ALLEGRO
Detector Concept Status

Emmanuel Monnier (CPPM) & Martin Aleksa (CERN)

- ALLEGRO Detector Contacts
- Some Changes in the Lay-Out
- ALLEGRO Solenoid
- ALLEGRO Sub-Detectors
- Simulation
- Next Steps

Material from ALLEGRO General Meeting https://indico.cern.ch/event/1716681/

Many thanks for contributions from H. Chen, B. François, S. Snyder, G. Marchiori, P. Iengo, O. Kortner, A. Koulouris, A. Macchiolo, N. Morange, M.-A. Pleier, J. Qian, S. Schramm, T. Wengler, H. Wilkens, et al.

What is ALLEGRO?

- **It started with a noble-liquid calorimeter for future experiments**
  - In 2015 started to think about a noble-liquid ECAL for FCC-hh, part of the FCC-hh reference detector → CDR in 2019, input to the ESU 2019
  - CDR, FCC-hh calorimeter (arxiv:1912.09962), FCC-hh reference detector: CERN Yellow Report
- **After 2020 ESU focus shifted to FCC-ee**
  - We adapted noble-liquid ECAL to work in a lepton collider experiment, performance studies showed that it is very competitive compared to other proposals (Si/W, dual read-out calorimetry) - (see arxiv:2109.00391)
  - Noble-liquid calorimetry became work-package inside CERN EP R&D and later part of DRDCalo as WP2 (link)
- **In 2022 proposed a detector concept based on noble-liquid ECAL**
  - Implemented a version into FCC SW which consisted of a noble-liquid ECAL and some "reasonable" choices for the other sub-detectors. Different choices can easily be tried due to the modularity of the FCC SW. Close collaboration with Sci/Fe HCAL (TileCal) from FCC-hh days
  - Presented detector concept during FCC Weeks, FCC PED Workshops and conferences → triggered interest
  - In 2023 survey to find a name → **ALLEGRO** (**A** **L**epton **L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut) was born
- **Current situation**
  - **Strong noble-liquid ECAL team** collaborating within **DRD6 WP2 (link)**
  - **ALLEGRO kick-off meeting** in Nov. 2024 **(link)**
  - **Expressions of Interest (EoI) for Full Detector Concept submitted to 2025/26 European Strategy for Particle Physics Update (link)**
  - **Call for sub-detector contact persons** issued in summer 2025, all contact persons **identified and announced** end 2025.
  - Well attended **ALLEGRO sub-detector working group** meetings and **ALLEGRO general** meetings have started beginning of 2026 (**link**)
  - **Web page:** https://allegro.web.cern.ch

→ A detector concept in its beginnings

EoI for Full Detector Concept

Sub-Detector	Institutes
Vertex Det. and MDI Region	ETH Zurich (CH), Univ. of Zurich (CH), PSI (CH), BNL (US), INFN Pisa (IT), INFN Frascati (IT), IPHC (FR), CPPM (FR), LPNHE (FR), APC (FR), IP2I (FR)
Tracker	Univ. of Michigan (US), MPP Munich (DE), BNL (US), UT Austin (US), IJCLab (FR), EPFL (CH)
Timing Layer	Univ. of Zurich (CH), PSI (CH), BNL (US), CEA-Irfu (FR), IP2I Lyon (FR)
Electromagnetic Calorimeter	CERN, APC (FR), IJCLab (FR), CPPM (FR), OMEGA (FR), LAPP (FR), MPP Munich (DE), TU Dresden (DE), BNL (US), Brown Univ. (US), NYU (US), Columbia Univ. (US), SMU (US), Univ. of Arizona (US), UT Austin (US), Stony Brook (US), Charles Univ. (CZ), IFIN-HH and UPB (RO), IEP SAS Kosice (SK)
Solenoid and Cryostat	CERN
Hadronic Calorimeter	ITIM Cluj Napoca (RO), LIP (PT), IFIC Valencia (ES), Bergen (NO), FZU (CZ), Charles Uni (CZ), Tbilisi (GE), CERN
Muon System	MPP Munich (DE), Weizmann Institute (IL), Univ. of Napoli (IT), Rome 1 (IT), Rome 3 (IT), Univ. of Michigan (US)
Luminosity Calorimeter	Univ. of Geneva (CH), Univ. of Zurich (CH), Univ. of Copenhagen (DK)
Read-Out and Trigger	CERN, Univ. of Geneva (CH), HEPIA (CH), Univ. of Zurich (CH), ZHAW (CH), MPP Munich (DE)
Software and Simulation	CERN, APC (FR), IJCLab (FR), LAPP (FR), UT Austin (US), B.K.C College (IN)

- **EoI for full detector concept** submitted to the European Strategy for Particle Physics 2025/26 (link)
  - **170 authors from 47 institutes**
- **Most** of these **groups** have also **submitted EoI's for sub-detectors** (link) and are working together within the framework of **DRDs**

Expression of Interest for the ALLEGRO Full-Detector Concept for FCC-ee

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EoI's for sub-detectors

Sub-Detector	EoI IDs
Vertex Det. and MDI Region	ID0019, ID0027, ID0036, ID0047, ID0069, ID0088, ID0105
Tracker	ID0015, ID0024, ID0043, ID0061, ID0080, ID0085, ID0098, ID0099
Timing Layer	ID0080, ID0096, ID0098, ID0099
Electromagnetic Calorimeter	ID0023, ID0031, ID0064, ID0067, ID0082
Solenoid and Cryostat	
Hadronic Calorimeter	ID0086
Muon System	ID0011, ID0016, ID0037, ID0049, ID0060, ID0069, ID0078, ID0084
Luminosity Calorimeter	ID0104
Read-Out and Trigger	ID0017, ID0092, ID0103

https://indico.cern.ch/event/1439855/contributions/6461614/

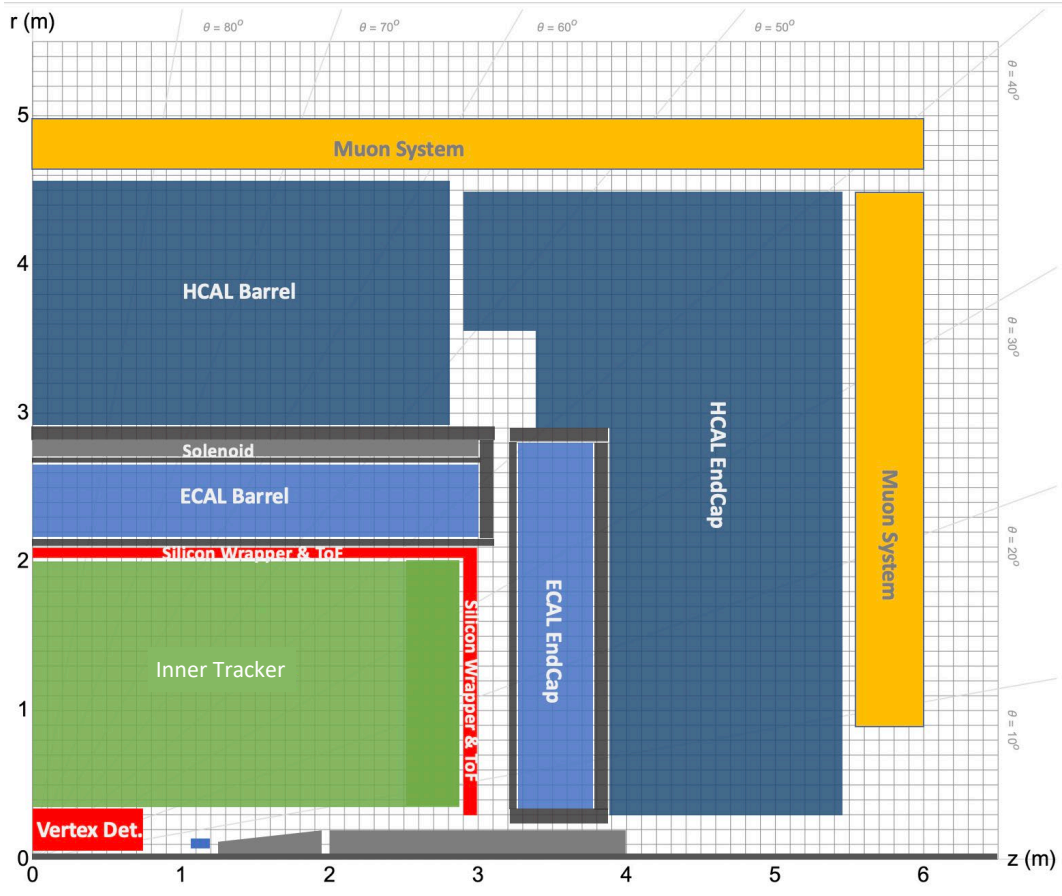
ALLEGRO Detector Contacts

Sub-Detector	Detector Contact
Vertex Det. and MDI Region	Oliver Kortner (MPP Munich)
Tracker	Anna Macchiolo (UZH)
Timing Layer	
Electromagnetic Calorimeter	Nicolas Morange (IJCLab)
Solenoid and Cryostat	
Hadronic Calorimeter	Henric Wilkens (CERN)
Muon System	Jianming Qian (U. of Mich.) & Paolo Iengo (U. of Napoli)
Luminosity Calorimeter	
Read-Out and Trigger	Steven Schramm (U. of Geneva) & Thorsten Wengler (CERN)
Software and Simulation	B. François (CERN) & G. Marchiori (APC) & S. Snyder (BNL)

Role of contact persons:

- **Oversee the progress in their respective field**
- **Coordinate ALLEGRO-specific aspects in their respective field**
- **Act as contacts to the FCC PED generic system-level studies groups/meetings**
- **ALLEGRO-specific sub-system working group meetings** will be organized to discuss ALLEGRO-specific aspects – those meetings are of course open to everybody!

ALLEGRO Detector Concept



ALLEGRO

A Lepton **L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut

Vertex Detector

Tracking

Silicon Wrapper + ToF

High Granularity ECAL

- Excellent resolution, linearity, stability
- Optimised for particle flow
- Noble-liquid as active material

Solenoid B=2T (studying option for **B=3T**), sharing cryostat with ECAL, between ECAL and HCAL

- Light solenoid coil ≈ 0.76 X_0 (<15cm radial thickness)
- Low-material cryostat < 0.1 X_0

High Granularity HCAL (Iron Yoke?)

Muon System (Iron Yoke?)

First introduced at FCC Week 2022 in Paris (link to talk)
See webpage at https://allegro.web.cern.ch

ALLEGRO Layout – Comments & Recent Changes

- **Muon Tagger → Muon System:**
  - Originally only a muon tagger was assumed (one layer of muon chambers tagging muons). No magnetic field outside the barrel HCAL → the HCAL could act as iron yoke.
  - However, physics case for a more sophisticated muon system exists: Long Lived Particles (LLPs), displaced vertex reconstruction, momentum reconstruction: For momentum reconstruction some magnetic field is necessary → the iron yoke could be inside the muon system (similar to CMS)
- **HCAL EndCap → HCAL Extended Barrel & smaller EndCap** (see talk by Mattia Soldani in the ALLEGRO General Meeting)**:**
  - The proposed TileCal design for the barrel HCAL is challenging for the EndCaps → new design to be developed (could be CMS HGCal-like, Shashlik, …)
- **Solenoid Coil** (see talk by Matthias Mentink)**:**
  - First preliminary designs of a 2T coil with 5.8m outer diameter seem to indicate that the solenoid will lead to a distance between ECAL and HCAL of $\Delta r \geq 40$cm → Simulations must determine whether a space of ≥ 40cm between ECAL and HCAL makes sense or whether that would destroy/reduce particle flow performance.
- **Solenoid Coil 2T → Investigate Option of 3T:**
  - A 3T coil would store 2x the energy of a 2T coil → The coil thickness would further increase (by ~20cm). However in case we can mitigate that effect it is worth to be invested (better tracking performance).
  - For a 3T coil the tracker radius could maybe be reduced a bit?
- **Bunch Spacing 5ns, 25ns and 50ns:**
  - Some discussion took place in a Detector Concepts Meeting in April (https://indico.cern.ch/event/1660110/)
  - FCC-ee accelerator designers wanted to know limitations from detectors (ALLEGRO response see link)
  - The situation seems to be rather complex (see e.g. summary slide at link), needs further work from the machine

Updated Version: ALLEGRO Detector Concept



ALLEGRO

A Lepton **L**epton collider **E**xperiment with **G**ranular **R**ead-**O**ut

Vertex Detector

Tracking

Silicon Wrapper + ToF

High Granularity ECAL

- Excellent resolution, linearity, stability
- Optimised for particle flow
- Noble-liquid as active material

Solenoid B=2T (studying option for **B=3T**), sharing cryostat with ECAL, between ECAL and HCAL

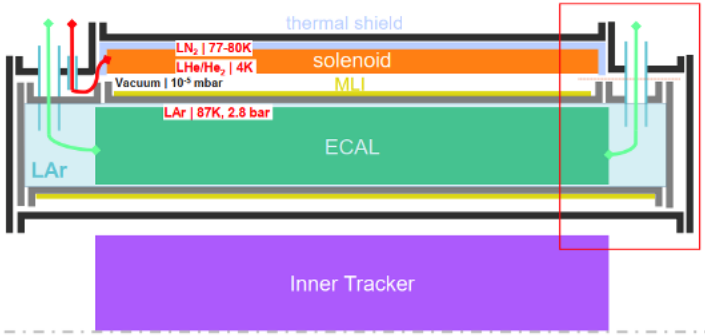
- Light solenoid coil ≈ 0.76 X_0 → see next slide and next talk
- Low-material cryostat < 0.1 X_0

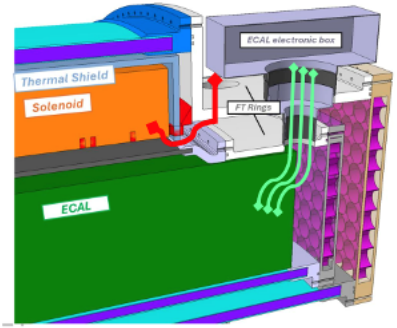
High Granularity HCAL, endcap divided into two wheels

Muon System including momentum measurement and pointing → if magnetic field for momentum measurement is necessary iron yoke needs to be interleaved with muon chambers

ALLEGRO Solenoid

- **ALLEGRO solenoid** should **share cryostat** with **noble-liquid calorimeter**
- For the moment assuming **2T** but will study also options with **higher field → 3T**
- Originally assuming very light solenoid coil (≈ 0.76 X_0, 10cm cold mass) designed for a location inside the ECAL
- Now focussing on option with **solenoid coil between ECAL and HCAL →** first study shows large increase of thickness (due to higher radius)
  - Cold mass diameter ~5.8m, length ~5.5m
  - → currently leading to distance between ECAL and HCAL of $\Delta r \geq 40$cm
- **→ Currently evaluating with simulation whether such a thick un-instrumented zone between the ECAL and the HCAL is viable for particle flow**

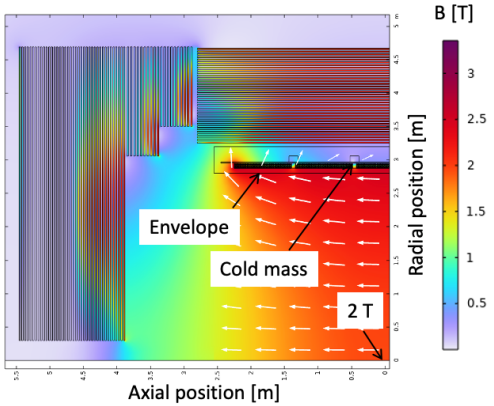




EP R&D presentation, Allegro case study, presented by Alexandre Looten, April 2026

Parameter	Value
Magnetic field in the center of the bore	2 T
Operating current	12.3 kA
Stored magnetic energy	280 MJ
Inductance	3.7 H
Approximate cold mass weight (not yet including thermal shields etc)	25.2 t
Energy density	11.0 kJ/kg

Overview of properties



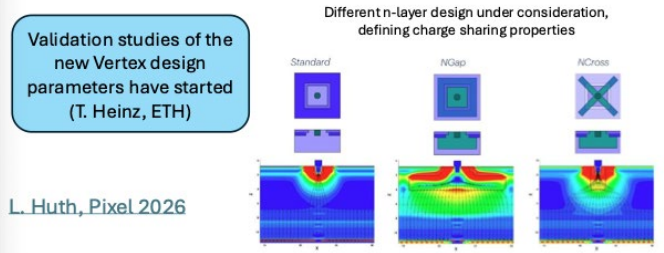
See talk by M. Mentink at the ALLEGRO General Meeting!

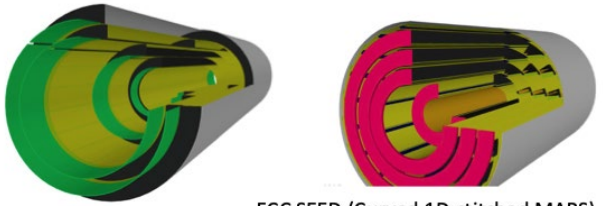
Progress on ALLEGRO Inner Detector (1/2)

- **Plan for the next months:** Investigate **different layouts of the Inner Detector** with full simulations to identify the best comb. to address physics requirements
- **Vertex Design**
  - New baseline design for ALLEGRO Vertex detector
    - All five vertex layers with 20x20 µm^2 pitch with 3 µm resolution
    - This resolution can be achieved with the OCTOPUS design in 65 nm TPSCo technology
  - Pixel technology R&D embedded in DRD3: e.g. Octopus project in 65 nm Tower Partners Semiconductor Co., Ltd. (TPSCo) technology
  - Possible alternative designs: Ultralight vertex layout with curved sensors in the Inner Barrel, FCC-Seed Vertex Layout
  - Planned studies on Vertex Layouts:
    - Optimisation of endcap geometry
    - Re-evaluation of layer and disk positioning in baseline layout
    - Evaluate performance with other inner vertex designs
    - Impact of outermost vertex layer with precision timing on low momentum particle ID
- **Vertex Detector Simulation:**
  - New look up table (LUT) based digitiser for Key4hep based on detailed simulations of sensors in TPSCo 65 nm CMOS proces
  - 3D in-pixel binning: “voxels”
- **Si Wrapper**
  - Present baseline: Monolithic pixels with a pitch of 50x50 µm^2
  - University of Bern developed pipeline to study the performance of ToF using Full Sim with the ALLEGRO detector

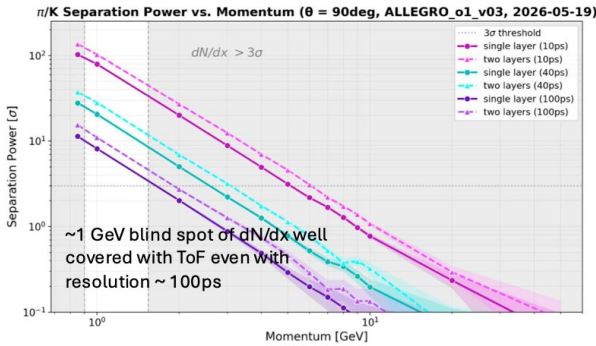
Validation studies of the new Vertex design parameters have started (T. Heinz, ETH)

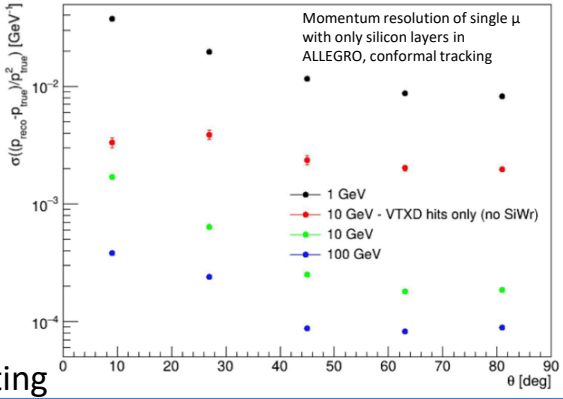
L. Huth, Pixel 2026





FCC SEED (Curved 1D-stitched MAPS)

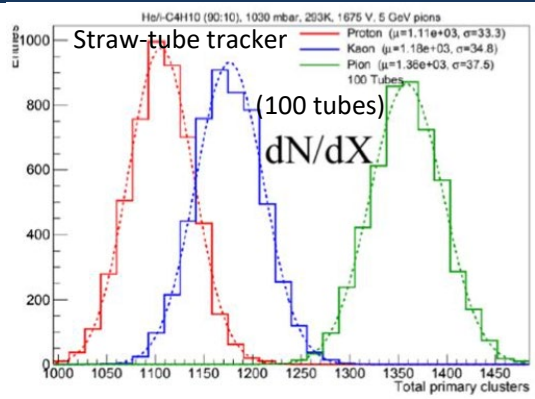




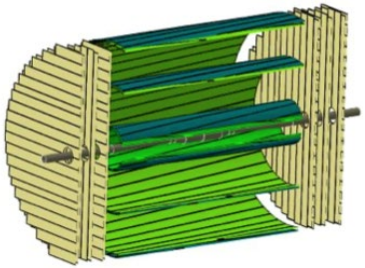
See talk by A. Macchiolo at the ALLEGRO General Meeting

Progress on ALLEGRO Inner Detector (2/2)

- **Central Tracker**
  - Three technologies for the Central Trackers being considered: Drift Chamber, Straw Tube Tracker and SciFi Tracker
  - Very active R&D for the Straw Tube tracker and the SciFi tracker
- **Straw-tube tracker:**
  - 4 m straw-tube chamber protot. under construction
  - Design studies for tube endplugs & endplate ongoing

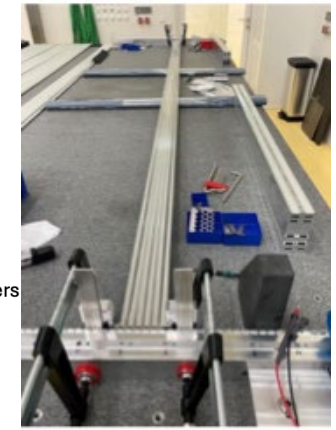


Full-Barrel Sci-Fi tracker



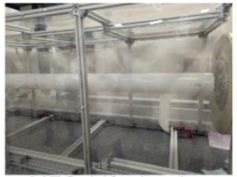
The full Geant4 simulation is already available and working.
DD4Hep implementation is on the way

4m straw-tubes prototype chamber under construction



- **SciFi tracker:**
  - **Advantages:** Low cost (cmp. to Si), 30 µm single mat resolution + angular very good z-position (<500 µm) and timing resolution (<400 ps)
  - **Drawbacks:** Higher material budget, limited PID
  - Digital SPADs (single photon avalanche diod) for reading out single fibers
  - Plan to build physical barrel prototypes (4m mats with mechanical structure)

Drift Chamber (as in IDEA)

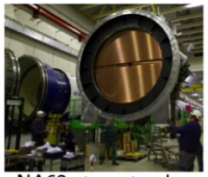


MEG drift chamber

- $O(100)$ hits with around 100 μm resolution
- Ultra-low X_0
- dN_{ion}/dx for PID

Difficulties/features:
- Wire snapping, replaceability (350k wires)
- Large mechanical forces on the endplates

Straw tube tracker

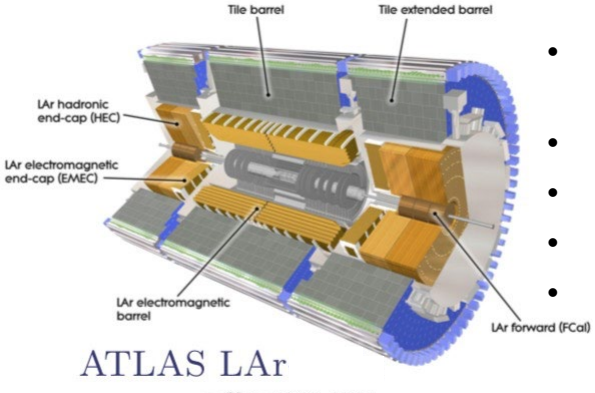


NA62 straw tracker

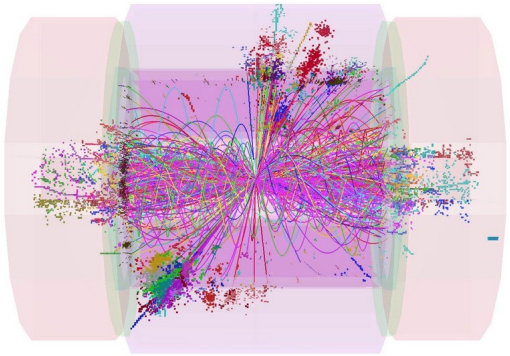
- $O(100)$ hits with around 100 μm resolution
- Independent tubes →Different gases, diameters
- Low material budget
- dE/dx (dN_{ion}/dx)

Difficulties/features
- Large mechanical forces on the endplates

ALLEGRO ECAL – The Best of Two Worlds



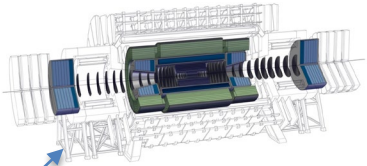
- Good intrinsic energy resolution
- Radiation hardness
- High stability
- Linearity and uniformity
- Easy to calibrate



- High granularity
  - → Pile-up rejection
  - → Particle flow
  - → Particle ID,
  - → Tracking inside Calo
  - → 3D/4D/5D imaging

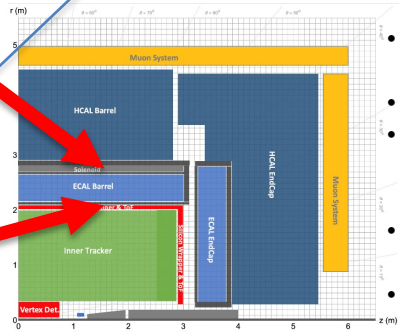
CLIC Detector

FCC Calorimetry



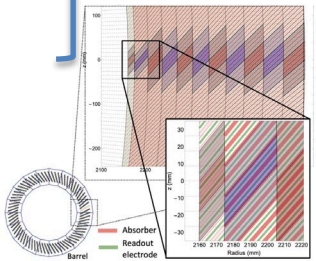
FCC-hh

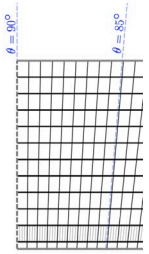
CERN Yellow Report

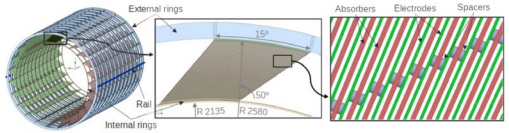


FCC-ee

- Pb/LAr sampling (or W/LKr)
- 1.2–2.4mm LAr gaps
- 1536 absorbers + multilayer PCB electrodes
- Baseline: cold electronics
- 2 M channels (10 x ATLAS)





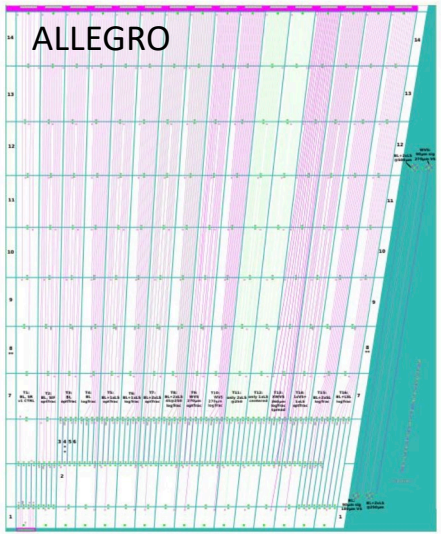


~ 50 deg electrode & absorber tilt angle (figure F. Zarate)

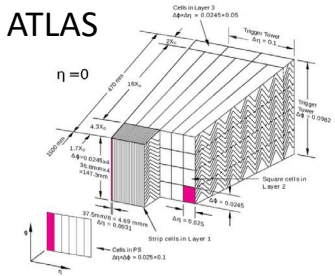
DRDCalo WP2 & WP3

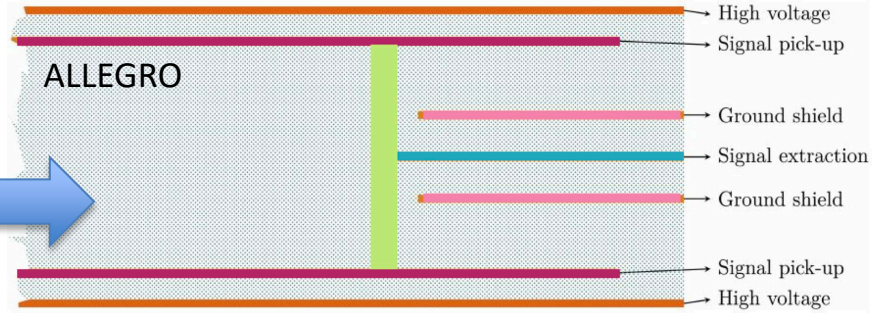
ECAL – How to Achieve High Granularity

- **Calorimeter collects ionization charge**
  - Granularity of the calorimeter
  - → granularity of the readout electrodes
- **ATLAS:** copper/kapton electrode (accordion)
  - Traces to read out middle cells take place on back layer
  - → Limits on longitudinal granularity
- **FCC-ee requirements**
  - High jet energy resolution needed
  - Particle flow algorithms take advantage of much finer granularity
- Solution for **noble-liquid calo for FCC**
  - Multi-layer PCB to route signals inside
  - Allows for **~10x ATLAS granularity**





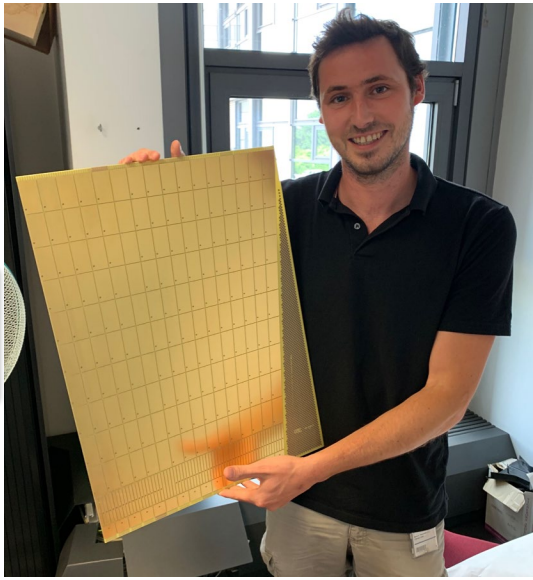


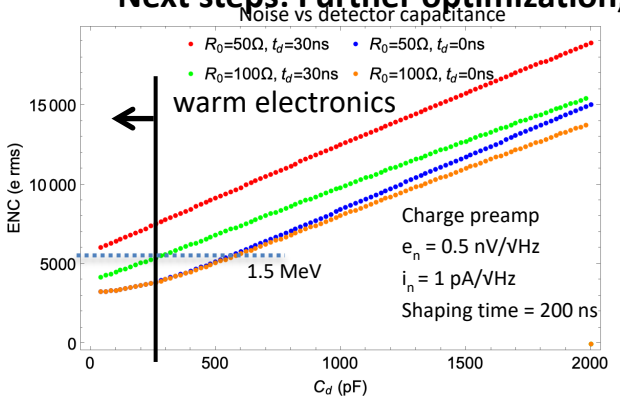


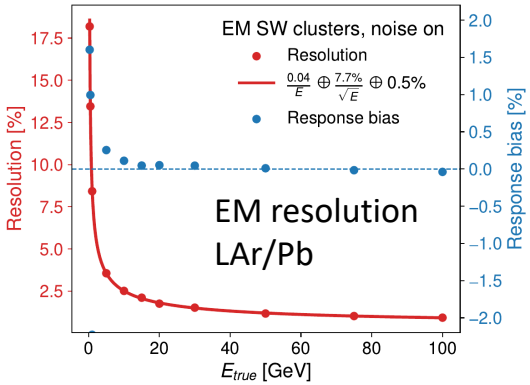
ECAL Challenges: Resolution, Noise and Crosstalk

- **EM resolution** with sampling term of 5% – 8%, constant term <1%
- **Noise vs cross-talk challenge:** traces need to be shielded to minimize cross-talk → grounded shields increase detector capacitance and hence noise → need to find best compromise – **several prototype electrodes produced & measured**
  - **Noise** of < 1.5 MeV per cell for **warm electronics** and transmission lines of R_0 = 100 Ω and τ = 200 ns ($C_d \leq 250$ pF)
    - → MIP S/N > 5 reached for all layers
  - **Noise** factor 5 less for **cold electronics → baseline solution**
  - **Cross-talk** of < 1% for shaping times τ ≥ 20 ns
- **Baseline: LAr/Pb, but options with LKr and W studied**
- **Next steps: Further optimization, then small test module for testbeam**

See talk by N. Morange at the ALLEGRO General Meeting







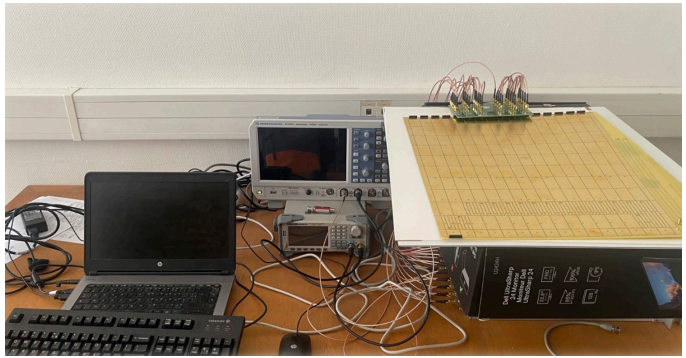
Simulated cross-talk 2 shields < 1% for τ ≥ 20 ns confirmed by measurements on prototype

Cross-talk (%) Shaping time (ns) ↓	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6
No shaper	0.54	0.85	0.85	2.31	2.62	9.11
20	0.03	0.04	0.01	0.09	0.11	0.75
50	0.01	0.02	0.0	0.04	0.05	0.37
100	0.01	0.01	0.0	0.02	0.03	0.23
150	0.0	0.01	0.0	0.02	0.02	0.18
200	0.0	0.01	0.0	0.01	0.02	0.15
300	0.0	0.0	0.0	0.01	0.01	0.13

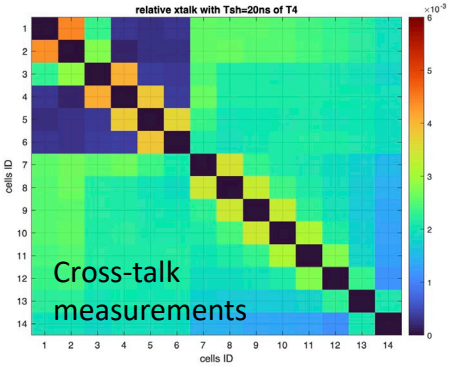
Progress on ALLEGRO ECAL – DRDCalo WP2 (1/2)

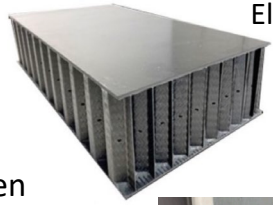
- **Electrodes:**
  - Large-scale prototypes built with many design options (different shieldings of signal traces)
  - → Sub-per-mille level cross-talk achievable
  - Good agreement with FEM simulations
  - **High Voltage (HV)** test on-going
- **Cold electronics:**
  - CHARMS250: further development of Dune electronics
  - CALOROC1C: On-going development at OMEGA
- **Absorbers:**
  - 1.8mm lead plates, sandwiched between stainless steel, sheets, glued by prepreg
- **Cryostat (carbon fibre):**
  - Wall thickness down to few % X_0 per wall
  - First prototypes built, now planning for 1m^3 prototype

See talk by N. Morange at the ALLEGRO General Meeting

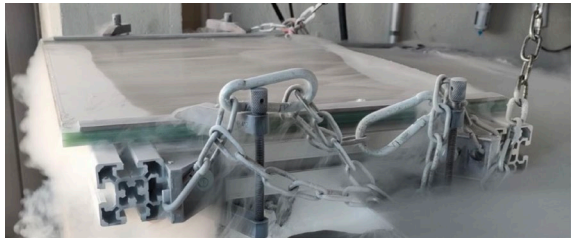


Electrode test set-up



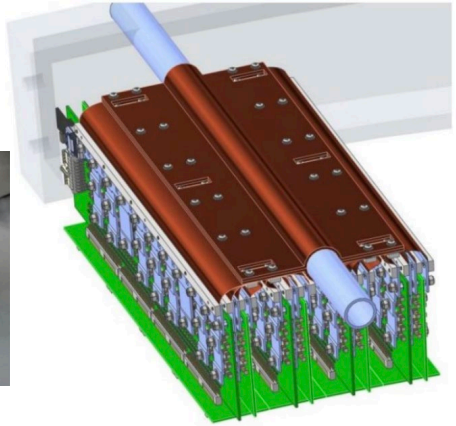


Carbon fibre wall for cryostat



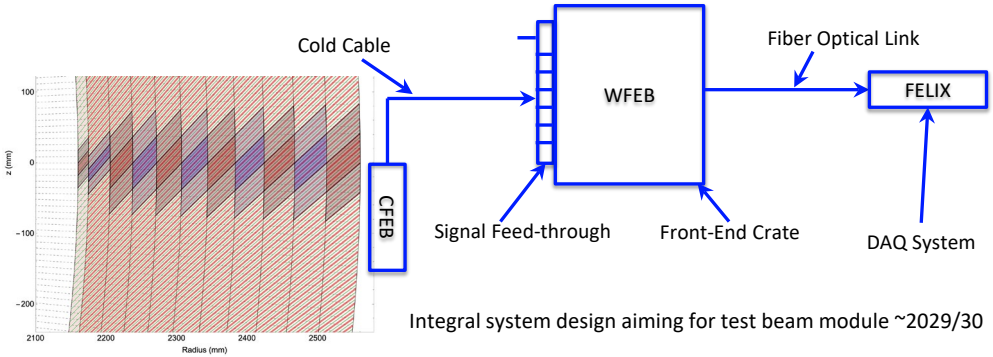
Absorber cold test

Cold electronics at the outer rim

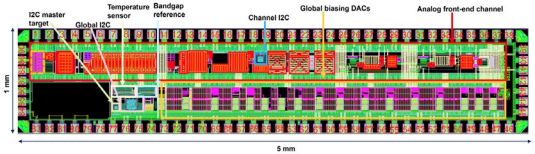


Progress on ALLEGRO ECAL – DRDCalo WP2 (2/2)

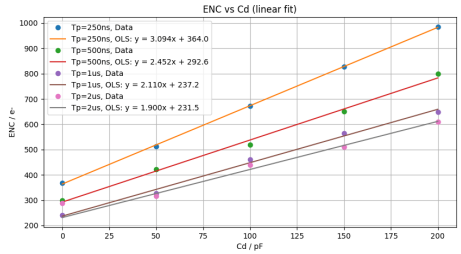
- **Integral System Design**
  - Integration of cold front-end electronics with detector electrodes is crucial
  - The power management is critical for the integration, since FCC-ee has more stringent requirements due to continuous high-rate readout
- **Front-End Cold Readout Electronics**
  - Studies of electronics requirements (noise & dynamic range) to guide the ASIC development
    - CHARMS250: further development of DUNE electronics at BNL, well cold tested
    - CALOROC1C: further development of CMS HGCROC at OMEGA, test ongoing
  - CFEB prototype produced, to be tested soon



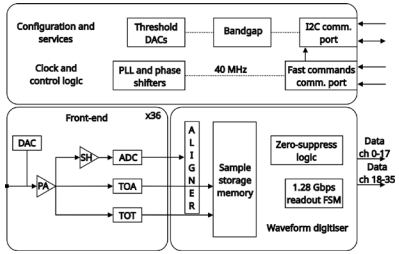
Integral system design aiming for test beam module ~2029/30



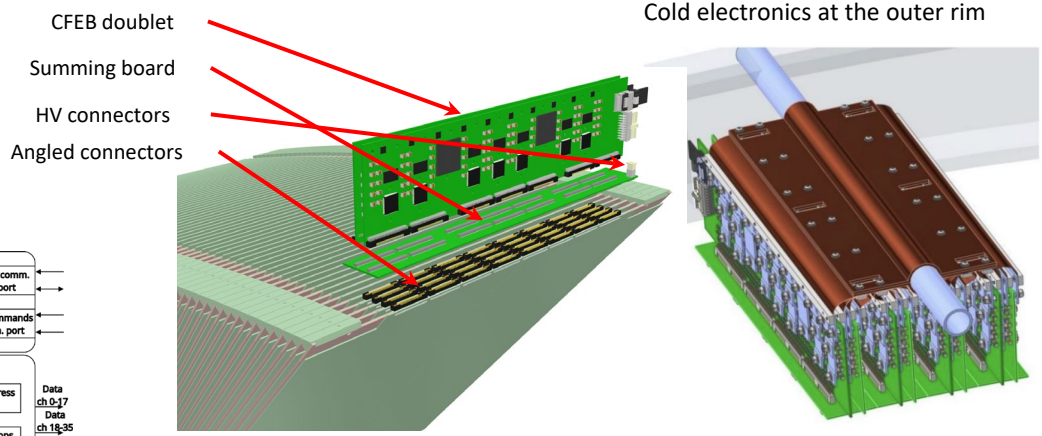
CHARMS250 layout & cold test



CALOROC1C design



Cold electronics at the outer rim

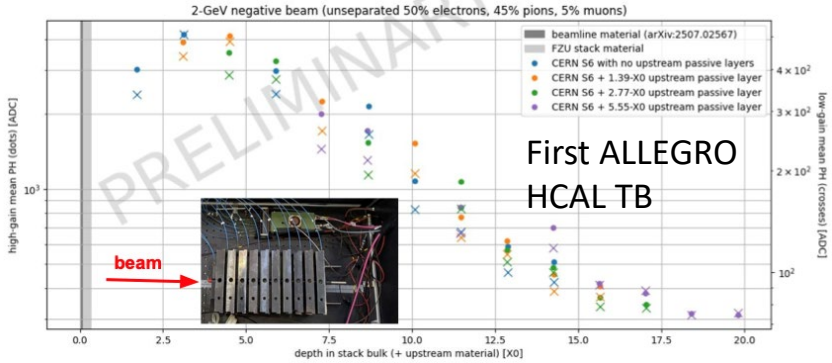


CFEB interface to electrode & cryogenic system

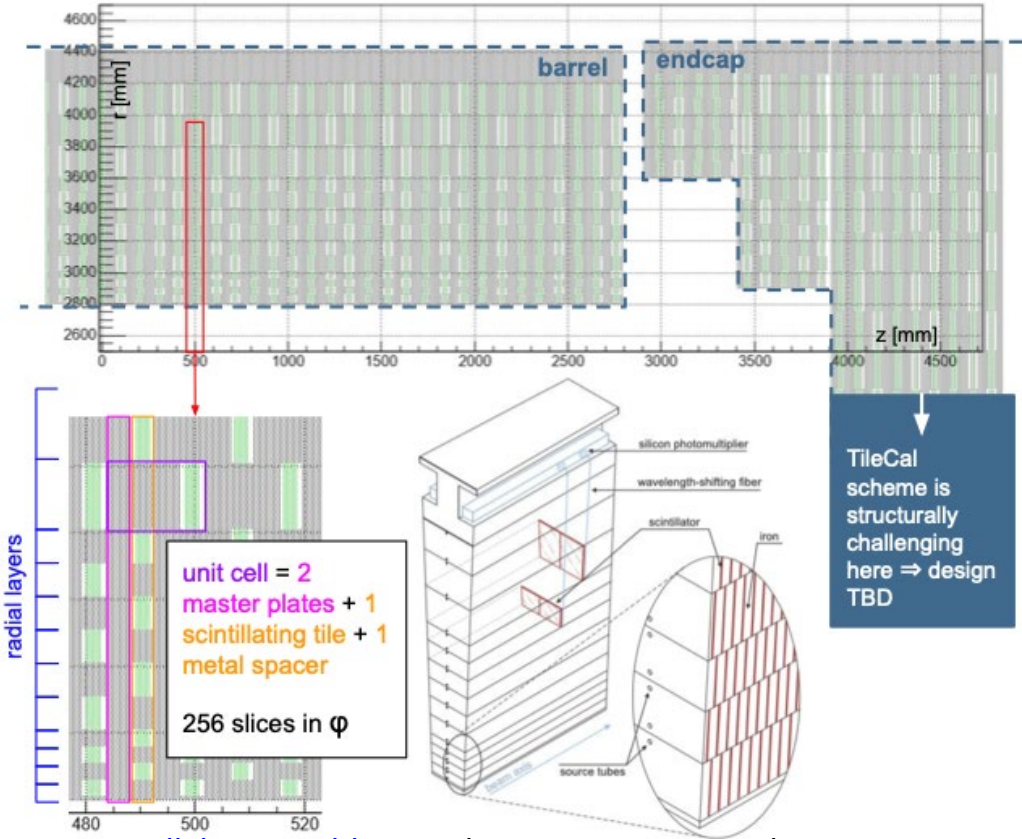
See talk by N. Morange at the ALLEGRO General Meeting

Progress on ALLEGRO HCAL

- **Simulation:** Full integration with key4hep / Gaudi ⇒ for use with PandoraPFA
- Planning for **first 25% prototype** 2028-2030 (mechanical prototype built)
- **Scintillator:** lab testing (cosmics, radioactive sources) at CERN and LIP
- **Fibres:** coupled to the tile outer edge without glue/grease
- **Sensors:** baseline SiPMs: Hamamatsu S13360 series, 8x8 arrays (custom matrix design), 1.3-mm channel size, 25 µm pitch
- **First testbeam** in May 2026 at PS T10 (hadrons, electrons, muons) → major success, analysis ongoing



First ALLEGRO HCAL TB

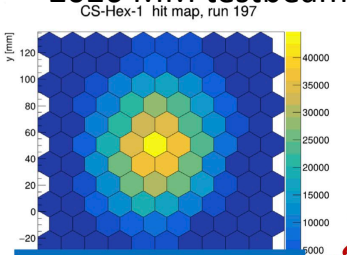


See talk by M. Soldani at the ALLEGRO General Meeting

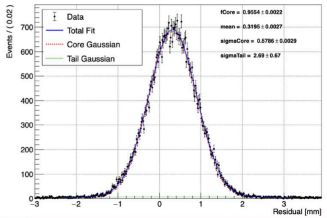
Progress on ALLEGRO Muon System

- **Options are wide open**, a dozen groups are exploring different technologies for high precision, fast timing and cost effective large area muon system, including big-gap RPCs (environmental friendly gas mixture), MPGDs (GEMs, MicroMegas, μ−RWELL,…), drift tubes and scintillators
  - ALLEGRO Muon Detector Working Group Meetings (link, link)
- **The optimal design of the muon system depends on several key considerations:**
  - **Physics motivation:** What are the primary benchmark physics channels driving the detector design?
    - LLP searches are frequently cited as a motivating case, however, a set of concrete benchmark scenarios is needed to define the performance requirements.
  - **Muon system functionality**
    - Is a robust muon identification/tagging capability sufficient, or is an independent momentum measurement in the muon system also required?
  - **Overall detector concept**
    - Will the detector include a magnetic flux return yoke? What constraints will the magnetic field configuration impose on the muon system?

First results with 1cm drift gap from 2026 MM testbeam



hexagonal readout pads hitmap



preliminary

same spatial resolution of ~580 μm (from ~20mm pad pitch) of that measured with 5mm drift gap

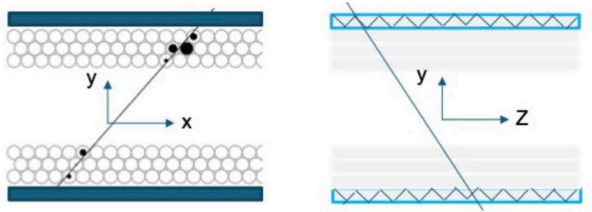
4-layer detector FULL EFFICIENT (~98%) already at 500V !

Scintillator production in Fermilab



Triangular Strips brought back from Fermilab to UM to make prototypes

→ **Simulation studies needed!**

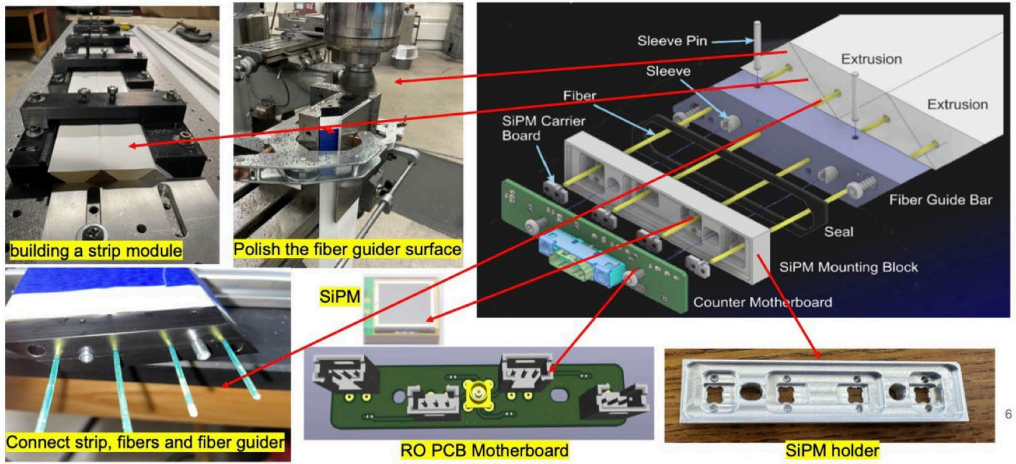


- **MicroMegas (MM):**
  - Goal: development of large-area resistive Micromegas detectors with pad readout, high performance and high operational stability, for low/medium-rate applications
  - Tests of different pad geometries and multilayer capacitive layouts in several test-beam campaigns performed in 2025–2026
  - Industrialisation in collaboration with ELTOS company → first successful validation of the ELTOS production workflow on medium-size MM
- **Scintillator and Fibre Detector & Drift Tubes:**
  - LEMUR: (L)ight (E)mission based (M)(U)on (R)econstructor: Muon trigger and tracking detector with scintillators and WLS fibres – R&D efforts at Michigan and Rome
  - Spatial resolution σ_{xy} = 100μm per tube, σ_z = 1mm, σ_t = 200ps from scintillator strips
  - Scintillator strip detector construction at university of Michigan and Rome
  - Testbeam
    - T9 beam line at CERN sMDT + scintillator strip detector,
    - H6 beam line with wo prototypes of muon detectors with triangular shaped scintillator arrays

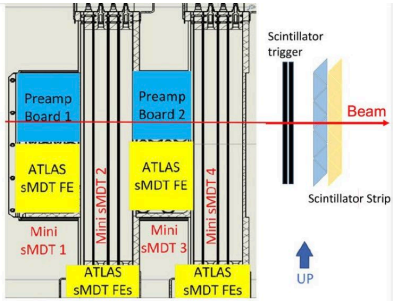
Muon Syst.: Scintillator Strip Det. Constr. at UM & Testbeam

Scintillator Strip Detector Construction at University of Michigan

Triangular scintillator strips: 4 cm base, 2 cm height, and 1 m long, from Fermilab, **WLS fibers**: Kuraray YS-2M and YS-4M, 1.5mm diameters; **Hamamatsu S13360-3075PE SiPMs** on both ends.



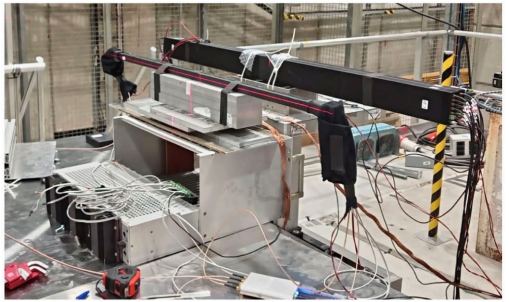


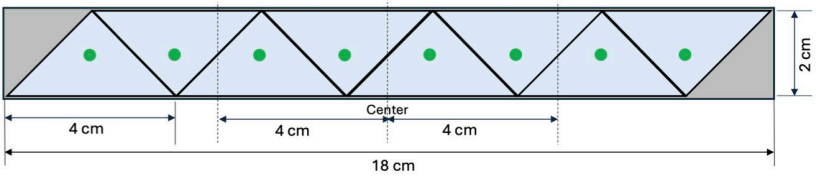


- Joined 2 test beams at T9 to verify performance of scint strips with 10 GeV hadron beam.
- Mini-SMDT chambers provide 3D tracks. (93:7 ArCO2 + 2730V)
- ATLAS MDT electronics readout.
- Good efficiency between DAQs.
- Similar setup as proposed.

TB setup CERN T9

TB setup CERN H6

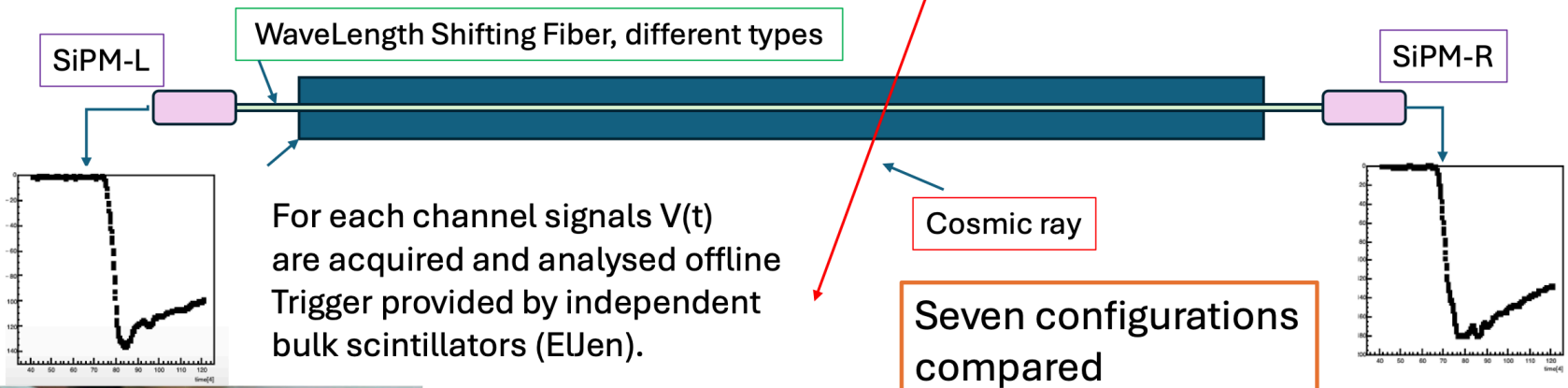




WLS fibers: Kuraray YS-2M, YS-4M
Hamamatsu S13360-3075PE SiPMs on both ends.

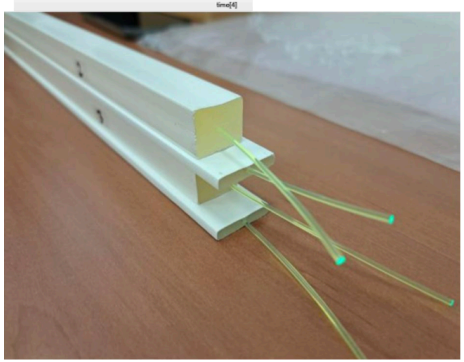
Muon Syst.: LEMUR Activity at Sapienza and INFN Rome

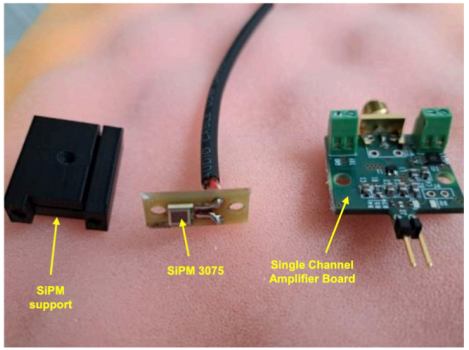
→ **Cosmic-ray characterization of a timing detector based on extruded scintillators and wavelength-shifting fibers read-out through SiPMs**



For each channel signals V(t) are acquired and analysed offline
Trigger provided by independent bulk scintillators (ElJen).

Seven configurations compared

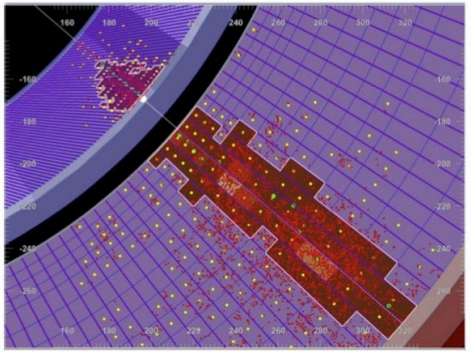


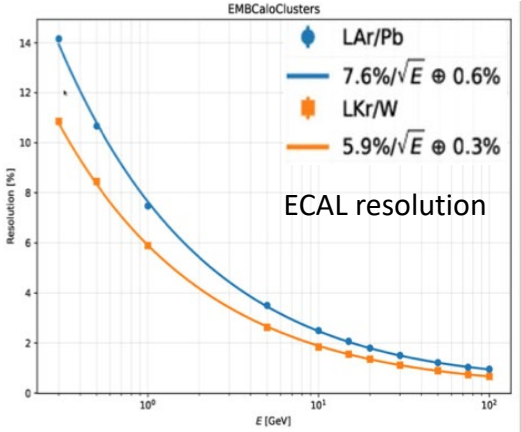


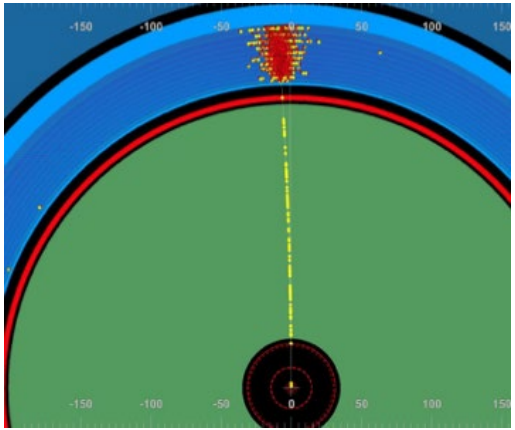
Conf	Extr	Thickness (mm)	WLS fiber	Diameter (mm)	τ (ns)	λ_{emis} (nm)
1	Thick	16	YS-2	2.0	3.2	474
2	Thick	16	YS-2	1.5	3.2	474
3	Thick	16	YS-4	1.5	1.4	470
4	Thick	16	YS-6	1.0	1.3	462
5	Thin	6.5	YS-2	1.5	3.2	474
6	Thin	6.5	YS-4	1.5	1.4	470
7	Thin	6.5	YS-6	1.0	1.3	462

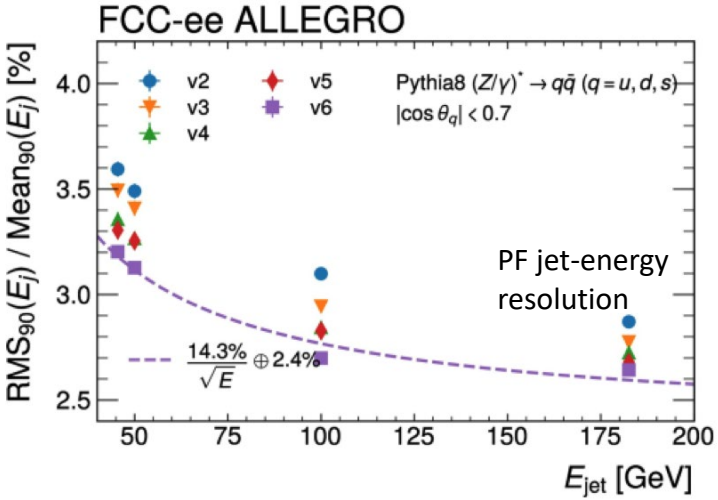
ALLEGRO Simulation & Reconstruction

- **ALLEGRO simulation is fully integrated in the Key4hep framework**
- **What is currently available for the ALLEGRO reconstruction**
  - **Vertex det.**: IDEA VXD, Ultralight VXD, FCC-SEED, gaussian smearing, but new digitizers being implemented (LUT, ..)
  - **Tracking:** Geometric Graph Track Finder, work to use Conformal Tracking and ACTS, track fitting: GenFit2
  - **Calorimetry:** Fairly detailed calorimeter geometry and digitization (calibration, noise, cross-talk).
    - Updated HCAL geometry, also refining ECAL geometry (mech. structure, endcap)
    - Several calorimeter clusterings: sliding window, topological clustering, CLUE
    - MVA based π^0/photon separation algorithm
  - **Particle-flow** object (PFO) reconstruction with PandoraPFA is working
    → ML optimization of 800 parameters, also ML-PFlow under development









See talk by S. Snyder in ALLEGRO General Meeting

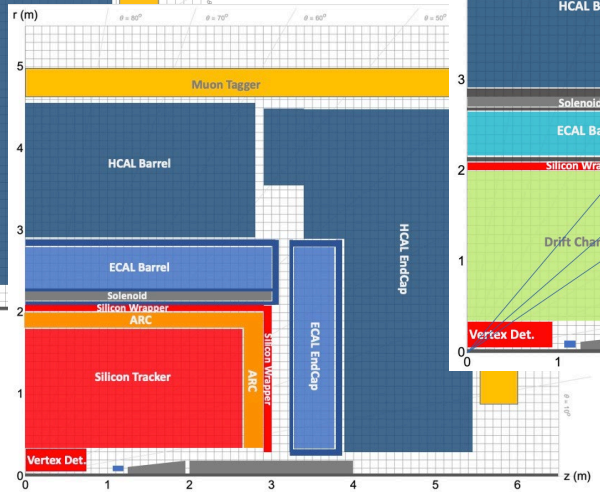
ALLEGRO Detector Concept

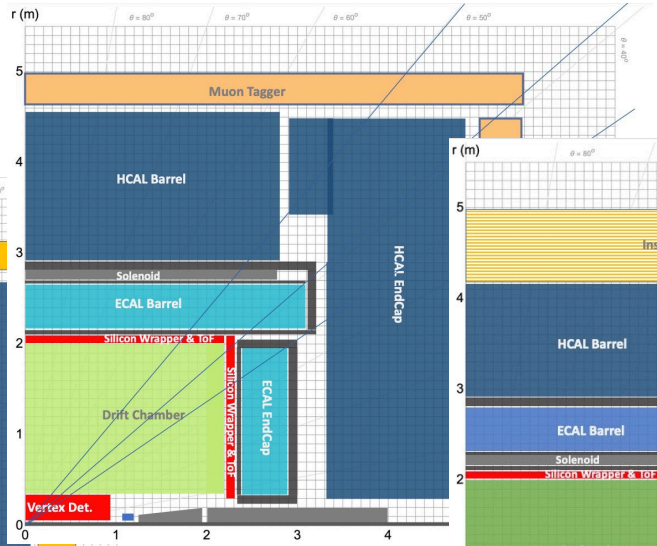
From the beginning many different ideas/options → we should stay open for new ideas

Envelopes need to be optimised/adapted to chosen technologies → discussions in meetings of contact persons

At the moment some versions were implemented into FCC SW, but all proposed sub-detectors should be implemented into FCC SW to be able to do thorough performance comparisons.









Conclusions

- **ALLEGRO** has been proposed as a **high-performance general-purpose detector concept for FCC-ee** – an **EoI was submitted for the ESU**
- There is a **strong noble-liquid ECAL** team (20 institutes) and a **strong HCAL** team (8 institutes)
- We have **collected interests to work on ALLEGRO** – no commitments at this stage, but interests expressed by 47 institutes, 170 authors
- **ALLEGRO sub-detector study groups** have been set-up, contact persons nominated, recurrent meetings held to discuss progress of ALLEGRO-specific aspects
- **A lot of progress during the last year in all different sub-detector study groups!**
- We expect a **decision on FCC-ee in 2 years** from now. We will gently have to ramp up and then enter the CDR and later TDR phase.
- The **invitation to join ALLEGRO is of wide open** – there is plenty of space to contribute!

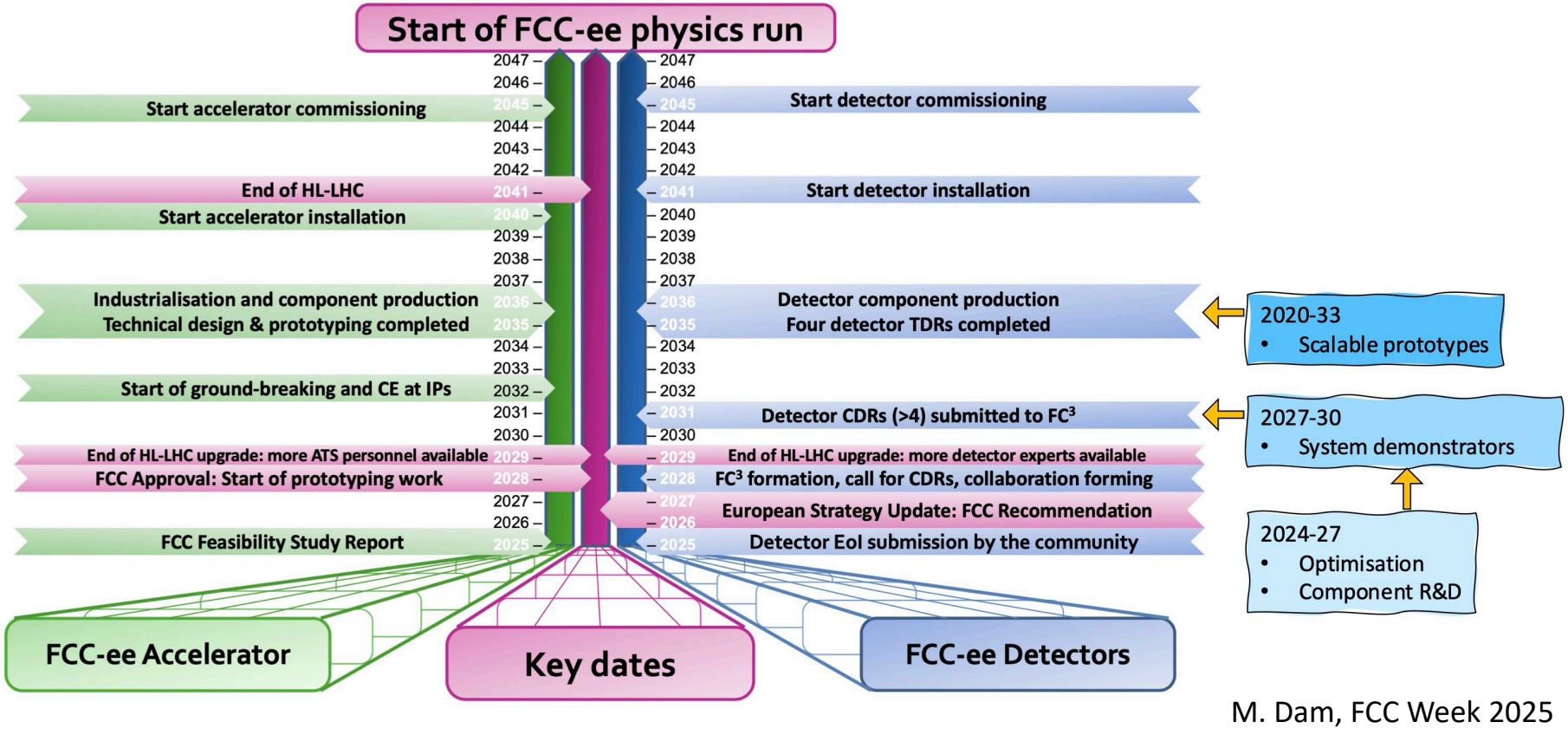
Thank You !

谢谢！



Back-Up

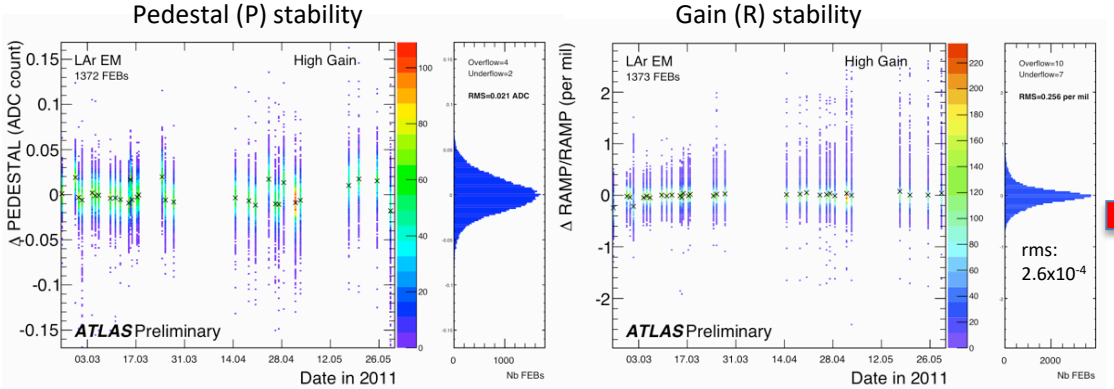
Next Steps – FCC Detector Concepts Group

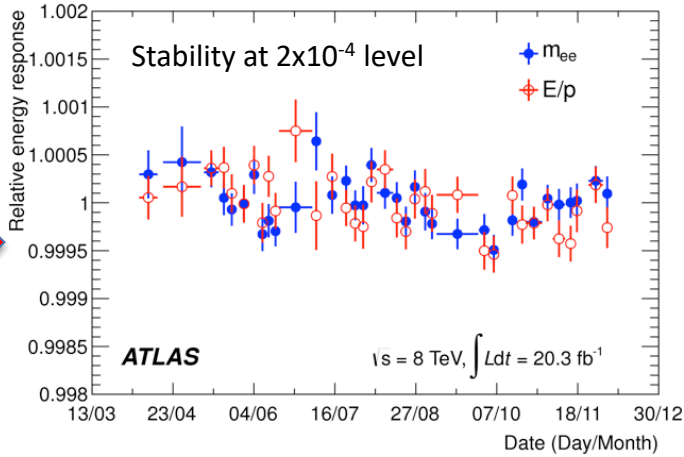


M. Dam, FCC Week 2025

Example – Stability of ATLAS LAr Energy Scale

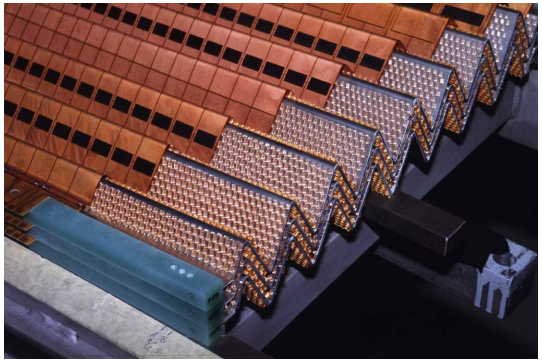
- **Noble-liquid calorimetry:** High intrinsic stability (see gain and pedestal stability)
  - Pedestal stability < 100 keV (!)
  - Gain stability 2.6×10^{-4}
- These parameters are monitored in daily calibration runs → constants are updated when necessary (about once a month)
- → Leading to high stability of the energy scale of 2×10^{-4}, monitored by invariant mass m_{ee} (Z→ee events) and E/p

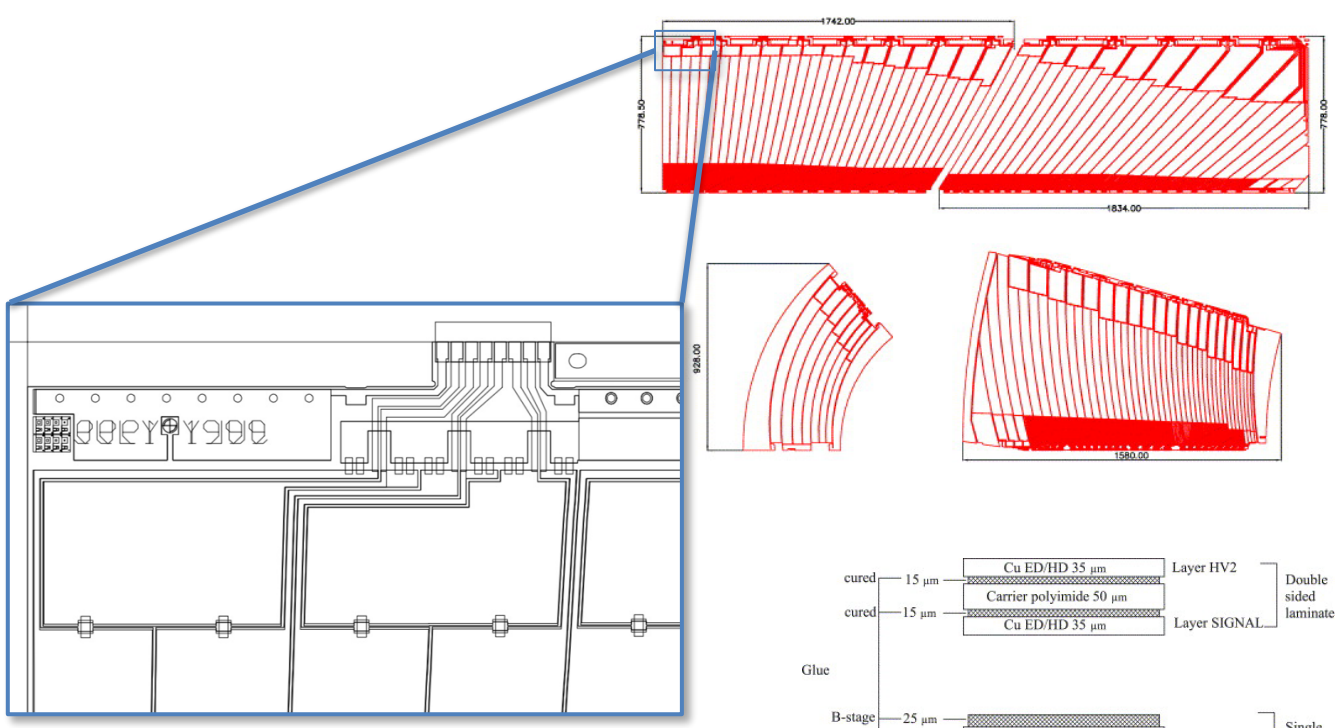




Granularity – What are the Limits in ATLAS LAr?

- **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



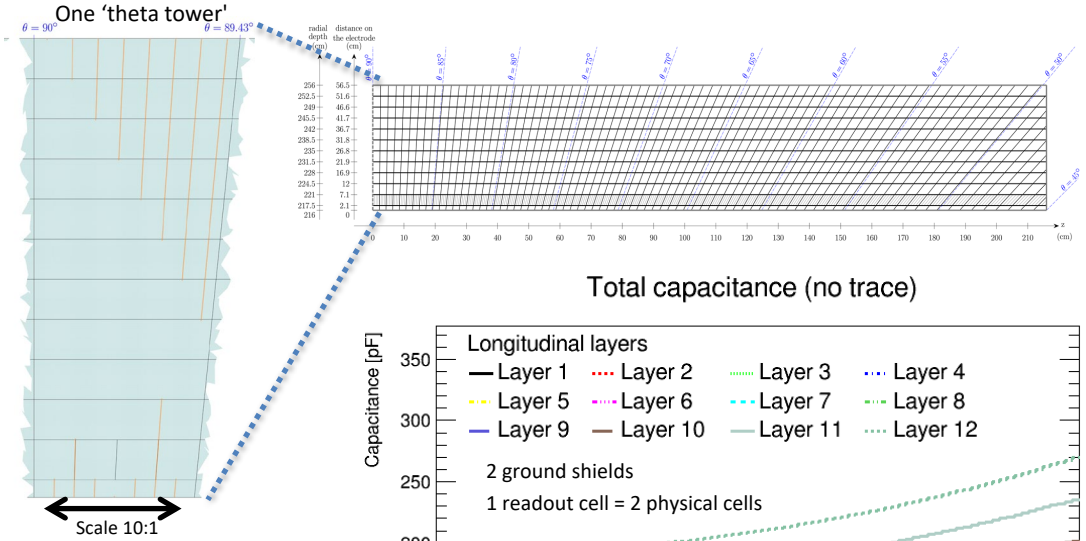


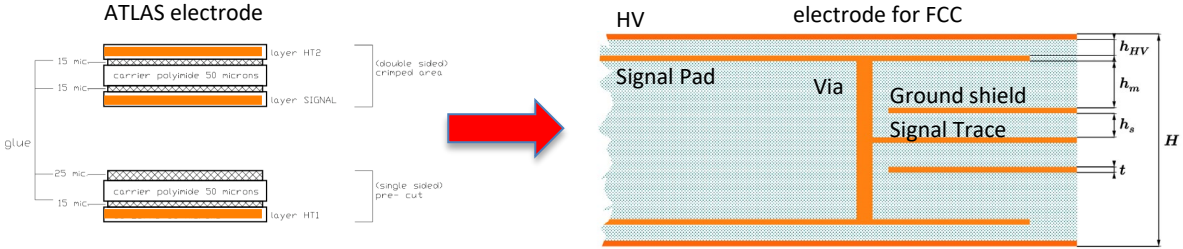
→ O(200k) read-out cells – particle flow reconstruction possible, but not optimal

Noble-Liquid Calo: How to Achieve High Granularity?

Realize electrodes as multi-layer PCBs (*H*=1.2mm thick), 5 to 7 layers

- HV and read-out
- Signal traces (width w_t) in dedicated signal layer connected with vias to the signal pads
- Traces shielded by ground-shields (width w_s , dist. h_s) forming 50Ω – 80Ω transmission lines
  - Optimizing between 0, 1 or 2 shield layers
- → capacitance between shields and signal pads C_s will add to the detector capacitance via the gap C_d
- → $C_{cell} = C_s + C_d \approx 25 – 300$pF
- The higher the granularity the more shields are necessary → C_s increases, C_d decreases (smaller cells)





In principle any granularity realisable → cost in cross-talk and noise → careful optimization!

Highly Granular Noble-Liquid Calorimeter (DRDCalo WP2)

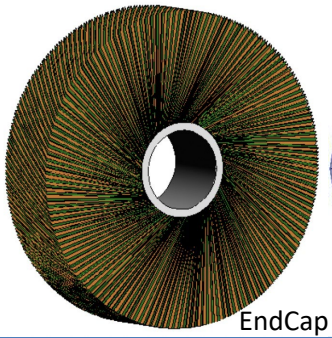
Developed in the framework of DRDCalo WP2

Baseline design

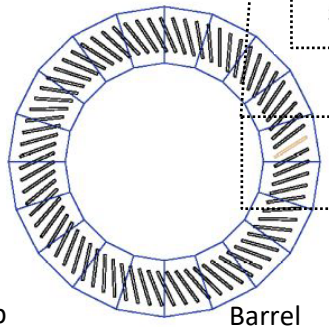
- 1536 straight inclined (50.4°) 1.8mm Pb absorber plates
- R_i=216cm, R_o=256cm (small adjustments possible/probable)
- Multi-layer PCBs as readout electrodes
- 1.2 – 2.4mm LAr gaps
- 40cm deep (≈ 22 X_0)
- Segmentation:
  - $\Delta\theta$ = 10 (2.5) mrad for regular (1st comp. strip) cells,
  - $\Delta\phi$ = 8 mrad
  - → cell size in strips: 5.4mm x 17.8mm x 30mm
- 11 longitudinal compartments
- Implemented in FCC-SW Fullsim
- Exact radius and lateral and longitudinal segmentation subject to further optimization!

Possible Options

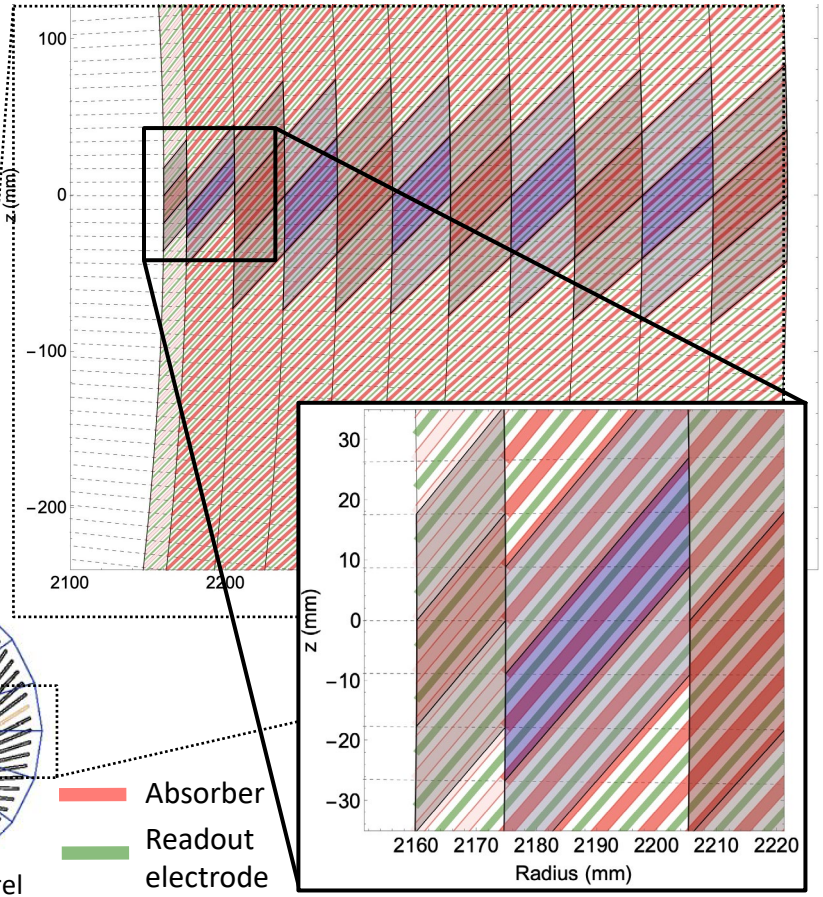
- LKr or LAr, W or Pb absorbers,
- Absorbers with growing thickness
- Granularity optimization
- Al or carbon fibre cryostat
- Warm or cold electronics



EndCap



Barrel



DRDCalo WP2 – ALLEGRO ECAL

WP2 reminder: organisational structure

See talk by Zuchen Huang on Thursday

- **Currently** contributing institutes

APC (Paris, France)
BNL (Brookhaven, USA)
Brown University (Providence, USA)
CERN
CPPM (Marseille, France)
CUNI (Prague, Czech Republic)
IFIN-HH + UNSTPB (Bucharest, Romania)
IJCLab (Orsay, France)
LAPP (Annecy, France)
LPSC (Grenoble, France)
MPI Munich (Germany)
NYU (NY, USA)
Omega (Palaiseau, France)
Southern Methodist University (Dallas, USA)
Stony Brook University (USA)
TU Dresden (Germany)
IEP SAS Kosice (Slovakia)
University of Arizona (USA)
University of Columbia (NY, USA)
UT Austin (USA)



Speakers Committee
Jana Faltova

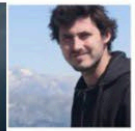
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ALLEGRO ECAL (now DRDCalo WP2) Meetings:
https://indico.cern.ch/category/18309/ & https://indico.cern.ch/category/8922/

Calorimetry

Energy coverage < 300 GeV → 22 X_0, 7λ

Precise jet angular resolution

Jet energy: $\sigma(E_{jet})/E_{jet} \simeq 30\% / \sqrt{E}$ [GeV]

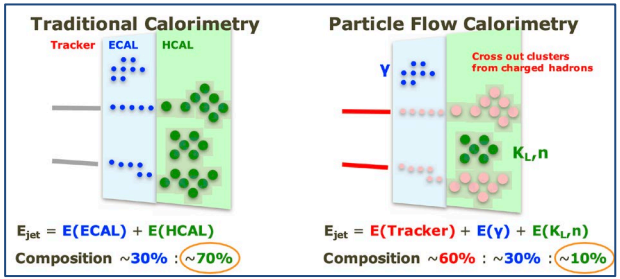
⇒ Mass reconstruction from jet pairs

Resolution important for control of (combinatorial) backgrounds in multi-jet final states with E_T^{miss}

How to achieve jet energy res. of ~3-4% at 50GeV:

- **Highly granular calorimeters**
- **Particle flow reconstruction and possibly in addition techniques to correct non-compensation (e/h≠1), e.g. dual read-out**

- **Excellent Jet resolution:** ≈ 30%/√E
- **ECAL resolution:**
  - Higgs physics ≈ 15%/√E
  - But for heavy flavour programme better resolution beneficial: → 8%/√E → 3%/√E
- **Fine segmentation for PF algorithm** and powerful **γ/π^0 separation** and measurement



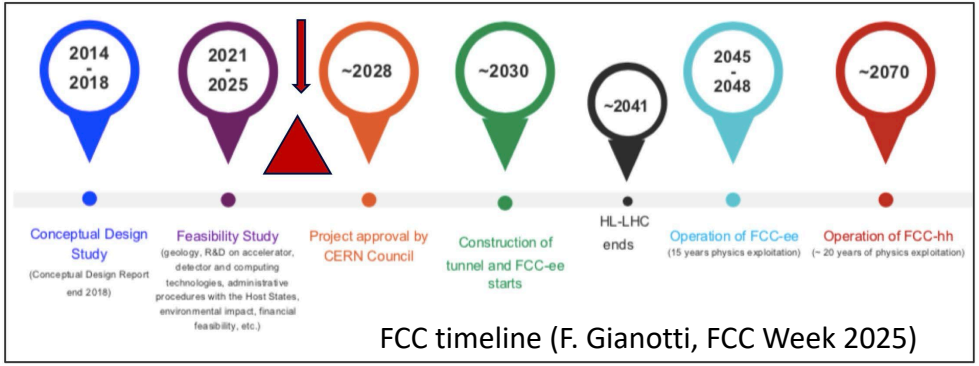
Detector technology (ECAL & HCAL)	E.m. energy res. stochastic term	E.m. energy res. constant term	ECAL & HCAL had. energy resolution (stoch. term for single had.)	ECAL & HCAL had. energy resolution (for 50 GeV jets)	Ultimate hadronic energy res. incl. PFlow (for 50 GeV jets)
Highly granular Si/W based ECAL & Scintillator based HCAL	15 – 17 % [12,20]	1 % [12,20]	45 – 50 % [45,20]	≈ 6 % ?	4 % [20]
Highly granular Noble liquid based ECAL & Scintillator based HCAL	8 – 10 % [24,27,46]	< 1 % [24,27,47]	≈ 40 % [27,28]	≈ 6 % ?	3 – 4 % ?
Dual-readout Fibre calorimeter	11 % [48]	< 1 % [48]	≈ 30 % [48]	4 – 5 % [49]	3 – 4 % ?
Hybrid crystal and Dual-readout calorimeter	3 % [30]	< 1 % [30]	≈ 26 % [30]	5 – 6 % [30,50]	3 – 4 % [50]

For more information see https://link.springer.com/article/10.1140/epjp/s13360-021-02034-2

Next Steps – ALLEGRO

- Prepared an EoI for the ALLEGRO full-detector concept for the ongoing European Strategy Update (ESU) in response to the EoI call for full-detector concepts

- We aim to propose ALLEGRO as a high-performance general-purpose detector concept for FCC-ee, that will fulfil all the requirements of its ambitious physics program. While the concept is centred around a noble-liquid based ECAL, the technology choices concerning all other sub-detectors are fully open



FCC timeline (F. Gianotti, FCC Week 2025)

- At this stage there is no formation of any collaboration planned yet, no commitment by any of the groups, we would just like to start listing interested institutes and groups who are planning to possibly contribute in one way or another to the ALLEGRO detector concept. We are very open to any contributions and proposals for sub-detectors provided they are thought to be suited to comply with the physics benchmarks of FCC-ee

- All generic aspects of the sub-detectors will be discussed in the dedicated central FCC PED Generic System Level Studies Meetings (see before), only detector-concept specific discussions will take place in the dedicated ALLEGRO meetings. Regular overviews of corresponding ALLEGRO developments will be given in the general Detector Concepts meetings.

- In the coming years there could be several options for the different ALLEGRO sub-detector systems. We encourage of course to work together and possibly converge. A down-selection to baseline options and the formation of a proto-collaboration we expect once a decision on FCC-ee has been taken and once we enter the CDR and later TDR phase (possibly in the coming 5 years → in line with the timeline proposed in the slide before: ~2028)

- Until then it is important that all sub-detectors get further developed within the DRDs, including system demonstrators and those detectors get fully integrated into the FCC SW to enable us to do ALLEGRO full detector simulations with different sub-detectors