Meeting Minutes of the
198th FCC-ee Accelerator Design Meeting
and 69th FCCIS WP2.2 Meeting

Indico: `https://indico.cern.ch/event/1480401/`
When: 27.11.2024 10:00-12:00 GVA time

Agenda

Presenter	Title
J. Keintzel	**Updates from the Optics Tuning Working Group**
D. d'Enterria	**Low center-of-mass FCC-ee Runs**
G. Roy	**Beam Crossings in Technical Insertions**

1 General information

F. Zimmermann opens the meeting. The minutes of the previous meeting are approved without any further comments.

F. Zimmermann welcomes **T. Mori** from KEK who will work for a year on beam dynamics after injection with beam-beam.

F. Zimmermann presents highlights of different events since the past meeting.

- **SAC meeting #8:** He reports on some discussion points including the choice of a baseline optics, the monochromatization optics, filling time from scratch (with the possibility to inject pre-polarized pilot bunches), 100 um initial quad-BPM alignment on the girder has been questioned.
  F. Zimmermann adds that with Beam-Based Alignment (BBA) one gets to 10-20μm perhaps it can be relaxed. **G. Roy** asks if one could check the alignment on the girder before taking it down in the tunnel. **C. Carli** comments that if the BPM is fixed to the quadrupole it could be done with very high precision in a lab.
  The a_4 tolerance in the sextupoles is a problem as powering the skew quadrupoles embedded in the sextupoles create a_4 beyond the tolerance. Error effects and beam-beam interactions on injection efficiency.
  X. Buffat comments that **P. Kicsiny** has studied the longitudinal injection efficiency including beam-beam interactions without showing any decrease in performance (without the lattice). It could be presented in a future meeting.

- **MDI Mini-workshop discussions:** Improvements to the Interaction Region design expected after the FSR document. Use of the LCC design including non-local compensation solenoid. Can the Tungsten shielding in the Final Focus quadrupole could be used as another chamber wall (*e.g.* vacuum, heat shield).

- **CERN-KEK committee meeting #19:** SuperKEKB status and collaboration proposal with one main topic on beam-beam interactions. KEK colleagues would be interested in having beam-beam simulations including the lattice, impedance and errors. Because they observe specific luminosity similar to beam-beam simulations including longitudinal impedance but no crab waist whereas they run with crab waist.
  F. Zimmermann wonders whether space charge and/or chromatic coupling could also explain a luminosity drop.
  SuperKEKB model of LER and HER in Xsuite including IR and solenoid, allowing optics, beam-beam, collimation, SR background and injection studies/contributions.
  F. Zimmermann points out that KEK colleagues have asked how to keep the Xsuite sequence up-to-date. **J. Salvesen** answers that the SAD-Xsuite converter is work in progress, SAD coupling to Xsuite to also have .

- **FSR:** contributions are coming in, four more weeks till Christmas. He points out to be careful with duplication of references if one write separate documents for the FSR.

- **Timeline for pre-TDR:** New collider baseline optics by early 2026; possibly LCC optics, it must have integrated collimation, RF, inj/extr insertion straights and potentially the non-local solenoid compensation. Milestones should be defined in 2025 to get there.
  M. Koratzinos suggests to include whether or not the Short Straight Section (SSS) should be cold or warm. **F. Zimmermann** agrees
  Should the CEA team be strengthen in view of the work needed for the booster optics.
  Explore polarized injector for pilot bunches, transfer lines with spin rotators, polarizer ring.

2 Updates on Optics Tuning Working Group

J. Keintzel presents an update on the Optics tuning working group, focusing on the ballistic optics, and bba.

She highlights the design of “GHC" ballistic optics, which switches off quadrupoles closer to the IP leading to reduced chromaticity and peak beta functions, decreased sextupole strengths, larger dynamic aperture (DA) for a perfect machine (without errors) compared to the nominal optics; while the MA is sufficient, it is not yet as good as the nominal optics. Halving the sextupole strengths. Mitigation of vertical emittance blow-up observed when sextupole strengths are halved in nominal optics.

A commissioning sequence has been developed beginning with the ballistic optics, followed by the relaxed optics, gradually decreasing the β^* step-by-step until reaching the nominal optics.

The DA of the ballistic optics with sextupoles off and nominal errors is sufficient after dispersion free steering to enable turning on sextupoles, and proceed to BBA and optics corrections.

J. Keintzel presents two techniques to perform Beam-based Alignment (BBA) achieving about 10-20 microns in arc quadrupoles. She also highlights that it is fundamental to measure and correct phase advances and coupling using AC dipoles.

The DA of the ballistic optics after BBA and optics corrections (with nominal errors, 50μm IR quadrupole misalignments, and 10μm BPM-to-quadrupole alignment accuracy) is close to the nominal DA, with 3 seeds out of 20 failing.

R. Tomás comments that in the FSR the misalignment and errors in the interaction region are left out, it will be worked on after the FSR. **J. Wenninger** asks where the IR starts and finishes because maintaining 50μm over a kilometer appears challenging compared to having this constraint only in the MDI region.

J. Keintzel highlights results from multipole tolerances which are very strict. Particularly the nested skew quadrupoles in the sextupoles causes a a_4 of about 65 units which exceeds the limit of 30 units. Independent skew quadrupoles may be required. First results of the implementation of chromaticity correction and beam-beam interactions slightly relaxed the multipole tolerances.

M. Koratzinos raises concern on how to achieve dipoles with such multipole constraints, it will be very expensive. **J. Keintzel** answers that corrections are not implemented yet and improvements are expected.

She presents sextupole optimization in Xsuite with the objective to optimize the momentum acceptance giving encouraging results. The polarization with off Z-pole scan, some seeds appear beyond the 100 keV systematic errors even with optimistic errors (20-50μm in the arcs and 10μm in the IR).

J. Wenninger comments that a strong correlation seems to be present meaning the accuracy on the Z-mass might be affected but not on the Z-width. **F. Zimmermann** asks if **Y. Wu** uses E. Musa lattice with errors and corrections. **J. Keintzel** answers that she most likely does not and **F. Zimmermann** suggests that she should use one of these lattices. **K. Oide** ask why there is a horizontal spread for each reference energy, is it for visibility reason. **J. Keintzel** confirms that it is for readability reasons.

3 Lower Center-of-mass FCC-ee Runs

D. d'Enterria outlines the scientific potential and feasibility of special low-energy runs in the FCC-ee for precise QCD studies, building on the limited datasets currently available from B-factories and LEP-I. Two approaches were proposed to obtain hadronic data at low center-of-mass (c.o.m.) energies:

- **Fixed c.o.m. Energy Runs:** Operation in the 40 to 80 GeV range, with approximately 1 month per energy point based on initial luminosity scaling to obtain 10^9 events. A beam energy precision within 100 MeV should be sufficient, less stringent as for Z-pole operation.
- **ISR (Initial State Radiation) Event Analysis:** Leverage high integrated luminosity Z-pole runs data collection. Estimate if a several billion ISR events over 20 to 80 GeV range, scaling from LEP experience.

M. Koratzinos questions if ISR events "come for free" and notes that the energy precision can not reach 100 MeV. **D. d'Enterria** clarifies that ISR offers high statistics (*e.g.* billions of events at 30-50 GeV) but lacks the fine granularity of fixed c.o.m. runs.

K. Oide identifies challenges with beam dynamics; maintaining a constant beam current (equivalent to the Z-pole) is difficult due to instabilities arising from running at lower beam energy (than Z-pole). **K. Oide** also points out that the emittance and damping times will increase with smaller beam energy degrading luminosity. **F. Zimmermann** suggests to change the optics to which **K. Oide** answers that it is very difficult to modify the optics to compensate for the emittance increase. **J. Wenninger** proposes to assume that the beam parameters evolve with the beam energy and analyze the resulting luminosity. **F. Zimmermann** proposes to specifically look at one energy and define beam parameters. It is agreed that beam parameters and luminosity for 40 and 60 GeV center-of-mass energies should be given as inputs.

A. Verbytskyi asks about the time required to run at the different beam energy. **J. Wenninger** answers that it depends how often one changes the beam energy, with experience it will become faster. **K. Oide** adds that changing between calibration runs could take about a day, however for luminosity run it could take a week to a month. **J. Wennigner** mentions that from LEP experience, it was one to two weeks to change the beam energy for luminosity runs.

A. Verbytskyi asks if less precision in energy helps from the machine point of view. **J. Wenninger** answers that one can remove the polarization of pilot bunches.

4 Beam Crossing in Technical insertions

G. Roy presents initial results on parasitic interactions in beam crossings of the FCC-ee technical insertions, detailing challenges and a mitigation strategy.

He recalls that beam crossings in the technical insertions transition from outside to inside to ensure that at the four experimental IPs (A, D, G, J), the beams cross from inside to outside. A 1.6 mrad full crossing angle) is considered to limit the synchrotron radiation power and accommodate tunnel dimensions. Common crossing schemes are planned for points B, F and L, with a different crossing scheme at ZH and ttbar in point H (collider RF location) due to the use of electromagnetic separator elements.

The high number of bunches at Z and W operation modes results in long-range beam-beam encounters and interactions in the crossing regions of the technical insertions. These long-range beam-beam interactions cause a change of the beam orbits, bunch-by-bunch orbit spread (PACMAN effect) due to the bunch train structure featuring gaps, (some bunches are missing parasitic encounters). The horizontal orbit spread is in the order of the beam size, which is significant, requiring mitigation.

G. Roy presents a solution based on a vertical bump of 350µrad providing a 70 mm vertical separation, accommodating two separate beam pipe radius to suppress long-range interactions.

with a small effect on the vertical emittance (4.3 fm.rad vertical emittance growth). The effect on the polarization is expected to be very small as it is a closed bump, but will need to be confirmed.

C. Carli asks about the length of the vertical bump. **G. Roy** replies that most of the available drift is used. He also wonders if the vertical bump is compatible with the transition from Z to ZH operation modes.

M. Koratzinos wonders if keeping a single beam pipe with adding a vertical separation is possible. **X. Buffat** answers that a shared beam pipe with vertical separation could cause stronger perturbations of the orbit. **K. Oide** highlights the benefit of separate beam pipes, as the impedance associated with merging pipes is suppressed. He also points out that chicanes will be needed to adjust the pathlength from IP and this vertical bump could be used as such.

36 Participants:
K. André, M. Boscolo, G. Broggi, Q. Bruant, X. Buffat, H. Burkhardt, C. Carli, B. Dalena, D. Domange, D. d'Enterria, A. Ghribi, C. Goffing, G. Iadarola, I. Karpov, J. Keintzel, P. Kicsiny, R. Kieffer, M. Koratzinos, S. Liuzzo, L. Mether, T. Mori, G. Nigrelli, A. Novokhatski, K. Oide, F. Poirier, G. Roy, L. Sabato, J. Salvesen, K. Skoufaris, R. Soos, R. Tomás, L. van Riesen-Haupt, A. Verbytskyi, J. Wenninger, S. Yue, and F. Zimmermann