Summary of machine studies

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Acknowledgements:

SuperKEKB KCG and BCG

SuperKEKB mini optics meeting

Jul. 04, 2019, KEK

Outline

- ➤ 2019.06.22: Beam-beam tune shift study
- ➤ 2019.06.20: V-angle change during collision tuning
- ➤ 2019.06.23: Tune scan study

1. 2019.06.22: Beam-beam tune shift study

➤ Machine study set-up (expected)

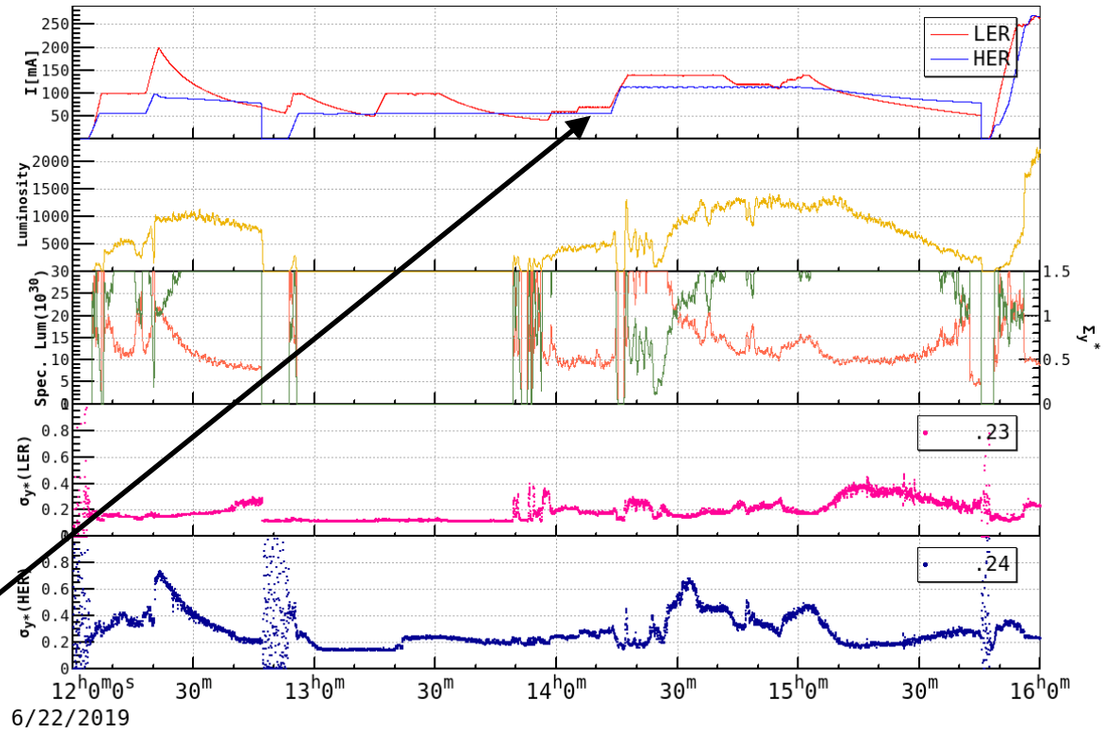
- **Filling pattern: #bunch=398, 12 bucket spacing**
- **Beam currents (consider energy transparency 4 GeV: 7 GeV):**
  - *** 100 mA (e+) x 57 mA (e-), $I_+ * I_- = 0.036$ mA^2**
  - *** 200 mA (e+) x 114 mA (e-), $I_+ * I_- = 0.144$ mA^2**
- **Feedback system (Thanks to M. Tobiyama)**
  Log: http://kekbbpmdev5.kek.jp
- **Fractional ν_y = .6075**

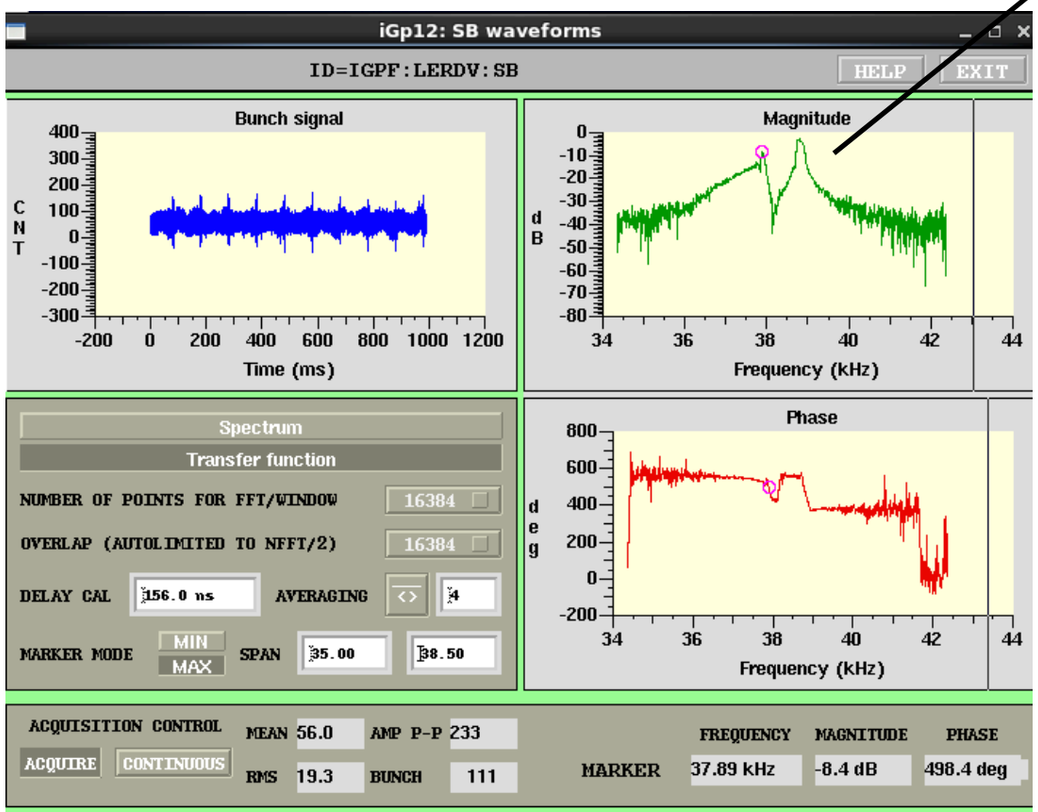
1. 2019.06.22: Beam-beam tune shift study

➤ Experimental observations

- First observation: 14:13 PM
- 70 mA (e+) x 57 mA (e-)
- σy*(e+)=0.18 μm, σy*(e-)=0.29 μm [XRM]
- Lum. ~$5*10^{32}$ $cm^{-2}s^{-1}$
- Beam-beam parameter estimated from lum.:
  ξ_{y-} ~0.022, ξ_{y+} ~0.011
- From feedback system:
  ξ_{y+} ~(38.79-37.89) kHz /99.39 kHz ~0.009

Fairly good consistency?





$$\mathcal{L} = \mathcal{L}_0 \cdot R_\theta \qquad \mathcal{L}_0 = \frac{N_\mathrm{p} N_\mathrm{e} f N_\mathrm{b}}{2\pi\sqrt{\sigma_\mathrm{xp}^{*2}+\sigma_\mathrm{xe}^{*2}}\sqrt{\sigma_\mathrm{yp}^{*2}+\sigma_\mathrm{ye}^{*2}}}$$

$$R_\theta \approx \frac{1}{\sqrt{1+\frac{\sigma_\mathrm{zp}^{*2}+\sigma_\mathrm{ze}^{*2}}{\sigma_\mathrm{xp}^{*2}+\sigma_\mathrm{xe}^{*2}}\tan^2\frac{\theta}{2}}}$$

$$\xi_{\mathrm{ye}0} = \frac{N_\mathrm{p} r_\mathrm{e} \beta_\mathrm{ye}^*}{2\pi\gamma_\mathrm{e}\sigma_\mathrm{xp}^*\sigma_\mathrm{yp}^*} \frac{1}{\sqrt{\left(\frac{\sigma_\mathrm{zp}^*}{\sigma_\mathrm{xp}^*}\tan\frac{\theta}{2}\right)^2+1}+\frac{\sigma_\mathrm{yp}^*}{\sigma_\mathrm{xp}^*}}$$

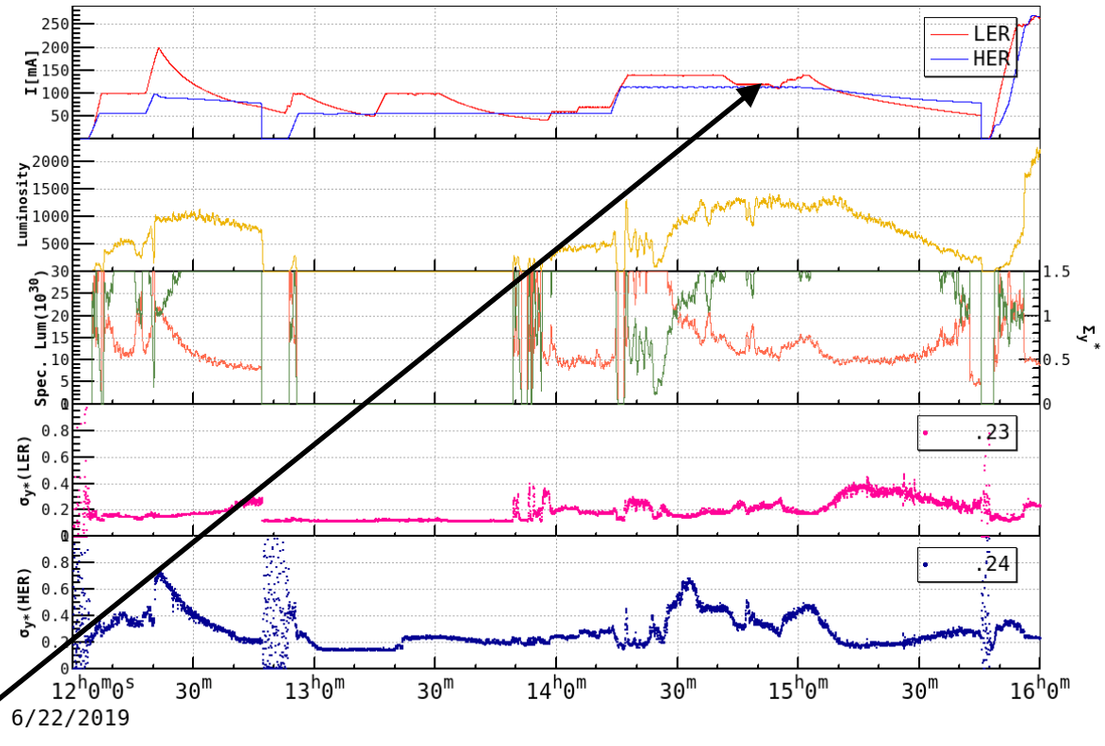
$$\mathcal{L} = \frac{\gamma_\pm}{2er_e}\frac{I_\pm\xi_\pm}{\beta_{y\pm}^*}\frac{2\sigma_{x\mp}^*\sigma_{y\mp}^*}{\sqrt{\sigma_{x+}^{*2}+\sigma_{x-}^{*2}}\sqrt{\sigma_{y+}^{*2}+\sigma_{y-}^{*2}}}$$

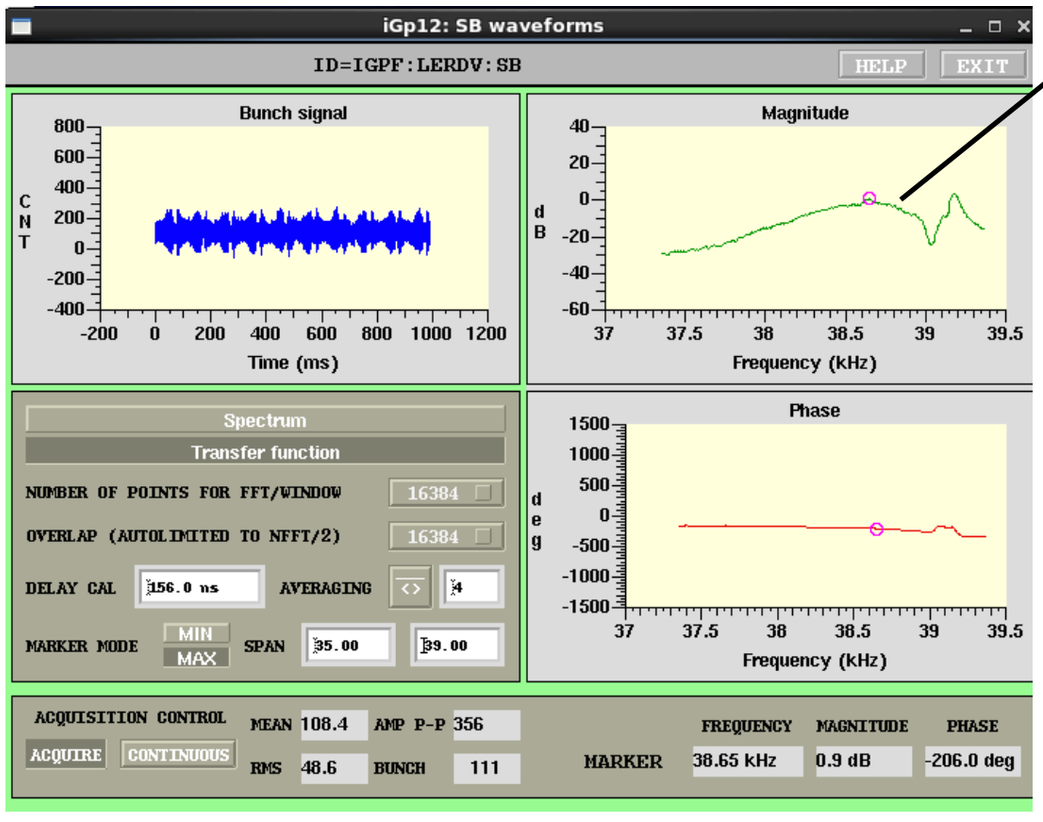
Correct formula?

1. 2019.06.22: Beam-beam tune shift study

➤ Experimental observations

- Second observation: 14:51 PM
- 119 mA (e+) x 113 mA (e-)
- σy*(e+)=0.23 μm, σy*(e-)=0.33 μm [XRM]
- Lum. ~$12.5*10^{32}$ $cm^{-2}s^{-1}$
- Beam-beam parameter estimated from lum.:
  ξ_{y-} ~0.024, ξ_{y+} ~0.018
- From feedback system:
  ξ_{y+} ~? kHz /99.39 kHz ~?

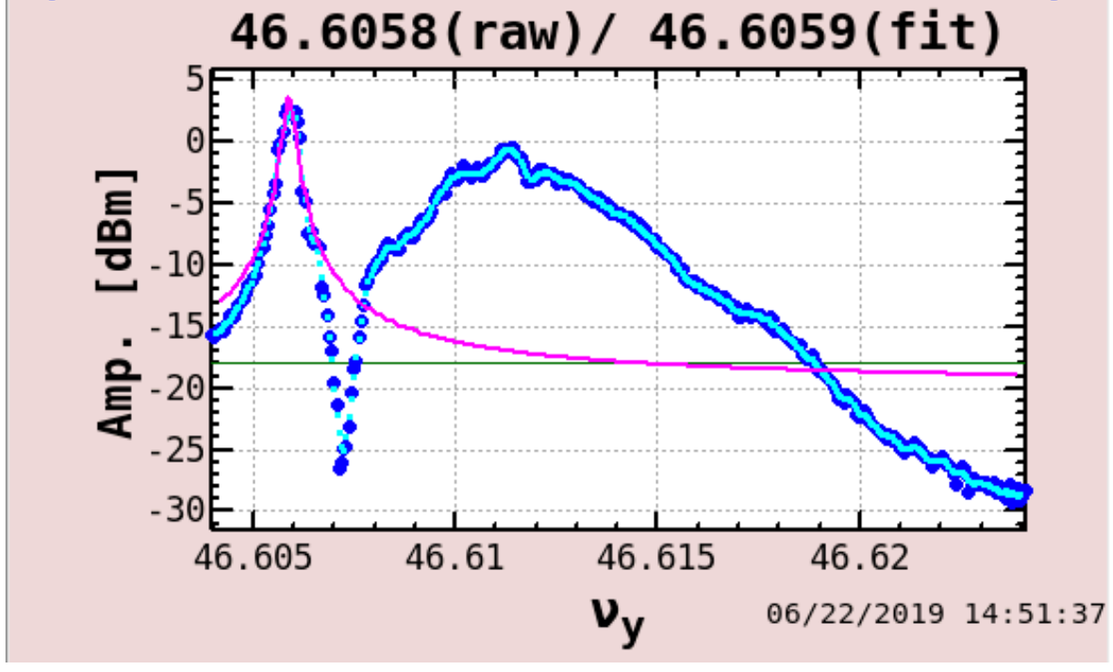




K. Ohmi:

The excitation strength may be too strong.

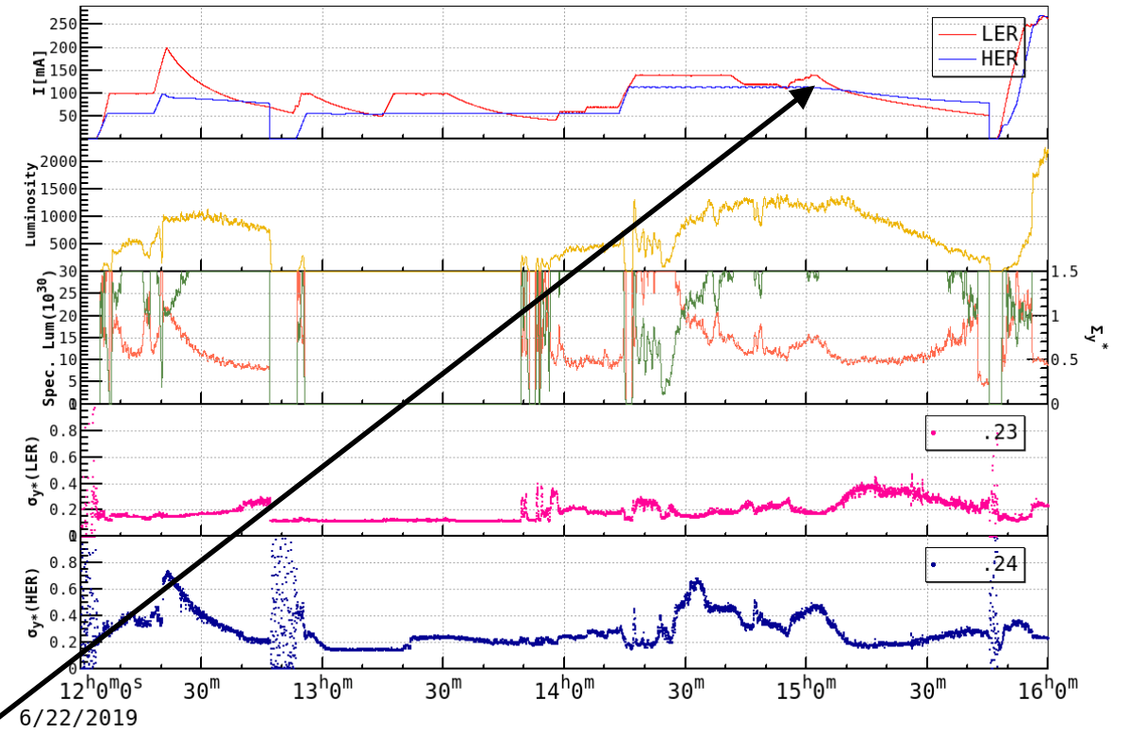
Equalization of two tune shift was not easy.

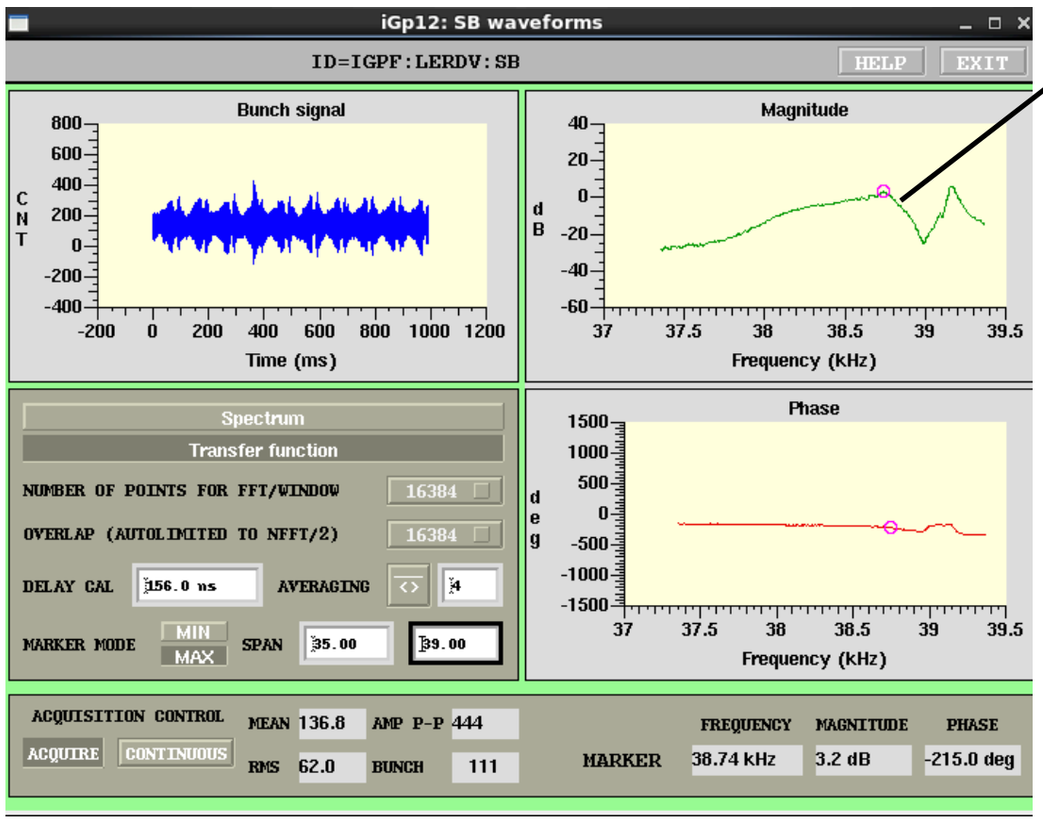


1. 2019.06.22: Beam-beam tune shift study

➤ Experimental observations

- Third observation: 15:02 PM
- 140 mA (e+) x 113 mA (e-)
- σy*(e+)=0.17 μm, σy*(e-)=0.46 μm [XRM]
- Lum. ~$11.5*10^{32}$ $cm^{-2}s^{-1}$
- Beam-beam parameter estimated from lum.:
  ξ_{y-} ~0.031, ξ_{y+} ~0.015
- From feedback system:
  ξ_{y+} ~? kHz /99.39 kHz ~?





K. Ohmi:

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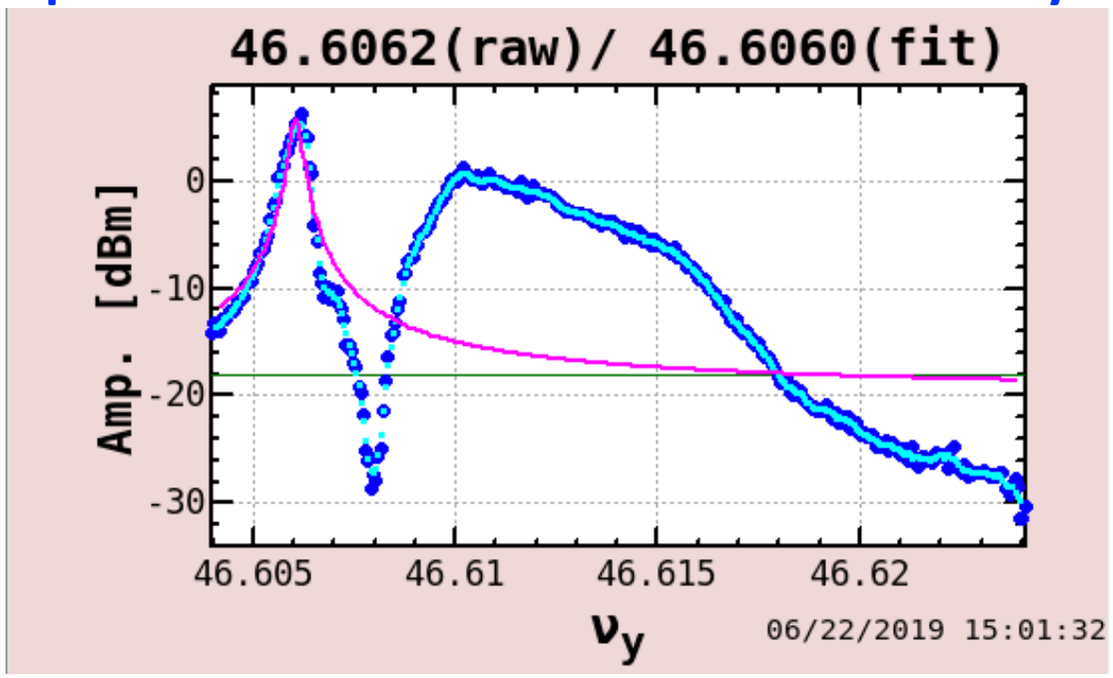


1. 2019.06.22: Beam-beam tune shift study

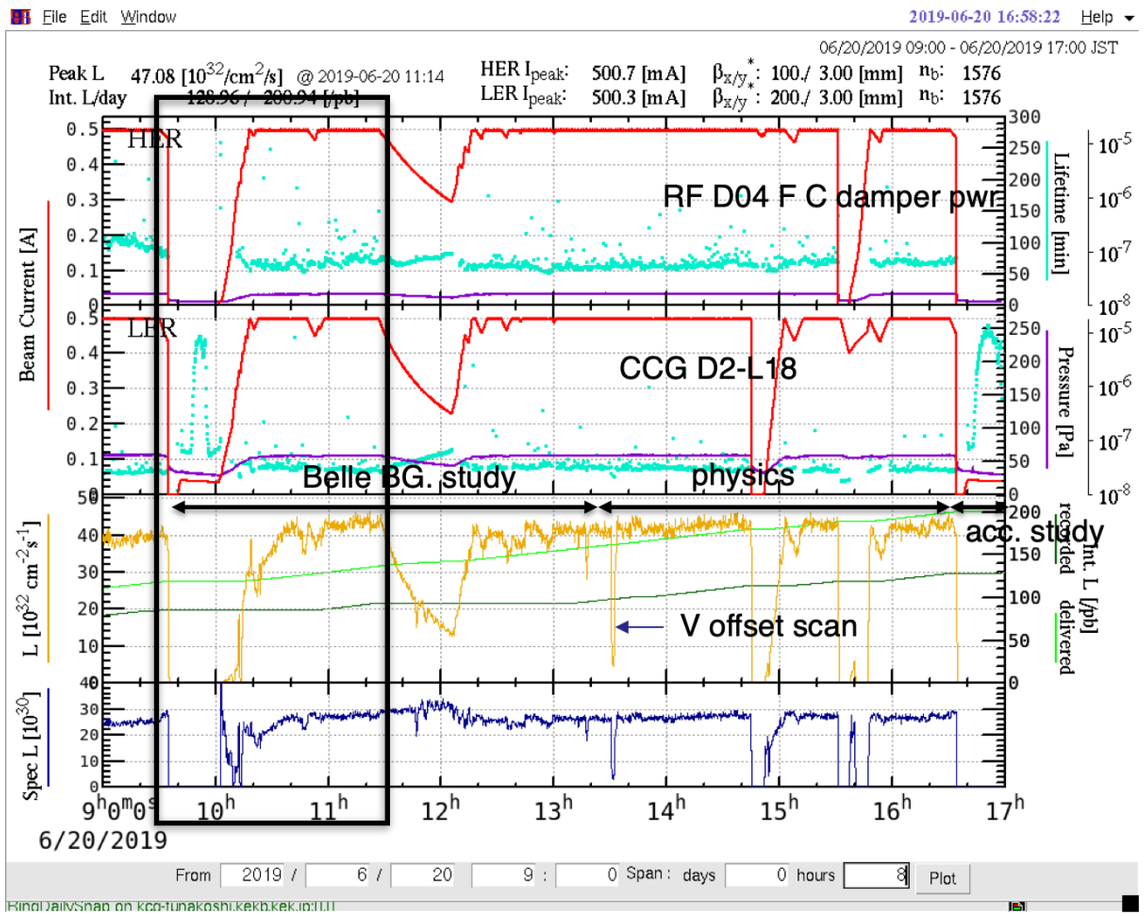
➤ Future study

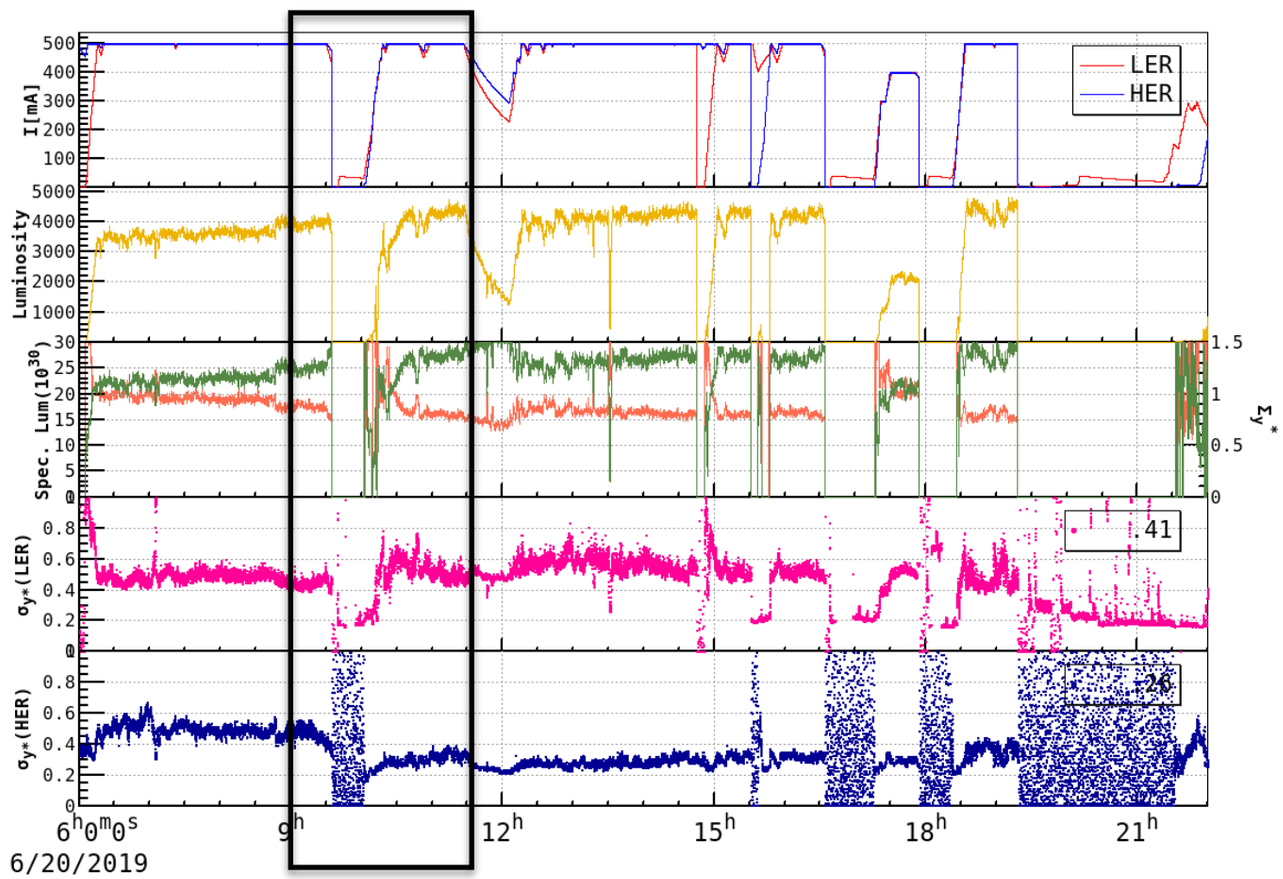
- Better balanced beam
- Adjust excitation force of feedback system
- Better collision condition (IP knobs optimized, such as iBump V-offset, stabilized vertical beam sizes, equalized beam-beam tune shift for two beams, etc.)
- … …

2. 2019.06.20: V-angle change during collision tuning

➤ Experimental observations

- **Remarkable improvement in luminosity by adjusting V-angle during background study**
- **Vertical size of e- beam reduced significantly**





Day shift report on 2019.06.20 (Fukuma-san)

2. 2019.06.20: V-angle change during collision tuning

➤ BBWS simulations to explain the experimental observations

- BBWS: Beam-Beam Weak-Strong simulation code by K. Ohmi
- ζ_y as the input parameter to model the V-angle
- ε_{y-}=7.5 pm, ε_{y+}=18 pm: Estimated from XRM data for single beams (without collision)

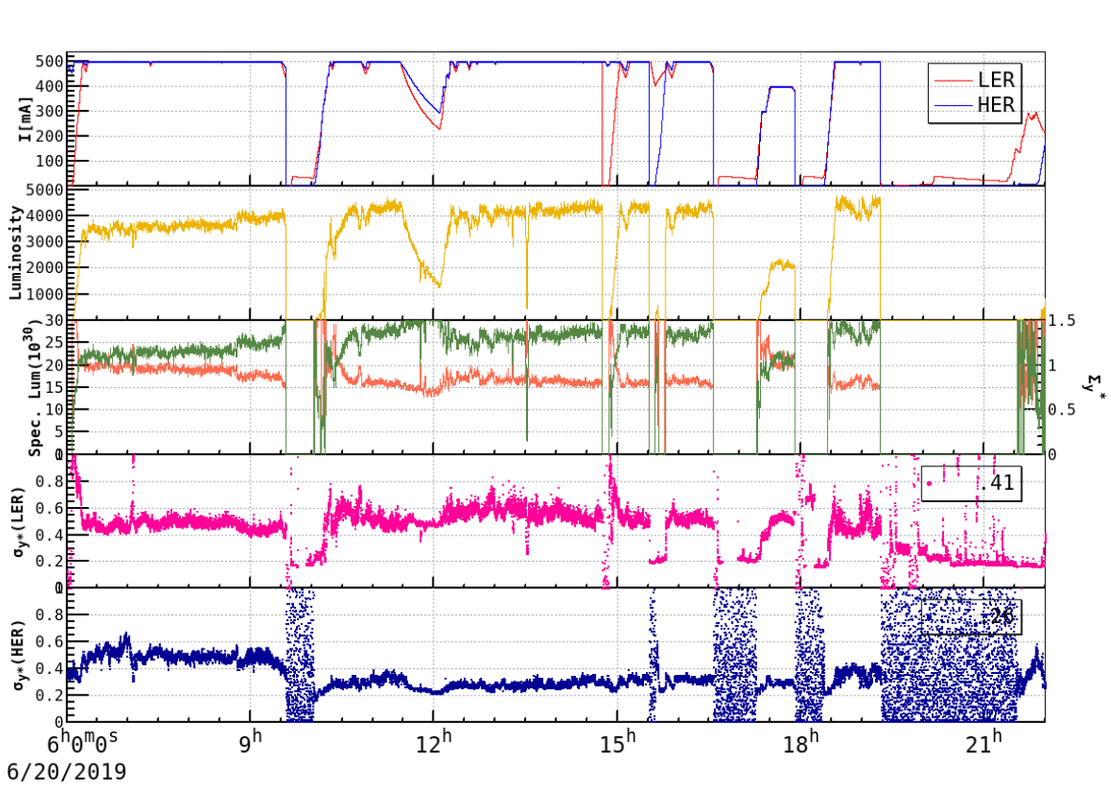
	2019.06.20 (case 1)		2019.06.20 (case 2)		2019.06.20 (case 3)	
	HER	LER	HER	LER	HER	LER
I_b (A)	0.5	0.5	0.5	0.5	0.5	0.5
# bunch	1576		1576		1576	
ε_x (nm)	4.537	1.64	4.537	1.64	4.537	1.64
ε_y (pm)	7.5	18	50	18	50	80
β_x (mm)	100	200	100	200	100	200
β_y (mm)	3	3	3	3	3	3
σ_z (mm)	5.5	5.0	5.5	5.0	5.5	5.0
σ_y (nm)	150	232	387	232	387	490
ν_x	45.5439	44.559	45.5439	44.559	45.5439	44.559
ν_y	43.6082	46.618	43.6082	46.618	43.6082	46.618
ν_s	0.02718	0.023	0.02718	0.023	0.02718	0.023
ξ_y(Geom.)	0.041	0.1	0.041	0.039	0.019	0.039
$\mathcal{L}$(Geom.)	1.16E+34		7.1E+33		5.1E+33	

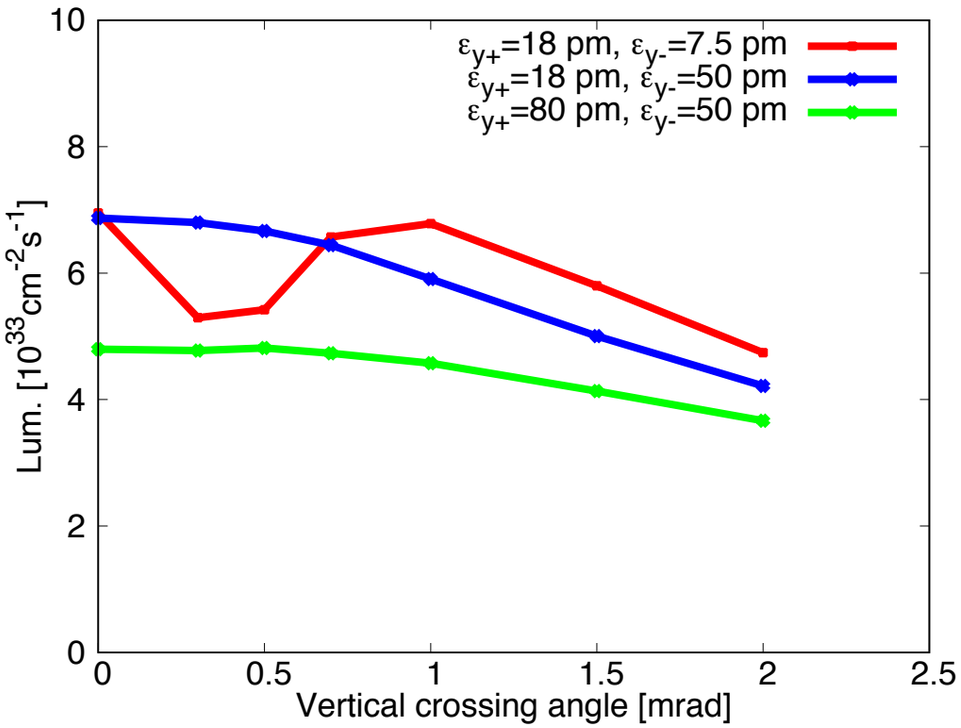
2. 2019.06.20: V-angle change during collision tuning

➤ BBWS simulations to explain the experimental observations

- The observed lum. improvement was mainly from the reduced vertical e- beam size
- Vertical angle can cause luminosity loss: just geometric loss if there is no instability
- BUT, if two beams with small vertical emittance collide and there is beam-beam instability, the beam instability is also sensitive to vertical crossing angle (see the red line) => Then curing vertical crossing angle will create additional again

Somehow consistent with experimental observations?

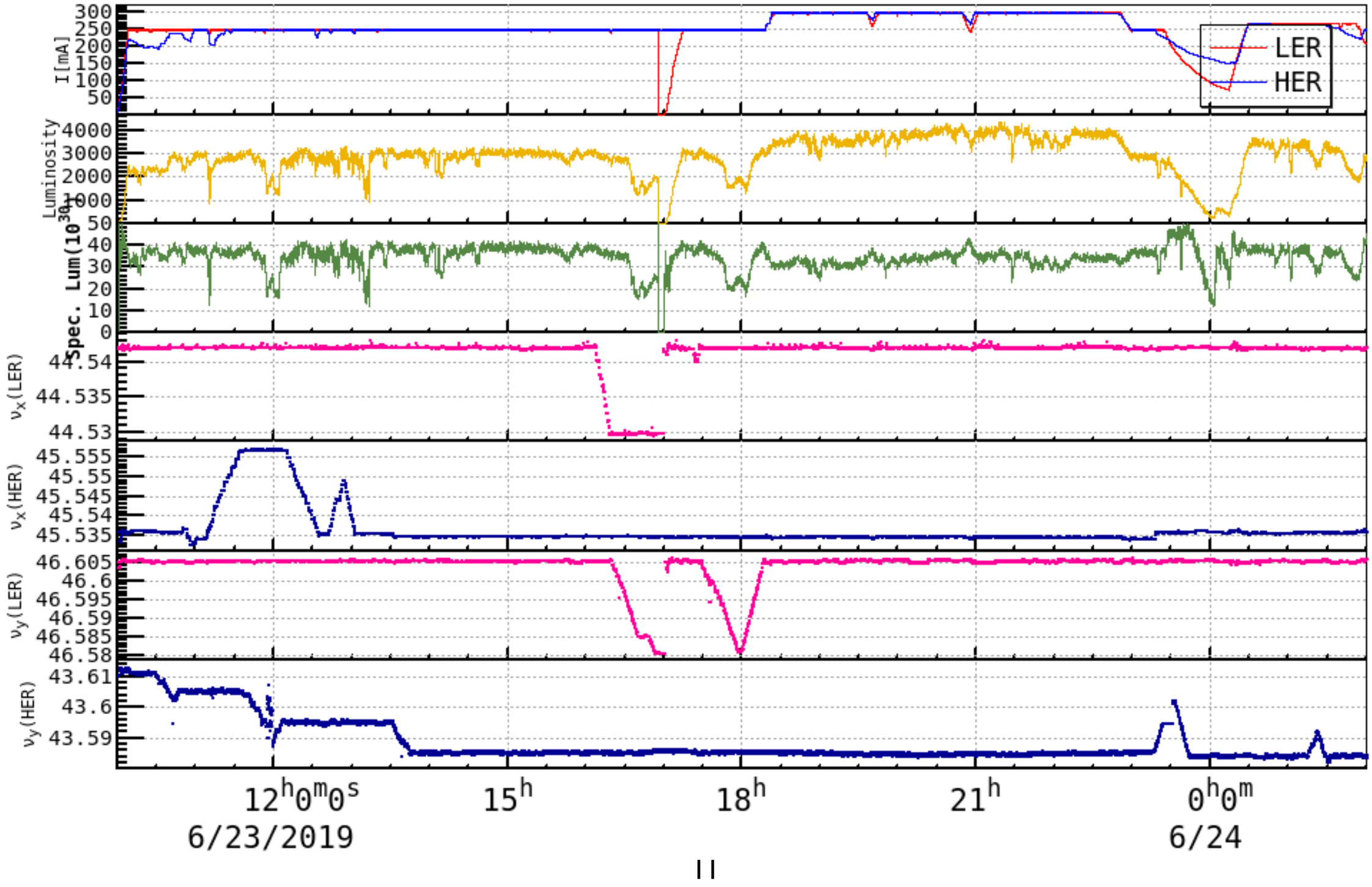




3. 2019.06.23: Tune scan study

➤ Tune scans were done at both HER and LER

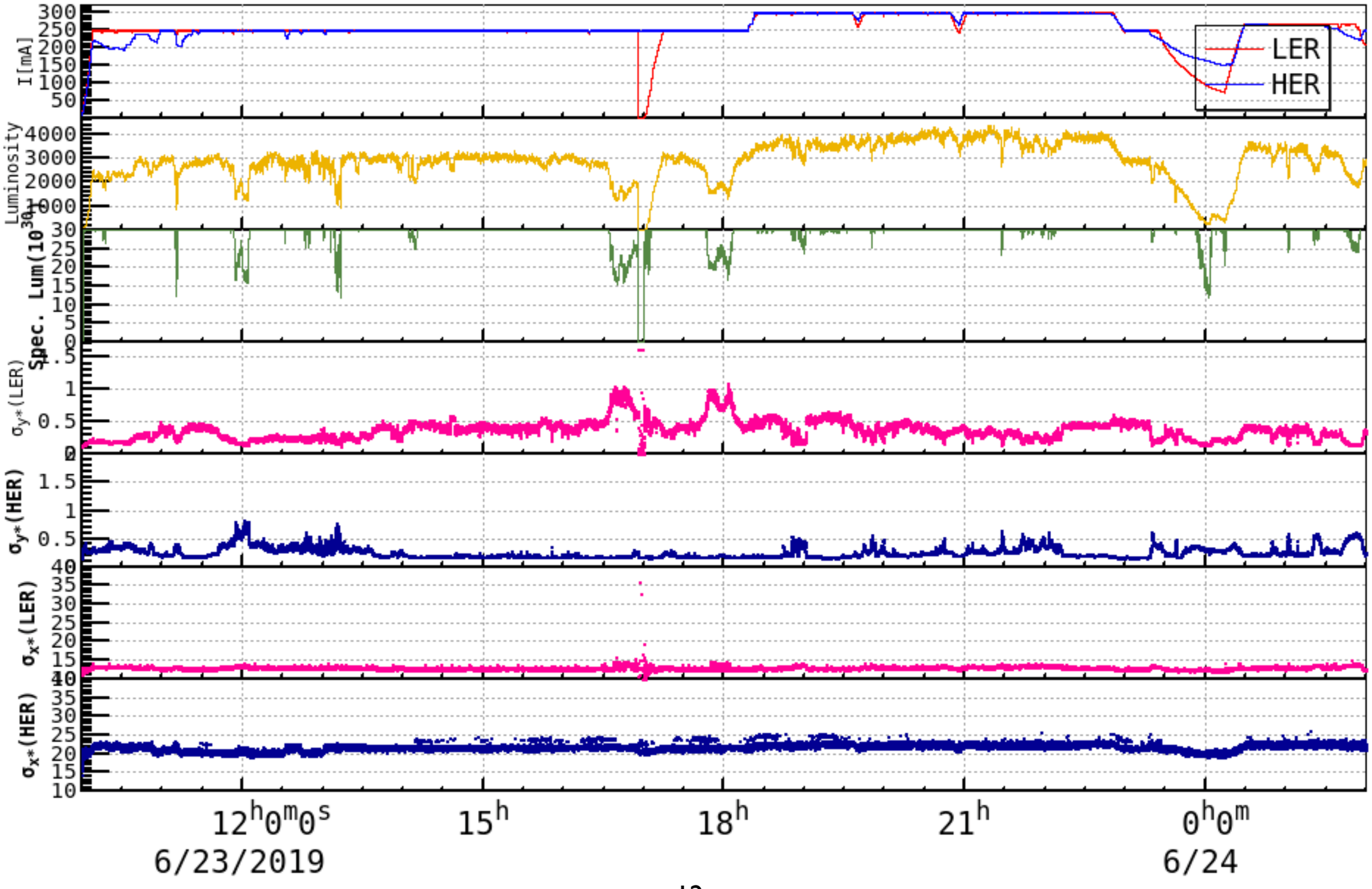
- **Horizontal and vertical tunes were scanned one by one**



3. 2019.06.23: Tune scan study

➤ Tune scans were done at both HER and LER

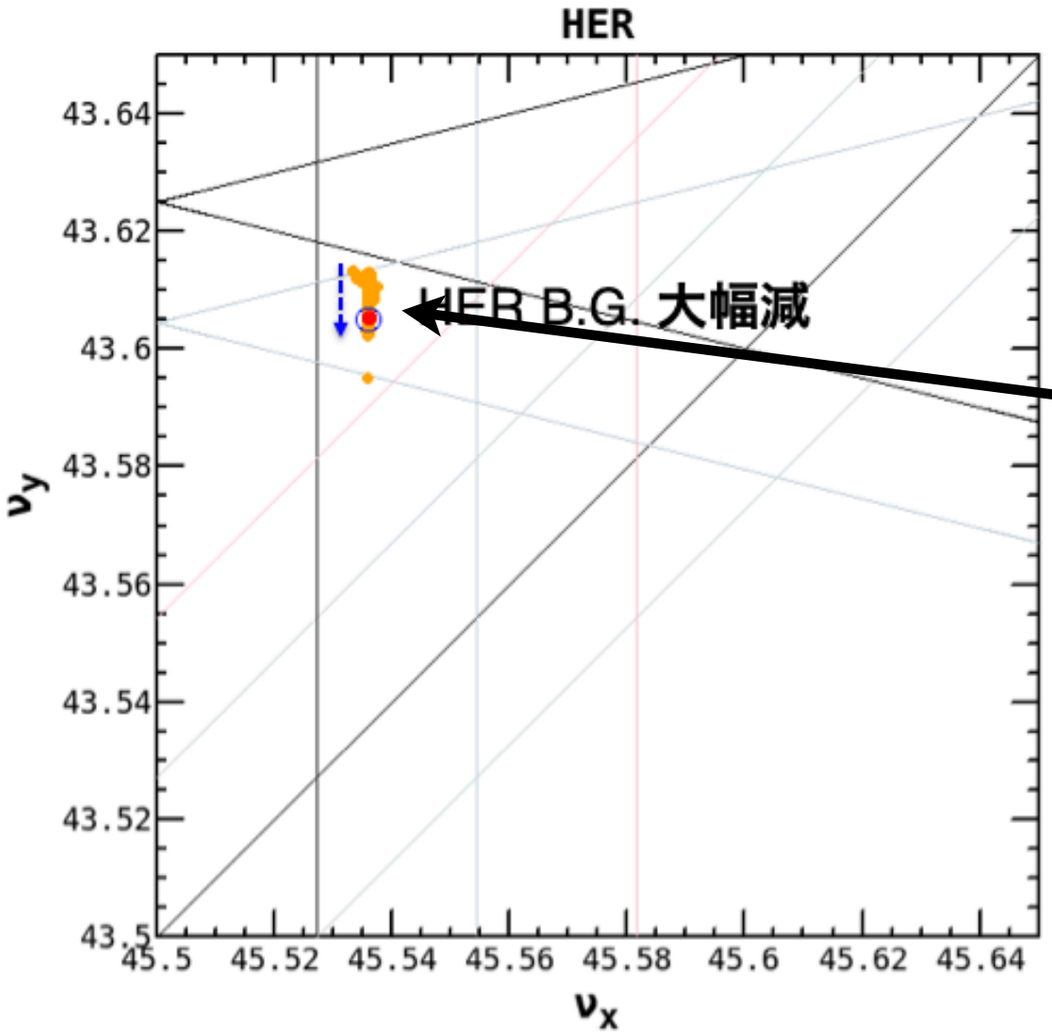
- **Tune dependent luminosity, beam sizes, Belle-II background were observed**

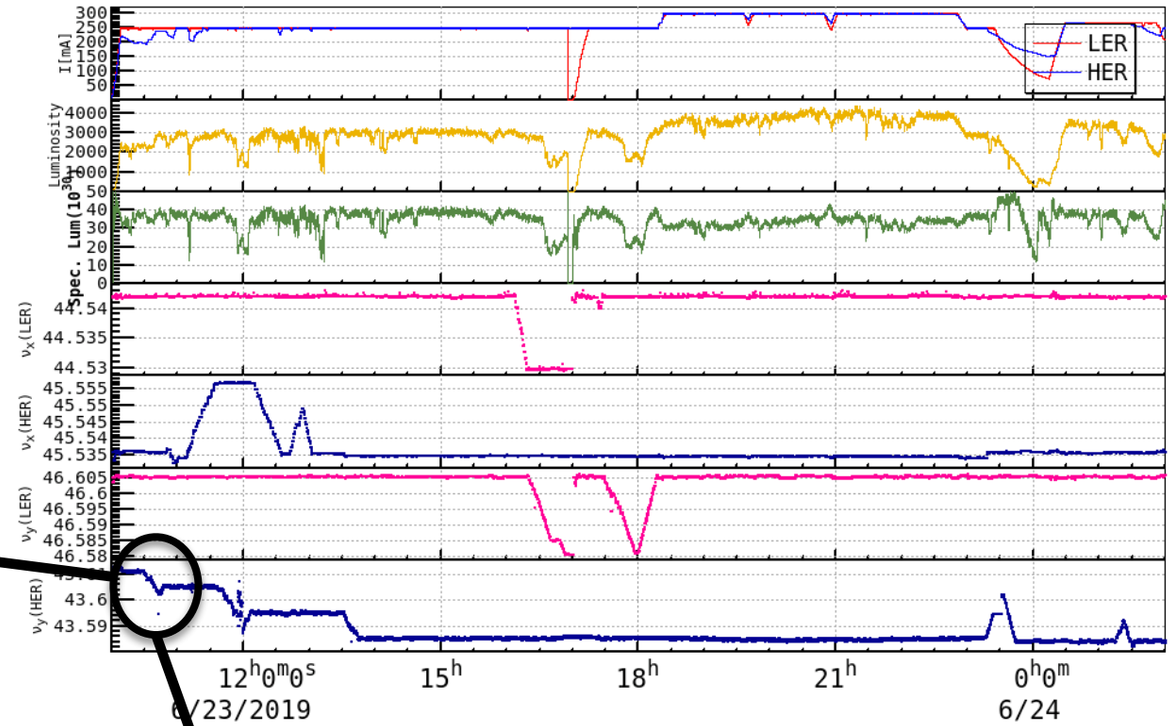


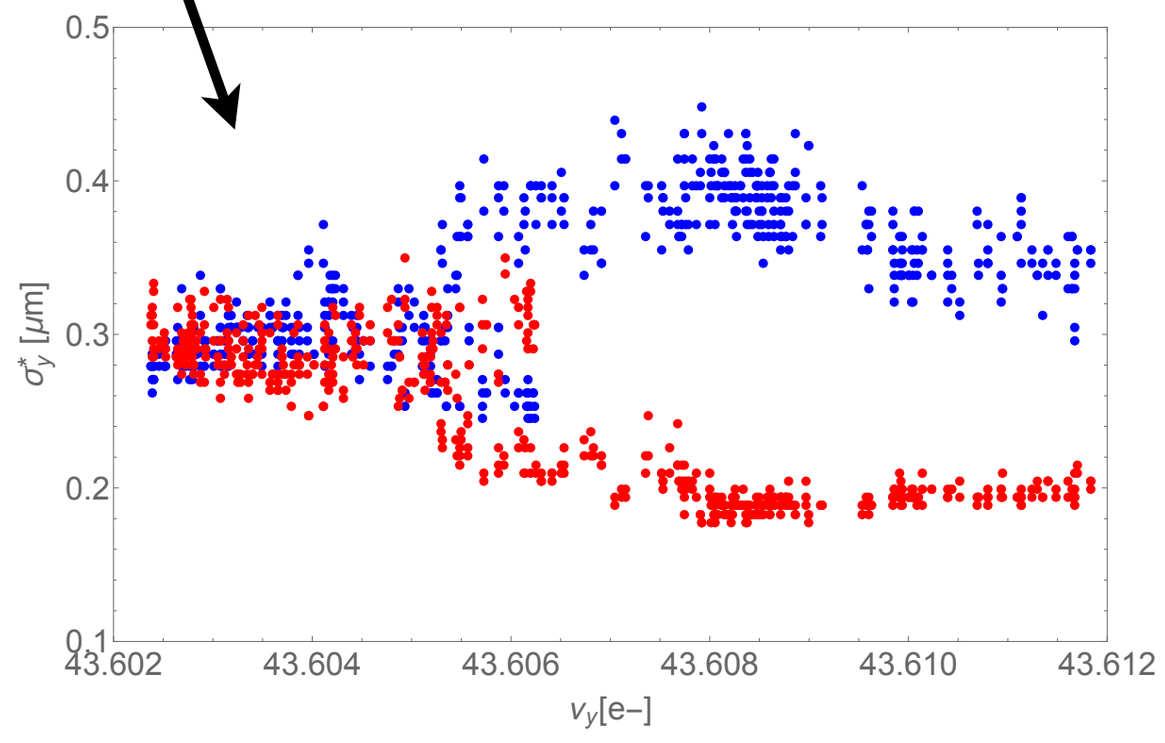
3. 2019.06.23: Tune scan study

➤ HER ν_y scan with ν_x = 45.536

- **Note that HER beam current was not constant, so it's hard to draw conclusion from beam sizes**





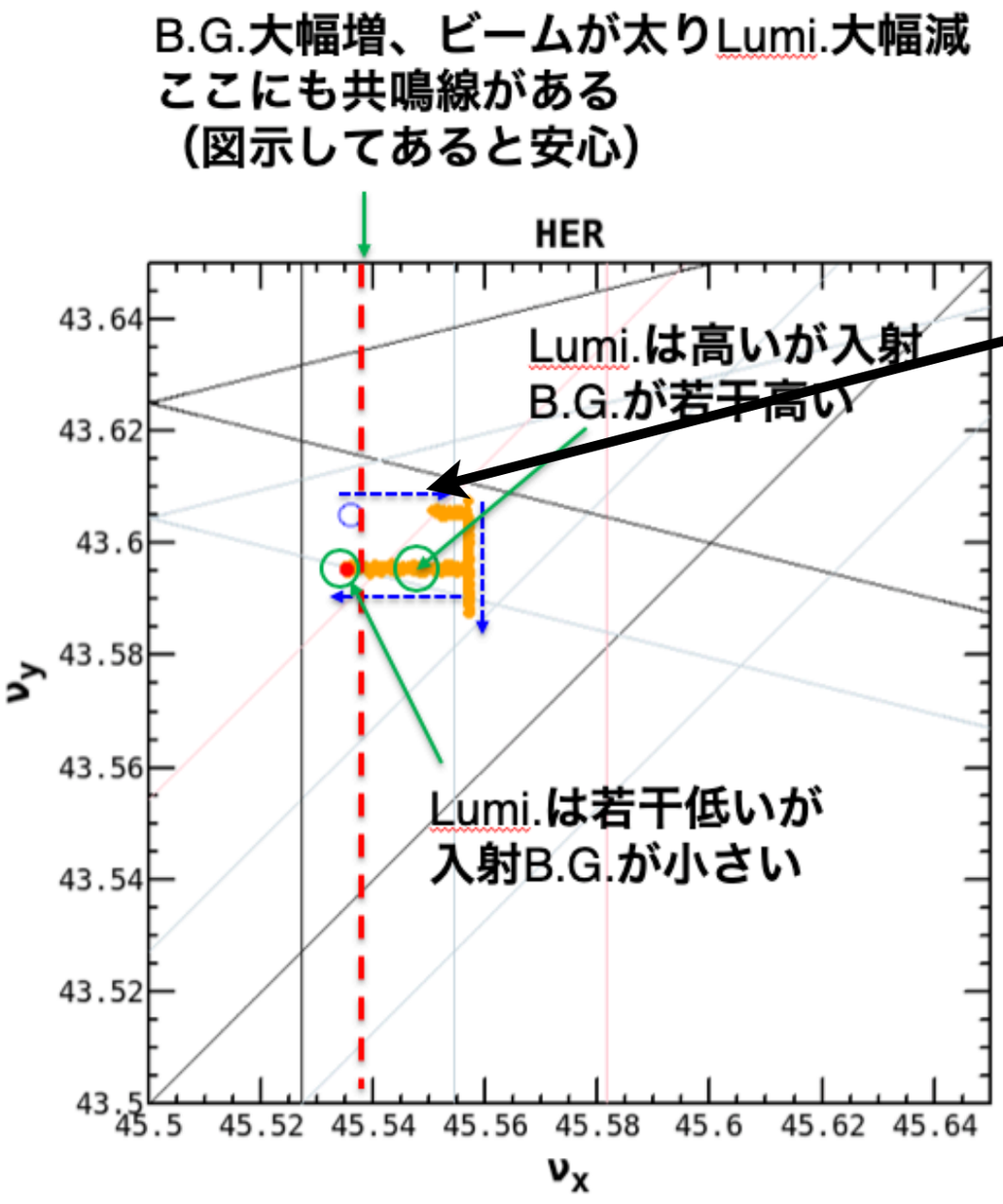


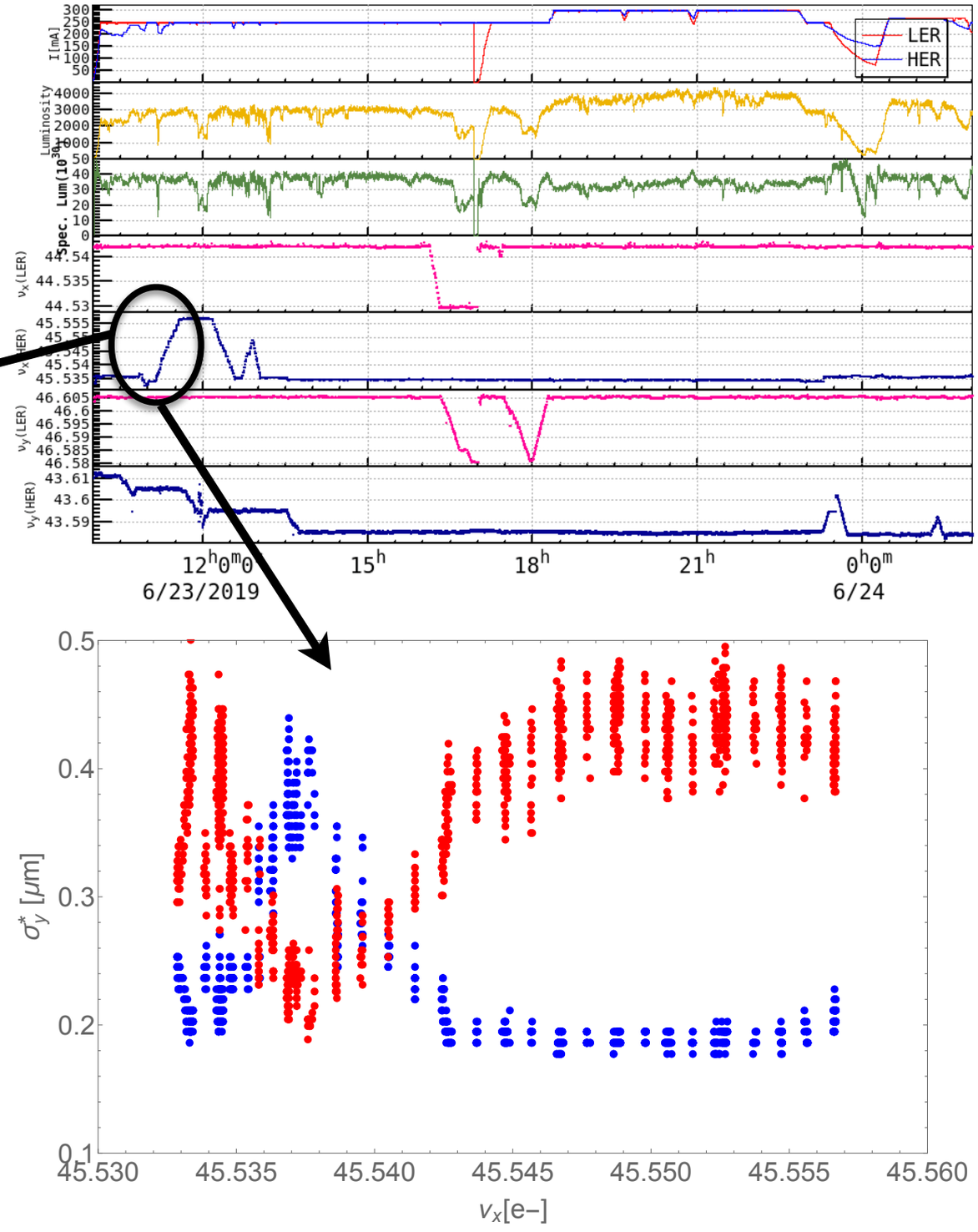
Ref. K. Shibata, KCG shift report

3. 2019.06.23: Tune scan study

➤ HER ν_x scan with ν_y = 43.605

- **Plausible resonance around ν_x = 45.537. How to explain it?**



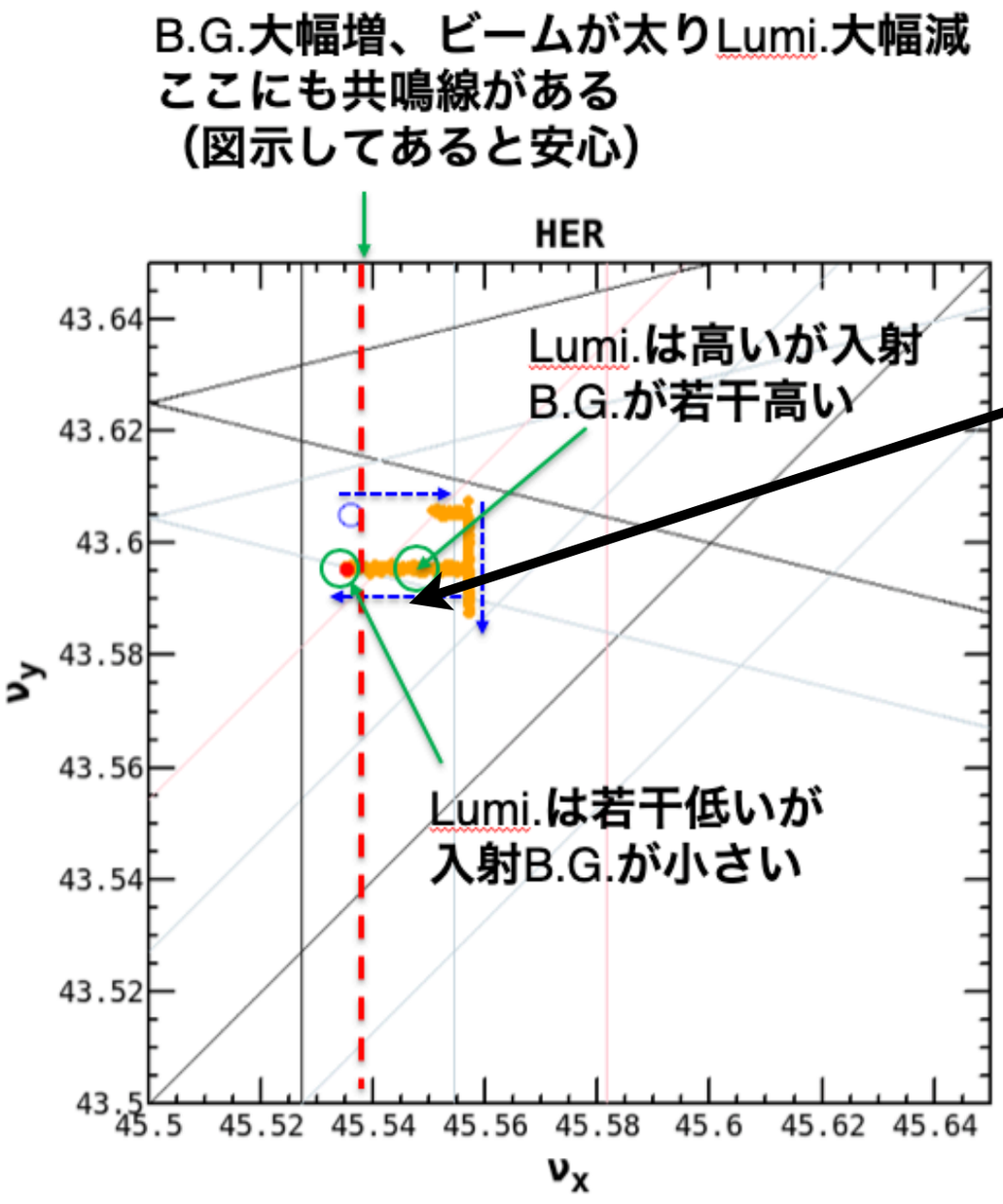


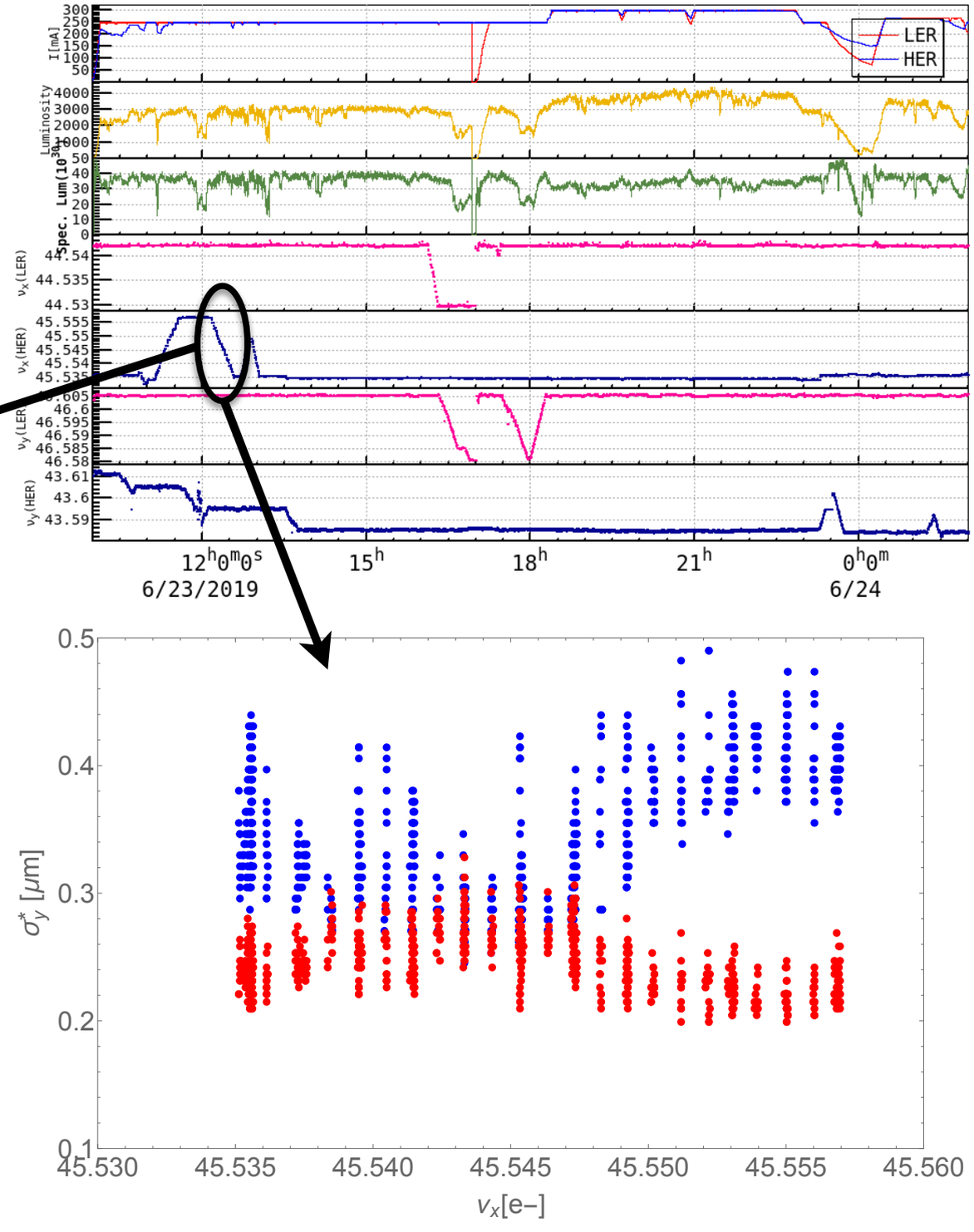
Ref. K. Shibata, KCG shift report

3. 2019.06.23: Tune scan study

➤ HER ν_x scan with ν_y = 43.595

- Resonance around ν_x = 45.537 is not clear now.
- Flip-flop phenomenon?!



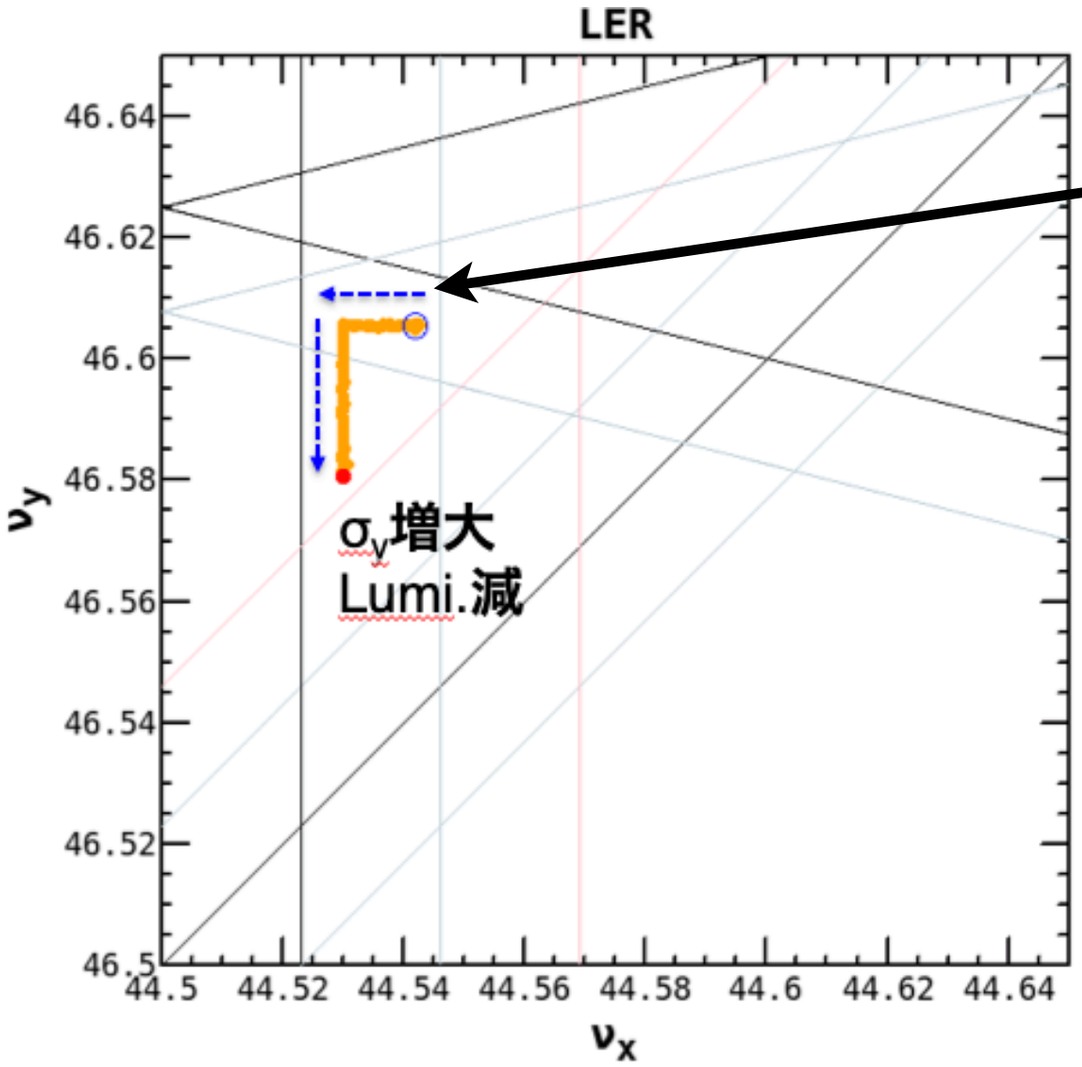


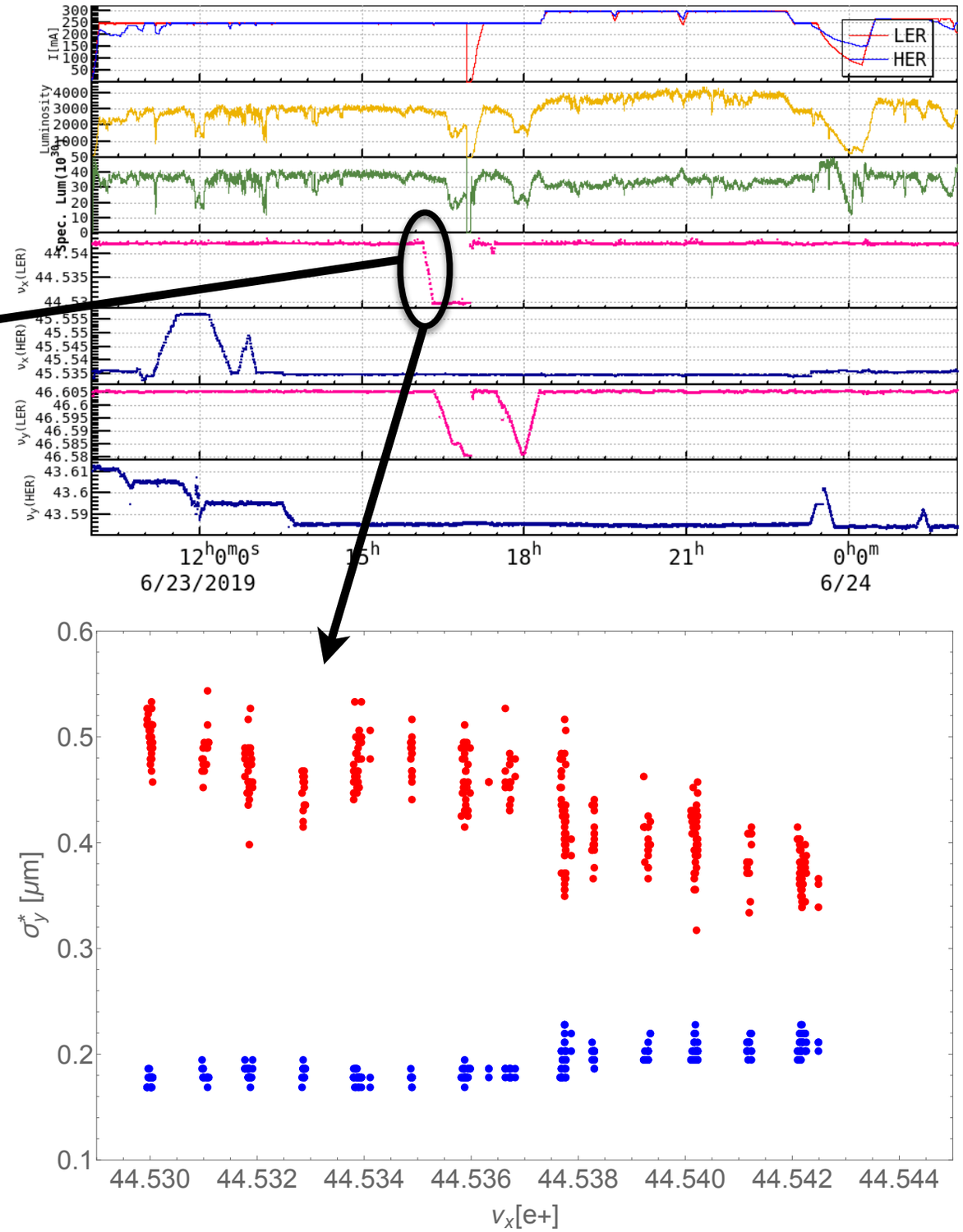
Ref. K. Shibata, KCG shift report

3. 2019.06.23: Tune scan study

➤ LER ν_x scan with ν_y = 46.606

- **No resonance around $2\nu_x + 3\nu_s = N$.**



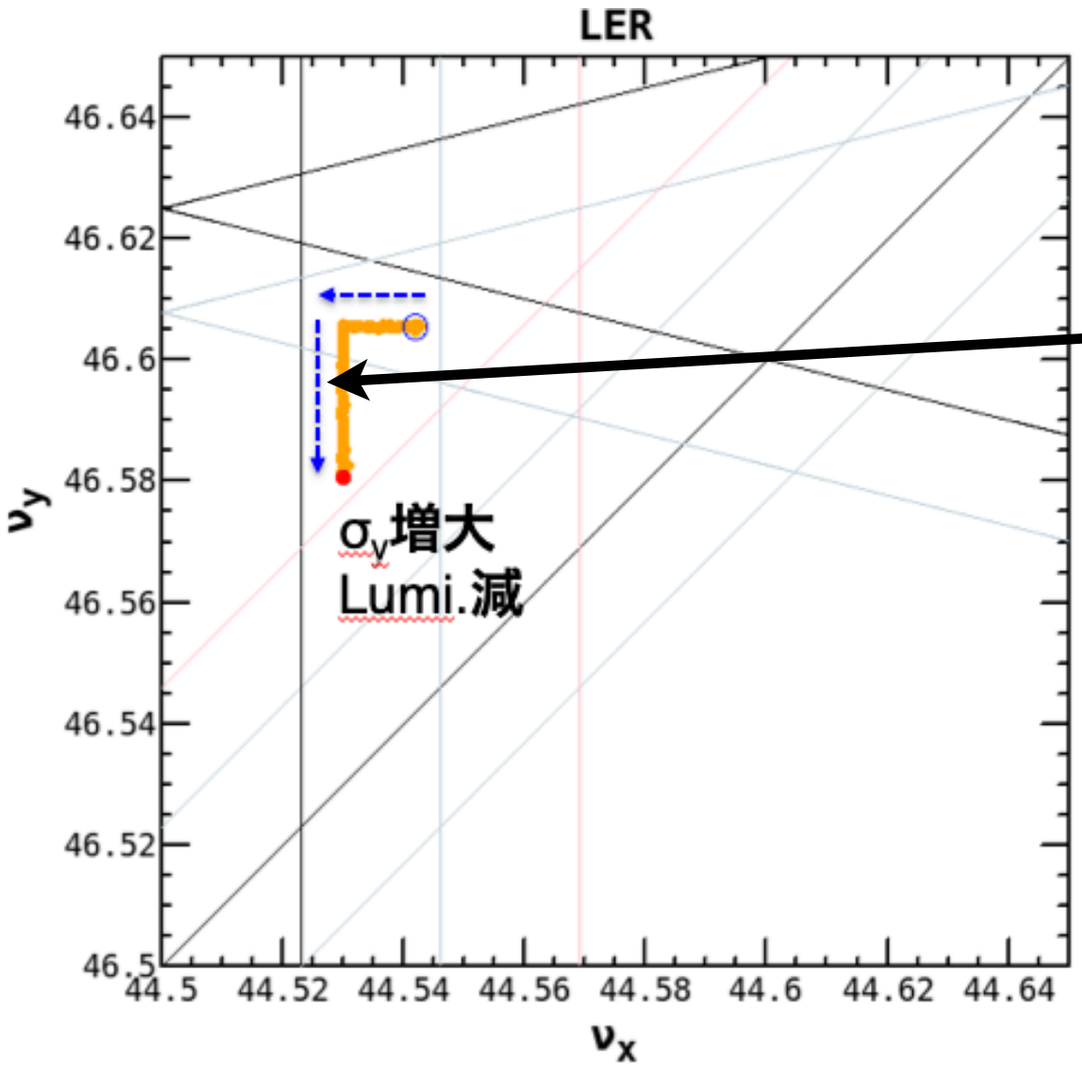


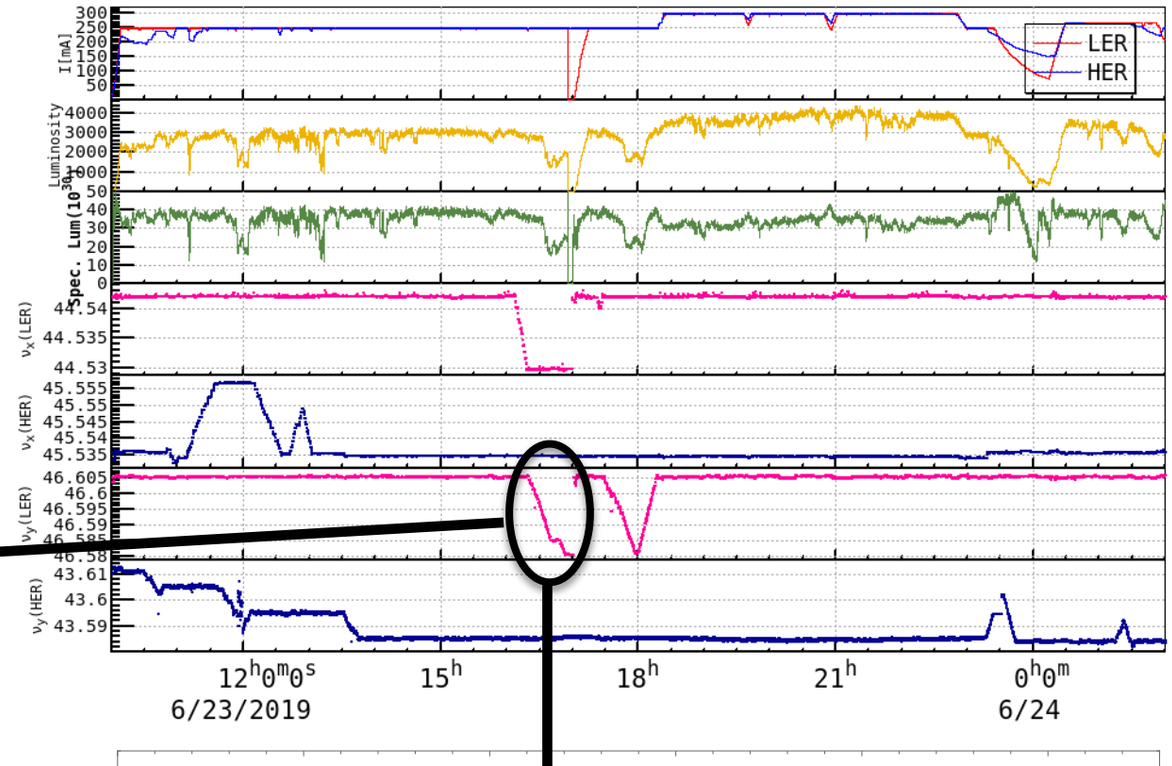
Ref. K. Shibata, KCG shift report

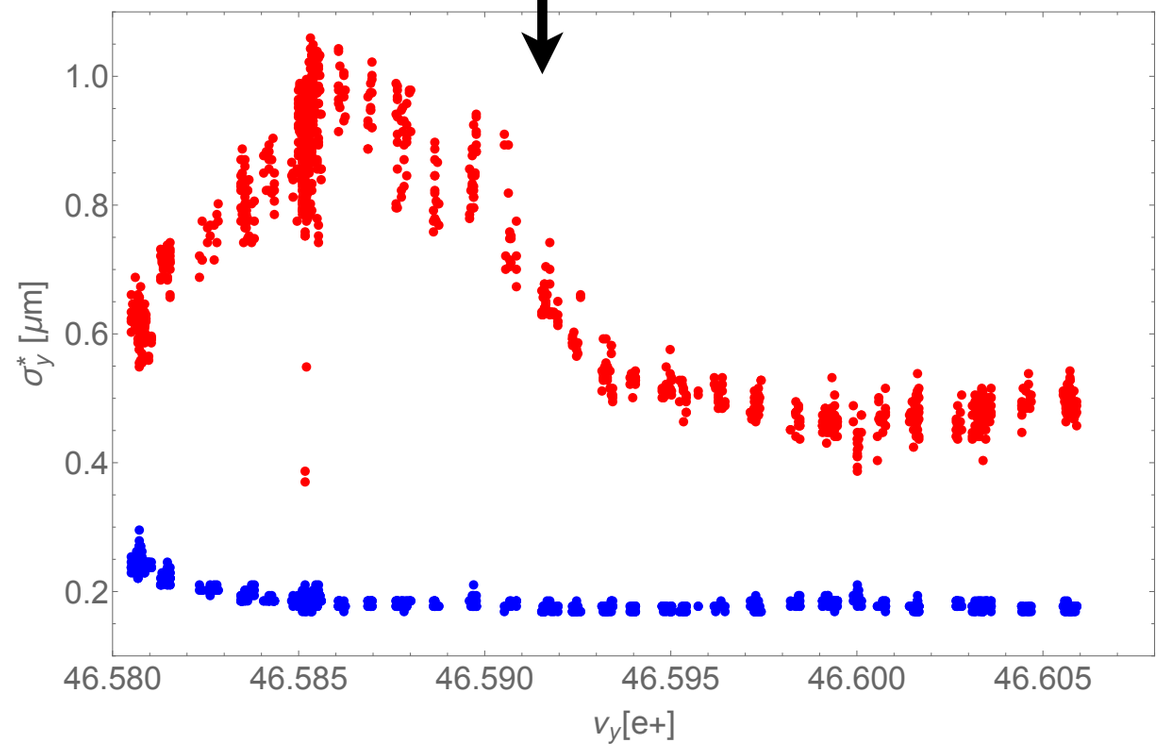
3. 2019.06.23: Tune scan study

➤ LER ν_y scan with ν_x = 44.53

- No resonance around ν_y = 44.586 ?! Unbelievable…
- Need optics correction around (.53,.58) ?





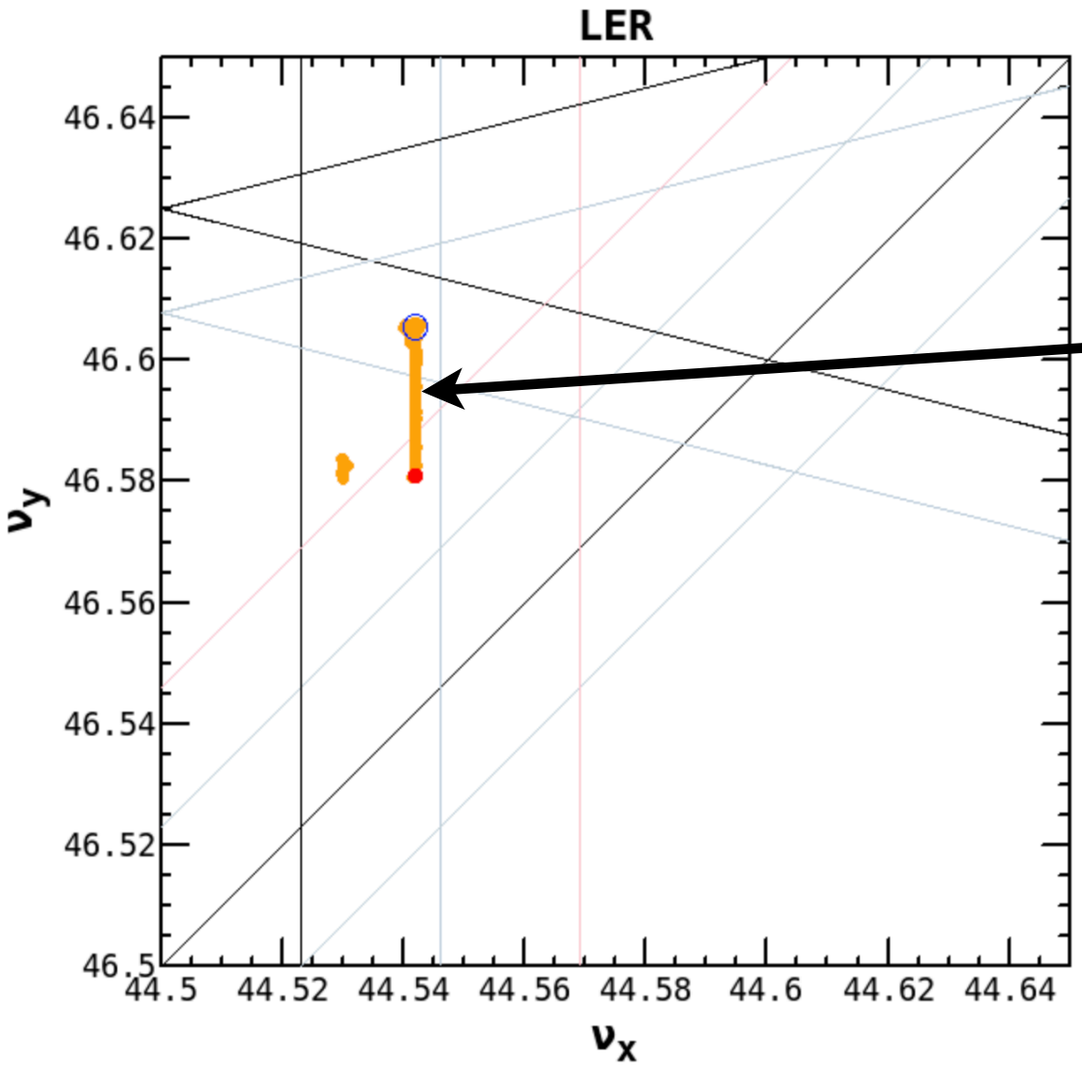


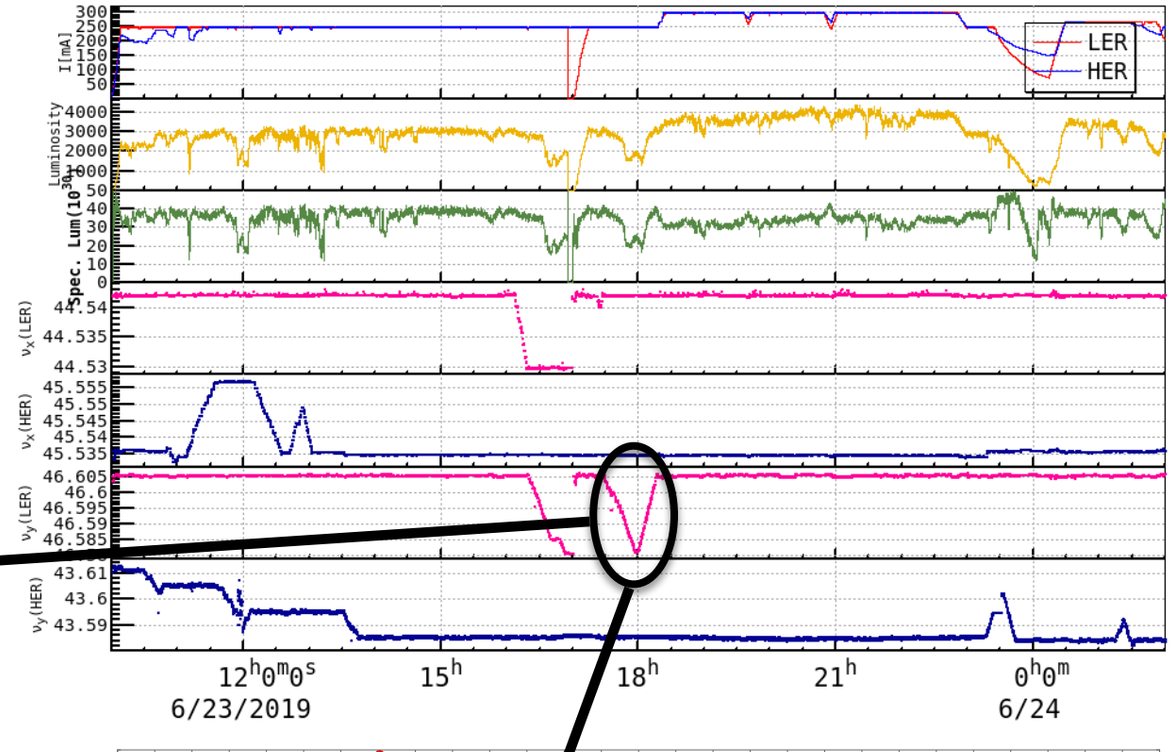
Ref. K. Shibata, KCG shift report

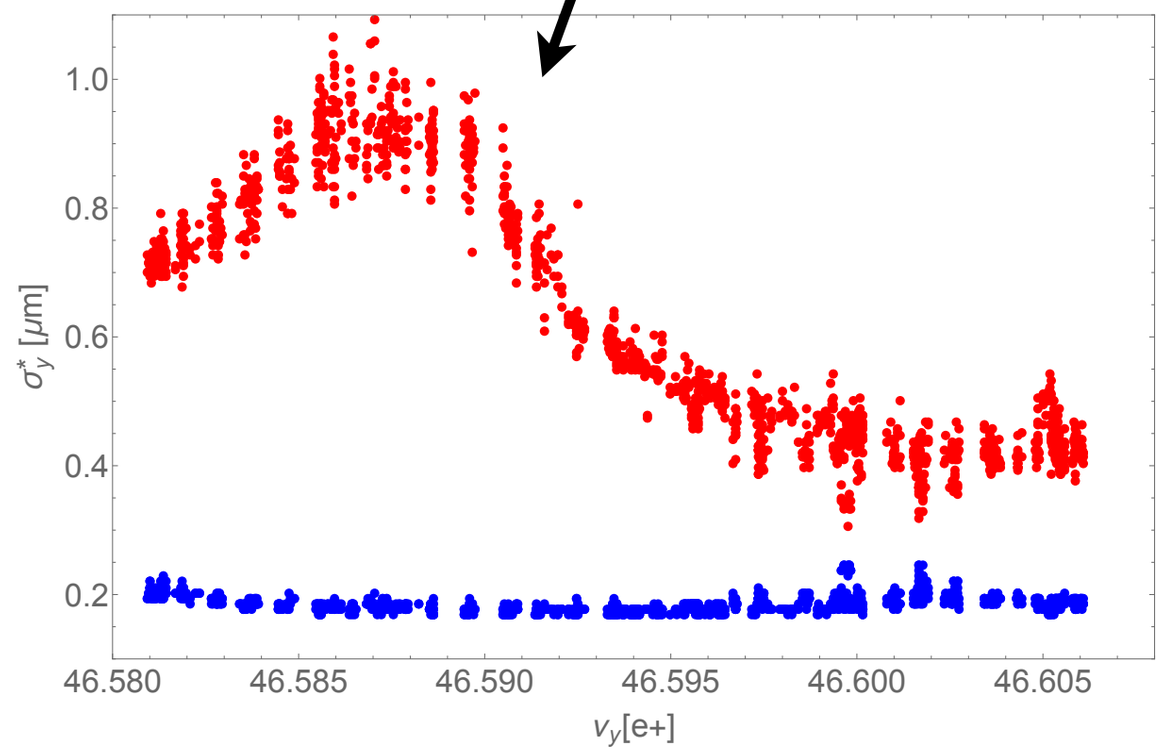
3. 2019.06.23: Tune scan study

➤ LER ν_y scan with ν_x = 44.542

- No resonance around ν_y = 44.586 ?! Unbelievable…
- Need optics correction around (.53,.58) ?







Ref. T. Kawamoto, KCG shift report

4. Last week of operation

➤ Beam sizes at IP