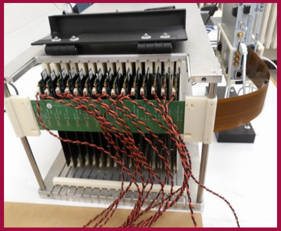
Addressing technological challenges on sensor-electronics hybridization for compact silicon tungsten electromagnetic calorimeters

Adrián Irles*, Yan Benhammou (TAU), Dirk Zerwas (DMLab)

***AITANA group at IFIC – CSIC/UV**

Introduction



CALICE -type calorimeter

FCAL-type calorimeter

DRD6

ILD LUXE

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

LLR

九州大学 KYUSHU UNIVERSITY

KEK High Energy Accelerator Research Organization

CERN

CNRS IN2P3 Les deux infinis

LPNHE PARIS

OMEGA Microelectronics

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TEL AVIV UNIVERSITY אוניברסיטת תל אביב

UNIVERSITAS VARSOVIENSIS

AGH

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DESY.

Common R&D: module hybridization.
Assembly lab being set-up at IFIC

A.I., C. Blanch, C. Orero, M. Almanza, S. Huang

Outline

- ▷ High granular silicon-ecals : what for?
- ▷ SiW-ECAL challenges
- ▷ Ultra Compact ECAL challenges
- ▷ Summary

High Granular Calorimetry R&D: what for?

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▶ **Higgs Factories – Particle FLOW calorimeters**

- **All projects** (linear/circular) **consider Particle Flow detector options**
- **Requires high granular and compact sandwich calorimeters** (i.e. ECAL silicon + tungsten)
- Fully embedded electronics & minimal moliere radius

▷ **Strong-Field QED** experiments **(LUXE)**

- **Features two silicon-tungsten** highly granular and compact **ECALs** (CALICE and FCAL adaptations). Eu.XFEL pulsed electron beam (as ILC)
- Excitement and ambitious program to study **SFQED** in high detail → **uncharted territory**
- From the point if view of Higgs Factories: also a stepping stone on detector R&D program

▷ Dark Photon, ALPs Experiments

- LUXE-NPOD, ...

SiW ECAL Technological requirements

Sandwich calorimeters – High Granularity –

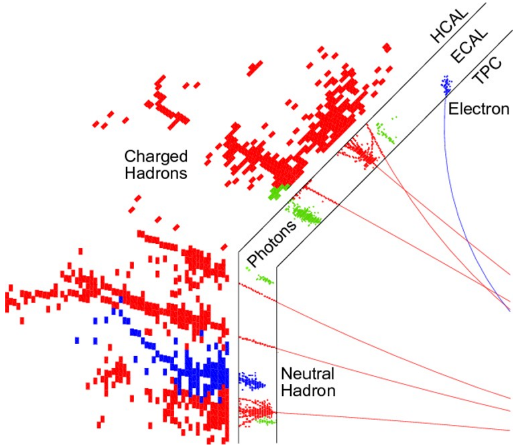
▷Particle Flow, Luminosity measurements, Energy Flow, shower overlapping

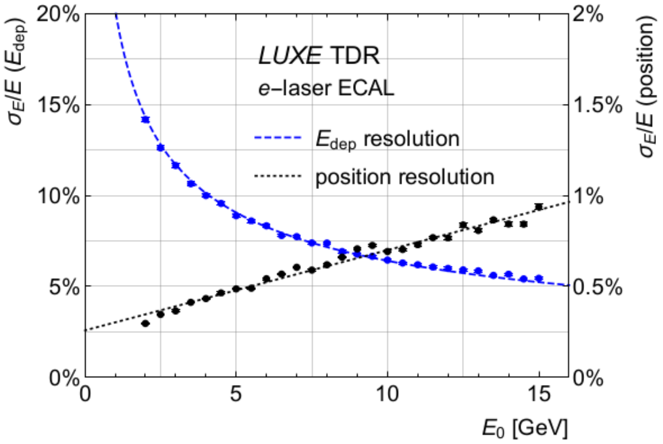
▷Tungsten as absorber material

- Narrow showers
- Assures compact design

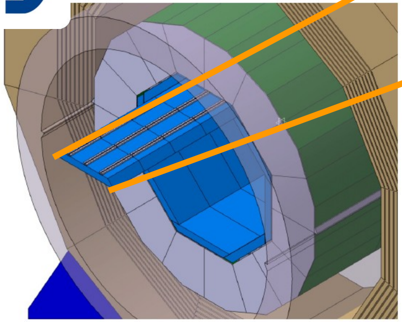
▷Silicon as active material

- Support compact designs
- Allows pixelisation → good position resolution
- Robust technology
- Excellent signal/noise ratio



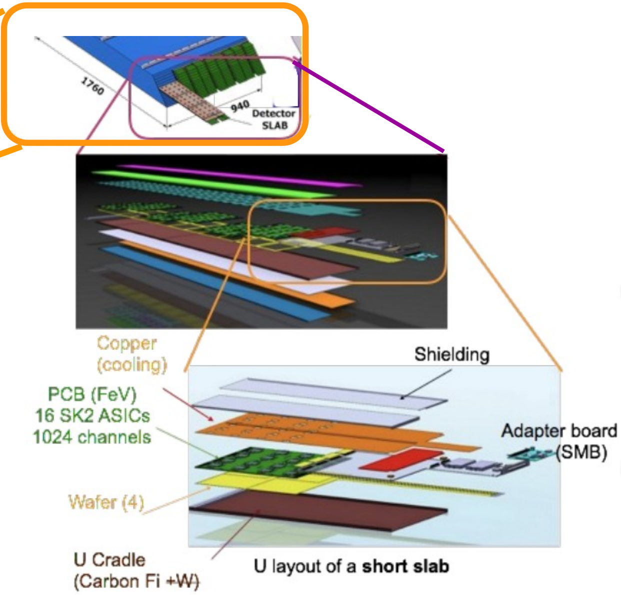


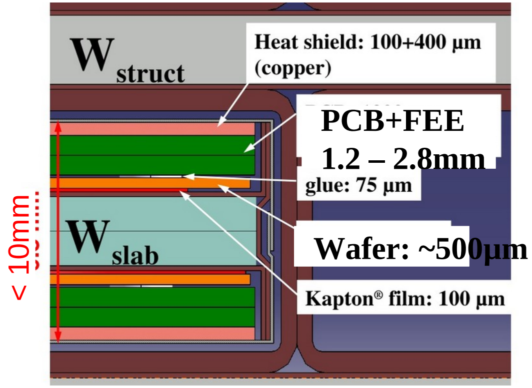
Requirements: highly integrated



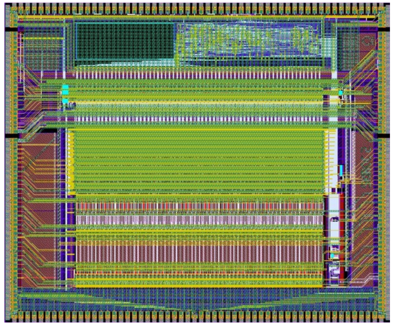
The SiW ECAL in the ILD Detector

SiW Ecal





e.g. SKIROC (for SiW Ecal)



Barrel

- ▷O(10^4) slabs
- ▷O(10^5) ASUs (PCB+wafer+ASIC+DigReadout)
- ▷O(10^{6-7}) ASICS
- ▷O(10^8) cells
  - 2000 m^2 of Si
- ▷130 T of tungsten

Cell size of 5x5 mm → all cells are self triggered + zero suppression

Size 7.5 mm x 8.7 mm,

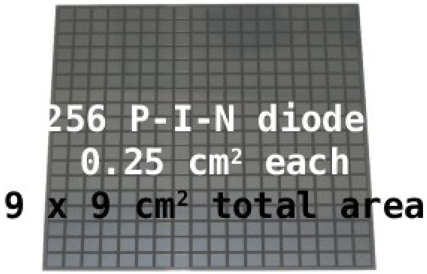
64 channels

Dual gain, autotrigger, powerpulsed

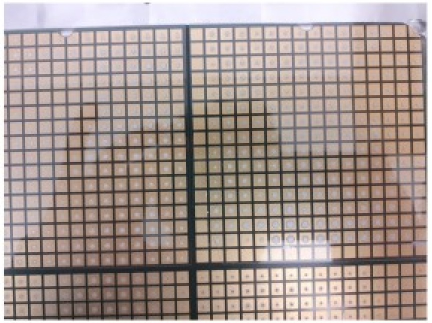
(goal of 25uW / chn)

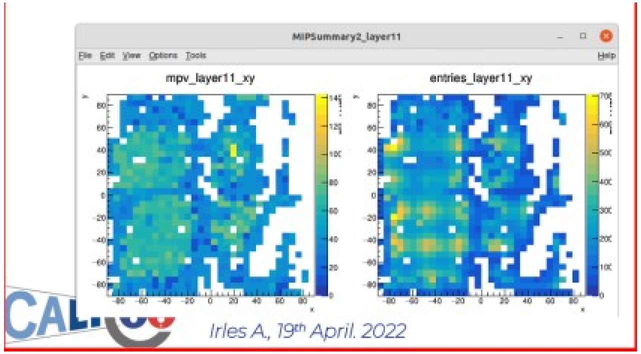
SiW ECAL: the basics

- ▷ Very dense PCBs
- ▷ 4 silicon sensors
  - PiN Diodes of 90x90mm²
  - 55x55mm² cells
- ▷ No space for wirebonding
- ▷ Glue with conductive epoxy+silver mixes
  - Low temperature curing (40-80 degrees)
- ▷ **Delamination observed** in several modules → partial (or almost total) **wafer-pcb separation** with time

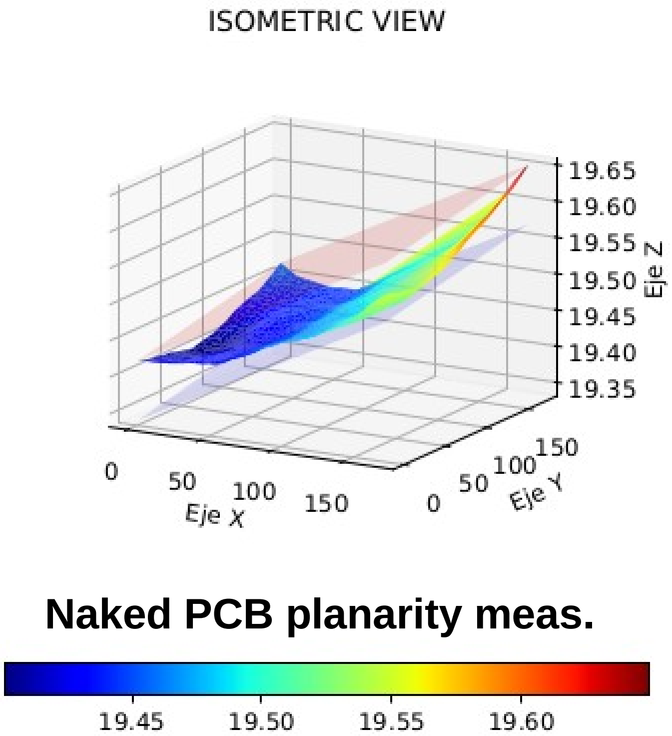


EUDET layout
Prototype from Hamamatsu

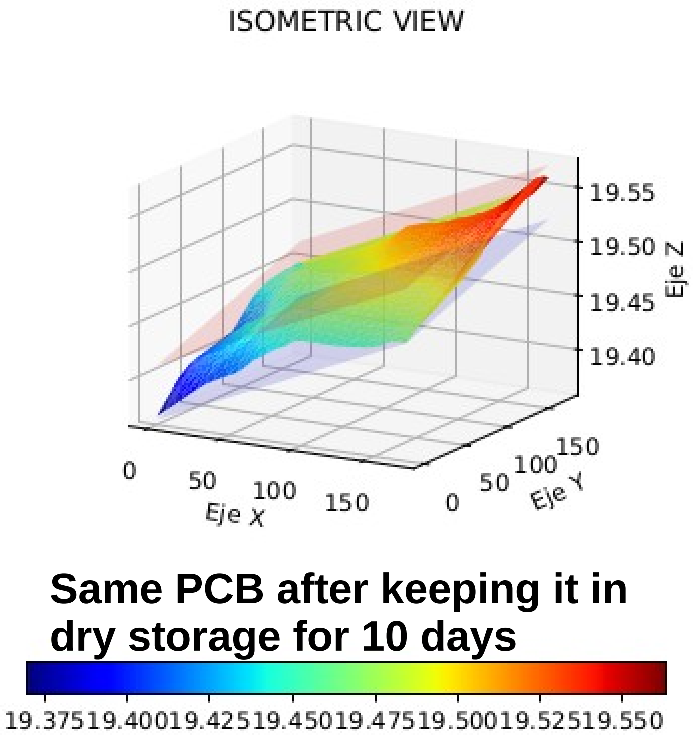




SiW ECAL: PCB planarity



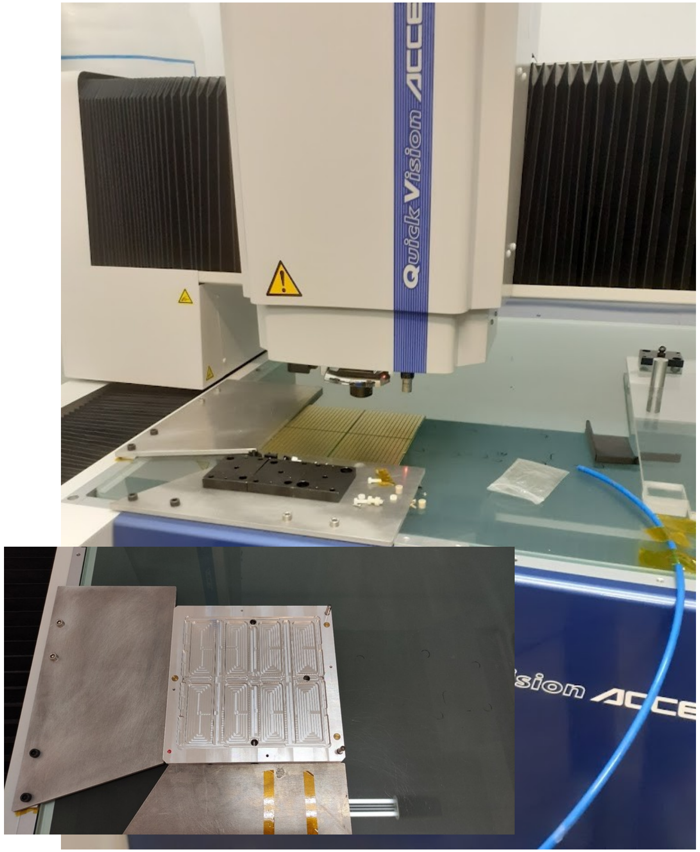
Naked PCB planarity meas.



Same PCB after keeping it in dry storage for 10 days

Measurements by C. Orero, IFIC

SiW ECAL: PCB planarity



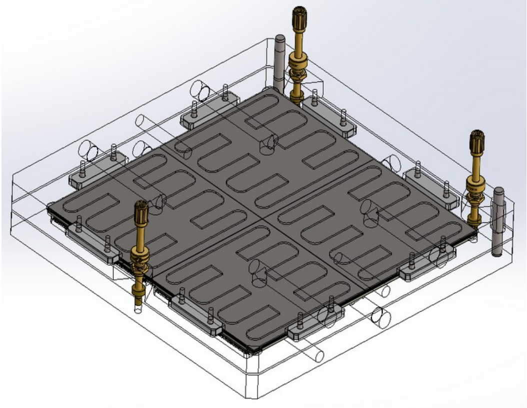
Mitutyo Quick Vision Accel, Modelo 808

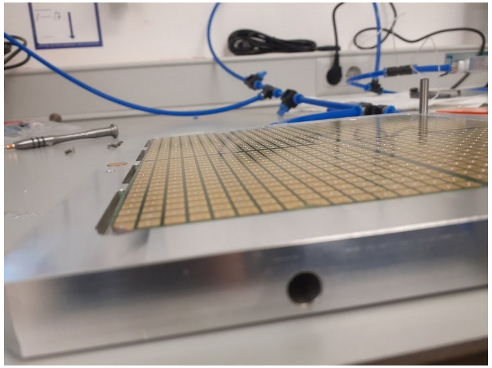
Measurements by C. Orero

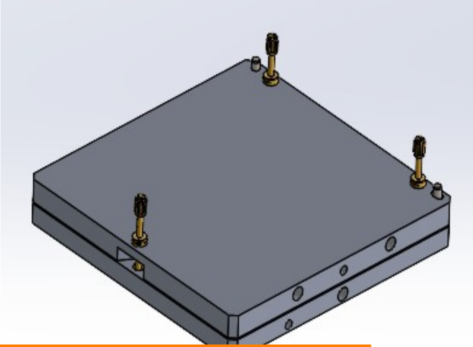
- Planarity measurements being doing consistently and under different storage conditions
- Naked board PCB planarity : varies between 80-160um depending on the board
- Similar planarity for boards equipped with components (less statistics)
- Planarity depends on storage conditions. Systematic improvement observed.
  - Global planarity improves in ~60% (50-80um)
  - Local differences are larger, up to few 100um

SiW ECAL hybridization / integration

- ▷ Cluing training + tests ongoing
- ▷ Setup in new clean installation being deployed at IFIC







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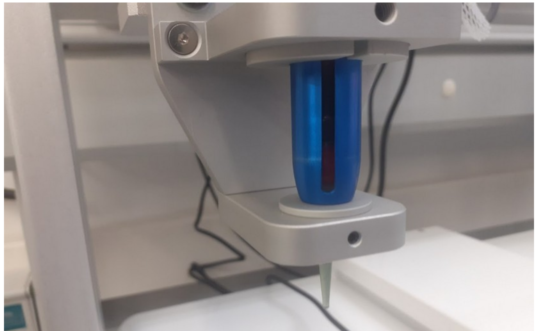
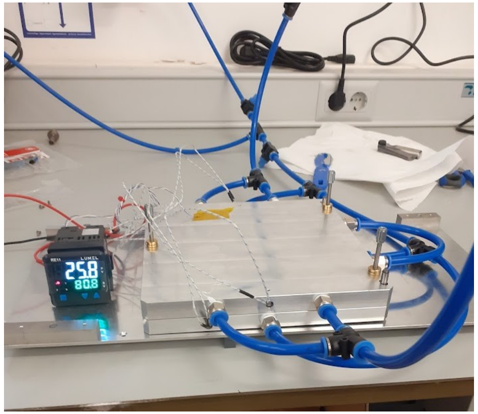
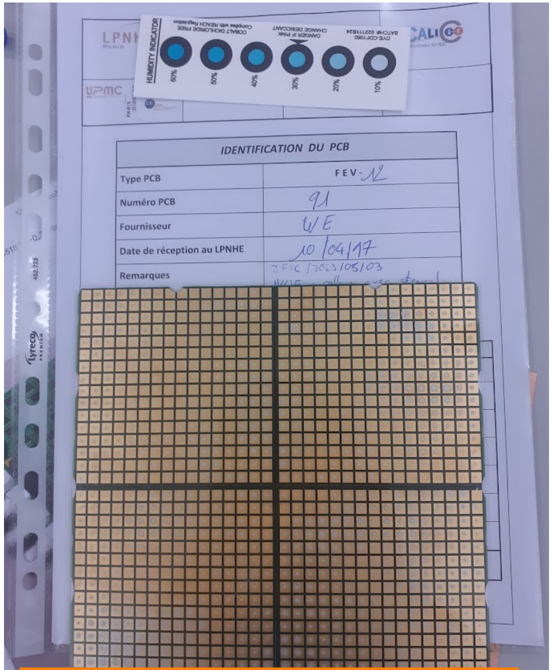


3D robot with volumetric dispenser system

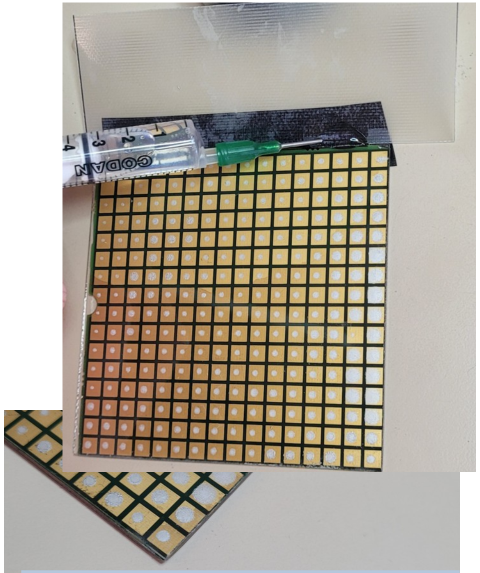


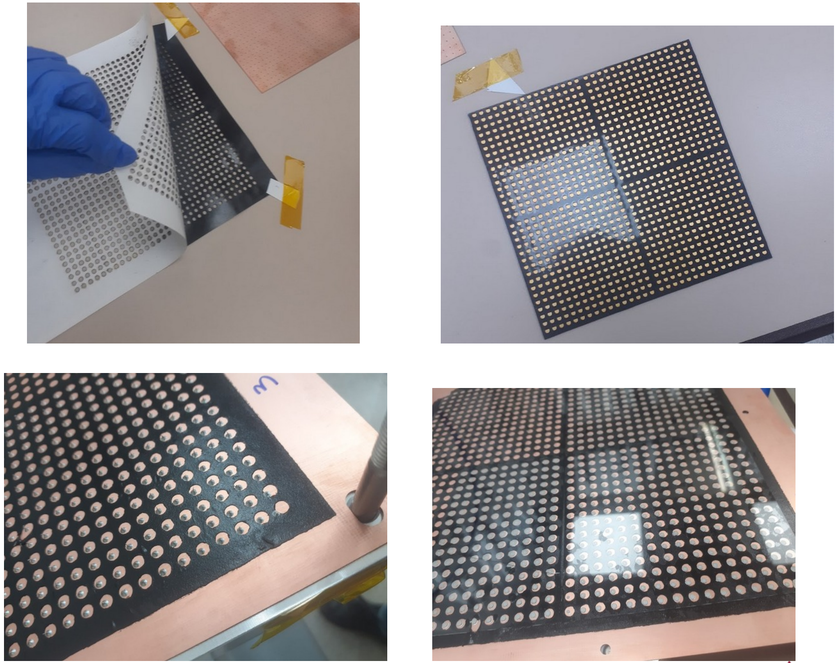
SiW ECAL: double adhesive solution for hybridization

- Keeping control on the deformation of PCB
  - Wip: study of the stress forces invovled (IJCLab)
- Two solutions being explored, both still with epoxy-silver glue dots for the electrical conductivity
  - Undefill glue (EPO-TEK 301-2FL) → involves second curing.
  - Double tape (3M 5907-F) used as stencil/mask for adherence

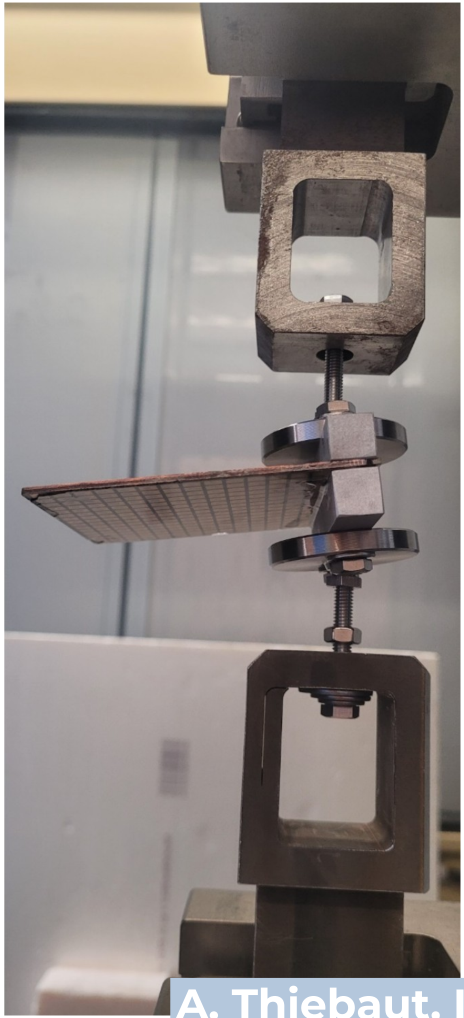


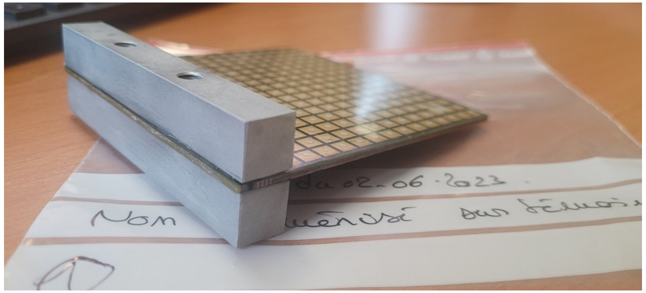
C. Blanch, A.I IFIC

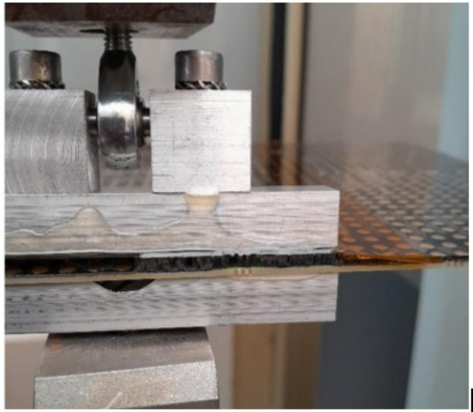

A. Thiebaut, IJCLab

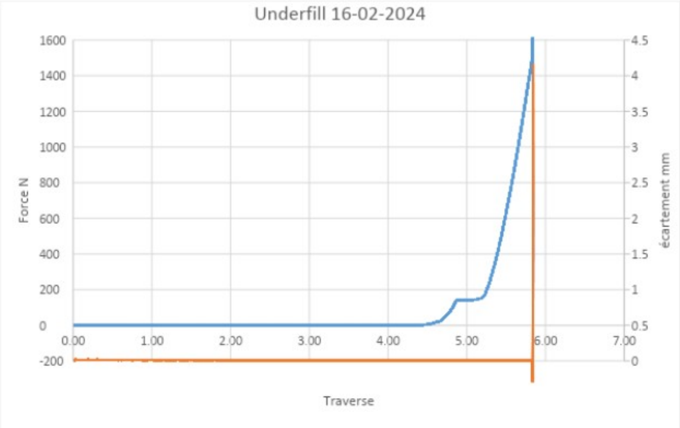

C. Blanch, A.I IFIC

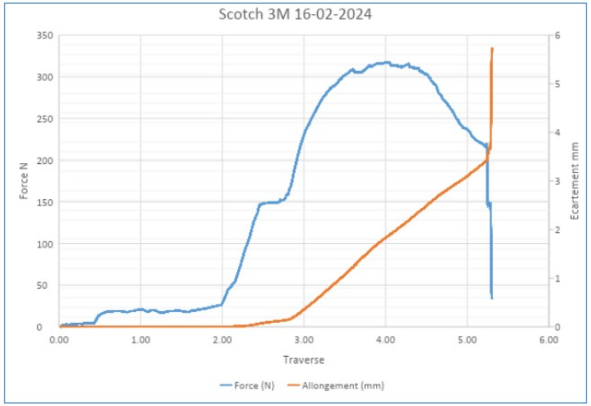
Mechanical tests











A. Thiebaut, IJCLab

Requirements: highly compact

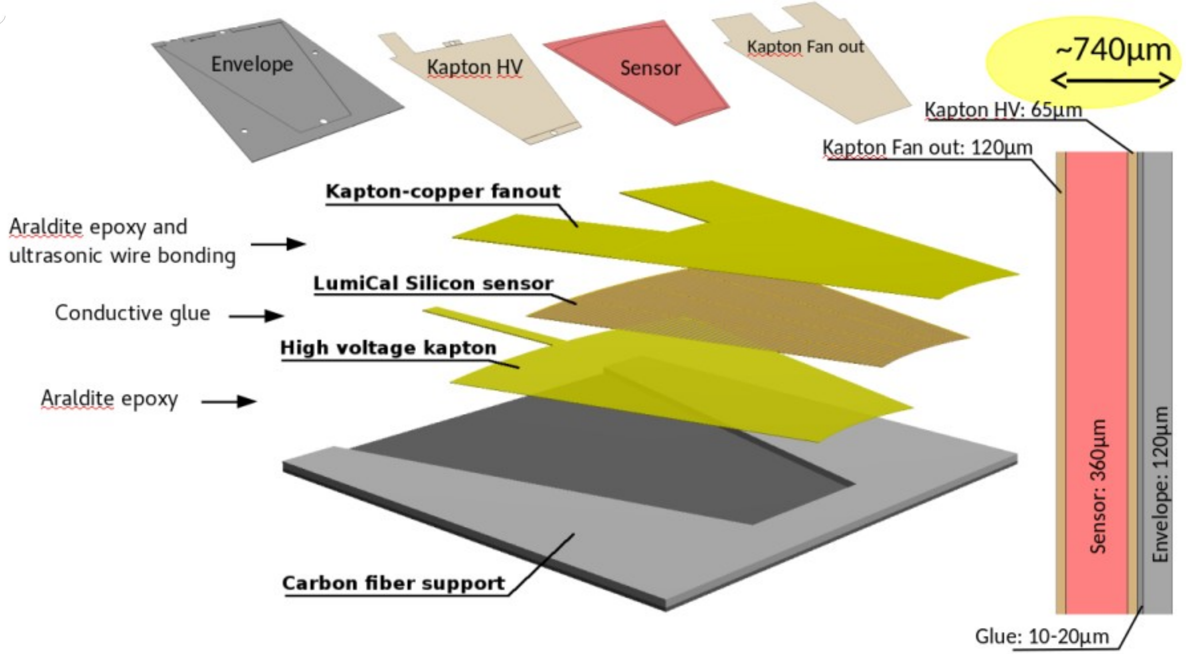


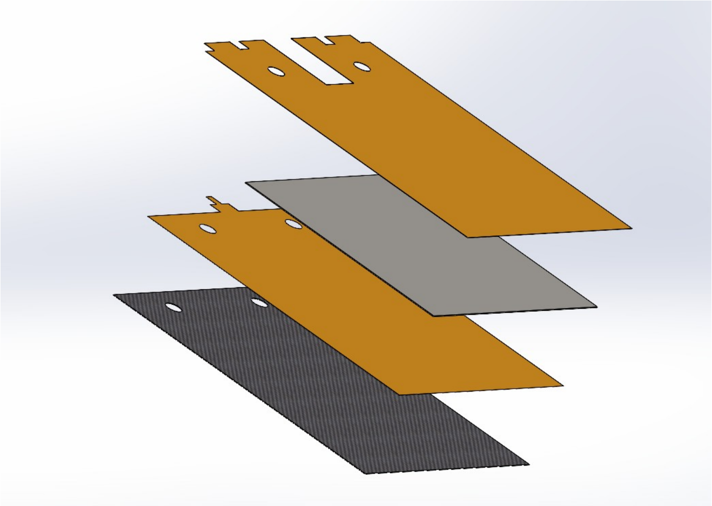
Figure 5.13. Structure of a sensitive layer of the LumiCAL calorimeter.

Forward region (LUMICAL)

- Ultra thin layers <1mm for minimal Moliere Radius
- Not embedded electronics
- Higher radiation levels

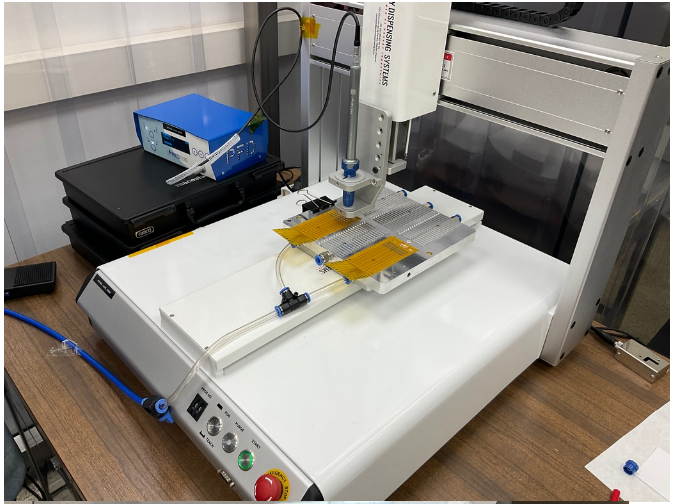
Ultra Compact Calo Hybridization

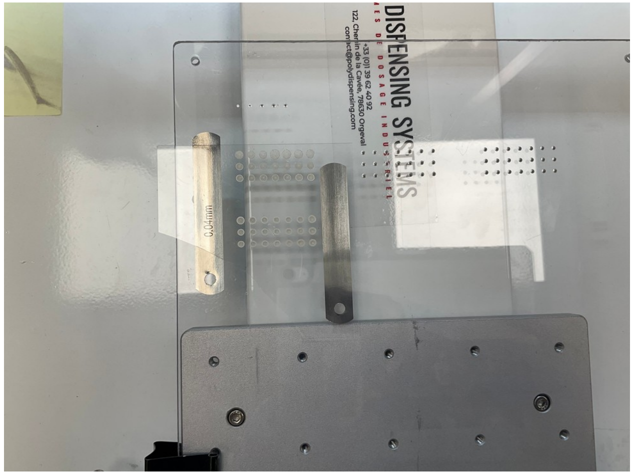
- Large sensors (9x9cm^2) and **flexible PCBs (compact calo)**
- **Material budget, thickness:**
  - **Total bellow 1mm**
  - 200um CF + 320um sensor
  - ~500um for fanout + HV kapton + 3 layers of glue/Adhesive

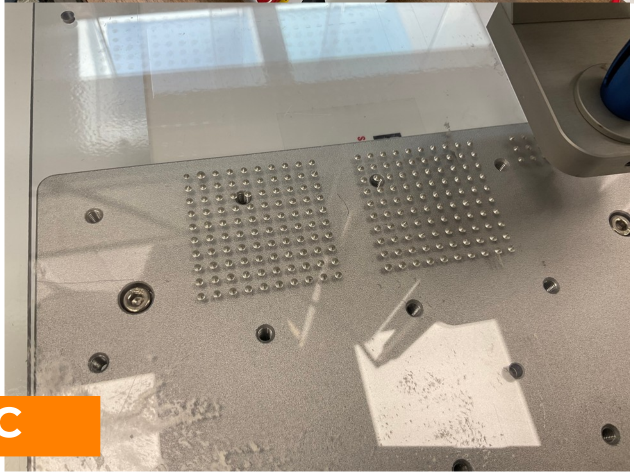


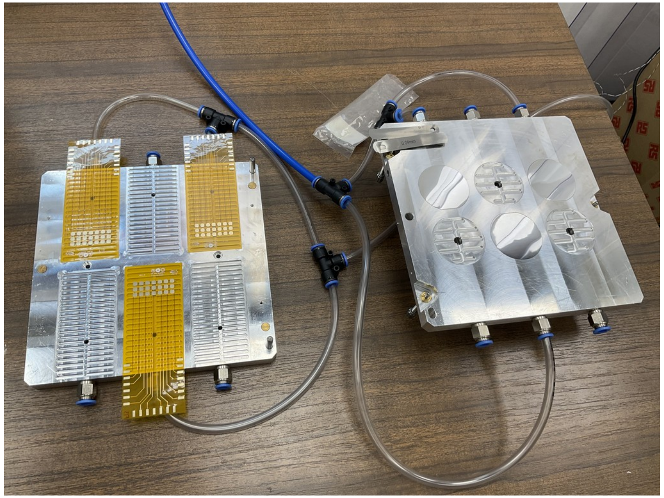
- The main challenge is to obtain a very thin layer of glue, with high repeatability

Ultra Compact Calo Hybridization









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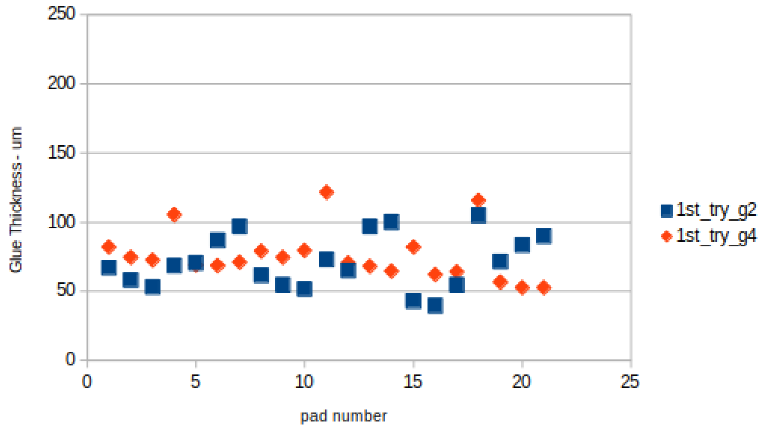
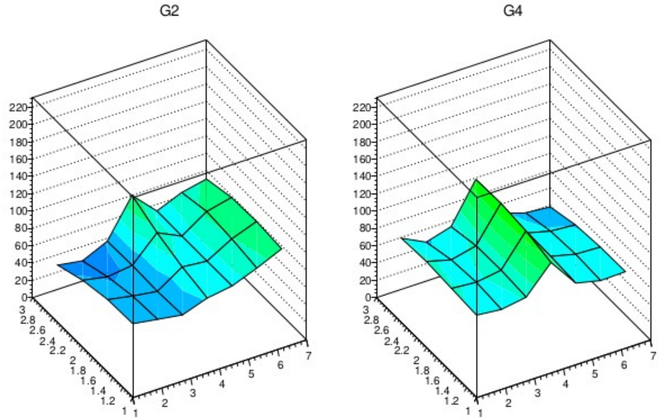
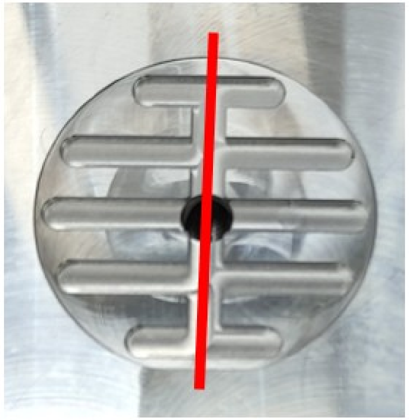
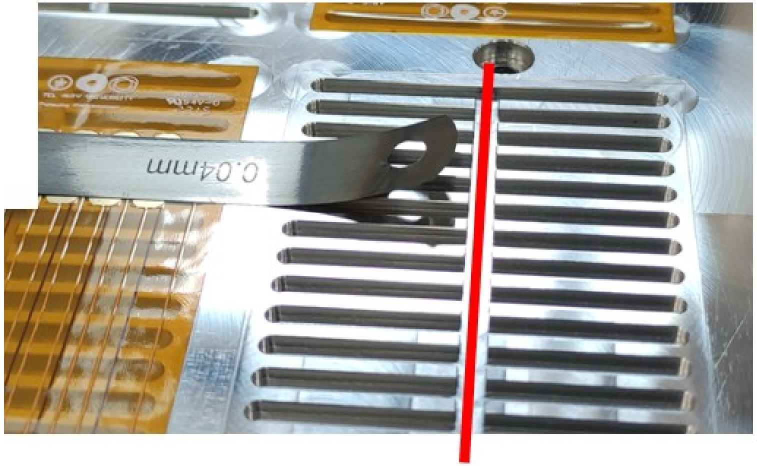
Glue thickness study









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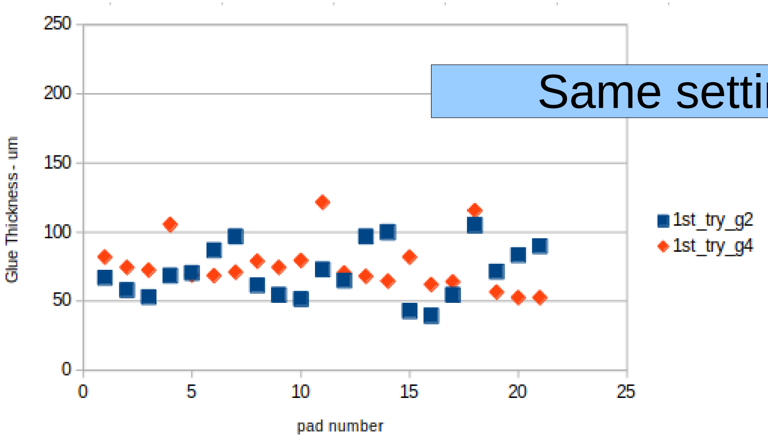

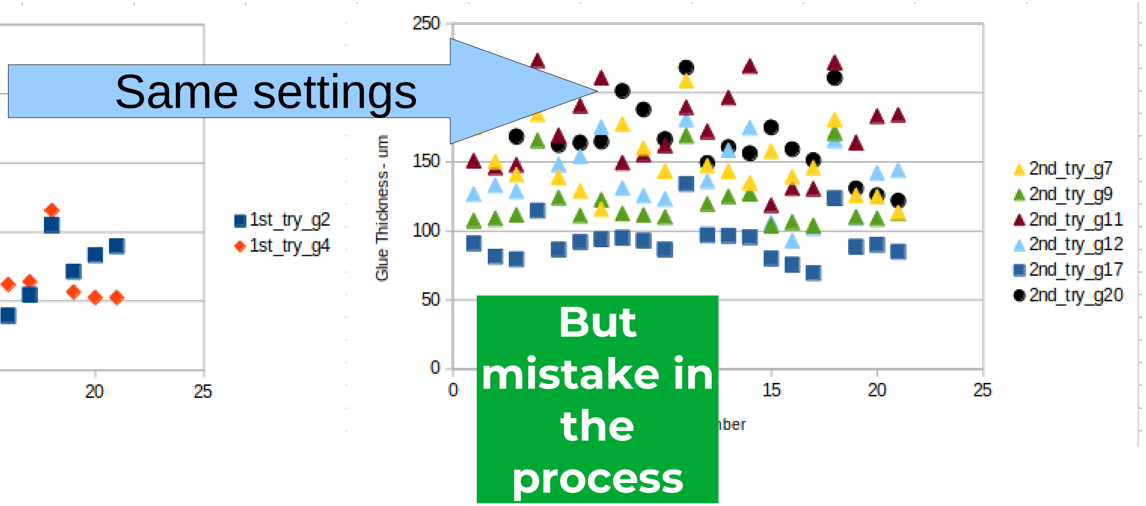

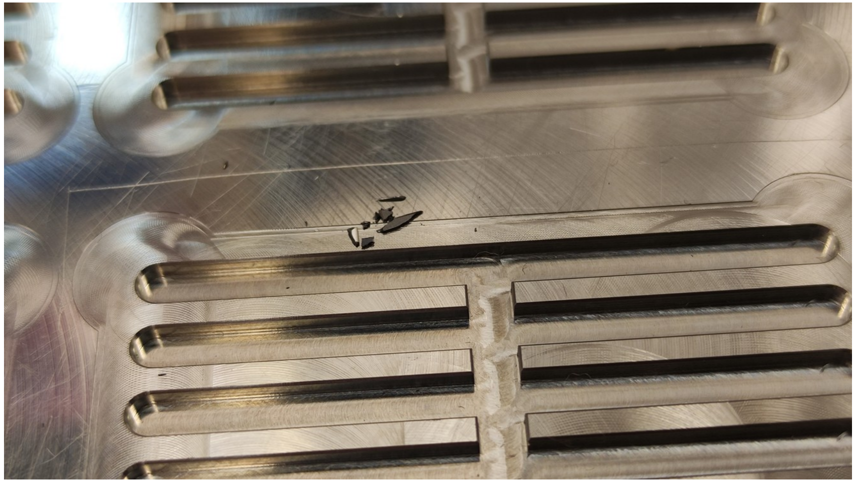

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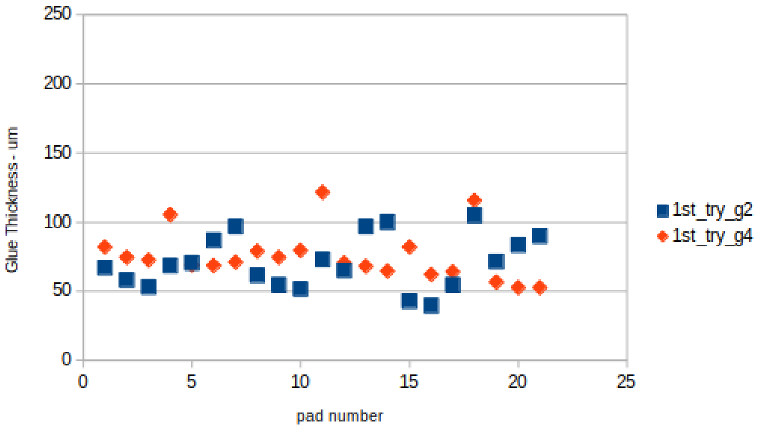
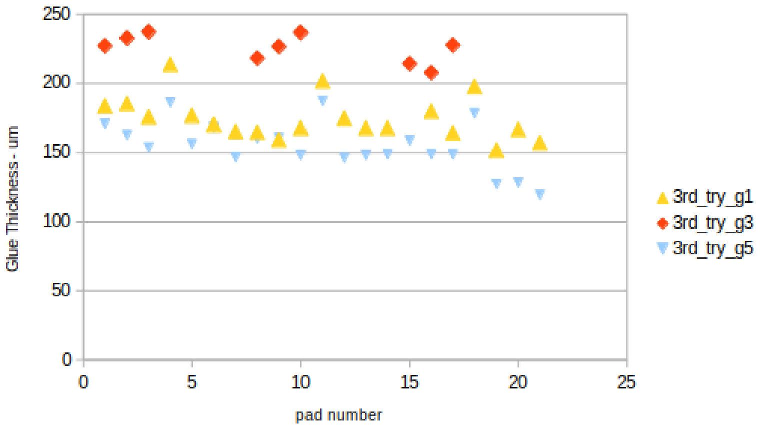
Glue thickness study

Change of dosification needle





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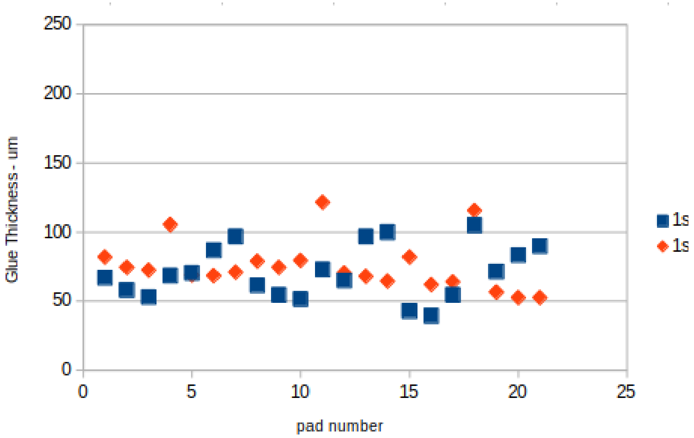

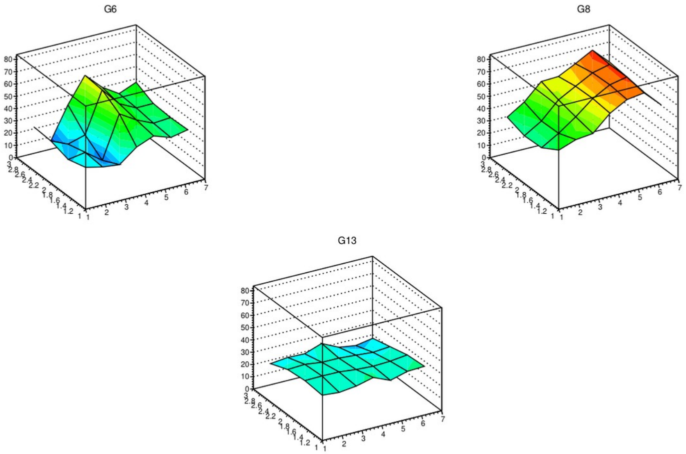

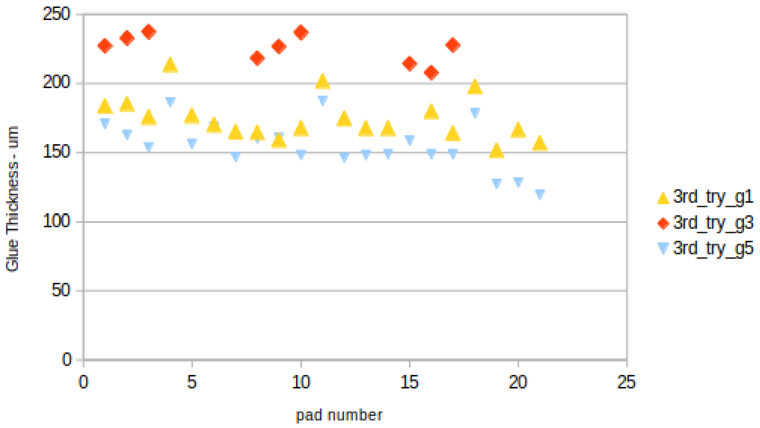

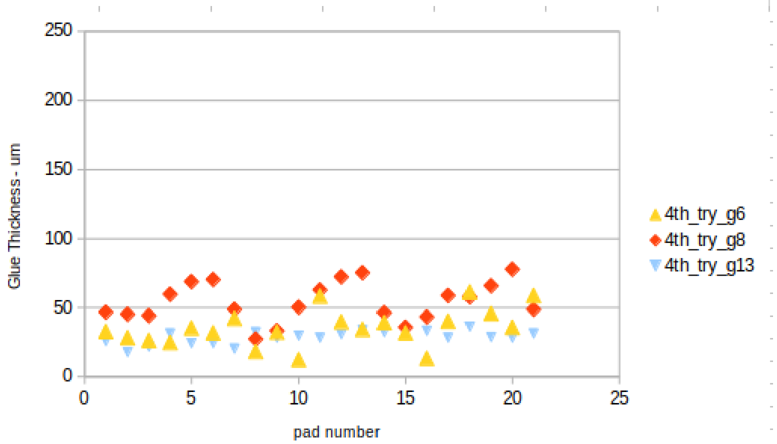

Release of vacuum before curing

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Tooling for precise hybridization

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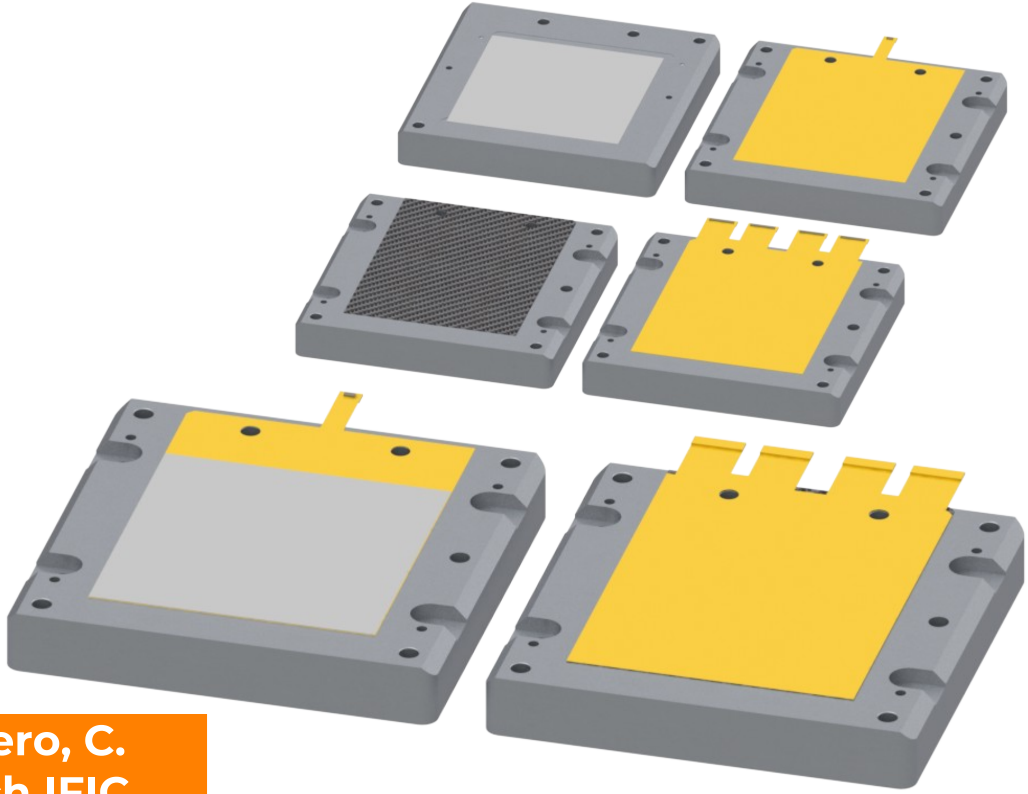
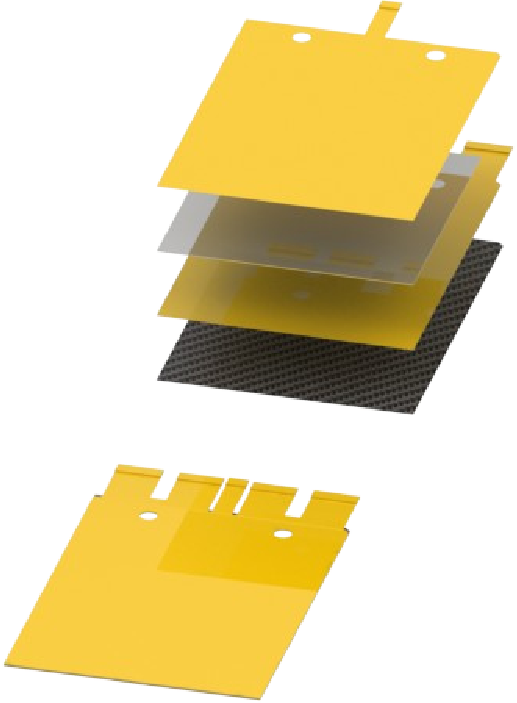
▷ **Work in progress** – design and optimization of the gluing process





C. Orero, C. Blanch IFIC

Summary / next steps

- ▷High granular silicon ECALs with embedded electronics and compact design poses several challenging on the hybridization.
- ▷Comprehensive studies been pursued within detector R&D collaborations (DRD6) but also driven by specific projects: ILD, LUXE

Thanks

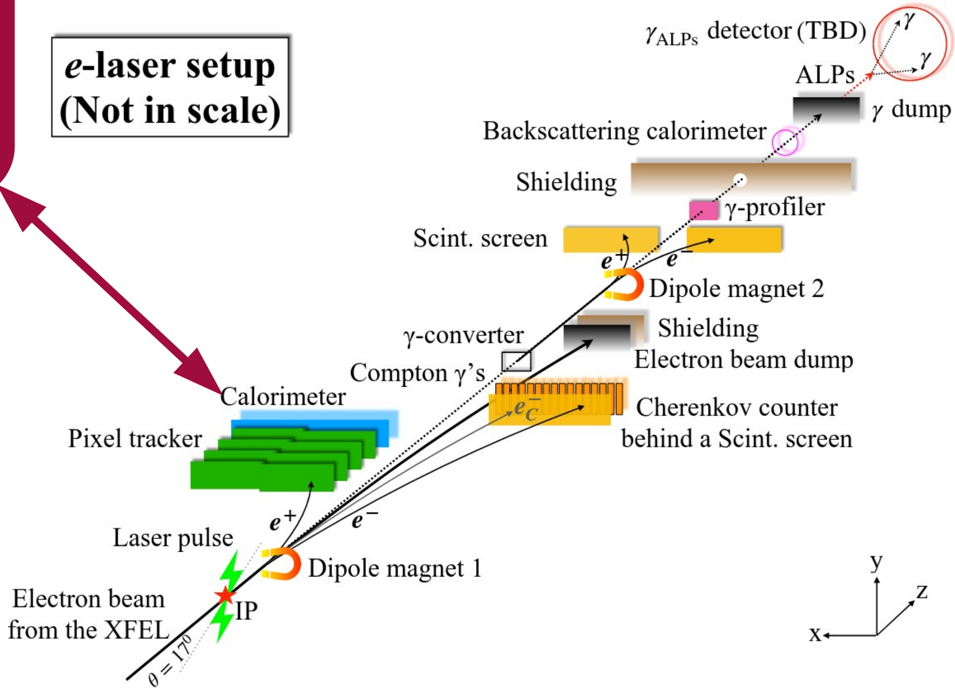
Back-up slides

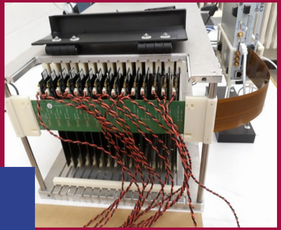
DRD6 - Higgs Factories - LUXE

FCAL-type calorimeter

ILD LUMICAL
(Compact ECAL)

adapted for high rate positron measurement at LUXE





CALICE -type calorimeter

ILD Barrel SiECAL

adapted for BSM direct searches with wigh angular resolution for photon separation

LUXE

Strong-Field QED experiments

Si ECAL hybridization / integration

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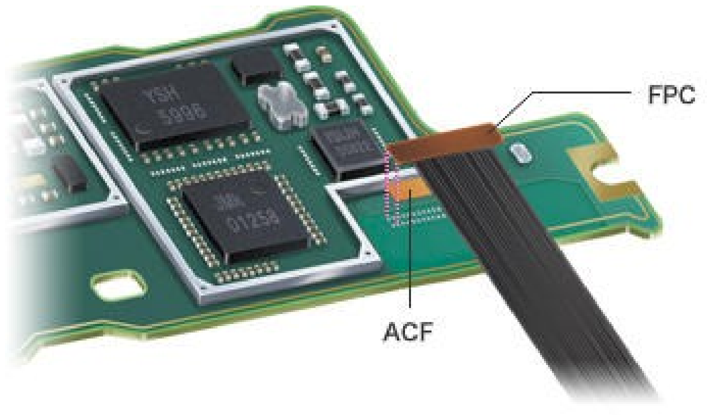
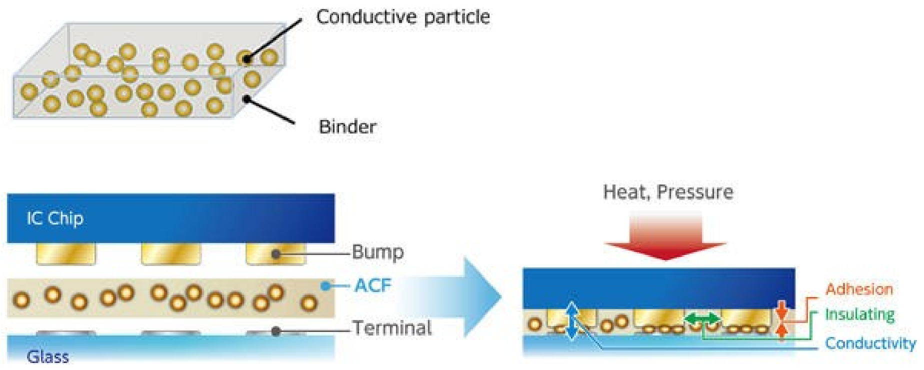
Common R&D Mid-term

▷ R&D Alternative solutions:

- Check what the industry is doing (smartphones, LCD screens, etc)
- → Anysotropic Conductive Films, Micropearls... (investigated also in the context of AIDAInnova & LUXE)
- Affordable for large surface sensors in rigid PCBs ??

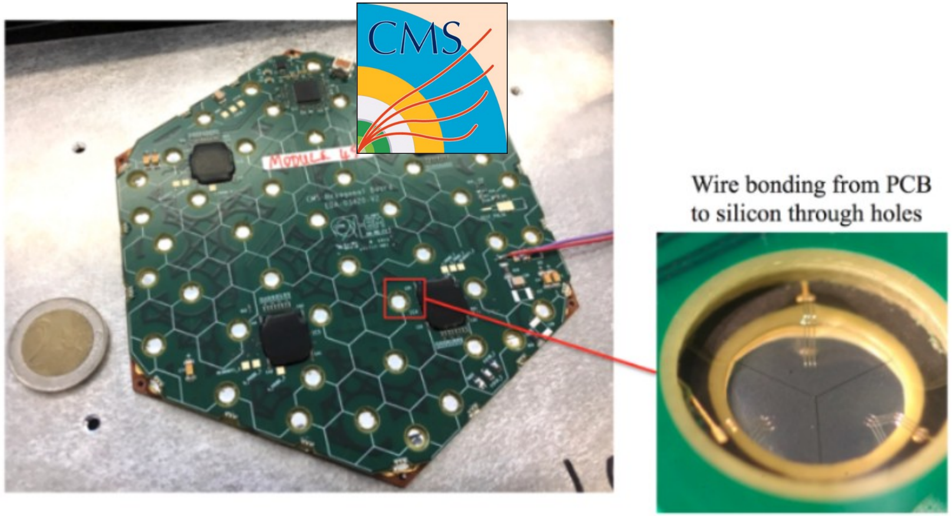




PCBs

▷ Very dense **PCBs:**

- i.e. at SiW-ECAL they are known as featuring 1024 readout channels (with digital, analogue, clock signals) in a 18x18 cm^2 board



CMS HGCAL Hexaboard

Wire bonding from PCB to silicon through holes

SiW-ECAL current prototype solution.

Meets industry requirements → bulky components **compromise compactness**

LUXE

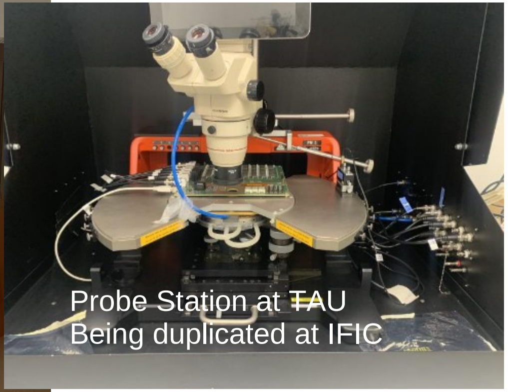
membership of Russian institutes suspended

Queen's University Belfast
Royal Holloway University of London
UCL
University of Plymouth
CNRS IN2P3 – École Polytechnique – LLR
CNRS IN2P3 – Université Paris-Saclay – IJCLab Irène Joliot-Curie
Uni Freiburg
IFIC Institut de Física Corpuscular
INFN – Alma Mater Studiorum Università di Bologna
INFN – Università degli Studi di Padova
Universitas Gothoburgensis 1891
mpsd Max-Planck-Institut für Struktur und Dynamik der Materie
DESY.
Helmholtz Helmholtz-Institut Jena
Friedrich-Schiller-Universität Jena
Universitas Varsoviensis
AGH University of Science and Technology
KIT
ISS
Technion Israel Institute of Technology
Tel Aviv University
מכון ויצמן למדע
Weizmann Institute of Science

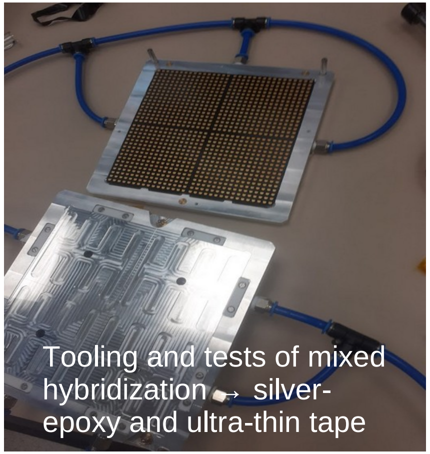
IFIC-Lab for ECAL hybridization

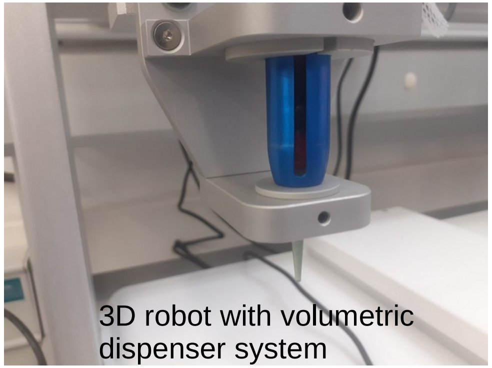
- ▷ **New facility and capabilities at IFIC**
- ▷ **Funding: CIDEGENT/ASFAE/CNS** → In line with ECFA – R&D roadmap, DRD6, Future Colliders
- ▷ **IFIC will become** the hub for module hybridization R&D / production / commissioning for DRD6 Si-ECALs and for the LUXE experiment

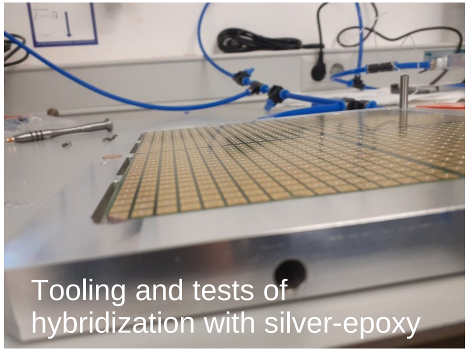

New installation at IFIC
(to be finished in ~~March/Abril~~ May/June 2024)


Probe Station at ~~TAU~~
Being duplicated at IFIC


Dry cabinet, curing oven


Tooling and tests of mixed hybridization → silver-epoxy and ultra-thin tape


3D robot with volumetric dispenser system


Tooling and tests of hybridization with silver-epoxy