FCC-ee
Collaboration(s) forming

Gregorio Bernardi
APC Paris, CNRS/IN2P3

On behalf of the FCC collaboration

Special thanks to
M.Benedikt, C. Grojean, P. Janot,
E.Tsesmelis, G. Wilkinson, F. Zimmermann

US-FCC, SLAC, September 9th, 2026

Overall Summary of the ESPP

Machine	Precision Physics	BSM physics	Physics vs CEPC	Technical readiness	Constr. cost (BCHF)	Time scale	Path to ≥10 TeV
FCC-ee	22	23			15.3	2046-2060	
Descoped FCC-ee	15	17			12.9	2046-2055	
LCF550	15	17			14.8	2045-2065	
CLIC1500	14	18			14.6	2045-2066	
LCF250	10	16			9.4	2045-2053	
CLIC380	10	16			7.5	2045-2054	
LEP3	15	17			4.1	2047-2062	
LHeC	8	7			2.1	2044-2051	

Plan A

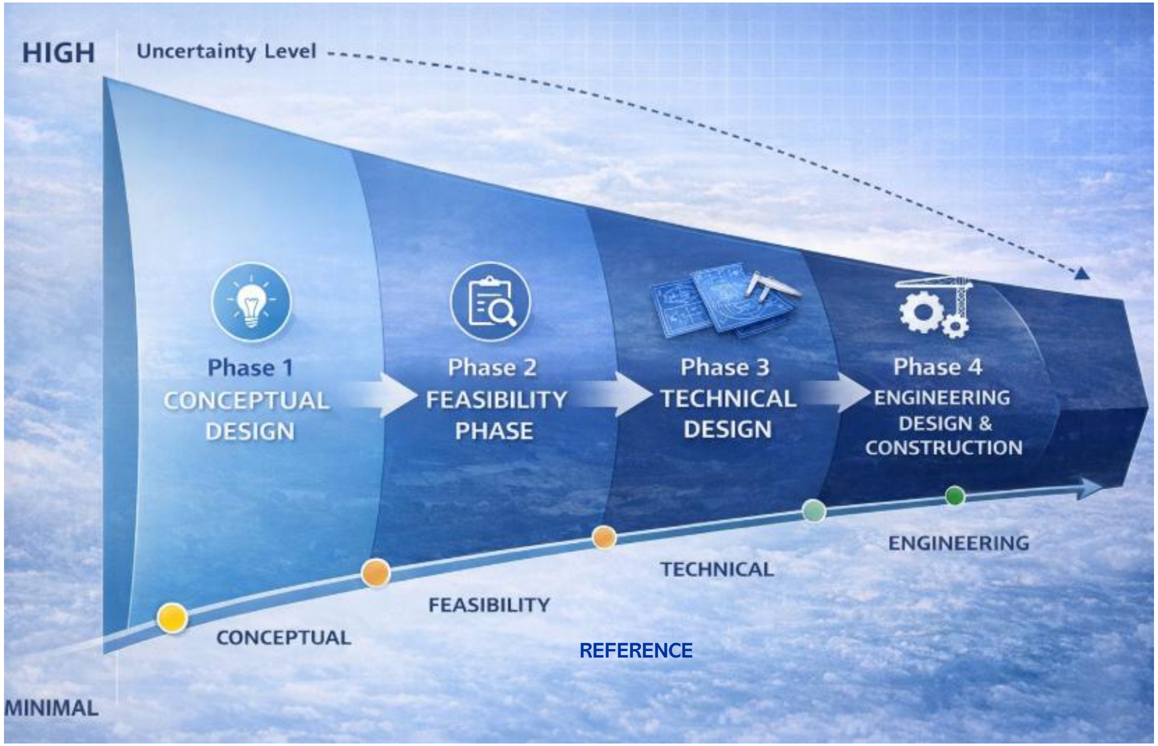
Plan B

Plan A

Plan B

Physics: from WG2b (sum of precision/BSM physics)
Physics vs CEPC: competitiveness, assuming CEPC is running in parallel
Technical readiness: from WG2a
Construction cost: from proponents + exp. (CERN part)

From Feasibility Study to Project Realisation



Following positive results of Feasibility Study and European Strategy process, **FCC moves towards technical design**

Expertise across CERN and from collaboration partners required to deliver integrated technical design, with cost estimate and schedule, bearing in mind project authorisation processes, societal acceptance, & procurement strategy

- **2026-2028 Reference Design Phase**
- **2029-2032 Technical Design Phase**

Aiming for project decision after the Reference Design Phase

"We aim to be in a position for CERN Council to take a decision from June 2028"

DG, CERN 'Town Hall' meeting 23/4/26

Recommendations of the FCC feasibility study review committee related to the FCC community development

1. to work with the scientific community, institutes, laboratories and funding agencies to ensure support and resources for at least **four experiments…**, for the exploitation of the full scientific potential of the FCC-ee facility;

2. to dedicate additional human and financial resources to the project, with a resource-loaded schedule of work;

3. to develop the coordination and structure to enable theoretical work needed to match the anticipated experimental precision of the FCC data, both at CERN and by engaging Collaborating Institutes.

…

➔ We need to enlarge further our collaboration to convince our governments to fund FCC

Community building is critical for the success of the FCC project, because it fosters political, public, and financial support, encourages collaboration/innovation and promotes education and outreach. ➔ long-term sustainability.

➔ The FCC collaboration gives high priority to collaboration building, to reach scientific success of the project:

- Establish a Global Scientific Network
- Develop Transdisciplinary Collaboration
- Inspire the Next Generation of Scientists and Engineers

Enlarging the Collaboration

FCC Global Collaboration Working Group (FGC)

International Forum of National Contacts (IFNC)

Two approaches, one globally-oriented (FGC), the other more PED oriented (IFNC), both 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 Feasibility Study

- **Work with national laboratories, institutes and universities** as well as **industry** to carry out the following mandate:
  - Explore **opportunities** for future prospective participants, in particular on the Accelerator side
  - Support new participants in **application process**.
    AND 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**

→ **MoU and Collaboration Board**

Convened by E. Tsesmelis (CERN international relations)

- **Contact directly Physics groups in a country,** typically from LHC or Future Colliders groups to invite them to **join as new institution**
  - Discuss the physics case and the opportunities
    → To study **R&D/ Detector concepts** for FCC, and expand the FCC Physics scope
    → 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 at least one **National Contact** to exchange information between country situation and FCC management, and to strengthen the national community
  - Exchange experience across countries(**IFNC meetings**)

→ **MoU + GreyBook and IFNC**

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

FCC

Examples of IFNC / Collaboration activities

PED kick-off meetings (most recent)

France (Paris)	December 2020
Nordic Countries (Denmark, Norway, Sweden, Finland)	March 2021
India (Bangalore)	November 2022
Brazil (Rio de Janeiro)	March 2023
Mexico (Mexico City)	November 2024
Chile (Santiago)	January 2025
Canada (Ottawa)	June 2026

Yearly Reports in the IFNC plenary from:

11 European regions (corresponding to ~30 countries)

- Spain+Portugal
- France
- UK
- Italy
- Germany
- Belgium+Netherland
- Nordic+Baltic countries
- Switzerland
- Austria+Slovenia+Croatia
- Poland+Czekia+Slovakia+Hungary
- Romania+Bulgaria+Serbia+Greece+Turkey+Israel

+ Non EU countries or regions:

- India
- Korea/Japan
- Brazil/Argentina/Chile/Mexico
- USA / Canada

Last reviews at FCC Physics workshops, January 2025 & 2026

How to register as an FCC PED team in the Grey book

- join FCC by registering in the Grey book, after signing an MoU if not done yet

Memorandum of Understanding for the Technical Design Phase of the Future Circular Collider (FCC) hosted by CERN

Registration of a new FCC Team in the CERN Grey Book for Physics, Experiments and Detectors (PED) activities:

1. The institution signs the MoU for the FCC Feasibility Study (contact: fcc.office@cern.ch) See also Collaboration | Future Circular Collider
2. The institution sends the form 'Appointmentform_TL_DTL.pdf' to the PED Pillar Coordinator Patrick Janot for approval with fcc.office@cern.ch in copy. See also Duties and Obligations of the Team Leader | Users Office
3. Once approved by Patrick Janot, the FCC Study Office liaise with the CERN Grey Book for the registration of the team and the appointment of team leader and deputy/ies.

NB: institutions that participate in activities other than PED cannot request a team in the CERN Grey Book. Their participation and the registration of their members are handled via collaboration agreements (addenda to FCC MoU).

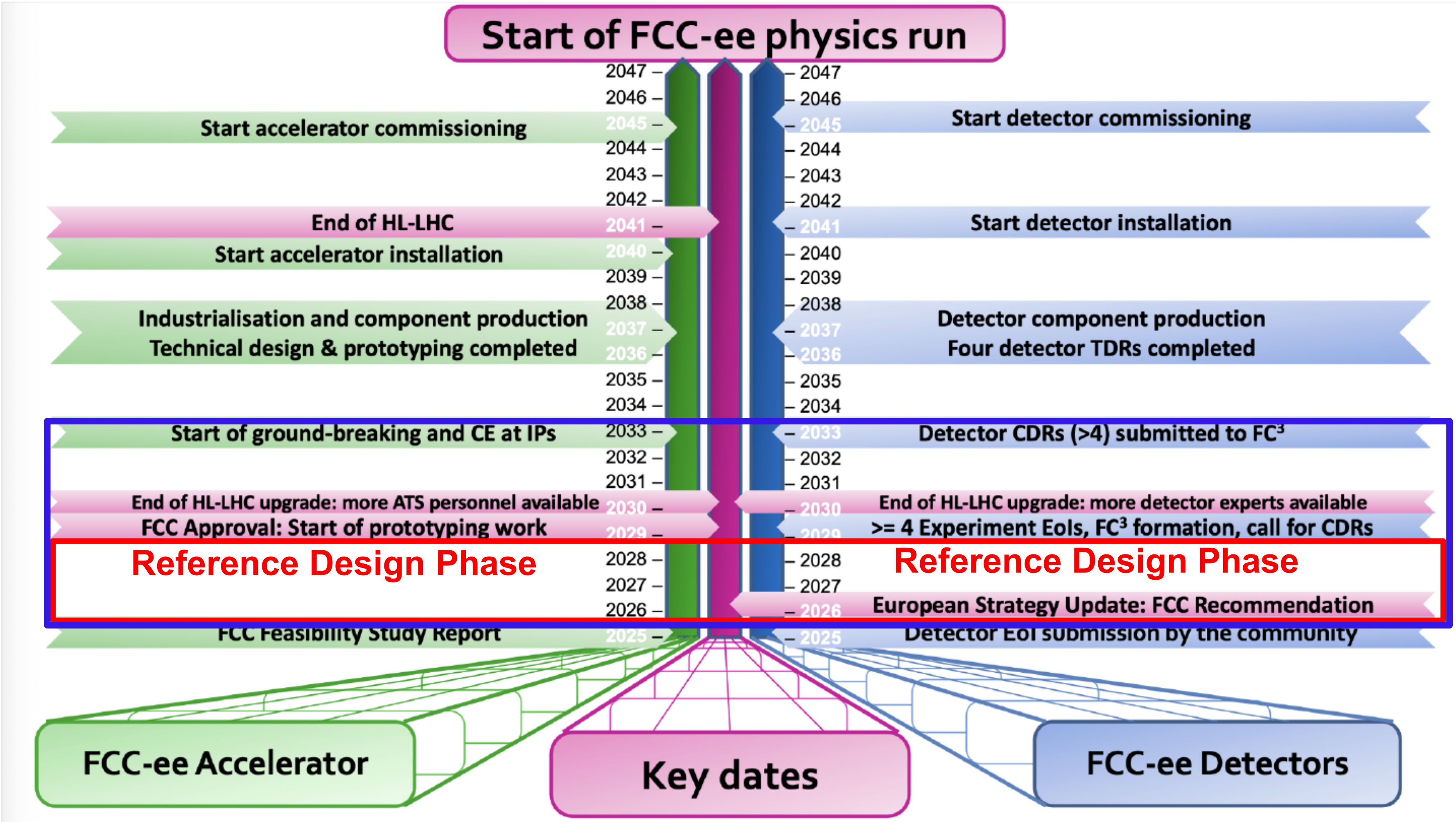
1		contact name	contact email
2	U.-mass Amherst	Stephane Willocq	Stephane.Willocq@cern.ch
3	ANL	Jinlong Zhang	zhangjl@anl.gov
4	AZ	Erich Varnes	varnes@physics.arizona.edu
5	Brandeis	Aram Apyan	aram.apyan@cern.ch
6	BNL	Marc-Andre Pleier	mpleier@bnl.gov
7	BROWN	Loukas Gouskos	Loukas.Gouskos@cern.ch
8	BU	Zeynep Demiragli	zeynep.demiragli@cern.ch
9	Caltech	Maria Spiropulu	smaria@caltech.edu
10	Carnegie Melon	John Alison	johnalison@cmu.edu
11	Columbia	John Parsons	parsons@nevis.columbia.edu
12	Duke	Ashutosh Kotwal	kotwal@phy.duke.edu
13	FIT	Marcus Hohlmann	hohlmann@fit.edu
14	FNAL	Daniel Elvira	daniel@fnal.gov
15	Indiana	Chris Meyer	chris.meyer@cern.ch
16	Iowa	Yasar Onel	Yasar.Onel@cern.ch
17	Jefferson lab	Kondo Gnanvo	kagnanvo@jlab.org
18	JOHN HOPKINS	Andrei Gritsan	gritsan@jhu.edu
19	Maryland	Alberto Belloni	abelloni@umd.edu
20	Michigan	Jianming Qian	qianj@umich.edu
21	Michigan state	Reinhard Schwienhorst	schwier@msu.edu
22	MIT	Christoph Paus	paus@mit.edu
23	Northeastern	Louise Skinnari	l.skinnari@northeastern.edu
24	Notre Dame	Randy Rutchi	rruchti@nd.edu
25	Oak Ridge	Marcel Demarteau	marcel.demarteau@cern.ch
26	PRINCETON	Chris Tully	chris.tully@cern.ch
27	Purdue	Andreas Jung	anjung@purdue.edu
28	Rochester	Aran Garcia Bellido	aran@pas.rochester.edu
29	SLAC	Charlie Young	young@slac.stanford.edu
30	Stony Brook	Dmitri Tsybychev	Dmitri.Tsybychev@stonybrook.edu
31	Syracuse	Marina Artuso	martuso@syr.edu
32	Texas austin	Tim Andeen	tandeen@utexas.edu
33	tufts	Hugo Beauchemin	hugo.beauchemin@tufts.edu
34	UCSC	Mike Hance	mhance@ucsc.edu
35	UC Irvine	Anyes Taffard	anyes.taffard@cern.ch
36	UNM	Sally Seidel	seidel@unm.edu
37	VIRGINIA	Bob Hirosky	hirosky@virginia.edu

Today in the Grey book, from the US side

Institute Name	Institute Parent Name	Town	Country	Team Leader & Deputy Team Leader(s)
Santa Cruz Institute for Particle Physics	University of California,Santa Cruz	Santa Cruz	United States	(TL) HANCE, MICHAEL (DTL) AFFOLDER, ANTHONY (DTL) MAZZA, SIMONE MICHELE
Enrico Fermi Institute	University of Chicago	Chicago	United States	(TL) BADEA, ANTHONY
Department of Physics	University of Florida	Gainesville	United States	(TL) TAKAHASHI, YUTA (DTL) CHANG, PHILIP
University of Virginia		Charlottesville	United States	(TL) HIROSKY, ROBERT JAMES (DTL) NGUYEN, HUONG THI
Department of Physics & Astronomy	Stony Brook University	Stony Brook	United States	(TL) PIACQUADIO, GIACINTO (DTL) TSYBYSHEV, DMITRY
Massachusetts Inst. of Technology		Cambridge	United States	(TL) PAUS, CHRISTOPH (DTL) SMITH, ELUNED ANNE
Purdue University		West Lafayette	United States	(TL) JUNG, ANDREAS WERNER
Brookhaven National Laboratory		Upton	United States	(TL) PLEIER, MARC-ANDRE (DTL) RAJAGOPALAN, SRINIVASAN
Fermi National Accelerator Lab.		Batavia	United States	(TL) ELVIRA, VICTOR DANIEL (DTL) CANEPA, ANADI (DTL) APRESYAN, ARTUR
Syracuse University		Syracuse	United States	(TL) RUDOLPH, MATTHEW SCOTT (DTL) ARTUSO, MARINA
Indiana University		Bloomington	United States	(TL) MEYER, CHRISTOPHER JOHN (DTL) LAMMERS, SABINE WEDAM
Princeton University		Princeton	United States	(TL) TULLY, CHRISTOPHER (DTL) LANGE, DAVID JOHN

FCC Physics, Experiments, Detectors (PED)

Objectives for the Reference Design Phase (2026-2028) Inside the Technical Design Phase (→ 2033)



FCC

PED Objectives during the RDP

- Consolidation of the **interaction region layout**, **detector integration**, and **beam-induced background mitigation**
- Optimised **procedures for √s calibration** and for **effective operation** at √s = 125 GeV
- Finalising the **common software/analysis framework** and developing a **common computing architecture**
- Realistic implementation of algorithms to **control the experimental systematic uncertainties** for the most demanding measurements ➔ **requirements on detectors, collider, and theory**
- Proposals for staging implementation and for an improved **staged/descoped FCC-ee**

- **Engagement of the theory community** to address theory challenges and attract the young generation
- Continue developing the **high-energy physics international community**
- Prepare to answer call for (at least 4) documented **EoI's for FCC-ee detector concepts** by mid 2028

Theoretical challenges ahead

Theoretical work needed to enable *extraction* of EWPO from measurements (additional work needed for making predictions)

Quantity	Current precision	FCC-ee stat. (syst.) precision	Required theory input	Theory status as of today	Needed theory improvement†
m_Z (MeV)	2.0	0.004 (0.1)	non-resonant $e^+e^- \to f\bar{f}$, initial-state radiation (ISR)	NLO, ISR logarithms up to 6th order	NNLO for $e^+e^- \to f\bar{f}$
Γ_Z (MeV)	2.3	0.004 (0.012)			
$\sin^2\theta^\ell_{\mathrm{eff}}$	1.6×10^{-4}	$1.2\,(1.2)\times10^{-6}$			
m_W (MeV)	9.9	0.18 (0.16)	lineshape of $e^+e^- \to WW$ near threshold	NLO ($e^+e^- \to 4f$ or EFT framework)	NNLO for $e^+e^- \to WW$, $W \to f\bar{f}'$ in EFT setup
HZZ coupling	– *	0.1%	cross section for $e^+e^- \to ZH$	NLO EW plus partial NNLO QCD/EW	full NNLO EW
m_{top} (MeV)	290	4.2 (4.9)	threshold scan $e^+e^- \to t\bar{t}$	N^{3}LO QCD, NNLO EW, resummations up to NNLL, $\mathcal{O}$(30 MeV) scale uncert.	Matching fixed orders with resummations, merging with MC, α_S (input)

† The necessary theory calculations mentioned are a minimum baseline; additional partial higher-order contributions may also be required.

* No absolute value for the HZZ coupling can be extracted from the LHC data without additional assumptions.

[from FSR and Freitas *et al.* arXiv:1906.05379]

Constraints from physics

- Non-trivial requirements at the Z pole, e.g.
  - Z width (momentum resolution @ 45 GeV)
  - τ lifetime (absolute vertex det. dimensions)
  - τ polarisation (calorimeter granularity)
  - Luminosity with di-photons (FW acceptance determination, photon angular resolution)
  - Flavours (beam pipe material, IP resolution, particle identification)
  - LLPs (continuous tracking and calorimetry)
- Higgs and top physics will also benefit from
  - Particle Flow reconstruction (calorimeter granularity, jet energy and angular resolution)
  - Flavour tagging (also gluon and s quarks)
- Far from an exhaustive list !
  - Much remains to be understood/studied in RDP
  - Even the conservative (partial) list is challenging
- There will be no universal detector solution
  - Calls for complementary detector concepts
  - Four interaction points

Constraints from the machine

- Invasive final focus system (1.4 m) and large horizontal crossing angle (30 mrad)

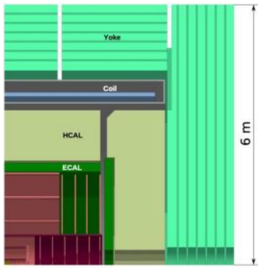
  Mechanical integration of beam pipe, vertex detector, and luminometers
  - Detector assembly, opening, and maintenance strategy
  - Compact and extremely precise [O(1 μm)] luminometers with small-angle Bhabha scattering

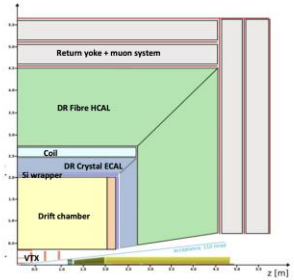
  The crossing angle is an essential input for detector acceptance in-situ determination

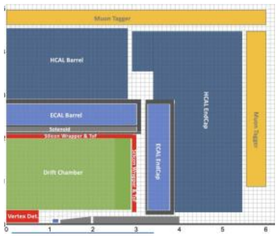
  The crossing angle depends on the colliding bunch parameters.
- The detector magnetic field causes emittance blow-up that affects luminosity at the Z pole
  - Used to limit the solenoid field to 2 T with local compensation
  - Working hypothesis: increase to 3 T with non-local compensation
- Large beam-induced backgrounds (synchrotron radiation, incoherent pair creation, …)
  - Causes significant detector occupancy (vertex, tracker, luminometers
  - May influence detector technology choices, detector segmentation, and beam pipe radius

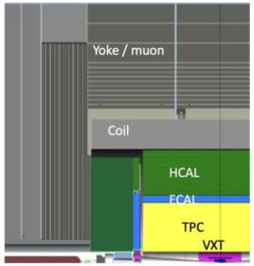
Detector and accelerator optimisation must therefore proceed together

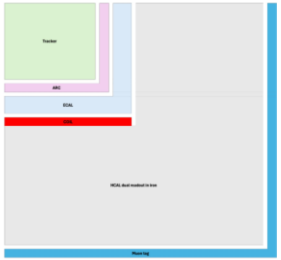
Detector concepts: a broad spectrum of complementary ideas

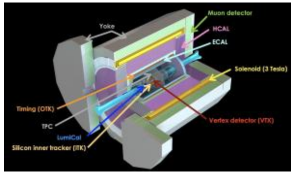








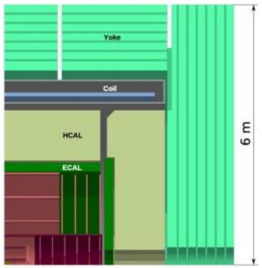


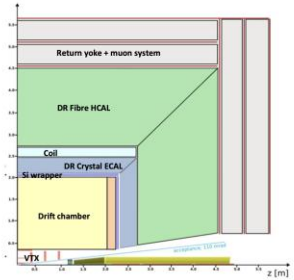


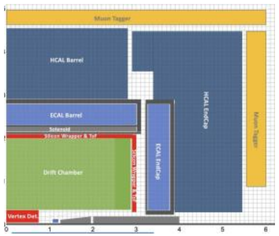
	CLD	IDEA	ALLEGRO	ILD	ALFA emerging	AGORA from CEPC, new for FCC-ee
Vertex	Si	MAPS (ITS-3 like)	MAPS (ITS-3 like)	Si	MAPS (ITS-3 like)	MAPS
Tracker	Full Si	Drift Chamber + Si strip	DCH / Straw / SciFi + Si	TPC + Si strips	All MAPS	TPC + Si strips
ECAL	Si-W highly granular	Crystals w. DR	Noble Liquid (LAr)	Si-W highly granular	GRAiNITA (crystal grains)	Crystals
HCAL	Scint. sampling	Fibre DR	TileCal (steel/scint.)	Scint. or RPC	Tile DR + steel yoke	Glass scint. + steel
Muon	RPC in iron yoke	µRWELL	TBD	Scint. in iron yoke	TBD	Scint. in yoke
PID	RICH (option)	tracker dN/dx (+ TOF)	tracker dN/dx (+ TOF)	tracker dN/dx (+ TOF)	Čerenkov ARC	tracker dN/dx (+ TOF)
Coil **B-field**	Outside HCAL 2T	Inside HCAL 2T (3T HTS R&D)	Inside HCAL 2T	Outside HCAL 3.5 T -> 2-3 T	Inside HCAL 3T	Outside HCAL 3T

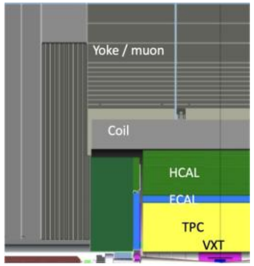
14

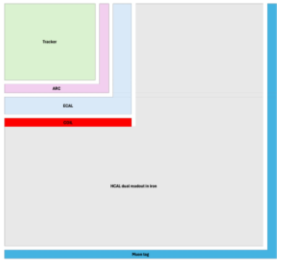
How the (US) teams will push their favorite concepts in the next 2-3 years?

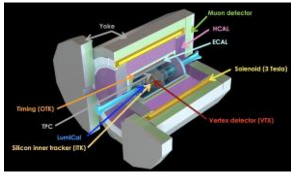












CLD	IDEA	ALLEGRO	ILD	ALFA	AGORA
				emerging	from CEPC, new for FCC-ee

- National Contacts and Team Leaders (+DTL) will play a crucial rôle in the EoI definitions.
- Funding is not at the level yet of biasing the choices
- In the large countries, coherent efforts will help to select the best subdetectors towards the best detector concepts
- Time is running short to weight in, better to engage significantly now ;)
- Let’s be ready « administratively » by early 2027 with all the interested teams registered

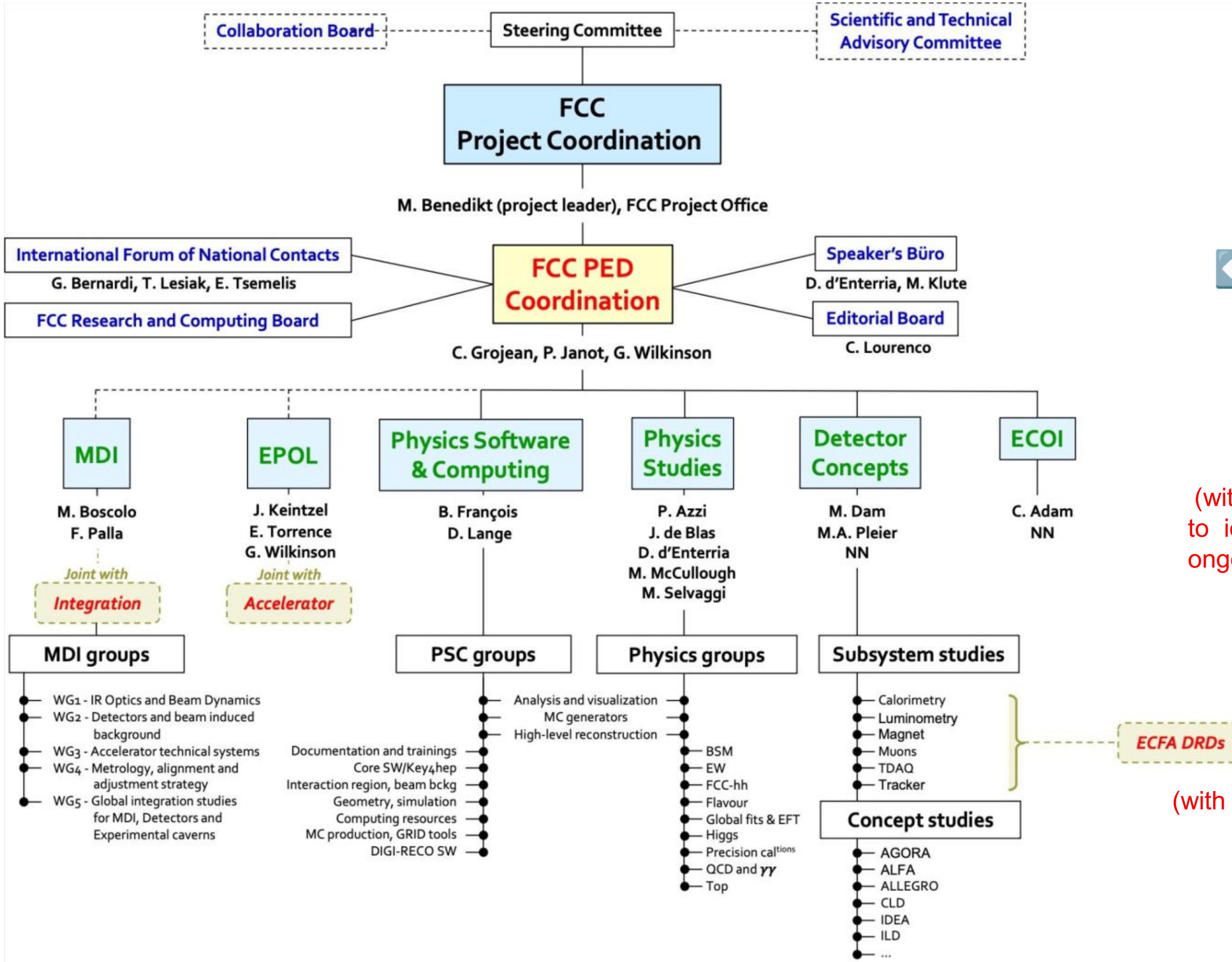
Possible Scenario post RDP (i.e. after 2028)

- Call for EoI's once the definite go-ahead is given in 2028
- ~6 EoI's/CDR are submitted: each Team can typically be part of one or two EoI
- 2029-2030: Efforts to merge some of the EoI 's into 4 CDRs, possibly driven by FCCC or ECFA in « Evian-like » workshops
- 2030-2032: CDRs being prepared/detailed to become the base of 4 experiments
- 2032-2033: CDR's submitted to the FCC-Committee (FC3)

Funding for the different CDR's becomes concrete

It's coming soon, let's get ready organizing our teams and their priorities !

PED collaboration structure



Direct access to RCS

⬅ PED as one of the 9 FCC pillars

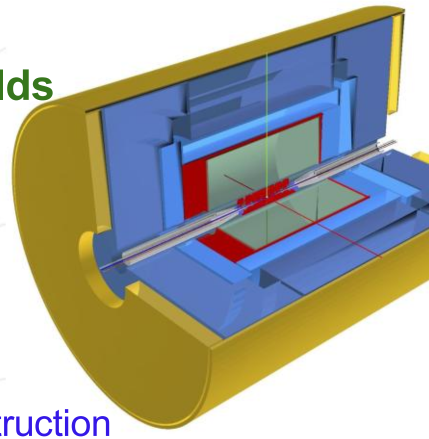
⬅ 6 WPs
(with public call for nomination to identify coordinators – Call ongoing for Detector Concepts)

⬅ 36 WGs
(with public call for nomination to identify conveners)

Technologies come together into detector "concepts"

- **Already six detector concepts under study – they are not experiment collaborations**
  - Two new concepts, ALFA and AGORA, have been presented during the FCC Week in Helsinki
  - A healthy situation at this point of the studies – **more concepts are possible**
    - It shows the interest / the commitment of the particle-physicist community towards FCC-ee
    - It allows different associations of many different subsystem technologies to be explored and validated (or not)
    - It increases the probability that four complementary detectors eventually satisfy all requirements

- **Detector concepts also provide the link between three different worlds**
  - They translate **physics requirements** into detector performance
  - They confront ambitions with **technological and engineering capabilities**
  - They naturally identify the still **necessary R&D and test-beam** campaigns



- **Ingredients needed for a complete study**
  - Full simulation of detector subsystems, including digitisation and local reconstruction
    - Provides freedom to combine technologies ("plug'n'play" in key4hep software)
    - Enables validation of single particle performance measured with prototypes
    - Realistically predicts the full event performance, and allows detector concept comparisons
  - Detailed engineering
    - Respond to and act on the constraints from the integration in the machine-detector interface (MDI) layout
    - Guide the optimisation of the global structure and parameters
  - Realistic design with progressively more mature demonstrators
    - Mechanical engineering, electronics, cooling, prototype scalability, component production strategy, …

Next Steps in FCC Collaboration building, from the PED side

The FCC project is based on MoU's.   FCC-PED management interacts with National Contacts and Institute contacts.

To be more organized in PED, we aim at having all the participating institutes/Universities "registered" in the same way

We have now the possibility to register the institutes under the FCC collaboration, to appear in the CERN Grey book, with a Team Leader (and possibly one or two Deputy Team Leader).

1) have the current PED institutes to register in the Grey Book, with a TL and possibly a DTL.

2) Obtain from the TL/DTL the expertise of the lab, and the activities in which the institute is involved and wants to be involved. This will allow to have a better estimate of the forces to realize the FCC projects

3) With the help of the National/Institute Contacts, contact more LHC or FC teams (there are 244 in ATLAS, 257 in CMS, 98 in LHCb..) to ask when they would join FCC, starting from the countries already active at LHC !