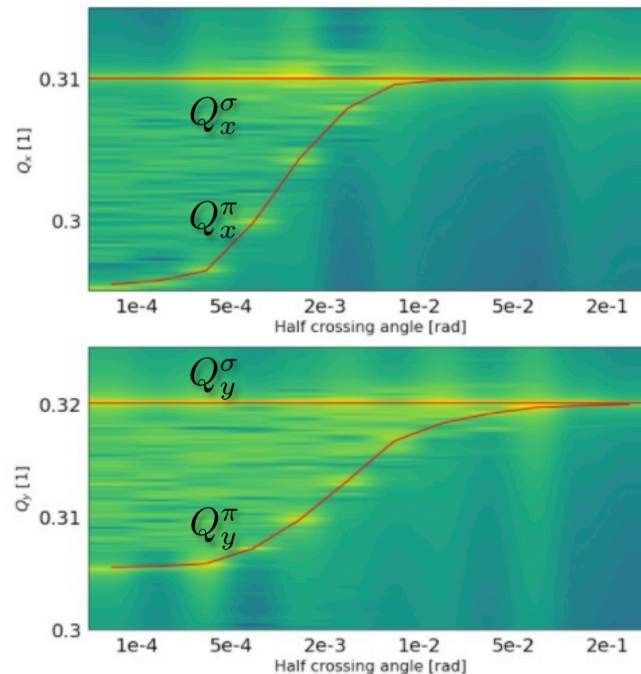


## Scientific Report of the project: FCC-ee Dynamics

Following the initial review period and developments of tapering schemes for Bmad and pyAT, work started on the development of a lattice manager to improve the interface between different simulation tools. The purpose of this lattice manager is to provide a central place where conversion tools between simulation codes can be implemented, as well as have a robust and flexible framework in Python to adapt FCC-ee lattices, assign errors and misalignments, and control the state of the lattice. This can greatly improve model creations and facilitate simulation campaigns on computing clusters, as well as ensure consistency of lattices between different codes in order to perform comparative studies.

A first working version of this framework, named 'xsequence', has been developed and presented. This framework contains several conversion codes to or from MAD-X, cypmad, pyAT, SAD and xline. It furthermore includes specific functionalities to adapt and adjust models for simulations. A robust workflow, including automatic tests of the code, has been implemented in Github to improve maintainability and provide a clear path for stable future developments. The developments have been coordinated with recent developments of the new simulation tools at CERN named 'xsuite', and strong synergies have been found to use the new simulation tools for improved FCC-ee modelling.



**Figure 1 COHERENT BEAM-BEAM MODES AS A FUNCTION OF THE HALF CROSSING ANGLE AT THE IP. SIMULATIONS RESULTS ARE PLOTTED VERSUS ANALYTICAL EXPECTATIONS (RED LINE)**

Secondly, following the developments of Bmad for the FCC-ee, a new project was

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started on using Bmad as a simulation code for the study of spin dynamics in the FCC-ee. A new MSc. student from EPFL (Y. Wu) started her specialisation project specifically on this topic, with the aim to develop perform the first simulations of spin polarization in the FCC-ee using Bmad. An initial period was dedicated to the study of the relevant spin dynamics theory, before moving on to the first simulations in Bmad. Work is now ongoing to probe different Z and W FCC-ee models including misalignments and errors to set tolerances on allowed orbit deviations. At a later stage, simulations of resonant depolarization for energy calibration can be envisaged for the FCC-ee as well. This latest work serves as an exploratory study to the polarization studies for the FCC-ee design.

The study on beam-beam effects have started with the hiring of a PHD student Peter Kicsiny in May 2021. The first phase of the study was dedicated to the study of the impact of the linearized beam-beam force and its impact on the beam orbit and optics. This study allowed for the learning of the basics of beam dynamics as well as the usage of MAD-X and its python interface cpyrad. The need for self-consistency in the modelling of the two beams was approached and an algorithm based on the code TRAIN was implemented within cpyrad. Preliminary benchmarks of the numerical model to analytical expectations have been carried out and have shown very good agreement. In Figure 1 the dependency of the coherent beam-beam modes versus the crossing angle is shown.

The main task has been the implementation of a soft-Gaussian strong-strong beam-beam simulation model and its extension to simulate Beamstrahlung. The model has been developed and optimized to an efficiency that is on par with other state of the art frameworks, such as COMBI. An initial parallelized version of the code using MPI has also been developed. Preliminary benchmark studies have been performed using COMBI (runtimes, tune spectra) and GUINEA-PIG (Beamstrahlung). Some limitations of the current implementation have been identified and are currently being addressed.

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## Presentations:

Status reports of the project activity have been presented at the dedicated EPFL-LPAP meetings ( <https://indico.cern.ch/category/9606/> ) and at the latest FCCIS workshop in December.

- FCC-ee Software Framework  
[https://indico.cern.ch/event/1085318/contributions/4582723/subcontributions/354655/attachments/2355534/4019941/FCCIS\\_workshop\\_FS\\_Carlier.pdf](https://indico.cern.ch/event/1085318/contributions/4582723/subcontributions/354655/attachments/2355534/4019941/FCCIS_workshop_FS_Carlier.pdf)
- Status of Collimation tracking code development  
<https://indico.cern.ch/event/1085318/contributions/4582724/subcontributions/357241/attachments/2356463/4021460/CollimationSimulations-FCCISWP2-20211201.pdf>
- 6D Beam-beam Modelling in Xsuite  
[https://indico.cern.ch/event/1085318/contributions/4582729/subcontributions/355430/attachments/2356471/4021479/pkicsiny\\_beambeam\\_6d.pdf](https://indico.cern.ch/event/1085318/contributions/4582729/subcontributions/355430/attachments/2356471/4021479/pkicsiny_beambeam_6d.pdf)
- Code developments  
<https://indico.cern.ch/event/1090005/contributions/4599697/attachments/2357406/4023531/CODE1.pdf>