

Strategy of Phase 2

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Verification of Nano-Beam Scheme

Low Emittance with Large Piwinski Angle

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

$L_{sp} = 1.7 \times 10^{31} @ \text{KEKB}$

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 5 months from mid of February to mid of July.

Luminosity

$$L = \frac{N_+ N_- n_b f_0}{4\pi \sigma_x^* \sigma_y^*} R_L$$

N: number of particles per bunch
 n_b: number of bunches
 f₀: revolution frequency
 R_L: reduction factor
 σ*: beam spot-size at IP
 I: bunch beam current
 φ_x: half crossing angle

Specific Luminosity

$$L_{sp} = \frac{L}{I_+ I_- n_b} = \frac{1}{4\pi e^2 f_0} \frac{R_L}{\sigma_x^* \sigma_y^*} \propto \frac{\xi_{y+}}{I_- \beta_{y-}^*}$$

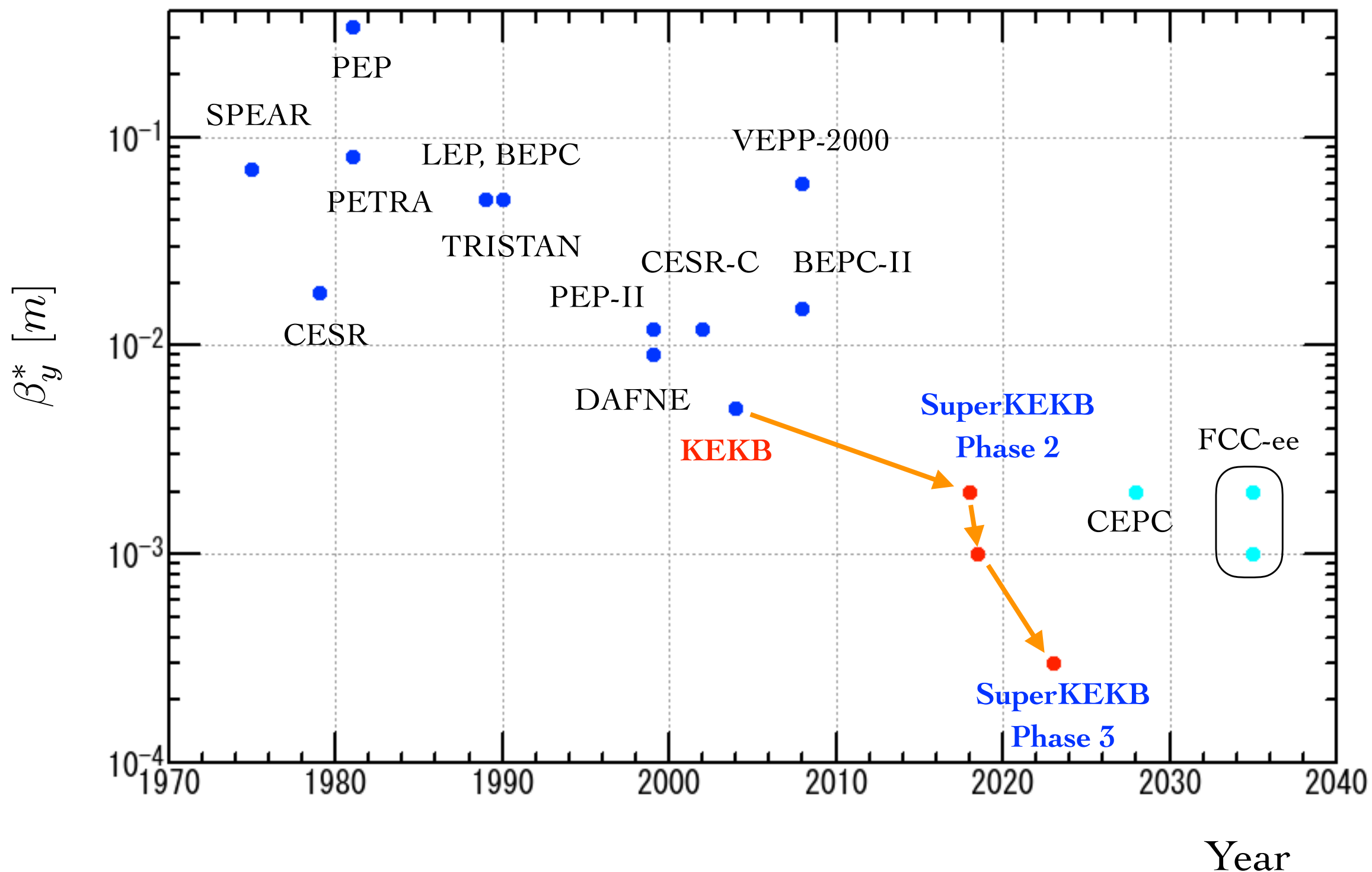
Beam-Beam Parameter and Luminosity

small β_y* requires small ε_y
to keep ξ_y

$$\xi_{y+} = \frac{r_e \beta_{y+}^*}{2\pi \gamma_+} \frac{N_-}{\sigma_{y-}^* (\sigma_{x-}^* + \sigma_{y-}^*)} R_{\xi_y} \simeq \frac{r_e}{2\pi \gamma_+} \frac{N_-}{\sigma_z \phi_x} \sqrt{\frac{\beta_y^*}{\epsilon_y}} R_{\xi_y}$$

$$L = \frac{\gamma_+}{2er_e} \left(1 + \frac{\sigma_y^*}{\sigma_x^*} \right) \frac{n_b I_+ \xi_{y+}}{\beta_{y+}^*} \frac{R_L}{R_{\xi_y}} \simeq \frac{\gamma_+}{2er_e} \frac{n_b I_+ \xi_{y+}}{\beta_{y+}^*} \frac{R_L}{R_{\xi_y}}$$

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



We start very big beta at IP to find closed orbit with Final Focus System (Phase 2.0).

Phase 2.1 may be skipped.

Beta squeezing can be done without changing between IP and local chromaticity corrections in principle from Phase 2.2.

Phase	LER			HER		
	β_x^* [mm]	β_y^* [mm]	scale	β_x^* [mm]	β_y^* [mm]	scale
2.0*	384	81	12 x 300	400	81	16 x 270
2.1	384	5.4	12 x 20	400	6.0	16 x 20
2.2	256	2.16	8 x 8	200	2.4	8 x 8
2.3	128	2.16	4 x 8	100	2.4	4 x 8
2.4	128	1.08	4 x 4	100	1.2	4 x 4
3.x	32	0.27	1 x 1	25	0.30	1 x 1

$\simeq \sigma_z$

adiabatic squeezing

* QCS tuning, optics tuning, hardware check and test, no collision during Phase 2.0.

Piwinski Angle

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

	KEKB (2006)		Phase 2.2		Phase 2.3		Phase 2.4		Phase 3	
	LER	HER	LER	HER	LER	HER	LER	HER	LER	HER
β_x [mm]	590	560	256	200	128	100	128	100	32	25
β_y [mm]	6.5	5.9	2.16	2.40	2.16	2.40	1.08	1.2	0.27	0.30
ε_x [nm]	18	24	2.1	4.6	2.1	4.6	2.1	4.6	3.2	4.6
$\varepsilon_y/\varepsilon_x$ [%]	3	2.5	5.0		1.4		0.7		0.27	0.28
σ_x^* [μm]	103	116	23.2	30.3	16.4	21.4	16.4	21.4	10.1	10.7
σ_y^* [nm]	1900	1900	476	743	252	393	126	197	48	62
σ_z [mm]	7	7	6	5	6	5	6	5	6	5
ϕ_x [mrad]	11		41.5		41.5		41.5		41.5	
Φ	0.75	0.66	10.7	8.2	15.2	9.7	15.2	9.7	24.7	19.4
Remark	$1.72 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$		$10^{34} \text{ cm}^{-2} \text{ s}^{-1}$		$2 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$		$4 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$		$8 \times 10^{35} \text{ cm}^{-2} \text{ s}^{-1}$	

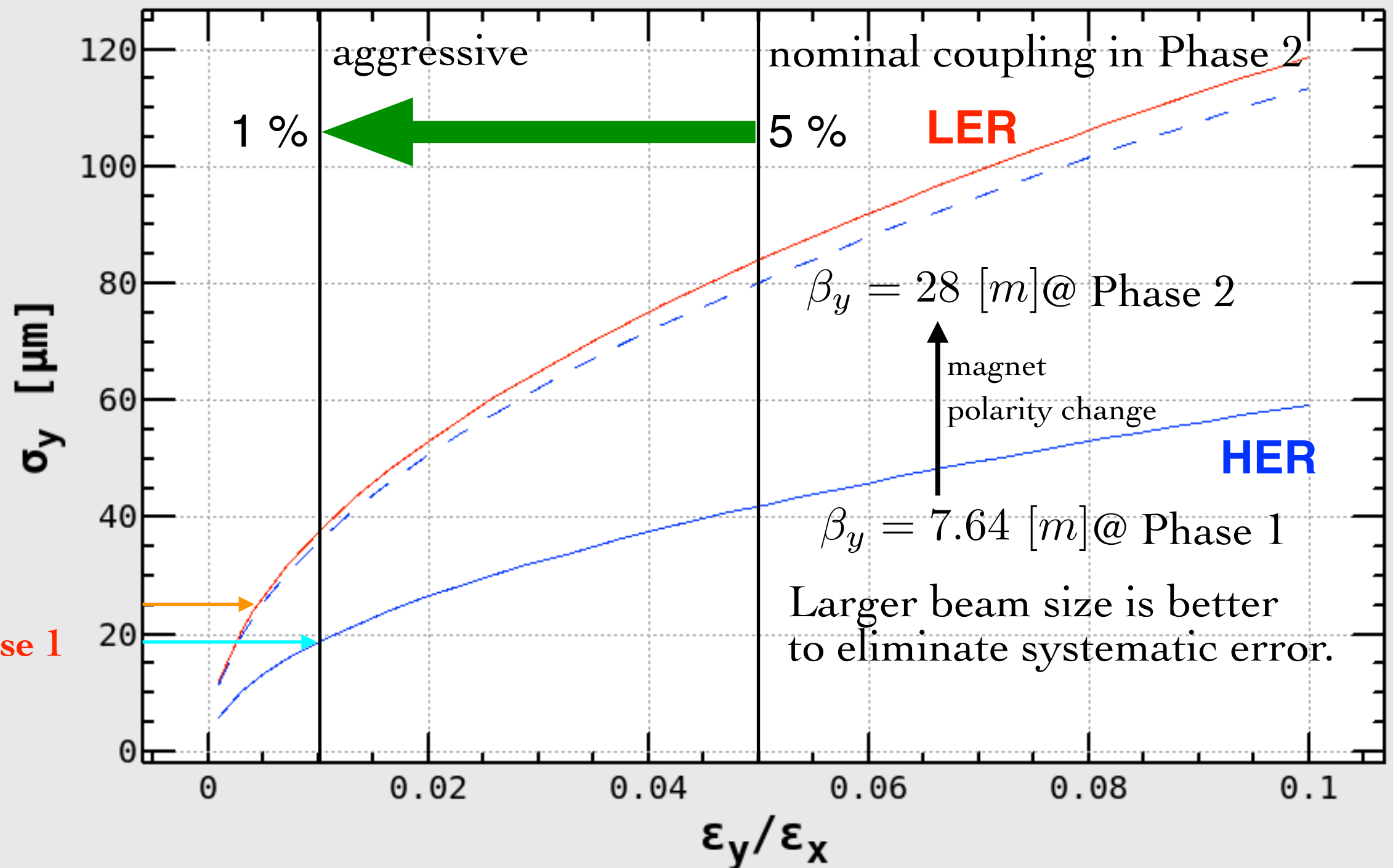
No crab-crossing

Large Piwinski Angle

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

	Phase 2.3 (4x8)				Phase 2.4 (4x4)		Phase 3 (1x1)	
	LER	HER	LER	HER	LER	HER	LER	HER
$I_L \times I_H, n_b$	1 A x 0.8 A, 1576 bunches (3-bucket spacing)						3.6 A 2500	2.6 A 2500
β_x^* [mm]	128	100	128	100	128	100	32	25
β_y^* [mm]	2.16	2.4	2.16	2.40	1.08	1.20	0.27	0.30
$\varepsilon_y/\varepsilon_x$ [%]	5.0		1.4		0.7		0.27	0.28
ξ_x	0.0052	0.0020	0.0053	0.0021	0.0053	0.0021	0.0028	0.0012
ξ_y	0.0257	0.0264	0.0484	0.0500	0.0496	0.0505	0.0881	0.0807
I_{bunch} [mA]	0.64	0.51	0.64	0.51	0.64	0.51	1.44	1.04
L [cm ⁻² s ⁻¹]	1 x 10³⁴ (tentative target)		2 x 10³⁴		4 x 10³⁴		8 x 10³⁵	
L_{sp} [cm ⁻² s ⁻¹ /mA ²]	1.97 x 10³¹		3.94 x 10³¹		7.88 x 10³¹		2.14 x 10³²	

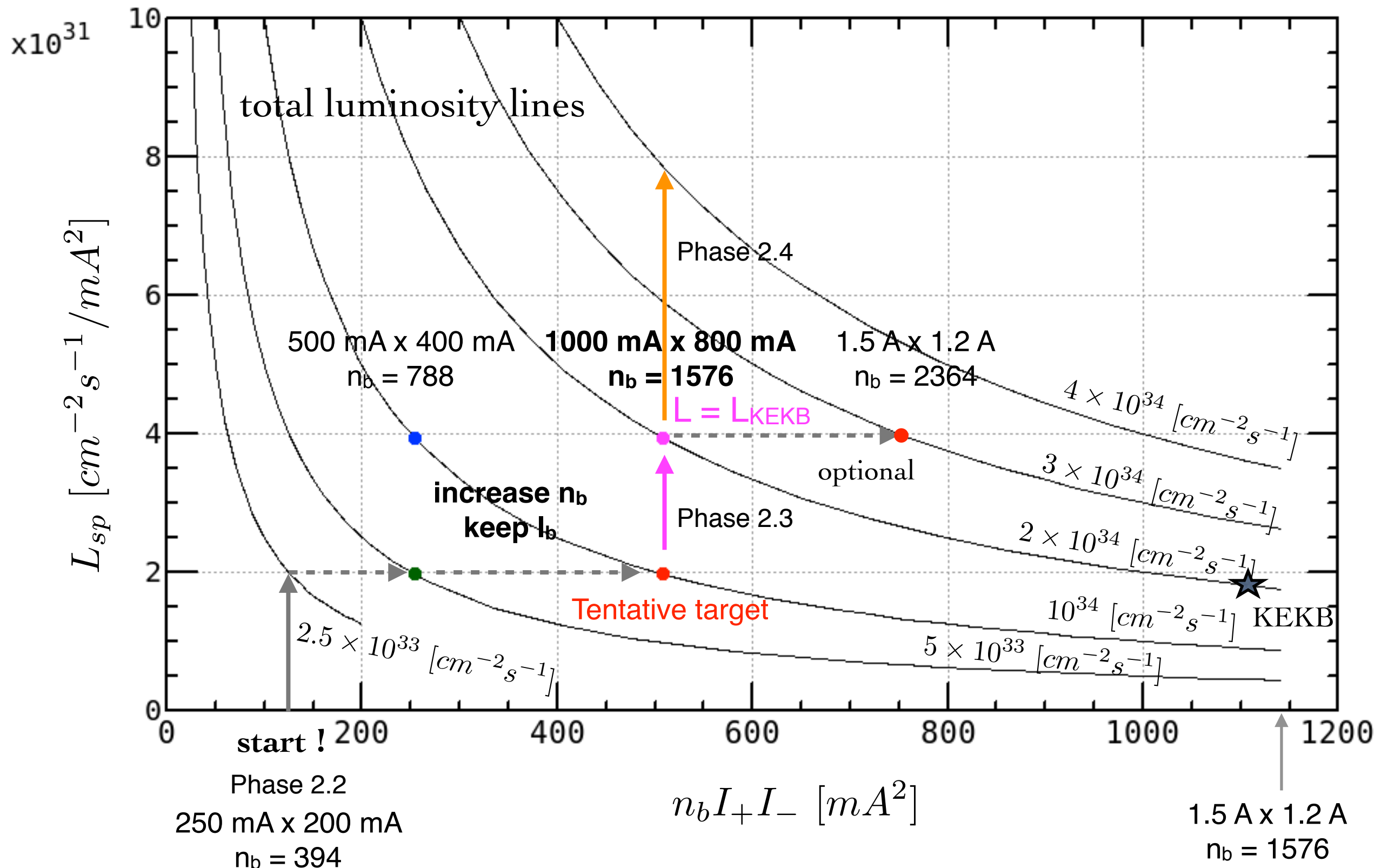
The key point is how we can suppress beam-beam blow-up.



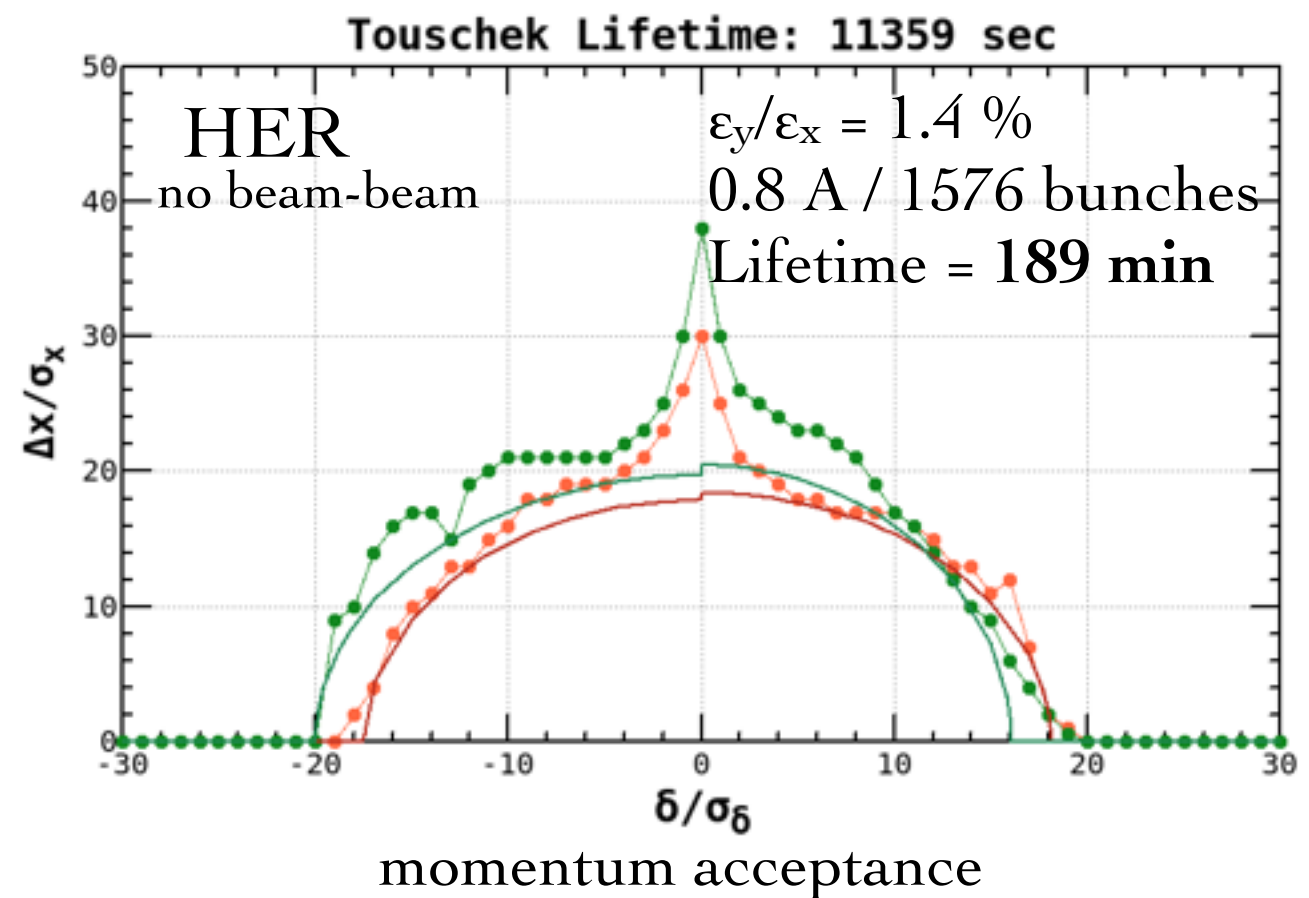
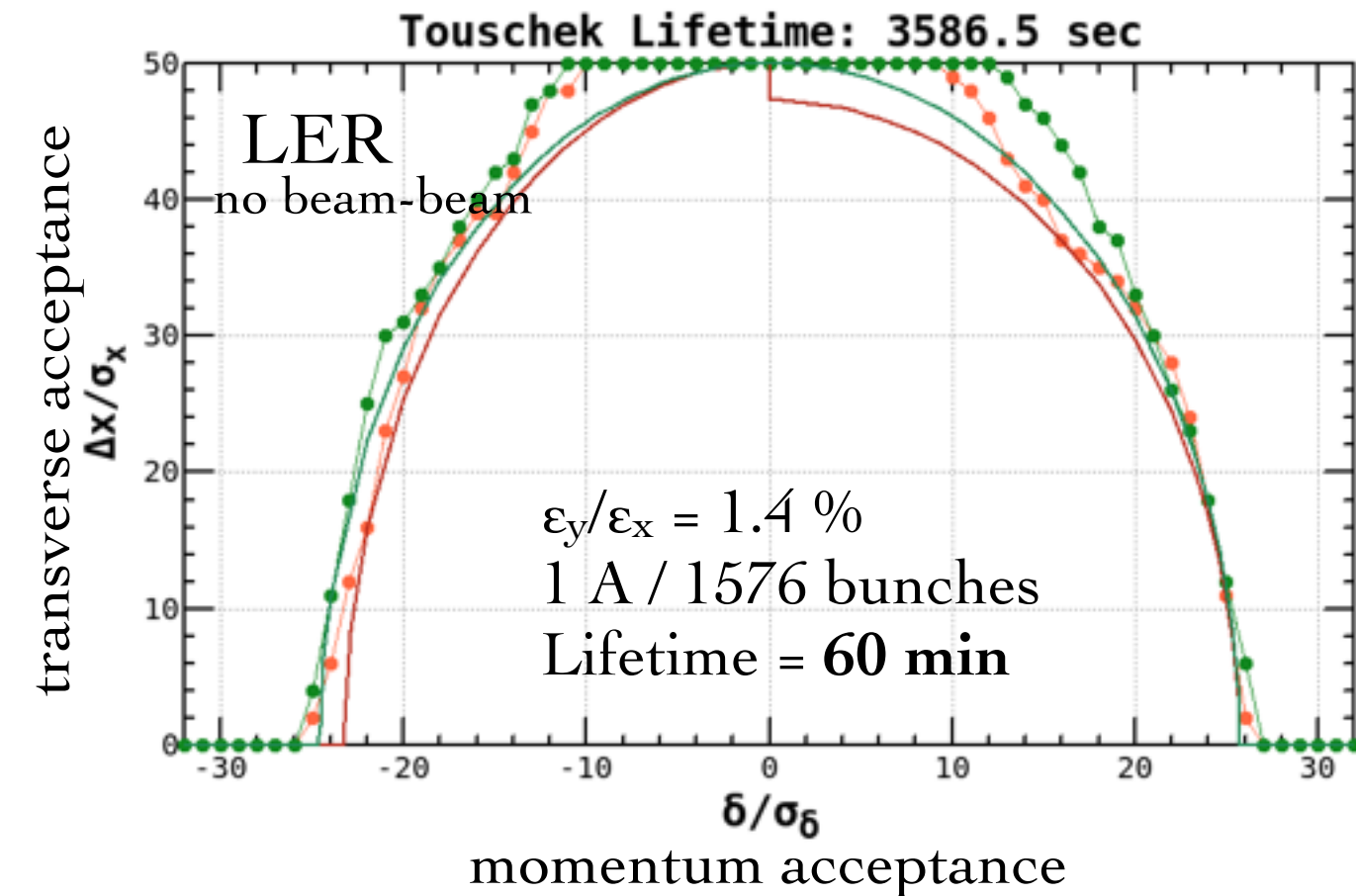
Results
from Phase 1
(w/o FF)

LER and HER achieved less than 1 % coupling during Phase 1.

We try to improve the specific luminosity with keeping bunch currents.



Phase 2.3 (4x8 β eta)



Difference between without beam-beam and with beam-beam is less than 10 %.

The machine error reduces the dynamic aperture about 10 - 20 %.

We assume that **total lifetime** is 40 min in LER and 150 min in HER during Phase 2.

↓
Loss rate = 26 GHz (1 A)

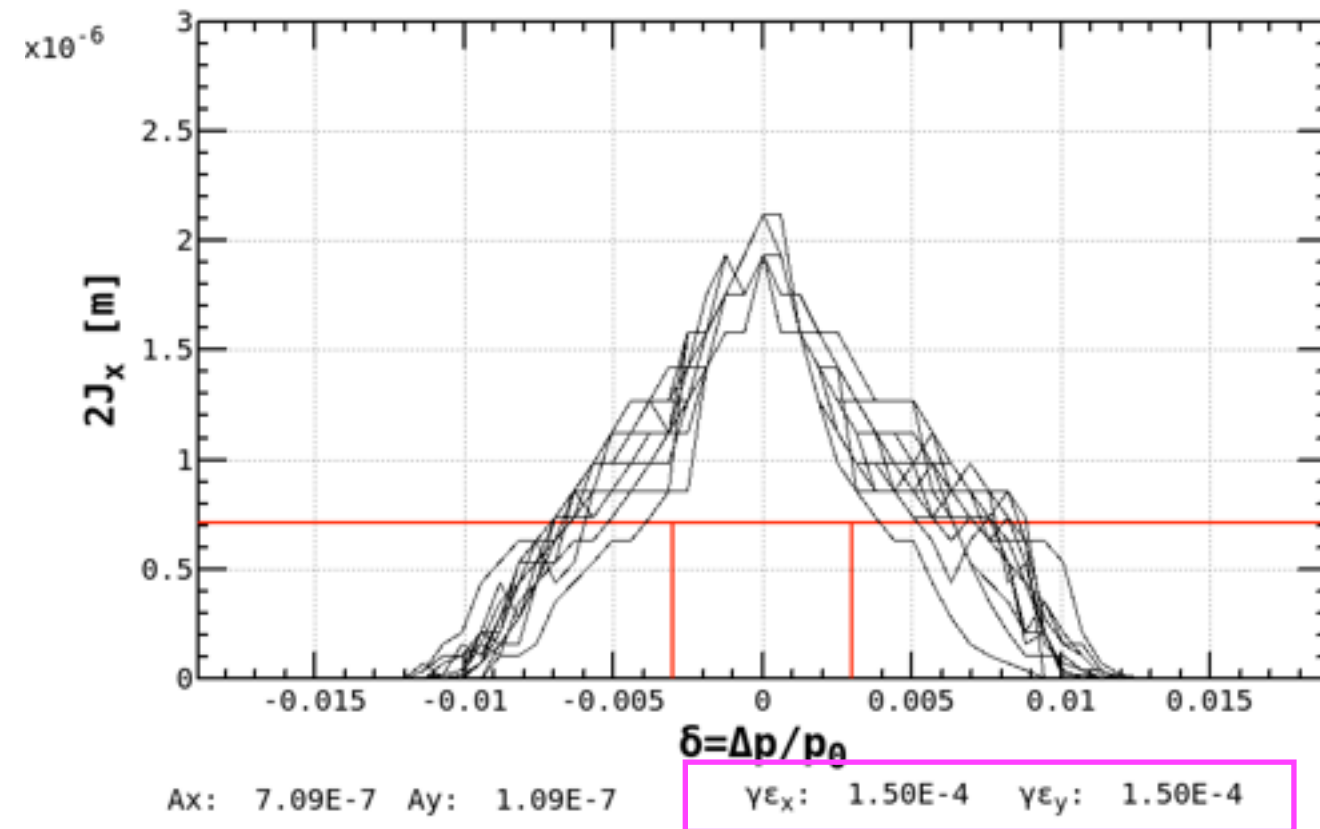
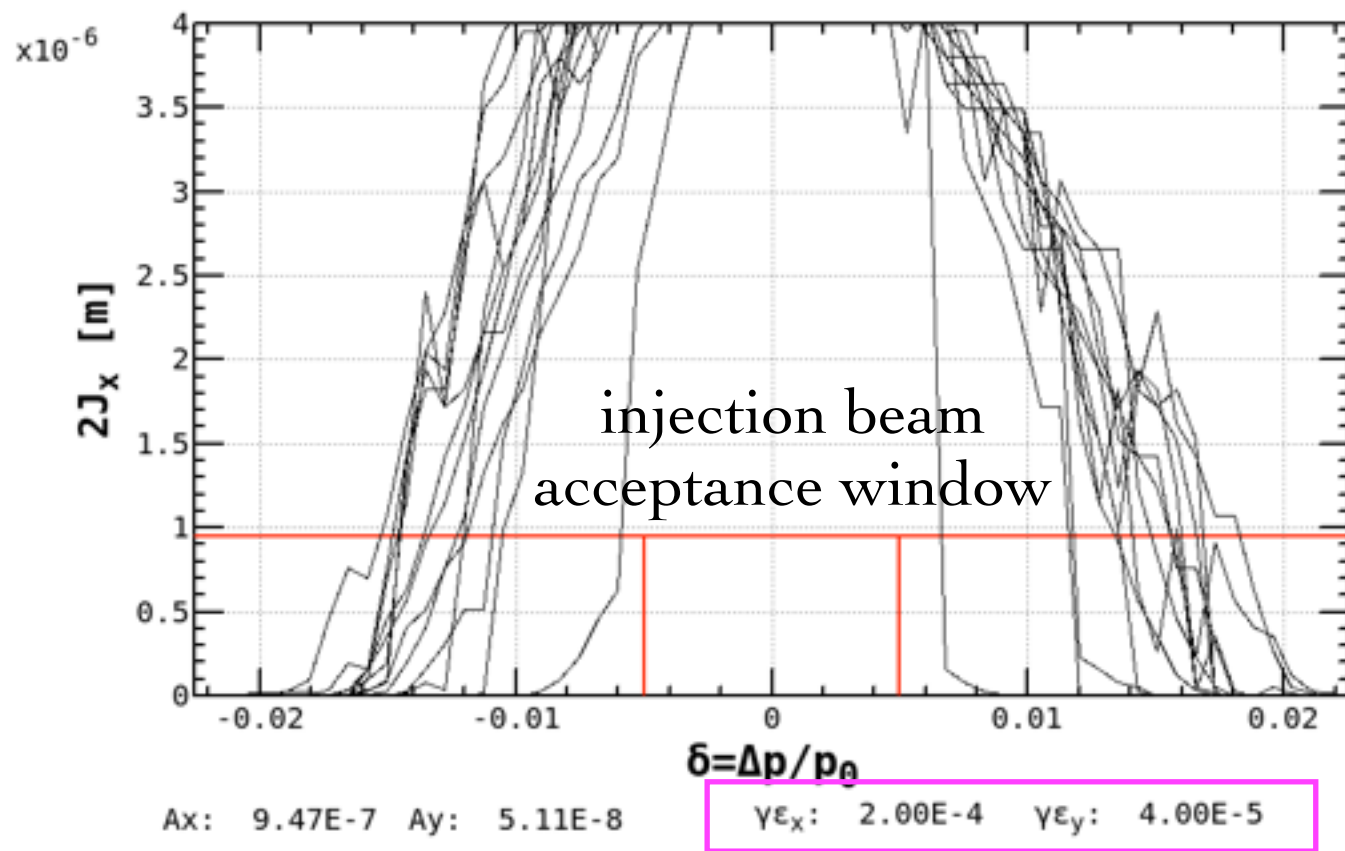
↓
Loss rate = 5.6 GHz (0.8 A)

Phase 2.3 (4x8 β eta) no beam-beam

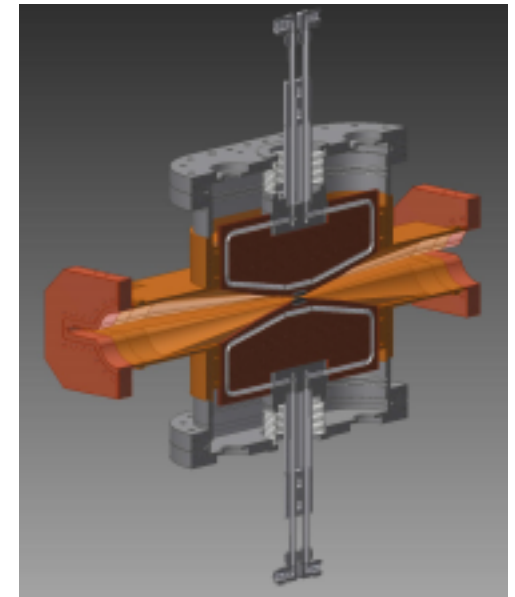
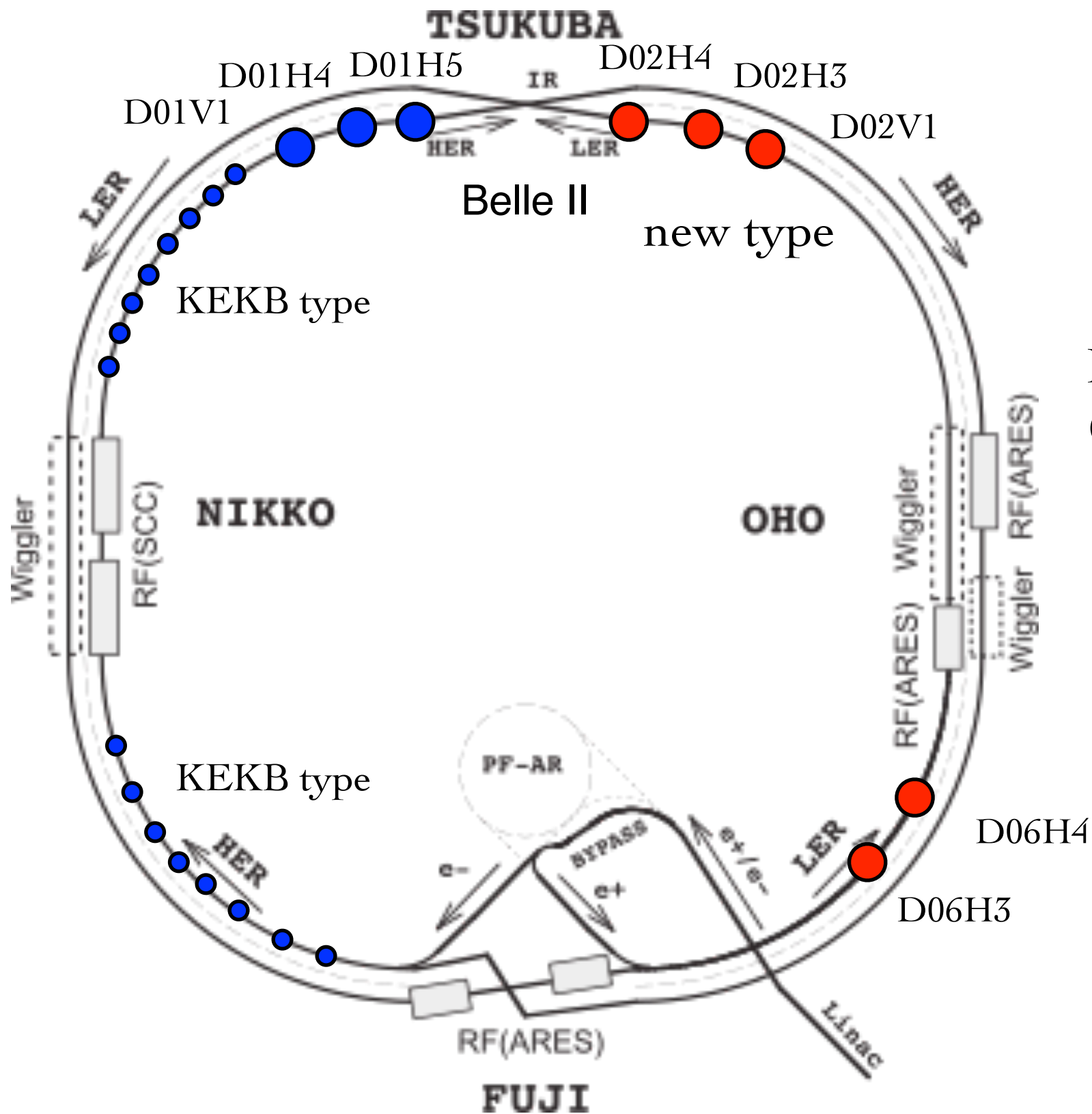
sextupole field error : 1 % of rated current

LER

HER



入射陽電子ビームの規格化エミッタンス [m]

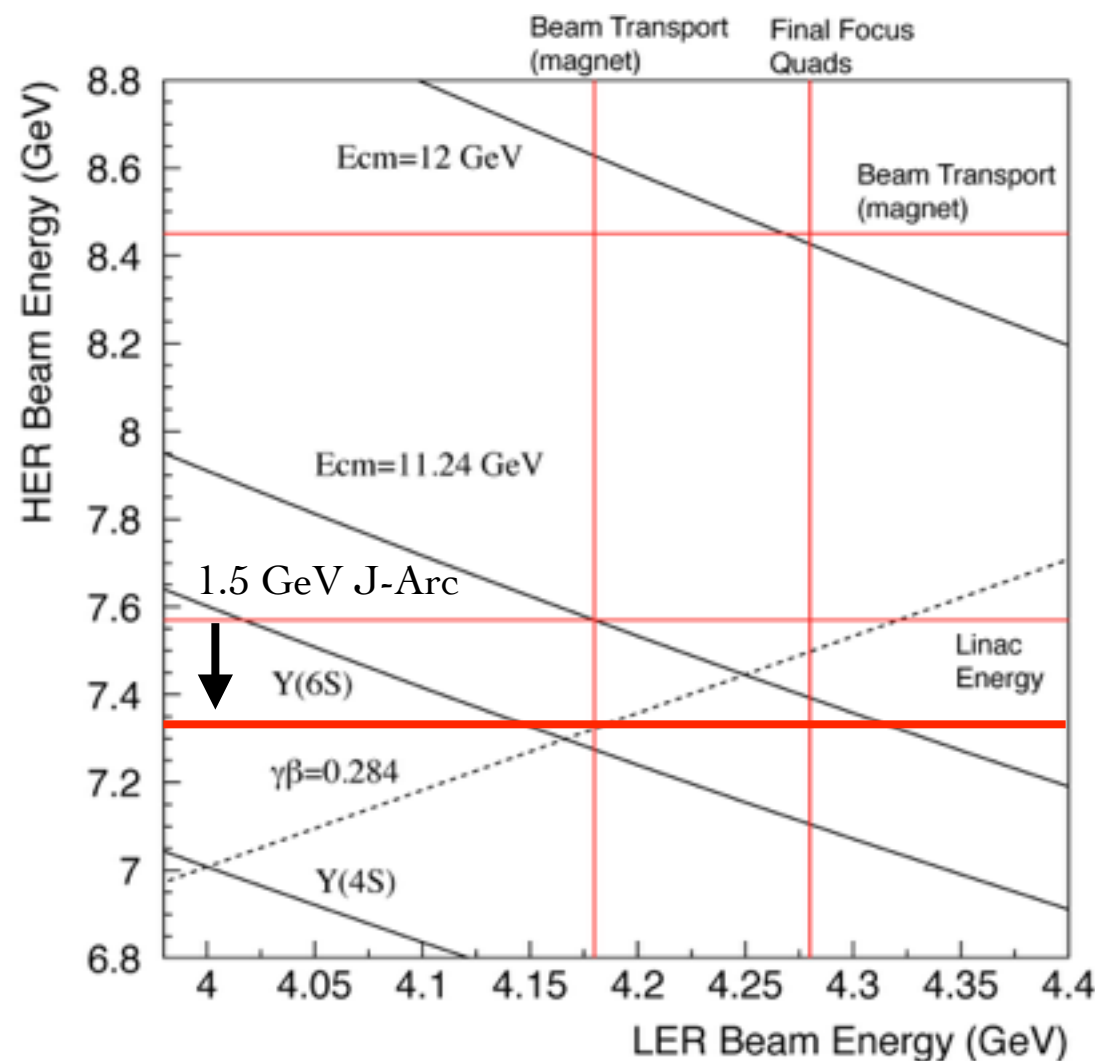


BCG
(Belle II Commissioning Group)

has a responsibility of movable mask control.

Compromise lifetime, injection,
and detector background.





Y(4S)

HER: 7 GeV

LER: 4 GeV

A - B sector : 1 backup unit

C - 2 sector: 1 backup unit

3 - 5 sector: 1 backup unit

(1 unit = 160 MeV)

C - 2 $\rightarrow$ 2 backup units in Phase 3

Y(6S)

HER: 7.30 GeV

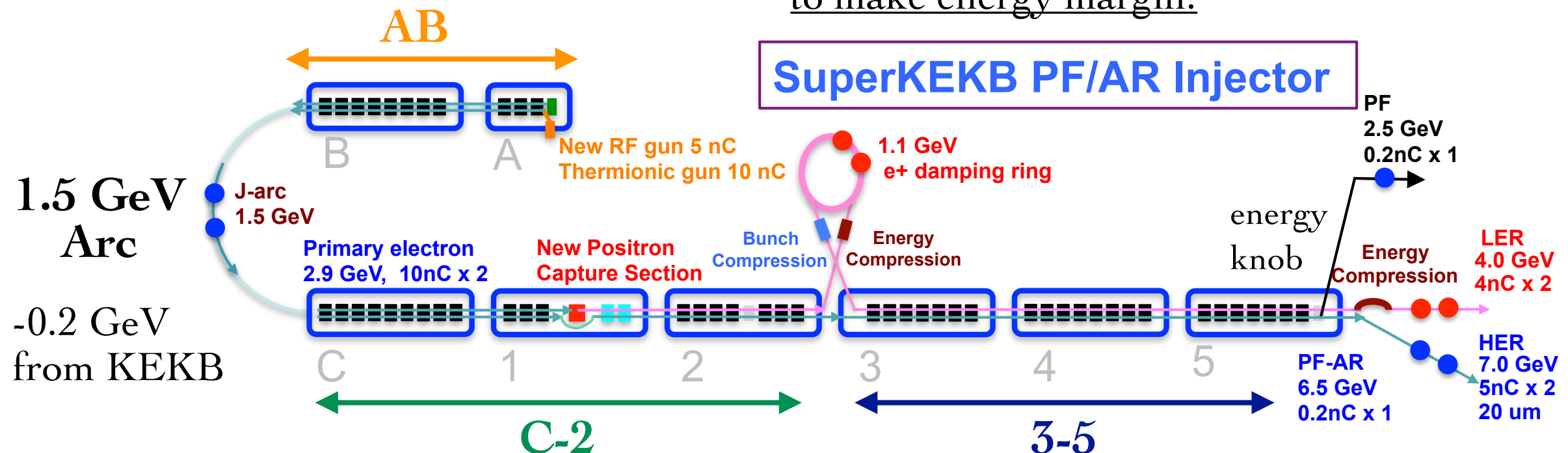
no backup unit in C - 5 sector(max 7.35 GeV)

LER: 4.16 GeV

no backup unit in 3 - 5 sector(max 4.18 GeV)

Risk at higher beam energy

The old accelerating structures should be replaced to make energy margin.



	Positron LER 4 GeV	Electron HER 7 GeV
Normalized emittance* ¹ $\gamma\beta\epsilon_x / \gamma\beta\epsilon_y$	200 / 40 [μm] with <i>DR</i>	150 / 150 [μm]* ²
Energy spread* ³ σ_δ	0.16 [%]	0.10 [%]
Bunch charge at injection point* ⁴	0.5 [nC]	1.0 [nC]

*¹ Area of 95.4 % occupied by particles defines $\pm 2\sigma$. The emittance is derived from σ .

*² 100 μm is preferable for Phase 2.4(4x4).

*³ Energy acceptance is 3 σ .

*⁴ Charge intensity of one bunch. Double for 2-bunch injection.

Thermionic gun is available for HER injection in Phase 2.
Damping Ring is necessary for LER injection.

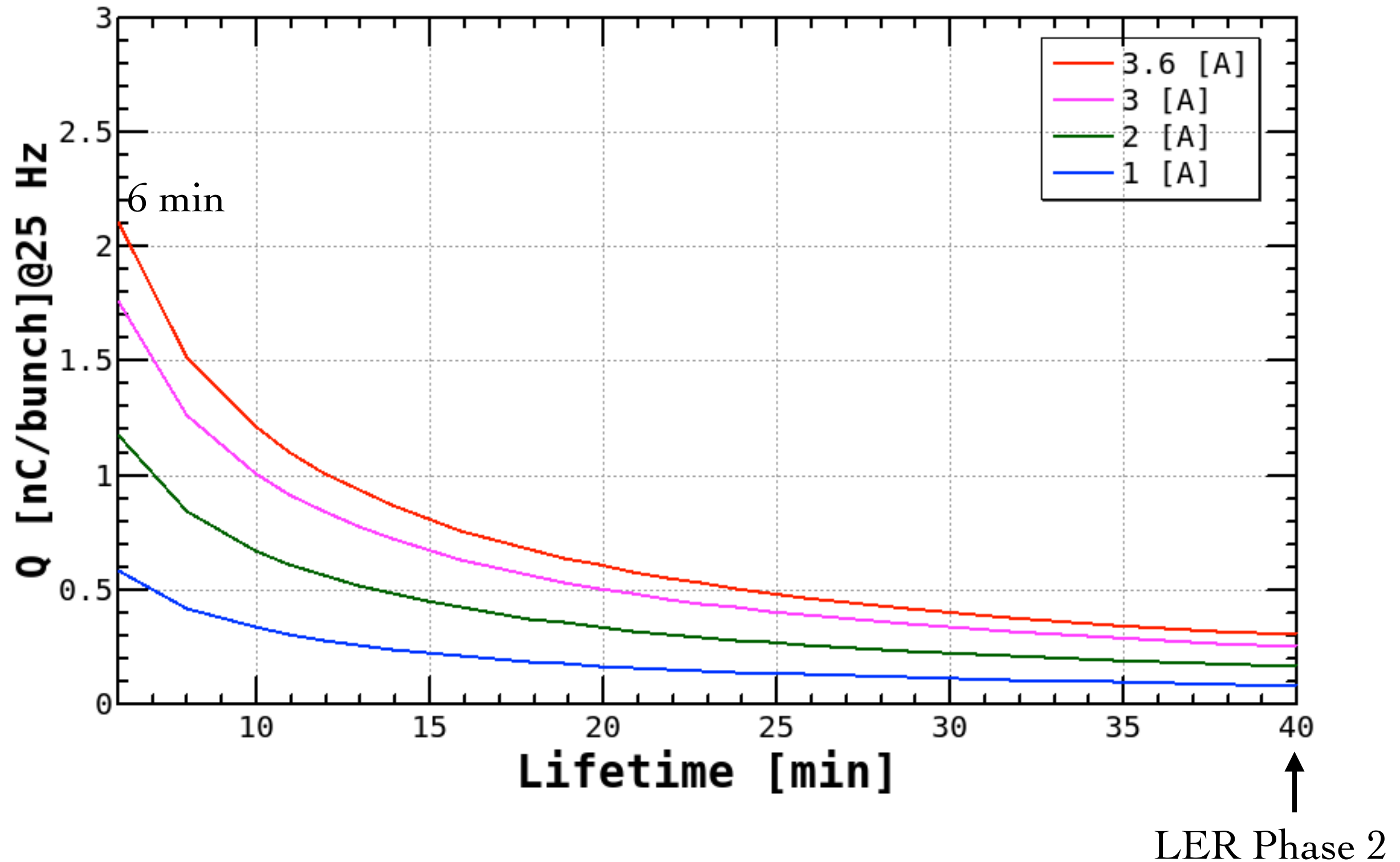
	Positron LER 4 GeV	Electron HER 7 GeV
Normalized emittance* ¹ $\gamma\beta\epsilon_x / \gamma\beta\epsilon_y$	100 / 15 [μm] with DR	40 / 20 [μm]
Energy spread* ² σ_δ	0.16 [%]	0.07 [%]
Bunch charge at injection point* ³	4.0 [nC]	4.0 [nC]

*¹ 95.4 %の粒子を占める範囲を、 $\pm 2\sigma$ と定義する。ここで得られた σ からエミッタンスを算出する。

*² エネルギー・アクセプタンスについて、 3σ と考える。

*³ 1 バンチあたりの電荷量. 2 バンチ入射の場合 2 倍となる。

100 % injection efficiency



Phase	Scale of β^*	LER		HER		Duration	
		β_x^* [mm]	β_y^* [mm]	β_x^* [mm]	β_y^* [mm]	month	
2.0	300	384	81	400	81	1	No collision
2.1*	20	384	5.4	400	6.0	0.5 - 1	Collision test ?
2.2	8 x 8	256	2.16	200	2.4	1	Collision tuning
2.3	4 x 8	128	2.16	100	2.4	1	Collision tuning
2.4	4 x 4	128	1.08	100	1.2	1	Collision tuning

*Phase 2.1 may be skipped. If some troubles occur in Phase 2.2, we go back to Phase 2.1.

The accelerator is optimized to Y(4S) energy, especially IR design. It is very difficult to change beam energy within a month.

● Phase 2.0

- 最初の入射、ビームを蓄積できる軌道を見つける。
- 各種ハードウェア、およびソフトウェアの試験、0バケツの決定等
- 3 BPMs、BPMゲインマッピング、QuadBPM
- QCSの誤差測定と補正、全体的な光学測定と補正、バンプ軌道による誤差診断
- 真空焼き (100 Ah、約 1 ヶ月)

● Phase 2.2

- 衝突点ベータを絞る(8x8)。
- ditheringシステムとiBumpなどの試験
- IPノブ (ウエスト、分散、X-Y結合) の試験
- ビーム・バックグラウンドのスタディ
- Luminosity Tuning

● Phase 2.3

- 衝突点ベータを絞る(4x8)。
- 光学測定および補正、バンブ軌道による誤差診断
- ビーム・バックグラウンドのスタディ
- Luminosity Tuning

● Phase 2.4

- 衝突点ベータを絞る(4x4)。
- 光学測定および補正、バンブ軌道による誤差診断
- ビーム・バックグラウンドのスタディ
- Luminosity Tuning

● 衝突点ベータを絞る試験

- 最終的なパラメータまで絞る。



Schedule of February - July, 2018

→ e+

→ LER

“tentative” and “informal”

→ e-

→ HER

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	→ e-																							
DR	e+																							
BT																								
2.0																								
2.1																								
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First collision (beam-beam deflection)

beta squeezing down to the final

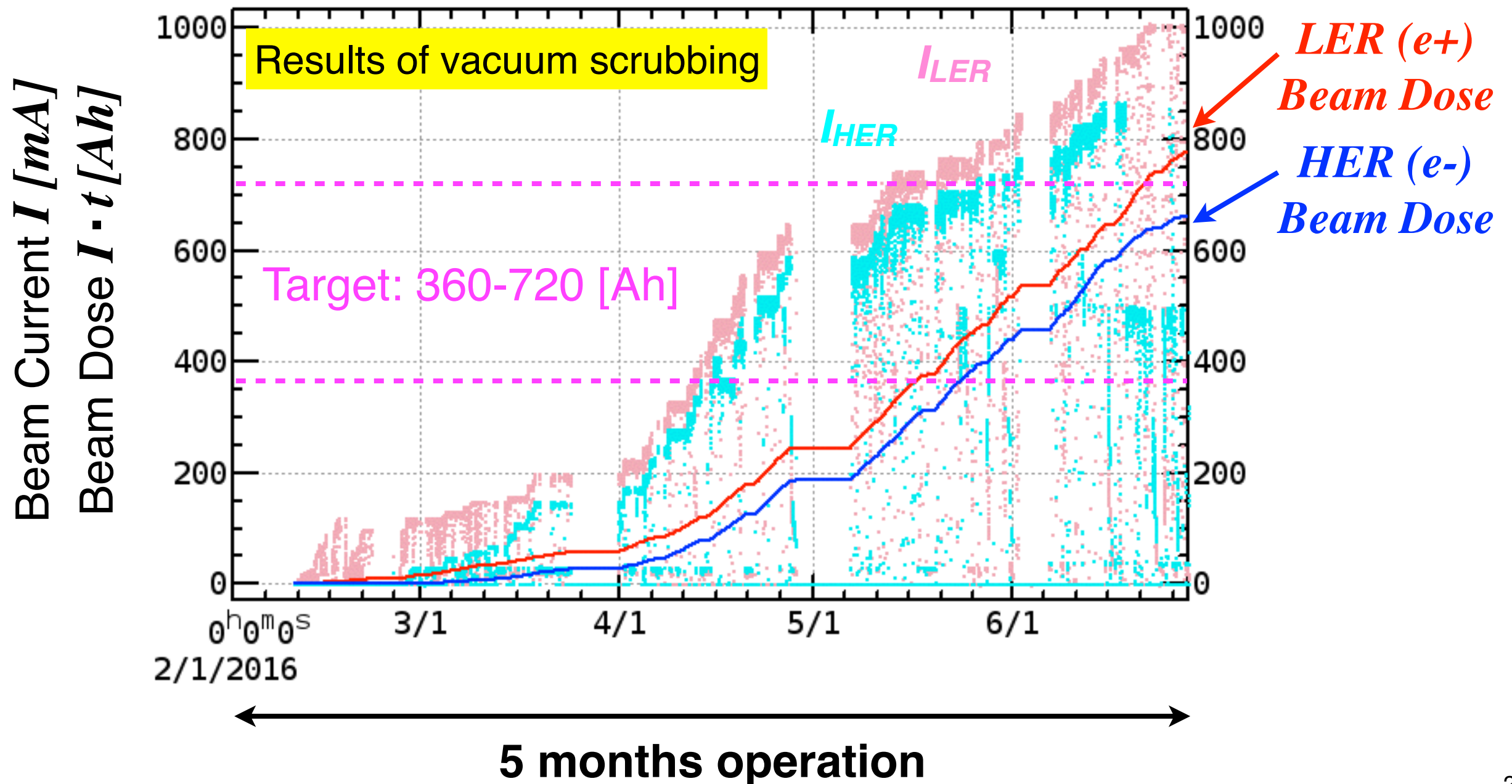
collision tuning

Beam current of 1 [A] and Beam dose of 780 [Ah] were achieved in LER.

Ave. pressure: $\sim 10^{-6}$ [Pa]

Beam current of 0.87 [A] and Beam dose of 660 [Ah] were achieved in HER.

Ave. pressure: $\sim 10^{-7}$ [Pa]



	Phase 2.0		Phase 2.3 (4x8)				Phase 2.4 (4x4)	
	LER	HER	LER	HER	LER	HER	LER	HER
$I_L \times I_H, n_b$	0.28 A	0.2 A	1 A x 0.8 A, 1576 bunches (3-bucket spacing)					
β_x^* [mm]	384	400	128	100	128	100	128	100
β_y^* [mm]	81	81	2.16	2.4	2.16	2.40	1.08	1.20
$\varepsilon_y/\varepsilon_x$ [%]	7.0		5.0		1.4		0.7	
ξ_x	0.0034	0.0020	0.0052	0.0020	0.0053	0.0021	0.0053	0.0021
ξ_y	0.0334	0.0337	0.0257	0.0264	0.0484	0.0500	0.0496	0.0505
I_{bunch} [mA]	0.18	0.13	0.64	0.51	0.64	0.51	0.64	0.51
L [cm ⁻² s ⁻¹]	1.1×10^{32}		1×10^{34} (tentative target)		2×10^{34}		4×10^{34}	
L_{sp} [cm ⁻² s ⁻¹ /mA ²]	3×10^{30}		1.97×10^{31}		3.94×10^{31}		7.88×10^{31}	