Beam-beam blowup issues @ FCC-ee

Dima El Khechen
Katsunobu Oide
Frank Zimmermann

FCC Week 2019
Brussels, 24-28 June 2019

Acknowledgements:

**Sandra Aumon, Tessa Charles,
K. Ohmi, Dmitri Shatilov, Tobias Tydecks,
Demin Zhou
and all FCC-ee optics and MDI teams**

Outline

→Definition of simulation setup

→Beam blowup in a coupled $t\bar{t}$ lattice

→Beam blowup after emittance tuning

→Summary

Beam-beam simulations

→ Simualtions were perfomed for the $t\bar{t}$ lattice @ 175 GeV

→ Beam-beam simulations were performed using the **Weak-Strong beam-beam** simulation code (BBWS, Ohmi et al.) integrated in SAD

→ **10^4 macroparticles** representing the beam were produced at the IP and then tracked through the lattice for **500 turns (10 transverse damping periods)**

→ **Projected vertical emittance** of the beam is calculated and plotted at the IP every turn

Parameter	**FCC-ee-$t\bar{t}$**
Beam energy (GeV)	175
Beam current (A)	6.4
Particles/bunch (10^{11})	2.2
(β_x^* , β_y^*) (m / mm)	(1, 2)
(ε_x , ε_y) (nm / pm)	(1.34, 2.7)
Transverse tunes (Q_x, Q_y)	(389.108, 389.175)
Synchrotron tune ν_s	0.0818
Energy acceptance (DA)(%)	-2.8 +2.4
Bunch length (SR/BS) (mm)	(2.01 / 2.62)
Energy Spread (SR/BS) (%)	(0.144 / 0.186)
Beam-beam parameter (x / y)	(0.097 / 0.128)
Luminosity/IP (10^{34} cm^{-2}s^{-1})	1.8

Tracking in a coupled lattice

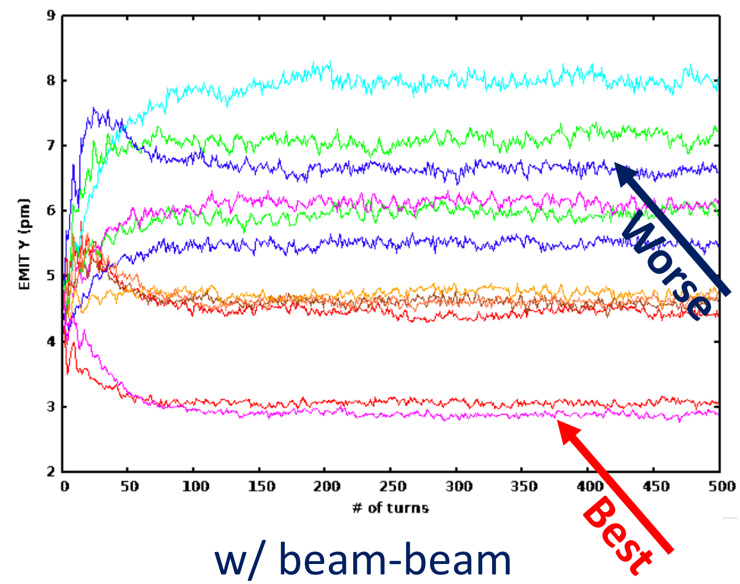
→ A coupled lattice is produced by introducing random vertical misalignments for all ring sextupoles to achieve a coupling value of 0.2%

→ Twelve different random seed generators were used to produce a **0.2% coupling factor**

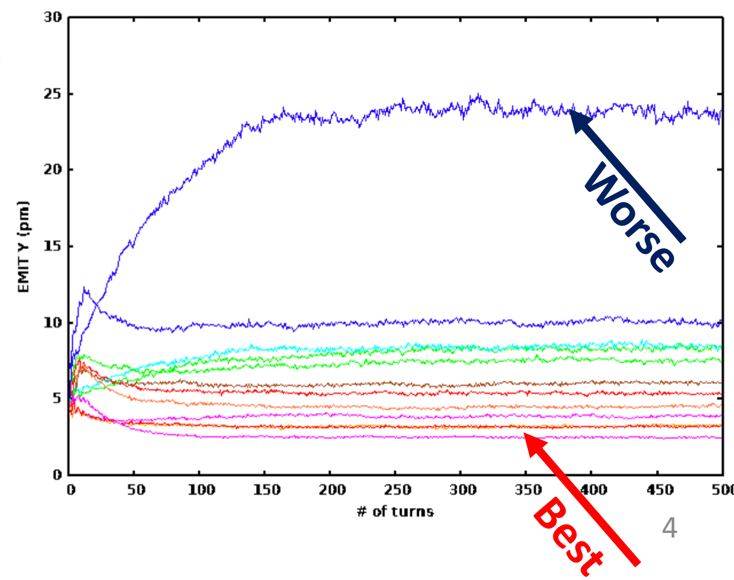
→ Tracking in the different seeds gave different results on vertical emittance blowup without and with beam-beam collisions

→ A further investigation on the **Best** and **Worse** random seed generators was performed

w/o beam-beam



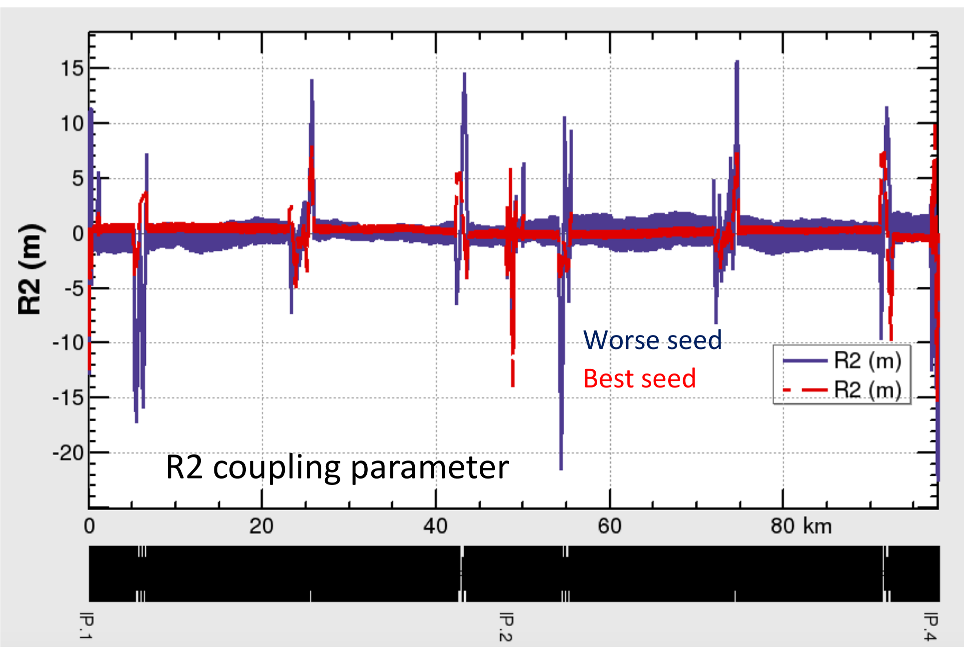
w/ beam-beam



Good and Bad seeds

→ In the presence of x-y coupling, the emittance cannot be expressed in terms of physical coordinates (Eq. 1), but in terms of betatron terms (Eq. 2)

→ The R2 coupling parameter overall the ring for the best seed is much smaller than that of the worse seed, thus explaining the observed blowup



$$\varepsilon_{x,y} = \frac{C_q}{J_{x,y}} \gamma_0^2 \frac{\oint \mathcal{H}_{x,y}/|\rho|^3 ds}{\oint 1/\rho^2 ds} \,, \qquad \text{Eq. 1}$$

$$\mathcal{H}_{x,y} \equiv \gamma_{x,y}\eta_{x,y}^2 + 2\alpha_{x,y}\eta_{x,y}\eta_{px,py} + \beta_{x,y}\eta_{px,py}^2$$

definition of x-y coupling parameter:

$$\begin{pmatrix} u \\ p_u \\ v \\ p_v \end{pmatrix} = \mathrm{R} \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} = \begin{pmatrix} \mu & . & -r_4 & r_2 \\ . & \mu & r_3 & -r_1 \\ r_1 & r_2 & \mu & . \\ r_3 & r_4 & . & \mu \end{pmatrix} \begin{pmatrix} x \\ p_x \\ y \\ p_y \end{pmatrix} \,, \qquad \text{Eq. 2}$$

betatron coordinate

physical coordinate

Emittance tuning

→ Low emittance tuning studies are performed by inserting different quantitative and qualitative machine errors and performing optics corrections accordingly. (T. Charles presentation, 26/06)

→ So far, such studies show the possibility of achieving considerably low vertical emittance in the $t\bar{t}$ lattice

→ The machine errors considered in our simulations are summarised in the table below:

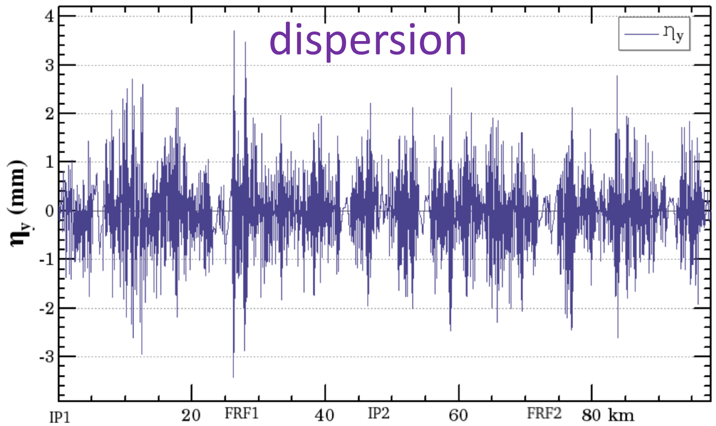
Optical elements	σ_x (μm)	σ_y (μm)	σ_θ (μrad)
Quadrupoles	100	100	100
Sextupoles	100	100	No

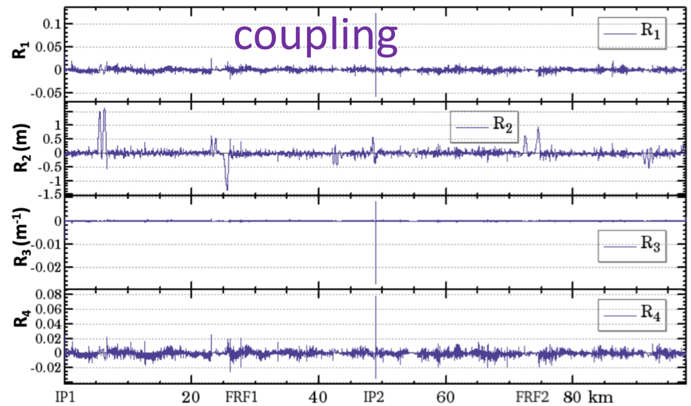
→ The optics corrections considered include β beat, dispersions, coupling and tune corrections.

→ So far only one random generator seed chosen among the successful seeds used for emittance tuning, has been studied as an attempt to understand the behaviour of the beam blowup.

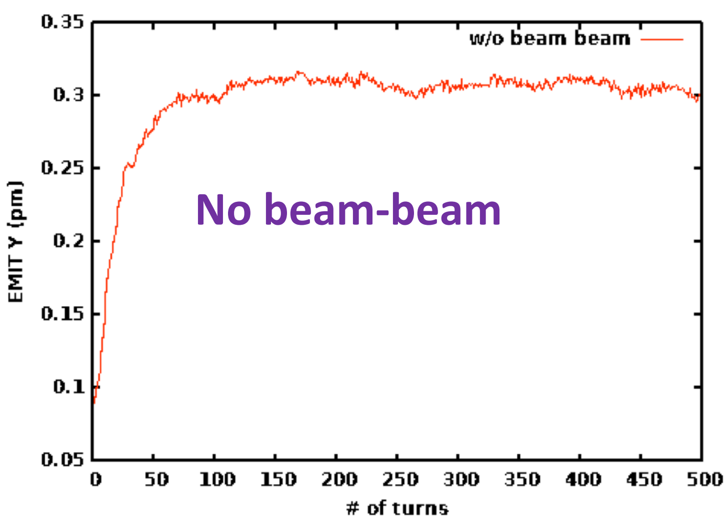
Tracking in a corrected lattice

→ The low emittance tuning with the used seed results in an invariant vertical emittance of the ring of 0.08 pm (≈ 34 times lower than the design $\mathcal{E}_v$=2.7 pm)





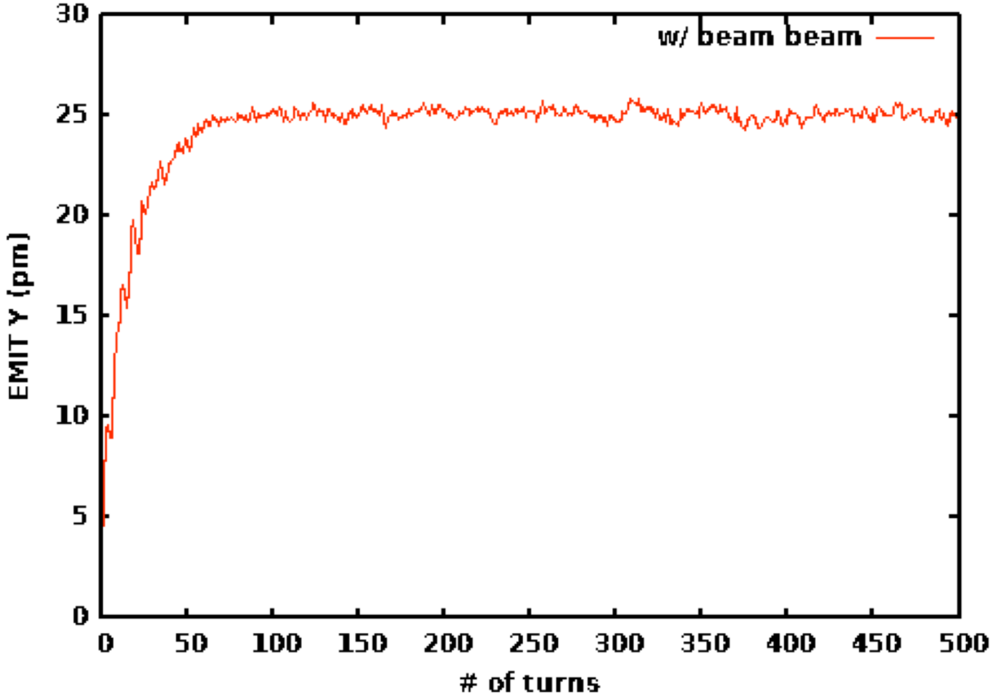
→ The projected vertical emittance of the beam at the IP was observed to blowup four times higher to 0.3 pm without beam collisions.



Beam blowup in the absence of beam collisions was described in the paper by K. Oide and H. Koiso: « Anomalous equilibrium emittance due to chromaticity in electron storage rings », Phys. Rev. E **49**, 4474 – Published 1 May 1994

Tracking with collisions

→ Tracking in the presence of the beam-beam resulted in a huge blowup to 25 pm



→ As to understand this huge blowup, several issues have been checked to confirm if the blowup is purely due to beam-beam or due to some other issues related to emittance tuning.

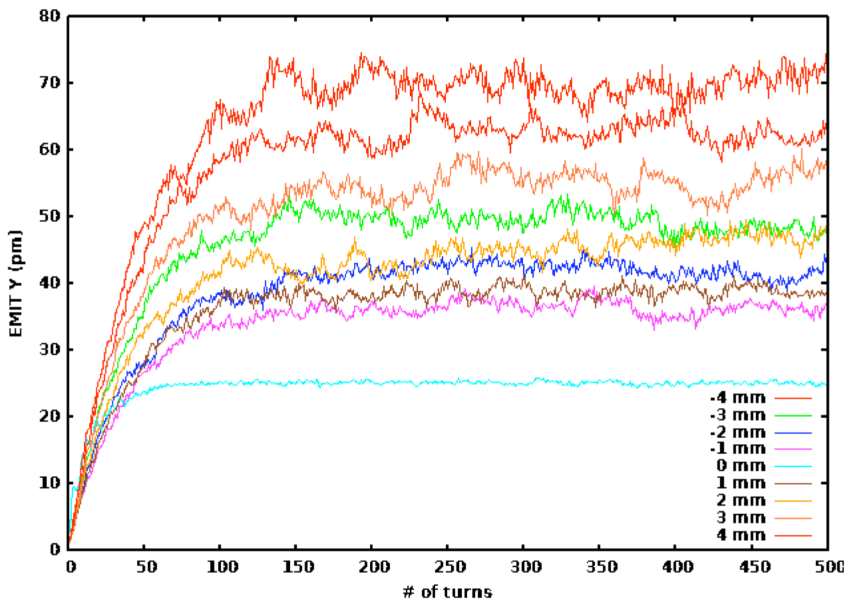
Waist scans

→ A shift in the waist point will shift the interaction point and thus the two beams might miss each other resulting in a huge blowup.

→ A waist scan was performed by shifting the strong beam at both IP in the range of [- 4 mm to + 4 mm]

→ The blowup of the weak beam was observed to become worse as shifting the strong beam

→ The blowup has nothing to do with the waist so far



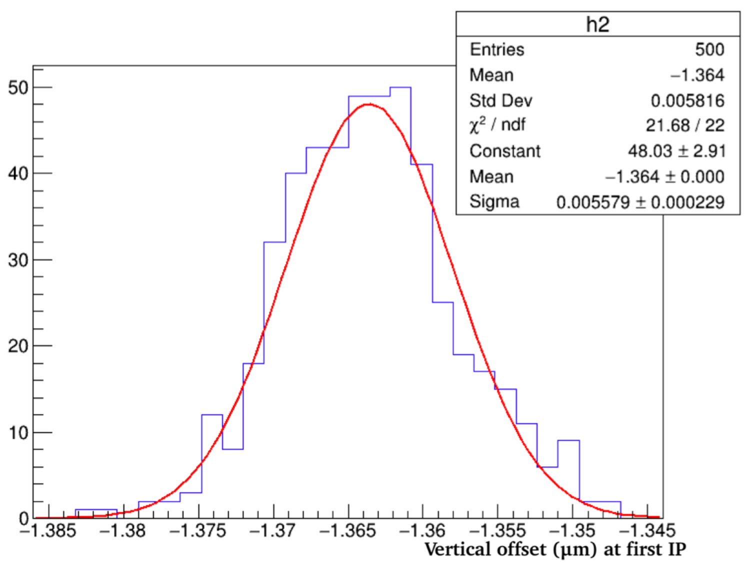
IP offset scans

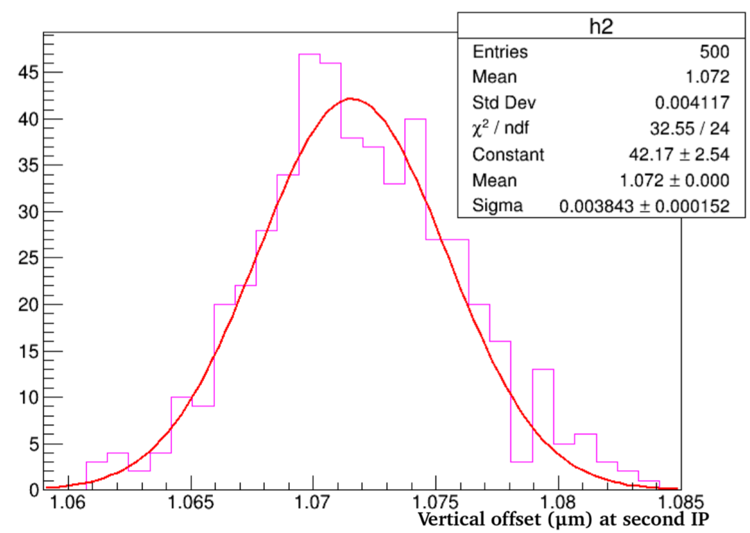
→ Further investigations allowed to observe a residual offset at the IP of - 0.5 μm and -1.5 μm in the horizontal and vertical planes respectively.

→ Given that the vertical offset at the IP is so huge compared to the vertical beam size at the IP (σ_y^*= 66 nm), it is basically the main contributer to the huge beam bowup

→ To correct for this offset, the weak beam was tracked in the presence of the beam-beam element.

→ Every turn the vertical offset of the weak beam is calculated at the IP just before the beam-beam element



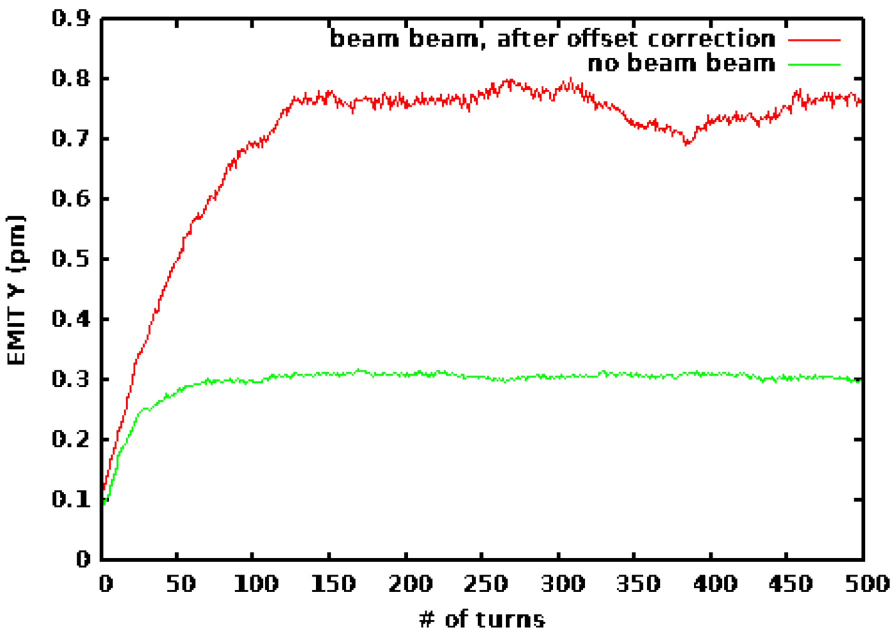


IP offset correction

→ The mean values of the vertical offsets are pretty similar at both IPs in the order of ±1 μm.

→ The correction of such offset is done by offsetting the strong beam at both IPs by the same mean values obtained for the weak beam vertical offsets

→ Correction of vertical offset resulted in a much smaller vertical emittance blowup of the weak beam from 25 pm to ≈ 0.8 pm



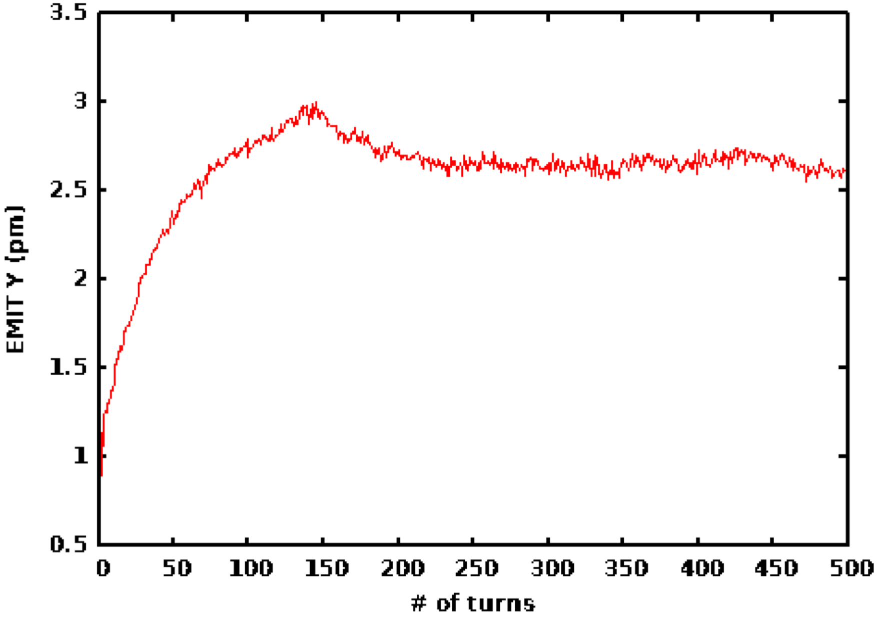
Achieving design emittance after beam-beam blowup

→ In the presence of beam-beam blowup, limitations on the highest vertical emittance that could be achieved by emittance tuning, should be defined

→ The beam-beam blowup was studied for different values of invariant vertical emittance.

→ The vertical emittance of the ring was varied by changing the strength of skew quadrupole elements

→ It has been observed that an invariant emittance of **0.4 pm is enough to achieve the design emittance of 2.7 pm** in the presence of beam-beam blowup



Summary

→ Beam blowup has been observed earlier through tracking in a coupled lattice with and without beam collisions

→ After emittance tuning, a huge beam-beam blowup has been observed to be caused by residual vertical offsets at the IP

→ Beam-beam blowup introduces limitations on the highest vertical emittance achieved by emittance tuning

→ Further studies using more random seed generators will be considered

Thank you for your attention