Integrated Luminosities and Sequence of Events for the FCC Feasibility Study Report

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The FCC-ee baseline configuration has significantly evolved since the Conceptual Design Report [1], with impact on the luminosity. The changes made for the FCC Feasibility Study Mid-Term report [2] are summarized in Ref. [3]. Since then, the Mid-Term Review Committees and the CERN Council found *"the proposal to include more than two IPs an attractive option"* and recommended to *"construct 4 IPs for FCC-ee from the beginning, on the basis of the strong physics case, the improved sustainability in terms of electricity cost per unit of luminosity, and the increased size of the community and diversity of the physics which can be supported."*. Since then, the FCC-ee machine parameters were, therefore, further optimised [4] in this sole configuration.

The outcome of these optimisations at the time of the feasibility report, for this new baseline configuration with four interaction points, is presented in Table 1. The table considers the four baseline centre-of-mass energy stages at the Z pole, the WW production threshold, the ZH production cross-section maximum, and the top-pair production, in this chronological order. In order to determine the total integrated luminosity and the number of events expected to be produced (in the last two rows of the table), the luminosity is assumed to be half the design value during the first two years at the Z pole and for the first year at the $\mathrm{t\bar{t}}$ threshold. At the Z pole, the integrated luminosity is distributed as follows: $40\,\mathrm{ab}^{-1}$ at 87.9 GeV, $125\,\mathrm{ab}^{-1}$ at 91.2 GeV, and $40\,\mathrm{ab}^{-1}$ at 94.3 GeV. The number of Z decays results from this setup. At the WW threshold, the run time is evenly distributed between 157.5 GeV and 162.5 GeV. The number of WW events include all $\sqrt{s}$ values from 157.5 GeV up.

Figure 1 displays the corresponding sequence of events, which was taken as a baseline for the Mid-Term Report. The major two changes with respect to the sequence presented in the Mid-Term report are *(i)* a larger luminosity for the ZH and $\mathrm{t\bar{t}}$ stages, resulting from the aforementioned optimisation; and *(ii)* the removal of a one-year shutdown between the Z pole and the WW threshold stages, benefitting from a new versatile RF design common to the first three stages. Conservatively, this saved year is not used to increase the duration of FCC-ee operation, in order not to delay the construction of the succeeding hadron collider, FCC-hh.

Table 1 The baseline FCC-ee operation model with four interaction points, showing the centre-of-mass energies, design instantaneous luminosities for each IP, integrated luminosity per year summed over 4 IPs. The integrated luminosity values correspond to 185 days of physics per year and 75% operational efficiency (i.e., 1.2 10^7 seconds per year) [5], in the Z, WW, ZH, $t\bar{t}$ baseline sequence. The last two rows indicate the total integrated luminosity and the total number of events expected to be produced in the four detectors.

Working point	Z pole	WW thresh.	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated Lumi (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	$6\,10^{12}$ Z	$2.4\,10^{8}$ WW	$2.2\,10^{6}$ HZ + 65k WW $\rightarrow$ H	$2\,10^{6}$ $t\bar{t}$ +370k HZ +92k WW $\rightarrow$ H	

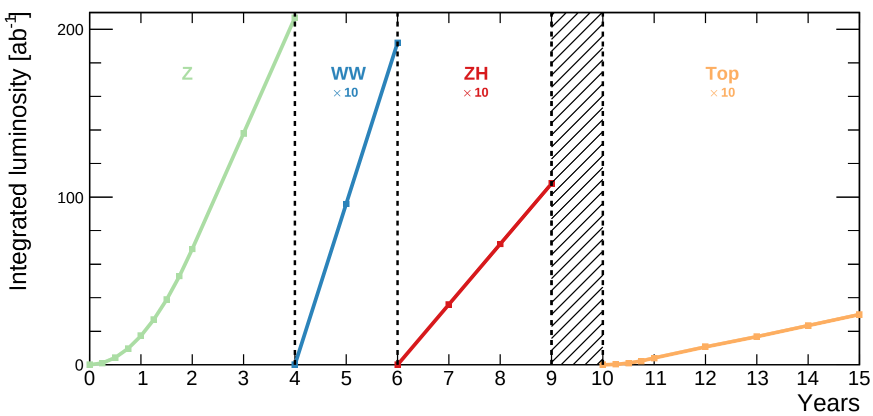

Fig. 1 Baseline operation model for FCC-ee with four interaction points, showing the integrated luminosity at the Z pole (pink), the WW threshold (blue), the Higgs factory (red), and the top-pair threshold (green) as a function of time. In this baseline model, the sequence of events goes with increasing centre-of-mass energy. The integrated luminosity delivered during the first two years at the Z pole and the first year at the $t\bar{t}$ threshold is half the annual design value. The hatched area indicates the shutdown time needed to prepare the collider for the higher energy runs at the top-pair production threshold and above.

In Ref. [6], however, it was deemed essential to establish the technical and financial feasibility of scheduling a Z pole run after the ZH run or the WW threshold run, ideally with a first Z pole run during the initial period of FCC-ee operation. Indeed, the Z pole run, while extremely fertile in physics opportunities, is undoubtedly the most ambitious and demanding part of the programme from all point of views (accelerator, energy calibration, detectors systematic biases, theory calculations). It will be extremely challenging to achieve all the goals of the Z pole run during the first four years of the collider operation.

This requirement from physics was compounded by a recommendation from the mid-term review committees to *consolidate (and ideally simplify) the design of the RF system to allow efficient energy-staging, as well as to reduce complexity, risk, and cost; and to study options to avoid the 1-cell/2-cell RF cavity reconfiguration between Z and ZH/WW running, in order to simplify the SRF system implementation and to improve flexibility in the physics programme.* The new versatile RF system designed accordingly, indeed, enables a quasi-total flexibility to choose the running sequence. For example, it would allow for short initial Z pole and WW threshold runs, to commission the collider and the detectors, to establish the resonant depolarisation procedures, etc. The ZH run could then proceed, before going back to the Z pole and the WW threshold, both now at full luminosity, with fully functional resonant depolarisation, and complete understanding of the collider.

It will ultimately be up to the experimental collaborations and the relevant scientific committees to optimise the time flexibility and to tailor the FCC-ee operation scenario according to a number of factors that cannot be mastered today. For example, external events such as the FCC-hh magnet readiness or the CERN financial situation may call for an increase of the overall duration of the FCC-ee running time. In such an extended run, the new RF design flexibility would also fit the ambitious project of running at $\sqrt{s} = m_{\mathrm{H}}$ to measure the electron Yukawa coupling with the $\mathrm{e^+e^-} \to \mathrm{H}$ direct production, which cannot happen before the ZH run (where the Higgs boson mass is precisely measured) and for which the centre-of-mass energy calibration and the monochromatisation schemes will have to be tested and demonstrated at the Z pole. Such a run would have, however, to take place before the installation of the RF system needed for the $\mathrm{t\bar{t}}$ run.

The estimates and the sequences briefly discussed in this note are preliminary, and provisional. New avenues will be explored during the FCC pre-TDR phase, between April 2025 and the end of 2027, towards increasing the luminosities at all energies.

A quasi-total flexibility

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