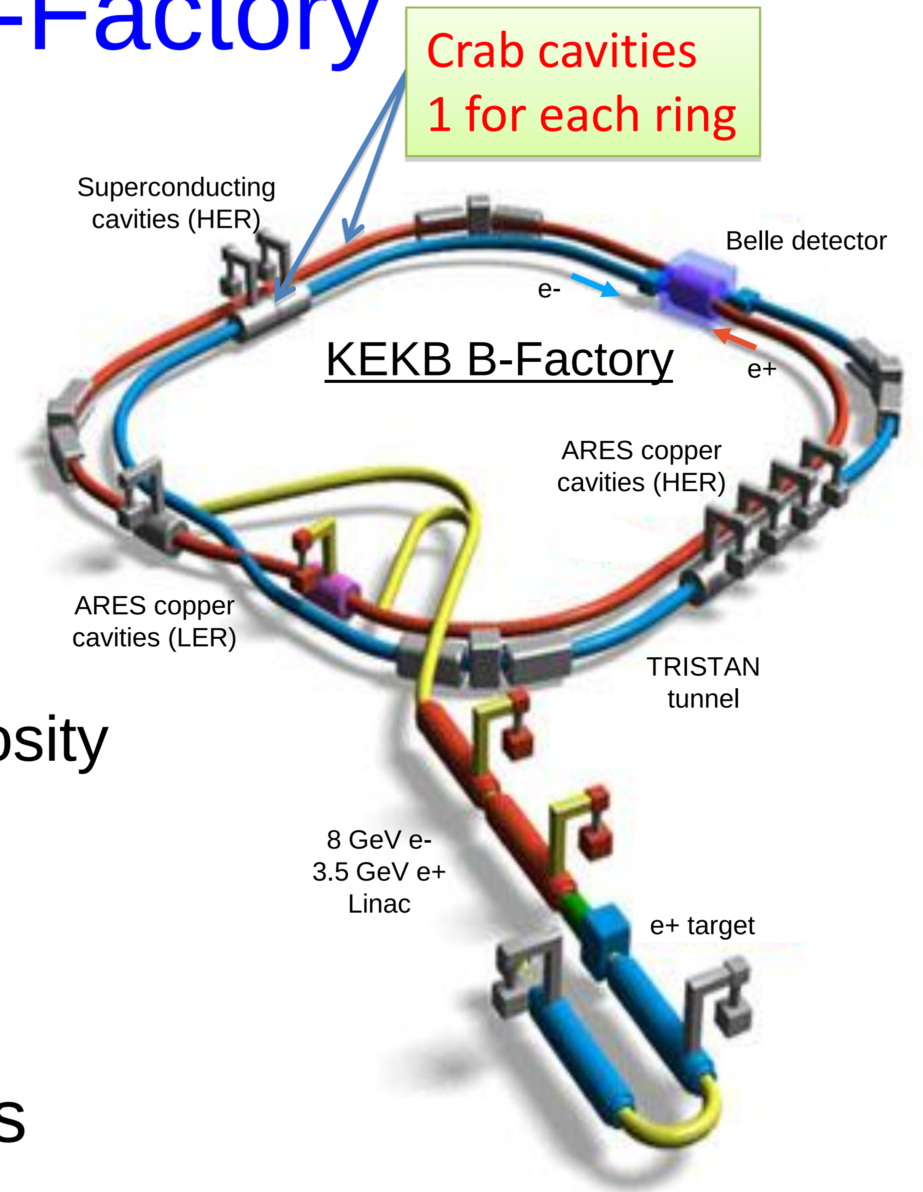
Recent progress of KEKB

Y. Funakoshi
for the KEKB commissioning group

KEKB B-Factory



♦World-highest Peak Luminosity

- $2.11 \times 10^{34} cm^{-2}s^{-1}$
- Twice as high as design value

♦World-highest Integrated Luminosity

- Total: $1010 fb^{-1}$ as of Dec. 24 2009

♦Crab crossing

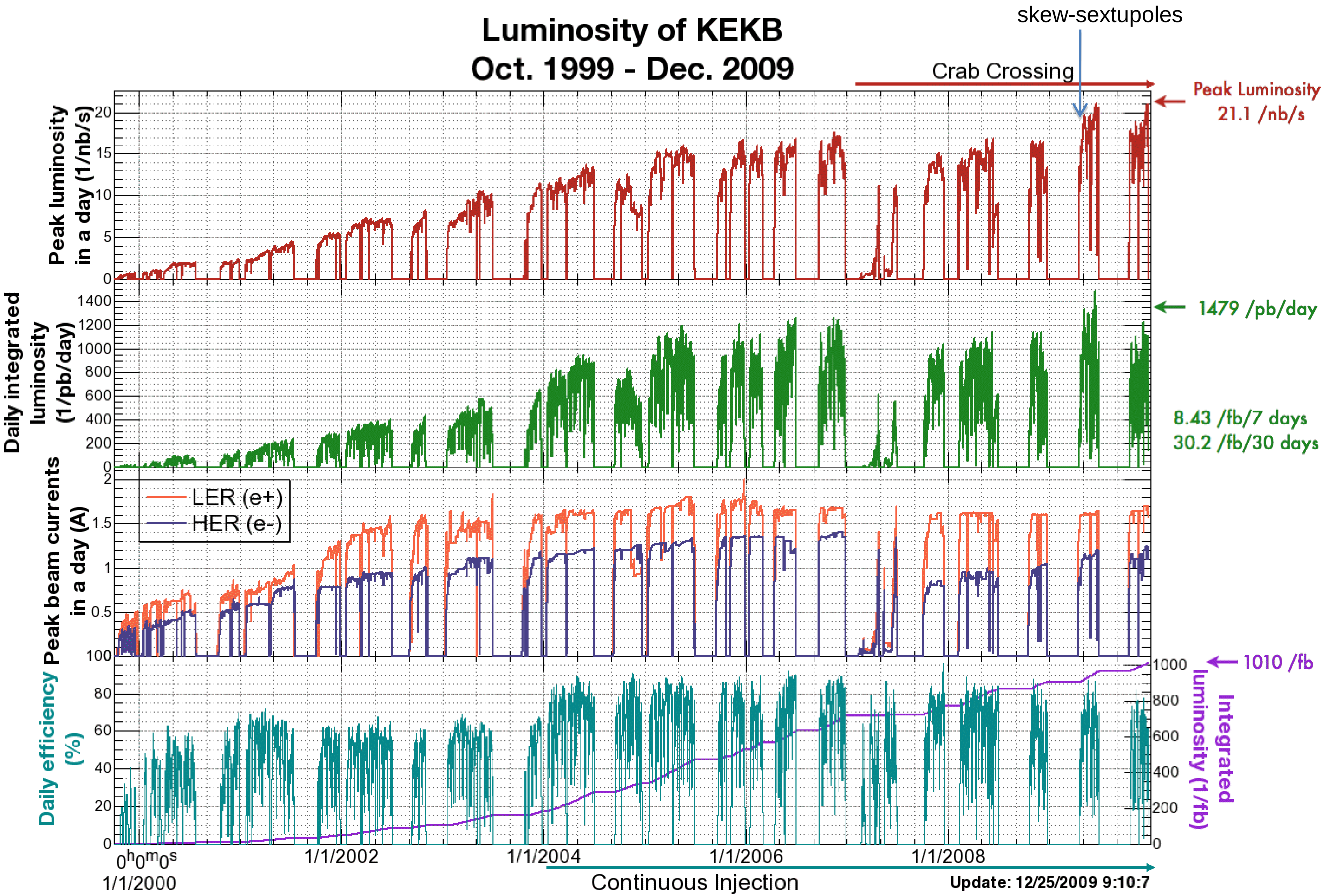
♦Skew-sextupole magnets

Finally two crab cavities were installed in KEKB one for each ring in January 2007

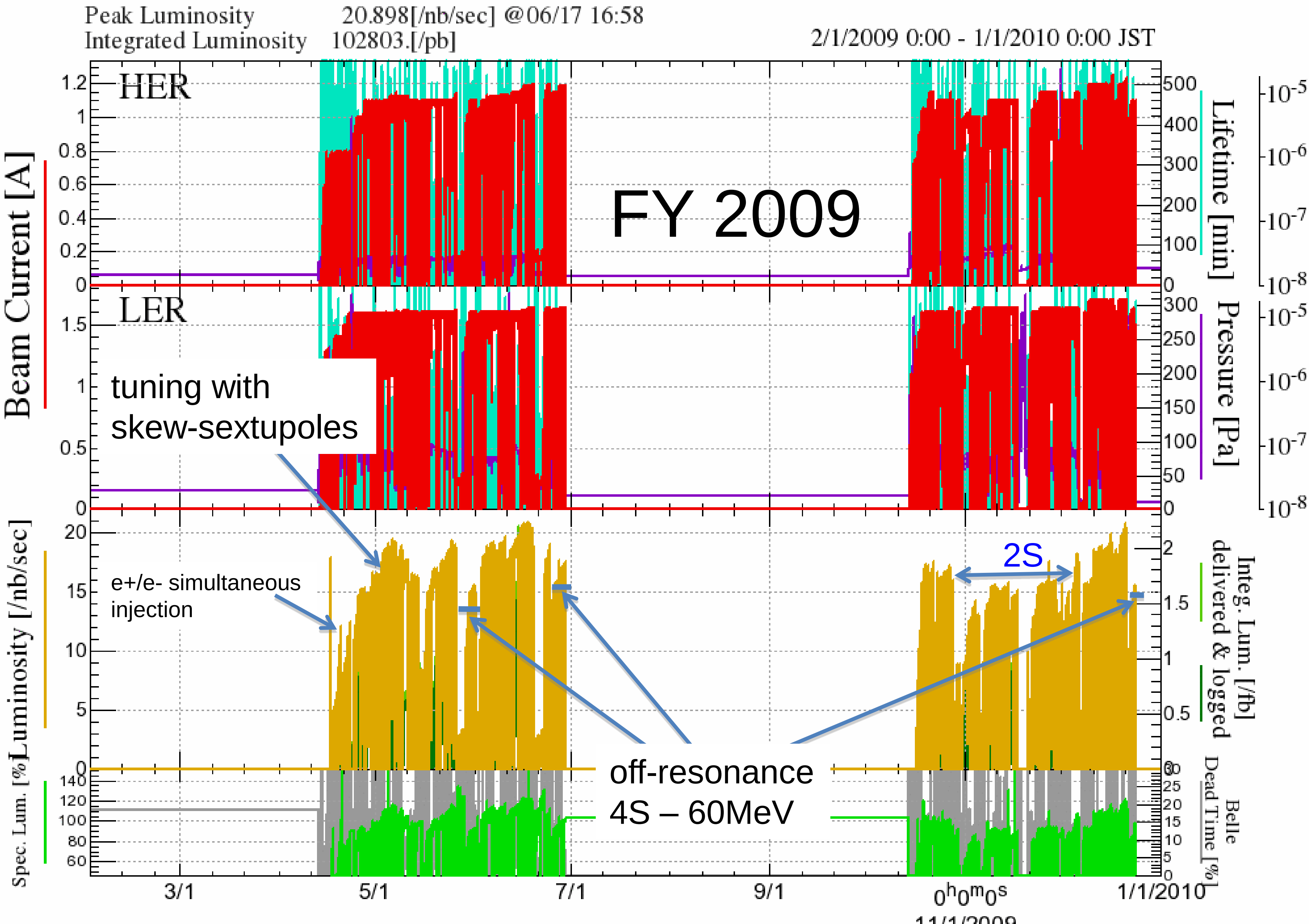
HER (e−, 8 GeV)

LER (e+, 3.5 GeV)

…..after 13 years’ R&D from 1994



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



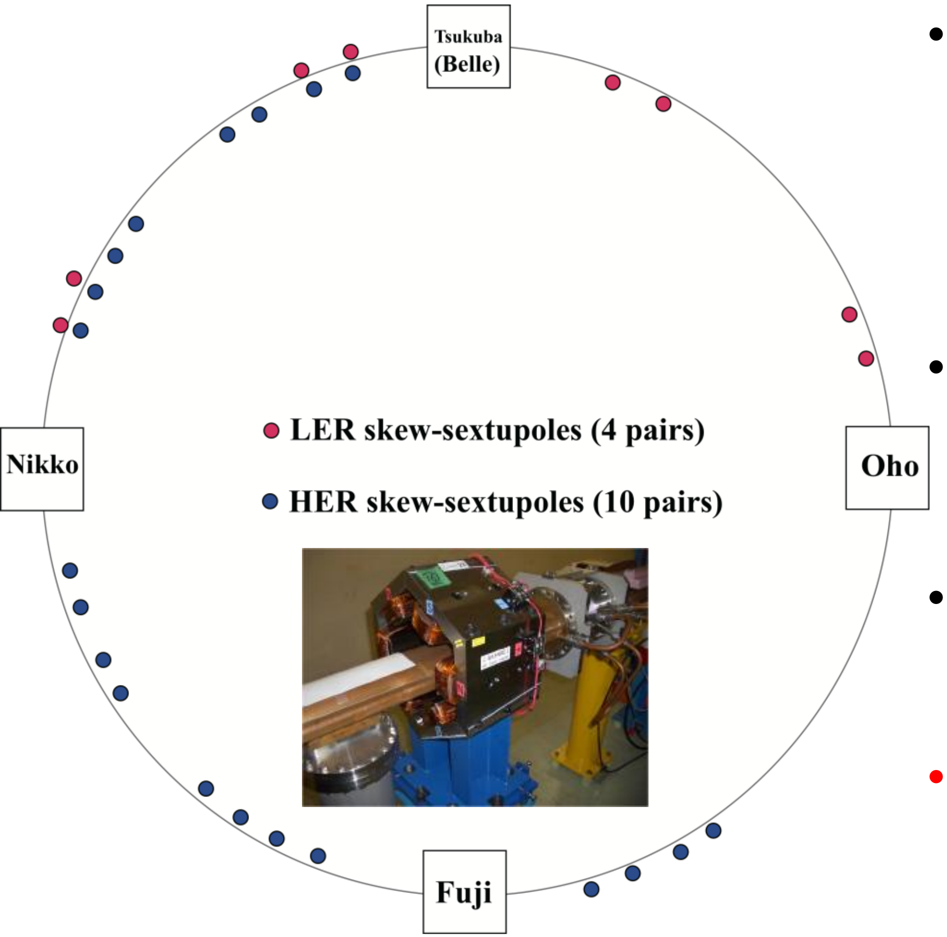
KEKB was operated at Y(5S), Y(2S) and off-resonance(4S-60MeV).

Machine parameters

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

Tuning with skew-sextupole magnets

Chromaticity of x-y coupling at IP



- Ohmi et al. showed that the linear chromaticity of x-y coupling 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 were installed during winter shutdown 2009.
- The skew sextuples are very effective to increase the luminosity at KEKB.
- The gain of the luminosity by these magnets is ~15%.

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

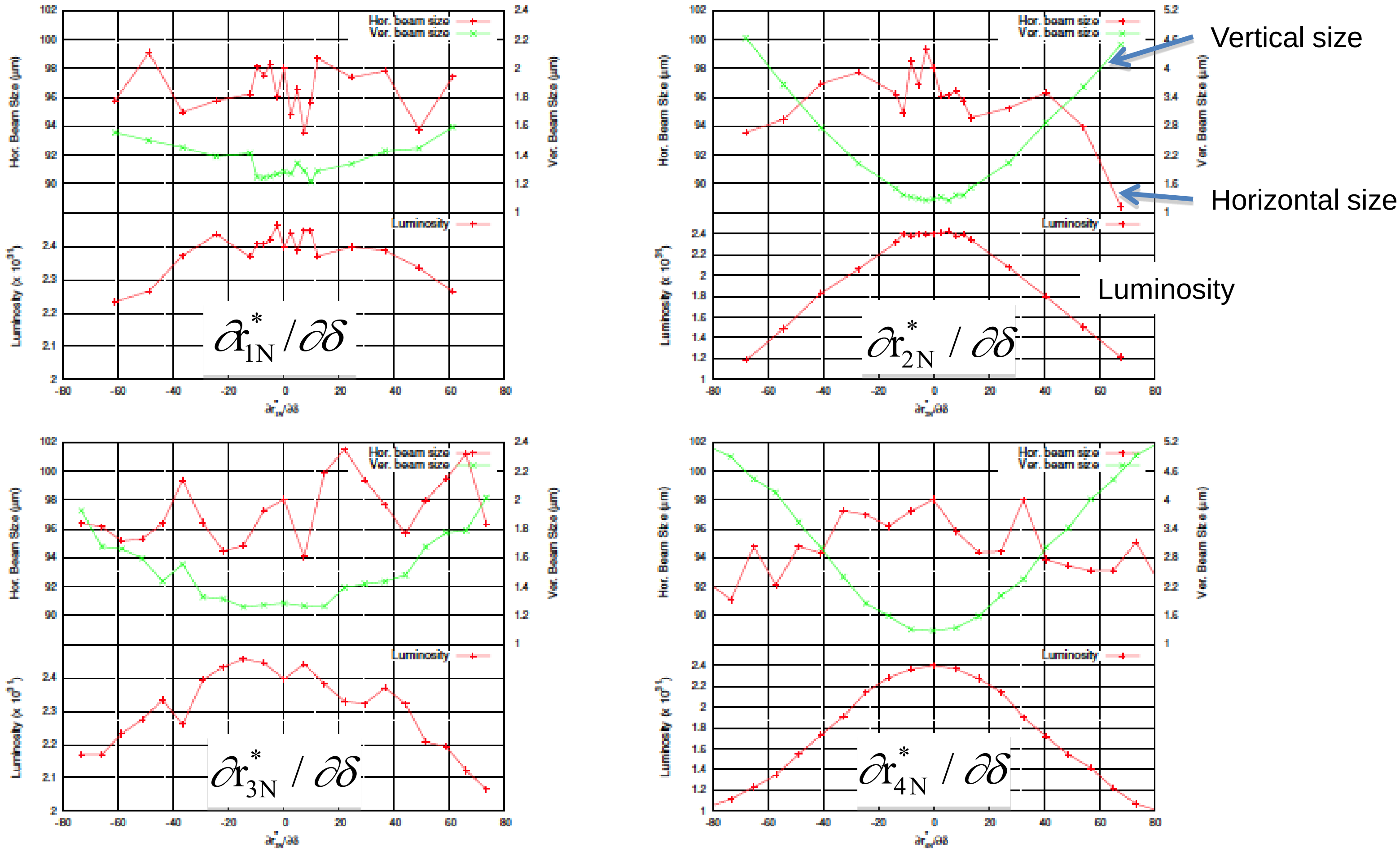


Figure 8: Scan of first order chromaticity of coupling parameters at IP (Top left: $\partial r^*_{1N}/\partial\delta$, Top right: $\partial r^*_{2N}/\partial\delta$, Bottom left: $\partial r^*_{3N}/\partial\delta$, Bottom right: $\partial r^*_{4N}/\partial\delta$)

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

Definition of x-y coupling parameters (SAD notation)

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

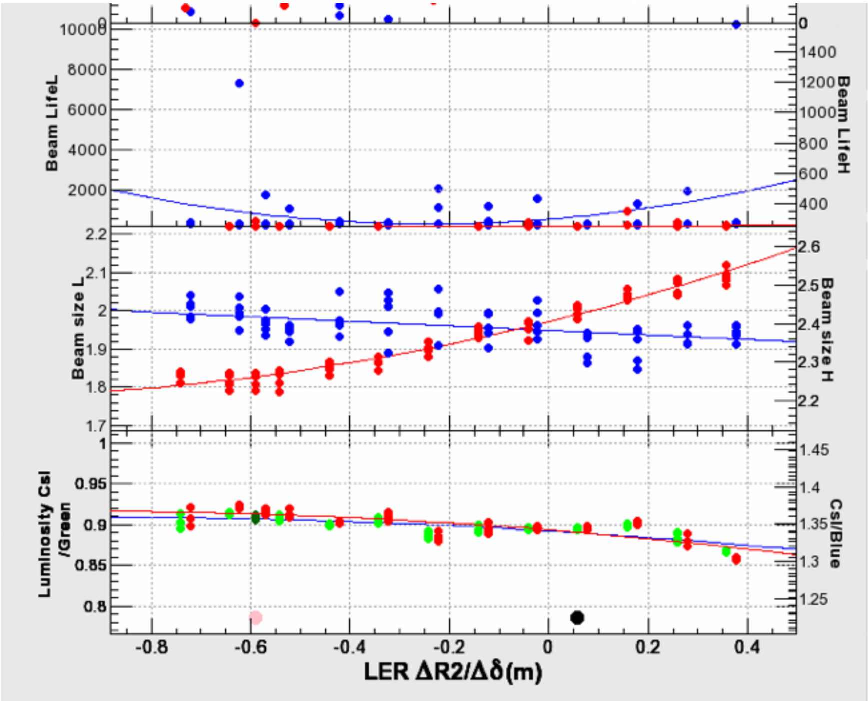
$$T(s) = \begin{pmatrix} \mu I & SR^t S \\ R & \mu I \end{pmatrix} = \begin{pmatrix} \mu & 0 & -R_4 & R_2 \\ 0 & \mu & R_3 & -R_1 \\ R_1 & R_2 & \mu & 0 \\ R_3 & R_4 & 0 & \mu \end{pmatrix}$$

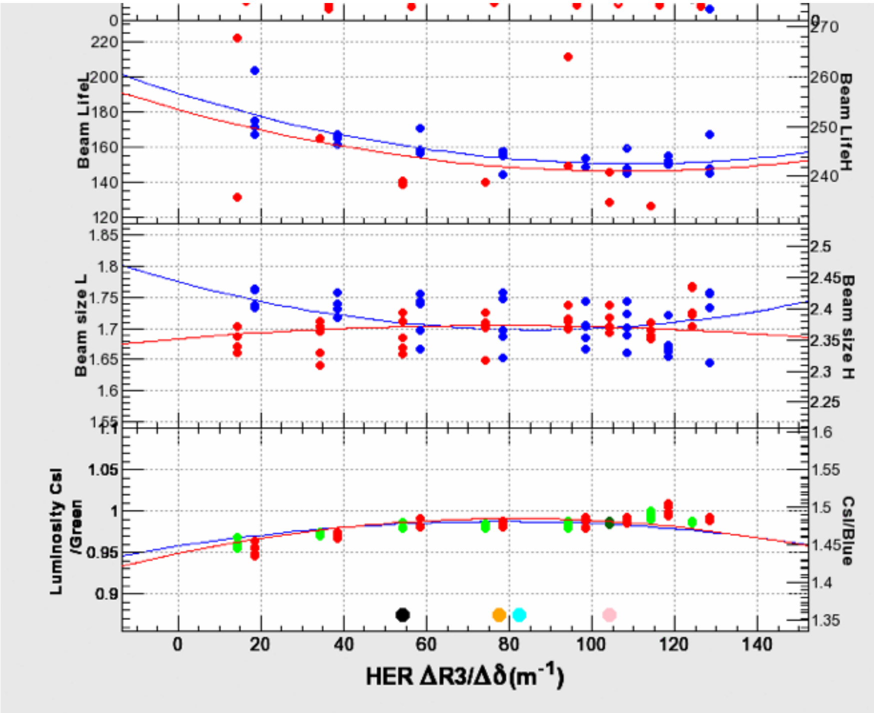
$$S = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \quad \mu^2 + \det R = 1$$

Normal (decoupled) coordinate

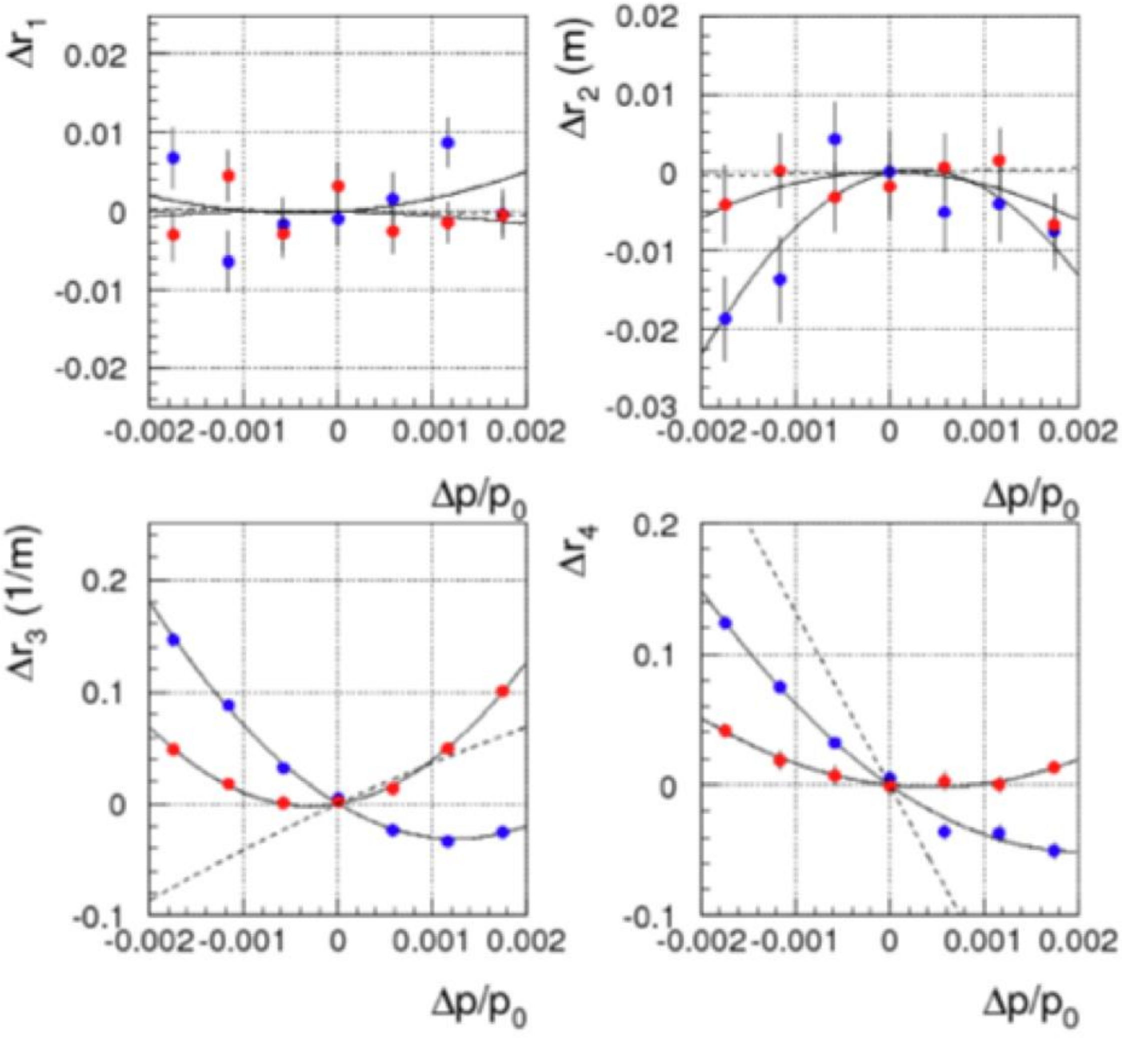
Usual coordinate

Examples of scan of chromatic x-y coupling at IP





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



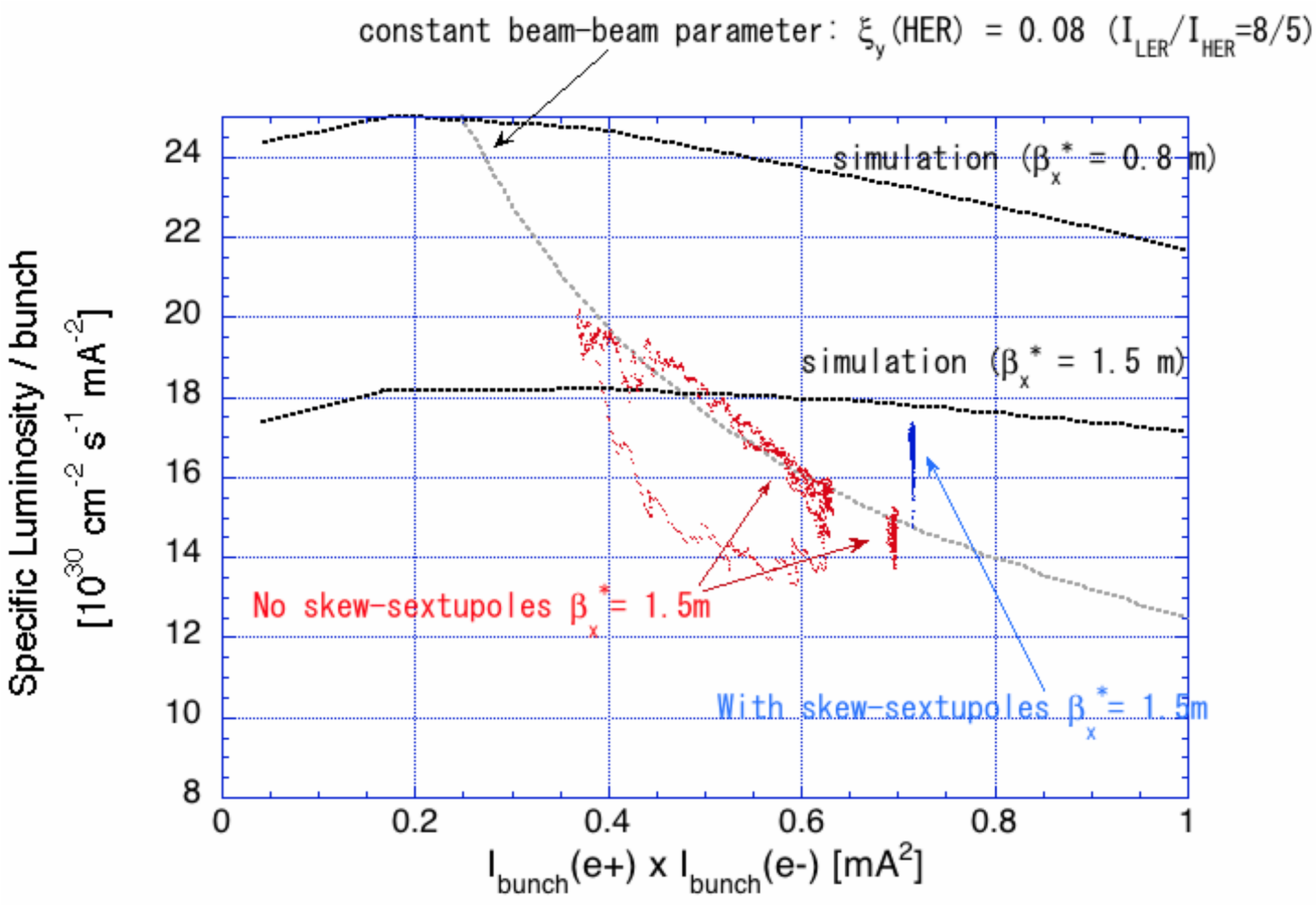
blue: without skew-sextuples

red: with skew-sextuples (after luminosity tuning)

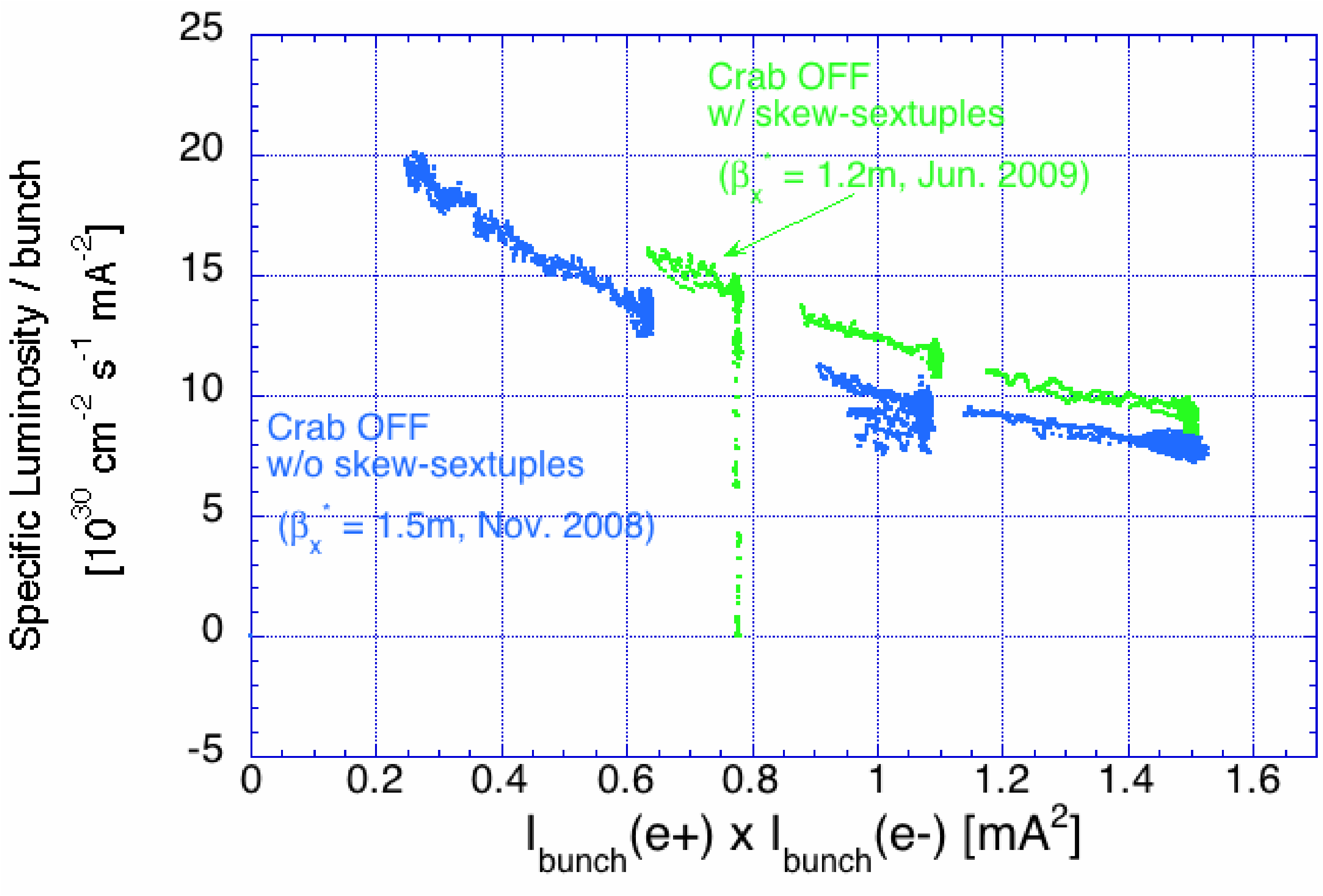
dotted line: model optics without machine errors

Y. Ohnishi

Effectiveness of skew-sextupole magnets (crab on)

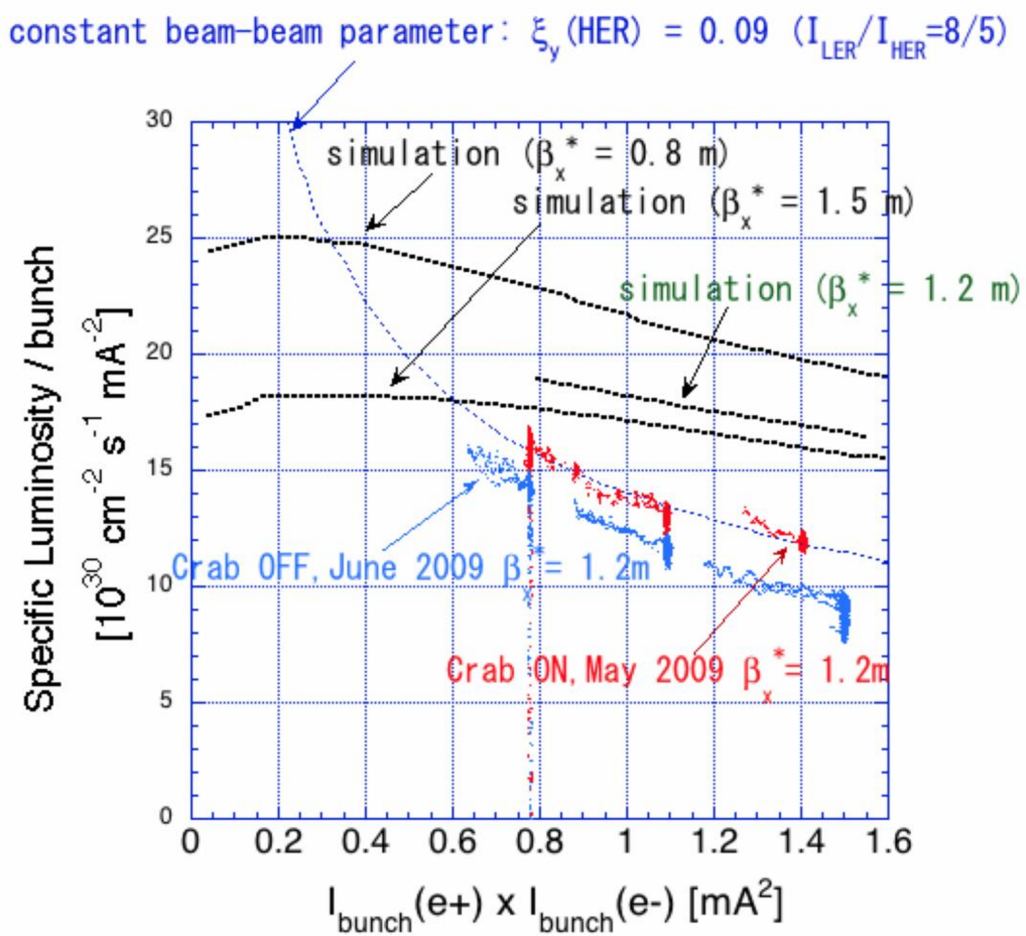


Effectiveness of skew-sextupole magnets (crab off)



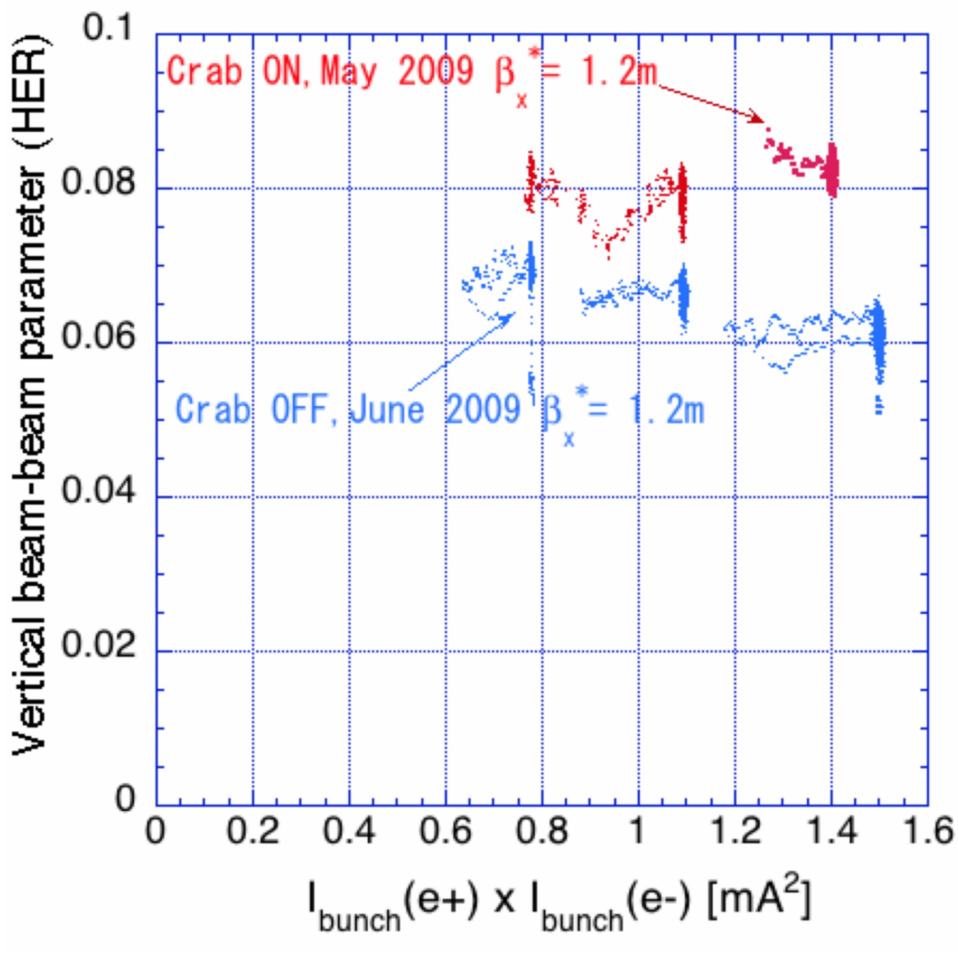
Effect of the crab cavities on the luminosity and the beam-beam parameter

Specific luminosity (crab on/off)



Luminosity improvement by crab cavities is about 20%.
Geometrical loss due to the crossing angle is about 11%.

Beam-beam parameter (crab on/off)



	Crab on	Crab off
R_L	0.828	0.763
$R_{\xi y}$(HER)	1.15	0.993

Calculation of beam-beam parameter

- Reduction factor for beam-beam parameter

$$\xi_y = R_{\xi_y} \xi_{y0} \qquad \xi_{y0} = \frac{r_e}{2\pi\gamma} \frac{\beta_y^* N}{\sigma_y^* \left(\sigma_x^* + \sigma_y^*\right)}$$

  – 2 sources of reduction
    - hourglass effect and finite crossing angle

$$R_{\xi_y} = \int_{-\infty}^{\infty} \sqrt{1 + \left(\frac{z/2}{\beta_y^*}\right)^2} f_y\left(x, \sigma_x, \sigma_y\right) \rho(z) dz$$

Montague's factor

$$f_y\left(x,\sigma_x,\sigma_y\right) = \frac{k}{k-1}\left[\left(1 - e^{-\frac{x^2}{2\sigma_x^2}} \frac{1}{k}\right) + \frac{i\sqrt{\pi}x}{\sigma_x\sqrt{2\left(1-k^2\right)}}\left\{ w\left(\frac{x}{\sigma_x\sqrt{2\left(1-k^2\right)}}\right) - e^{-\frac{x^2}{2\sigma_x^2}} w\left(\frac{kx}{\sigma_x\sqrt{2\left(1-k^2\right)}}\right)\right\}\right]$$

$$k = \frac{\sigma_y}{\sigma_x}$$

$$\rho(z) = \frac{1}{\sqrt{2\pi}\sigma_z} e^{-\frac{z^2}{2\sigma_z^2}}$$

Calculation of beam-beam parameter [cont'd]

- Reduction factor for luminosity

$$R_L \equiv \frac{L}{L_0} = \sqrt{\frac{2}{\pi}} a e^b K_0(b)$$

$$a = \frac{\beta_y^*}{\sqrt{2}\sigma_z}, \quad b = a^2\left[1 + \left(\frac{\sigma_z}{\sigma_x^*}\tan\phi\right)^2\right]$$

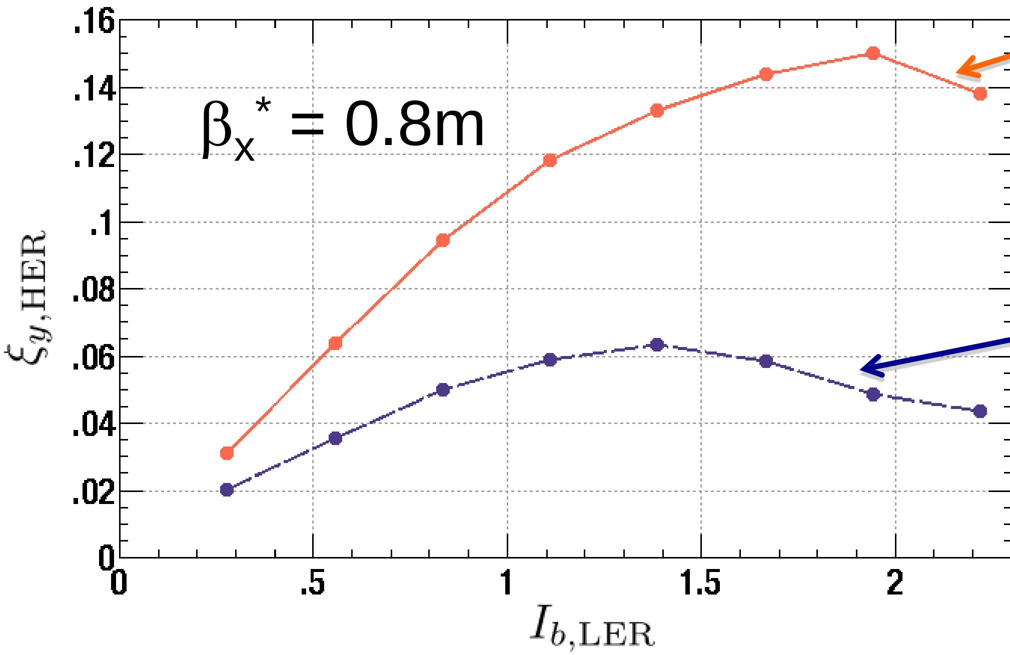
  - Luminosity

$$L = \frac{1}{4\pi}\frac{N^+N^-}{\sigma_x^*\sigma_y^*} f_{col} R_L$$

  - We use calculated values for σ_x^* and calculate σ_y^* and ξ_{y0} from observed luminosity.

Beam-beam parameter (simulation)

- Crab Crossing can boost the beam-beam parameter higher than 0.15 ! (K. Ohmi)



Head-on (crab)

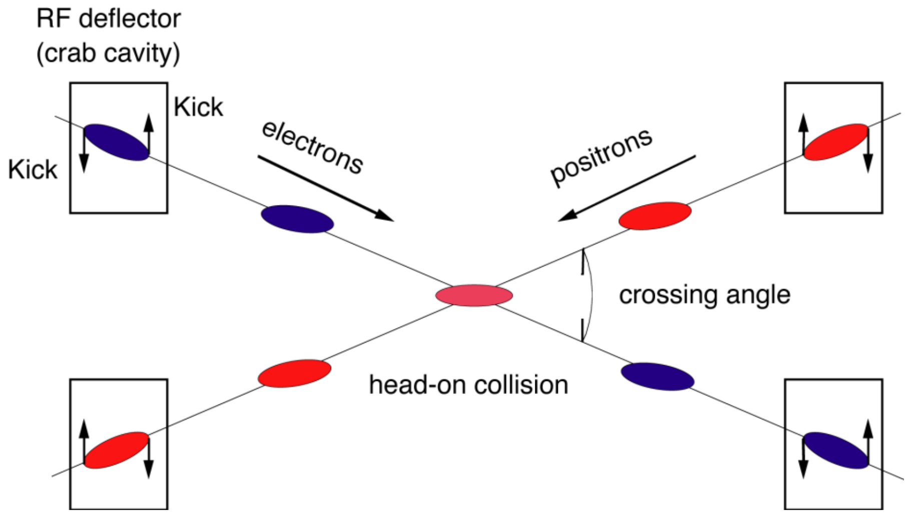
Strong-strong beam-beam simulation

22mrad crossing angle

Head-on

ν_x =.508

} → ξ_y ~0.15



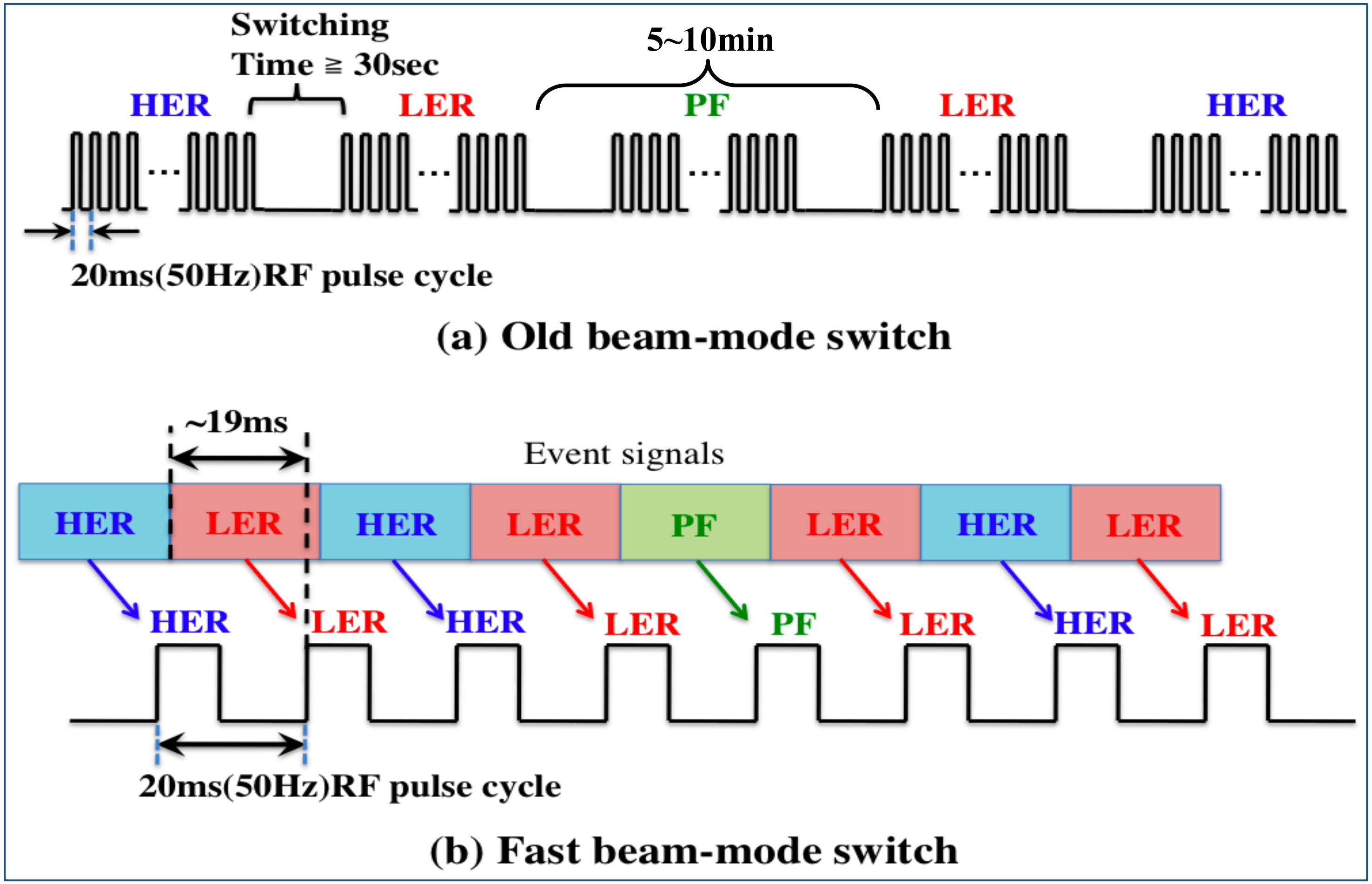
Summary of crab cavity operation

- The crab cavities at KEKB did work and brought the luminosity increase by ~20%.
- The highest luminosity with crab is 2.1 x 10^{34} $cm^{-2}s^{-1}$.
  - Skew-sextupoles
  - Increase of HER beam current by solving the physical aperture problem
- There still exists a large discrepancy between the luminosity achieved and the beam-beam simulation.
  - The simulation predicted that the luminosity would be doubled.
  - Side effects of large tuning knobs to compensate the machine errors?
  - Horizontal dipole oscillation of the beams in collision?

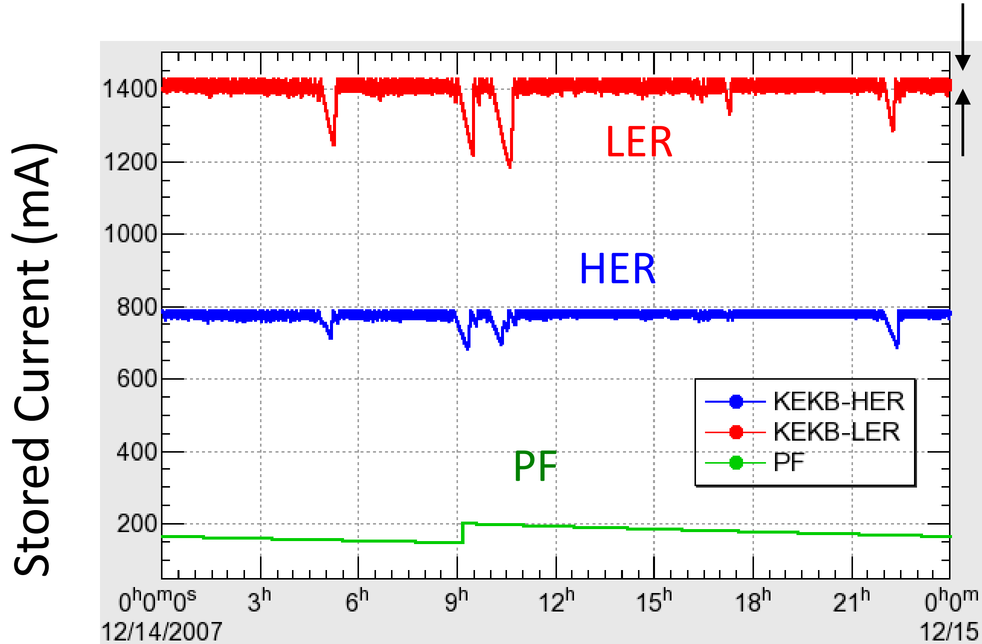
e+/e- simultaneous injection (fast beam mode switching)

- e+/e-/PF(e-) simultaneous injection was finally realized in April 2009.
- e+/e-/PF(e-) simultaneous injection
  - 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.



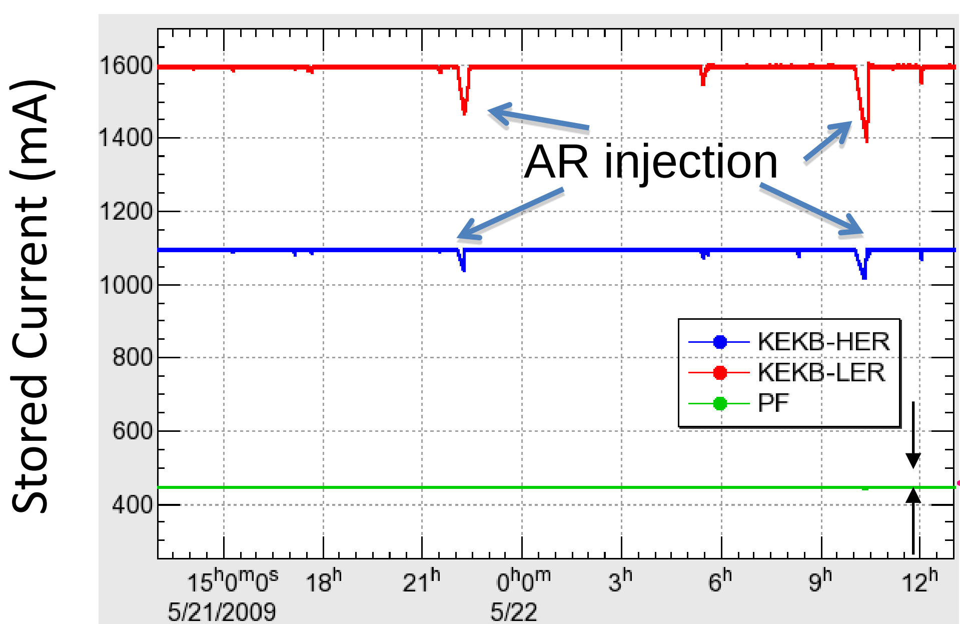
Schematic view of the beam-mode switches.
The block pulses show beam gate timings.



~50mA

Slow switching

One day



< ~1mA

< ~33μA

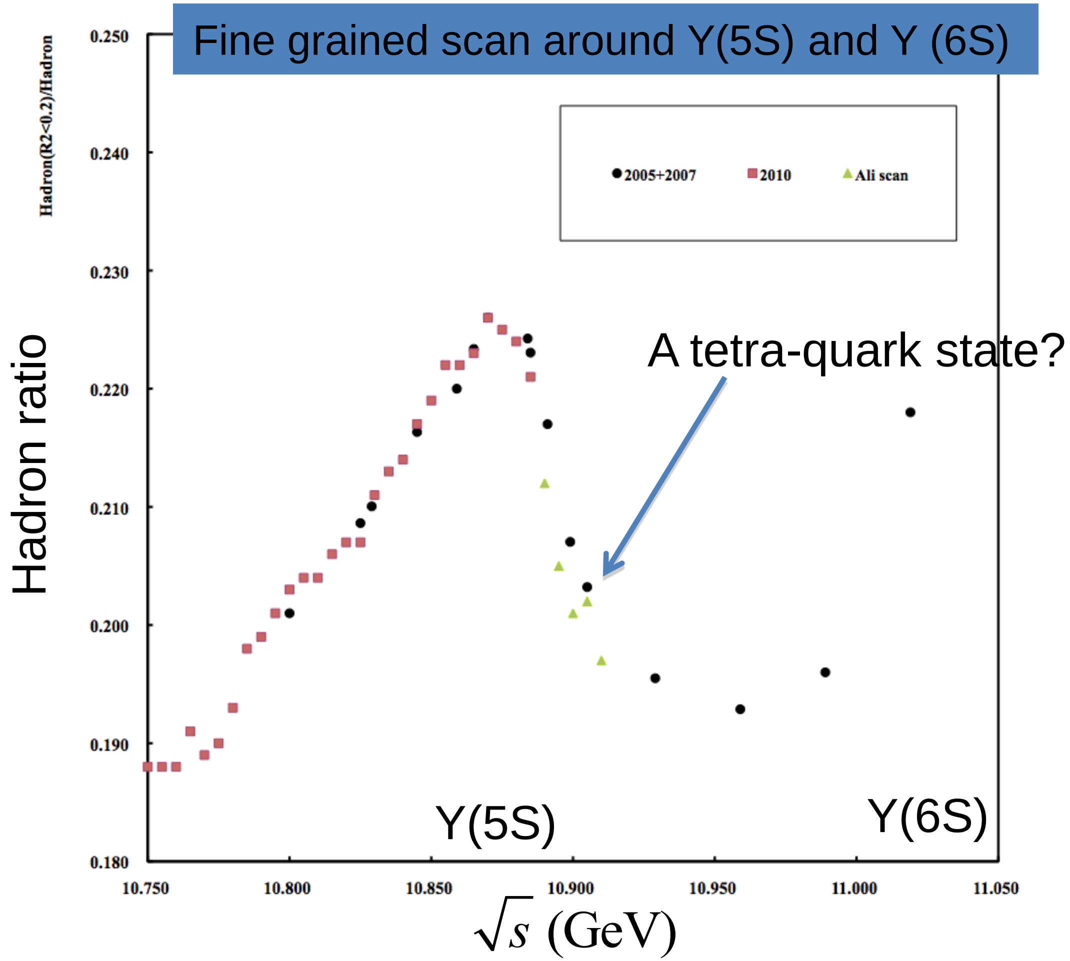
After achievement of pulse-to-pulse switching injection

AR has not participated in the simultaneous injection yet.

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

KEKB operation in 2010

- The KEKB operation was resumed on May 13th.
- The KEKB operation will be terminated at the end of June.
  - Physics operation: energy scan (3 weeks)
  - Machine study: (2 weeks)



Machine studies

- SuperKEKB
  - Vacuum R&D
    - Counter-measures for ECI (pervious talk by Y. Suetsugu)
    - Movable mask, radiation from vacuum chamber etc.
  - RF system
    - High power operation of klystron
    - SCC reverse phase operation
  - Beam monitor system
    - Bunch-by-bunch feedback system
    - BPM signal detection circuit
  - Beam transport
    - Beam abort window

Machine studies [cont'd]

- SuperKEKB (cont'd)
  - Beam behavior, beam dynamics
    - Stability of beam orbit, effects of electron clouds
  - Physics Detector
    - Background study
- KEKB performance
  - e-/e+/PF simultaneous injection
  - 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

Summary and future prospects

- A new luminosity record was made by using skew-sextupole magnets.
- The crab cavities did work and brought the luminosity improvement by about 20%.
- This improvement is still lower than the beam-beam simulation.
- e+/e- simultaneous injection was realized.
- KEKB/Belle has accumulated the integrated luminosity of 1000 fb^{-1}.
- KEKB is being used also as an R&D machine.

- The KEKB operation will be terminated at the end of coming June. We plan to start the construction of SuperKEKB.
- The design luminosity of SuperKEKB is 8 x 10^{35} $cm^{-2}s^{-1}$ (x40 of KEKB). (Talk by M. Masuzawa: FRXBMH01)