Meeting Minutes of the
194th FCC-ee Accelerator Design Meeting
and 65th FCCIS WP2.2 Meeting

Indico: https://indico.cern.ch/event/1468042/
When: 17.10.2024 11:00-12:30 GVA time

Agenda

Presenter	Title
S. Yue	**Top-up Injection in the Collider**
L. Sabato	**E-cloud Studies in the Collider**
K. Cantun	**E-cloud Studies in the Booster**

1 General information

K. André opens the meeting. The minutes of the previous meeting are approved without any further comments.

I. Karpov comments on the estimation of the figure of merit for polarization, emphasizing that the calculations should use the parameters of the pilot bunches, which do not experience beam-beam interactions. This implies that $\nu_s \sigma_\delta / Q_s$ would likely be smaller than the value presented in the last meeting. He suggests that this adjustment should be confirmed in the future.

2 Top-up Injection in the Collider

S. Yue presents the baseline top-up injection scheme for the feasibility study report, featuring an on-axis conventional injection scheme. This method, requires a septum gap between injected and circulating beams opened by dispersion and momentum offset, requiring sufficient Momentum Acceptance (MA).

Initially, the goal was to have a 1% energy offset for on-axis injection. However, integrating the injection optics in the collider layout reduces the MA, leading to the adoption of a hybrid injection scheme, which combines both off-energy and off-axis injection. Ongoing discussions with **K. Oide** aim to improve the MA including the injection optics but also to study the solution preserving super-periodicity presented in the last meeting.

With the hybrid scheme the horizontal offset is defined as $\Delta x_{\text{offset}} = 5\sigma_{cir} + S + 5\sigma_{inj} - |D_x \delta|$. The injection efficiency is modelled to be above 95% without machine errors or collective effects considered. The W-mode is the most challenging due to the larger beam size caused by the larger horizontal emittance, which demands an increased betatron injection offset. Still 80% injection efficiency is used for the sizing of he injector complex.

For the hardware system, a thin magnetic septum and lumped inductance kicker are considered. A reduction from 1100 ns to 600 ns of the kicker rise/fall time is currently being investigated.

It is proposed to resume the discussion withing the top-up injection working group regarding: the Multipole Kicker Injection (MKI), the implementation of collective effects, synchrotron radiation and machine errors into the simulations, as well as to discuss injection/machine protection systems.

Regarding the collider dump, vertical dispersion is used to increased the beam size at the location of the dump. Optics optimization aims to maximize the beam size, reduce the energy density at the dump, and minimise the influence of kicker ripples with a phase advance close to π. While up to 20% kicker ripple seems acceptable as well as the loss of one module, failure cases and mitigation methods remain to be studied.

Y. Dutheil mentions that kicker rise/fall time of 600 ns is being studied. **K. Oide** wonders if an even shorter rise/fall time is feasible and what the limitations are. **Y. Dutheil** responds that it depends on the cost and complexity one is willing to invest, as these factors define the generators, number of kickers, and their locations with respect to the collider tunnel (*e.g.* alcove).

C. Carli comments that having an horizontal offset at injection is not ideal to minimize backgrounds in the experiments. **Y. Dutheil** agrees and highlights the need to restart the discussions within the injection working group.

C. Carli and **Y. Dutheil** discuss the need for the injection bump to be closed within one turn to prevent the newly injected beam (with an energy offset) from hitting the back of the septum. Further details regarding the implementation of the bunch pattern filling scheme still need to be addressed.

3 E-Cloud Studies in the Collider

L. Sabato presents the status of the e-cloud studies for the FCC-ee collider, focusing on the challenges posed by secondary electron yield (SEY) multipacting thresholds. He provides material constraints to avoid e-cloud avalanche multiplication, especially for operations at the Z-pole mode, where beam parameters impose tight SEY limits around 1

Quadrupoles and sextupoles have the lowest SEY multipacting thresholds, independent of the filling scheme (20 or 25 ns bunch spacing), particularly for bunch intensities of 1.0×10^{11} and 1.5×10^{11} ppb which are the most critical.

He introduces mitigation strategies to relax the tight constraints on the SEY multipacting thresholds.

- **Increasing the bunch spacing:** A spacing up to 50 ns could raise the SEY multipacting threshold to 1.3, though it could lead to issues with other collective effects, as increasing the bunch spacing requires boosting the bunch population to maintain the same beam current.
- **Special filling schemes during the accumulation phase:** These could lower the SEY multipacting threshold for the critical bunch intensities. Nevertheless, the SEY thresholds for the quadrupoles and sextupoles remain about 1.1. Furthermore, he adds that colliding bunches should have a charge asymmetry no greater than 5% to prevent the flip-flop mechanism, as observed by **P. Kicsiny** in this paper.
- **Non-uniform bunch spacing:** Schemes with empty bunches to reduce the e-cloud build-up have been considered (similar to the LHC approach). The most effective results in the dipole elements are obtained with 5 ns bunch spacing and 8 empty bunches every 2 bunches. Still, he notes that the bunch spacing might be too short as two consecutive bunches could be simultaneously inside the common beam pipe of the interaction region. Further studies are ongoing for the other elements such as drift spaces, quadrupoles and sextupoles.

Preliminary results suggest that nested magnets (combining dipolar, quadrupolar and sextupolar magnetic fields) have a lower SEY multipacting thresholds than dipole magnets. More studies are needed to understand the influence of the magnetic field polarity and magnitude in these magnets on the e-cloud build-up.

M. Koratzinos and **K. Oide** note a discrepancy between **P. Kicsiny**'s results and those of **D. Shatilov** concerning the beam-beam flip-flop. In **D. Shatilov**'s studies, luminosity could not be recovered when charge asymmetry exceeded 5%. **P. Kicsiny** responds that the luminosity can be recovered by injecting particles to balance the bunch charge. **C. Carli** adds that the bunch lifetime decreases as the charge imbalance increases, so one should eventually observes more than say 5% charge imbalance.

K. Oide asks if a special coating for the quadrupoles could be considered to manage with the lower SEY multipacting threshold present in these elements. **L. Mether** answers that it needs to be discussed with the vacuum experts.

C. Carli asks if a dependence with the bunch length is observed. **L. Sabato** answers that there is no strong dependence of the SEY threshold on the bunch length. **I. Karpov** wonders if also the lower bunch population studies considered a bunch length of 15.5 mm. **L. Sabato** confirms this.

M. Zobov remarks that having two consecutive bunches in the common beam pipe aperture of the interaction region with the 5 ns bunch spacing is not an issue, based on past collider experience.

I. Karpov notes that the RF frequency should be checked to ensure that all necessary bunch spacings are available in any proposed scheme.

4 E-cloud Studies in the Booster

K. Cantun presents the results of the e-cloud studies in the FCC-ee booster for positron injection and extraction scenarios. The studies did not consider the effects of photo-electrons.

At extraction energy a SEY multipacting below 1.5 is observed for a bunch spacing of 25 ns, with the quadrupole and sextupole showing the smallest thresholds, similarly to what is observed in the collider. The SEY multipacting threshold decreases with decreasing bunch spacing.

She notes that the SEY multipacting thresholds are comparable between the two injection options (from a high-energy damping ring or a linac). The constraints at the injection energy are weaker than at the extraction energy. A SEY above 1.7 should be sufficient with a bunch spacing of 25 ns. Therefore, the extraction energy in the booster seems to be the most critical configuration for e-cloud build-up. Considering a 60 mm diameter copper beam pipe, **K. Cantun** wonders if the presented SEY can be achieved without NEG-coating.

B. Dalena asks why positrons are the focus in this study. **K. Cantun** answers that she expected more e-cloud build-up from a beam of positrons. **B. Dalena** observes that the required SEY in the booster is higher than the one needed in the collider. **L. Sabato** confirms this observation also because the bunch population is smaller in the booster.

L. Mether comments that scrubbing will likely be needed in the booster if NEG-coating is not an option. She adds that photoelectrons should be studied, as there are no absorbers in the booster to handle the photons.

Y. Dutheil asks whether for the Z-pole mode 11200 bunches are considered because it should be only 1120 bunches at once, besides certain filling schemes might lead to a higher SEY multipacting threshold. **L. Mether** answers that the study assumed a worst case scenario.

Y. Dutheil wonders if e-cloud is a concern in the injection section. **L. Mether** responds that while e-cloud poses issues for vacuum reasons, the main concern for beam dynamics would be in regions with large beta functions, such as the interaction region quadrupoles.

41 Participants:
M. Ady, M. Aiba, K. André, W. Bartmann, M. Boscolo, C. Bracco, G. Broggi, K. Cantun, C. Carli, A. Ciarma, B. Dalena, H. Damerau, D. Domange, Y. Dutheil, A. Frasca, C. Garcia, V. Gawas, A. Ghribi, C. Goffing, C. Hernalsteens, S. Jagabathuni, P. Janot, I. Karpov, J. Keintzel, R. Kersevan, P. Kicsiny, M. Koratzinos, A. Lechner, G. Lerner, S. Liuzzo, L. Mether, G. Nigrelli, K. Oide, T. Pieloni, L. Sabato, J. Salvesen, K. Skoufaris, S. Yue, C. Zannini, F. Zimmermann, and M. Zobov