was realized.
  - We conducted many machine studies for KEKB and SuperKEKB.

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?

Slide shown in the last MAC on Feb.9th 2009 by Funakoshi

Chromaticity of x-y coupling at IP



- Ohmi et al. showed that the chromaticity of x-y coupling parameters (R-parameters) at IP could degrade the luminosity, if the residual values, which depend on machine errors, are large.
- To control the chromaticity, skew sextupole magnets, 10 pairs for HER and 4 pairs for LER, were installed during winter shutdown 2009.
- It turned out that the skew sextuples are very effective to increase the luminosity at KEKB. The knobs to control the chromaticity of the x-y coupling parameters at IP were introduced for beam operation on May 2 2009.
- The gain of the luminosity by these magnets is 15~17%.

D. Zhou, K. Ohmi, Y. Seimiya,

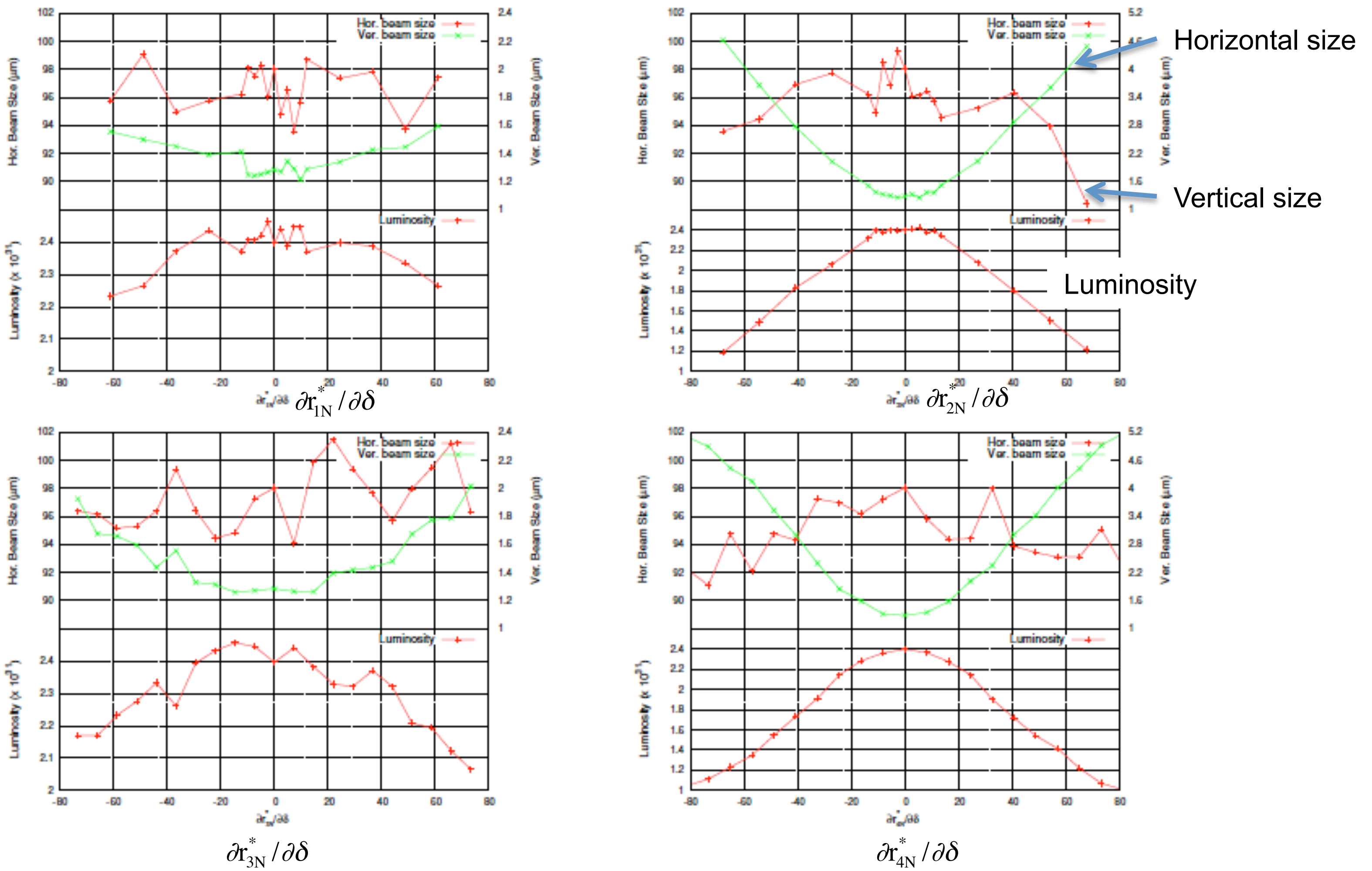


Figure 8: Scan of first order chromaticity of coupling parameters at IP (Top left: $\partial r^*_{1N}/\partial\delta$, Top right: $\partial r^*_{2N}/\partial\delta$, Bottom left: $\partial r^*_{3N}/\partial\delta$, Bottom right: $\partial r^*_{4N}/\partial\delta$)

$$\begin{pmatrix} r^*_{1N} & r^*_{2N} \\ r^*_{3N} & r^*_{4N} \end{pmatrix} = \begin{pmatrix} R^*_1\sqrt{\beta^*_x/\beta^*_y} & R^*_2/\sqrt{\beta^*_x\beta^*_y} \\ R^*_3\sqrt{\beta^*_x\beta^*_y} & R^*_4\sqrt{\beta^*_y/\beta^*_x} \end{pmatrix}$$

Definition of x-y coupling parameters (SAD notation)

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = T \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix}$$

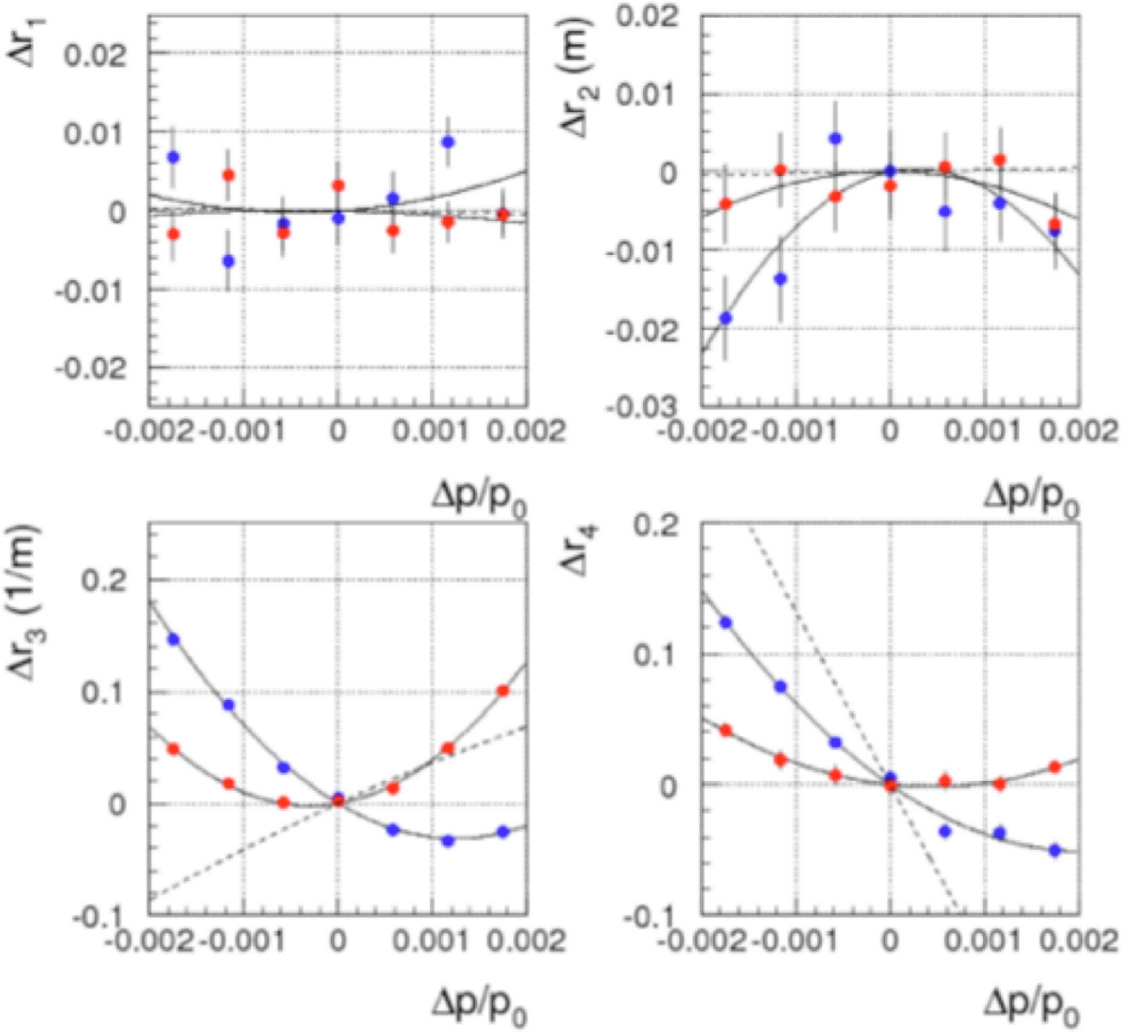
$$T(s) = \begin{pmatrix} \mu I & SR^t S \\ R & \mu I \end{pmatrix} = \begin{pmatrix} \mu & 0 & -R_4 & R_2 \\ 0 & \mu & R_3 & -R_1 \\ R_1 & R_2 & \mu & 0 \\ R_3 & R_4 & 0 & \mu \end{pmatrix}$$

$$S = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \quad \mu^2 + \det R = 1$$

Normal (decoupled) coordinate

Usual coordinate

Measurement on chromaticity of x-y coupling at IP (HER)

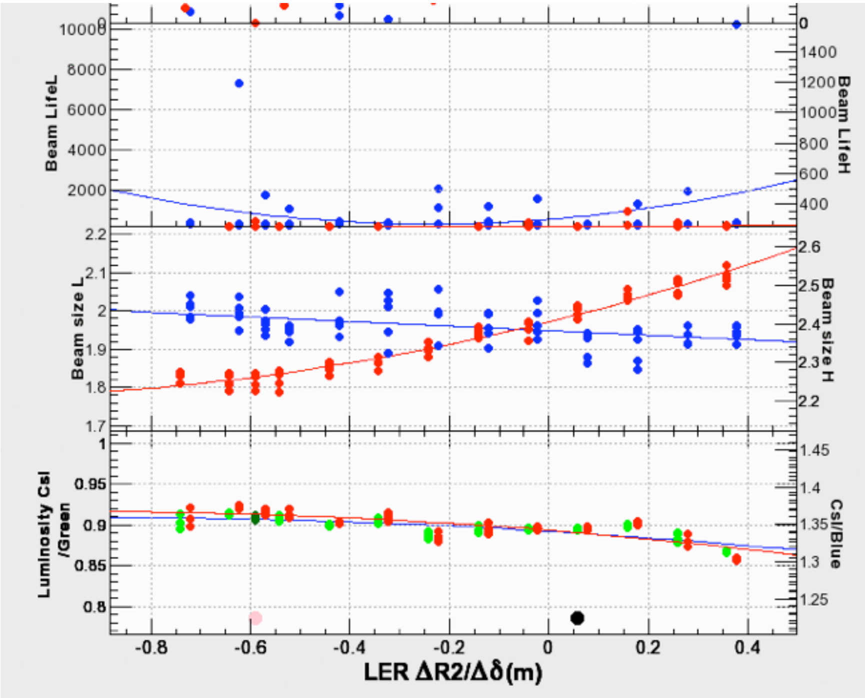


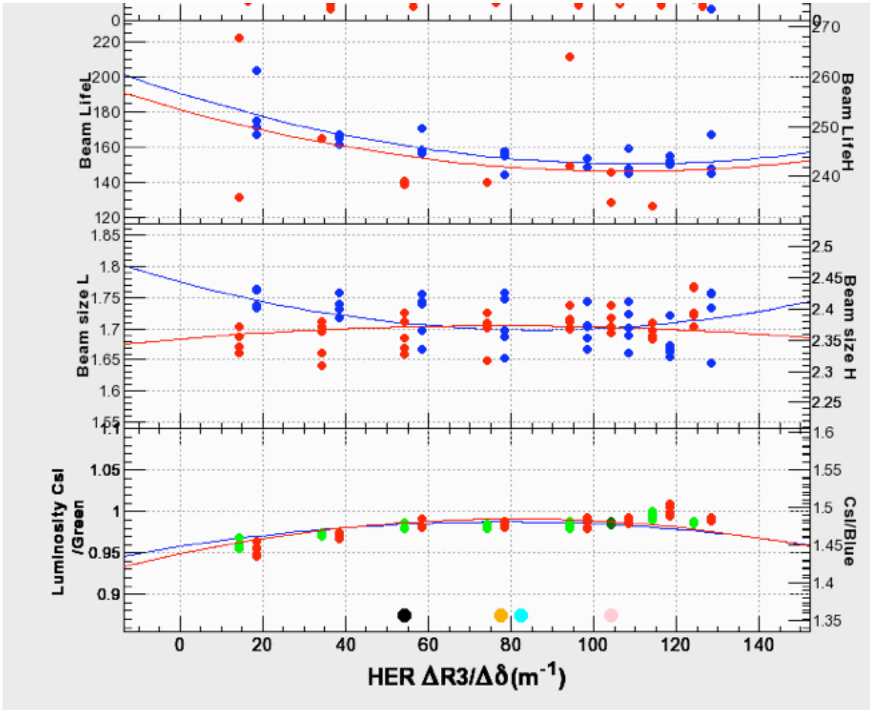
blue: without skew-sextuples

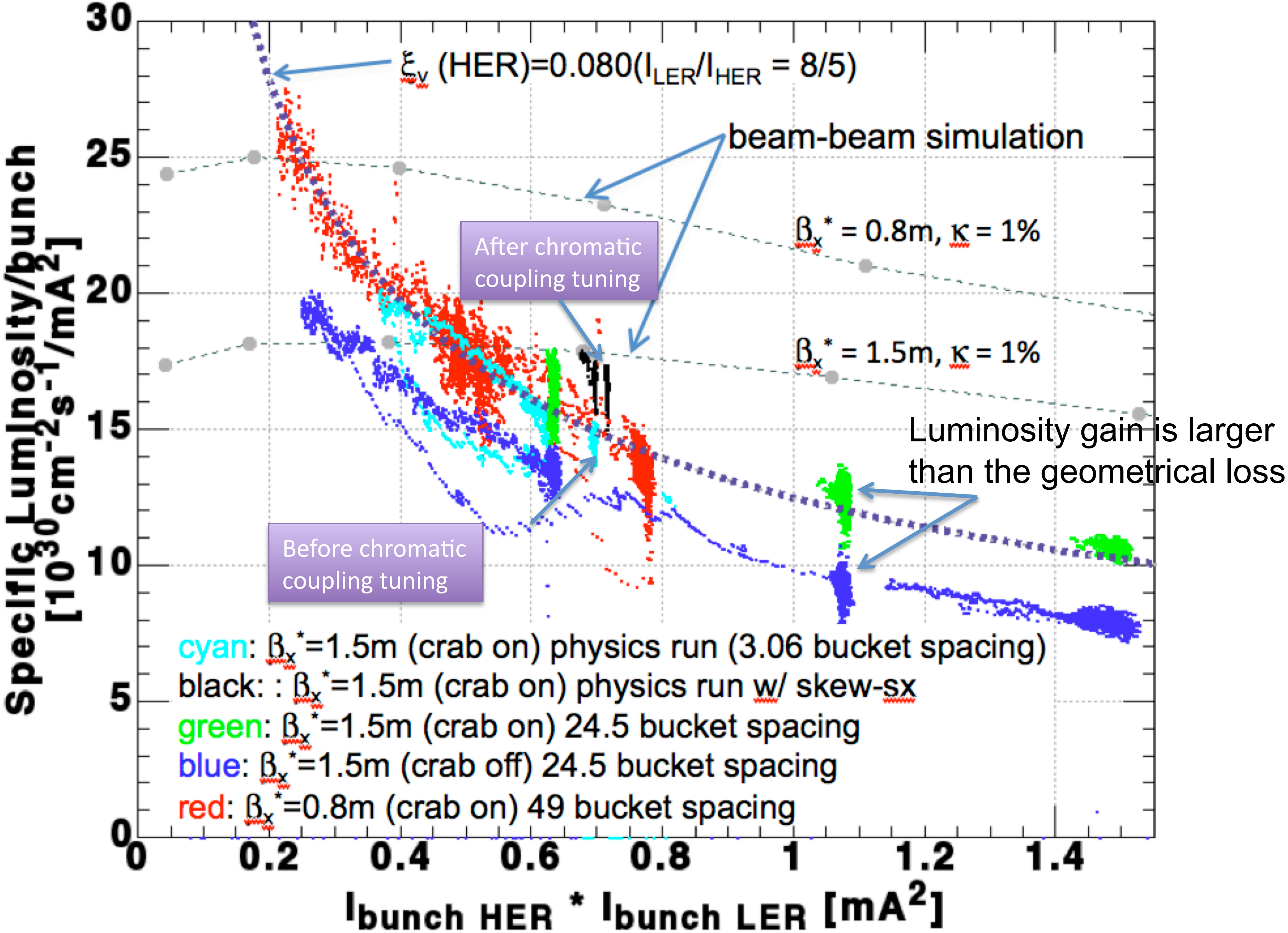
red: with skew-sextuples
(after luminosity tuning)

Y. Ohnishi

Examples of scan of chromatic x-y coupling at IP

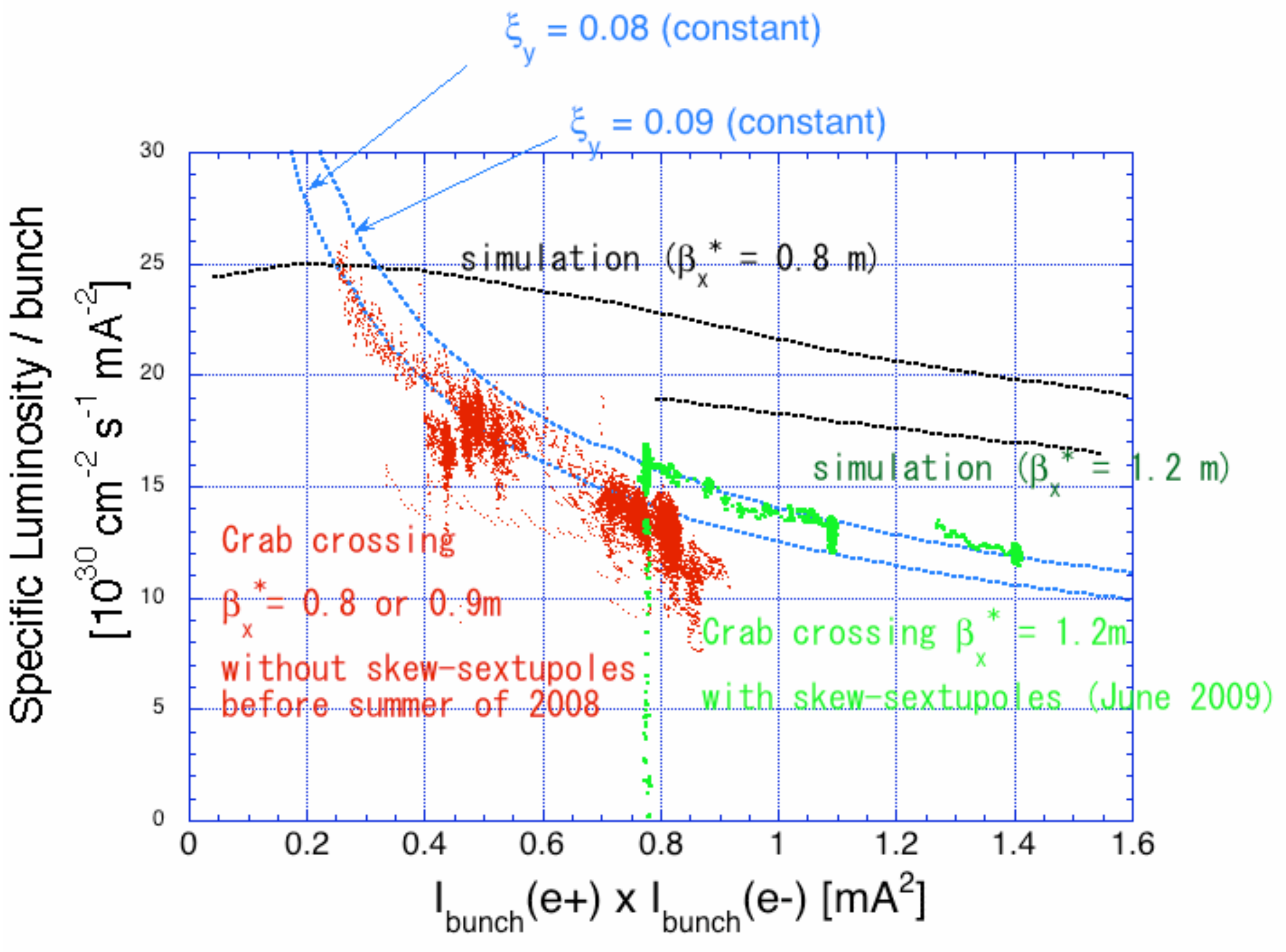




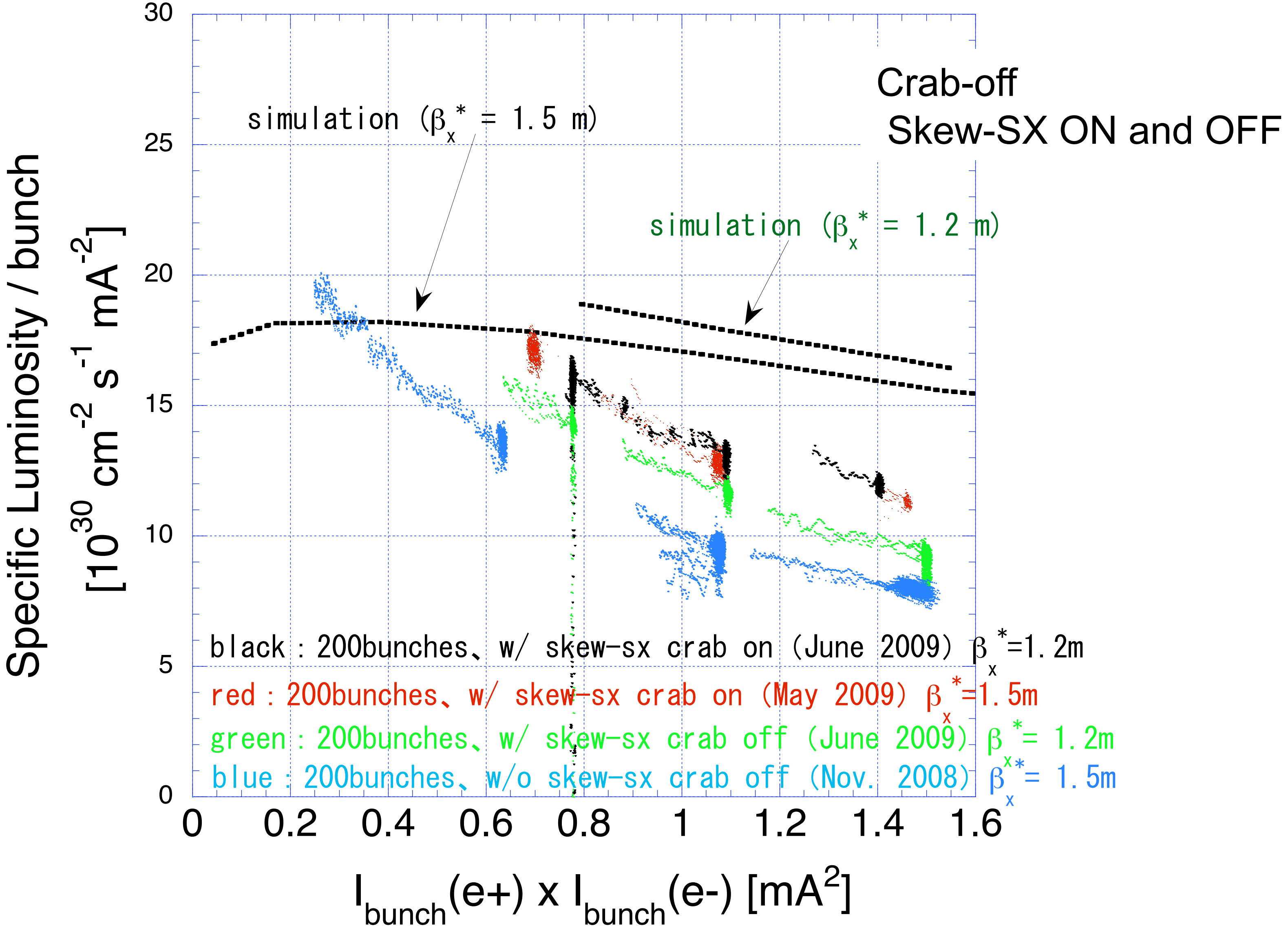


ξy (HER)=0.080(ILER/IHER = 8/5)
beam-beam simulation
βx* = 0.8m, κ = 1%
βx* = 1.5m, κ = 1%
After chromatic coupling tuning
Before chromatic coupling tuning
Luminosity gain is larger than the geometrical loss
cyan: βx*=1.5m (crab on) physics run (3.06 bucket spacing)
black: : βx*=1.5m (crab on) physics run w/ skew-sx
green: βx*=1.5m (crab on) 24.5 bucket spacing
blue: βx*=1.5m (crab off) 24.5 bucket spacing
red: βx*=0.8m (crab on) 49 bucket spacing
Specific Luminosity/bunch [10^30 cm^-2 s^-1/mA^2]
Ibunch HER * Ibunch LER [mA^2]

Specific luminosity with fewer number of bunches (200 bunches/beam)



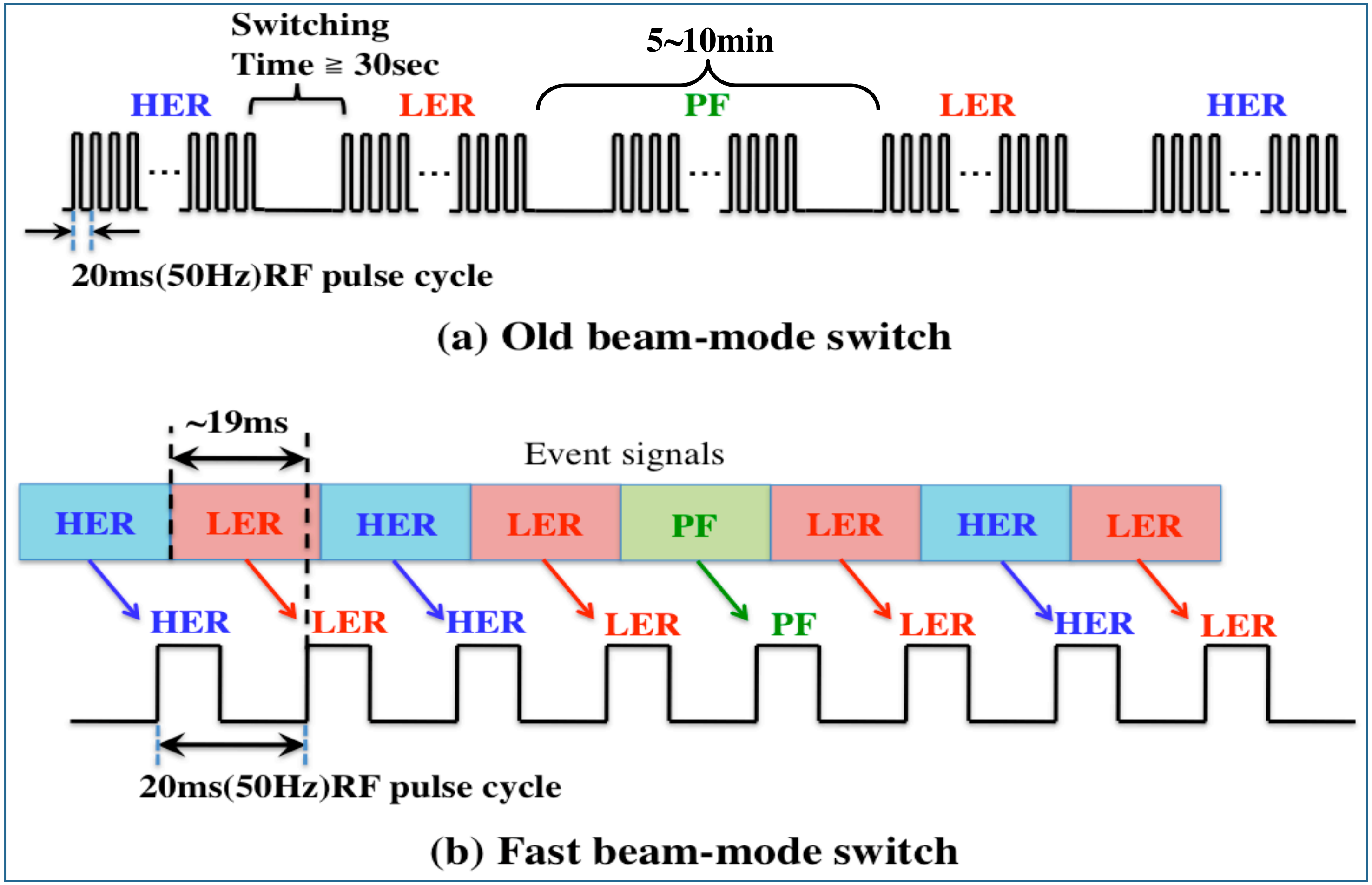
Specific luminosity with fewer number of bunches (200 bunches/beam)



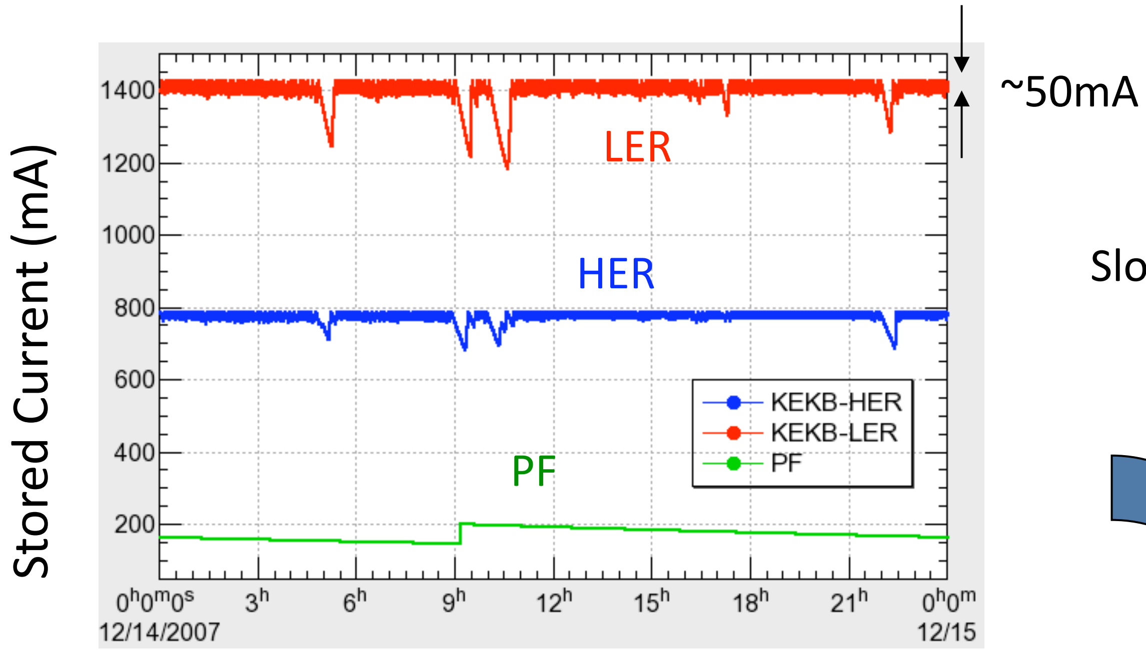
e+/e- simultaneous injection (fast beam mode switching)

- e+/e-/PF(e-) simultaneous injection was finally realized in April 2009 !!!.
- e+/e-/PF(e-) simultaneous injection (Furukawa's talk)
  - Switch beam mode fast (in principle pulse-to-pulse for 50Hz linac pulses)
  - Magnet settings in the linac are unchanged among the modes. We use some pulse steering/bending magnets.
  - Many timing signals and klystron phases are switched pulse-to-pulse.
- Benefits of the simultaneous injection
  - The beam condition became more stable.
  - Much faster beam tuning became possible.
  - The luminosity decrease during the PF injection and the PF machine study can be avoided.

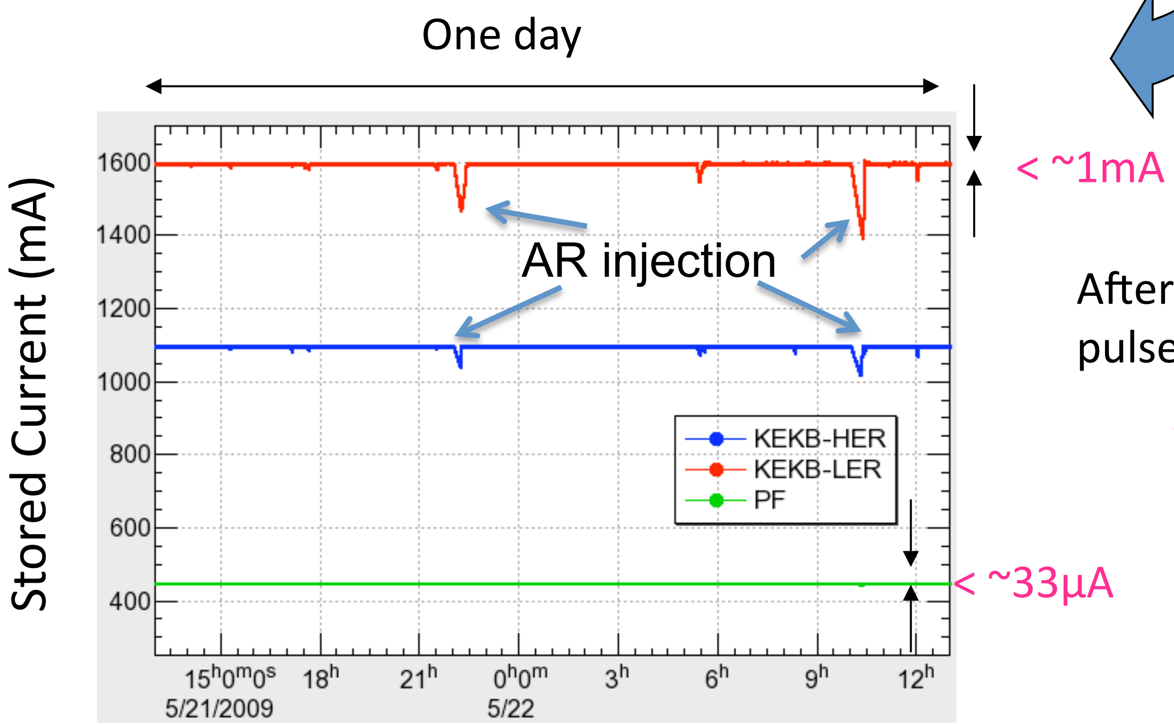
Fast beam mode switch scheme is strongly required.



Schematic view of the beam-mode switches.
The block pulses show beam gate timings.



Slow switching



After achievement of pulse-to-pulse switching injection

AR has not participated in the simultaneous injection yet.

- HER:12.5Hz
- LER:12.5Hz
- PF:0.5Hz

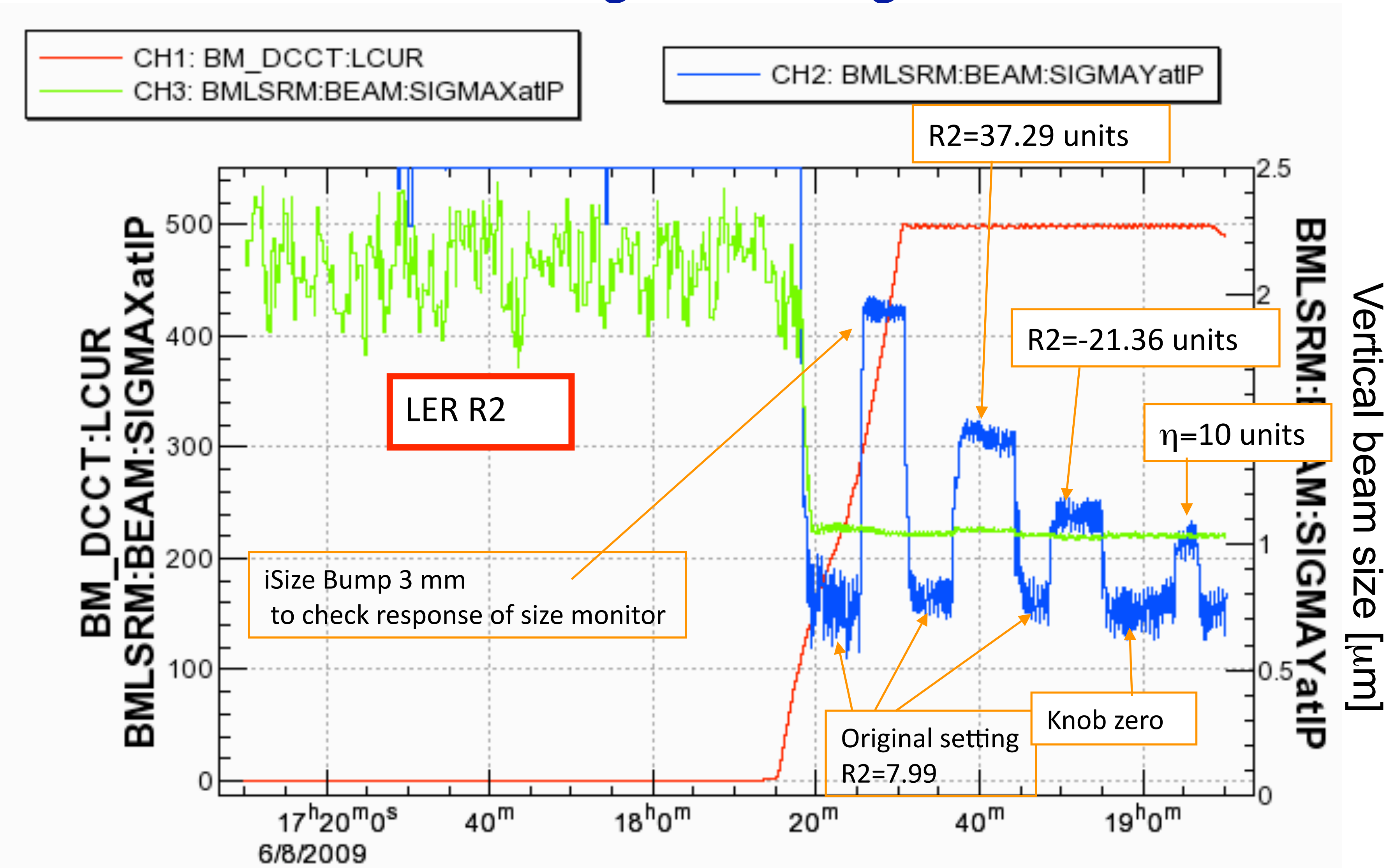
Machine studies

- SuperKEKB
  - Vacuum R&D (Suetsugu's talk)
    - Counter-measures for ECI
    - Movable mask, radiation from vacuum chamber etc.
  - RF system
    - High power operation of klystron
    - SCC reverse phase operation (Y. Morita's talk)
  - Beam monitor system
    - Feedback system
    - BPM signal detection circuit
  - Beam transport
    - Abort window (Mimashi's talk)

Machine studies [cont'd]

- SuperKEKB (cont'd)
  - Beam behavior, beam dynamics
    - Stability of beam orbit, effects of electron clouds
  - Physics Detector
    - Background study (Iwasaki's talk)
- KEKB performance
  - e-/e+/PF simultaneous injection (Furukawa's talk)
  - Side effect of large tuning knobs
  - effect of compensation solenoid
  - Measurement of x-y coupling at IP and its chromaticity
  - Horizontal oscillation in physics run
- Others
  - Study for LHC crab cavity, Positron target for ILC

Side effect of a large tuning knob



- The vertical beam size is enlarged due to the side effect of a large tuning know such as 30 units of R2 knob.
- If a large x-y coupling remains at IP, the luminosity degradation may not be recovered by the tuning knobs.

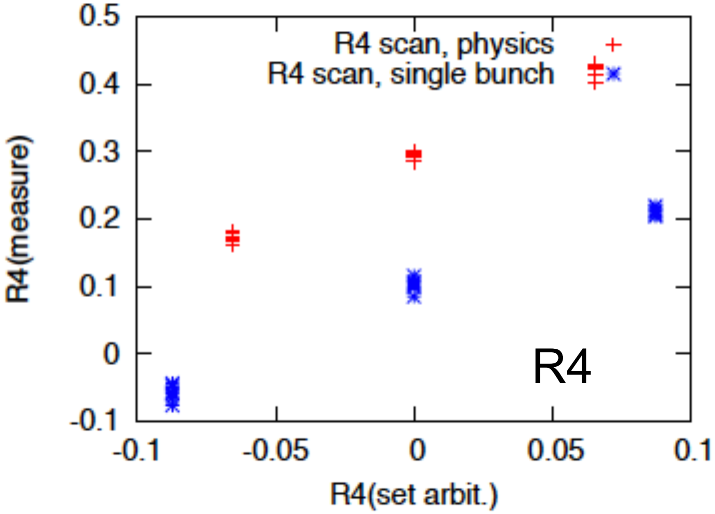
x-y coupling measurements at IP

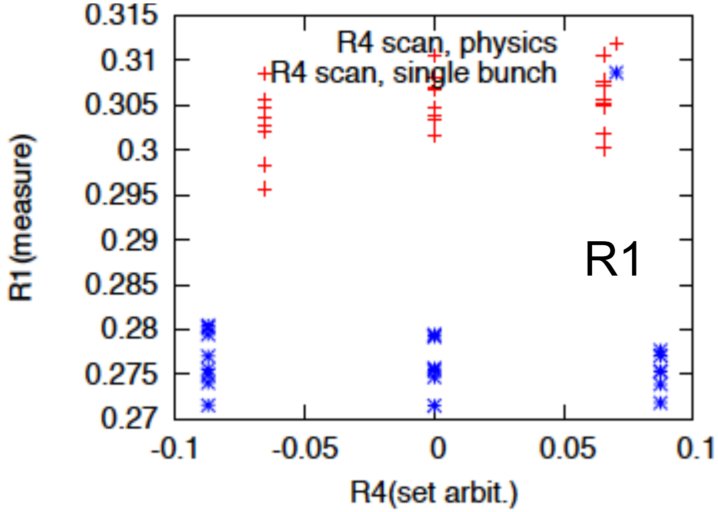
(Ohmi, Tobiyama, Ieiri, Seimiya, Zhou, Ohnishi)

- Methods
  - Kick the beam horizontally by injection kicker or PLL
  - Measure the horizontal and vertical (turn-by-turn)positions near IP (at OctoPos BPM or QCS BPM).
  - Both the cases of single beam (single bunch) and the the pilot bunch (physics run) were measured.
- Preliminary results
  - Measured values of coupling at IP are different between the single beam and the physics run.

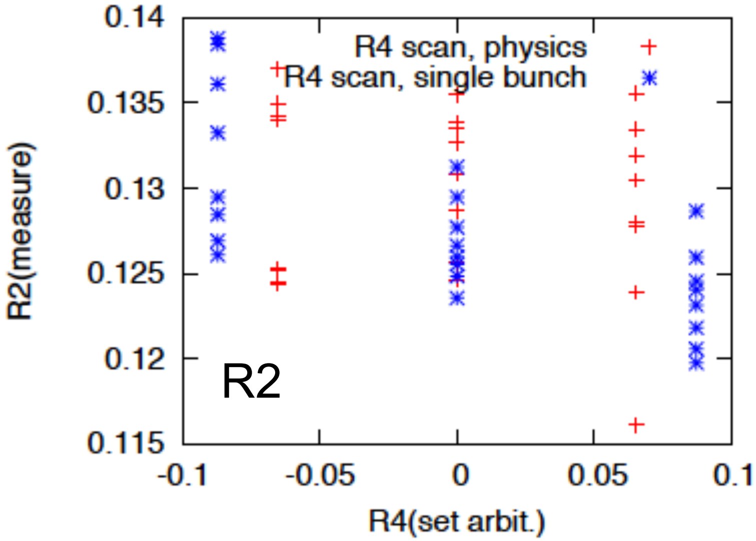
HER R4 scan

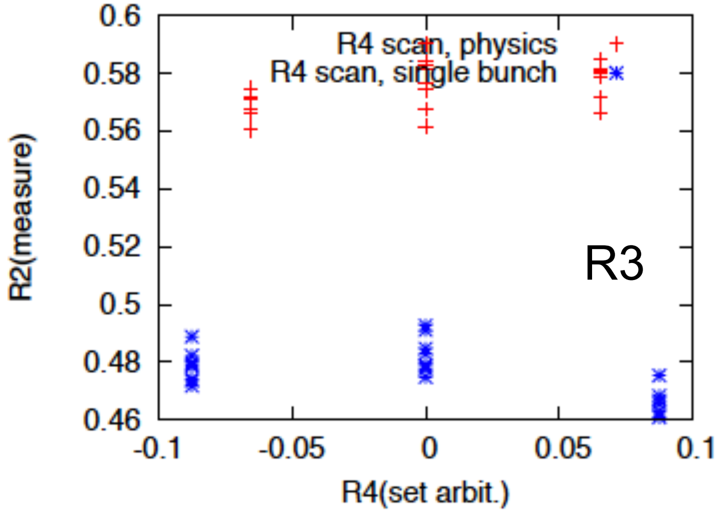
- There is a big difference between the single beam and physics run.





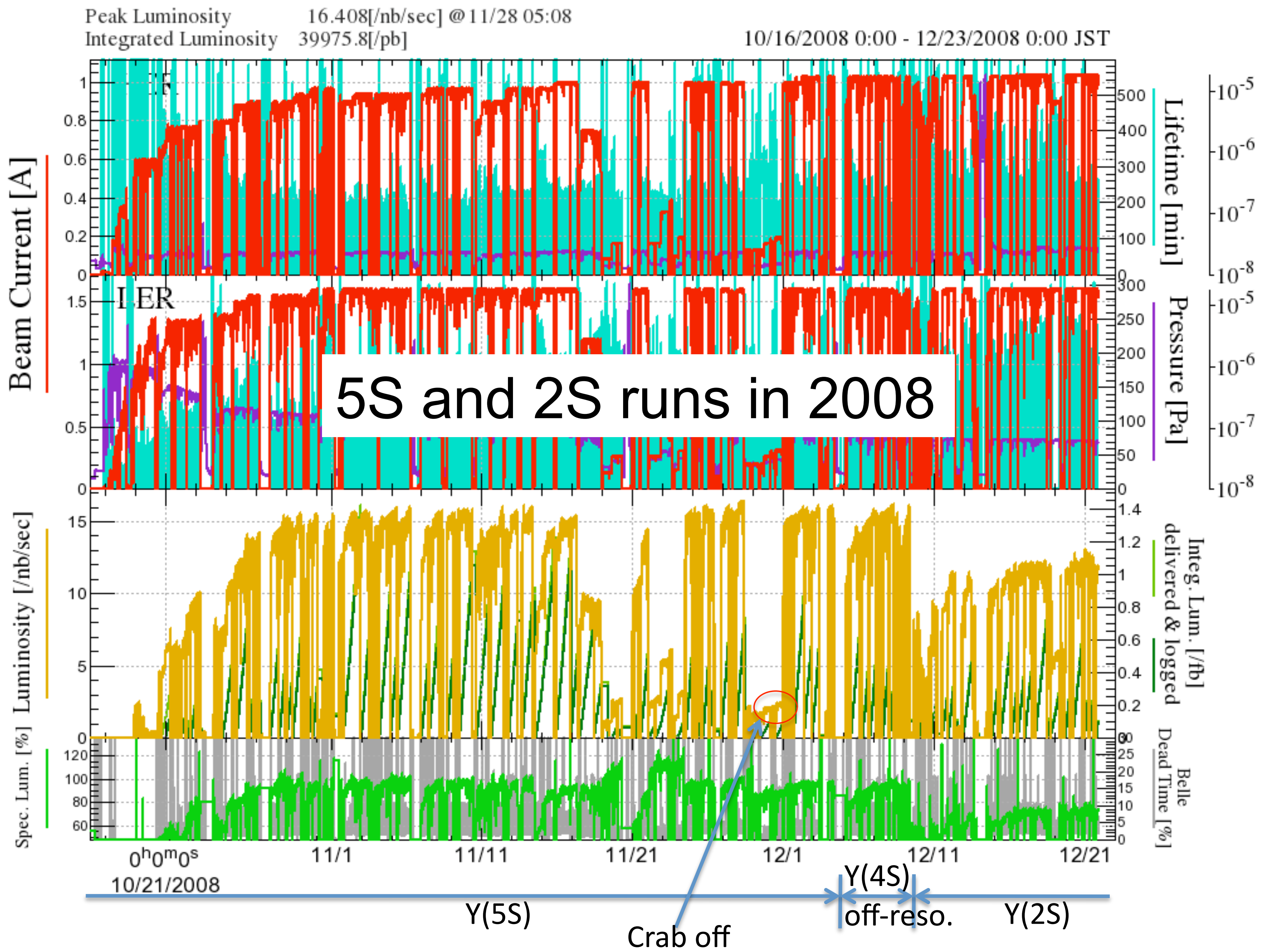
Monitor calibration is not enough.





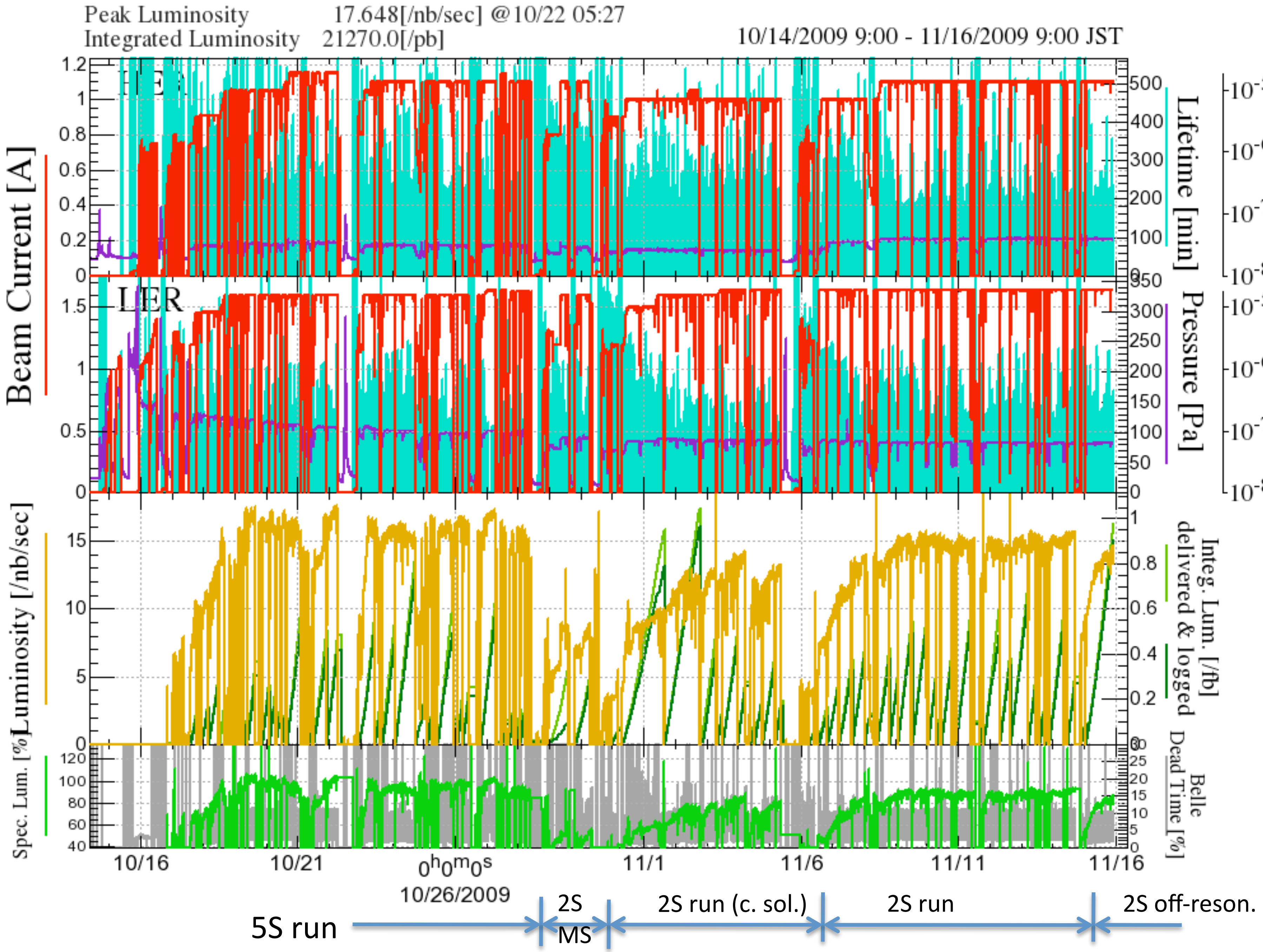
Machine study on the effect of Belle solenoid

- It has been known that the luminosity at 1S or 2S is much lower than that at 4S or 5S.
- At KEKB, the strength of Belle solenoid and the compensation solenoid are not changed depending on the beam energy.
- It was suspected that this untracked solenoid field is responsible for the lower luminosity at 2S and 1S
- A machine study was done at 2S with the Belle solenoid and compensation solenoid which is tracked to the beam energy.



Peak Luminosity 16.408[/nb/sec] @11/28 05:08
Integrated Luminosity 39975.8[/pb]
10/16/2008 0:00 - 12/23/2008 0:00 JST
5S and 2S runs in 2008
Beam Current [A]
LER
Lifetime [min]
Pressure [Pa]
Luminosity [/nb/sec]
Integ. Lum. [/fb] delivered & logged
Spec. Lum. [%]
Belle Dead Time [%]
0h0m0s 10/21/2008
11/1
11/11
11/21
12/1
12/11
12/21
Y(5S)
Y(4S)
off-reso.
Y(2S)
Crab off

Machine Study on the effect of Belle solenoid at 2S

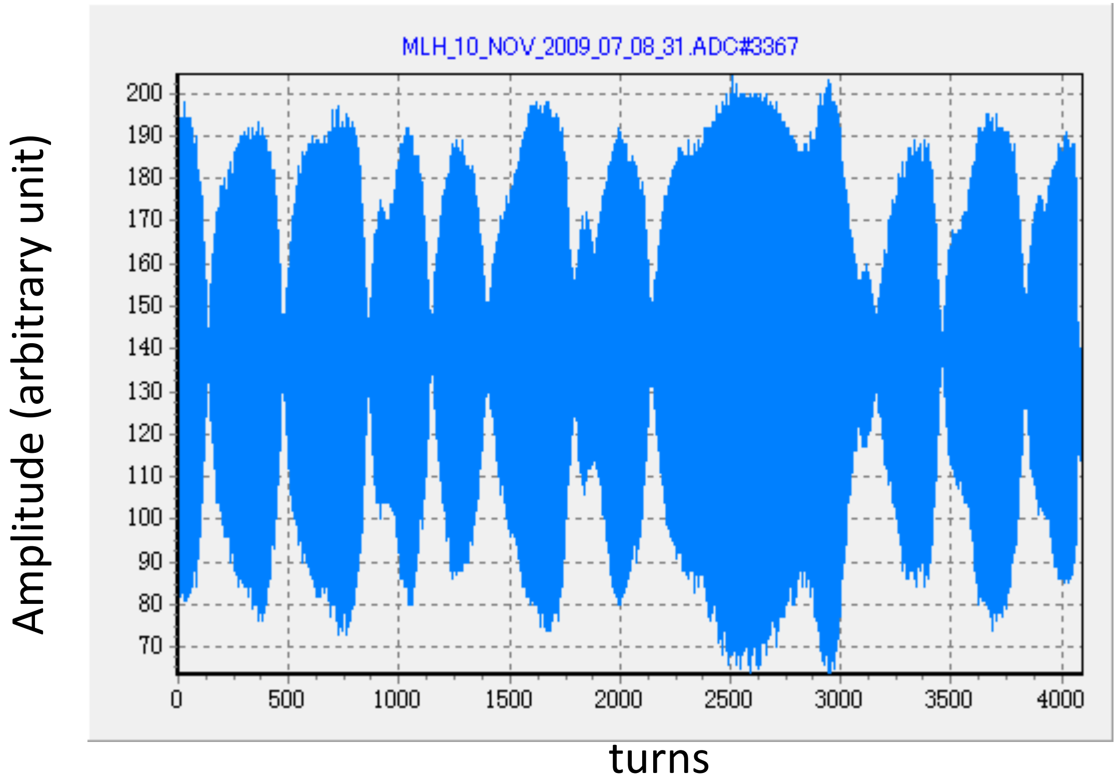


Horizontal dipole oscillation

- Observations
  - In the physics run, the both beams oscillate continuously in the horizontal direction.
  - The oscillation frequency corresponds to the π-mode of the beam-beam interaction.
  - The oscillation amplitude changes like a saw-tooth instability. One cycle of the saw-tooth is about 300 turns (~3 msec). The maximum amplitude is about 1/3 σ_x.
  - Some luminosity degradation may be brought by this oscillation.
  - This oscillation became conspicuous in FY2009, although the oscillation had been observed before depending on the beam currents.

Example of Horizontal oscillation of an LER bunch

This oscillation exists constantly during the physics.

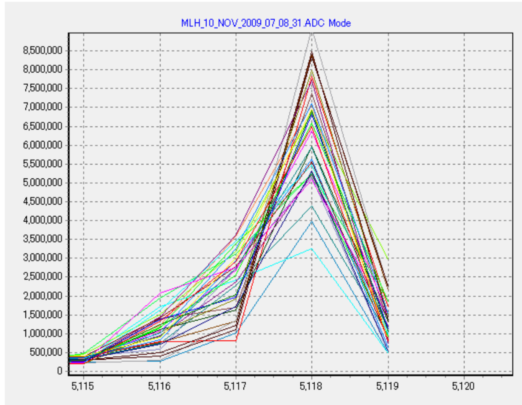


The amplitude is ~ 1/3 σ_x.

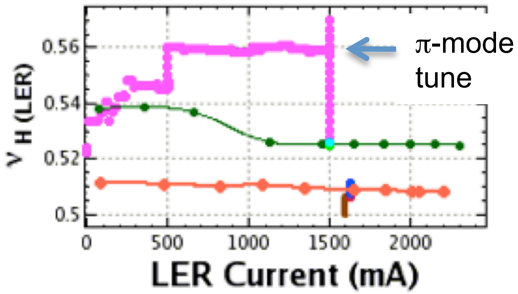
M. Tobiyama

Horizontal dipole oscillation [cont'd]

- Machine studies and data analysis
  - Coupled bunch mode?
    - -2 mode is dominant (M. Tobiyama)

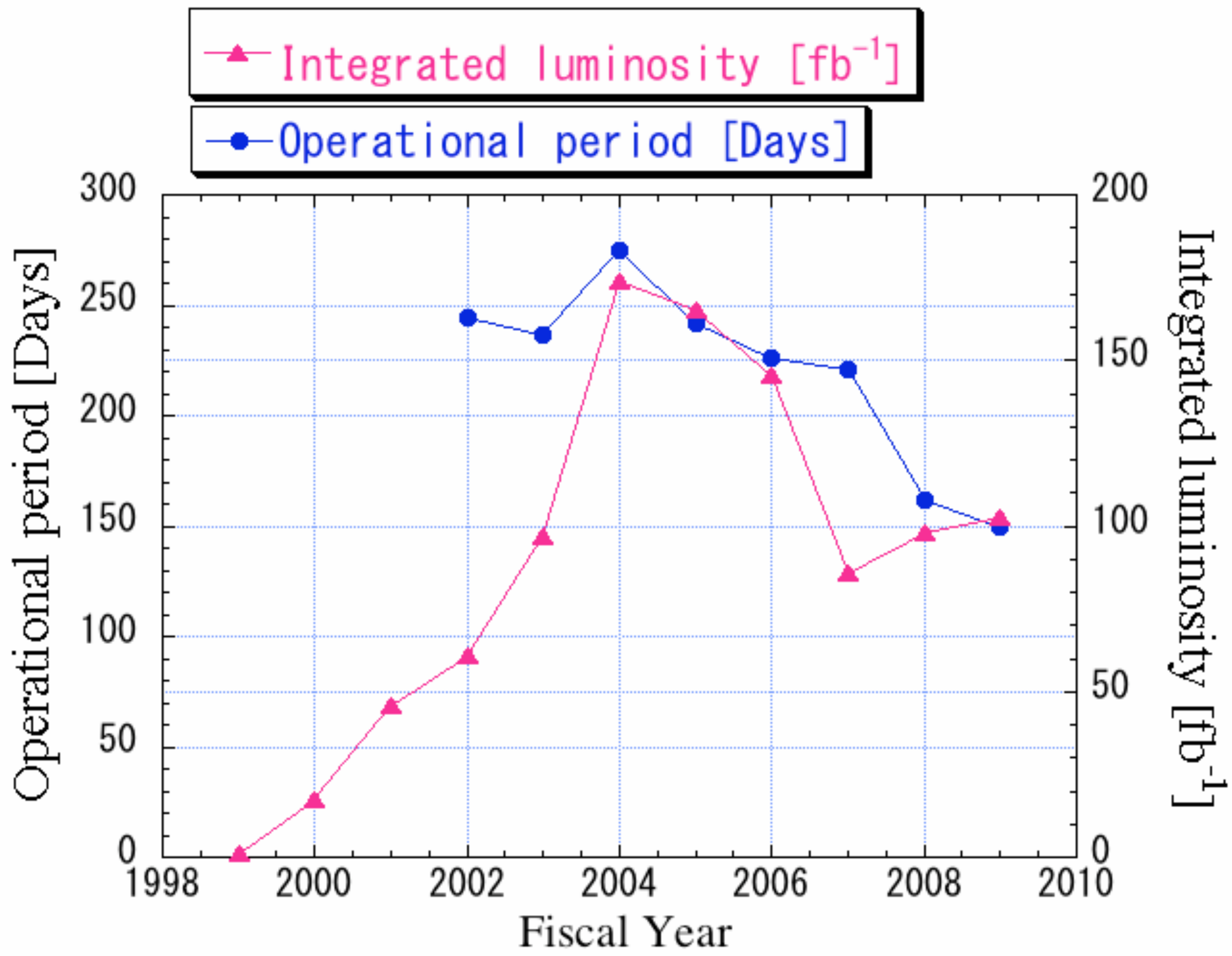


  - Small number of bunches
    - ~100 bunches: No oscillation was observed with the same bunch currents.
  - Single beam with the same number of bunches
    - No coupled bunch oscillation was observed even at the π-mode tune.

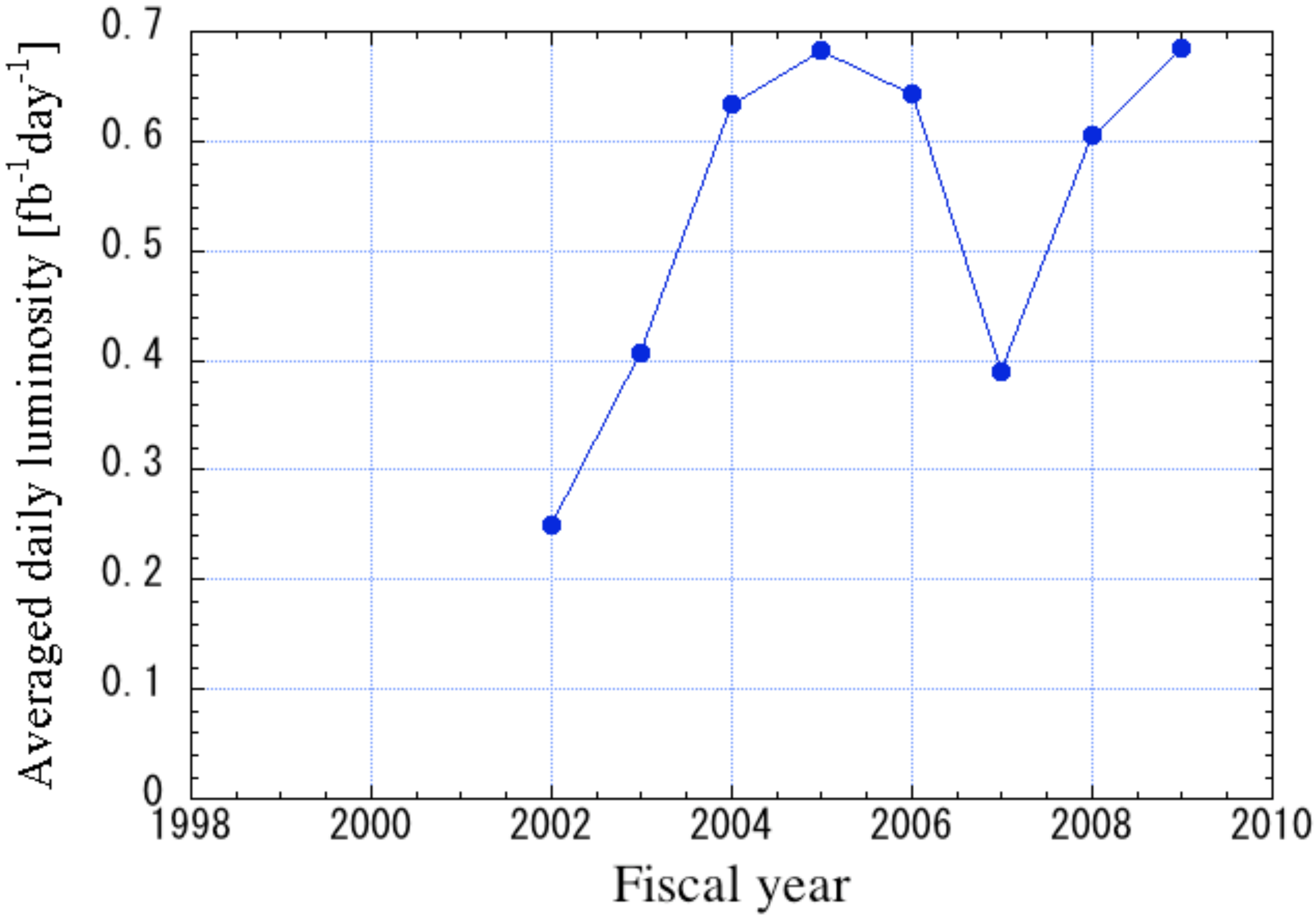


Operation statistics

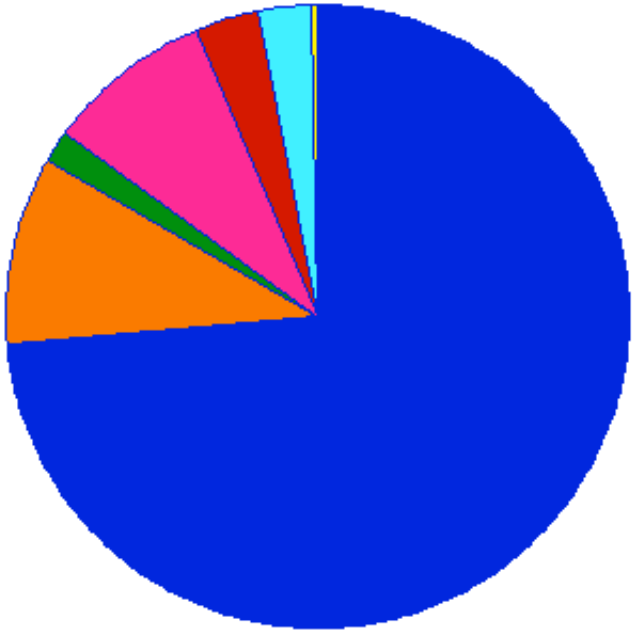
Annual integrated luminosity



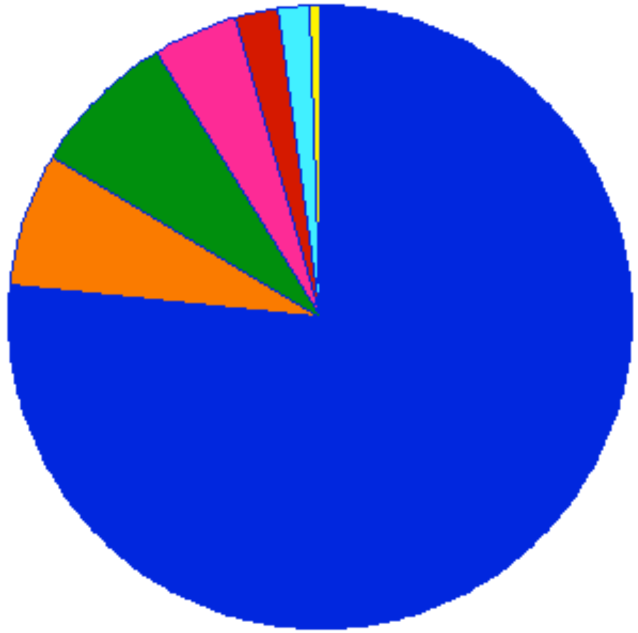
Averaged daily luminosity



Operation statistics

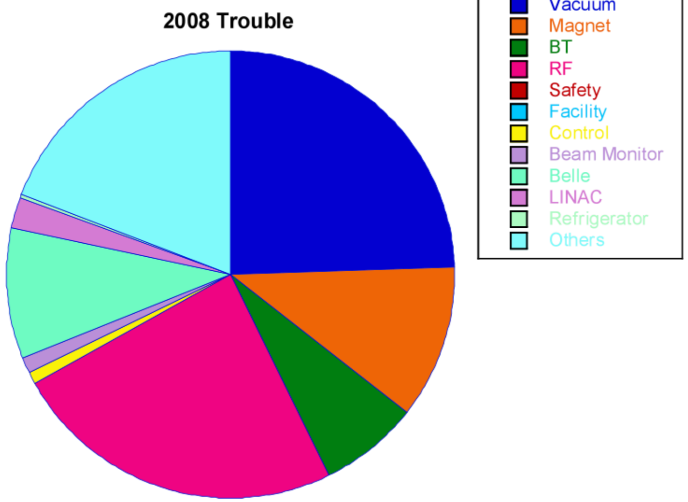


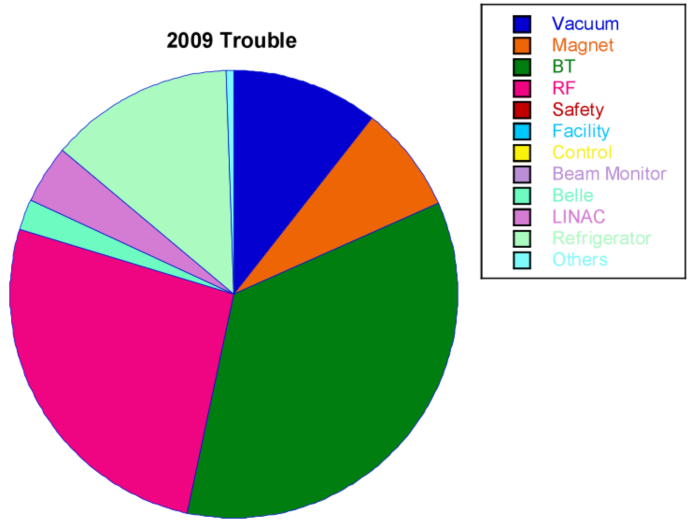
2008	[%]
Physics Run	73.5
Machine Study	9.8
Machine Tuning	1.7
Beam Tuning	8.5
Trouble	3.5
Maintenance	2.7
Others	0.3



2009	[%]
Physics Run	76.8
Machine Study	6.8
Machine Tuning	7.5
Beam Tuning	4.4
Trouble	2.2
Maintenance	1.9
Others	0.4

Troubles

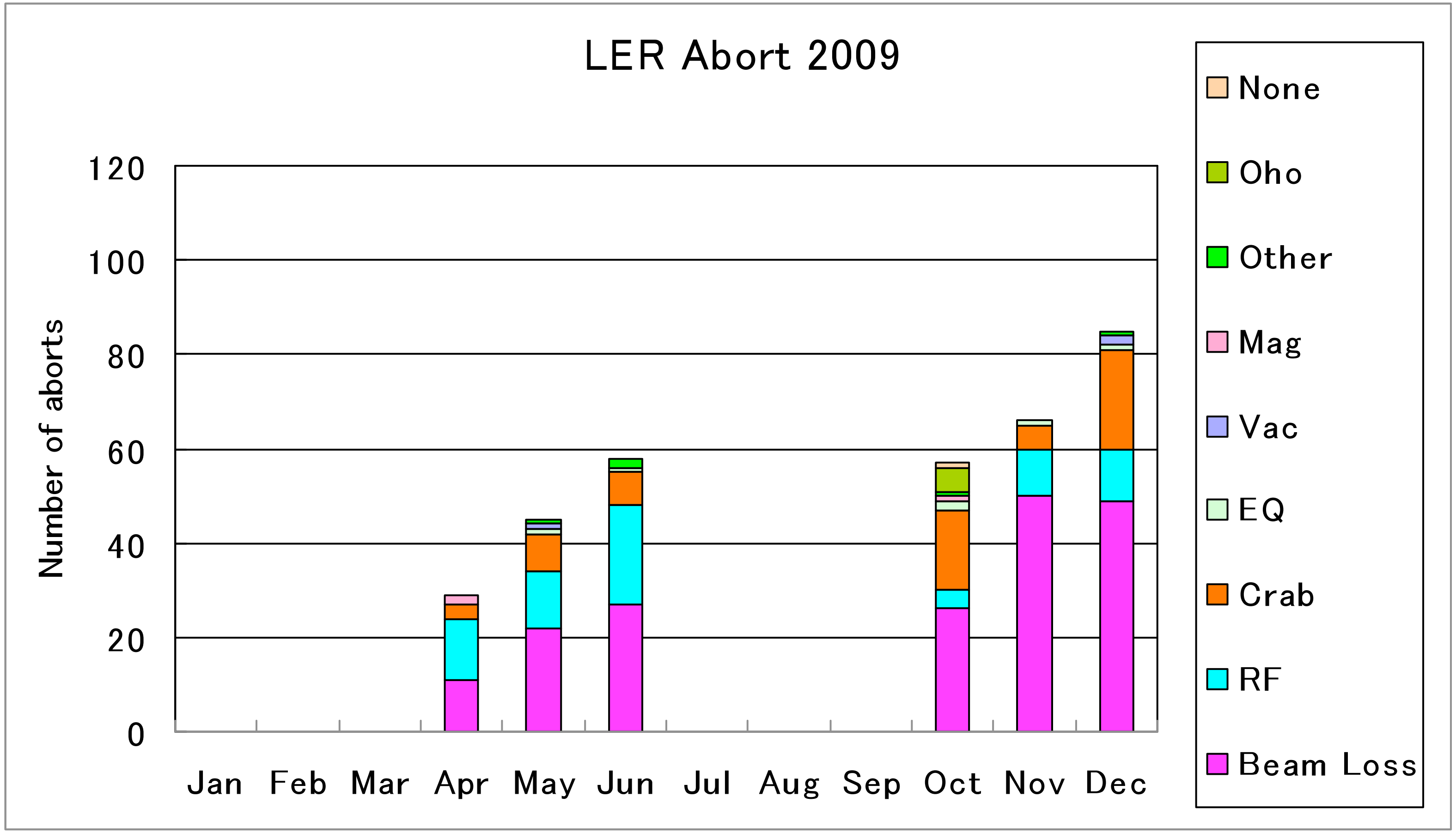




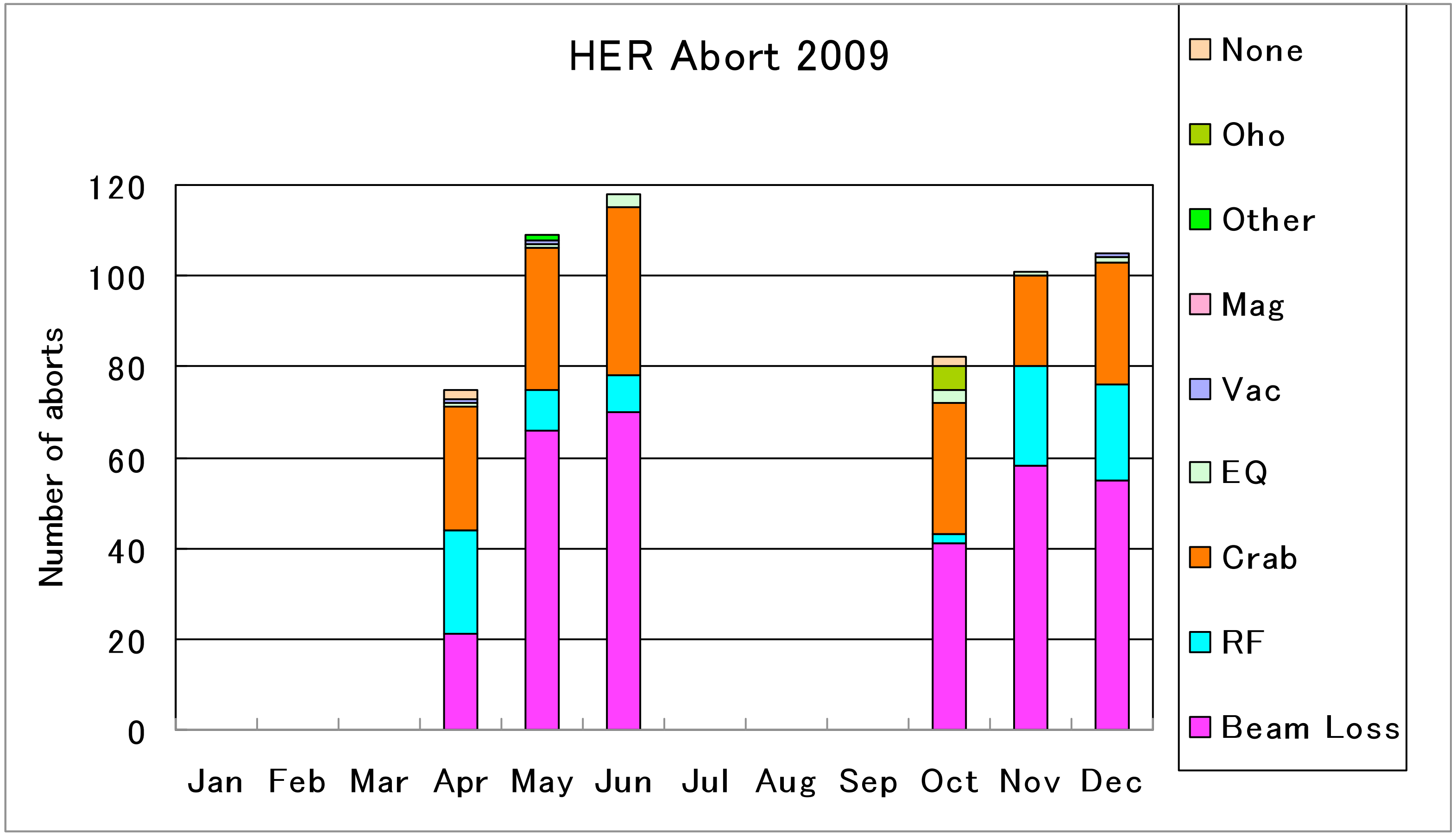
2008	[%]
Vacuum	24.5
Magnet	11.0
BT	7.3
RF	24.2
Safety	0.0
Facility	0.0
Control	0.7
Beam Monitor	1.1
Belle	9.5
LINAC	2.2
Refrigerator	0.4
Others	19.0

2009	[%]
Vacuum	10.5
Magnet	7.8
BT	35.0
RF	26.5
Safety	0.0
Facility	0.0
Control	0.0
Beam Monitor	0.0
Belle	2.2
LINAC	4.2
Refrigerator	13.2
Others	0.6

Beam aborts (LER)



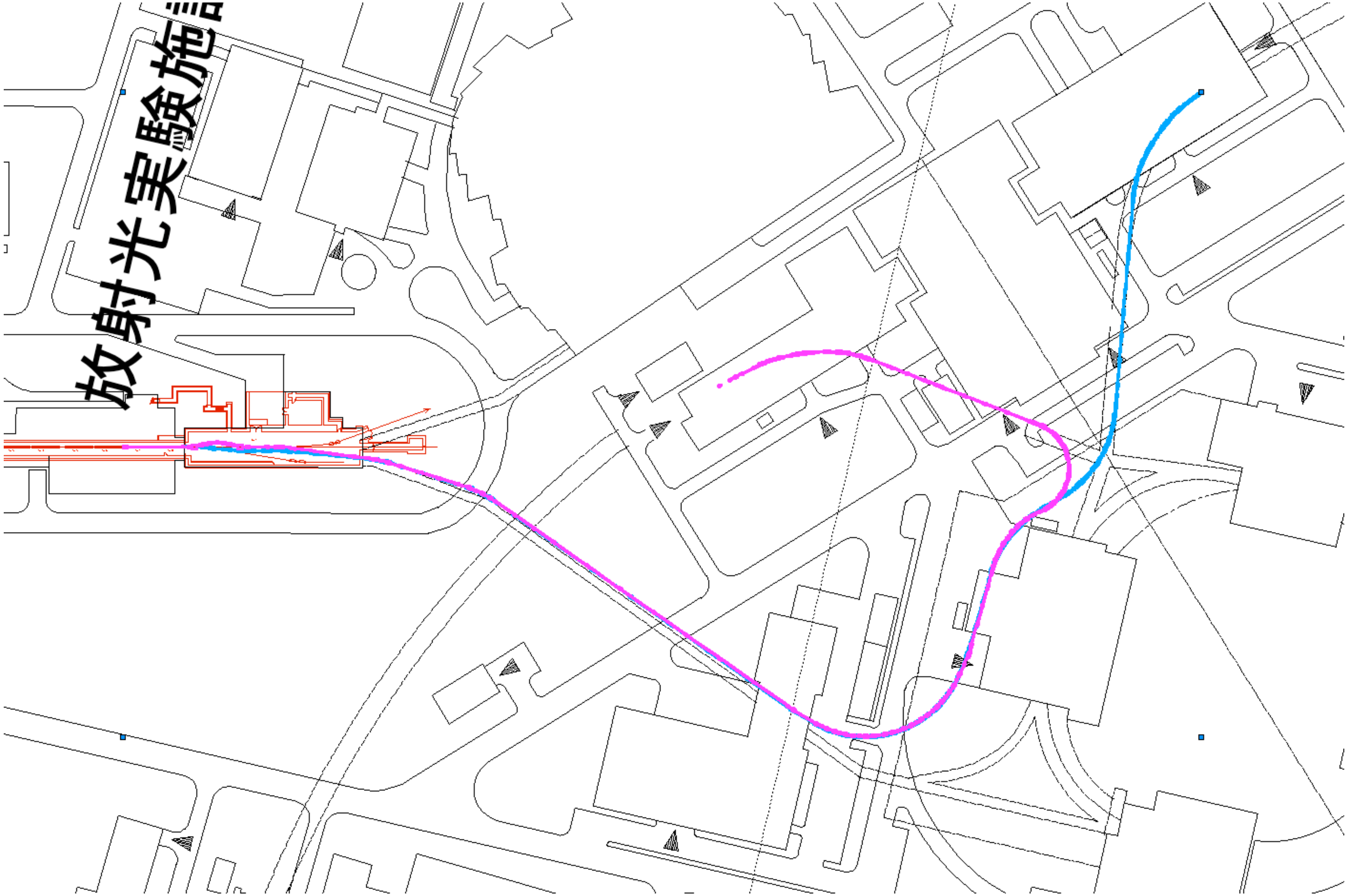
Beam aborts (HER)



Summary and future prospects

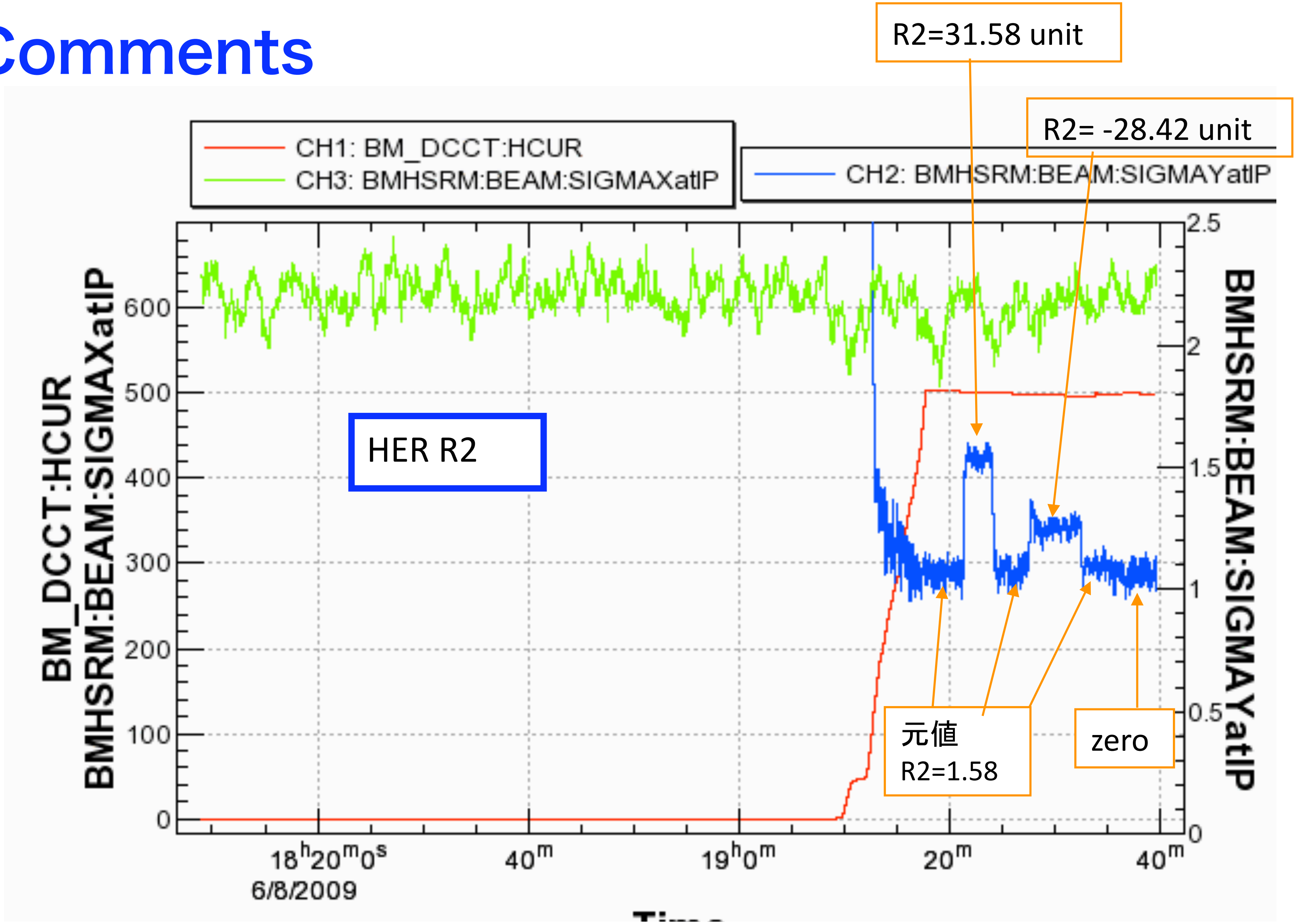
- The total integrated luminosity accumulated by Belle detector reached 1000 fb-1 on Nov. 29th .
- The peak luminosity exceeded 2 x 10^{34} cm^{-2} s^{-1} by using skew-sextupole magnets.
- e+/e- simultaneous injection was realized.
- We are still making efforts to increase luminosity with crab crossing.
- Since KEKB is the world-highest luminosity machine, anything that improves its performance might be important in SuperKEKB.
- KEKB has been useful for the R&D machine for SueprKEKB.
- In the next fiscal year, 1 or 2 months' beam operation is scheduled. We will make the best use of this last opportunity at KEKB for SuperKEKB.

SPARE SLIDES


放射光実験施

2S run in Autumn 2009

Comments



（1）HERも　Knobを大きく(30 unit) 立てると副作用でビームが太る。

（2）HERも　Knobを戻せばビームサイズは戻る。再現性は良い。

Comments

Side effect is large also in calculation.

Emittance and horizontal beta-function at IP becomes large. （1.5 m→ 2m）

Emittance X	= 1.79828E-8 m	Emittance Y	= 1.6909E-12 m
Emittance Z	= 3.40305E-6 m	Energy spread	= 7.26725E-4
Bunch Length	= 4.68290109 mm	Beam tilt	= -1.7104E-8 rad
Beam size xi	= .16422683 mm	Beam size eta	= 1.01458E-4 mm

↓

Emittance X	= 1.86589E-8 m	Emittance Y	= 9.6696E-11 m
Emittance Z	= 3.40166E-6 m	Energy spread	= 7.26665E-4
Bunch Length	= 4.68137449 mm	Beam tilt	= .00143278 rad
Beam size xi	= .19836794 mm	Beam size eta	= .00180254 mm

Summary of R(0) measurements

		4/30	5/13	5/26
HER	r1	0.0112	0.0142	0.00974
	r2	0.00163	0.00139	0.00169
	r3	0.0616	0.111	0.0618
	r4	-0.0547	-0.0926	0.0245
LER	r1	0.0104	0.0085	0.00961
	r2	0.0137	0.0137	0.0131
	r3	0.673	0.189	0.221
	r4	-0.144	0.0277	-0.061

- LER R2 is very large.

1 unit (R2)=4.1×10^{-4}m

K. Ohmi

Possible scenario

- Remaining R2 of LER at IP even after the optics correction is very large.
- But, it can not be corrected by the tuning knob due to the side effect of the knob.
  - Belle solenoid compensation is not good?
    - Change the solenoid field slightly?
    - Re-consider the method of optics correction?

D. Zhou, K. Ohmi, Y. Seimiya, Y. Ohnishi

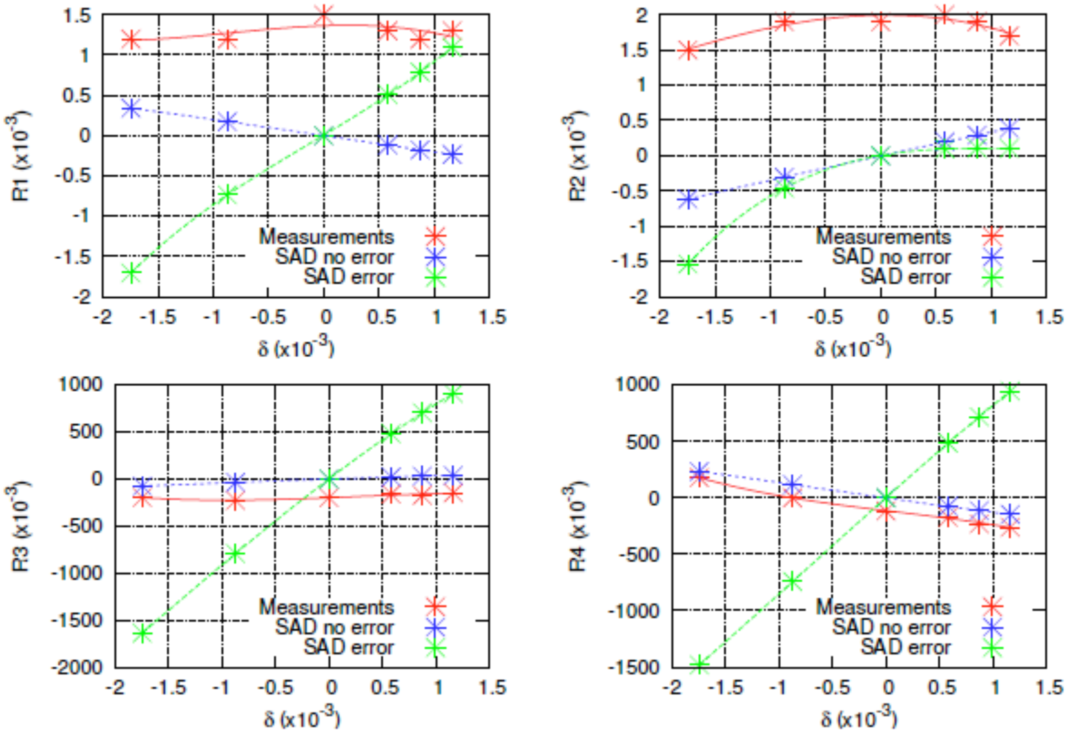


Figure 3: X-Y coupling parameters as function of momentum deviation

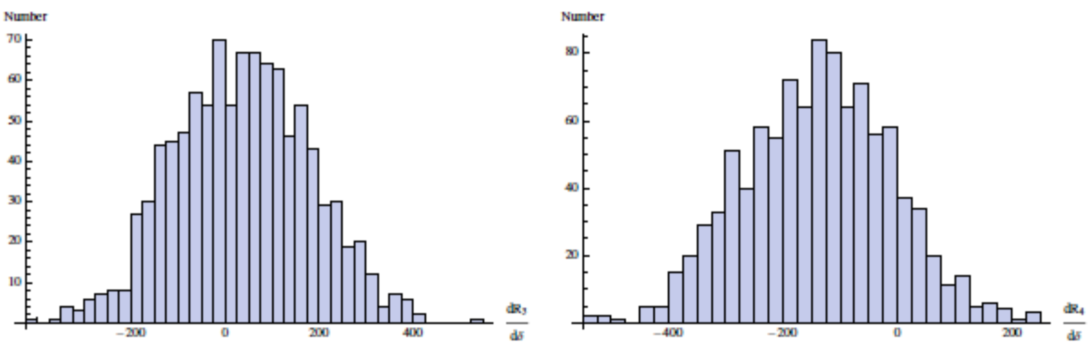
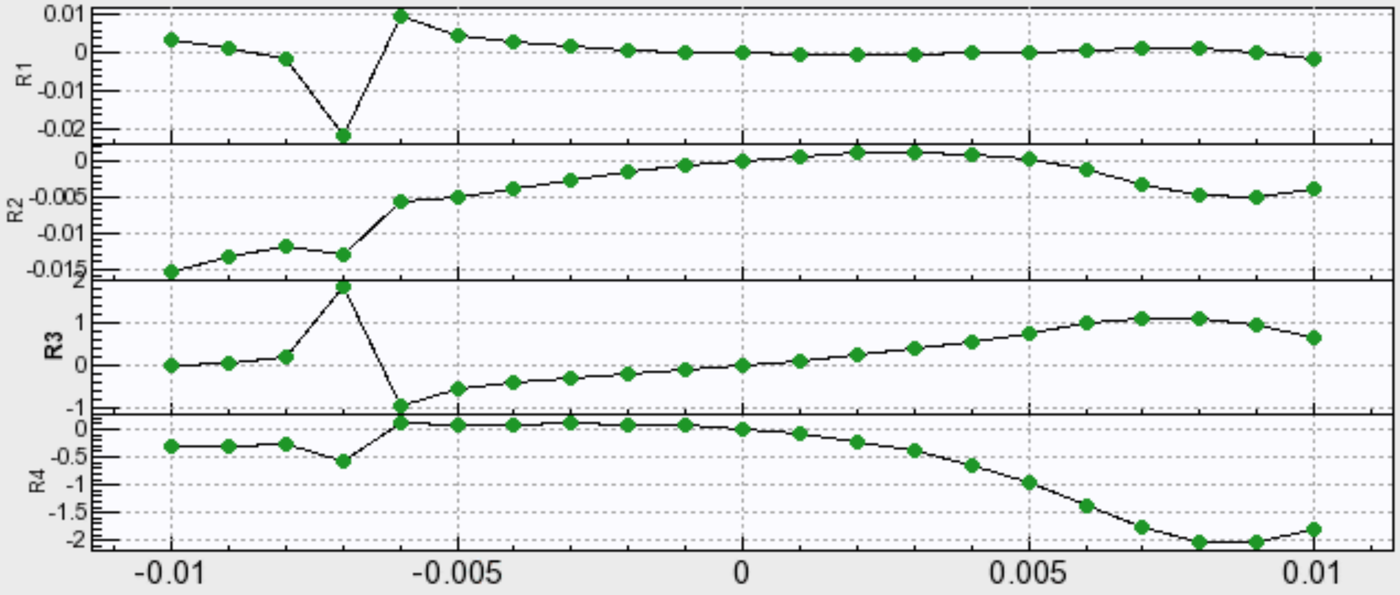


Figure 4: Histogram of $\partial r_3/\partial\delta$ and $\partial r_4/\partial\delta$ with 1000 seeds

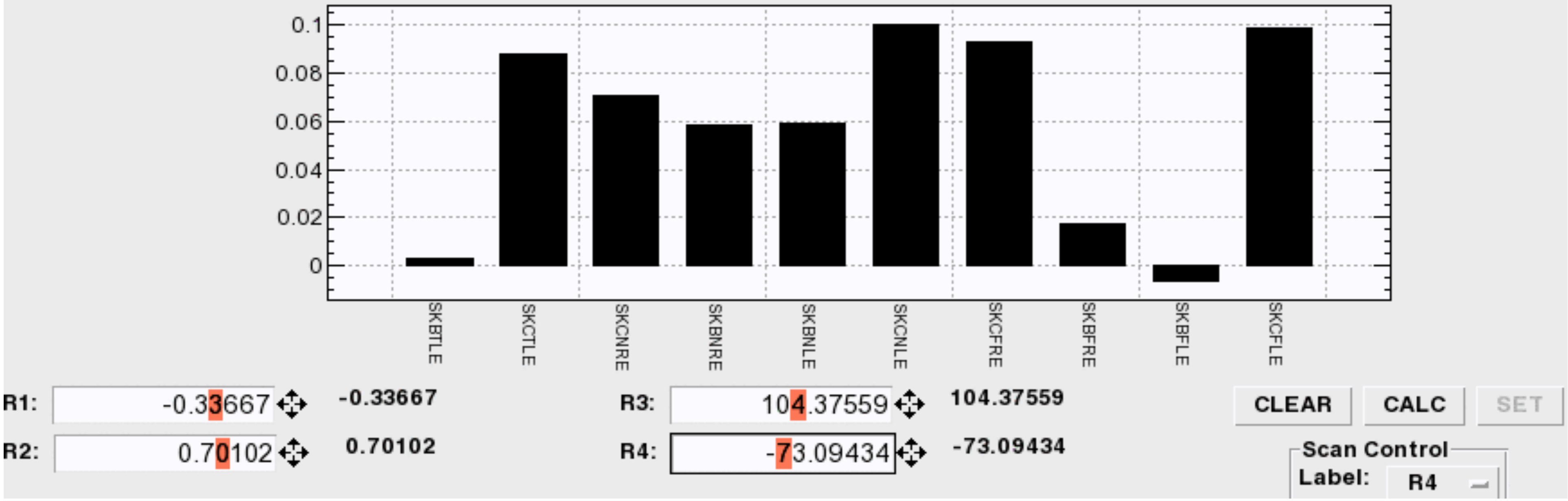
$$\begin{pmatrix} r_{1N}^* & r_{2N}^* \\ r_{3N}^* & r_{4N}^* \end{pmatrix} = \begin{pmatrix} r_1^*\sqrt{\beta_x^*/\beta_y^*} & r_2^*/\sqrt{\beta_x^*\beta_y^*} \\ r_3^*\sqrt{\beta_x^*\beta_y^*} & r_4^*\sqrt{\beta_y^*/\beta_x^*} \end{pmatrix}$$

$$\sqrt{\beta_x^*\beta_y^*} \cong 0.094\mathrm{m}$$

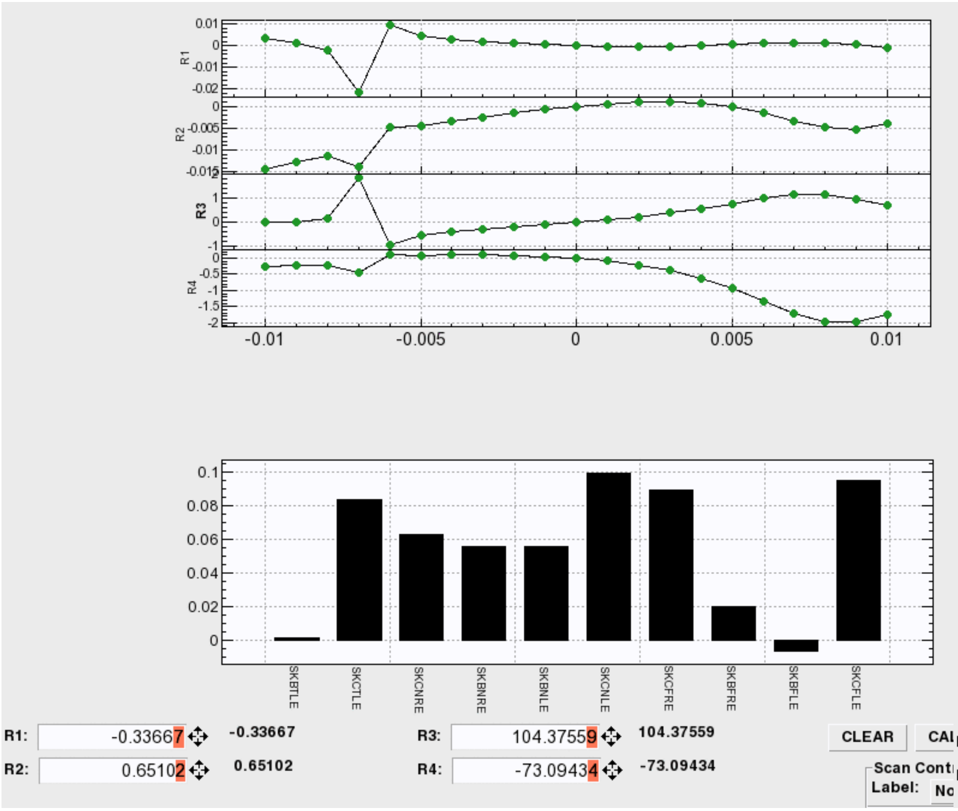
$$\sqrt{\beta_y^* / \beta_x^*} \cong 0.063$$



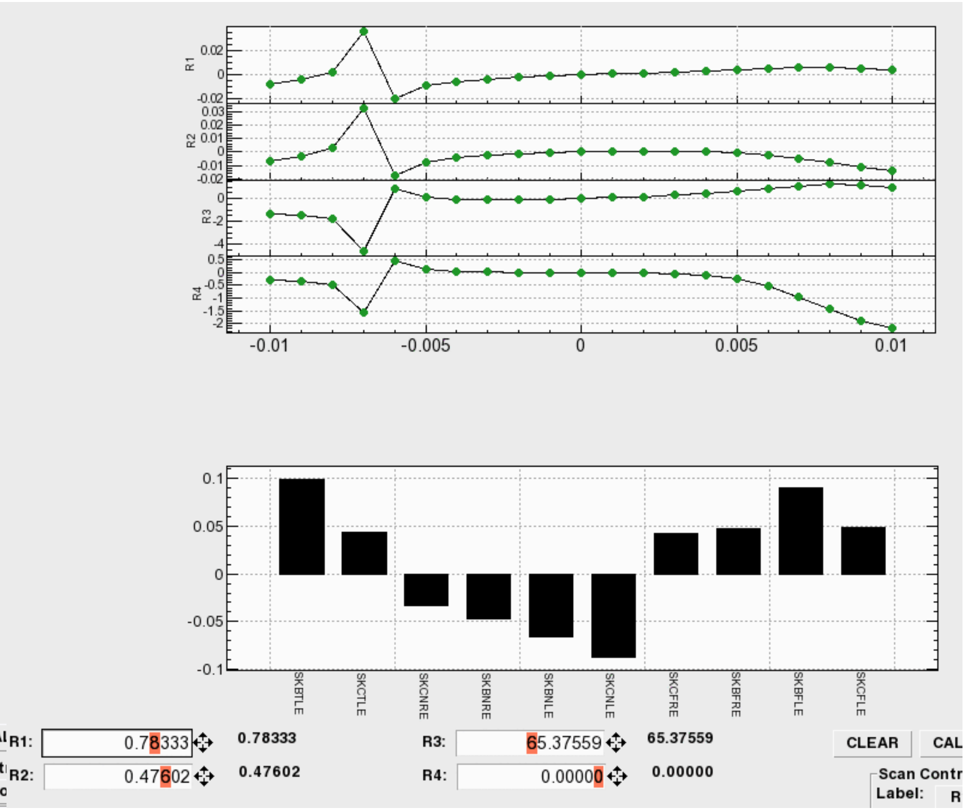
HER coupling chromaticity scan panel



R-chromaticity knob (HER)

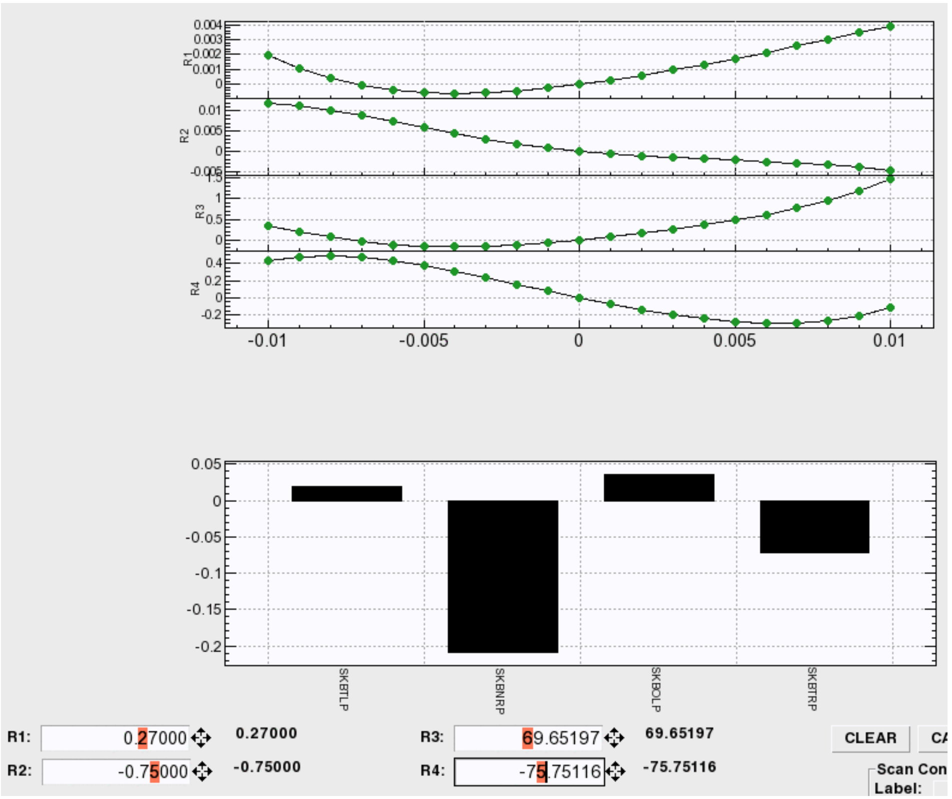


5/3 evening

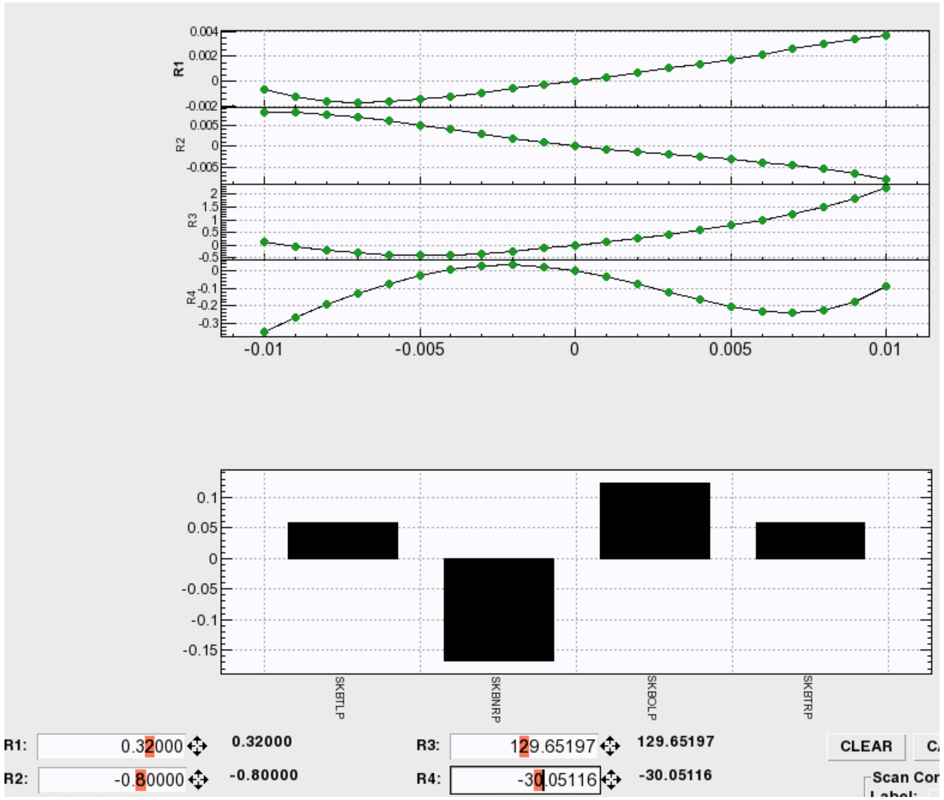


5/6 morning

R-chromaticity knob (LER)



5/3 evening



5/6 morning