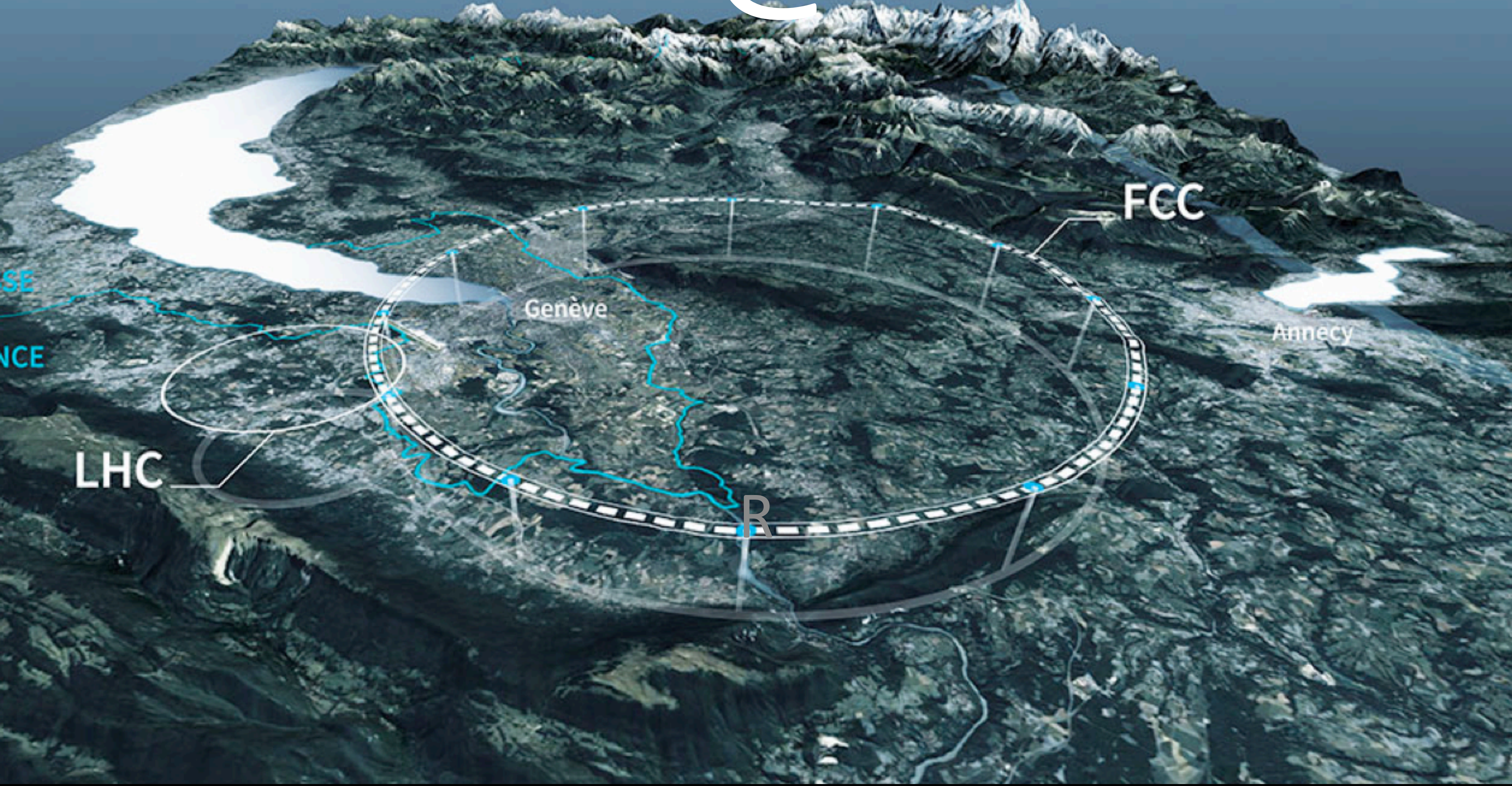
FCC @ LIP



1290 UNIVERSIDADE D COIMBRA

LIP

FCC

CERN

FCT Fundação para a Ciência e a Tecnologia

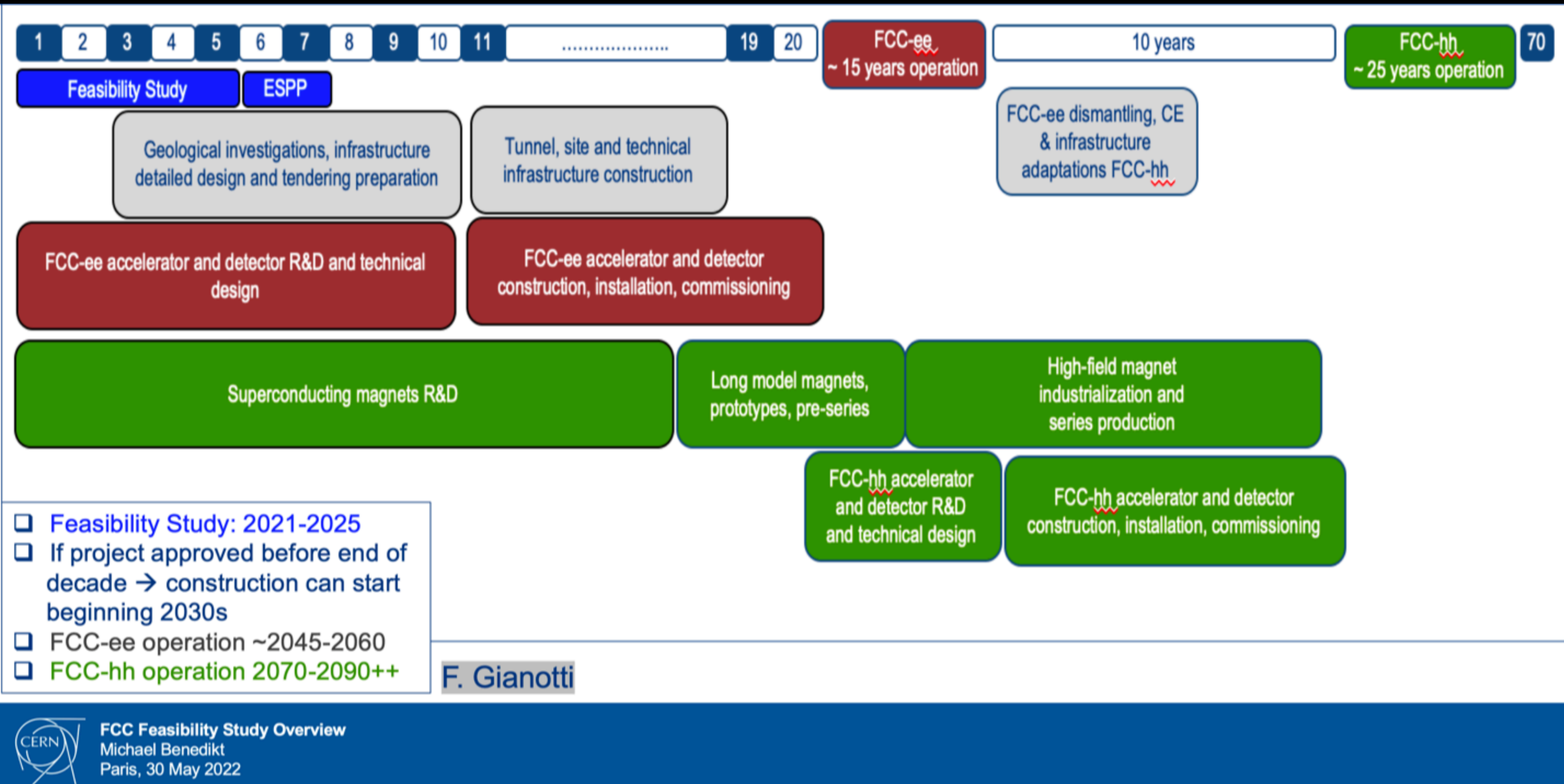
The FCC Feasibility Study

- International study for FCC “Conceptual Design” as part of European Strategy discussion
  - Comprehensive study of physics case and enabling technologies
  - 1350 contributors from 370 institutes, including LIP

- Mainly two accelerators using the same tunnel:
  - **FCC-ee**: 90, 240 to 350 GeV e+e- collider
  - **FCC-hh**: 100 TeV p-p and ion collider
  - 80 - 100 km perimeter tunnel!

- Evolved to “**FCC Feasibility Study**” approved by CERN Council to **conclude in 2025**

Future Circular Collider



FCC-ee Physics Landscape

"Higgs Factory" Programme

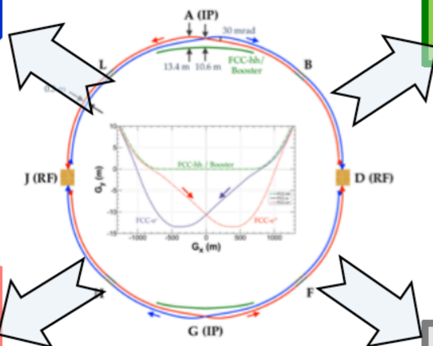
- At two energies, 240 and 365 GeV, collect in total
  - 1.2M HZ events and 75k WW → H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (2-4 σ) via loop diagrams
- Unique possibility: measure electron coupling in s-channel production $e^+e^- \rightarrow H$ @ $\sqrt{s}$ = 125 GeV

Ultra Precise EW Programme & QCD

Measurement of EW parameters with factor ~300 improvement in *statistical* precision wrt current WA

- 5×10^{12} Z and 10^8 WW
  - m_Z, Γ_Z, Γ_{inv}, $\sin^2\theta_W^{eff}$, R^Z_ℓ, R_b, α_s, m_W, Γ_W,…
- 10^6 tt
  - m_{top}, Γ_{top}, EW couplings

Indirect sensitivity to new phys. up to Λ=70 TeV scale



Heavy Flavour Programme

- Enormous statistics: 10^{12} bb, cc; 1.7×10^{11} ττ
- Extremely clean environment, favourable kinematic conditions (boost) from Z decays
- CKM matrix, CP measurements, "flavour anomaly" studies, e.g. b → sττ, rare decays, CLFV searches, lepton universality, PNMS matrix unitarity

Feebly Coupled Particles - LLPs

Intensity frontier: Opportunity to directly observe new feebly interacting particles with masses below m_Z:

- Axion-like particles, dark photons, Heavy Neutral Leptons
- Signatures: long lifetimes – LLPs

Mogens Dam, CERN EP&RD Days, Jun 2022

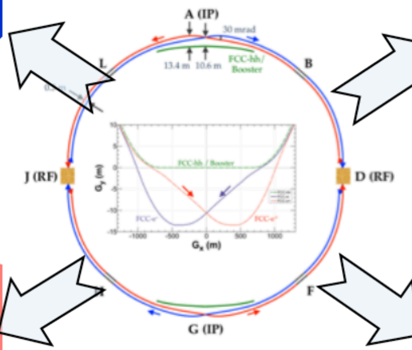
Detector Requirements

"Higgs Factory" Programme

- Momentum resolution at $p_T \sim 50$ GeV of $\sigma_{pT}/p_T \simeq 10^{-3}$ commensurate with beam energy spread
- Jet energy resolution of $30\%/\sqrt{E}$ in multi-jet environment for Z/W separation
- Superior impact parameter resolution for c, b tagging

Ultra Precise EW Programme & QCD

- Absolute normalisation (luminosity) to 10^{-4}
- Relative normalisation (e.g. $\Gamma_{had}/\Gamma_{\ell}$) to 10^{-5}
- Momentum resolution "as good as we can get it"
  - Multiple scattering limited
- Track angular resolution < 0.1 mrad (BES from $\mu\mu$)
- Stability of B-field to 10^{-6} : stability of $\sqrt{s}$ meast.



Heavy Flavour Programme

- Superior impact parameter resolution: secondary vertices, tagging, identification, life-time measts.
- ECAL resolution at the few $\%/\sqrt{E}$ level for inv. mass of final states with π^0s or γs
- Excellent π^0/γ separation and measurement for tau physics
- PID: K/π separation over wide momentum range for b and τ physics

Feebly Coupled Particles - LLPs

Benchmark signature: $Z \rightarrow \nu N$, with N decaying late

- Sensitivity to far detached vertices (mm $\rightarrow$ m)
  - Tracking: more layers, continous tracking
  - Calorimetry: granularity, tracking capability
- Large decay lengths $\Rightarrow$ extended detector volume
- Precise timing for velocity (mass) estimate
- Hermeticity

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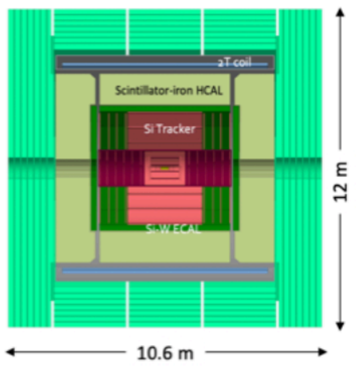
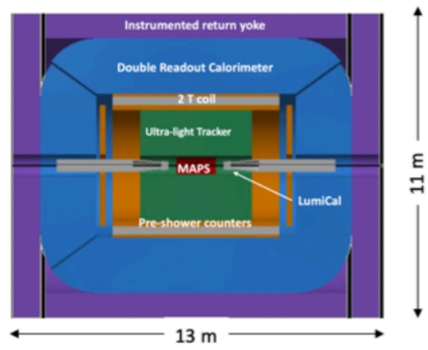
Detector Concepts

CLD

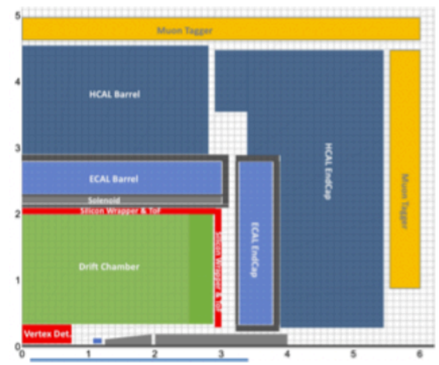


CDR

IDEA



Noble Liquid ECAL based



new

CLD

- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker; CALICE-like calorimetry; large coil, muon system
- Engineering still needed for operation with continous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …

IDEA

- Less established design
  - But still ~15y history: ILC 4th Concept
- Si vtx detector; ultra light drift chamber w powerfull PID; compact, light coil; monolitic dual readout calorimeter; muon system
  - Possibly augmented by crystal ECAL
- Very active community
  - Prototype designs, test beam campaigns, …

Noble Liquid ECAL based

- A design in its infancy
- High granularity Noble Liquid ECAL is core
  - PB+LAr (or denser W+LCr)
- Drift chamber (or Si) tracking; CALICE-like HCAL; muon system.
- Coil inside same cryostat as LAr, possibly outside ECAL
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

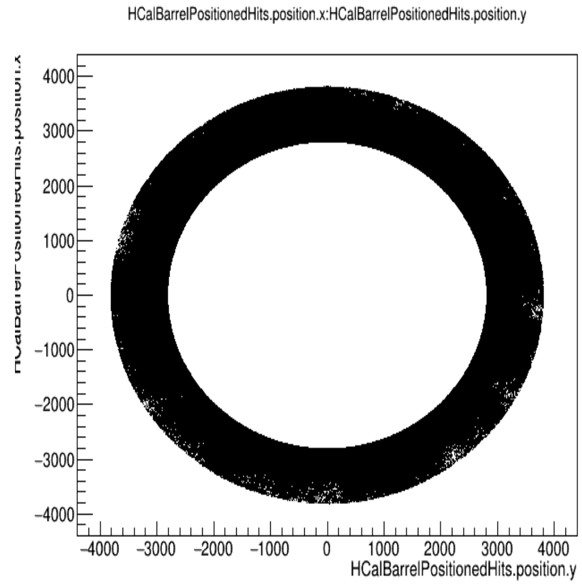
Mogens Dam, CERN EP&RD Days, Jun 2022

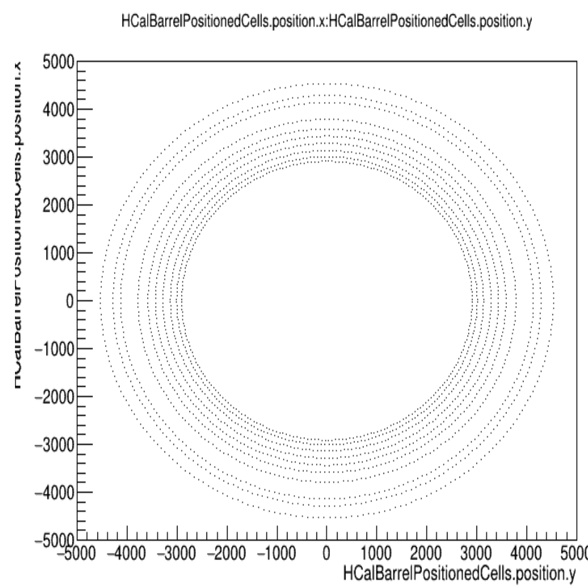
@LIP: Performance Studies for FCC-ee HCal

- Requirements for the precision goals
  - High granularity
  - Good energy resolution

- The HCal is composed of
  - 10 readout layers in R
  - Steel, lead and scintillator plates

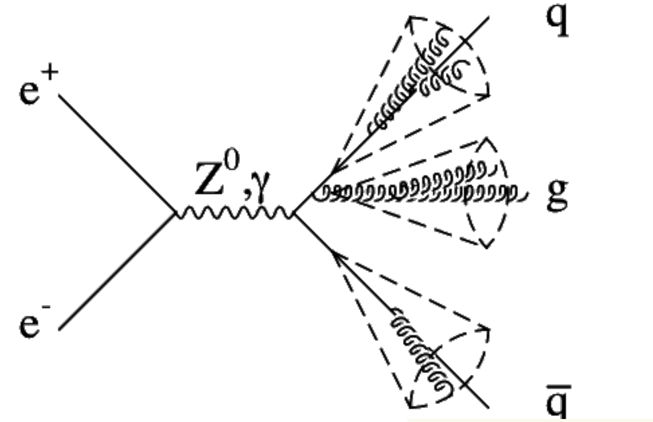
- We have started simulation of a scintillator tile sampling calorimeter with a particle gun of
  - 20 GeV charged pions (Figures)
  - 20 GeV Muons
  - 45 GeV electrons





@LIP: QCD Precision Programme at FCC-ee

- Clean environment! No parton distributions functions, hadron remnant, or underlying event!



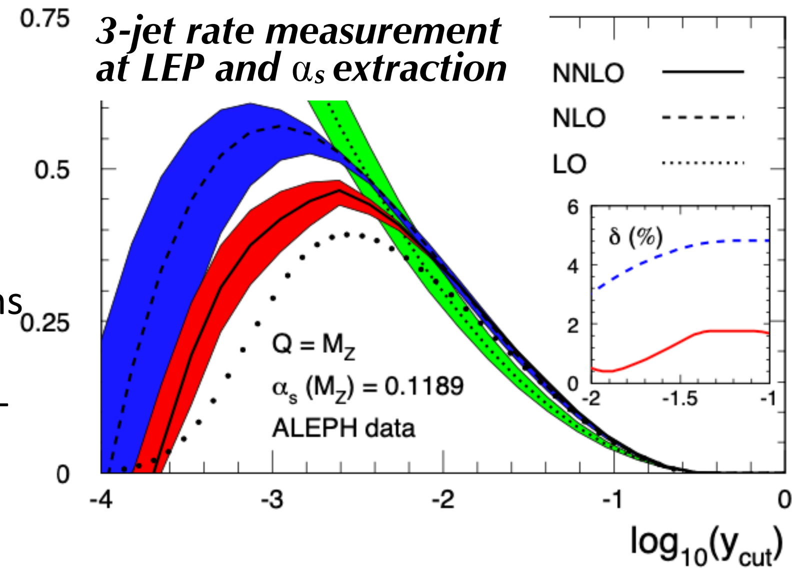
QCD programme

- Enormous statistics with $Z \to \ell\ell$, qq(g)
- Complemented by 100,000 $H \to gg$

1. $\alpha_S(m_Z)$ with per-mil accuracy
2. Quark and gluon fragmentation studies
3. Clean non-perturbative QCD studies

5×10^{12} $e^+e^- \to Z$ → **LEP x 10^5**

Aim one order of magnitude improvement in the precision of α_s with FCC-ee



$\alpha_s(M_Z) = 0.1175 \pm 0.0020(exp) \pm 0.0015(th)$

- Theory challenges:
  - Extend NNLOJET program to describe e+e- collisions with higher-order perturbative QCD effects
  - Calculate **$e^+e^- \to$ 3 j** at N3LO and include massive b-quark effects
  - Search for observables with smaller hadronization corrections (e.g., groomed event shapes)

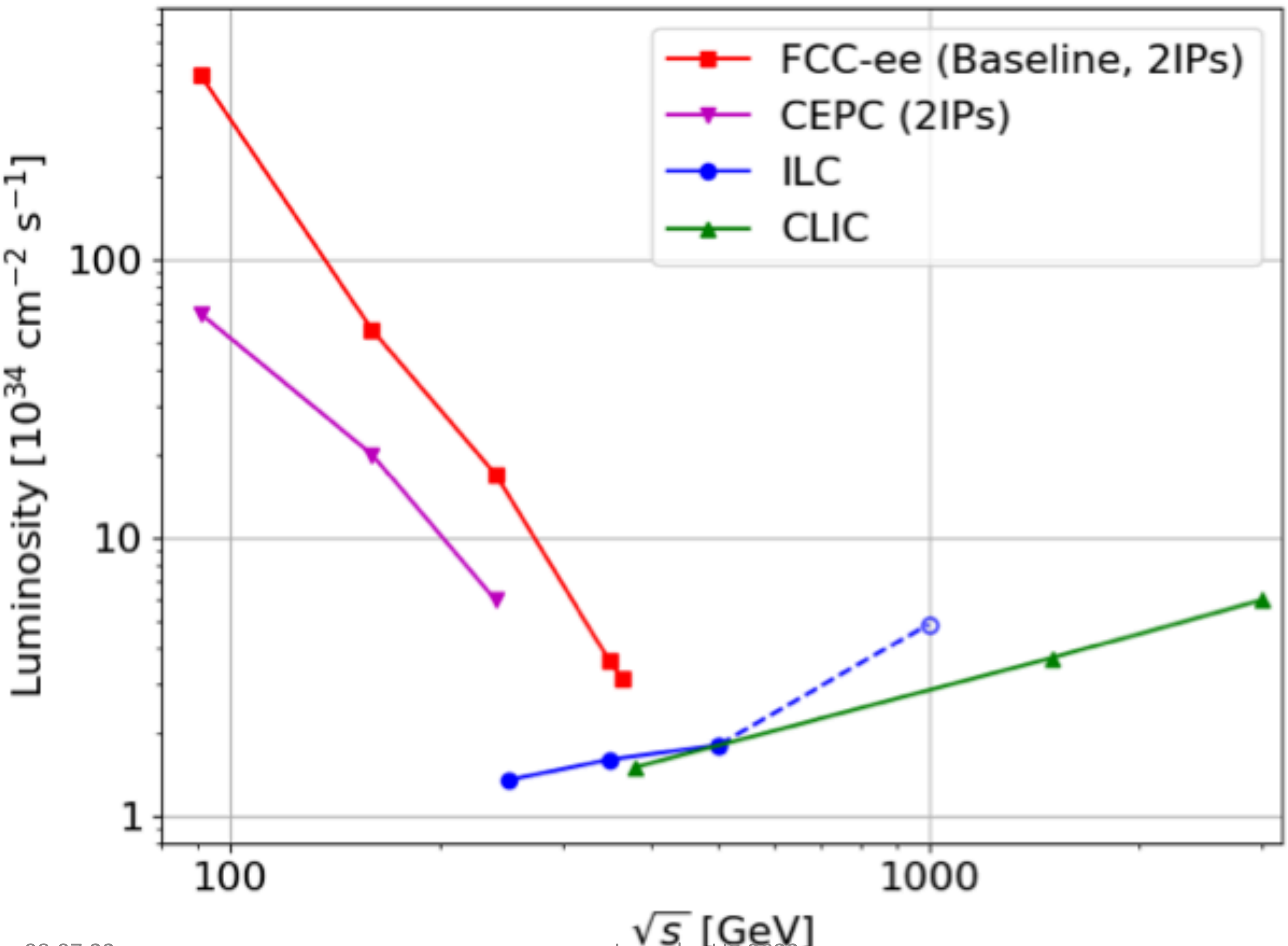
FUTURE CIRCULAR COLLIDER
Innovation Study

Status of Global FCC Collaboration

Thank you!

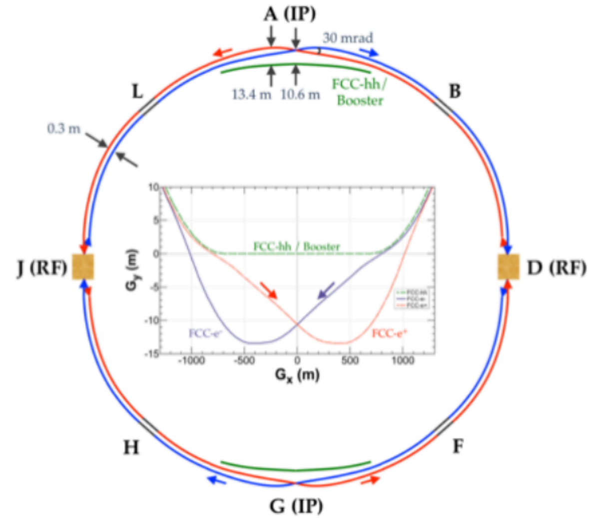
LIP

LET’S INSPIRE PEOPLE


FCC-ee (Baseline, 2IPs)
CEPC (2IPs)
ILC
CLIC
Luminosity [10^{34} cm^{-2} s^{-1}]
100
10
1
100
1000
$\sqrt{s}$ [GeV]

FCC-ee Experimental Challenges Overview

- 30 mrad beam crossing angle
  - Detector B-field limited to 2 Tesla
  - Very complex and tightly packed MDI (Machine Detector Interface)
- ”Continuous” beams (no bunch trains); bunch spacing down to 30 ns
  - Power management and cooling (no power pulsing)
- Extremely high luminosities
  - High statistical precision ⇒ control of systematics down to 10^{-5} level
  - Online and offline handling of $\mathcal{O}(10^{13})$ events for precision physics:
    ”Big Data”
- Physics events at up to 100 kHz
  - Fast detector response ($\lesssim 1$ μs) to minimise dead-time and event overlaps (pile-up)
  - Strong requirements on sub-detector front-end electronics and DAQ systems
    - At the same time, keep low material budget: minimise mass of electronics, cables, cooling, …



Central part of detector volume – top view