Goals of the Workshop

4th FCC / DRD France Workshop, Strasbourg (Nov.22-24/2023)

Gregorio Bernardi

The FCC integrated program (FCC-INT) at CERN goes well beyond the successful LEP – LHC (1976-2041) program

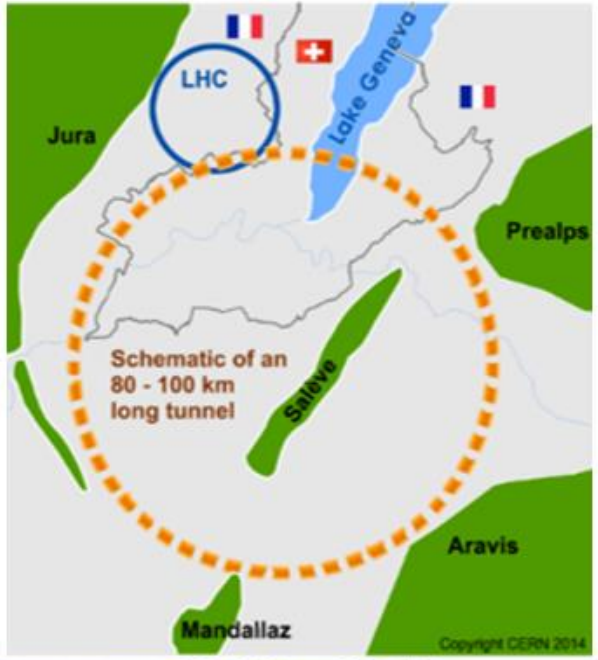
Comprehensive cost-effective program maximizing physics opportunities

- Stage 1: FCC-ee (Z, WW, H, tt, m_H?) as best Higgs, EW, Heavy Flavour and top factory at the highest luminosities
- Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with heavy ions and eh options

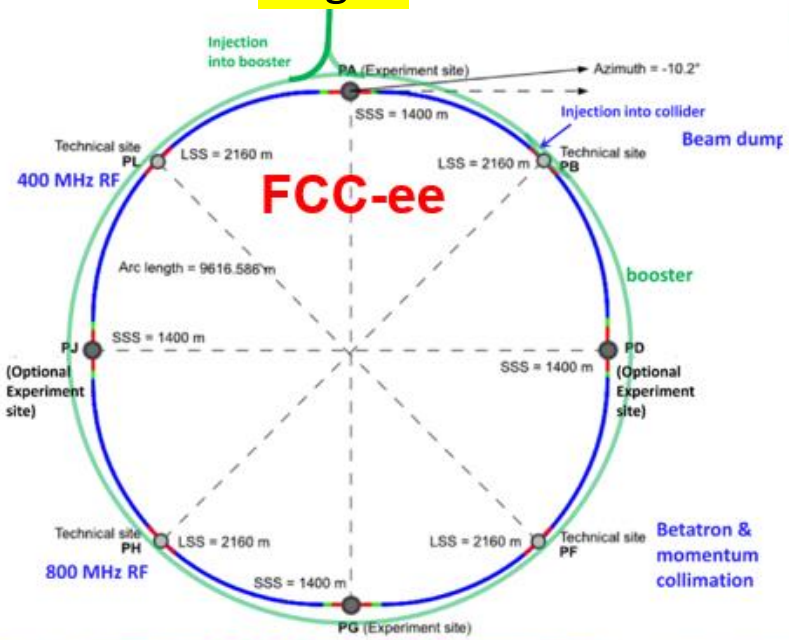
Complementary physics

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

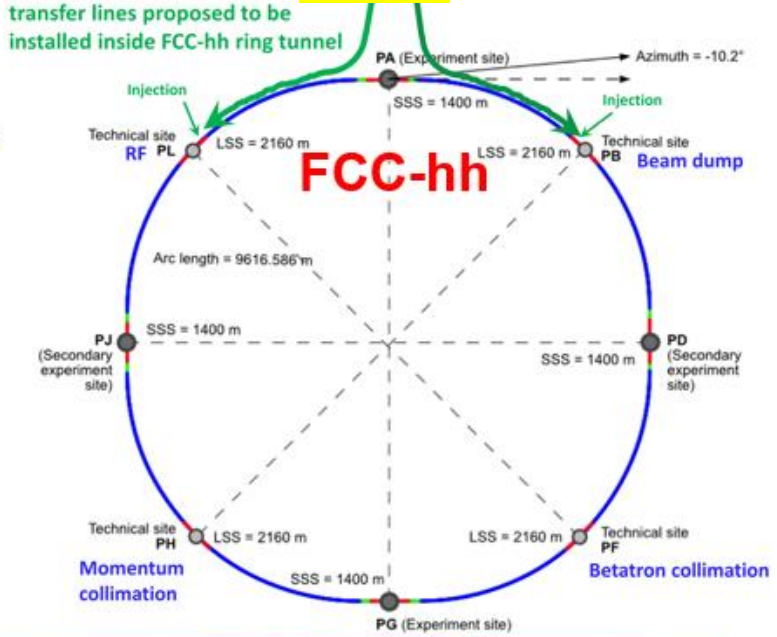
The FCC-INT project is fully integrated with HL-LHC exploitation and provides a natural transition for higher precision, energy & scope



Stage 1

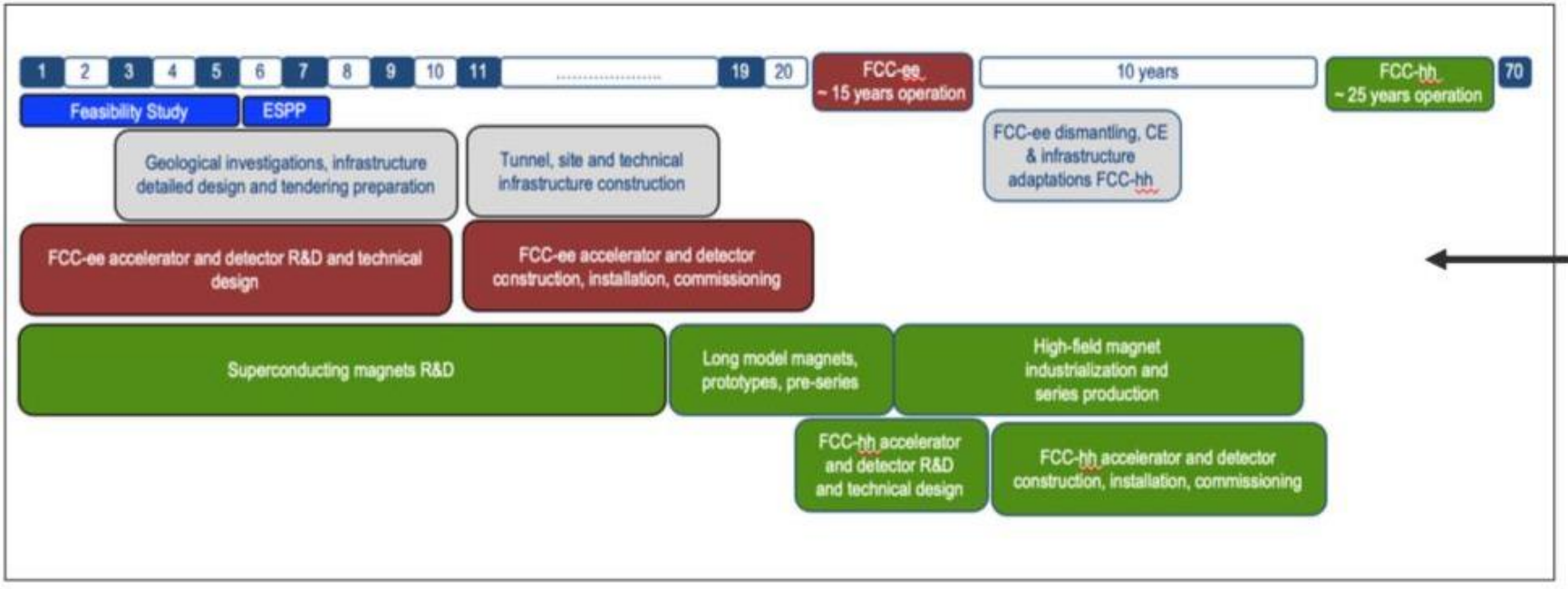


Stage 2



2020 - 2040 | 2045 - 2060 | 2065 - 2090

FCC timeline



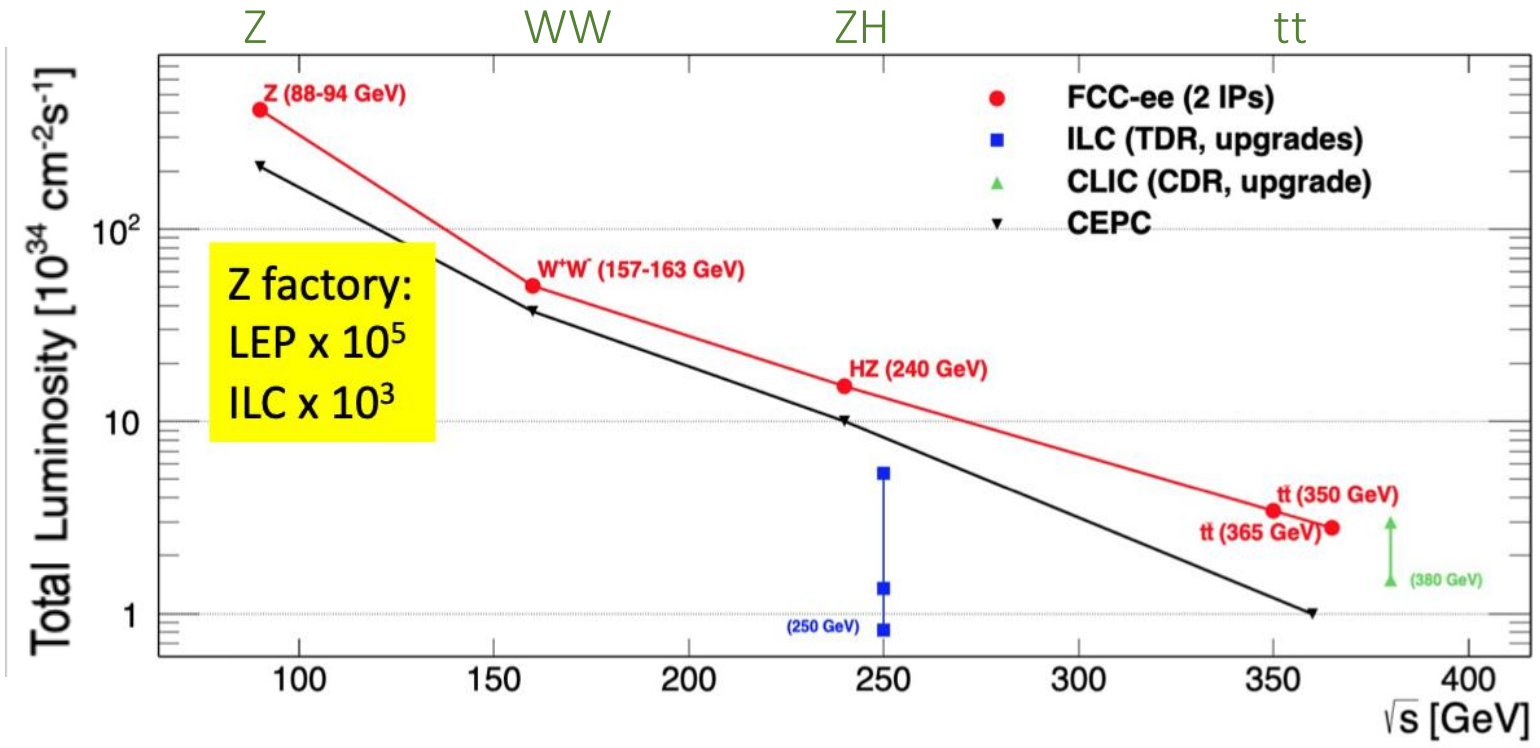
Note: FCC Conceptual Design Study started in 2014 leading to CDR in 2018

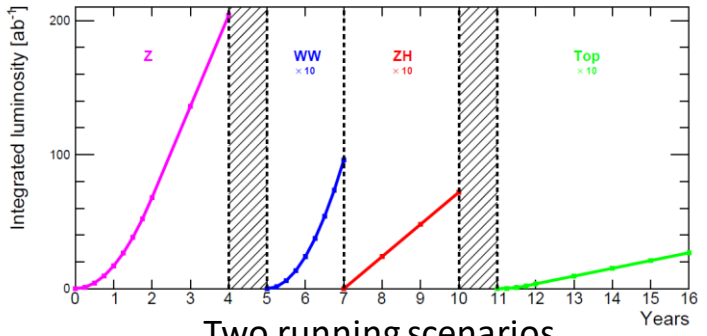
Technical schedule:
FCC-ee could start operation **in 2040 or earlier**

Realistic schedule takes into account:
- ❑ CERN Council approval timeline
- ❑ past experience in building colliders at CERN
- ❑ that HL-LHC will run until ~ 2041

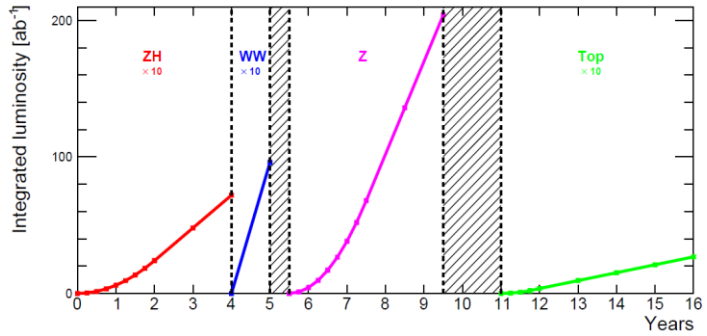
→ **ANY future collider at CERN cannot start physics operation before 2045-2048** (but construction will proceed in parallel to HL-LHC operation)

FCC-ee run plan





Two running scenarios



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 (2 IP)

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)

FCC main goals until 2025, Outlook

Overall goal:

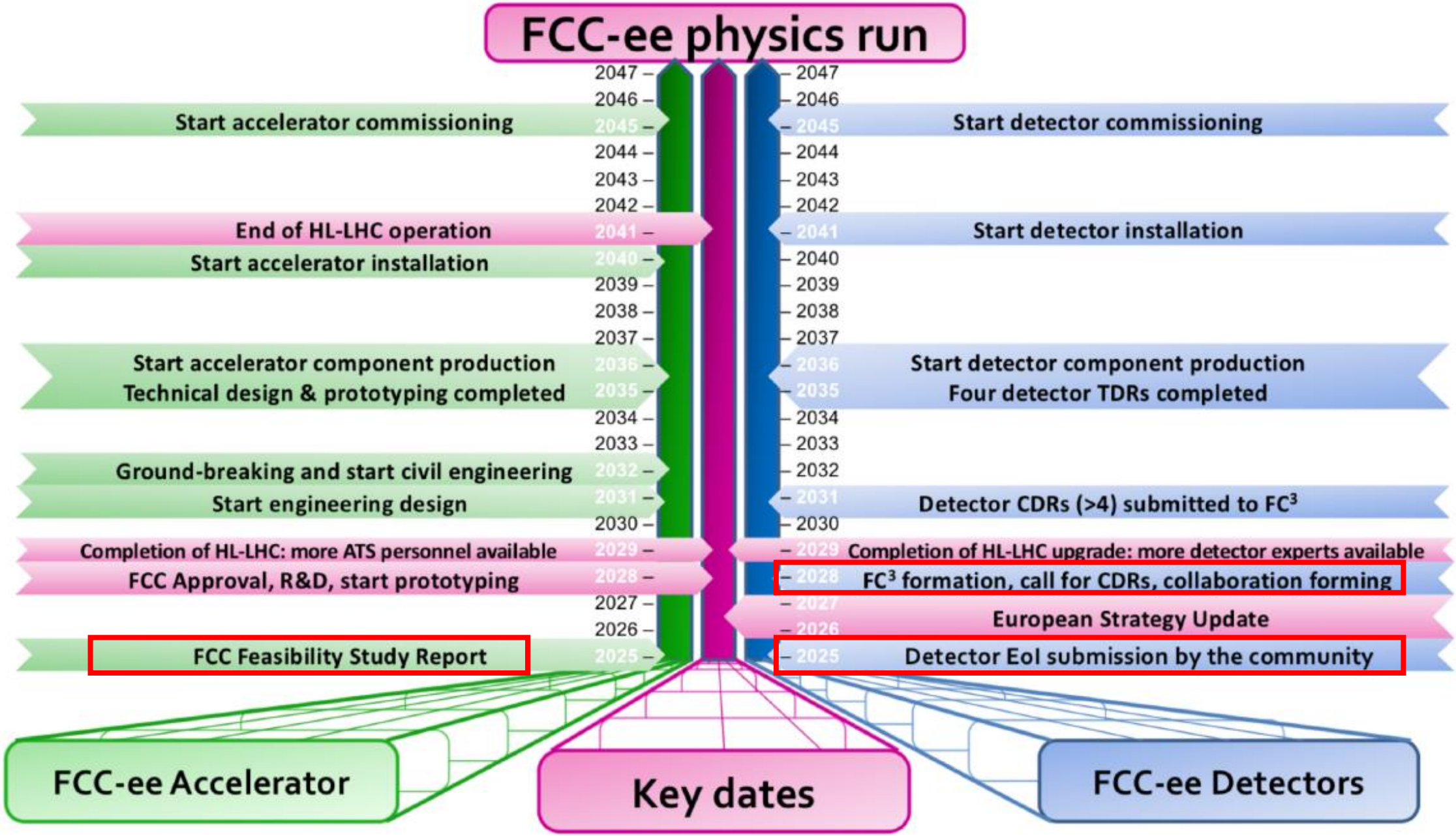
- Perform all necessary steps and studies to enable a project decision by 2028/29, at the anticipated date for the next ESU, and a subsequent start of civil engineering construction by 2032/33.

This requires successful completion of the following 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 R&D, and physics/experiment studies:

- Machine designs and main technology R&D lines
- Completion of physics case studies → detector requirements → **detector concepts & focused R&D**
- Reach out to all 'European and International Partners'
- Establish user communities, work towards proto experiment collaboration by 2026/27
- **Physics potential:**
  - Higgs (including self-coupling and 1st generation)
  - Heavy Flavor Physics and Tau physics
  - Precision EW, top, and QCD measurements
  - LLP's detection and other BSM searches


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

Detector Concepts Outloook

- Recent restructuring of the detector R&D community ➔ formation of DRD collaborations (1/1/2024)
- The detector community is well connected worldwide and this is now reflected by the ongoing integration of non-European groups and projects into the new DRD structure.

The timeline for FCC-ee foresees:

- Physics in the second half of the 2040s
- TDRs in the mid 2030s, backed by realistic prototypes
- CDRs in the early 2030s, with demonstrators that address the main integration challenges

➔ the R&D in the next 3-year period (2024-26) will have to focus on conceptual and component studies, with system aspects in focus from the beginning, to prepare for the development of demonstrators soon after, and for the construction of realistic modules by 2035

The work on other aspects of technology R&D already started during the conceptual design study will be pursued (e.g., highly-granular liquid argon calorimeter, silicon vertex detectors, CALICE-based calorimeters, particle identification detectors, dual readout calorimeters, gaseous trackers, luminosity monitors, etc...).

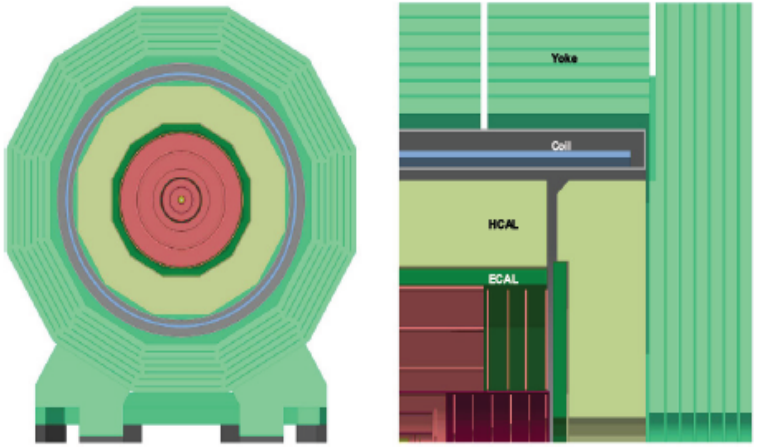
many R&D issues are common to linear and circular colliders, and can now be addressed in joint efforts.

➔ For this, the ECFA Higgs/EW/top factory study is currently a good framework.

➔ **Expression of Interests for the detectors/subdetectors expected in 2025**

Detectors under Study

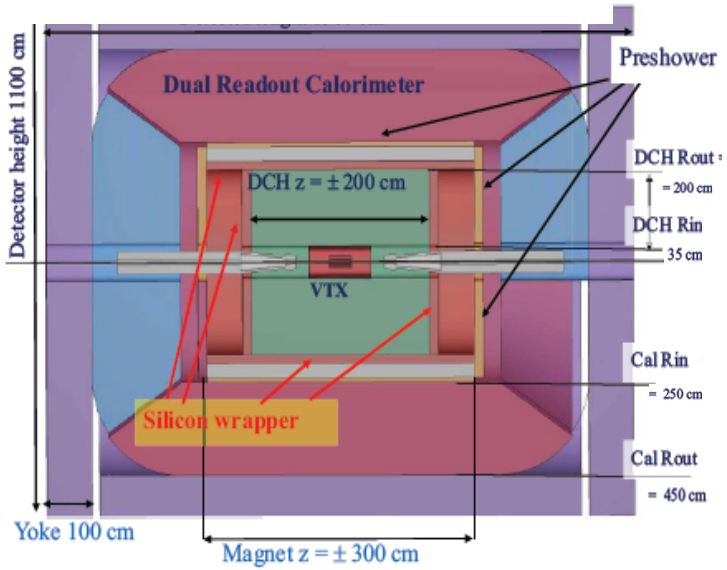
CLD



conceptually extended from the CLIC detector design

- full silicon tracker
- 2T magnetic field
- high granular silicon-tungsten ECAL
- high granular scintillator-steel HCAL
- instrumented steel-yoke with RPC for muon detection

IDEA



explicitly designed for FCC-ee/CepC

- silicon vertex
- low X_0 drift chamber
- drift-chamber silicon wrapper
- MPGD/magnet coil/lead preshower
- dual-readout calorimeter: lead-scintillating cerenkhov fibers

ALLEGRO

explicitely designed for FCC-ee, recent concept, under development

- silicon vertex
- low X_0 drift chamber + silicon wrapper
- Thin Solenoid before the Calorimeter
- High Granularity Liquid Argon Calorimetry

But several other options, like **ILD'**, or Crystal Calorimetry in IDEA(active in US, Italy), are under study (similarly for tracking, muons and particle ID)

With potentially 4 experiments, many complementary options will be implemented

Goal 1: Prepare participation to the future detectors EoI's

16:30 → 19:00 **Participations Françaises aux futures EoI des detecteurs et sous-détecteurs** — Bâtiment 25, Amphi Grünewald

16:30	**ALLEGRO concept (presentation and discussion)** **Orateur**: Martin Aleksa (CERN)	30m
17:00	**ILD' and CLD concept (presentation and discussion)** **Orateur**: Roman Poeschl (LAL Orsay)	30m
17:30	**IDEA concept (presentation and discussion)** **Orateur**: Paolo Giacomelli (INFN Bologna)	30m
18:00	**Possible sub-detectors EoI (presentations and discussions)**	30m
18:30	**Global discussion (including "next steps in tracking R&D")**	30m

Software and Computing Outloook

- Improve the accuracy of Monte Carlo physics generators to the statistical precision expected at FCC-ee, in particular at the Z pole.
  In addition to theoretical refinements (higher EW and QCD orders, improved treatment of initial and final state radiation etc.), this also includes the simulation of beam-energy spread, bunch length & transverse size, final state particle deflection by colliding bunches

- Complete the simulation of the interaction region (also know as Machine Detector Interface (MDI) in view of the final evaluation and mitigation of beam-related backgrounds in the detectors.

- Proceed with the full and parameterised simulations (and their interplay) of the relevant sub-detectors currently considered, including digitisation and sub-detector interchange with a “plug’n’play” framework, to enable the study of the performance of a large variety of detector concepts.

- Develop and implement the various reconstruction and analysis tools for use by all collaborators, reaping the benefits, whenever relevant, from LHC experience and past linear collider studies.

- Continue with the development of the common software framework (Key4hep) and common data format (edm4hep), as well as the procedures for software building, testing, and deployment.

- Evaluate the need for computing resources and proceed with regular simulated data production.

- Provide the users with detailed documentation and regular didactic tutorials

Présidents Emmanuel Macron and Alain Berset visited CERN and ATLAS on 16/11/2024

Emmanuel Macron (translated):
« If I came here today, it is to reiterate my confidence in the scientific community and our ambition to maintain our leadership in this domain [particle physics] »
Original:
« Si j'ai voulu venir là aujourd'hui, c'est pour témoigner ma confiance aux équipes et notre volonté, notre ambition, de conserver la première place dans ce domaine [physique de particules].

Comité Interministériel for FCC

A new Comité Interministeriel is now in charge of assessing the feasibility study of the FCC carried out by CERN and of analyzing alternative or competing projects, in order to feed into the French position on this FCC project. It is composed of representatives of

- Minister of higher education and research (MESR),
- Minister of the budget,
- Minister of public accounting and civil service,
- Minister of Europe and foreign affairs,
- Minister of ecological transition and territorial cohesion,
- Minister of the General Secretariat for Investment (SGPI),
- and of the Prefecture of the Auvergne-Rhône-Alpes Region,
- as well as qualified personalities and observers.

Comité interministériel pour FCC / Questions

- Impacts scientifiques
o Intérêt scientifique / solidité du « science case » (au-delà du SM)
o Besoins des futurs utilisateurs
o Perception scientifique des projets alternatifs ou concurrents
o Rôle de l'IA

- Impacts technologiques (équipements)
o Maturité technologique, verrous
o Savoir-faire des laboratoires et industriels français
o Programme de R&D à visée sobriété énergétique
o Mutualisations avec d'autres infrastructures de recherche
o Bénéfices/retombées envisagés pour d'autres applications

- Impacts économiques
o Maîtrise des coûts et du planning
o Retombées économiques et industrielles pour la France
o Perspectives de développement d'écosystèmes d'innovation territoriaux

- Impacts sociaux
o Création d'emplois
o Mobilité
o Acceptabilité, opposants
o Nuisances pour les riverains pendant les travaux
o Cas des huit sites en surface

- Impacts internationaux
o Position Suisse (autre pays hôte)
o Position pays membres
o Position US, Japon, Chine (qui ont des accords avec le CERN et représentent environ 20% des utilisateurs du CERN)
o Partenariats
o Concurrence internationale du FCC
o Situation géopolitique
o Évolution de la gouvernance et du modèle économique

- Impacts environnementaux
o Respect et préservation de la biodiversité des milieux concernés
o Perturbation des strates géologiques
o Conception durable des installations et respect des normes sociales et environnementales
o Optimisation énergétique
o Empreinte carbone

- Impacts foncier et juridique
o Prise en considération des caractéristiques des localités aux alentours des accès au tunnel (identité paysagère et architecturale, activité économique, transports etc.)
o Procédures réglementaires

Goal 2: Have answers to the frequent questions (and the others) and convince our colleagues

Questions on the scientific case, like:

- Why fcc is better ?
- What are the guaranteed and likely discoveries to be made at FCC?
- 2 ou 4 expts ?
- Do we need ttbar ?
- between hh and ee what should we choose?
- What about LLP's, what is the potential at FCC-ee?

Strategics Questions

- **What to do if CEPC moves forward ?**
- Questions on US, China, Japan, India

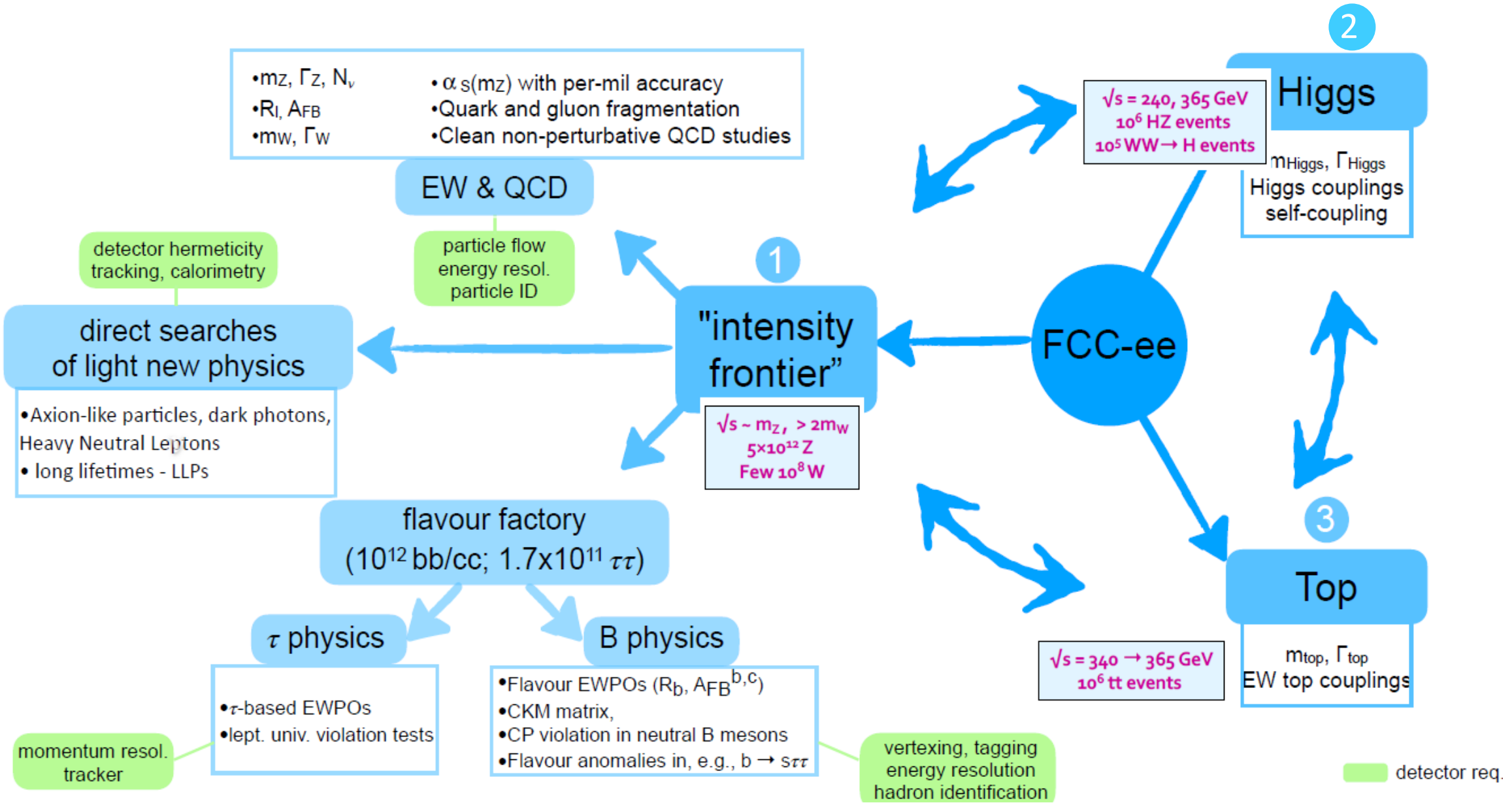
Questions about the industrial return

Questions on Rhones-Alpes development (cf Annecy among other)

Questions on ecology, and sustainability

IT IS IMPORTANT FOR OUR COMMUNITY TO BE ABLE TO ANSWER THE QUESTIONS RAISED AND TO CONVINCE « ALL » OF OUR COLLEAGUES THAT FCC-ee, FOLLOWED by FCC-hh, IS THE BEST SOLUTION FOR OUR FIELD. LET'S MAKE PROGRESS ON THE QUESTIONS/ANSWERS DURING THIS WORKSHOP

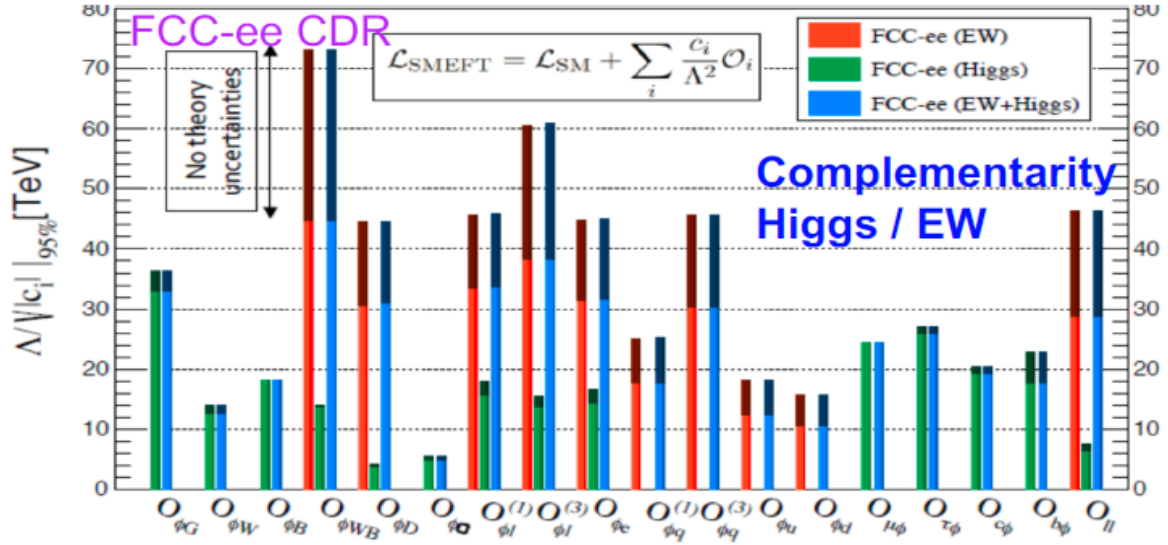
Goal 3: Physics Preparation at Circular Colliders with its Rich e^+e^- Physics Program



EW & QCD precision measurement examples

(*) current guess

	stat	w/ syst (*)	improvement
M_W	400 keV	500 keV	30
M_Z	4 keV	< 100 keV	> 20
Γ_Z	4 keV	< 25 keV	> 100
$\sin^2\theta_{eff}$ (τ pol)		$3\ 10^{-6}$	60
$\alpha_{QED}(m^2_Z)$	$3\ 10^{-5}$	$3\ 10^{-5}$	4 (stat. lim. !)
Rb	$3\ 10^{-7}$	$2\ 10^{-5}$	30
alphaS(m2Z)	10^{-5}	10^{-4}	30
Mtop	20 MeV	40 MeV	12
…			



- Huge statistics: very small stat errors call for very small syst uncertainties too.
  - E.g. acceptances, should be known to 10-4 – 10-5
- Goal: σ(exp syst) ≈ σ(stat)
- Work on theo. side also critical (and initiated, 1809.01830)

One key experimental handle: knowledge of √s (exquisite at circular collider with resonant depolarisation method, at Z & WW)

In terms of weakly-coupled new physics: FCC-ee precision corresponds to sensitivity on Λ_{NP} up to 70 TeV, anticipating what FCC-pp would focus on.

Goals of the Workshop

- Progress on the French priorities in terms of detector concepts, towards the EoI, including associated software
- Progress on the conviction that FCC-ee+FCC-hh is the future of our field, and on the strategy to share it
- Progress on the coverage of the Physics Topics by our community