FCC

Future Circular Collider Physics-Experiment-Detectors in the pre-TDR period (2025-2028)

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(on behalf of the PED coordination group)

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Disclaimer

- Last June, we received a request from Council/SPC/FCC-management to propose some PED priorities/deliverables/milestones for the period till the approval of the project.

- 5-10 **priorities** x 5 **deliverables** x 3 **milestones** = 75-150 milestones!
  - An administrative language not well-mastered by particle physicists.

- The outcome is a first attempt that is likely to evolve
  - It needs further discussions with PED coordination group and with all the stakeholders.
  - Please view today talk as a proposal to engage discussion and to collect feedback.

- “Pre-TDR phase” is not a well-adapted naming convention for PED
  - Detector TDR activities won’t start after this “pre-TDR” phase
  - To avoid this confusion, suggest to call it “**pre-approval phase**” instead

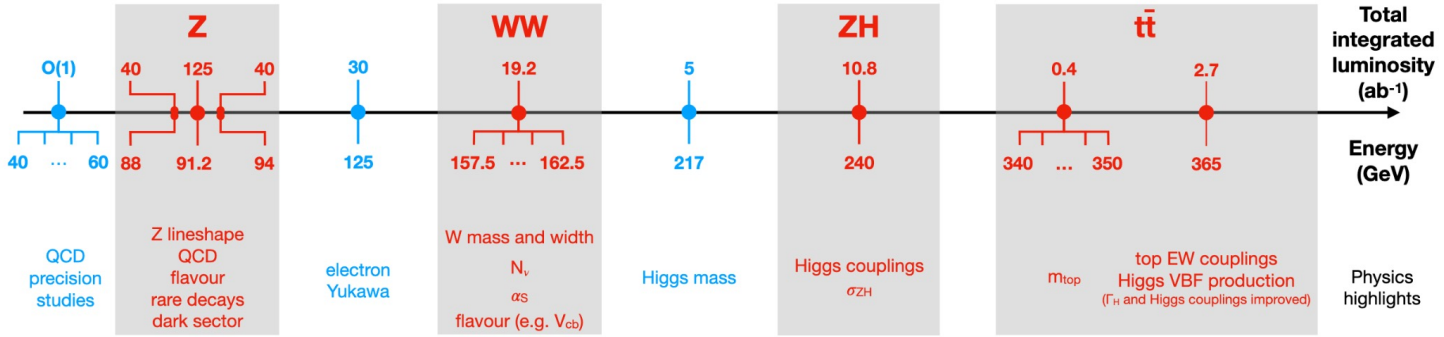
FCC history reloaded

After just over a decade of pioneering work, huge progress has been achieved:

- The first proposal of a high-luminosity **e^+e^- circular collider** to study the Higgs boson was made **fourteen years** ago (December 2011);
- The Future Circular Collider collaboration was created **twelve years** ago, towards the conceptual design study of a **100 TeV pp collider**, with an e^+e^- Higgs factory as a potential intermediate step;
- The **Conceptual Design Reports** of the FCC physics case, and of the FCC-ee and FCC-hh colliders, were published **six years** ago and submitted to the 2018-19 European Strategy Update;
- The CERN Council updated the European Strategy **five years** ago, stating that an e^+e^- Higgs factory would be the highest priority next collider, to be followed by a proton-proton collider at the highest achievable energy;
- **Four years** ago, the CERN Council consequently initiated and funded a **technical and financial feasibility** study for FCC with focus on an e^+e^- electroweak and Higgs factory as a first stage;
- **Two years** ago, a 700+ pages **mid-term report** about the FCC feasibility was submitted to the CERN Council for a thorough review, with a conclusion expected at the beginning of 2025. Very positive feedback from CERN council in **Feb. 2, 2024;**
- **Half-a-year** ago, the **Feasibility Study** 1300+page **report** was submitted to the European Strategy Update and to the CERN Council. Extensive reviews.

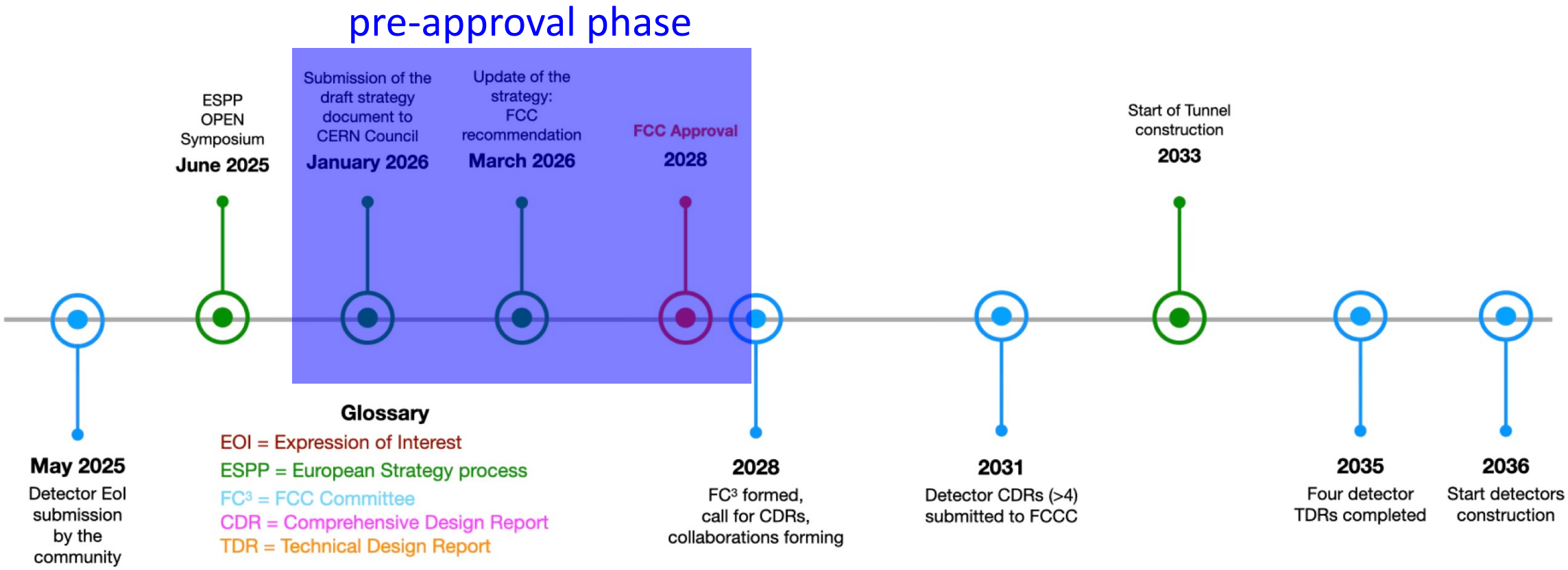
FCC: an exciting challenge for everyone

- FCC-ee provides attractive challenges for all skills in particle physics
  - Detector technology, design, R&D; computing; software; analysis; theory; …
- The challenge arises from the very richness of the program
  - Many opportunities to be creative in matching experiment and theory uncertainties to statistical errors and the detector setup to the variety of channels, centre of mass energies and discovery cases.



- A lot of opportunities for (young) scientists to study a case from A to Z
  - Learning many different aspects, taking initiatives, getting one-name publications, …
  - And most of all, have an impact on the future of the field.
- It is now possible to join FCC team with creative enthusiasts poised to tackle this exciting set of challenges (even in parallel with work on running experiments/on-going theory projects).

Timeline



P. Janot/P. Giacomelli

Overarching (PED) objectives

- Ensure that studies required for a **positive CERN Council decision** are completed:
  - The Council did not ask anything (yet) specific to Physics, Experiments, Detectors.
  - The approval will rely primarily on the **collider** aspects (cost, R&D results, acceptability).
  - However, even if PED cannot win the bid alone, any showstopper on our side may derail the process: We must be ready to answer all questions of this kind.
- Engage the international community towards the formation of **proto-collaborations**:
  - Without creating four experiment collaborations (yet) – it would be far too early.
  - Collaborations will gather naturally after the project approval: the needed human and financial resources won't become available before then anyway.
  - At this time, a worldwide organisation around common priorities is more effective than starting a competition (with effort duplication) between several experiments.
  - Detector concepts, ideally suited for the FCC-ee physics program, are not established
    - As many Detector Concept and Sub-system study groups as possible are encouraged in the PED study organisation, for merging into experiment collaborations at a later time.

PED priority items for the pre-approval phase

1. Lay the foundations for the conceptual design studies of four (or more) **detectors**
2. Consolidate **IR** layout, detector integration, and related background mitigation
3. Collaborate with **IT** to develop a computing architecture model for experiments
4. Complete the **software & analysis toolkit** to ease detector performance comparison
5. Confirm, with full analyses, the current uncertainty estimates on **EWPOs** (Z and W)
6. Gather the worldwide **theory community** to address the theoretical challenges
7. Streamline and optimise the procedure for **centre-of-mass energy calibration**
8. Develop an efficient PED **Education/Communication/OutReach/InReach** strategy
9. Ascertain the **detector cost estimate**
10. Articulate the physics case, feasibility, and schedule implications of **other √s stages**
11. Anticipate FCC-PED **structure and management** in the project phase (2027-2033)

Not included in the PED priorities for the pre-approval phase

- **WILL NOT DO**: Create four experiment collaborations (NOT NOW!)
  - Collaborations will gather naturally after the project approval;
  - The needed human and financial resources won't become available before then;
  - At this time, a worldwide organisation around common priorities is more effective than starting a competition (with effort duplication) between several experiments;
  - **Detector concepts**, ideally suited for the FCC-ee physics program, are not established;
  - Still, detector concept (DC) study groups will be supported within PED, as an important element (among others) for accelerating community building. As many DC study groups as possible will be encouraged, for merging into experiment collaboration at a later time.
- **WILL DO**: All the work that will have to be done towards the FCC future successes
  - Business as usual;
  - Even if not necessary for the Council to take an approval decision.

Deliverables for PED priority items #1 (Conceptual Design Studies of 4 Detectors)

- Deliverables are in preparation. The detector concept group is being restructured.
- Mandate(s) is being finalised. Call for convenerships is on-going.
- The new group architecture will aim at fostering collaboration across the DRDs and the laboratories, universities, institutes, towards building a “library” of **detector subsystems** with different technologies (vertex detectors, trackers, luminometers, calorimeters, muon detectors, magnets, …) and related software tools (geometry, digitisation, simulation, reconstruction and performance figures).
- Workshops on each category of detector subsystems will be regularly organised with this aim (Particle flow reconstruction, Vertex detector R&D, TDAQ).
- The design of **detector concepts** will largely benefit from the fact that detector subsystems are largely interchangeable. They can be used in a plug-and-play strategy to study and optimise their performance (physics, occupancies, data flow) in several versions of detector concepts.
- Study groups based on existing and not-yet existing detector concepts are being formed.

Deliverables for PED priority items #2 (IR layout, ddct integration, bckgd mitigation)

- Definition of **beam pipe** material, geometry, cooling technique, bellows, cooling technique, and remote vacuum connections for each centre-of-mass energy. Finalisation of **cavern dimensions**, detector position, detector & acceleration opening strategy for maintenance. (NB. Surface sites, size of assembly halls).
- Final design of SC IR **cryostat** technology & configuration, IR cryo-magnets and supporting structures, IR correction tunings, and geometrical parameters (crossing angle, L*, …).
- Optimisation of material, collimators, masks, and shielding for both the accelerator elements and detectors with the chosen optics and operation margins, in view of minimising the **beam-induced backgrounds** (BIB) in the detectors.
- Sub-detector data rates, fluences, and total ionisation doses.
- Study of the detector-opening scenarios (3 scenarios: Longitudinal end-cap opening; end-cap splitting; transverse translation before opening).

Deliverables for PED priority items #3 (IT: computing architecture model)

- NB: Solutions should cover the needs of all experiments, to avoid the proliferation of cases observed at LHC.
- Define possible **data taking** scenarios. Consolidate understanding of data rates and define possible plans accordingly, including trigger or trigger-less operation, lossless or lossy data compression
- Collect all relevant information from running experiments, in particular LHC, but not only. This might be done organising a dedicated workshop, using the information collected during the previous phase for preparation.
- Report describing what **computing** could look like at FCC-ee, based on the predicted conditions and the current experience. The report should identify solutions addressing the needs of the diverse operational conditions, possible commonalities, assumption caveats and areas requiring further investigation.

Deliverables for PED priority items #4 (software & analysis toolkit)

- Software (digitizers) for **local reconstruction** in trackers and calorimeters. Essential for realistic Beam Induced Background (**BIB**) studies. Make it generic when possible, or factorize the sub-detector specific part out of the main algorithm when not.
- Software (vertexing, tracking, clustering, track-cluster association, …) for **global reconstruction** (particle identification, flavour tagging, particle-flow reconstruction). Implementation and optimisation for all envisioned detector concepts, trying to make it generic when possible, or to factorize the sub-detector specific part out of the main algorithm when not.
- **Realistic BIB studies**. Design of efficient and effective zero-suppression algorithms, impact on tracking and clustering performance, and feedback loop to/from integration region and detector concept layouts, with enhanced interplay between stakeholders.

Deliverables for PED priority items #5 (uncertainty estimates on EWPOs)

- Z peak cross section, number of light neutrinos: Integrated luminosity measurement with diphoton final state, acceptance in-situ determination.
- Leptonic EWPOs at the Z pole (leptonic branching fractions and forward-backward asymmetries): acceptance in-situ determination.
- Heavy-flavour EWPOs at the Z pole: differential calibration of the flavour-tagging algorithm.
- W mass at the WW threshold: scan strategy, physics backgrounds, kinematic fits, in-situ alignment.
- Electromagnetic coupling constant $\alpha_{QED}(m_Z)$. Off- and on-peak methods.
- Understand the impact on FCC-hh run.

Deliverables for PED priority items #6 (worldwide theory community)

- Initiate dedicated (annual) **training schools** for PhD students and young postdocs.
- Organise Les Houches-style **workshops** to draw the wish lists of the needed computations and event generators, and to establish a development strategy in the short and long term.
- Establish an **exchange programme for PhD** students among key institutions (CERN, U. Zurich, KIT, Durham, UC Louvain, DESY, LPTHE/IPhT…).
- Secure a **FCC fellowship** and **visitor** programme at **CERN.**
- Propose a coordinated **resource plan** for the next 20 years to develop and reinforce the theory community.
- Create an **Early Career Researcher** forum to discuss job opportunities and to stir up community engagement thanks to appropriate accolades.
- Participate to **ECOI** activities and contribute to the composition of **FCC narratives**.
- Elaborate on the **synergy** FCC-ee/FCC-hh

Deliverables for PED priority items #7 (centre-of-mass energy calibration)

- Strategy for injecting of polarised bunches (Z, W, H) for **resonant depolarisation.**
- Full conceptual design of **polarimeter** and **depolariser system** that fulfils both the precision and efficiency requirements.
- Obtain solid estimate of ultimate achievable precision on **absolute** (i.e. m_Z) and **point-to-point** (i.e. Γ_Z) **energy calibration** at Z pole
- Obtain deeper understanding of procedure and ultimate precision for **√s calibration** for the W mass and width.
- Development of full model of **energy evolution around the ring** integrating in situ measurements from experiments

Deliverables for PED priority items #8 (Edu/Comm./OutReach/InReach)

- Compose **narratives** for funding agencies and governmental authorities.
- Instigate a **communication program** targeting the broader scientific community and the neighbouring fields.
- Prepare **general talks for science festivals and public events; t**rain a pool of (young) physicists to deliver these talks and represent FCC.
- Edit **pitches** accompanying scientific publications / studies.
- Redesign the **PED web page** and launch a resource portal with updates plots / tables.
- Organise a contest to redefine the meaning of the **FCC acronym**.

Deliverables for PED priority items #9 (detector cost estimate)

- Related to this priority item, we will continue to… *“work with the scientific community, institutes, laboratories and funding agencies to ensure support and resources for four experiments”* (Cost Review Panel recommendation during the mid-term review).

Deliverables for PED priority items #10 (other √s stages)

- Feasibility of a run at √s = **125** GeV (monochromatisation vs luminosity)
- Added value of runs at √s = **40, 60** GeV with respect to a complete analysis of radiative hadronic events at the Z pole
- Optimised **scan strategy of the WW** threshold
- Optimised **scan strategy of the top pair** threshold
- Optimised **scan strategy of the Z** resonance
- Optimisation of the centre-of-mass energy for **ZH** production (236 vs 240 vs 245 Gev)