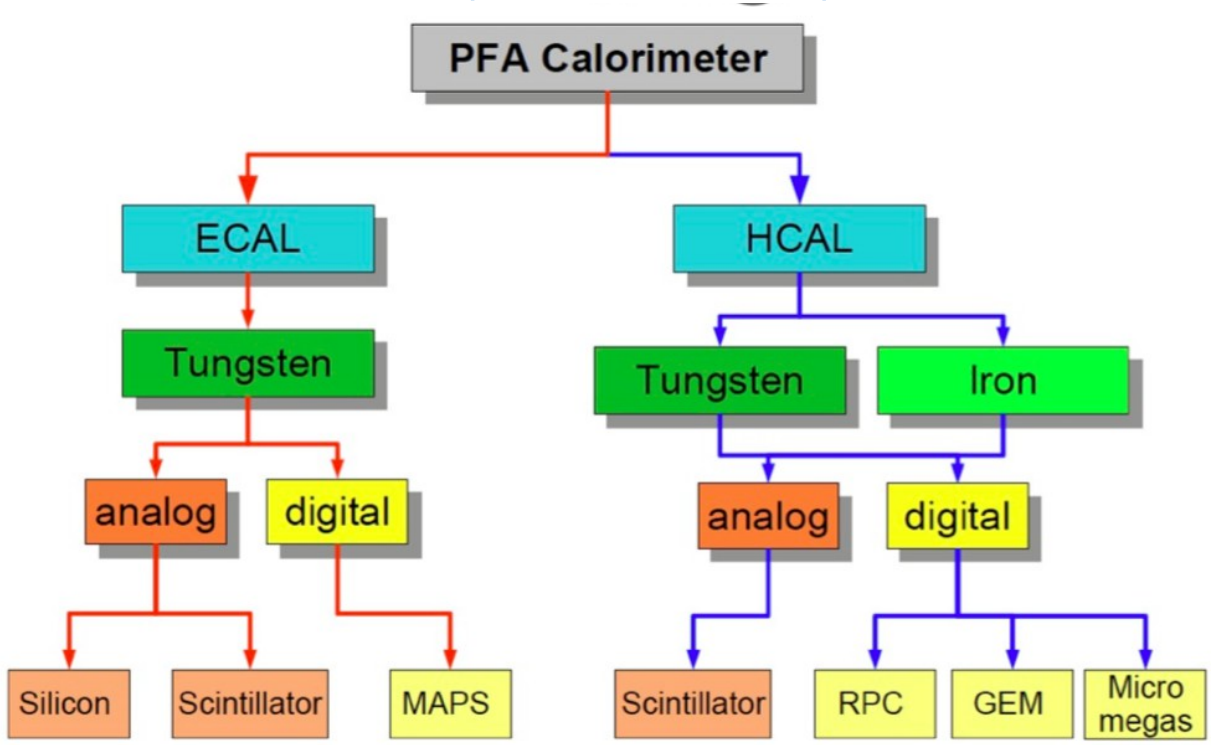
Calorimetry (former TF6 of Detector roadmap)

- DRD kick-off meeting took place on 12th January.
- Work split in 3 + 1 "tracks":
  - Track 1: Sandwich calorimeters with fully embedded electronics (connects with UK work on Calice, FOCAL/DECAL – CMS upgrade?
  - Track 2: Liquified Noble Gas calorimeters (not immediately relevant for UK (?)).
  - Track 3: Optical calorimeters (connects with UK activities on dual-readout/fibre based R&D)
  - Track 4: Alternative or transversal proposals (no connection with UK?)
- **Request for proposals sent from DRD coordinators with deadline 24th March.**

Track 1 – Sandwich calorimeters

- UK involved in CALICE R&D Collaboration since 2001, ~280 physicists/engineers
- International project, develop **complete** PF calorimeter **system**, initial e^+e^- focus
- Reviewed regularly, e.g. by ECFA detector R&D panel
  - https://twiki.cern.ch/twiki/pub/CALICE/WebHome/CALICEReport2018_final.pdf
- Scope indicator:
  - 10 x Snowmass 2021LoI
- Original UK interests
  - DAQ/readout
  - Simulation
  - PFA algorithms (Pandora)
  - MAPS ECAL
  - (Bhm, Bris, Cam, IC, Man, RHUL, Sussex, UCL)



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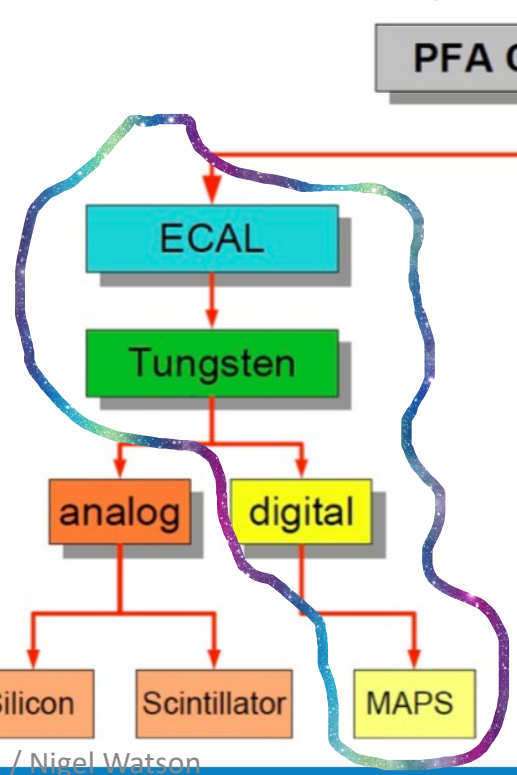
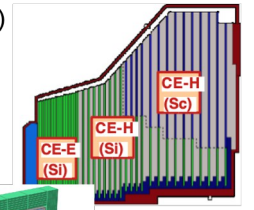
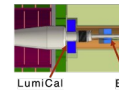
- **Current** UK interests
  - ~~DAQ/readout~~
  - ~~Simulation~~
  - ~~PFA algorithms (Pandora)~~
  - MAPS ECAL (calo and sensor)



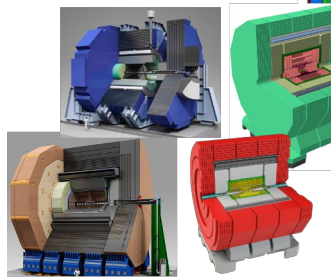
- Grouped into two categories:
  Main calorimeters of collider experiments
  (barrel and / or endcap)

CMS HGCAL
(ECAL, part of HCAL)





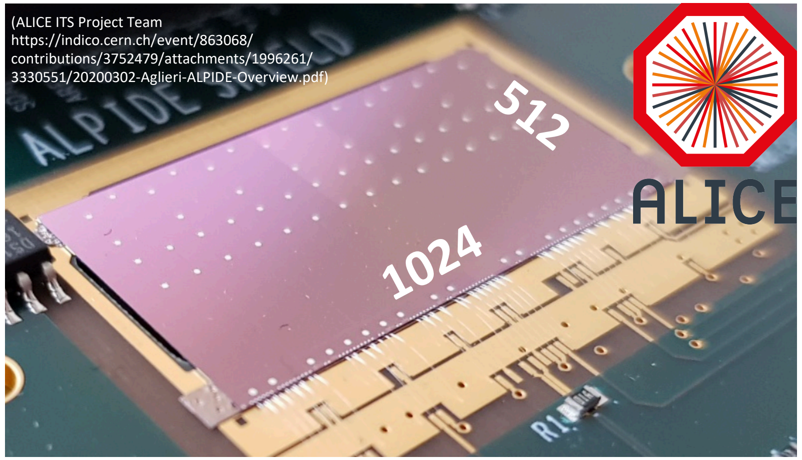
Non-
...



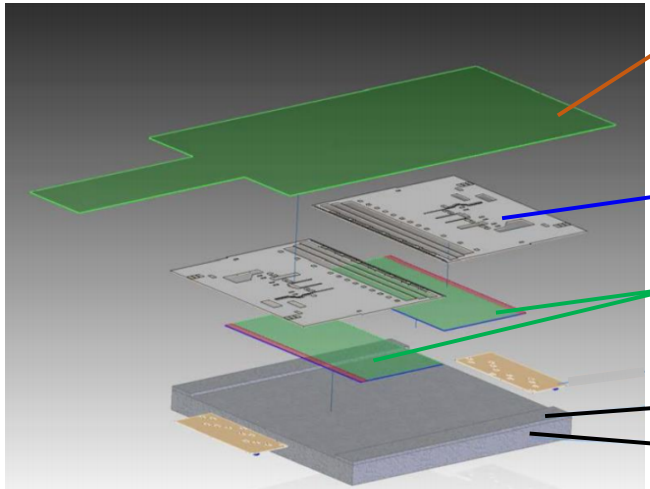
ECALs of Higgs Factory detectors
(linear and circular colliders);
Muon colliders

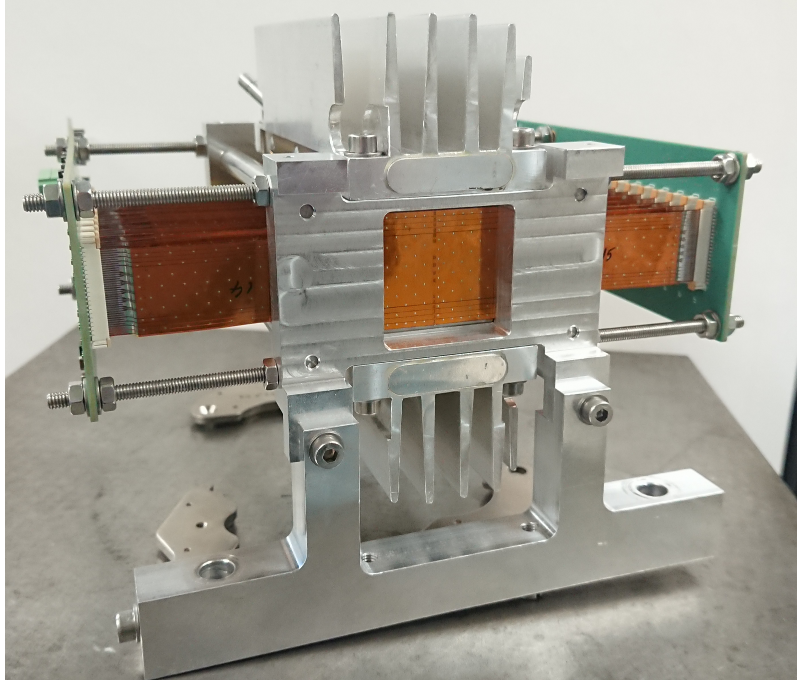
Electromagnetic Pixel Calorimeter 2 (EPICAL-2)

- **second prototype:**
  → related to Bergen pCT Collaboration
  → in context of R&D for planned LHC-ALICE FoCal upgrade in ~2026
  → **fully digital calorimeter** prototype
- **24 layers** with **two ALPIDE chips each**
  → chip size: 30 mm x 15 mm
- **512 x 1024 pixels per chip**
  → pixel size: 26.88 μm x 29.24 μm



[T Rogoschinski]





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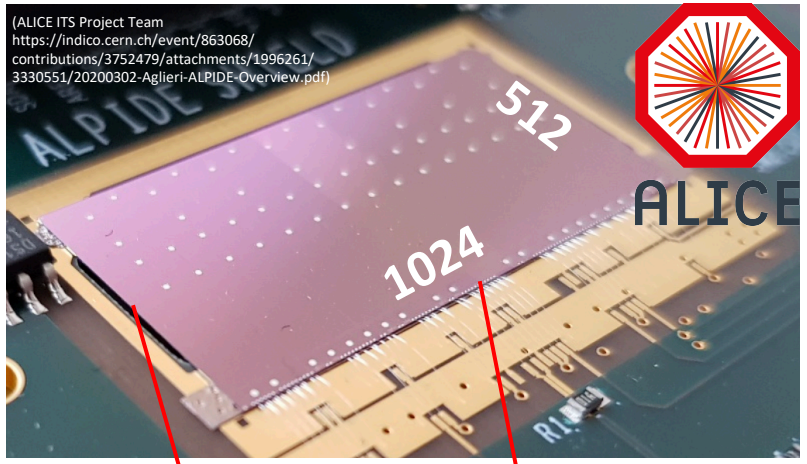
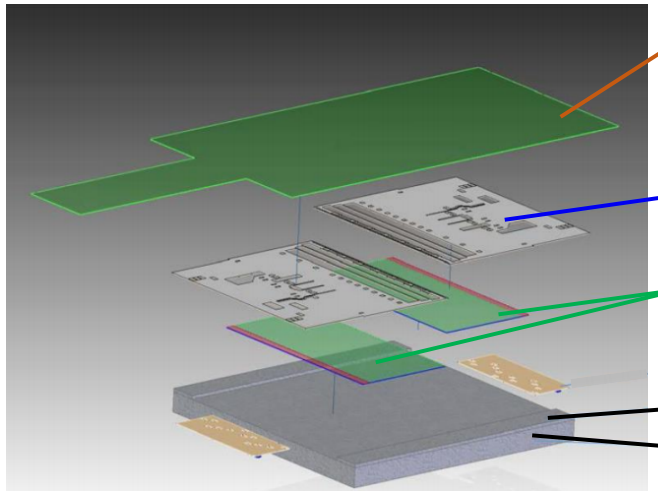
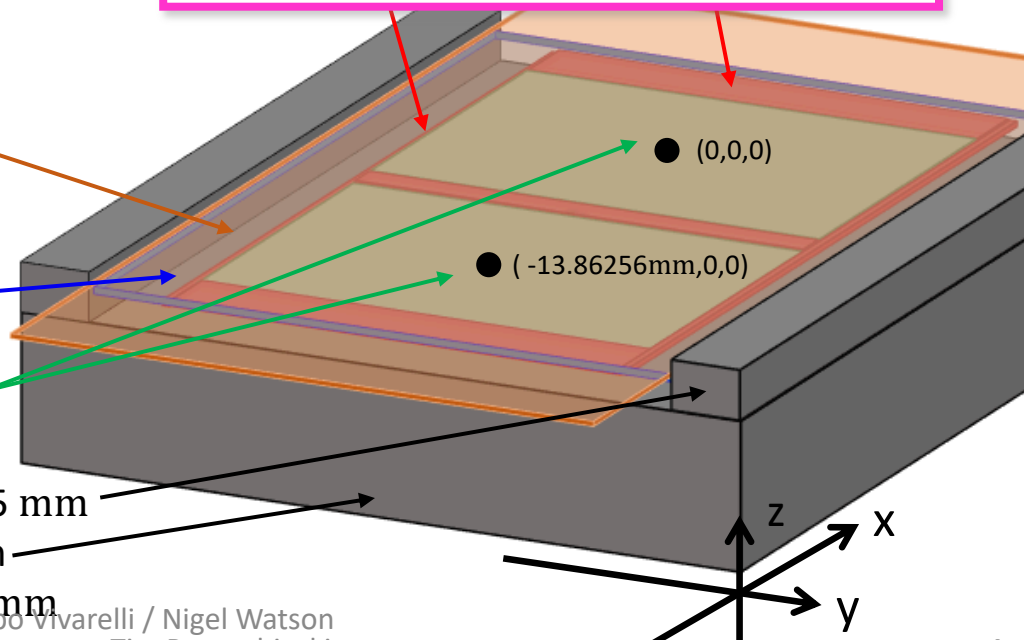
- **512 x 1024 pixels per chip**
  → pixel size: 26.88 µm x 29.24 µm
- **simulation** utilizing **Allpix² framework**
  → **precise geometry implementation**

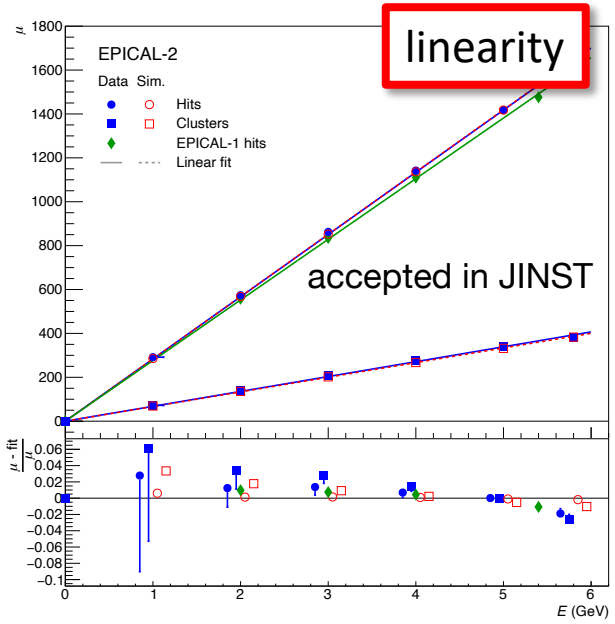


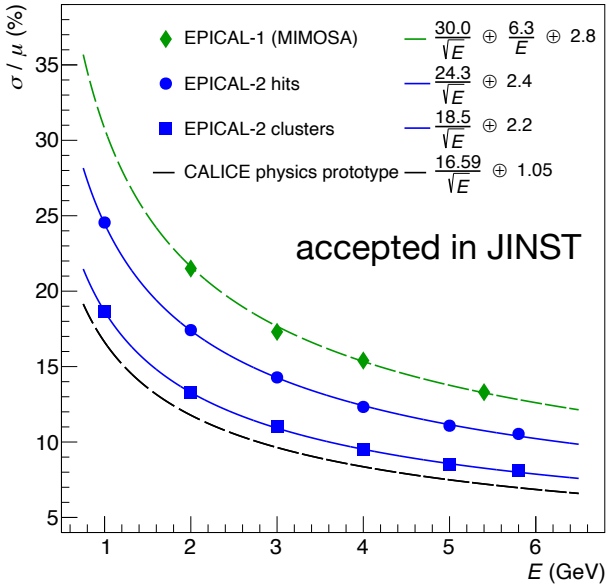
Derived from UK student project

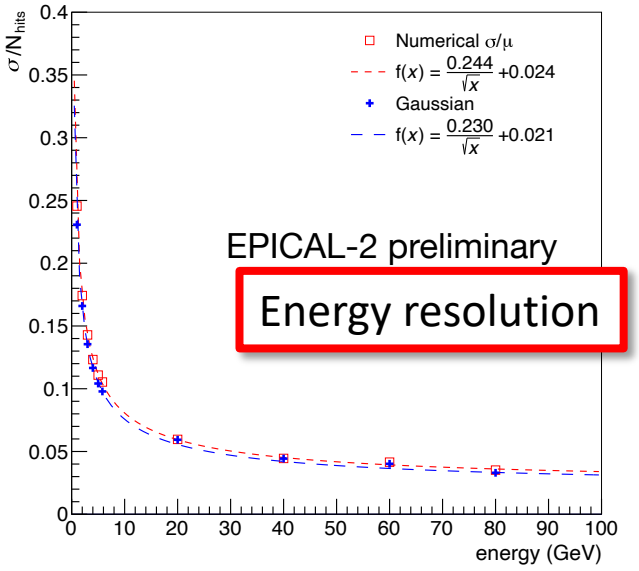




Good ‘Standard’ Performance







- Calorimetric response evaluated in test beams
  - ‘Conventional’ observables first: total number of hits or clusters
- Low energy (DESY)
  - Good linearity
  - ‘Particle counting’ (N_{clus}) shows competitive resolution at low energy
- High energy (SPS)
  - Resolution for N_{hits} consistent with low energy
  - Usage of N_{clus} observable under study

5

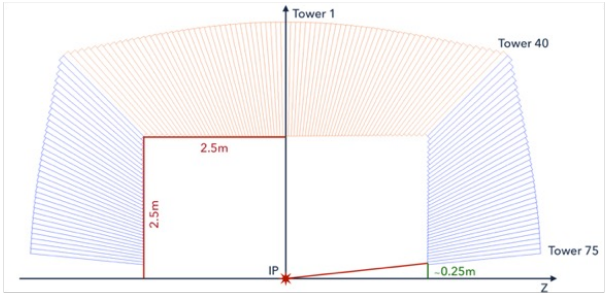
See *JINST* 18 (2023) 01, P01038

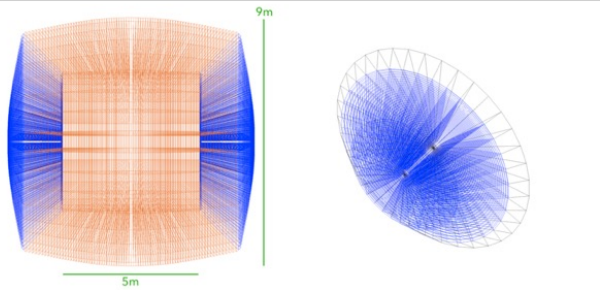
Future Opportunities for UK - SiW

- **Si-W calorimetry can give excellent PFA performance**
  - Potential to use same technology for outer tracker/preshower/ECAL
- Affordable Si-W (Si-Pb) calorimeters, need sensor costs ~ CHF/cm^2 (active areas > 10^7cm^2)
  - Potentially achievable with CMOS technologies, expanding market
- Power needs study, CMOS estimates range ~50-100mW/cm^2 (no pulsing)
- Prototype demonstrating concept of digital ECAL, in same CMOS line as CERN et al, can deliver radiation hardness to > 10^{15}neq/cm^2
- **Digital EM calorimetry, high potential esp. for future e^+e^-**
  - Ultra-high granularity can benefit physics as well as cost (boosted decays)
  - Fast charge collection
  - Currently, UK (Birmingham) working with ALICE FoCAL/pCT groups on EpiCAL-2
  - Perfect time to expand/lead novel concept for future projects

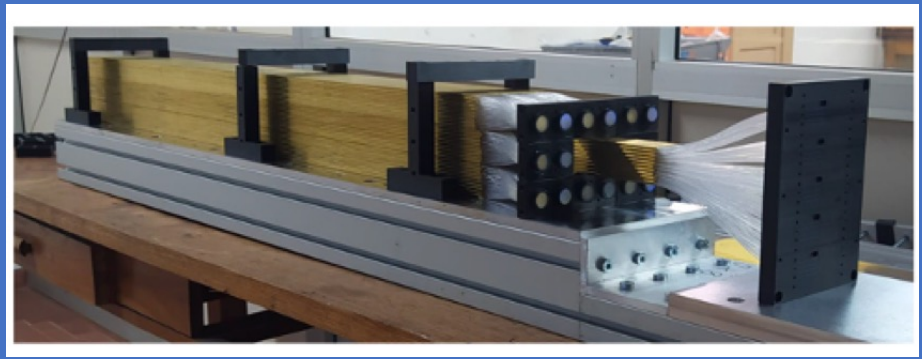
Track 3 – Optical calorimeters

- University of Sussex part of an **international proto-collaboration** including institutions from Korea, US, Italy for R&D on dual-readout for e^+e^- colliders.
- R&D **fully integrated in ECFA process since the beginning** (R. Ferrari (Pavia and INFN) is one of the conveners of the DRD).
  - DRD presentation about dual-readout
  - Test beams performed in 2021 and 2022 (EM-size prototypes). One more planned for 2023 (towards had-size prototype).
  - A few recent publications: arXiv:2203.04312, Instruments 2022 6(4), 59, arXiv:2202.01474.
- Total funding for activities ~ 4M currency units to INFN/Korea/US for construction of hadronic-size fibre-based prototype + Crystal based dual readout.
- Challenges:
  - **Tens of millions of SiPM** readout to be read. **Digital SiPM**?
  - Increase **Cherenkov light collection efficiency**. Blue/near UV fiber + SiPM?
  - Timing to resolve energy deposits at different points in the fiber.
  - Develop a **calibration system**.

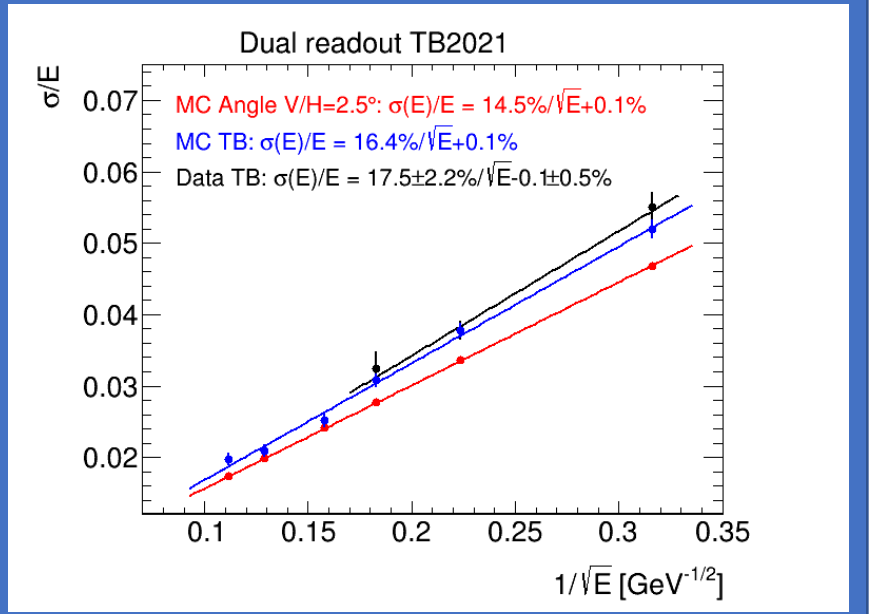


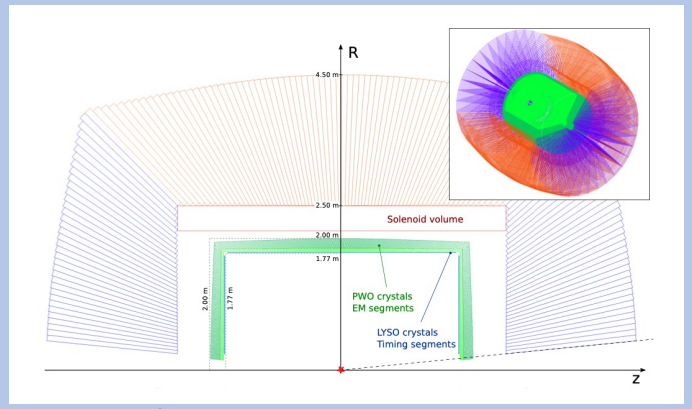


Overview



- 2021 test beam: EM performance test of capillary tube mechanical structure
  - Tested with beam at DESY and CERN
  - Characterised in terms of linearity, resolution, granularity



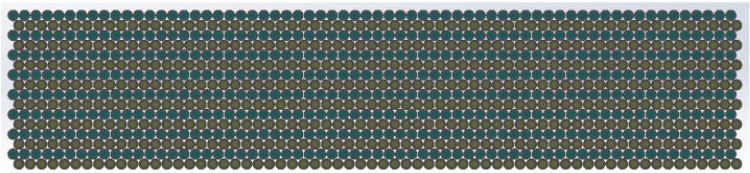


Taken from https://doi.org/10.1088/1748-0221/17/06/P06008

- Option with a crystal-based, dual-readout EM section
- Superior EM and Had resolution
- Suitable for particle flow applications

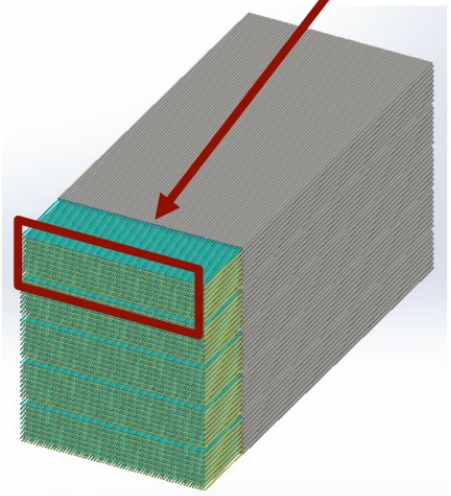
Immediate future – hadronic size prototype

The Mini-Module



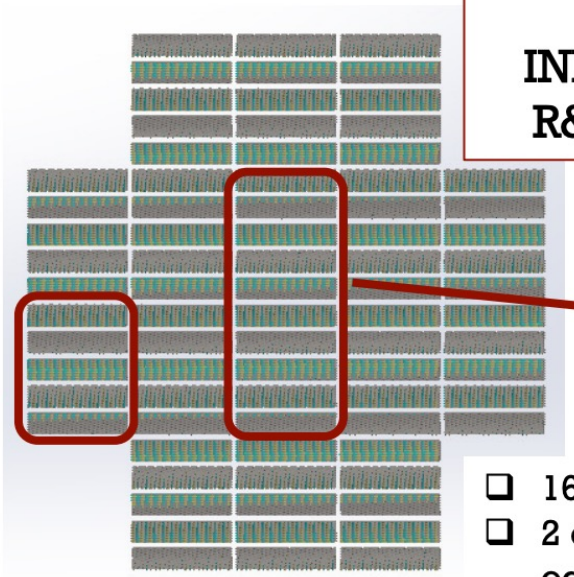
64 x 16 capillaries

The Module



5 Mini-modules
~ 13 x 13 x 250 cm^3

The hadronic prototype



HiDRa
INFN-funded
R&D project

The highly granular modules

- 16 modules in total
- 2 central modules equipped with SiPMs
- 14 modules equipped with PMTs
- ~ 65 x 65 x 250 cm^3

The challenge:

We have10240 SiPMs, fitting the back side of the detector

UK contribution to track 3

- University of Sussex funded via **AIDAInnova, capital equipment and CG**.
- Current: **simulation, performance, test beam analysis, monitoring ands DAQ, optical fibre** characterisation, **SiPM** timing performance measurement.
- Mid-term feasible contributions:
  - **Fibre characterisation** for Had-size prototype, monitoring and DAQ.
  - Fibre+SiPM **calibration system** for calorimeter.
  - Trasverse to multiple DRDs: **Digital SiPM** (connection with, e.g., noble liquid caloriemeters, tracking (SciFi) LiquidO, etc.)
- Connections that could be explored: crystal work in the US.

Connections with smaller – mid-term projects

- Intersecting with **DRD activities**: **small(er) size physics projects** may need calorimeters on the short term:
  - E.g. Forward Physics Facility – some experiments see large UK involvement
    - For example: **FASER2** will need a **1x3x3 m^3 high-granularity calorimeter** on the timescale of a few years.
  - Potential to be able to address "system" issues on a system of a feasible size. Should be integral part of the R&D programme.

Outlook

- Two tracks of DRD Calo have UK participation
- Scope for potential coordinated UK effort in Calorimetry DRD
- Initial Zoom meeting, 6th of March,15.00, Meeting ID: 925 9141 1782
- All very welcome

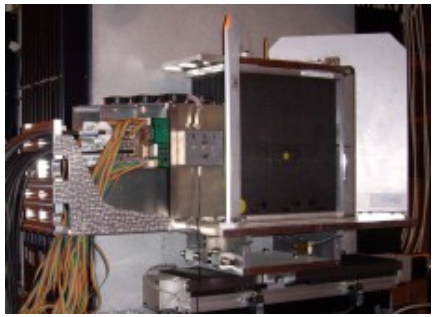
Extras

Historical context

Steps of R&D

Physics Prototype

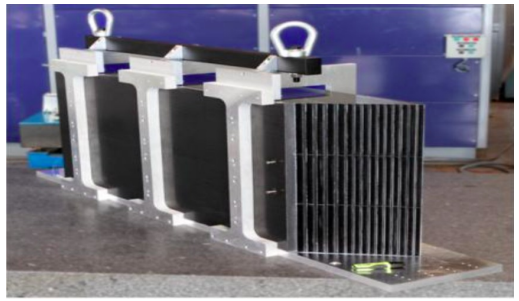
2003 - 2012



- Proof of principle of granular calorimeters
- Large scale combined beam tests

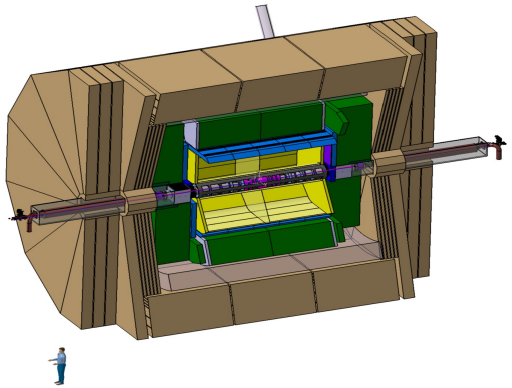
Technological Prototype

2010 - ...



- Engineering challenges
- Higher granularity
- Lower noise
- **Today**

LC detector



- The goal
  - Typically 10^8 calorimeter cells
- Compare:
  - ATLAS LAr ~10^5 cells
  - CMS HGCAL ~10^7 cells

[Roman Poeschl, Calor'22]