Meeting Minutes of the
138th FCC-ee optics design meeting
and 9th FCCIS WP2.2 meeting

Indico: `https://indico.cern.ch/event/1033064/`
When: 07.05.2021 9:00-11:00 CET

Agenda

Presenter	Title
O. Brunner	**SRF baseline and alternative**
I. Karpov	**Beam-cavity interactions for FCC-ee**
D. Shatilov	**Effect of RF frequency change on luminosity performance**
N. Nikolopoulos	**Resistive wall and photon stopper impedance**

1 General information

F. Zimmermann opens the meeting by welcoming the newcomers. **P. Kicsiny** started as a PhD Student at CERN on beam-beam effects in FCC-ee, under the supervision of **X. Buffat**. **M. Migliorati** introduces two newcomer from DESY, **C. Li** and **Y.-C. Chae**, who are working in the CREMLIN+ project on collective effects and who are also now consulting on FCC-ee.

2 SRF baseline and alternative

O. Brunner presents an overview of the baseline SRF strategy and a recently developed alternative, which were also discussed in the SRF review two weeks prior. In the baseline scenario, the FCC-ee base RF frequency is set to 400 MHz, with single-cell cavities used at the Z operation mode, and which will be replaced by 4-cell cavities for the following operation mode and later on using 800 MHz for the $t\bar{t}$ operation. The choice of frequency derives from the FCC-hh and the LHC and in planning, focus was put on optimum re-usage and strict timeline of the machine. However, the baseline strategy provides several technical challenges, e.g. the development of compact high efficiency klystrons and for the integration into the tunnel. At the end of 2020, during discussions a new cavity design was proposed, called Slotted Waveguide Elliptical (SWELL), and operating at a higher frequency of around 600 MHz. Compared to the baseline design based around both single-cell or 4-cell elliptical cavities, two-cell SWELL cavities can be used during all operation modes, thus requiring less effort in terms of installation. A comparison for both scenarios in terms of cavity requirements and potential issues is then presented, again illustrating the re-usability of the SWELL cavity type. A comprehensive R&D program is planned for the next years to demonstrate the feasibility of the SWELL cavity type.

M. Migliorati asks if the quoted numbers for the cryo-modules are for both beams or only for a single beam. **O. Brunner** clarifies that this numbers represent the total number.

M. Koratzinos wonders how easily one can adapt to the EIC frequency of 591 MHz and if the design remains the same. **O. Brunner** answers that if the cavity design is for a specific frequency, the bandwidth is usually quite small. However, the design can be easily scaled and the proposed 600 MHz is a first guess and for the time being rather a frequency range around this point should be considered. For example, if 650 MHz is feasible, this would allow the booster to operate at 1.3 GHz, in terms easing the procurement as it is closer to the ILC specifications. **F. Zimmermann** adds that the compatibility with the injector has to be considered as well. **O. Brunner** agrees.

R. Bruce comments that for collimation tracking studies, details such as the layout and overall length of the RF-section as well as voltage are required. As the design appears not fully finalised, he wonders to which degree such parameters might be available. **O. Brunner** notes that the cavity length depends on the RF frequency, which is not yet determined, but some rough estimates can be provided. **F. Zimmermann** notes that with this change, also the beam parameters have to be adjusted. **G. Roy** adds that he is working on integrating the RF-section in the lattice and he would be interested how the length of the RF-section will change. **I. Karpov** replies that in the new design, the length of the RF-section should be similar or shorter. **G. Roy** further proposes to add a lattice model with RF at 600 MHz, an arbitrary reference value in the range 591 to 650 MHz, to help with collimation studies.

F. Zimmermann asks if the price of copper is a significant factor in the cavity design, seeing as parts are made of solid copper blocks. **O. Brunner** replies that the design is preliminary and will be optimized in the future. The overall cost of the new cavity is not expected to increase compared to a standard elliptical cavity.

3 Beam-cavity interactions for FCC-ee

I. Karpov present the case of beam-cavity interactions for FCC-ee, with the main effects being beam loading, coupled-bunch instabilities, and higher order mode (HOM) power losses. In terms of these effects, the most challenging operation mode is the Z-case with its large beam current and number of bunches. In this talk, studies for both the baseline single-cell elliptical cavity design and the newly proposed two-cell SWELL cavity design are presented. For the steady-state beam loading, at the maximum cavity voltage for the respective design, the single-cell features a factor 5 smaller detuning compared to the 57 kHz of the two-cell SWELL cavity. The larger detuning of the SWELL cavity could pose problems due to longitudinal coupled bunch instabilities (LCBI) and affect luminosity via transient beam loading. Transient beam loading will occur due to gaps in the filling scheme to account for the abort gap, and will result in a modulation of the bunch length and phase, in turn potentially affecting luminosity. The effect can be partly mitigated by matching the abort gaps between the two rings. Taking into account also a potential charge imbalance of 5 % between the beams, for abort gaps above 2.5 μs, the collision point may shift by 0.2 σ in the single-cell elliptical case and up to 1 σ for the SWELL cavity case. For the LCBI, while in the single-cell elliptical cavity case the growth rate is below the synchrotron radiation damping time, this is not the case for the SWELL cavity and additional damping by a direct RF feedback and using a one turn delay dual comb filter is required. Similar so, a bunch-by-bunch feedback system is needed to damp transverse coupled bunch instabilities due to HOMs. HOM power loss below cut-off frequency for both cavities is below 2 kW and deemed feasible, with more calculations needed for multi-cavity structures.

D. Shatilov asks if results are based on baseline beam parameters, and how those would change if the number of bunches is halved and other parameters such as the bunch population increased accordingly. **I. Karpov** replies that HOM power loss above the cut-off frequency should increase, while for the resonant case, the change depends strongly on the filling scheme and can be beneficial or detrimental. **D. Shatilov** adds that the increase in bunch length might help a bit.

A. Blondel notes that any change of number of bunches will also affect the pile-up at Z operation, which already is non negligible, and a significant decrease of the number of bunches will lead to a drastic increase of the pile up and a loss of precision. **F. Zimmermann** adds that the bunch spacing was changed in the past, and pile up was so far not considered. **K. Oide** comments that such pile up events could be discarded. **A. Blondel** warns that this could introduce a bias but notes that the horizontal beam size is larger than the vertex resolution. **D. Shatilov** asks what the time resolution will be as with the longer bunches, events can be distinguished by this.

K. Oide comments that for the transient beam loading, the charge imbalance is on a bunch by bunch basis and the overall loading should be equal. **I. Karpov** answer that the presented studies show the worst case, but studying a randomly distributed imbalance is certainly interesting and could be studied in the future. **K. Oide** asks what the tolerance on the shift of the collision point is in view of its effect on beamstrahlung and bunch-length. **D. Shatilov** replies that this has not been looked into yet.

I. Karpov comments that in the 4 IP case, 4 abort gaps have to be used to allow for matching.

4 Effect of RF frequency change on luminosity performance

D. Shatilov presents the effects of the RF frequency change to 650 MHz on parameters such as the bunch length, which in turn affect the luminosity performance. For the highest energy operation mode ($t\bar{t}$ at 182.5 GeV), parameters can remain the same as no problems are expected. For ZH at 120 GeV, the horizontal tune has to be decreased slightly to avoid a coherent beam-beam instability, and number of bunches and bunch population needs to be changed slightly, though as for the previous case no big problems are expected. Adapted RF parameters are presented for the WW case at 80 GeV, with a lower RF voltage required. If the RF voltage is left at 750 MV as used in the 400 MHz case, the synchrotron tune will increase, which is beneficial for depolarization. At the Z operation mode using the baseline $60^\circ/60^\circ$ arc cell phase advance, the synchrotron tune increases and the range of good horizontal tunes moves upward, which once impedance is taken into account in the simulations could become a problem. Using an arc cell phase advance of $45^\circ/45^\circ$, this issue is partly mitigated, however the number of bunches is increased by roughly a factor 1.5, which might pose problems due to electron cloud. Using a higher order harmonic RF allows to use a lower number of bunches and a better synchrotron tune for depolarization can be used.

F. Zimmermann notes that with the longer bunches, the tolerance on the charge imbalance could be relaxed as beamstrahlung becomes less important. **D. Shatilov** replies that the linear bunch density remains roughly the same, as does the energy spread, thus the tolerance should not be affected.

M. Koratzinos asks how the RF acceptance will change if the RF voltage is increased to 750 MV. **D. Shatilov** replies that it will increase. **F. Zimmermann** asks what the luminosity value for the different cases are. **D. Shatilov** replies that all values are chosen to keep the same luminosity.

A. Blondel asks if new constraints have arisen on the synchrotron tune since the publication of the last report on polarization in FCC-ee in 2019. **D. Shatilov** replies that there are no news and that a synchrotron tune below 0.05 is problematic, and higher values are preferred as at lower values more complicated procedures are required.

K. Oide asks how feasible the proposed 3$^{\text{rd}}$ harmonic RF parameters are. **I. Karpov** notes that the transient beam loading could lead to a different deformation of bunches around the ring, and that to his knowledge synchrotron light sources have tried this in the past but problems were encountered. **K. Oide** asks if the EIC uses a 3$^{\text{rd}}$ harmonic RF. **F. Zimmermann** notes that for the crab cavities such a system is used, but likely not for the main acceleration.

5 Resistive wall and photon stopper impedance

N. Nikolopoulos presents studies on the change of the resistive wall impedance due to smaller winglets, in response to question raised in the 132nd FCC-ee optics design meeting for the case of nesting arc quadrupoles and sextupoles. A recap of the relevant formulas and the beam pipe design in the CDR is presented, as well as results from first consistency checks using a round beampipe. In the following, a model with a smooth transition from a winglet width of 110 mm to 86 mm is used, and the loss factor is presented for an incoming and an outgoing beam. Different photon stopper geometries were studied and the total power consumption using the obtained loss factor is presented. Overall, in the new design, the required power increases by 70 kW.

F. Zimmermann asks why a second customised copper is used in the studies and if these will be implemented in the machine. **N. Nikolopoulos** replies that this is used as a second consistency check and there is no practical relevance. **M. Koratzinos** adds that this was tried as CST studio might not be particularly accurate at high conductivities. He notes that the total resistive wall power remains under 3 MW.

R. Kersevan comments that while in the CDR, a winglet width of 110 mm is given, in the latest design this was increased to 120 mm. **M. Koratzinos** comments that this will likely not change the results much. **B. Humann** adds that FLUKA studies were conducted with the 120 mm winglet width design and that it fits in the sextupoles, but some design changes are required to allow also for a cooling pipe to fit in.

K. Oide notes that the loss factor with increase stopper distance does not seem to converge towards the case where no stopper is present. **M. Koratzinos** agrees that these curves should converge at around 55 mm, but notes that the accuracy of these points is of the order of 10-20 %. He highlights that the process from the design of such a model in a CAD program and then analysing it using CST studio is quite seamless and fast.

Follow-up items

TASK
Establish tolerance on shift of collision point
Look into EIC RF system and use of higher order harmonic RF

41 Participants:
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