Development of simulation framework for FCC-ee

F. Carlier 01/09/2021

On behalf of the EPFL-CERN collaboration:
A. Abramov, M. Benedikt, R. Bruce, X. Buffat, R. De Maria, A. Faus-Golfe, W. Herr, G. Iadarola, K. Oide, T. Pieloni, F. Schmidt, D. Schulte, M. Seidel, R. Tomas, S. White, Y. Wu, F. Zimmermann

Future Circular Collider e+e- : next generation e+e- circular collider

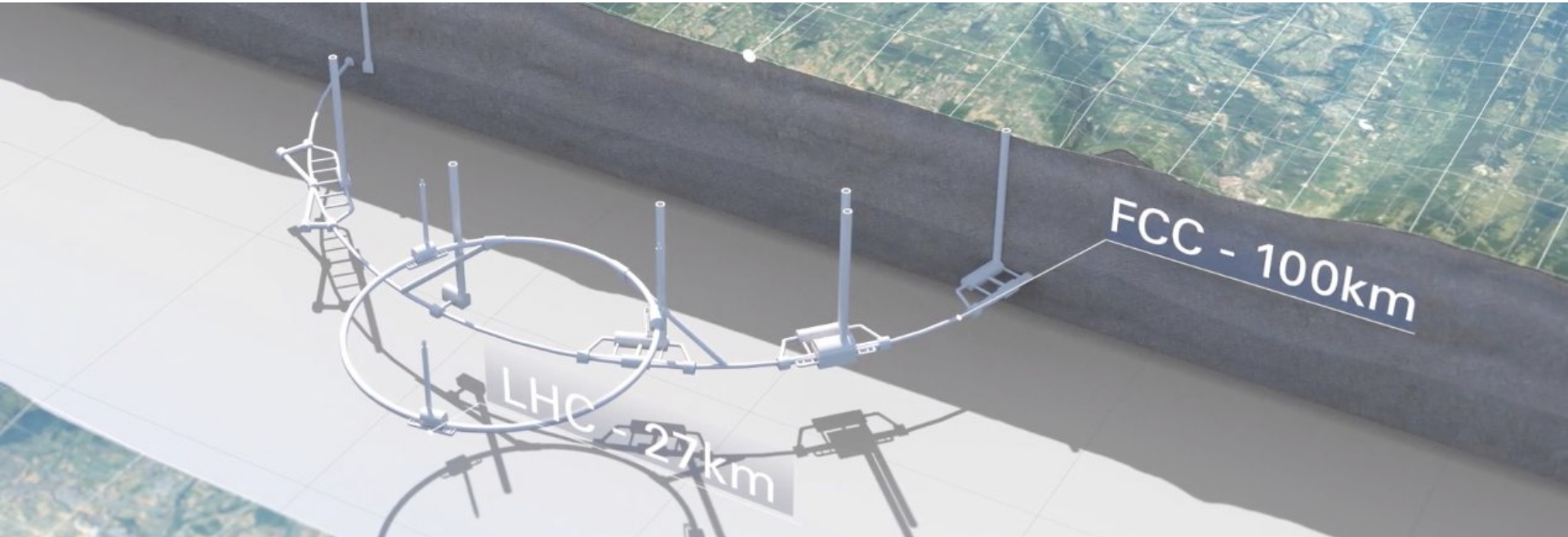
FCC-ee promises to be Higgs factory, electroweak & and top factory at highest luminosities.

- Report on feasibility study due in 2025

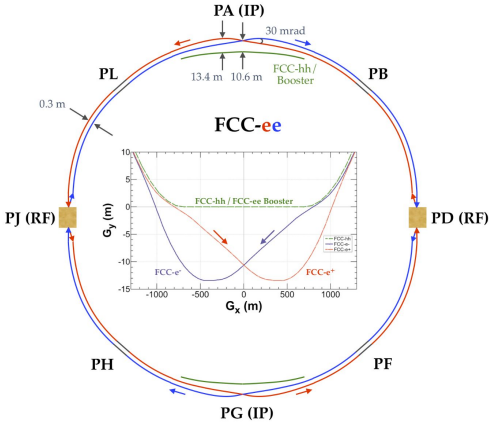
Requires

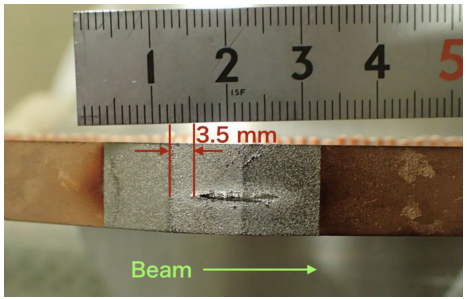
- **Extensive simulation campaigns**
- **Currently unavailable simulations for FCC-ee**

Overview talk on FCC:
M. Benedikt Thursday 10:50 Room A



Some key FCC-ee beam dynamics simulation challenges





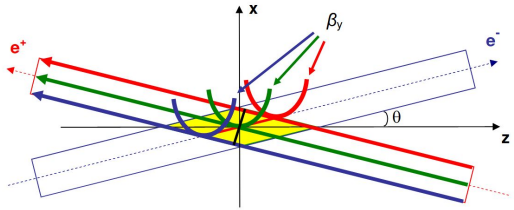
Damaged collimator in SuperKEKB, PRAB 23, 053501 (2020)

Optics
- Collision point optics optimization
- Linear & nonlinear optics corrections
- Dynamic aperture + off-momentum

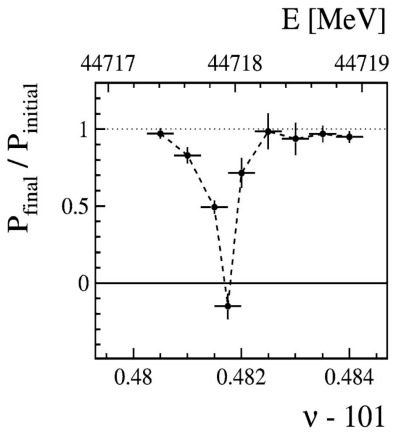
Beam-beam effect
- Control of instabilities
- Self-consistent optics & dynamic beta
- Crab-waist and beamstrahlung

Collimation
- Develop physical aperture model
- Particle-matter interaction simulations
- Model impedance from collimators

Spin dynamics
- Spin depolarization for energy meas.
- Correction of spin perturbations and resonances

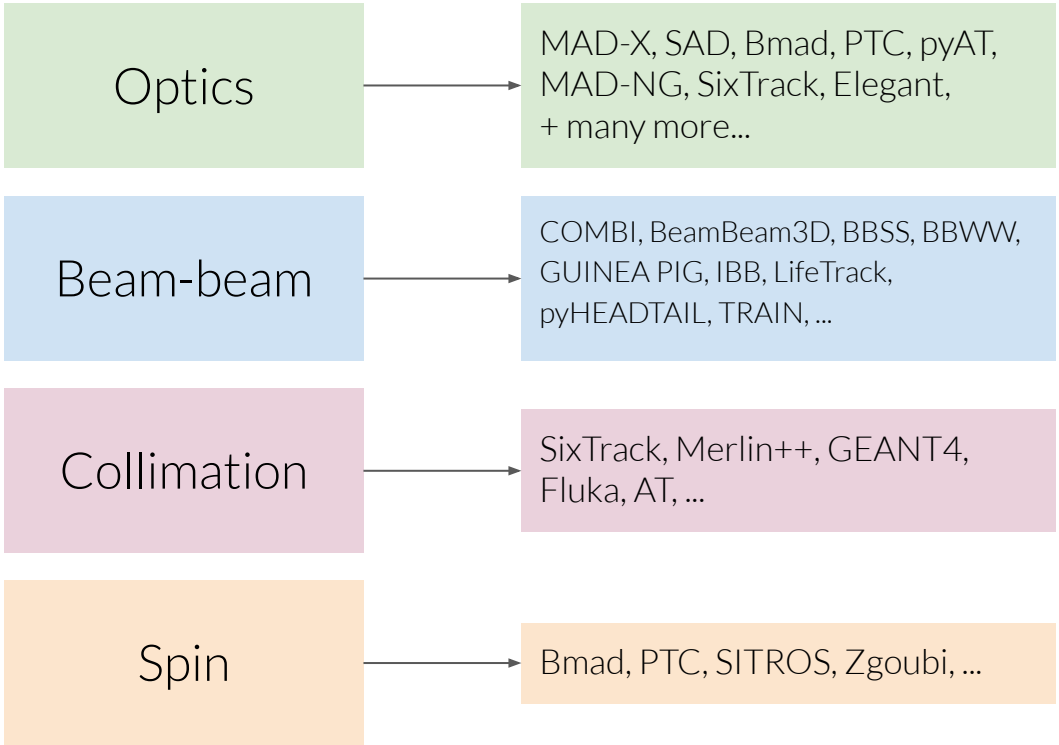


Crabbed waist scheme
https://arxiv.org/pdf/physics/0702033.pdf

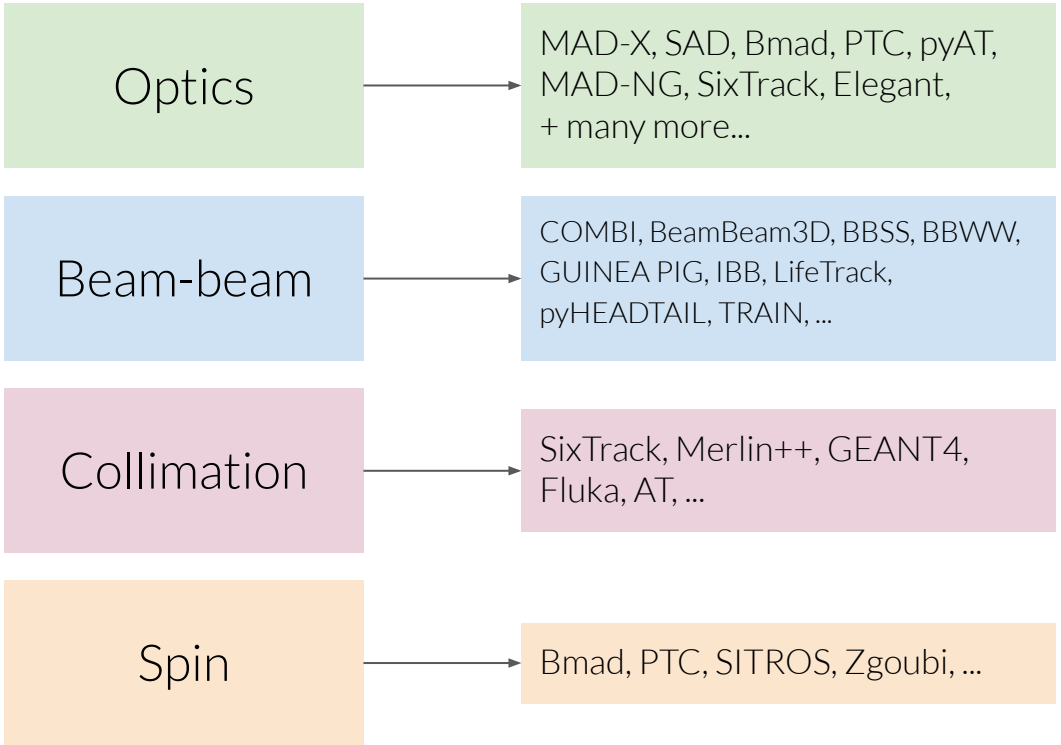


LEP depolarization for energy calibration
https://doi.org/10.1016/S1631-0705(02)01401-9

Many different simulation codes exist, each with specialized functionality



Many different simulation codes exist, each with specialized functionality



FCC-ee requires combinations of different codes for specific simulations

Not easy..

- Little to no mutual interface
- Different languages
- Different conventions
- Different philosophies
- Different maintainers and laboratories

A CHART funded project to address simulation challenges

Establish a modern and maintainable simulation framework to address key limitations for the FCC-ee

- Integrate and merge functionalities of different established simulation tools
- Develop new simulation modules to replace outdated legacy codes
- Perform key simulation campaigns with developed tools: beam-beam, spin dynamics, collimation...
- Collaboration between EPFL & CERN in synergy with current LHC based efforts at CERN.

CERN

EPFL

CHART

Swiss Accelerator Research and Technology

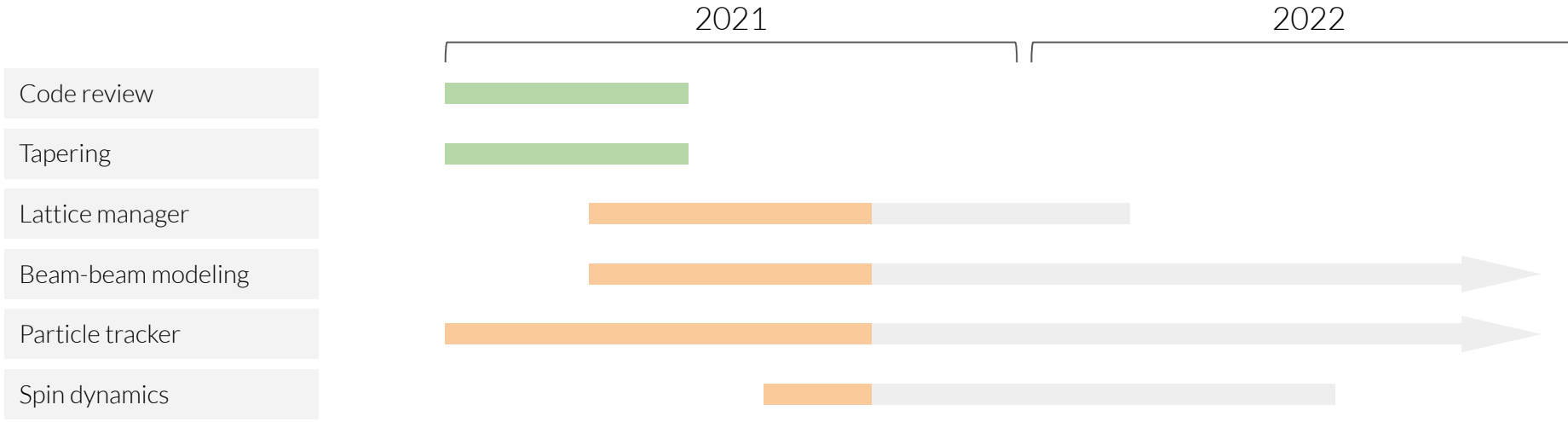
FUTURE CIRCULAR COLLIDER

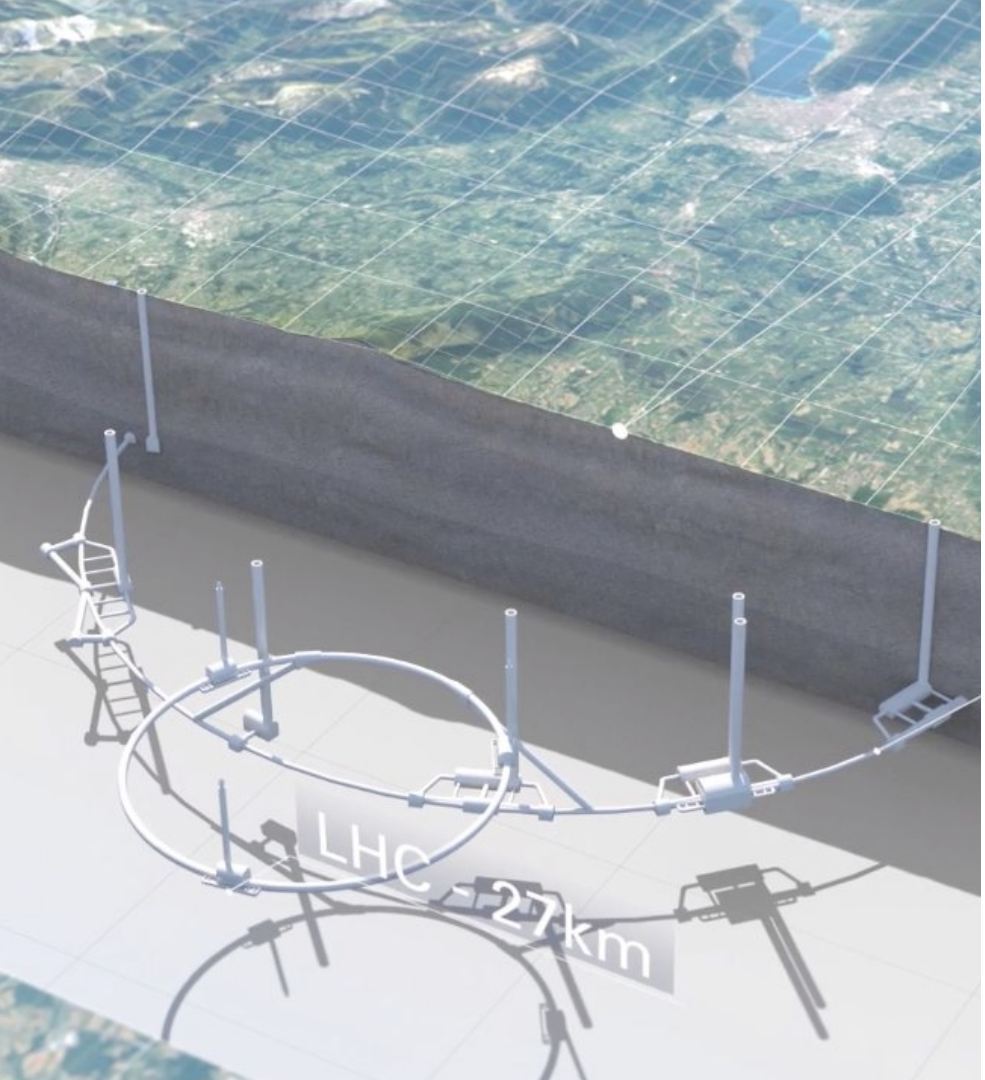
Specific objectives

Team: 1 PostDoc, 2 Ph.D. students, 1 MSc. student, and with potential to grow

Current developments focus on:

1. Updating codes to accept FCC-ee model → Tapering, solenoid modelling
2. Improving interface between codes for functionality merging → Lattice manager
3. Developing new simulation modules to gradually replace old codes → Beam-beam, tracker





Highlight some results of the first few months:

1. **Tapering**
2. Lattice manager
3. Beam-beam

Tapering was developed for Bmad and pyAT

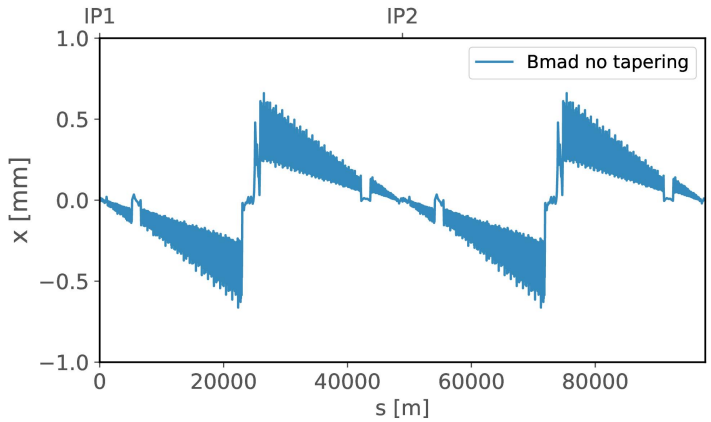
Loss of energy due to synchrotron radiation changes strength of:

Dipoles → Sawtooth orbit offsets throughout accelerator

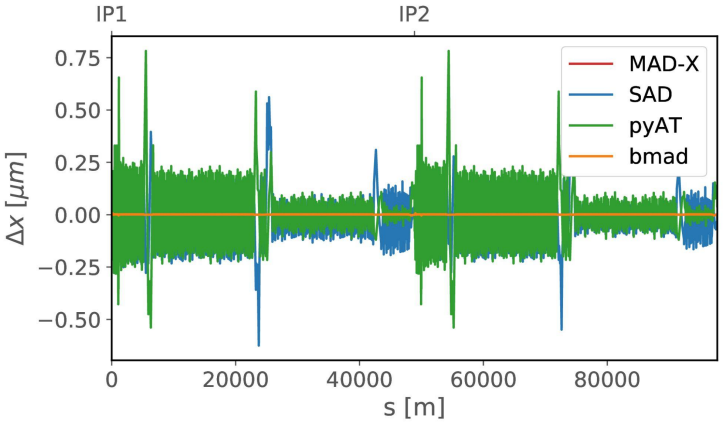
Other magnets → Perturbation of optics

Tapering scheme: Adjusting magnetic strengths to compensate for energy loss and retrieve reference orbit and optical functions

SAD comparison (L. van Riesen-Haupt)
https://indico.cern.ch/event/923801/
Bmad (F. Carlier)
https://indico.cern.ch/event/1018475/
pyAT (S. White, M. Rakic, F. Carlier)
https://indico.cern.ch/event/1018475/
F. Carlier
https://indico.cern.ch/event/995850/



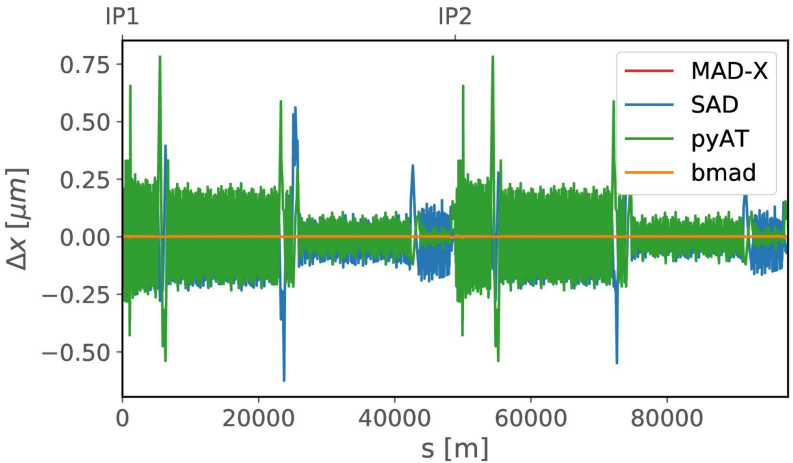
Tapering

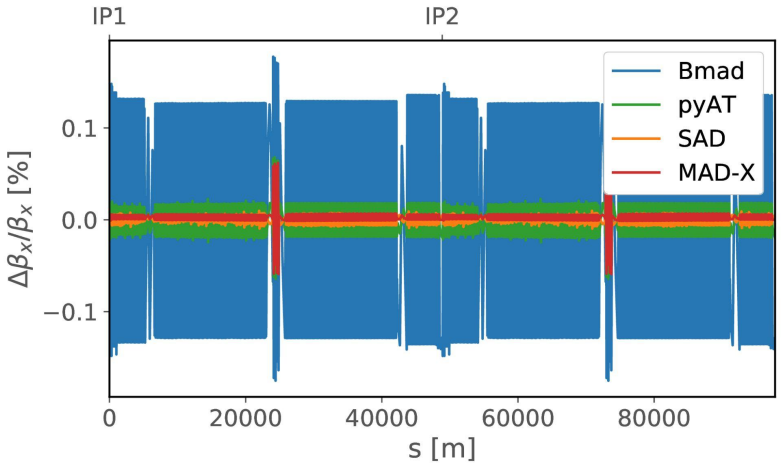


Now successful tapering schemes for multiple codes

New tapering schemes were developed for Bmad and pyAT increasing available codes for FCC-ee studies

- Good control of orbits < 1μm
- Good control of optics < 0.15 % of unperturbed optics

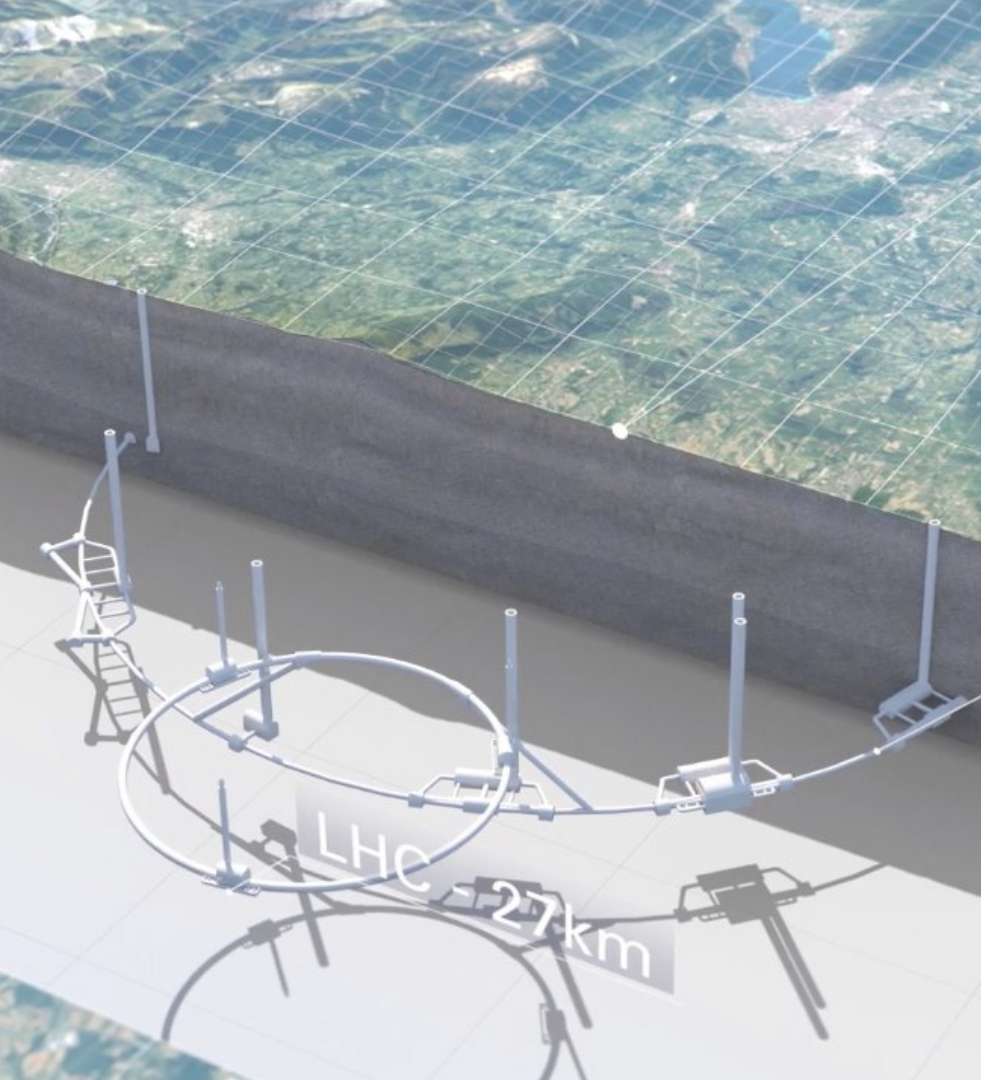




FCC-ee optics can now be modeled in: SAD (KEK), MAD-X (CERN), Bmad (Cornell), and pyAT (ESRF)

Sparked new studies for:

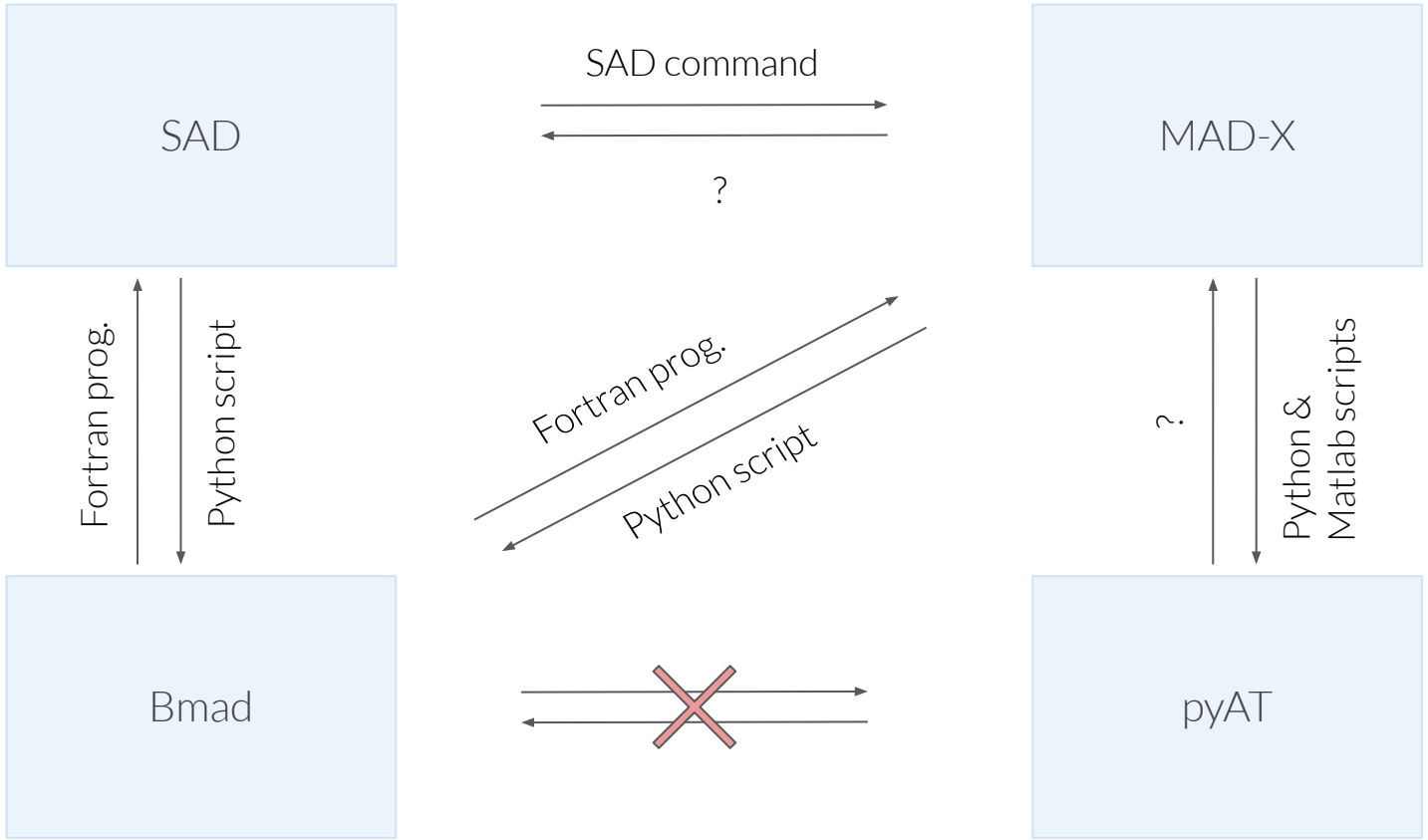
- Collimation using pyAT (A. Abramov CERN https://indico.cern.ch/event/995850/)
- Spin dynamics using Bmad (Y. Wu EPFL)



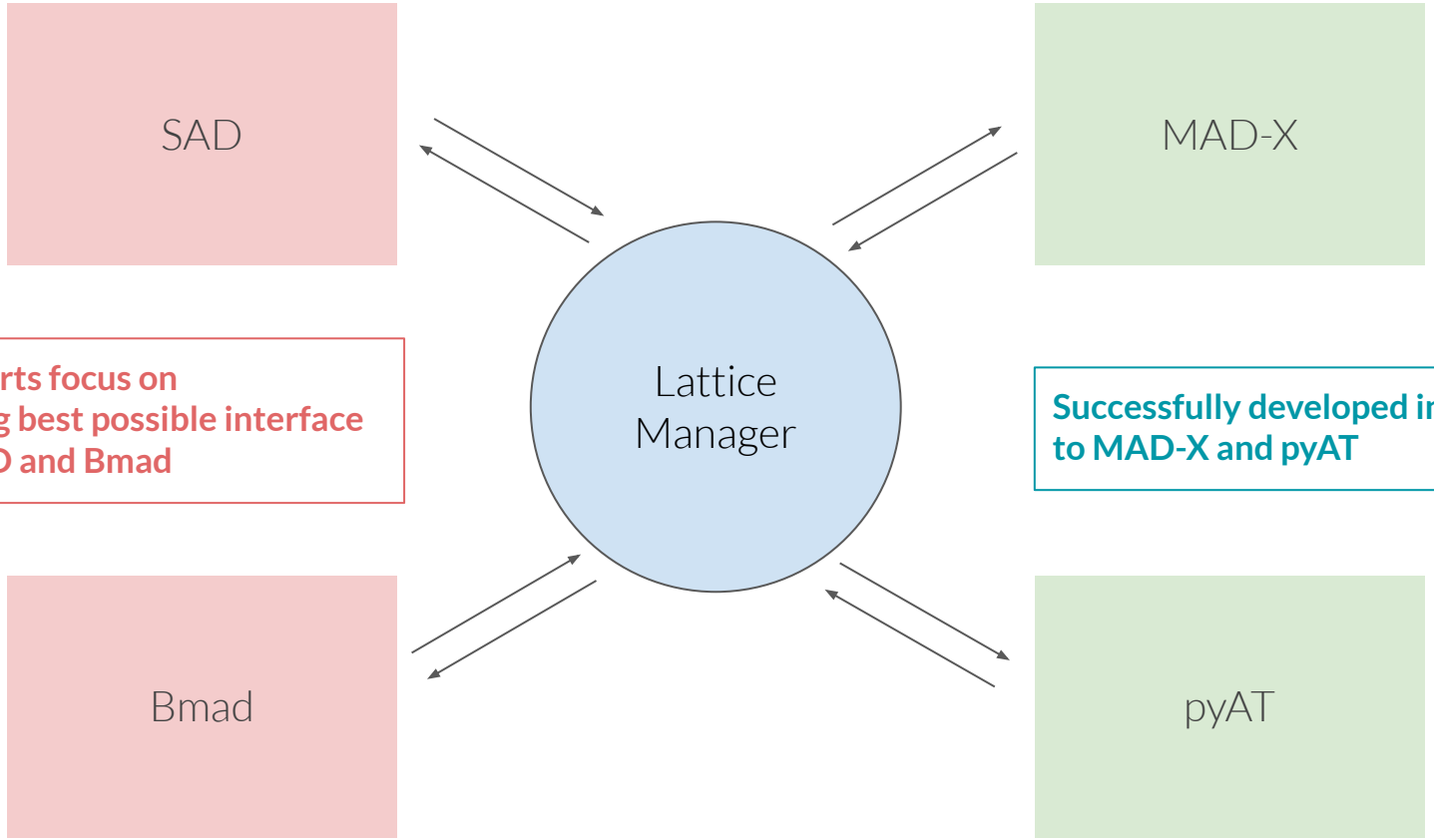
Highlight some results of the first few months:

1. Tapering
2. **Lattice manager**
3. Beam-beam

Bad interface between codes complicates simulations for FCC-ee



Centralized lattice manager in python for translation between codes



Current efforts focus on

1. **finding best possible interface to SAD and Bmad**

Successfully developed interface to MAD-X and pyAT

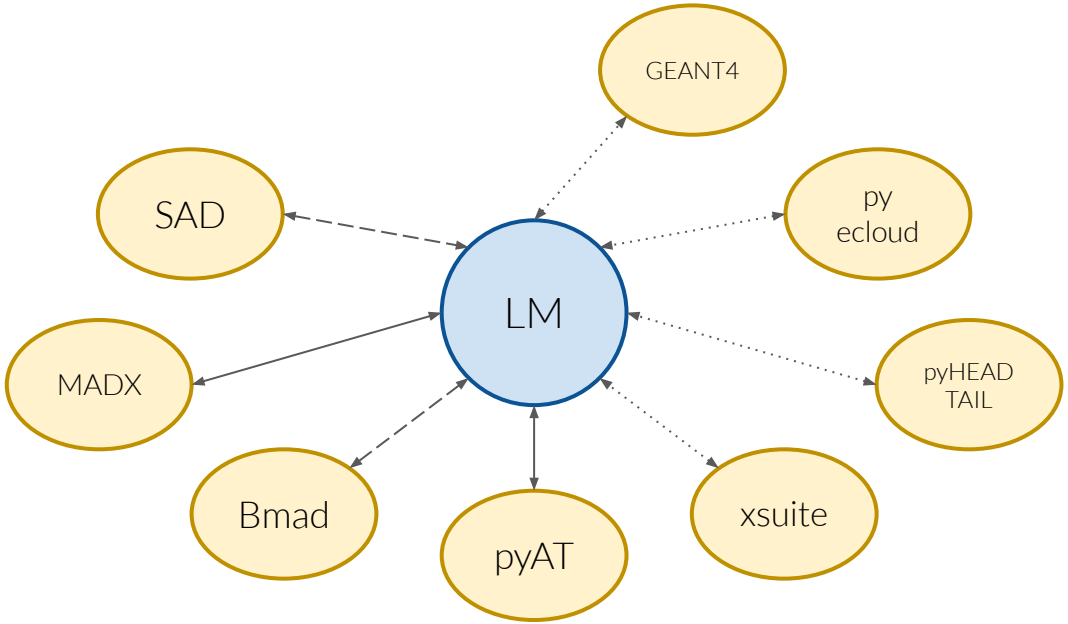
Future functionalities for lattice manager

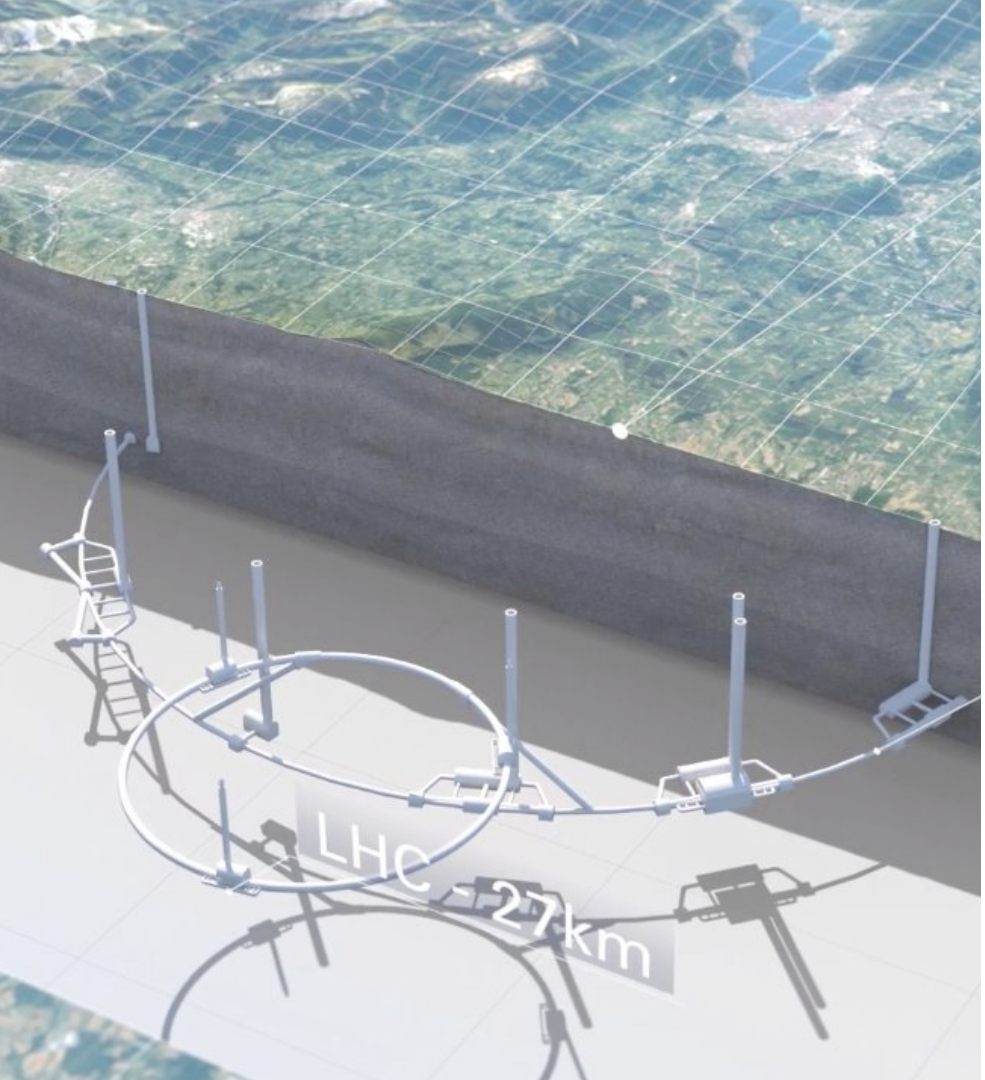
A stable centralized lattice manager

- ensures model consistency between different codes.
- allows alternative lattice exploration: thin/thick, alternative slicing, ..
- first step towards integration of previously separate codes

Merging functionalities can provide new simulations previously unavailable:

- Beam-beam with full machine description
- Spin dynamics with machine errors
- GPU particle tracking for DA and collimation





Highlight some results of the first few months:

1. Tapering
2. Lattice manager
3. **Beam-beam**

Beam-beam modelling for FCC-ee

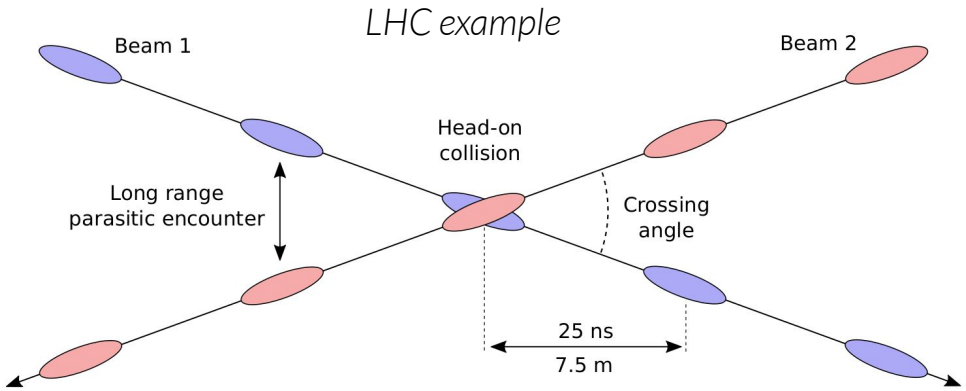
Beam-beam collisions cause large disruptive perturbations for particle dynamics

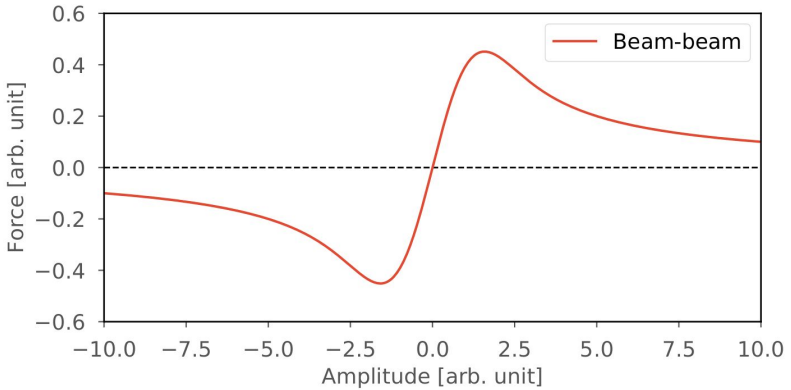
- Highly nonlinear periodic interaction

In e+e- colliders, the beam-beam effect is one of the most limiting factors to the collider performance!

Proper simulation of beam-beam effect is critical to the FCC-ee project

→ Requires new simulation tools



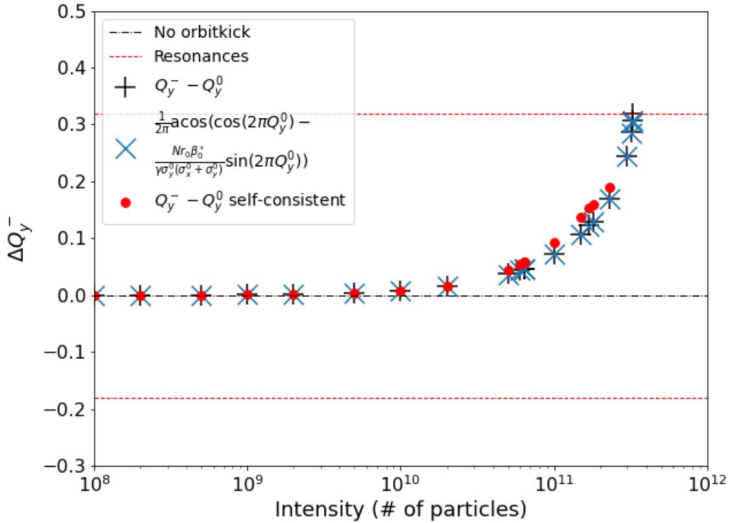


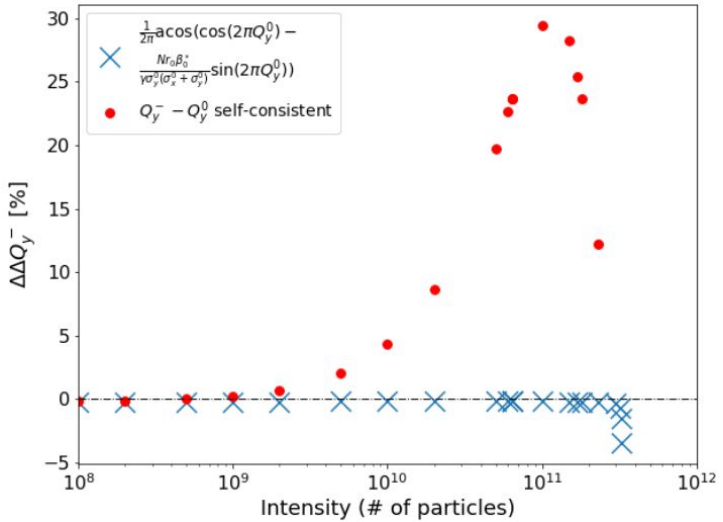
Self-consistent optics for FCC-ee (P. Kicsiny & X. Buffat)

First test of self-consistent optics for FCC-ee with 4D beam-beam lens in MAD-X using cpymad wrapper (P. Kicsiny https://indico.cern.ch/event/1022020/)

Self-consistent tune shifts and dynamic betas deviate from static models

- Motivates new developments of strong-strong beam-beam modeling for optics simulations





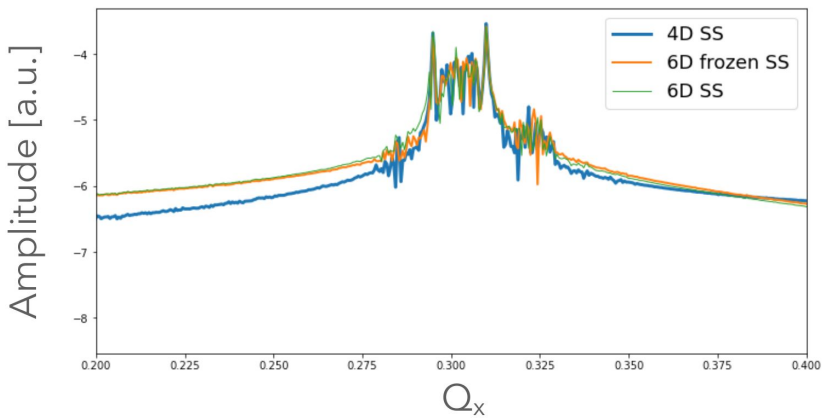
Beam-beam modelling for FCC-ee (P. Kicsiny & X. Buffat)

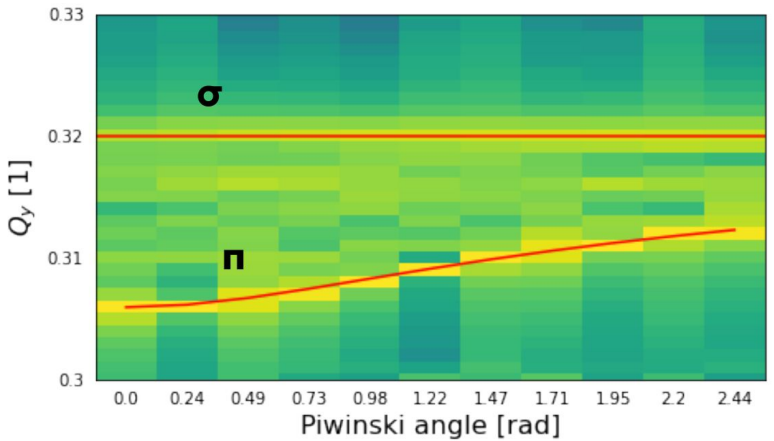
Goal of development campaign:

- Simulate dynamical effects with various levels of approximations for the beam-beam interaction, lattice and wakefields in a flexible manner

Using new 6D sliced beam-beam model together with newly developed particle tracker Xsuite

- First benchmarks performed with 6D BB approximation shows good reproduction of π and **σ** modes for test HL-LHC model.





Conclusions

Development a new simulation framework for the FCC-ee has successfully started

- Tapering schemes have been developed for Bmad and pyAT allowing new studies
  - collimation studies using pyAT
  - spin dynamics studies using Bmad
- First model translations between codes using centralized manager achieved.
- Beam-beam developments are a promising step towards new self-consistent framework

Developments also valuable beyond FCC-ee → lightsources, muon colliders..