STATUS OF FCC-EE BEAM-BEAM STUDIES

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Outline

1. Introduction

2. First studies with FCC-ee nonlinear lattice

3. Bhabha scattering lifetimes

4. SuperKEKB studies

5. Summary

Outline

First studies with FCC-ee nonlinear lattice

- Beam-beam collisions in FCC-ee
  - Harmful consequences on beam dynamics
  - 3D flip-flop, coherent synchro-betatron instability (not discussed here)
  - Emittance growth, dynamic aperture, beam lifetime

- Goal: benchmark FCC-ee nonlinear lattices with beam-beam against results with SAD obtained by K. Oide [1], to later study instabilities, collimation, impact of machine errors etc...

- This enables more detailed studies of beam lifetimes due to Bhabha scattering & beamstrahlung (in progress)

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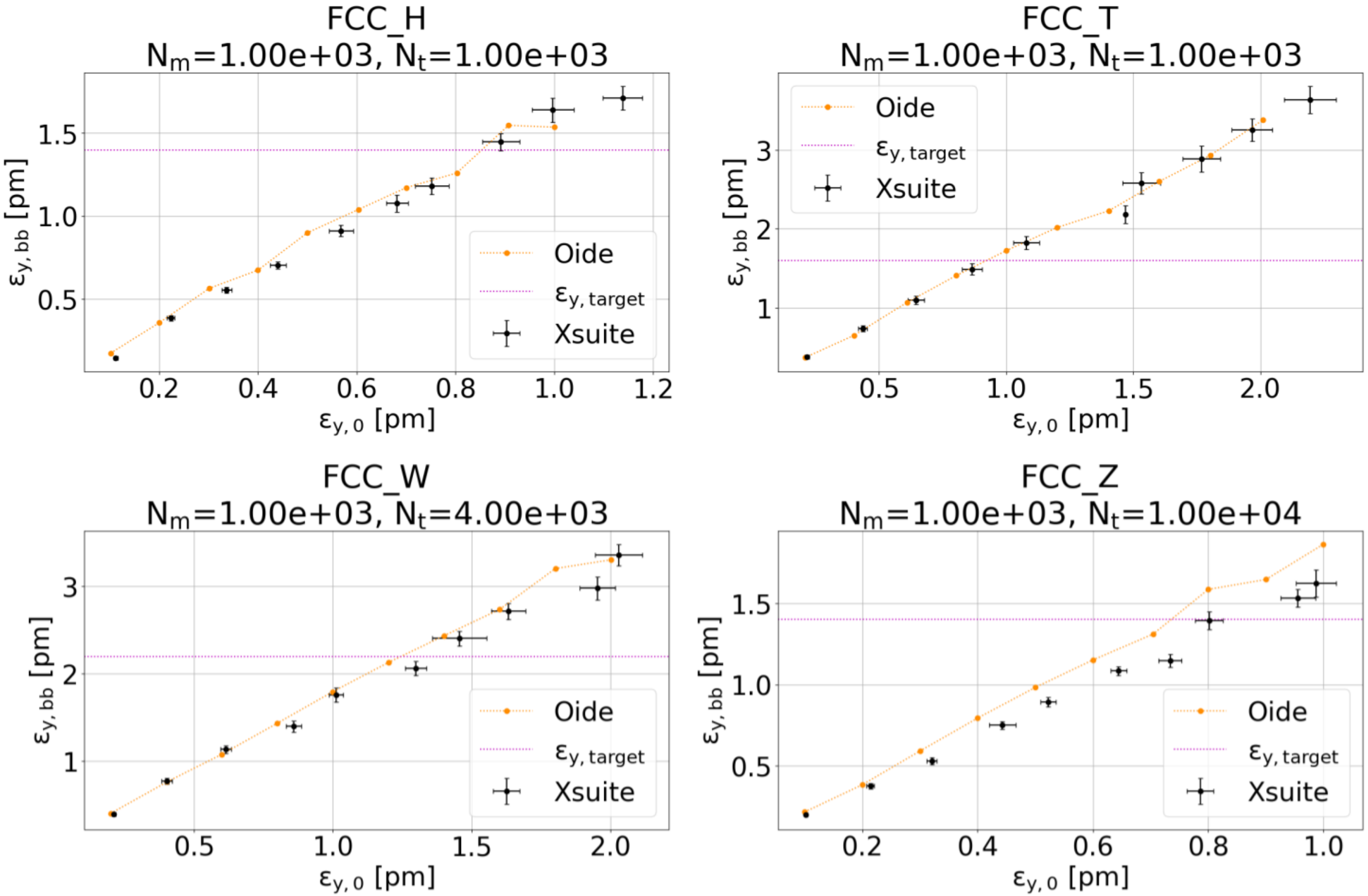
Emittance scan

- In the lattice models we need to introduce vertical dispersion artificially which will give the lattice a vertical emittance
- Introduce vertical dispersion by adding wigglers (e.g. SBEND in MAD-X) [2]
- ε_y can be tuned by the magnet strength of the wigglers
- After inserting these wigglers, the ε_y can be cross-checked by tracking [3]
- Presence of beam-beam collisions results in a transverse (mostly vertical) emittance blowup
- Cross-check lattice ε_y with tracking + quantify blowup due to beam-beam

Emittance scan results

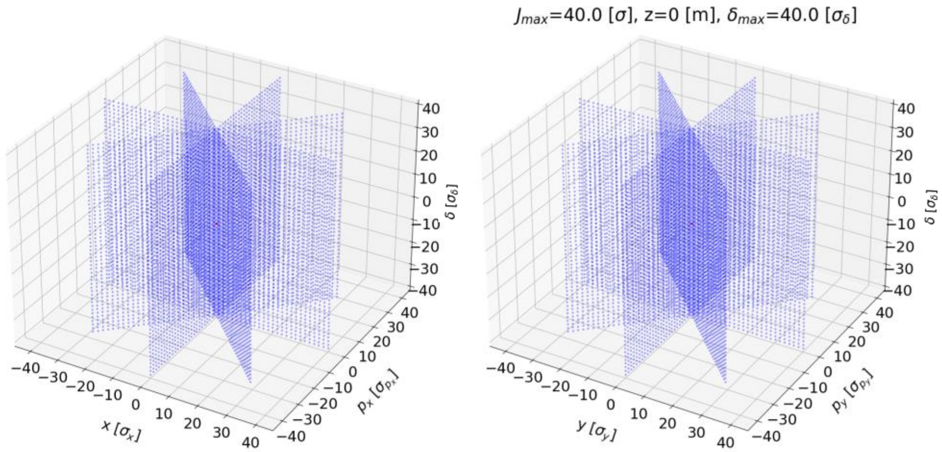
- $\varepsilon_{y,0}$: only lattice
- $\varepsilon_{y,bb}$: with beam-beam+beamstrahlung

- Black: tracked results with Xsuite
- Pink: ε_y "target" from parameter table (~desired max. ε_y with beam-beam) [1]
- Orange: data provided by K. Oide



Dynamic aperture - setup

$$J_i = \sqrt{\left(\frac{i}{\sigma_i}\right)^2 + \left(\frac{p_i}{\sigma_{p_i}}\right)^2}, i \in \{x, y\}$$

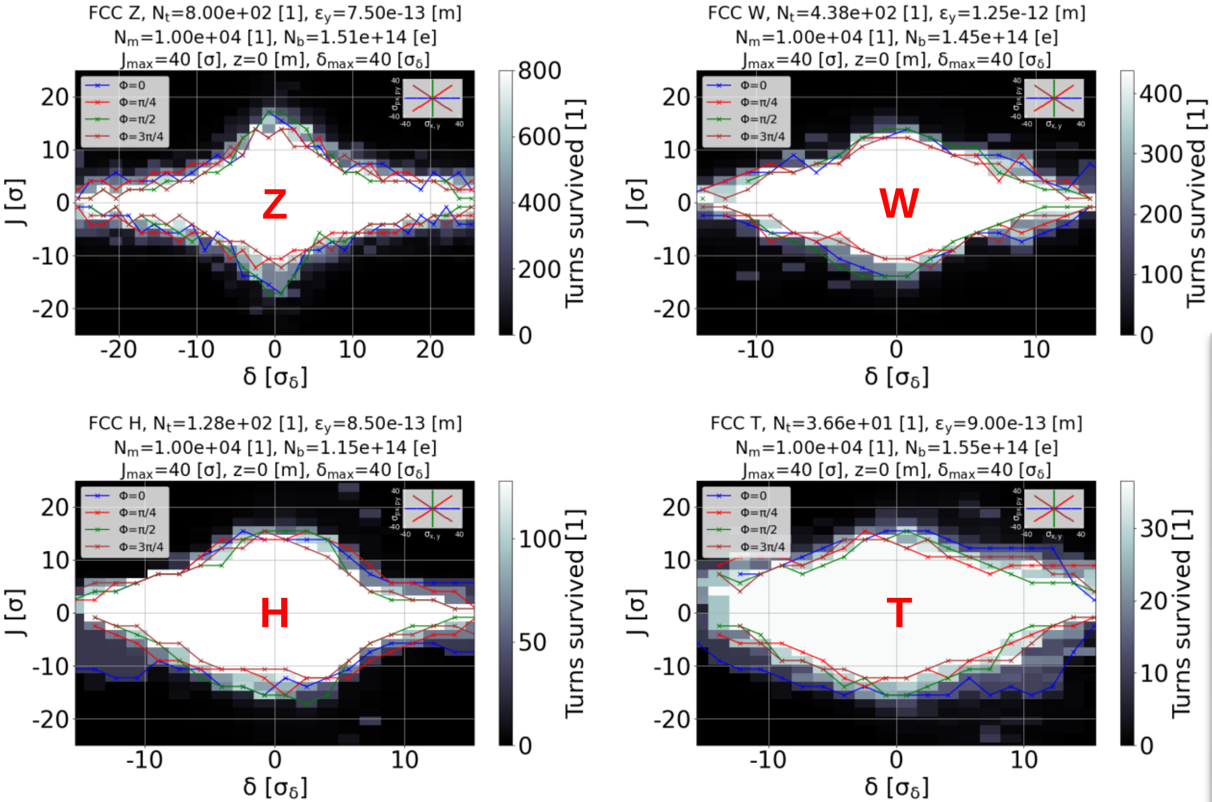


- 10,000 test particles on a grid (4 phases)

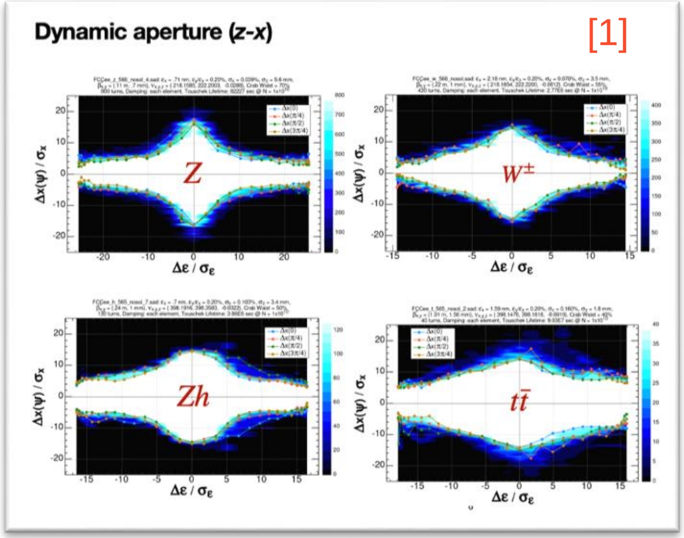
- Track the grid
  - Lattice+weak bunch set to nominal ε_y,
  - Strong bunch set to target ε_y
  - Mean synrad
  - Beam-beam
  - No beamstrahlung

- Record the number of survived turns T_{surv} for each particle
  - Colormap on next slide: average T_{surv} over the phases

Dynamic aperture



- Qualitative comparison
- Good agreement of limits for all resonances



Conclusions

- Equilibrium emittances & dynamic aperture with beam-beam successfully benchmarked against SAD
- Possible next step: similar studies with relaxed optics

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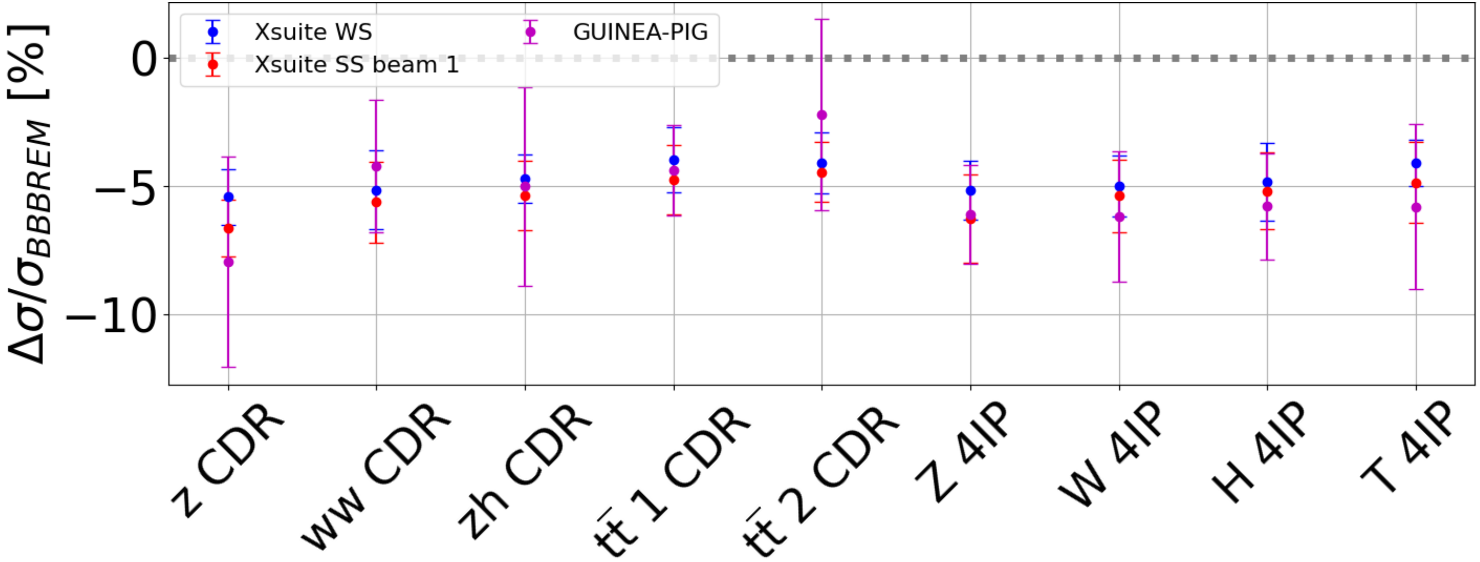
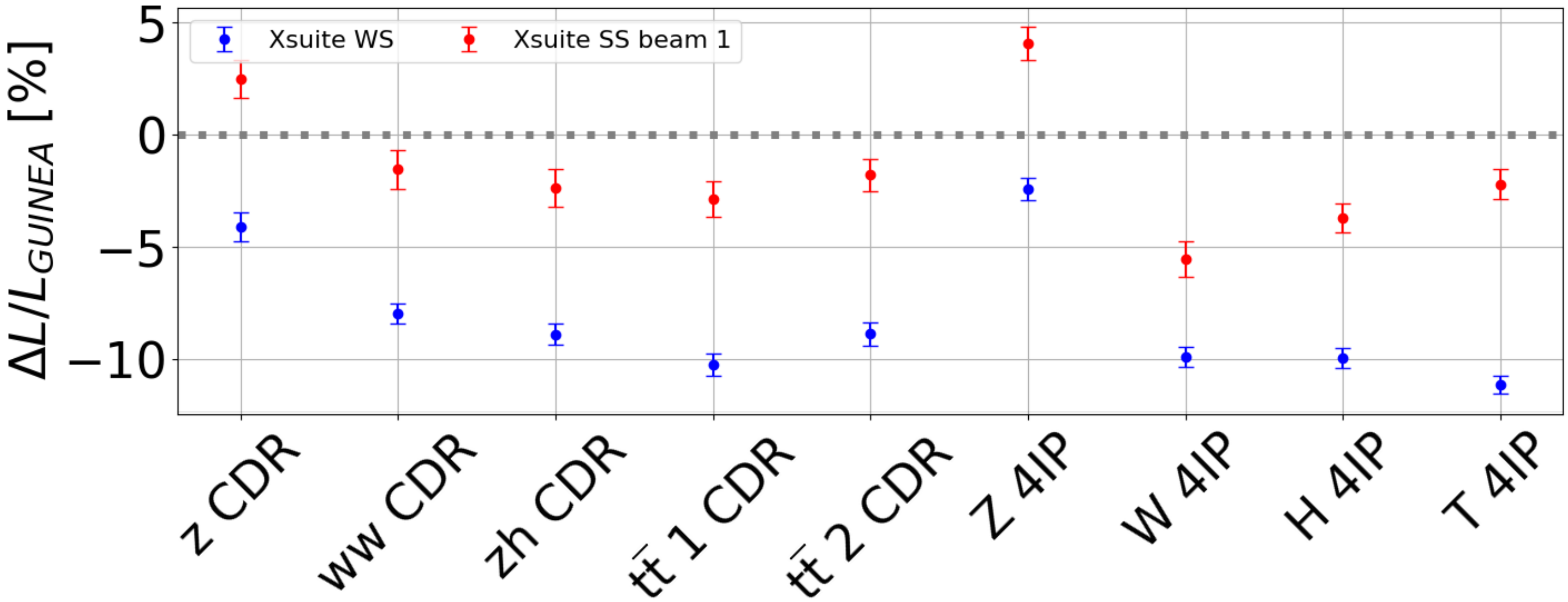
Bhabha scattering – Cross section

- Event generator adapted from GUINEA-PIG [4]
- Method of equivalent photons:
  1. Generate virtual photons of beam 1 slice
  2. Compton scatter virtual photons on beam 2 macroparticle
- Bhabha cross section from single collision: count emitted photons above mom. acceptance (1-2%, from [1] & [5])



Bhabha scattering - Luminosity

- Comparison of luminosity in GUINEA-PIG and Xsuite
- **PIC vs soft-Gaussian**
- Xsuite WS to GUINEA-PIG: ~10% less lumi
- Xsuite SS to GUINEA-PIG: ~5% less lumi, except Z where soft Gaussian is the least accurate

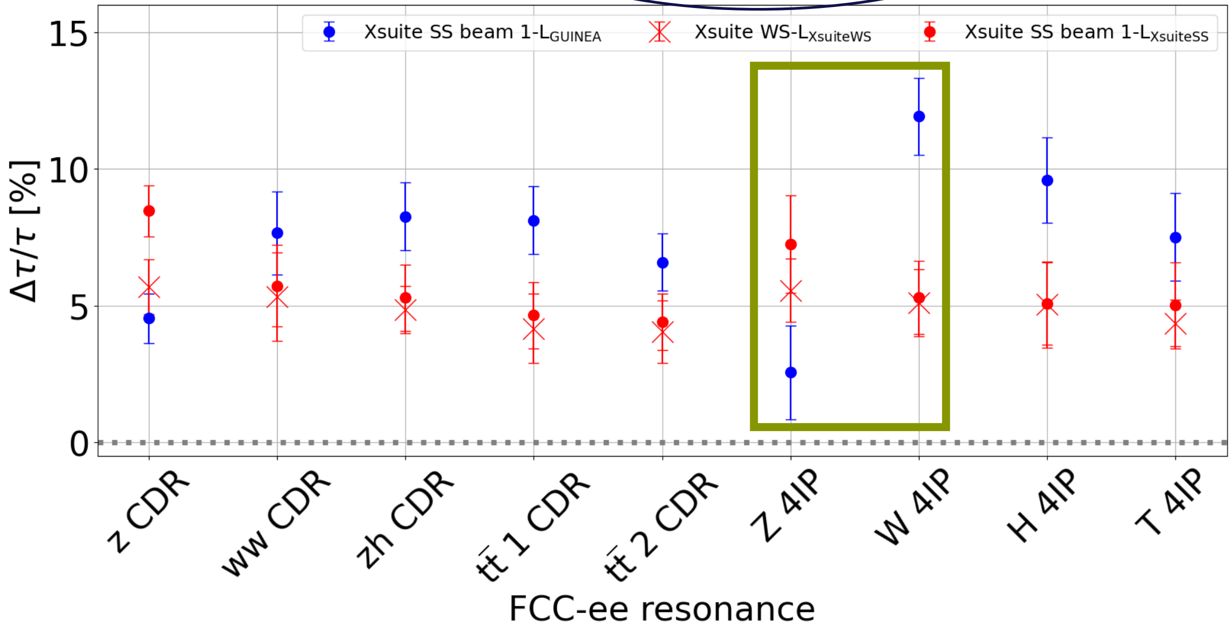


Bhabha lifetimes

from BBBREM | from Xsuite/GUINEA-PIG | Bhabha count > mom. acc.

$$\frac{1}{\tau} = \frac{1}{N_b}\frac{dN_b}{dt} = \frac{1}{N_b}\sigma_{Bhabha} L_{inst} \cdot N_{IP} = \frac{1}{N_b} R_b \cdot f_{rev} \cdot N_{IP}$$

reference | simulation



	FCC-ee pole	D_x $[10^{-3}]$	D_y [1]
CDR [5]	Z	0.138	0.886
	WW	0.558	1.231
	ZH	0.599	1.340
	$t\bar{t}1$	2.238	1.829
	$t\bar{t}2$	2.239	1.774
4 IP [1]	Z	0.154	0.940
	W	1.039	1.861
	H	0.459	0.880
	T	1.551	1.577

1. Red: σ_{BBBREM} + L_{Xsuite}: ~5% syst. unc. of event generator compared to BBBREM
2. Blue: σ_{BBBREM} + $L_{GUINEA\text{-}PIG}$: unc. up to ~10% due to 1. + lumi error from PIC-soft-Gaussian difference

Conclusions

- Xsuite Bhabha scattering event generator successfully benchmarked
- Can be used in other types of studies (MDI & collimation)
- In progress: lifetimes from tracking in nonlinear lattice

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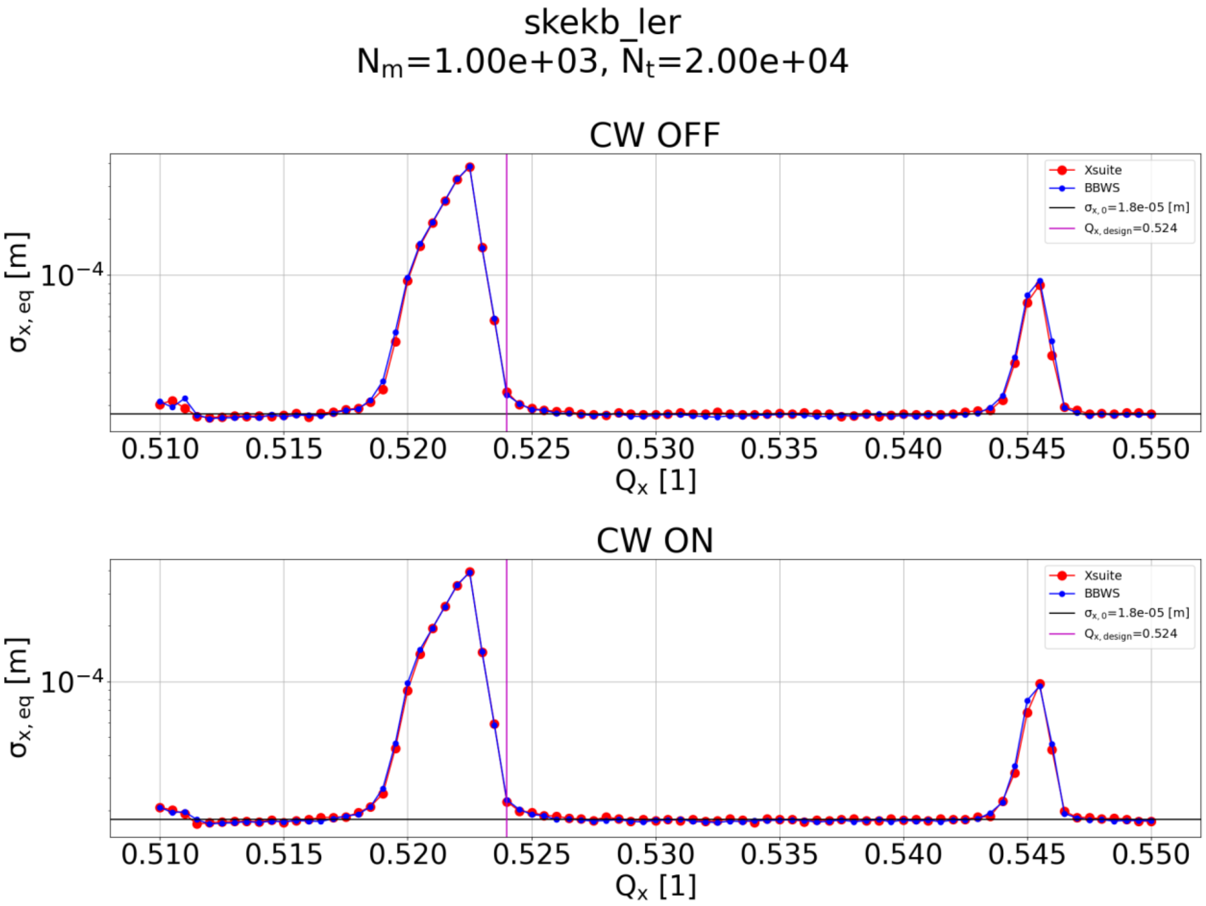
SuperKEKB studies

- Goals:
  1. Review of experimental and simulated beam-beam effects at SuperKEKB
  2. Xsuite simulation benchmarks with the SuperKEKB machine
  3. Investigation of beam-beam driven synchro-betatron resonances and instability analysis to explain this phenomenon observed at SuperKEKB via experiments and simulations.

SuperKEKB studies

- Collaboration with D. Zhou @ KEK
- Starting point: Xsuite simulation benchmarks with the SuperKEKB machine
- Linear lattice
- synrad + BB (no BS)
- Scan Qx with LER parameters
- Compare eq. beam sizes Xsuite WS vs BBWS
- Good agreement between the 2 codes



Outline

Summary

Nonlinear lattice

- Low energies (Z, W) likely need to track for more turns to see converged emittances
- Possible next step: similar studies with relaxed optics

Bhabha lifetimes

- Good agreement
  - Xsuite with BBBREM & GUINEA-PIG
  - Lifetimes using linear tracking + hard edge acceptance
- Next step: lifetimes from tracking in nonlinear lattice

SuperKEKB studies

- Good progress so far, good agreement between BBWS and Xsuite
- Next step: simulate with longitudinal wakefields+BB in Xsuite

Thank you!

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References

[1] https://indico.cern.ch/event/1202105/contributions/5408583/attachments/2659051/4608141/FCCWeek_Optics_Oide_230606.pdf

[2] https://github.com/xsuite/xtrack/blob/main/examples/fcc_ee/install_wigglers.madx

[3] https://indico.cern.ch/event/1330032/contributions/5599084/attachments/2724483/4734409/010_eq_emittances.pdf

[4] https://gitlab.cern.ch/clic-software/guinea-pig-legacy

[5] https://cds.cern.ch/record/2651299/files/CERN-ACC-2018-0057.pdf

[6] https://github.com/xsuite/xtrack/blob/main/examples/fcc_ee/000_build_xsuite_model.py

[7] https://gitlab.cern.ch/acc-models/fcc/fcc-ee-lattice/-/tree/V18_xsuite

BACKUP

Workflow – everything in Xsuite

Prepare Xtrack line once [6]:

- load MAD-X sequence [7]
- add wigglers
- convert to Xtrack line
- build + twiss 4D
- slice sequence
- build + twiss 4D
- save Xtrack line

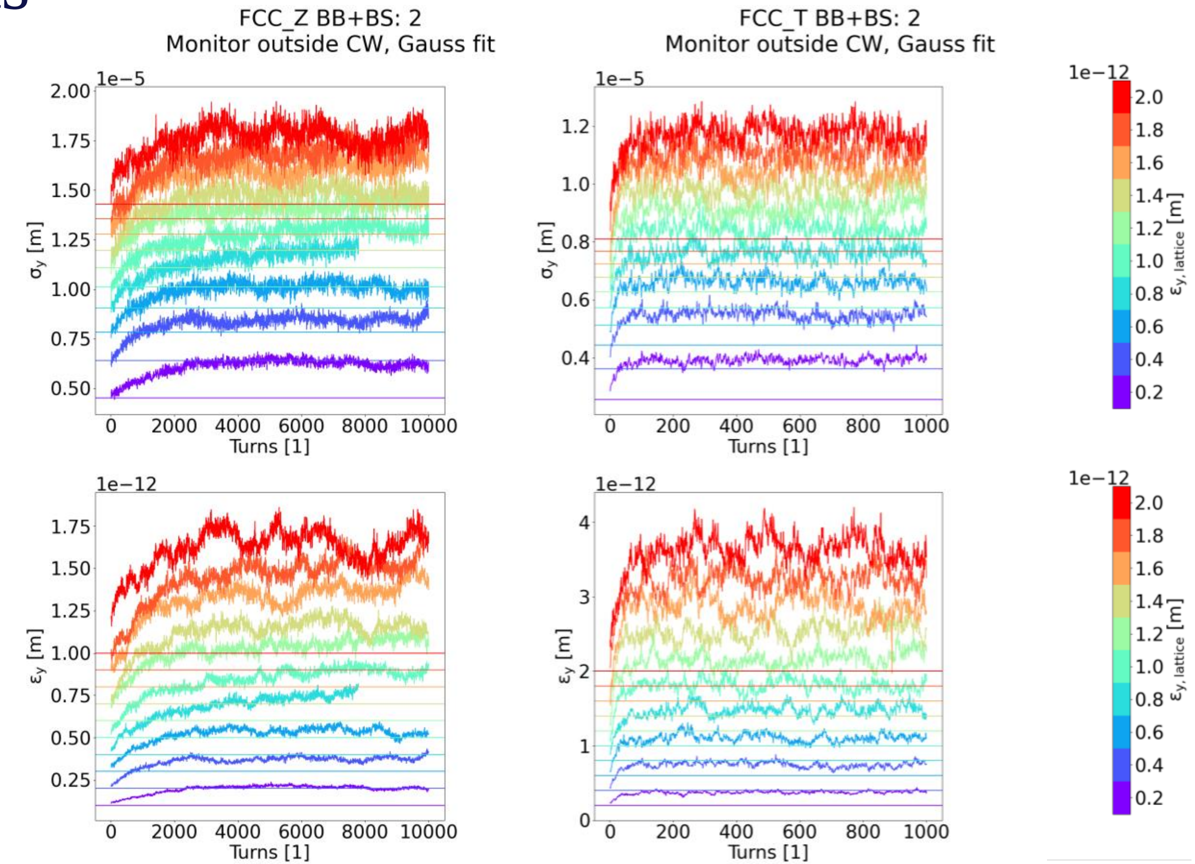
Loop over a range of ε_y values:

- load Xtrack line
- add observation point @ RF
- build + twiss 4D
- twiss 6D mean synrad + tapering
- match ε_y
- twiss 6D mean synrad + tapering
- ⋮

- ⋮
- add beam-beam element (optional)
- build
- set quantum synrad
- track
- repeat with next ε_y

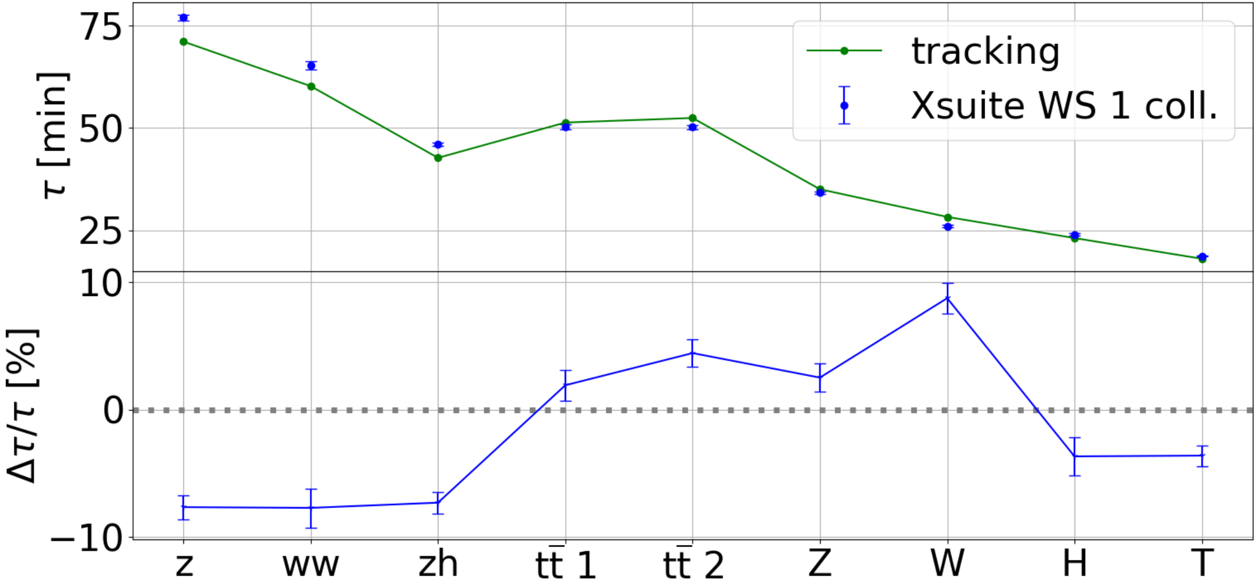
Emittance scan results

- Small discrepancy compared to SAD results
- Xsuite likely not yet converged
- Need more turns to see converged emittances



Bhabha lifetimes

- Linear lattice
- Hard edge momentum acceptance



Bhabha lifetimes

$$\frac{1}{\tau} = \frac{1}{N_b}\frac{dN_b}{dt} = \frac{1}{N_b}\sigma_{Bhabha}L_{inst} \cdot N_{IP} = \frac{1}{N_b}R_b \cdot f_{rev} \cdot N_{IP}$$

- τ: Bhabha lifetime [s]
- N_b: bunch intensity [1]
- σ_{Bhabha}: Bhabha cross section [m^2]
- N_{IP}: number of Ips [1]
- $L_{inst}=L*f_{rev}$: instantaneous lumi of 1 bunch crossing [m^-2 s^-1]
- L: integrated lumi of a single collision (collision luminosity) [m^-2]
- f_{rev}: revolution frequency [s^-1]
- $R_b= \sigma_{Bhabha}*L$: number of emitted Bhabha photons with E above mom. acceptance [1]