Implementation of large imaging calorimeters

Roman Pöschl

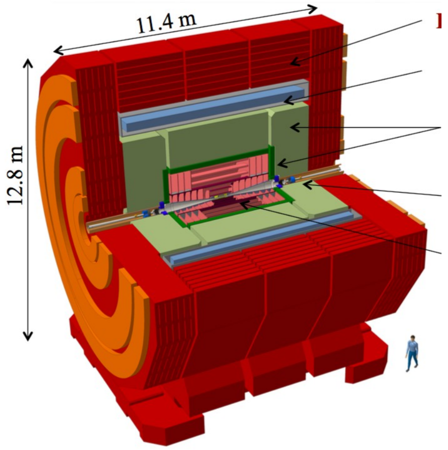
On behalf of the CALICE Collaboration

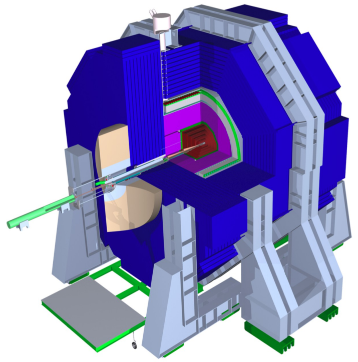
France-Italy FCC Workshop November 2022, Lyon,France

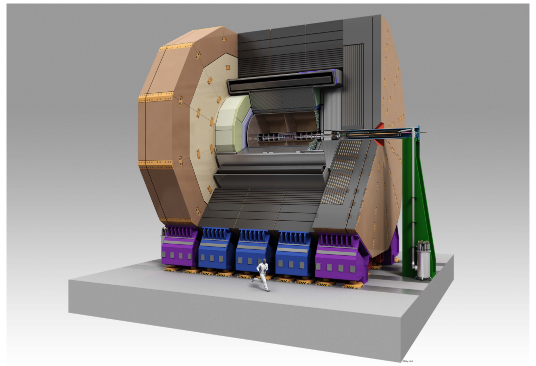
Supported by AIDA innova

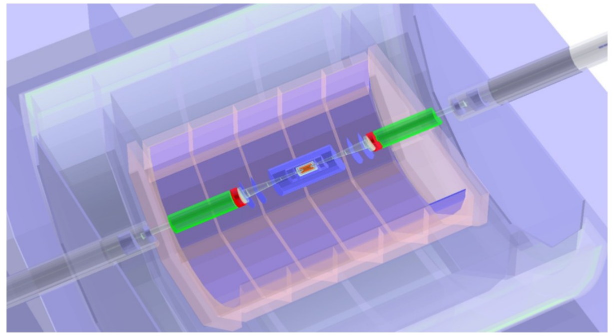
Detector systems – Target projects

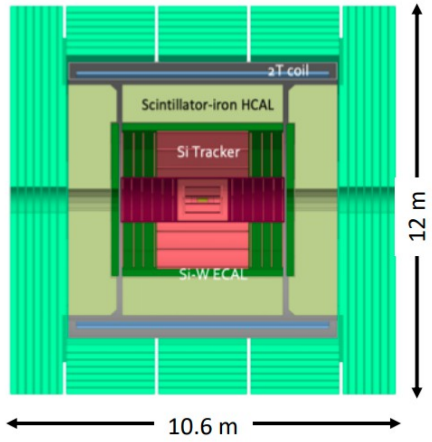
Detectors for Higgs Factories



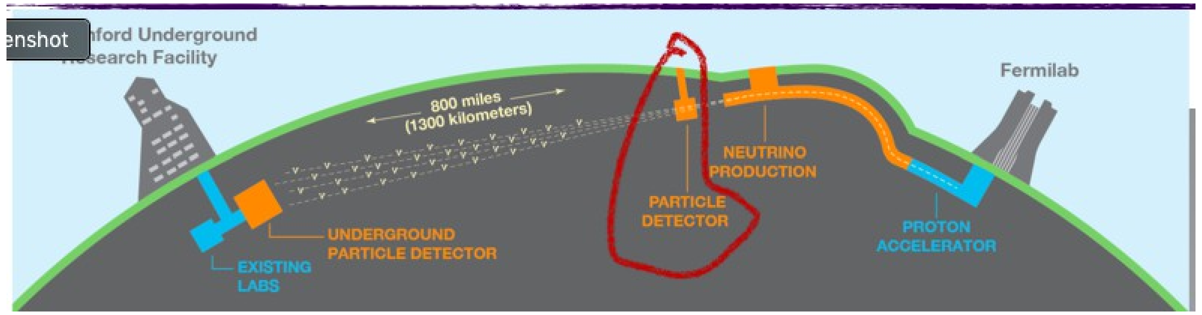








DUNE??

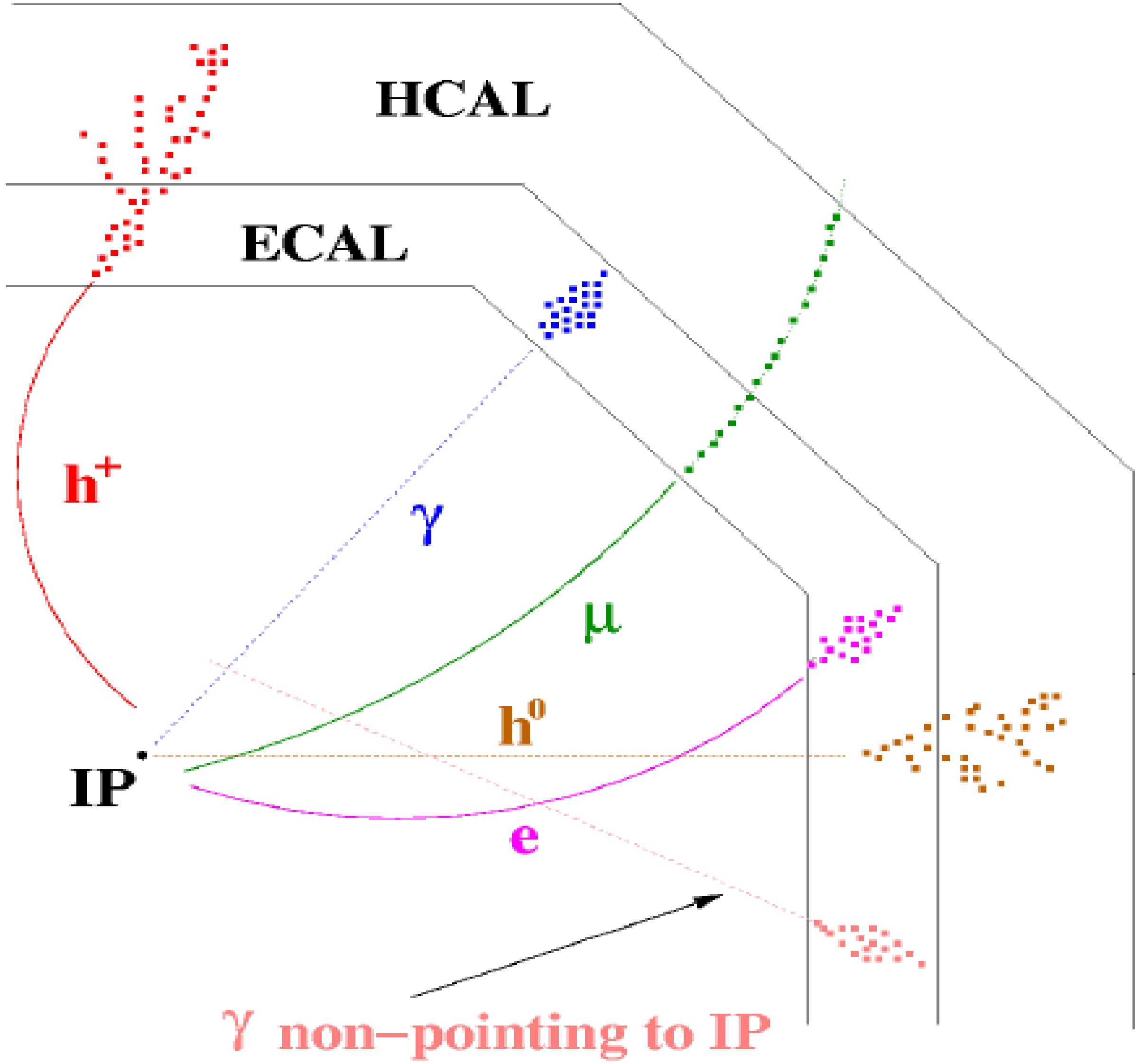


Near detector

Particle Flow Detector

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

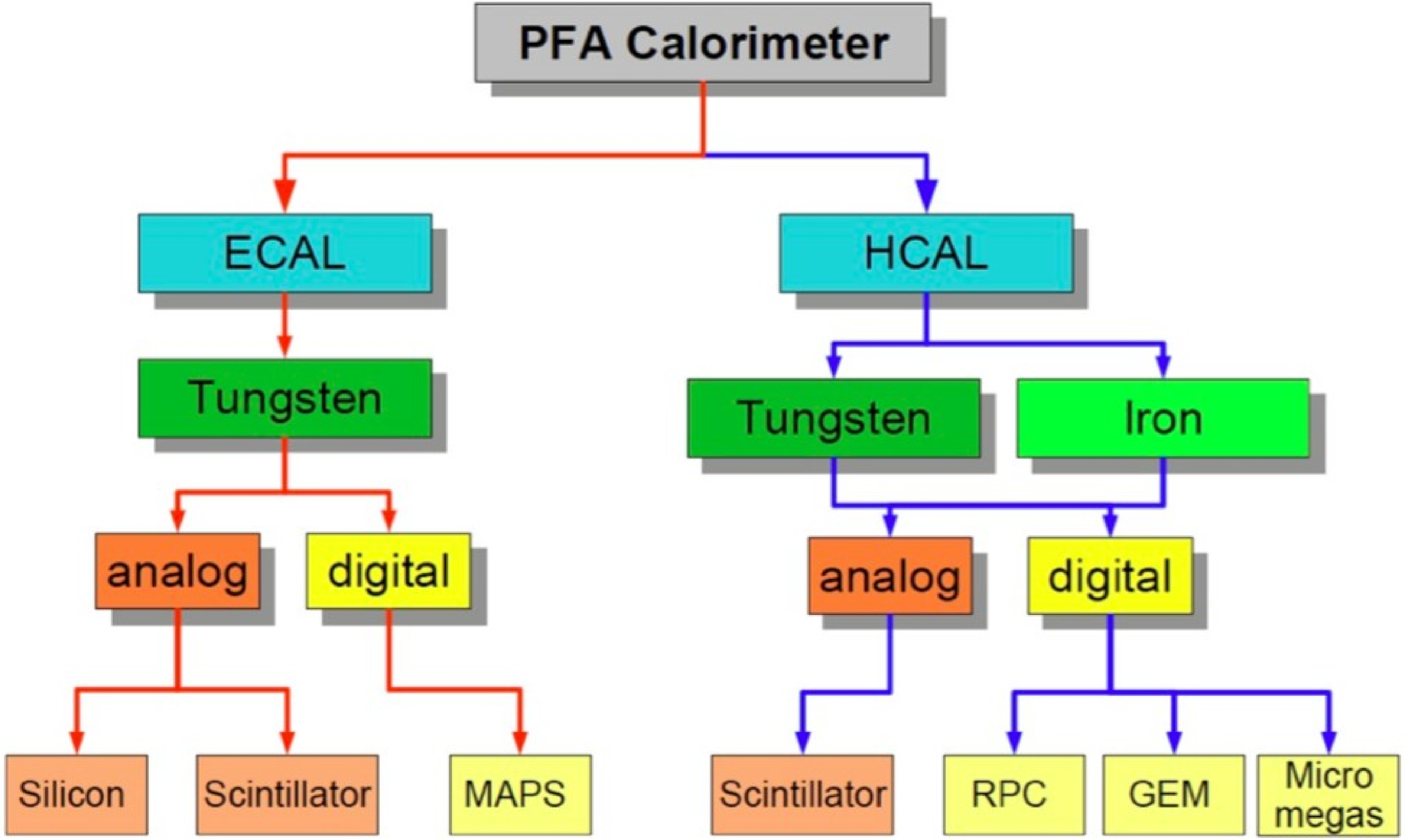
- large radius and length
  - → to separate the particles
- large magnetic field
  - → to sweep out charged tracks
- “no” material in front of calorimeters
  - → stay inside coil
- small Molière radius of calorimeters
  - → to minimize shower overlap
- **high granularity of calorimeters**
  - → to separate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



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

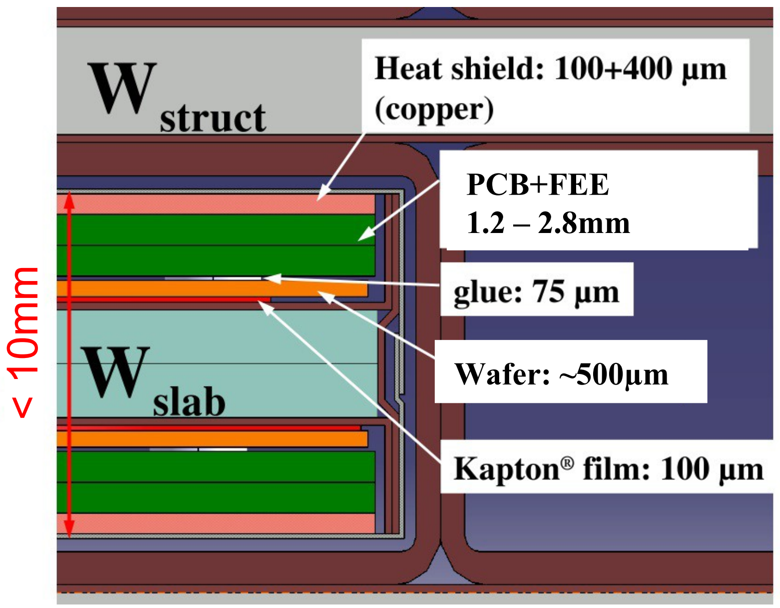
Calorimeters for PFA

Mainly organised within the: CALICE Collaboration

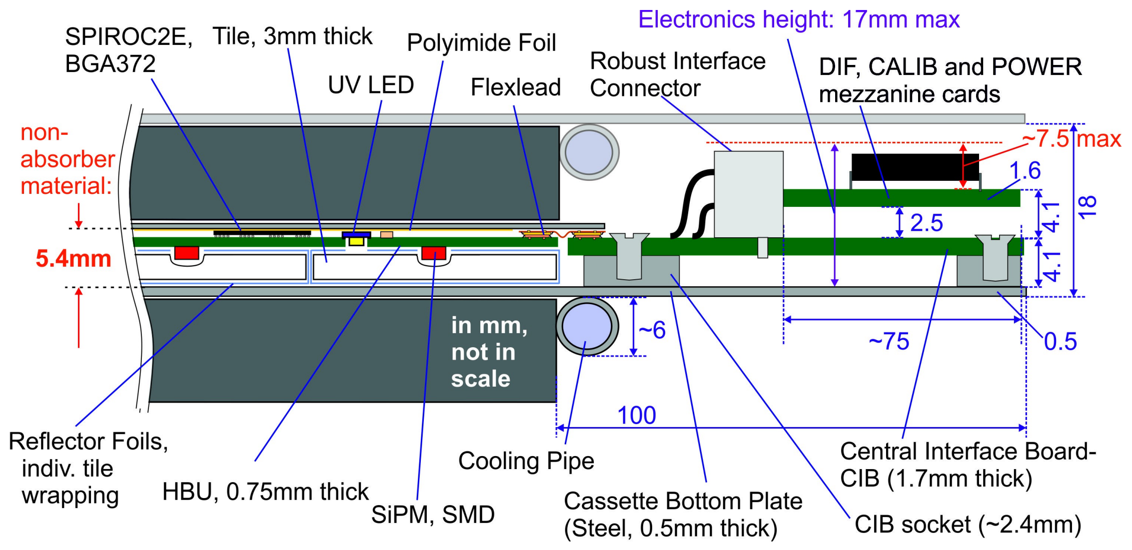


Technological solutions for a final detector I

SiW ECAL

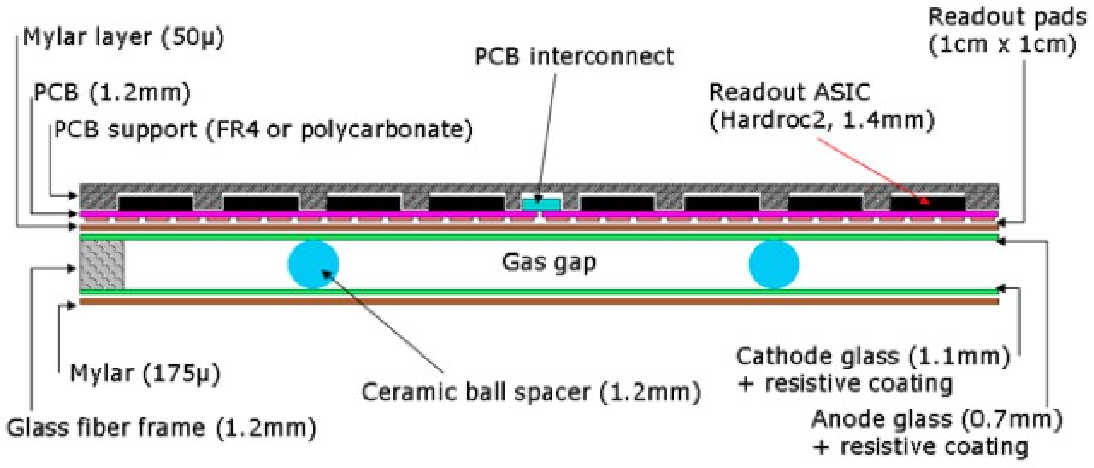


Analogue Hcal and Scintillator Ecal



Optical readout

Semi-digital Hcal



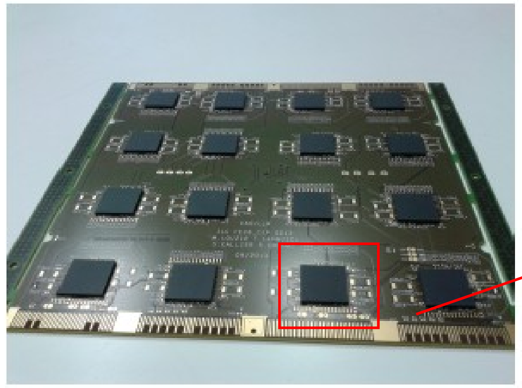
Gaseous readout

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

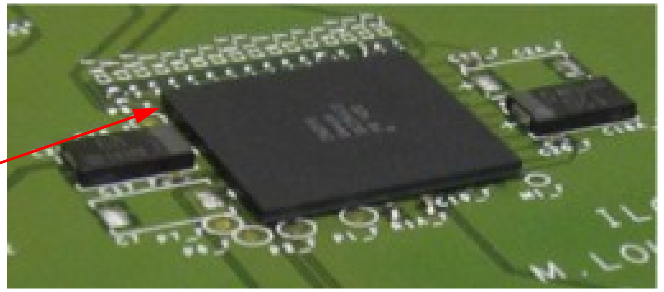
  No drawback for precision measurements *NIM A 654 (2011) 97*
- Small power consumption (Power pulsed electronics)

SiW ECAL – Elements of a (long) layer

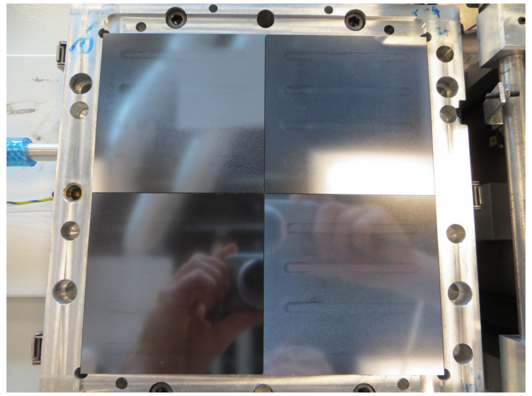
ASIC+PCB+SiWafer
=ASU
Size 18x18 cm^2

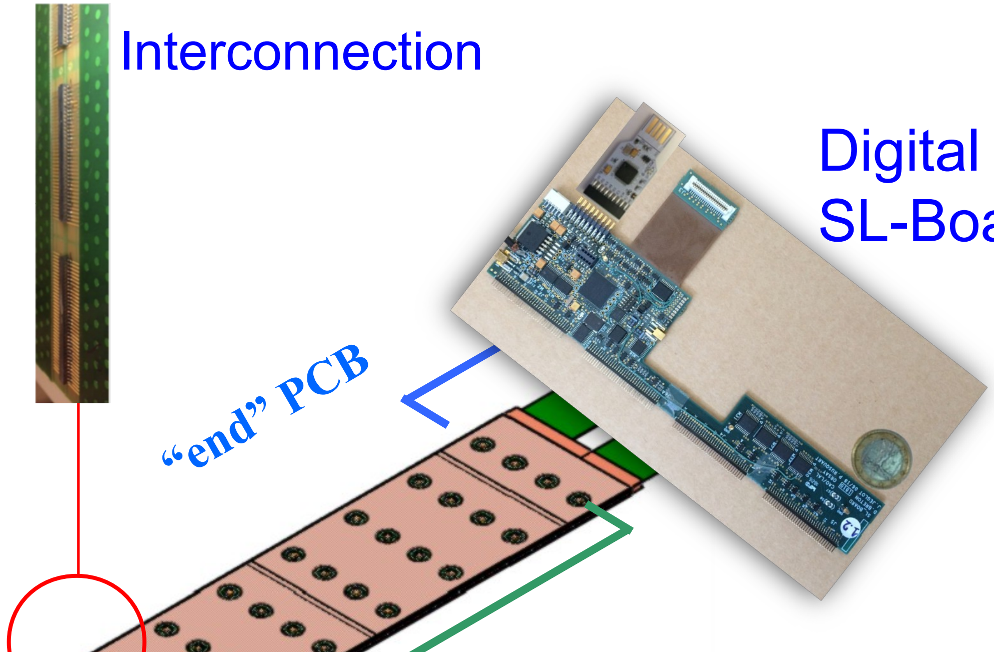
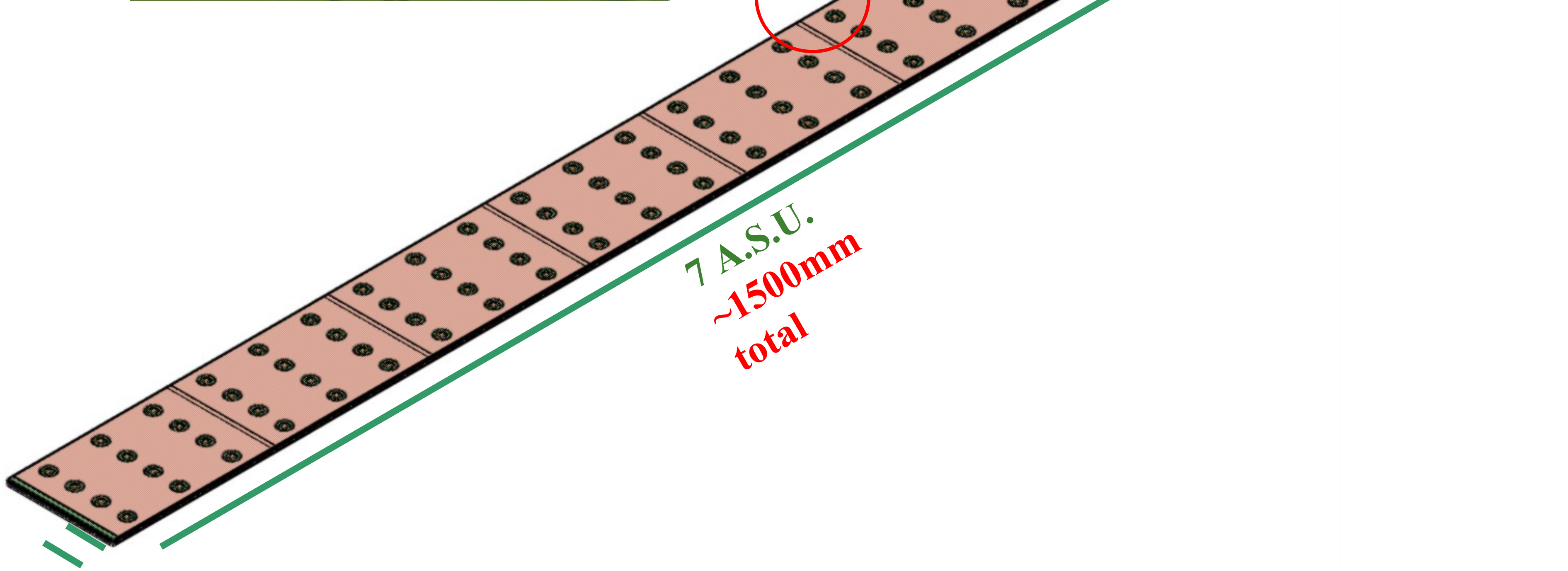


ASIC SKIROC2(a)
Wire Bonded or
In BGA package



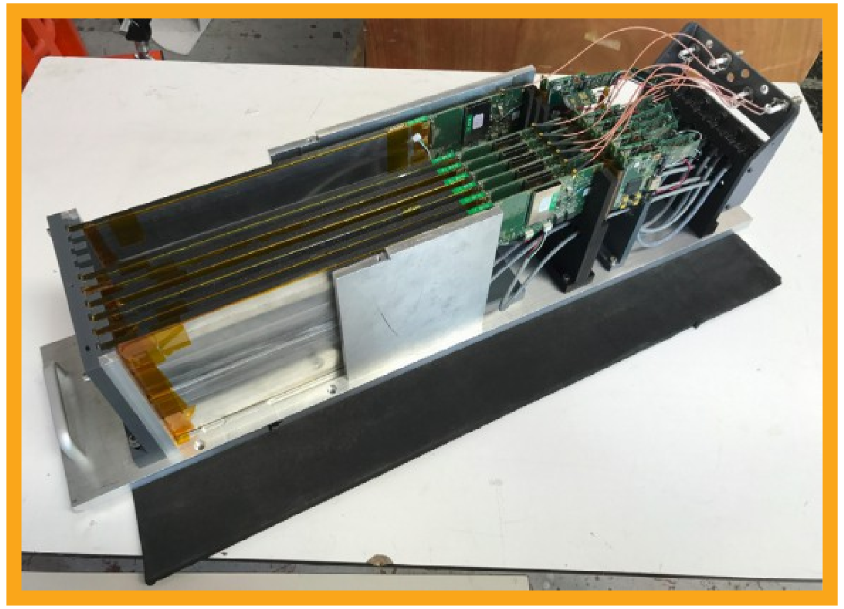
SiWafers glued onto PCB
Pixel size
5.5x5.5 mm^2

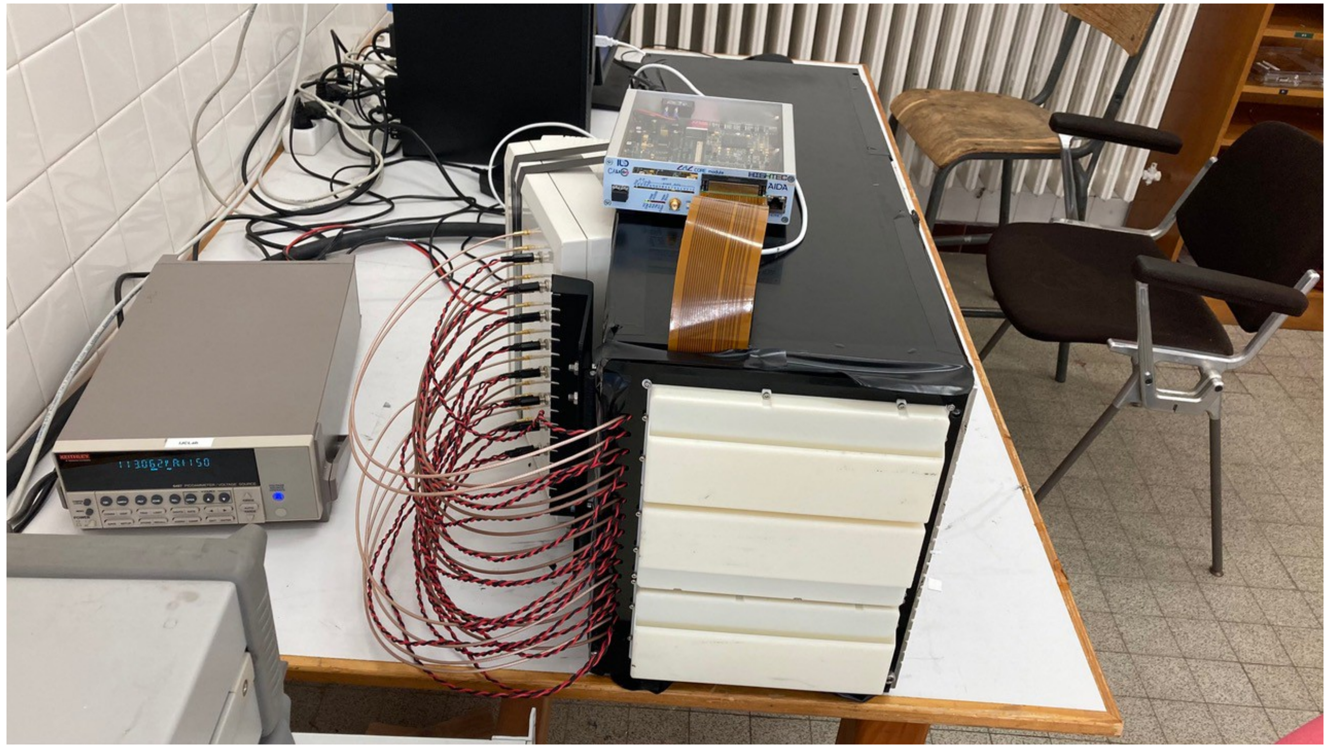


The beam test set ups consist of a **stack of short layers** built from one ASU and a readout card each

SiW ECAL: < 2018 → 2022





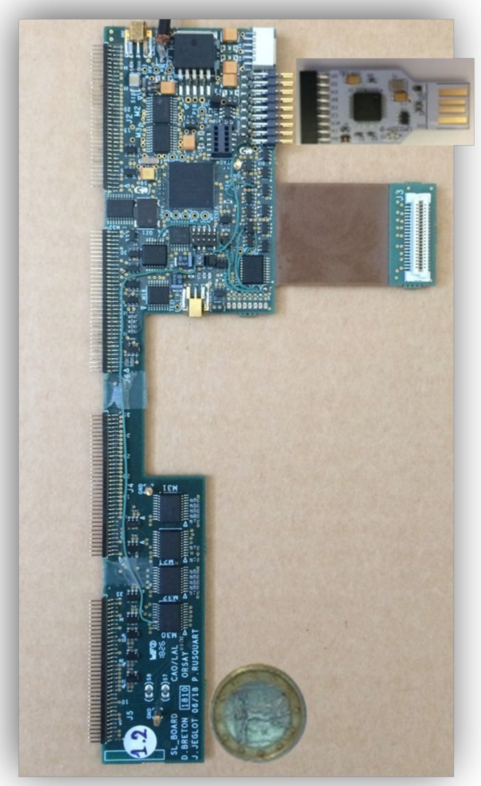
- 7 short layers (18x18x0.5cm^3)
- 1024 channels per layer => 7186 cells
  - Assembly chains in France and Japan
  - Beam tests at DESY and CERN since 2016

- 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
- Commissioned 2020-2022
  - ~450000 calibration constants for one ASIC feedback capa setting

Testbeams (finally) in November 2021 and during 2022

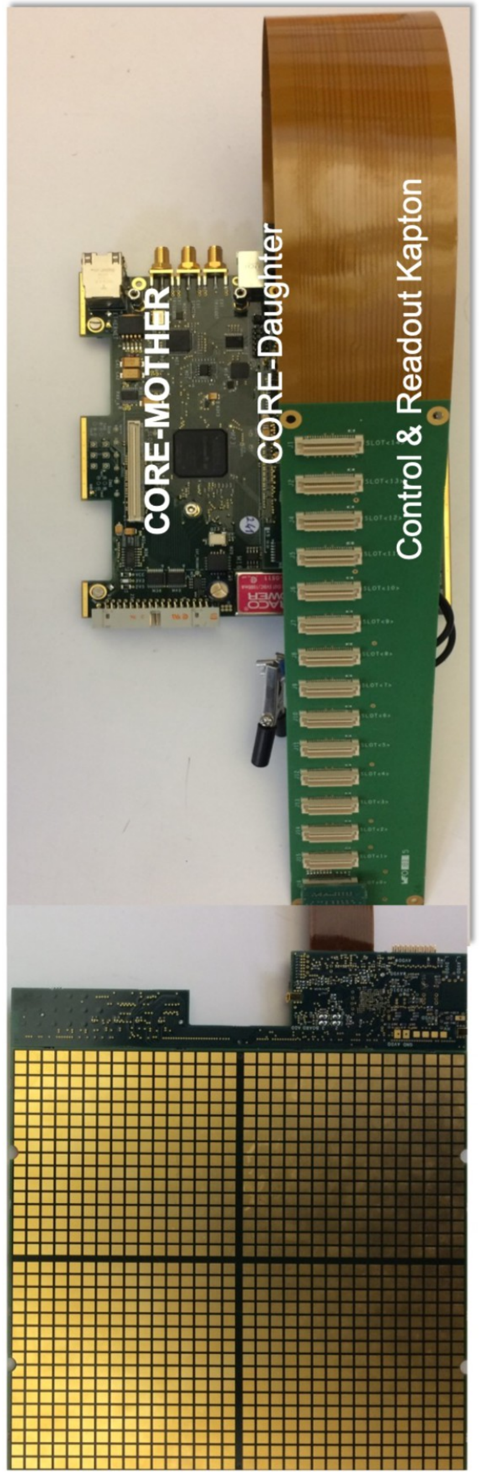
Compact readout of SiW ECAL

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



SL Board

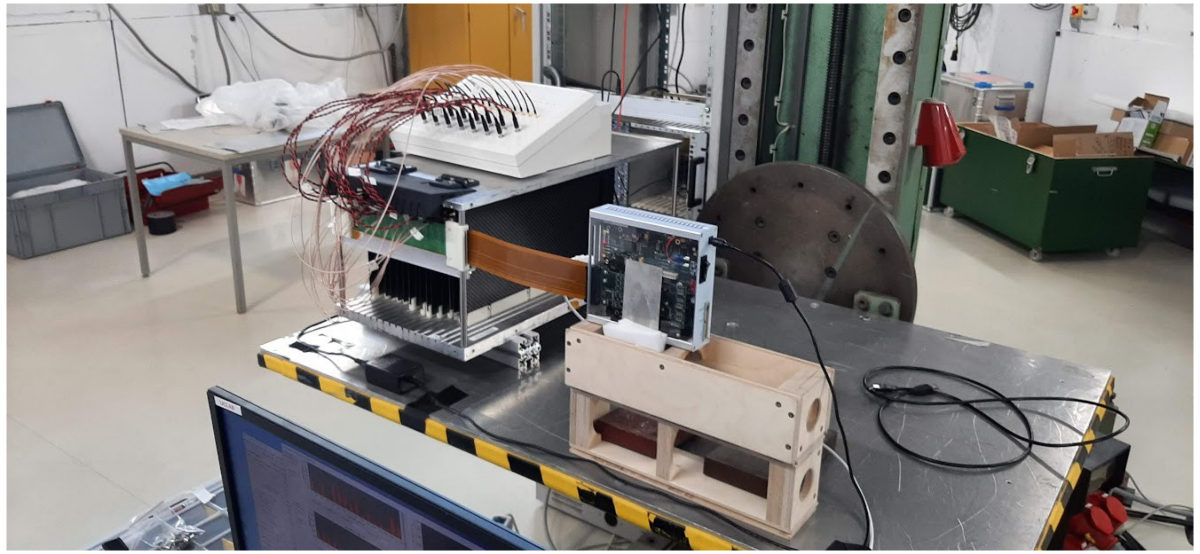
Complete readout system



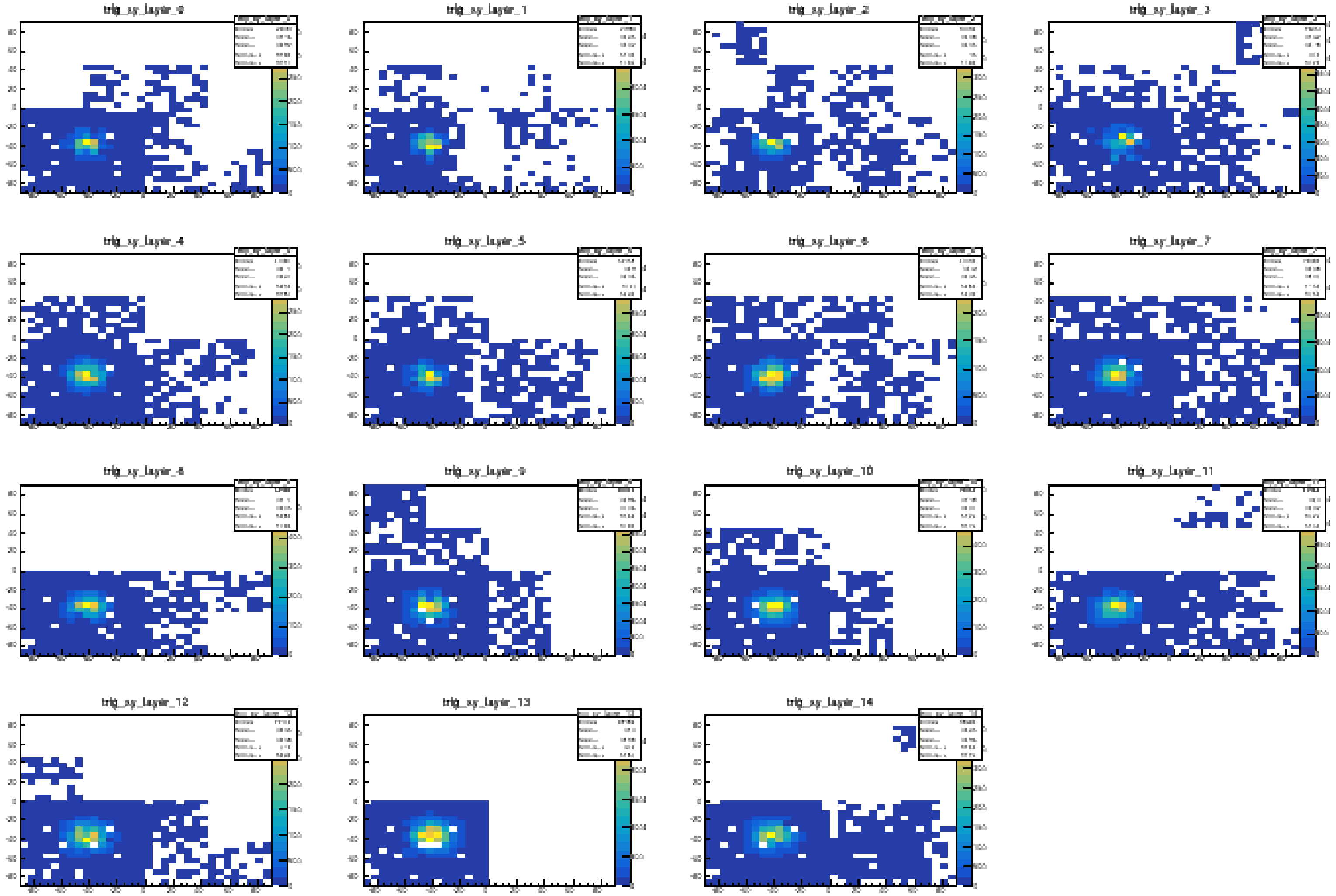
- “Dead space free” granular calorimeters put tight demands on compactness
- Current developments in CALICE for SiW ECAL meet these requirements
- Can be applied/adapted wherever compactness is mandatory
- Components will/did already go through scrutiny phase in beam tests

SiW-ECAL in beam test @ DESY

Detector Setup



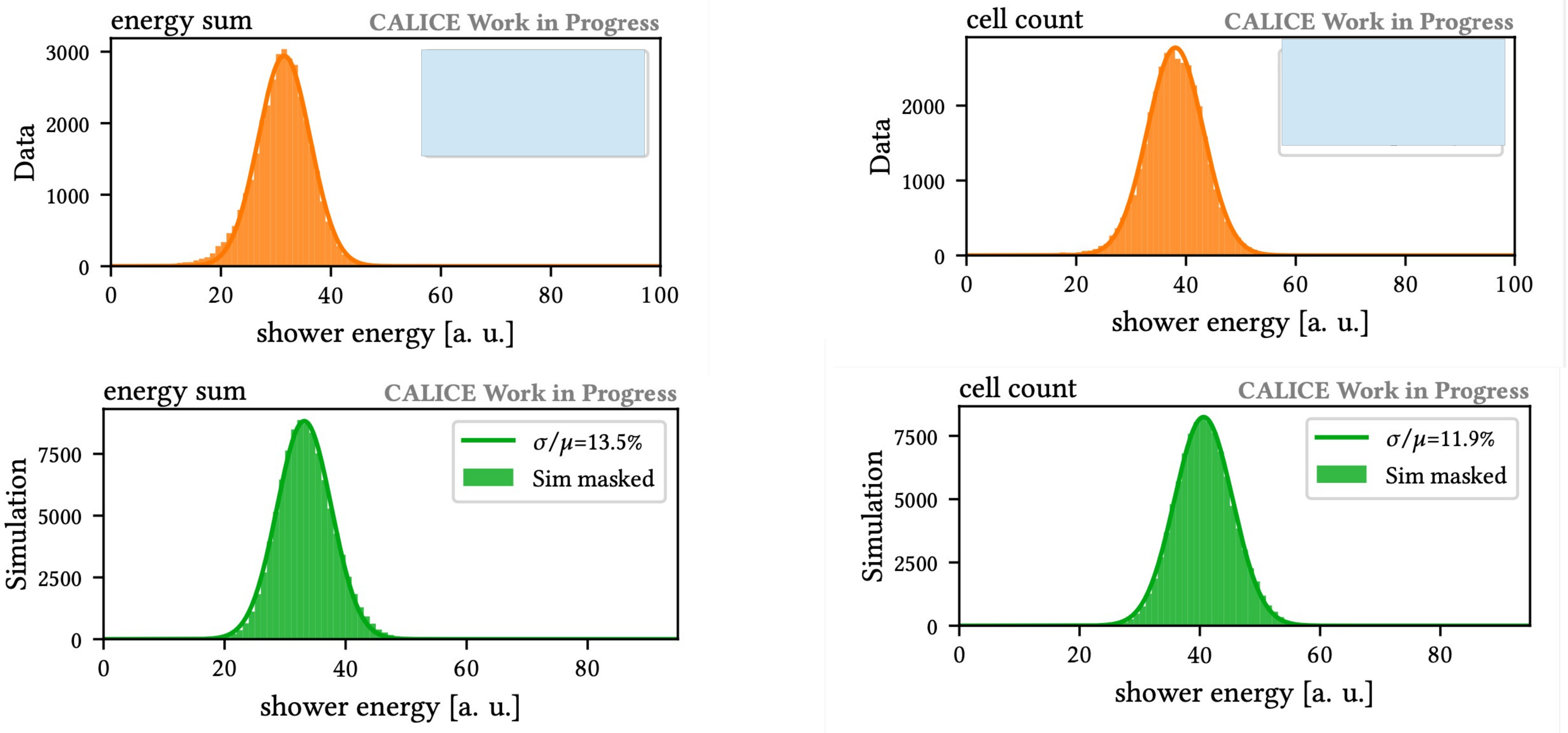
Detector in beam position



- 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

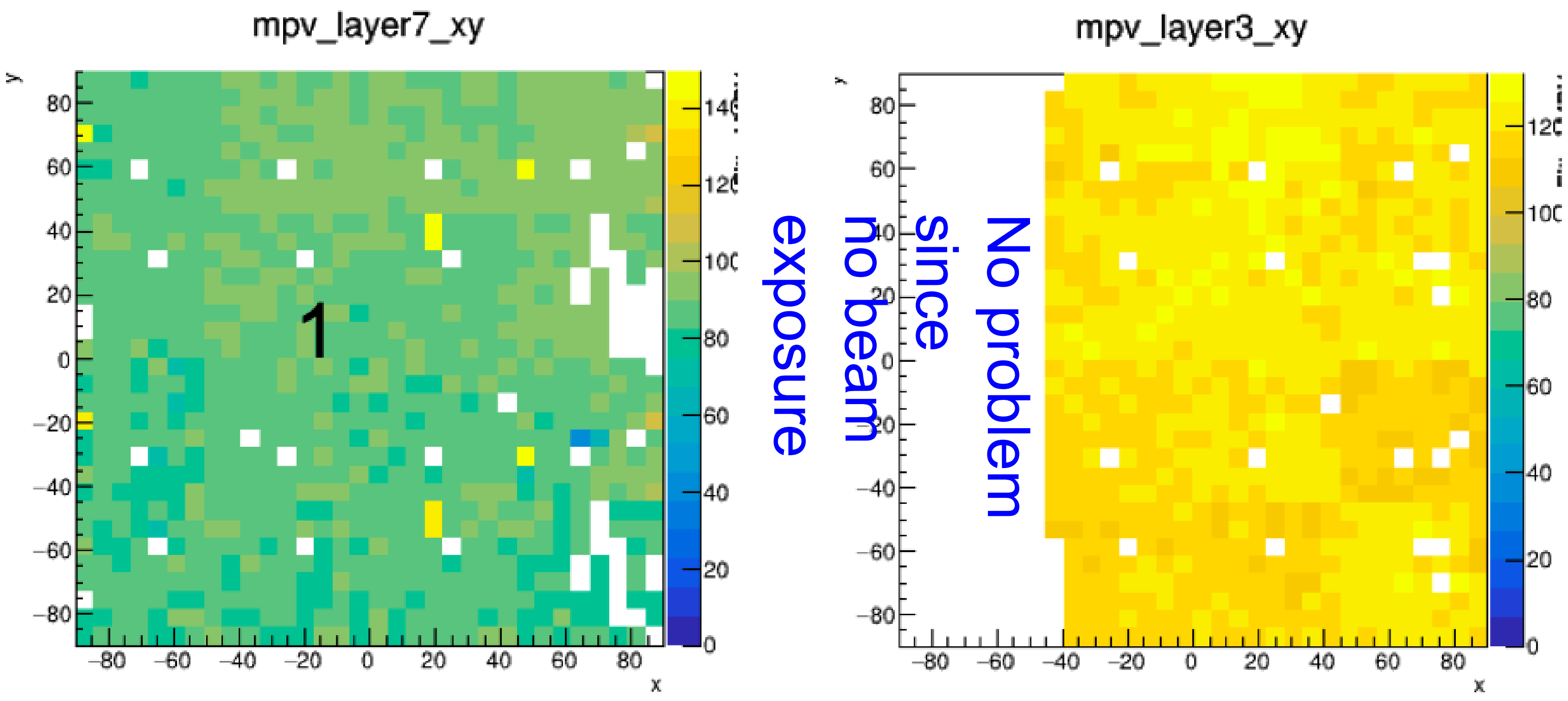
J. Kunath, F. Jimenez-Morales, SiW Ecal Analysis Meeting, 22/09/22



After proper filtering energy resolution in right ballpark for current prototype
Convergence in agreement data/MC

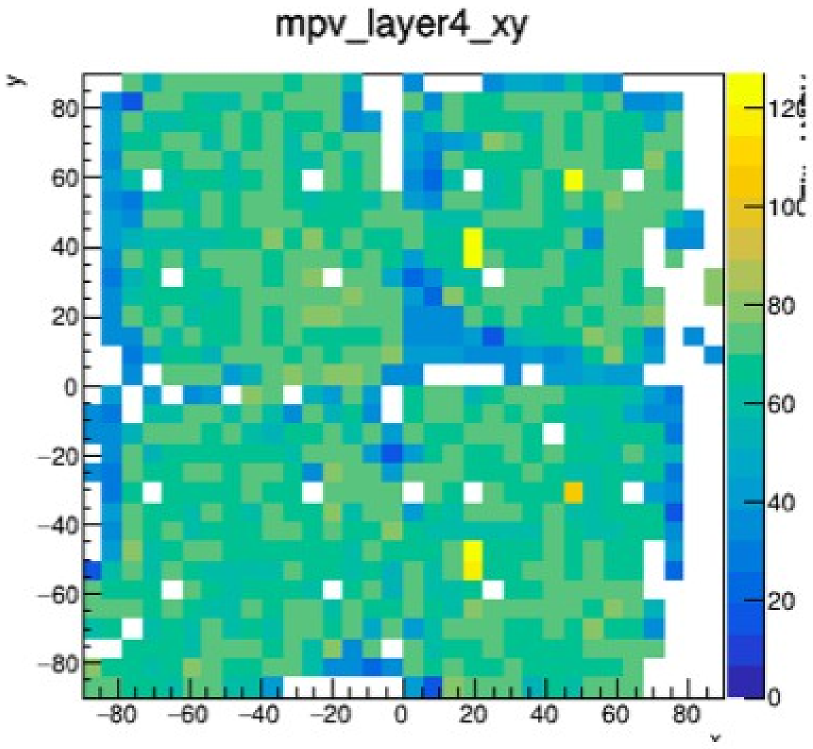
SiW-ECAL beam tests - Further observations

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

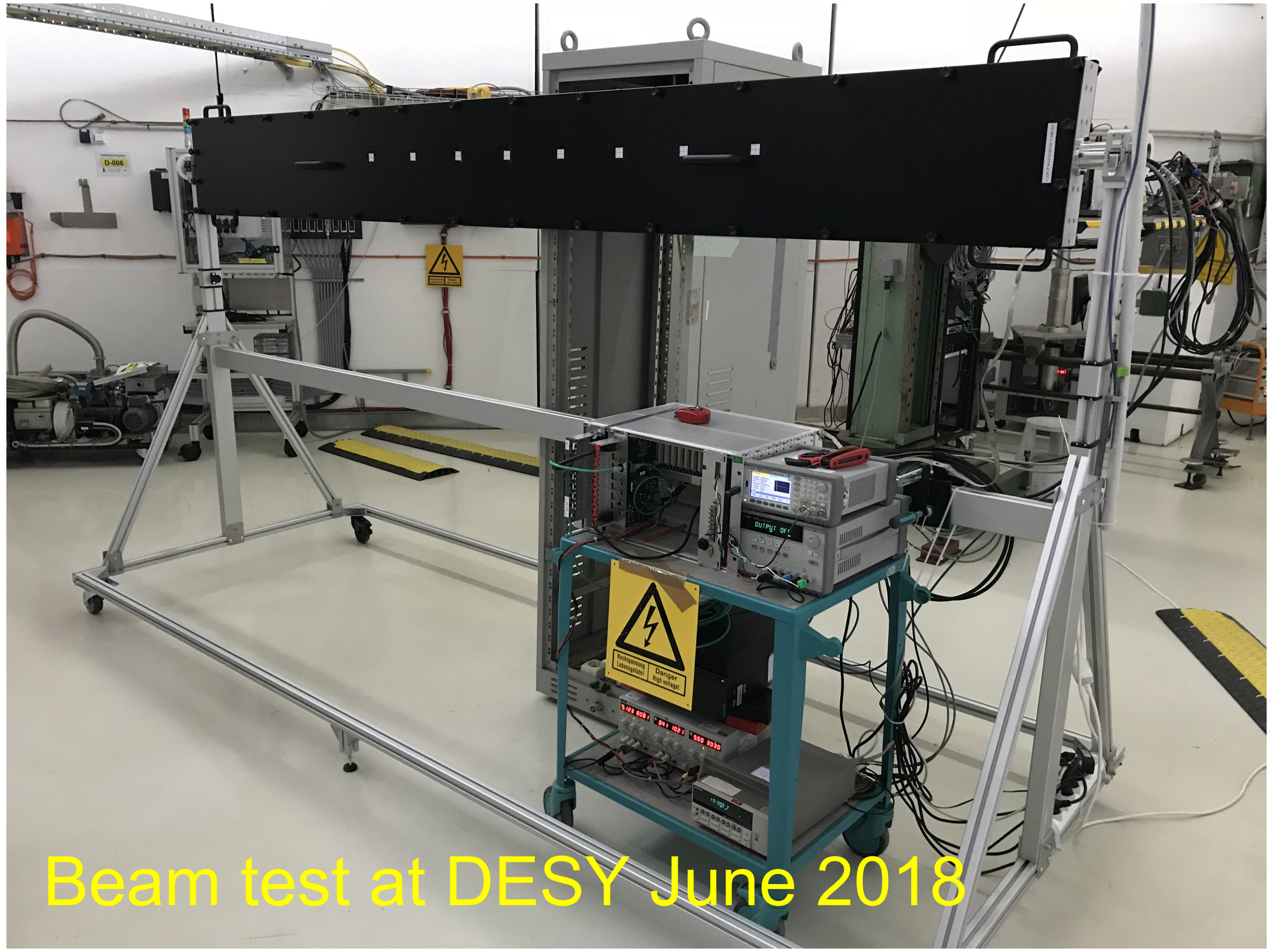
- Partially even no response at all, in particular at the wafer boundaries
- Not seen in 2017, degradation observed during 2018/19
- To be understood, **about to start with dedicated aging studies**

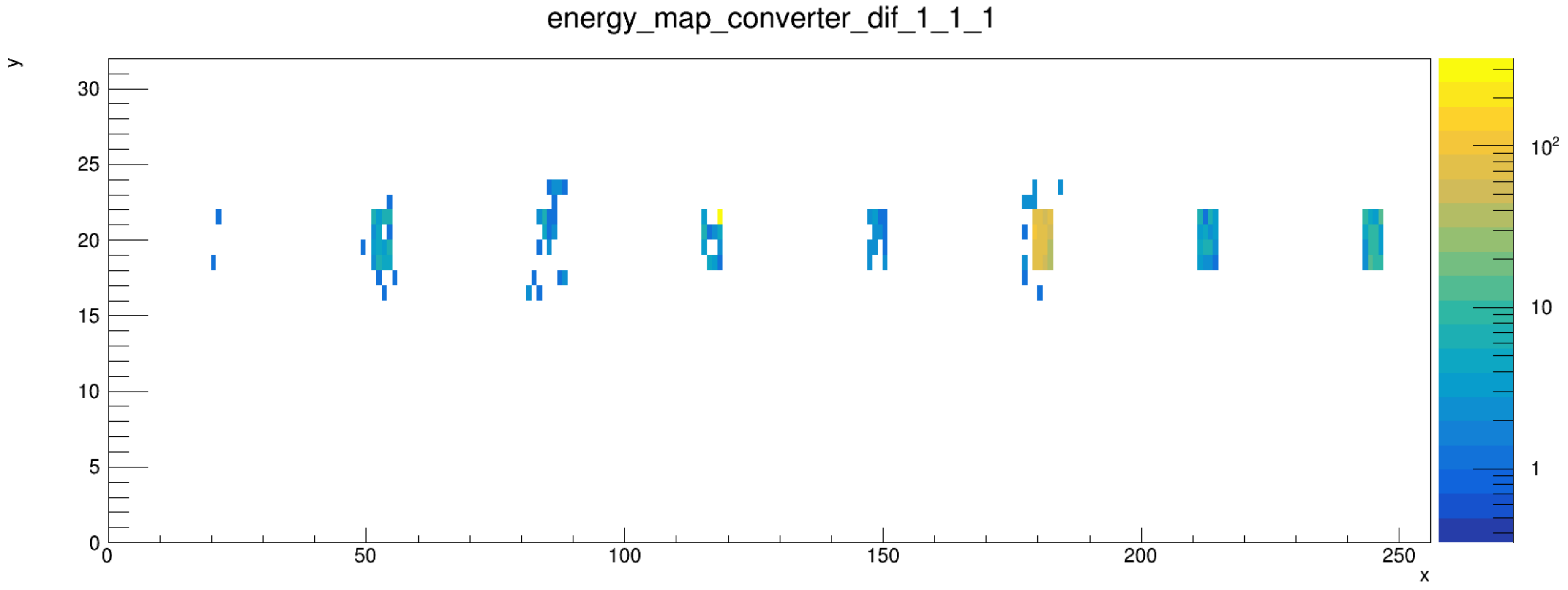
Since Summer 2022 access to the different stages of the ASICs

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

(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

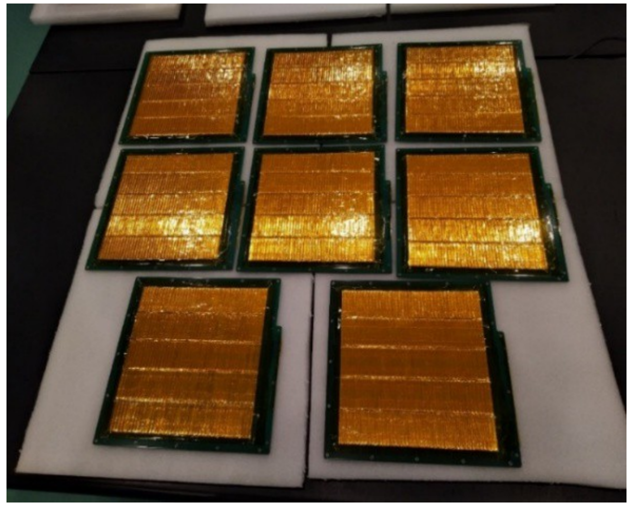
Long slab studies will be resumed with new FEV (see later)

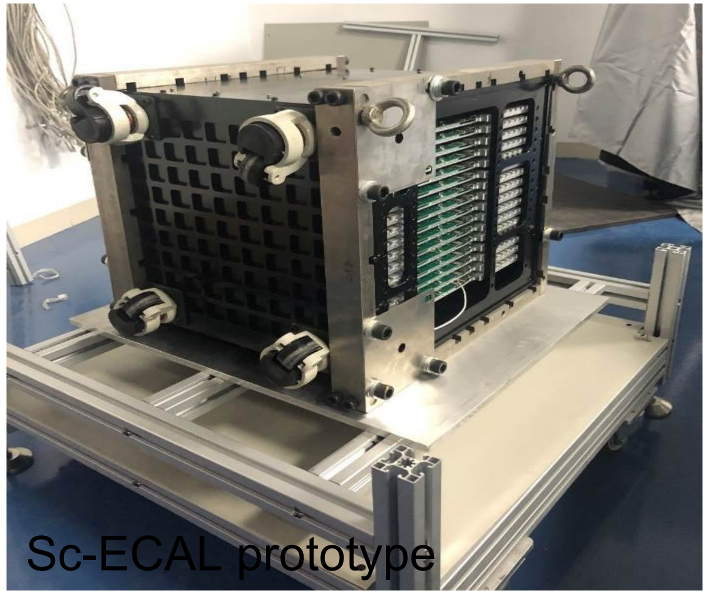
- Adapted for power pulsing, will avoid voltage drop, etc ...

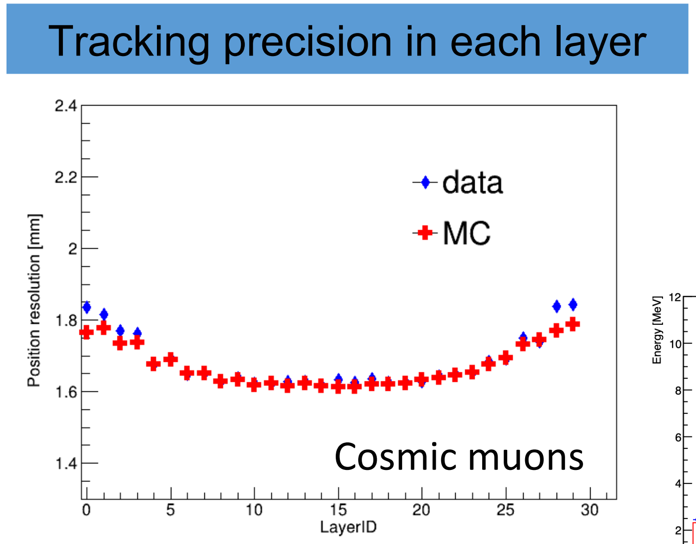
Technological Prototype Sc-Ecal

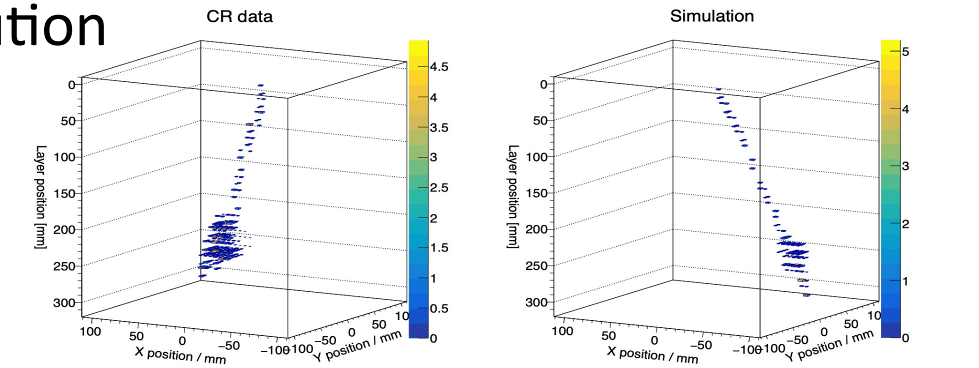
- Sc-ECAL prototype: successful construction during 2019-2020
  - Effective granularity 5×5mm², 32 sensitive layers composed of **scintillating strips** and CuW absorber plates
  - 6700 readout channels in total

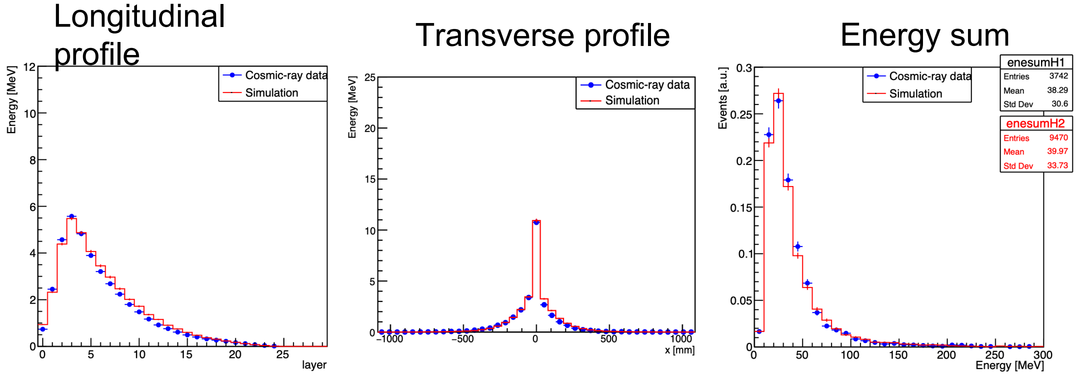
- Successful commissioning and long-term cosmic-ray tests (2020-2021)
  - Calibration of all SiPMs and SPIROC2E chips; MIP response calibration
  - Tracking performance: achieved better than 2mm positioning resolution





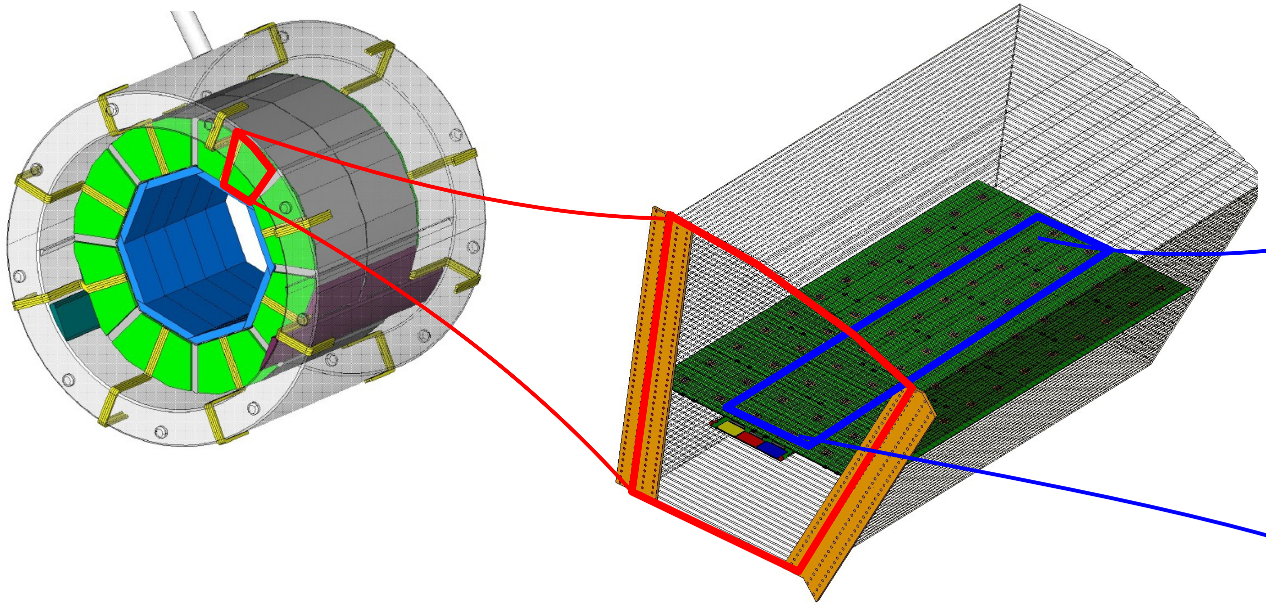


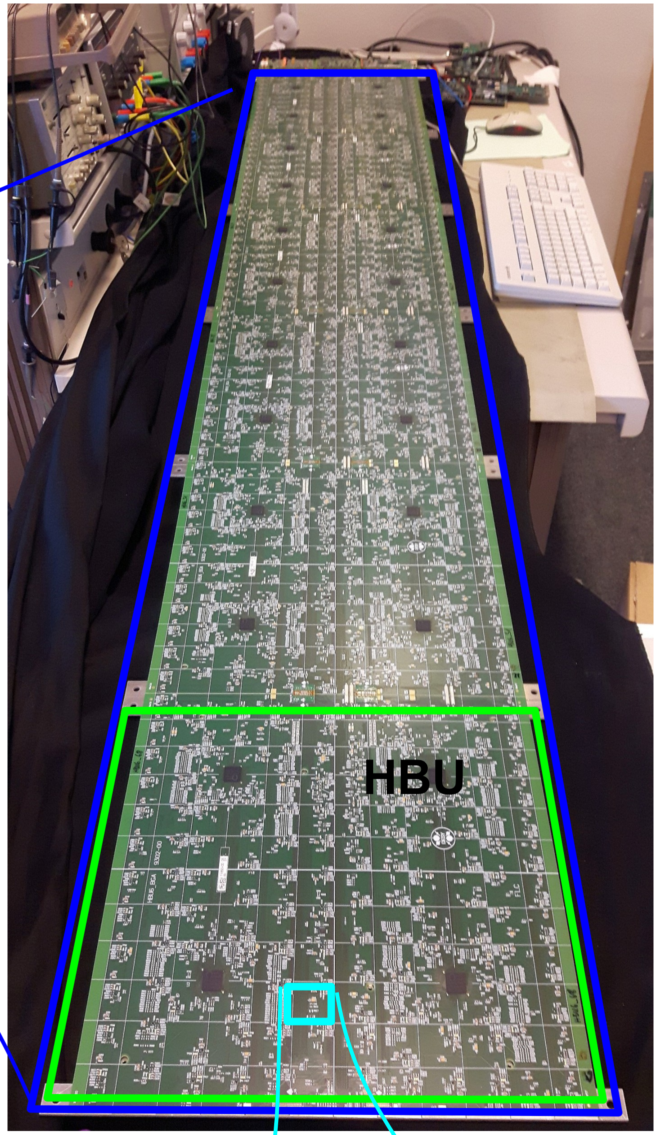


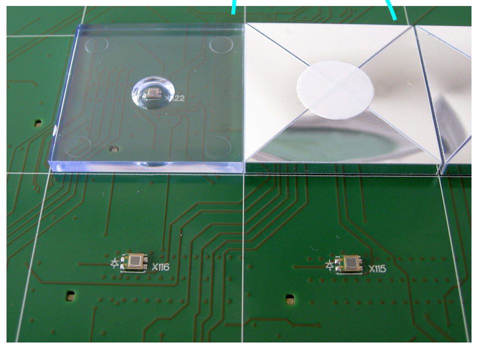


- Gearing up for beam test at CERN in October 2022

AHCAL Technological Prototype



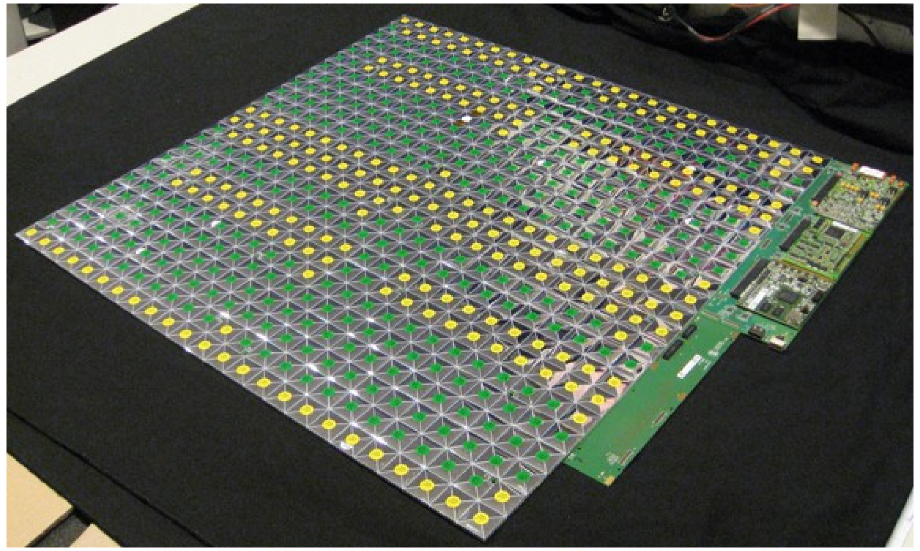




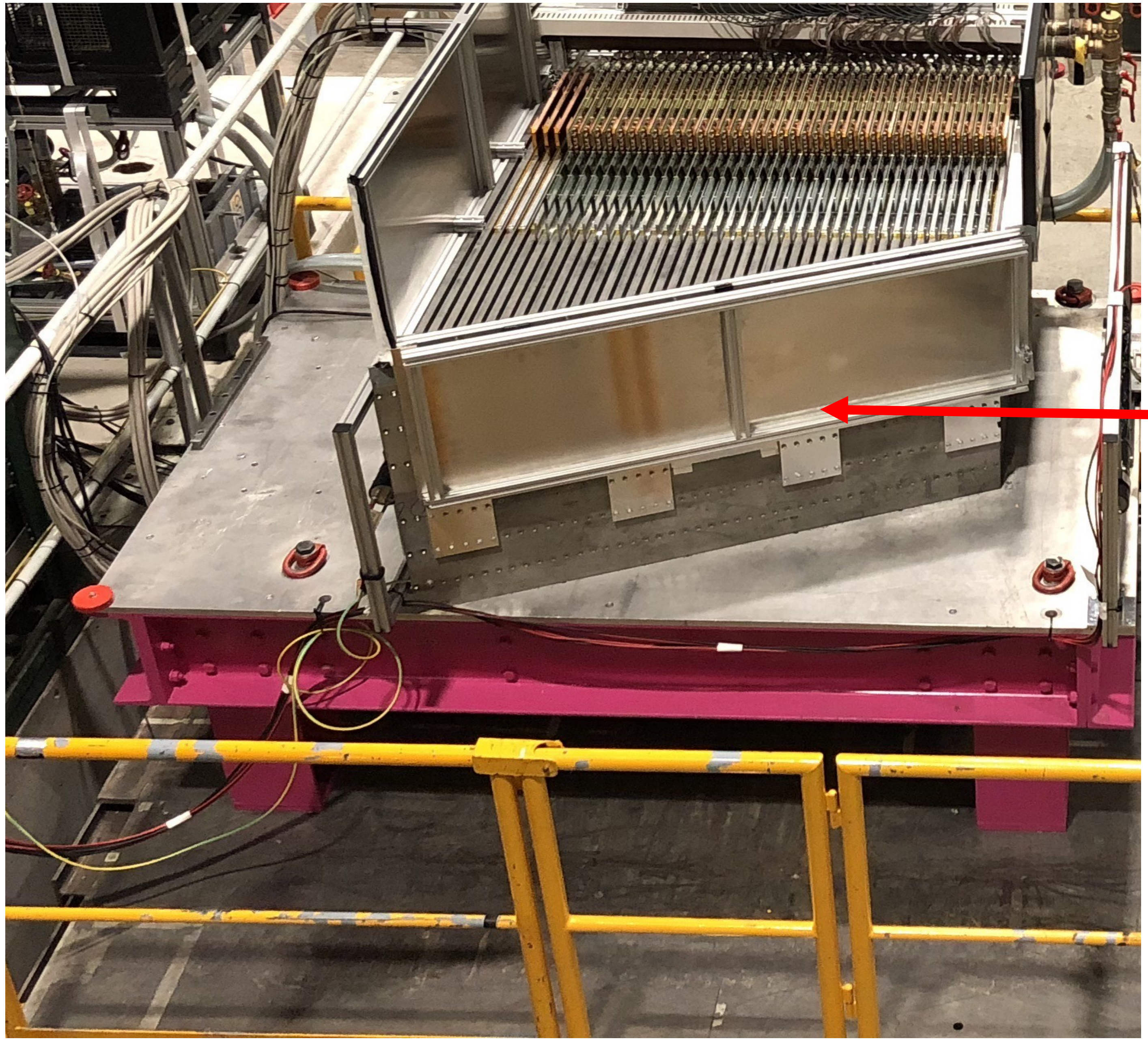
- highly granular scintillator SiPM-on-tile hadron calorimeter, 3*3 cm² scintillator tiles optimised for uniformity
- **fully integrated design**
  - front-end electronics, readout
  - voltage supply, LED system for calibration
  - no cooling within active layers -> **power pulsing**
- **scalable** to 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

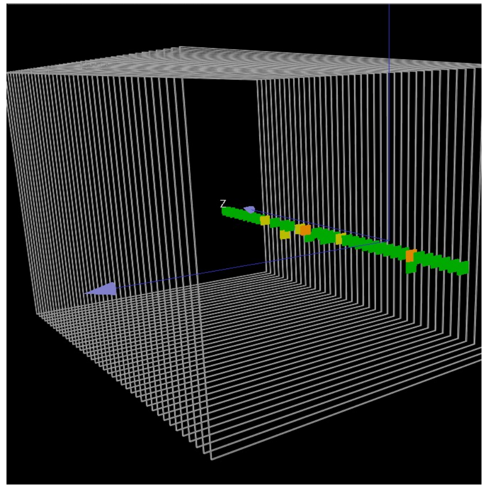
- Large enough to contain hadron showers
  - 38 active layers of 72*72 cm²
  - 4 HBUs per module
  - in total: 608 SPIROC2E ASICs, **~22000 channels**
  - SiPMs: Hamamatsu S13360-1325PE
- All modules interchangeable
- Built with scalable production techniques in ~2 years
- Operated in beam tests with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

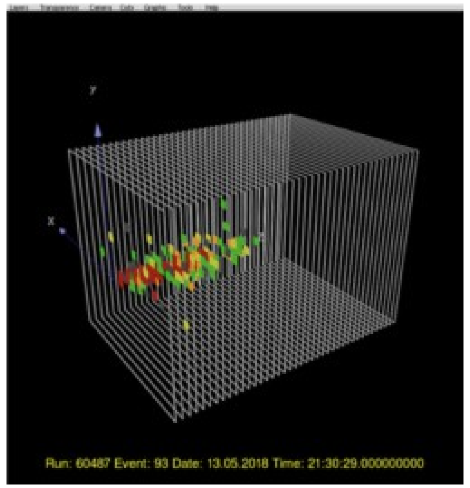


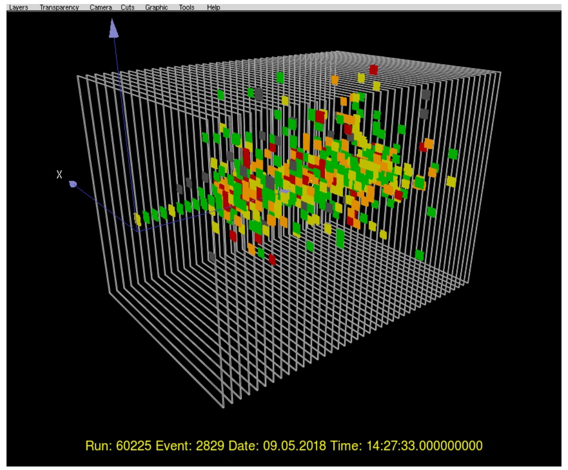
AHCAL Technological Prototype at SPS Testbeam



beam





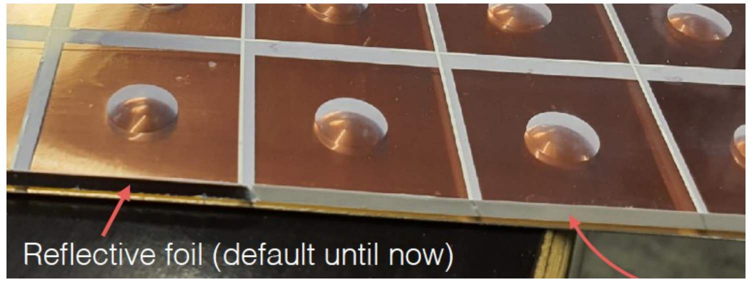


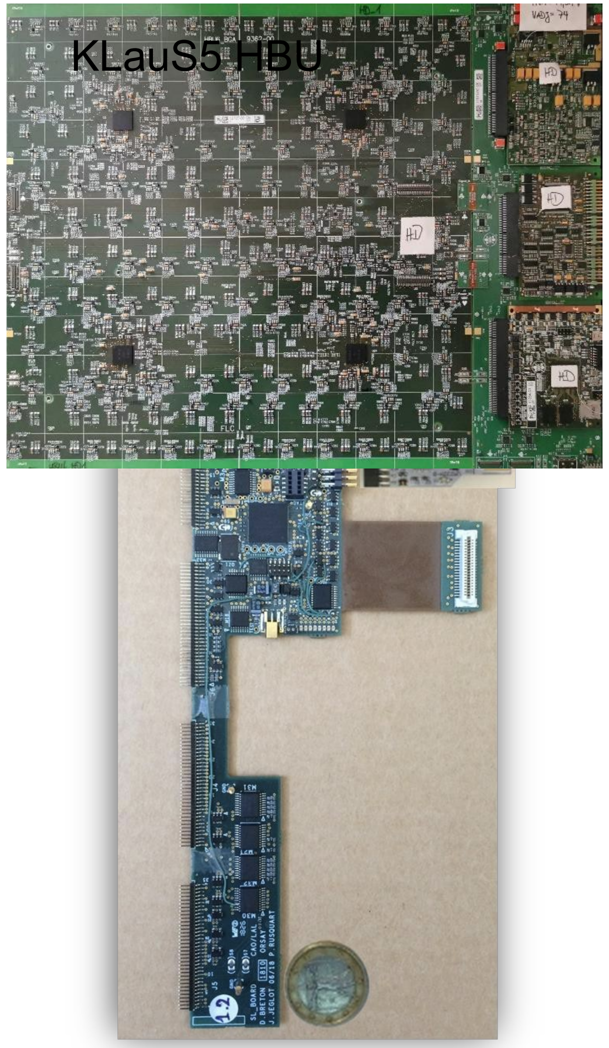
AHCAL Plans - Hardware Development

- 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

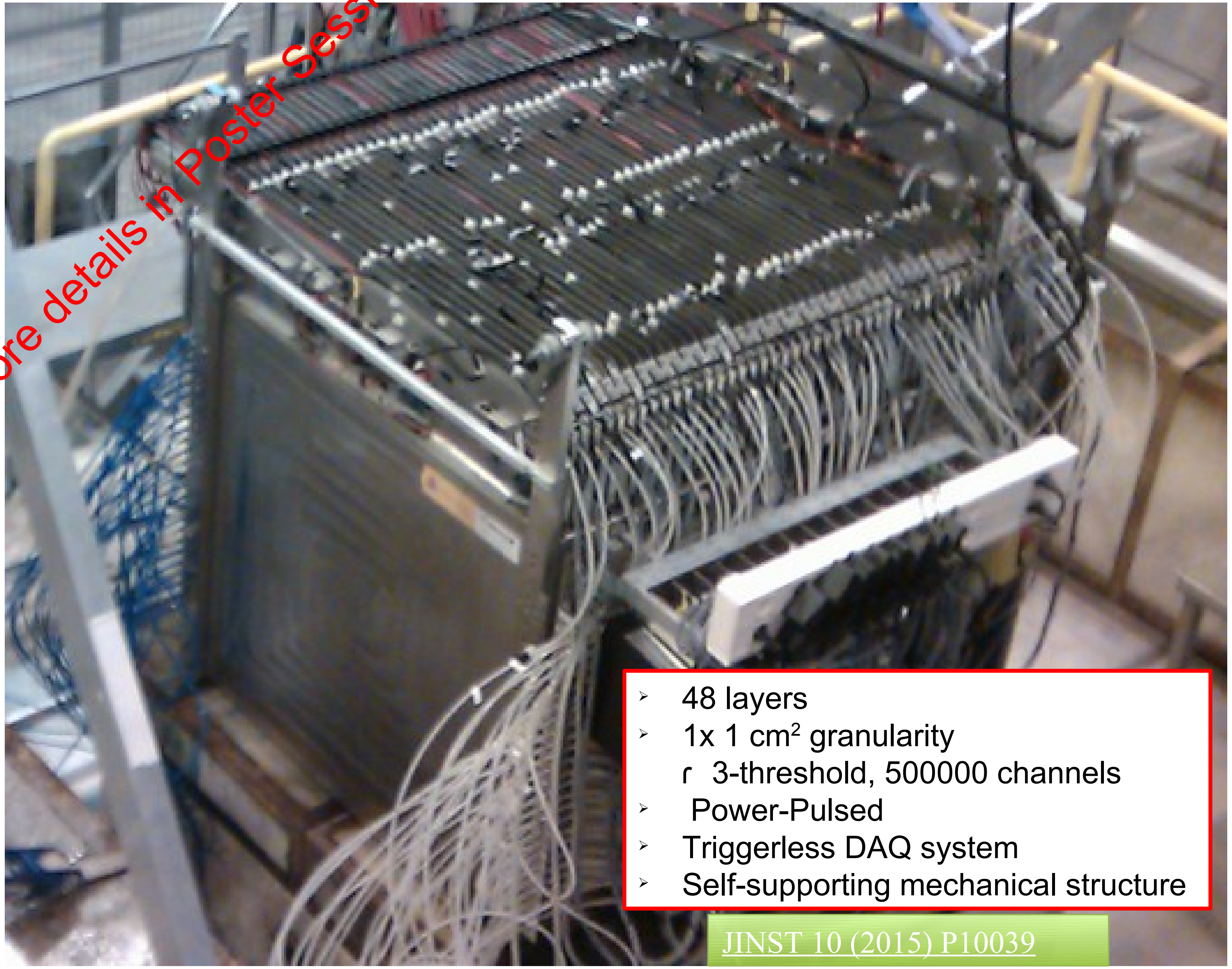
- Common Readout
- Harmonise readout between CALICE SiW ECAL and AHCAL
- Status: First round of discussion for AIDAinnova MS Report





Semi-Digital HCAL – Technological Prototype

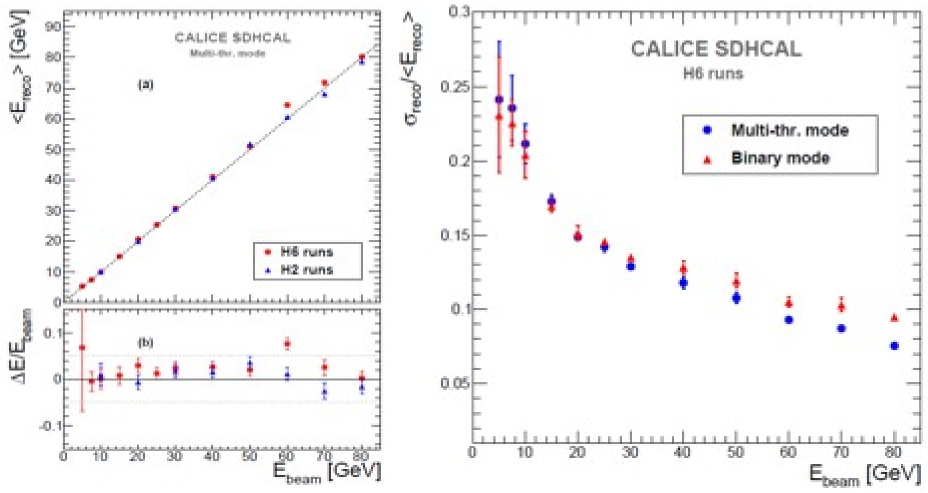
More details in Poster Session

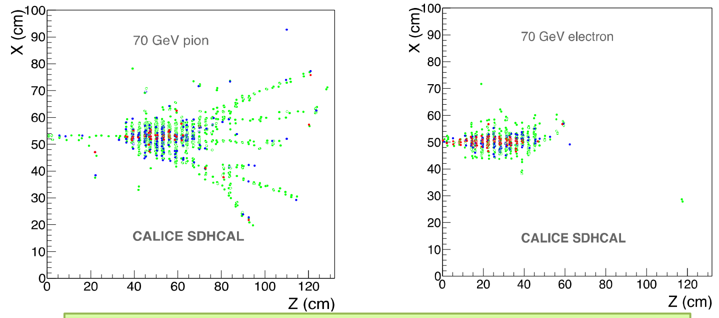


- 48 layers
- 1x 1 cm^2 granularity
  - 3-threshold, 500000 channels
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure

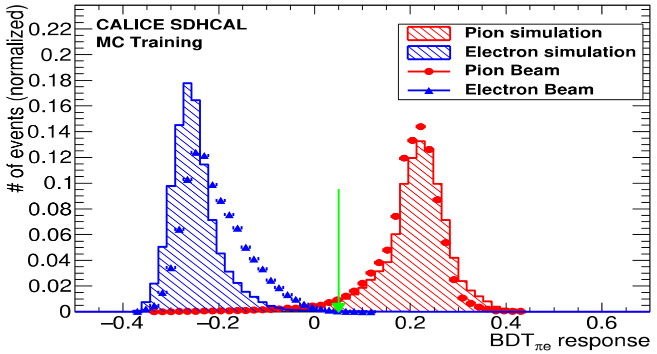
JINST 10 (2015) P10039

JINST 11 (2016) P04001



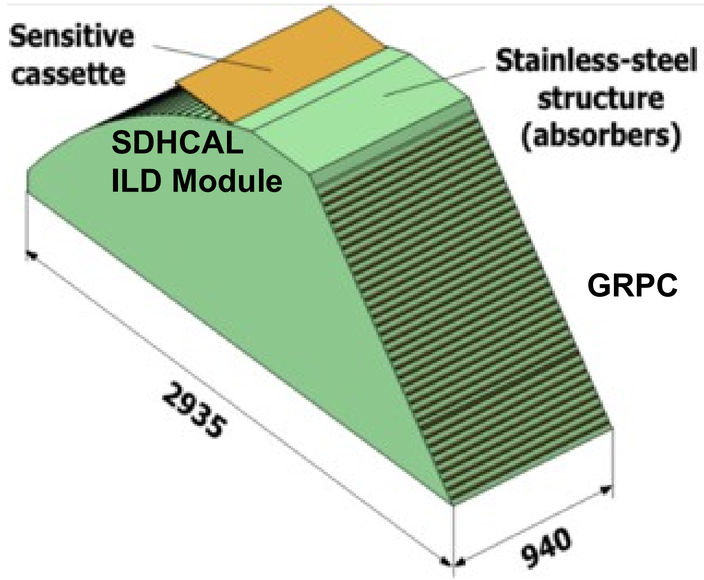


JINST 15 (2020) P10009

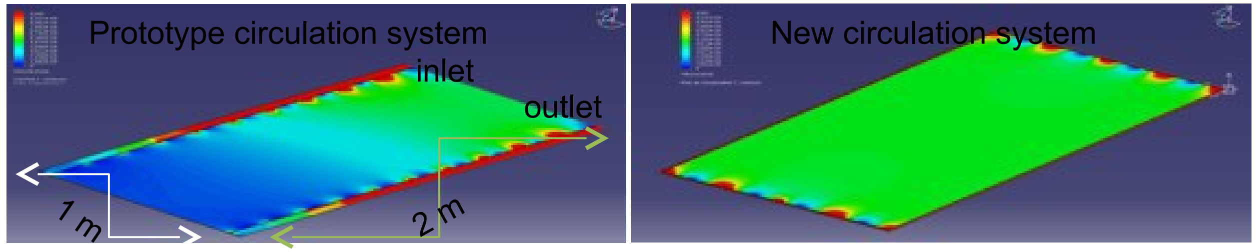


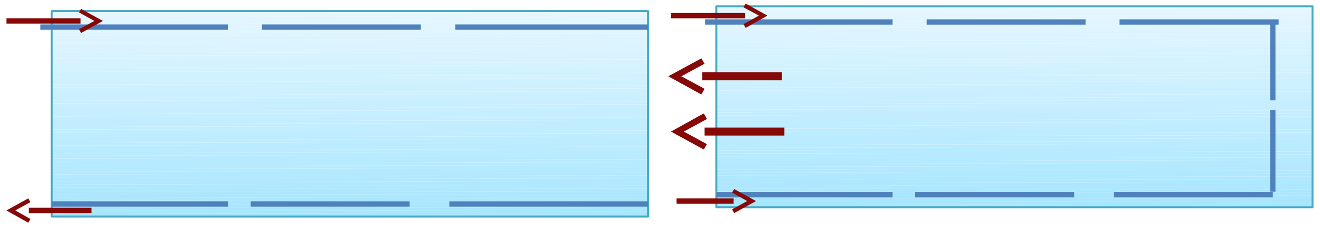
SDHCAL – Large Structures

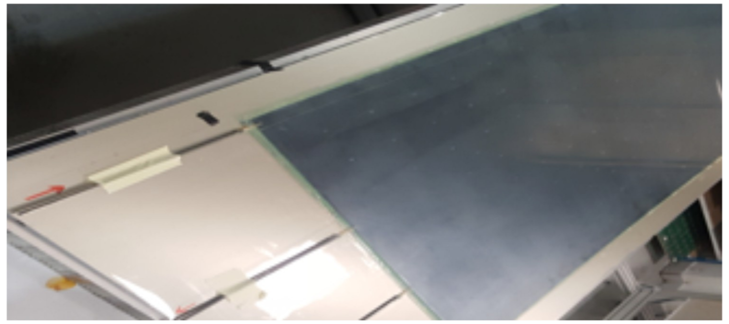
- Detectors as large as $3x1m^2$ need to be built
- Electronic readout should be the most robust with minimal intervention during operation.
- Mechanical structure with minimal dead zone
- Include time information **SDHCAL -> T-SDHCAL**



Large RPC detectors







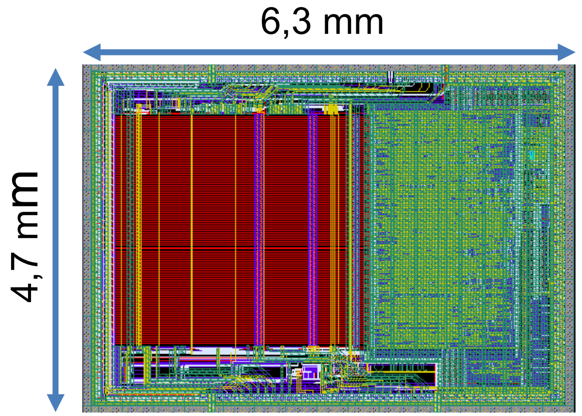
Large mechanical structure

Flatness
Using roller leveling

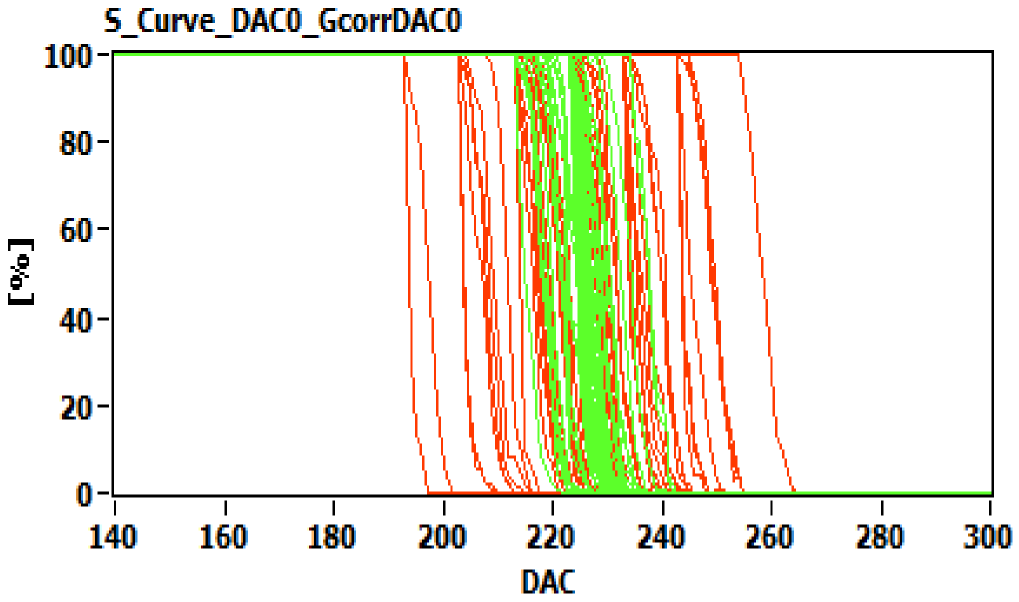
Reduced dead zone
Using electron beam weilding

SDHCAL – New electronics readout

HARDROC2→HARDROC3

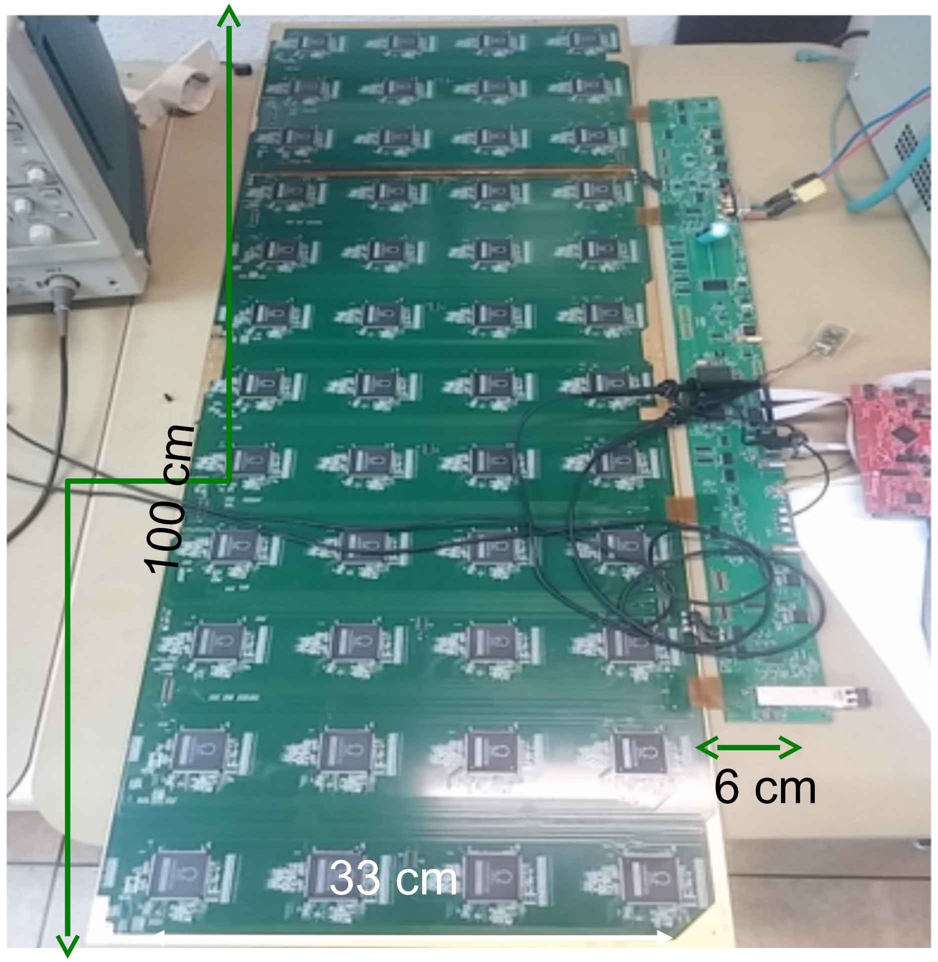


- **Independent channels**
- **Zero suppression**
- Extended dynamic range (**up to 50 pC**)
- **I2C link with triple voting for slow control parameters**



786 HR3 produced and tested , Yield : 83.3 %

- Larger PCB (**100x33 cm²**)
- Detector InterFace (**DIF**) to read out up to 432 ASICs



13 ASUs & 5 DIF produced and being tested

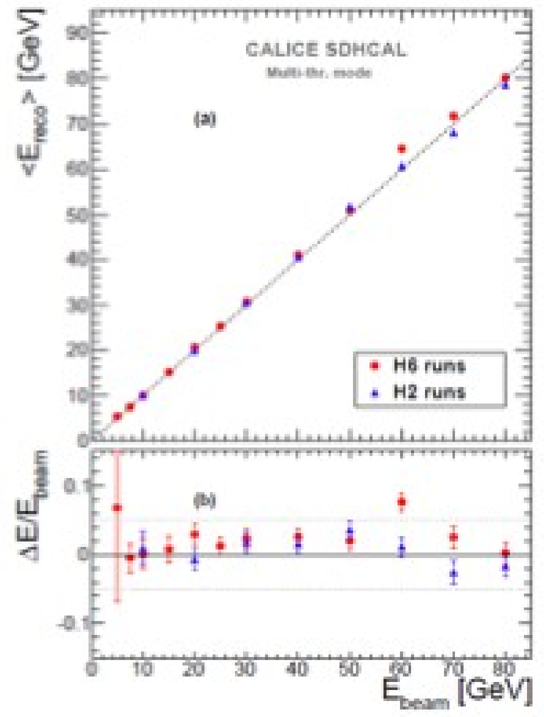
SDHCAL – TB2022

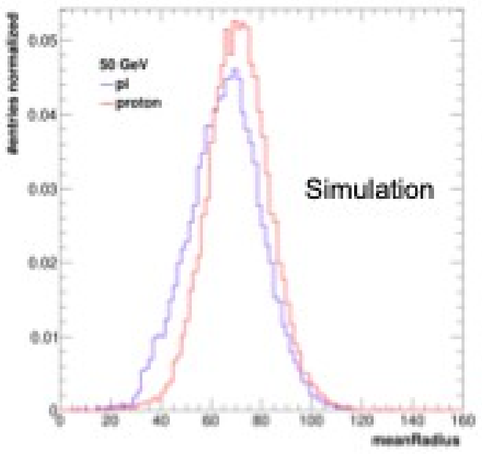
Highlight II: SDHCAL testbeam

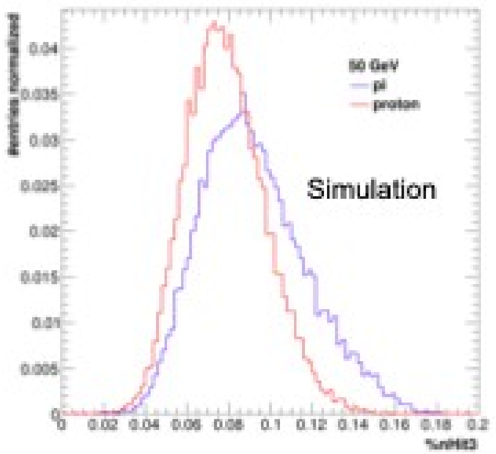
$$E_{rec} = \alpha(N_{tot})\, N_1 + \beta(N_{tot})\, N_2 + \gamma(N_{tot})\, N_3$$

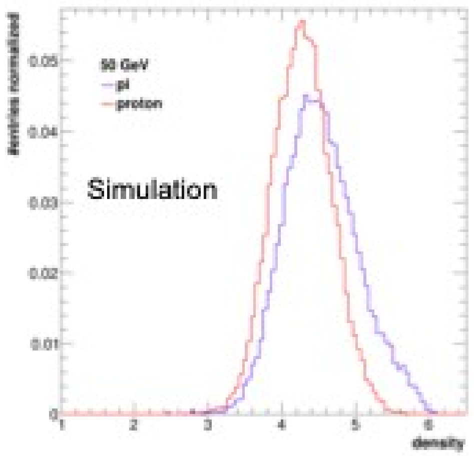
2 weeks of beam test at CERN SPS: 14 - 28 September 2022

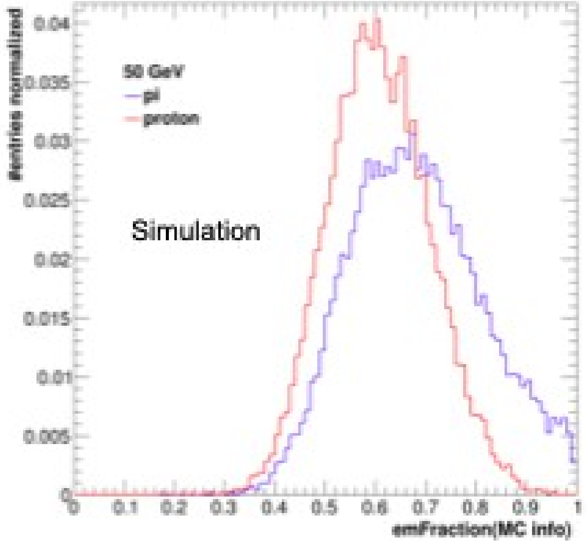
- Observation in previous beam tests: (slightly) different reconstructed hadron energy in two beam lines at SPS, which have different mixtures of pions and protons
- Goal for this testbeam: use Cherenkov detectors to separate pions and protons
- Expectation: pion showers have higher EM fraction and more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









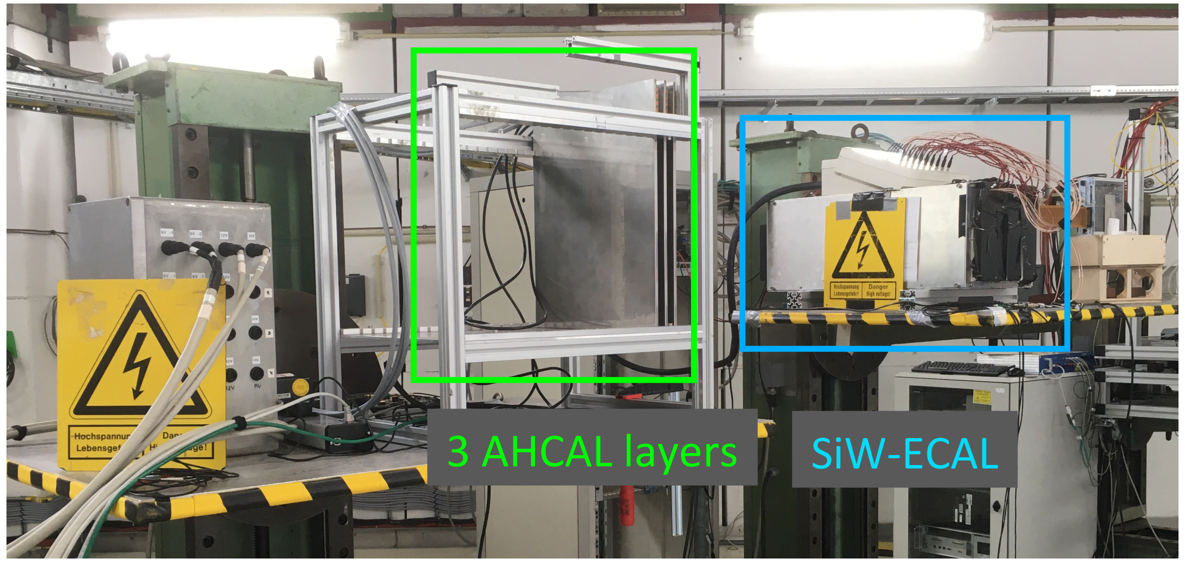


From K. Krüger this morning

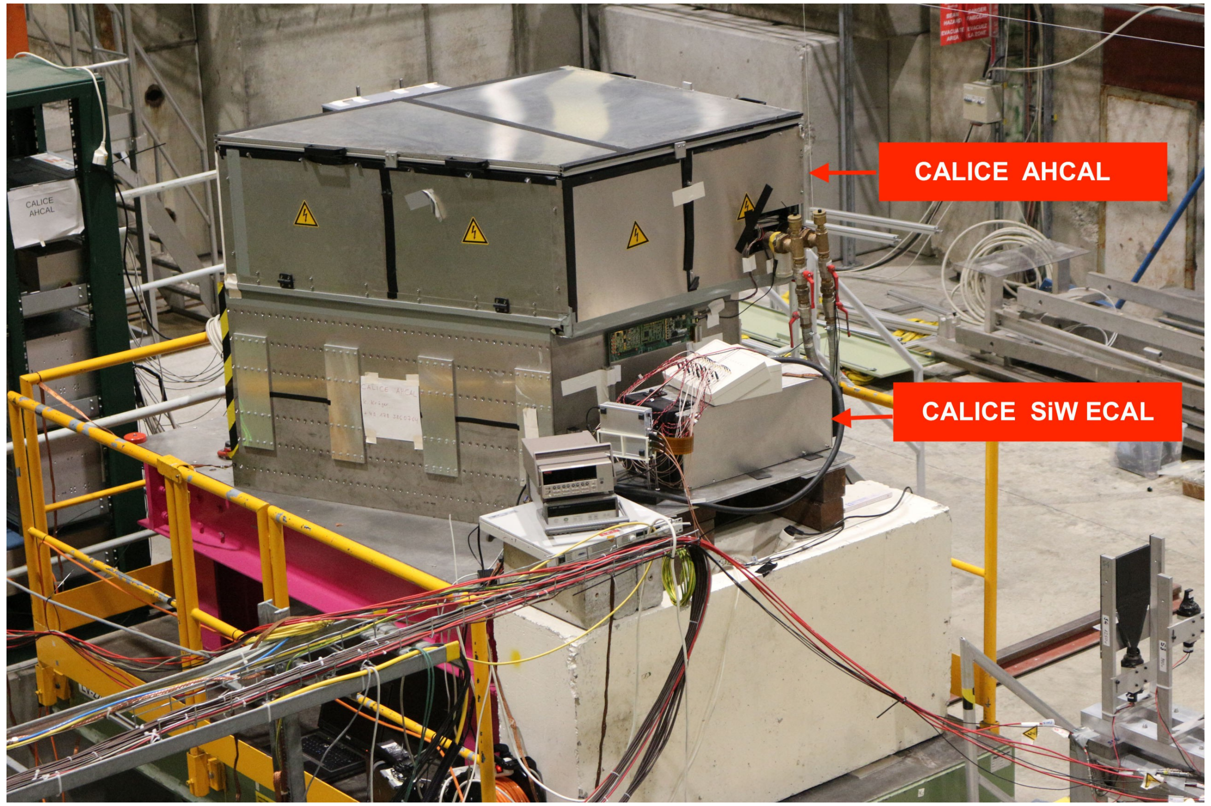
Common beam tests I

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

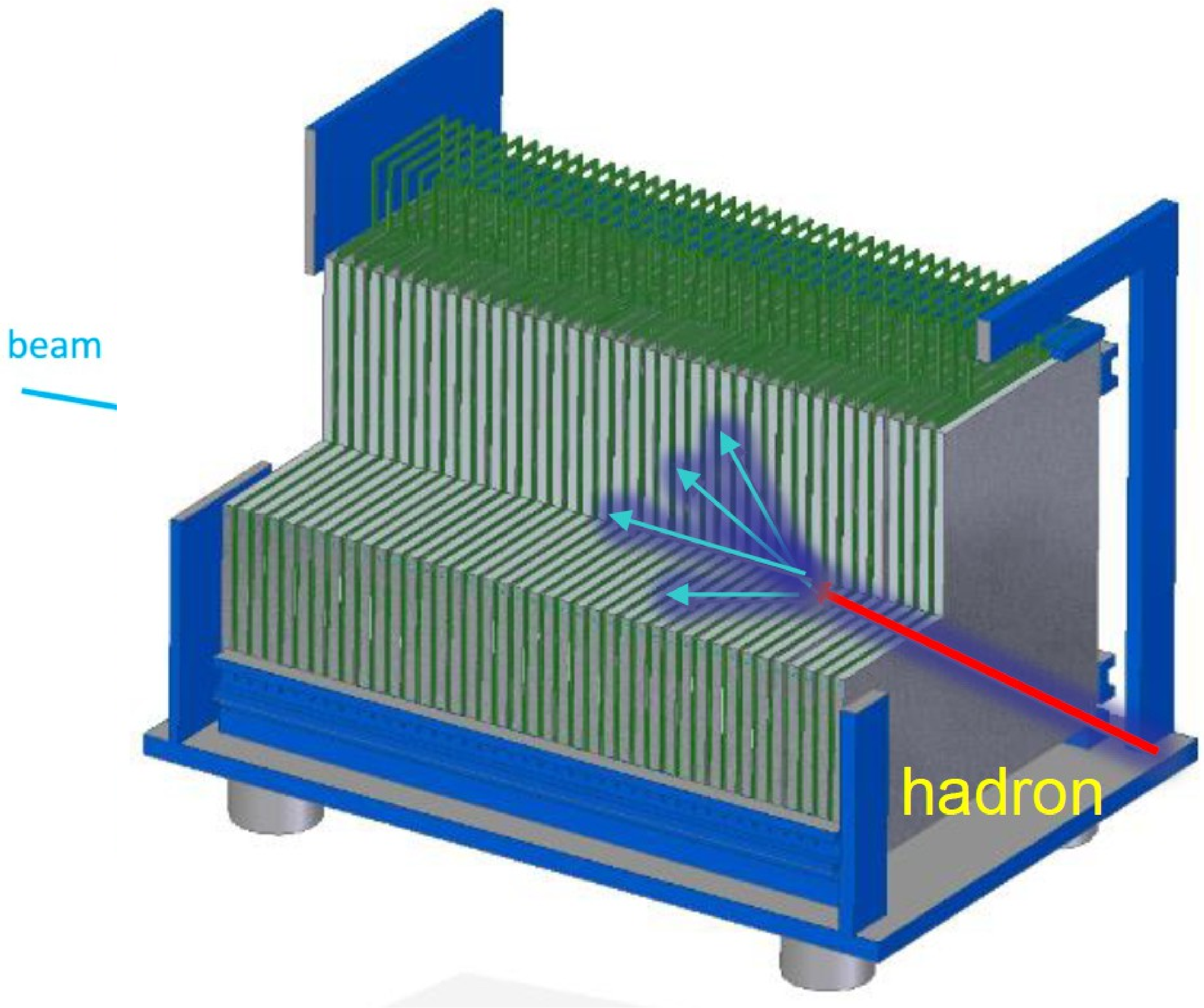
- First step of ***knowledge transfer*** on compact readout system to AHCAL → AIDA innova

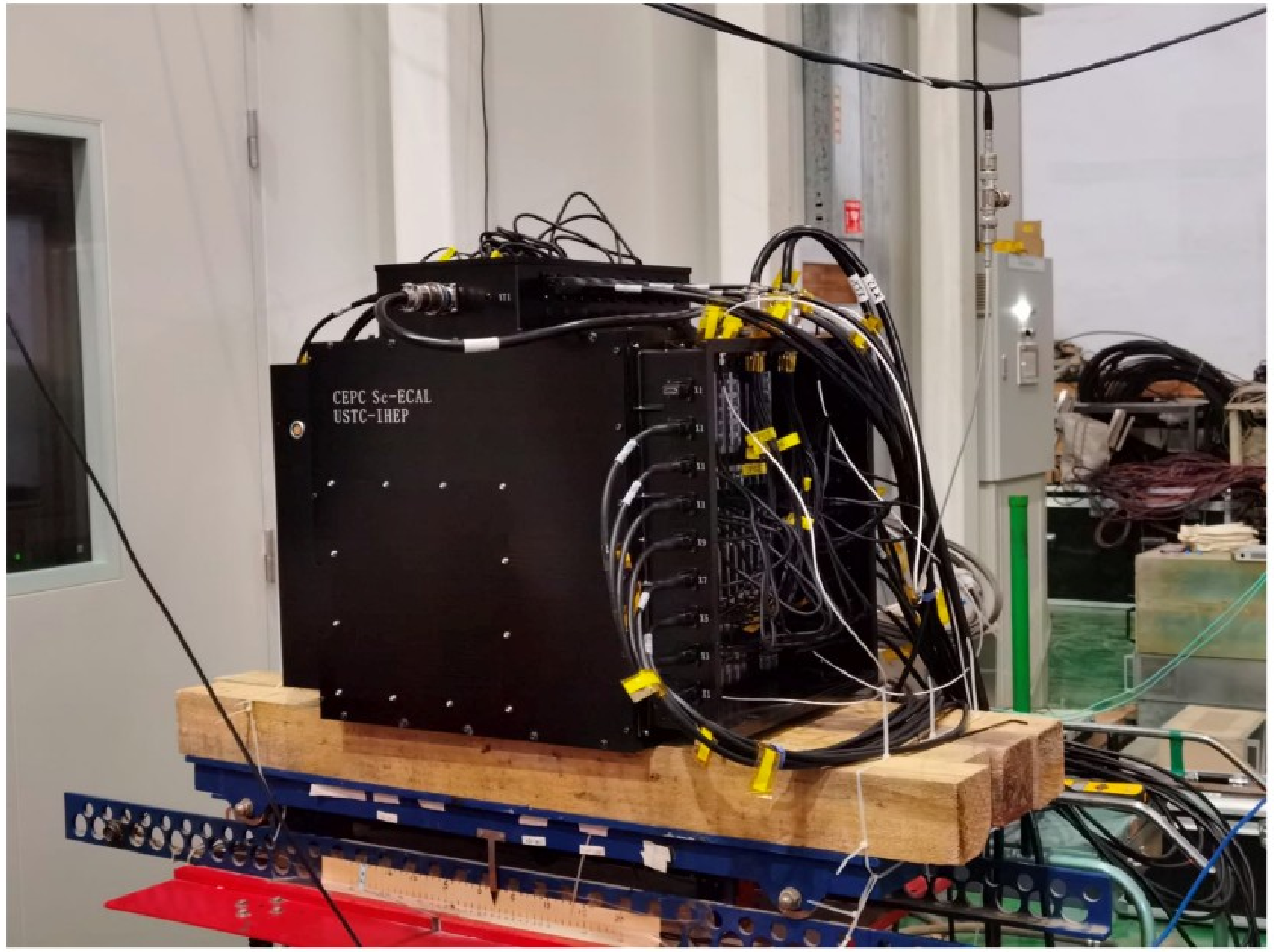
Common running makes full use of EUDAQ tools (developed within European projects)

Common data analysis ongoing

Common beam tests II

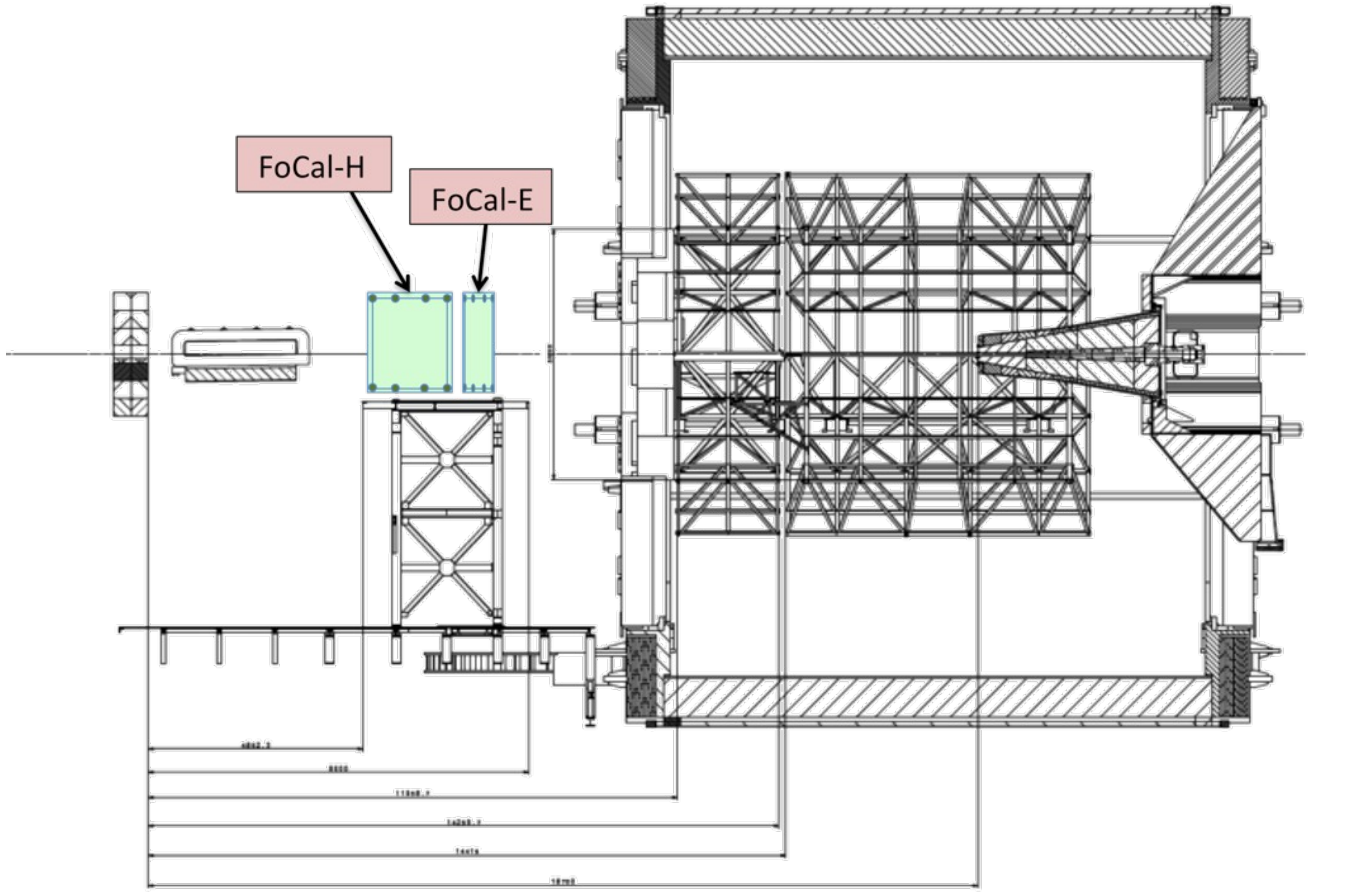
Common beam test Sc ECAL + AHCAL at CERN in October 2022





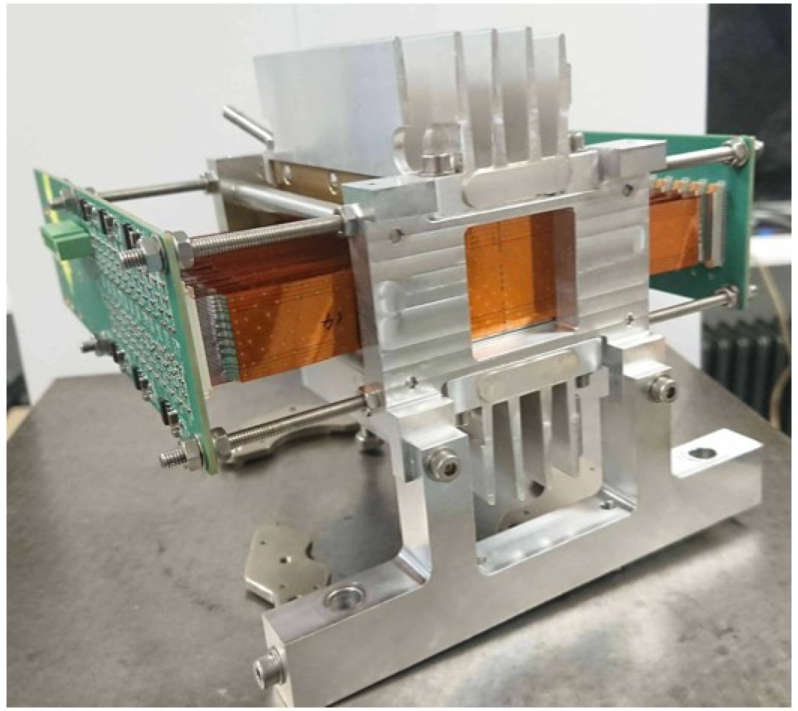
MAPS ECAL

Ultrahigh granular calorimeter is under consideration for ALICE ...



Numbers for FOCAL   assuming ≈ 1m^2 detector surface

	LG	HG
pixel/pad size	≈ 1 cm^2	**≈ 30x30 μm^2**
total # pixels/pads	≈ 2.5 x 10^5	**≈ 2.5 x 10^9**
readout channels	≈ 5 x 10^4	**≈ 2 x 10^6**

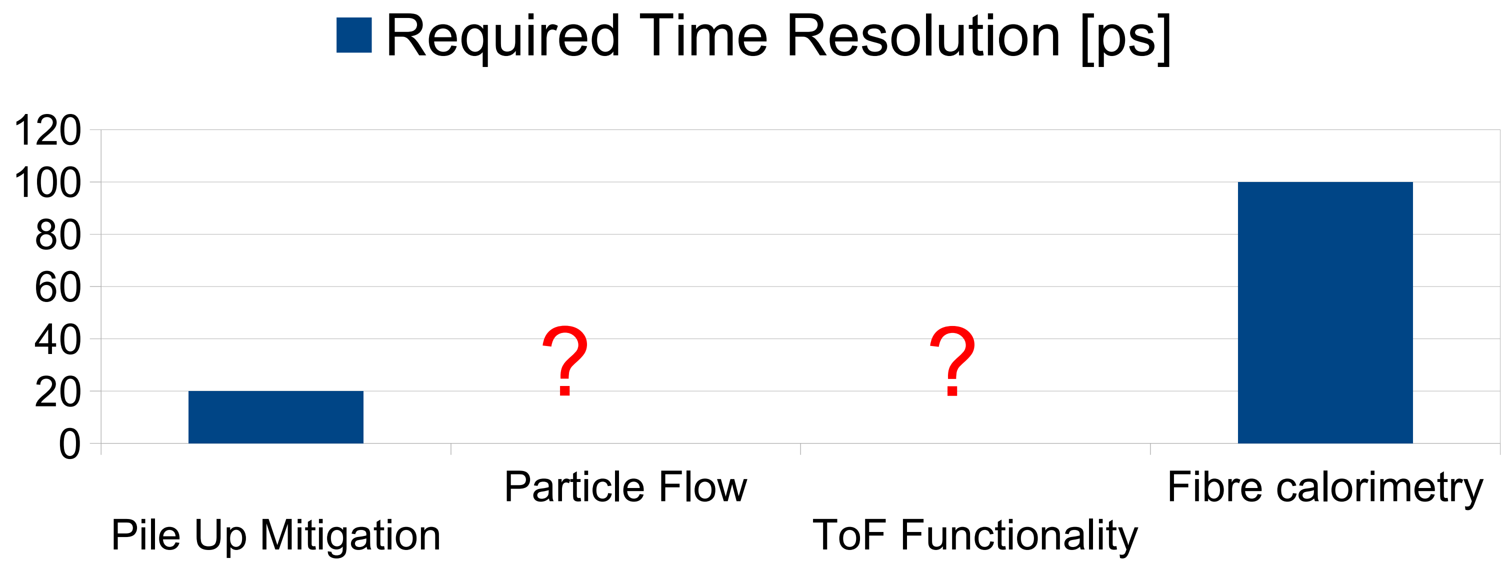


- Prototype with ALPIDE
- Arxiv:2209.02511

... but also for SiD-ILC, FCC-hh

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



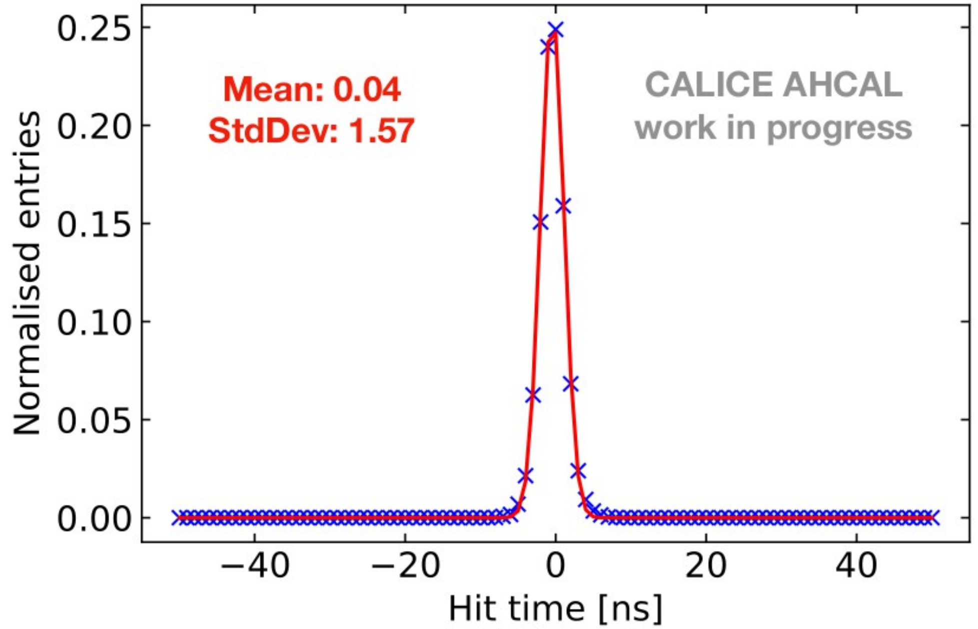
- A topic on which calorimetry has to make up it's mind
  - Remember also that time resolution comes at a price -> High(er) power consumption and (maybe) higher noise levels

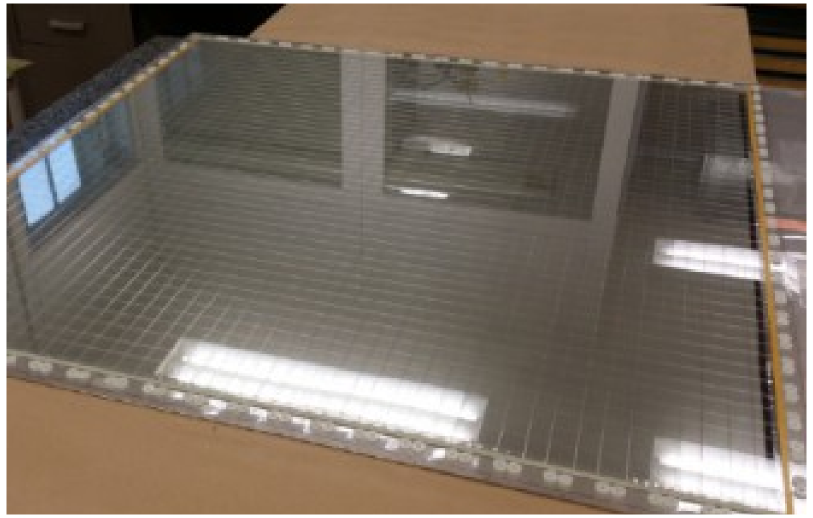
The next decade – ps timing in calorimeters

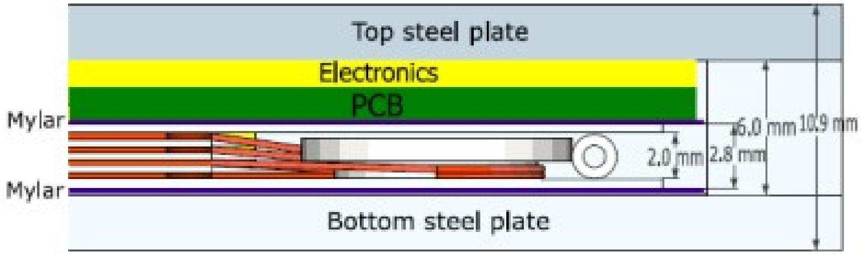
Pioneered by LHC Experiments, timing detectors are/will be also under scrutiny by CALICE Groups

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

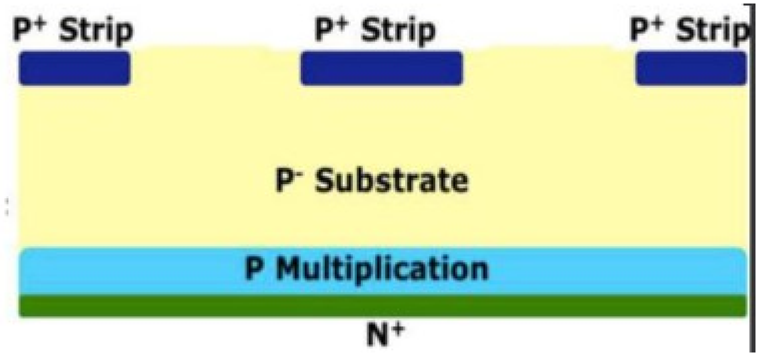
Clock frequency 5 MHz,
Powering pulsing







Inverse APD as LGAD?



Inverse APD
by Hamamatsu

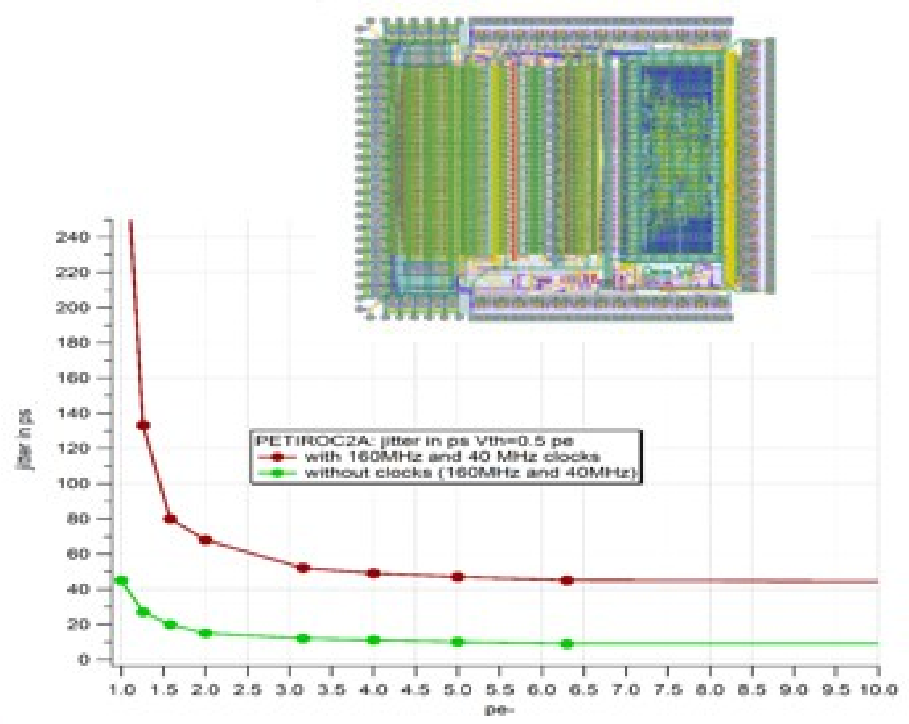
Gain ~ 50

Timing SDHCAL

Timing is an important factor to identify delayed neutrons and better reconstruct their energy and hadronic shower separation (PFA)

An **ASIC** with a fast preamplifier, precise discriminator and excellent TDC are needed

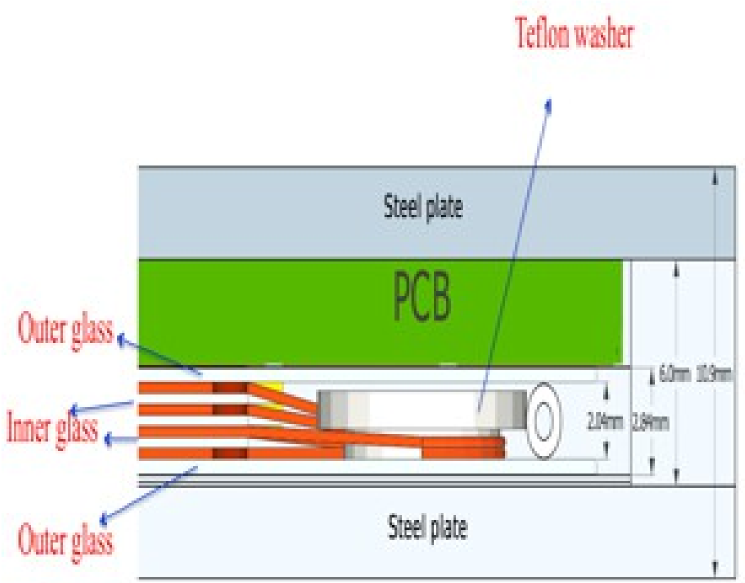
→**PETIROC** 32-channel, high bandwidth preamp (GBWP> 10 GHz), <3 mW/ch, dual time and charge measurement (Q>50 fC)
jitter < 20 ps rms @ Q>0.3 pC
Internal TDC (50 ps time resolution)

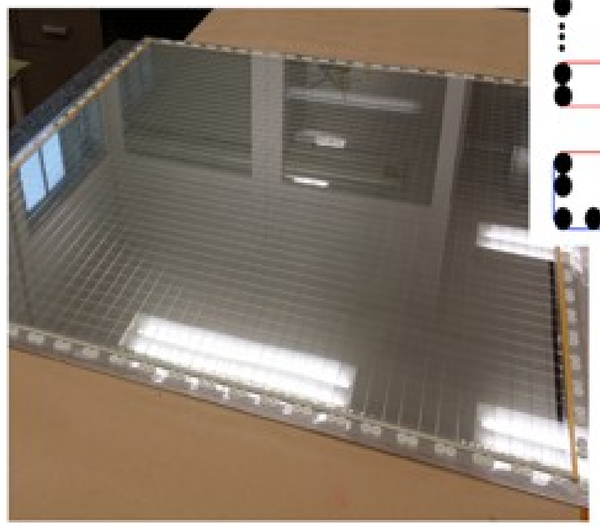


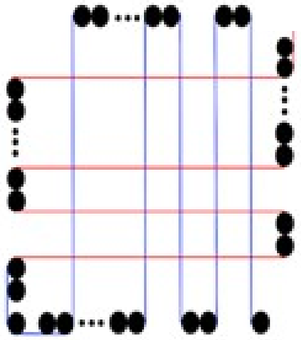
A fast-time **DETECTOR**

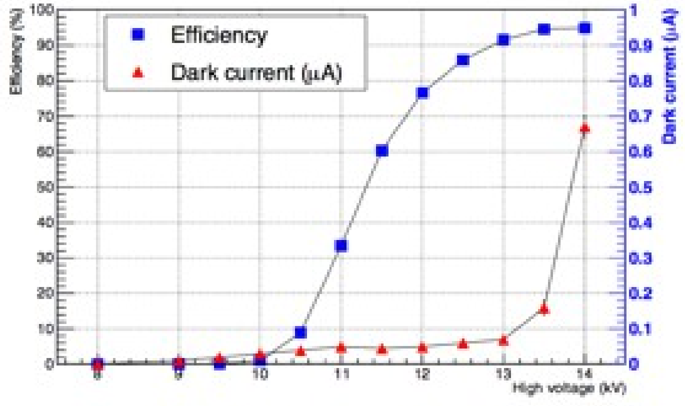
- **Multi-gap** RPC is an excellent candidate.

4-5 gaps of 250 µm each can provide 100 ps time resolution









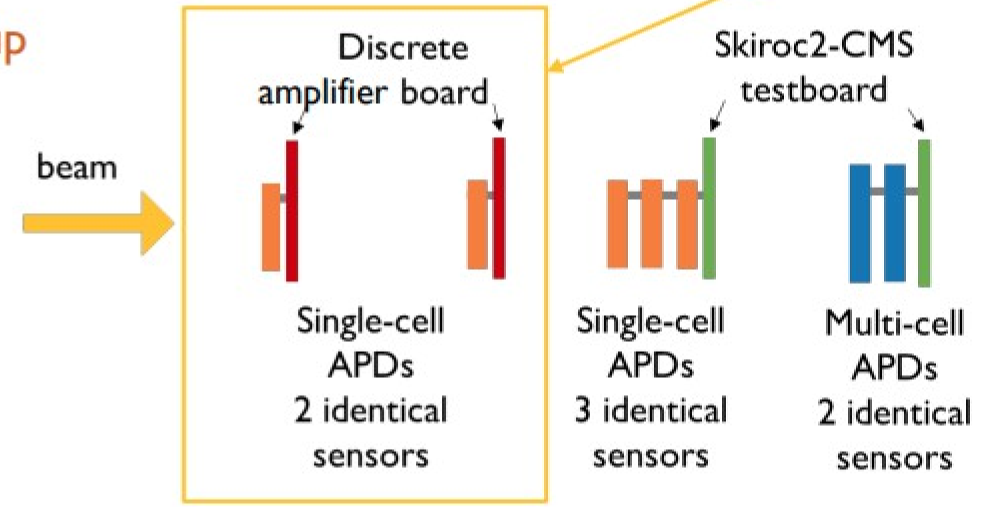
Threshold sets at 114 fC

Timing studies with APDs

6-8 Oct. 2021 at ELPH, Tohoku University

- 3 days × 12 hours positron beam: ~770 MeV

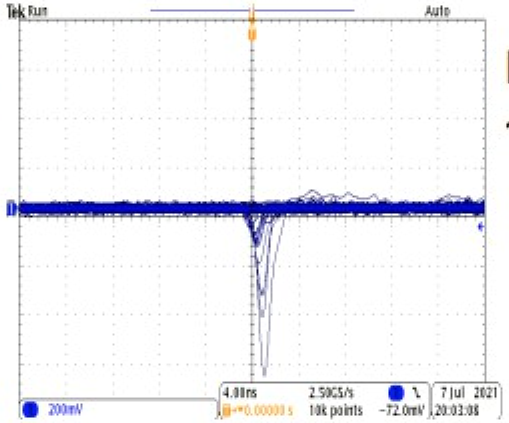
Setup



amplifier board

2 stages

Waveform output from the amp. board



Rising time ~1 nsec

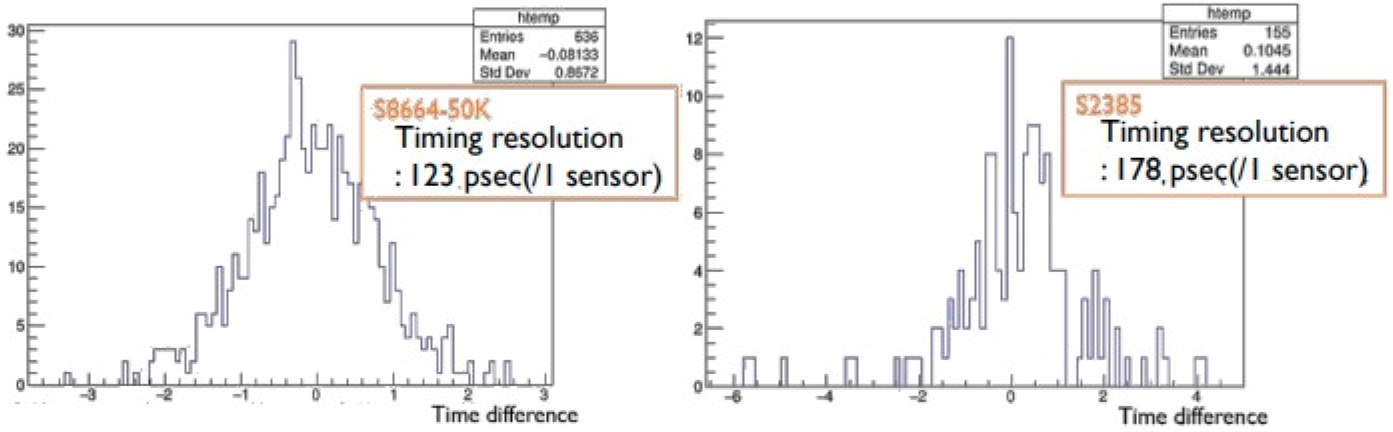
Amplifier chip

- GALI-S66+ (Mini-circuit)
- Gain: 20 dB
- Wide bandwidth 3GHz

APD

APD sensor	Cut of charge	Timing resolution
S8664-50K (Inverse type)	> 18 fC	123 ps
	> 36 fC	63 ps
S2385 (reach through type)	> 18 fC	178 ps
	> 36 fC	89 ps

Time difference between the two APDs (charge > 18 fC)

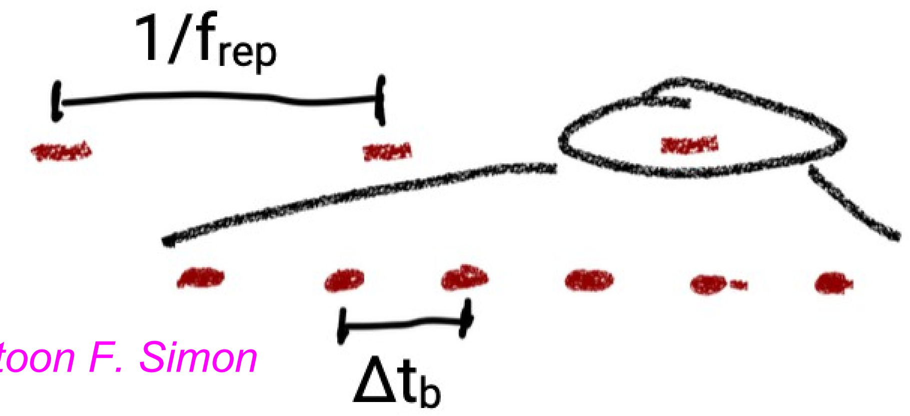


- Timing resolution of S8664-50K is better

→ Difference in capacitance related to signal rising time (S8664-50K: 55 pF S2385: 95 pF)

Operation mode- pulsed or continous

- Linear Colliders operate in bunch trains



Cartoon F. Simon

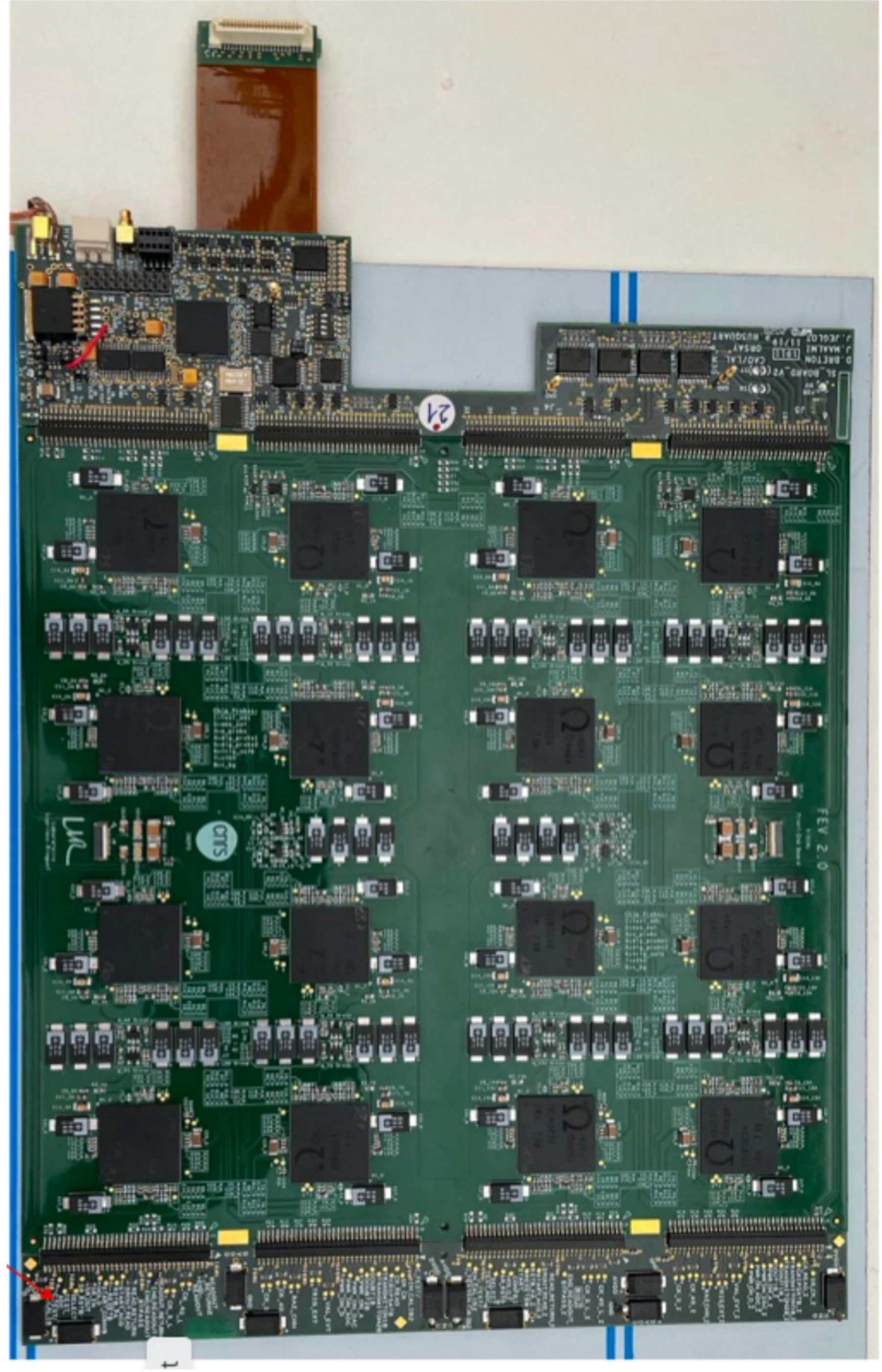
CLIC: Δt_b ~ 0.5ns, frep = 50Hz
ILC: Δt_b ~550ns, frep = 5 Hz (base line)

- 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

New FEV 2.1

LLR, IJCLab, LPNHE, OMEGA



Improved Layout

- Better shielding of AVDD and AVDD PA plans and minimisation of cross-talk between inputs and digital signals.

Power Pulsing Mode: new philosophy

- limiting the current through the Slab (current limiter present on the SL Board) to:
  - avoid driving high currents through the connectors and makes the current peaks **local** around the SKIROCs chips
  - avoid voltage drop along the slab
  - ensure temperature uniformity
- We add large capacitors with low ESR for **local** energy storage (around each SKIROC chip)
- Generate **local** power supply with LDO (Low Drop Out) to avod voltage variations

Clean clock distribution all over the slab

- for Slow Control and Readout Clocks

Parallel configuration and readout over 2 partitions.

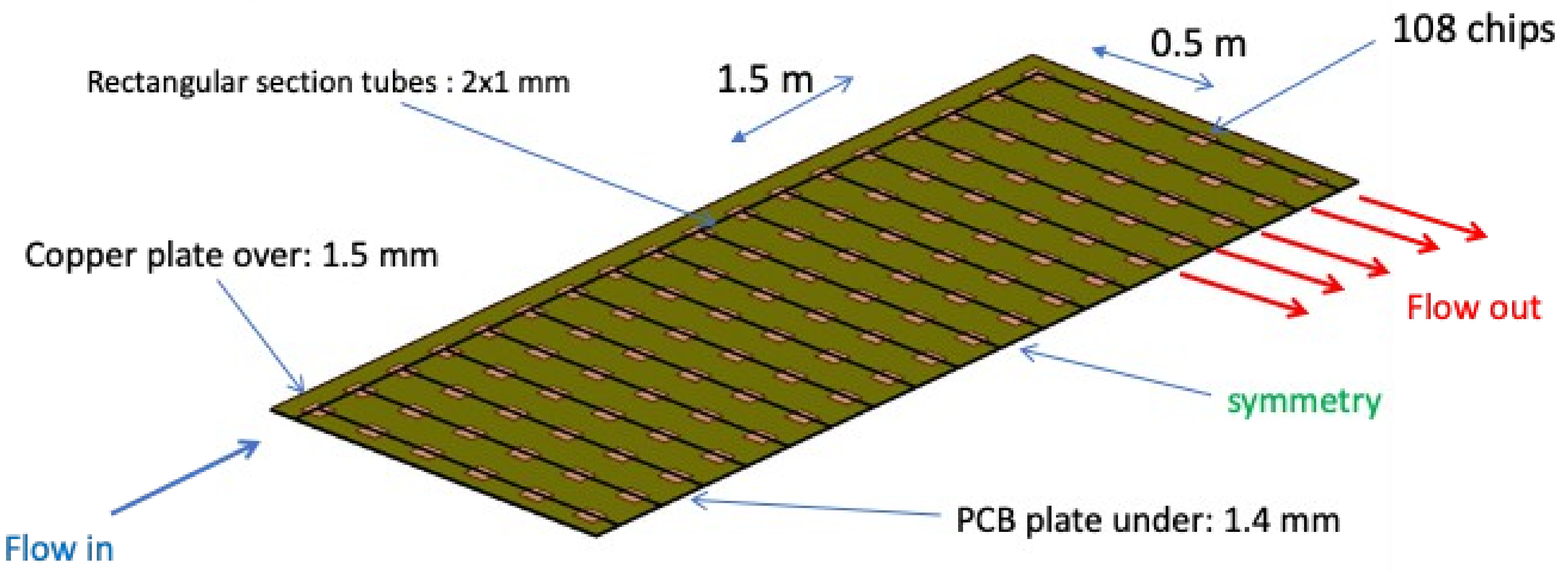
Driving high voltage up to 350V for 750µm wafer (via the ASU connectors)

- Adding a filter for each wafer HV and limit the current in case of wafer failure

SDHCAL power consumption and cooling

The duty cycles of CEPC/FCCee are different from that of ILC and no power pulsing is possible.
The power consumption is therefore increased by a factor of 100-200 with respect to ILC and active cooling is needed.
Lyon and Shanghai groups worked on a simple cooling system for SDHCAL based on using water circulating into copper pipes

0.8 mW/chips with power pulsing → 80 mW/chips without power pulsing



Next generation ASICs?

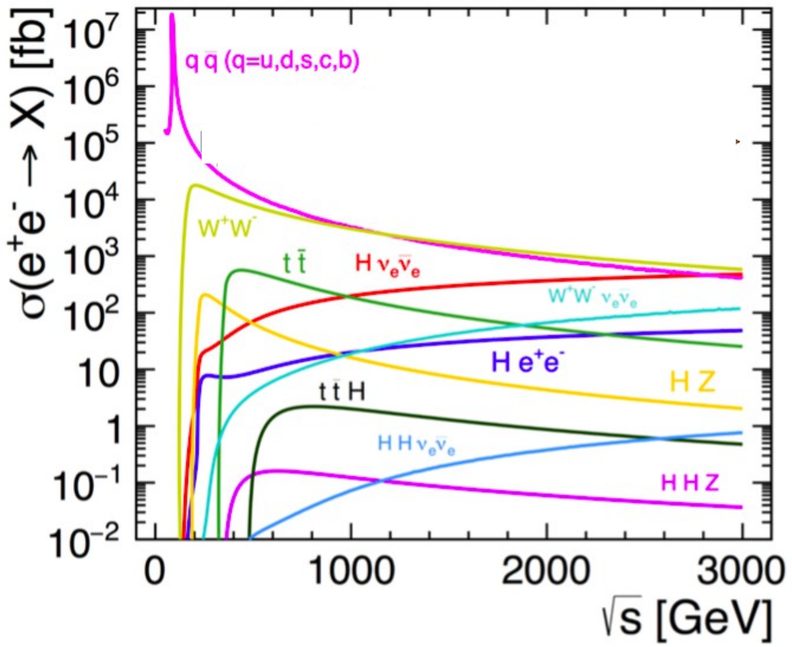
Ch. de la Taille
CALICE Meeting, Valencia

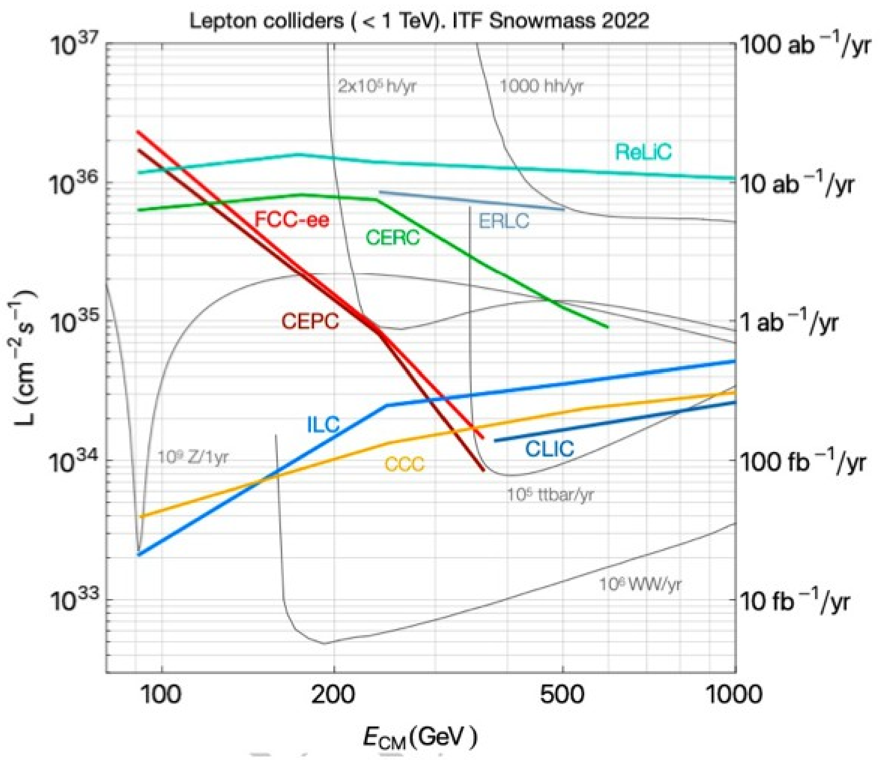
- Dynamic gain preamp or TOT ?
- 200 ns shaping, 10 MHz ADC, several samples on the waveform
- Timing capability ? Auto-trigger and zero suppression
- Target ~1 mW power/ch and possible power pulsing
- I^2C slow control ? New readout protocol ?
- Include 2.5V LDO inside VFE ?
- Compatible with FCC LAr.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

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

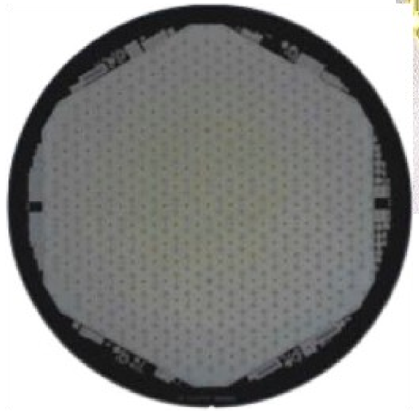
"Tendencies" from discussions in last weeks

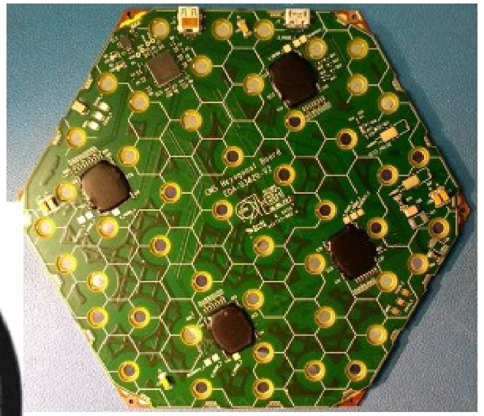
- Event and data rates have to looked at differentially
  - In terms of running scenarios and differential cross sections
  - Optimisation/development for Higgs Factory different than for Z factory

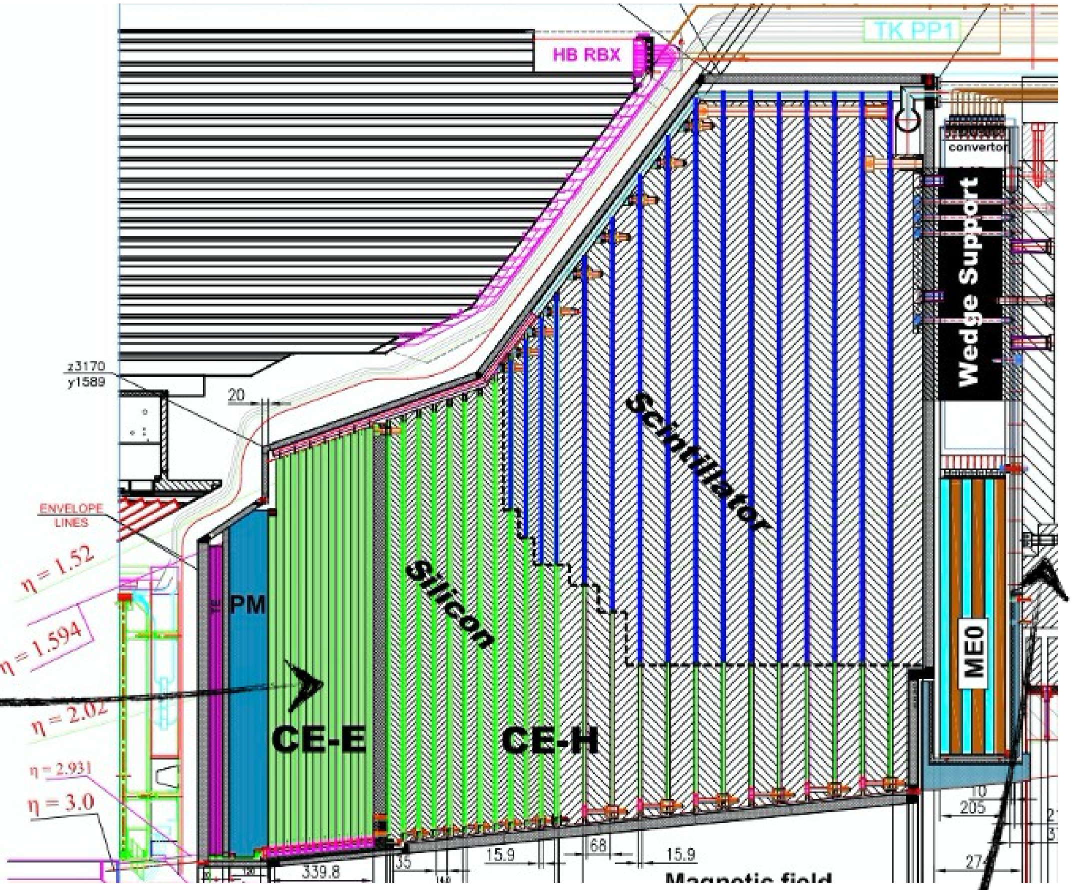
HL-LHC Upgrades

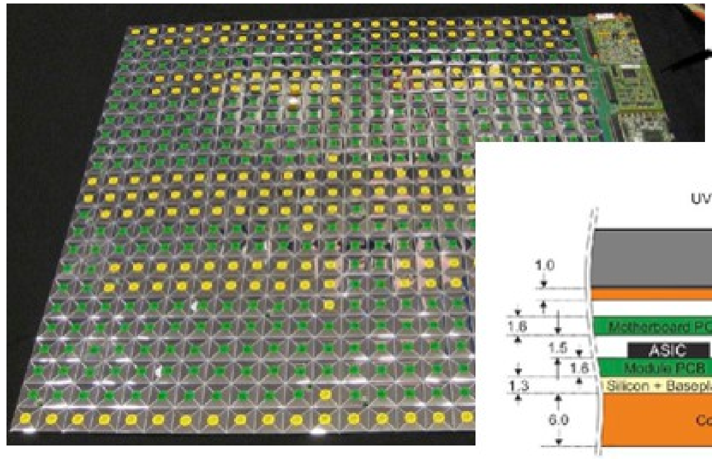
- The developments in CALICE have paved the way for a number of applications of highly granular calorimeters and related technologies in HEP

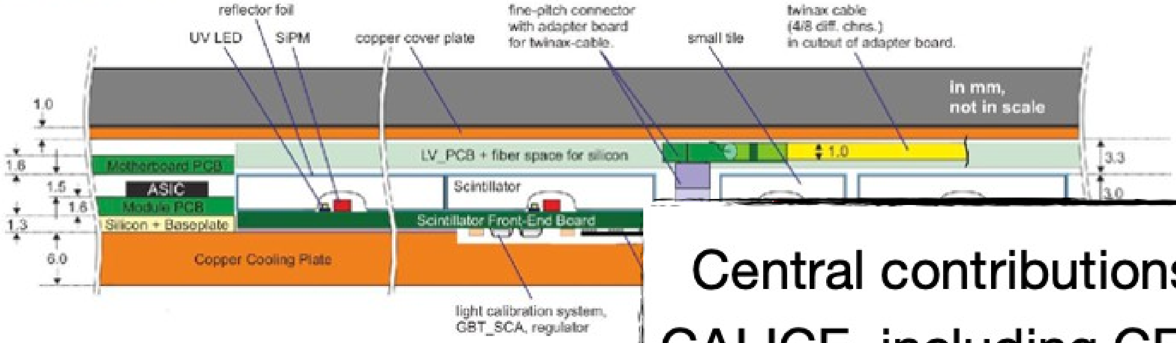
Most prominent: The CMS Endcap Calorimeter Upgrade HGCal











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

Summary and conclusion

- CALICE pioneered R&D on highly granular calorimeters
  - Large scale prototypes with rich set of results obtained in combined beam tests
  - Successful R&D inspired CMS to opt for a highly granular calorimeter for the LHC Phase 2 Upgrade
  - Further Spin-offs ALICE FOCAL, DUNE ND, Belle II CLAWS

- Technological prototypes address technological challenges of highly granular calorimeters
  - High level integration => dense detector layers
  - Collaboration allows to address common issues on readout and detector integration
  - Power pulsing requires further scrutiny
  - Versatile mechanics to avoid inactive detector zones
  - Timing capabilities studied and will be exploited further
  - Scale of prototypes will allow for producing new physics results to tune e,g. GEANT4

- Ways forward (not mutually exclusive)
  - Finalise R&D for Linear Collider experiments
  - Common beam tests
  - Address new challenges at Circular Colliders

- Precious feedback from LHC Upgrades
  - System integration, timing, active cooling

- Application in small scale experiments (KEK, LUXE, Lohengrin)

Towards the future – ECFA Detector R&D Roadmap

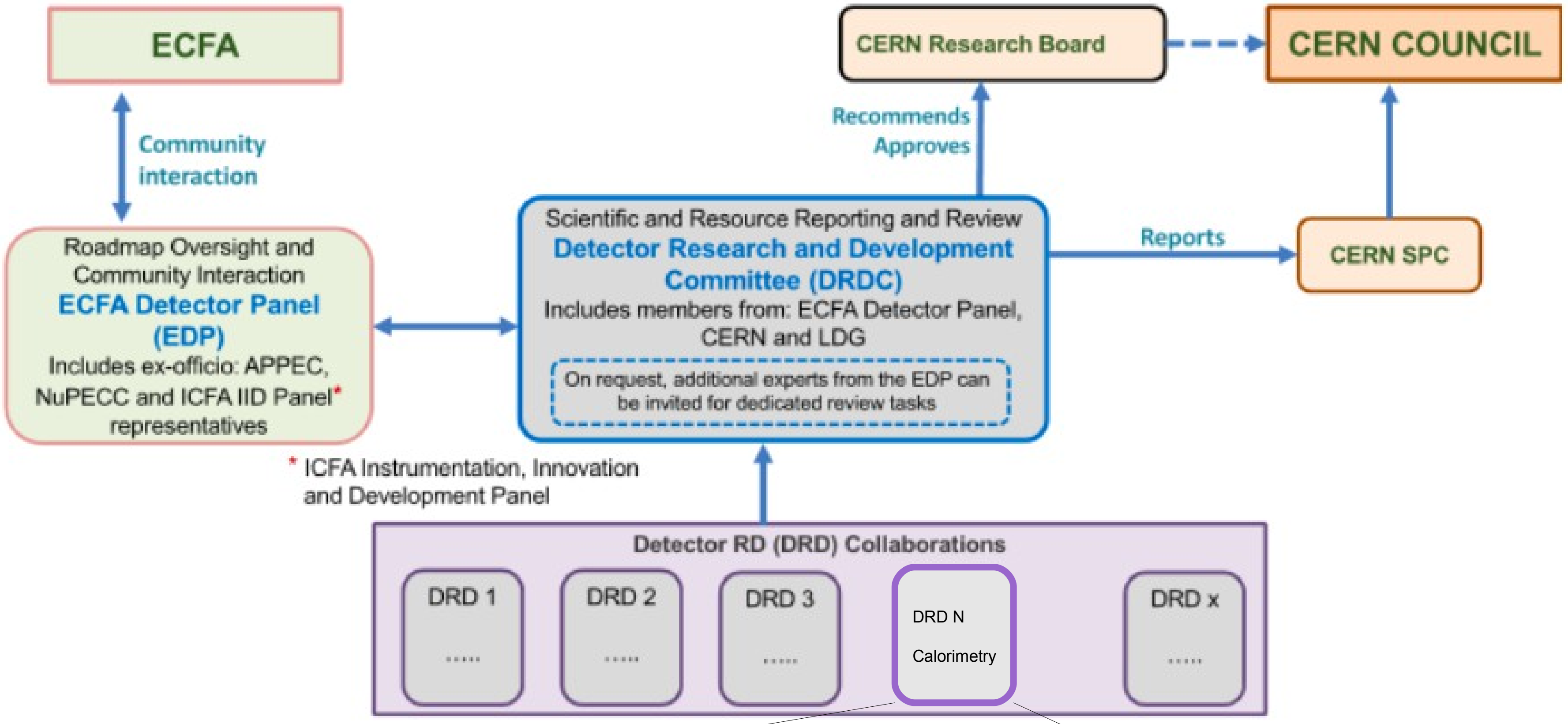
- ECFA R&D Roadmap
  - Roadmap Document CERN-ESU-017 https://cds.cern.ch/record/2784893
- The future R&D will be organised around DRDs
  - DRD – Detector R&D collaborations
  - ... mostly identical to task forces for Roadmap Document
  - These DRD should enable strategic R&D for future large collider projects
  - DRD will benefit from experience of existing R&D Collaborations such as RDNN, CALICE, Crystal Clear, LCTPC etc.
  - DRD Expected to be in place at the beginning of 2024
  - R&D proposals for Summer 2023
  - Task Forces will oversee the transition phase
  - Details see e.g. https://agenda.linearcollider.org/event/9076/contributions/51323/

Timeline of large projects
As in Roadmap Document

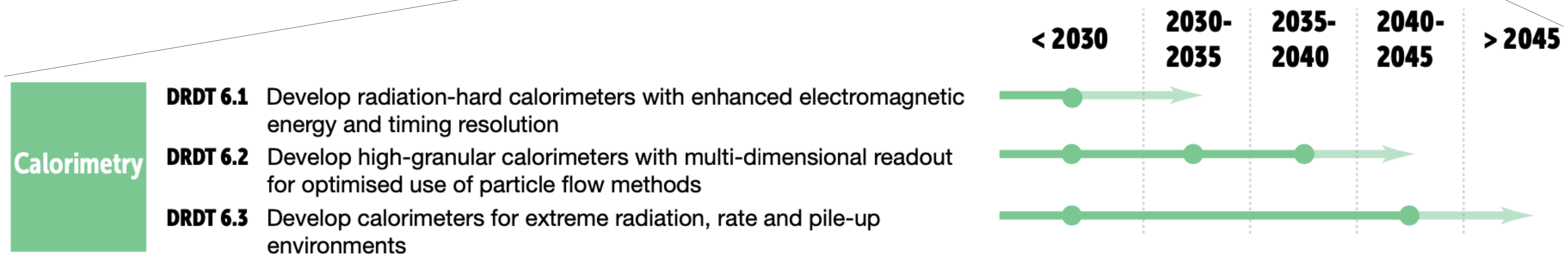
Toward DRD Calorimetry I

Proposed organisation scheme :

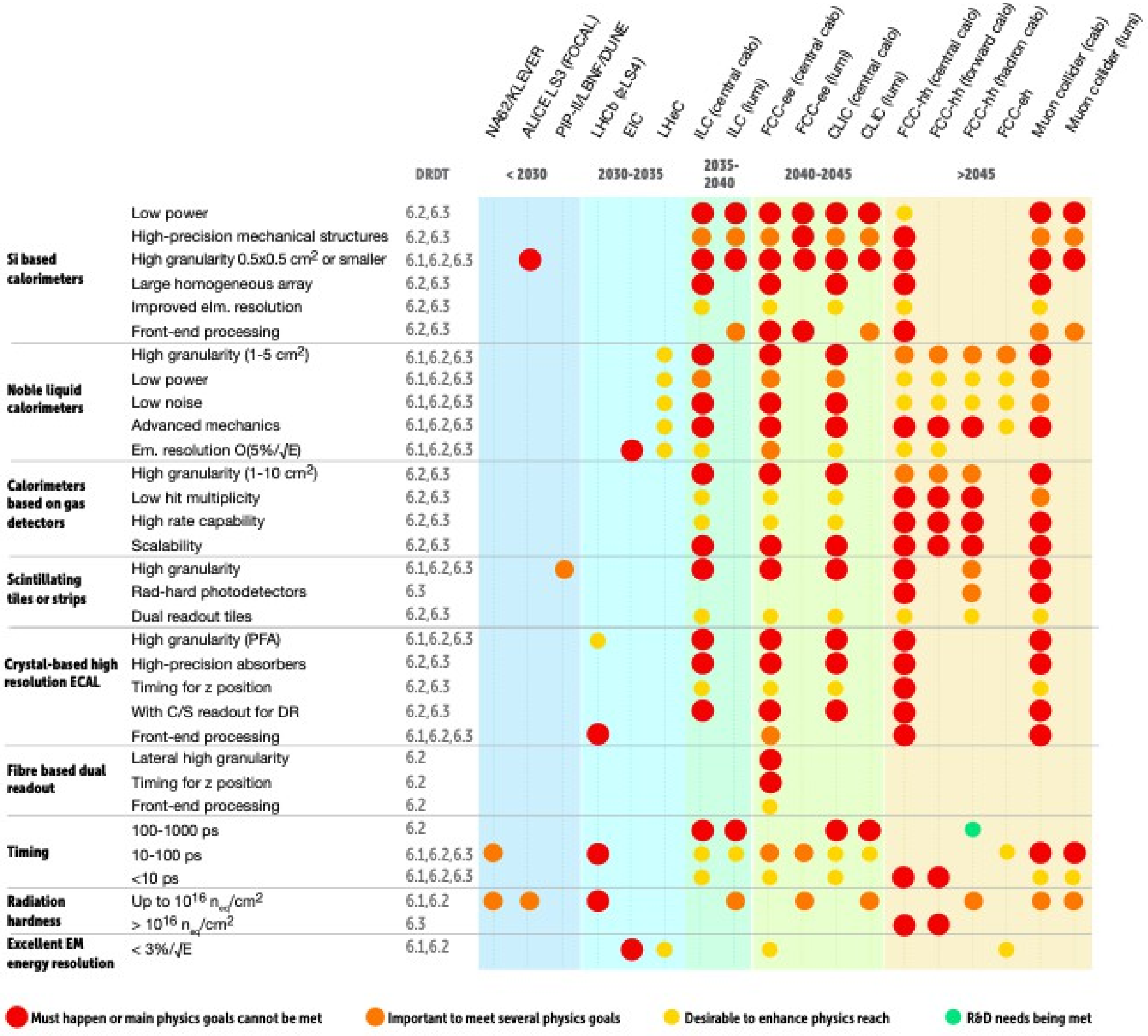
Endorsed by CERN Council in Sept. 2022



Research themes calorimetry:



Towards DRD Calorimetry – Identified R&D needs

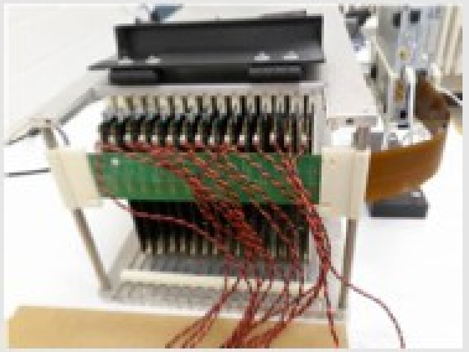
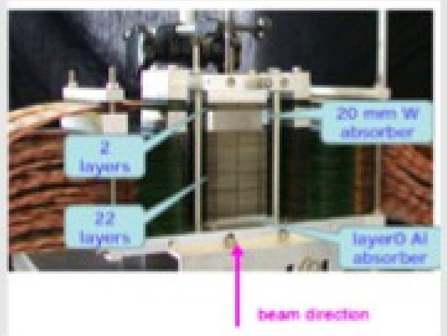


		DRDT	NA62/KLEVER	ALICE LS3 (FOCAL)	PIP-II/LBNF/DUNE	LHCb (LS4)	EIC	LHeC	ILC (central calo)	ILC (lumi)	FCC-ee (central calo)	FCC-ee (lumi)	CLIC (central calo)	CLIC (lumi)	FCC-hh (central calo)	FCC-hh (forward calo)	FCC-hh (hadron calo)	FCC-eh	Muon collider (calo)	Muon collider (lumi)
			< 2030			2030-2035			2035-2040		2040-2045				>2045					
Si based calorimeters	Low power	6.2,6.3							🔴	🔴	🔴	🔴	🔴	🔴	🟡				🔴	🔴
	High-precision mechanical structures	6.2,6.3							🟠	🟠	🟠	🔴	🟠	🟠	🔴				🟠	🟠
	High granularity 0.5x0.5 cm^2 or smaller	6.1,6.2,6.3		🔴					🔴	🔴	🔴	🔴	🔴	🔴	🔴				🔴	🔴
	Large homogeneous array	6.2,6.3							🔴		🔴		🔴		🔴				🔴	
	Improved elm. resolution	6.2,6.3							🟡		🟡		🟡		🟡				🟡	
	Front-end processing	6.2,6.3								🟠	🔴	🔴		🟠	🔴				🟠	🟠
Noble liquid calorimeters	High granularity (1-5 cm^2)	6.1,6.2,6.3						🟡	🔴		🔴		🔴		🟠	🟠	🟠	🟠	🔴	
	Low power	6.1,6.2,6.3						🟡	🟠		🟠		🟠		🟡	🟡	🟡	🟡	🟠	
	Low noise	6.1,6.2,6.3						🟡	🔴		🔴		🔴		🟡	🟡	🟡	🟡	🟠	
	Advanced mechanics	6.1,6.2,6.3						🟡	🔴		🔴		🔴		🔴	🔴	🔴	🟡	🔴	
	Em. resolution O(5%/√E)	6.1,6.2,6.3					🔴	🟡	🟡		🟠		🟡		🟡	🟡				
Calorimeters based on gas detectors	High granularity (1-10 cm^2)	6.2,6.3							🔴		🔴		🔴		🟠	🟠	🟠		🔴	
	Low hit multiplicity	6.2,6.3							🟡		🟡		🟡		🔴	🔴	🔴		🟠	
	High rate capability	6.2,6.3							🟡		🟡		🟡		🔴	🔴	🔴		🔴	
	Scalability	6.2,6.3							🔴		🔴		🔴		🔴	🔴	🔴		🔴	
Scintillating tiles or strips	High granularity	6.1,6.2,6.3			🟠				🔴		🔴		🔴		🔴		🟠		🔴	
	Rad-hard photodetectors	6.3													🔴		🟠		🔴	
	Dual readout tiles	6.2,6.3							🟡		🟡		🟡		🟡		🟡		🟡	
Crystal-based high resolution ECAL	High granularity (PFA)	6.1,6.2,6.3				🟡			🔴		🔴		🔴		🔴				🔴	
	High-precision absorbers	6.2,6.3							🔴		🔴		🔴		🔴				🔴	
	Timing for z position	6.2,6.3							🟡		🟡		🟡		🔴				🟡	
	With C/S readout for DR	6.2,6.3							🔴		🔴		🔴		🔴				🔴	
	Front-end processing	6.1,6.2,6.3				🔴					🟠				🔴				🔴	
Fibre based dual readout	Lateral high granularity	6.2									🔴									
	Timing for z position	6.2									🔴									
	Front-end processing	6.2									🟡									
Timing	100-1000 ps	6.2							🔴	🔴			🔴	🔴			🟢			
	10-100 ps	6.1,6.2,6.3	🟠			🔴			🟡	🟡	🟠	🟠	🟡	🟡				🟡	🔴	🔴
	<10 ps	6.1,6.2,6.3							🟡		🟡		🟡		🔴	🔴			🟡	🟡
Radiation hardness	Up to 10^{16} n_{eq}/cm^2	6.1,6.2	🟠	🟠		🔴				🟠		🟠		🟠			🟠		🟠	🟠
	> 10^{16} n_{eq}/cm^2	6.3													🔴	🔴				
Excellent EM energy resolution	< 3%/√E	6.1,6.2					🔴	🟡			🟡							🟡		

🔴 Must happen or main physics goals cannot be met 🟠 Important to meet several physics goals 🟡 Desirable to enhance physics reach 🟢 R&D needs being met

Summarz CALICE Prototypes

- CALICE runs more prototypes than those in the focus of this contribution

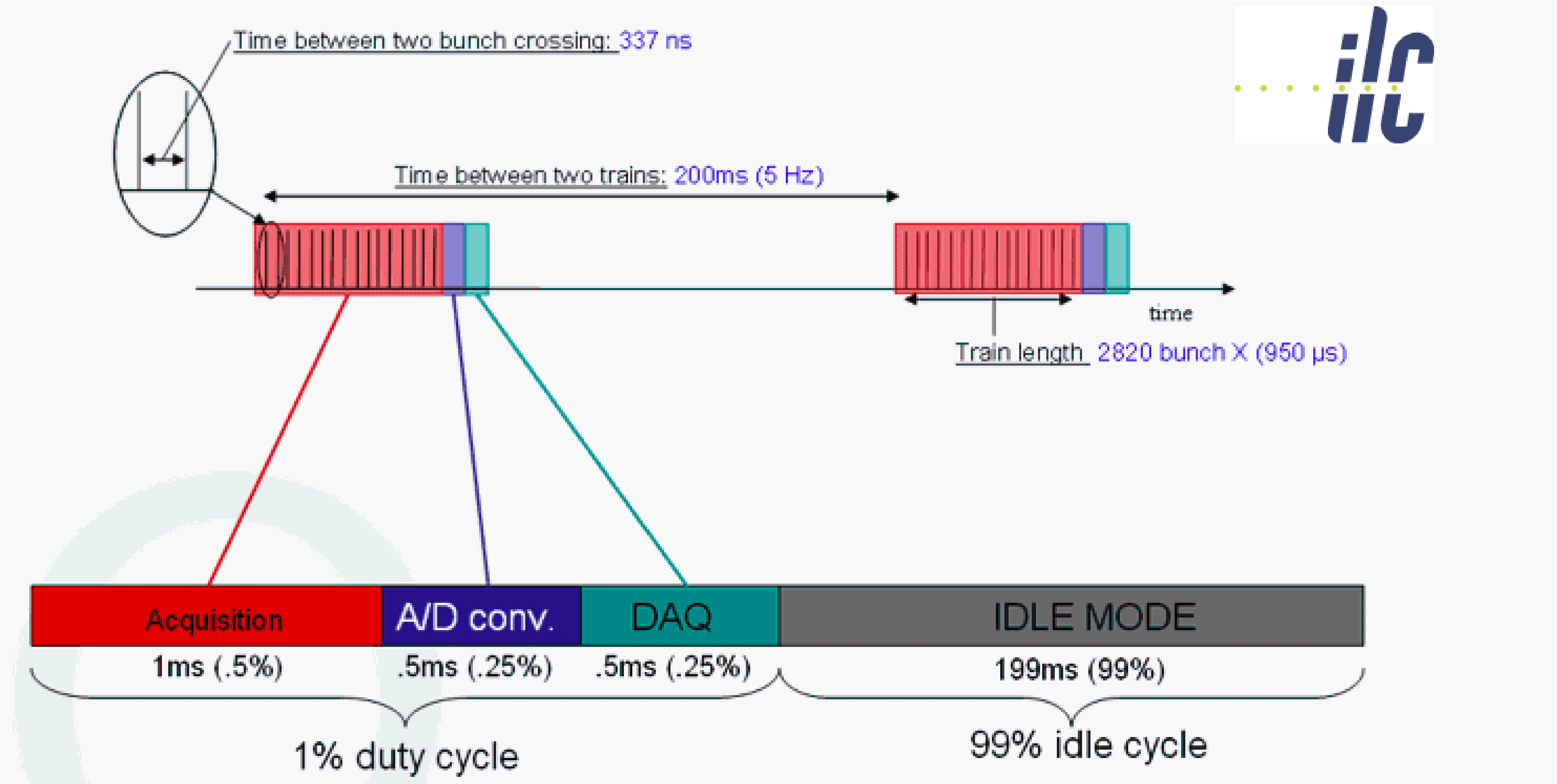
Si-W ECAL	(ALICE FoCAL)	[Scint-W ECAL]	AHCAL	SDHCAL
				
0,5×0,5 cm^2 ×15 (→30) Si layers + W	0,003×0,003 cm^2 × 24 MIMOSA layers + W	0,5×4,5 cm^2 ×30 Scint+SiPM lay. + SS	3×3 cm^2 × 38 Scint+SiPM lay. + SS	1×1 cm^2 × 48 layers GRPC + SS

V. Boudry, FCC Workshop

- The federation under one roof allows for common development and comparison on equal footing

Backup

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

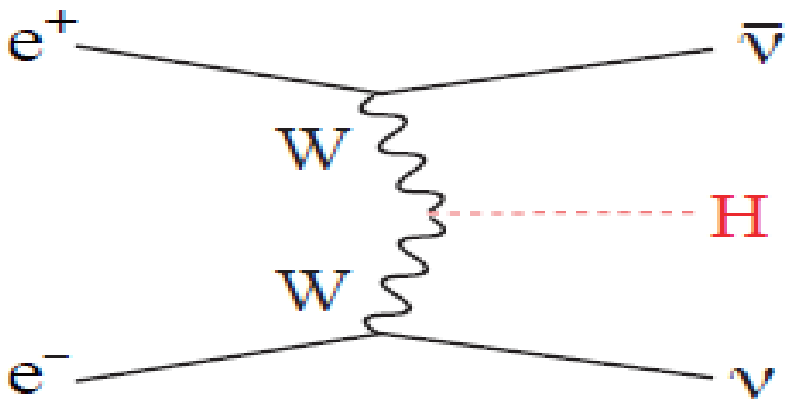
Mastering of technology is essential for operation of ILC detectors

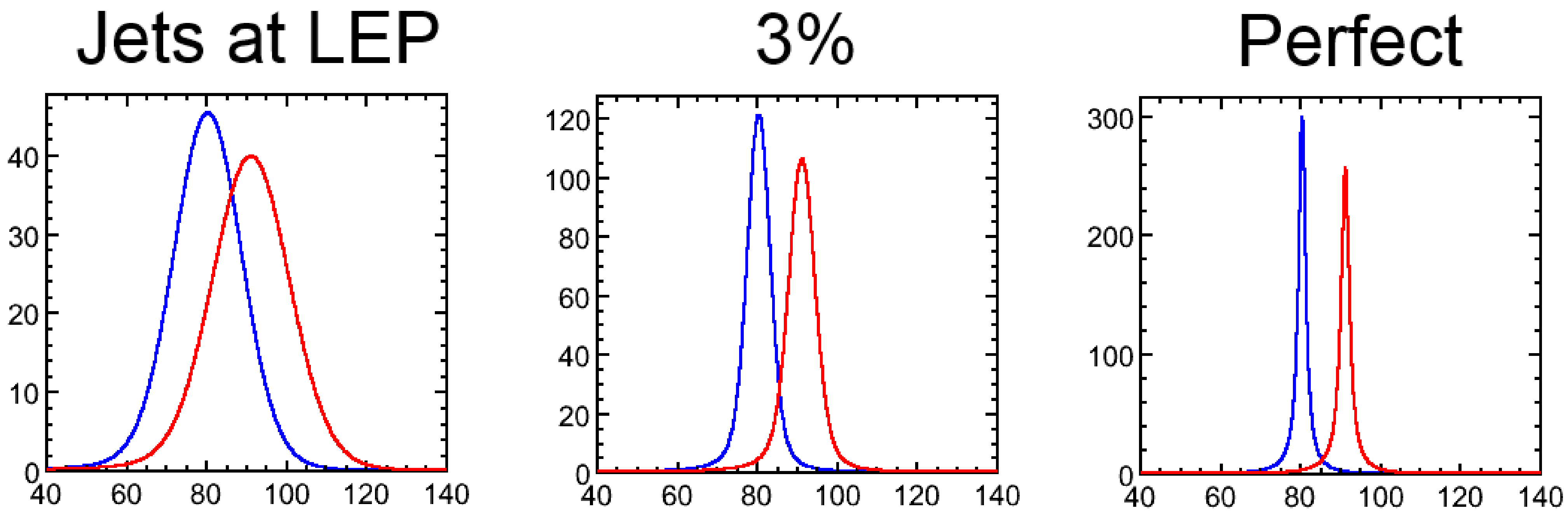
Detector requirements in high energy e+e- collision

Examples:

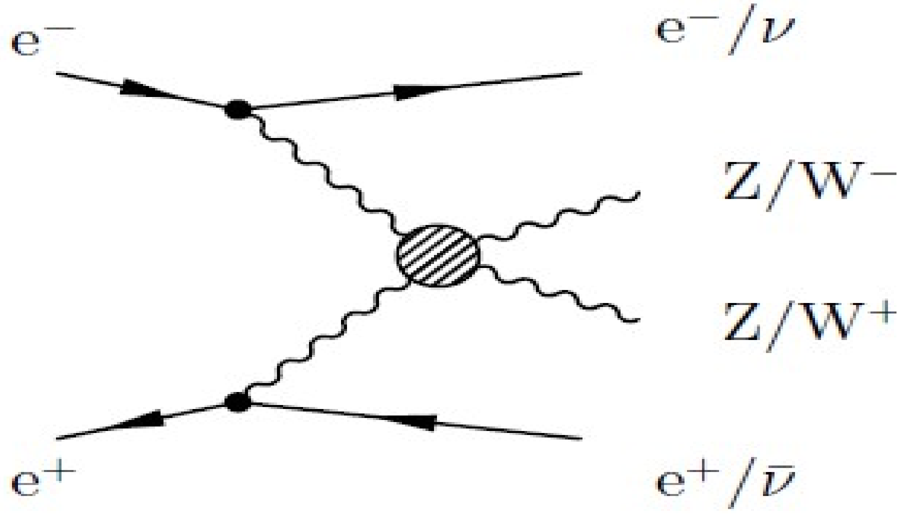
- W Fusion with final state neutrinos requires reconstruction of H decays into jets

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





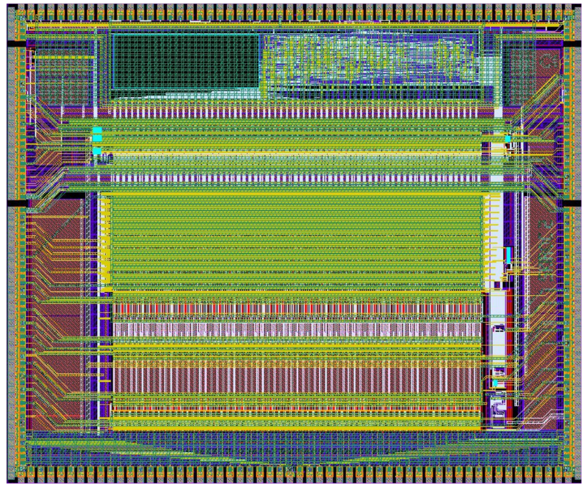
M. Thomson



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

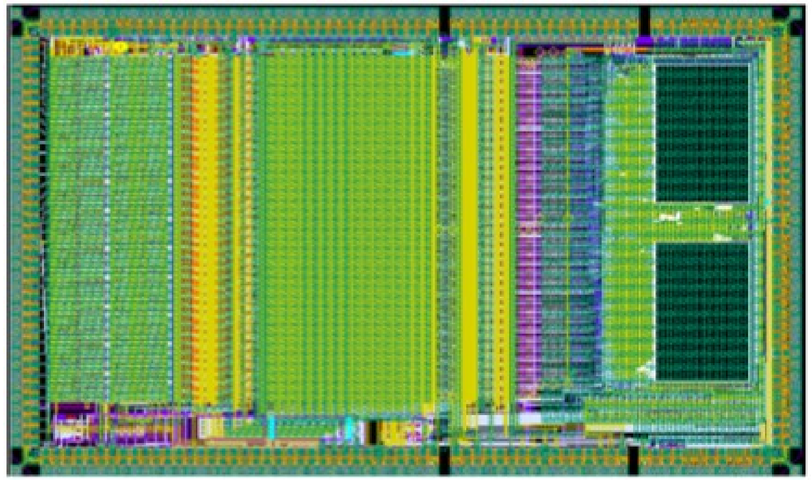
ASICs – The "ROC Family"

SKIROC
(for SiW Ecal)



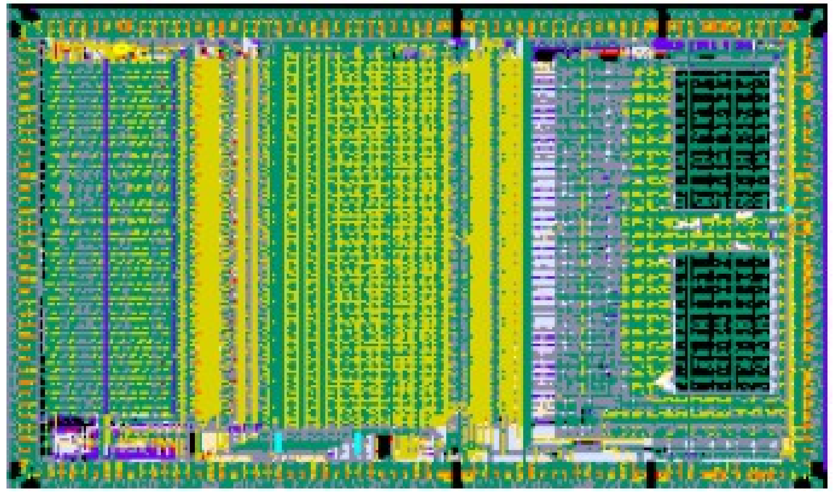
SiGe 0.35µm AMS,
Size 7.5 mm x 8.7 mm, 64 channels
High integration level
(variable gain charge amp,
12-bit Wilkinson ADC, digital logic)
Large dynamic range (~2500 MIPS)
low noise (~1/10 of a MIP, 400 fC)
Auto-trigger at ½ MIP
Low Power: (25µW/ch) power pulsing

SPIROC
For optical readout, Tiles + SiPM

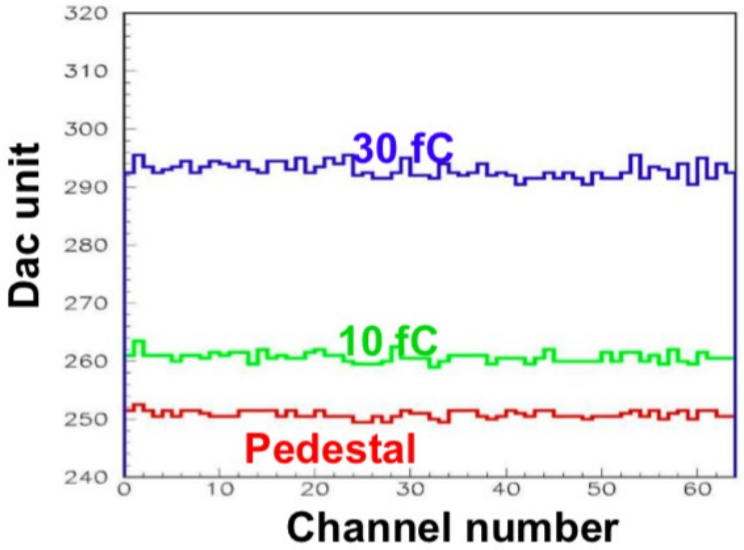


Variant of SKIROC
36 channels, 15 bit readout
Auto-trigger down to ½ p.e,
80 fC for G=1x10^6
Timing to ~ 1ns
Low Power: (25µW/ch) power pulsing

HARDROC
For gaseous r/o - GRPC

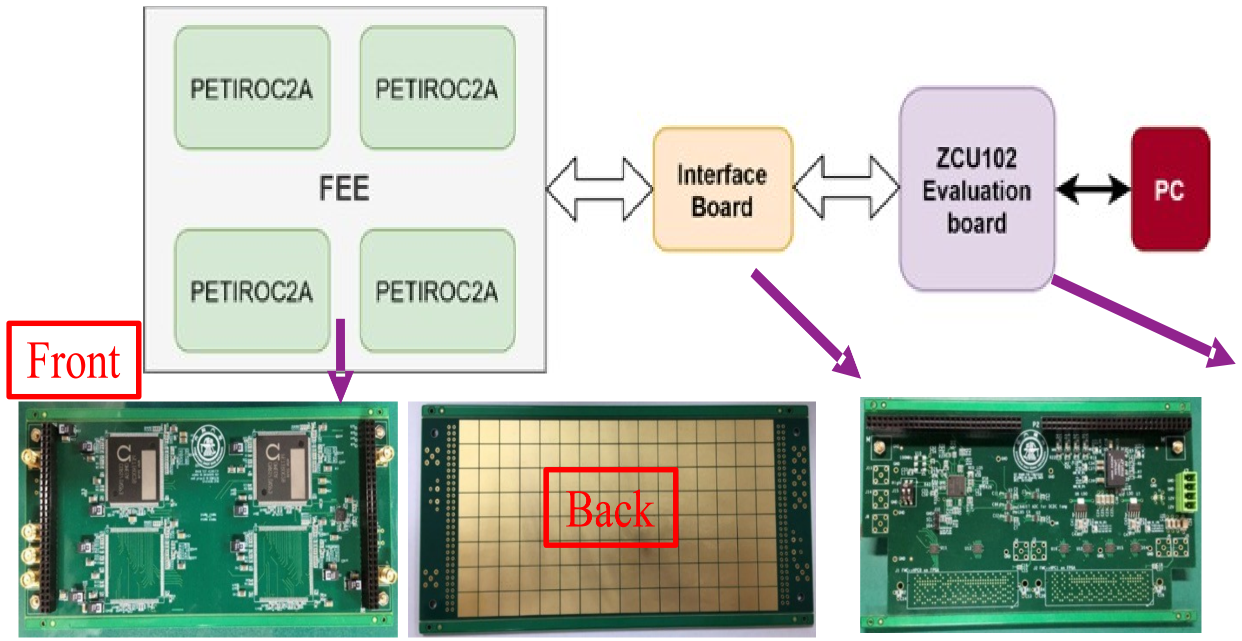


64 Channels with three thresholds



Power pulsing
Variant for Micromegas: MICROROC

SDHCAL -> Time SDHCAL – First Steps



- Front-End Electronics for MRPC readout with high timing resolution
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system(DAQ) based on ZCU102.

Test System and Setup