Highly Granular Calorimetry in DMLAB

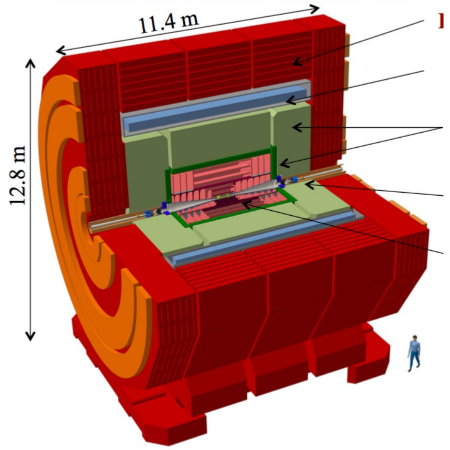
Roman Pöschl and Katja Krüger

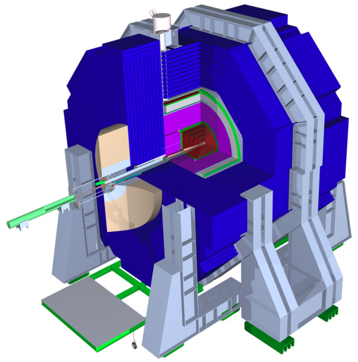
DMLAB Meeting – November 2023 KIT, Germany

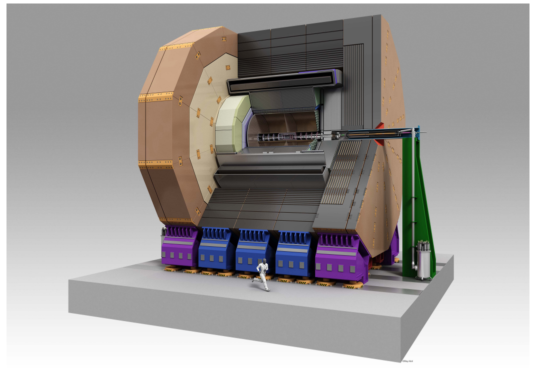
Also supported by

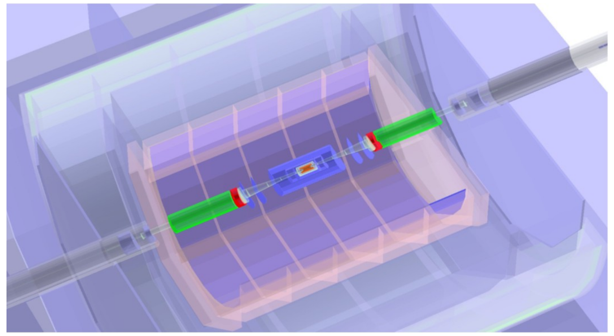
Detector systems – Target projects

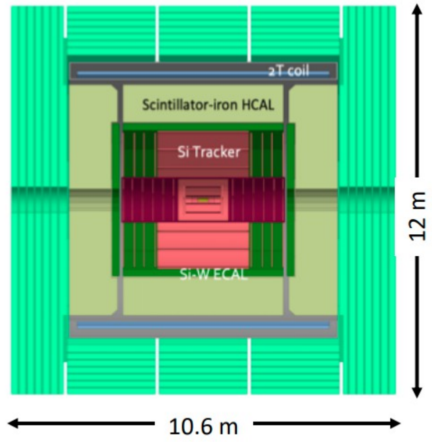
Detectors for Higgs Factories



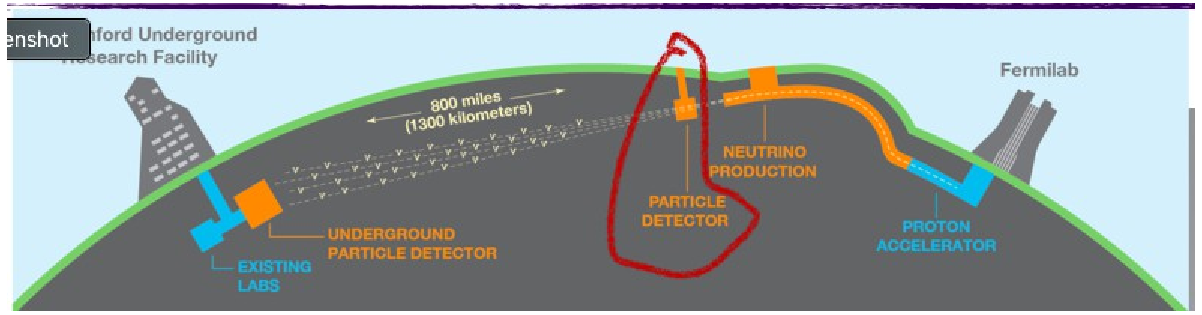








DUNE??



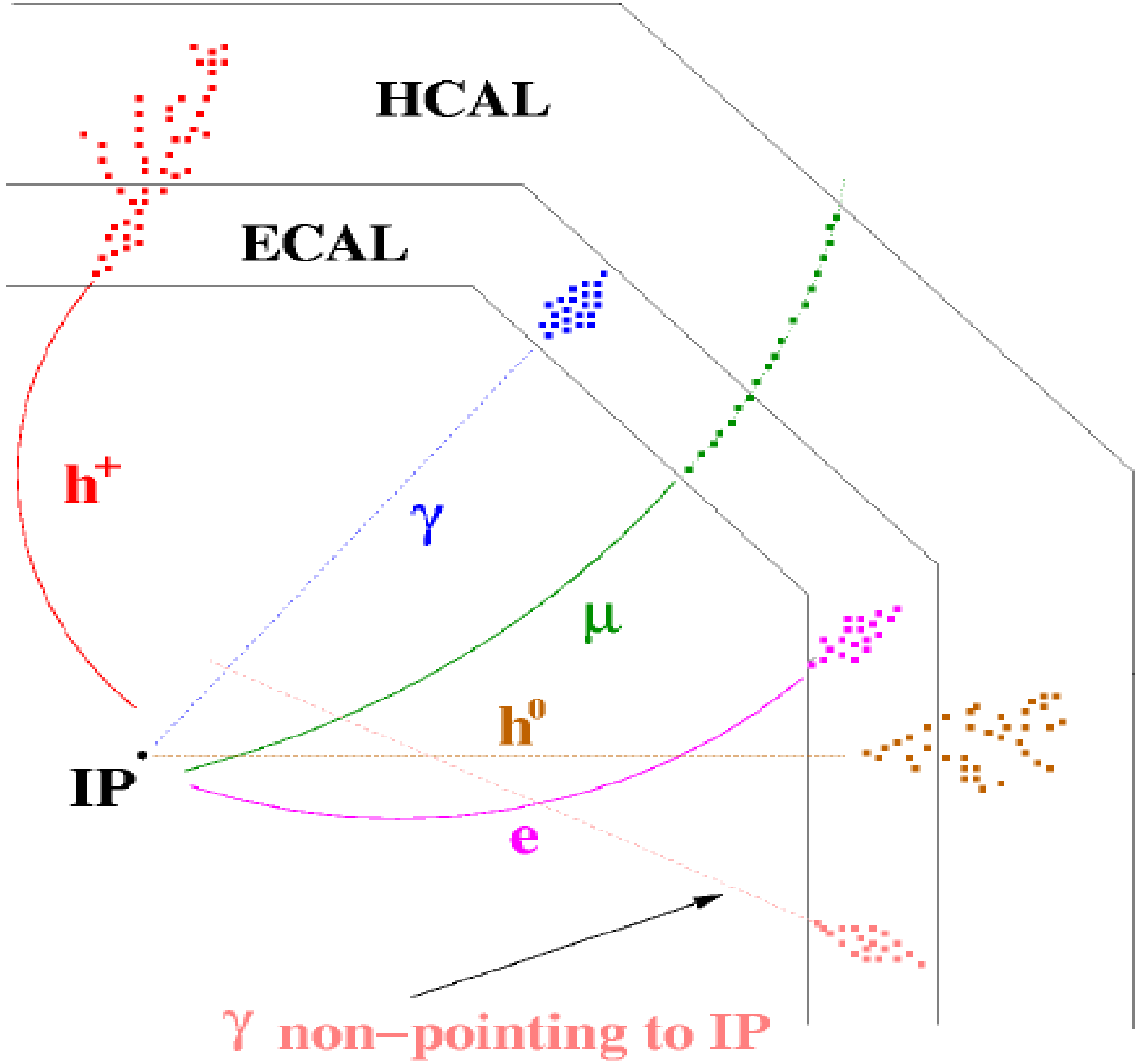
Near detector

QED, Dark Matter Experiments, see later

Particle Flow Detector

Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

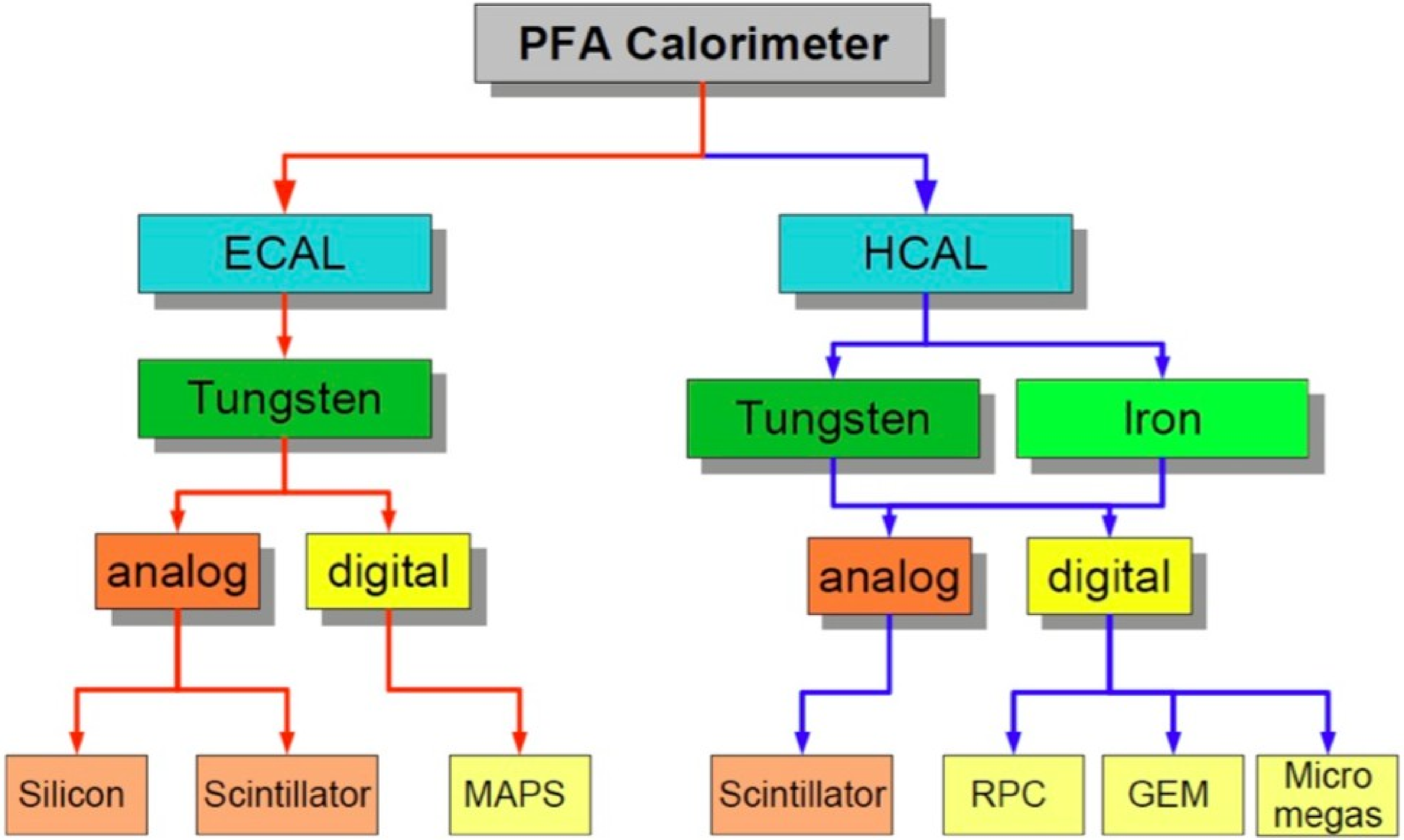
- large radius and length
  - ➔ to separate the particles
- large magnetic field
  - ➔ to sweep out charged tracks
- "no" material in front of calorimeters
  - ➔ stay inside coil
- small Molière radius of calorimeters
  - ➔ to minimize shower overlap
- **high granularity of calorimeters**
  - ➔ to separate overlapping showers



Particle flow as privileged solution for experimental challenges
=> Highly granular calorimeters!!!
Emphasis on tracking capabilities of calorimeters

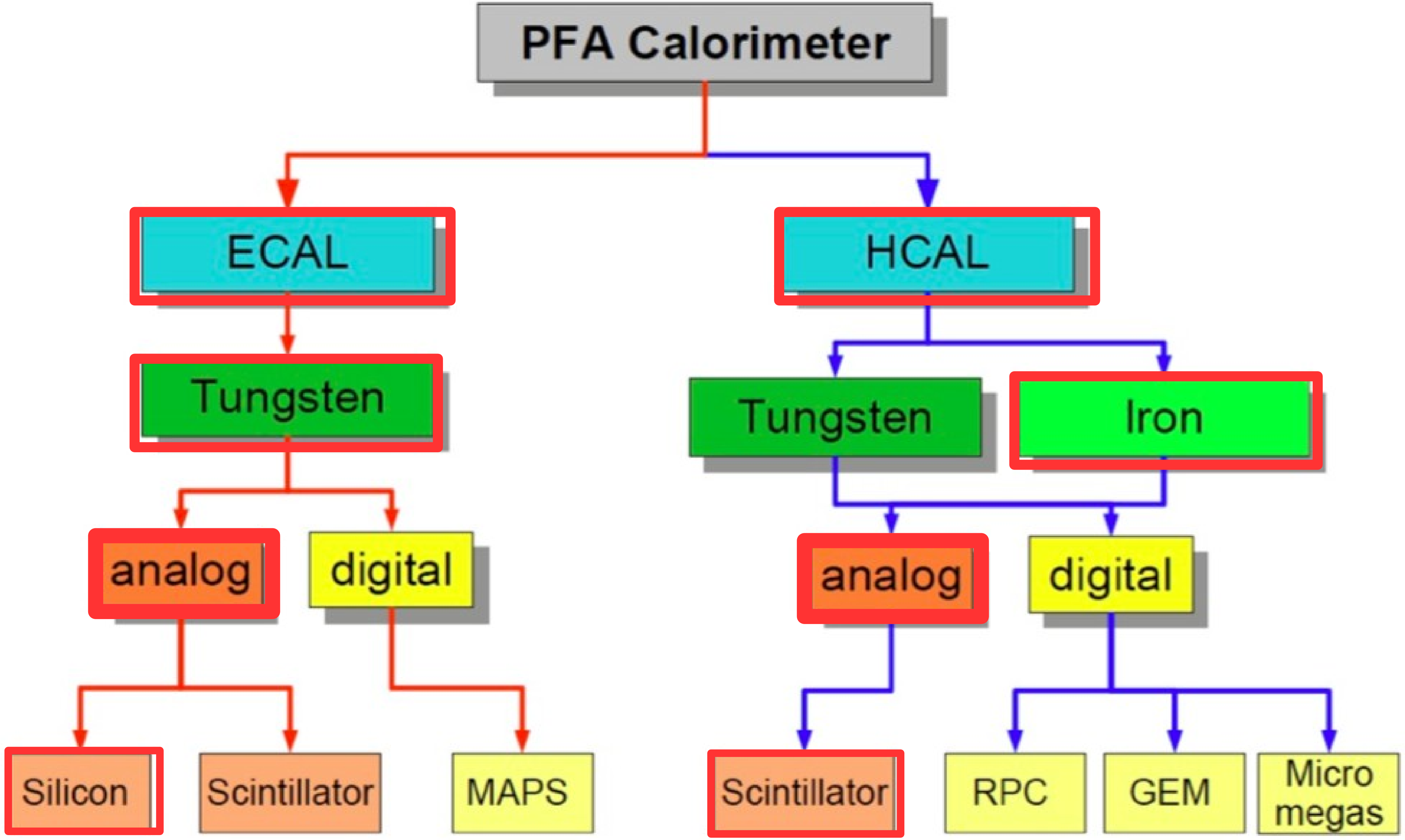
Calorimeters for PFA

Mainly organised within the: CALICE Collaboration

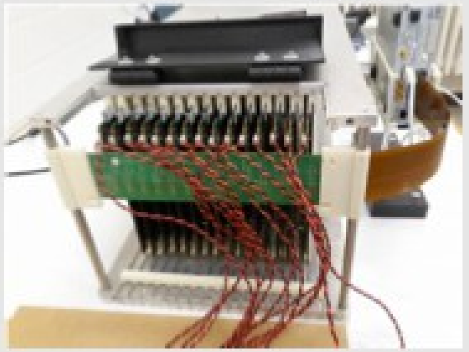
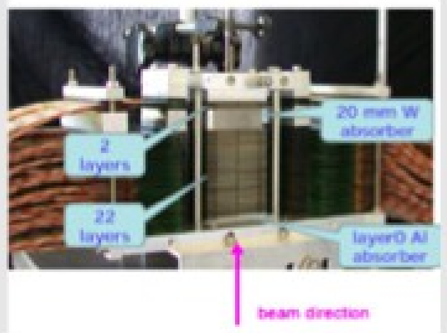


Calorimeters for PFA

Mainly organised within the: CALICE Collaboration



Summary CALICE Prototypes

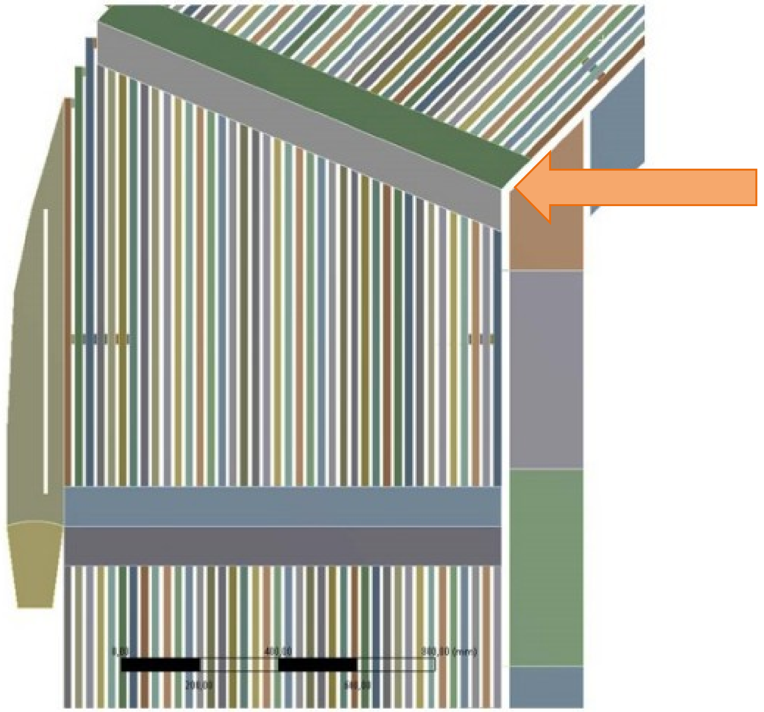
Si-W ECAL	(ALICE FoCAL)	[Scint-W ECAL]	AHCAL	SDHCAL
				
0,5×0,5 cm² ×15 (→30) Si layers + W	0,003×0,003 cm² × 24 MIMOSA layers + W	0,5×4,5 cm² ×30 Scint+SiPM lay. + SS	3×3 cm² × 38 Scint+SiPM lay. + SS	1×1 cm² × 48 layers GRPC + SS

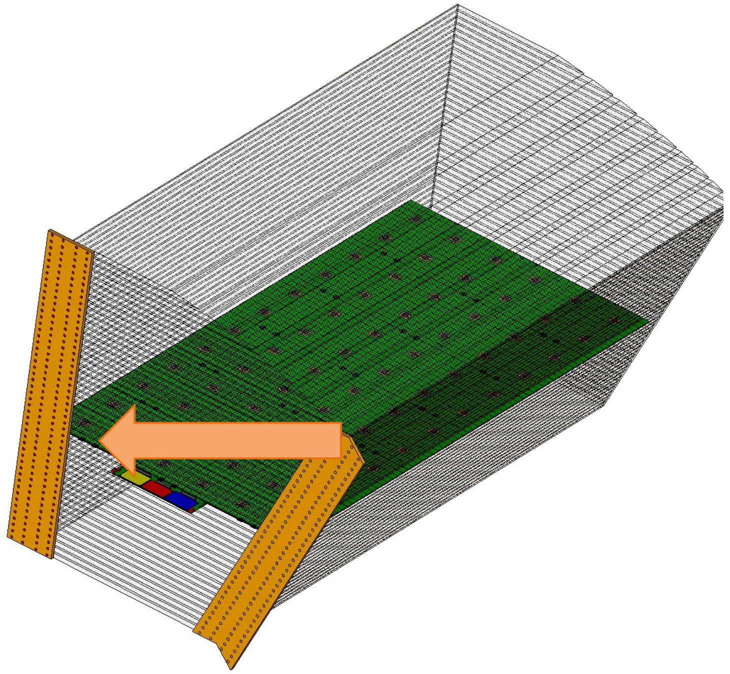
V. Boudry, FCC Workshop

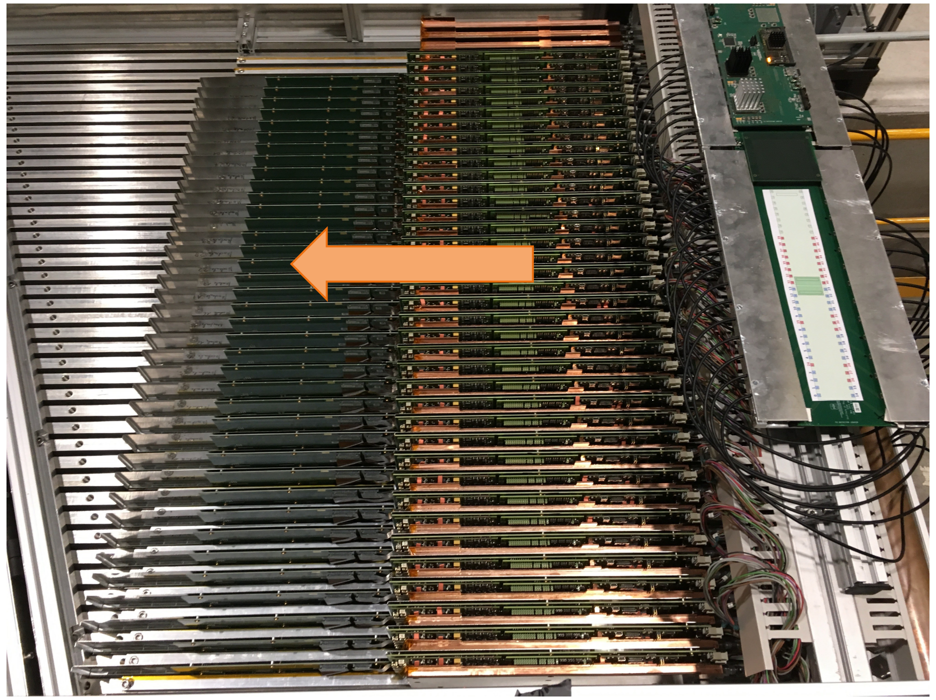
- Realistic dimensions
  - Structures of up to 3m
- Integrated front end electronic
- Small power consumption (Power pulsed electronics)

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)

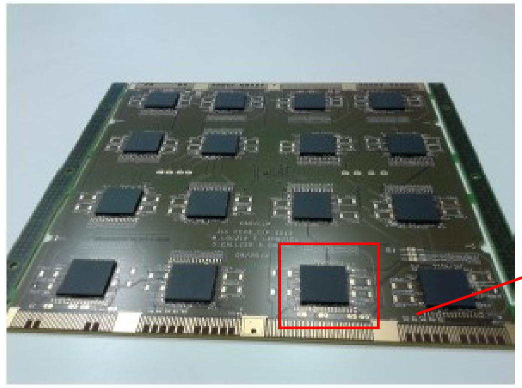




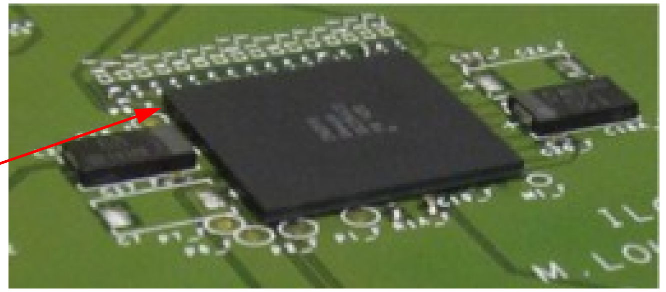


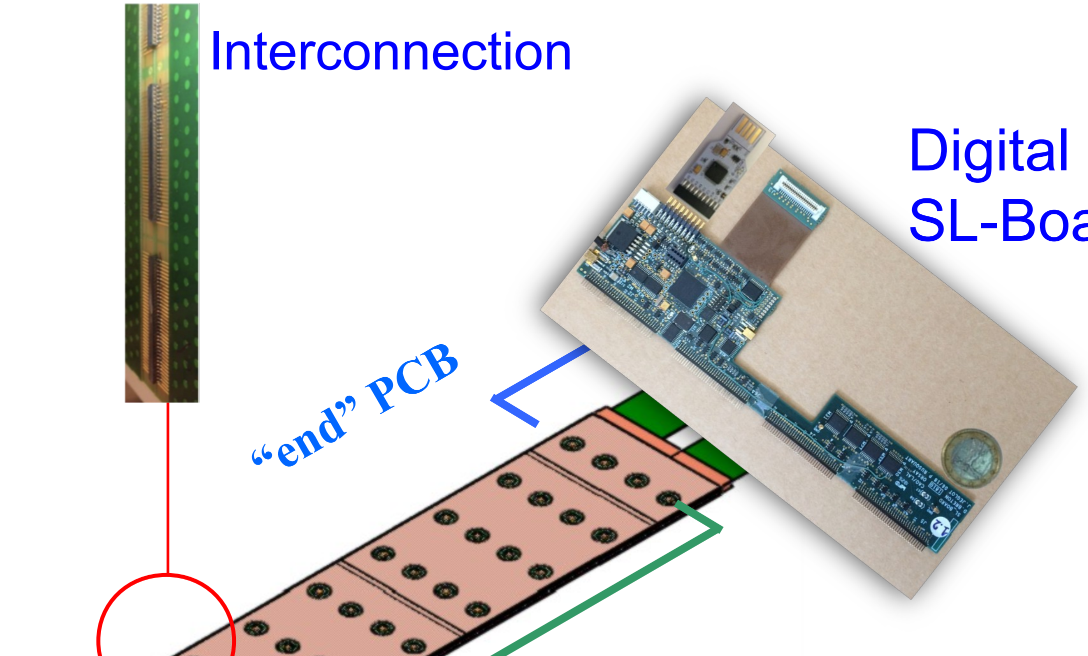
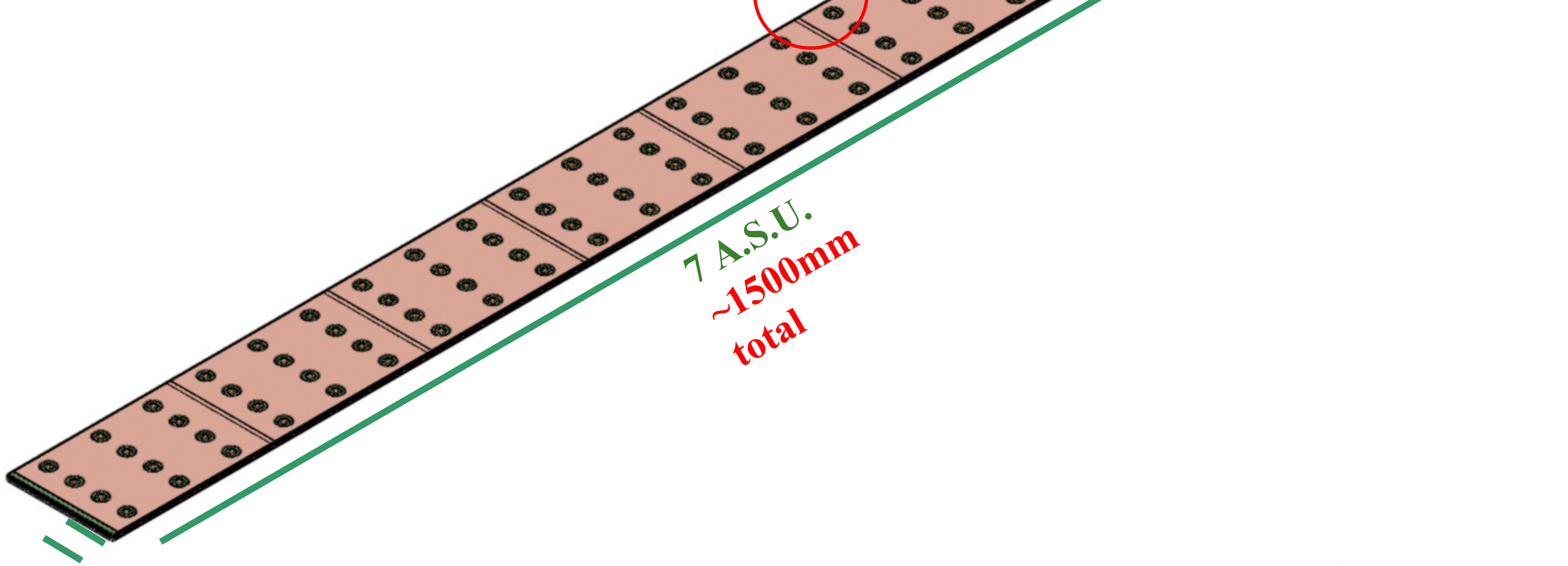
SiW ECAL – Elements of a (long) layer

ASIC+PCB+SiWafer
=ASU
Size 18x18 cm^2

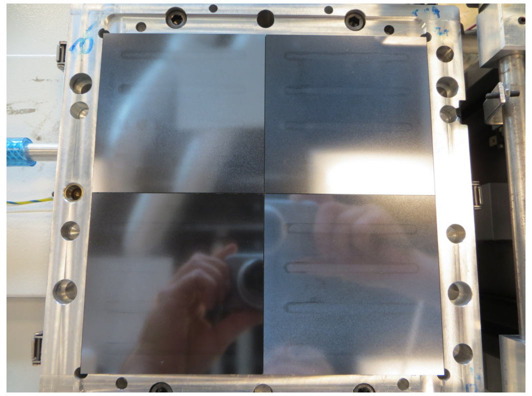


ASIC SKIROC2(a)
Wire Bonded or
In BGA package



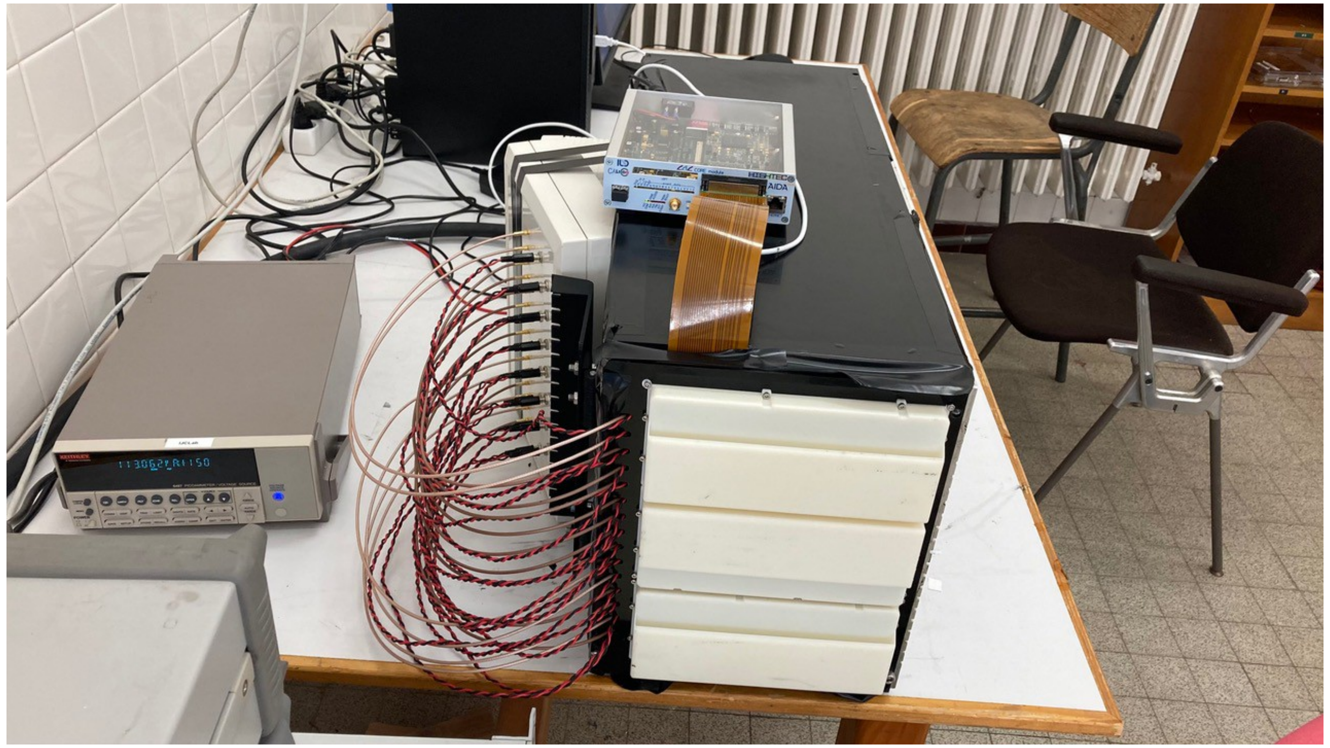



SiWafers
glued
onto PCB
Pixel size
5.5x5.5 mm^2



The beam test set ups consist of a **stack of short layers** built from one ASU and a readout card each

SiW ECAL: 2022



- 15 short layers equivalent to 15360 readout cells
  - Up to 21 X_0
  - Overall size 640x304x246mm^3
  - Flexible mechanical structure to adapt to beam conditions
  - Most of the layers produced 2016 - 2017
- Commissioned 2020-2022
  - ~450000 calibration constants for one ASIC feedback capa setting
- Testbeams (finally) in November 2021 and during 2022
- Mainly technical tests but also first real showers

“The FEV Zoo”

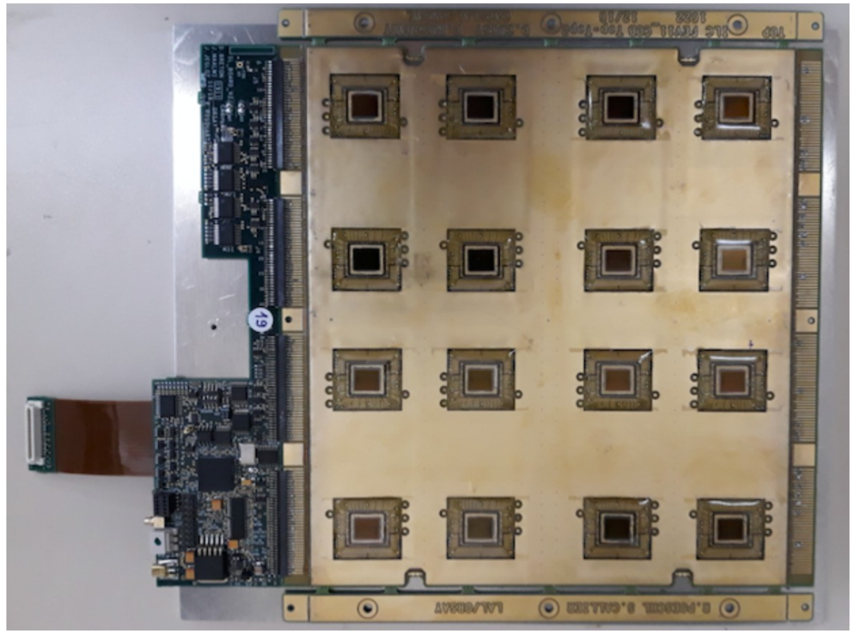
In recent years the SiW ECAL has developed and used several PCB variants

- To make sure that you don't get lost, here comes an introduction

FEV10-12

ASICs in BGA Package
Incremental modifications
From v10 -> v12
Main “Working horses” since 2014

FEV_COB

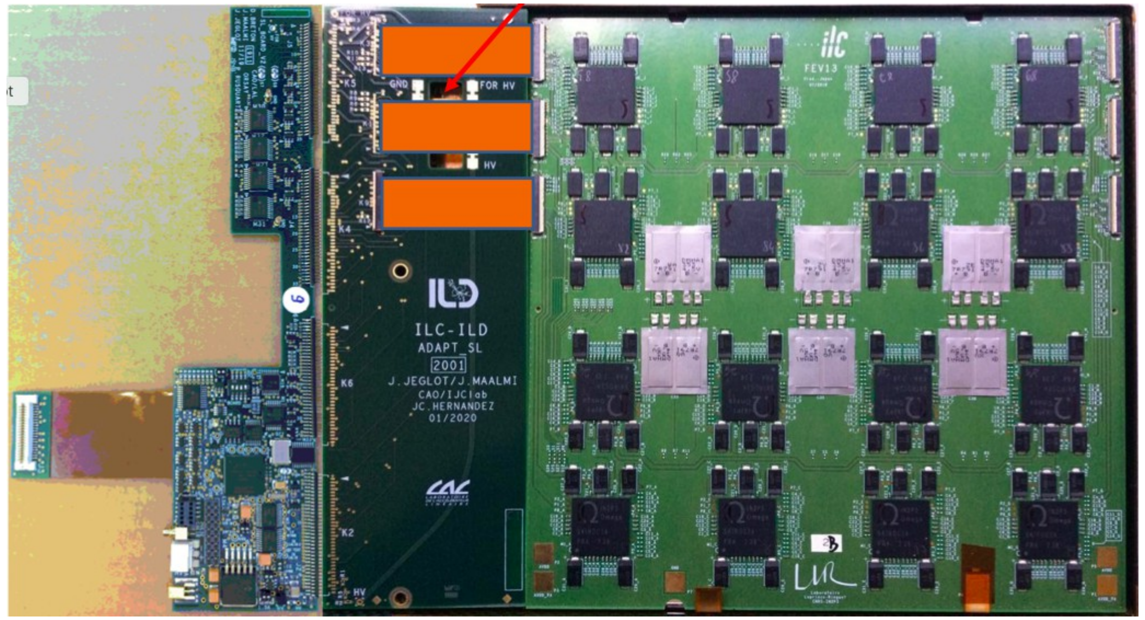


ASICs wirebonded in cavities

- COB = Chip-On-Board

Current version FEV11_COB
Thinner than FEV with BGA
External connectivity compatible with BGA based FEV10-12

FEV13

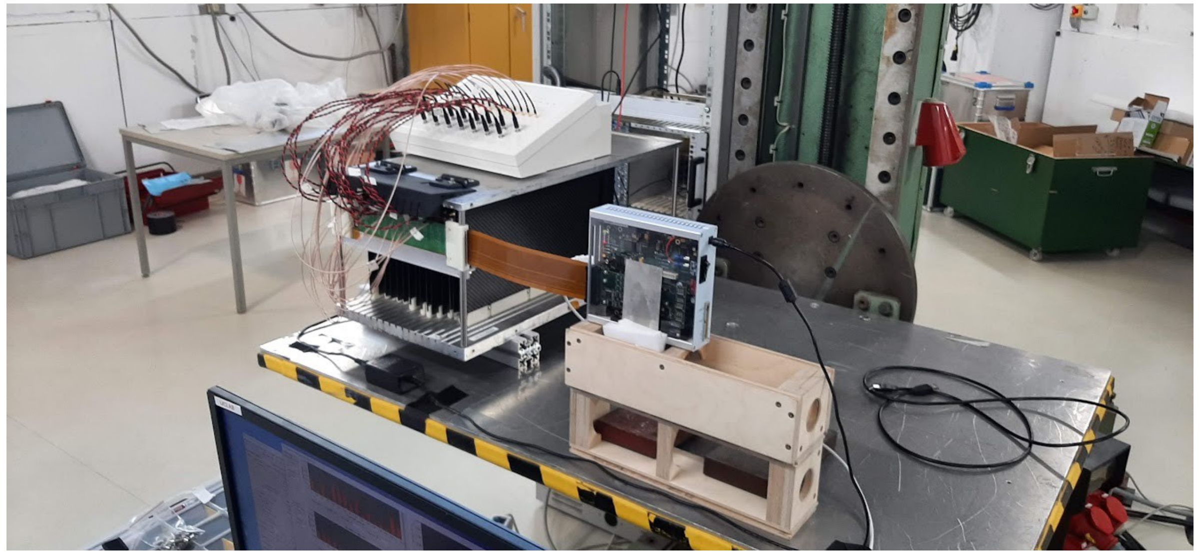


Also based on BGA packaging
Different routing than FEV10-12
Different external connectivity

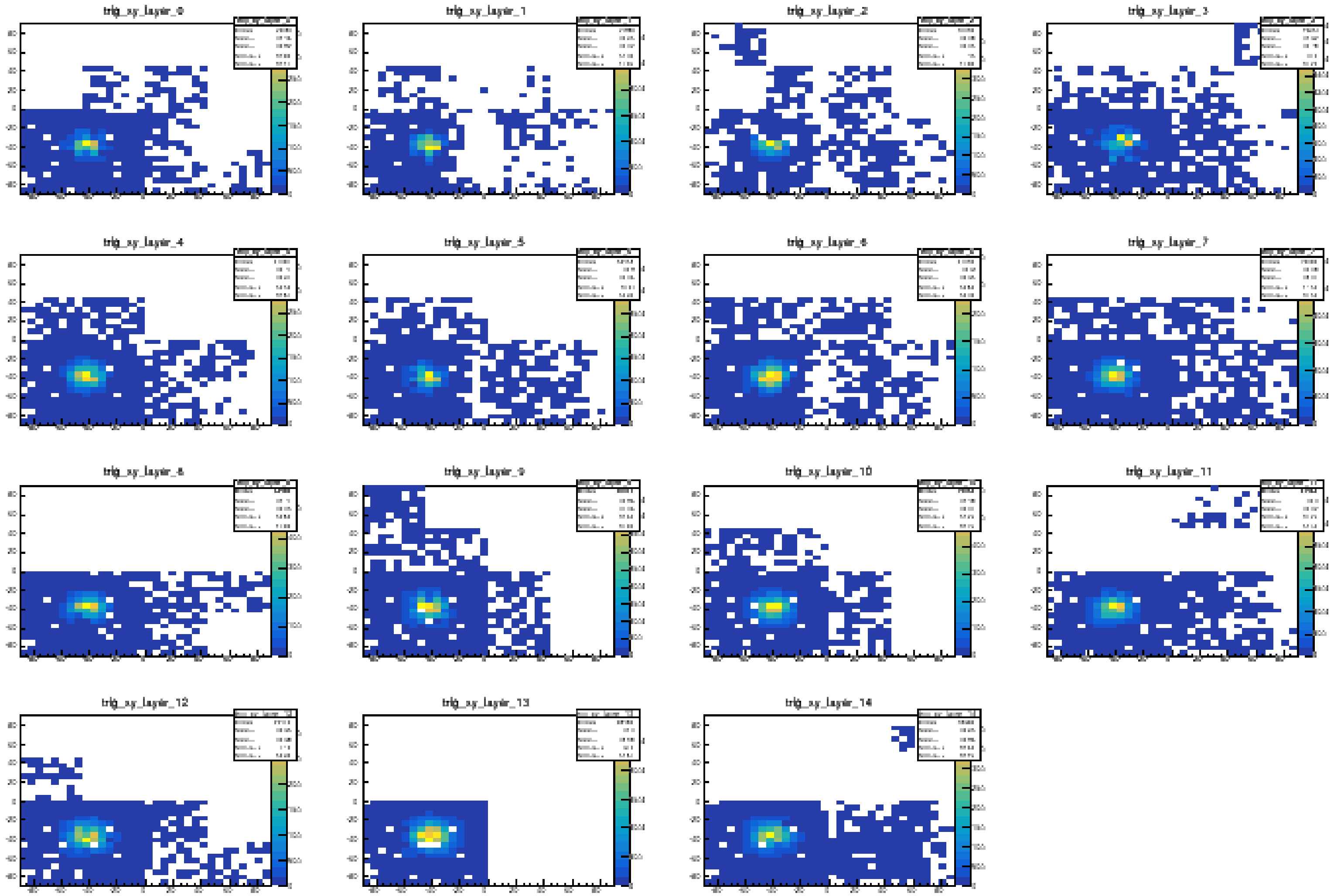
Current prototype (see later) is equipped with all of these PCBs

SiW-ECAL in beam test @ DESY

Detector Setup



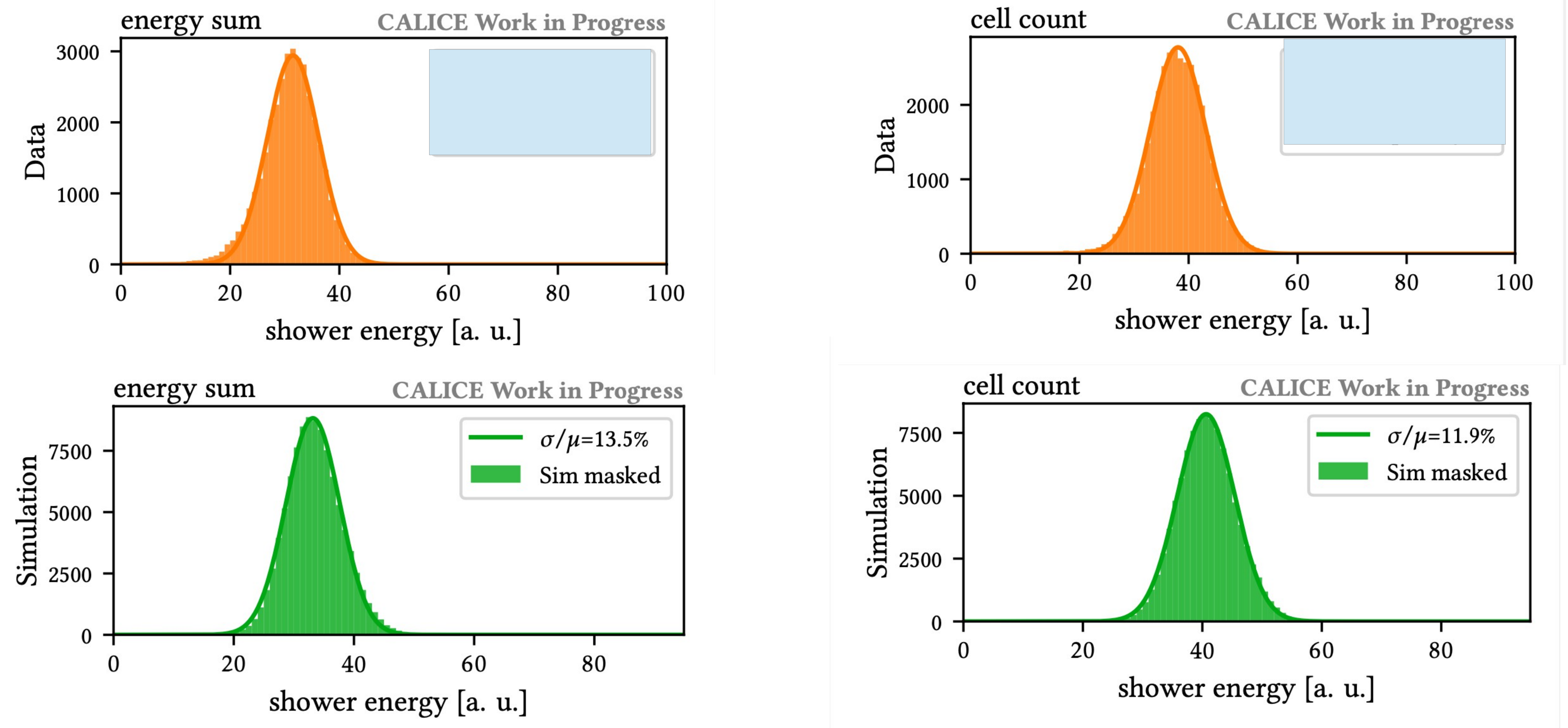
Detector in beam position



- Beam spot in 15 layers
- Analysis ongoing
- *For a summary of technical aspects of DESY and CERN see Instruments* 6 (2022) 75 • e-Print: 2211.07457 [physics.ins-det]

SiW-ECAL in beam test @ DESY – First results

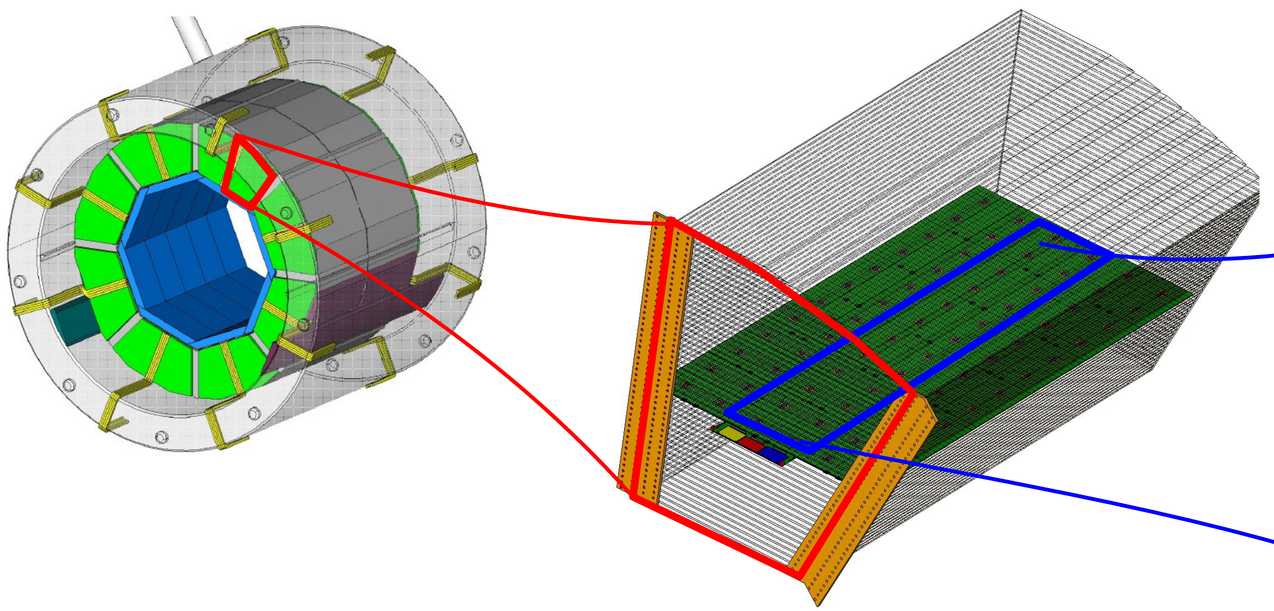
J. Kunath, F. Jimenez-Morales, SiW Ecal Analysis Meeting, 22/09/22

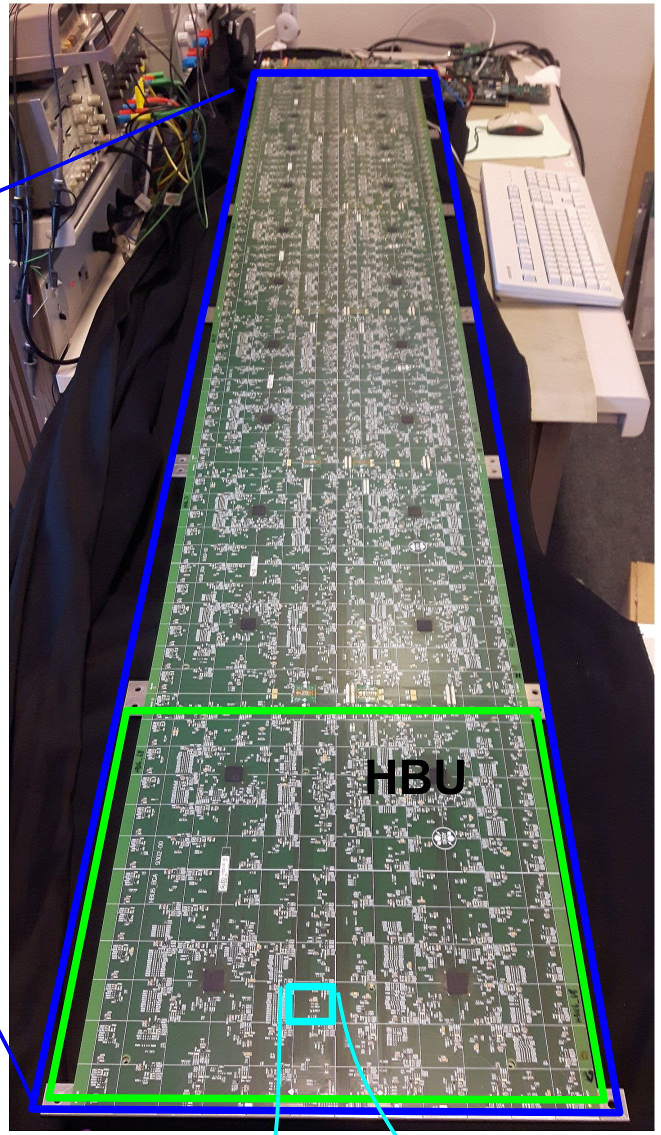


After proper filtering energy resolution in right ballpark for current prototype

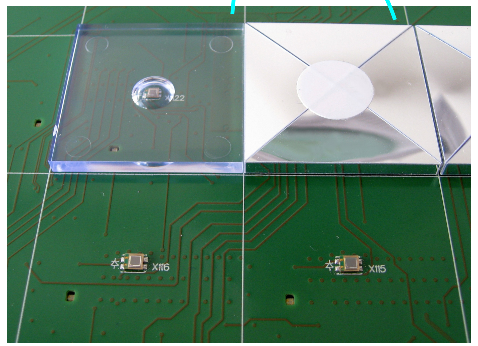
Convergence in agreement data/MC

AHCAL Technological Prototype



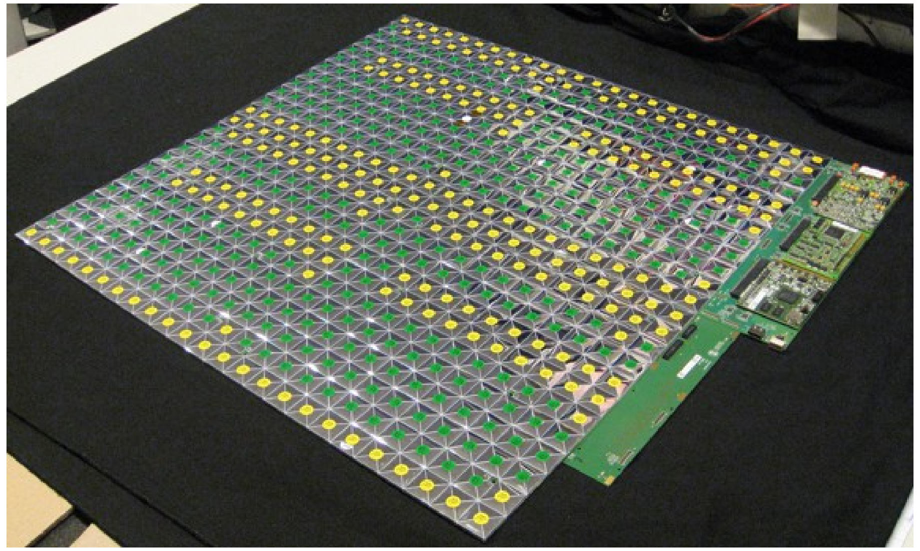


- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to full detector (~8 million channels)
- geometry inspired by ILD, similar to SiD and CLICdp
- HCAL Base Unit: 36*36 cm2, 144 tiles, 4 SPIROC2E ASICs
  - slabs of 6 HBUs, up to 3 slabs per layer



AHCAL Technological Testbeam Prototype

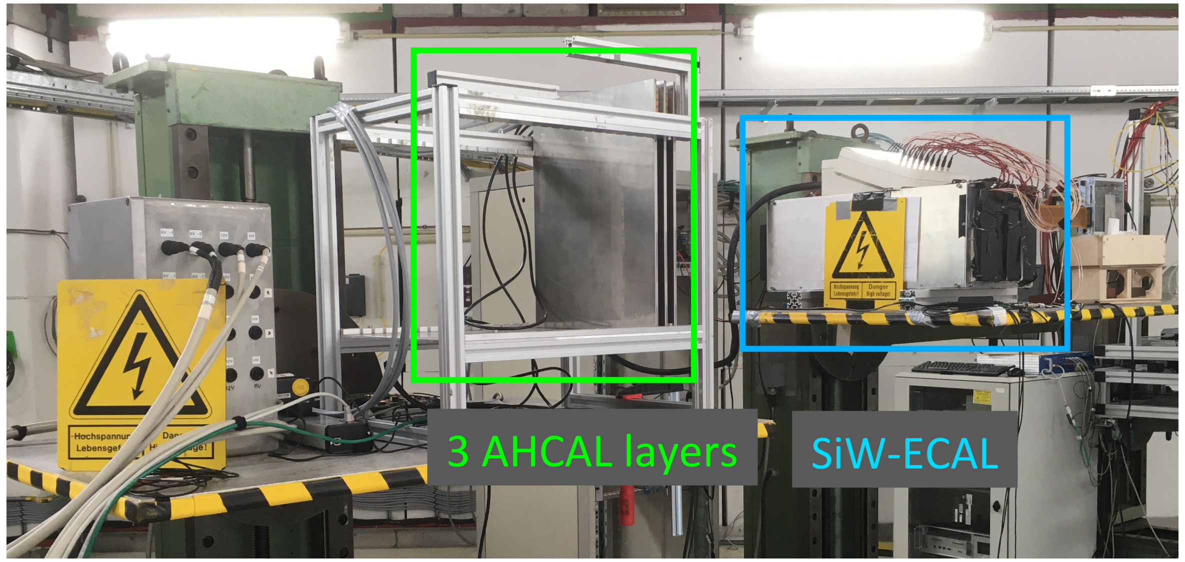
- Large enough to contain hadron showers
  - 38 active layers of 72*72 cm²
  - 4 HBUs per module
  - in total: 608 SPIROC2E ASICs, **~22000 channels**
  - SiPMs: Hamamatsu S13360-1325PE
- All modules interchangeable
- Built with scalable production techniques in ~2 years
- Operated in beam tests with muons, electrons and pions at CERN SPS in 2018 and 2022
  - 3 weeks of beam time
  - Collected O(100) mio events
  - Very stable running
  - **Nearly noise free**
  - **< 1 per mille dead channels**



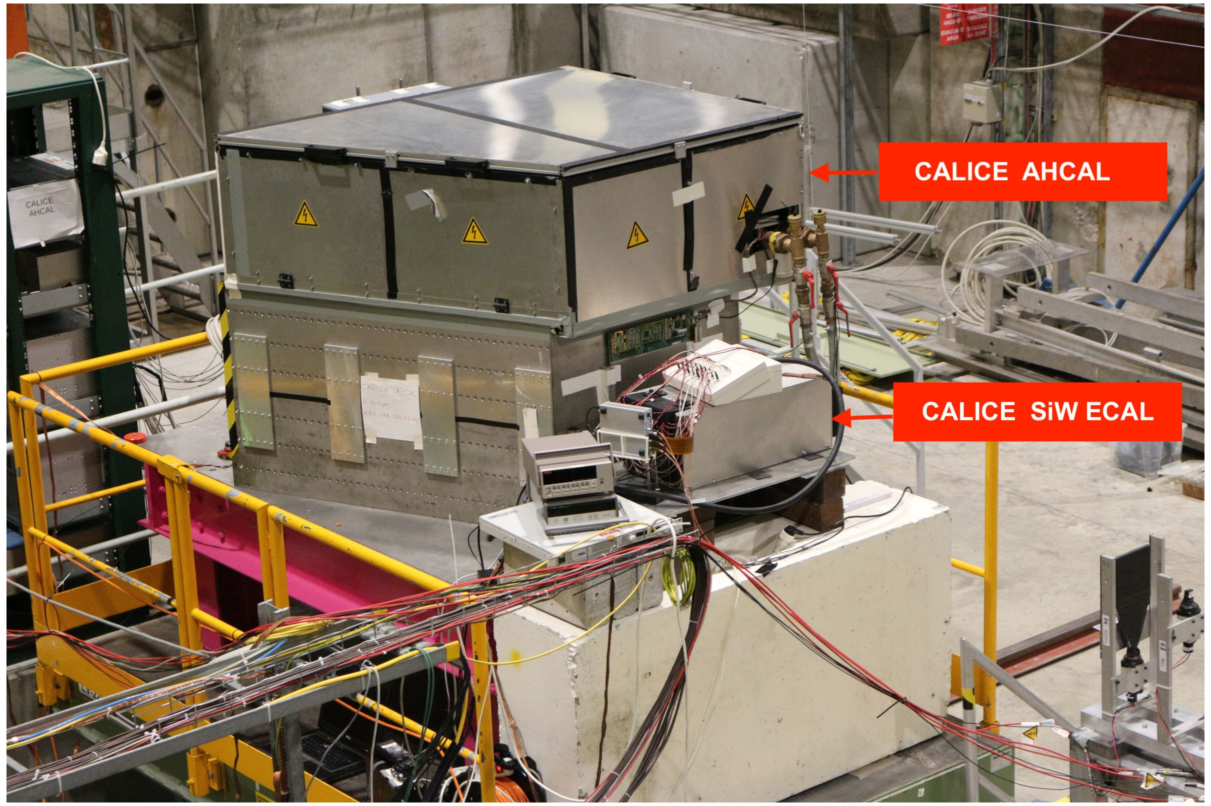
Common beam tests I

CALICE meets DARK MATTER LAB

SiW-ECAL + AHCAL DAQ test @ DESY in March 2022



Common setup at CERN June 2022



15360 + 22000 (full analogue) readout cells

Successful synchronisation of data recorded with SIW-ECAL and AHCAL

- First step of ***knowledge transfer*** on compact readout system to AHCAL → AIDA innova

Common running makes full use of EUDAQ tools (developed within European projects)

Common data analysis ongoing

Data sets and event Displays

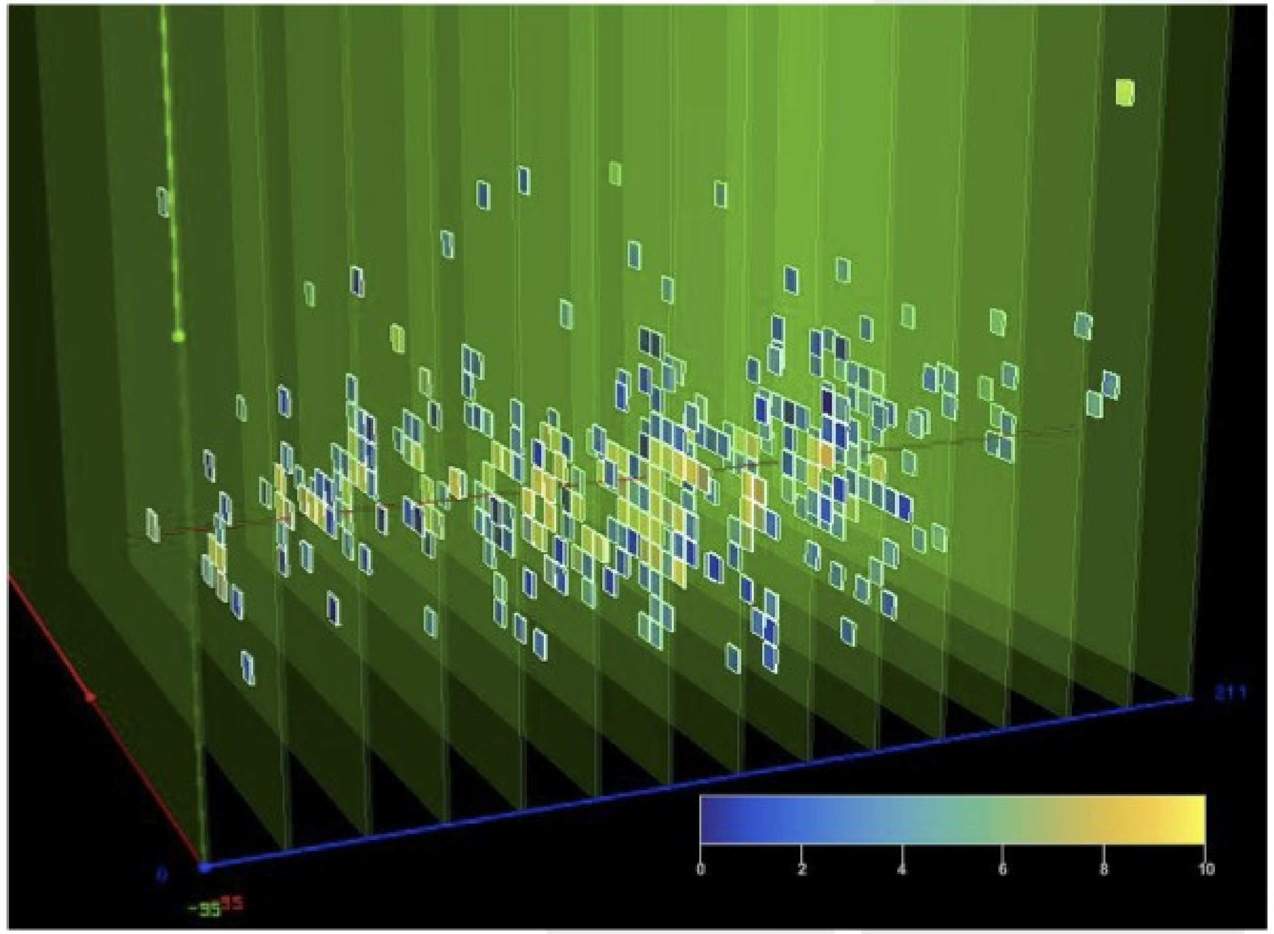


Fig. SiWECAL Electron 40 GeV

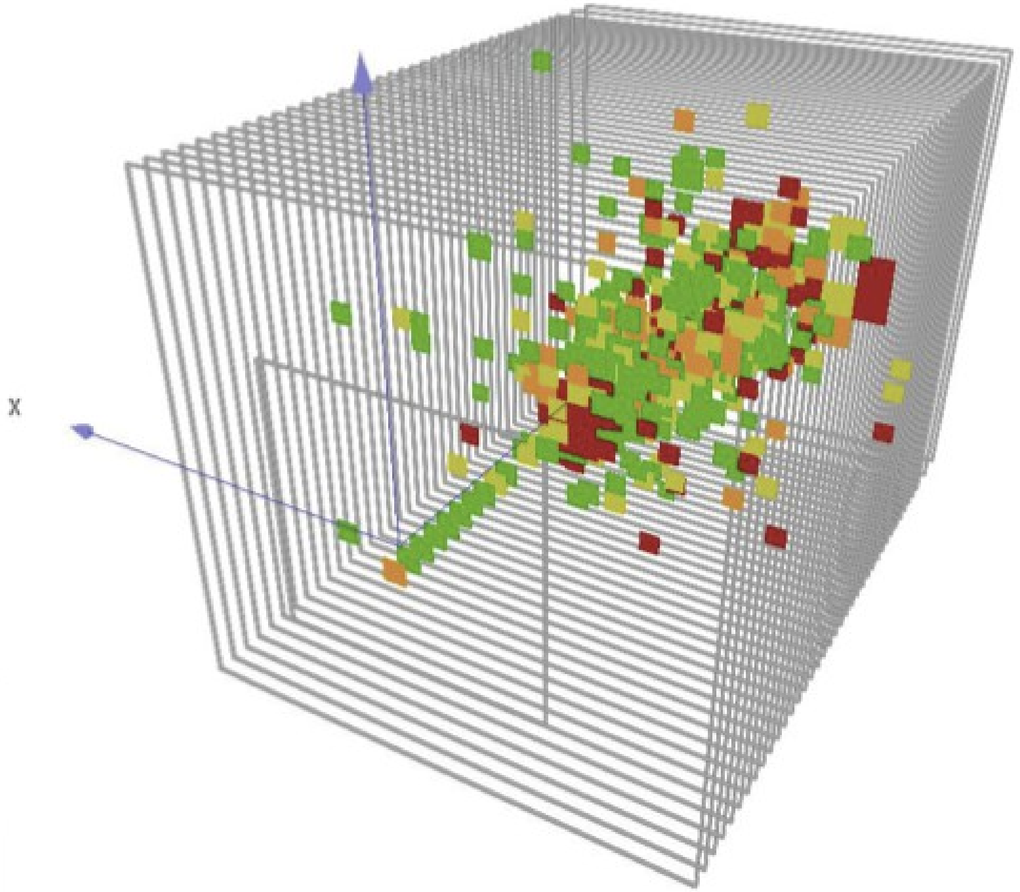
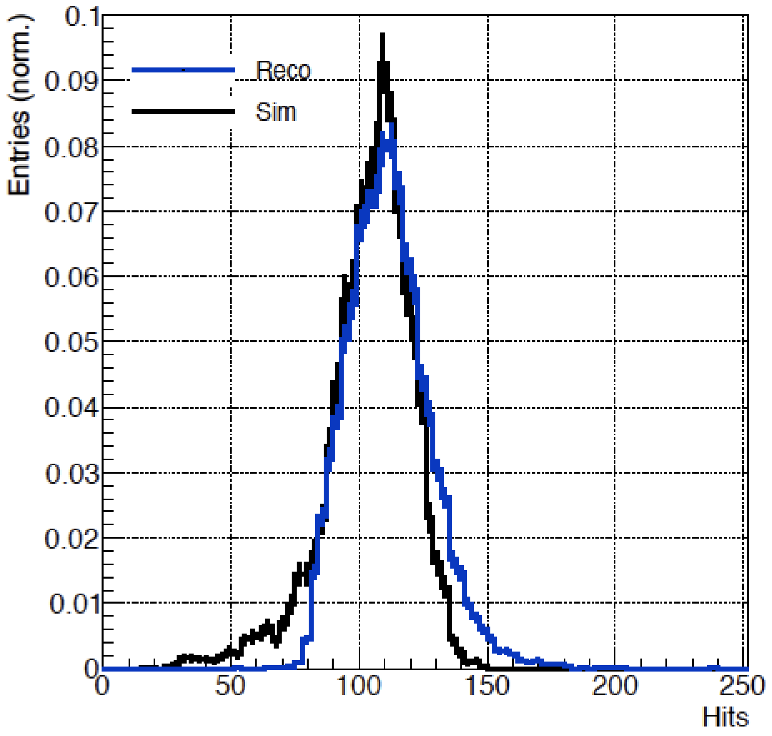


Fig. AHCAL Pion 106 GeV

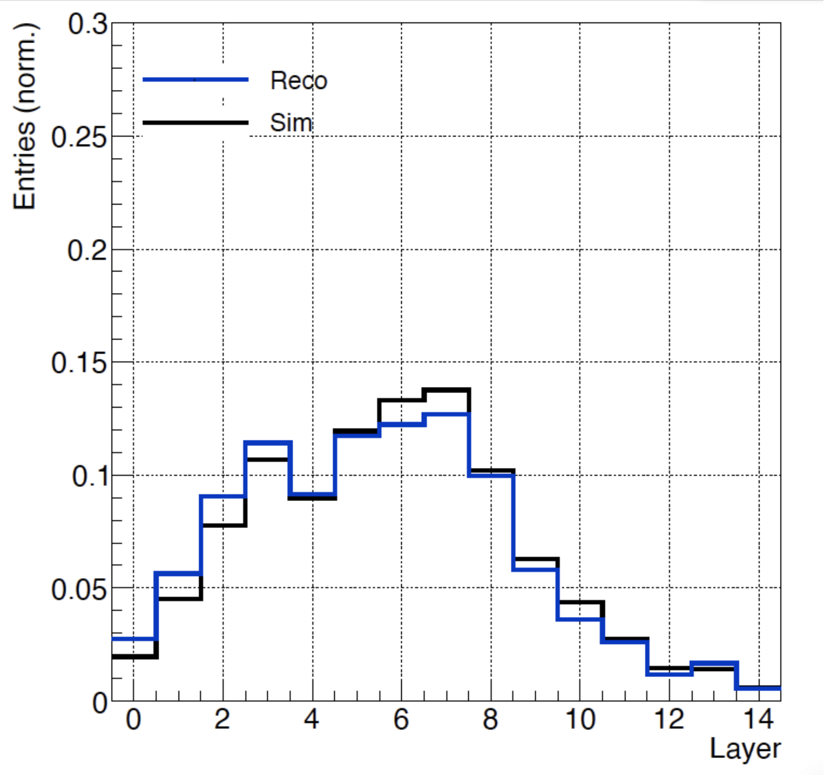
- Combined beam test deliver unique date sets (e.g. Higher transversal granularity in SiW Ecal than in HGCAL)
  - Extremely valuable for GEANT4 validation
- Still separate analyses and event displays
  - Goal should be to combined analyses and combined event displays
    - Work has started
    - Will benefit from new groups (outside F and D) and new F and D funding (see below)

CERN Data – Analysis 10 GeV e-

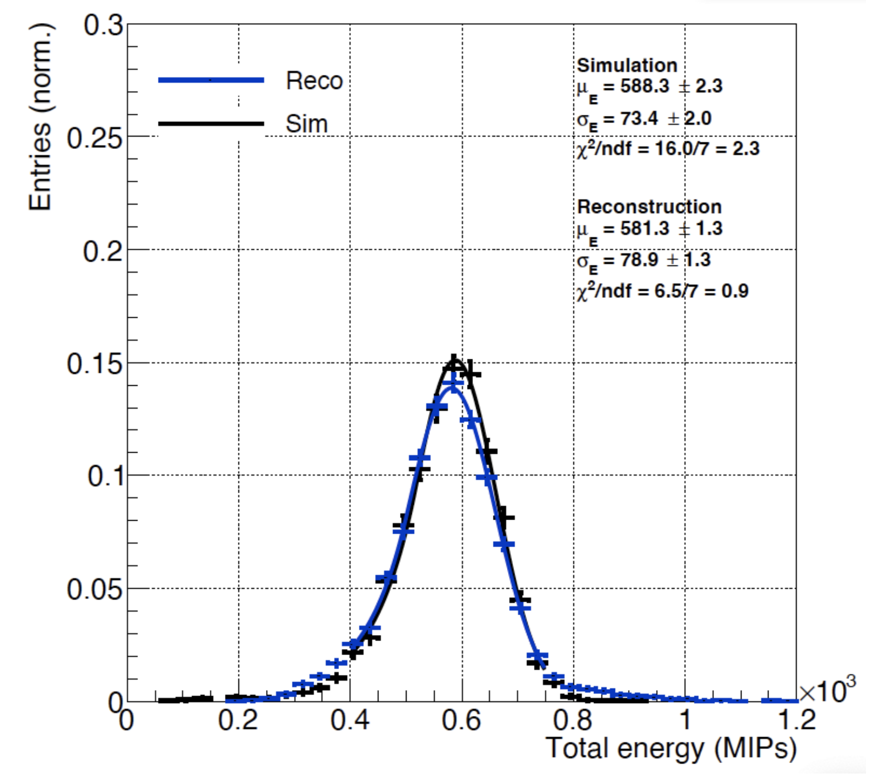
Total #of hits



Hits/layer



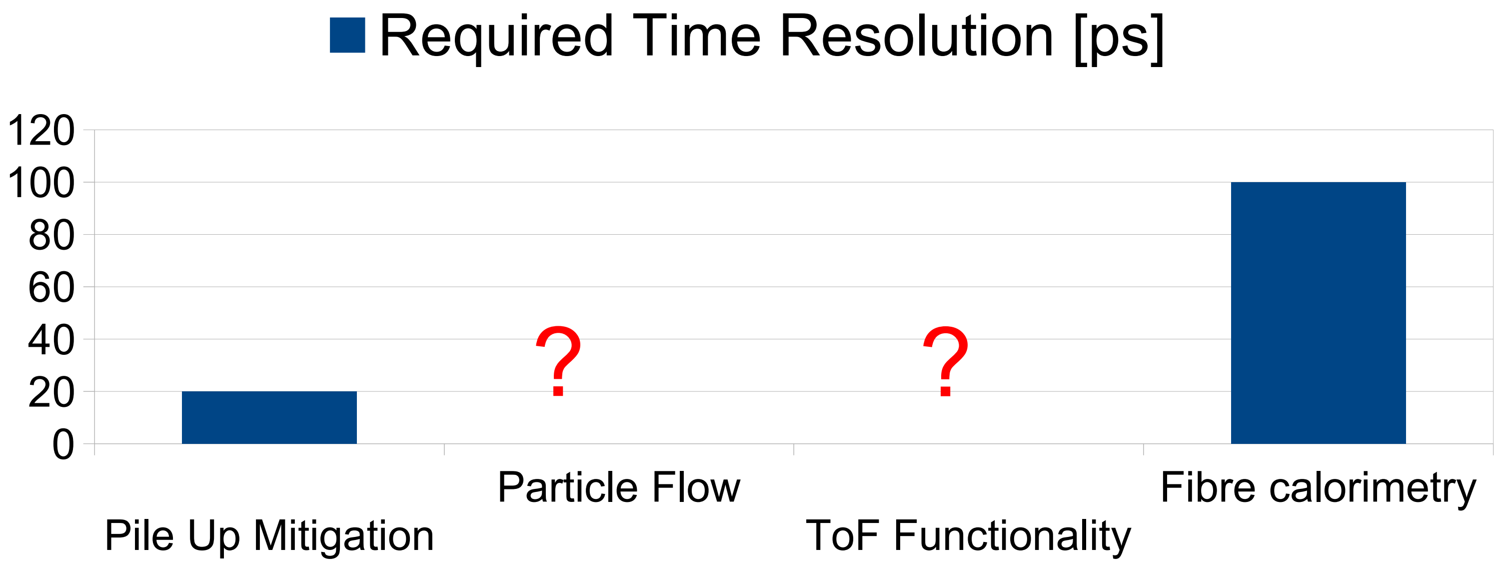
(Total Energy)/MIPS



- Reasonable agreement betqeen data and MC
- Energy resolution in expected ball park
- ILD: $\sigma E/E \sim 15\%/\sqrt{E}$ here ~12-13%
  - reason: ~factor 2-3 worse sampling ratios, “small” number of hits

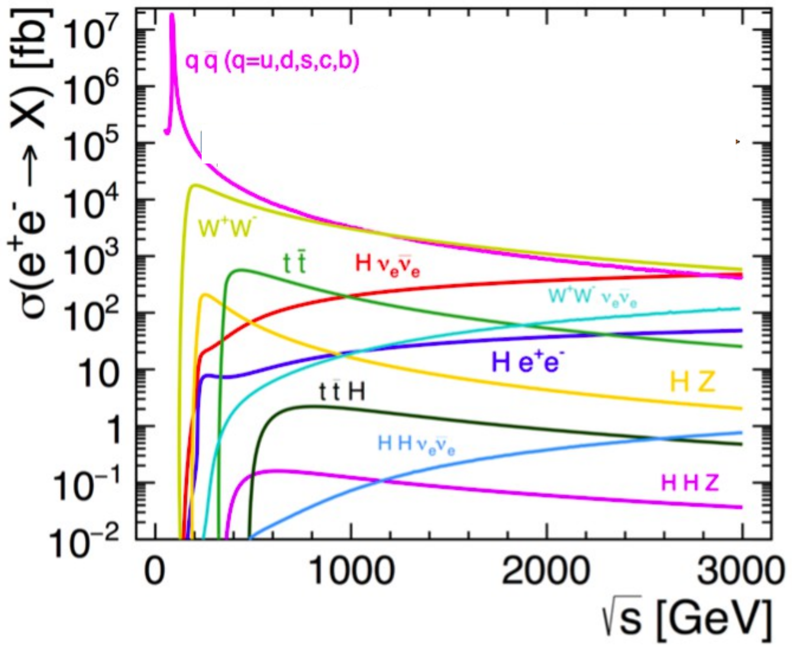
Timing ?

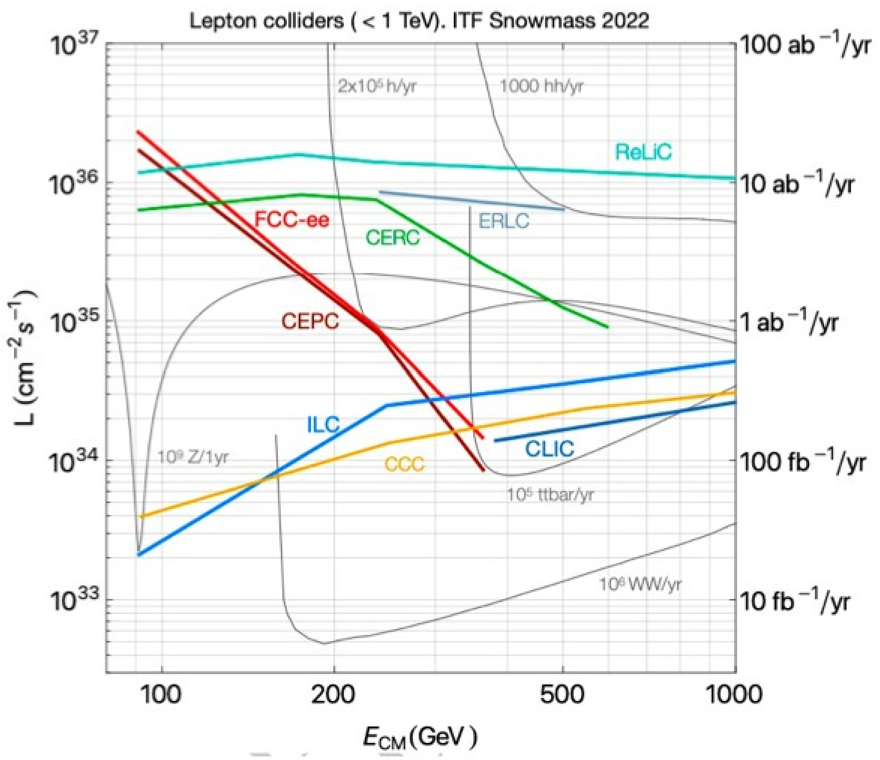
- Timing is a wide field
- A look to 2030 make resolutions between 20ps and 100ps at system level realistic assumptions
- At which level: 1 MIP or Multi-MIP?
- For which purpose ?
  - Mitigation of pile-up (basically all high rate experiments)
  - Support of PFA – unchartered territory
  - Calorimeters with ToF functionality in first layers?
    - Might be needed if no other PiD detectors are available (rate, technology or space requirements)
    - In this case 20ps (at MIP level) would be maybe not enough
  - Longitudinally unsegmented fibre calorimeters



- A topic on which calorimetry has to make up it's mind
  - Remember also that time resolution comes at a price -> High(er) power consumption and (maybe) higher noise levels

Future Colliders - Impact of event rates





High energy e+e- colliders:

- Physics rate is governed by strong variation of cross section and instantaneous luminosity
- Ranges from 100 kHz at Z-Pole (FCC-ee) to few Hz above Z-Pole
- (Extreme) rates at pole may require other solutions than rates above pole

"Tendencies" from discussions in last weeks

- Event and data rates have to looked at differentially
  - In terms of running scenarios and differential cross sections
  - Optimisation/development for Higgs Factory different than for Z factory

CALO5D

AAPG2023	CALO5D		Funding instru.
Coordinated by:	Roman Pöschl	36 months	ANR Requested Funding
Scientific evaluation panel CE31. Axe G.2, Physique subatomique et astrophysique			

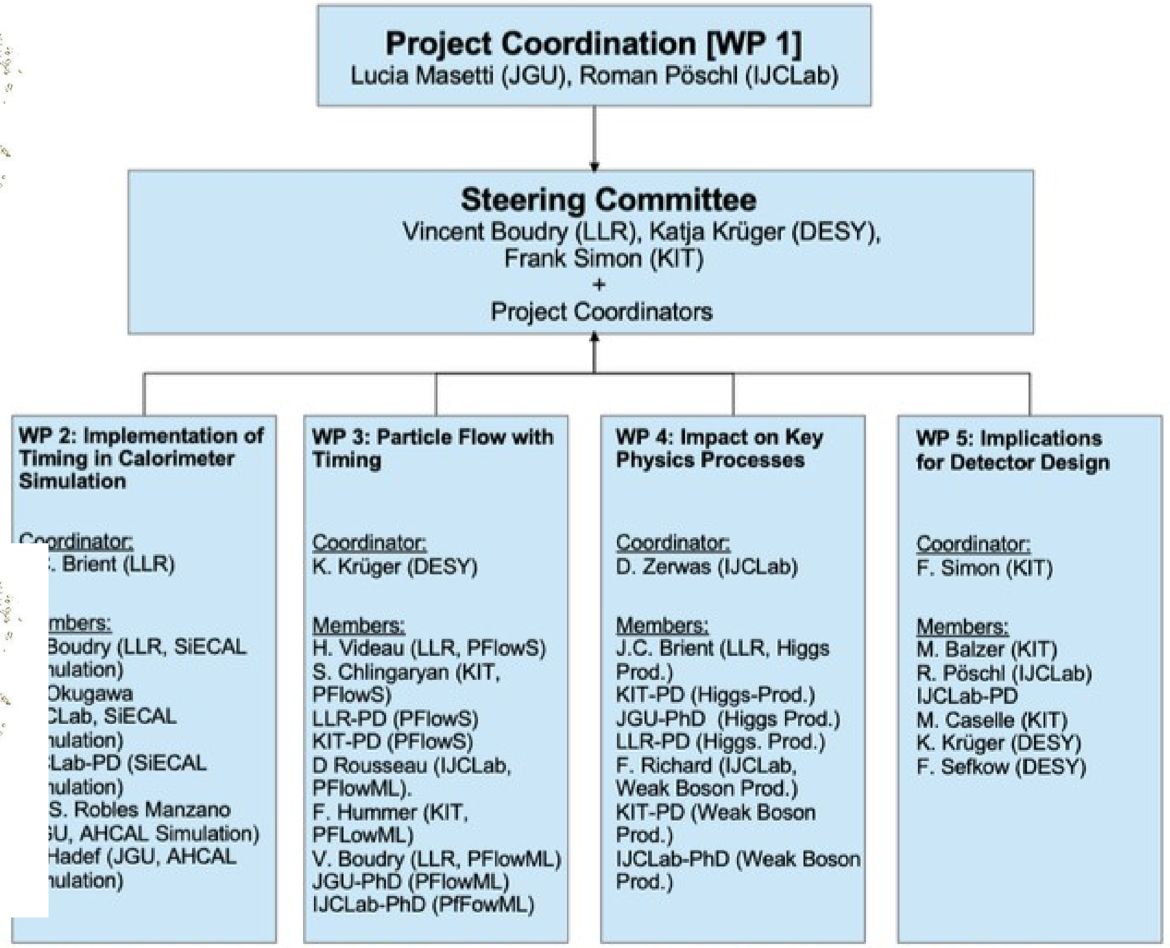


Figure 2: Organisational chart of CALO5D. Note, that the two upper levels will be in charge of Work Package 1.

- Joined French ANR – German DFG Project on "CALOrimetry in 5 Dimensions
- Approved on October 19th for a total sum of around 1M EUR (about 50/50 between F and D)
  - Mainly postdocs, PhD Students and missions
- DMLAB explicitly mentioned as follow-up forum

CALO5D – Workpackges and Delivrables

- Work Package 1: Management
  - Deliverable (Month 3): Project Webpage (M3)

- Work Package 2 : Implementation of Timing in Calorimeter Simulation (Lead LLR)
  - Deliverable (Month 12): Documented algorithms that implement timing in the simulation of granular calorimeters.

- Work Package 3: Particle Flow with Timing (Lead DESY)
  - Classical cut based PFA and application of Machine Learning
  - Deliverable (Month 30): Improved particle flow algorithms using space-time and energy information.

- Work Package 4: Impact on Key Physics Processes (Lead IJClab)
  - Higgs Boson prodiuction and weak boson production
  - Deliverable (Month 36): Demonstrate the benefit for the physics analyses from improved PFA and hence from timing. The results will be presented in the form of scientific documents such as pre-prints or conference proceedings.

- Work Package 5: Implications for Detector Design (Lead KIT)
  - Deliverable (Month 36): The deliverable of this task is a scientific document in the form of an arXiv pre-print that summarises hardware requirements for the realisation of a detector that meets the timing requirements formulated in Work Packages 3 and 4.

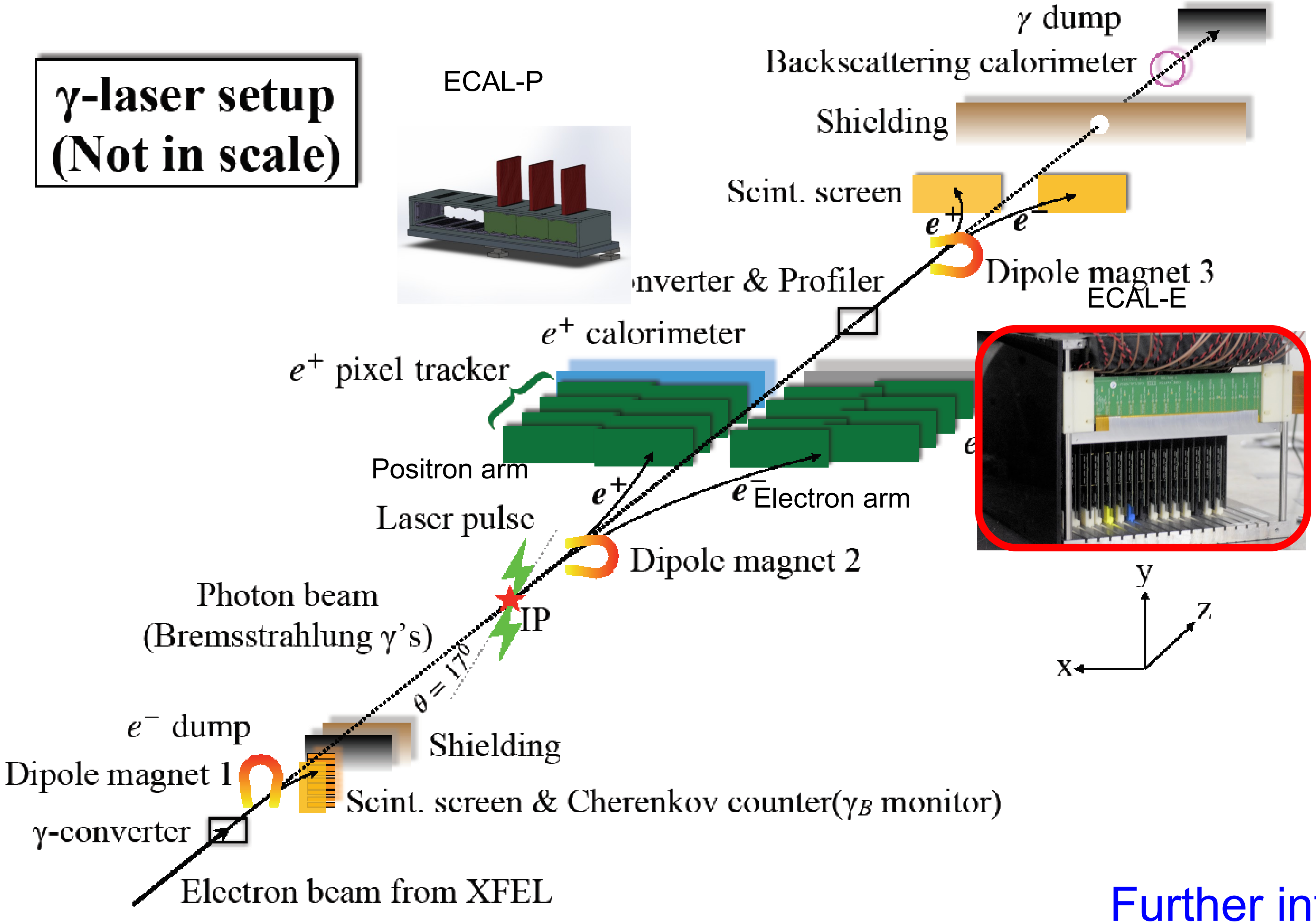
CALO5D – Timeplan

	Year 1	Year 2	Year 3	ANR-DFG
WP 1 Management				
WP 2 Implementation of Timing into Calorimeter Simulation				
Task 2.1				IJCLab-PD
Task 2.2				
WP 3 Particle Flow with Timing				
Task 3.1				LLR-PD, KIT-PD, JGU-PhD, IJCLab-PhD
Task 3.2				
WP 4 Impact on Physics Processes				
Task 4.1				IJCLab-PhD, KIT-PD, LLR-PD, JGU-PhD
Task 4.2				
WP 5 Implications for Detector Design				IJCLab-PD

- Three years project
- Start foreseen around February 2023
- Search for talented young researchers starts now
- Mainly analysis but there is also room
- For people imterested in hardware
- Role of PD and PhD see timetable

"Early Applications" of CALICE Technologies - LUXE

Laser Und Xfel Experiment – QED in extreme fields



CALICE meets LUXE

Granular calorimeters in positron and electron arms of spectrometer

- Our focus ECAL-E
- Main application electron measurement of Breit-Wheeler process in γ-laser setup
- Could also be used in early LUXE phase in case of delays of ECAL-P
  - *Dark photon search next to γ dump could be further option*
  - *Note here that already our short layers would have (almost) sufficient acceptance*
- Ideal application(s) of CALICE SiW Ecal technological prototype

Further interest by dark photon experiments EBES (KEK) and Lohengrin (Uni Bonn)

New PCB Version

New FE boards

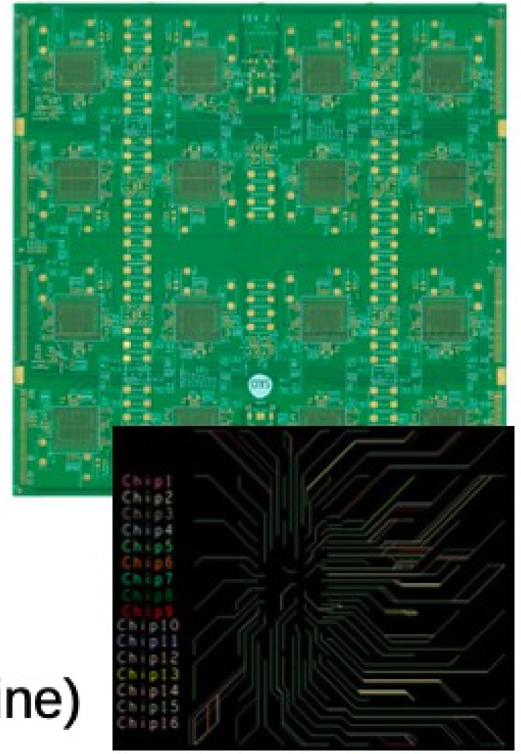
LLR, IJCLab, LPNHE, OMEGA

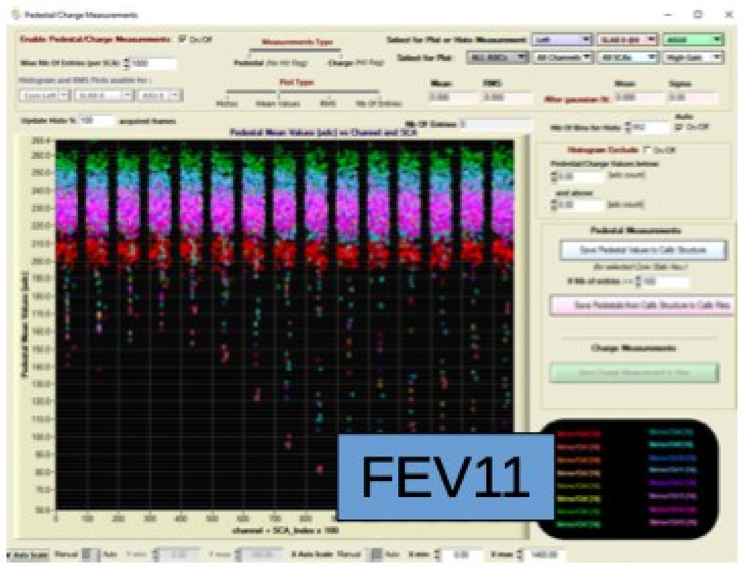
Improvements:

- Power distributions
  - Local power regulation
  - Local High Voltage filtering & Supply
- Signal distribution (buffering), data paths
- Monitoring (single ID, temp, probe analogue line)
- ASIC shielding/routing

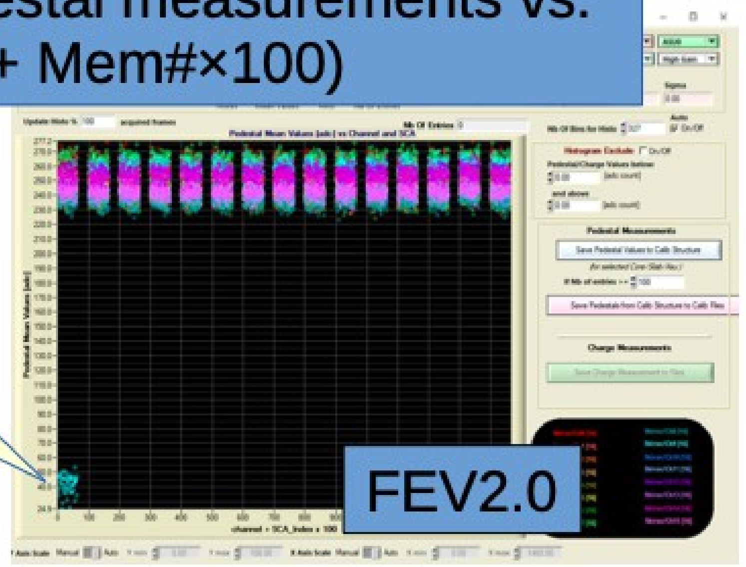
Status:

- pre-version 2.0 tested, minor corrections needed
  - Noise uniformity dramatically improved (ex: outliers in thr. / 20 !)
- version 2.1 produced, … in metrology
  - before cabling, 2nd metrology, gluing, …
  - All material available : ASICs being tested





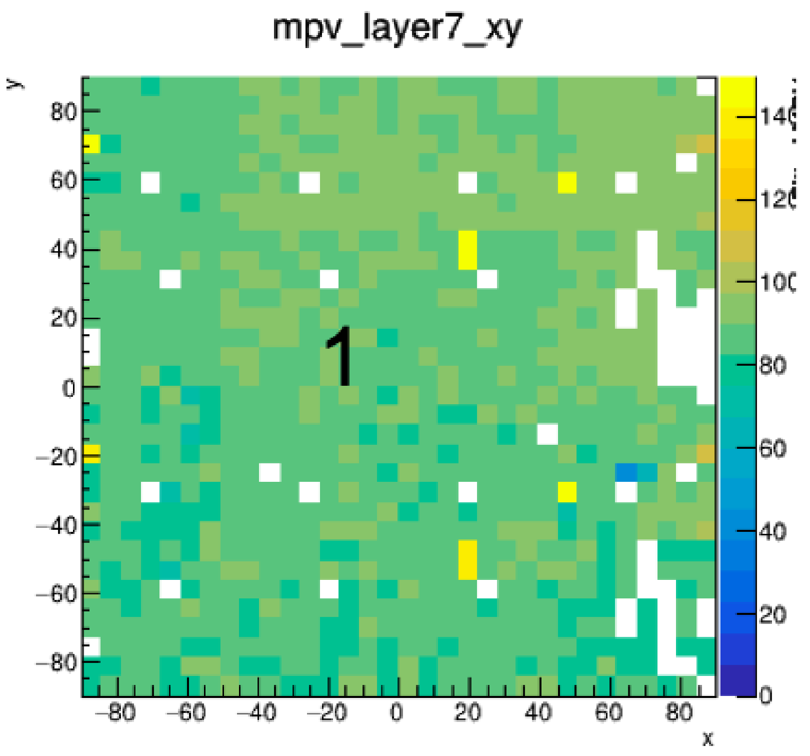
Pedestal measurements vs. Ch# + Mem#×100)

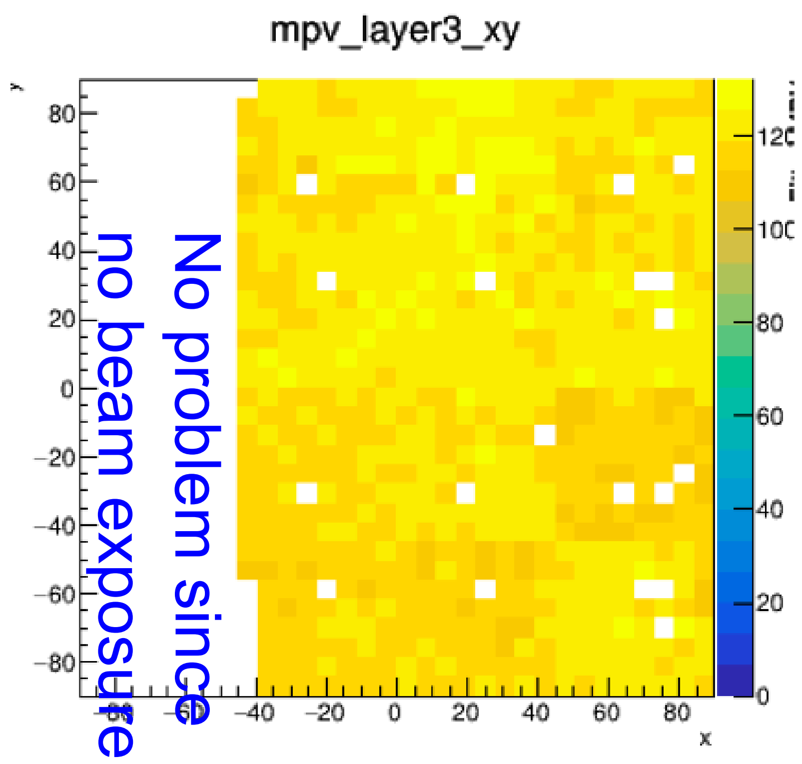


Goal: build 15 layer stack for 2024 based on these Boards

SiW-ECAL beam tests - Further observations

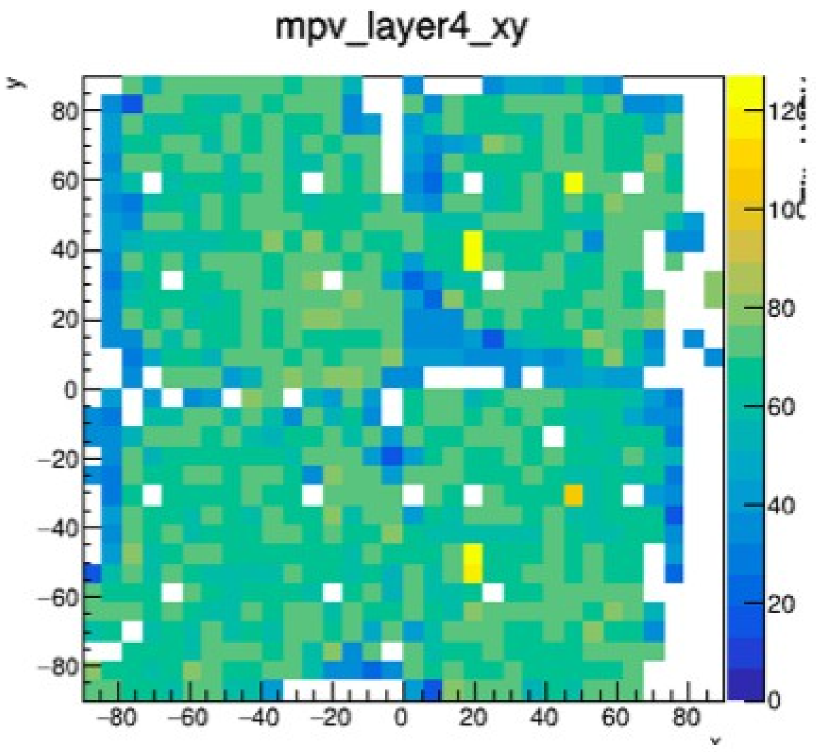
Adrian Irles





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

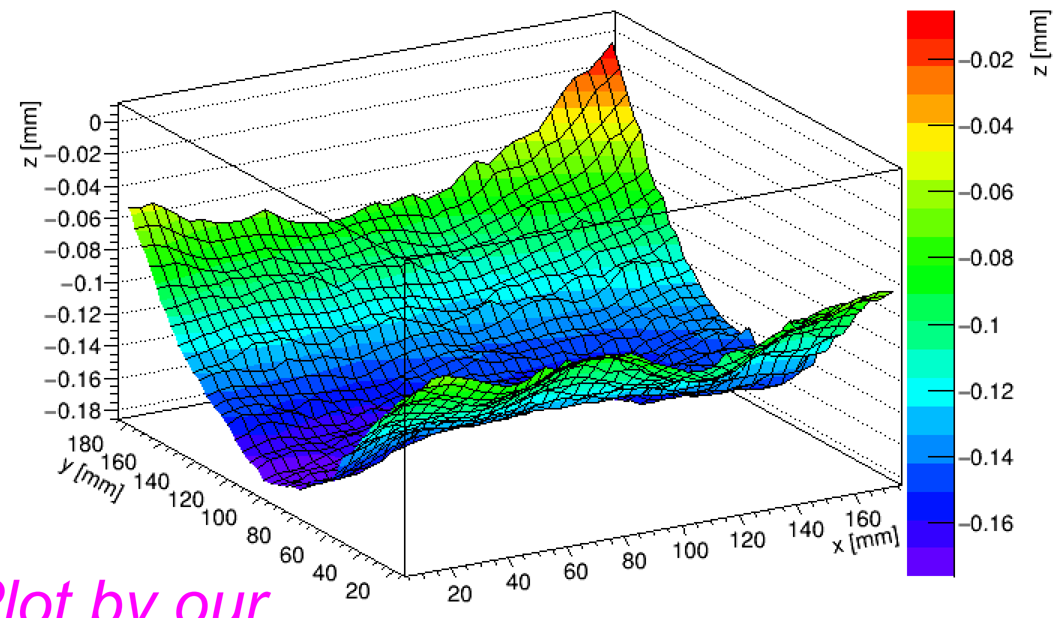
- Partially even no response at all, in particular at the wafer boundaries
- Not seen in 2017, degradation observed during 2018/19
- To be understood, **about to start with dedicated aging studies**

Since Summer 2022 access to the different stages of the ASICs

- => analogue probes, <u>major</u> debugging tool

Systematic studies to avoid delamination – “Hybridisation”

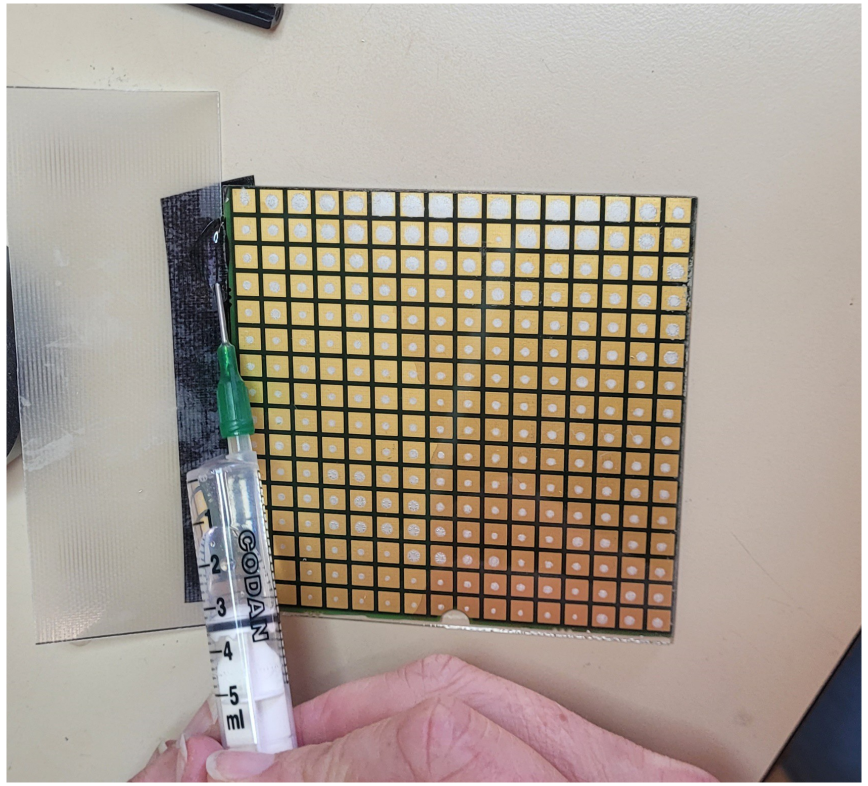
Control of PCB Deformation



Plot by our Director D. Zerwas

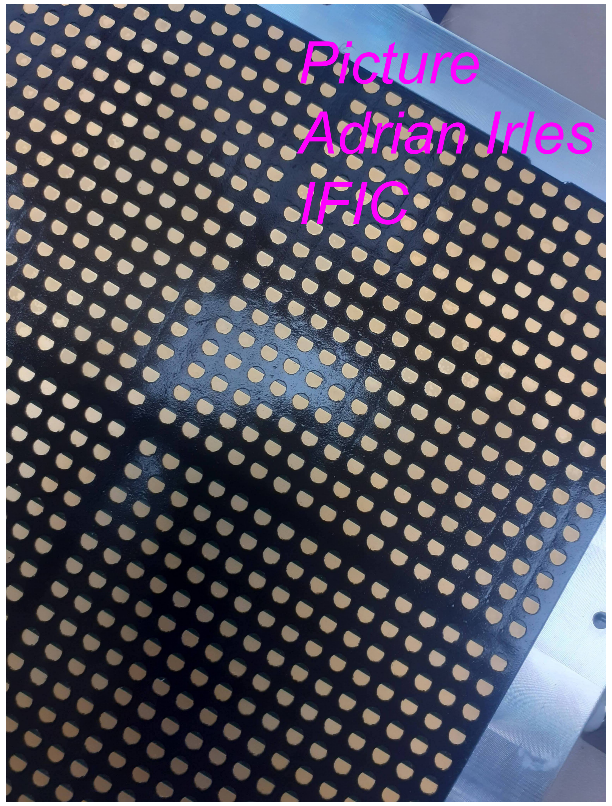
- We suspect mechanical deformation of PCB to be at the origin of the delamination
- => Control PCB shape at different steps of manipulation (e.g. After heating during cabling)

“Underfill”



- Low viscosity glue flows around glue dots
- Development in close contact with Epotek
- Seems to work but requires second curing step
- First mechanical tests encouraging

“Double sided tape”

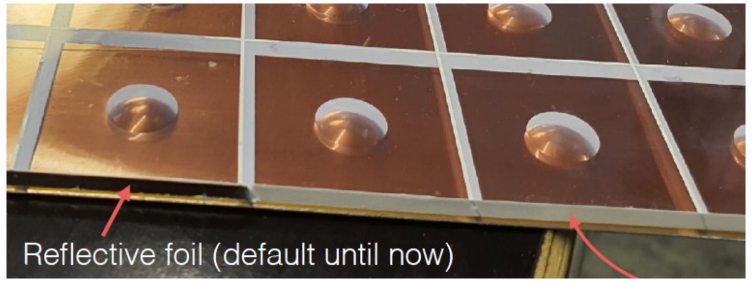


Picture Adrian Irles IFIC

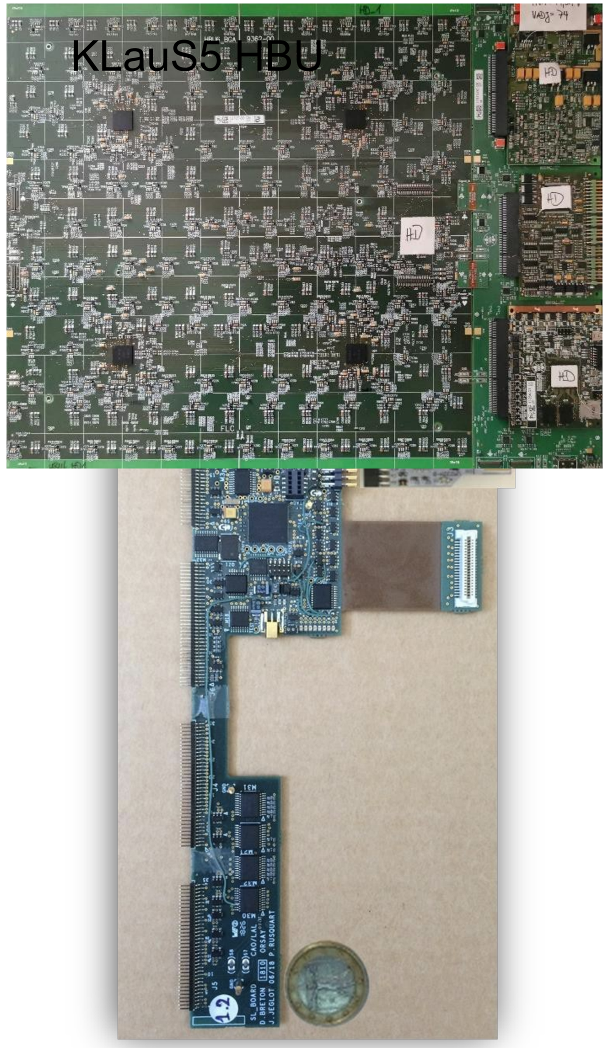
- Undrfill “replaced” by double-sided tape
  - Holes with laser
- Encouraging first experience
- Close consultation with 3M

AHCAL Plans - Hardware Development

- Alternative scintillator geometry
- Megatiles would allow larger units for mechanical assembly
- Status: Ongoing effort, optimization of uniformity and cross talk



- Alternative Readout ASIC (KLauS)
- Wide range of applications
- Possible application at circular Higgs factories
- Optimised for SiPMs with small pixels (10µm) -> possible application in ECAL
- Status: KLauS6 with full functionality available, ongoing effort to integrate into AHCAL DAQ



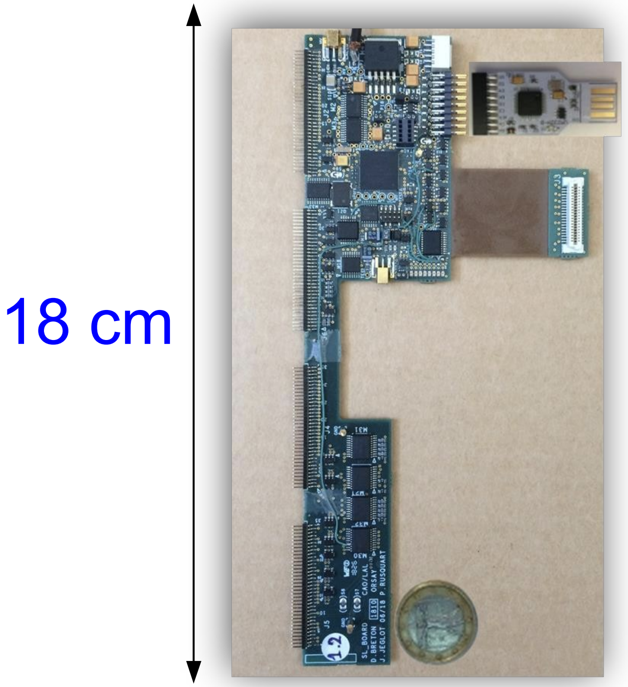
- Common Readout
- Harmonise readout between CALICE SiW ECAL and AHCAL
- Status: First round of discussion for AIDAinnova MS Report

Common Hardware Development

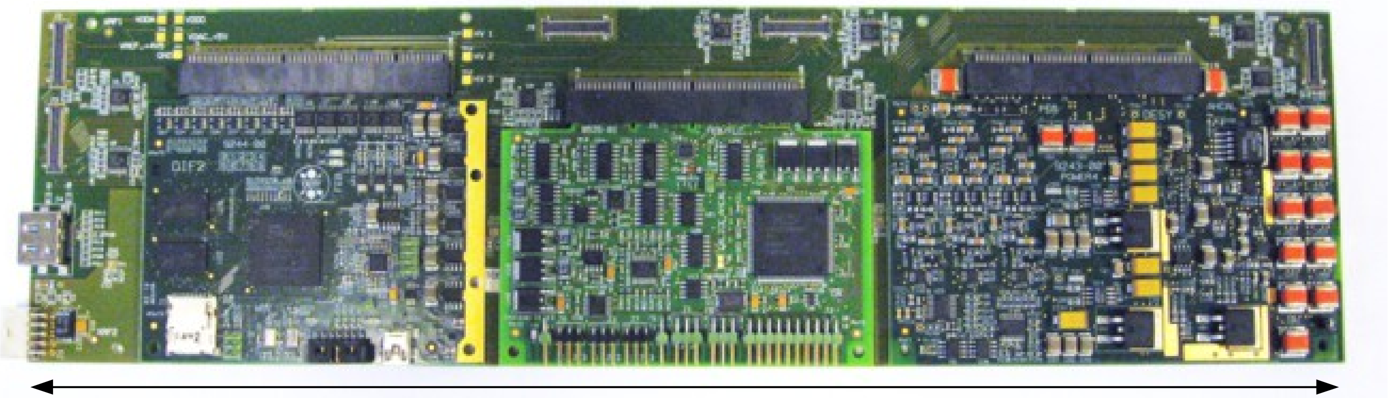
Readout Electronics

- 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



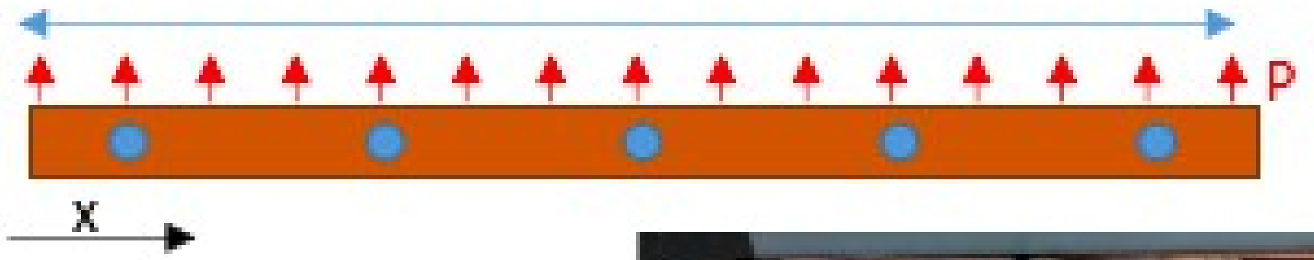
AHCAL interface boards



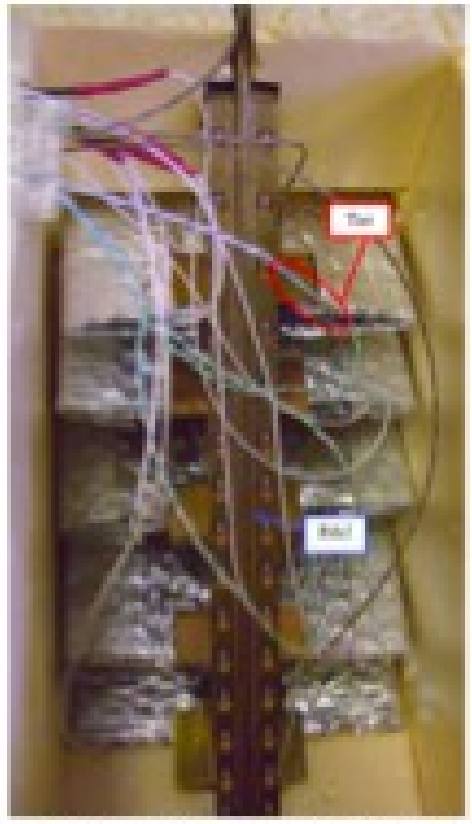
Active cooling?

Passive cooling

Active cooling

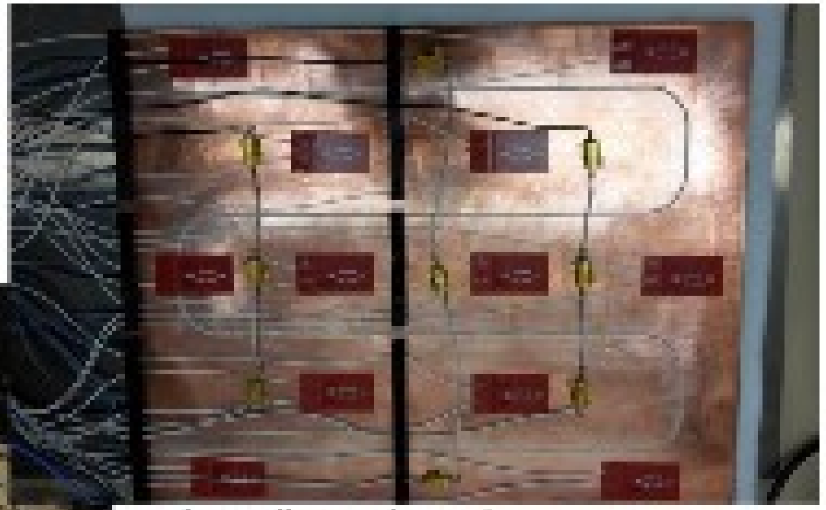


Passive cooling ramp example



Passive cooling ramp set up test

Active cooling set up test with water at room temperature



Active cooling test layout (400mm x 300mm x 3mm thick copper plate with 1,8OD pipes embedded)

Next generation ASICs?

Ch. de la Taille
CALICE Meeting, Valencia

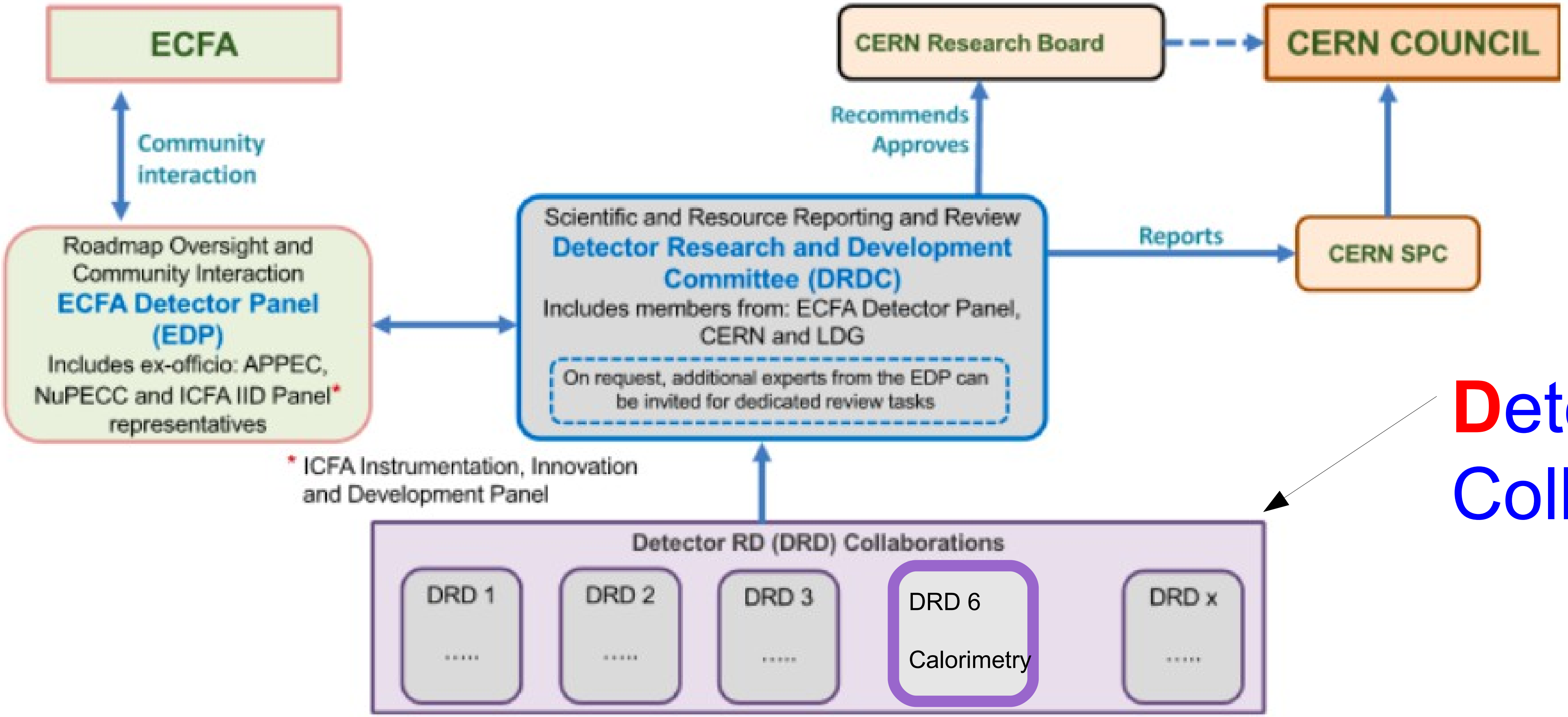
- Dynamic gain preamp or TOT ?
- 200 ns shaping, 10 MHz ADC, several samples on the waveform
- Timing capability ? Auto-trigger and zero suppression
- Target ~1 mW power/ch and possible power pulsing
- I^2C slow control ? New readout protocol ?
- Include 2.5V LDO inside VFE ?
- Compatible with FCC LAr. SiPM/RPC tbd

	experiment	Sensor	capacitance	shaping	power	data	techno	Vdd	slow control
SKIROC2	CALICE	Si	30 pF	300 ns	5 mW/ch	5 MHz	SiGe 350n	3.3 V	SPI
HGCROC	CMS	Si	50 pF	20 ns	20 mW/ch	1.2 Gb/s	TSMC 130n	1.2 V	I^2C
FCC	LAR	Lar	50-200 pF	200 ns	<1 mW	Gb/s	TSMC 130n	1.2 V	I^2C
SKIROC3	CALICE	Si	50 pF	200 ns	<1 mW	Mb/S	TSMC 130n	1.2 V	?

CdLT CALICE meeting 20 apr 2022

See also yesterdays' talk by C. de la Taille

Future Organisation of Detector R&D (in Europe)



Detector R&D Collaborations

- Current model: DRD will be hosted by CERN and therefore become legally CERN collaborations
  - Significant participations by non-European groups is explicitly welcome and needed
  - World wide collaborations!
- The progress and the R&D will be overseen by a DRDC that is assisted by ECFA
  - https://committees.web.cern.ch/drdc
  - Thomas Bergauer of ÖAW/Austria appointed as DRDC-Chair
- The funding will come from national resources (plus eventually supranational projects)

DRD Calo - Proposal Team

Coordinators: Roberto Ferrari, Gabriella Gaudio (INFN-Pavia), R.P.

Representative from Coordination Team: Felix Sefkow

Track 1: Sandwich calorimeters with fully embedded Electronics – Main and forward calorimeters

Track conveners: Adrian Irles (IFIC, adrian.irles@ific.uv.es), Frank Simon (KIT, frank.simon@kit.edu), Jim Brau (University of Oregon, jimbrau@uoregon.edu), Wataru Ootani (University of Tokyo, wataru@icepp.s.u-tokyo.ac.jp), Imad Laktineh (I2PI, imad.laktineh@in2p3.fr)

Track 2: Liquified Noble Gas Calorimeters

Track Conveners: Martin Aleksa (CERN, martin.aleksa@cern.ch), Nicolas Morange (IJCLab, nicolas.morange@ijclab.in2p3.fr), Marc-Andre Pleier (mpleier@bnl.gov)

Track 3: Optical calorimeters: Scintillating based sampling and homogenous calorimeters

Track Conveners: Etiennette Auffray (CERN, etiennette.auffray@cern.ch),
Gabriella Gaudio (INFN-Pavia, gabriella.gaudio@pv.infn.it),
Macro Lucchini (University and INFN Milano-Bicocca, marco.toliman.lucchini@cern.ch),
Philipp Roloff (CERN, philipp.roloff@cern.ch), Sarah Eno (University of Maryland, eno@umd.edu),
Hwidong Yoo (Yonsei University, hdyoo@cern.ch)

Track 4: Transversal activities.

Christophe de la Taille (OMEGA, taille@in2p3.fr), Alberto Gola (FBK, gola@fbk.it)

Summary and conclusion

- R&D on highly granular calorimeters is active field in DMLAB

- About to digest conclusions from common beam test in 2022
  - Data analysis
  - New hardware developments

- Short term applications
  - CMS HGCAL
  - QED and Dark Matter Experiments like LUXE, LOHENGRIN, EBES

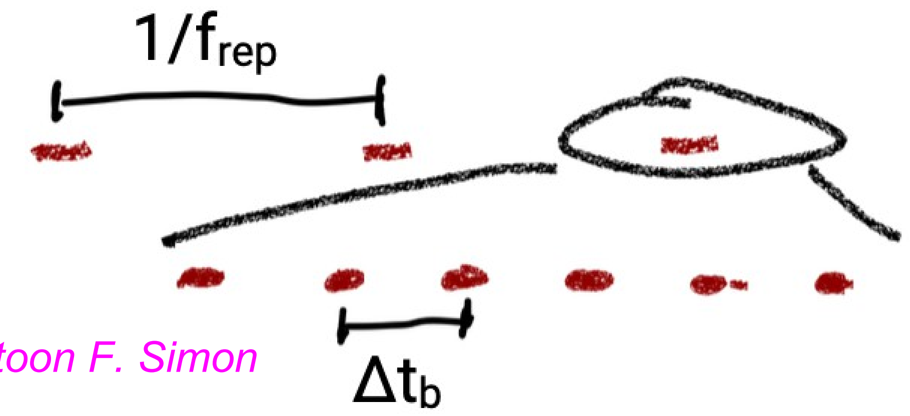
- Approval of CALO5D is major success and will boost German-French collaboration
  - DMLAB is ideal framework to follow up
  - Synergies between two prototype projects and Machine Learning Workpackage

- Expertise on Calorimetry present in DMLAB help to shape the international R&D landscape

Backup

Operation mode- pulsed or continous

- Linear Colliders operate in bunch trains



Cartoon F. Simon

CLIC: Δt_b ~ 0.5ns, frep = 50Hz
ILC: Δt_b ~550ns, frep = 5 Hz (base line)

- Power Pulsing reduces dramatically the power consumption of detectors
  - e.g. ILD SiECAL: Total average power consumption 20 kW for a calorimeter system with 10^8 cells
- Power Pulsing has considerable consequences for detector design
  - Little to no active cooling
  - => Supports compact and hermetic detector design
- Have to avoid large peak currents
- Have to ensure stable operation in pulsed mode

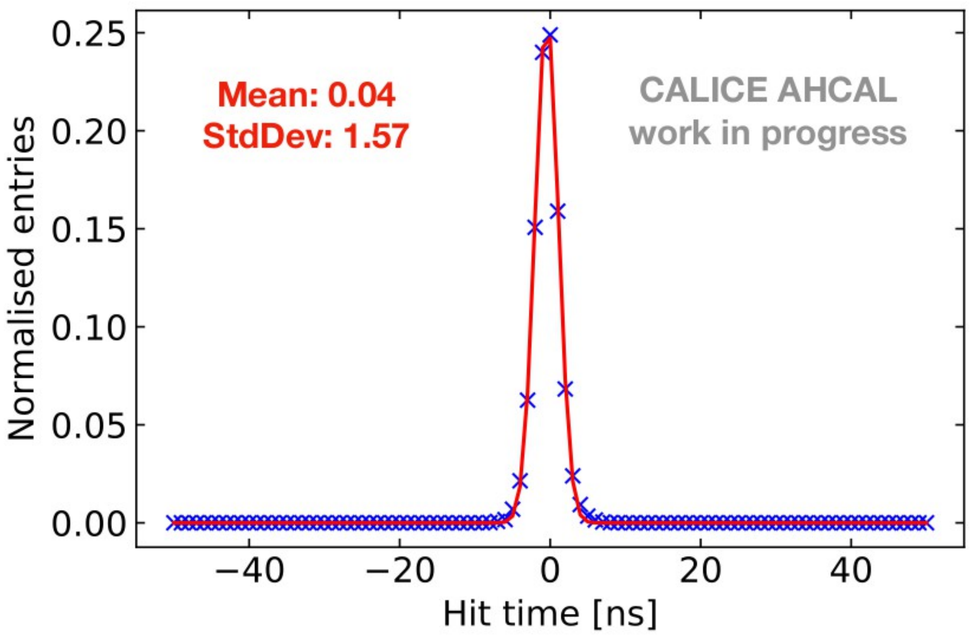
- Upshot: Pulsed detectors face other R&D challenges than those that will be operated in “continuous” mode
  - Tendency: Avoid also active cooling in continous mode

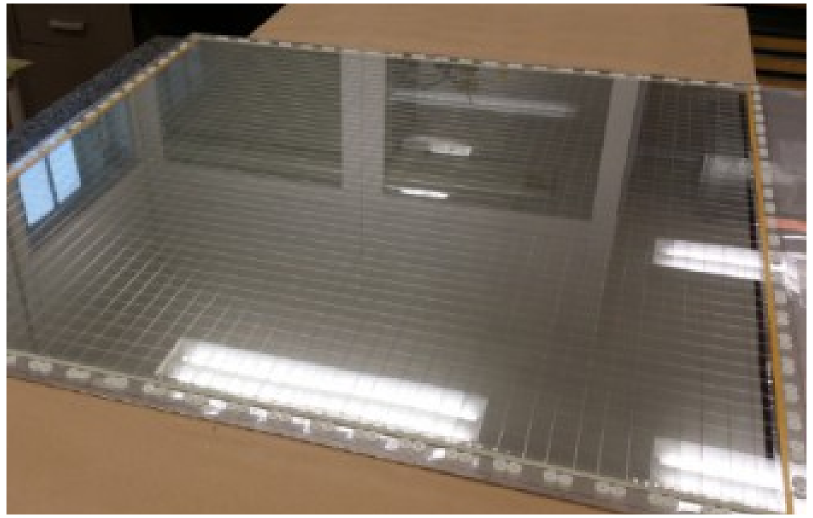
The next decade – ps timing in calorimeters

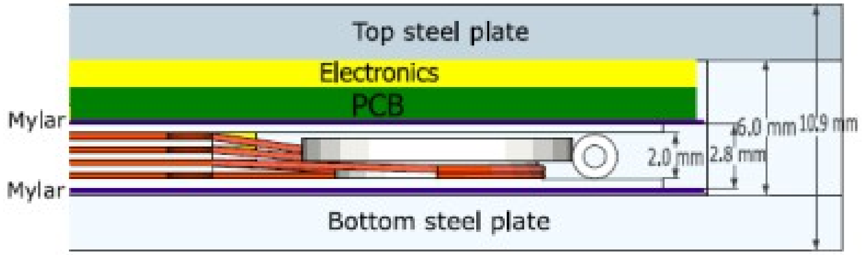
Pioneered by LHC Experiments, timing detectors are/will be also under scrutiny by CALICE Groups

Hit time resolution:
Results from 2018 beam test of AHCAL with muons

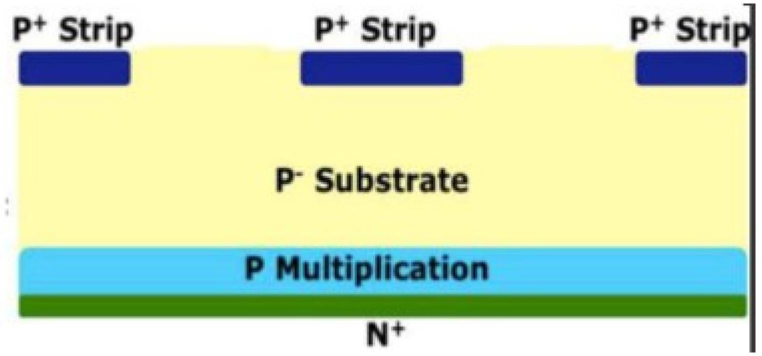
Clock frequency 5 MHz,
Powering pulsing







Inverse APD as LGAD?

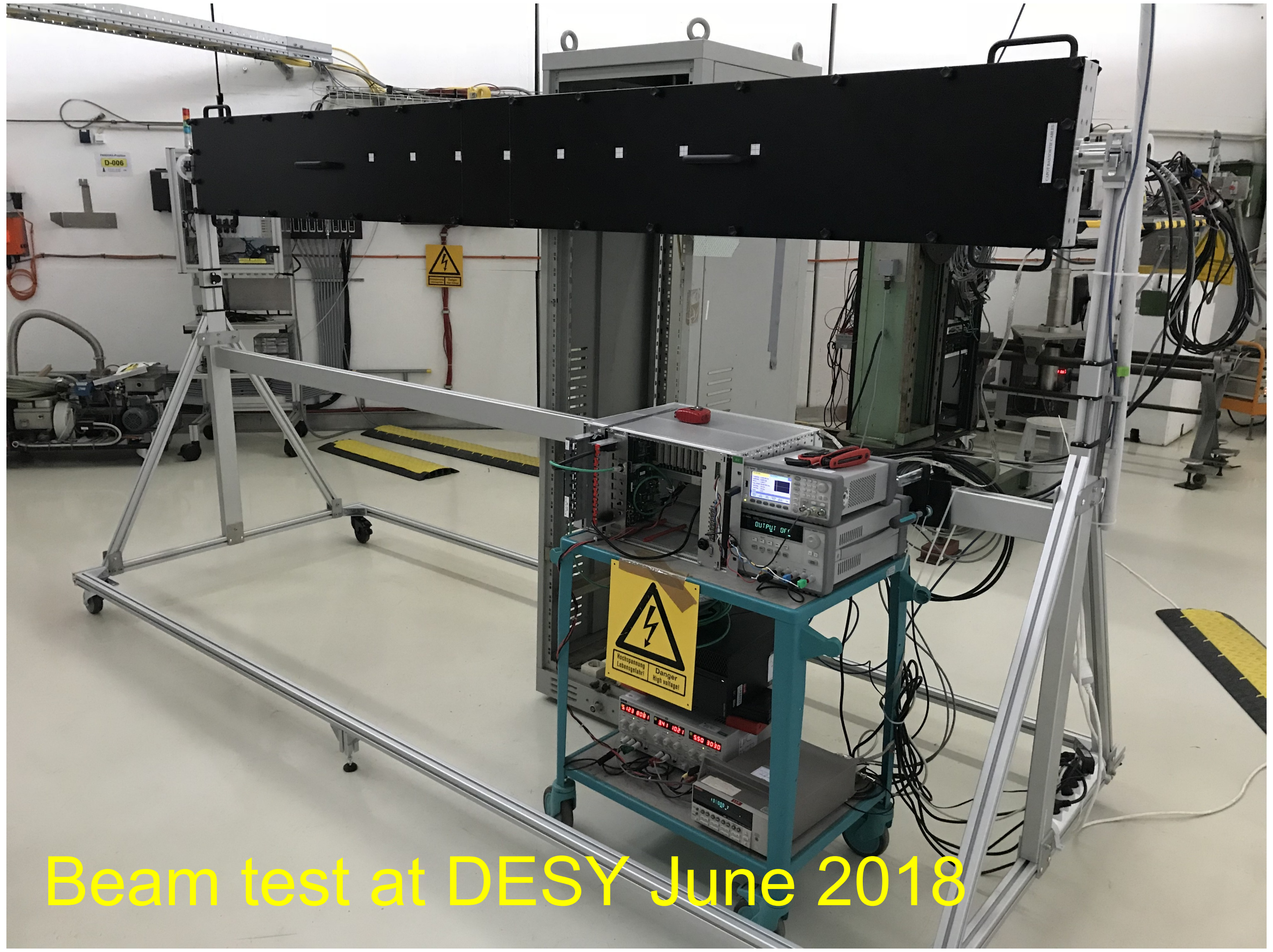


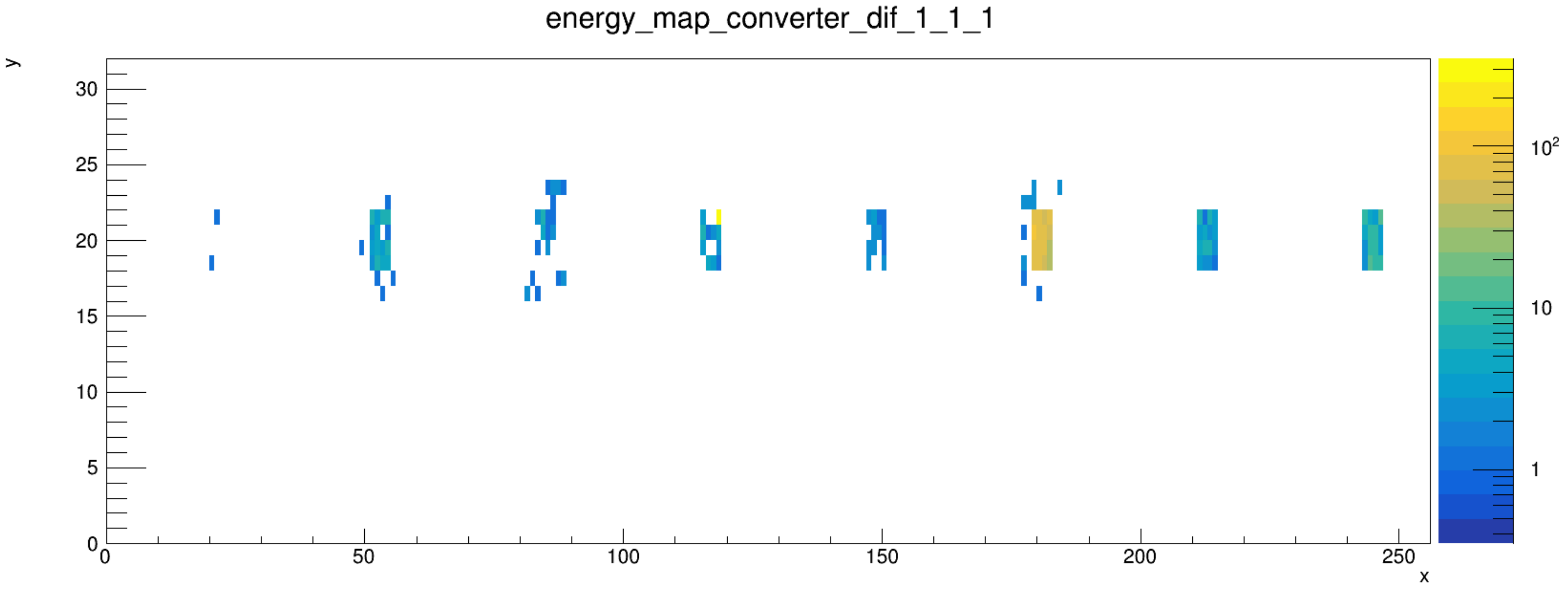
Inverse APD
by Hamamatsu

Gain ~ 50

(One of) Next step(s) – Slab long

Chain of
8 detection elements
~2m





Very encouraging results in first beam test in 2018

- Credibility for concept as foreseen for e.g. ILD
- Issues with signal drop towards extremities

Long slab studies will be resumed with new FEV (see later)

- Adapted for power pulsing, will avoid voltage drop, etc ...

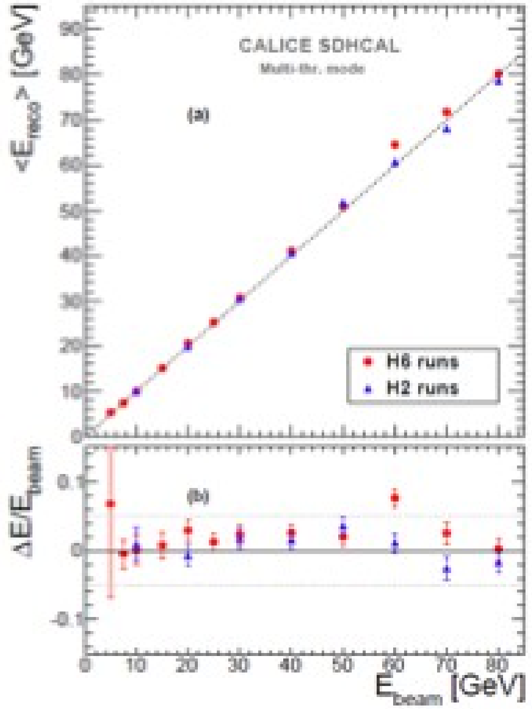
SDHCAL – TB2022

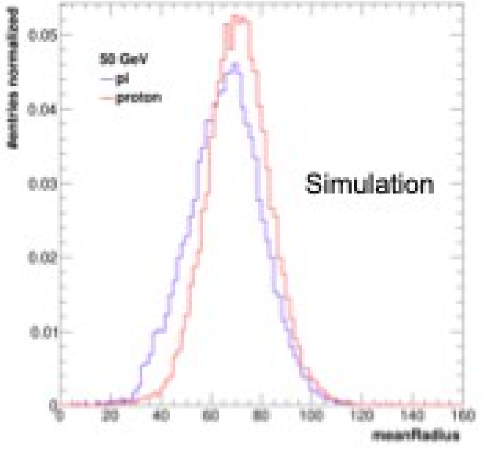
Highlight II: SDHCAL testbeam

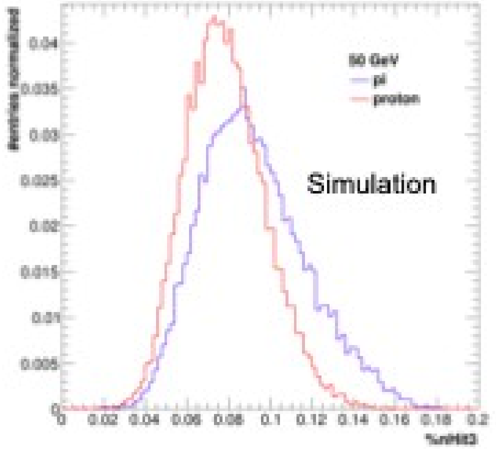
$$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$$

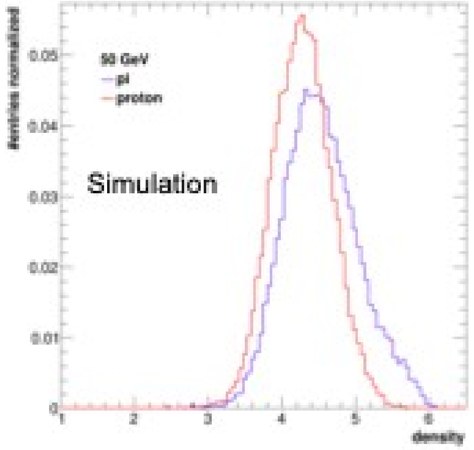
2 weeks of beam test at CERN SPS: 14 - 28 September 2022

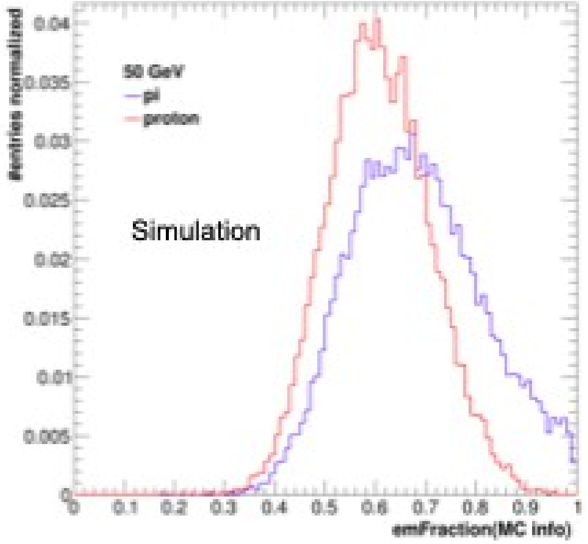
- Observation in previous beam tests: (slightly) different reconstructed hadron energy in two beam lines at SPS, which have different mixtures of pions and protons
- Goal for this testbeam: use Cherenkov detectors to separate pions and protons
- Expectation: pion showers have higher EM fraction and more hits
- Optimise α,β,γ separately for pions and protons
- Investigate calorimeter quantities that might allow pion/proton distinction







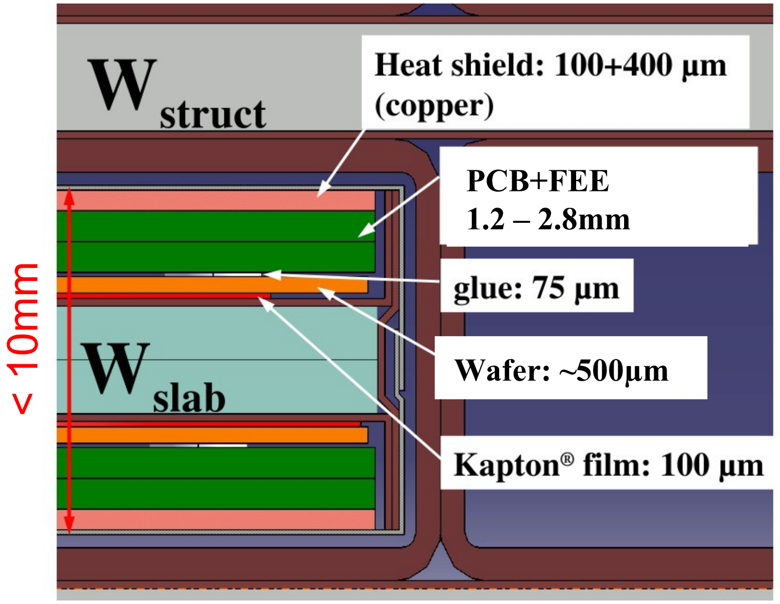




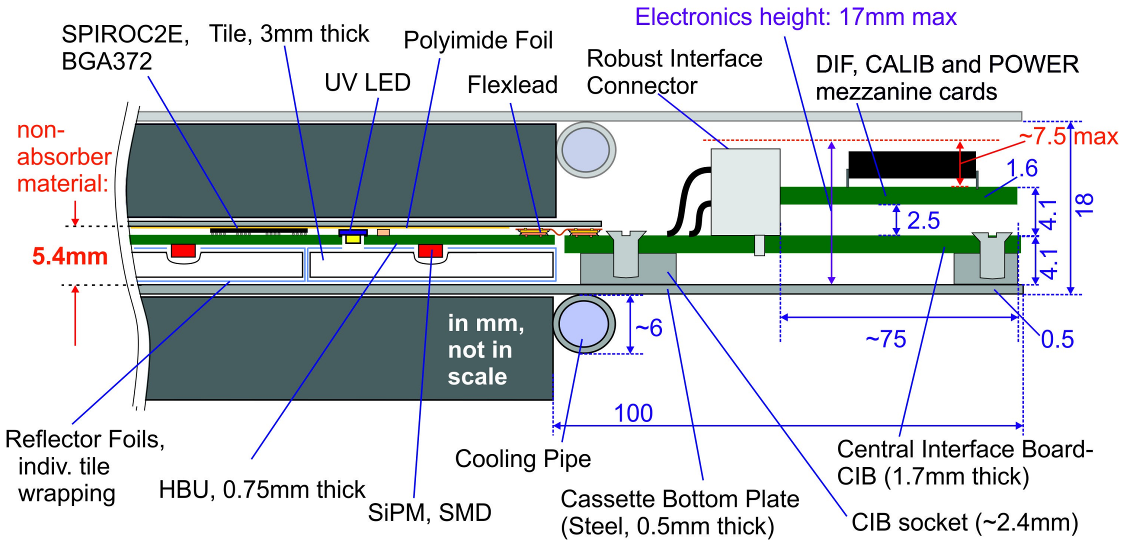
From K. Krüger this morning

Technological solutions for a final detector I

SiW ECAL

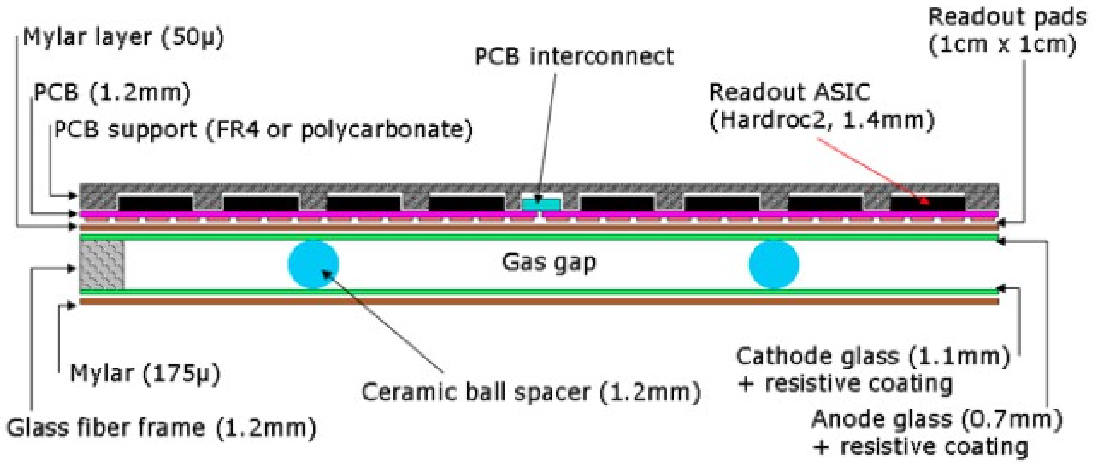


Analogue Hcal and Scintillator Ecal



Optical readout

Semi-digital Hcal



Gaseous readout

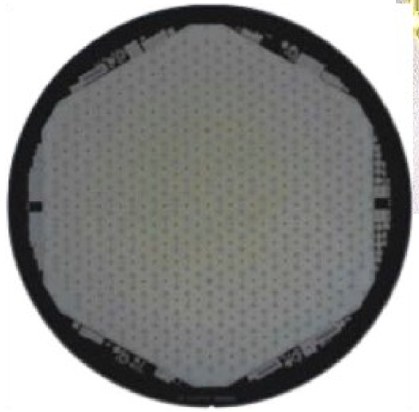
- Realistic dimensions
  - Structures of up to 3m
- Integrated front end electronics

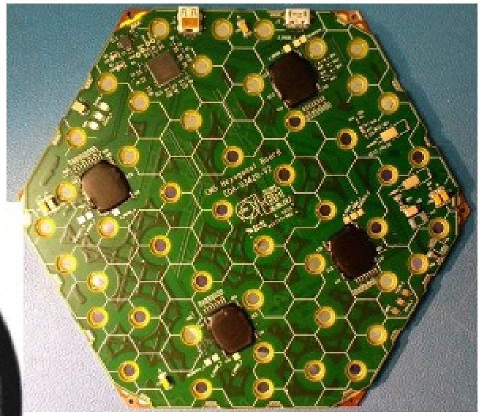
  No drawback for precision measurements *NIM A 654 (2011) 97*
- Small power consumption (Power pulsed electronics)

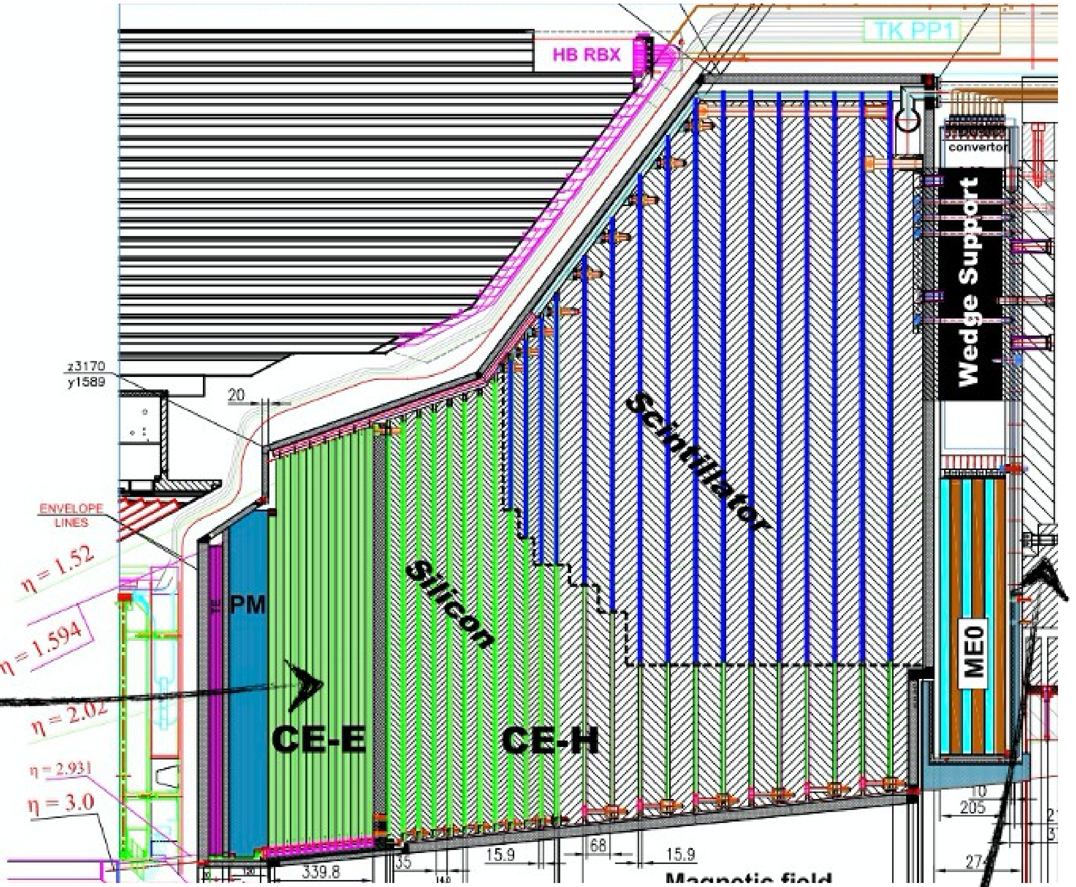
HL-LHC Upgrades

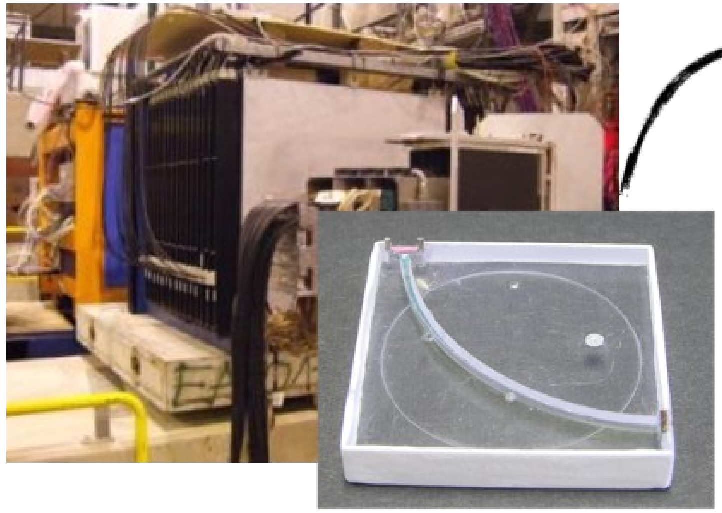
- The developments in CALICE have paved the way for a number of applications of highly granular calorimeters and related technologies in HEP

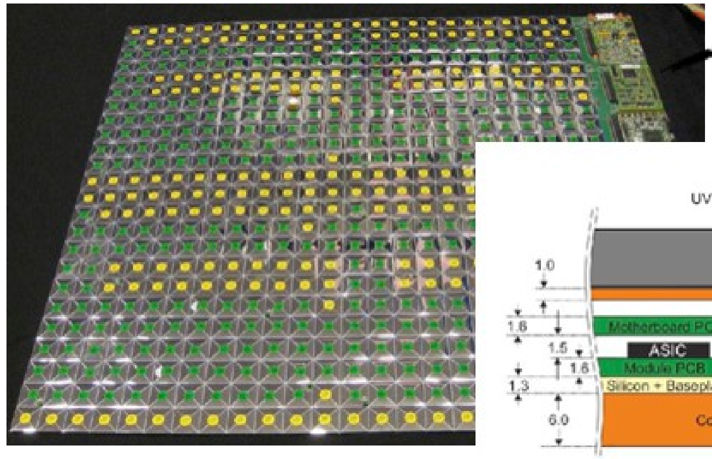
Most prominent: The CMS Endcap Calorimeter Upgrade HGCal

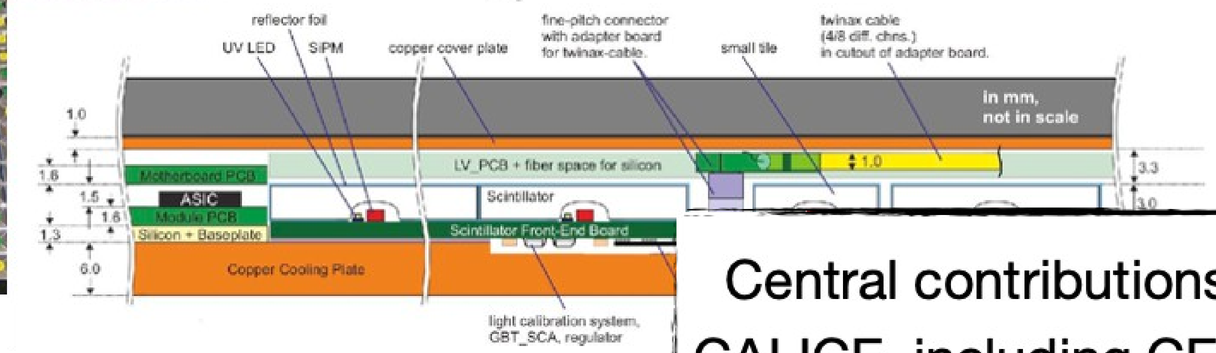








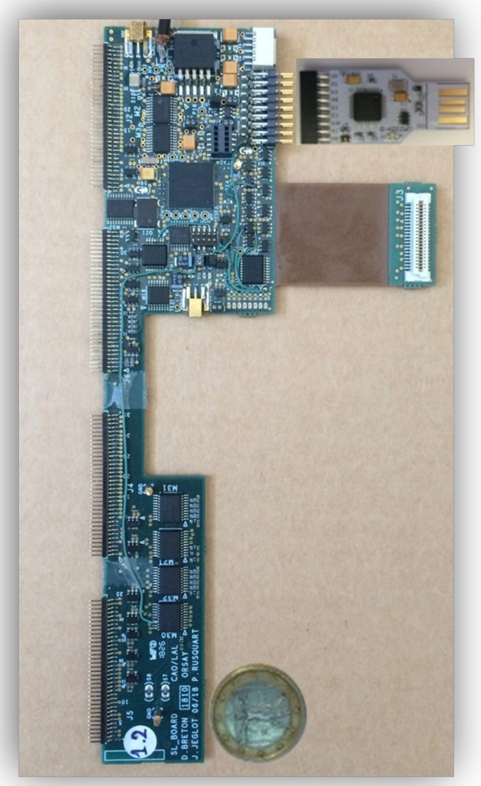




Central contributions by groups very active in CALICE, including CERN, DESY, LLR, OMEGA.

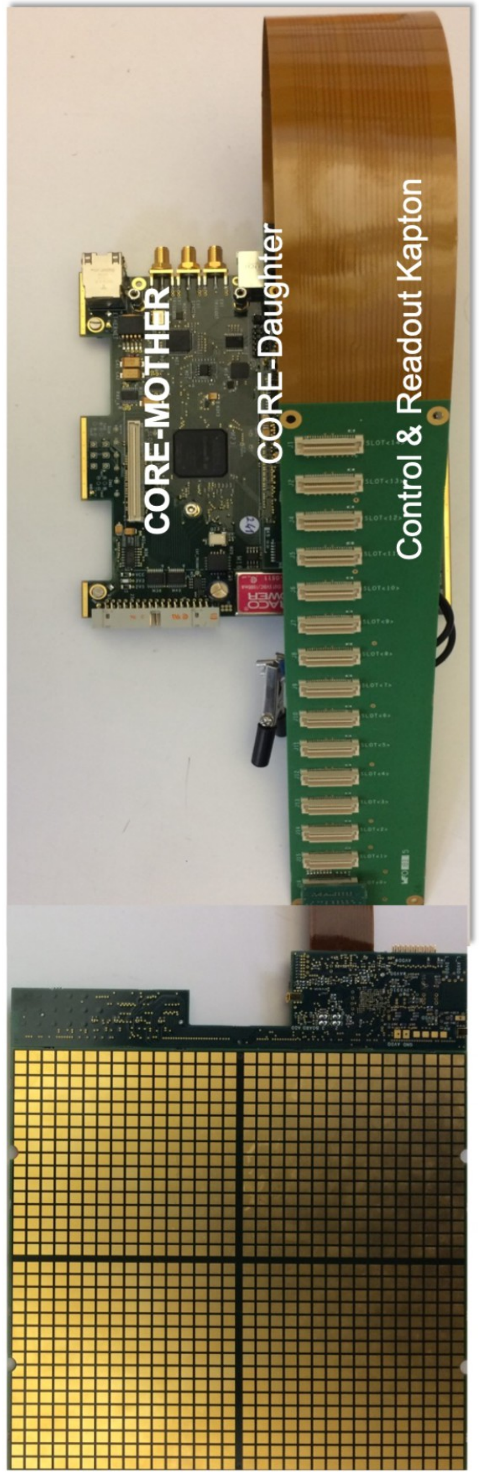
Compact readout of SiW ECAL

Current detector interface card (SL Board) and zoom into interface region



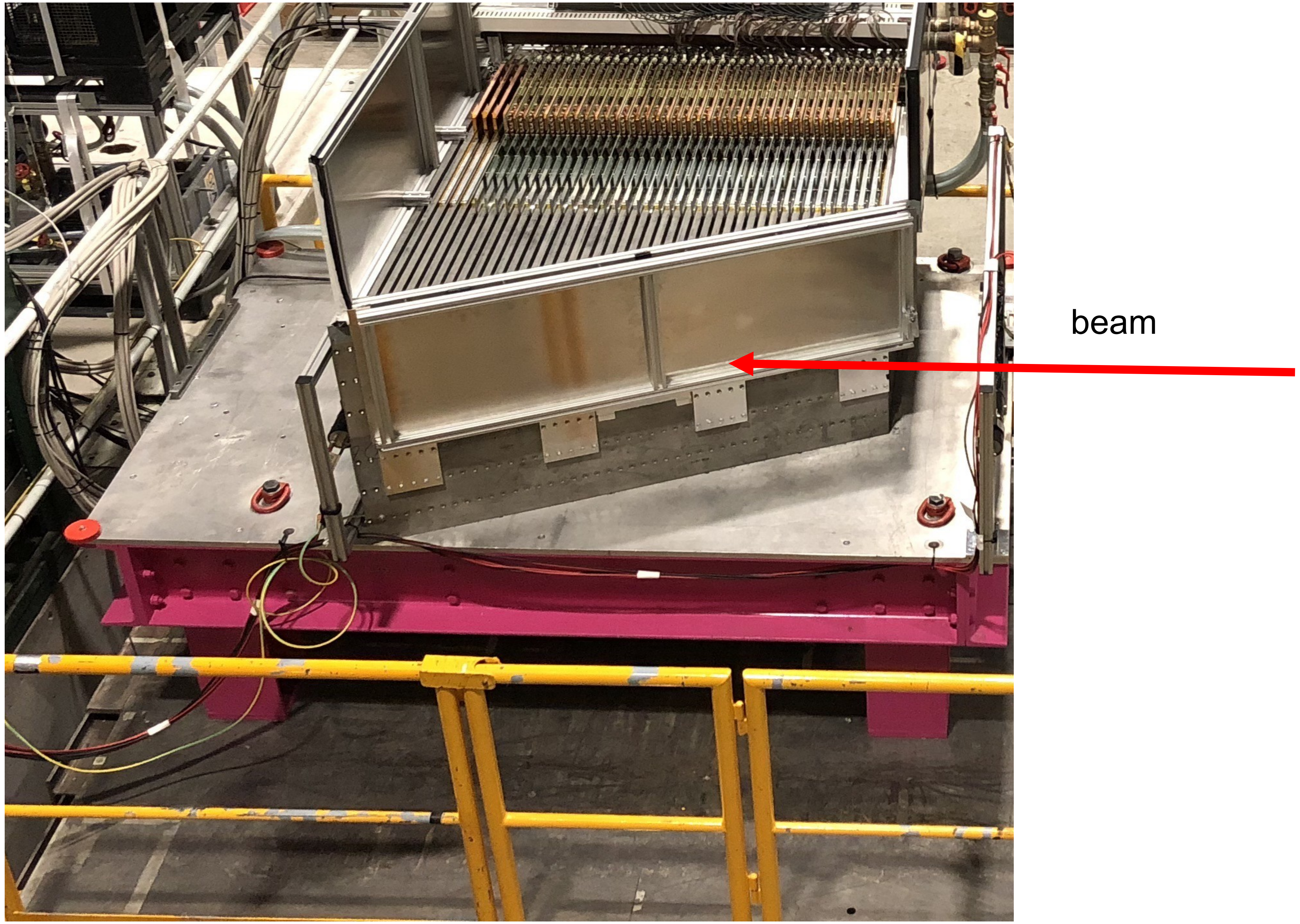
SL Board

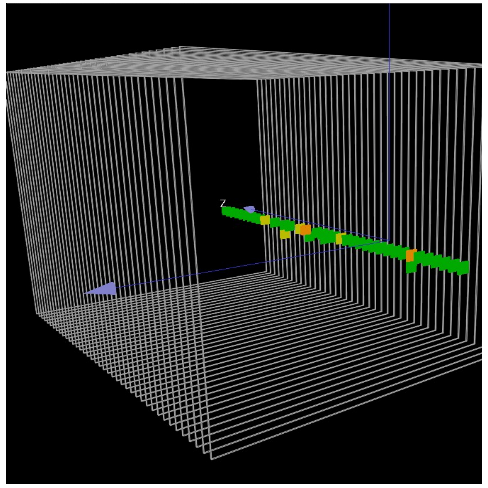
Complete readout system

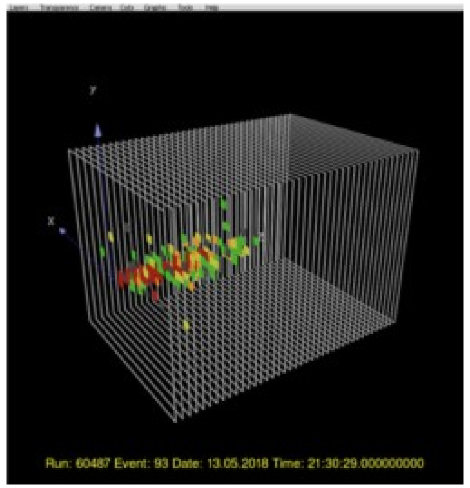


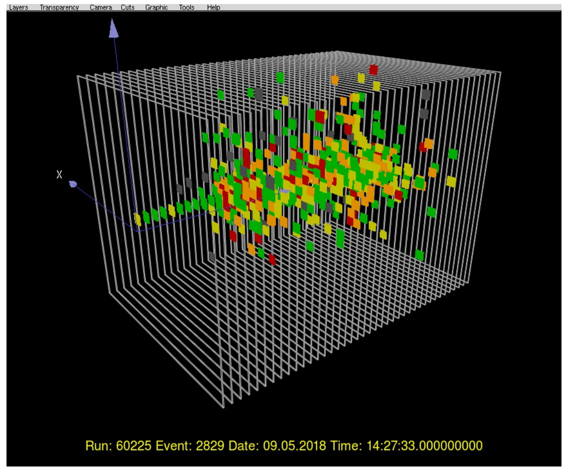
- “Dead space free” granular calorimeters put tight demands on compactness
- Current developments in CALICE for SiW ECAL meet these requirements
- Can be applied/adapted wherever compactness is mandatory
- Components will/did already go through scrutiny phase in beam tests

AHCAL Technological Prototype at SPS Testbeam

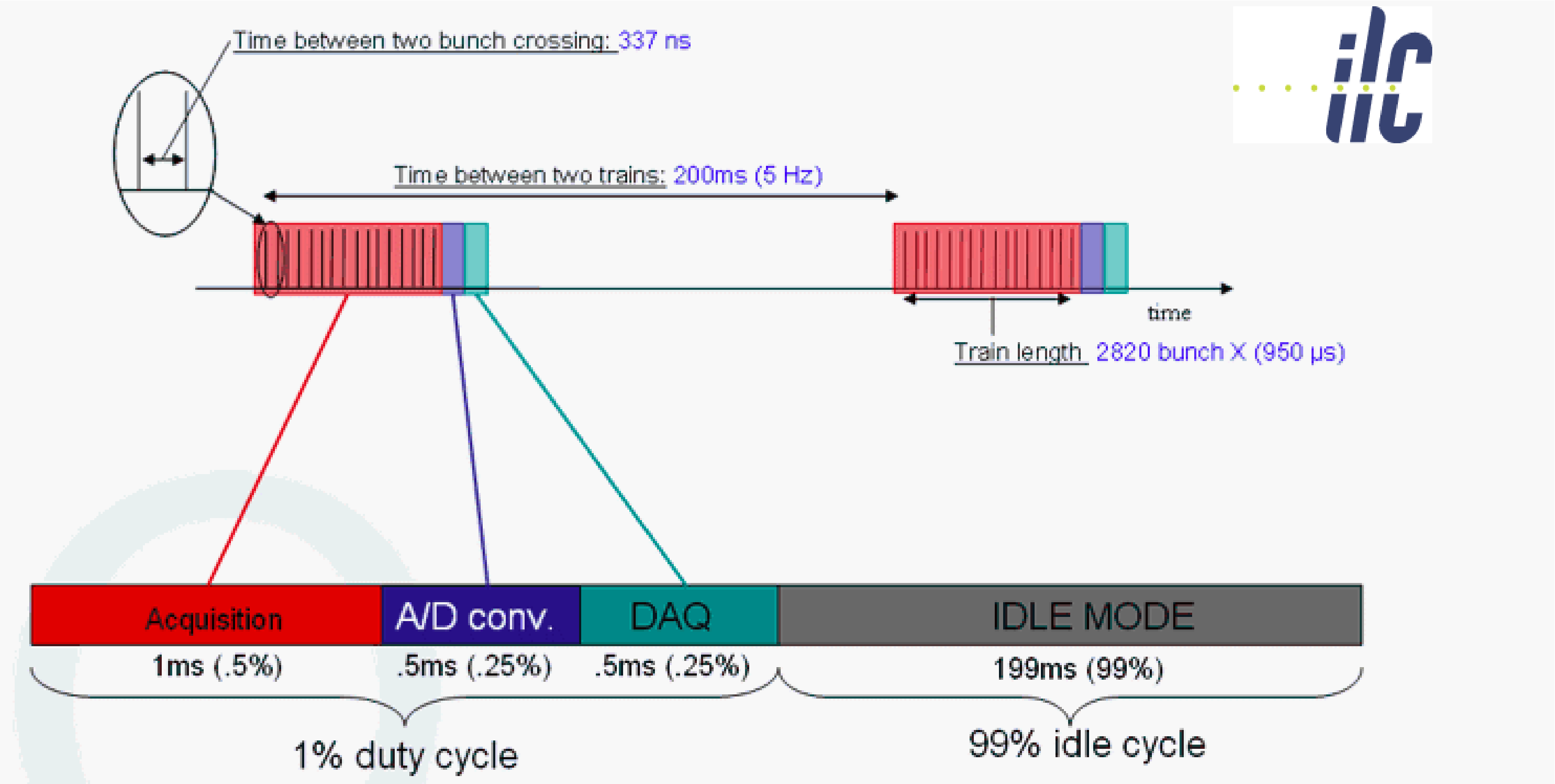








Intermezzo – Power pulsing



N.B. Final numbers may vary

- Electronics switched on during > ~1ms of ILC bunch train and data acquisition
- Bias currents shut down between bunch trains

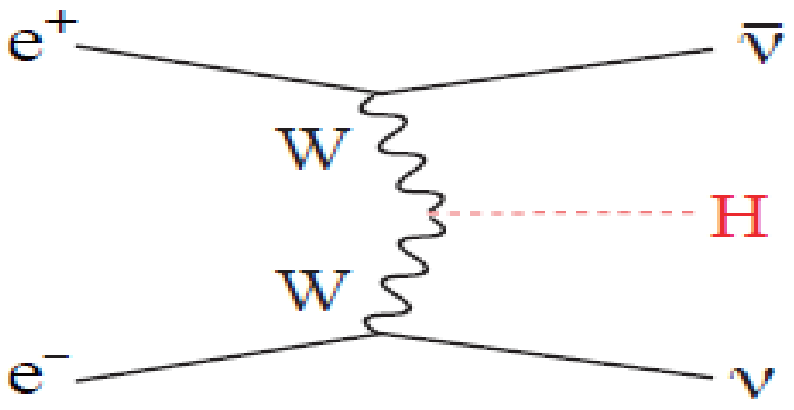
Mastering of technology is essential for operation of ILC detectors

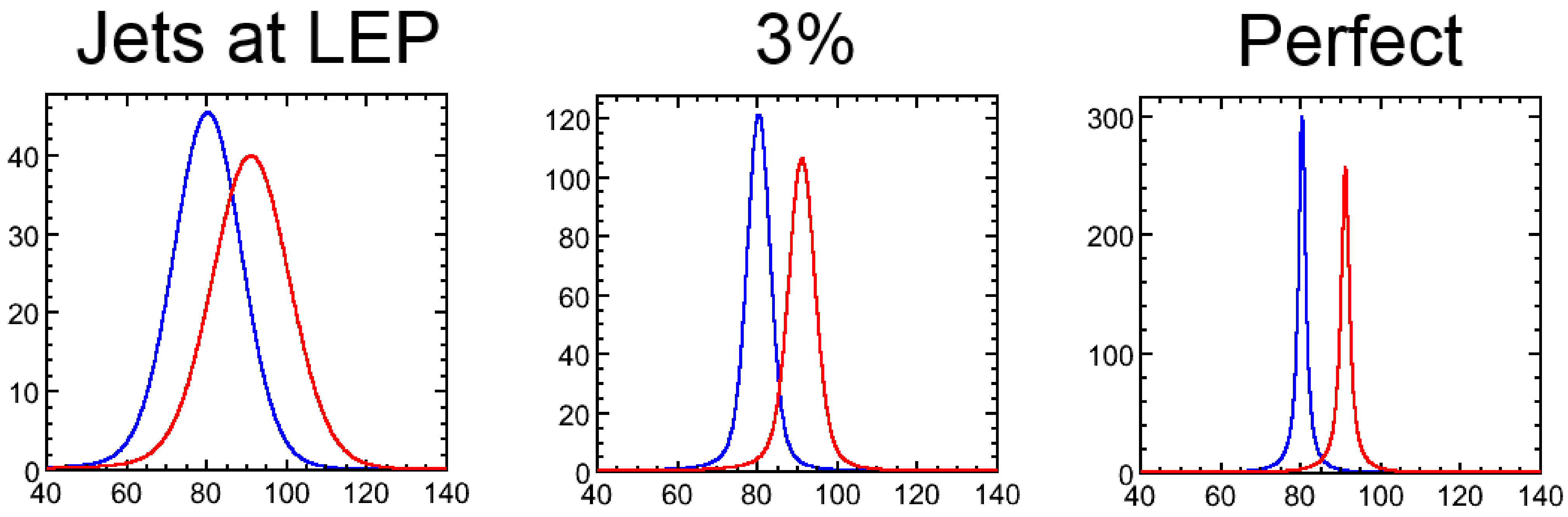
Detector requirements in high energy e+e- collision

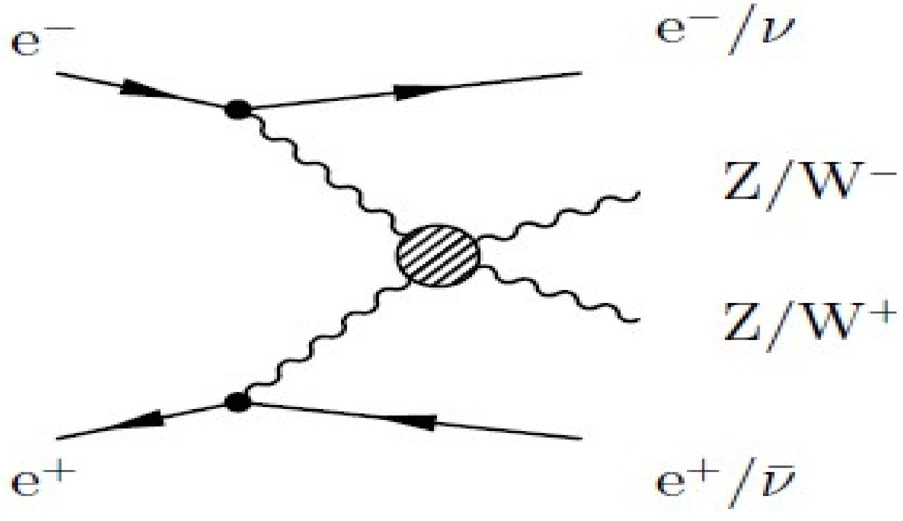
Examples:

- W Fusion with final state neutrinos requires reconstruction of H decays into jets

- Jet energy resolution of ~3% for aclean W/Z separation





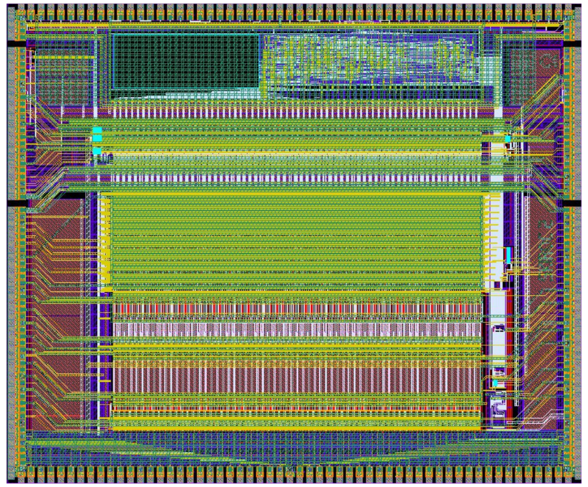


M. Thomson

Slide: F. Richard at International Linear Collider – A worldwide event

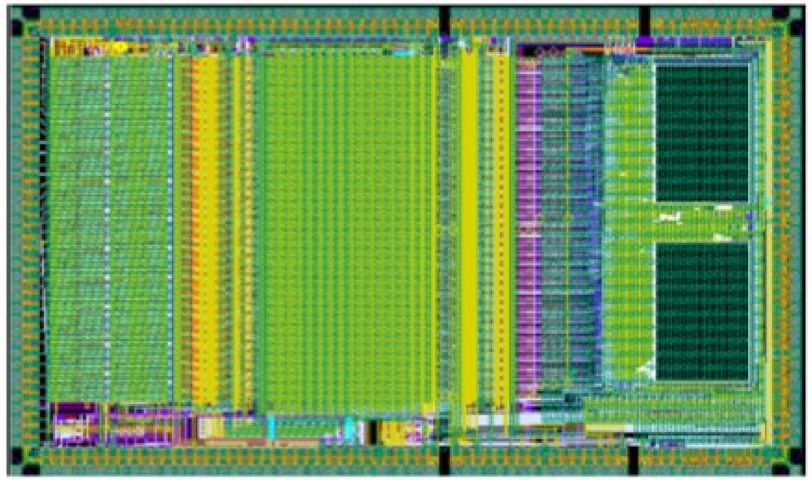
ASICs – The "ROC Family"

SKIROC
(for SiW Ecal)



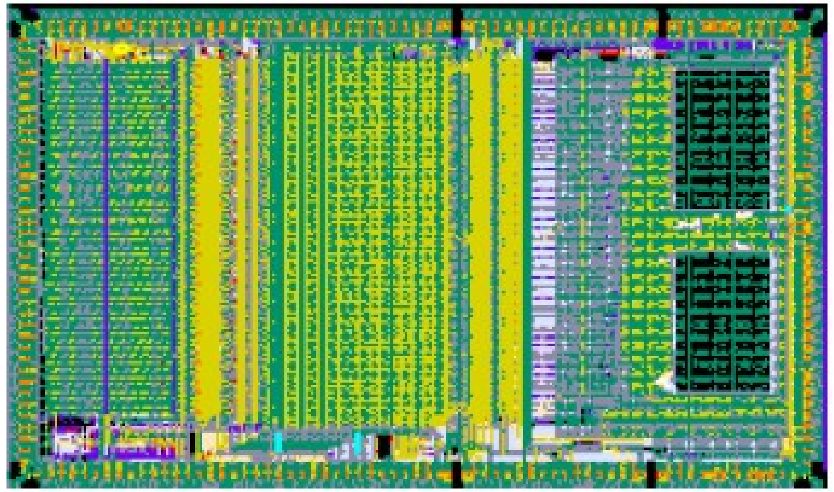
SiGe 0.35µm AMS,
Size 7.5 mm x 8.7 mm, 64 channels
High integration level
(variable gain charge amp,
12-bit Wilkinson ADC, digital logic)
Large dynamic range (~2500 MIPS)
low noise (~1/10 of a MIP, 400 fC)
Auto-trigger at ½ MIP
Low Power: (25µW/ch) power pulsing

SPIROC
For optical readout, Tiles + SiPM

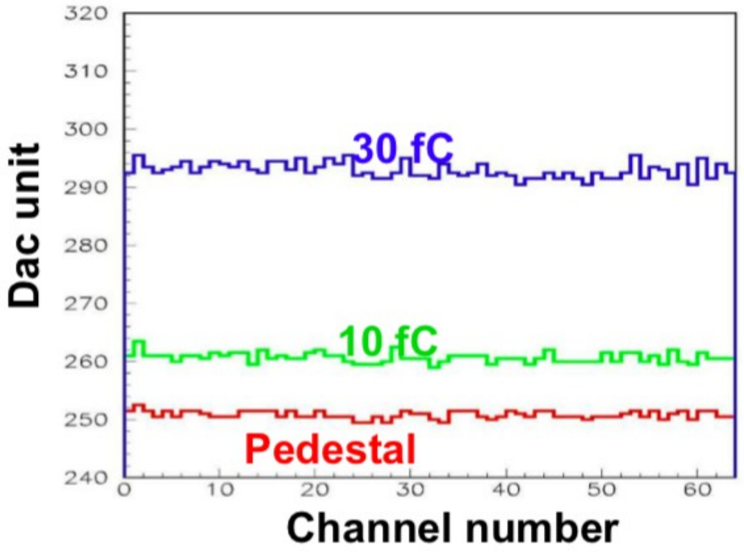


Variant of SKIROC
36 channels, 15 bit readout
Auto-trigger down to ½ p.e,
80 fC for G=1x10^6
Timing to ~ 1ns
Low Power: (25µW/ch) power pulsing

HARDROC
For gaseous r/o - GRPC



64 Channels with three thresholds



Power pulsing
Variant for Micromegas: MICROROC

ASICs – The “ROC Family”