FUTURE CIRCULAR COLLIDER
Innovation Study

Future Circular Collider

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IFJ PAN
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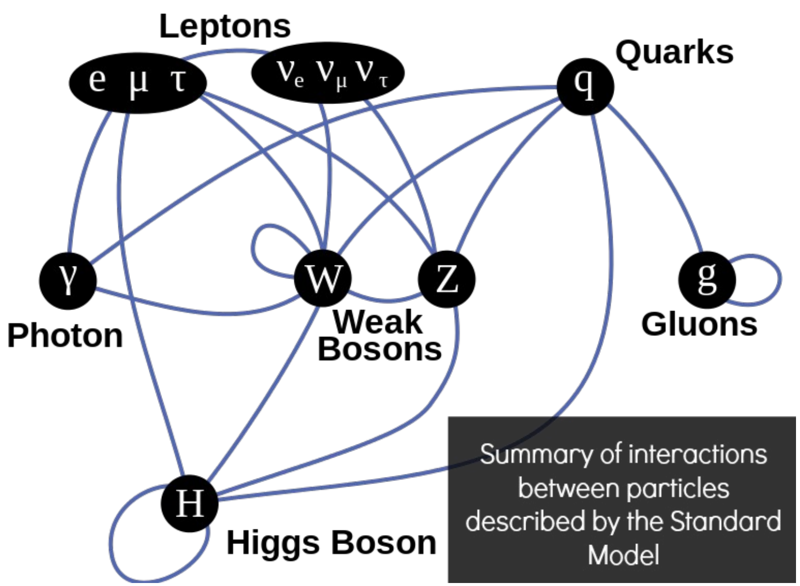
Where are we in HEP?



Summary of interactions between particles described by the Standard Model

"Hey everybody -we've discovered the Higgs boson!
It was hidden under this big pile of equations all the time!"

After the discovery of Higgs the SM is complete!

Where are we in HEP?

SM cannot be the final theory of particle physics:

- neutrino oscillations
- dark matter, dark energy
- CP violation
- Hierarchy problem, fine tunning

Something is clearly missing in SM and we have to find it!!

ATLAS SUSY Searches* - 95% CL Lower Limits

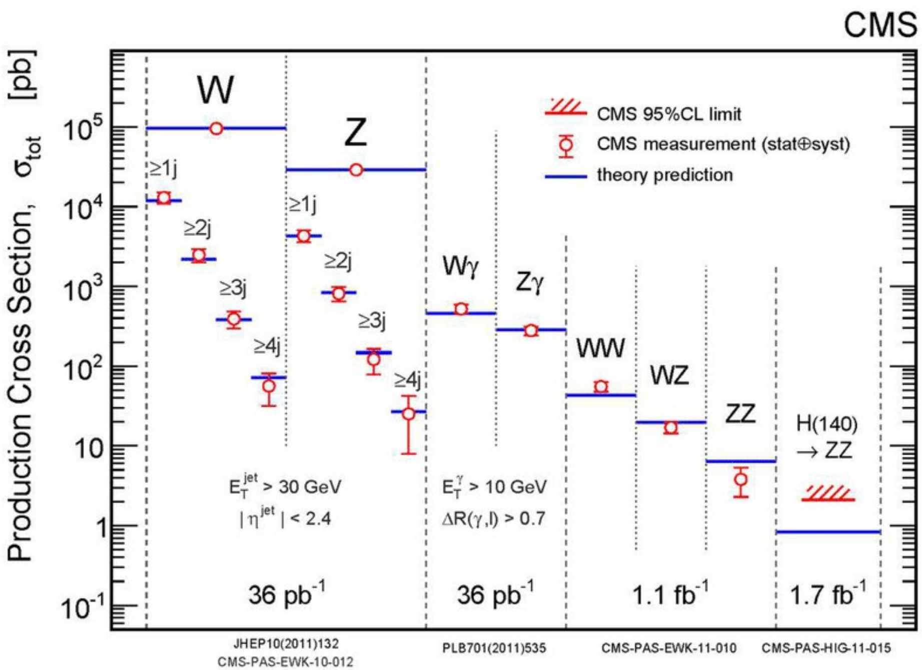
July 2019

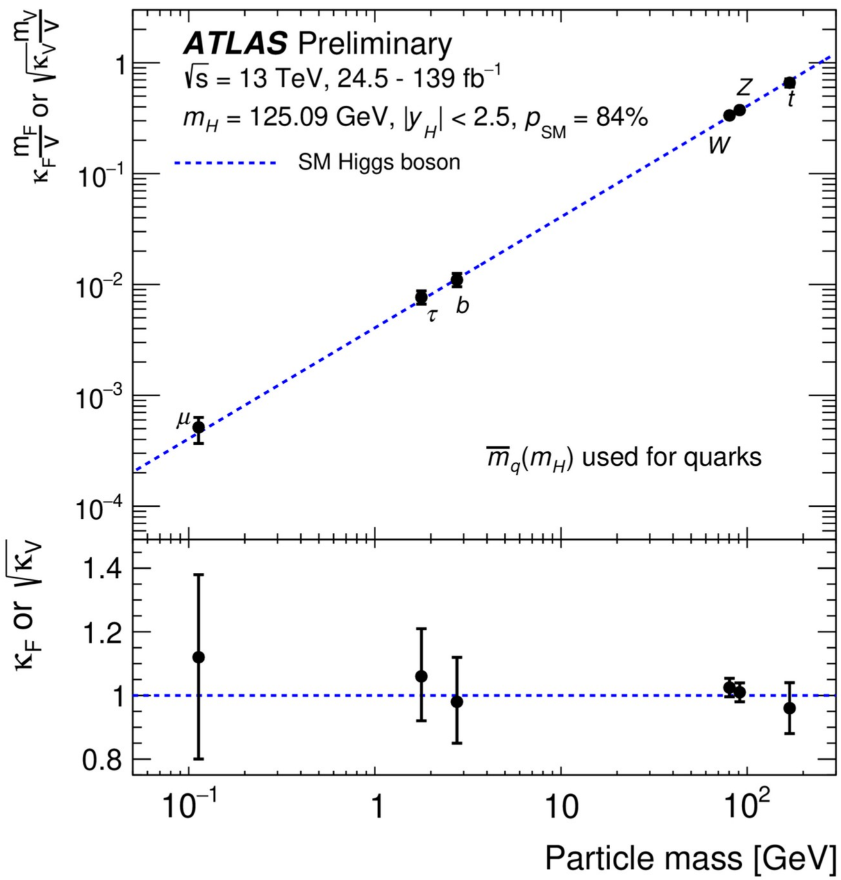
ATLAS Preliminary

$\sqrt{s}$ = 13 TeV

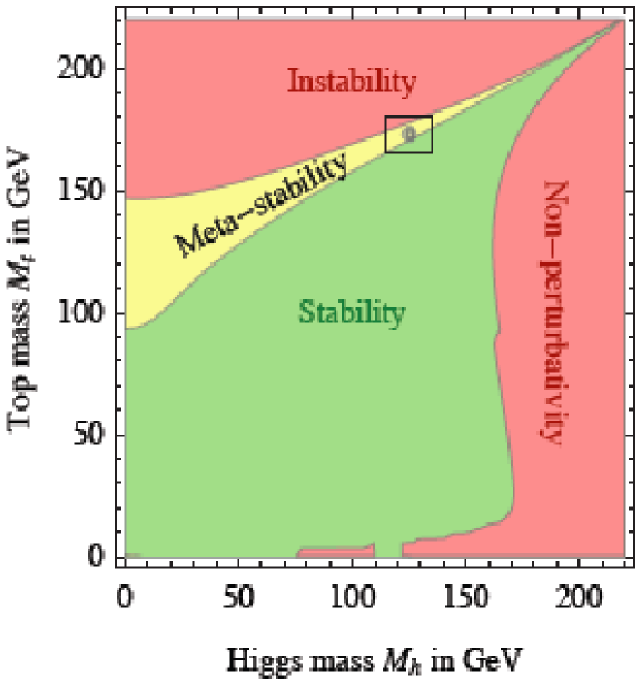
	Model	e,μ,τ,γ	Jets	E_T^{miss}	$\int\mathcal{L}\,dt$ [fb^{-1}]	Mass limit		Reference
Inclusive Searches	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0 e,μ	2-6 jets	E_T^{miss}	36.1	$\tilde{q}$ [2x, 8x Degen.] 0.9, 1.55	m($\tilde{\chi}_1^0$)<100 GeV	1712.02332
		mono-jet	1-3 jets	E_T^{miss}	36.1	$\tilde{q}$ [1x, 8x Degen.] 0.43, 0.71	m($\tilde{q}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0 e,μ	2-6 jets	E_T^{miss}	36.1	$\tilde{g}$ 2.0	m($\tilde{\chi}_1^0$)<200 GeV	1712.02332
						$\tilde{g}$ Forbidden 0.95-1.6	m($\tilde{\chi}_1^0$)=900 GeV	1712.02332
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	3 e,μ	4 jets		36.1	$\tilde{g}$ 1.85	m($\tilde{\chi}_1^0$)<800 GeV	1706.03731
		$ee,\mu\mu$	2 jets	E_T^{miss}	36.1	$\tilde{g}$ 1.2	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.11381
	$\tilde{g}\tilde{g}, \tilde{g}\to qqWZ\tilde{\chi}_1^0$	0 e,μ	7-11 jets	E_T^{miss}	36.1	$\tilde{g}$ 1.8	m($\tilde{\chi}_1^0$) <400 GeV	1708.02794
		SS e,μ	6 jets		139	$\tilde{g}$ 1.15	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=200 GeV	ATLAS-CONF-2019-015
	$\tilde{g}\tilde{g}, \tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	E_T^{miss}	79.8	$\tilde{g}$ 2.25	m($\tilde{\chi}_1^0$)<200 GeV	ATLAS-CONF-2018-041
		SS e,μ	6 jets		139	$\tilde{g}$ 1.25	m($\tilde{g}$)-m($\tilde{\chi}_1^0$)=300 GeV	ATLAS-CONF-2019-015
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0/t\tilde{\chi}_1^\pm$		Multiple		36.1	$\tilde{b}_1$ Forbidden 0.9	m($\tilde{\chi}_1^0$)=300 GeV, BR($b\tilde{\chi}_1^0$)=1	1708.09266, 1711.03301
			Multiple		36.1	$\tilde{b}_1$ Forbidden 0.58-0.82	m($\tilde{\chi}_1^0$)=300 GeV, BR($b\tilde{\chi}_1^0$)=BR($t\tilde{\chi}_1^\pm$)=0.5	1708.09266
			Multiple		139	$\tilde{b}_1$ Forbidden 0.74	m($\tilde{\chi}_1^0$)=200 GeV, m($\tilde{\chi}_1^\pm$)=300 GeV, BR($t\tilde{\chi}_1^\pm$)=1	ATLAS-CONF-2019-015
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_2^0\to bh\tilde{\chi}_1^0$	0 e,μ	6 b	E_T^{miss}	139	$\tilde{b}_1$ Forbidden 0.23-1.35	Δm($\tilde{\chi}_2^0,\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=100 GeV	SUSY-2018-31
						$\tilde{b}_1$ 0.23-0.48	Δm($\tilde{\chi}_2^0,\tilde{\chi}_1^0$)=130 GeV, m($\tilde{\chi}_1^0$)=0 GeV	SUSY-2018-31
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$ or $t\tilde{\chi}_1^0$	0-2 e,μ	0-2 jets/1-2 b	E_T^{miss}	36.1	$\tilde{t}_1$ 1.0	m($\tilde{\chi}_1^0$)=1 GeV	1506.08616, 1709.04183, 1711.11520
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to Wb\tilde{\chi}_1^0$	1 e,μ	3 jets/1 b	E_T^{miss}	139	$\tilde{t}_1$ 0.44-0.59	m($\tilde{\chi}_1^0$)=400 GeV	ATLAS-CONF-2019-017
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to\tilde{\tau}_1 b\nu, \tilde{\tau}_1\to\tau\tilde{G}$	1 τ + 1 e,μ,τ	2 jets/1 b	E_T^{miss}	36.1	$\tilde{t}_1$ 1.16	m($\tilde{\tau}_1$)=800 GeV	1803.10178
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$ / $\tilde{c}\tilde{c}, \tilde{c}\to c\tilde{\chi}_1^0$	0 e,μ	2 c	E_T^{miss}	36.1	$\tilde{c}$ 0.85	m($\tilde{\chi}_1^0$)=0 GeV	1805.01649
						$\tilde{t}_1$ 0.46	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}_1^0$)=50 GeV	1805.01649
		0 e,μ	mono-jet	E_T^{miss}	36.1	$\tilde{t}_1$ 0.43	m($\tilde{t}_1$,$\tilde{c}$)-m($\tilde{\chi}_1^0$)=5 GeV	1711.03301
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+h$	1-2 e,μ	4 b	E_T^{miss}	36.1	$\tilde{t}_2$ 0.32-0.88	m($\tilde{\chi}_1^0$)=0 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)= 180 GeV	1706.03986
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ	1 b	E_T^{miss}	139	$\tilde{t}_2$ Forbidden 0.86	m($\tilde{\chi}_1^0$)=360 GeV, m($\tilde{t}_1$)-m($\tilde{\chi}_1^0$)= 40 GeV	ATLAS-CONF-2019-016
EW direct	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via WZ	2-3 e,μ		E_T^{miss}	36.1	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ 0.6	m($\tilde{\chi}_1^0$)=0	1403.5294, 1806.02293
		$ee,\mu\mu$	$\geq$ 1	E_T^{miss}	139	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ 0.205	m($\tilde{\chi}_1^\pm$)-m($\tilde{\chi}_1^0$)=5 GeV	ATLAS-CONF-2019-014
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ via WW	2 e,μ		E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 0.42	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2019-008
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ via Wh	0-1 e,μ	2 b/2 γ	E_T^{miss}	139	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ Forbidden 0.74	m($\tilde{\chi}_1^0$)=70 GeV	ATLAS-CONF-2019-019, ATLAS-CONF-2019-XYZ
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$ via $\tilde{\ell}_L/\tilde{\nu}$	2 e,μ		E_T^{miss}	139	$\tilde{\chi}_1^\pm$ 1.0	m($\tilde{\ell}$,$\tilde{\nu}$)=0.5(m($\tilde{\chi}_1^\pm$)+m($\tilde{\chi}_1^0$))	ATLAS-CONF-2019-008
	$\tilde{\tau}\tilde{\tau}, \tilde{\tau}\to\tau\tilde{\chi}_1^0$	2 τ		E_T^{miss}	139	$\tilde{\tau}$ [$\tilde{\tau}_L$, $\tilde{\tau}_{R,L}$] 0.16-0.3, 0.12-0.39	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2019-018
	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0 jets	E_T^{miss}	139	$\tilde{\ell}$ 0.7	m($\tilde{\chi}_1^0$)=0	ATLAS-CONF-2019-008
		2 e,μ	$\geq$ 1	E_T^{miss}	139	$\tilde{\ell}$ 0.256	m($\tilde{\ell}$)-m($\tilde{\chi}_1^0$)=10 GeV	ATLAS-CONF-2019-014
	$\tilde{H}\tilde{H}, \tilde{H}\to h\tilde{G}/Z\tilde{G}$	0 e,μ	$\geq$ 3 b	E_T^{miss}	36.1	$\tilde{H}$ 0.13-0.23, 0.29-0.88	BR($\tilde{\chi}_1^0\to h\tilde{G}$)=1	1806.04030
		4 e,μ	0 jets	E_T^{miss}	36.1	$\tilde{H}$ 0.3	BR($\tilde{\chi}_1^0\to Z\tilde{G}$)=1	1804.03602
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	E_T^{miss}	36.1	$\tilde{\chi}_1^\pm$ 0.46	Pure Wino	1712.02118
						$\tilde{\chi}_1^\pm$ 0.15	Pure Higgsino	ATL-PHYS-PUB-2017-019
	Stable $\tilde{g}$ R-hadron		Multiple		36.1	$\tilde{g}$ 2.0		1902.01636,1808.04095
	Metastable $\tilde{g}$ R-hadron, $\tilde{g}\to qq\tilde{\chi}_1^0$		Multiple		36.1	$\tilde{g}$ [$\tau(\tilde{g})$ =10 ns, 0.2 ns] 2.05, 2.4	m($\tilde{\chi}_1^0$)=100 GeV	1710.04901,1808.04095
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu,e\tau,\mu\tau$			3.2	$\tilde{\nu}_\tau$ 1.9	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1607.08079
	$\tilde{\chi}_1^\pm\tilde{\chi}_1^\mp/\tilde{\chi}_2^0\to WW/Z\ell\ell\ell\ell\nu\nu$	4 e,μ	0 jets	E_T^{miss}	36.1	$\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$ [$\lambda_{i33}\neq 0, \lambda_{12k}\neq 0$] 0.82, 1.33	m($\tilde{\chi}_1^0$)=100 GeV	1804.03602
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^0, \tilde{\chi}_1^0\to qqq$		4-5 large-R jets		36.1	$\tilde{g}$ [m($\tilde{\chi}_1^0$)=200 GeV, 1100 GeV] 1.3, 1.9	Large λ''_{112}	1804.03568
			Multiple		36.1	$\tilde{g}$ [λ''_{112}=2e-4, 2e-5] 1.05, 2.0	m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}\tilde{t}, \tilde{t}\to t\tilde{\chi}_1^0, \tilde{\chi}_1^0\to tbs$		Multiple		36.1	$\tilde{g}$ [λ''_{323}=2e-4, 1e-2] 0.55, 1.05	m($\tilde{\chi}_1^0$)=200 GeV, bino-like	ATLAS-CONF-2018-003
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to bs$		2 jets + 2 b		36.7	$\tilde{t}_1$ [qq, bs] 0.42, 0.61		1710.07171
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to q\ell$	2 e,μ	2 b		36.1	$\tilde{t}_1$ 0.4-1.45	BR($\tilde{t}_1\to be/b\mu$)>20%	1710.05544
		1 μ	DV		136	$\tilde{t}_1$ [1e-10< λ'_{23k} <1e-8, 3e-10< λ'_{23k} <3e-9] 1.0, 1.6	BR($\tilde{t}_1\to q\mu$)=100%, cosθ_t=1	ATLAS-CONF-2019-006

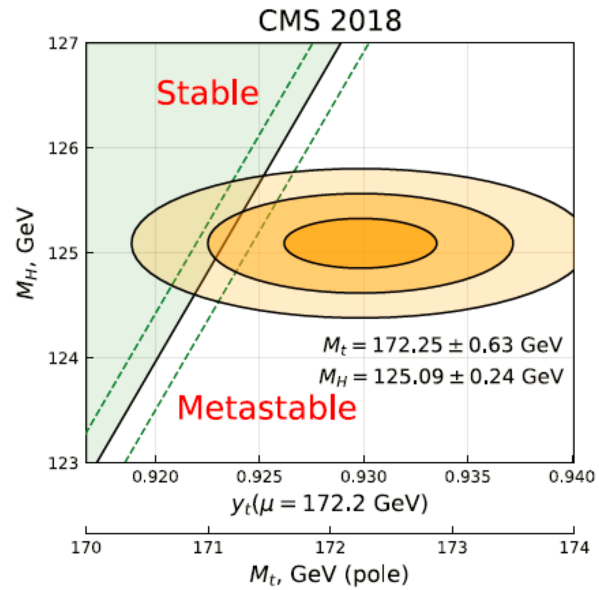
Where are we in HEP?



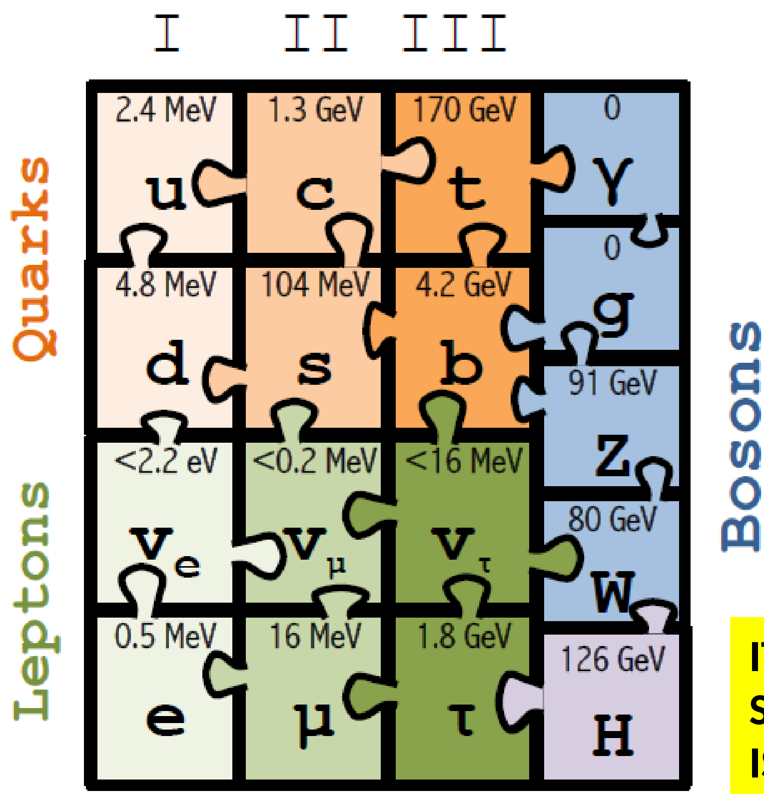


The Standard Model is a very consistent and complete theory.
It explains all known collider phenomena and almost all particle physics (except ν's)
– this was beautifully verified at LEP, SLC, Tevatron and the LHC.
-- the EWPO radiative corrections predicted top and Higgs masses
assuming SM *and nothing else*
we can even extrapolate the Standard Model all the way to the the Plank scale :





Some signs of New Physics in Flavour sector?

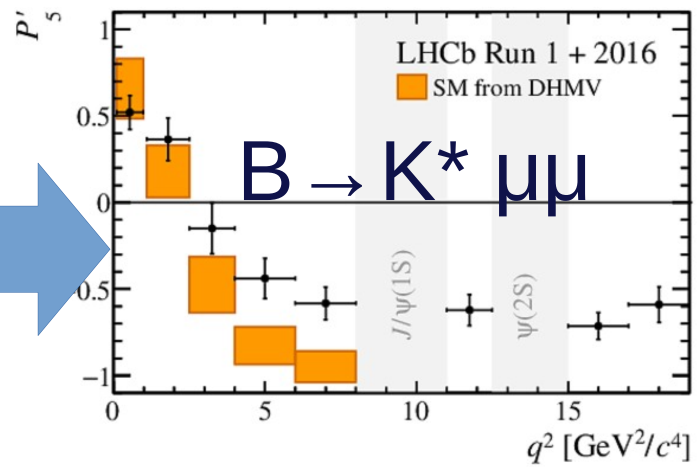


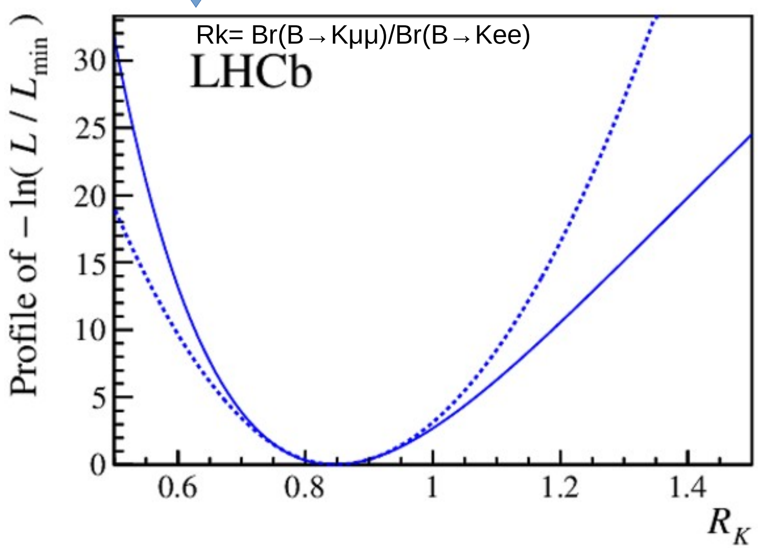
NB in fact we know from oscillations and cosmology that all 3 neutrino masses are less than ~0.1 eV

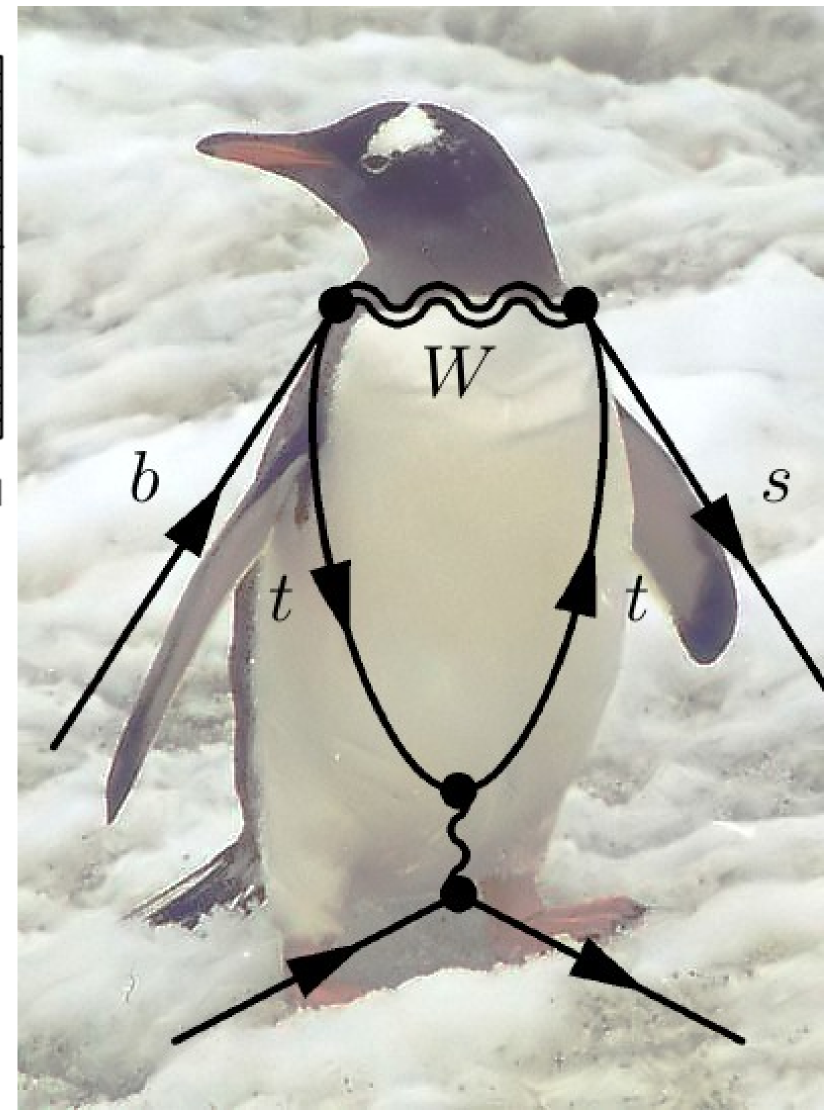
IT LOOKS LIKE THE STANDARD MODEL IS COMPLETE…..

Some signs of New Physics in Flavour sector?

There is a set of consistent discrepancy in the b→s ll transitions







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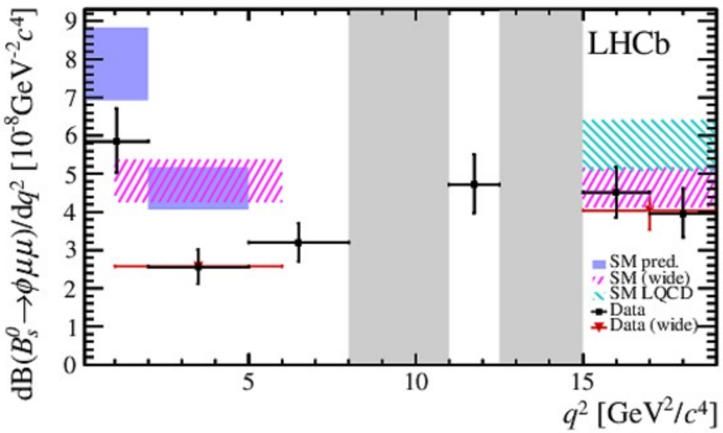
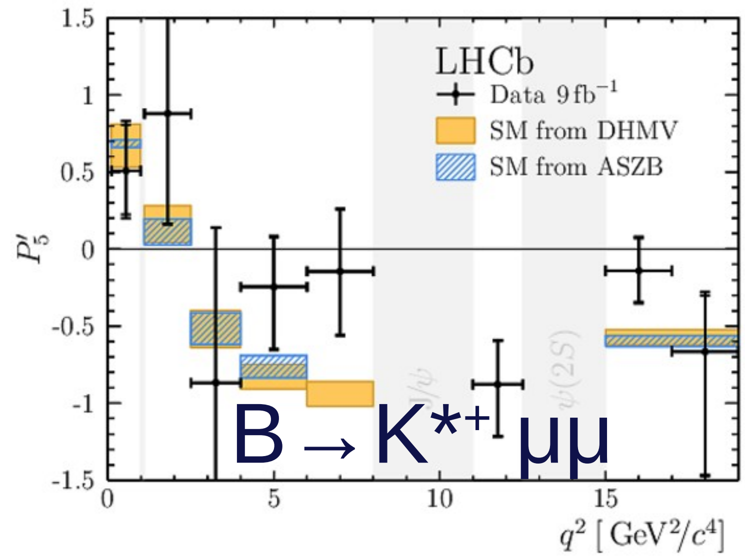
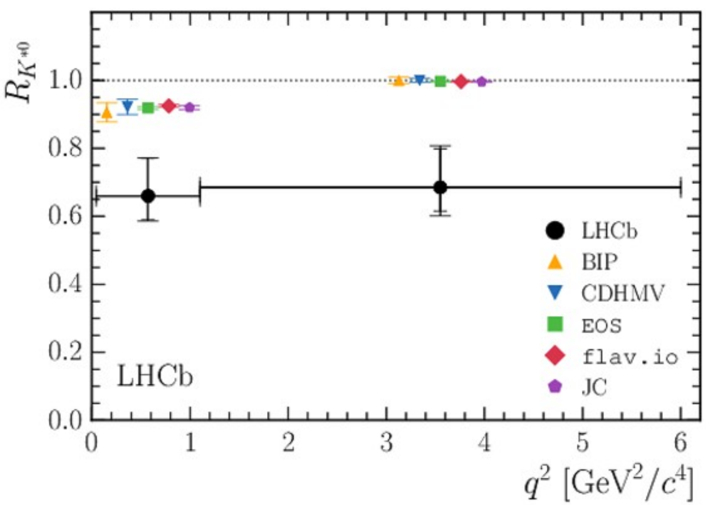
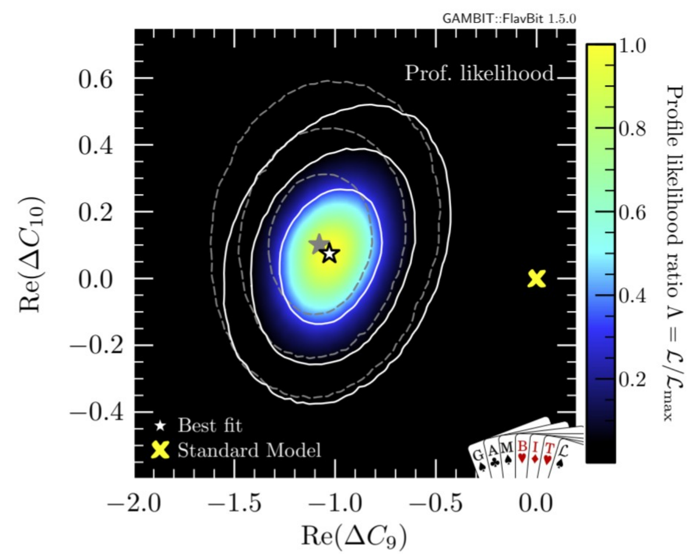




$B \to K^{*+} \mu\mu$



This is all very promising but cannot give definite answer about the final theory of particle physics!



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

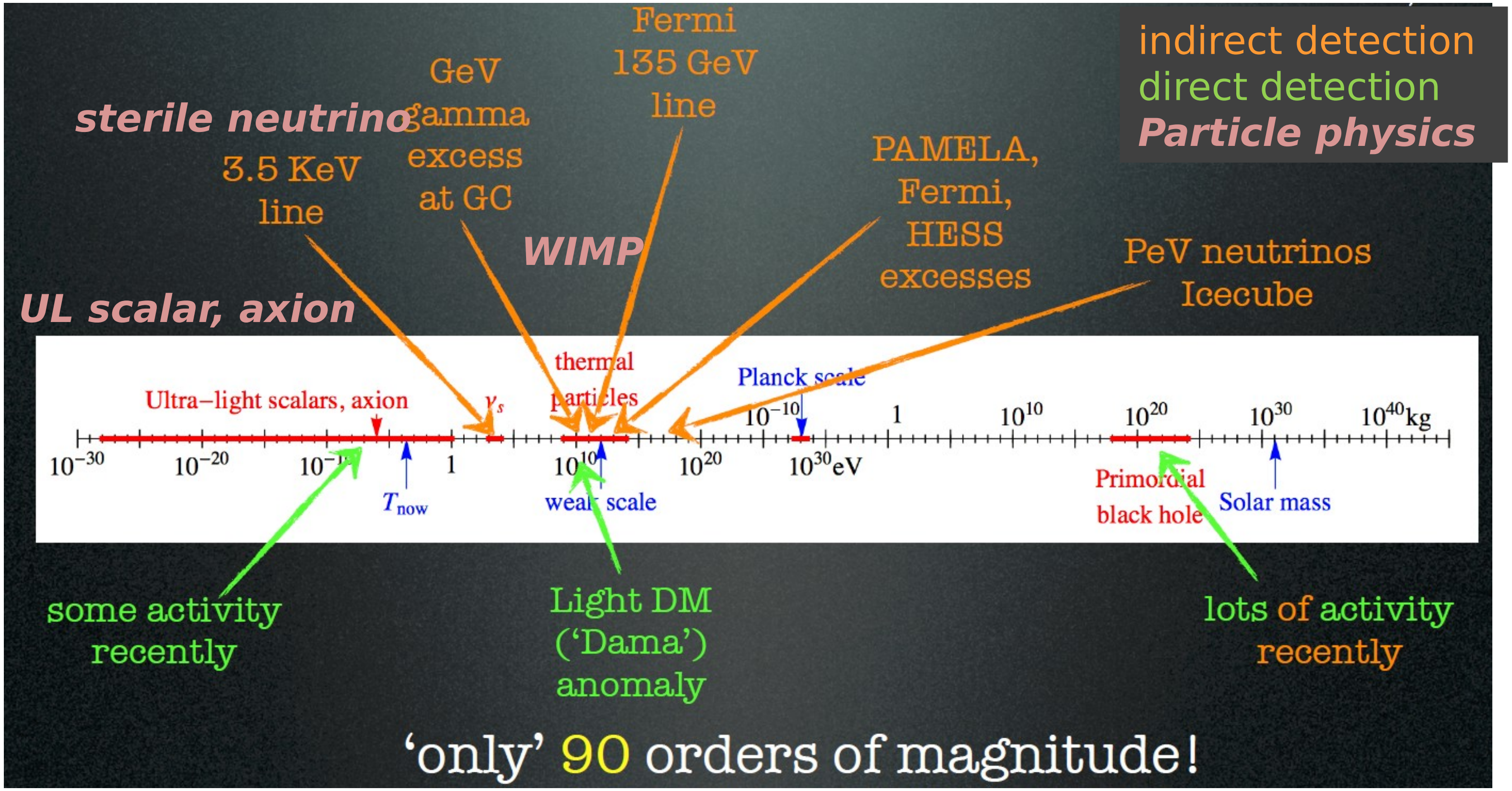
The next facility must be versatile with as broad and powerful reach as possible, as there is no precise target

⇒ more Sensitivity, more Precision, more Energy

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

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

Plausible candidates:



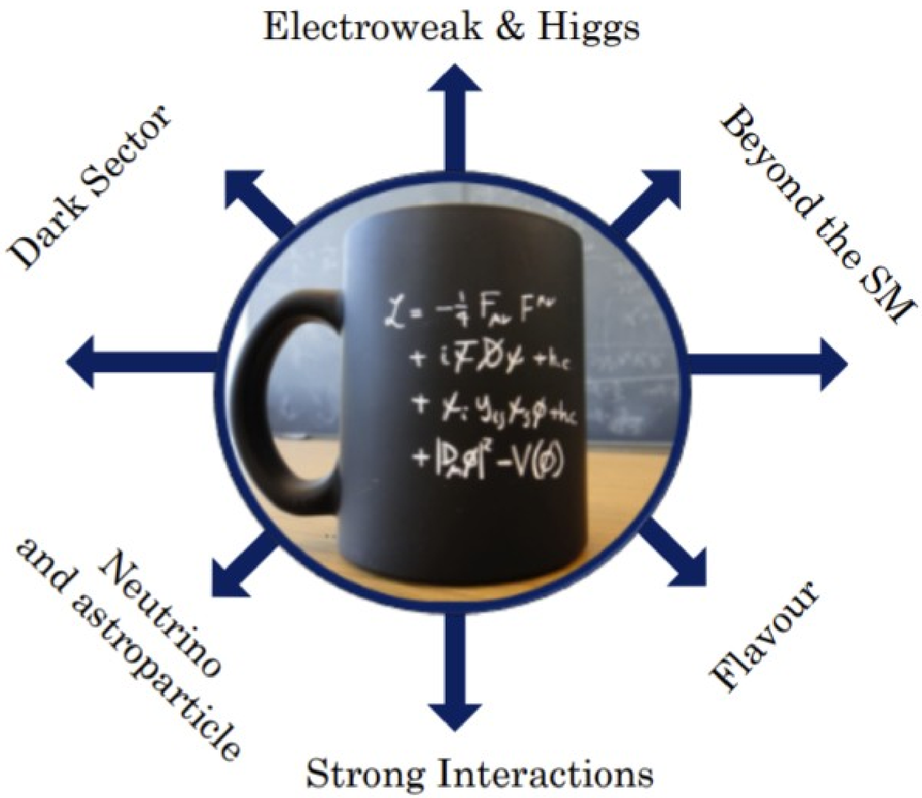
Cirelli

Principle avenues to seek new physics phenomena

Through theoretical research the open questions in particle physics can be related to several observable phenomena that can be captures in some principle categories

(here the physics themes of the Open Symposium of the European Strategy for Particle Physics in Granada, but surely other sets could be used as well)

Requires a profound empiric exploration with colliders at the intensity and energy frontier, primary and secondary beams at accelerators, storage rings, high-power lasers, precision instrumentation, nuclear reactors, underground facilities, interferometers, cosmic sources, detectors in orbit, …



This vast portfolio calls for coherent and community-wide Strategies

The European Strategy

In the coming decade, the LHC, including its high-luminosity upgrade, will remain the world's primary tool for exploring the high-energy frontier. Given the unique nature of the Higgs boson, there are compelling scientific arguments for a new electron-positron collider operating as a "Higgs factory". Such a collider would produce copious Higgs bosons in a very clean environment, would make dramatic progress in mapping the diverse interactions of the Higgs boson with other particles and would form an essential part of a research programme that includes exploration of the flavour puzzle and the neutrino sector.

High-priority future initiatives

A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

- *the particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors;*

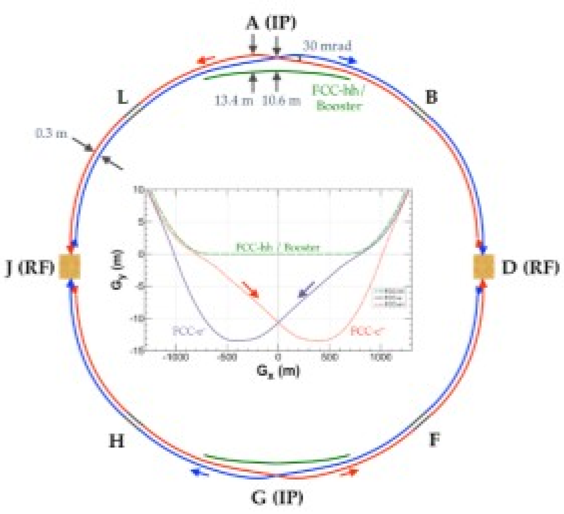
- *Europe, together with its international partners, should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage. Such a feasibility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

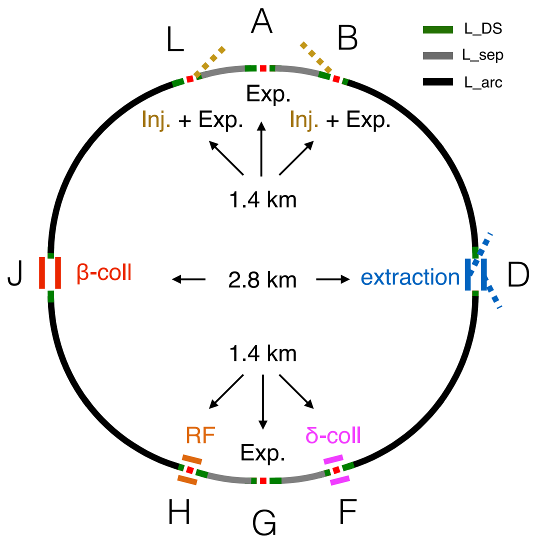
The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

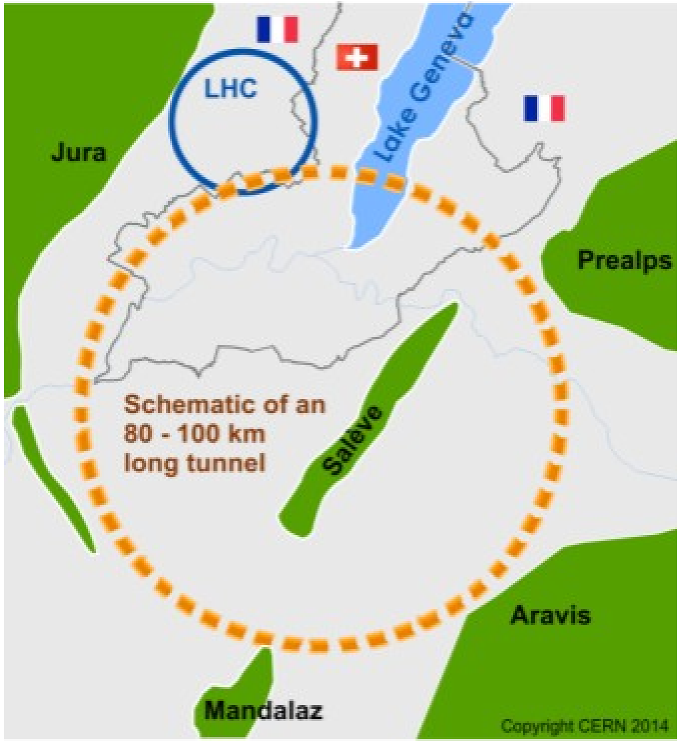
The FCC integrated program at CERN inspired by successful LEP – LHC

Comprehensive cost-effective program maximizing physics opportunities

- **Stage 1: FCC-ee (Z, W, H, tt) as first generation Higgs EW and top factory at highest luminosities.**
- **Stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options.**
- **Complementary physics**
- Integrating an ambitious high-field magnet R&D program
- Common civil engineering and technical infrastructures
- Building on and reusing CERN's existing infrastructure.
- **FCC-INT project plan is fully integrated with HL-LHC exploitation and provides for seamless continuation of HEP**







Is the history repeating itself…?

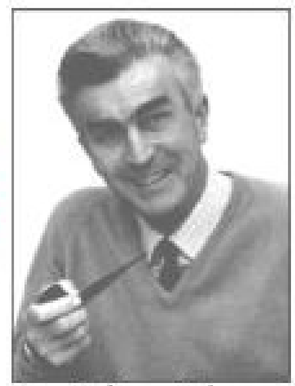
When Lady Margaret Thatcher visited CERN in 1982, she also asked the then CERN Director-General Herwig Schopper ***how big the next tunnel after LEP would be.***

Margaret Thatcher,
British PM 1979-90

Dr. Schopper's answer was ***there would be no bigger tunnel at CERN***.

Herwig Schopper
CERN DG 1981-88
built LEP

Lady Thatcher replied that she had „obtained ***exactly the same answer from Sir John Adams when the SPS was built" 10 years earlier***, and therefore she didn't believe him.



John Adams
CERN DG 1960-61 & 1971-75
built PS & SPS

maybe the Prime Minister was right!?

Herwig Schopper, private communication, 2013

CDR + Documentation

- **FCC-Conceptual Design Reports:**
- **Vol 1 – Physics**
- **Vol 2 – FCC-ee,**
- **Vol 3 – FCC-hh,**
- **Vol 4 – HE-LHC**
  - **1338 authors**
  - Preprints since 15 January 2019 on http://fcc-cdr.web.cern.ch/ and INSPIRE
  - **CDRs published in European Physical Journal C (Vol 1) and ST (Vol 2 – 4)**
  - **ESPP summaries: FCC-integral, FCC-ee, FCC-hh, HE-LHC** http://fcc-cdr.web.cern.ch/

A public presentation of the CDR was given on 4-5 March at CERN https://indico.cern.ch/event/789349/
FCC Phys. Workshop Jan 20 **https://indico.cern.ch/event/838435/**
FCC Phys workshop Nov 9-13 2020 **https://indico.cern.ch/event/932973/**
many further details can be found there!

- FCC-ee «Your questions answered» https://arxiv.org/abs/1906.02693v1
- “Circular vs linear, another story of complementarity” arXiv:1912.11871v2
- LOIs to Snowmass, **challenges**: https://indico.cern.ch/event/951830/

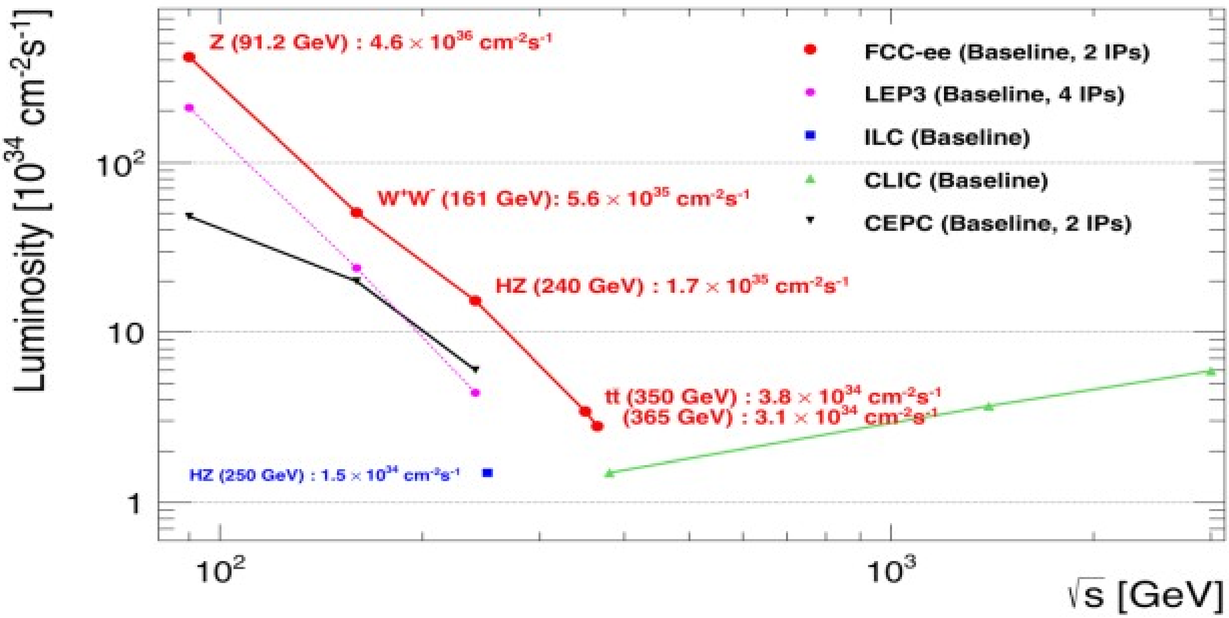
FCC physics program

working point	assumed typical luminosity/IP [10^{34} $cm^{-2}s^{-1}$] = design value minus 15(10)%	total luminosity (2 IPs)/ yr; half of typical luminosity assumed in 1st two years (Z) and 1st year ($t\bar{t}$)	physics goal	run time [yr]
Z first 2 years	100	26 ab^{-1}/year	150 ab^{-1}	4
Z later	200	48 ab^{-1}/year		
W	25	6 ab^{-1}/year	10 ab^{-1}	1-2
H	7.0	1.7 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	0.34 ab^{-1}/year	1.5 ab^{-1}	4

total program duration: 15 years – *incl. machine modifications*

phase 1 (*Z*, *W*, *H*): 9 years, phase 2 (top): 6 years

FCC physics program



Event statistics :

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

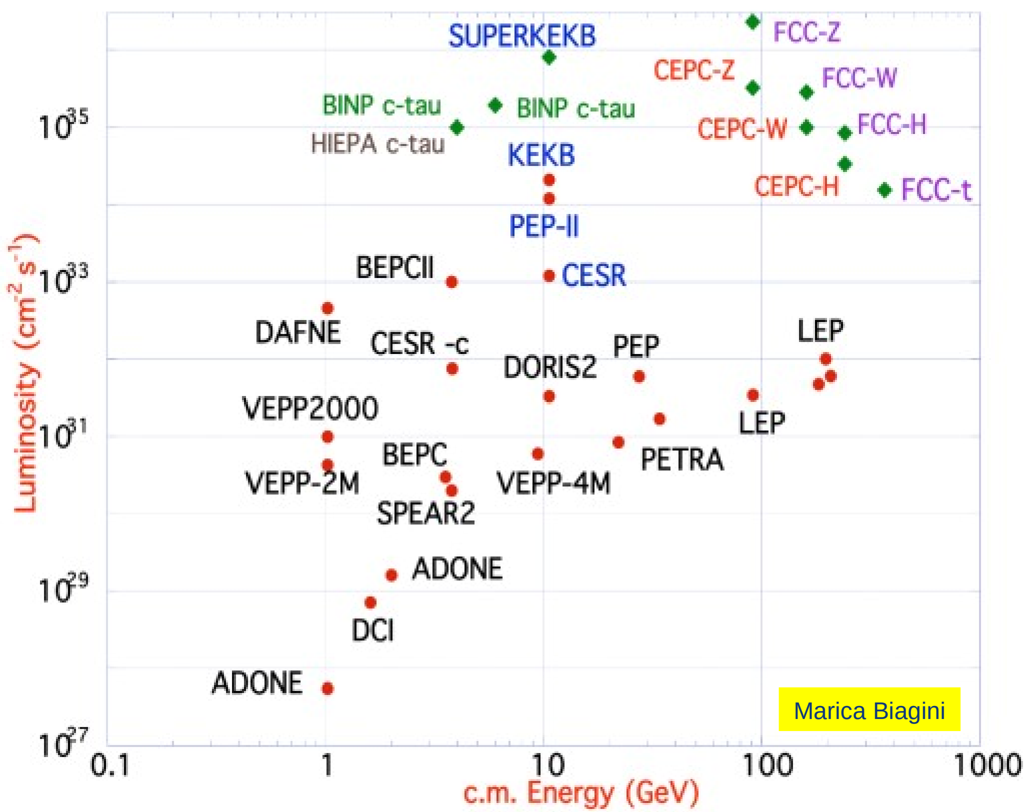
E_{CM} errors: (last column)

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

FCCee 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} $cm^{-2}s^{-1}$]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

FCC physics program



B-factories: KEKB & PEP-II:
- double-ring lepton colliders,
- high beam currents,
- top-up injection

DAFNE: crab waist, double ring

SuperB-factories, S-KEKB: low β_y^*

LEP: high energy, SR effects

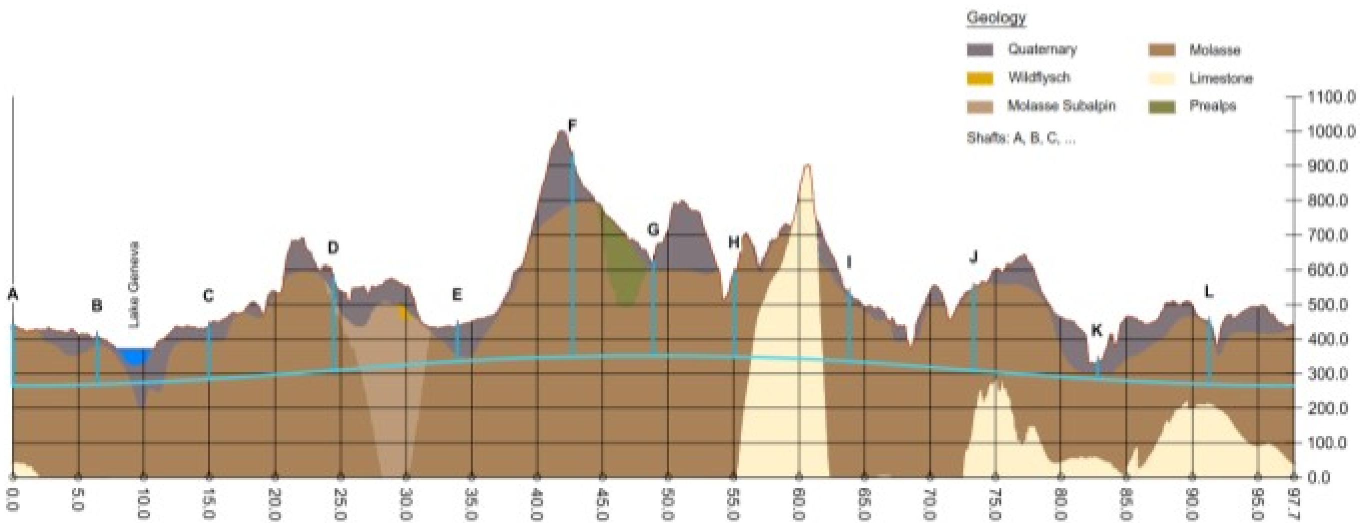
VEPP-4M, LEP: precision E calibration

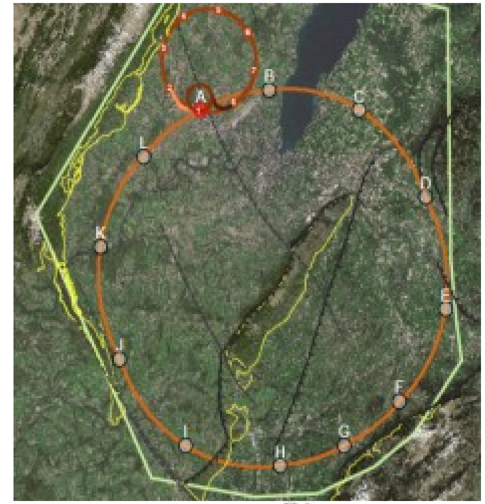
KEKB: *e^+* source

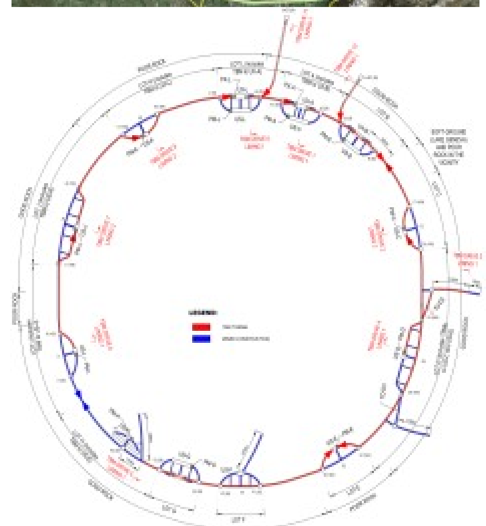
HERA, LEP, RHIC: spin gymnastics

combining successful ingredients of several recent colliders → highest luminosities & energies

FCC physics program





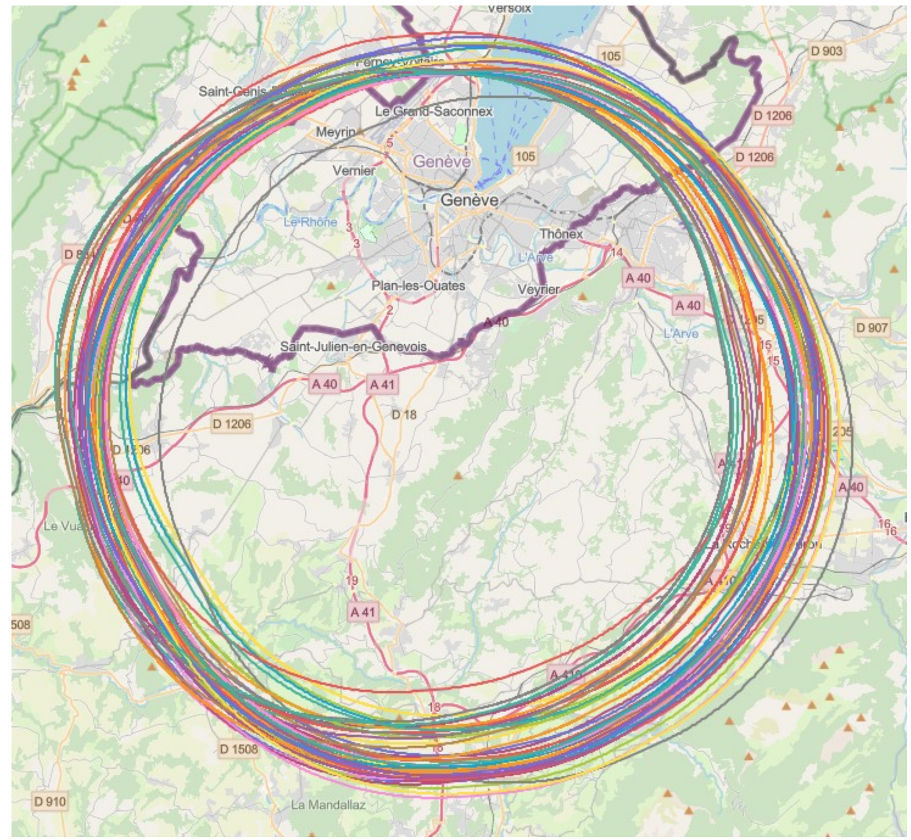


- **Present baseline position was established considering:**
- lowest risk for construction, fastest and cheapest construction
- feasible positions for large span caverns (most challenging structures)

- **More than 75% tunnel in France, 8 (9) / 12 access points in France.**
- **next step review of surface site locations and machine layout**

Collider placement optimisation

- An overall layout and placement optimisation process across both host states that follows the "avoid-reduce-compensate" directive according to European and French regulatory frameworks.
- Process integrates a diverse set of requirements and constraints, such as
  - performance for the scientific research to be competitive at international scale
  - civil engineering technical feasibility and subsurface constraints
  - territorial constraints at surface and subsurface
  - nature, accessibility, technical infrastructure and resource needs and constraints
  - economic factors including the development of benefits for and synergies with the regional developments
- Work takes place as a collaborative effort by technical experts at CERN, consultancy companies and government notified bodies

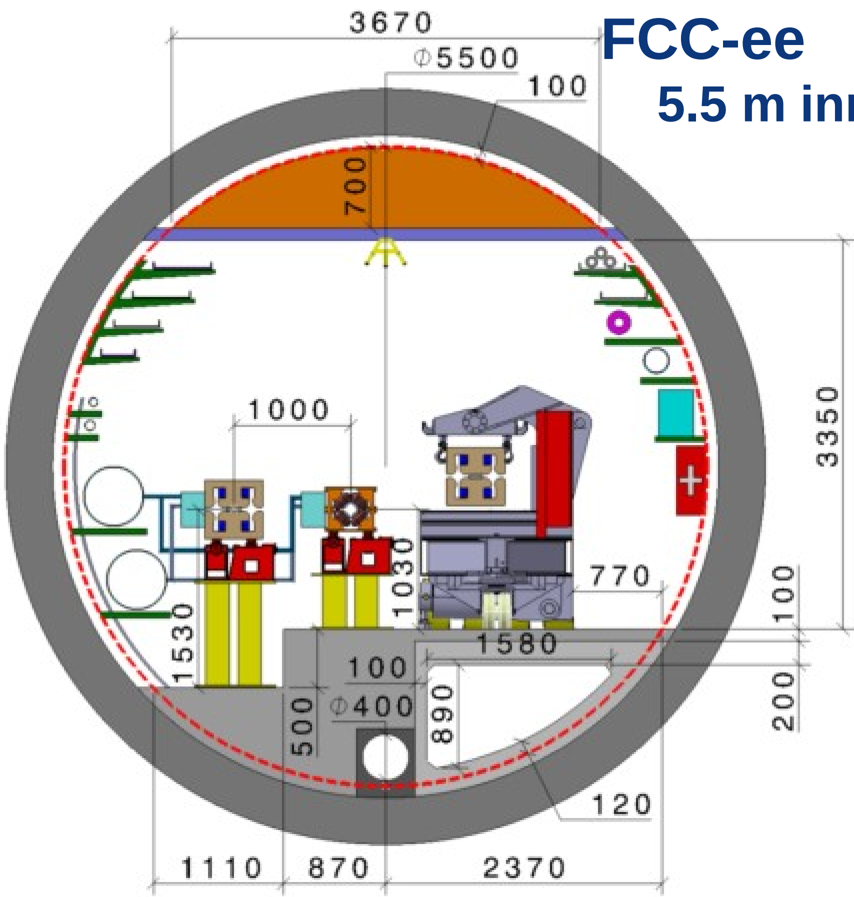


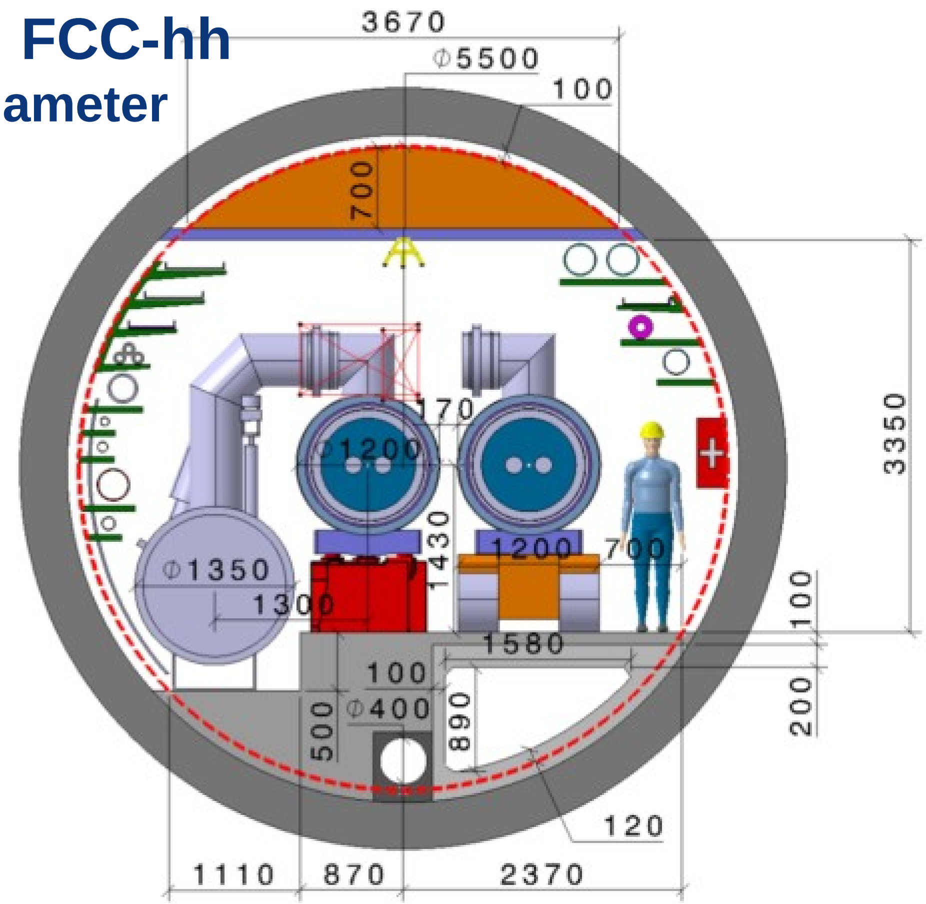
FCC-tunel integration in arcs

FCC-ee

FCC-hh

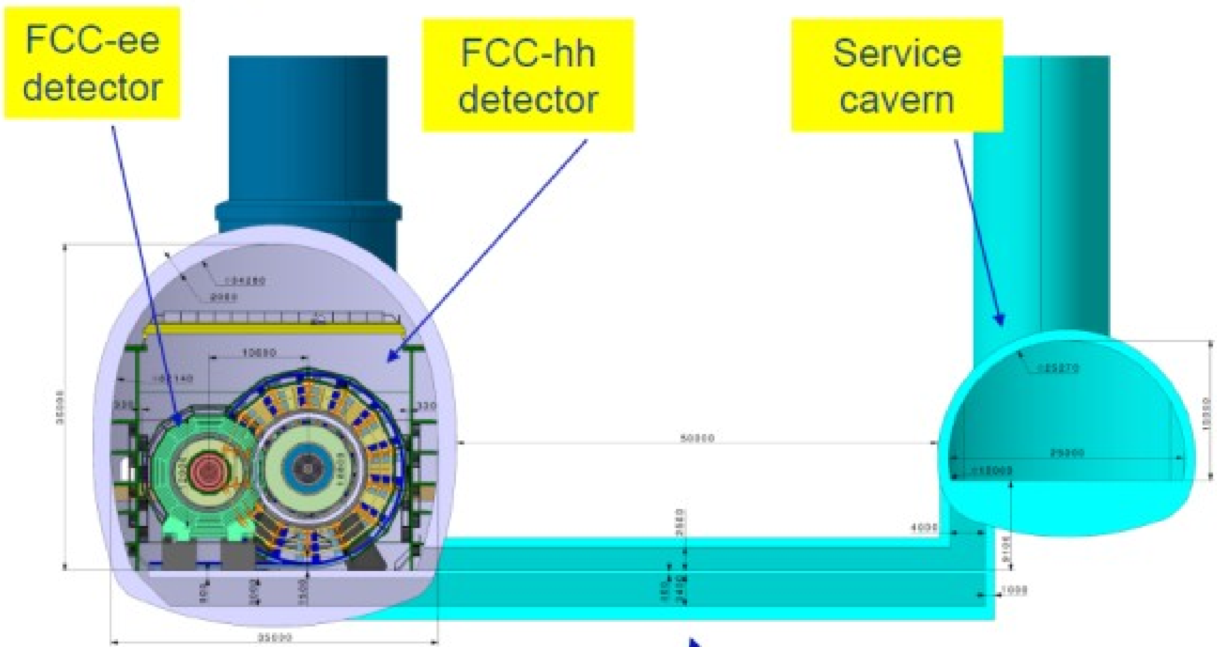
5.5 m inner diameter

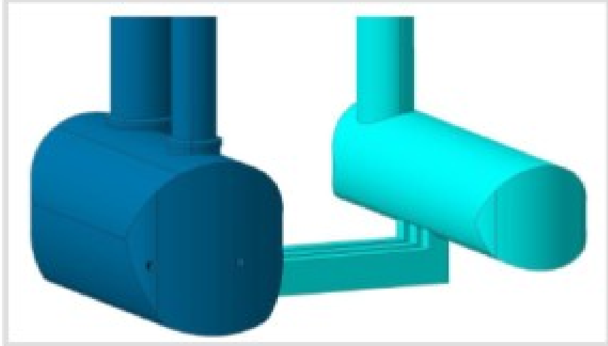




Common experimental points (A, G)

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





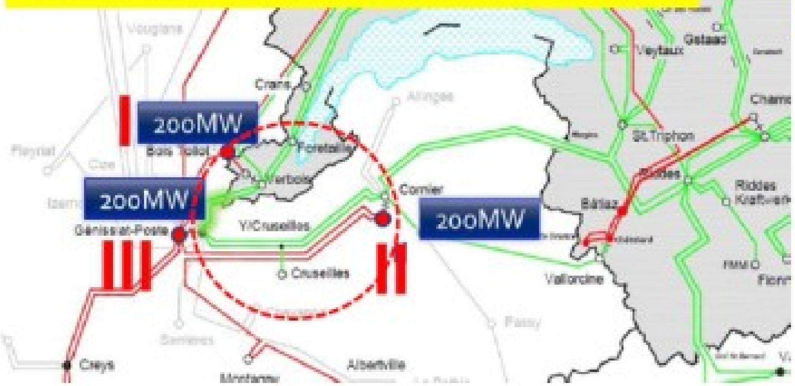
Preliminary design of access and cable paths

Power consumption

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

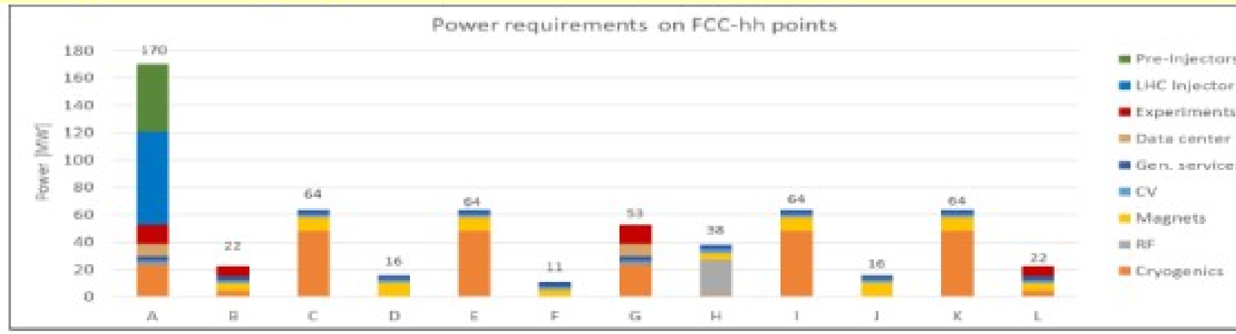
Supply and distribution of electrical energy

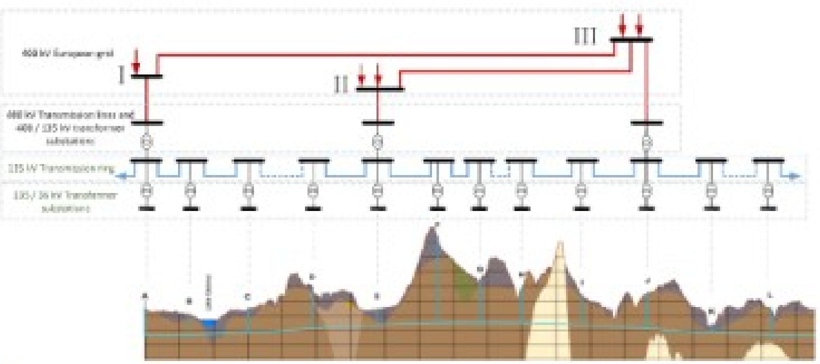
Additional 200 MW available for FCC at each of the three 400 kV sources.



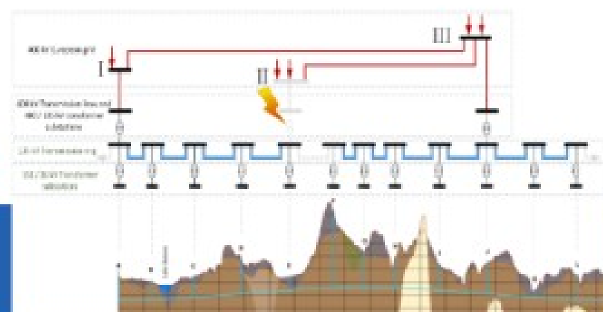
---- 400 kV ---- 230 kV

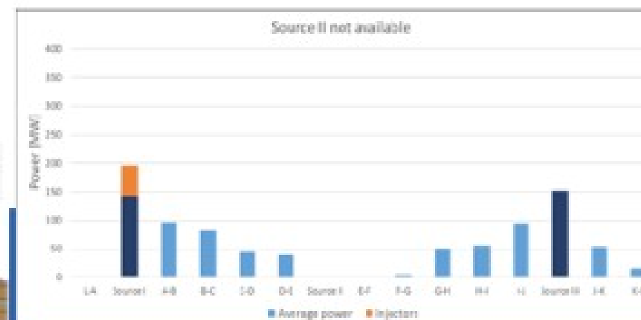
Per-point power requirements as input for infrastructure-optimized conceptual design. (Peak FCC-ee 260 - 340 MW, total FCC-hh 550 MW





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.

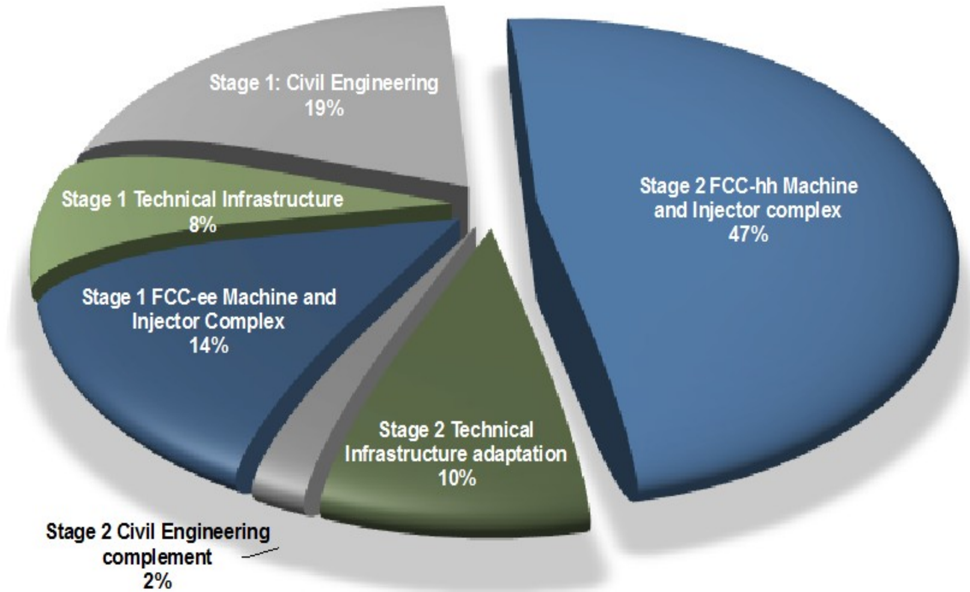




3 x 400 kV connections
+ 135 kV underground power distribution (NC)

Costs

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**



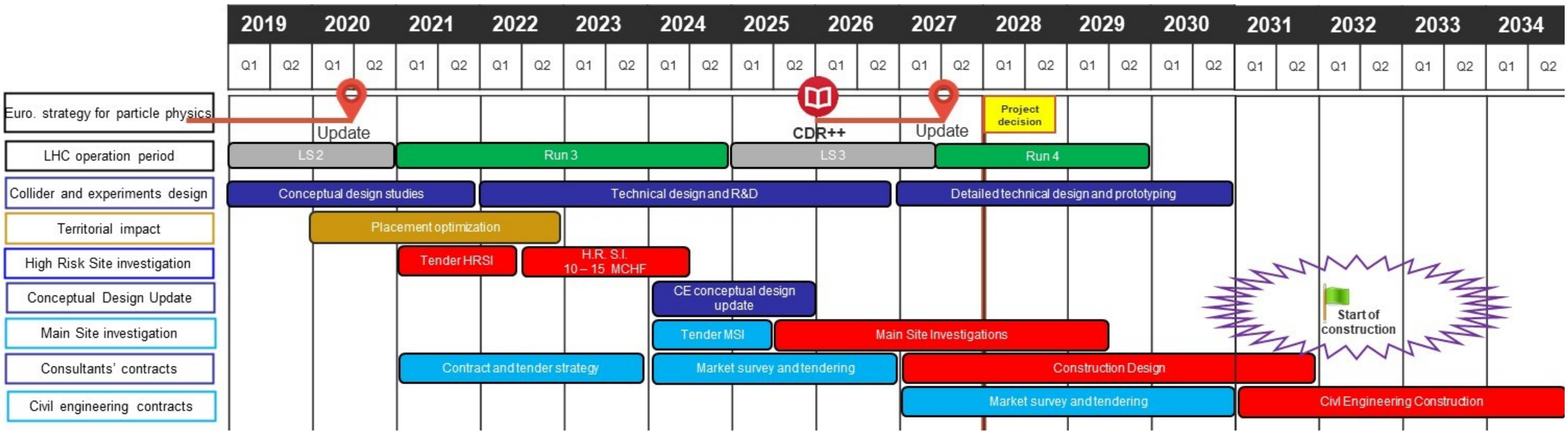
Total construction cost FCC-ee (Z, W, H) amounts to 10,500 MCHF & 1,100 MCHF (tt).

- Associated to a total project duration of ~20 years (2025 – 2045)

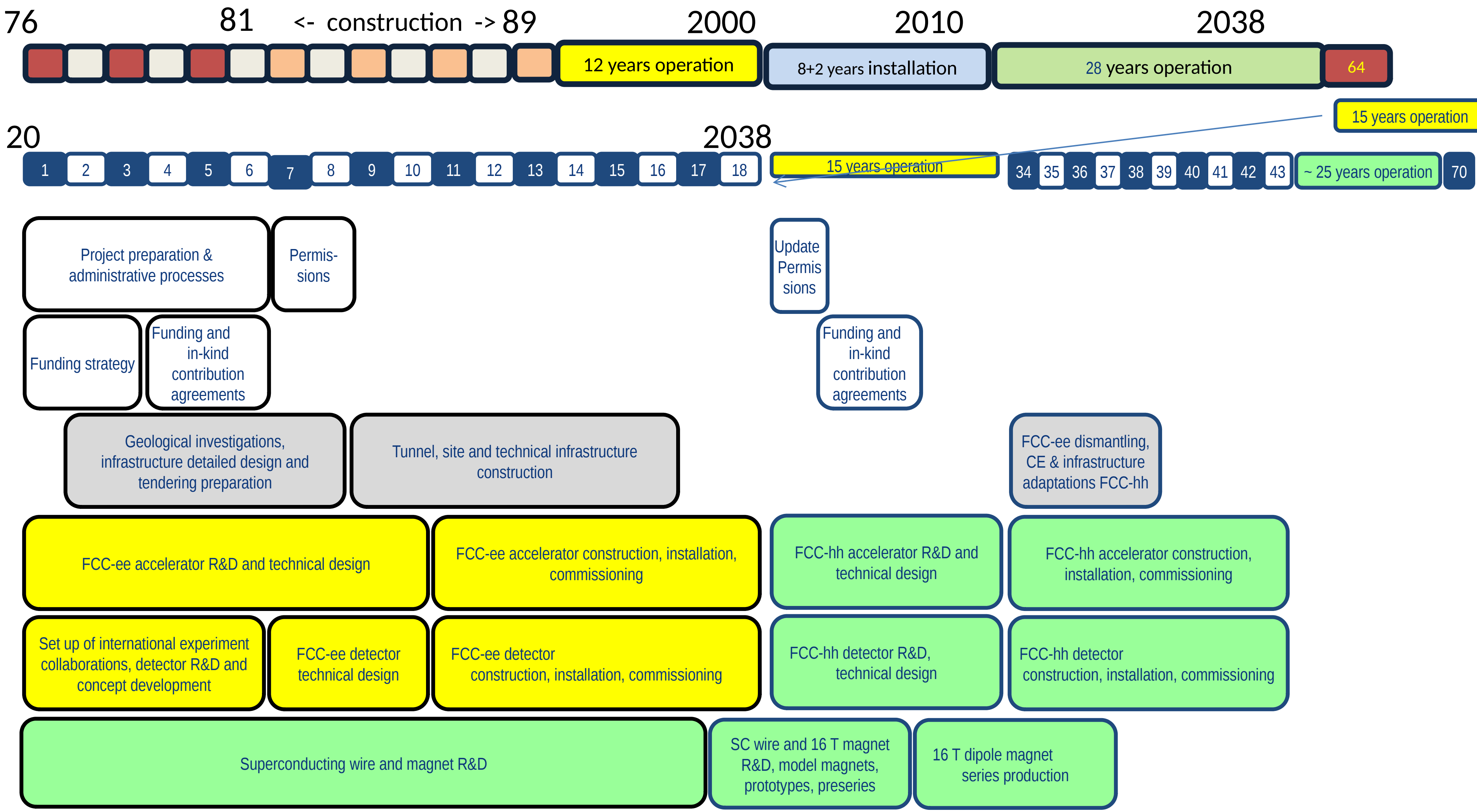
Total construction cost for subsequent FCC-hh amounts to 17,000 MCHF.

- Associated to a total project duration of ~25 years (2035 – 2060) (FCC-hh stand alone 25 BCHF)

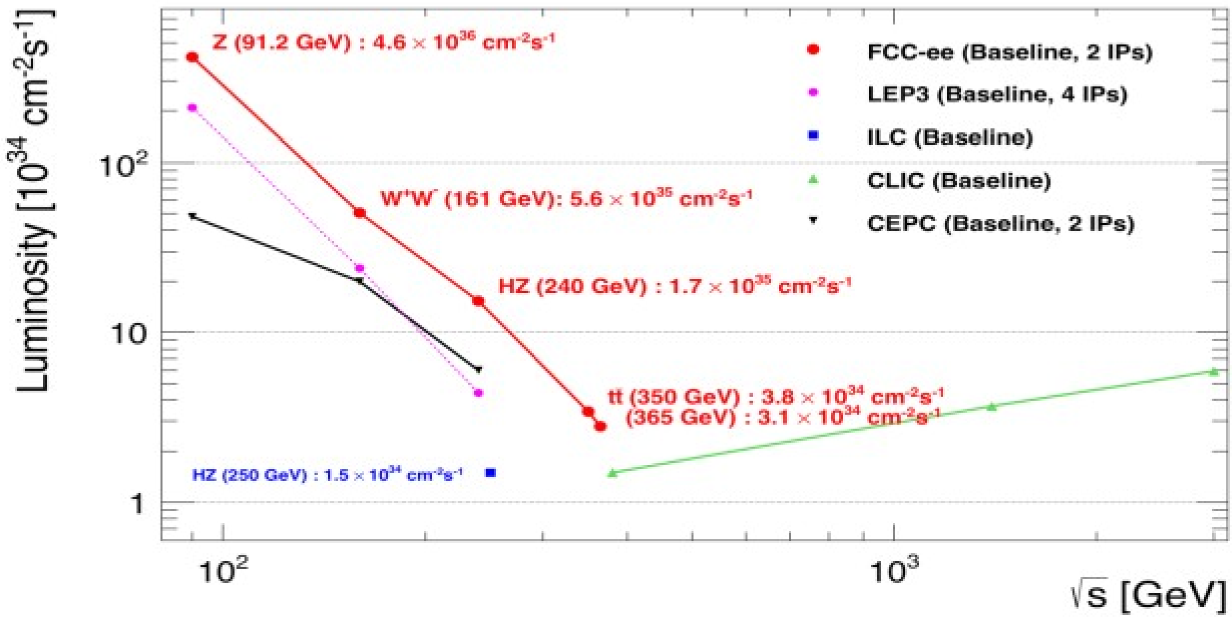
Civil Engeneering prepartor activities 2020-2030



- Technical schedule of main processes leading to start of construction begin 2030ies
- For proof of principle feasibility: High risk area site investigations, 2022 – 2024
- Followed by update of civil engineering conceptual design and CE cost estimate 2025


76
81
<- construction -> 89
2000
2010
2038
12 years operation
8+2 years installation
28 years operation
64
15 years operation
20
2038
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
15 years operation
34
35
36
37
38
39
40
41
42
43
~ 25 years operation
70
Project preparation & administrative processes
Permis-sions
Update Permis sions
Funding strategy
Funding and in-kind contribution agreements
Funding and in-kind contribution agreements
Geological investigations, infrastructure detailed design and tendering preparation
Tunnel, site and technical infrastructure construction
FCC-ee dismantling, CE & infrastructure adaptations FCC-hh
FCC-ee accelerator R&D and technical design
FCC-ee accelerator construction, installation, commissioning
FCC-hh accelerator R&D and technical design
FCC-hh accelerator construction, installation, commissioning
Set up of international experiment collaborations, detector R&D and concept development
FCC-ee detector technical design
FCC-ee detector construction, installation, commissioning
FCC-hh detector R&D, technical design
FCC-hh detector construction, installation, commissioning
Superconducting wire and magnet R&D
SC wire and 16 T magnet R&D, model magnets, prototypes, preseries
16 T dipole magnet series production

FCC physics program



Event statistics :

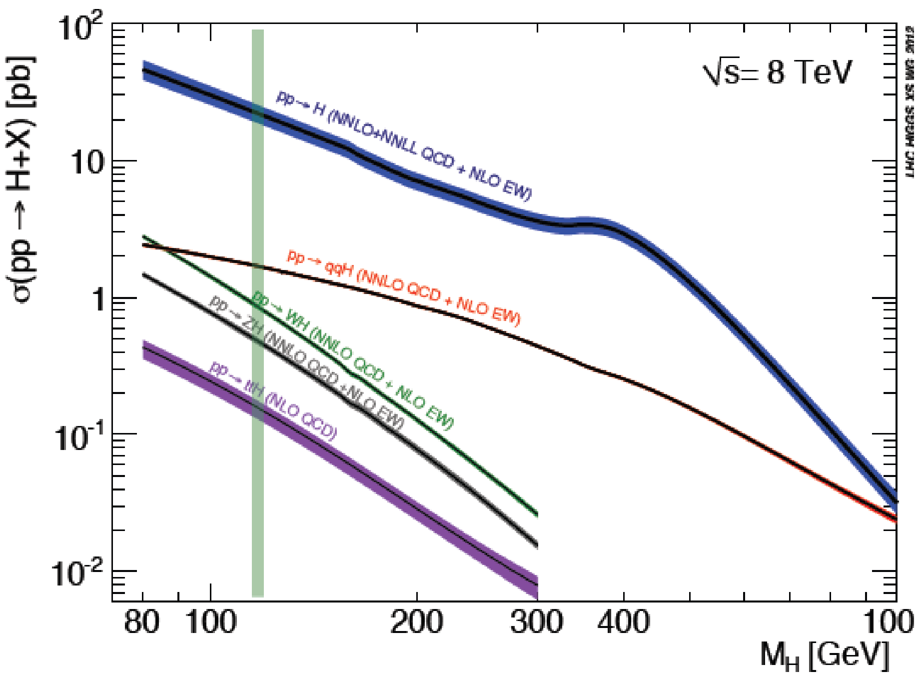
Z peak	E_{cm} : 91 GeV	$5\ 10^{12}$	e+e- -> Z	LEP x 10^5
WW threshold	E_{cm} : 161 GeV	10^8	e+e- -> WW	LEP x 2.10^3
ZH threshold	E_{cm} : 240 GeV	10^6	e+e- -> ZH	Never done
$t\bar{t}$ threshold	E_{cm} : 350 GeV	10^6	e+e- -> $t\bar{t}$	Never done

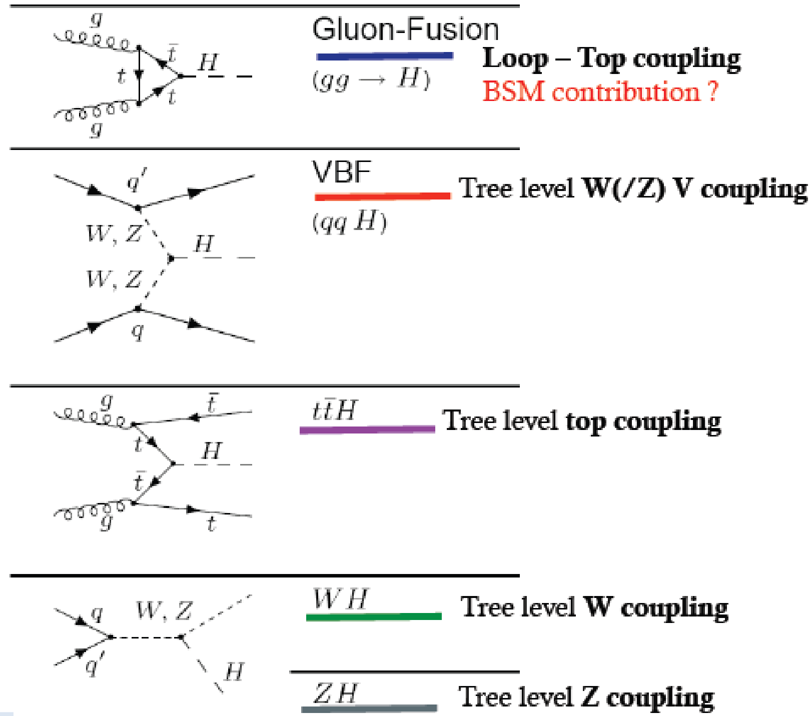
E_{CM} errors:

<100 keV
<300 keV
2 MeV
5 MeV

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

LHC is the Higgs factory!!!





THE LHC is a Higgs Factory…BUT

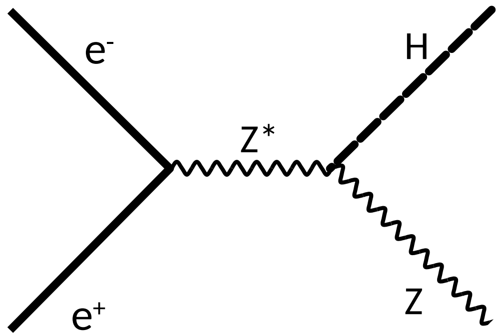
$$\sigma_{i \to f}^{observed} \propto \sigma_{prod} \frac{(g_{Hi})^2 (g_{Hf})^2}{\Gamma_H}$$

relative error scales with
1/purity and 1/efficiency of signal

We don't know this until measured directly

Higgs production mechanism

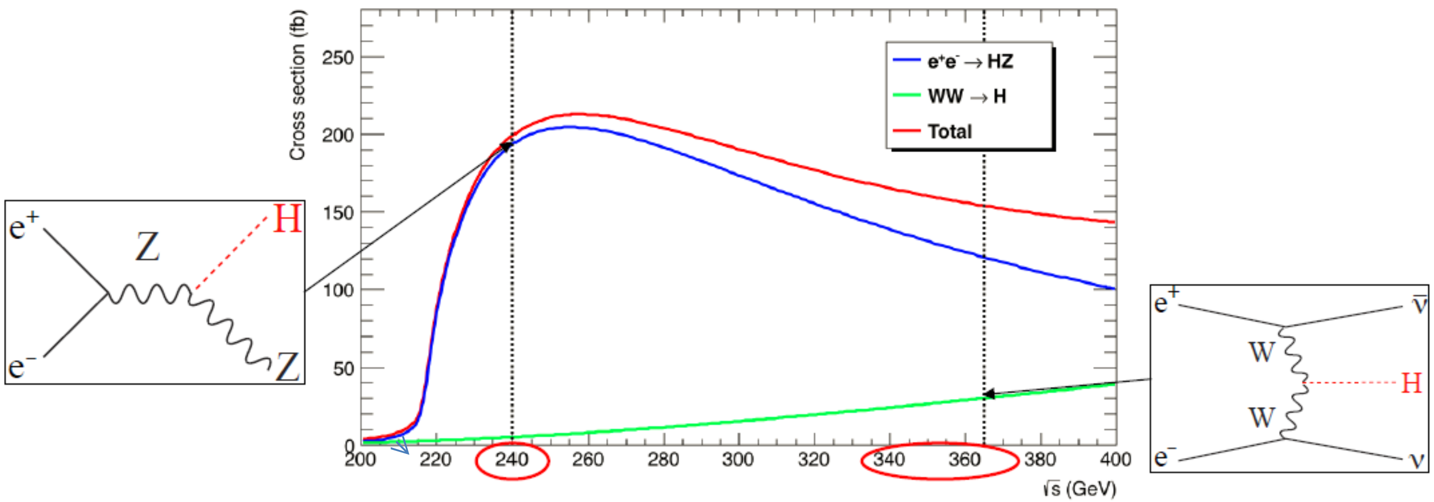
"higgstrahlung" process close to threshold
Production xsection has a maximum at near threshold ~200 fb
$1.7\ 10^{35}/cm^2/s$ => 340'000 HZ events per year.



Z – tagging
by missing mass

For a Higgs of 125GeV, a centre of mass energy of 240-250 GeV is optimal
kinematical constraint near threshold for high precision in mass, width, selection purity

Higgs production mechanism



LEP ⬆

10^6 e+e- → ZH events with 5 ab-1

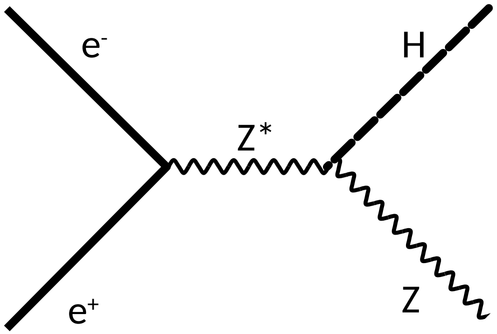
- **Target : few per-mil precision, statistics-limited.**
- **Complemented with 200k events at √s = 350 – 365 GeV**

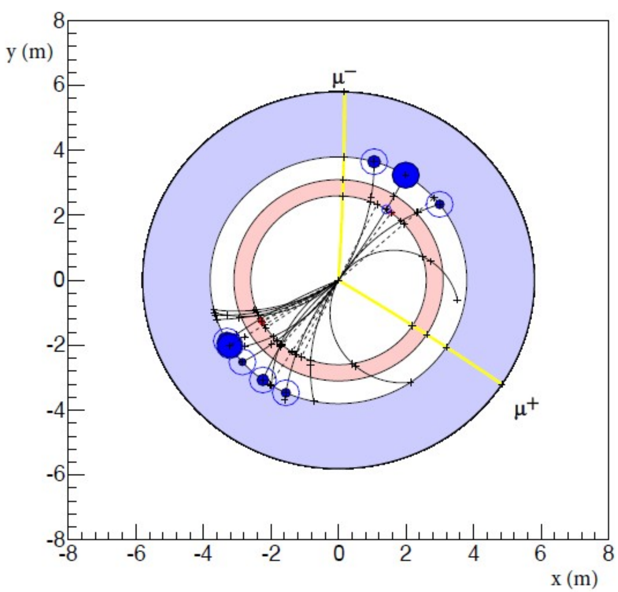
  Of which 30% in the WW fusion channel (useful for the Γ_H precision)

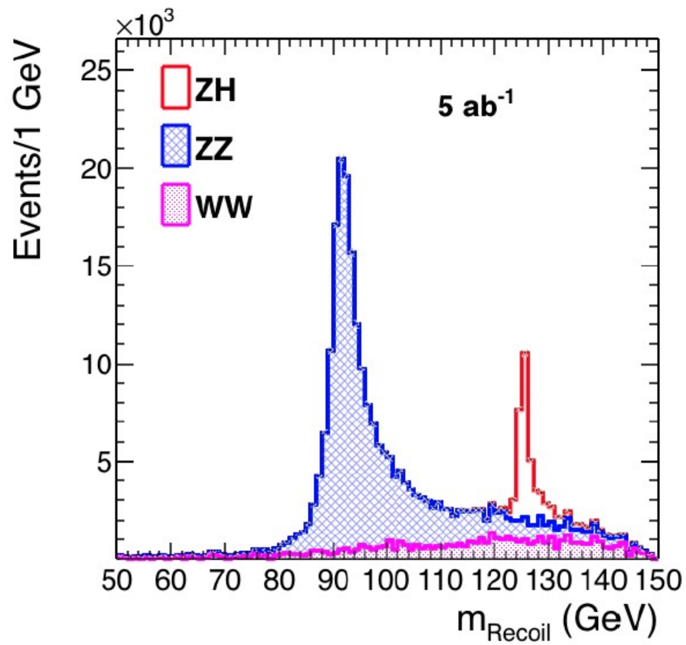
Higgs – missing mass

total rate $\propto g_{HZZ}^2$
ZZZ final state $\propto g_{HZZ}^4 / \Gamma_H$
➔ **measure total width Γ_H**

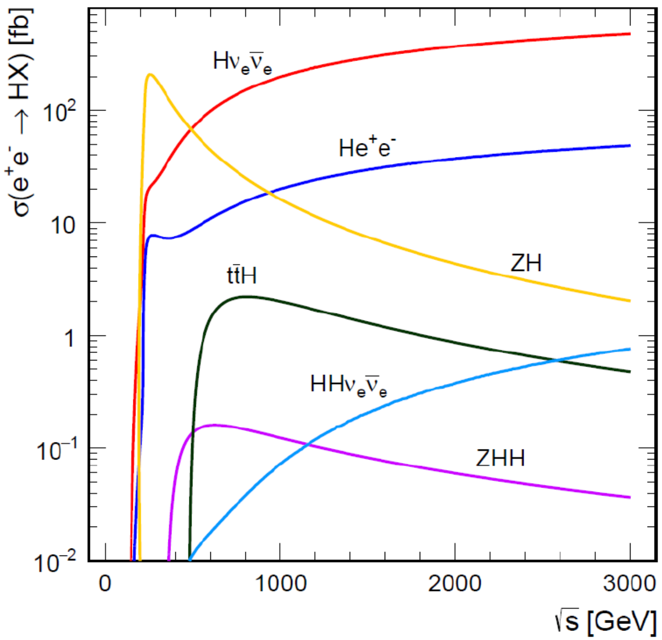
g_{HZZ} to ±0.2% and many other partial widths
empty recoil = invisible width
'funny recoil' = exotic Higgs decay
easy control below theshold







FCCee + FCChh unbetable!



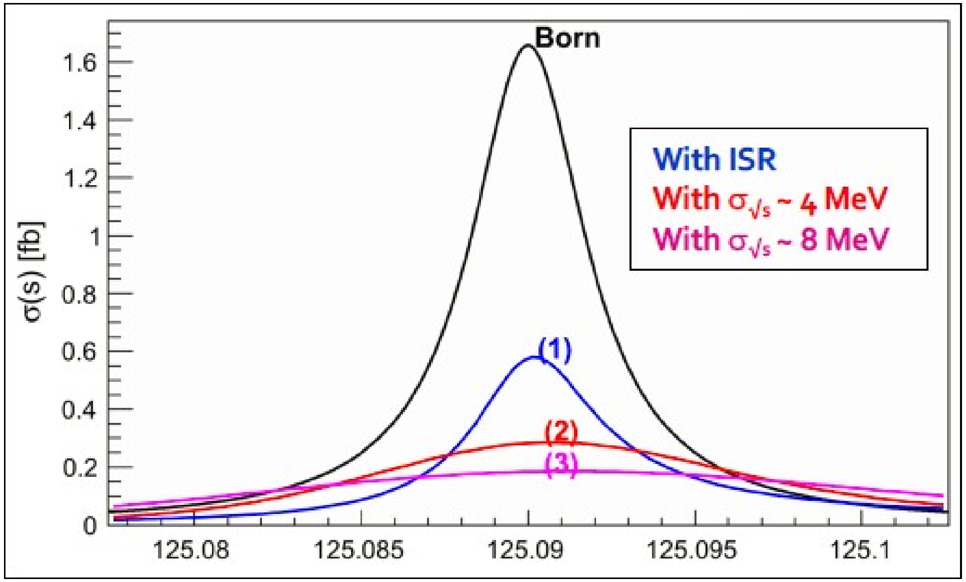
Collider	ILC_{500}	ILC_{1000}	CLIC	FCC-INT	
g_{HZZ} (%)	0.24 / 0.23	0.24 / 0.23	0.39 / 0.39	0.17 / 0.16	
g_{HWW} (%)	0.31 / 0.29	0.26 / 0.24	0.38 / 0.38	0.20 / 0.19	
g_{Hbb} (%)	0.60 / 0.56	0.50 / 0.47	0.53 / 0.53	0.48 / 0.48	
g_{Hcc} (%)	1.3 / 1.2	0.91 / 0.90	1.4 / 1.4	0.96 / 0.96	
g_{Hgg} (%)	0.98 / 0.85	0.67 / 0.63	0.96 / 0.86	0.52 / 0.50	
$g_{H\tau\tau}$ (%)	0.72 / 0.64	0.58 / 0.54	0.95 / 0.82	0.49 / 0.46	
$g_{H\mu\mu}$ (%)	9.4 / 3.9	6.3 / 3.6	5.9 / 3.5	0.43 / 0.43	
$g_{H\gamma\gamma}$ (%)	3.5 / 1.2	1.9 / 1.1	2.3 / 1.1	0.32 / 0.32	
$g_{HZ\gamma}$ (%)	– / 10.	– / 10.	7. / 5.7	0.71 / 0.70	
g_{Htt} (%)	6.9 / 2.8	1.6 / 1.4	2.7 / 2.1	1.0 / 0.95	
g_{HHH} (%)	27.	10.	9.	5.	
Γ_H (%)	1.1	1.0	1.6	0.91	ee
BR_{inv} (%)	0.23	0.22	0.61	0.024	hh
BR_{EXO} (%)	1.4	1.4	2.4	1.0	ee

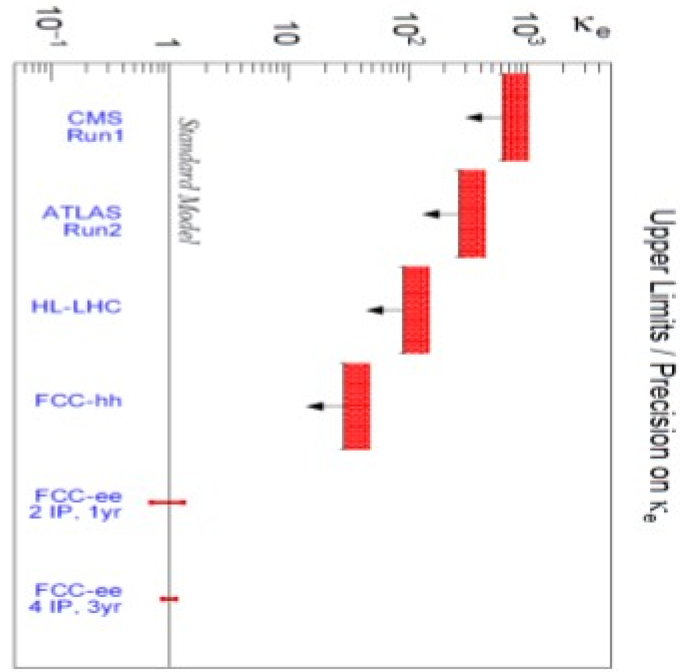
ee

FCC-hh > 10^{10} H produced, +
FCC-ee measurement of g_{HZZ}
→ g_{HHH} , $g_{H[illegible]}$, $g_{HZ[illegible]}$, $g_{H[illegible]}$, BR_{inv}

(*)see M. Selvaggi, 3d FCC physics workshop,
9% precision in 3 years of FCC-hh running, 2004.03505v1

Unique measurement!





e+e- -> H @ 125.xxx GeV requires
-- Higgs mass to be known to <5 MeV from 240 GeV run (CEPC group almost there)
-- **Huge luminosity**
-- **monochromatization** (opposite sign dispersion using magnetic lattice) to reduce σ_{ECM}
-- **continuous monitoring and adjustment of E_{CM}** to MeV precision (transv. Polar.)
-- an extremely sensitive event selection against backgrounds
-- a generous lab director to spend 3 years doing this and neutrino counting

Detectors

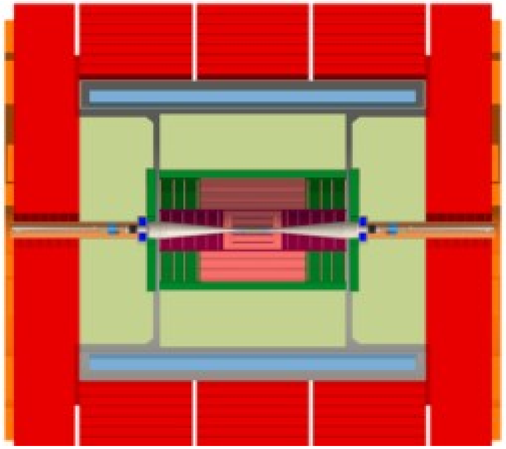
Detectors can be done and work for the FCC-ee but physics optimization remains to be done.

Two integration, performance and cost estimates:

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

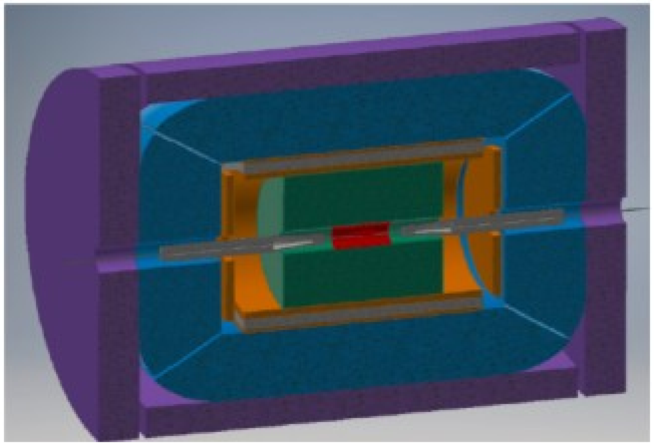
-- IDEA, detector specifically designed for FCC-ee (and CEPC)

"CLIC-detector revisited"



SiD at ILC, CLD at FCC-ee

"IDEA"



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

IDEA at FCC-ee & CEPC

Many challenges to come mainly because of the Z run.

The Z peak

Is the most unique, most challenging and (once you get used to it) the most promising part of the program!

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} , $\sin^2{}_{W}^{eff}$, R_b , ¬⅄$_{QED}$ (m_z) ¬⅄$_s$ (m_z m_W), Higgs and top quark couplings

model independent «fixed candle» for Higgs measurements, ee-H coupling.

DISCOVER a violation of flavour conservation or universality and unitarity of PMNS @10^{-5}

-- ex FCNC (Z --> mu tau , eτ) in 5 10^{12} Z decays and τ BR in 2 10^{11} Z-> $\tau\tau$

+ flavour physics (10^{12} bb events) (B-> $\tau\tau$ 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

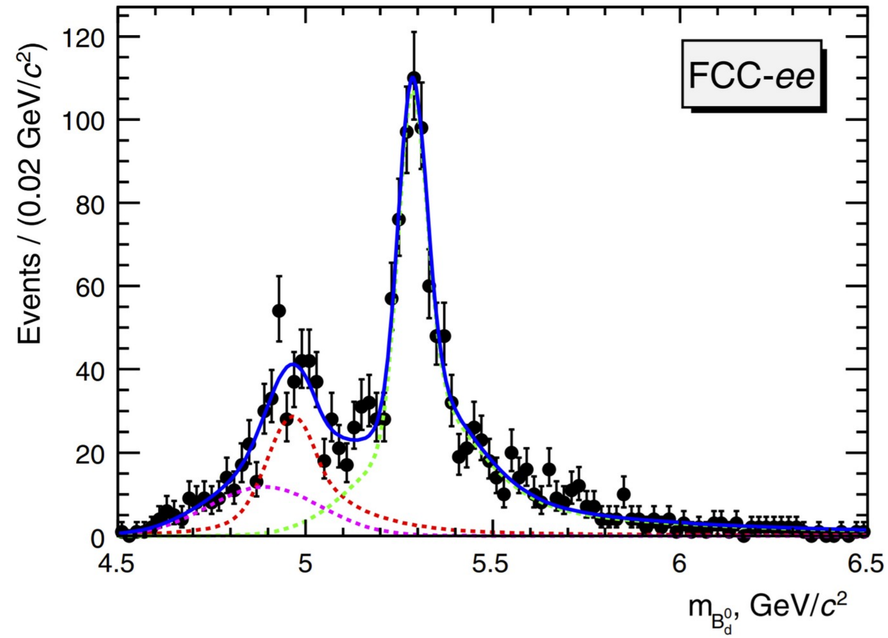
such as: Right-Handed neutrinos, Dark Photons, ALPS, etc…

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

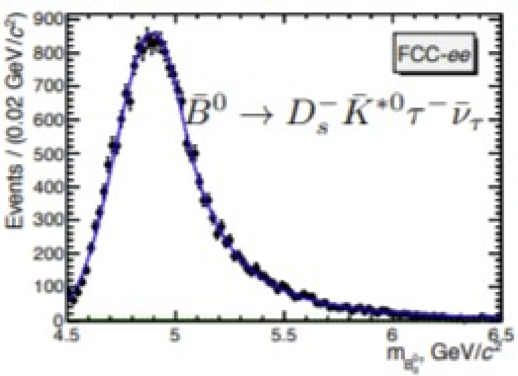
Flavour Physics – holy grail hunt

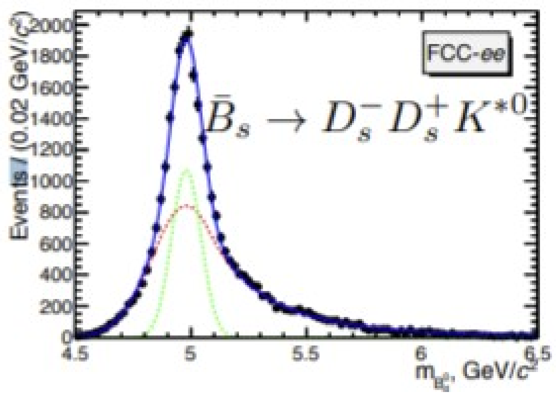
If the flavour anomalies are true this is the holy grail of NP $B^0 \to K^{0*}\tau^+\tau^-$

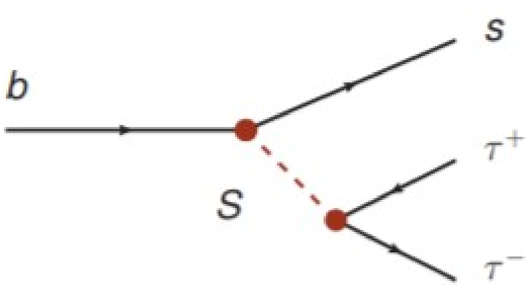
1000 events expected in FCCee!!!!

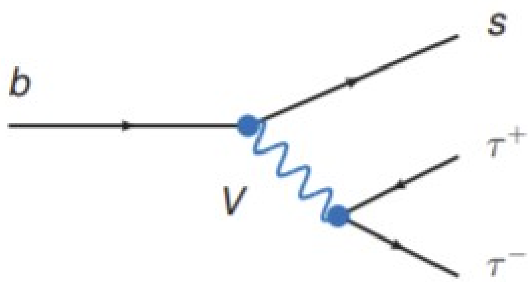


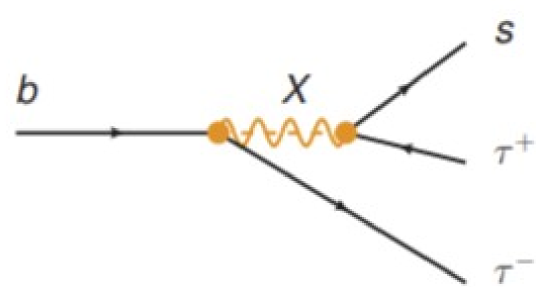
Backgrounds:



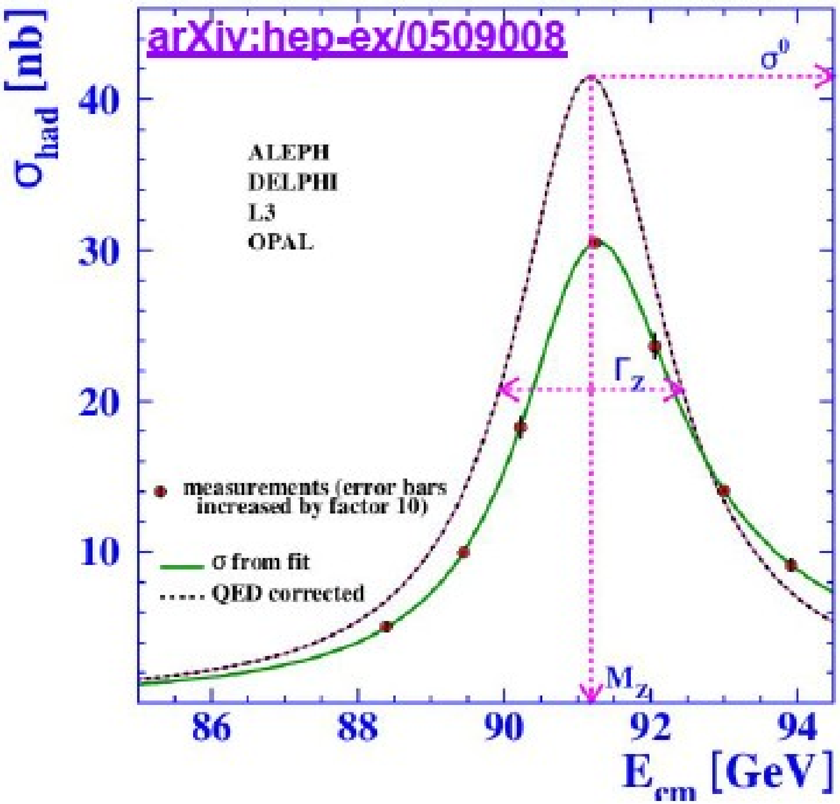


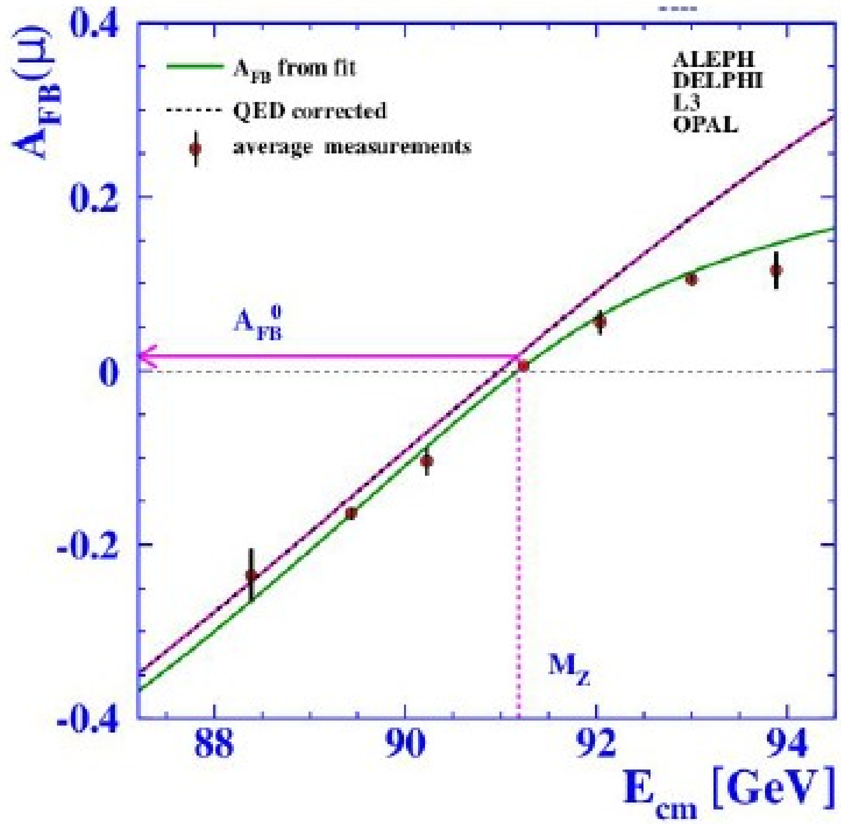






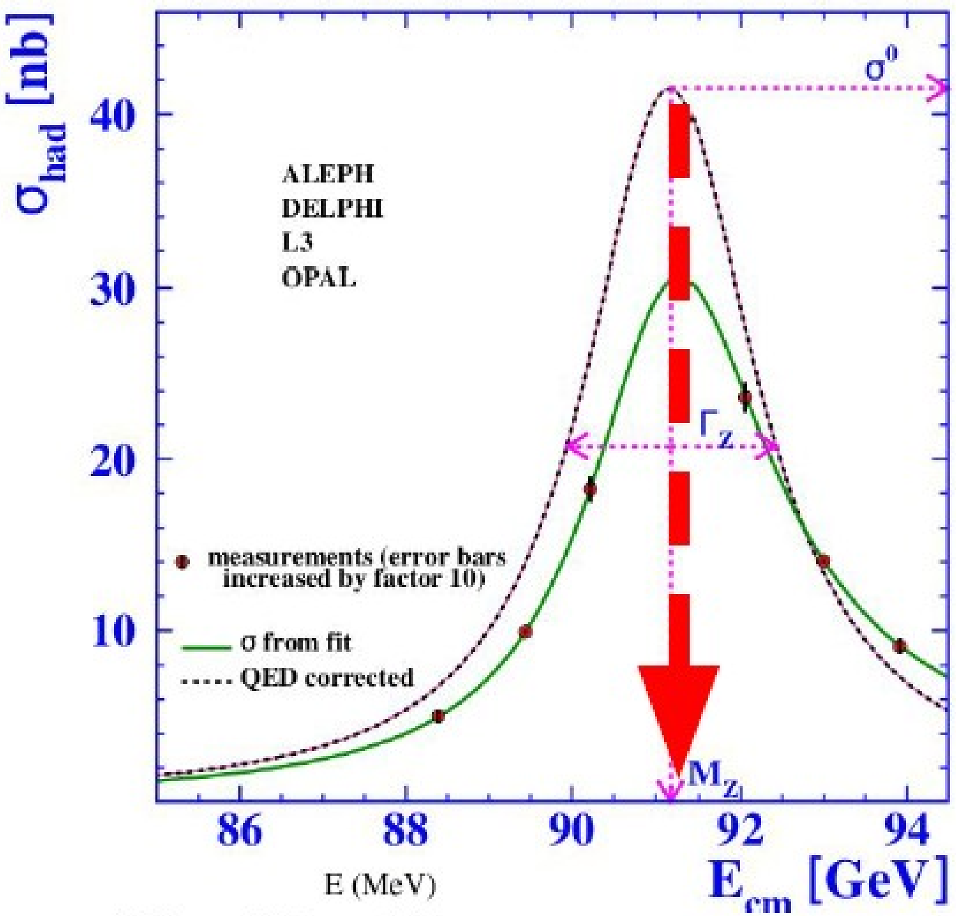
Z lineshape measurements



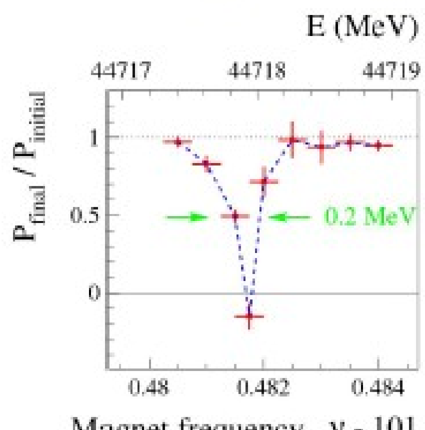


- Expected precisions in a nutshell:
  - ≈ 10^{-4} on cross sections (aimed luminosity uncertainty); possibility to reduce it by an order of magnitude using the measured $\sigma(ee \to \gamma\gamma)$ as reference
  - ≈ 10^{-6} statistical uncertainties (≈ $1/\sqrt{N}$) on relative measurements like forward-backward charge asymmetries
  - Ultimate uncertainties typically dominated by systematics; precious value of "Tera" Z samples to study / constrain many of those uncertainties

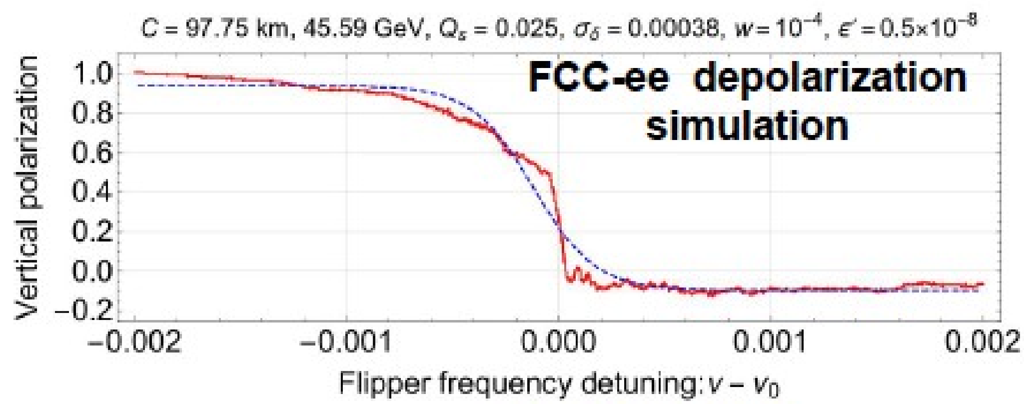
Z lineshape: mass



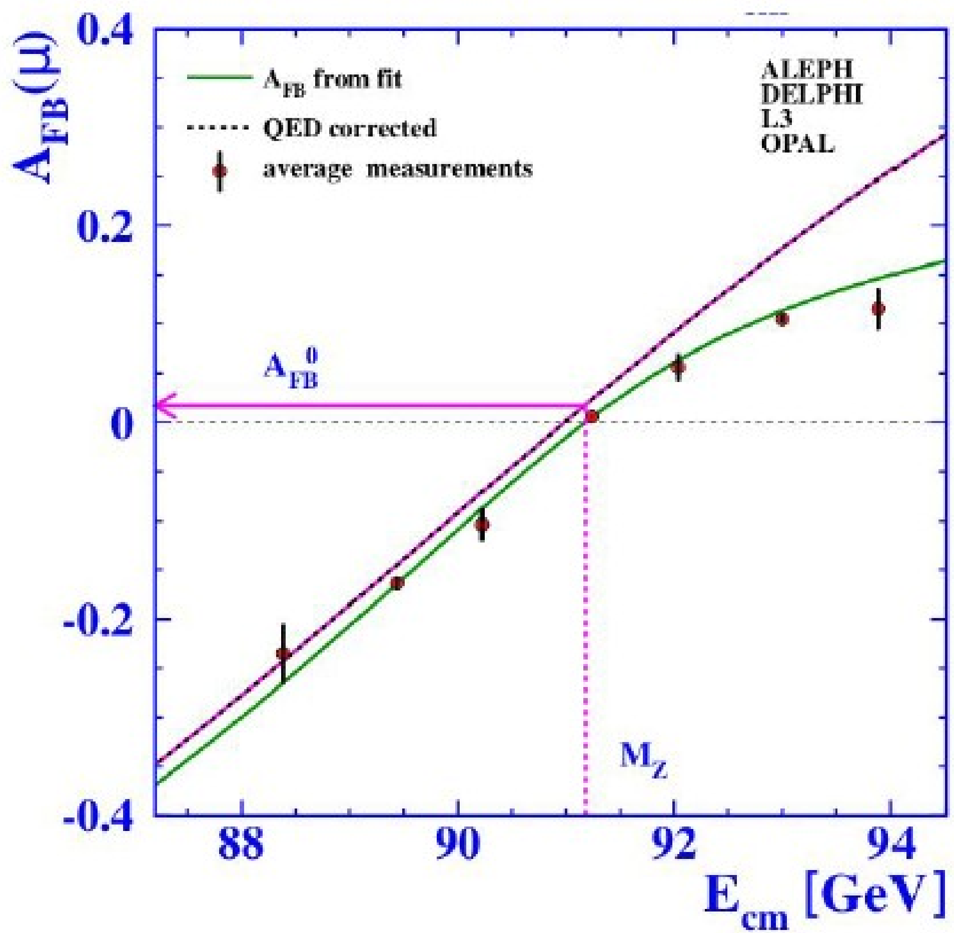
- m_Z: position of Z peak
- Beam energy measured with extraordinary precision ($\Delta\sqrt{s}\approx100$ keV) using resonant depolarization of transversely polarized beams (method already used at LEP, much better prepared now, calibrations in situ with pilot bunches, no energy extrapolations, …)
- Beam width/asymmetries studied analyzing the longitudinal boost distribution of the $\mu\mu$ system



Resonant depolarization at LEP



$\sin^2\theta_W^{eff}$ and $\alpha_{QED}(m^2_Z)$



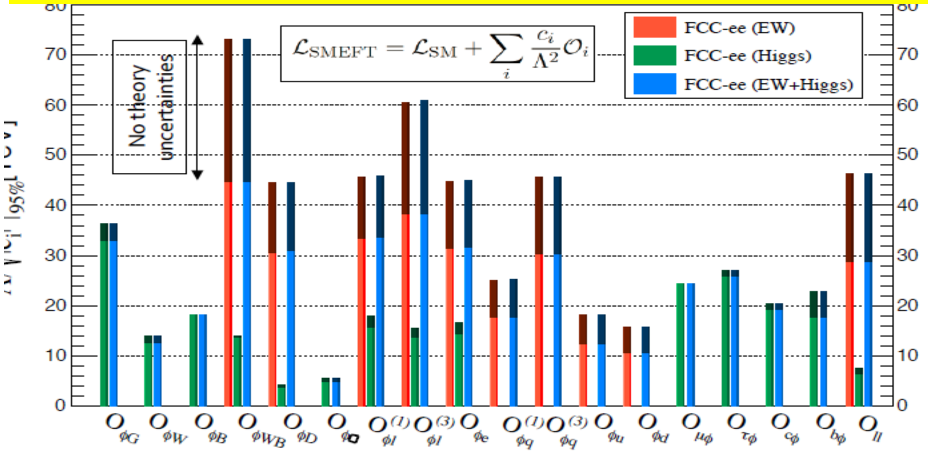
- $\sin^2\theta_W$ effective: g_V/g_A coupling ratio → forward-backward charge asymmetries (most precise in $\mu\mu$ in final state)
- $\alpha_{QED}(m^2_Z)$: off-peak/peak evolution of the asymmetry (due to interference with γ^* exchange)
- Measurement approaching the ultimate statistical sensitivity: 3×10^{-6}
- 3 energy points (≈88, 91.2, 94 GeV)
- **Studies to establish the experimental/theoretical needs (energy resolutions, exact angular description at this level of precision, ...)**

The opportunities

The challenges

Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and leading exp. error
m_Z (keV)	91186700 ± 2200	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	**4**	25	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{\rm eff}(\times 10^6)$	231480 ± 160	**2**	2.4	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{\rm QED}(m_Z^2)(\times 10^3)$	128952 ± 14	**3**	small	from $A_{FB}^{\mu\mu}$ off peak QED&EW errors dominate
R_ℓ^Z $(\times 10^3)$	20767 ± 25	**0.06**	0.2-1	ratio of hadrons to leptons **acceptance for leptons**
$\alpha_s(m_Z^2)$ $(\times 10^4)$	1196 ± 30	**0.1**	0.4-1.6	from R_ℓ^Z above
$\sigma^0_{\rm had}$ $(\times 10^3)$ (nb)	41541 ± 37	**0.1**	4	peak hadronic cross section luminosity measurement
$N_\nu(\times 10^3)$	2996 ± 7	**0.005**	1	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216290 ± 660	**0.3**	< 60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD
$A_{FB}^b, 0$ $(\times 10^4)$	992 ± 16	**0.02**	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{{\rm pol},\tau}$ $(\times 10^4)$	1498 ± 49	**0.15**	<2	τ polarization asymmetry τ decay physics
τ lifetime (fs)	290.3 ± 0.5	**0.001**	0.04	radial alignment
τ mass (MeV)	1776.86 ± 0.12	**0.004**	0.04	momentum scale
τ leptonic $(\mu\nu_\mu\nu_\tau)$ B.R. (%)	17.38 ± 0.04	**0.0001**	0.003	e/μ/hadron separation
m_W (MeV)	80350 ± 15	**0.25**	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
$\alpha_s(m_W^2)(\times 10^4)$	1170 ± 420	**3**	small	from R_ℓ^W
$N_\nu(\times 10^3)$	2920 ± 50	**0.8**	small	ratio of invis. to leptonic in radiative Z returns
$m_{\rm top}$ (MeV/c^2)	172740 ± 500	**17**	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\Gamma_{\rm top}$ (MeV/c^2)	1410 ± 190	45	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{\rm top}/\lambda_{\rm top}^{\rm SM}$	1.2 ± 0.3	**0.10**	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	± 30%	0.5 – 1.5%	small	From $\sqrt{s} = 365$ GeV run

Precision EW measurements: is the SM complete?



-^- EFT D6 operators (some assumptions)

-^- Higgs and EWPOs are complementary

-^- top quark mass and couplings essential!

(the 100km circumference is optimal for this)

<-- systematics are preliminary
(aim at reducing to systematics)

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

<-- complemented by high energy FCC-hh

Theory work is critical and initiated *1809.01830*

Tau physics at FCC-ee

Snowmass2021 - Letter of Interest

Tau lepton properties and lepton universality measurements at the FCC-ee

Thematic Areas:
- EF04: EW Physics: EW Precision Physics and constraining new physics
- EF03: EW Physics: Heavy flavor and top quark physics

Contact Information:
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Authors:
Alain Blondel[1], Mogens Dam[2], Patrick Janot[3]

LoI #252

Abstract:
The FCC-ee is a frontier Higgs, Top, Electroweak, and Flavour factory. It will be operated in a 100-km circular tunnel built in the CERN area, and will serve as the first step of the FCC integrated programme towards $\geq$ 100-TeV proton-proton collisions in the same infrastructure [1]. With its huge luminosity at Z-pole energies, unrivalled samples of 5×10^{12} Z decays will be produced at multiple interaction points. The five orders of magnitude larger statistics than at LEP opens the possibility of much improved measurements of τ-lepton properties—lifetime, (leptonic) branching fractions, and mass—in $\tau^+\tau^-$ final states. Such measurements provides interesting tests of lepton universality, in effect probing whether the Fermi coupling constant is the same in τ decays as in μ decays. The ultimate goal, that experimental errors match the statistical accuracy, leads to highly demanding requirements on detector design. This Letter of Interest describes some of the many challenges presented by this benchmark measurement.

Snowmass2021 - Letter of Interest

Tau exclusive branching fractions and tau polarisation observables at the FCC-ee

Thematic Areas:
- EF04: EW Physics: EW Precision Physics and constraining new physics
- EF05: QCD and strong interactions:Precision QCD

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Mogens Dam (Niels Bohr Institute, Copenhagen University) [dam@nbi.dk]

Authors:
Alain Blondel[1], Mogens Dam[2], Clement Helsens[3], Patrick Janot[3]

LoI #255

Abstract:
The FCC-ee is a frontier Higgs, Top, Electroweak, and Flavour factory. It will be operated in a 100-km circular tunnel built in the CERN area, and will serve as the first step of the FCC integrated programme towards $\geq$ 100 TeV proton-proton collisions in the same infrastructure [1]. With its huge luminosity at Z-pole energies, unrivalled samples of 5×10^{12} Z-decays will be produced at multiple interaction points. This opens the possibility for very precise measurements of τ leptons including their exclusive branching fractions and their polarisation in Z decays, one of the most precise electroweak observables. This letter of interest concentrates on some of the main experimental challenges in τ-lepton measurements, namely the inter-channel separation and the precise measurement of the final state kinematics. This relies critically on the precise measurement of photons and π^0's (and other neutral particles) in the calorimeter system, on the precise tracking of high-multiplicity collimated topologies, and—at least for the exclusive branching fractions—on the ability to separate pions from kaons over the full momentum range.

τ-lepton properties and Lepton Universality

Snowmass2021 - Letter of Interest

Tau lepton properties and lepton universality measurements at the FCC-ee

Thematic Areas:
■ EF04: EW Physics: EW Precision Physics and constraining new physics
■ EF03: EW Physics: Heavy flavor and top quark physics

Contact Information:
Mogens Dam (Niels Bohr Institute, Copenhagen University) [dam@nbi.dk]

Authors:
Alain Blondel[1], Mogens Dam[2], Patrick Janot[3]

Abstract:
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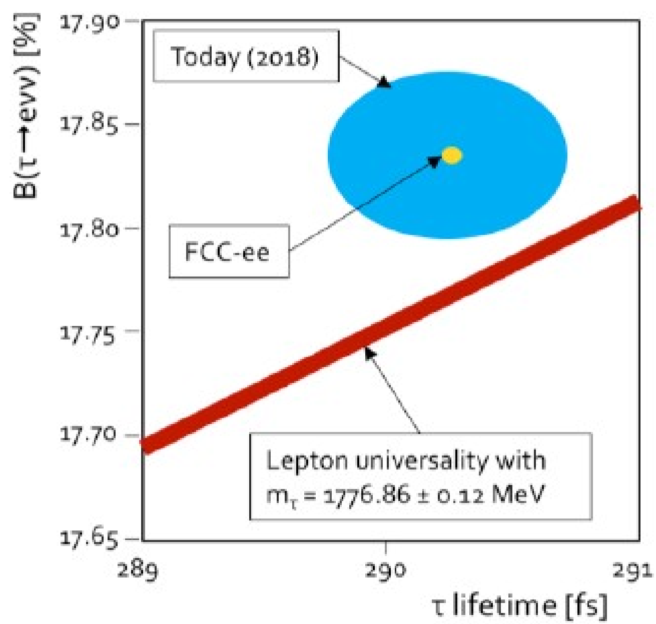
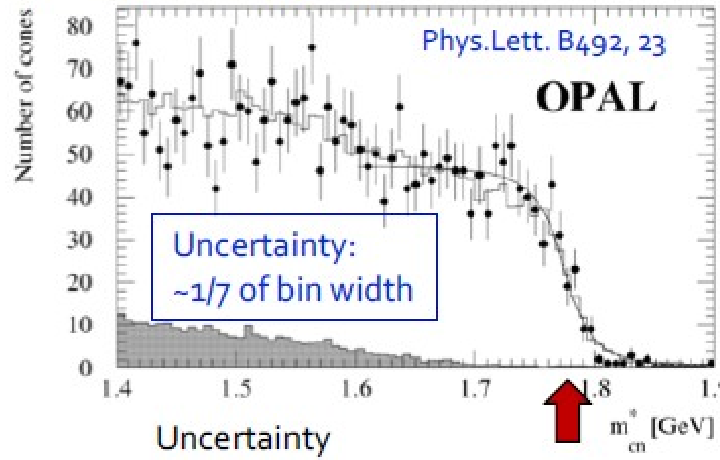
a) Mass
b) Lifetime
c) Leptonic branching fractions



Tau Mass (i)

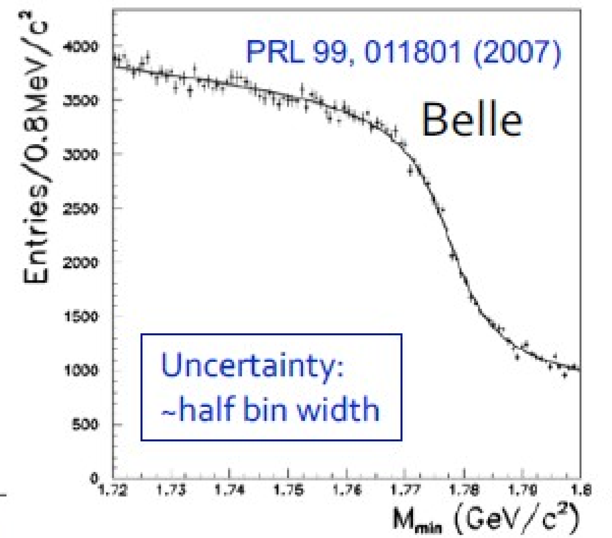
- **Current world average:** **m_τ = 1776.86 ± 0.12 MeV**
- Best in world: BES3 (threshold scan) $m_\tau = 1776.91 \pm 0.12\ (\text{stat.})\ ^{+0.10}_{-0.13}\ (\text{syst.})$ MeV
- Best at LEP: OPAL $m_\tau = 1775.1 \pm 1.6\ (\text{stat.}) \pm 1.0\ (\text{syst.})$ MeV
  - About factor 10 from world's best
  - Main result from endpoint of distribution of pseudo-mass in $\tau \to 3\pi^\pm(n\pi^0)\nu_\tau$
  - Dominant systematics
    - Momentum scale: 0.9 MeV
    - ECAL scale: 0.25 MeV (including also π^0 modes)
    - Dynamics of τ decay: 0.10 MeV



- Same method from Belle
  - Main systematics
    - Beam energy & tracking system calib.: 0.26 MeV
    - Parameterisation of the spectrum edge: 0.18 MeV

$m_\tau = 1776.61 \pm 0.13\ (\text{stat.}) \pm 0.35\ (\text{syst.})$ MeV

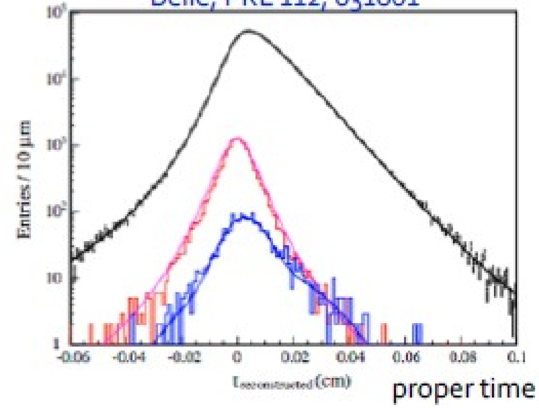
Pseudo-mass: $M_{min} = \sqrt{M_{3\pi}^2 + 2(E_{beam} - E_{3\pi})(E_{3\pi} - P_{3\pi})}$



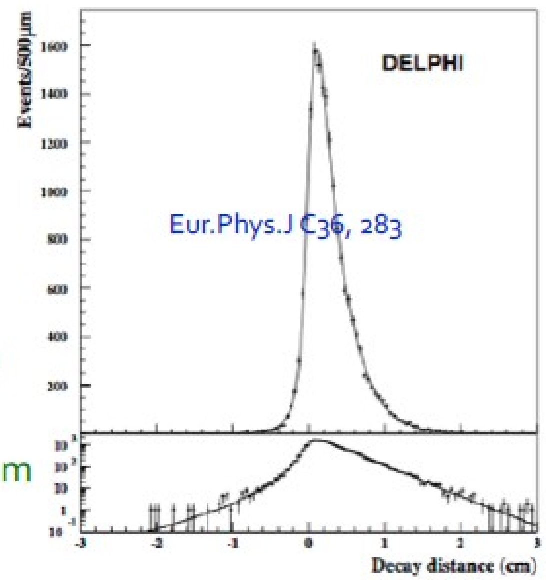
Tau Lifetime (i)

- **Current world average:** $\tau_\tau = 290.3 \pm 0.5$ fs
- **Best in world** (Belle): $\tau_\tau = 290.17 \pm 0.53_{stat} \pm 0.22_{syst}$ fs
  - Large statistics: 711 fb^{-1} @ $\Upsilon(4S)$: 6.3×10^8 $\tau^+\tau^-$ events
  - Use 3 vs. 3 prong events (1.1M events); reconstruct 2 secondary vertices + primary vertex
  - Measure flight distance ⇒ proper time
  - Dominant systematics: Vertex detector alignment to ~0.25 μm
    - Vertex detector outside 15 mm beam pipe

Belle, PRL 112, 031801



- **Best at LEP** (DELPHI): $\tau_\tau = 290.0 \pm 1.4_{stat} \pm 1.0_{syst}$ fs
  - "Low" statistics: ~250,000 $\tau^+\tau^-$ events
  - Three methods:
    - Decay length (1v3 + 3v3), impact parameter difference (1v1), miss distance (1v1)
  - Lowest systematics from decay length method (1v3)
    - Dominant systematics: Vertex detector alignment to 7.5 μm
      - Alignment with data ($q\bar{q}$ events): statistics limited
    - Vertex detector: 7.5 μm point resolution at 63, 90, and 109 mm



Eur.Phys.J C36, 283

The Flavour Factory

Progress in flavour physics wrt SuperKEKb/BELLEII requires > 10^{11} b pair events,
FCC-ee(Z): will provide ~10^{12} b pairs. "**Want at least 5 10^{12} Z…"**

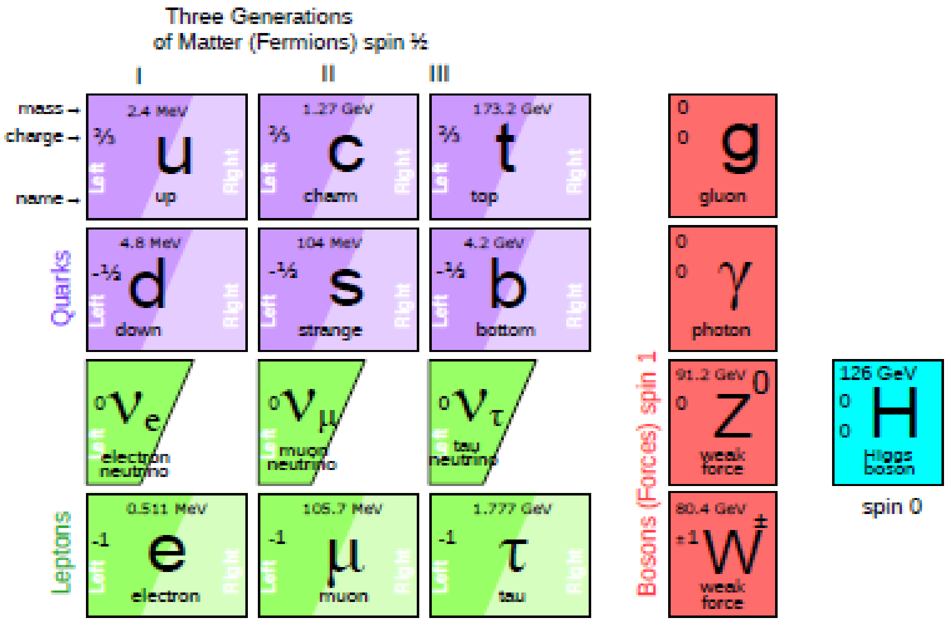
-- precision of CKM matrix elements
-- Push forward searches for FCNC, CP violation and mixing
-- Study rare penguin EW transitions such as $b \to s\, \tau^+ \tau^-$, spectroscopy (produce b-baryons, B_s …)
-- Test lepton universality with 10^{11} τ decays (with τ lifetime, mass, BRs) at 10^{-5} level, LFV to 10^{-10}
-- all very important to constrain / (provide hints of) new BSM physics.

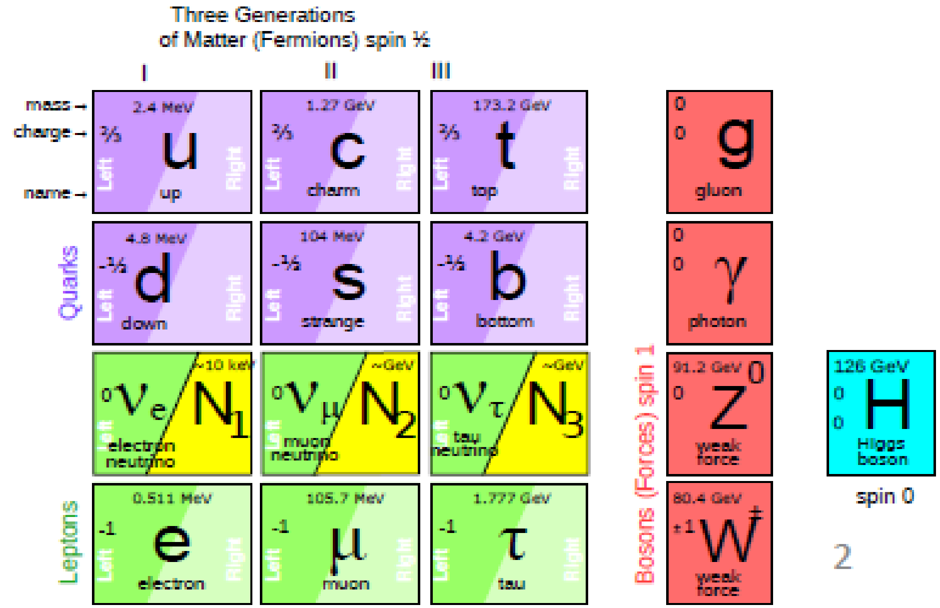
need special detectors (PID); a story to be written!

The 3.5 × 10^{12} hadronic Z decay also provide precious input for QCD studies

High-precision measurement of $\alpha_s(m_Z)$ with R_ℓ in Z and W decay, jet rates, τ decays, etc. : $10^{-3} \to 10^{-4}$
huge √s lever-arm between 30 GeV and 1 TeV (FCC vs ILC), fragmentation, baryon production …

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

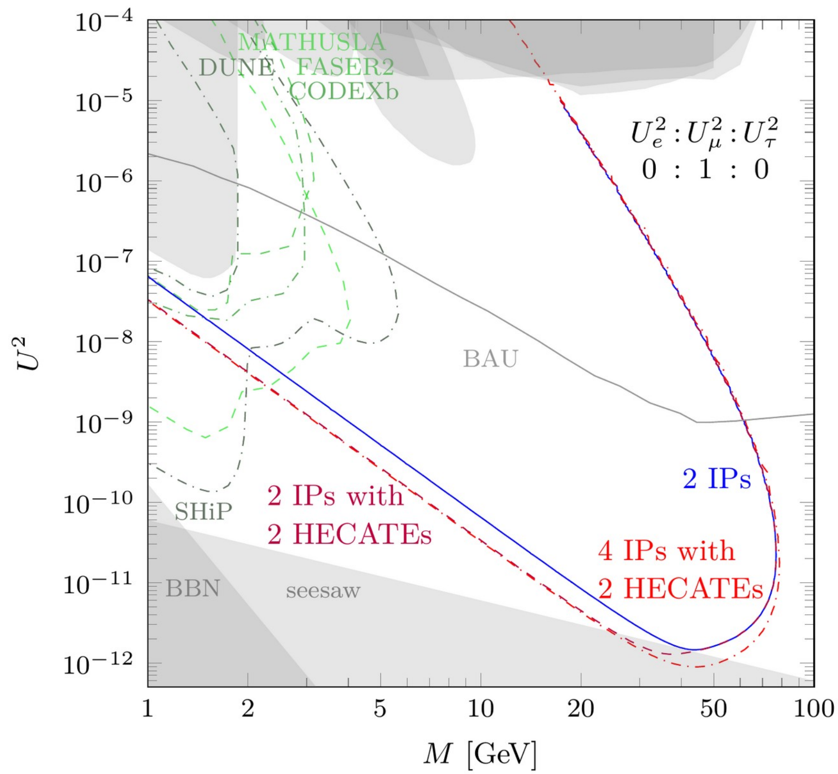
completely unknown masses (eV to ZeV), nearly impossile to find.

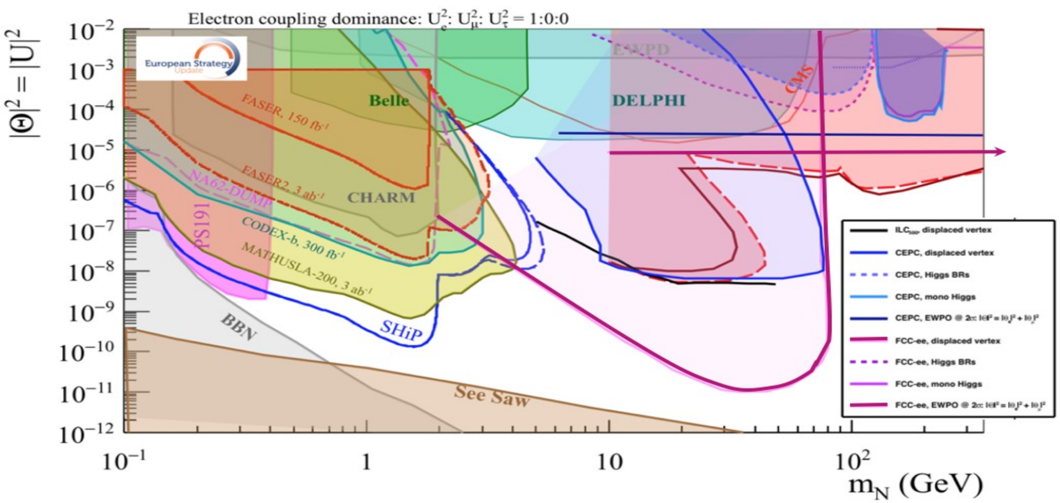
.... but could perhaps explain all: DM, BAU, ν-masses

FCC for hunting RHN neutrinos

https://arxiv.org/abs/2011.01005

FCCee is the only experiment that can reach the See Saw bound
No background for this kind of processes.





Conclusions

=> FCC has just started to discover its physics potential.
=> Much much more studies to be conducted.
=> Unique opportunities in Higgs, EW, Flavour Phvsics.
=> Detector optimization moving forward.
=> More groups and countries are joining.

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The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

THANK YOU