Response to Referee Report on *"Physics case for low-$\sqrt{s}$ QCD studies at FCC-ee"*

The Authors

December 5, 2025

Introduction

We are pleased that the referee finds our manuscript well written and recognize its potential to open a new pathway for QCD studies at intermediate energies using e^+e^- collisions at the future FCC-ee collider. Below, we address the specific concerns raised.

1 Report 1 by Referee 1 on 2025-6-10 (Invited Report)

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Report 1 by Anonymous (Referee 1) on 2025-6-10 (Invited Report)
Strengths
1-First idea of FCC-ee sensitivity for QCD studies in the intermediate energy range (30-80 GeV)
2-Two different avenues (ISR/FSR and low energy runs) are explored
Weaknesses
1-Lack of detailed studies to build an actual physics case: The ISR/FSR sensitivity is based on L3
extrapolation but it's not clear if this is a valid assumption for an actual FCC-ee detector. Also the actual
feasibility of low energy runs (luminosity, requirements for the detector) are not studied.
Report
Hadronic final states in e+e-
collisions in the intermediate energy range (roughly between the Y(4S) and the Z
poles) have not been studied in recent experiments and available statistics are low. This paper explores how
this energy range could be accessed at the future FCC-ee, either in ISR/FSR events while running at the Z pole,
or in dedicated low energy runs.

The projections are based on the extrapolation of an L3 paper for the ISR/FSR approach and on a some assumption
for the FCC-ee luminosity at low energies. In both cases the sensitivities are assessed merely in terms of the
HFS event statistics but no detailed studies involving simulated detector performance have been carried out.

So, I would say this paper is interested for getting a first idea of the sensivity of FCC-ee for QCD studies at
intermediate energies but clearly more research using full simulation is necessary to establish the physics
case. I would judge that the acceptance criterium "Opens a new pathway in an existing or a new research
direction, with clear potential for multi-pronged follow-up work" is met. The paper itself is well written
(clarity, level of detail, relevant references, abstract/conclusion, reproducibility ). I therefore recommend
publication after the detailed comments below have been considered by the authors.
Requested changes

1-p. 5, Table 2: Are the expected yields at FCC-ee for one experiment, for all for 4 together? This should be
clarified.

2-p. 8, last paragraph: Luminosity scales as sqrt(s). As this is a key assumption for the results you present
in this section, is there no way to find a more rigorous justification than a 'private communication'?

3-p. 9, first paragraph: It should be added that the time estimate of 1-3 weeks plus 1 week for setup is *for
every c.m. energy point*.
Recommendation

Ask for minor revision
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1.1 Future detector modeling and feasibility of low-energy runs in terms of detector requirements

Our studies are based on fast (parametrized DELPHES) simulations of the current FCC-ee IDEA detector concept. Therefore, despite its intrinsic limitations, this is a state-of-the-art approach to account for the instrumental effects of a typical FCC-ee detector on the event selection. The studies will be updated in lockstep with the developments of future FCC-ee detectors and will be redone once their full simulations are available.

In the performed studies, no detector requirements for the low-energy runs were explicitly considered, as one of the key aspects of the proposal is to make the low-energy dedicated runs a low-budget extension of the main FCC-ee program. Therefore, the baseline assumption is that no dedicated modifications should be made to the detector proposals to accommodate such runs. (If anything, in the case of dedicated low-$\sqrt{s}$ runs, one could consider lowering the magnetic field of the detectors, which would lead to further improved low-momentum charged-particle tracking performances).

1.2 Comparison to L3 detector performance

The experience from the existing L3 measurements provides a reliable baseline for the expected event selection at future experiments. The reason is that while detectors built for the FCC-ee will benefit from major advances in detector technologies, these improvements will primarily enhance the resolution of reconstructed quantities and enable data acquisition at rates several orders of magnitude higher, but the purity and selection efficiency of ISR/FSR samples at LEP were fundamentally limited by the underlying physics. A textbook example is the fact that even with state-of-the-art 4π solid angle tracking and calorimeter systems, a fraction of the energy escapes the detector (e.g. from the produced neutrinos and very low-angle ISR photons) and therefore the total registered energy will differ from $2 \times E_{beam}$.

1.3 Further studies to establish the physics case more rigorously

Studies are currently ongoing to make a stronger physics case by exploiting a concrete case: comparing the precision achieved for measurements of event shape observables obtained via ISR/FSR at the Z pole and from dedicated low-energy runs. However, the quality of reconstruction of those quantities is closely related to the quality of reconstruction of the HFS (e.g. the invariant mass of HFS), already presented in the current study.

1.4 Requested changes 1

Yes, the luminosity is given for the 4 interaction points combined. The text has been updated as follows:

- "FCC-ee" $\longrightarrow$ "FCC-ee (4 IPs combined)"

1.5 Requested changes 2

The performance of the accelerator running at lower energies is indeed a more complex topic. However, at our request, parametric simulations were performed by the accelerator experts (K. Oide and F. Zimmermann), following similar early estimates for the FCC-ee Feasibility Report, keeping an upper limit on the beam current equal to that at $\sqrt{s} = 91$ GeV. Those results were used in the estimations of the run duration in this study (Table 4). Based on the beam parameters setup of Table 4, the accelerator experts conclude that the textbook assumption that the luminosity follows the standard Lorentz γ_L-dependence of the beam energies (i.e. the $\mathcal{L} \propto \sqrt{s}$ scaling of luminosity) is reasonable for the conditions they used. The text has been updated as follows:

- "the luminosity follows the standard Lorentz $\gamma_{\rm L}$-dependence of the beam energies, namely $\mathcal{L} \propto \sqrt{s}$ [43]." $\longrightarrow$ "the luminosity follows the standard Lorentz $\gamma_{\rm L}$-dependence driven by the beam energies[footnote: Such a dependence is approximately confirmed with the simulated collider parameters of Table 4.], namely $\mathcal{L} \propto \sqrt{s}$."

1.6 Requested changes 3

Text updated as follows:

- "plus 1-week of additional beam-setup time [43]." $\longrightarrow$ "plus 1-week of additional beam-setup time [43], for each single CM-energy point."

1.7 Feedback

We are pleased that the relevance, clarity, and potential impact of our study have been appreciated. We agree that both proposed approaches (radiative return and dedicated low-energy runs) offer complementary paths toward enriching the FCC-ee physics program and improving our understanding of QCD in a previously underexplored regime.

Sincerely,
The Authors