Introduction to the FCC projects

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With inputs from many people

What is FCC?

- Future-Circular-Colliders

- Build a 80-100 km tunnel to host new collider(s)

  - 1) pp-collider (FCC-hh) → defining infrastructure requirements
    - ~8.3 Tesla (LHC dipoles) $\Rightarrow \sqrt{s}$=42 TeV pp in 100 km (NbTi)
    - ~16 Tesla $\Rightarrow \sqrt{s}$=100 TeV pp in 100 km ($NbSn_3$)
    - ~20 Tesla $\Rightarrow \sqrt{s}$=100TeV pp in 80 km (HTS)
    - Lead-Lead collider possibility

  - 2) e^+e^- collider (FCC-ee, old TLep) as potential intermediate step
    - Tera-Z, Oku-W, Mega-H, Mega-Top

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

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Events

- FCC Kick-off meeting 02/2014: http://indico.cern.ch/event/282344/
- First FCC-hh workshop 05/2014: http://indico.cern.ch/event/304759/

- FCC-hh meetings: https://indico.cern.ch/category/5258/
- Subscribe to the mailing list! https://e-groups.cern.ch/e-groups/ and search for “fcc-experiments-hadron”

FCC
hh ee he

Outline

1. Introduction
2. Infrastructures
3. Accelerator
4. Radiations
5. Detectors
6. Physics
7. Summary

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Presenting today only a selection of some aspects of the project.
Give a taste of what defining a new project like the FCC is, with some of challenges/issues

1. Introduction

European Strategy (Summary)

European Strategy Update 2013 Design studies and R&D at the energy frontier

…."to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy update":

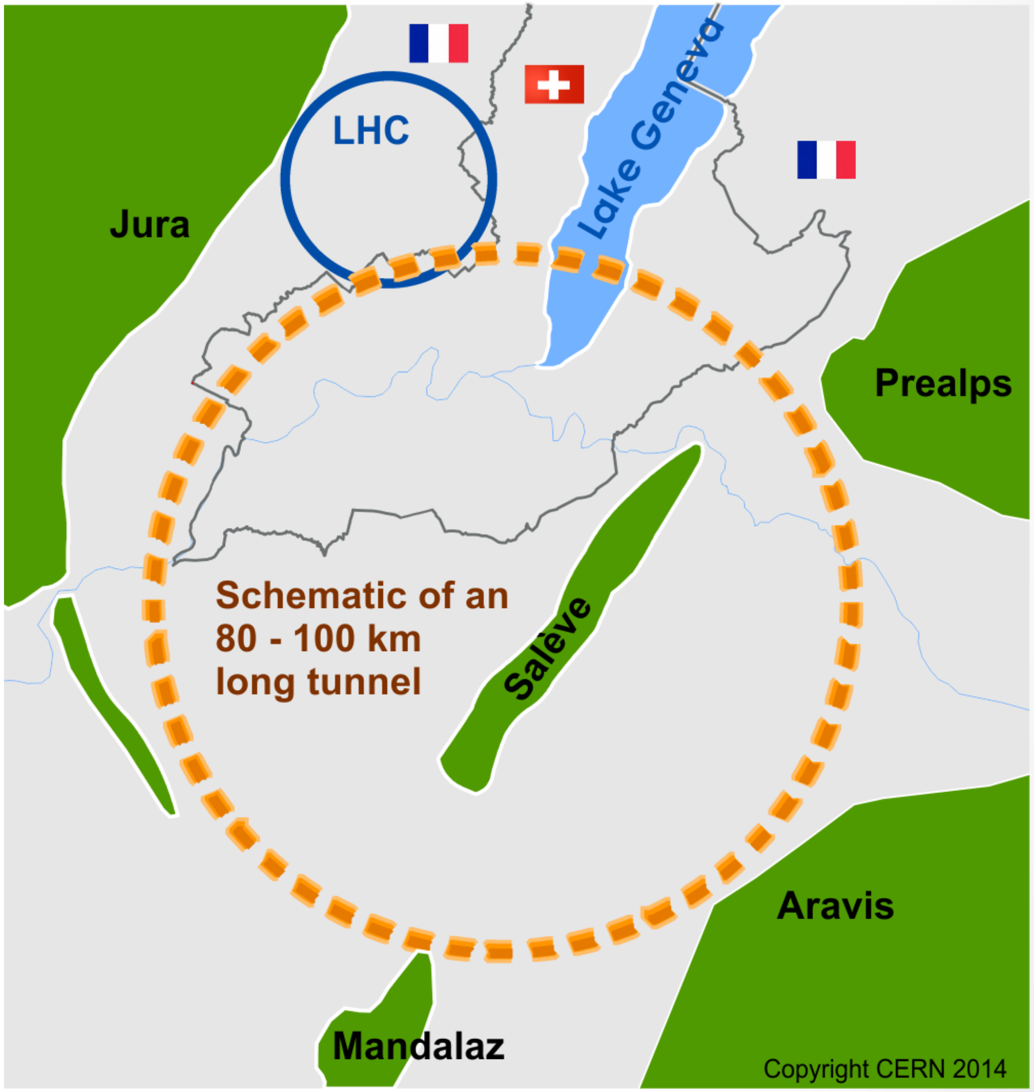
d) CERN should undertake design studies for accelerator projects in a global context,

- with emphasis on proton-proton and electron-positron high-energy frontier machines.
- These design studies should be coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures,
- in collaboration with national institutes, laboratories and universities worldwide.

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

FCC, but where?

- One possibility could be to host the collider in the Geneva area
- Strong support from CERN
- Various infrastructures already exist
- Including injectors (LHC as injector?)



FCC, but who?

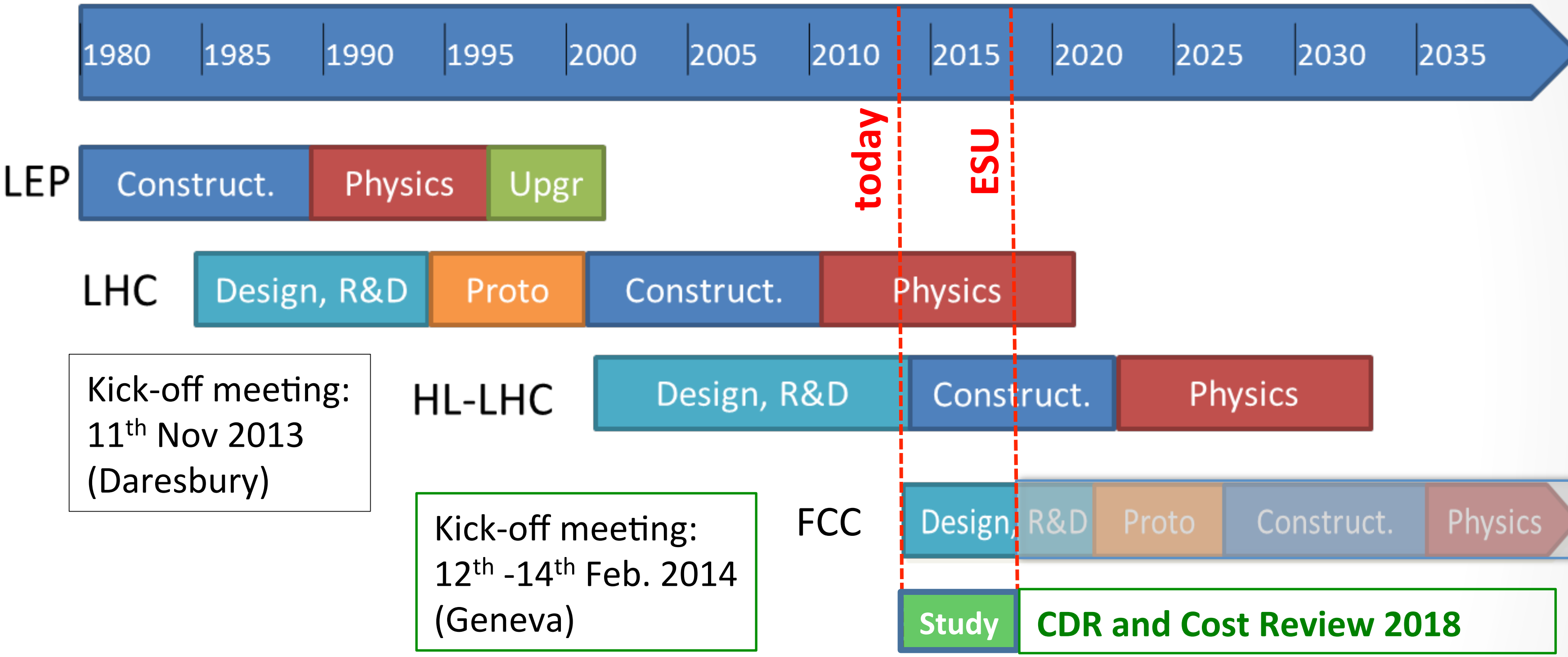
- Following a recommendation of the European Strategy report, in Fall 2013 CERN Management set up the FCC project, with the main goal of preparing a Conceptual Design Report by the time of the next ES (~2018)
- Links established with similar studies in China and in the US

- China:
  - Future High-Energy Circular Colliders WS, Bejing, 16-17 December 2013 http://indico.ihep.ac.cn/conferenceDisplay.py?confId=3813
  - 1st CFHEP (Center for Future High Energy Physics) Symposium on Circular Collider Physics, Beijing, 23-25 February 2014 http://cfhep.ihep.ac.cn

- US:
  - Physics at a 100 TeV Collider SLAC, 23-25 April 2014 https://indico.fnal.gov/conferenceDisplay.py?confId=7633
  - Next steps in the Energy Frontier Hadron Colliders, FNAL, 25-28 August 2014 https://indico.fnal.gov/conferenceDisplay.py?confId=7864

Timeline

M. Benedickt



- LHC and HL-LHC operation until ~2035
- Must start now developing FCC concepts to be ready in time

Main areas for design study

Preparatory group for a kick-off meeting
=> Steering committee

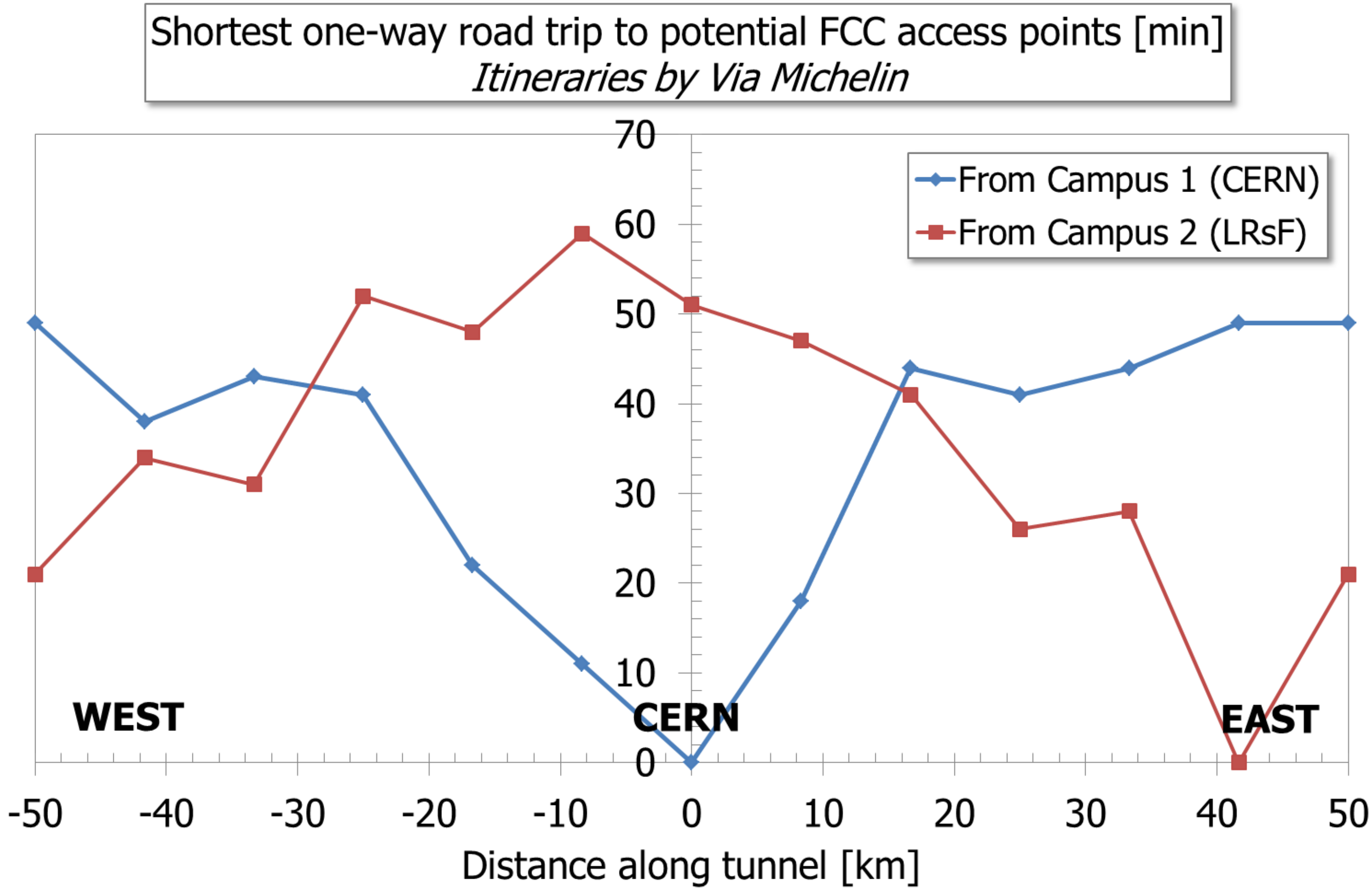
Machines and infrastructure conceptual designs	Technologies R&D activities Planning	Physics experiments detectors
Infrastructure	High-field magnets	Hadron physics experiments interface, integration
Hadron collider conceptual design	Superconducting RF systems	$e^+ e^-$ coll. physics experiments interface, integration
Hadron injectors	Cryogenics	e^- - p physics and integration aspects
Lepton collider conceptual design	Specific technologies	
Safety, operation, energy management environmental aspects	Planning	

PP-131007-MBE_FCC Design Study

2. Infrastructure

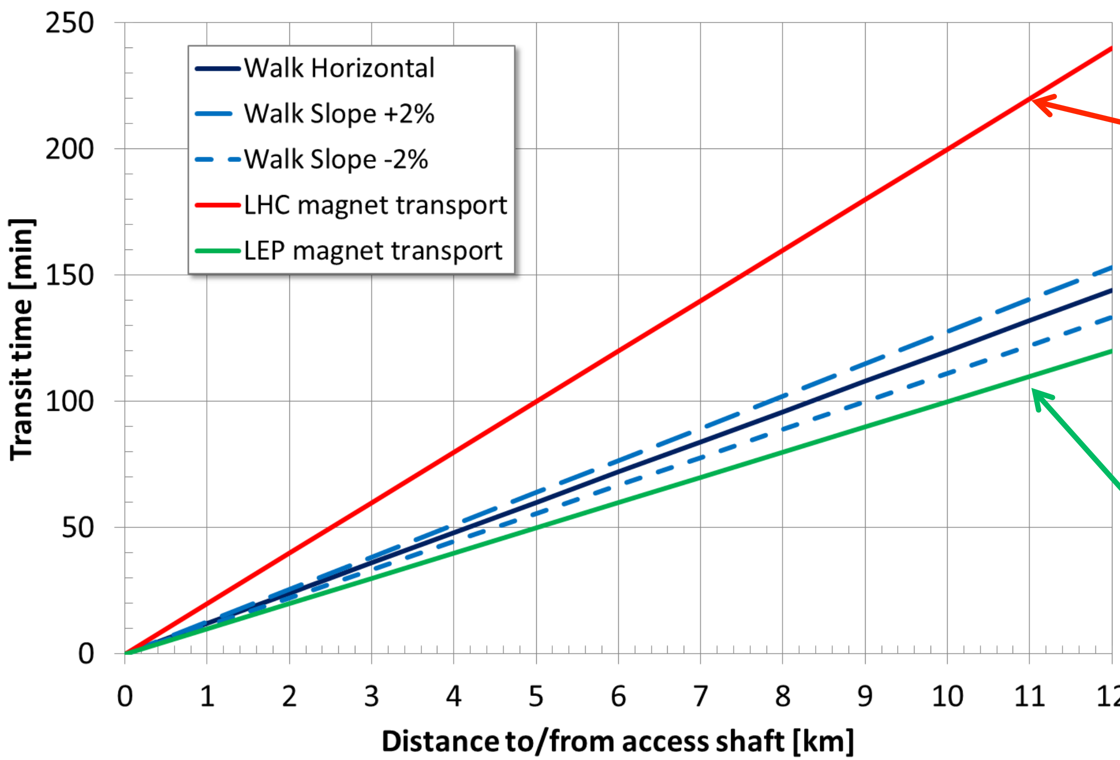
Access time

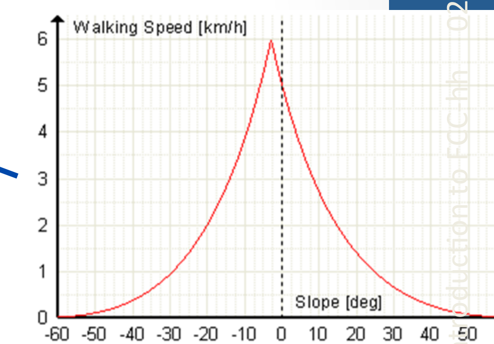
Ph. Lebrun



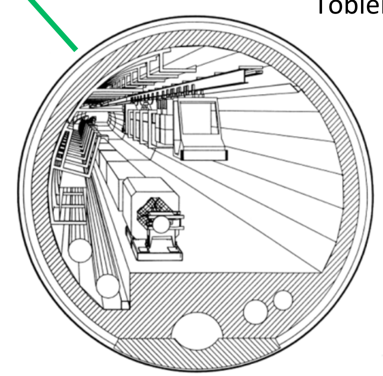
Sector length

Ph. Lebrun





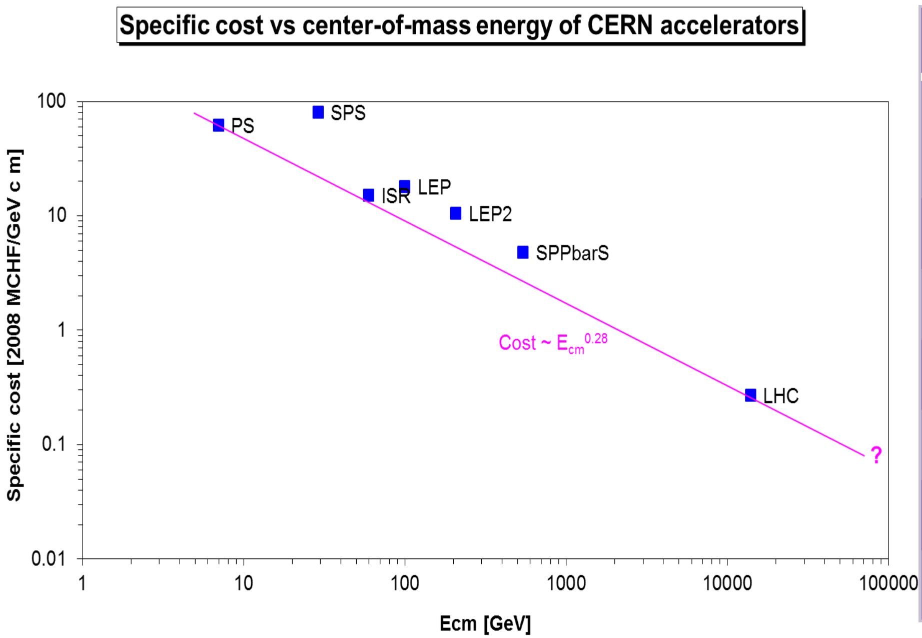
Tobler's hiking function



3. Accelerator

Cost and electricity

Ph. Lebrun

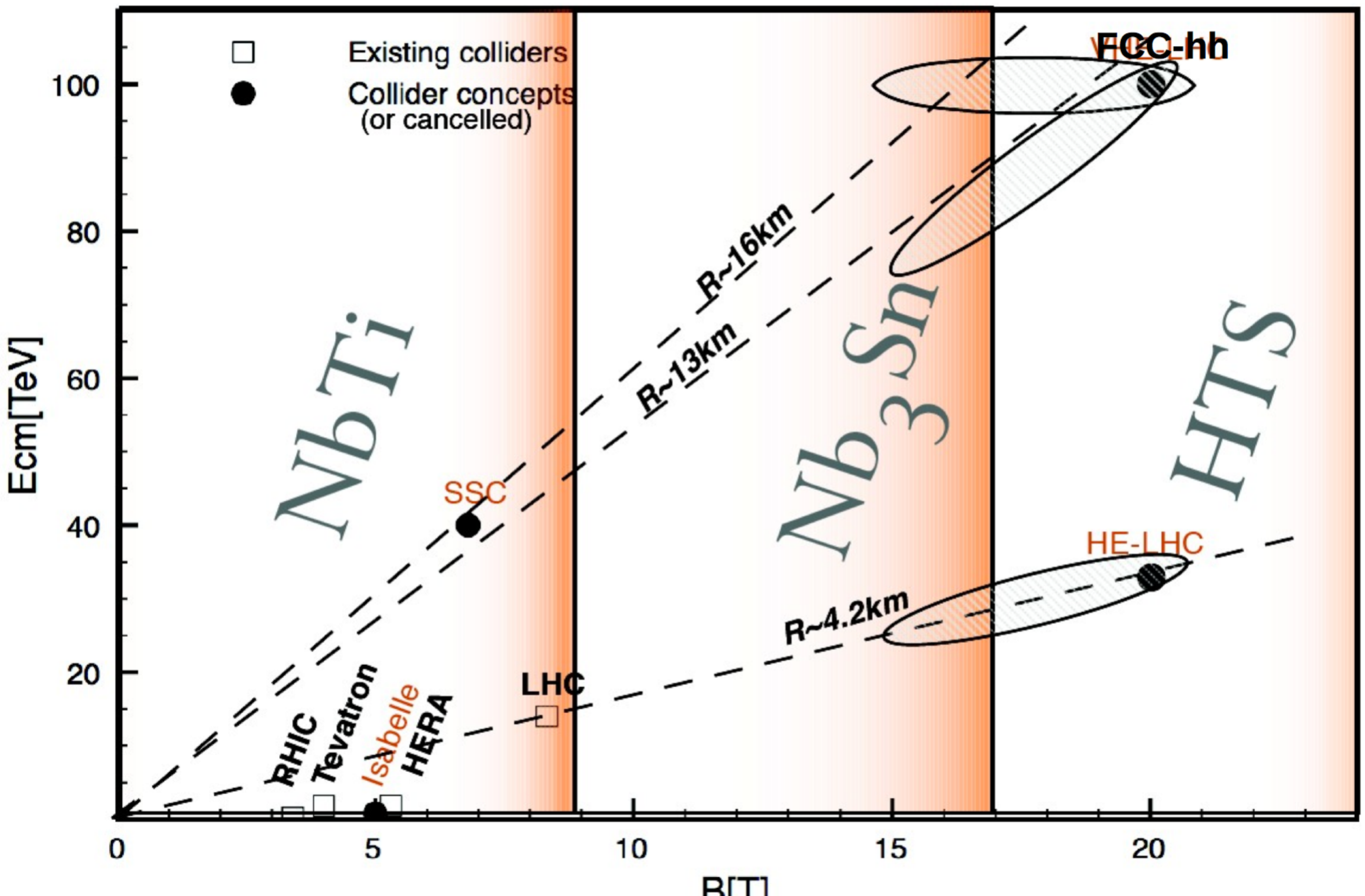


Electrical power consumption		
Accelerator complex	Nominal [MW]	Standby [MW]
LHC	122	89
HL-LHC	141	101
CLIC 500 GeV	235	167
CLIC 1.5 TeV	364	190
FCC e+e-	300?	100?
FCC pp	250?	150?

Will FCC pass below the specific cost of 100 kCHF/GeV c.m.?

E_{cm} [TeV] versus B [Tesla]

Role of the superconductor in energy reach at hadron colliders



arXiv:1310.0290

E=0.3Bρ

Rational Parameter Choice

D. Schulte

- Put together something that is reasonable
  - Somewhat conservative
  - With some aggressive choices to avoid excessive cost
  - To criticise and improve
  - To guide the design work and identify challenges
  - Seed of the baseline

- More aggressive choices will be considered as alternatives
  - When more R&D is required
  - When they involve a performance/cost trade-off
  - http://indico.cern.ch/event/282344/material/3/

Physics/machine parameters

D. Schulte

	LHC	HL-LHC	HE-LHC	FCC-hh
√s energy [TeV]	14		33	100
Luminosity [$10^{34}cm^{-2}s^{-1}$]	1	5	5	5
Bunch distance [ns]	25			25 (5)
Background events/bx	27	135	147	170 (34)
Bunch length [cm]	7.5	7.5	7.5	8
Dipole field [T]	8.33		20	16 (20)
Magn. Aperture [mm]	56		40	40
Arc fill factor [%]	79		79	79
Straight section	8x0.5km			16.8km
Total length	26.7km			100(83)km
Stored Energy (MJ)	362	694	601	4573

Synchrotron radiation

D. Schulte

	LHC	HL-LHC	HE-LHC	FCC-hh
Dipole field [T]	8.33	8.33	20	16 (20)
Synchr. Rad. in arcs [W/m/aperture]	0.17	0.33	4.35	28 (44)
Eng. Loss p. turn [MeV]	0.007		0.2	4.6 (5.9)
Crit. eng. [keV]	0.044		0.575	4.3 (5.5)
Total synr. Power [MW]	0.0072	0.0146	0.2	4.8 (5.8)
Long. Damp. Time [h]	12.9		1.0	0.54 (0.32)
Transv. Damp. Time [h]	25.8		2.0	1.08 (0.64)

- Values in brackets for 20T magnet field
- Radiation given by beam energy and dipole field
- Leads to damping of the longitudinal and transverse emittance
- Leads to significant power load on the beam screen

Luminosity considerations

D. Schulte

Luminosity is scales as: $$L \propto I\xi / \beta^* \propto P_{synrad}\xi / \beta^*$$

- Cannot increase the beam current very much
  - Machine protection
  - Arc and magnet design
  - Cooling and power consumption
  - Collective effects
  - Only a fraction of the ring that can be filled with bunches

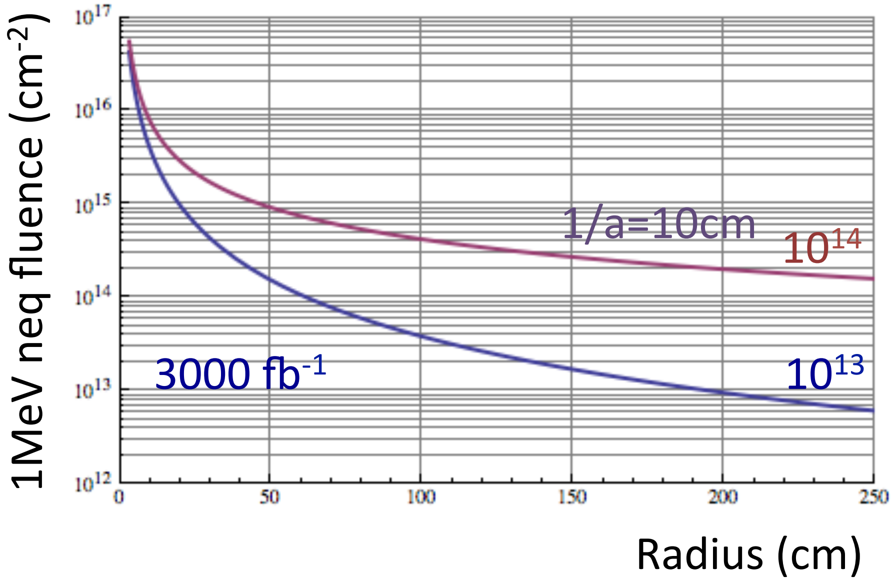
- Should be able to reduce the beta-function
  - It is easier to obtain small beta-functions with shorter L*
  - Will have a tendency to reduce L* -> impact the experimental area
  - L^* = 38m (goal >25m) β^* = 0.3m (goal <1.1m)

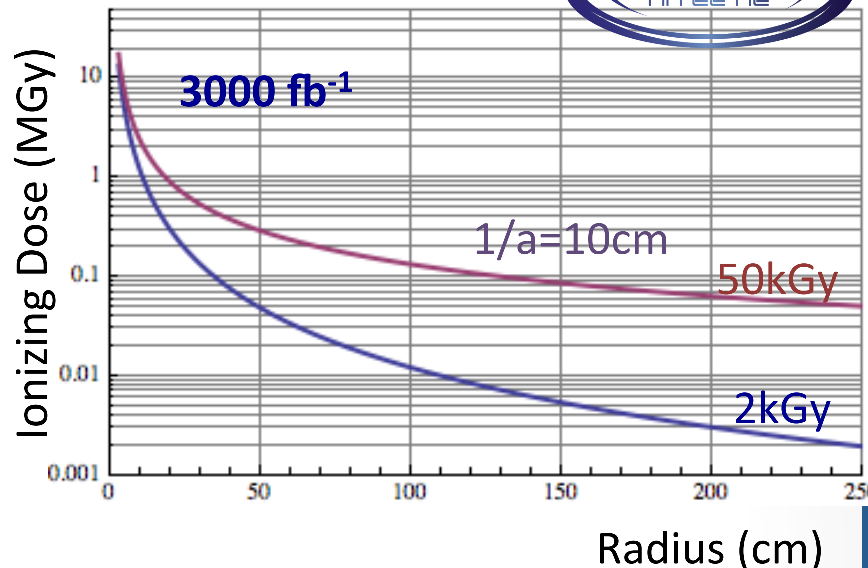
- Larger luminosity leads to more radiation in the IPs and more background

4. Radiations

1/a= distance where direct and secondary particles are in same numbers.

W. Riegler





3000 fb^{-1} 100mb inelastic pp cross-section

$3*10^{17}$ events

$dN/d\eta = N_0 = 8$ Pixel first layer at r = 3.7cm

$$\text{1MeV neq Fluence}[cm^{-2}] \approx \frac{N_0}{2\pi} \times N_{pp} \left(\frac{1}{r[cm]^2} + \frac{a[cm^{-1}]}{r[cm]} \right)$$

1MeVneq Fluence $=2.8*10^{16}$ cm^{-2}

Dose = 9 MGy

$$\text{Dose}[Gray] \approx 3.2 \times 10^{-10} \frac{N_0}{2\pi} \times N_{pp} \left(\frac{1}{r[cm]^2} + \frac{a[cm^{-1}]}{r[cm]} \right)$$

Assuming L = 3000 fb^{-1} and the first pixel layer at r=3.7cm from the IP the fluence and dose for 14(100)TeV are $1.5(3)10^{16} cm^{-2}$ and 5(10)Mgy

Numbers for an FHC detector are only ~2 the HL-LHC numbers (unless one puts the first pixel closer).

The fluence and dose numbers for a distance of 2.5m from the IP for 3000 fb^{-1} of 100TeV collisions are between 10^{13} and 10^{14} cm^{-2} and 2-50 kGy.

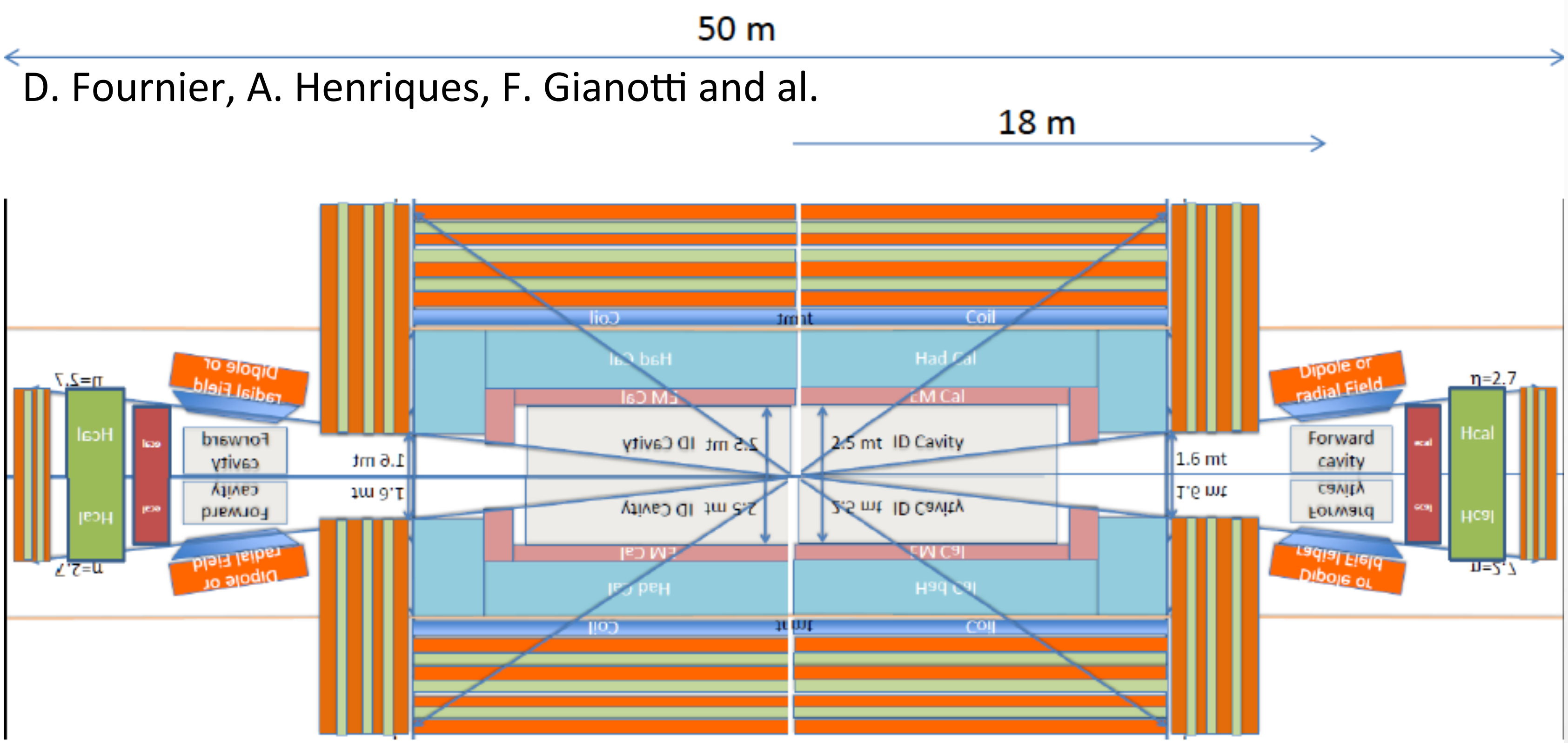
5. Detectors

What do we need?

- Higher energy in the center of mass:
  - More forward particles to detect
  - Particles with higher energies
- Implies:
  - Larger radius (Tracker, more X0 in E-Cal and λ in H-Cal)
  - Longer detector
    - To gain 1 η unit, a detector of fixed inner radius needs to be moved 2.7 times further away from the IP
    - Calo at 10cm of the beam pipe -> η=6 == 20m!!
  - Stronger magnetic field to get a decent resolution at high p_T
    - higher collision energy 14 to 100TeV, to obtain the same tracking resolution BL^2 has to be increased by factor 7!
    - Field in single solenoid up to 6.0 T (a la CMS)

Option 1 (CMS inspired)

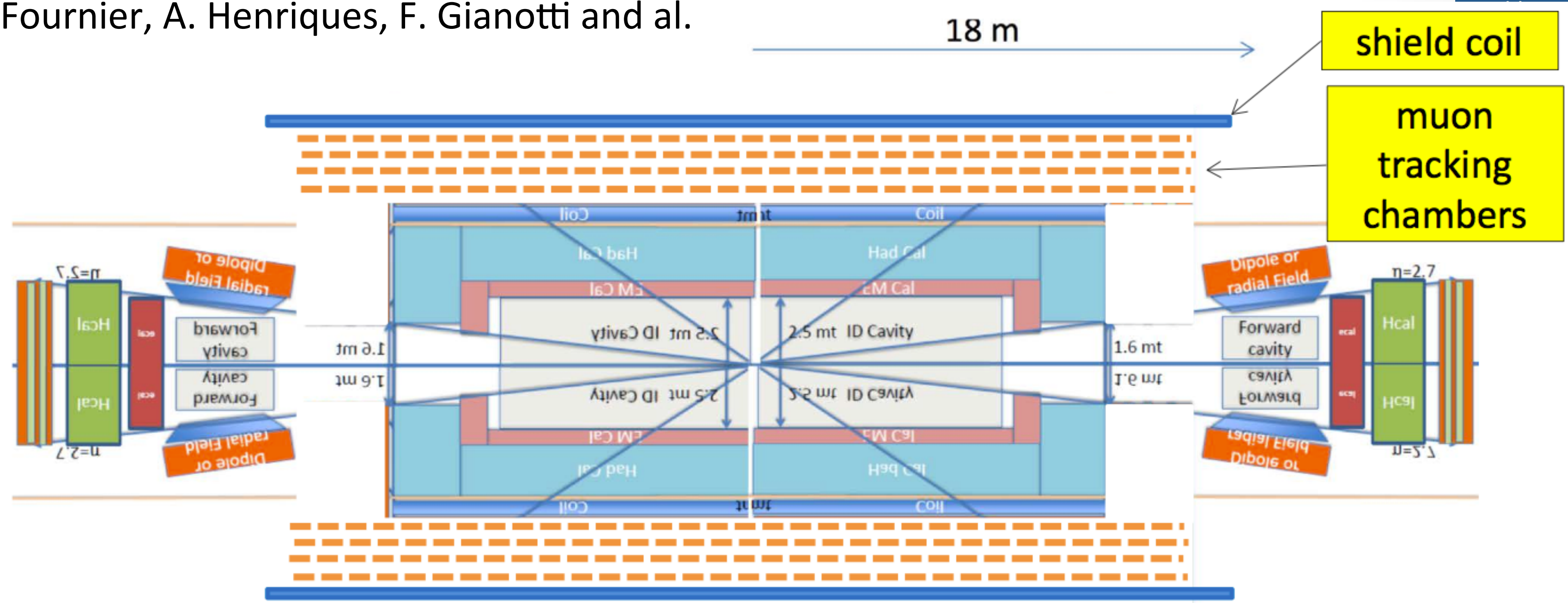
- 10-12 m diameter, 5-6 T, 23 m long + massive Iron yoke for flux shielding and muon tagging
- Yoke: 6.3 m thick iron needed to have the 10 mT line at 22 m
- 15 m^3 mass ≈120,000 tons (>250 M€ raw material)… not viable



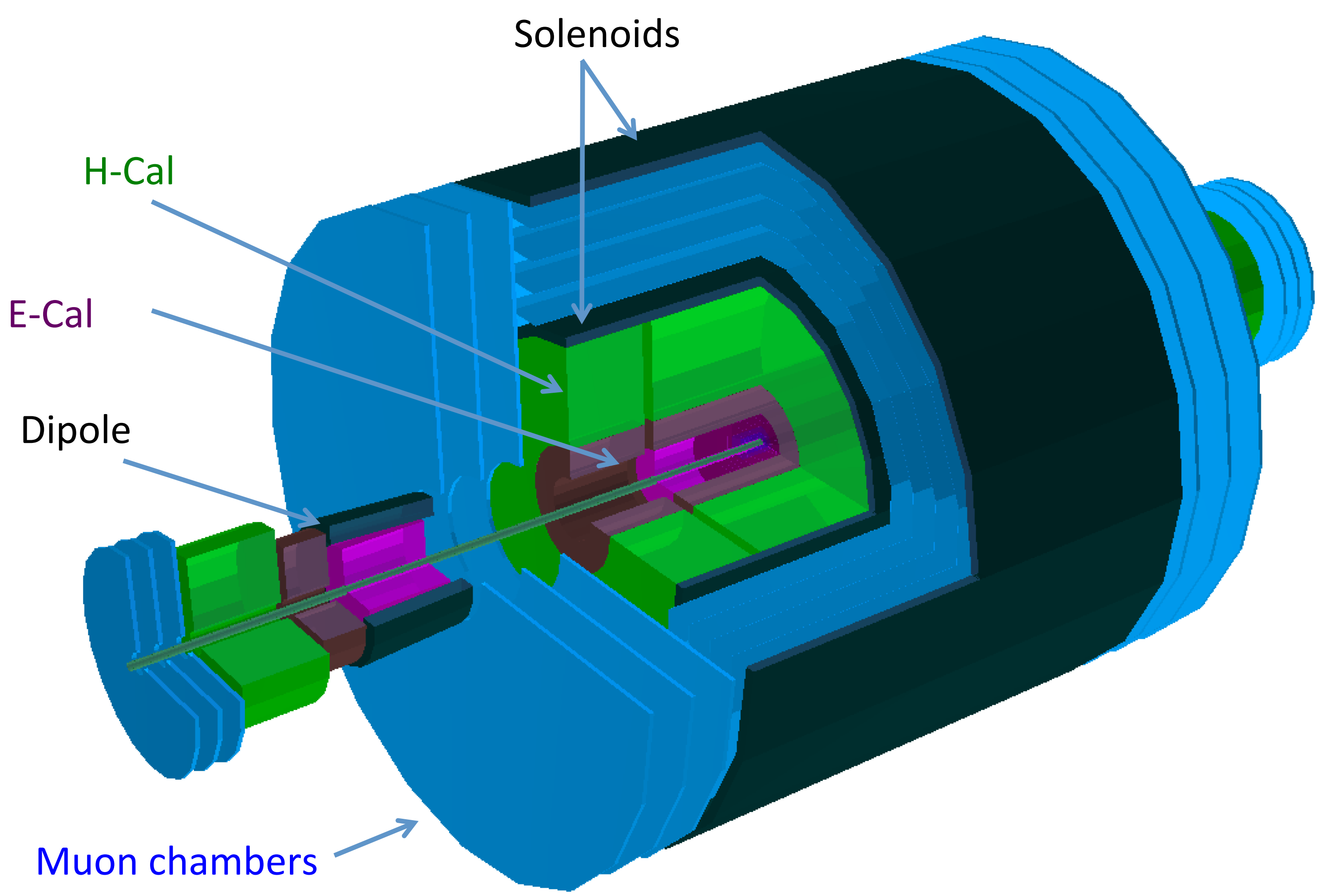
Option 2

- A 6 T, 12 m diam x 23 m long main solenoid + an active shielding coil
- Important advantages:
  - Nice muon tracking space area with 2 to 3 T (muon tracking in 4 layers?)
  - Very light 2 coils + structures, ≈ 5 kt, only ≈ 4% of the option with iron yoke!
  - Much smaller system outer diameter is significantly less than with iron

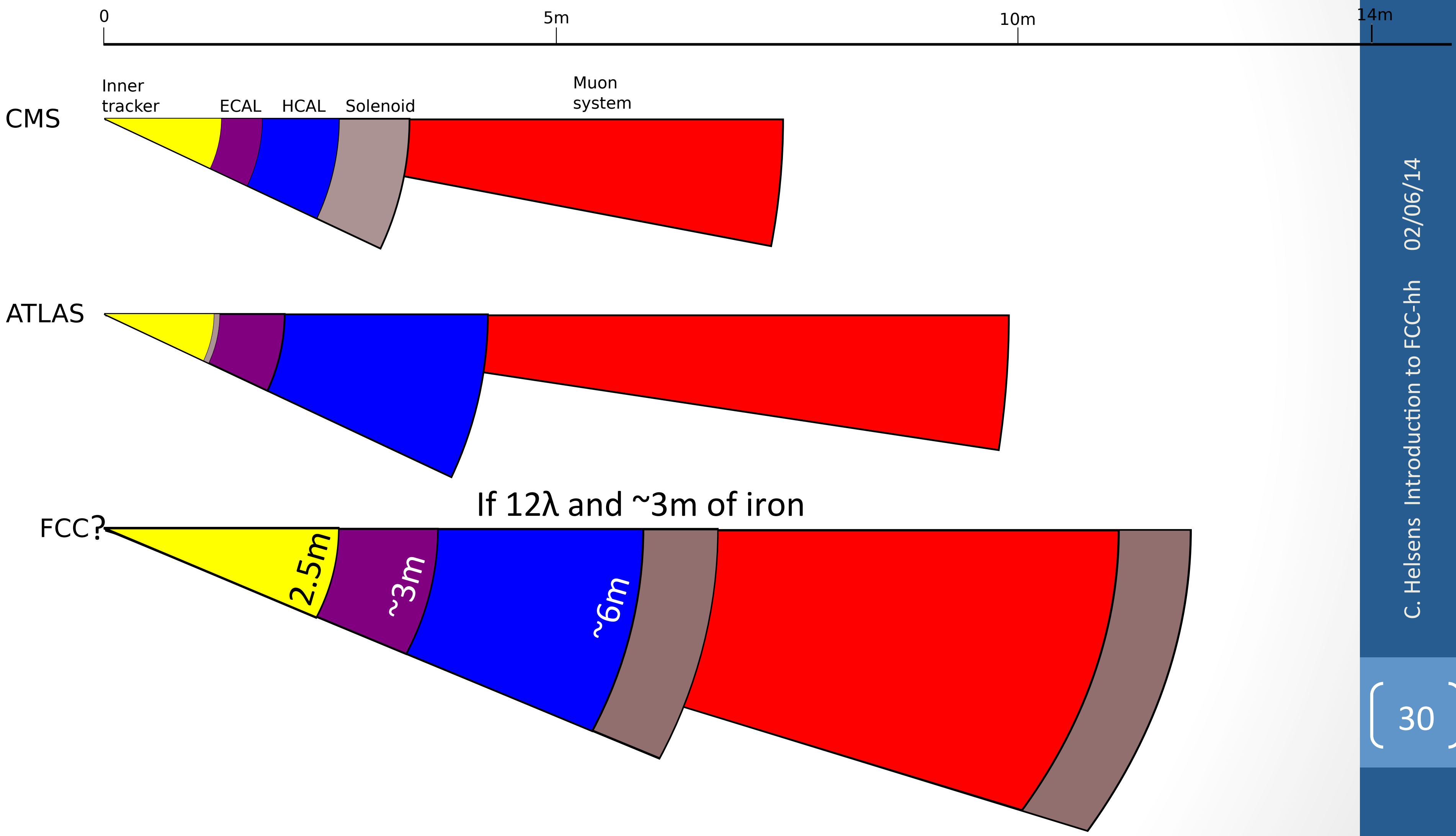
D. Fournier, A. Henriques, F. Gianotti and al.



FCC simulation



Detectors dimensions



Thanks to C. Bernet for the source

Others

- Transport element on-site

- Detector maintenance scenarios
- The complexity of the magnetic systems, particularly regarding maintenance raises the question:
  - all-capable experiments to $|\eta|<6$
  - high p_T experiments to $|\eta|<3$
  - forward experiments $2<|\eta|<6$
- Radiation fields
  - Emergency maintenance crews will encounter dose rates of few x 100 microSv/hr x a few worse than at HL-LHC (detailed FLUKA simulations needed)
- Vastly increased trigger bands, HLT intelligence and processing power, read-out and storage technology and strategies

6. Physics

The landscape at the TeV scale

M. Mangano

- What's hiding behind/beyond the TeV scale ?
  (Fine tunning ~ E^2_{cm})
- A few crucial questions specific to the TeV scale demand an answer and require exploration:
- Hierarchy problem/Naturalness
  - where is everybody else beyond the Higgs ?
- EW dynamics above the symmetry breaking scale
  - weakly interacting? strongly interacting ? other interactions, players ?
- Dark matter
  - is TeV-scale dynamics (WIMPs) at the origin of Dark Matter ?
- Cosmological EW phase transition
  - is it responsible for baryogenesis ?

pp at 100 TeV opens three windows:

M. Mangano

Access to new particles

→ 30 TeV mass range beyond LHC reach

Immense/much-increased rates for phenomena in the sub-TeV mass range

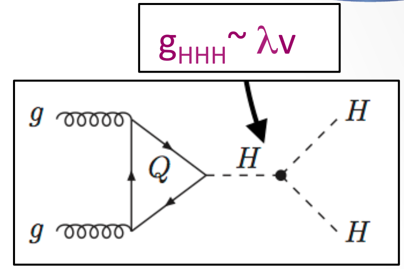
→ increased precision w.r.t. LHC and possibly ILC

Access to very rare processes in the sub-TeV mass range

→ search for stealth phenomena, invisible at the LHC

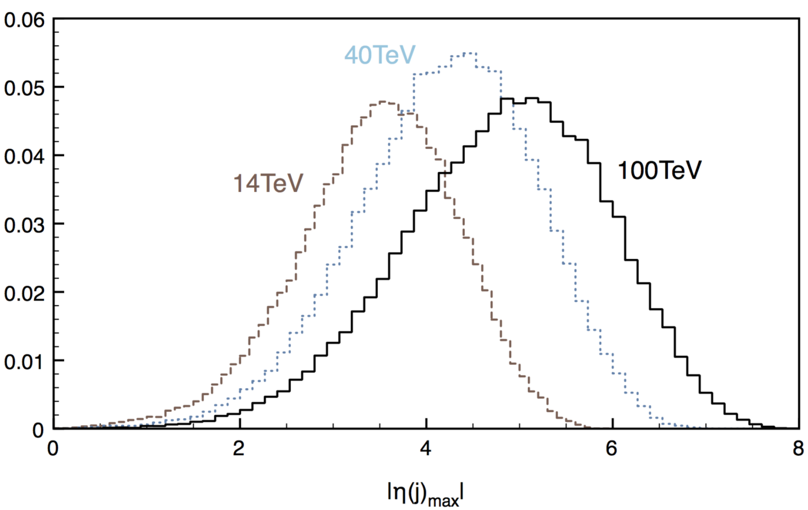
Each of these windows requires dedicated physics studies, and poses different challenges to the detector design

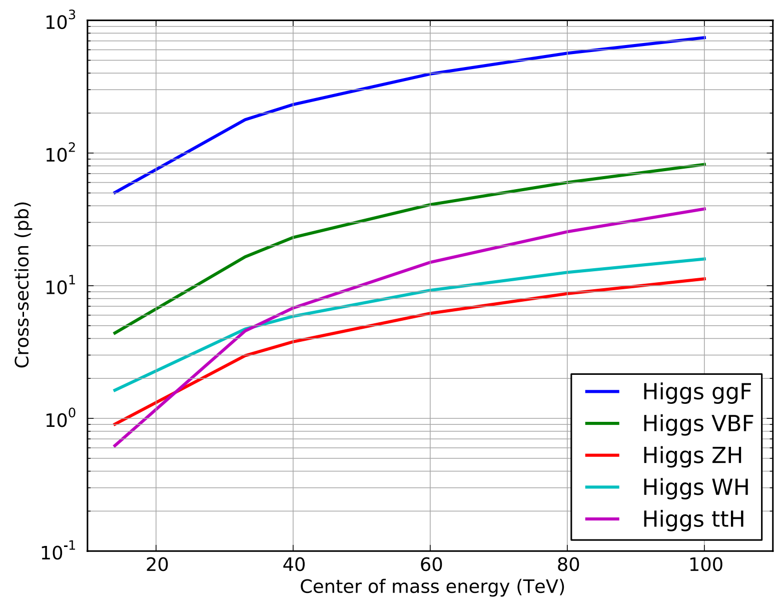
Higgs physics



- Why still Higgs physics in ~ 2040 ?
- "Heavy" final states require high √s, e.g.:
  - HH production (including measurements of self-couplings λ)
  - ttH   (note: ttH→ ttμμ, ttZZ "rare" and particularly clean)

R. Contino   VBF Higgs





7. Summary

- Intellectually very-stimulating activity:
  - Establishing the physics potential
  - Conceiving challenging experiments at a challenging machine from scratch
  - Developing/improving (new) detector technologies

- A future 100 TeV pp collider is an extremely challenging project
- As scientists we have the duty to examine it
- In the meantime:
  - correct approach is not to give up to financial and technical challenges
  - use our creativity to develop the technologies needed to make it financially and technically affordable

- Hope to attract many (young) people so that FCC -> PCC