Design and performance studies of the calorimeter system for an FCC-hh experiment

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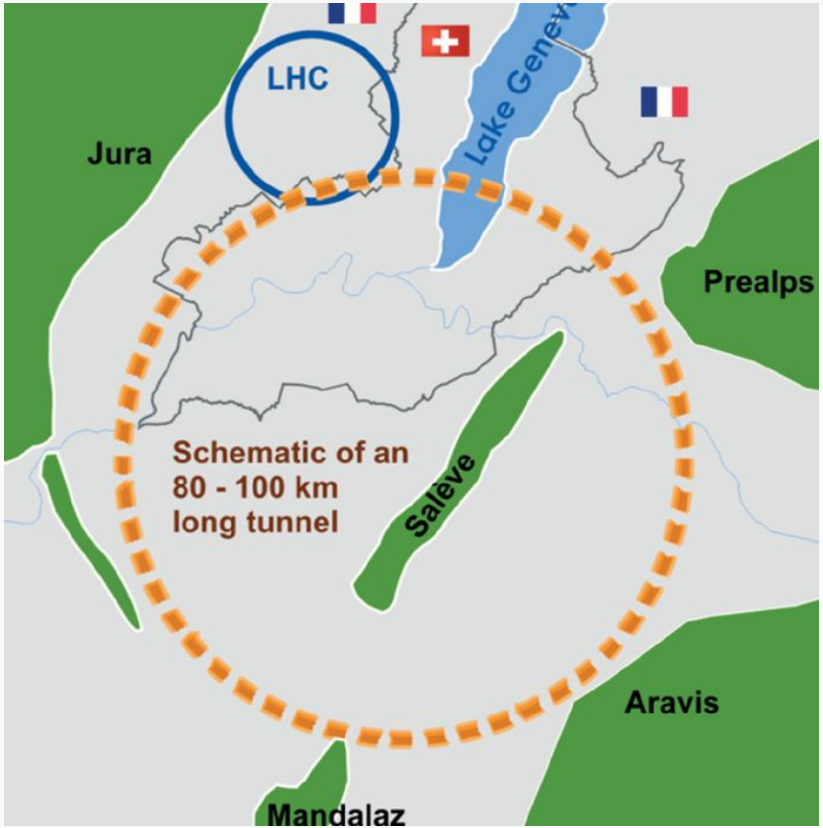
Future Circular Collider (FCC) project

International collaboration (hosted at CERN) to study

- e+e- collider (FCC-ee)
  - Potential first step, √s = 90 – 365 GeV
- pp collider (FCC-hh)
  - √s = 100 TeV
  - Ongoing R&D on Nb_3Sn 16 T magnets
  - Main goal of the project
- pe (FCC-he)

Conceptual Design Report
for European Strategy Update 2019/20
https://fcc-cdr.web.cern.ch/



FCC-hh parameters

Operation scenario

- 10 years with ~250 fb^{-1} / year
- 15 years with ~1000 fb^{-1} / year

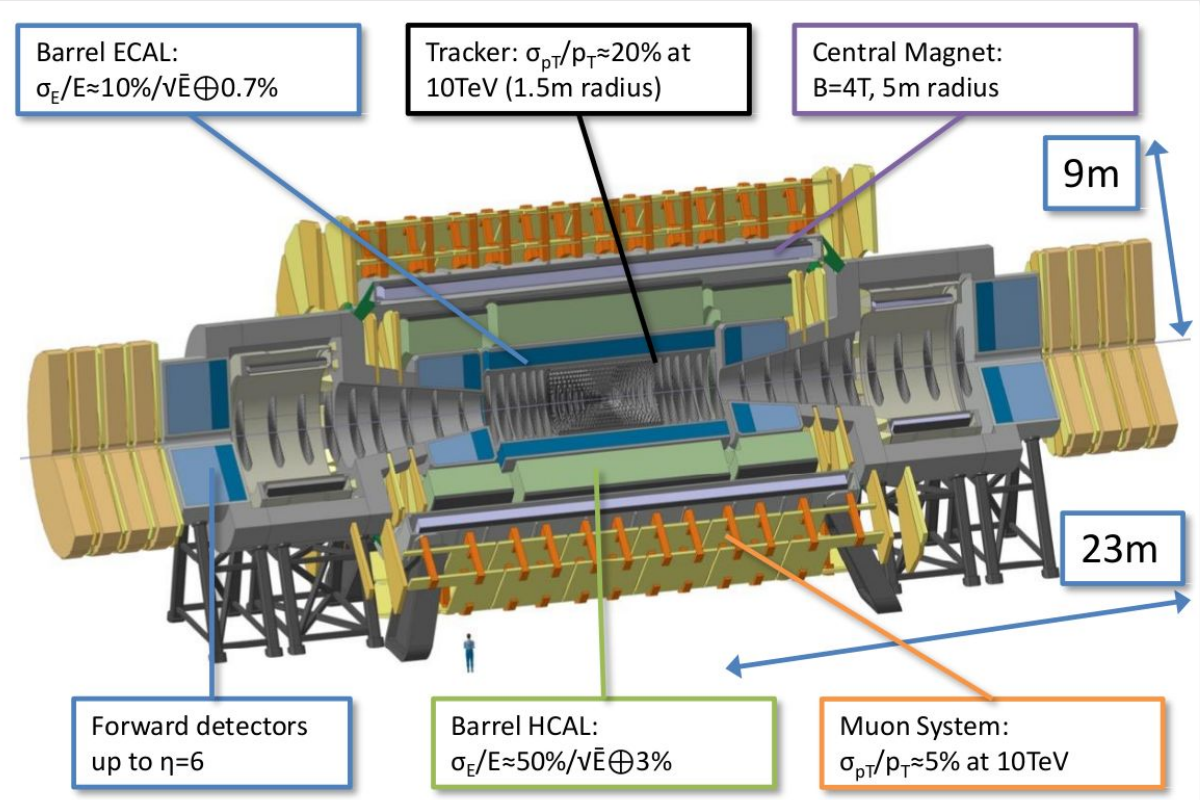
→ In total O(20) ab^{-1} over 25 years of operation

Pile-up of 1000 in the ultimate scenario

- 5 x more than on HL-LHC!

Parameter	FCC-hh		HE-LHC	HL-LHC
collision energy cms [TeV]	100		27	14
dipole field [T]	16		16	8.33
circumference [km]	97.75		26.7	26.7
beam current [A]	0.5		1.1	1.1
bunch intensity [10^{11}]	1	1	2.2	2.2
bunch spacing [ns]	25	25	25	25
synchr. rad. power / ring [kW]	2400		101	7.3
SR power / length [W/m/ap.]	28.4		4.6	0.33
long. emit. damping time [h]	0.54		1.8	12.9
beta* [m]	1.1	0.3	0.45	0.15 (min.)
normalized emittance [μm]	2.2		2.5	2.5
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	5	30	16	5 (lev.)
events/bunch crossing	170	1000	460	132
stored energy/beam [GJ]	8.4		1.4	0.7

FCC-hh reference detector



Reference detector to show feasibility of the project

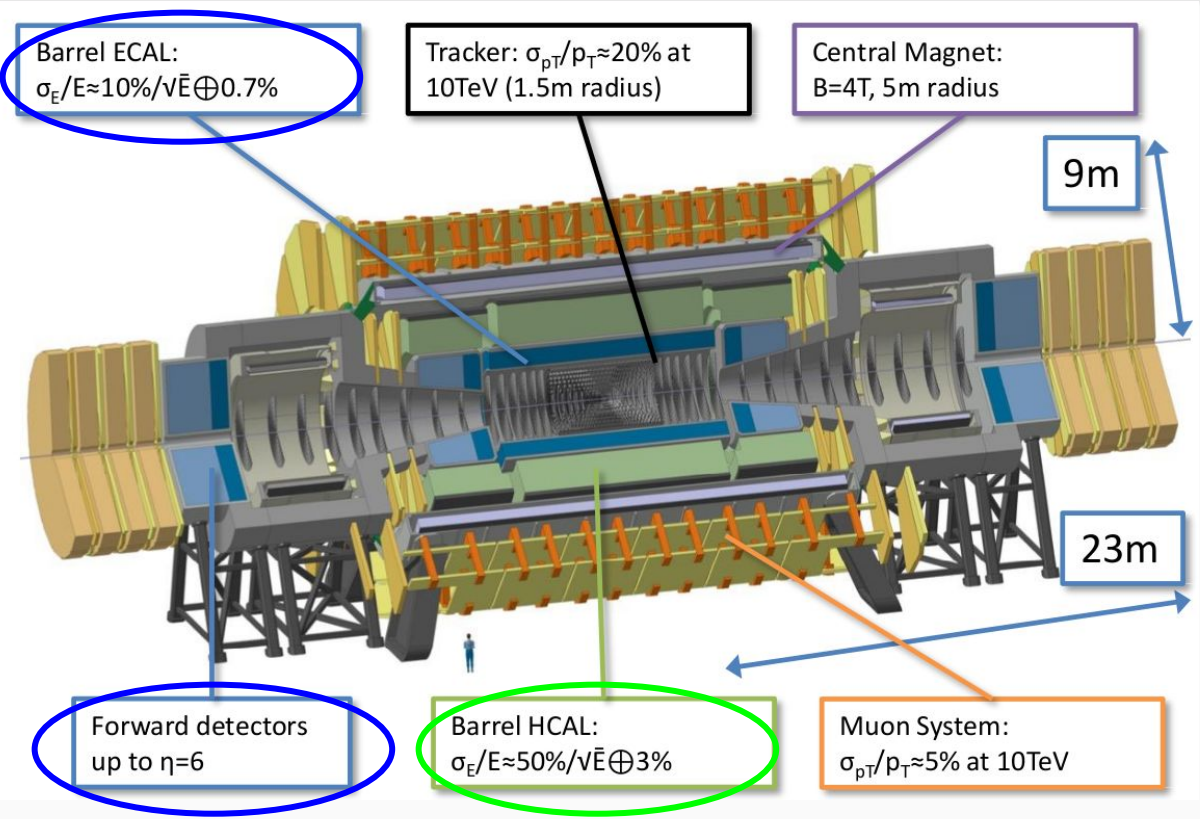
Main problems

- High radiation
- High pile-up

FCC software (FCCSW)

- Full simulations (Geant4)
- Fast simulations (Delphes)

Calorimetry system



ECAL
Forward and Endcaps
LAr/Pb (Cu)

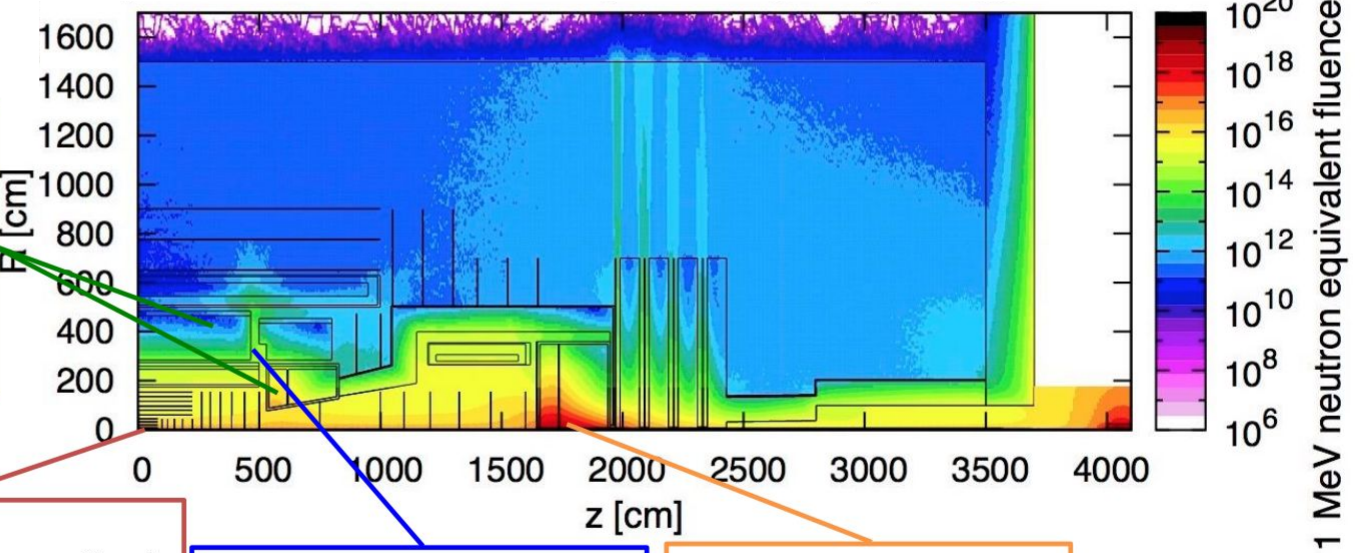
Central HCAL
Scintinllating tiles
/ Fe + Pb

- Inspired by ATLAS calorimetry, but with fine segmentation
- Documented here: Calorimeters for the FCC-hh

Radiation hardness

1 MeV neutron equivalent fluence for 30 ab^{-1}

- ~10-30 times worse than HL-LHC roughly



Barrel calorimeter:
EM-calo: 4 10^{15} cm^{-2}
HAD-calo: 4 10^{14} cm^{-2}
End-cap calorimeter:
EM-calo: 2.5 10^{16} cm^{-2}
HAD-calo: 1.5 10^{16} cm^{-2}

Central tracker:
- first IB layer (2.5 cm): ~5-6 10^{17} cm^{-2}
- external part: ~5 10^{15} cm^{-2}

Calorimeter gap:
from 10^{16} cm^{-2} to 10^{14} cm^{-2}

Forward calorimeters:
~5 10^{18} cm^{-2} for both the EM and the HAD-calo

Electromagnetic calorimeter (ECAL)

Finer lateral and longitudinal segmentation than in ATLAS

- Optimised for particle flow
- Pile-up suppression

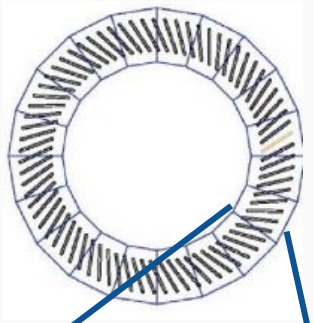
Noble liquid (LAr) calorimeter

- Radiation hardness, linearity, uniformity, stability

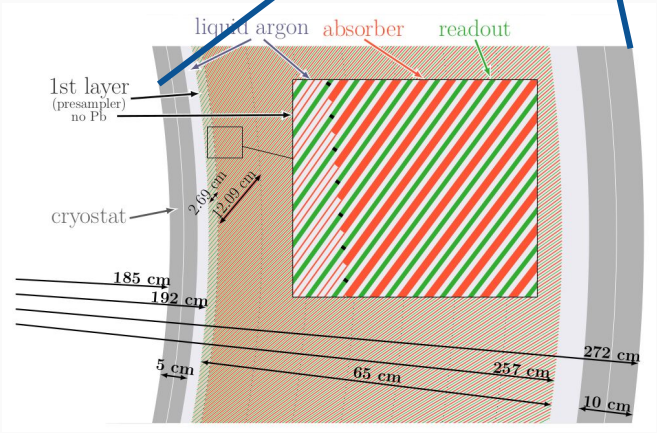
ECAL barrel

- Straight multilayer electrodes
- Inclined Pb plates -> increasing LAr gaps
  - Sampling fraction changes with depth
  - Longitudinal segmentation essential for calibration

2 mm Pb/steel plates inclined by 50°
LAr gap increases with radius:
1.15 mm-3.09 mm
8 longitudinal layers
$\Delta\eta = 0.01$ $\Delta\phi = 0.009$



ZOOM



Performance of ECAL

Energy resolution

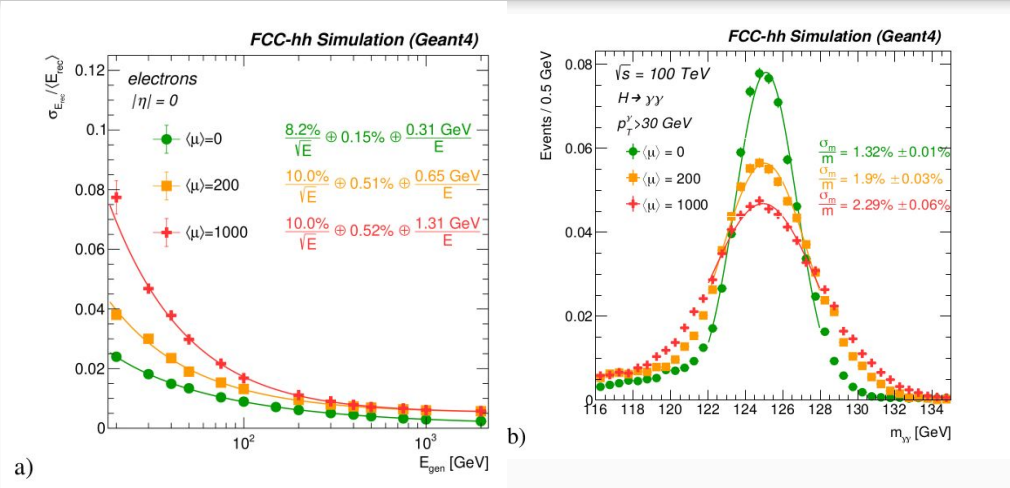
- Sampling term ≤ 10%/√E
- Constant term well below 0.7%

  -> Required energy resolution achieved

Noise term

- Electronic noise of ~300 MeV
- In-time pile-up of <μ> = 1000 leads to a noise term of 1.3 GeV

  → Efficient in-time suppression is crucial



Measurement of Higgs self-coupling with *HH* → bbγγ

- $\Delta m_{\gamma\gamma}$ = 1.3 GeV → precision of 7%

ECAL concept is also considered for e^+e^- collisions

- Optimisation of the electronic noise essential

Central hadronic calorimeter

Scintillator tiles + steel, Pb

Higher granularity than in ATLAS

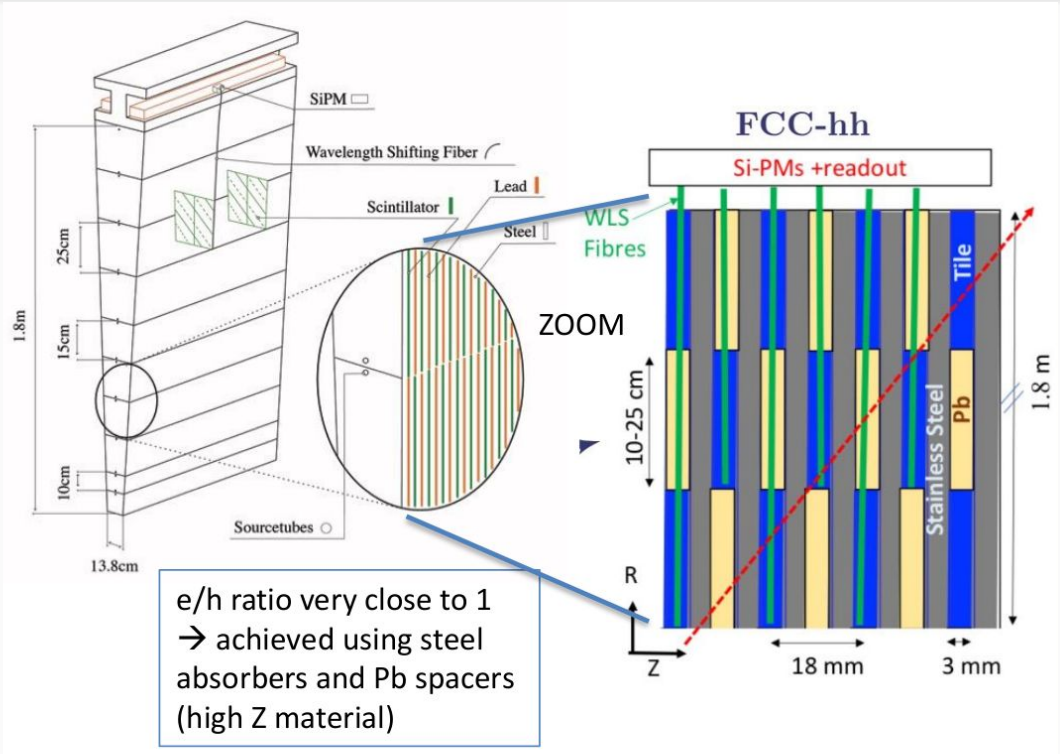
- Δη x Δφ = 0.025 x 0.025
- 10 instead of 3 longitudinal layers

  -> Total of 0.3M channels

SiPM readout fast, low noise, little space

Calibration system

- Cs source (scintillators + SiPM)
- LEDs or laser (SiPM)



First tests with tiles and SiPMs in the laboratory

Performance of the calorimetry system

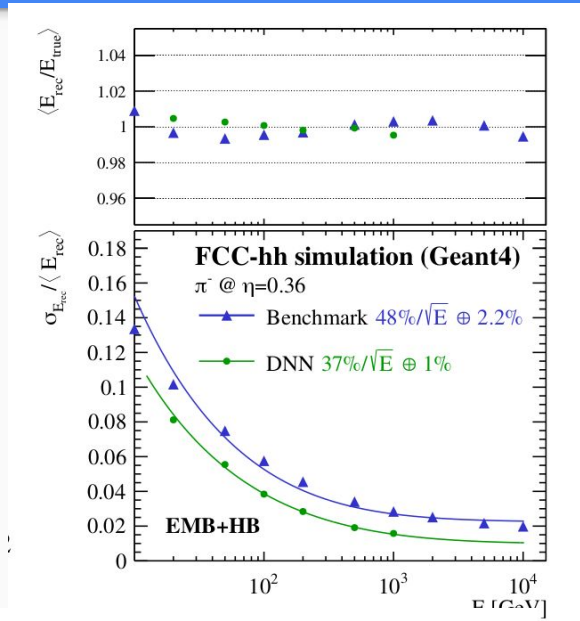
Full Geant4 simulations of single pions in calorimeters only

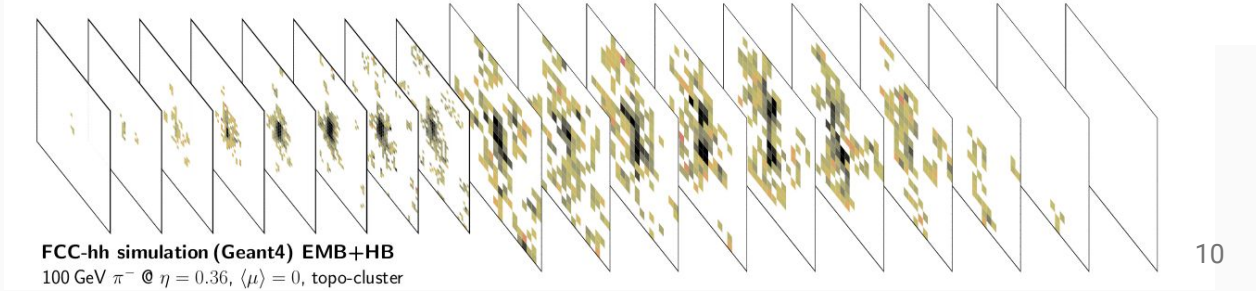
Conventional calibration

- Calorimeter cells clustering algorithm and simple calibration
- Sampling term of 48%/√E, constant term ~2%

Convolutional neural network (DNN)

- Make use of the fine granularity of the calorimeters
- **Sampling term of 37%/√E achieved!**





CERN EP R&D projects

Noble Liquid Calorimetry: Read-Out Electrode Design and Performance Optimization

- Electronic noise crucial for FCC-ee

Noble Liquid Calorimetry: High Density Feed Through Design Investigations

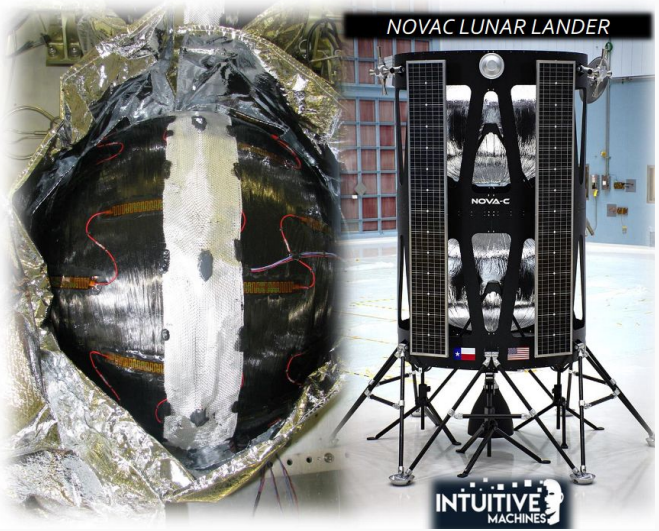
- 10x more signal cables compared to ATLAS

Carbon Composite Cryostats

- Ultra thin cryostats for future experiments

General SW framework & support for finalization of LAr calorimeter implementation into FCCSW

4 fellows at CERN



Summary

Reference calorimetry system for FCC-hh experiment

- Designed, optimised and documented
- Fulfils physics requirements based on simulations

R&D projects to develop necessary hardware started

References:

[1] Abada, A. et al., FCC-hh: The Hadron Collider, Eur. Phys. J. Spec. Top. **228, 755-1107** (2019), https://doi.org/10.1140/epjst/e2019-900087-0

[2] Aleksa, M. et al., Calorimeters for FCC-hh, https://arxiv.org/abs/1912.09962