FCC software infrastructure status

Clément Helsens, CERN-PH

CLIC collaboration meeting 10-11 June 2014

On behalf of the FCC-software task force (experiments and SFT)

Many thanks to B. Hegner for the input

Outline

1. Introduction
2. Software environment for FCC
3. Framework / Data model
4. Detector description
5. Simulation / Reconstruction and analysis code
6. FCC-hh example
7. Next steps

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FCC-software is a common effort between hh, ee and he

Effort just started, so more questions than answers in this talk

1. Introduction

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) ⇒ $\sqrt{s}$=42 TeV pp in 100 km (NbTi)
    - ~16 Tesla ⇒ $\sqrt{s}$=100 TeV pp in 100 km ($NbSn_3$)
    - ~20 Tesla ⇒ $\sqrt{s}$=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

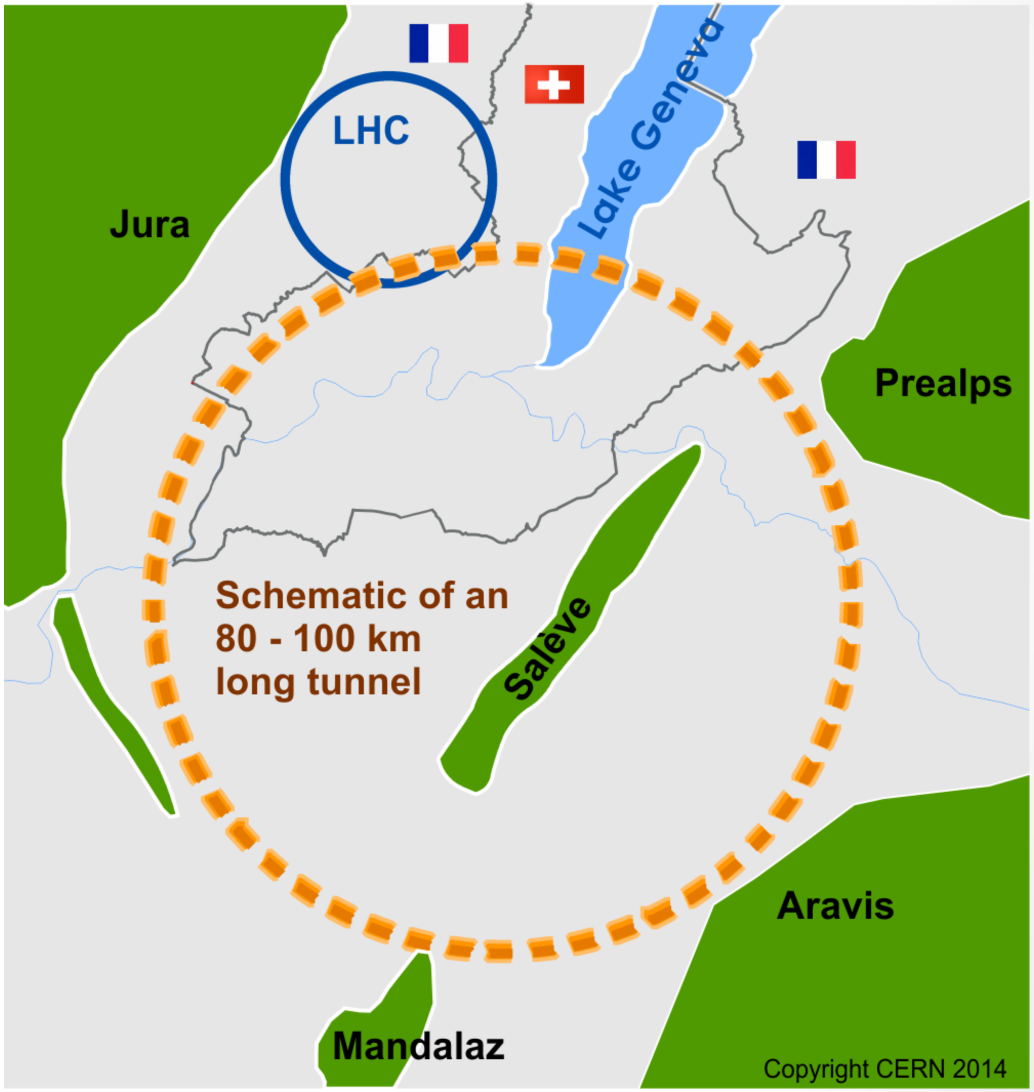
Events

- FCC Kick-off meeting 02/2014: http://indico.cern.ch/event/282344/
- First FCC-hh workshop 05/2014: http://indico.cern.ch/event/304759/
- 7th FCC-ee workshop: 19-21/06 http://indico.cern.ch/event/313708/

- FCC-software task force: fcc-experiments-sw-dev@cern.ch

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

2. Software environment

Where we are

- With respect to the LHC
  - We are in a quite rosy situation
  - Large choice of SW products to choose from in terms of generators, detector simulation, visualization, reconstruction, analysis...
- No pre-canned solution
  - We have to work out our own way
  - The best we can do is to isolate promising packages
  - Evaluate and figure out if they satisfy our needs
- What we should start to do
  - Gathering requirements is the principle activity we should concentrate on
  - We are not aiming at coming up with the ultimate solution either, the idea being to support simulation activities in the next few years
  - At some point will have to wrap up all ideas and get to a synthesis

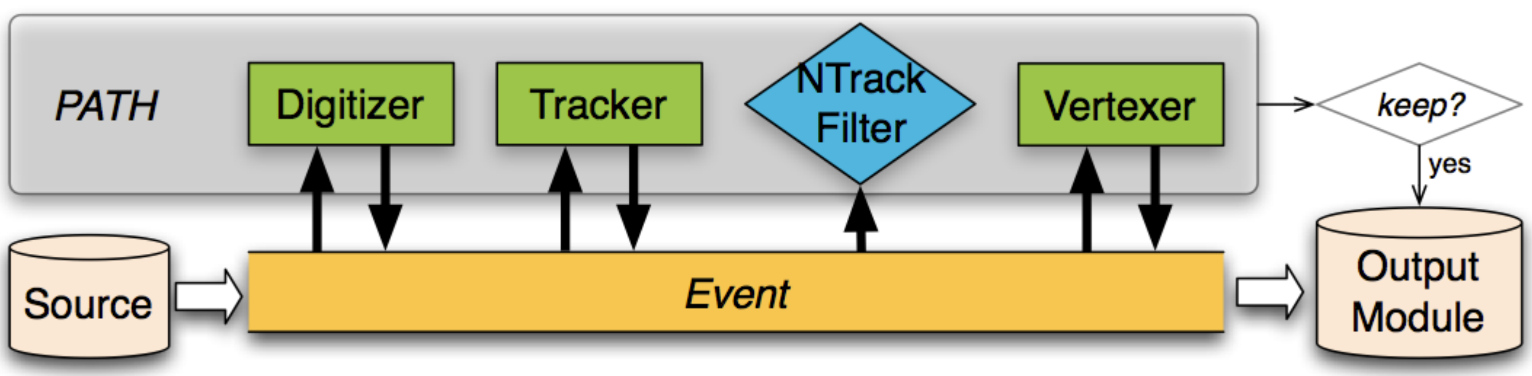
Software environment

- <u>Fields to find solutions for:</u>
  - Core Framework
  - Simulation, Detector Description, Reconstruction
  - Data Model, Analysis
  - Development Environment
- <u>Driving considerations:</u>
  - Not many people and ambitious goals
    - → pragmatic start needed and share software whenever possible
  - LHC software turned out to be complex and specific
    - → FCC has to start as simple as possible
  - As time progresses move to more sophisticated solutions
    - Allow components to be replaced later on, Flexibility
  - Take advantage of effort of other people
    - Give and take
    - Aim for, but don't blindly force, synergy with other communities

3. Framework / Data model

Why a software framework

- Initially one has to be very pragmatic
- Start with simple buildings blocks and make them gradually more sophisticated
- However one has to ensure their interpolability
- A good framework hides complexity
  - With slightly higher costs at the beginning than putting first pieces together directly
  - Allows gradual evolution of the code



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- FCC will most likely choose GaudiHive STF project
  - Production quality (use by multiple experiments already)
  - Designed for flexibility
  - Experts at CERN
  - Ensure its future-proofness

The data model

- The Data Model defines common data structures for tracks, jets, etc…
- It is one of the most central pieces of the SW
  - Every algorithmic code and every physicist is exposed to it
  - Changing it afterwards is costly, if not impossible
- A good data model is essential for being efficient in development and runtime
- The LHC experiments have very complex data models
  - First of all, they worked
  - Fairly hard to adapt to new technologies like vectorization
  - Not future-proof

If there is one component to really spend time on, it is the data model

4. Detector Description

Detector Description

- Detector Description (DD):
  - Most obvious candidate singled out to be DD4HEP (used by LC community) http://aidasoft.web.cern.ch/DD4hep
  - Generic, XML-based DD system
  - Detector visualization and geometry model provided by Root
  - Provides straight path to Geant4 via GDML and generic detector constructors, sensitive elements etc…
- Yes, look promising but:
  - Pretty much embedded into the AIDA toolkit for the ILC/ CLIC
  - That makes it hard to install it in standalone mode
  - First tests were quite frustrating
  - Thanks to B. Hegner who set up a common environment activities are now taking off
  - Rather painful and steep learning curve

5. Simulation/ Reconstruction / Analysis code

Simulation

- <u>At different stages different level of detail required</u>
  - generator smearing vs. fast sim vs. full sim
- <u>FCC choices are</u>
  - Custom fast simulation
  - Delphes (https://cp3.irmp.ucl.ac.be/projects/delphes)
  - Geant4
  - GeantV in the future
- Interfacing it to the same framework is the way to progress
- Generators trivially covered – HepMC as input standard
- Lots of work, but rather clear what to do
- First visible milestone for new SW would be reproducing existing results w/ Delphes previously

Reconstruction / Analysis

- Reconstruction
  - Obviously no global solution around, but many individual solutions one can select from
  - Requires assessment of existing code
  - Whatever is chosen, needs to be adapted to common data model
    - So getting that done is a pre-requisite to everything else
- Analysis
  - Allow multiple paradigms to do analysis
    - C++ and Python
  - Many (n-tuple based) solutions exist
    - People come with their code from different experiments
  - Common solution very desirable, but hard to achieve
  - Need to collect requirements and needs

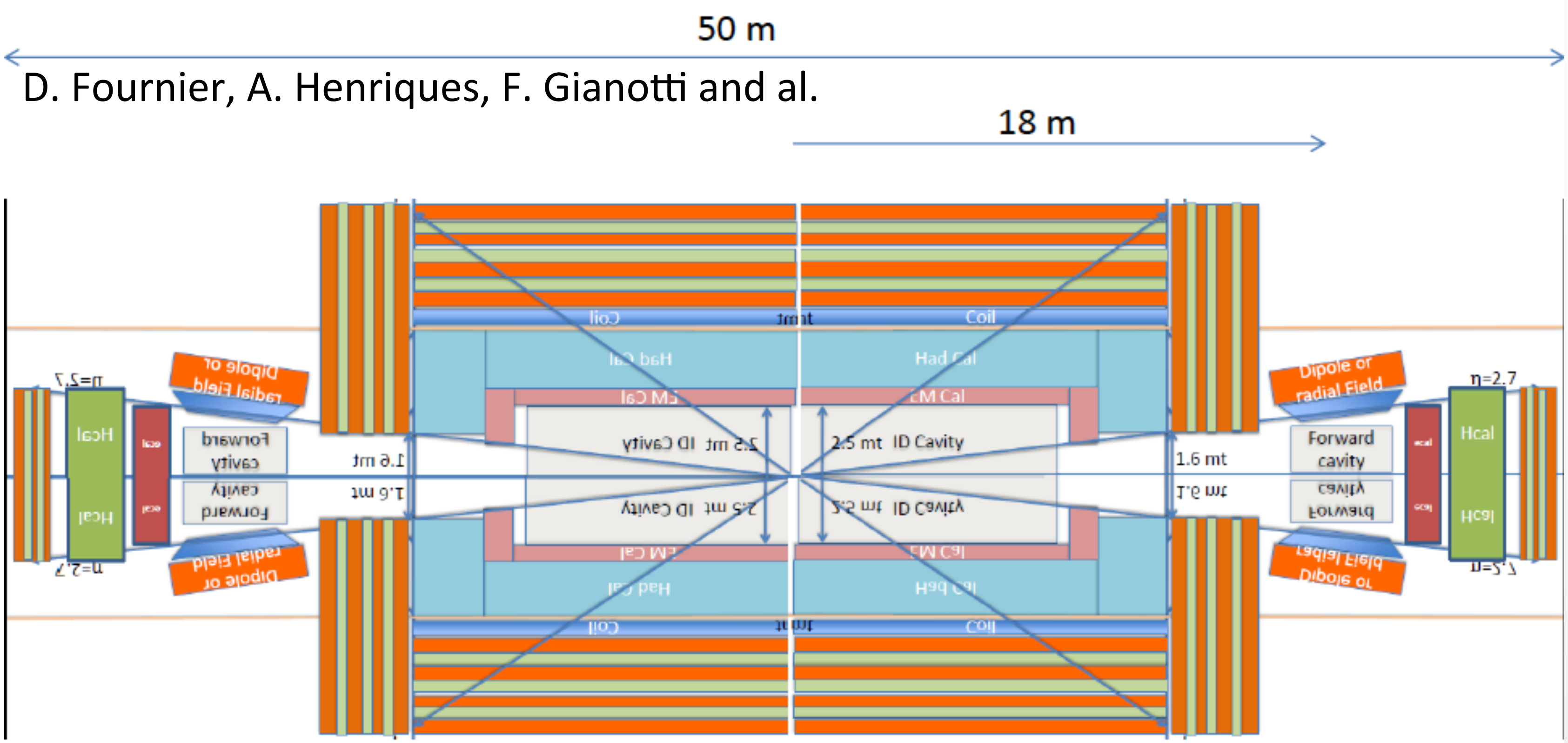
6. FCC-hh detector example

What FCC-hh needs?

- <u>Higher energy in the center of mass:</u>
  - More forward particles to detect
  - Particles with higher energies
- <u>Implies:</u>
  - 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
    - To obtain the same tracking resolution from 14 to 100TeV 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

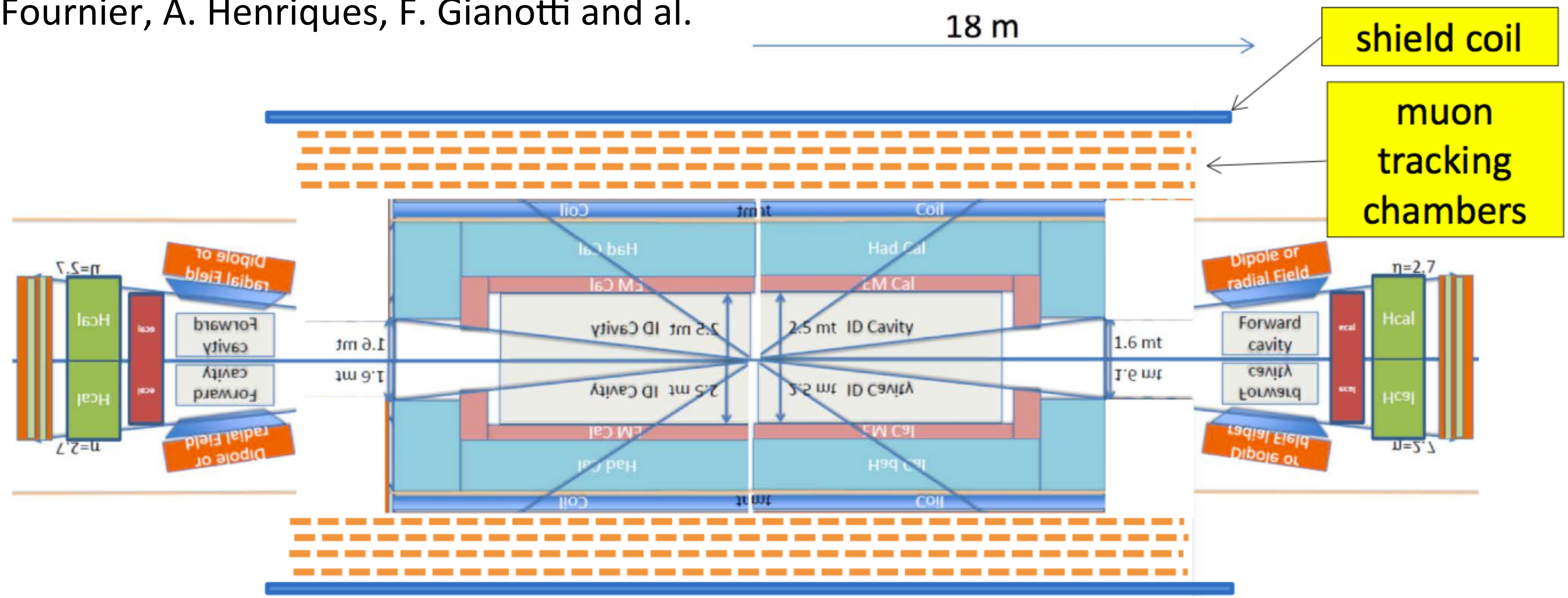


D. Fournier, A. Henriques, F. Gianotti and al.

Option 2

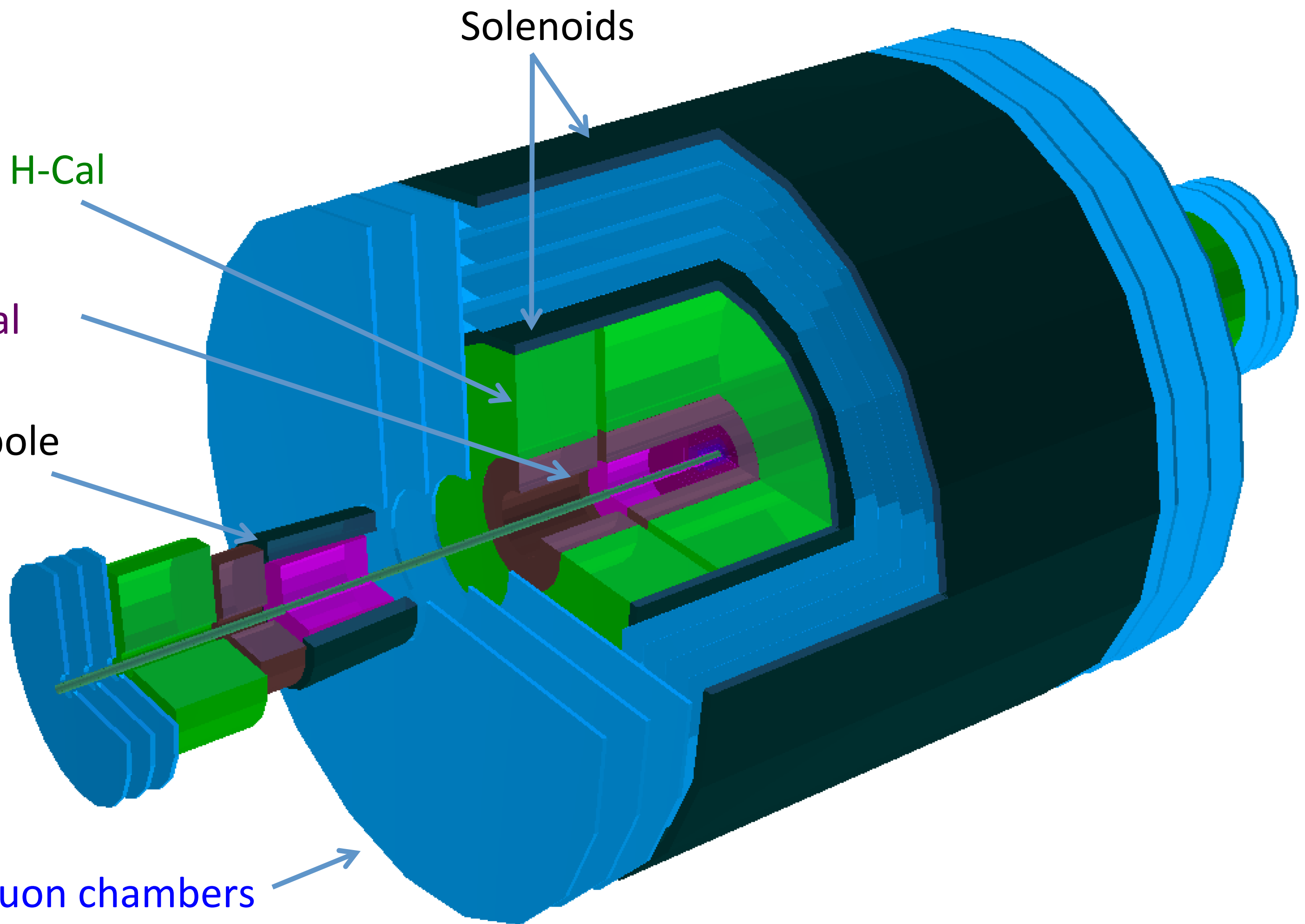
- A 6 T, 12 m diam x 23 m long main solenoid + an active shielding coil
- Important advantages:
  - Nice muon tracking space area with 2 to 3 T (muon tracking in 4 layers?)
  - Very light 2 coils + structures, ≈ 5 kt, only ≈ 4% of the option with iron yoke!
  - Much smaller system outer diameter is significantly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

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



FCC-hh layout

C. Helsens, C. Solans, A. Dell' Acqua



6. Next steps

What is the work ahead?

- <u>Detectors are mostly empty boxes</u>
  - Add more details to our conceptual detector
  - Need to fill them with realistic sensitive material
  - Add more layouts
- <u>Progress with Geant4 simulation ongoing</u>
  - Reshuffle Geant4 code to go our own
  - Add field maps
  - Produce hits and stream them out into a Root tree
  - Plenty of playground for anybody willing to have "fun"
  - Able to shoot single particle into the detector

What is the work ahead?

- External software (ROOT, Geant4, Generators)
  - Infrastructure in place and candidate build in active use
- Geometry Description (DD4hep)
  - Test setup in place
- Core Framework
  - Chose framework and set up examples for FCC
- Data Model
  - Create a data model
- Simulation
  - Interface Delphes, other fastsim, and Geant4 to FWK
- Reconstruction and Analysis
  - Solutions to be chosen
  - Adaption to common data model
- Documentation and Training

Physics milestones and timescales define how pragmatic every item has to be tackled

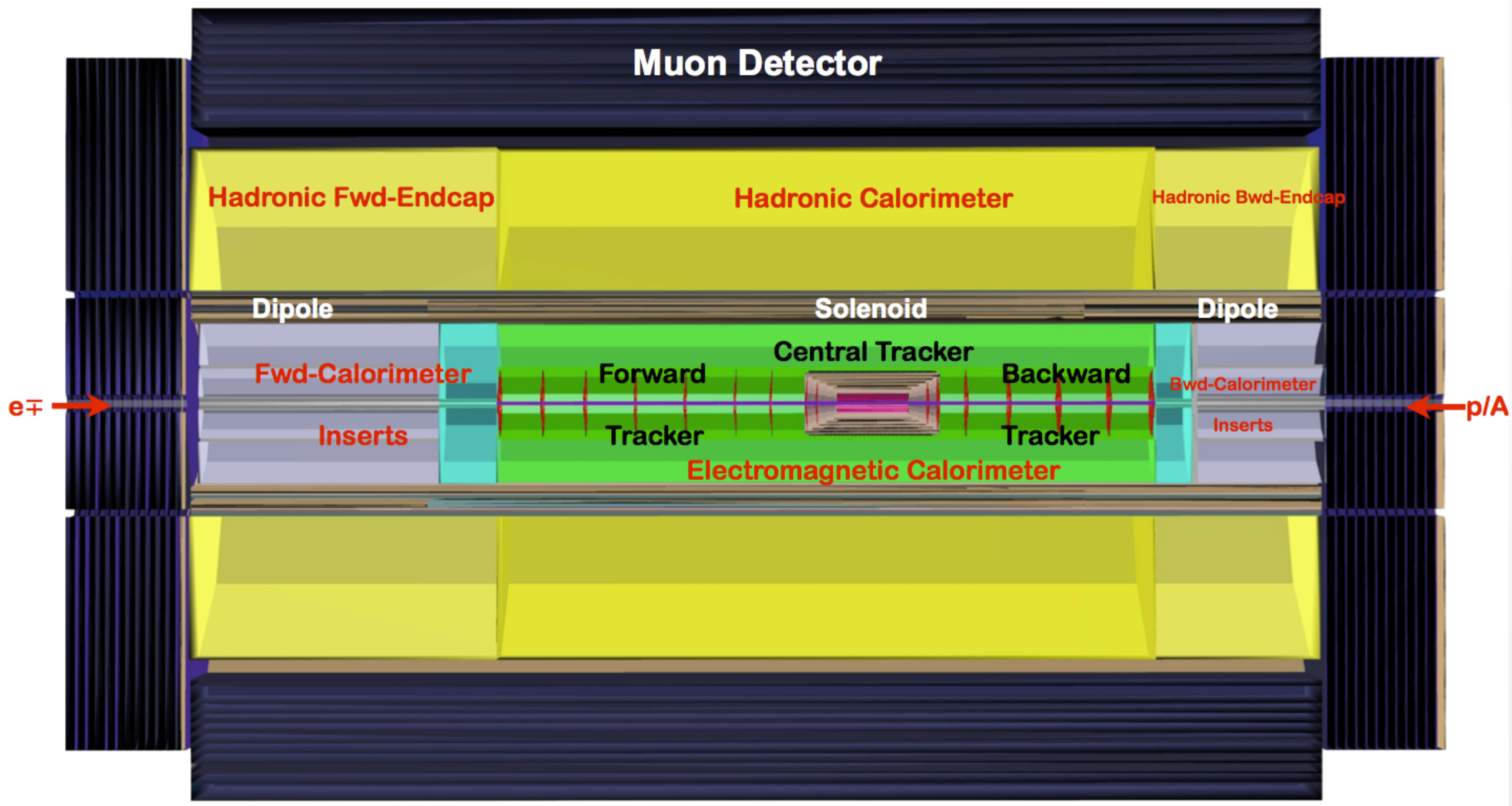
7. Summary

- Only the first disorganized steps but gaining momentum
- Plenty of room for developers to come and play
- We “Keep It Simple” for the time being!
- Dedicated mailing list set up fcc-experiments-sw-dev@cern.ch
- Synergies with CLIC more than welcome:
  - DD4HEP
    - Common interfaces between DD4HEP and the world
    - Common repository?
    - Common developments?
  - Monte-Carlo database:
    - We are all facing the same problems I guess
    - How to produce/store/share/follow different productions
    - Is it possible to design a common tool ?

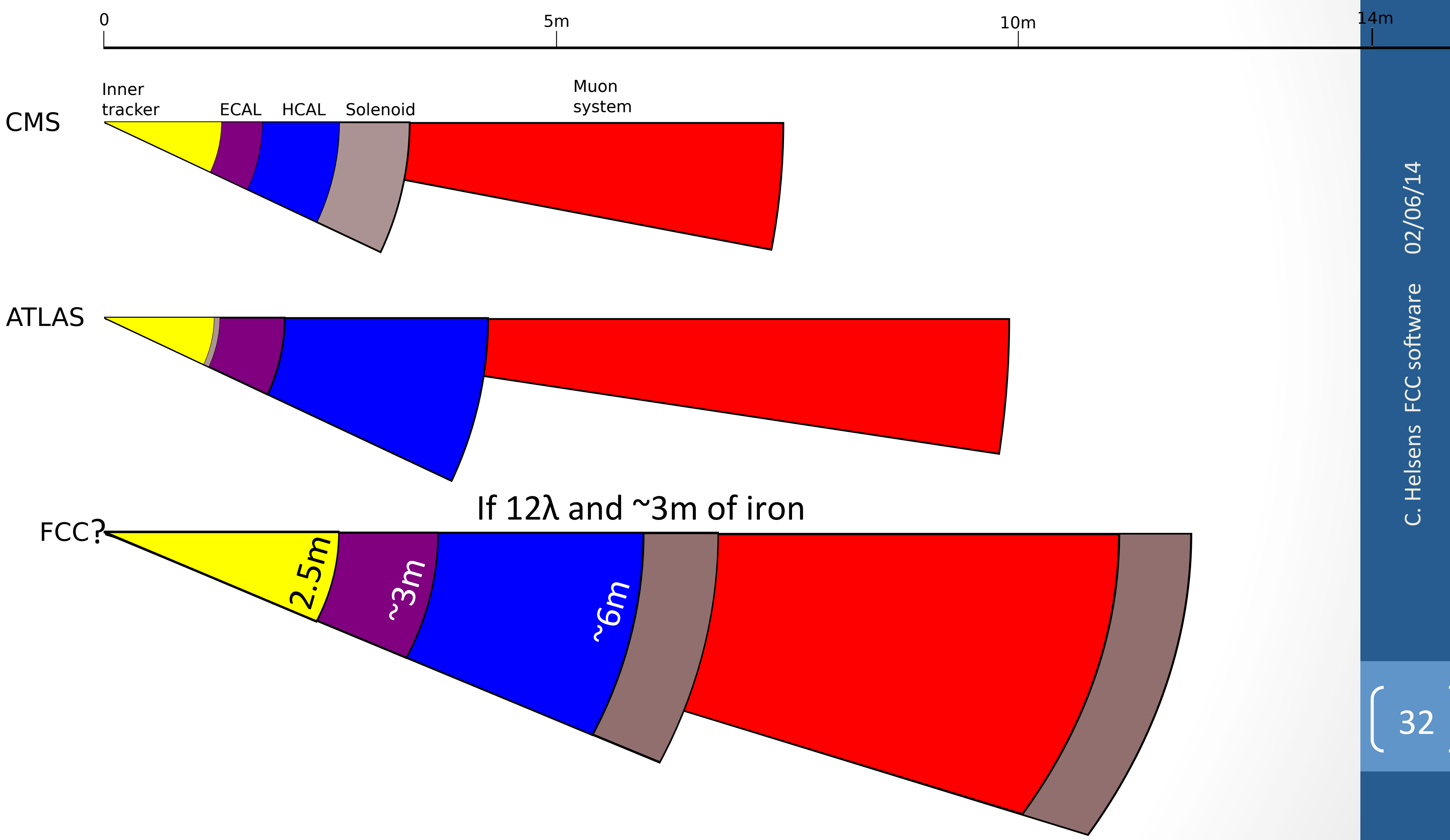
Bonus

FCC-he simulation

P. Kostka
Volumes created using the CLICSiD example



FCC-hh dimensions



Thanks to C. Bernet for the source

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”:

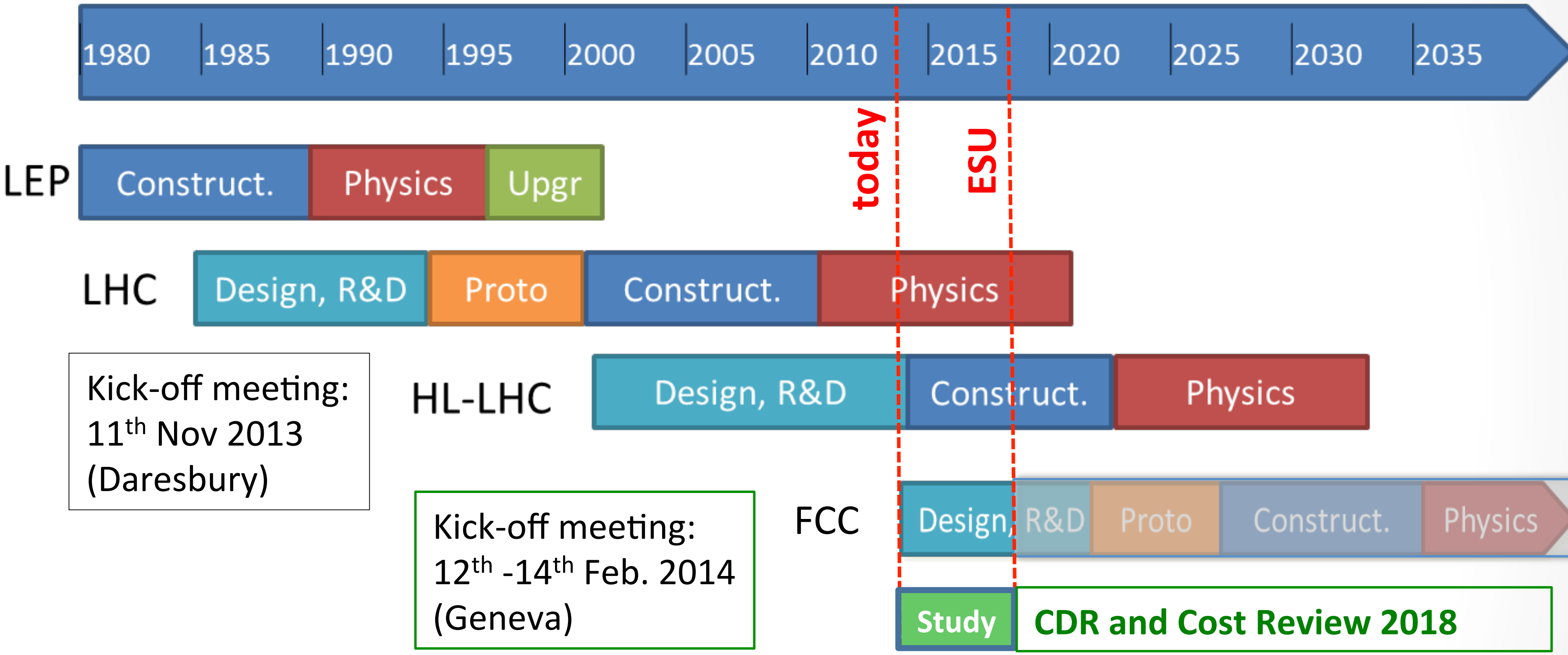
d) CERN should undertake design studies for accelerator projects in a global context,

- 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

Timeline

M. Benedickt



Kick-off meeting:
11th Nov 2013
(Daresbury)

Kick-off meeting:
12th -14th Feb. 2014
(Geneva)

- 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

- Infrastructure
- Hadron collider conceptual design
- Hadron injectors
- Lepton collider conceptual design
- Safety, operation, energy management environmental aspects

Technologies R&D activities Planning

- High-field magnets
- Superconducting RF systems
- Cryogenics
- Specific technologies
- Planning

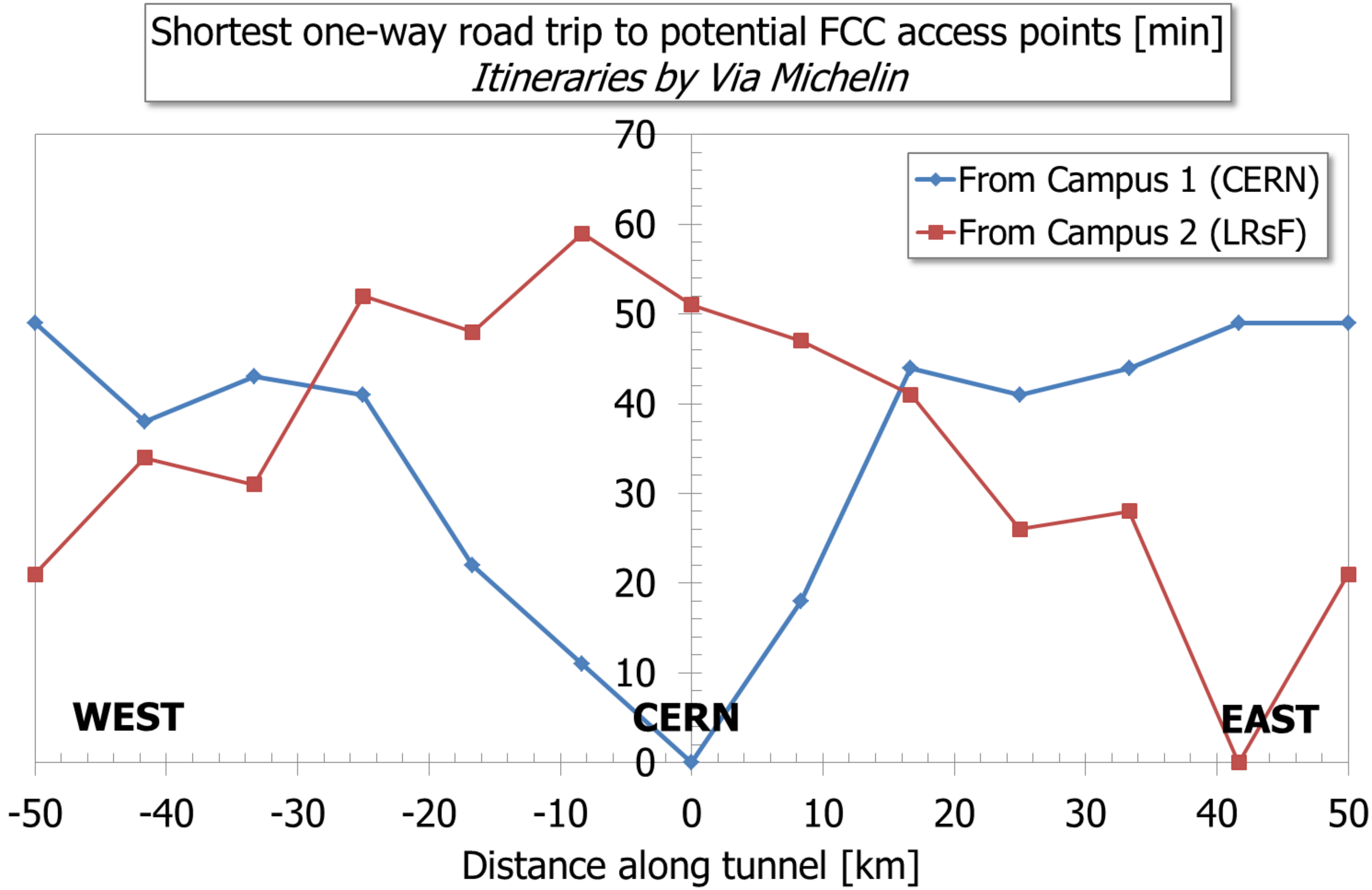
Physics experiments detectors

- Hadron physics experiments interface, integration
- $e^+ e^-$ coll. physics experiments interface, integration
- e^- - p physics and integration aspects

PP-131007-MBE_FCC Design Study

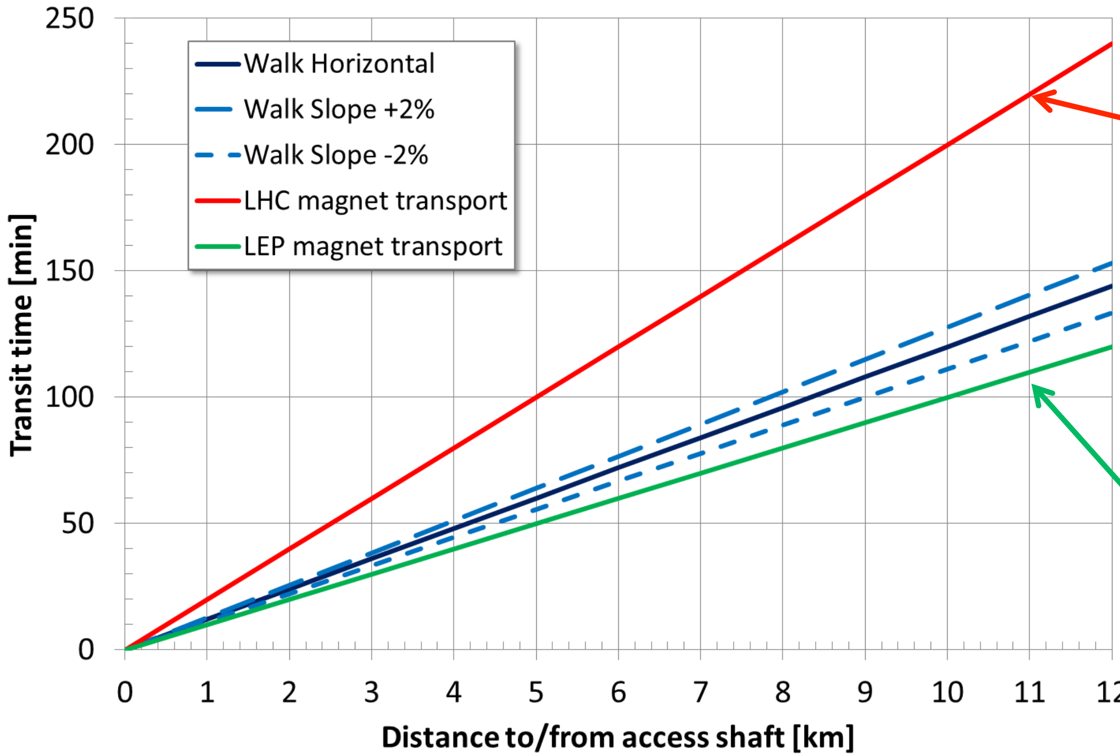
Access time

Ph. Lebrun

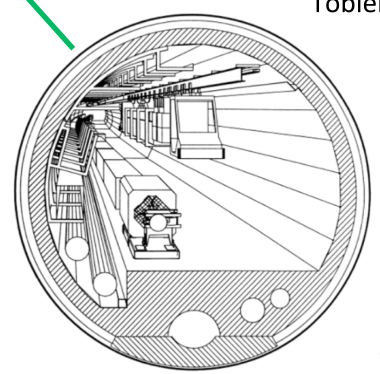


Sector length

Ph. Lebrun

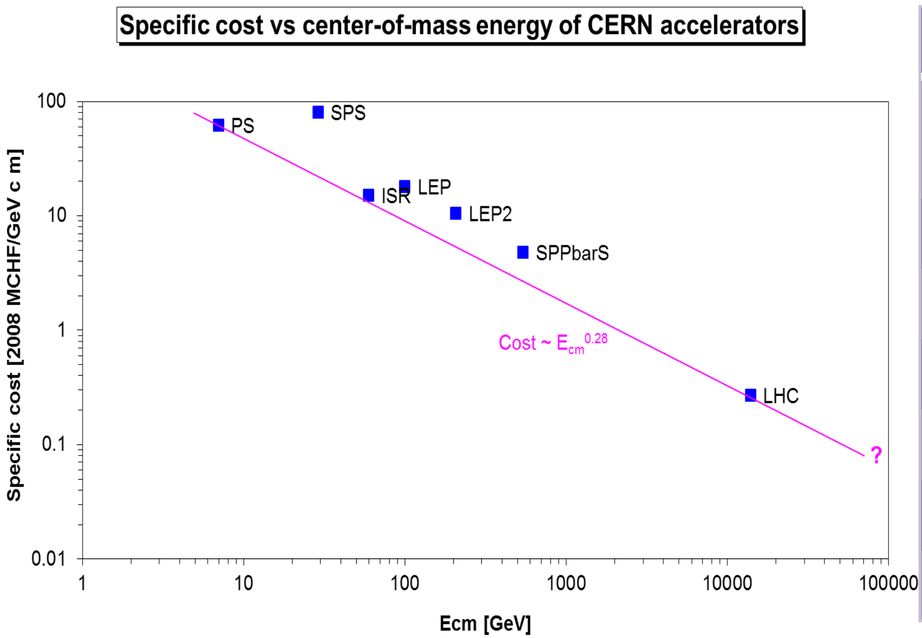


Tobler's hiking function



Cost and electricity

Ph. Lebrun

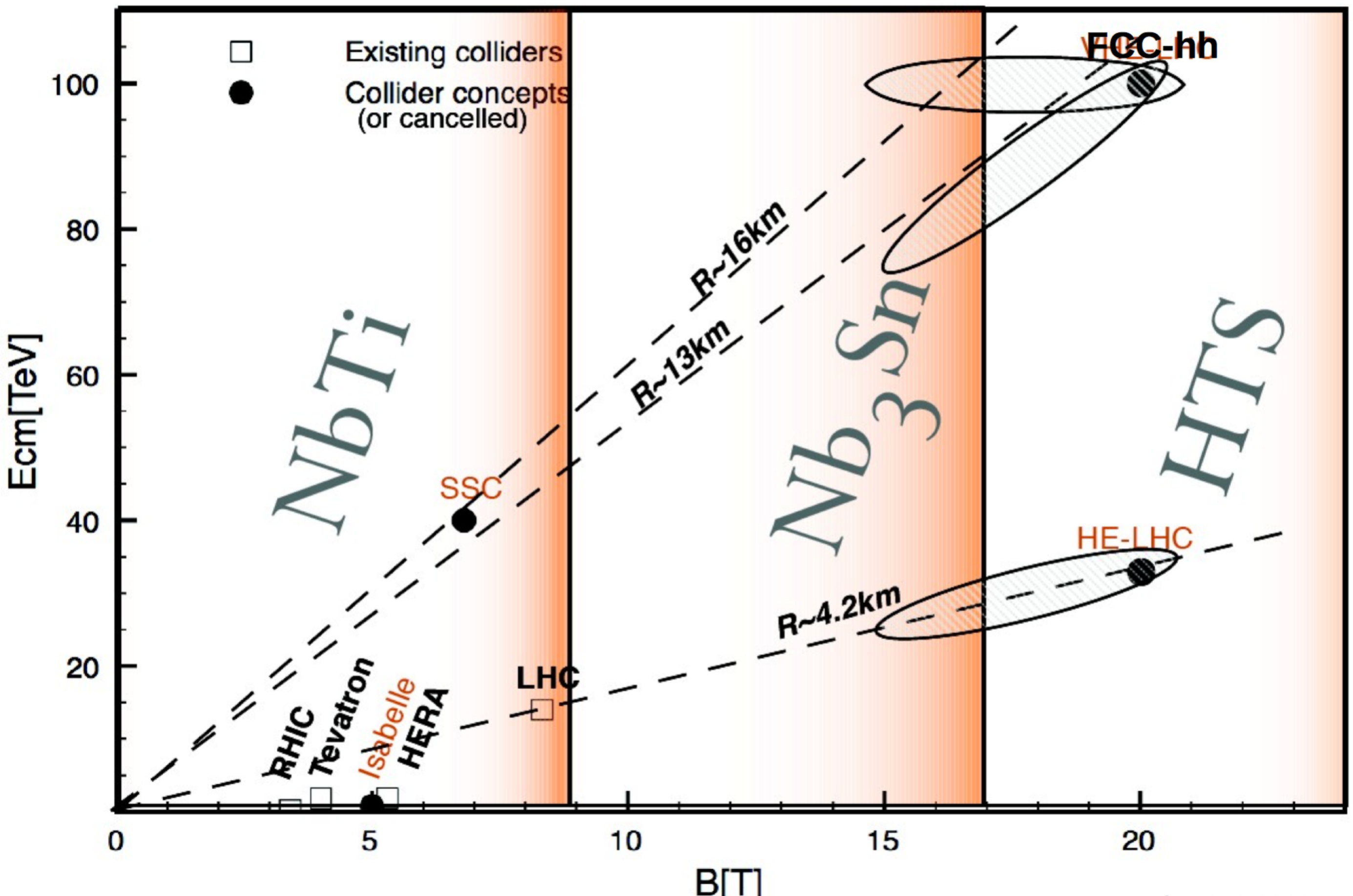


Electrical power consumption		
Accelerator complex	Nominal [MW]	Standby [MW]
LHC	122	89
HL-LHC	141	101
CLIC 500 GeV	235	167
CLIC 1.5 TeV	364	190
FCC e+e-	300?	100?
FCC pp	250?	150?

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

- <u>Put together something that is reasonable</u>
  - 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

- <u>More aggressive choices will be considered as alternatives</u>
  - 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

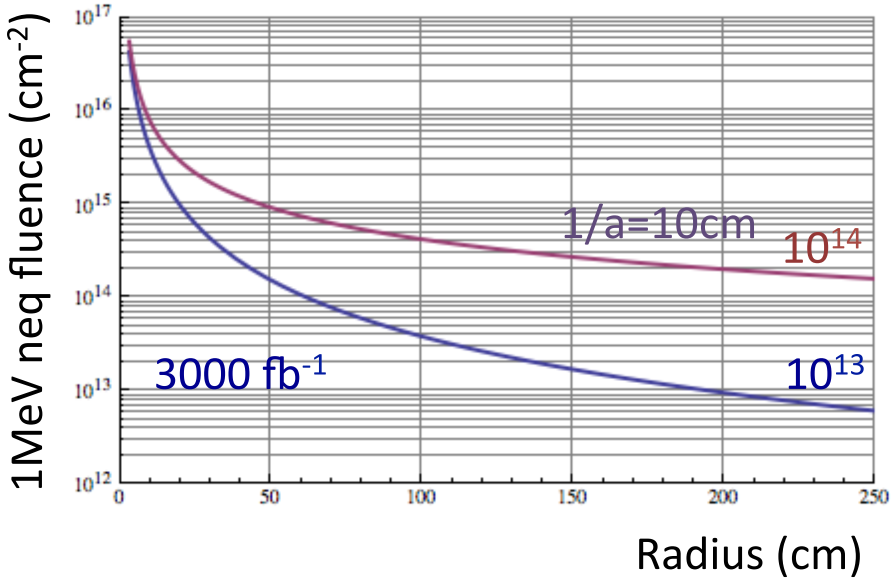
D. Schulte

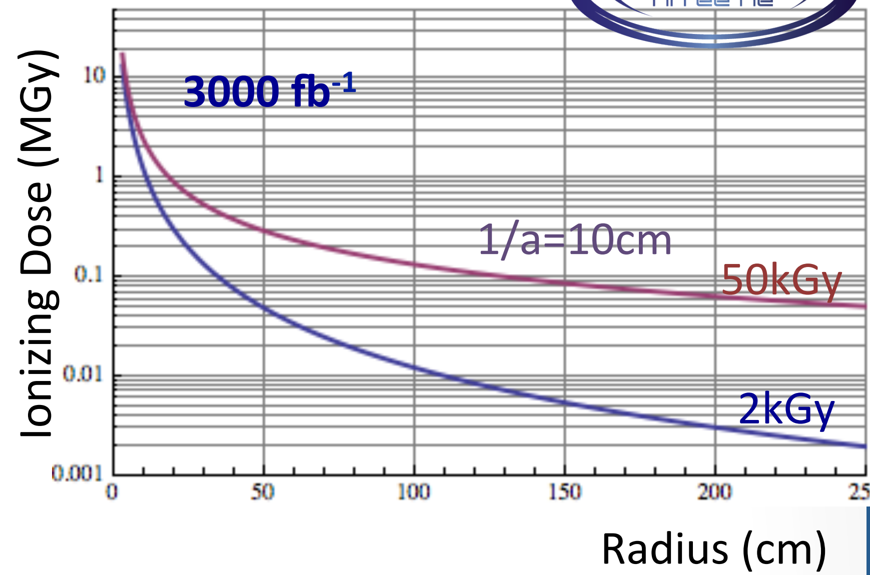
Luminosity is scales as: $L \propto I\xi / \beta^{*} \propto P_{synrad}\xi / \beta^{*}$

- 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

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.

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

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

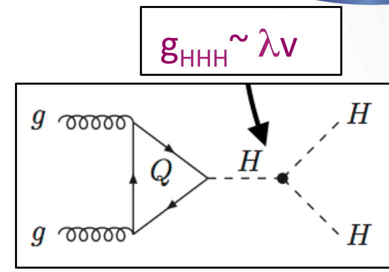
→ increased precision w.r.t. LHC and possibly ILC

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