Beam Commissioning of SuperKEKB

Y. Funakoshi for SuperKEKB Commissioning Group
Accelerator Laboratory, KEK

2016.05.10@IPAC2016

SuperKEKB

- **Upgrade project of KEKB B-factory**
  - Search for new physics beyond the standard model at B-meson regime
- **e^{-} - e^{+} two-ring collider consisting of**
  - Injector (Linac): *L* ~600 m
  - Damping ring (e^{+}): *C* ~100 m
  - Main ring (MR): *C* ~ 3016 m
    - HER: 7 GeV e^{-}, 2.6 A
    - LER: 4 GeV e^{+}, 3.6 A
  - Belle-II detector
- **Design luminosity**
  - 80 x 10^{34} $cm^{-2}s^{-1}$ (~40 times of KEKB)

SuperKEKB master schedule

.. JFY2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | …

Now (May, 2016)

KEKB operation

SuperKEKB construction

Dismantle KEKB

Startup and conditioning

Phase 1 commissioning :
- Vacuum scrubbing
- Optics study

Phase 2 commissioning :
- Squeezing beta at IP
- Beam collision tuning
- Start physics data taking

Phase 3 commissioning :
- Physics run with full Belle II with VXD

Phase 1 | Phase 2, 3

SuperKEKB operation

DR

DR commissioning starts prior to Phase 2.

Belle II Roll-in
Install QCS

For about 10 years


First day of removing magnets

SuperKEKB Commissioning Phases

2016 Feb. ~ June	2017 Oct. ~ 2018 Mar.	2018 Oct. ~
Phase 1 w/o QCS and Belle II basic machine tuning vacuum scrubbing Optics tuning BKG study	Phase 2 w/QCS and Belle II w/o Vertex detector BKG study Luminosity tuning Target luminosity: 1×10^{34} cm^{-2} s^{-1}	Phase 3 w/ full Belle II Physics Run Luminosity tuning

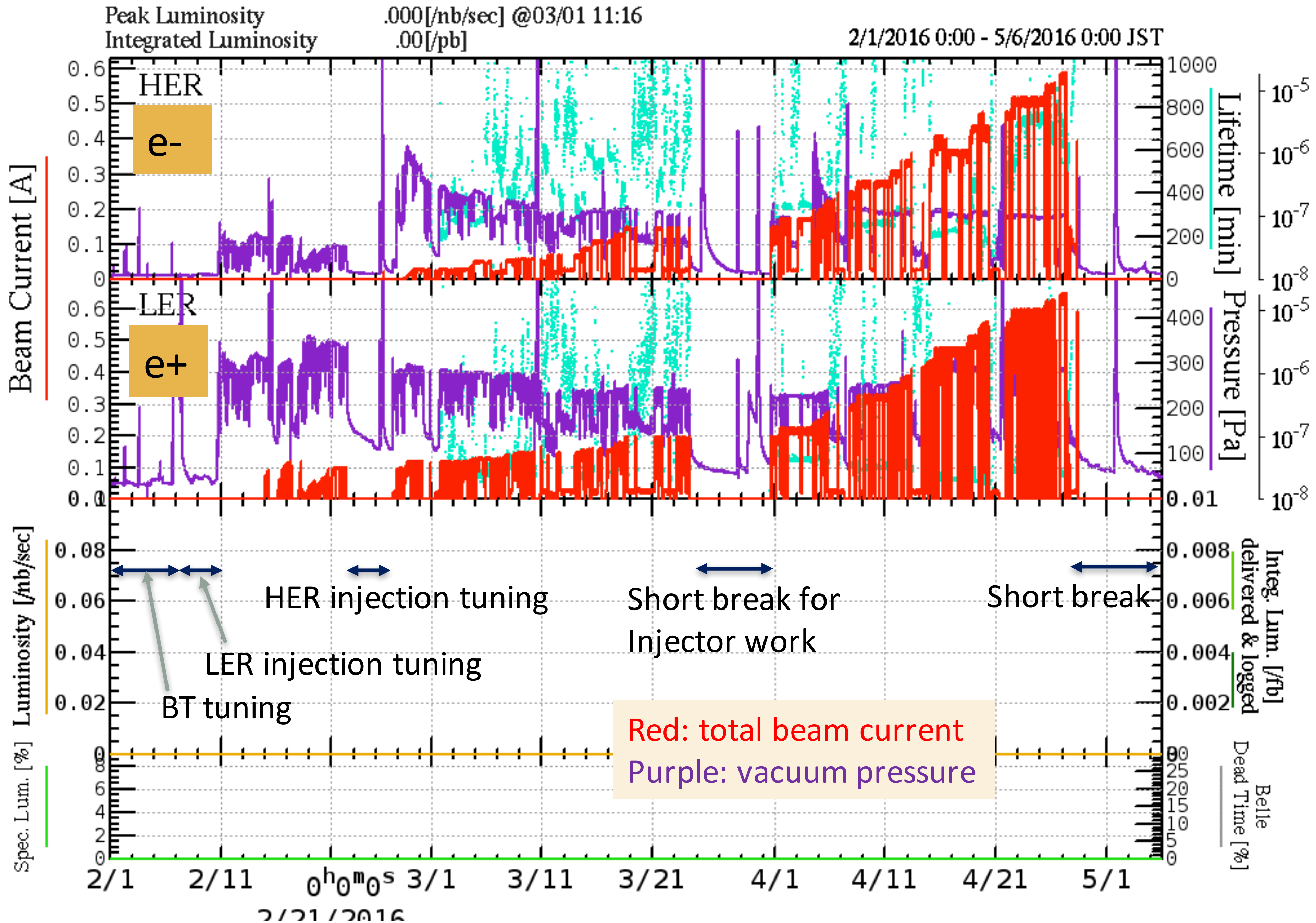
Mission of Phase 1 operation (Feb. 2016 ~ June 2016)

- Startup of each hardware system
- Establish beam operation software tools
- Preparation for installation of Belle-II detector
  - Enough vacuum scrubbing
    - Request from Belle-II group: ~1 month vacuum scrubbing with beam current of 05~1A (360~720Ah).
  - Beam background study with test detector (named Beast)
- Optics study w/o IR (no detector solenoid)
  - Low emittance tuning
- Other machine studies

Machine parameters in Phase 1

April 4, 2016	LER	HER	unit	
E	4.000	7.007	GeV	
I	250.0	200.0	mA	
Number of bunches	1,576	953		
Bunch Current	0.16	0.21	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	1.8/-	**4.6/-**	nm/pm	zero current
Coupling	-	-		includes beam-beam
Crossing angle	83		mrad	
α_p	2.45×10^{-4}	4.44×10^{-4}		
σ_δ	7.7×10^{-4}	**6.3×10^{-4}**		zero current
V_c	7.9	9.4	MV	
σ_z	5	**6.2**	mm	zero current
ν_s	-0.0196	-0.0216		
ν_x/ν_y	44.59/46.63	45.57/43.61		measurement
U_0	1.87	**2.43**	MeV	
$\tau_{x,y}/\tau_s$	43/22	**58/29**	msec	
	wigglers ON	**wigglers ON**		

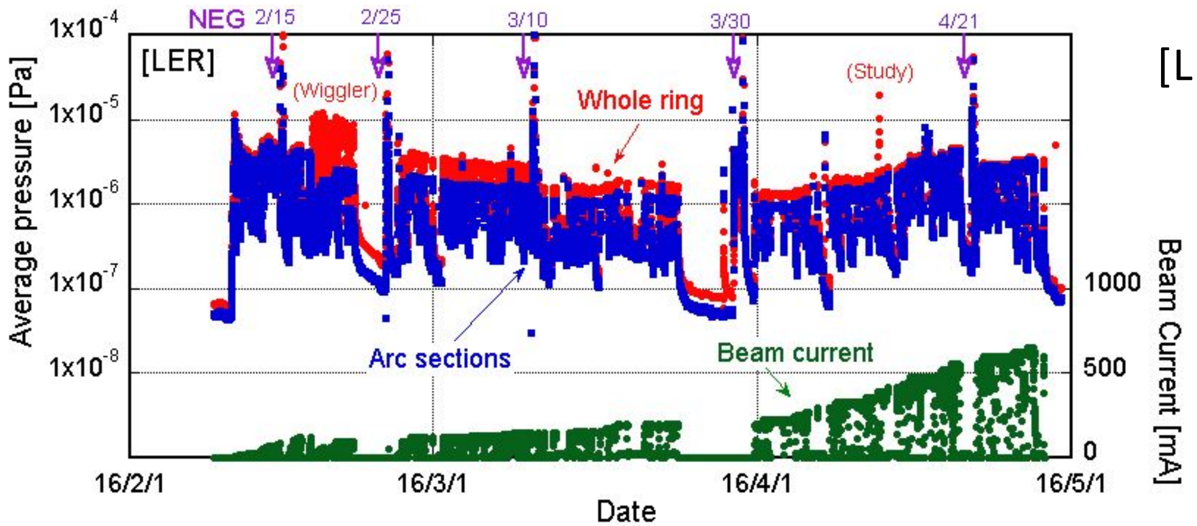
History of Phase 1 operation



History of vacuum scrubbing

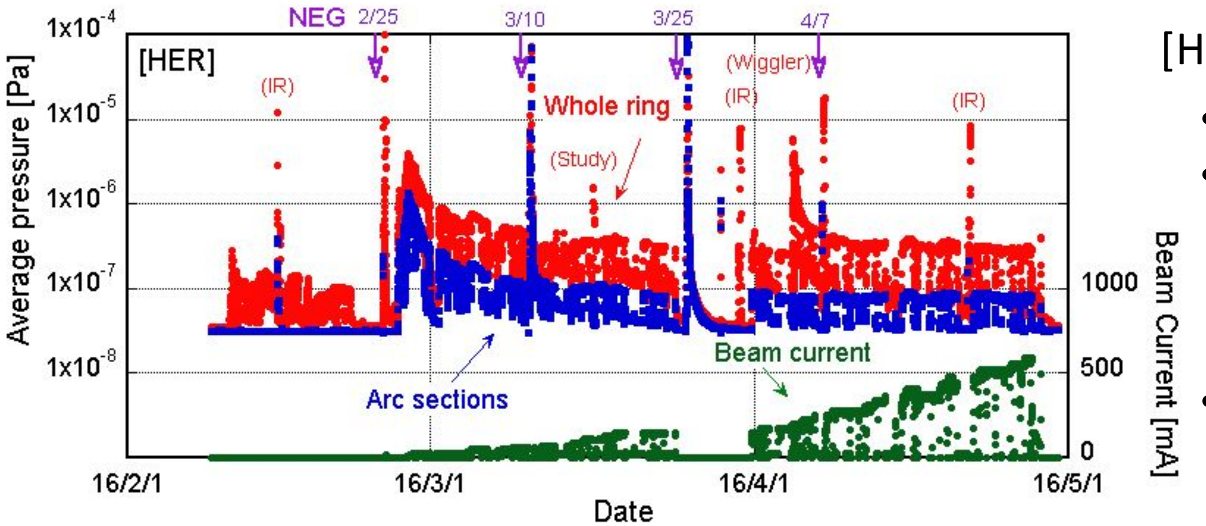
Y. Suetsugu

➢ **The beam currents and average pressures (2016/4/30)**



[LER]

- Max. Beam current: 650 mA
- Avg. Pressure ~ 3×10^{-6} Pa
- Life time ~ 60 min.

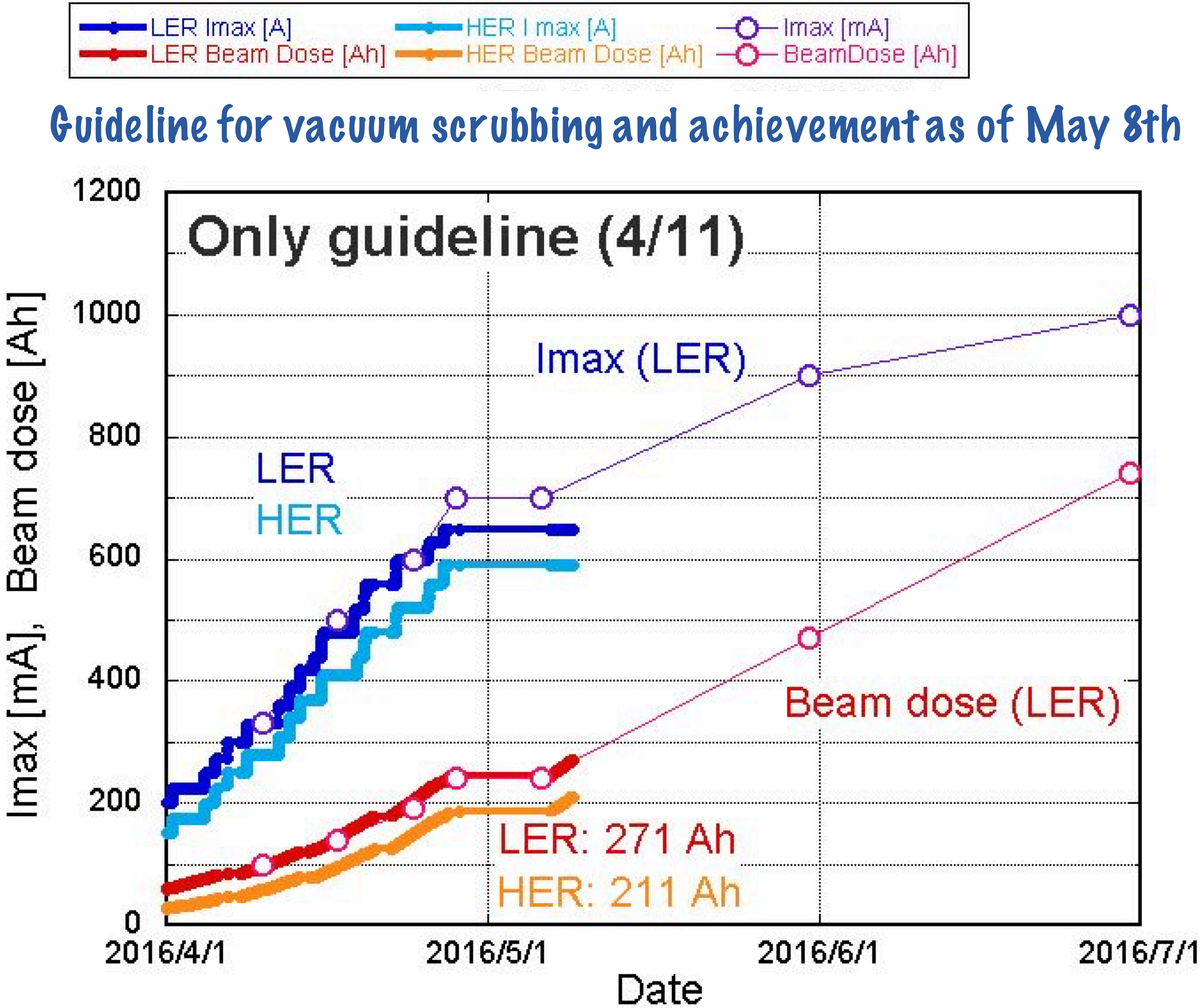


[HER]

- Max. Beam current: 590 mA
- Avg. Pressure ~ 3×10^{-7} Pa (whole ring) ~ 1×10^{-7} Pa (arc sections)
- Life time ~ 600 min.

Request from Belle-II group: ~1 month vacuum scrubbing with beam current of 05~1A.

Guideline for vacuum scrubbing and achievement as of May 8th

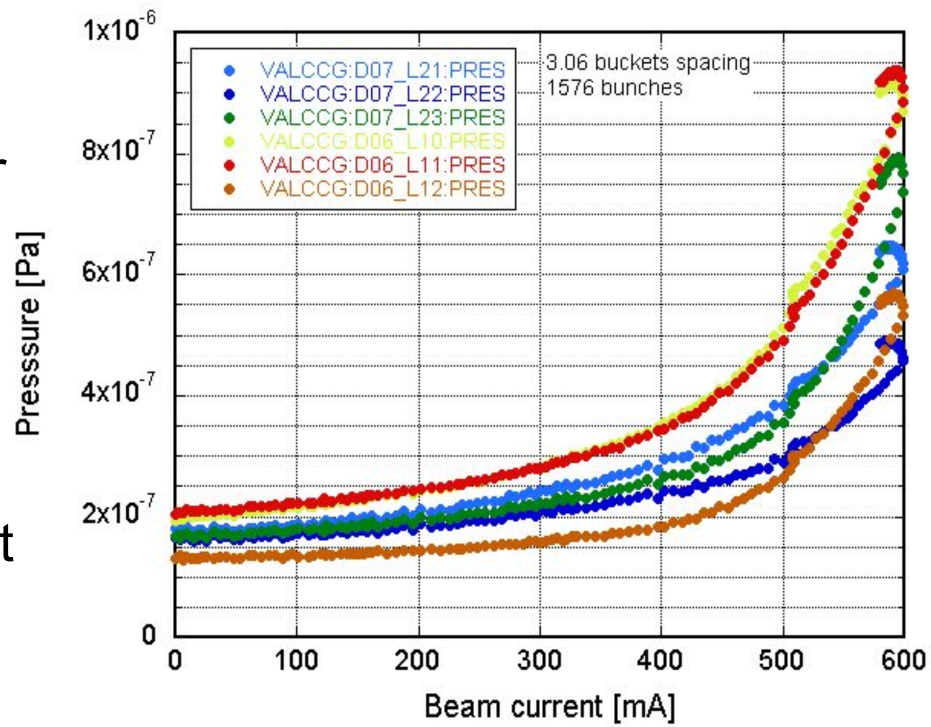


Y. Suetsugu

Problem (vacuum)

- **Non-linear pressure rise against beam current in LER**
  - The pressures at whole LER ring showed the nonlinear behavior against the beam current.
  - The behavior is quite similar to that of electron currents measured at aluminum parts without TiN coating.

- We have aluminum bellows chambers along the ring without TiN coating. The bellows chamber has a length of 0.2 m and located every 3 m on average.
- Counter-measure
  - Installation of solenoid magnets at the bellows.
  - A preliminary test showed that this method should work.



More details are discussed in the talk by Y. Suetsugu (TUOCB01).

Startup of SuperKEKB (3 months)

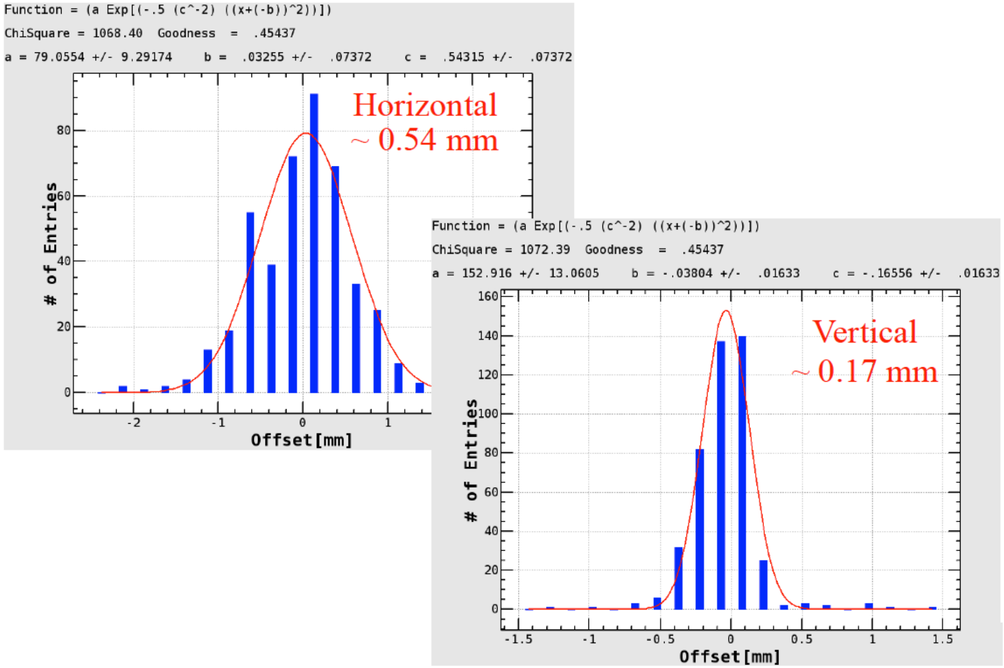
- Much faster startup than KEKB
  - KEKB beam currents achieved after first 3 months
    - LER: ~300mA, HER: ~200mA
  - SuperKEKB beam currents achieved after first 3 months
    - LER: ~650mA, HER: ~590mA
- Compared with KEKB...
  - Each hardware component has been upgraded with experiences at KEK and has worked fine (RF, Magent, Vacuum...)
  - The bunch-by-bunch feedback system has more effectively suppressed instabilities.
  - Operational tools (such as closed orbit correction system) has worked fine based on experiences at KEKB.
  - Less machine troubles than KEKB so far

Optics corrections

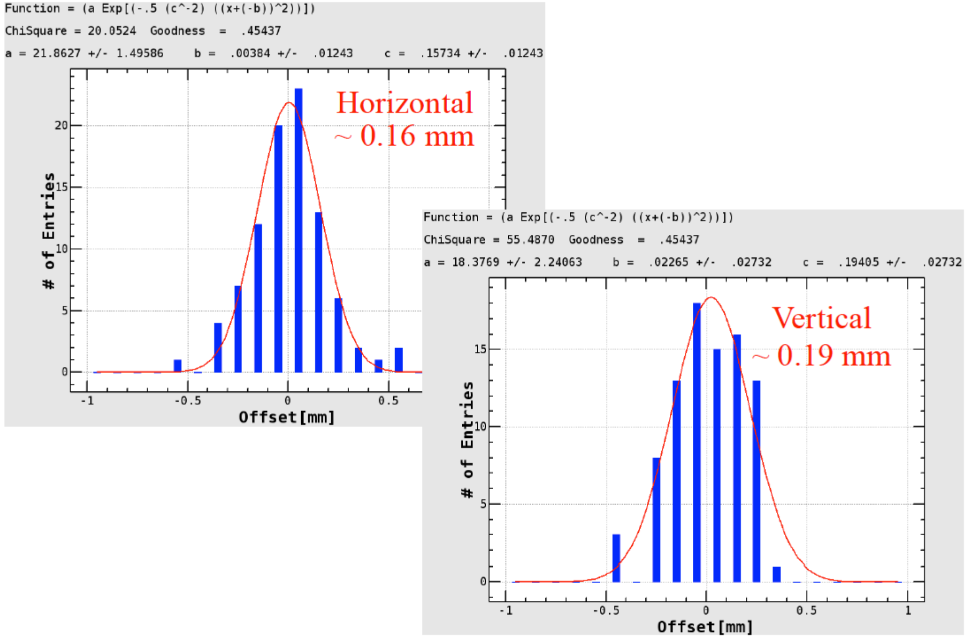
- Base measurements for hardware system check
  - BPMs
    - BPM check with beams (orbit bumps) -> We found mis-connection or mis-cabling of BPM cables with ~>20 BPMs.
    - Gain calibrations of BPMs have been done with beams.
    - Quad-BPM measurements (to measure difference between field center of quadrupole magnets and the center of near-by BPM) have been almost finished.
  - Steering magnet
    - Check with beams (orbit bumps) -> We found an error with the excitation curve of steering magnets.
  - Closed orbit correction system
    - Closed orbit correction is a basis of optics correction. A reliable closed orbit correction system has been established based on the above measurements and modifications.

Beam based BPM offset measurement

LER Quadrupole Offset Distribution



LER SextBPM



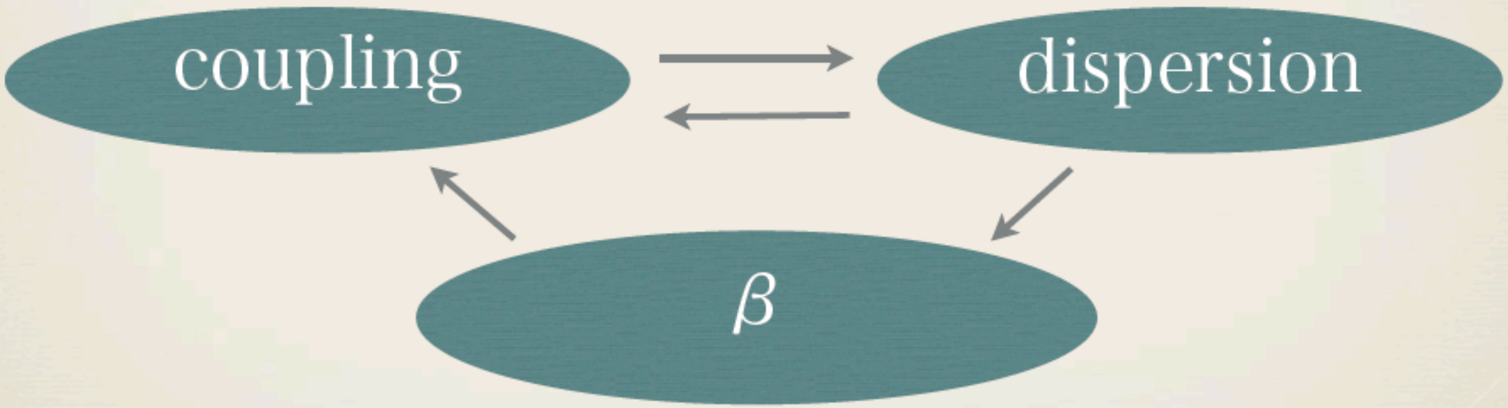
Method of optics correction

- At SuperKEKB, we follow the method successfully used at KEKB.
- Optics corrections on X-Y coupling, dispersions and beta-beat are done iteratively.
- Since there are not enough single path BPMs, we rely on conventional BPMs.
- For the measurements of X-Y coupling and beta-beta, orbit responses are measured with single kicks by steering magnets.
- For the measurement of dispersion, we use a usual RF phase frequency change.

Iteration

2008_06_19_19_06_29fop	Fill-Length Optimization
2008_06_19_19_06_32luh	Beam Collision Panel
2008_06_19_19_09_12XY_Coupling	MeasOptHER
2008_06_19_19_12_59Dispersion	MeasOptHER
2008_06_19_19_18_27XY_Coupling	MeasOptHER
2008_06_19_19_21_34Dispersion	MeasOptHER
2008_06_19_19_22_29Dispersion	MeasOptHER
2008_06_19_19_23_29Dispersion	MeasOptHER
2008_06_19_19_31_36Global_Beta	MeasOptHER
2008_06_19_19_38_29Global_Beta	MeasOptHER
2008_06_19_20_16_46_amsad8	amsad8 screen capture
2008_06_19_20_34_16_amsad8	amsad8 screen capture

* A loop of coupling, dispersion, β corrections takes **30-60 minutes** per ring to converge. (1 correction takes 3.5 to 7 minutes)



* We do not have to solve the entire problem at once by a single big matrix.

* Although these corrections are not independent, their cross-talks are smaller than the diagonal parts, so the iteration converges quickly.

XY-Coupling Correction

H. Sugimoto

- Correction with the additional skewQ coils.
- The vertical leakage orbit is effectively reduced.

Measurement:

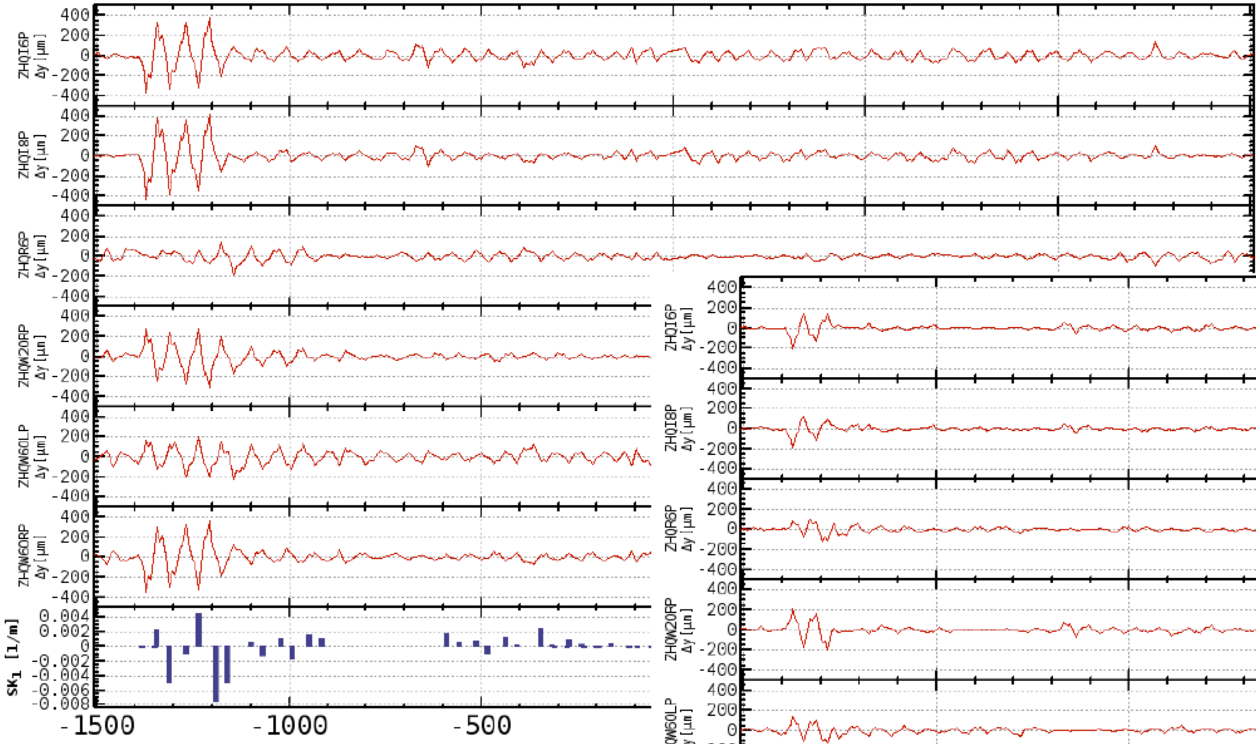
Vertical leakage orbit induced by independent 6 steering kicks.

- Induced horizontal orbit amplitude Is about 2-3 mm in its peak.

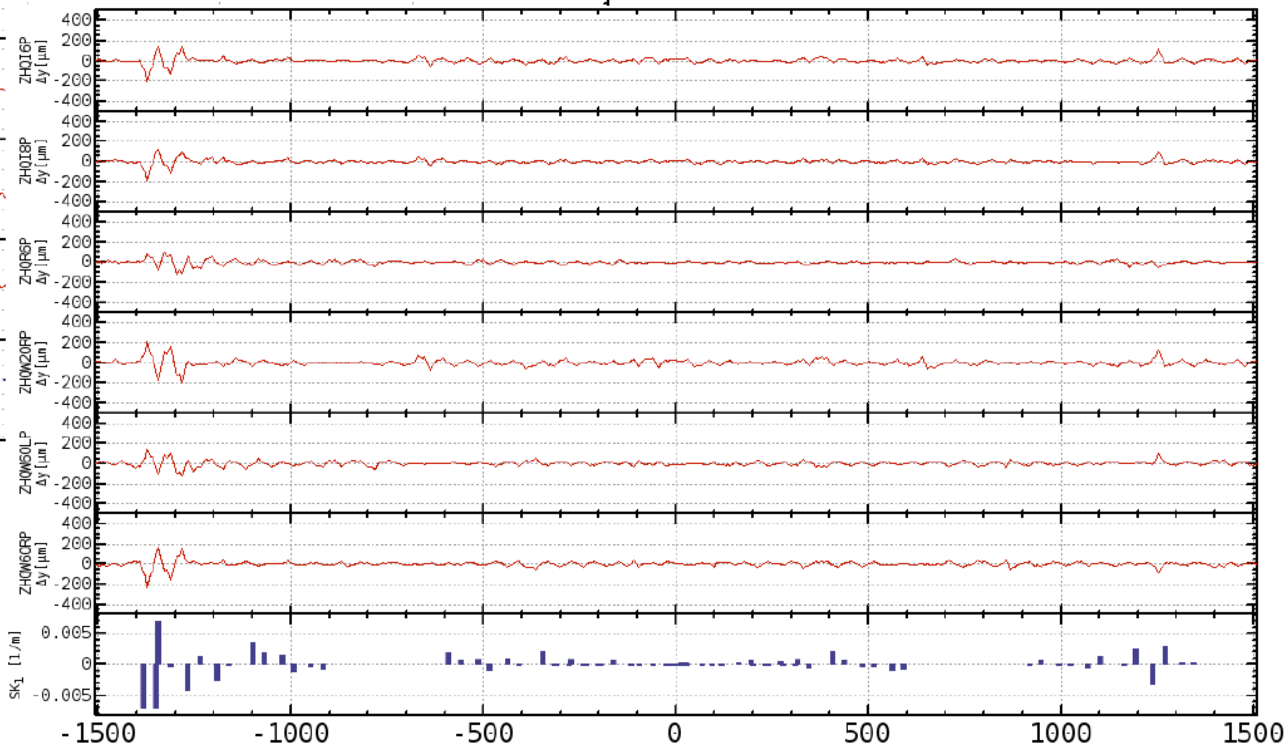
Correctors:

SkewQ winding of sextupoles

Before Correction

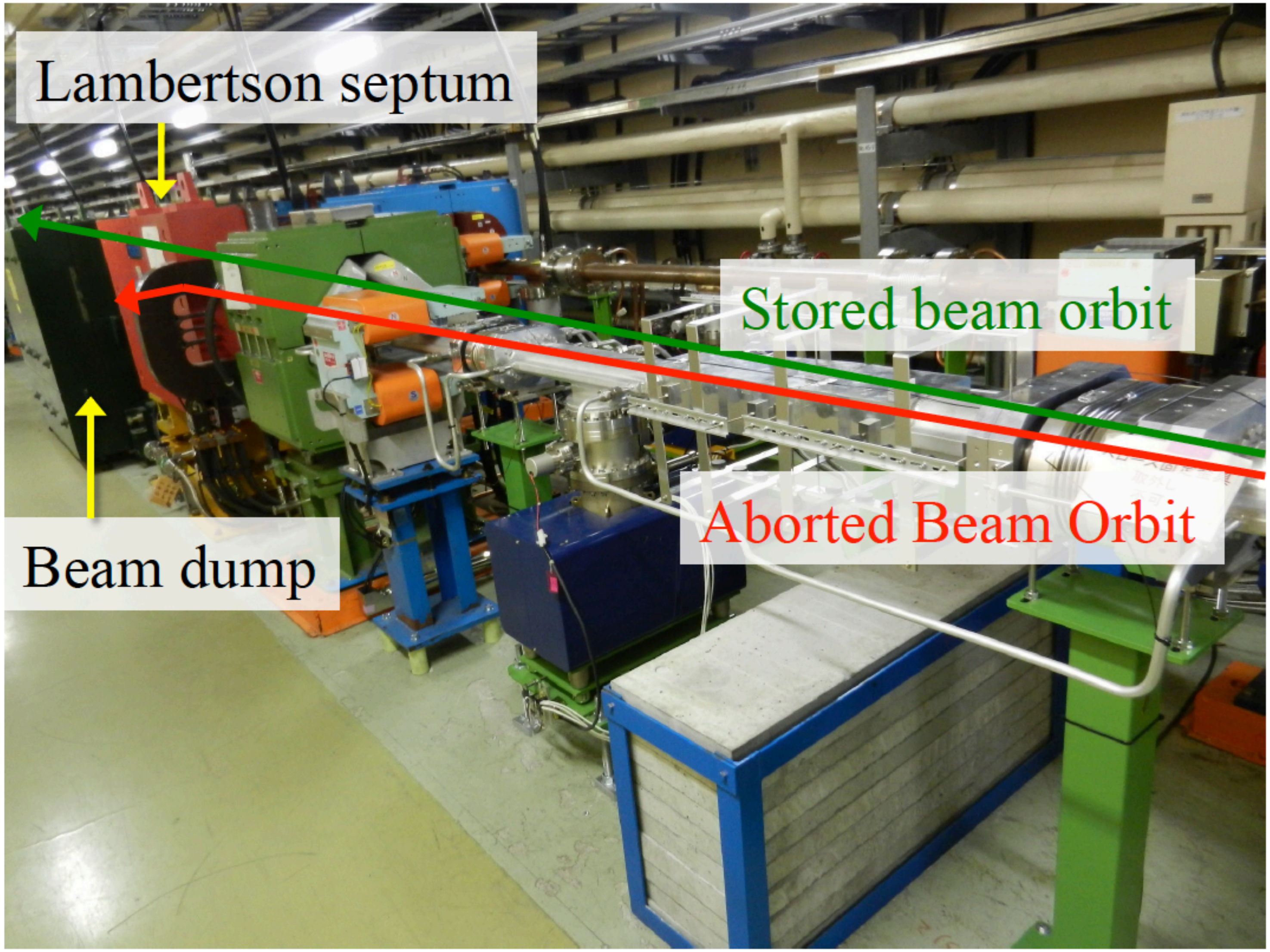


After Correction



Leakage Field from Lambertson Septum

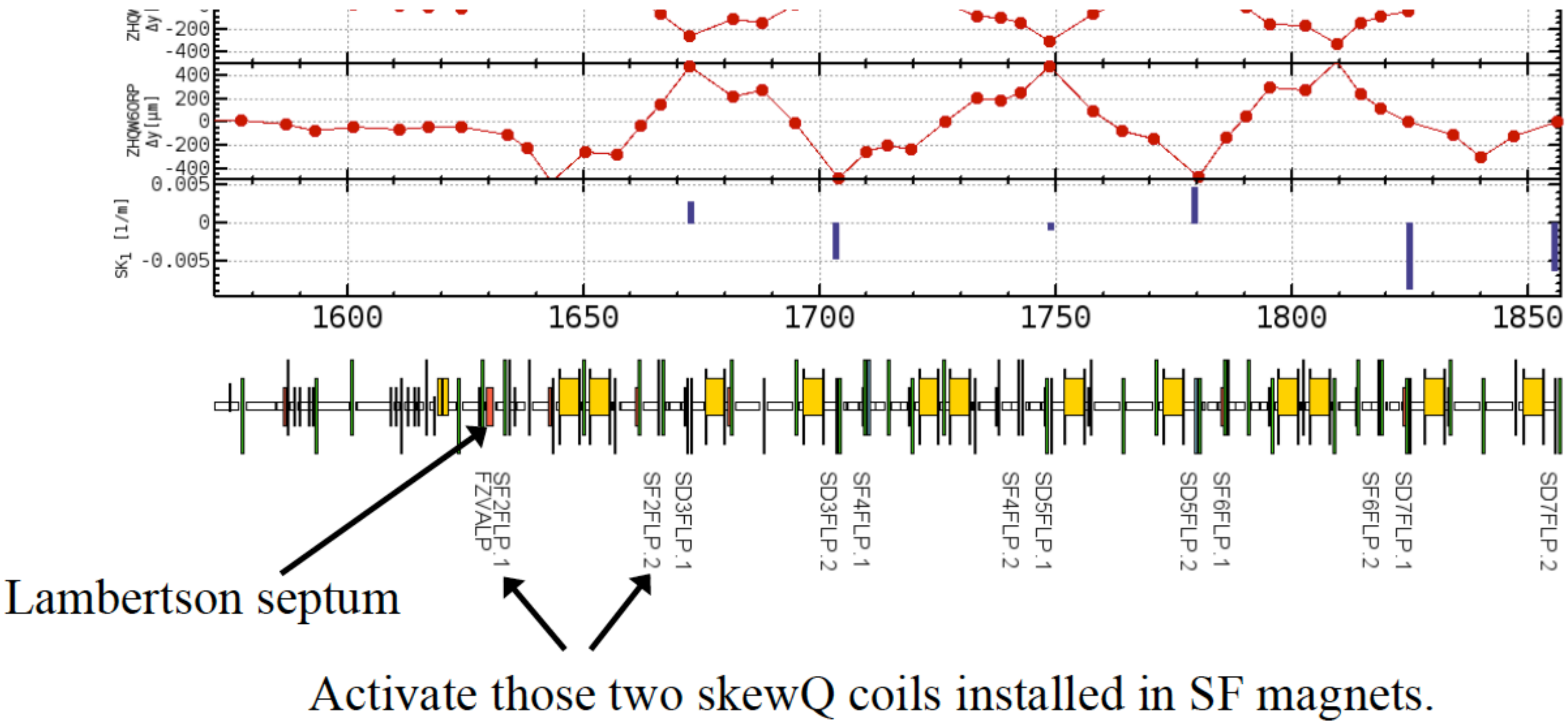
- A Lambertson septum is used to deliver aborted beam to a beam dump.
- This magnet creates unexpected leakage field to stored beam line.



H. Sugimoto

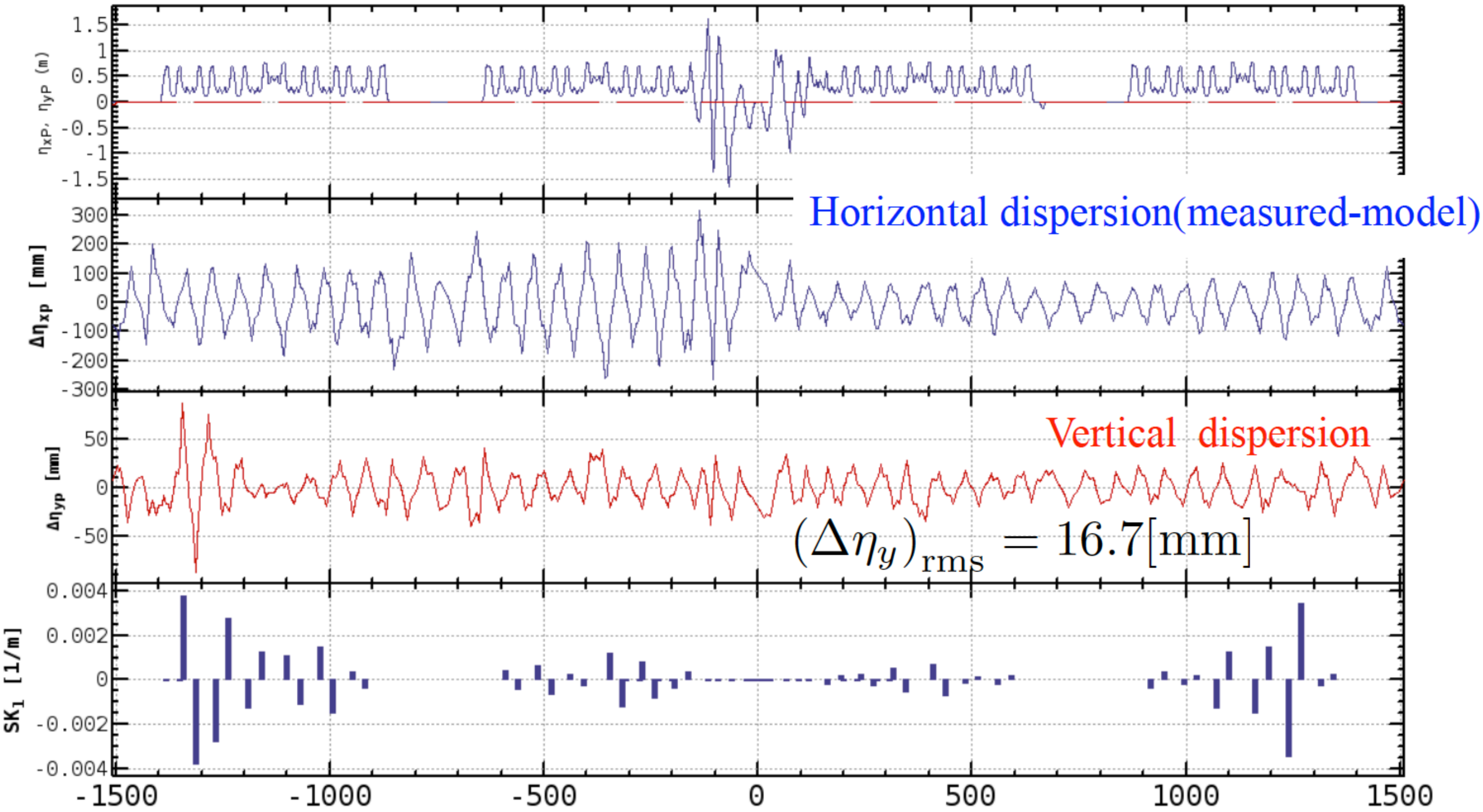
Add Skew Correctors

- All focusing (SF) and defocusing (SD) sextupole magnet have skewQ coil.
- As for Phase 1, Power supplies (PS) for skewQ are prepared only for SD magnets.
- We activate skewQ coils of one SF pair near the septum by using standby PS.



H. Sugimoto

LER Vertical Dispersion *Before* Correction

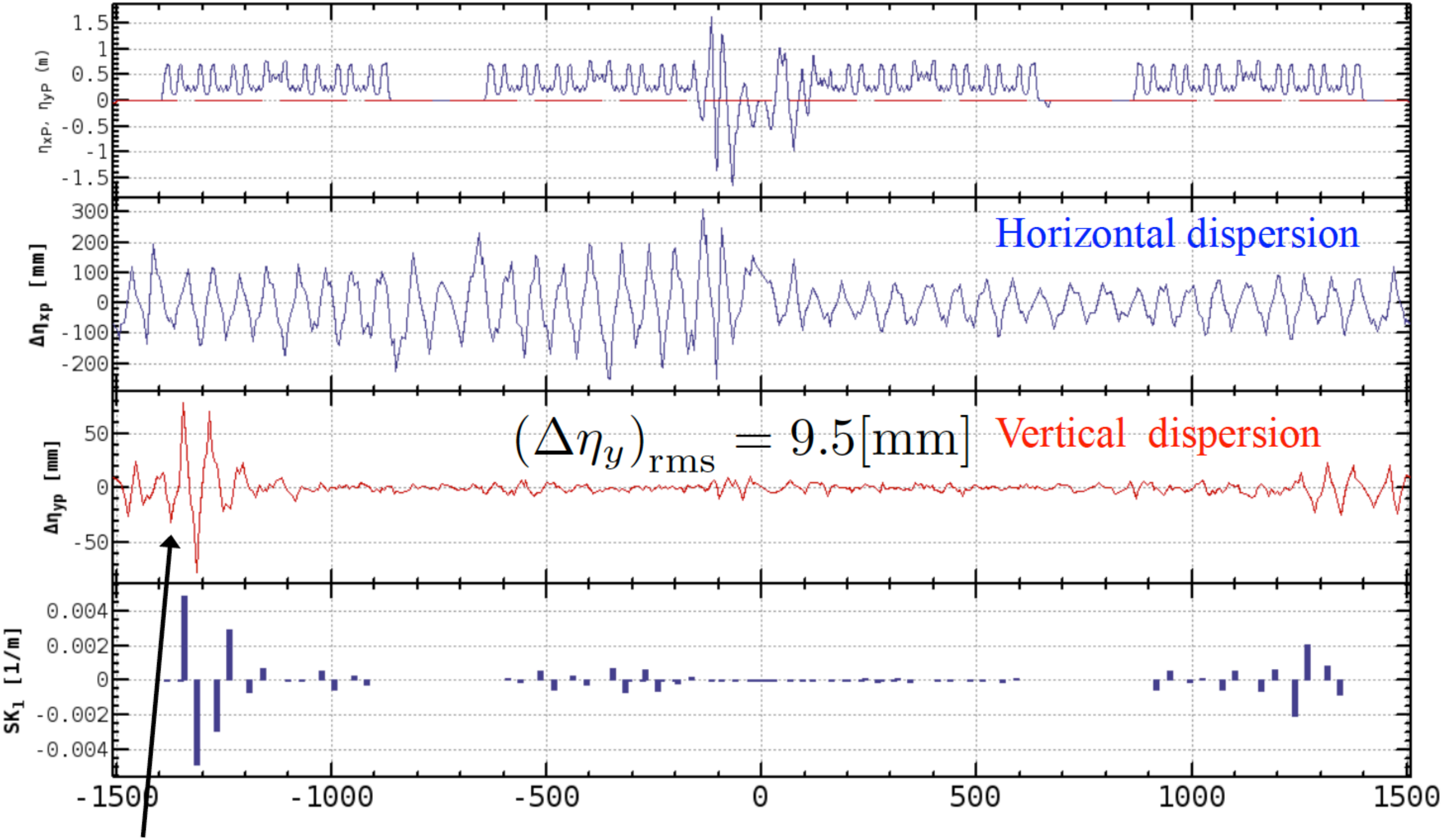


Correctors:

SkewQ winding of sextupoles

H. Sugimoto

LER Vertical Dispersion *After* Correction



- This peak is not correctable due to hardware limit of SkewQ corrector strength.
- We have a plan to enforce SkewQ correctors.

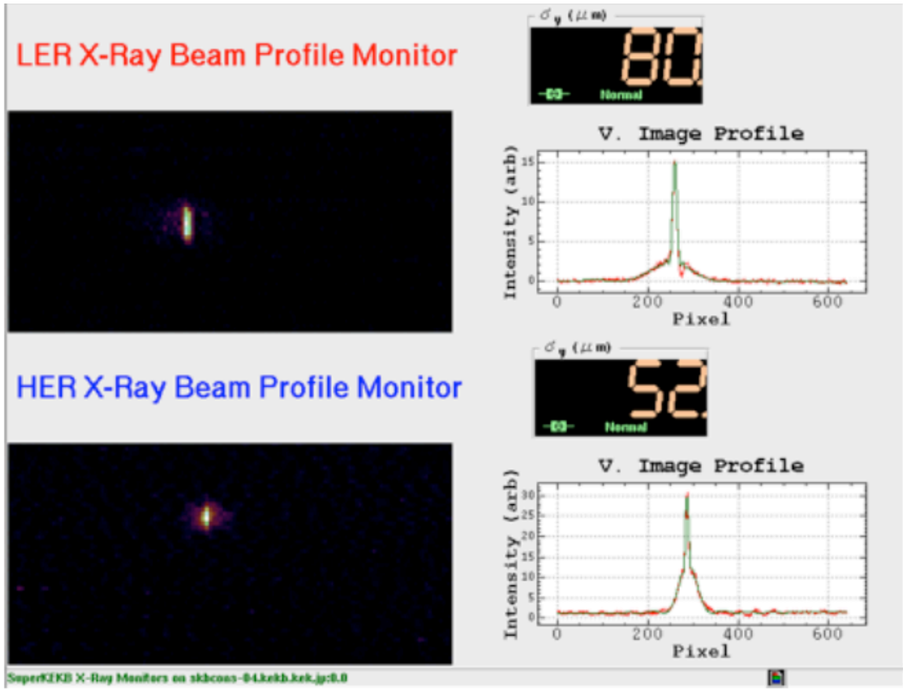
Present status of optics corrections

Items	LER	HER	KEKB typical value (LER)	Unit
X-Y coupling average of rms ($\Delta y_{1\text{-}6}$)	23.6	7.7		μm
H. Dispersion rms ($\Delta\eta_x$)	14.8	16.1	10	mm
V. Dispersion rms ($\Delta\eta_y$)	9.5	4.8	8	mm
Beta-x rms ($\Delta\beta_x/\beta_x$)	4.9	4.3	6	%
Beta-y rms ($\Delta\beta_y/\beta_y$)	5.3	3.7	6	%

A simulation shows that LER X-Y coupling (average) and vertical dispersion (rms) can be decreased down to 18.0μm and 4.1mm, respectively by using more skew-Q correctors near the Lambertson septum. We will install shortly skew-Q correctors made of permanent magnets.

More details will be discussed in the poster by Y. Ohnishi et al. (THPOR007).

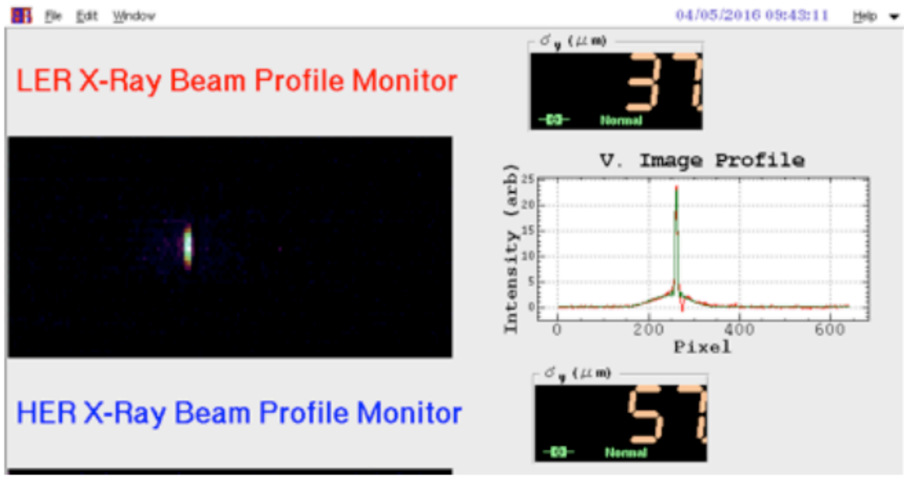
Beam size measurement by using X-ray monitor



ε_y = 96 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$= 5.3 % ($\varepsilon_x$ = 1.8 nm)

March 23, 2016

ε_y = 280 pm (β_y = 9.7 m@source)
$\varepsilon_y / \varepsilon_x$= 5.3 % ($\varepsilon_x$ = 5.3 nm)



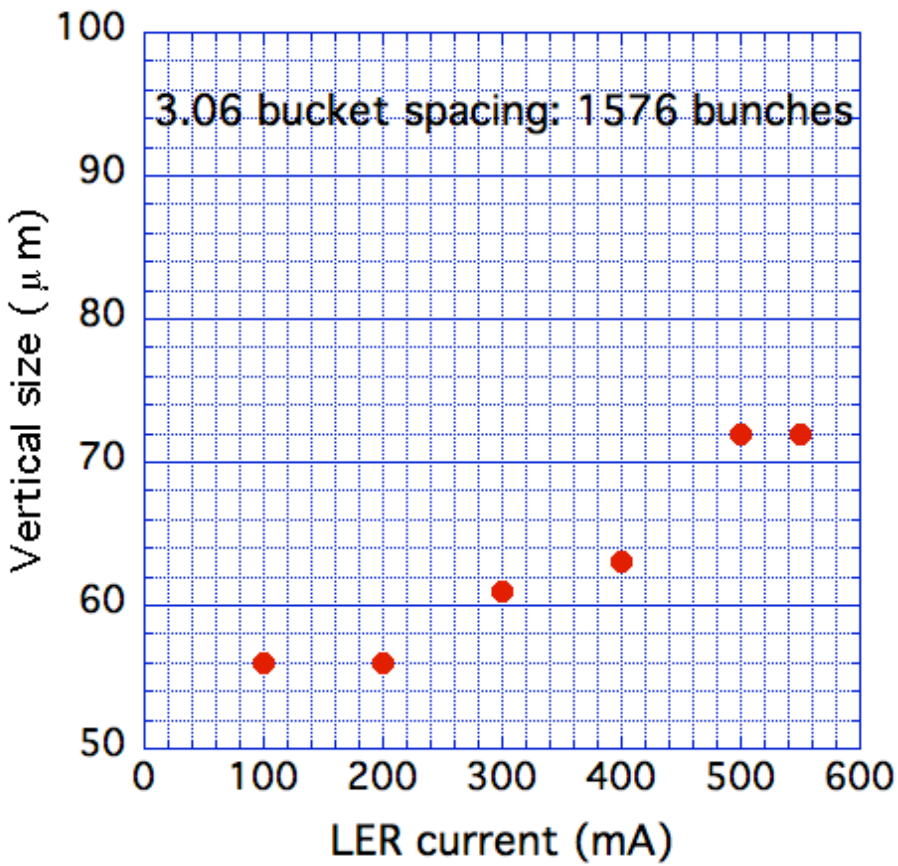
April 5, 2016

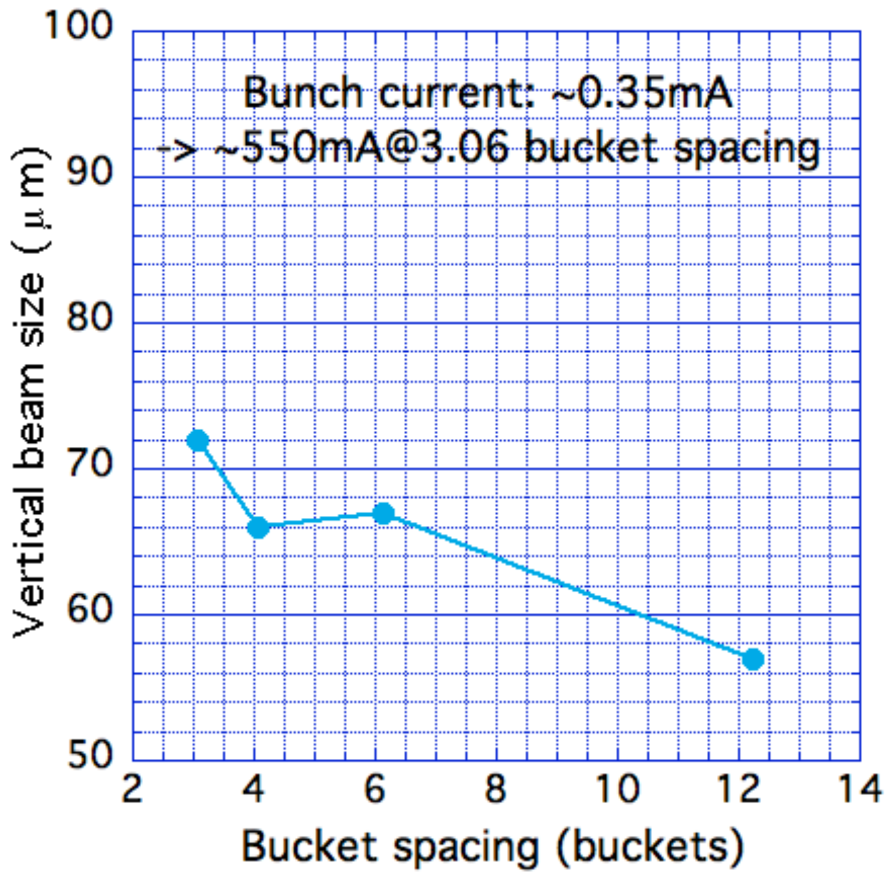
ε_y = 20 pm (β_y = 67 m@source)
$\varepsilon_y / \varepsilon_x$= 1.1 % ($\varepsilon_x$ = 1.8 nm)

Target vertical emittance in Phase 1 is 10pm.

Work for calibration of X-ray monitor beam size monitor is on the way.

Beam current dependence of LER vertical beam size





We observed beam current dependent vertical size blowup in LER (positron ring). This blowup is not a single bunch effect and is possibly caused by the electron cloud effect. We plan to do more detailed study on this issue.

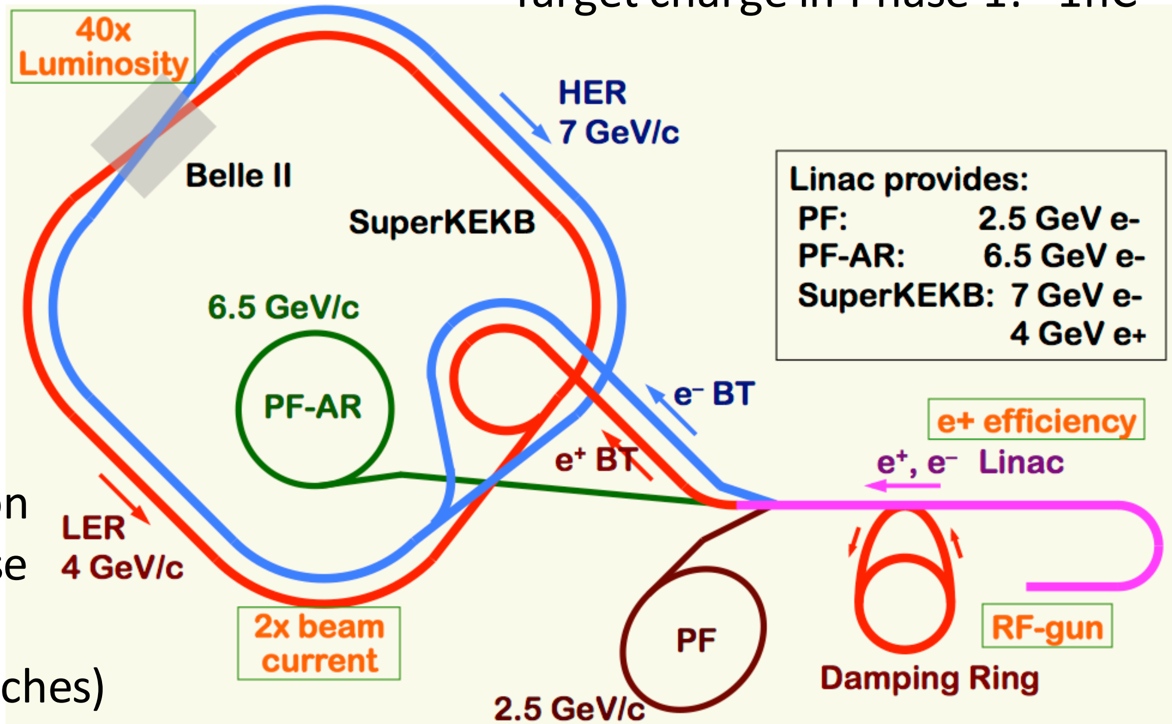
Injector Status

- Requirements to Linac
  - Higher charge for electron and positron
  - Lower emittance for electron and positron
- Linac challenges
  - Low emittance and high intensity e-
    - high-charge RF-gun
  - Low emittance e+
    - damping ring
  - Higher e+ beam current
    - new capture section with flux concentrator
  - Emittance preservation
    - precise beam control
- Status in Phase 1
  - RF gun: still under development
  - Damping ring: under construction
  - Flux concentrator: in practical use
  - Charge at end of BT
    - e-: ~0.6nC, e+:~0.6nC (2bunches)
  - Dedicated machine study for injector: 1 day / week

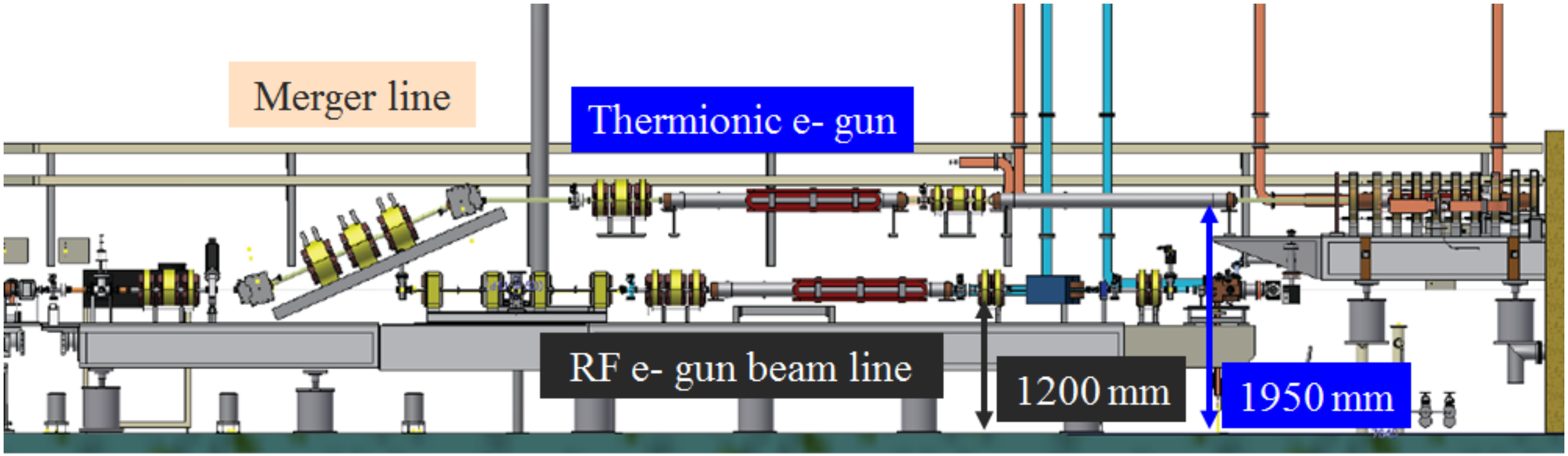
SuperKEKB requirements (Phase 3)

	KEKB (e+/e-)	SuperKEKB (e+/e-)
Charge [nC]	1/1	4/5
Normalized emittance[μm]	2100/300	100/50 (H)
		20/20 (V)

Target charge in Phase 1: ~1nC



Layout of electron gun (Thermionic DC gun and photo-cathode RF gun)

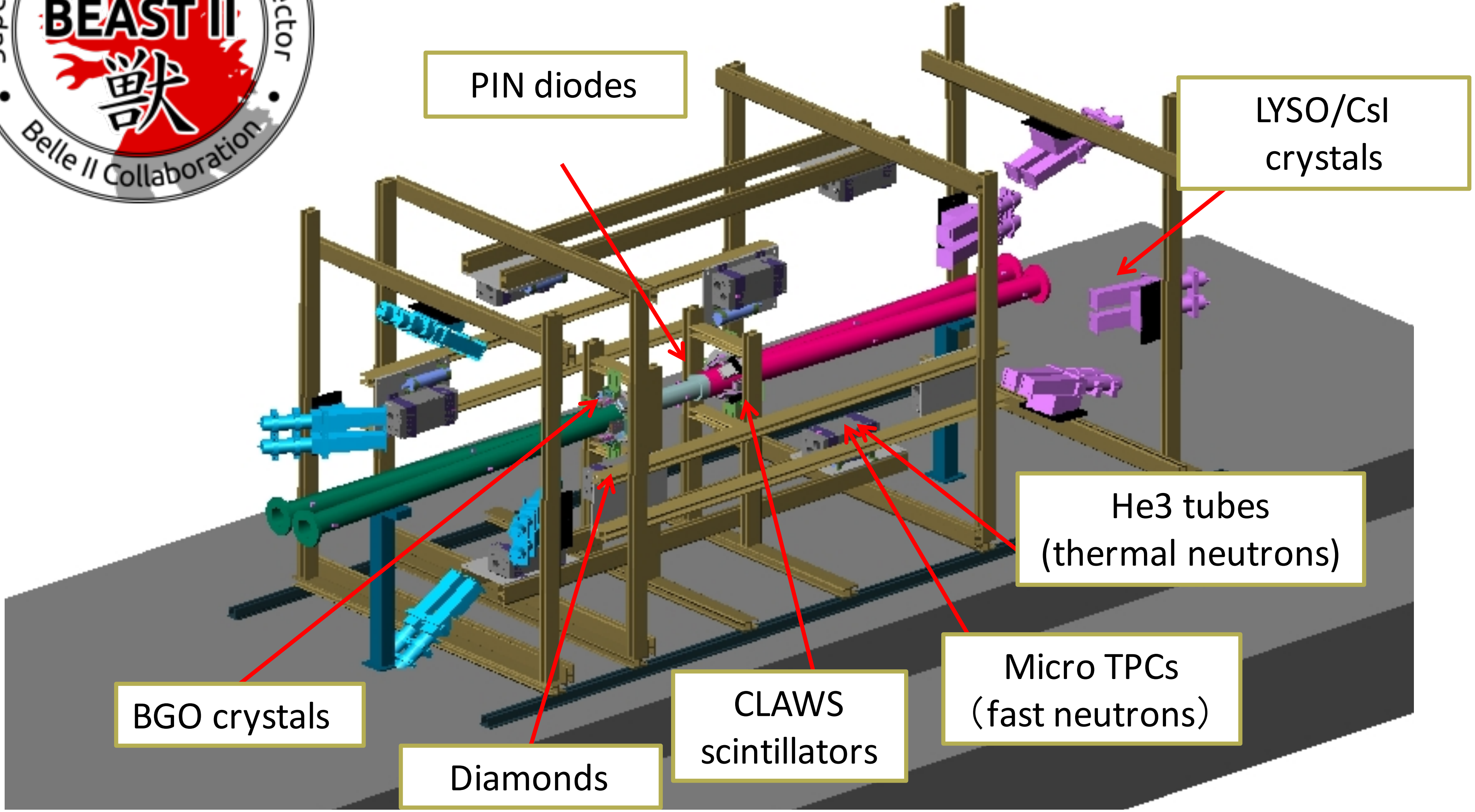


Commissioning more details

- Ring circumference
  - LER: $C_{Measurement} – C_{Design}$ ~2.0mm (Cir: 3016m)
  - $C_{LER} – C_{HER}$ ~ 0.2mm (LER chicane can adjust +/- 3mm)
  - Magnet group has done a good job in the alignment work.
- Beast study (scheduled in mid. of May)
  - Compare experimental data with simulations
  - Study items
    - Vacuum bump
    - Touschek background (change vertical beam size)
    - Background associated with beam injection
    - Collimators

H. Nakayama

BEAST Phase1 sensors at IP



Various measurements (fast charged particle, high-energy photons, thermal/MeV neutron, dosimetry, etc..) to **validate beam loss simulation**

Machine study to be done in May and June (>30 shifts)

- More optics study
- X-ray monitor calibration
- LER beam size blowup
- Longitudinal/transverse bunch-by-bunch feedback system
- Beast background study
- Impedance measurement
- Rotational sextupole magnet
- Dithering coils
- Beam transport line study
- Linac study (RF gun etc.)

Summary

- After 5 year's upgrade work from KEKB, Phase 1 operation of SuperKEKB (w/o Belle-II detector and IR) started in Feb. 2016 and on the way.
- The startup of SuperKEKB operation is relatively smooth thanks to experiences at KEKB.
- In preparation for installation of Belle-II detector in Phase 2, vacuum scrubbing is being done and beam background study is scheduled with Beast detector.
- The optics correction study is going on energetically.
- There is some room for improvement in the low emittance tuning.
- The calibration of X-ray monitor is an important tuning item.
- We observed the vertical beam size blowup in LER. We need further study.
- Injector has worked stably. For Phase 2 and 3 operation, we will need more improvements.
- In the remaining period in Phase 1 (May and June), we will do more machine studies on various items (> 30 shifts).