PPAP Roadmap input: preliminary FCC-ee resources estimate

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This brief document is an accompaniment to 'PPAP roadmap input: FCC-ee', which was submitted to PPAP in October 2020 [1]. Here we make initial estimates for the scale of the UK contribution to the FCC-ee. To set the scene we present in Table 1 key dates in the countdown to first collisions.

Table 1 Key dates in FCC-ee timeline.

Date	Activity
2024/25	CDR++ submission
2025/26	Formation of proto-collaborations
2026/27	Next ESPPU
2028	Project approval
2030	Start of tunnel construction
2034	Start of detector construction
2037	Start of machine construction
2040	First collisions

It is assumed that the UK will play a major role in detector R&D and construction. An approximate detector-related resource estimate is given in Table 2. Some comments:

- No reliable estimates yet exist on detector costs. We therefore take the ATLAS CORE-accounting (*i.e.* installed equipment) cost-to-completion of MCHF 550 as a yardstick. Although many aspects of the e^+e^- environment are less challenging than at the LHC some are more so (*e.g.* extreme stability), and it is to be expected that the experiments will be ambitious in design; therefore we take MCHF 500 as the cost of an FCC-ee detector. We assume that the UK will aspire to contribute ~10% of the cost and that UK

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institutes will participate in two (or more) experiments, which we do not account for in this first iteration, but can be considered to be assumed in this estimate, since participation in multiple experiments will reduce the fractional contribution per experiment. We apply a 1:1 GBP:CHF exchange rate.

- We assume that staff costs (including the ring-fenced CG contributions) for the construction will be double the capital costs. We hypothesise a 6-year construction period, but acknowledge this could be aggressive. We note that with these assumptions the staff cost per annum essentially saturates the current STFC spend on particle physics salaries. Unless resolved by an increase in budget or reduced goals, this problem will have to be mitigated by increasing the construction period or developing more efficient approaches to detector construction.

- We assume a naïve 20% scale for the pre-construction R&D phase, and 10% of this for the pre-CDR++ initial period. This latter funding would be used to support detector R&D activities, which could largely be in common for those aimed at other e^+e^- projects, such as the ILC or CEPC.

The UK will also make vital contributions to the physics programme through the theory developments that are essential to match the experimental sensitivity. The UK community is well placed to play a leading role in the necessary phenomenological developments, through both the IPPP and the NexT institutes, which together provide a comprehensive portfolio of activities, including essential computing tools such as HERWIG, SHERPA, CalcHEP and HEPMDB, and also have very close links to experimental physicists. It is not yet possible to quantify the additional resources that may be needed to support this work leading into the FCC-ee era.

Table 2: Approximate detector-related resource estimate in GBP for each project phase.

Funding phase	**Capital costs: detector**	**Staff (including Consolidated Grant, when applicable)**
Pre-CDR++ (2021-2024)	1M	2M
Pre-construction (2025-2034)	10M	20M
Construction (2034-40)	50M	100M

Computing resources for storing and analysing the FCC-ee data samples are expected to be of a similar scale to those required for the HL-LHC, given the very loose triggering that will be deployed at the FCC-ee, and the high rate of interesting events, particularly at the Z pole. The cost for this component of the project is not included in this document.

We turn now to the costs of the tunnel and the machine, and the consequences for the UK. The total expenditure is estimated to be 10,500 MCHF, comprising 3,100 MCHF, 2,000 MCHF and 5,400 MCHF for the collider and accelerator complex, the technical infrastructure, and the civil

engineering, respectively [2]. (This estimate is for a scenario involving operation at the centre-of-mass energies required for Z, H and W physics. Top physics will necessitate the later installation of additional RF and cryogenics, which will increase expenditure by another 1,100 MCHF).

The CERN DG has stated that a new mechanism, outside the CERN budget, is required to fund the civil engineering costs, and financial feasibility studies will be conducted in the period up to the next European Particle Physics Strategy Update (~2026) to address this challenge [3]. Assuming this challenge is met, then the remaining costs would be of a similar scale to those required for the construction of the LHC, and could be met in a similar way. This would involve one-off contributions from non-member states, and might necessitate an uplift to the CERN subscription over a period of 10 to 20 years, which could be partially or fully met through in-kind contributions.

[1] PPAP Roadmap Input: FCC-ee, Nov 2020.
[2] Michael Benedikt, Future Circular Collider – the Lepton Collider (FCC-ee), addendum of submission 132 to EPPSU, Dec 2018.
[3] Fabiola Gianotti, address at Kick-off Meeting of FCC Innovation Study, 9 Nov 2020.