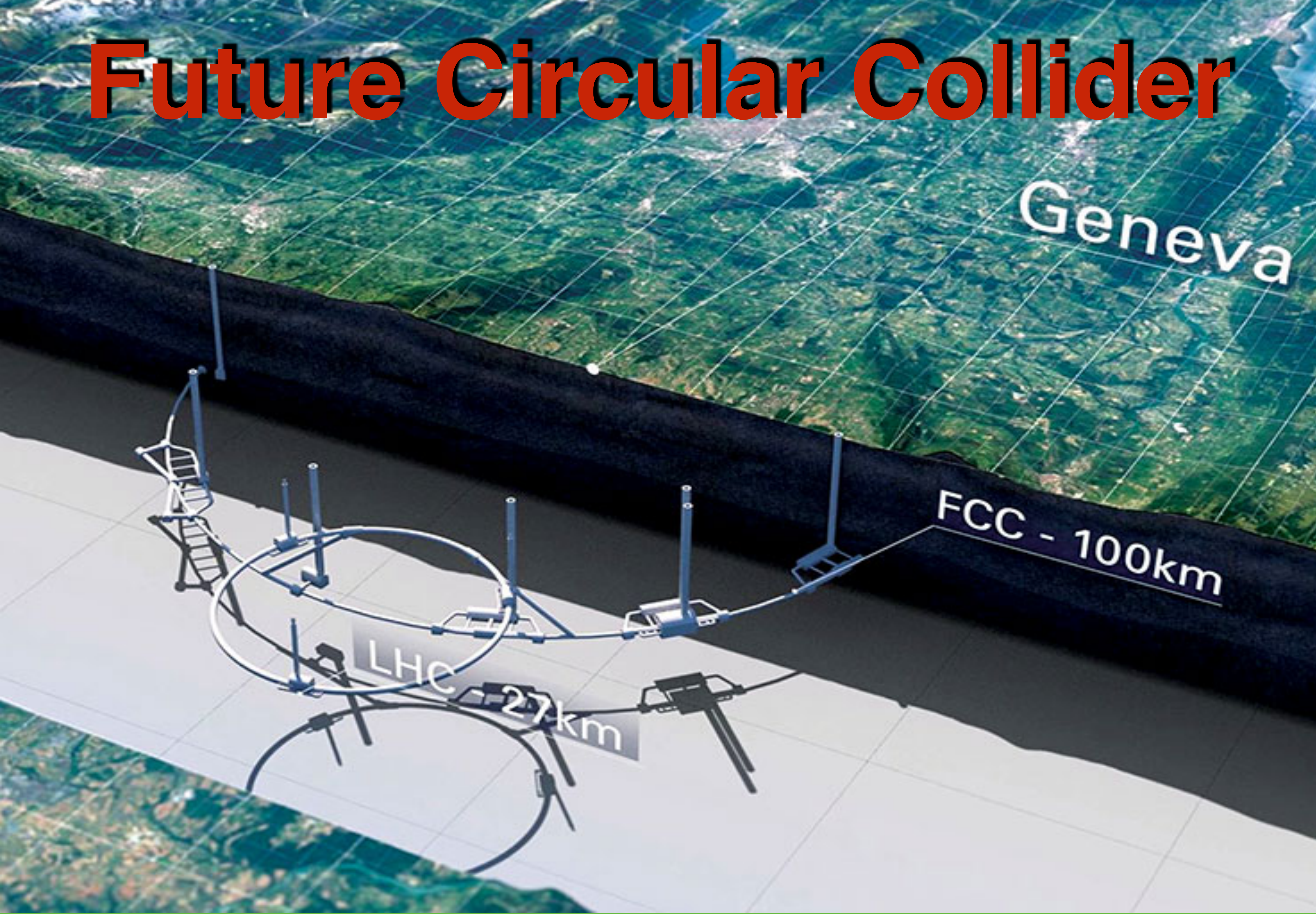
Future Circular Collider



Markus Klute (MIT) International Workshop on CEPC - Sep 16th, 2019

European Strategy Update 2013

Preamble

Since the adoption of the European Strategy for Particle Physics in 2006, the field has made impressive progress in the pursuit of its core mission, elucidating the laws of nature at the most fundamental level. A giant leap, the discovery of the Higgs boson, has been accompanied by many experimental results confirming the Standard Model beyond the previously explored energy scales. These results raise further questions on the origin of elementary particle masses and on the role of the Higgs boson in the more fundamental theory underlying the Standard Model, which may involve additional particles to be discovered around the TeV scale. Significant progress is being made towards solving long-standing puzzles such as the matter-antimatter asymmetry of the Universe and the nature of the mysterious dark matter. The observation of a new type of neutrino oscillation has opened the way for future investigations of matter-antimatter asymmetry in the neutrino sector. Intriguing prospects are emerging for experiments at the overlap with astroparticle physics and cosmology. Against the backdrop of dramatic developments in our understanding of the science landscape, Europe is updating its Strategy for Particle Physics in order to define the community's direction for the coming years and to prepare for the long-term future of the field.

General issues

a) The success of the LHC is proof of the effectiveness of the European organisational model for particle physics, founded on the sustained long-term commitment of the CERN Member States and of the national institutes, laboratories and universities closely collaborating with CERN. *Europe should preserve this model in order to keep its leading role, sustaining the success of particle physics and the benefits it brings to the wider society*.

b) The scale of the facilities required by particle physics is resulting in the globalisation of the field. *The European Strategy takes into account the worldwide particle physics landscape and developments in related fields and should continue to do so*.

High-priority large-scale scientific activities

After careful analysis of many possible large-scale scientific activities requiring significant resources, sizeable collaborations and sustained commitment, the following four activities have been identified as carrying the highest priority.

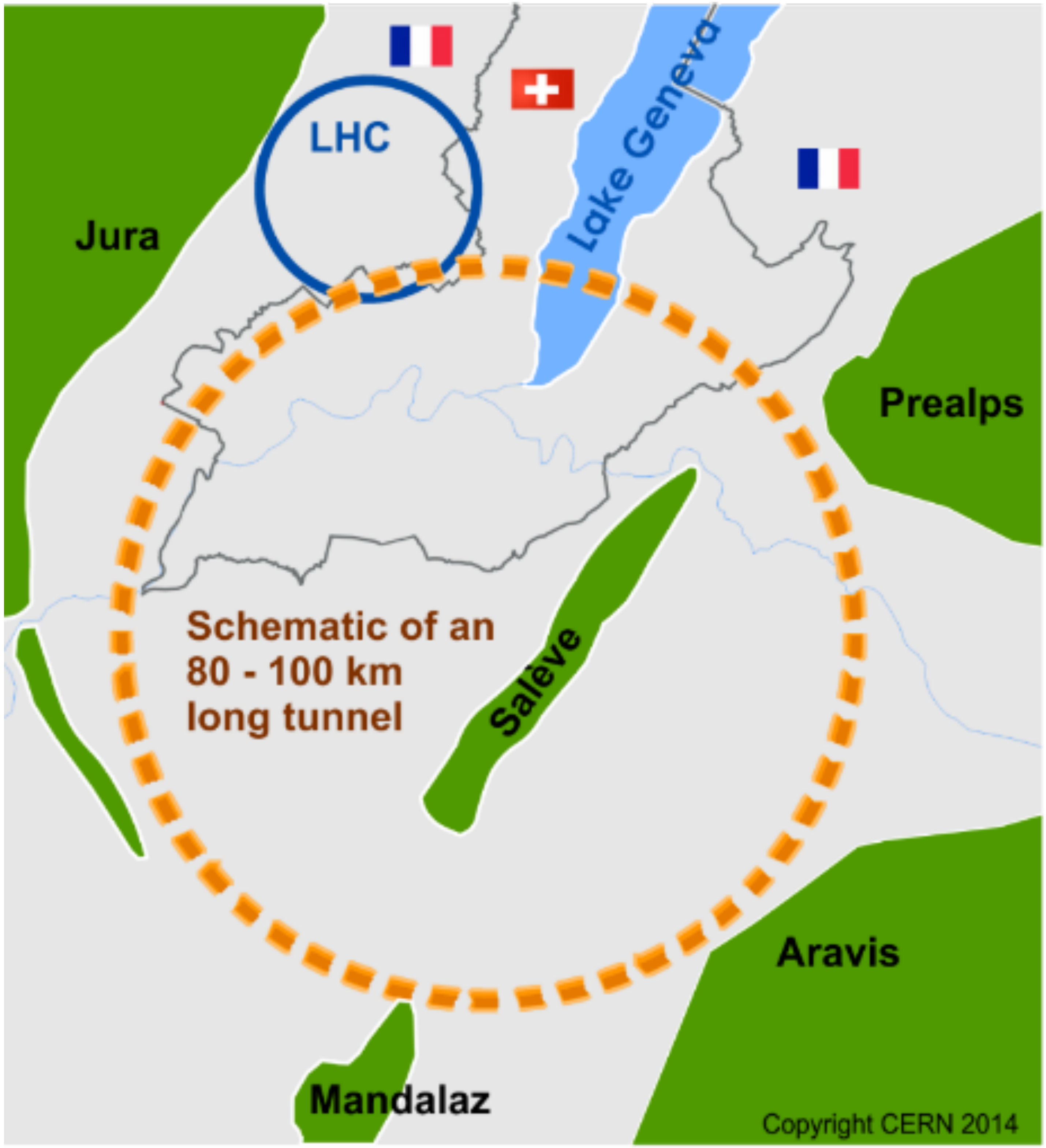
c) The discovery of the Higgs boson is the start of a major programme of work to measure this particle's properties with the highest possible precision for testing the validity of the Standard Model and to search for further new physics at the energy frontier. The LHC is in a unique position to pursue this programme. *Europe's top priority should be the exploitation of the full potential of the LHC, including the high-luminosity upgrade of the machine and detectors with a view to collecting ten times more data than in the initial design, by around 2030. This upgrade programme will also provide further exciting opportunities for the study of flavour physics and the quark-gluon plasma*.

d) To stay at the forefront of particle physics, Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14 TeV will be available. *CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy frontier machines. These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures, in collaboration with national institutes, laboratories and universities worldwide*.

http://cds.cern.ch/record/1567258/files/esc-e-106.pdf

To stay at the forefront of particle physics … CERN should undertake design studies … with emphasis on proton-proton and electron-positron high-energy frontier machines

Future Circular Collider Study



International FCC collaboration with CERN as host lab to study:

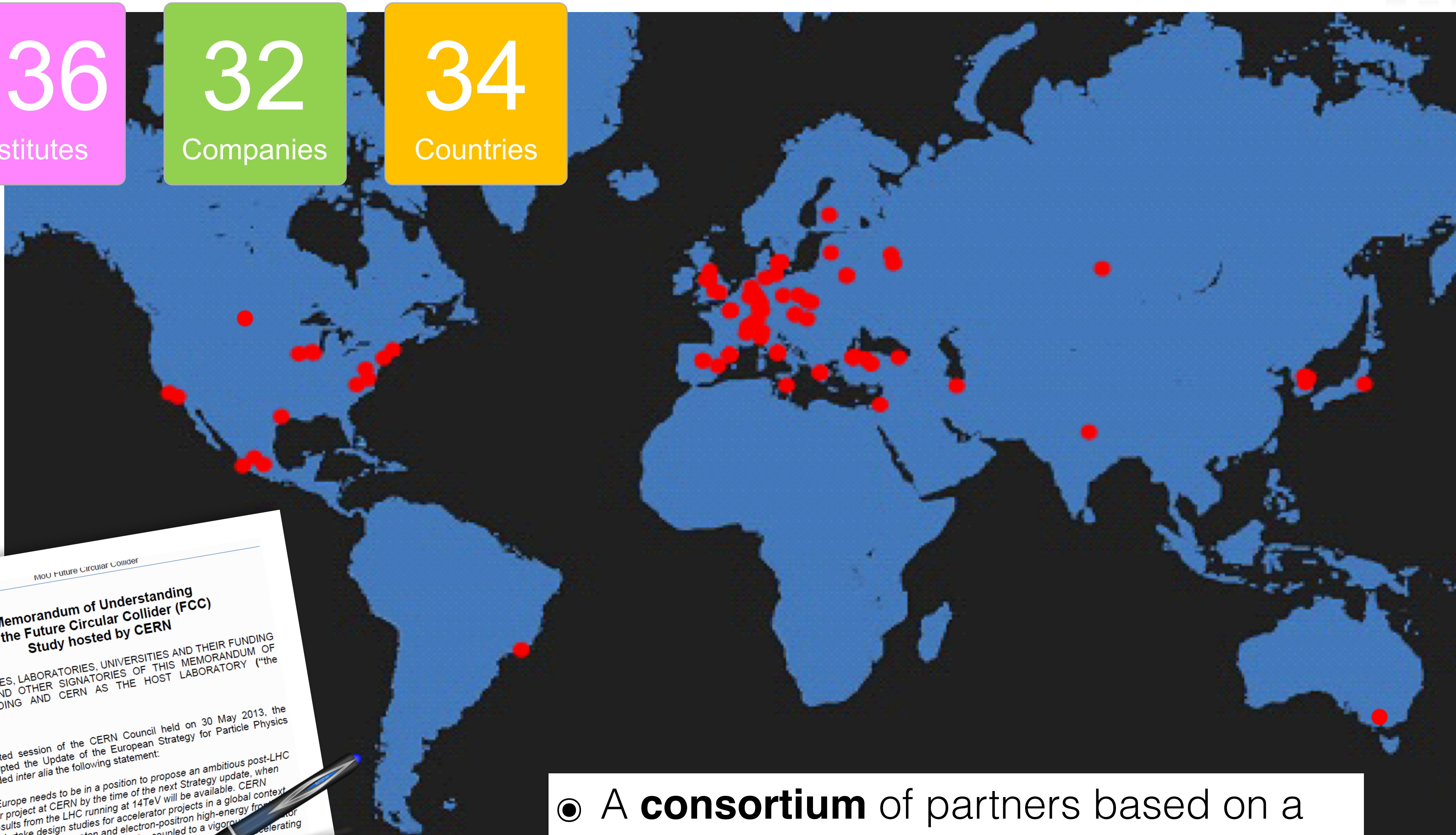
- ~100 km tunnel infrastructure in Geneva area and linked to CERN
- e^+e^- collider (FCC-ee) as potential first step
- pp-collider (FCC-hh) as long-term goal, defining the infrastructure requirements
  - ~16T => 100 TeV pp in 100 km
- HE-LHC with FCC-hh technology
- Ion and lepton-hadron options with hadron collider

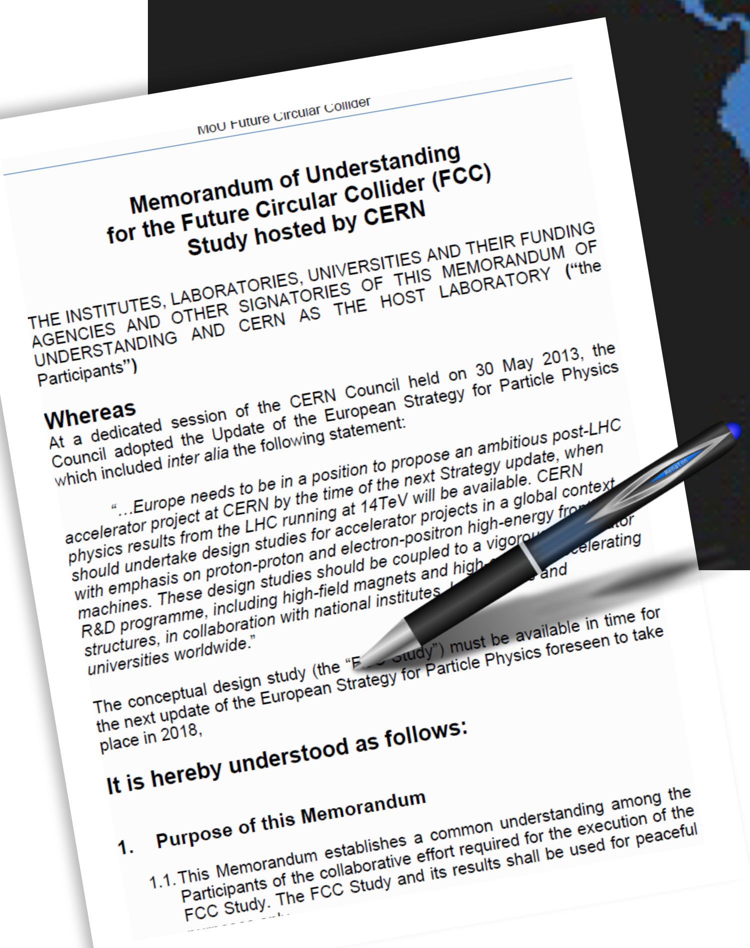
FCC Organization and Governance

136 Institutes

32 Companies

34 Countries





MoU Future Circular Collider

Memorandum of Understanding for the Future Circular Collider (FCC) Study hosted by CERN

THE INSTITUTES, LABORATORIES, UNIVERSITIES AND THEIR FUNDING AGENCIES AND OTHER SIGNATORIES OF THIS MEMORANDUM OF UNDERSTANDING AND CERN AS THE HOST LABORATORY ("the Participants")

Whereas

At a dedicated session of the CERN Council held on 30 May 2013, the Council adopted the Update of the European Strategy for Particle Physics which included *inter alia* the following statement:

"...Europe needs to be in a position to propose an ambitious post-LHC accelerator project at CERN by the time of the next Strategy update, when physics results from the LHC running at 14TeV will be available. CERN should undertake design studies for accelerator projects in a global context, with emphasis on proton-proton and electron-positron high-energy fro... machines. These design studies should be coupled to a vigoro... accelerating R&D programme, including high-field magnets and high... and structures, in collaboration with national institutes, ... universities worldwide."

The conceptual design study (the "F... Study") must be available in time for the next update of the European Strategy for Particle Physics foreseen to take place in 2018,

It is hereby understood as follows:

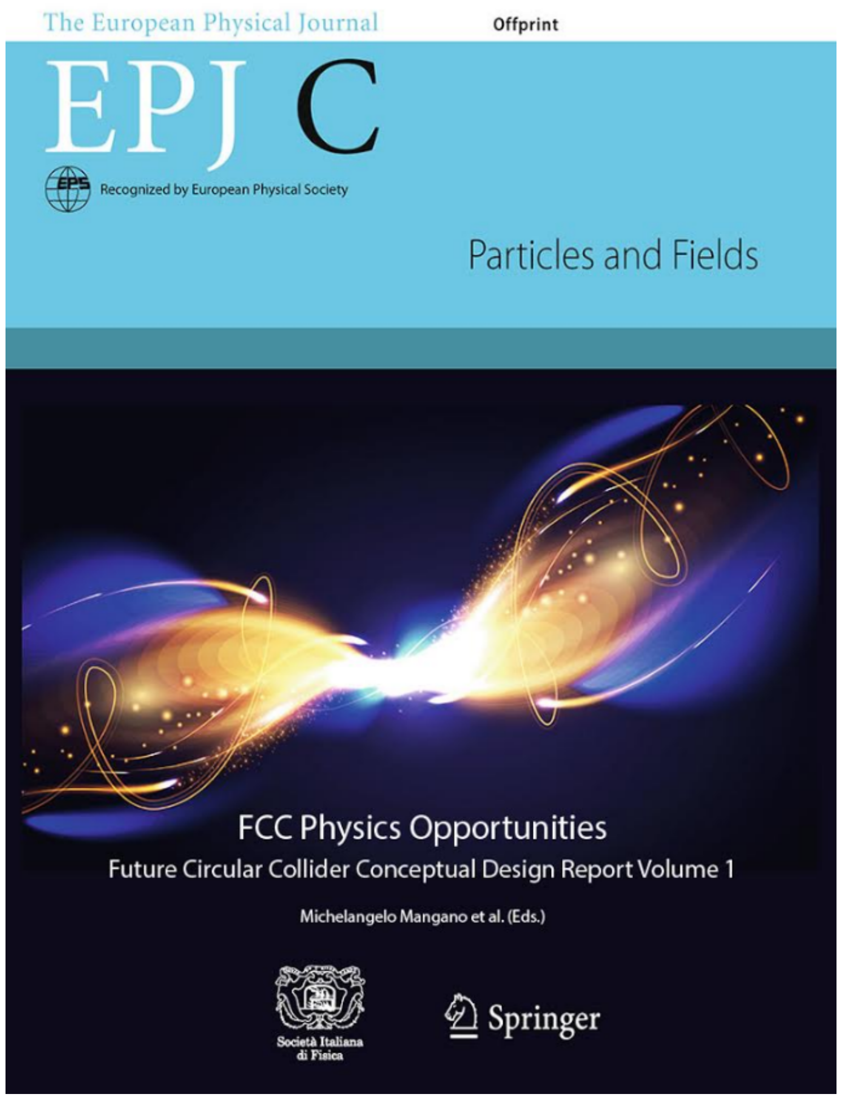
1. **Purpose of this Memorandum**

1.1. This Memorandum establishes a common understanding among the Participants of the collaborative effort required for the execution of the FCC Study. The FCC Study and its results shall be used for peaceful

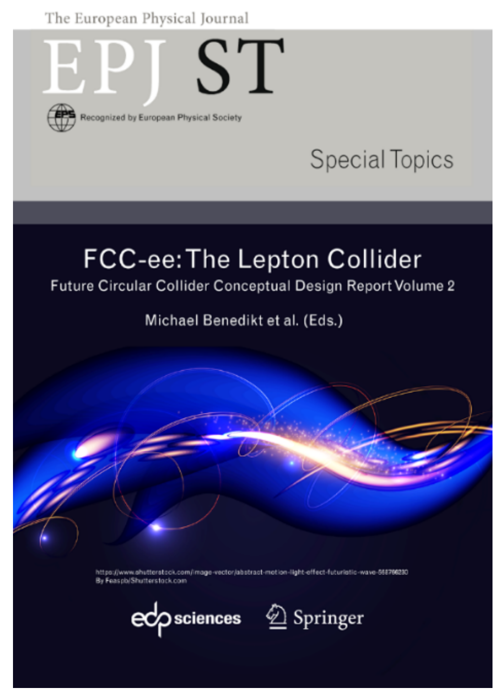
- A **consortium** of partners based on a Memorandum Of Understanding (MoU)
- Working together on a **best effort basis**
- Pursuing the same **common goal**
- Open to academia and industry

FCC Results

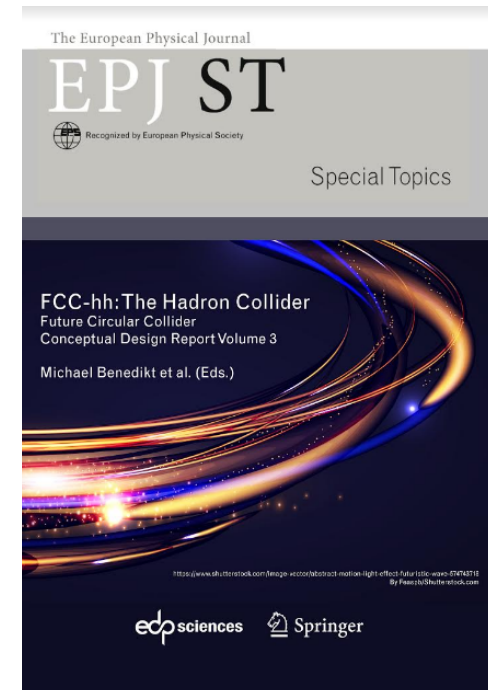
4 CDR volumes submitted to EPJ in December 2018.



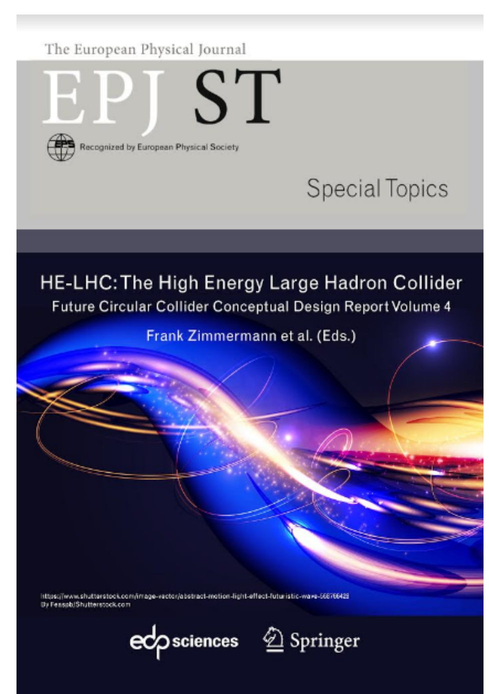
FCC Physics Opportunities



FCC-ee: The Lepton Collider



FCC-hh: The Hadron Collider



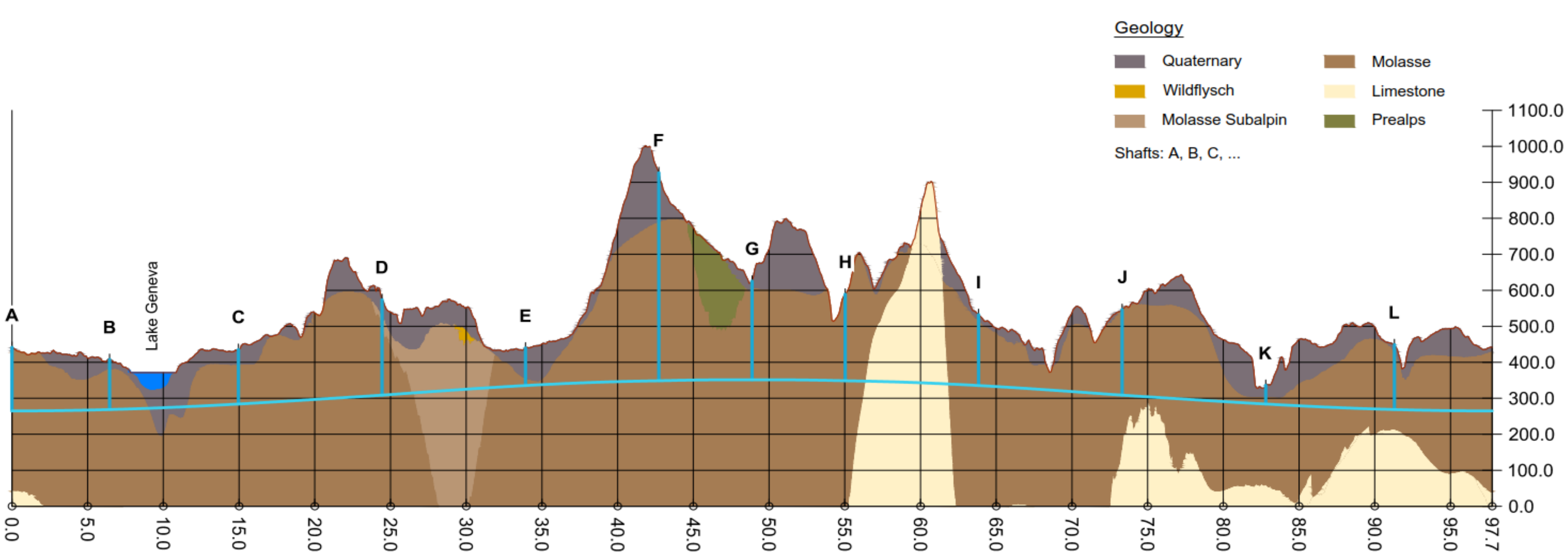
HE-LHC: The High Energy Large Hadron Collider

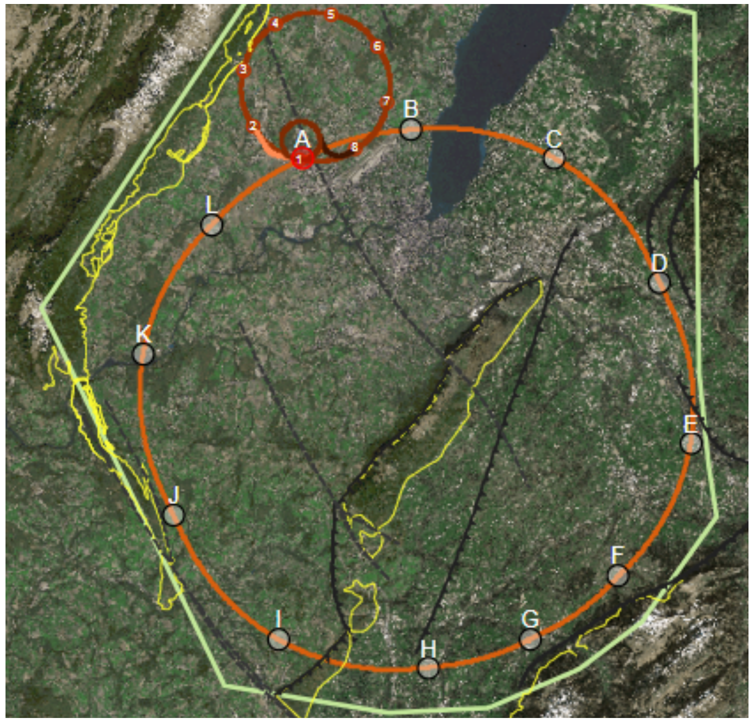
Copies can be requested at http://get-fcc-cdr.web.cern.ch

FCC Program

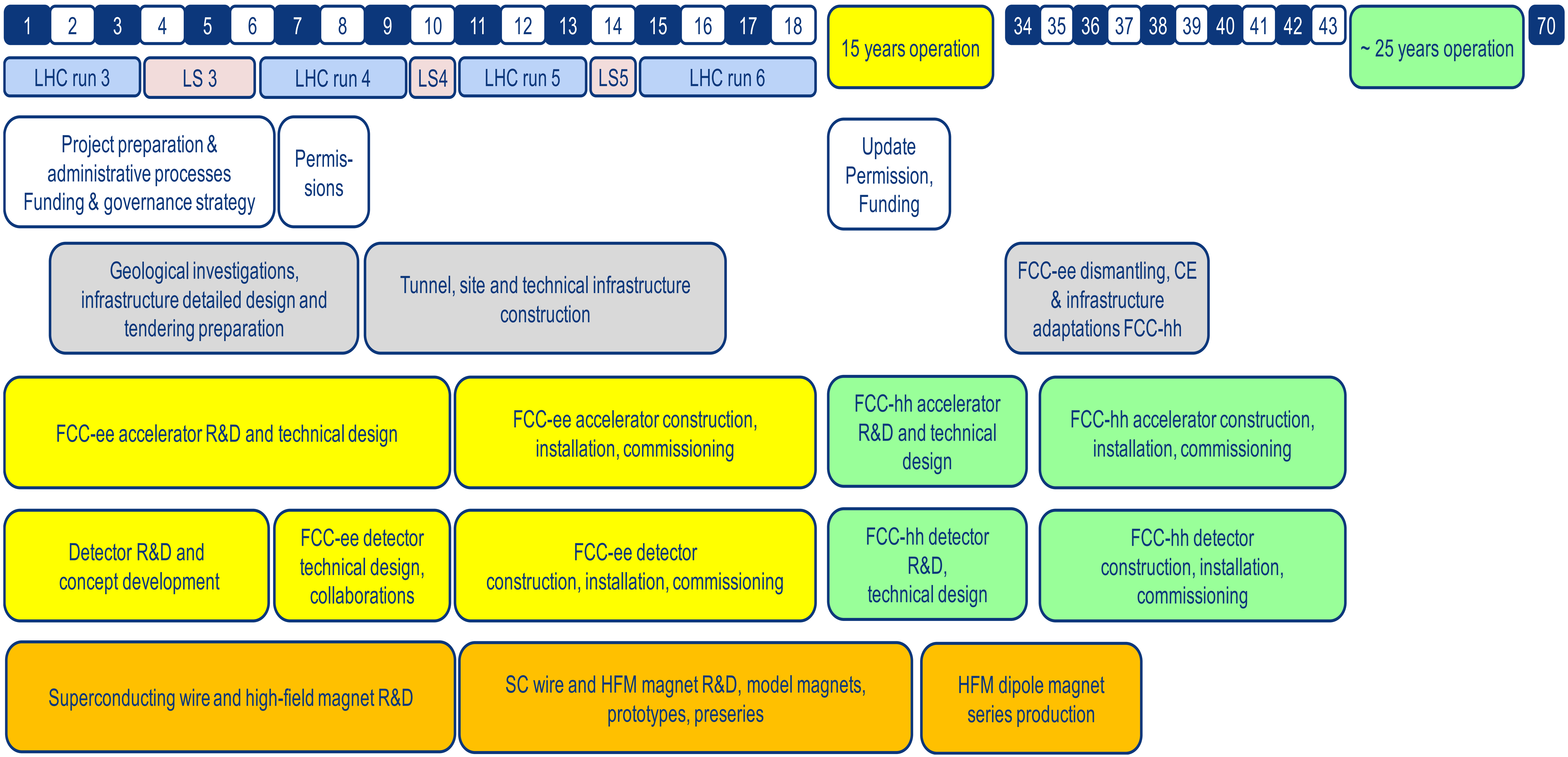
Program in two phase

- Phase 1: FCC-ee (Z, W, H, tt) as Higgs, EW and top factory at highest luminosities.
- Phase 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options.





FCC Technical Schedule



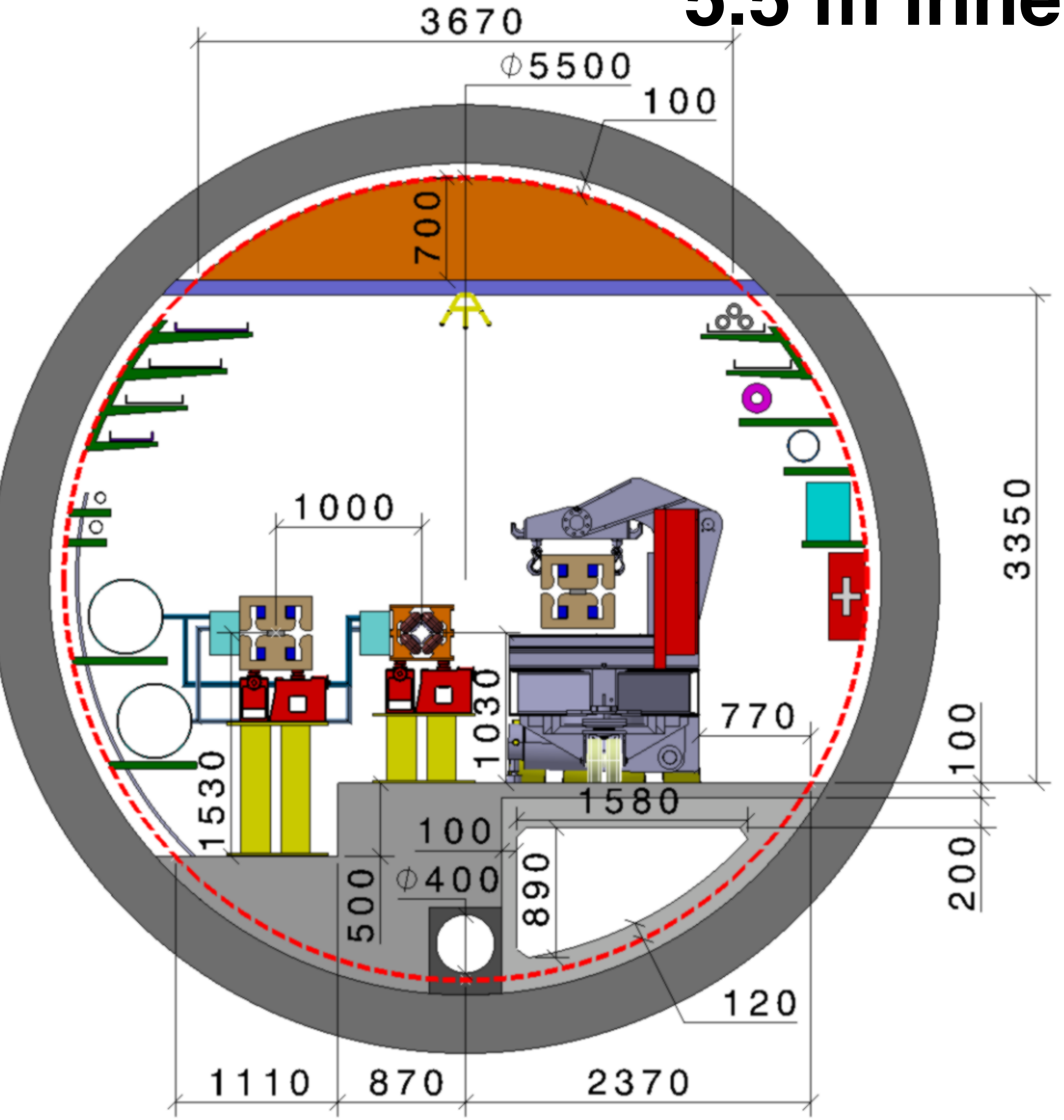
FCC project plan is fully integrated with HL-LHC exploitation and provides seamless continuation of high energy physics at the energy frontier

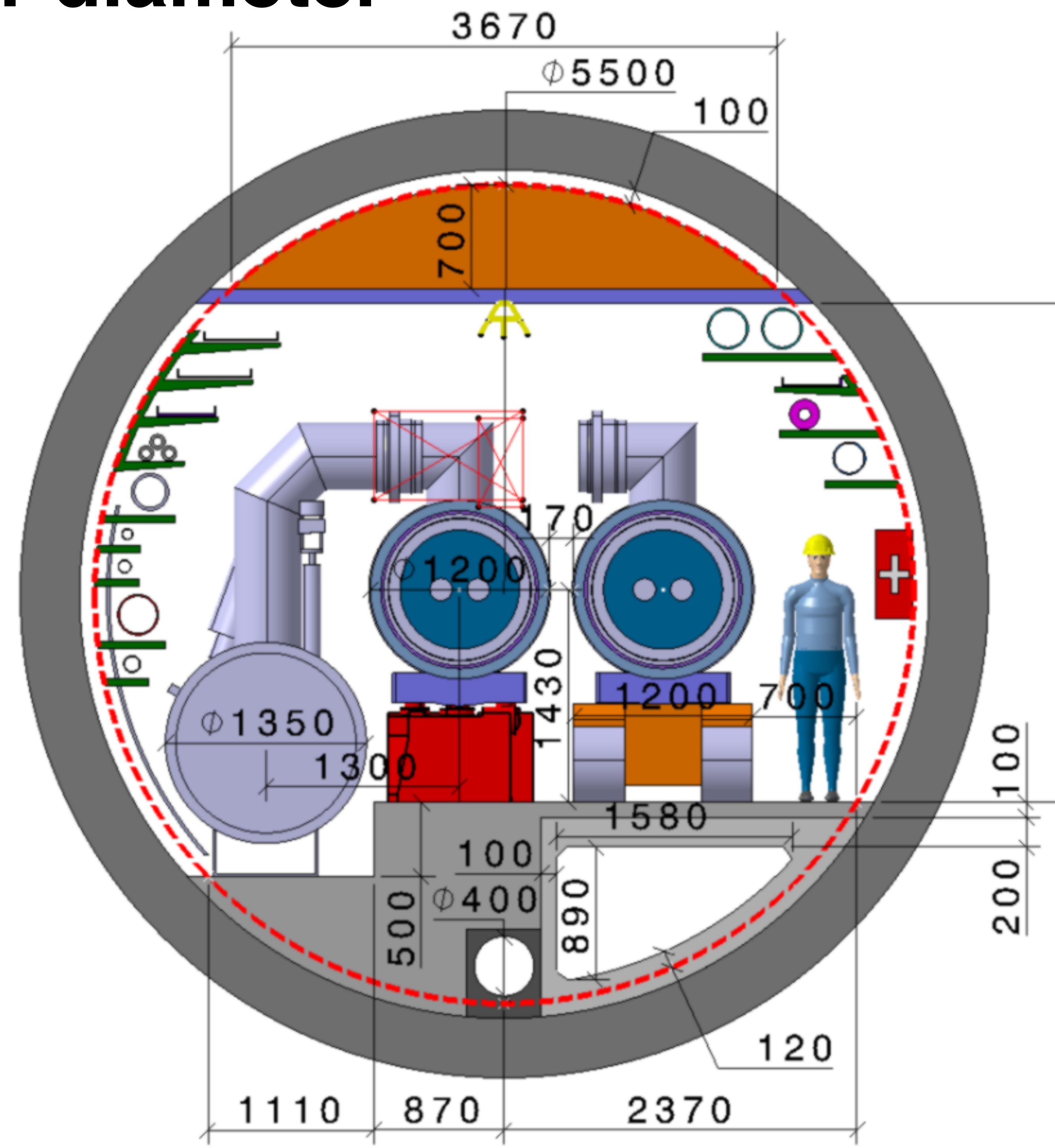
FCC Tunnel

FCC-ee

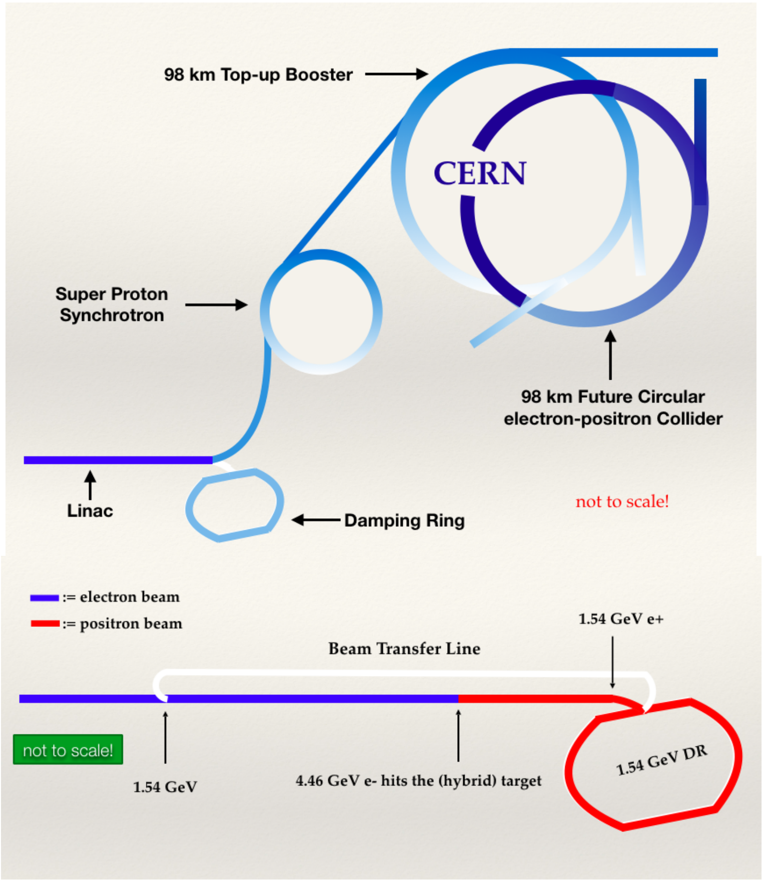
FCC-hh

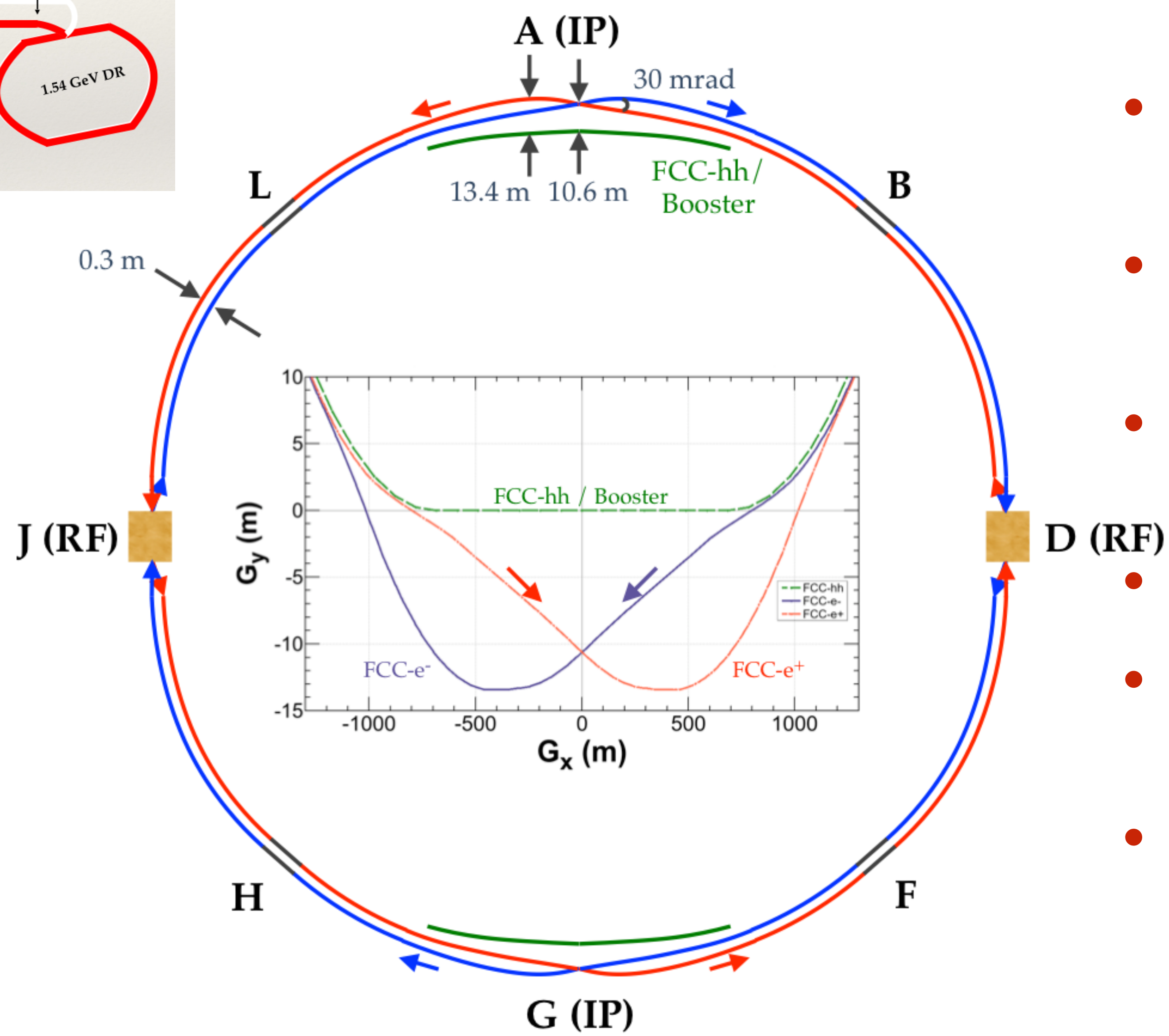
5.5 m inner diameter





FCC-ee Machine

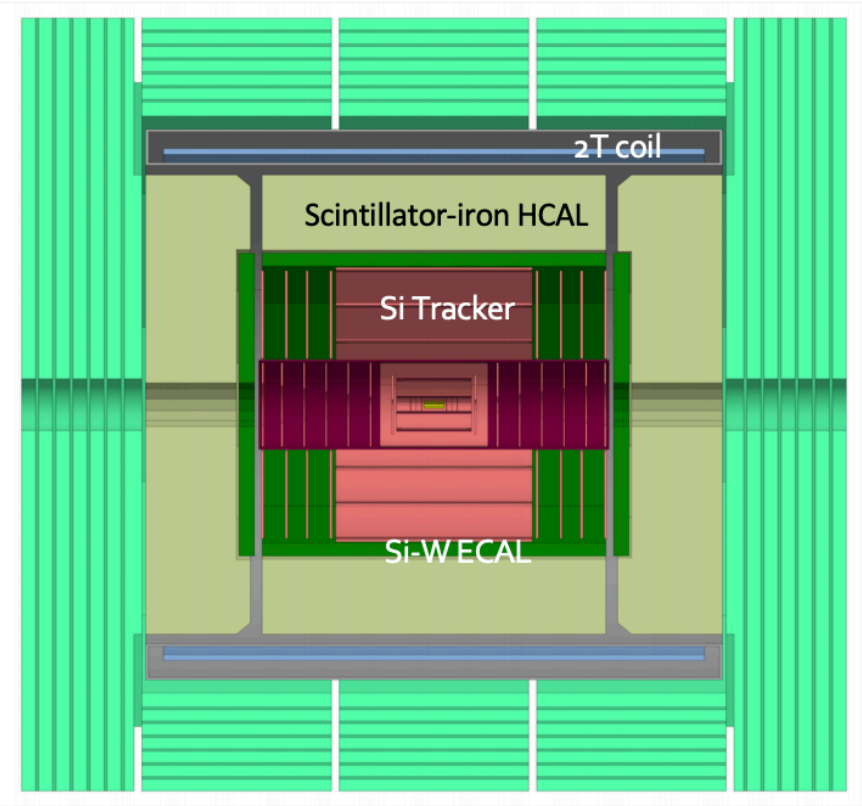




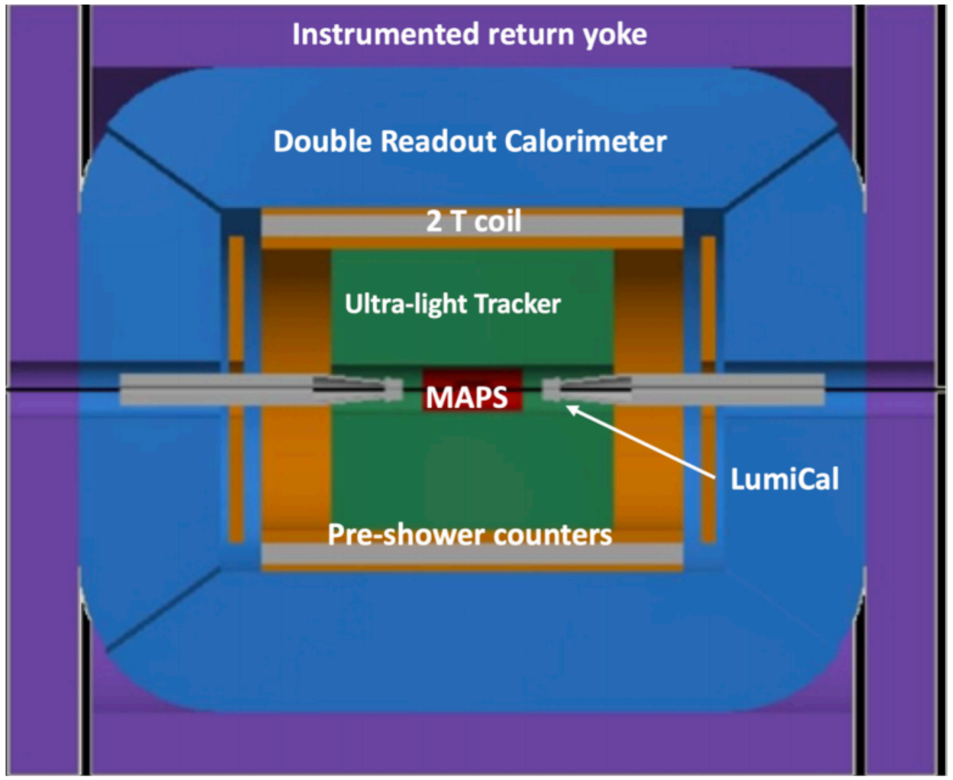
➡ Machine design

- ~100km double ring
- exploiting lessons from past and present collider design
- asymmetric IR layout and optics to limit synchrotron radiation towards the detector
- baseline has 2IPs, layouts with 3 or 4 IPs possible
- synchrotron radiation power of 50MW/beam at all energies
- RF cavities optimized for each running mode
- top-up injection scheme
- same footprint as FCC-HH design
- collider technology exists today

FCC-ee Detector Design



CLD



IDEA

- Consolidated option based on the detector design developed for CLIC
  - All silicon vertex detector and tracker
  - 3D-imaging highly-granular calorimeter system
  - Coil outside calorimeter system
- Proven concept, understood performance

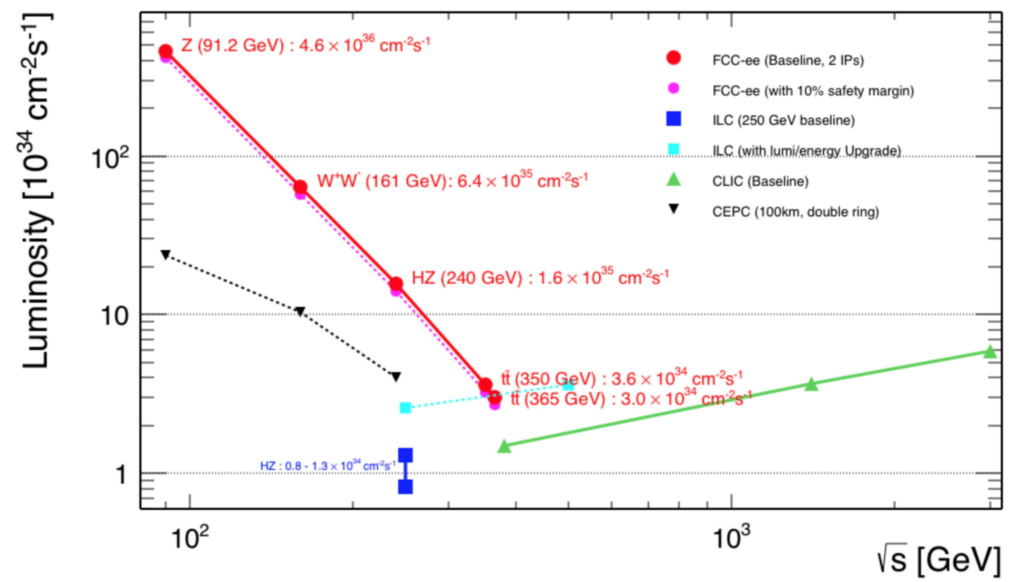
- New, innovative, possibly more cost-effective design
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil inside calorimeter system

Mogens Dam

Note: detector in beam line not before 2035

FCC-ee Operations

➡**A fantastic Higgs factory and much more**



➡Higgs factory

- 10^6 $e^+e^- \to HZ$

➡EW & Top factory

- 3×10^{12} $e^+e^- \to Z$
- 10^8 $e^+e^- \to W^+W^-$; 10^6 $e^+e^- \to tt$
- Transverse polarization
- Sensitive to NP up to 100 TeV

➡Flavor factory

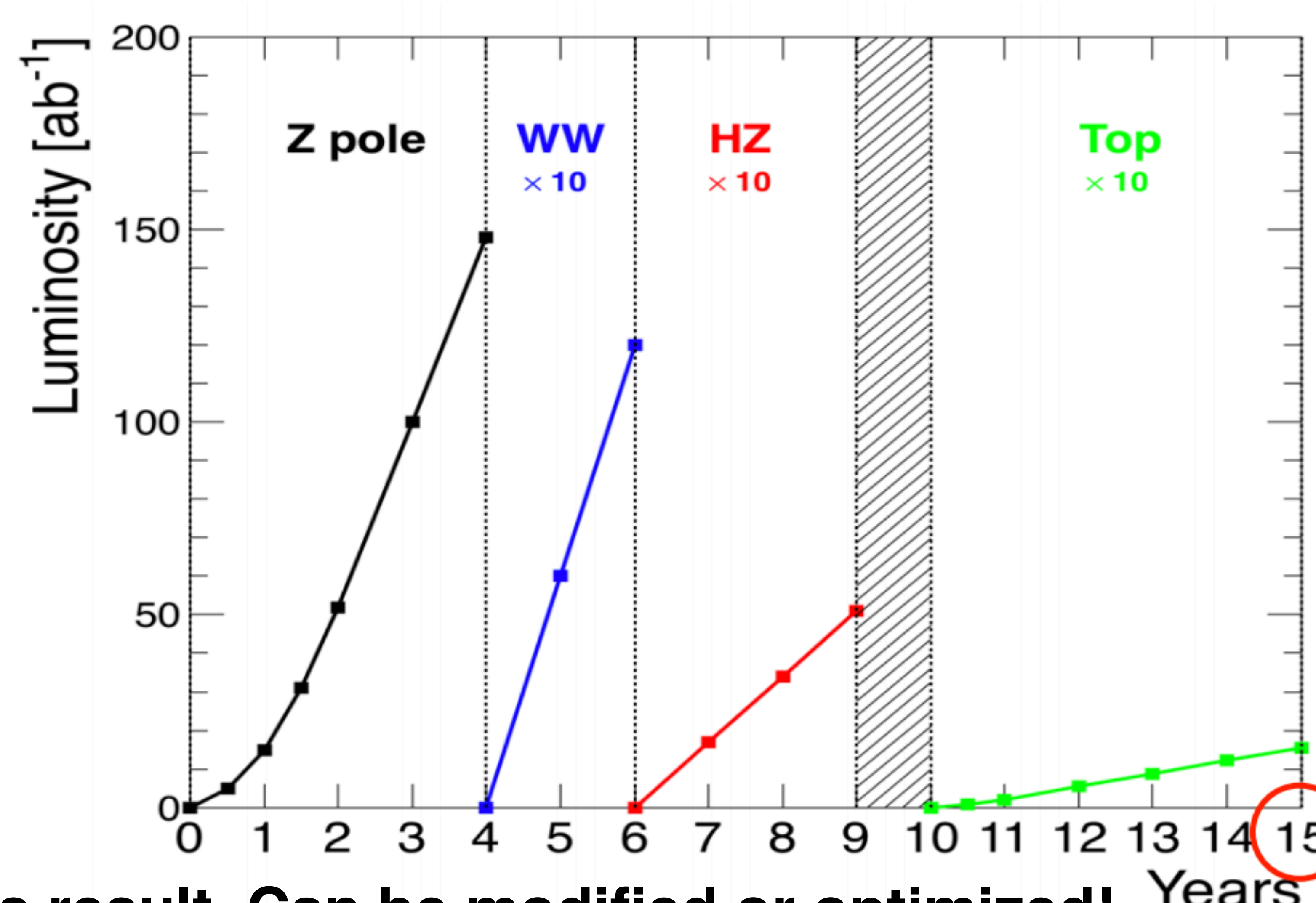
- 5×10^{12} $e^+e^- \to bb, cc$; 10^{11} $e^+e^- \to \tau^+\tau^-$

➡Precision tool

- QED: (mZ), QCD (mZ), 10^5 $H \to gg$

➡Potential discovery of NP

- ALPs, RH ν's, …



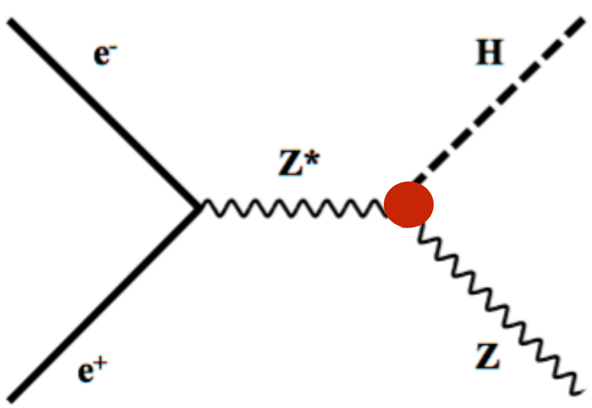
Schedule basis for CDR physics result. Can be modified or optimized!

Higgs coupling to Z bosons

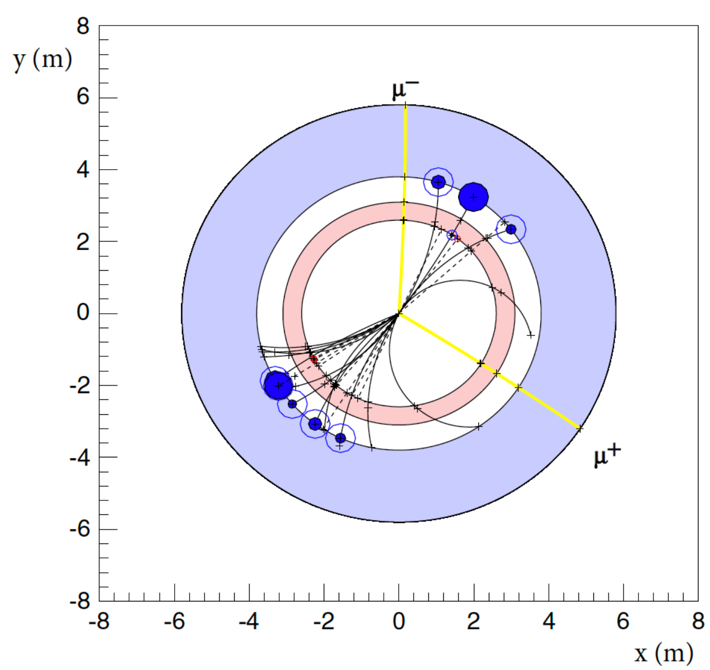
➡ **Recoil method provides unique opportunity for model independent measurement of HZ coupling**

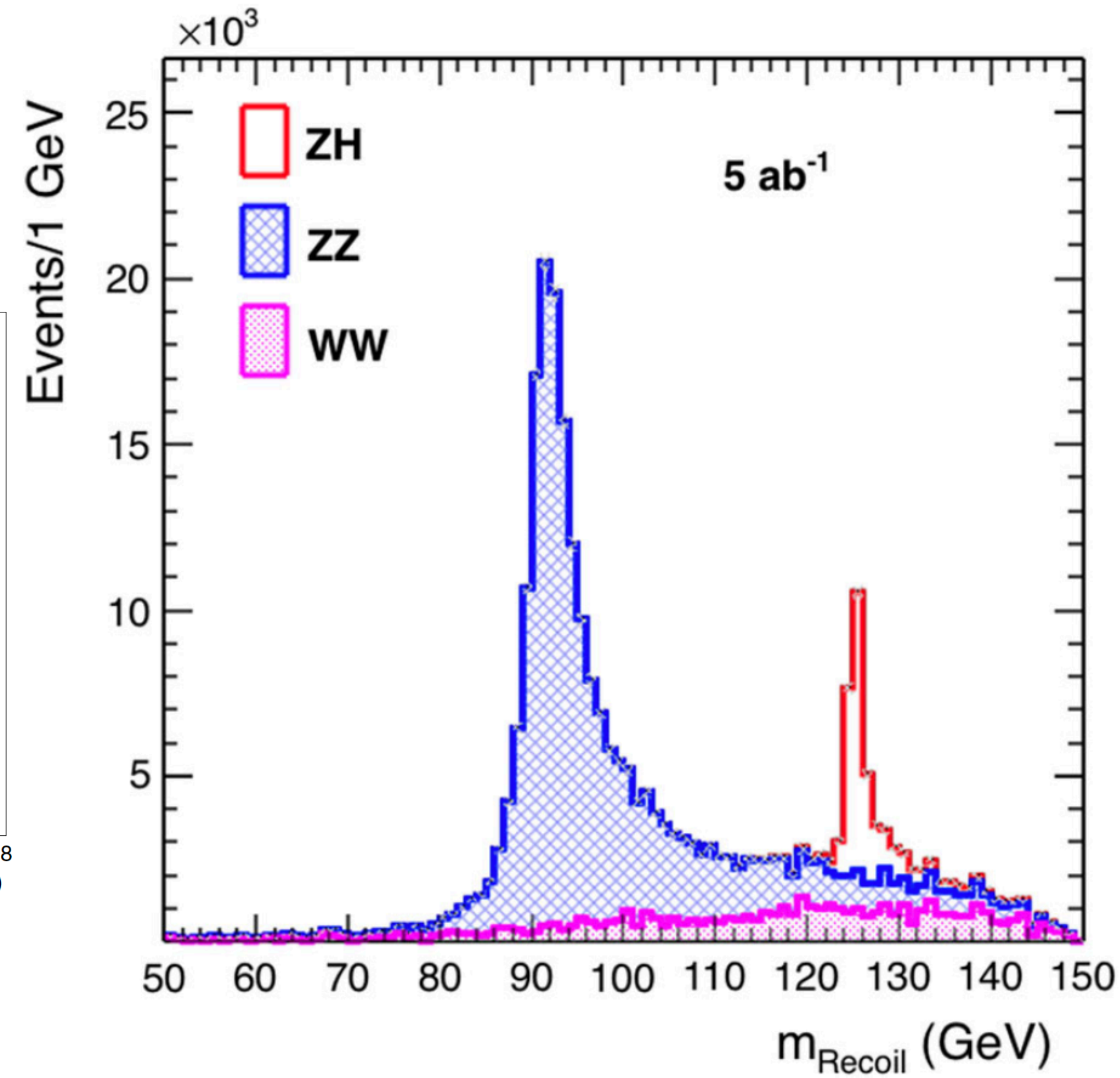
- Higgs events are tagged Higgs decay mode independent

$$\sigma(ee \to ZH) \propto g_{HZ}^2$$



$$m_R^2 = (\sqrt{s} - E_{\ell\ell})^2 - |\vec{p}_{\ell\ell}|^2$$





Total Higgs Boson Width

➡ **Total Higgs boson width can be extracted from a combination of measurements in a model independent way**

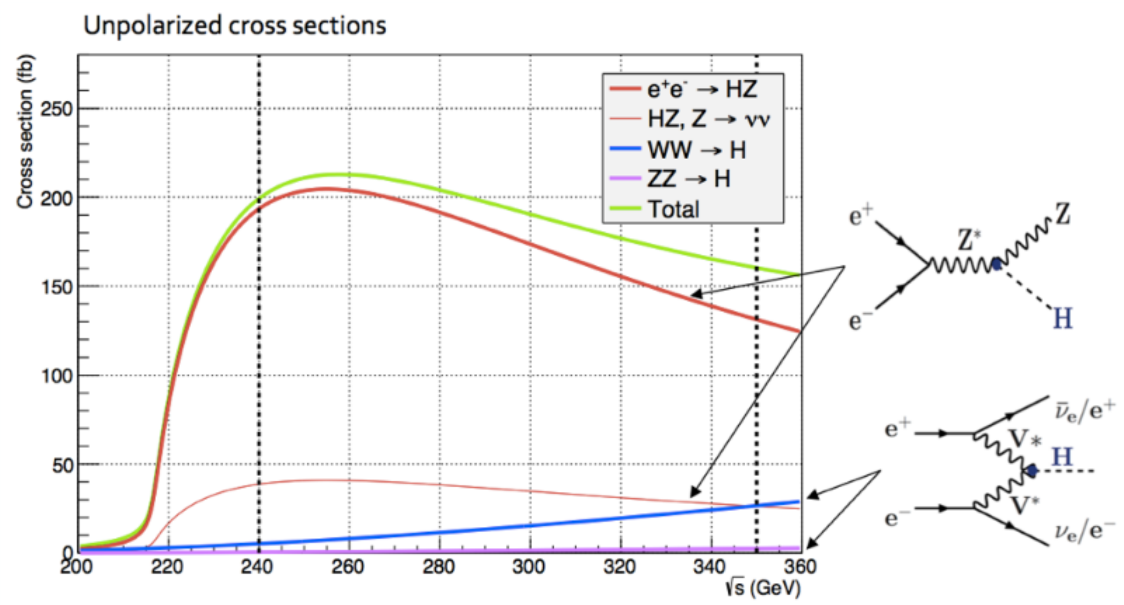
- **1) tagging Higgs final states**

$$\sigma(\mathrm{ee} \to \mathrm{ZH}) \cdot \mathrm{BR}(\mathrm{H} \to \mathrm{ZZ}) \propto \frac{g_{\mathrm{HZ}}^4}{\Gamma}$$

- **2) measurements of vector boson fusion production at 350/365 GeV**

$$\frac{\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{WW})\cdot\sigma(\mathrm{ee}\to\mathrm{ZH})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}{\sigma(\mathrm{ee}\to\nu\nu\mathrm{H})\cdot\mathrm{BR}(\mathrm{H}\to\mathrm{bb})}$$

$$\propto \frac{g_{\mathrm{HZ}}^2\cdot \cancel{g_{\mathrm{HW}}^2}}{\Gamma}\cdot\frac{g_{\mathrm{HZ}}^2\cdot \cancel{g_{\mathrm{Hb}}^2}}{\cancel{\Gamma}}\cdot\frac{\cancel{\Gamma}}{\cancel{g_{\mathrm{HW}}^2}\cdot \cancel{g_{\mathrm{Hb}}^2}} = \frac{g_{\mathrm{HZ}}^4}{\Gamma}$$



- **3) combination of all measurements**

FCC-ee Higgs Couplings

➡Unique measurements at highest precision

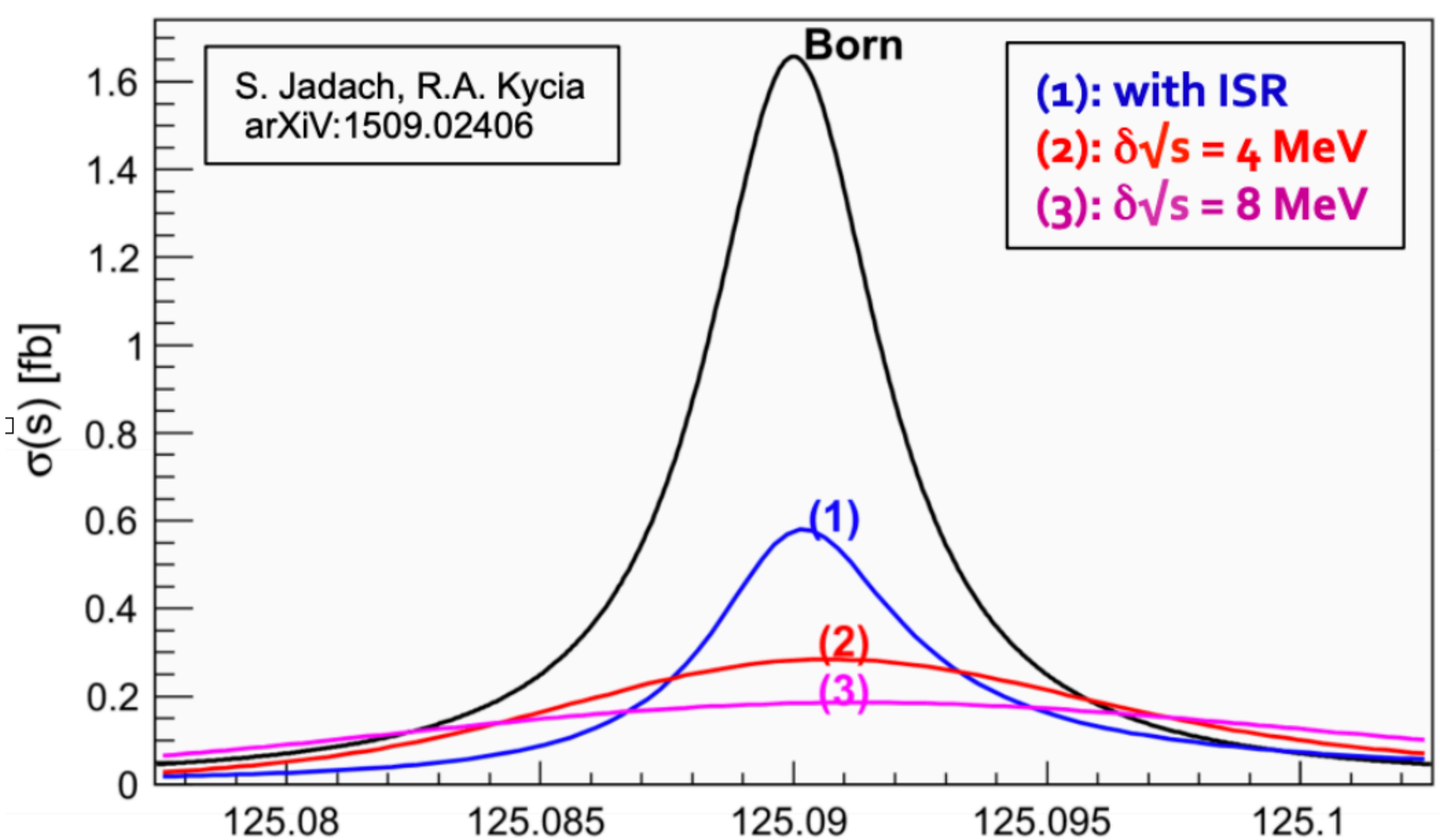
Collider	HL-LHC	ILC_{250}	$CLIC_{380}$	$CEPC_{240}$	$FCC\text{-}ee_{240\to365}$
Lumi (ab^{-1})	3	2	1	5.6	5 + 0.2 + 1.5
Years		11.5^{5}	8	7	3 + 1 + 4
g_{HZZ} (%)	1.5 / 3.6	0.29 / 0.47	0.44 / 0.66	0.18 / 0.52	**0.17 / 0.26**
g_{HWW} (%)	1.7 / 3.2	1.1 / 0.48	0.75 / 0.65	0.95 / 0.51	**0.41 / 0.27**
g_{Hbb} (%)	3.7 / 5.1	1.2 / 0.83	1.2 / 1.0	0.92 / 0.67	**0.64 / 0.56**
g_{Hcc} (%)	SM / SM	2.0 / 1.8	4.1 / 4.0	2.0 / 1.9	**1.3 / 1.3**
g_{Hgg} (%)	2.5 / 2.2	1.4 / 1.1	1.5 / 1.3	1.1 / 0.79	**0.89 / 0.82**
$g_{H\tau\tau}$ (%)	1.9 / 3.5	1.1 / 0.85	1.4 / 1.3	1.0 / 0.70	**0.66 / 0.57**
$g_{H\mu\mu}$ (%)	4.3 / 5.5	4.2 / 4.1	4.4 / 4.3	3.9 / 3.8	**3.9 / 3.8**
$g_{H\gamma\gamma}$ (%)	1.8 / 3.7	1.3 / 1.3	1.5 / 1.4	1.2 / 1.2	**1.2 / 1.2**
$g_{HZ\gamma}$ (%)	11. / 11.	11. / 10.	11. / 9.8	6.3 / 6.3	**10. / 9.4**
g_{Htt} (%)	3.4 / 2.9	2.7 / 2.6	2.7 / 2.7	2.6 / 2.6	**2.6 / 2.6**
g_{HHH} (%)	50. / 52.	28. / 49.	45. / 50.	17. / 49.	**19. / 34.**
Γ_H (%)	SM	2.4	2.6	1.9	**1.2**
BR_{inv} (%)	1.9	0.26	0.63	0.27	**0.19**
BR_{EXO} (%)	SM (0.0)	1.8	2.7	1.1	**1.0**

➡Uncertainties not limited by experimental or theoretical uncertainties. Statistics sets the floor.

First generation Higgs couplings

➡Unique measurement at FCC-ee

- **Not part of baseline run plan but a few years at √s = mH with high luminosity is an interesting add-on**
- **Expected signal significance of 0.4σ / √ year in option 1 and 2 (see below)**
  - **Set a electron Yukawa coupling upper limit: $k_e < 2.5$ @95% CL**
  - **Reaches SM sensitivity after 5 years**



FCC-ee monochromatization setups

- **Default: δ√s = 100 MeV, 25ab^{-1} / year**
- **Option 1: δ√s = 10 MeV, 7ab^{-1} / year**
- **Option 2: δ√s = 6 MeV, 2ab^{-1} / year**

FCC-ee EW & Top Physics Program

Table 3.1 Measurement of selected electroweak quantities at the FCC-ee, compared with the present precisions

Observable	Present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and dominant exp. error
m_Z (keV)	$91{,}186{,}700 \pm 2200$	5	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	$2{,}495{,}200 \pm 2300$	8	100	From Z line shape scan Beam energy calibration
R_ℓ^Z ($\times 10^3$)	$20{,}767 \pm 25$	0.06	0.2–1.0	Ratio of hadrons to leptons acceptance for leptons
$\alpha_s(m_Z)$ ($\times 10^4$)	1196 ± 30	0.1	0.4–1.6	From R_ℓ^Z above [43]
R_b ($\times 10^6$)	$216{,}290 \pm 660$	0.3	< 60	Ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD [44]
σ^0_{had} ($\times 10^3$) (nb)	$41{,}541 \pm 37$	0.1	4	Peak hadronic cross-section luminosity measurement
N_ν ($\times 10^3$)	2991 ± 7	0.005	1	Z peak cross sections Luminosity measurement
$\sin^2\theta_W^{eff}$ ($\times 10^6$)	$231{,}480 \pm 160$	3	2–5	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z)$ ($\times 10^3$)	$128{,}952 \pm 14$	4	Small	From $A_{FB}^{\mu\mu}$ off peak [34]
$A_{FB}^{b,0}$ ($\times 10^4$)	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 and charge asymmetry τ decay physics
m_W (MeV)	$80{,}350 \pm 15$	0.5	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
$\alpha_s(m_W)$ ($\times 10^4$)	1170 ± 420	3	Small	From R_ℓ^W [45]
N_ν ($\times 10^3$)	2920 ± 50	0.8	Small	Ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	$172{,}740 \pm 500$	17	Small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV)	1410 ± 190	45	Small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	0.1	Small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	$\pm 30\%$	0.5–1.5%	Small	From $E_{CM} = 365$ GeV run

Z pole

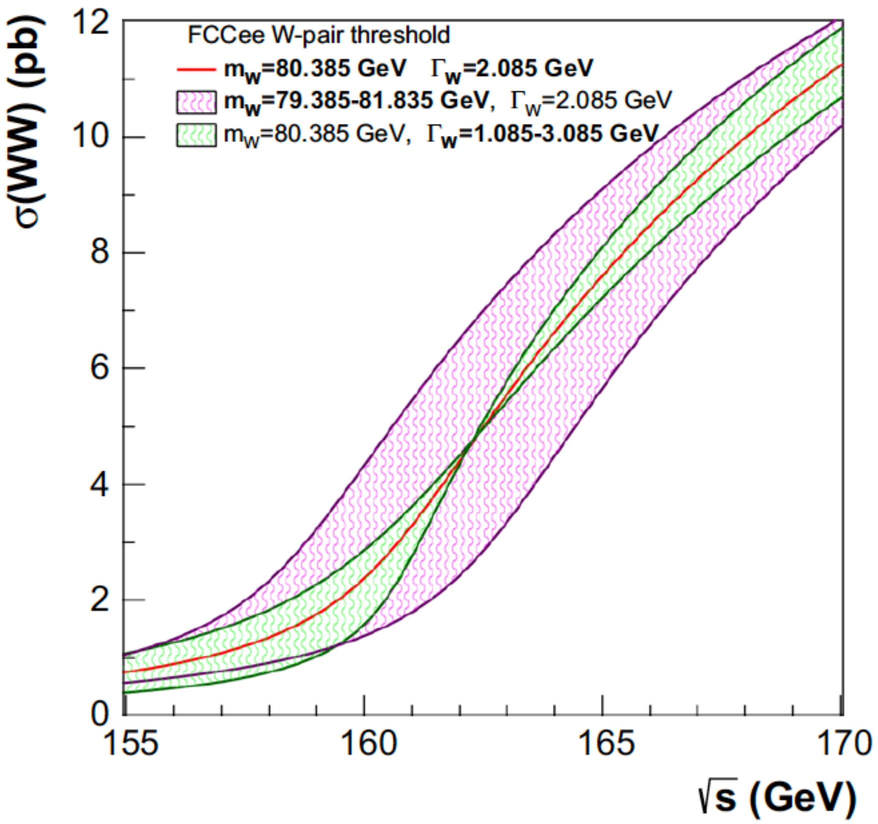
WW

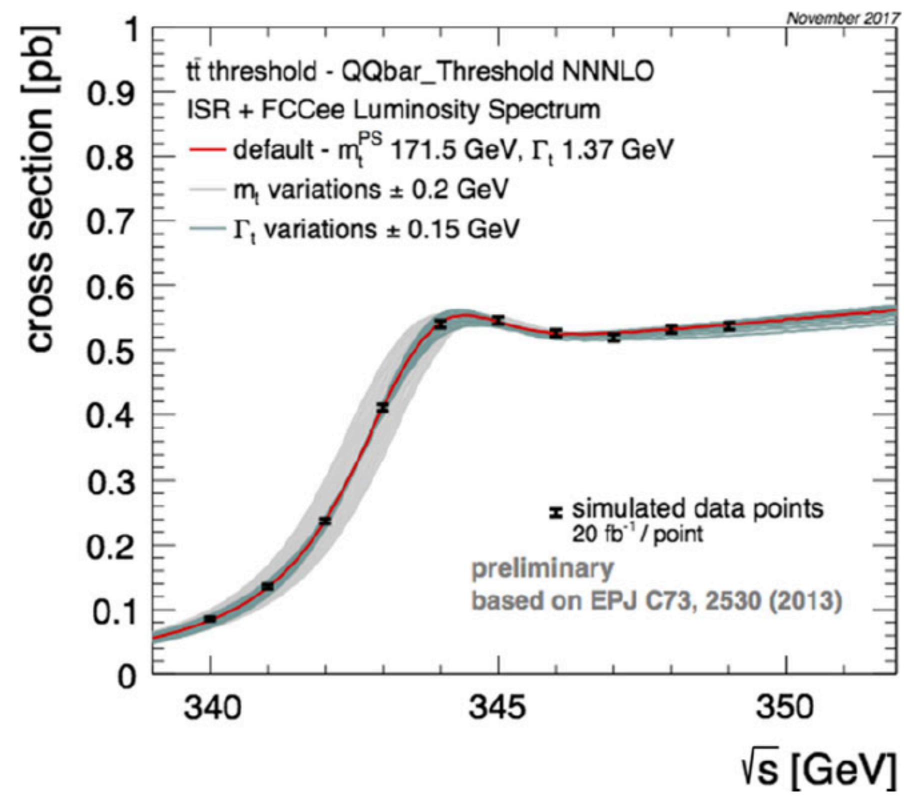
tt

➡ First set of main observables

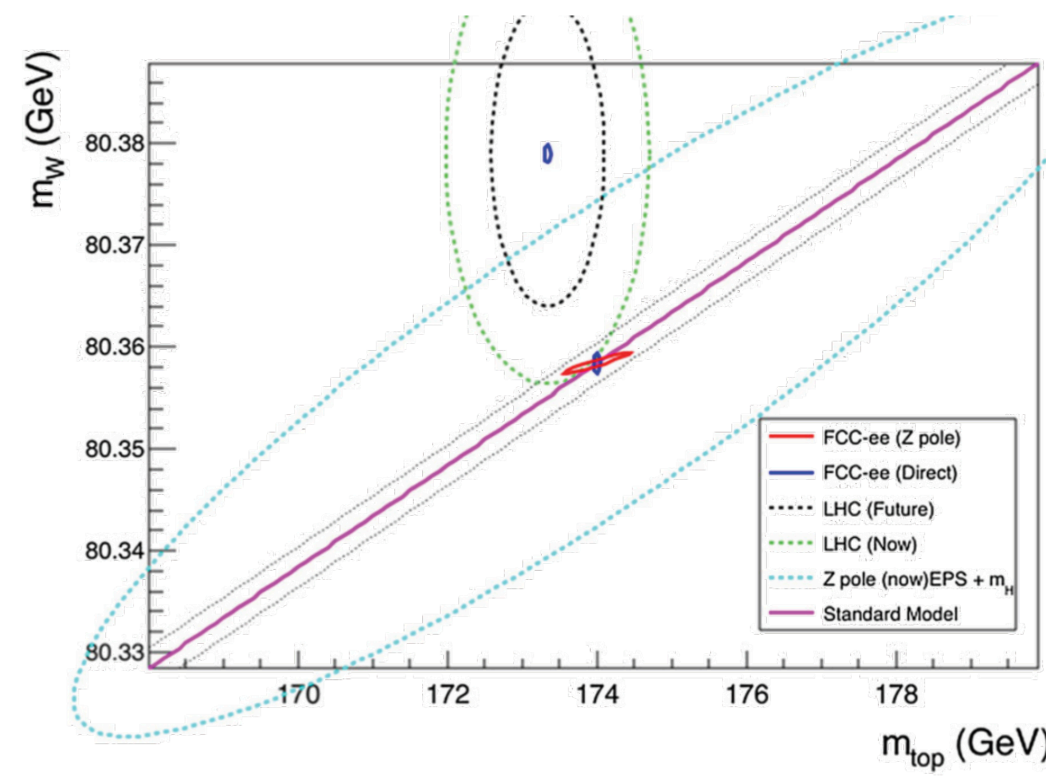
- Statistical precision follows straight forward
- For Z and W boson mass, center-of-mass energy uncertainty will dominate
- For cross-section measurements the luminosity measurement will be limiting
- Possible experimental uncertainties are indicative

W+W- and tt threshold scans





- ➡ **W: uncertainty of 0.5 (1.2) MeV on mass (width)**
  - $6ab^{-1}$ at 157.5 and 162.5 GeV
  - Requires control of systematics: √s < 0.5 MeV; acceptance and WW cross section prediction variation < 10^{-4}.
  - Complementary measurement from direct reconstruction of W boson
- ➡ **Top: uncertainty of 17 (45) MeV on mass (width)**
  - $25fb^{-1}$ at 8 different center-of-mass energies
  - Today, higher order corrections to cross section result in 40 MeV uncertainty on mass and width



Global EW and Higgs Fits

➡ **Estimation of sensitivity to new physics**

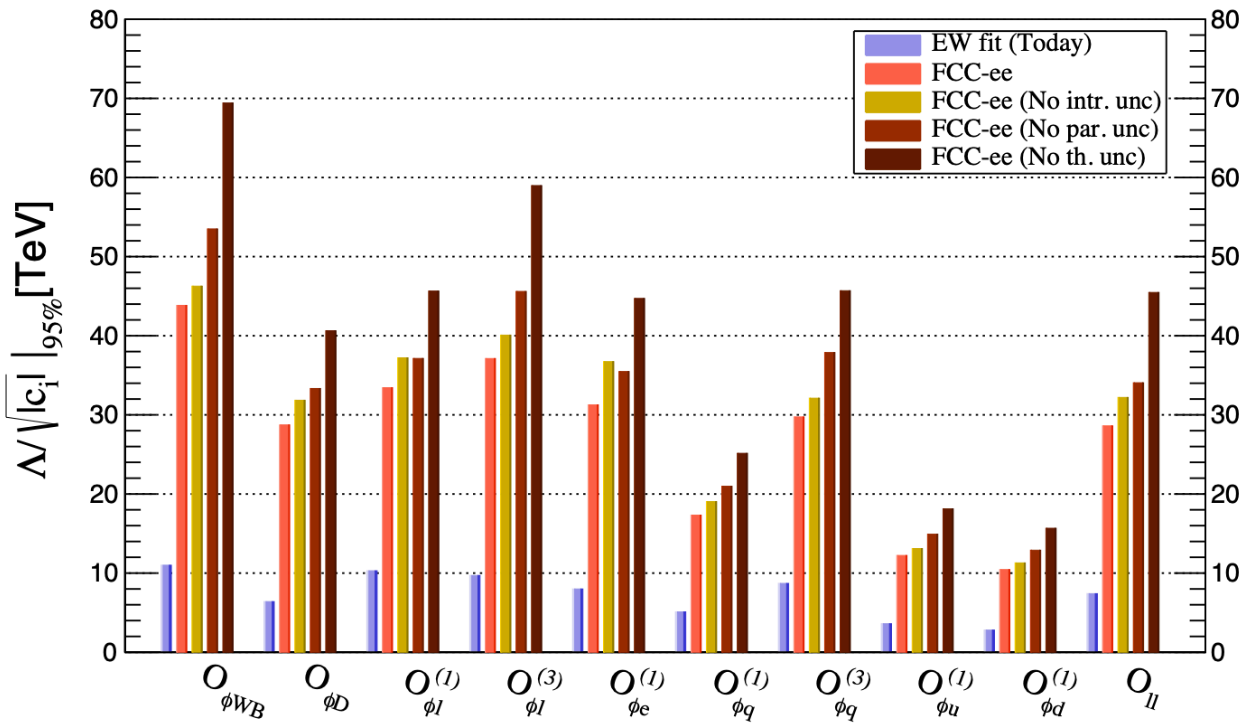
➡ **Dimension 6 SMEFT**

- assumes new physics is heavy and particles and symmetries of low energy theory (SM) decouple

$$O = O_{\rm SM} + \delta O_{\rm NP}\frac{1}{\Lambda^2}$$

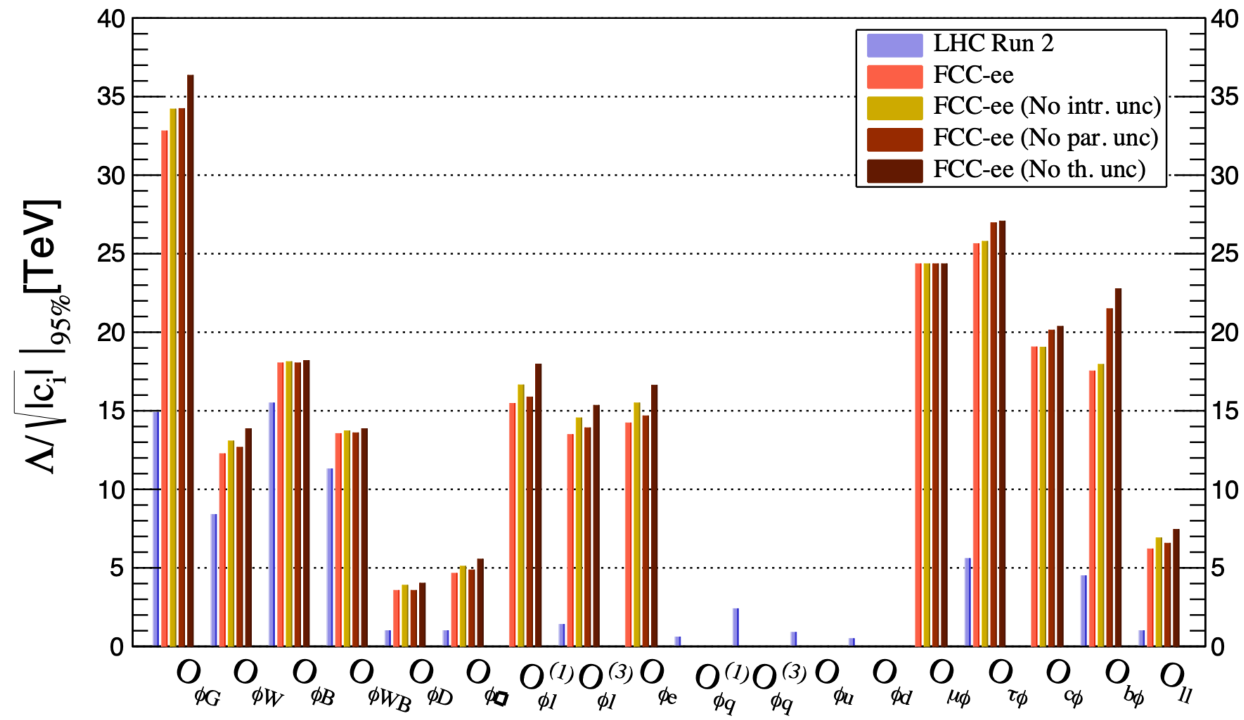
➡ **Fit one parameter at the time**

EW observables

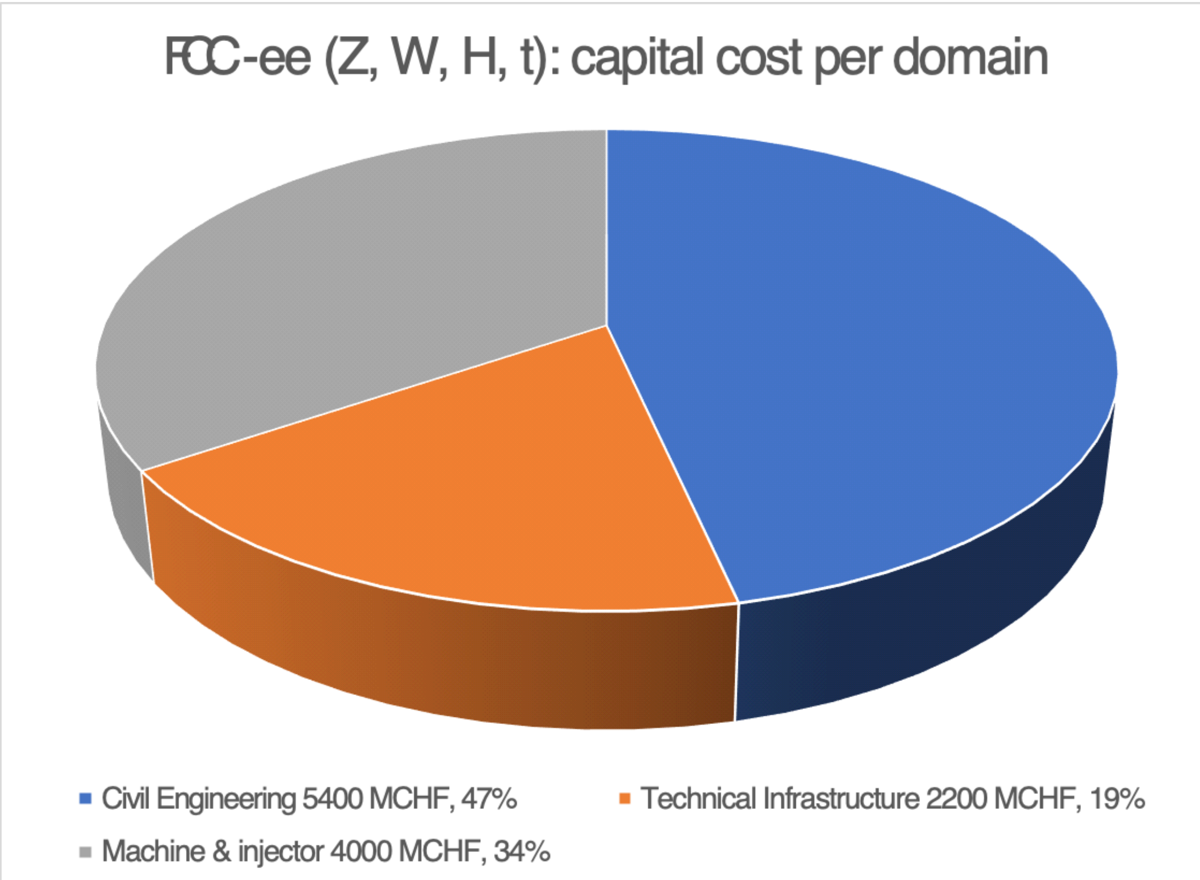


	Current Exp.	Current SM	FCCee Exp.	FCCee SM (par.)	FCCee SM (th.)
δM_W [MeV]	±15	±8	±1	$\pm0.6/\pm1$	±1
$\delta\Gamma_Z$ [MeV]	±2.3	±0.73	±0.1	±0.1	±0.2
$\delta\mathcal{A}_\ell\,[\times10^{-5}]$	±210	±93	±2.1	$\pm8/\pm14$	±11.8
$\delta R^0_b\,[\times10^{-5}]$	±66	±3	±6	±0.3	$\pm$ 5

Higgs observables

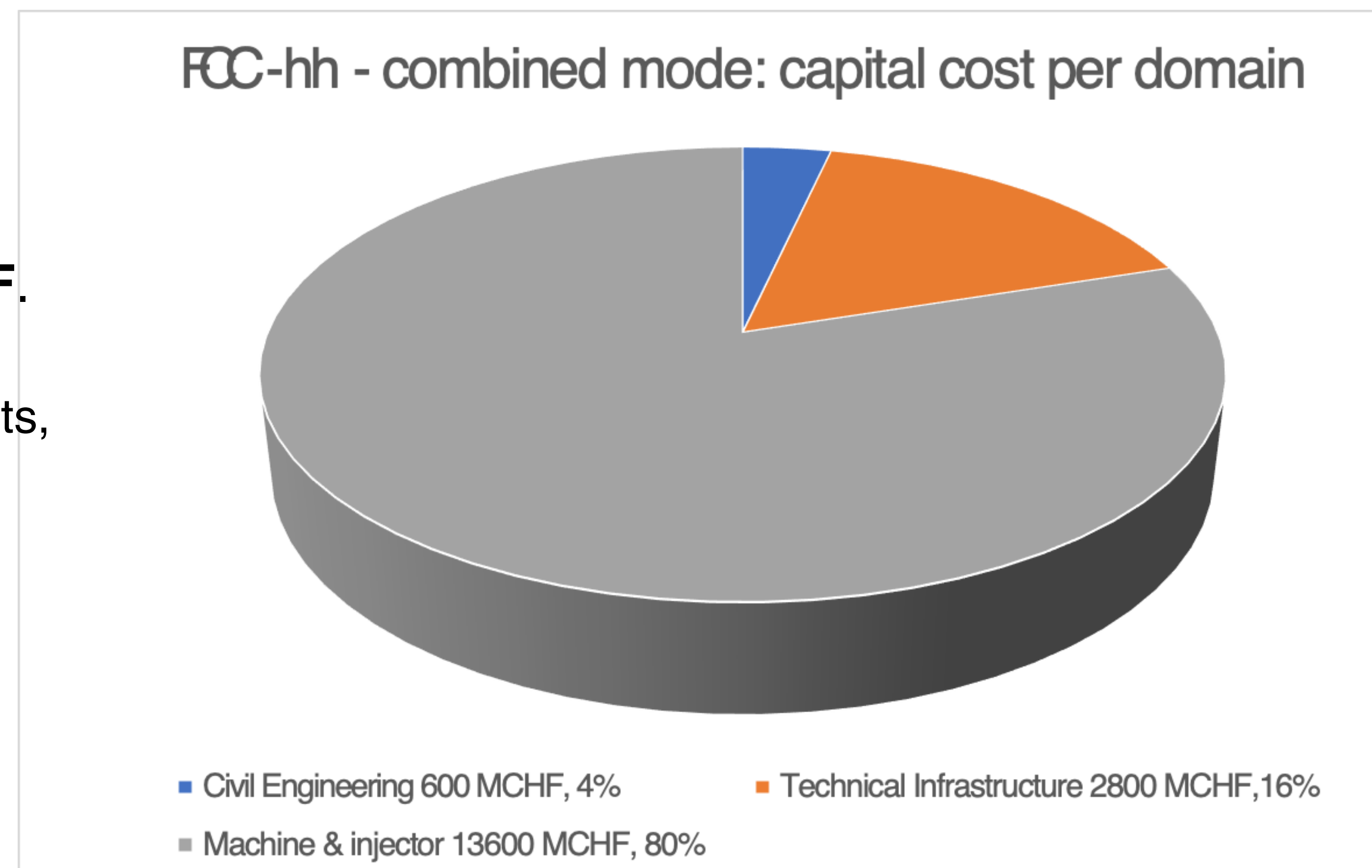


FCC Cost Estimate



Construction cost Phase 1 (FCC-ee) is 11.6 BCHF

- 5.4 BCHF for civil engineering (47%)
- 2.2 BCHF for technical infrastructure (19%)
- 4.0 BCHF accelerator and injector (34%)



Construction cost Phase 2 (FCC-hh) is 17.0 BCHF.

- 13.6 BCHF accelerator and injector (57%)
  - Major part for4,700 Nb_3Sn 16 T main dipole magnets, totalling 9.4 BCHF, targeting 2 MCHF/magnet.
- CE and TI from FCC-ee re-used
  - 0.6 BCHF for adaptation
- 2.8 BCHF for additional TI, driven by cryogenics

(Cost FCC-hh stand alone would be 24.0 BCHF.)

FCC Next Steps (2019-2020)

- Iterate on tunnel and surface structure layout and implementation plan with host states
- Optimize implementation of CE, machine designs, etc.
- Following Integral Project proposal, presently focus on FCC-ee as potential first step **(awaiting strategy recommendation)**.
  - Review and more detailed design for FCC-ee injector concept
  - Detailed design of technical infrastructure for FCC-ee

FCC Next Steps (2020-2026)

2020/21–2025/26 project preparation phase
(if supported by EPPSU and CERN Council)

- Project preparatory activities with host states
- Civil engineering site investigations and construction tender planning
- Technical design towards CDR++/TDR (Accelerators, technology, technical infrastructure)
- Development of financing and governance models for project and operation phases including international in-kind contributions (CERN Council and Directorate).

Working towards a level which allows definitive project decision by 2025/26 for all 4 activities

Concluding Remarks: FCC-ee

- FCC-ee is a Z, W, H, top (and NP) factory with exciting opportunities
- FCC-ee Higgs factory offers a unique dataset from 240 to 365 GeV
  - **Delivers model-independent precision measurements of all Higgs properties**
  - **Couplings including self-coupling, mass, CP, …**
  - **The floor is statistical**
- EW and Higgs observables probe the scales to up to 50 TeV
  - **Gain of 1-2 orders of magnitude in precision**
- Synergy and complementarity to hadron collider physics programs (HL-LHC, FCC-hh)
- The CDRs and this talk just scratch the surface of physics opportunities

Concluding Remarks: FCC

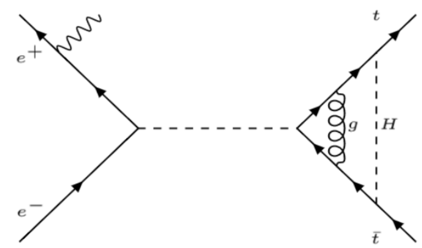
- **International FCC study** focused on the conceptual design of high-performance **energy frontier circular colliders for the post-LHC era**.
- The **first phase of FCC conceptual design studies is completed**.
- Baseline machine designs and associated infrastructures, with performance matching the physics requirements, were established and are documented in **4 CDRs**.
- **Conditional on European Strategy recommendations**, the next steps will develop a concrete implementation plan in collaboration with host states, accompanied by machine optimization, physics studies and technology R&D.

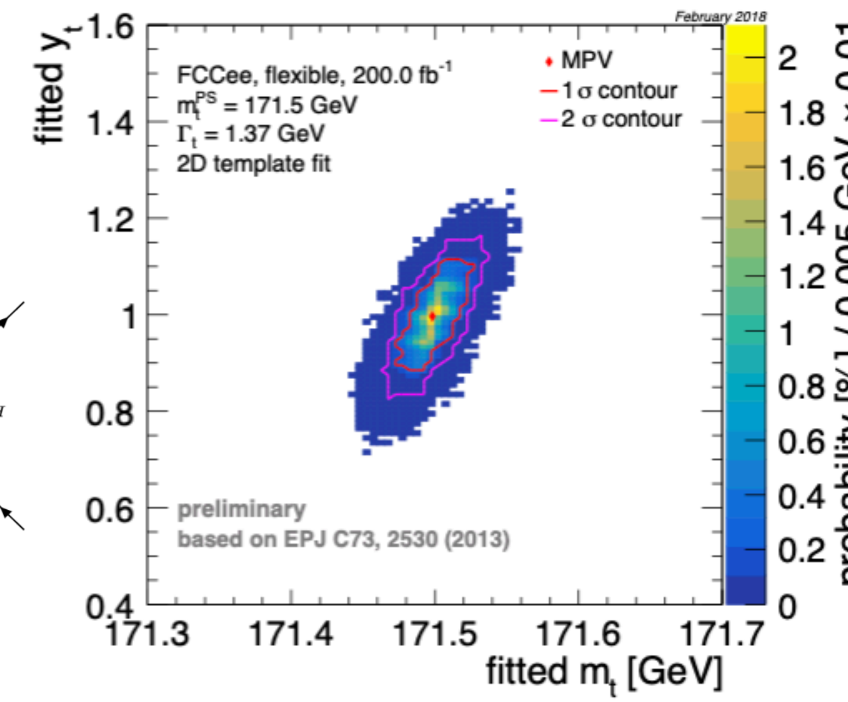
References

- ➡ 4 CDR volumes submitted to EPJ in December 2018
- ➡ Overview of the FCC studies by Michael Benedict. Talk during 2019 FCC week.
- ➡ First look at the physics case of TLEP
  - JHEP 1401 (2014) 164; > 500 citations
- ➡ FCC The Lepton Collider
  - Eur. Phys. JST (2019)
- ➡ FCC Physics Opportunities
  - Eur. Phys. J. C. (2019) 79:474
- ➡ FCC-ee: Your Questions Answered
  - arXiv:1906.02693

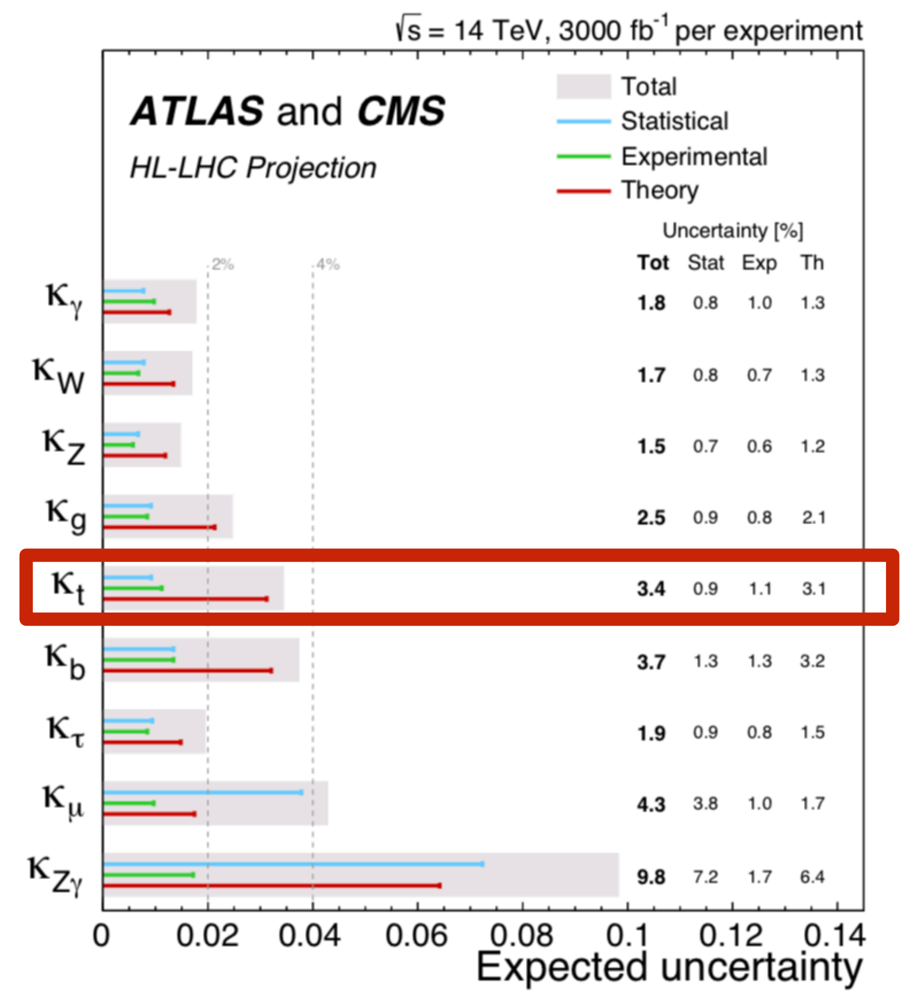
Top Yukawa Coupling

- ➡ **Top-pair threshold scan @350 GeV provides ~10% measurement through vertex correction**



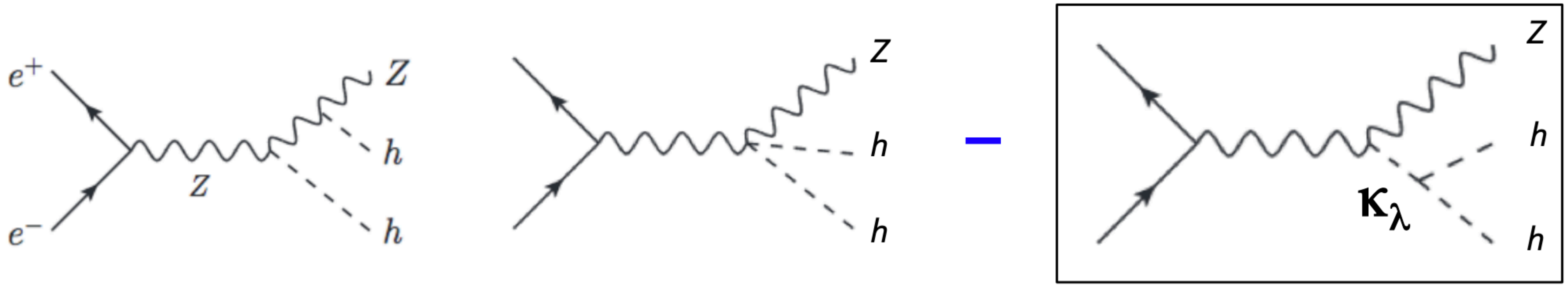


- ➡ **Much better measurement available at HL-LHC**
  - ◉ **Today's uncertainty on Y_t already at 10% level**
  - ◉ **3.4% expected with 3ab^{-1} per experiment**
- ➡ **FCC-ee breaks the model dependence with absolute coupling and width measurement**
  - ◉ **Absolute precision of 3.1% after 7y of operations**

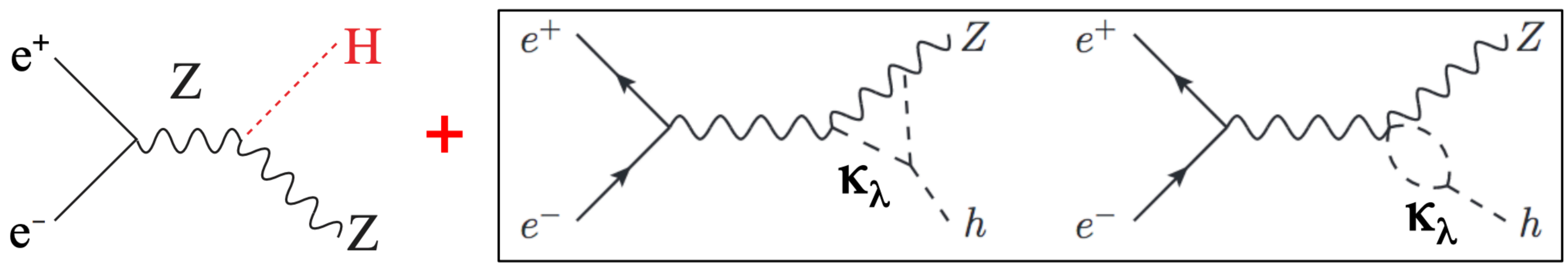


Higgs self-coupling

➡ **At √s > 500 GeV, k_λ is measured using double Higgs production**



➡ **At FCC-ee, due to precision single Higgs production can be exploited**

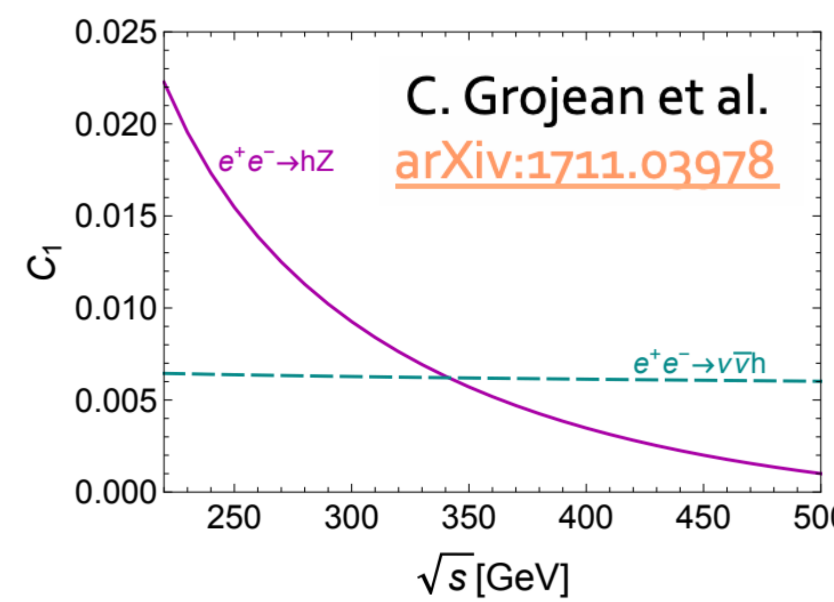


M. McCullough
arXiv:1312.3322

➡ **Effect is large wrt exp. precision**

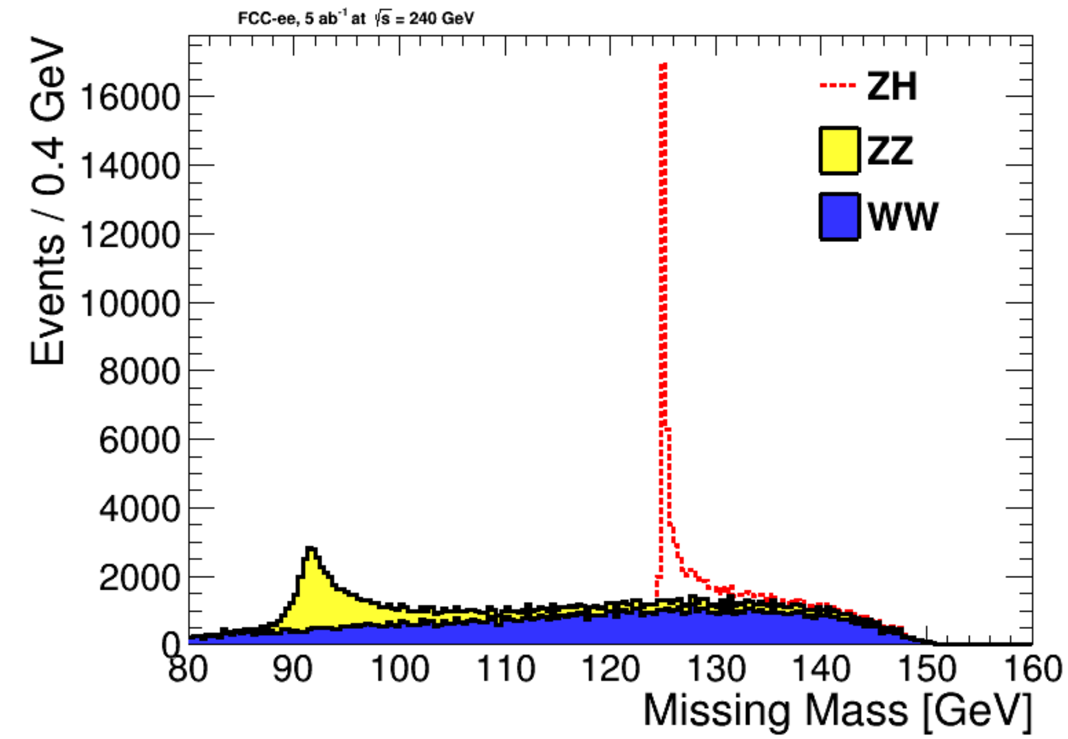
➡ **~12% precision on k_λ with 2IP**

- **Assuming other couplings are SM-like**



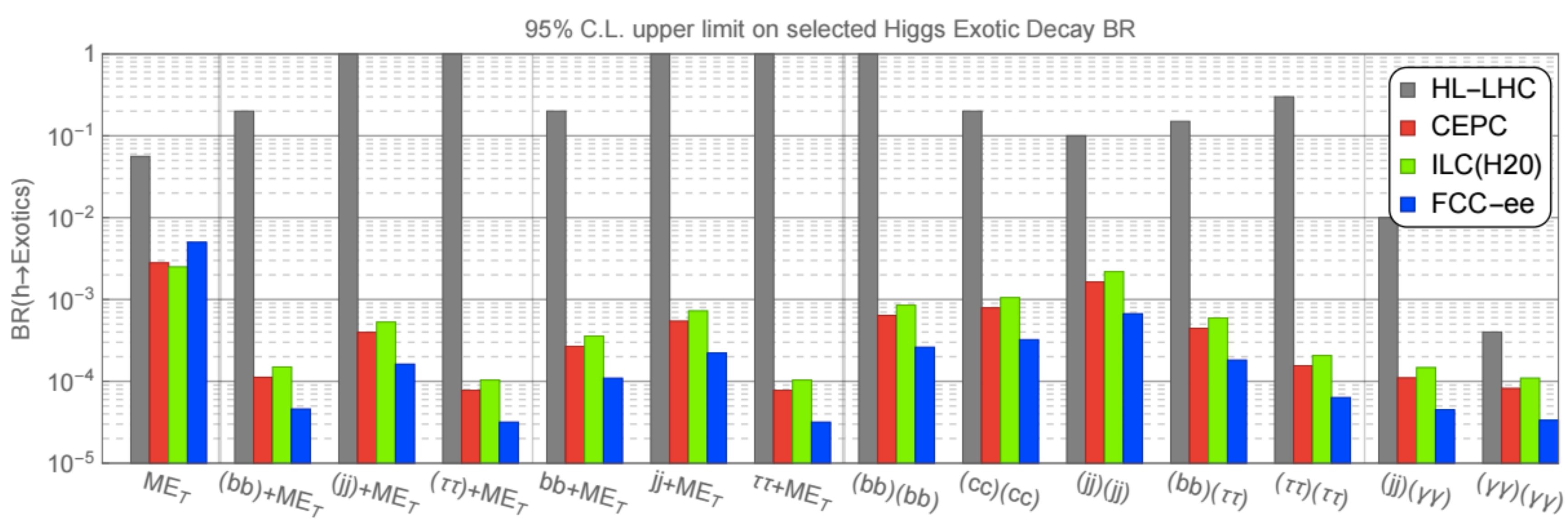
BSM Higgs Studies

- ➡ **Example: Higgs to invisible decays**
  - follows ZH cross section measurement
  - for visualization BR(H->inv) = 100%
  - 95%CL upper limit using 5ab^{-1} is 0.44%
  - study published using leptonic Z decays in Eur. Phys. J. C (2017) 77: 116
  - hadronic Z decays under study. Shows similar performance



- ➡ **Incredible opportunities for BSM Higgs searches**

arXiv:1612.09284

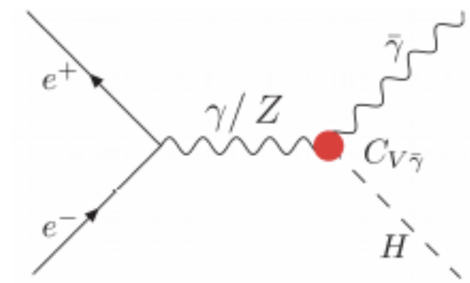


Dark Photon Searches via Higgs Production

Biswas, Gabrielli, Heikinheimo, Mele

JHEP 1506 (2015) 102 + arxiv:1703.00402

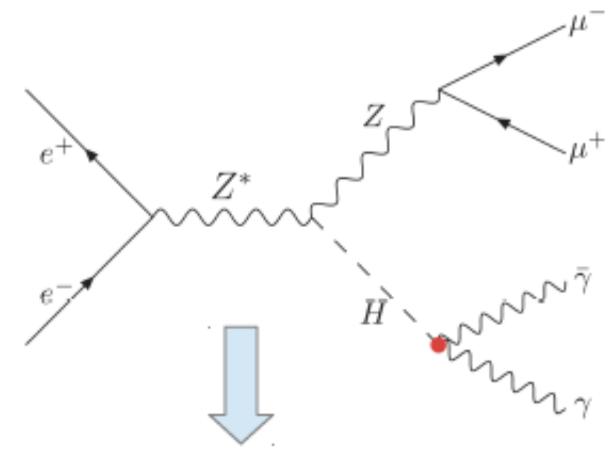
Phys.Rev. D96 (2017) no.5, 055012



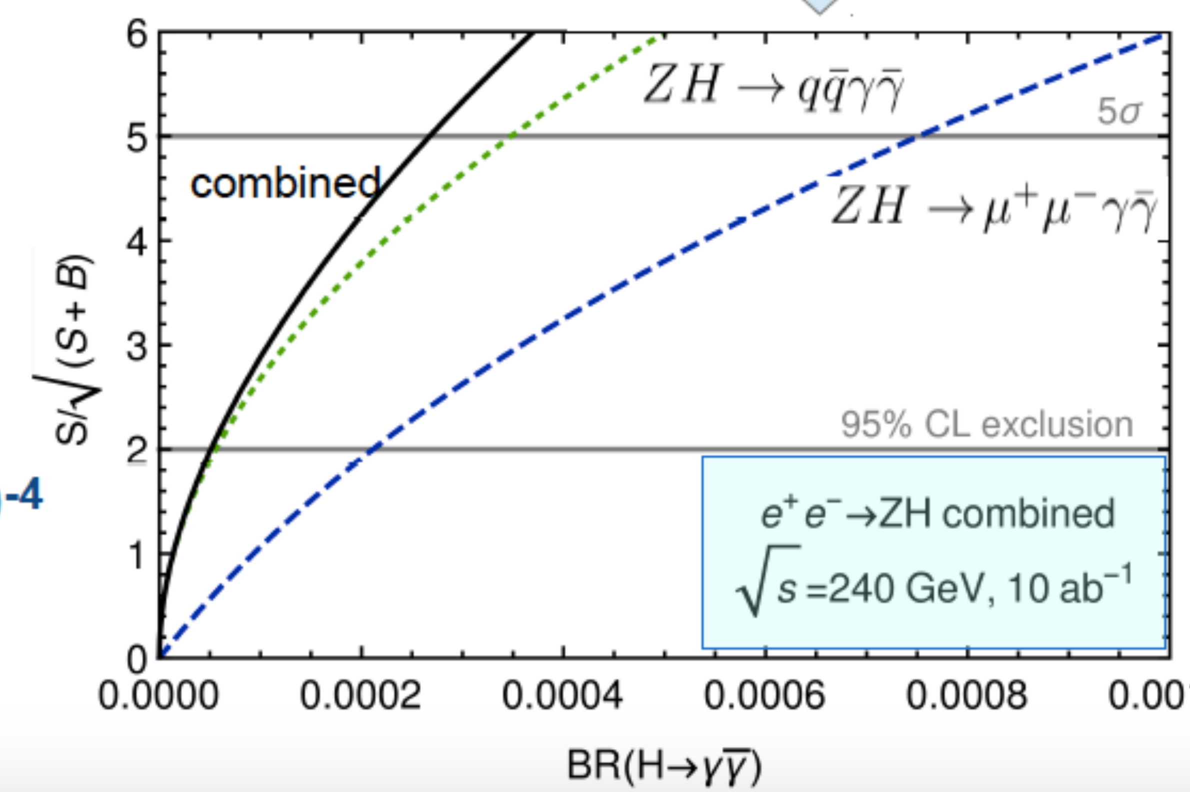
Massless Dark Photon $\bar{\gamma}$

$$e^+e^- \to H\bar{\gamma} \to b\bar{b}\bar{\gamma}$$

$$e^+e^- \to ZH \to (\mu^+\mu^-, q\bar{q})(\gamma\bar{\gamma})$$



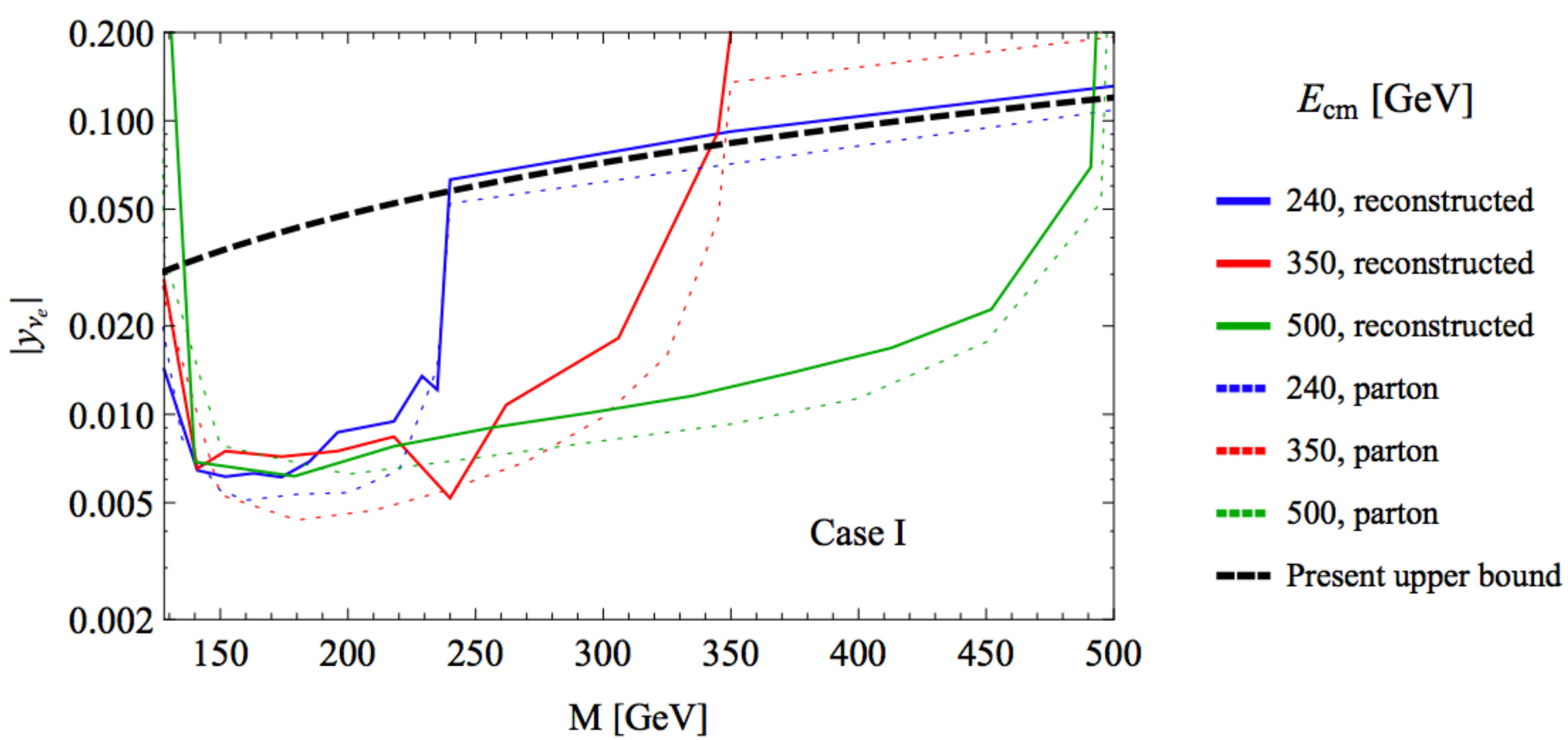
Large effects expected due to
→ Higgs non-decouplings
→ large U(1) couplings in dark sector

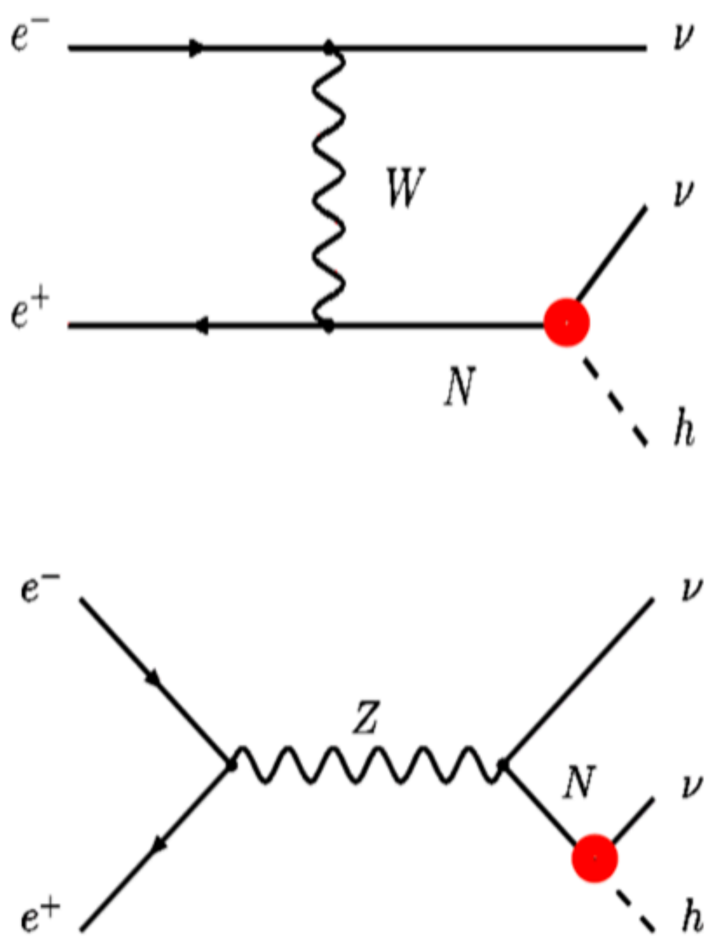


- **unexplored signatures !**
  massless invisible system
- **5 σ sensitivity for BR(H → $\gamma\bar{\gamma}$) ~ 3x10^{-4}**
- **3 times better than LHC @ 300 fb^{-1}**
  Biswas et al. PRD 93 (2016) 093011

Heavy Neutrinos

- ➡ **Low-mass seesaw scenario with 2 sterile neutrinos (N)**
- ➡ **Studied N decay to h+v in mono-Higgs plus missing energy signature**





- ➡ **FCC-ee with sensitivity to $|y_{\nu e}|$ ~ 5x10-3 for m_N ~ 100-300 GeV**

Lower Energy Hadron Collider

parameter	FCC-hh		FCC-hh-6T	HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		37.5	27	14	14
dipole field [T]	16		6	16	8.33	8.33
beam current [A]	0.5		0.6	1.1	1.1	0.58
synchr. rad. power/ring [kW]	2400		57	101	7.3	3.6
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	10 (lev.)	16	5 (lev.)	1
events/bunch crossing	170	1000	~300	460	132	27
stored energy/beam [GJ]	8.4		3.75	1.4	0.7	0.36

- **NbTi technology from LHC, magnet with single-layer coil providing 6 T at 1.9 K:**
  - Corresponding beam energy 18.75 TeV or 37.5 TeV c.m.
  - Significant reduction of synchrotron radiation wrt FCC-hh (factor 50) and corresponding cryogenic system requirements.
- **Luminosity goal 10 ab^{-1} over 20 years or 0.5 ab^{-1} annual luminosity:**
  - Beam current 0.6 A or 20% higher than for FCC-hh, 1.2E11 ppb (FCC-hh: 1.0 ppb).
  - Stored beam energy 3.75 GJ vs 8.4 GJ for FCC-hh.
- **Analysis of physics potential, technology requirements and cost ongoing.**

FCC Organization and Governance