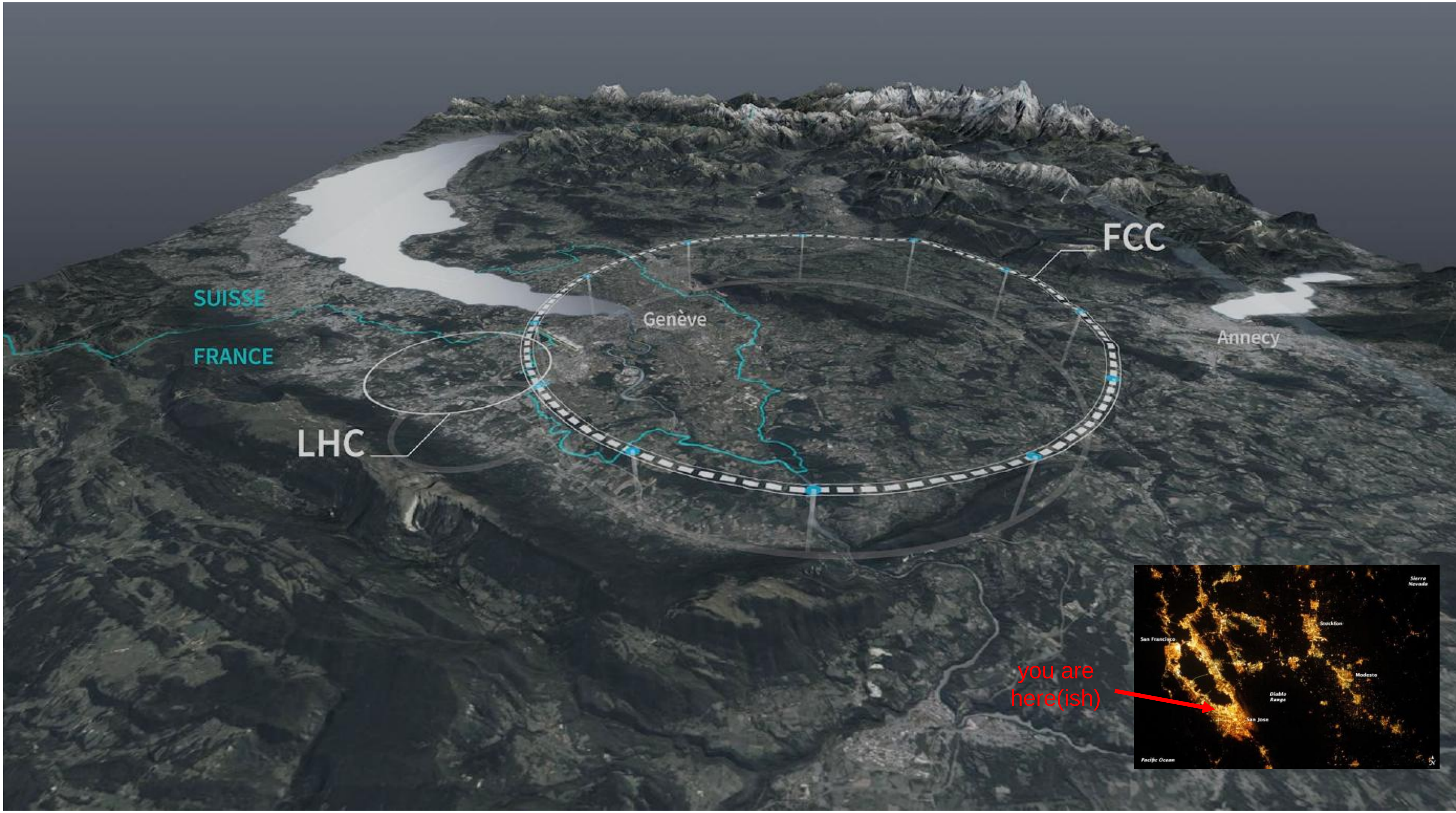
FCC-ee physics, experiments and detectors (PED) in the Reference Design Phase: status, plans and opportunities for engagement



Fourth US FCC meeting,
SLAC, 9/9/26

Guy Wilkinson
University of Oxford

Outline

- Where are we now, and how did we get here?
- The Reference Design Phase, and updated PED organisation
- PED principal goals in the Reference Design Phase
    - Detector concepts
    - MDI
    - Computing and s/w
    - Physics activities (experiment and theory)
    - Other running points and dataset optimisation
    - ECM calibration
    - Descoping and staging
- Conclusions

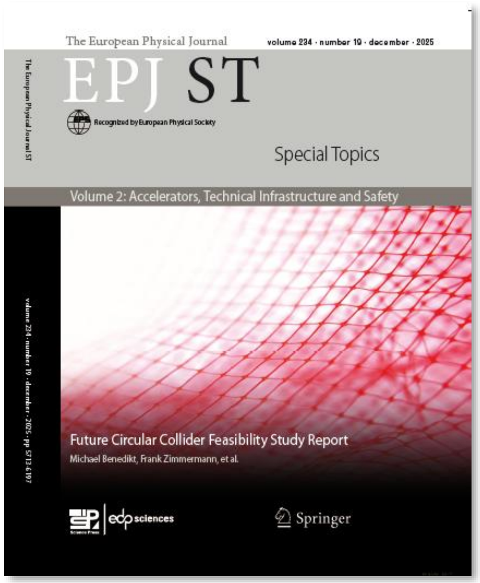
Where are we now ?

The concept of FCC-ee, and its precursors, dates back to 2011. Since then successive studies have taken place, investigating all aspects of the project: physics, accelerator, civil engineering and infrastructure, environmental impact…

Last year saw the culmination of a 4.5 year full scale Feasibility Study:

[CDS, arXiv:2505.00272]

[CDS, arXiv:2505.00274]



[CDS, arXiv:2505.002743]

The Feasibility Study Report (FSR) and accompanying documents was a critical input to the European Strategy for Particle Physics Update (ESPPU).

International consensus

Outcome of ESPPU process:

“ The next CERN flagship collider project

A. The e^+e^- Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

B. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN.”

Approved by CERN Council in June.

CERN responds accordingly

Outcome of ESPPU was very clear, and has now been adopted through a resolution by CERN Council. Situation has been well articulated by CERN DG, for example in plenary ECFA meeting in Amsterdam in July [link].

FCC was a key topic of the update of the ESPP

The key points from the European Strategy Group (ESG) report regarding FCC:

- Overwhelmingly strong endorsement of the physics and strategic case for FCC-ee as the next flagship collider at CERN
  - Consensus within the particle physics communities in CERN's Member States
- *A* descoped/staged FCC-ee is preferred to other options as **the** alternative
- **FCC-ee is far ahead of other concepts**

Will return to this later

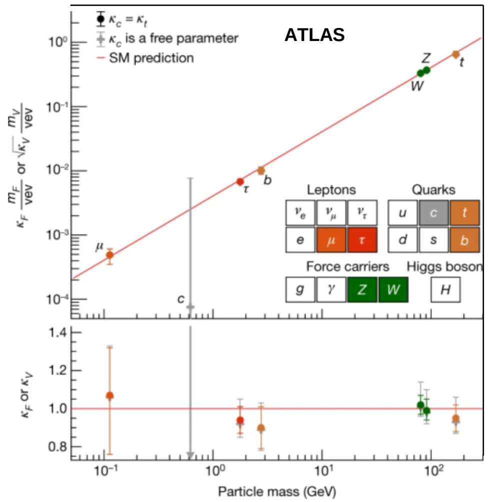
The update of ESPP, endorsed FCC-ee as CERN's scientific vision for the future:

- CERN **strongly** supports this objective
- ***Our clear aim is to be ready*** **for a decision on FCC-ee in 2028**
- CERN's highest objective for the long-term future is to be in a position in 2028 to propose to Council FCC-ee as CERN's next flagship collider
- Seeking a decision on FCC-ee, not a choice between options, that choice has been made in the European Strategy update

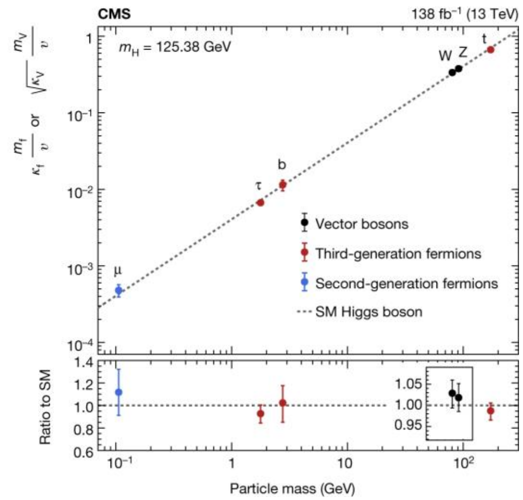
But why did this consensus emerge ? Why did the community select FCC-ee ?

Community priority – learn more about the Higgs

Great work of LHC, ATLAS and CMS → Higgs superficially behaving as in SM.



[ATLAS, Nature 607 (2022) 52]



[CMS, Nature 607 (2022) 60]

However, much too early to declare ‘mission accomplished’:

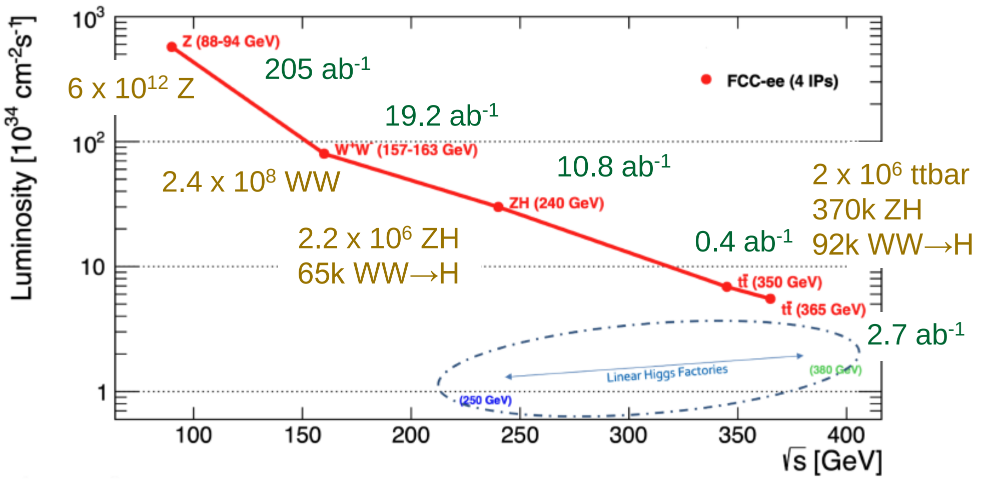
- Precision on couplings (~5% in best case) not yet in ‘interesting regime’;
- Very limited information on second generation quarks;
- Nothing known about how Higgs couples to ‘everyday’ matter (first generation);
- All results model dependent, as Higgs width is badly known;
- Essentially no knowledge on how the Higgs couples to itself.

HL-LHC will make progress (*e.g.* self-coupling)…
…but high-luminosity e^+e^- machine needed to advance on (most of) these topics.

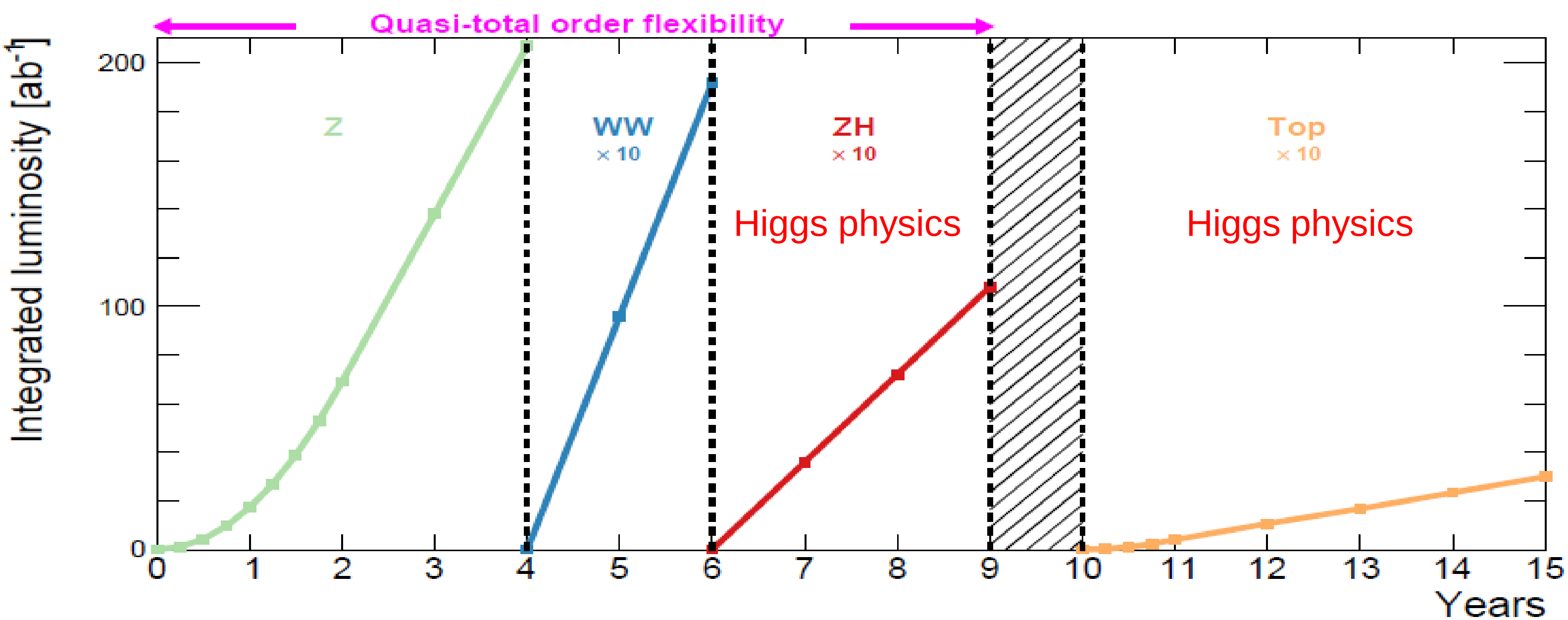
FCC-ee essentials and enabling characteristics

FCC-ee enabling characteristics:

- Huge samples → extreme precision;
- Four (+) energy points, explored in a compact 15-year programme;
- With exciting options for extension.



Physics goals encompass Higgs studies:



Higgs-coupling measurements at FCC-ee

Sensitivity of HL-LHC and FCC-ee projections, as ratios of measured coupling to SM expectation ('κ'):

- FCC-ee reaches 0.1-0.5% precision on many of the most interesting couplings;
- Accesses, for the first time, second-generation quarks;
- Results are model independent;
- Achieved in a compact period of eight-years operation.

Coupling	HL-LHC	FCC-ee
κ_Z (%)	1.3*	0.10
κ_W (%)	1.5*	0.29
κ_b (%)	2.5*	0.49
κ_g (%)	2*	0.54
κ_τ (%)	1.6*	0.46
κ_c (%)	–	0.87
κ_γ (%)	1.6*	1.1
$\kappa_{Z\gamma}$ (%)	10*	4.3
κ_t (%)	3.2*	3.1
κ_μ (%)	4.4*	3.3
$\lvert\kappa_s\rvert$ (%)	–	$^{+29}_{-67}$
Γ_H (%)	–	0.78
$\mathcal{B}_{inv}$ (<, 95% CL)	1.9×10^{-2} *	5×10^{-4}
$\mathcal{B}_{unt}$ (<, 95% CL)	4×10^{-2} *	6.8×10^{-3}

* next to HL-LHC numbers → not model independent

No question that FCC-ee is a superlative machine for Higgs physics. Furthermore, building the tunnel and related infrastructure will prepare the way for FCC-hh, which can complete the job with the rarer decay modes, and make a correspondingly precise measurements of the self-coupling parameter κ_λ.

FCC-ee essentials and enabling characteristics

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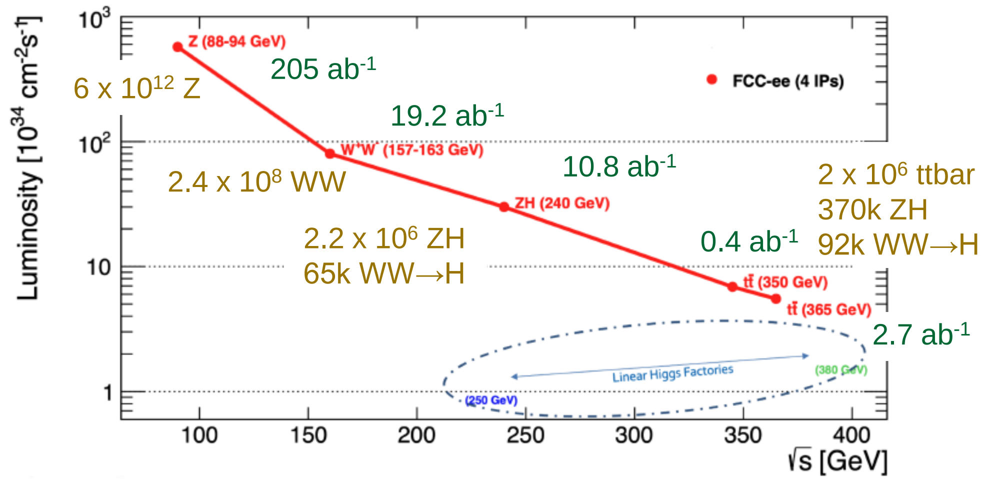
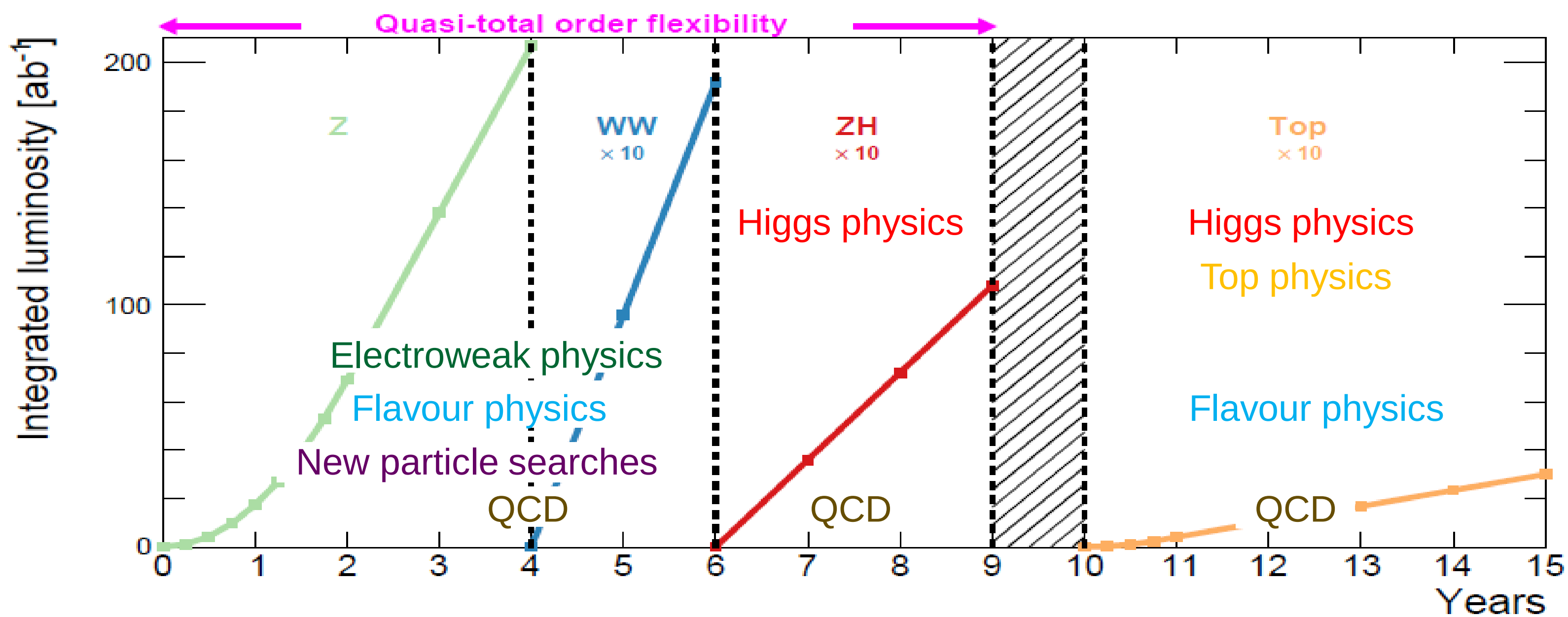
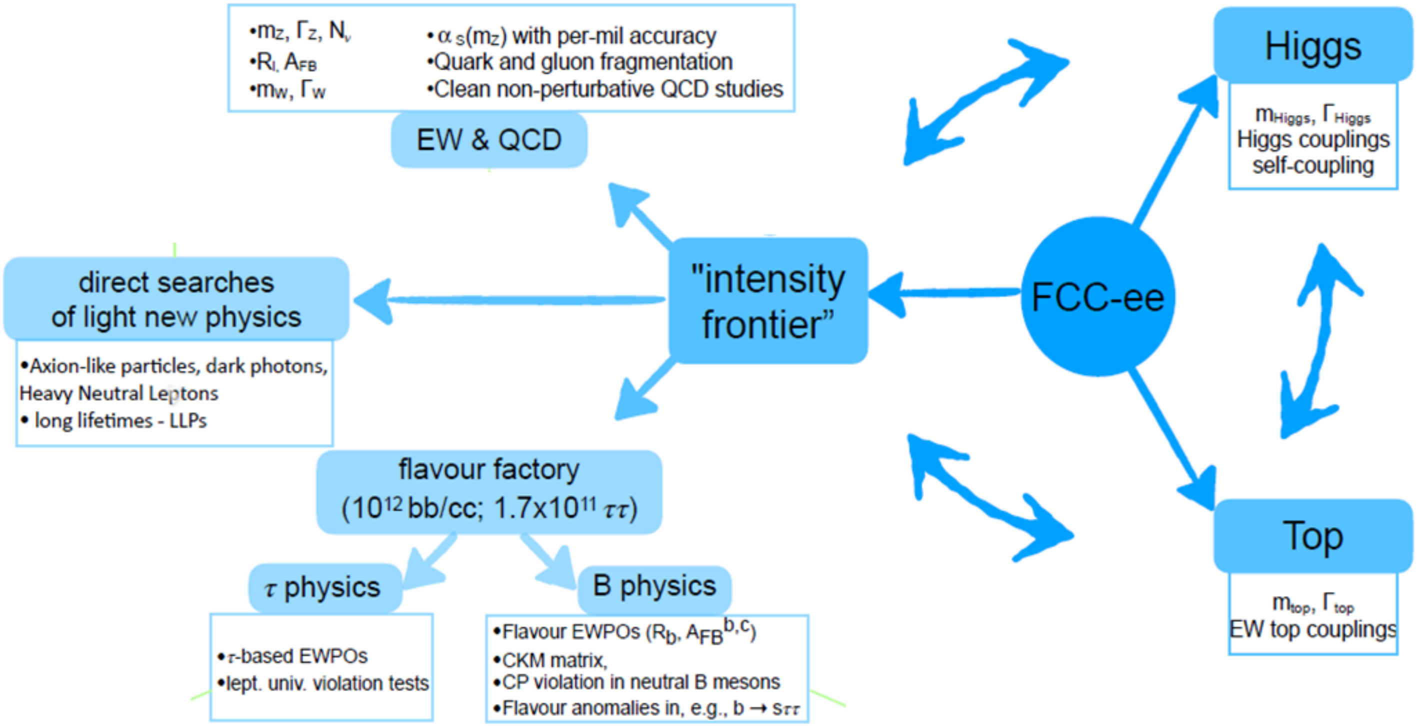


Physics goals encompass Higgs studies, and very much more:



Why did community choose FCC-ee ?

The FCC-ee is much, much more than a Higgs factory. Its very high luminosity across a range of energies gives it an immensely broad physics programme.

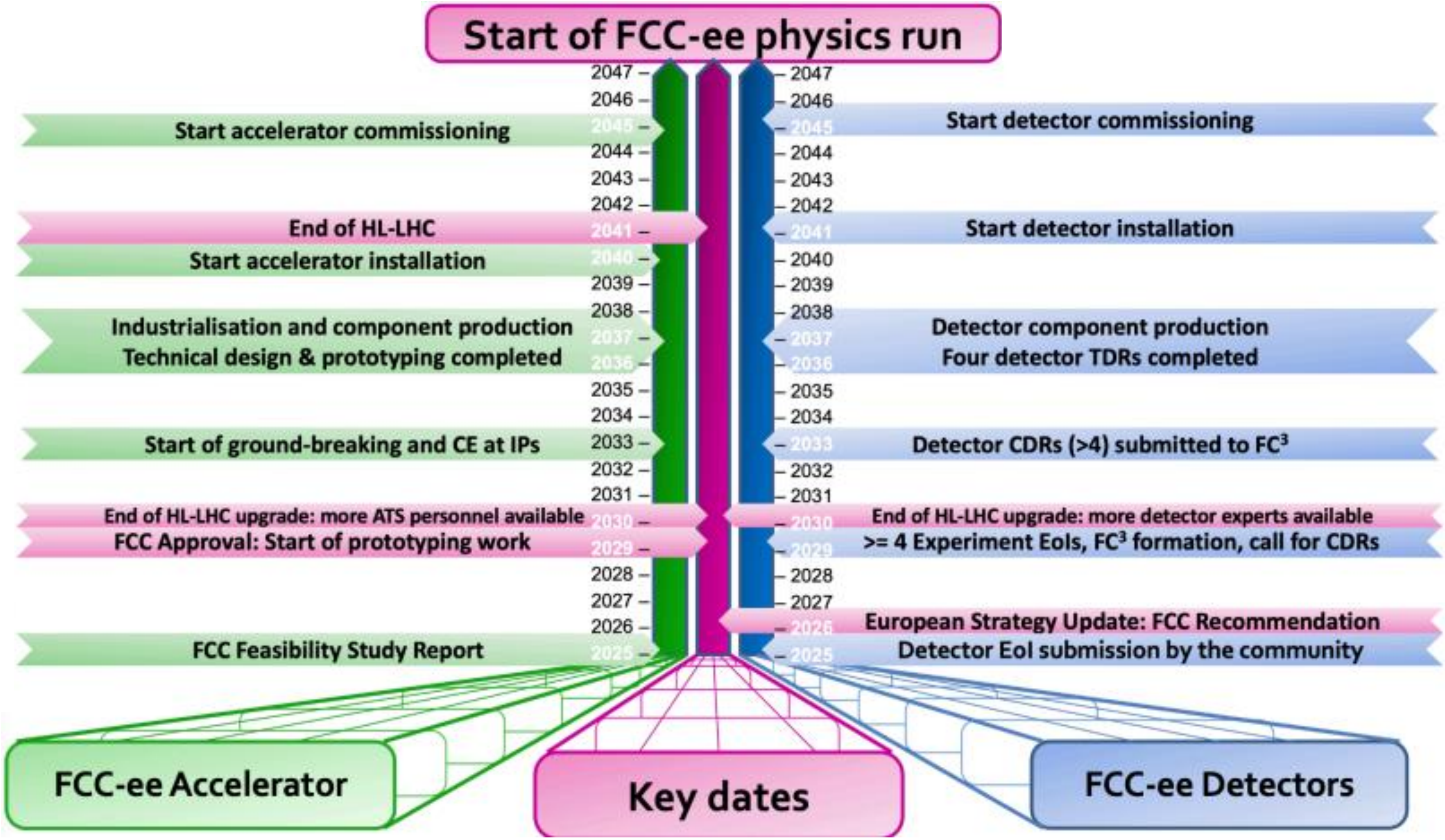


[Christophe Grojean]

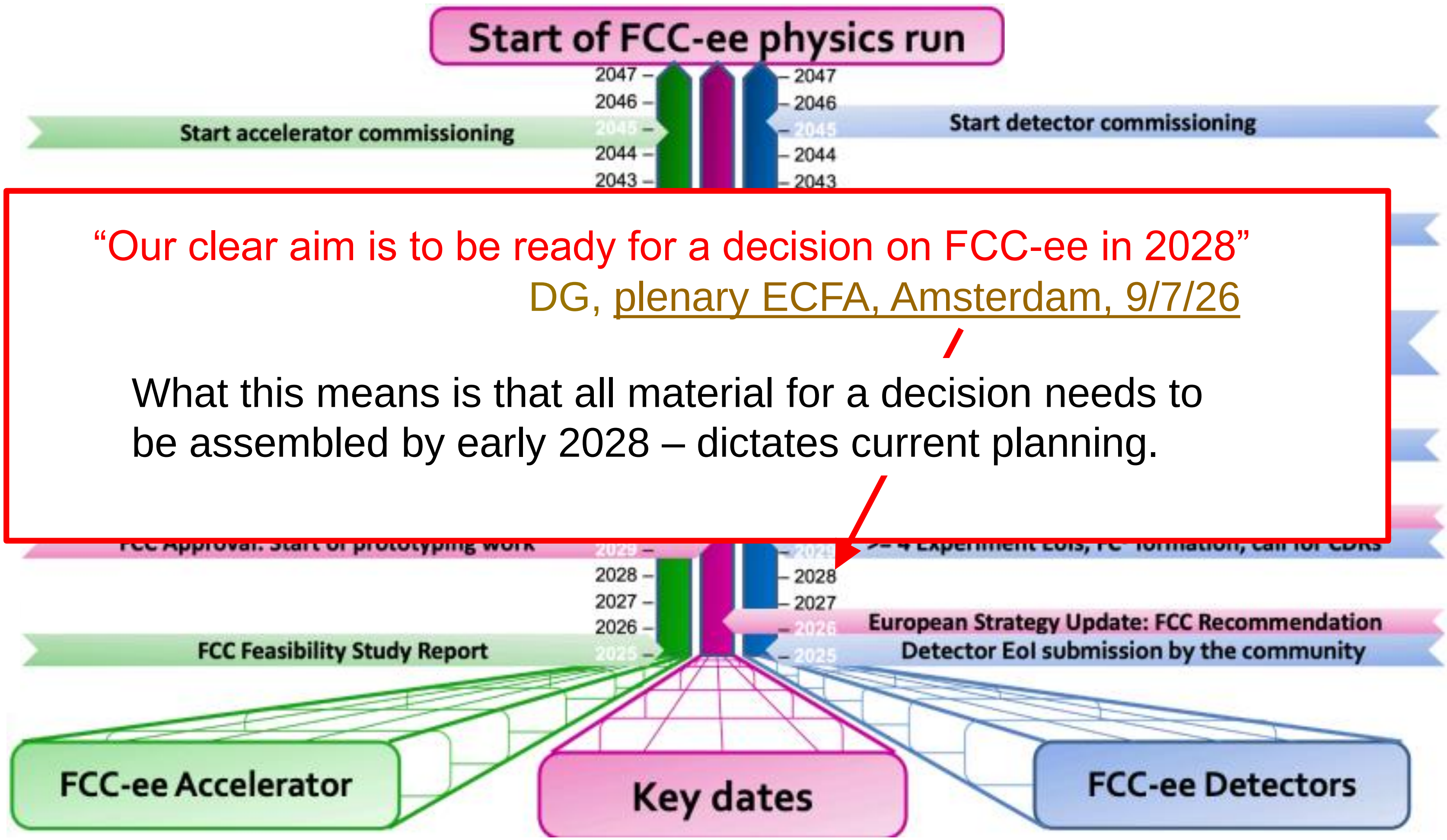
Invaluable in providing the highest possible reach for new physics discovery, and characterising any signature that might emerge through its imprint in multiple sectors.

(Physics breadth a critical consideration when it comes to the detector challenges.)

Countdown to physics



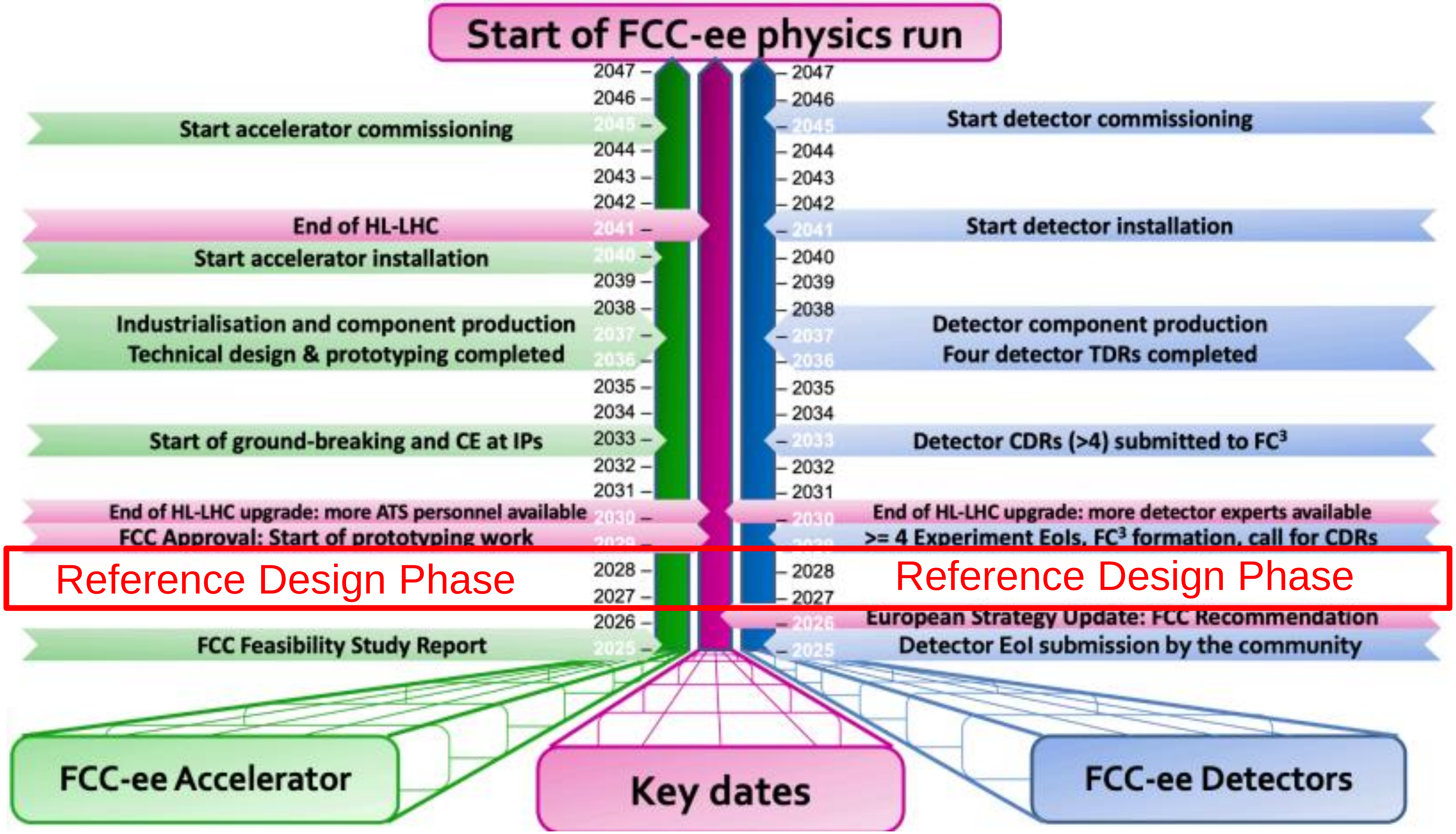
Countdown to physics



"Our clear aim is to be ready for a decision on FCC-ee in 2028"
DG, plenary ECFA, Amsterdam, 9/7/26

What this means is that all material for a decision needs to be assembled by early 2028 – dictates current planning.

Countdown to physics



FCC Reference Design Phase

The purpose of the Reference Design Phase (RDP) is to consolidate the technical, organisational, implementation, schedule and cost elements of the project at a higher level of maturity than that achieved during the Feasibility Study phase, establishing the reference design for the project.

RDP aims to deliver a coherent, integrated and sufficiently mature project definition that will allow for a decision on project approval. If approved…

…the RDP will be followed by the Technical Design Phase, starting in ~2029.

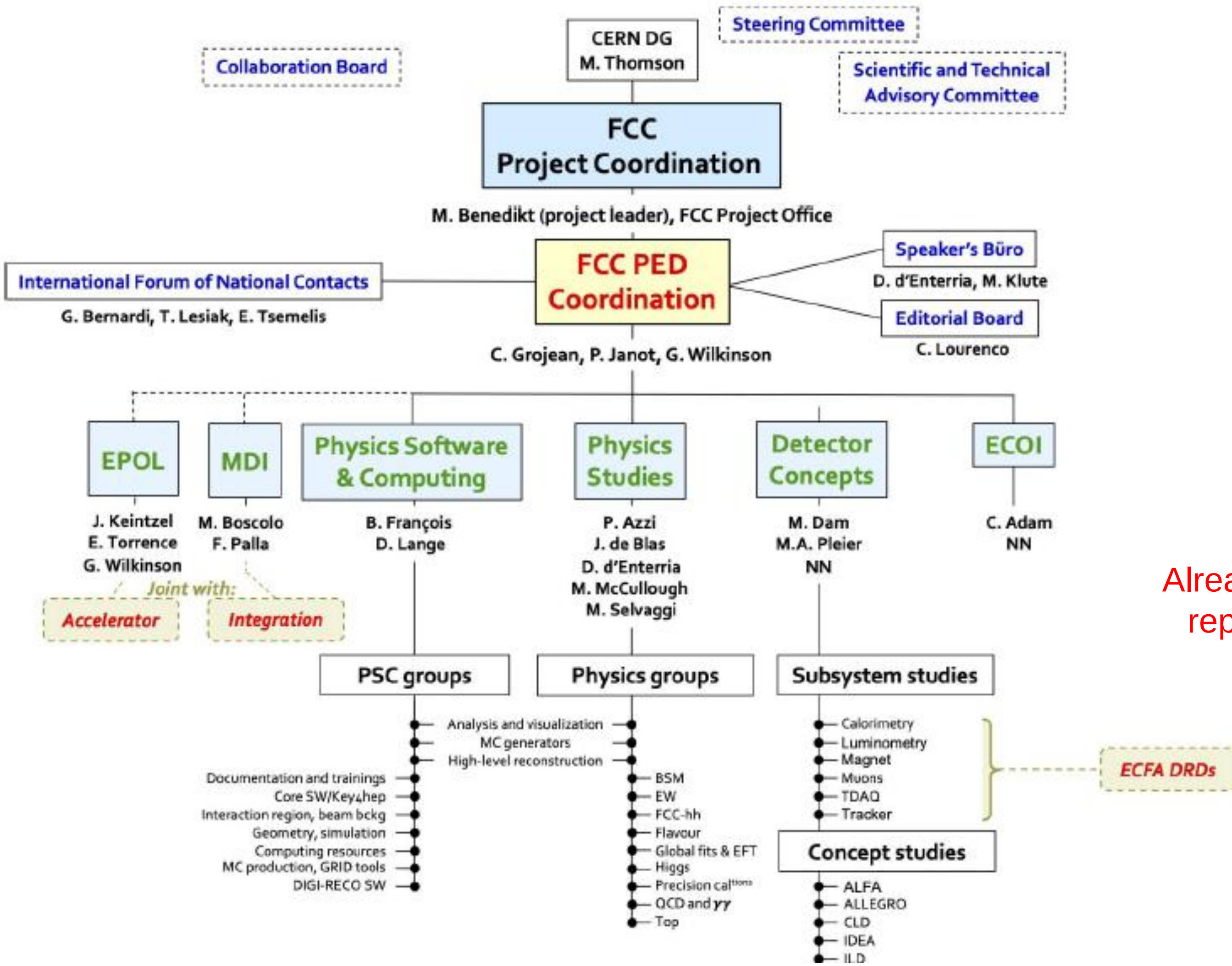
What does this mean for PED ?

PED objectives during the RDP

The following is the list of key PED objectives during RDP:

- Continuation of the development of specific conceptual detector designs with the international HEP community;
- Consolidation of IP region layouts & detector integration;
- Background mitigation strategies & machine-detector interface (MDI) optimisation;
- Development of a common computing architecture model & finalisation of a common software/analysis framework;
- Realistic implementation of some of the algorithms needed to confirm the experimental systematic uncertainties on EW precision observables;
- Coordination of the theory community to address the corresponding theory challenges for the FCC-ee;
- Assessment of the physics case, feasibility, and schedule implications for different centre-of-mass energy stages;
- Streamlining & optimisation of the procedures for centre-of-mass energy calibration & for possible monochromatic operation at 125 GeV to explore the electron Yukawa coupling;
- Proposal for staging implementation & improvements of the (staged/descoped) FCC-ee.

Organisation of Physics, Experiments and Detectors in Reference Design Phase



Already strong US representation !

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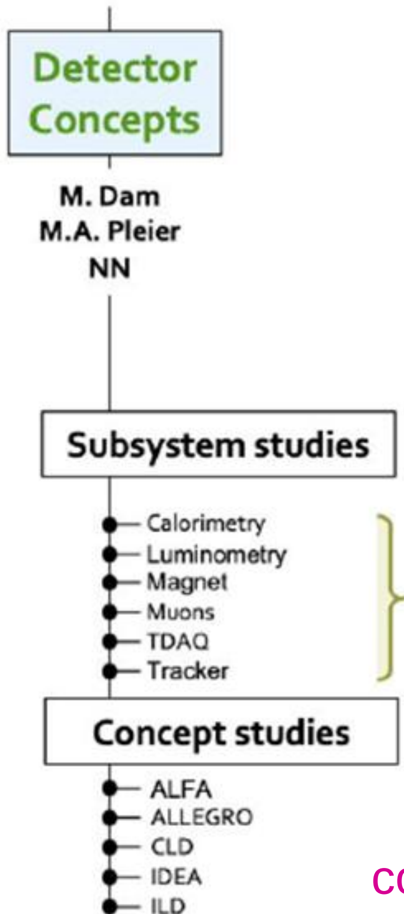
Detector activities



Goals of 'Detector Concepts' WP in Reference Design Phase is to ensure that at time of decision on project approval:

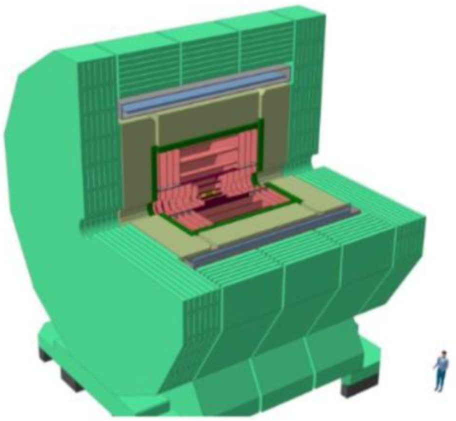
- It should be clear that there is a path towards detector solutions that will be able to exploit fully the physics opportunities (Higgs, EW, flavour, LLP…);
- Collaborations are ready to form immediately, in preparation for down-select of experiments.

with the EPPSU outcome, the DRDs are being encouraged to align more tightly with the needs of FCC-ee !

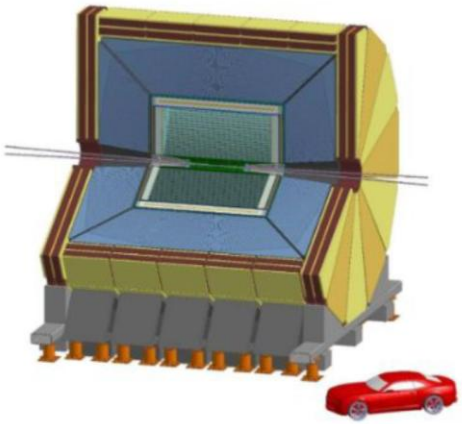
Parallel work on both subsystems and on individual concepts, with concept advocates contributing to the subsystem activities, and vice versa – too early for collaborations or competition !

Emerging detector concepts

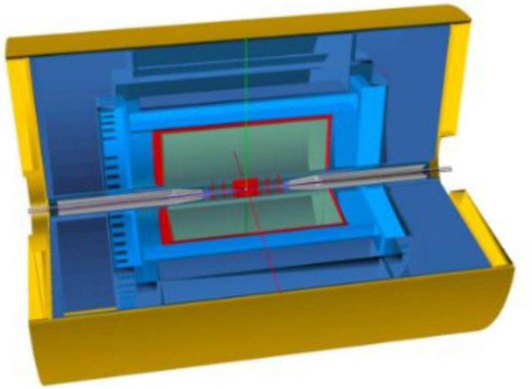
CLD



IDEA

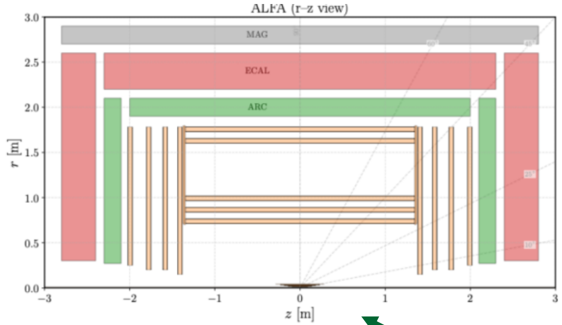


ALLEGRO

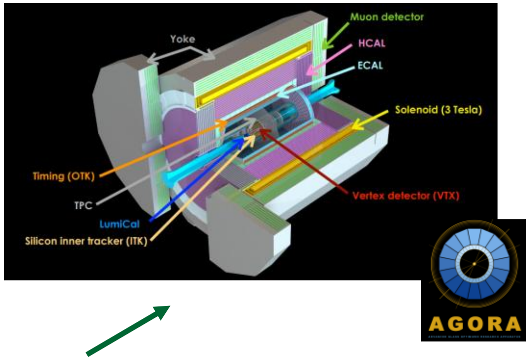


ILD (being ported from ILC)

ALFA



AGORA (being ported from CEPC)



New additions

Not yet collaborations ! These will only form after project approval.

Detector concepts: distinguishing features

	Tracker	PID	ECAL
CLD [FCC week link]	Si based (precise technology under review)	Option for RICH (‘ARC’)	Silicon tungsten
IDEA [FCC week link]	Drift chamber, plus Si wrapper	dE/dx, dN/dx, plus TOF	Crystal dual readout
ALLEGRO [FCC week link]	Drift chamber or straw tube or SciFi, plus Si wrapper	dE/dx, dN/dx (if available), plus TOF	Noble-liquid
ILD [FCC week link]	TPC	dE/dx, dN/dx, possibly plus TOF	Silicon tungsten
ALFA [FCC week link]	MAPS	RICH (‘ARC’)	GRAiNITA (novel crystal-based), better than 2%/sqrt(E) + 1%
AGORA [FCC week link]	TPC (for now)	dE/dx, dN/dx Possible forward RICH	BGO crystal 2%/sqrt(E) + 1%

Vertex Detectors

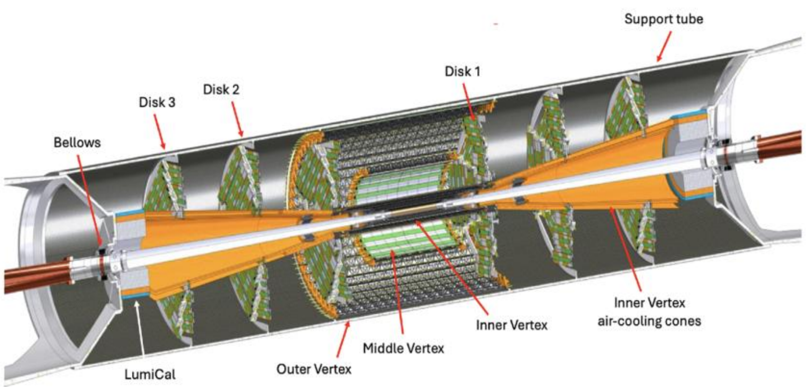
Vertex detector developments highly inspired by ALICE ITS2 and ITS3 designs

- All based on thinned and stitched MAPS
- Ultra-low material, micron precision, low power, efficient cooling, lightweight mechanics, all ~1cm from IP

[Workshop, Oct. 2025]

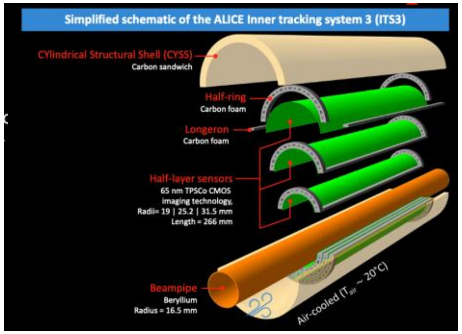
IDEA Vertex Detector (INFN Pisa, Frascati)

- Fully integrated in MDI design
- All sensors are 50 μm MAPS
- Three inner barrel layers: 25 x 25 μm², 50 mW/cm², air cooling
- Middle + outer layers: 150 x 50 μm², water cooled
- Three disks both forward and backward
- Hit resolution: ~3 μm; material: 2.5% X_0 at 90°



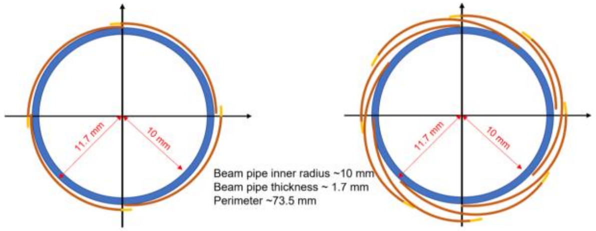
FCC-SEED: curved sensors wrapping around beam pipe (French institutes)

ALICE ITS3 with air cooling under development



12-mm curvature reached

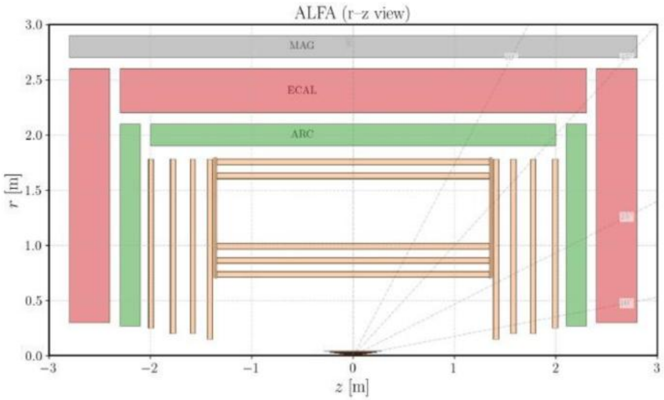
FCC-SEED



Central Trackers

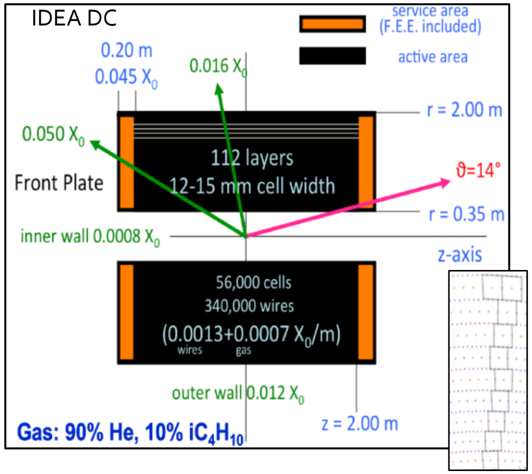
[Sign up for workshop: CERN,16-20 Nov]

Tracking is one of the places where the relevant design space remains widest.

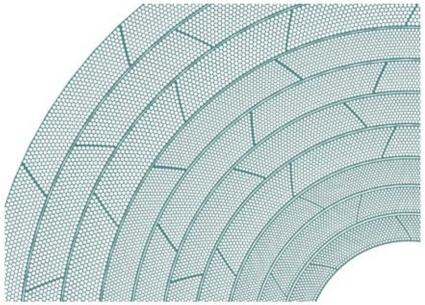


Full silicon tracker
- CLD
- ALFA

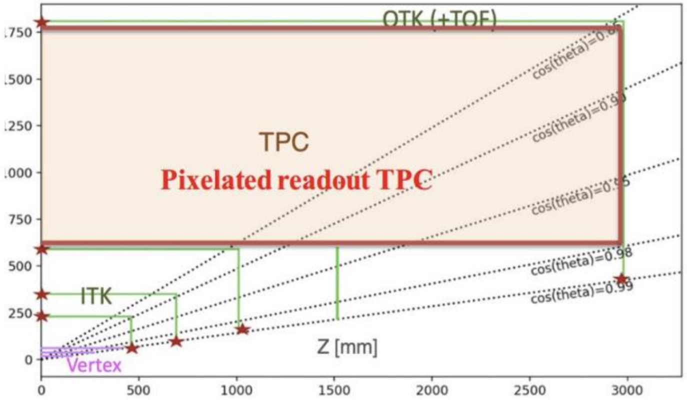
Drift Chamber
- IDEA
- ALLEGRO



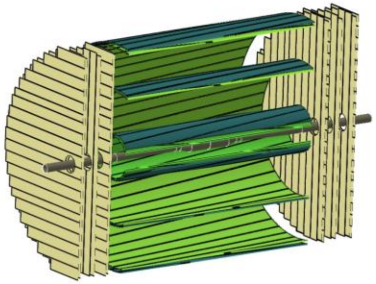
Straw Tracker (ALLEGRO ?)
Robust alternative to DCH?



Time Projection Chamber
- ILD and AGORA



Scintillating Fibre (SciFi) Tracker
- studied for ALLEGRO



Central Trackers: gaseous or Si ?

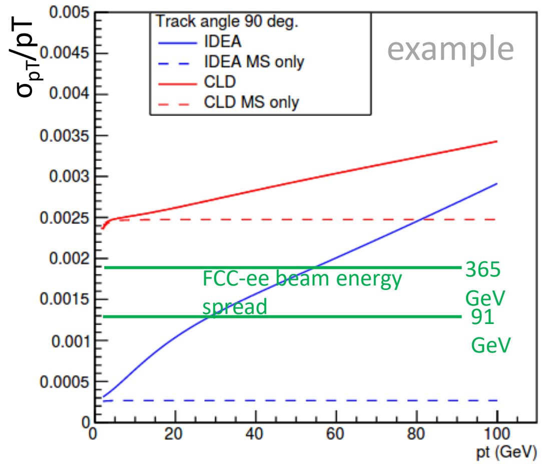
[Sign up for workshop: CERN,16-20 Nov]

At FCC-ee energies, momentum resolution in the CLD Si Tracker limited by multiple scattering.

$$\sigma(p_{\mathrm{T}})/p_{\mathrm{T}}^{2} = a \oplus \frac{b}{p\sin\theta}$$

mult.scat

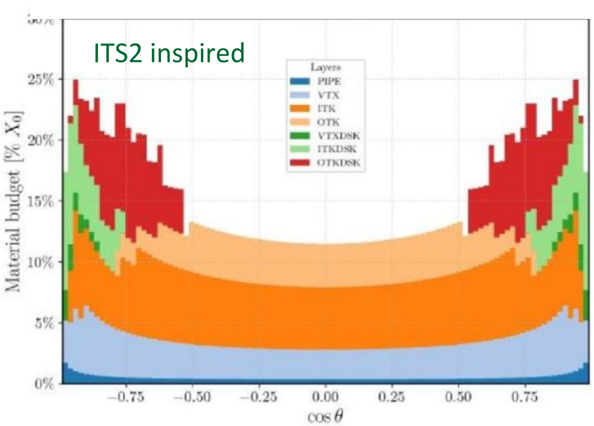
point resolution



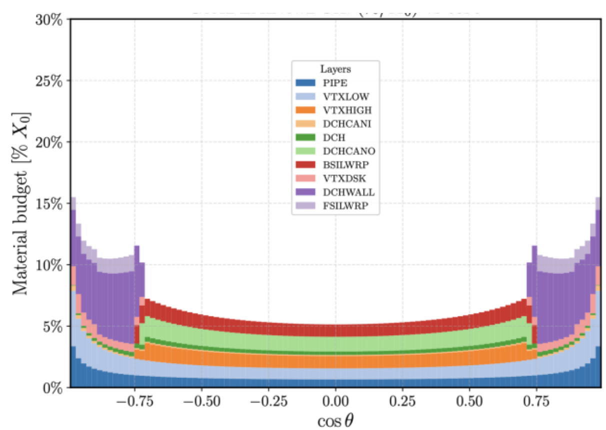
There used to be a strong case for gaseous trackers.

ALFA all-MAPS tracker has a competitive material budget !

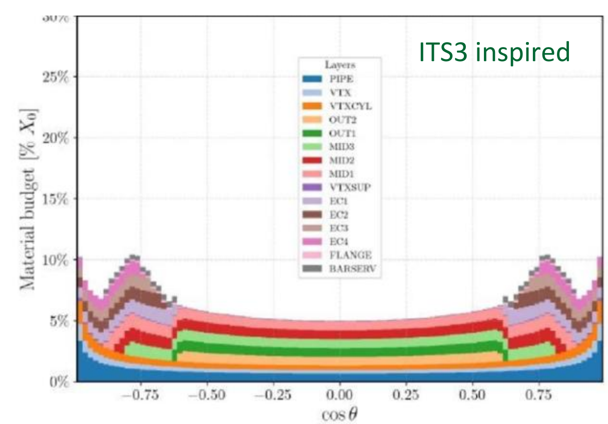
CLD Si pixels + strips



IDEA Drift Chamber + Si



ALFA full Si MAPS

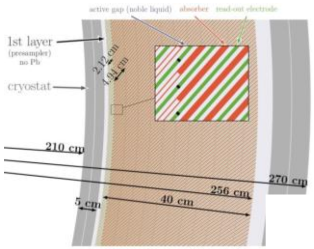


Calorimetry

All concepts aim at Particle Flow reconstruction
- with different emphasis on granularity, energy resolution, stability
- R&D activities concentrated within DRD6 (DRDcalo)

Noble Liquid ECAL + Tile HCAL:
- fine longitudinal sampling (w.r.t. ATLAS, 4 → 12 layers)
- Pb+LAr or denser W+LKr; cold (or warm) electronics
- CALICE or ATLAS style scintillating tile HCAL

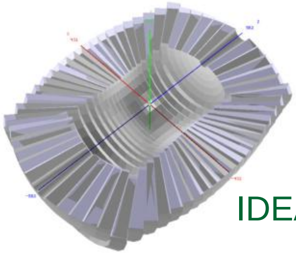
EM: $\sigma(E)/E \simeq 8\text{-}10\%/\sqrt{E}$
Jet: $\sigma(E)/E \simeq 4\%$ @ 50 GeV



Allegro

Fibre-based Dual Readout :
- copper or steel matrix; Cherenkov and scintillating fibres, SiPMs
- very fine transverse granularity, (some) longitudinal inf. via timing

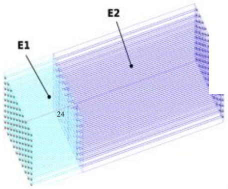
EM: $\sigma(E)/E \simeq 11\%/\sqrt{E}$
Jet: $\sigma(E)/E \simeq 3\text{-}4\%$ @ 50 GeV



IDEA

Segmented crystals with Dual Readout:
- Fine transverse segmentation, two longitudinal layers; SiPMs
- Excellent EM energy resolution of ~3%/√E
- Combined with fibre-based DR calorimeter as HCAL

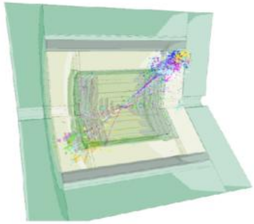
EM: $\sigma(E)/E \simeq 3\%/\sqrt{E}$
Jet: $\sigma(E)/E \simeq 3\text{-}4\%$ @ 50 GeV



CLD,ILD

CALICE-style sandwich with embedded front-end electronics:
- Tungsten-silicon ECAL; extremely fine segmentation: $(0.5\text{ cm})^3$
- Steel-scintillator HCAL; SiPM-on-Tile; fine segmentation: $(2.5\text{ cm})^3$

EM: $\sigma(E)/E \simeq 16\%/\sqrt{E}$
Jet: $\sigma(E)/E \simeq 3\text{-}4\%$ @ 50 GeV

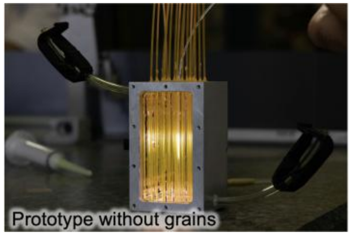


Calorimetry – new additions

ALFA: Grainita ECAL concept

- 1mm crystal grains ($ZnWO_4$) immersed in heavy liquid (sodium-tungstate-water solution) or resin
- Emitted light collected by WLS fibres

Incoming particle

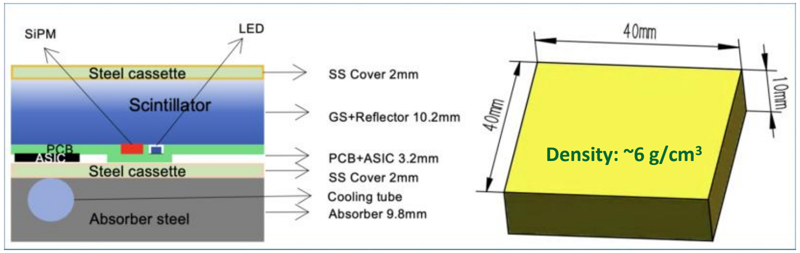


- Excellent energy resolution
- High transverse granularity
- Cost-effective compared to homogenous crystals
- First (small) prototype: 28x28x55 mm^3

ALFA: Dual-Readout Tile HCAL ?

- For example, CALICE-style Steel / Quartz / Scintillator Tile HCAL
- Also to function as a yoke
- To be studied as an extension of AHCAL (DRD6) ?

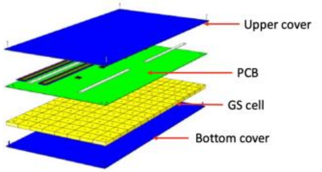
AGORA: Glass Scintillator HCAL



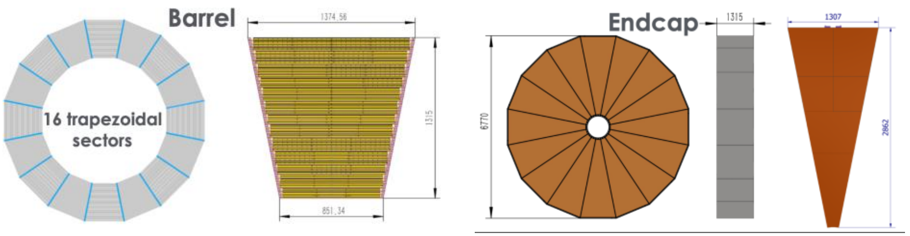
Single layer structure

Total of 85 m^3 glass scintillator

- High sampling fraction (~30%)
- Resolution of ~30%/√E



48 layers stacked per module



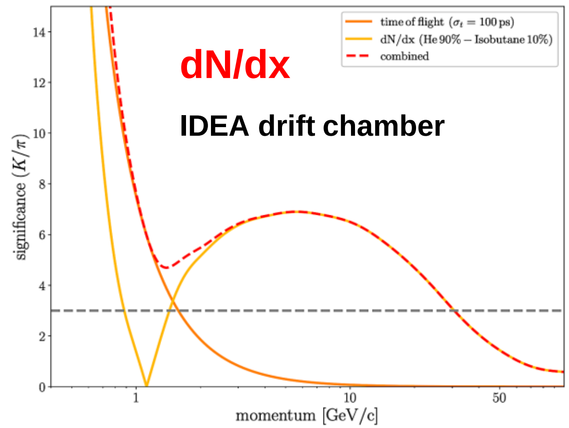
Charged-particle identification

[Sign up for workshop: CERN,16-20 Nov]

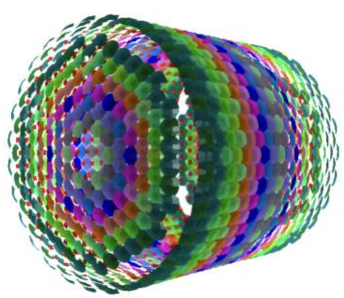
Essential for flavour physics, over a wide momentum range (up to 50 GeV).
Useful also for flavour-tagging jets in Higgs, W and top physics.

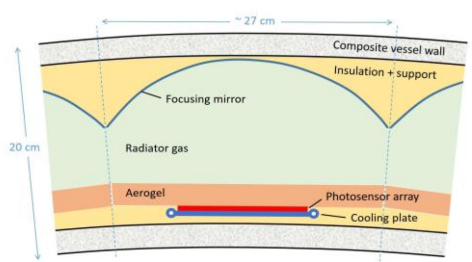
With gaseous tracking chamber, dE/dx, or even better dN/dx (cluster counting).

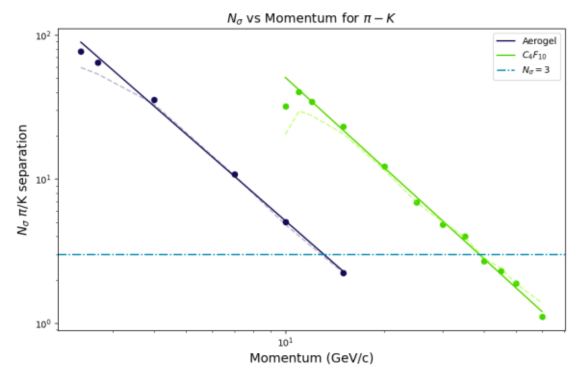
Complemented by TOF at low momentum, provided by *e.g.* LGADs in Si wrapper.



With Si tracker, there needs to be a dedicated PID detector, preferably RICH to cover full momentum range, *e.g.* ARC.







The path towards Collaboration formation

From the 'FCC Objectives, Deliverables, Milestones' Council Document:

These 6(+) EoIs can already be prepared during the RDP, so they can be made public very soon after project approval.

> These activities are aimed at demonstrating feasibility, integration compatibility and cost realism for the FCC-ee detectors, without committing to a final detector selection or to experiment collaborations forming. Expressions of interest for FCC-ee detectors will be invited after the project approval, with a view to moving towards detector conceptual design reports by 2033.

It is suggested (by PED [see P. Janot article in 17th ECFA newsletter]) that a process begin immediately after project approval (assumed 2028) to enable community-wide discussion and synthesis of best elements of existing proposals towards four robust LoIs, and collaborations to form by early 2030.

ECFA could facilitate this process through arranging series of `Evian-like' workshops (recall Evian Meeting of 1992, two years before LHC approval, which considered 12 LHC EoIs and cleared the way to the final configuration).

Everyone is encouraged to widen their engagement with FCC Detector Concepts so that they can play a central role in these discussions !

PED objectives during the RDP

The following is the list of key PED objectives during RDP:

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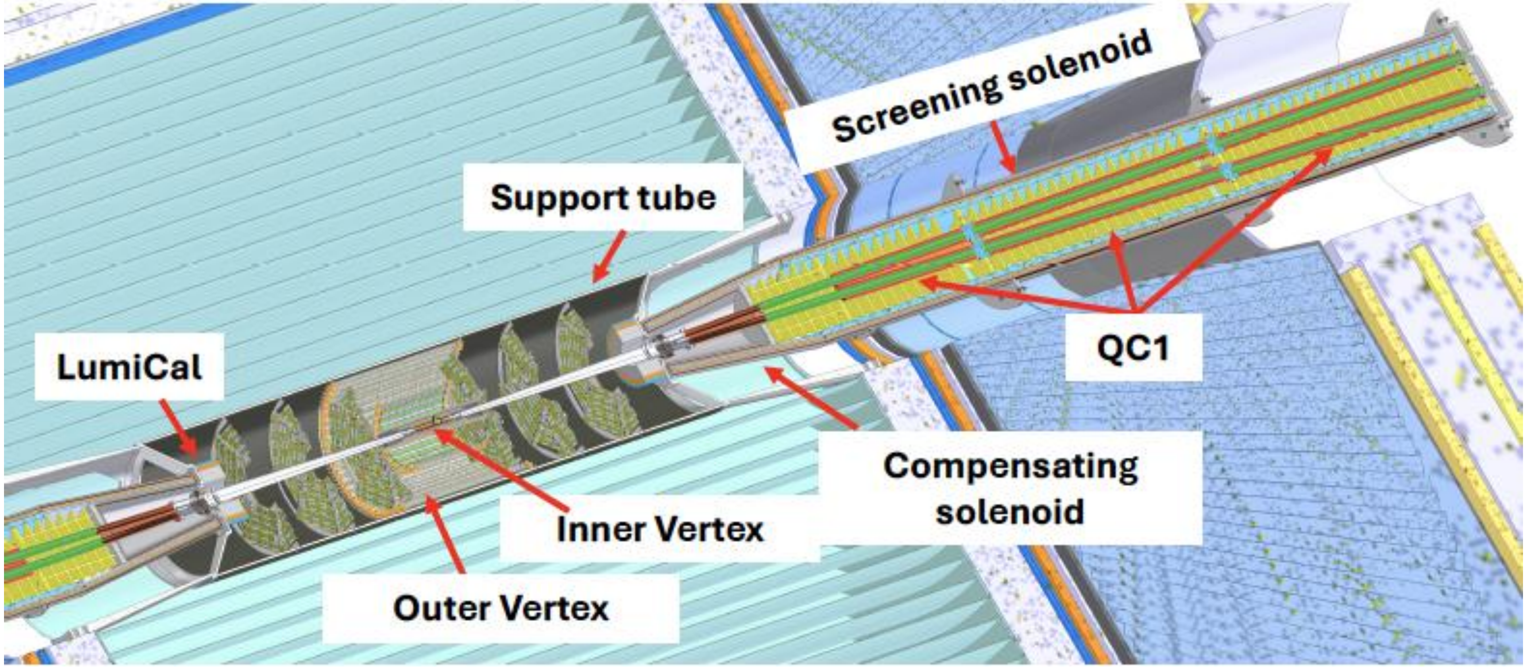
Machine detector interface

Common activity – not specific to a particular Detector Concept !

FCC-ee interaction region is a highly complex and crowded environment, whose optimisation demands very close cooperation between physicists & machine.



Key topics:

- Design and implementation of lumi cal & vertex detector.
- Beam pipe design, including cooling.
- Optimisation of collimators, masks and shielding.
- Evaluation of all sources of machine background.
- Detector opening strategy and impact on cavern dimensions.

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Computing and s/w

Common activity – not specific to a particular Detector Concept !

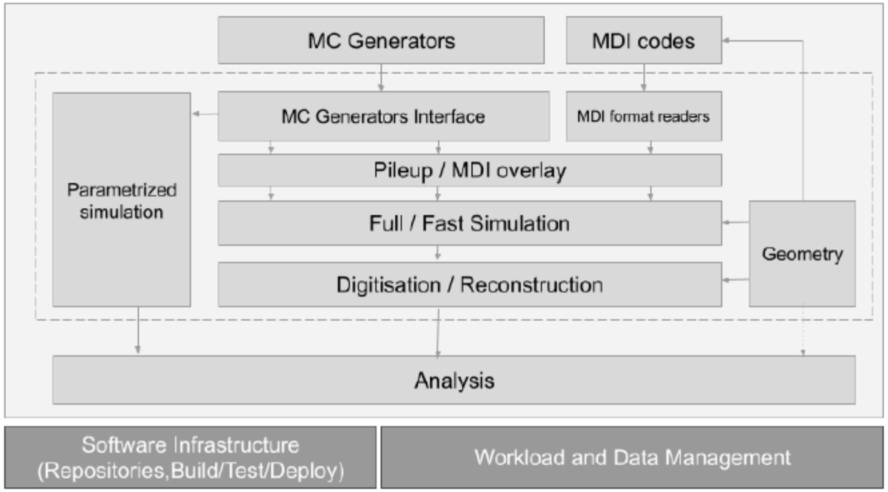
Ever since launch of Conceptual Design Study (2014), the driving goal has been the development of unified, synergistic, and adaptable s/w 'ecosystem'.

This will continue into operation phase (shared environment for all expts !).

Common s/w framework (KEY4HEP) and data format (EDM4HEP).

Many workflows to be supported.

Help very welcome !



[The FCC software for PED studies]

Bulk of physics studies conducted so far have been based on DELPHES-level parametrised MC, but G4 simulation for all detectors now being implemented.

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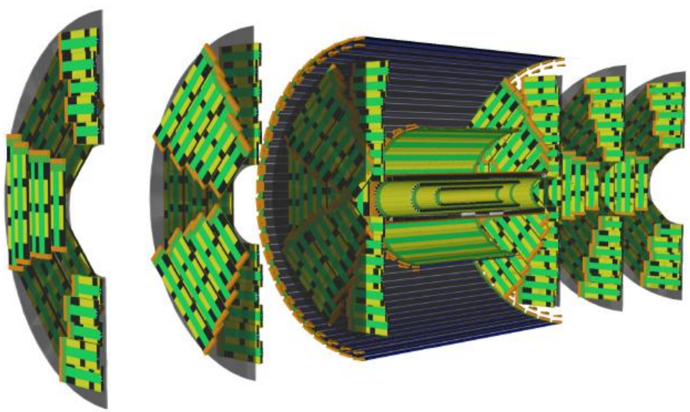
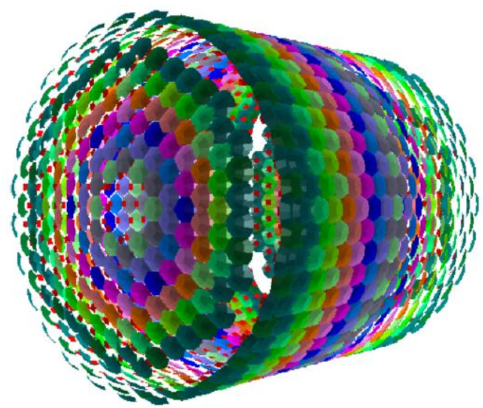
Progress on detailed detector descriptions

Vertex detector



RICH (ARC concept)



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Daunting challenge posed by huge sample sizes for EWPO

Electroweak precision observables

Observable	present value	±	present uncertainty	FCC-ee Stat.	FCC-ee Syst.	Comment and leading uncertainty
m_Z (keV)	91 187 600	±	2000	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2 495 500	±	2300	**4**	12	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{\rm eff}$ ($\times 10^6$)	231,480	±	160	**1.2**	1.2	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z^2)$ ($\times 10^3$)	128 952	±	14	**3.9** **0.8**	small tbc	From $A_{FB}^{\mu\mu}$ off peak From $A_{FB}^{\mu\mu}$ on peak QED&EW uncert. dominate
R_ℓ^Z ($\times 10^3$)	20 767	±	25	**0.05**	0.05	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_S(m_Z^2)$ ($\times 10^4$)	1 196	±	30	**0.1**	1	Combined R_ℓ^Z, $\Gamma_{\rm tot}^Z$, $\sigma_{\rm had}^0$ fit
$\sigma_{\rm had}^0$ ($\times 10^3$) (nb)	41 480.2	±	32.5	**0.03**	0.8	Peak hadronic cross section Luminosity measurement
N_ν ($\times 10^3$)	2 996.3	±	7.4	**0.09**	0.12	Z peak cross sections Luminosity measurement
R_b ($\times 10^6$)	216 290	±	660	**0.25**	0.3	Ratio of $b\bar{b}$ to hadrons
$A_{FB}^{b,0}$ ($\times 10^4$)	992	±	16	**0.04**	0.04	b-quark asymmetry at Z pole From jet charge
$A_{FB}^{{\rm pol},\tau}$ ($\times 10^4$)	1 498	±	49	**0.07**	0.2	τ polarisation asymmetry τ decay physics
τ lifetime (fs)	290.3	±	0.5	**0.001**	0.005	ISR, τ mass
τ mass (MeV)	1 776.93	±	0.09	**0.002**	0.02	estimator bias, ISR, FSR
τ leptonic ($\mu\nu_\mu\nu_\tau$) BR (%)	17.38	±	0.04	**0.00007**	0.003	PID, π^0 efficiency
m_W (MeV)	80 360.2	±	9.9	**0.18**	0.16	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2 085	±	42	**0.27**	0.2	From WW threshold scan Beam energy calibration
$\alpha_S(m_W^2)$ ($\times 10^4$)	1 010	±	270	**2**	2	Combined R_ℓ^W, $\Gamma_{\rm tot}^W$ fit
N_ν ($\times 10^3$)	2 920	±	50	**0.5**	small	Ratio of invis. to leptonic in radiative Z returns
$m_{\rm top}$ (MeV)	172 570	±	290	**4.2**	4.9	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\Gamma_{\rm top}$ (MeV)	1 420	±	190	**10**	6	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\lambda_{\rm top}/\lambda_{\rm top}^{\rm SM}$	1.2	±	0.3	**0.015**	0.015	From $t\bar{t}$ threshold scan QCD uncert. dominate
ttZ couplings		±	30%	**0.5–1.5 %**	small	From $\sqrt{s} = 365$ GeV run

Zoom-in on selected examples

	Current knowledge			FCC uncertainties Stat	FCC uncertainties Syst
Γ_Z (keV)	2 495 500	±	2300	**4**	12
$\sin^2\theta_W^{\rm eff}$ ($\times 10^6$)	231,480	±	160	**1.2**	1.2
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$A_{FB}^{b,0}$ ($\times 10^4$)	992	±	16	**0.04**	0.04

In some cases improvement from LEP is in excess of naïve expectation of factor ~600 through , *e.g.* R_b, ML-aided advances (*e.g.* in jet tagging), smaller beampipe *etc.* !

This must be done through data driven studies. RDP aims to see progress on this goal, and impact of realistic detector effects.

Theory must also rise to the challenge.

Theoretical challenges ahead

e.g. 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)			
$\sin^2\theta^{\ell}_{\text{eff}}$	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, $\mathcal{O}(30\,\text{MeV})$ 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]

Physics activities during the RDP

Physics structure reorganised for coming period:

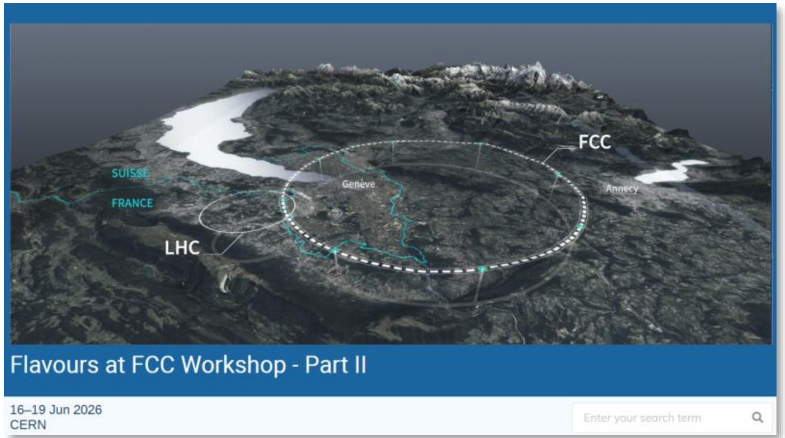
- BSM
- EW
- FCC-hh
- Flavour
- Global fits and EFT
- Higgs
- Precision calculations
- QCD and γγ
- Top

and, in common with s/w and computing:

- Analysis and visualisation
- MC generators
- High-level reconstruction

One important point of emphasis is to explore more deeply those areas where the potential is clear, but where studies are lagging behind those in areas such as Higgs and EW.

e.g. 'Flavours at FCC' – two-year workshop with bi-annual in-person events (Nov '25, June '26).



Watch out for workshops in other areas !

e.g. BSM: CERN, 23-25 Sept

FCC-hh: CERN, 22 Sept

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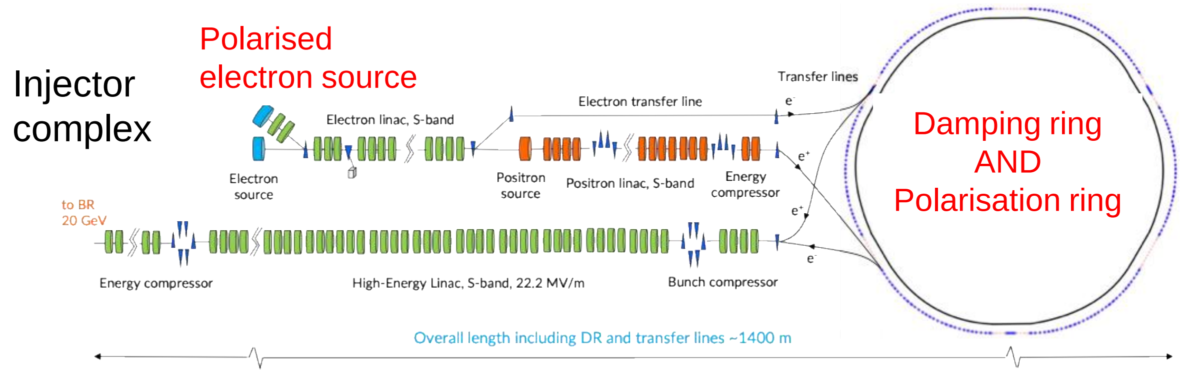
E_{CM} calibration ('EPOL')

Ultra-precise collision energy calibration a unique strength of FCC-ee, and essential for electroweak programme. Programme relies on transversely polarised beams and resonant depolarisation, but plenty of scope for particle physicist involvement

- Polarimeter development
- Measurement of E_{CM} related quantities (crossing angle, longitudinal boost, E_{CM} itself…) with physics events *e.g.* $e^+e^- \rightarrow \mu^+\mu^-$

Interesting developments:



1) Moving towards strategy of injecting polarised beams, rather than 'wasting' ~2 hours at start of fill to wait for polarisation to build up → greater machine availability / more time for physics !

2) New idea: measure dimuon production from collision of beam positrons with electrons in injected gas target. Threshold is very close to E_b = 45 GeV and can be measured very precisely. Again, more help welcome !

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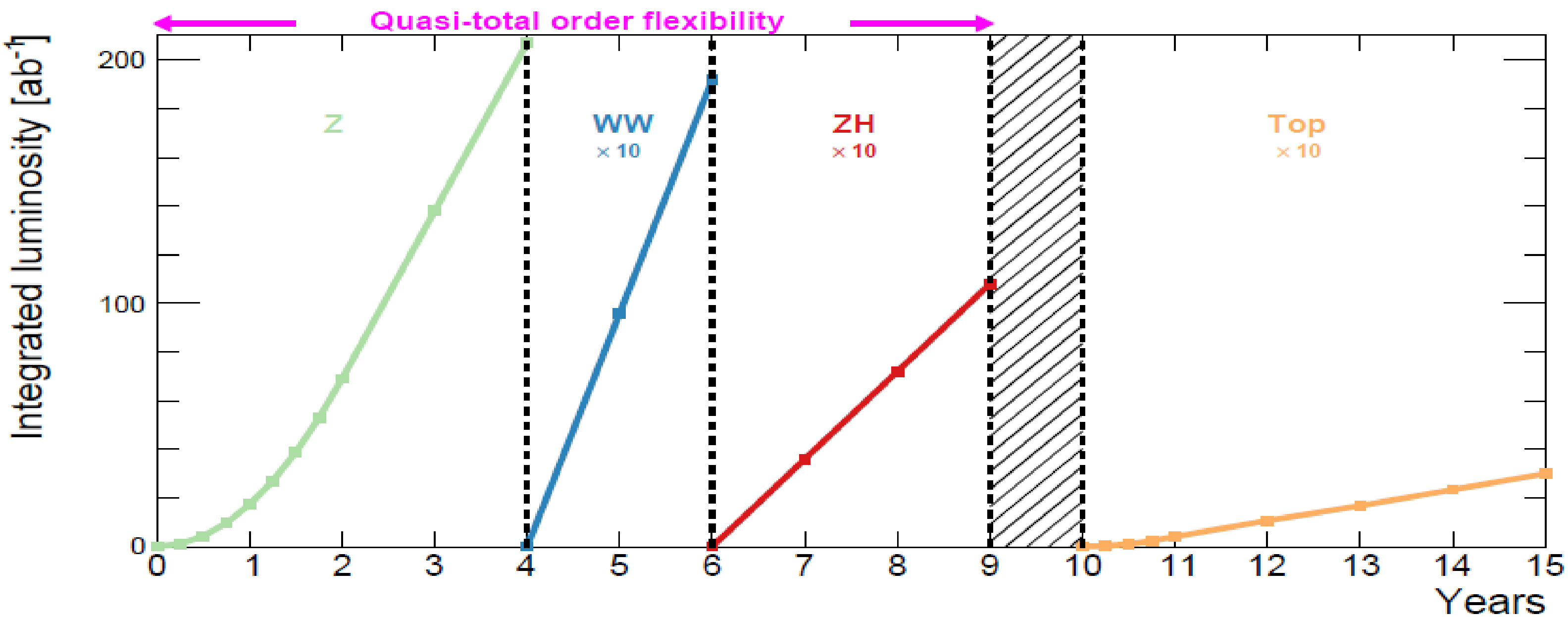
Optimisation of running strategy

The current baseline plan, which (probably) will be that presented for approval:



Working point	Z pole	WW thresh.	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated lumi. (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	6×10^{12} Z	2.4×10^{8} WW	2.2×10^{6} ZH + 65k WW $\rightarrow$ H	2×10^{6} $t\bar{t}$ + 370k ZH + 92k WW $\rightarrow$ H	

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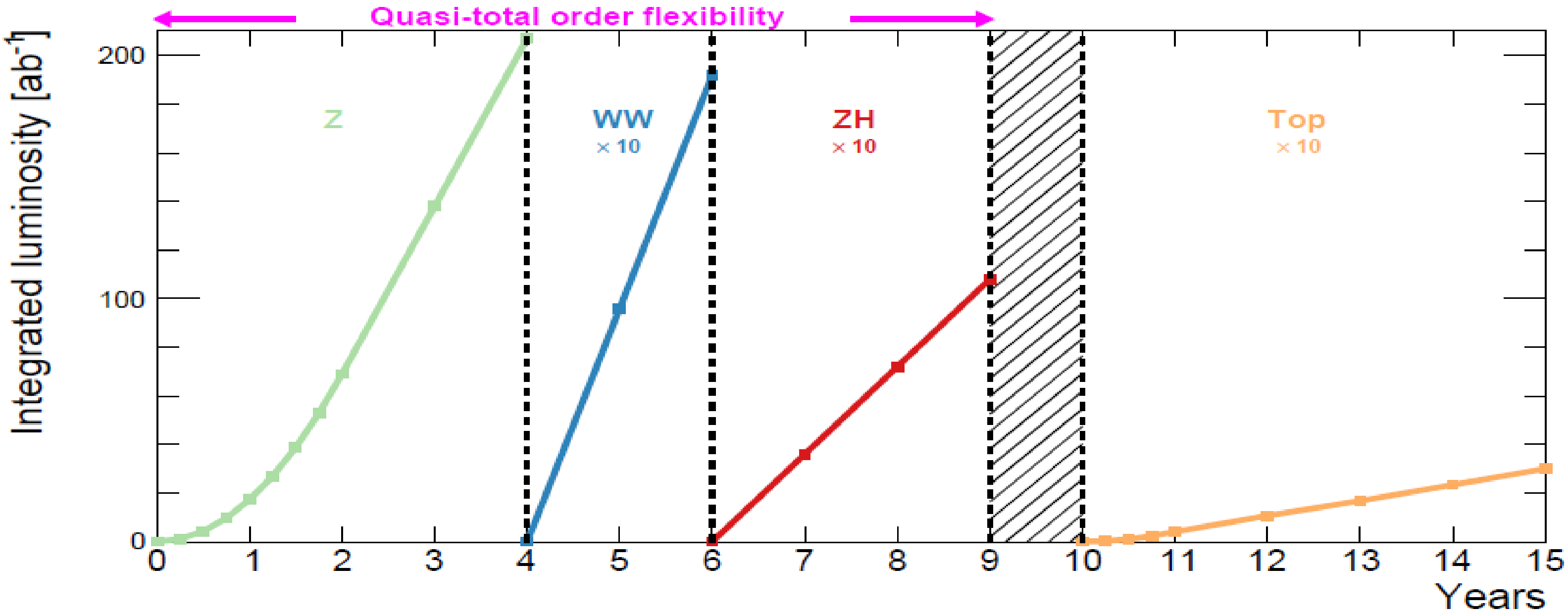
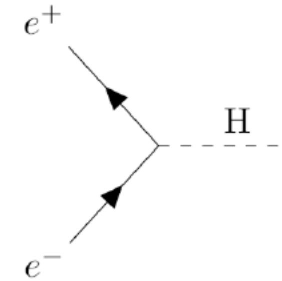


However, this is not set in stone. Imaginative thinking about how this could be adjusted, or what additional running points could be added, are welcome !

In general, flexibility of operation means no decisions need to be taken now.

Run at 125 GeV ?
s-channel Higgs production

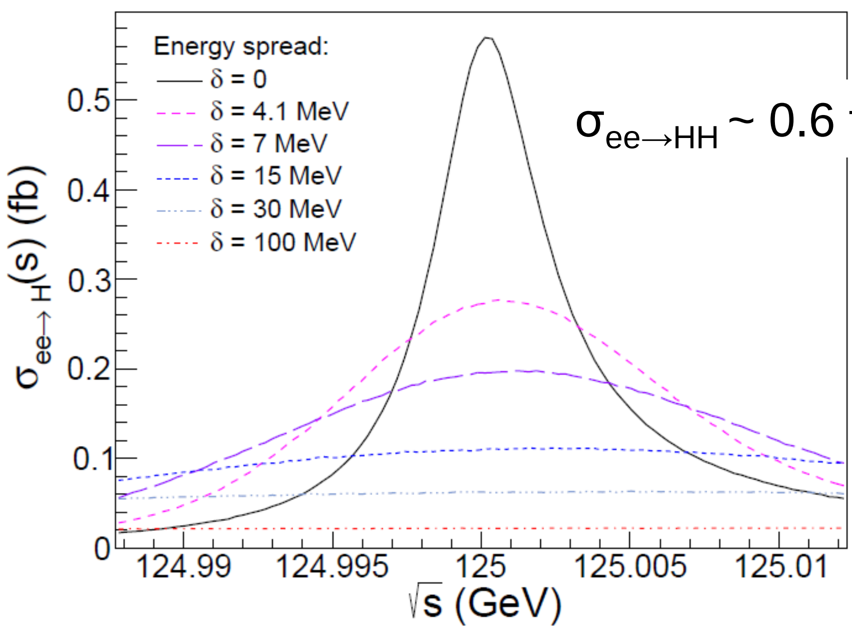


A tantalising possibility, under evaluation and not in FSR baseline, is to devote a few years operation at $E_{CM}=m_H=125$ GeV to measure Yukawa coupling to electrons.

But cross-section is tiny…

…& effectively decreased further through ISR and because Higgs width (~4 MeV) small compared to E_{CM} spread.

Note that natural E_{CM} spread for colliding beams is ~70 MeV. This must be reduced: requires *monochromatisation*.

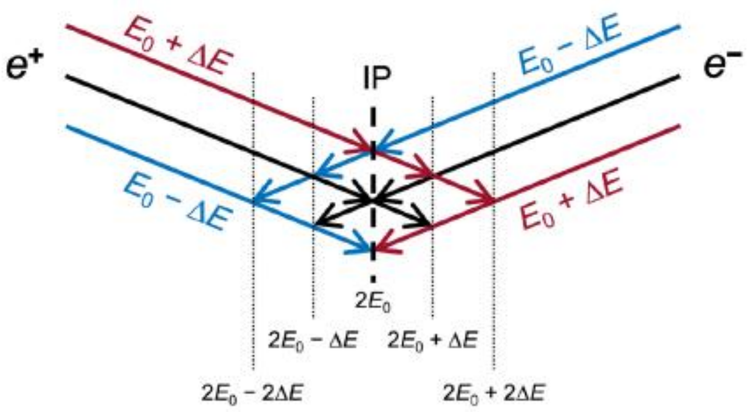


Also need good knowledge of m_H (~ Γ_H), good E_{CM} knowledge, & high E_{CM} stability.

In addition, must develop refined analysis exploiting all Higgs decay modes to separate signal from background (*e.g.* Higgs →gg becomes an important channel).

The Higgs-pole challenge

Monochromatisation can be achieved through introduced opposite-sign dispersion.



The problem is that this generally also results in an emittance blow up, and hence a decrease in luminosity. Need to find the sweet spot in $\delta_{\sqrt{s}}$ vs. L plane !

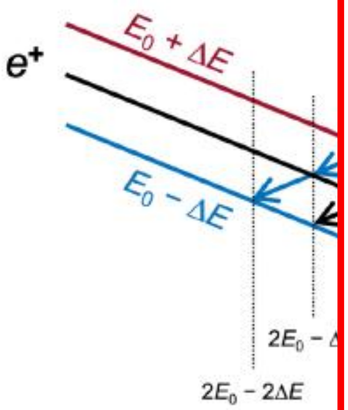
First serious attempt to implement such a scheme [Zhang *et al.*, arXiv:2411.04210] achieves monochromatisation factors of >2. With such a performance, it would be possible to set 95% CL limit of 2.5x SM value in 1 year, ~20-40x better than is foreseeable at HL-LHC. Efforts ongoing to improve further.

A complementary approach: collide longitudinally polarised beams, with helicities set for Higgs, not Z, production. Not foreseen in Feasibility Study design, but made more conceivable by ongoing studies (transverse) polarised (pilot) bunch injection.

Goal – reach a clearer idea on feasibility by end of RDP, but not in baseline !

The Higgs-pole challenge

Monochromatis … sign dispersion.



… erally also … up, and hence … eed to find the … !

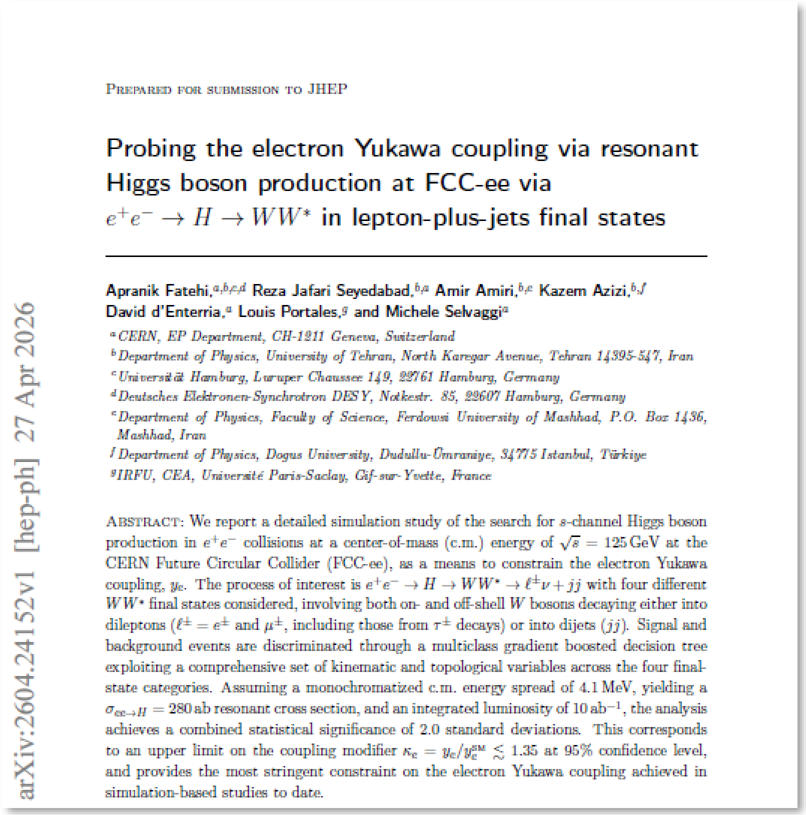
… ment such a … 4210] achieves … of >2. With such

a performanc … M value in 1 year,
~20-40x bette … improve further.

A complemen … s, with helicities
set for Higgs, … design, but made
more conceiv …) bunch injection.

Goal – reach … n baseline !

Recent developments – a significant (four-fold) improvement in H→WW*→lepton + jets channel, now matching previous golden mode, H→gg.



PREPARED FOR SUBMISSION TO JHEP

Probing the electron Yukawa coupling via resonant Higgs boson production at FCC-ee via $e^+e^- \to H \to WW^*$ in lepton-plus-jets final states

Apranik Fatehi,[a,b,c,d] Reza Jafari Seyedabad,[b,a] Amir Amiri,[b,e] Kazem Azizi,[b,f] David d'Enterria,[a] Louis Portales,[g] and Michele Selvaggi[a]

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[e] Department of Physics, Faculty of Science, Ferdowsi University of Mashhad, P.O. Box 1436, Mashhad, Iran
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[g] IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France

ABSTRACT: We report a detailed simulation study of the search for s-channel Higgs boson production in e^+e^- collisions at a center-of-mass (c.m.) energy of $\sqrt{s} = 125\,\mathrm{GeV}$ at the CERN Future Circular Collider (FCC-ee), as a means to constrain the electron Yukawa coupling, y_e. The process of interest is $e^+e^- \to H \to WW^* \to \ell^\pm\nu + jj$ with four different WW^* final states considered, involving both on- and off-shell W bosons decaying either into dileptons ($\ell^\pm = e^\pm$ and $\mu^\pm$, including those from $\tau^\pm$ decays) or into dijets (jj). Signal and background events are discriminated through a multiclass gradient boosted decision tree exploiting a comprehensive set of kinematic and topological variables across the four final-state categories. Assuming a monochromatized c.m. energy spread of 4.1 MeV, yielding a $\sigma_{ee\to H} = 280$ ab resonant cross section, and an integrated luminosity of $10\,\mathrm{ab}^{-1}$, the analysis achieves a combined statistical significance of 2.0 standard deviations. This corresponds to an upper limit on the coupling modifier $\kappa_e = y_e/y_e^{\mathrm{SM}} \lesssim 1.35$ at 95% confidence level, and provides the most stringent constraint on the electron Yukawa coupling achieved in simulation-based studies to date.

arXiv:2604.24152v1 [hep-ph] 27 Apr 2026

[arXiv:2604.24152]

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Descoping, staging (and upscoping?)

Reminder:
EPPSU plan B

B. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN.

Descoping scenarios include removing the top-quark run, constructing two rather than four interaction regions and experiments and decreasing the radiofrequency (RF) system power. These measures would reduce the construction cost by approximately 15%. Although this would have a significant impact on the breadth of the physics programme and the precision achieved, the descoped FCC-ee would still provide a very strong physics programme and a viable path towards high energies, compared to the alternative collider options. Should additional resources become available, these descoping scenarios would be reversible.

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Physics community needs to be vocal in what would be lost in a true descoping, and push instead that this option be recast as a staging scenario.

Recoverable descopes: lower RF power (probably reversible), deferred top run

Not recoverable, and a false economy: excavating only two experimental caverns

Meanwhile, recent and ongoing developments may already bring cost benefits

- Very recent adoption of new optics (‘LCC’ replacing ‘GHC’) means same luminosity with reduced beam power (OR 10% more lumi for same power);
- Possible further optimisation of RF system requiring fewer cavities & cryo modules, and the increased facilitation of in-kind contributions.

Concluding message

DG message from plenary ECF, July 2026 [link]:

FCC-ee

The next two years will be critical to our success

- **FCC-ee** is the clear best option for the future of CERN **and for global particle physics**
  - **the outcome of the European Strategy Update is crystal clear**
- At CERN, we will do everything possible to ensure the realisation of FCC-ee

At this time, it is important that the whole community gets behind our collective goal to secure FCC-ee as CERN's next flagship collider

The RDP is a critical period for the FCC, laying both the foundations for project approval and for the future direction of the project.

Much to be done in Physics, Experiments and Detectors. All welcome !

Backups

Practical information

E-groups that all can sign up for. The clickable links here will not work, but they will on the version of this list uploaded to indico page of meeting.

= send an email to the full e-group
= link to an open e-group = link to a closed/cumulative e-group
= send an email to the coordinators/conveners

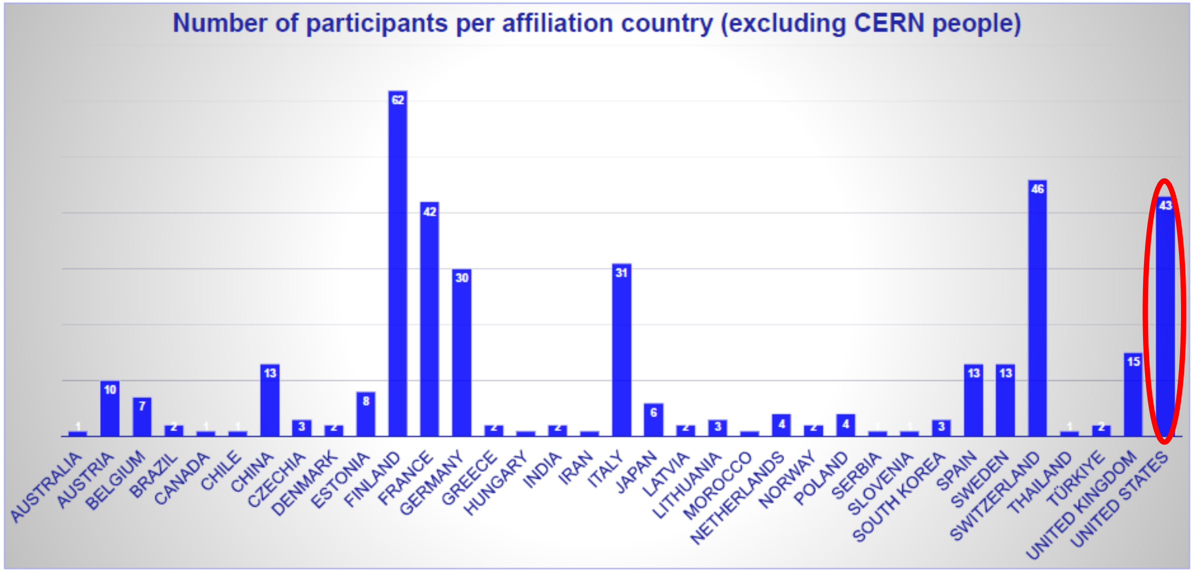
FCC-PED =

- > **FCC-PED-Physics**
  - FCC-PED-PhysicsCoordinationGroup
  - FCC-PED-PhysicsGroup-BSM
  - FCC-PED-PhysicsGroup-EWPrecision
  - FCC-PED-PhysicsGroup-Flavours
    - FCC-PED-PhysicsGroup-Flavours-Coordination
    - FCC-PED-PhysicsGroup-Flavours-CPC
    - FCC-PED-PhysicsGroup-Flavours-Charm
    - FCC-PED-PhysicsGroup-Flavours-CPV
    - FCC-PED-PhysicsGroup-Flavours-Rare
    - FCC-PED-PhysicsGroup-Flavours-TauEW
  - FCC-PED-PhysicsGroup-GlobalFits
  - FCC-PED-PhysicsGroup-hh
  - FCC-PED-PhysicsGroup-Higgs
  - FCC-PED-PhysicsGroup-HighLevelReco
  - FCC-PED-PhysicsGroup-MCgenerators
  - FCC-PED-PhysicsGroup-PrecisionCalculations
  - FCC-PED-PhysicsGroup-QCD
  - FCC-PED-PhysicsGroup-Top
- > **FCC-PED-SoftwareAndComputing**
  - FCC-PED-SoftwareAndComputing-Coordination
  - FCC-PED-SoftwareAndComputing-Analysis
  - FCC-PED-SoftwareAndComputing-Core
  - FCC-PED-SoftwareAndComputing-DB
  - FCC-PED-SoftwareAndComputing-DigiReco
  - FCC-PED-SoftwareAndComputing-Documentation
  - FCC-PED-SoftwareAndComputing-Full-Simulation
  - FCC-PED-SoftwareAndComputing-Generators
  - FCC-PED-SoftwareAndComputing-LEPdata
  - FCC-PED-SoftwareAndComputing-MCproduction
  - FCC-PED-SoftwareAndComputing-Resource
  - FCC-PED-SoftwareAndComputing-MDI
- > **FCC-PED-DetectorConcepts**
  - FCC-PED-DetectorConcepts-Coordination
  - FCC-PED-DetectorConcepts-Calorimetry
  - FCC-PED-DetectorConcepts-Luminometry
  - FCC-PED-DetectorConcepts-Magnet
  - FCC-PED-DetectorConcepts-Muon
  - FCC-PED-DetectorConcepts-TDAQ
  - FCC-PED-DetectorConcepts-Tracker
  - FCC-PED-DetectorConcepts-ALFA
  - FCC-PED-DetectorConcepts-ALLEGRO
  - FCC-PED-DetectorConcepts-CLD
  - FCC-PED-DetectorConcepts-IDEA
  - FCC-PED-DetectorConcepts-ILD
- > **FCC-ee-MDI**
- > **FCC-ee-PolarizationAndEnergyCalibration**
- > **FCC-PED-ECOI**
- > **FCC-International-Forum-National-Contacts**
- > **FCC-PED-CoordinationGroup**
- > **FCC-PhysicsAndExperiments-SteeringGroup**
- > **FCC-PED-SpeakersBuro**
- > **FCC-PED-EditorialBoard**

List of regular meetings on indico: https://indico.cern.ch/category/5251/

Concluding messages

FCC is entering a decisive phase – now would be an excellent time for UK to increase its involvement, which until now lags behind other international partners.



FCC Week 2027

Next FCC collaboration meeting will be the FCC Week 2027 in Madrid, this year including an integrated FCC Physics Workshop (previously a separate event).

Entire community invited and welcome !

(warning: I've heard rumours that the dates could still be changed, so check before booking !)

Progress with EPOL

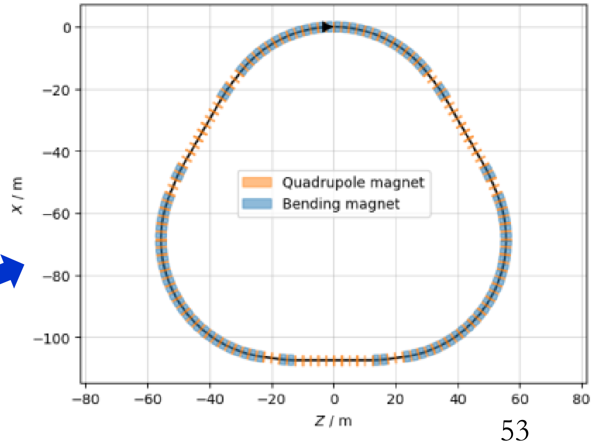
Success of Z lineshape and W mass measurements heavily dependent on success of calibration of collision energy, where the central tool is resonant depolarisation (the other 'RDP'). Plays a central role in machine planning (*c.f.* afterthought at LEP).

Already impressive progress during FSR, but the goal is to do still better

Uncertainty	Observable				
	m_Z (keV)	Γ_Z (keV)	$\sin^2\theta_W^{\rm eff}$ ($\times 10^{-6}$)	$\frac{\Delta\alpha_{\rm QED}(m_Z^2)}{\alpha_{\rm QED}(m_Z^2)}$ ($\times 10^{-5}$)	m_W (keV)
Absolute	100	2.5	–	0.1	150
Point-to-point	14	11	1.2	0.5	50
Sample size	1	1	0.1	–	3
Energy spread	–	5	–	0.1	–
Total $\sqrt{s}$-related	101	12	1.2	0.5	158
FCC-ee statistical	4	4	1.2	3.9	180

Interesting new ideas, *e.g.* cross-checking E_b scale through $\mu^+\mu^-$ production from e^+ beam on gas target

Possible design of polarisation ring

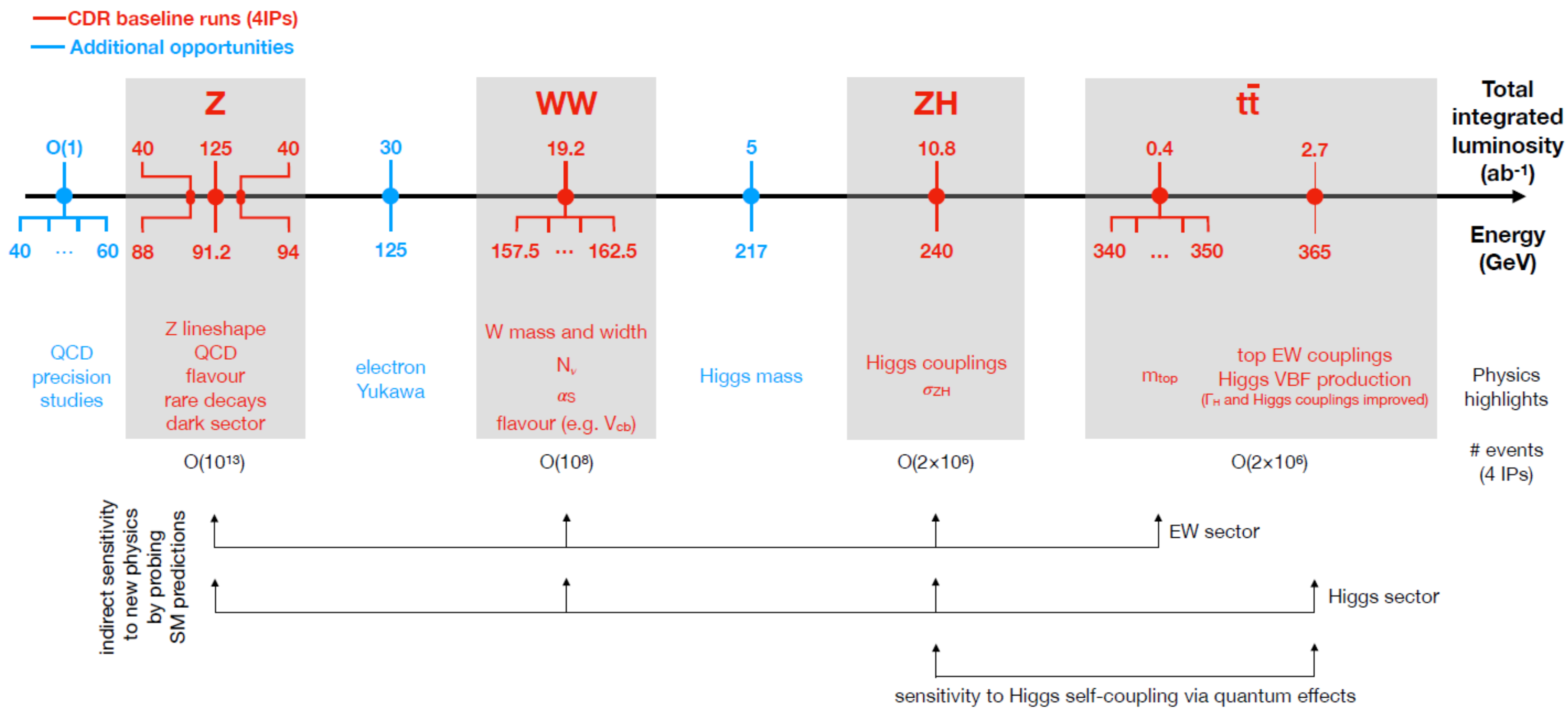


Furthermore, operation is being streamlined.
Until now, Z operation would have had 2 'dead' hours at start of fill, devoted to building-up polarisation on pilot bunches used for RDP. Now, moving towards a mode where we will directly inject polarised bunches.

More robust operation and ~10% more physics time !

Other running points and dataset optimisation

The run schedule presented in FSR is not set in stone. Other energy points are under consideration, as is the optimisation of the relative sizes of datasets.



Currently under discussion: 40-60 GeV for QCD production studies, 125 GeV for a measurement of the electron Yukawa, and 217 GeV for a Higgs threshold m_H scan.

Optimisation of running strategy

Working point	Z pole	WW thresh.	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated lumi. (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	6×10^{12} Z	2.4×10^{8} WW	2.2×10^{6} ZH + 65k WW $\rightarrow$ H	2×10^{6} $t\bar{t}$ + 370k ZH + 92k WW $\rightarrow$ H	

Baseline: about 40 ab^{-1} (one year each) above and below pole. Off-pole running clearly needed for Z width, but this requirement set by need to measure $\alpha_{QED}(m_z^2)$ from QED-EW interference in $A_{FB}^{\mu\mu}$ at level needed for m_W-m_t closure test.

New strategies under study that only requires on-pole data [Riembau, arXiv:2501.05508].

Some measurements may be systematics limited with 6 x 10^{12} Z decays, but many will not be (*e.g.* in flavour physics or in searches for weakly-coupled particles).

Possibly then an argument for more Z data - to be optimised. However, there is no rush to decide. Full flexibility exists in running strategy when below ttbar !

Optimisation of running strategy

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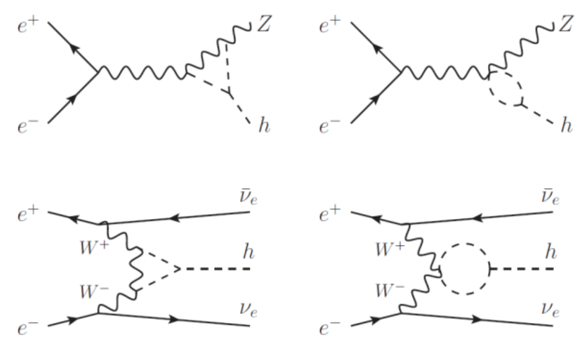
Other questions:

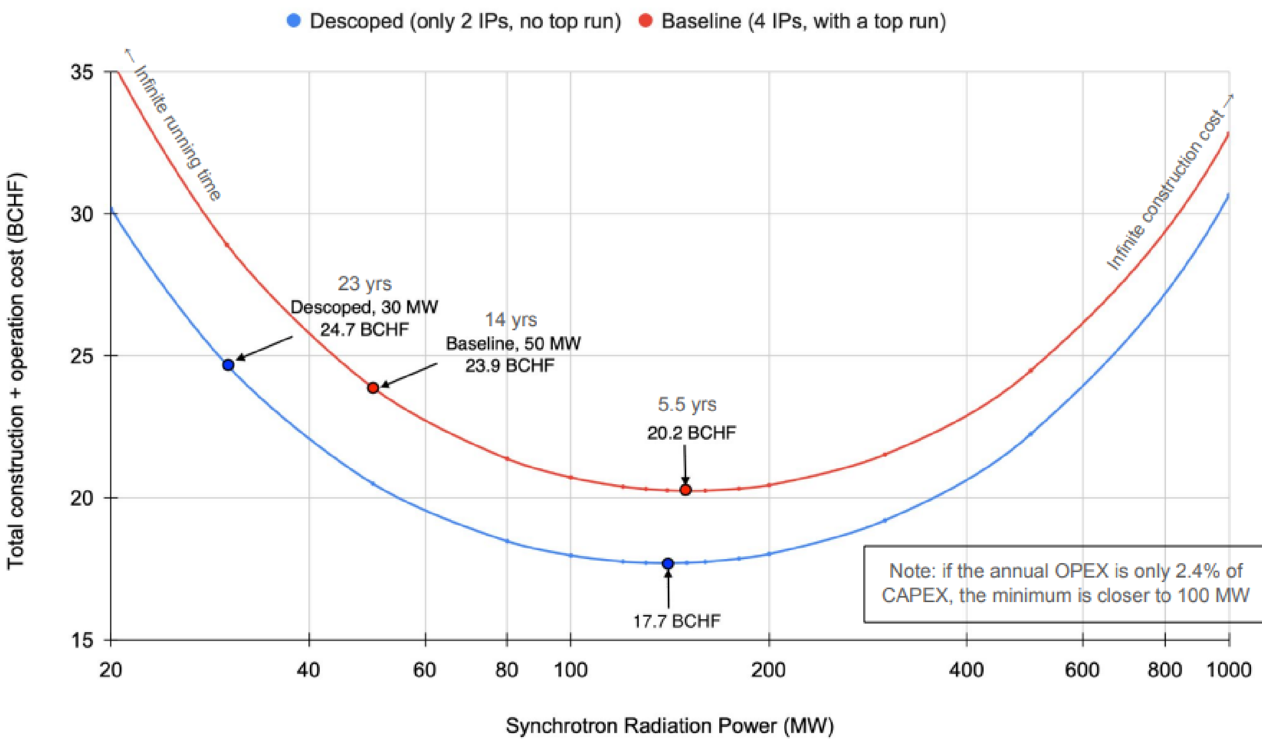
- Is there need for more data at WW threshold, for m_W and V_{CKM} studies ? (*i.e.* what are the ultimate systematic uncertainties on these measurements)

- Is the balance of the 340+ GeV samples correct ? Relevant for assessing indirect sensitivity to Higgs self-coupling, which comes from Higgs x-sec at different energies.



Descoping RF power – a false economy ?

For fixed physics output, it is cheaper (measured in construction + operation costs) to increase RF power rather than decrease it, as latter increases running time.



[P. Janot]

Of course, increased RF power has other consequences, *e.g.* detector backgrounds, so this should not be taken as a proposal, just an observation…