Liquid argon calorimetry for a detector at a future circular e^+e^- collider

Thibault Guillemin (LAPP)

Journées nationales de prospectives 2020: détecteurs et instrumentation associée

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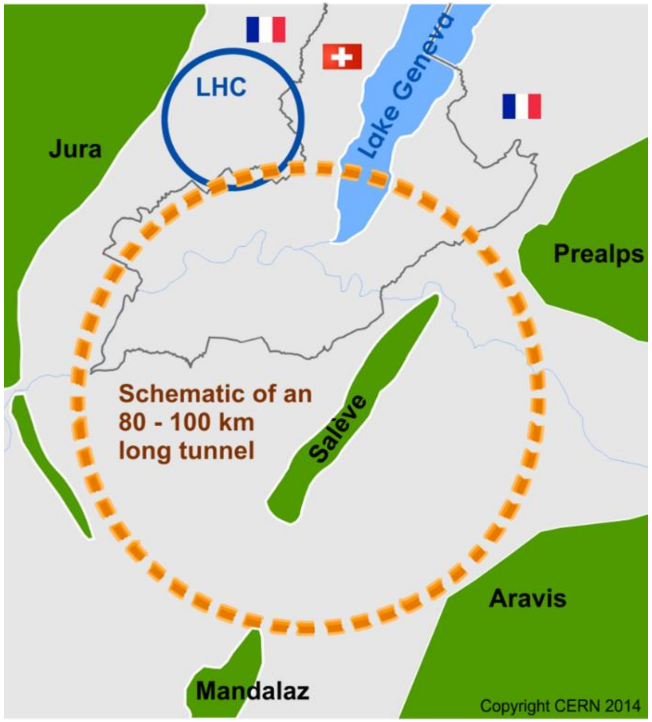
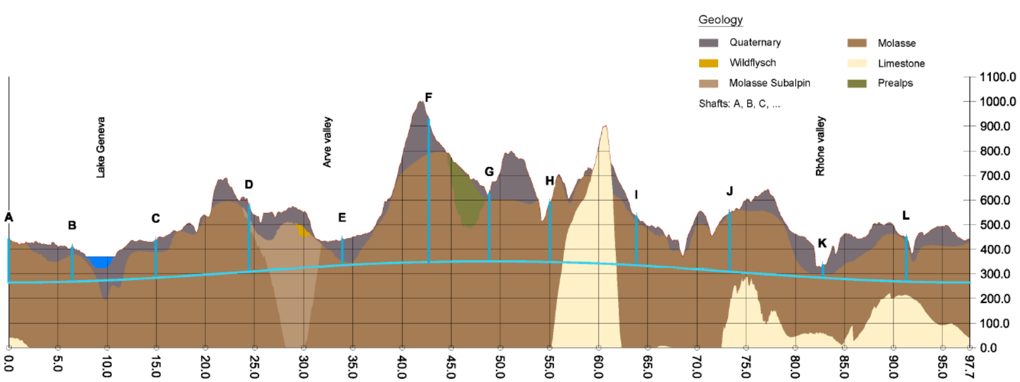


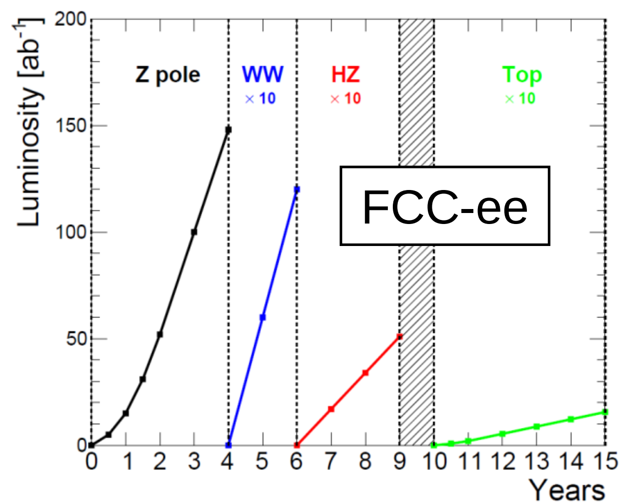
FCC project at CERN: 100 km tunnel

- Stage 1 (~2040-2055): **FCC-ee** (Z, W, H, tt) as first generation Higgs, electroweak and top factory at highest luminosities
- Stage 2 (~2065-2090): **FCC-hh** (~100 TeV) as natural continuation at energy frontier, with ion and ep options

Key technological challenge: 16 T dipoles

Conceptual Design Reports (machine, detector, physics) released in February 2019

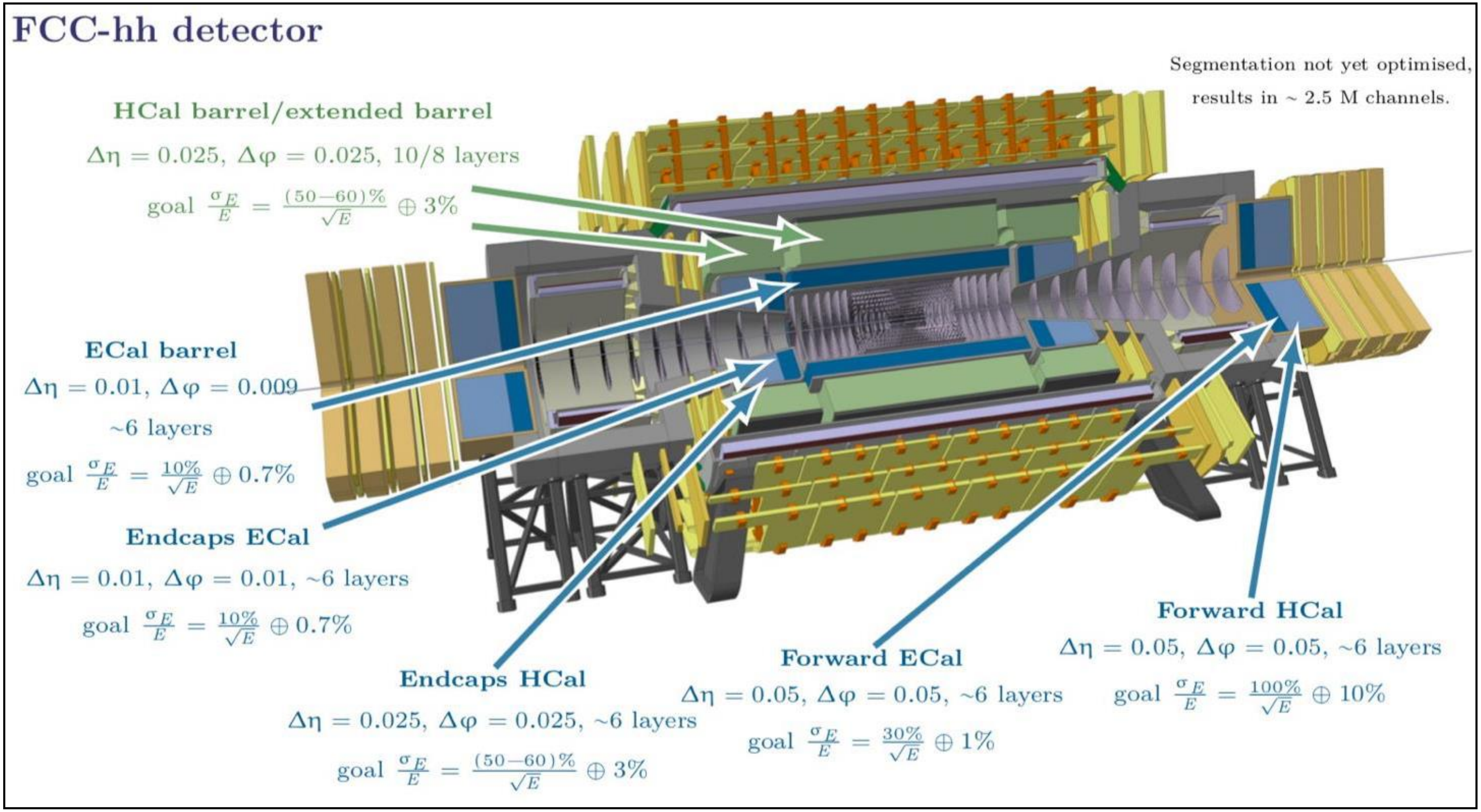




Outline

- LAr calorimeter in the FCC-hh CDR
- Could LAr calorimetry work at FCC-ee?
- Recent interest from IN2P3 groups

FCC-hh calorimeter

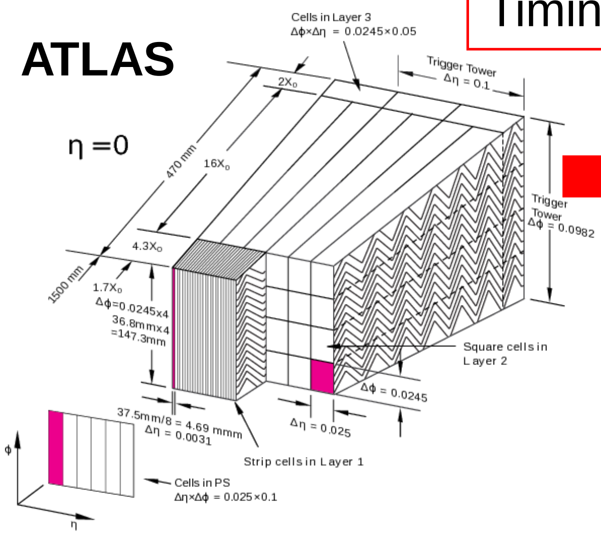


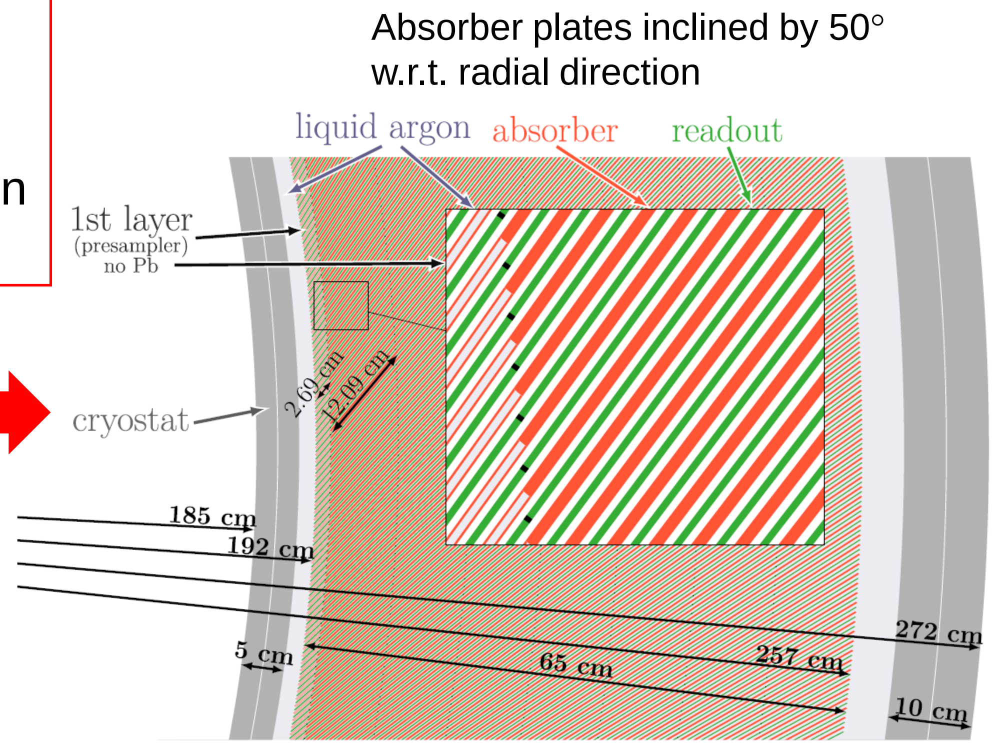
ATLAS-like calorimeter, with higher granularity

- ECal, HCal endcap and forward calorimeter (≥30 X_0): LAr / Pb (Cu)
- HCal barrel and extended barrel (≥10 λ): scintillating tiles / Fe(+Pb) with SiPM

FCC-hh electromagnetic calorimeter

Requirements:
High granularity
Radiation hard
Energy resolution
Timing





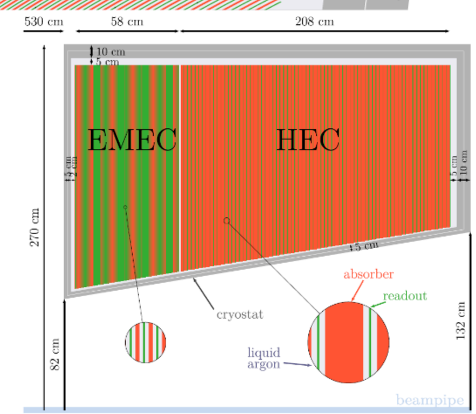
Much finer lateral and longitudinal granularity than ATLAS (×10)
- 8 longitudinal layers
- ΔηxΔφ~0.01x0.01 (0.0025x0.02 for first layer)

➔ 2.5 M readout channels

➔ **Possible thanks to straight multilayer electrodes**

(PCB, 7 layers, 1.2 mm thick)

⚠ Design and prototype



Outline

- LAr calorimeter in the FCC-hh CDR

- Could LAr calorimetry work at FCC-ee?

From P.D.G.

Liquid Ar/Pb (NA31)	$27X_0$	$7.5\%/\sqrt{E} \oplus 0.5\% \oplus 0.1/E$	1988
Liquid Ar/Pb (SLD)	$21X_0$	$8\%/\sqrt{E}$	1993
Liquid Ar/Pb (H1)	20–30X_0	$12\%/\sqrt{E} \oplus 1\%$	1998
Liquid Ar/depl. U (DØ)	$20.5X_0$	$16\%/\sqrt{E} \oplus 0.3\% \oplus 0.3/E$	1993
Liquid Ar/Pb accordion (ATLAS)	$25X_0$	$10\%/\sqrt{E} \oplus 0.4\% \oplus 0.3/E$	1996
Liquid Ar/Pb (straight PCB)	22 X_0	$a\%/\sqrt{E} \oplus c\% \oplus b/E$	2025?

Requirements for the FCC-ee calorimetry

Energy coverage
<200 GeV ➔ 22 X_0 and 7 λ

e/γ energy
δE/E ≤ 10%/√E [GeV]
Photons down to 300 MeV
(low noise term)

Jet energy
δE/E ≤ 30%/√E [GeV]
p-flow

Particle identification
Excellent e/γ ID

Radiation hardness
Loose

Time stability and acceptance knowledge
➔ Normalization to 10^{-5} level

Physics event rates up to 100 kHZ

Cost

EM resolution for FCC-ee

- Dimension

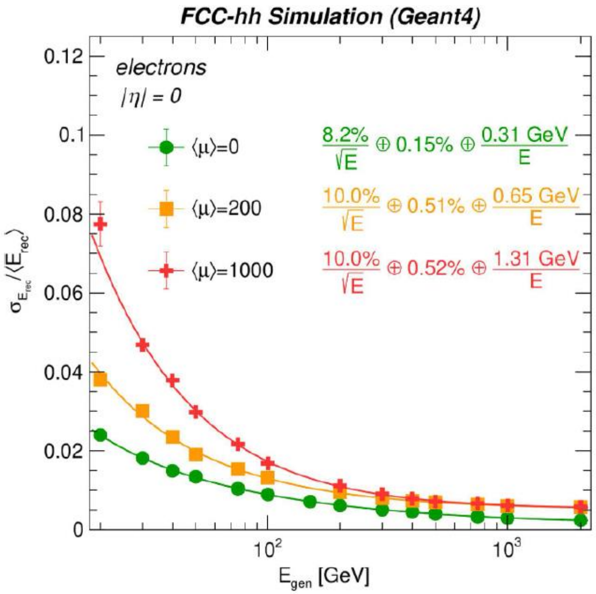
22 X_0 ➔ ~60 cm radial space required
With W instead of Pb: reduced to 45 cm

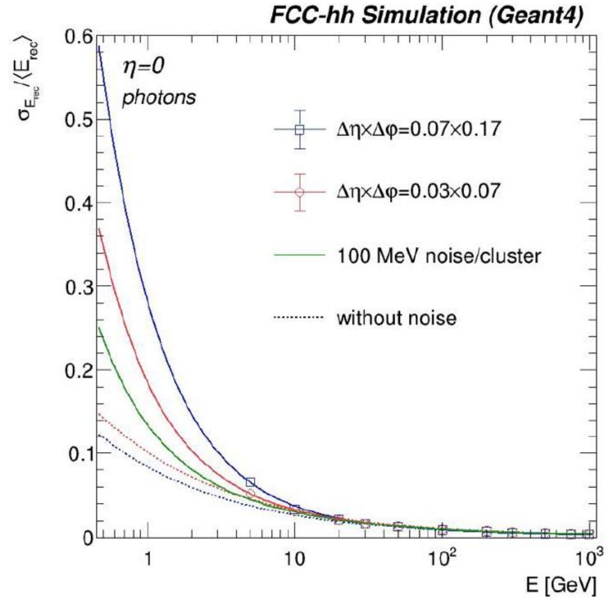
- EM resolution

- Sampling term: 8%/√E achieved in FCC-hh simulation (in the no-pileup case)

- Noise term
300 MeV in FCC-hh simulation at cluster level
Possible to reduce the electronics noise:
→ Adjusting cluster size
→ Increasing the shaping time
(up to 1 μs w.r.t. 45 ns used)

- Constant term <1% to not degrade in the 100-200 GeV range
(ATLAS 0.7%)



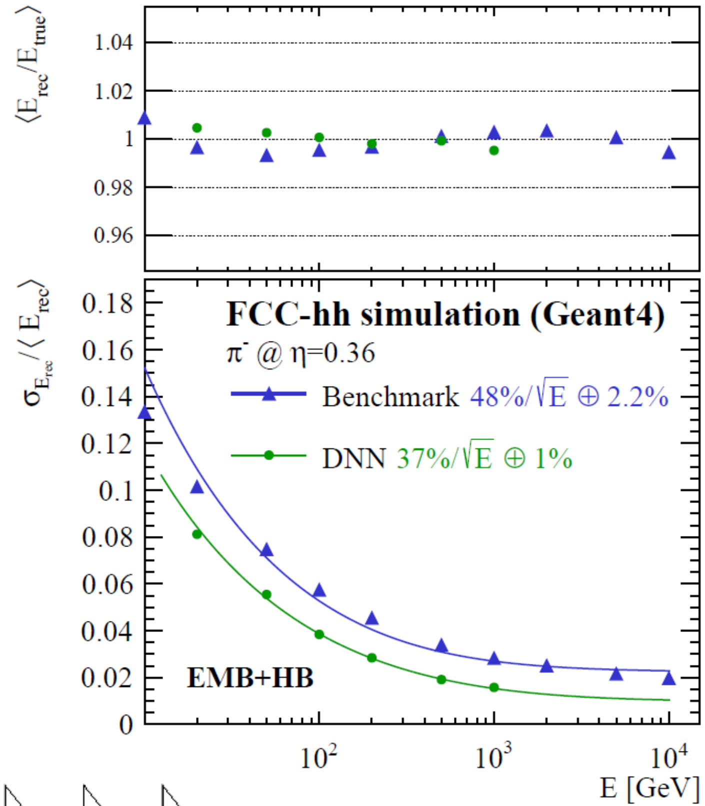


Jet resolution for FCC-ee

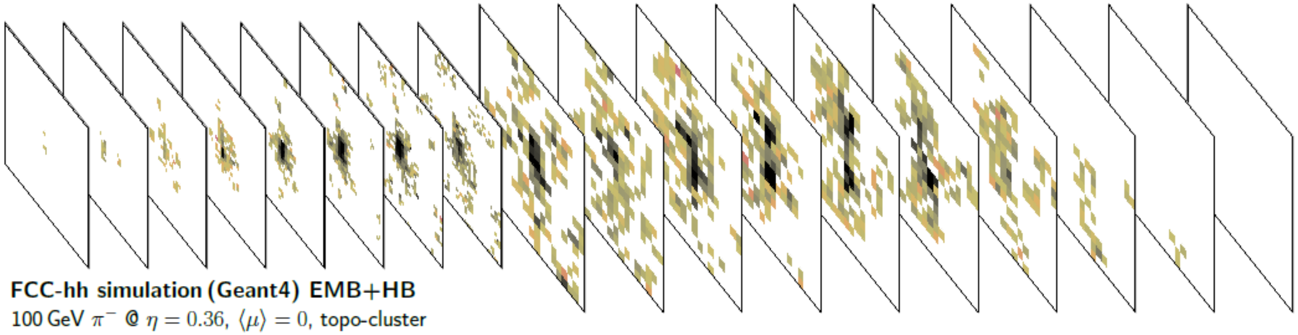
- Performance estimated using the reference FCC-hh HCAL

Pion resolution:
Reference: 48%/√E
DNN: 37%/√E (calorimeter only, no electronics noise)

- Particle flow will allow to improve further the jet resolution ➔ Work started to implement p-flow in FCCSW



From C. Neubuser, J. Kieseler



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Expression of interest for AIDA++

R&D for future high-granularity noble liquid calorimetry

- Project led by Martin Aleksa (CERN)
- 6 (4) institutes (in France) participating

Participating institute / company	Main contact person	E-mail
CERN	Martin Aleksa	martin.aleksa@cern.ch
LAL Orsay (IN2P3)	Nicolas Morange	nicolas.morange@cern.ch
OMEGA (IN2P3)	Christophe de la Taille	taille@in2p3.fr
Prague Charles University	Jana Faltova	jana.faltova@cern.ch
LAPP Annecy (IN2P3)	Thibault Guillemin	thibault.guillemin@cern.ch
CPPM Marseille (IN2P3)	Emmanuel Monnier	monnier@in2p3.fr

The following project is proposed:

- 2020-2021: Simulation and design of a multi-layer read-out + HV electrode (PCB) for a possible noble-liquid calorimeter.
- 2022-2023: Production of up to three prototype electrode PCBs
- 2024-2025: Electrical measurements of electrodes (attenuation, capacitances, cross-talk) at room temperature.
- 2024-2025: Measurements including read-out electronics (preamplifier, shaper ASIC) at room temperature (and possibly in cryogenic temperatures).

Discussions about the contributions are starting: kick-off meeting in February.

ANR proposal just submitted: GRANULAR

High granularity liquid argon calorimetry for a detector at a future circular electron-positron collider

- Funding requested: 600 k€ (two 3-year postdoctorants + 100 k€ material)
- A way for french members to get organized to contribute

Work packages	LAPP	LAL	OMEGA
Design optimization for FCC-ee	x	x	
Performance assessment from simulation	x	x	
PCB electrode design		x	
Outside/inside-cryostat electronics (ASICS)			x
Engineering/mechanics for a small-scale calorimeter module	x		
Laboratory and test beam measurements	x	x	

Conclusion

- **Liquid Argon calorimetry being explored for the FCC-ee case**

➔ Interest of several IN2P3 researchers from different institutes

- Expression of Interest for AIDA++ signed
- ANR GRANULAR submitted

➔ Plan to start simulation work now

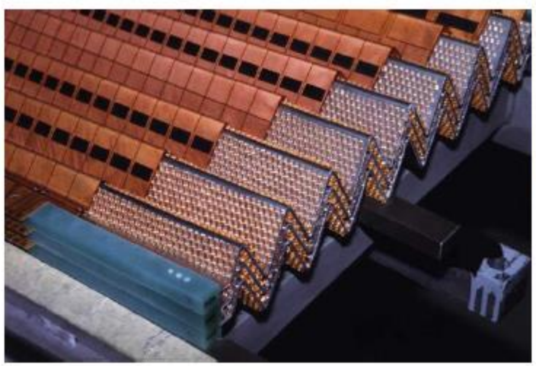
- Other options to be investigated to optimize specifically for the FCC-ee case: W absorber, LKr as active material, alternative geometry, LAr for HCAL, etc.

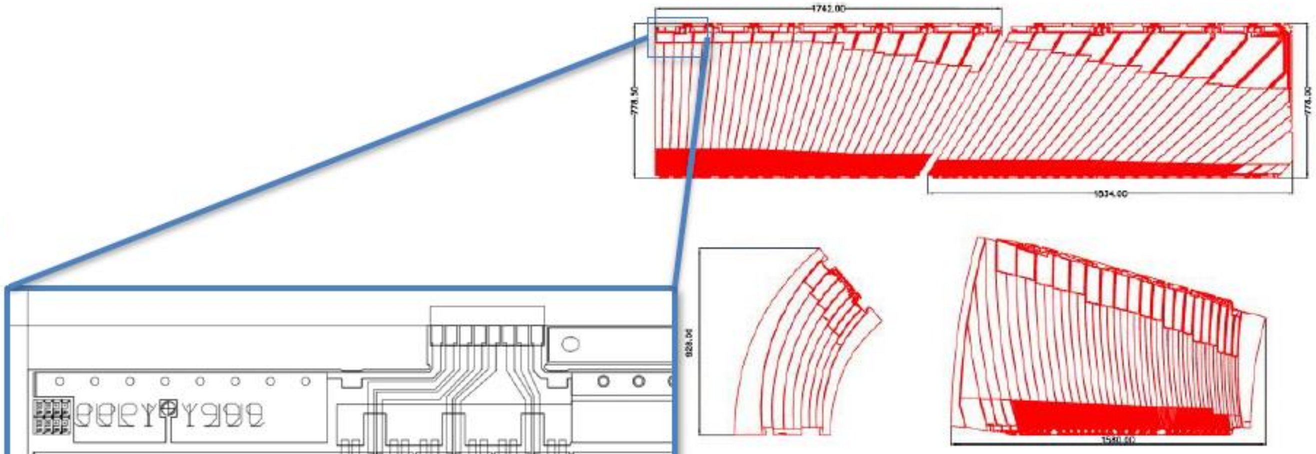
N.B: plan to go towards proto-collaborations by 2026, before moving to a TDR phase.

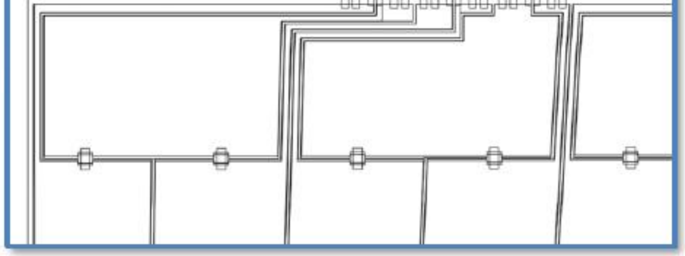
Backup

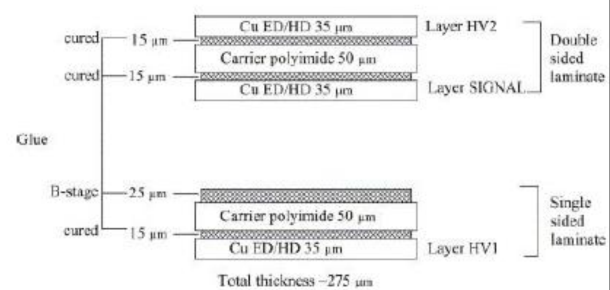
ATLAS granularity

- **In the ATLAS LAr calorimeter** electrodes have 3 layers that are glued together (~275µm thick)
  - 2 HV layers on the outside
  - 1 signal layer in the middle
- **→ All cells have to be connected with fine signal traces** (2-3mm) to the edges of the electrodes
  - Front layer read at inner radius
  - Middle and back layer read at outer radius
- **→ limits lateral and longitudinal granularity**
- → maximum 3 long. layers







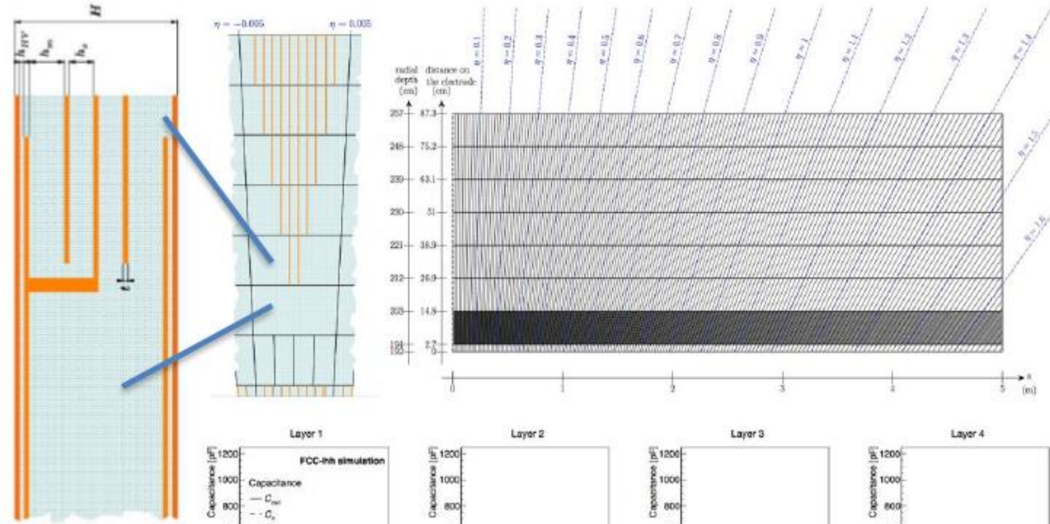


From M. Aleksa

Achieving high granularity

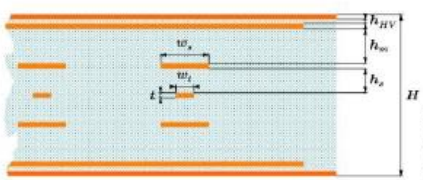
Realize read-out electrodes as multi-layer PCBs (1.2mm thick)

- Signal traces (width w_t) in dedicated signal layer connected with vias to the signal pads
- Traces shielded by ground-shields (width w_s) forming 25Ω – 50Ω transmission lines
- → capacitance between shields and signal pads C_s will add to the detector capacitance C_d
- → $C_{cell} = C_s + C_d \approx 100 - 1000$pF
- The higher the granularity the more shields are necessary → C_{cell} increases

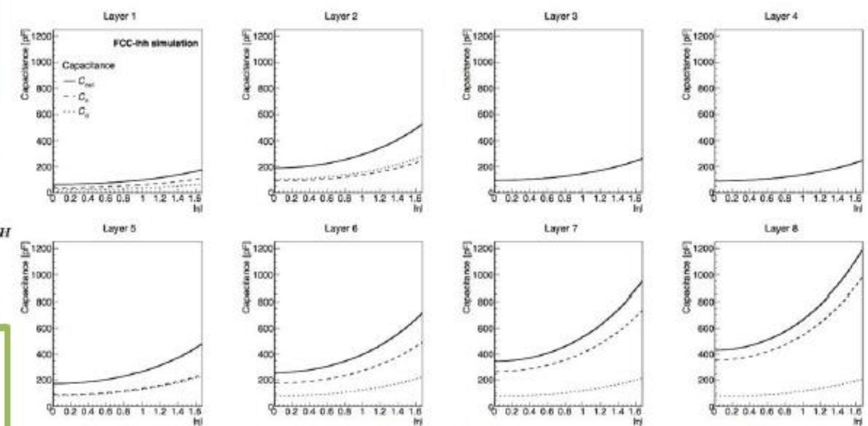


→ Serial noise contribution proportional to capacitance C_{cell}

→ 4 – 40MeV noise per read-out channel assuming ATLAS-like electronics



Hadronic showers:
Energy sums over O(500-10000) cells

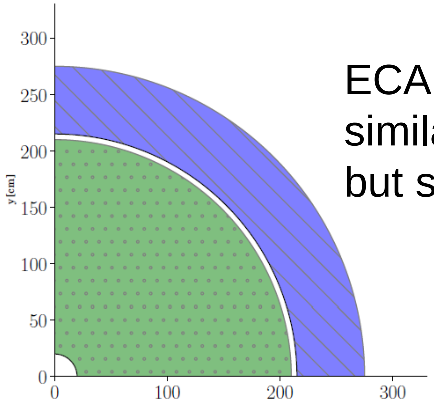


Plots A. Zaborowska, J. Faltova

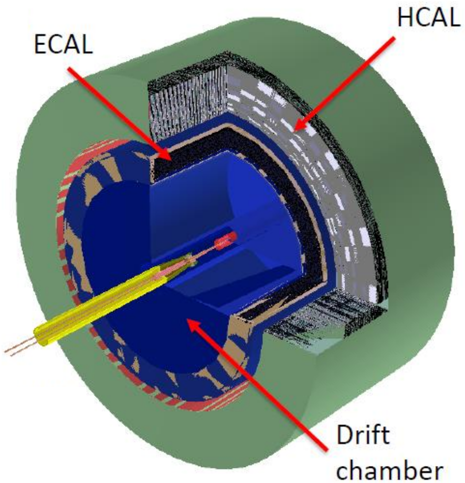
From M. Aleksa

Towards a first simulated design for FCC-ee

First version implemented in simulation
- Inner tracker (IDEA drift chambers)
- Scaled FCC-hh calorimeters
- Solenoid outside calorimeter

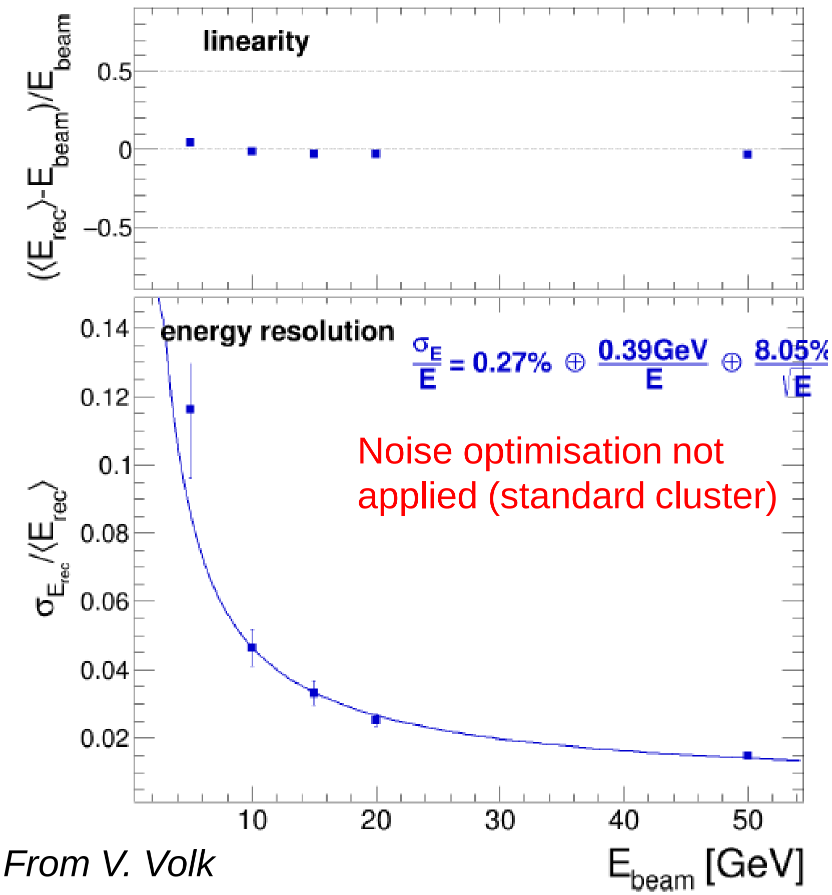


ECAL scaled to 60 cm: similar layer structure but smaller LAr gap



FCC-ee preliminary

- single electron energy resolution
  - with electronics noise
  - no backgounds
  - no magnetic field



From V. Volk