IPAC 2018, Vancouver, April 30

http://www-superkekb.kek.jp

https://www.belle2.org/

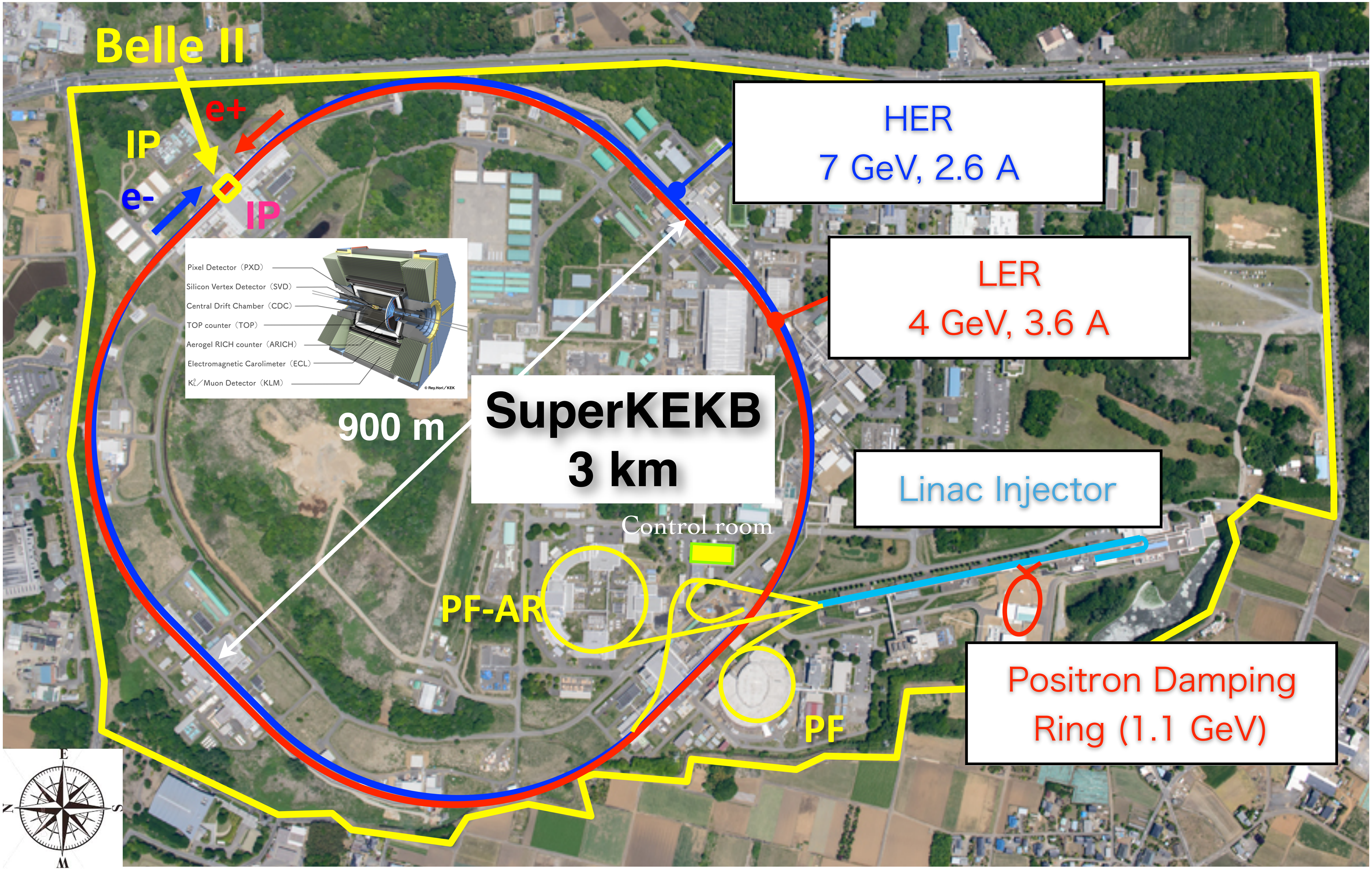
Report on SuperKEKB Phase 2 Commissioning

Y. Ohnishi (KEK)

on behalf of the SuperKEKB commissioning group
and the Belle II commissioning group

Design of SuperKEKB

Target Luminosity: 8 x 10^{35} cm^{-2} s^{-1}



SuperKEKB
3 km

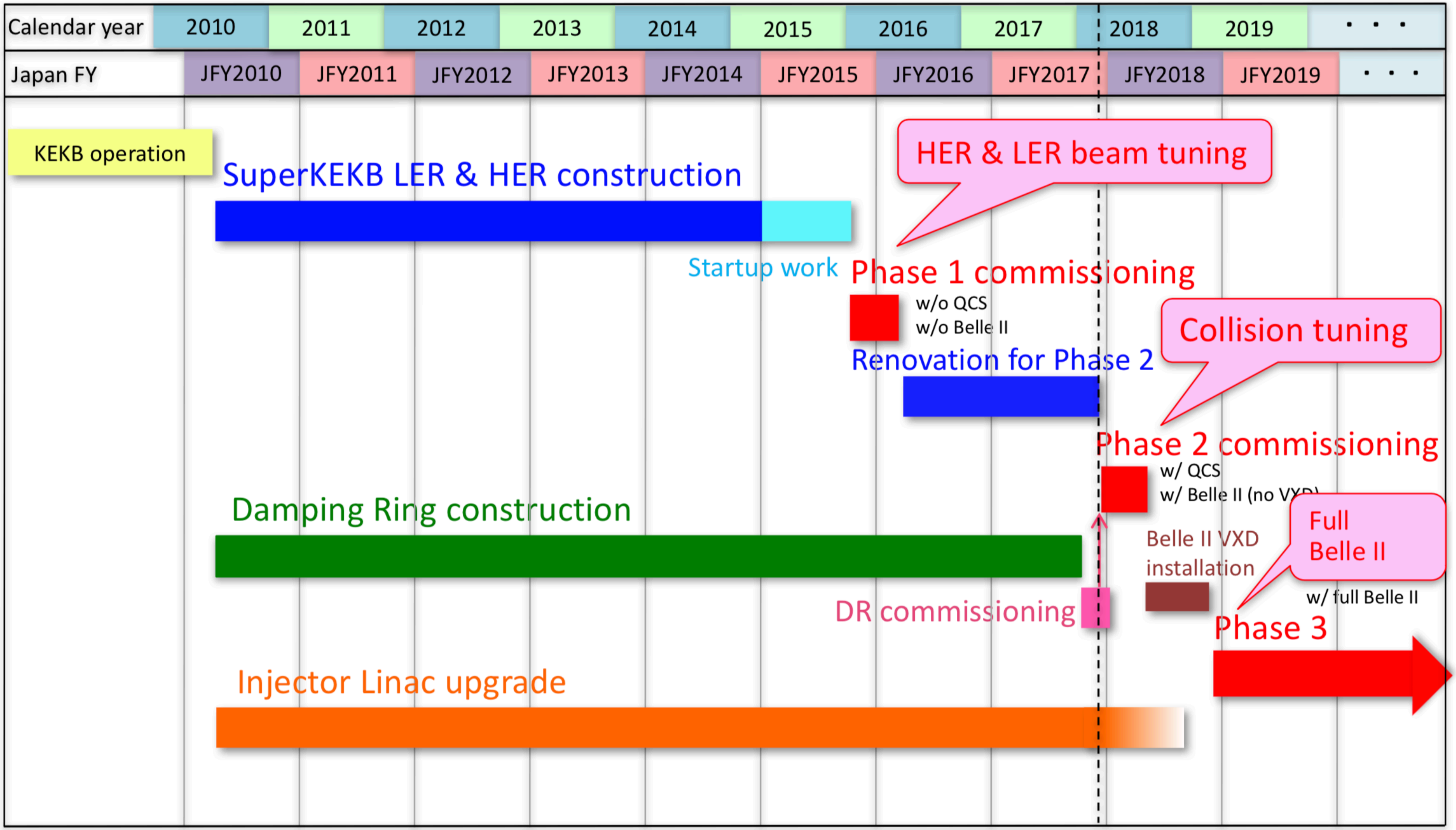
HER
7 GeV, 2.6 A

LER
4 GeV, 3.6 A

Linac Injector

Positron Damping Ring (1.1 GeV)

Project History and Near-term Plan



Calendar year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	. . .
Japan FY	JFY2010	JFY2011	JFY2012	JFY2013	JFY2014	JFY2015	JFY2016	JFY2017	JFY2018	JFY2019	. . .

KEKB operation

SuperKEKB LER & HER construction

Startup work

HER & LER beam tuning

Phase 1 commissioning

w/o QCS
w/o Belle II

Renovation for Phase 2

Collision tuning

Phase 2 commissioning

w/ QCS
w/ Belle II (no VXD)

Damping Ring construction

Belle II VXD installation

Full Belle II

w/ full Belle II

DR commissioning

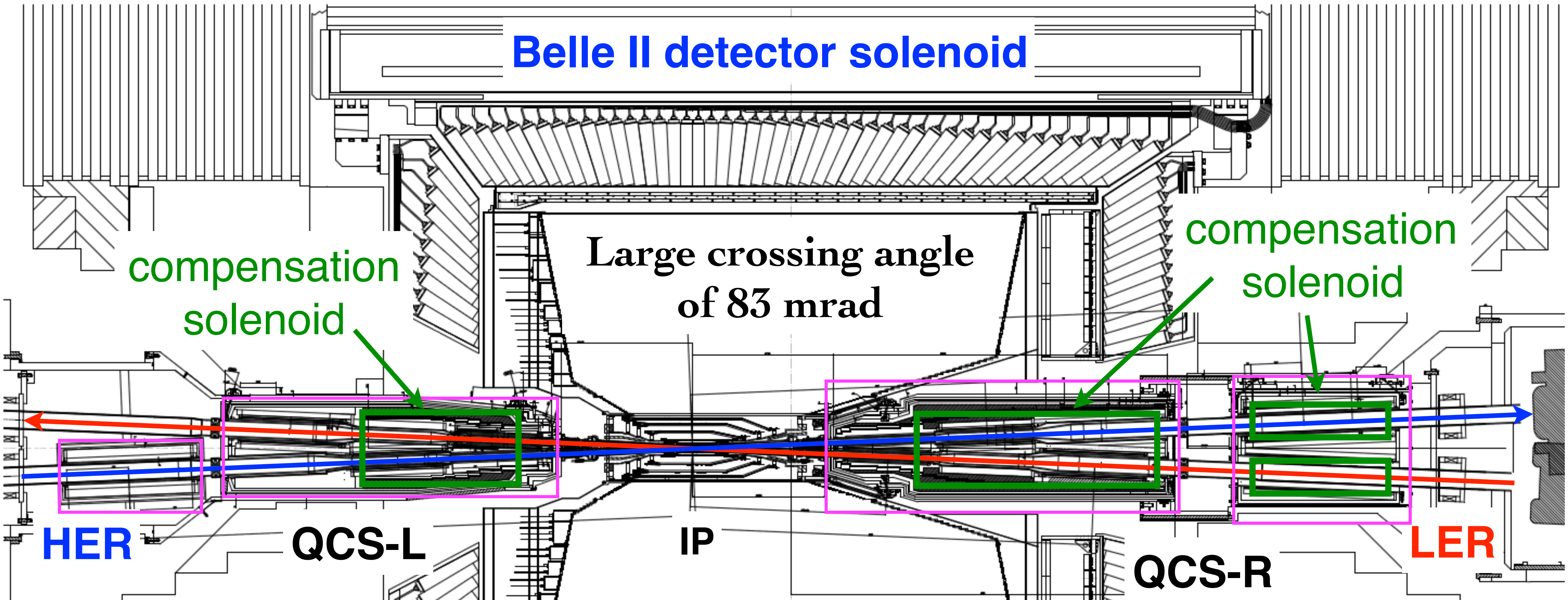
Phase 3

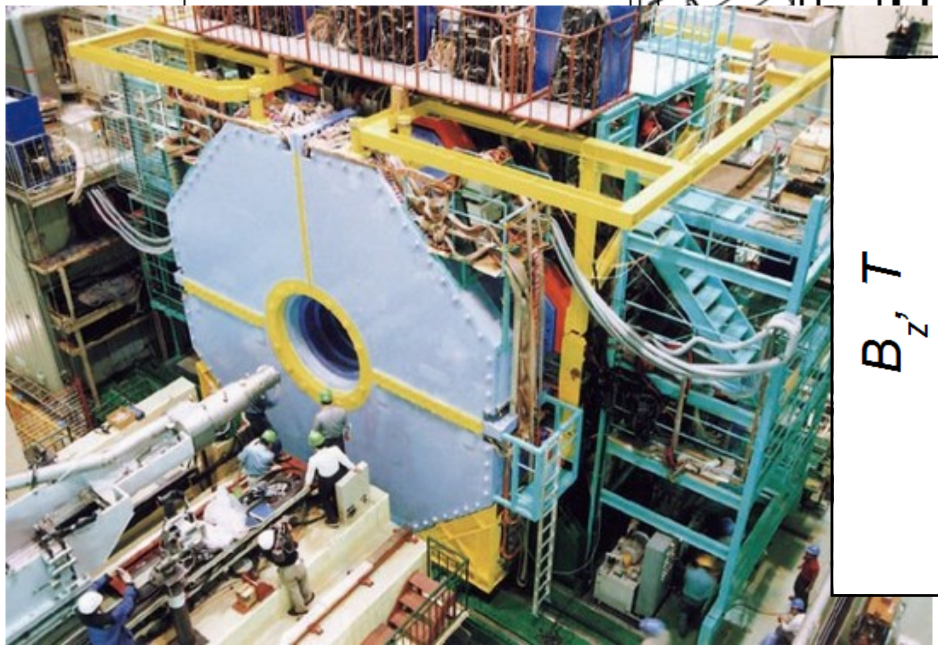
Injector Linac upgrade

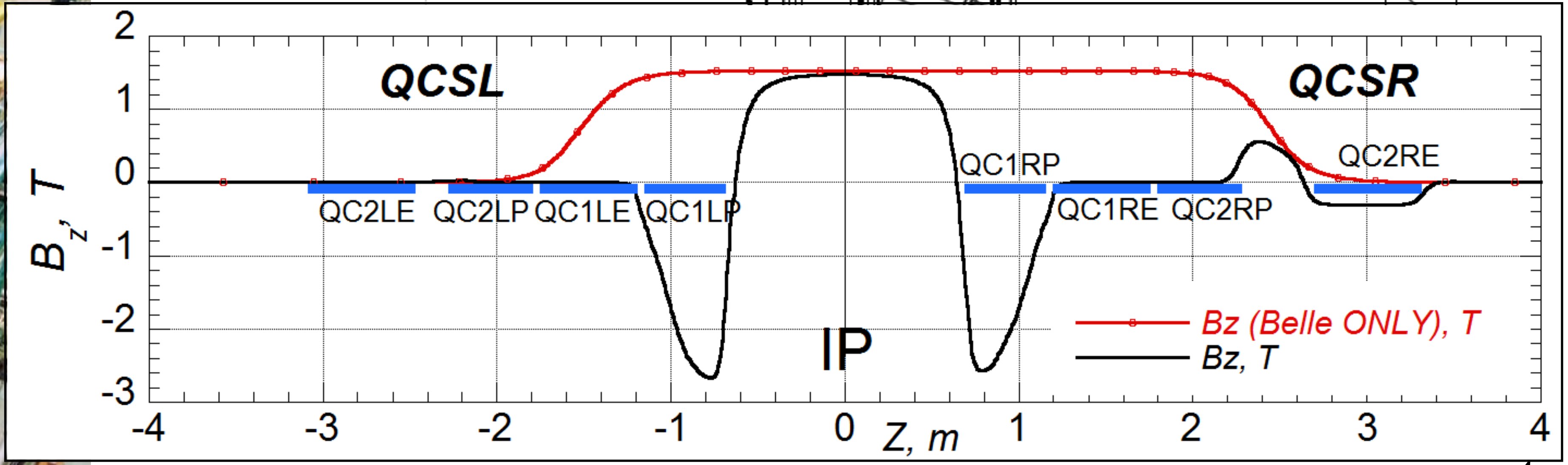
K. Akai et al.

Interaction Region

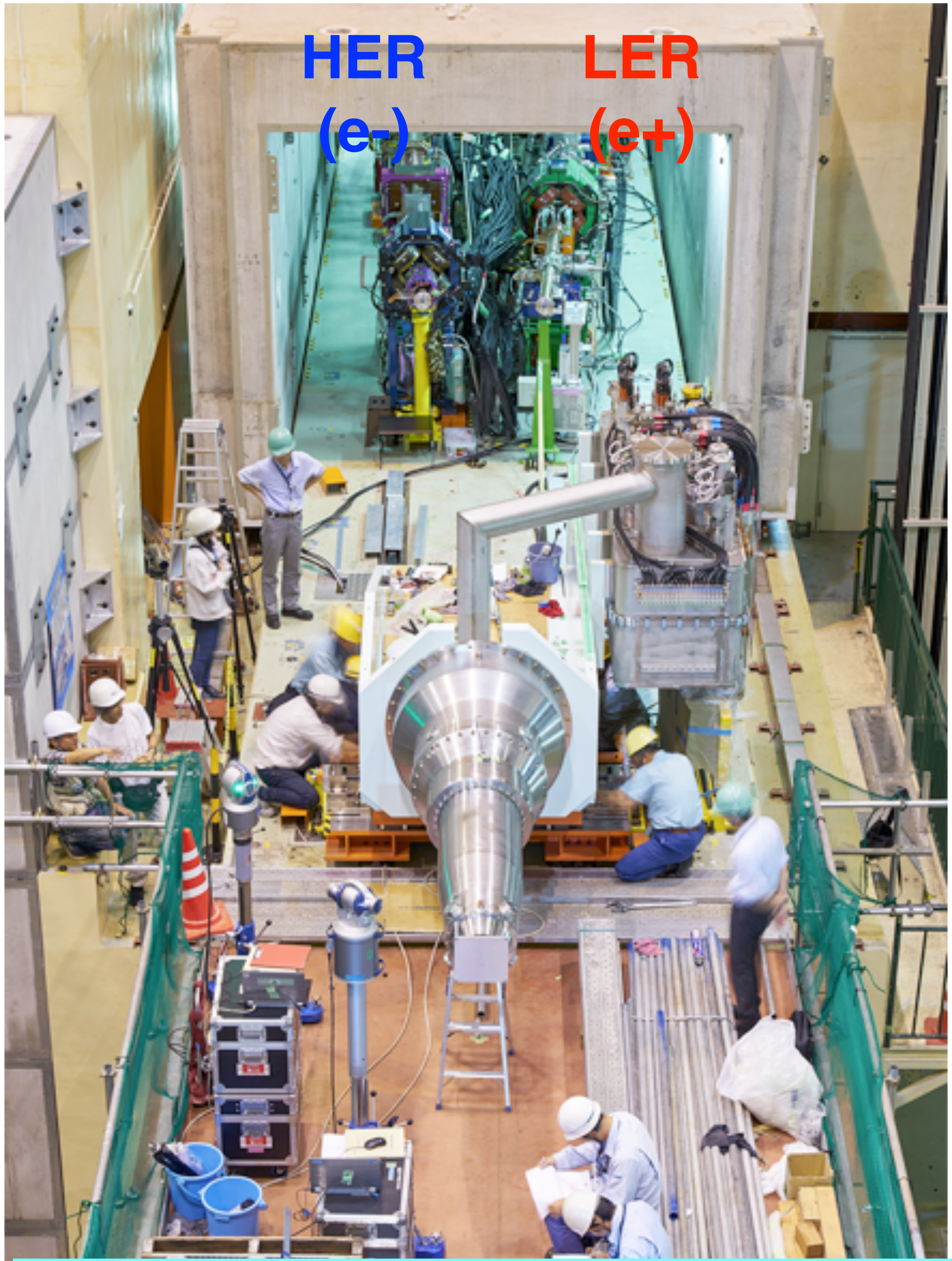
Superconducting Final Focus Magnets

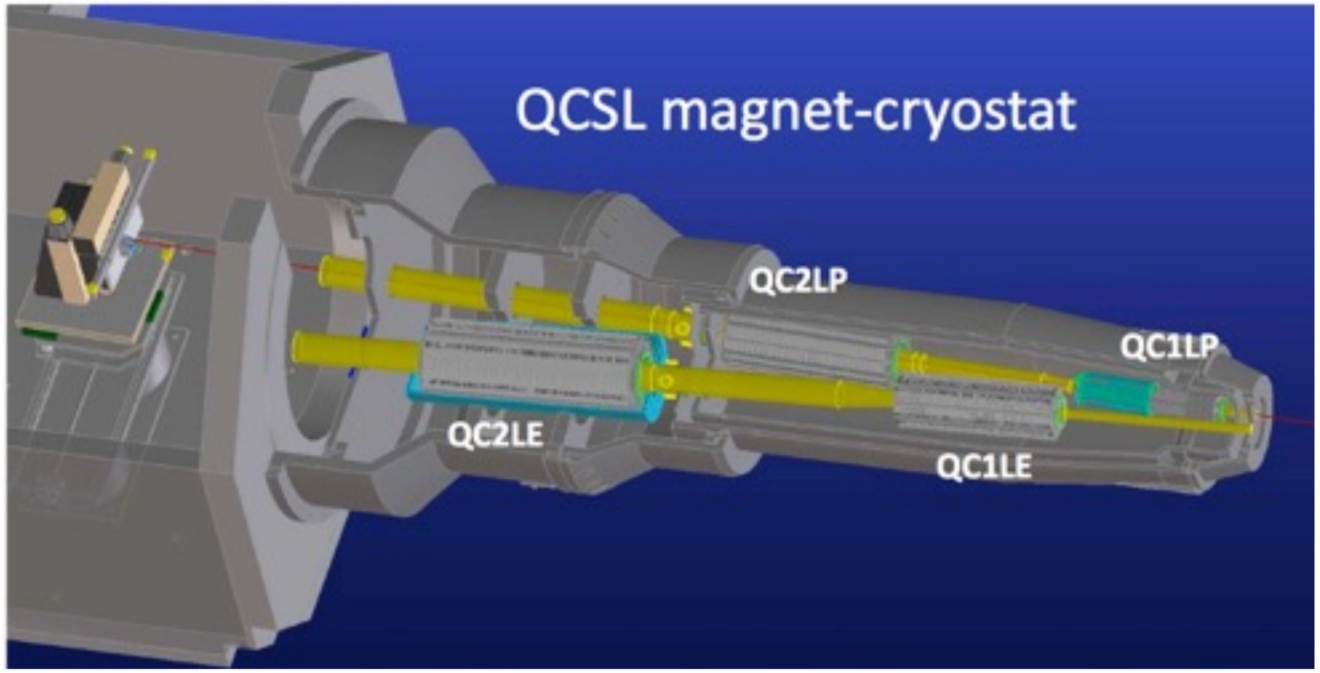






Final Focus (Superconducting)





4 quadrupoles (QC1s, QC2s)
8 dipole corrector coils
4 skew quad. corrector coils
2 octupole coils
2 skew sextupole, etc for each ring.

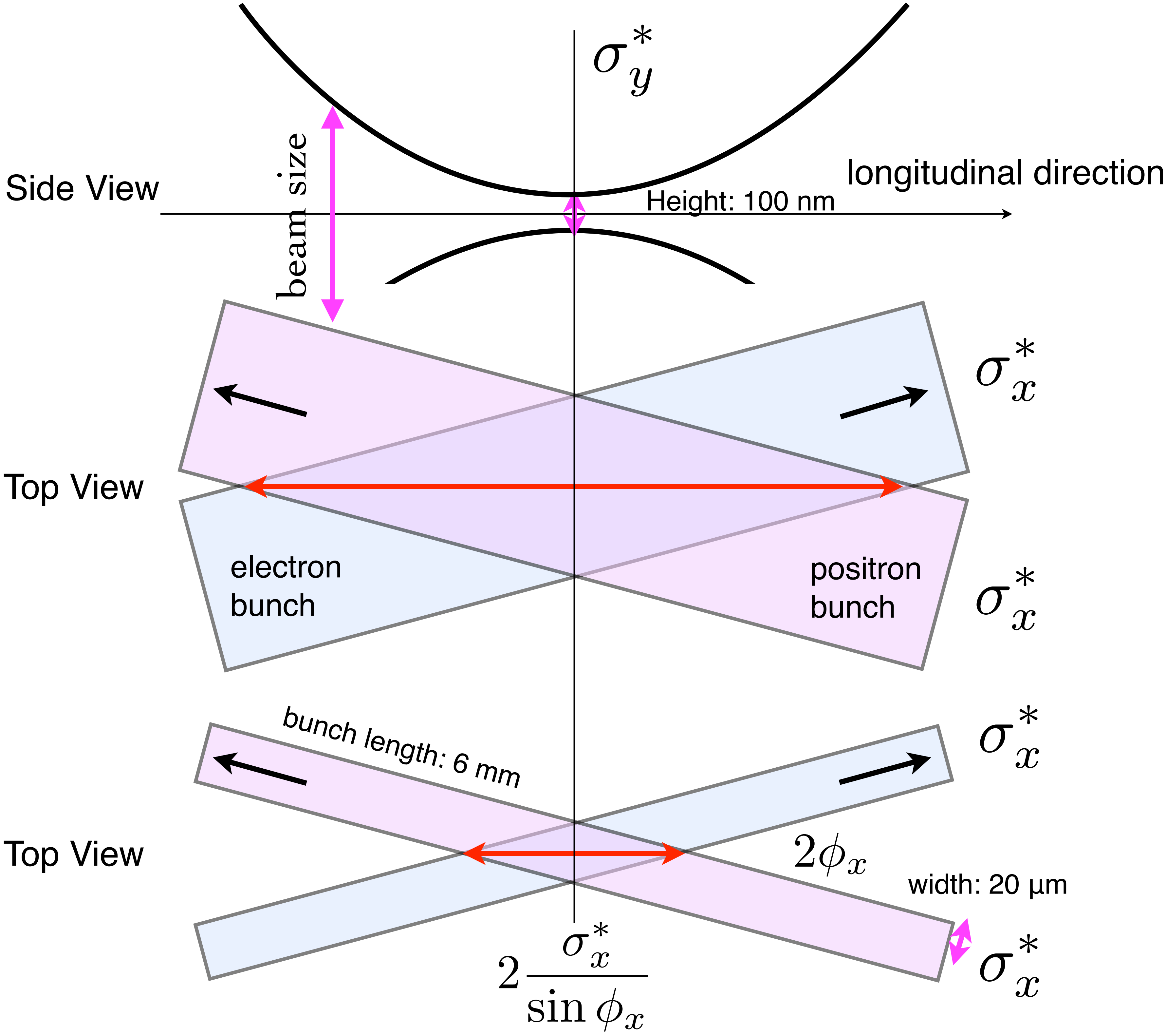
Number of coils is 55 !

Quadrupoles and Compensation Solenoids (QCS)

N. Ohuchi et al., TUZGBE2

How to make focal length extremely short ?

To make shorter focal length,
it is necessary to collide **narrow beams with a large crossing angle.**



Squeeze beam by strong focus lens

☞ Shallow depth of field

“wide beam”
out of focus

collide in the large beam size area in the vertical direction

“narrow”
in focus

always collide in the small beam size area
“Nano-Beam” scheme

Luminosity and beam-beam parameter formulae are modified as:

$$L = \frac{N_+ N_-}{4\pi\sigma^*_{x,eff}\sigma^*_y} f \qquad \xi_{y\pm} = \frac{r_e}{2\pi\gamma_\pm}\frac{\beta^*_{y\pm} N_\mp}{\sigma^*_y(\sigma^*_{x,eff} + \sigma^*_y)}$$

$$L = \frac{N_+ N_-}{4\pi\sigma_z \sin\phi_x \sigma^*_y} f \propto \frac{1}{\sin\phi_x \sqrt{\boxed{\varepsilon_y \beta^*_y}}} \qquad \sigma^*_{x,eff} = \sigma_z \sin\phi_x$$

If the vertical emittance and beta at IP are same for both beams:

$$\varepsilon_y = \varepsilon_{y+} = \varepsilon_{y-}$$

$$\beta^*_y = \beta^*_{y+} = \beta^*_{y-}$$

$$\xi_{y\pm} \simeq \frac{r_e}{2\pi\gamma_\pm}\sqrt{\frac{\beta^*_y}{\varepsilon_y}}\frac{N_\mp}{\sigma_z \sin\phi_x} \propto \frac{1}{\sin\phi_x}\sqrt{\boxed{\frac{\beta^*_y}{\varepsilon_y}}}$$

Luminosity can be large with keeping the beam-beam parameter constant when the both the vertical beta function and the vertical emittance can be small by the same ratio.

On the other hand,

$$\xi_{x\pm} = \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{x\pm} N\mp}{\sigma^*_{x,eff}(\sigma^*_{x,eff} + \sigma^*_y)}$$

In the case of the nano-beam scheme,

$$\xi_{x\pm} \simeq \frac{r_e}{2\pi\gamma_\pm} \frac{\beta^*_{x\pm} N_\mp}{(\sigma_z \sin\phi_x)^2}$$

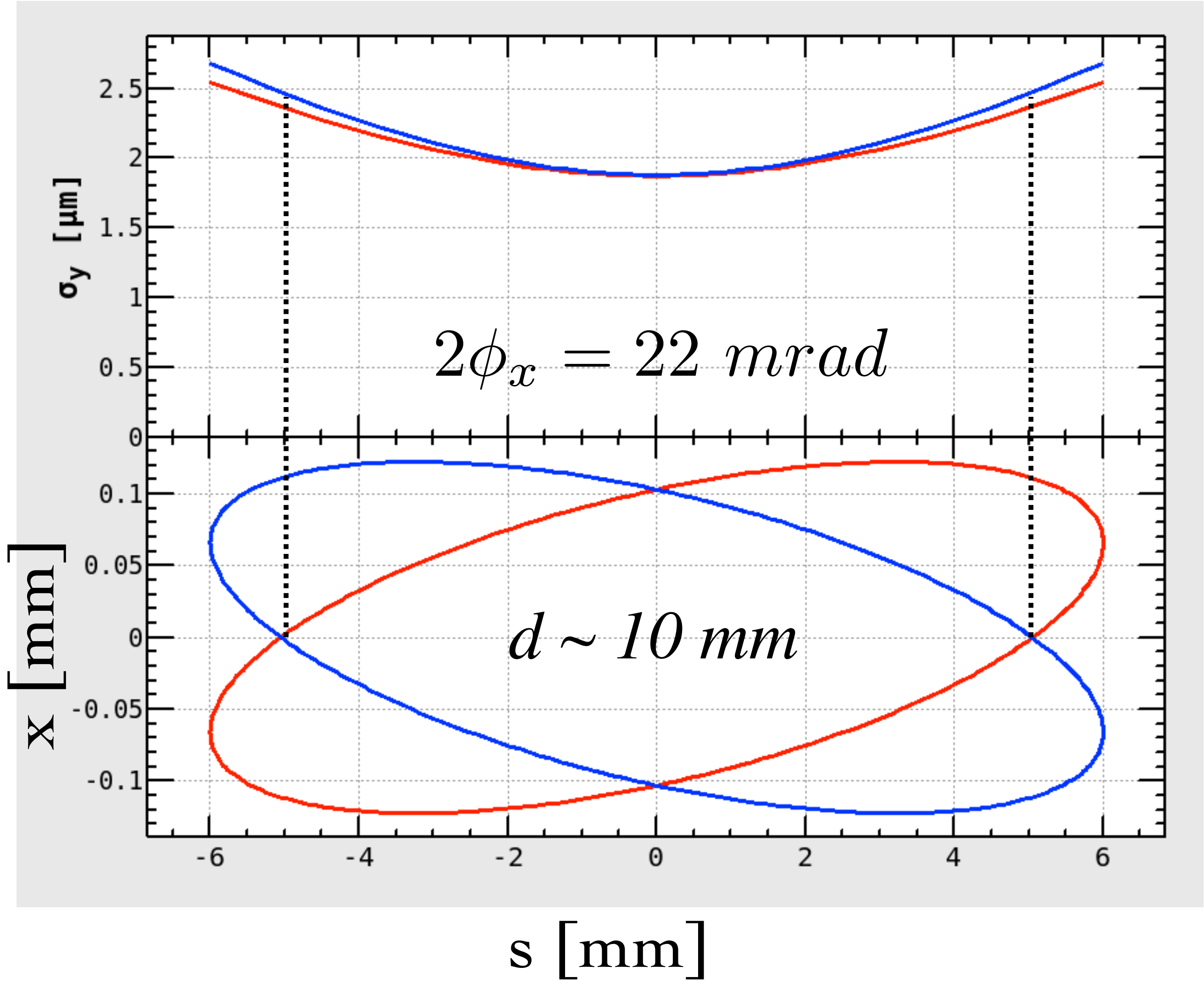
If we push to make the horizontal emittance small,
the horizontal beam-beam parameter is not affected.

Horizontal bean-beam is very small, therefore we can ignore dynamic emittance and dynamic beta. (Aperture problem can be avoided.)

N:	number of particles per bunch
n_b:	number of bunches
f_0:	revolution frequency
R_L:	reduction factor
σ^*:	beam spot-size at IP
I:	bunch beam current
ϕ_x:	half crossing angle

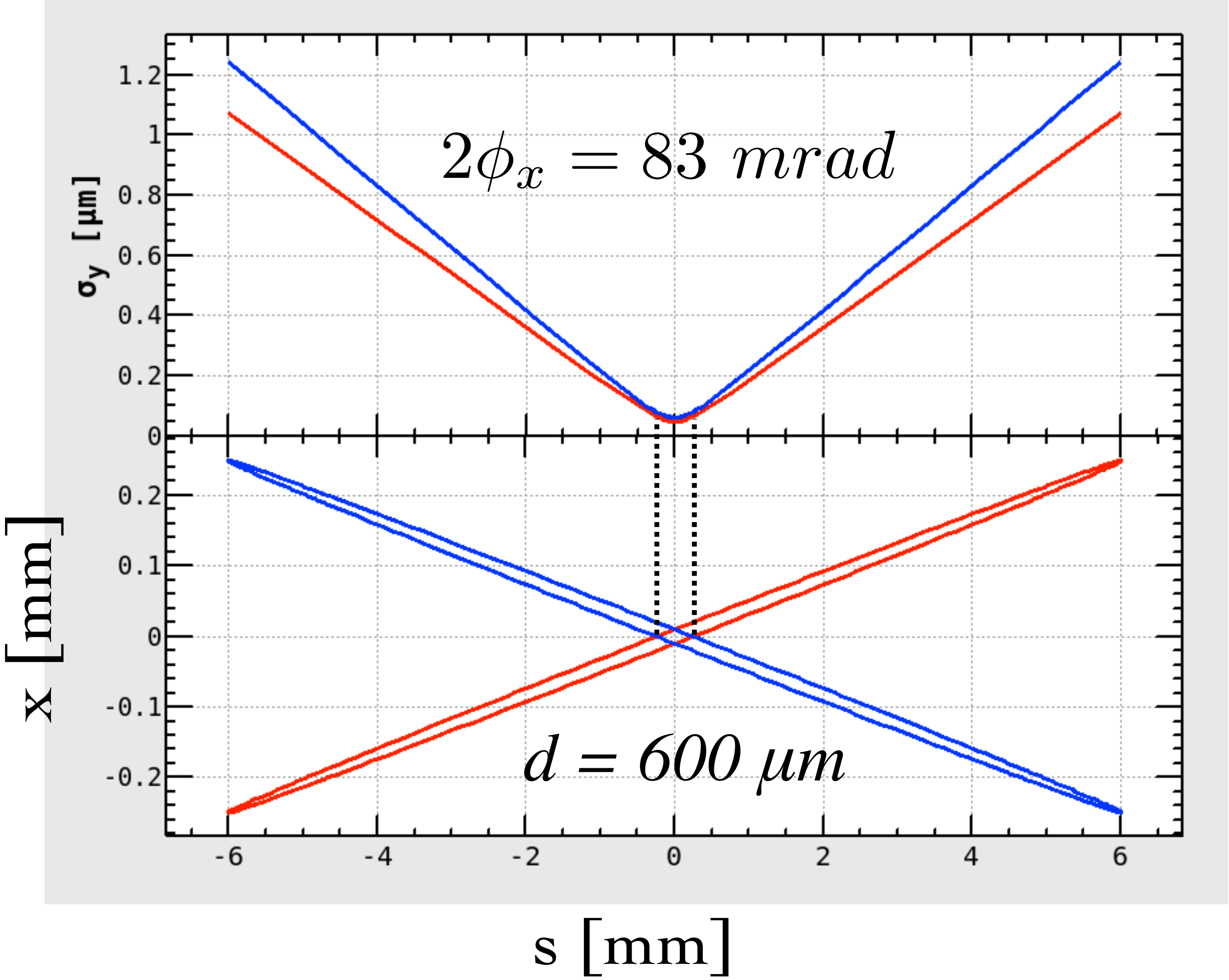
Beam “Spot” in Nano-Beam Scheme

KEKB



Ordinary crossing angle

SuperKEKB (Final Design)



Collision region is very short !

$$d = 2\frac{\sigma_x^*}{\phi_x} = 2\frac{\sigma_z}{\Phi}$$

$$\Phi = \frac{\sigma_z}{\sigma_x^*}\phi_x$$ Piwinski angle

Beam profiles at the IP are quit different between KEKB and SuperKEKB.

Target of Commissioning in Phase 2

Verification of Nano-Beam Scheme

Low Emittance with Large Piwinski Angle

Specific Luminosity, $L_{sp} > 4 \times 10^{31}$ [$cm^{-2}s^{-1}/mA^2$]

$L_{sp} = 1.7\times10^{31}$@KEKB

Beam-Beam Parameter, $\xi_y > 0.05$

Reduce **Beam Background** for Belle II detector
before we move on Phase 3

Phase-2 commissioning is only **4 months** from mid of March to mid of July.

The "Nano-beam" scheme has been proposed by P. Raimondi for super B factory.

Piwinski Angle in Phase 2

Piwinski Angle

$$\Phi = \frac{\sigma_z}{\sigma_x^*} \tan \phi_x$$

Large Piwinski Angle >> 1

	KEKB (2006)		Phase 2.1		Phase 2.2		Phase 2.3		Phase 2.4	
	LER	HER	LER	HER	LER	HER	LER	HER	LER	HER
β_x [mm]	590	560	200	200	256	200	128	100	128	100
β_y [mm]	6.5	5.9	8	8	2.2	2.4	2.2	2.4	1.1	1.2
ε_x [nm]	18	24	2.1	4.6	2.1	4.6	2.1	4.6	2.1	4.6
σ_x^* [μm]	103	116	20	30	23.2	30.3	16.4	21.4	16.4	21.4
σ_z [mm]	7		6		6		6		6	
ϕ_x [mrad]	11		41.5							
Φ	**0.75**	**0.66**	**12.5**	**8.3**	**10.7**	**8.3**	**15.2**	**11.6**	**15.2**	**11.6**

Phase 3.x : Φ = 24.7 / 19.4

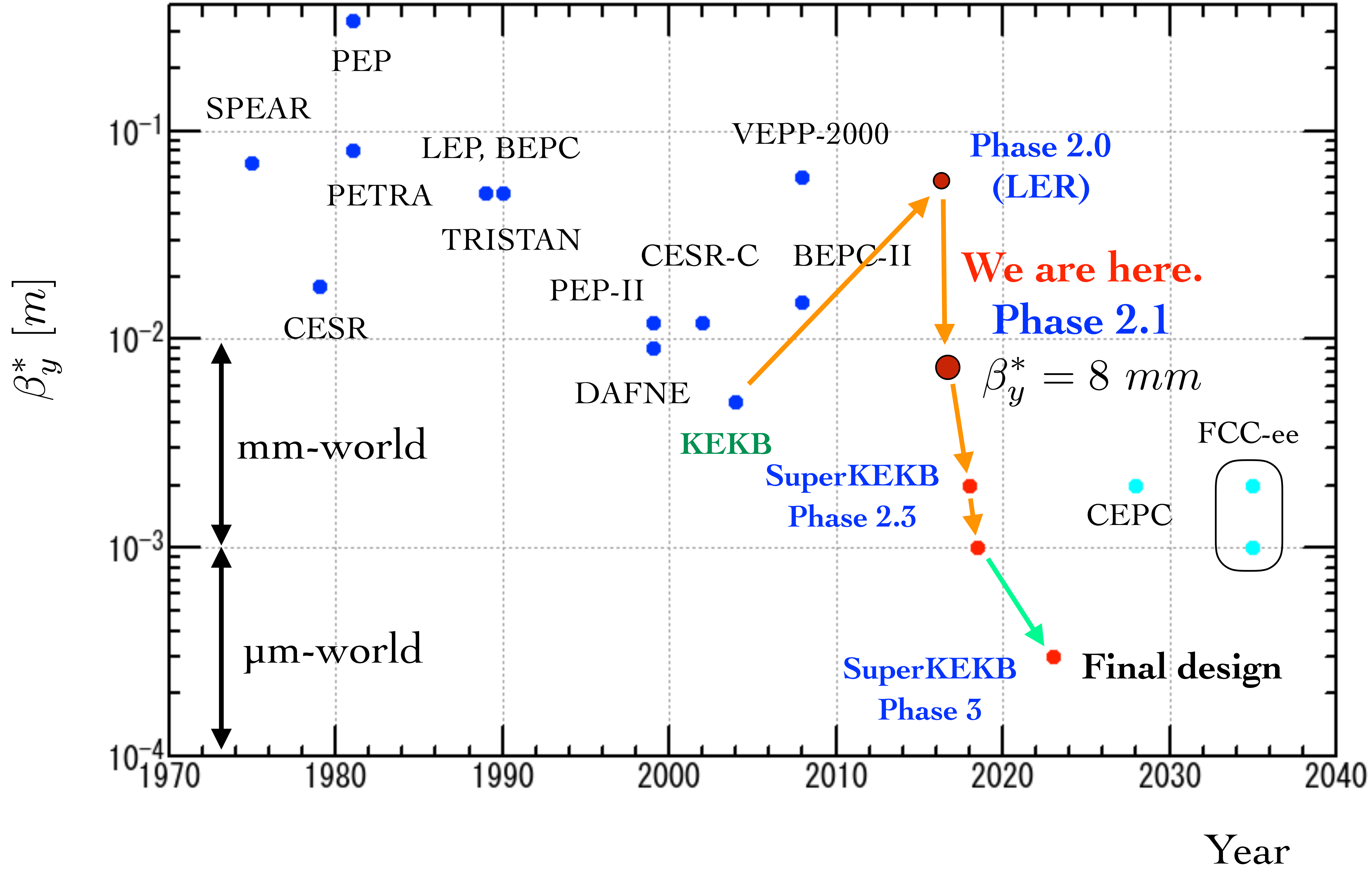
Machine Parameters (Design)

SuperKEKB can exceed the peak luminosity of KEKB when we achieve $\xi_y > 0.05$

	Phase 2.1		Phase 2.3		Phase 2.4		Phase 3.x	
	LER	HER	LER	HER	LER	HER	LER	HER
I_L / I_H	**0.25 A**	**0.22 A**	**1 A / 0.8 A (30 % of design)**				**3.6 A**	**2.6 A**
n_b	400		1576 bunches				2500	
β_x^* [mm]	200	200	128	100	128	100	32	25
β_y^* [mm]	8	8	2.2	2.4	1.1	1.2	0.27	0.30
$\varepsilon_y/\varepsilon_x$ [%]	**10**	**10**	**1.4**		**0.7**		**0.28**	
ξ_x	0.0055	0.0036	0.0052	0.0021	0.0053	0.0021	0.0028	0.0012
ξ_y	0.03	0.03	0.0484	0.0500	0.0496	0.0505	0.0881	0.0807
I_{bunch} [mA]	0.625	0.55	0.64	0.51	0.64	0.51	1.44	1.04
L_{sp} [$cm^{-2}s^{-1}/mA^2$]	7×10^{30}		3.9×10^{31}		7.9×10^{31}		2.14×10^{32}	
L [$cm^{-2}s^{-1}$]	1×10^{32}		**2×10^{34}**		4×10^{32}		8×10^{35}	

β_y* Evolution over 50 Years

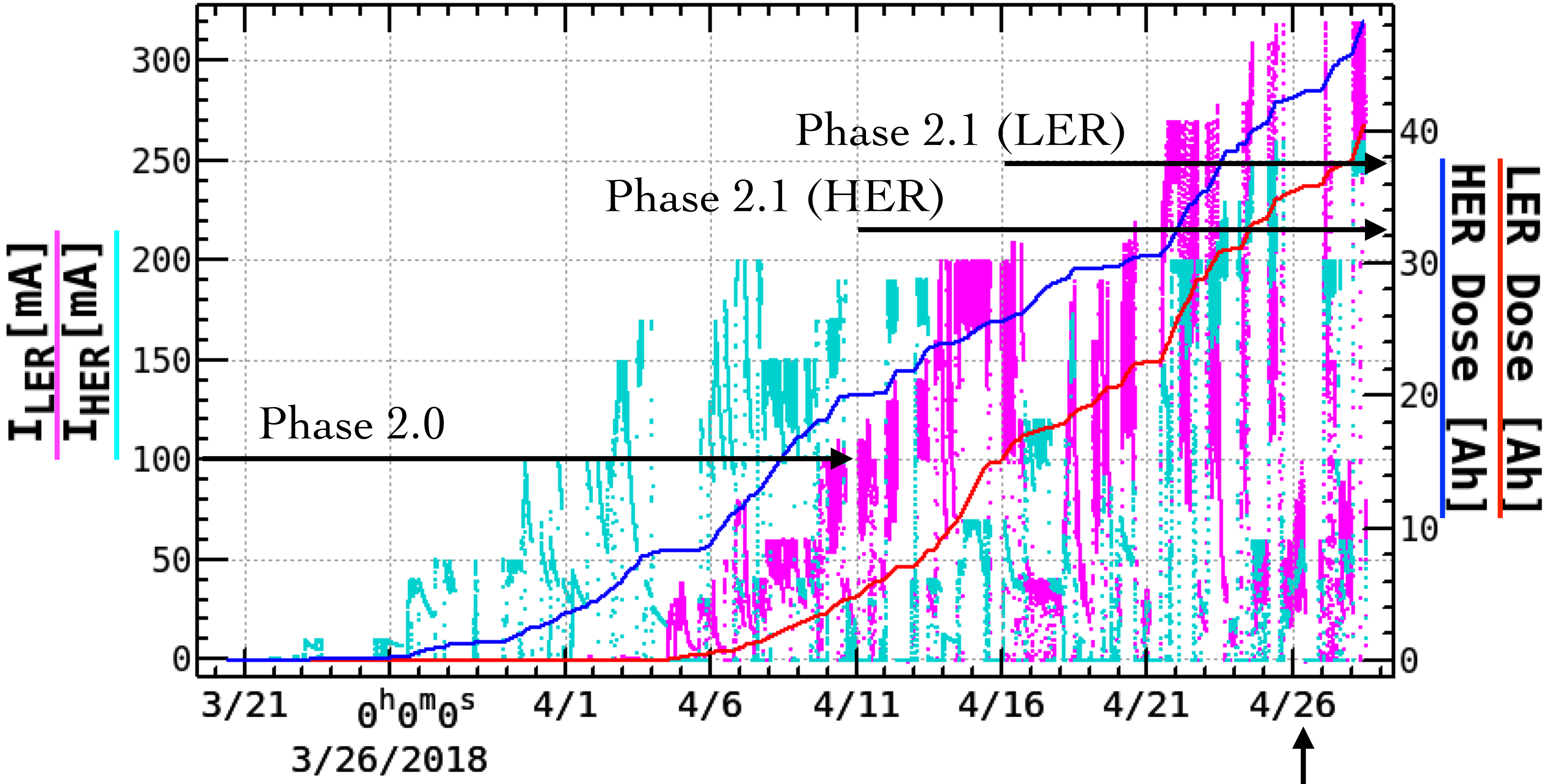
SuperKEKB will try to make the smallest β_y* in the world !



History of Commissioning

Beam dose: 40 Ah in LER / 48 Ah in HER (target: 100 Ah)

Max. beam current: 320 mA in LER / 260 mA in HER



March 19 Phase 2 commissioning started.
April 25 First Beam-Beam deflection was observed.
April 26. First Collision (Physics event) was observed.

Conclusions

- **Positron Injection**
  - Thermionic gun provides large charge beams to produce positrons with the flux concentrator.
  - Damping ring (DR) is working well to provide low emittance beams to the LER.
  - Injection efficiency is typically 90 - 100 % in the LER.
- **Electron Injection**
  - RF gun was tested. It provides low emittance beams to the HER.
  - Both of the thermionic and RF gun are available in Phase 2.
  - The emittance of the thermionic gun does not restrict the HER injection so far. Injection efficiency is typically 50 - 70 %.
    (The X-Y coupling correction has not yet been done well in HER.)

Conclusions (cont'd)

- **Simultaneous injection for LER and HER is very effective to the machine operation.**
  - Thermionic gun can provide beams for 4 rings; the LER, HER, and two photon factories, which are different energies.
  - Switch between two guns will be pulse magnets near future.
- **Final Focus System (Quadrupole and Compensation Solenoid)**
  - QCS has been operated successfully with the beam commissioning.
  - In the early commissioning, we figured out the wiring mistake between the skew dipole and the skew quadrupole coil in the LER. Even though the mistake, we could store positron beams with very small current by crazy injection tuning and ring dipole correctors. However, we had many QCS quench events due to hitting of injected beams. About 8000 particles can make QCS quench from calculations.

Conclusions (cont'd)

- **Collimators (movable)**
  - The collimators are necessary not only to reduce beam background for the Belle II detector but also to avoid QCS quench.
  - During several experiences of QCS quench, the collimators were loose settings. No QCS quench after maintaining the collimators so as to be appropriate and smaller apertures than those of QCS.
- **Lattice**
  - Phase 2.0 (initial detuned optics for check of hardwares)
    - β_x^* / β_y^* = 384 mm / 48.6 mm in the LER and 400 / 81 mm in the HER
  - Phase 2.1 (collision optics)
    - β_x^* / β_y^* = 200 mm / 8 mm for both of the LER and HER
    - **Local chromaticity corrections** in both of the x and y direction

Conclusions (cont'd)

- Status of optics measurements and corrections (under way)

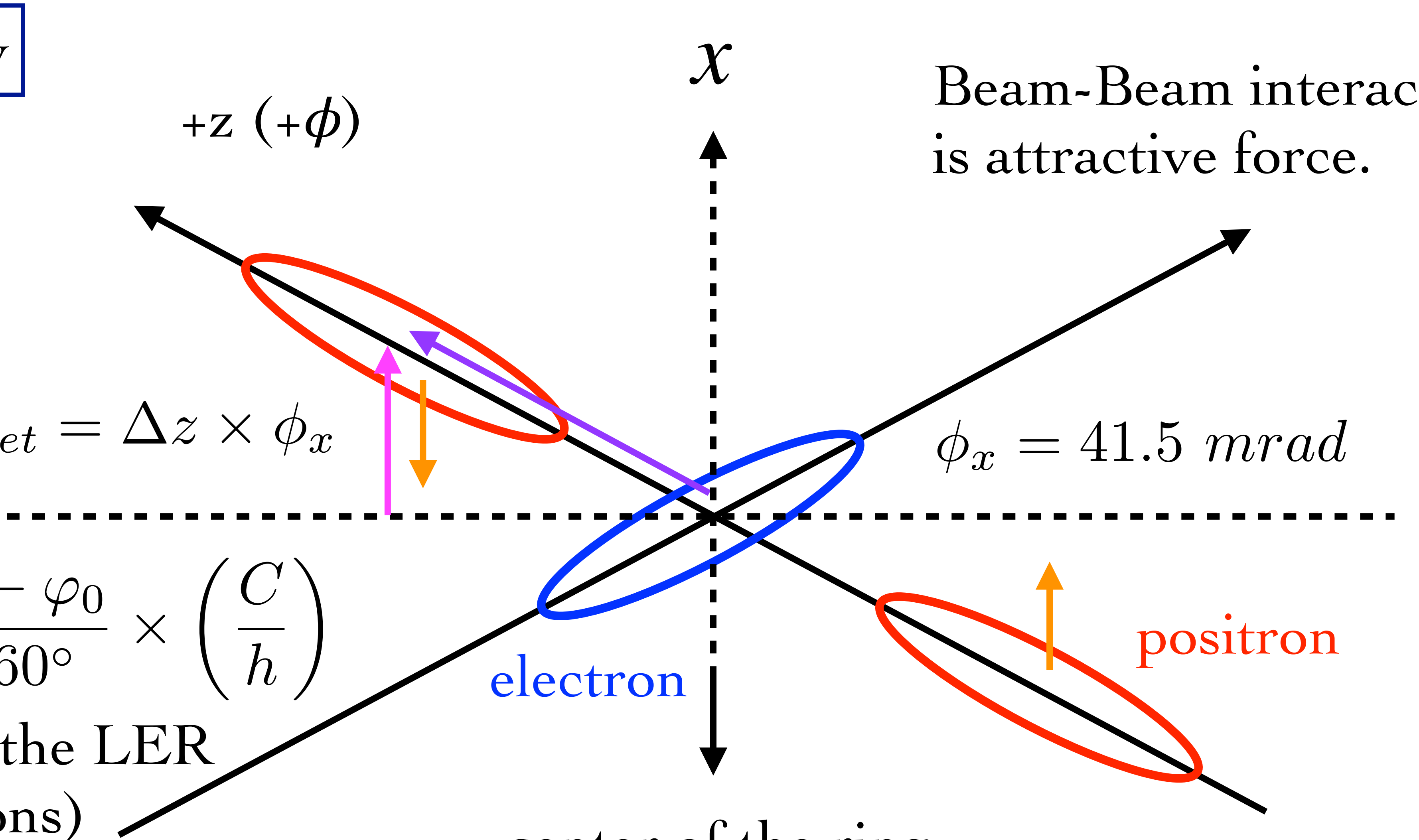
		LER	HER
X-Y coupling	$(\Delta y)_{rms} / (\Delta x)_{rms}$	0.024	0.077
Displersions	$(\Delta\eta_x)_{rms}$, $(\Delta\eta_y)_{rms}$	20 mm , 5 mm	16 mm , 19 mm
Beta-beat	$(\Delta\beta_x / \beta_x)_{rms}$	4%	18%
	$(\Delta\beta_y / \beta_y)_{rms}$	8%	13%
Emittance ratio (X-ray monitor)	$\varepsilon_y / \varepsilon_x$	3.4%	10%
Chromaticity	ξ_x , ξ_y	2.39 , 0.24	0.46 , -0.36

- We will perform further optics corrections.
- Lifetime: 500 min @ 250 mA in HER / 90 min @300 mA in LER (n_b = 1576)

Beam-Beam Deflection with RF Phase Scan (LER)

Horizontal Scan (utilizes crossing angle)

Top View



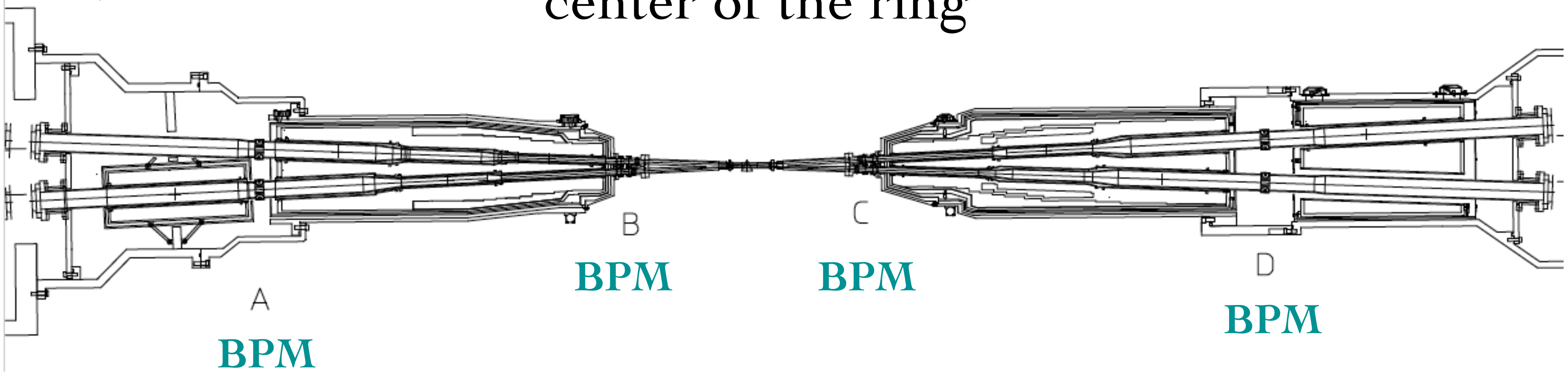
Beam-Beam interaction
is attractive force.

$$x_{offset} = \Delta z \times \phi_x$$

$$\phi_x = 41.5\ mrad$$

$$\Delta z = \frac{\varphi - \varphi_0}{360^\circ} \times \left(\frac{C}{h}\right)$$

RF phase in the LER
(positrons)



C = 3016.3 [m]
h = 5120

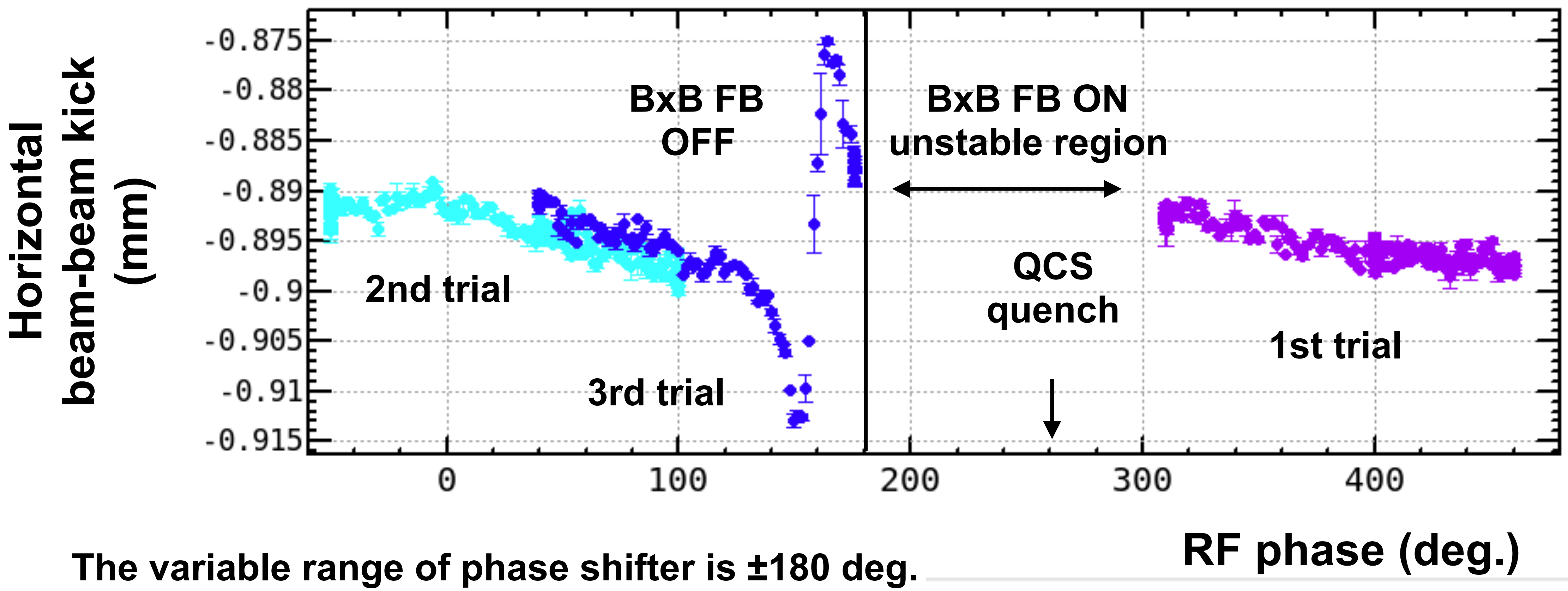
$$x_{offset} = \frac{\phi - \phi_0}{360} \times 0.6\ (m) \times 0.0415\ (rad)$$

First observation of beam-beam deflections

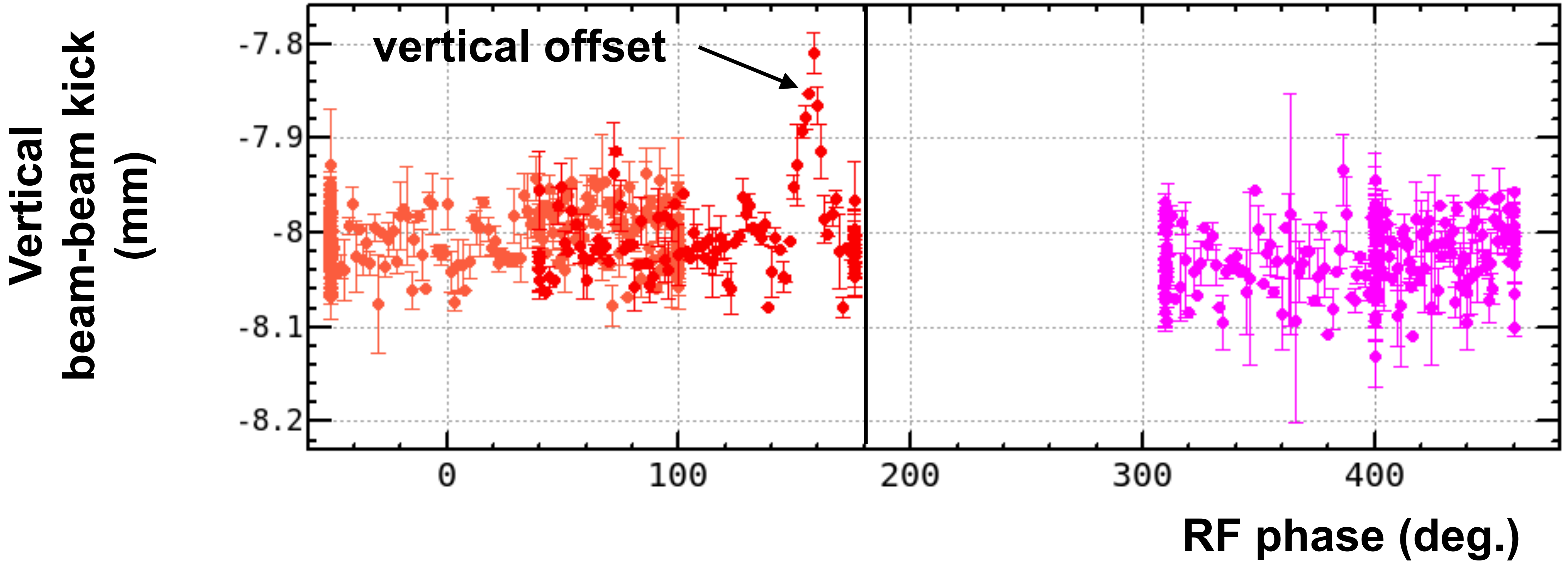
April 25 2018

HER - LER = 57 was also surveyed. →

HER - LER = 55 bunches HER - LER = 56 bunches



The variable range of phase shifter is ±180 deg.



Horizontal Scan of Beam-Beam Deflection

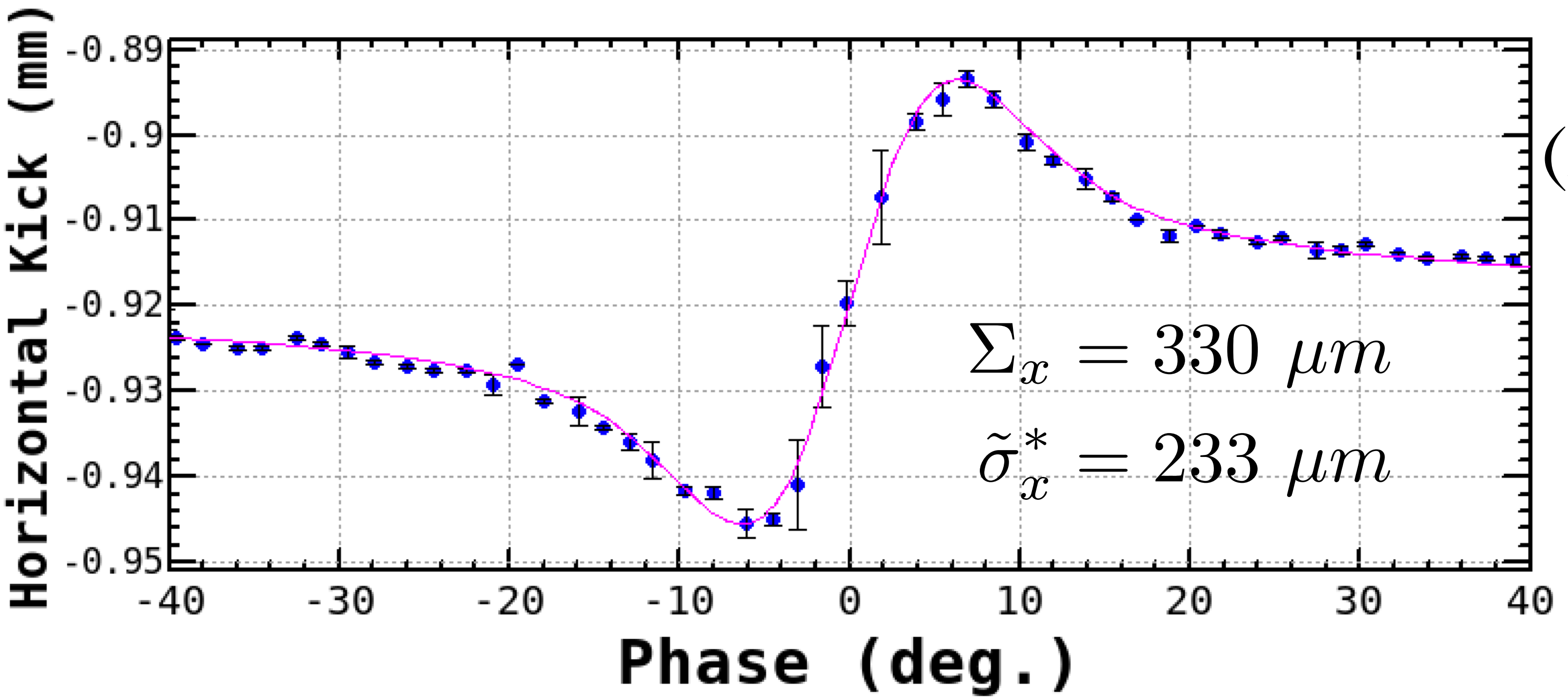
Estimated value from the design : $\tilde{\sigma}_x^* = \sigma_z \phi_x = 224\ \mu m$

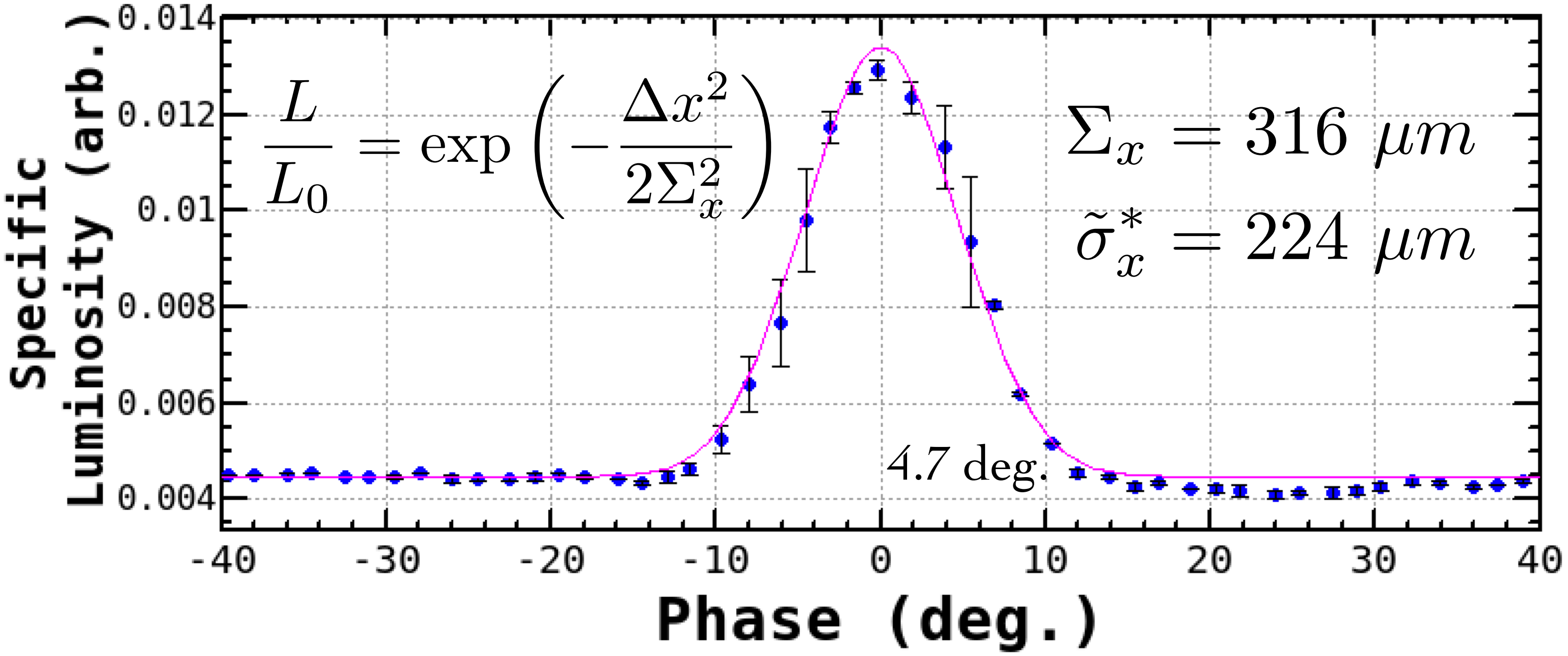
$\phi_x = 41.5\ mrad$

$\sigma_z = 5.4\ mm$

@ 0 A

(250 μm @ 6mm)



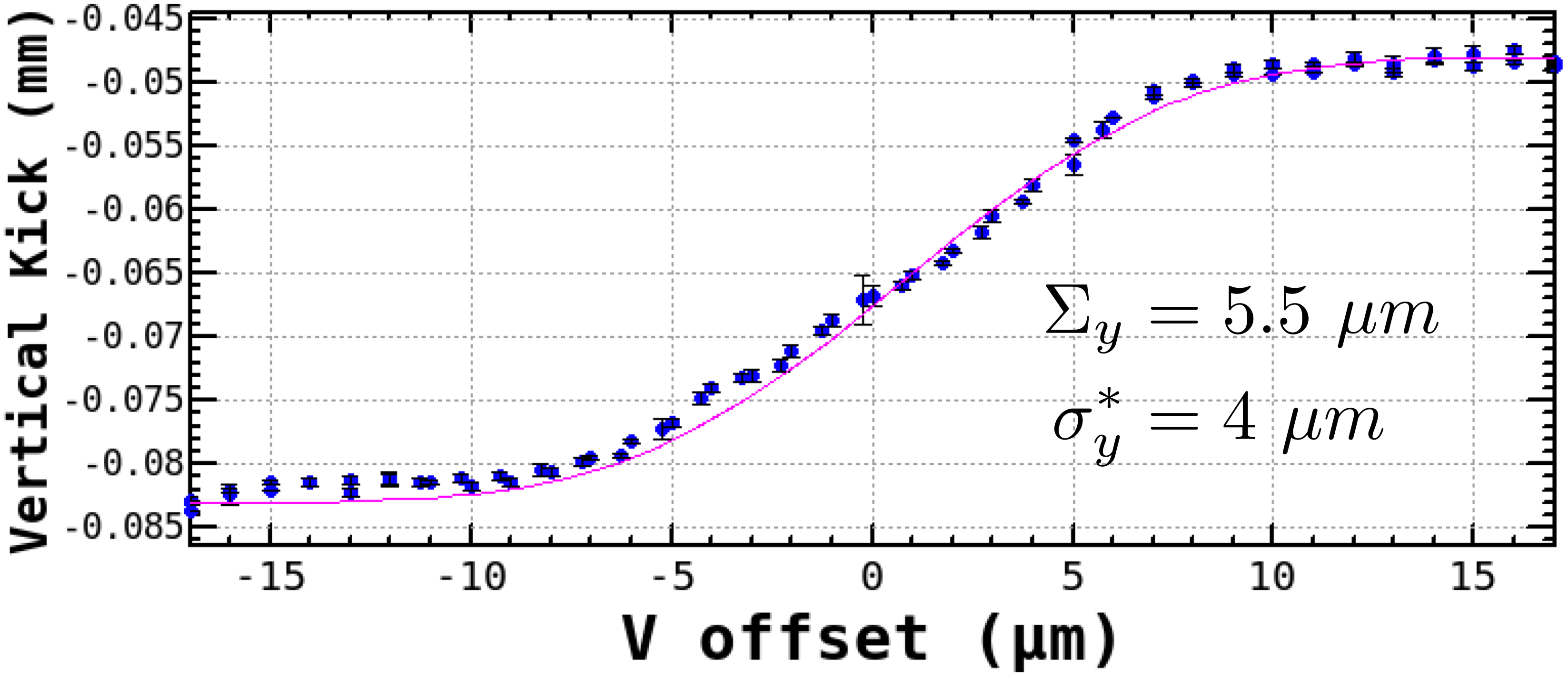


Vertical Scan of Beam-Beam Deflection

Vertical-orbit scan by using HER correctors

$LER: \quad \nu_x/\nu_y = 44.58/46.61$

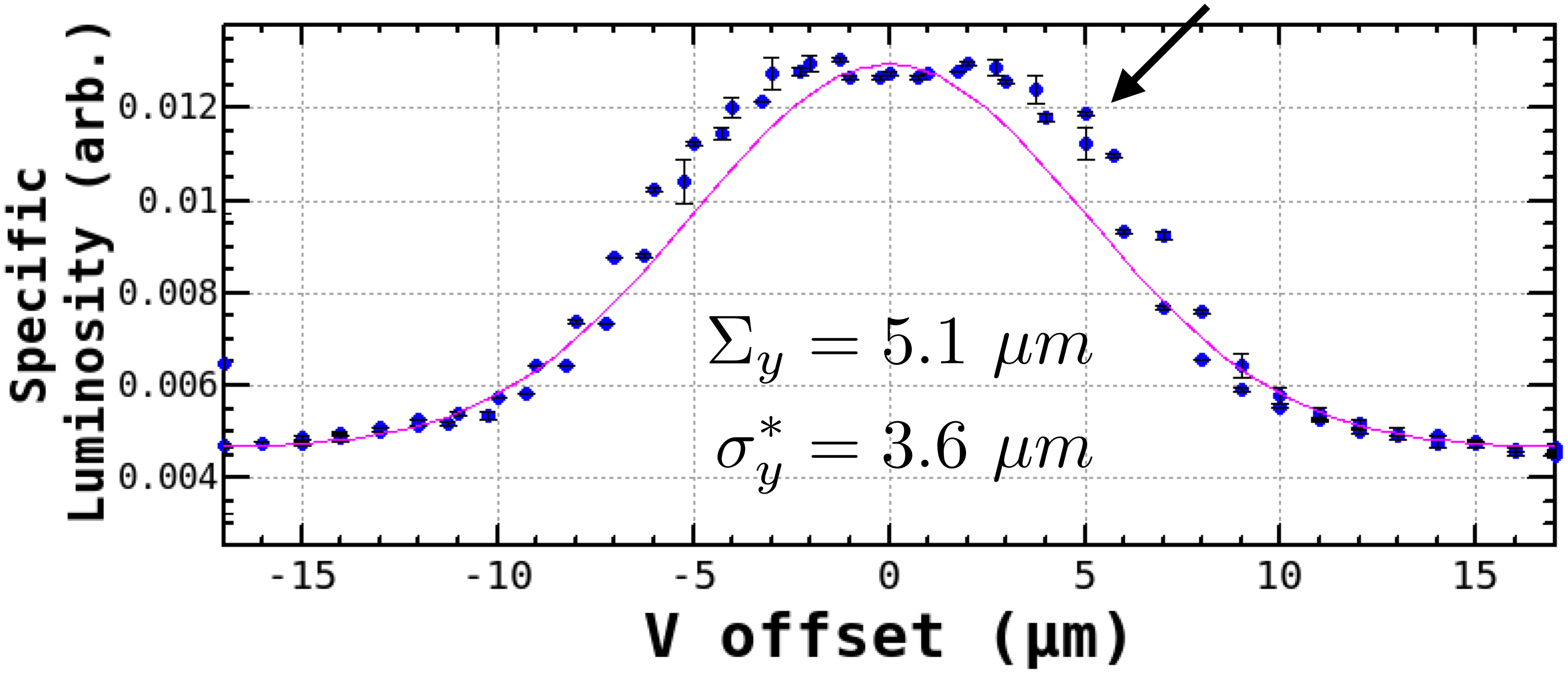
$HER: \quad \nu_x/\nu_y = 45.57/43.61$



$\Sigma_y = 5.5\ \mu m$

$\sigma_y^* = 4\ \mu m$

Double peak due to vertical angle of HER orbit.



$\Sigma_y = 5.1\ \mu m$

$\sigma_y^* = 3.6\ \mu m$

Conclusions (cont’d)

Luminosity is estimated by the beam-size. preliminary !

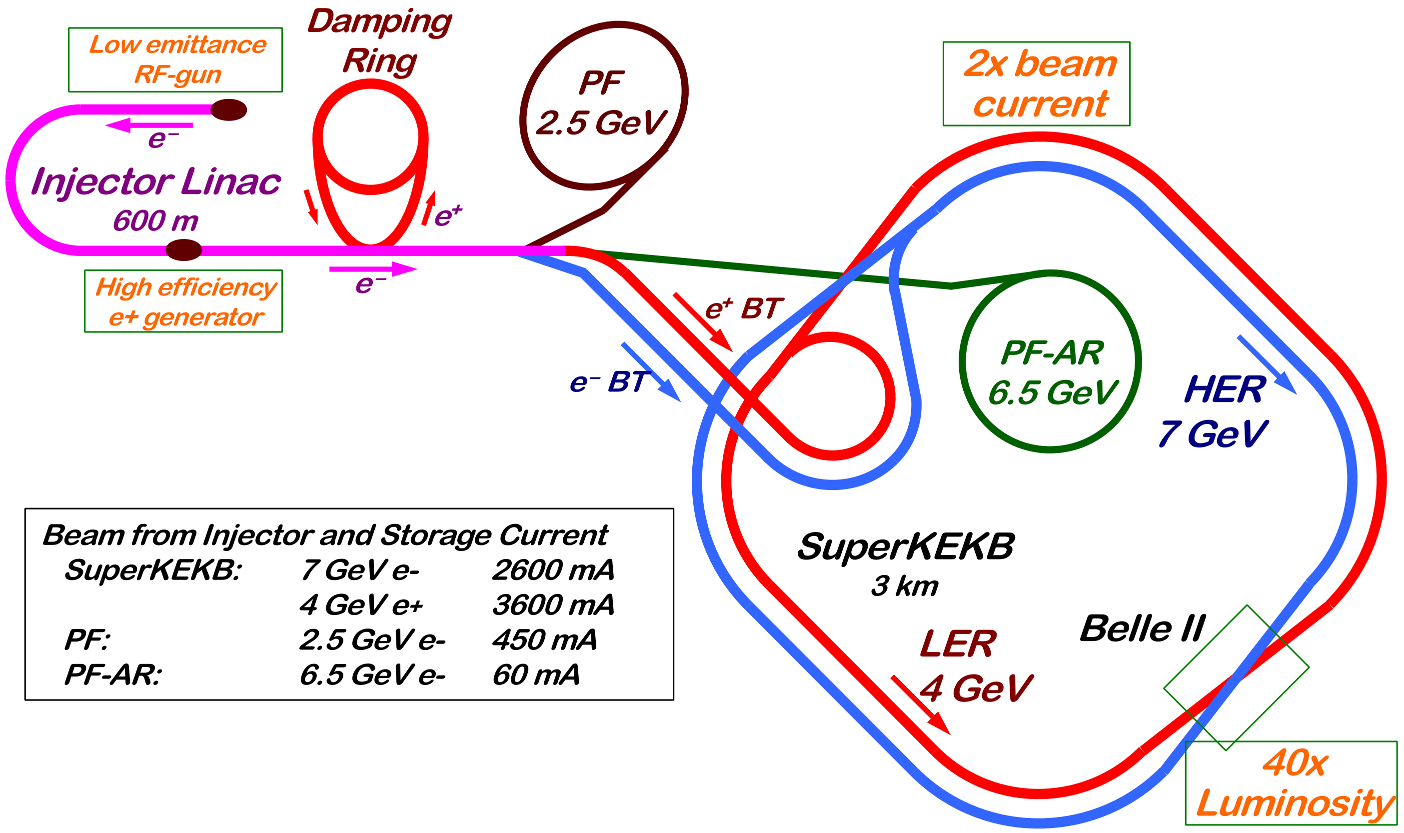
Phase	Phase 2.1 Achieved		Phase 2.1 Target		Phase 2.3 Target	
MR	LER	HER	LER	HER	LER	HER
I [mA]	77	59	250	220	1000	800
No. bunches	300		400		1576	
β_x^* [mm]	200	200	200	200	128	100
β_y^* [mm]	8	8	8	8	2.2	2.4
$\sigma_{x,\mathrm{eff}}^*$ [μm]	**224**		**250**		**250**	
σ_y^* [μm]	**4**		**1.6**		**0.33**	
I_{bunch} [mA]	0.26	0.20	0.625	0.55	0.64	0.51
L_{sp} [$\mathrm{cm}^{-2}\mathrm{s}^{-1}/\mathrm{mA}^2$]	2.1 x 10^{30}		7 x 10^{30}		3.9 x 10^{31}	
L [$\mathrm{cm}^{-2}\mathrm{s}^{-1}$]	3.2 x 10^{31}		1 x 10^{32}		**2 x 10^{34}**	

Remaining Issues

- X-Y couplings in the HER
- Beta-beat in the HER
- IP knobs to optimize luminosity;
  - IP couplings (r_1^*,r_2^*,r_3^*,r_4^*)
  - IP dispersions (η_y^*, η_{py}^*)
  - Waist (α_y^*)
  - Scan of the vertical angle at the IP
- Fast bump-orbit feedback (collision feedback)
- Dithering system and feedback with luminosity monitors
- Short Touschek lifetime in the LER; optimization of DA with octupoles.
- Further squeezing beta at the IP down to 2 mm level, … etc.

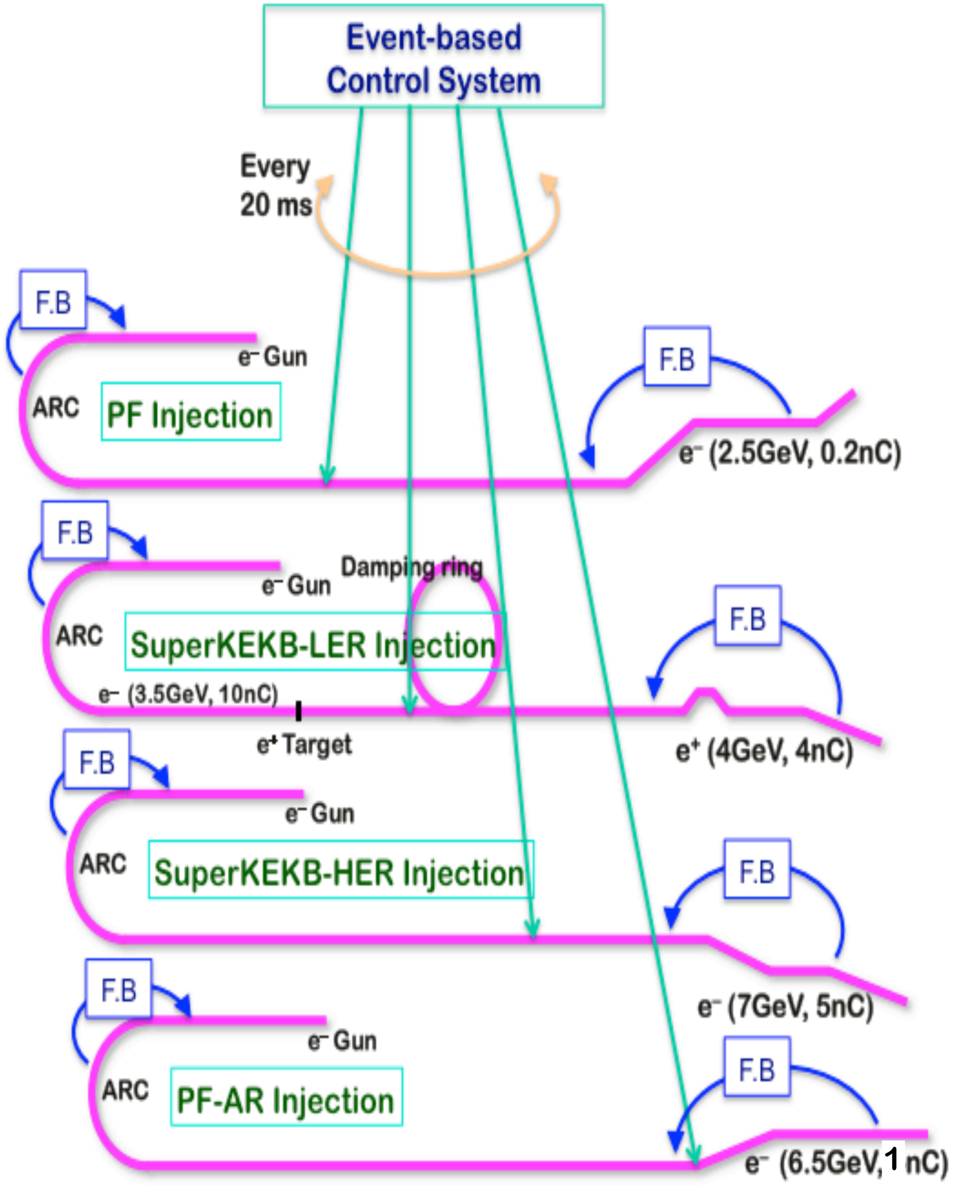
Electron/positron Injector in SuperKEKB

- **For higher luminosity in SuperKEKB collider**
- **Low emittance & low energy spread injection beam with 4-5 times more beam current**
  - New high-current photo-cathode RF gun developments
  - New positron capture section
  - Damping ring construction
  - Optimized beam optics and correction
  - Precise beam orbit control with long-baseline alignment
  - Simultaneous top-up injection to DR/HER/LER/PF/PFAR
- **Balanced injection for the both photon science and elementary particle physics experiments**



Beam from Injector and Storage Current

SuperKEKB:	*7 GeV e-*	*2600 mA*
	4 GeV e+	*3600 mA*
PF:	*2.5 GeV e-*	*450 mA*
PF-AR:	*6.5 GeV e-*	*60 mA*

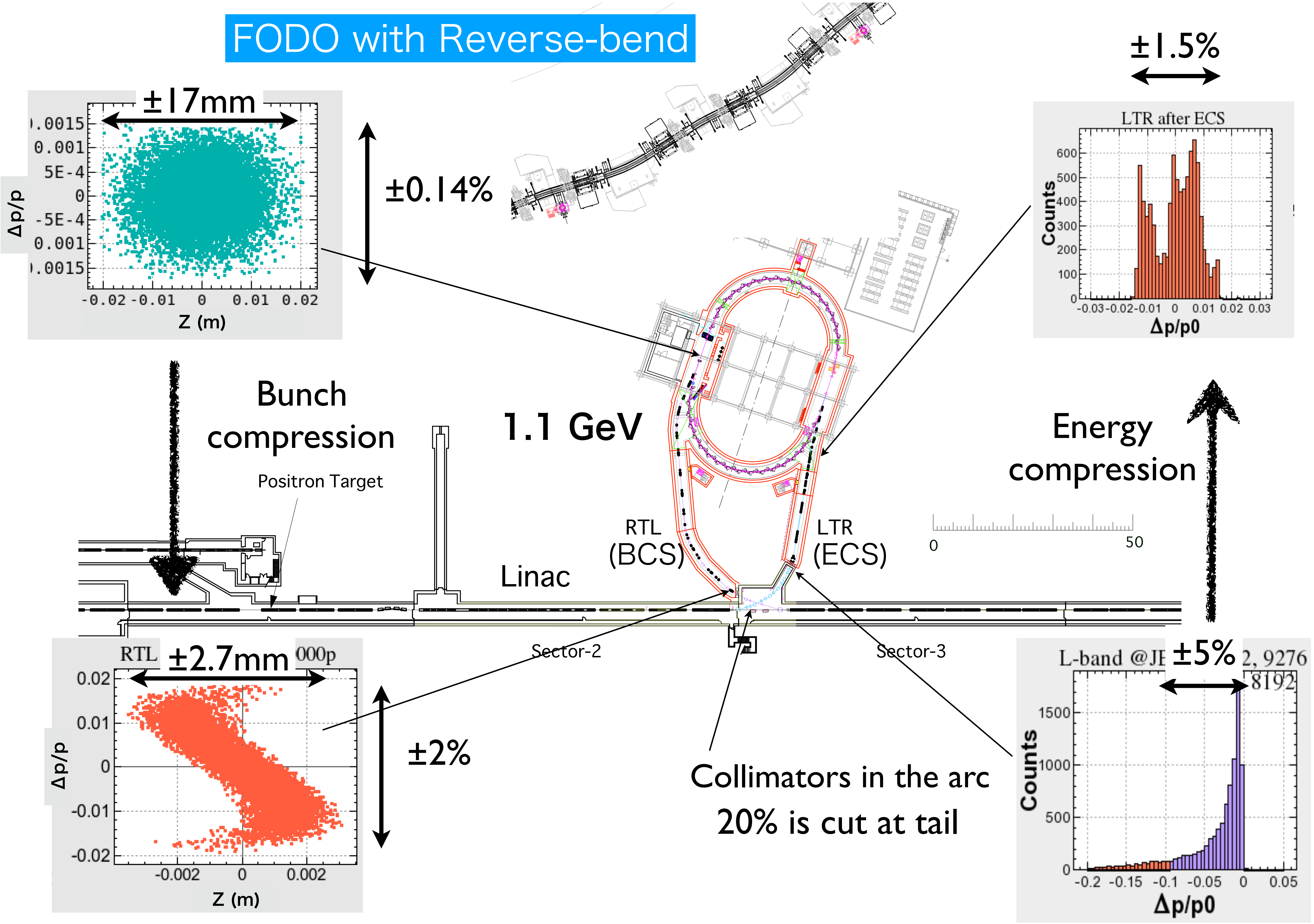


The single injector would behave as multiple injectors to multiple storage rings by the concept of virtual accelerator

K. Furukawa et al.

Positron Damping Ring

M. Kikuchi et al.



FODO with Reverse-bend

±17mm

±0.14%

±1.5%

Bunch compression

1.1 GeV

Energy compression

Positron Target

RTL (BCS)

LTR (ECS)

Linac

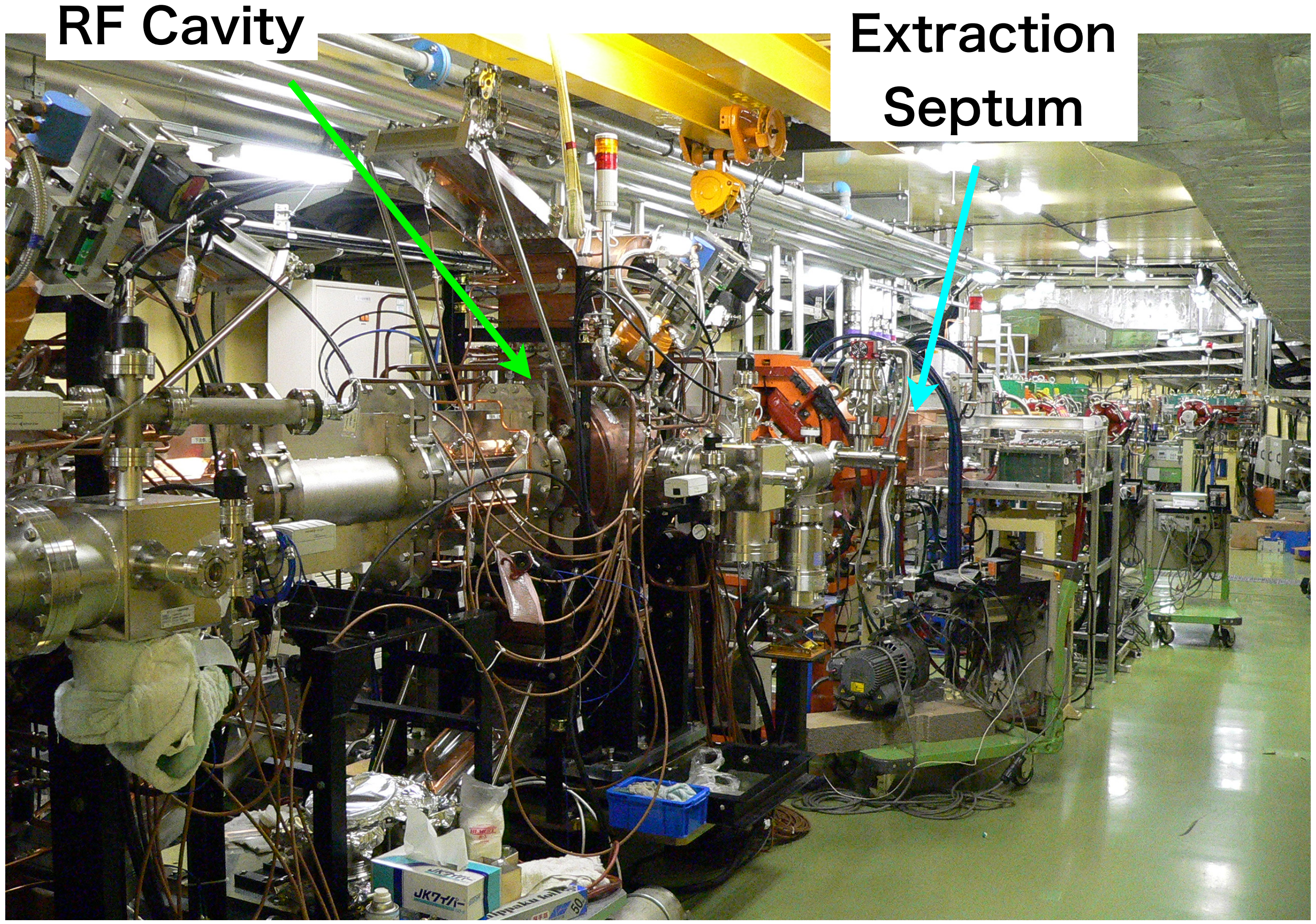
±2.7mm

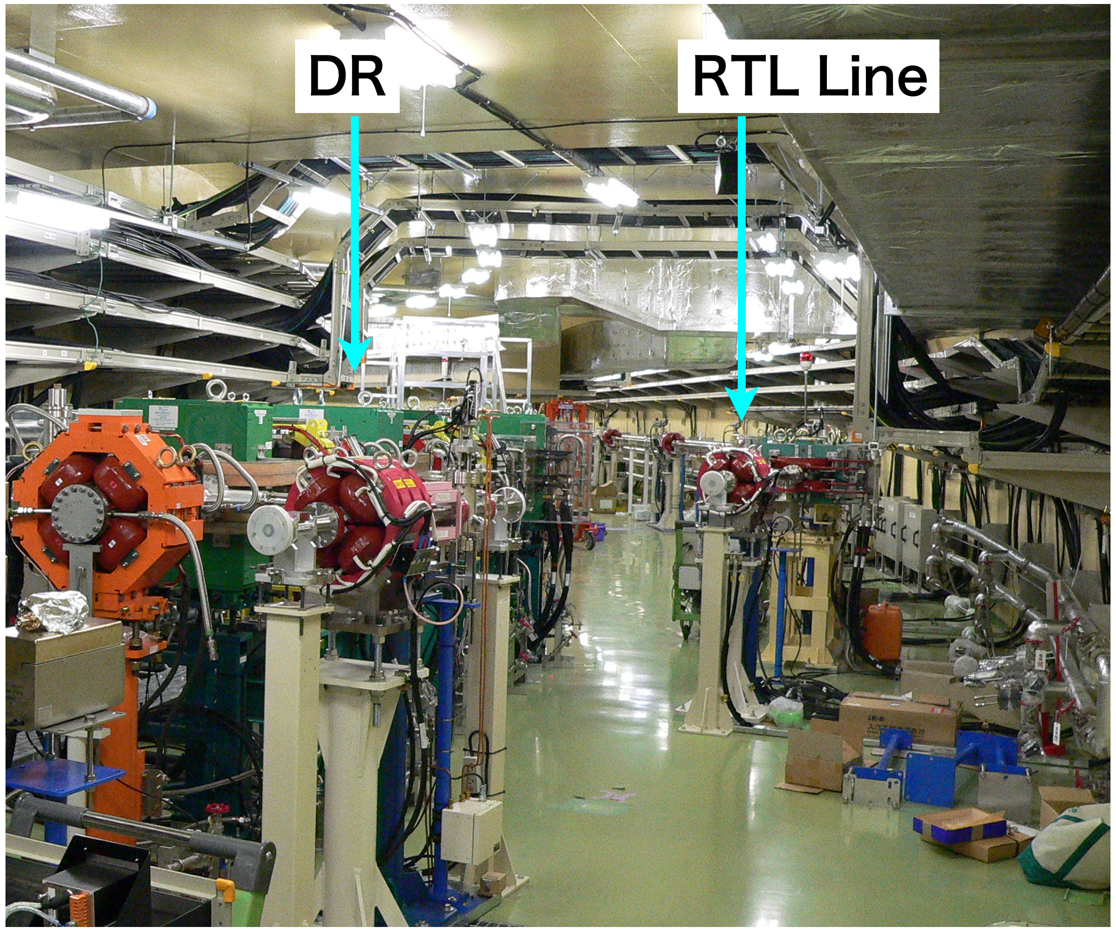
±2%

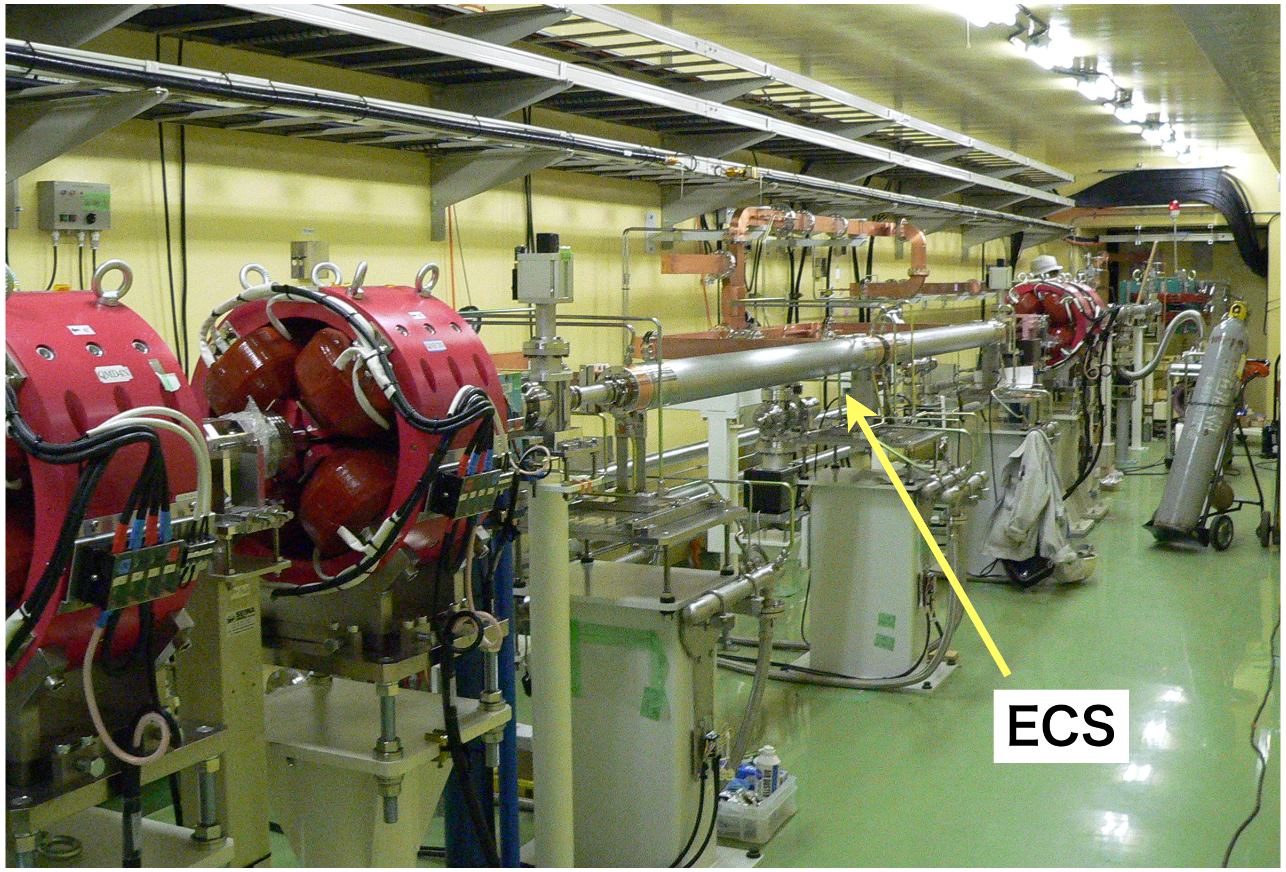
Collimators in the arc

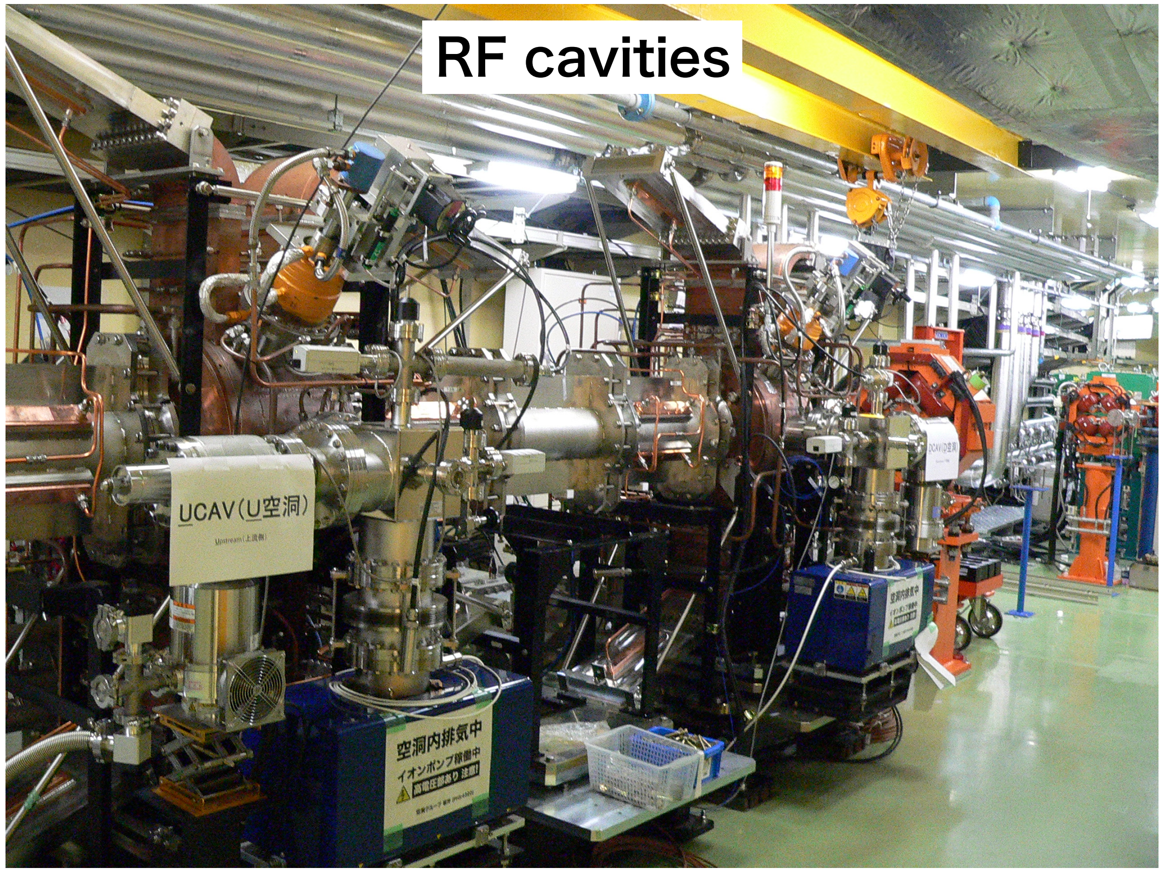
20% is cut at tail

±5%

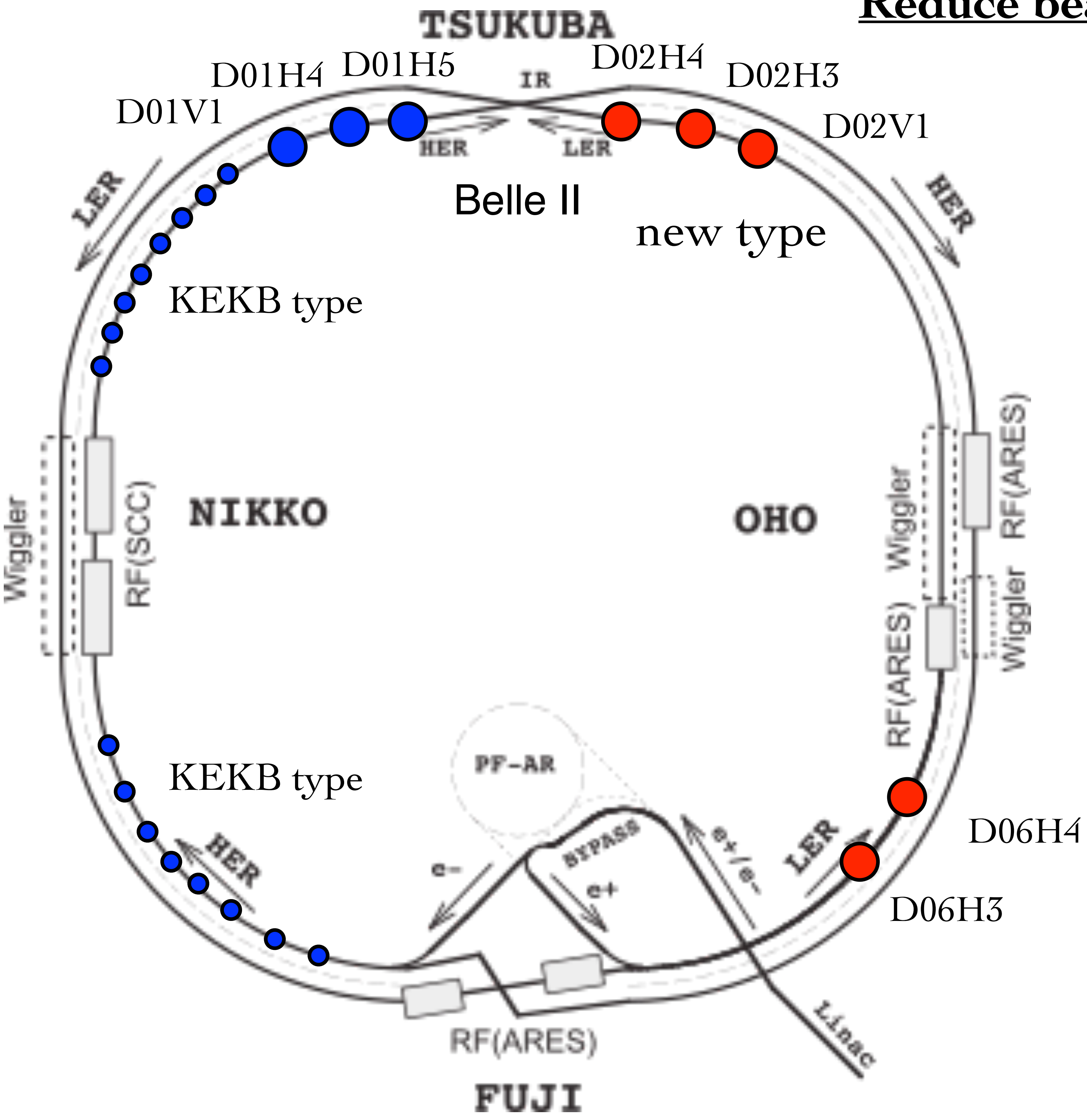

RF Cavity
Extraction Septum


DR
RTL Line


ECS


RF cavities
UCAV(U空洞)
空洞内排気中

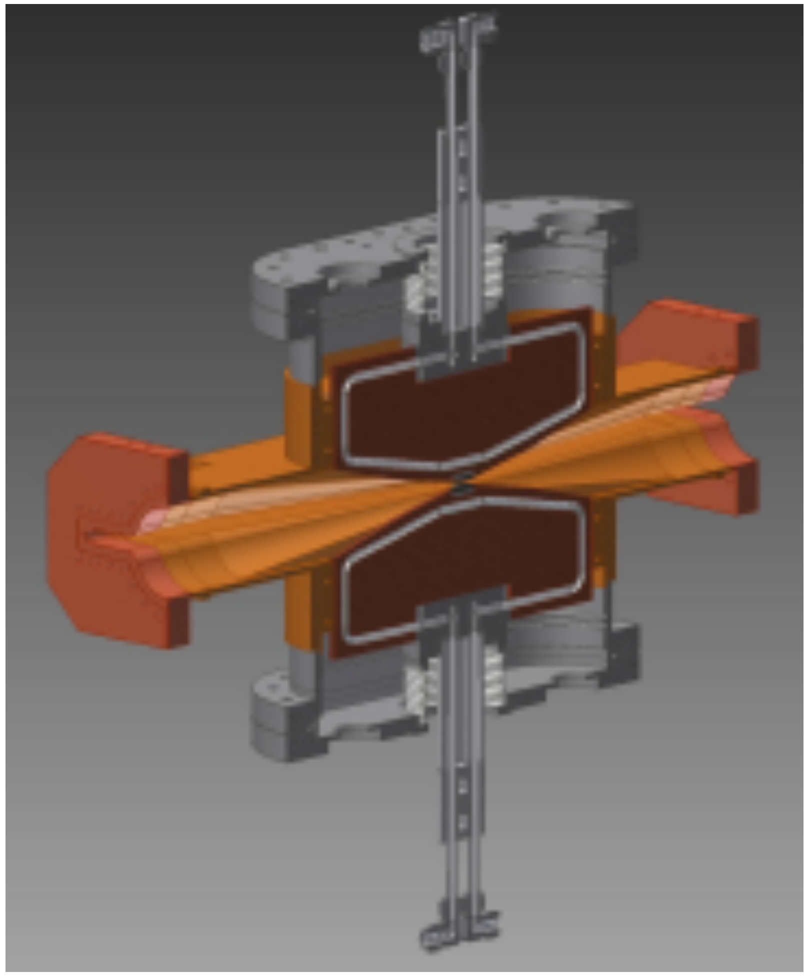
Movable Collimators



Reduce beam background

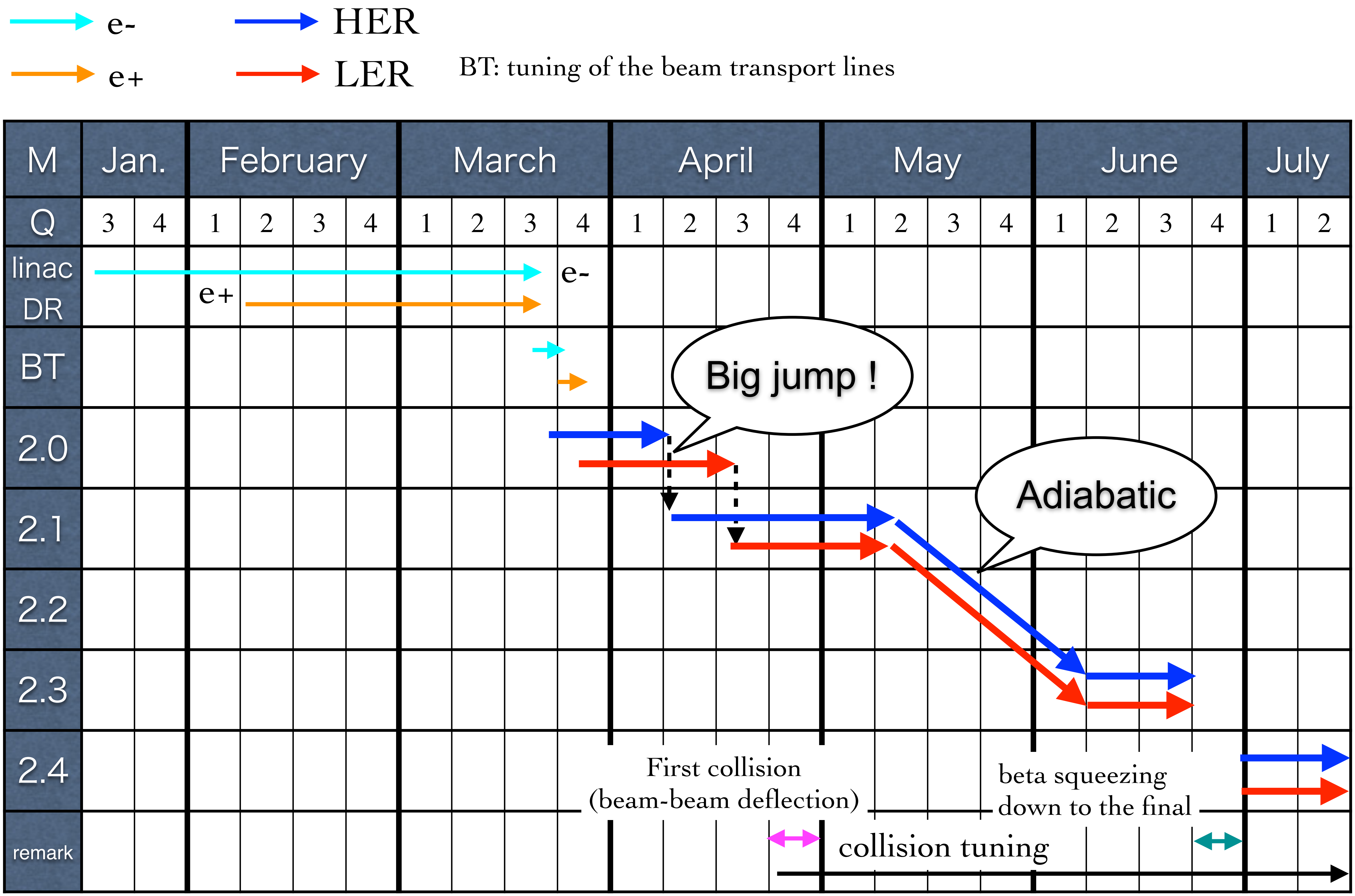
Compromise lifetime, injection, and detector background.

New collimator (SLAC type)



Y. Suetsugu, T. Ishibashi, S. Terui

Schedule of February - July 2018



e-

e+

HER

LER

BT: tuning of the beam transport lines

M: Jan., February, March, April, May, June, July

Q: 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2

linac

DR

BT

2.0

2.1

2.2

2.3

2.4

remark

e-

e+

Big jump !

Adiabatic

First collision
(beam-beam deflection)

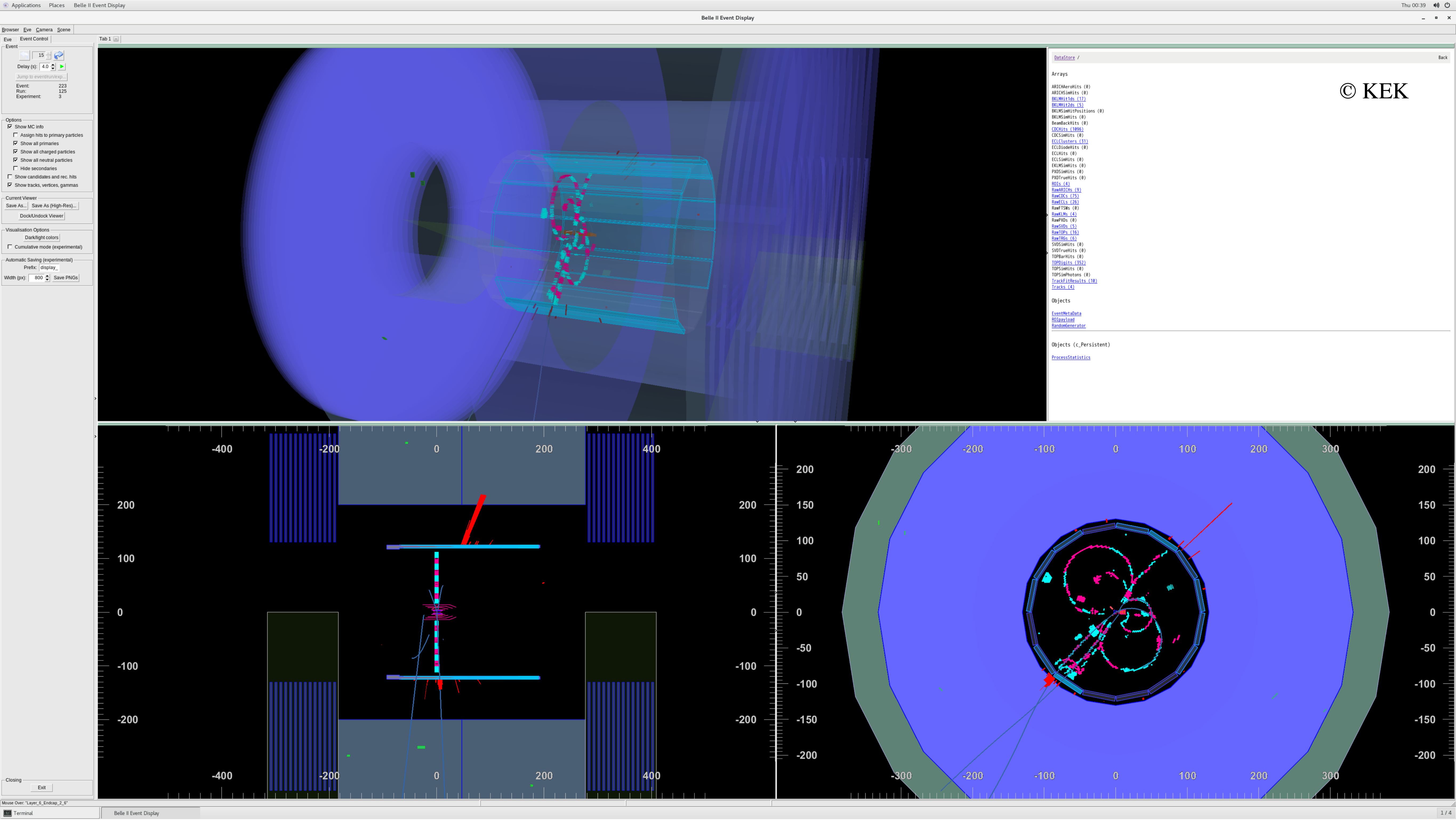
beta squeezing
down to the final

collision tuning

The First Hadronic Event !

April 26 00:38

Belle II / SuperKEKB



© KEK

Event
15
Delay (s): 4.0
Jump to event/run/exp...
Event: 223
Run: 125
Experiment: 3

Options
☑ Show MC info
☐ Assign hits to primary particles
☑ Show all primaries
☑ Show all charged particles
☑ Show all neutral particles
☐ Hide secondaries
☐ Show candidates and rec. hits
☑ Show tracks, vertices, gammas

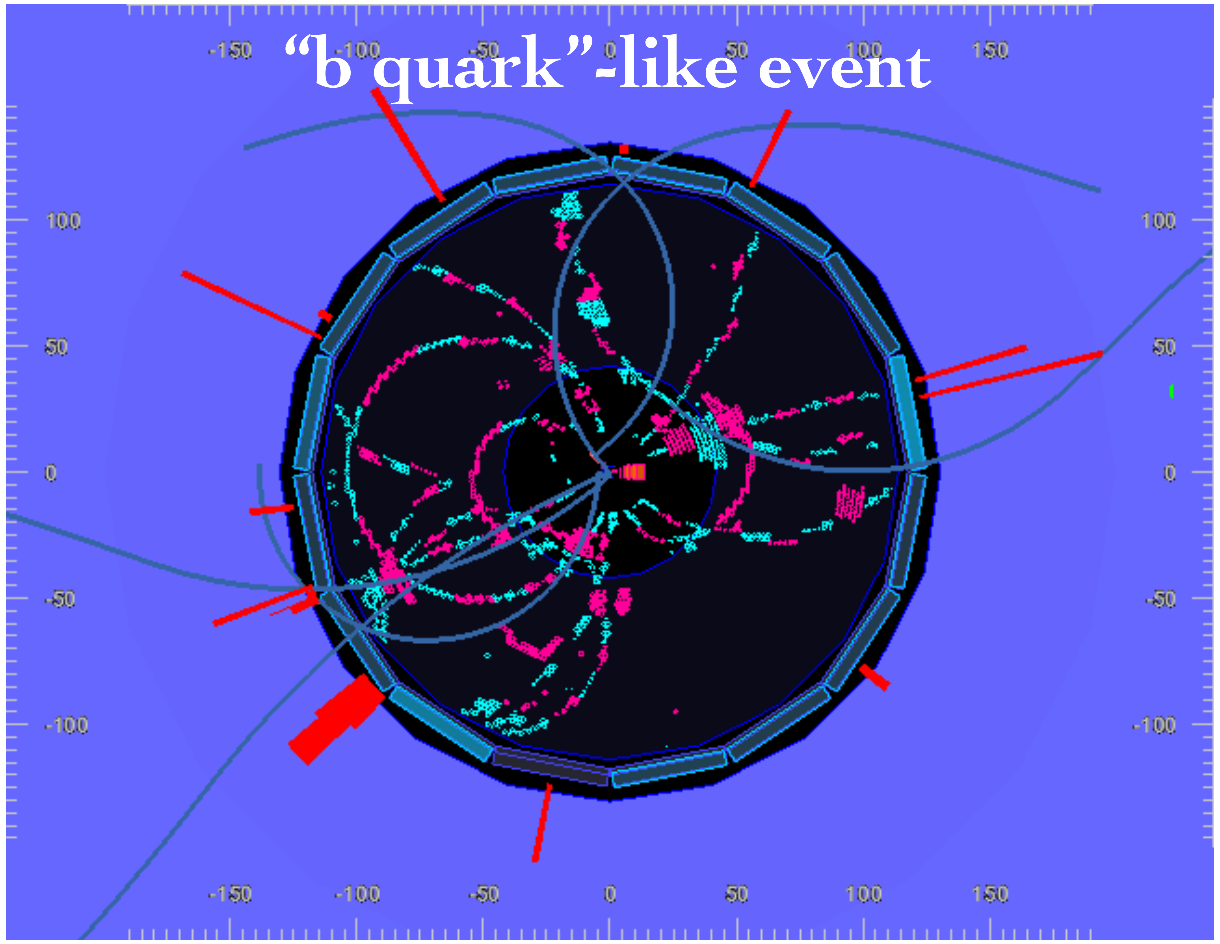
Current Viewer
Save As...
Save As (High-Res)...
Dock/Undock Viewer

Visualisation Options
Dark/light colors
☐ Cumulative mode (experimental)

Automatic Saving (experimental)
Prefix: display_
Width (px): 800
Save PNGs

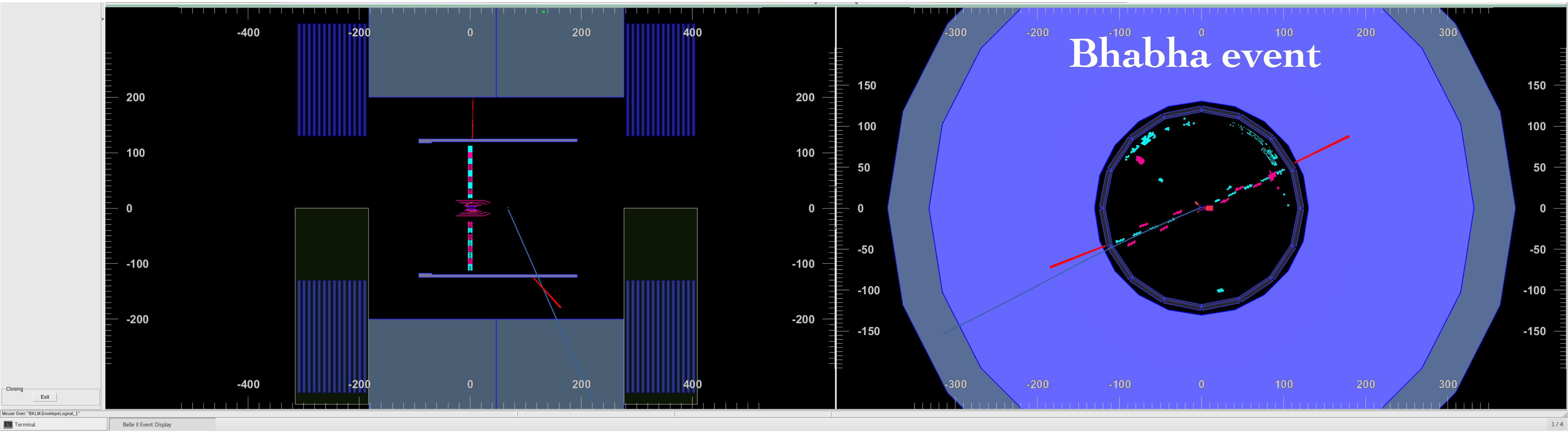
```
DataStore /

Arrays

ARICHAeroHits (0)
ARICHSimHits (0)
BKLMHit1ds (17)
BKLMHit2ds (5)
BKLMSimHitPositions (0)
BKLMSimHits (0)
BeamBackHits (0)
CDCHits (1096)
CDCSimHits (0)
ECLClusters (31)
ECLDiodeHits (0)
ECLHits (0)
ECLSimHits (0)
EKLMSimHits (0)
PXDSimHits (0)
PXDTrueHits (0)
ROIs (4)
RawARICHs (9)
RawCDCs (75)
RawECLs (26)
RawFTSWs (0)
RawKLMs (4)
RawPXDs (0)
RawSVDs (5)
RawTOPs (16)
RawTRGs (6)
SVDSimHits (0)
SVDTrueHits (0)
TOPBarHits (0)
TOPDigits (352)
TOPSimHits (0)
TOPSimPhotons (0)
TrackFitResults (10)
Tracks (4)

Objects

EventMetaData
ROIpayload
RandomGenerator

Objects (c_Persistent)

ProcessStatistics
```

Belle II / SuperKEKB



“b quark”-like event

© KEK



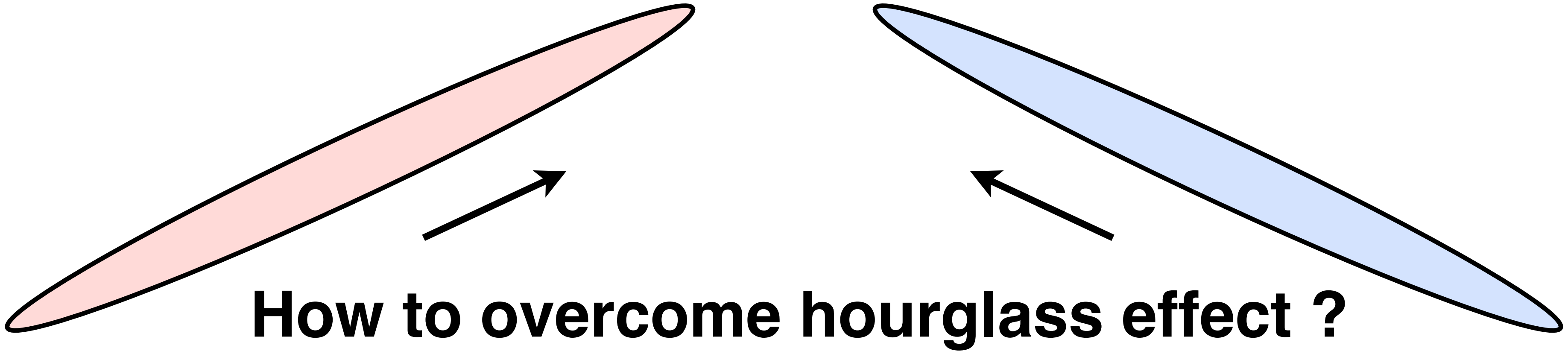
Bhabha event

We have just started !

Appendix

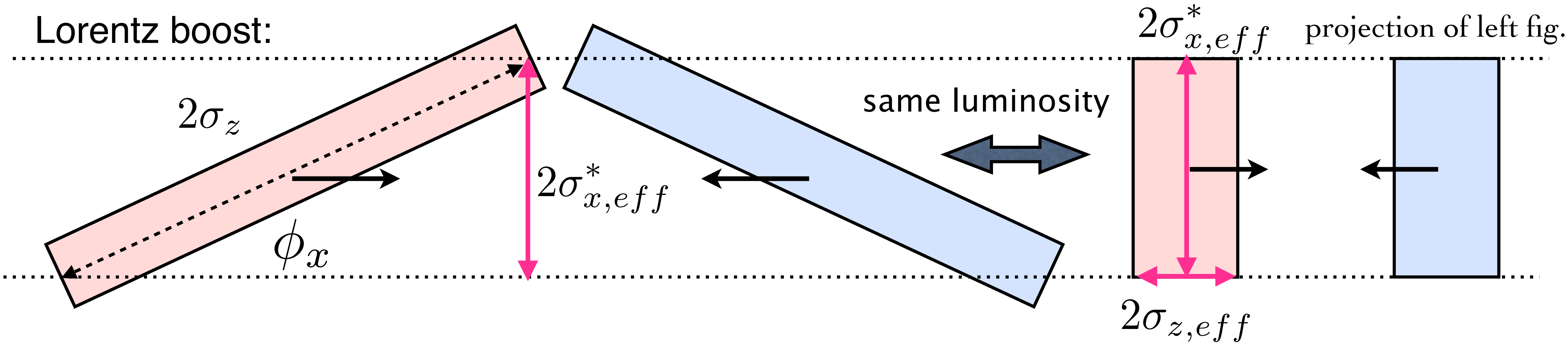
Nano-Beam Scheme

Laboratory frame to head-on frame with Lorentz boost:



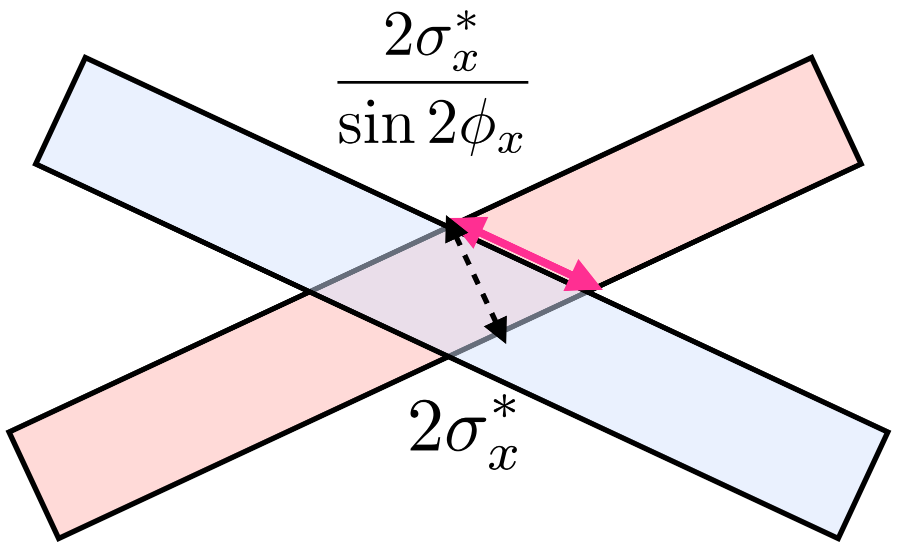
How to overcome hourglass effect ?

Lorentz boost:



$$\sigma_{x,eff} = \sigma_z \sin\phi_x$$

$$\sigma_{z,eff} = \frac{\sigma^*_x}{\sin\phi_x}$$



Narrow beams with a large crossing angle

RF Cavities: Large Beam Currents

To compensate energy loss due to synchrotron radiation,
10～15 MV of accelerating voltage is necessary.

Normal ARES：30 units

22 for LER, 8 for HER

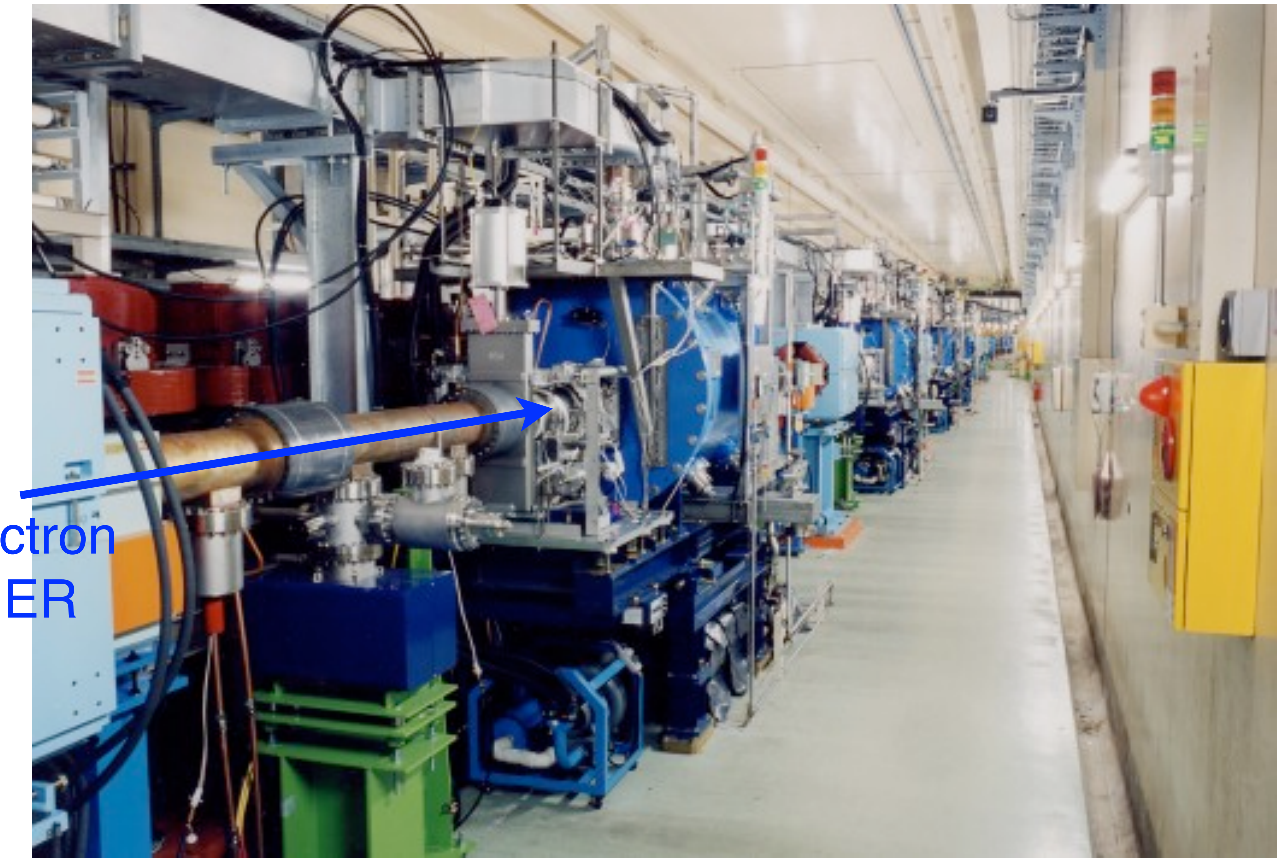
Fuji

positron, LER   electron, HER

0.5 MV / cavity

Superconducting Cavity：8 units

only for HER

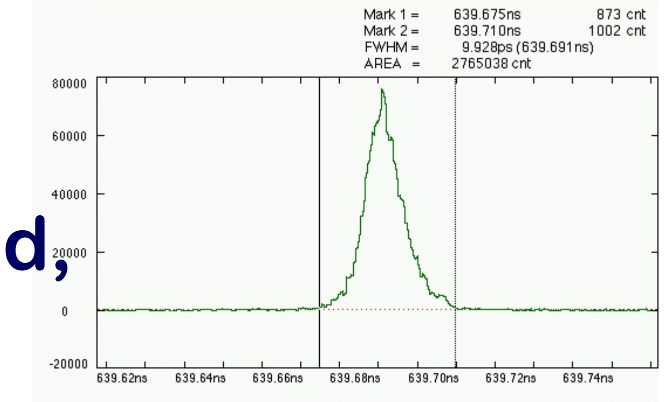


1.5 MV / cavity

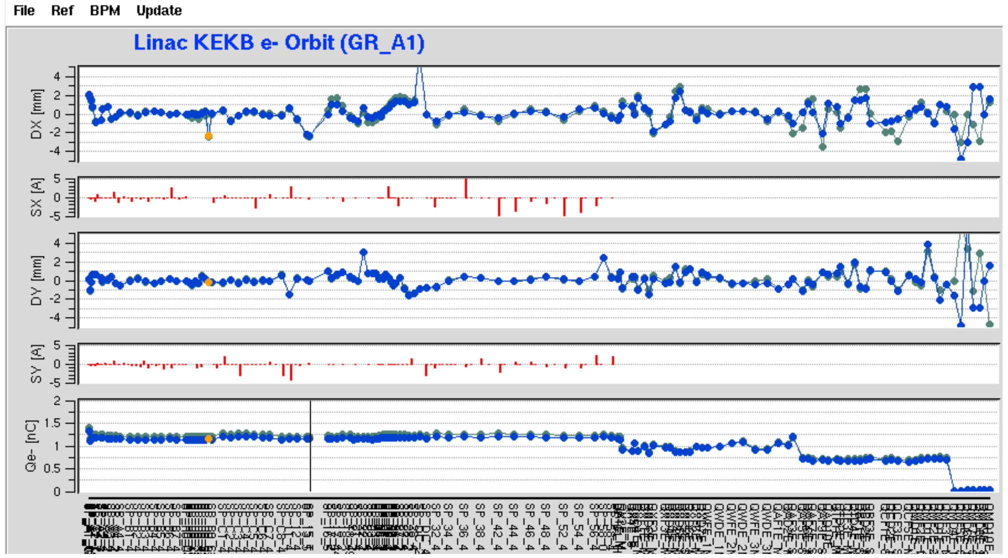
Nikko

Low-emittance e$^-$ with Photo-cathode RF Gun

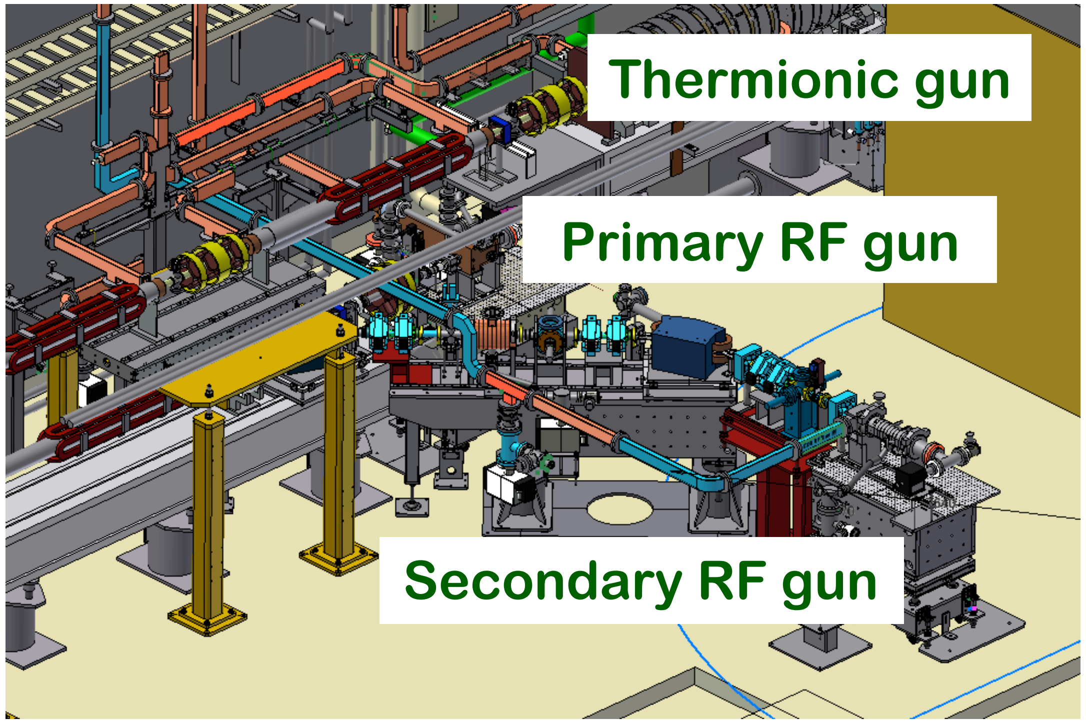
- Succeeded in injection for SuperKEKB Phase 1 & 2 commissioning
- Employs Yb-doped-fiber and Nd/Yb:YAG laser, Ir5Ce cathode, QTWSC or cut disk cavities
- Stability improving to achieve 4 nC, 20 mm.mrad, 0.1% energy spread
- Comparison with simulation codes
- Secondary RF gun is being tuned as a backup

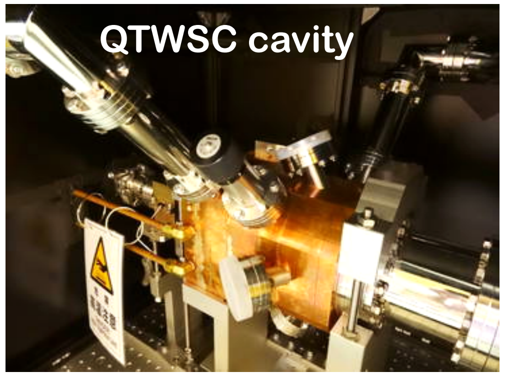


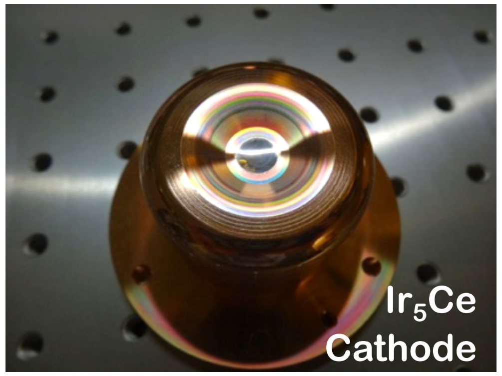
Bunch width

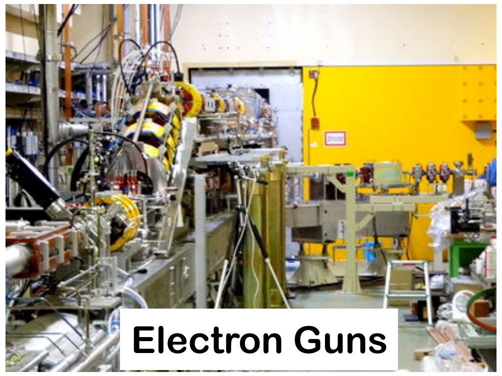


Beam orbit measurement



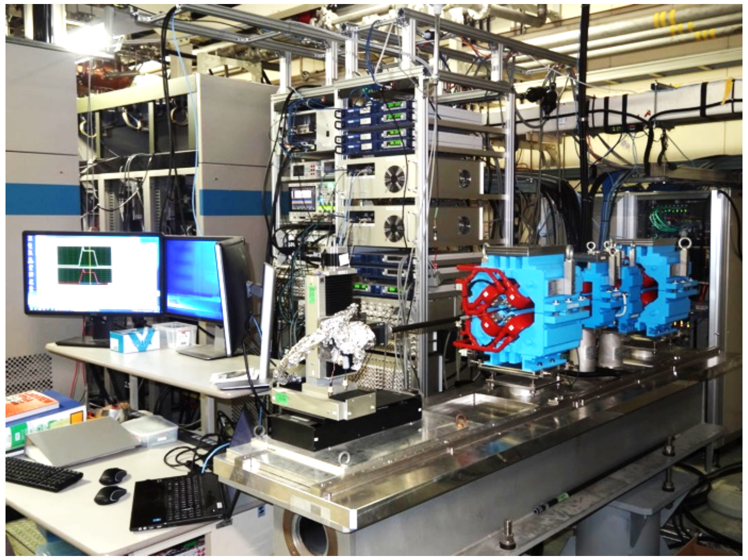




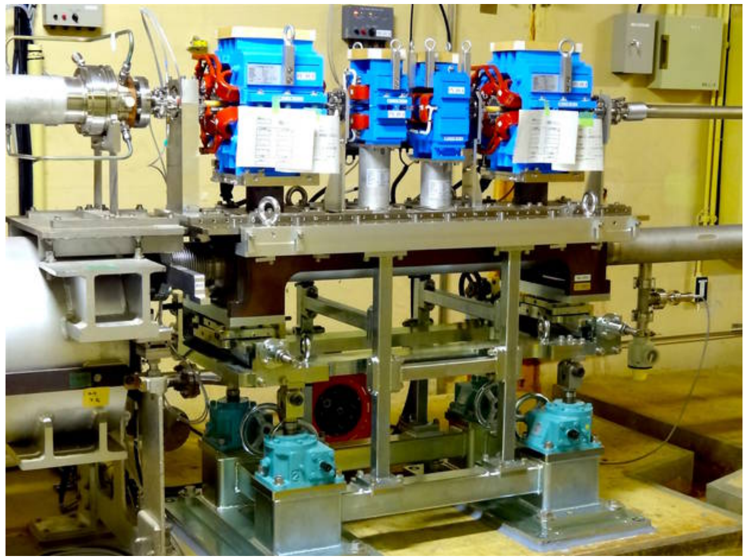


Successful Operation of New Pulsed Magnets

- Pulsed magnet installations were scheduled in FY2017 for resource optimization
- 30 quads, 34 steerings, 13 girders were fabricated and installed in FY2017
- Quads with advanced design at 1 mH, 330 A, 340 V, 1 ms with energy recovery up to 70%
- Essential for SuperKEKB low emittance injection and simultaneous injections
- 4+1 ring pulse-to-pulse 50 Hz injections with virtual accelerator concept
- Long term stability of 0.01% even under variable pulse-to-pulse operation



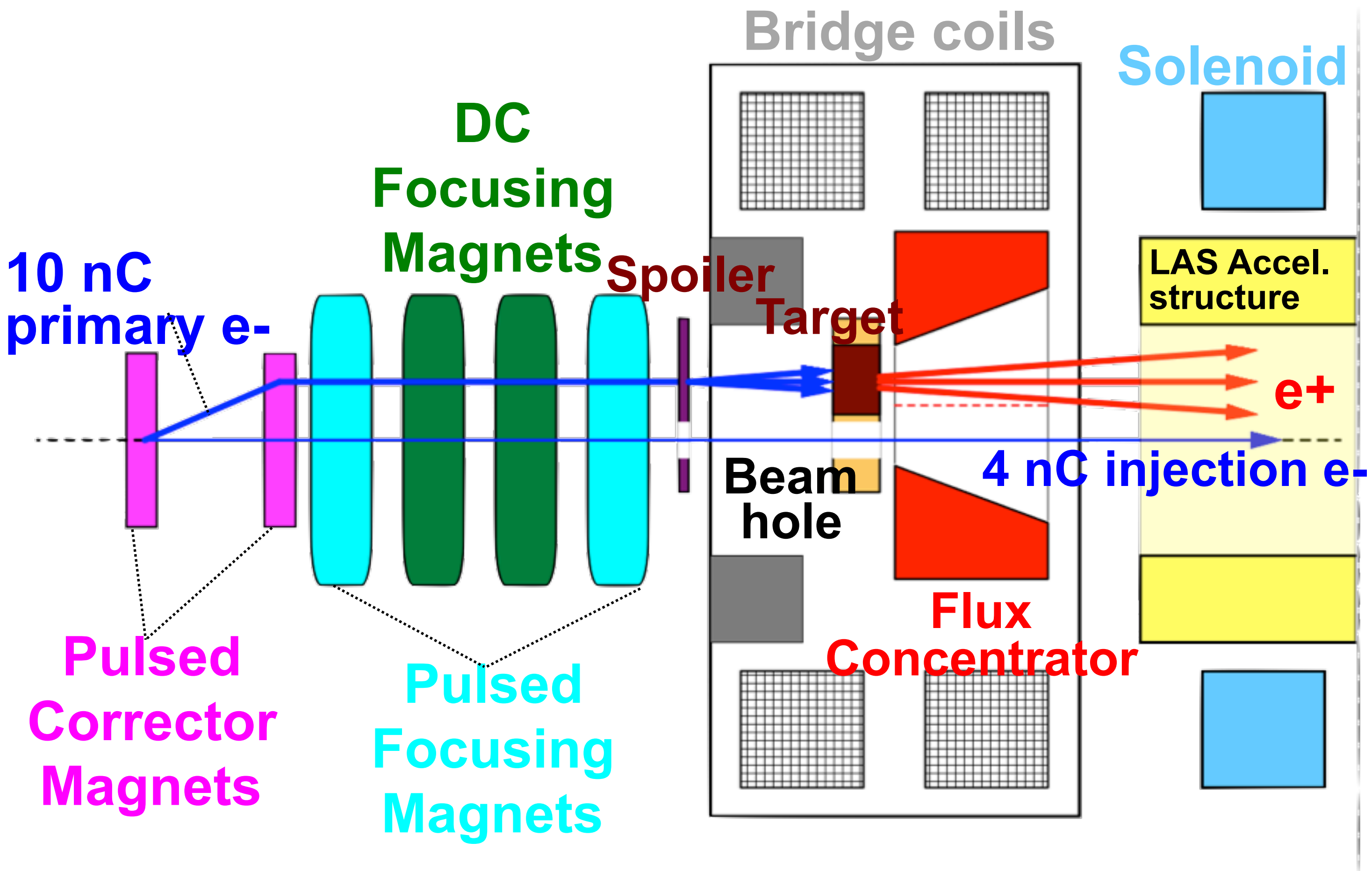
- Long term tests at a stand
- Satisfies specifications
- Synchronous operation
- Online diagnosis at 50 Hz

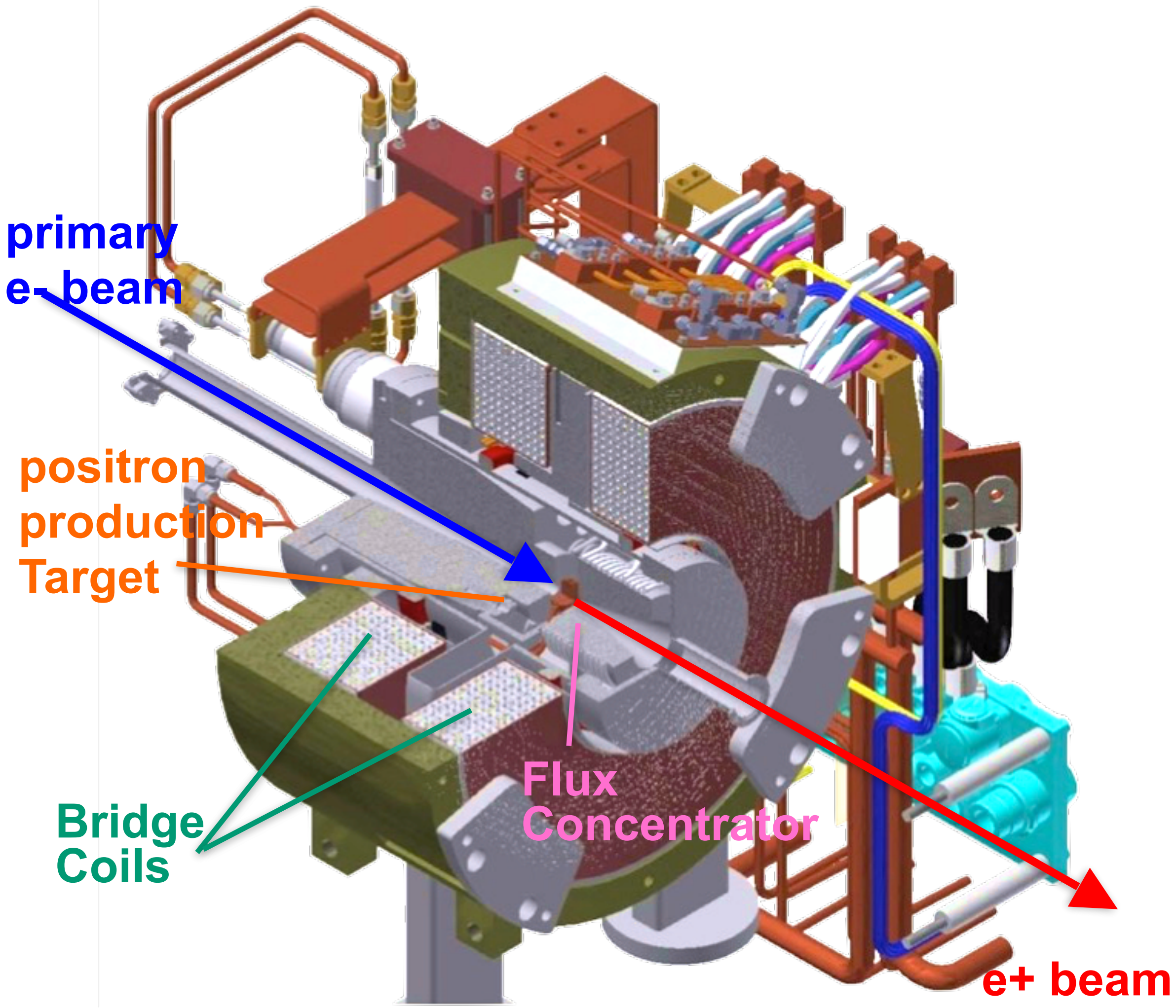


- 64 magnets, 13 girders installed
- Girders were tested as well
- In-house drawings to save resouces
- 0.1mm alignment precision
- Many additions planned

- Compact power supplies
- One-month test before operation
- Event synchronized controls
- Successful fast beam switches
- Ready for Phase-3 upgrade

Positron Generator Intensity Upgrade





- New **positron generation and capturing facility** :
  Positron target, Flux concentrator (FC), Large-aperture S-band structure (LAS)
- Consecutive **focusing magnets** arrangement for over 80 m
- **Velocity bunching** method employed to improve bunching and to suppress beam losses
- Should deliver up to 4 nC / bunch, 20 mm.mrad with help by the damping ring
- Tungsten target (φ 3.5mm, length 14mm) and a pinhole (φ 2mm) beside to pass electrons
- Retraction mechanism being developed to replace components under high radiation

Optics Measurement Method

- Measurement with orbit response analysis.

  - Beta function:

    Orbit response analysis with DC dipole kicks.

$$\Delta x_i = \frac{\sqrt{\beta_i \beta_0}}{2 \sin \pi \nu} \theta \cos \left(|\phi_i - \phi_0| - \pi \nu \right)$$

  - Dispersion:

    Response with RF frequency change.

$$\eta_x = \overset{\text{RF frequency}}{f_0} \frac{\overset{\text{Orbit change}}{\Delta y}}{\underset{\text{Frequency change}}{\Delta f}} \xi \quad \text{Phase slip factor}$$

  - Horizontal-vertical (XY) coupling:

    Vertical leakage orbits induced by horizontal kicks.

$$\Delta \tilde{y} \equiv \Delta y / \left(\Delta x \right)^{\mathrm{rms}}$$

Global Beta-beating *Before* Correction

LER

- Extracted from COD response associated with dipole kicks
- Twelve orbit responses are used. (Six orbits per each direction)

$\Delta\beta_x/\beta_x$ [%]

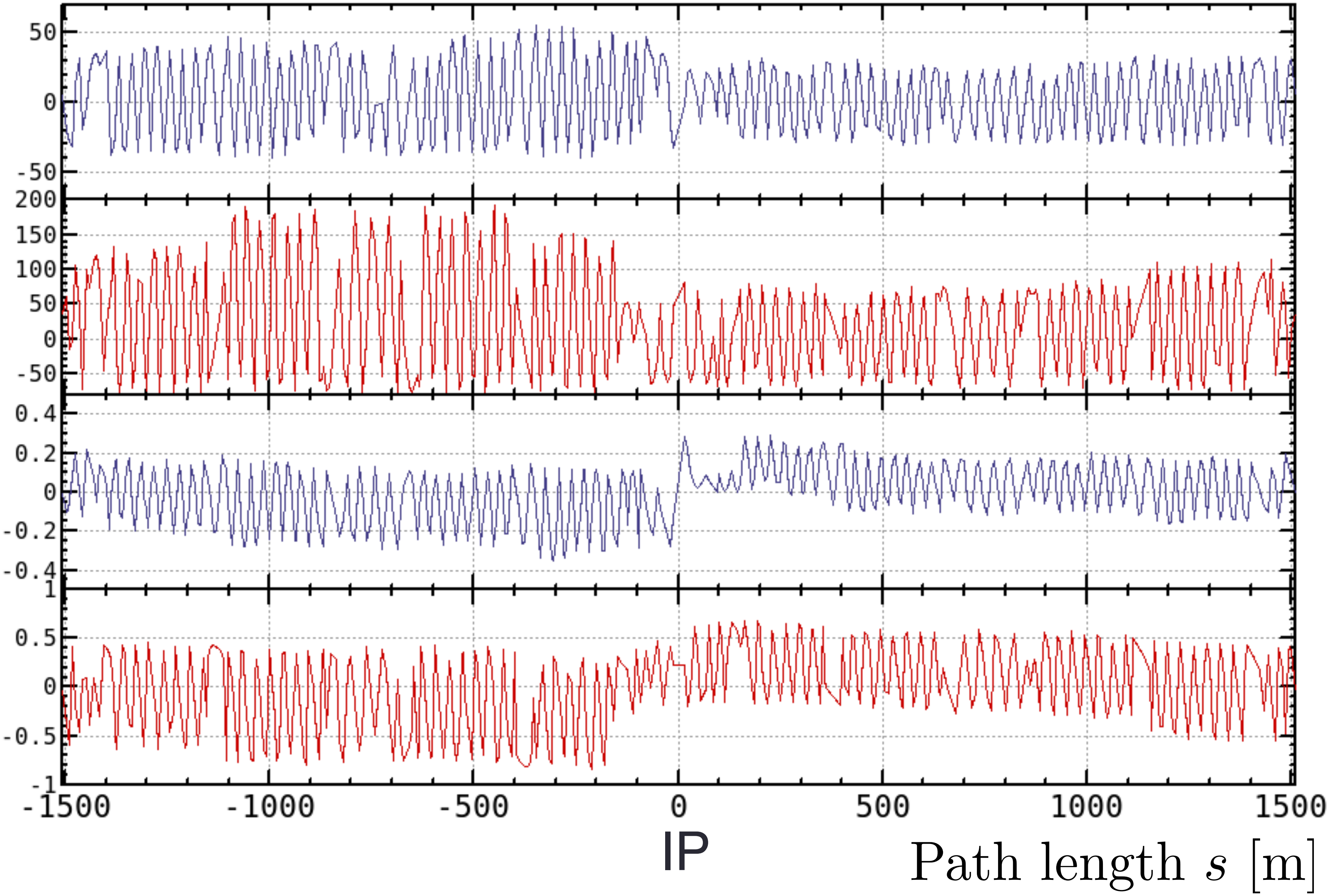
~ 26 %

$\Delta\beta_y/\beta_y$ [%]

~ 75 %

$\phi_x^{\mathrm{meas}} - \phi_x^{\mathrm{model}}$ [rad]

$\phi_y^{\mathrm{meas}} - \phi_y^{\mathrm{model}}$ [rad]



Global Beta-beating *After* Correction

LER

- Global correction by adjusting quadrupole families along the ring.

$\Delta\beta_x/\beta_x$ [%]

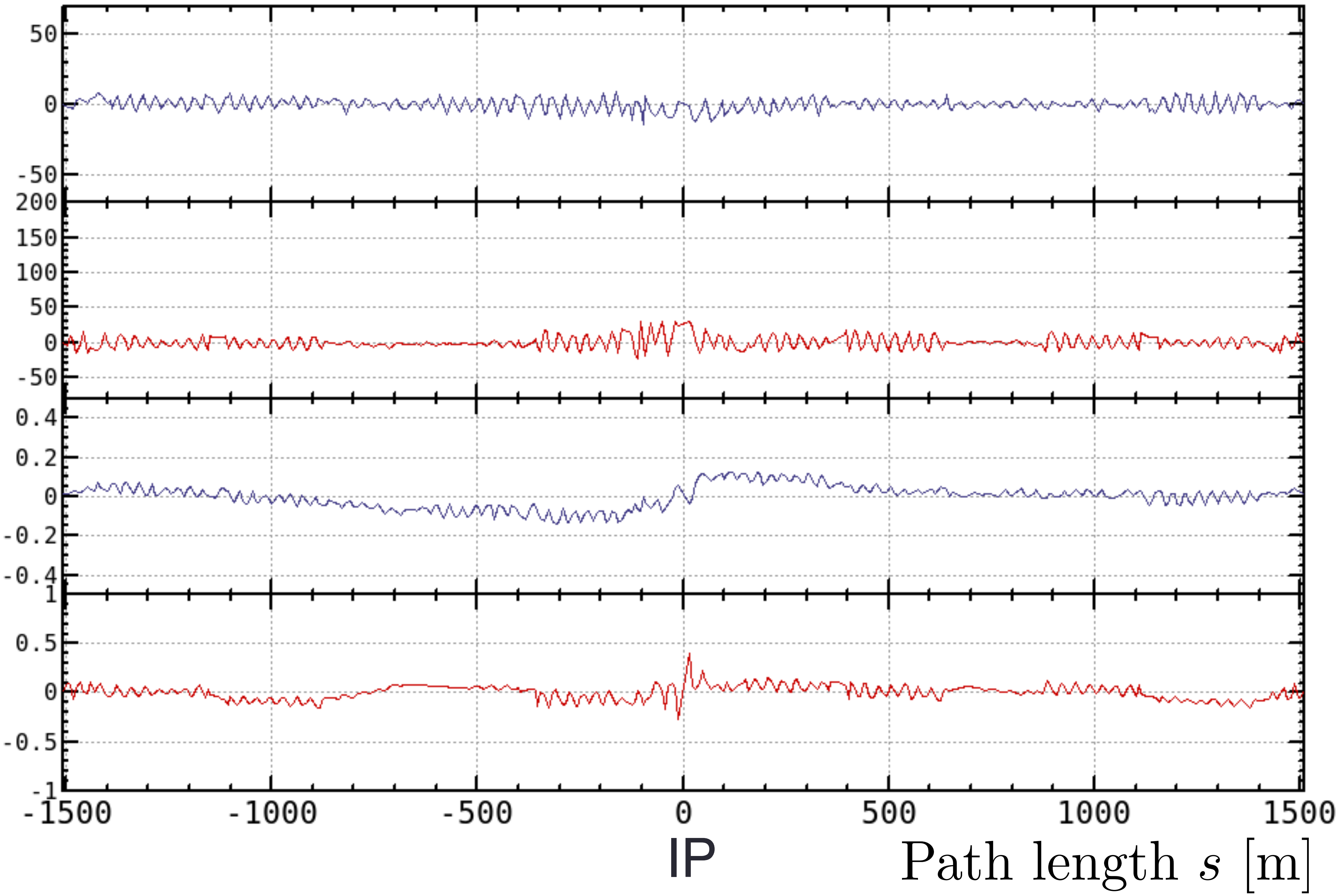
~ 4 %

$\Delta\beta_y/\beta_y$ [%]

~ 8 %

$\phi_x^{\mathrm{meas}} - \phi_x^{\mathrm{model}}$ [rad]

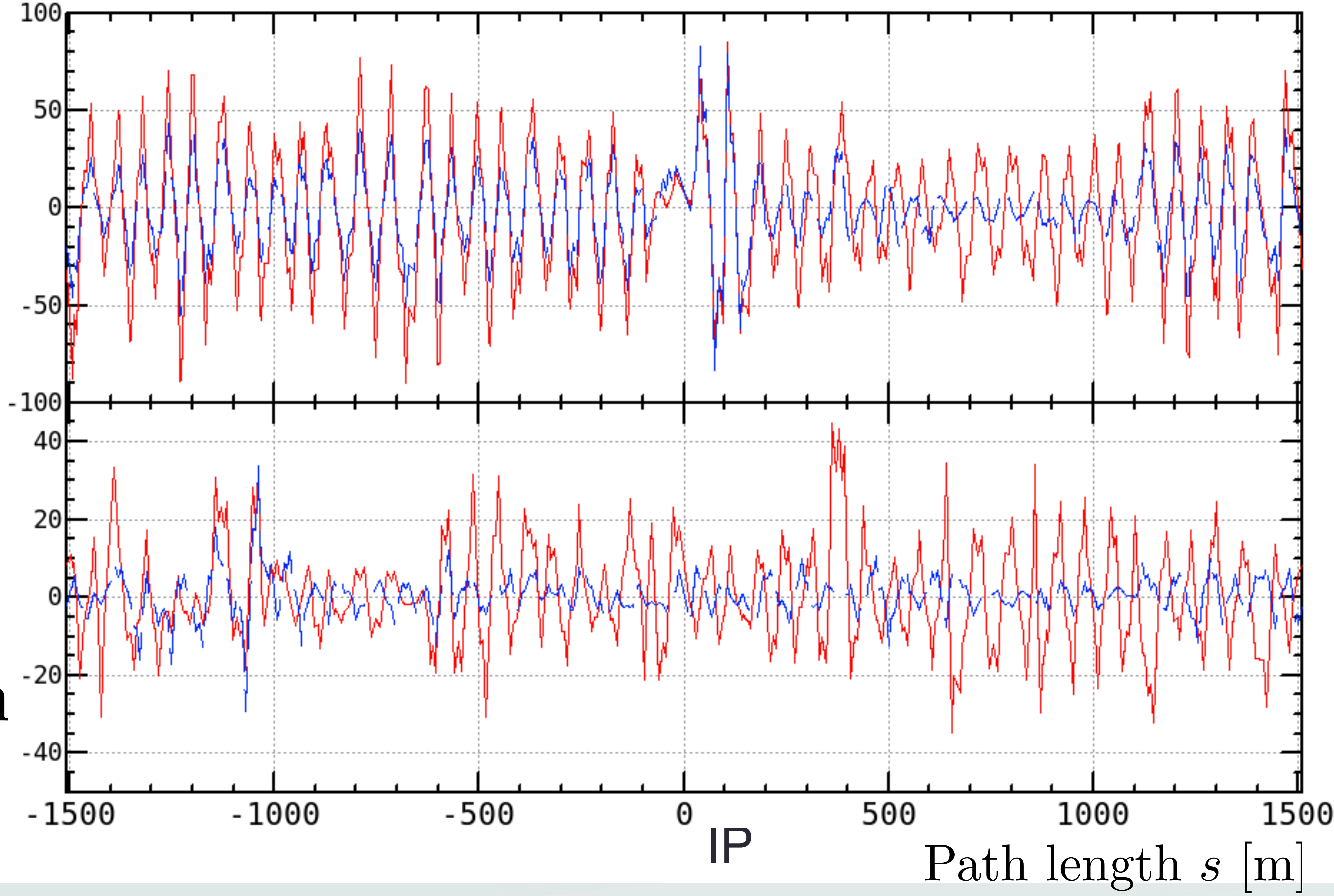
$\phi_y^{\mathrm{meas}} - \phi_y^{\mathrm{model}}$ [rad]



Dispersion Correction

LER

- Use skew quadrupole coils installed in sextupole magnets.
- Skew quadrupole corrector coils of final-focus magnets are also utilized.



$\Delta\eta_x$ [mm]

34 mm

→ 20 mm

$\Delta\eta_y$ [mm]

13 mm

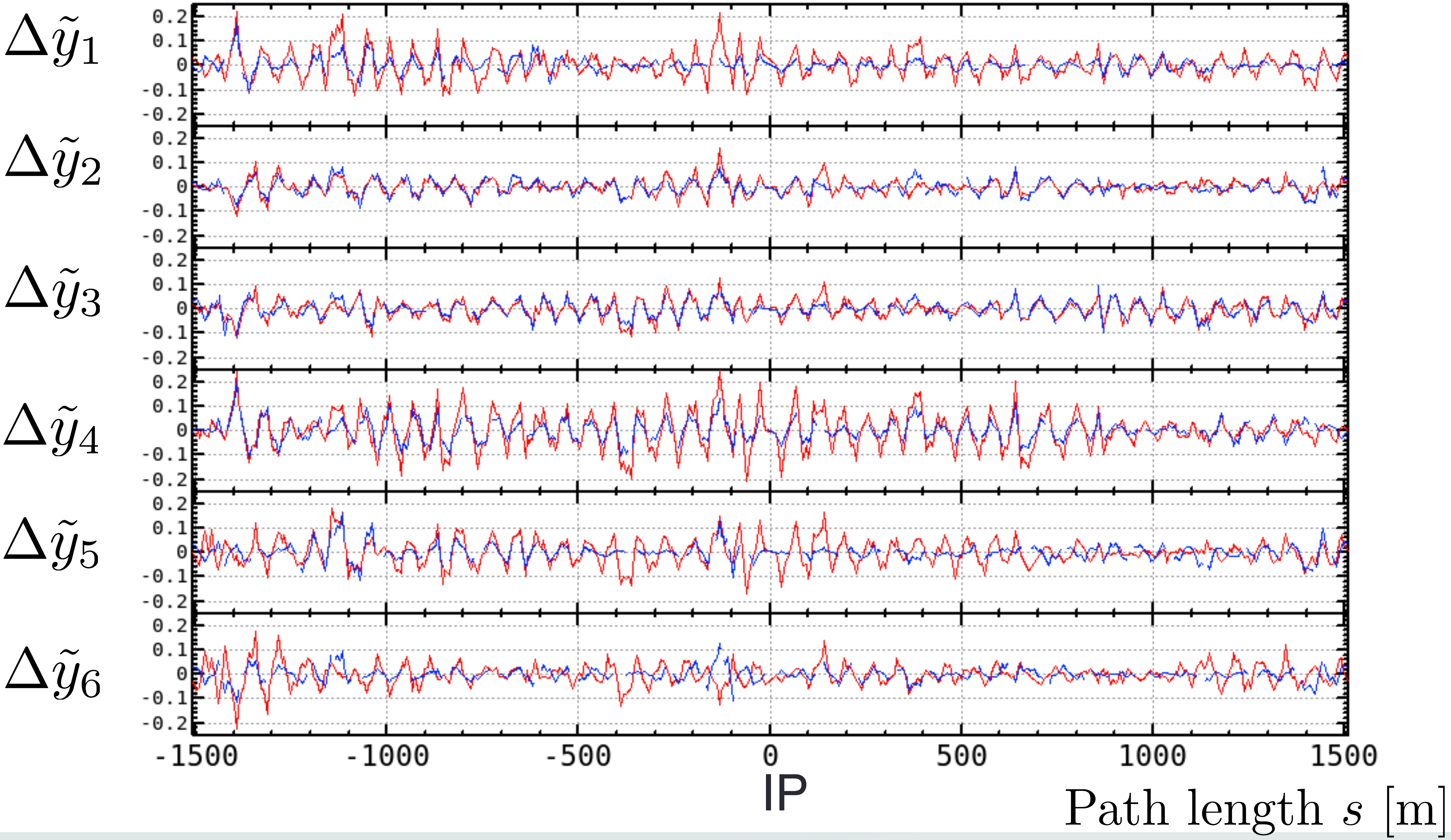
→ 5 mm

XY-coupling Correction

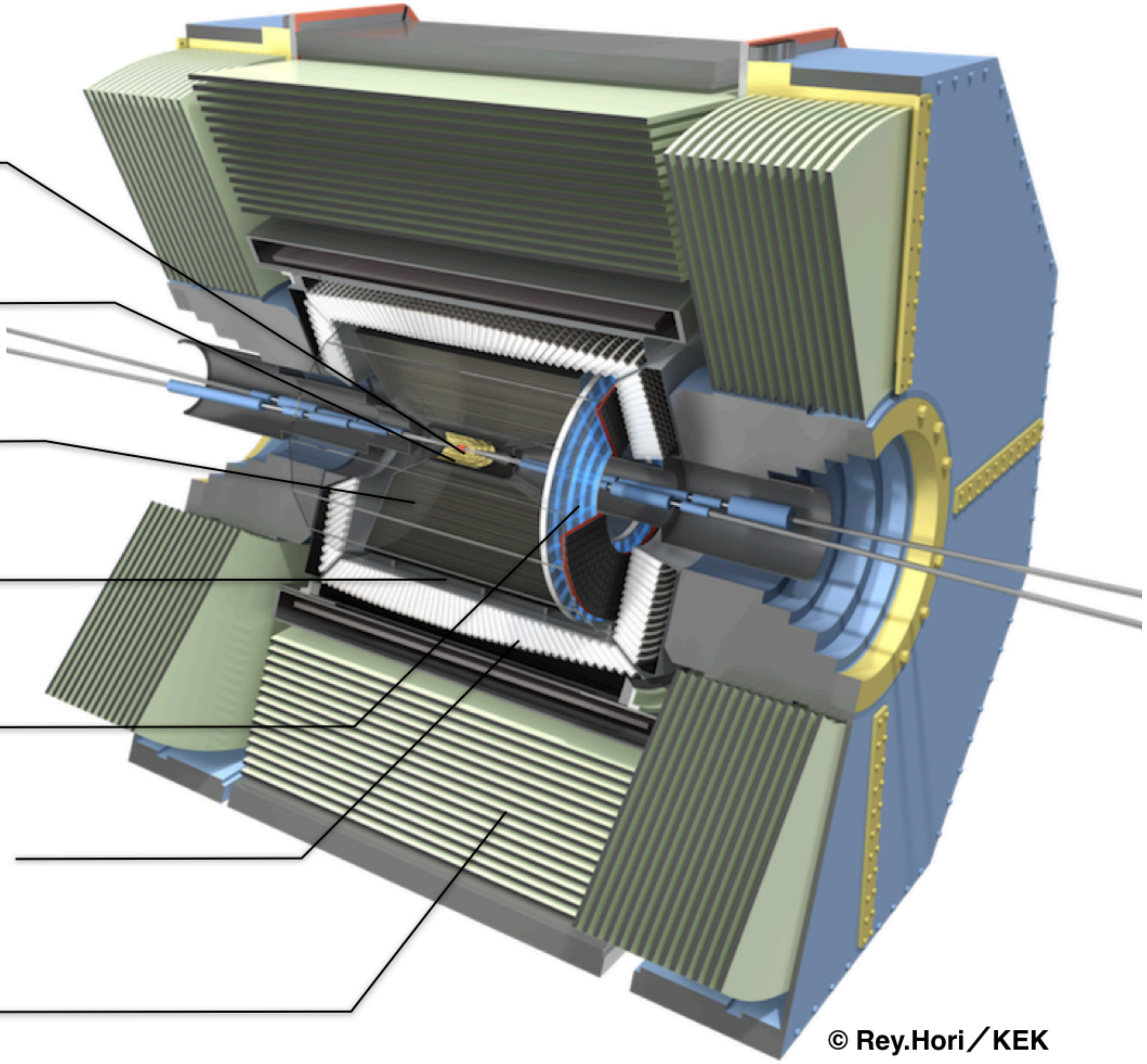
LER

- Suppress the vertical leakage orbit associated with horizontal dipole kick.
- Utilize skew quadrupole correctors.

$$\Delta\tilde{y} \equiv \Delta y / (\Delta x)^{\text{rms}}$$



Belle II Detector



Pixel Detector（PXD）

Silicon Vertex Detector（SVD）

Central Drift Chamber（CDC）

TOP counter（TOP）

Aerogel RICH counter（ARICH）

Electromagnetic Carolimeter（ECL）

K_L^0／Muon Detector（KLM）

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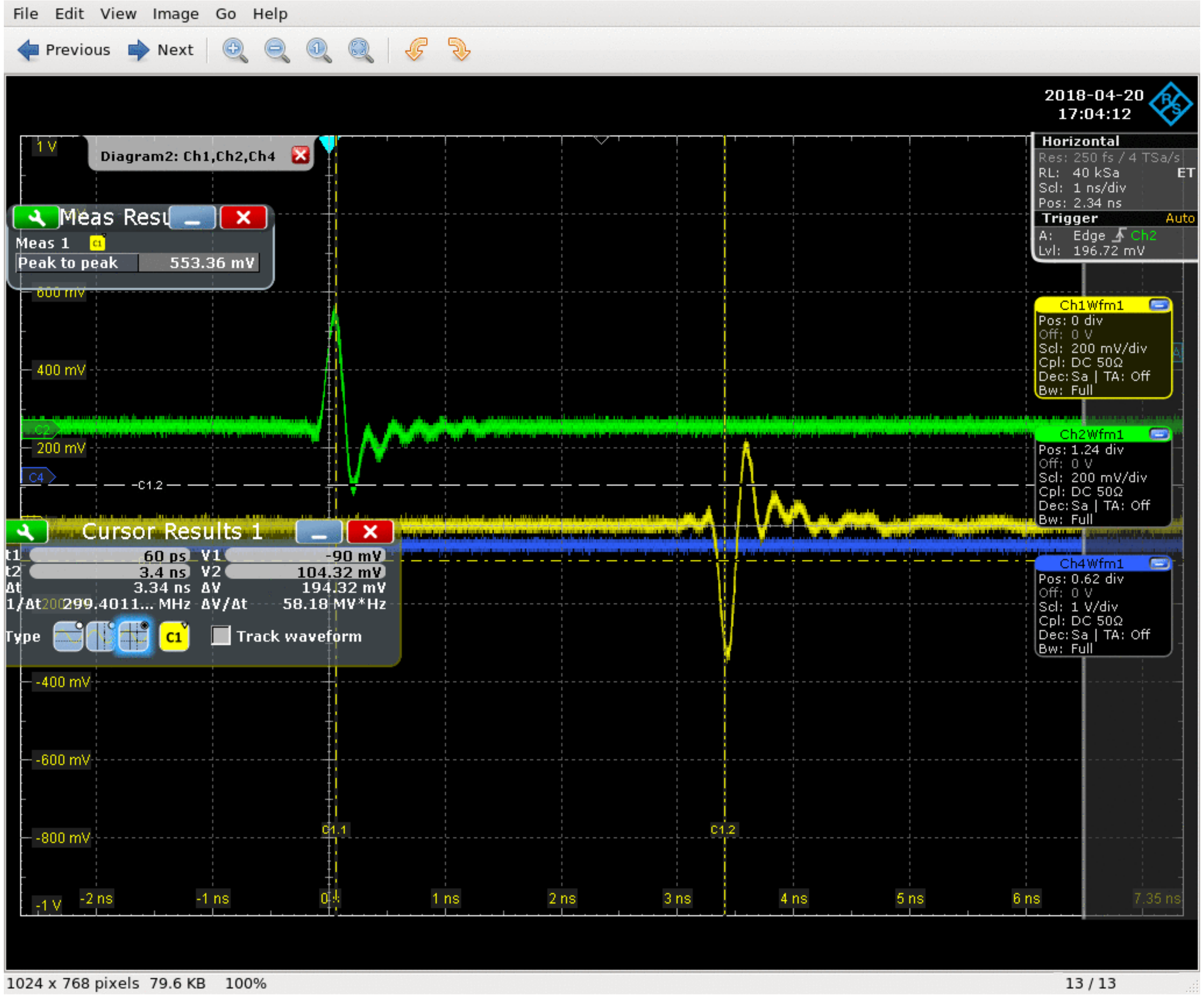
Measurement of Collision Timing



Meas 1 C1
Peak to peak 553.36 mV

t1 60 ps V1 -90 mV
t2 3.4 ns V2 104.32 mV
Δt 3.34 ns ΔV 194.32 mV
1/Δt 299.4011... MHz ΔV/Δt 58.18 MV*Hz

☐ Track waveform

Horizontal
Res: 250 fs / 4 TSa/s
RL: 40 kSa ET
Scl: 1 ns/div
Pos: 2.34 ns

Trigger Auto
A: Edge Ch2
Lvl: 196.72 mV

Ch1Wfm1
Pos: 0 div
Off: 0 V
Scl: 200 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

Ch2Wfm1
Pos: 1.24 div
Off: 0 V
Scl: 200 mV/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

Ch4Wfm1
Pos: 0.62 div
Off: 0 V
Scl: 1 V/div
Cpl: DC 50Ω
Dec: Sa | TA: Off
Bw: Full

The time difference of 3.34 ns was 4.37 ns due to cable length correction.

R-side LER: -1.728 ns / HER: +1.748 ns => 3.476 ns

The real time difference is 4.37 - 3.476 = 0.894 ns (near 180 deg.)