Update on CALICE/DRD Calo SiW Ecal

- Tracing the Odds -

Roman Pöschl

On behalf of the SiW ECAL Groups in CALICE/DRD Calo:

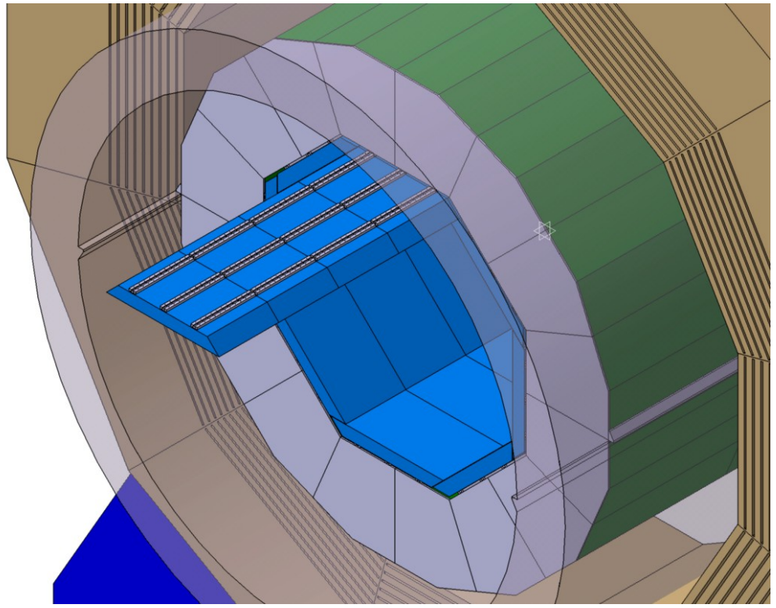
CALOR 2024 – Tsukuba/Japan May 2024

This project has received funding from the European Union's Horizon 2020 Research and Innovation programmes under GAs no 101004761 and 101086276

Silicon tungsten electromagnetic calorimeter

DRD Calo/CALICE

Optimised for Particle Flow: Jet energy resolution 3-4%, Excellent photon-hadron separation



The SiW ECAL in the ILD Detector

- O(10^8) cells
- “No space”

=> Large integration effort

Basic Requirements:

Extreme high granularity

Compact and hermetic

(inside magnetic coil)

Basic Choices:

Tungsten as absorber material

X_0=3.5mm, R_M=9mm, λ_I=96mm

Narrow showers

Assures compact design

Silicon as active material

Support compact design

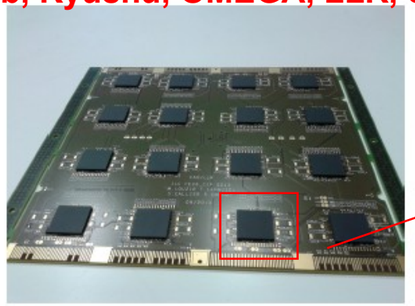
Allows for pixelisationRobust technology

Excellent signal/noise ratio: 10 as design value

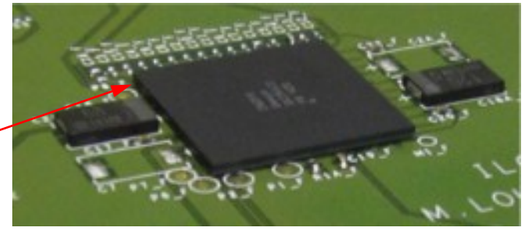
- All future e+e- collider projects feature at least one detector concept with this technology
- Application in small and medium size experiments as LUXE, Lohengrin, EBES, Ship (?)

SiW Ecal – Elements of (long) layer

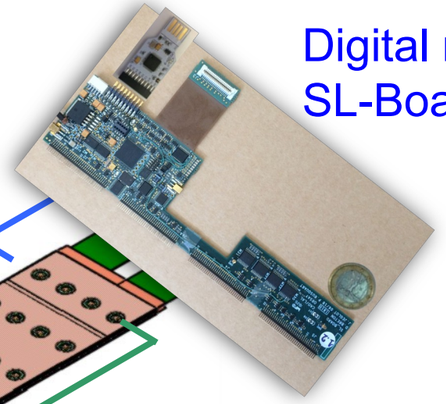
ASIC+PCB+SiWafer
=ASU
Size 18x18 cm²
(IJCLab, Kyushu, OMEGA, LLR, SKKU)



ASIC SKIROC2(a)
(OMEGA)
Wire Bonded or
In BGA package
(IJCLab, Kyushu, LLR)

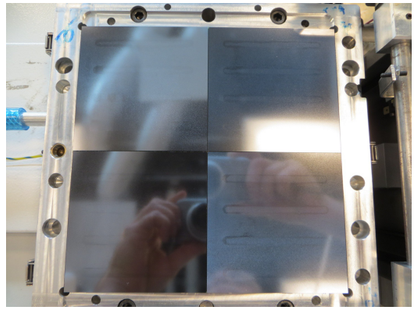


Interconnection
(IJCLab)



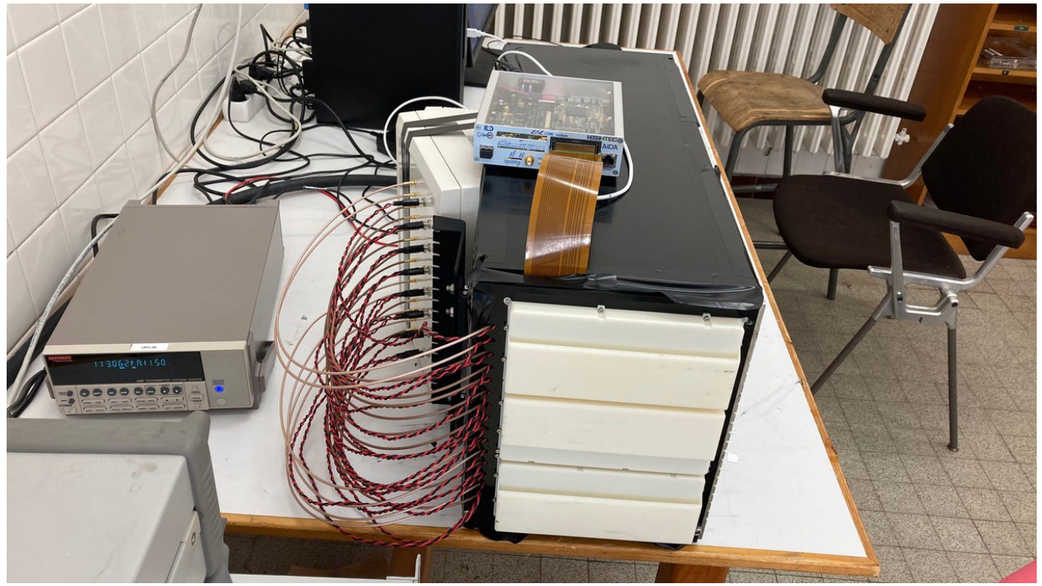
Digital readout
SL-Board (IJCLab)

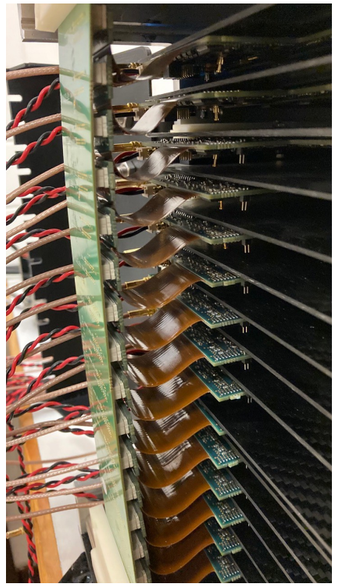
SiWafers glued onto PCB
Pixel size
5.5x5.5 mm²
(LPNHE)



The beam test set up will consist of a **stack of short layers** consisting of one ASU and a readout card each

SiW ECAL: 2022





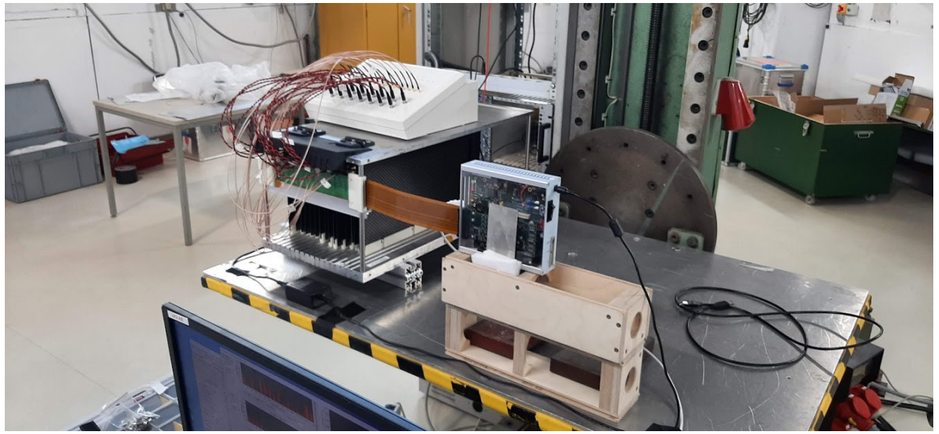
- 15 short layers equivalent to 15360 readout cells
  - Up to 21 X_0
  - Most of the layers produced 2016 - 2017
- Commissioned 2020-2022
  - ~450000 calibration constants for one ASIC feedback capa setting
- Testbeams (finally) in November 2021 and during 2022
- Mainly technical tests but also first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

- This talk ...
  - Lessons from the 2021/22 beam tests and the preparation of the upgrade of the stack

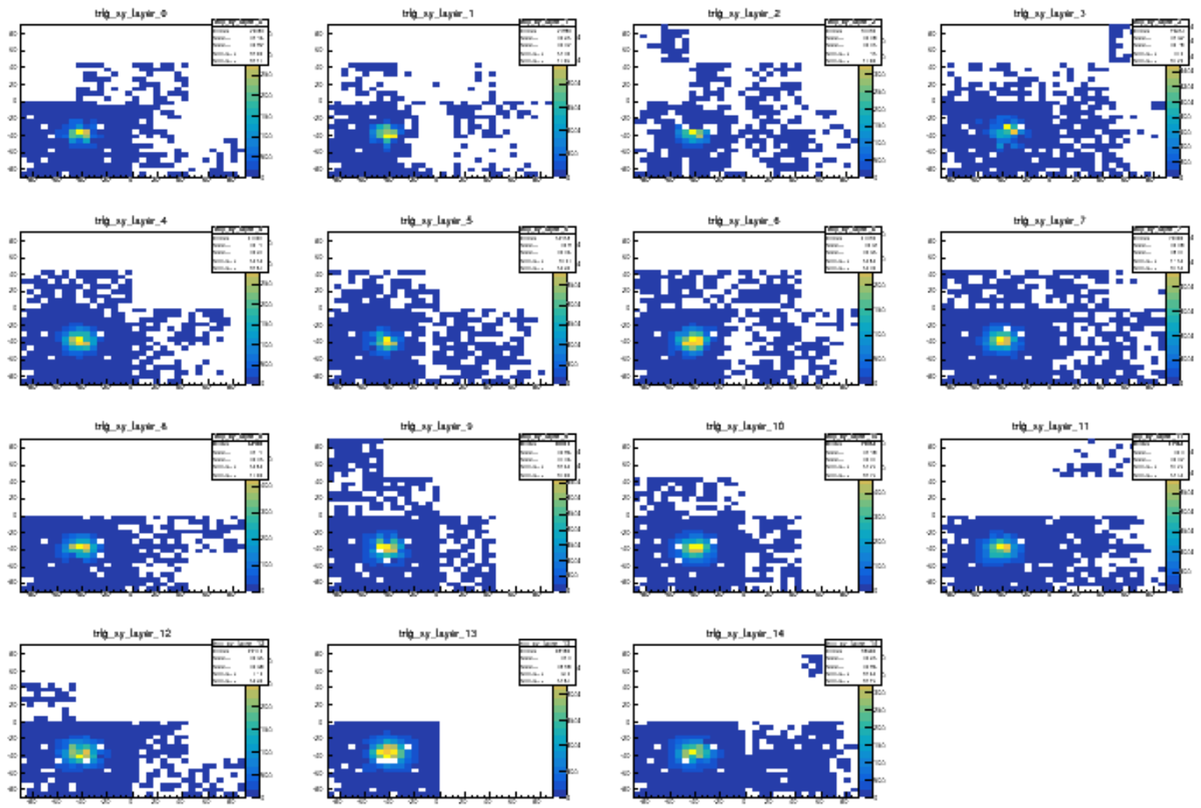
SiW-ECAL in beam test @ DESY

DRD Calo/CALICE

Detector Setup



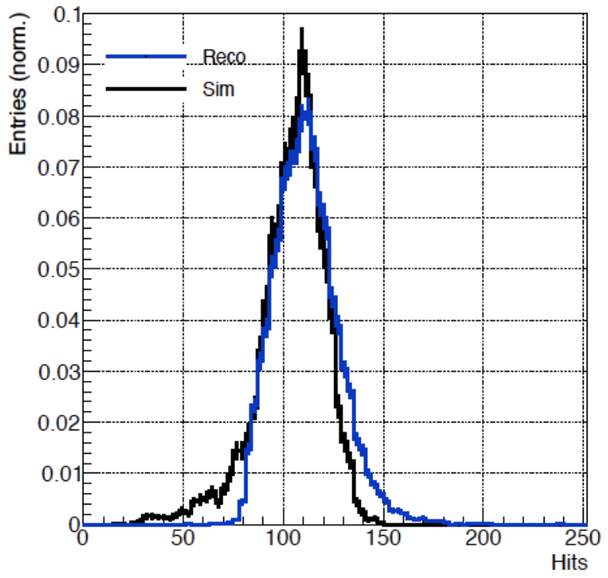
Detector in beam position



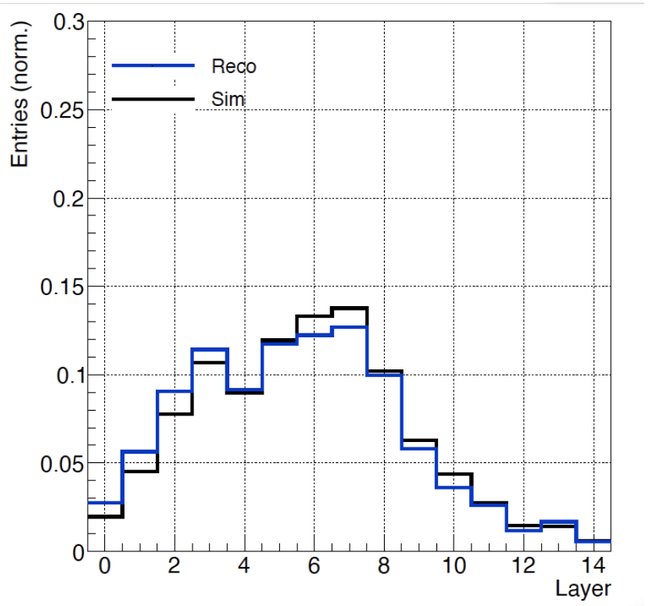
Beam spot in 15 layers

CERN Data – Analysis 10 GeV e-

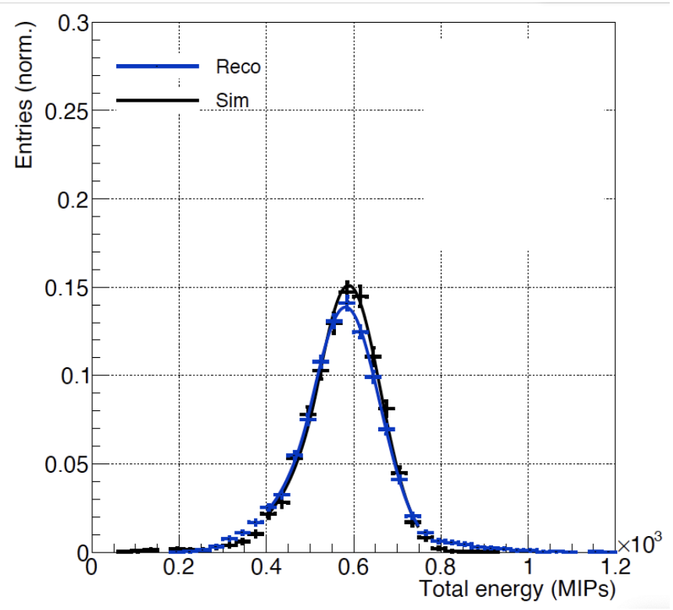
Total #of hits



Hits/layer



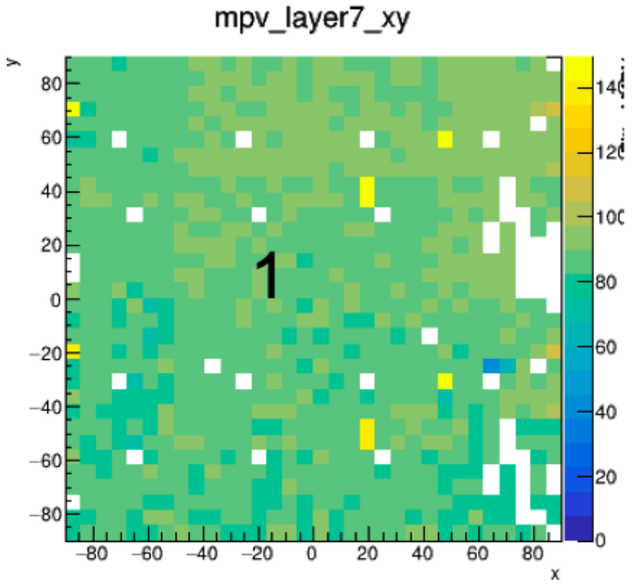
(Total Energy)/MIPS

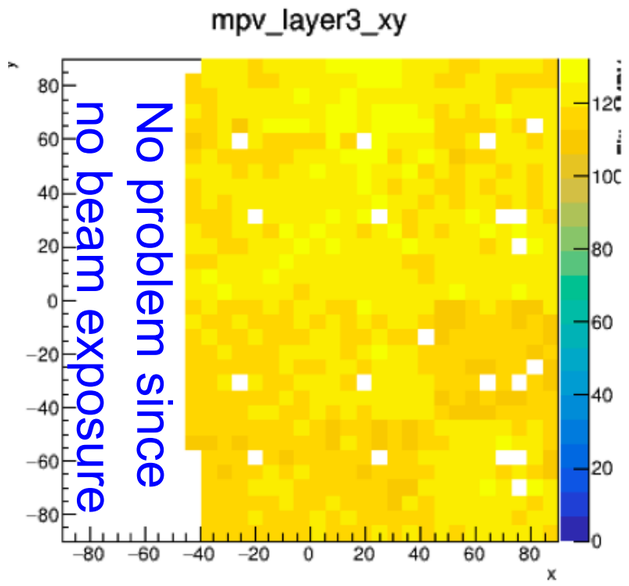


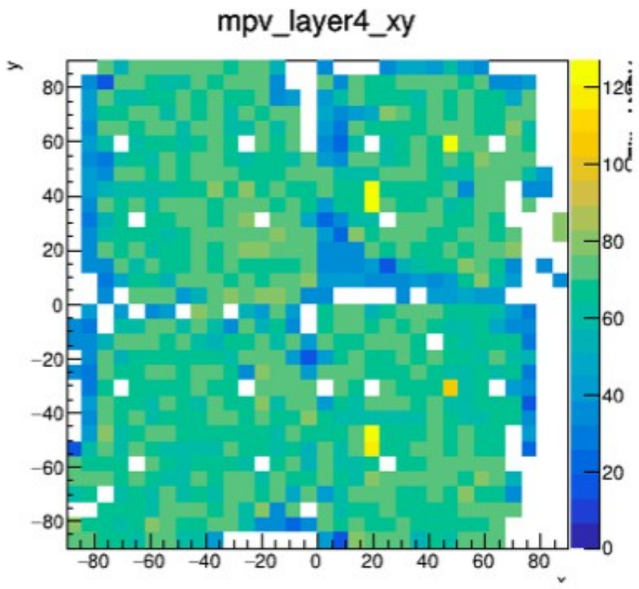
- Reasonable agreement between data and MC
  - ,,, after correction of MC for acceptance issues and adjusting the beam spot
- Energy resolution in ball park expected from simulation
- More analysis work required (including combined analyses)

PhD Thesis Y. Okugawa, IJCLab and Tohoku University

Sensor delamination







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 corrected

... and bad layers

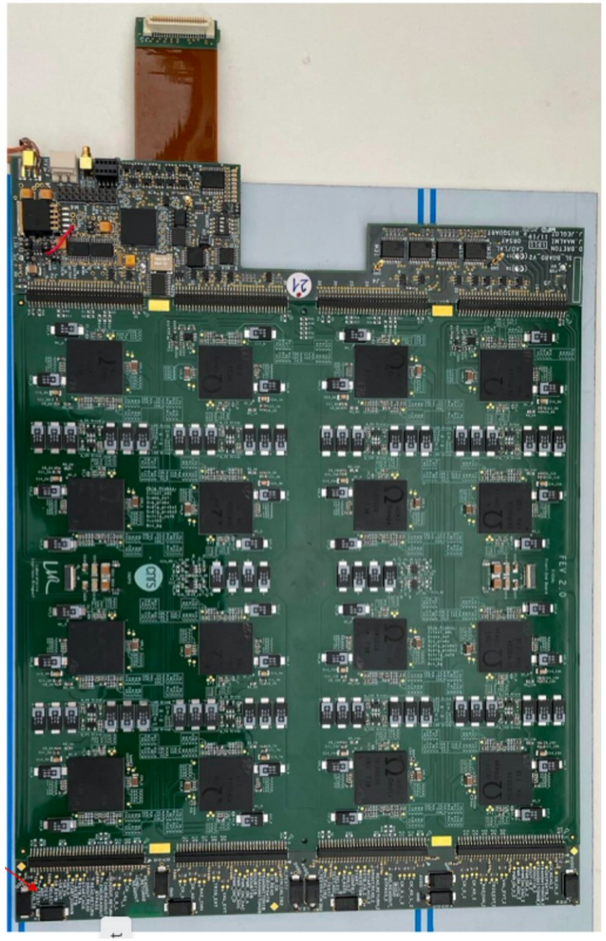
Inhomogeneous response to MIPs

- Partially even no response at all, in particular at the sensor boundaries
- Visual inspection confirmed with electrical tests show that the sensor got delaminated from the PCB -> glue dots have failed
- ***Serious problem and intensive topic of study***

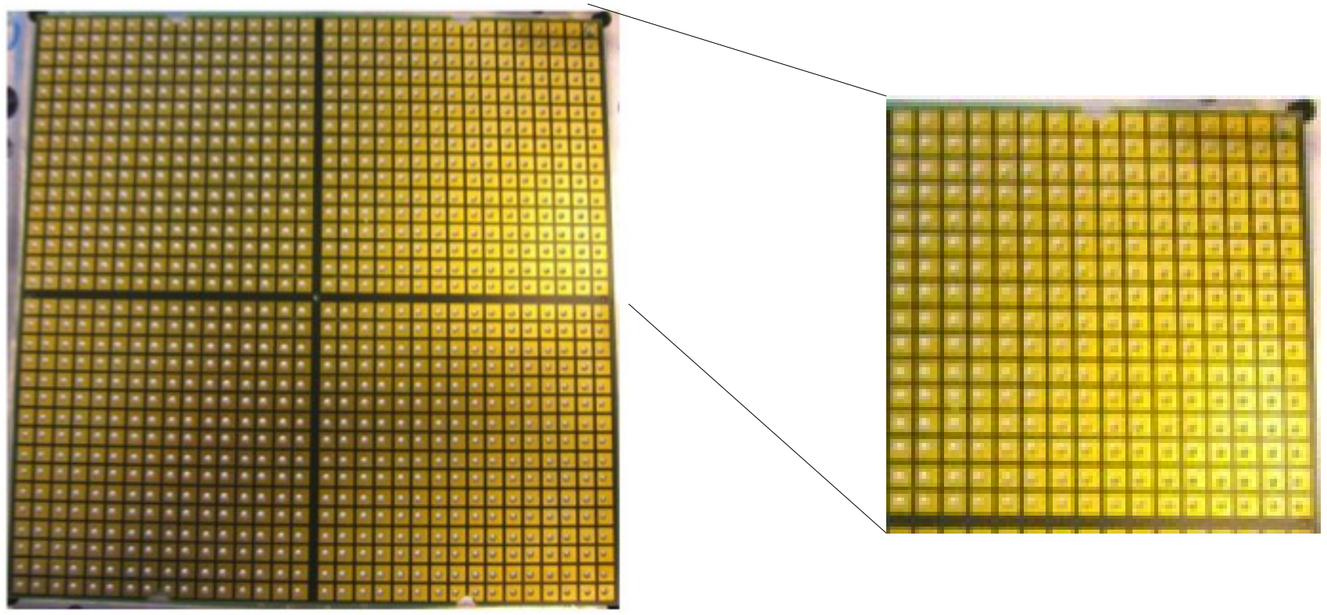
Sensor delamination – Reminder

Overall size – 18x18x~0.5cm^3

Upside: PCB with Electronics



Downside: Si sensors (here glass plates) glued to PCB



Glue: Epotek 4110 (conductive glue)
Dimensions of glue dots ~Ø 2.5mmx0.1mm

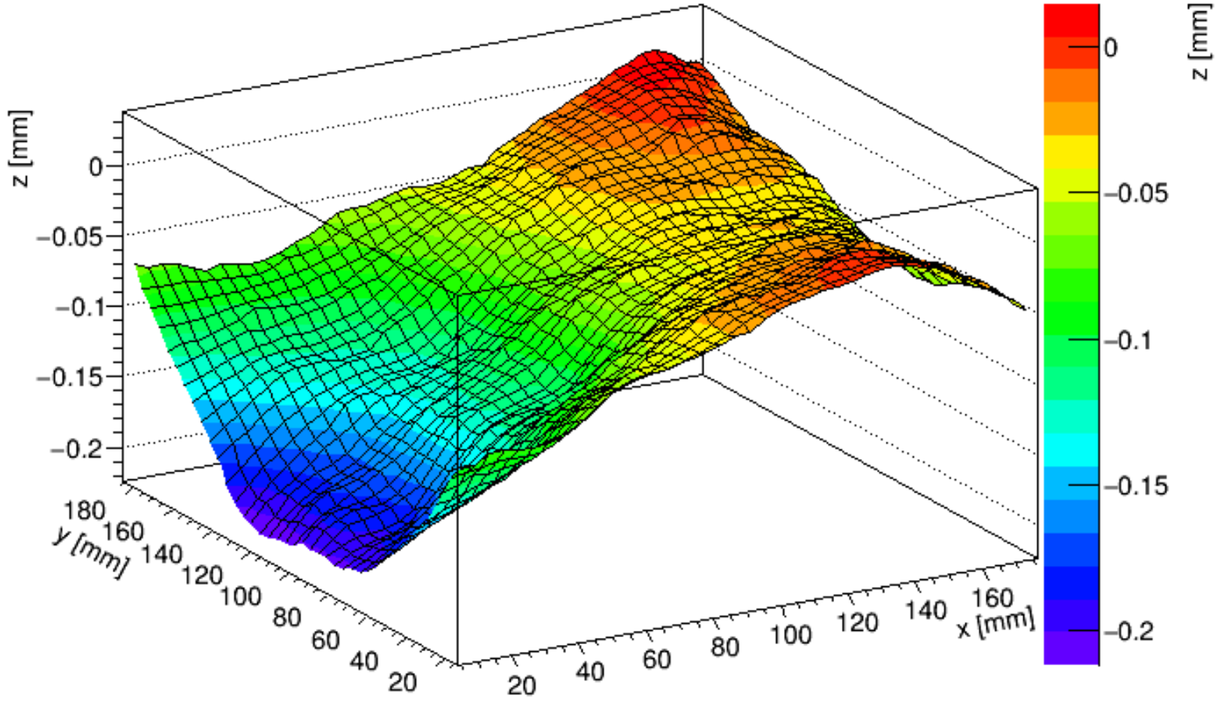
Sensor delamination – Steps of Study

- Hypothesis and foundation
  - Deformation of PCBs pulls on glue dots
  - Conductive glue has no mechanical stability and unpredictable behaviour (dixit Epotek)
  - Replace Epotek 4110 by Epotek H20E after consultation of other research teams and Epotek
- Metrology
  - What are the deformations we are dealing with?
- Hybridisation
  - Develop methods that allow keeping constant the distance between PCB and sensor
- Stress tests

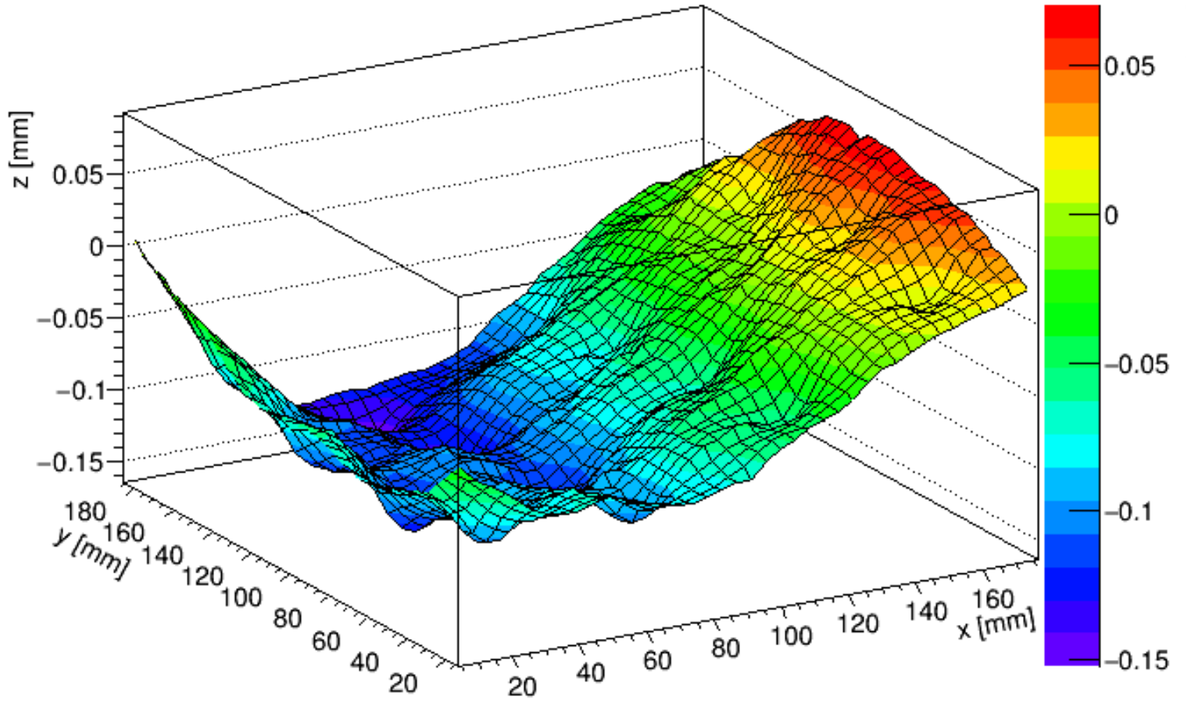
Sensor delamination – Metrology

Several PCBs were measured at IJCLab before and after mounting of components in IJCLab Workshop
Component mounting includes a short (~10s) heating cycle to about 300°C

Before:



After:



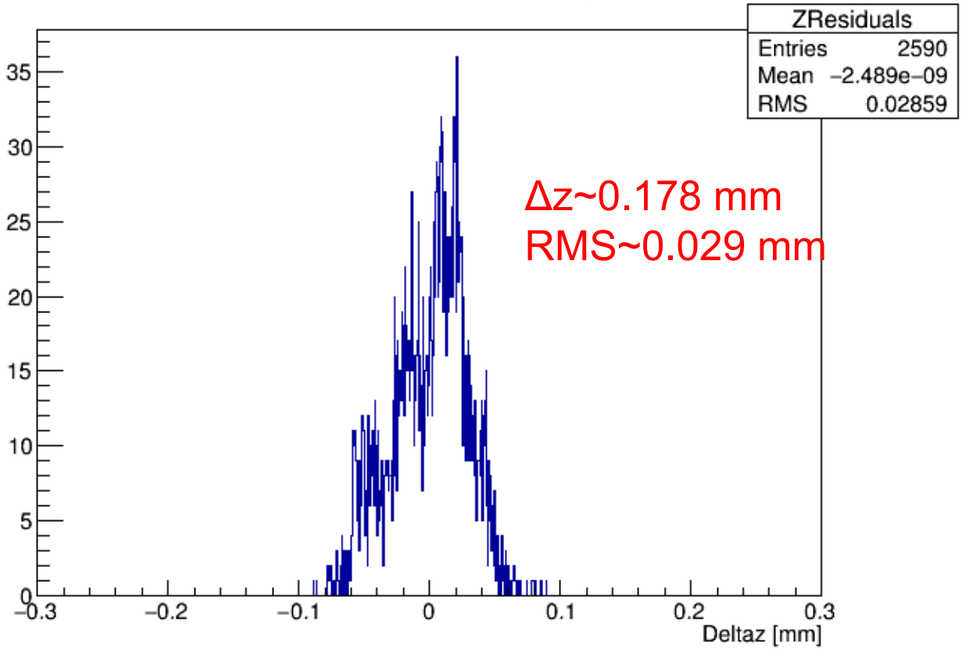
Measurements with Zeiss Acura

A. Thiebault, D. Zerwas + Mechanics Department of IJCLab

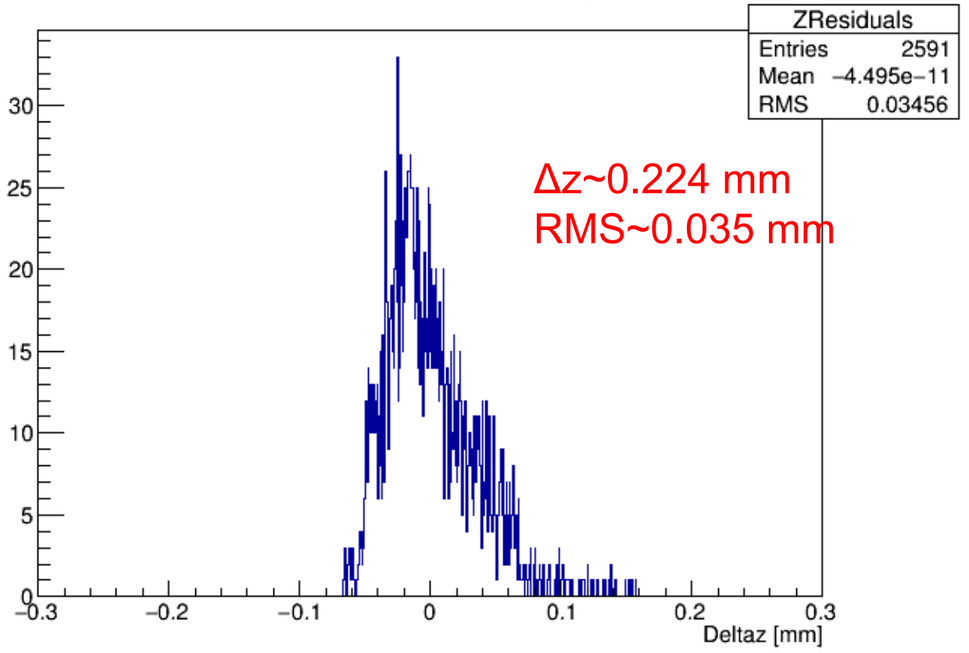
PCB Metrology at IJCLab

A plane was fitted to the point cloud of measurements
Residuals w.r.t. fitted plane

Before: Residuals wrt to fitted plane



After: Residuals wrt to fitted plane

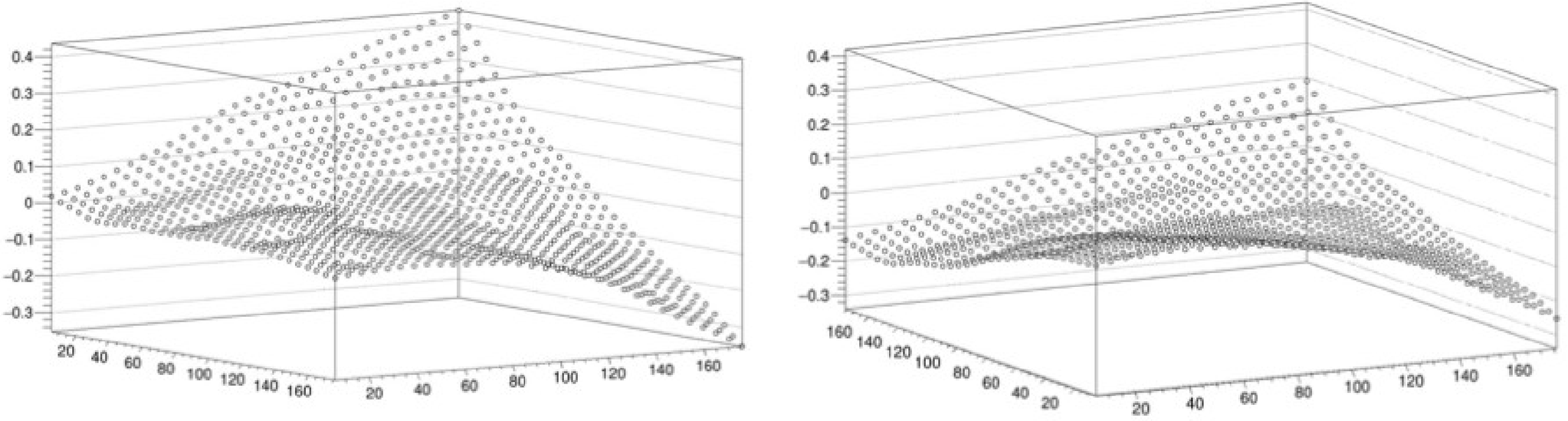


- Major part of deformation before mounting of component
- Recent measurement confirms deformation of “naked board” and allows for estimating systematic error to be of O(10mum)

A. Thiebault, D. Zerwas + Mechanics Department of IJCLab

PCB Metrology at IFIC

Measurement device: Mitutoyo Quick Vision Accel, Modelo 808



- Current results are surprising
  - Left: Equipped PCB after reception at IFIC from IJCLab, up to 800um deformation
    - N.B.: to be compared with right hand sides on previous two slides
  - Right: Same PCB after having been carefully “dried out”, deformation reduced to 450um)
  - In addition the PCB was subject to humidity cycles
- Systematic study to understand differences between IFIC and IJCLab ongoing
  - Metrology with well defined protocol

A. Irles + Mechanics Department of IFIC

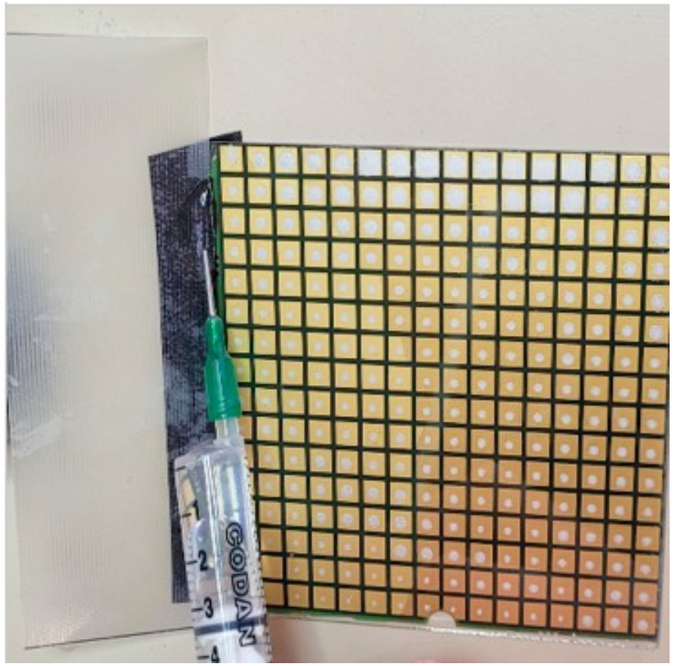
Hybridisation - Underfill

Support conductive glue dots with supplementary potting resine

EPO-TEK® 301-2

- From data sheet
  - Two component optical and semiconductor grade epoxy resin
  - Low viscosity, long potlife and good handling characteristics

Injection of underfill



- Resin propagates via capillary effect
- Takes ~20 min. to fill 9x9 cm^2 surface

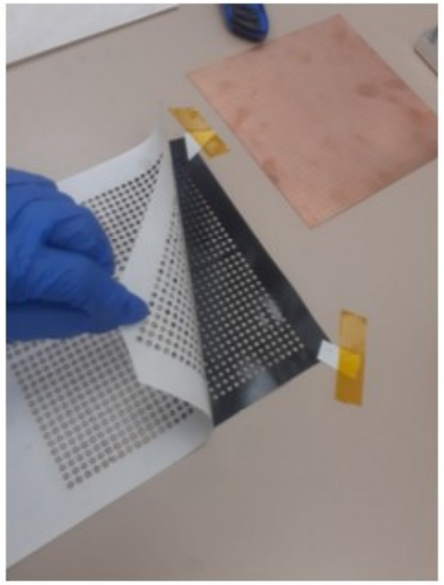
Requires curing at 80°C ...

... but remains flexible after curing

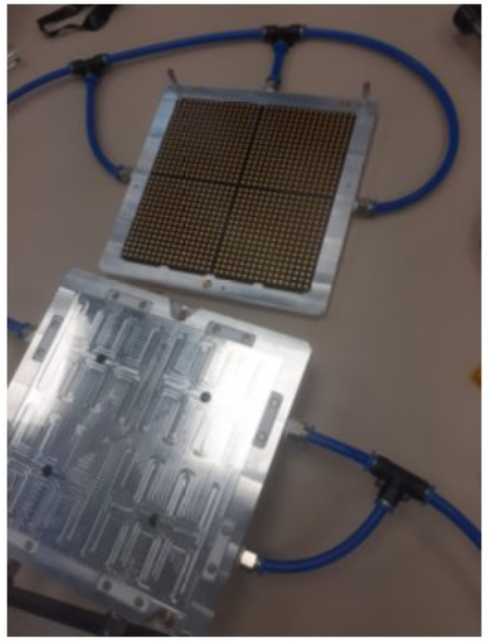
A. Thiebault, A. Gallas+ Mechanics Department of IJCLab

Hybridisation – Double sided tape

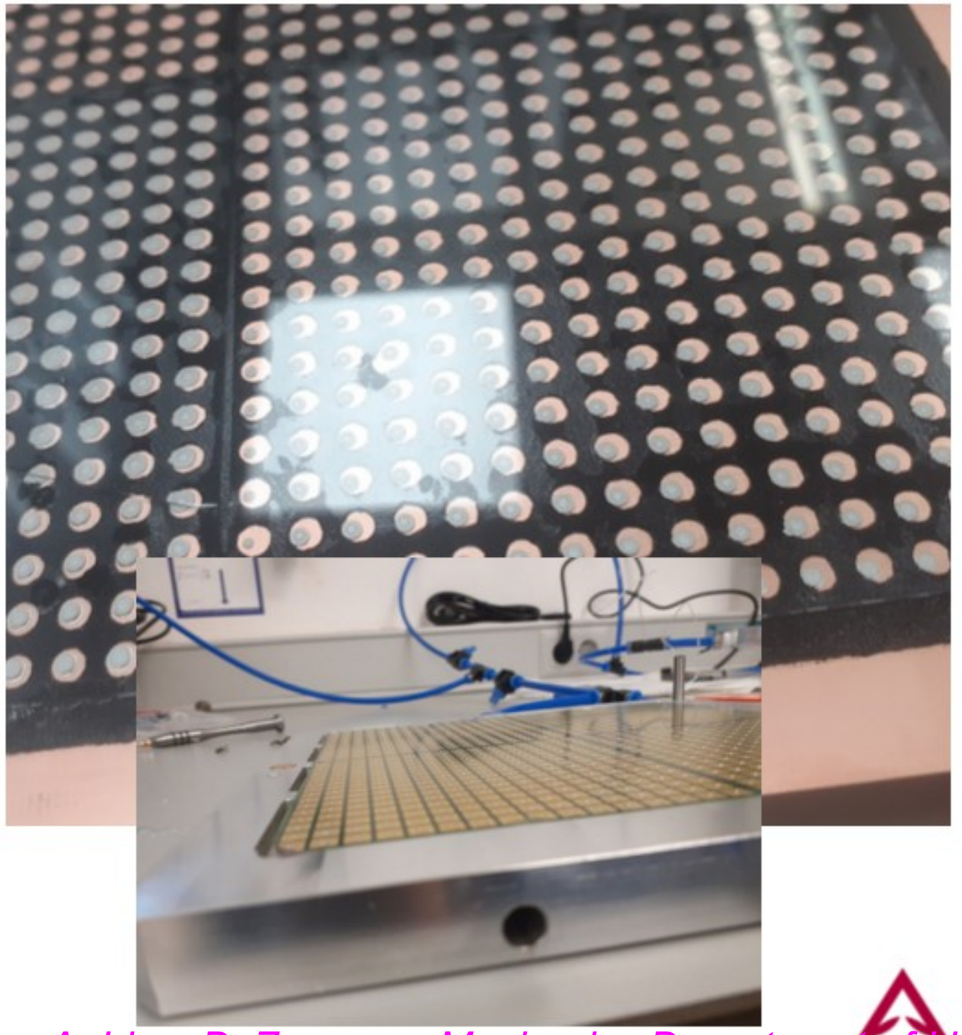
- Perforated stencil of thin 250um double tape 3M VHB 5907F
- Idea inspired by CMS HGCAL



Stencil made at IFIC (laser drill)



One 18x18cm^2 model completed at IFIC



A. Irles, D. Zerwas + Mechanics Department of IJCLab

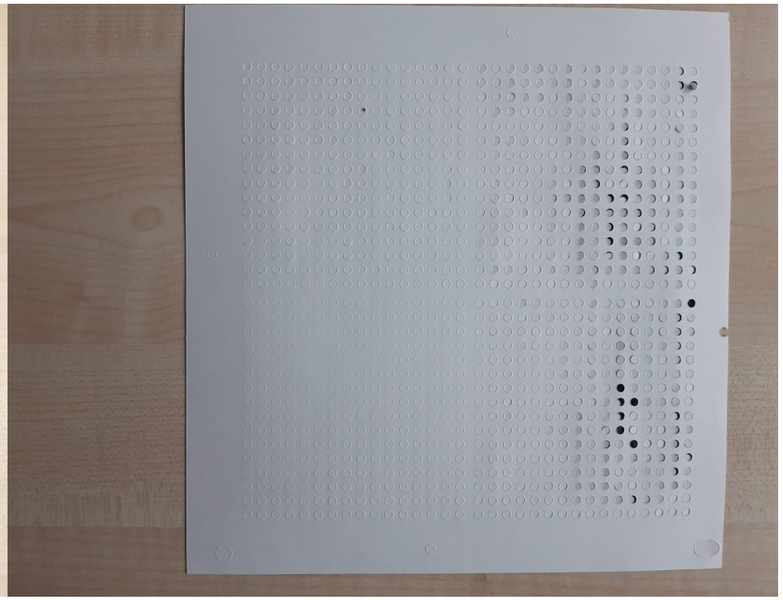
Hybridisation – Double sided tape – Alternative Perforation

Aristo@DESY

Die cutter

3M Front Side

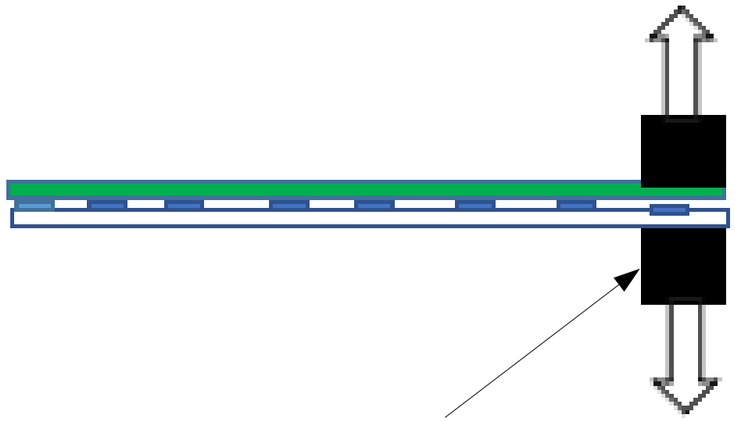
3M Back Side



- 1024 holes in 15 minutes
  - Much faster than laser cutting
- Action coordinated by DMLAB (French-German Lab)
  - Help by DESY engineers !!!

Tensile Tests

Principle of tensile test

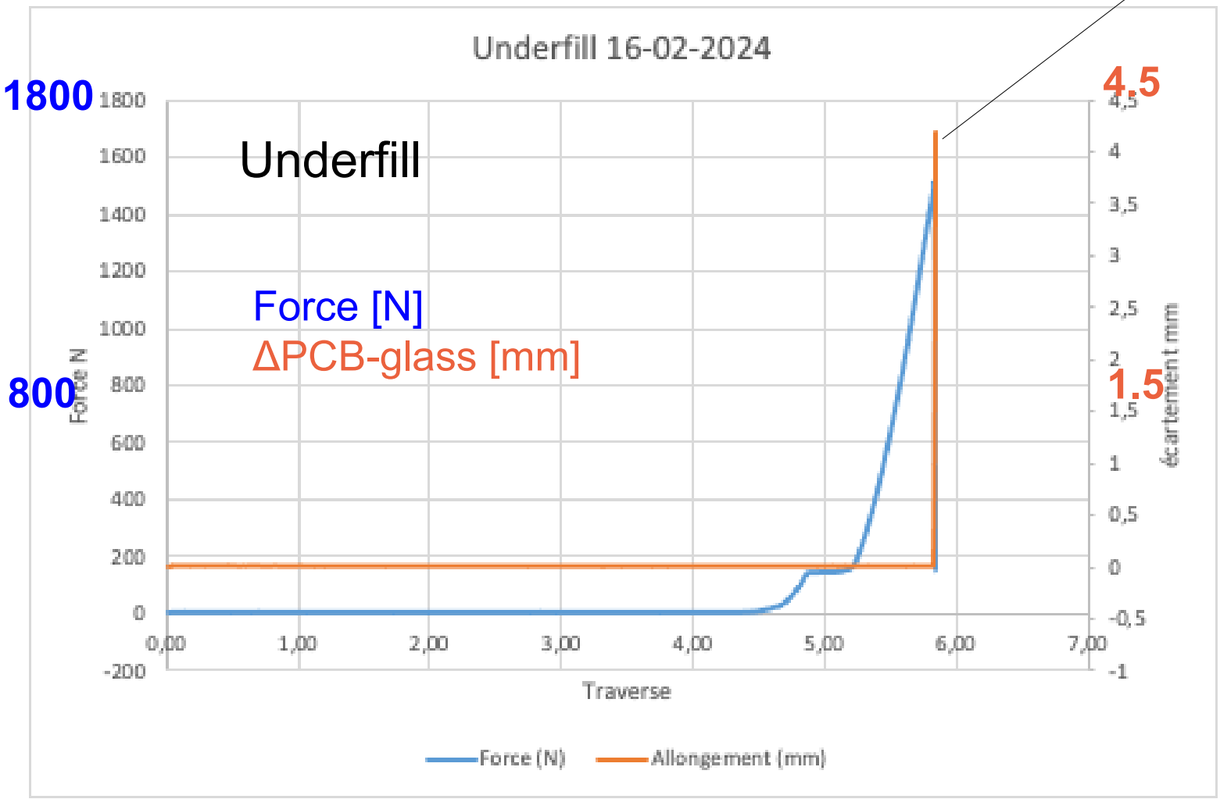


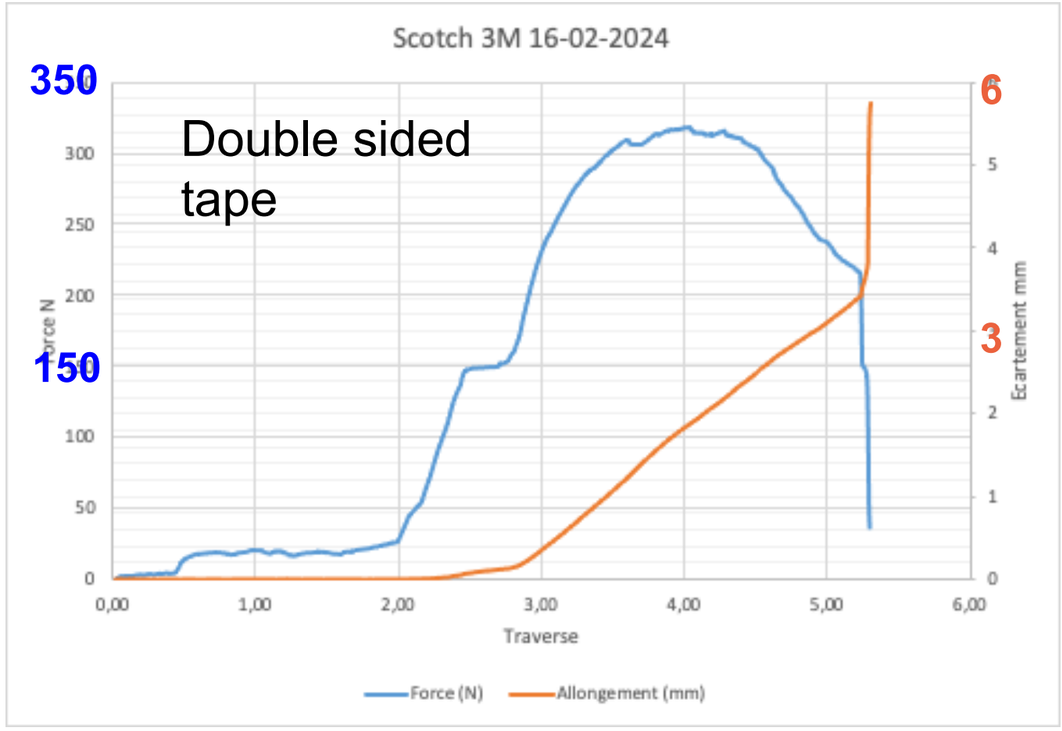
Bars are glued
to transmit force
to card under test

A. Thiebault + Mechanics Department of IJCLab

Tensile Tests – First Results

Bar dissolves from card under test

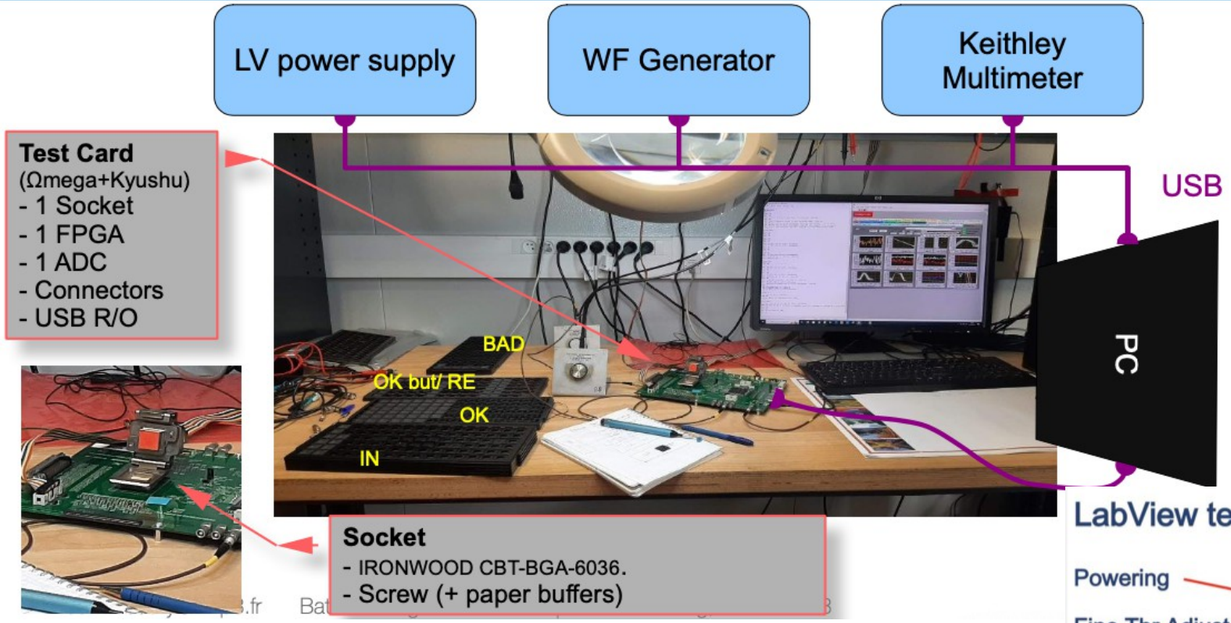




- First test reveals that underfill resists to even strong external forces
- Set up to measure actual force on glue dots in place (but no results yet)

A. Thiebault + Mechanics Department of IJCLab

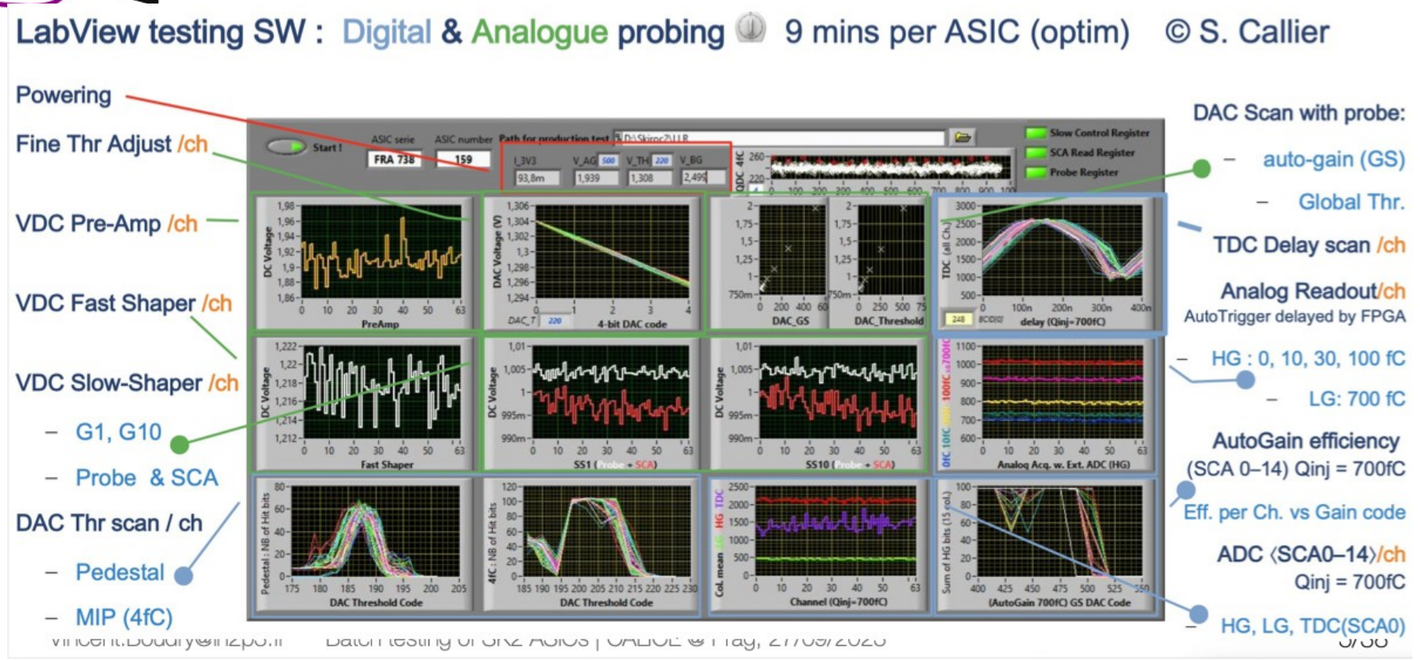
Towards revised stack - ASIC Tests in 2023 *DRD Calo/CALICE*



Testbench at LLR

- 151/400 SKIROCs tested until September 2023 (more since)
- Satisfactory yield

Testprotocol by OMEGA



New FE boards

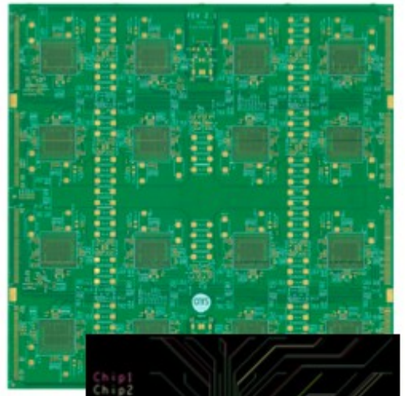
LLR, IJCLab, LPNHE, OMEGA

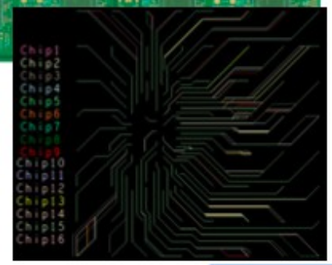
Improvements:

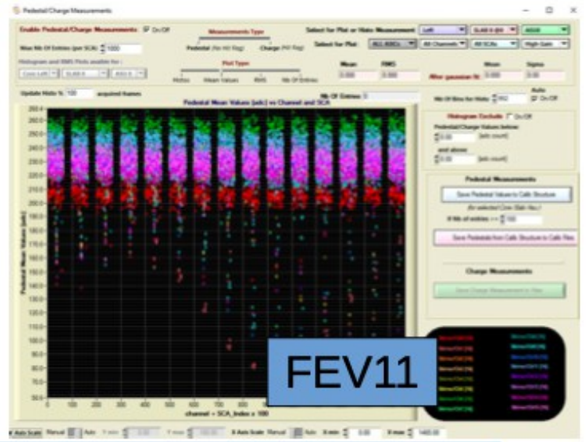
- Power distributions
  - Local power regulation
  - Local High Voltage filtering & Supply
- Signal distribution (buffering), data paths
- Monitoring (single ID, temp, probe analogue line)
- ASIC shielding/routing

Status:

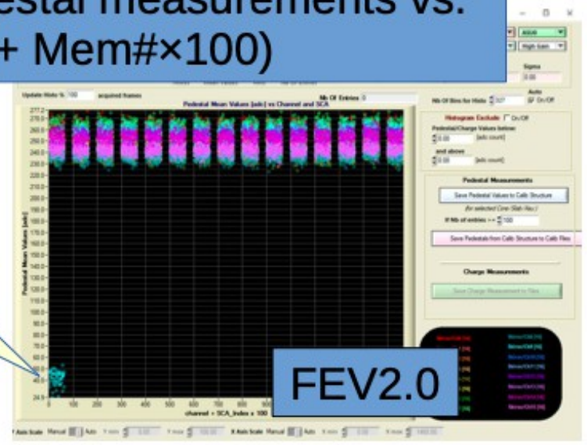
- pre-version 2.0 tested, minor corrections needed
  - Noise uniformity dramatically improved (ex: outliers in thr. / 20 !)
- version 2.1 produced, … in metrology
  - before cabling, 2nd metrology, gluing, …
  - All material available : ASICs being tested







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



SIngle channel → the fault on the ASIC/packaging

Goal: build 15 layer stack based on these Boards

Summary and Outlook

- Slow but steady progress on SiW Ecal
  - Visible progress on data analysis
    - Need to ensure knowledge transfer since PhD student(s) are on leave
  - New PCBs available
  - ASICs available
  - Sensors for revision of CALICE stack available

- Understanding of sensor delamination problem are at the heart of current R&D
  - Systematic studies throughout 2023 and ongoing
  - Metrology seems to indicate that component mounting is not culprit for deformation
  - Drying seems to help, avoid humidity?
  - Discrepancies between screening results at IJCLab and IFIC to be understood

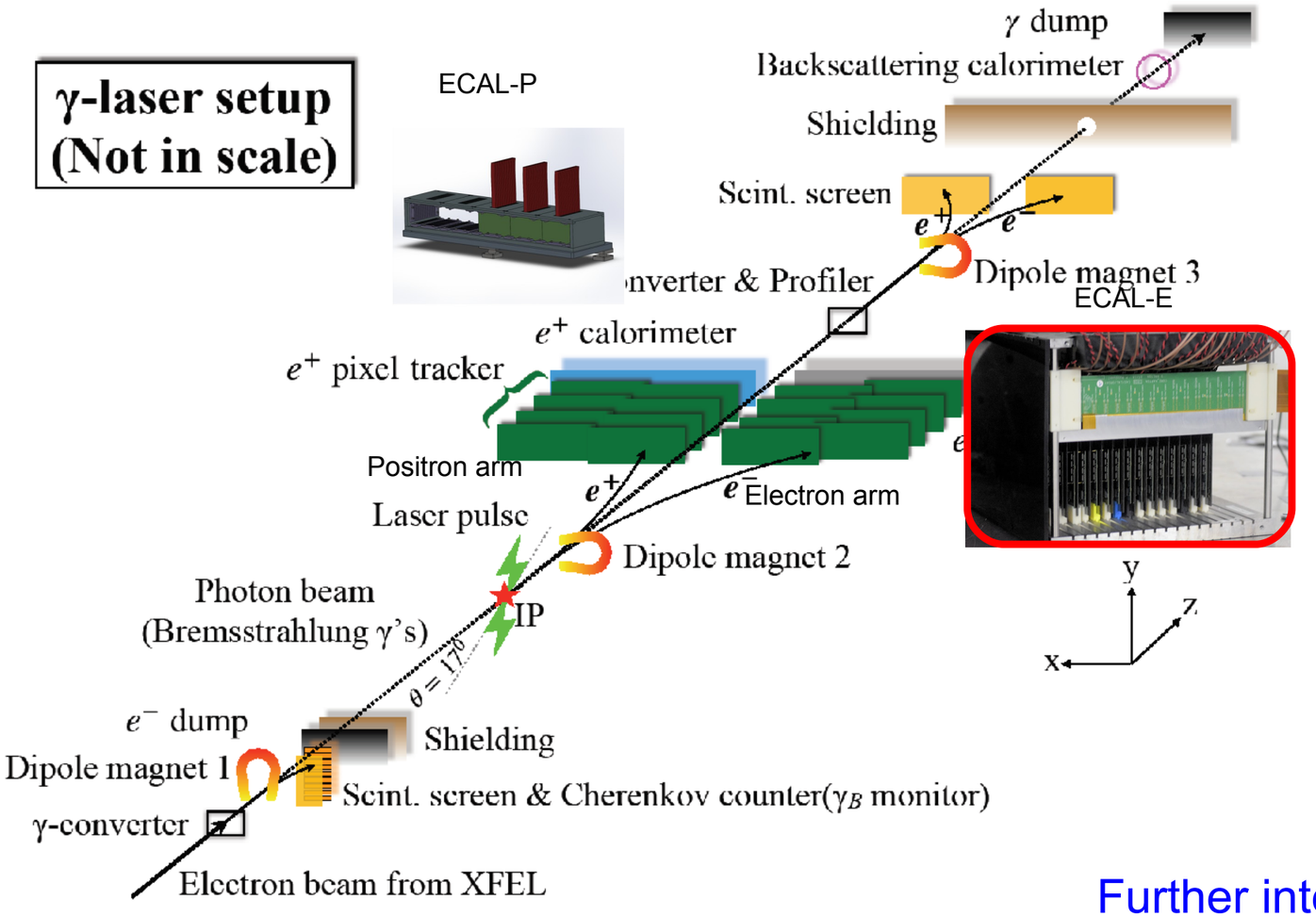
- Progress on two methods for for hybridisation
  - Underfillll
  - Double sided tape (after all a “pre-polymerised” material)
  - Have to learn now how to build ASUs using these technologies
    - Proper perforation and placement of perforated tape
    - Application of underfill to 18x18 cm^2 surface

- Next steps
  - ... build two new layers still in 2024
  - ... and extend to 15 layers if resources will permit

Backup

“Early Applications” of CALICE Technologies - LUXE

Laser Und Xfel Experiment – QED in extreme fields



CALICE meets LUXE

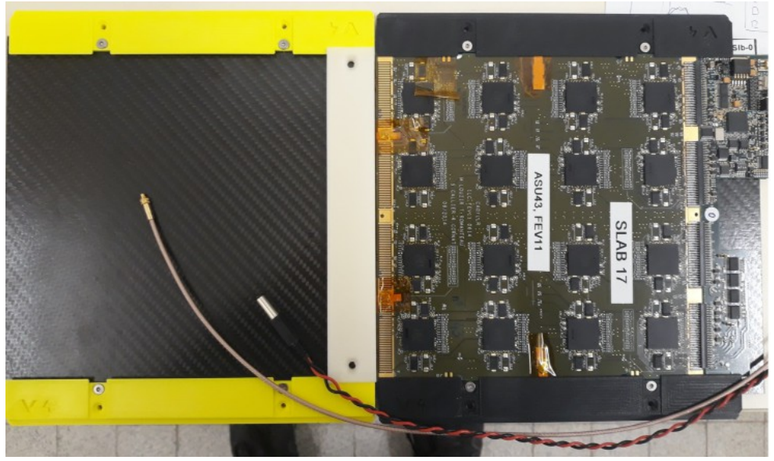
Granular calorimeters in positron and electron arms of spectrometer

- 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)

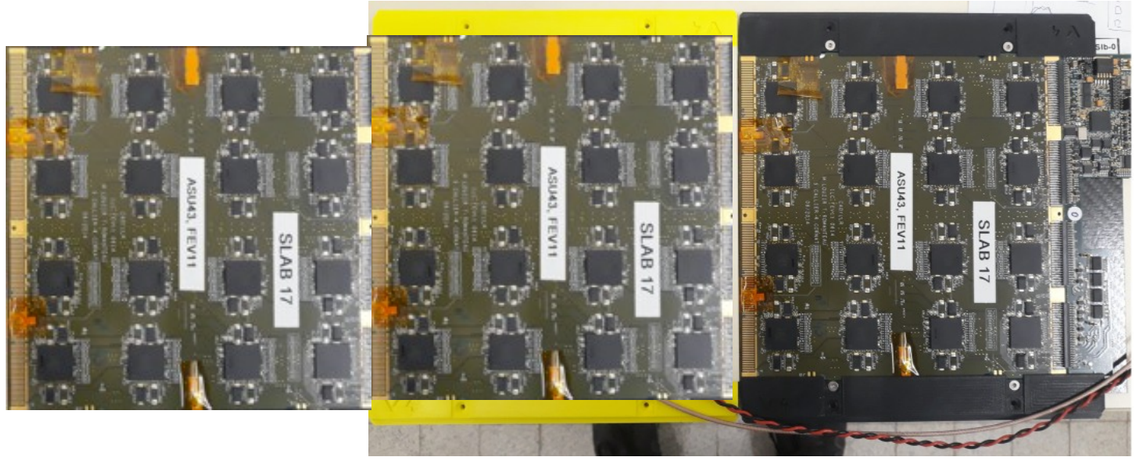
Plans (not only) for LUXE

Current: Tower of 15 18x18cm^2 layers



- Stack under revision
- Revision possible with small amount of funding
- Revised stack should/could be available during 2024

Future: Lateral extension to up to 18x54cm^2 layer (three towers), up to 15 layers of this type



- Straightforward application of work for CALICE
- **Details of implementation in LUXE requires simulation study**
- **=> need dedicated funding including person power!**

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- LUXE stack = v0 of SiW ECAL engineering prototype