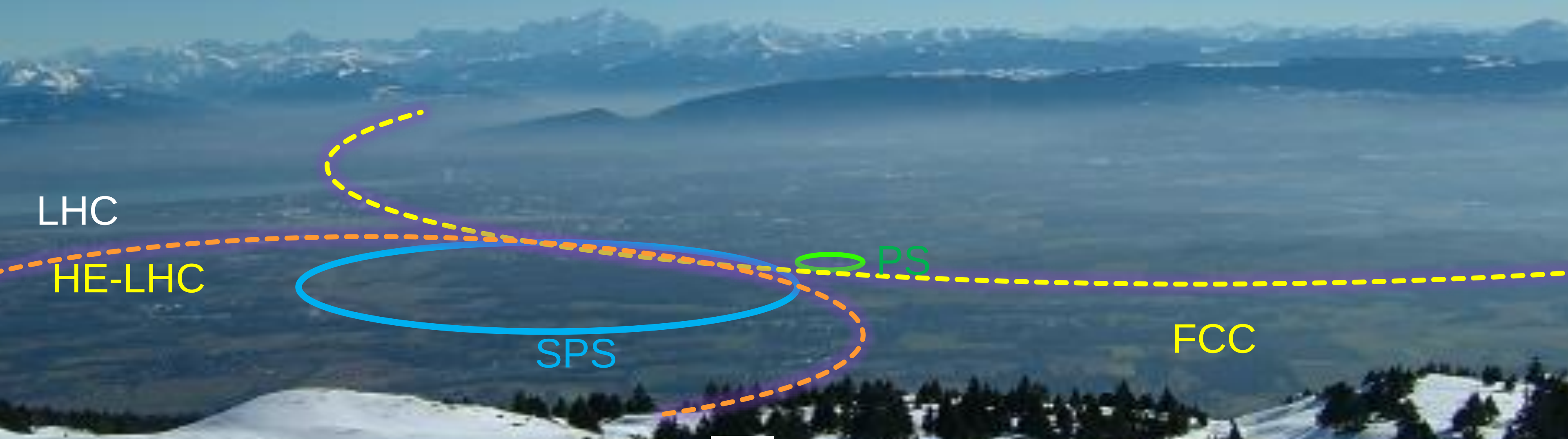
Status of the FCC

Alain BLONDEL

IN2P3, CERN, University of Geneva

With many thanks to all in the FCC collaboration!

Future Circular Collider Study



http://cern.ch/fcc

*Work supported by the **European Commission** under the **HORIZON 2020 projects EuroCirCol**, grant agreement 654305; **EASITrain,** grant agreement no. 764879; **ARIES**, grant agreement 730871; and **E-JADE,** contract no. 64547*

Horizon 2020 European Union funding for Research & Innovation

photo: J. Wenninger

The Future Circular Colliders
CDR and cost review Q4 2018 for ESU

International collaboration to Study Colliders fitting in a new ~100 km infrastructure, fitting in the *Genevois*

- ***Ultimate goal:***
  ***≥100 TeV pp*-collider (*FCC-hh*)**

≥16 T magnets

→ defining infrastructure requirements

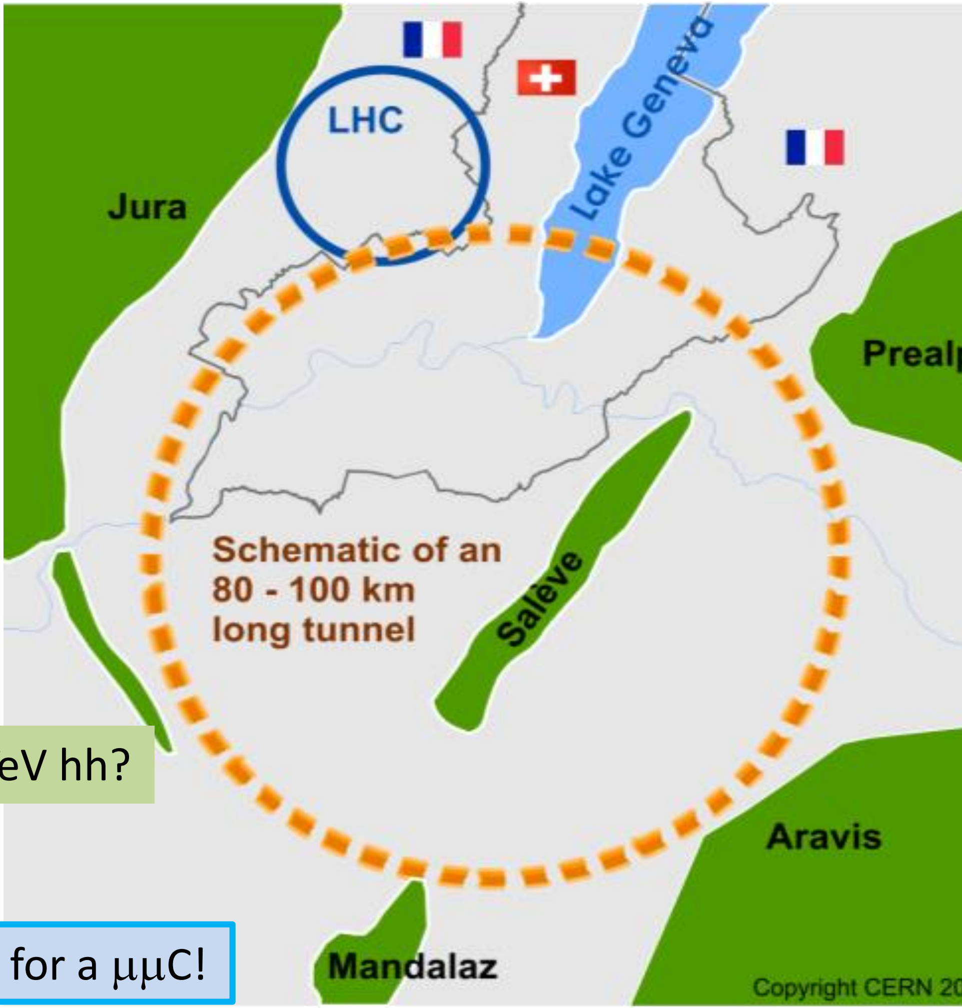
Two possible first steps:

- **e^+e^- collider (*FCC-ee*)**
  High Lumi, E_{CM} =90-400 GeV
- ***HE-LHC* 16T ⇒ 27 TeV**
  in LEP/LHC tunnel

or a 37.5 TeV hh?

***p-e* (*FCC-he*) option**

It's also a good start for a μμC!



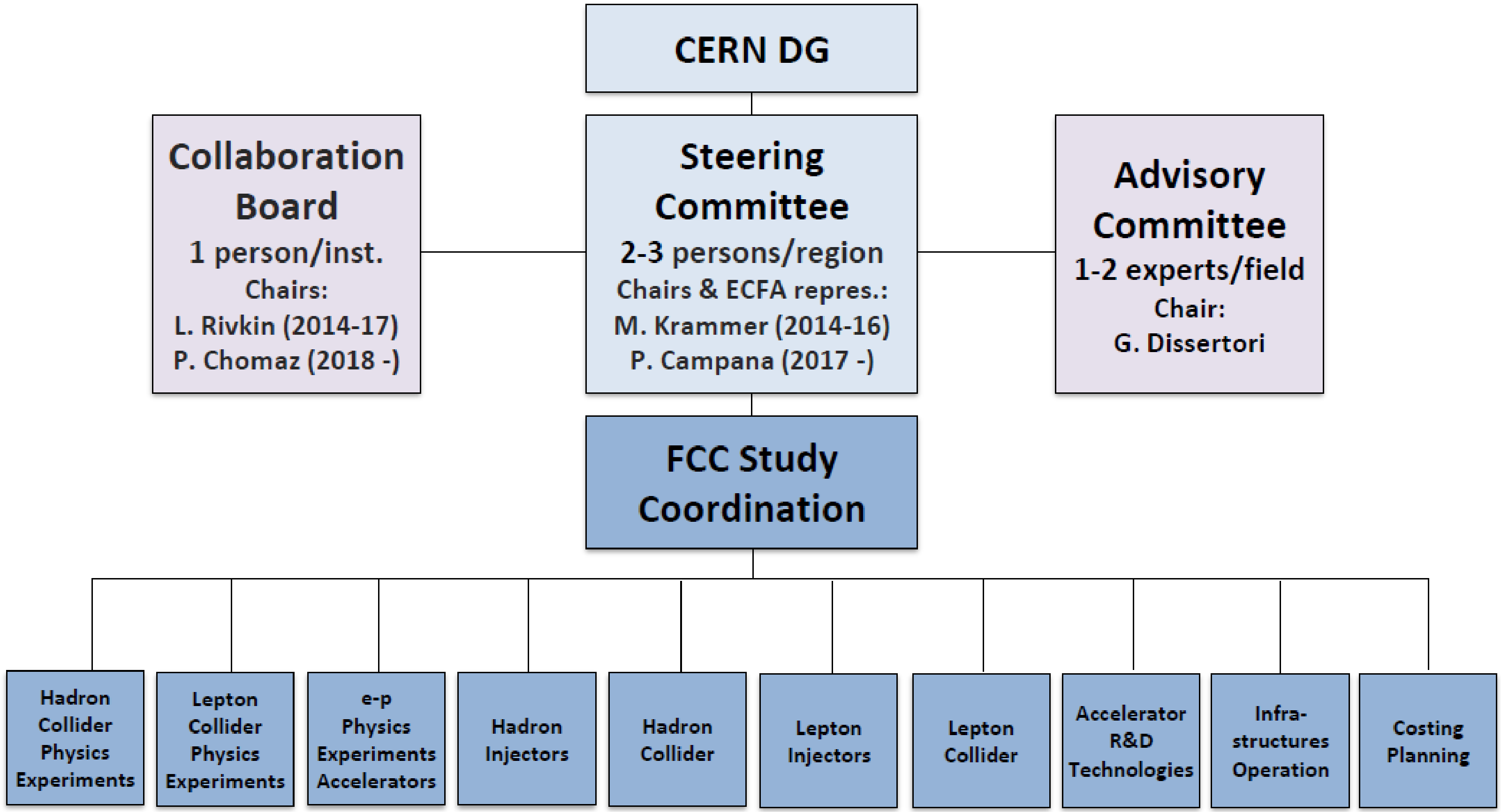
CDR is PUBLISHED

- **FCC-Conceptual Design Reports:**
  - **Vol 1 – Physics**
    Vol 2 – FCC-ee,
    Vol 3 – FCC-hh,
    Vol 4 – HE-LHC
    1338 authors

A public presentation of the CDR was given on 4-5 March at CERN https://indico.cern.ch/event/789349/
→ **many further details can be found there!**

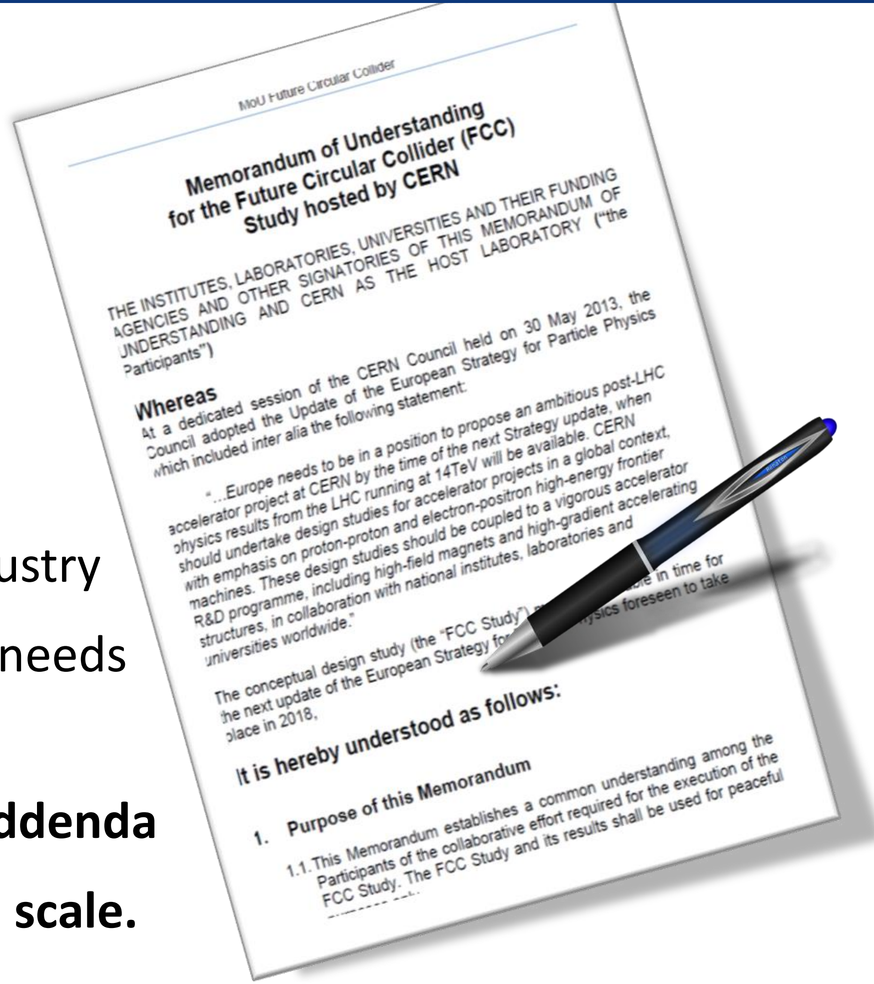
  - Preprints since 15 January 2019 on http://fcc-cdr.web.cern.ch/ and INSPIRE
  - CDRs to be published in **European Physical Journal C (Vol 1) and ST (Vol 2 – 4)**
- **Summary documents provided to EPPSU SG in December 2018**
  - **FCC-integral, FCC-ee, FCC-hh, HE-LHC** http://fcc-cdr.web.cern.ch/
  - **Your questions answered: https://arxiv.org/abs/1906.02693v1**

The Global FCC Collaboration

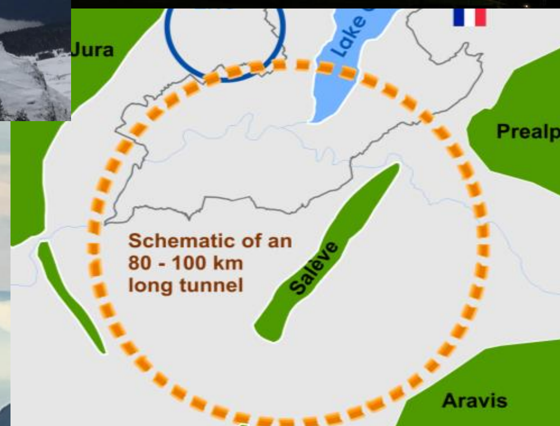

CERN DG
Collaboration Board
1 person/inst.
Chairs:
L. Rivkin (2014-17)
P. Chomaz (2018 -)
Steering Committee
2-3 persons/region
Chairs & ECFA repres.:
M. Krammer (2014-16)
P. Campana (2017 -)
Advisory Committee
1-2 experts/field
Chair:
G. Dissertori
FCC Study Coordination
Hadron Collider Physics Experiments
Lepton Collider Physics Experiments
e-p Physics Experiments Accelerators
Hadron Injectors
Hadron Collider
Lepton Injectors
Lepton Collider
Accelerator R&D Technologies
Infra-structures Operation
Costing Planning

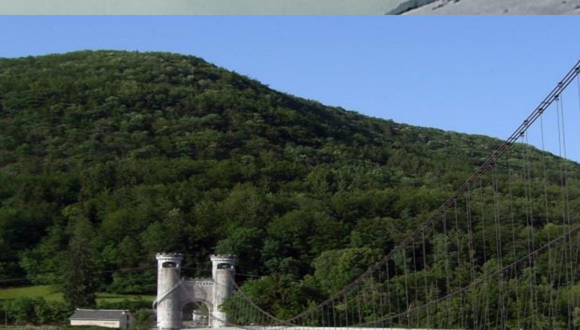
FCC collaboration framework

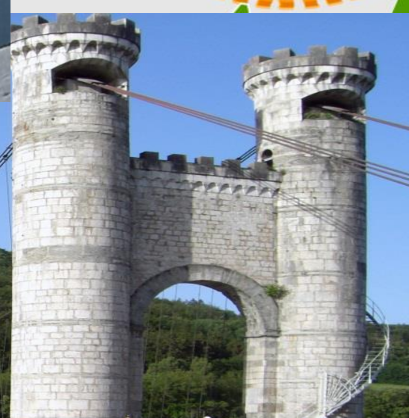
- A **consortium** of partners based on a Memorandum Of Understanding (MoU)
- Working together on a **best effort basis**
- Pursuing the same **common goal**
- **Self governed**
- **Incremental & open** to academia and industry
- **Light general framework**, adapted to the needs during a conceptual design study
- Detailed project descriptions in **specific addenda**
- **Welcome new contributors even at small scale.**



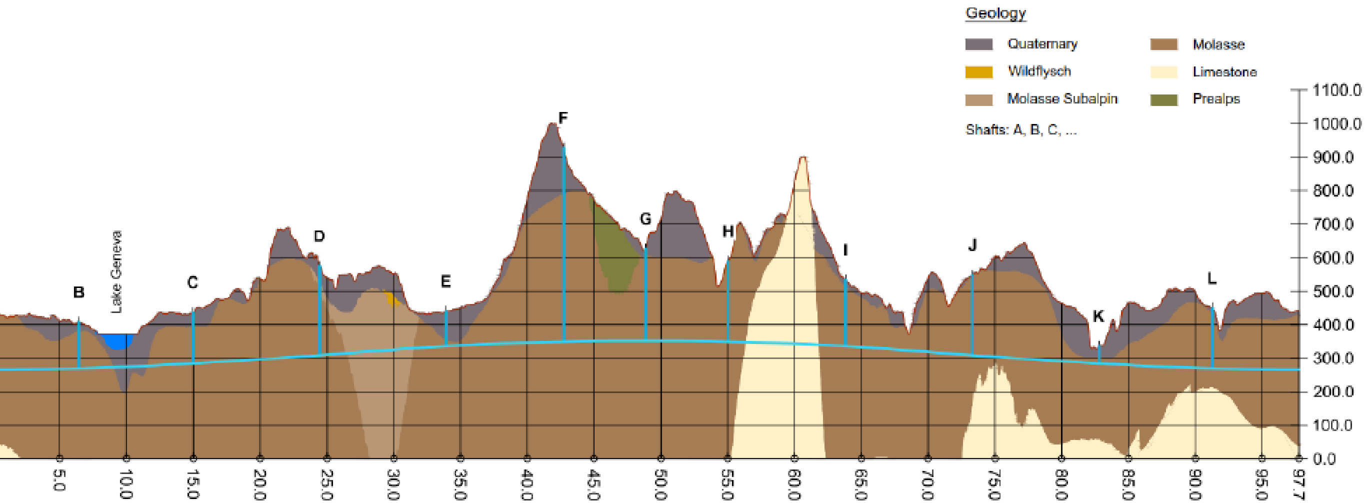
contact: michael.benedikt@cern.ch

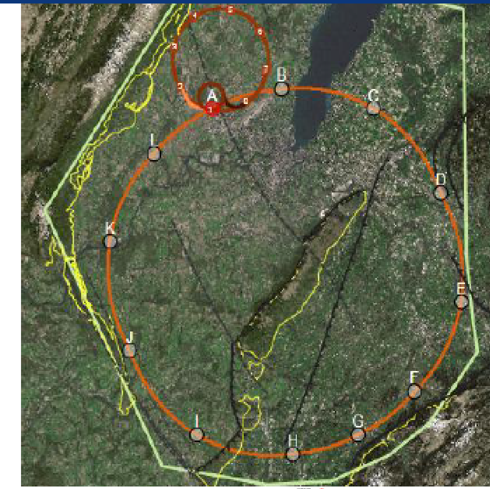

Jura
Lake
Prealps
Schematic of an
80 - 100 km
long tunnel
Saleve
Aravis

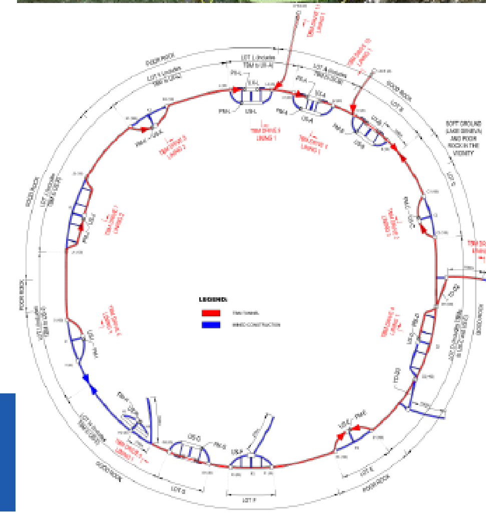




FCC implementation - footprint baseline







Present baseline position was established considering:

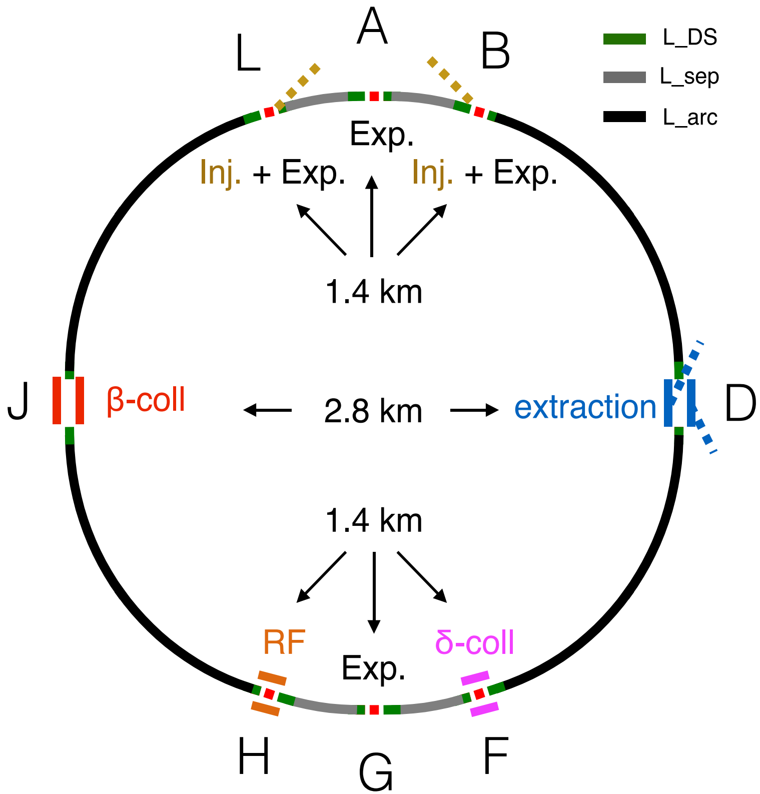
- lowest risk for construction
- fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)

next step: review of surface site locations and machine layout

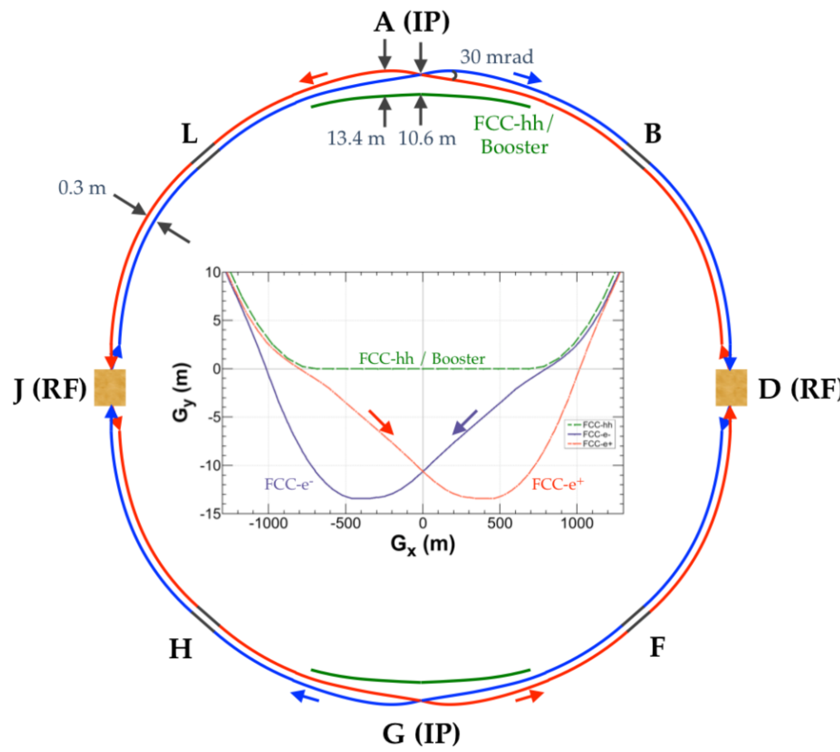
FCC-common layouts

- **Common footprint except around IPs**
- **Asymmetric IR layout** to limit synchrotron radiation

FCC-hh



FCC-ee



1st Step : the e+e- collider: FCC-ee Z, W, Higgs & top factory «Electroweak Factory»

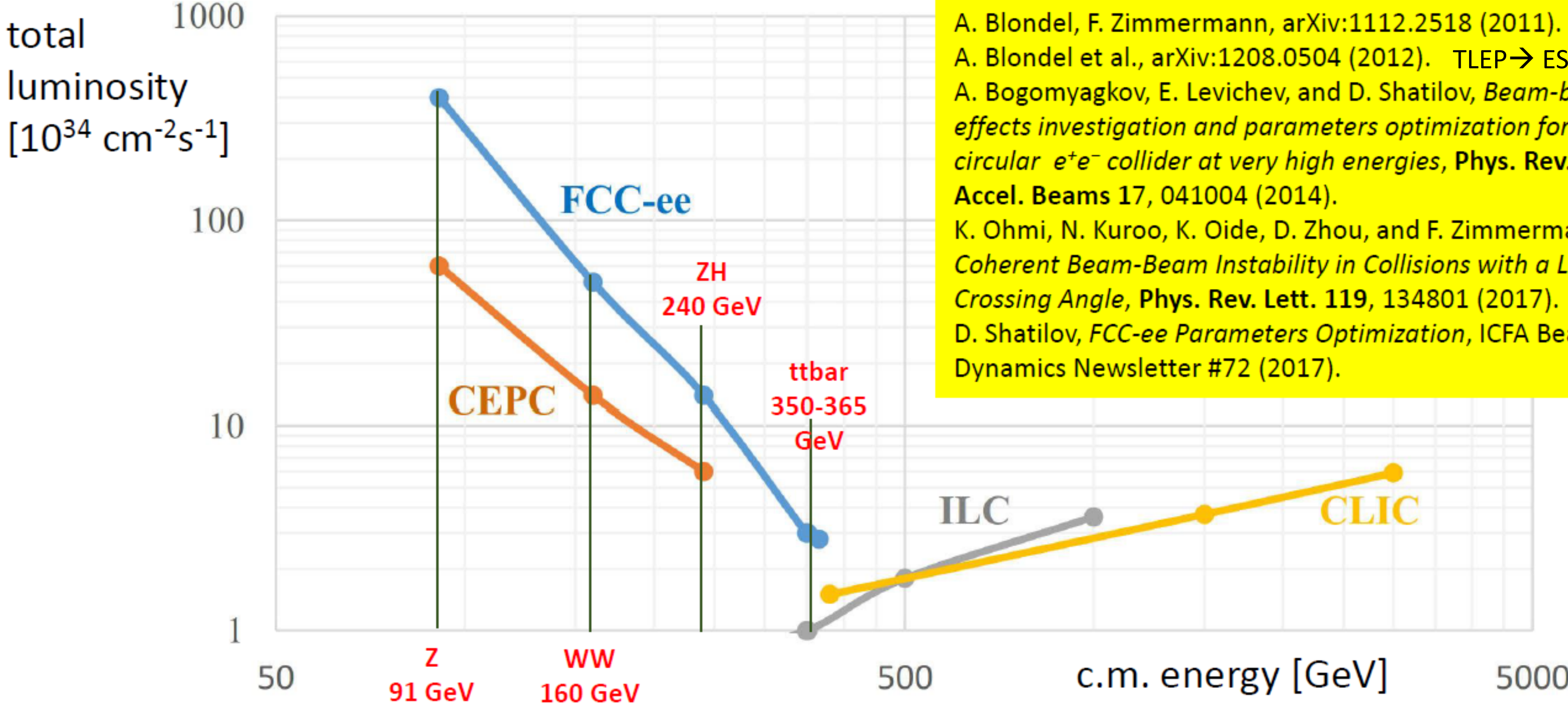
-- Very High Luminosities in 100 km tunnel
-- Centre-of-mass energy calibration based on resonant depolarization (100keV)
-- Very small beams and clean experimental conditions
Unique precisions and sensitivities to rare processes

-- Very mature technology with very large expertise active in the world
LEPI/II, b and c/tau factories, circular light sources.
We know how to do it, we also know how we should improve it.
– little risk concerning performance.

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

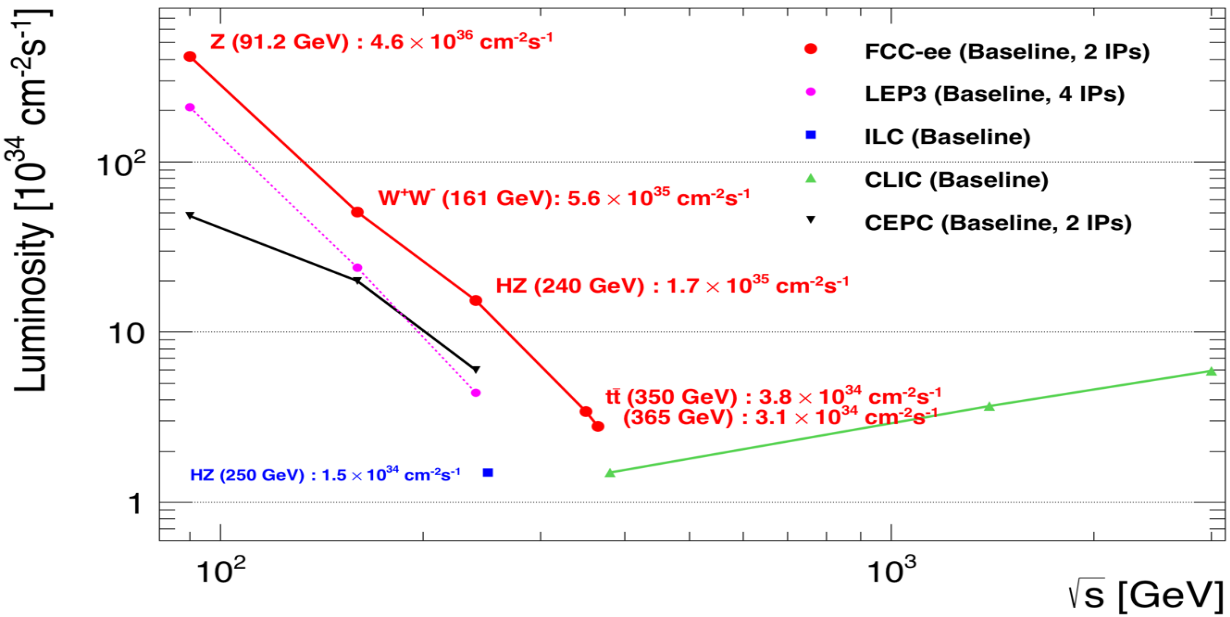
FCC-ee luminosity versus energy



A. Blondel, F. Zimmermann, arXiv:1112.2518 (2011).
A. Blondel et al., arXiv:1208.0504 (2012). TLEP→ ESPP2012
A. Bogomyagkov, E. Levichev, and D. Shatilov, *Beam-beam effects investigation and parameters optimization for a circular e^+e^- collider at very high energies*, **Phys. Rev. ST Accel. Beams 17**, 041004 (2014).
K. Ohmi, N. Kuroo, K. Oide, D. Zhou, and F. Zimmermann, *Coherent Beam-Beam Instability in Collisions with a Large Crossing Angle*, **Phys. Rev. Lett. 119**, 134801 (2017).
D. Shatilov, *FCC-ee Parameters Optimization*, ICFA Beam Dynamics Newsletter #72 (2017).

FCC-ee

Z WW HZ tt



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	2 MeV
$t\bar{t}$ threshold	E_{cm} : 350 GeV	10^6	e+e- → $t\bar{t}$	Never done	5 MeV

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

FCC-ee Polarization and Centre-of-mass Energy Calibration

The FCC-ee energy and polarization Working group – we need list of authors and institutes
CERN, Geneva, Switzerland

Abstract
A significant part of the FCC-ee physics program lays in the precise (ppm) measurements of the W and Z masses and widths, as well as for-

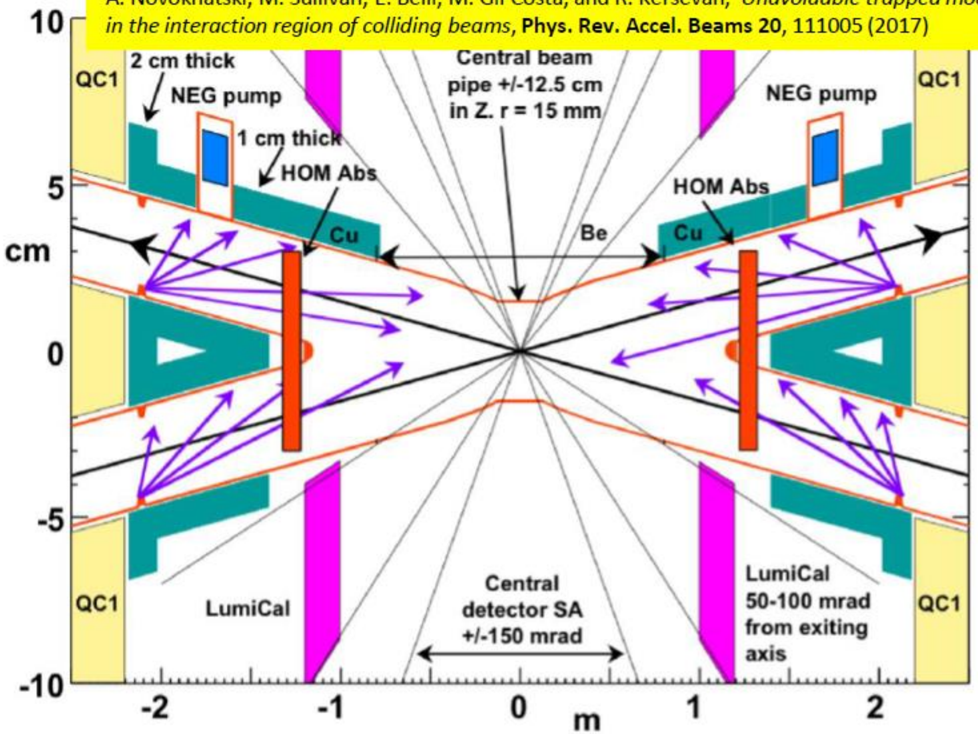
Table 15: Calculated uncertainties on the quantities most affected by the center-of-mass energy uncertainties, under the final systematic assumptions.

Quantity	statistics	ΔE_{CMabs} 100 keV	$\Delta E_{CMSyst-ptp}$ **40 keV**	calib. stats. 200 keV/$\sqrt{(N^i)}$	σE_{CM} (84) ± **0.05** MeV
m_Z (keV)	4	100	**28**	1	–
Γ_Z (keV)	7	2.5	**22**	1	**10**
$sin^2\theta_W^{eff} \times 10^6$ from $A_{FB}^{\mu\mu}$	2	–	**2.4**	0.1	–
$\frac{\Delta\alpha_{QED}(M_Z)}{\alpha_{QED}(M_Z)} \times 10^5$	3	0.1	**0.9**	–	**0.05**

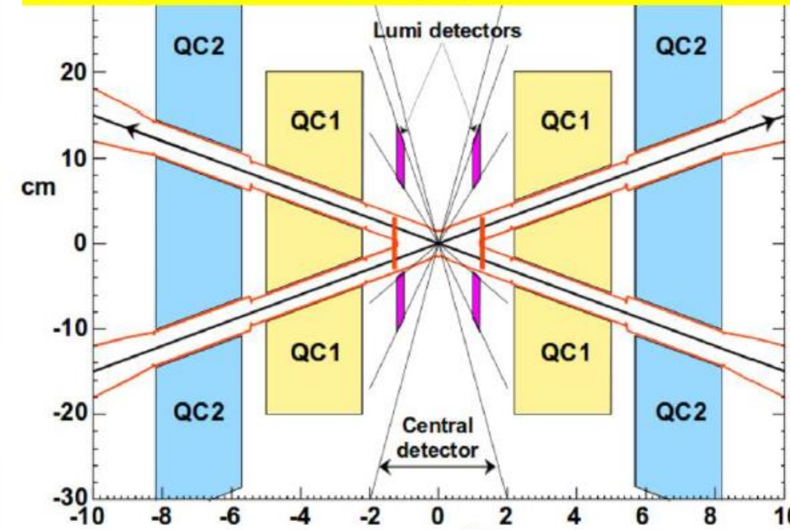
- **The Z width can be known (experimentally) to better than 25 keV, and $sin^2\theta_W$ to better than 3×10^{-6}**
  - **Factor 3-4 better than anticipated in the CDR – will be communicated to the ESPP.**

FCC-ee interaction region

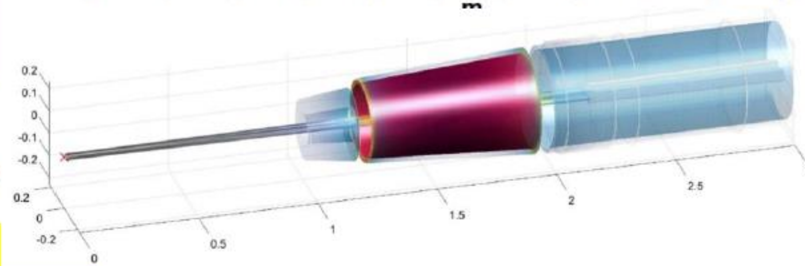
A. Novokhatski, M. Sullivan, E. Belli, M. Gil Costa, and R. Kersevan, *Unavoidable trapped mode in the interaction region of colliding beams*, **Phys. Rev. Accel. Beams 20**, 111005 (2017)



M. Boscolo, H. Burkhardt, and M. Sullivan, *Machine detector interface studies: Layout and synchrotron radiation estimate in the future circular collider interaction region*, **Phys. Rev. Accel. Beams 20**, 011008 (2017)



3D sketch of IR magnet system in the first 3 m from the IP



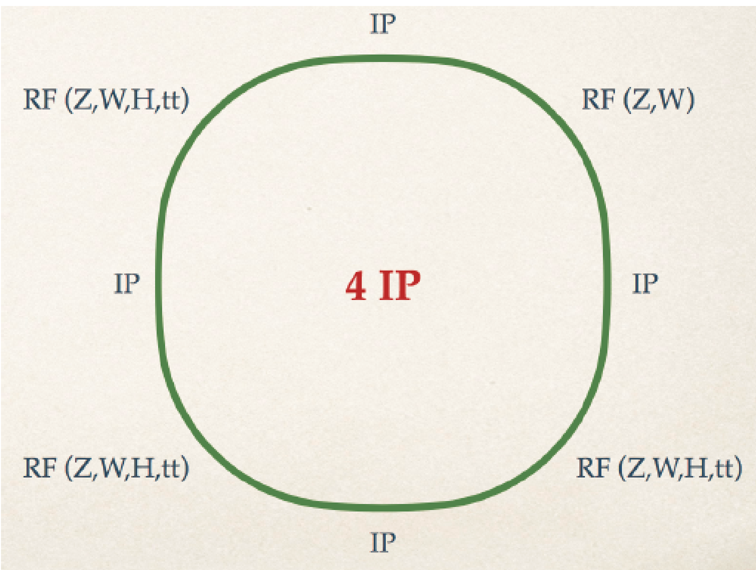
M. Boscolo, N. Bacchetta, H. Burkhardt, M. Dam, D. El Khechen,
M. Koratzinos, E. Levichev, M. Luckhof, A. Novokhatski, M. Sullivan, et al.

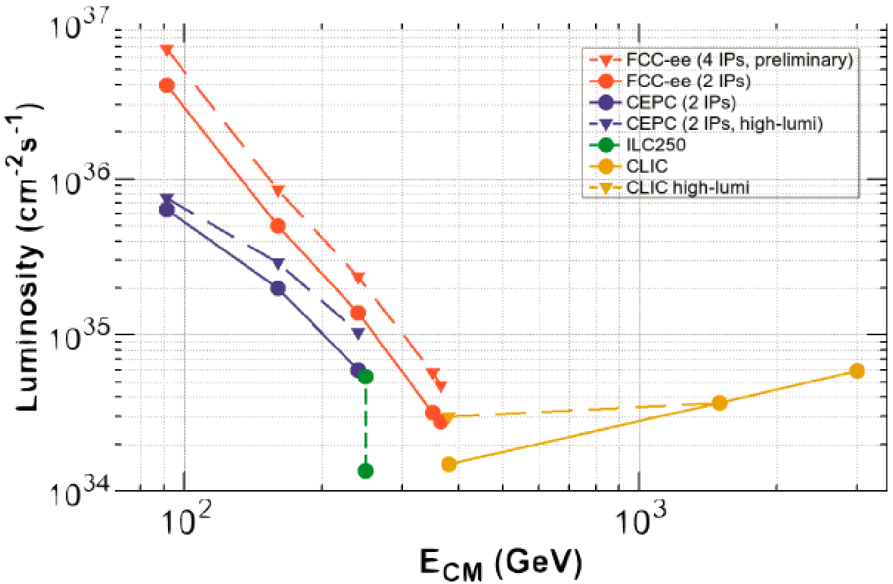
full simulations show very clean conditions

How many detectors ?

- Baseline design (CDR) has 2 interaction points, hence 2 detectors
  - Study ongoing for a layout with 4 IPs (four-fold symmetry will impact the FCC-hh layout)
    - Luminosity multiplied by ~1.8 – beam-beam instabilities seem manageable
    - Must be ready to provide material for four detectors in 2026

K. Oide, D. Shatilov





100 TeV

Hadron colliders will remain for the foreseable future the most efficient way to reach high energy (> 3 TeV) parton-parton collisions

(100 TeV pp can reach up to 15-30 TeV for SM couplings)

1. As energy increases high Pt (mass) interactions become well distinguished from backgrounds

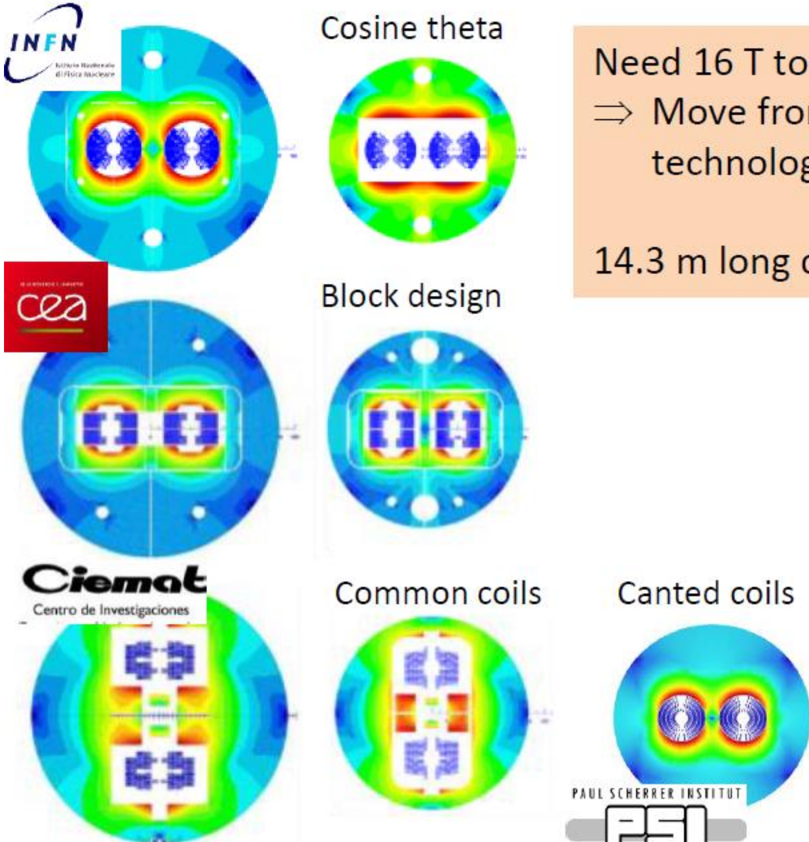
2. LHC demonstrated ability to build and operate detectors for precision measurements with high pile up environment (Higgs mass is known to <±200 MeV)

3. difference with e.g. e+e- machines reduces as energy grows

Hadron Collider Parameters

	LHC / HL-LHC	HE-LHC (tentative)	FCC-hh Initial	FCC-hh Ultimate
Cms energy [TeV]	14	27	100	100
Luminosity [$10^{34} cm^{-2} s^{-1}$]	1 / 5	28	5	20-30
Machine circumference	27	27	97.75	97.75
Arc dipole field [T]	8	16	16	16
Bunch charge	1.15 / 2.2	2.2	1	1
Bunch distance [ns]	25	25	25	25
Background events/bx	27 / 135	800	170	<1020
Bunch length [cm]	7.5	7.5	8	8

Magnet Development



Need 16 T to reach 50 TeV /beam
$\Rightarrow$ Move from NbTi (LHC technology) to Nb_3Sn

14.3 m long dipoles

Magnet is key cost driver

- Improve cable performance
- Reduce cable cost
- Improve fabrication of magnet
- Minimise amount of cables
- Push lattice filling factor

Safety margin from 18% to 14%
Reduced inter-beam distance from 250 to 204 mm
Stray field up to 0.1 T
$\Rightarrow$ Total conductor (incl. copper) from O(10 kt) to 7.6 kt

Short models in 2018 – 2023
Prototypes 2026 -- 2032

D. Tommasini et al.

Deliverable 5.4: a contribution of the US MDP

Grant Agreement No: 654305

EuroCirCol

European Circular Energy-Frontier Collider Study

Horizon 2020 Research and Innovation Framework Programme, Research and Innovation Action

DELIVERABLE REPORT

MANUFACTURING FOLDER FOR REFERENCE DESIGN DIPOLE SHORT MODEL

Document identifier:	EuroCirCol-P3-WP5-D5.4 EDMS 2041779
Due date:	End of Month 46 (April 1, 2019)
Report release date:	26/03/2019
Work package:	WP5 (High-field accelerator magnet design)
Lead beneficiary:	CERN
Document status:	IN WORK (V0.2)

Abstract:

Manufacturing folder for a novel high-field cosine-theta model magnet, suitable for the hadron collider designed in the scope of the EuroCirCol project, which is part of the international Future Circular Collider study.

1. INTRODUCTION

The specifications and parameters, set by the EuroCirCol WP5, have been implemented in the engineering design of a cos-theta dipole model magnet developed by Fermilab in the framework of the US Magnet Development Program (MDP), which includes Fermilab, LBNL, NHMFL and recently BNL. The magnet design and manufacturing has been in part adapted to the tooling used for the 11 T dipole for the HL-LHC upgrade project, which was available at FNAL when the activity started.

The status of advancement of the model magnet is well beyond the initial goal of EuroCirCol, going beyond the delivery of a manufacturing folder. At the time of the writing of this report all magnet parts have been manufactured and the magnet is assembled and ready for testing (Fig.1).

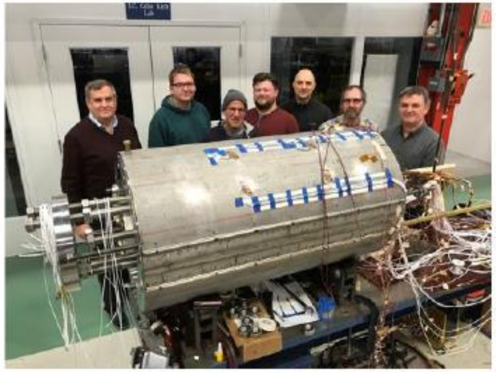


Fig.1 The cos-theta dipole model magnet with project leader A.V. Zlobin and his team (FNAL).

15 T magnet dipole prototype has been built (Fermilab)

2. MAGNET PARAMETERS

The magnet is based on a 4-layer graded cos-theta coil with 60 mm aperture and cold iron yoke. To counteract the large Lorenz forces, a novel mechanical structure based on a vertically split iron yoke, locked by large aluminum I-clamps and supported by a thick stainless steel skin, has been developed at FNAL.

The main magnet parameters are summarized in Table 1.

Table 1: main parameters of the cos-theta model magnet.

Parameter	*Unit*	*Value*
Magnet free aperture	mm	60
Bore field at short sample limit @ 1.9 K	T	17.0
Peak field at short sample limit @ 1.9 K	T	17.7
Current at short sample limit @ 1.9 K, I_{ss}	kA	12.5
Inductance at I_{ss}	mH/m	26
Number of cable strands (Cable1/Cable2)		28/40
Cable width (Cable1/Cable2) after reaction	mm	15.10/15.10
Cable mid-thickness (Cable1/Cable2) after reaction	mm	1.870/1.319

3. MANUFACTURING FOLDER

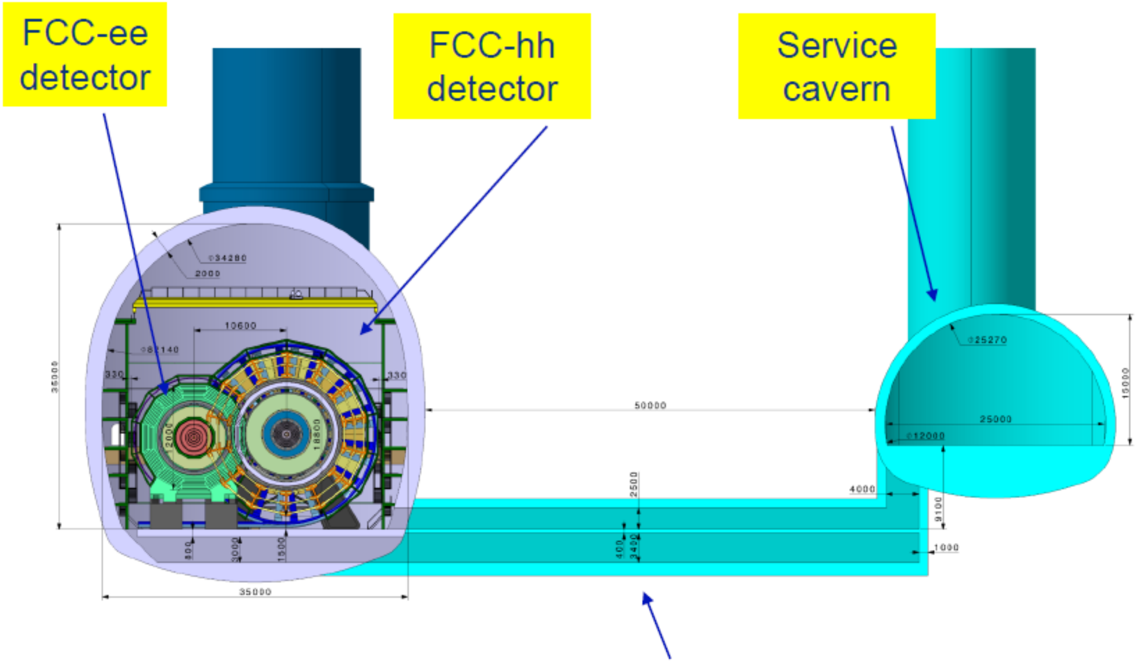
The manufacturing folder is composed of the following drawings.

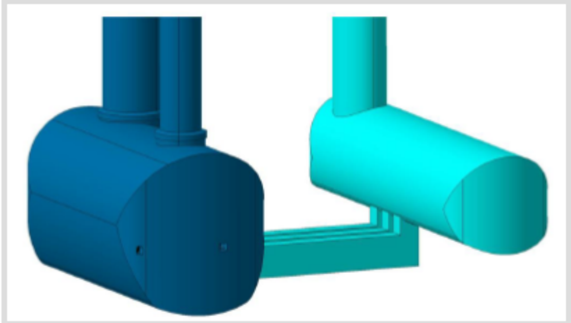
- F10050785_15T Assembly
- F10050871_I-clamp
- F10050291_Iron Lamination
- F10047874_Coil assembly
- F10055320_Coil L1-2
- F10055321_Coil L3-4
- F10047809_L1 Pole LE
- F10047844_L1 Pole RE
- F10048996_L2 Pole LE
- F10049080_L2 Pole RE
- F10054821_L1 Splice Block
- F10054822_L2 Splice Block
- F10052356_L1 Wedge
- F10052369_L2 Wedge
- F10047811_L1 Spacer1 LE
- F10047813_L1 Spacer2 LE
- F10047825_L1 Spacer3 LE
- F10047843_L1 Spacer4 LE
- F10047863_L1 Spacer1 RE
- F10047864_L1 Spacer2 RE
- F10049005_L2 Spacer1 LE
- F10049010_L2 Spacer2 LE
- F10049011_L2 Spacer3 LE

SYNERGY AND COMPLEMENTARITY

Common experimental points (A, G)

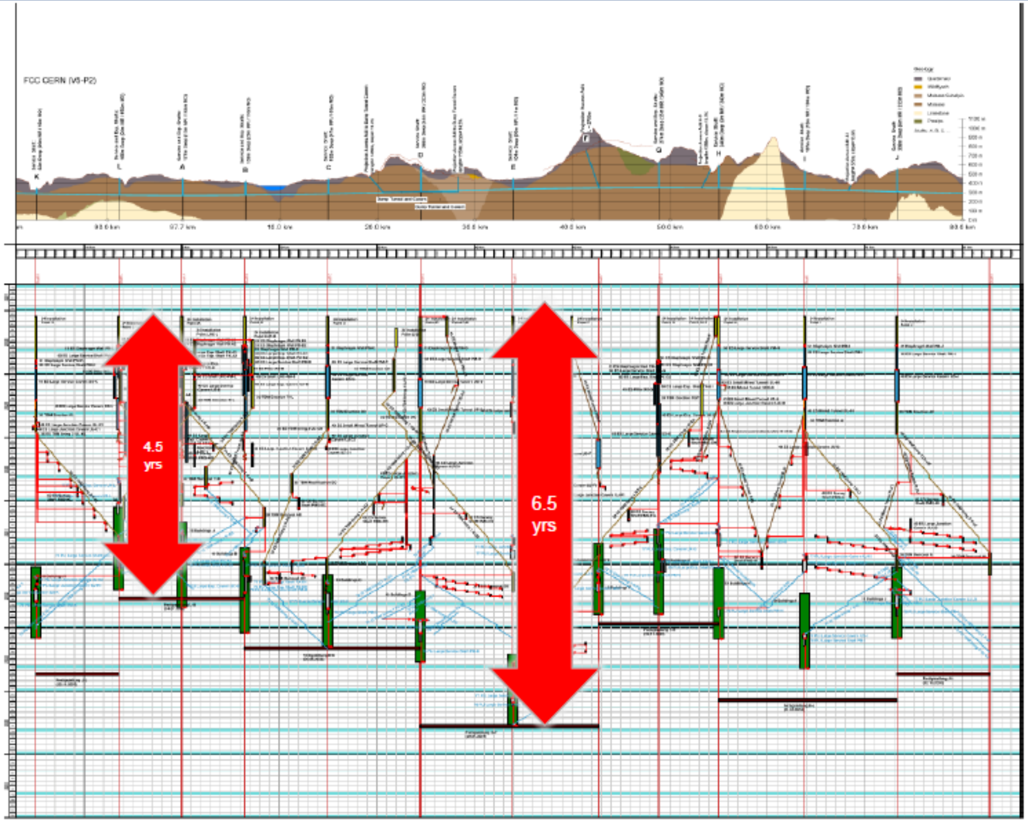
Distance between detector cavern and service cavern 50 m.
Strayfield of unshielded detector solenoid < 5mT.

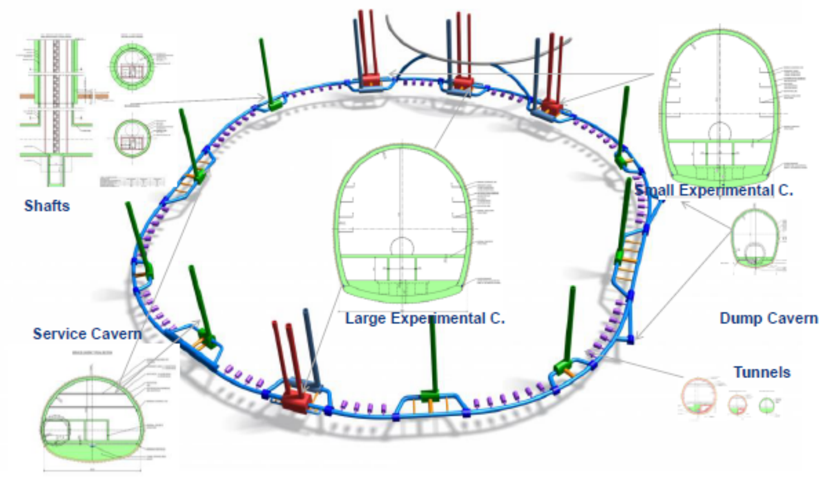




Preliminary design of access and cable paths

CE schedule studies

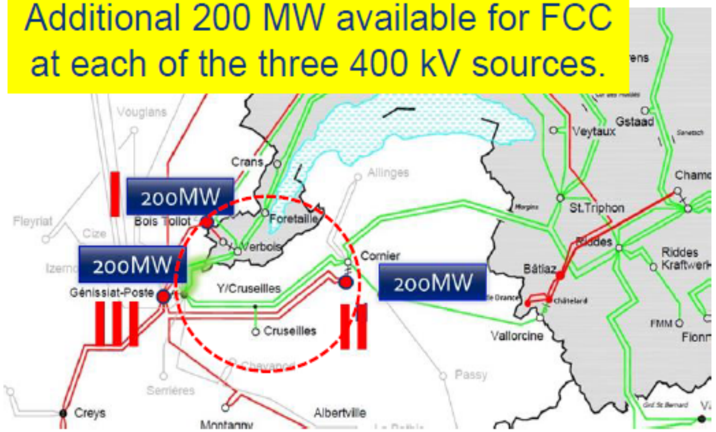




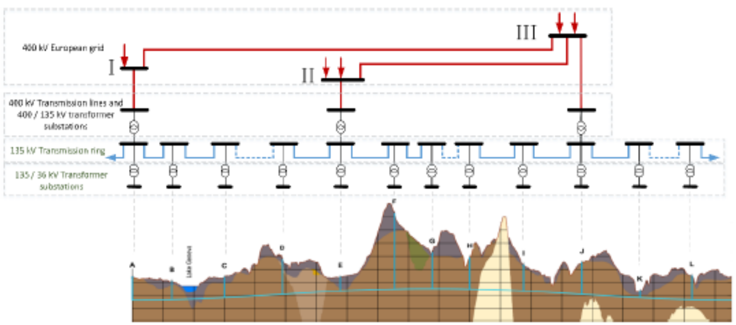
- Total construction duration 7 years
- First sectors ready after 4.5 years

Supply and distribution of electrical energy

Additional 200 MW available for FCC at each of the three 400 kV sources.

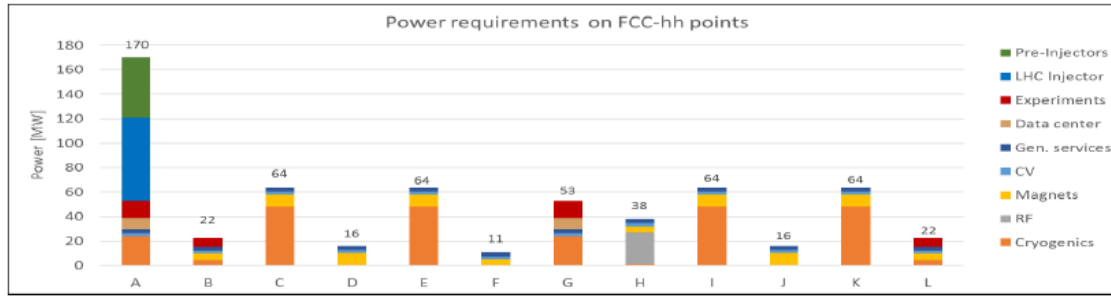


---- 400 kV ---- 230 kV

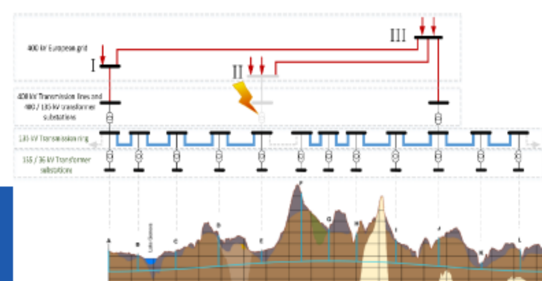


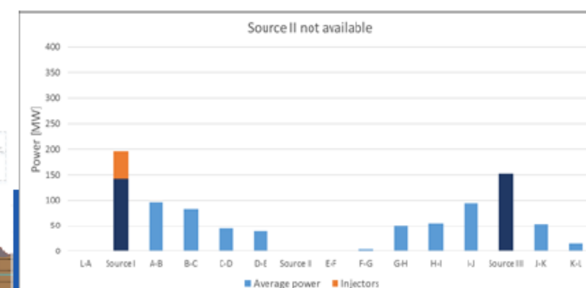
3 x 400 kV connections
+ 135 kV underground power distribution (NC)

Per-point power requirements as input for infrastructure-optimized conceptual design. (Peak FCC-ee 260 - 340 MW, total FCC-hh 550 MW)



If one power source goes down fall back to „degraded mode“: FCC remains cold, vacuum preserved, controls on, RF off, no beam (“standby”). All FCC points supplied from 2 other 400 kV points, through the power transmission line.

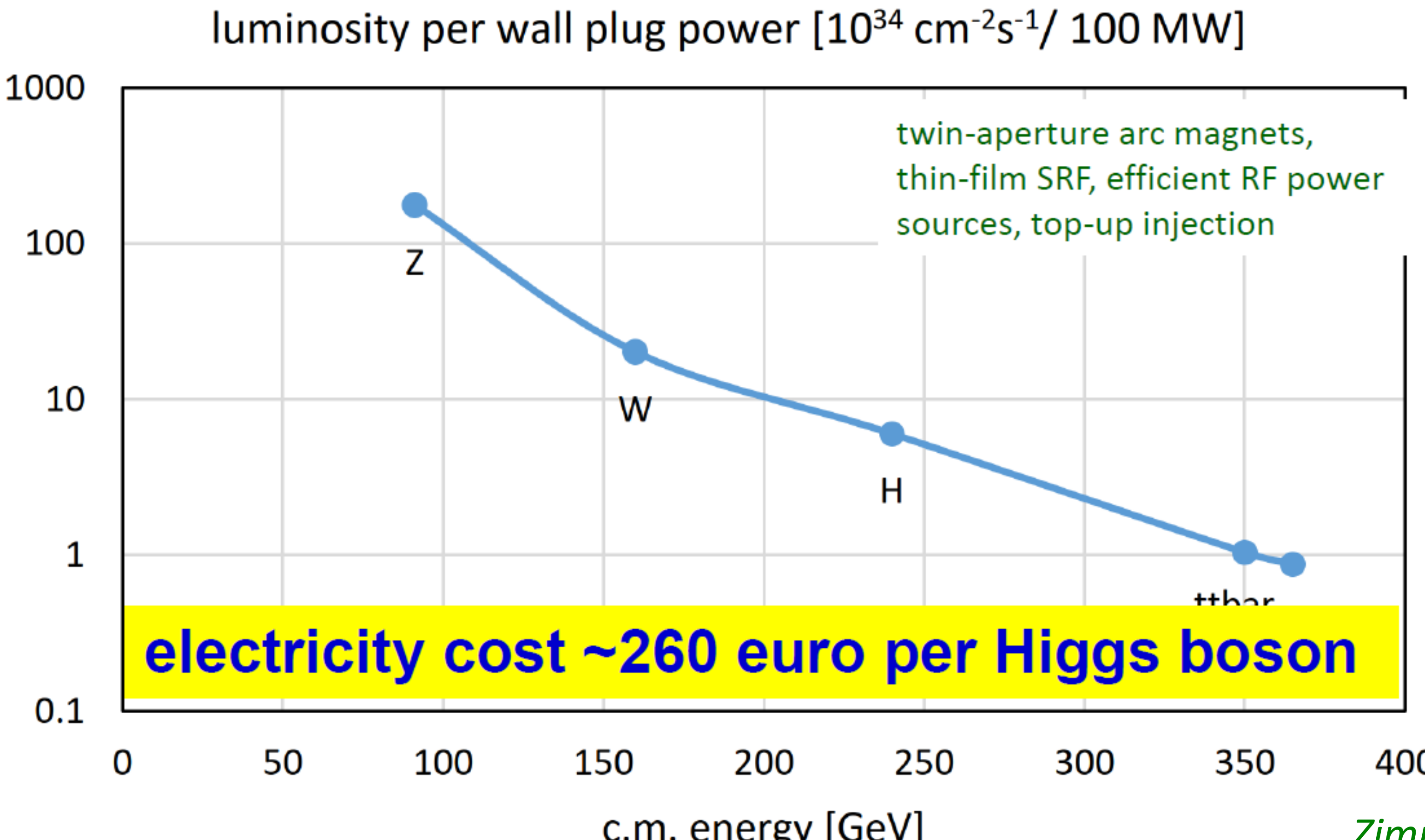




FCC-ee el. power consumption [MW]

Beam energy (GeV)	45.6 Z	80 W	120 ZH	182.5 ttbar
RF (SR = 100)	163	163	145	145
Collider cryo	1	9	14	46
Collider magnets	4	12	26	60
Booster RF & cryo	3	4	6	8
Booster magnets	0	1	2	5
Pre injector	10	10	10	10
Physics detector	8	8	8	8
Data center	4	4	4	4
Cooling & ventilation	30	31	31	37
General services	36	36	36	36
Total	259	278	282	359

FCC-ee: a sustainable accelerator



Zimmermann

integrated luminosity per construction cost

for the H running, **with 5 ab^{-1} accumulated over 3 years**, the total investment cost corresponds to
10 kCHF per produced Higgs boson

for the Z running with **150 ab^{-1} accumulated over 4 years** the total capital investment cost corresponds to
10 kCHF per 5×10^{6} Z bosons
= the number of Z bosons collected by each experiment during the entire LEP programme !

construction cost per luminosity dramatically decreased compared with LEP !

FCC work with Host States

General secretariat of the region Auvergne-Rhône-Alpes
and notified body “Centre d'études et d'expertise sur les risques, l'environnement, la mobilité et l'aménagement” CEREMA

Working group with representatives of federation, canton and state of Geneva and representation of Switzerland
at the international organisations and consultancy companies

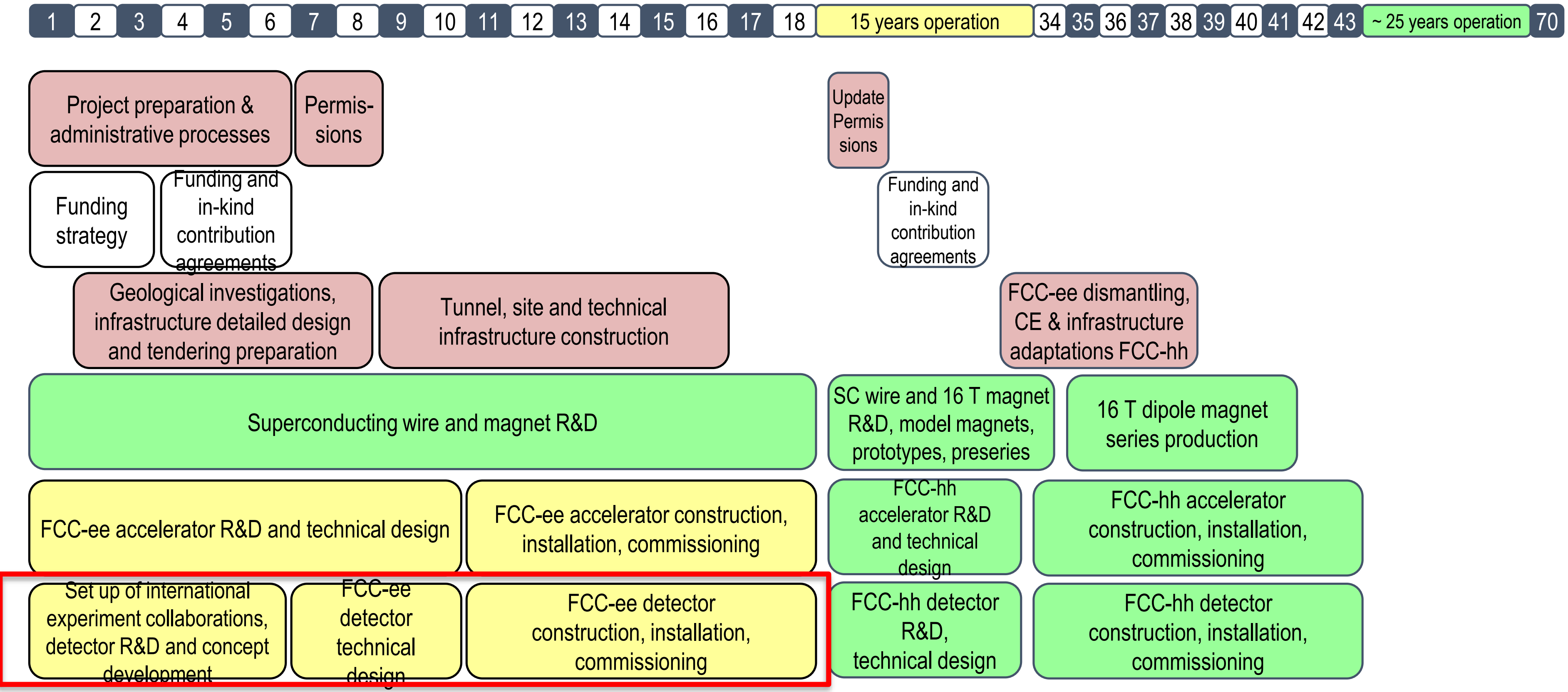
- Administrative processes for project preparatory phase developed.
- First review of tunnel placement performed.
- Requirements for urbanistic, environmental, economic impact, land acquisition and construction permit related processes defined.
- **For 2019-20, common optimization of collider tunnel and surface site infrastructure implementation planned.**

SCHEDULE

Input to schedule studies

- Results of discussions with host state authorities for definition of preparatory phase duration
- Present CERN procurement rules for duration of tendering and adjudication phases
- CE consultants input for duration of various planning phases, site investigations and CE construction
- Detailed CERN schedule study for FCC-hh, based on experience from LHC, HL-LHC (learning curves, LS1, taking into account number of persons underground, number of crews, structuring of industrial installation contracts, etc.)
- Adaptation to FCC-ee by scaling from FCC-hh study and experience from LEP (e.g. cryo module installation, etc.)

FCC integrated project timeline



work is cut out for physics and detectors

ESPP

70 years seems like a long time!

PHYSICS WITH VERY HIGH ENERGY
e^+e^- COLLIDING BEAMS

CERN 76-18
8 November 1976

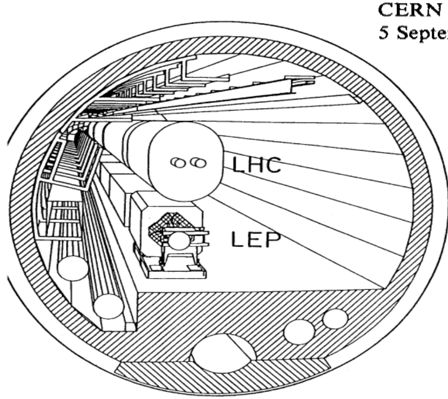
L. Camilleri, D. Cundy, P. Darriulat, J. Ellis, J. Field,
H. Fischer, E. Gabathuler, M.K. Gaillard, H. Hoffmann,
K. Johnsen, E. Keil, F. Palmonari, G. Preparata, B. Richter,
C. Rubbia, J. Steinberger, B. Wiik, W. Willis and K. Winter

ABSTRACT

This report consists of a collection of documents produced by a Study Group on Large Electron-Positron Storage Rings (LEP). The reactions of

Did these people know that we would be running HL-LHC in that tunnel >**60 years later?**

ECFA 84/85
CERN 84-10
5 September 1984



LARGE HADRON COLLIDER
IN THE LEP TUNNEL

Vol. I

Let’s not be SHY!

Input to cost estimates

- CE consultants cost study for complete CE construction (including access roads, spoil transport and removal cost, normalized with ~10 large European tunnel projects)
- Machine technical designs as available
- Scaling from LEP, LHC cost and HL-LHC, LIU activities
- Further input from other machines and research centres, e.g. SuperKEKB injector linac, etc.

BEWARE: cost optimization has yet to be performed.

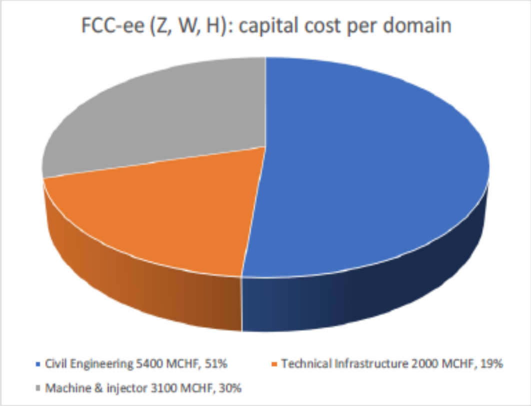
FCC-ee cost estimate

Total construction cost phase1 (Z, W, H) amounts to 10,500 MCHF

- 5,400 MCHF for civil engineering (51%)
- 2,000 MCHF for technical infrastructure (19%)
- 3,100 MCHF accelerator and injector (20%)

most of this to be recuperated for FCC-hh!

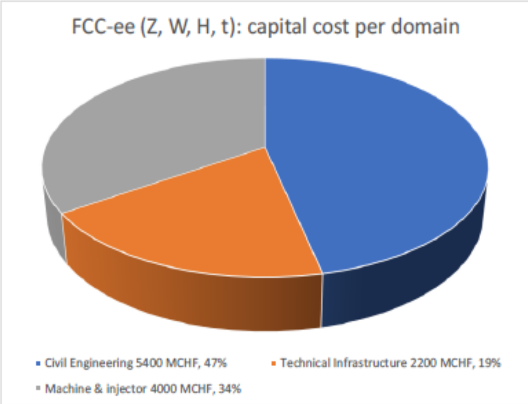
First step is O(10BCHF)



Complement cost for phase2 (tt) amounts to 1,100 MCHF

- 900 MCHF for RF, 200 MCHF for associated technical infrastructure

over following 10 years.

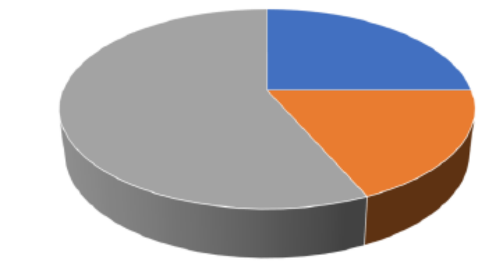


Future Circular Collider Study
Michael Benedikt
Physics at FCC, 4 March 2019
19

FCC-hh cost estimate

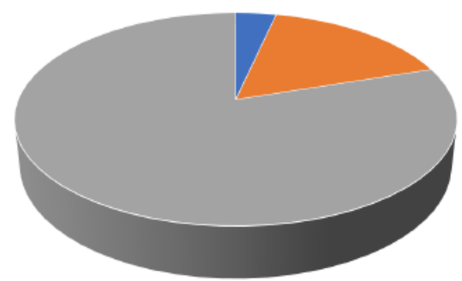
Total construction cost in "stand-alone" is 24,000 MCHF

- 13,600 MCHF accelerator and injector (57%)
  - Major part corresponds to the 4,700 Nb_3Sn 16 T main dipole magnets, totalling 9,400 MCHF, at cost target of 2 MCHF/magnet.
- 6,000 MCHF construction cost for surface and underground civil engineering (25%)
- 4,400 MCHF for technical infrastructures (18%)



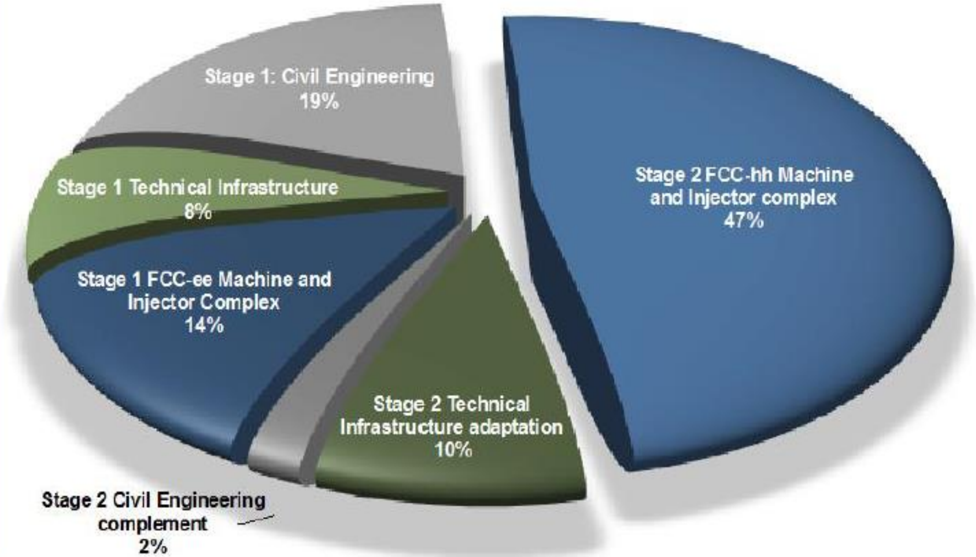
Total construction cost in "combined mode" following FCC-ee is 17,000 MCHF.

- CE and TI from FCC-ee re-used
- 600 MCHF for additional CE structures:
  - Two experiment caverns for the lower luminosity experiments
  - Beam dump tunnels and the two transfer lines from LHC
- 2,800 MCHF for additional TI, driven by cryogenics infrastructure



FCC-integrated cost estimate

Domain	Cost in MCHF
Stage 1 - Civil Engineering	5,400
Stage 1 - Technical Infrastructure	2,200
Stage 1 - FCC-ee Machine and Injector Complex	4,000
Stage 2 - Civil Engineering complement	600
Stage 2 - Technical Infrastructure adaptation	2,800
Stage 2 - FCC-hh Machine and Injector complex	13,600
TOTAL construction cost for integral FCC project	**28,600**



could we start with a cheaper hadron collider instead of the lepton collider?
request from ESPP to CERN management:

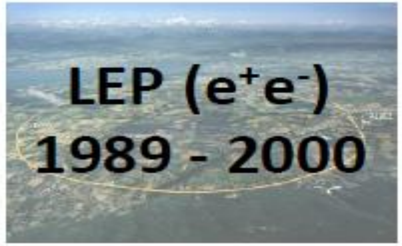
parameter	FCC-hh		FCC-hh-6T	HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	100		37.5	27	14	14
dipole field [T]	16		6	16	8.33	8.33
beam current [A]	0.5		0.6	1.1	1.1	0.58
synchr. rad. power/ring [kW]	2400		57	101	7.3	3.6
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	10 (lev.)	16	5 (lev.)	1
events/bunch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

but we know it is significantly more expensive and not sooner than FCC-ee!

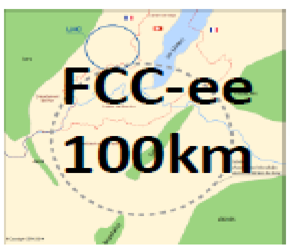
AND THE WINNER IS…..

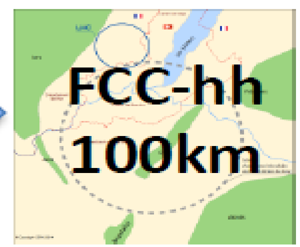
- 27km tunnel

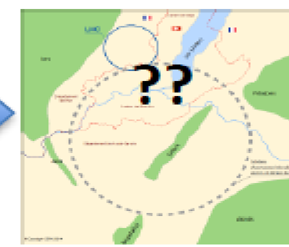


M. Aleksa

- The next step: 100km tunnel







a 10-20 TeV muon collider using the 45 GeV stored e+ as LEMMA SOURCE?

FCC data taking starts at the end of HL-LHC

We have gone a long way!

2010-11-12 : ideas, wishes, basic concepts, (VHE-LHC, LEP3, TLEP), Higgs discovery
2013 ESPP2013 wants «ambitious post-LHC accelerator projcet »
2014 Kick-off meeting

2018 ESPP contributions and CDR submitted

FCC can be done!

Starting with the e+ e- collider.

2019→ Start of a new era towards realization

2019 Press release on FCC CDR release
FCC CDR physics presentation 4-5 March at CERN;
Plenary Meeting (ESPP) Granada 13-17 May
FCC General meeting in 24-28 June in Brussels https://indico.cern.ch/event/727555

FCC-ee discovery potential and Highlights

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
-- ~20-100 fold improved precision on many EW quantities (equiv. to factor 5-10 in mass)
$m_{Z,}$ m_W, m_{top} , $\sin^2\theta_w^{eff}$, R_b , α_{QED} (m_z) α_s $(m_z\, m_W\, m_\tau)$, Higgs and top quark couplings
model independent «fixed candle» for Higgs measurements

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..)

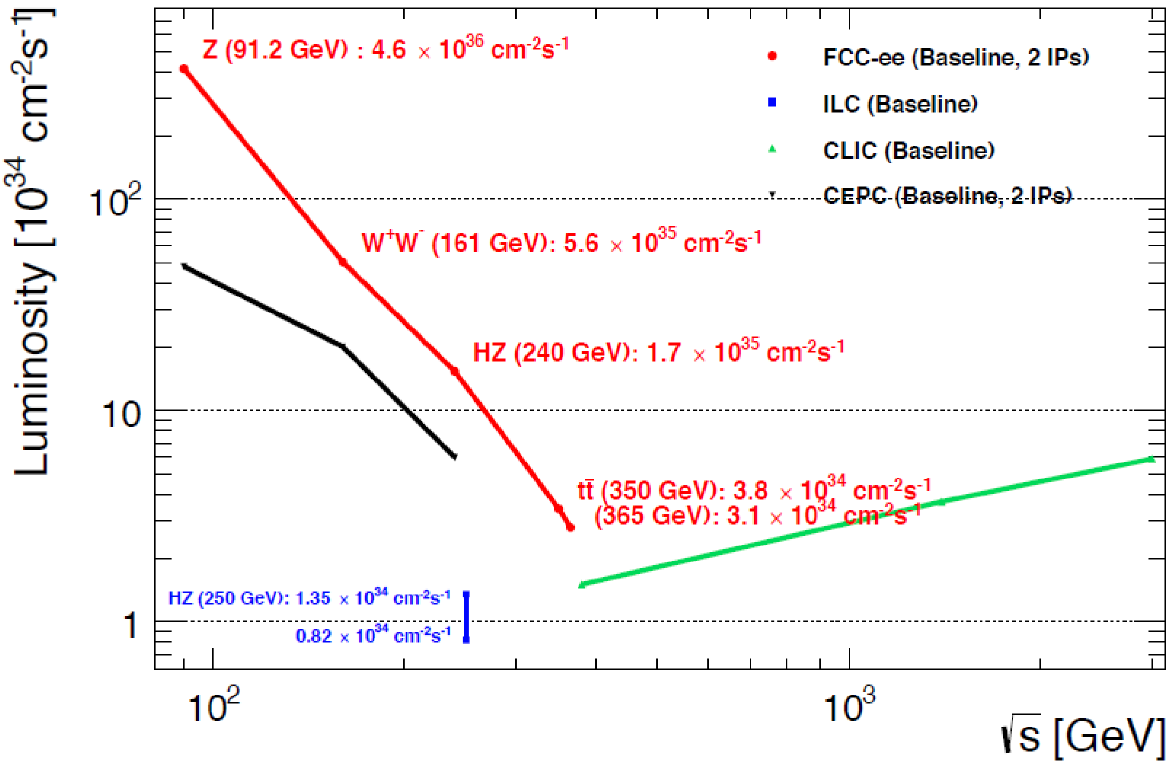
DISCOVER dark matter as «invisible decay» of H or Z (or in LHC loopholes)

DISCOVER very weakly coupled particle in 5-100 GeV energy scale
such as: Right-Handed neutrinos, Dark Photons, ALPS, etc…
+ and many opportunities in – e.g. QCD (α_s @ 10^{-4}, fragementations, H→ gg) etc….

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

The FCC-ee offers a lot more

- Ultimate e^+e^- collider as
  - Higgs factory 10^6 $e^+e^- \to HZ$
  - EW & top factory
    - 5×10^{12} $e^+e^- \to Z$
    - 10^8 $e^+e^- \to W^+W^-$, 10^6 $e^+e^- \to t\bar{t}$
    - Transverse polarization
    - Sensitive to NP up to 100 TeV
  - Flavour factory
    5×10^{12} $b\bar{b}$, $c\bar{c}$ & 10^{11} $\tau^+\tau^-$ events
  - Precision tool
    - QED: $\alpha_{QED}(m_Z)$
    - QCD: $\alpha_S(m_Z)$, 10^5 $H \to gg$
  - Potential discovery of FIP
    - ALPs, RHν's,...



- FCC-ee measurements complementary to and synergistic with 100 TeV pp collisions

FCC-hh discovery potential and 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

<u>Give the final word on natural Supersymmetry, and WIMPS</u>

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

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

FCC-eh Discovery Potential and Highlights

FCC-ep explores hitherto untouched domain of (x,q2) DIS plane and provides production of high mass SM particles (H, top) in cleaner conditions than pp.

-- extremely precise structure function work

important input on structure functions for FCC-hh

complete resolution of the partonic contents of the proton, for the first time

high precision α_s $O(10^{-4})$ similar to FCC-ee from totally different source

-- $2\ 10^6$ Higgs produced from from W & Z to deliver precise H couplings

complementary to ee -- esp (g_{HWW})

-- Searches for new physics (Leptoquarks, RH neutrinos, etc...)

in new domain of mass and couplings

-- rich top (Vtb @% level, FCNC) and HF physics program

-- Discovery in QCD: non-linear parton evolutions, instantons?, ..

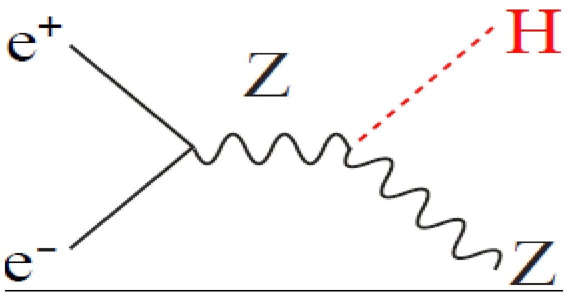
-- Unique electron-ion physics related to QGP physics arXiv:1906.02693, FCC-ee: Your questions answered

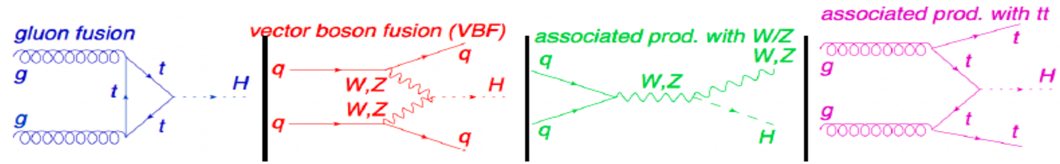
e⁺e⁻ collisions | pp collisions

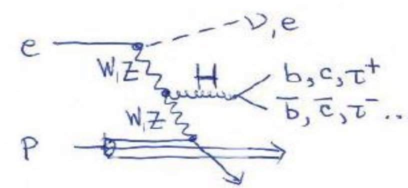
Physics ↓ / $\sqrt{s}$ →	m_Z	$2m_W$	HZ max. 240-250 GeV	$2m_{top}$ 340-380 GeV	500 GeV	1.5 TeV	3 TeV	28 TeV 37 TeV 48 TeV	100 TeV	Leading Physics Questions
Precision EW (Z, W, top)	Transverse polarization	Transverse polarization		m_W, α_S						Existence of more SM-Interacting particles
QCD (α_S) QED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

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

The FCC integrated program FCC (ee and hh, ep) by way of
<u>synergy and complementarity</u>
will provide the most complete and model-independent studies of the Higgs boson







ee provides 10^6 ZH + 10^5 Hνν evts

-- Model-Independent Γ_H determination

-- g_{HZZ} Higgs coupling to Z at 0.17%

→fixed candle for all measurements

(WW, bb, ττ, cc, gg etc… <% level)

→ even possibly Hee coupling!

also first 40% effect of g_{HHH} from loop effect (22% with 4 IPs)

pp provides 2.10^{10} Higgs !

(Using **ee** 'candle') will provide

-- model-independent ttH coupling to <1%

-- rare decays (μμ, γγ, Zγ …)

-- invisible width to 5 10^{-4} BR

-- Higgs self coupling g_{HHH} to 5%

ep will produce 2.5 10^6 Higgs

(using **ee** 'candle') **further improves on several measurements esp. g_{HWW} coupling**

Superb complementarity!

CONCLUSIONS

-- The FCC design study has established the feasibility -- or the path to feasibility -- of an ambitious set of colliders after LEP/LHC, at the cutting edge of knowledge and technology. **FCC can be done!**

-- FCC-ee and FCC-hh have outstanding physics cases each in their own right

-- the sequential implementation of FCC-ee, FCC-hh (AA) with eh option offers the broadest physics expolration proposed today

big jumps in **Sensitivity, Precision, Energy**

The discussions within the community (European Strategy for Patricle Physics 2010) as well as with the host states (France and Switzerland) are in taking place

-- An attractive scenario of staging and implementation covers (>) 70 years of exploratory physics, taking full advantage of the **synergies and complementarities**.

FCC (ee) can start seamlessly at the end of HL-LHC

FINAL WORDS

The proposed integrated FCC is a large, ambitious, expensive facility

The size is optimal for studying the heavy particles of the Standard Model with an e+e- collider, using them to search for new physics;
It guarantees a big jump in energy reach for the hadron collider, which is itself a formidable heavy particle factory.

Alternative facilities that are proposed to provide e.g. the same table of Higgs properties are 1) less precise 2) not much cheaper and 3) considerably less broad in physics ability.

The other routes to 100 TeV are less precise, less complete, and more expensive.

CERN is the best place for such a challenging enterprise, given its demonstrated extraordinary competence, its international membership, and the CERN existing infrastructure: accelerator complex, including the injectors, cryogenics, etc.
(Building FCC in a green field would be much more challenging and risky)

NEXT STEPS 2019-2010

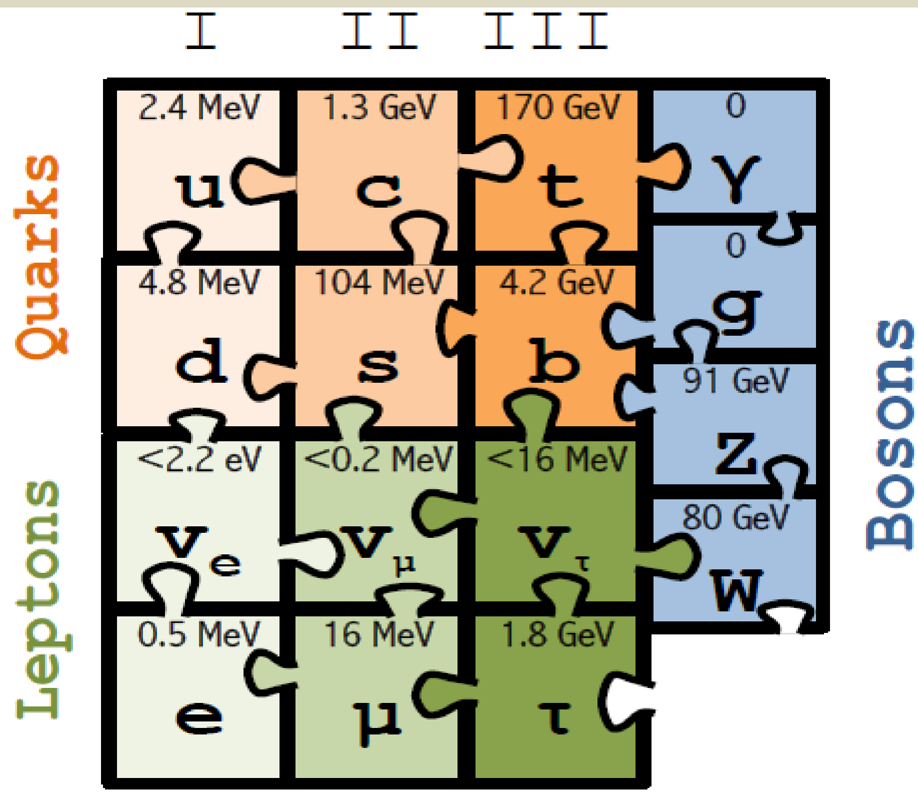
Iteration of tunnel and surface structures layout and implementation with host states.

- **Adaptation of CE, machine designs, etc. according to implementation optimisation.**
- **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**
- **Preparation of EU H2020 DS project (INFRADEV call November 2019), focused on preparations for infrastructure implementation.**

SPARES

Particle physics has arrived at an important moment of its history

1989-1999: top mass predicted (LEP, mostly Z mass&width)
top quark discovered (Tevatron)
t'Hooft and Veltman get Nobel Prize 1999

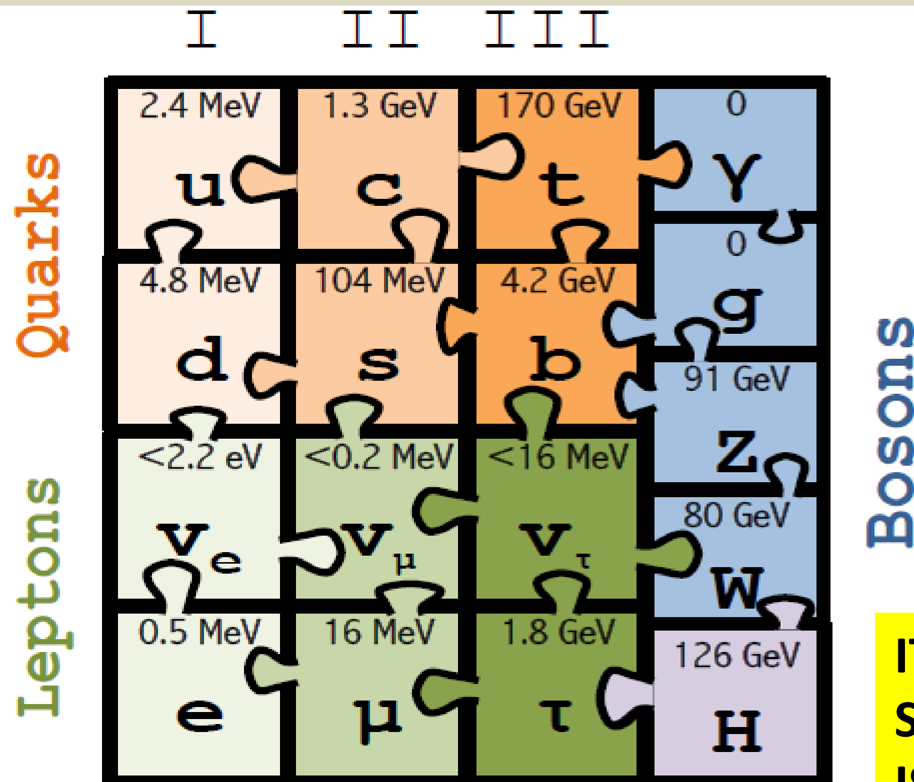


(c) Sfyrla

1997-2013 **Higgs boson mass cornered** (LEP H, M_Z etc +Tevatron m_t , M_W)

Higgs Boson discovered (LHC)

Englert and Higgs get Nobel Prize 2013

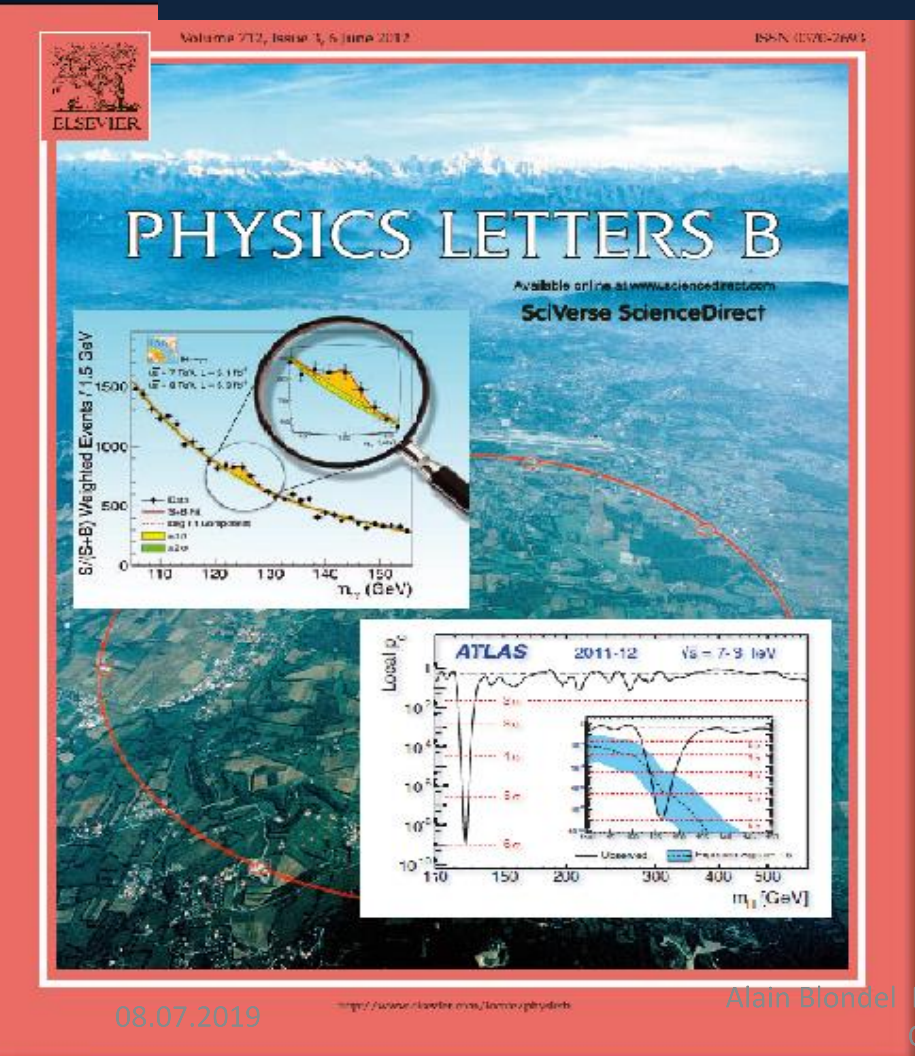


(c) Sfyrla

IT LOOKS LIKE THE STANDARD MODEL IS COMPLETE.....

NB in fact we know from oscillations and cosmology that all 3 neutrino masses are less than ~0.1 eV

SEVEN YEARS AGO ALREADY



The Standard Model is a very consistent and complete theory.

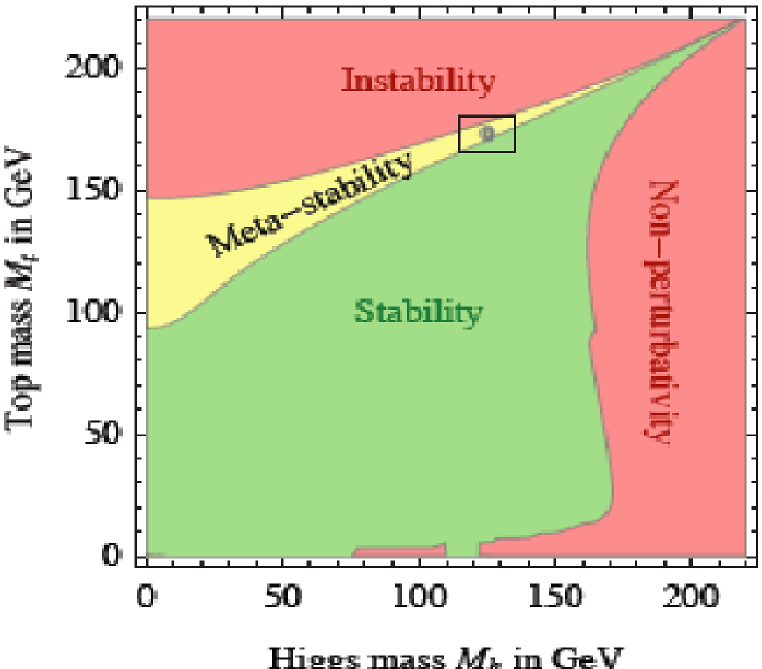
It explains all known collider phenomena and almost all particle physics (except ν's)

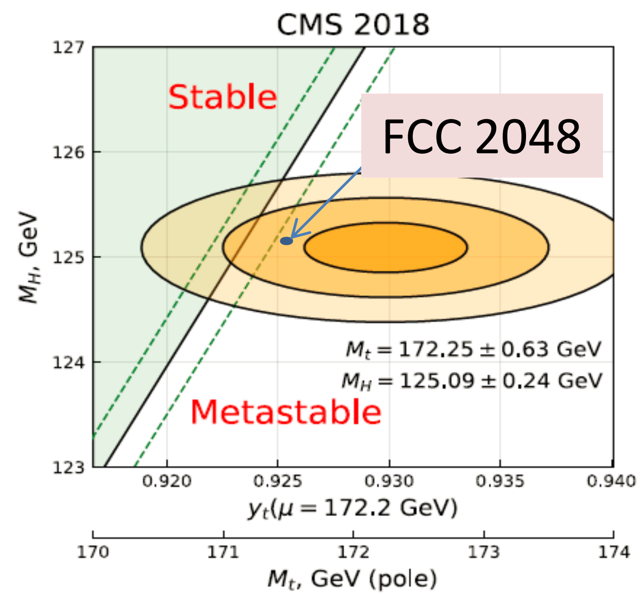
– this was beautifully verified at LEP, SLC, Tevatron and the LHC.

-- the EWPO radiative corrections predicted top and Higgs masses

assuming SM *and nothing else*

we can even extrapolate the Standard Model all the way to the the Plank scale :





Asymptotic safety of gravity and the Higgs boson mass

Mikhail Shaposhnikov
Institut de Théorie des Phénomènes Physiques, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

Christof Wetterich
Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, D-69120 Heidelberg, Germany

12 January 2010

Abstract

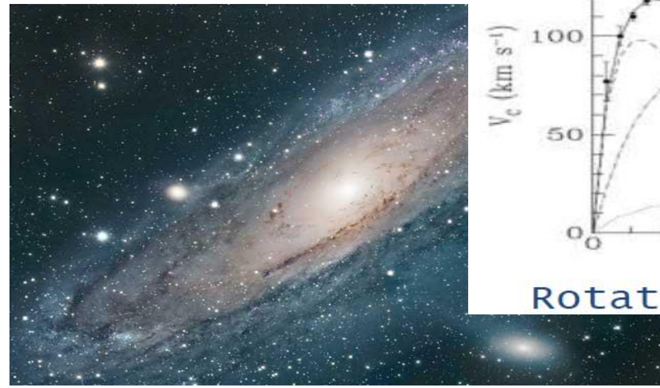
There are indications that gravity is asymptotically safe. The Standard Model (SM) plus gravity could be valid up to arbitrarily high energies. Supposing that this is indeed the case and assuming that there are no intermediate energy scales between the Fermi and Planck scales we address the question of whether the mass of the Higgs boson m_H can be predicted. For a positive gravity induced anomalous dimension $A_\lambda > 0$ the running of the quartic scalar self interaction λ at scales beyond the Planck mass is determined by a fixed point at zero. This results in $m_H = m_{\min} = 126$ GeV, with only a few GeV uncertainty. This prediction is independent of the details of the short distance running and holds for a wide class of extensions of the SM as well. For $A_\lambda < 0$ one finds m_H in the interval $m_{\min} < m_H < m_{\max} \simeq 174$ GeV, now sensitive to A_λ and other properties of the short distance running. The case $A_\lambda > 0$ is favored by explicit computations existing in the literature.

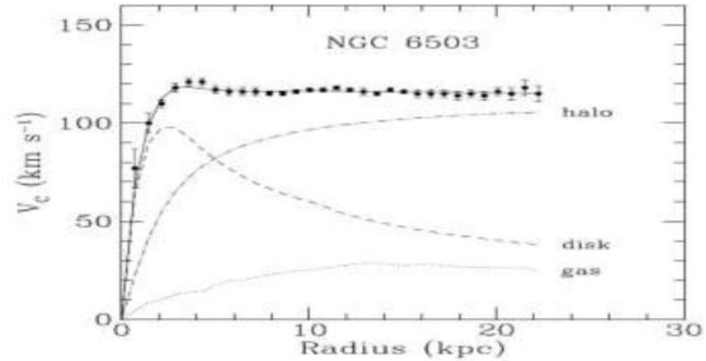
Key words:
Asymptotic s...
PACS: 04.60....

Detecting the Higgs scalar with mass around 126 GeV at the LHC could give a strong hint for the absence of new physics influencing the running of the SM couplings between the Fermi and Planck/unification scales.

Is it the end?

We cannot explain:



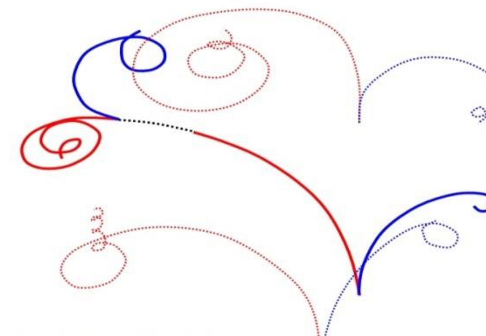


Rotation curve for Galaxy

Dark matter

Standard Model particles constitute only 5% of the energy in the Universe

Were is antimatter gone?



What makes neutrino masses?

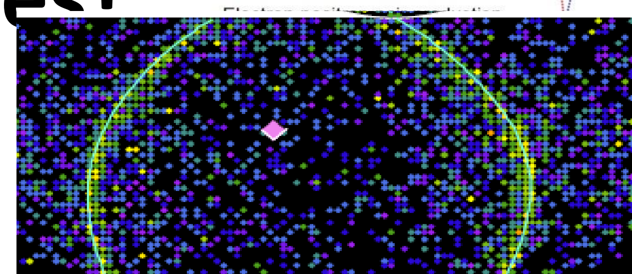
Not a unique solution in the SM --

Dirac masses (why so small?)

Majorana masses (why not Dirac?)

Both (the preferred scenarios, see-saw…) ?

➔ heavy right handed neutrinos?



Is it the end?

Certainly not!

-- Dark matter

-- Baryon Asymmetry in Universe

-- Neutrino masses

These facts require particle physics explanations.

To which one can add many theoretical questions on the SM

are experimental proofs that there is more to understand.

We must continue our quest, but HOW?

Direct observation of new particles (but not only!)

New phenomena (ex: Neutral currents, neutrino oscillations, CP violation..)

Deviations from precise predictions

(ref. Uranus to Neptune, Mercury's, perihelion

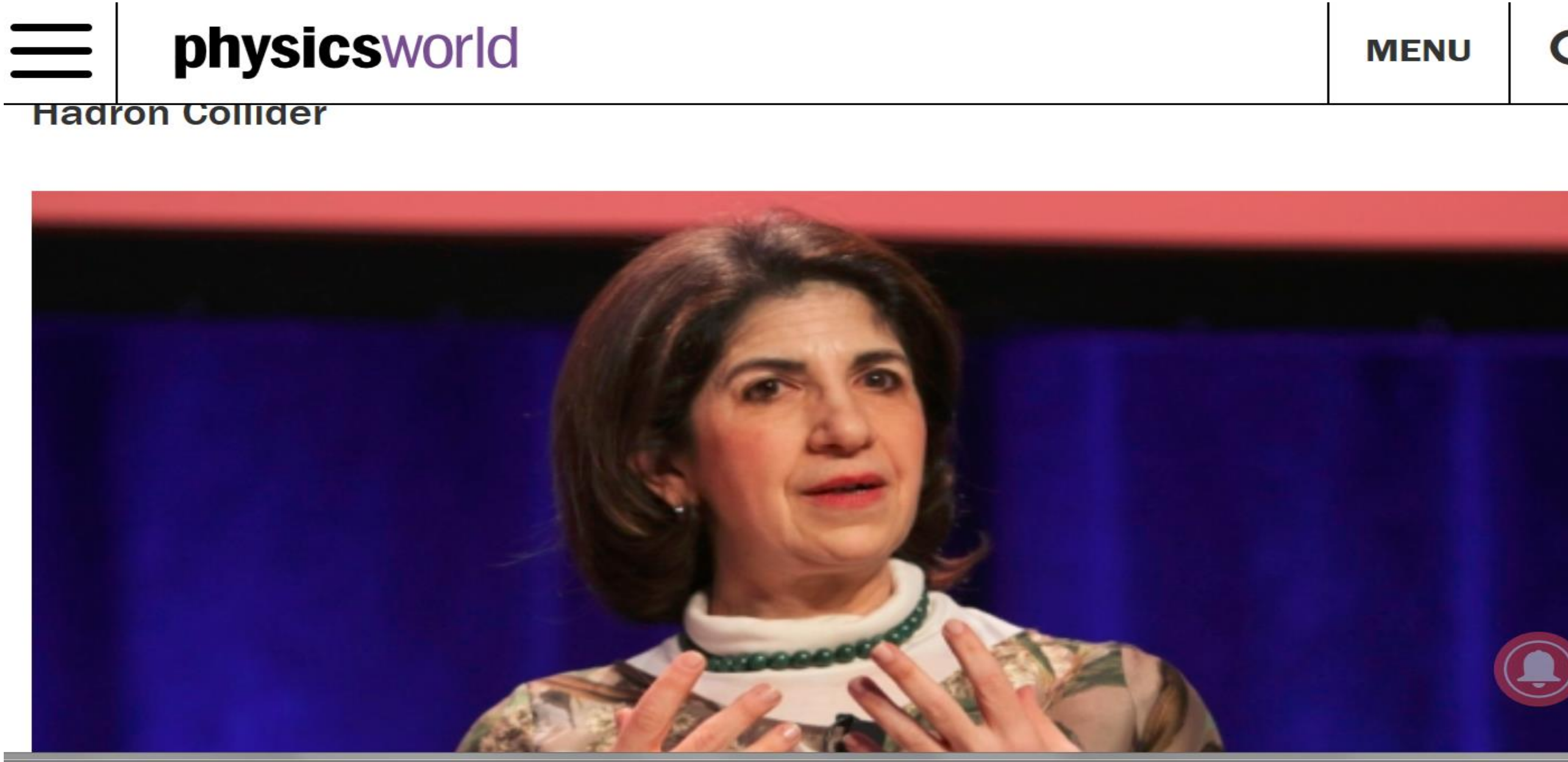
The Physics Landscape

We are in a fascinating situation: where to look and what will we find?

For the first time since Fermi theory, WE HAVE NO SCALE

The next facility must be versatile with as broad and powerful reach as possible, as there is no precise target

FCC , thanks to synergies and complementarities, offers the most versatile and adapted response to today's physics landscape,

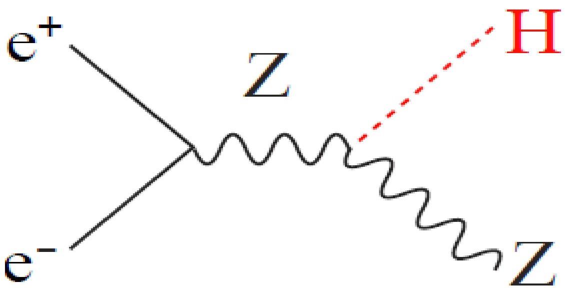


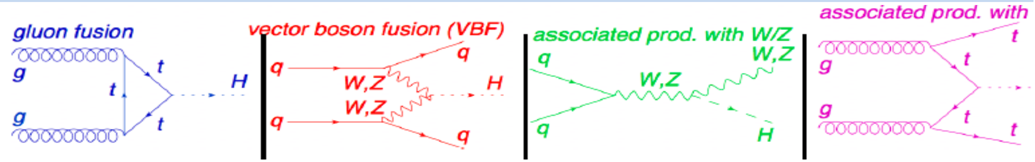
“ *“Discoveries make the front pages of the newspapers, while precise measurements of known particle don’t, but scientifically they are just as important."*

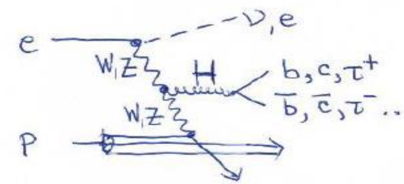
The FCC integrated program FCC (ee and hh, ep) by way of

synergy and complementarity

will provide the most complete and model-independent studies of the Higgs boson







ee provides 10^6 ZH + 10^5 Hvv evts

-- Model-Independent Γ_H determination

-- g_{HZZ} Higgs coupling to Z at 0.17%

→fixed candle for all measurements

(WW, bb, ττ, cc, gg etc… <% level)

→ even possibly Hee coupling!

also first 40% effect of g_{HHH} from loop effect (22% with 4 IPs)

pp provides 2.10^{10} Higgs !

(Using **ee** ‘candle’) will provide

-- model-independent ttH coupling to <1%

-- rare decays (μμ, γγ, Zγ …)

-- invisible width to $5\ 10^{-4}$ BR

-- Higgs self coupling g_{HHH} to 5%

ep will produce $2.5\ 10^6$ Higgs

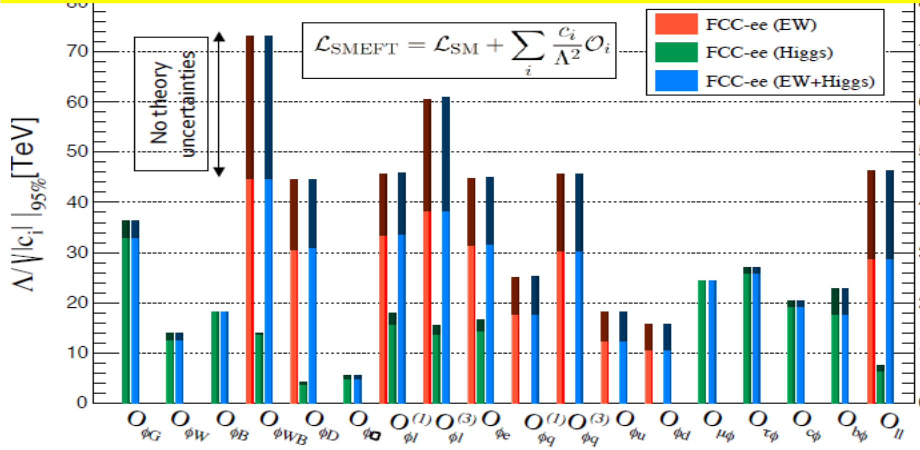
(using **ee** ‘candle’) **further improves on several measurements esp. g_{HWW} coupling**

Superb complementarity!

Pecision EW measurements: is the SM complete?

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/c^2)	91186700 ± 2200	5	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	8	100	From Z line shape scan Beam energy calibration
R_ℓ^Z ($\times 10^3$)	20767 ± 25	0.06	0.2-1	ratio of hadrons to leptons acceptance for leptons
$\alpha_s(m_Z)$ ($\times 10^4$)	1196 ± 30	0.1	0.4-1.6	from R_ℓ^Z above [29]
R_b ($\times 10^6$)	216290 ± 660	0.3	<60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD [30]
σ^0_{had} ($\times 10^3$) (nb)	41541 ± 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
$\sin^2\theta_W^{eff}$($\times 10^6$)	231480 ± 160	3	2 - 5	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z)$($\times 10^3$)	128952 ± 14	4	small	from $A_{FB}^{\mu\mu}$ off peak [20]
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 (keV/c^2)	80350000 ± 15000	600	300	From WW threshold scan Beam energy calibration
Γ_W (keV)	2085000 ± 42000	1500	300	From WW threshold scan Beam energy calibration
$\alpha_s(m_W)$($\times 10^4$)	1170 ± 420	3	small	from R_ℓ^W [31]
N_ν($\times 10^3$)	2920 ± 50	0.8	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV/c^2)	172740 ± 500	20	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV/c^2)	1410 ± 190	40	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	0.08	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	<2%	small	From E_{CM} = 365GeV run



-^- EFT D6 operators (some assumptions)

-^- Higgs and EWPOs are complementary

-^- top quark mass and couplings essential!

(the 100km circumference is optimal for this)

<-- many systematics are preliminary
and should improve with more work.

<-- tau b and c observables still to be added

<-- complemented by high energy FCC-hh

Theory work is critical and initiated

Theoretical challenges

FCC proposes a HUGE step in statistical precision w.r.t. LEP/SLC/Tevatron/LHC
(up to factor sqrt(N)~400 improvement)
Also rare processes at the level of **<10^{-12}** of Z decays (10^{-8} for W, 10^{-6} for H and top)

→ need to know rare SM processes at that kind of level!

Experiment (i.e. accelerator physics + experimental physics) will work hard to make sure that this is matched by experimental systematics and experimental backgrounds

This is a huge challenge for the theoretical community!

QED
QCD (incl. quark masses)
EW

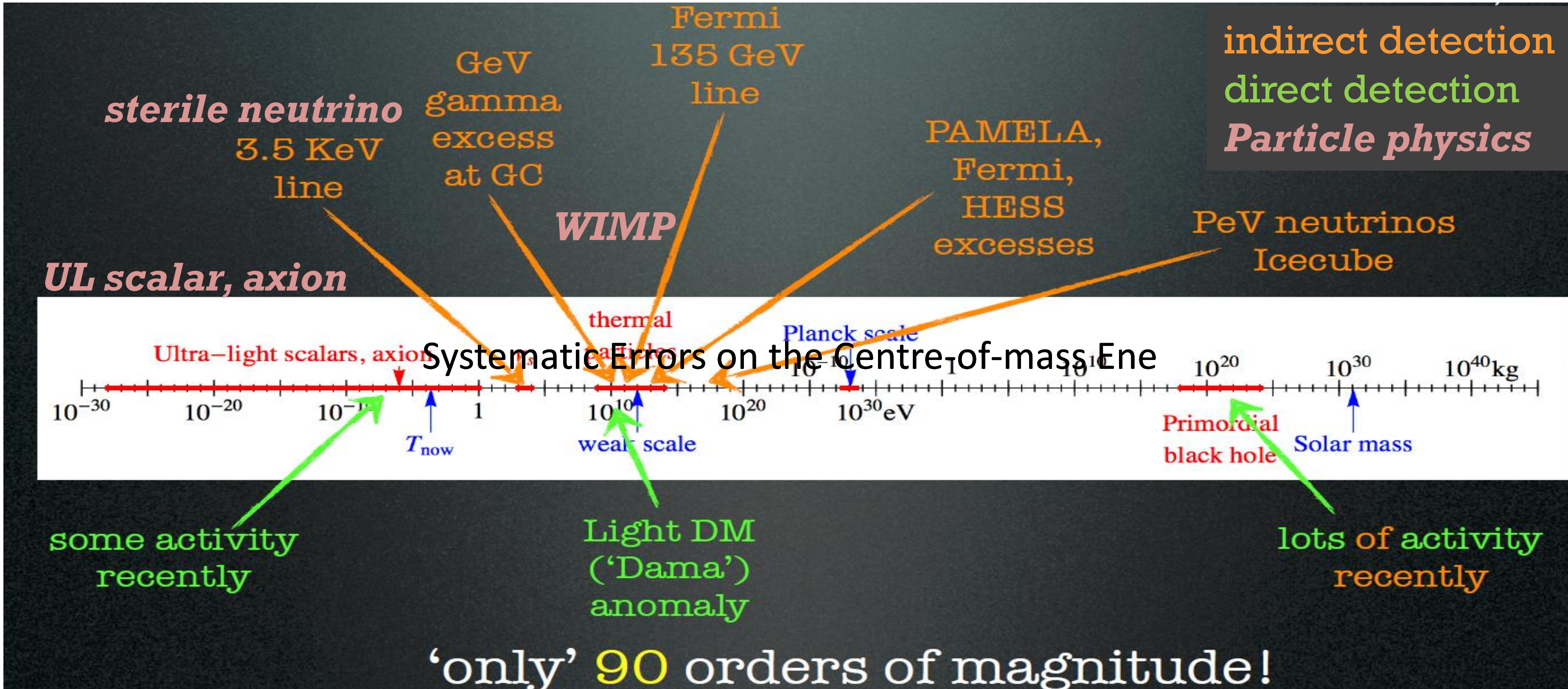
Insufficient level of theoretical precision and accuracy.	Full exploitation of machine's capabilities depends on accurate theoretical predictions of SM phenomena at levels where higher-order contributions become significant.	Set up an international collaboration, leveraging existing world-wide HEP computing infrastructures, to develop the tools and to carry out the necessary computations. This effort is assumed to require substantial committed engagement of personnel by the collaborating institutes during the design, construction and operation phases.

Nima

At higher masses -- or at smaller couplings?

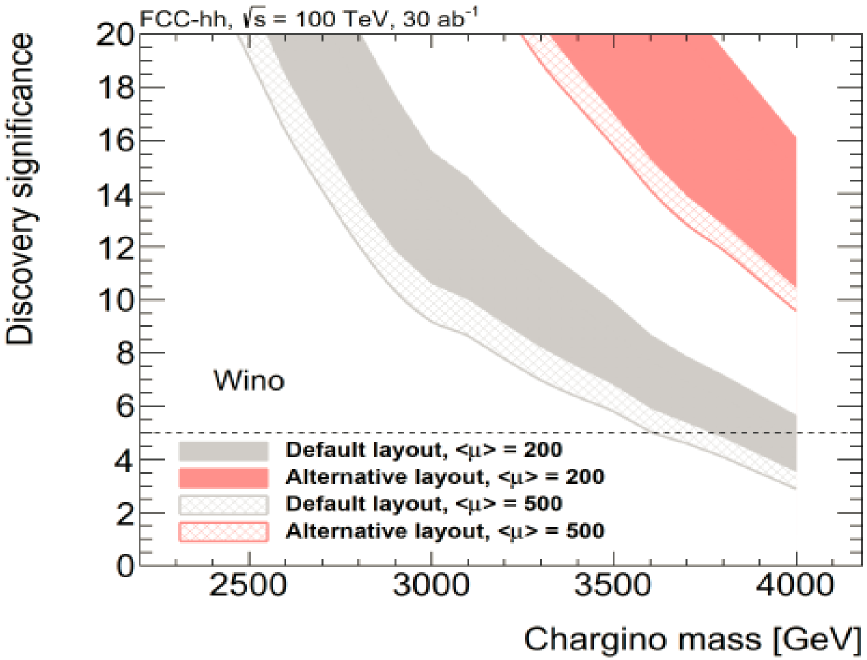
Dark Matter exists. It is made of very long lived neutral particle(s).

Plausible candidates:

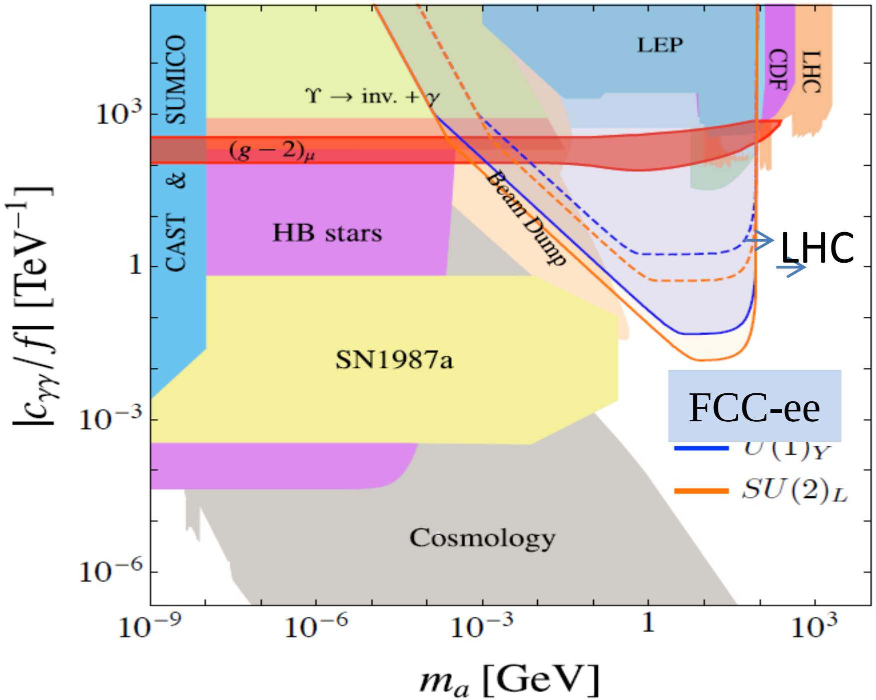


Cirelli

DM neutralino search at the FCC-hh



FCC-ee Z Axion-like particle



"FCC-hh covers the full mass range for the discovery of these WIMP Dark Matter candidates"

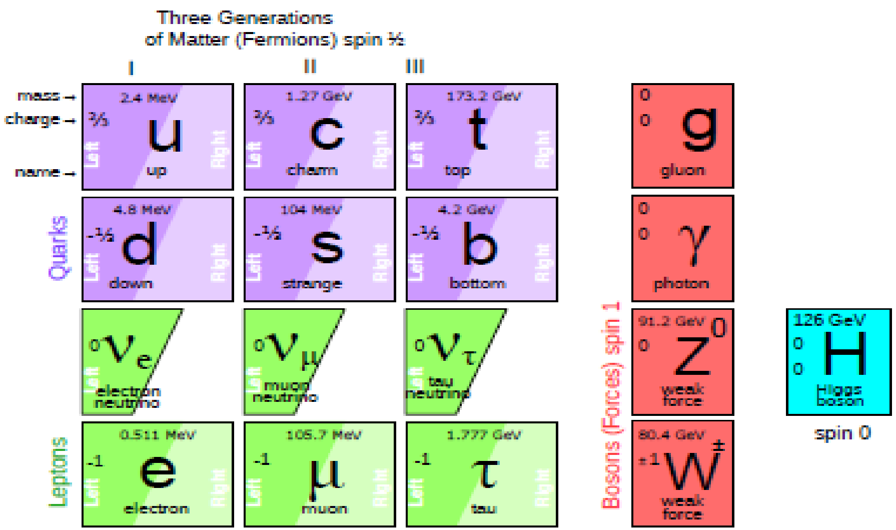
$Z \to \gamma a$ with $a \to \gamma\gamma$

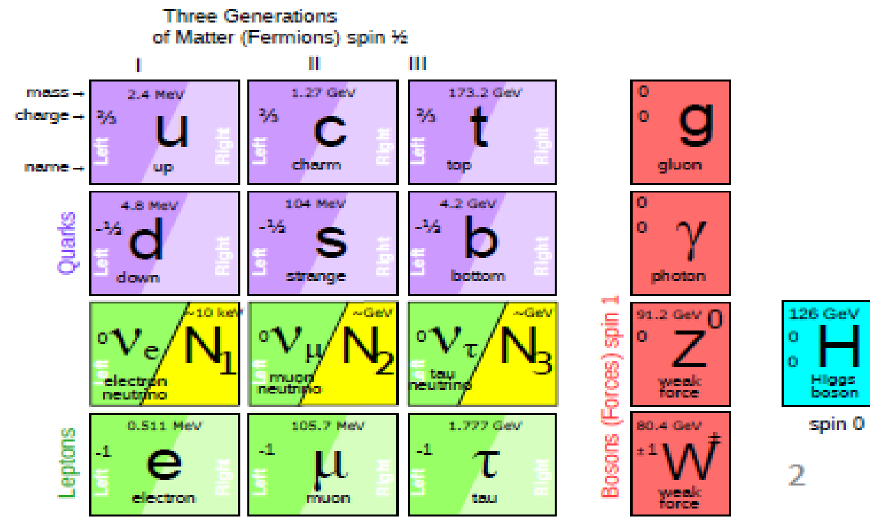
FCC-ee (solid lines)

Run-2 of the LHC with 300 fb^{-1} (dashed)

«The Z run of FCC-ee is particularly fertile for discovery of particles with very small couplings»

at least 3 pieces are still missing





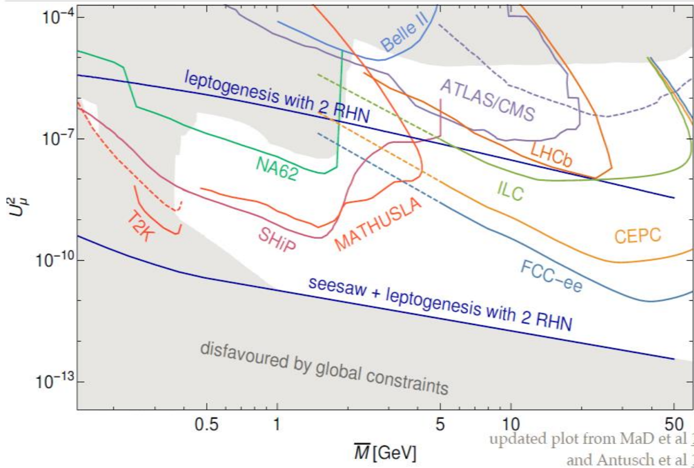
2

Since 1998 it is established that neutrinos have mass (oscillations) and this very probably implies new degrees of freedom

➔ «sterile», very small coupling to known particles

completely unknown masses (eV to ZeV), nearly impossile to find.

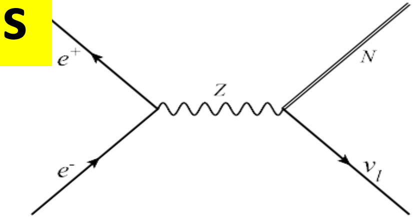
.... but could perhaps explain all: DM, BAU, ν-masses



updated plot from MaD et al 1609.09069
and Antusch et al 1710.03744
cf. also Cai et al 1711.02180

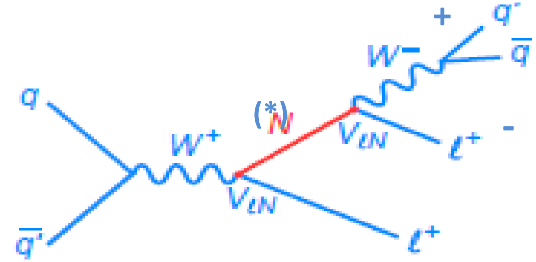
Heavy neutrinos

FCC-ee Z



or $l^{\pm}\nu$

FCC-hh



FCC-ee

-- EWPO : sensitivity 10^{-5} up to very high masses

-- high sensitivity to single N(→ $l_2^{\pm}$W) in Z decay

FCC-hh

-- production in W-> $l_1^{\pm}$ + N(→ $l_2^{\pm}$W) (LNV+LFV)

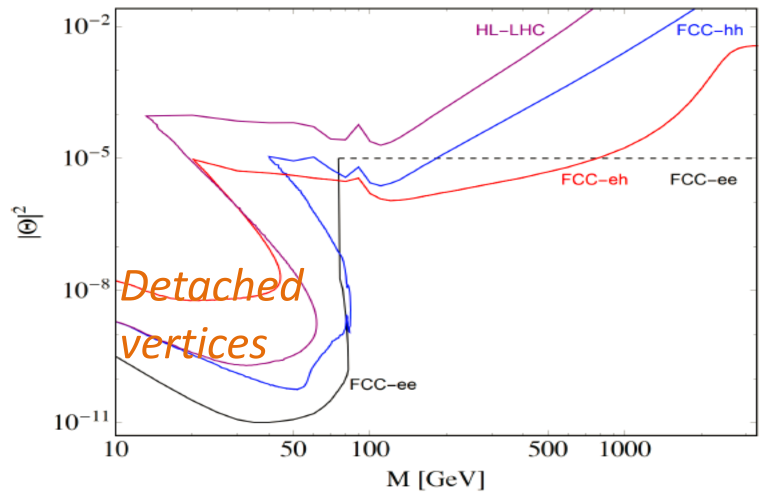
with initial and final lepton charge and flavour

FCC e-p

-- production in CC $e^{\pm}$ p → X N(→ $l^{\pm}$W) high mass

Complementarity:

discovery + studies of FNV and LFV!



Massive neutrino mechanisms for generating the matter-antimatter asymmetry in the Universe should be a central consideration in the selection and design of future colliders. (neutrino town meeting report to ESPP)

FCC-ee discovery potential and Highlights

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

-- ~20-100 fold improved precision on many EW quantities (equiv. to factor 5-10 in mass)

m_Z, m_W, m_{top} , $\sin^2 \theta_w^{eff}$, R_b , α_{QED} (m_z) α_s $(m_z\, m_W\, m_\tau)$, Higgs and top quark couplings

model independent «fixed candle» for Higgs measurements

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, ALPS, etc…

+ and many opportunities in – e.g. QCD (α_s @ 10^{-4}, fragementations, H→ gg) etc….

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

FCC-hh discovery potential and 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, and WIMPS

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.**

FCC-eh Discovery Potential and Highlights

FCC-ep explores hitherto untouched domain of (x,q2) DIS plane and provides production of high mass SM particles (H, top) in cleaner conditions than pp.

-- extremely precise structure function work

important input on structure functions for FCC-hh

complete resolution of the partonic contents of the proton, for the first time

high precision α_s $O(10^{-4})$ similar to FCC-ee from totally different source

-- $2\ 10^6$ Higgs produced from from W & Z to deliver precise H couplings

complementary to ee -- esp (g_{HWW})

-- Searches for new physics (Leptoquarks, RH neutrinos, etc...)

in new domain of mass and couplings

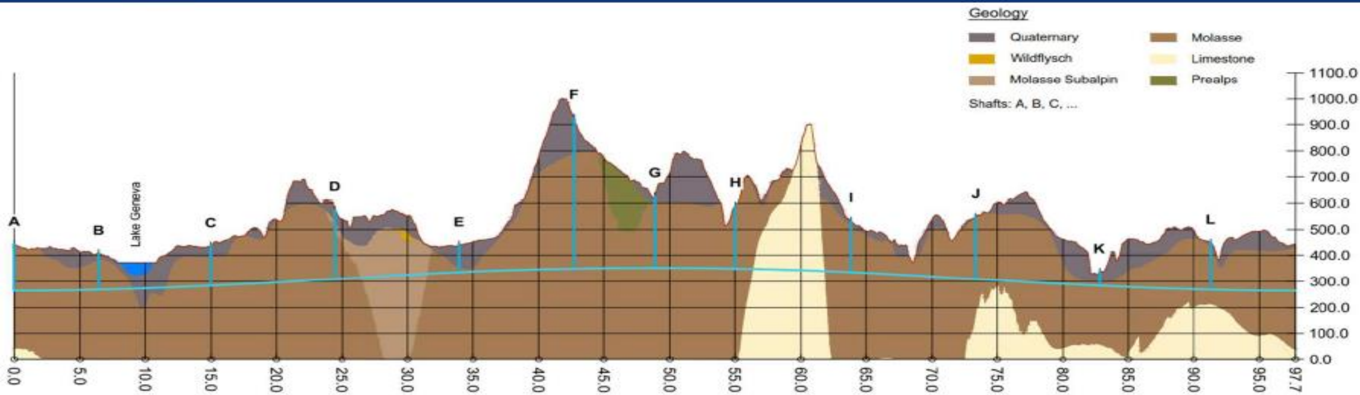
-- rich top (Vtb @% level, FCNC) and HF physics program

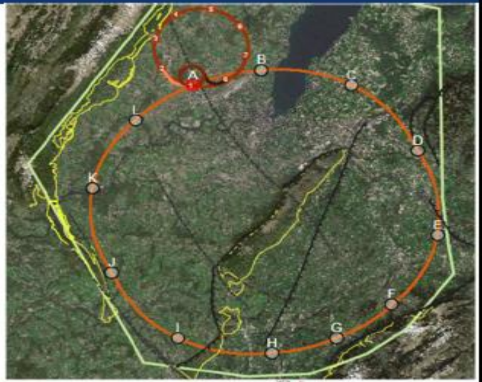
-- Discovery in QCD: non-linear parton evolutions, instantons?, ..

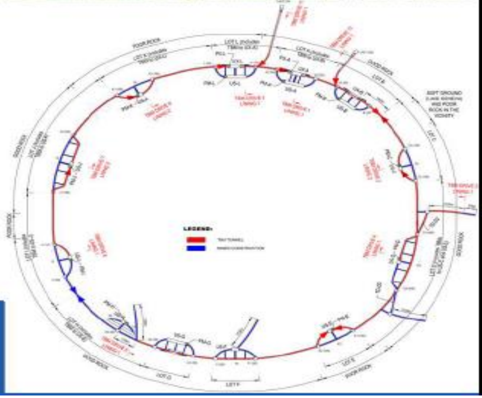
-- Unique electron-ion physics related to QGP physics

SYNERGY

FCC implementation - footprint baseline







Present baseline position was established considering:

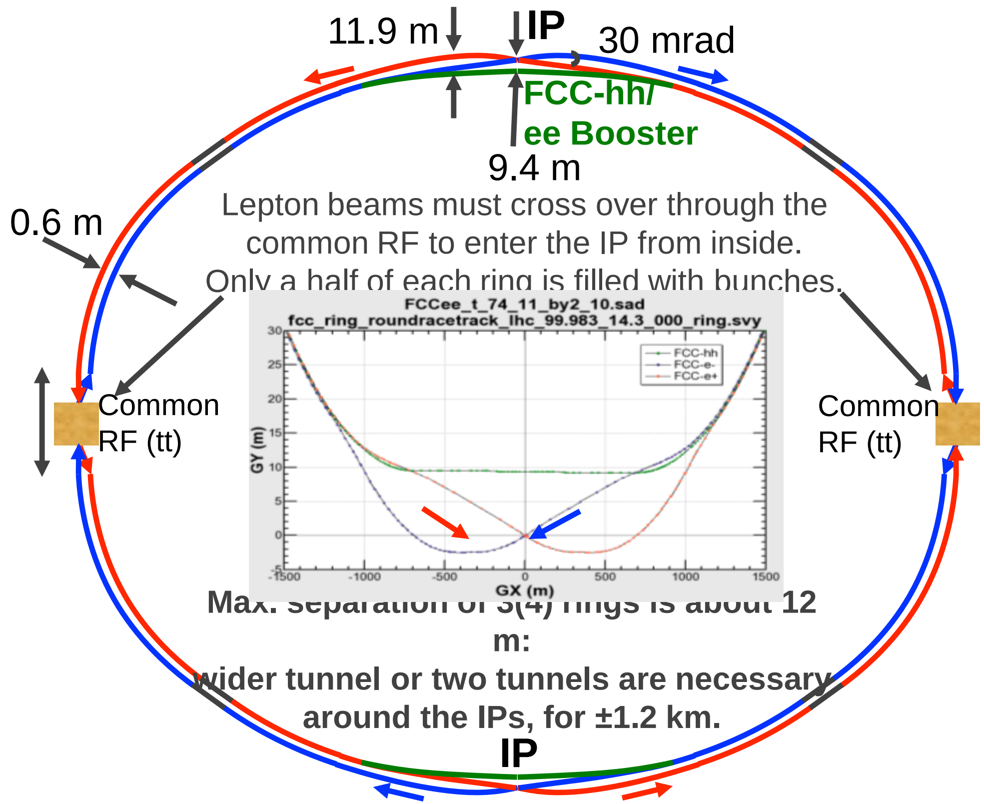
- lowest risk for construction
- fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)

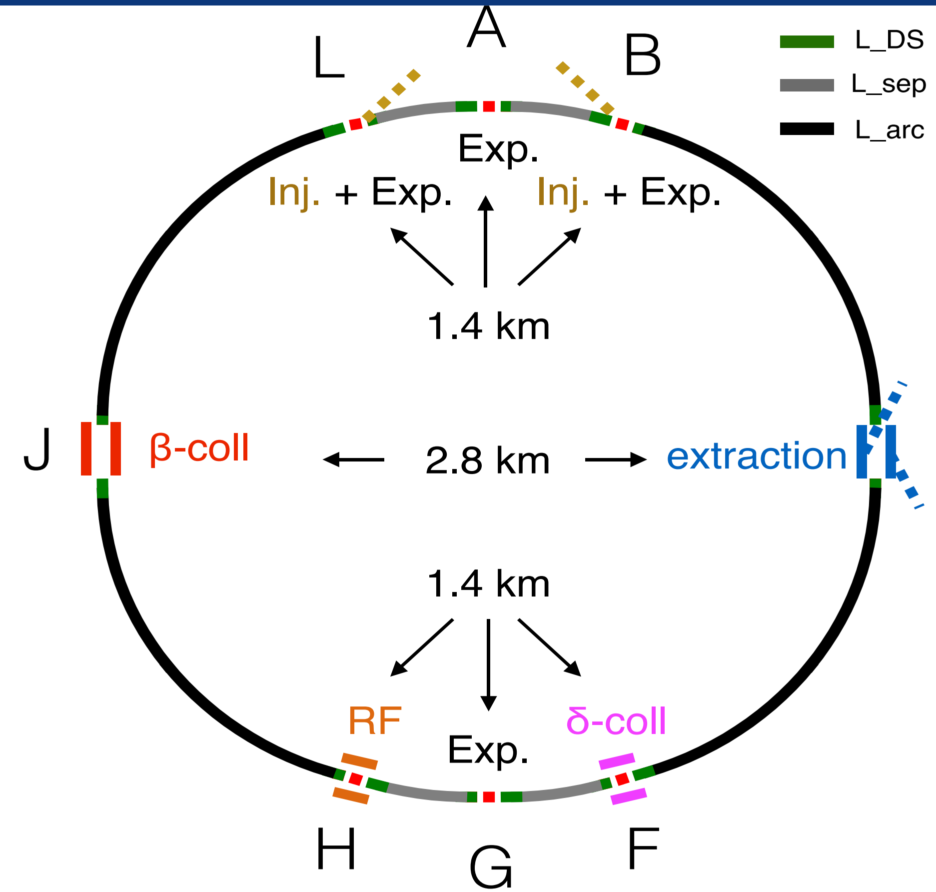
next step: review of surface site locations and machine layout

Future Circular Collider Study
Michael Benedikt
9th IPAC Vancouver, 3 May 2018

Sharing the same tunnel

common layouts for hh & ee



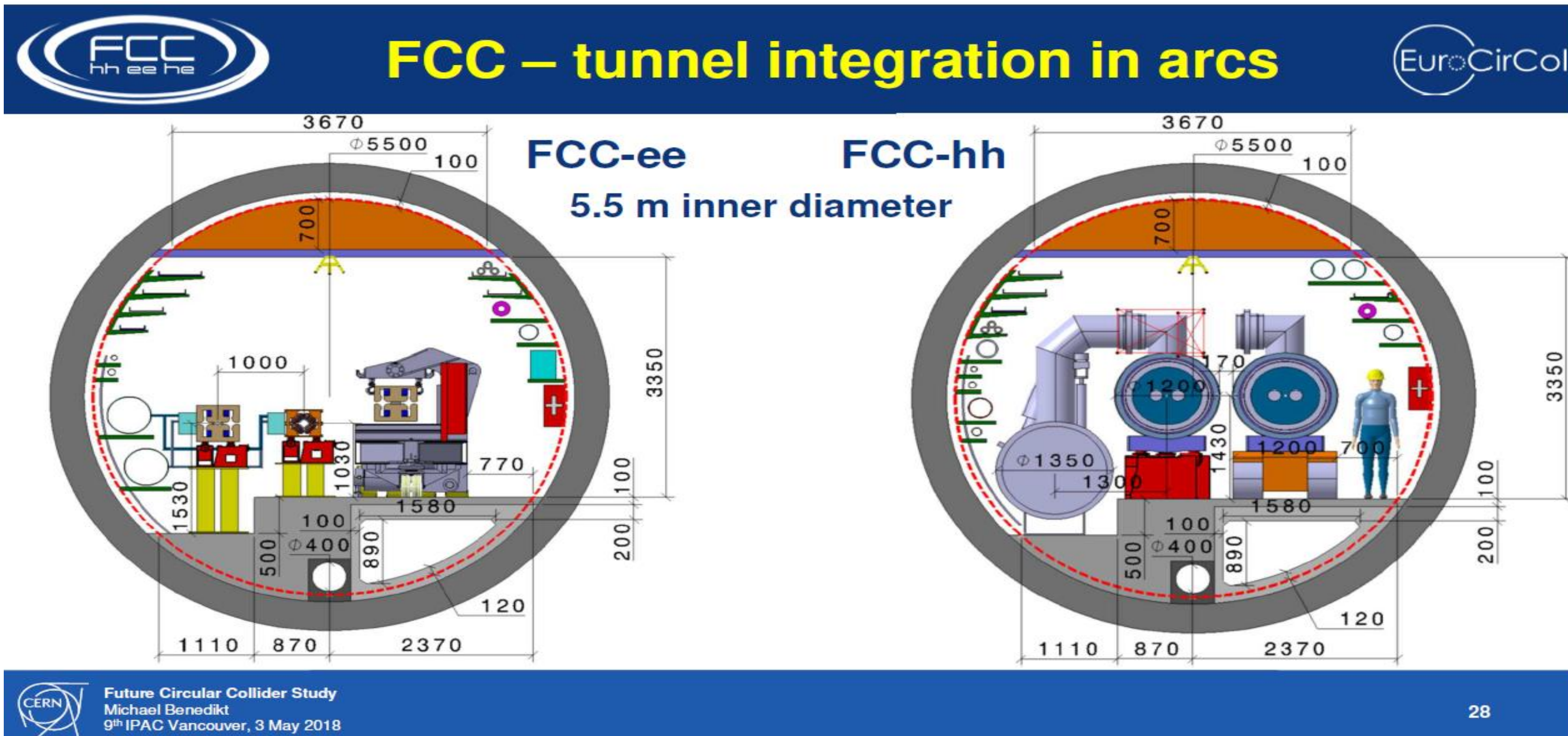


FCC-ee 1, FCC-ee 2,

FCC-ee booster (FCC-hh footprint)

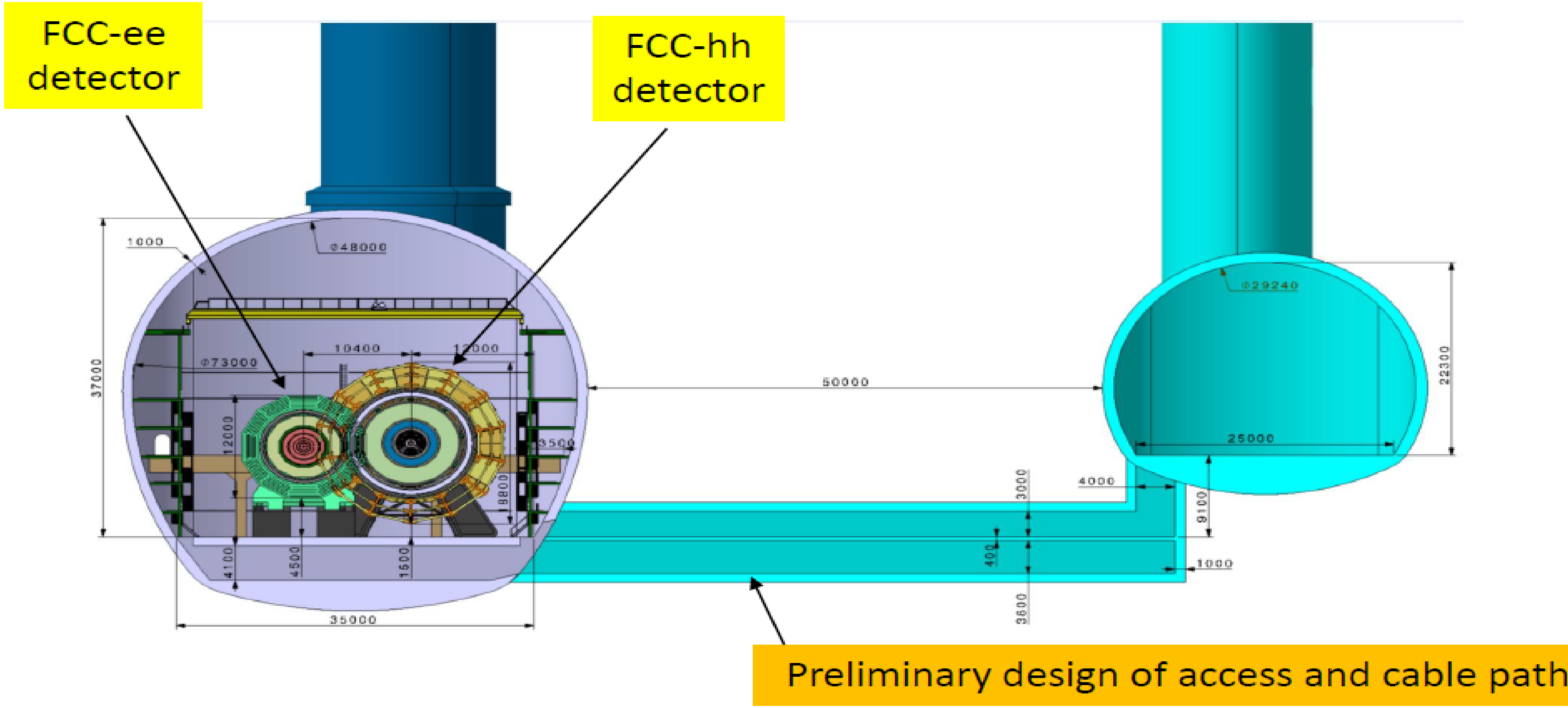
Asymmetric IR for ee, limits SR to expt

2 main IPs in A, G for both machines

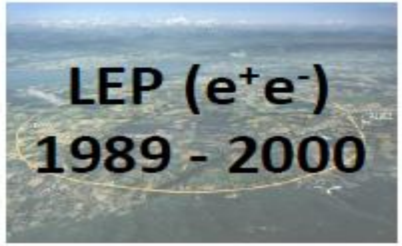

FCC – tunnel integration in arcs
FCC hh ee he
EuroCirCol
FCC-ee
FCC-hh
5.5 m inner diameter
3670
Φ5500
100
700
3350
1000
1030
770
1530
1580
100
Φ400
500
890
200
120
1110
870
2370
170
Φ1200
Φ1350
1300
1430
1200
700
Future Circular Collider Study
Michael Benedikt
9th IPAC Vancouver, 3 May 2018
28

The same caverns

Distance between detector cavern and service cavern 50 m.

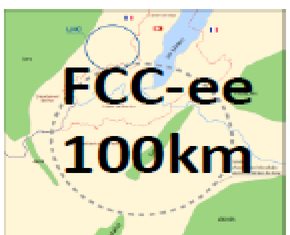


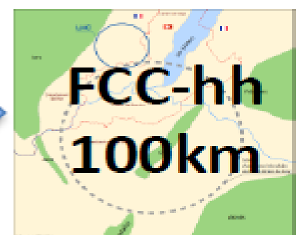
- **27km tunnel**



M. Aleksa

- **The next step: 100km tunnel**





a 10-20 TeV muon collider using the 45 GeV stored e+ as LEMMA SOURCE?

FCC data taking starts at the end of HL-LHC

We have gone a long way!

2010-11-12 : ideas, wishes, basic concepts, (VHE-LHC, LEP3, TLEP), Higgs discovery
2013 ESPP2013 wants «ambitious post-LHC accelerator projcet »
2014 Kick-off meeting

2018 ESPP contributions and CDR submitted

FCC can be done!

Starting with the e+ e- collider.

2019➔ Start of a new era towards realization

2019 (15 January) CERN directorate New Year Presentation
https://indico.cern.ch/event/779524/
Press release on FCC CDR release
FCC CDR physics presentation 4-5 March at CERN;
Plenary Meeting (ESPP) Granada 13-17 May
FCC General meeting in 24-28 June in Brussels https://indico.cern.ch/event/727555

CONCLUSIONS

-- The FCC design study has established the feasibility -- or the path to feasibility -- of an ambitious set of colliders after LEP/LHC, at the cutting edge of knowledge and technology. **FCC can be done!**

-- FCC-ee and FCC-hh have outstanding physics cases

-- each in their own right

-- the sequential implementation of FCC-ee, FCC-hh with eh option offers the broadest physics reach proposed today

big jumps in **Sensitivity, Precision, Energy**

-- An attractive scenario of staging and implementation cover 70 years of exploratory physics, taking full advantage of the **synergies and complementarities**.

FINAL WORDS

The proposed integrated FCC is a large, ambitious, expensive facility

The size is optimal for studying the heavy particles of the Standard Model with an e+e- collider, using them to search for new physics,
It guarantees a big jump in energy reach for the hadron collider, which is itself a formidable heavy particle factory.

Alternative facilities that are proposed to provide e.g. the same table of Higgs properties are 1) less precise 2) not much cheaper and 3) considerably less broad in physics ability.

The other routes to 100 TeV are less precise, less complete, and more expensive.

CERN is the best place for such a challenging enterprise, given its demonstrated extraordinary competence, its international membership, and the CERN existing infrastructure: accelerator complex, including the injectors, cryogenics, etc.
(Building FCC in a green field would be much more challenging and risky)