How to Build a Modern Calorimeter - The CALICE (AHCAL) Story

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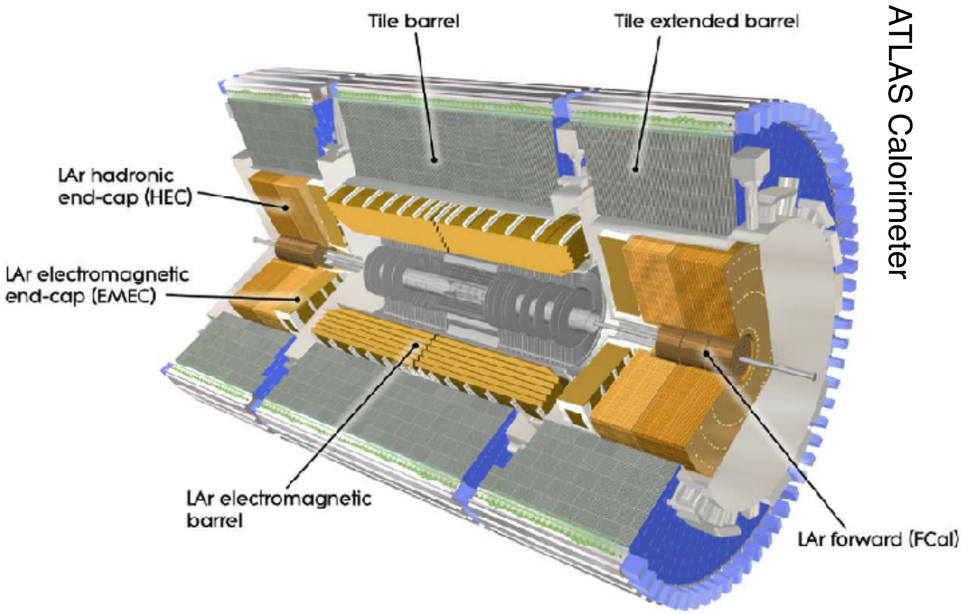
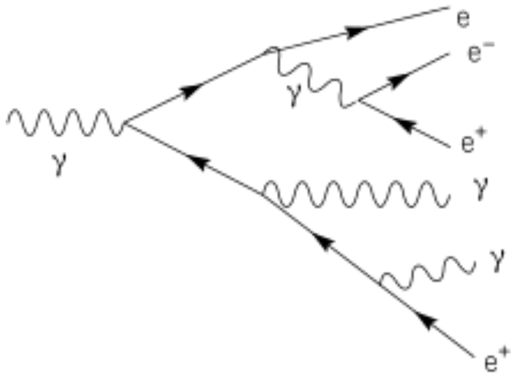
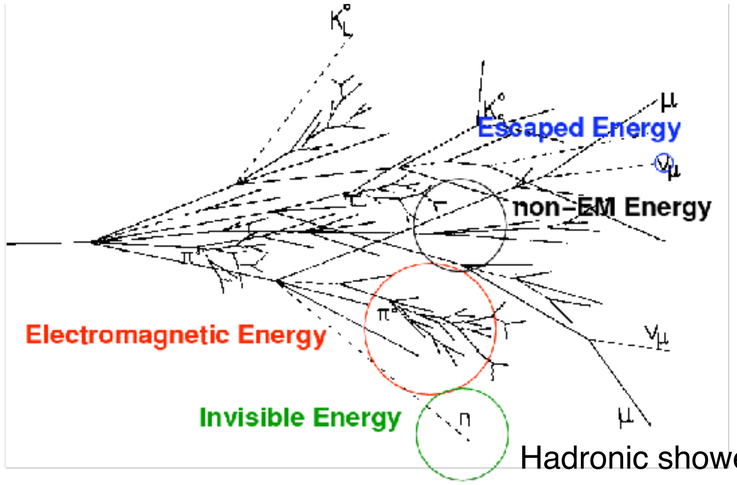
Calorimetry

- **Calorimetry in HEP:** Measure energy by absorption
- Two different length scales for em (X_0) and hadronic showers (λ_I)
- *Electromagnetic* and *hadronic* calorimeter
- Often: sampling calorimeter
  - Active layer / absorber
  - More compact
  - Cheaper





Electromagnetic shower

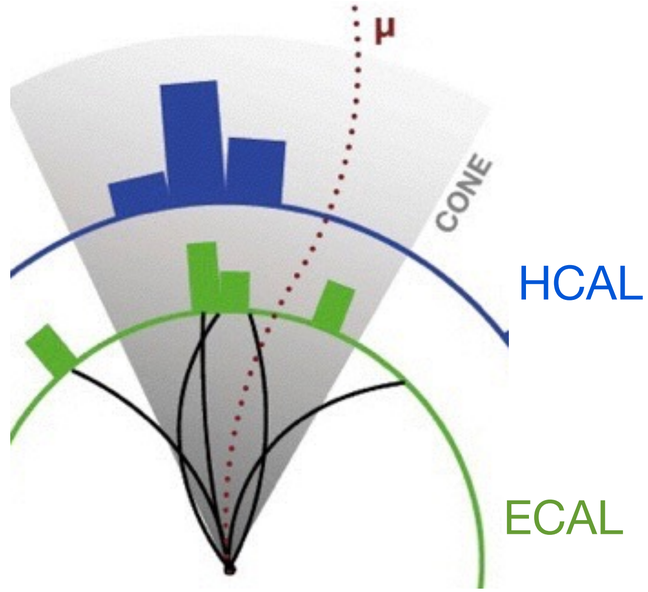


Hadronic shower

Jet Energy Resolution

- **Jet Energy:** sum up all the energy in a *cone*
- Hadronic calorimeter usually has worst energy resolution
- If we could separate single particles in a jet we can use the best suited detector for each!

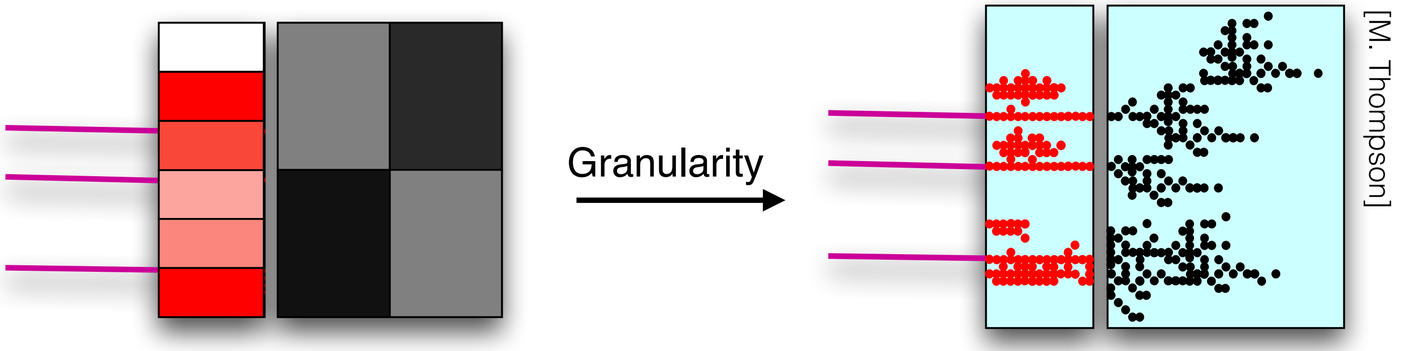
Detector	Particles	ATLAS	CMS
Tracker	Electrons, Muons, Pions, …	$5*10^{-5}\ p_t$	$5*10^{-4}\ p_t$
Em Cal	Photons, Electrons, Pions, …	$10\% / \sqrt{E} \oplus 1\%$	$3\% / \sqrt{E} \oplus 1\%$
Had Cal	Neutrons, Pions, Kaons, …	$50\% / \sqrt{E} \oplus 3\%$	$100\% / \sqrt{E} \oplus 4\%$



Go with the Flow

- **Particle flow algorithms** may enhance jet energy resolution by using best suited detector
- Charged particles will be measured in the tracker, photons in the ECAL, neutral hadrons in the HCAL
- Each shower in the calorimeters needs to be assigned to the correct track

Content of a „typical“ jet:
- 60% charged particles
- 30% photons
- 10% neutral hadrons
- 1% neutrinos

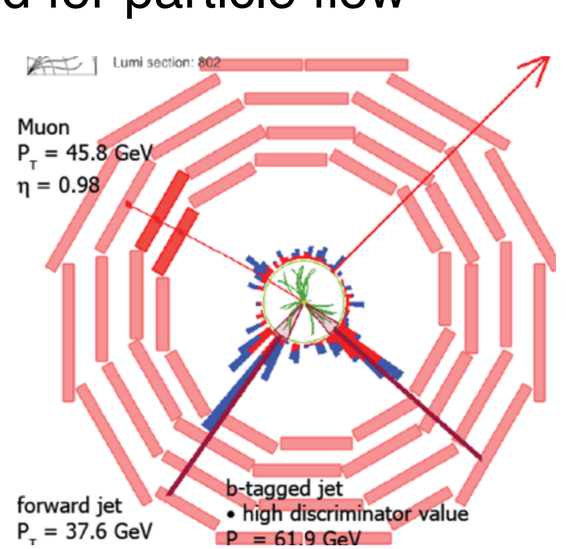


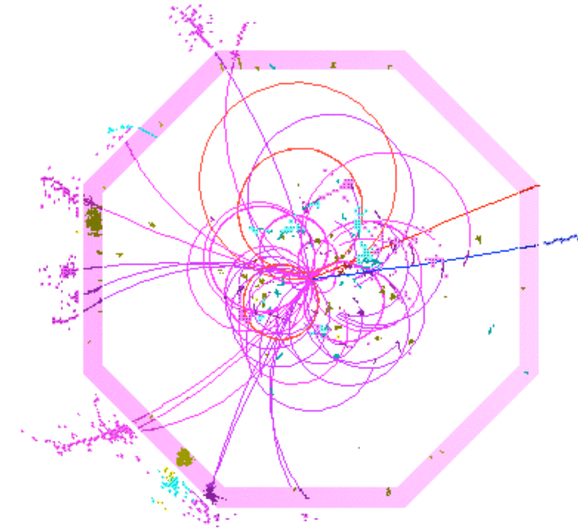
$$E_{\text{jet}} = E_{\text{em}} + E_{\text{had}} \longrightarrow E_{\text{jet}} = E_{\text{photon}} + E_{\text{n.had}} + E_{\text{tracks}}$$

Go with the Flow

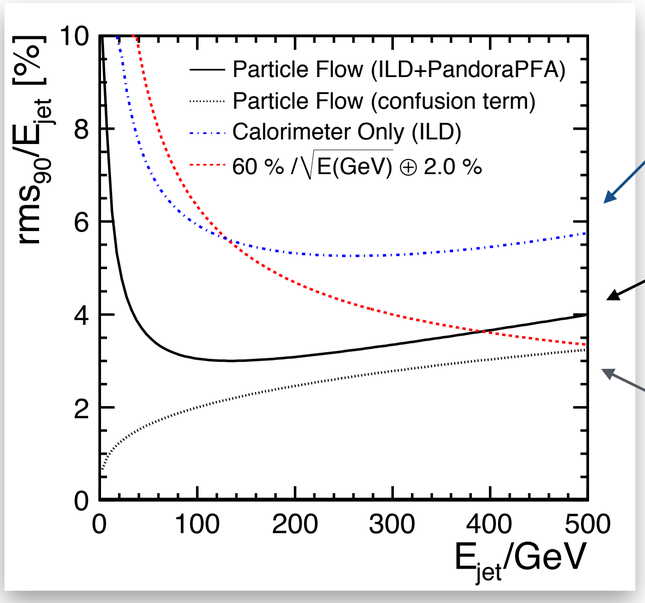
- For future e^+e^- colliders: Design detector optimized for particle flow

- "CMS like" detector:
  - Calorimeters inside magnets
  - Strong magnetic field





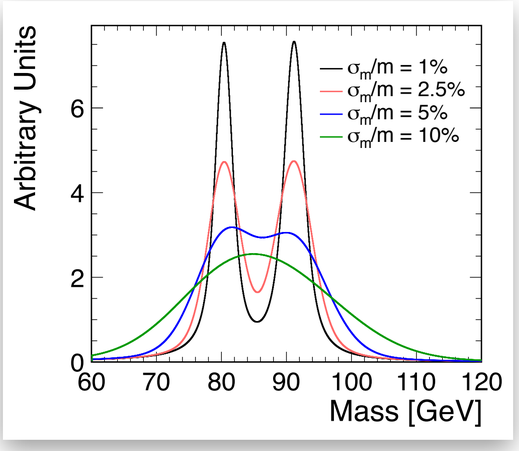
[Thompson, 2009]



realistic calorimeter (no PF)

realistic Calorimeter with particle flow

confusion

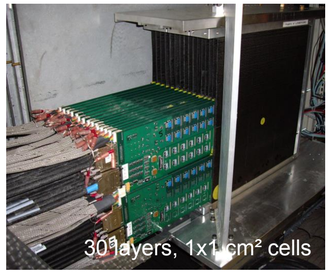


[CLIC - CDR]

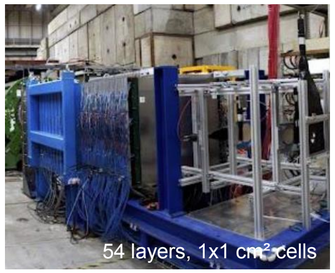
CALICE

- **Aim**: Development of new technologies for calorimetry with highly granular detectors
- Several technologies under study
- This talk: focus on **analog hadronic calorimeter** (AHCAL)

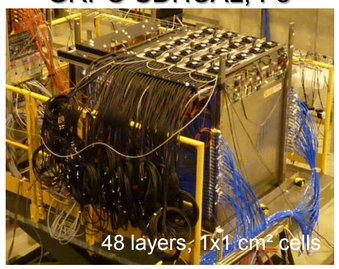
Si-W ECAL



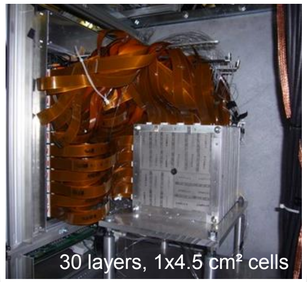
RPC-DHCAL, Fe&W



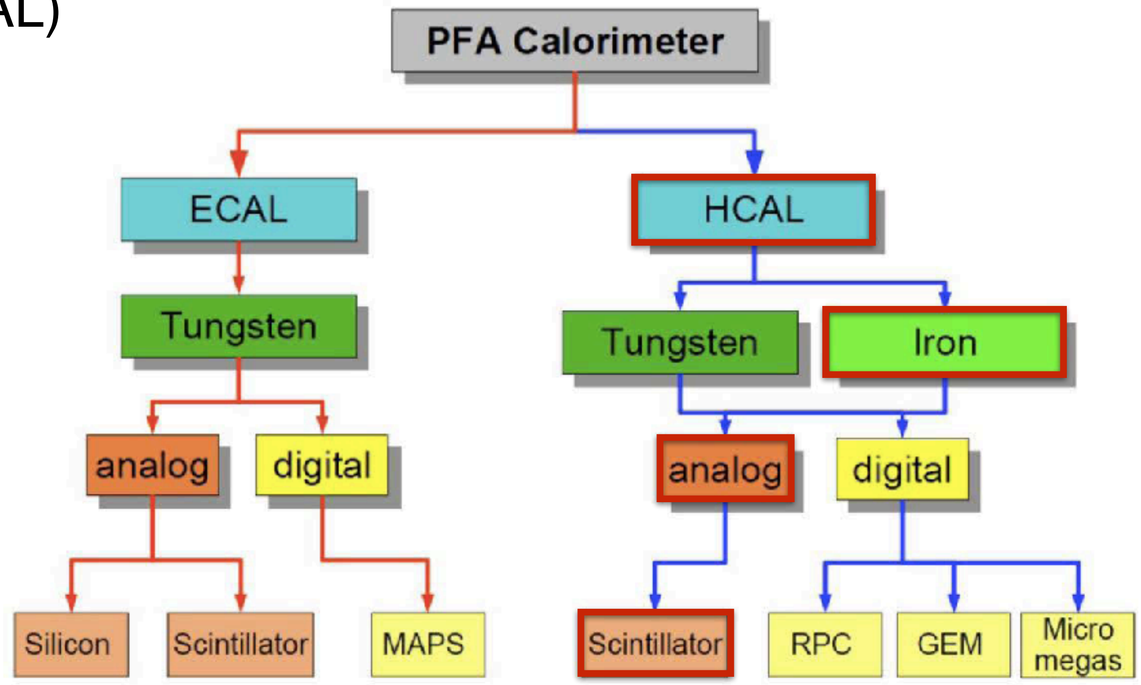
GRPC-SDHCAL, Fe



Sc-W ECAL



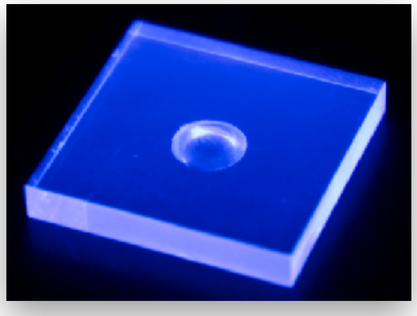
Sc-AHCAL, Fe



Silicon Photomultiplier

- Silicon Photomultipliers (SiPMs) are a key technology for scintillator based highly granular calorimeters

- Semiconductor photodetectors
  - ✓ Small size
  - ✓ Low costs



Scintillator

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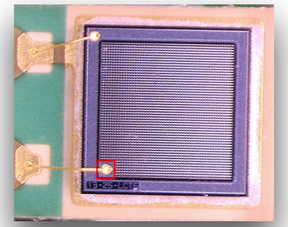
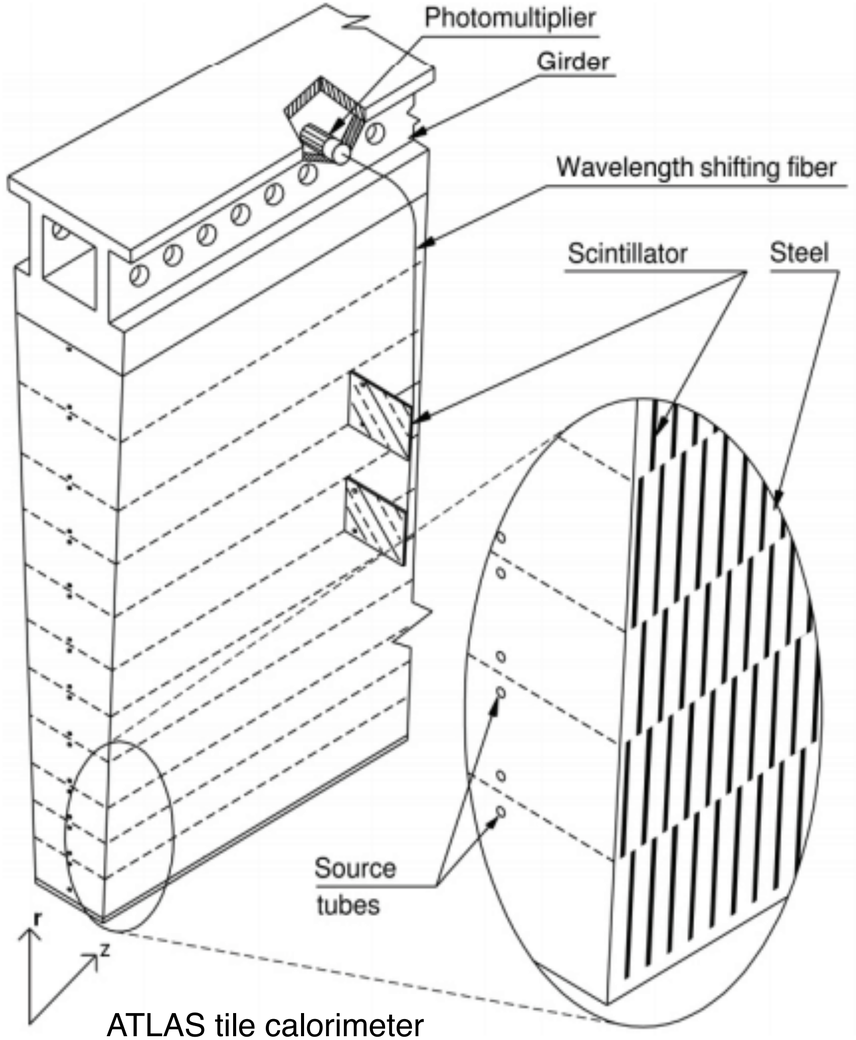


SiPM

Photomultiplier tube

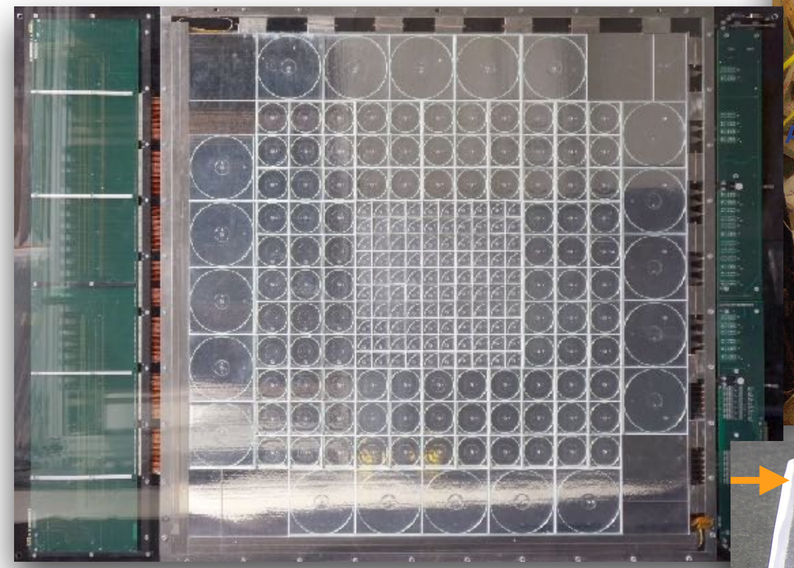


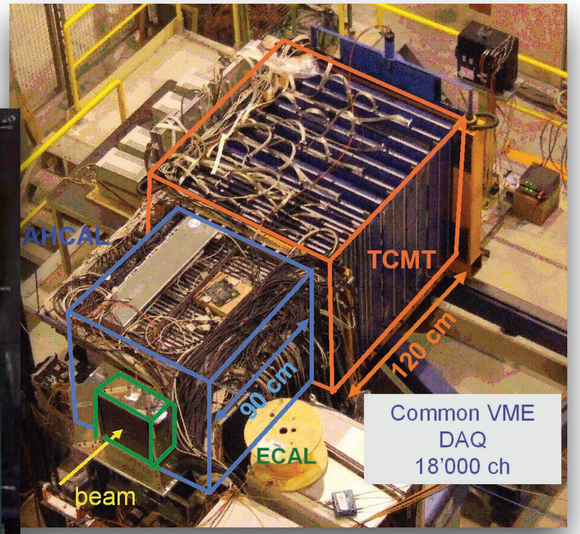
ATLAS tile calorimeter

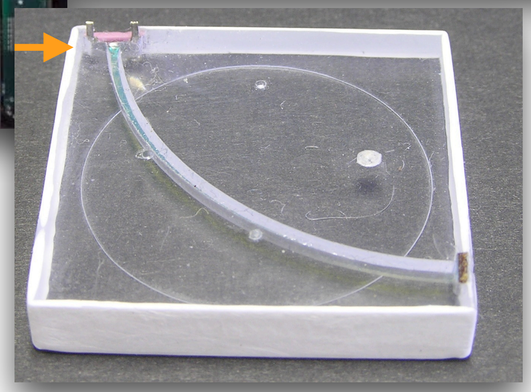
Physics Prototype

2001	2006	2015	2015 - 2018	2018	???
CALICE founded	**Physics prototype**	Technological prototype	Prove concept of techn. prototype	Large techn. prototype	Full Detector

- Scintillator tiles of different sizes
- Read out by wave length shifting fibers
- ~8'000 channels
- Combined test beams with ECAL & Tailcatcher

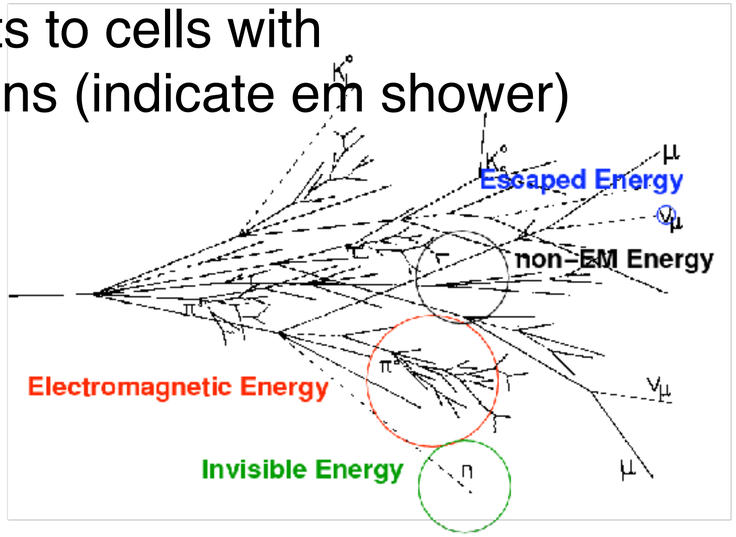


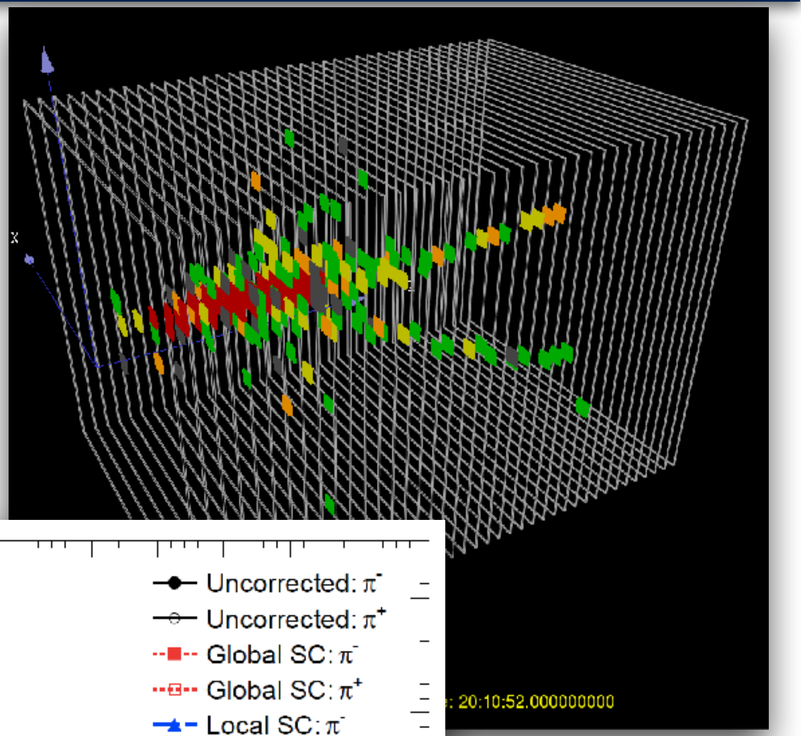


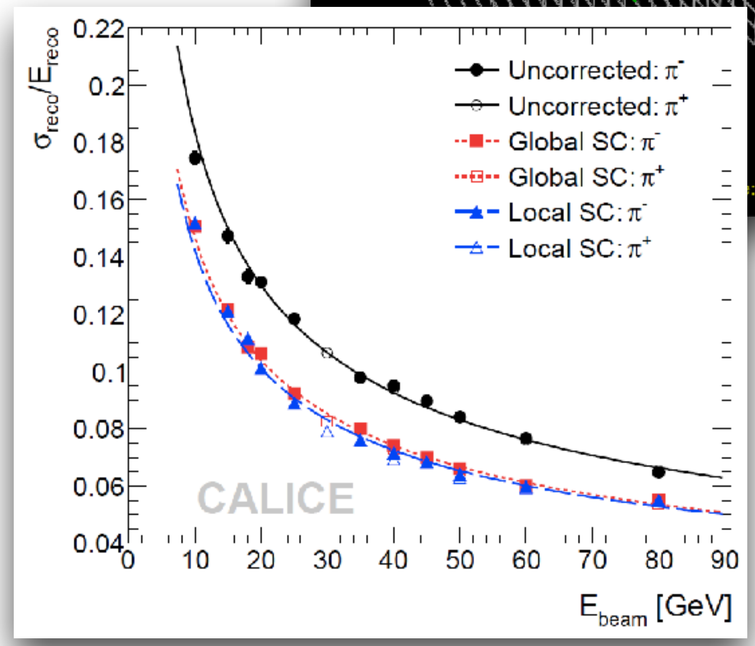


Physics Prototype - Software Compensation

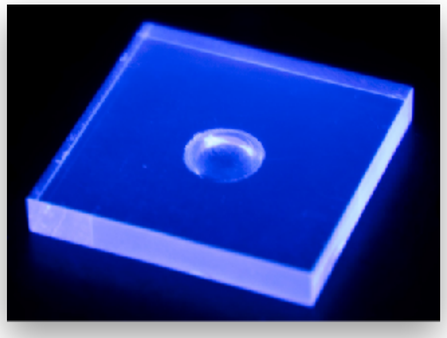
- Enhance energy reconstruction by software compensation
- Non-compensating calorimeters give different response for electromagnetic and hadronic part of shower
- Large fluctuations in fraction of electromagnetic part
- Exploit granularity of detector:
  Apply different weights to cells with
  high energy depositions (indicate em shower)







AHCAL - Concept



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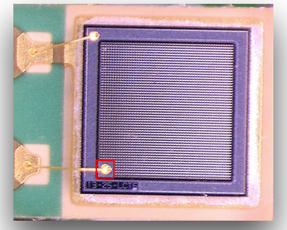
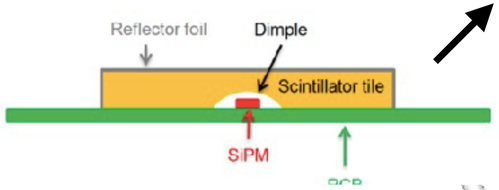
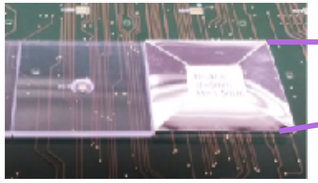
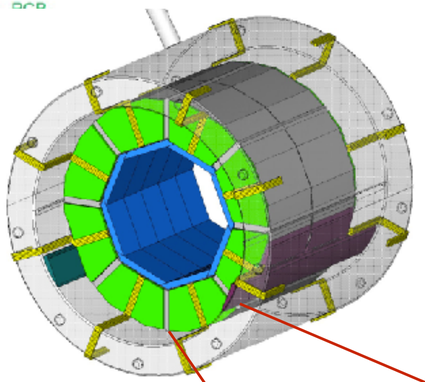
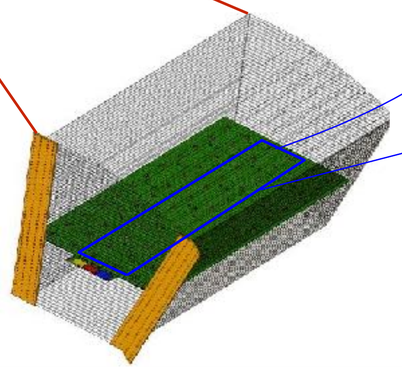
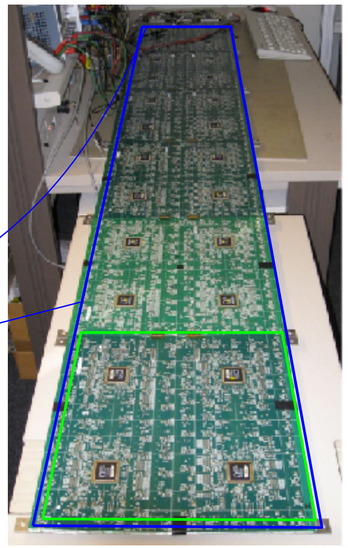






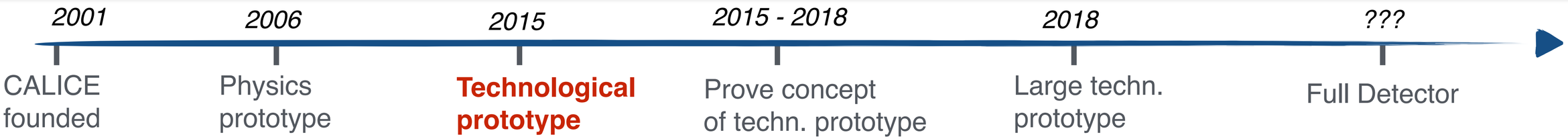




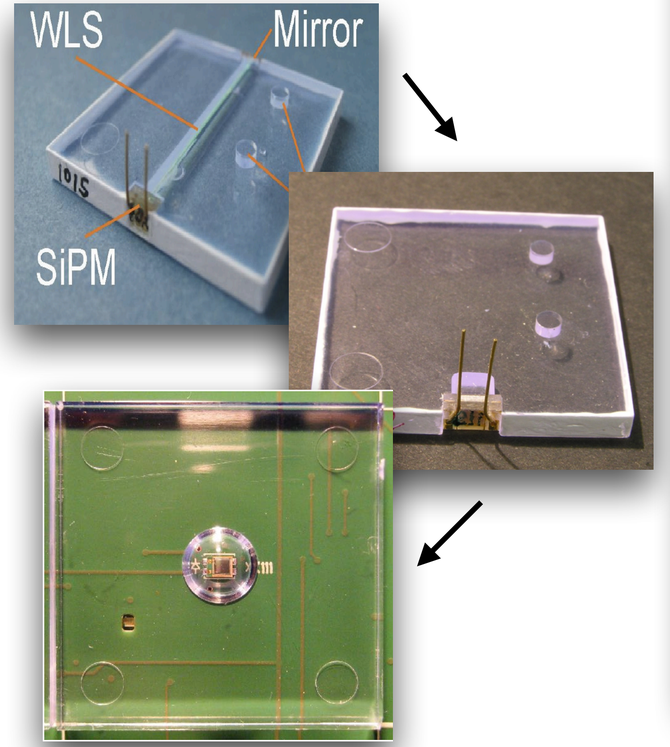


- Sampling calorimeter based on scintillators and silicon photomultipliers (SiPMs)
- Scintillator tiles of size 3 x 3 x 0.3 cm^3, dimple for light focussing, wrapped in reflecting foil
- HCAL base unit (HBU) with fully integrated electronics

Technological Prototype



- Build a prototype within the specifications of a *real detector*
  - Integrated electronics
  - Power consumption
  - Cooling
  - Mass production
- Testing different technologies
- Different SiPMs / scintillating tile designs



Technological Prototype

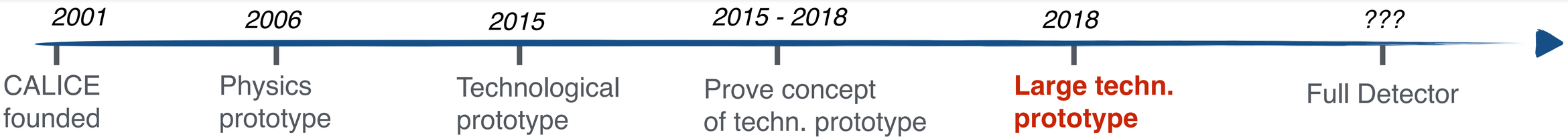
Technological Prototype

- Testing new features:
  - Timing capabilities
  - Power pulsing
  - Temperature compensation
- Test in high magnetic fields

Technological Prototype

Technical Prototype in small steel stack

Large Technological Prototype

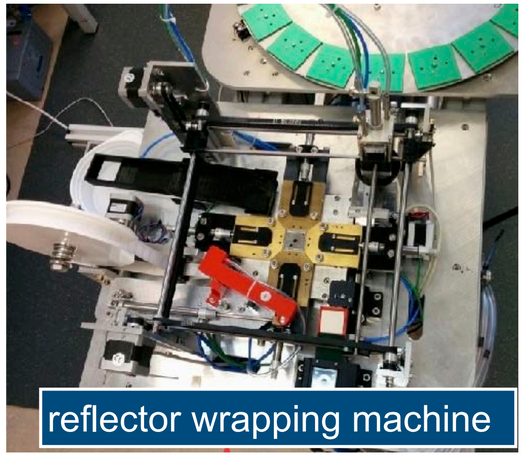


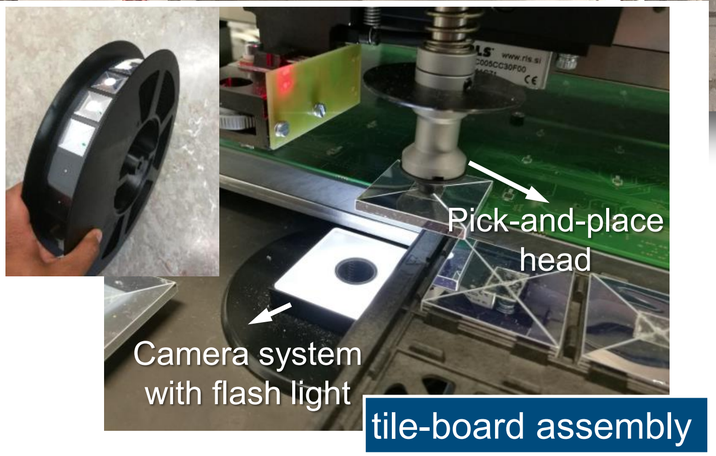
- Prototype with nearly 22’000 channels in 38 layers

- Large scale production
  - Injection moulded tiles
  - Automated tile wrapping (*start in Oct '17*)
  - Pick and place machine (*start in Nov '17*)

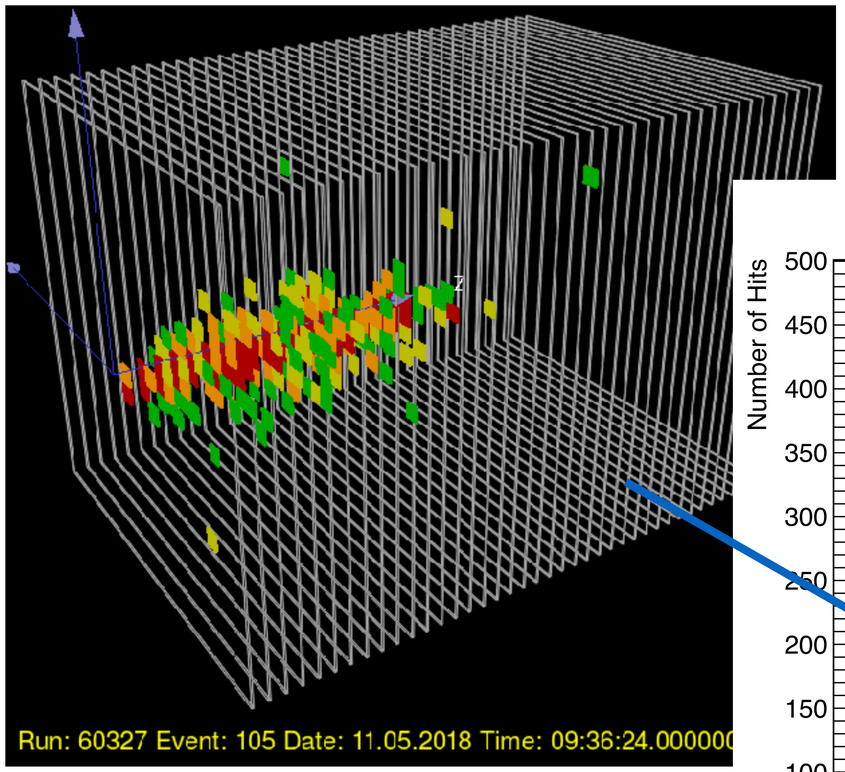
- Two test beam campaigns in May / June at CERN

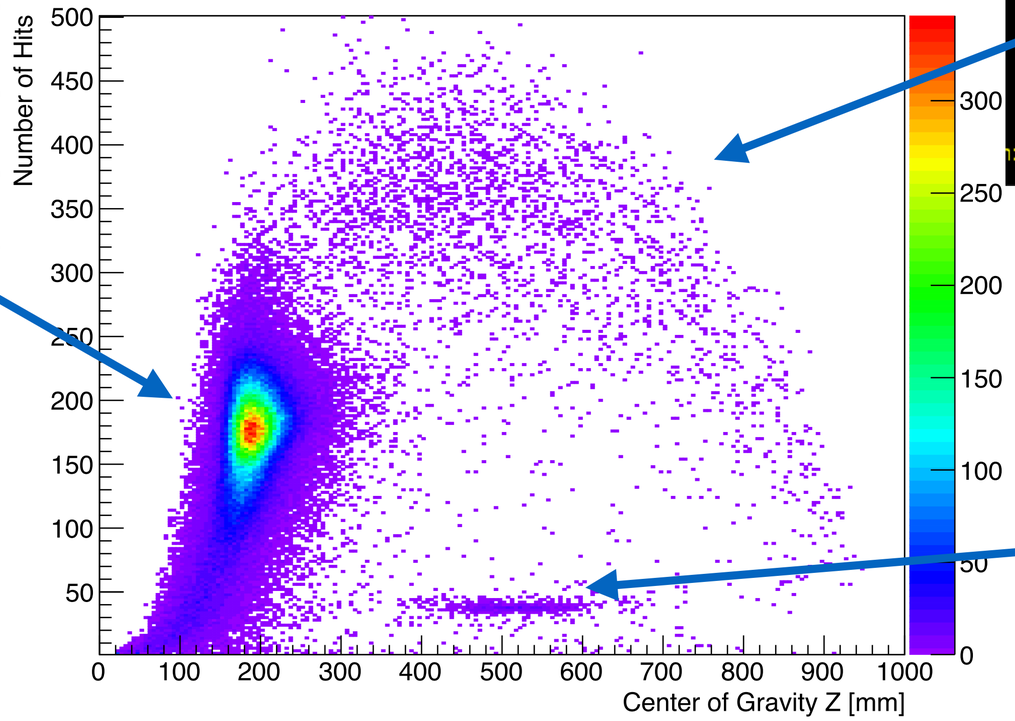
- Final detector will have ~10M channels

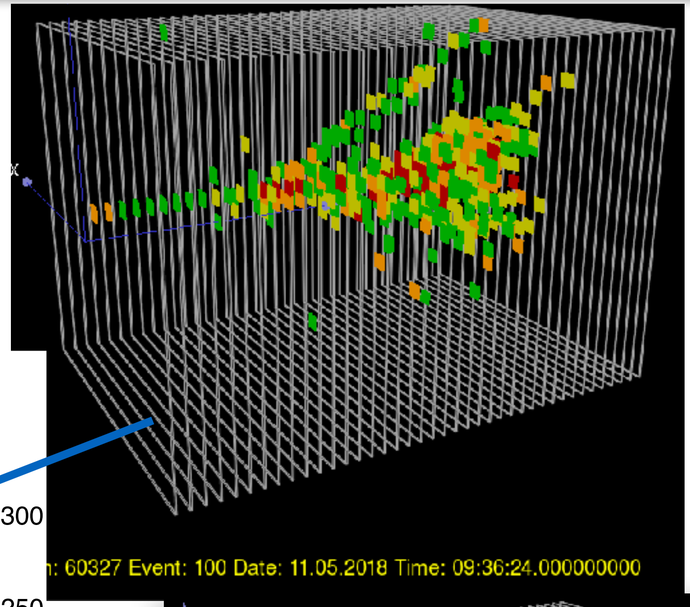

reflector wrapping machine

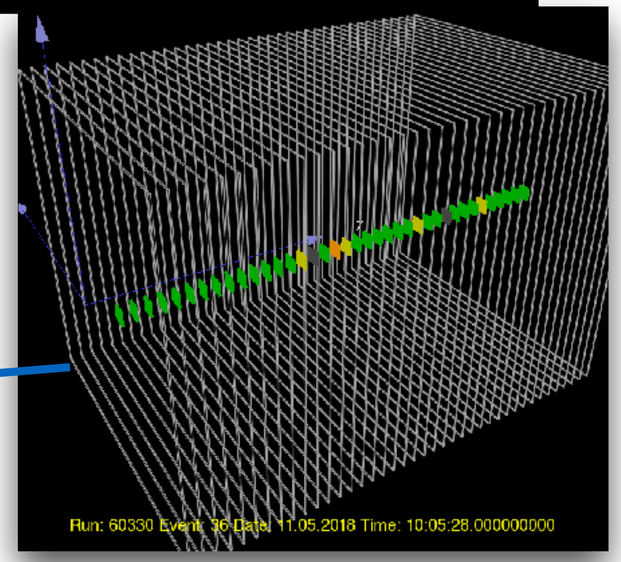


First Impressions from Recent Test Beams









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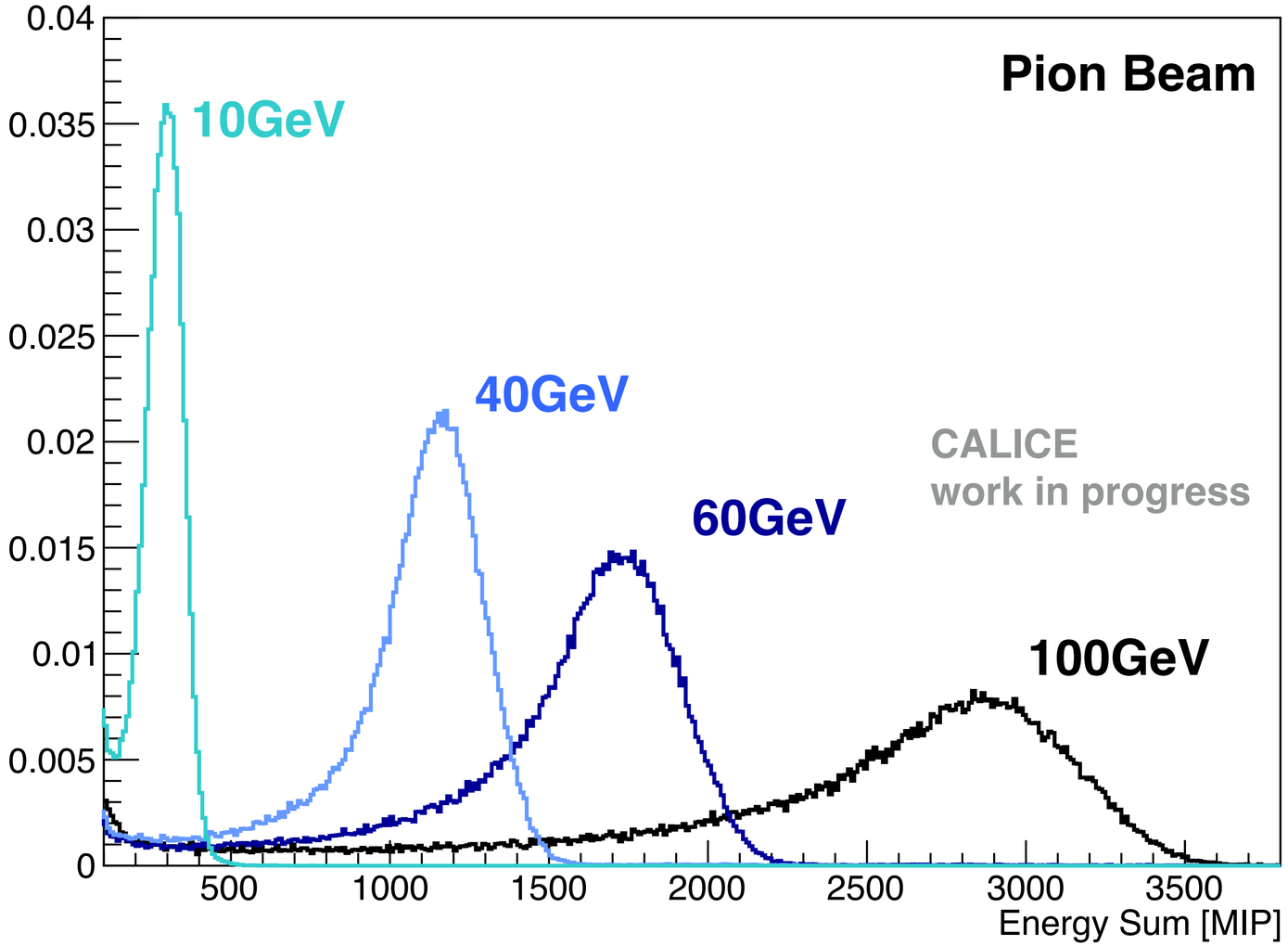

Summary

- CALICE develops highly granular calorimeter for particle flow focussed future linear collider experiments

- Technology used / considered in various other experiments:
  - CMS HGCAL
  - Dune

- Two successful test beam campaigns with a large AHCAL technological prototype with nearly 22’000 channels