Phase 2 Commissioning Plan

Y. Ohnishi / KEK
@ KEKB Review 2018

Note: IP feedback system and the dithering system are omitted in this talk.
See T. Oki's talk at the 19th KEKB Review.

Verification of Nano-Beam Scheme

Low Emittance with Large Piwinski Angle

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

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

Beam-Beam Parameter, $\xi_y > 0.05$

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

Background from stored beam : lifetime ~ 40 min in LER for 1 A
Background from injected beam
Movable collimator system works to reduce backgrounds

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

Verification of Nano-Beam Scheme

- Step 1
  - Detuned beta at IP to find closed orbit as much as possible.
  - Test of QCS system(Final Focusing), Optics measurements and corrections
  - Local bumps in IR, TbT measurements, Final Quads excitation, …
  - X-Y couplings and vertical dispersions should be corrected in the IR region consistent with those of arc sections.
- Step 2
  - Collision tuning with squeezing beta at IP and luminosity run
  - Tentative target is 10^{34} $cm^{-2}s^{-1}$ (KEKB design)
    - Beam current for LER is 1 [A] and 0.8 [A] for HER (design of 30 %)
  - Back ground study for Belle II detector with collimator controls
- Step 3 (very challenging)
  - Further squeezing beta at IP.
  - Target luminosity is 2 x 10^{34} $cm^{-2}s^{-1}$ (recorded peak at KEKB)

Beta Functions in Phase 2

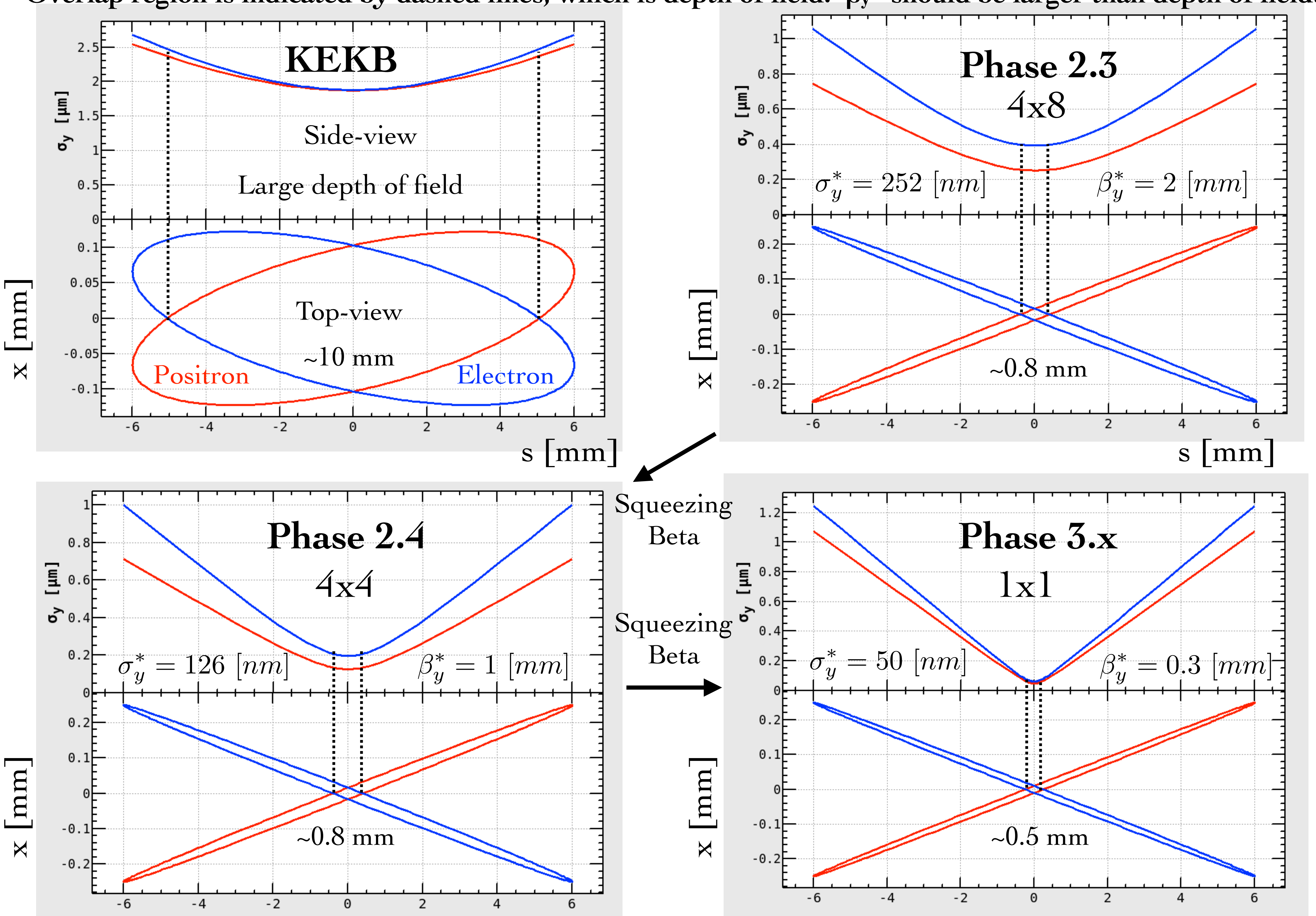
Phase 2.0: No collision, extremely large beta at IP, do IR optics study
Phase 2.1: Vacant phase (for backup study, $\beta_y^* \sim \sigma_z$ if necessary)
Phase 2.2 - 2.4: Collision tuning with background study

Beta functions in the horizontal (x) and vertical (y) direction

Phase	LER			HER			
	β_x^* [mm]	β_y^* [mm]	scale	β_x^* [mm]	β_y^* [mm]	scale	
2.0*	384	48.6	12 x 180	400	81	16 x 270	Step 1
2.2	256	2.16	8 x 8	200	2.4	8 x 8	Step 2
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	Step 2
3.x	32	0.27	1 x 1	25	0.30	1 x 1	Ultimate

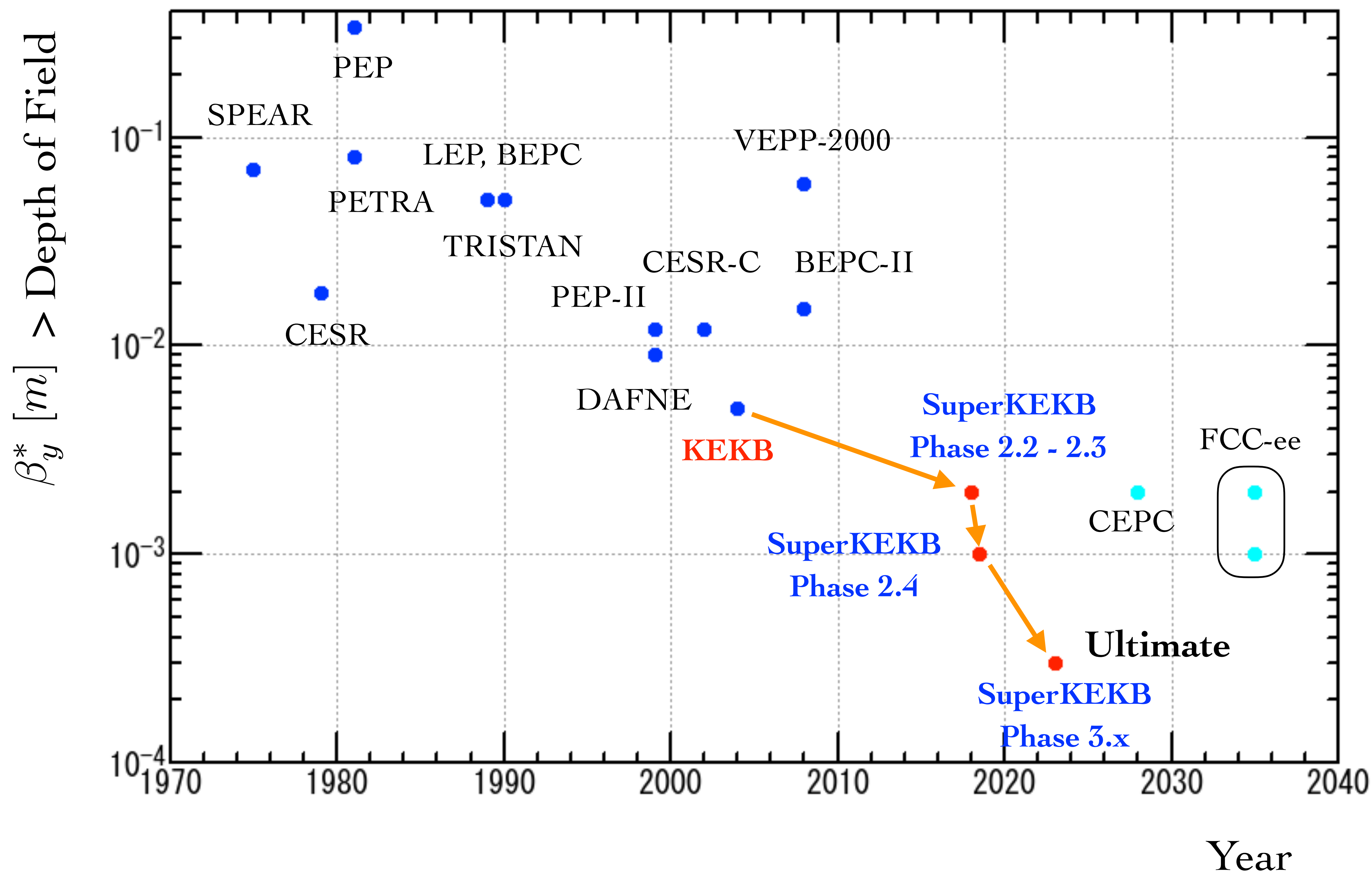
Beta Function at IP and Depth of Field

Overlap region is indicated by dashed lines, which is depth of field. β_y* should be larger than depth of field.



History of Vertical Beta Function at IP

SuperKEKB is trying to make the smallest β_y* in the world !



Piwinski Angle

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

Large PA can make small β_y^*.

	KEKB (2006)		Phase 2.2		Phase 2.3		Phase 2.4		Phase 3.x	
	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	1.72×10^{34} cm^{-2}s^{-1}		10^{34} cm^{-2}s^{-1}		2×10^{34} cm^{-2}s^{-1}		4×10^{34} cm^{-2}s^{-1}		8×10^{35} cm^{-2}s^{-1}	

No crab-crossing

Large Piwinski Angle

cf. DAFNE: PA = 2

Luminosity and Beam-Beam Parameter

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
f_0: revolution frequency
R_L: reduction factor
σ*: beam spot-size at IP
I_b: bunch beam current
ϕ_x: half crossing angle

Specific Luminosity

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

Beam-Beam Parameter and Luminosity

small β_y^* requires small ε_y to keep ξ_y

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

$$L = \frac{\gamma_+}{2er_e}\left(1 + \frac{\sigma_y^*}{\sigma_{x,eff}^*}\right) \frac{n_b I_{b+} \xi_{y+}}{\beta_y^*} \frac{R_L}{R_{\xi_y}} \propto \frac{N_+ N_-}{\sigma_z \phi_x \sqrt{\varepsilon_y \beta_y^*}}$$

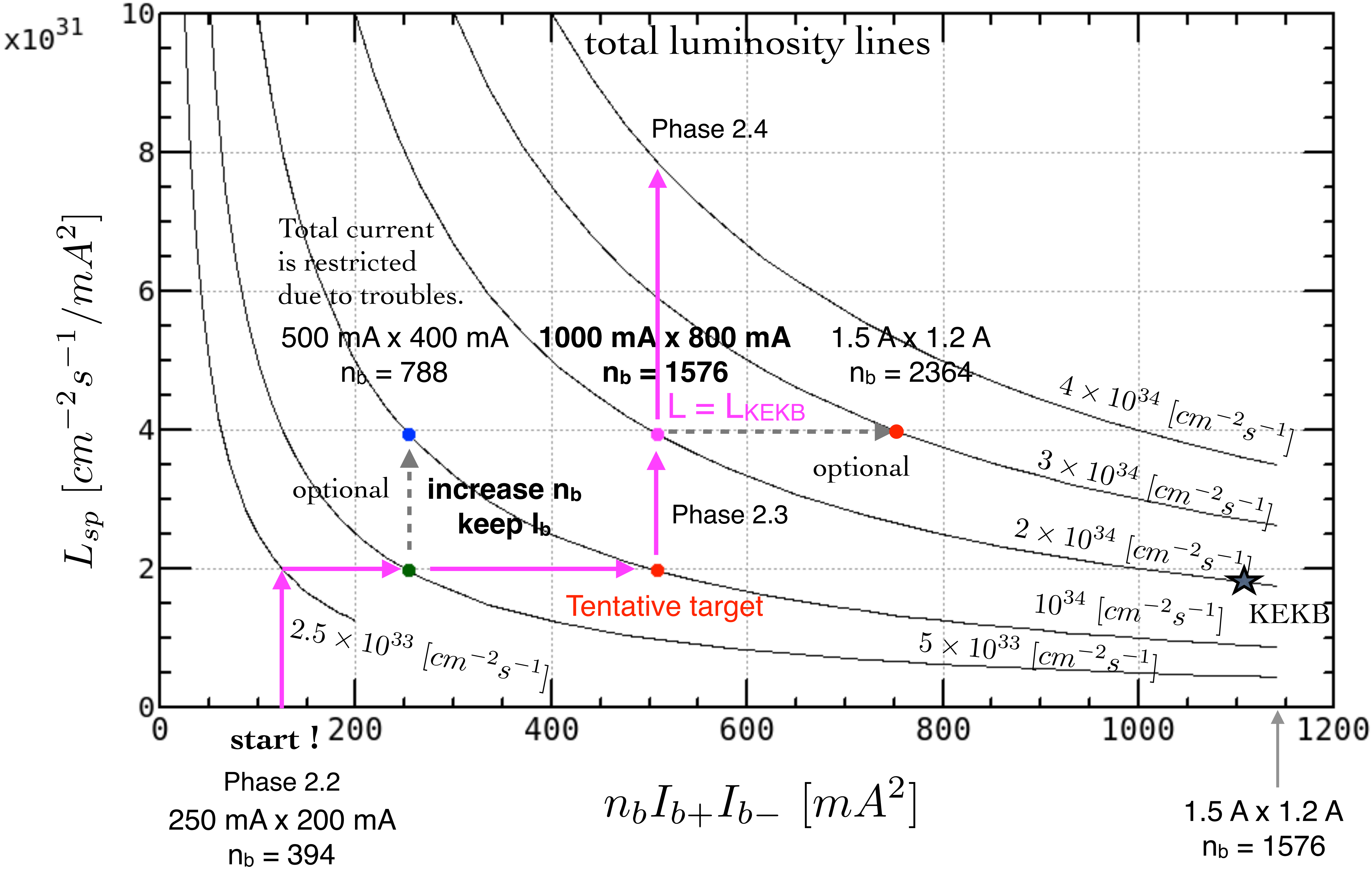
Machine Parameters

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.x (1x1)	
	LER	HER	LER	HER	LER	HER	LER	HER
I_L x 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 [$cm^{-2}s^{-1}$]	**1×10^{34} (tentative target)**		2×10^{34}		4×10^{34}		8×10^{35}	
L_{sp} [$cm^{-2}s^{-1}/mA^2$]	1.97×10^{31}		3.94×10^{31}		7.88×10^{31}		2.14×10^{32}	

Travel Guide for Phase 2 at SuperKEKB

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



Requirements for LINAC in Phase-2

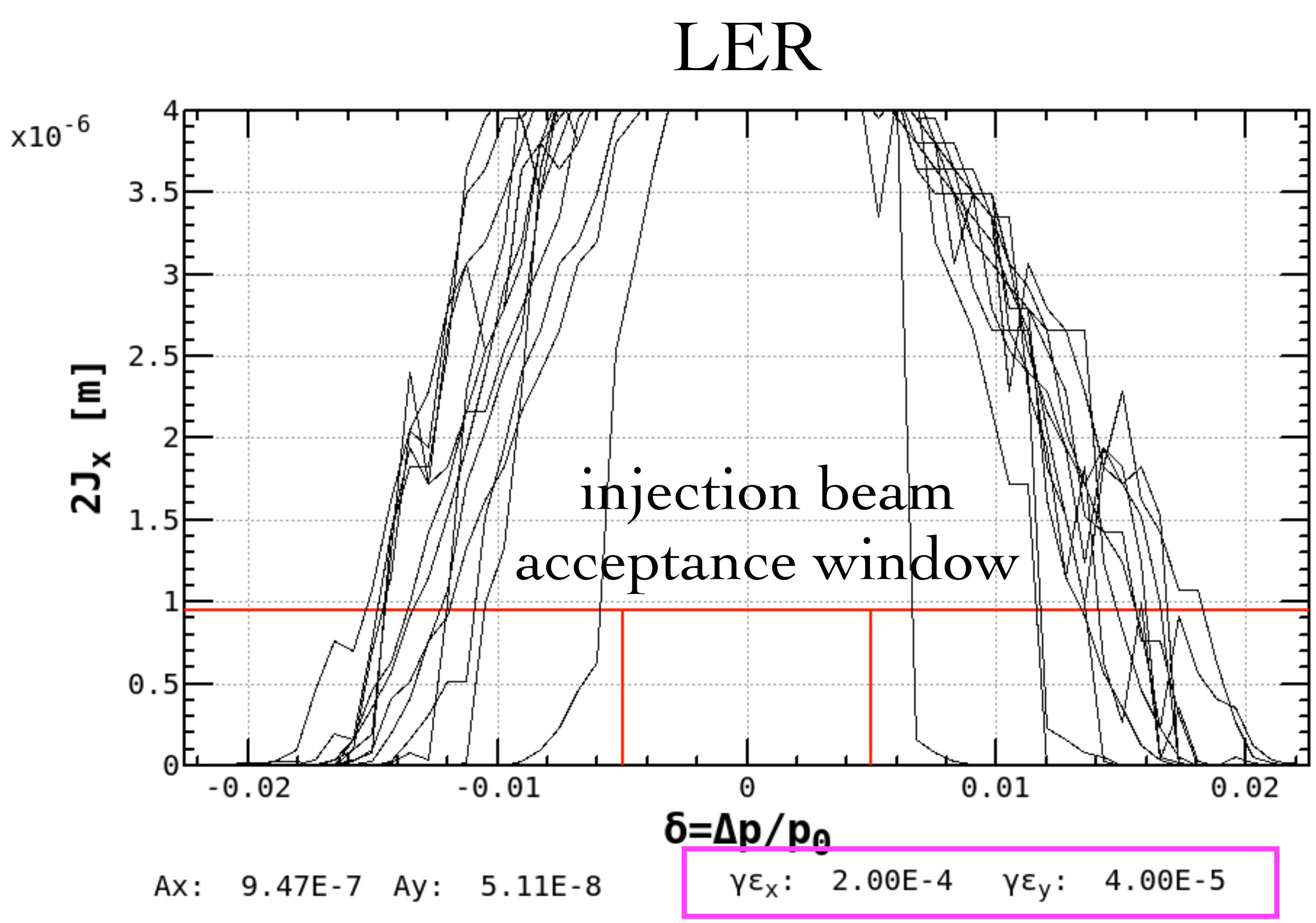
	Positron LER 4 GeV	Electron HER 7 GeV
Normalized emittance*1 $\gamma\beta\varepsilon_x$ / $\gamma\beta\varepsilon_y$	200 / 40 [μm] with *DR*	150 / 150 [μm]*2
Energy spread*3 σ_δ	0.16 [%]	0.10 [%]
Bunch charge at injection point*4	0.5 [nC]	1.0 [nC]
Ring Acceptance	$A_x = 9.4 \times 10^{-7}$ m $A_y = 6.8 \times 10^{-9}$ m	$A_x = 7.1 \times 10^{-7}$ m $A_y = 1.1 \times 10^{-7}$ m

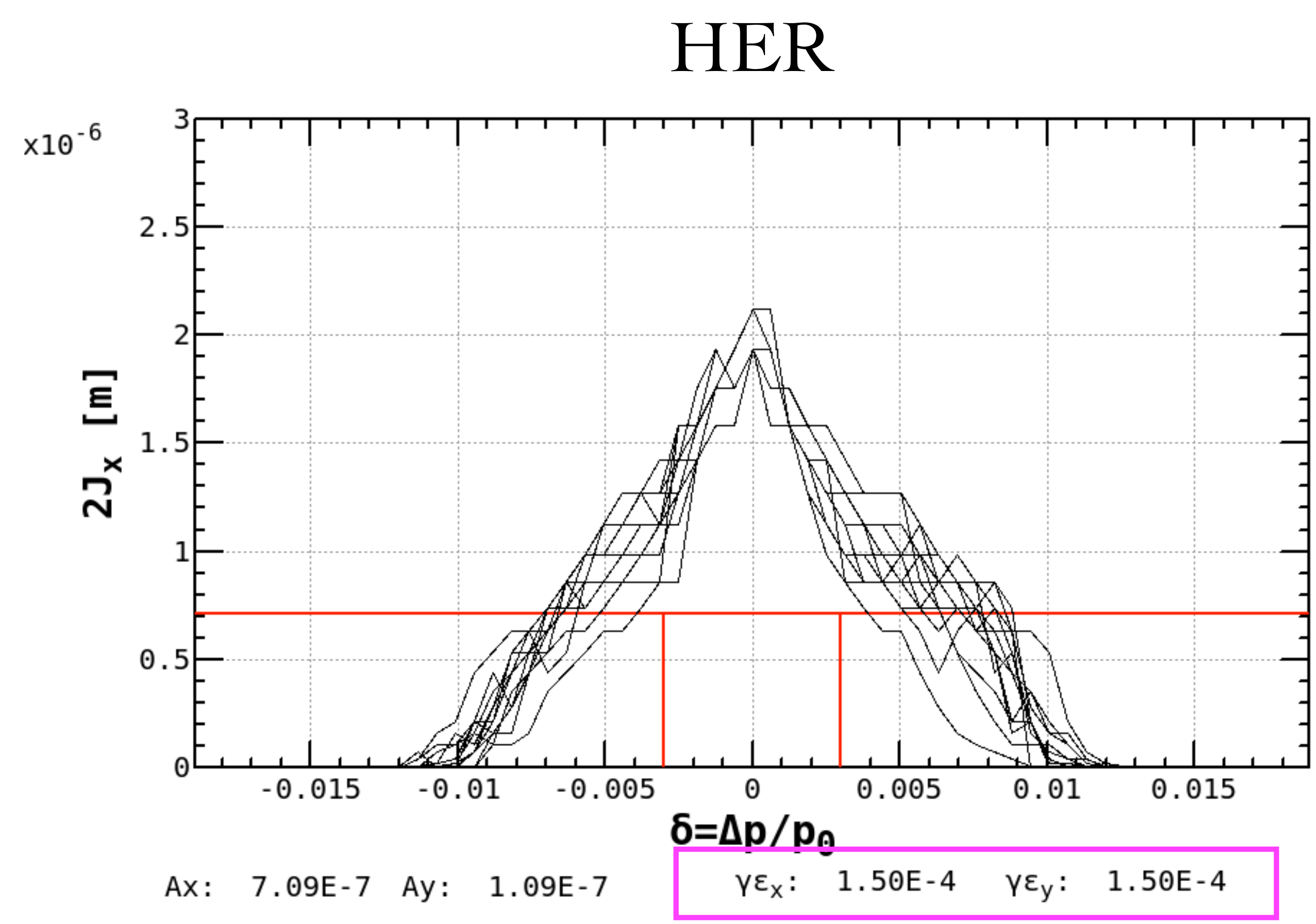
*1 Area of 95.4 % occupied by particles defines ±2σ. The emittance is derived from σ.
*2 100 μm is preferable for Phase 2.4(4x4).
*3 Energy acceptance is 3 σ.
*4 Charge intensity of one bunch. Double for 2-bunch injection.

Injection Aperture: Phase 2.3

Phase 2.3 (4x8 βeta) no beam-beam

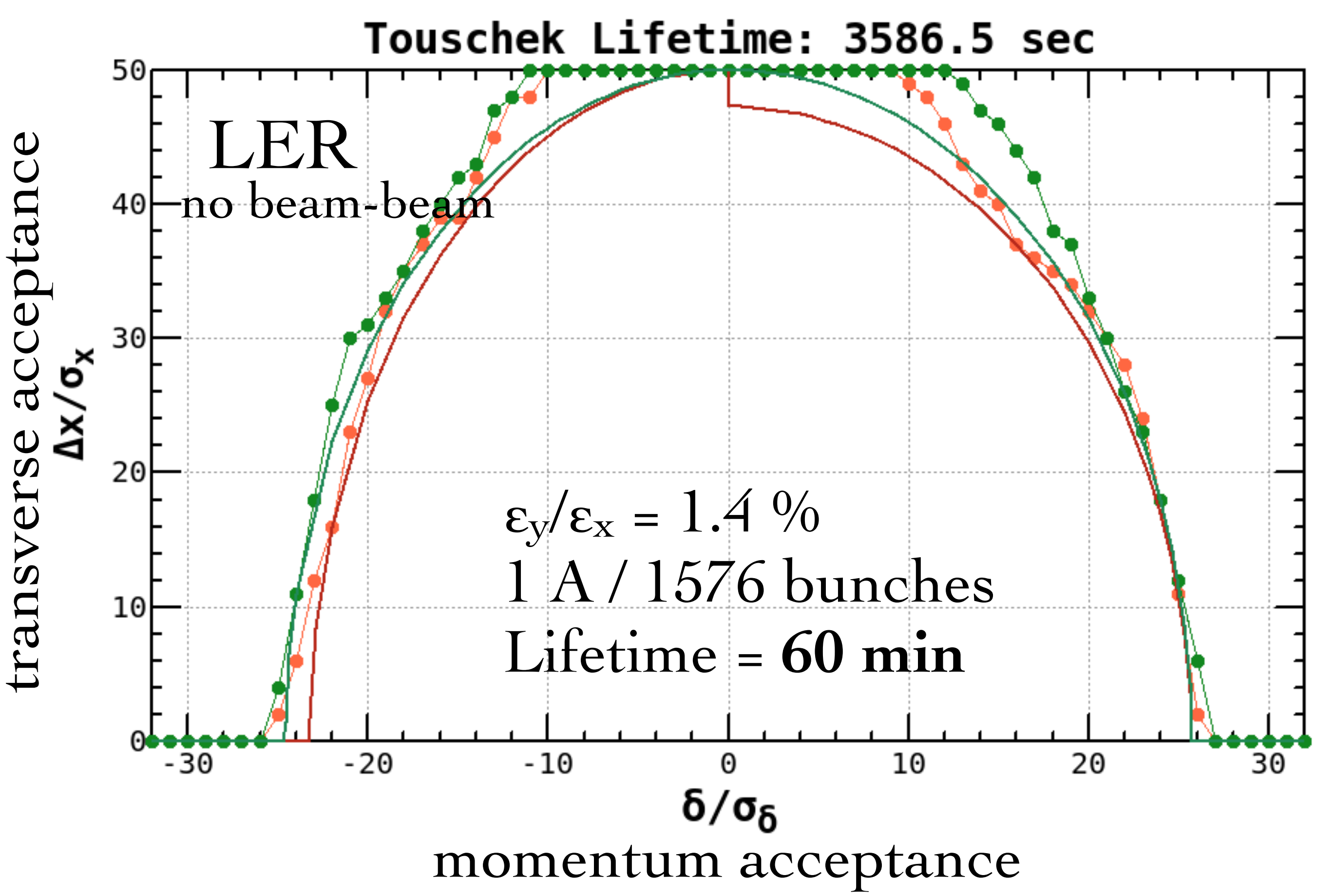
sextupole field error : 1 % of rated current

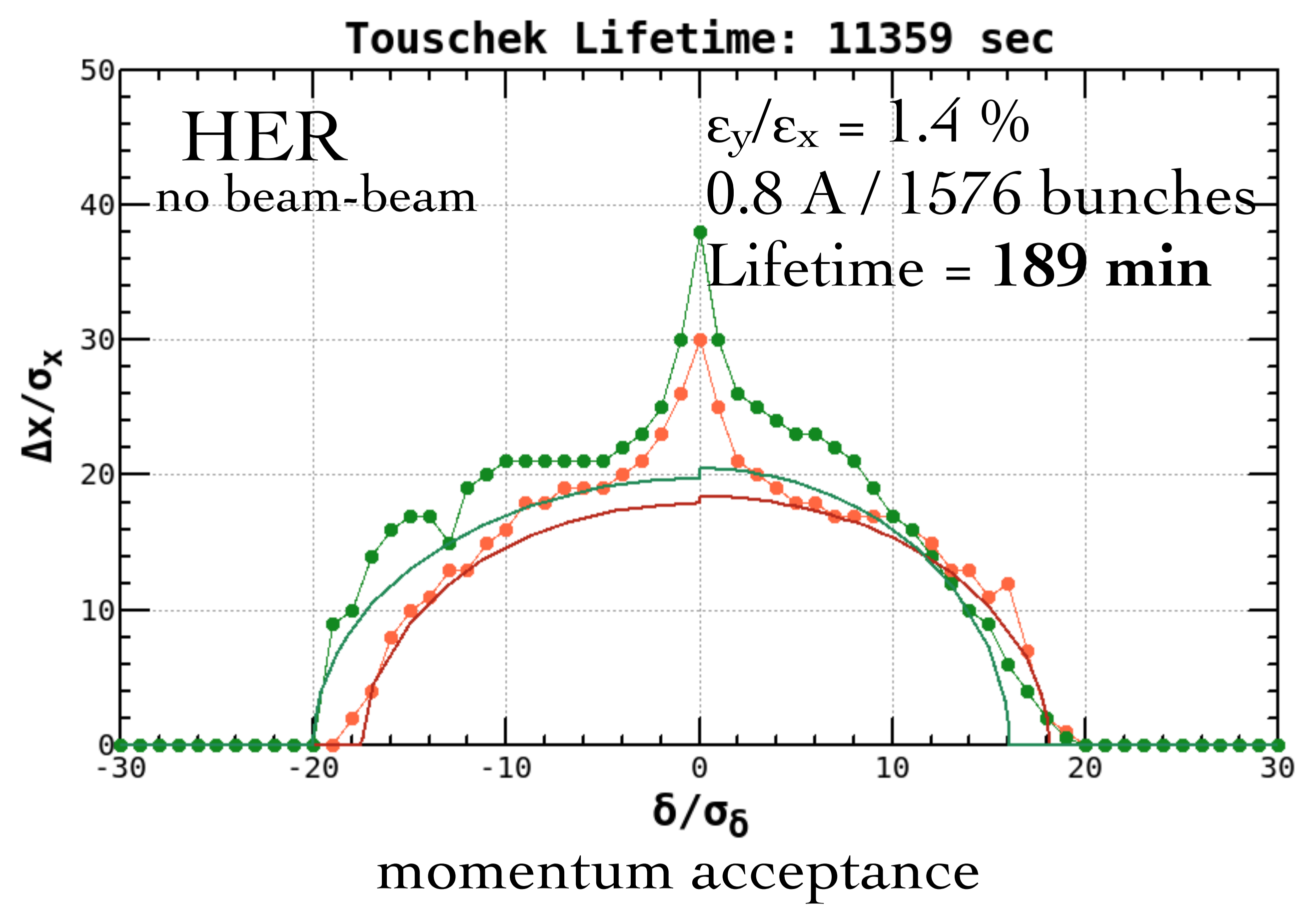




normalized emittance of injection beam [m]

Phase 2.3 (4x8 βeta)





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

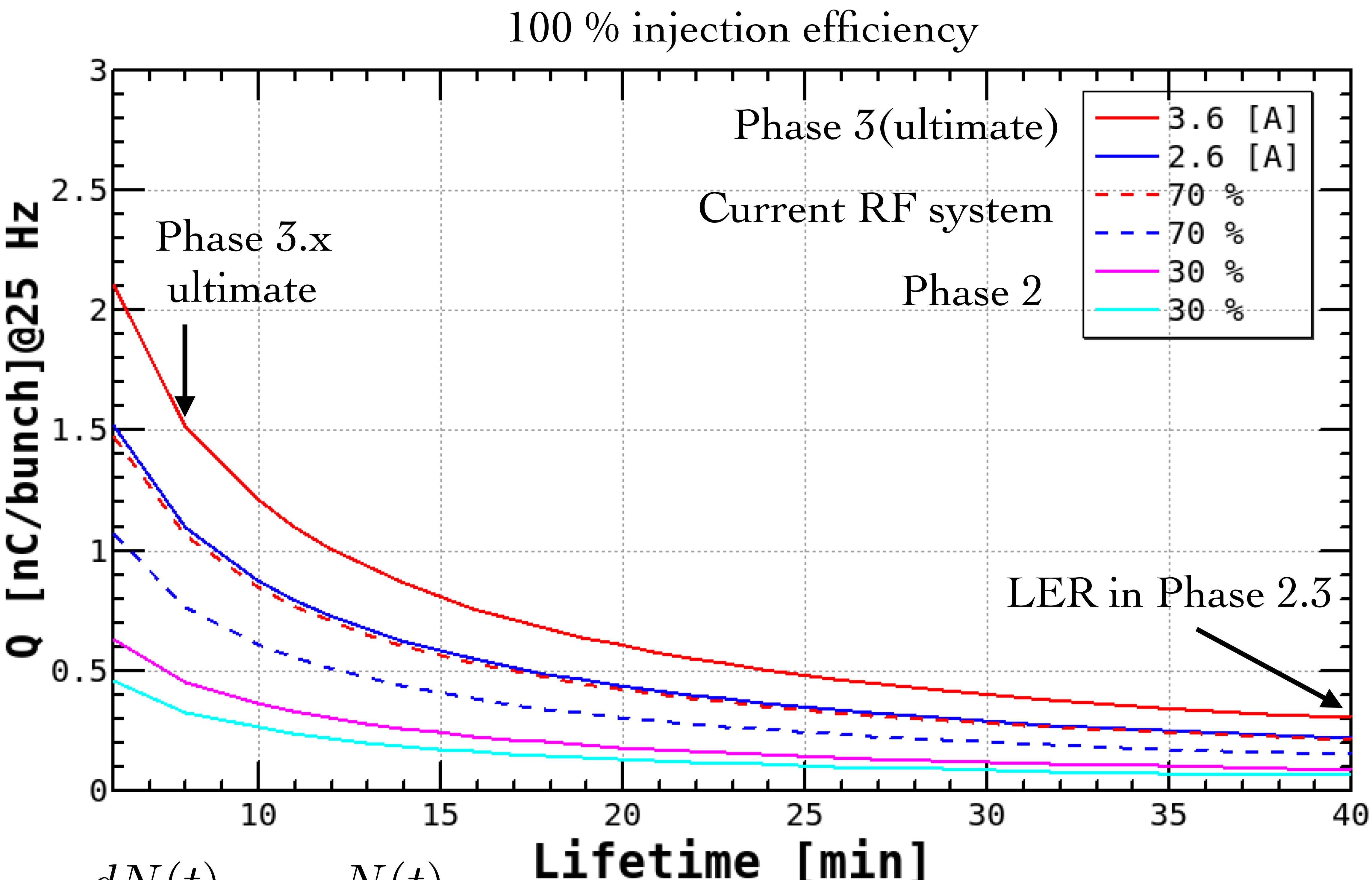
The machine error reduces the dynamic aperture about 10 - 20 %.

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

↓ Loss rate = 26 GHz (1 A)

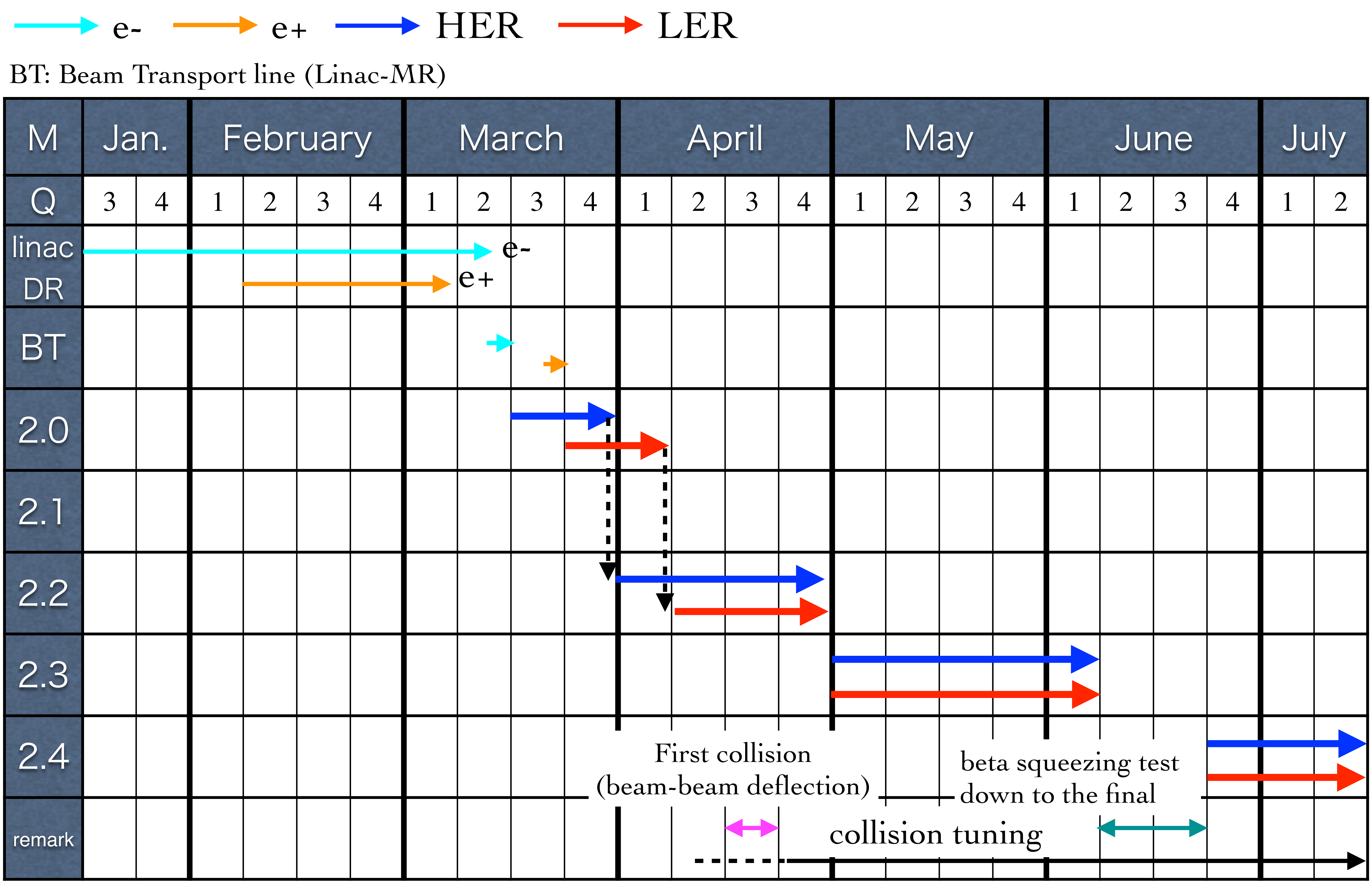
↓ Loss rate = 5.6 GHz (0.8 A)

Lifetime and Injection Charge



$$\frac{dN(t)}{dt} = -\frac{N(t)}{\tau}$$

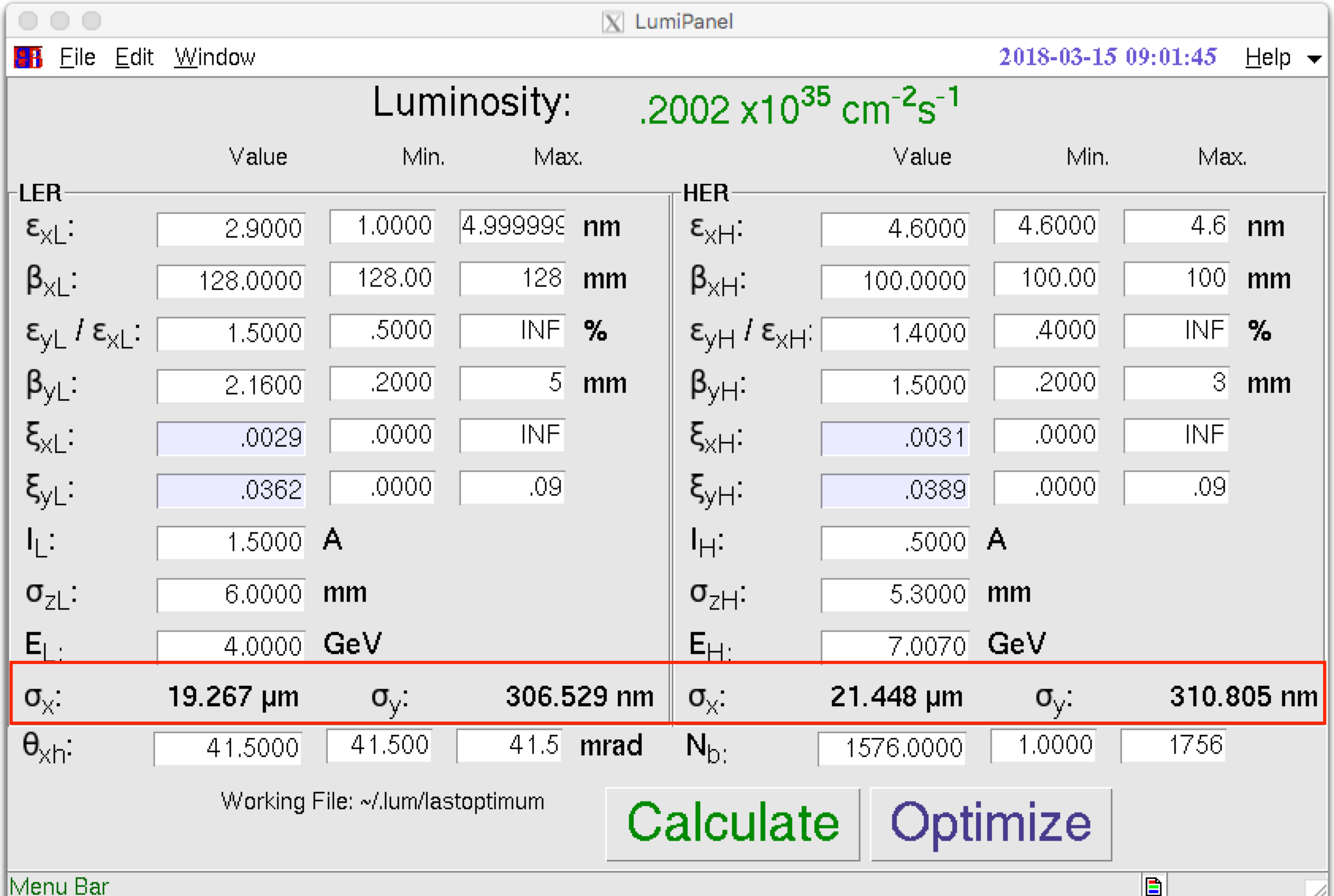
Schedule of February - July, 2018



Appendix

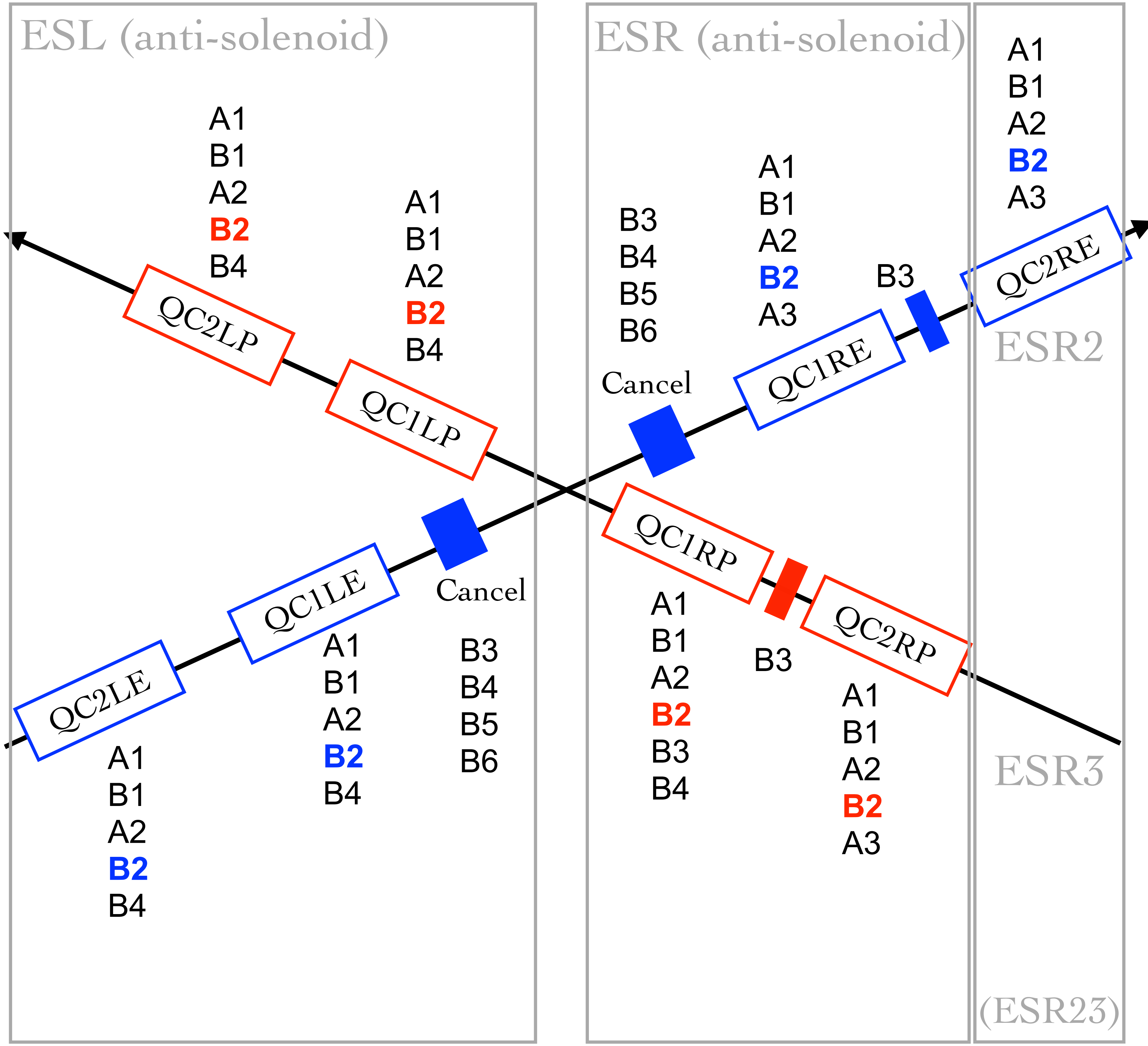
Alternative Machine Parameters

The vertical beam size of LER and HER are same.



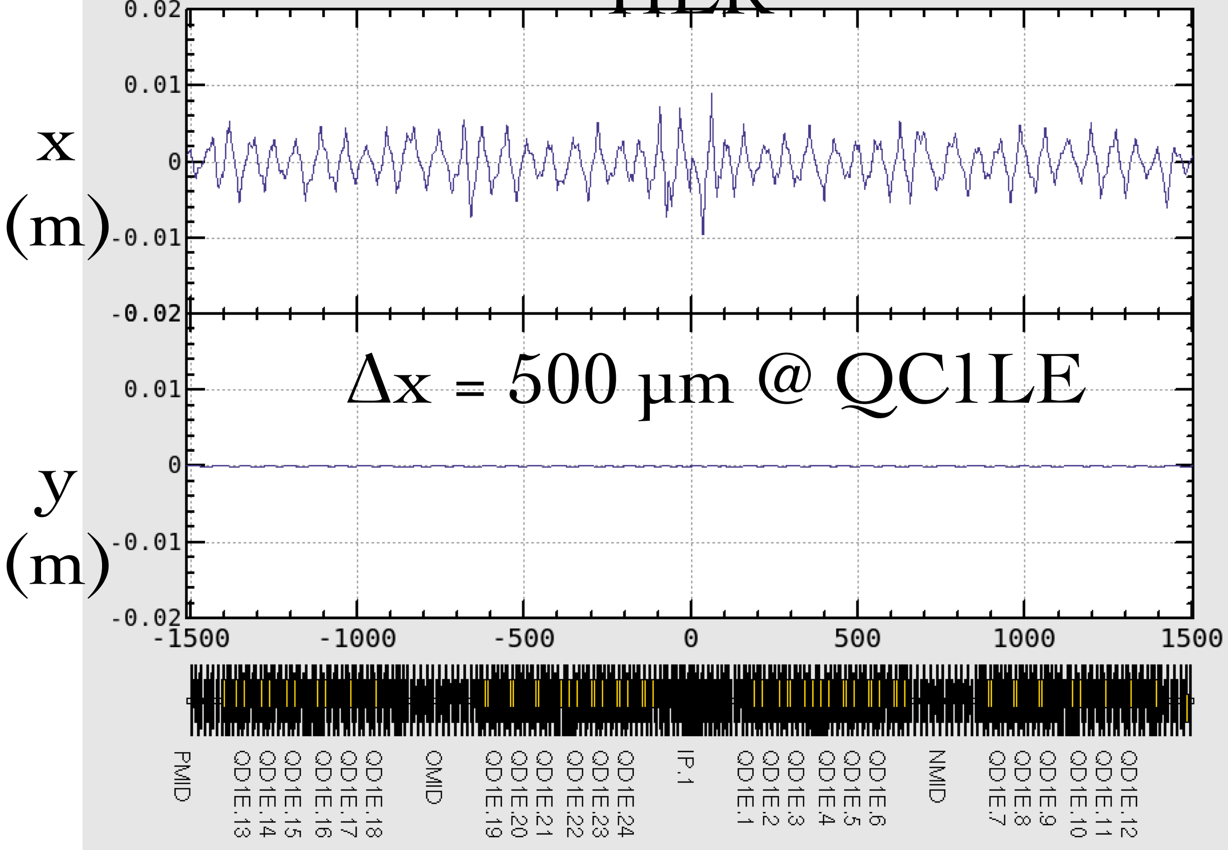
QCS Setup

Total: 51 coils

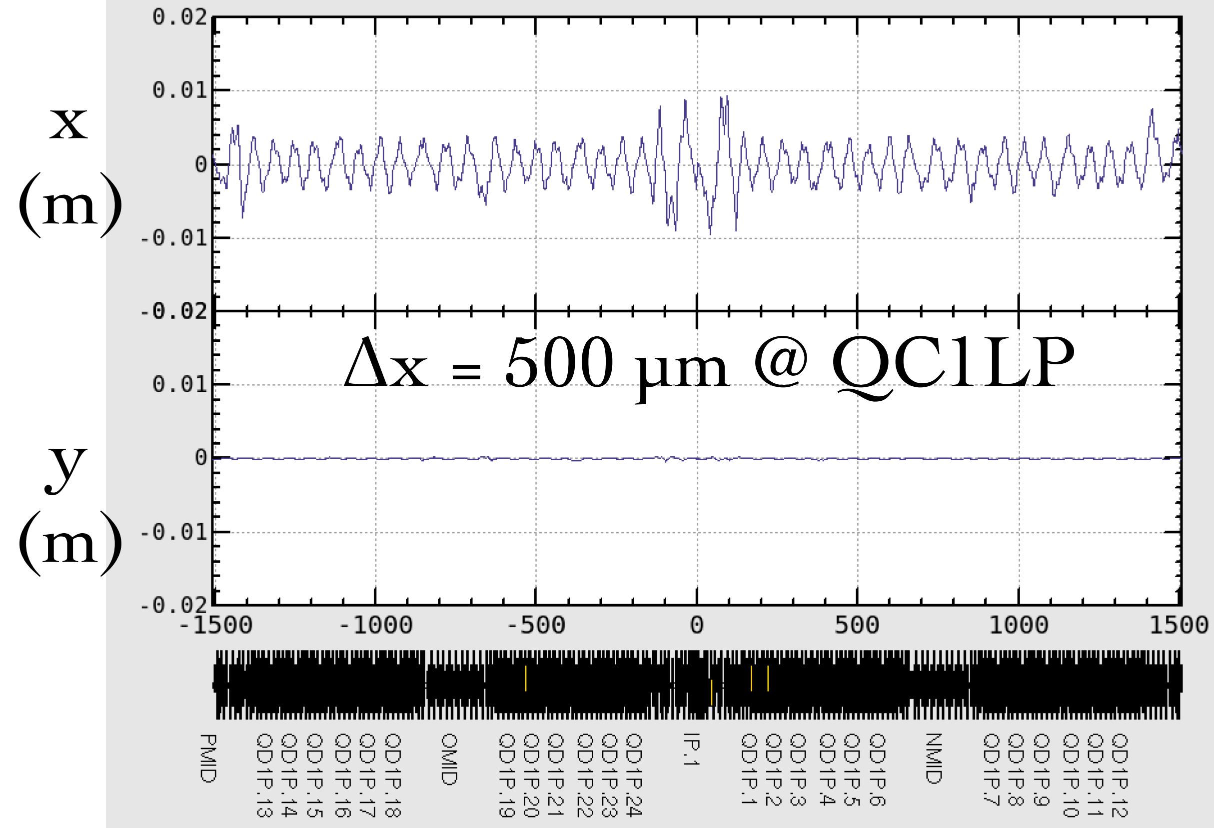


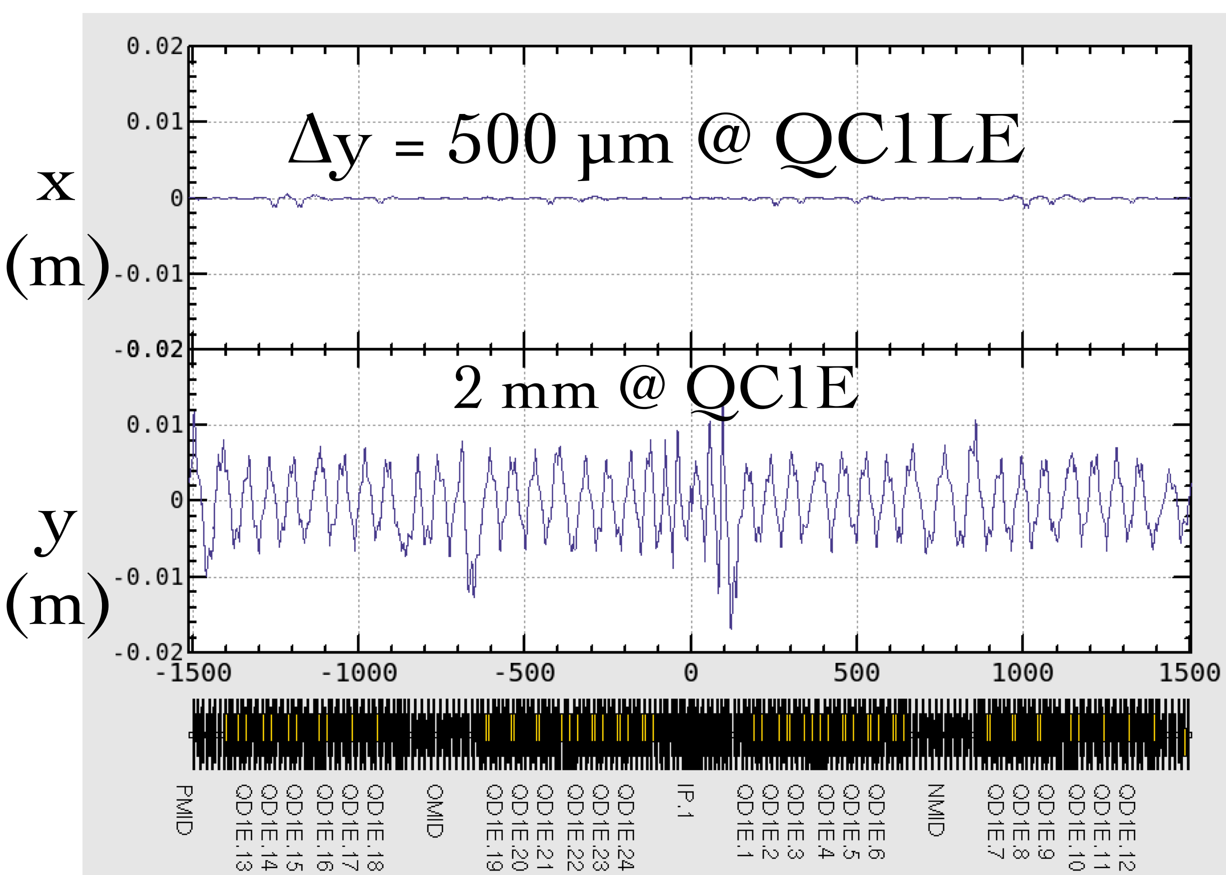
Misalignment of QCS in Phase 2.0

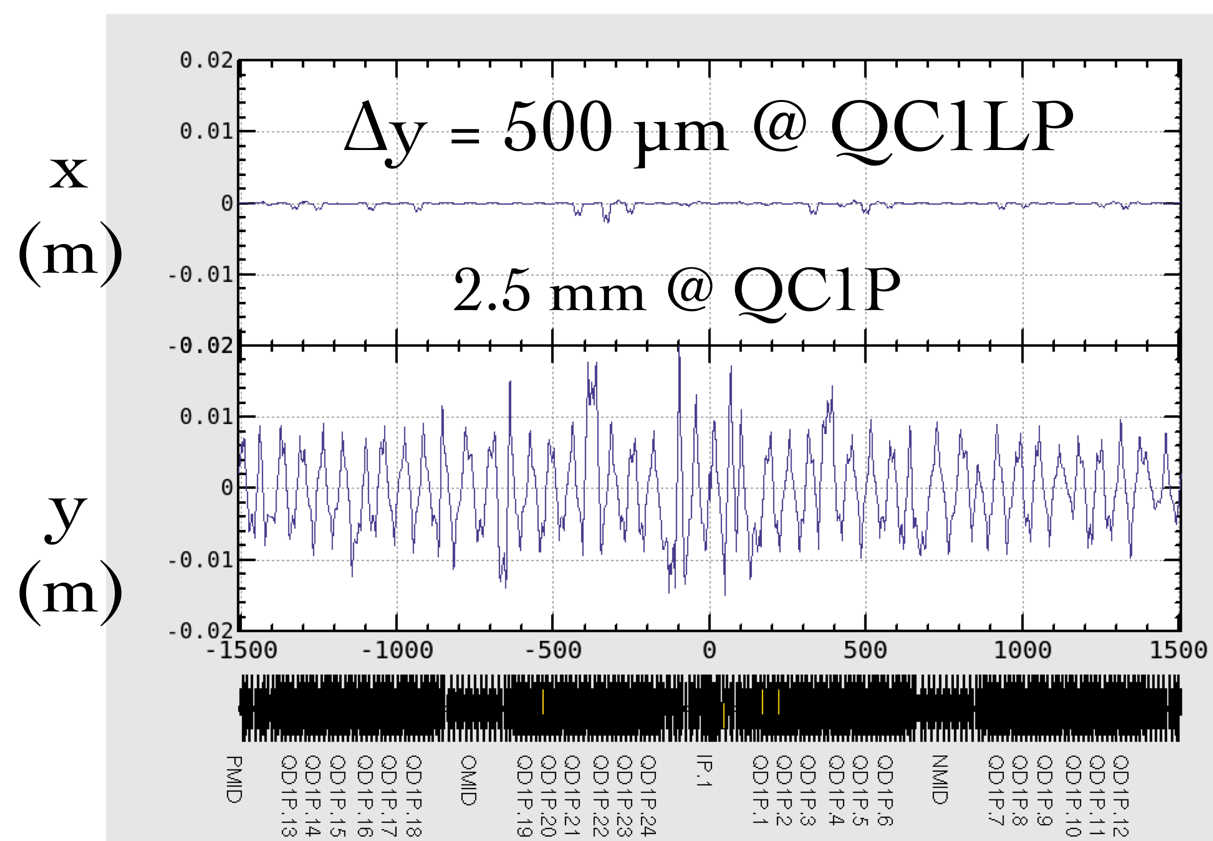
HER



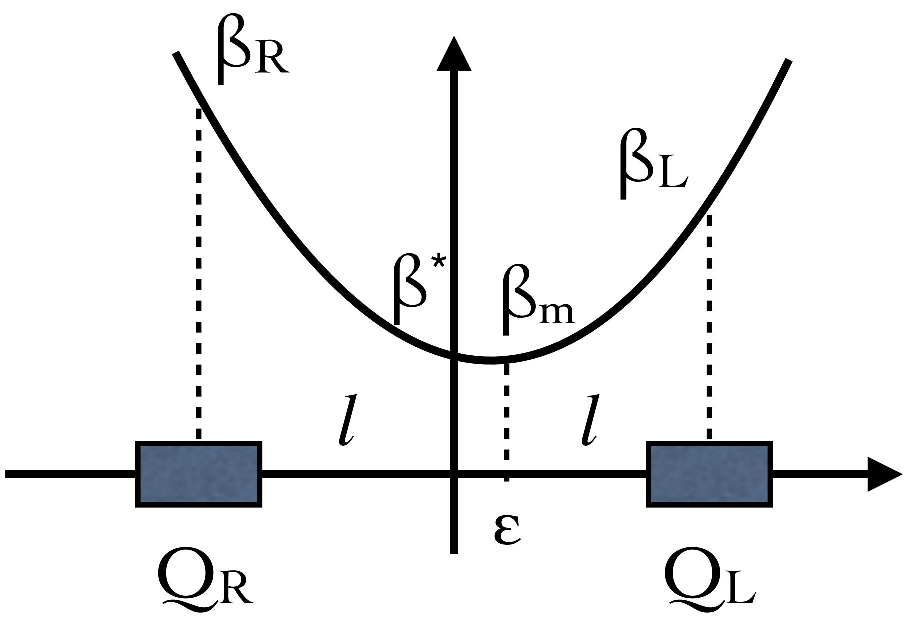
LER







Beta Measurement by Quadrupole Excitation



$$\beta_L = \beta_m + \frac{(l-\varepsilon)^2}{\beta_m}$$

$$\beta_R = \beta_m + \frac{(l+\varepsilon)^2}{\beta_m}$$

$$\beta_R - \beta_L = \frac{4l}{\beta_m}\varepsilon$$

$$\Delta\nu_L = \frac{\beta_L}{4\pi}\Delta K$$

$$\Delta\nu_R = \frac{\beta_R}{4\pi}(-\Delta K)$$

β_L and β_R are averaged β functions

$$\varepsilon = \frac{\beta_m \pi}{l\Delta K}(\Delta\nu_L + \Delta\nu_R)$$

$$\beta^* = \beta_m + \frac{\varepsilon^2}{\beta_m} \longrightarrow \beta^* = \beta_m \left\{ 1 + \left(\frac{\pi}{l\Delta K}\right)^2 (\Delta\nu_L + \Delta\nu_R)^2 \right\}$$

LER

l = 0.93 β_L = 338.7 [m] K1 = -1.7213 [1/m]

Phase 2.3

β_R = 338.6 [m] K1 = -1.7229 [1/m]

SAD for Phase 2.3:

QC1LP : ΔK1/K1 = +0.1 % $\Delta\nu_y$ = +0.0374 β_L = 273.14 [m]

QC1RP : ΔK1/K1 = +0.1 % $\Delta\nu_y$ = +0.0374 β_L = 273.06 [m]

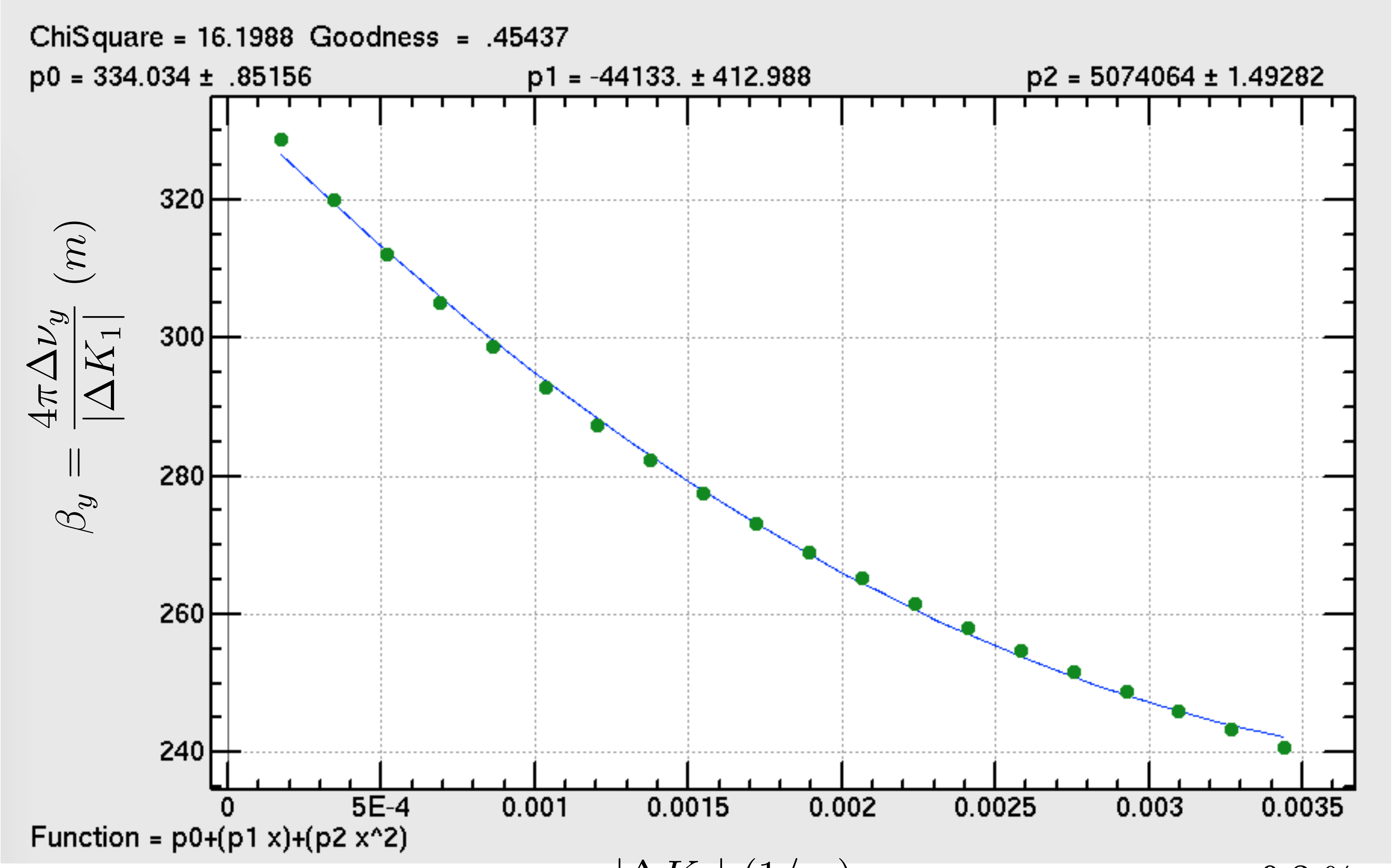
If we change -0.1 %, beam iis unstable.
(tune should be changed higher than 0.57)

If we apply +0.1 % for left-side and -0.1 % for right-side,
the tune shift should be canceled.

$$\beta^* = \beta_m \left\{ 1 + \left(\frac{\pi}{l \Delta K} \right)^2 (\Delta\nu_L + \Delta\nu_R)^2 \right\}$$

QC1LP (LER, Phase 2.3)

Accuracy is 1 ~ 2 % β_L = 338.7 [m] average



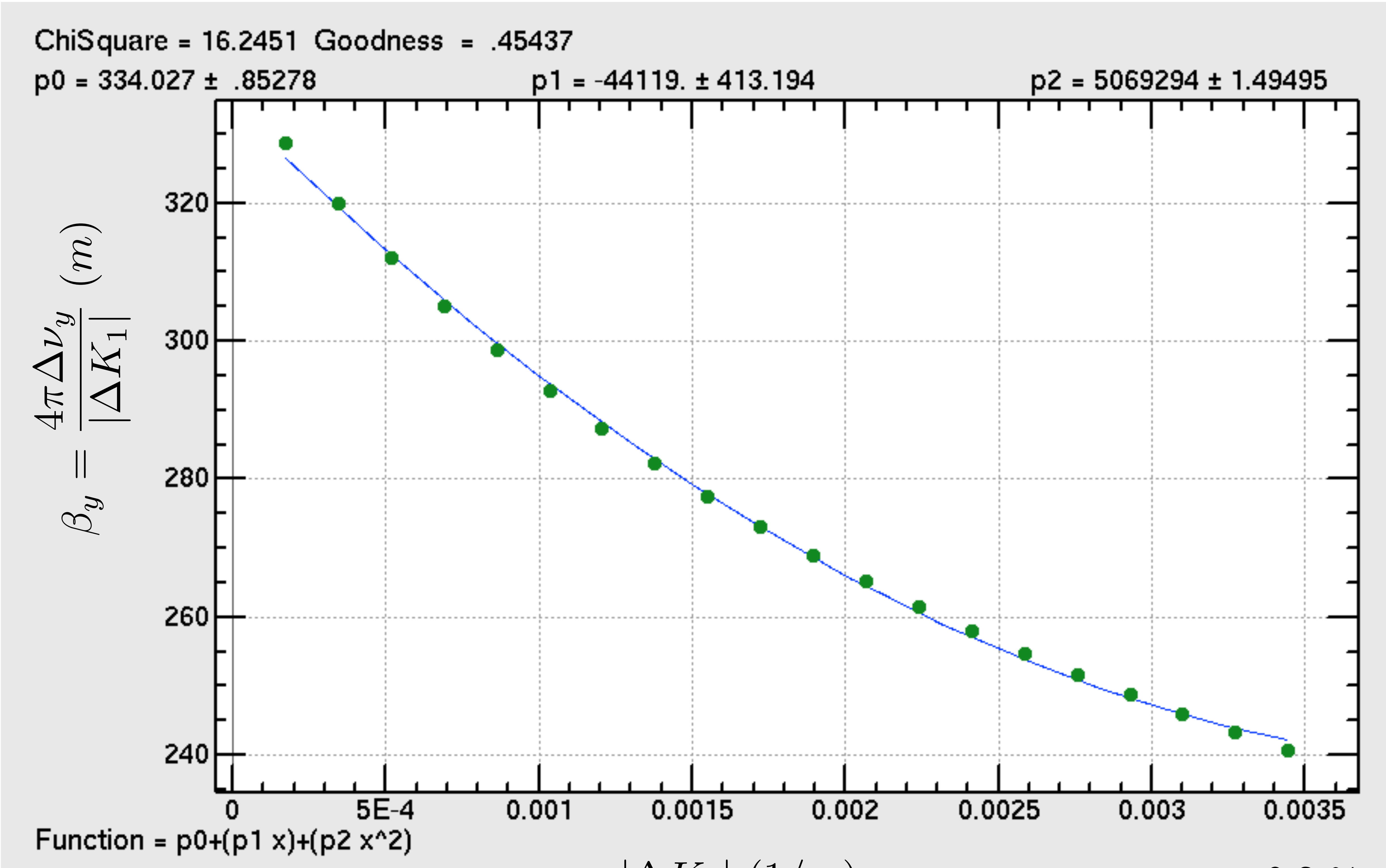
$$\beta_y = \frac{4\pi\Delta\nu_y}{|\Delta K_1|}\ (m)$$

$|\Delta K_1|\ (1/m)$

0.2 %

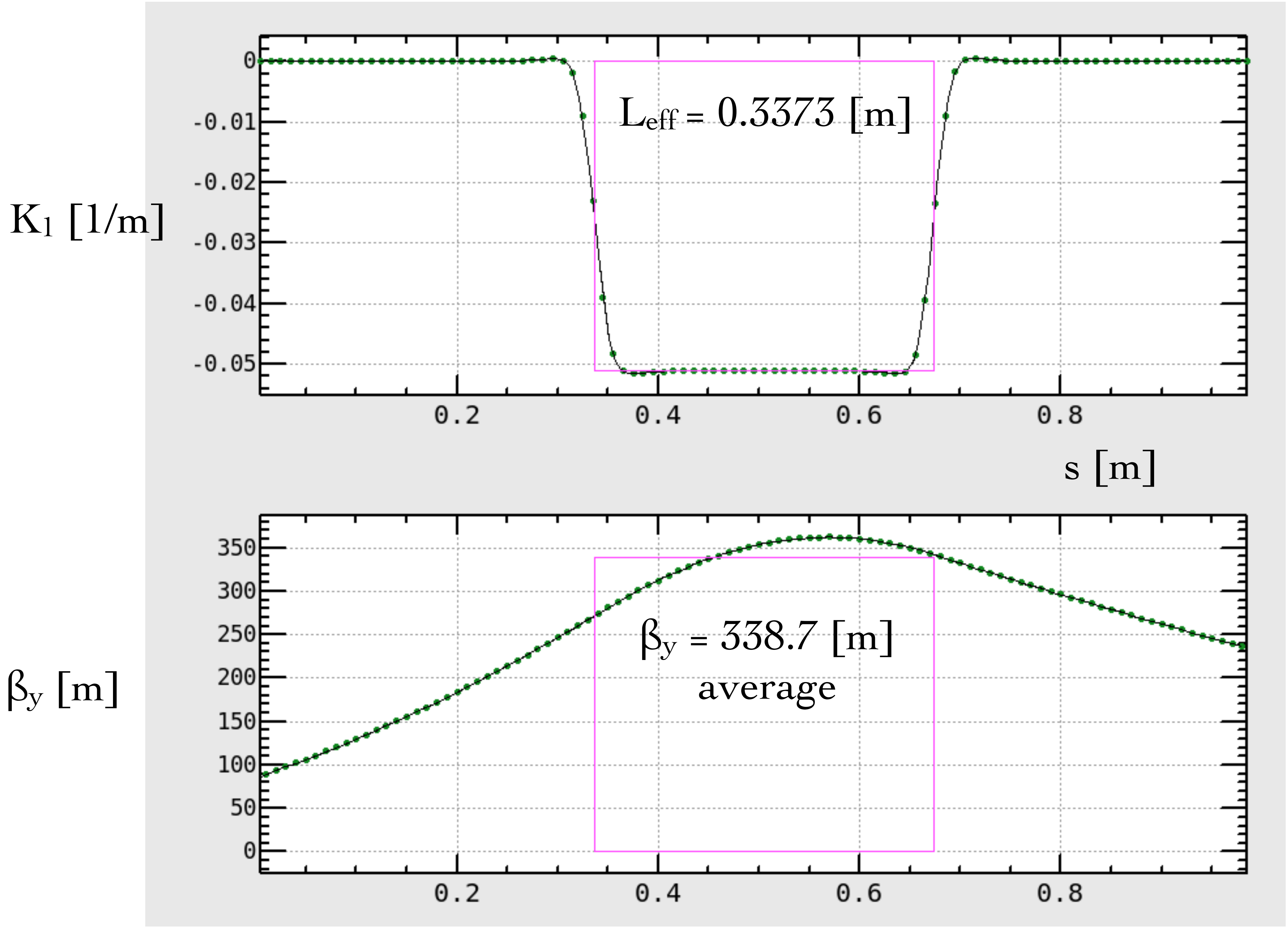
QC1RP (LER, Phase 2.3)

β_R = 338.6 [m]   average



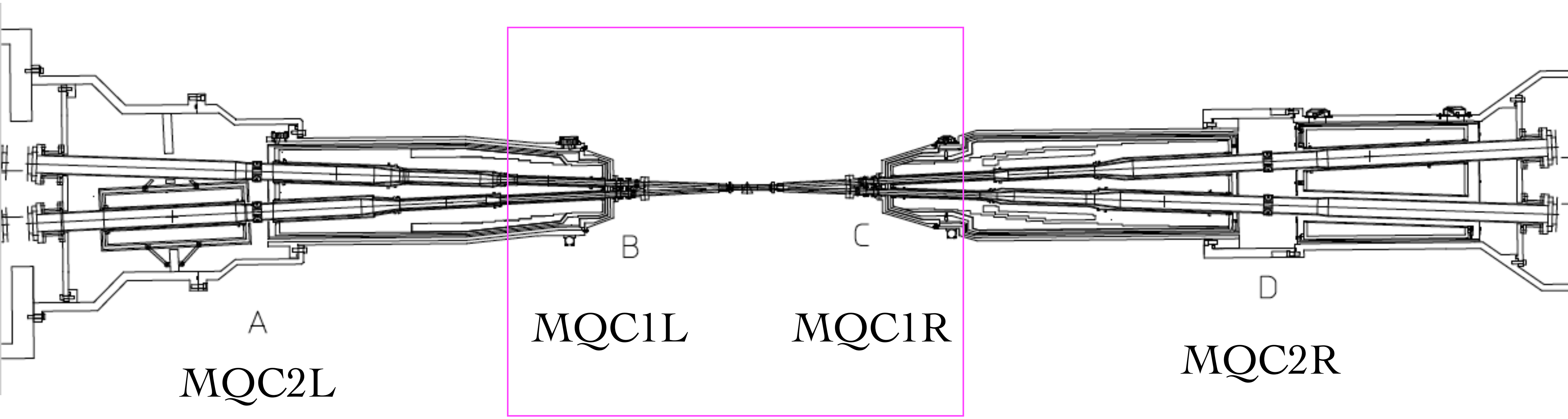
$|\Delta K_1|\ (1/m)$

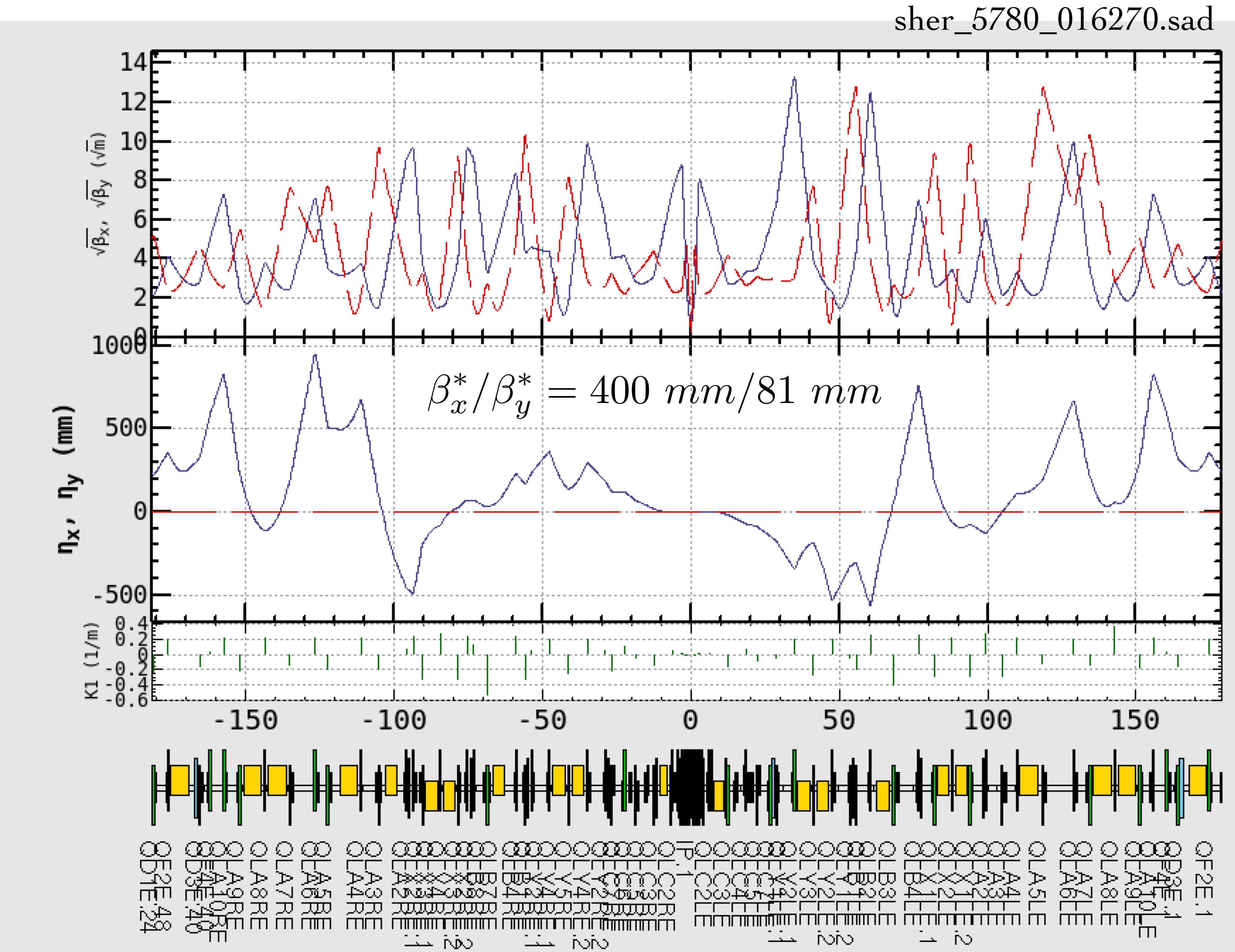
0.2 %



K_1 [1/m]
0
-0.01
-0.02
-0.03
-0.04
-0.05
L_{eff} = 0.3373 [m]
0.2
0.4
0.6
0.8
s [m]
β_y [m]
350
300
250
200
150
100
50
0
β_y = 338.7 [m]
average
0.2
0.4
0.6
0.8

QC1 BPMs





Tune:

$$\nu_x/\nu_y = 44.55/43.573$$

$$\nu_s = -0.0239$$

$$V_c = 11.2\ MV$$

Emittance:

$$\varepsilon_x = 4.5\ nm$$

(w/o intra beam)

Beam stay clear:

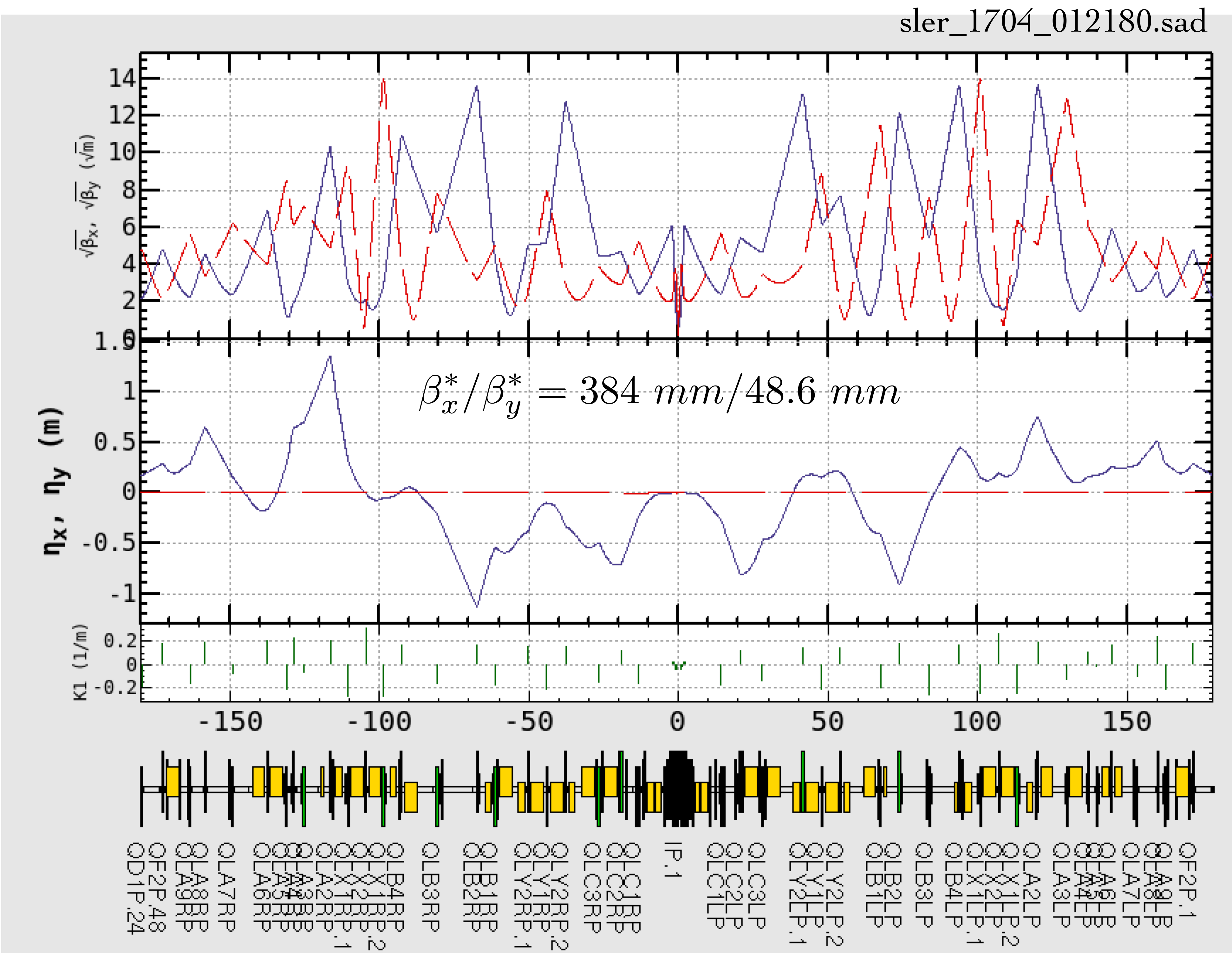
$$\frac{A_{QC2}}{\sigma_x} = 60$$

$$\frac{A_{QC1}}{\sigma_y} = 48$$

(100 % coupling)

Octupoles at QC1LE, QC2LE are zero field.
SLY and **SLX** are almost zero field

Phase 2.0: TSUKUBA in LER



Tune:

$$\nu_x/\nu_y = 44.55/46.58$$

$$\nu_s = -0.0232$$

$$V_c = 8.8\ MV$$

Emittance:

$$\varepsilon_x = 2.07\ nm$$

(w/o intra beam)

Beam stay clear:

$$\frac{A_{QC2}}{\sigma_x} = 112$$

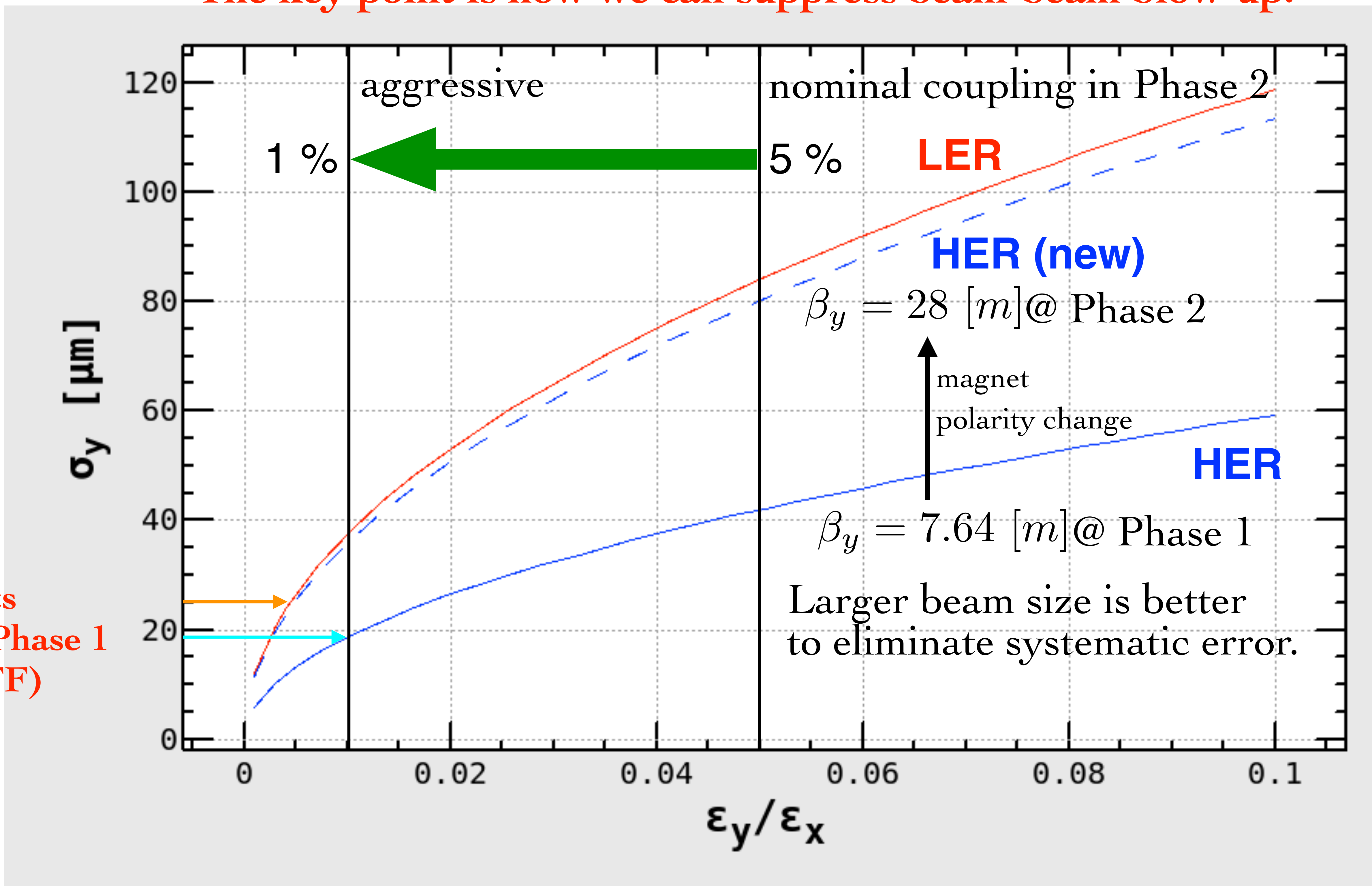
$$\frac{A_{QC1}}{\sigma_y} = 55$$

(100 % coupling)

Octupoles at QC1LP, QC2LP, QC1RP are zero field.
SLY and **SLX** are almost zero field
Rotatable sextupole: **rotation angle** = 0

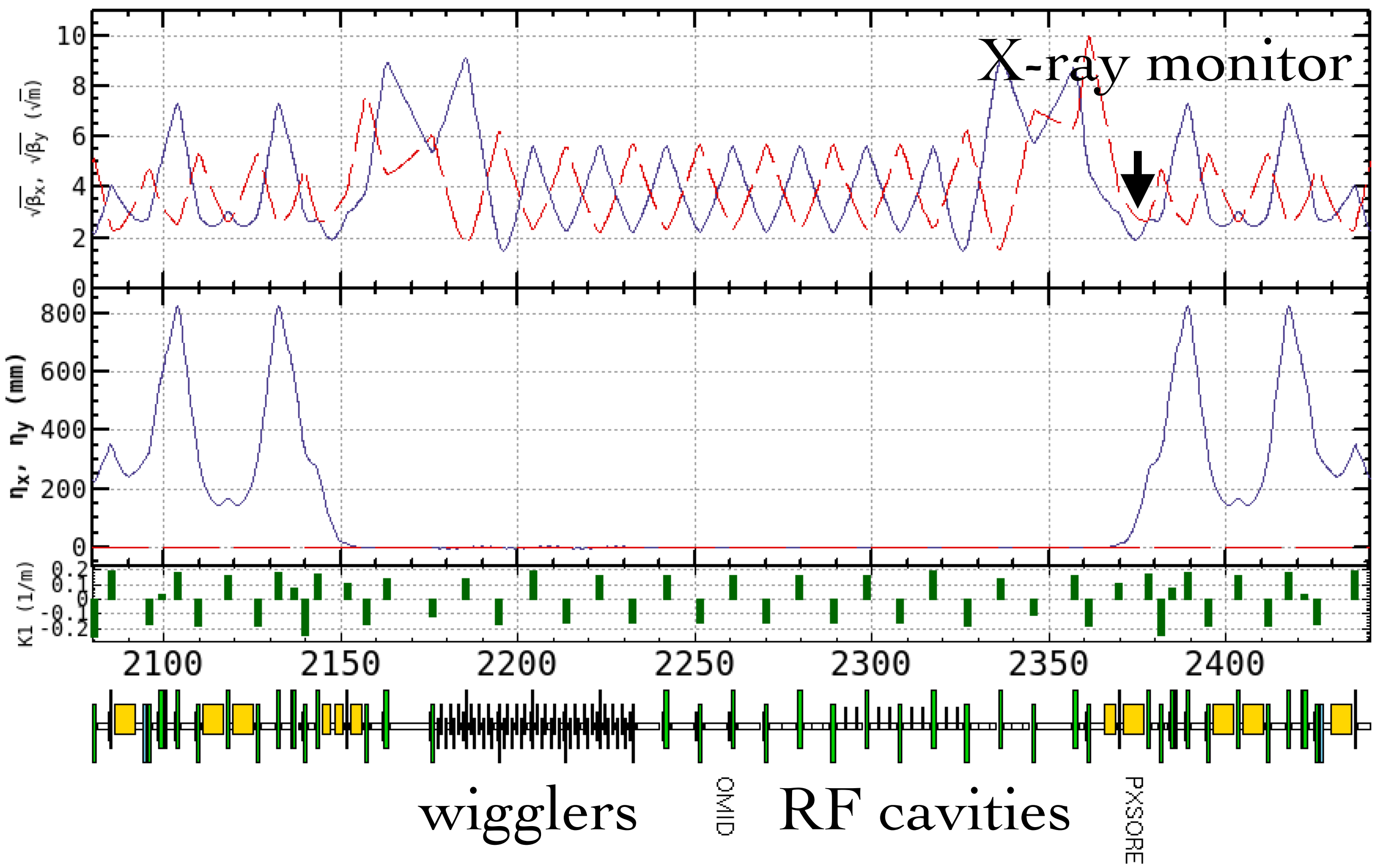
Vertical Beam Size at X-ray Monitor

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



Results from Phase 1 (w/o FF)

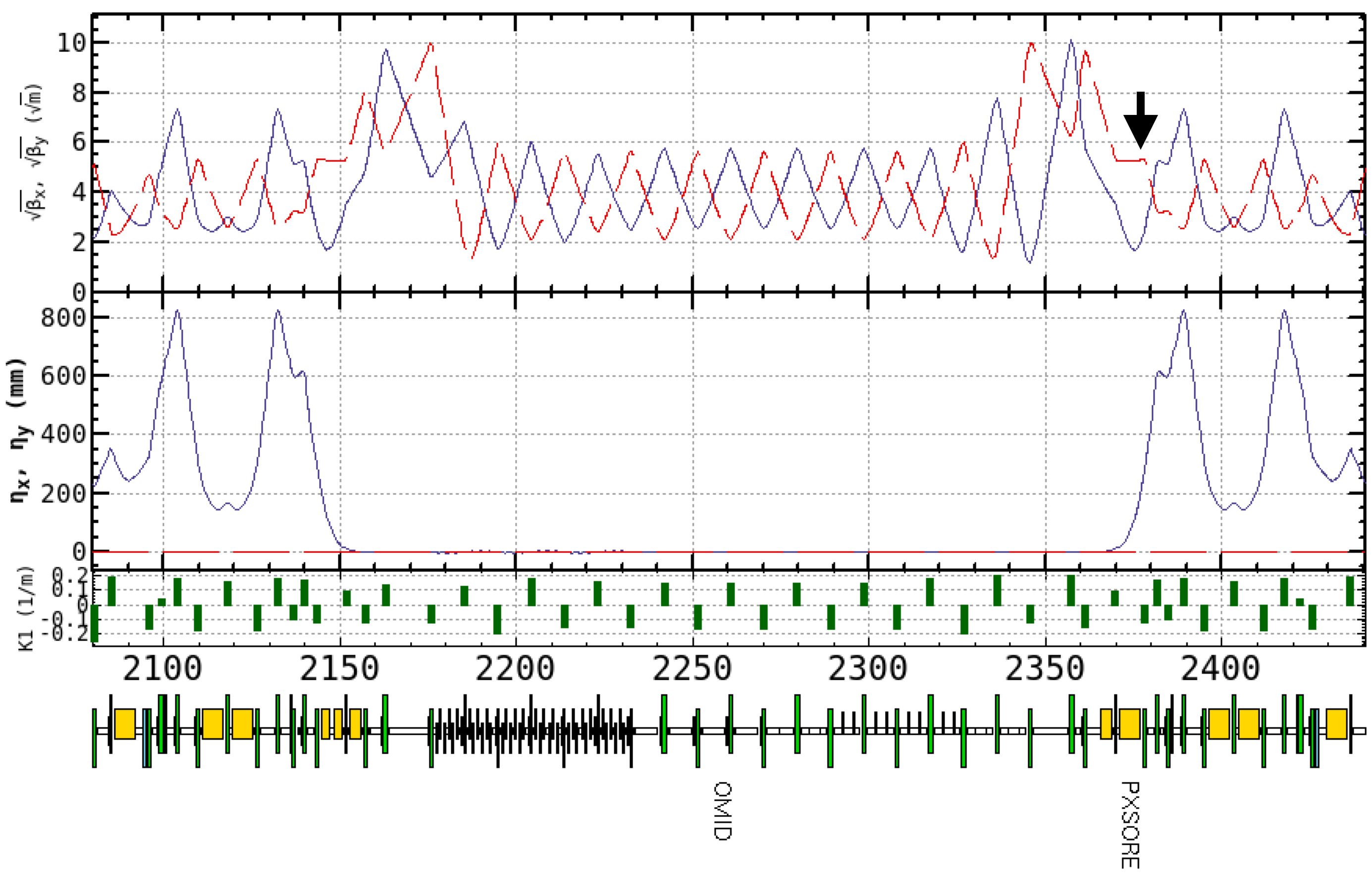
LER and HER achieved less than 1 % coupling during Phase 1.



sher_5780_016270_1.sad

$$\beta_y = 7.64 \; [m]$$

Start-up lattice is the same of Phase 1 as much as possible.

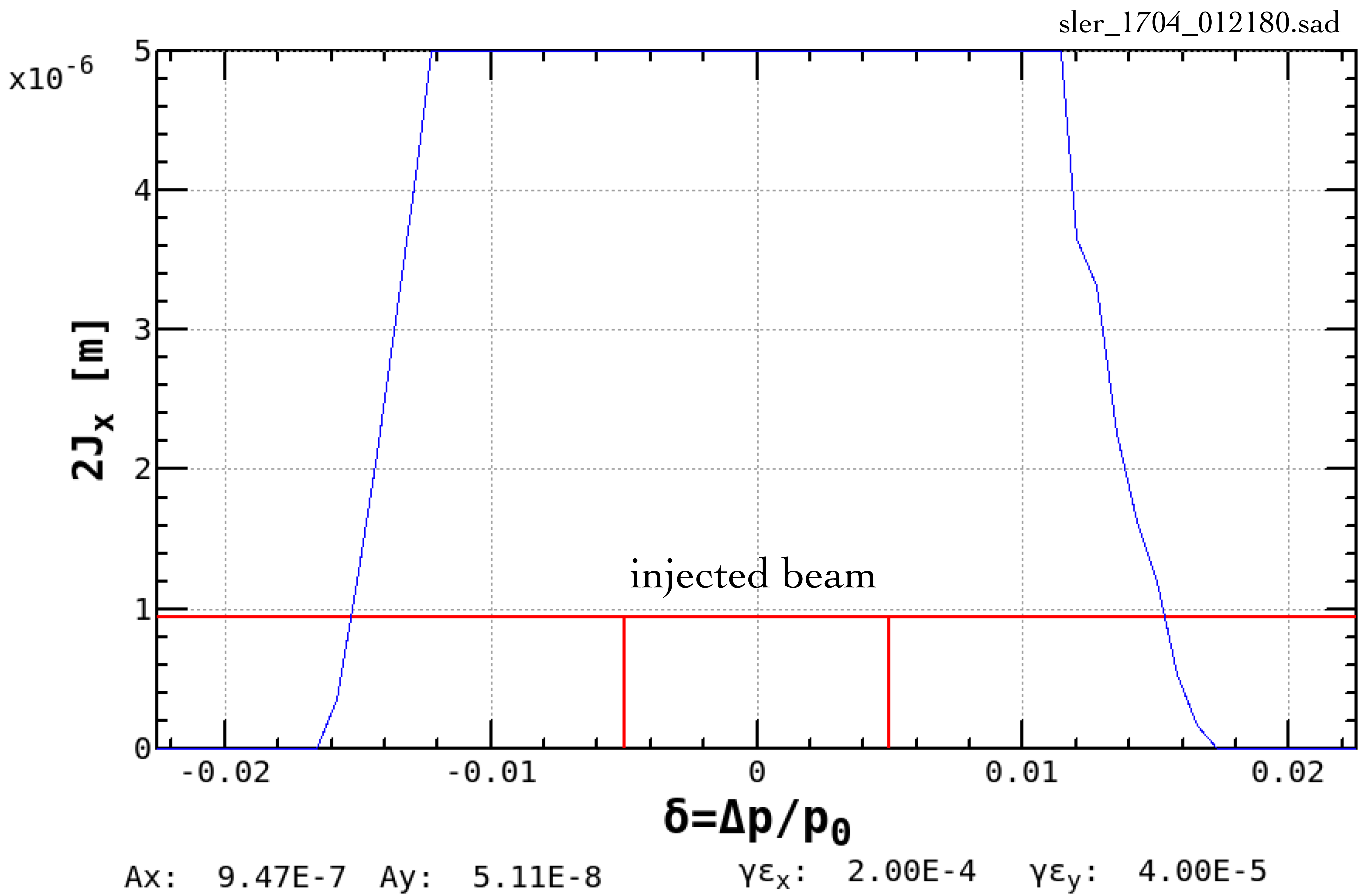


sher_5780_016270_2.sad

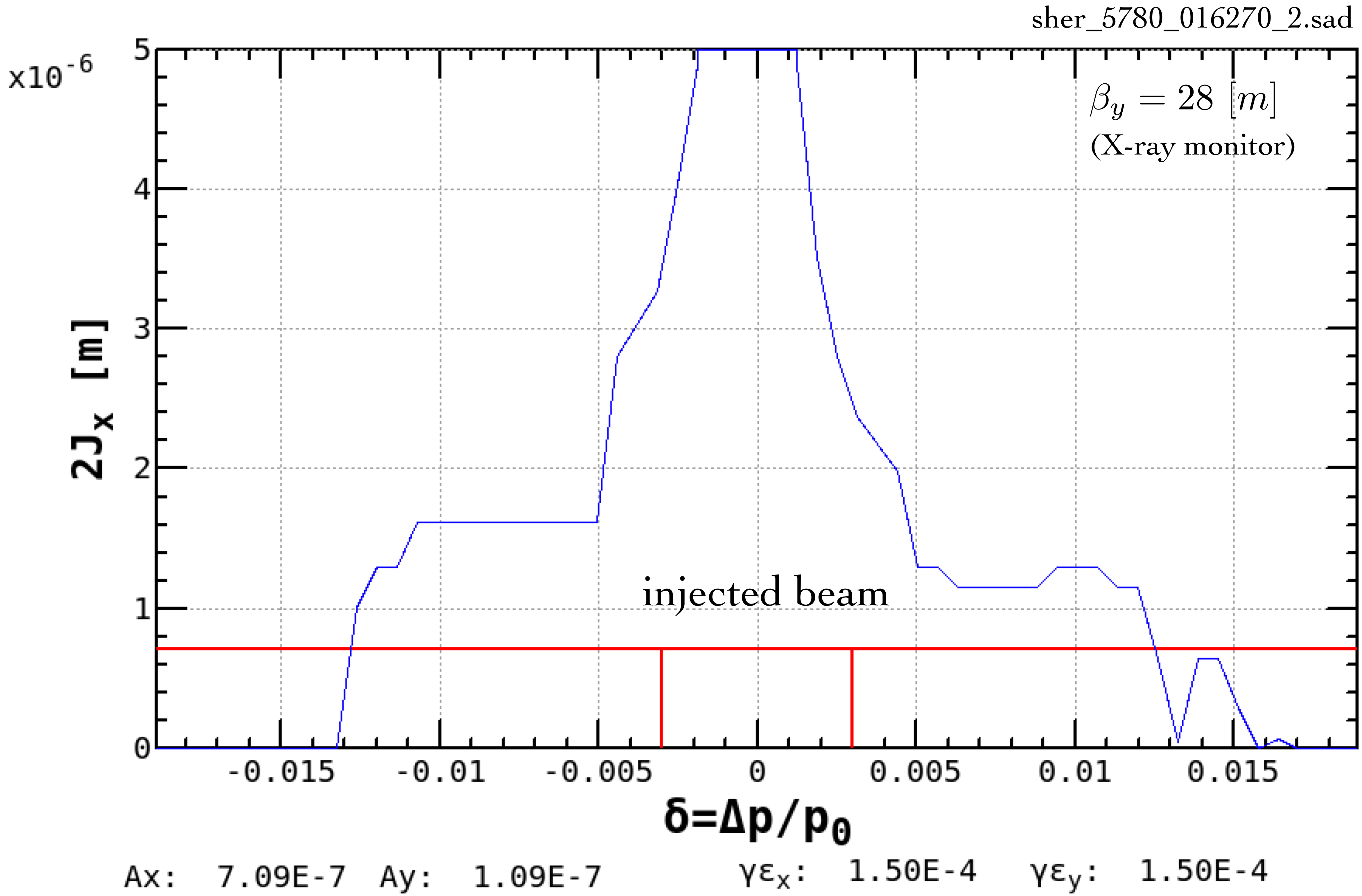
$$\beta_y = 28 \; [m]$$

When we make a stable lattice above,
we will change a polarity of QS4OE
to enlarge the vertical beta at source point.

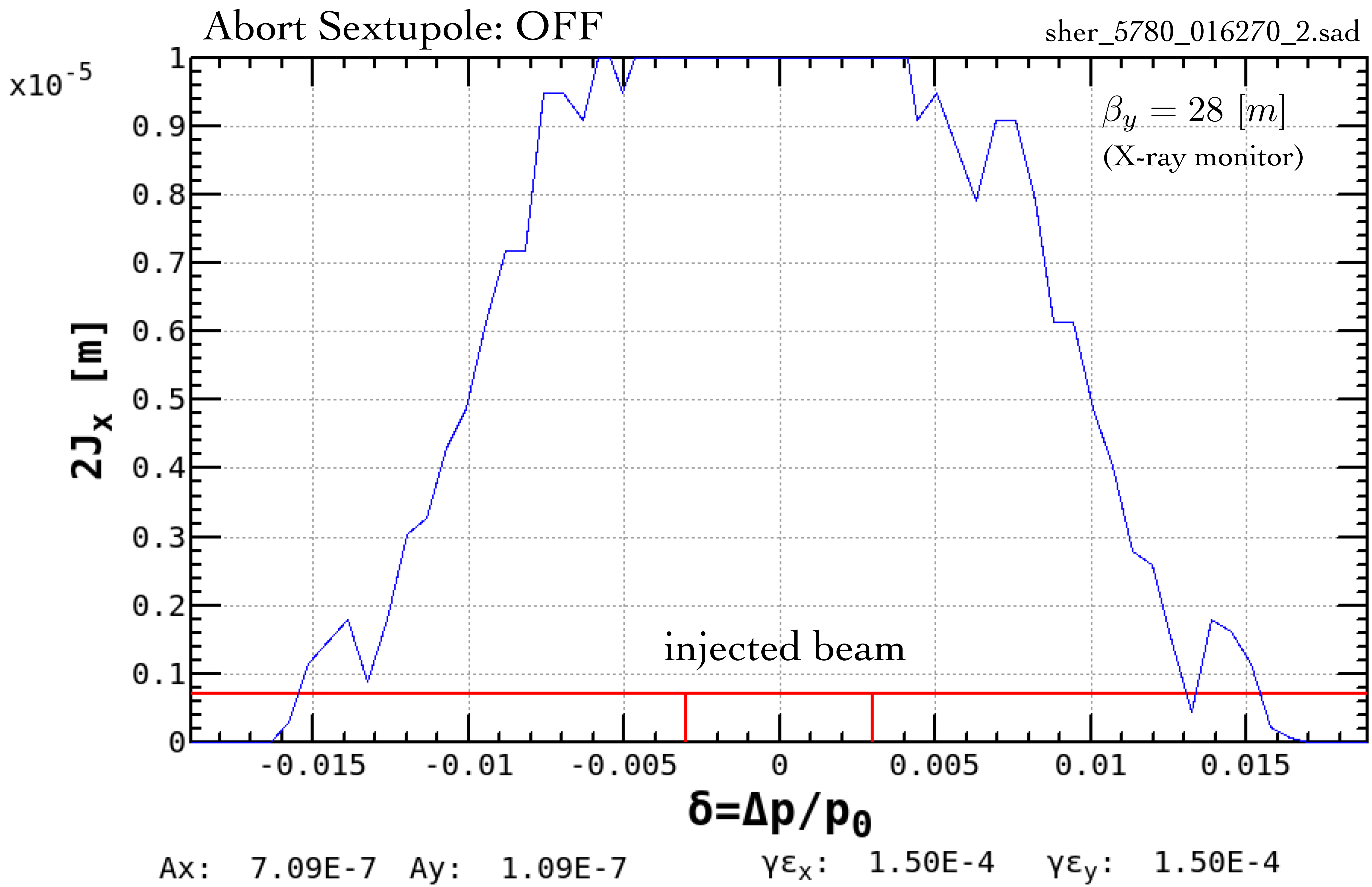
Phase 2.0: Dynamic Aperture for Injection in LER



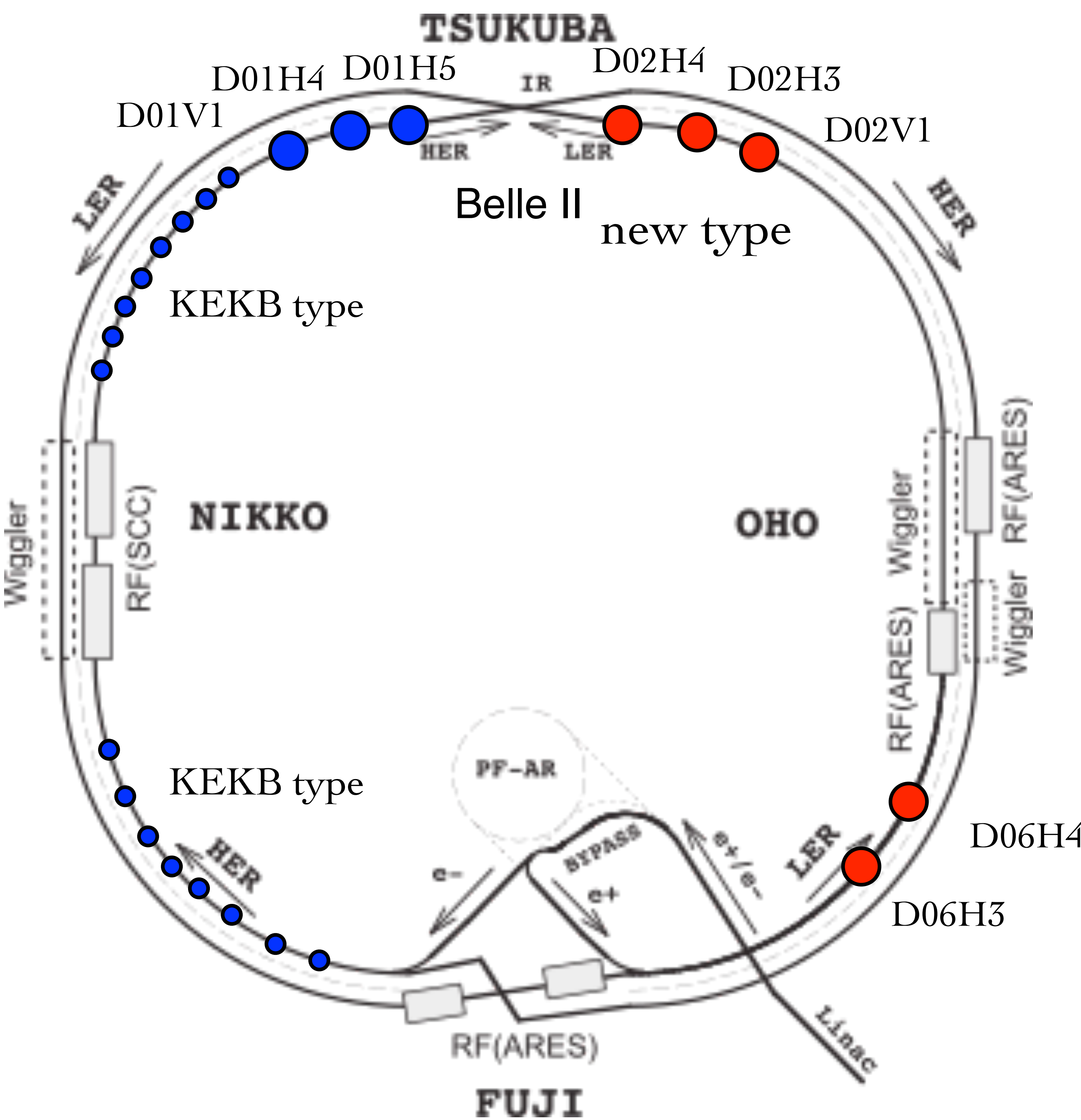
Phase 2.0: Dynamic Aperture for Injection in HER

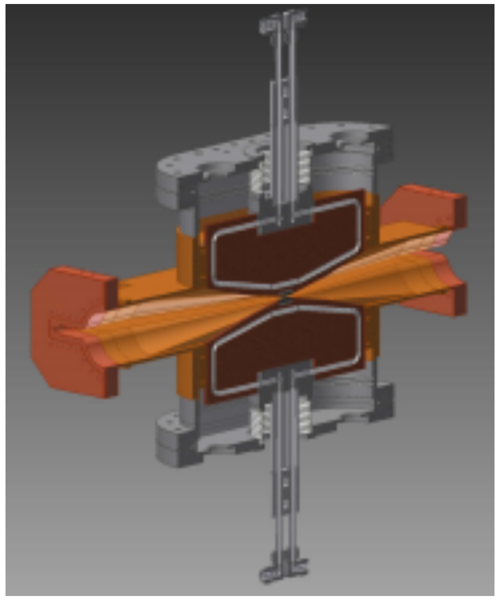


Phase 2.0: Dynamic Aperture for Injection in HER



Movable Collimators (Masks)





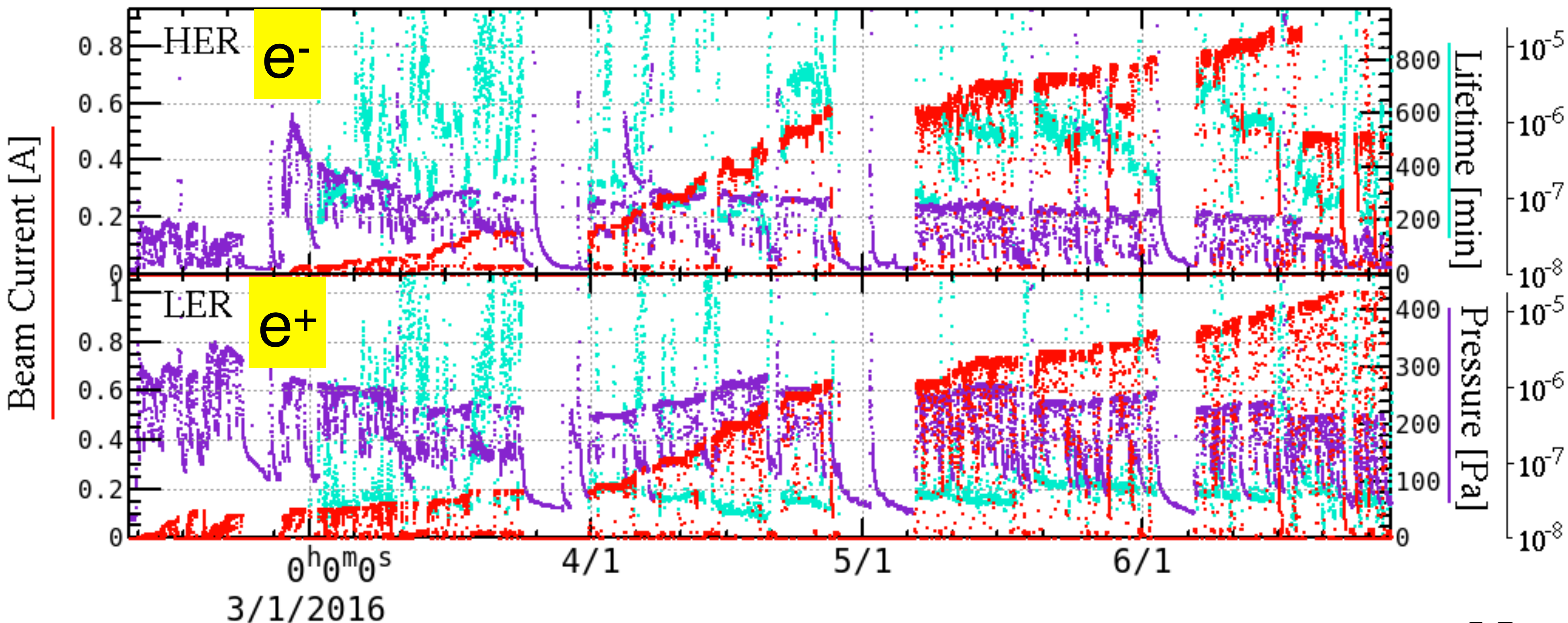
BCG
(Belle II Commissioning Group)

has a responsibility of movable mask control.

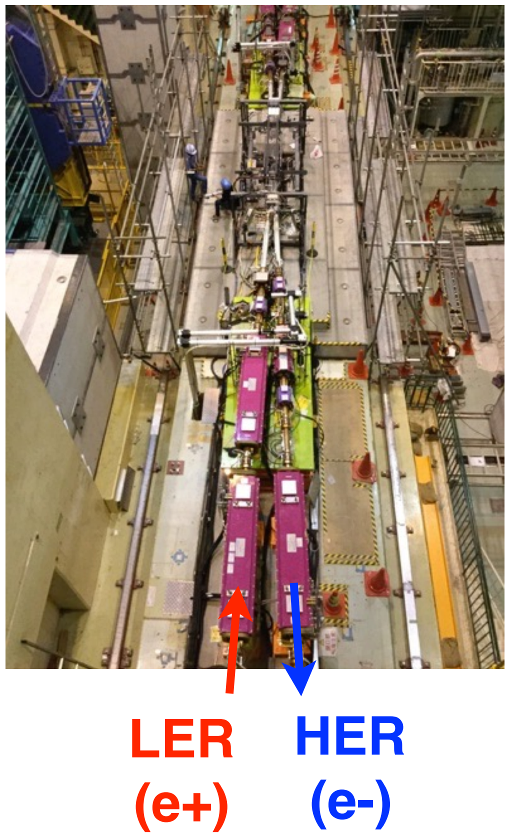
Compromise lifetime, injection, and detector background.

Phase 1 : Vacuum Scrubbing

Phase 1 (no QCS): Feb. - end of June, 2016

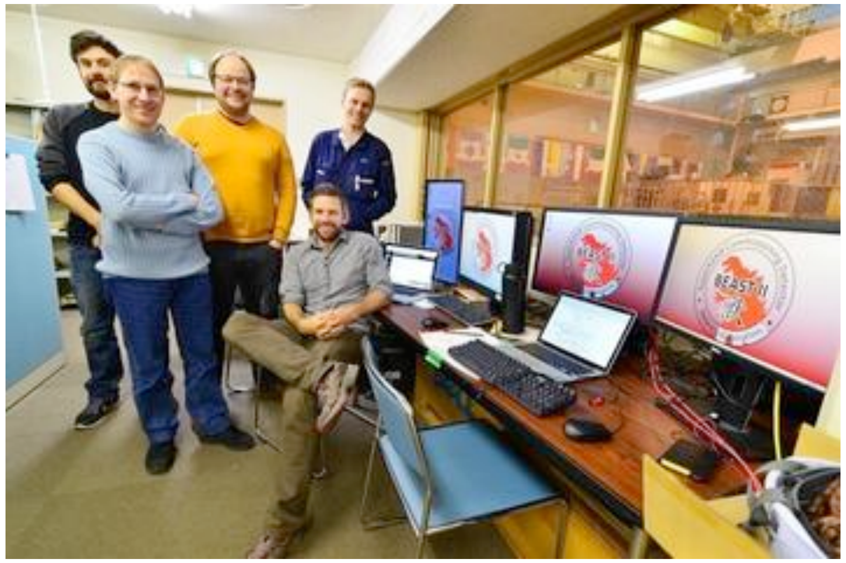


LER has stored 1 [A] beam current.



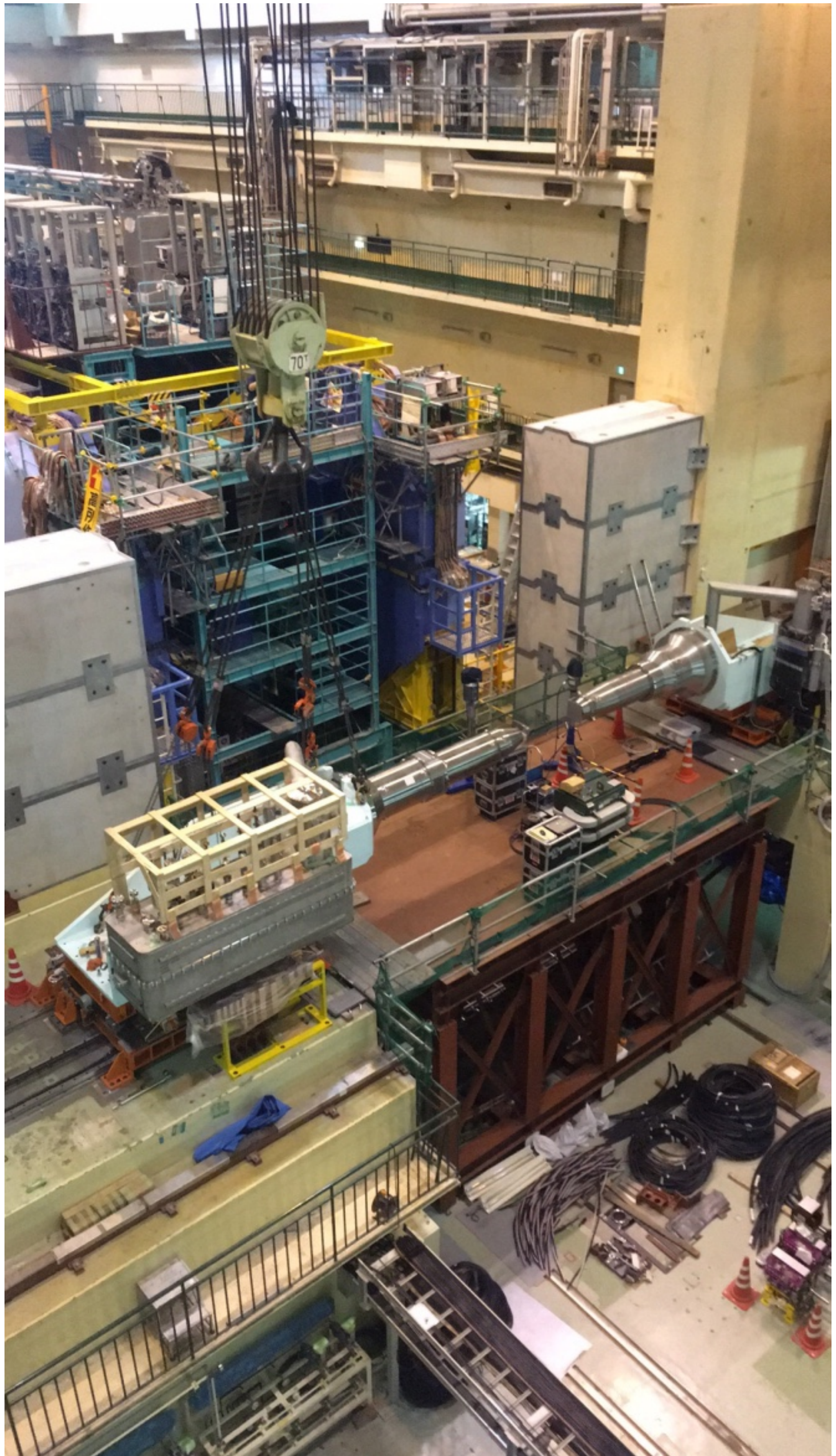
No QCS and Belle II

SuperKEKB control room

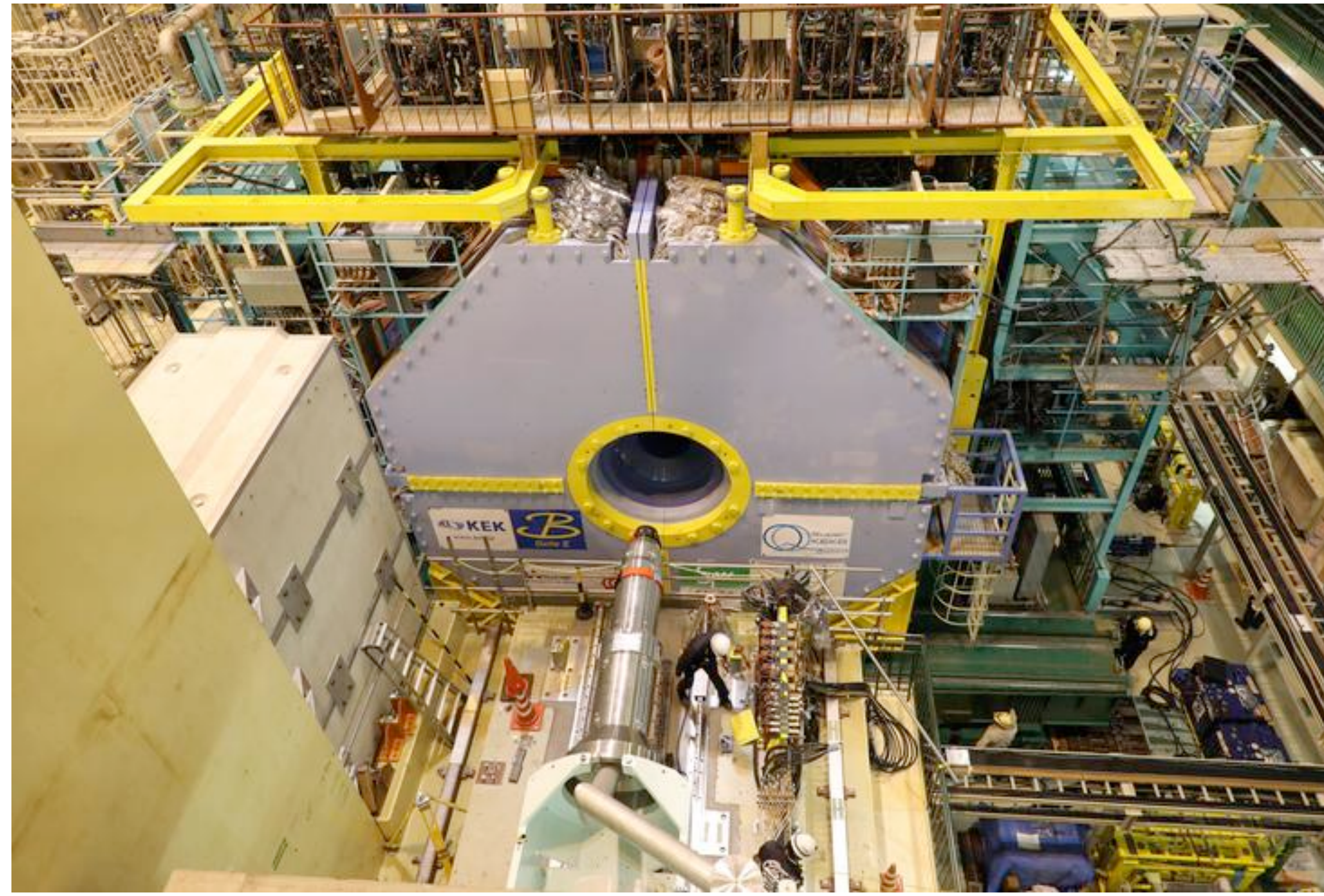


Beast II group

Interaction Region



Installation of QCS (Feb/13, 2017)



Belle II detector roll-in (April/11, 2017)

QCS: Backward position

Very strong focus magnets: QCS
(Superconducting magnets)