tests on sensor-electronics hybridization for compact silicon tungsten electromagnetic calorimeters

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

AITANA group at IFIC – CSIC/UV

Financiado por la Unión Europea NextGenerationEU

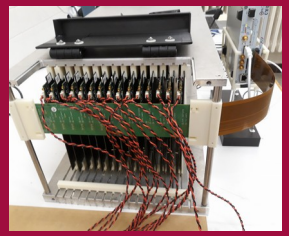
Plan de Recuperación, Transformación y Resiliencia

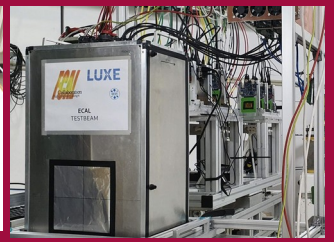
GENERALITAT VALENCIANA

GVANEXT Fondos Next Generation en la Comunitat Valenciana

Gen—T

Introduction





CALICE -type calorimeter

FCAL-type calorimeter

DRD6

ILD LUXE

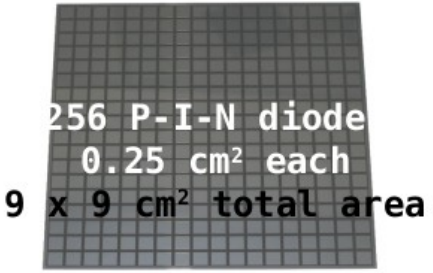
Common R&D: module hybridization.
Assembly lab being set-up at IFIC

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

ECALe (aka SiWECAL)

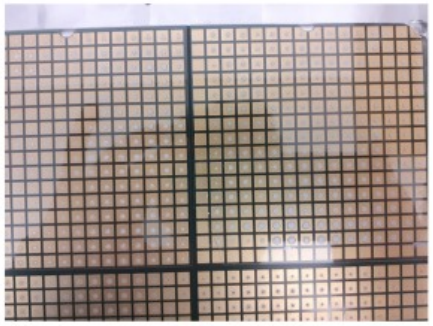
SiW ECAL: the basics

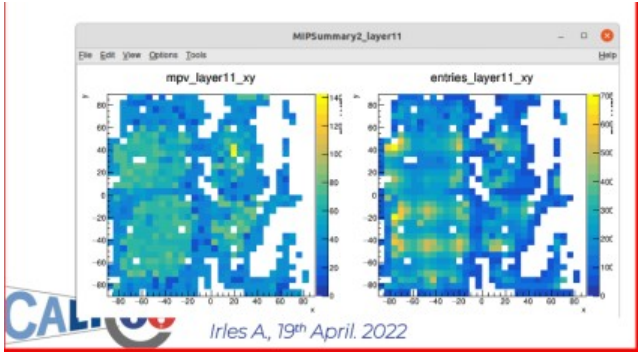
- Very dense PCBs
- 4 silicon sensors
  - PiN Diodes of 90x90mm²
  - 55x55mm² cells
- No space for wirebonding
- Glue with conductive epoxy+silver mixes
  - Low temperature curing (40-80 degrees)
- **Delamination observed** in several modules → partial (or almost total) **wafer-pcb separation** with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



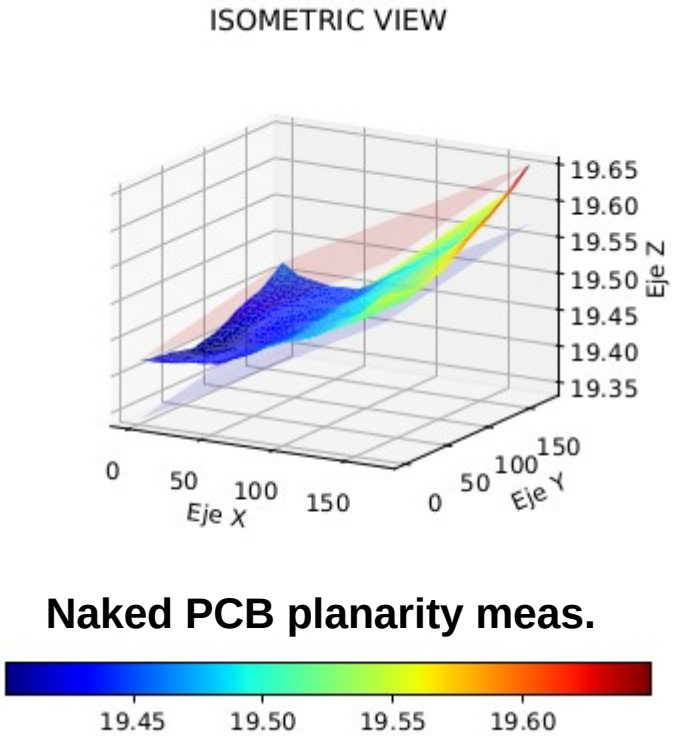
EUDET layout

Prototype from Hamamatsu

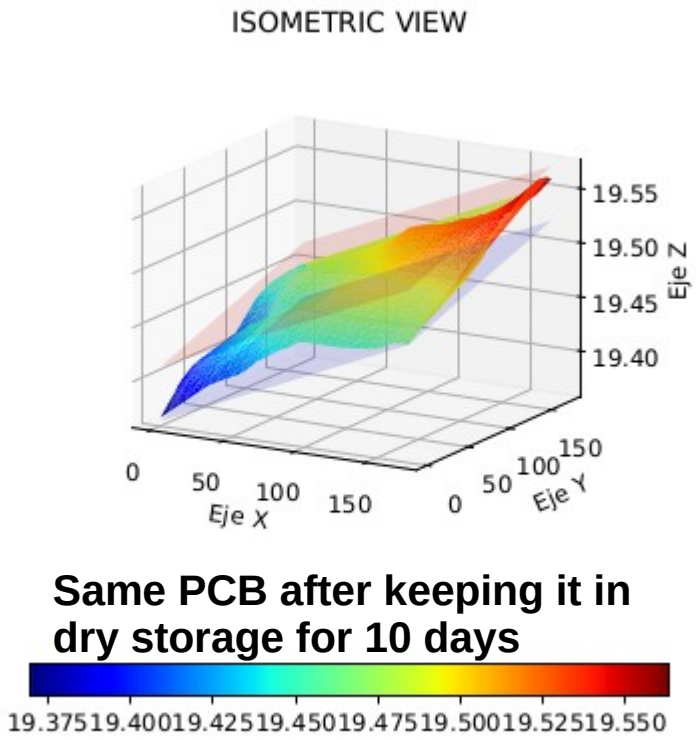




SiW ECAL: PCB planarity



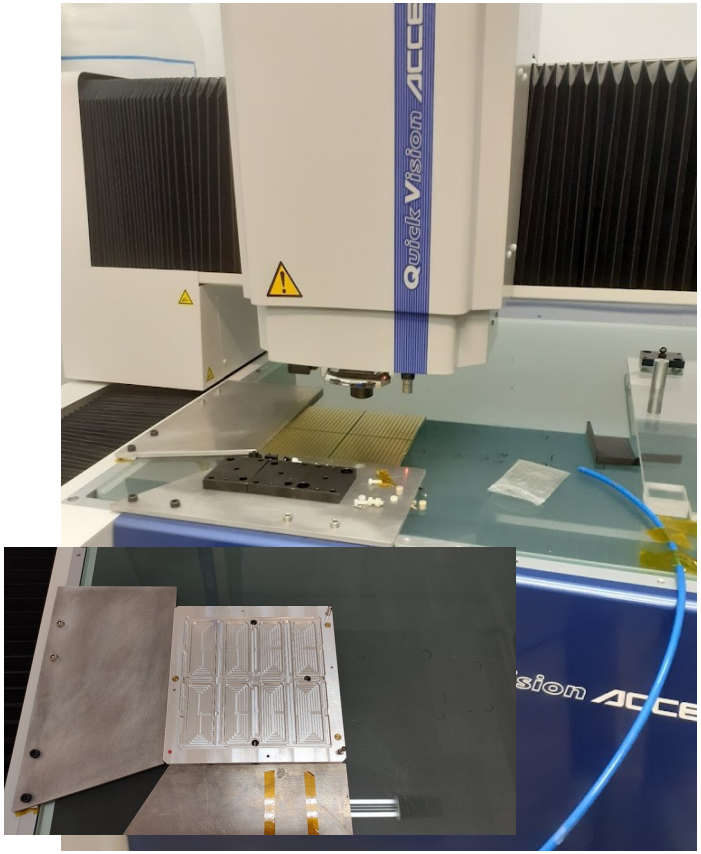
Naked PCB planarity meas.



Same PCB after keeping it in dry storage for 10 days

Measurements by C. Orero, IFIC

SiW ECAL: PCB planarity



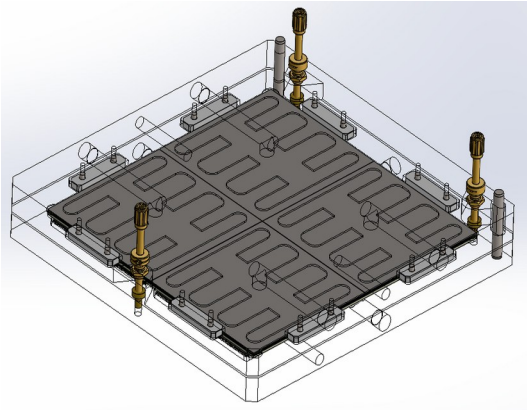
Mitutyo Quick Vision Accel, Modelo 808

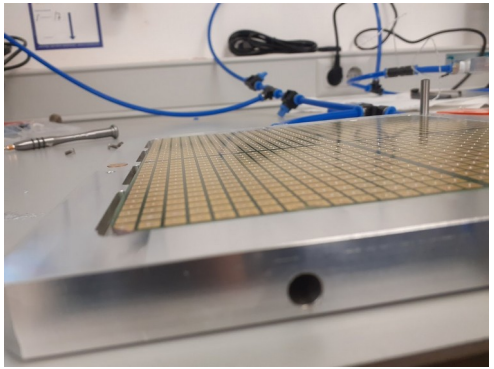
Measurements by C. Orero

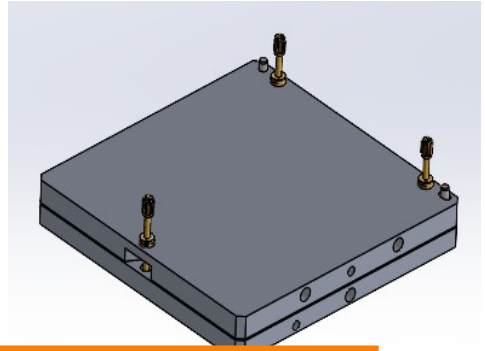
- Planarity measurements being doing consistently and under different storage conditions
- Naked board PCB planarity : varies between 80-160um depending on the board
- Similar planarity for boards equipped with components (less statistics)
- Planarity depends on storage conditions. Systematic improvement observed when the PCBs are dried and kept in dry conditions
  - Global planarity improves in ~60% (50-80um)

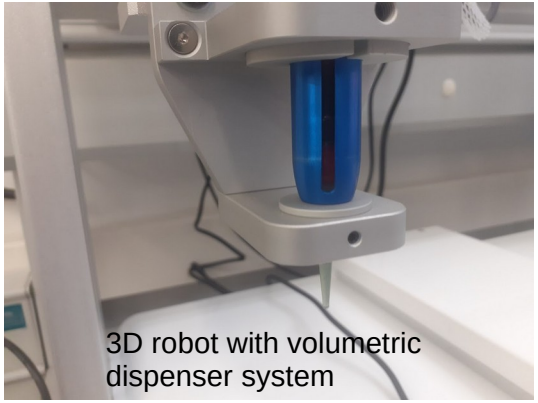
SiW ECAL hybridization / integration

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

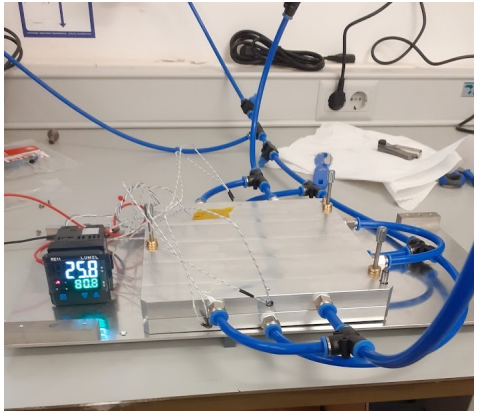








3D robot with volumetric dispenser system

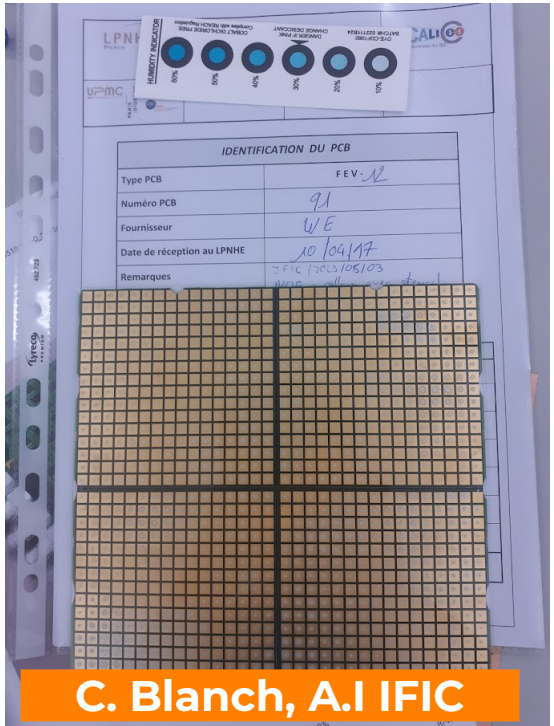


C. Blanch, A.I IFIC

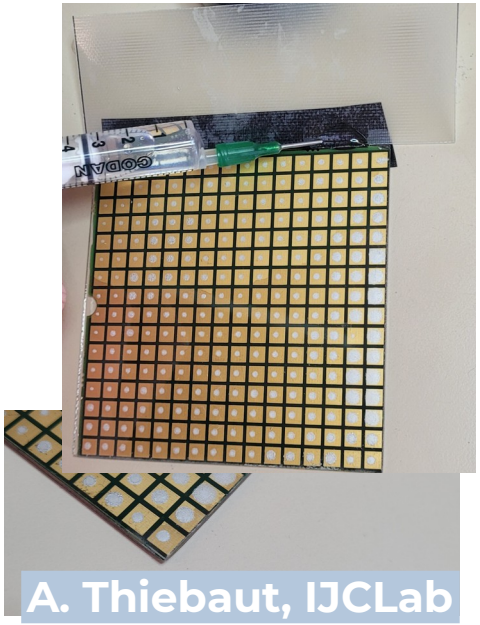
SiW ECAL: double adhesive solution for hybridization

IFIC INSTITUT DE FÍSICA CORPUSCULAR

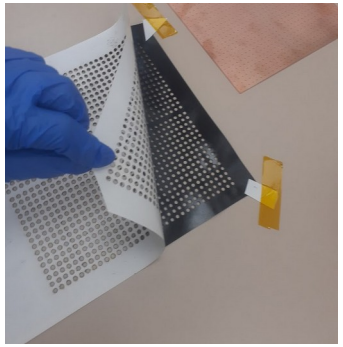
- Keeping control on the deformation of PCB
  - Wip: study of the stress forces invovled (IJCLab)
- Two solutions being explored, both still with epoxy-silver glue dots for the electrical conductivity
  - Undefill glue (EPO-TEK 301-2FL) → involves second curing.
  - Double tape (3M 5907-F) used as stencil/mask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

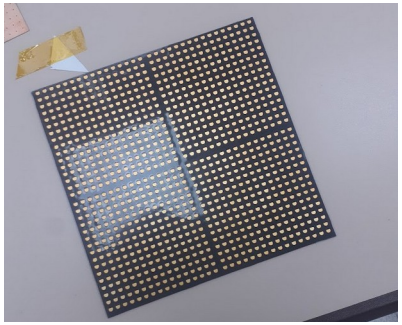


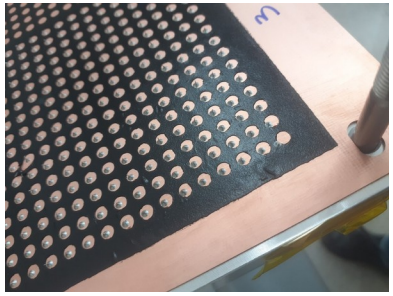
C. Blanch, A.I IFIC

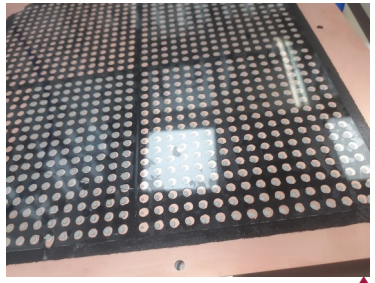


A. Thiebaut, IJCLab



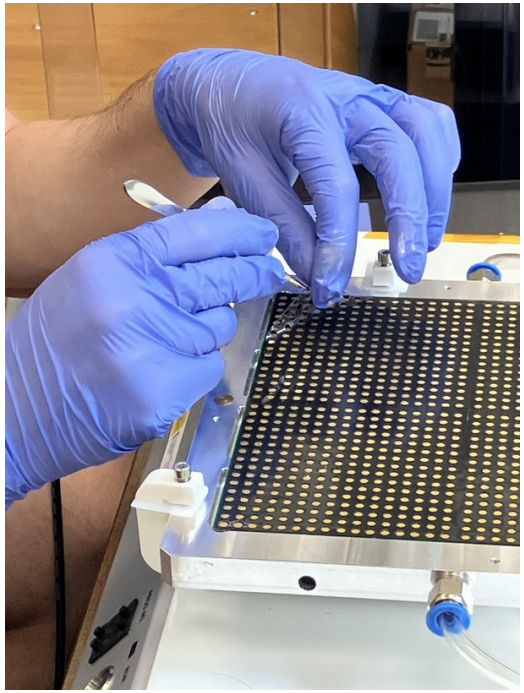


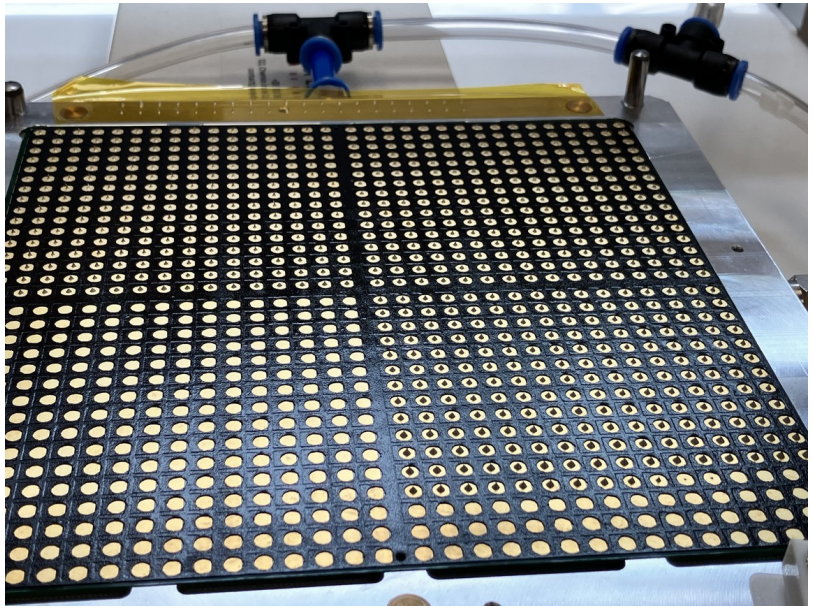




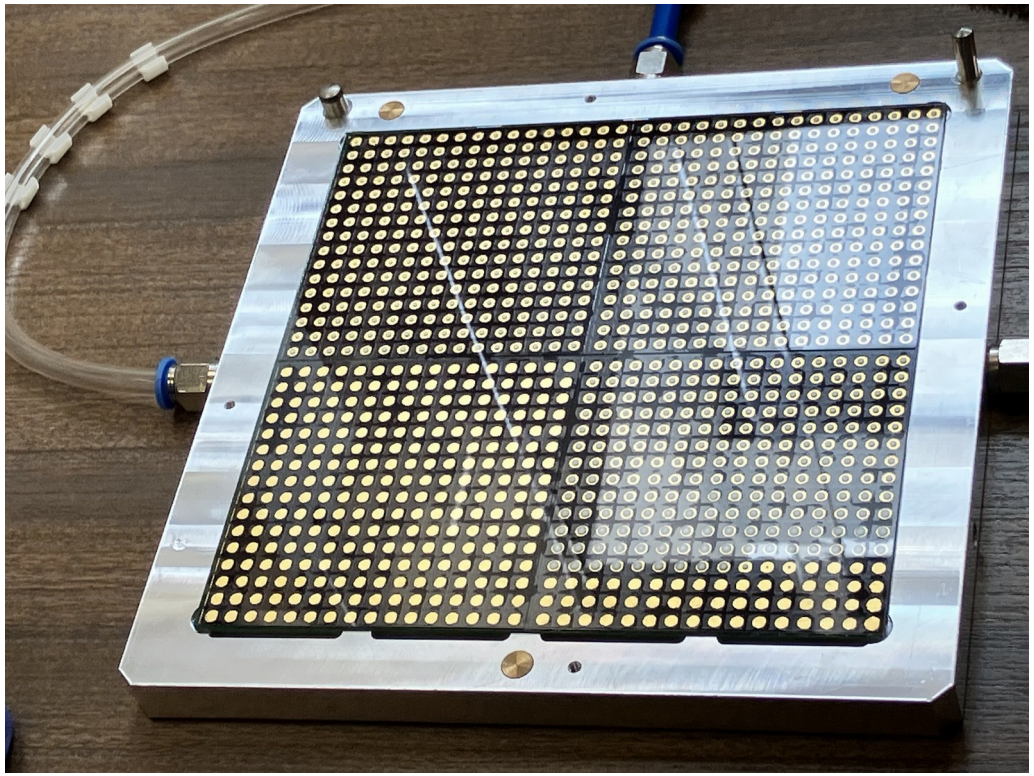
C. Blanch, A.I IFIC

Tests with real PCBs (no ASICs)





Tests with real PCBs (no ASICs)



- Satisfactory results, already discussed with SiW-ECAL team.

- We are ready to glue 2 real PCBs with 8 Silicon sensors (500um) for a testbeam in 2025 (begining of the year?)
  - Goal for gluing: February
  - As soon as we receive characterized sensors and fully equipped and tested PCBs.

ECALp

Requirements: highly compact

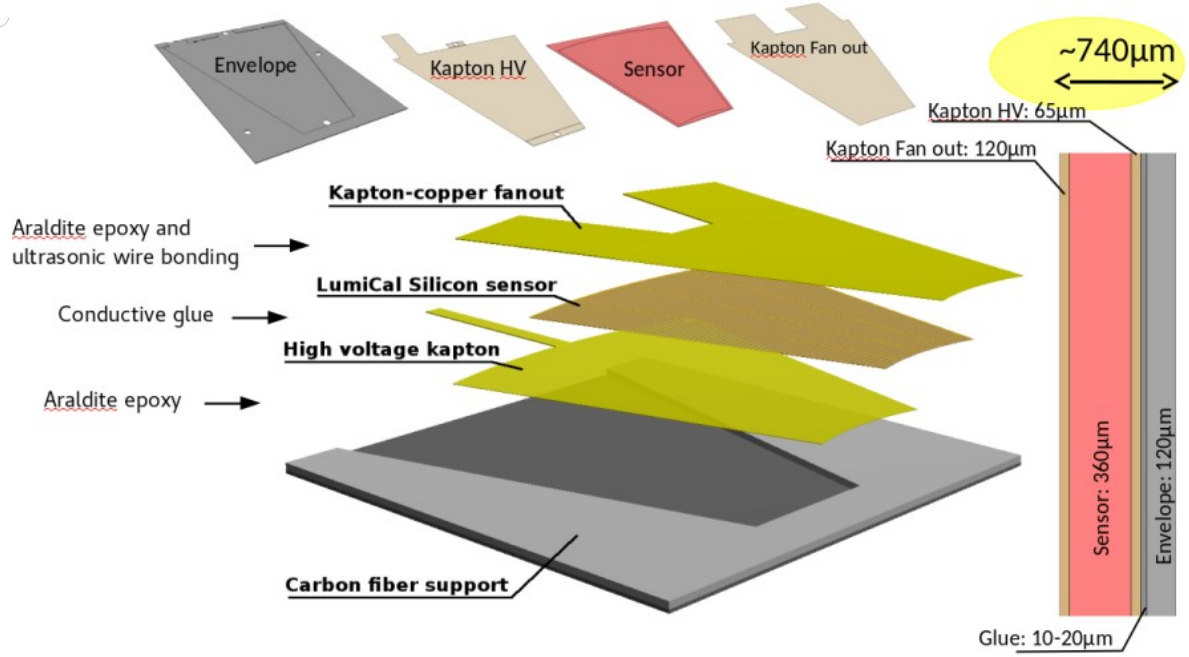


Figure 5.13. Structure of a sensitive layer of the LumiCAL calorimeter.

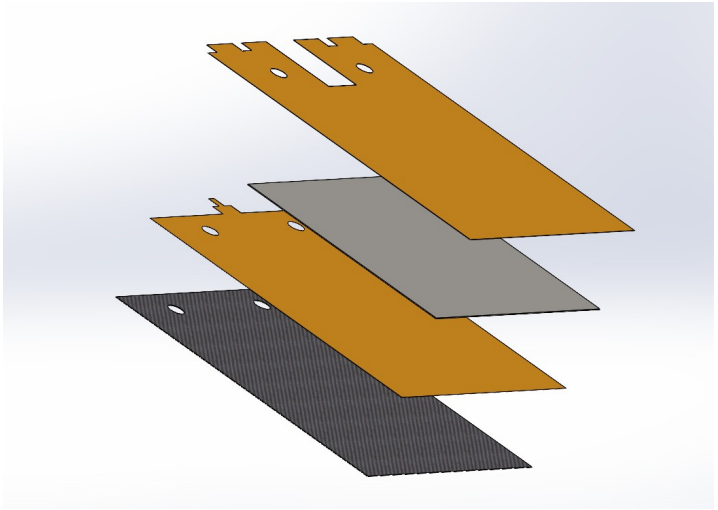
Forward region (LUMICAL)

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

Ultra Compact Calo Hybridization

IFIC INSTITUT DE FÍSICA CORPUSCULAR

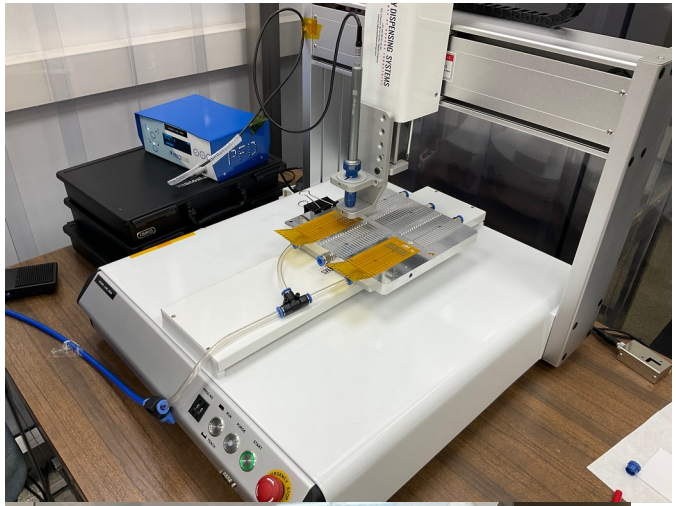
- Large sensors (9x9cm²) and **flexible PCBs (compact calo)**
- **Material budget, thickness:**
  - **Total bellow 1mm**
  - ~200um CF + 320um sensor
  - ~500um for fanout + HV kapton + 3 layers of glue/Adhesive

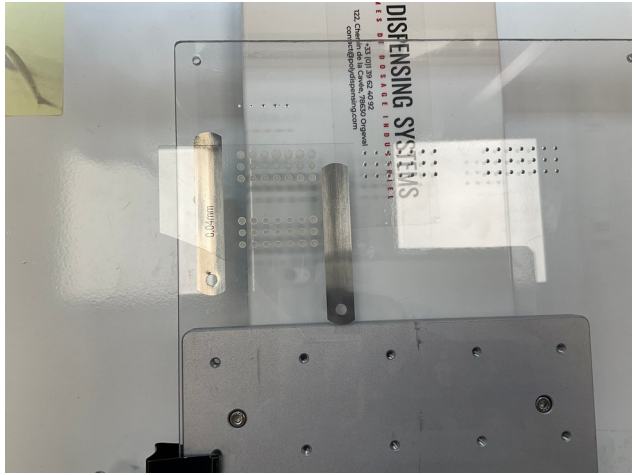


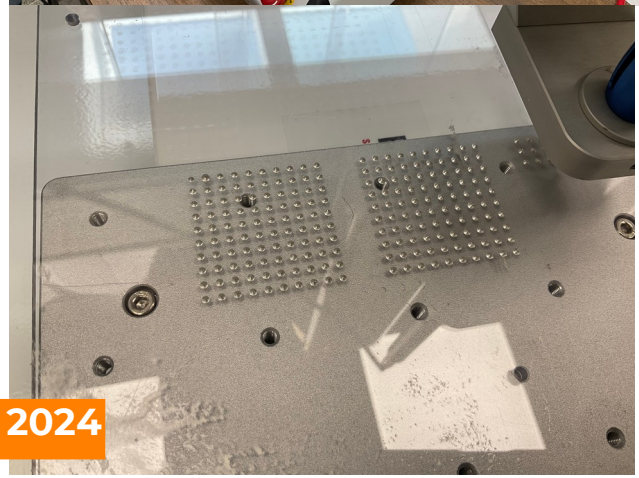
- The main challenge is to obtain a very thin layer of glue, with high repeatability

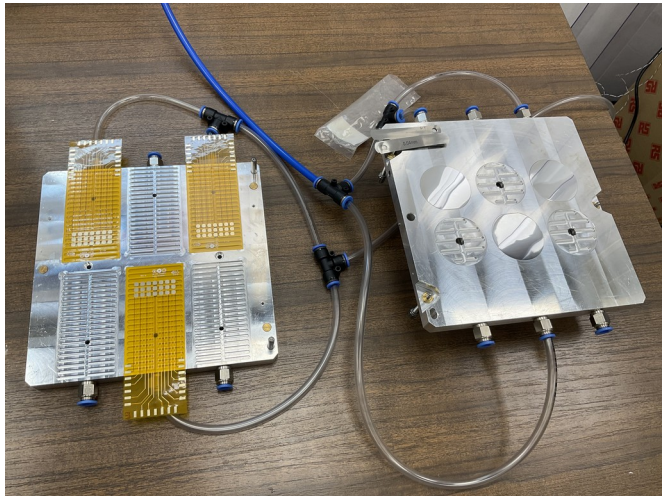
- **DISCUSSED IN CARLOS' TALK**

Ultra Compact Calo Hybridization



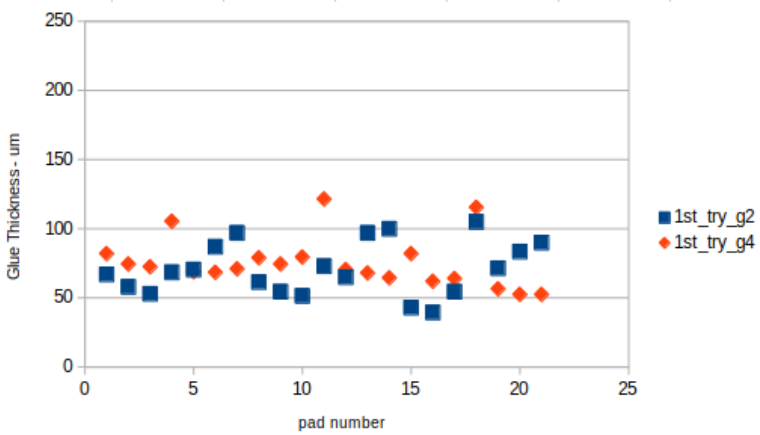


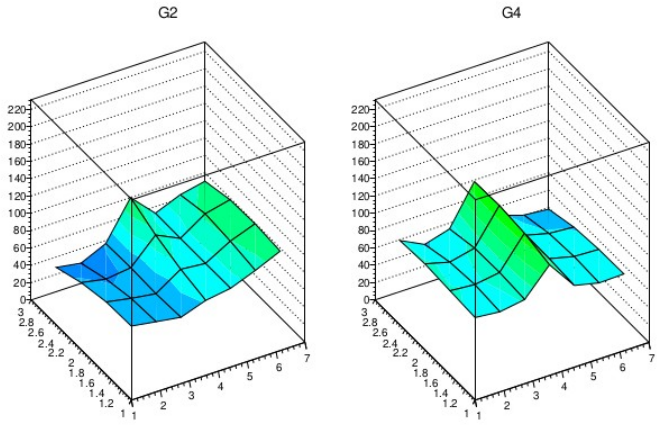


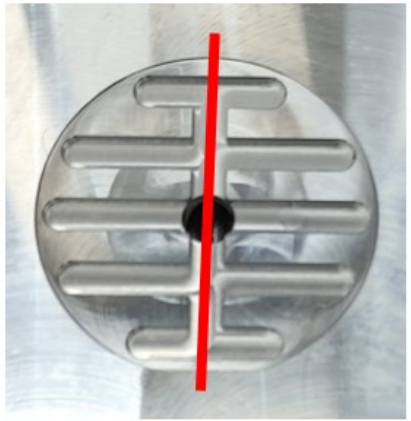


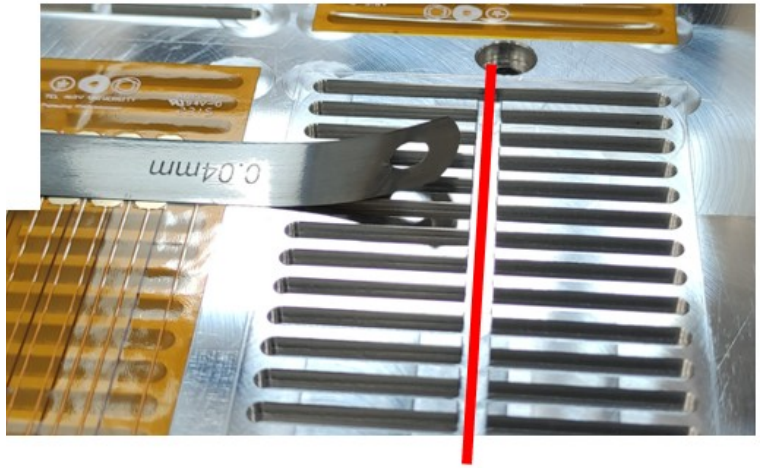
Spring 2024

Glue thickness study



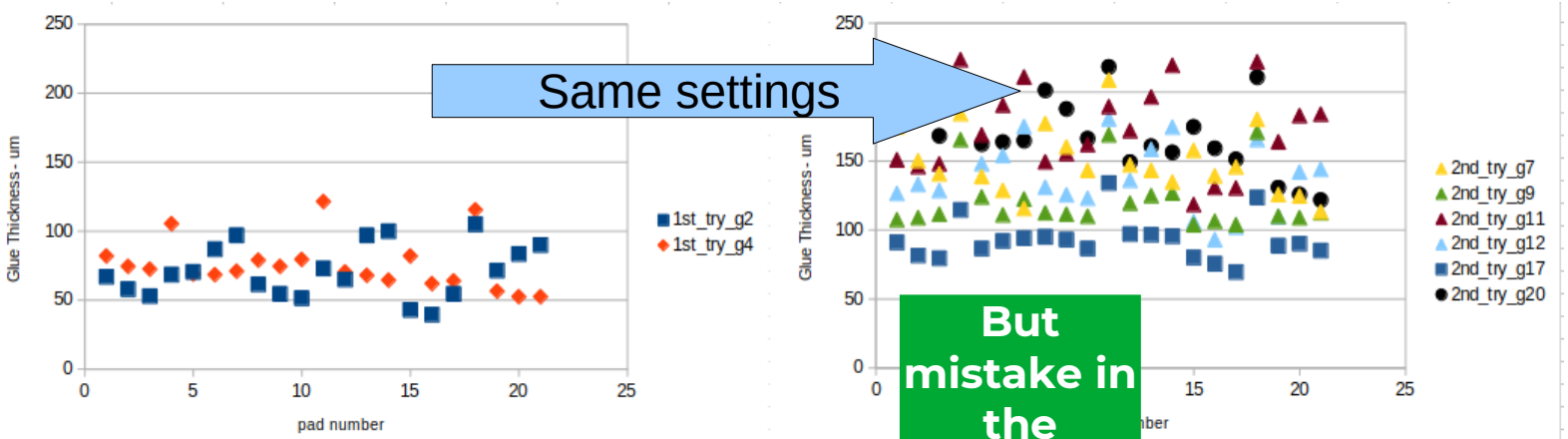


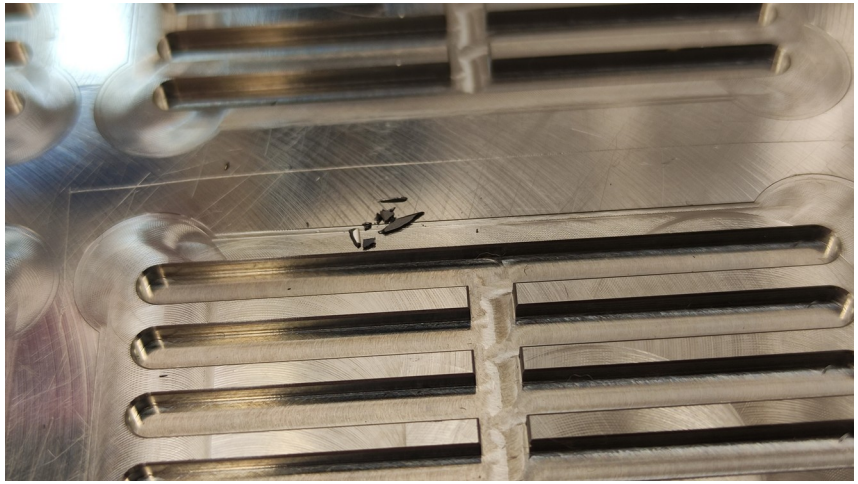




Spring 2024

Glue thickness study

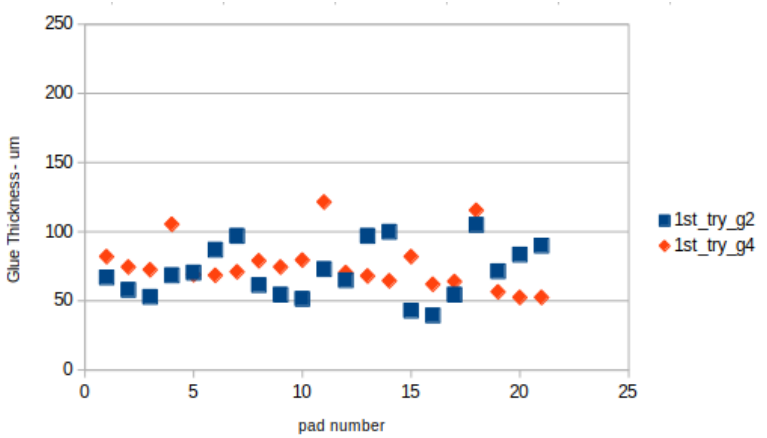


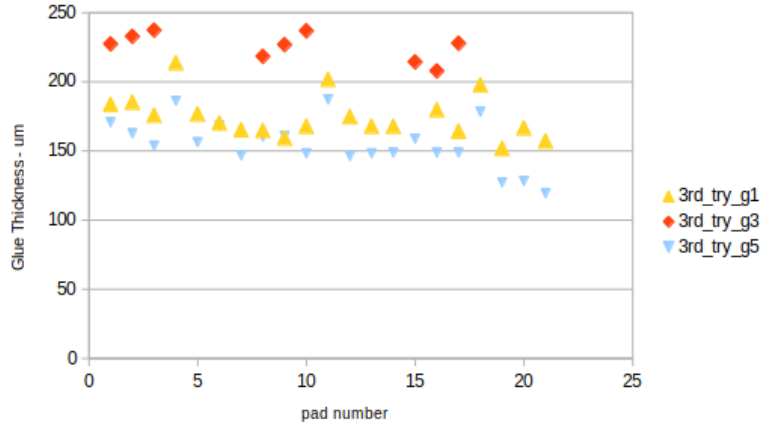


Spring 2024

Glue thickness study

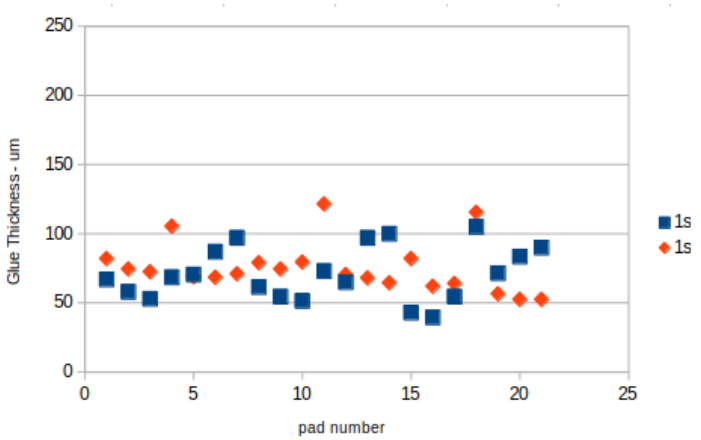
Change of dosification needle

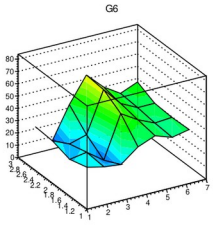


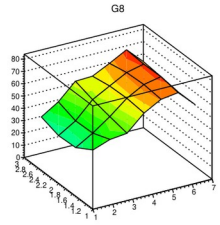


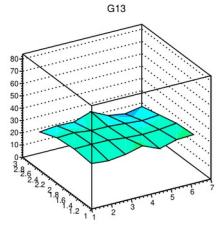
Spring 2024

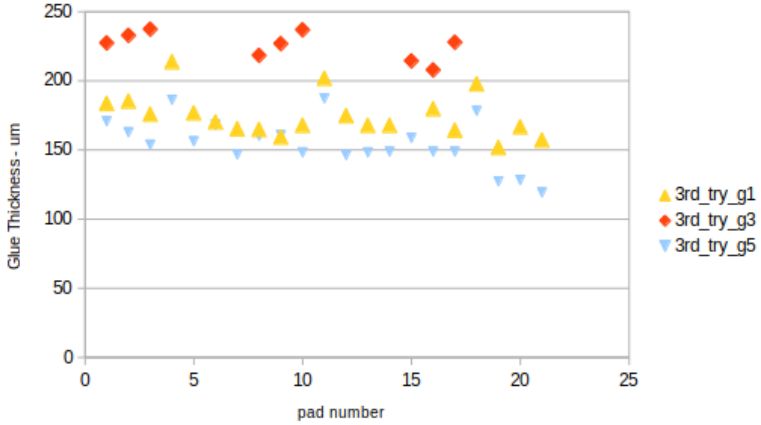
Glue thickness study

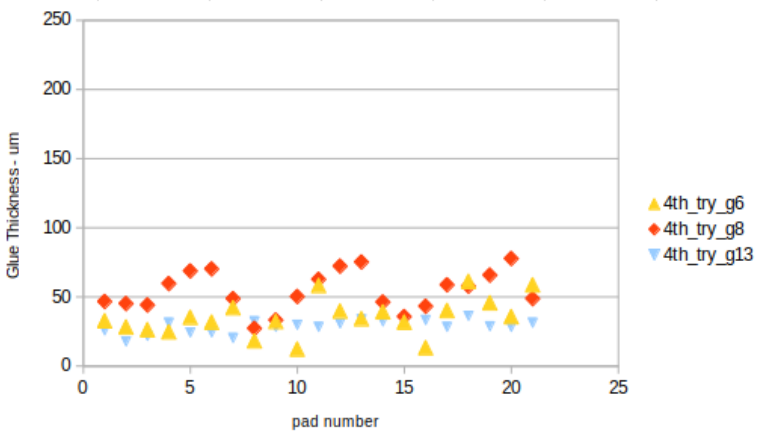








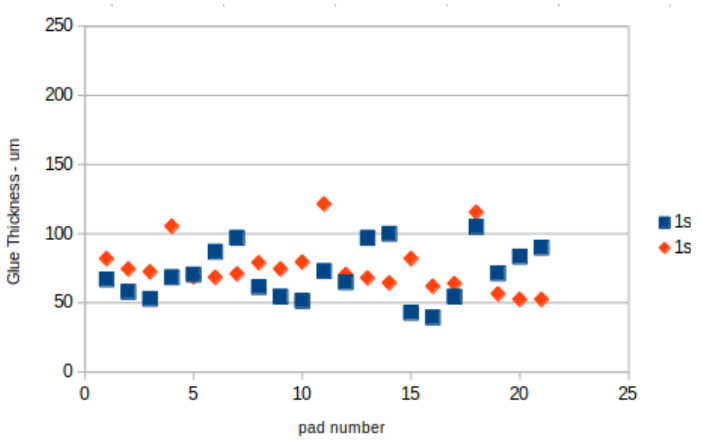


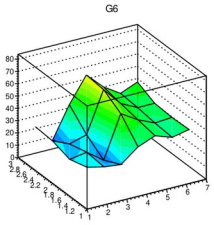


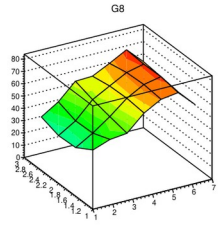
Release of vacuum before curing

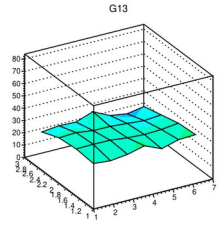
Spring 2024

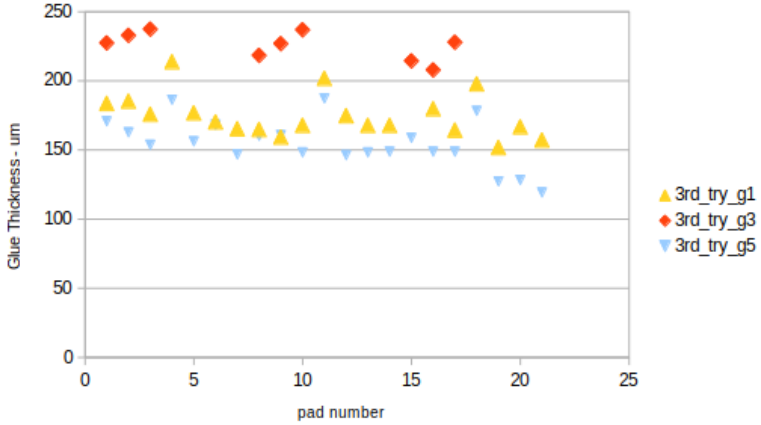
Glue thickness study

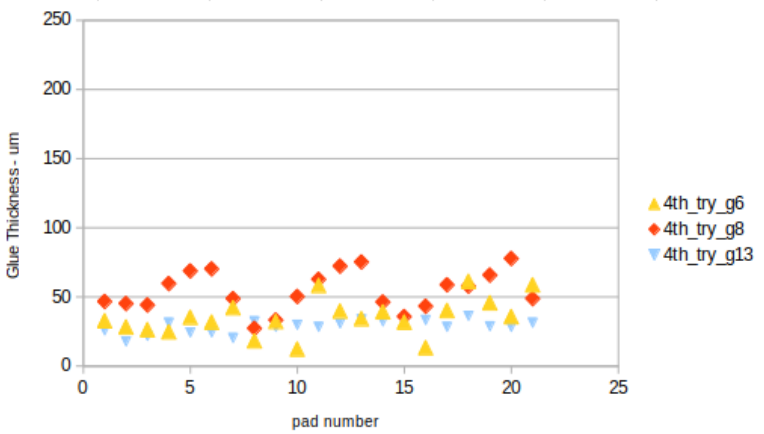


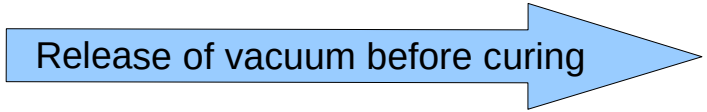










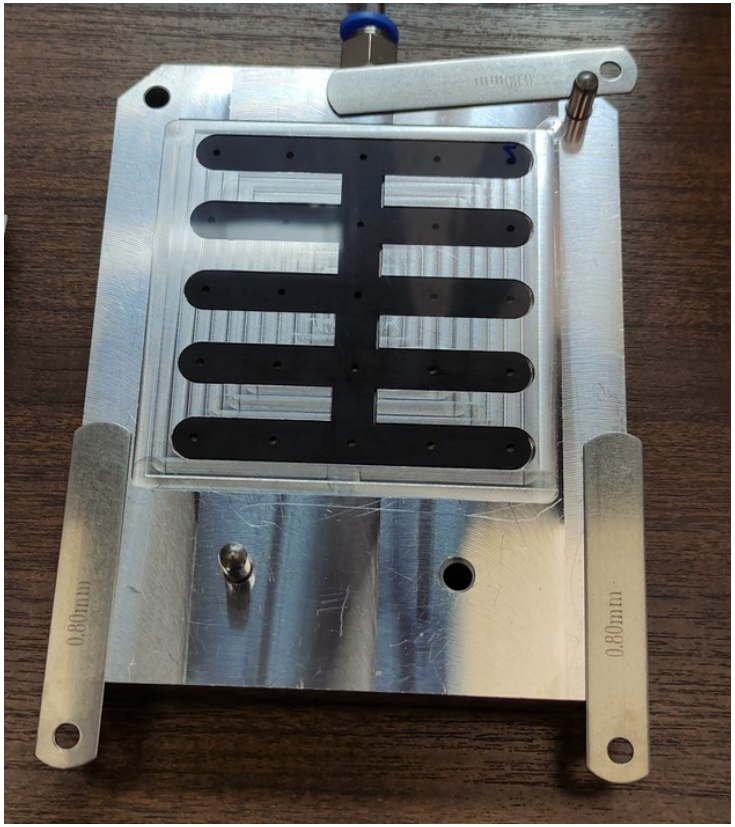


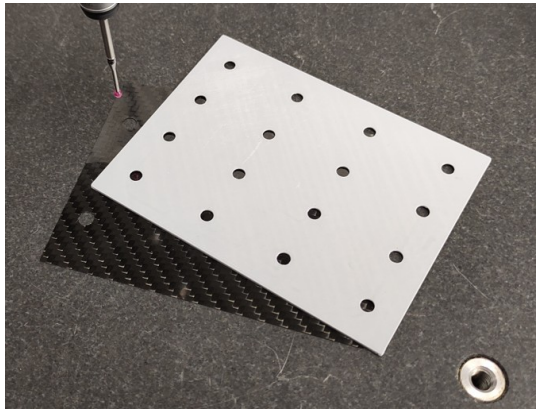
Spring 2024

Glue thickness study

IFIC INSTITUT DE FÍSICA CORPUSCULAR

- Tests with carbon fiber (CF) and glass wafers (G)
  - CF + glue (H20E) + G
- **PROCEDURE**
  - Measure raw thicknesses of CF and G separately
  - The “step” inside the jig was also measred (average deep of 144um)
  - Playing with the total thickness of CF, G and the jig, we define the goal of the glue thickness using feeler gauges

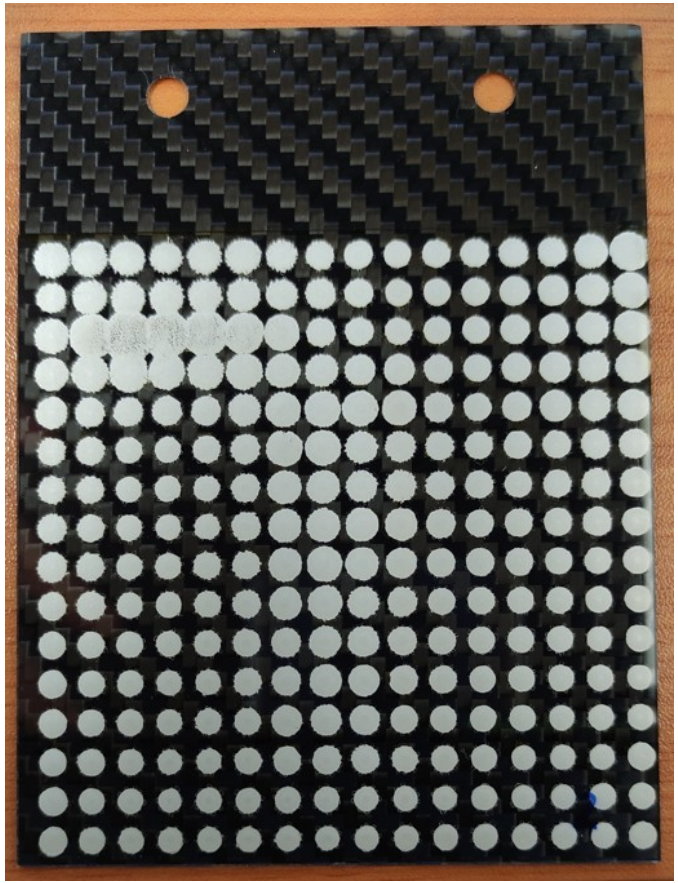




Glue thickness study

IFIC INSTITUT DE FÍSICA CORPUSCULAR

- Tests with carbon fiber (CF) and glass wafers (G)
  - CF + glue (H20E) + G
- **CF3+G2**
  - 197+715um (912um)
  - Feeler gauge of 800um (+144 of the step) = 944um
  - Glue layer thickness (goal) = **32um**
  - **Measured = 46um**



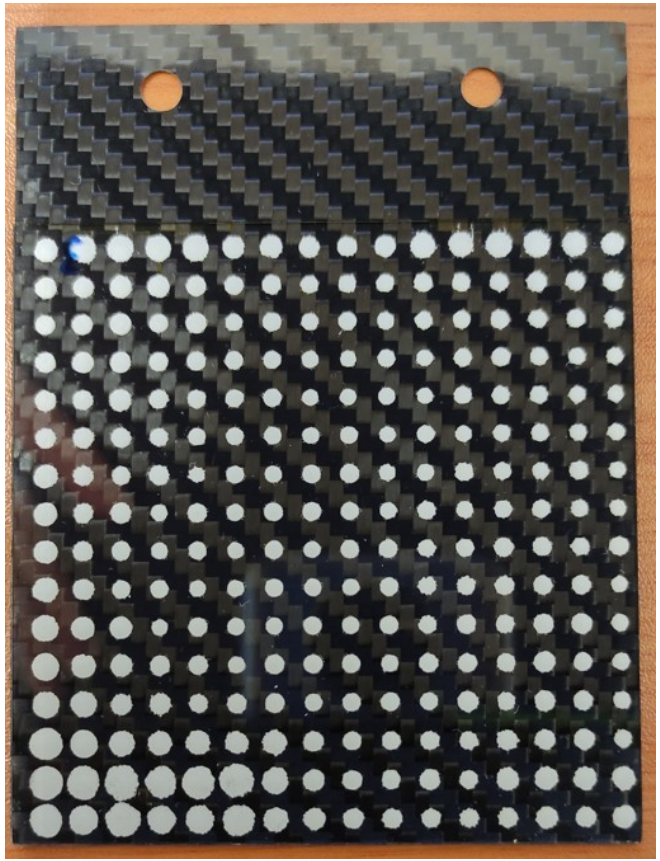
- Observations:
  - Untuned glue deposition settings (we used one from the spring tests).
  - Glue after ~24h of pre-curing at room temperature (we found that this is best for the good viscosity and consistency of the glue)

September 2024

Glue thickness study

IFIC
INSTITUT DE FÍSICA CORPUSCULAR

- Tests with carbon fiber (CF) and glass wafers (G)
  - CF + glue (H20E) + G
- **CF5+G3**
  - 194+719um (913um)
  - Feeler gauge of 800um (+144 of the step) = 944um
  - Glue layer thickness (goal) = **31um**
  - **Measured = 42um**



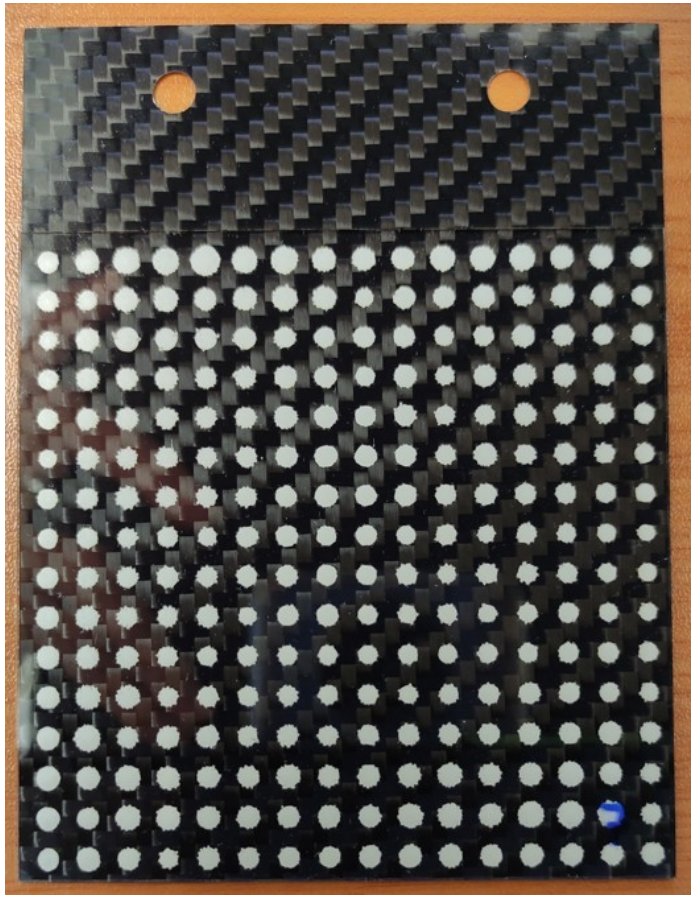
- Observations:
  - Optimized glue deposition settigns.
  - Test done same day than the previous.

September 2024

Glue thickness study

IFIC INSTITUT DE FÍSICA CORPUSCULAR

- Tests with carbon fiber (CF) and glass wafers (G)
  - CF + glue (H20E) + G
- **CF7+G7**
  - 224+720um (944um)
  - Feeler gauge of 850um (+144 of the step) = 994um
  - Glue layer thickness (goal) = **50um**
  - **Measured = 78um**



- Observations:
  - The combination of feeler gauges and total thickness of the sandwich was a bit unfortunate.
  - Next day test – with new tune of the settings for deposition (the H20E had a more “paste” viscosity and density) → too close of end of pot-life.

Glue thickness study – some lessons

IFIC INSTITUT DE FÍSICA CORPUSCULAR

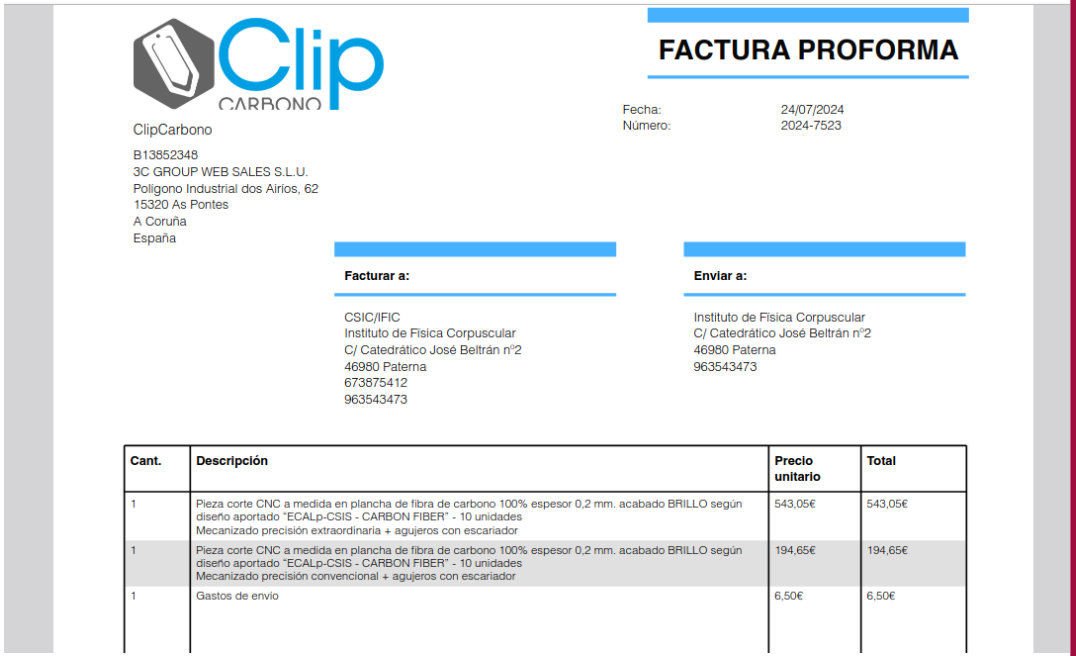
- Decisive study to design the final jigs (Carlos' talk)
- Glue dots can be controlled to be bellow 50um thickness.
- If required, we can glue after 2 days of the mix preparation
- Differences in glue dot size are not related to the robot but to the small differences of planarity/ thickness of the components (jigs, CF, glass)
  - We will work with better CFs (hopefully!), better tools and the Hamamatsu Si sensors… which are expected to be very well within specs (to be checked?)

Fanout -to- CF gluing

CF

- 20 samples about to be received with new design
  - 10 samples with “exceptional” precision (quite expensive) ~ 50€/piece
  - 10 samples with “standard” precision but holes made with specific reamer ~ 20€/piece

- measurements to be done upon arrival (this week?)



ClipCarbono

B13852348
3C GROUP WEB SALES S.L.U.
Polígono Industrial dos Airios, 62
15320 As Pontes
A Coruña
España

FACTURA PROFORMA

Fecha: 24/07/2024
Número: 2024-7523

Facturar a:

CSIC/IFIC
Instituto de Física Corpuscular
C/ Catedrático José Beltrán nº2
46980 Paterna
673875412
963543473

Enviar a:

Instituto de Física Corpuscular
C/ Catedrático José Beltrán nº2
46980 Paterna
963543473

Cant.	Descripción	Precio unitario	Total
1	Pieza corte CNC a medida en plancha de fibra de carbono 100% espesor 0,2 mm. acabado BRILLO según diseño aportado “ECALp-CSIS - CARBON FIBER” - 10 unidades Mecanizado precisión extraordinaria + agujeros con escariador	543,05€	543,05€
1	Pieza corte CNC a medida en plancha de fibra de carbono 100% espesor 0,2 mm. acabado BRILLO según diseño aportado “ECALp-CSIS - CARBON FIBER” - 10 unidades Mecanizado precisión convencional + agujeros con escariador	194,65€	194,65€
1	Gastos de envío	6,50€	6,50€

Studied solutions

IFIC INSTITUT DE FÍSICA CORPUSCULAR

- 3M 82600 – double face tape **(5 um !!!)**
  - https://www.3m.com/3M/en_US/p/d/v000204581/
  - Adhesive enough? (tbc)
  - Supports 149° C (short time)
- "Standard" double side tape ~ 40-50um
  - AT395 https://es.rs-online.com/web/p/cintas-de-doble-cara/7703422
  - Not very clean/easy to use (burrs, imperfections... see sample)
  - 40-50um. Max temp according datashet = 100°C (but tested in 140°C)
- Spray adhesive → solution explored but very unsatisfactory https://es.rs-online.com/web/p/adhesivos/0558013
- Other glues?
  - Just ordered a sample of DOWSIL 736 heat resistant sealant
  - https://www.farnell.com/datasheets/3971861.pdf?_gl=1*gn8pf9*_gcl_au*Njk3ODUxNTgzLjE3MjY3NDE0OTM

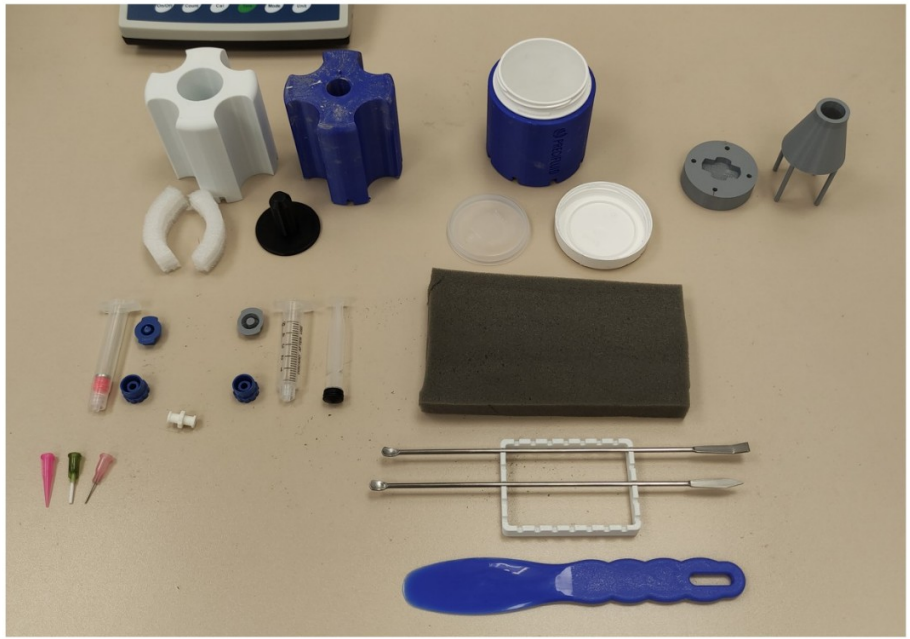
Studied solutions

- Tests done using 100um-thin PEEK sheets mimicking the fanouts.
- Fake CSIS: using CF + PEEK + AT395+fake sensor 300um + AT395 + PEEK
  - Thickness between 850 and 950 um, with local variations (due to the AT tape)
  - Tests finished last week… no time for metrology
- We tried also different solutions for the CF to Fanout gluing.
  - In this case we glued PEEK to PEEK.
- Rookie mistake: the PEEK did not hold the high temperatures in the oven cycle…

Glue “fabrication”

Glue protocol

- We are confident to say that we master the process now.
- New tools and updated procedure (see additional material).
- We spotted a crucial fabrication error of fabrication of the “plunge” of the syringes :
  - That was behind some inconsistencies and loses of glue in one of every 3 tests.
  - Fully controlled now and we got free replacement of those pieces.



Back-up slides

High Granular Calorimetry R&D: what for?

IFIC INSTITUT DE FÍSICA CORPUSCULAR

▶ **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)** 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, ...

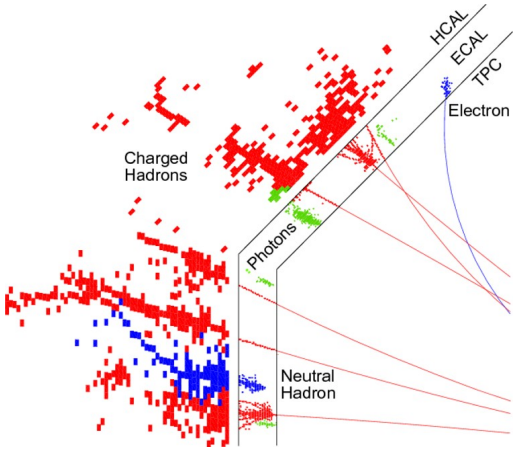
SiW ECAL Technological requirements

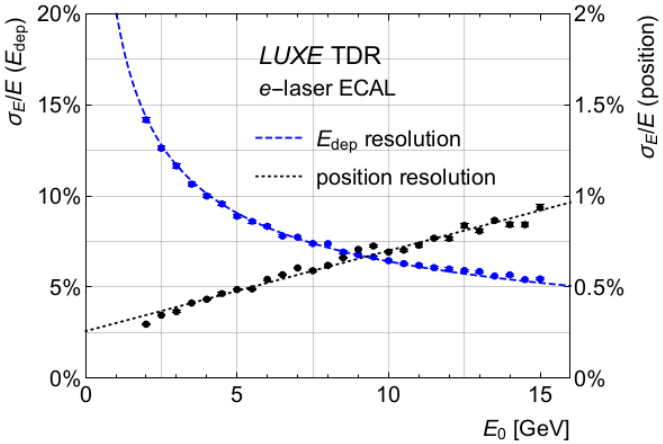
Sandwich calorimeters – High Granularity –

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

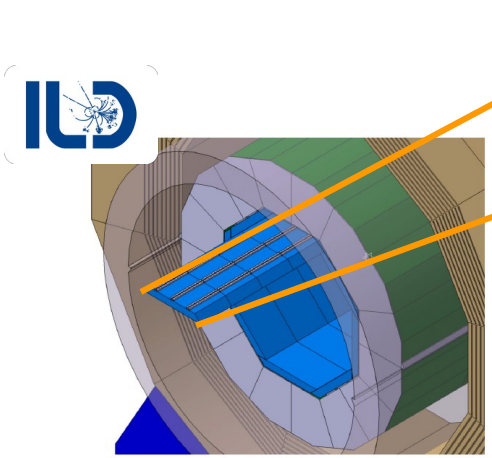
- Tungsten as absorber material
  - Narrow showers
  - Assures compact design

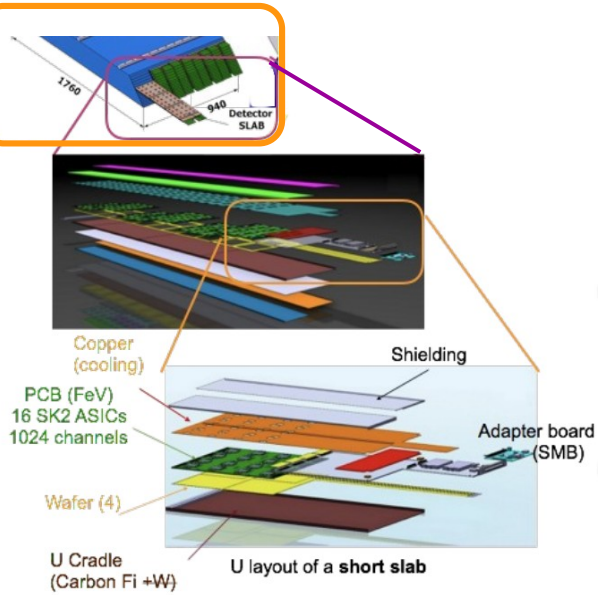
- Silicon as active material
  - Support compact designs
  - Allows pixelisation → good position resolution
  - Robust technology
  - Excellent signal/noise ratio



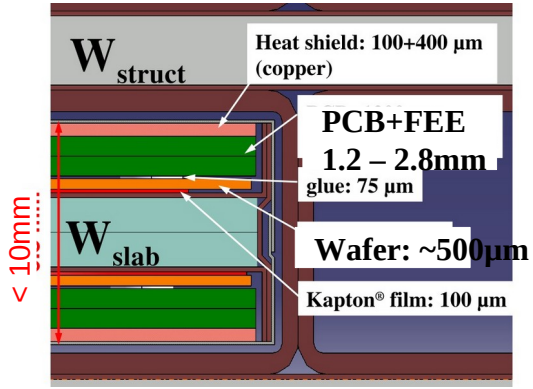


Requirements: highly integrated

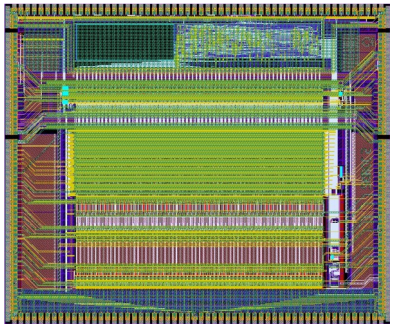

The SiW ECAL in the ILD Detector



SiW Ecal



e.g. SKIROC (for SiW Ecal)



Size 7.5 mm x 8.7 mm,

64 channels

Dual gain, autotrigger, powerpulsed

(goal of 25uW / chn)

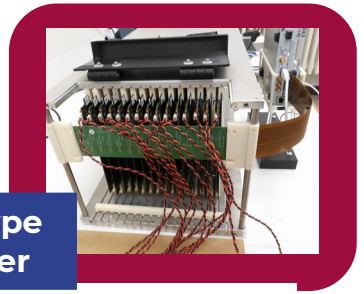
Barrel

- 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

DRD6 - Higgs Factories - LUXE

FCAL-type calorimeter



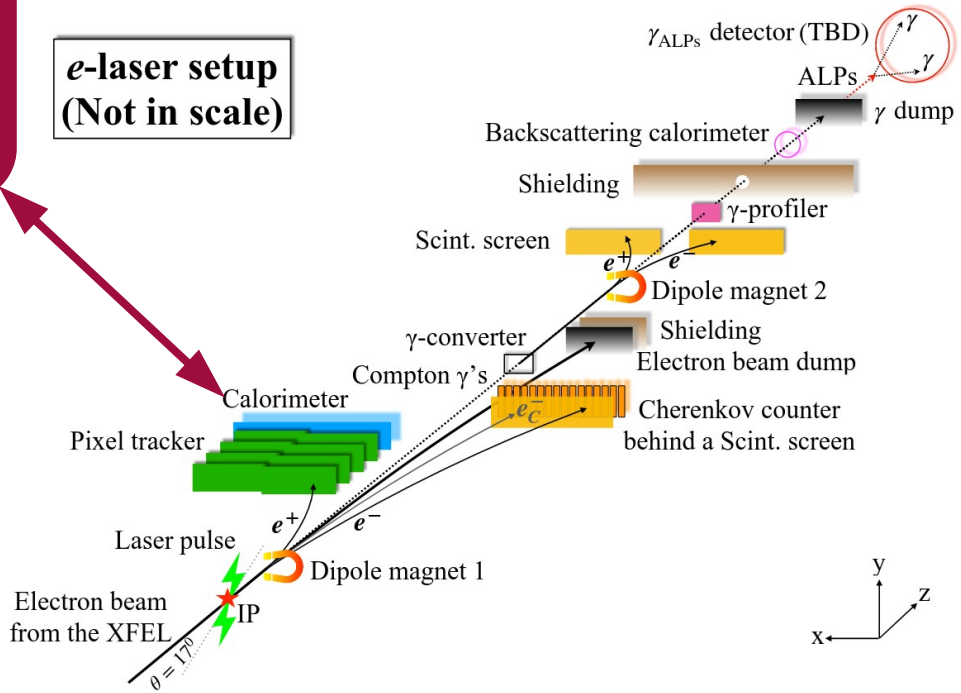
CALICE -type calorimeter

ILD Barrel SiECAL

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

ILD LUMICAL (Compact ECAL)

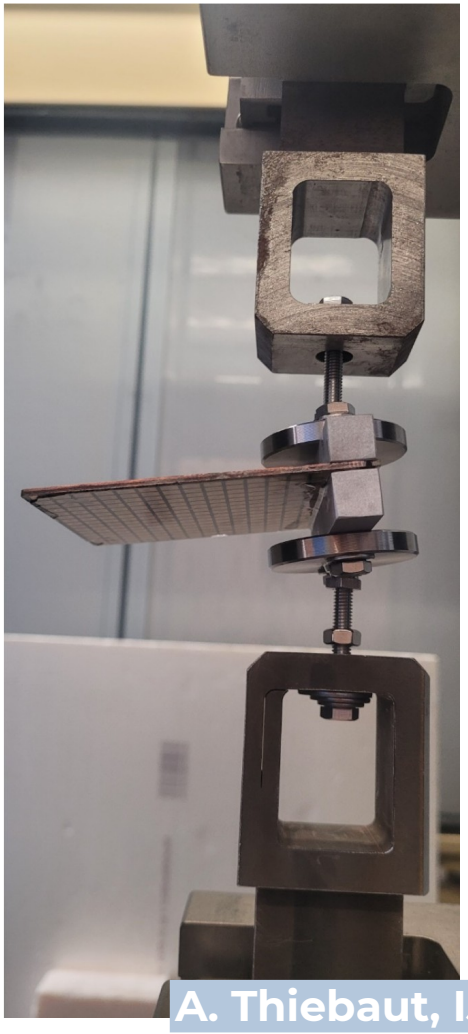
adapted for high rate positron measurement at LUXE

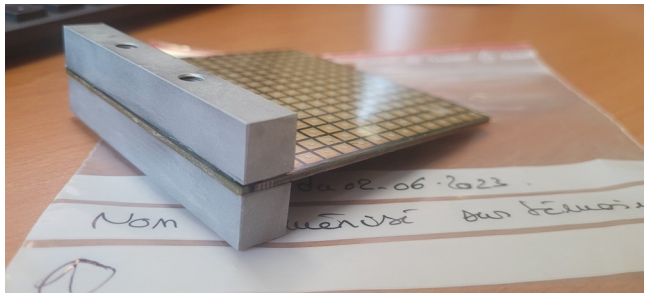


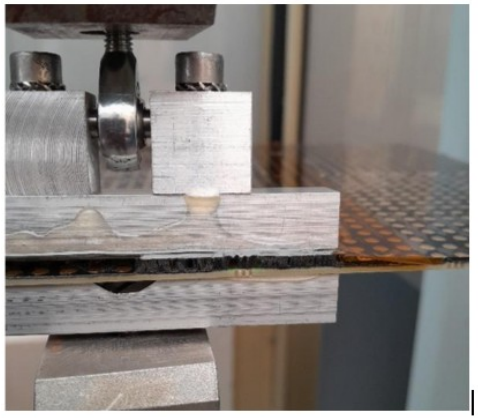
LUXE

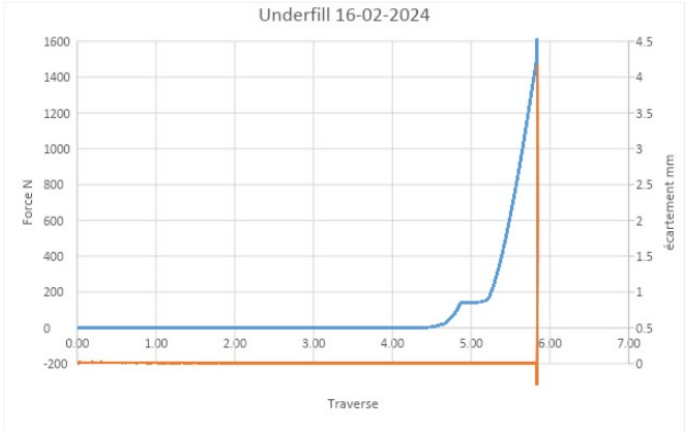
Strong-Field QED experiments

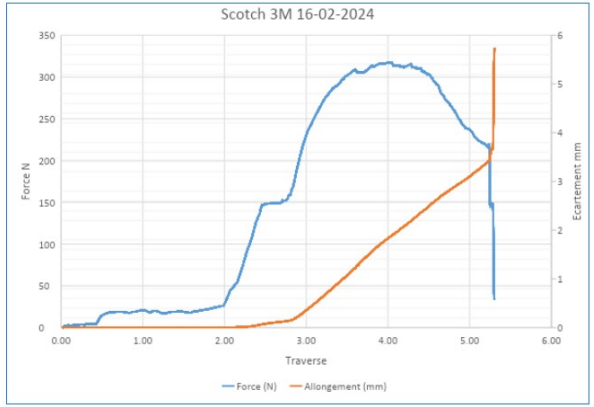
Mechanical tests











A. Thiebaut, IJCLab

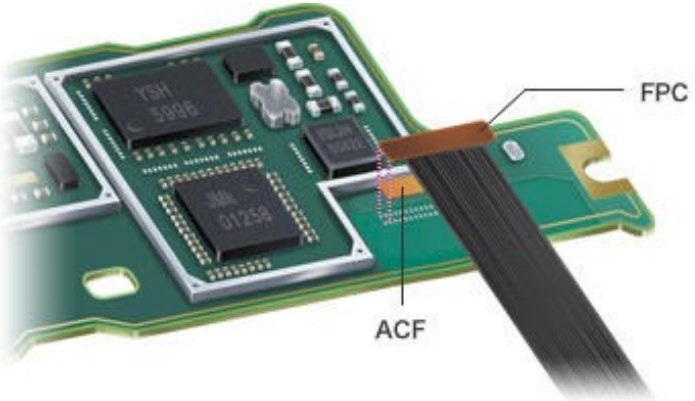
Si ECAL hybridization / integration

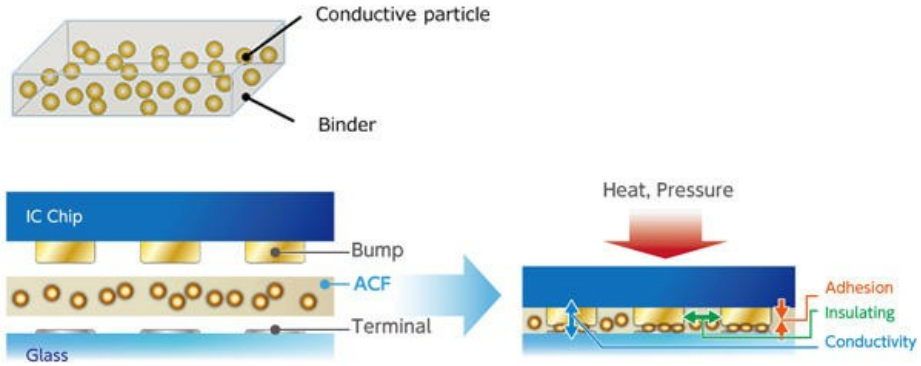
IFIC INSTITUT DE FÍSICA CORPUSCULAR

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 ??



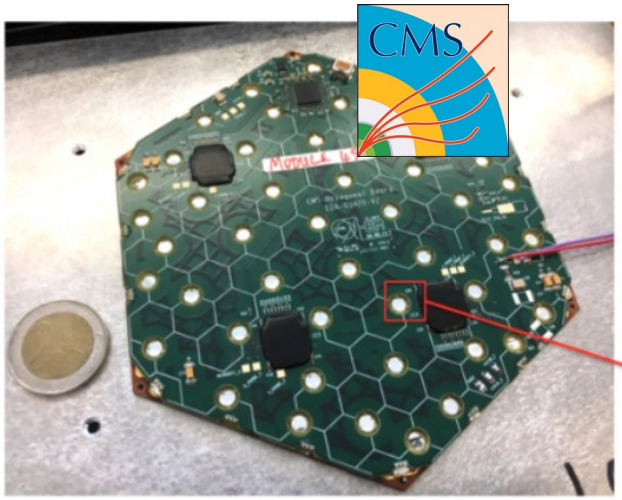


PCBs

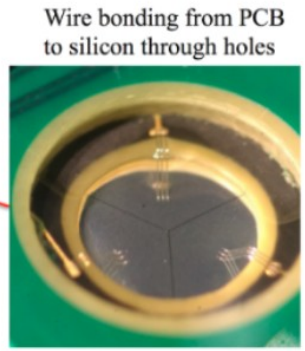
IFIC INSTITUT DE FÍSICA CORPUSCULAR

▷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**

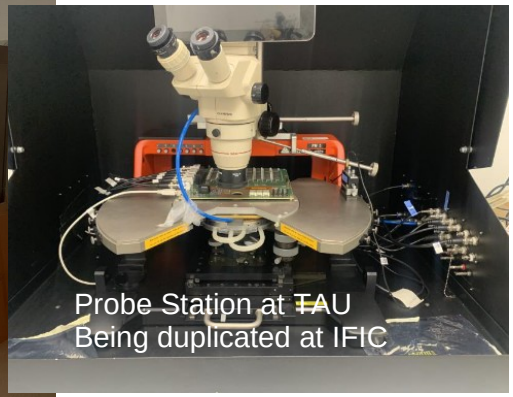
LUXE

membership of Russian institutes suspended

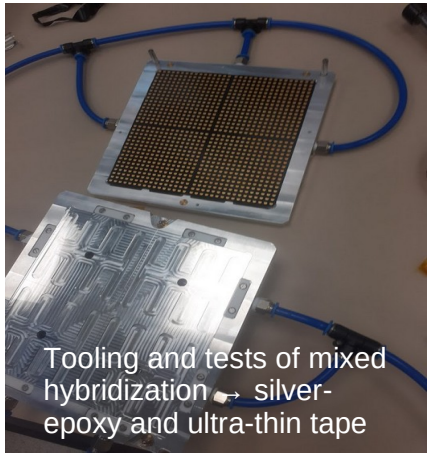
IFIC-Lab for ECAL hybridization

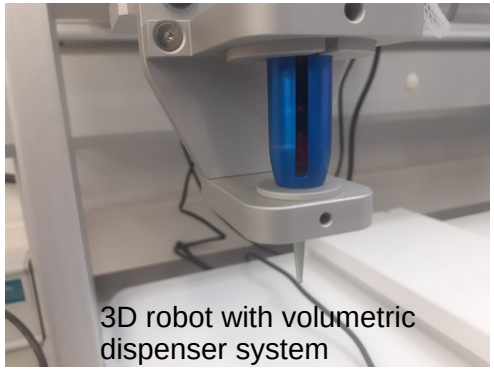
- **New facility and capabilities at IFIC**
- **Funding: CIDEGENT/ASFAE/CNS** → In line with ECFA – R&D roadmap, DRD6, Future Colliders
- **IFIC will become** the hub for module hybridization R&D / production / commissioning for DRD6 Si-ECALs and for the LUXE experiment

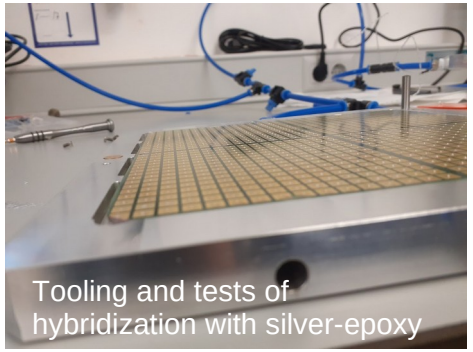

New installation at IFIC
(to be finished in ~~March/Abril~~ May/June 2024)


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