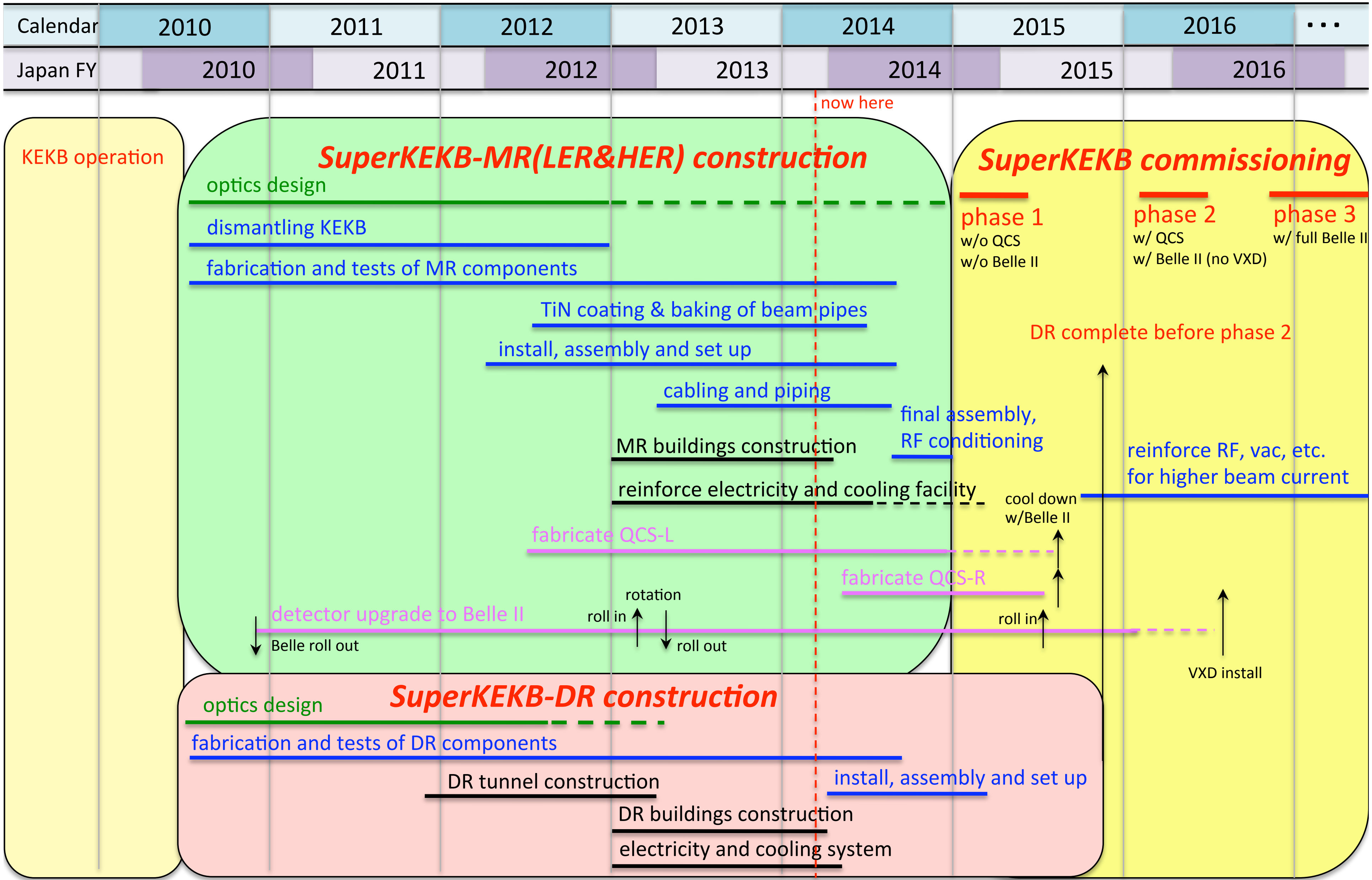
Ring commissioning

2014.3.4

SuperKEKB Review

Y. Funakoshi for the SuperKEKB commissioning group

SuperKEKB rings master schedule



K. AKAI, Overview of ring construction status and schedule, 19th KEKB Accelerator Review, Mar. 3, 2014, KEK

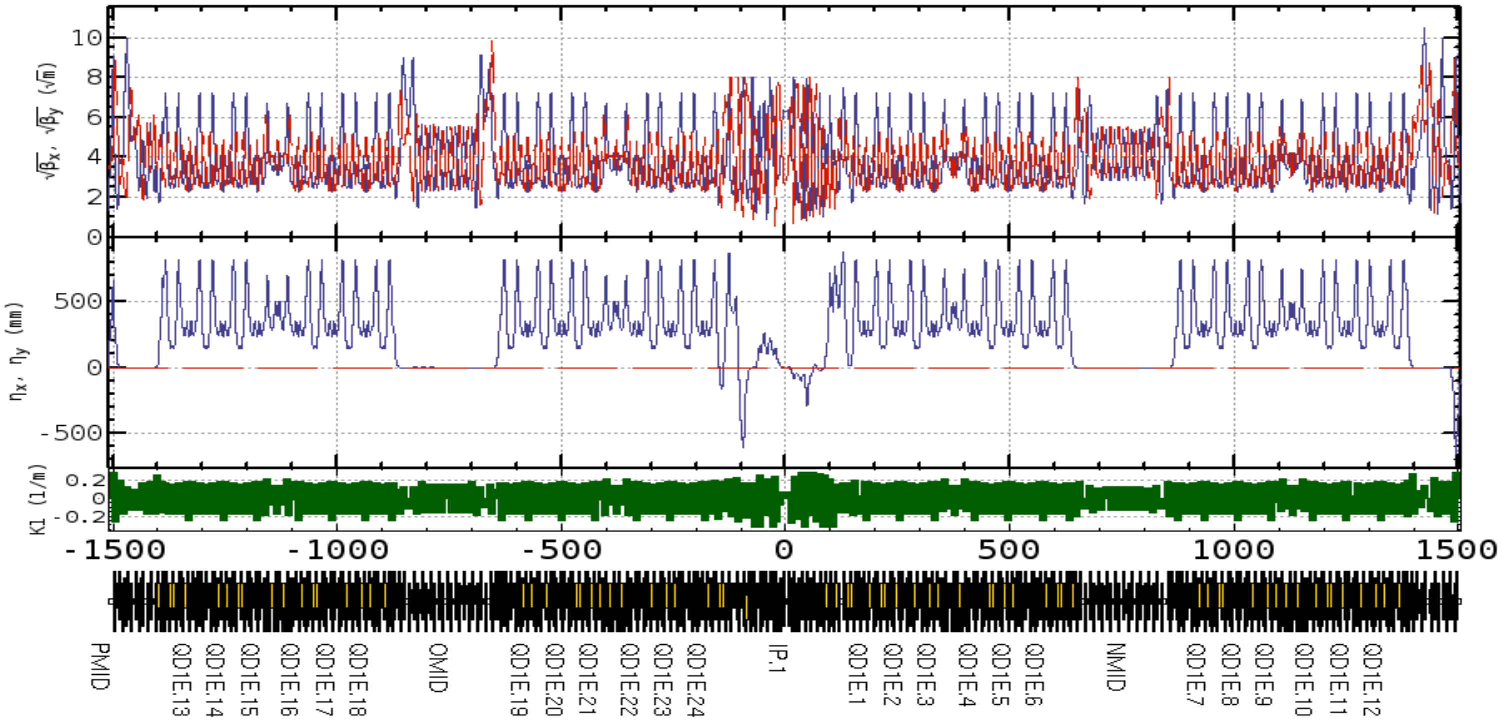
Commissioning phase 0 (2013 Sep. ~ 2014 Dec.)

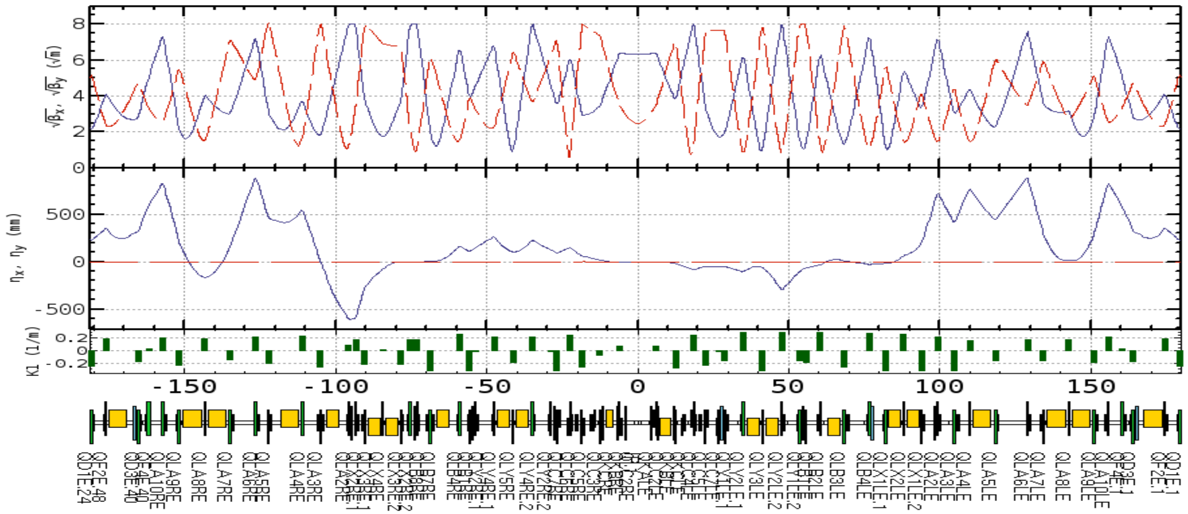
- Machine condition
  - SuperKEKB rings: construction
  - Linac commissioning in parallel with its construction
- Tuning items
  - Presented by the talk by Satoh san this morning.
  - The ring commissioning team is participating to the linac commissioning.
  - In parallel, the commissioning software for SuperKEKB rings is being prepared (A. Morita).

Commissioning phase 1 (2015 Jan. ~ June)

- Machine condition
  - No QCS, No solenoid (no Belle II), No beam collision
- Tuning items
  - Linac tuning (if necessary)
  - Basic commissioning of machine (~ 1.5 month)
    - Injection tuning, Hardware check and bug fix, software bug fix
  - Vacuum scrubbing (>~3 months)
    - Belle II people request enough vacuum scrubbing in this stage (before Belle II roll-in). At least one month with beam currents of 0.5 ~ 1 A.
  - Damping ring commissioning (start from May 2015)
    - Beam injection with damping ring
  - Detector beam background
    - Study with Beast detectors, check of collimator system (two new-type collimators in LER)
  - Some optics tuning
    - With day-1 optics
    - Low emittance tuning w/o Belle-II solenoid
  - Study of beam instability (FII, e-cloud)
    - Tuning on bunch-by-bunch feedback

Phase 1 optics (HER)





DR: Commissioning issues

M. Kikuchi
Commissioning WS

- Apr. 2014 : Installation in the tunnel will start (cabling, magnets, etc.)
- May 2015: Beam commissioning to be started
- June 2015: Injection to LER

- Hardware check
  - Polarity, RF conditioning, kicker timing, etc
- Machine protection
  - Beam Loss Monitor (BLM) vs radiation monitor
- Energy collimation / Emittance collimation
- RTL / LTR tuning
- Optics / orbit measurement, correction
- Vacuum scrubbing
- Tuning satellite bunches
- Injection to Linac (emittance measurement)
- ....

All should be done within one month

The is the original scenario.
It is desirable to complete the commissioning of DR before Belle II roll-in.
There is no "Damping Ring Group". The same stuffs as SuperKEKB team must do the the commissioning. Collaborators (from SLAC?) for DR commissioning will be welcome.

Phase 1 beam monitors

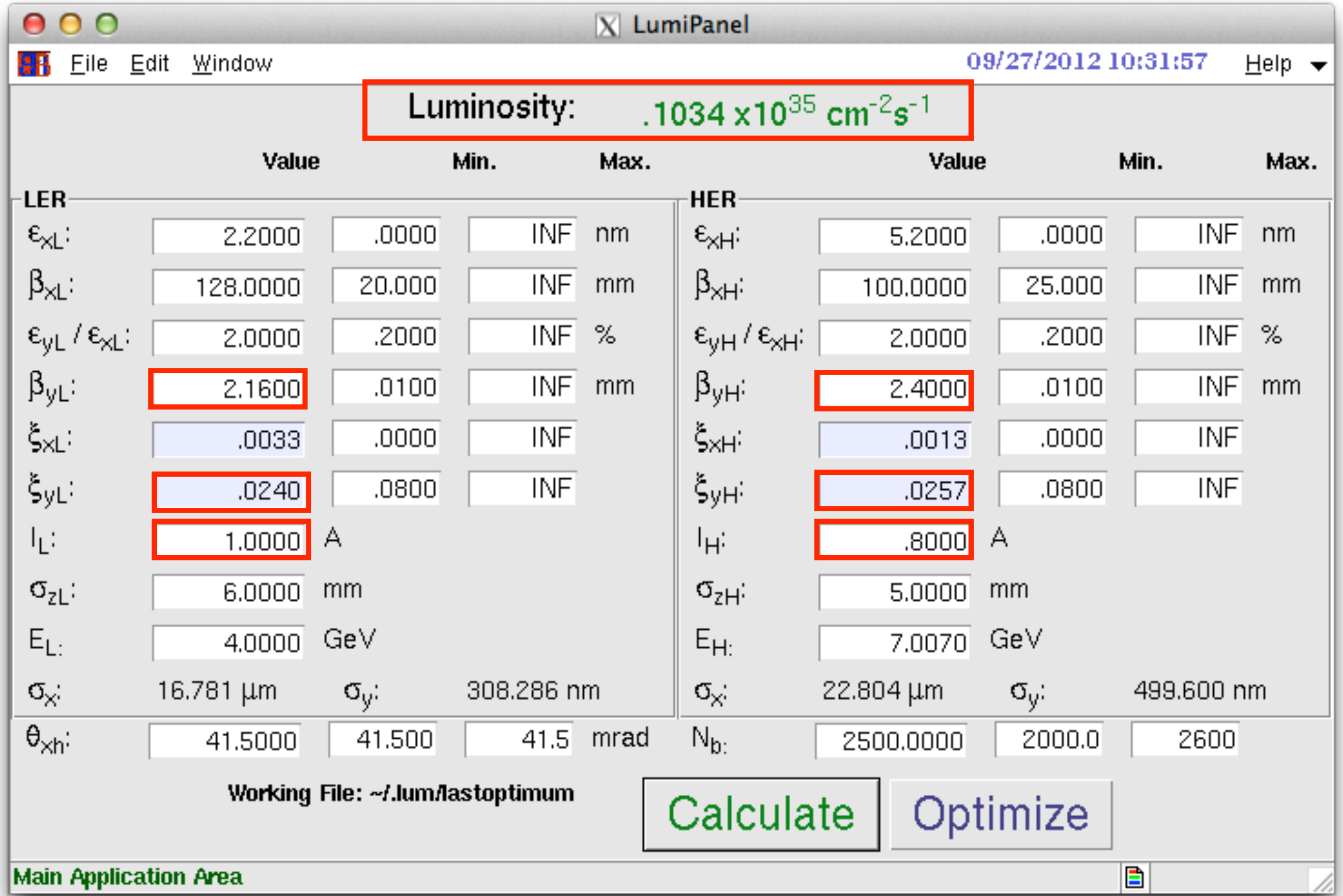
- X-ray monitor
  - Can measure vertical emittance with small beam currents (~30mA) with nominal bunch current.
- Streak camera
  - Can measure bunch length
- Turn-by-burn BPM
  - ~110 bpms
- Energy spread measurement
  - Not easy
  - At KEKB, the measurement was done by using Belle detector (hadron ratio) at narrower resonance (Υ(2S)). We didn't notice that the microwave instability actually happened in KEKB LER for a long time.

Commissioning phase 2 (2016 Feb. ~ June)

- Machine condition
  - w/ QCS, w/ Belle II (w/o VXD),TOP detectors partially installed, full accelerator tuning, no physics experiment
- Tuning items
  - Optics tuning
    - Tentative target values of IP beta's: β_x^*: x4, β_y^*: x8
    - Optics tuning with QCS and Belle II solenoid
    - Low emittance tuning w/ Belle II solenoid
    - Optics tuning w/ beam collision
  - Detector beam background
    - Study with Belle II detector, Beast II detector, test of continuous injection
  - Increase of beam currents (instability, RF power, vacuum issues)
    - Detector background will be tested.
    - Continue upgrade for RF system (support ~70% of design beam currents)
  - Beam collision tuning
    - Orbit feedback (fast vertical feedback, dithering system)
    - Collision tuning w/ "Nano-Beam" scheme
  - Luminosity tuning
    - Tuning knobs (x-y coupling at IP etc.)
    - Target luminosity: 1 x 10^{34} cm^{-2} s^{-1} (design of KEKB)

Detuned Optics (4x8)

Example of machine parameters for 10^{34} $cm^{-2}s^{-1}$



β_x^*: x4, β_y^*: x8, x-y coupling =2 %, ξ_y ~ 0.025, I_{LER} = 1 A.

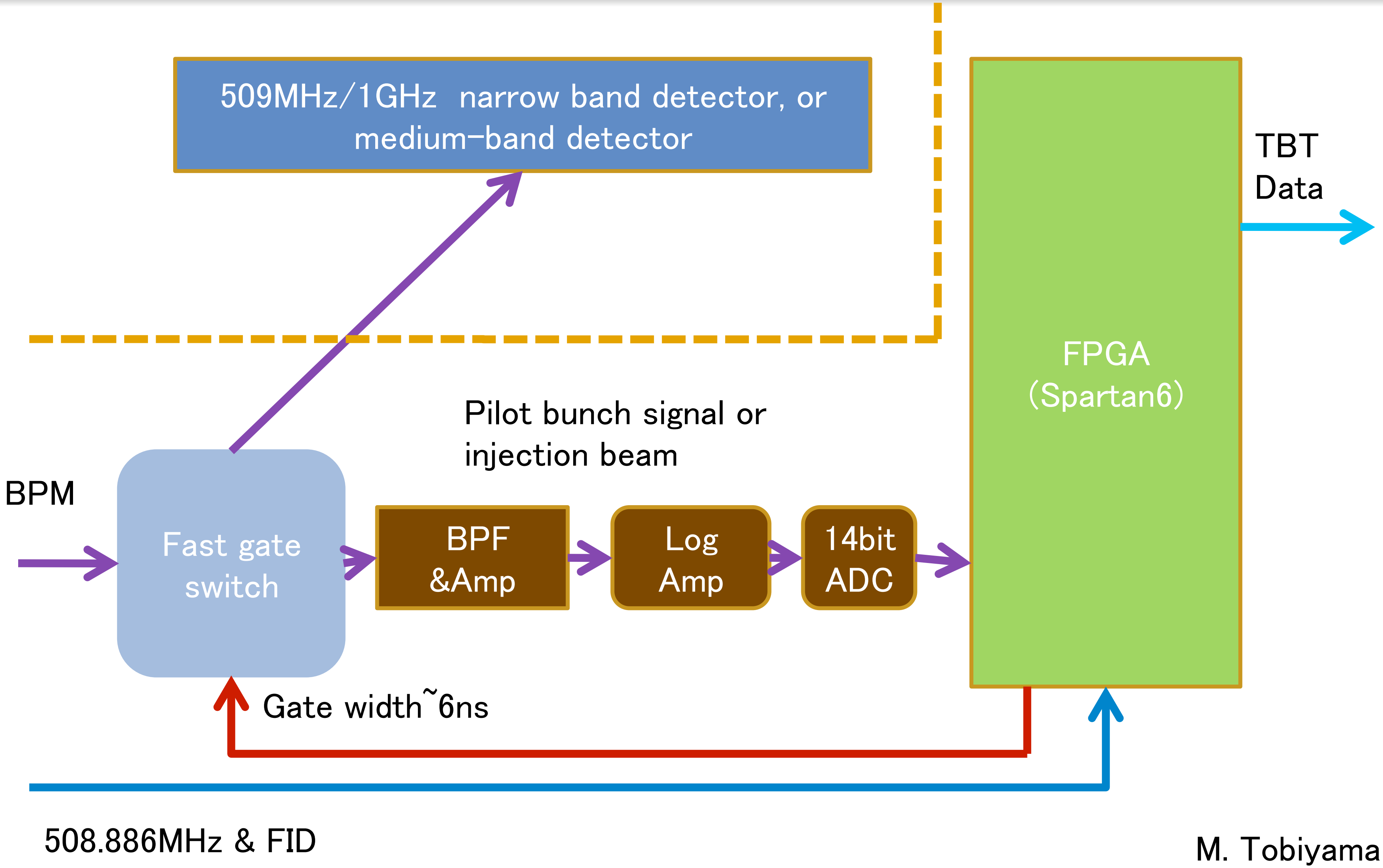
Commissioning phase 3 (2016 Oct. ~)

- Machine condition
  - Full set of Belle II, Physics experiment will start.
    - Maybe some TOP counters will be delayed.
- Tuning items
  - Optics tuning
    - Toward design values of IP beta's
      - Maybe it will take several years.
    - Low emittance tuning:
      - Design values for vertical emittances are very small. Demonstration of feasibility of TLEP.
    - Optics tuning w/ beam-beam effect
  - Detector beam background
    - Establishment of continuous injection (azimuthal VETO)
  - Increase of beam currents
    - Design values are as twice high as those of KEKB.
  - Luminosity tuning
    - Study on effects of lattice non-linearity and space-charge and their corrections or compensations?
    - Stability of tuning will be an important issue. (continuous optics correction?)
    - The first important milestone in phase 3 is to achieve the luminosity 1 x 10^{35}.

Beam monitors in phase 2, 3

- Turn-by-turn BPM
  - ~270 BPMs
- Gated turn-by-turn BPM
  - Measure oscillations of pilot bunches
    - Enable continuous optics correction?
- BPM for orbit interlock
  - Libera Brilliance+
    - turn–by–turn mode, latency <10 turns
    - Evaluation in progress: Latency < 4 turns
- Beamstrahlung monitor
- BPM for IP orbit feedback
- Fast luminosity monitor (S. Uehara, P. Bambade)

Gated turn-by-turn monitor



M. Tobiyama

Lattice preparation

Y. Ohnishi

phase	sub-phase	IR status	lattice, commissioning	I_b (mA)
Phase 1	Phase 1.1	No QCS No Belle II	wiggler off, device check, optics tuning, vacuum scrub.	< 30-100
	Phase 1.2		wiggler on, circumference, optics tuning	< 30
	Phase 1.3		high emittance for **vacuum scrubbing** (LER)	500-1000
	Phase 1.4		**optics tuning (low emittance)**	< 30
Phase 2	Phase 2.1	QCS Belle II w/o VXD	vertical beta* = 80 mm, optics and injection tuning	< 30
	:		:	:
	Phase 2.x		vertical beta* = 2.2 mm, **optics and luminosity tuning**	1000/800
Phase 3	Phase 3.1	QCS Belle II with VXD (Physics Run)	vertical beta* = 2.2 mm, optics and luminosity tuning	1000/800
	:		:	:
	Phase 3.x		**ultimate beta***, optics and luminosity tuning	3600/2600

Injection/Abort Construction Schedule

T. Mori
Commissioning WS

- **Phase *1***
  - The new HER injection/abort system is installed
    - This is urgent issue & main topic of this talk
  - The KEKB LER injection/abort system is preserved.
    - DR is not ready at the beginning of Phase 1
      - Emittance is large; new LER system doesn't work well for Phase 1
    - The LER current must be low to protect the abort window (< 500mA)

      Or the ring emittance should be enlarged.
- **Phase *2***
  - The new LER injection/abort system is installed
    - DR is ON
    - New LER chambers has smaller apertures than those of KEKB
      - They should be installed at the same time not to build cavity structures
      - New injection channel can't be used for large emittance beam of Phase 1

ICFA Mini-Workshop on Commissioning of SuperKEKB and e+e- colliders

- 11-13 November 2013 *KEK*
- *Registrated attendees: ~70*
- http://kds.kek.jp/conferenceDisplay.py?ovw=True&confId=12760
- Reports from LHC, BEPC-II , PEP-II, CesrTA, DAΦNE, τ-Charm plans at LNF and SuperKEKB

Challenges at SuperKEKB
Summary of SuperKEKB commissioning workshop (by U. Wienands)*)

- Emittance tuning and getting the beam optics under control
  - Should learn from other machines (CesrTA, LHC, DAΦNE,…)
- Electron-cloud effects
  - Maybe no problem at SuperKEKB?
- HOM heating and discharges
  - "High beam current supervisor"
- IR and background tuning
  - More collaborative works between accelerator and Belle II people than KEKB will be needed.
- Injector tuning
  - Should learn from FACET and ATF.

*) to be appeared in ICFA Beam dynamics Newsletter

More challenges at SuperKEKB

- Beam-beam related issues (most serious issues so far)
  - Dynamic aperture with beam-beam effects
  - Beam-beam + lattice nonlinearity
  - Beam-beam + space charge
- Instabilities and their suppression by feedback system
  - So far, it seems that we will well control the instabilities by using feedback system based on experiences at KEKB.
- Damping ring issues
  - No experience at KEKB.
- Radiation safety issues
  - Study has just started.

Beam lifetime

	KEKB (design)		KEKB (operation)		SuperKEKB	
	LER	HER	LER	HER	LER	HER
Radiative Bhabha	21.3h	9.0h	6.6h	4.5h	28min.	20min.
Beam-gas	45h[a)]	45h[a)]			24.5min.[b)]	46min. [b)]
Touschek	10h	-			10min. (3.85min.[c)])	10min.
Total	5.9h	7.4h	~133min.	~200min.	6min. (2.97min.)	6min.
Beam current	2.6A	1.1A	1.6A	1.1A	3.6A	2.6A
Loss Rate	0.12mA/s	0.04mA/s	0.23mA/s	0.11mA/s	10mA/s (20.2mA/s)	7.2mA/s
					4nC@25Hz (8nC@25Hz)	2.9nC@25Hz

a) Bremsstrahlung

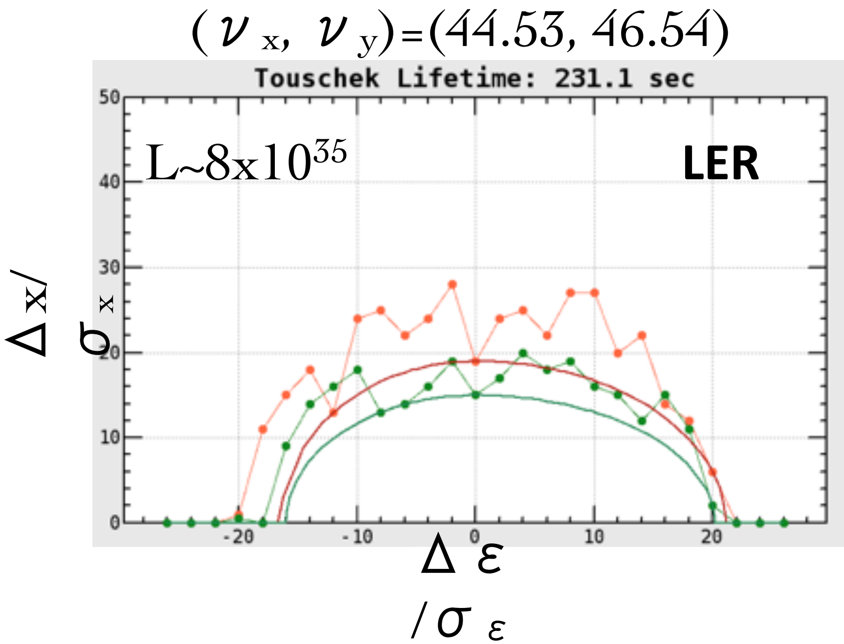
b) Coulomb scattering, sensitive to collimator setting

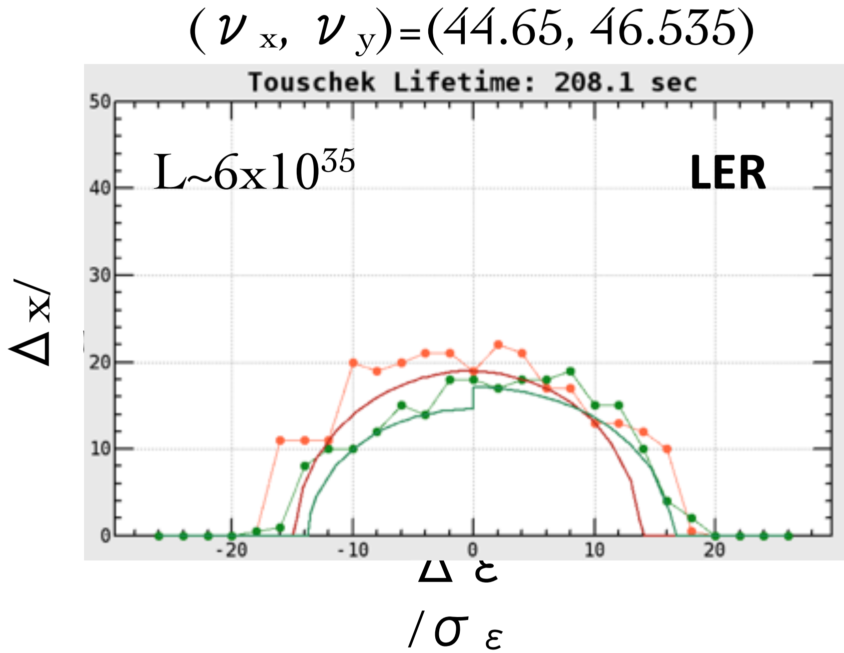
c) With beam-beam best so far

As for loss rate, beam loss accompanied with the beam injection should be added.

Optimization of DA with beam-beam effect

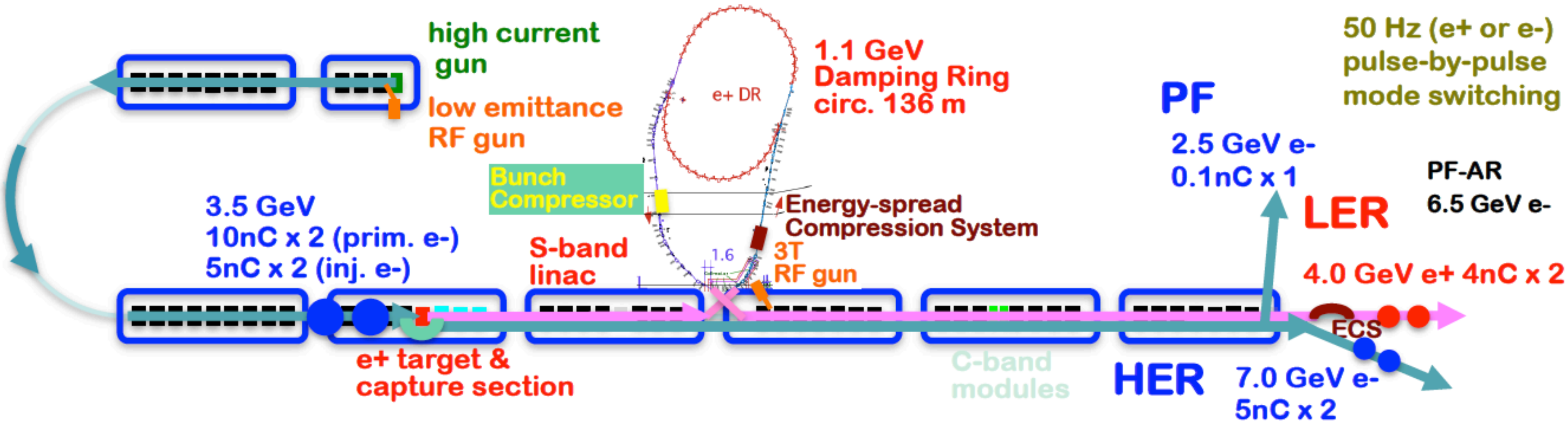
H. Sugimoto





Optimization is done by sextupoles, skew sextupoles, and octupoles.
Touschek lifetime is improved up to 230 sec. Still short lifetime.

Linac



Positron capture section 920 kVA, 900 lit/min	Damping ring BT (LTR, RTL) 310 kVA	Switch yard (3SY) 300 kVA, 460 lit/min

- RF low-emittance gun for 5 nC
- Improve positron source for 4 nC
- Low-emittance transport
  - alignment error tolerance is 0.1 mm locally (0.3 mm global).
- Simultaneous and top-up injection (accompany PF and PF-AR)

SuperKEKB requirements (tentative)

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

K. Furukawa, M. Satoh, M. Yoshida, T. Kamitani

Summary of Session on *Ring Optics and Intensity Effects*

Frank Zimmermann

SuperKEKB Commissioning Workshop

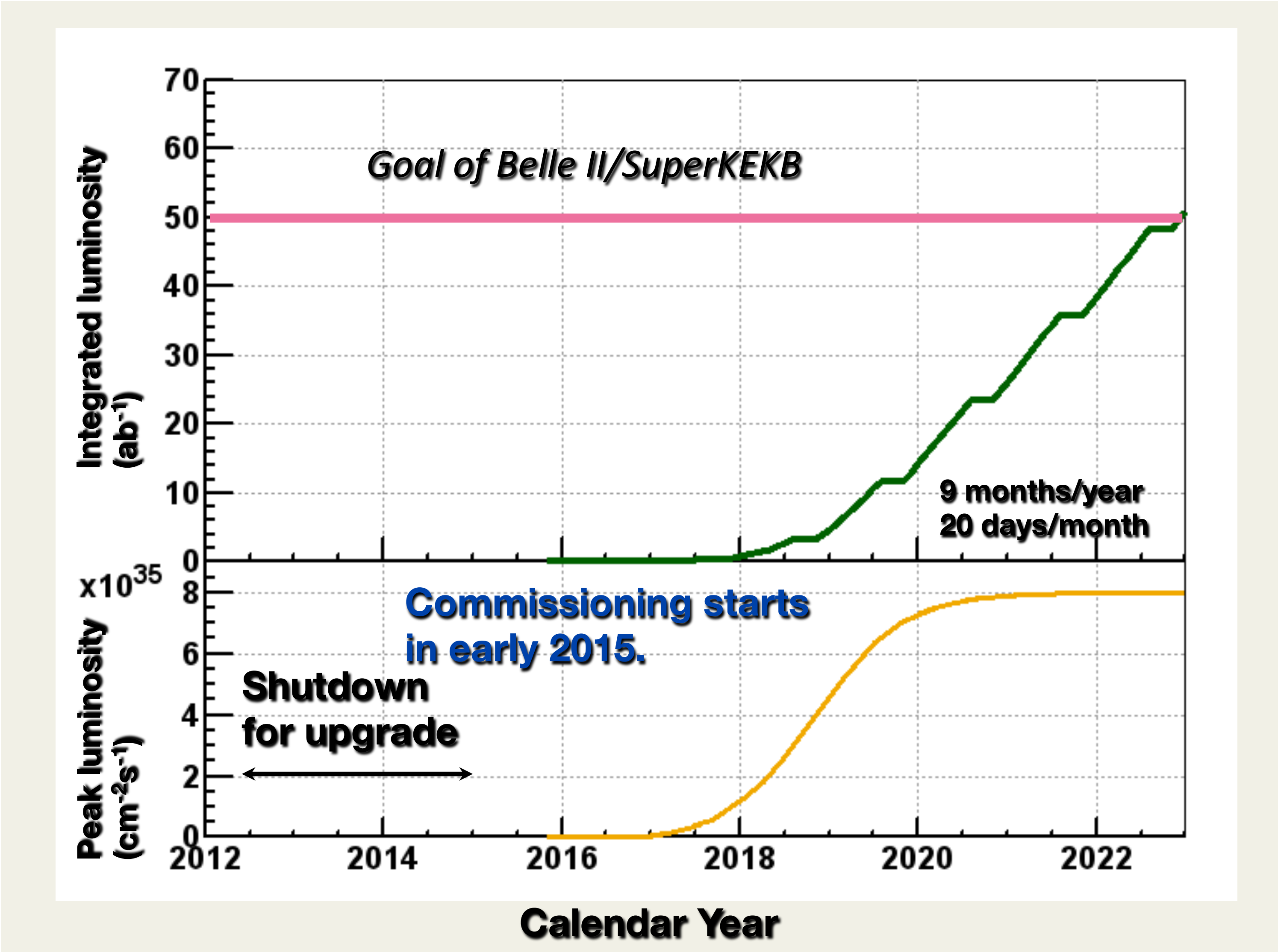
KEK, Tsukuba, 13 November 2013

F. Zimmermann

“to do” list:

- off-momentum optics correction
- identify *dominant lattice nonlinearities* in both rings affecting luminosity
- develop *nonlinear* optics measurement & *correction scheme*
- optimize *nonlinear optics & DA including space charge & beam-beam effect*
- *compensation scheme for space charge*
- *correction scheme with/for crab waist*

SuperKEKB luminosity projection

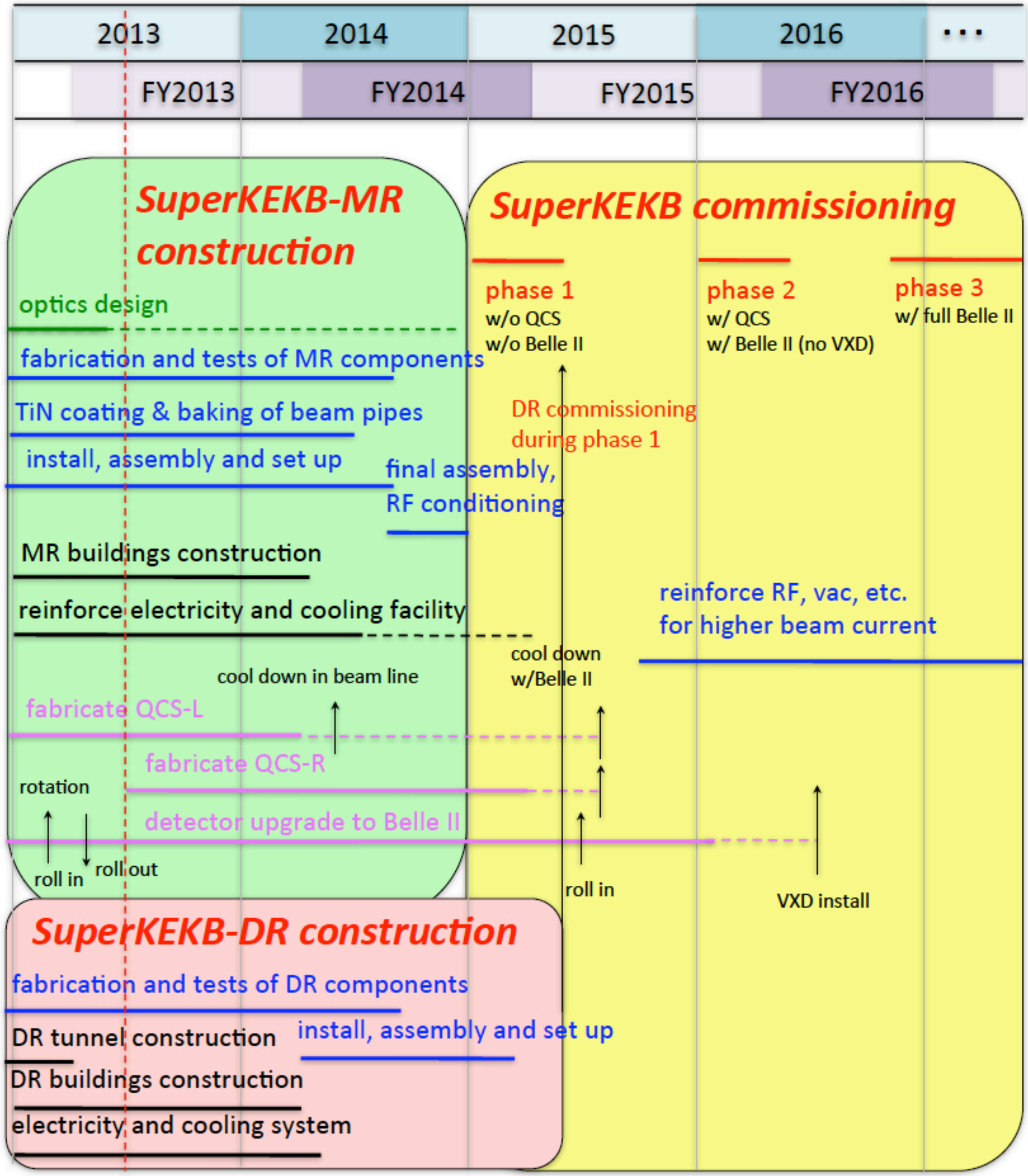


Spare slides

Software development (A. Morita)

- Develop base software
  - Class-based software stack
  - Reuse of software components will be easier by using an abstracted layer.
  - Offer an abstracted layer to apply to LER/HER/DR.
    - Optics model
    - Communication between software panels
      - Optics panel, COD correction panel …

We are here.



K. Akai

Master Schedule

Phase-1
w/o QCS and Belle II

2015 Jan.–June

Phase-2
with QCS and Belle II

2016 Jan.–May

Phase-3
Physics Run

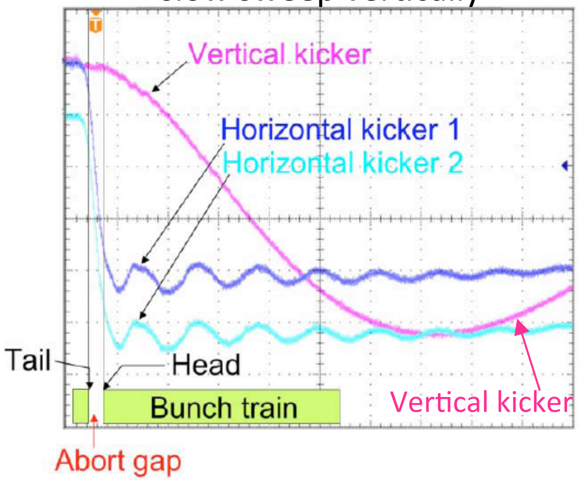
2016 Oct.–

Abort system of SuperKEKB

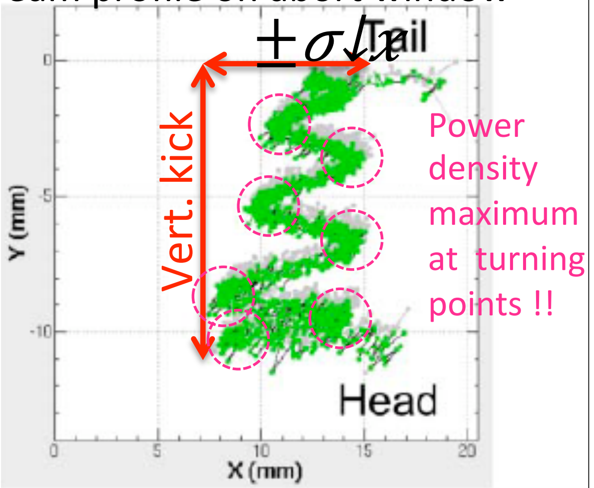
T. Mori

KEKB

Horizontal kicker :
fast kick to abort window
Vertical kicker :
slow sweep vertically



Beam profile on abort window



- Low emittance beam has higher possibility of destroying abort window than KEKB beam
- Enlarging horizontal beam size required additionally

SuperKEKB(LER)

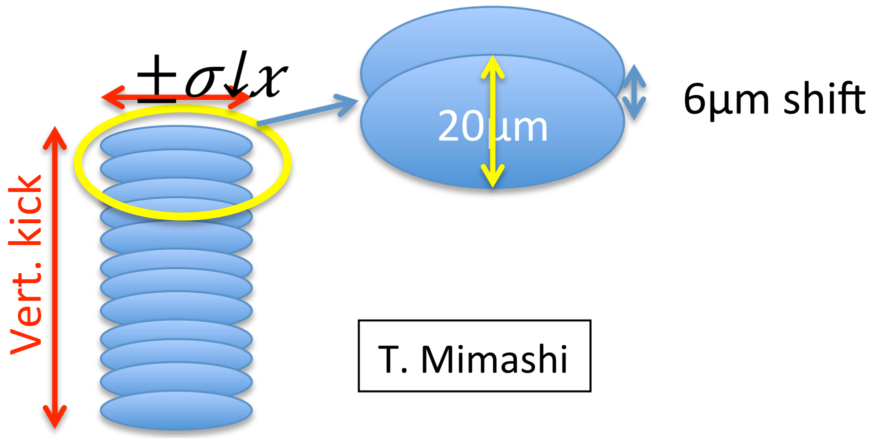
Horizontal kicker :
fast kick to the Abort window
Vertical kicker :
slow sweep vertically
PULSED quadrupole :
enlarge the horizontal beam size

SuperKEKB(HER)

Horizontal kicker :
fast kick to the Abort window
Vertical kicker :
slow sweep vertically
DC sextupole :
enlarge the horizontal beam size

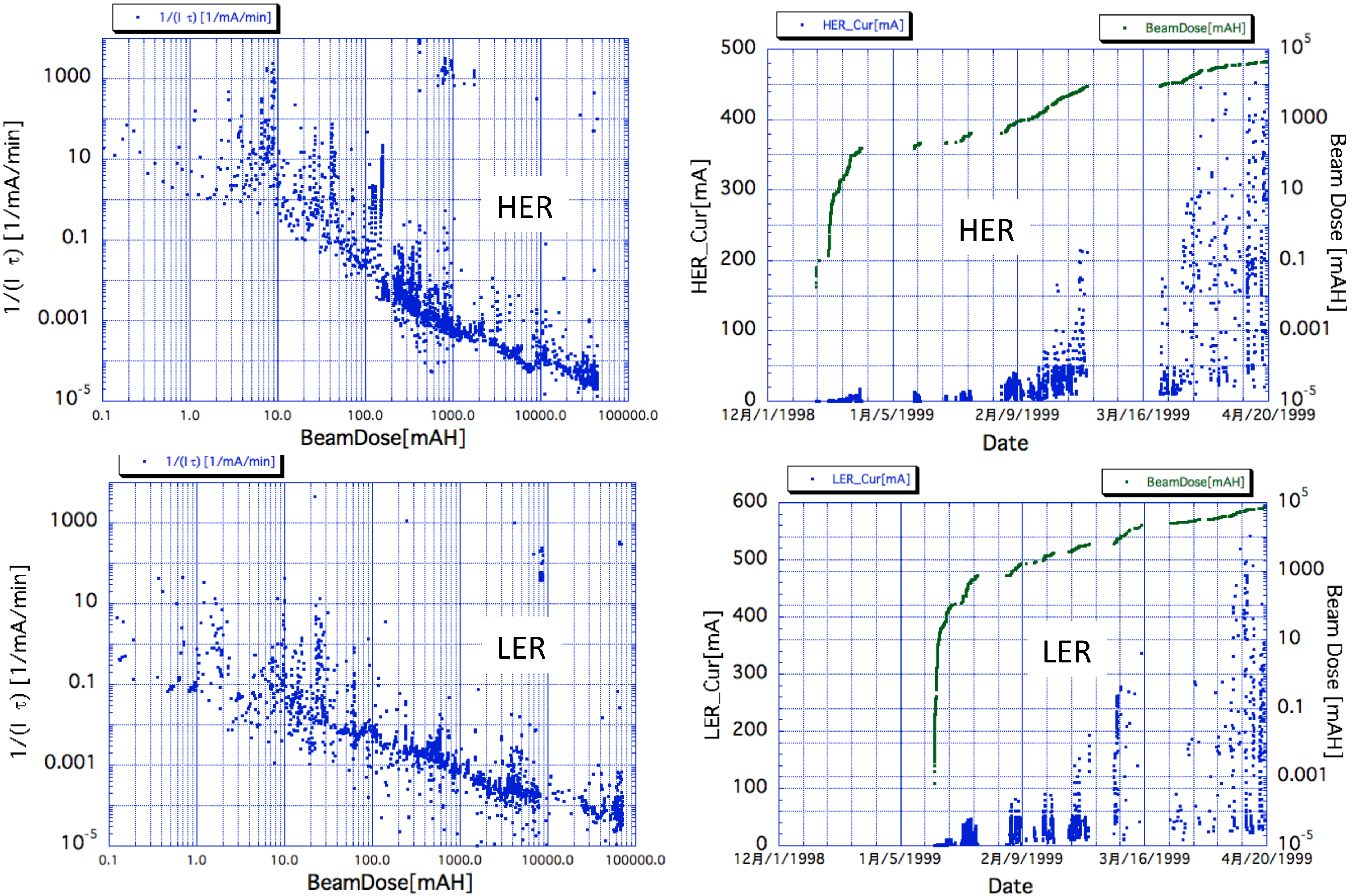
Abort fail-safe system like KEK is also designed

Schematic view of new beam profile on abort window



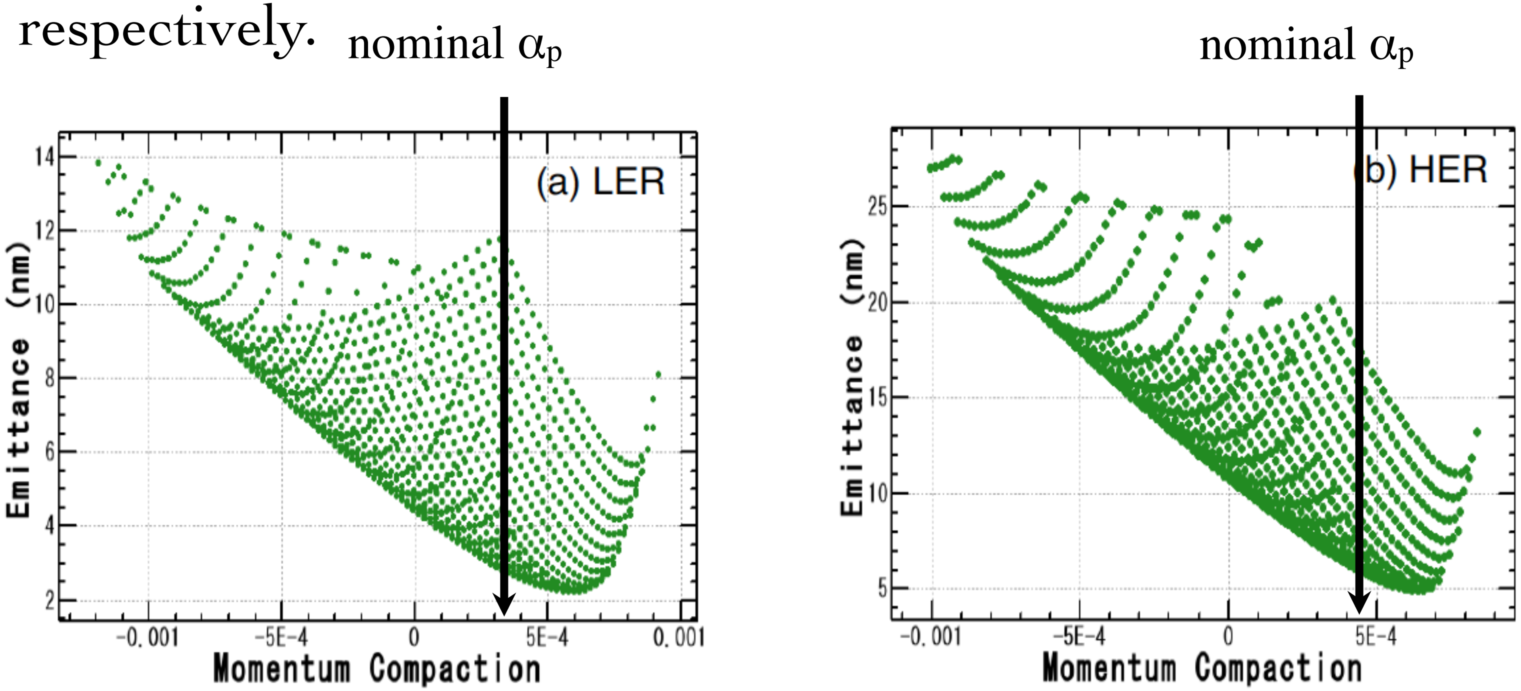
T. Mimashi

Vacuum scrubbing at KEKB (HER/LER)



Emittance change in arc

- Emittance of arc cell can be changed by field strength of quadrupols.
- Range is from 2 to 12 nm in LER and from 5 to 17 nm in HER, respectively.

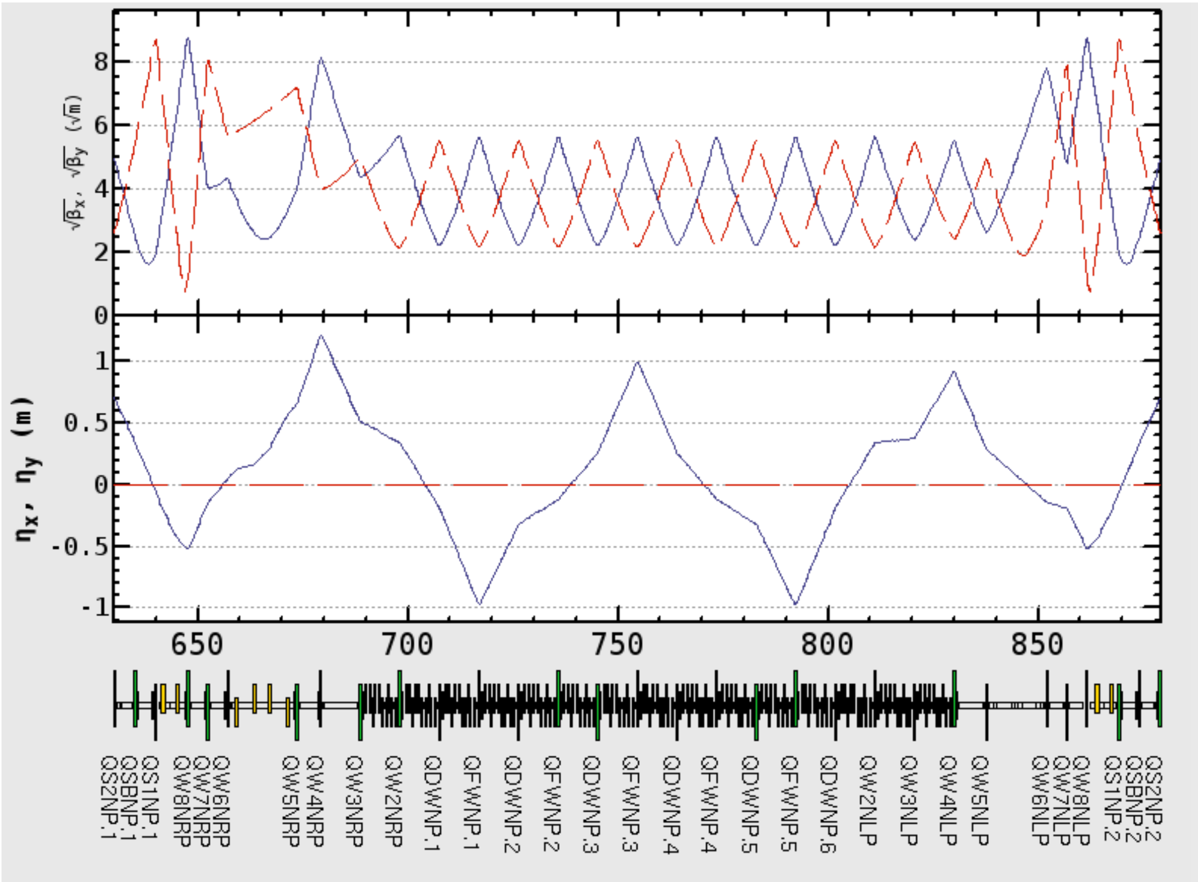


LER: Emittance change in wiggler section

- Emittance can be adjusted by optics in Nikko section(No cavity).
- Only adjust field strength of the quadrupole magnets
- Emittance becomes 20* nm in case of 1 m dispersion at midpoint the straight section.

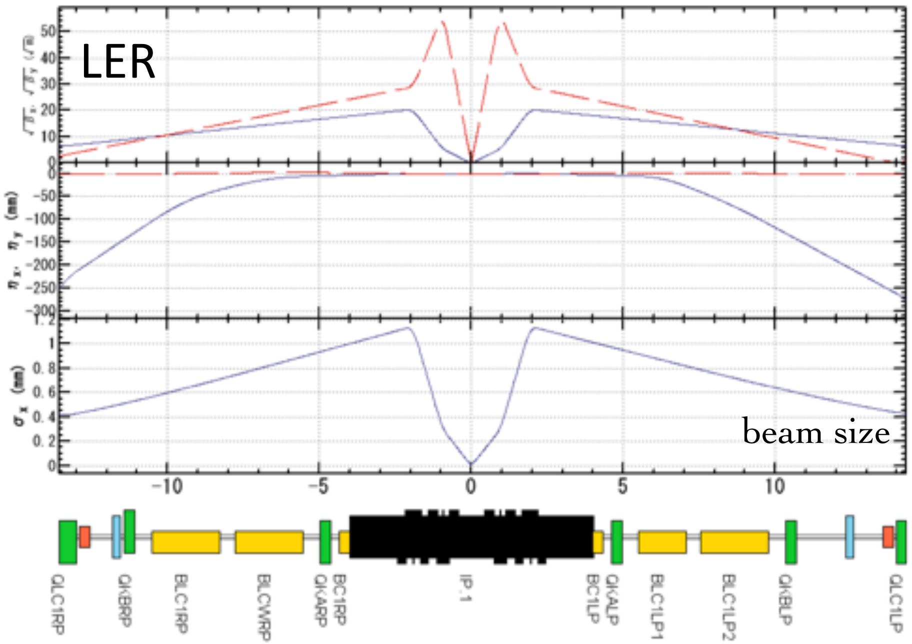
LER: Nikko

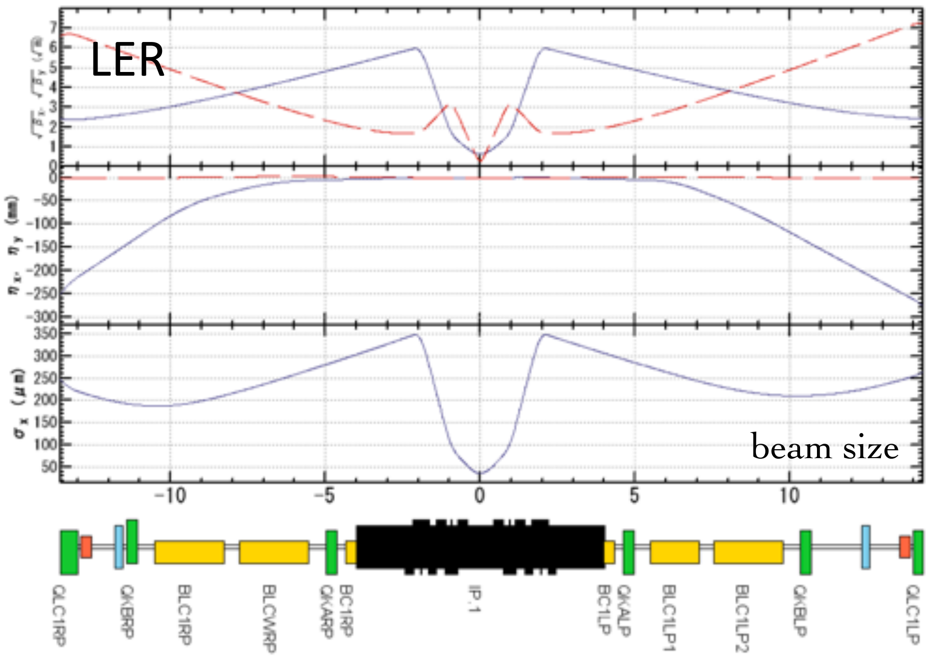
* without intra-beam scattering



Phase 2.1 LER (1/2)

Phase 3.x $\beta_x^* = 32\ mm$ $\beta_y^* = 0.27\ mm$ → Phase 2.1 $\beta_x^* = 400\ mm$ $\beta_y^* = 80\ mm$





σ_x = 1100 μm at QC2
r_b = 35 mm at QC2
r_b/σ_x = 31 (linear calc.)

σ_x = 350 μm at QC2
r_b = 35 mm at QC2
r_b/σ_x = 100 (linear calc.)

KEKB	$\beta_x^* = 590\ mm$ $\beta_y^* = 5.9\ mm$

Phase 2.1 LER (2/2)

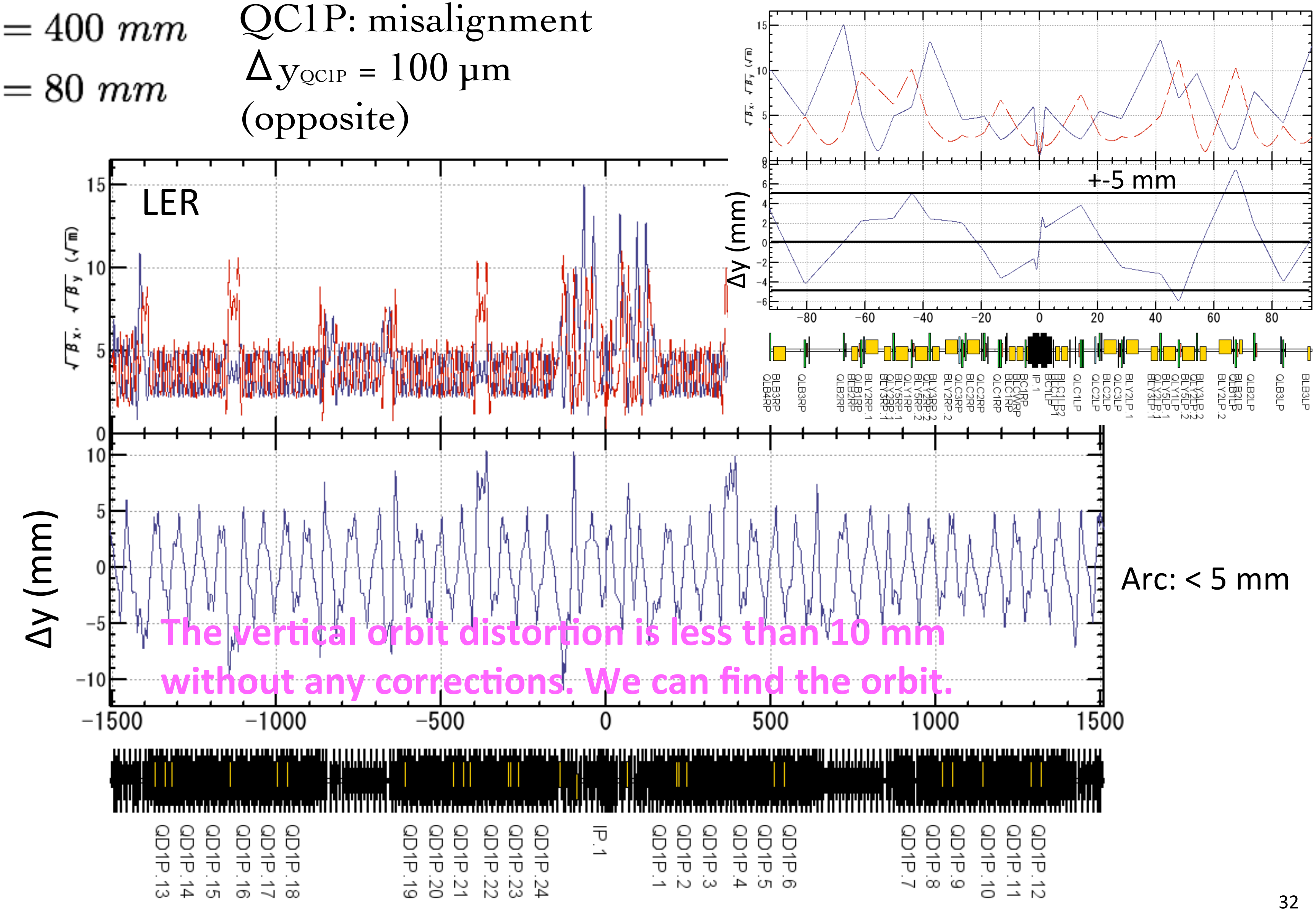
$\beta_x^* = 400\ mm$

$\beta_y^* = 80\ mm$

QC1P: misalignment

Δy_{QC1P} = 100 μm

(opposite)



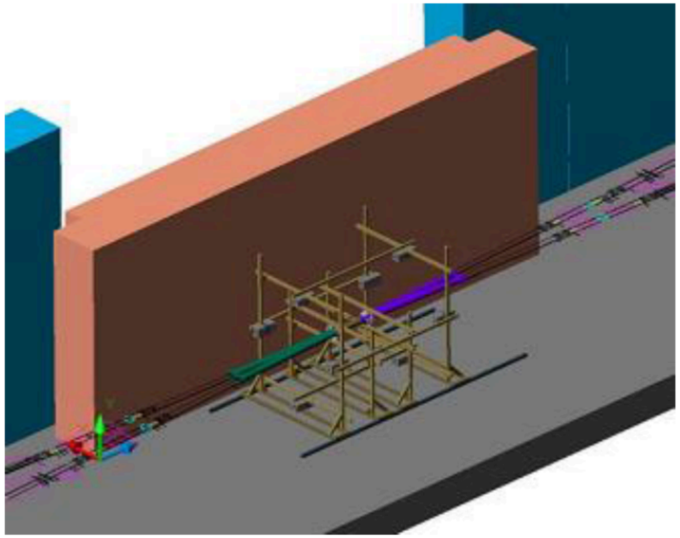
Machine parameters with QCS

Pilot run Ultimate

Parameters	symbol	Phase 2.x		Phase 3.x		unit
		LER	HER	LER	HER	
Energy	E	4	7.007	4	7.007	GeV
#Bunches	n_b	2500		2500		
Emittance	ε_x	2.2	5.2	3.2	4.6	nm
Coupling	$\varepsilon_y/\varepsilon_x$	2	2	0.27	0.28	%
Hor. beta at IP	$\beta_x{}^*$	128	100	32	25	mm
Ver. beta at IP	$\beta_y{}^*$	2.16	2.4	0.27	0.3	mm
Bunch current	I_b	1	0.8	3.6	2.6	A
Beam-beam	ξ_y	0.024	0.0257	0.088	0.081	
Hor. beam size	$\sigma_x{}^*$	16.8	22.8	10	11	μm
Ver. beam size	$\sigma_y{}^*$	308	500	48	62	nm
Luminosity	L	1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

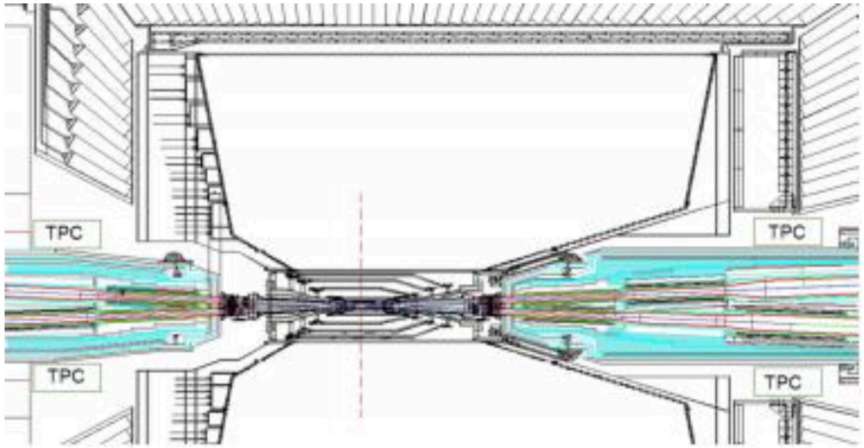
BEASTII

BEAST phase 1 ~2015 Jan.



BG monitoring on vacuum scrubbing
Belle is not installed

BEAST phase II ~2016 Feb.



No VXD detector
BelleII DAQ test start without VXD
Beam abort setting optimization
BG study by BEAST sensors

BEAST systems: 8 BGO crystals, 2 TPCs, 1-2 He-3 tubes, BEAST DAQ, PIN diode

PIN diodes / loss monitors:
TPCs: fast neutrons
He-3 tubes: thermal neutrons
VXD test sensors
BGO for luminosity measurement
Diamond sensor for VXD abort settings

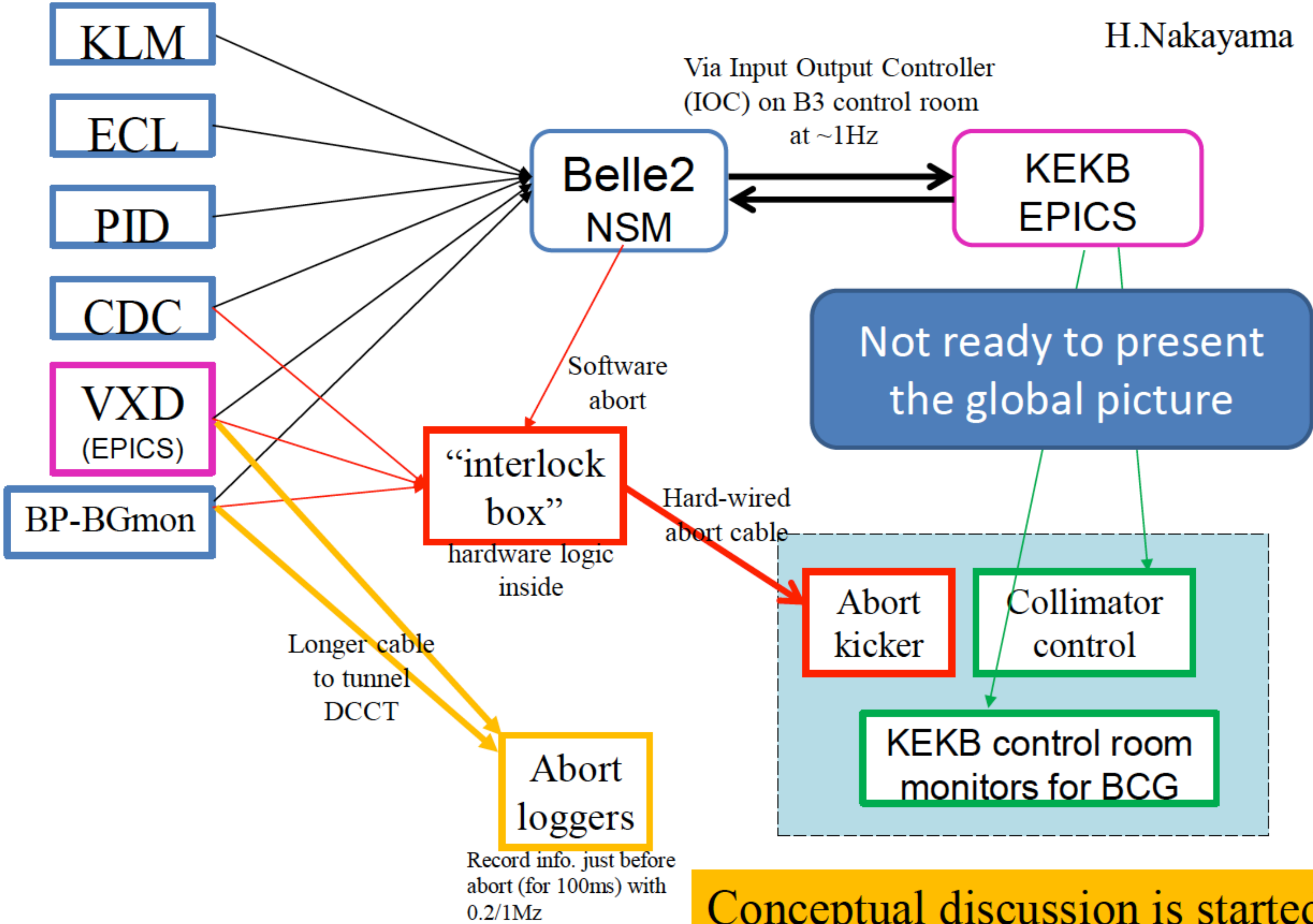
Collimator control systems

- Careful operation is important at SuperKEKB/Belle-II
  - Keep IR loss <1GHz, while total collimator loss >600GHz
  - Miss-operation of collimator(espc. vertical ones) easily results in x10 or even x100 detector background level
  - Aim to develop semi-automatic control algorithm
- Input information:
  - beam lifetime, loss rates at collimators, sub-detector BG levels, injection efficiency, and IR loss distributions, etc..
- IR loss rate distribution gives insight on which BG source and therefore which collimator we should adjust
- IR loss monitor R&D has started

New activity

Data flow diagram(monitor)

H.Nakayama



Conceptual discussion is started

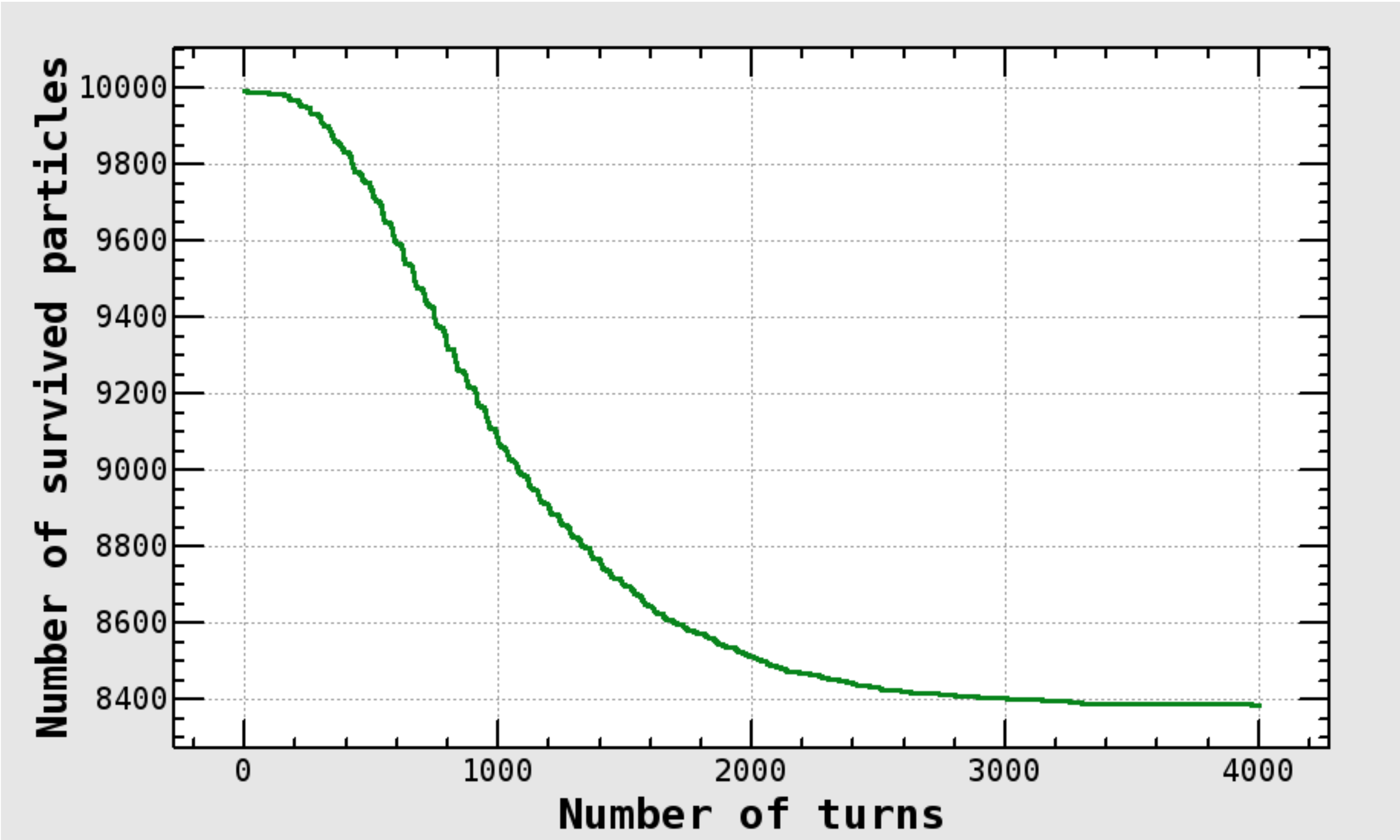
Difficulty of SuperKEKB

- The commissioning phase 3 will be the most critical phase.
  - The true difficulty of SupeKEKB will be recognized in this phase.
    - Corrections of machine errors seem the key issue.
    - Stability of machine condition seems important.
      - Continuous optics correction?
  - Some unknown difficulties will possibly appear.
  - My personal impression: Important milestone of luminosity: 1×10^{35} cm^{-2} s^{-1}.

Detector beam background

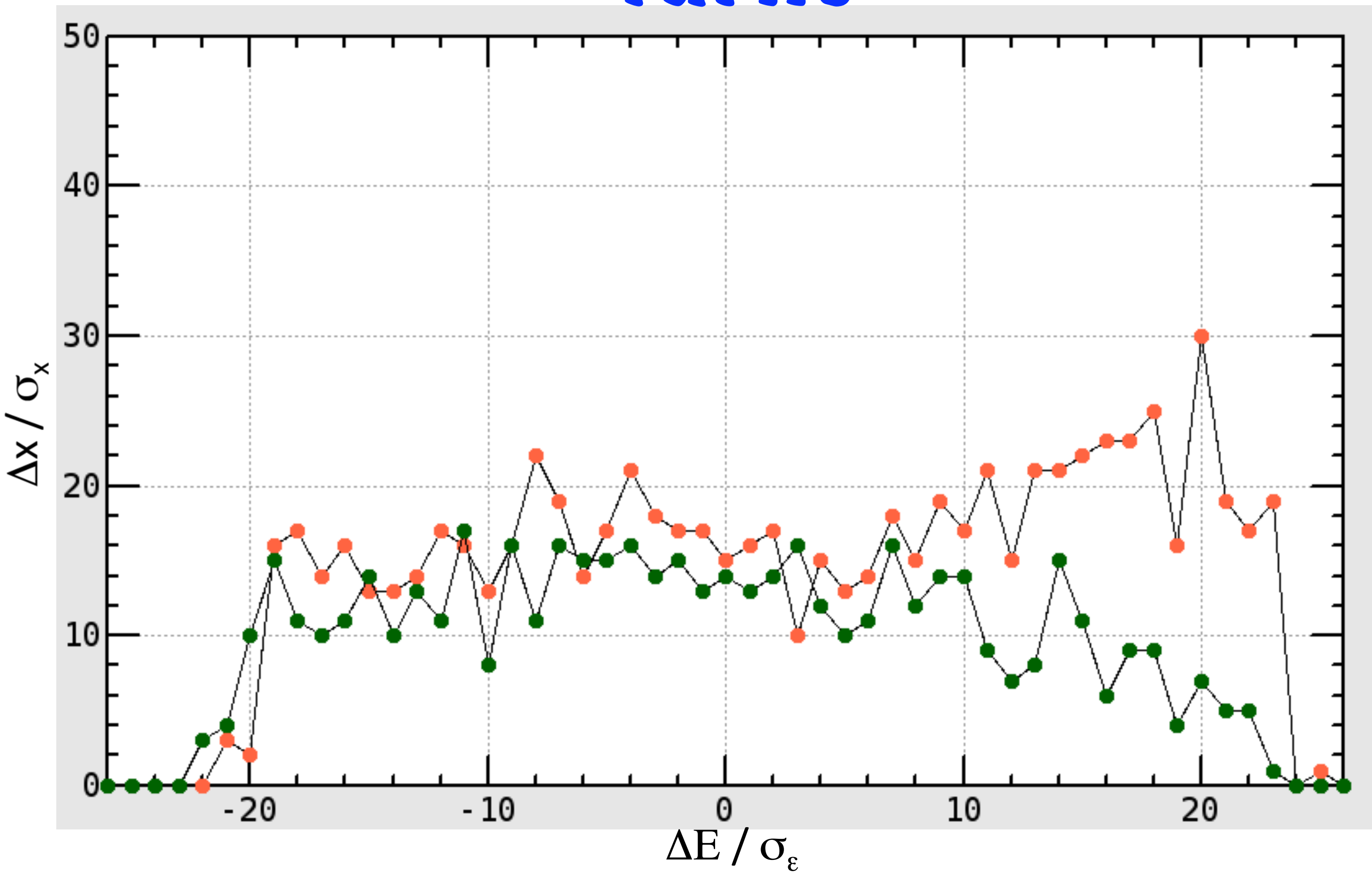
- Belle II has to be operated under the situation of low beta and low emittance optics and high beam currents.
- In phase 2 and 3, we will study the beam background under the realistic beam condition.
  - Setting of Belle abort level is important.
  - Tuning with collimators (movable masks) is essentially important.
  - Comparison with simulation is important.
  - We will need an extrapolation to lower beta functions
    - Radiative Bhabha process: relatively straightforward
    - Touschek effect: not so straightforward -> rely on simulation (step-by-step)
    - Beam-gas scattering: not so straightforward -> rely on simulation (Step-by-step)
  - Beam current increase will be done with carefully observing the beam background.
  - More closer collaborative works between accelerator and Belle II people than in KEKB will be essential.

w/ beam-beam w/ damping and radiation excitation



CoordinateBeamLossInjectionLER2013_8_28_14_50_7.dat
CoordinateBeamLossInjectionLER2013_8_28_14_50_7_SelectedEvents.dat (-4m < IP < 4m):
9 events -> ~781 MHz

Dynamic Aperture with beam-beam (sler_1686) with damping 4000 turns



σ_x@Injection = 0.55mm
-> $14\sigma_x$ ~ 7.7mm

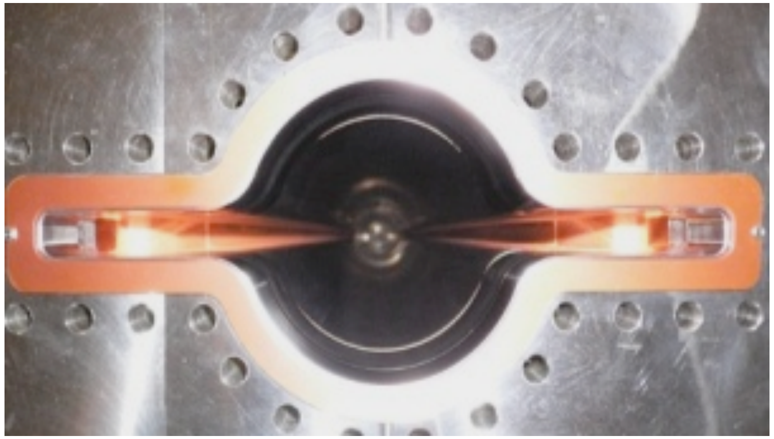
Countermeasures

Y. Suetsugu

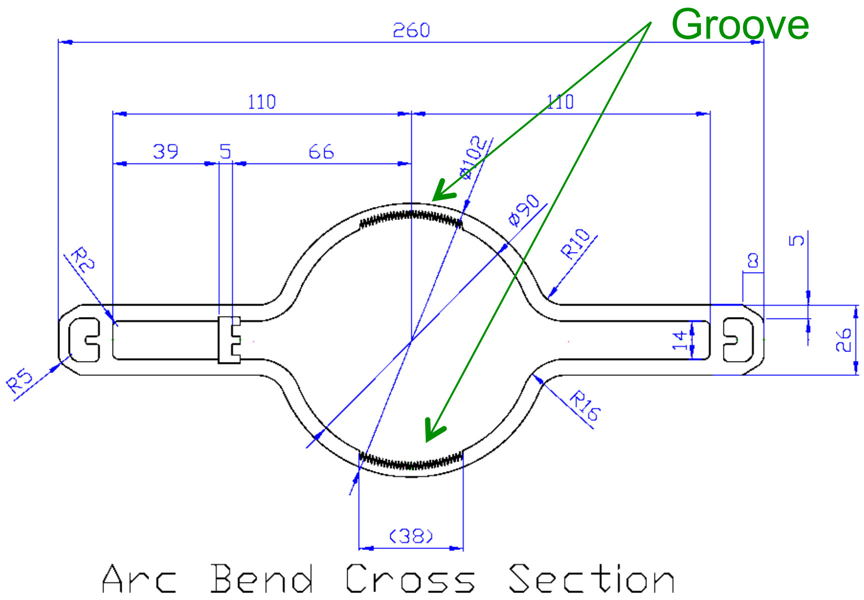
- For the upgrade of the vacuum system for SuperKEKB, the electron cloud is a key issue.
- Countermeasures are carefully chosen based on the various studies.

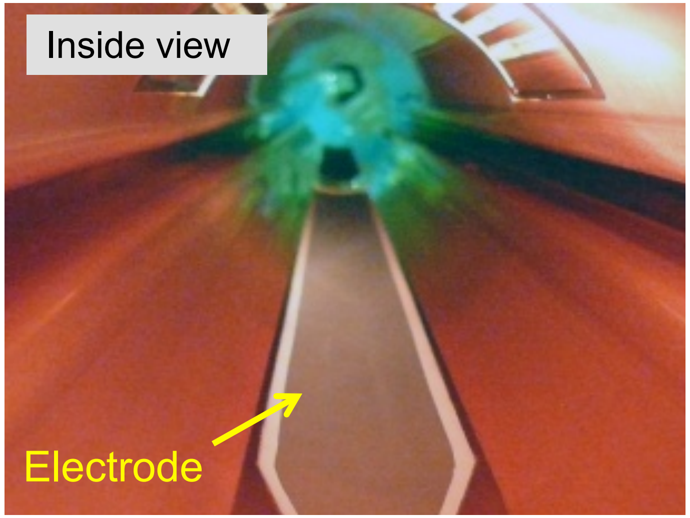
Drift section	Antechamber +Solenoid +TiN Coating
Q and Sx mag.	Antechamber +Solenoid +TiN Coating
Bend section	Antechamber +Groove+ TiN Coating
Wiggler section	Antechamber +Electrode (Cu)

Countermeasures for electron clouds



Drift section: Antechamber + TiN coating





Wiggler section:
Antechamber + Clearing electrode

Y. Suetsugu

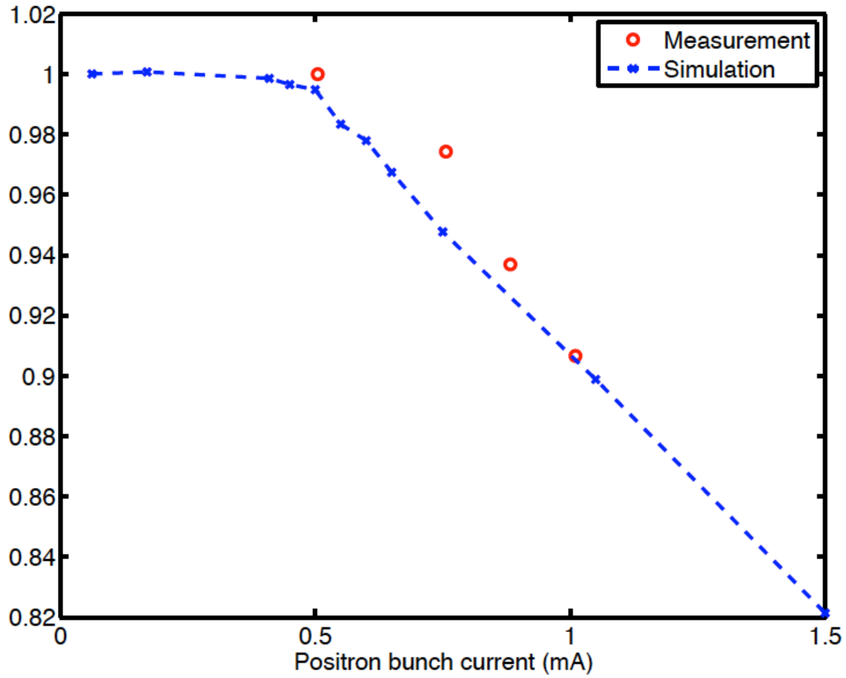
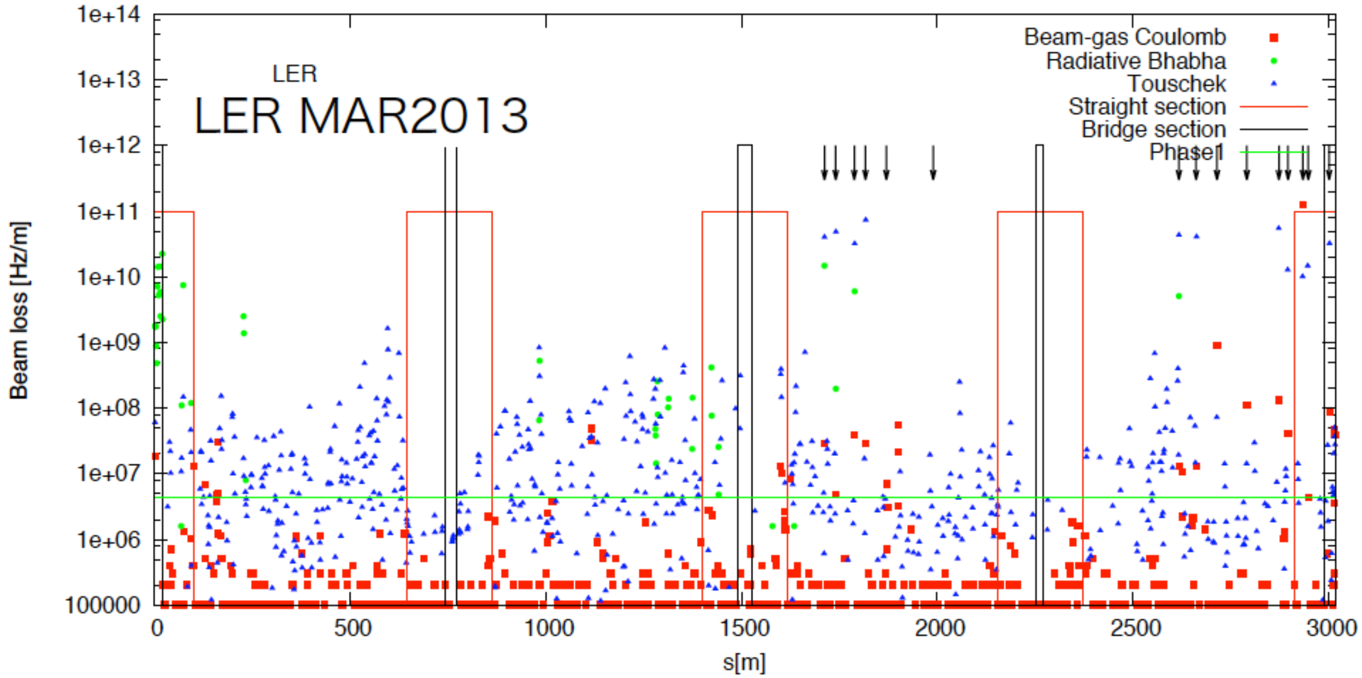


Figure 5: *Ratio of hadron events to Bhabha was measured as a function of positron bunch current using the BELLE detector. The data is normalized to the measured value at 0.5 mA. The result of simulation is plotted according to Eq. (18) and the energy spreads at zero currents are used for the normalization.*

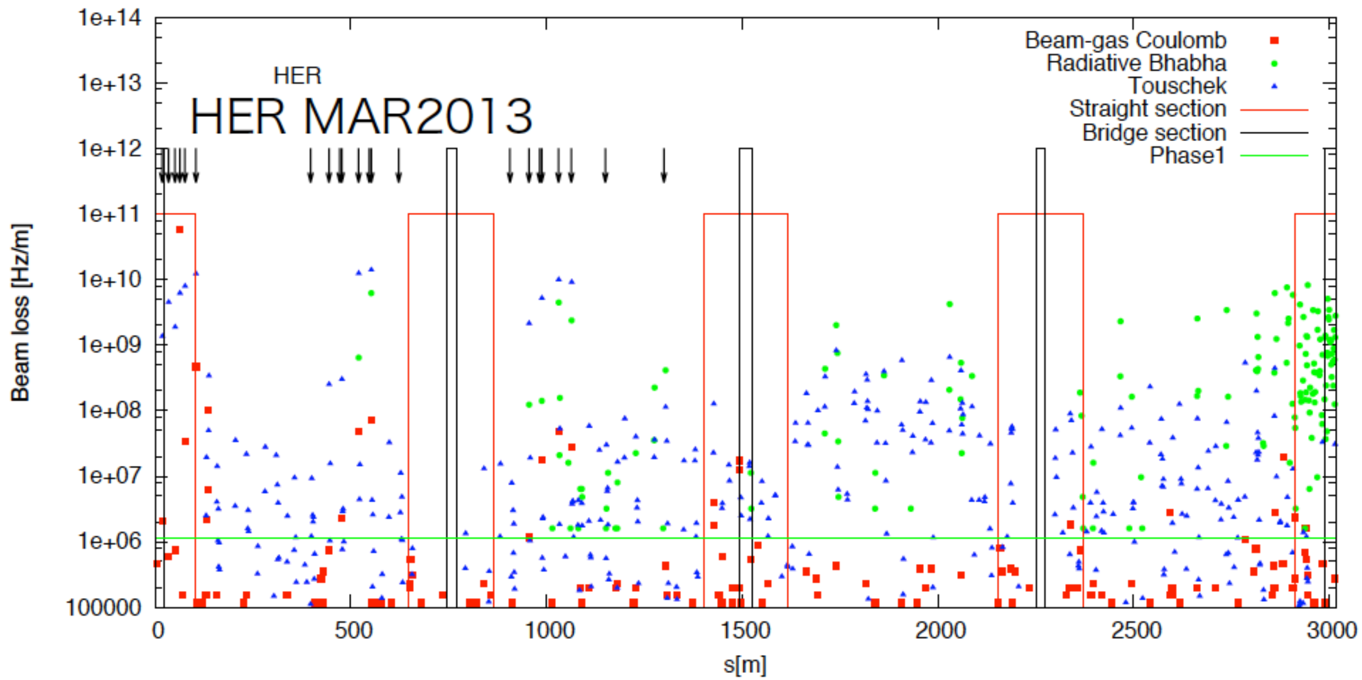
Design specifications

	KEKB KEK internal 2002-4	SKB phase1	SKB phase2	SKB phase3
Beam energy and current	LER 3.5GeV / 2.9A HER 8 GeV / 1.2A	LER 4GeV / 1A HER 7 GeV / 1A	LER 4GeV / 1.8A HER 7 GeV / 1.3A	LER 4GeV / 3.6A HER 7 GeV / 2.6A
Target luminosity	1×10^34	0	1×10^34	80×10^34
Duration	1998/11/4～ 2009/6/30	2014/12/1～ 2015/6/30	2015/12/1～ 2016/6/30	2016/10/1～
Operation mode	Physics run	Beam injection, Vacuum scribing, without Belle2	Collision tuning with limited number of cavities, without SVD	Physics run

Enough duration among phases to revise specifications (it takes 3 month, at least)
Step by step, to increase maximum power with confirmation of leakage dose and induced radio activitiy



LER
LER MAR2013
Beam-gas Coulomb
Radiative Bhabha
Touschek
Straight section
Bridge section
Phase1
Beam loss [Hz/m]
s[m]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+08
1e+07
1e+06
100000
0
500
1000
1500
2000
2500
3000



HER
HER MAR2013
Beam-gas Coulomb
Radiative Bhabha
Touschek
Straight section
Bridge section
Phase1
Beam loss [Hz/m]
s[m]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+08
1e+07
1e+06
100000
0
500
1000
1500
2000
2500
3000