Meeting Minutes of the
187th FCC-ee Accelerator Design Meeting
and 58th FCCIS WP2.2 Meeting
joint with Accelerator Technical Design Committee

Indico: `https://indico.cern.ch/event/1427822/`
When: 27.06.2024 15:00-17:00 GVA time

Agenda

Presenter	Title
J. Wenninger	**Considerations on alignment and vibrations for FCC-ee**
J. Keintzel	**Introduction to polarimetry discussion**
R. Kieffer	**Polarimeter and related civil engineering**
S. White	**Update on dynamic aperture optimization for the LCC lattice**

1 General information

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

First meeting joint with Accelerator Technical Design Committee (ATDC).

2 Considerations on alignment and vibrations for FCC-ee

J. Wenninger presents the considerations on alignment and vibrations for FCC-ee based on past experiences from LEP and LHC. He begins with ground motion highlighting that the LHC tunnel at an average depth of 100 m does not experience machine technical noise. At 1 Hz, the vertical amplitude is about 1 nm. He suggests that the much deeper FCC tunnel should perform at least equivalently. From the LHC tunnel data, the integrated noise can be assumed to be about 10 nm for frequency above 1 Hz.

LEP was performing yearly vertical re-alignment from 1993 to 1999 summarized in the CLIC note 422. Typical movements were around 0.1 mm/year, with peaks up to 0.3-1 mm/year in some areas, particularly near newly excavated regions. To avoid more than one major re-alignment per year, FCC-ee should tolerate movements of 0.1 mm/year in addition to the initial alignment tolerance which one could aim at 150 µm for the arcs and less critical straight sections, and a “special treatment” for the low-beta insertions. From the experience with the low-beta triplets at LHC, cryostat movements over one year ranged from 0.05 to 0.1 mm, generally due to magnet quenches.

He also analyses the alignment procedure planned for CEPC, described in their TDR which target an initial alignment of 100 µm. This involves three steps: pre-alignment of components on the girder by 16 teams over about six years; initial alignment of components in the tunnel during installation by 16 teams over about two years; and iterative survey and re-alignment around a smooth line by 64 teams, assuming 2-3 iterations but without a time estimate provided.

J. Wenninger notes that no permanent monitoring of the component alignment is foreseen for cost reasons, and a yearly re-alignment is planned during 3-4 months of shutdown.

He then highlights the effect of vibrations on the beam and performance. Lower frequency movements (<1 Hz) movements can be efficiently damped by a beam orbit feedback. At medium frequencies, it might be too high frequencies for feedback and is impacted by the girder design (damper and mechanical resonances). At higher frequencies (>10 Hz) movements can be tolerated. Separating the requirements for the low-beta insertions (not covered) from the rest of the ring, he notes that light sources achieve orbit feedback bandwidth greater than 100 Hz but with a revolution frequency of the order of megahertz, compared to kilohertz revolution frequency of FCC-ee. LHC uses a central architecture for the orbit feedback system with a typical collection time below 5 ms, which could be faster.

T. Lefevre comments that the latency between signals could be an issue for FCC-ee. **J. Wenninger** answers that the network latency will not be the issue but the latency from the read-out might be, especially given the challenge of having enough measurements with a small number of bunches during H and $t\bar{t}$ operation modes.

FCC-ee should aim for an orbit feedback bandwidth superior to few Hertz and an orbit acquisition greater than 100 Hz. This solution should be checked by the beam instrumentation group, particularly in case of a low number of bunches. The requirements for the kick change rates should be established as it will impact the design of power converters and magnets.

Vibrations above 1 Hz, should not be an issue in the horizontal plane whereas the movements would approach 5% of the beam size (excluding low-beta regions) in the vertical plane. Additionally, the mechanical resonances of the girder need careful attention, as they can amplify ground motion onto the beam by up to two orders of magnitude. At LHC, the mechanical resonances of the quadrupole assembly is clearly visible with peaks 5-10 times larger than the rest of the spectrum.

Distant earthquake have a frequency spectrum in the millihertz range, whereas local seismic events will extend to 100 Hz. Earthquake of magnitude beyond 7 anywhere on the planet are visible mainly from radial oscillations due to pressure waves with an equivalent peak-to-peak $dp/p \simeq 10^{-4}$ at LHC and should be greater than 10^{-3} for FCC-ee. Local earthquake of magnitude above 4 are visible on the LHC BPM system but does not stop LHC operation, raising the question of FCC-ee's response.

F. Carra wonders if the booster will have the same constraints. **J. Wenninger** answers that the booster beam will not be colliding, therefore it should be much more relaxed compared to the collider.

T. Lefevre suggests converging on a pre-alignment target for the arcs, alignment on the girder, and girder-to-girder, which would also be important for the arc mock-up design. **R. Tomás** responds that all elements on a girder are assumed to be aligned to 50 µm, with Beam-Based Alignment (BBA) performed from this assumption.

F. Zimmermann comments that the alignment of the BPM could perhaps be relaxed. **J-P. Burnet** adds that in light sources, BPMs are on a support to have a precise knowledge of their positions. **T. Lefevre** comments that this concept would require additional bellows. CLIC has a design with BPM solidly attached to the quadrupole. Moreover, the signal from the BPM will be digitized locally (due to the radiation level), and the temperature surrounding the equipment must be very well controlled to achieve the expected precision.

T. Lefevre asks if an orbit feedback is expected in the booster. **J. Wenninger** answers that the machine will be ramping, it might be necessary. **Y. Dutheil** adds that a damper (transverse feedback) is needed for injection to damp the beam centroid due to jitter from the linac.

3 Introduction to polarimeter discussion

J. Keintzel introduces the polarimeter requirements, detailing the operational scenario: few hundred (1̃60) non-colliding pilot bunches polarized via wigglers to achieve up to 5-10% vertical polarization at Z and WW energies.

An alternative scheme is also under consideration where the bunches are polarized in the injector chain, with studies showing that 92%, 60% and 10% of the polarization could be preserved during the energy ramp for Z, WW and ZH energies, respectively.

The main requirements for the polarimeter are:

- **Baseline method:** Resonant DePolarization (RDP), which measures the average beam energy of pilot bunches. This method is independent of the polarimeter's location in the lattice.
- **Residual polarization:** Residual polarization could spoil physics experiments, so the polarization of physics bunches should be monitored down to 10^{-5} accuracy.
- **Energy stages:** The polarimeter should be available at all energy stages, because Z-calibration runs are expected even during $t\bar{t}$-mode operations.
- **Accessibility:** At least one polarimeter per beam with continuous laser accessibility is essential. Redundancy could be necessary to mitigate laser/detector down-time.

4 Polarimeter and related civil engineering

R. Kieffer presents the FCC-ee Compton polarimeter that would be used for center-of-mass energy calibration with resonant depolarization scans on pilot bunches, direct energy measurement by Compton electrons pattern position, precise 3D polarization measurement on physics bunches and free spin precession although this is considered challenging.

The polarimeter implementation requires a dedicated powerful laser, a custom vacuum chamber for laser-Compton interaction, a spectrometer magnet equipped with Hall sensors for precise magnetic field measurement, a Compton electron/photon extraction line, particle sensors like silicon pixel detectors, and RF kickers to apply resonant depolarization.

In the baseline scenario with one polarimeter per beam is placed at IP A. The instrument is located at the end of the Long Straight Section (LSS), using the dipole "BL1" as a spectrometer. There is 75-meter drift to separate the Compton electrons/photons from the main beam. The laser room needs a 24/7 access, dedicated laser hutch, and access tunnels, situated near the laser interaction point (5̃0 m max) with minimal mirrors and viewports to maintain highest laser circular polarization. The average beam energy is inferred from a single measurement point. A key point highlighted is the accuracy of the polarization measurement is directly linked to the precision of the circular laser polarization.

An alternative scenario is under study, where the polarimeter would be placed at point L, where the booster RF insertion is located but does not have a special function for the collider. This option may require adaptations of the collider beam optics, beamline transverse separation, and tunnel width to fit the polarimeter equipements. The laser hutch would be located in the klystron gallery above the collider tunnel. Redundancy options are also being investigated with polarimeters at other experimental points necessitating additional dedicated laser hutches and access tunnels. This would allow calibration at multiple IPs to reduce systematic errors.

Developing a fully automated system with 24/7 up-time over several months is a considered but requires substantial R&D. The cost of the continuous access to the laser hutch needs assessment, potentially compared to the actual cost of down-time and dedicated tunnels.

The Compton electron extraction line features a small tapering angle to mitigate wakefields. The Compton electrons pattern for each energy exits the separation chamber at 96 m from the laser interaction point. The detector size varies from 1.1 m wide to 4.4 m from Z-mode to $t\bar{t}$-mode, respectively.

J. Keintzel wonders if the transport of the laser could be extended to avoid additional tunnels. **R. Kieffer** answers that the current design is at its limit, and the preservation of the precision of the laser polarization should be evaluated by laser experts.

M. Koratzinos questions why this equipment is the only one requesting 24/7 access and the impact of the polarimeter down-time. **J-P. Burnet** answers that the objective is to have solutions to maximise availability.

F. Zimmermann emphasises that using the insertion at point L for the polarimeter should be studied as this insertion does not yet have a specific function yet and could be tailored to the polarimeter needs. **S. Mazzoni** adds that the laser hatches could be used for beam instrumentation, such as longitudinal measurements, in addition to polarization measurements.

5 Update on dynamic aperture optimization for the LCC lattice

S. White presents update on the dynamic aperture and momentum acceptance for the LCC lattice at $t\bar{t}$ energy assuming 16 GV total RF voltage, 400 MHz RF frequency and 40% crab sextupole strength.

He highlights that synchrotron radiation has a major impact on the DA, corroborating the work of **P. Raimondi** to minimize the synchrotron radiation emitted in quadrupoles along the ring. His optimization protocol optimizes first one of the two sextupole families with a 2D-scan to enhance DA and MA, while the second sextupole family is used to conserve the chromaticity to the original design value. An strength increase of 16% of SF2 only (SD2 is unchanged) leads to an increase of the DA width to $[-20\sigma_x, 14\sigma_x] \times 90\sigma_y$ and MA close to $\pm 4\%$.

Then adding the octupoles present in the lattice to the optimization procedure, he observed that only 2 families called OCT2 and OCT3 have a significant effect on DA/MA. He looked at an asymmetric powering of the octupoles left/right for OCT2 and OCT3 without significant gain but he observed correlation that may be useful to build knobs in the future. In the frame of his optimization he kept the powering symmetric.

Finally, he optimized the powering of decapoles observing a marginal gain with 2D-scan and leaving the decapoles at their original values.

The final optimization results in a DA extending from $[-19\sigma_x, 16\sigma_x] \times 120\sigma_y$ and a MA of $\pm 3.5\%$ that are beyond FCC-ee requirements. He emphasizes that these results are still without errors.

The optimization procedure is robust and simple to perform provided that the magnet definition remains the same in future updates. Further improvements could be to combined knobs to reduce the number of variables used in the optimization routine. The substantial DA/MA gains obtained with this method could help to recover performance for lattices with errors.

58 Participants:

K. André, W. Bartmann, G. Broggi, R. Bruce, J-P. Burnet, P. Burrows, D. Butti, C. Carli, F. Carra, B. Dalena, H. Damerau, Z. Duan, Y. Dutheil, C. Garcia, C. Garion, M. Gasior, V. Gawas, C. Goffing, E. Granados, M. Guinchard, E. Howling, B. Humann, P. Hunchak, A. Inane, P. Janot, V. Kain, J. Keintzel, R. Kieffer, M. Koratzinos, S. Kostoglou, G. Lavezarri, T. Lefevre, A. Lechner, A. Martens, S. Mazzoni, M. Migliorati, M. Morrone, A. Piccini, S. Pittet, F. Poirier, P. Raimondi, S. Redaelli, L. Rivkin, L. Sabato, J. Salvesen, G. Tang, R. Tomás, F. Valchkova-Georgieva, U. van Rienen, L. van Riesen-Haupt, R. Wanzenberg, L. Watrelot, J. Wenninger, S. White, B. Wicky, F. Yaman, S. Yue, and F. Zimmermann