Optics & Beam-Beam Issues

Akio Morita

KEKB Review 2020.07.15

Major Issues

- Global XY-Coupling Correction
- IP Local Coupling
- Injection Kicker Local Coupling
- LER High Emittance Optics
- Crab Waist Optics
- IP Chromatic Coupling

Global XY-Coupling Correction (1)

- One of key components for nano-beam collision:
  - Smaller ε_y is required for squeezing down β^*_y in order to keep beam-beam parameter.
  - It is minimizing L^2-norm of vertical orbit crosstalk errors induced by 6-kinds of horizontal steering single kicks.
    - L^2-norm minimizing are performed by using SVD and optics model response against skew quadrupole correctors.

Global XY-Coupling Correction (2)

- Strange behavior of XRM beam size during xy-coupling correction iterations:
  - XRM vertical beam size *increases* after xy-coupling correction.
    - This behavior trends to increase after β^*_y squeezing down to 1mm.
  - XRM beam size is reproduced by rolling back/forward the set of skew quadrupole corrector parameters.
  - In some case, the reduced vertical orbit crosstalks are observed by xy-coupling measurement after beam size increasing.
  - In some case, recorrection with different SVD tolerance and damping factor (typically weaker correction) achieves vertical beam size shrink or same beam-size.
  - Empirically, skew quadrupole corrector on SL (local chromaticity corrector sextupole) makes bad results.

Global XY-Coupling Correction (3)

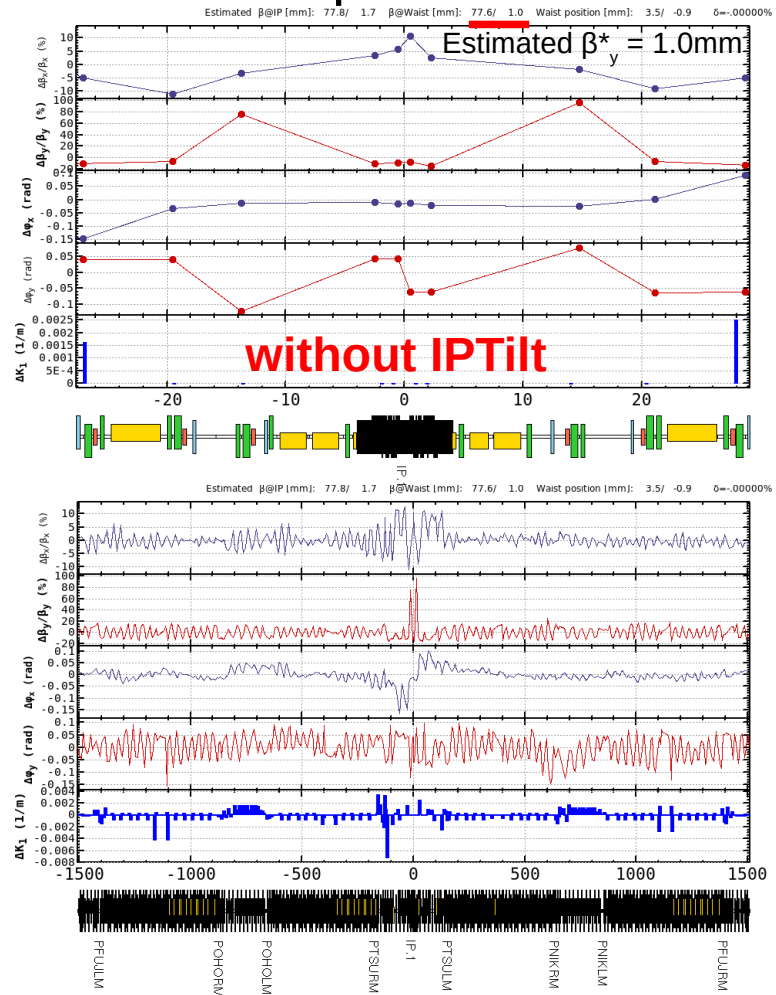
- Strange behavior of XRM beam size during xy-coupling correction iterations:
  - Where these behaviors come from?
    - Correction side effect to X-ray radiation point for XRM
    - Correction vector exceeding linear perturbation region
    - Lack of XRM beam size monotonicity against xy-coupling correction iterations (Eitehr algotithm or observation operator issue?)
    - Modeling Error (Modeling parameter mistakes, missing field components?)
  - We HAVE TO establish stable xy-coupling correction scheme for sqeezing down to design β^*_y.
    - Such cut & try of xy-coupling needs extra time to startup accelerator after regular maintenance.

IP Local Coupling (1)

- For maximizing L_{sp}, R1~R4, η_y and η'_y at IP are adjusted by using skew quadrupole correctors so called “IPTilt knob”. (QK{A…} & QKSLY in Tsukuba section and QKS{DF} on arc sextupole nearby Tsukuba section)
- A few mm R2* knob is required to maximize L_{sp}.
  - Optics measurement CAN observe localized XY-coupling & V-dispersion induced IPTilt knob, however, vertical beam-size measured by XRM is minimized such IPTilt knob setting.
  - Typical IPTilt knob setting during collision operation exceeds linear perturbation region, and COULD make side effect to other optical function.

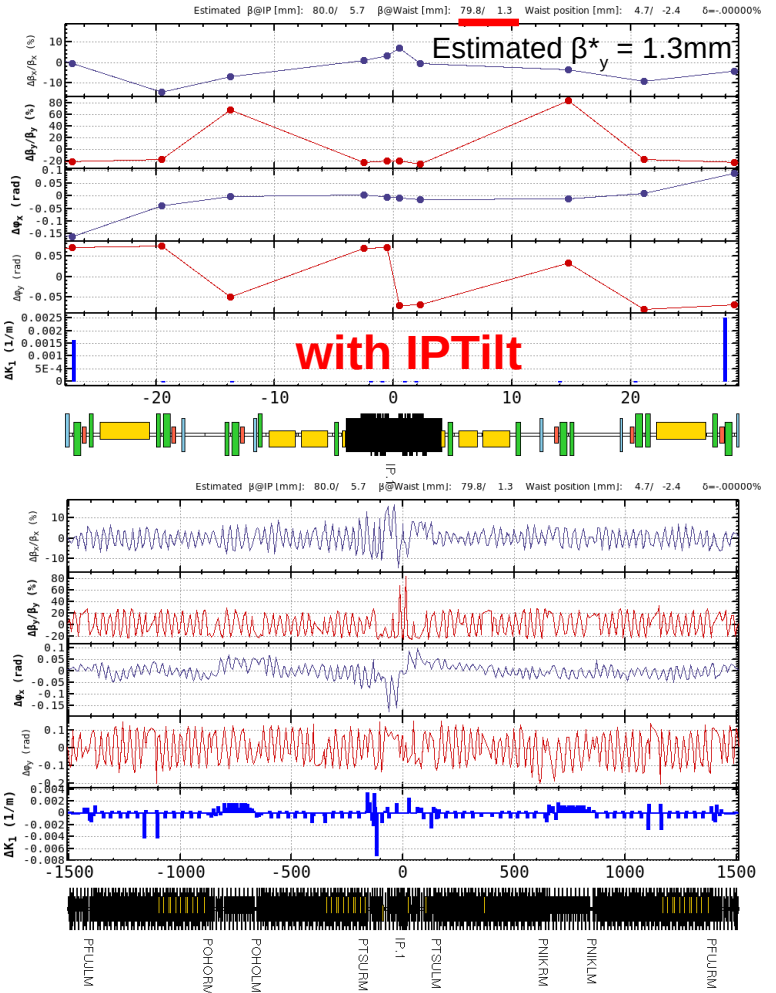
IP Local Coupling (2)

- LER optics measurement result with/without IPTilt knob @ 2020/06/22:



Turn on IPTilt

R1	4.306 mrad
R2	4.8 mm
R3	-0.6 m^{-1}
R4	0 mrad
EY	-15 μm
EPY	40 mrad



IP Local Coupling (3)

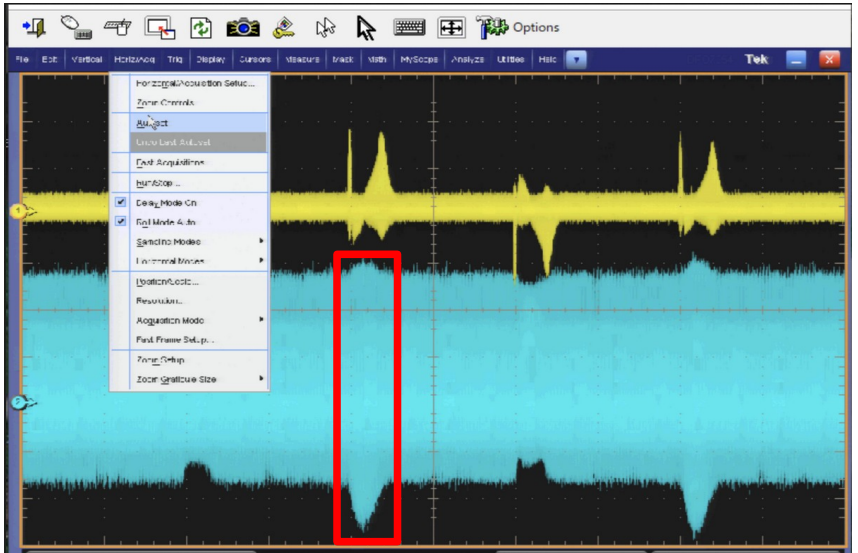
- XY-Coupling Correction with QC1 R2* Knob:
  - In order to reduce IPTilt R2* knob height, yet another R2* knob by using skew quadrupole corrector on QC1* are applied before xy-coupling correction.
    - QC1 R2* knob adjustment would be right correction if such big R2* error came from rotation alignment error of QCS.
    - R2 perturbation of QC1 R2* knob is almost localized like the IP waist knob, however, other R# coupling parameters are not localized.
    - In order to control global coupling, xy-coupling correction after QC1 R2* knob adjustment is required.

IP Local Coupling (4)

- XY-Coupling Correction with QC1 R2* Knob:
  - QC1 R2* preset knob reduces IPTilt R2* knob height for maximizing L_{sp}, however, strong global xy-coupling correction reduces QC1 R2* preset knob effect.
    - We HAVE TO correct global xy-coupling, however, SHOULD NOT correct IR xy-coupling related R2*.
    - Systematic & stable correction scheme is not established at this moment.
  - What's happened?
    - At the view point of vertical orbit crosstalk against horizontal single kicks, machine optics on optimum IP coupling seems different with ideal model optics one.
    - R2* error source may not be simple QCS rotation alignment error.
    - If machine optics is systematically different with model optics, we SHOULD update optics modeling.
      - How to measure exact optical parameters?
      - How to survey source of modeling error?

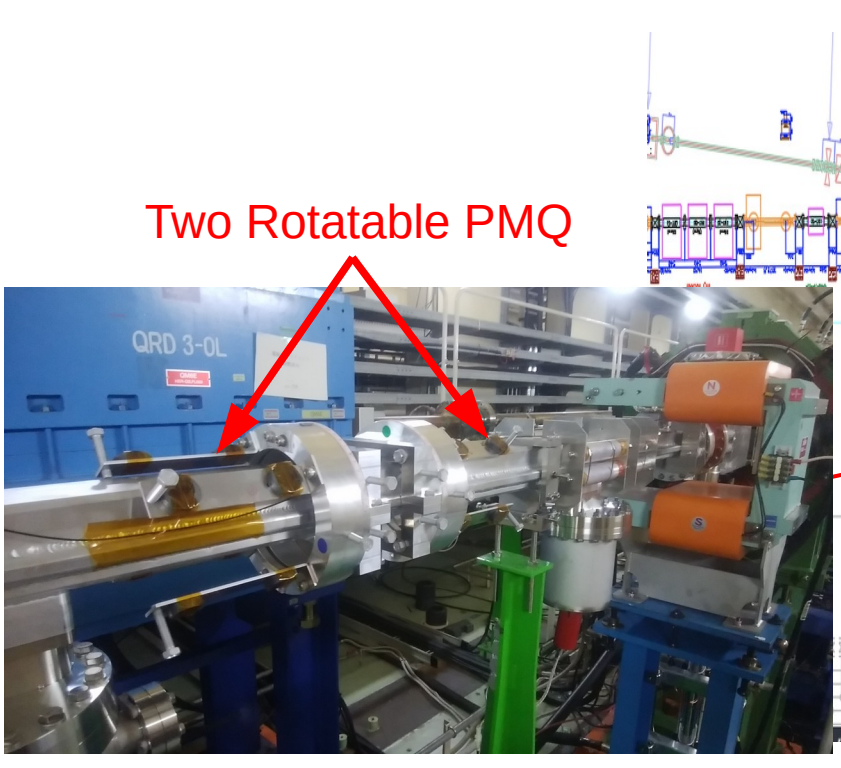
Injection Kicker Local Coupling (1)

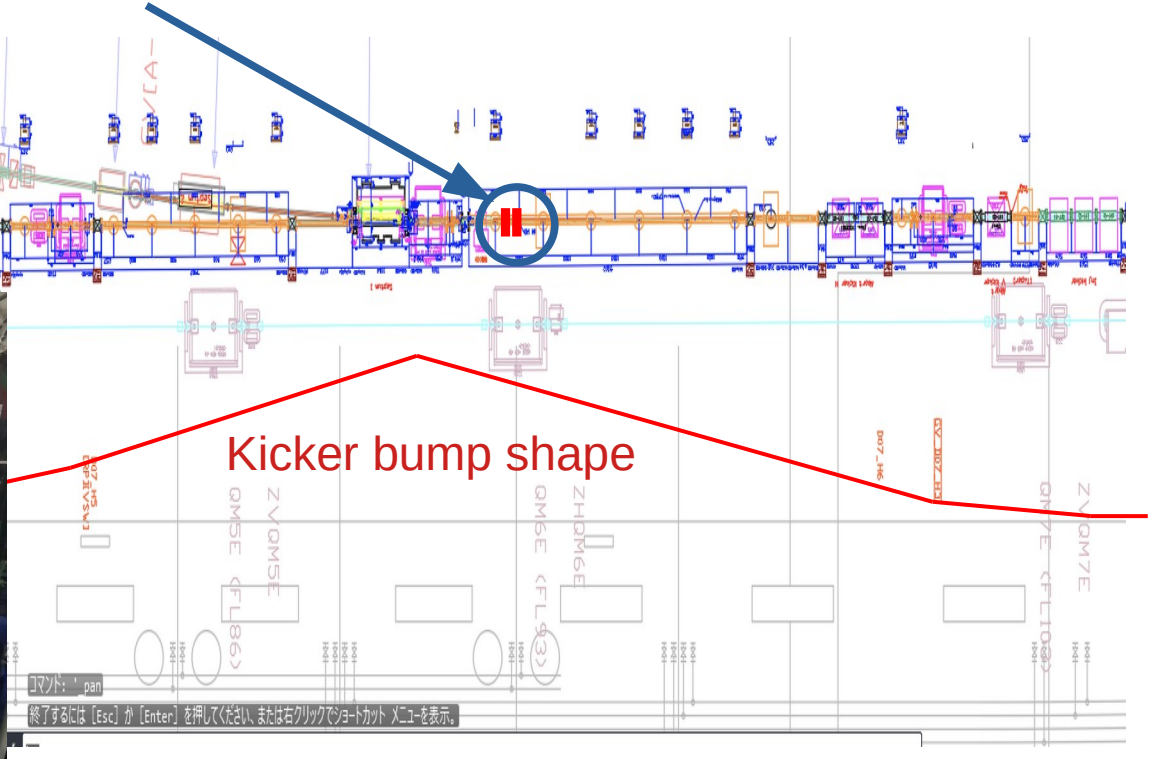
- From investigation of LER beam oscillation signal due to injection, correlation between vertical beam oscillation signal due to injection and injection kicker field pattern is found. In the other hand, horizontal beam oscillation signal is not correlated with kicker pattern.
  - Either kicker rotation alignment error or xy-coupling error between kicker pair is suggested.



Injection Kicker Local Coupling (2)

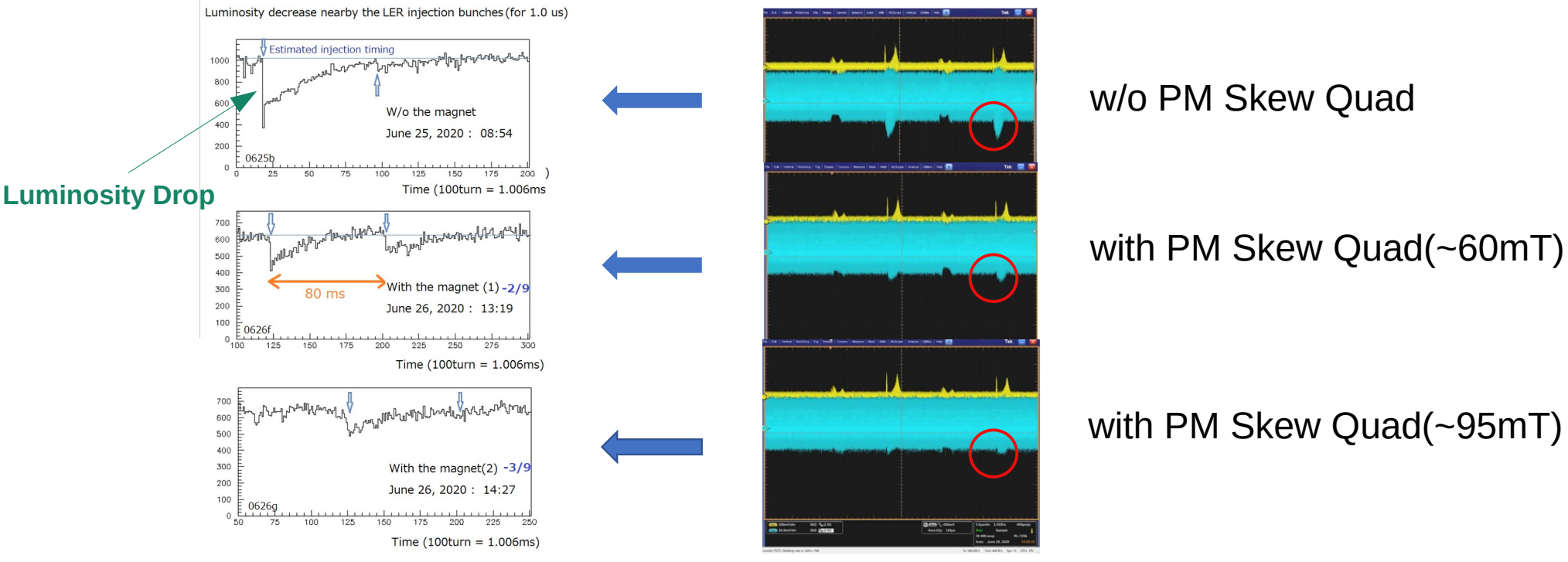
- Try to correct vertical kicks from injection kicker system by installing permanent skew quadrupole magnet between kicker pair.





Injection Kicker Local Coupling (3)

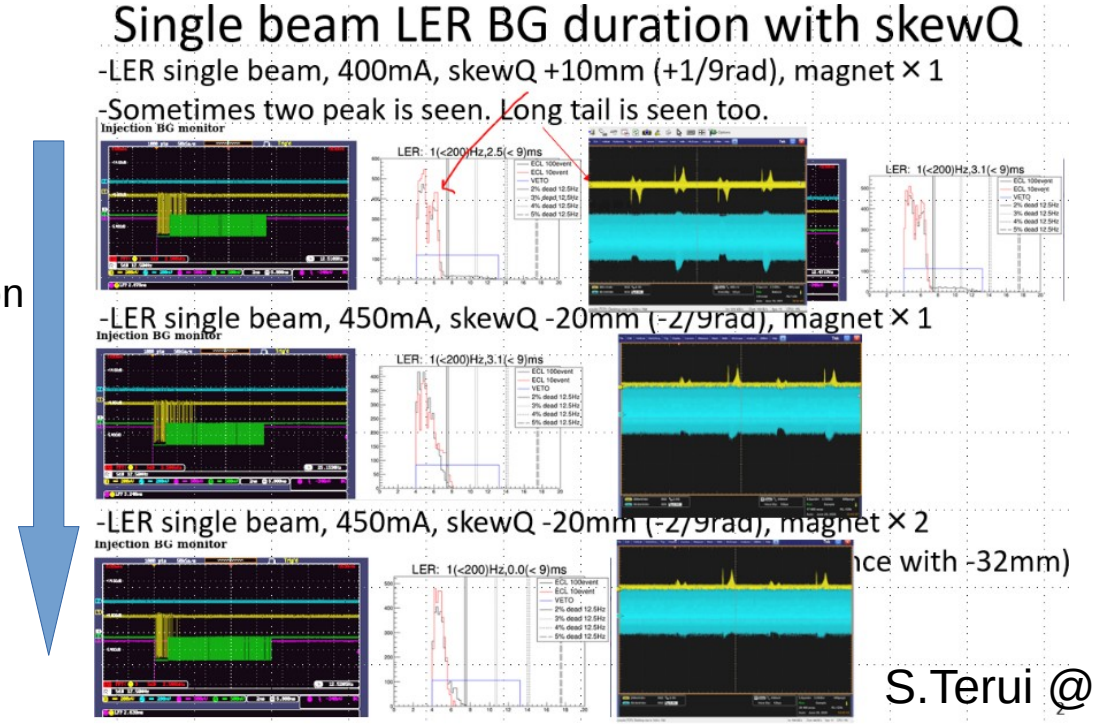
- Significant improvement of both vertical beam oscillation signal during injection and luminosity drop during injection oscillation decay is observed by adjusting PM skew quadrupole.
- Injection background duration of Belle II detector is improved too.



Injection Kicker Local Coupling (3)

- Significant improvement of both vertical beam oscillation signal during injection and luminosity drop during injection oscillation decay is observed by adjusting PM skew quadrupole.
- Injection background duration of Belle II detector is improved too.

Reduce background duration by PM skewQ tuning.



S.Terui @ 2020.06.26

Injection Kicker Local Coupling (4)

- During operation after PM skew quadrupole adjustment study, increasement of vertical beam oscillation signal during LER injection are reported.
  - Either PMQ rotation angle drift or optics/orbit drift is suggested.
  - We start to consider replacement of these PM quadrupoles with electromagnetic skew quadrupole magnet dedicated for online tuning.
- How to survey and find & correct such localized optics error?
  - This would be important things to achieve ultimate low emittance.

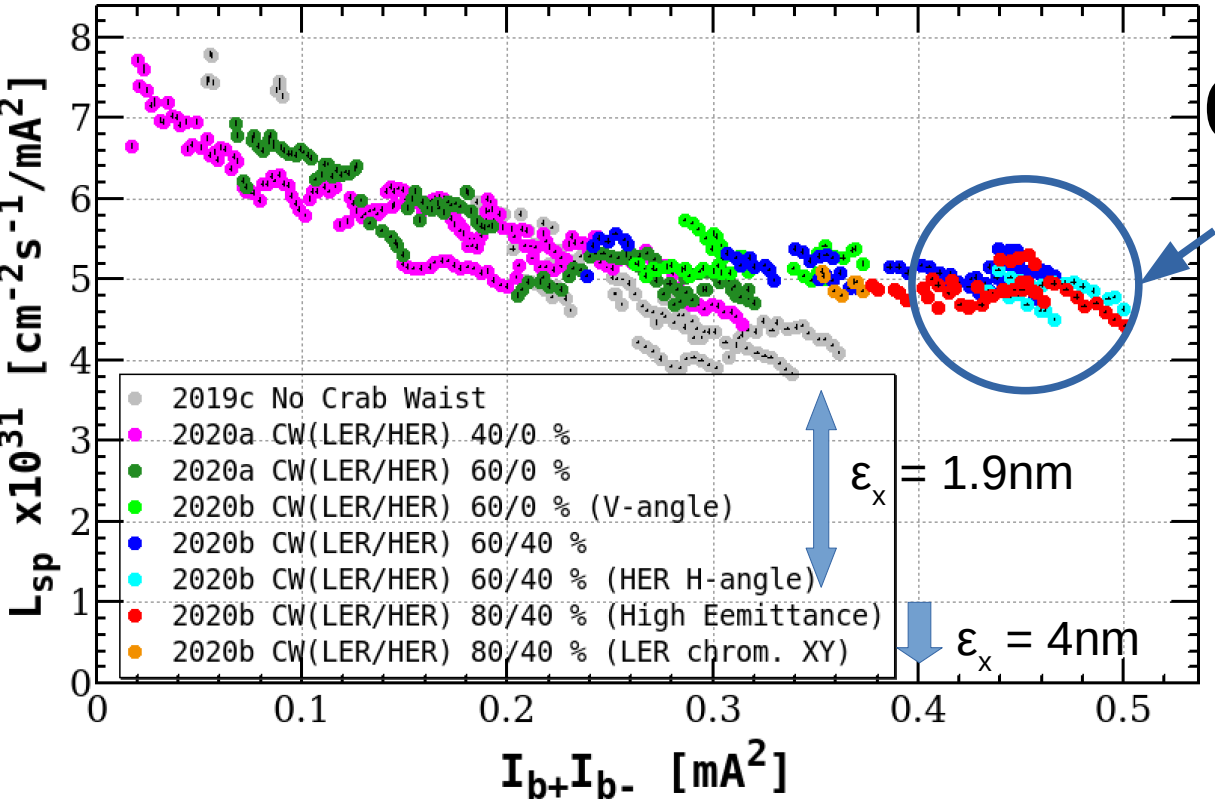
LER High Emittance Optics

- Merit – Improvement of Touschek lifetime.
  - Maximum stored current WOULD be improved under insufficient injector power.
    - Current injector power is not enough to keep >1A e^+ beam stably during β^*_y=1mm collision.
- Side Effect – Increasing of effective bunch length at collision.
  - HER design emittance is larger than LER one.
  - Demerit is depending with β^*_y.

- We tried ε_x = 4nm LER optics instead of ε_x = 1.9nm optics.
  - Significant demerit for L_{sp} is not observed.
  - Should further emittance optimization be considered for specific operating point?
    - For example, in the case that operatable lower bound of β^*_y is limited by QCS quench & detector background due to beam loss at QC1 physical aperture.

LE CS

- Merit – Improv
  - Maximum stor
    - Current injec
- Side Effect – Ir
  - HER design e
  - Demerit is dep



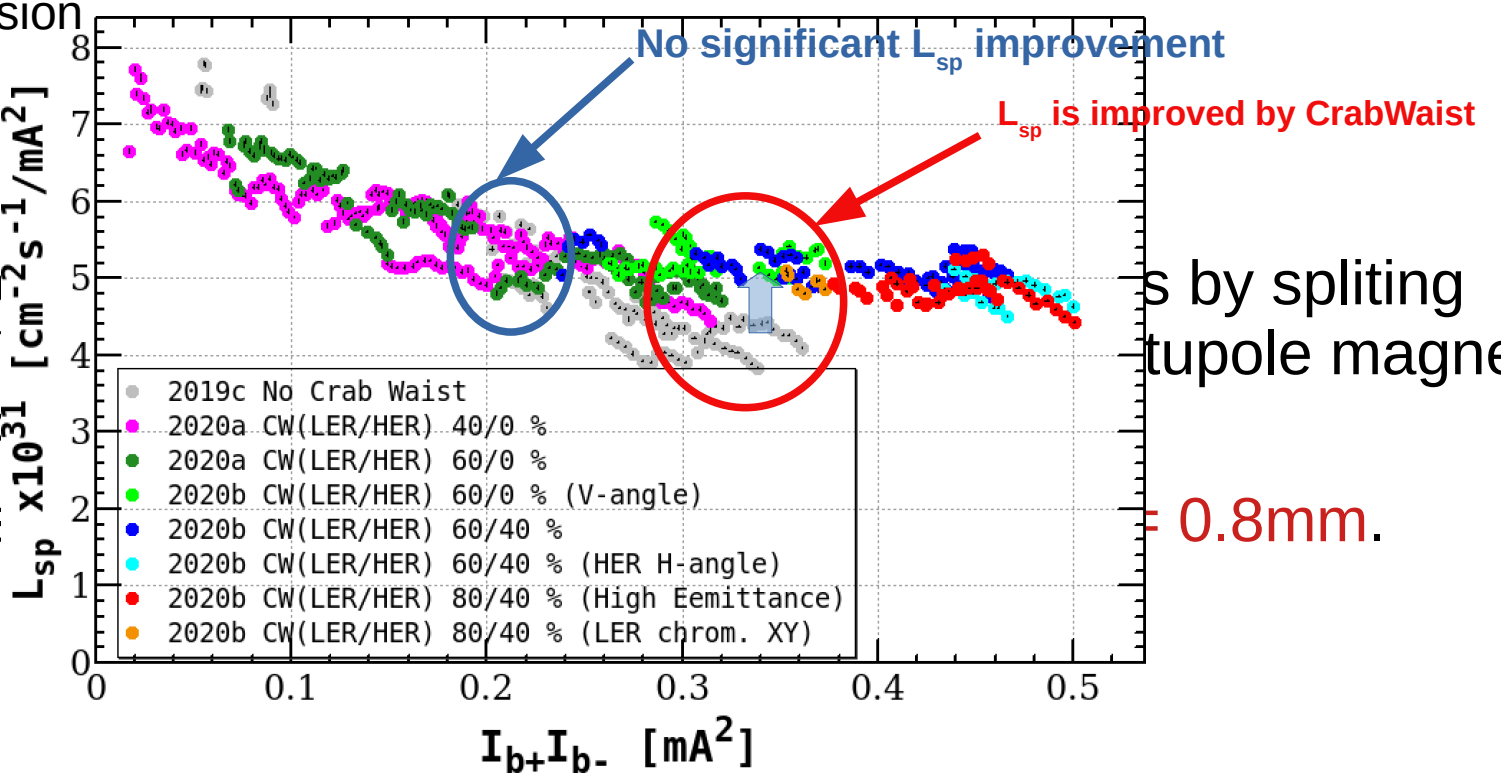
- We tried ε_x = 4nm LER optics instead of ε_x = 1.9nm optics.
  - Significant demerit for L_{sp} is not observed.
  - Should further emittance optimization be considered for specific operating point?
    - For example, in the case that operatable lower bound of β^*_y is limited by QCS quench & detector background due to beam loss at QC1 physical aperture.

Crab Waist Optics (1)

- FCC-ee like crab waist is implemented into both rings by spliting PS for SLY* vertical local chromaticity correction sextupole magnet pairs. (2 additional PS / ring)
- Beam collision with crab waist is confirmed until $\beta^*_y = 0.8mm$.

- Crab waist improves beam-beam blowup in high bunch current product region (>0.3mA^2).
- It looks like no significant L_{sp} improvement in low bunch current product region (~0.2mA^2).

L_{sp} of β^*_y = 1mm collision



- FCC-ee lik s by spliting PS for SLY tupole magnet pairs. (2 ac
- Beam collis = 0.8mm.
- Crab waist improves beam-beam blowup in high bunch current product region (>0.3mA^2).
- It looks like no significant L_{sp} improvement in low bunch current product region (~0.2mA^2).

Crab Waist Optics (2)

- Remarks for further operation with crab waist
  - Operation feasibility of FCC-ee like crab waist lattice with design β^*_y=0.3mm is not confirmed at this moment.
  - In the past simulation study, design β^*_y=0.3mm lattice with additional dedicated sextupole pairs for crab waist shows significant degradation of dynamic aperture by turning on crab waist sextupole. (different design case)

IP Chromatic Coupling (1)

- Existence of big IP chromatic coupling error is suggested from beam-beam simulation in order to explain the observed beam-beam blowup bigger than beam-beam simulation expectation.
- IP chromatic coupling measurement & correction study are performed by using TbT-BPM system and rotatable sextupole on LER.

IP Chromatic Coupling (2)

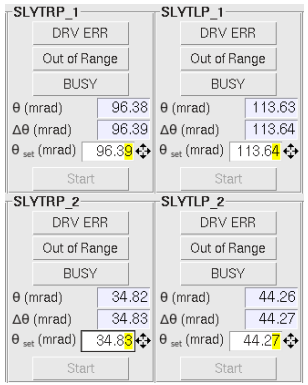
- IP chromatic coupling correction studies:
  - 2020/06/05 at β* = (80mm, 1mm) optics
    - Correction parameter constraint: R1*’ = 2rad, R3*’ = 780m^{-1}
    - Rotate 4 SLY* sextupole magnets
    - Chromatic coupling measurements are performed befor & after correction.
  - 2020/06/08 at β* = (80mm, 1mm) optics
    - Correction parameter constraint: R1*’ = 1.5rad
    - Rotate 24 sextupole magnets
  - 2020/06/24 at β* = (60mm, 0.8mm) optics
    - Rotate 24 sextupole magnets

IP Chromatic Coupling (3)

- IP chromatic coupling correction study @ 2020/06/05:

Ohmi

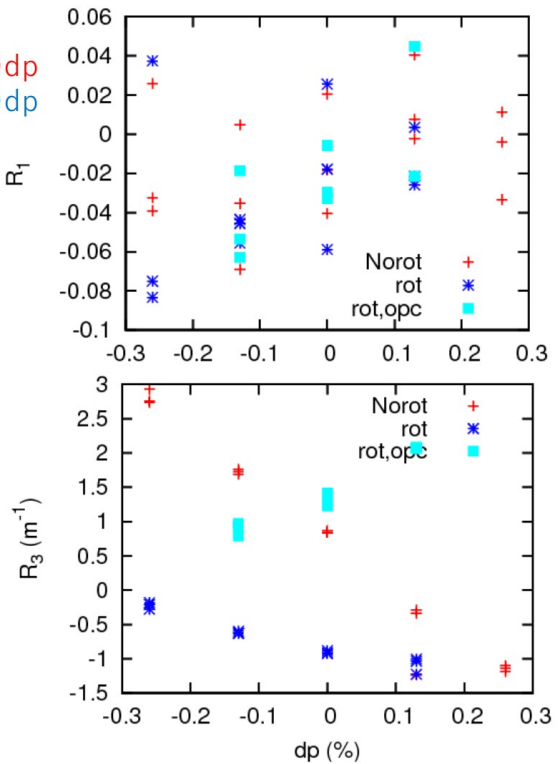
Rotation Angle

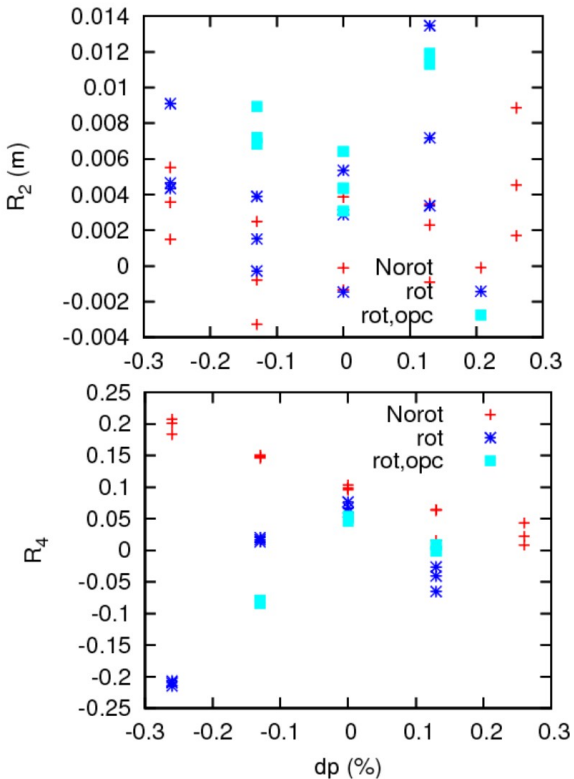


Chromatic coupling

-0.01+4.7(+-4.2)dp
-0.02+8.4(+-7.4)dp

+ before rotation
✳ after rotation
■ after rotation & optics correction

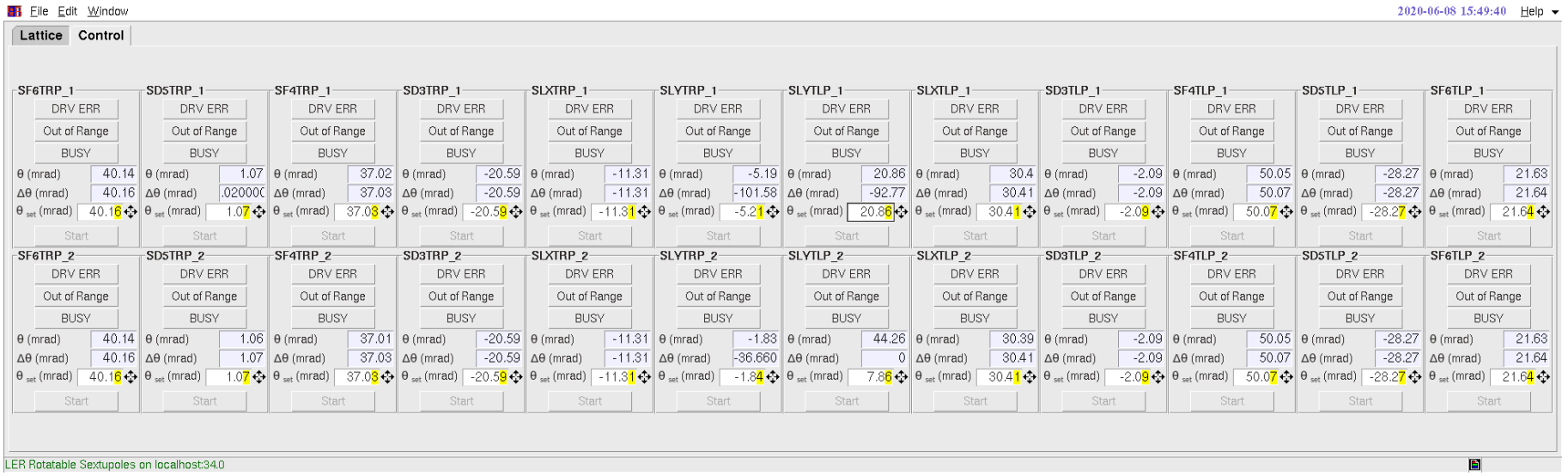




- Bad S/N for extracting R1* chromaticity signal.
- R3* chromaticity seems different before/after rotation.
- Optics correction affects R3* chromaticity?

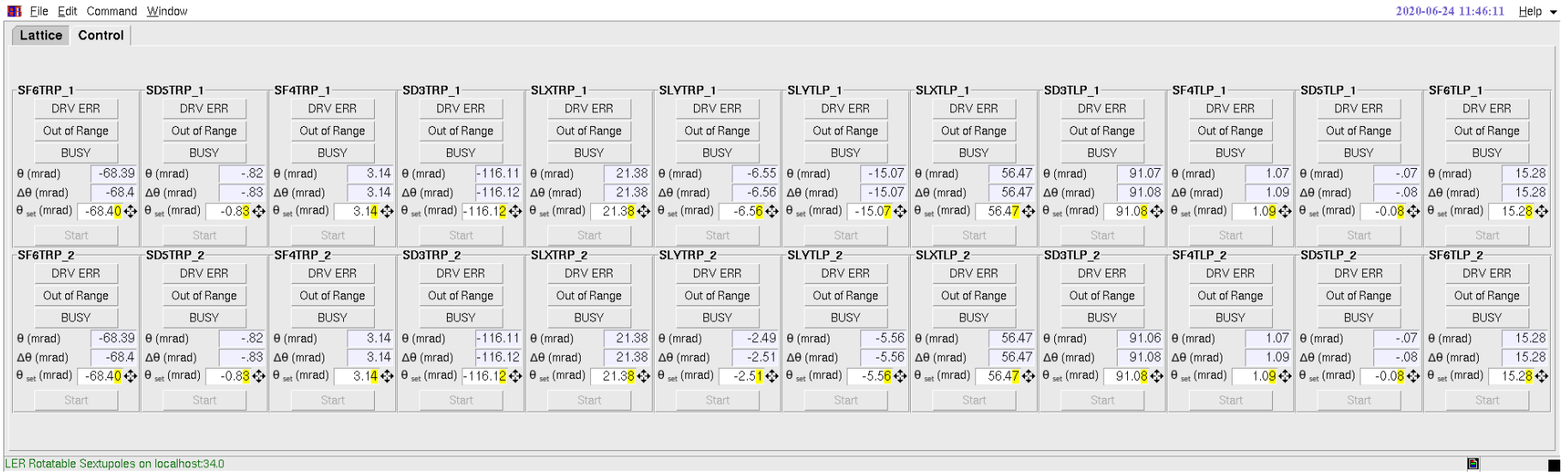
IP Chromatic Coupling (4)

- IP chromatic coupling correction study @ 2020/06/08:



IP Chromatic Coupling (5)

- IP chromatic coupling correction study @ 2020/06/24:



IP Chromatic Coupling (6)

- After IP Chromatic Coupling Correction:
  - Significant L_{sp} improvement is not observed.
  - Detector background is improved after many tuning iterations including collision tuning (collision feedback and IPTilt knob), injection tuning, beam collimator tuning, etc. Contribution of IP chromatic coupling correction is not clear.

Summary

- Optics correction becomes difficult by squeezing β^*_y.
  - We should improve measurement & correction scheme in order to achieve stable operation with further squeezed β^*_y.
- Crab waist works fine, and it improves beam-beam blowup in high bunch current region.
- One of LER injection background sources is identified and resolved.
- LER IP chromatic coupling correction is tried, however, significant improvement is confirmed.