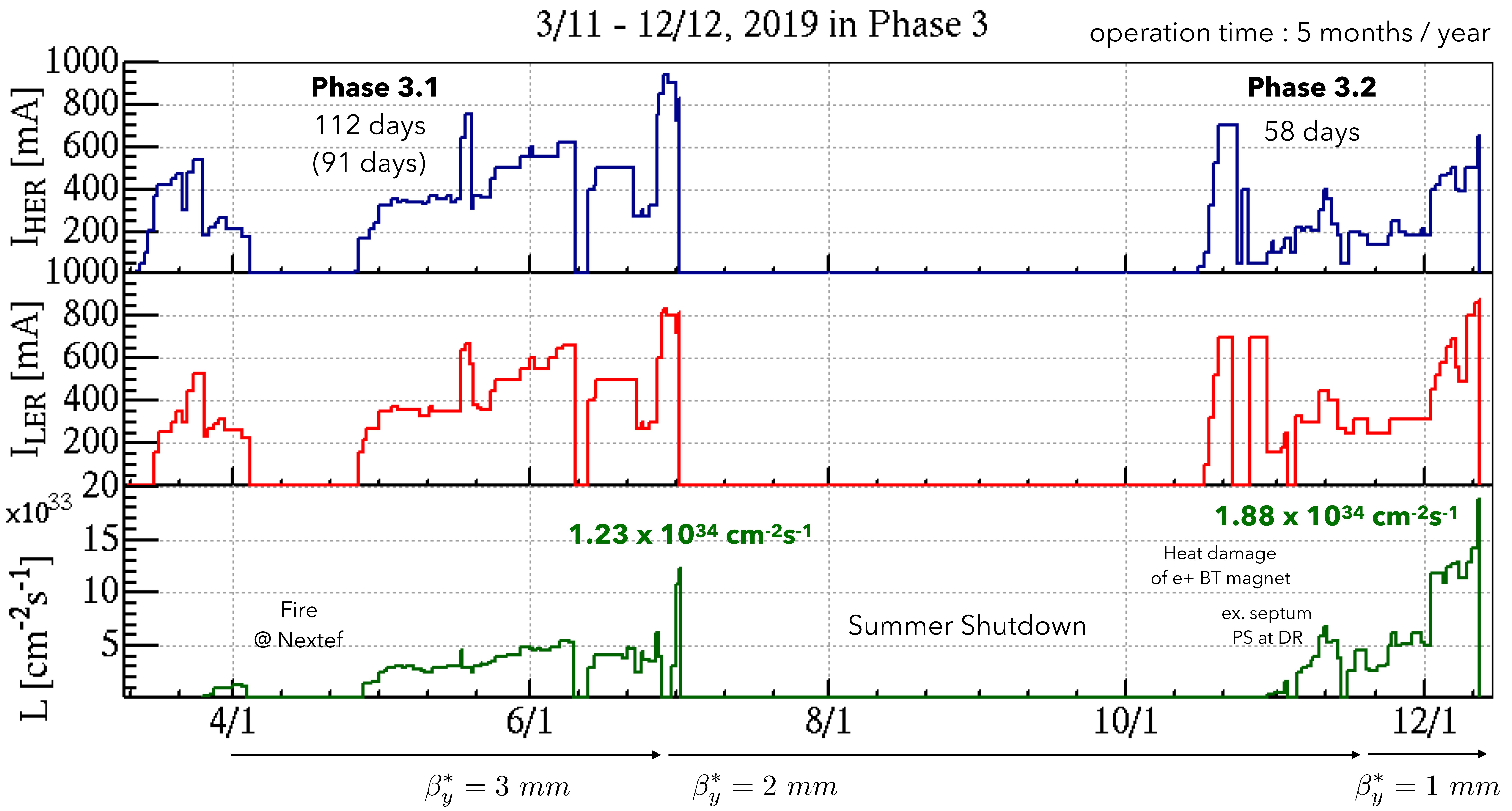
Status of SuperKEKB and Plan of Spring Run 2020 (2020a+2020b or 2020ab ?)

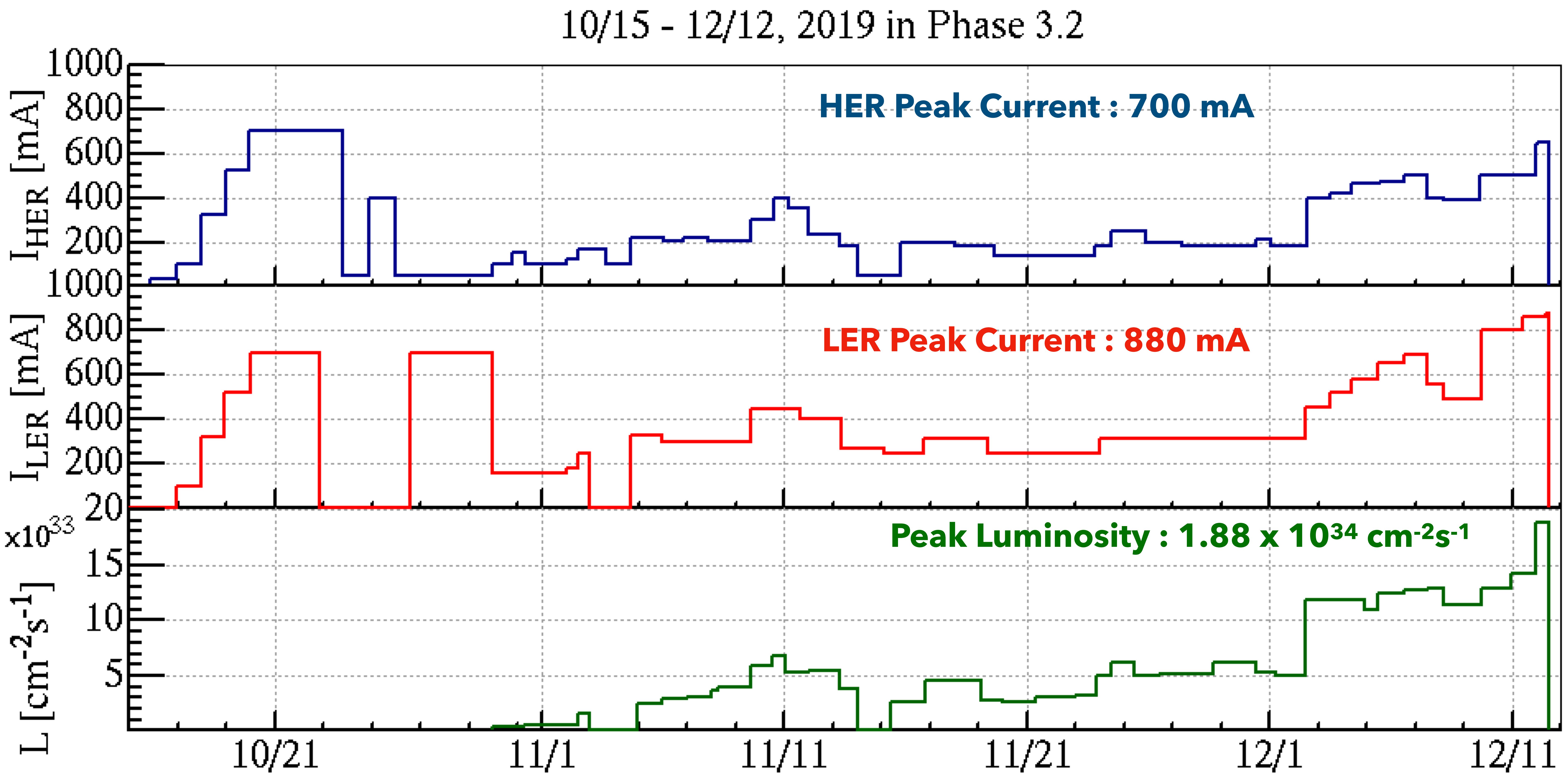
Y. Ohnishi

Phase 3



3/11 - 12/12, 2019 in Phase 3
operation time : 5 months / year
Phase 3.1
112 days
(91 days)
Phase 3.2
58 days
I_{HER} [mA]
I_{LER} [mA]
L [$cm^{-2}s^{-1}$]
x10^{33}
1.23 x 10^{34} $cm^{-2}s^{-1}$
1.88 x 10^{34} $cm^{-2}s^{-1}$
Heat damage
of e+ BT magnet
ex. septum
PS at DR
Fire
@ Nextef
Summer Shutdown
4/1
6/1
8/1
10/1
12/1
$\beta_y^* = 3\ mm$
$\beta_y^* = 2\ mm$
$\beta_y^* = 1\ mm$

Luminosity and Beam Currents



Vacuum scrubbing

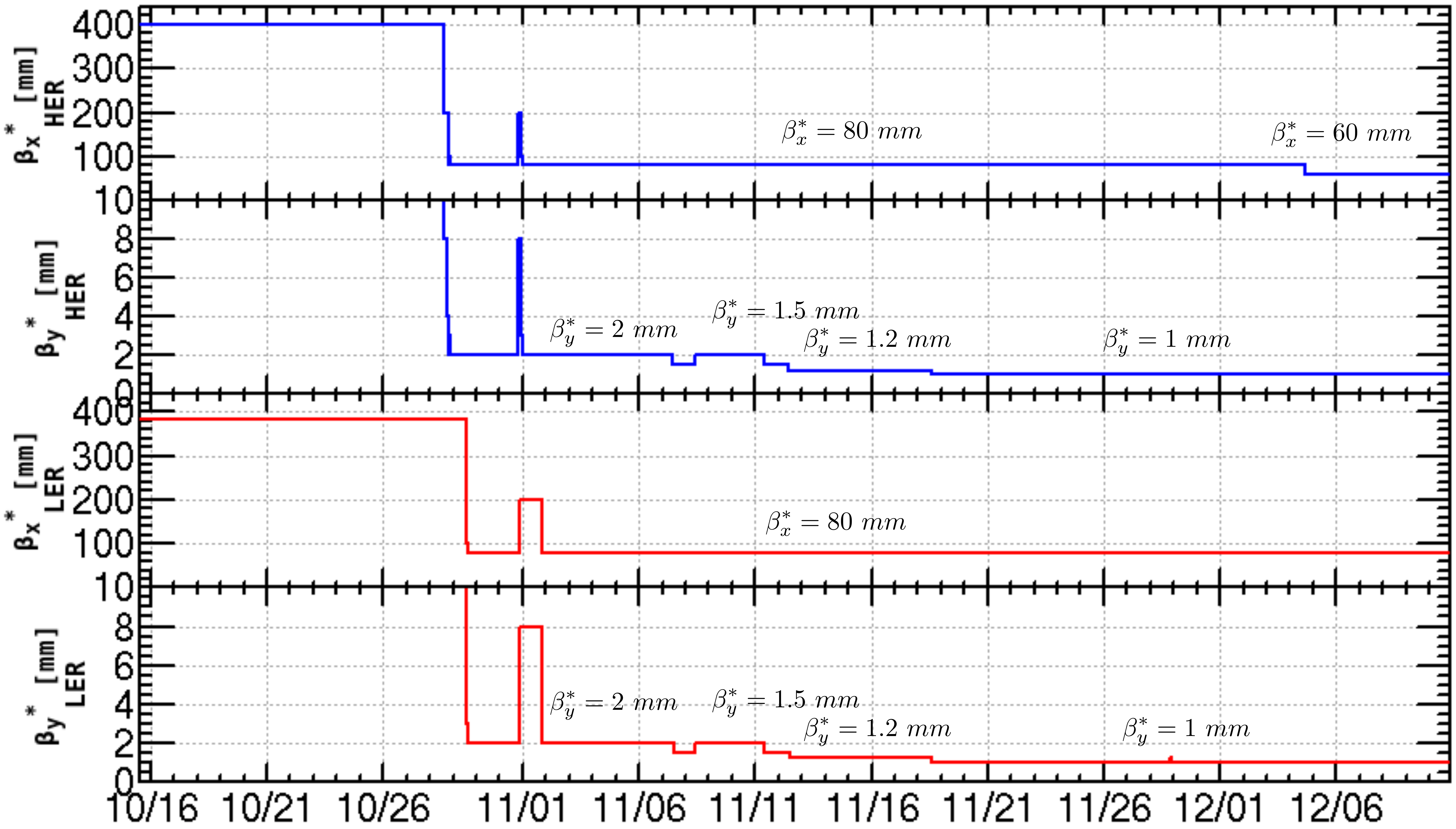
BT(e+) magnet trouble

ext. septum PS trouble in DR

$\beta_y^* = 1\ mm$

The smallest β_y^* in the world for e^+e^- colliders

Oct.15 - Dec.12, 2019



Luminosity

General formula:

$$L = \frac{N_+ N_- n_b f_0}{2\pi \Sigma_x^* \Sigma_y^*} = \frac{N_+ N_- n_b f_0}{2\pi \phi_x \sqrt{\sigma_{z+}^2 + \sigma_{z-}^2}\sqrt{\varepsilon_{y+}\beta_{y+}^* + \varepsilon_{y-}\beta_{y-}^*}}$$

$$\Sigma_x^* = \sqrt{\sigma_{x+}^{*2} + \sigma_{z+}^2 \tan^2\phi_x + \sigma_{x-}^{*2} + \sigma_{z-}^2 \tan^2\phi_x} = \sqrt{\sigma_{x+}^{*2}(1+\Psi_+^2) + \sigma_{x-}^{*2}(1+\Psi_-^2)} \simeq \phi_x \sqrt{\sigma_{z+}^2 + \sigma_{z-}^2}$$

$$\Psi_\pm = \frac{\sigma_{z\pm}}{\sigma_{x\pm}^*}\tan\phi_x$$

Nano-beam scheme Piwinski angle : $\Psi_\pm \simeq 18 >> 1$

Vertical emittance should be small.
X-Y couplings and vertical dispersion affect the vertical emittance.

Bunch lengthening should be small.
For instance, impedance affects bunch lengthening.

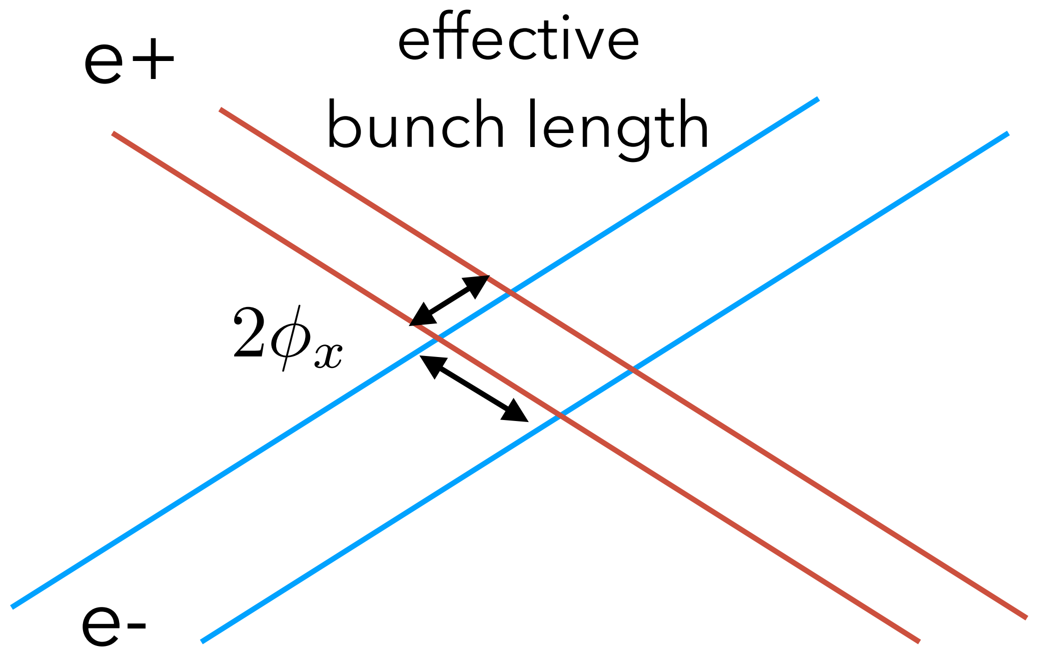
To avoid **hourglass effect**:

$$\beta_y^* > \tilde{\sigma}_z = \frac{\sigma_x^*}{\phi_x} = \frac{\sigma_z}{\Psi}$$

$$\sigma_x^* = \sqrt{\varepsilon_x \beta_x^*}$$

Horizontal emittance : $\varepsilon_{x+} = 2\ nm$, $\varepsilon_{x-} = 4.6\ nm$

$\beta_{x+}^* = 80\ mm / \beta_{x-}^* = 60\ mm$ $\tilde{\sigma}_{z+} = 305\ \mu m / \tilde{\sigma}_{z-} = 400\ \mu m$



Definition of specific luminosity

$$L_{sp} = \frac{L}{I_{b+} I_{b-} n_b}$$

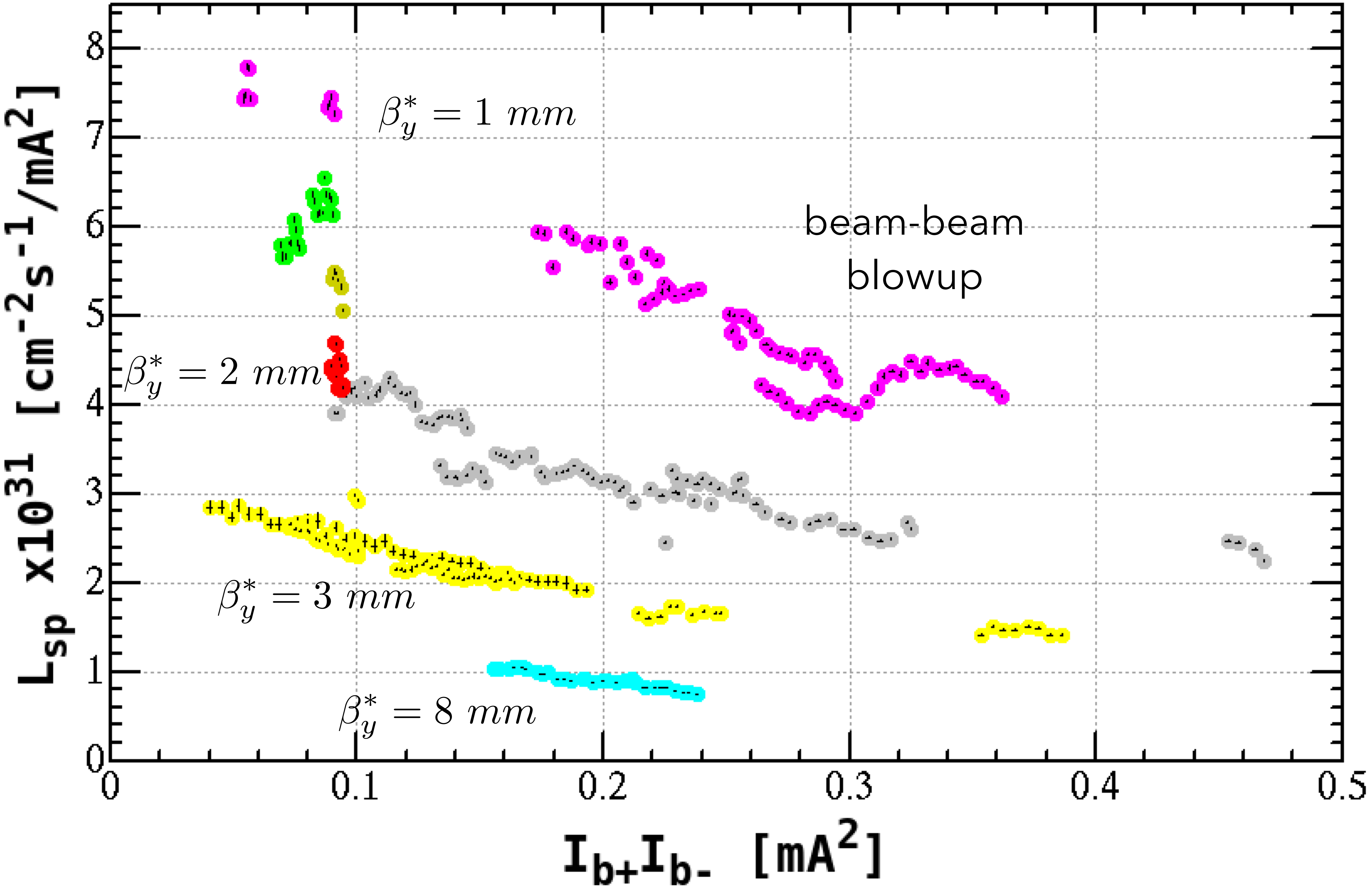
Definition of beam-beam parameter (here)

$$\xi_{y\pm} = \frac{2 e r_e \beta_{y\pm}^*}{\gamma_\pm I_\pm} L$$

Specific Luminosity

$$L_{sp} \propto \frac{1}{\sqrt{\varepsilon_y \beta_y^*}}$$

beam-beam parameter $\xi_y \propto \sqrt{\frac{\beta_y^*}{\varepsilon_y}}$



design	LER	HER	
$\varepsilon_y/\varepsilon_x$	0.27	0.28	%
ε_y	8.6	13	pm
β_y^*	0.27	0.3	mm
β_y^*/ε_y	3.1x10^7	2.3x10^7	
σ_y^*	0.05	0.06	μm

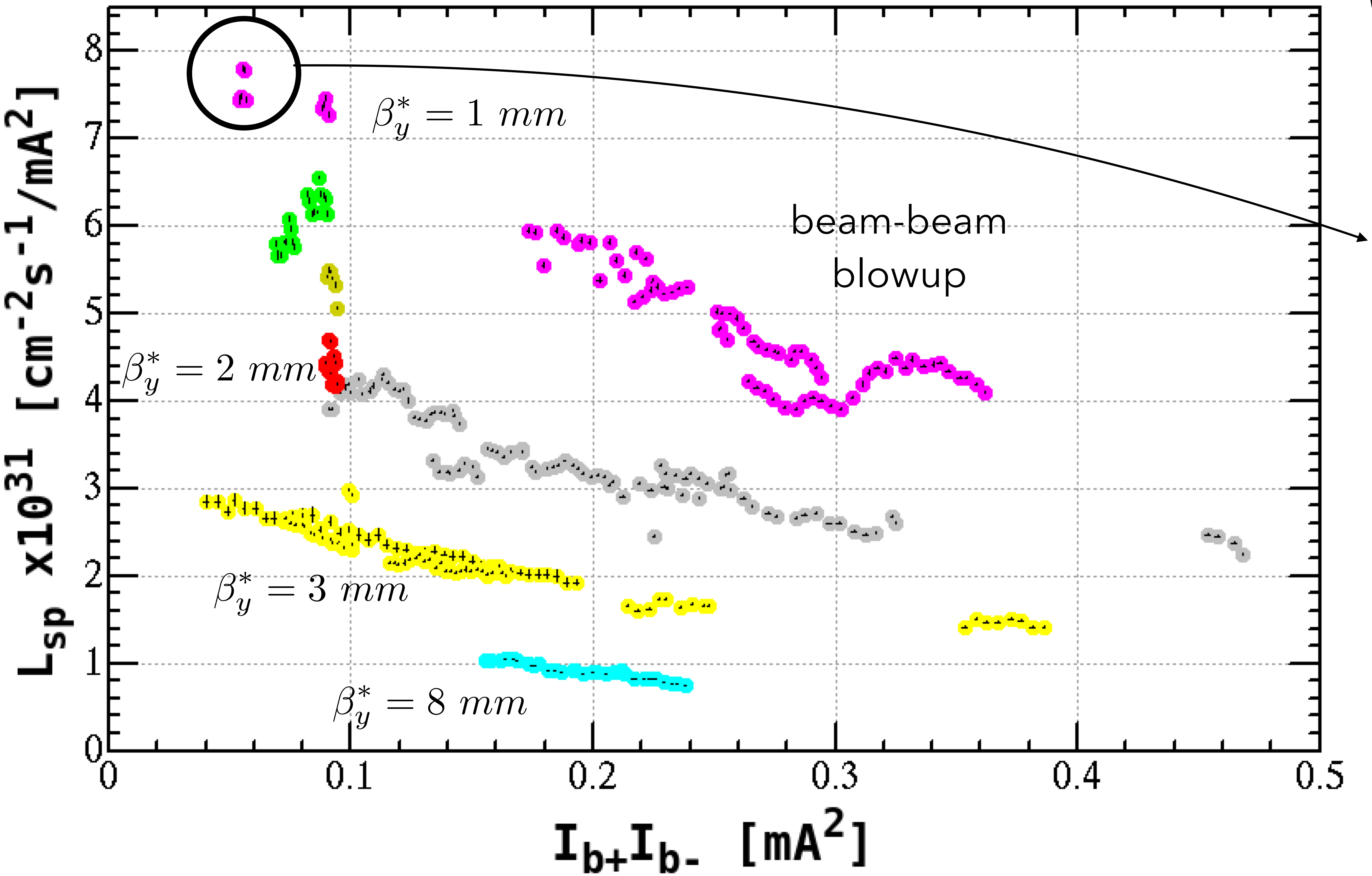
We can squeeze βy* down to 0.6 mm with the same vertical emittance.

Specific Luminosity

250 mA / 140 mA (n_b : 783)
L = 3.45 x10[33]

$$L_{sp} \propto \frac{1}{\sqrt{\varepsilon_y \beta_y^*}}$$

beam-beam parameter $$\xi_y \propto \sqrt{\frac{\beta_y^*}{\varepsilon_y}}$$



2019c	LER	HER	
$\varepsilon_y/\varepsilon_x$	1.0	0.7	%
ε_y	20	32	pm
β_y^*	1	1	mm
β_y^*/ε_y	5×10^7	3.1×10^7	
σ_y^*	0.14	0.18	μm

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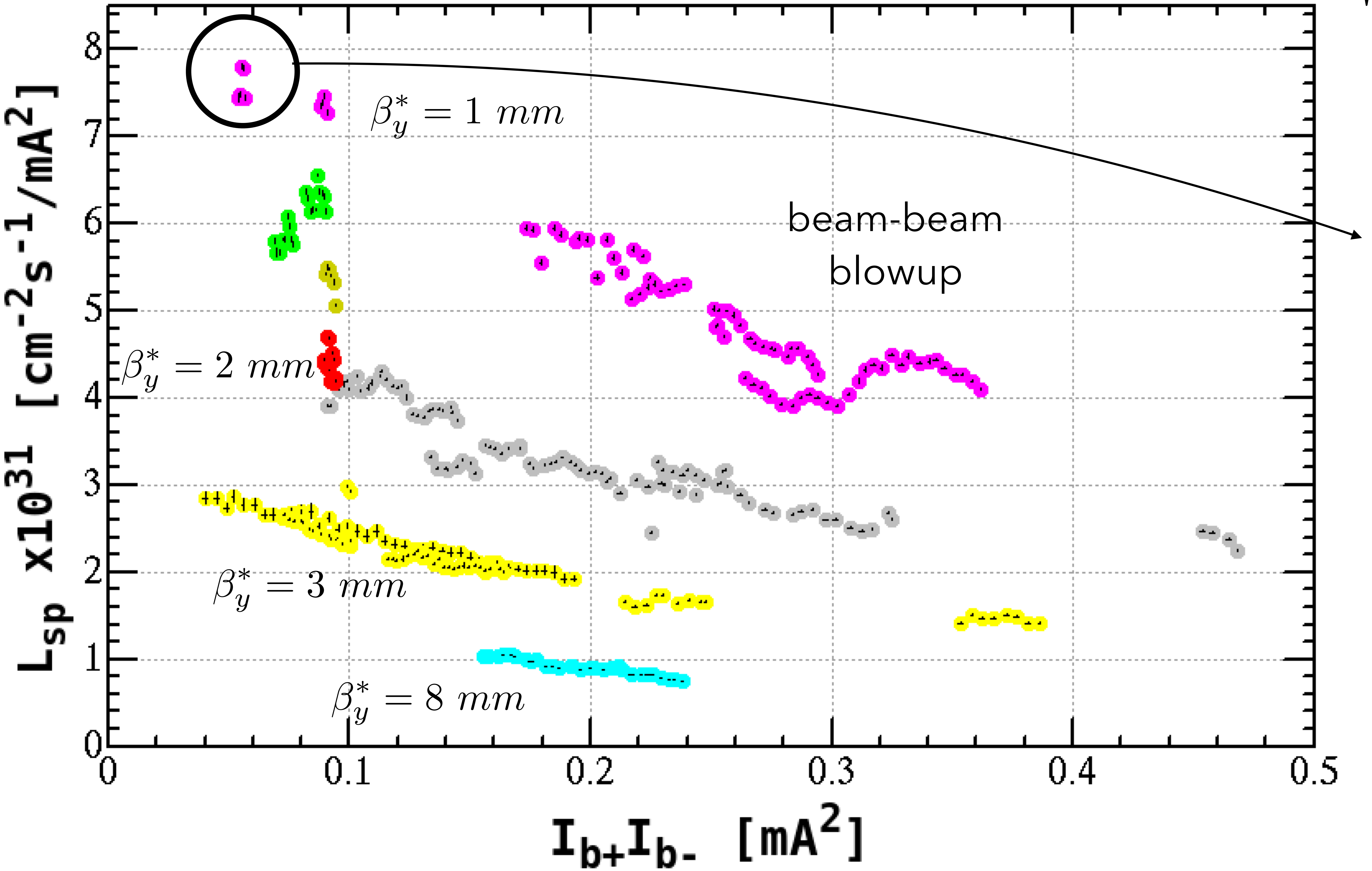
OK at lower bunch current



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What limits luminosity performance at higher bunch current ?

What is a source of beam-beam blowup ?

Large Piwinski angle is problem ?

Chromatic X-Y couplings at IP ? ← X-Y couplings at IR

Interference between lattice nonlinearity and beam-beam ?

Higher bunch current product > 0.3 mA^2

stored beam and injected beam

stored beam	injected beam
injection error (kickers)	injection error (septum, kickers)
misalignment of kickers	misalignment of kickers
beam lifetime	emittance (horizontal/vertical)
beam tails	energy and energy spread
betatron tunes	betatron tunes
collimators	collimators

X-Y couplings

Issues of Machine Operation

A. Luminosity Performance

1. X-Y coupling and chromatic X-Y coupling
   - Correction scheme of X-Y couplings both local and global.
   - X-Y coupling at IP and Y-LCC (source of chromatic X-Y couplings)
2. Injection
   - Stability of bunch charge and small emittance
   - 2-bunch injection operation (bunch charge equalization)
   - Orbit stability of injected beams (Linac and BT)

   X-Y coupling affects both injection and BG.
3. Unstable for higher bunch current due to Beam-Beam: $I_{+}I_{-} > 0.3$ mA^2
4. Horizontal beta squeezing in HER (down to 60 mm)
   - Synchrotron radiation on PXD
   - Adjustment of horizontal angle at IP affects horizontal dispersion. (Need to correct)

B. Belle II Beam Background

- Injection background in LER (spikes, long-time consecutive background)

We keep β_y^* = 1 mm as the baseline.

Number of bunches is 783 or 1565 for physics run.

Startup and Machine study for 3 weeks in Match

Physics run is for about 100 days.

Target : Average luminosity for physics run is more than1.8 x 10^{34} $cm^{-2}s^{-1}$.

Make veto dead time less than 5 %.

New additional vertical collimator in LER (D06V1)

3 vertical collimators in total (D02V1, D06V1, D06V2)

We expect detector background can be reduced in LER.

Crab waist in LER

Preparation for HER is on-going.

We expect improvement of luminosity performance and reduce beam-tails (a part of BG source)

February 25 - March 2

LER operation only (17 shifts)

Vacuum scrubbing (10 shifts x 0.5 A x 8h = 40 Ah)

Study of X-Y coupling in LER (2 shifts)

Study of injection background in LER (2 shifts)

Crab waist at LER single beam (2 shifts)

Others (1 shift)

March 2 - March 22 (March 12 : maintenance, March 20 : Power limit < 50 MW)

LER/HER startup, machine study, physics run (58 shifts)

Hardware check and BPM calibration (2 shifts)

Correction of horizontal dispersions in HER (3 shifts)

Study of X-Y coupling in LER/HER (6 shifts)

Study of injection background (10 shifts)

Crab waist with collision (10 shifts)

Physics run (21 shift) The owl shift is dedicated to physics run or background study.

Others (6 shifts)

Run Plan (3)

March 23 - July 1 (100 days)

Physics run (300 shifts includes maintenance+α :14 shifts)

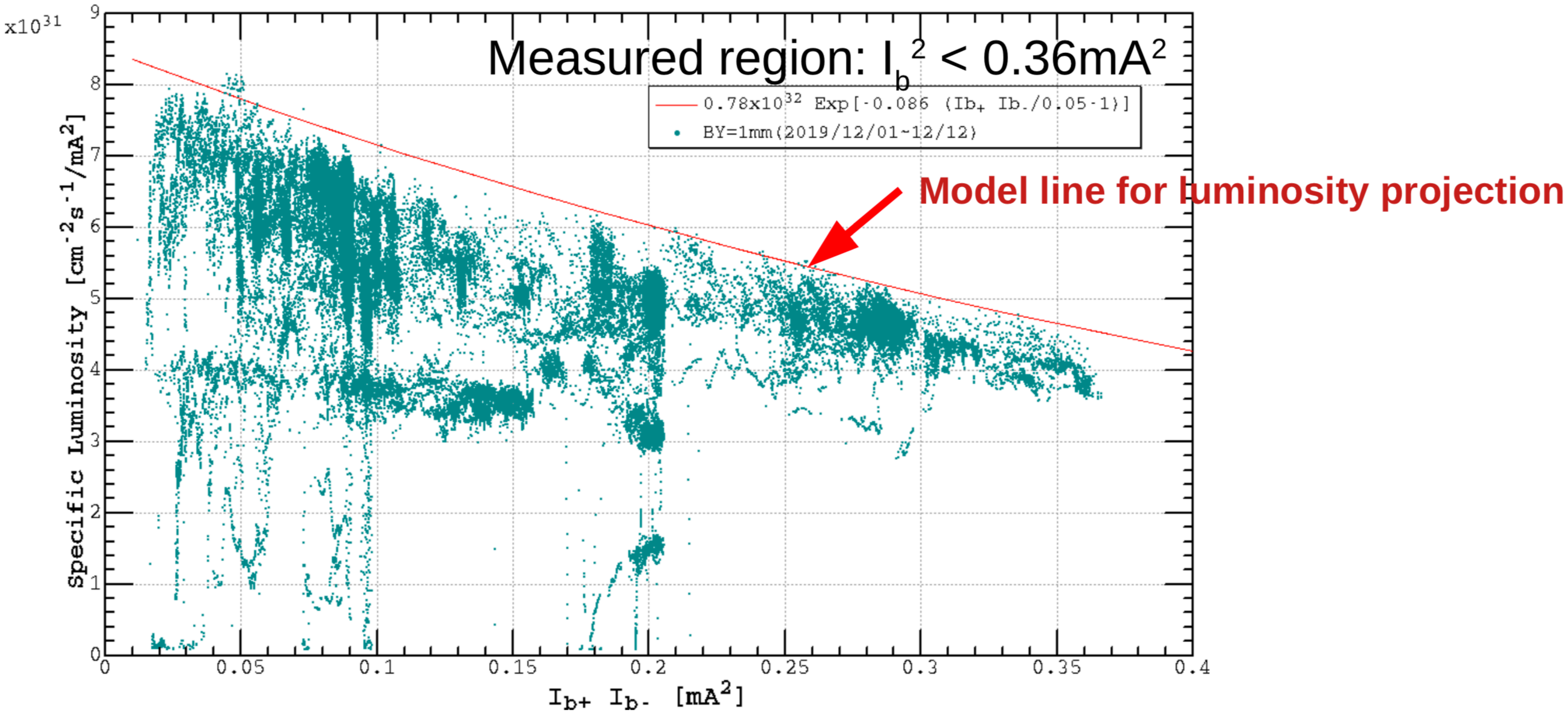
Machine study (average : 3 shifts per week)

linac study is included.

Conservative estimation

A. Morita
SuperKEKB WS

Bunch current product dependency of L_{sp} @ β^*_y=1mm collision

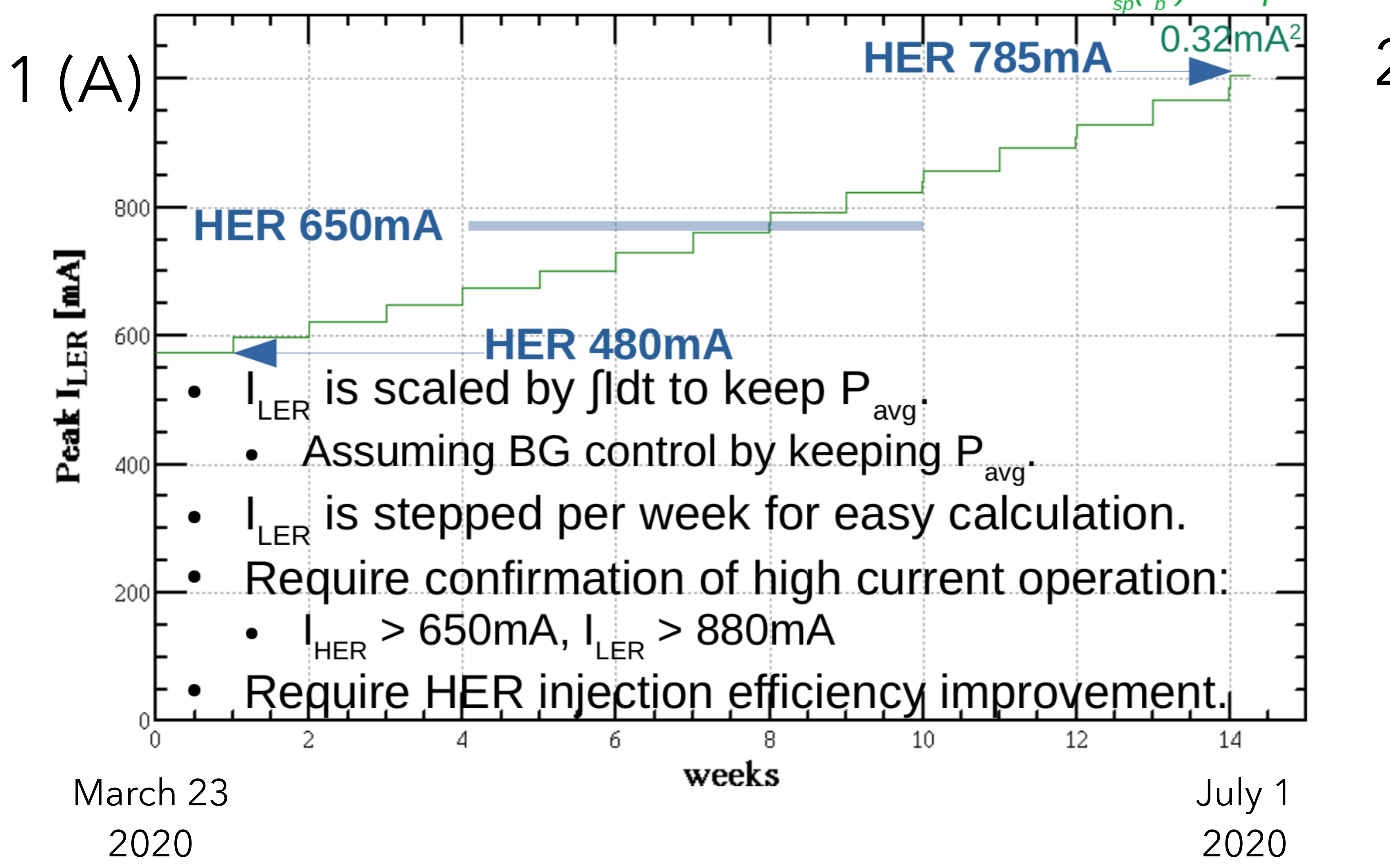


Conservative estimation

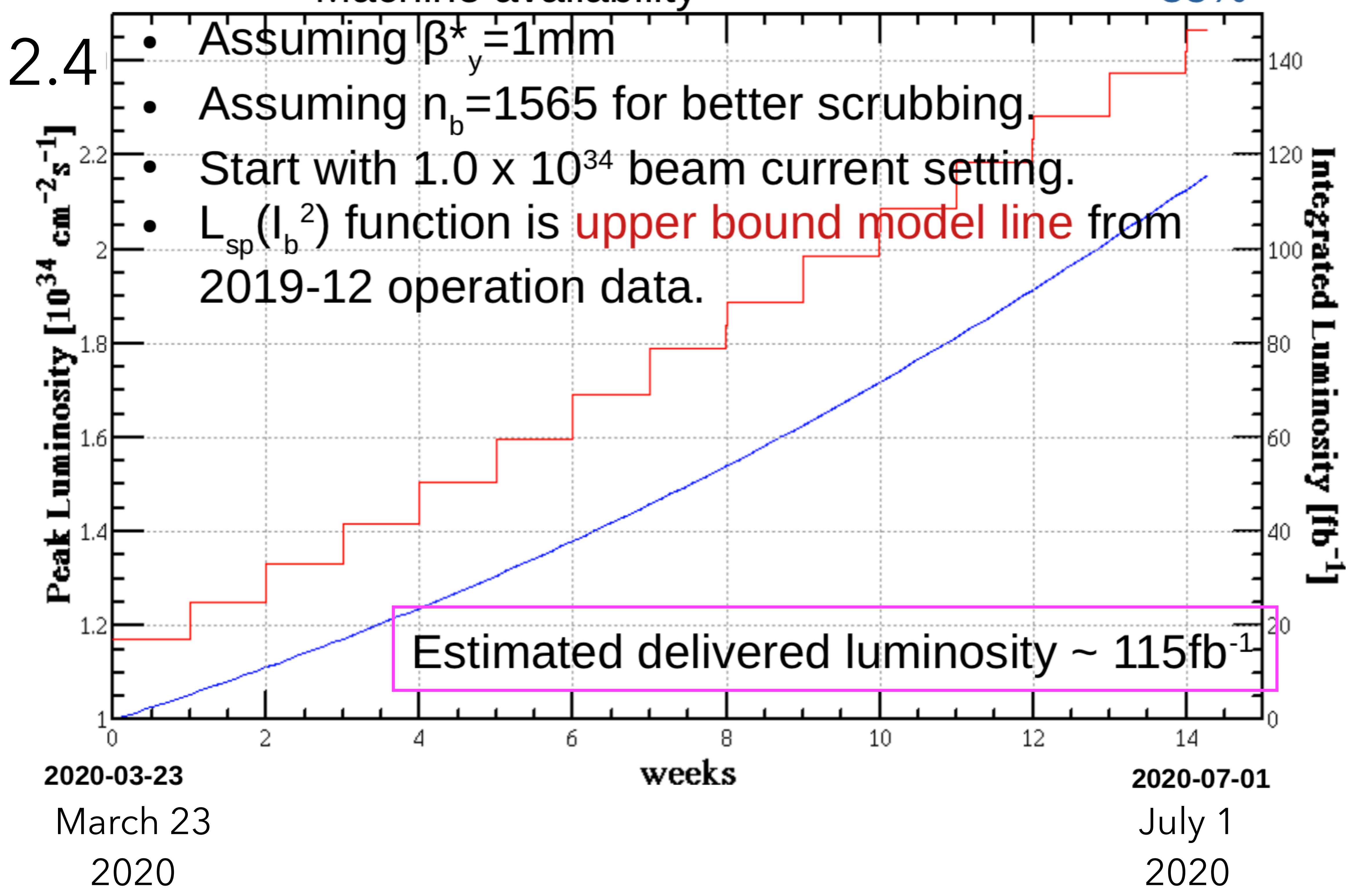
A. Morita
SuperKEKB WS

Estimation based on 2019-12 operation performance.

- **No extra beam-beam performance improvement is taken into account.**
- **No machine study time is taken into account.**
  Vacuum pressure assumed to be constant.



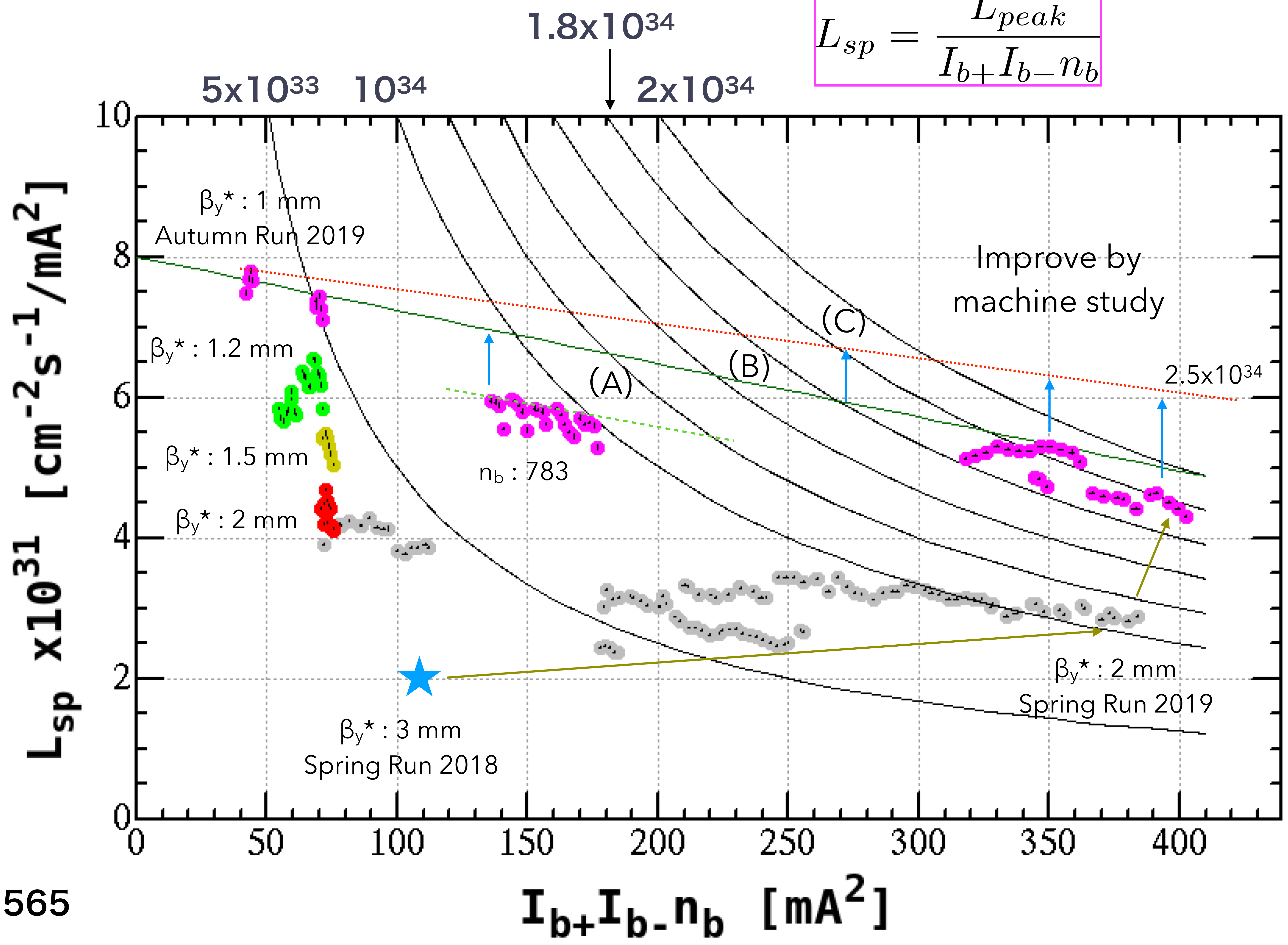
- I_{LER} is scaled by ∫Idt to keep P_{avg}.
  - Assuming BG control by keeping P_{avg}.
- I_{LER} is stepped per week for easy calculation.
- Require confirmation of high current operation:
  - I_{HER} > 650mA, I_{LER} > 880mA
- Require HER injection efficiency improvement.



- Integral efficiency 76%
  - Excluding Linac study & Maintenance 89%
  - Machine availability 85%
- Assuming β^*_y=1mm
- Assuming n_b=1565 for better scrubbing.
- Start with 1.0 x 10^{34} beam current setting.
- $L_{sp}(I_b^2)$ function is upper bound model line from 2019-12 operation data.

conservative initial parameters

$$L_{sp} = \frac{L_{peak}}{I_{b+} I_{b-} n_b}$$



n_b = 783 / 1565

(A)
LER : 700 mA
HER : 400 mA
n_b : 1565
I_{b+} : 0.44 mA
I_{b-} : 0.25 mA
$I_{b+}I_{b-}n_b$: 180 mA^2
L : 1.2 x10^{34} $cm^{-2}s^{-1}$

(B)
LER : 500 mA
HER : 370 mA
n_b : 783
I_{b+} : 0.64 mA
I_{b-} : 0.47 mA
$I_{b+}I_{b-}n_b$: 236 mA^2
L : 1.46 x10^{34} $cm^{-2}s^{-1}$
(achieved: 1.19 x10^{34} $cm^{-2}s^{-1}$)

If everything works well, physics run with 2.5 x 10^{34} $cm^{-2}s^{-1}$ can be done at the next operation.