Calorimeters

Partners:

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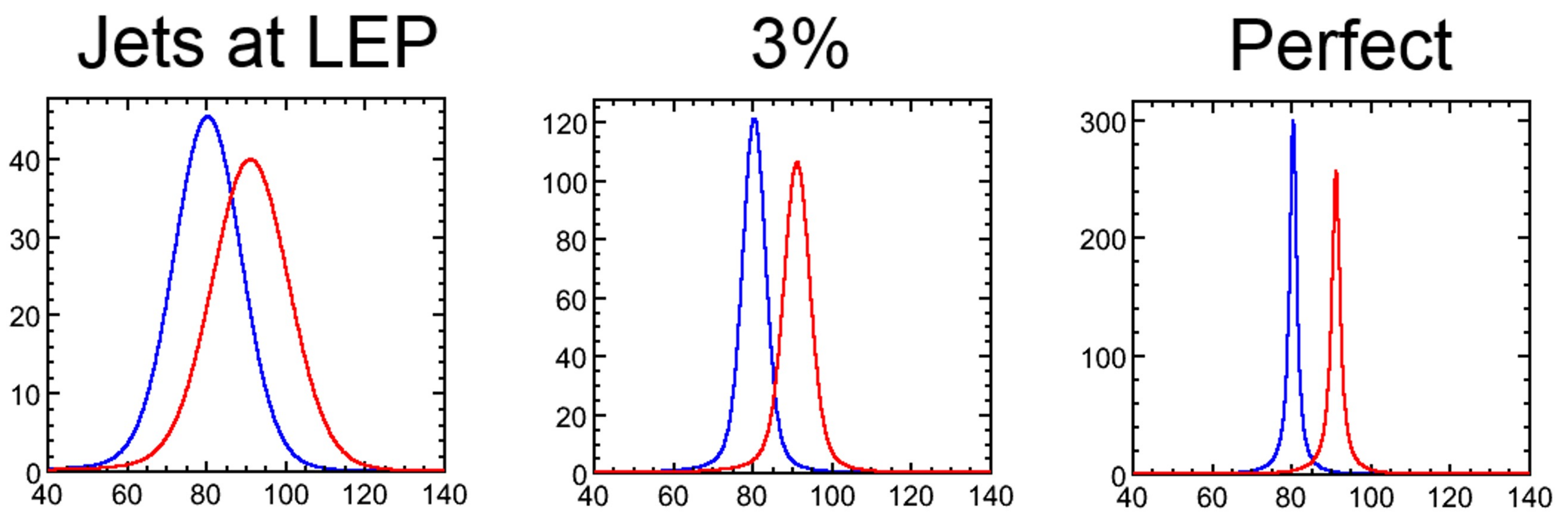
Second DMLab Meeting
DESY, 12. December 2022

Motivation for Highly Granular Calorimeters

Detector requirements in high energy e+e- collision

- goal: distinguish the decays $W \rightarrow jet\ jet$ and $Z \rightarrow jet\ jet$ by their reconstructed mass

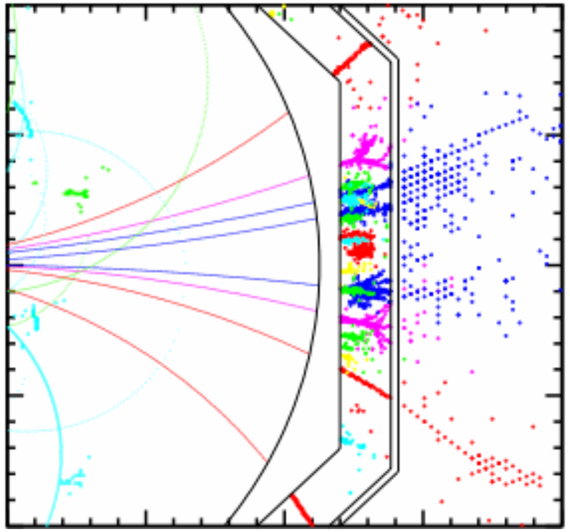


from Cambridge HEP group

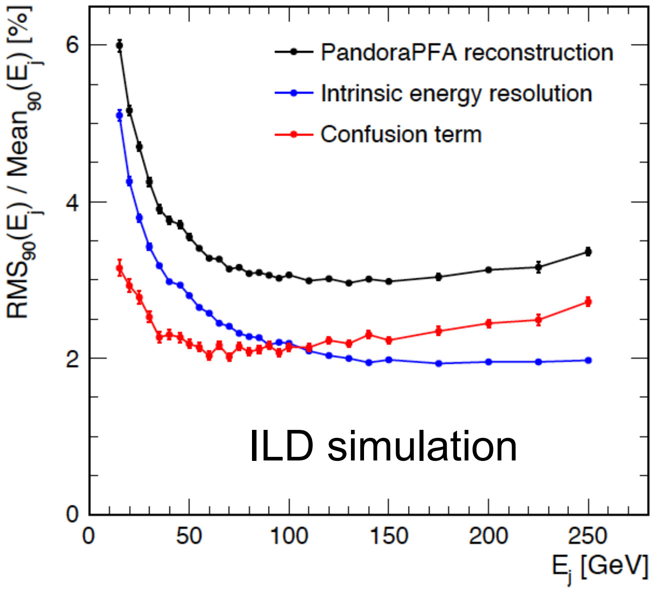
- required resolution: $\sigma(E_{jet})/E_{jet} \approx$ 3-4%
- not reachable with LEP (and existing collider) detectors!

Requirements for Calorimeters

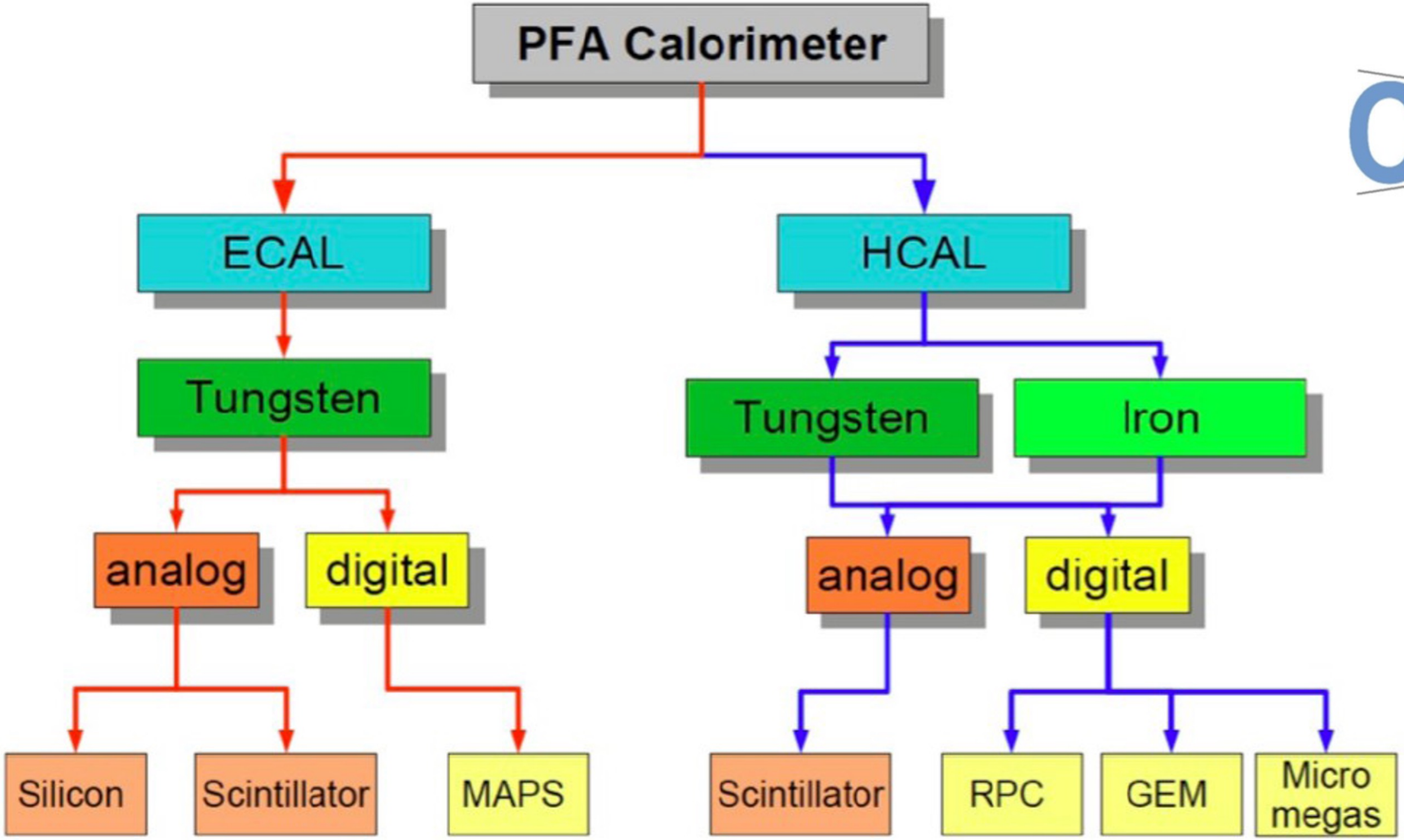
- main objective: superior jet energy resolution
- can be reached by particle flow algorithms (PFA)
  - for each particle within a jet: use the subdetector with optimal resolution
  - need to avoid double counting and wrong merging
- need an imaging calorimeter!



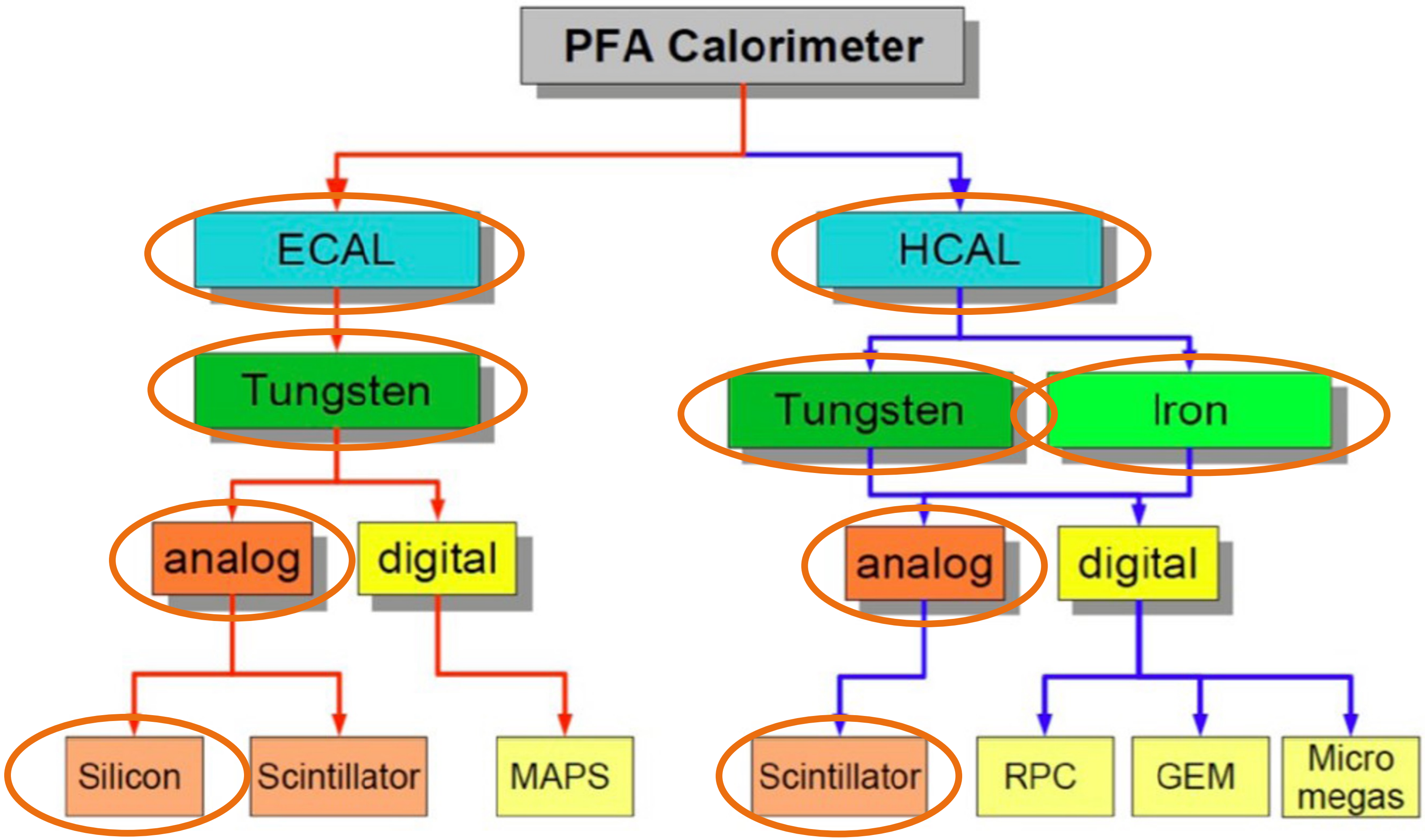
- requirements for the calorimeter:
  - highly granular
  - reconstruction of neutral particles: good energy resolution
  - avoid/reduce dead material between tracker & calo
    - calorimeter within magnet coil: very compact or
    - calorimeter outside magnet coil: thin magnet
- more possible benefits of high granularity
  - particle identification (μ, τ, …)
  - reconstruction of long-lived particles



Highly Granular PFA Calorimeter Concepts



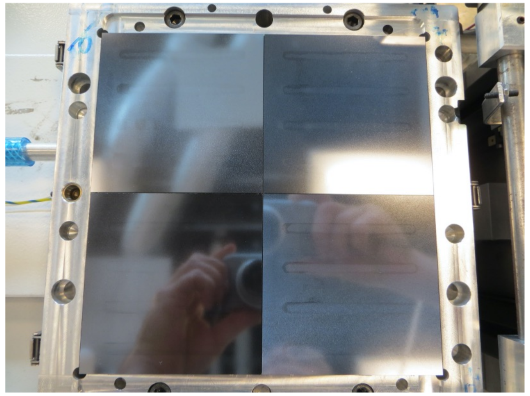
Highly Granular PFA Calorimeter Concepts

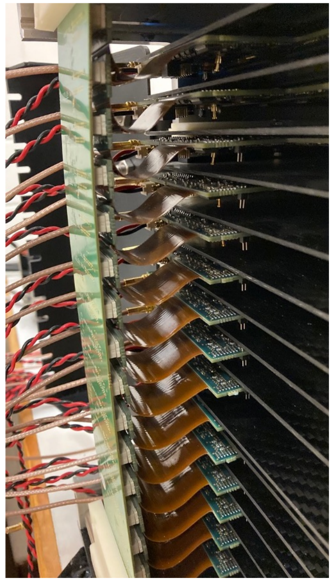


SiW ECAL

The technological prototype

- highly granular scintillator silicon electromagnetic calorimeter, 0.55*0.55 cm² pads
- fully integrated design
- scalable to full detector (~100 million channels)
- **ASU**: ASIC+PCB+SiWafer
  - 18*18 cm^2, 1024 channels, 16 SKIROC2(a) ASICs
  - Si wafer glued to PCB
- **current status**
  - 15 layers of 1 ASU, equivalent to 15360 channels
  - several generations of PCB design
  - up to 21 X_0
  - overall size 640x304x246mm^3
  - flexible mechanical structure
  - commissioned 2020-2022
- testbeams (finally) in November 2021 and during 2022

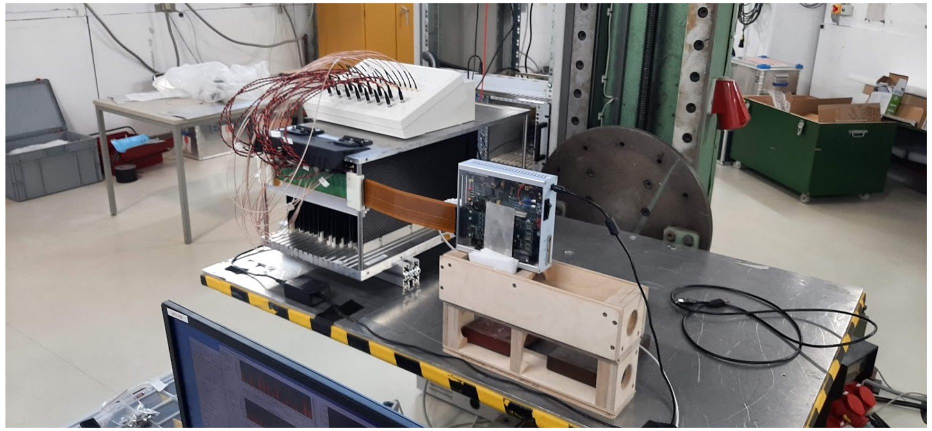




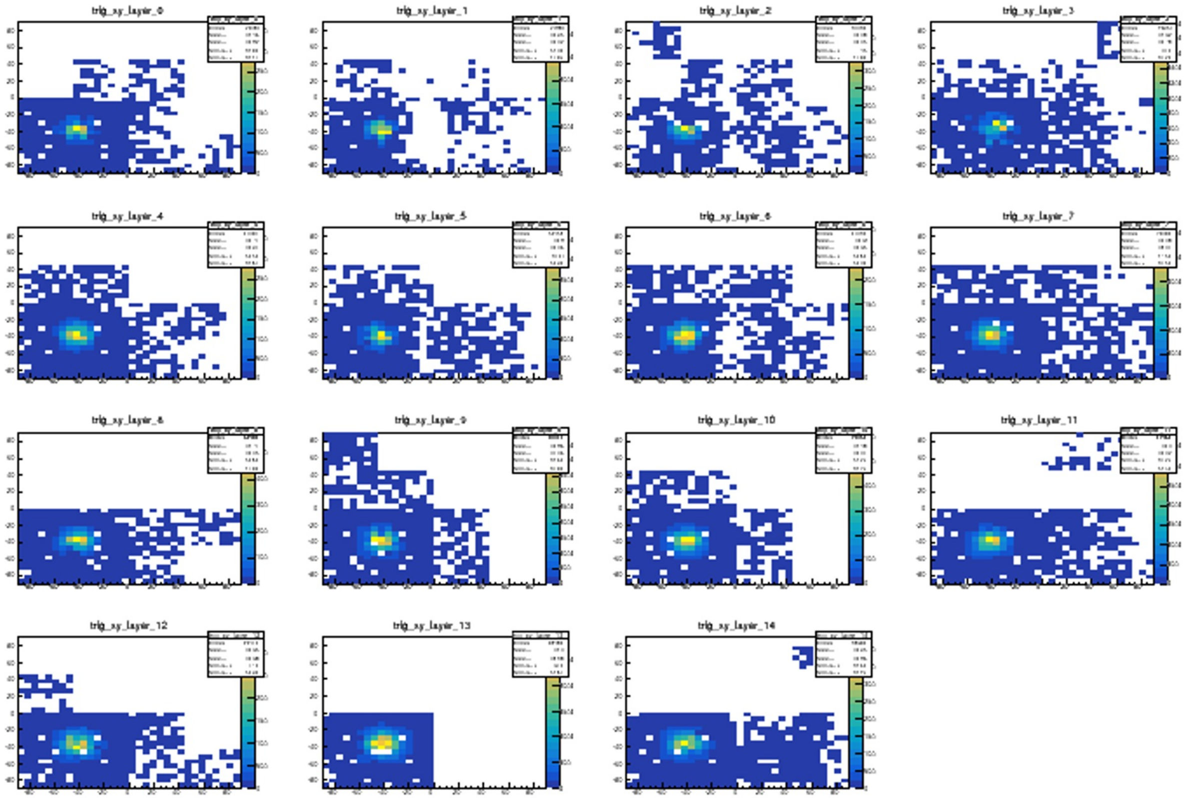
SiW ECAL

Testbeam at DESY

Detector Setup



Detector in beam position

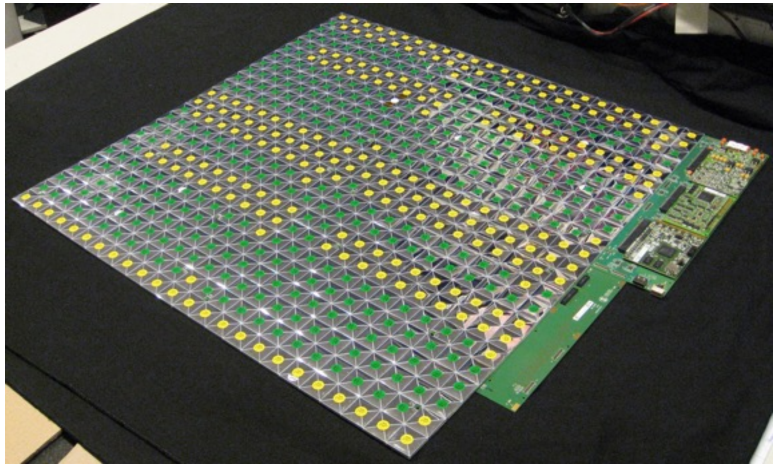


- Beam spot in 15 layers
- Analysis ongoing

CALICE AHCAL

The technological prototype

- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- fully integrated design
- scalable to full detector (~8 million channels)
- **H**CAL **B**ase **U**nit: 36*36 cm^2, 144 tiles, 4 SPIROC2E ASICs
- large enough to contain hadron showers
  - 38 active layers of 72*72 cm²
  - 4 HBUs per module
  - in total: 608 ASICs, ~22000 channels
- all modules are interchangeable
- built with scalable production techniques in ~1 year
- several beam tests in 2018
  - Several analyses involving ML: PID, 2-particle separation, software compensation

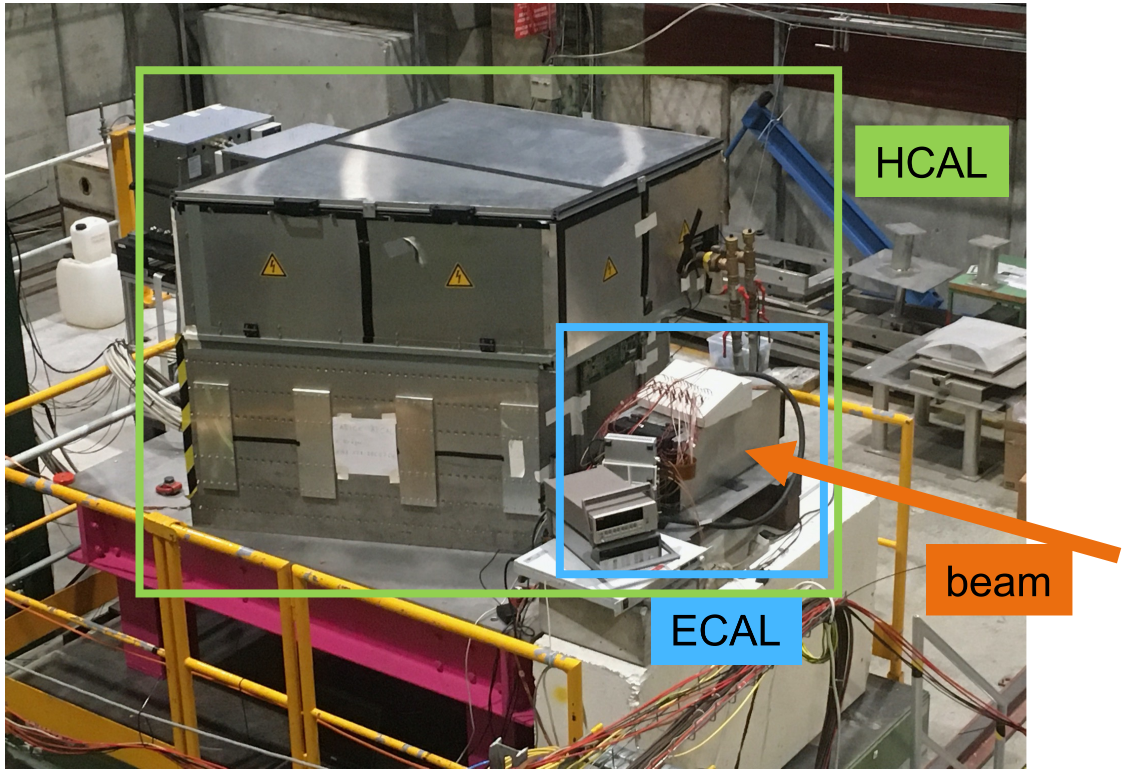


Combined Testbeam

SiW-ECAL + AHCAL

- 2 weeks of combined SiW-ECAL + AHCAL testbeam at CERN SPS in June 2022
- Successful synchronized data taking
- Muon data for calibration
- Energy scans for electrons and hadrons
- Unexpected effects at high amplitudes / large hit densities in ECAL

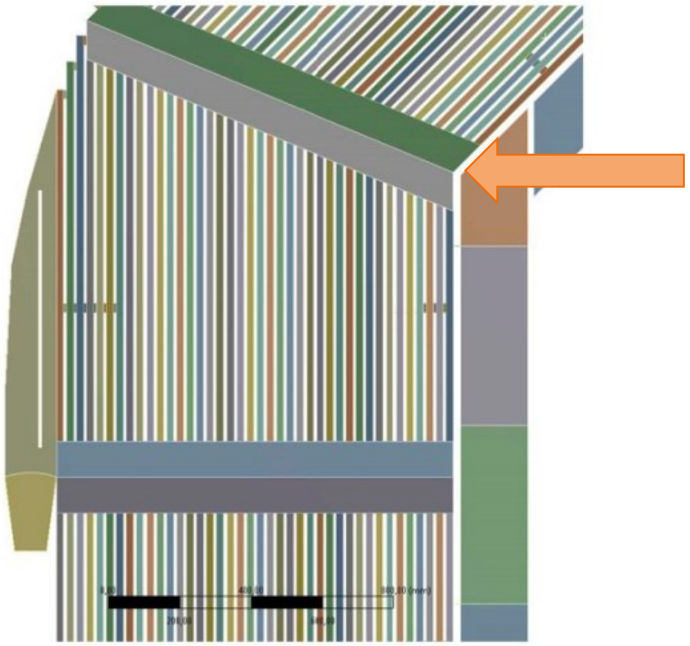
- Milestone in our program reached!
- Future beam test program to be defined
  - Tungsten stack available

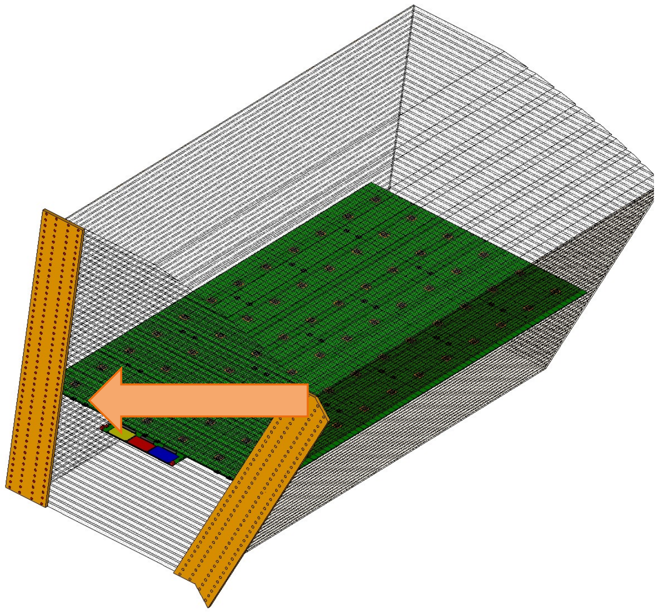


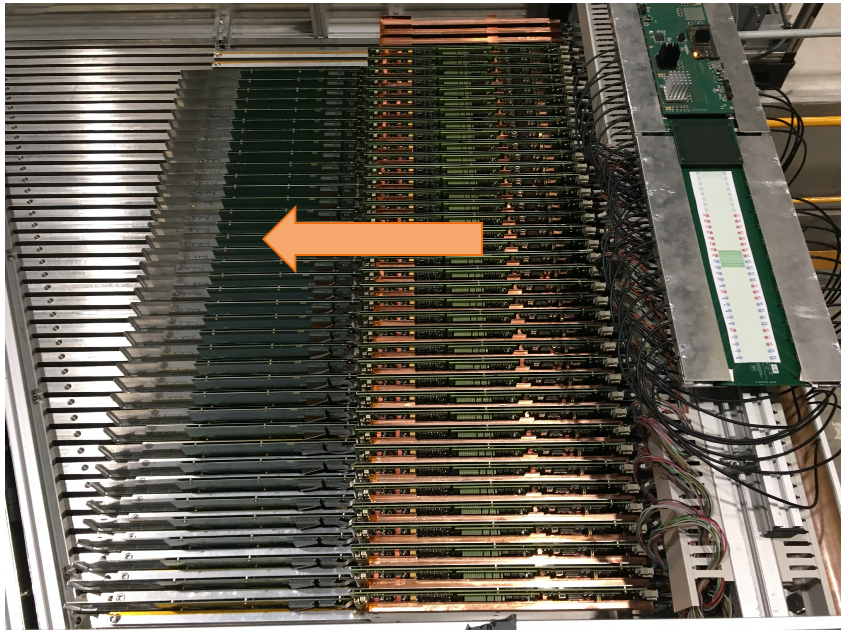
Common Challenges

Space

- Successful application of PFA requires calorimeters to be inside the magnetic coil
- => Tight lateral and longitudinal space constraints
- Both for readout components and services (power, cooling)





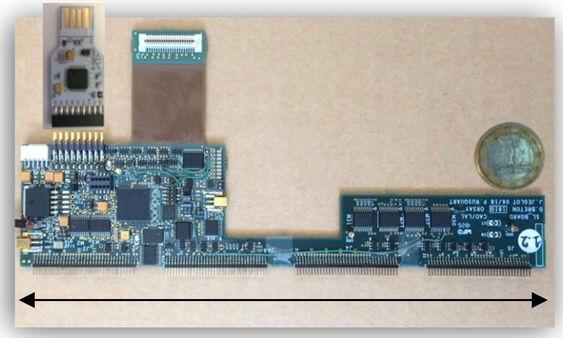


Common Developments

Readout Electronics

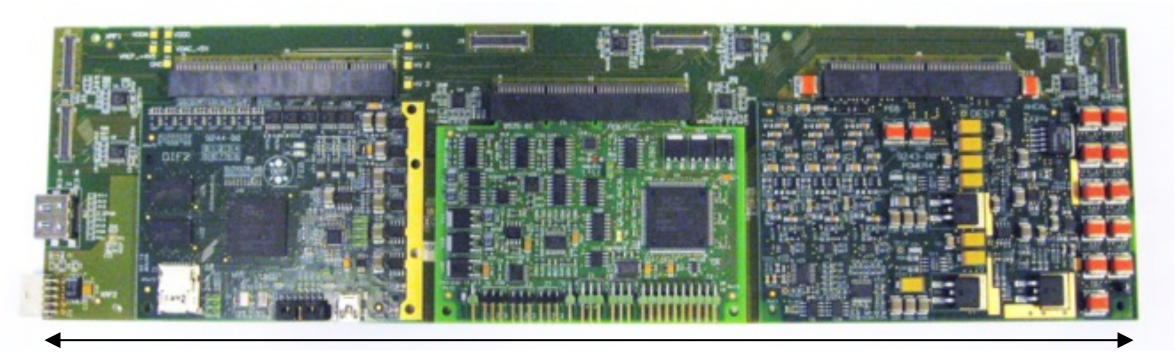
- Harmonise readout between CALICE SiW ECAL and AHCAL
- New SiW ECAL interface board (SL board) optimized for compactness
- Current AHCAL interface board design is from 2007, with focus on modularity
  - Plan to follow SiW design as much as possible
    - Some differences in powering concept
    - Additional LED calibration system in AHCAL
  - Status: detailed discussions between French and German engineers, ideas how to address differences in powering concept

SiW ECAL SL board



18 cm

AHCAL interface boards



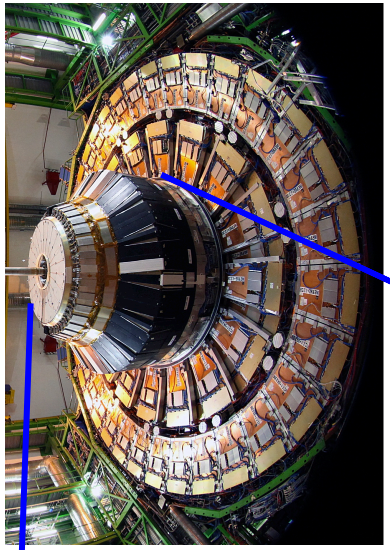
36 cm

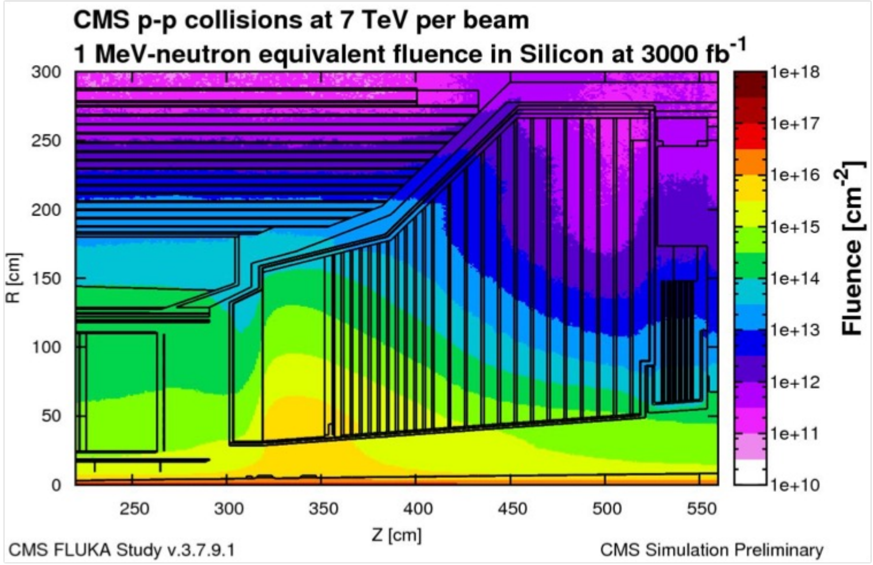
Highly Granular Calorimeters beyond CALICE

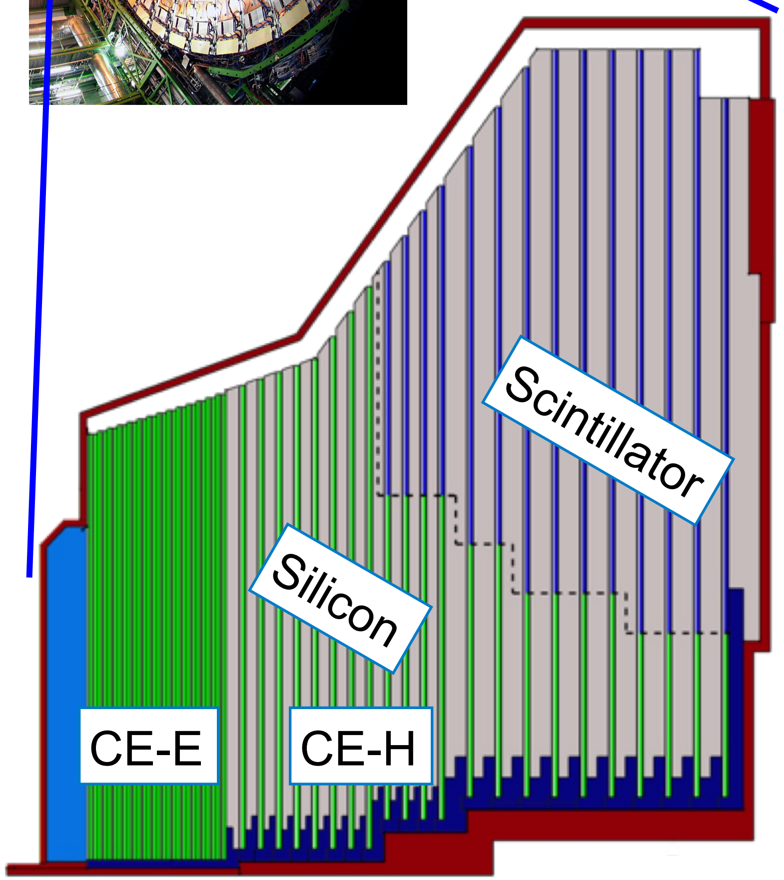
CMS HGCAL

Overview

- current CMS calo endcap will not survive in HL-LHC conditions
- in 2015, decided to replace it with silicon-based **H**igh-**G**ranularity **cal**orimeter
- synergy with CALICE high granularity calorimeter concepts
  - Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
  - Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H





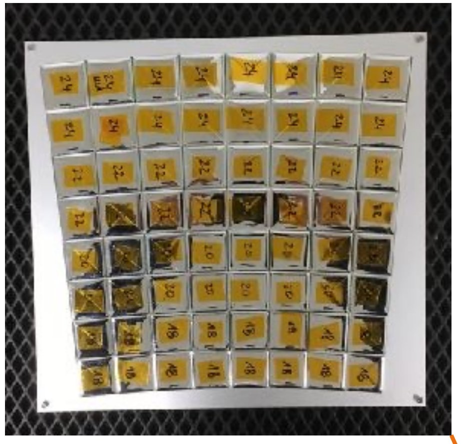


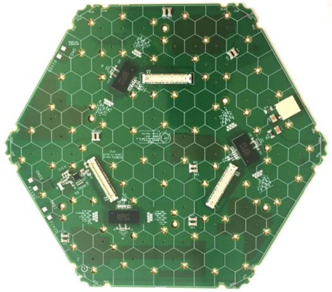
CMS HGCAL

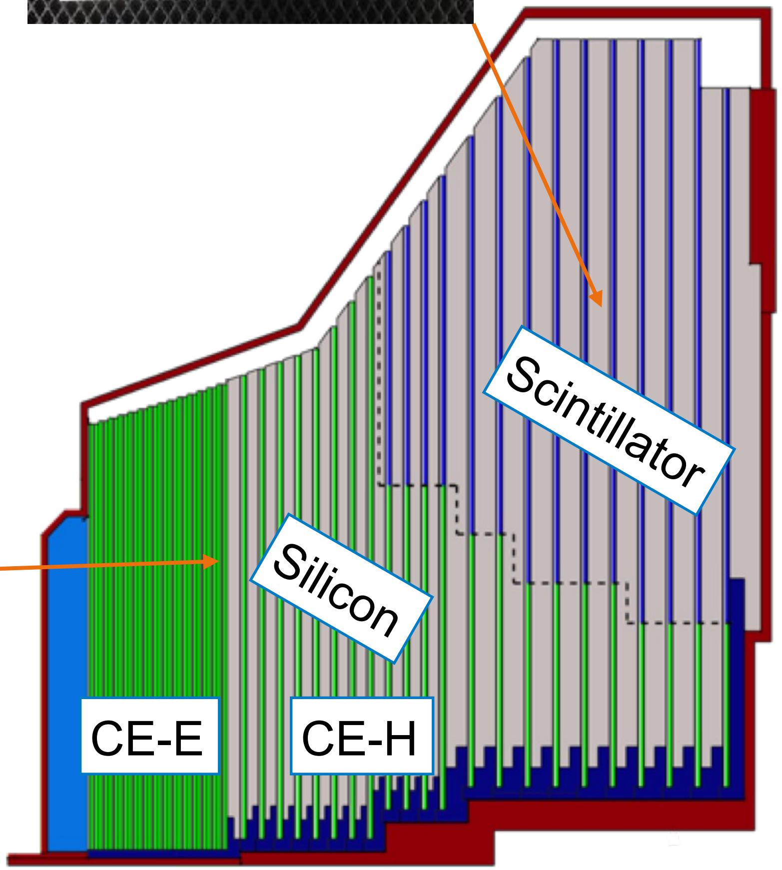
Technology

- current CMS calo endcap will not survive in HL-LHC conditions
- in 2015, decided to replace it with silicon-based **H**igh-**G**ranularity **cal**orimeter
- synergy with CALICE high granularity calorimeter concepts
  - Hexagonal modules based on Si sensors in CE-E and high-radiation regions of CE-H
  - Scintillating tiles with on-tile SiPM readout in low-radiation regions of CE-H
- ~620m^2 Si sensors in ~26000 modules
- ~6M Si channels, 0.6 or 1.2cm^2 cell size
- ~370m^2 of scintillators in ~3700 boards
- ~240k scint. channels, 4-30cm^2 cell size

Central contributions by groups very active in CALICE, including CERN, DESY, LLR, OMEGA.

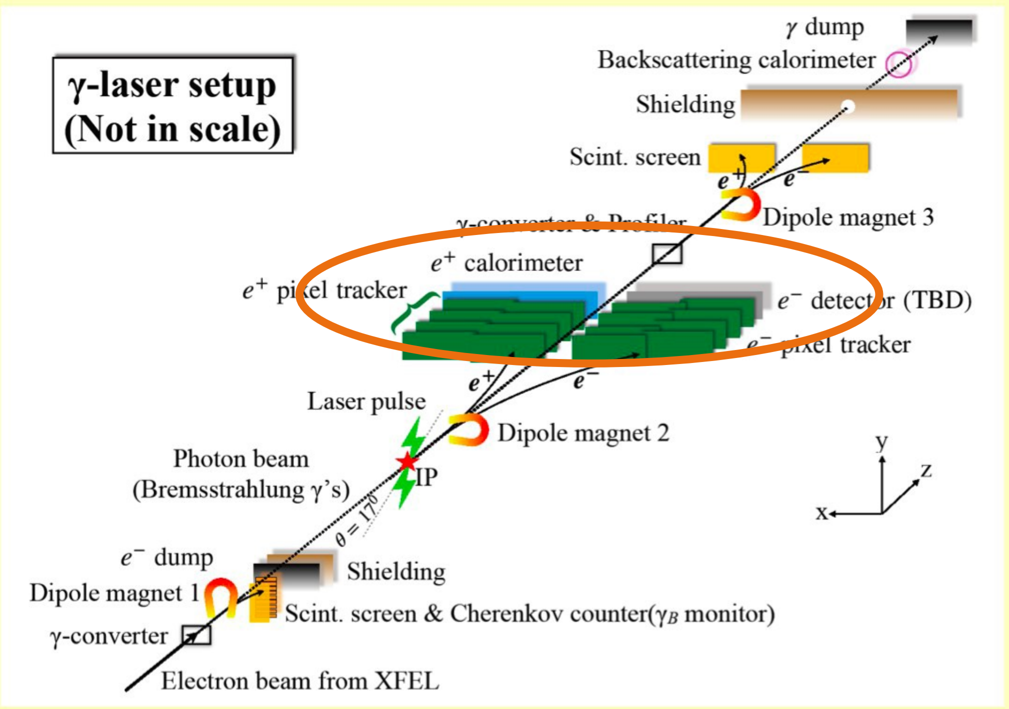






LUXE

- Laser Und XFEL Experiment
- Electron-photon & photon-photon scattering: XFEL + laser
- Test Schwinger limit of electric field, where non-perturbative regime starts and e**+**e**-** pairs can be created out of the vacuum
- Experiment TDR underway, CD1 granted
- Calorimeter needs:
  - EM calorimeter with small Moliere radius
  - Has to cope with very high rates
  - SiW technology chosen
    - Both FCAL-type and CALICE SiW-ECAL-type being investigated
- Strong support from DESY management

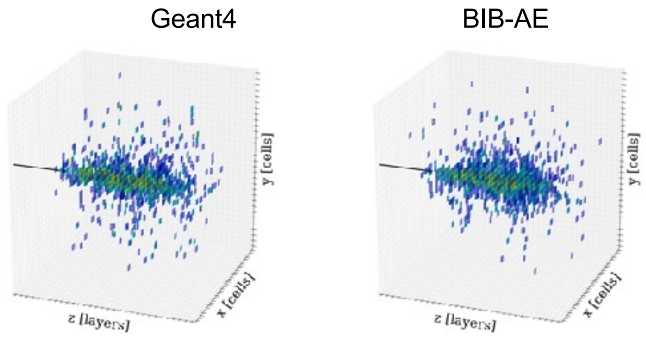


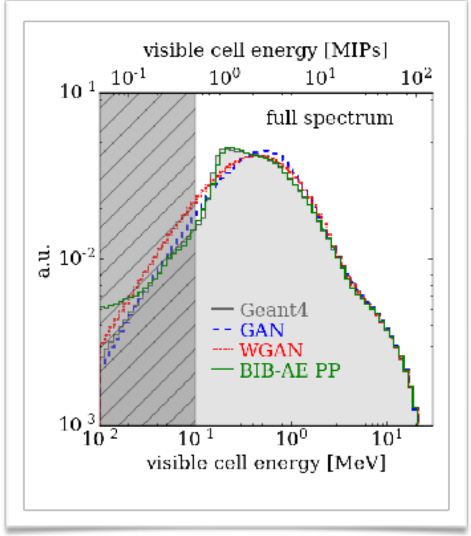
Machine Learning for Highly Granular Calorimeters

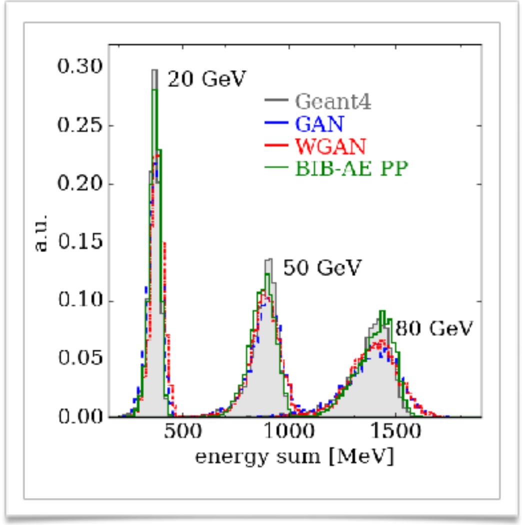
Machine Learning for Simulation

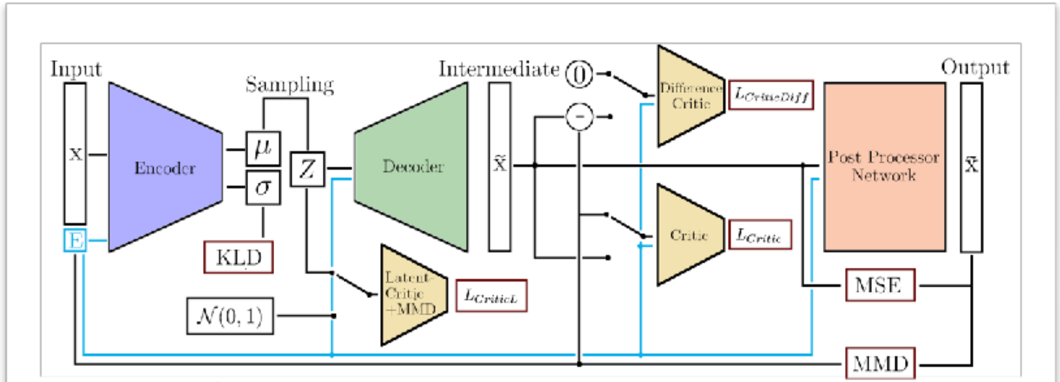
Photon showers in SiW-ECal

- fast ML-based shower simulation
- use sample of photons at 90 deg impact angle in CALICE / ILD SiW-ECAL with uniform energies 10-100 GeV
- achieve high fidelity in distributions of relevant physical variables
- using Bounded-Information-Bottleneck Auto Encoder (BIB-AE) w/ post-processing
- also compared to GAN and WGAN

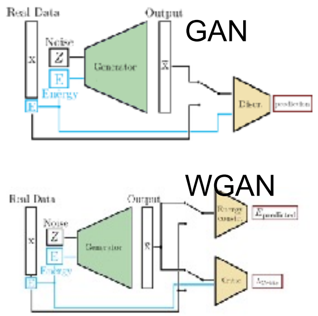








Bounded-Information-Bottleneck Auto Encoder with Post Processing

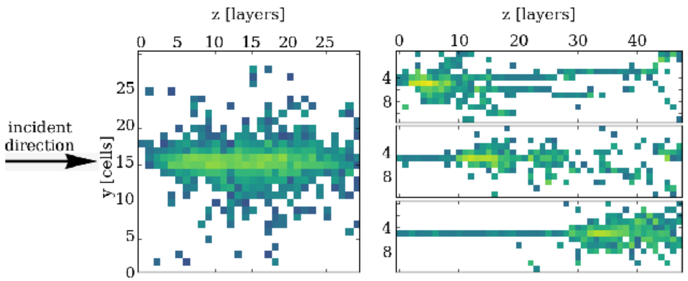


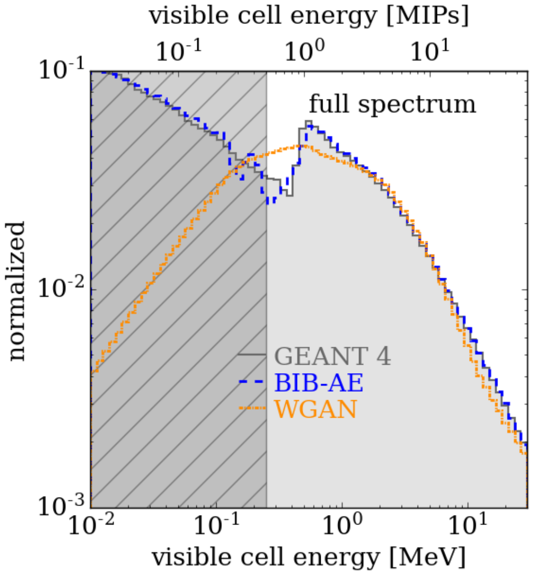
Getting High: High Fidelity Simulation of High Granularity Calorimeters with High Speed, Erik Buhmann (Hamburg U.) Sascha Diefenbacher (Hamburg U.), Engin Eren (DESY), Frank Gaede (DESY), Gregor Kasieczka (Hamburg U.), Katja Krüger (DESY) et al. (May 11, 2020), e-print: 2005.05334 to be published in Computing and Software for Big Science

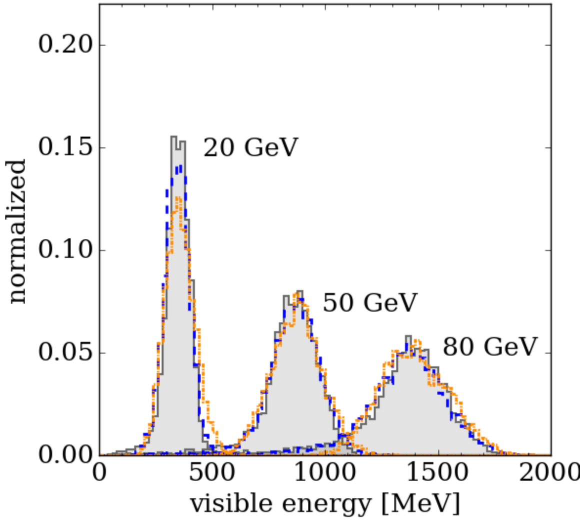
Machine Learning for Simulation

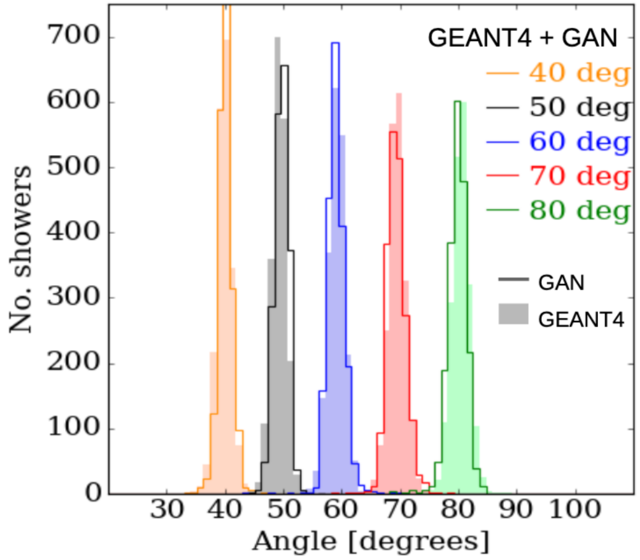
Hadron showers in AHCAL

- significant progress in fast simulation of hadron showers (pions) in the CALICE / ILD AHCAL
  - more complex shower structure -> harder to get right
  - publication in preparation









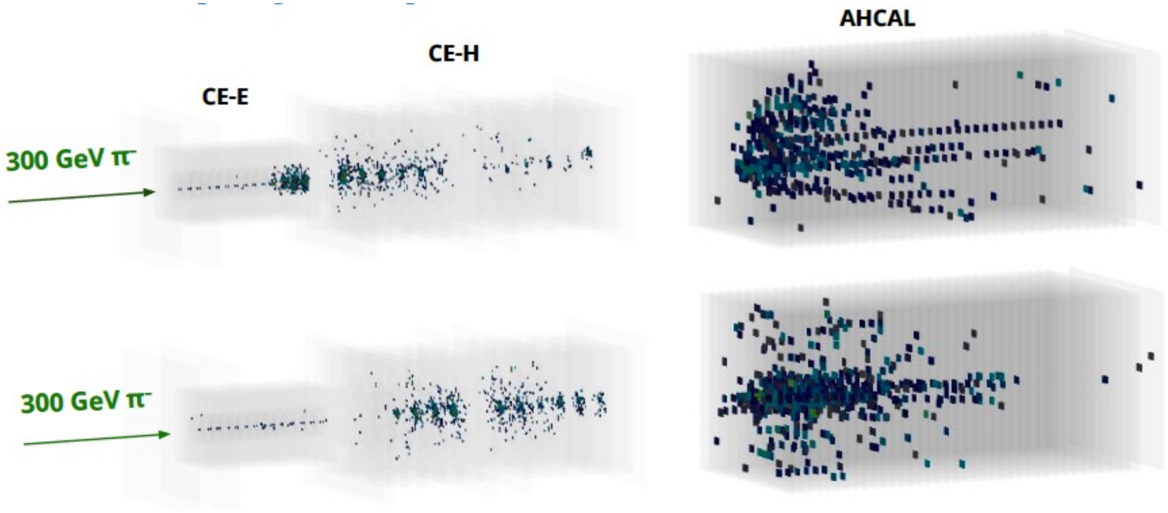
- successfully implemented angular conditioning for photon showers
- now working on combining energy & angular conditioning

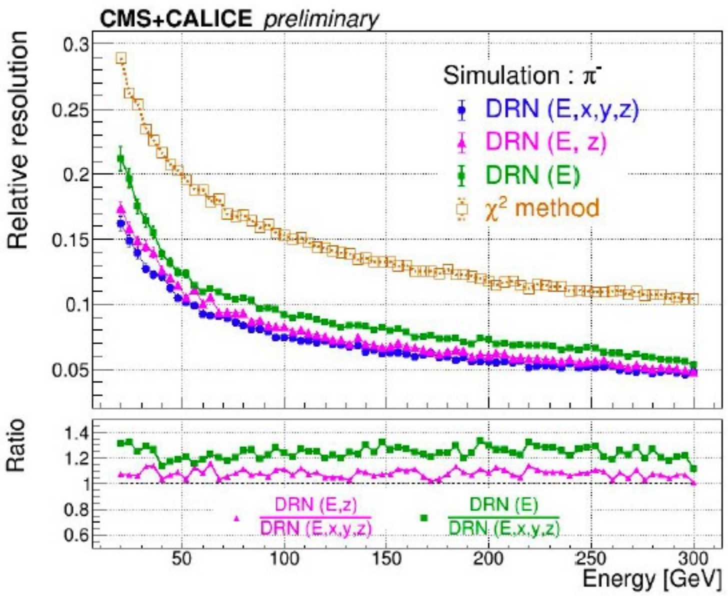
Reconstruction

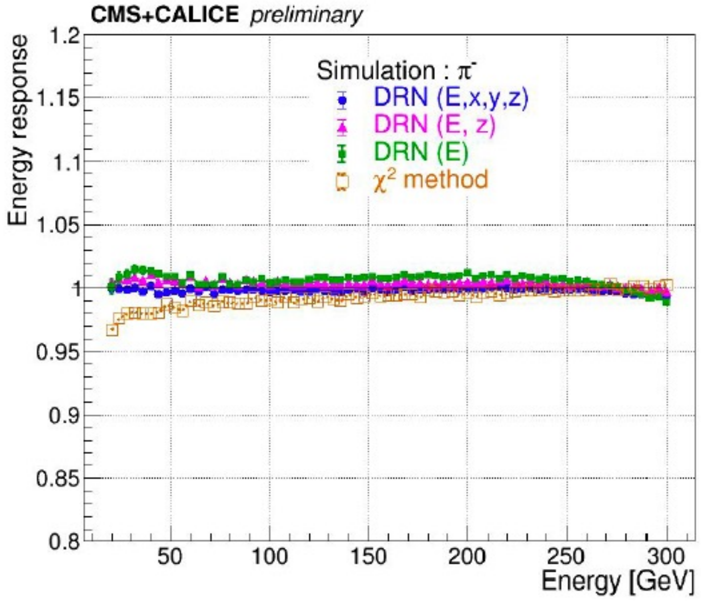
A. Sirohi BTTB 2022

Example from CMS HGCAL + AHCAL testbeam

- High granularity can help in energy reconstruction of hadronic showers
- Exploit with ML: Dynamic Reduction Network (DRN).
- Comparison with per-layer weighted energy.
  - Promising resolution and linearity performance.
  - Developing understanding of performance.







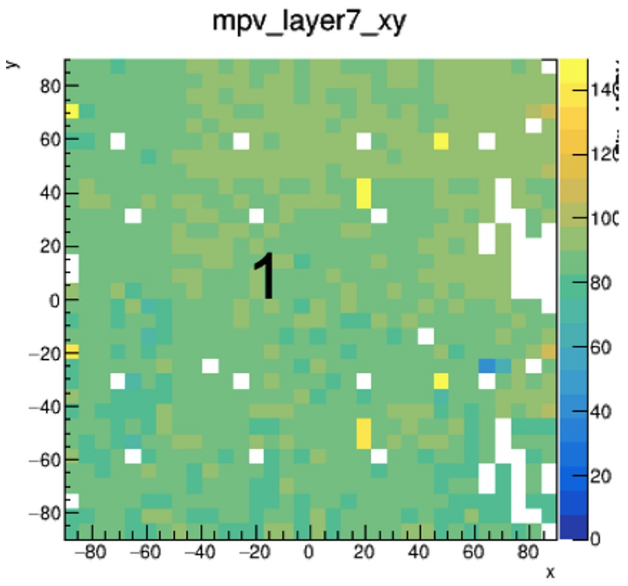
Summary

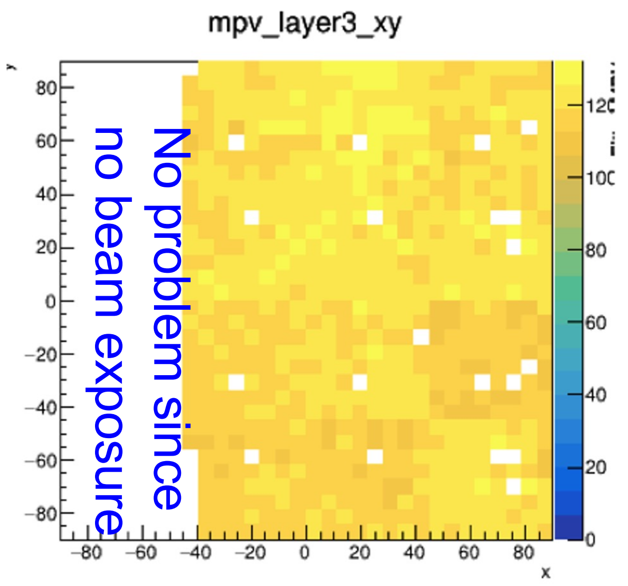
- Collaboration between French and German partners in Calorimetry is well established
  - DMLab adding momentum
- Several areas
  - Common testbeams of prototypes
  - Development of readout hardware
  - Analysis: ML activities just starting
- Collaboration and promotion of project within DMLab is an important element for success

Backup

SiW-ECAL beam tests - Further observations

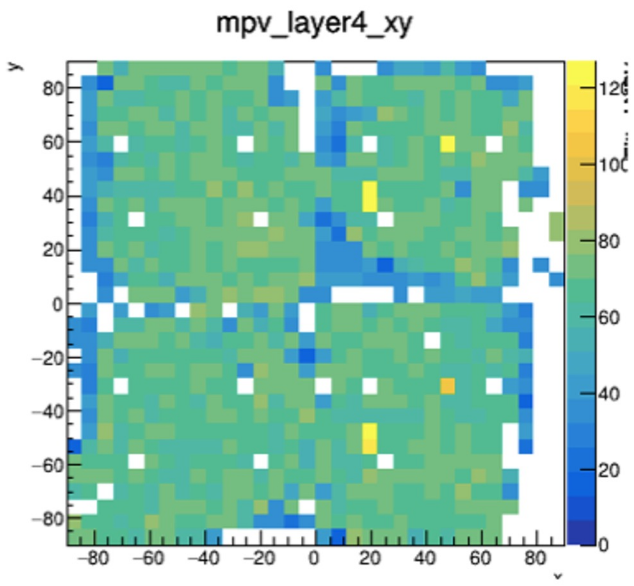
Adrian Irles





We have good layers ...

- Homogeneous response to MIPs
- over layer surface
- > 90% efficiency for MIPs
- Here white cells are
- masked cells due to PCB routing
- understood and will be corrected



... and not so good layers

Inhomogeneous response to MIPs

- Partially even no response at all, in particular at the wafer boundaries
- Not seen in 2017, degradation observed during 2018/19
- To be understood, **about to start with dedicated aging studies**

Since Summer 2022 access to the different stages of the ASICs

- => analogue probes, major debugging tool

Summary

From last year

- Development of granular calorimeters is active field in France and in Germany
- ● Common development would benefit by “borderless” mutual access to facilities
- ● Office space, workspace (e.g. For setting up testbenches), access to stores and (hardware) pools
- ● DESY beam test is of course a unique asset for our field
- ● A small French team on site at DESY would allow to make optimal use of this infrastructure
- ● A “sabbatical” at DESY may allow for example help to prepare a common infrastructure
- ● For a seamless exchange a team at e.g. DESY is for sure helpful
- ● A running experiment as LUXE would clearly as well motivate longer stays at DESY
- ● Shorter stays (~weeks) in France or in Germany for data analysis and development of algorithms
- ● Application of timing and/or ML is largely unchartered territory for granular calorimeters