Commissioning of the Phase-1 SuperKEKB B-Factory and Update on the Overall Status

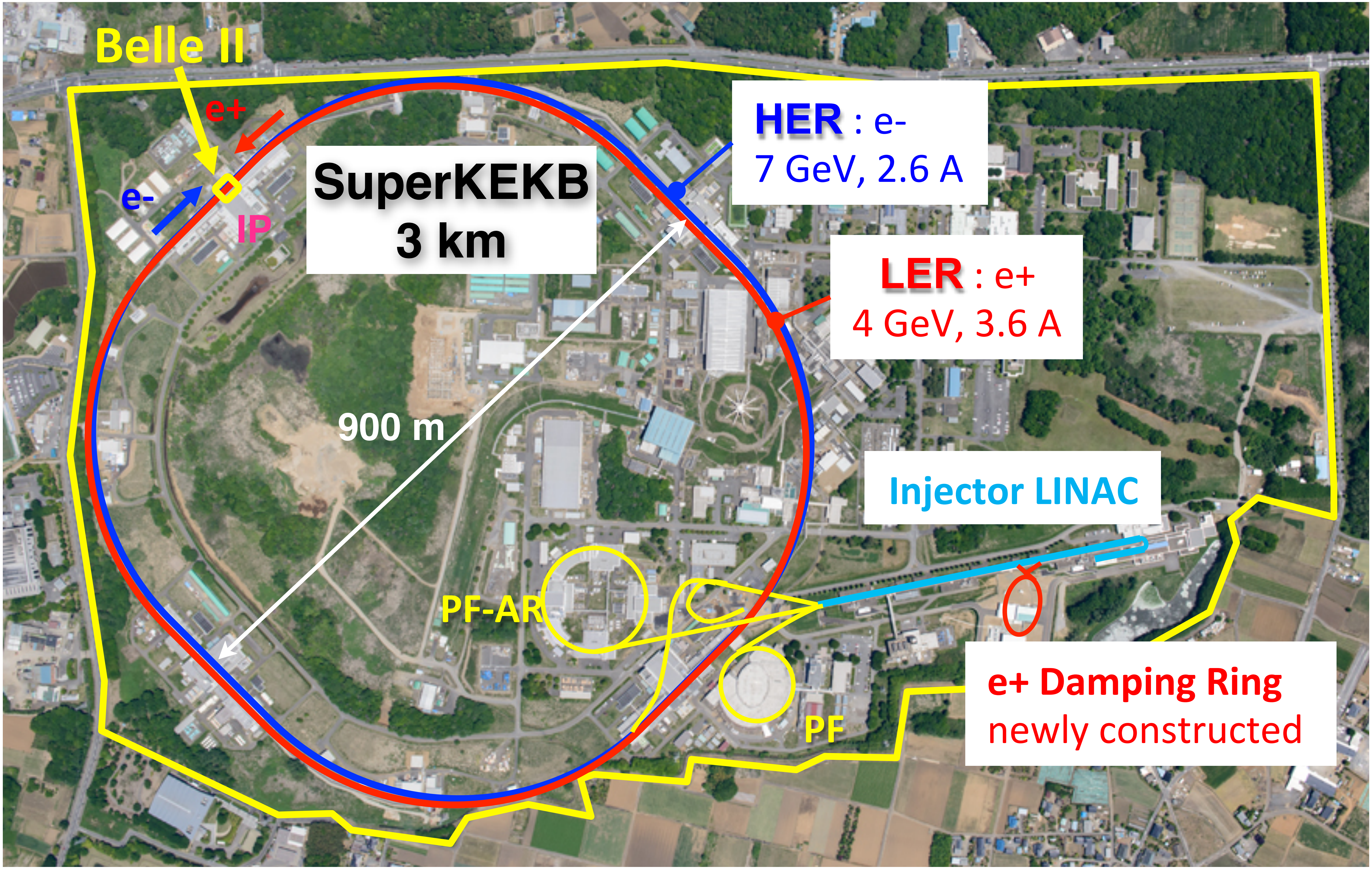
Y. Ohnishi (KEK)

on behalf of SuperKEKB accelerator group

MOB3IO01

SuperKEKB Accelerator

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



The Highest Luminosity Record in the World

KEKB achieved $2x10^{34}$ $cm^{-2}s^{-1}$.

Target of SuperKEKB is $8x10^{35}$ $cm^{-2}s^{-1}$.

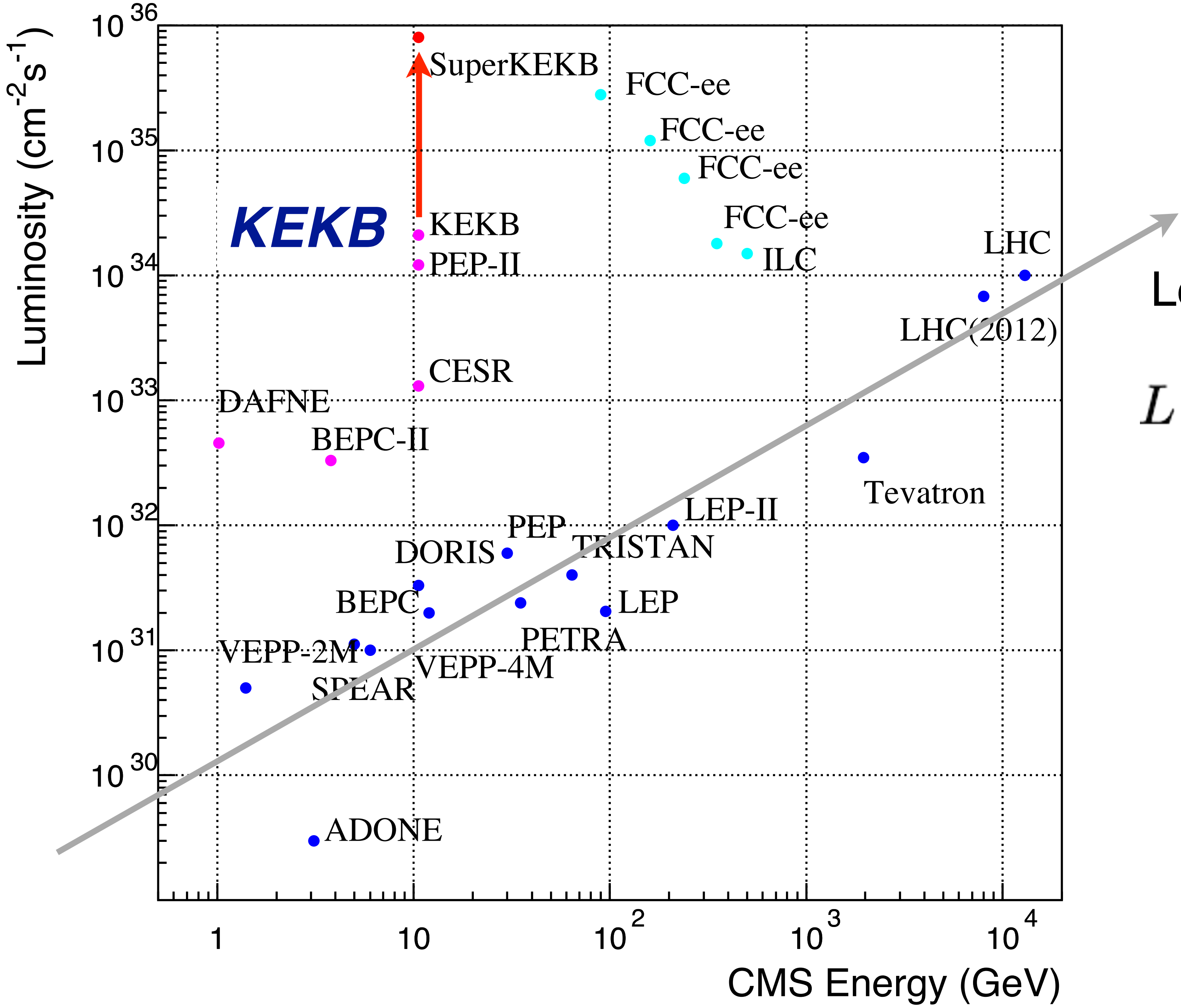
Luminosity VS CMS Energy

Luminosity Frontier

10^{36} cm^{-2}s^{-1}

Factory machine

SuperKEKB



High energy machine

Lorentz factor

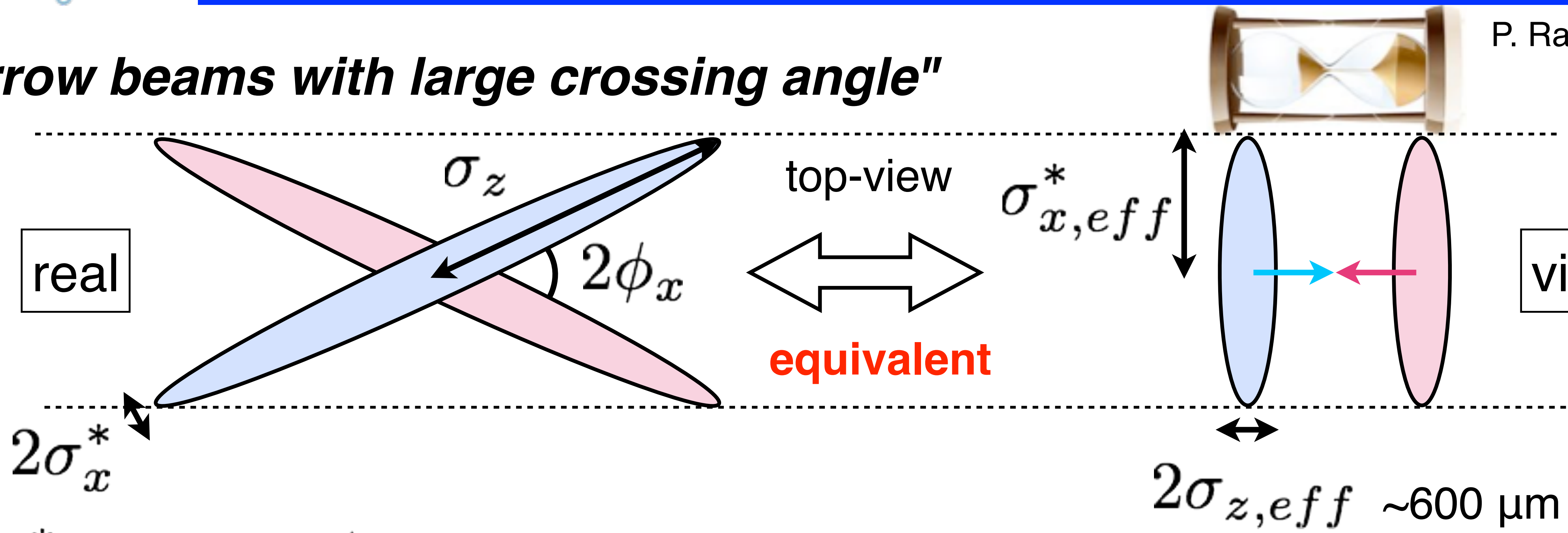
$$L = \frac{\gamma}{2er_e}\frac{I\xi_y}{\beta_y^*}$$

Energy Frontier

Nano-Beam Scheme

P. Raimondi et al.

"Narrow beams with large crossing angle"



$$\sigma^*_{x,eff} = \sigma_z \phi_x \longleftarrow$$ x and z can be exchanged.

$$\sigma_{z,eff} = \frac{\sigma^*_x}{\phi_x} < \beta^*_y$$

"***Extremely short bunch"*** is indispensable.
The small horizontal beam-size makes it possible.

$$L = \frac{N_+ N_- f}{4\pi \sigma^*_x \sigma^*_y} = \frac{N_+ N_- f}{4\pi \sigma_z \phi_x \sqrt{\varepsilon_y \beta^*_y}}$$

If we can make both ε_y and β_y^* small with keeping their ratio constant, the luminosity can be boosted.

Vertical emittance(ε_y) is one of keys.

$$\xi_y \propto \frac{1}{\sigma_z \phi_x} \sqrt{\frac{\beta^*_y}{\varepsilon_y}}$$

Beam-beam parameter has an upper limit.

Strategy of Luminosity Upgrade

Alternative luminosity formula: $L \propto \frac{\xi_y \cdot I}{\beta_y^*}$ $\sigma_y^* = \sqrt{\varepsilon_y \beta_y^*}$

	KEKB		SuperKEKB		Luminosity gain
	LER	HER	LER	HER	
ξ_y	0.129	0.09	0.088	0.081	x 1
β_y^* [mm]	5.9	5.9	0.27	0.30	x 20
I [A]	1.64	1.19	3.6	2.6	x 2
σ_y^* [nm]	940	940	48	62	nano beam !
ε_y [pm]	150	150	8.5	12.8	Low emittance
L [cm^{-2}s^{-1}]	2.1×10^{34}		8×10^{35}		x 40

***Phase-1**: February 1st, 2016 - June 28th, 2016.* ✓

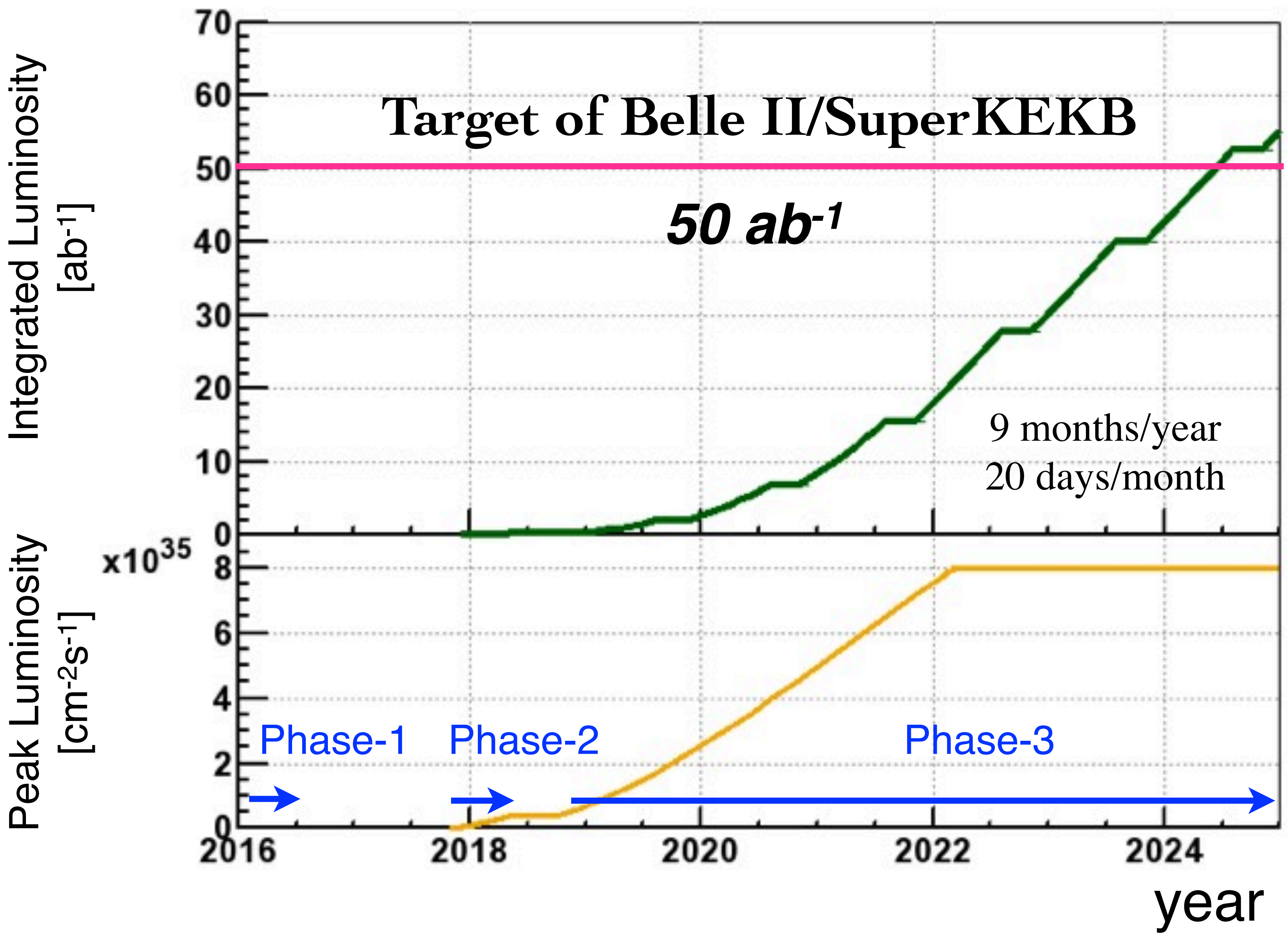
No final focus system, vacuum scrubbing, low emittance tuning

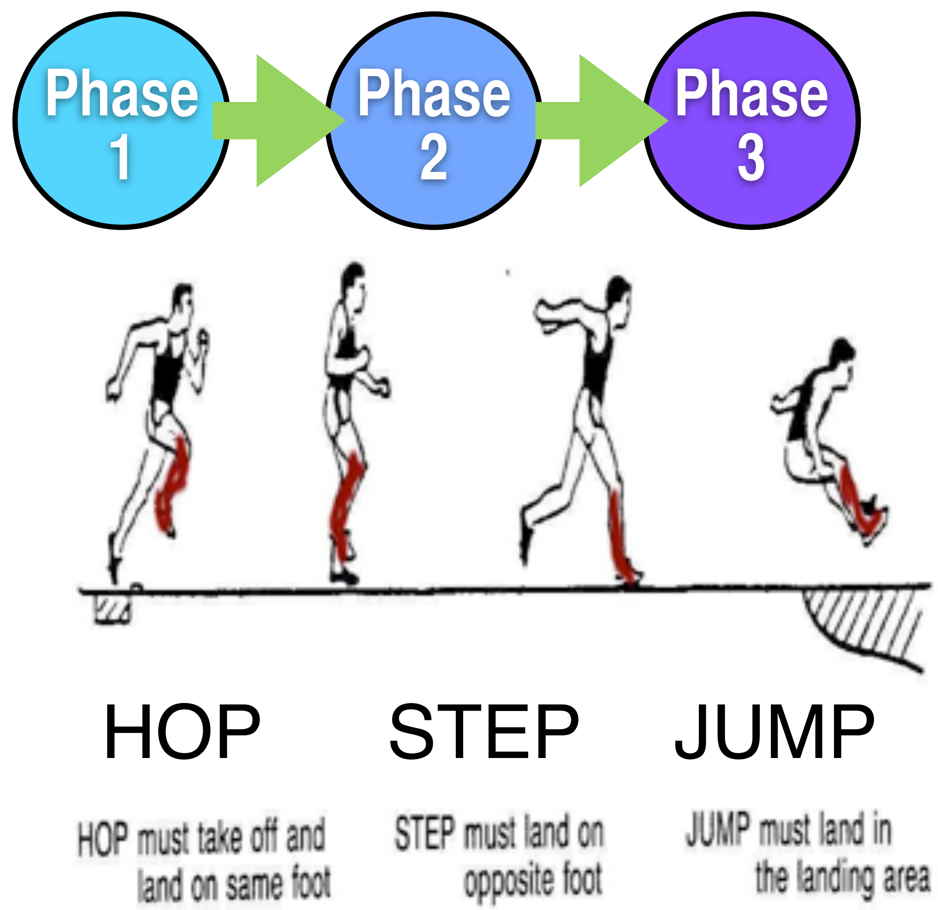
***Phase-2**: Late 2017 - June 2018*

Final focus system, Belle II without vertex detector, the first collision

***Phase-3**: October 2018 -*

Physics run **with full detector**, squeezing beta and increasing currents





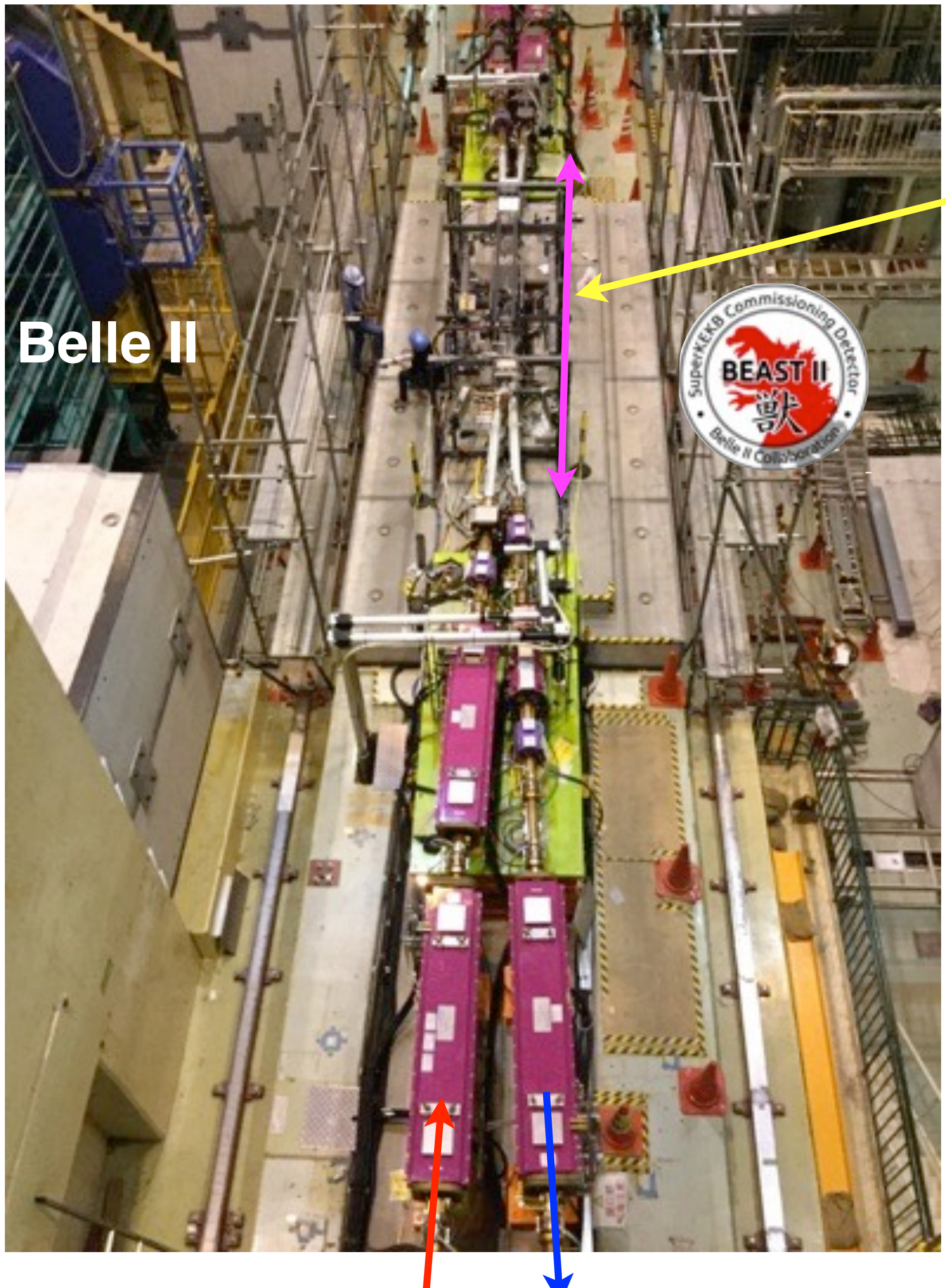
Five Big Issues (FBI)

Issues in the initial commissioning (Phase-1)

1. **Beta Functions at IP ($\beta_{x,y}^*$)**
   - Final Focus system (FF) to squeeze beams at the IP
2. **Vertical Emittance (ε_y)**
   - How to reduce machine error ?
3. **Collective Effects and Lattice Nonlinearity**
   - Beam-Beam, **Electron-Cloud**, nonlinear magnetic fields of FF
4. **Beam Lifetime and Detector Background**
   - **Touschek effect, Beam-gas scattering(vacuum pressure), Movable Collimators**
5. **Beam Energy**
   - Υ(1S) to Υ(6S)

Phase-I

"Interaction Region"



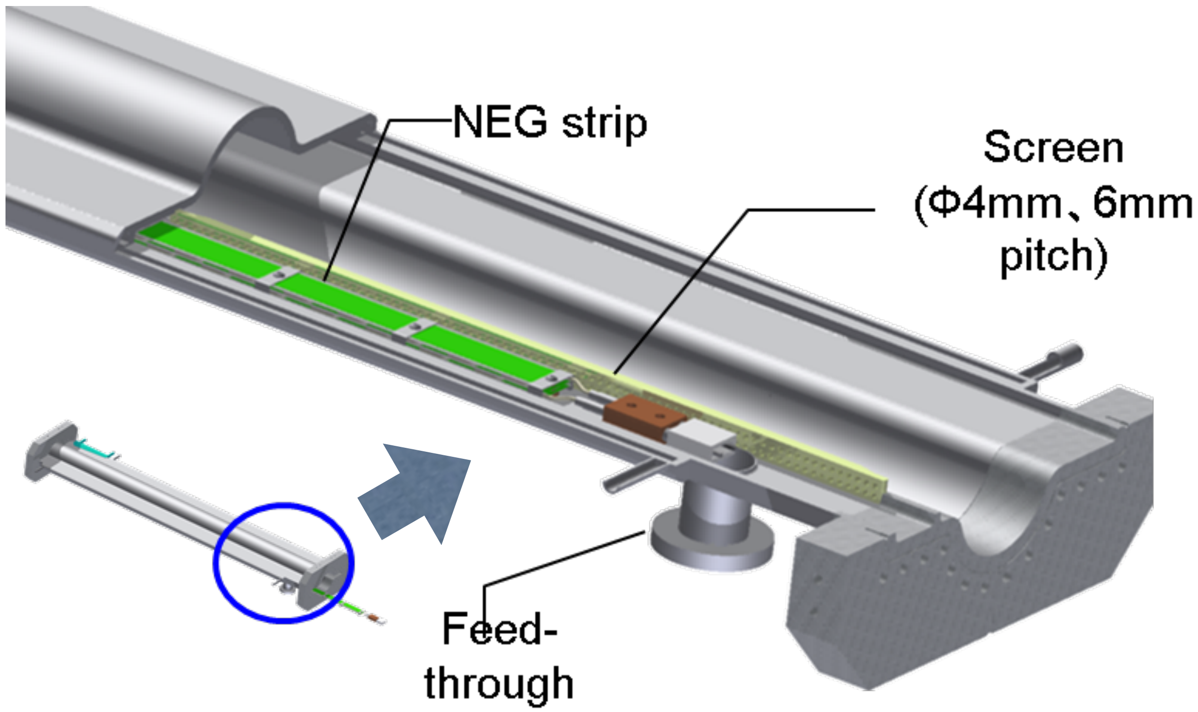
LER (e+) HER (e-)

crossing angle: 83 mrad

No Final Focus system,
BEAST detector to study backgrounds (outside of the region, the same magnet configuration as the Phase-2.)

- **Vacuum scrubbing**
  - new ante-chambers
  - to reduce detector background in Phase-2
- **Check of apparatus & software**
  - RF system and Vacuum system
  - magnet control and beam monitors
- **Low emittance tuning**
  - vertical emittance, reduction of machine error

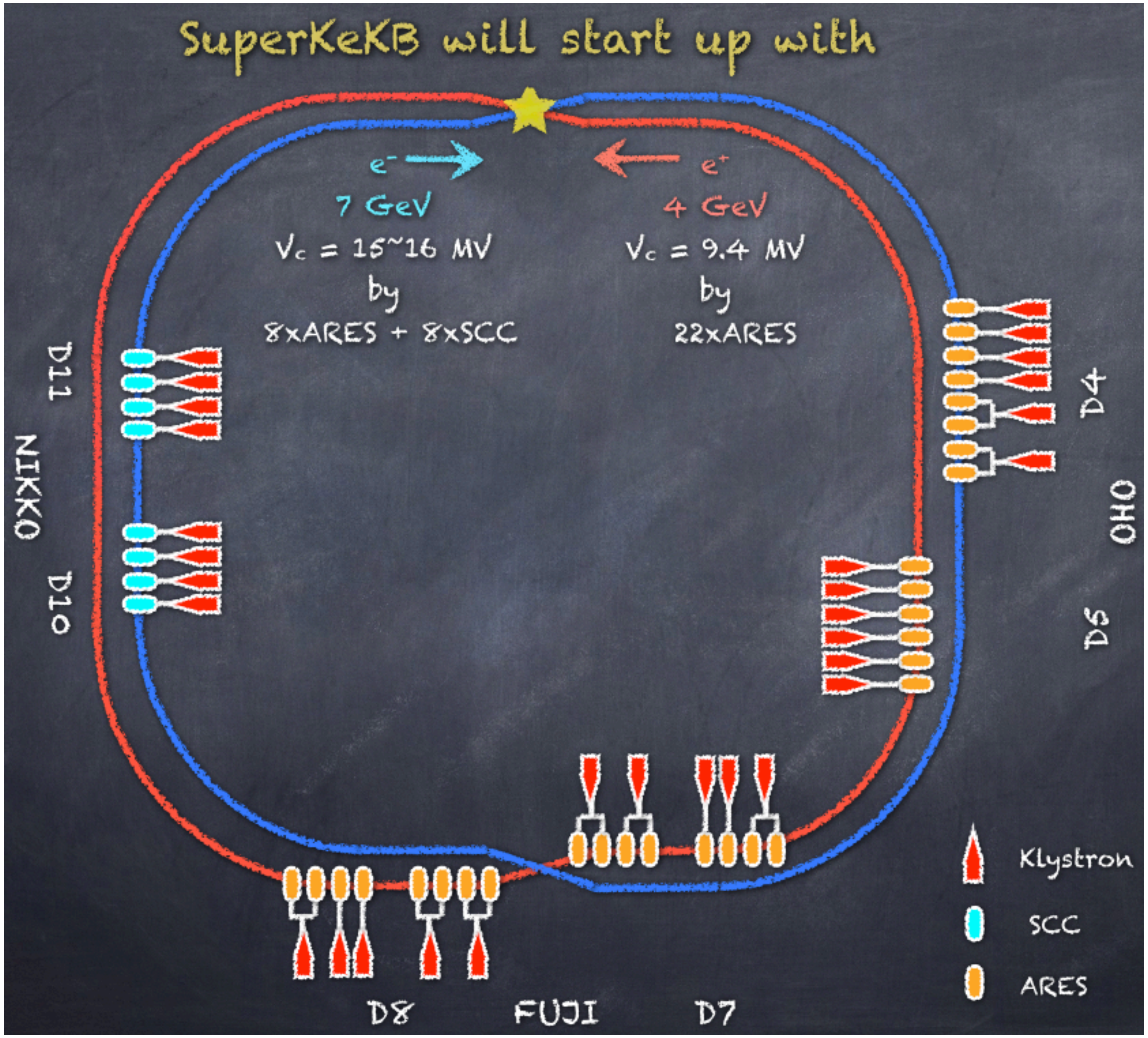
Vacuum Pipe in LER



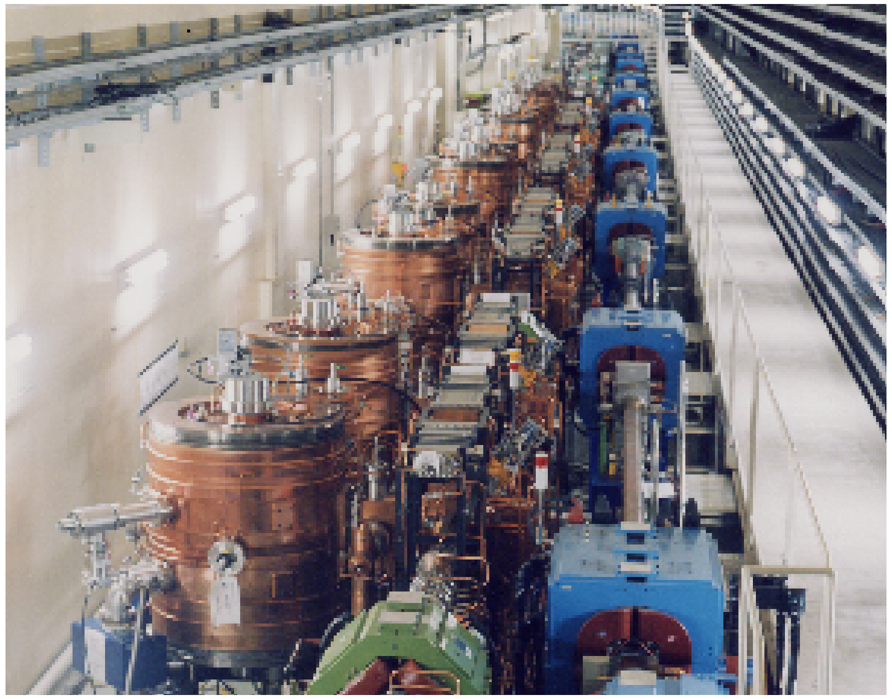
- New ante-chamber with TiN coating in the arc section
- Aluminum-alloy
- Absorb intense synchrotron radiation
- Ante-chamber+TiN coating suppress electron cloud effects.
- Bellows chamber made of aluminum-alloy without TiN coating (~800)

RF system has been operated without serious trouble.

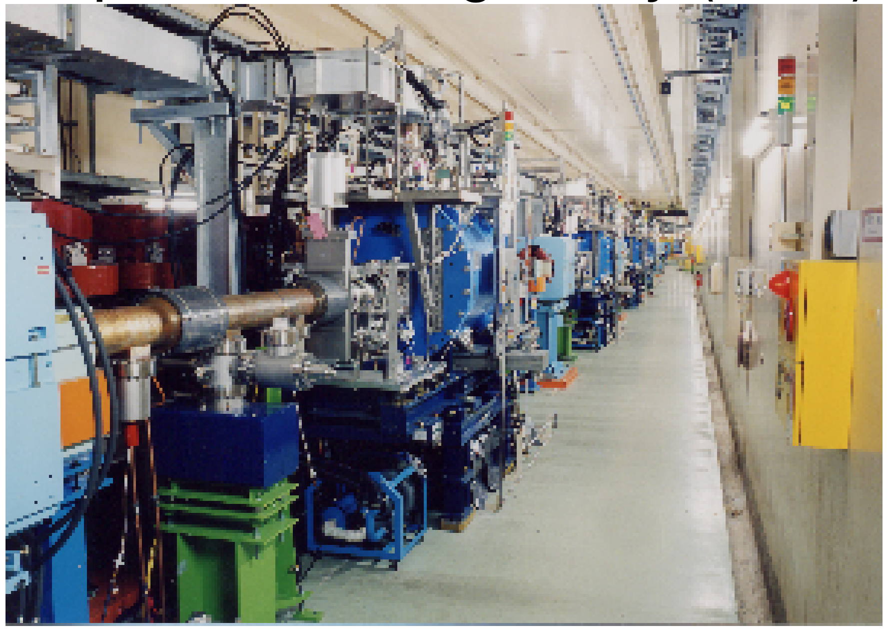
Total Vc: 8 MV in LER / 12.5 MV in HER at Phase-1



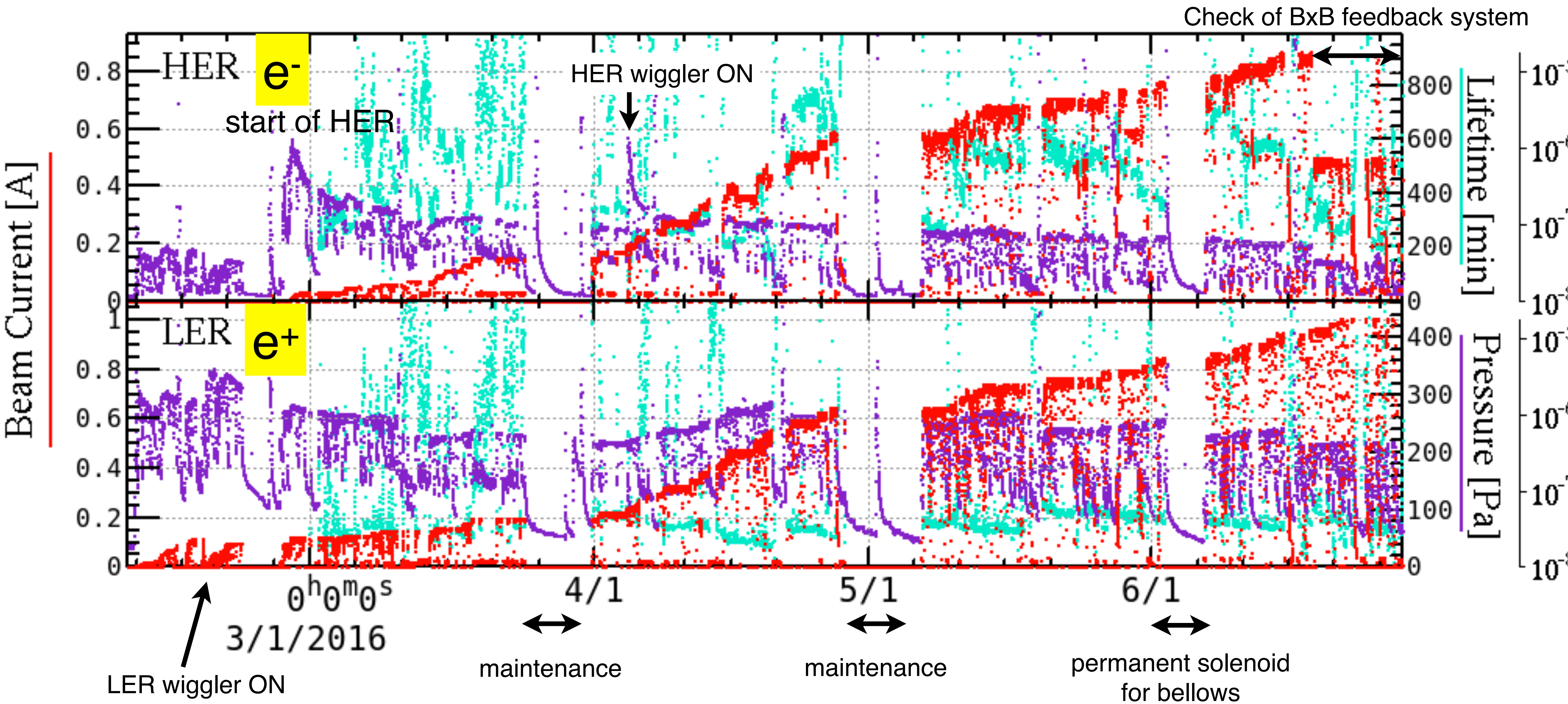
Normal conducting cavity (ARES)



Superconducting cavity (SCC)



Phase-I Commissioning

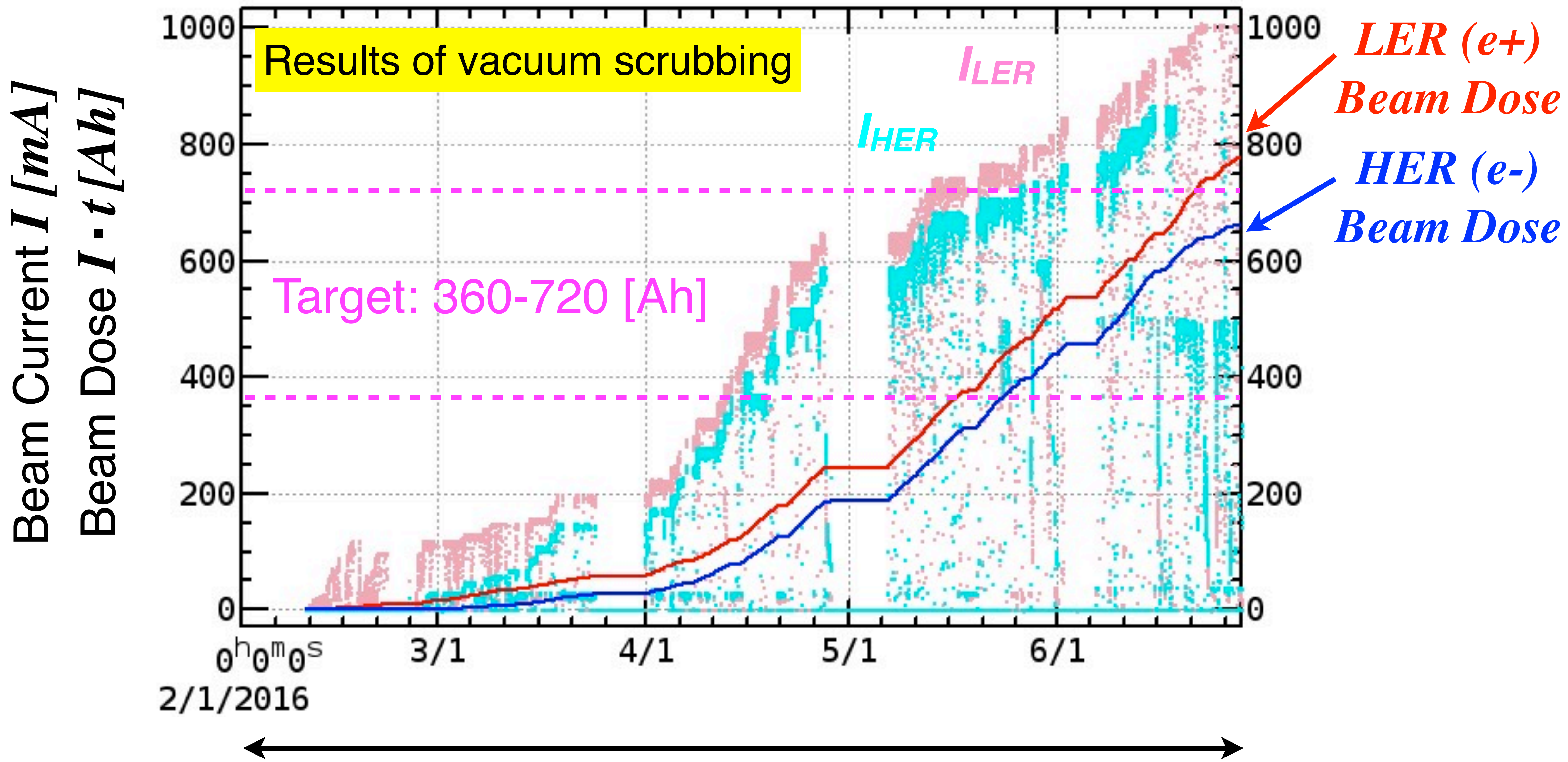


- Total beam current of 1.01 [A] in LER, 0.87 [A] in HER.
- Check of hardwares such as RF, vacuum system, beam instrumentation, etc.
- 5 months operation

Vacuum Scrubbing

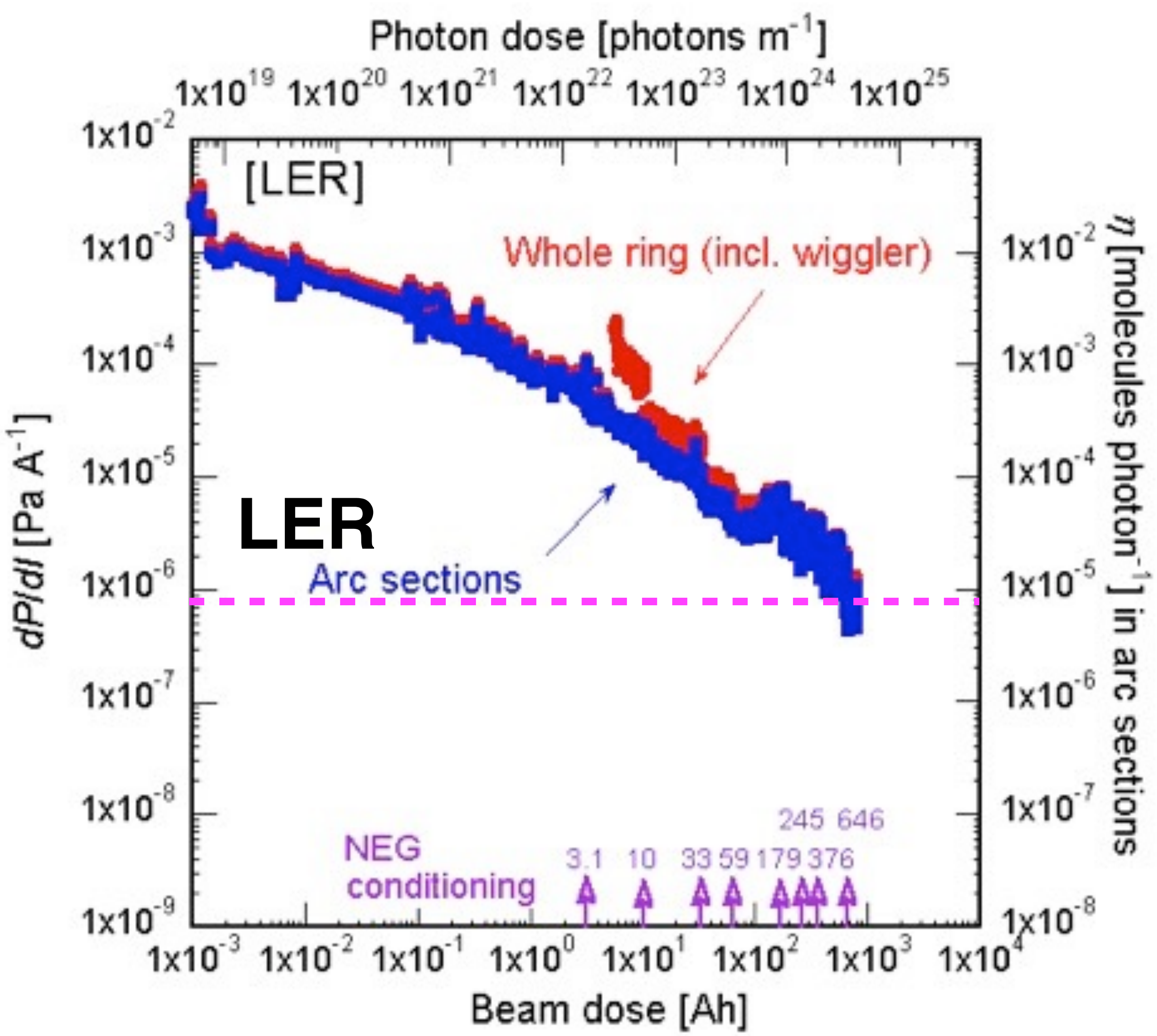
Beam current of 1 [A] and **Beam dose of 780 [Ah]** were achieved in LER.
Ave. pressure: ~10^{-6} [Pa]

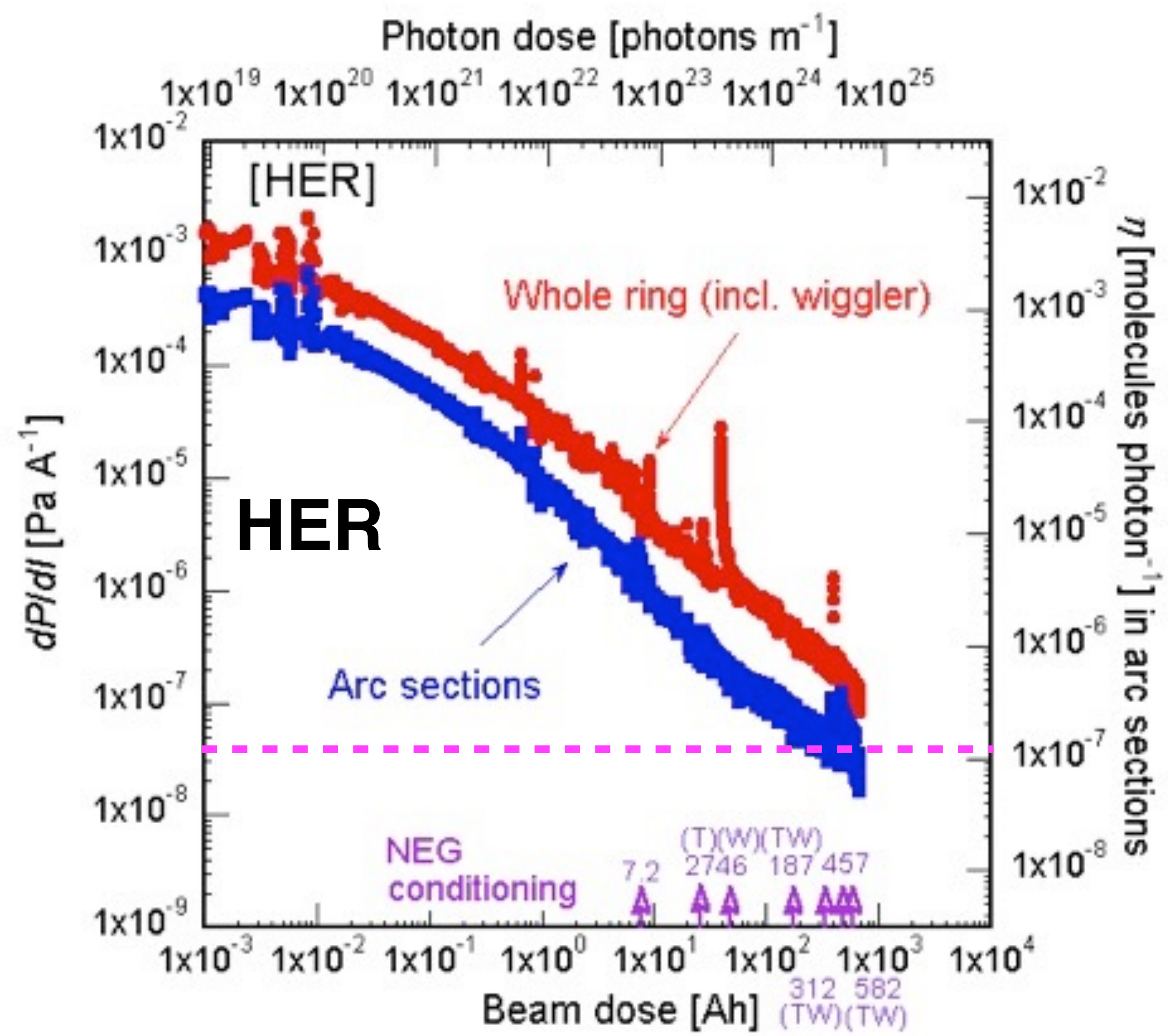
Beam current of 0.87 [A] and **Beam dose of 660 [Ah]** were achieved in HER.
Ave. pressure: ~10^{-7} [Pa]



5 months operation

Vacuum Scrubbing





Pressure rise becomes $8x10^{-7}$ PaA^{-1}.

Gas desorption rate becomes $9x10^{-6}$ molecules photon^{-1}. (0.06 m^{3}s^{-1}m^{-1})

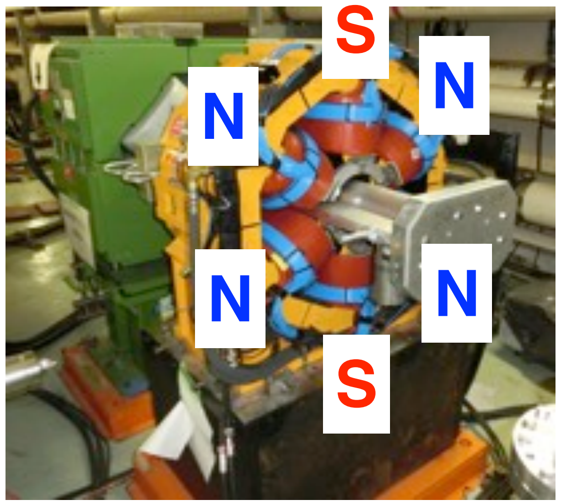
Pressure rise becomes $4x10^{-8}$ PaA^{-1}.

Gas desorption rate becomes ~$1x10^{-7}$ molecules photon^{-1}. (0.03 m^{3}s^{-1}m^{-1})

Optics Tuning

Beta Functions, Horizontal and Vertical Dispersions, and X-Y Couplings for Low Emittance Tuning

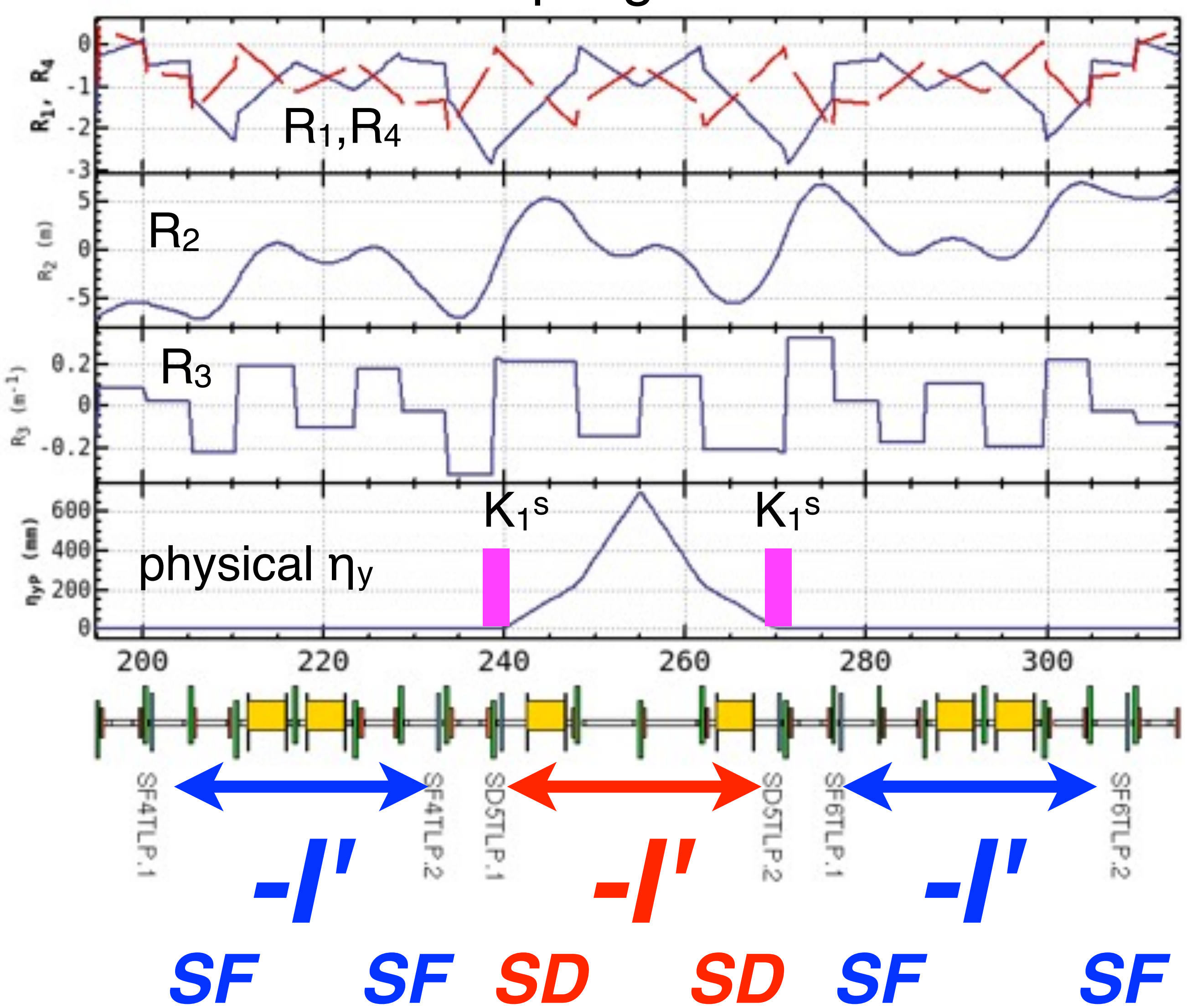
Corrector: X-Y Coupling and Vertical Dispersion



Skew Q-like corrector coils are installed for each sextupole (SD).

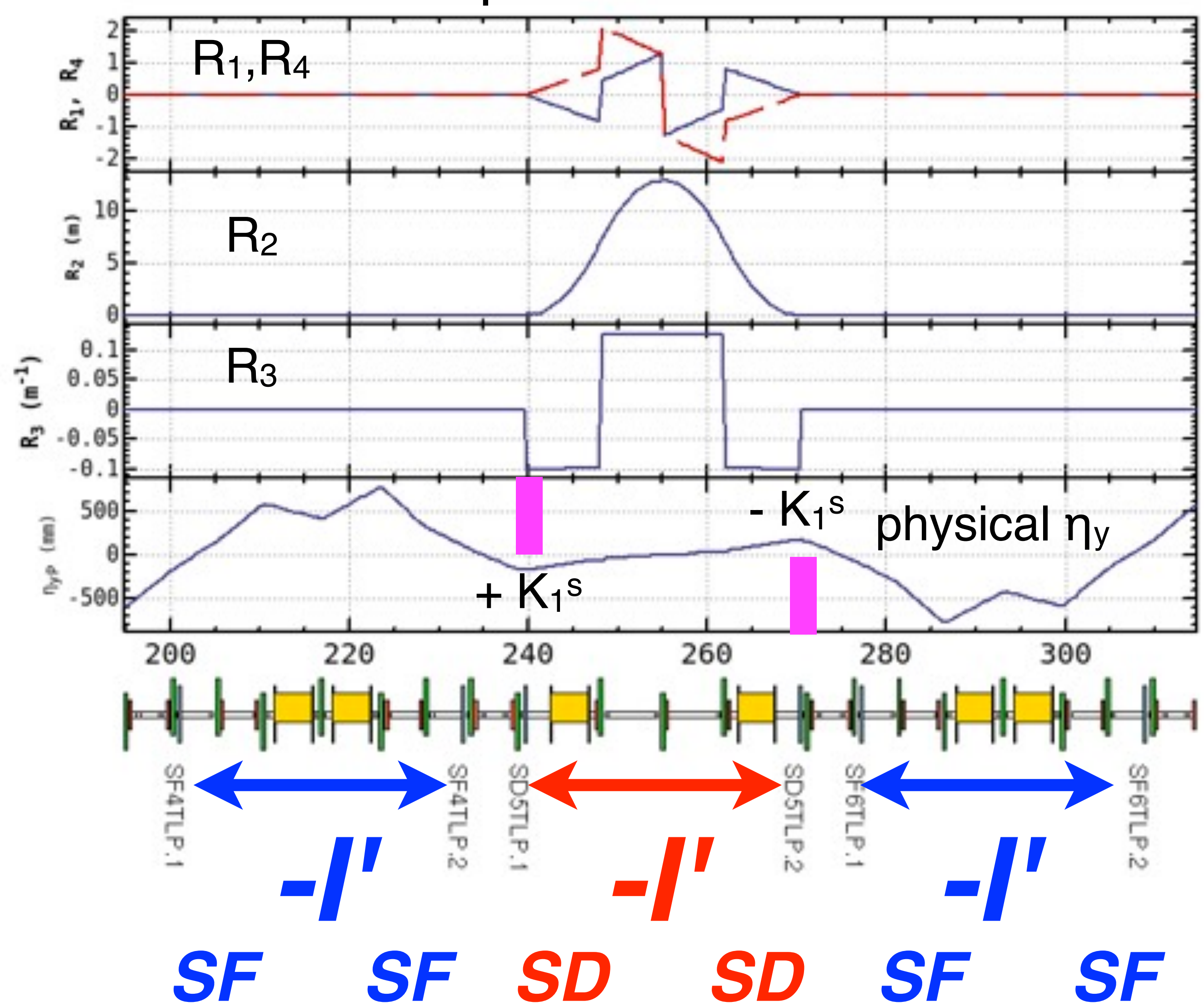
Skew Q generates X-Y couplings.
X-Y couplings can be corrected independent of physical vertical dispersion (vice versa).

X-Y coupling corrector



same sign of K_1

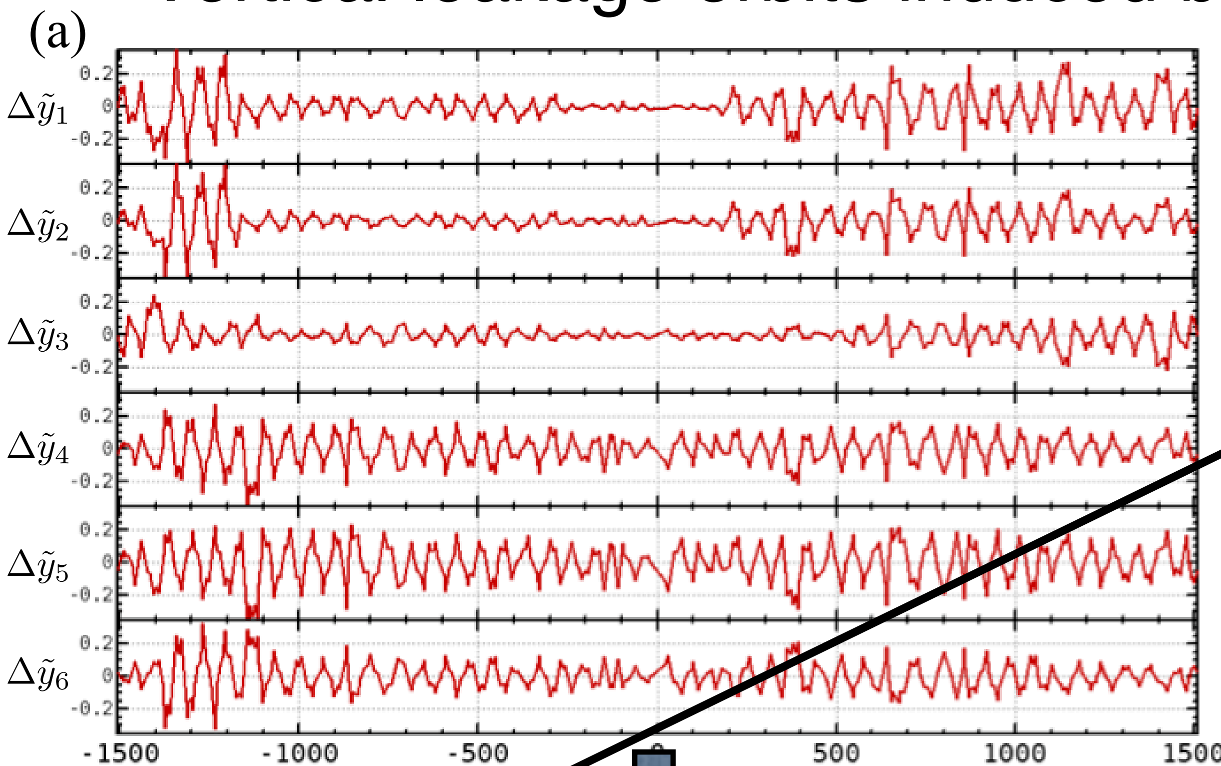
Dispersion corrector



opposite sign of K_1

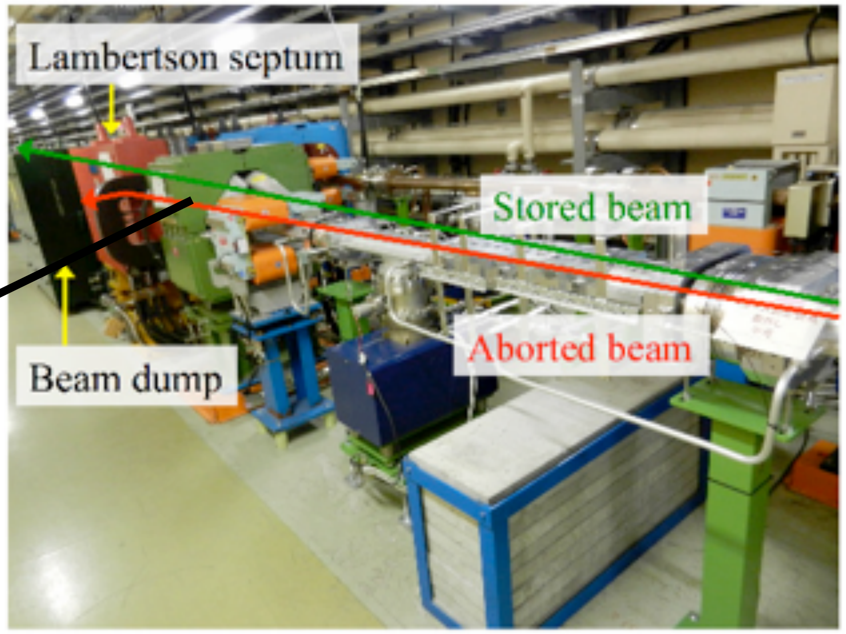
Correction of X-Y Couplings in LER

Vertical leakage orbits induced by 6 kinds of horizontal dipole correctors.

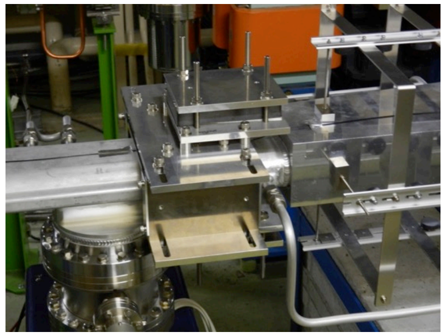


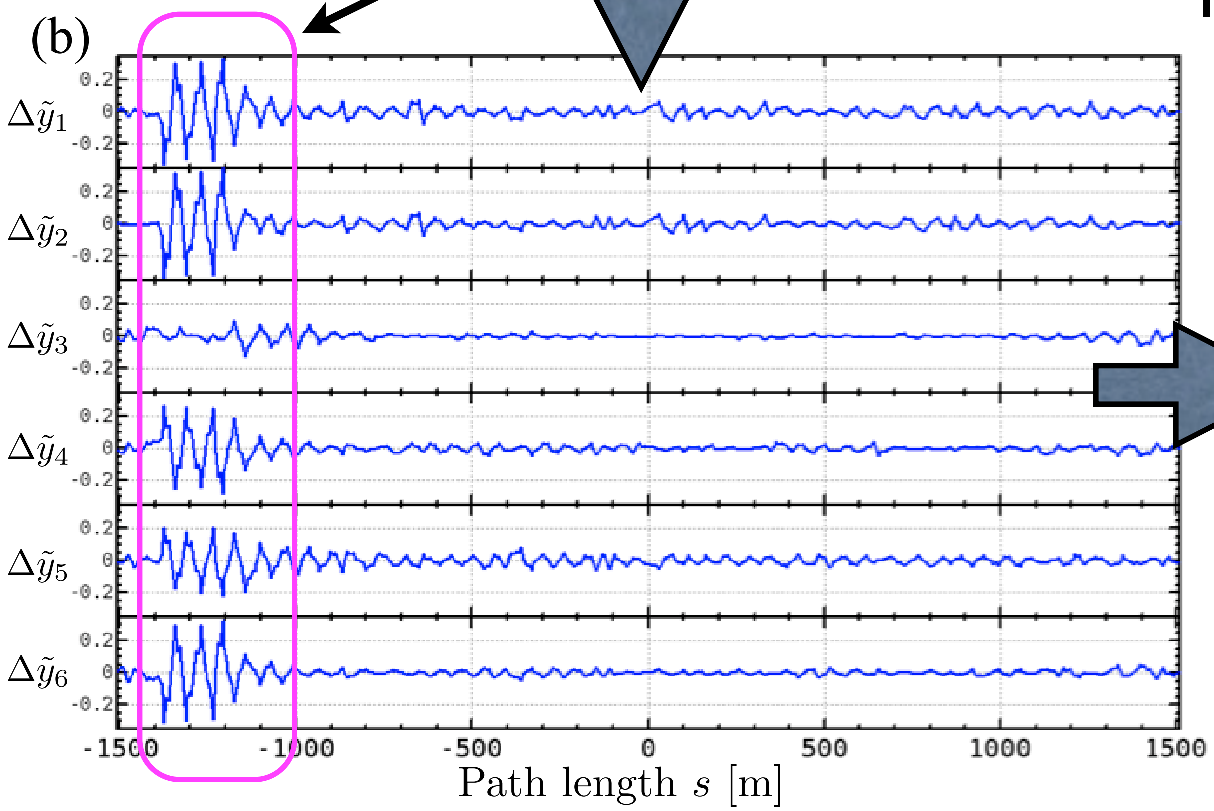
s [m]

Lambertson leakage field generates X-Y couplings

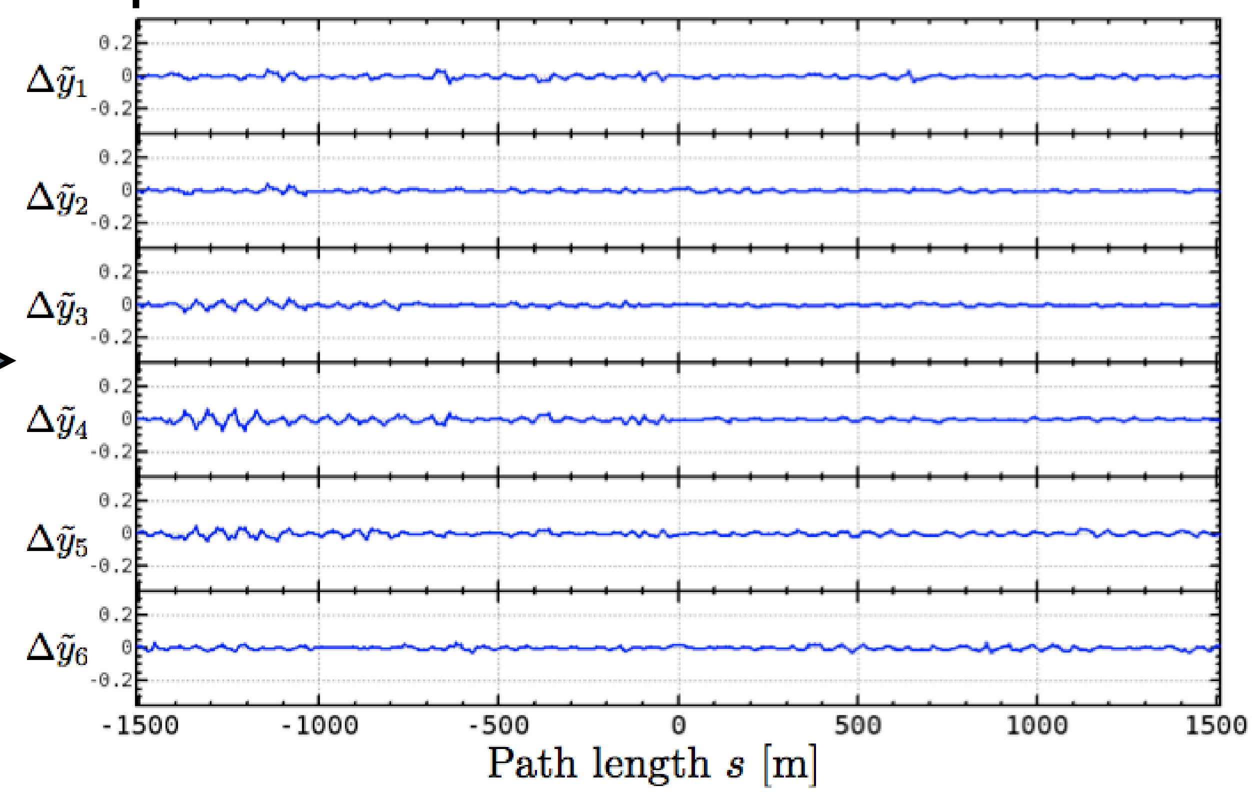


H. Sugimoto
N. Iida et al.





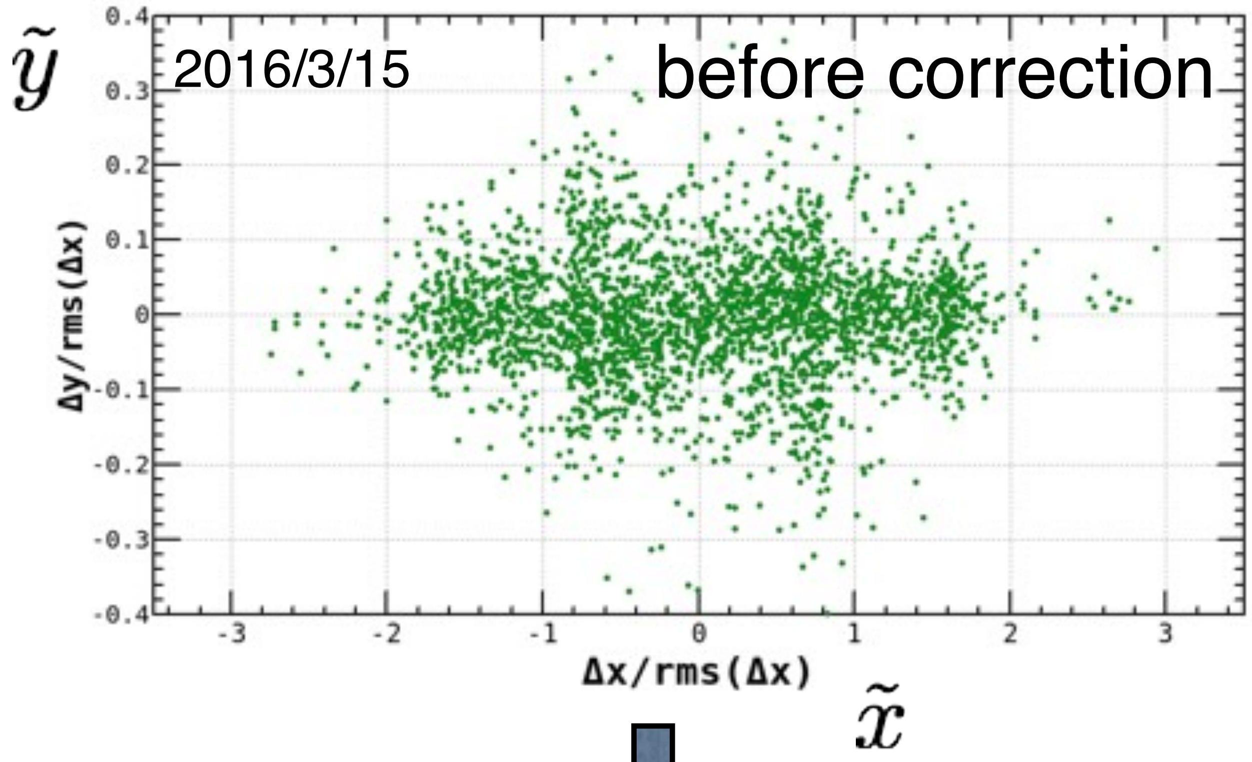
Install permanent skew Q @ Lambertson

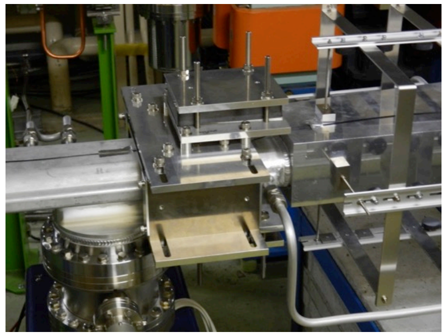


Residual X-Y coupling can be corrected.

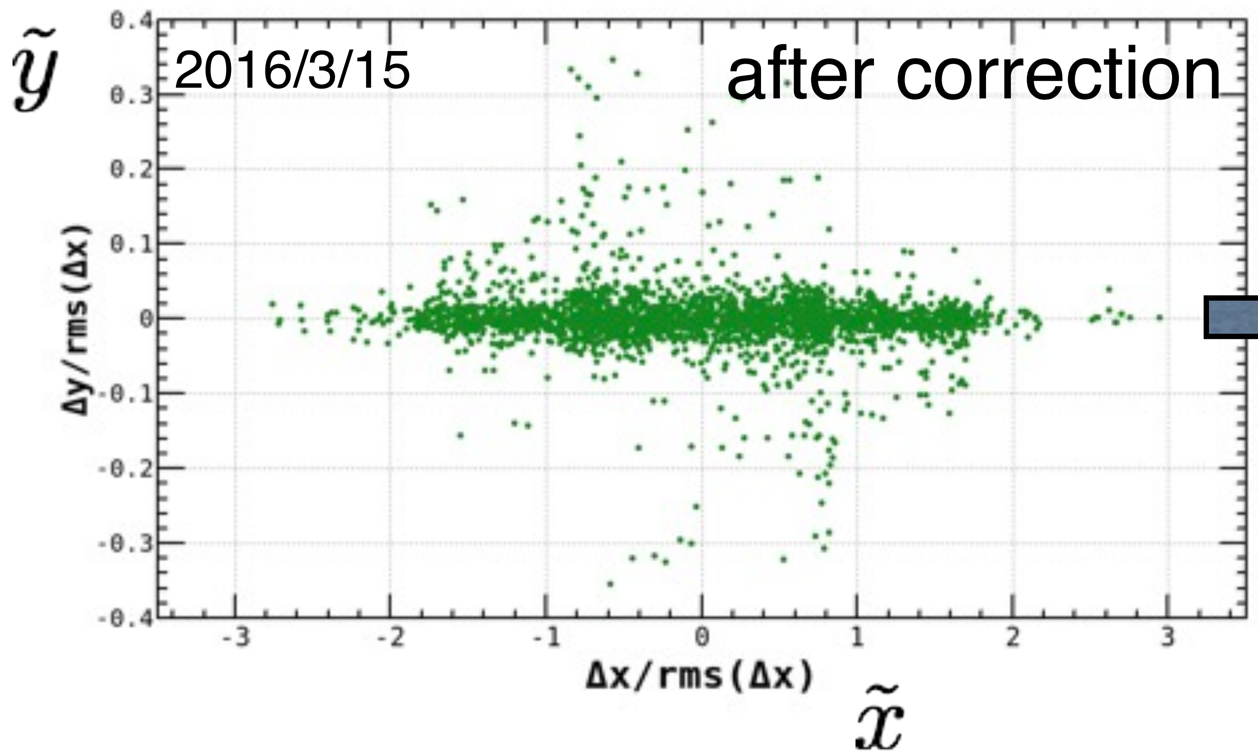
Correction of X-Y Couplings in LER

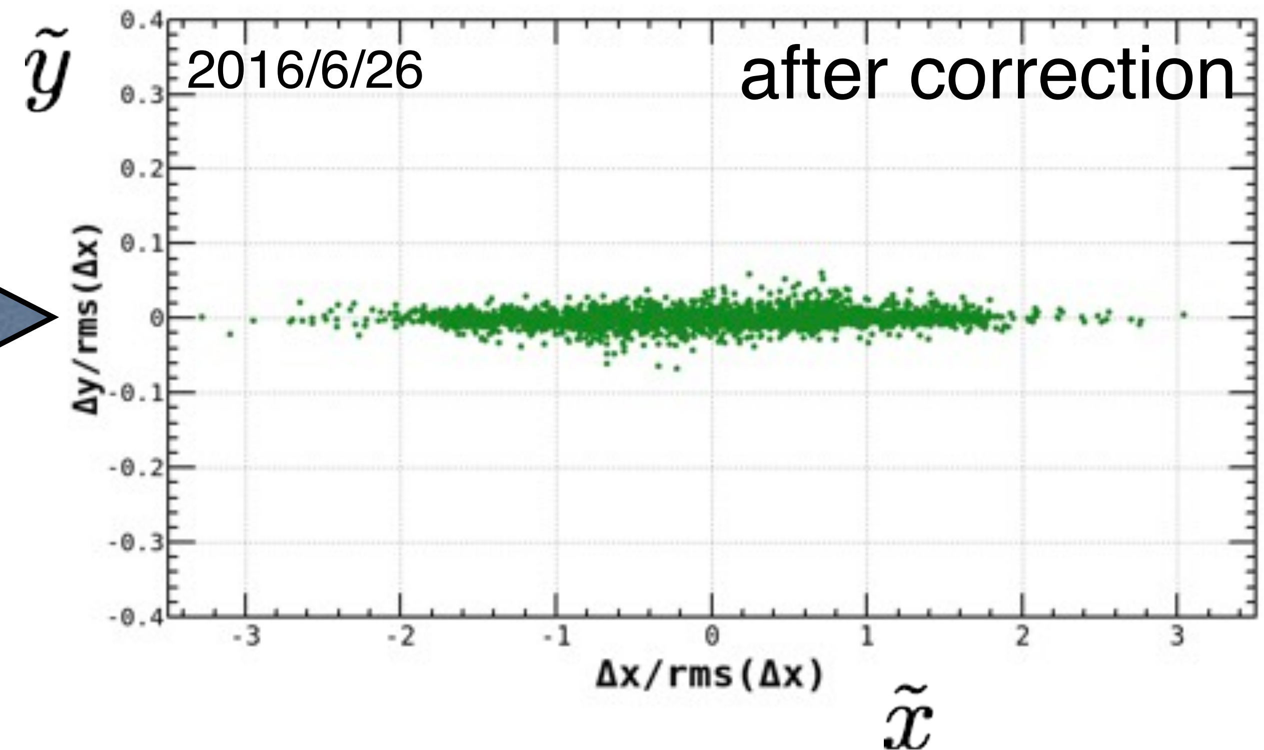
$$\tilde{x} = \frac{\Delta x_i}{rms(\Delta x_i)} \qquad \tilde{y} = \frac{\Delta y_i}{rms(\Delta x_i)}$$





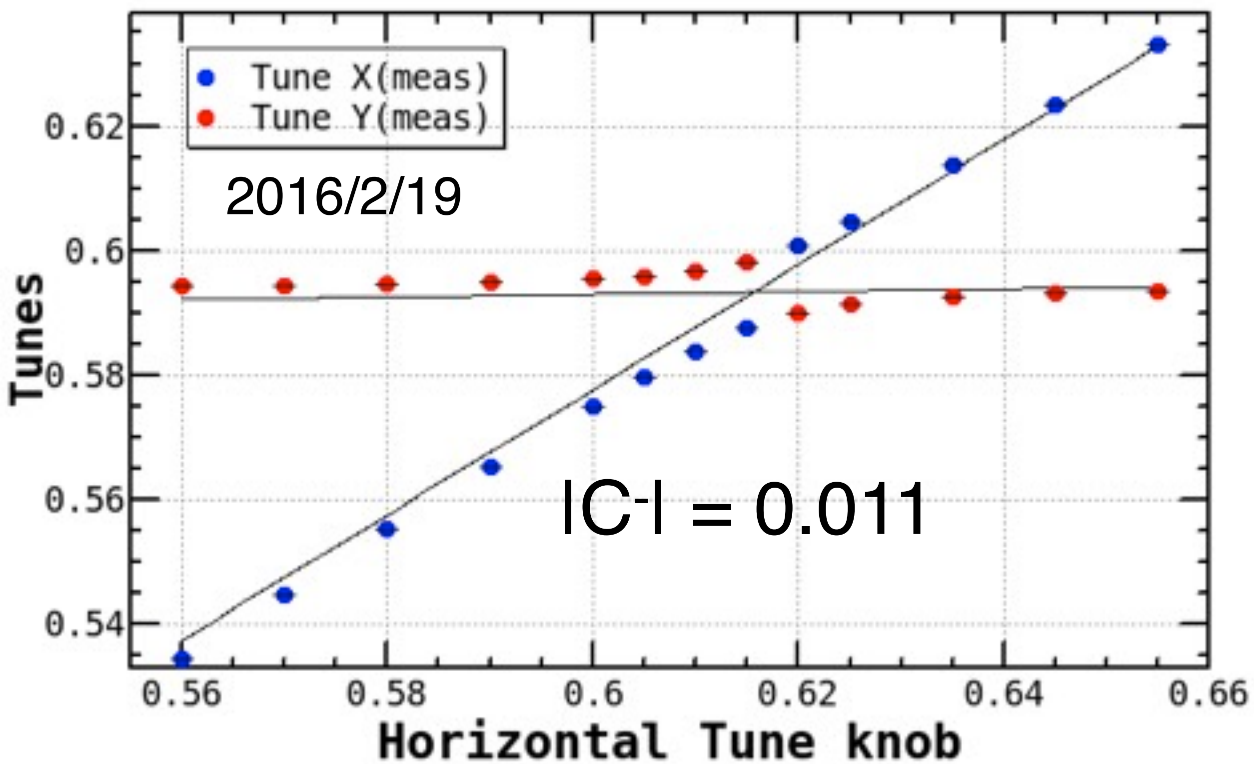
Install permanent skew Q
@ Lambertson

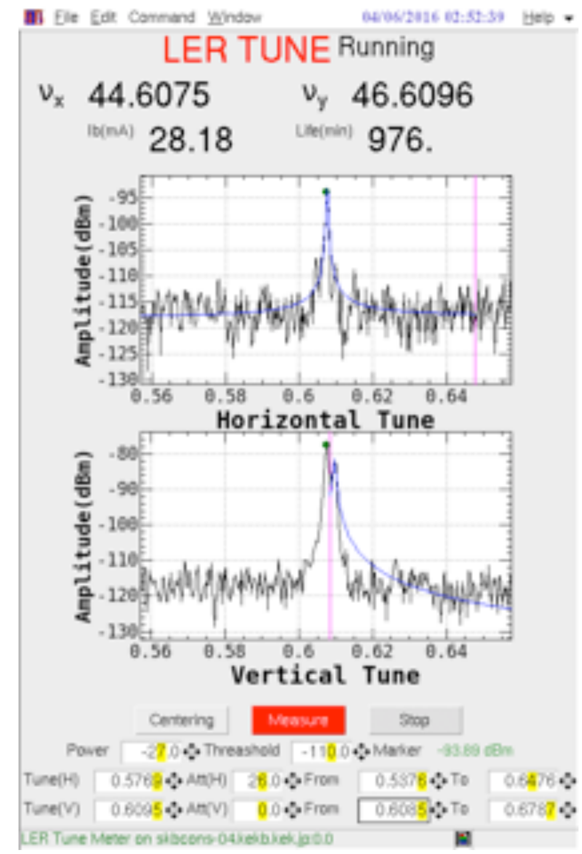




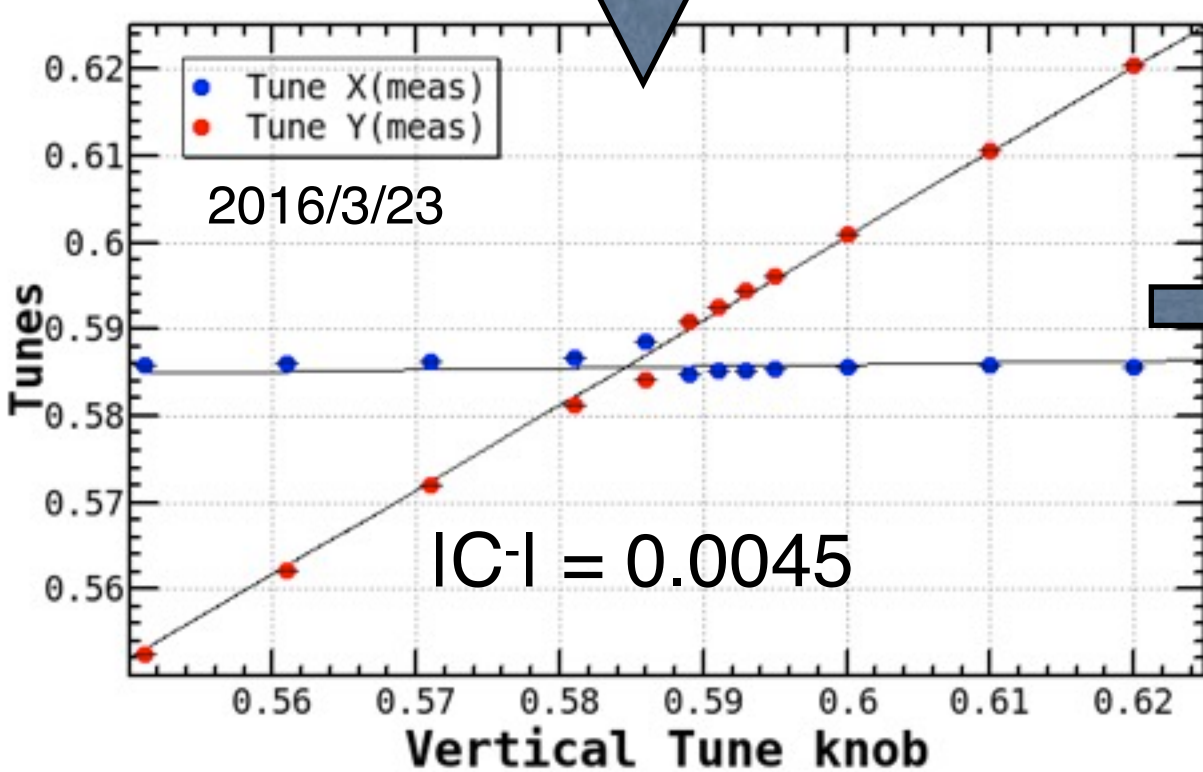
Closest Tune Approach in LER

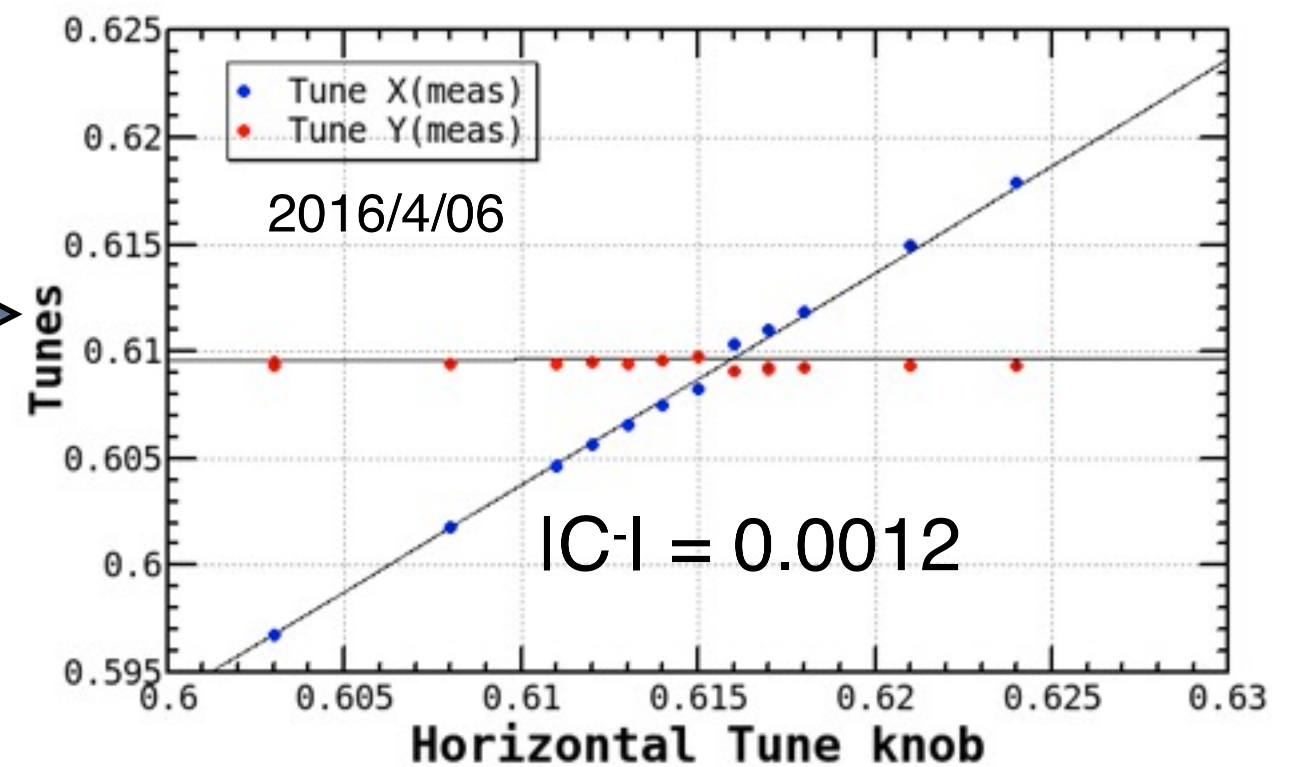
Coupling strength is improved as the X-Y coupling is getting smaller.





$$\frac{|C^-|^2}{2\Delta^2 + |C^-|^2} = 0.00045$$



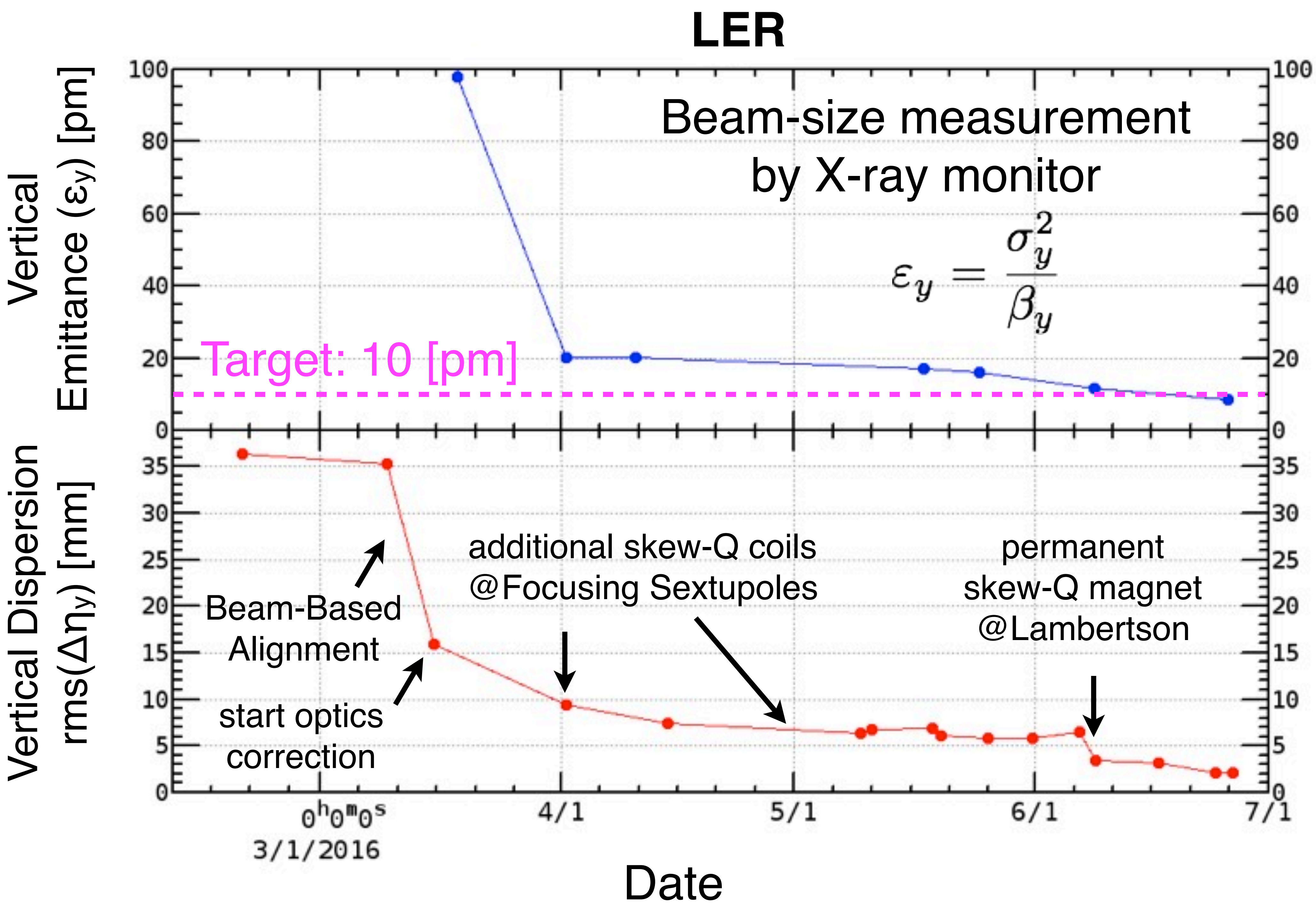


Results of Optics Tuning in Phase-I

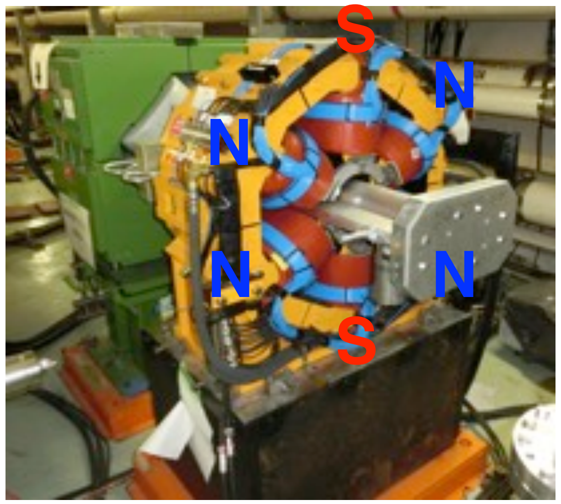
Items	Symbol	LER	HER
Coupling strength	$\|C\|$	1.2×10^{-3}	2×10^{-3}
X-Y Coupling	$rms(\Delta y)/rms(\Delta x)$	0.9%	0.6%
Horizontal Dispersion	$rms(\Delta\eta_x)$	8 mm	11 mm
Vertical Dispersion	$rms(\Delta\eta_y)$	2 mm	2 mm
Horizontal Beta Beat	$rms(\Delta\beta_x/\beta_x)$	3%	3%
Vertical Beta Beat	$rms(\Delta\beta_y/\beta_y)$	3%	3%
Horizontal Tune	$\Delta\nu_x$	2×10^{-4}	5×10^{-4}
Vertical Tune	$\Delta\nu_y$	5×10^{-4}	1×10^{-4}

Low Emittance Tuning: Reduce Machine Error

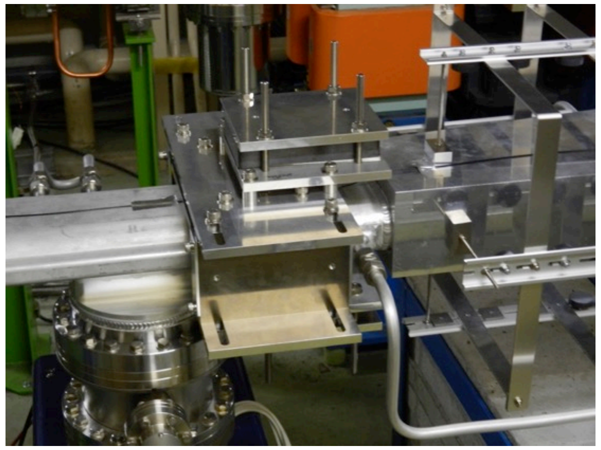
Optics corrections have been worked successfully.
Vertical emittance of 9 [pm] has been achieved in LER.



skew-Q corrector coil (cyan) @ sextupole



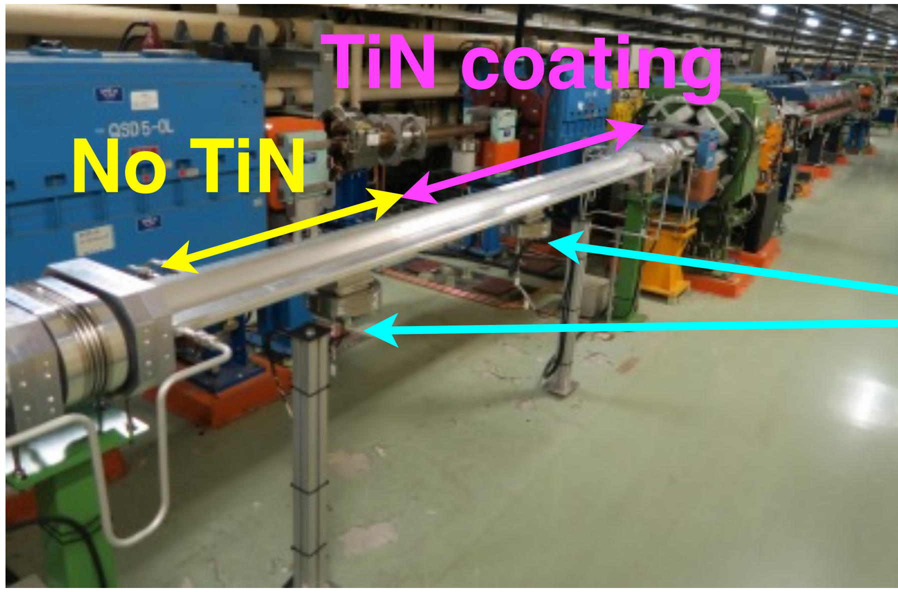
permanent skew-Q to correct error field @Lambertson



Electron Cloud

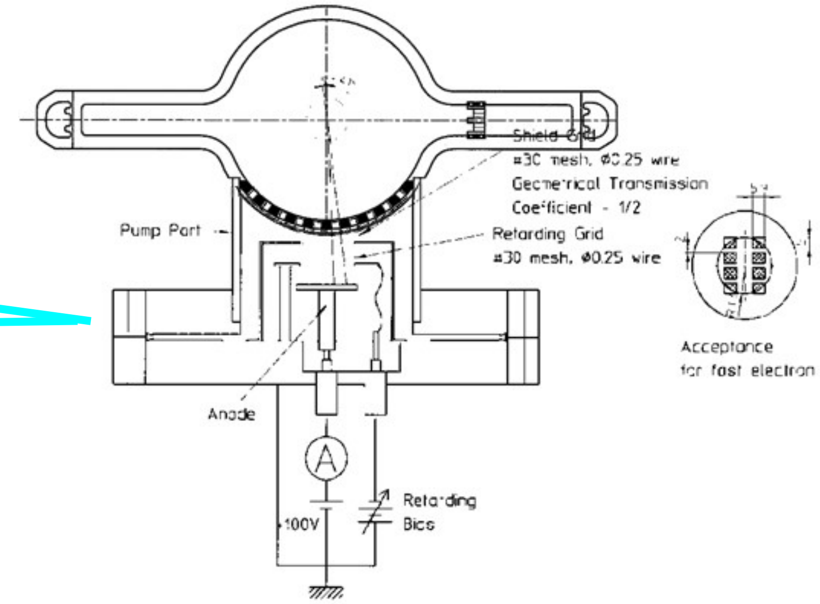
Electron Cloud

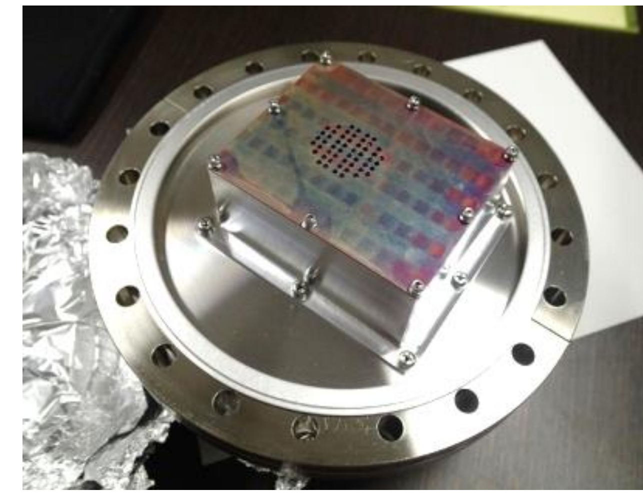
Ante-chamber (Al)

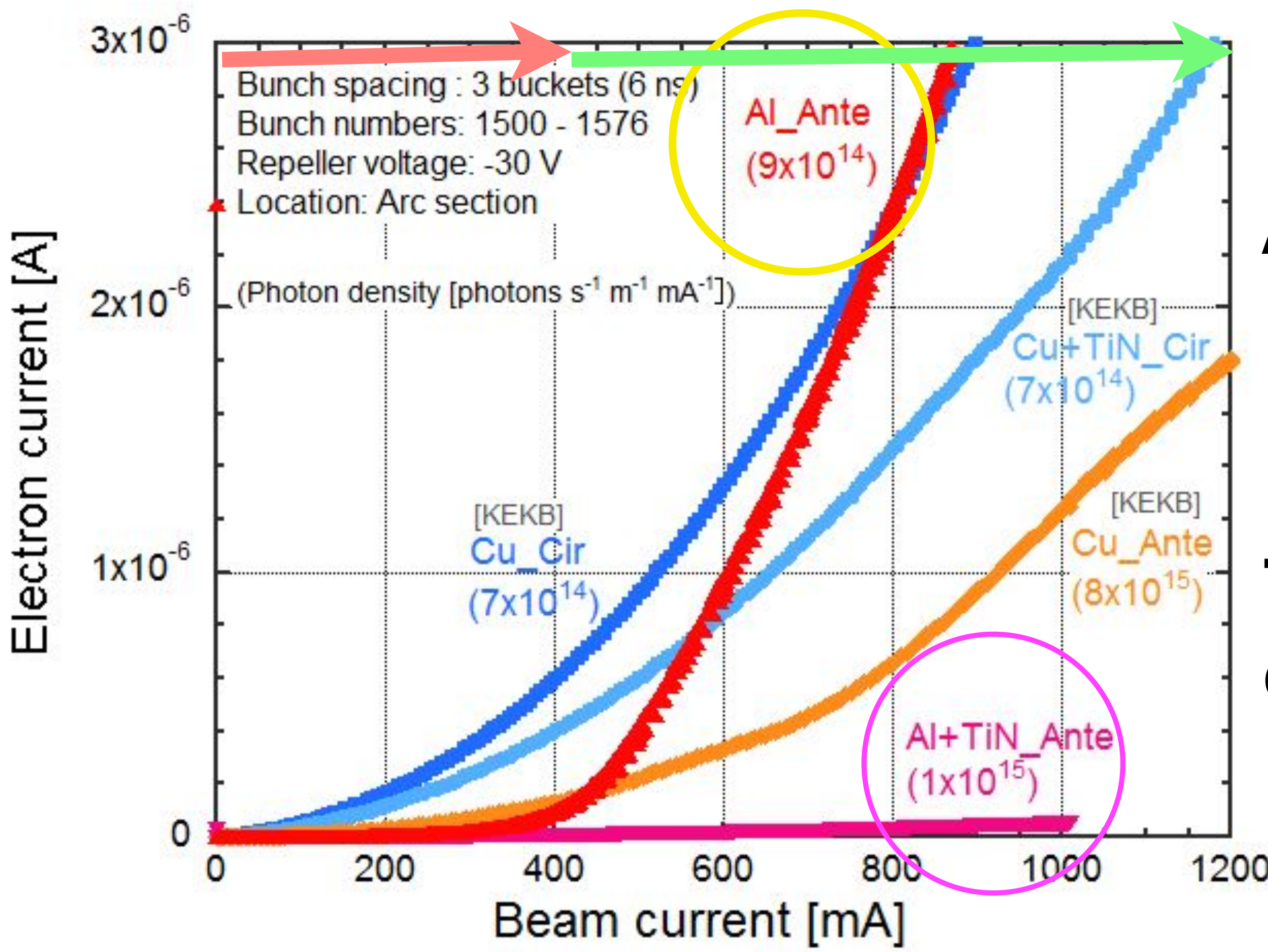


Electron Monitor

K. Kanazawa & Y. Suetsugu







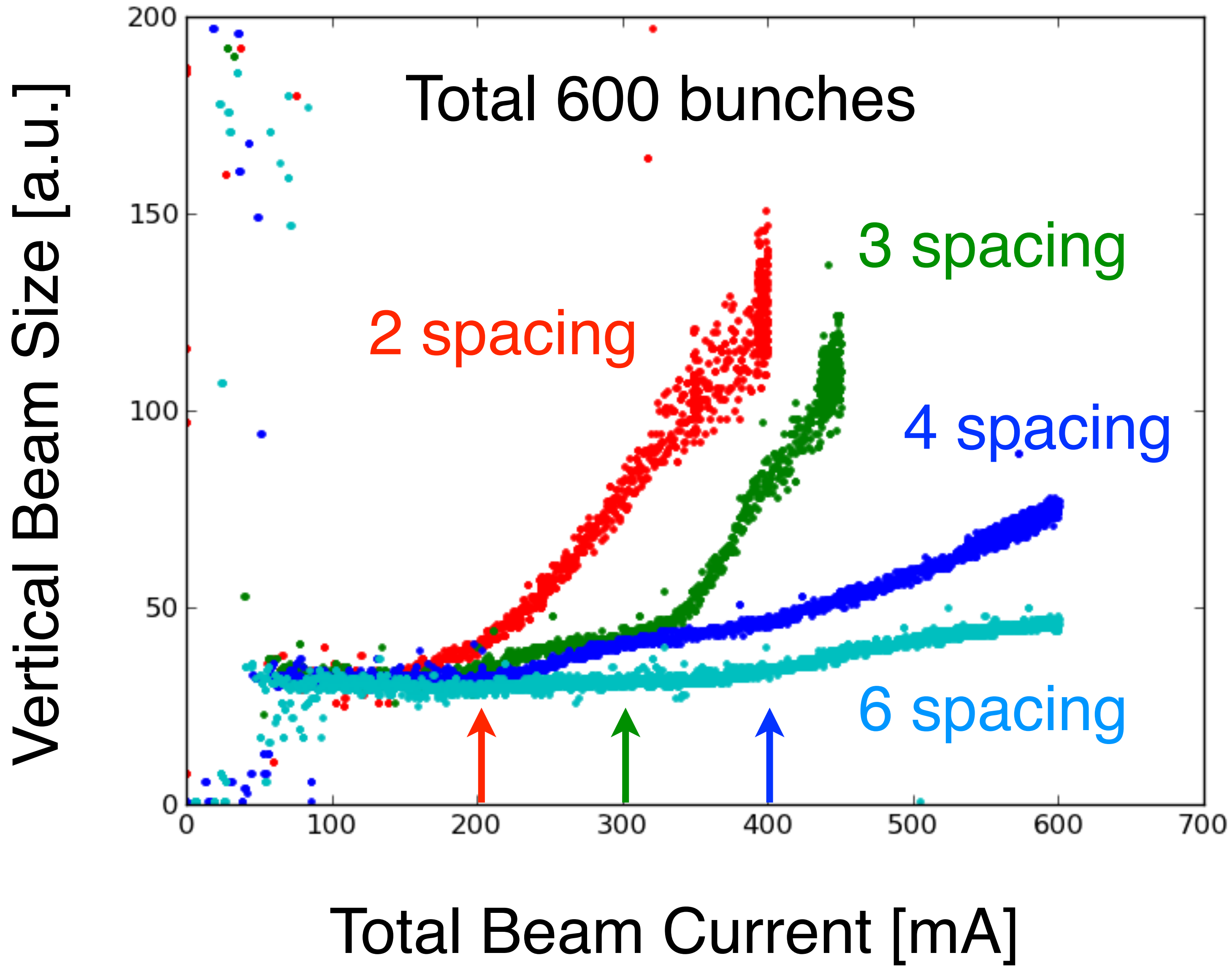
Photoelectrons

Ante-chamber suppress photoelectrons.

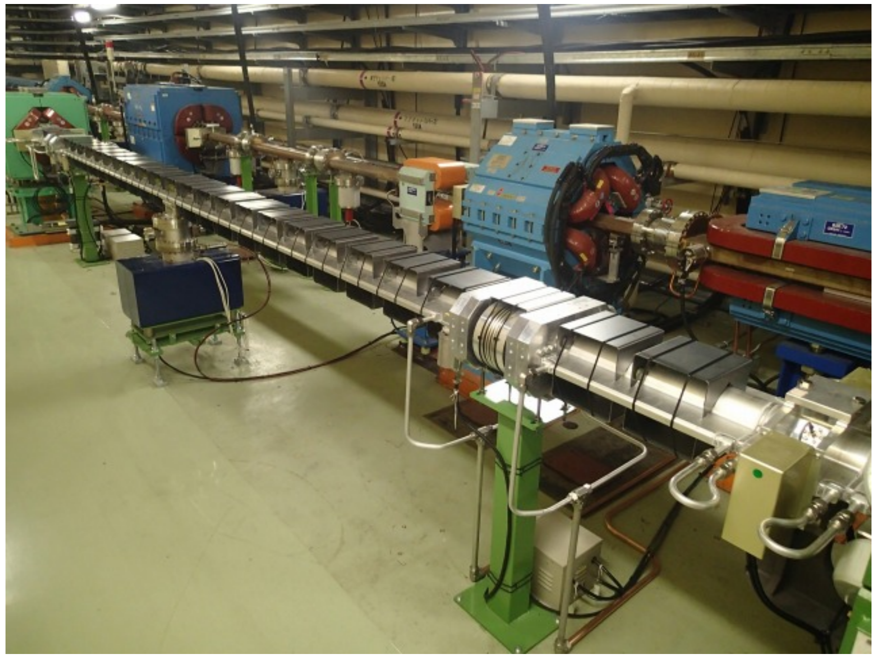
Secondary Electrons

TiN coating suppress multiplications of electrons.

Beam-Size Blowup



Additional mitigation of EC is permanent solenoid-like magnet.



Shorter bucket spacing becomes lower threshold of the beam-size blowup.

$$\rho_{th} = \frac{I}{n_b n_{sp}} = 0.17\ [mA]$$

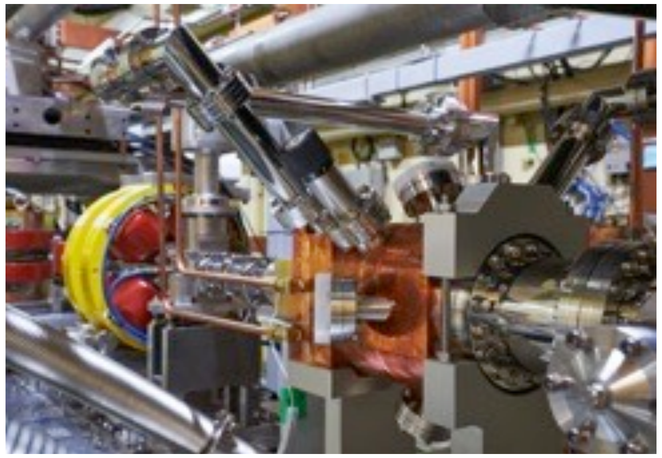
No blowup up to 1 [A] with 4 spacing and 1578 bunches.

We will install more permanent solenoid-like magnets to store design beam current without beam-size blowup.

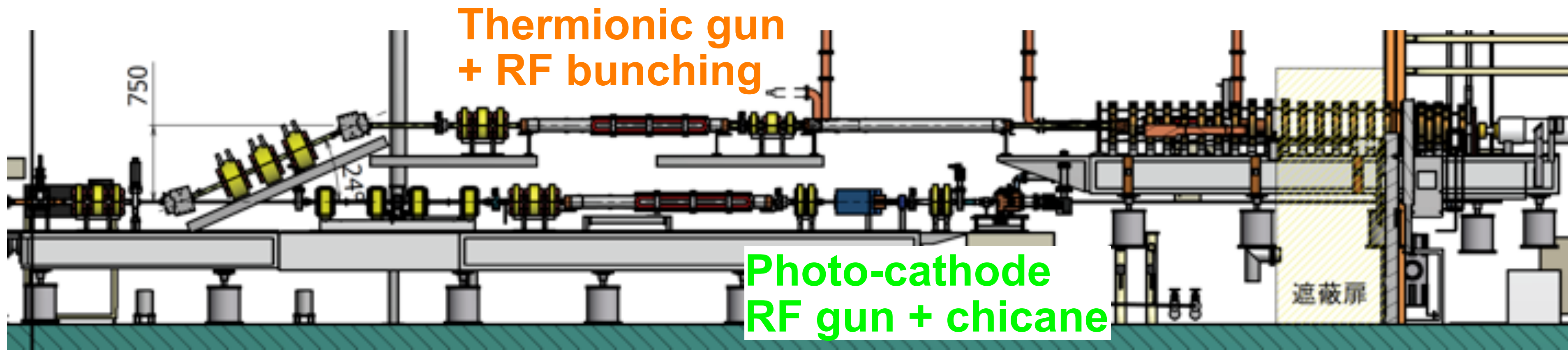
Injector Linac

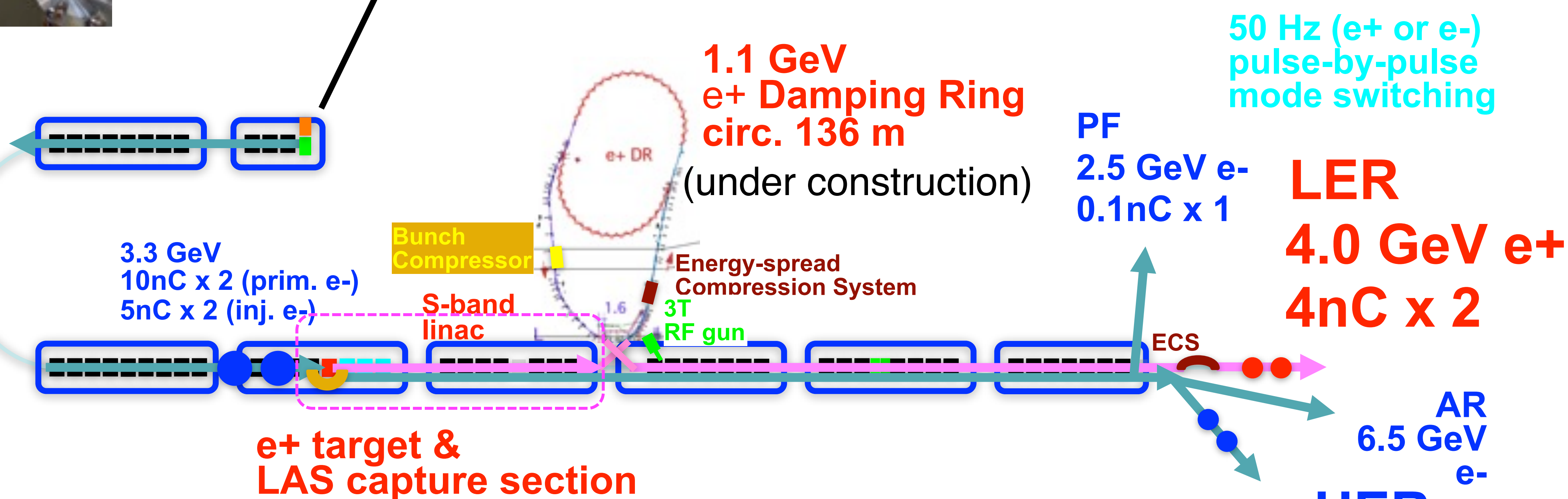
Injector Linac

Photo-cathode rf Gun



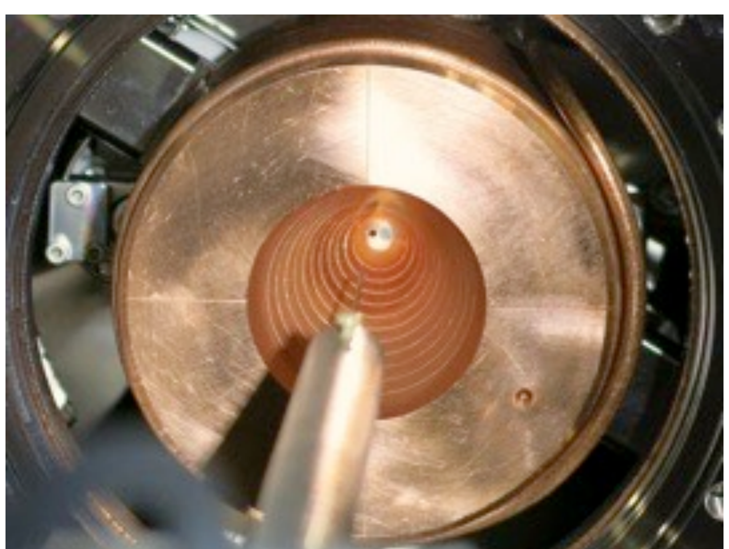
* Ir_5Ce cathode
* Yb doped laser
* fiber-based amp. +Yb:YAG multi-pass amp.
* Quasi-traveling side-coupled cavity





HER
7.0 GeV e-
5nC x 2

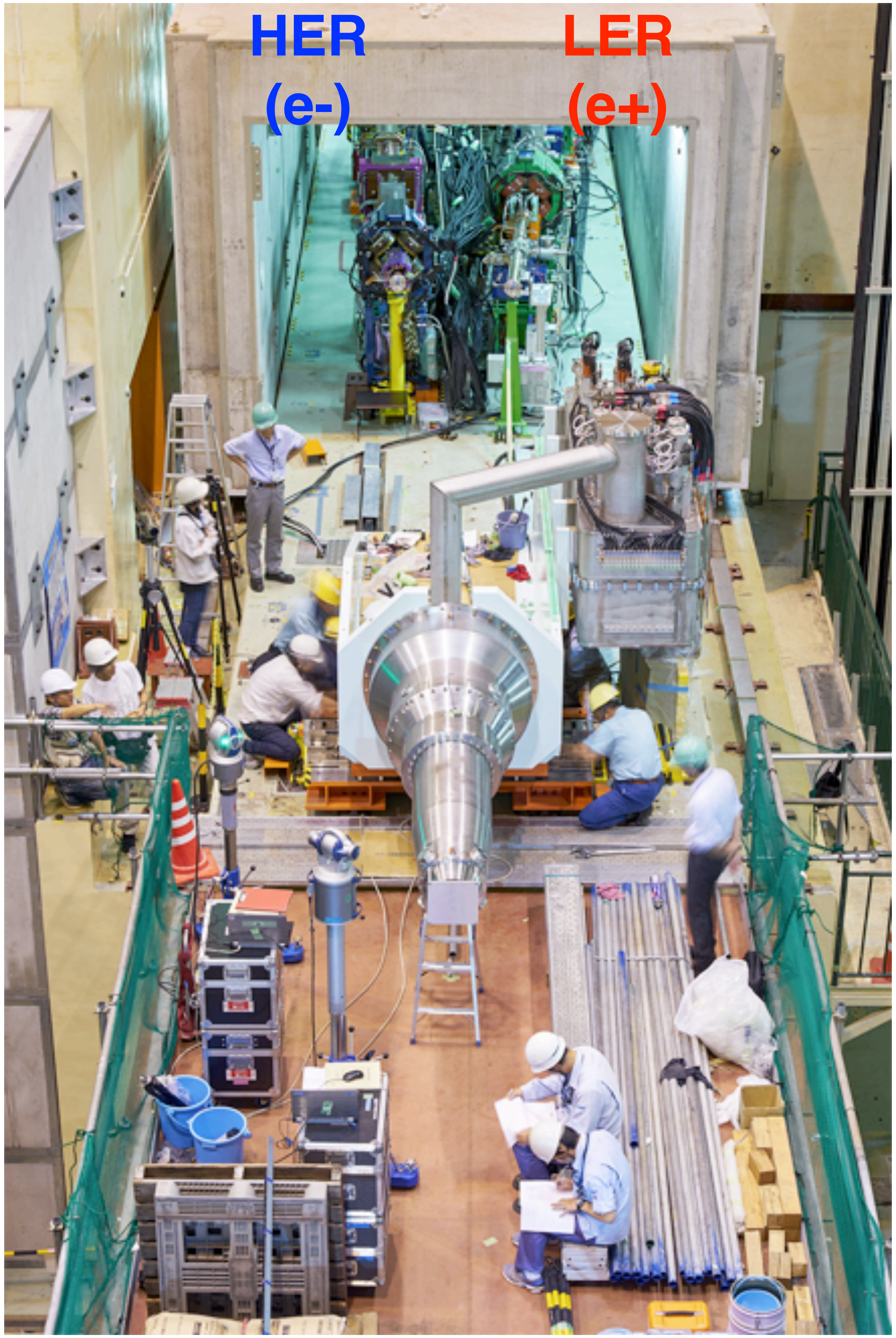
Flux Concentrator



Phase-1	Thermionic	RF gun	e+
Charge @linac end	0.8 nC	0.7 nC	0.6 nC
$\gamma\varepsilon_x$ / $\Upsilon\varepsilon_y$	160/300 μm	20/18 μm	1000/1200 μm

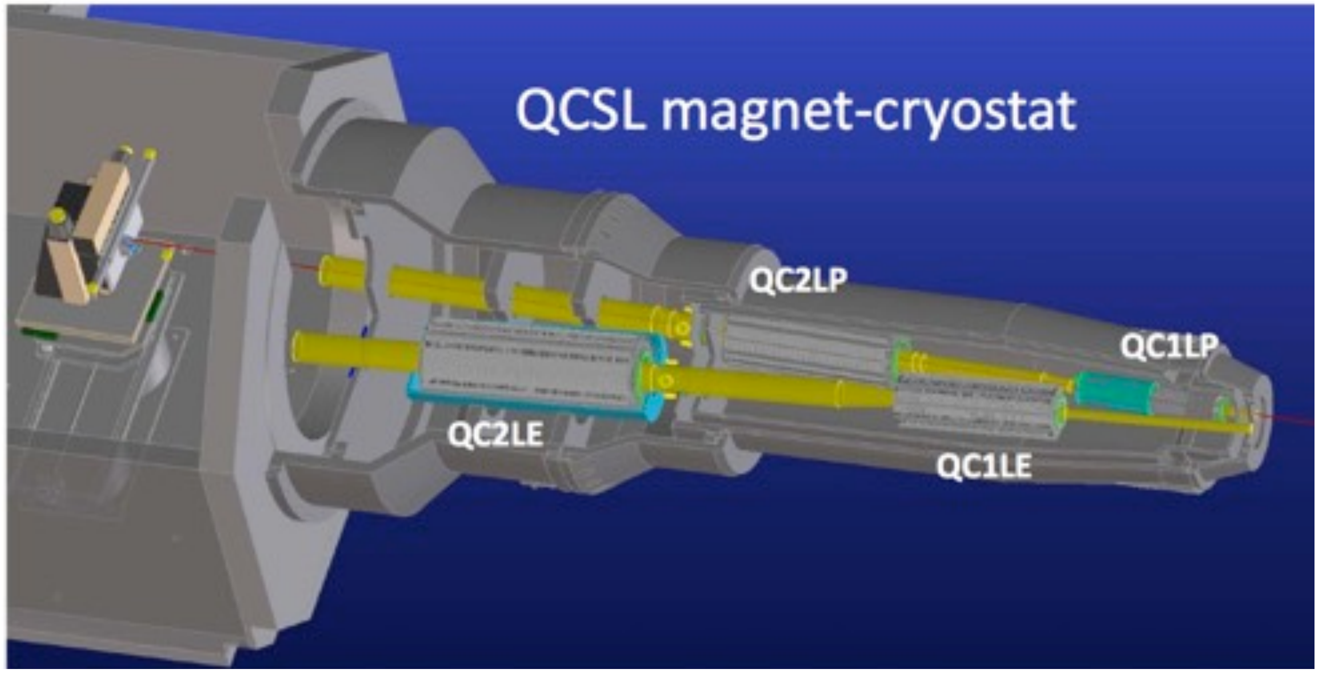
Final Focus System
for Phase-2 and later

Final Focus Magnets in the Beam-line



August 1st, 2016

Superconducting Magnets



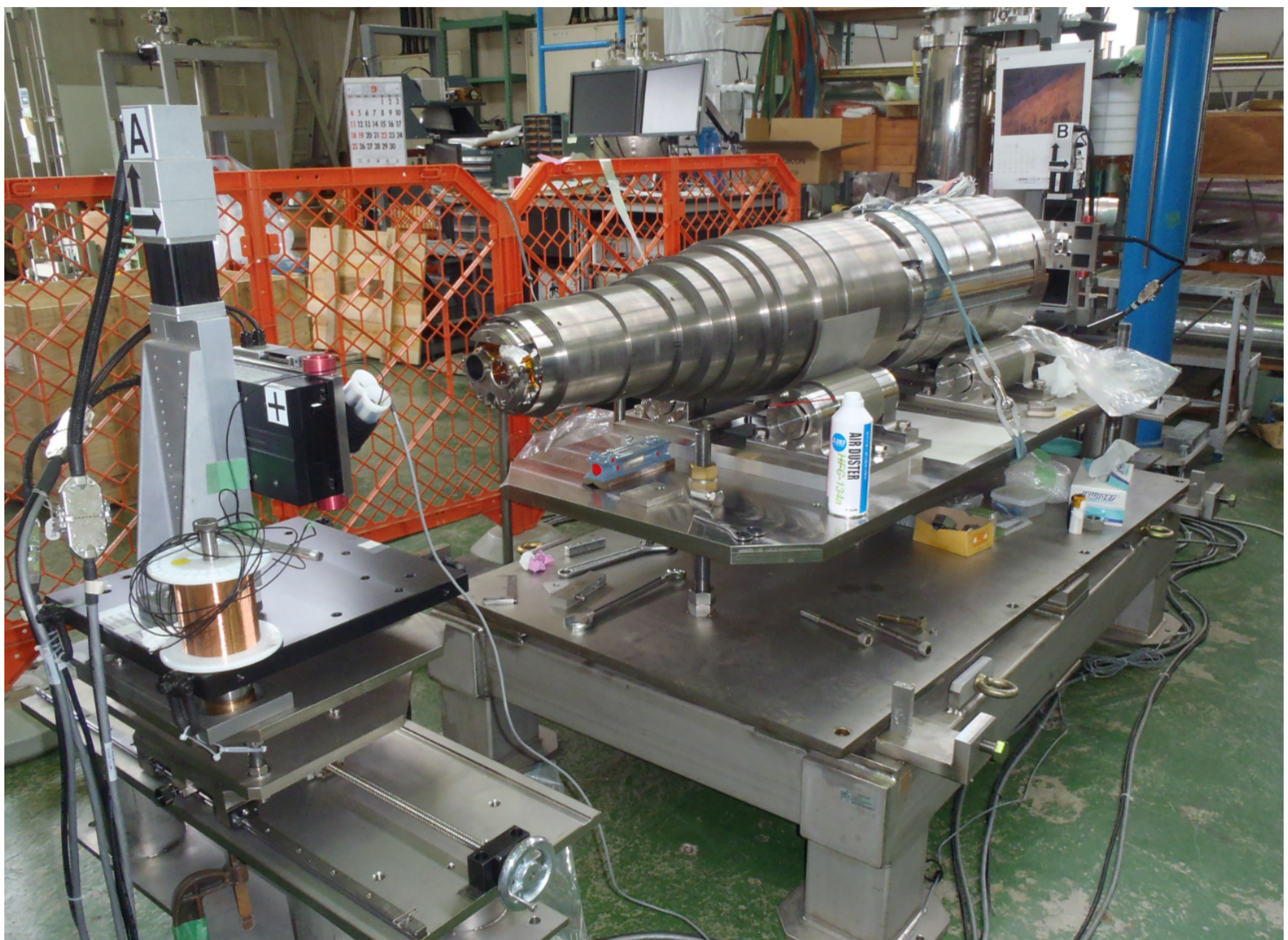
4 quadrupoles (QC1s, QC2s)
+ 16 corrector coils
+ 4 cancel coils (for leakage field)
+ anti-solenoid

The left side is completed !

BROOKHAVEN NATIONAL LABORATORY

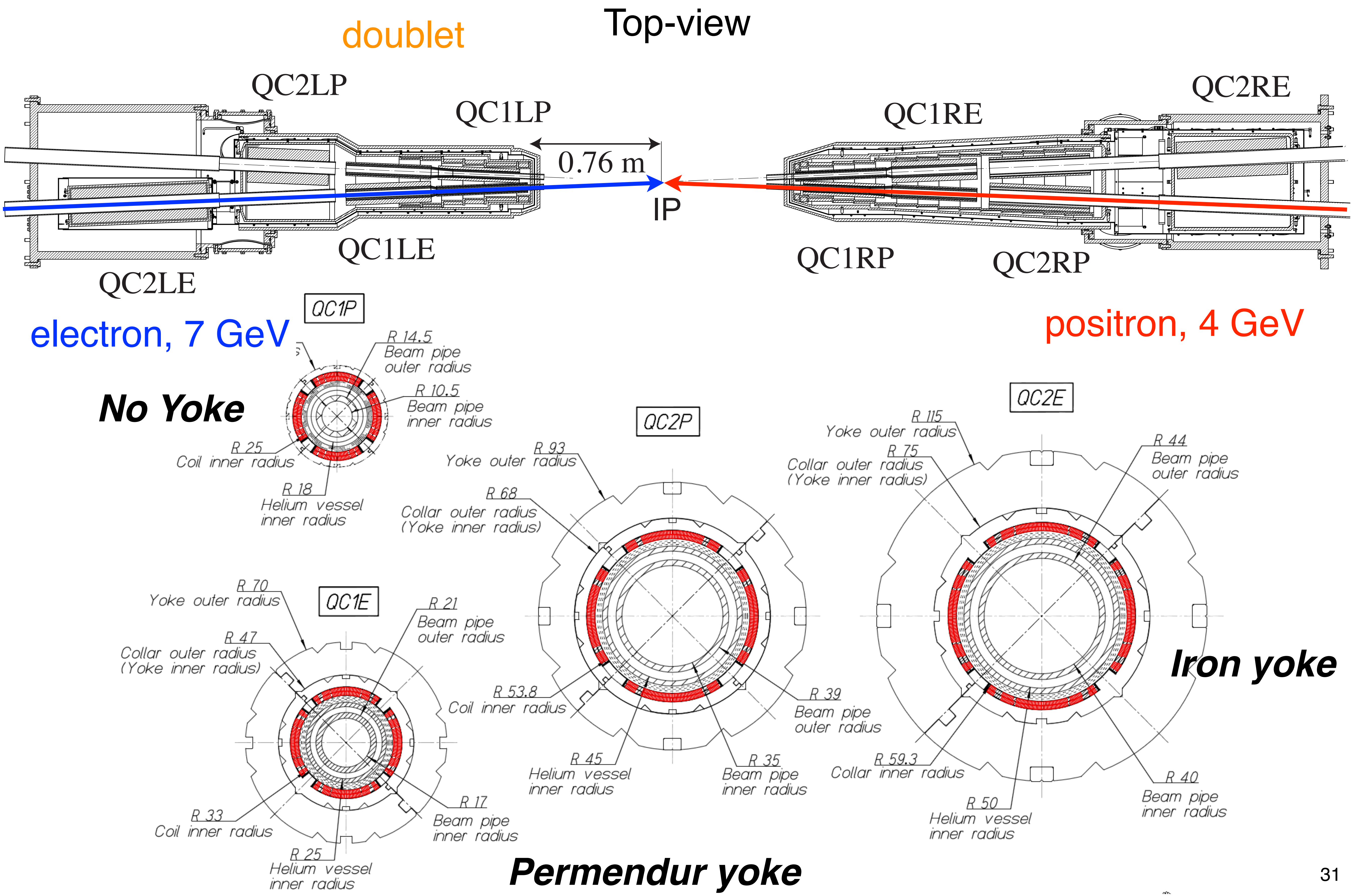
Fermilab contributes the calibration of the final focus system.

Measurement of the magnetic field and center position of the field by using the single stretched wire(SSW).



Cold mass (Right-side):
QC1RP
QC2RP
QC1RE
23 corrector coils

How to squeeze Beta Functions at IP ?



Conclusion

- Vacuum scrubbing was finished with 1 [A] and more than 720 [Ah] in LER.
- Apparatus such as RF system, beam instrumentations, etc. were operated in good shape.
- Low emittance tuning has been performed.
- We are ready to Phase-2; Machine commissioning for collision. Next milestone is a proof of "Nano-Beam" scheme.
- First physics runs in late 2017 or early 2018
- Countdown to the next generation B-factory toward more than 10^{35} $cm^{-2}s^{-1}$