FCC Collaboration building and Milestones

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For the FCC Collaboration

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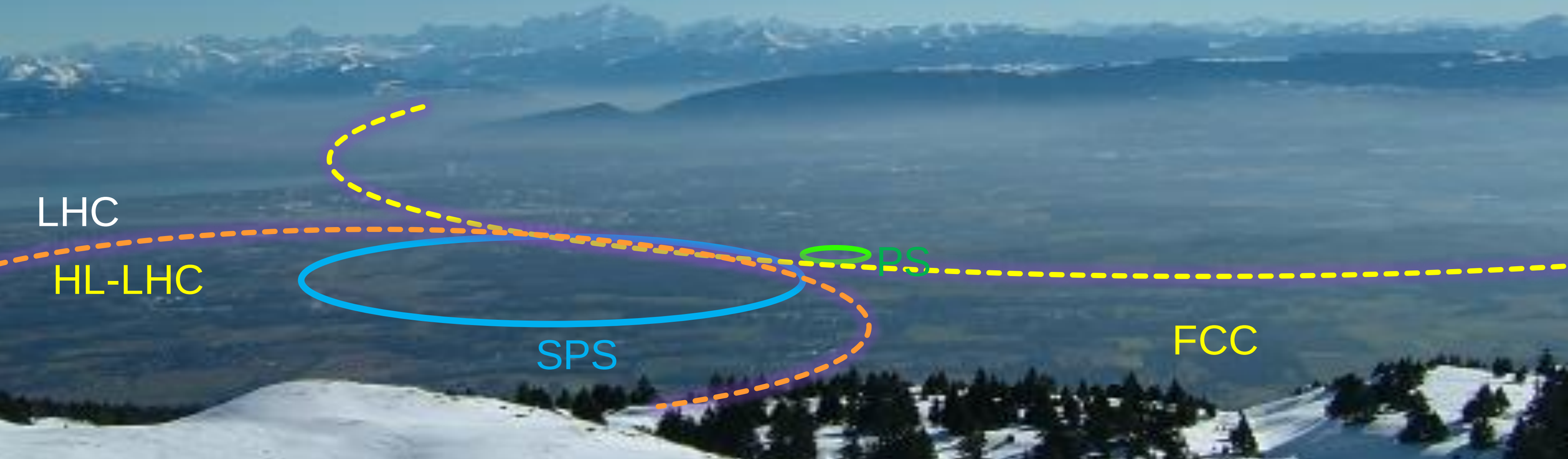
Recommendations from the European Strategy for Particle Physics

2013: “There is a strong scientific case for an **electron-positron collider,** complementary to the LHC, that can study the properties of the Higgs boson&other particles with unprecedented precision and whose energy can be upgraded.. CERN should undertake design studies for accelerator projects in **a global context**, with emphasis **on pp and ee high-energy** frontier machines.“ → 4 volumes delivered in 2018/19, describing the physics cases, the design of the lepton and hadron colliders (also HE-LHC), and the underpinning technologies and infrastructures

2020: “ Europe, **together with its international partners**, should investigate the technical and financial feasibility of a **future hadron collider at CERN** with a centre-of-mass energy of at least 100 TeV, with an **electron-positron Higgs and electroweak factory** as a possible first stage.”
“ Such a feasibility study of the colliders and related infrastructure should be established as a **global endeavour** and be completed on the timescale of the next Strategy update.”

Future Circular Collider Feasibility Study

The FCC FS is organized as an international collaboration. The FS and a possible future project profit from CERN's decade-long experience with successful large international accelerator projects, e.g., the LHC and HL-LHC, and the associated global experiments, such as ATLAS and CMS.



Goal of the study:

Provide by 2025 conclusions on the technical and financial feasibility of the FCC project, to be submitted/approved at the next European Strategy in 2026-2027, eventually allowing to start digging the tunnel by 2030

http://cern.ch/fcc

photo: J. Wenninger

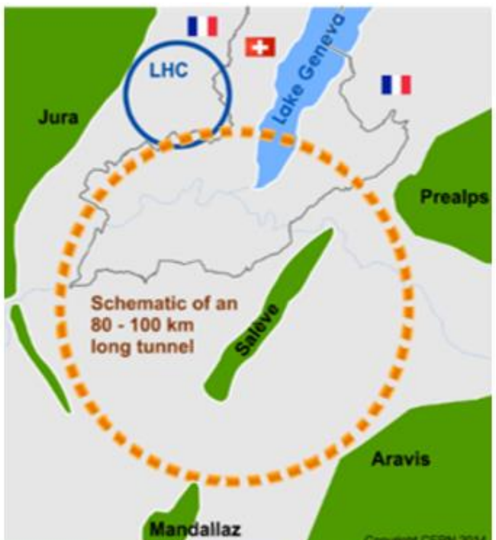
The FCC integrated program (ee+hh) at CERN can do even better than the very successful LEP – LHC (1976-2041) program

Comprehensive cost-effective program maximizing physics opportunities

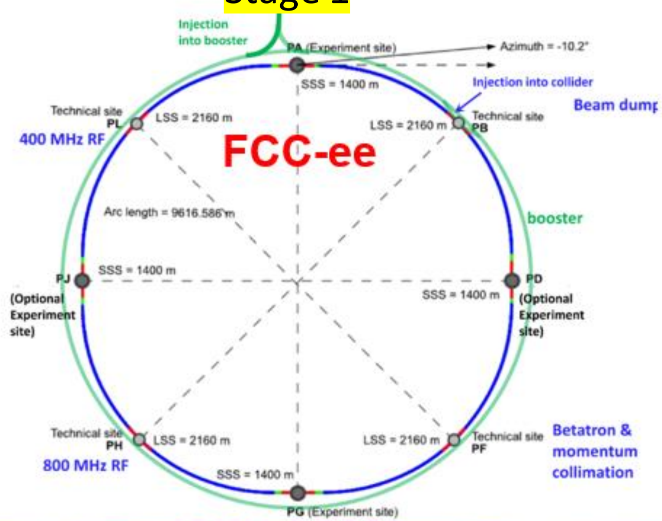
- Stage 1: FCC-ee (Z, W, ZH, tt, H?) as first generation Higgs, EW and top factory at highest luminosities.
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with heavy ions and eh options.

- Complementary and Synergetic physics programmes
- Integrating an ambitious high-field magnet R&D program
- Common civil engineering and technical infrastructures
- Building on and reusing CERN's existing infrastructure.

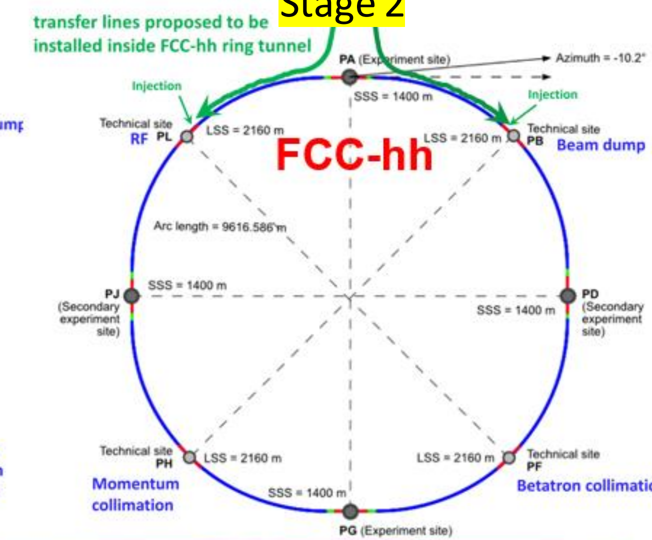
The FCC project is fully integrated with the HL-LHC exploitation and provides a natural transition for higher precision and energy



Stage 1



Stage 2



2020 - 2040 | 2045 - 2060 | 2065 - 2090

FCC-ee Design Choices → "Lowest Risk" Layout

Double ring e+ e- collider

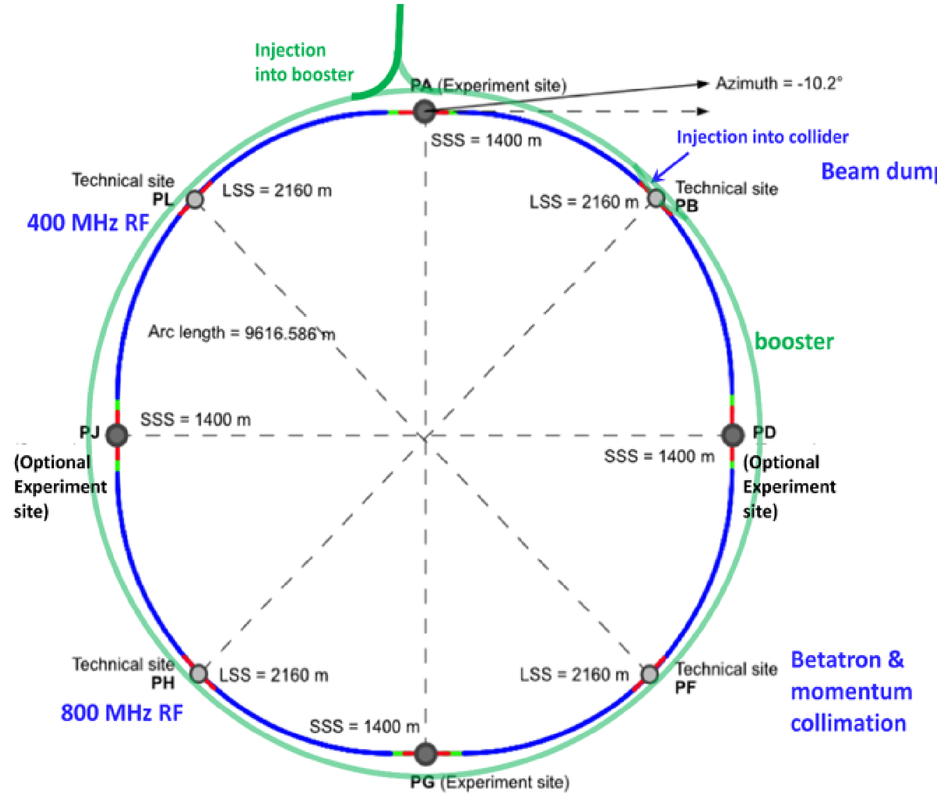
Common footprint with FCC-hh,

Asymmetric IR layout and optics to limit synchrotron radiation towards the detector

~~2 or~~ **4 IPs, large** horizontal crossing angle **30 mrad, crab-waist collision optics**

Synchrotron radiation power 50 MW/beam at all beam energies

Top-up injection scheme for high luminosity
Requires **booster synchrotron in collider tunnel**



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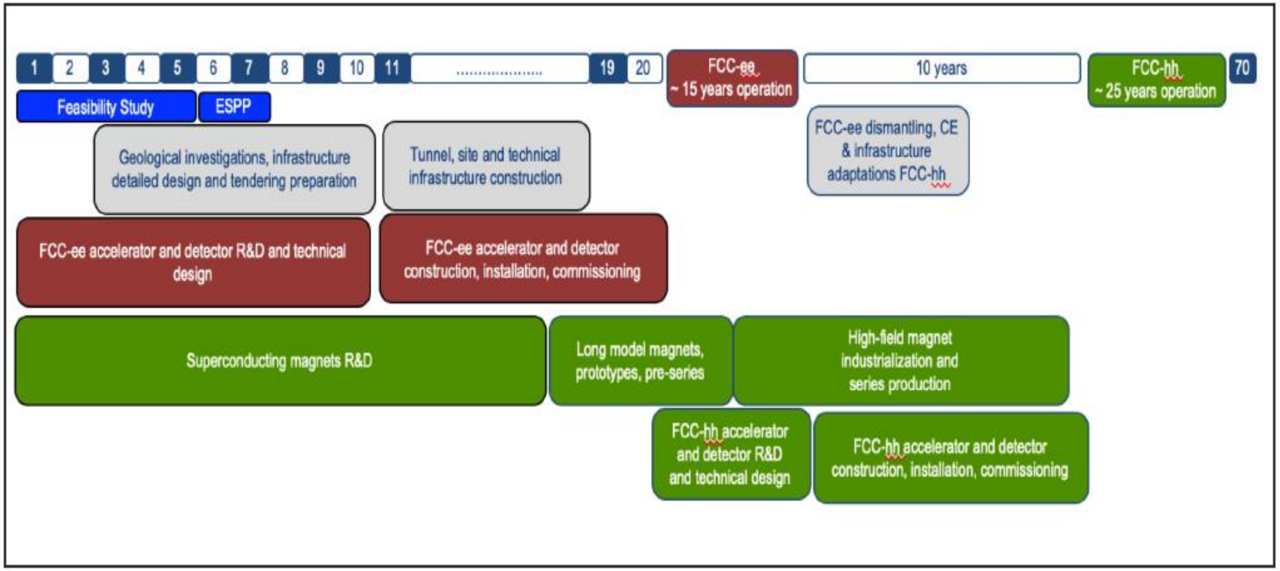
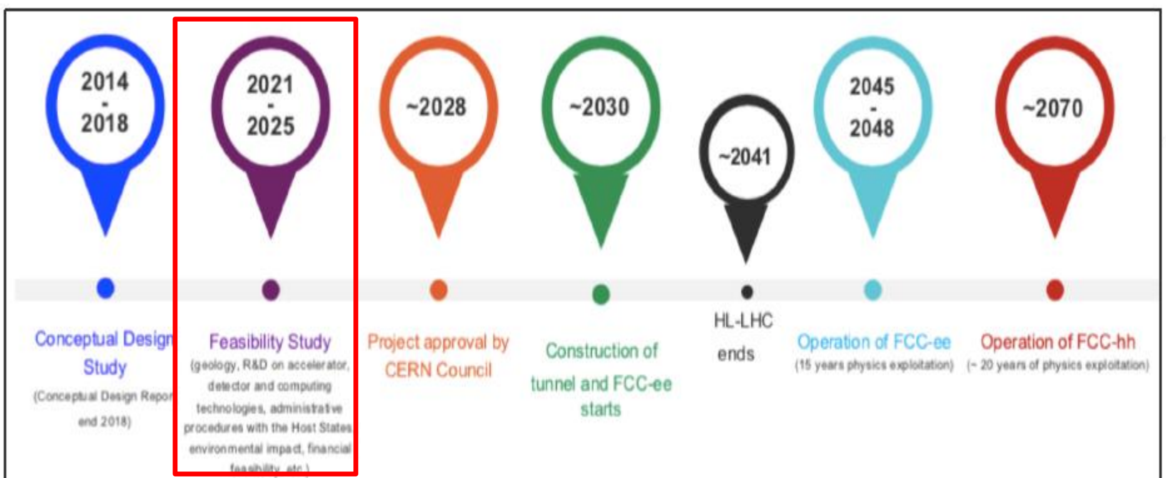


Technical schedule:
FCC-ee could start operation **in 2040 or earlier**

➔Trying to find globally additional funds to start earlier!

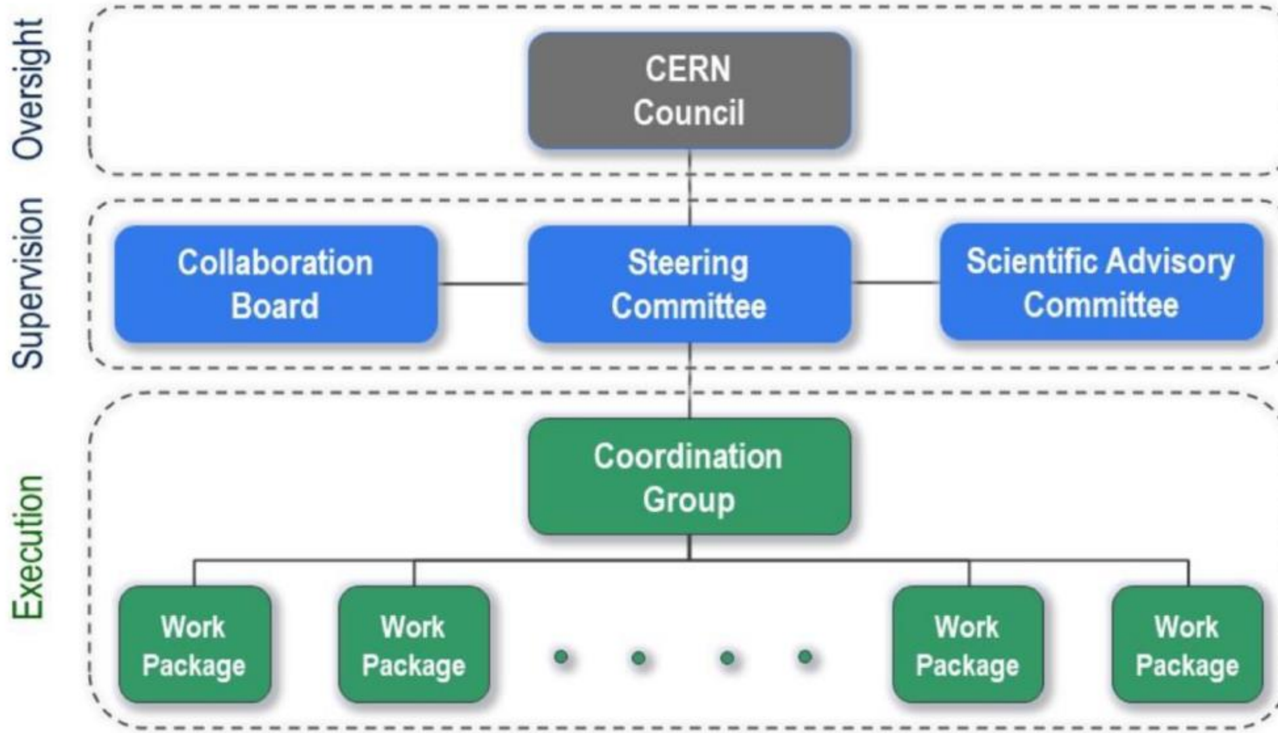


Realistic schedule takes into account:

- ❑ past experience in building colliders at CERN
- ❑ CERN Council approval timeline
- ❑ that HL-LHC will run until ~ 2041

→ **ANY future collider at CERN cannot start physics operation before 2045-2048** (but construction will proceed in parallel to HL-LHC operation)

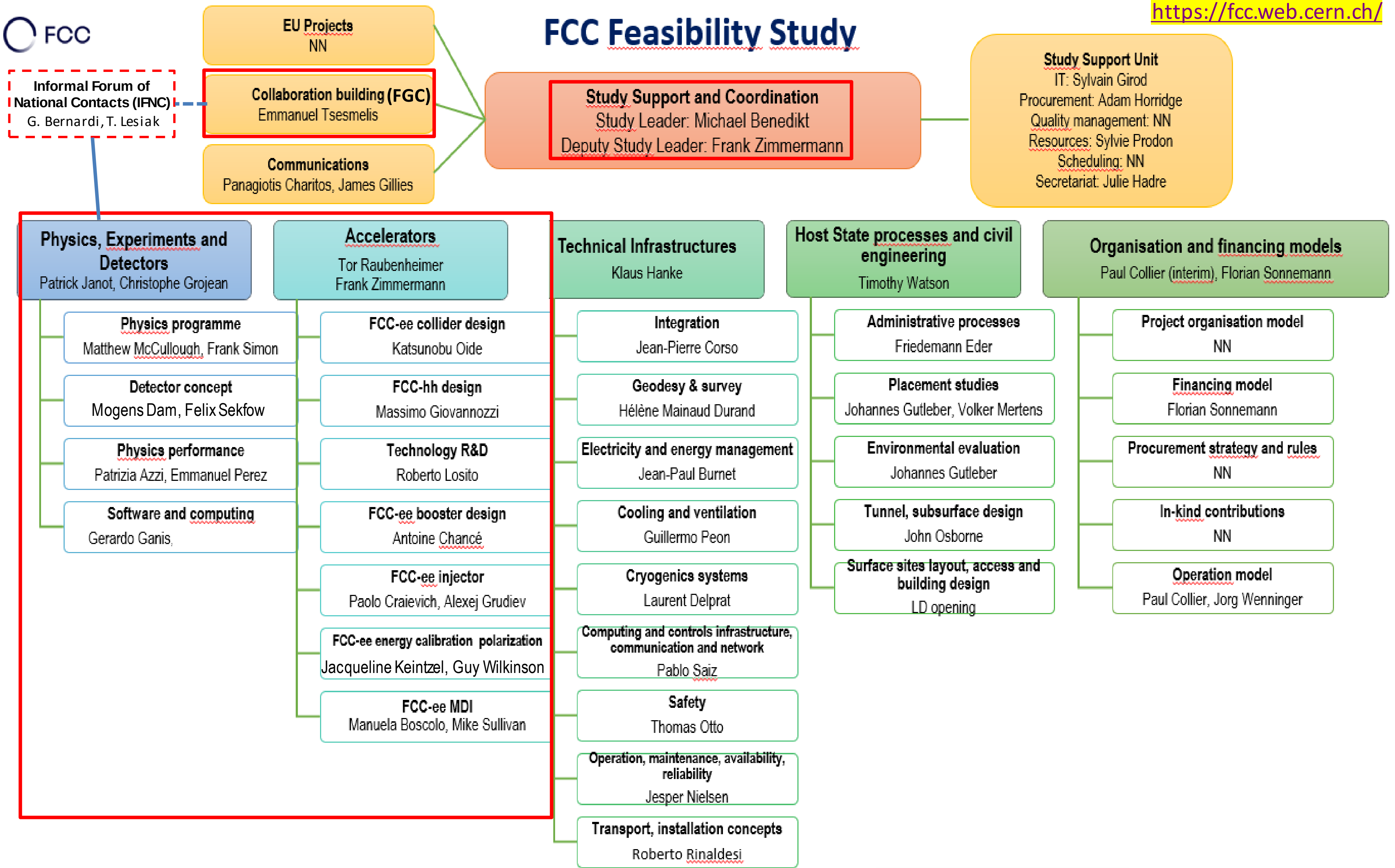
FCC Feasibility Study Organization (2021-2025)



Lia Merminga (FNAL) is member of Steering Committee
Andy Lankford (UC Irvine) is vice-Chair of Collaboration Board
Tor Raubenheimer (SLAC) is co-convener of Accelerators Work Package and member of Coordination group
Michiko Minty (BNL) is member of Scientific Advisory Committee

FCC Feasibility Study

https://fcc.web.cern.ch/



Status of Global FCC Collaboration @ CDR

Increasing international collaboration as a prerequisite for success:
→links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

FCC Feasibility Study: Aim is to increase further the collaboration, on all aspects, in particular, on Accelerator and Particle/Experiments/Detectors (PED), to render it a **fully global project**

Status of Global FCC Collaboration @ CDR

Increasing international collaboration as a prerequisite for success:
→ links with science, research & development and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

- US scientists involved since the initial Conceptual Design Study (2014)
- US involved in physics and detector studies, accelerator design and technologies for FCC-ee and FCC-hh, and civil engineering
- Several US scientists now at the top level of the FCC Feasibility Study international organisational structure
- Recently: US FCC Accelerator and FCC Physics, Experiment and Detector Coordination Groups started

Further US involment is essential to realize FCC

Plenty of Opportunities for interesting and crucial work (new detector concepts, advanced accelerator technologies, physics case studies, theoretical calculations, environmental impact and sustainability etc..

Enlarging the Collaboration

FCC Global Collaboration Working Group (FGC)

Informal Forum of National Contacts (IFNC)

Two approaches, one more formal (FGC), one more informal (IFNC) to engage with countries with mature communities, a long-standing participation in CERN's programmes and the potential to contribute substantially to the Organization's long-term scientific objectives, to facilitate opportunities for national participation in the FCC Feasibility Study

- **Work with national laboratories, institutes and universities** as well as **industry** to carry out the following mandate:
  - Encourage an **expanded membership**.
  - Explore **opportunities** for future prospective participants, in particular on the Accelerator side
  - Support new participants in **application process**.
  - Assist the new participants in defining **areas of collaboration**.
  - Conclude relevant **agreements**.
  - Facilitate the **integration** process.
  - Facilitate interest in **CERN non-core areas** - geology, geodesy, logistics, materials science.
  - Prepare the foundations for research and contributions by **industry.**
  - Liaise with **national contact persons** and **forums**.

Convened by E. Tsesmelis (CERN international relations)

- **Contact directly Physics groups in a country, typically from LHC or Future Colliders groups to ask them to join !**
  - Discuss the physics case and the opportunities
  - → To study R&D/ Detector concepts for FCC
  - → To expand the FCC Physics scope via the study of physics case studies
  - → To improve the theoretical calculations to exploit the FCC physics potential
  - Help forming a national FCC group, with strong PED component, which can hold its national FCC meetings, including the Accelerator community when possible
  - Identify one or several National Contacts to exchange information between country situation and FCC management. (e.g. for the U.S.:J. Butler, D. Denisov, S. Eno) and to strengthen the national community
  - Exchange experience across countries (IFNC meetings)

Convened by G. Bernardi and T. Lesiak (National Contacts)

FGC: FCC Engagement Meetings

- **Overview**
  - Extended forums with interested countries to discuss collaboration with FCC on all topics
  - Topics:
    - Introduction to FCC Feasibility Study.
    - Presentation of FCC physics, experiment, detector, accelerator and global collaboration.
    - Presentations from the country scientific community.
- **Recent Meetings**
  - Mexico (mini meeting on accelerator)
    - 21 June 2021
  - Republic of Korea
    - 3 September 2021
  - Pakistan
    - 14 September 2021
  - Portugal
    - 26 November 2021
  - Estonia
    - 2 March 2022
  - Greece
    - 18 January 2023

Much interest expressed by participating countries and the FCC looks forward to stronger / deeper involvement

IFNC: FCC PED kick-off Meetings

- **Overview**
  - Forums with interested countries to discuss collaboration with FCC on PED topics
  - Topics:
    - Introduction to FCC Feasibility Study.
    - Detailed presentations of FCC physics, experiment, detector. More general on accelerator and global collaboration.
- **Recent Meetings (examples)**
  - Nordic Countries (Denmark, Norway, Sweden, Finland)
    - March 2021
  - India
    - November 2022
  - Brazil
    - March 2023
- **On-going discussions**
  - Chile, Canada... (Japan and China have special status…)
  - Not yet deeply involved European countries
  - Not yet fully convinced (European) countries → ECFA

>10 outside-Europe countries with National Contacts identified

Status of the enlargement of the collaboration to be provided at mid-term & final review

FCC and ECFA*

ECFA has been charged during the European Strategy to:

1) Develop a Detector R&D Roadmap

2) Organize workshops on Physics, Experiments and Detectors for Future Higgs Factories to bring together the community working on different future projects

(*) ECFA = European Committee for Future Accelerators
- Restricted committee (one representative per member state)
- Plenary committee (more representatives per state, up to 10, as a fct of size)
- Elected Chair (2021-2023): Karl Jakobs

1. Implementation of the 2021 ECFA Detector R&D Roadmap

Q4 2022: Detector R&D Roadmap Task Forces organise community meetings to establish the scope and scale of the community wishing to participate in the corresponding new DRD activities (✓)

Q1 2023: DRDC mandate formally defined and agreed with CERN management
EDP mandate plus membership updated (✓)

Q1-Q2 2023: Develop the new **DRD proposals** based on the detector roadmap and community interest in participation, including light-weight organisational structures and work plan for R&D programme to start in 2024

Q3 2023: **Review of proposals by DRDC** leading to recommendations for formal establishment of the DRD collaborations

Q4 2023: Discussion of approval by the CERN Research Board

Q1 2024: New structures operational, ramp-up of resources throughout 2024 – 2025

Through 2023, mechanisms will need to be agreed with funding agencies in parallel to the process above for country-specific DRD collaboration funding requests for Strategic R&D and for developing the associated MoUs.

ECFA Detector Panel (EDP):

The ECFA Detector Panel (EDP) is a subcommittee of ECFA, hosted at DESY
So far: a committee to review detector development efforts for future projects

2. ECFA Study on Physics, Experiments and Detectors at a Future e^+e^- Factory

*"ECFA recognizes the need for the experimental and theoretical communities involved in physics studies, experiment designs and detector technologies at future Higgs factories to gather. **ECFA supports a series of workshops** with the aim to **share challenges and expertise, to explore synergies in their efforts** and to respond coherently to this priority in the European Strategy for Particle Physics (ESPP)."*

Goal: bring the entire e^+e^- Higgs factory effort together, foster cooperation across various projects; collaborative research programmes are to emerge

WG 1: Physics Potential
Convener: Patrick Koppenburg (Nikhef), Jenny List (DESY), Fabio Maltoni (UC Louvain/Bologna), Jorge de Blas (Granada)

WG 2: Physics Analysis Methods
Convener: Patrizia Azzi (INFN-Padova / CERN), Fulvio Piccinini (INFN Pavia) and Dirk Zerwas (IJCLab / DMLab)

WG 3: Detector R&D
Convener: Marie Cruz Fouz (CIEMAT - Madrid), Giovanni Marchiori (APC Paris) and Felix Sefkow (DESY)

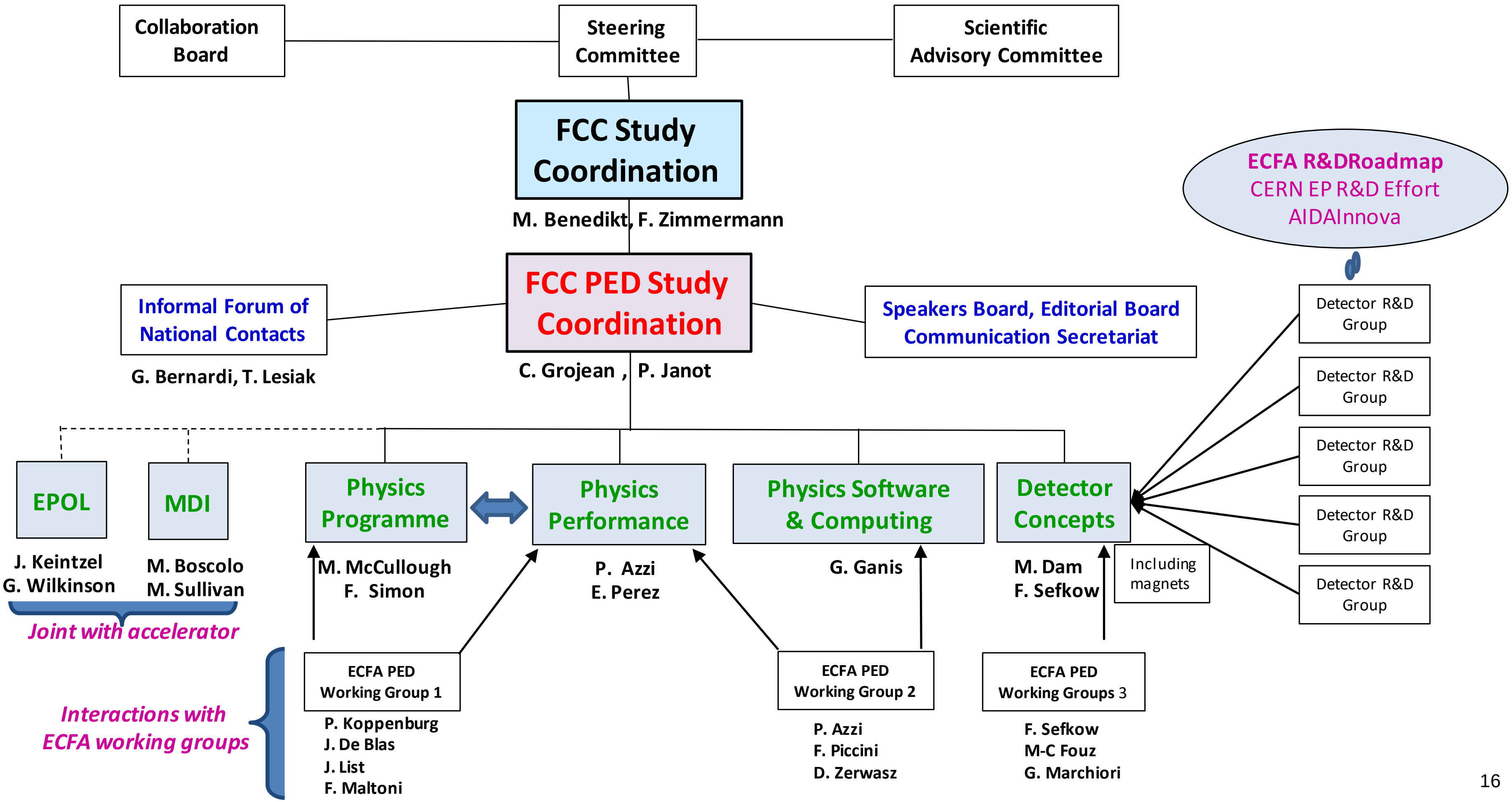
Full information about the full study is available here:
https://ecfa.web.cern.ch/ecfa-study-higgs-ew-top-factories

3. Accelerator R&D roadmap developed (→now being executed)

CERN pursue R&D on high-field magnets, SCRF, proton-driven plasma wakefield acceleration, and R&D and design studies for CLIC and muon colliders to prepare alternative options to FCC if not pursued

FCC PED Organisation & Conveners + interactions with ECFA

https://fcc-ped.web.cern.ch/



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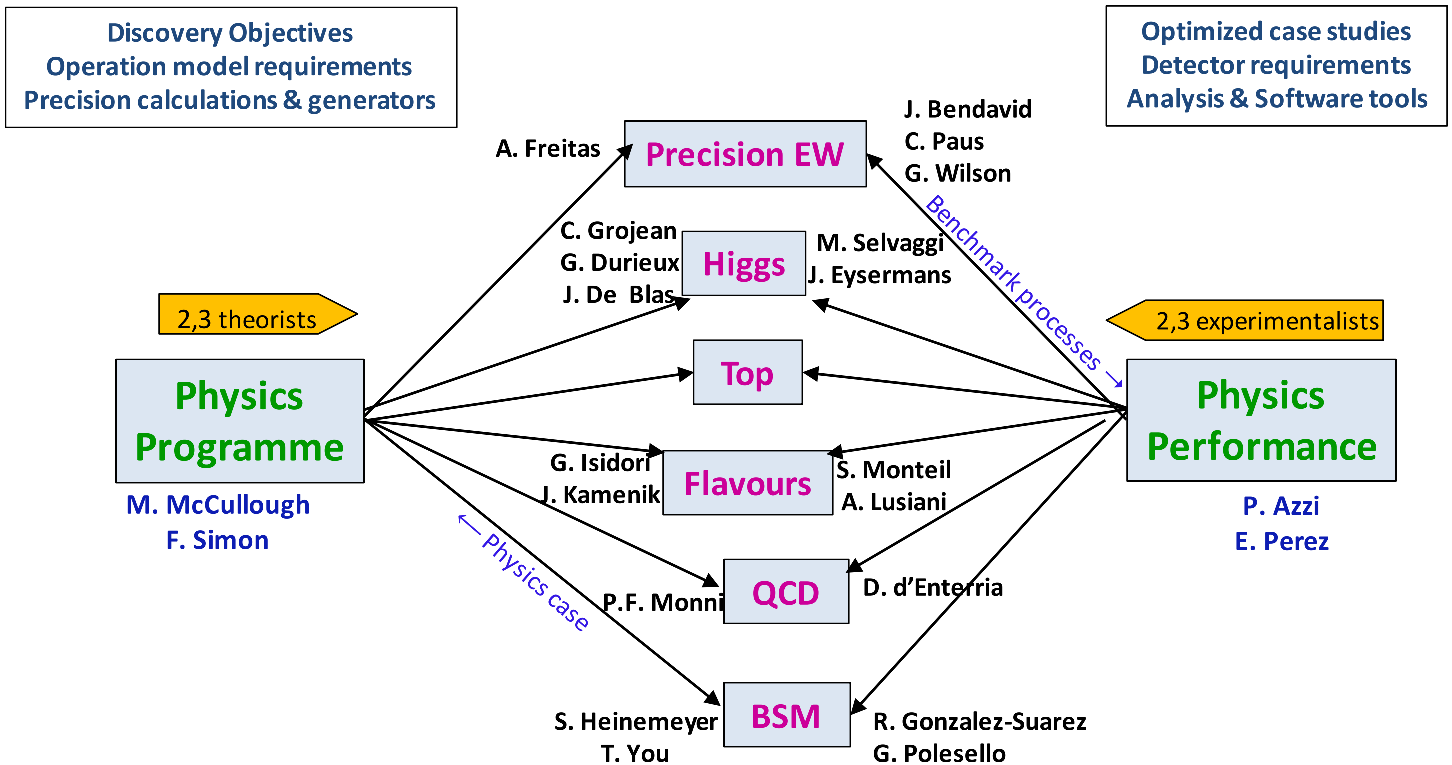
FCC Physics groups



All FCC-PED information can be retrieved from: https://fcc-ped.web.cern.ch/

FCC Feasibility Study Organization: Main Objectives

- Demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of placement and layout of the ring and related infrastructure

- Pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval

- Optimisation of the design of FCC-ee and FCC-hh colliders and their injector chains, supported by R&D to develop the needed key technologies

- Elaboration of a sustainable operational model for the machine and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency

- Development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation (emphasis on FCC-ee).
  Current cost estimate from 2018 CDR (https://fcc-cdr.web.cern.ch): 12 BCHF for tunnel and FCC-ee; 17 BCHF for FCC-hh

- Identification of substantial resources from outside CERN's budget for the implementation of first stage project (tunnel and FCC-ee)

- Consolidation of the physics case and detector concepts and technologies. Estimate of detectors cost and schedule.

Feasibility Study funded from CERN budget (~ **35 MCHF/year** over 5 years, including high-field magnet R&D).
Additional funding from the European Commission and collaborating institutes (e.g. CHART collaboration with Switzerland)

Mid-term review end of 2023 → final results in Feasibility Study Report by end of 2025

Mid-Term Review, Cost Review

Mid-term review report, supported by additional documentation on each deliverable, will be submitted to review committees and to Council and its subordinate bodies, as input for the review.

Results of both general mid-term review and the cost review should indicate the main directions and areas of attention for the second part of the Feasibility Study

Infrastructure & placement

- Preferred placement and progress with host states (territorial matters, initial states, dialogue, etc.)
- Updated civil engineering design (layout, cost, excavation)
- Preparations for site investigations

Technical Infrastructure

- Requirements on large technical infrastructure systems
- System designs, layouts, resource needs, cost estimates

Organisation and financing:

- Overall cost estimate & spending profile for stage 1 project

Environmental impact, socio-economic impact:

- Initial state analysis, carbon footprint, management of excavated materials, etc.
- Socio-economic impact and sustainability studies

Accelerator design FCC-ee and FCC-hh

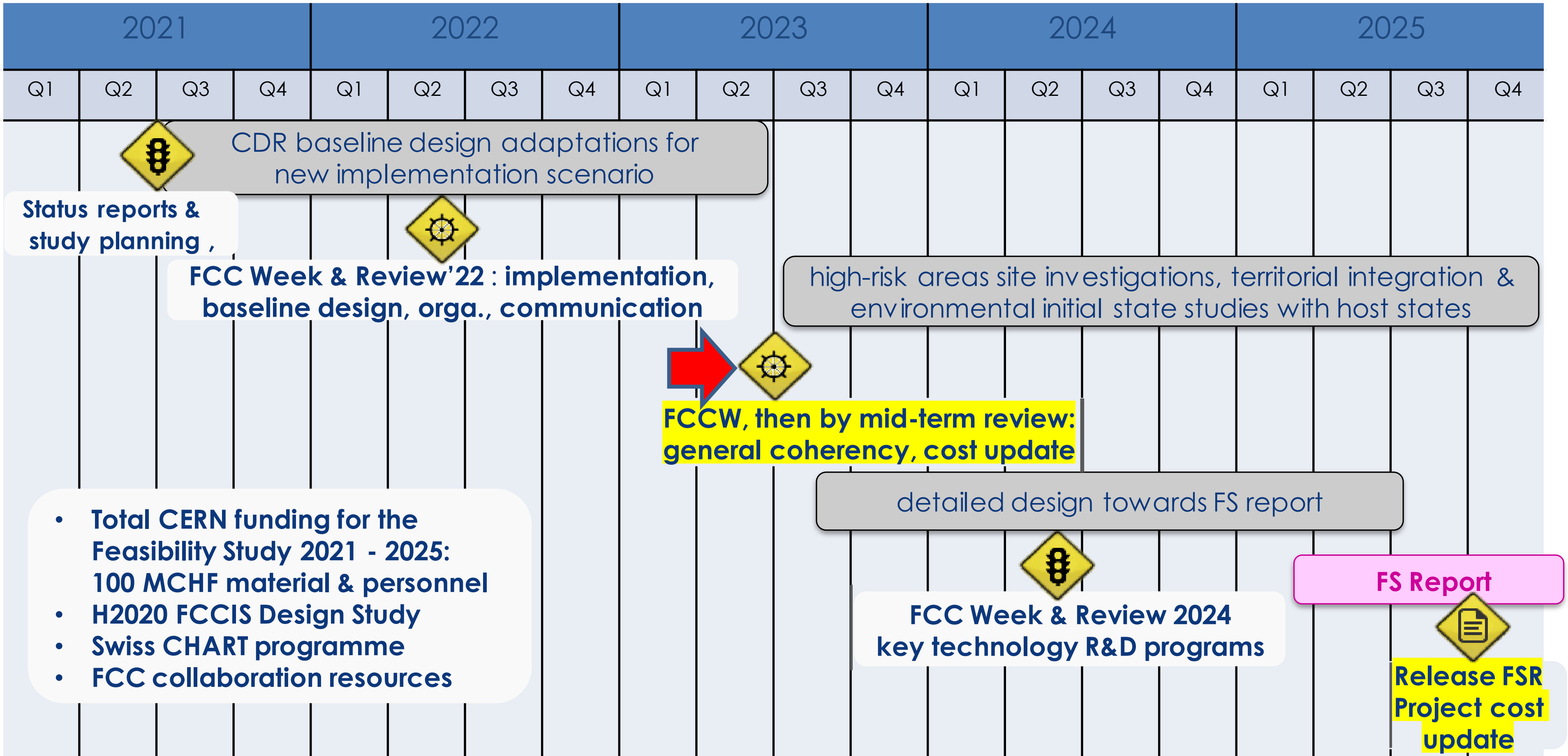
- FCC-ee overall layout with injector
- Impact of operation sequence: Z, W, ZH, $t\bar{t}$ vs start at ZH
- Comparison of the SPS as pre-booster with a 10-20 GeV linac
- Key technologies and status of technology R&D program
- FCC-hh overall layout and injection lines from LHC and SC-SPS

Physics, experiments, detectors:

- Documentation of FCC-ee and FCC-hh physics cases
- Plans for improved theoretical calculations to reduce theoretical uncertainties towards matching FCC-ee statistical precision for the most important measurements.
- First documentation of main detector requirements to fully exploit the FCC-ee physics opportunities

FCC

FCC Feasibility Study Timeline



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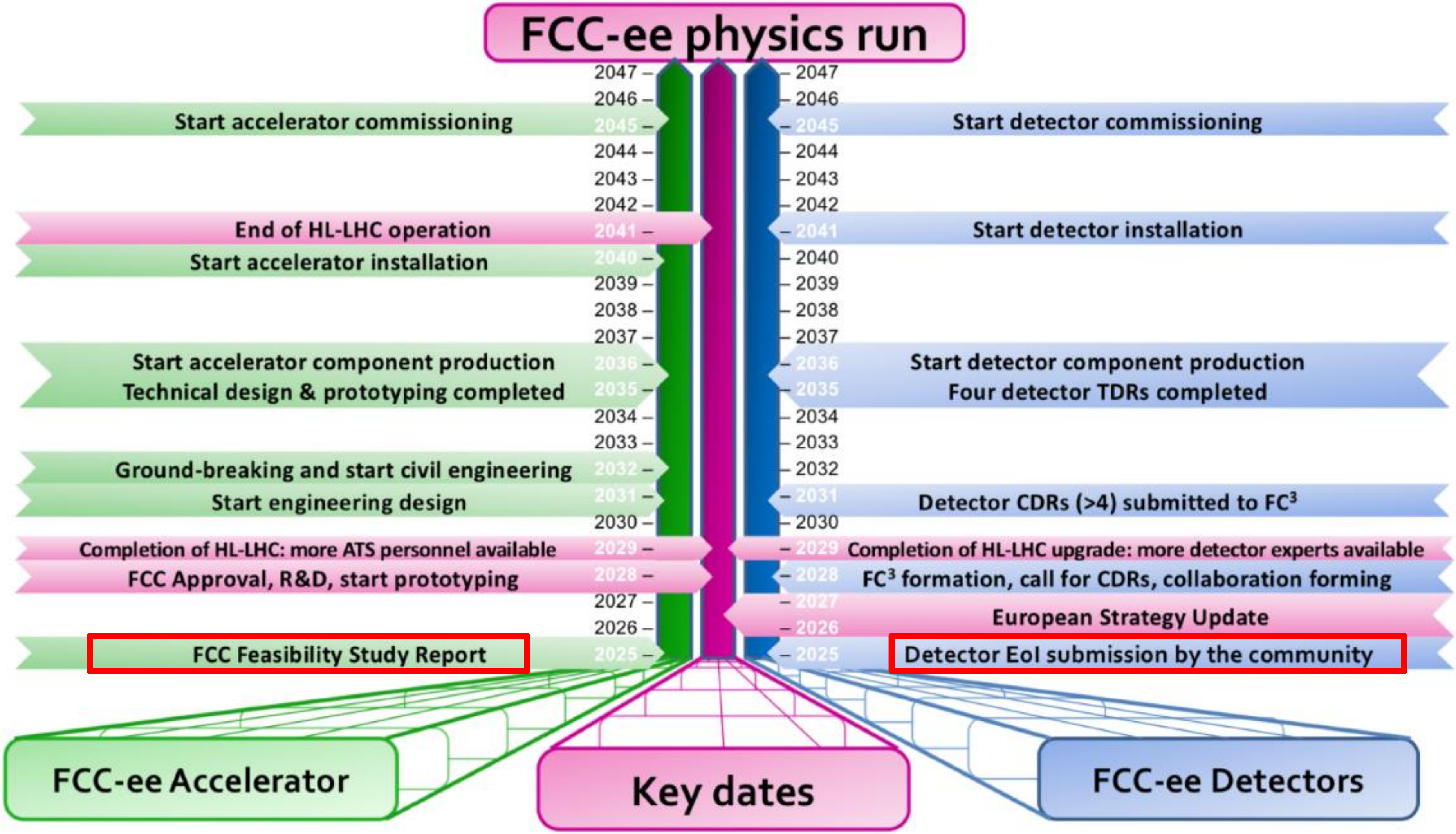


FCC-ee physics run
2047
2046
Start accelerator commissioning
2045
Start detector commissioning
2044
2043
2042
End of HL-LHC operation
2041
Start detector installation
Start accelerator installation
2040
2039
2038
2037
Start accelerator component production
Technical design & prototyping completed
2036
2035
Start detector component production
Four detector TDRs completed
2034
2033
Ground-breaking and start civil engineering
2032
Start engineering design
2031
Detector CDRs (>4) submitted to FC³
2030
Completion of HL-LHC: more ATS personnel available
2029
Completion of HL-LHC upgrade: more detector experts available
FCC Approval, R&D, start prototyping
2028
FC³ formation, call for CDRs, collaboration forming
2027
European Strategy Update
2026
FCC Feasibility Study Report
2025
Detector EoI submission by the community
FCC-ee Accelerator
Key dates
FCC-ee Detectors

FCC main goals until 2025

Overall goal:

- Perform all necessary steps and studies to enable a project decision by 2026/27, at the anticipated date for the next European Stratagy Update, and a subsequent start of civil engineering construction by 2030

This requires successful completion of the following four main activities:

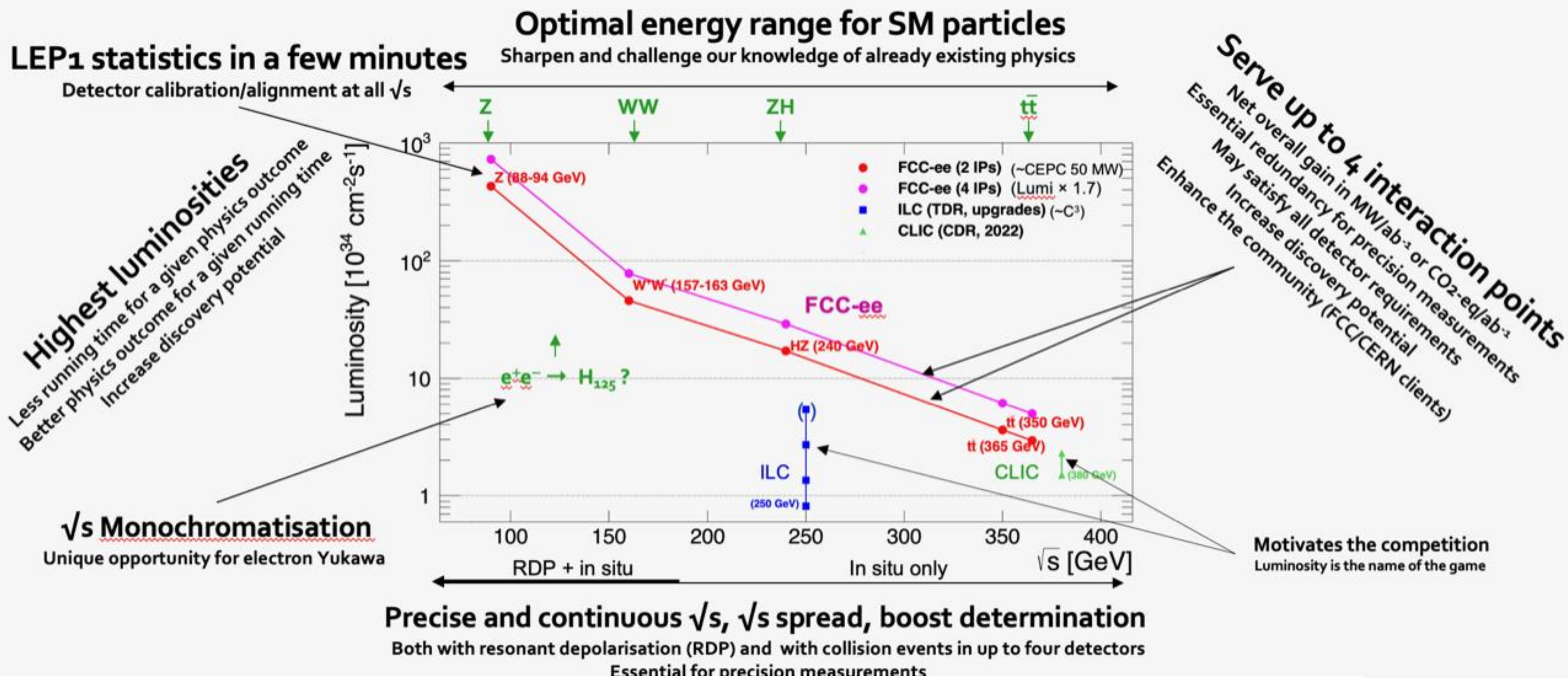
- Develop and establish a governance model for project construction and operation
- Develop and establish a financing strategy, including in-kind contributions
- Prepare all required project preparatory and administrative processes with the host states
- Perform site investigations to enable Civil Engineering planning and to prepare its tendering.

In parallel development preparation of TDRs and physics/experiment studies:

- Machine designs and main technology R&D lines
- completion of first physics case studies in 2022-23 → detector requirements
- reach out to all 'European and International Partners'
- Establish user communities, work towards detectors EoI by 2025

- **US HEP/Accelerator community can bring enormously to the FCC project,** also by contributing to **R&D/detector concept studies** and/or by reinforcing even further the excellent and very wide **physics potential of FCC-ee,** which covers all aspects of LHC & Belle Physics (Higgs, EW, Heavy Flavor, Top, QCD ….)


FCC WEEK
2023
5 – 9 June
Great to be here! We also hope to see you in London



Phase	Run duration (years)	Center-of-mass Energies (GeV)	Integrated Luminosity (ab^{-1})	Event Statistics
FCC-ee-Z	4	88-95 ± <100 KeV	150	3×10^{12} visible Z decays
FCC-ee-W	2	158-162 <200 KeV	12	10^8 WW events
FCC-ee-H	3	240 ± 1 MeV	5	10^6 ZH events
FCC-ee-tt	5	345-365 ± 2 MeV	1.5	10^6 $t\bar{t}$ events

Extracted from FCC CDR

LEP * 10^5
LEP * 2.10^3
Never done
Never done

+ possible Run at the H pole (125 GeV) to access the Hee Yukawa coupling (never done, not doable anywhere else)