R&D on Experimental Technologies

High Granularity Noble Liquid Calorimetry for Future Accelerator Experiments
Contributions by EP R&D WG3, WG4, WG7

May 2020

Martin Aleksa (CERN)

Introduction

Noble Liquid Calorimetry

Requirements for e^+e^- Collider Experiments

Agenda

Noble Liquid Calorimetry for Future Accelerator Experiments

Wednesday 13 May 2020, 15:00 → 17:00 Europe/Zurich

Vidyo Only

Description The Vidyo Pin is 2020

Videoconference Rooms FCC_Noble_Liquid_Calorimetry_Meeting Join

15:00 → 15:20	**Introduction** Speaker: Martin Aleksa (CERN)	20m
15:25 → 15:45	**EP R&D Project on Noble Liquid Calorimetry - Read-Out Electrode Design and Performance Otpimization** Speaker: Marina Beguin (CERN)	20m
15:50 → 16:10	**EP R&D Project on SW Framework for Future Accelerator Experiments and SW for FCC Calorimeter** Speaker: Valentin Volkl (University of Innsbruck (AT))	20m
16:15 → 16:35	**EP R&D Project on Noble Liquid Calorimetry - High Density FeedThrough Design Investigations** Speaker: Maria Asuncion Barba Higueras (CERN)	20m
16:40 → 17:00	**EP R&D Project on Carbon Composite Cryostats** Speaker: Maria Soledad Molina Gonzalez (Universidad de Sevilla (ES))	20m

Introduction – Meeting Scope

- **This meeting is the first meeting of a series**
  - bi-weekly, slot to be defined
- It should be seen as a **continuation of the R&D effort** during the last 5 years that was focused on developing an FCC-hh Calorimeter in the framework of the international FCC Study (documented in https://arxiv.org/abs/1912.09962).
- The scope has changed during last year. This meeting will now **focus on an application of noble liquid calorimetry in e^+e^- collider experiments**, but parts of the R&D will be generic and independent of the experiment.
- **The scope of this series of meetings** will be to create a forum to present, discuss and follow-up on the R&D work that is related to high-granularity noble liquid calorimetry for future accelerator experiments
- **Today:** Introduction followed by overview talks of the different activities

Introduction – CERN EP R&D

- **The CERN EP R&D Program** was initiated two years ago, **a report was published** end 2018 (link) and **funding has started** beginning of 2020.
- **Work on noble liquid calorimetry related subjects is starting as part of this EP R&D program**
  - **WG3 (Calorimetry and light based detectors)**
    - 1 fellow: Performance & Physics simulation to define necessary granularity. Read-out PCB design for required granularity while keeping low noise requirement. Studies on optimization of timing resolution.
    - 1 fellow: Cryogenic feed-through design for high-density signal feed-throughs
  - **WG4 (Detector mechanics)**
    - 1 technical student: R&D on low-mass composite cryostats
  - **WG7 (Software)**
    - 1 fellow: General SW framework & support for finalization of LAr calorimeter implementation into FCC SW. Work on implementation of particle flow
  - **Related, but not directly linked: WG8 (Detector magnets)**
    - 1 fellow will start on R&D on low-mass superconducting coils and cryostats
- **In addition interest by institutes in F, CZ and US to collaborate**
- In July 2019 submitted **Expressions of Interest (EoI) for H2020 Innovation Pilot, AIDANova** – some funding for collaboration has been allocated (waiting for final OK)

Noble-Liquid Calorimetry – ATLAS LAr EM Calorimeter

Sampling calorimeter

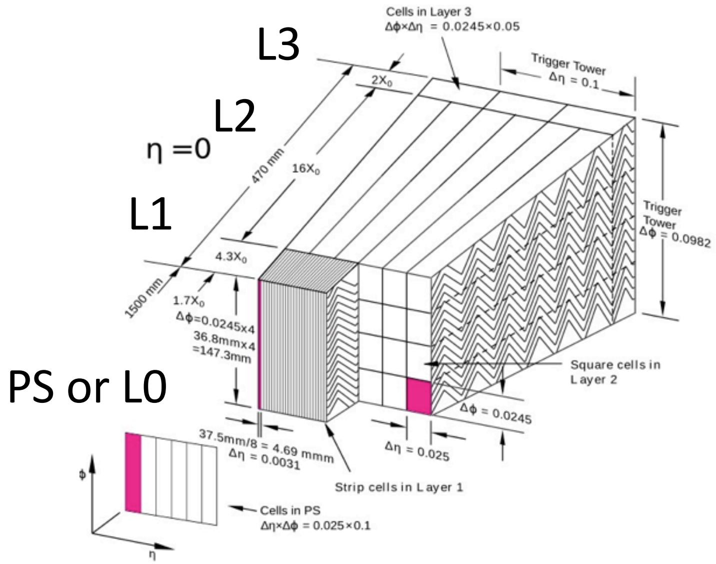
- with Pb absorbers and active LAr gaps (2mm in barrel, 1.2 – 2.7mm in endcap)

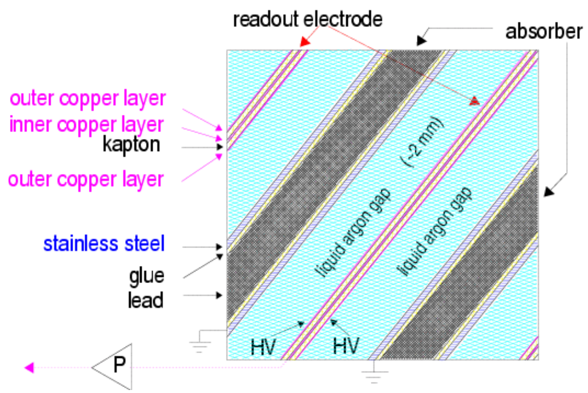
Advantages of **liquid argon (LAr) as active material**

- linear behavior
- stability of the response over time
  - ideal to understand systematic effects using large statistics of e.g. Z→ee events and develop corrections
- radiation tolerance

Advantages of **accordion geometry**

- it allows **a very high η-ϕ granularity** and **longitudinal segmentation** (PS, L1, L2, L3)
- it allows for very **good hermeticity** since HV and signal cables run only at front and back faces of the detector
- it allows for **a very high uniformity** in ϕ

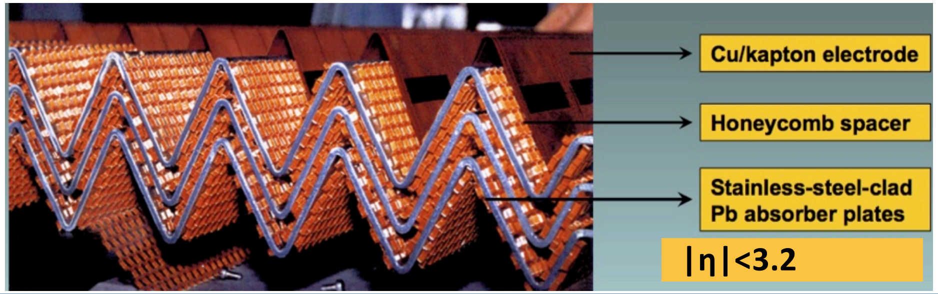


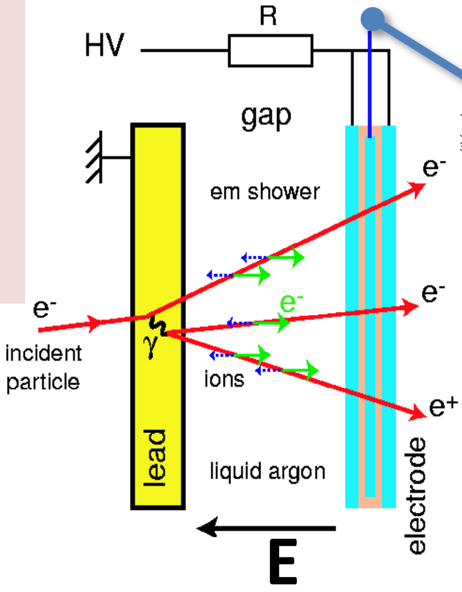


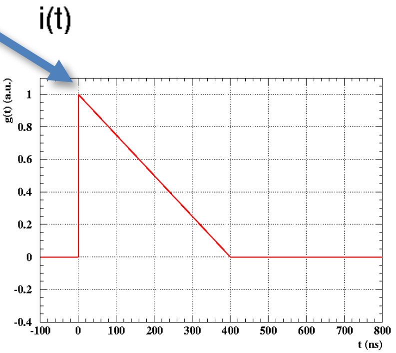
Incident electrons create **EM showers** in Pb (X_0=0.56cm) and LAr gaps (X_0=14.2cm)

secondary e^+ and e^- create e^-–ion pairs in LAr (W=23.3eV)

Ionized electrons and ions drift in electric field (2kV for 2mm gaps in barrel) and **induce triangular signal** (≈450ns e^- drift time)







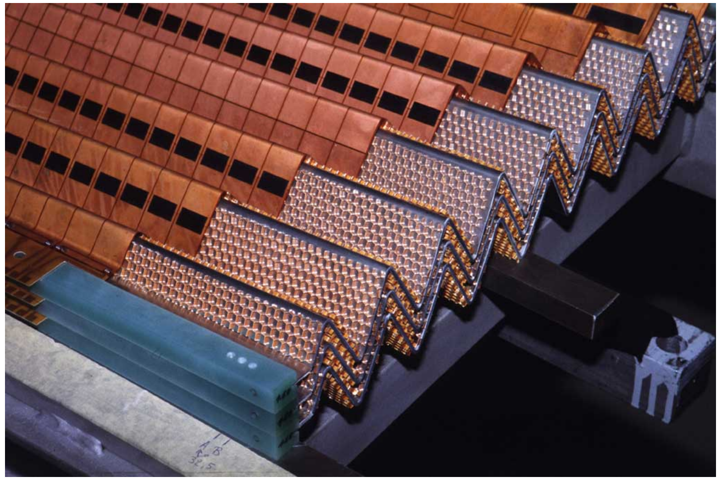
$\tau_{drift} \approx 450$ ns

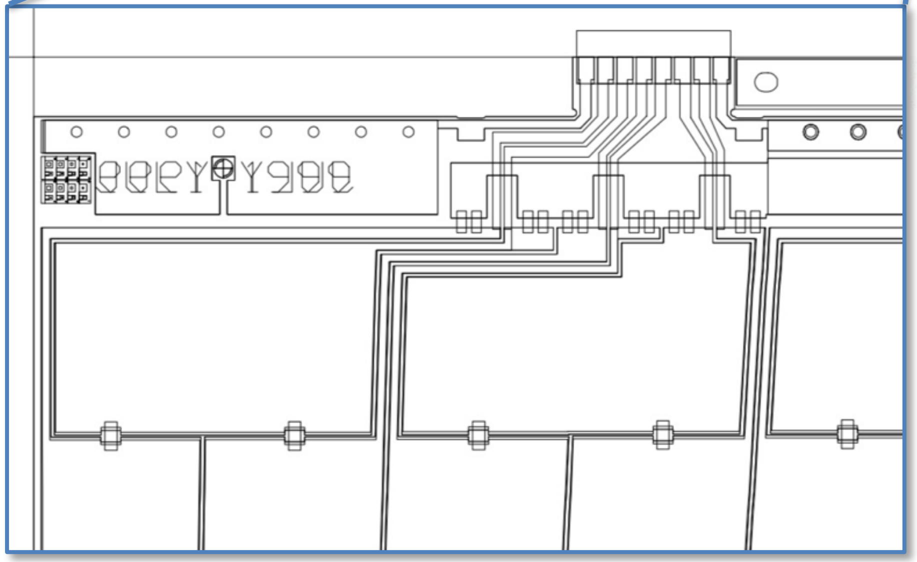
Design resolution:

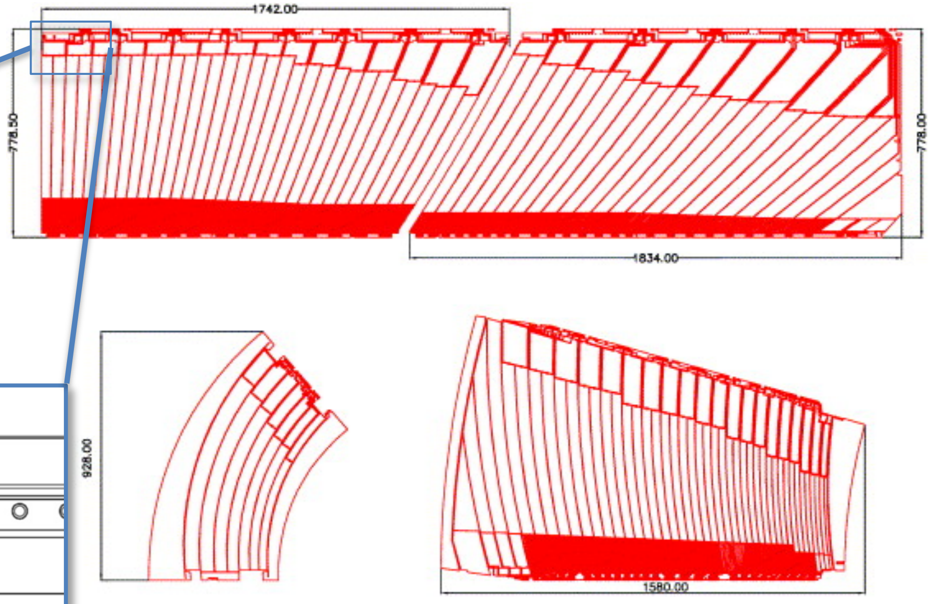
$$\frac{\sigma(E)}{E} = \frac{10\%}{\sqrt{E}} \oplus \frac{0.2}{E} \oplus 0.2\%$$

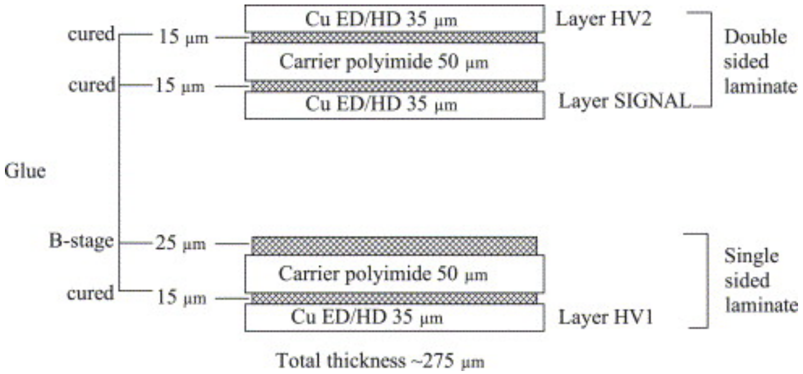
What Limits Granularity in ATLAS LAr?

- **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

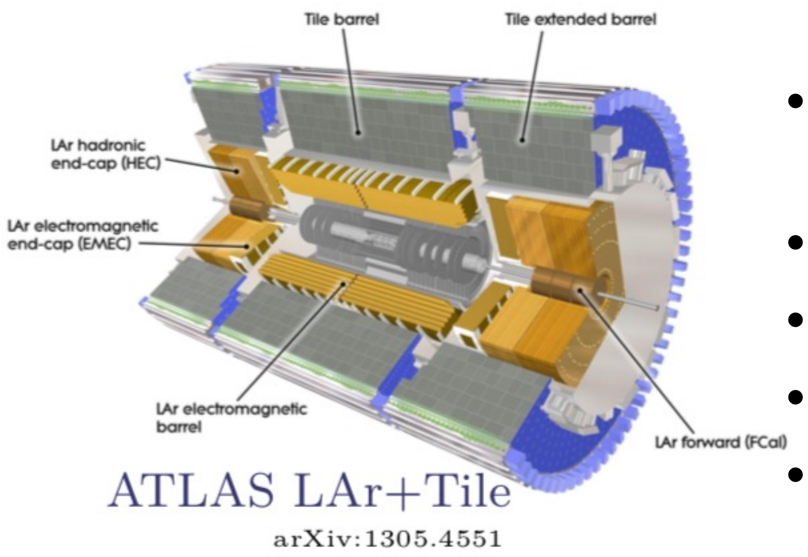


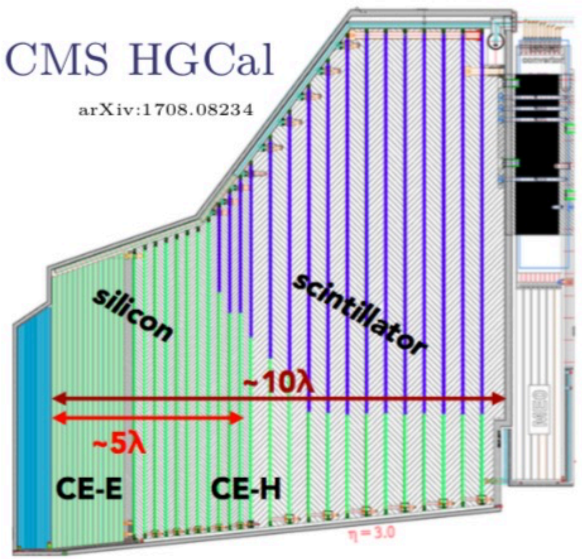






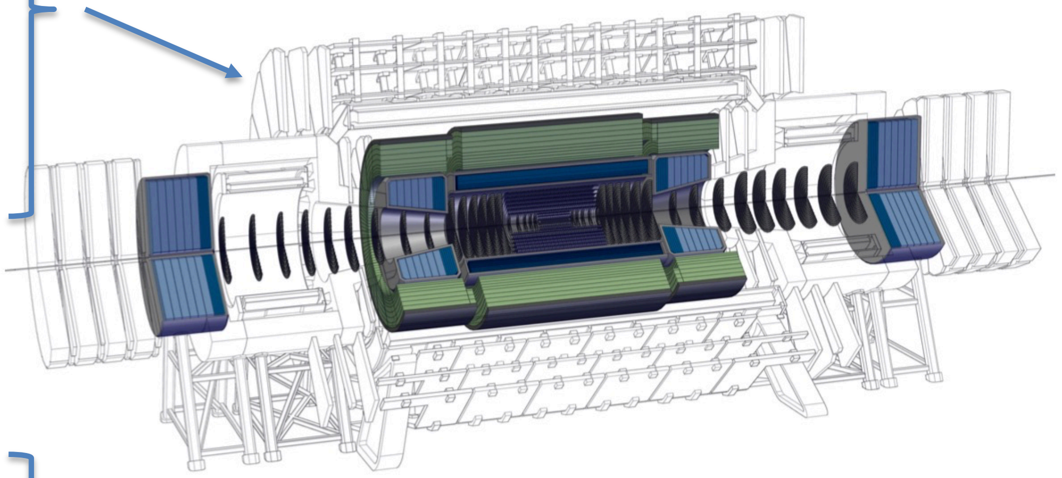
FCC-hh Calorimetry





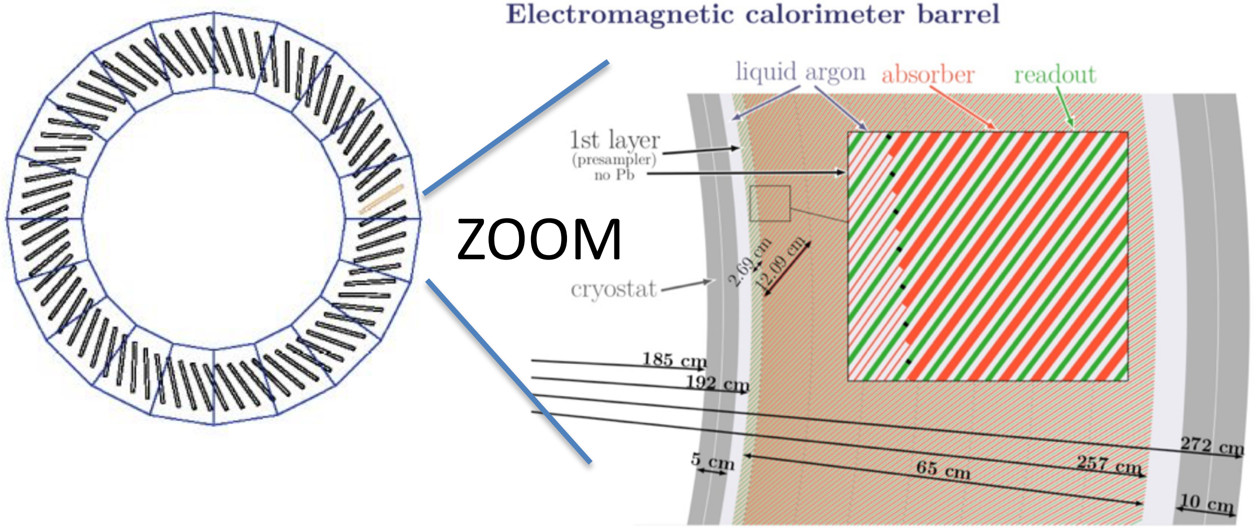
- Good instrinsic energy resolution
- Radiation hardness
- High stability
- Linearity and uniformity
- Easy to calibrate

FCC-hh Calorimetry

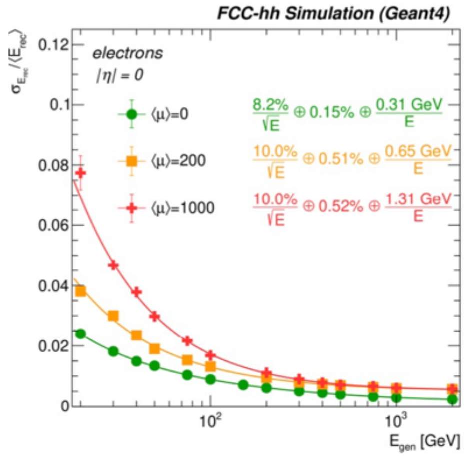


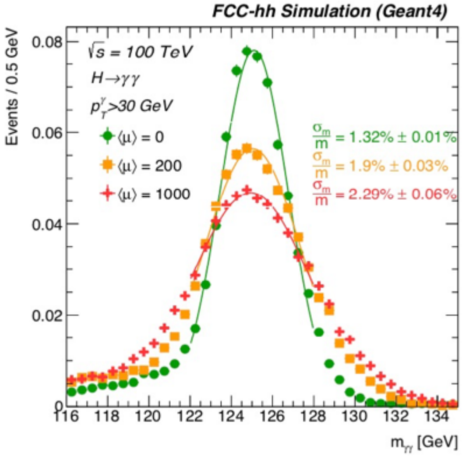
- High granularity
  - → Pile-up rejection
  - → Particle flow
  - → 3D/4D/5D imaging

FCC-hh Electromagnetic Calorimeter (ECAL)

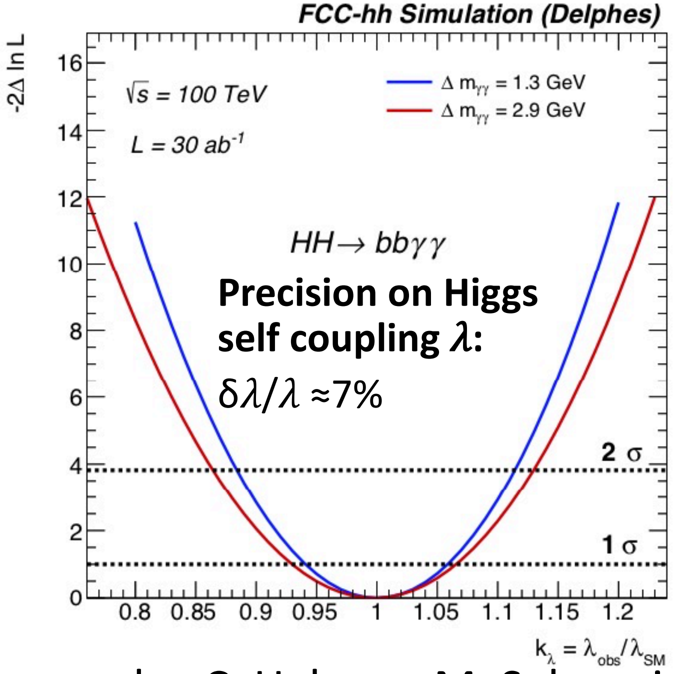


- 2 mm absorber plates inclined by 50° angle;
- LAr gap increases with radius: 1.15 mm–3.09 mm;
- 8 longitudinal layers (first one without lead as a presampler);
- $\Delta\eta = 0.01$ (0.0025 in 2nd layer);
- $\Delta\varphi = 0.009$;





- Compared to ATLAS, **FCC-hh Calo** needs **finer longitudinal and lateral granularity**
  - **Optimized for particle flow**
  - **8 longitudinal compartments**, fine lateral granularity
  - **Granularity:** $\Delta\eta \times \Delta\phi \approx 0.01 \times 0.01$; first layer $\Delta\eta \times \Delta\phi \approx 0.0025 \times 0.02$ → ~2.5M channels
- **Possible only with straight multilayer electrodes (no accordion)**
  - Active material LAr
  - Straight absorbers (Pb + stainless steel sheets), 50° inclined with respect to radial direction
  - Readout and HV on straight multilayer electrodes (PCBs, 7 layers, 1.2mm thick)
  - → Sampling fraction changes with depth $f_{sampl} \approx 1/7$ to $1/4$ (LAr gap 2 x 1.15mm to 2 x 3.09mm)
- **Required energy resolution achieved**
  - Sampling term ≤ 10%/√E, only ≈300 MeV electronics noise despite multilayer electrodes
  - Impact of in-time pile-up at <μ> = 1000 of ≈ 1.3GeV pile-up noise
  - →Efficient in-time pile-up suppression will be crucial (using the tracker)

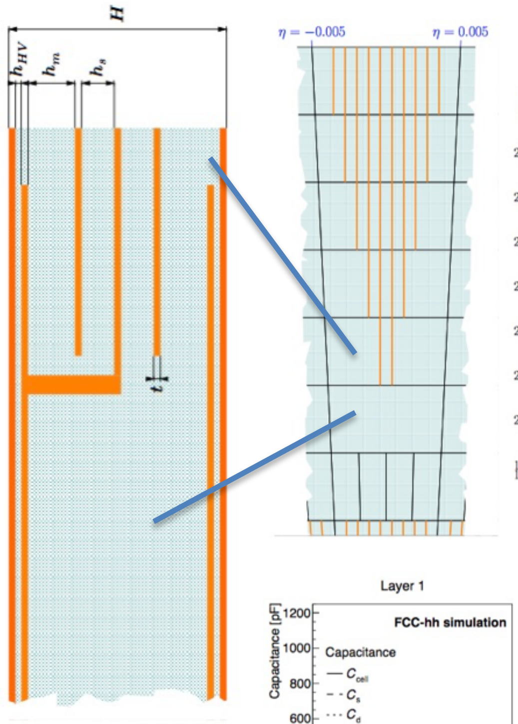


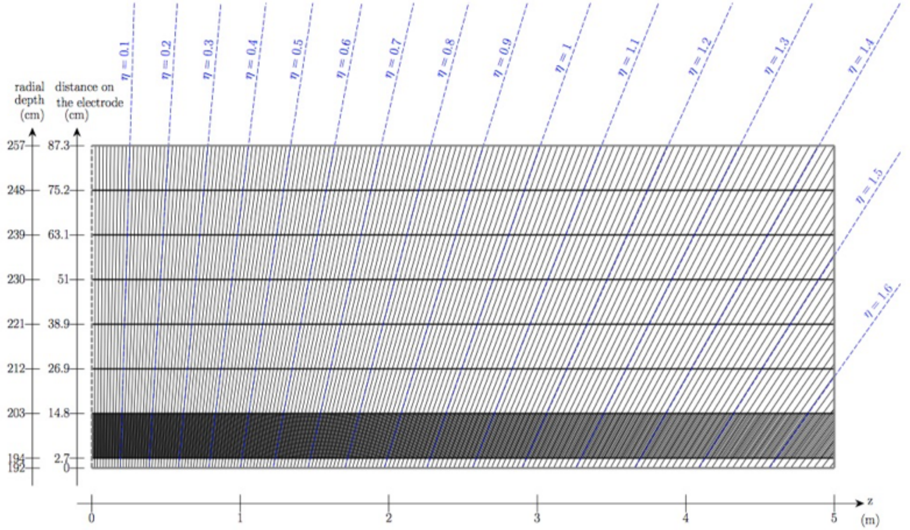
Plots A. Zaborowska, C. Helsens, M. Selvaggi

How to Achieve High Granularity?

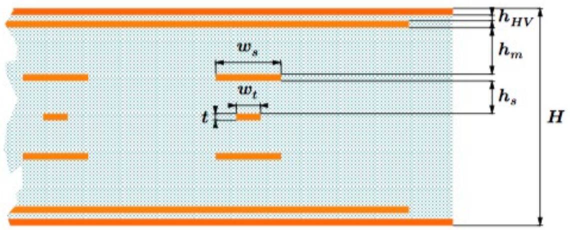
Realize read-out electrodes as multi-layer PCBs (1.2mm thick)

- 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

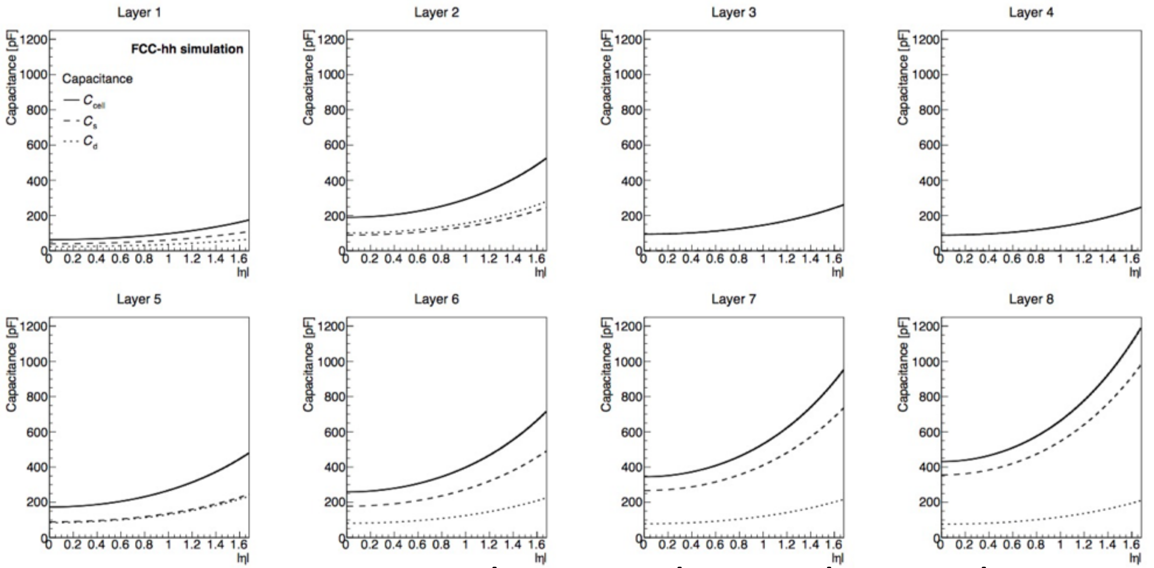




→ Serial noise contribution proportional to capacitance C_{cell}
→ 4 – 40MeV noise per read-out channel assuming ATLAS-like electronics



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

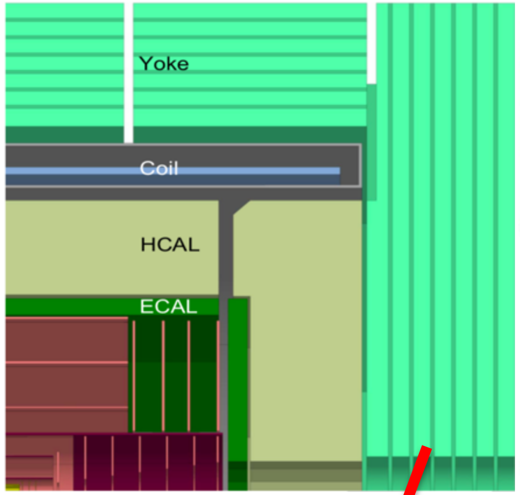


Plots A. Zaborowska, J. Faltova

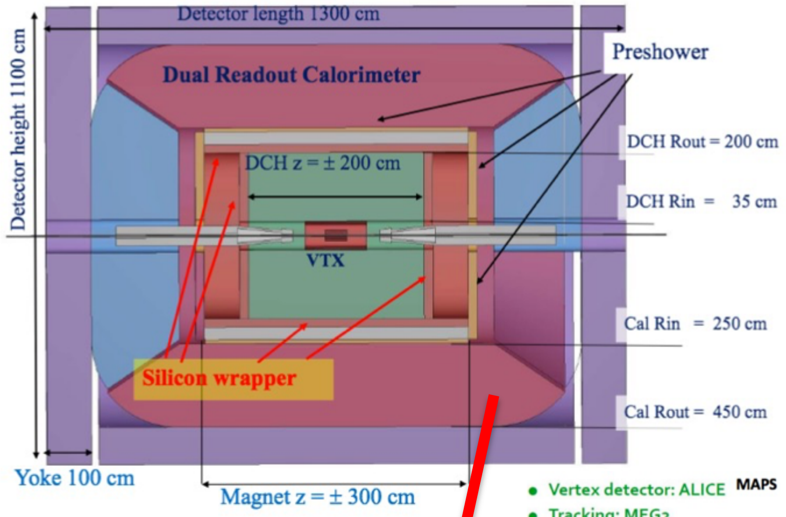
Future e⁺e⁻ Collider Experiments (FCC-ee, CepC, …)

- **Calorimetry requirements**:
  - ***Excellent jet energy resolution*** (~30%/√E)
  - ***Particle ID***
- **→ High granularity calorimetry based on particle flow**
  - **Same technologies as for CLIC/ILC under study**
    - e.g. Si/W ECAL and Scintillator/Iron HCAL
  - **On top of that fibre-sampling dual-readout calorimetry** could be a very interesting option for future leptonic colliders
    - Fine transverse granularity
    - Need longitudinal segmentation to separate e/γ from $\pi^{\pm}$! → Idea with fibres of different length
    - Excellent hadronic resolution (simulation ~35%/√E)
  - **Noble liquid based calorimetry**
    - Calo only: Simulation with DNN calib. for LAr ECAL + TileCal HCAL: ~37%/√E
    - Fine granularity → particle flow reco with ID

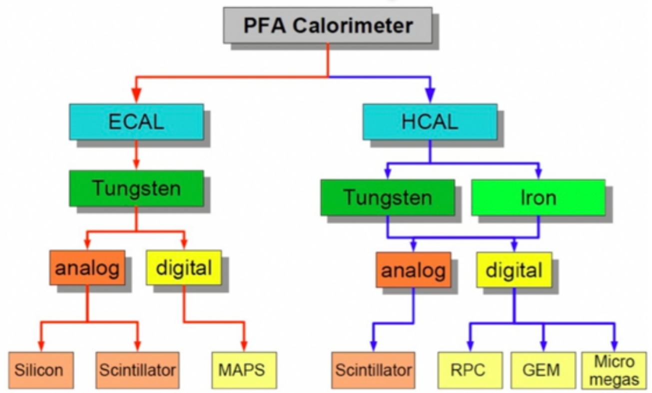
"CLIC-detector revisited - CLD"

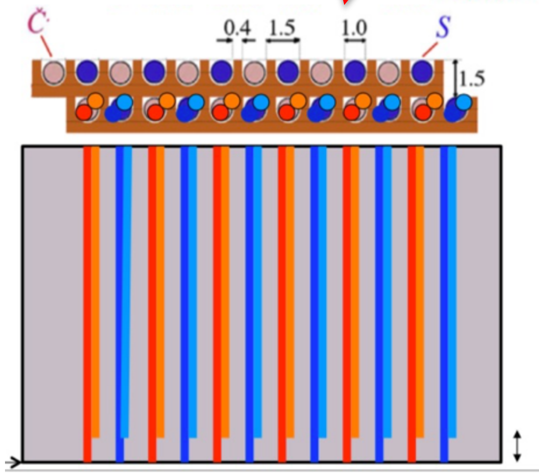


"IDEA"



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





Inspired from CMS HF Calo [Only Č fibres]

Requirements for e^+e^- Collider Experiments' Calorimetry

- **Energy range of particles:**
  - All particles ≤ 182.5 GeV → $22X_0$ and 5-7λ sufficient
  - → EM Calorimetry in Δr = 60 cm radial space for FCC-hh type LAr/Pb calorimeter (including 15cm cryostat thickness), Δr = 45 cm for LAr/W
- **Measure particles down to 300 MeV (e.g. photons)**
  - **→ Little material in front of the calorimeter → low-mass cryostats and coils (EP R&D program WG4, WG8)**
  - **→ Low noise (noise term dominant at small energies, *b* ≪ 300 MeV)! → Electrode optimization (EP R&D WG3)**
- **EM resolution as good as possible** (≤ 15%/√Ē)
  - e.g. for CLFV τ decays $\tau \to \mu\gamma$
  - **→ Optimization of read-out electrode (EP R&D WG3)**
- **Jet resolution must be excellent** (~ 30%/√Ē) to separate W and Z decays
  - **→ Such excellent jet resolution can be achieved with particle flow techniques (EP R&D WG7, WG3)**
  - **→ High granularity of read-out (3D or 4D imaging) (EP R&D WG3, FT design, electrode design)**
- **Position resolution of photons:** $\sigma_x = \sigma_y = (6\ \mathrm{GeV}/E \oplus 2)$ mm **Particle ID:**
  - $e^\pm/\pi^\pm$ separation,
  - τ decays with collimated final states, separate different decay modes with minimal overlap (e.g. π_0 close to $\pi^\pm$)
  - **→ High granularity of read-out (3D or 4D imaging) (EP R&D WG3, FT design, electrode design)**

Outlook

- I am confident that with your help these meetings will become a forum where we can exchange, discuss and follow-up the progress of the work done in the different working groups
- We hope that these meetings will foster exchange and collaboration between the different working groups, especially between the fllows and technical students who have started work
- To give a perspective we will also include physics related topics (probably mainly from FCC-ee) that have an impact on calorimetry requirements
- Format and frequency of the meetings can of course be adjusted to our needs
- Common cernbox folder for exchanging information: "/eos/project/e/ep-rdet/WG3-Calorimetry-and-light-based-detectors/Noble Liquid Calorimetry for Future Accelerator Experiments".
  - Please drop me a mail, if you want to access this folder
- E-group has been created (ep-rdet-WG3-Cal-Noble-Liquid@cern.ch) Please subscribe!
- Possible slots for bi-weekly meeting:
  - Tuesdays 9:00 – 11:00
  - Thursdays 9:00 – 11:00
  - Fridays 9:00 – 11:00

Backup