The FCC Project
Future Circular Colliders

Albert De Roeck
CERN

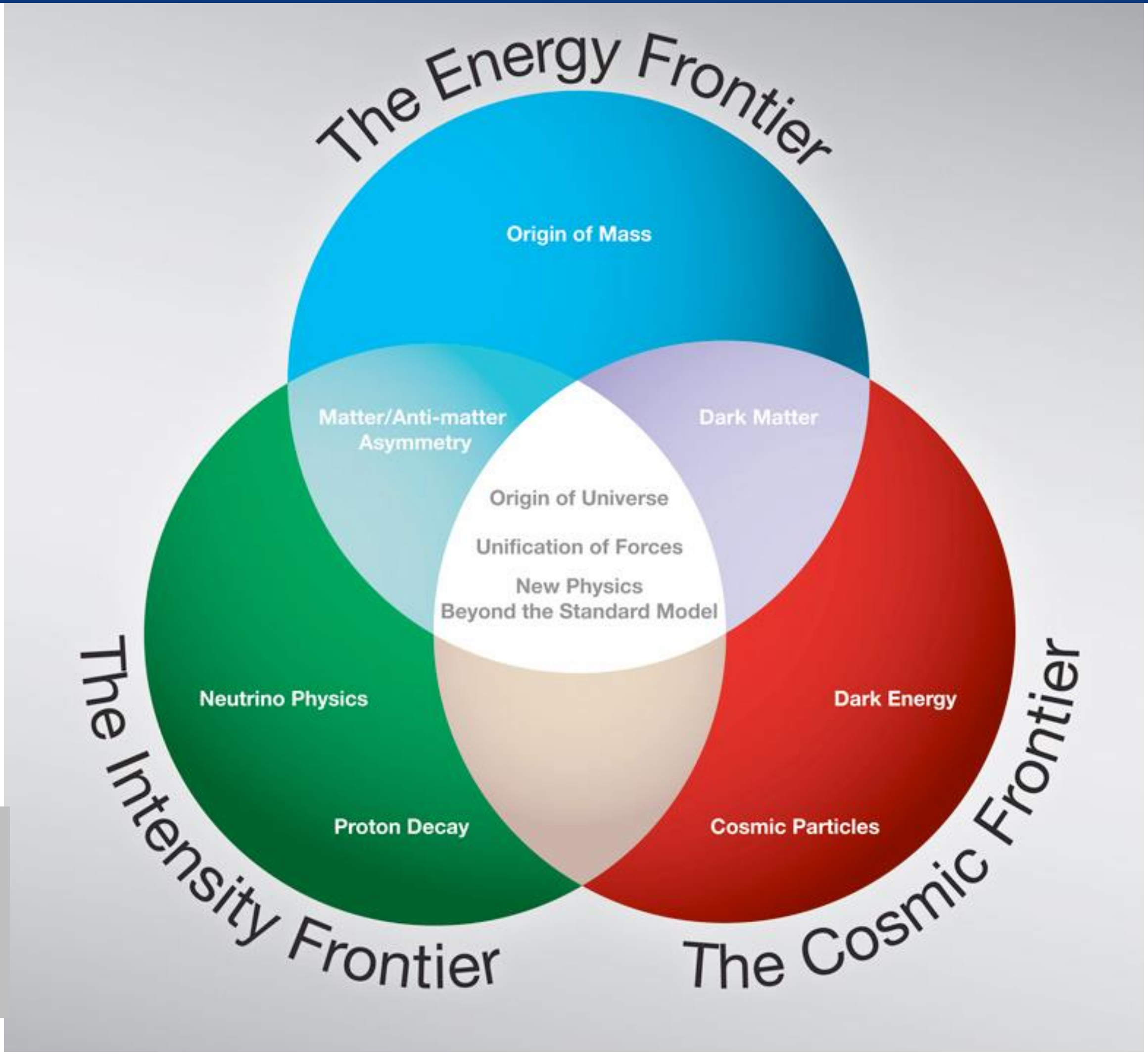
5 September 2018

Future HEP: The Three Frontiers

After the Higgs discovery

2012-2014

Evaluation in all regions: Europe Asia, the Americas



- European strategy group
- Snowmass study and IP5
- Japan strategy group

Will concentrate here on the Energy Frontier

=> The CERN Roadmap

F. Bodry , March 2015

The CERN Medium Term Plan approved by June'14 Council, implements the **European Strategy** including a long-term outlook.

The scientific programme is concentrated around four priorities:

1. **Full LHC exploitation** – the highest priority - including the construction of the High Luminosity Upgrade until 2025
2. **High Energy Frontier** – CERN's role and preparation for the next large scale facility
3. **Neutrino Platform** – allow for to contribute to a future long baseline facility in the US and for detector R&D for neutrino experiments
4. **Fixed-target programme** – maintain the diversity of the field and honour ongoing obligations by exploiting the unique facilities at CERN

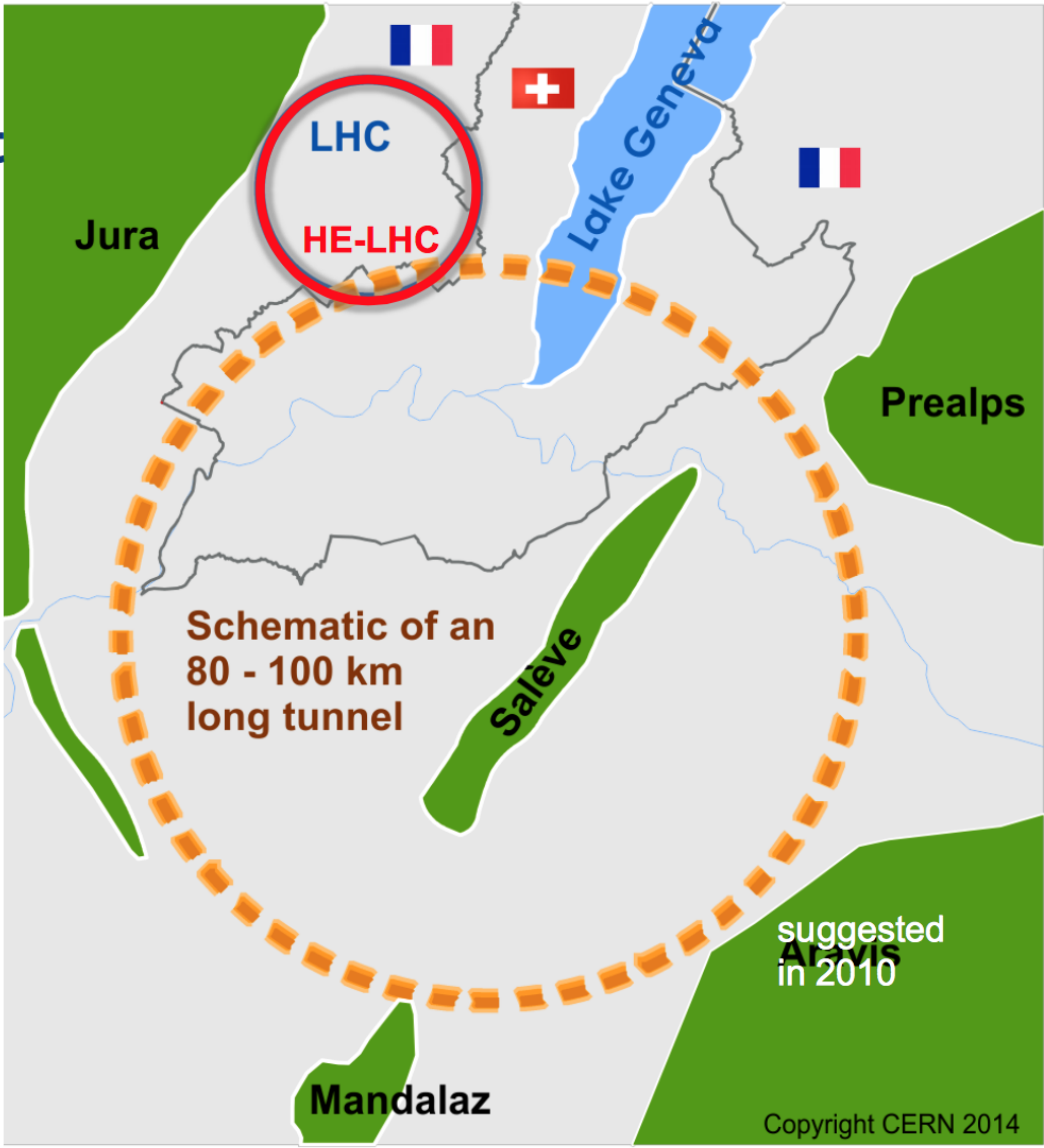
Future Circular Collider Study
Goal: CDR for European Strategy Update 2018/19

International FCC collaboration (CERN as host lab) to design:

- ***pp*-collider (*FCC-hh*)**
  → main emphasis, defining infrastructure requirements

~16 T $\Rightarrow$ 100 TeV *pp* in 100 km

- **80-100 km tunnel infrastructure** in Geneva area, site specific
- ***e^+e^-* collider (*FCC-ee*),** as a possible first step
- ***p-e* (*FCC-he*) option,** one IP, FCC-hh & ERL
- **HE-LHC** w *FCC-hh* technology



FCC General Yearly Meeting May 2017

FCC WEEK 2018

AMSTERDAM, 9-13 April 2018

also: 2018 FCC Physics Workshop, 15-19 January 2018, CERN

Slides from M. Benedikt, M. Mangano, W. Riegler, Y. Wang, F.Zimmerman, A Blondel

Call for input to the European Strategy update

by Matthew Chalmers

Conclusions in May 2020

The European Strategy for Particle Physics, which is due to be updated by May 2020, will guide the direction of the field to the mid-2020s and beyond. To inform this vital process, the secretariat of the European Strategy Group (ESG) is calling upon the particle-physics community across universities, laboratories and national institutes to submit written input by 18 December 2018.

Kick-off October 2018 (announcement CERN council web pages)
18 December 2018 for contributing reports

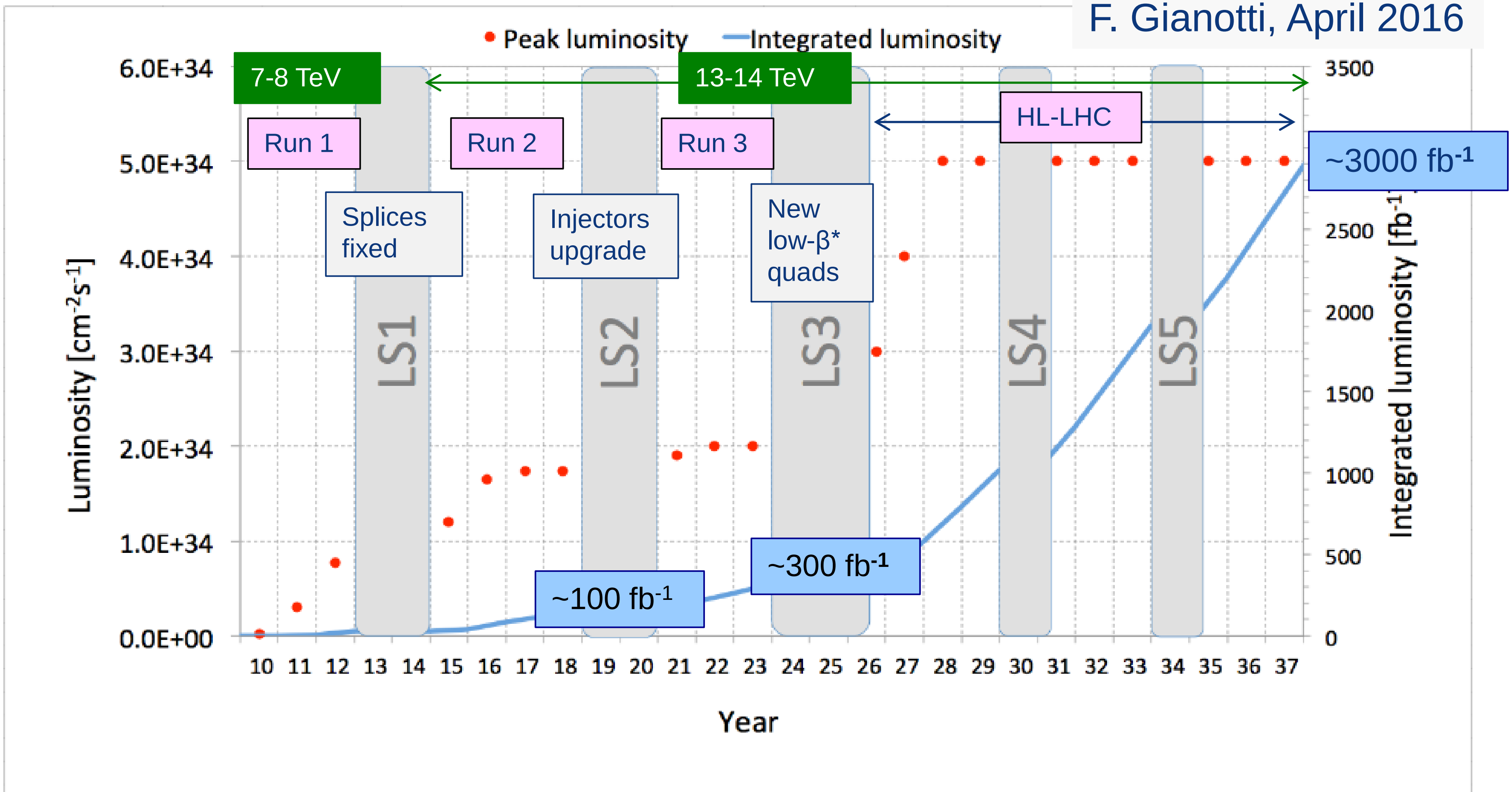
-Open symposium meeting: Granada, Spain, 13-16 May 2019
-Strategy drafting session: Bad Honnef Germany, 20-24 January 2020

Also a "Snowmass" meeting planned in the US in 2019

The LHC Upgrade

The LHC Approved LHC Roadmap

F. Gianotti, April 2016



Approved program at CERN to collect 3000 fb^{-1} with the LHC (HL-LHC)

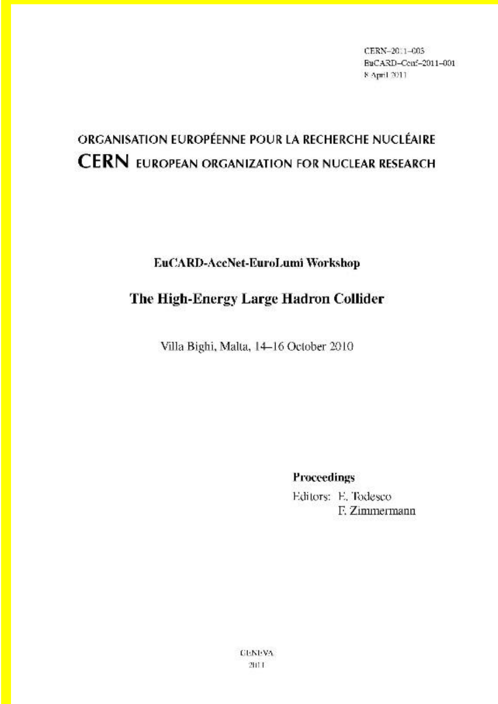
Maximize the reach for searches and for precision measurements (eg Higgs)

-> See Yannis talk Sunday

High-Energy LHC??

FCC study continues effort on **high-field collider in LHC tunnel**

2010 EuCARD Workshop Malta;
Yellow Report CERN-2011-1



CERN–2011–003
EuCARD–Conf–2011–001
8 April 2011

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

EuCARD-AccNet-EuroLumi Workshop

The High-Energy Large Hadron Collider

Villa Bighi, Malta, 14–16 October 2010

Proceedings
Editors: E. Todesco
F. Zimmermann

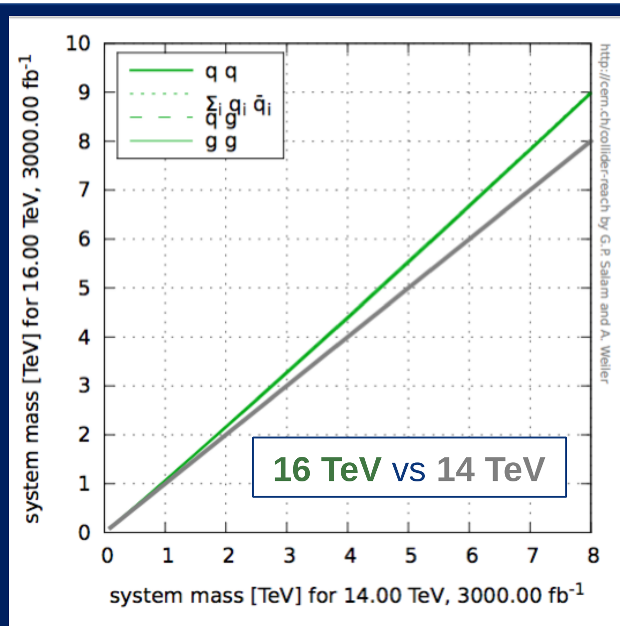
GENEVA
2011

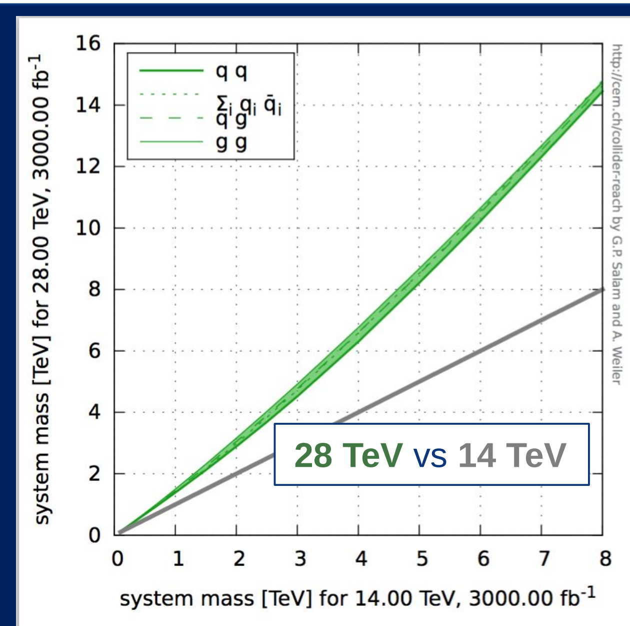
EuCARD-AccNet-EuroLumi Workshop: The High-Energy Large Hadron Collider - HE-LHC10, E. Todesco and F. Zimmermann (eds.), EuCARD-CON-2011-001; arXiv:1111.7188; CERN-2011-003 (2011)

- based on 16-T dipoles developed for FCC-hh
- extrapolation of other parts from the present (HL-)LHC and from FCC developments

CM Energy 25-28 TeV

High-Energy LHC





F. Gianotti
FCC meeting
Rome April 2016

Various options, with increasing amount of HW changes, technical challenges, cost, and physics reach

WG set up to explore technical feasibility of pushing LHC energy to:
1) design value: 14 TeV
2) ultimate value: 15 TeV (corresponding to max dipole field of 9 T)
3) beyond (e.g. by replacing 1/3 of dipoles with 11 T Nb_3Sn magnets)
→ Identify open risks, needed tests and technical developments, trade-off between energy and machine efficiency/availability

HE-LHC (part of FCC study): ~16 T magnets in LHC tunnel (→ √s~ 27 TeV)

- ❑ uses existing tunnel and infrastructure; can be built at fixed budget
- ❑ strong physics case if new physics from LHC/HL-LHC
- ❑ powerful demonstration of the FCC-hh magnet technology

Higgs physics at HE-LHC (27 TeV, 15 ab^{-1})

Primary goals in the Higgs sector:

(a) sensitivity to the Higgs self-coupling

(b) reduce to the few percent level all major Higgs couplings

(c) improve the sensitivity to possible invisible Higgs decays

(d) measure the charm Yukawa coupling

	$gg \to H$	WH	ZH	ttH	HH
N_{27}	2.2×10^8	5.4×10^7	3.7×10^7	4×10^7	2.1×10^6
N_{27}/N_{14}	13	12	13	23	19

$N_{27} = \sigma(27\ TeV) * 15\ ab^{-1}$

$N_{14} = \sigma(14\ TeV) * 3\ ab^{-1}$

- First results on Higgs selfcouplings measurement:

D. Gonçalves, T. Han, F. Kling, T. Plehn, and M. Takeuchi, *Higgs Pair Production at Future Hadron Colliders: From Kinematics to Dynamics*, arXiv:1802.04319 [hep-ph].

$\lambda/\lambda_{SM} = 1 \pm 0.3$ at 95%CL (1 ± 0.15 at 68%CL)

(compare to $-0.2 < \lambda/\lambda_{SM} < 2.6$ at HL-LHC)

F. Kling, T. Plehn, and P. Schichtel, *Maximizing the significance in Higgs boson pair analyses*, Phys. Rev. **D95** (2017) no. 3, 035026, arXiv:1607.07441 [hep-ph].

- For couplings like $H\gamma\gamma$, $HZ\gamma$, $H\mu\mu$, Htt, … , plan to repeat studies presented at 100 TeV

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

18-20 June 2018
CERN
Europe/Zurich timezone

Search...

Beyond the LHC

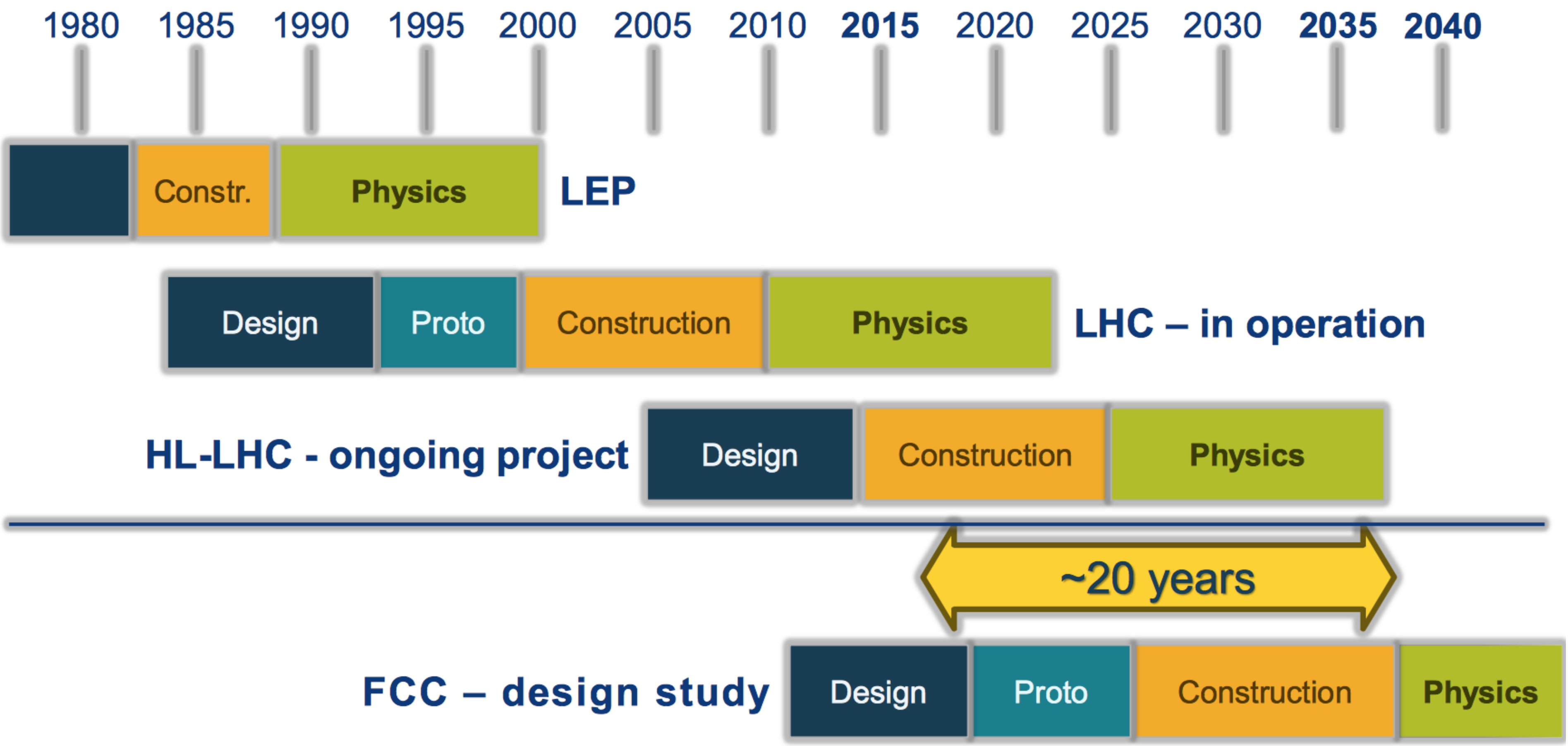
- Proton-proton machines at higher energy…

- Electron-positron machines for high precision…

- Both? And allowing for electron-proton collisions..?

New projects will take 10-20 years before they turn into operation, hence need a vision & studies now!

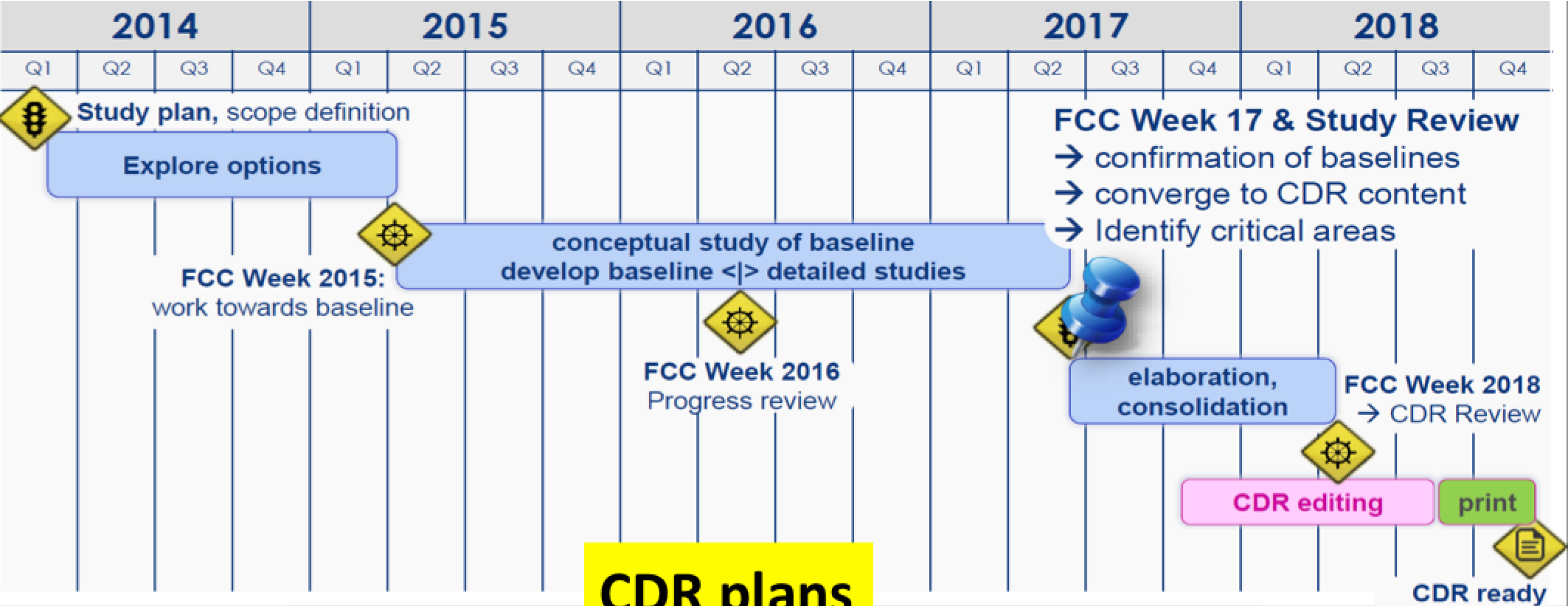
CERN Circular Colliders & FCC

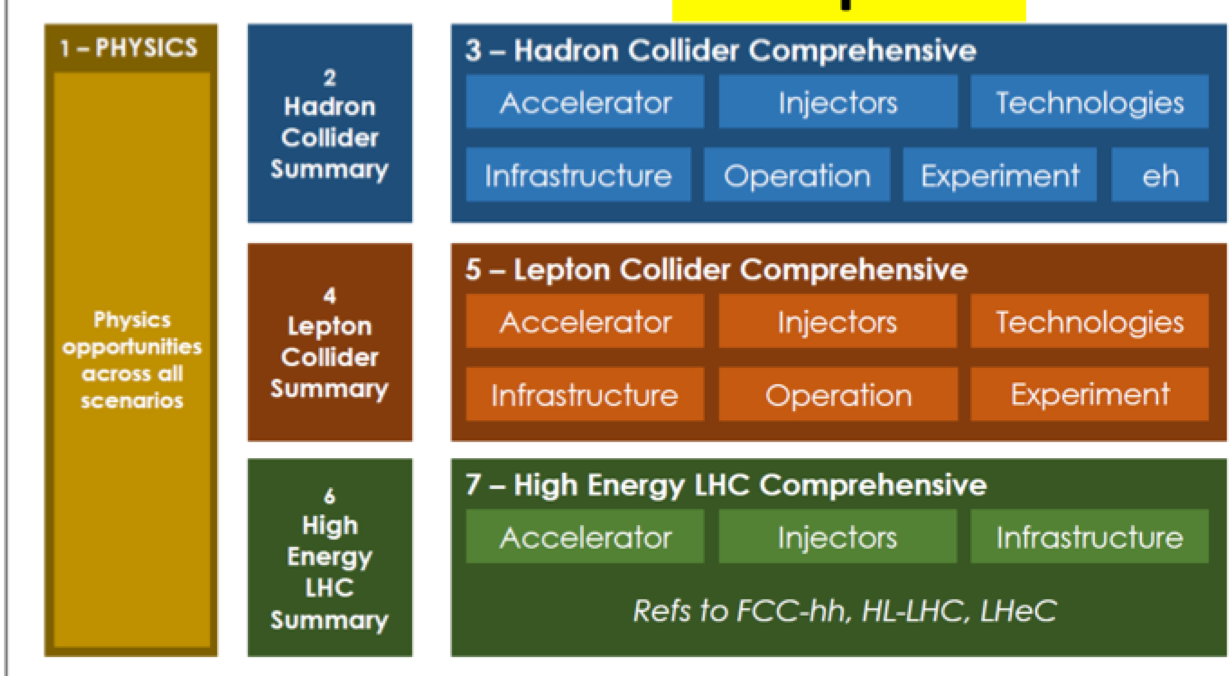


must advance fast now to be ready for the period 2035 – 2040

milestone: CDR by end 2018 for next update of European Strategy

CDR plans

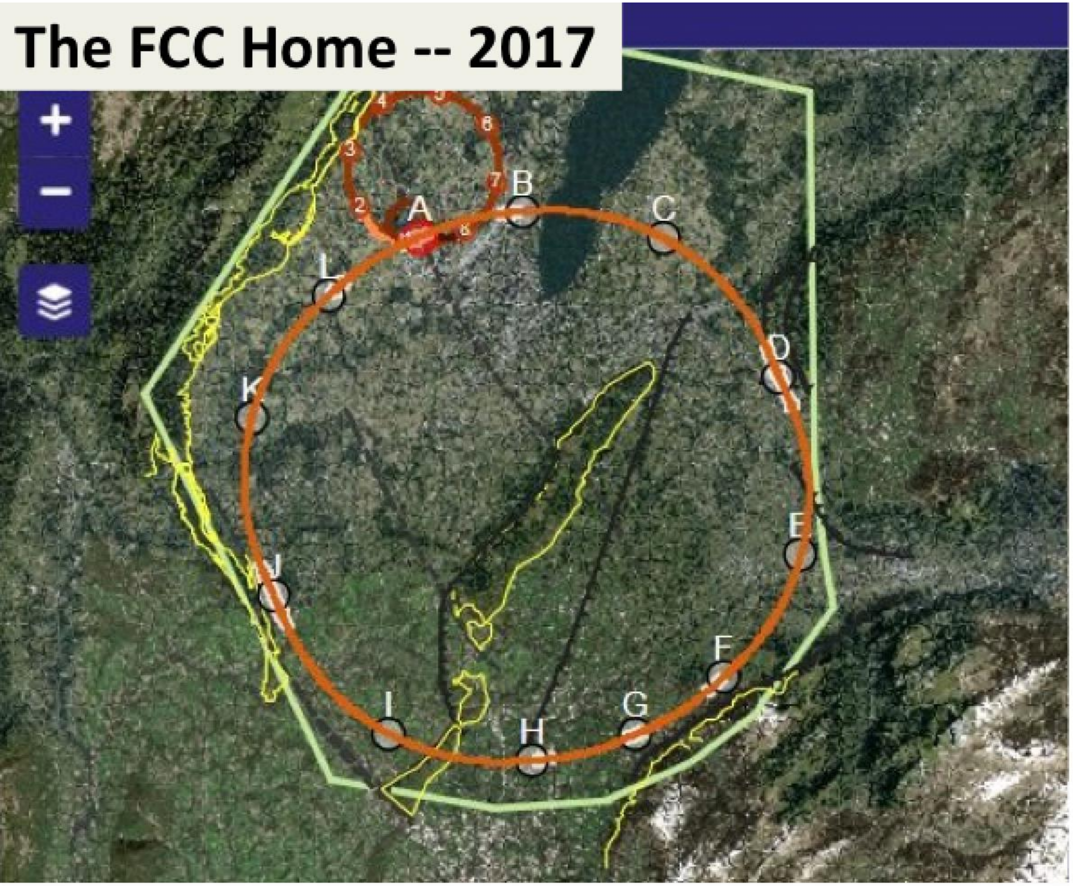




- **Required for end 2018, as input for European Strategy Update**
- **Common physics summary volume**
- **Three detailed volumes FCChh, FCCee, HE-LHC**

Note also the CDR of the CEPC (China) is expected to be released soon

The FCC Home -- 2017



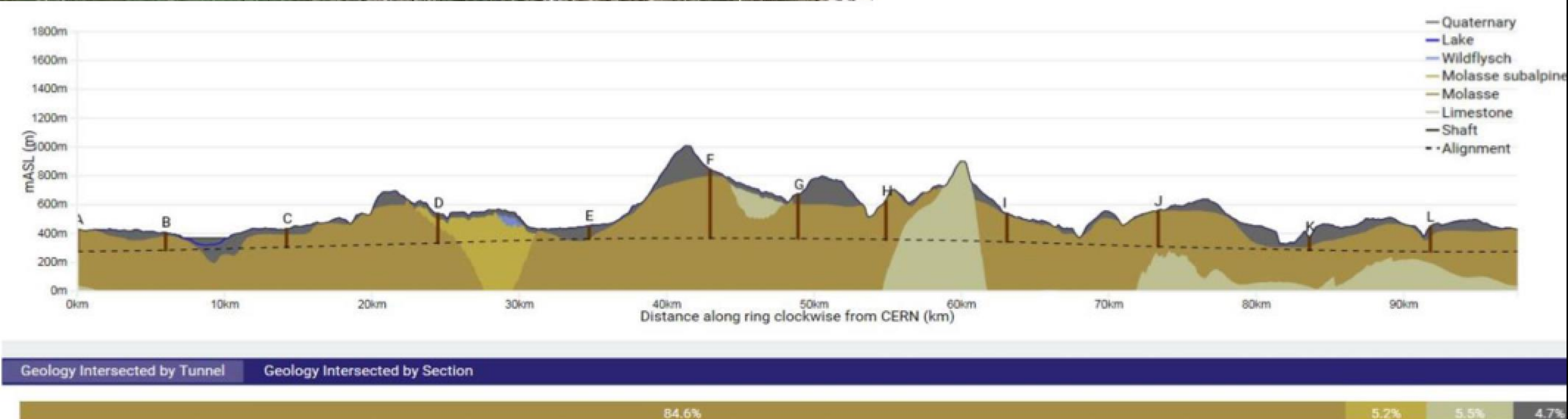
Optimisation in view of accessibility surface points, tunneling rock type, shaft depth, etc. optimum: **97.5 km**

Tunneling

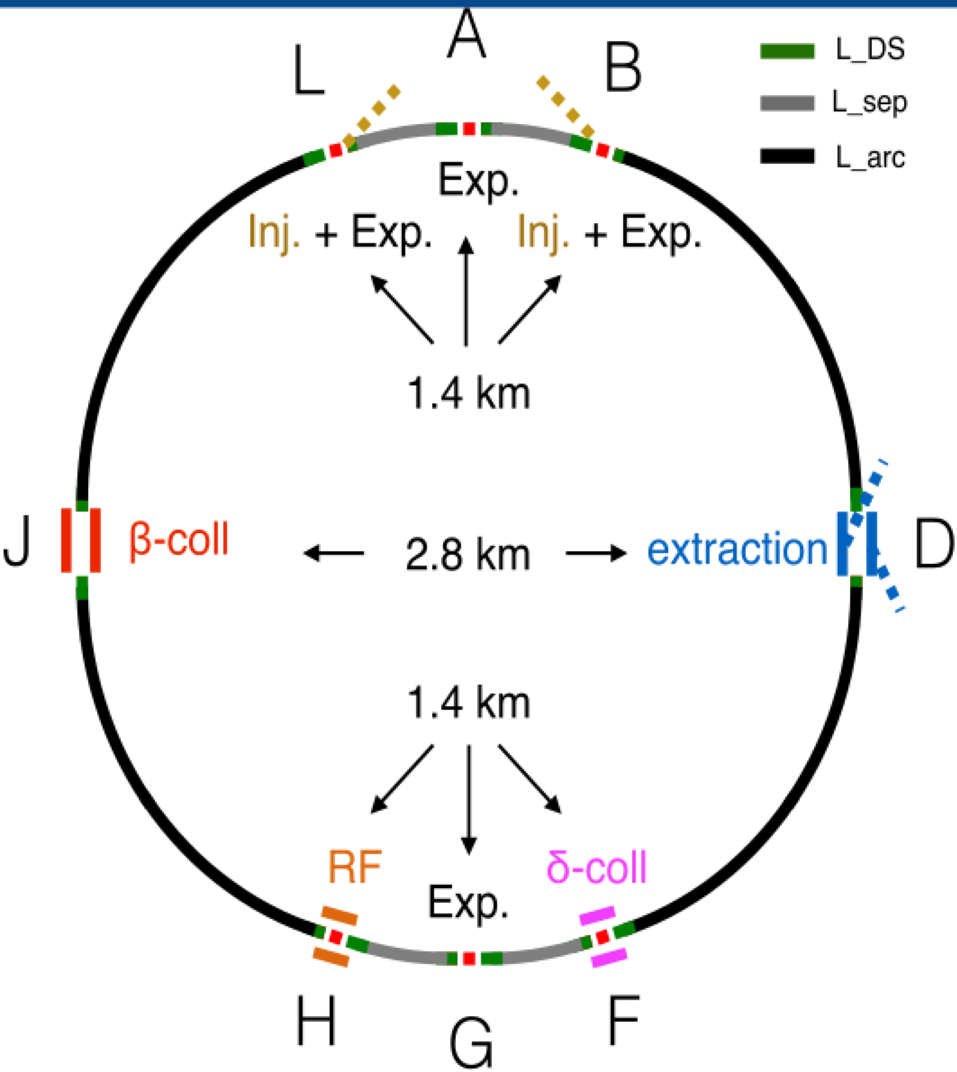
- Molasse 90% (good rock),
- Limestone 5%, Moraines 5% (tough)

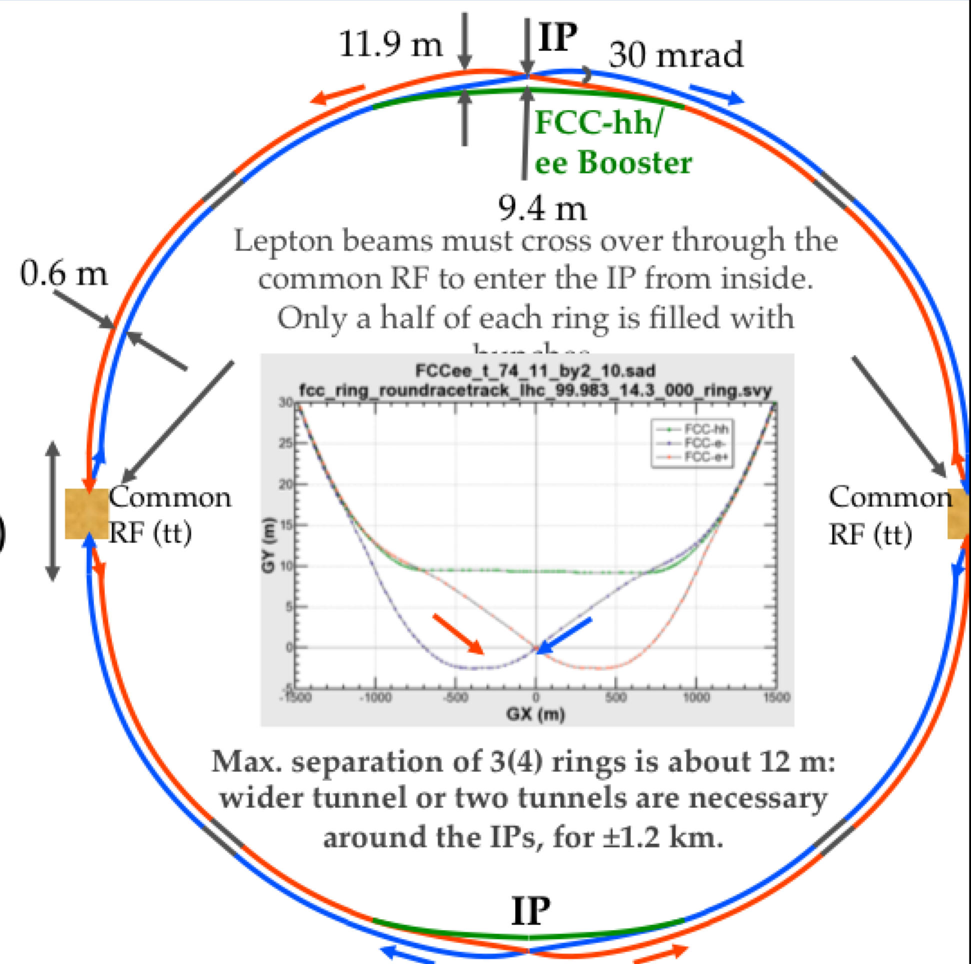
Shallow implementation

- ~ 30 m below Léman lakebed
- Reduction of shaft lengths etc...
- One very deep shaft **F** (476m) (RF or collimation), alternatives being studied, e.g. inclined access



common layouts for hh & ee





2 main IPs in A, G for both machines

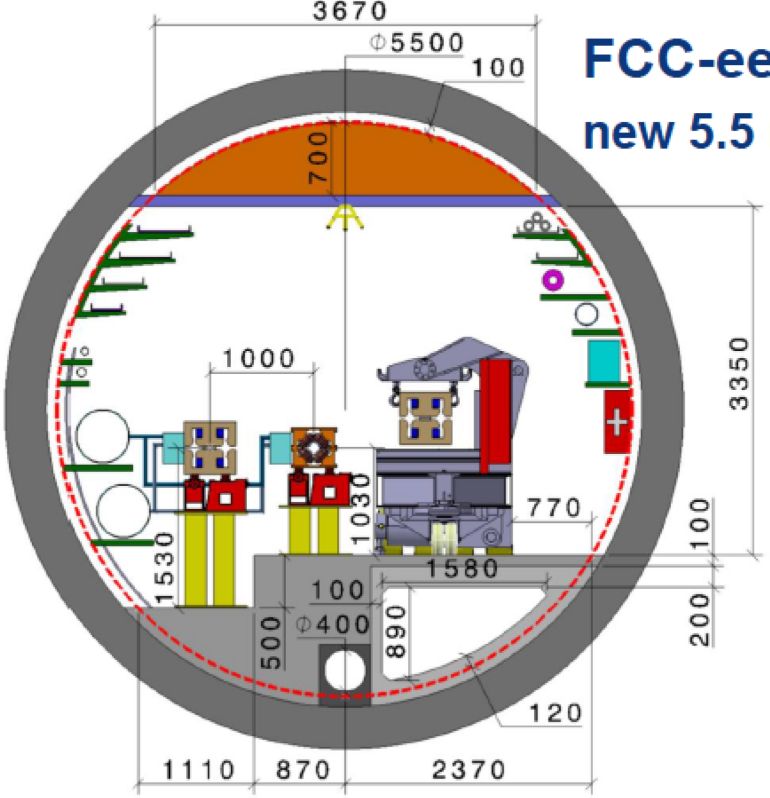
FCC-ee 1, FCC-ee 2,

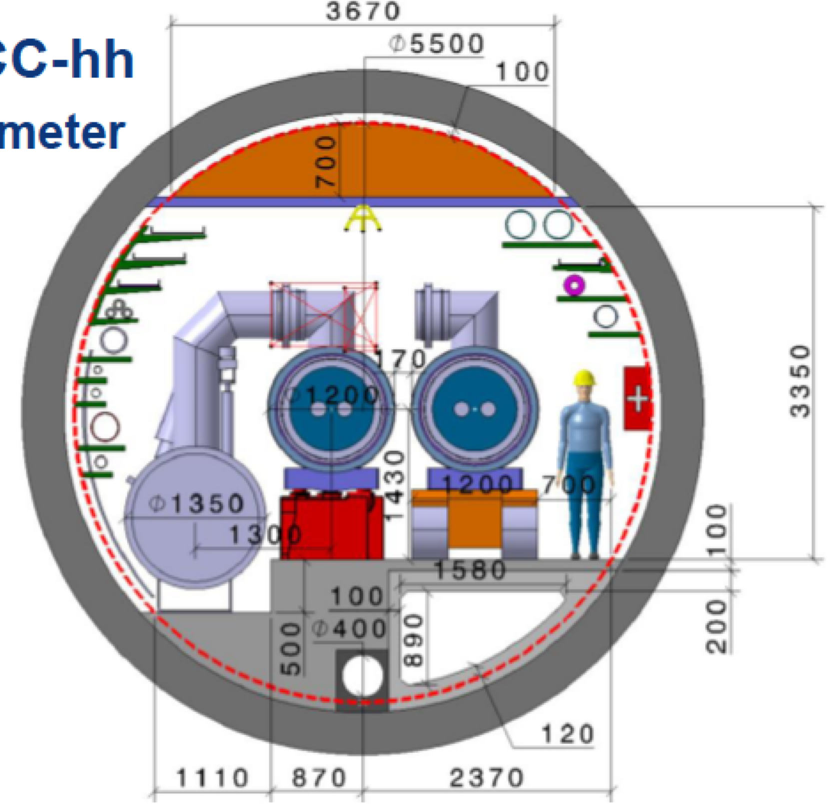
FCC-ee booster (FCC-hh footprint)

Asymmetric IR for ee, limits SR to expt

FCC-ee FCC-hh

new 5.5 m inner diameter





HE-LHC :

constraints:

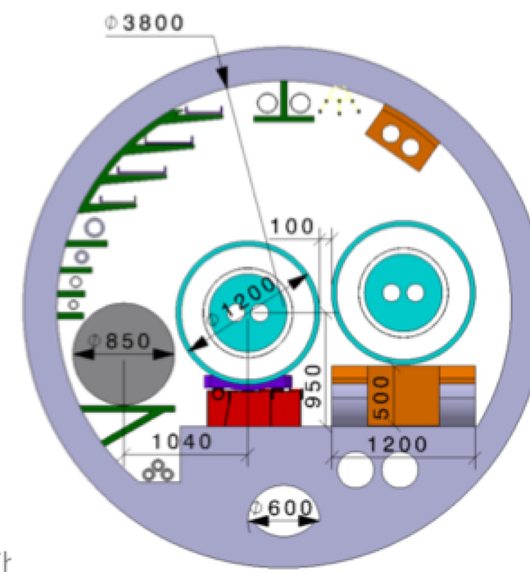
No civil engineering, same beam height as LHC

→ Magnets OD ca. 1200 m max

QRL (shorter than FCC) OD ca. 850 mm (all included)

Magnet suspended during „handover“
from transport vehicle to installation transfer table

Compliant 16T magnet design ongoing
+ still many items to study!

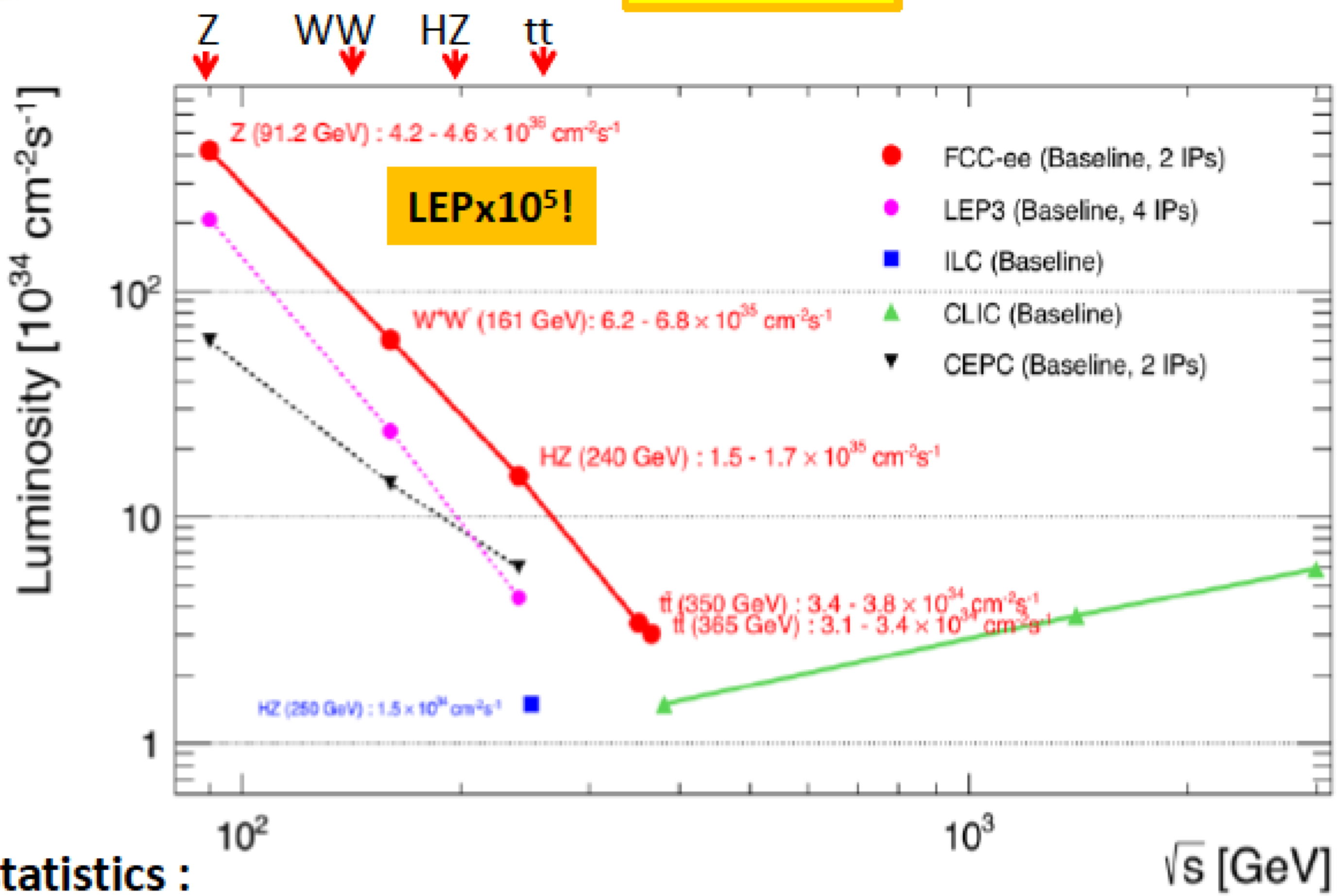


If HE-LHC can work in 3.8m ∅ ... it will feed-back to FCC tunnel design!

FCC-ee collider parameters

parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10^{11}]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	>200	>25	>7	>1.4
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

FCC-ee



Event statistics :

E_{CM} errors:

Z peak	E_{cm} : 91 GeV	$5\ 10^{12}$ e+e- → Z	LEP x 10^5	100 keV
WW threshold	E_{cm} : 161 GeV	10^8 e+e- → WW	LEP x 2.10^3	300 keV
ZH threshold	E_{cm} : 240 GeV	10^6 e+e- → ZH	Never done	1 MeV
$t\bar{t}$ threshold	E_{cm} : 350 GeV	10^6 e+e- → $t\bar{t}$	Never done	2 MeV

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

FCC-ee discovery potential

Today we do not know how nature will surprise us. A few things that FCC-ee could discover :

EXPLORE 10-100 TeV energy scale (and beyond) with Precision Measurements

-- ~20-50 fold improved precision on many EW quantities (equiv. to factor 5-7 in mass)
$m_{Z,}$ m_W, m_{top} , $\sin^2\theta_w^{eff}$, R_b , $\alpha_{QED}(m_z)$ $\alpha_s(m_z\, m_W\, m_\tau)$, Higgs and top quark couplings

DISCOVER a violation of flavour conservation or universality and unitarity of PMNS @10^{-5}
-- ex FCNC (Z --> $\mu\tau$, $e\tau$) in 5 10^{12} Z decays and τ BR in 2 10^{11} Z→ $\tau\,\tau$
+ flavour physics (10^{12} bb events) (B→s $\tau\,\tau$ etc..)

DISCOVER dark matter as «invisible decay» of H or Z (or in LHC loopholes)

DISCOVER very weakly coupled particle in 5-100 GeV energy scale
such as: Right-Handed neutrinos, Dark Photons etc…

+ an enormous amount of clean, unambiguous work on QCD (H→ gg) etc….

NB Not only a «Higgs Factory», «Z factory» and «top» are important for 'discovery potential'

“First Look at the Physics Case of TLEP”, JHEP 1401 (2014) 164

FCC-ee Detectors

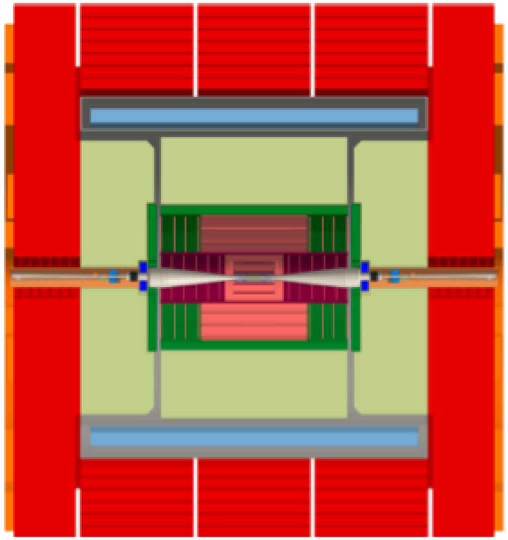
A. Blondel LP17

Two integration, performance and cost estimates ongoing:

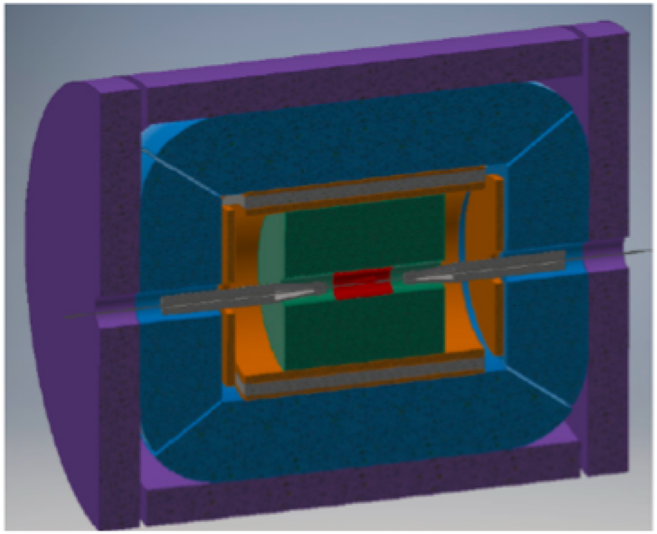
-- Linear Collider Detector group at CERN has undertaken the adaption of CLIC-SID detector for FCC-ee

-- new IDEA, detector specifically designed for FCC-ee (and CEPC)

"CLIC-detector revisited"



"IDEA"



- Vertex detector: ALICE MAPS
- Tracking: MEG2
- Si Preshower
- Ultra-thin solenoid (2T)
- Calorimeter: DREAM
- Equipped return yoke

Higgs

Precision Higgs physics is crucial, lepton colliders (at threshold) usually the best probe

Result of the coupling (a.k.a. κ) fit

- Comparison(*) with other lepton colliders at the EW scale (up to 380 GeV)

13	μColl$_{125}$	ILC$_{250}$	CLIC$_{380}$	LEP3$_{240}$	CEPC$_{250}$	FCC-ee$_{240}$	FCC-ee$_{365}$
Years	6	15	5	6	7	3	+4
Lumi (ab^{-1})	0.005	2	0.5	3	5	5	+1.5
δm_H (MeV)	0.1	t.b.a.	110	10	5	7	6
$\delta\Gamma_H / \Gamma_H$(%)	6.1	3.8	6.3	3.7	2.6	2.8	1.6
$\delta g_{Hb} / g_{Hb}$ (%)	3.8	1.8	2.8	1.8	1.3	1.4	0.70
$\delta g_{HW} / g_{HW}$ (%)	3.9	1.7	1.3	1.7	1.2	1.3	0.47
$\delta g_{H\tau} / g_{H\tau}$(%)	6.2	1.9	4.2	1.9	1.4	1.4	0.82
$\delta g_{H\gamma} / g_{H\gamma}$ (%)	n.a.	6.4	n.a.	6.1	4.7	4.7	4.2
$\delta g_{H\mu} / g_{H\mu}$ (%)	3.6	13	n.a.	12	6.2	9.6	8.6
$\delta g_{HZ} / g_{HZ}$ (%)	n.a.	0.35	0.80	0.32	0.25	0.25	0.22
$\delta g_{Hc} / g_{Hc}$ (%)	n.a.	2.3	6.8	2.3	1.8	1.8	1.2
$\delta g_{Hg} / g_{Hg}$ (%)	n.a.	2.2	3.8	2.1	1.4	1.7	1.0
Br$_{invis}$ (%)$_{95\%CL}$	SM	<0.3	<0.6	<0.5	<0.15	<0.3	<0.25
BR$_{EXO}$ (%)$_{95\%CL}$	-	<1.8	<3.0	<1.6	<1.2	<1.2	<1.1

Patrick Janot

Higgs properties @ Circular Lepton Colliders
1 June 2018

(*) Green = best
Red = worst

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FCC-ee: Need for Precise Theory

Theoretical limitations

FCC-ee

SM predictions (using other input)

$M_W = 80.3593 \pm$ 0.0002 $\pm$ 0.0001 $\pm$ 0.0003

0.0005 $\pm$ 0.0001 $\pm$ 0.0000 $M_H \pm 0.0040_{\text{theo}}$

$\sin^2\theta^{\ell}_{\text{eff}} = 0.231496 \pm$ 0.0000015 $\pm$ 0.000001 $\pm$ 0.000006

0.000006 $\pm$ 0.0000014 $\pm$ 0.000000 $\pm 0.000047_{\text{theo}}$

Experimental errors at FCC-ee will be 20-100 times smaller than the present errors.

BUT can be typically 10 -30 times smaller than present level of theory errors

<u>Will require significant theoretical effort and additional measurements!</u>

the above explains why we want the top running – and high Z statistics.

Freitas, Heinemeyer, Jadach, Gluza … need for 3 loop calculations for the future!

<u>Suggest including manpower for theoretical calculations in the project cost.</u>

FCC-ee operation model

working point	luminosity/IP [10^{34} cm^{-2}s^{-1}]	total luminosity (2 IPs)/ yr	physics goal	run time [years]
Z first 2 years	100	26 ab^{-1}/year	**150 ab^{-1}**	**4**
Z later	200	52 ab^{-1}/year		
W	25	7 ab^{-1}/year	**10 ab^{-1}**	**1**
H	7.0	1.8 ab^{-1}/year	**5 ab^{-1}**	**3**
machine modification for RF installation & rearrangement: **1 year**				
top 1st year (350 GeV)	0.8	0.2 ab^{-1}/year	**0.2 ab^{-1}**	**1**
top later (365 GeV)	1.4	0.36 ab^{-1}/year	**1.5 ab^{-1}**	**4**

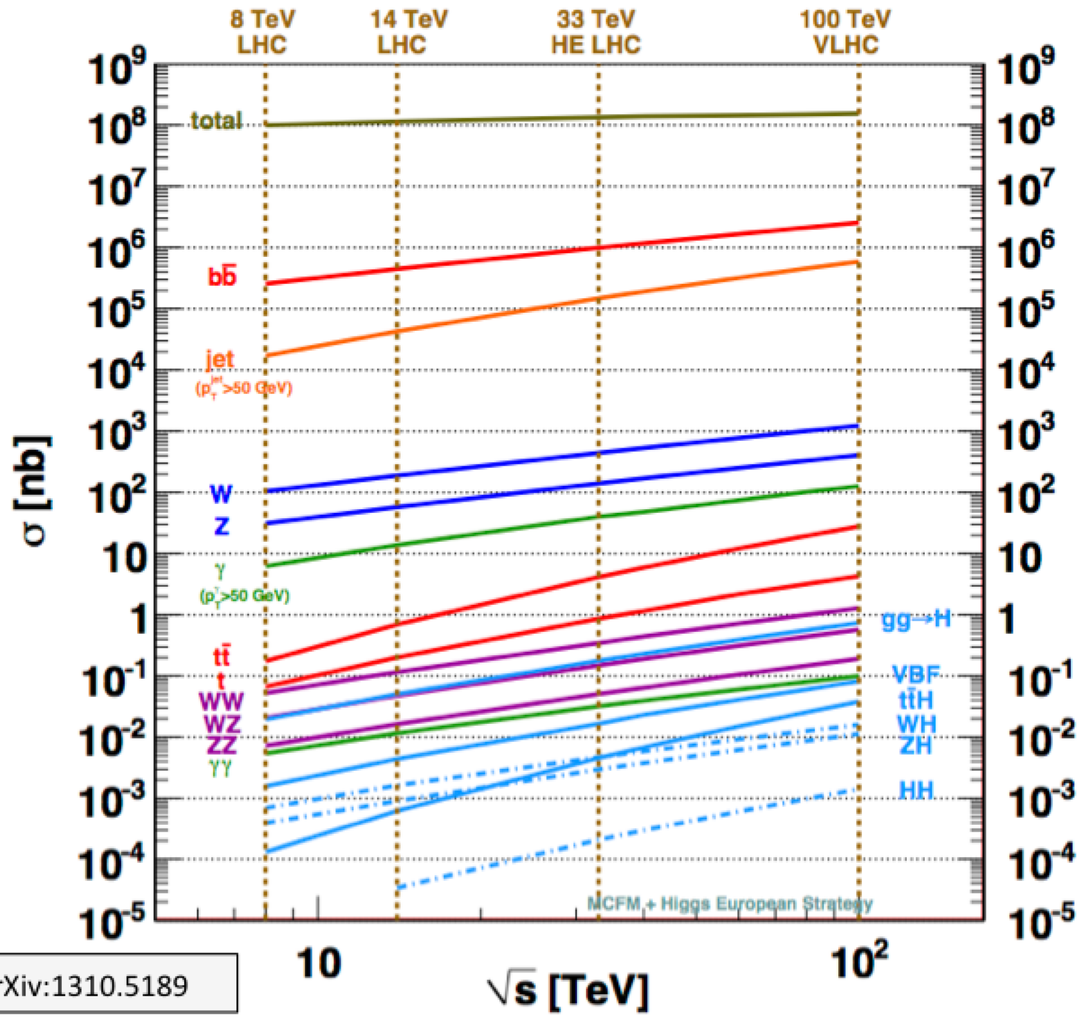
total program duration: 14 years - ***including machine modifications***

phase 1 (*Z*, *W*, *H*): 8 years, **phase 2 (top): 6 years**

FCC-pp collider parameters

parameter	FCC-hh		HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		27	14	14
dipole field [T]	16		16	8.33	8.33
circumference [km]	97.75		26.7	26.7	26.7
beam current [A]	0.5		1.1	1.1	0.58
bunch intensity [10^{11}]	1	1	2.2	2.2	1.15
bunch spacing [ns]	25	25	25	25	25
synchr. rad. power / ring [kW]	2400		101	7.3	3.6
SR power / length [W/m/ap.]	28.4		4.6	0.33	0.17
long. emit. damping time [h]	0.54		1.8	12.9	12.9
beta* [m]	1.1	0.3	0.25	0.15 (min.)	0.55
normalized emittance [μm]	2.2		2.5	2.5	3.75
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	28	5 (lev.)	1
events/bunch crossing	170	1000	800	132	27
stored energy/beam [GJ]	8.4		1.3	0.7	0.36

Hadron colliders: direct exploration of the "energy frontier"



arXiv:1310.5189

Gianotti

Process	σ (100 TeV)/σ (14 TeV)
Total pp	1.25
W	~7
Z	~7
WW	~10
ZZ	~10
tt	~30
H	~15 (ttH ~60)
HH	~40
stop (m=1 TeV)	$\sim 10^3$

With 40/ab at √s=100 TeV expect: $\sim 10^{12}$ top, 10^{10} H bosons, 10^5 m=8 TeV gluino pairs, …

If new (heavy) physics discovered at the LHC → completion of spectrum is a "no-lose" argument for future ~ 100 TeV pp collider: extend discovery potential up to m~50 TeV

FCC-hh discovery potential
Highlights

FCC-hh is a HUGE discovery machine (if nature ...), but not only.

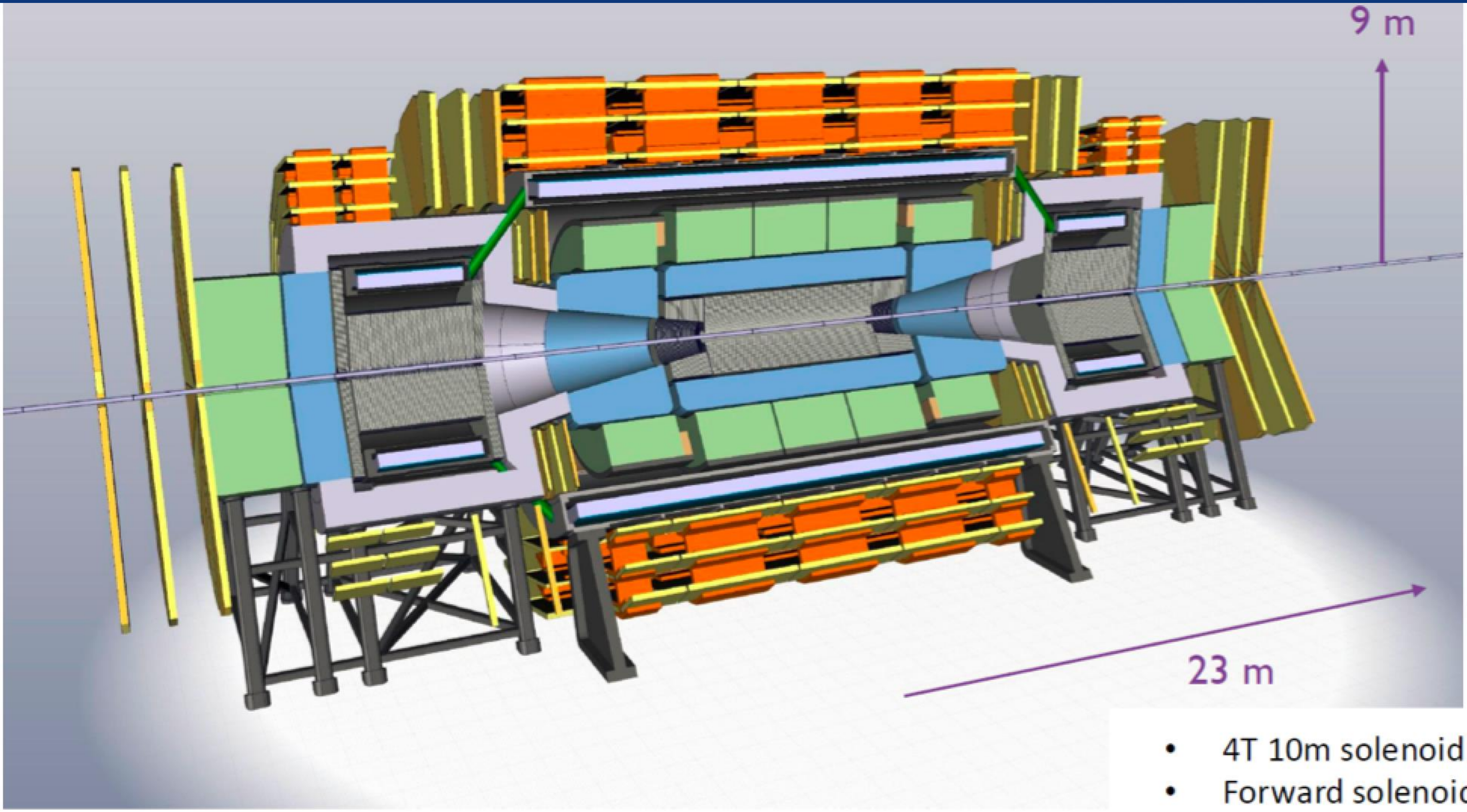
FCC-hh physics is dominated by three features:

-- Highest center of mass energy –> a big step in high mass reach!
ex: strongly coupled new particle up to >30 TeV
Excited quarks, Z', W', up to ~tens of TeV
Give the final word on natural Supersymmetry, extra Higgs etc.. reach up to 5-20 TeV
Sensitivity to high energy phenomena in e.g. WW scattering

-- HUGE production rates for single and multiple production of SM bosons (H,W,Z) and quarks
- -- Higgs precision tests using ratios to e.g. $\gamma\gamma/\mu\mu/\tau\tau/ZZ$, ttH/ttZ @<% level
- -- Precise determination of triple Higgs coupling (~3% level) and quartic Higgs coupling
- -- detection of rare decays H→ Vγ (V= ρ,φ,J/ψ,ϒ,Z...)
- -- search for invisibles (DM searches, RH neutrinos in W decays)
- -- renewed interest for long lived (very weakly coupled) particles.
- -- rich top and HF physics program

-- Cleaner signals for high Pt physics
-- allows clean signals for channels presently difficult at LHC (e.g. H→ bb)

FCC-hh Reference Detector 2017



- 4T 10m solenoid
- Forward solenoids
- Silicon tracker
- Barrel ECAL Lar
- Barrel HCAL Fe/Sci
- Endcap HCAL/ECAL LAr
- Forward HCAL/ECAL LAr

8

New Design 2017

Solenoids in Central *and* forward areas no flux return.

16 Tesla Magnets

FCC goal is 16 T operating field
- Requires to use Nb_3Sn technology
- At 11 T used for HL-LHC

⇒ Strong synergy with HL-LHC

R&D on cables in test stand at CERN

Target: $J_C > 2300$ A/mm² at 1.9 K and 16 T (**50% above HL-LHC**)

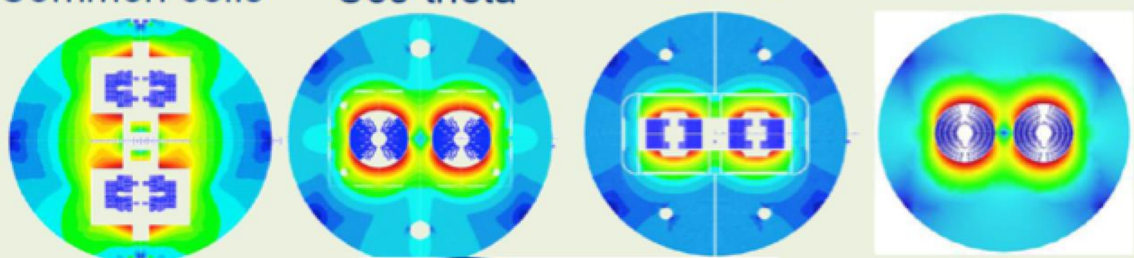
Industrial fabrication:
Target cost: 3.4Euro/kAm

Key cost driver
16 T demonstrated in coil
Hope for US model test early 2018: 14-15 T
Short magnet models in 2018 – 2023
12 T for HL-LHC

Magnet design to **minimise material** use and limit margins to essential level

D. Tommasini at al.

Common coils | Cos-theta | Blocks | Canted Coil



CIEMAT, CEA, INFN

EuroCirCol
A key to New Physics

Swiss contribution
via PSI

D. Schulte,

-- possible shorter term application SCSPS or HE-LHC
-- For longer timescale HTS is also studied → 20T

16 T ERMC construction at CERN

First ERMC coil winding

Aluminum shell

Magnet yoke

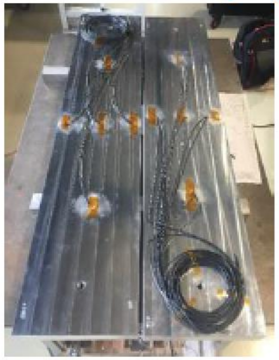
Coil Reaction Tool

Coil Impregnation Tool

Coil fabrication

- Winding of the first coil has been completed
- Preparation for reaction on-going
- All tooling for coil production ready

- ## Magnet assembly
  - components and tooling ready
  - Dummy assembly to characterize the structure behavior on-going.



Dummy coils

Axial rods

Ongoing magnet development eg at CERN

SM Higgs: event rates at 100 TeV

	gg→H	VBF	WH	ZH	ttH	HH
N_{100}	24×10^9	2.1×10^9	4.6×10^8	3.3×10^8	9.6×10^8	3.6×10^7
N_{100}/N_{14}	180	170	100	110	530	390

$N_{100} = \sigma_{100\,\text{TeV}} \times 30\ \text{ab}^{-1}$

$N_{14} = \sigma_{14\,\text{TeV}} \times 3\ \text{ab}^{-1}$

Will create a paradigm shift and need rethinking in how to do Higgs physics

Higgs at FCC-hh

λ_H at the few percent level

Table 1.2: Target precision for the parameters relative to the measurement of various Higgs couplings, the Higgs self-coupling λ, Higgs branching ratios B and ratios thereof. Notice that lagrangian couplings have a precision that is typically half that of what is shown here, since all rates and branching ratios depend quadratically on the couplings.

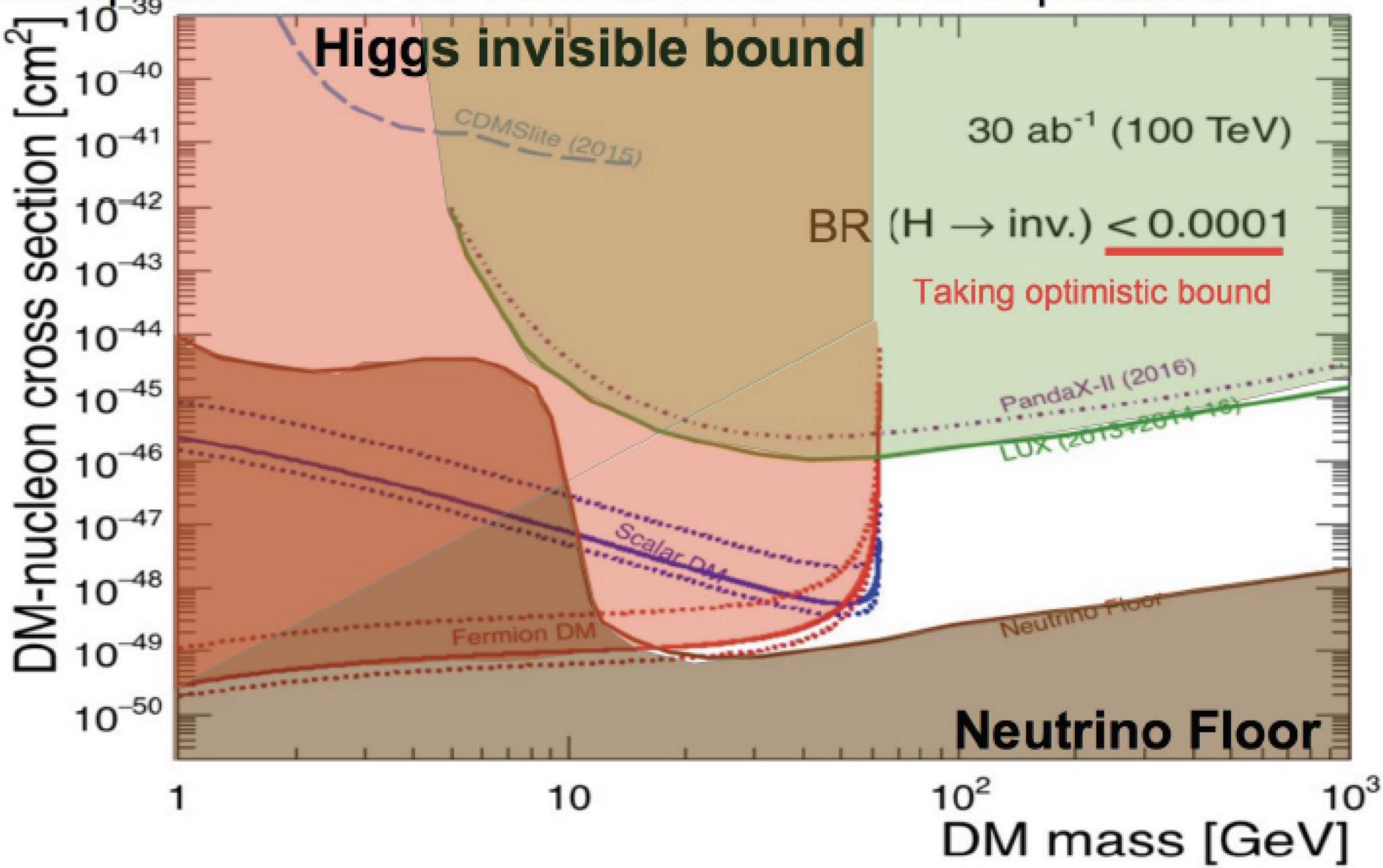
Observable	Parameter	Precision (stat)	Precision (stat+syst)
$\mu = \sigma(H) \times B(H \to \mu\mu)$	$\delta\mu/\mu$	0.5%	0.9%
$\mu = \sigma(H) \times B(H \to \gamma\gamma)$	$\delta\mu/\mu$	0.1%	1%
$\mu = \sigma(H) \times B(H \to 4\mu)$	$\delta\mu/\mu$	0.2%	1.6%
$\mu = \sigma(t\bar{t}H) \times B(H \to b\bar{b})$	$\delta\mu/\mu$	1%	tbd
$\mu = \sigma(HH) \times B(H \to \gamma\gamma)B(H \to b\bar{b})$	$\delta\lambda/\lambda$	3.5%	5.0%
$R = B(H \to \mu\mu)/B(H \to 4\mu)$	$\delta R/R$	0.6%	1.3%
$R = B(H \to \gamma\gamma)/B(H \to 2e2\mu)$	$\delta R/R$	0.17%	0.8%
$R = B(H \to \gamma\gamma)/B(H \to 2\mu)$	$\delta R/R$	0.6%	1.4%
$B(H \to \text{invisible})$	B@95%CL	1×10^{-4}	2.5×10^{-4}

To reach a precision on λ_H at the few percent level requires a linear collider of at least 3TeV (ILC 500 GeV can obtain a ±30% indication and CLIC 3TeV estimate is ±10%)

P.Harris & K.Hahn

Impact on DM bounds

Competitive with the best direct detection experiments



Higgs invisible of 10^{-4} corresponds to g_{SM} from 10^{-3} to 10^{-2}

HIGGS PHYSICS

Higgs couplings g_{Hxx} precisions

hh, eh precisions assume SM or ee measurements
FCC-hh : H→ ZZ to serve as cross-normalization

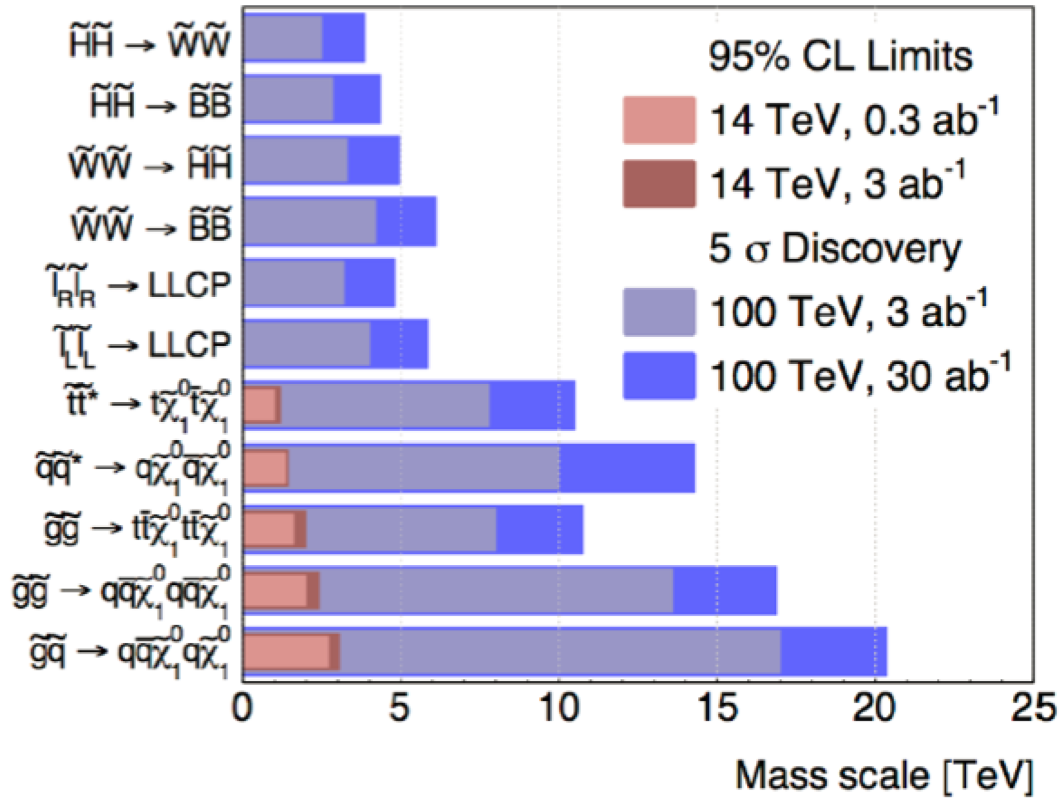
for ttH, combination of ±4% (model dependent)HL-LHC with FCC-ee will lead to ttH coupling to ± 3%...
model independent!

for g_{HHH} investigating now : the possibility of reaching 5σ obsservation at FCC-ee:
4 detectors
+ recast of running scenario

g_{Hxx}	FCC-ee	FCC-hh	FCC-eh
ZZ	**0.22 %**	**< 1% ***	
WW	**0.47%**		
Γ_H	**1.6%**		
γγ	4.2%	**<1%**	
Zγ	--	**1%**	
ttH	13%	**1%**	
bb	**0.7%**		0.5%
ττ	**0.8%**		
cc	**0.7%**		1.8%
gg	**1.0%**		
μμ	8.6%	**1-2%**	
uu,dd	H→ ργ?	H→ ργ?	
ss	H→ φγ ?	H→ φγ ?	
ee	**ee → H**		
HH	40%	**~3-5%**	20%
inv, exo	<0.55%	**10^{-3}**	5%

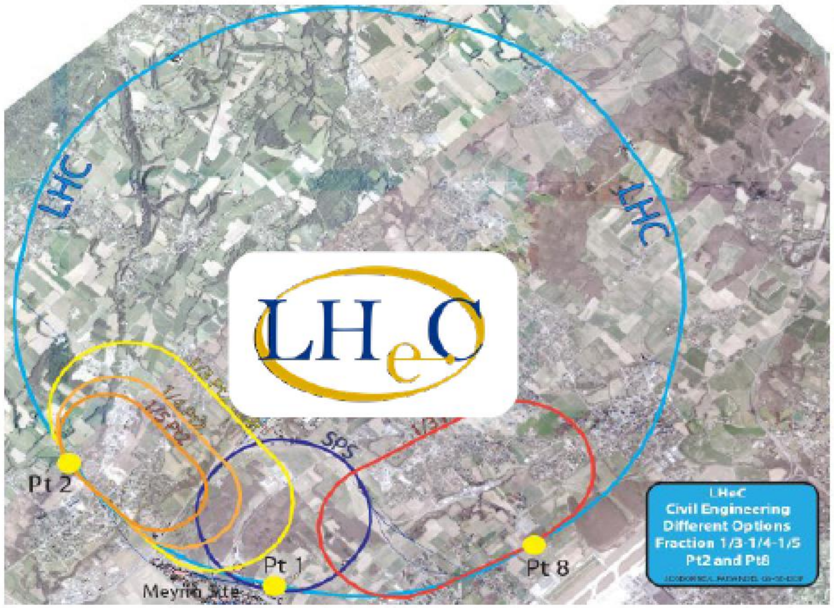
Supersymmetry

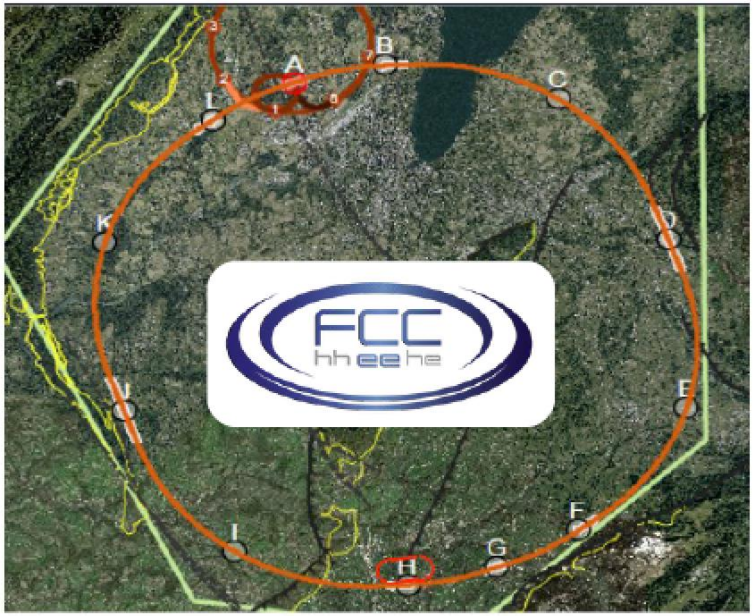
Summary from FCC Report:



The paradigm of low energy supersymmetry has dominated ideas in physics beyond the Standard Model for decades. FCC-hh would provide the final word, by pushing far beyond the naturalness paradigm.

Future proposed ep-colliders: LHeC & FCC-eh





Electron ring

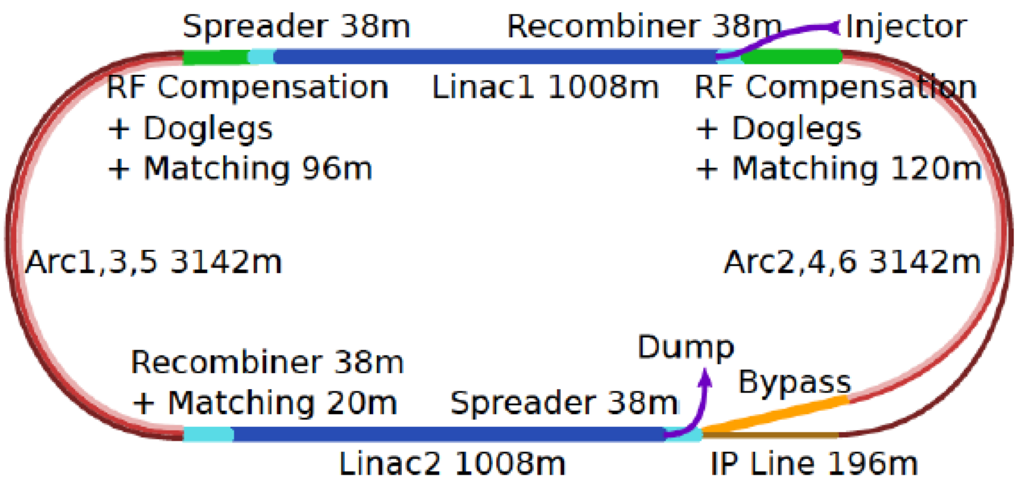
- Energy recovery linac: E_e = 60 GeV
- Polarisation up to P_e ~ 80%
- Similar concept for LHeC & FCC-eh

Center-of-mass energies

- LHeC: $\sqrt{s}$ ~ 1.3 TeV
- FCC-eh: $\sqrt{s}$ ~ 3.5 TeV
- Up to 1 ab^{-1} integrated luminosity

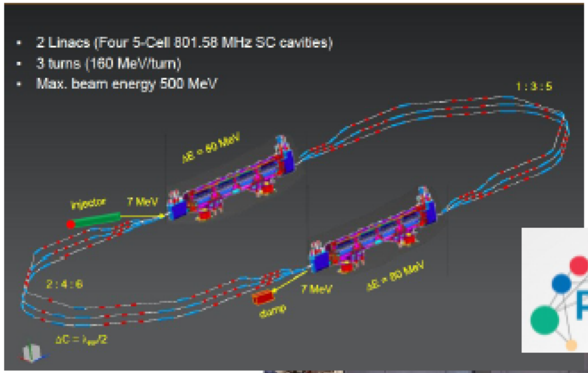
60 GeV Electron ERL

Electron beam
60GeV acceleration with Recirculating Linacs



A. Bogaz (JLab) @ ERL '15

Proof-of-concept under construction:
Powerful **ERL** for **E**xperiments **at Orsay**



PERLE

First 802 MHz cavity successfully built (Jlab)

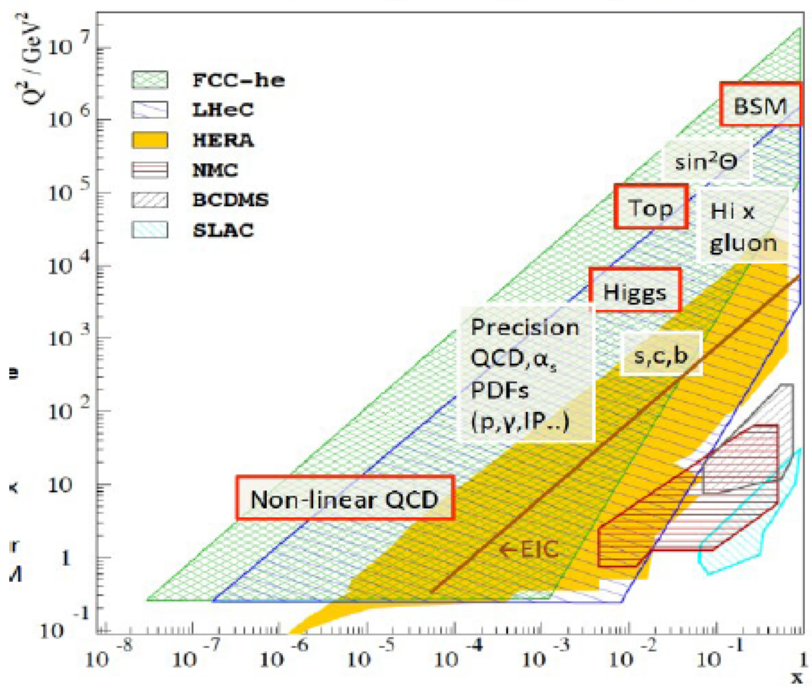
CDR 1705.08783 [J.Phys G] → TDR in 2019

Concurrent operation to pp. Power limit: 100 MW, 10^{34} cm^{-2} s^{-1} luminosity

- LHeC/FCCeh: 1000 times HERA luminosity. It therefore extends up to x~1.

LHeC & FCC-eh – kinematic range

e.g.: P. Newman [NPPS 191 (2009) 307]



Precise QCD constraints for pp

- PDFs
- Strong coupling
- Monte Carlo optimizations

Comprehensive physics programme

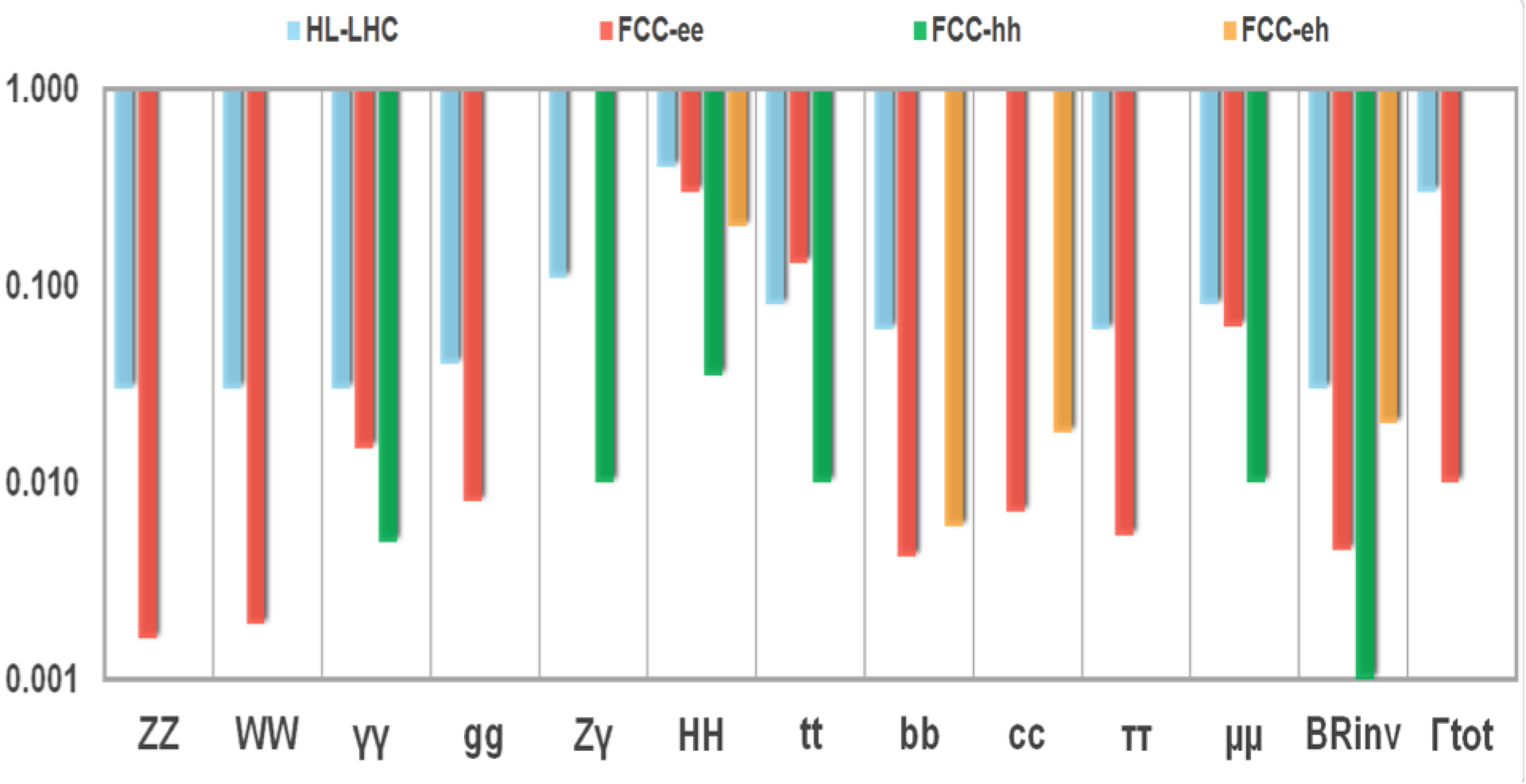
- Higgs physics
- Top-Quark (properties, top-PDFs)
- Heavy-quarks (s,c,b-quarks)
- low-x physics (non-linear QCD?),
- eA physics

Searches for BSM

- Complementary to e+e- and pp

factor of 15/120 (LHeC/FCCeh) extension of Q^2, 1/x reach w.r.t. HERA
Four orders of magnitude extension in lepton-nucleus (ion) DIS

FCC Complementarity



NB this is an 'impression plot' not the consistent result of a Higgs coupling fit!

hh, eh precisions assume SM or ee measurements!

Collaboration & Industry Relations


EuroCirCol Final Meeting
FCCWeek 2019
Tentatively:
Brussels
June, 2019

24-28 June

FCC: Summary

- FCC collider design is being developed as option for future flagship project at CERN for the world-wide high energy physics community. It includes hh-ee-eh options
  - Fast advancement of FCC studies in all areas in ‘17/18
  - Goal is to have CDR ready by end 2018 for European strategy update. The collider concept designs are ready for the CDR
  - **https://indico.cern.ch/category/5153/**
- A High Energy LHC scenario is also being studied
- Detailed physics studies for pp at 100 TeV, e+e- and ep at FCC continuing! Interested people are very welcome to join!

Backup