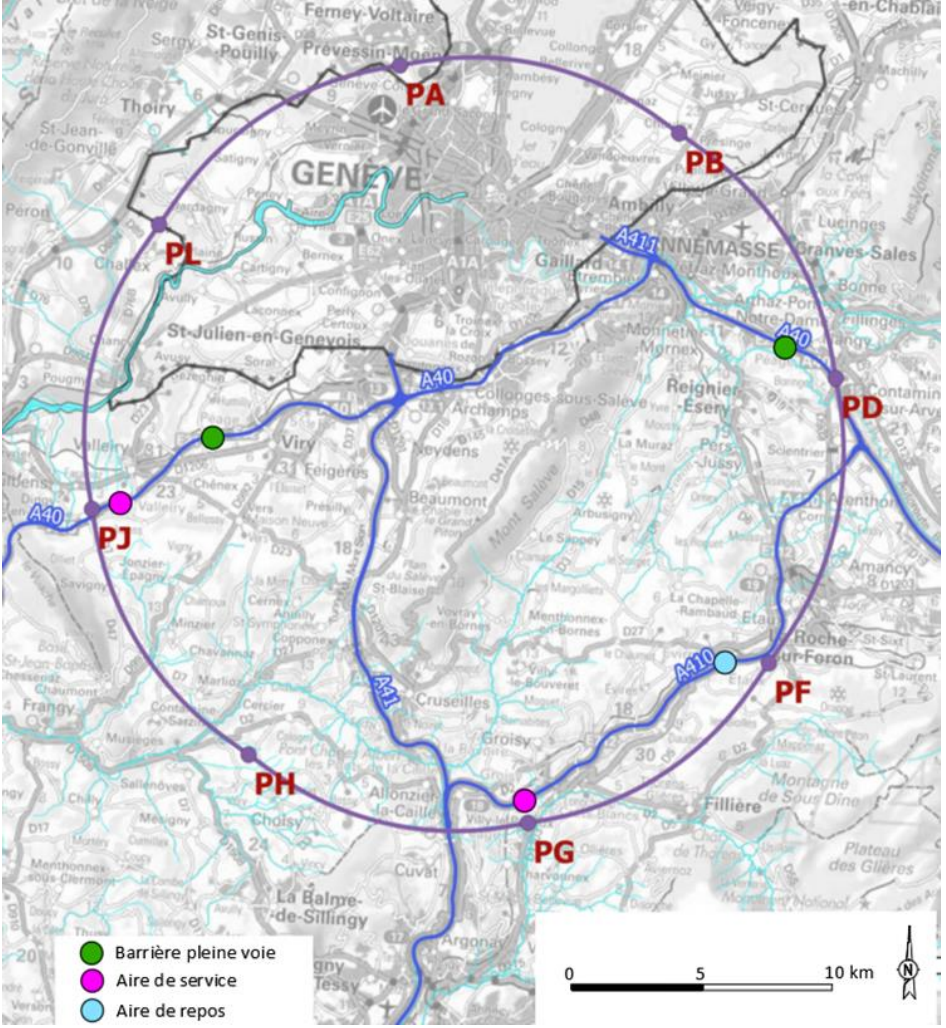


FCC Progress and Status

Alain BLONDEL
Uni. Geneva and Paris-Sorbonne

FCC Early Career Forum 13 January 2025

Much more information starting this afternoon at
https://indico.cern.ch/event/1439509/

FUTURE CIRCULAR COLLIDER Innovation Study | EuroCirCol A key to New Physics | EASITrain | iFAST | E-JADE | EAJADE | CHART Swiss Accelerator Research and Technology | http://cern.ch/fcc | CERN

FCC Feasibility Study & Accelerator Roadmap

Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **iFAST**, grant agreement 101004730, **FCCIS**, grant agreement 951754; **E-JADE,** contract no. 645479; **EAJADE**, contract number 101086276; and by the Swiss **CHART** program

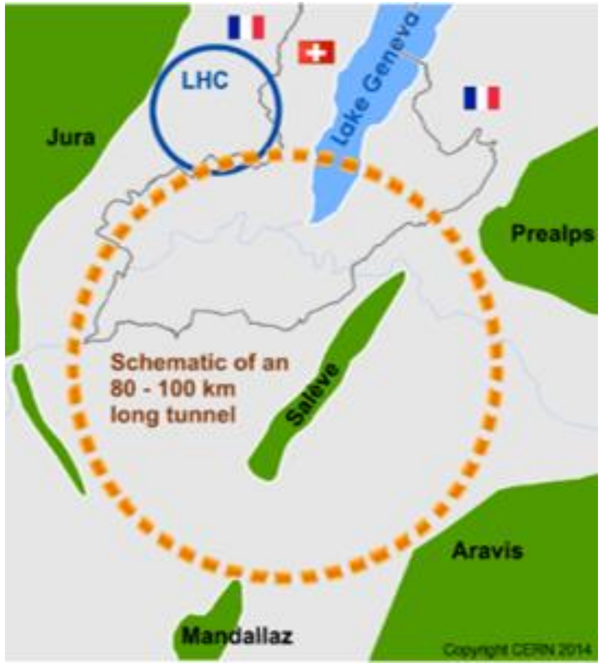
European Commission | Horizon 2020 European Union funding for Research & Innovation

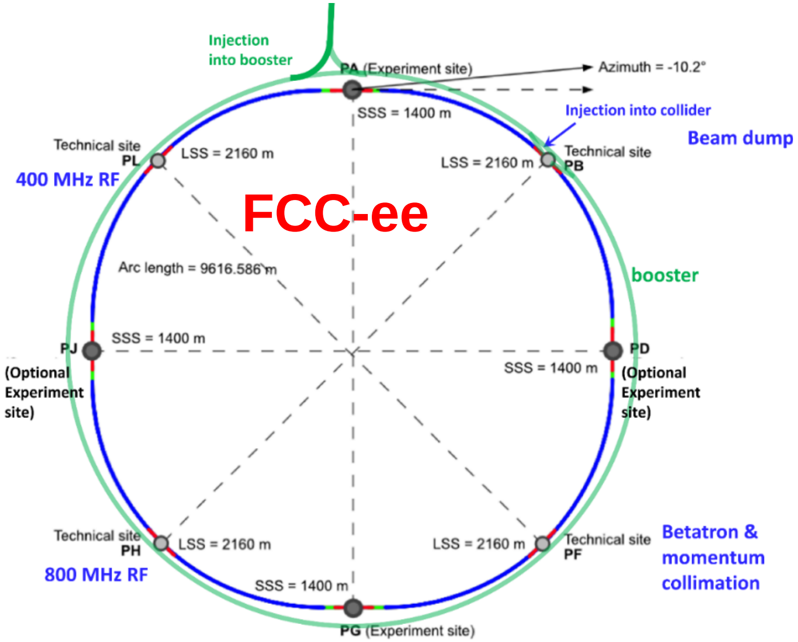
photo: J. Wenninger

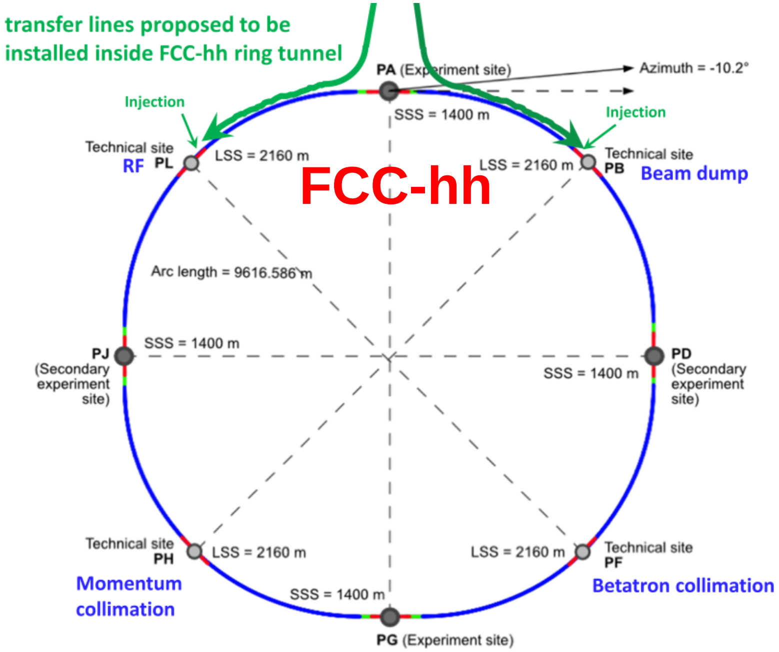
FCC integrated programme

comprehensive long-term programme maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC







2020 - 2045 | **2045 - 2065** | **2070 -**

a similar two-stage project CEPC/SppC is under study in China

FCC Feasibility Study (2021-2025): high-level objectives

- demonstration of the geological, technical, environmental and administrative feasibility of the tunnel and surface areas and optimisation of placement and layout of the ring and related infrastructure;
- pursuit, together with the Host States, of the preparatory administrative processes required for a potential project approval to identify and remove any showstopper;
- optimisation of the design of the colliders and their injector chains, supported by R&D to develop the needed key technologies;
- elaboration of a sustainable operational model for the colliders and experiments in terms of human and financial resource needs, as well as environmental aspects and energy efficiency;
- development of a consolidated cost estimate, as well as the funding and organisational models needed to enable the project's technical design completion, implementation and operation;
- identification of substantial resources from outside CERN's budget for the implementation of the first stage of a possible future project (tunnel and FCC-ee);
- consolidation of the physics case and detector concepts for both colliders.

Results are being summarised in a Feasibility Study Report to be released by March 2025

Status of FCC global collaboration

Increasing international collaboration as a prerequisite for success:
→ links with **science, research & development** and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

~150 Institutes

32 countries + CERN

FUTURE CIRCULAR COLLIDER
Feasibility Study

FCC Feasibility Study:
Aim is to further increase the collaboration, on all aspects, in particular on Accelerator and Particle/Experiments/Detectors

We have gone a long way!

2010-11-12 : ideas, wishes, basic concepts, (VHE-LHC, LEP3, TLEP), Higgs discovery
grassroots studies in EU context; «Higgs factory» in LHC, first, then in new 100km tunnel
LEP3 and TLEP submitted to ESPP2012 {TLEP + VHE-LHC ~FCC}
2013 ESPP2013 wants «ambitious post-LHC accelerator projet »

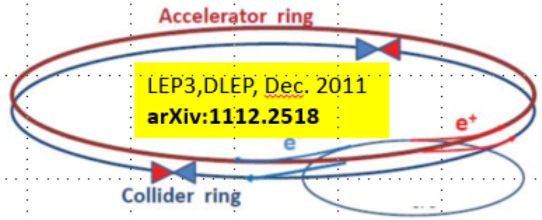
2014-02 Kick-off meeting of FCC design study FCC ee-ep-hh

2018 ESPP contributions and CDR submitted
➔ FCC can be done! Starting with the e+ e- collider

2019-2020 ESPP2020 long term vision: a 100 TeV pp collider
shorter term priority 'Higgs Factory'
recommends Feasibility study of 100km facity

Many new physics opportunities discovered esp. for O(10^{13}) Z factory! Great complementarity between ee and pp programmes

Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.
Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.

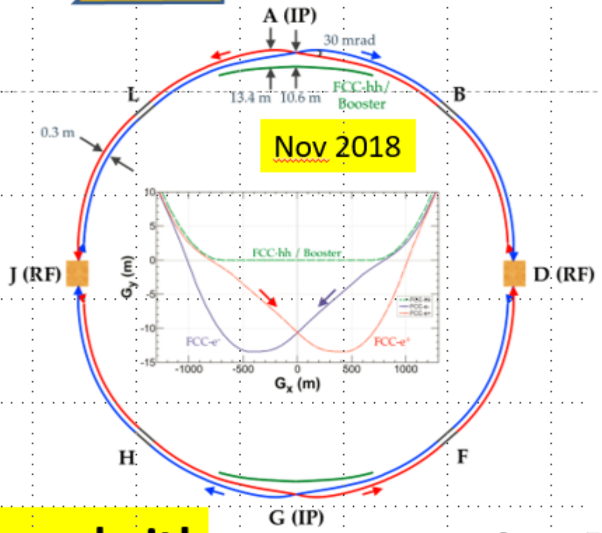


TLEP: arXiv:1208.0504
TLEP physics case: arXiv:1308.6176

Design Study

Feasibility Study

FCC-ee CDR: baseline design choices
- -- Follows footprint of FCC-hh, except around IPs
- -- ~100 km to reach tt production
- -- Double ring (e+, e-) collider, multi-bunch
- -- Top-up injection for high efficiency
  - → high-energy injector in collider tunnel
- -- Crab-waist optics to maximize luminosity @Z, W, H
  - 30 mrad crossing angle
- -- Asymmetric interaction region layout and optics
  - Limits synchrotron radiation in the detector
- -- four interaction points (IP) in A D G and J
- -- 50 MW/beam Synchrotron Radiation power :
  - at all energies
- -- Continuous E_{CM} calibration at Z and W (100 keV)
  - based on resonant transverse depolarization
  - polarimeter, wigglers, RF kicker
  - Only one RF section at these energies.



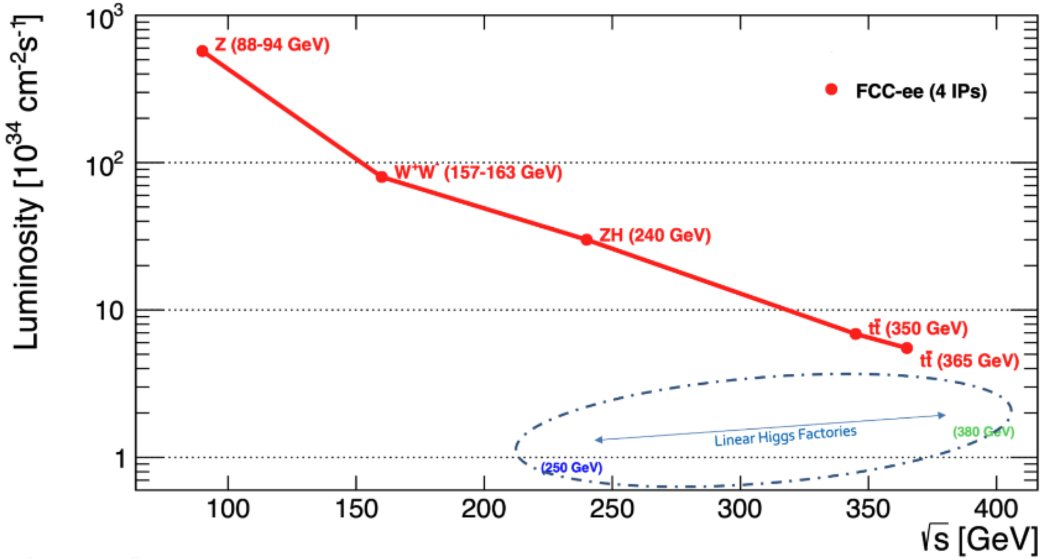


Fig. 1: The FCC-ee baseline design luminosity, summed over 4 IPs, displayed as a function of the centre-of-mass energy, from the Z pole to the $t\bar{t}$ threshold and beyond (red curve). The luminosity typically achievable by linear e^+e^- Higgs factories in a single IP between 250 and 380 GeV is also indicated (dash-dotted oval in the lower-right corner of the figure).

We can do it!

Event statistics :

				E_{CM} errors:
Z peak	E_{cm} : 91 GeV	$6\ 10^{12}$ e+e- → Z	LEP x $3\ 10^5$	110/20 ptp keV
WW threshold	E_{cm} : 161 GeV	$2.5\ 10^8$ e+e- → WW	LEP x 2.10^3	300 keV
ZH threshold	E_{cm} : 240 GeV	$2.4\ 10^6$ e+e- → ZH	Never done	<1 MeV
$\bar{t}\bar{t}$ threshold	E_{cm} : >350 GeV	$2\ 10^6$ e+e- → $t\bar{t}$	Never done	<2 MeV

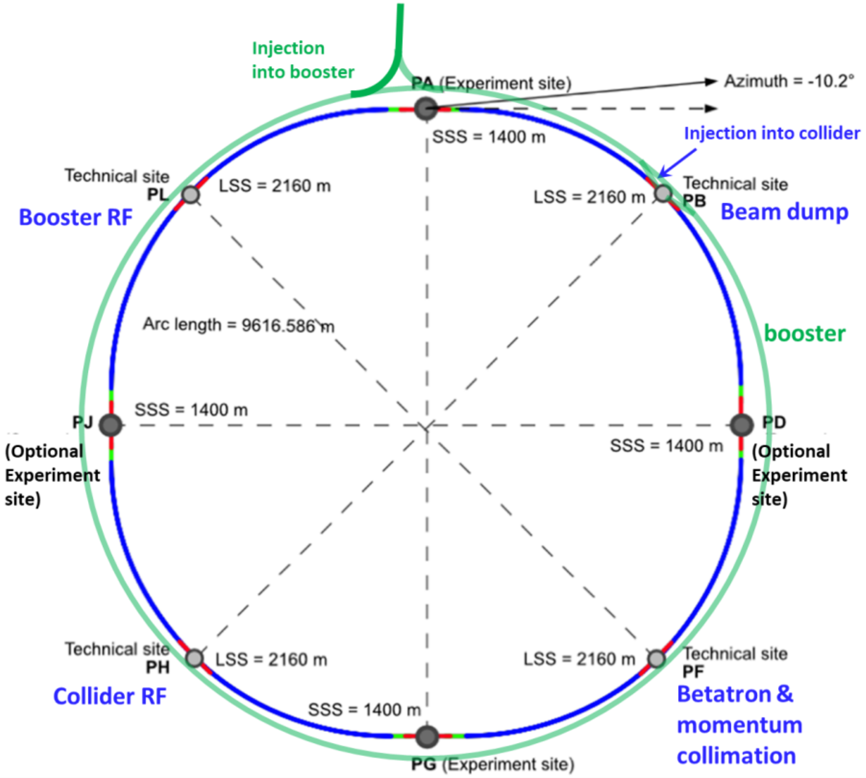
Great energy range for the heavy particles of the Standard Model.

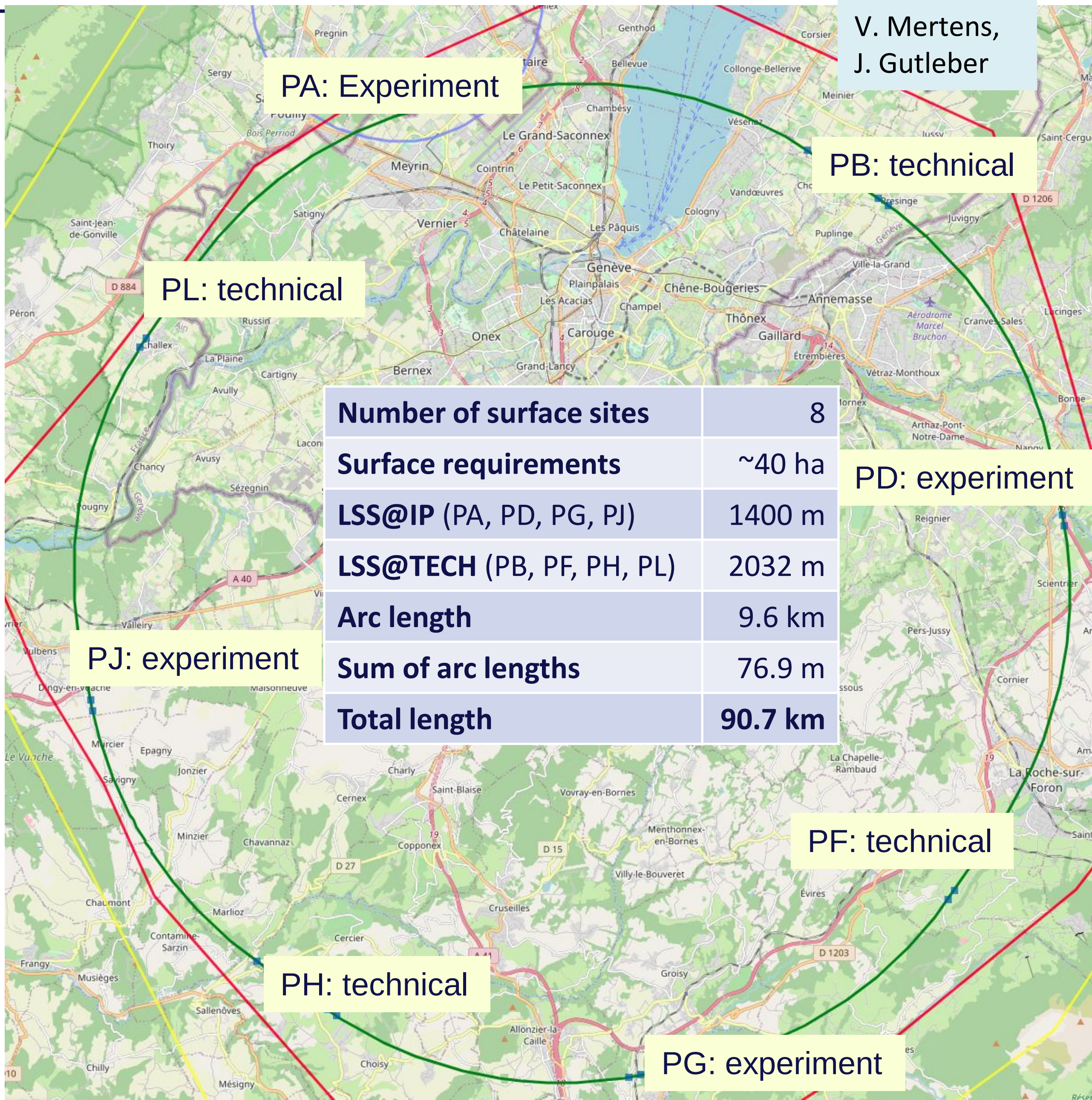
Reference layout and implementation: PA31 - 90.7 km

Layout chosen out of ~ 100 initial variants, based on **geology** and **surface constraints** (land availability, access to roads, etc.), **environment,** (protected zones), **infrastructure** (water, electricity, transport), **machine performance** etc.

“Avoid-reduce-compensate” principle of EU and French regulations

Overall lowest-risk baseline: 90.7 km ring, 8 surface points, 4-fold symmetry





Number of surface sites	8
Surface requirements	~40 ha
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.7 km**

Physics at FCC-ee

1. HIGGS FACTORY

Higgs provides a very good reason why we need e+e- (or $\mu\mu$) collider

2. ELECTROWEAK PRECISION (10^{-3} today → 10^{-5})

Z + WW + top required!

High precision determination of centre-of-mass (20-100 keV)

Test of the completeness of the SM

3. Z FACTORY

(5 10^{12} Z i.e. 1.5 10^{11} ee, $\mu\mu$, $\tau\tau$; ~0.7 10^{12} uu,dd,ss,cc,bb ; 10^{12} $\nu\nu$)

High statistics for Heavy Flavours, QCD

Search for Feebly Coupled Particles

Possible insight on Higgs coupling to neutrinos if HNL (right-handed neutrino) discovery

The place for 'direct discovery'

Aussi the most challenging for experiments!

+ comments on the synergy and complementarity of FCC-ee hh and eh

Complementarity: Higgs Physics at FCC

FCC-ee → g_{HZZ} to <±0.2% from σ_{ZH}
(model-independent standard candle)
and Γ_H, g_{Hbb}, g_{Hcc}, $g_{H\tau\tau}$, g_{HWW}

→fixes all HL-LHC / FCC-hh couplings

FCC-hh produces over 10^{10} Higgs bosons
use g_{HZZ} from FCC_{ee} will give $g_{H\mu\mu}$, $g_{H\gamma\gamma}$, $g_{HZ\gamma}$, Br_{inv}

FCC-ee also measures top EW couplings ($e^+e^- \to tt$)

FCC-hh produces 10^8 ttH and 2. 10^7 HH pairs
→ g_{Htt} and g_{HHH}, model-independent & precise!

FCC-ee / FCC-hh complementarity is outstanding

Comparison with other e+e- colliders in spares

Collider	HL-LHC	$FCC\text{-}ee_{240\to365}$	FCC-INT	
Lumi (ab^{-1})	3	5 + 0.2 + 1.5	30	
Years	10	3 + 1 + 4	25	
g_{HZZ} (%)	1.5	0.18 / 0.17	0.17/0.16	ee
g_{HWW} (%)	1.7	0.44 / 0.41	0.20/0.19	ee
g_{Hbb} (%)	5.1	0.69 / 0.64	0.48/0.48	ee
g_{Hcc} (%)	SM	1.3 / 1.3	0.96/0.96	ee
g_{Hgg} (%)	2.5	1.0 / 0.89	0.52/0.5	ee
$g_{H\tau\tau}$ (%)	1.9	0.74 / 0.66	0.49/0.46	ee
$g_{H\mu\mu}$ (%)	4.4	8.9 / 3.9	0.43/0.43	hh
$g_{H\gamma\gamma}$ (%)	1.8	3.9 / 1.2	0.32/0.32	hh
$g_{HZ\gamma}$ (%)	11.	– / 10.	0.71/0.7	hh
g_{Htt} (%)	3.4	10. / 3.1	1.0/0.95	hh
g_{HHH} (%)	50.	2 IP: 44./33. 4 IP: 27./24.	3-4	hh
Γ_H (%)	SM	1.1	0.91	ee
m_H (MeV)	30-50	3	3	
BR_{inv} (%)	1.9	0.19	0.024	hh
BR_{EXO} (%)	SM (0.0)	1.1	1	ee

ee only | LHC +ee

FCC-ee+hh+ep
ep → WW mostly

FCC

From upcoming FSReport (PED)

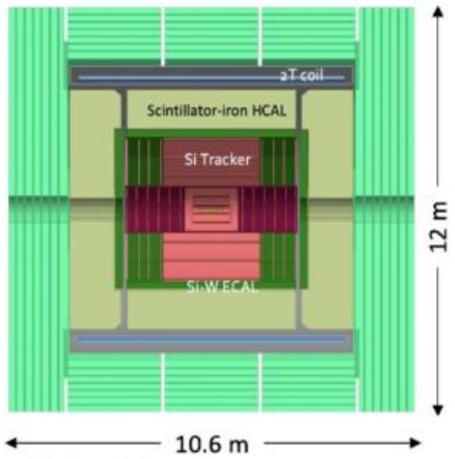
Table 2: Experimental (statistical and systematic) precision of a selection of measurements accessible at FCC-ee, compared with the present world-average precision. Some of the FCC-ee experimental systematic uncertainties (fourth column) are initial estimates from early 2021 [29]. The goal of further studies will be to improve then down the level of the statistical uncertainties (third column) with new ideas and innovative methods. This set of measurements, together with those of the Higgs boson properties, achieves indirect sensitivity to new physics up to a scale Λ of 100 TeV in an Effective Field Theory (EFT) description with dimension-6 operators (Section ??) and possibly much higher in specific new physics (non-decoupling) models.

Observable	present value	±	uncertainty	FCC-ee **Stat.**	FCC-ee Syst.	Comment and leading uncertainty
m_Z (keV)	91188000	±	2000	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495500	±	2300	**4**	11	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{\text{eff}}(\times 10^6)$	2312390	±	40	**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	**1**	1	Combined R_ℓ^Z, Γ_{tot}^Z, σ_{had}^0 fit
σ_{had}^0 $(\times 10^3)$ (nb)	41480.2	±	32.5	**0.1**	4	Peak hadronic cross section Luminosity measurement
$N_\nu(\times 10^3)$	2996.3	±	7.4	**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 polarisation asymmetry τ decay physics
τ lifetime (fs)	290.3	±	0.5	**0.001**	0.005	ISR, τ mass
τ mass (MeV)	1776.93	±	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)	80369.2	±	13.3	**0.18**	0.2	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085	±	42	**0.8**	0.2	From WW threshold scan Beam energy calibration
$\alpha_s(m_W^2)(\times 10^4)$	1010	±	270	**2**	2	Combined R_ℓ^W, Γ_{tot}^W fit
$N_\nu(\times 10^3)$	2920	±	50	**0.5**	small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	172570	±	290	**8**	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV)	1420	±	190	**12.5**	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2	±	0.3	**0.04**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings		±	30%	**0.5–1.5 %**	small	From $\sqrt{s} = 365$ GeV run

FCCee Detector Concepts

Defined by Calorimetry

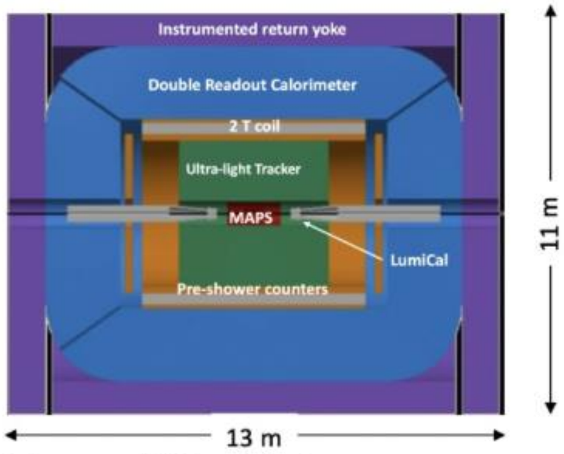
CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous 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)?

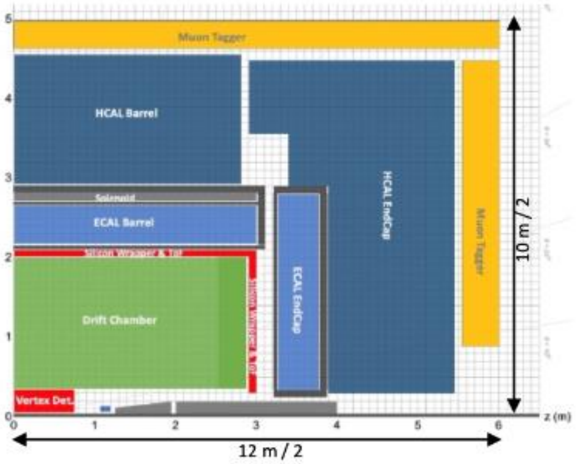
CDR

IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber with powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, …

ALLEGRO



- The "new kid on the block"
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies

DESY. FCC Annecy: Detector Highlights | Felix Sefkow | February 2024 6

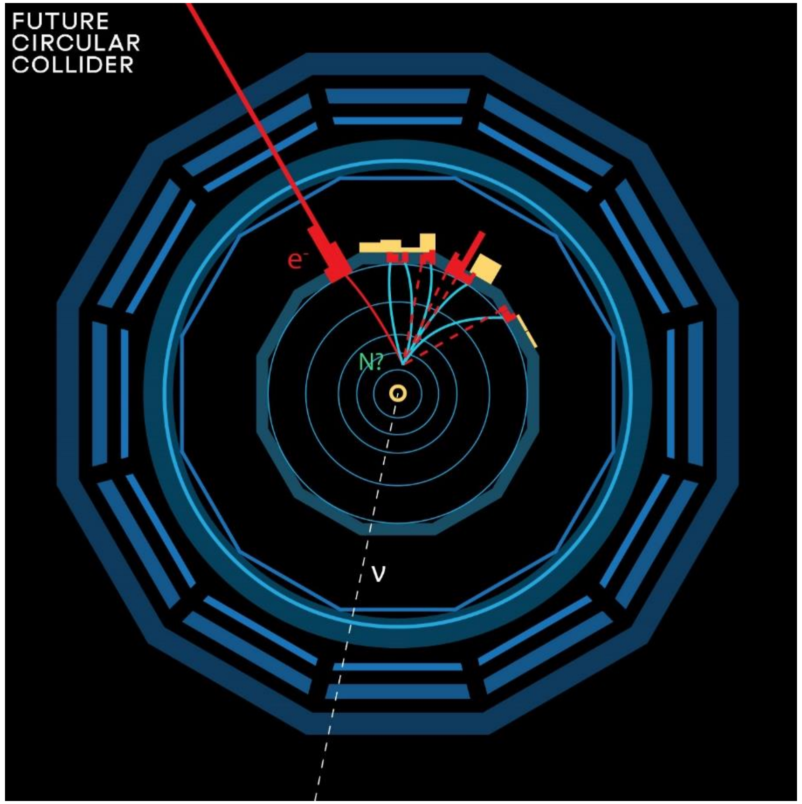
Also: ILD (IlC detector with TPC as inner tracker) working on adapting to FCC-ee – challenges due to high rate at Z-pole run

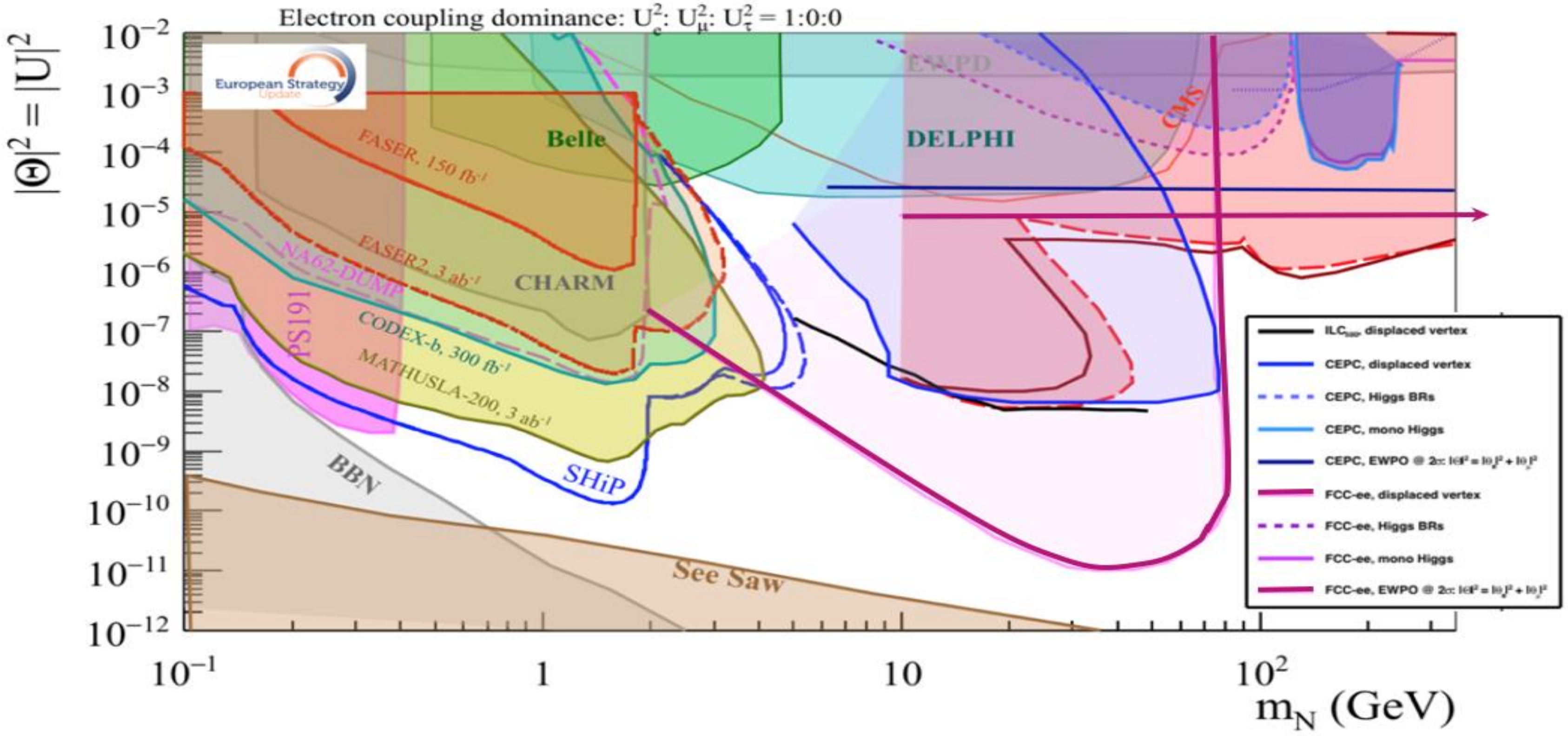
FCC

This picture is relevant to Neutrino, Dark sectors and High Energy Frontiers.

FCC-ee (Z) compared to the other machines for right-handed (sterile) neutrinos

How close can we get to the 'see-saw limit'?

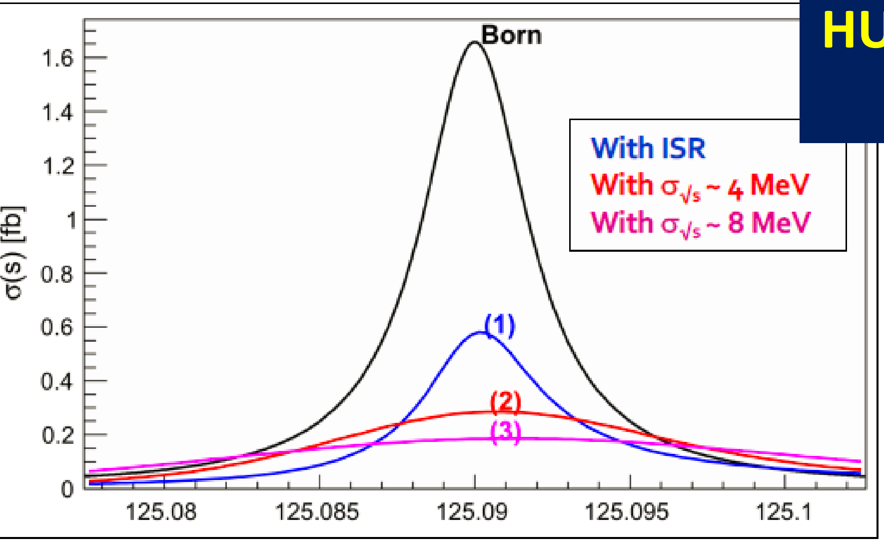




-- the purple line shows the 95% CL limit if no HNL is observed. (here for 10^{12} Z),

-- the horizontal line represents the sensitivity to **mixing of neutrinos** to the dark sector, using EWPOs (G_F vs $\sin^2\theta_W^{eff}$ and m_Z, m_W, tau decays) which extends sensitivity to 10^{-5} mixing all the way to very high energies (500-1000 TeV at least). arxiv:2011.04725

Unique: electron Yukawa coupling



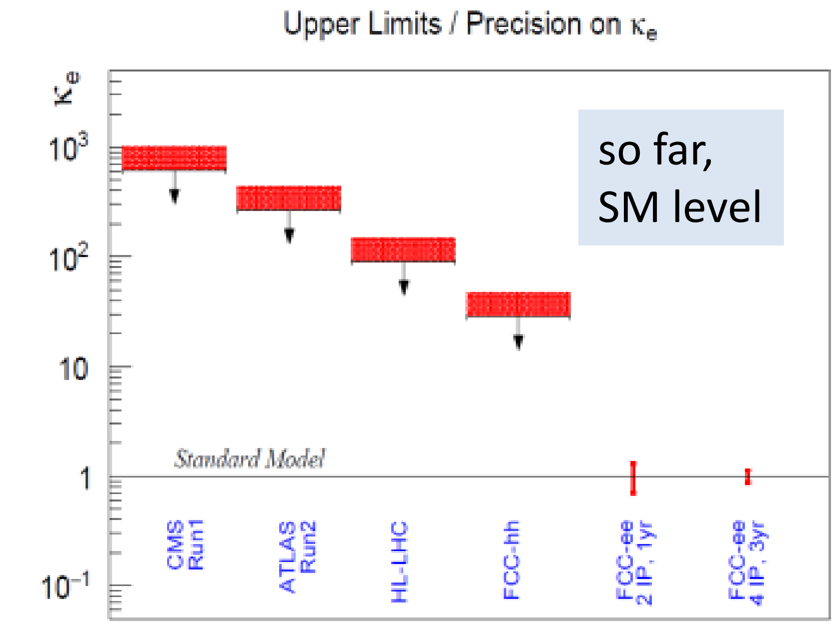
HUGE CHALLENGE under study

Measure e+e- → H @ 125.xxx GeV

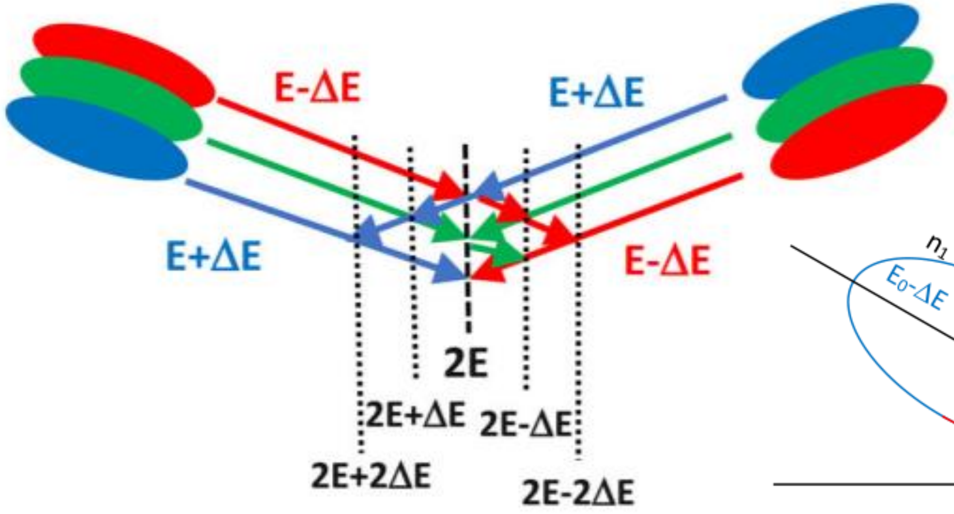
requires

-- Higgs mass to be known to <<5 MeV (OK, 3 MeV)
-- **Huge luminosity** (several years)
-- **monochromatization** to reduce σ_{ECM}
-- **continuous adjustment of E_{CM}** (transv. Polar.)
-- an extremely sensitive event selection

Monochromatization: **UNDER STUDY**
taking advantage of the separate e+ and e- rings, one can distribute in opposite way high and low energies in the beam (in x, z time)

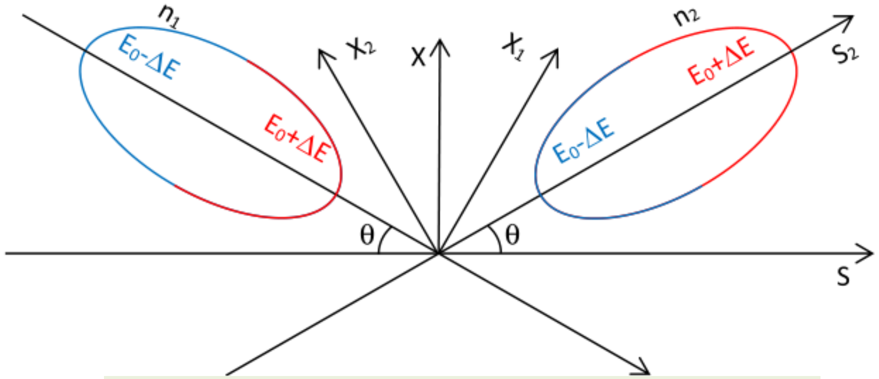


so far, SM level



opposite sign horizontal dispersion

combine?



opposite difference in arrival time

Why FCC ?

FUTURE CIRCULAR COLLIDER

F. Gianotti

1) **Physics : best overall physics potential of all proposed future colliders; matches the vision of the 2020 European Strategy:** "An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy."

- FCC-ee : **ultra-precise** measurements of the Higgs boson, indirect exploration of next energy scale (~ x10 LHC)
- FCC-hh : **only** machine able to explore next **energy frontier** directly (~ x10 LHC)
- Also provides for heavy-ion collisions and, possibly, ep/e-ion collisions
- **4 collision points** → robustness; specialized experiments for maximum physics output

[…]

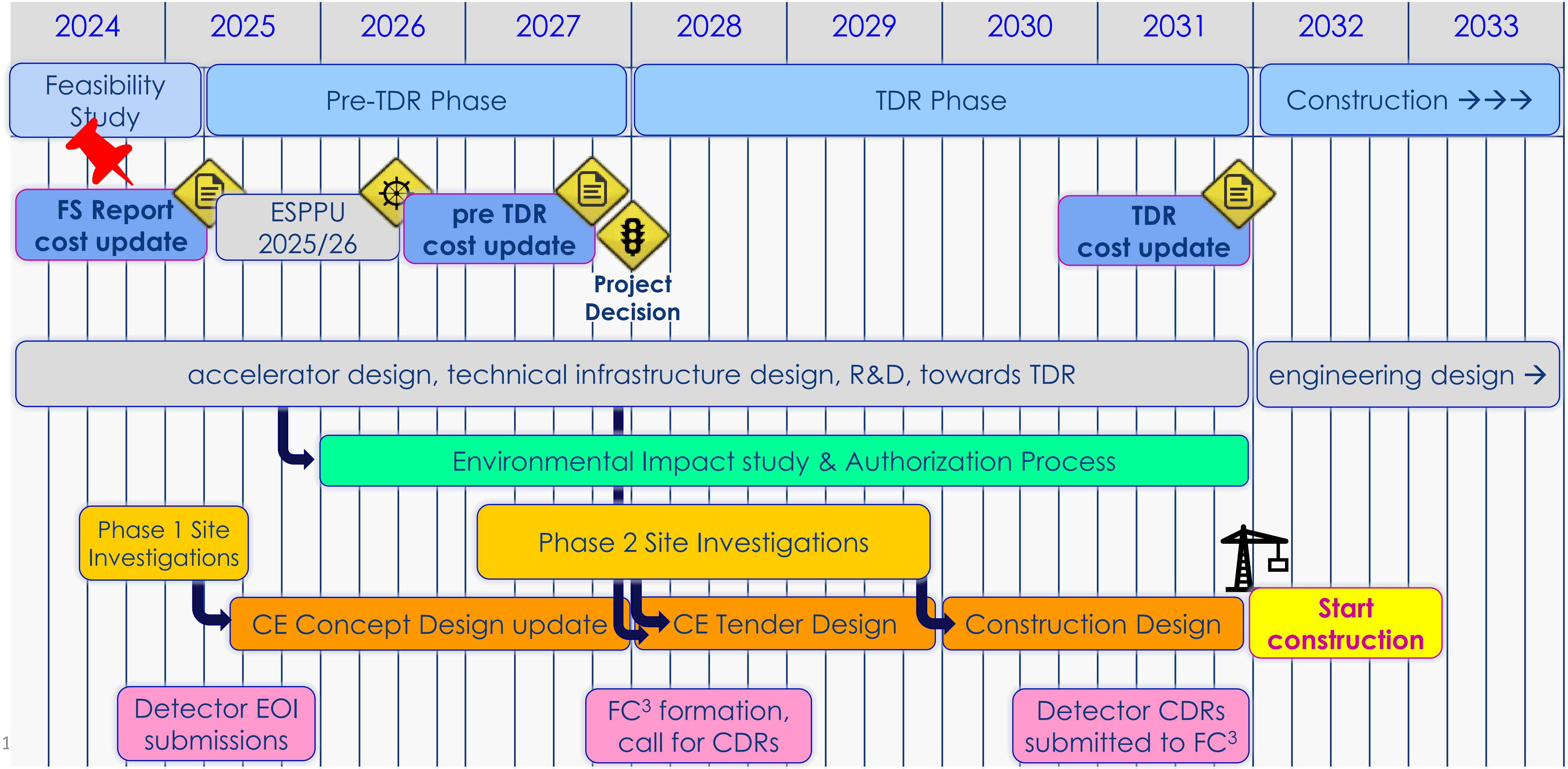
Is it feasible? Isn't it too ambitious?

-- Ongoing Feasibility Study showing spectacular progress

-- **FCC is big and audacious project, but so were LEP and LHC when first conceived** → they were successfully built and performed far beyond expectation → demonstration of capability of our community to deliver on very ambitious projects

-- FCC is the **best project for future of CERN** (for above reasons) → **we have to work to make it happen**

Expected time line till start of construction



EU competitiveness report

edited by Mario Draghi, and officially handed over to Ursula von der Leyen in September 2024

***"One of CERN's most promising current projects, with significant scientific potential, is the construction of the Future Circular Collider (FCC): a 90-km ring designed initially for an electron collider and later for a hadron collider.**.*

***Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority**, given the objective of maintaining European prominence in this critical area of fundamental research, which is expected to generate significant business spillovers in the coming years."*

https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en

CERN 70th anniversary, 1 October 2024

Le Cern soude l'Europe autour de l'accélérateur de 91 kilomètres

LE DAUPHINÉ libéré

Si le Centre européen de recherche nucléaire craignait une crise des 70 ans, les chefs d'États européens et la présidente de la Commission Européenne Ursula Von der Leyen l'ont écartée ce mardi, apportant un soutien franc.

Sébastien Colson - Hier à 19:25 | mis à jour hier à 19:41 - Temps de lecture : 4 min

Autour de la directrice générale du Cern, Fabiola Gianotti (au centre en blanc), des personnalités comme la présidente de la Confédération suisse, Viola Amherd, la Princesse Astrid de Belgique, ou les présidents de l'Italie ou la Serbie, Sergio Mattarella et Aleksandar Vucic, ont dit leur soutien comme la présidente de la Commission européenne, Ursula Von der Leyen (à droite en rose). Photo Le DL /Greg Yetchmeniza

YouTube · Open App

President Ursula von der LEYEN @ the Official Ceremony for CERN's 70th anniversary

1.7K views · Streamed 22 hours ago ...more

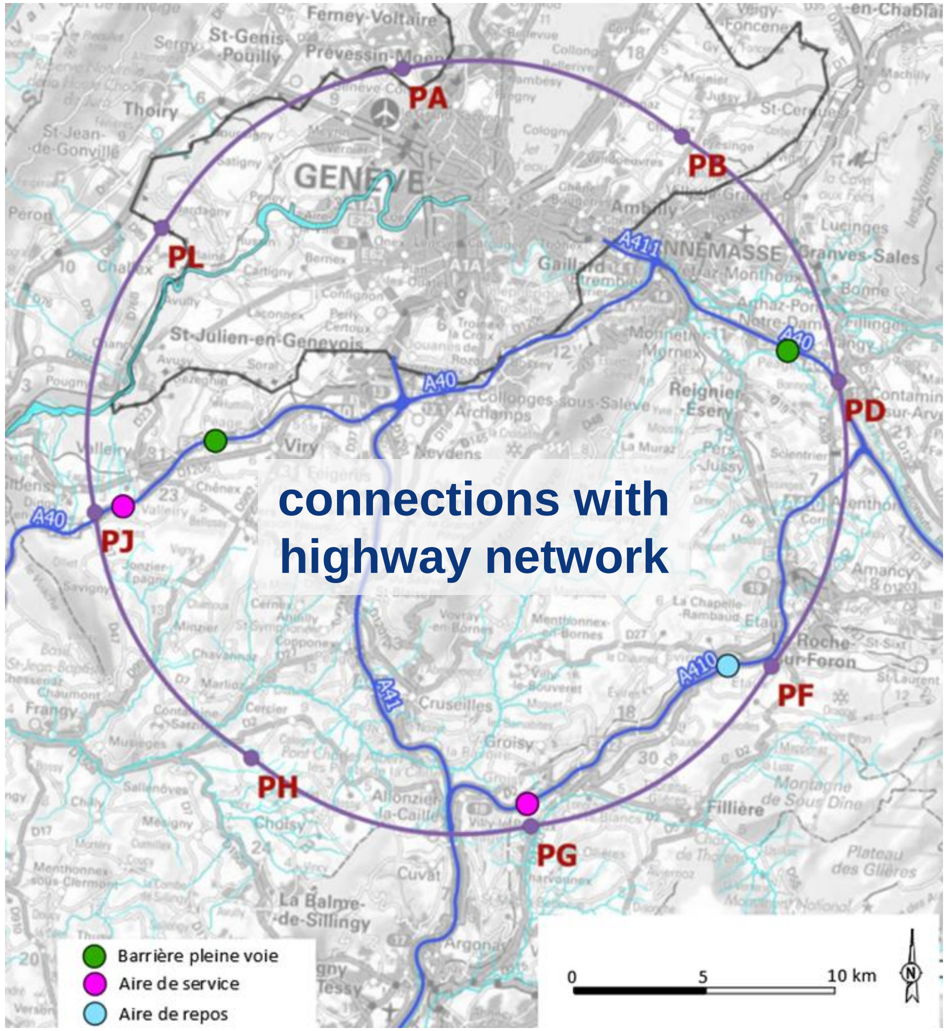
European Commission 187K · Subscribe

130 · Share · Save

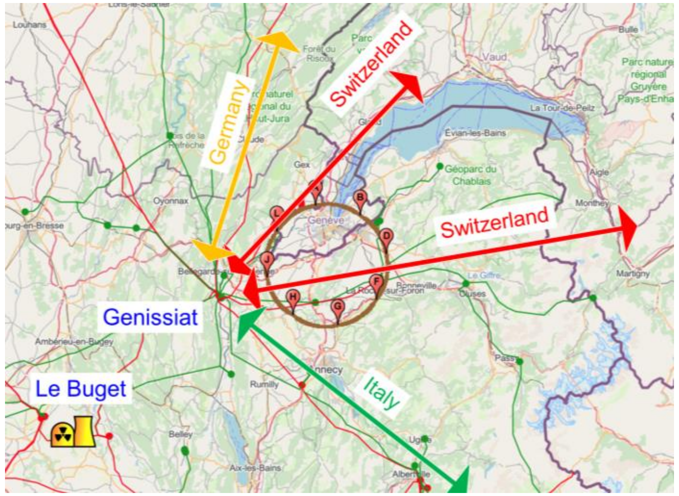
Complementary slides to show the great progress on the accelerator and infrastructure

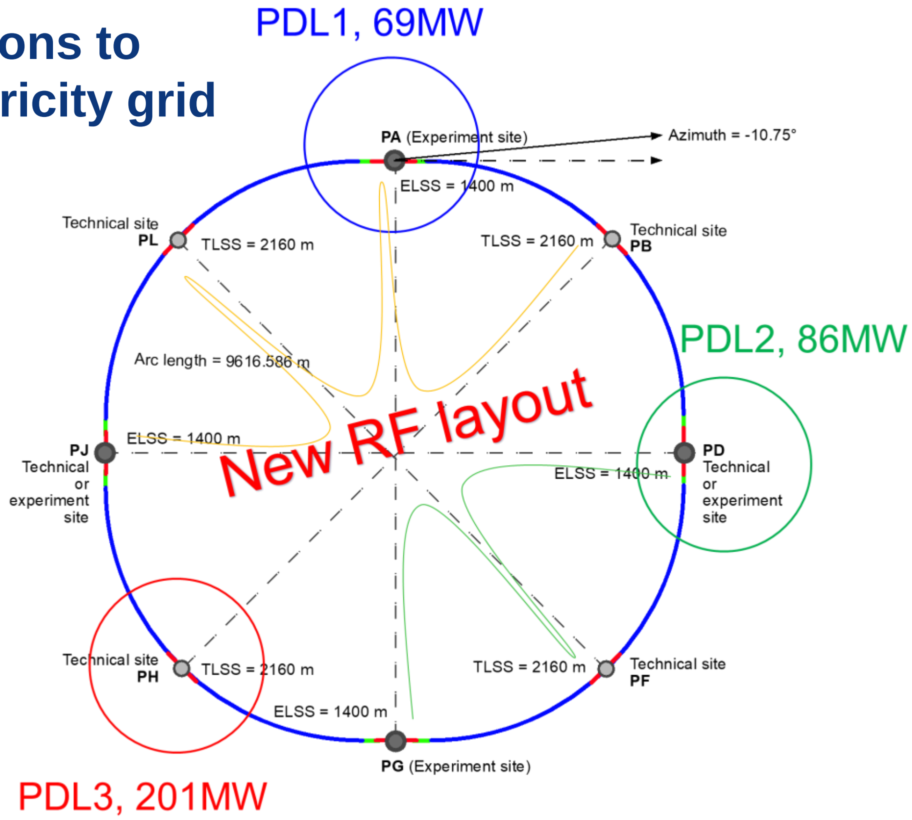
Integration with regional infrastructures

- **Road accesses developed for all 8 surface sites**
- **Four possible highway connections defined**
- **Less than 4 km of new roads required**



Connections to French electricity grid





- **Electrical connection concept developed with RTE (French electricity grid operator)**
- **Three HV supply points, two new stations & CERN Prevessin**

  ➔ requested loads have no significant impact on grid
- **R&D efforts aiming at reducing the energy consumption of FCC-ee and FCC-hh**

Feasibility Study Mid-Term Review passed !

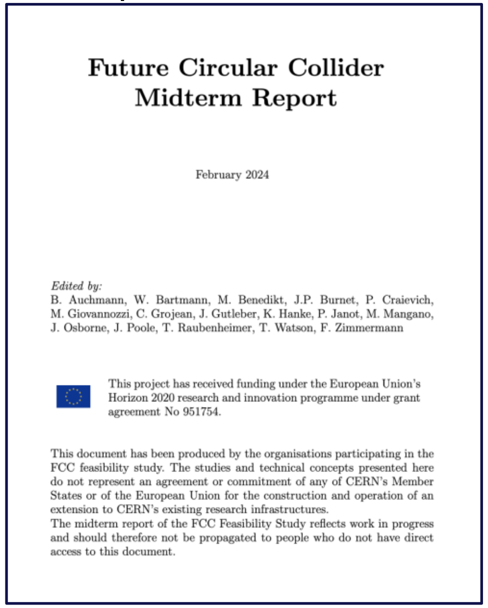
The goal of the FCC FS mid-term review is to assess the progress of the Study towards the final report.

Deliverables approved by the Council in September 2022:

https://indico.cern.ch/event/1197445/contributions/5034859/attachments/2510649/4315140/spc-e-1183-Rev2-c-e-3654-Rev2_FCC_Mid_Term_Review.pdf

Deliverables:

D1 : Definition of the baseline scenario
D2 : Civil engineering
D3 : Processes and implementation studies with the Host States
D4 : Technical infrastructure
D5 : FCC-ee accelerator
D6: FCC-hh accelerator
D7: Project cost and financial feasibility
D8: Physics, experiments and detectors


Future Circular Collider
Midterm Report

February 2024

Edited by:
B. Auchmann, W. Bartmann, M. Benedikt, J.P. Burnet, P. Craievich, M. Giovannozzi, C. Grojean, J. Gutleber, K. Hanke, P. Janot, M. Mangano, J. Osborne, J. Poole, T. Raubenheimer, T. Watson, F. Zimmermann

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The midterm report of the FCC Feasibility Study reflects work in progress and should therefore not be propagated to people who do not have direct access to this document.

Full Report
8 Chapters/Deliverables
~ 700pp document
~ 16 editors
~ 500 contributors

Many thanks to the SAC, CRP, SPC, FC and the Council for the very useful reviews!

Documents:

- ❑ Mid-term report (all deliverables except D7)
- ❑ Executive Summary of mid-term report
- ❑ Updated cost assessment (D7)
- ❑ Funding model (D7)

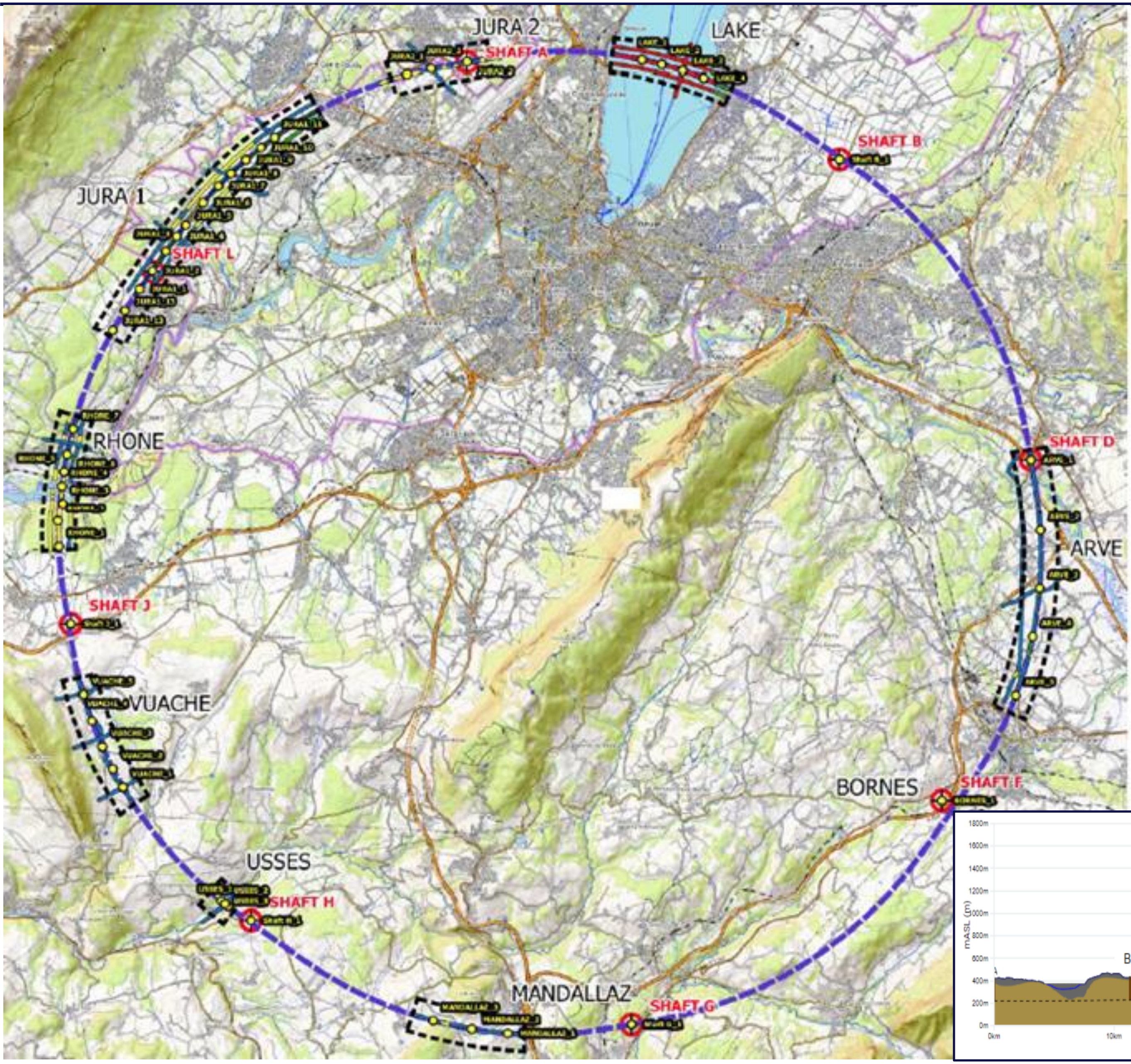
Review process:

- ❑ Oct 2023: Scientific Advisory Committee (scientific and technical aspects) and Cost Review Panel (ad hoc committee; cost and financial aspects)
- ❑ Nov 2023: SPC and FC
- ❑ 2 Feb 2024: Council

All deliverables met, no technical showstoppers

→**70-80 recommendations**

First series of site investigations



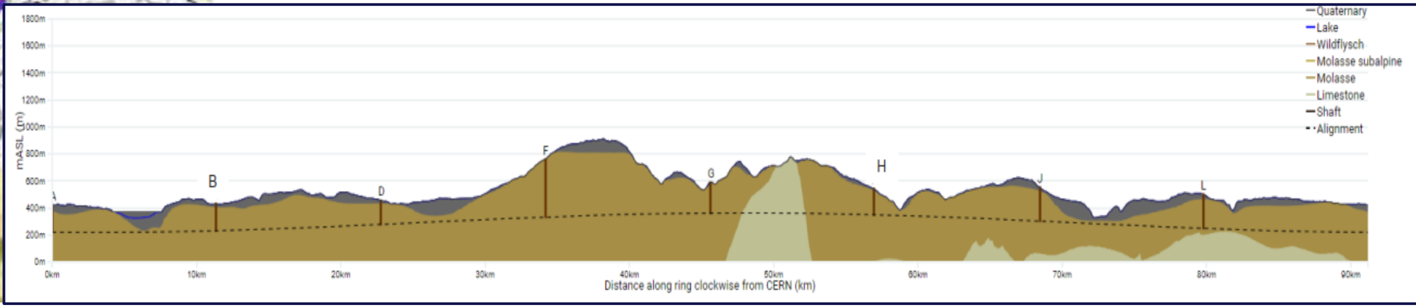
Site investigations to identify exact location of geological interfaces:

- Molasse layer vs moraines/limestone
- ~30 drillings and ~100 km seismic lines

→ **Vertical position and inclination of tunnel**

Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m^2)

Drilling works on the lake

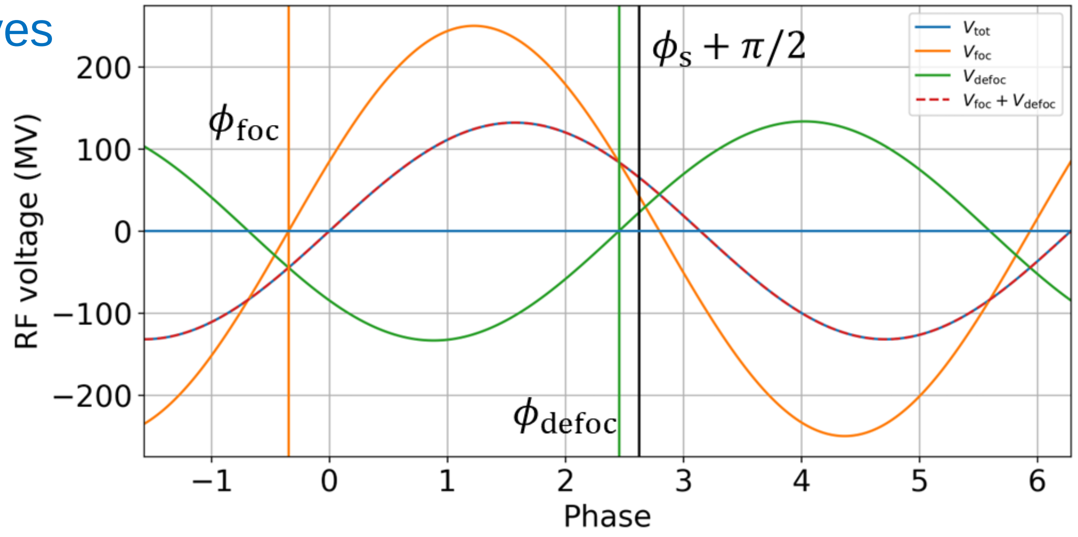


400 MHz SRF progress – one system for 3 energies

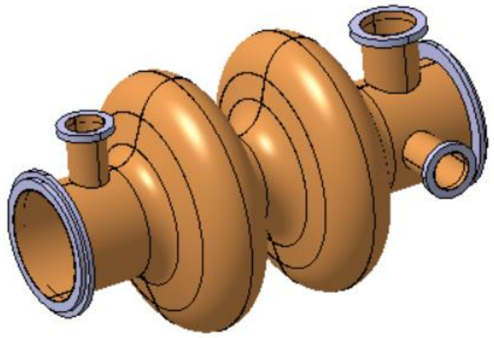
Same two-cell RF cavities for Z, WW and ZH operation with constant cavity coupling thanks to **reverse phase operation**: (1) experimentally verified w high beam loading at KEKB *(Y. Morita et al., 2009)*, (2) Baseline solution US EIC

- No longer any 1-cell 400 MHz cavities
- Reduced installation time
- Reduced commissioning effort
- Fast switching between Z, WW and ZH operation

RF waves



400 MHz cavities



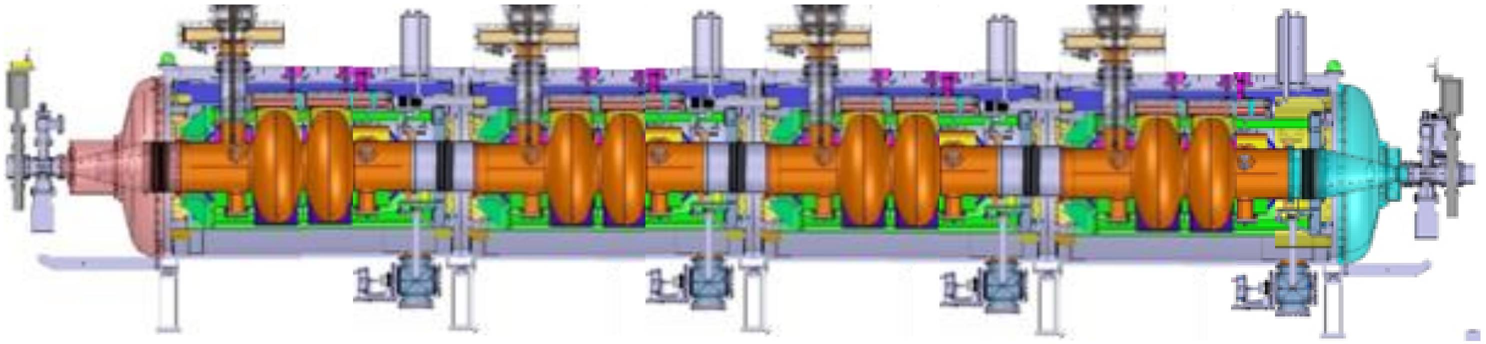
Z, W, ZH

X 264

400 MHz 2-cell cavity
Niobium thin film on Copper,
Operation at 4.5 Kelvin
Max. accel. gradient E_{acc} = 13 MV/m
Quality factor Q_0 = 3.3 x 10^9

cryomodule

X 66



400 MHz cryomodule, ~12 m long

FCC-ee main machine parameters

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter x_x / x_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	140	20	≥5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Design and parameters to maximise luminosity at all working points:

- allow for 50 MW synchrotron radiation per beam
- Independent vacuum systems for electrons and positrons
- full energy booster ring with top-up injection, collider permanent in collision mode

Improvements:

- x10-50 on all EW observables
- up to x 10 on Higgs coupling (model-indep.) measurements over HL-LHC
- x10 Belle II statistics for b, c, τ
- indirect discovery potential up to ~ 70 TeV
- direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points

→ robustness, statistics, possibility of specialised detectors to maximise physics

F. Gianotti

FCC-hh main machine parameters

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	84 - 120	14	
dipole field [T]	14 - 20	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1100 - 4570	7.3	3.6
SR power / length [W/m/ap.]	14 - 58	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} cm^{-2}s^{-1}]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.3 – 9.2	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

With FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies

Formidable challenges:
- ❑ high-field superconducting magnets: 14 - 20 T
- ❑ power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- ❑ stored beam energy: ~ 9 GJ → machine protection
- ❑ pile-up in the detectors: ~1000 events/xing
- ❑ energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

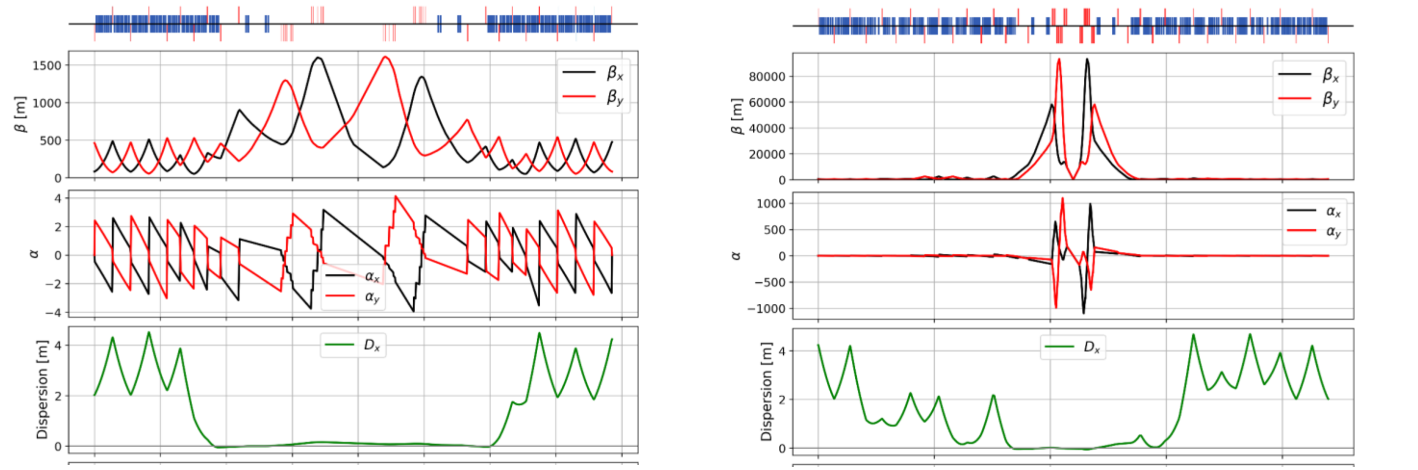
Formidable physics reach, including:
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, Zγ, μμ)
- ❑ Final word about WIMP dark matter

F. Gianotti

Key activities on FCC-hh: cryo magnet system & optics design

Optics design activities:

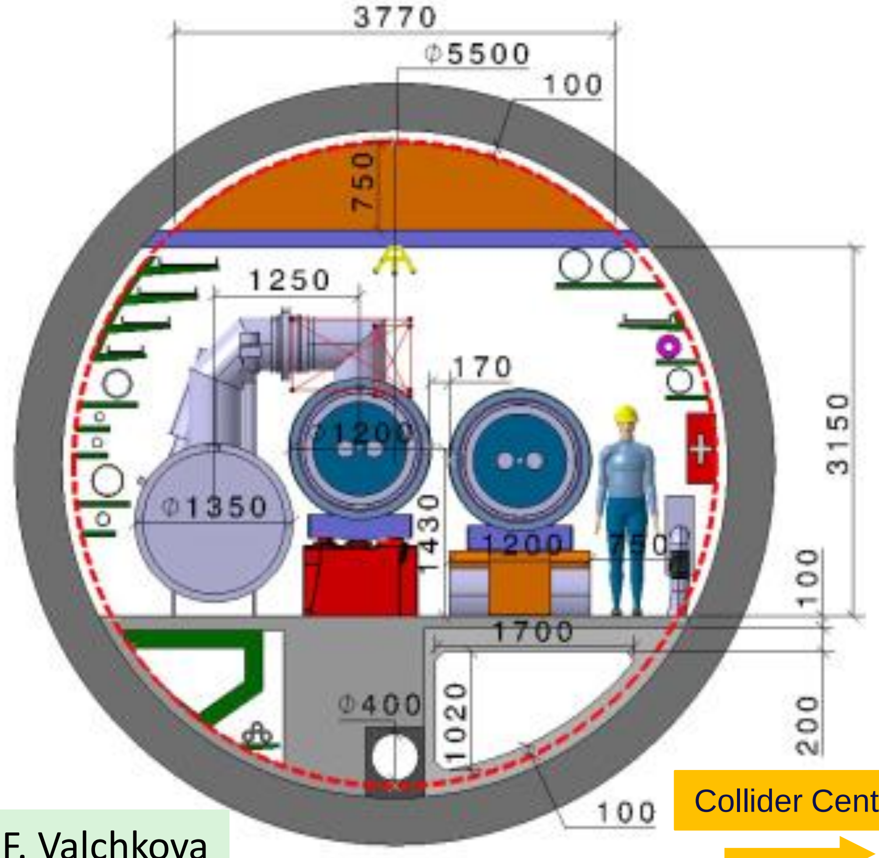
- adaptation to new layout and geometry
- shrink β collimation & extraction by ~30%
- optics optimisation (filling factor etc.)



betatron collimation straight

experimental straight

M. Giovannozzi. G. Perez, T. Risselada



F. Valchkova

Collider Center

High-field cryo-magnet system design

- Conceptual study of cryogenics concept and temperature layout for LTS and HTS based magnets, in view of electrical consumption
- Update of integration study for the ongoing HFM designs and scaling to preliminary HTS design
  → **Confirmation of tunnel diameter!**
- HFM R&D (LTS and HTS) on technology and magnet design, aiming also at bridging the TRL gap between HTS and Nb_3Sn

FCC Week 2024 – San Francisco – 10 to 14 June

449 participants : 75 remote, 374 on site including, 28 ‘1-day’ passes