Early Commissioning of the luminosity dither system for SuperKEKB

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Collaborators

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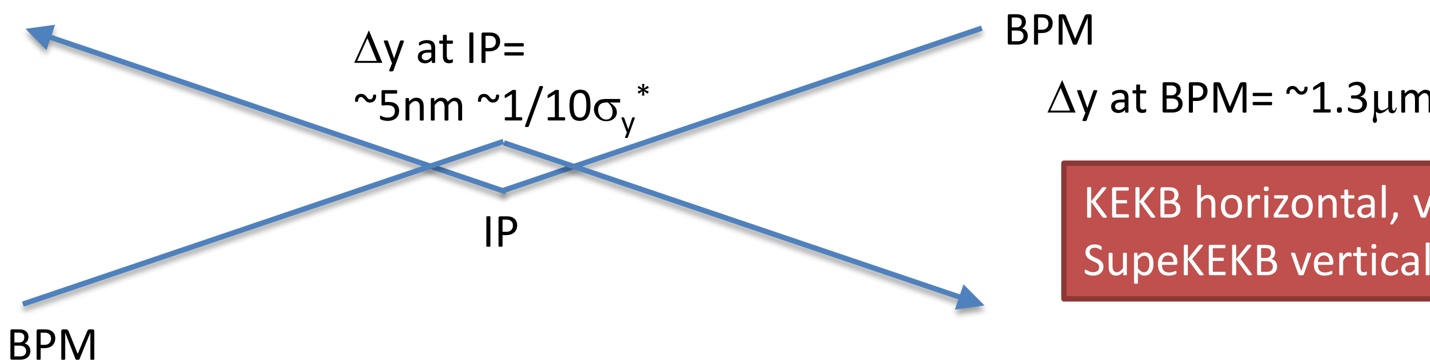
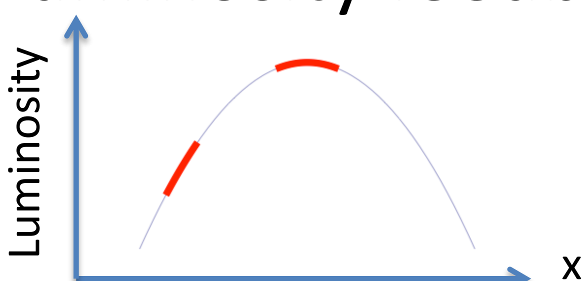
Orbit feedback at IP :Algorism

- Beam-beam deflection (SLC, KEKB)



KEKB horizontal, vertical
SupeKEKB vertical

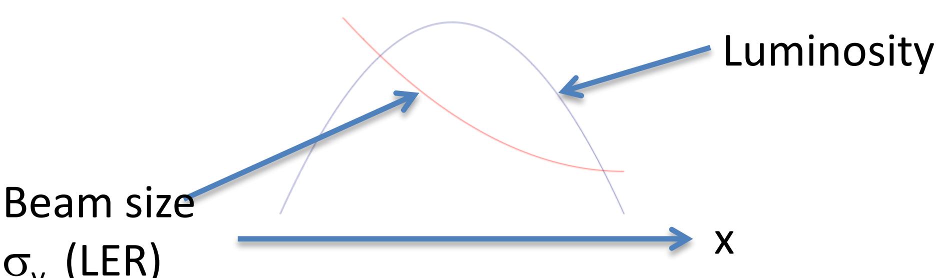
- Luminosity feedback (dithering)(PEP-II)



When we dither the beam at around the peak of the luminosity, the dithering frequency component in the luminosity becomes minimum.

SupeKEKB horizontal

- Beam size feedback (KEKB horizontal w/o crab)



At KEKB before installation of crab cavities, the vertical beam of LER was used for the horizontal orbit feedback at IP.

Need of dithering feedback in SuperKEKB horizontal orbit FB

	KEKB (achieved)		SuperKEKB (design)		
	LER	HER	LER	HER	
ξ_x	0.127	0.102	0.0028	0.0012	
σ_x	147.0	169.7	248.9 (effective)	207.4 (effective)	μm
β_x	1.2	1.2	0.032	0.025	m
ϕ_c	11		41.5		mrad
$\phi_{Piwinski}$	0.45	0.39	23.2	24.6	

In the horizontal direction, we cannot use the orbit feedback based on the beam-beam deflection, due to very small beam-beam parameters.

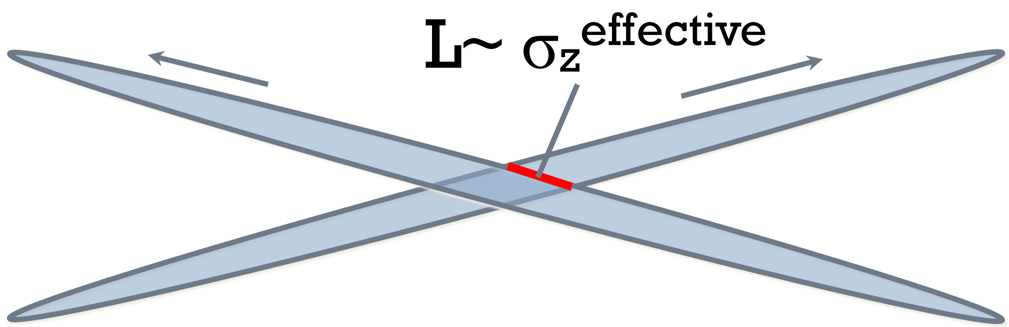
Nano beam scheme

- Luminosity

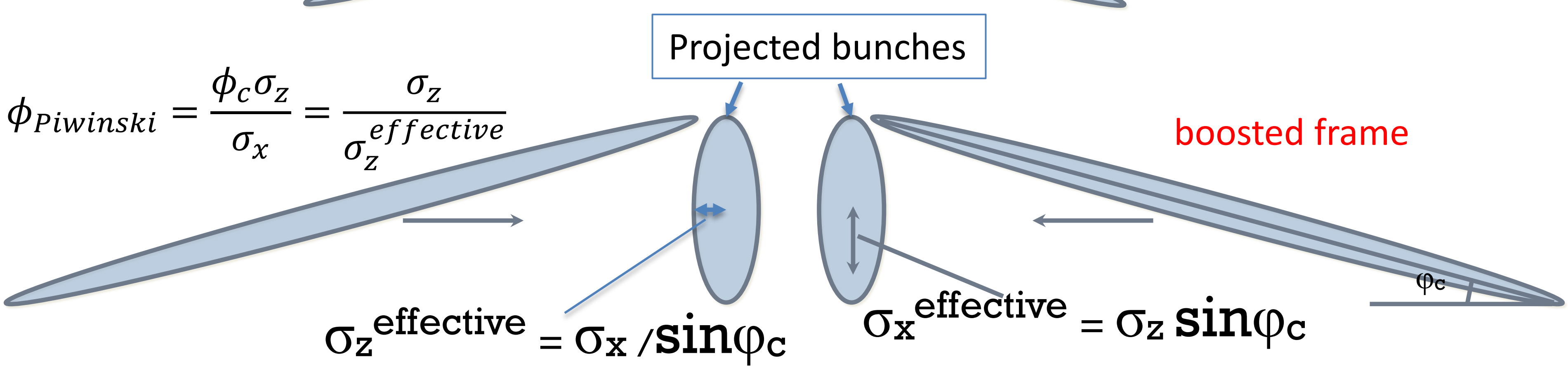
$$L = \frac{1}{2\sqrt{2}\pi} \frac{N^+ N^-}{(sin\phi_c \sigma_z)\sqrt{\sigma_{y+}^2 + \sigma_{y-}^2}} f_{col}$$

- Beam-beam parameter

$$\xi_{y\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta_{y\pm} N_\mp}{(sin\phi_c \sigma_z)\sigma_{y\mp}} \qquad \xi_{x\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta_{x\pm} N_\mp}{(sin\phi_c \sigma_z)^2}$$

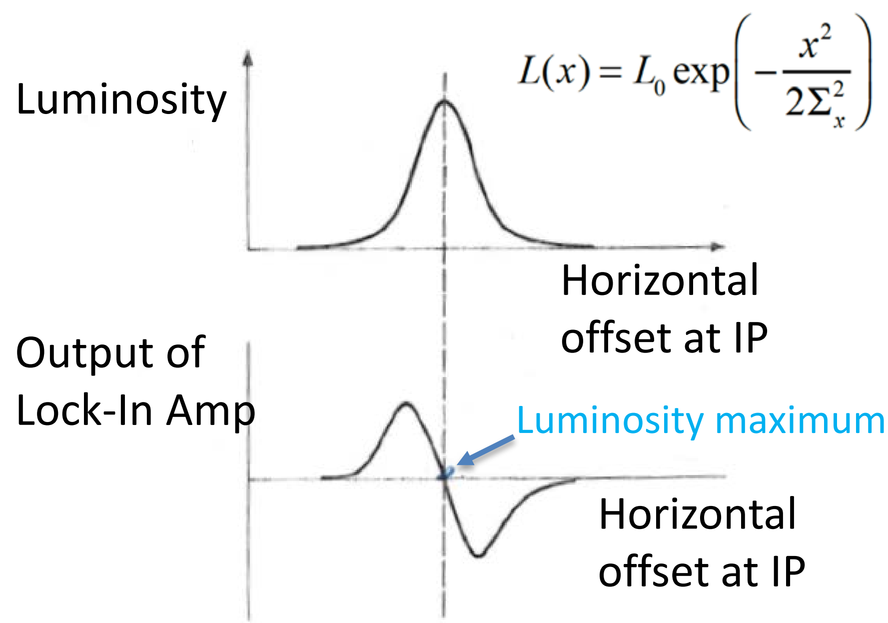


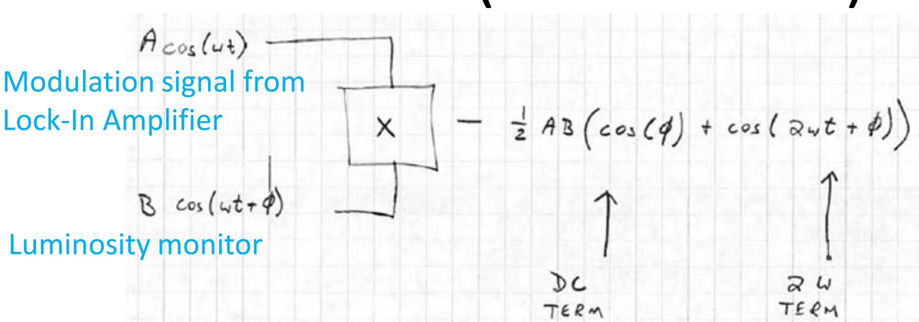
$$\phi_{Piwinski} = \frac{\phi_c \sigma_z}{\sigma_x} = \frac{\sigma_z}{\sigma_z^{effective}}$$



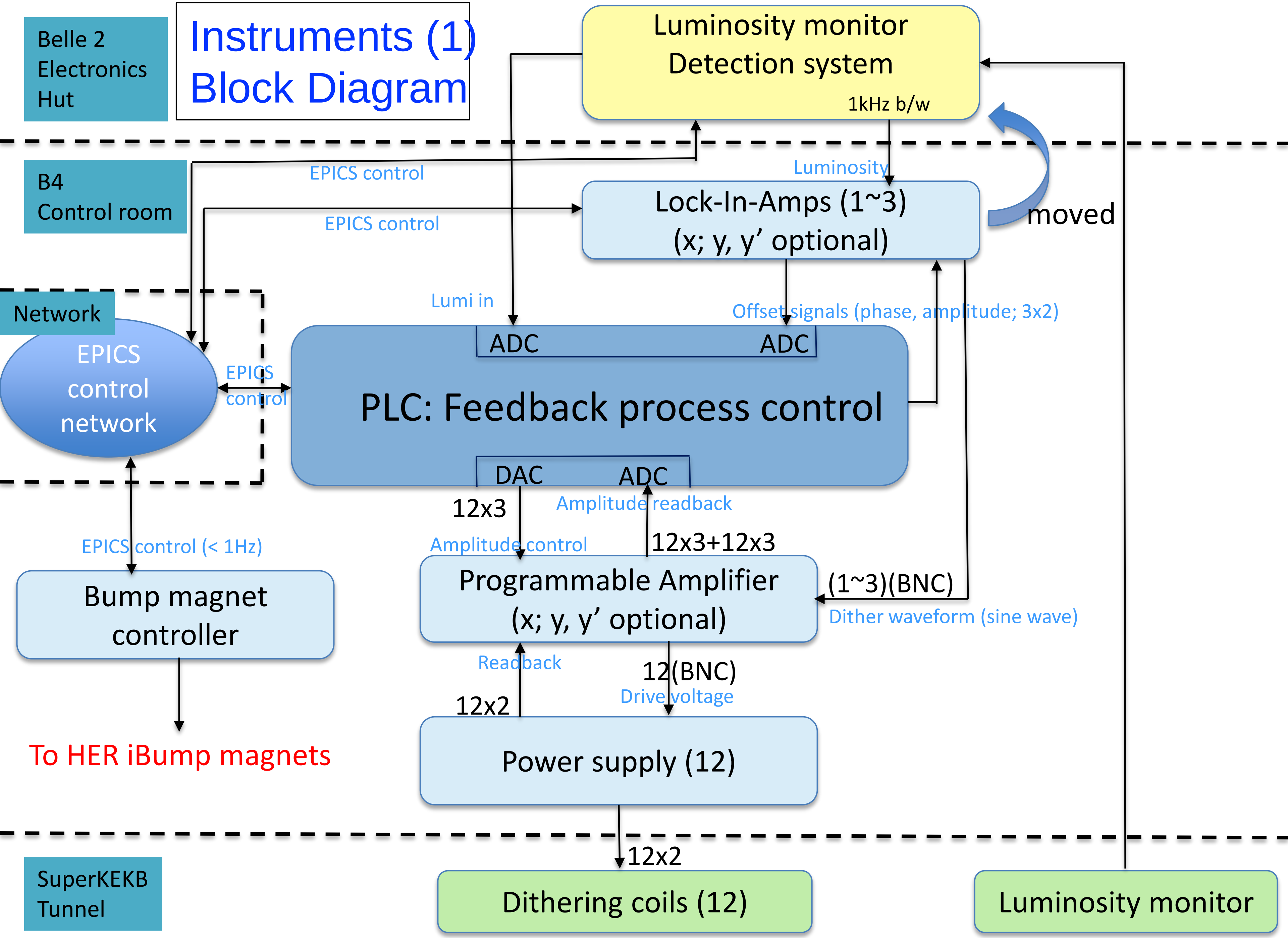
Principle of dither feedback

- Synchronous modulation
  - Modulate the LER beam position at IP at a known frequency (f_{mod}~79Hz) with a horizontal orbit bump.
  - Observe the luminosity modulation with a Lock-In Amplifier.
  - Dither feedback acts so that the output of Lock-In Amp becomes minimum (PI feedback).





Instruments (1) Block Diagram

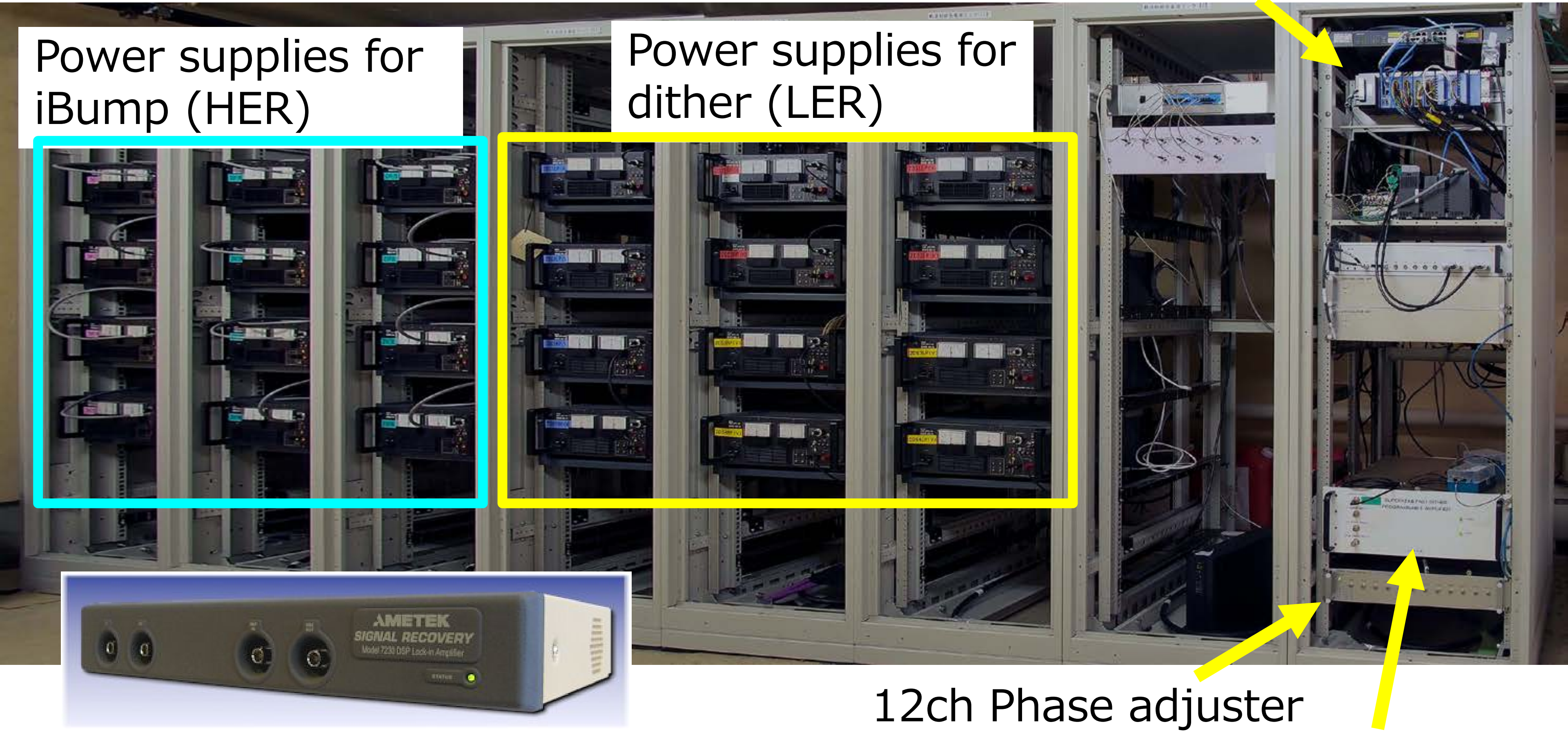


Instruments (2) Photo
Tsukuba B4 control room

PLC (Yokogawa), ADC, DAC

Power supplies for iBump (HER)

Power supplies for dither (LER)



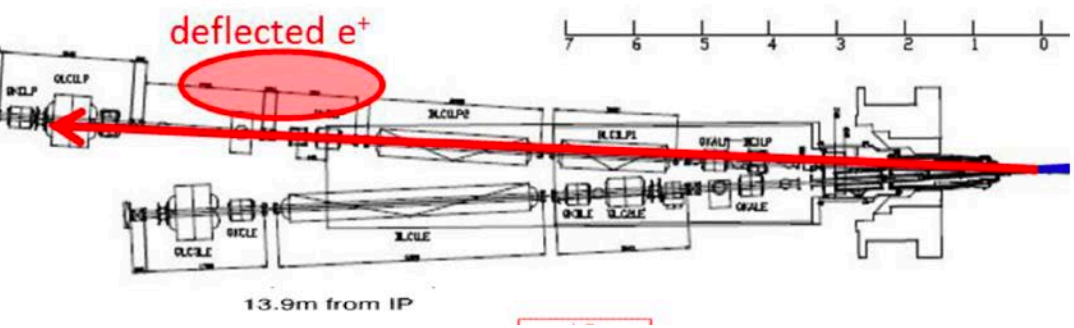
Lock-In Amplifier
Signal Recovery Model 7230 DSP
@Belle 2 Electronics Hut

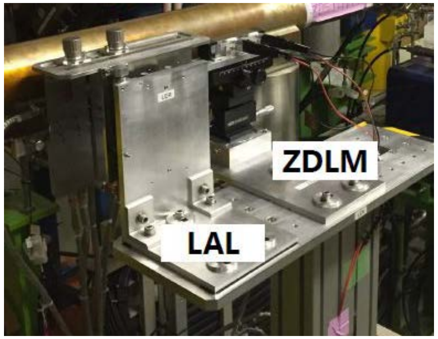
12ch Phase adjuster
12ch Programable amplifier
(fabricated at SLAC)

Instruments (3)
Fast luminosity monitor

- **Two complementary techniques developed at LAL and KEK:**
  - **~ 5x5x0.5 mm^3 single crystal CVD diamond sensors (CVD DS) pairs coupled to fast charge / current amplifiers (LAL group) (LumiBelle 2)**
  - **Cerenkov detector + scintillator (ZDLM group @ KEK)**

  positioned together outside of the beam pipe

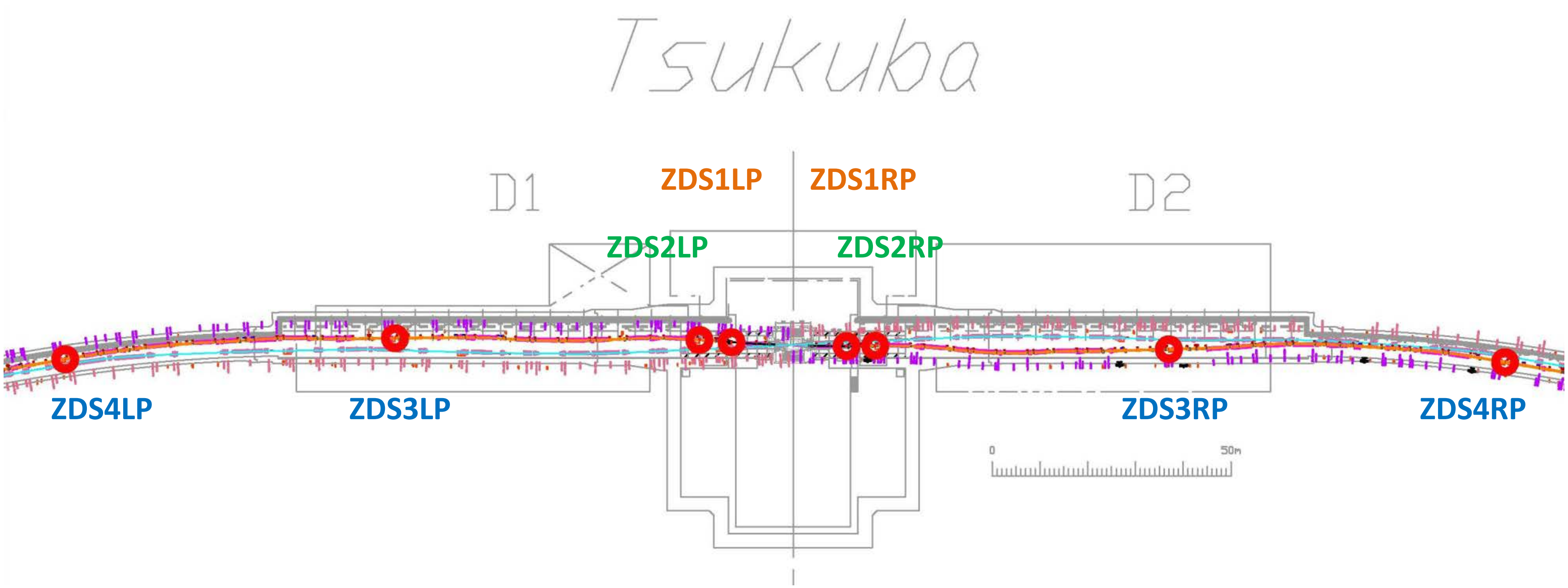




Detects positrons which lost energy due to radiative Bhabha process.

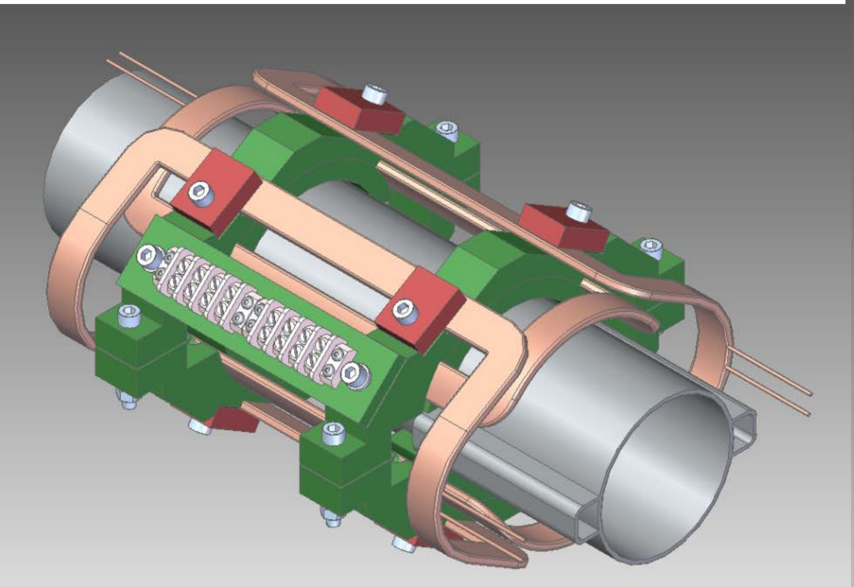
-> P. Bambade's talk

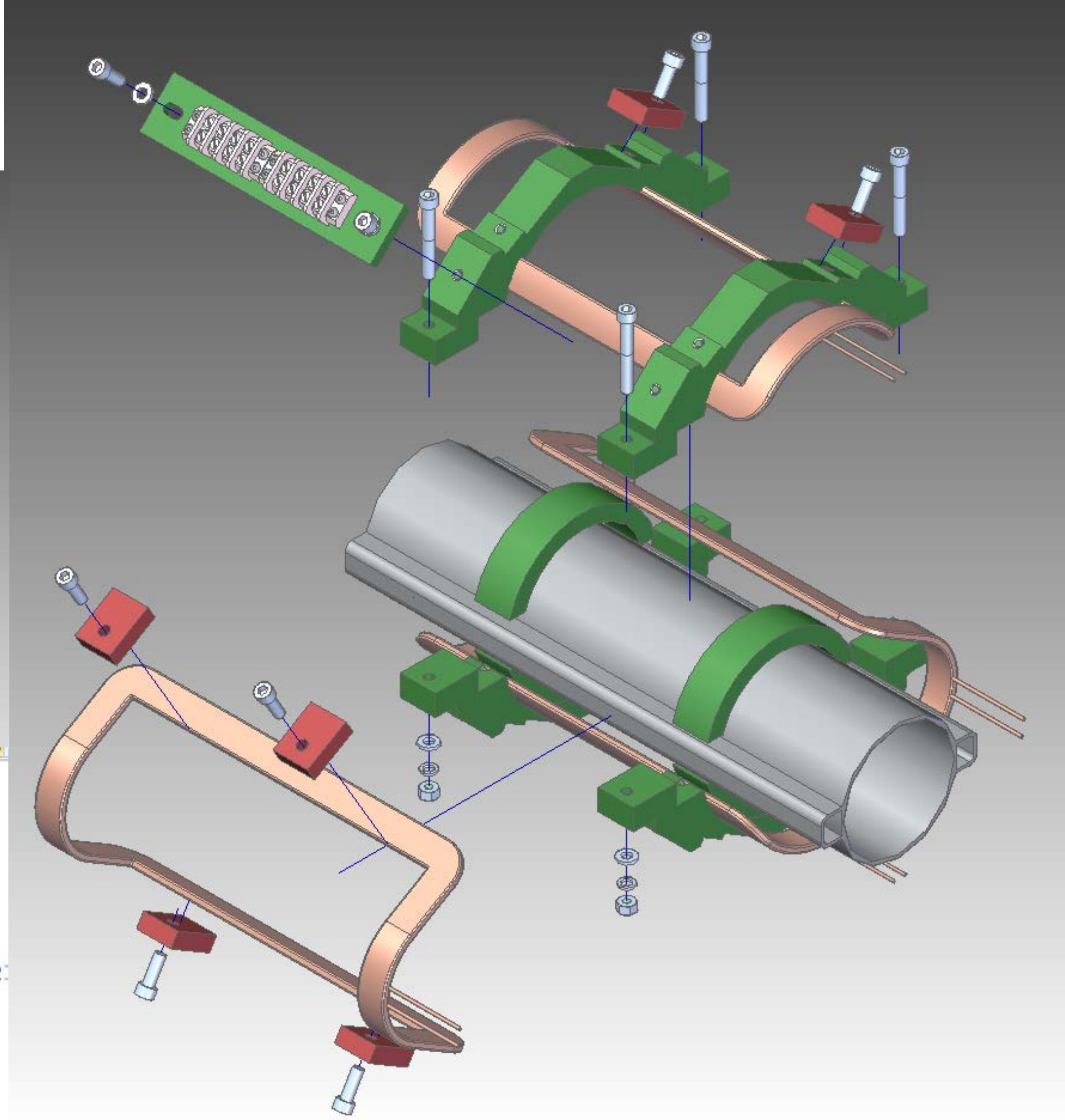
Instrument (4) dither coils

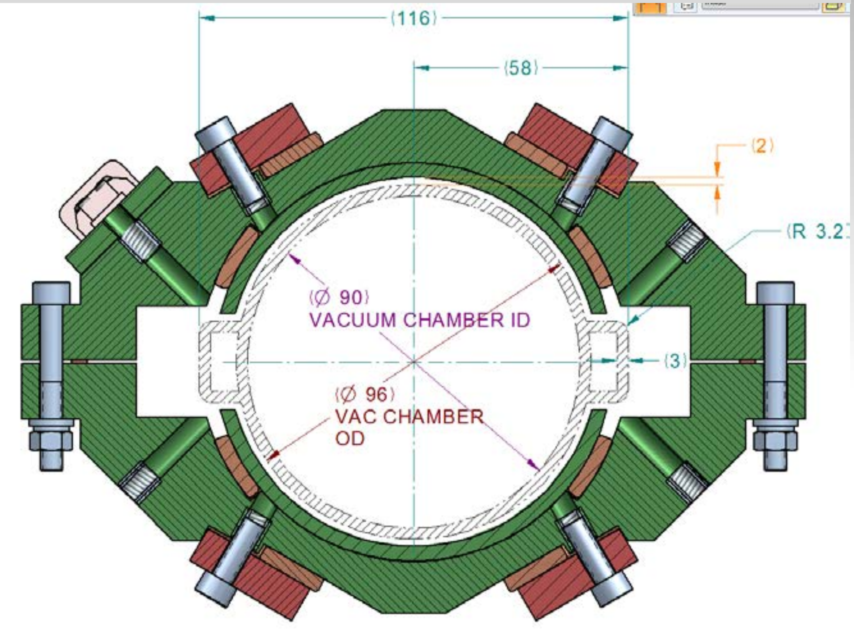


8 locations for 12 dithering coils in LER around IP.

Coil mechanical design







Fabricated by SLAC

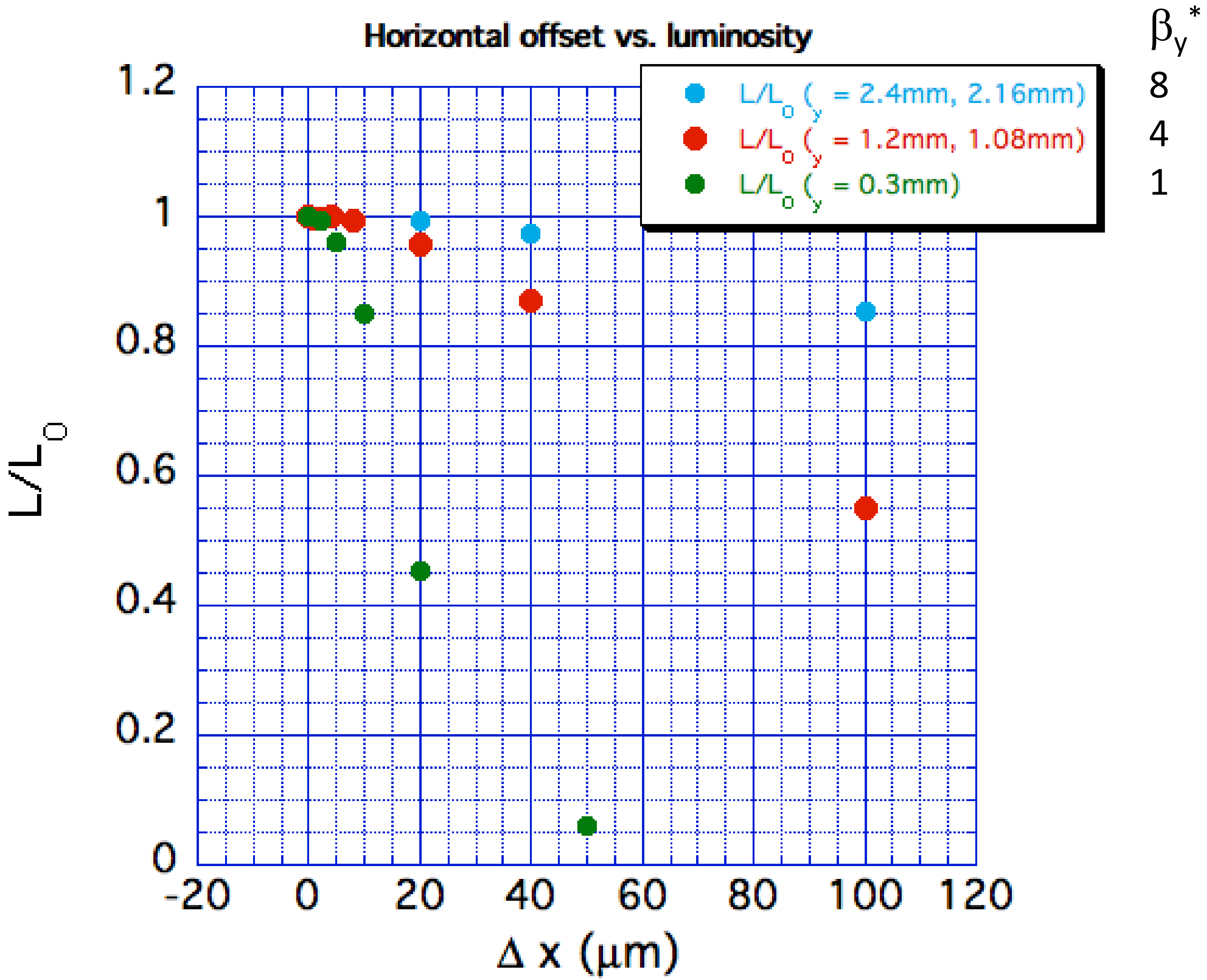
M. Kosovsky, SLAC

Parameters for dither simulation

	initial		intermediate		ultimate (design)	
Luminosity	**1×10^{34} cm^{-2} s^{-1}**		**1×10^{35} cm^{-2} s^{-1}**		**8×10^{35} cm^{-2} s^{-1}**	
	LER	HER	LER	HER	LER	HER
I_{beam} [A]	1.0	0.8	2.7	1.95	3.6	2.6
# of bunches	2500		2500		2500	
$\varepsilon_x/\varepsilon_y$ (nm/pm)	2.2/44	5.2/104	3.2/51.84	4.6/77.28	3.2/8.64	4.6/12.88
β_x^*/β_y^* (mm)	128/2.16	100/2.4	128/1.08	100/1.2	32/0.27	25/0.30
σ_x^*/σ_y^*(μm/nm)	16.8/308	22.8/500	20.2/237	21.4/305	10.1/48	10.7/59
$\sigma_{x\ \mathrm{eff}}^*$ (μm)	249	208	249	208	249	208
ξ_x/ξ_y	0.0033/0.024	0.0013/0.0257	0.0083/0.049	0.0052/0.046	0.0028/0.0881	0.0012/0.0807
Δx (90% lumi)	~80μm		~40μm		~ 8μm	
Lumi. meas.	1kHz		1kHz		1kHz	
accuracy	~5×10^{-3} (w/ radiator)		1.3×10^{-3}(w/o radiator)		1×10^{-3}	

$\sigma_{x\ \mathrm{eff}}^* = \sigma_z \sin\phi$

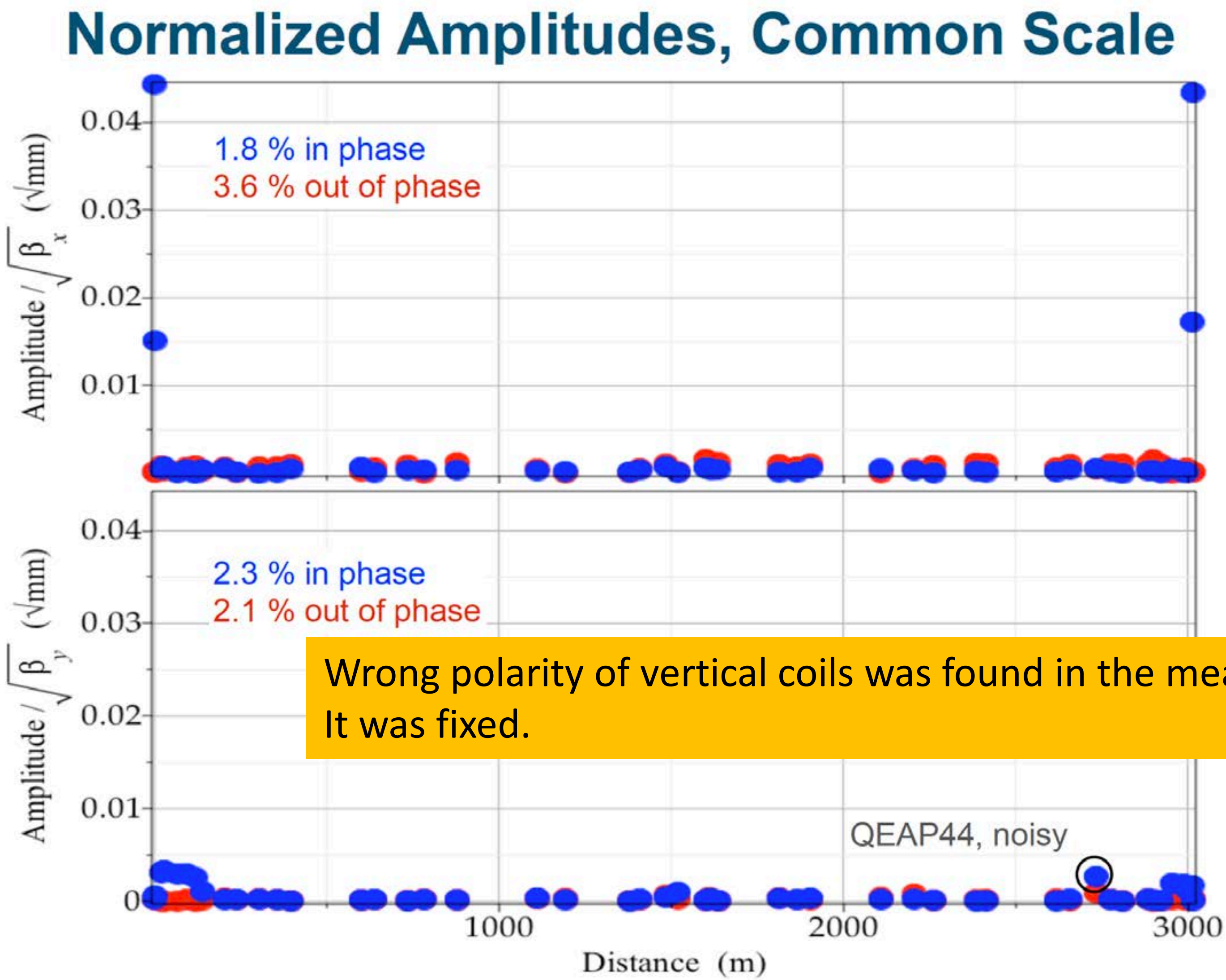
Luminosity degradation due to horizontal orbit shift at IP



Parameters

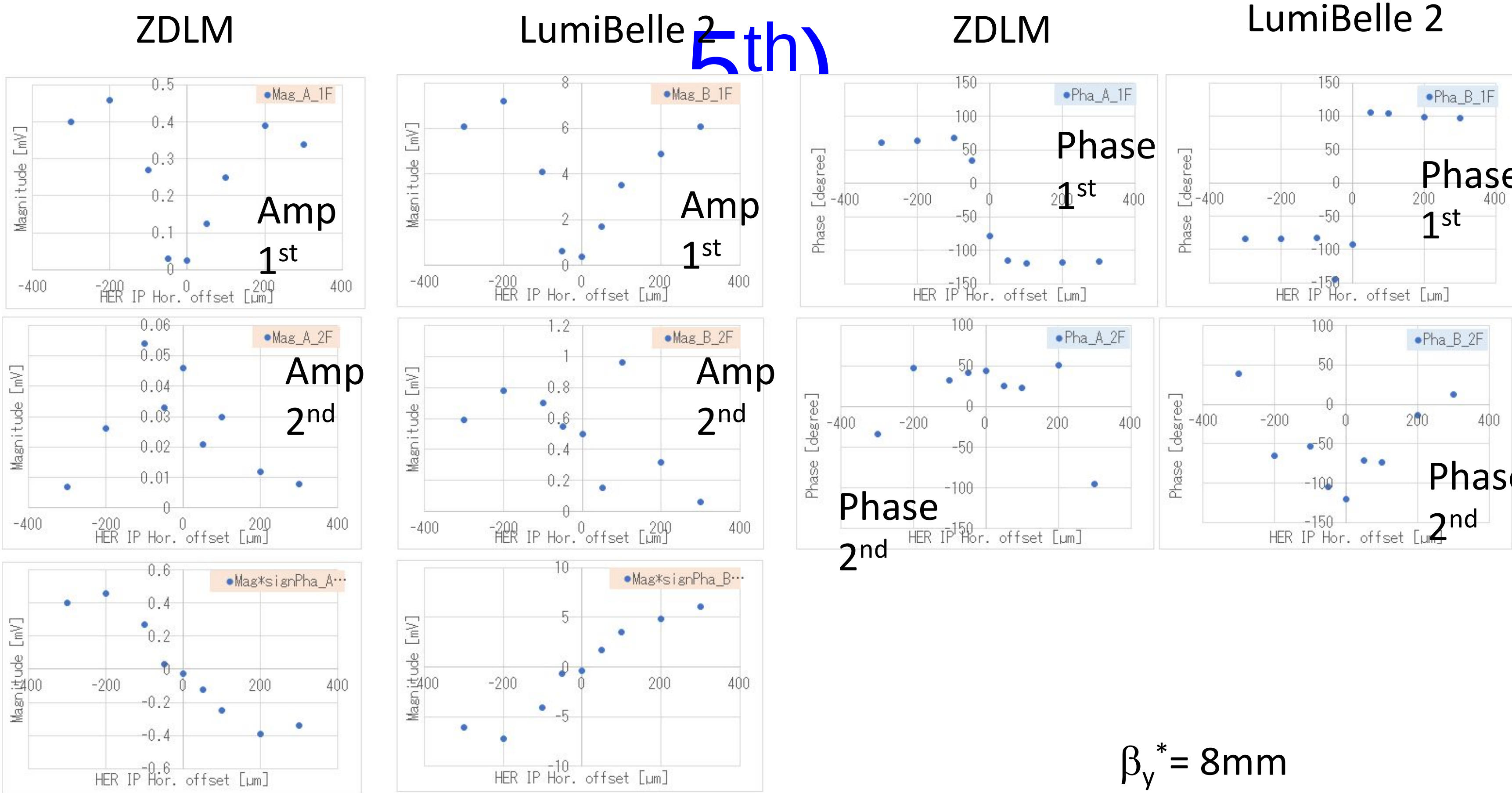
- Feedback cycle
  - ~< 1Hz
- Dither frequency
  - 79Hz
  - Dither amplitude: <40μm
- Luminosity monitor
  - Resolution: 10^{-2} at 1kHz
  - Dynamic range: 10^{32} - 10^{36} $cm^{-2}s^{-1}$

Dither bump closure measurement by using turn-by-turn BPM (LER)



Wrong polarity of vertical coils was found in the measurement.
It was fixed.

Dither test (1) Look-in amp output as function of IP H offset (May 5th)



Amp * Phase (sign) 1st

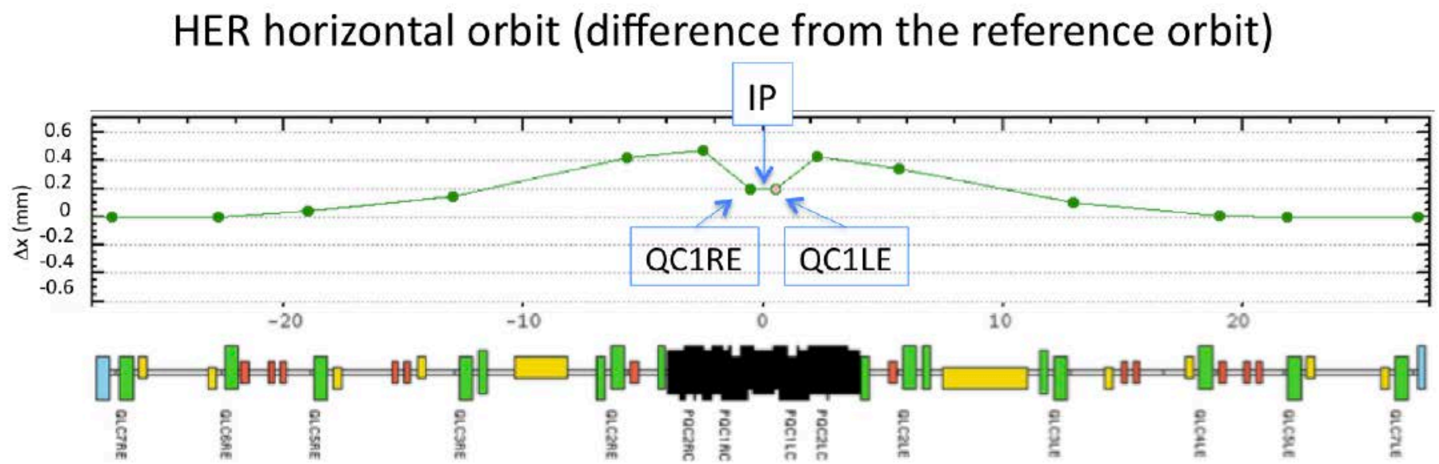
Amp * Phase (sign) 1st

$\beta_y^* = 8mm$

Dither amplitude = 40μm

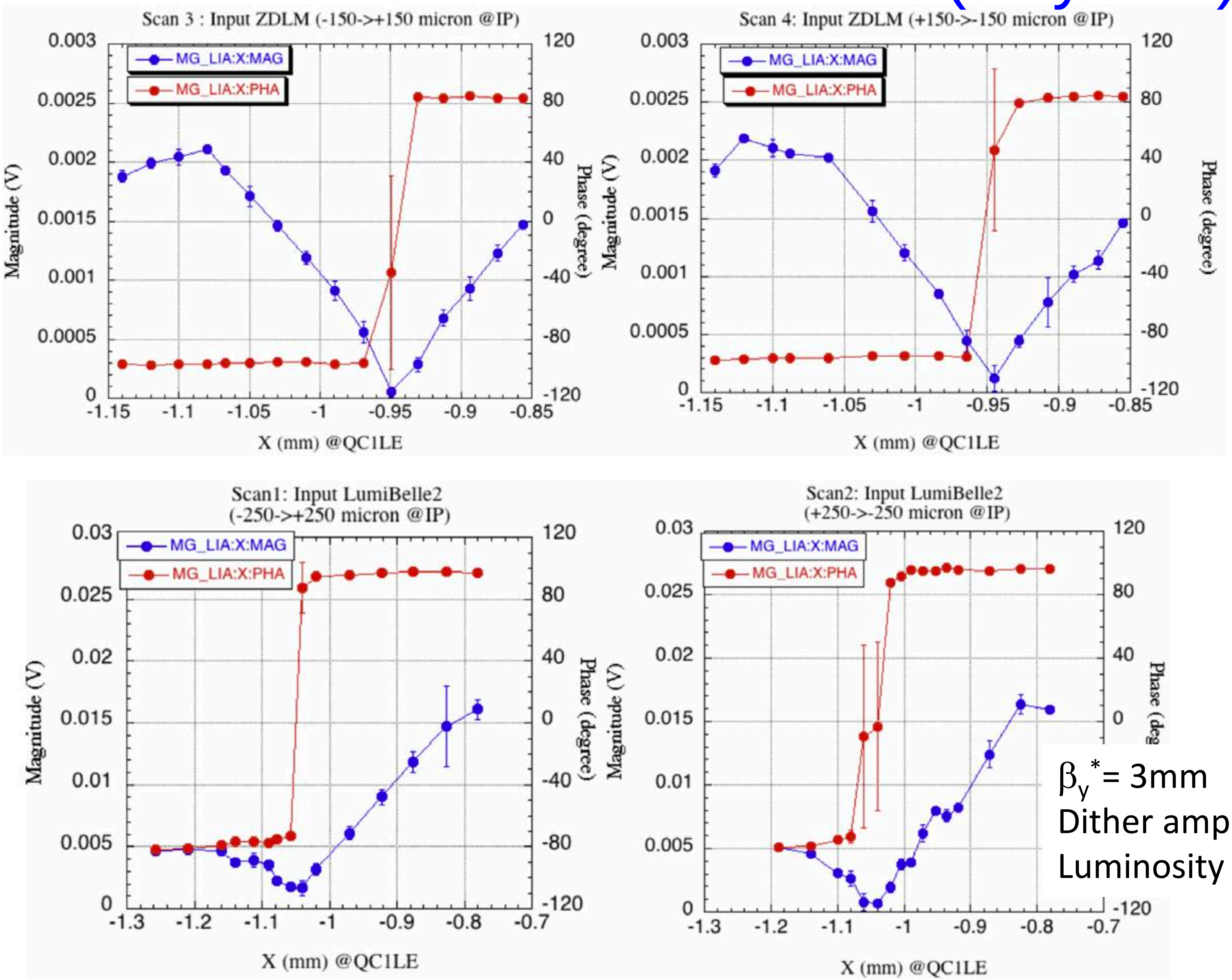
Luminosity < 10^{32} $cm^{-2}s^{-1}$

Dither test (2) Lock-in amp output as function of IP H offset (July 14^{th})



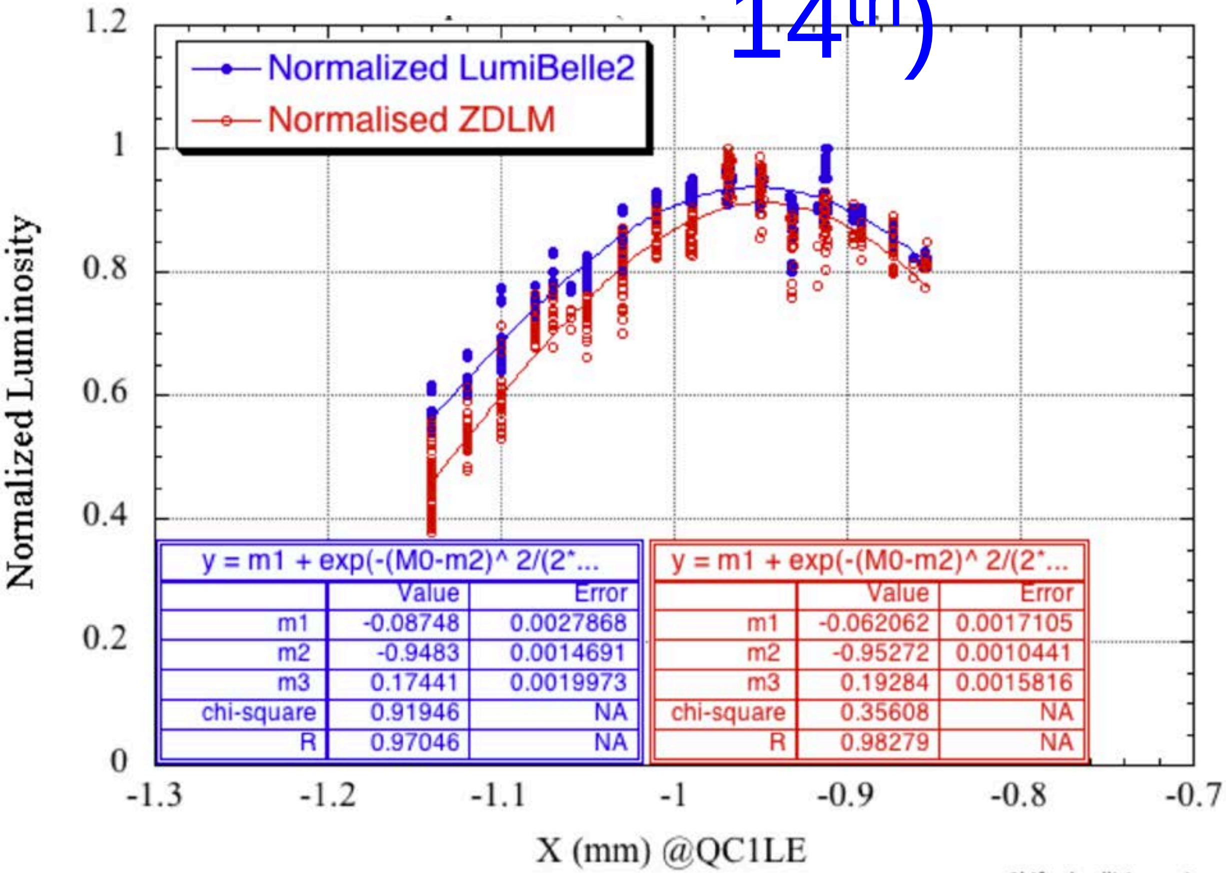
	Input to lock-in amplifier	Scan range (μm)
Scan 1	LumiBelle2	-250 ~ +250
Scan 2	LumiBelle2	+250 ~ -250
Scan 3	ZDLM	-150 ~ +150
Scan 4	ZDLM	+150 ~ -150

Dither test (2) Lock-in amp output as function of IP H offset (July 14th)



$\beta_y^* = 3mm$
Dither amplitude = 20μm
Luminosity = ~10^{33} $cm^{-2}s^{-1}$

Dither test (3) Luminosity as function of horizontal offset (July 14th)

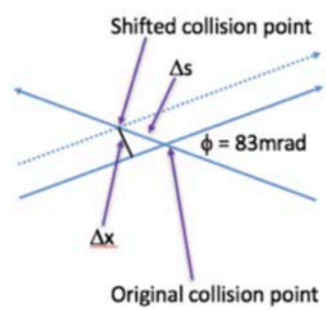


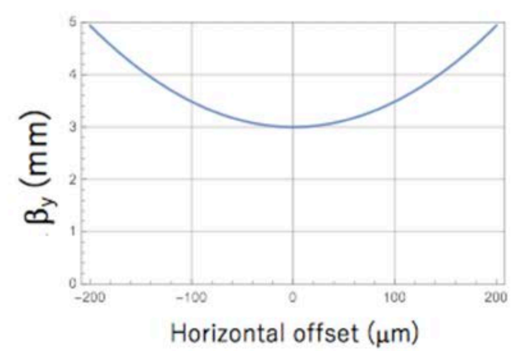
$$L_0 = m_1 + \exp\left(-\frac{(x - m_2)^2}{2m_3^2} \right)$$

Σ_x ~ 0.32 mm (from σ_x^{eff})

Detector	LumiBelle2		ZDLM	
Fit	m_2	m_3	m_2	m_3
Scan 1	-0.94	0.27	-0.95	0.24
Scan 2	-0.94	0.21	-0.95	0.18
Scan 3	-0.95	0.17	-0.95	0.19
Scan 4	-0.94	0.20	-0.95	0.18

Shift of collision point:
$\Delta x = 10\mu m \rightarrow \Delta s = 120.5\mu m$

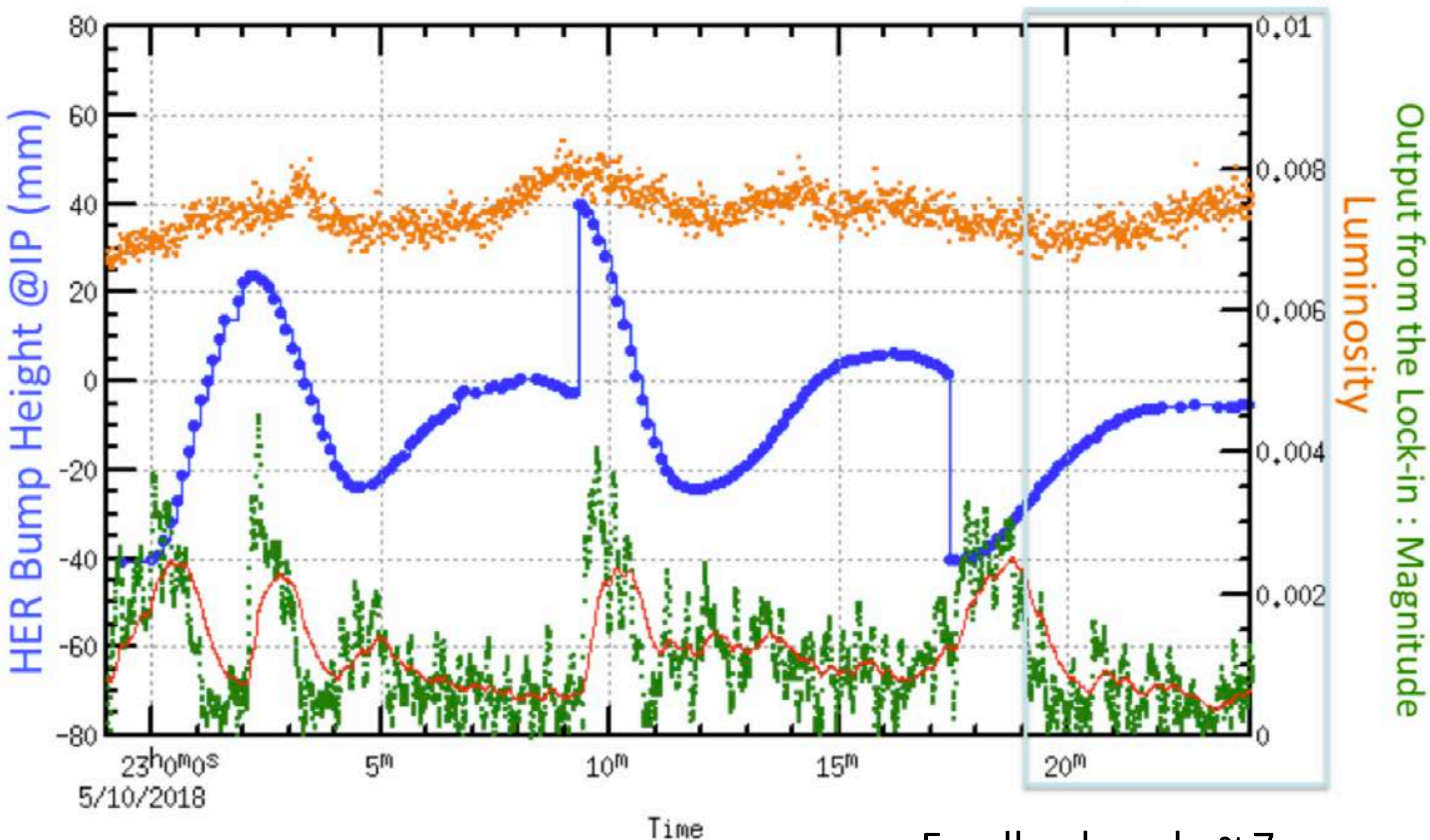




Dither test (4) dither feedback (May 5th)

Input: LumiBelle 2

Converged smoothly



Feedback cycle ~ 7 sec

Dither feedback worked well. But luminosity was not sensitive to the horizontal offset and fluctuated for other reasons. No vertical orbit feedback has been used yet.

Summary & future prospects

- The dithering system used for SLAC was successfully implemented for SuperKEKB. The system will be used for the horizontal orbit feedback at IP.
- In Phase 2 commissioning, only the system test was done, since luminosity is not so sensitive to the horizontal offset yet.
- The system work well except for LumiBelle 2 in the second test. The problem with LumiBelle 2 will be investigated at the beginning of Phase 3.
- In Phase 3, β_y^* will be squeezed further and the dither feedback may become important.
- The feedback software run on a PC connected via network in Phase 2. It will run on the PLC in Phase 3.

Spare slides

Dither simulation (1 x 10^{34} $cm^{-2}s^{-1}$)
U. Wienands

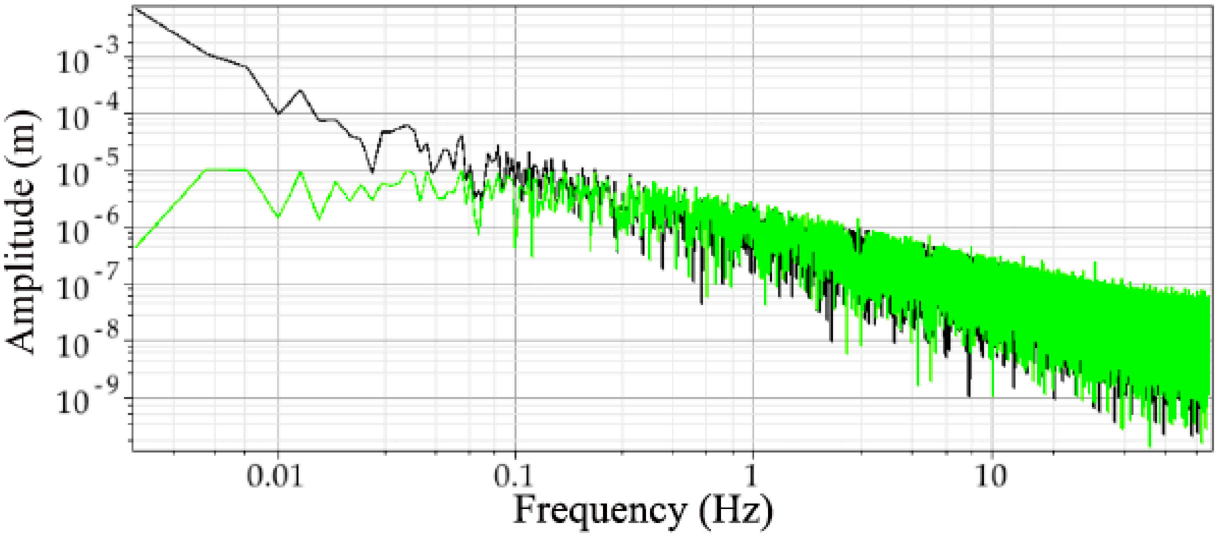


Figure 5: Spectrum of the orbit (black) and the orbit difference (green) with the dither feedback.

ZDS2RP:K0	3.9942282801351415e-06
ZDS1RP:K0	-1.5923910564584172e-05
ZDS1LP:K0	-1.634394142917688e-05
ZDS2LP:K0	4.013724682428702e-06
ZDS4RP:SK0	-3.849111775864118e-08
ZDS3RP:SK0	2.620678810744528e-07
ZDS2RP:SK0	4.575818508735658e-08
ZDS1RP:SK0	-4.4568315526718793e-07
ZDS1LP:SK0	5.127058079019328e-07
ZDS2LP:SK0	4.812823686335454e-07
ZDS3LP:SK0	-1.1280762540572501e-07
ZDS4LP:SK0	-3.381043387508759e-07

Dither coil field

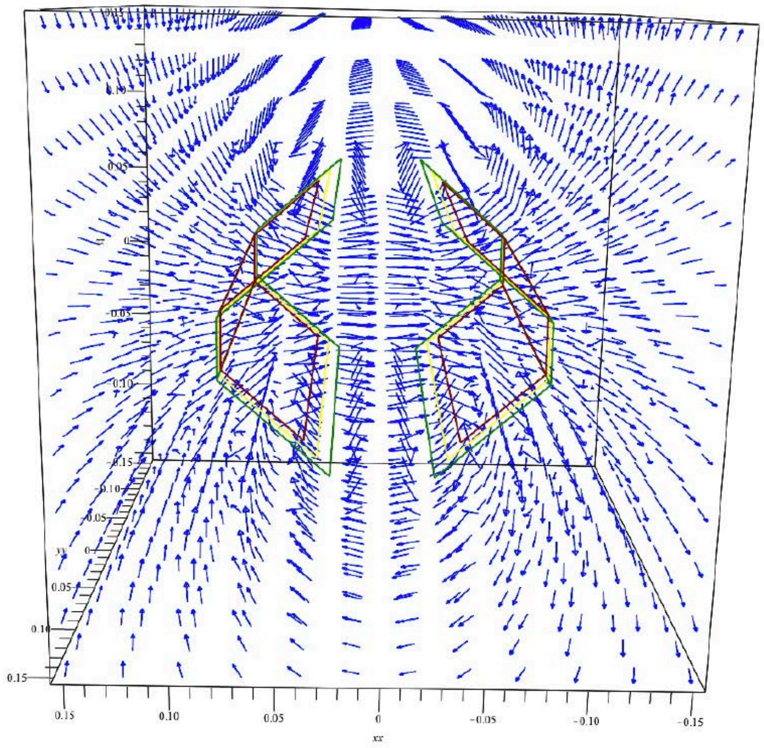


Figure 2: Field plot of the symmetric coil

Instrument (5) Programmable amp