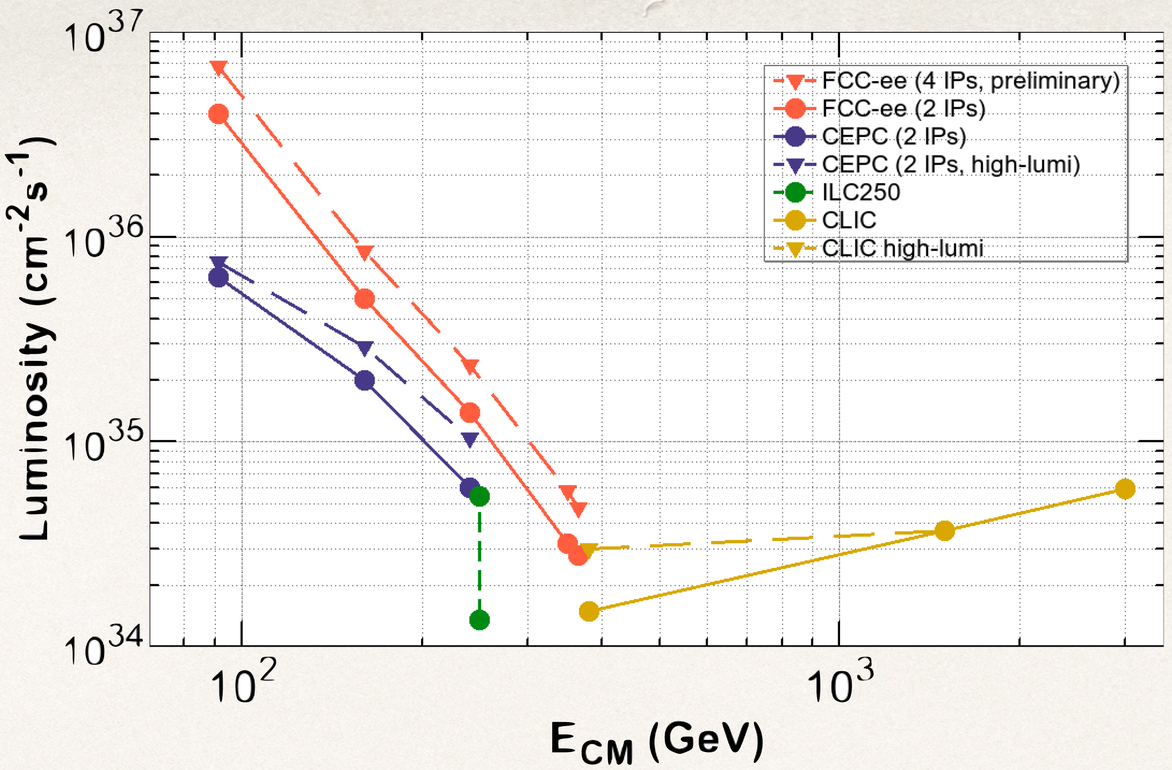


# The Next Step for FCC-ee (4 IP, final quads)

K. Oide (CERN)

**Many thanks to M. Benedikt, A. Blondel, P. Janot, K. Ohmi, D. Shatilov, Y. Suetsugu, M. Tobiyama, F. Zimmermann, and all FCC-ee collaborators.**

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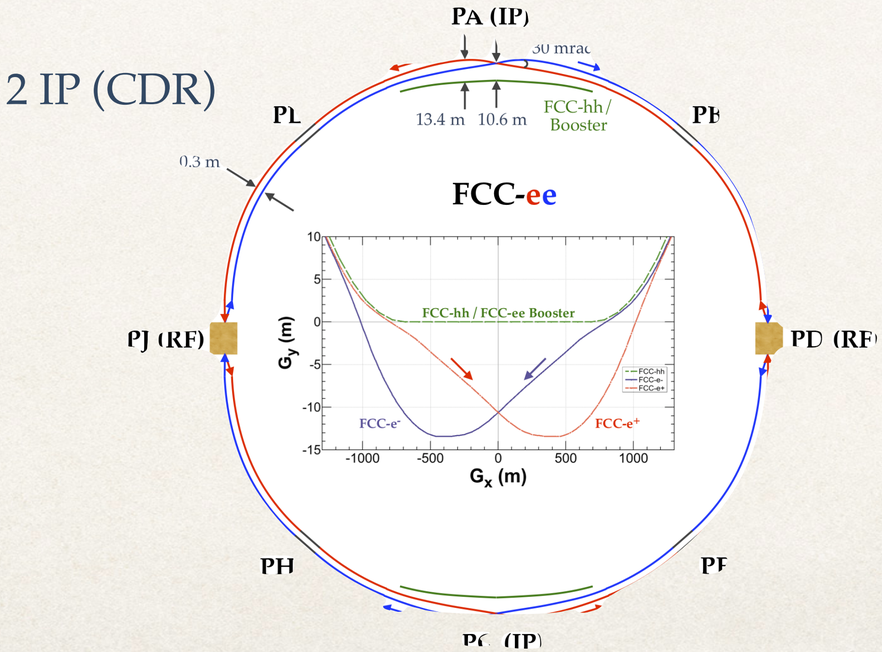
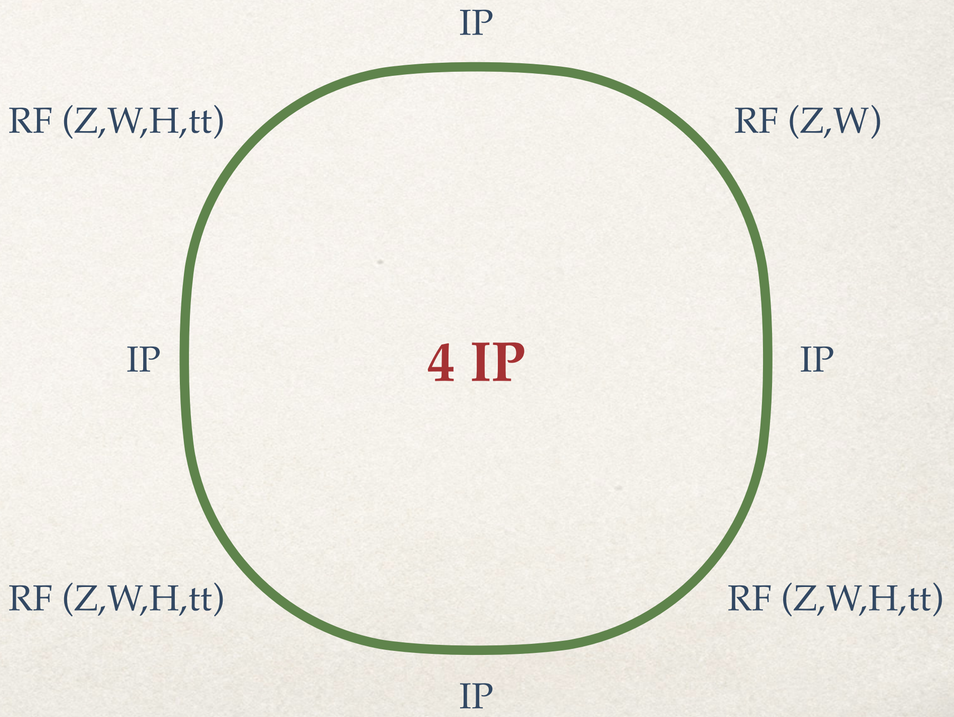
*June 26, FCC Week 2019 @ Brussels*

# 4 IP: layout with perfect period-4

- Equal spacing between IPs:
  - Otherwise more than 4 bunches couple together.
- Complete period 4 periodicity, including the RF (at least at ttbar):
  - For better beam-beam, dynamic aperture, etc.
- RF must be at the midpoint of 2 IPs:
  - For better dynamic aperture and beam cross over at the RF (ttbar).
- Thus the tunnel geometry deviates from the CDR and the current FCC-hh.



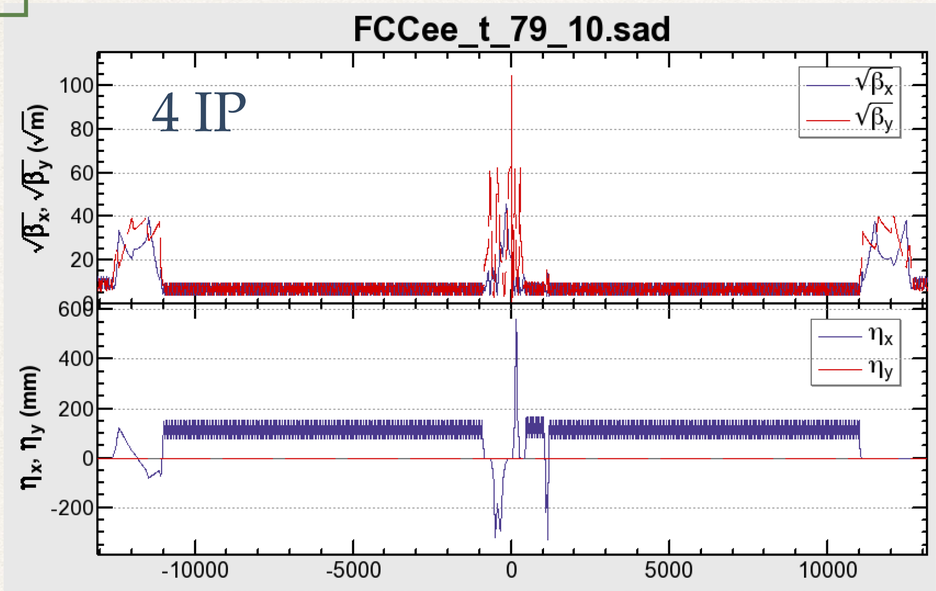



# Ideal case: perfect period 4, RF at 45°

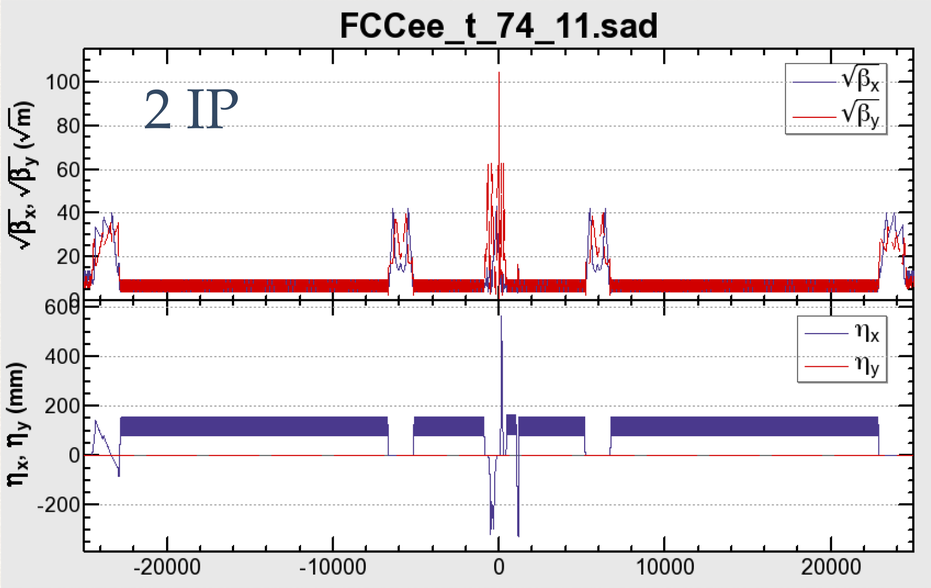
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)

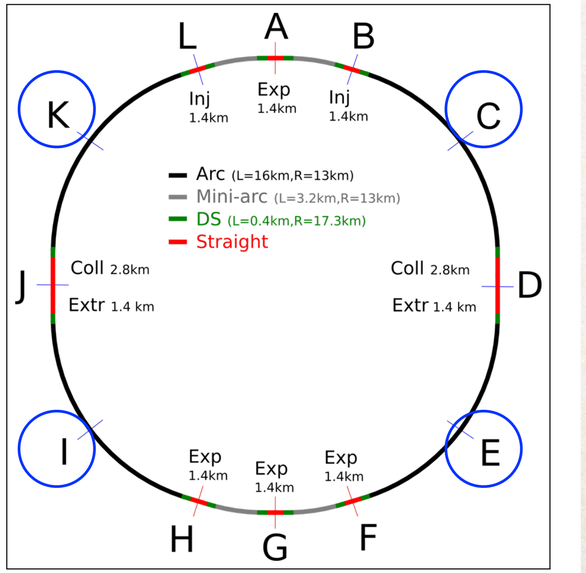
Period 4, 1/4 ring




Period 2, 1/2 ring



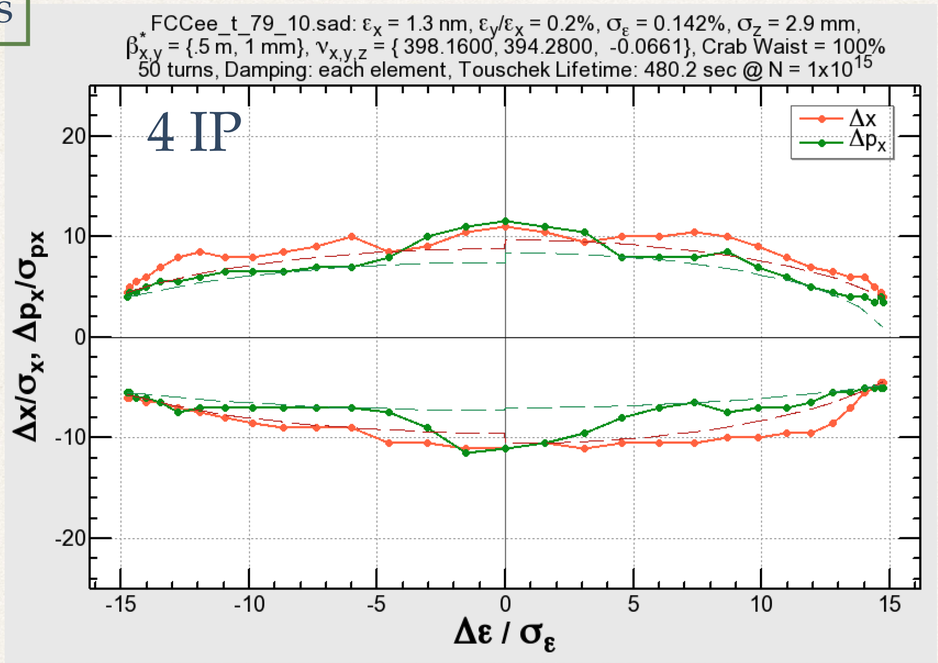

- First a perfect period 4 ring is tried as a nearly ideal case.
- RF is placed at 45°, in the midpoint of arc (CEIK of FCC-hh).
- IR and RF sections, and the arc unit cell are identical to the 2 IP optics.
- The beam line does not match the FCC-hh tunnel.

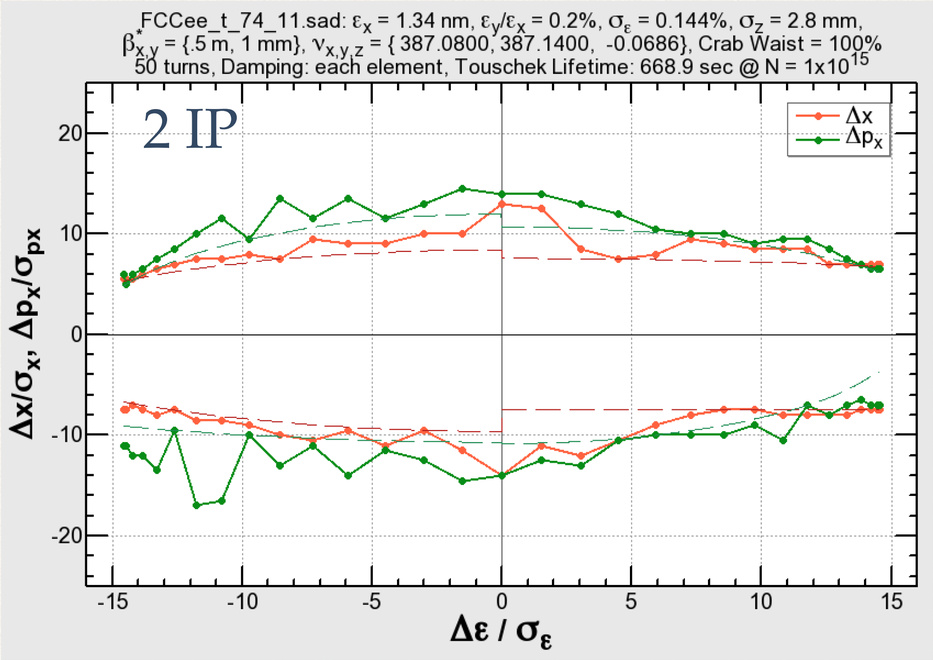


# Ideal case: perfect period 4, RF at 45° (2)

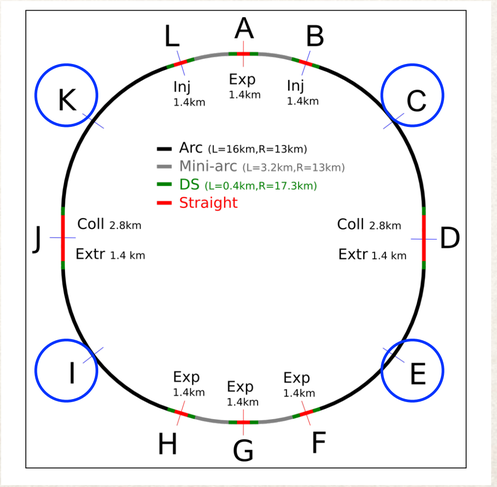
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)




- The impact on the dynamic aperture is small.
- Same momentum acceptance as 2 IP is maintained.

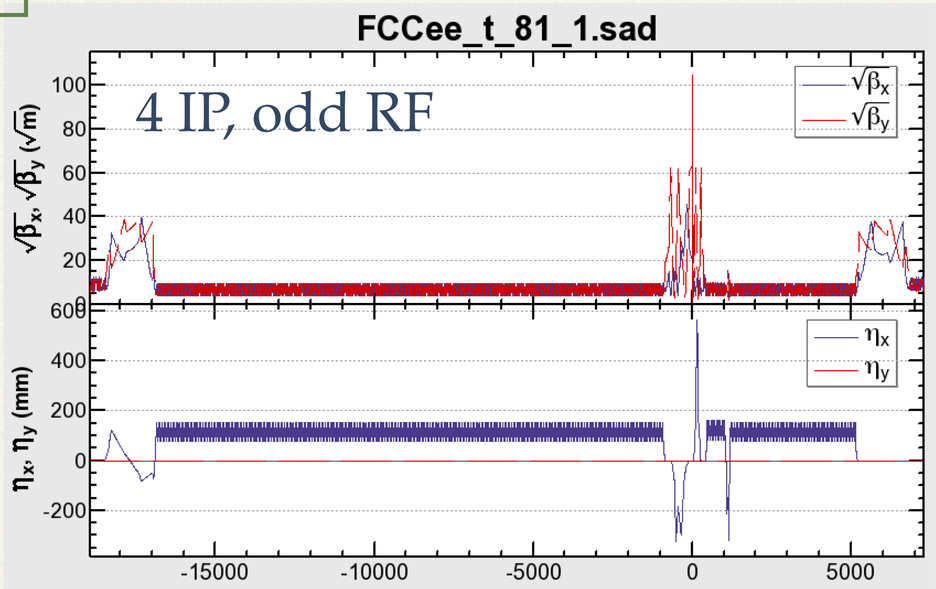


# RF at the odd straight: perfect period 4

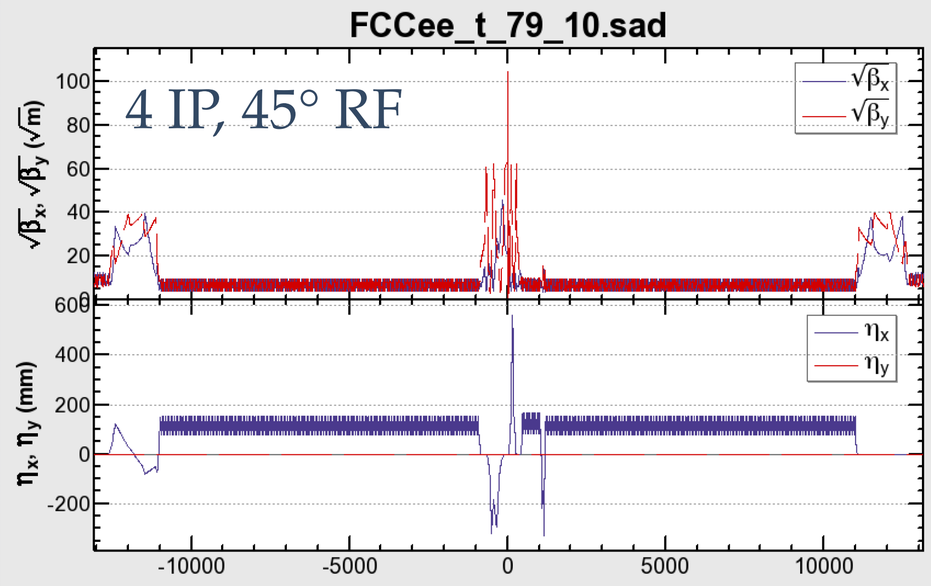
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)

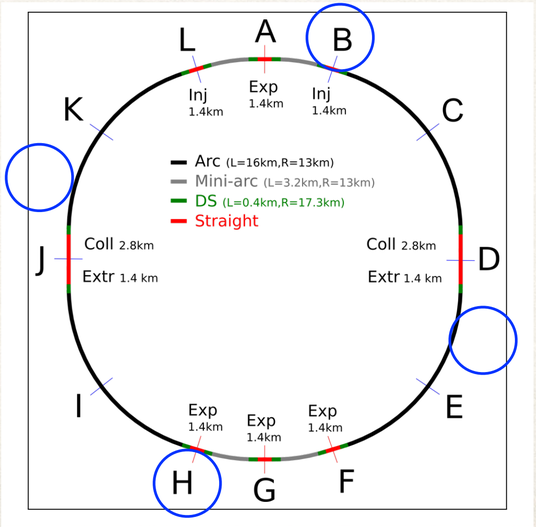
Period 4, 1/4 ring




Period 4, 1/4 ring



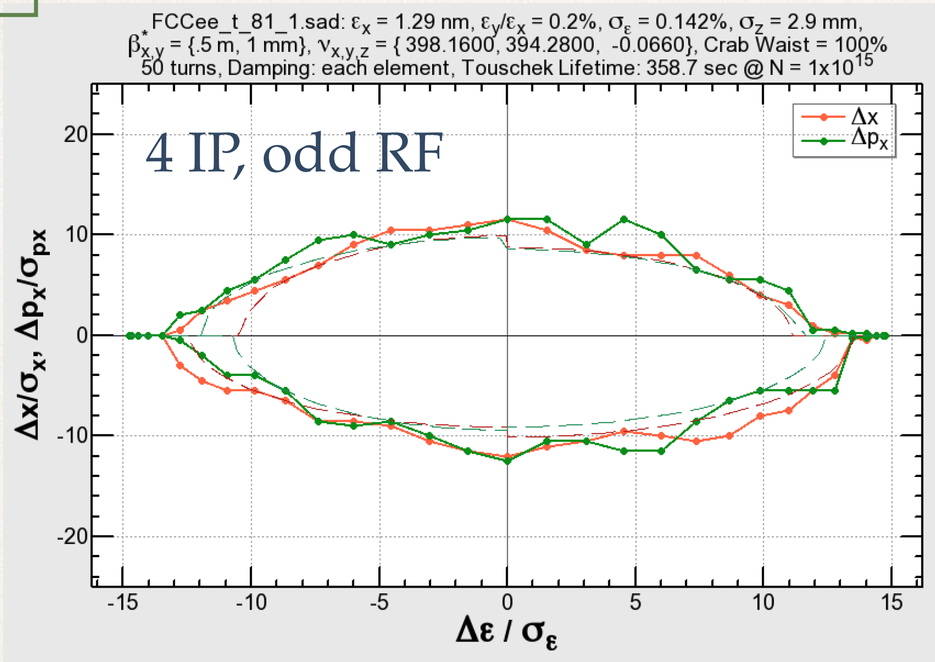

- As the RF should be placed at the short straights (B_H_) to utilize the FCC-hh layout.
- Still assume a complete period 4.
- The geometry is not yet close to FCC-hh.

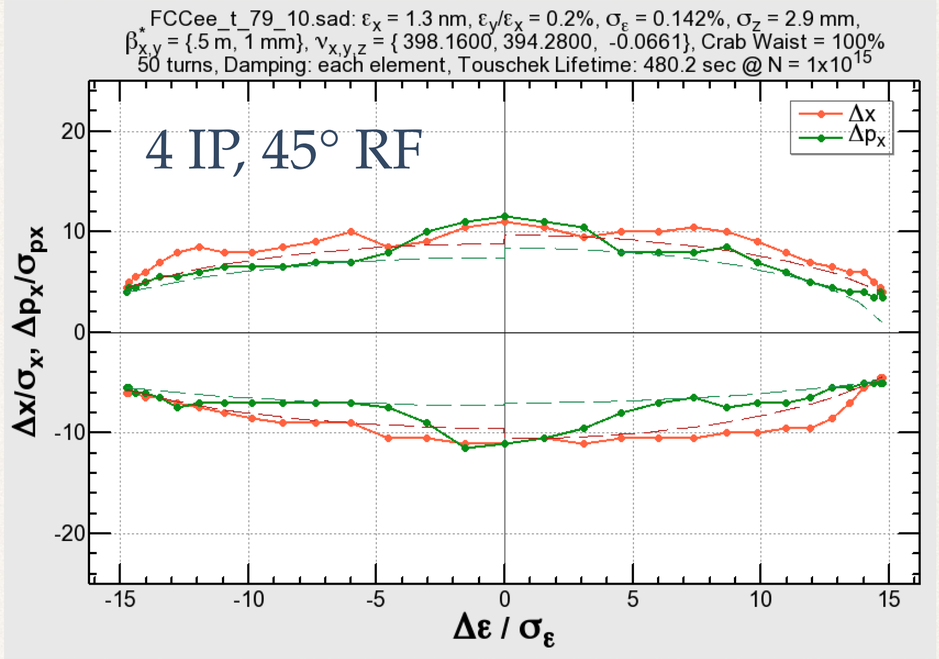


# RF at the odd straight: perfect period 4 (2)

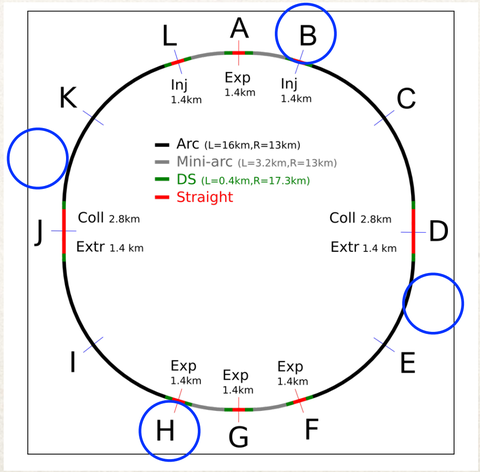
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)




- The dynamic aperture shrinks a little.
- The momentum acceptance has reduced to ±1.7%.

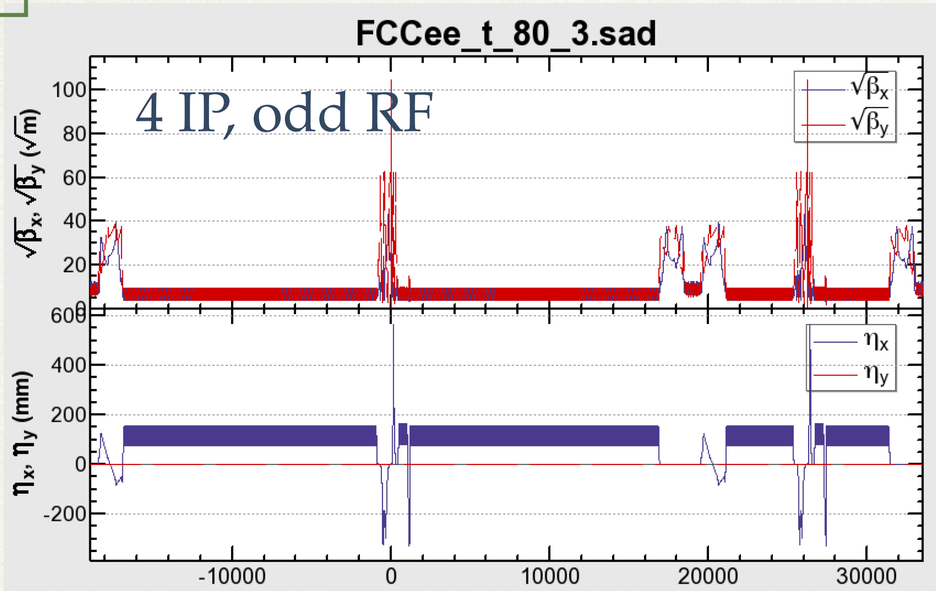


# RF at the odd straight, symmetric: period 2

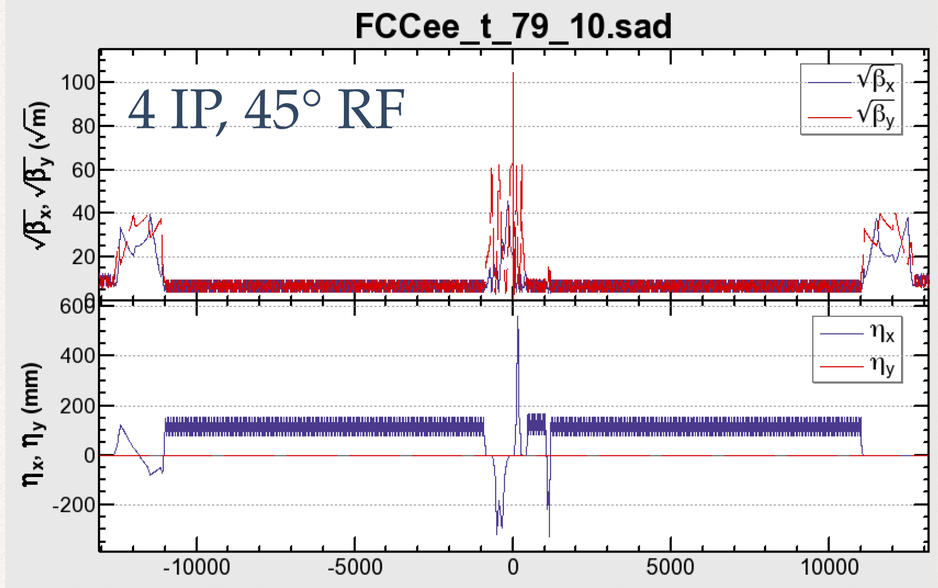
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)

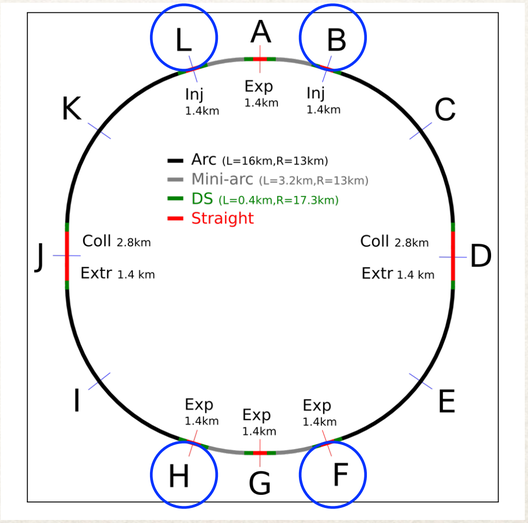
Period 2, 1/2 ring




Period 4, 1/4 ring



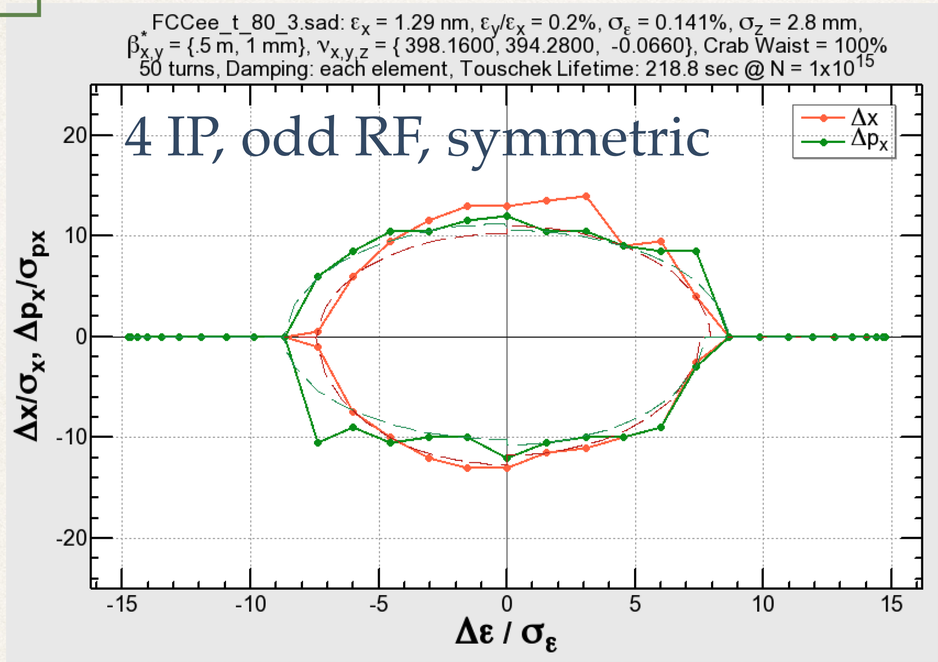

- If we place the RF symmetric, at sections BFHL,
- Then the periodicity is reduced to 2.
- The layout becomes closer to FCC-hh, but not perfect, since the lengths of the RF sections are not correct, and the 4 IPs (AG & DJ) are still identical.

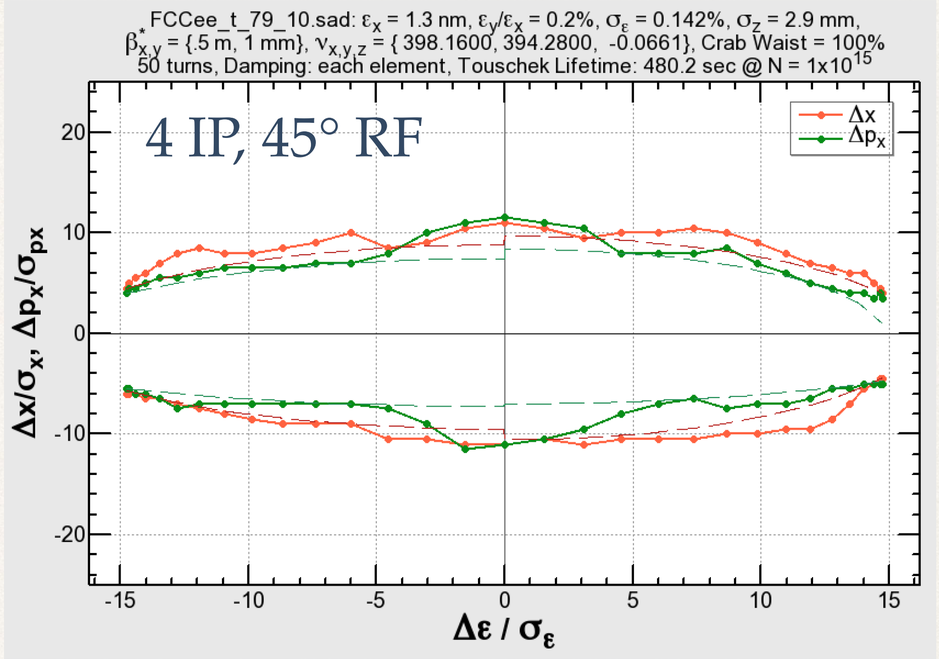


# RF at the odd straight, symmetric: period 2 (2)

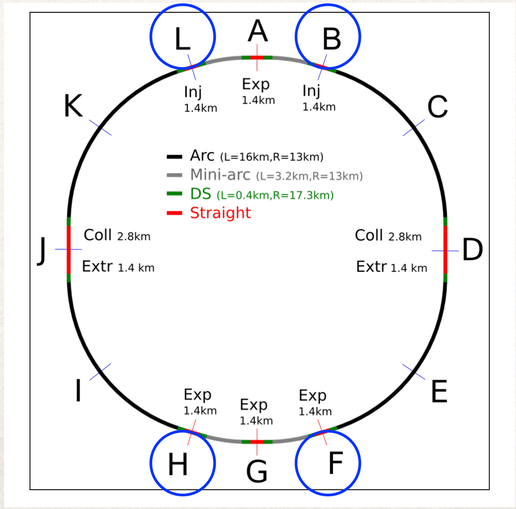
Comparison with 2016 optics

175 GeV, $\beta^*_{x,y}$ = (0.5 m, 1 mm)



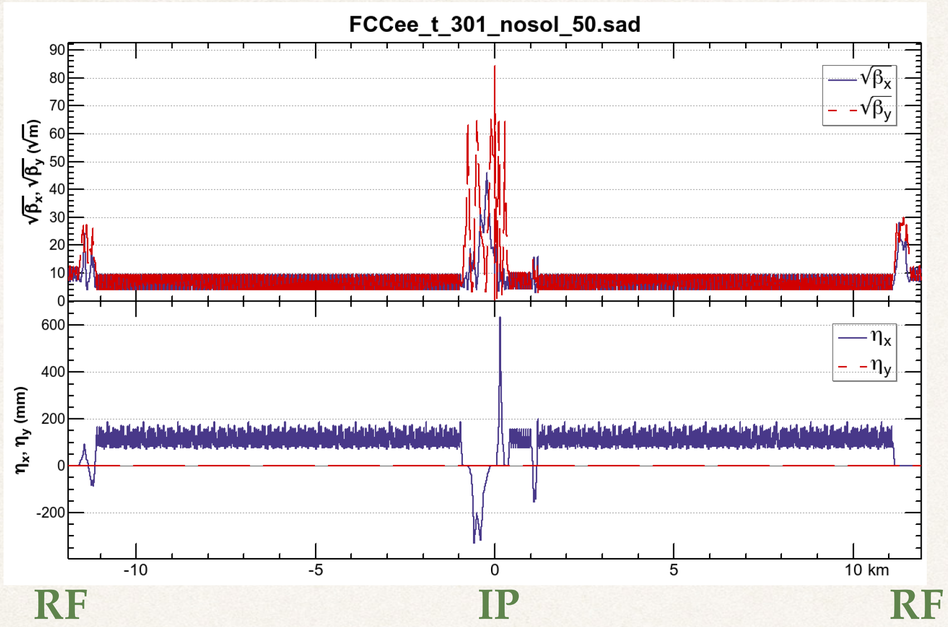



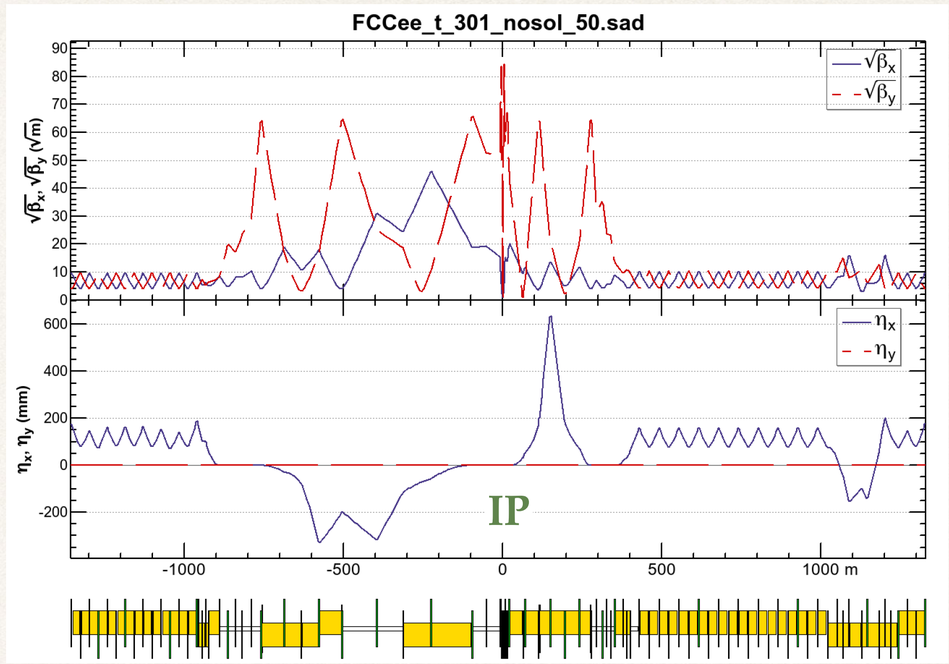

- The dynamic aperture has shrunk.
- The momentum acceptance has reduced to ±1.0%.
- If we put more conditions on the geometry & IR, it will be even worse.




K. Oide, July 18, 2016 @ MDI Meeting

# 1/4 ring and IR optics (ttbar)



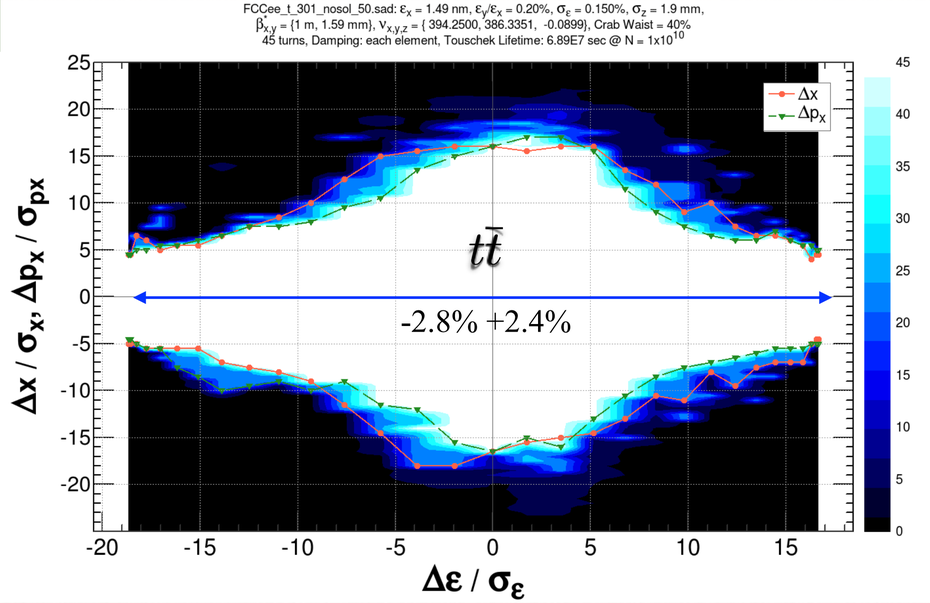




- Arc curvature ≈ $\rho_{hh}$ ≈ 13,170 m.
- Emittance, momentum compaction, etc., are close to the CDR values.
- Interaction region basically similar to the CDR.
- No extra straight sections: locations for injection, abort, collimation, wigglers, polarimeter, etc., must be found.

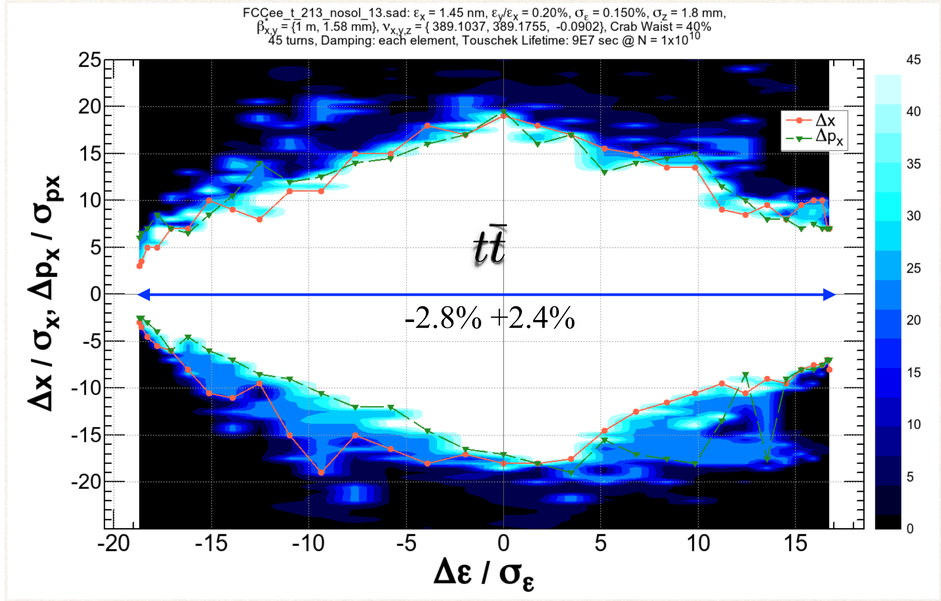
# Dynamic aperture with 4 IP (ttbar)

Comparison with 2019 optics

## 4 IP

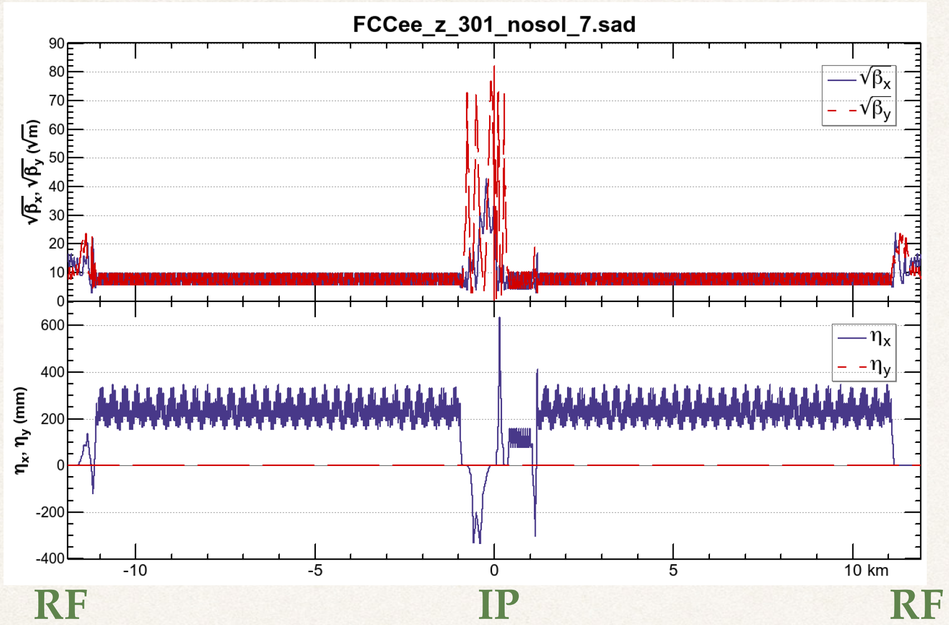


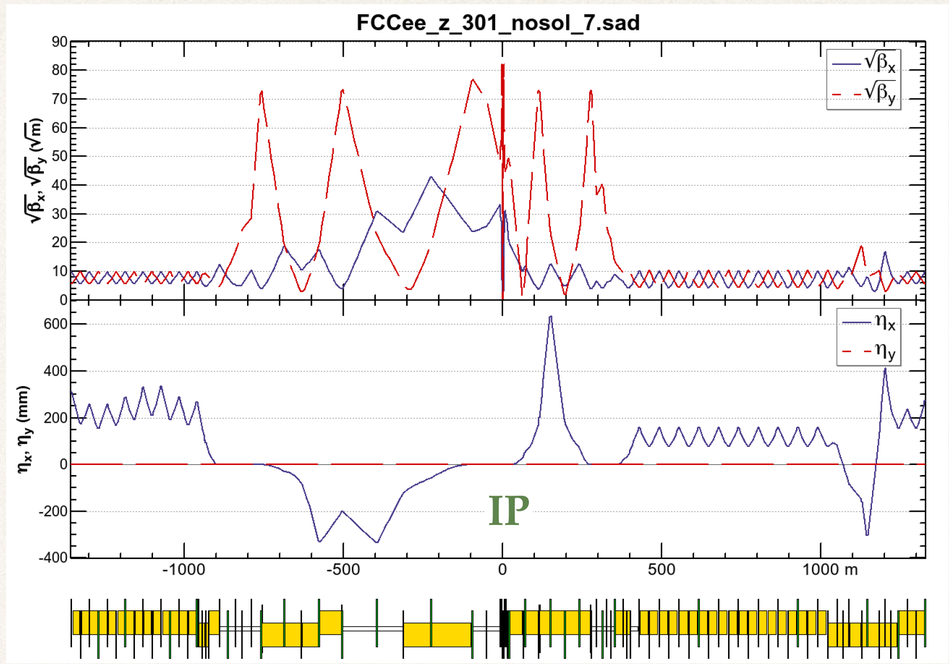

## 2 IP (CDR)




- At ttbar, the resulting dynamic aperture is acceptable. It looks slightly smaller than 2IP's, probably due to less damping per super period.
- *Additional multipole windings* on top of some sextupoles near the IR have been once tried to increase the momentum acceptance, but no longer needed in the example above.

# 1/4 ring and IR optics (Z)



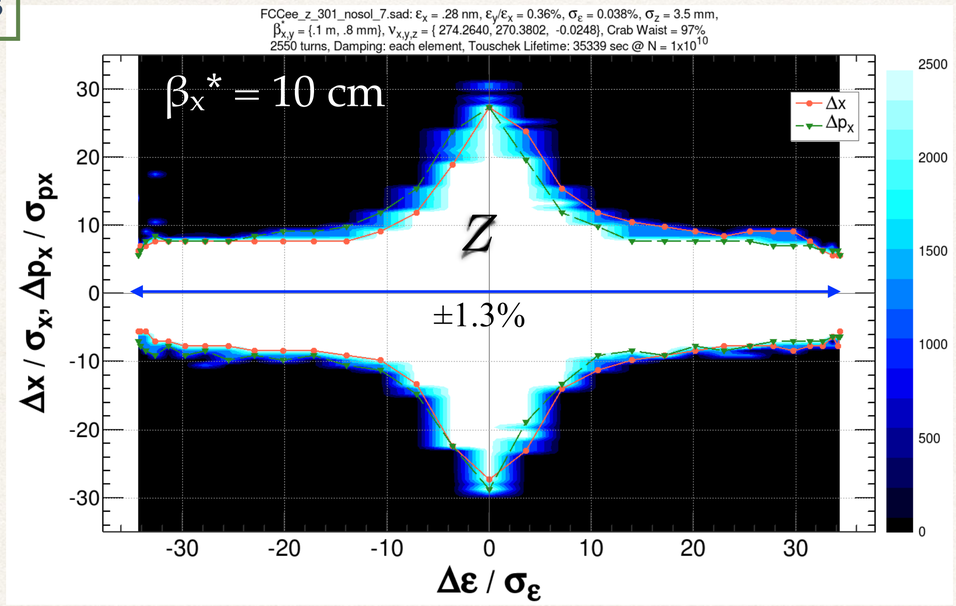




- $\beta_x^*$ is reduced to 10 cm (CDR: 15 cm) to suppress the x-z coherent instability (D. Shatilov).

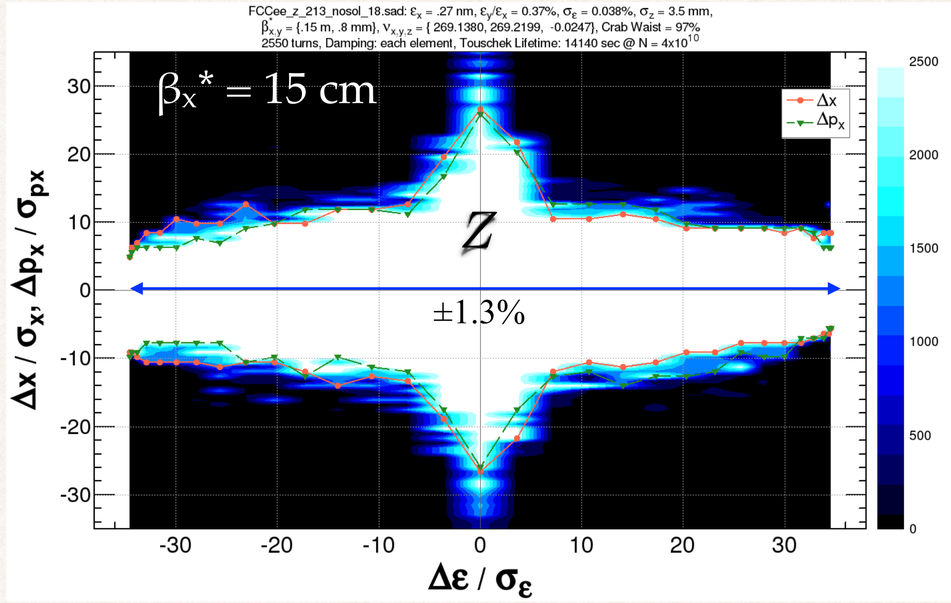
# Dynamic aperture with 4 IP (Z)

Comparison with 2019 optics

## 4 IP




## 2 IP (CDR)



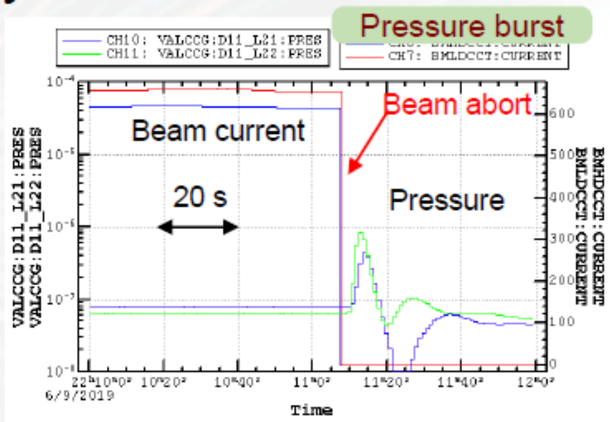

- At Z, the momentum acceptance looks OK with $\beta_x^* = 10$ cm.
- The transverse aperture at > 10 $\sigma_E$ is smaller than the 2 IP, but acceptable.
- The injector performance with the baseline scheme still satisfies the requirements with shorter lifetimes due to 4 IP at all energies (see presentation this afternoon).

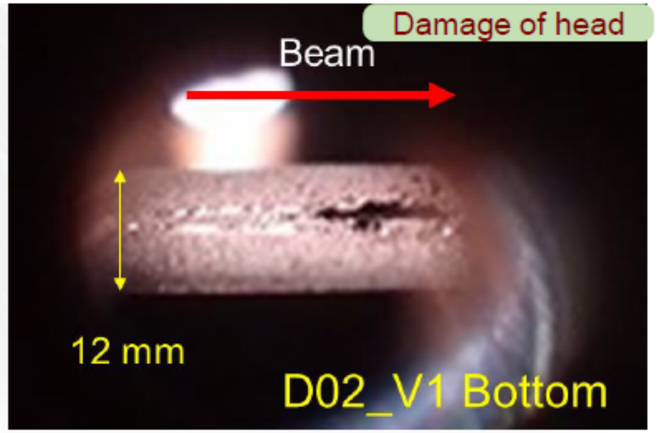
# Robustness of the final quads against beam loss

This is a warning from SuperKEKB!!

QCS quench [Type-2]

- Another quench on 31st, May, and 9th, June, were considered to be induced by beam-dust collision in LER.
  - A pressure burst was simultaneously observed at arc or wiggler section in each case.
  - Horizontal shift of the beam orbit due to the energy loss was observed just before the abort, although small.
- The second quench (6/9) was very sever.
  - High radiation dose damaged SVD.
  - Collimator heads of D02_V1 (vertical type collimator) were heavily damaged.
  - Liquid He of QCSR was completely evaporated.




M. Tobiyama, Y. Suetsugu
@ Belle II EB, 19 June 2019

# Robustness of the final quads against beam loss (2)

This is a warning from SuperKEKB!!

- The final quads and solenoids must be robust enough against beam losses. Esp. thin corrector windings.
- Otherwise a too deep collimation is required, which is even more dangerous against to occasional beam losses due to dusts, etc.
- A collimator right upstream the interaction region can be harmful to the detector by causing showers.
- In the worst case, we may have to redesign the final quads with larger apertures, which mean longer L* and/or larger crossing angle. Both affects the luminosity performance!

# Tentative Summary

- At least two issues (4 IP and final quads) have been addressed to go to the next step of FCC-ee beyond the CDR.
- 4 IP scheme looks acceptable so far: See D. Shatilov's presentation on the expected beam-beam performance and the luminosity.
- 4 IP will have a huge impact on the layout, FCC-hh design, many components such as RF, injection, beam abort, polarimeter, etc.
- Attention is necessary on the robustness of the final quads and solenoids against beam losses.
- Detailed design studies on various components must be done, after the above issues are fixed. Some items which are not much affected by the number of IP's can be started now.