TOWARDS BEAM-BEAM SIMULATIONS FOR FCC-EE

P. Kicsiny, X. Buffat, D. Schulte, G. Iadarola, T. Pieloni, M. Seidel

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F. Carlier, M. Hofer, D. Shatilov, K. Oide, D. Zhou

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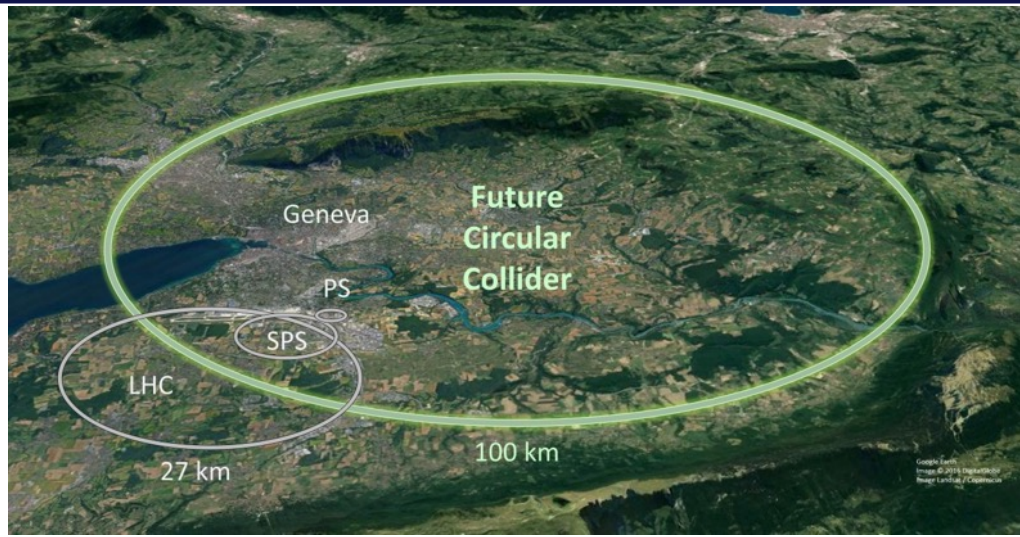
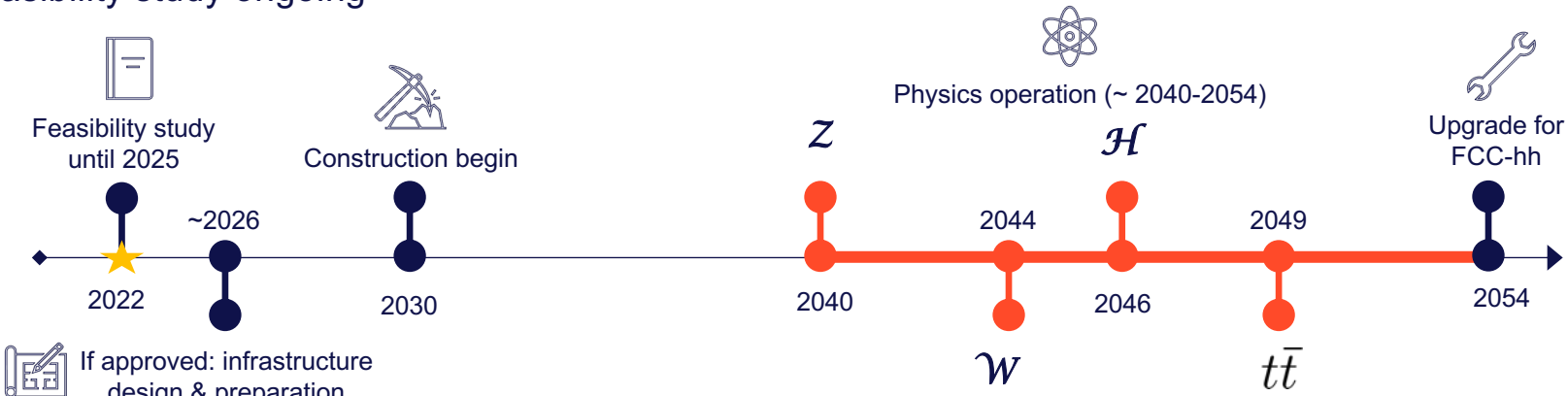
Overview

1. Introduction to FCC-ee
2. Beam-beam effects in FCC-ee
3. Overview of existing simulation tools for circular machines
4. Beam-beam models
5. First studies
6. Summary & next steps

FCC-ee

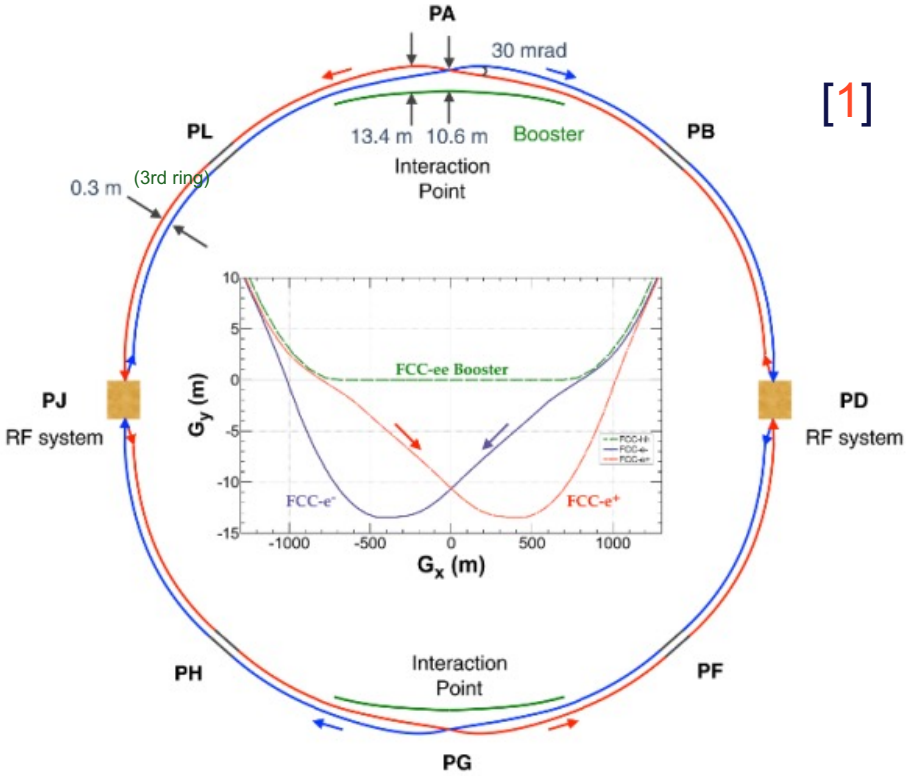
- The FCC-ee (Future Circular Collider): currently one of the most favored next colliders at CERN
- Study properties of standard model particles with unprecedented precision, up to 350 GeV
- A first stage towards a possible 100 TeV hadron collider (FCC-hh)
- Feasibility study ongoing





Layout

- Baseline with 2 IP
- 4 IP configuration under study
- Accelerator design aims to maximize luminosity and reduce beam-beam effects

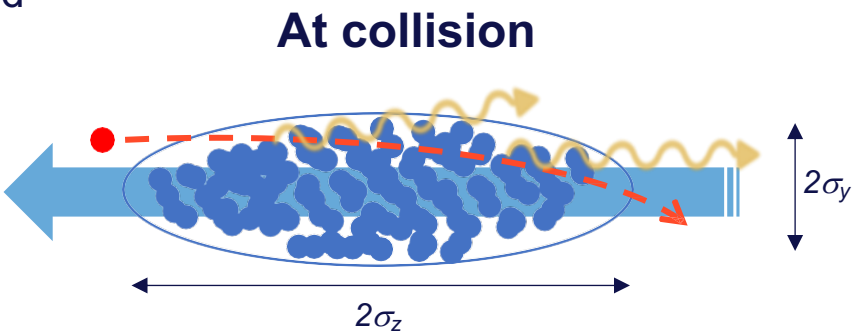


[1]

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

Beam-beam effects in FCC-ee

- Nonlinear kick
- No complete theory, simulations have to be used
- Beamstrahlung:
  - ➢ Increases bunch length (σ_z) & energy spread (σ_δ)
  - ➢ Decreases luminosity & beam lifetime

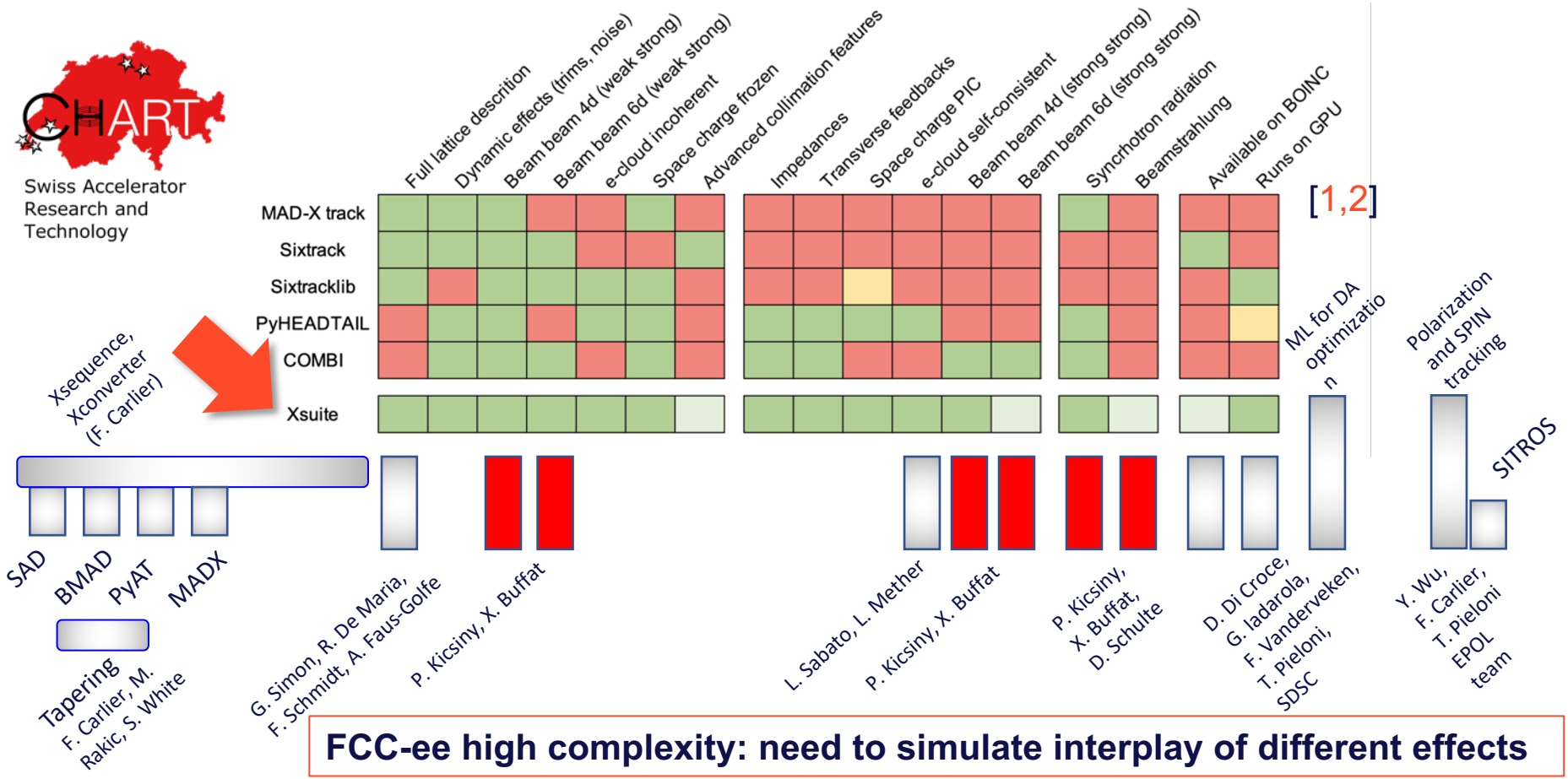


- Proposed setup to increase luminosity [1]:
  1. Large Piwinski angle + crab waist scheme [2]
     - ➢ Small beam size, crossing angle, crab sextupoles

1. Top-up injection scheme: continuous injection of new bunches
   - ➢ Maintains luminosity levels & compensates for decreased beam lifetime

[1] https://cds.cern.ch/record/2651299/files/CERN-ACC-2018-0057.pdf
[2] https://arxiv.org/pdf/1608.06150.pdf

CHART
Swiss Accelerator Research and Technology

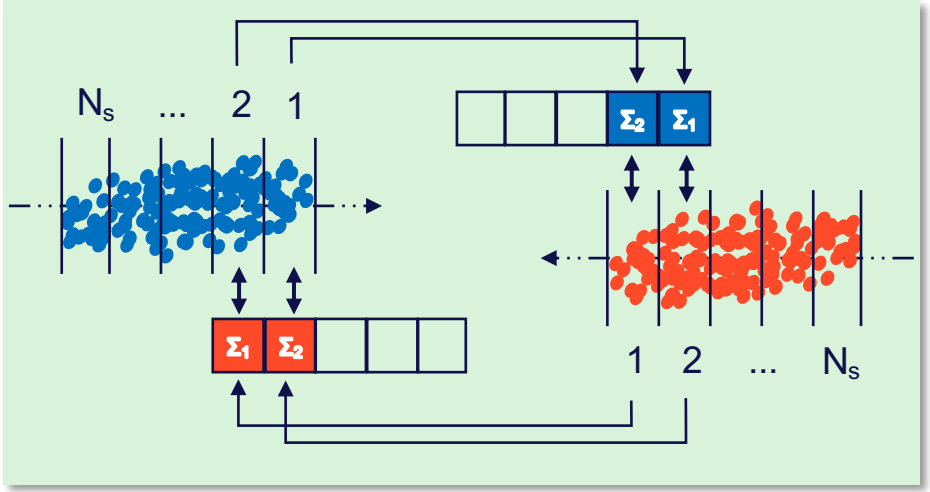


FCC-ee high complexity: need to simulate interplay of different effects

[1] G. Iadarola https://indico.cern.ch/event/1066779/contributions/4485729/attachments/2301867/3915592/019_Xsuite.pdf
[2] T. Pieloni https://indico.cern.ch/event/1064327/contributions/4893328/attachments/2454297/4206242/FCC%20Software%20framework%20developments.pdf

Beam-beam models

- ~10^4-10^7 particles per bunch
- Longitudinal slicing (simplecticity)
- Interaction of slice pairs
  - Compute kick using slice moments (Σ)
  - Update dynamical variables



multi-turn effects
single particle effects

low disruption parameter
slow instabilities

high disruption parameter
fast instabilities, wakefields

fastest & least accurate — **slowest & most accurate**

never
weak-strong [WS]

periodically
quasi strong-strong [QSS]

after each slice-slice interaction
strong-strong [SS]

Frequency of recomputing slice moments

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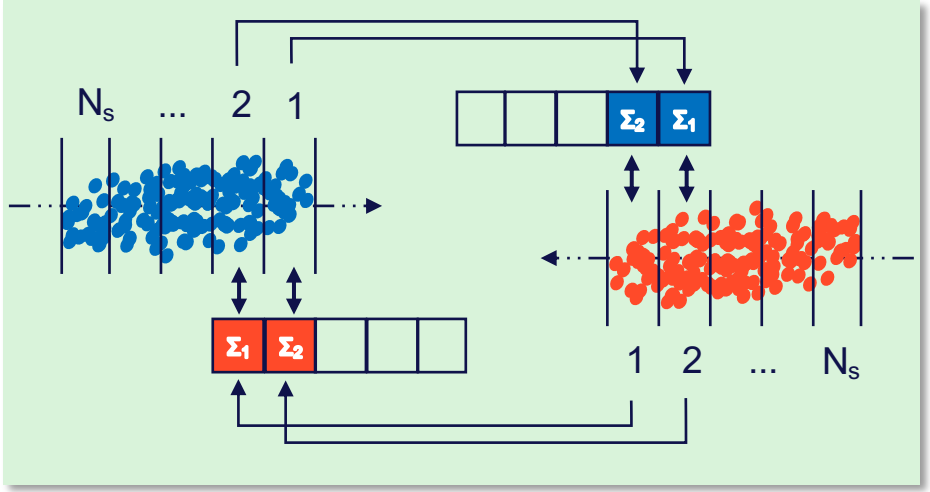
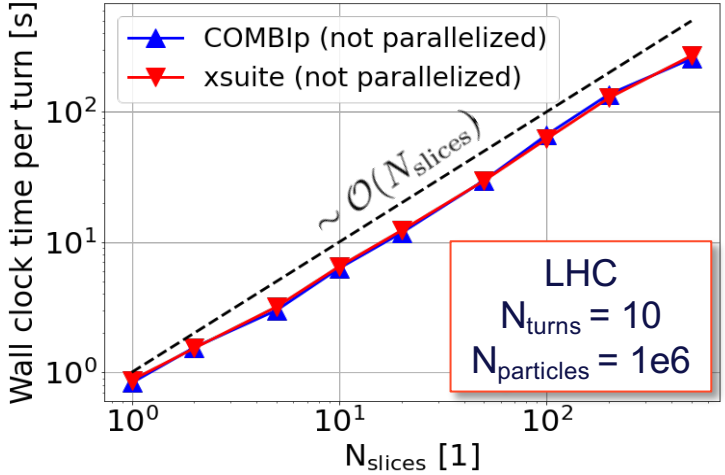


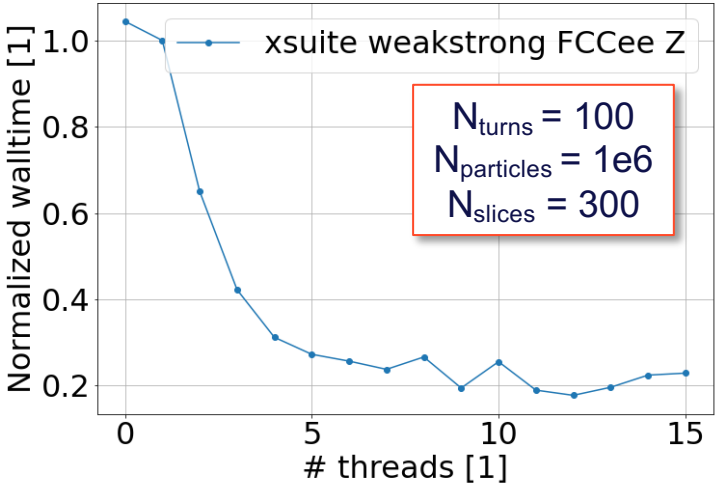
In xsuite:

- Core algorithm: single slice-slice interaction
- Flexible choice of model
- Force: soft-Gaussian kick by Bassetti-Erskine formula [1] (field solvers to be tested in future)
- Extendible: e.g. Beamstrahlung, Bhabha scattering

[1] https://cds.cern.ch/record/122227/files/198005132.pdf



- Benchmark of computation time for beam-beam (**strong-strong**) + linear tracking against reference code COMBIp [1]
- Time per turn scales approximately with the number of longitudinal slices



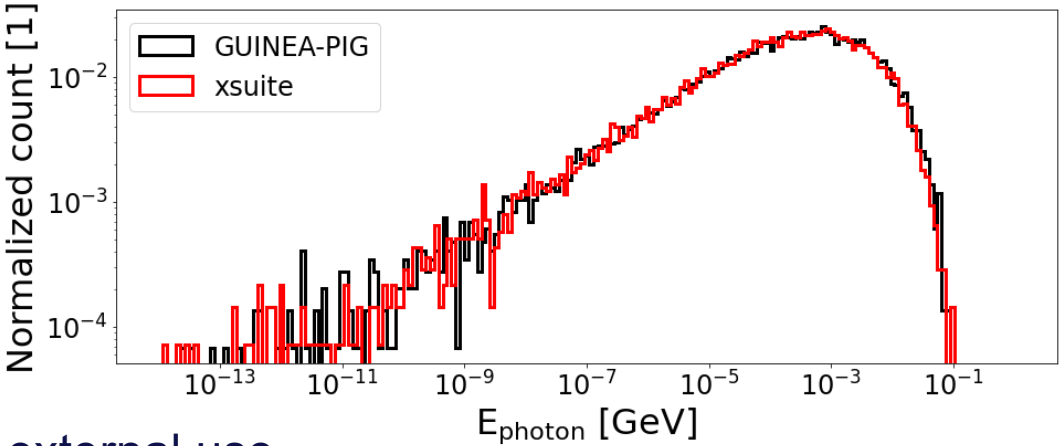
- Multithreading: ~x5 speedup
- GPU acceleration is available in xsuite
  - To be tested
  - Will be needed for full scale simulations

[1] https://twiki.cern.ch/twiki/bin/view/ABPComputing/COMBI

Beamstrahlung benchmark

- Benchmark against reference code GUINEA-PIG [1]
  - FCC-ee flat beams
  - Crossing angle: 15e-3 [rad]
  - Beamstrahlung model OK
  - xsuite: **weak-strong**
  - GUINEA-PIG: **strong-strong**

Beamstrahlung photon spectrum / coll.



- Possibility to generate photons for external use (collimation, MDI) [2]

- TODO: come up with an efficient model of Bhabha scattering

[1] https://twiki.cern.ch/twiki/bin/view/ABPComputing/Guinea-Pig
[2] https://xsuite.readthedocs.io/en/latest/internal_record.html#internal-record-for-elements-used-in-standalone-mode

Simplified tracking simulations with xsuite

- Exploit superperiodicity of machine (2 IP case)

- In code:
  - 1 IP + tracking over half arc with linear transfer matrix

  - Arc split into 3 segments

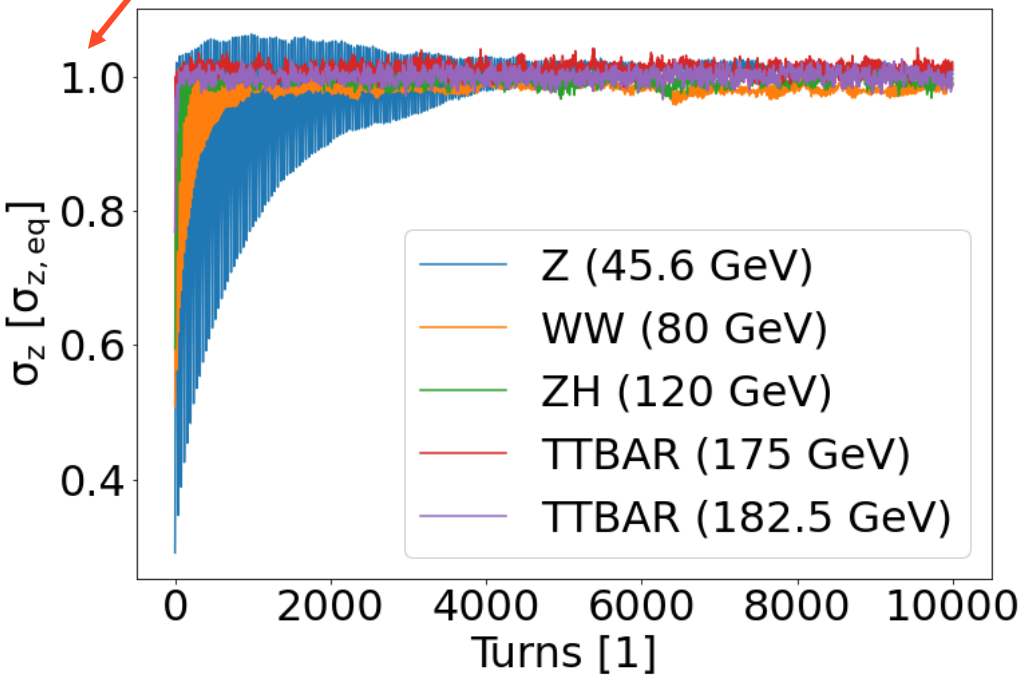
  - 2 crab sextupoles between arc segments

  - A «turn» begins in front of the right sextupole:
    - Observation point for emittances (by stat. definition from normalized coordinates)
  - Observation point for raw coordinates is before IP

  - Effective radiation (damping+noise) in arc, beamstrahlung in beam-beam

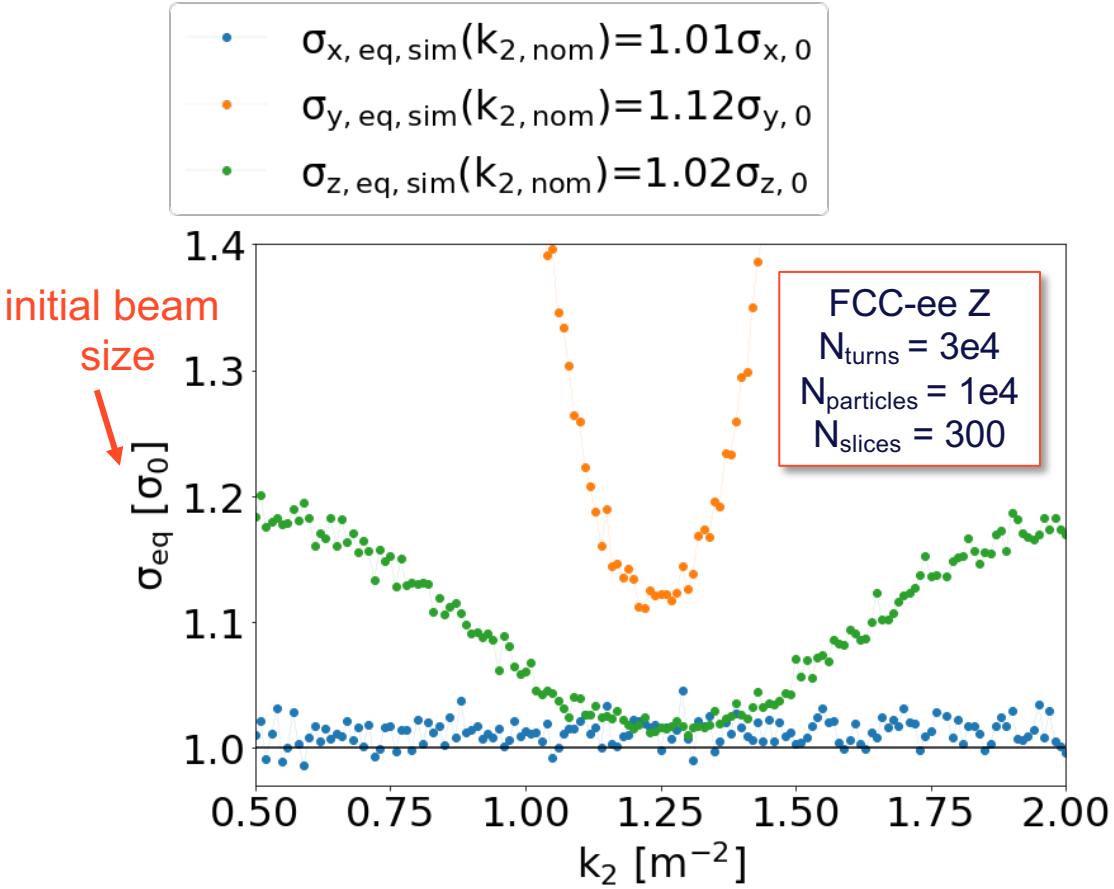
Equilibrium bunch length

normalized to design report values (SR+BS)



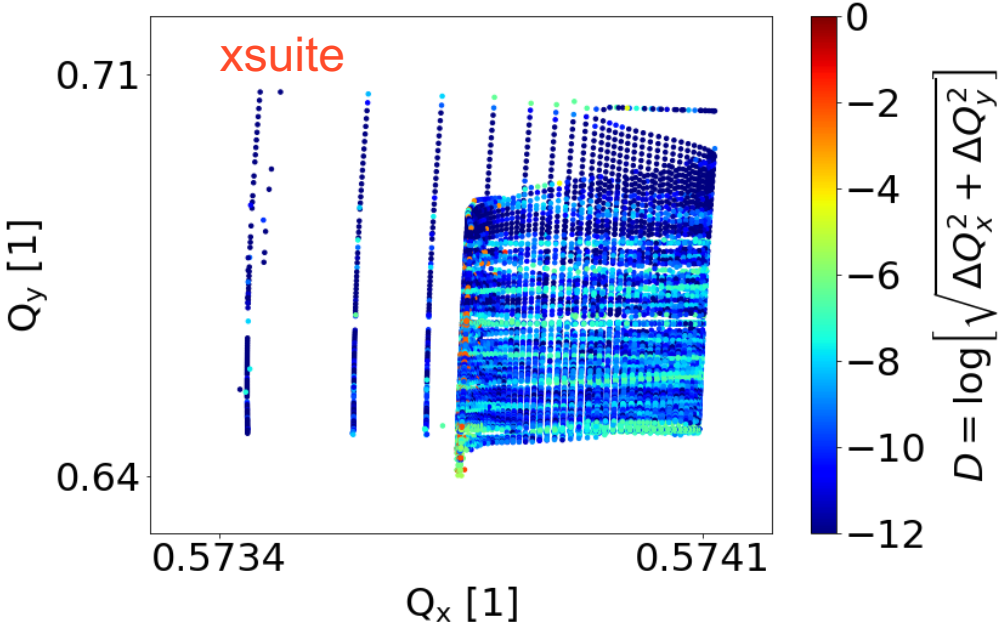
- **Weak-strong** model (1e4 particles)
- Equilibrium bunch length agrees with design report value for all resonances

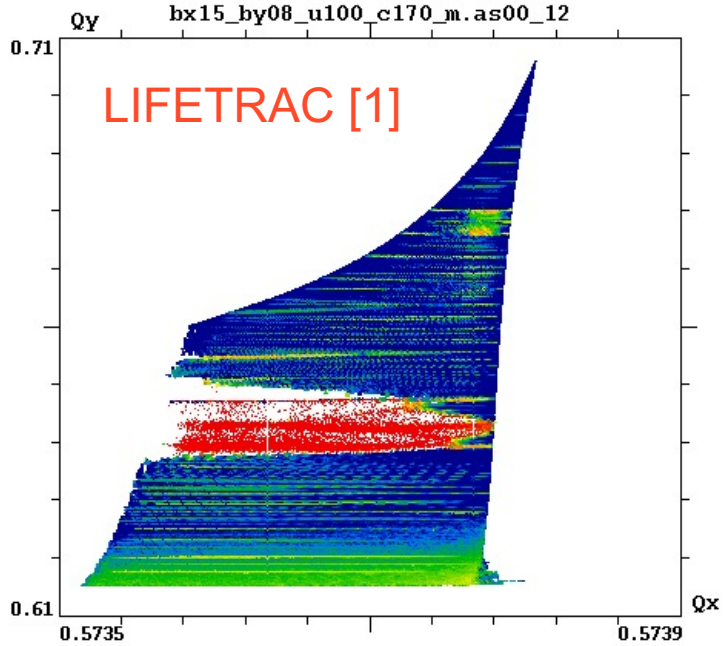
Crab waist & transverse blowup



- **Weak-strong** model
- Optimum k_2 close to nominal value (~0.97*$k_{2,nom}$ for Z resonance)
- ~10% blowup of vertical beam size (stat. errors ~1%)
- Not observed in other codes
- Investigation in progress

Understanding transverse blowup & benchmarking

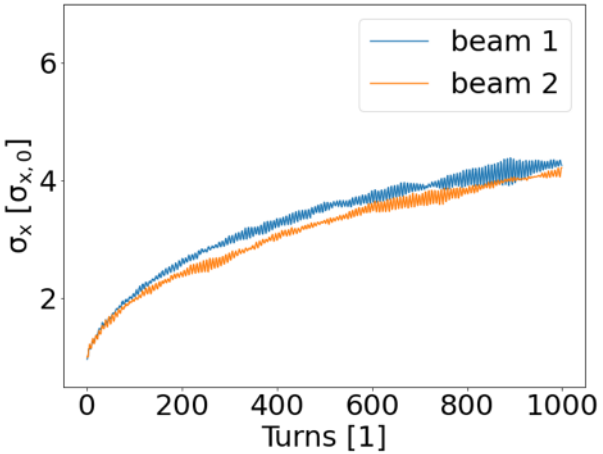


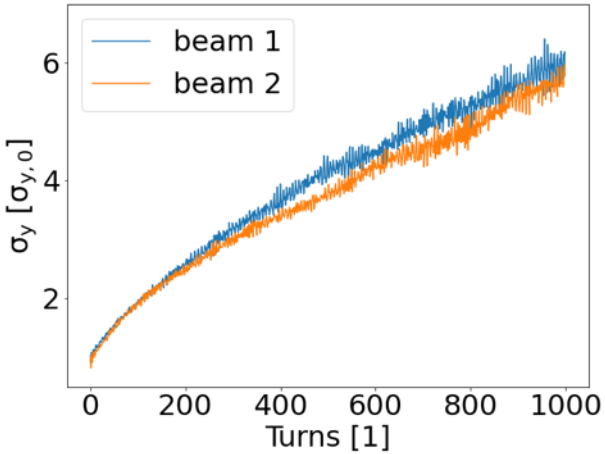


- FCCee Z tune footprint
- Differences to be understood

[1] Courtesy of D. Shatilov

Strong-strong simulations





FCC-ee Z
N_{turns} = 3e4
$N_{particles}$ = 1e4
N_{slices} = 300

- Fast blowup in x and y size (not observed in other codes)
- Coherent beam-beam instability? [1]
- Investigation in progress

[1] https://journals.aps.org/prl/pdf/10.1103/PhysRevLett.119.134801

Summary

Work so far: xsuite code development & benchmarks for FCC-ee

- Flexible beam-beam models (weak-strong, quasi strong-strong, strong-strong)
- Beamstrahlung: photon generation available
- Weak-strong benchmarks (understaning vertical blowup, FMA benchmark)
- Strong-strong benchmarks (understnad blowup, reproduce coherent instability)

Work ongoing

- Bhabha scattering
- 3D flip-flop
- Top-up injection

Other xsuite features targeted

- Impact of lattice imperfections
- Interplay with real lattice model
- Multiple IPs
- Monochromation
- Wakefields

Thank you!

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