FCC Physics, Experiments and Detectors (PED)

The alignment of stars towards FCC

- Discovery of the Higgs boson (2011-12) at 125 GeV – just above LEP limit
  - Possibility to (re)build an e^+e^- collider in the LEP/LHC tunnel to produce and study H_{125} ?
- Progress in circular collider technology (Super B, SuperKEKB)
  - Made it possible to exceed 10^{34} $cm^{-2}s^{-1}$ at the $e^+e^- \rightarrow ZH_{125}$ cross section max. (~240 GeV)
- Discussions about a new ring of 80-100 km circumference (ESPPU'12)
  - To increase the hadron collider energy to 100 TeV with 16-20 T magnets
- Happy coincidence !
  - 80-100 km is also required to reach the top-pair threshold in e^+e^- collisions (~350 GeV)
    - Enabling precise top-quark measurements essential to the EW precision physics programme
      - ➔ Just the right energy range to study all heavy particles of the Standard Model (Z, W, Higgs, top)
      - ➔ Fantastic springboard to a 100 TeV proton-proton collider
      - ➔ Great physics complementarity and synergies between the two colliders

A uniquely powerful long-term vision

FCC

- Alternative routes to 100 TeV were evaluated in "FCC-ee: Your questions answered"
  - Led to the conclusion that "FCC-Integrated" provides the most efficient implementation
    - When compared to lower-energy hadron collider, or linear e^+e^- Higgs factories, as a first step
- The vision of an integrated FCC programme was adopted by ESPPU 2020
  - To prepare a Higgs factory [top priority], followed by a hadron collider [ultimate goal]
    - With sensitivity to energy scales an order of magnitude higher than those of the LHC
  - To investigate a feasibility study of the colliders and related infrastructure
    - Completed on the timescale of the next Strategy update
- A FCC technical & financial feasibility study was launched accordingly
  - At the last FCC week (28 June – 2 July 2021)
- Work started on tunnel placement and layout, compatible with 2 or 4 IPs for FCC-ee
- These events bring both FCC-ee and FCC-hh closer to reality

Why are we here today ?

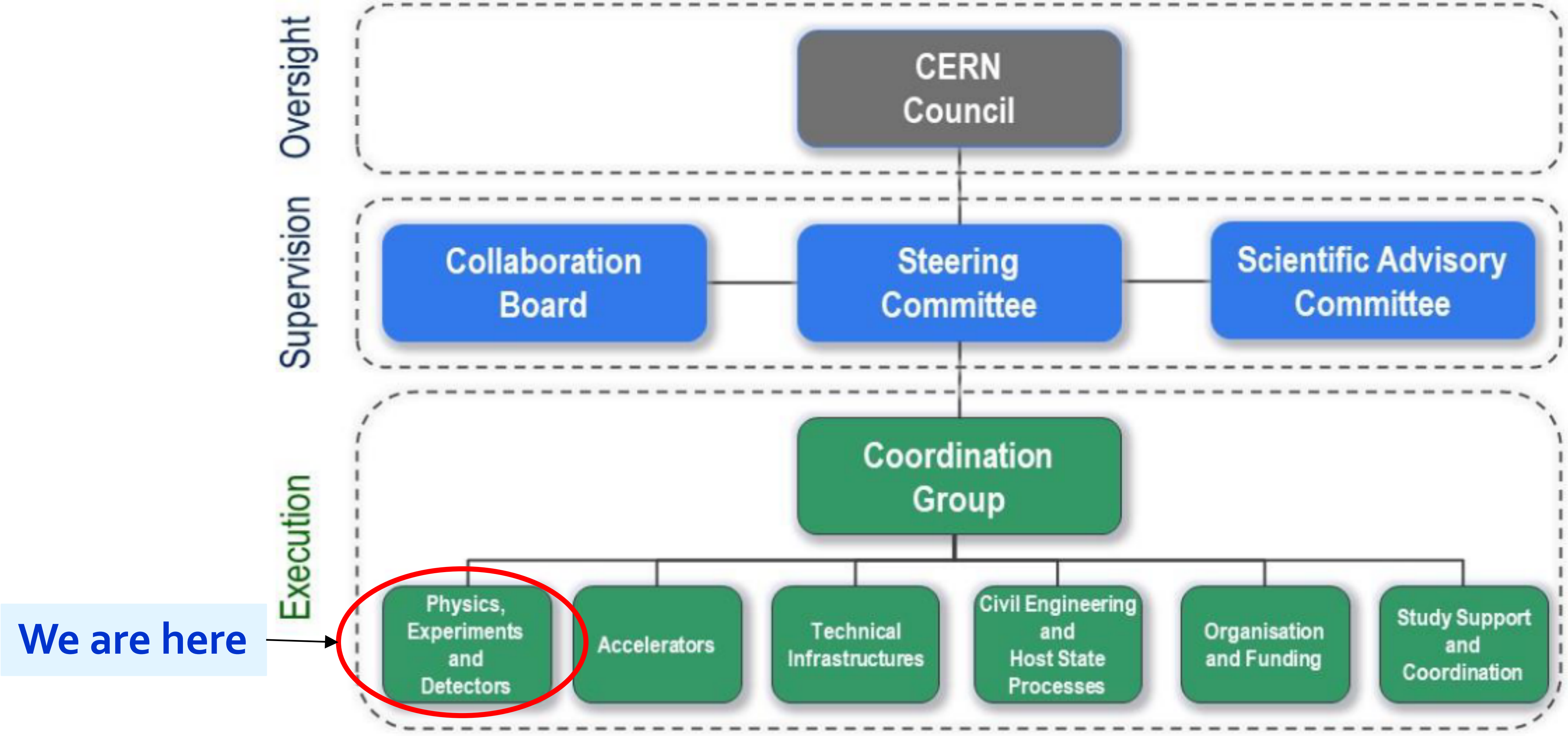
- We are now starting the second phase of the FCC Design Study (2021-2025)

Technical and Financial Feasibility Study

- Feasibility Study organisation proposed to CERN council & approved unanimously (06/21)
  - Organizational structure: http://cds.cern.ch/record/2774006/
  - Main deliverables and timeline: http://cds.cern.ch/record/2774007/
    - ➔ Funded at CERN with 100MCHF / 5 years
- The focus will be on the tunnel and the first-stage collider (FCC-ee) for a cost of ~10 BCHF
  - High-Field Magnet R&D is proceeding in parallel with high priority and similar funding (100MCHF)
  - Approval after the FCC Feasibility Study will only concern the tunnel and FCC-ee.
    - ➔ Work has already progressed significantly on the tunnel and surface site placement in the GVA area
    - ➔ Layout consistent with two or four interaction points for the e^+e^- collider
- Intermediate review mid 2023; Feasibility Study Report (FSR) end 2025

FCC Feasibility Study Organization

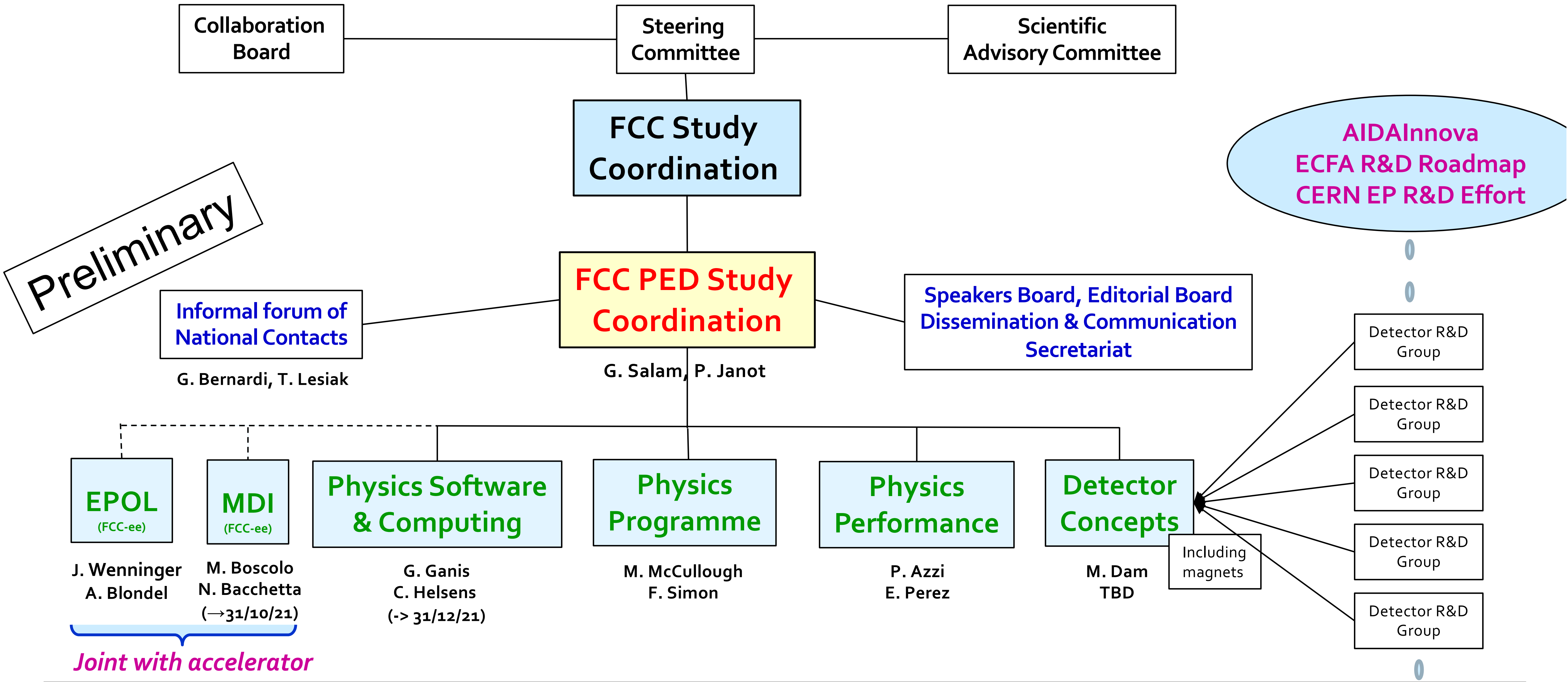
- **Organisational chart**



The PED pillar high-level objectives

- Consolidate the physics case for both colliders (FCC-ee and FCC-hh)
  - Focus: Demonstrate and communicate FCC-ee superiority over other "Higgs factories"
  - Continue to develop and explain the physics case of the FCC integrated programme
    - Build an international community of particle physicists around the project
- Provide coherent sets of detector requirements and physics analysis tools
  - To meet the challenges offered by ultra-precise Higgs and EW measurements
- Benchmark several detector concepts for FCC-ee to match these requirements
  - For proto-collaborations to have enough material to move forward efficiently afterwards
    - Towards FCC-ee detector proposals and TDRs after the next European Strategy update
      - ➔ NB. The FCC-hh detector concept must continue to be updated (e.g., with HL-LHC upgrade experience)
- Develop a common software infrastructure and provide computing requirements
  - To support and facilitate the above objectives, and to be used by all future experiments

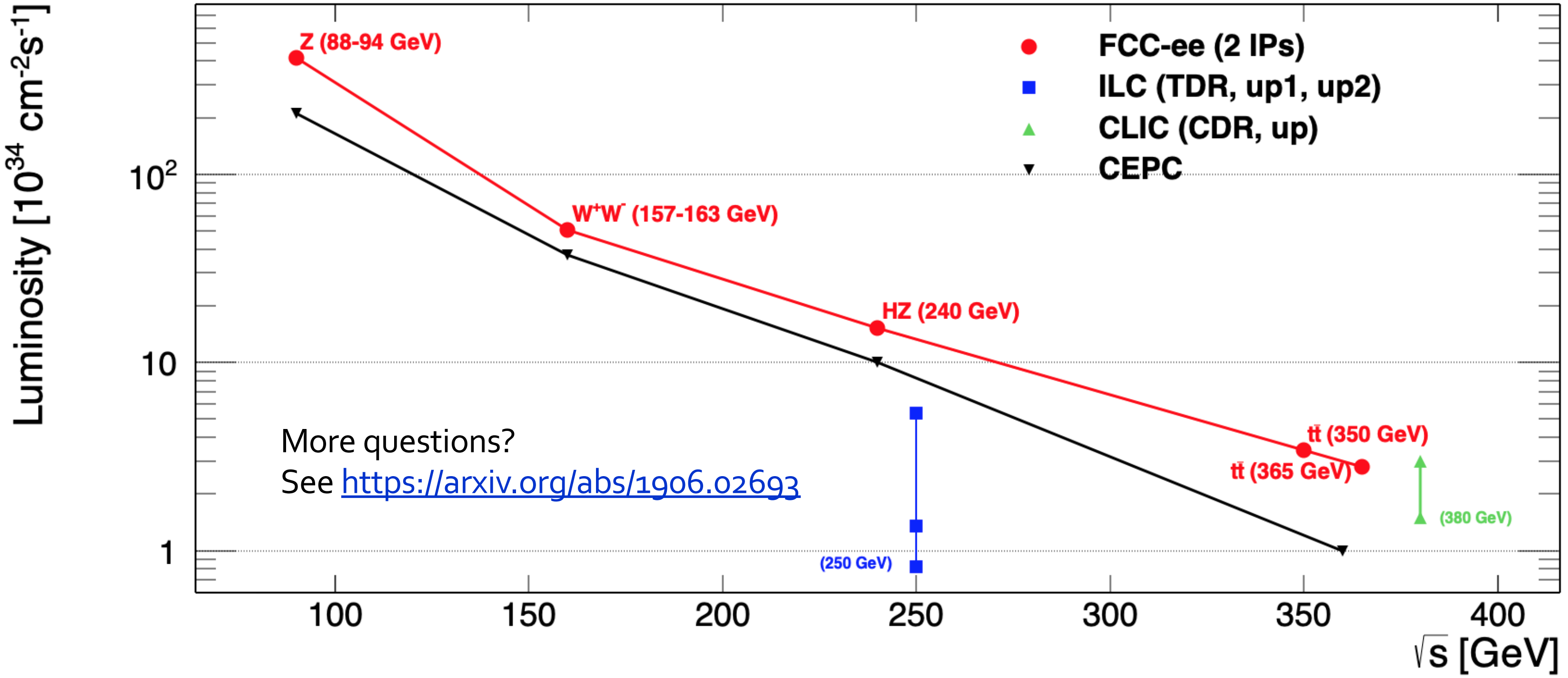
The PED Pillar Organisation - preliminary



FCC-ee: Higgs/Top/EW/Flavour factory

FCC

- Great energy range for the SM heavy particles + highest luminosities + √s precision



EPOL WG

					E_{CM} errors:
Z peak	E_{cm} ~ 91 GeV	5×10^{12}	e+e- → Z	LEP x 10^5	<100 keV
WW threshold+	$E_{cm} \geq 161$ GeV	$> 10^8$	e+e- → WW	LEP x 10^3	<300 keV
ZH threshold	E_{cm} : 240 GeV	10^6	e+e- → ZH	Never done	2 MeV
$t\bar{t}$ threshold	E_{cm} ~ 350 GeV	10^6	e+e- → $t\bar{t}$	Never done	5 MeV

FCC-ee Physics Programme: Opportunities

"Higgs Factory" Programme

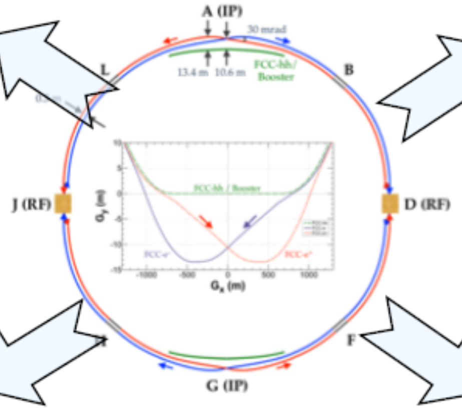
- At two energies, 240 and 365 GeV, collect in total
  - 1.2M HZ events and 75k WW → H events
- Higgs couplings to fermions and bosons
- Higgs self-coupling (2-4 σ) via loop diagrams
- Unique possibility: measure electron coupling in s-channel production $e^+e^- \rightarrow H$ @ $\sqrt{s}$ = 125 GeV

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



See https://arxiv.org/abs/2106.13885

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

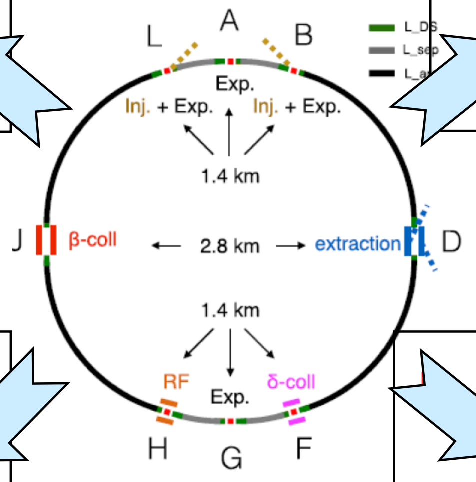
Intensity frontier: Opportunity to directly observe new feebly interacting particles with masses below m_Z :

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

FCC-hh physics programme: Opportunities

- **With 30 ab^{-1} @ 100 TeV in 25 years**
  - 2×10^{10} Higgs bosons (180 × HL-LHC)
    - 2×10^{7} Higgs pairs, 10^{8} ttH events
  - 10^{12} top pairs (300 × HL-LHC)
  - 5×10^{13} W, 10^{13} Z (70 × HL-LHC)
  - 10^{5} gluino pairs im m_{gluino} ~ 8 TeV
  - …

- **High precision study of H and top**
  - Exploration of EWSB in all details
    - Higgs self-coupling to 3-4%
  - Rare or BSM decays
    - BR(H → invisible) to 2.5×10^{-4} (DM!)
    - $g_{H\mu\mu}$, $g_{H\gamma\gamma}$, $g_{HZ\gamma}$ to 0.5%
      - ➔ FCC-ee standard candle essential



- **Sensitivity to heavy new physics**
  - With indirect precision probes
    - Multiple synergies with FCC-ee
  - Trade statistics for systematics
    - e.g., with cross-section ratios
    - e.g., with high-p_T final states
  - High-energy phenomena (VBS, DY)

- **Direct particle observation**
  - Mass reach enhanced by ~5 wrt LHC
    - New gauge bosons up to 40 TeV
    - Strongly interacting particles up to 15 TeV
    - Natural SUSY up to 5-20 TeV
    - Dark matter up to 1.5-5 TeV
      - ➔ Possibility to find or rule out thermal WIMP as DM candidates

Physics Programme: Structure

- Six working groups (with at least one experimentalist and one theorist conveners, tbd)
  - Focus on the phenomenological aspects of the integrated FCC programme
    1. Precision Electroweak Physics
       - ➔ Z peak and WW threshold (ee)
       - ➔ High-energy diboson and difermion (hh)
    2. Higgs physics
    3. Flavour (c, b, τ) physics
    4. BSM Physics
       - ➔ Indirect sensitivity from precision measurements (ee and hh)
       - ➔ Direct BSM searches at the smallest couplings (ee and hh) and highest masses (hh)
    5. QCD
    6. Top physics
  - To be considered in addition
    - Physics at FCC-hh with dedicated experiments (FCC-b, FCC-Alice, …)

Preliminary

Physics Programme: Key deliverables

- Within the domain of expertise of each working group
  - Bring together theorists and experimentalists
  - Plan for precision theory calculation development, <u>to match experimental uncertainties</u>
    - A strategic priority for FCC-ee – Such developments have focussed on LHC in the past 20 years.
  - Propose physics benchmark measurements
    - Which may lead to new detector performance requirements or theory precision requirements
  - Report on recent results in the literature and develop new ideas
    - New models to probe; new experimental tests to implement; new observables to test
    - Examine different operation models (L vs $\sqrt{s}$: values and time ordering)
    - Propose ancillary (in situ) measurements of key accelerator/detector parameters
  - Review existing MC generators
    - And plan for upgrade to include most recent theoretical progress
  - Deliver and test global fitting code and formulae
    - For standard model, specific BSM models, and generic Effective-Field-Theory (EFT) approach
  - Organize public documentation for the results of the working group

Physics Performance: The PED cornerstone

- This work package makes the link between
  - Physics Benchmark Measurements (proposed by "Physics Programme")
  - Detector Requirements (used by "Detector Concepts")

By means of concrete "Physics Case Studies"

See examples and documentation at https://github.com/HEP-FCC/FCCeePhysicsPerformance

- Mostly hands-on work, to implement the physics vision in practice
  - For each physics benchmark measurement
    - → Identify and implement one or several Case Studies to optimize the statistical sensitivity
    - → Identify and evaluate the limiting systematic uncertainties
    - → Establish detector requirements to match systematic uncertainties with statistical precision
  - Key deliverables
    - → Physics tools and analysis code, re-usable by others (in contact with "Physics Software")
    - → Coherent formulation of detector requirements (e.g., resolutions, alignment, stability ...)
    - → Public documentation (web, technical notes, conference presentations, preprints, papers, ...)

Physics Performance: The PED cornerstone

FCC

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By means of concrete "P

See examples and docum /FCCeePhysicsPerformance

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Ideal entry point to learn about and work on
(e^+e^-) Physics, Analysis, and Detector aspects
in small and motivated teams, with help from experts

Detector concepts: Key deliverables

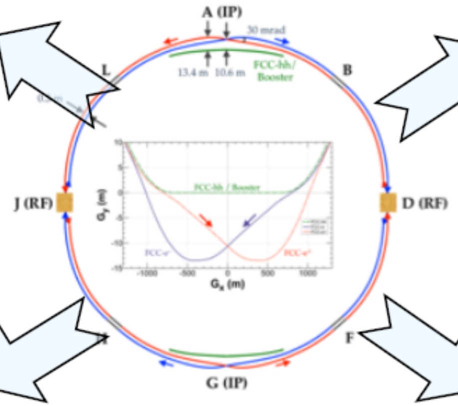
- Overall model of several FCC-ee Detector Concepts
  - For up to four interaction points
    - Allow for a range of complementary detector solutions to cover all FCC-ee physics opportunities
  - High-level figure-of-merit compatible with detector requirements from Physics Performance
  - Layout and technologies compatible with the MDI layout + background conditions
  - Make the link with low-level parameters and specific choices for sub-detectors
    - With geometrical description, low-level simulation, local reconstruction, magnet system, …
  - Overview of services, power consumption, ecological impact, construction/operation costs, …
- Selection of other key tasks
  - Establish links with a broad range of R&D groups (e.g., ECFA R&D Roadmap; AIDAInnova; CERN EP R&D effort)
    - Identify and encourage R&D work in the direction of the FCC-ee requirements
    - Follow technological developments that could lead to new physics opportunities
  - Promote the use of the common FCCSW platform and tools for performance simulation
    - In particular, fully exploit sub-detector "plug & play" to evaluate technology options
  - Maintain and update FCC-hh detector concept + study FCC-hh dedicated experiments
    - Following evolution of physics landscape and experience with HL-LHC detector upgrades

FCC-ee Detector Requirements: CDR Status

"Higgs Factory" Programme
- Momentum resolution of $\sigma_{p_T}/p_T^2 \simeq 2 \times 10^{-5}\,\mathrm{GeV}^{-1}$ commensurate with $\mathcal{O}(10^{-3})$ 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.

Being revisited in "Physics Performance"



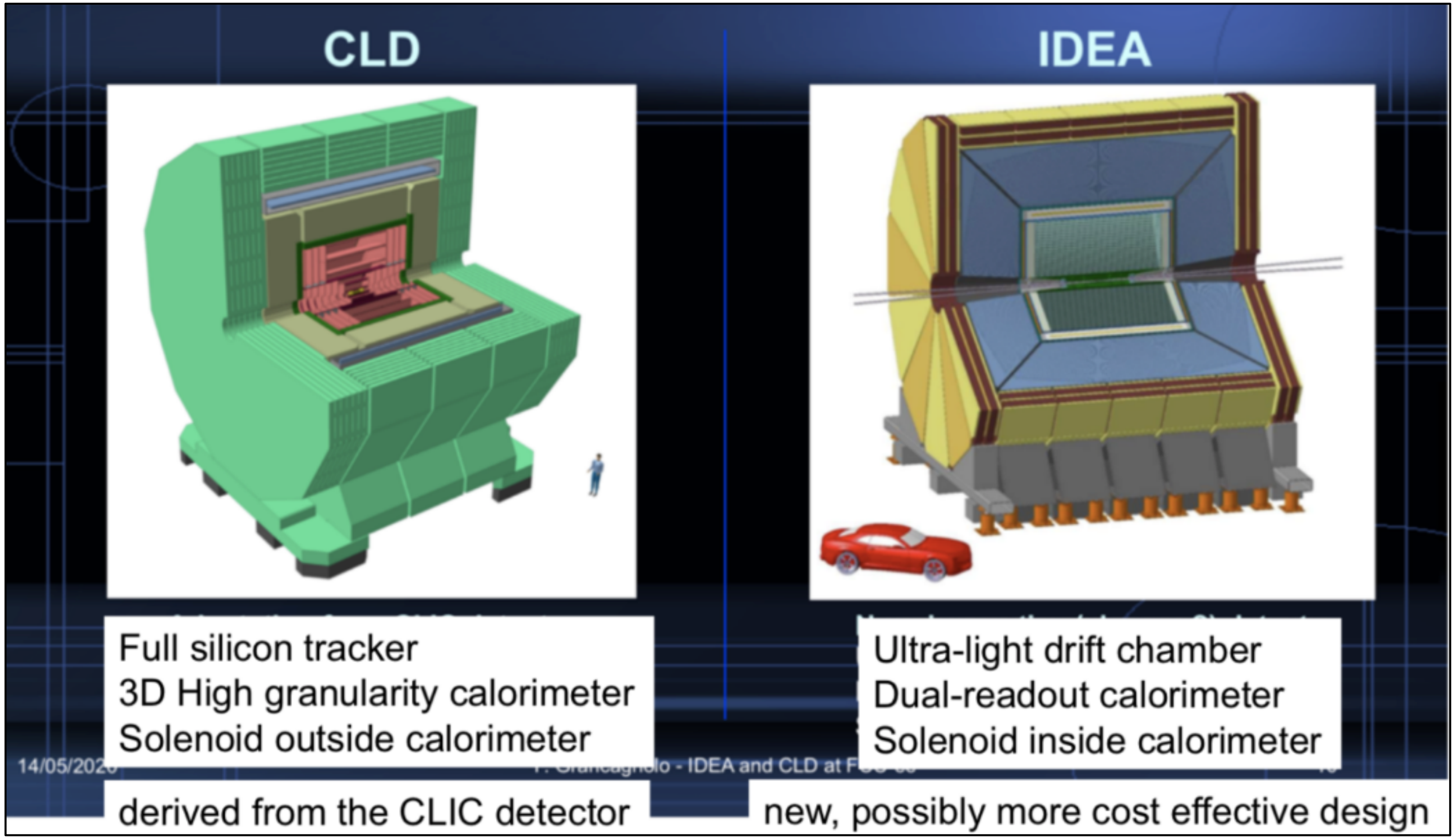
See https://arxiv.org/abs/2106.13885

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 → νN, with N decaying late
- Sensitivity to far detached vertices (mm → m)
  - Tracking: more layers, continous tracking
  - Calorimetry: granularity, tracking capability
- Large decay lengths ⇒ extended detector volume
- Hermeticity

Detector Concepts: Status in the CDR

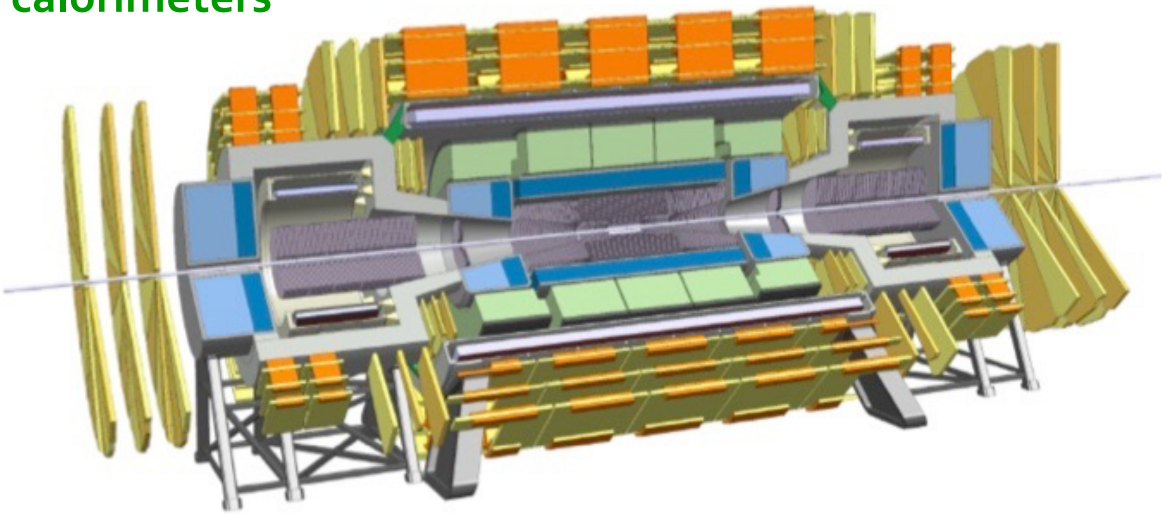
- **Two FCC-ee detector concepts were introduced – this is only the beginning.**



- **Other variants under study (e.g., Lar calorimeter, crystal-based ECAL, …) – more welcome!**

Detector Concepts: Status in the CDR

- FCC-hh, well beyond HL-LHC – to be revisited during FCC-FS with HL-LHC experience
  - Much larger longitudinal event boost
    - Enhanced coverage at large rapidity (with tracking and calorimetry)
    - Forward solenoids or dipoles
    - Length ~ 46 m
  - Zs, Ws, Higgses, tops will be highly boosted (esp. in high p_T final states)
    - High granularity tracking and calorimetry
    - 4T, 10 m bore main solenoid surrounding the calorimeters
  - Up to 1000 PU events over a bunch length of 5 cm
    - High resolution vertexing
    - Ultra fast detector / electronics
  - Energetic jets
    - 2m - thick HCAL
  - High p_T muons
    - 20% resolution @ 10 TeV
  - Radiation hardness



Complete documentation to appear soon

Software and Computing: Key deliverables

- **Key deliverables for FCC Software (FCCSW, key4hep, edm4hep)**
  - Provide a ready-to-use fully-fledged data processing solution for (future) HEP experiments
    - Appropriate sets of Monte Carlo generators (with input from "Physics Programme")
    - Framework for geometry, fast and full simulation (with input from "Detector Concepts")
      - ➔ Maximally flexible for detector optimization in the specific FCC environement (plug & play)
    - Framework for event reconstruction (with input from "Physics Performance")
    - User-friendly analysis framework for case studies and phenomenological studies
    - Framework for machine-induced background simulation (with input from "MDI")
    - Library of common tools (with input from all), event display(s), tutorial for users, …
  - Aimed at being commonly developed by/for all Higgs factory projects and FCC-hh
    - Another way to enter the project with hands-on activities

- **Key deliverables for computing**
  - Evaluation of the computing, storage, bookkeeping infrastructure for the FCC data
  - Enable use of distributed resources

Boundaries and interactions

Courtesy F. Sefkow

MDI (Joint with Accelerator pillar)
- Engineering of detector interface (BP, lumi, vertex)
- Beam backgrounds
- experimental hall infrastructure

Physics Programme
- Physics case
- Models, links to theory
- Theory precision
- Generators
- Global Fits
- running scenarios
- combination with LHC, FCChh

Benchmarks

Physics Performance (analysis forum)
- benchmark analyses
- common high-level tools (jet algorithms, flavour tagging, BDT based tags…)
- physics case studies for different detector concept variants (bigger/smaller, gaseous / silicon, DR vs PFlow)
  - link between physics performance (BR, M,…) and high-level detector performance (colourless object (diet) mass, c tag,…)
- comparisons between different detector concepts (IDEA, CLD, …)

Figures of merit
Detector requirements
Detector variants

Detector concepts
- overall model
  - **global** engineering (services, supports), magnet model
  - **full** (and realistic) simulations
- technology options ("plug & play")
- high-level performance figures of merit
  - link to low-level parameters (global and local (granularity, sampling fraction, noise, material, alignment / calibration,…)
  - low-level simulation (geometry, digitized hits) and reco (clusters, tracks)
- link DELPHES & full sim
- variations of global parameters (R, B, …),
- cost optimization, power consumption
- Compatible with operation conditions

guidance, priorities, requirements, constraints, performance impact

feasibility, validation low level parameters, test beam, prototype, validation of performance / simulation, cost drivers

- **R&D Groups**
- calo, tracking, vertex, PID, magnet technology (cables…)
- technologies (sensors, electronics)
  - limitations (pixel size, material, speed…)
  - scalability
- demonstrators and prototypes
- test bench, test beam
- low-level performance (pint resolution, X0, sigE)
- low-level simulations, digitisation

Software and Computing
- Common framework and tools, computing requirements, beam-background software, pile-up management, …
- Generator interfaces, analysis framework, detector geometry, high-level reconstruction, low-level reco, low-level simulation, event display, …

Final message

- The work for particle physicists in the feasibility study is clearly cut out
  - Design the experimental setup and prepare the theoretical tools for FCC-ee
    - To be able, demonstrably, to fully exploit the FCC-ee capabilities
    - To prepare the ground towards detector operation and data analysis in 2040
  - Maintain and update the FCC-hh detector concept and physics case
    - According to the scientific landscape evolution, and the HL-LHC upgrade experience

- To start with, the FCC-ee challenges arise from the richness of the program
  - Match the experimental and theoretical accuracy to the statistical precision
  - Match the detector configuration with the variety of channels and discovery cases
  - Match the computing infrastructure to the incredible statistics expected at the Z pole
  - Match the common physics software to the needs of up to four experiments

- The participation of the worldwide HEP community is the cornerstone of the success of this ambitious enterprise

Backup slides

FCC-ee/hh physics complementarity / synergies

- **Higgs physics**
  - ee breaks model dependence (Γ_H, g_{HZZ}) – and measures precisely top EW couplings
    - Turns σ(ttH) measurement @ HL-LHC to an absolute ttH coupling precision of 3%
    - First 3-4σ observation or 5σ discovery of the Higgs self coupling
  - pp measures ratios-of-BR and gives huge statistics of ttZ, ttH, and HH events
    - Bring top Yukawa and Higgs self coupling precisions to the per-cent level, in particular
- **Search for heavy physics (with at least weak couplings)**
  - ee gives precision measurements sensitive to heavy physics up to 70 TeV and more
    - Patterns of deviations may point to specific BSM physics
  - pp gives access to direct observation at unprecedented masses and p_T's
    - Also huge samples of Z, W, Higgs, top
- **Right-handed neutrinos (and all very weakly-coupled particles)**
  - ee: powerful and clean, but flavour blind: $Z \rightarrow \nu N$, all ν flavours together — 5×10^{12} Z
  - hh: more difficult, but charge- and flavour-sensitive: $W \rightarrow l_1 (Q_1) N$, $N \rightarrow l_2 (Q_2) W^*$ — 5×10^{13} W
- **Flavour "anomalies" (if they persist – rich flavour physics programme otherwise)**
  - ee beyond any foreseeable competition with $B \rightarrow K^{(*)} \tau^+\tau^-$ and $B_S \rightarrow \tau^+\tau^-$
  - hh gives direct access to Z' gauge bosons and leptoquarks
- **QCD**
  - ee gives α_S to ±0.0002 or better (R_l for Z and W), but also 100k $H \rightarrow gg$ (gluon fragmentation!)
  - Improves signal and background predictions for new physics discovery at pp

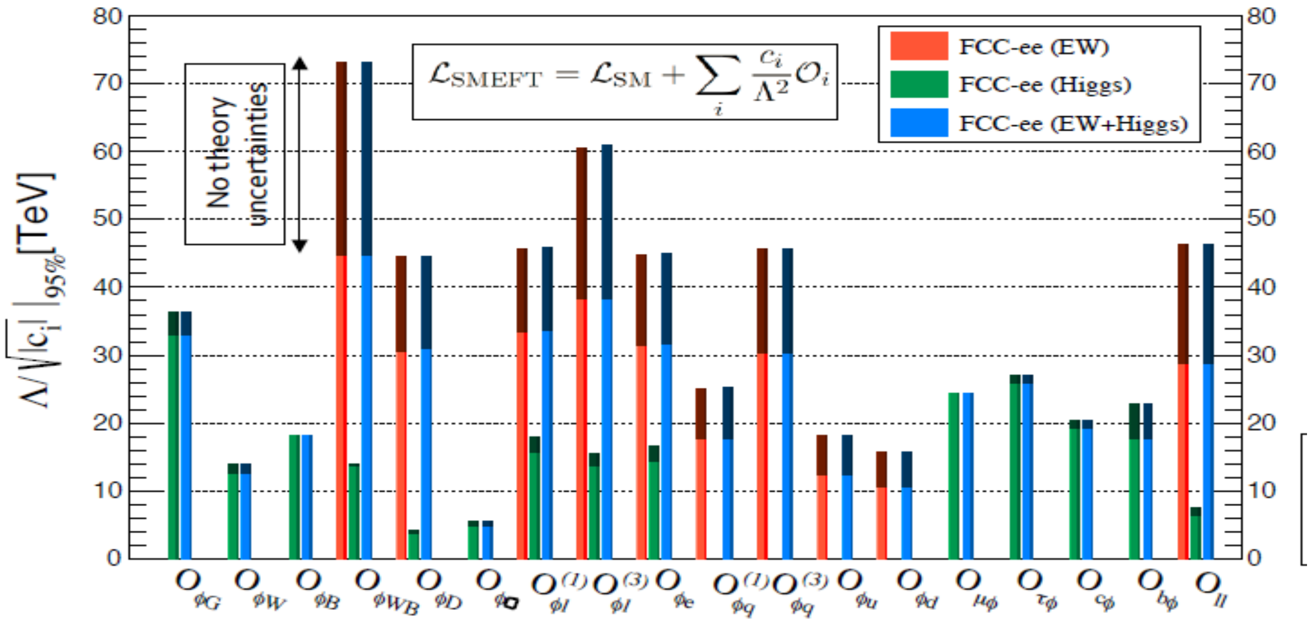
arXiv:1906.02693, FCC-ee: Your questions answered

Observable ↓ / $\sqrt{s}$ →	m_Z (e^+e^- collisions)	$2m_W$ (e^+e^- collisions)	HZ max. 240-250 GeV (e^+e^- collisions)	$2m_{top}$ 340-380 GeV (e^+e^- collisions)	500 GeV (e^+e^- collisions)	1.5 TeV (e^+e^- collisions)	3 TeV (e^+e^- collisions)	28 TeV 37 TeV 48 TeV (pp collisions)	100 TeV (pp collisions)	Leading Physics Questions
Precision EW (Z, W, top)	Transverse polarization	Transverse polarization		m_{top} (m_W, α_S)						Existence of more SM-Interacting particles
QCD (α_S) QED (α_{QED})	5×10^{12} Z	3×10^{8} W	10^5 H→gg							Fundamental constants and tests of QED/QCD
Model-independent Higgs couplings		ee → H $\sqrt{s} = m_H$	1.2×10^6 HZ and 75k WW→H at two energies						<1% precision (*)	Test Higgs nature
Higgs rare decays									<1% precision (*)	Portal to new physics
Higgs invisible decays									10^{-4} BR sensitivity	Portal to dark matter
Higgs self-coupling			3 to 5σ from loop corrections to Higgs cross sections						3% (HH prod) (*)	Key to EWSB
Flavours (b, τ)	5×10^{12} Z									Portal to new physics Test of symmetries
RH ν's, Feebly interacting particles	5×10^{12} Z								10^{11} W	Direct NP discovery At low couplings
Direct search at high scales					M_χ<250GeV Small ΔM	M_χ<750GeV Small ΔM	M_χ<1.5TeV Small ΔM		Up to 40 TeV	Direct NP discovery At high mass
Precision EW at high energy							*Y*		*W, Z*	Indirect Sensitivity to Nearby new physics
Quark-gluon plasma Physics w/ injectors										QCD at origins

Green = Unique to FCC; Blue = Best with FCC; (*) = if FCC-hh is combined with FCC-ee; Pink = Best with other colliders

FCC-ee Theory Requirements: Challenges

Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{eff} (\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	small	from $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2-1	ratio of hadrons to leptons **acceptance for leptons**
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4-1.6	from R_ℓ^Z above
σ_{had}^0 $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	peak hadronic cross section luminosity measurement
$N_\nu (\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD
$A_{FB}^b, 0$ $(\times 10^4)$	992 ± 16	**0.02**	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{pol,\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	radial alignment
τ mass (MeV)	1776.86 ± 0.12	**0.004**	0.04	momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38 ± 0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	1.2	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	small	from R_ℓ^W
$N_\nu (\times 10^3)$	2920 ± 50	**0.8**	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	45	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	0.5 – 1.5%	small	From $\sqrt{s} = 365$ GeV run



- **Precision EW measurements: is the SM (in)sufficient ?**
  - ➔ Higgs and EW precision observables are complementary
  - ➔ Top mass and couplings essential (100 km ring!)
  - ➔ More "Flavour" variables to be added
  - ➔ Aim is to reduce experimental systematic errors to the same level as statistical errors (formidable challenge!)
  - ➔ Theory work is critical and initiated to match stat. errors too

See https://arxiv.org/abs/1901.02648

Other useful references

- CDR Symposium (4-5 March 2019): https://indico.cern.ch/event/789349/
- Circular / Linear e^+e^- Collider Complementarity: https://arxiv.org/abs/1912.11871
- EPJ+ special issue, Focus on FCC-ee: "Challenges/Opportunities towards discovery"
  - Introduction
  - Part I: New accelerator technologies to reach the precision frontier
  - Part II: Physics opportunities and challenges towards discovery
  - Part III: Theoretical challenges at the precision frontier
  - Part IV: Software development and computational challenges
    - See this Overleaf document for a summary and references

- Snowmass LoI's
  - https://indico.cern.ch/event/951830/
- Documentation for the Physics Performance group (case studies, how-to, etc.)
  - https://github.com/HEP-FCC/FCCeePhysicsPerformance
- Register to FCC-ee mailing lists (remove "form/subscribe" to get the scheduled meetings)
  - https://fcc-ee.web.cern.ch/form/subscribe