

Construction of a highly compact and finely granulated electromagnetic calorimeter

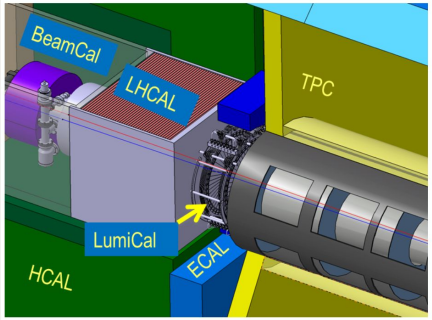
Melissa Almanza Soto on behalf of the FCAL Collaboration

International Workshop on Future Linear Colliders 2026
12/11/2026

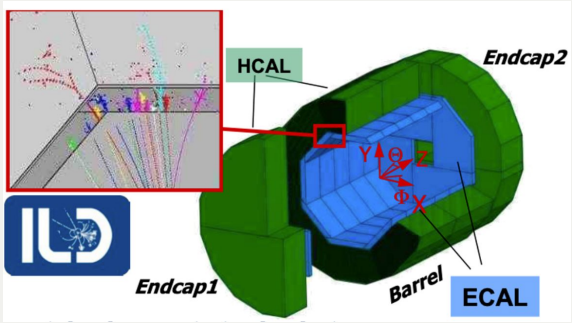
CSIC
Consejo Superior de Investigaciones Científicas
Vniversitat de València
IFIC Institut de Física Corpuscular
Excelencia Severo Ochoa
Agencia Estatal de Investigación
Gobierno de España
Ministerio de Ciencia, Innovación y Universidades
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Conselleria de Educación, Universidades y Empleo
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NextGenerationEU
Plan de Recuperación, Transformación y Resiliencia
AITANA

High granularity calorimetry at future e^+e^- colliders

- Luminometers
  - To give precise measurements of luminosity through detection of Beamsstrahlung and Bhabha scattering
- Main detector calo barrel/end cap
  - Allows application of particle flow methods
  - For improved jet resolution
  - Precision measurements of individual particle shower energy



Several technological solutions currently being developed within the DRDCalo collaboration

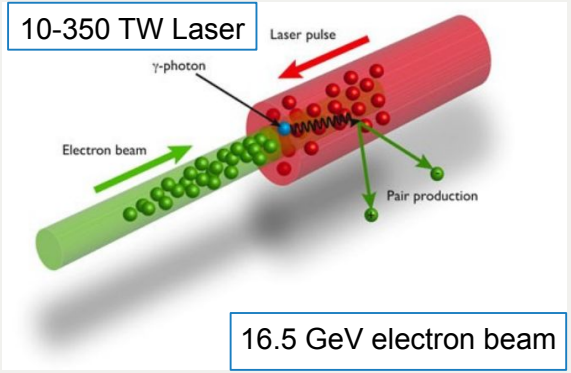


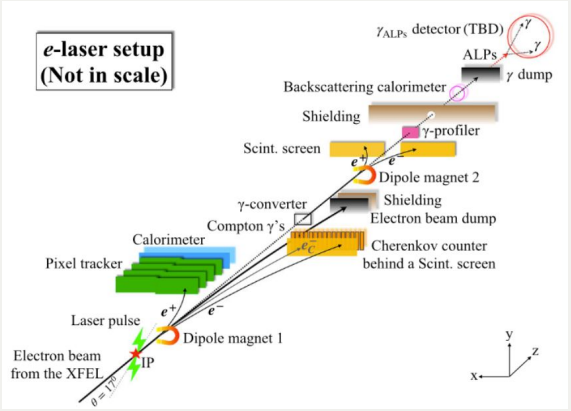
Challenges	Proposed Solutions
• EM shower overlap at high multiplicity • Low multiplicity showers immersed in widely spread background • Mechanical precision	• Compact sampling calorimeter • Small Molière radius • High granularity

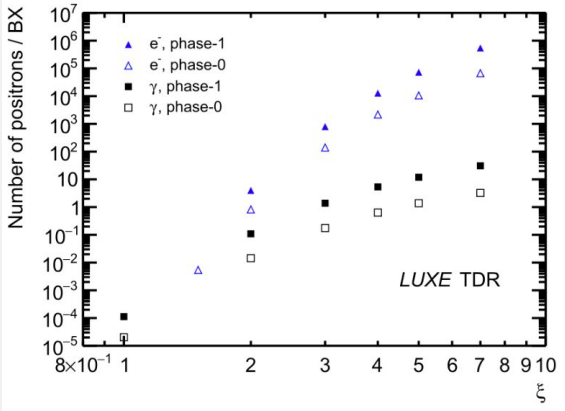
Strong-Field QED: LUXE (Laser Und XFEL Experiment)

Mission: Observe the behavior of QED in the strong field non-linear and non-perturbative regime

High-energy electron beam + **High-power laser** = **Production of physical e^-e^+ pairs from the QED vacuum**





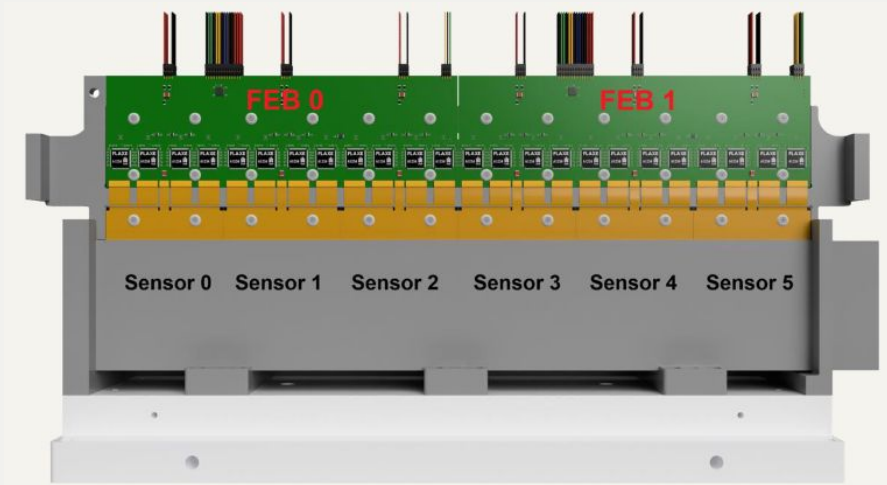


LUXE opens the possibility to study:

- The interaction of real photons with electrons and photons at field strengths where the coupling to charges becomes non-perturbative
- e^--ɣ and ɣ-ɣ interactions in the transition from perturbative to non-perturbative regime of QED
- Strong-field QED processes to design a sensitive search of new particles BSM that couple to photons

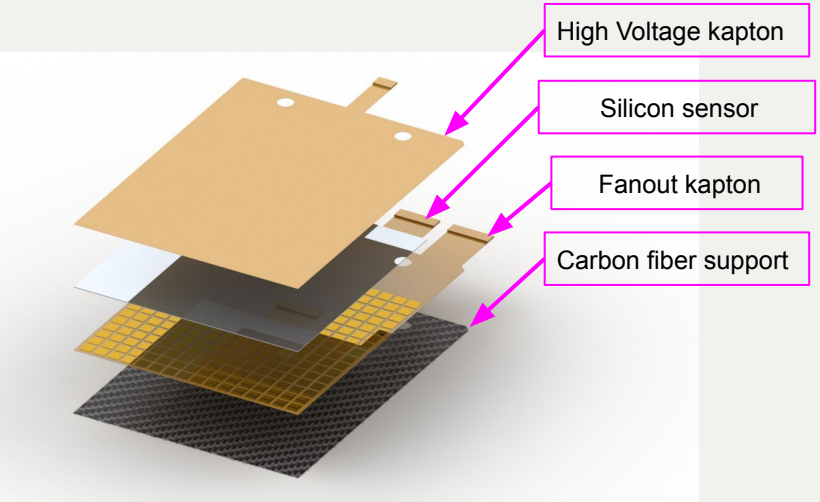
System overview: The ECAL-P design

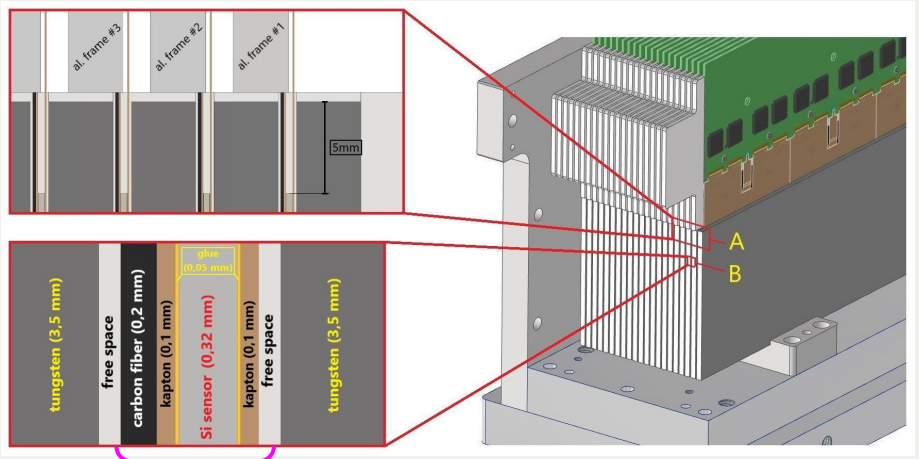
- Highly compact and granular sampling calorimeter
- Geometry for SF-QED experiments
- 21 tungsten plates of 1 X_0 (3.5mm)
- 20 layers of active planes
- 1mm space between W plates for Active plane insertion
- Each plane composed of 6 sensors with 256 pixels of 5.5 x 5.5 mm^2



System overview: The ECAL-P design

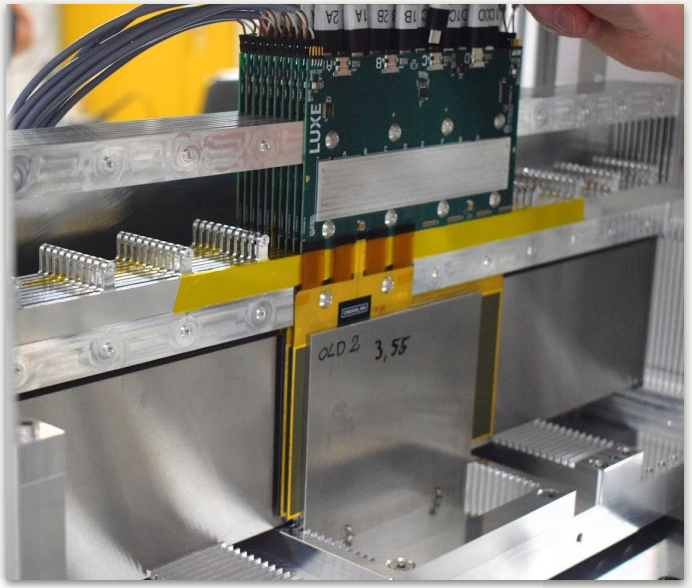
- Active plane design with fanout PCB with traces to keep FEB at the top of the calorimeter
- Active plane thickness below 1mm

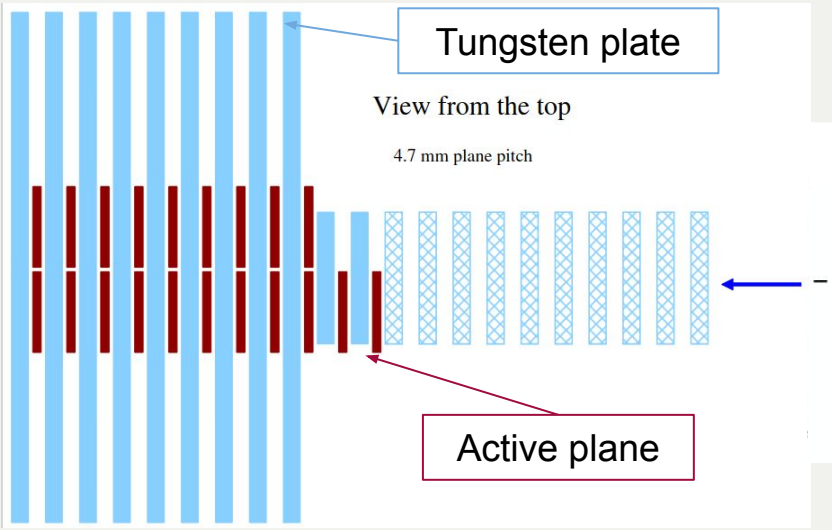


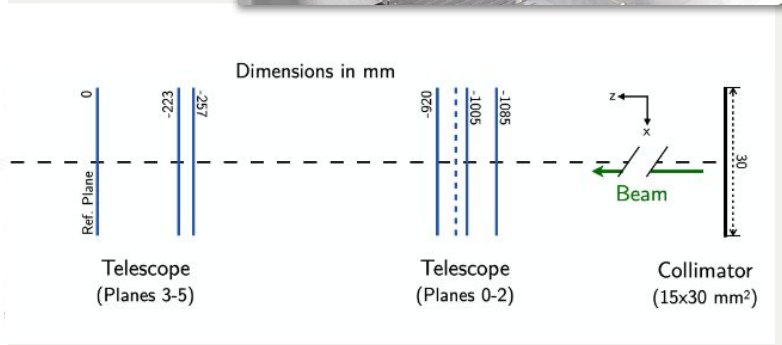


Testbeam 2025 at DESY

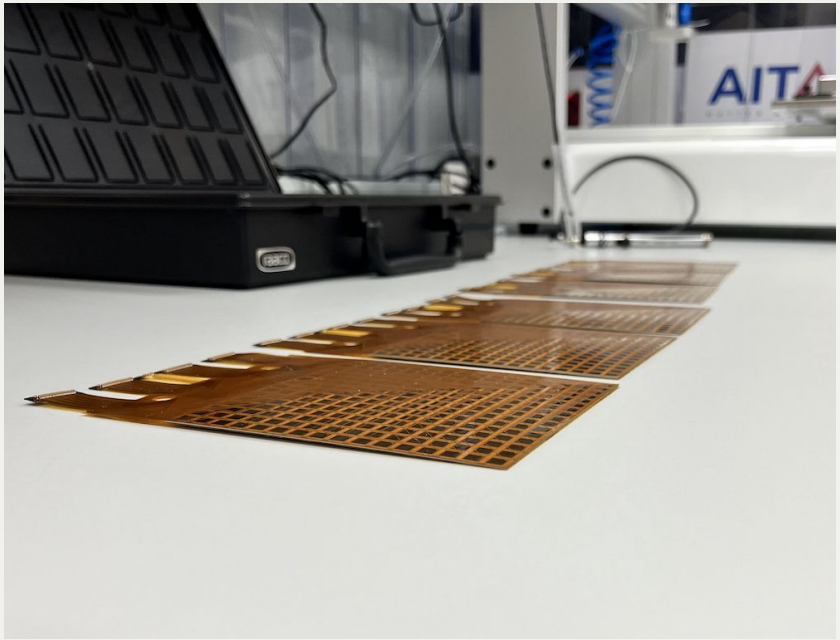
- 20 active planes distributed in two towers
- Energies from 1 to 5.6 GeV
  - Tracker mode (no absorber)
  - Calorimetry mode with 9 to 21 X_0







Active planes



CSIS: Compact Silicon Sandwich

Silicon sensors: 320 μm thick

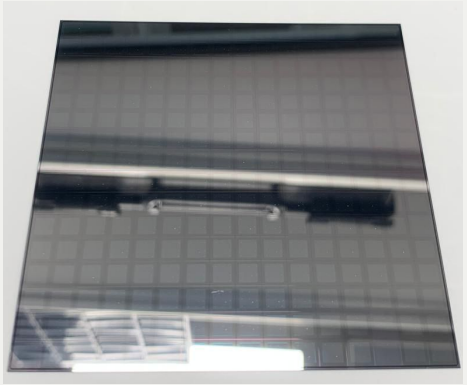
- Manufactured by Hamamatsu
- CALICE Design of sensor
- 5.5 × 5.5 mm^2 pad
- Small gap of 10 μm between pads

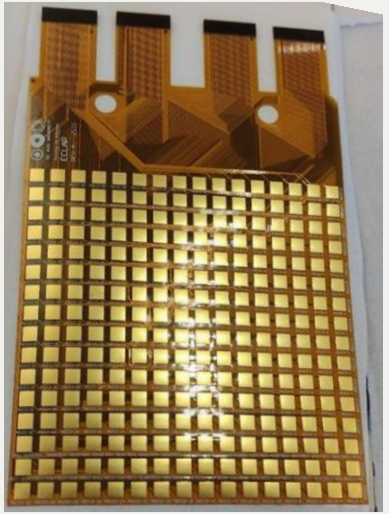
Fanout: 120μm thick

- Kapton Flex PCB
- With copper traces connected to the sensor pads with conductive glue.

High voltage kapton: 70μm thick

Carbon fiber support: 220μm thick



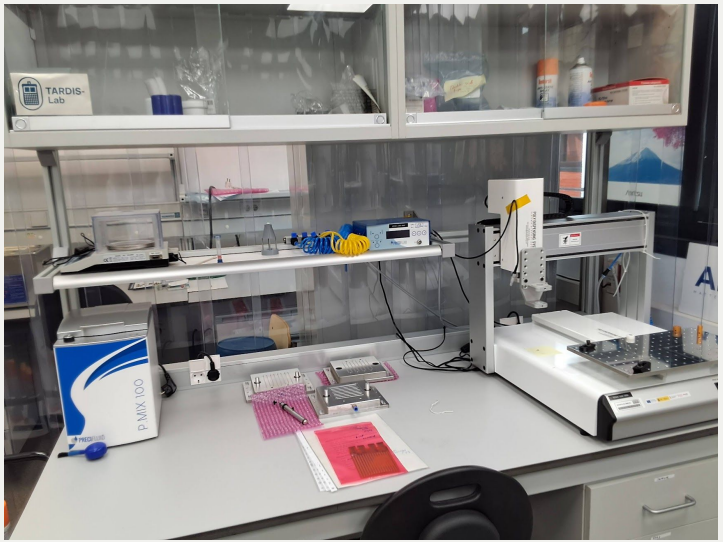






The TARDIS LAB at IFIC

- Facility for the characterization and hybridization of silicon
- ISO 7 Clean-room + dry cabinet + curing oven
- Glue depositing 3D Robot + Probe station

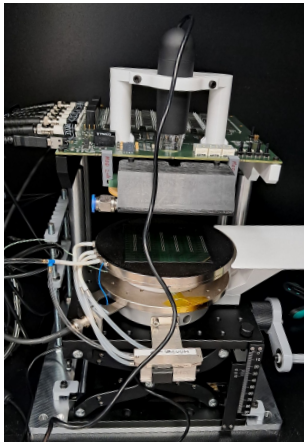


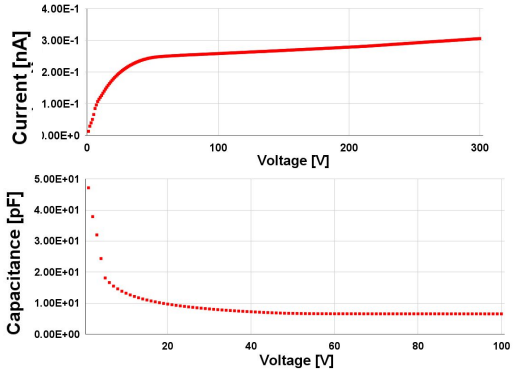


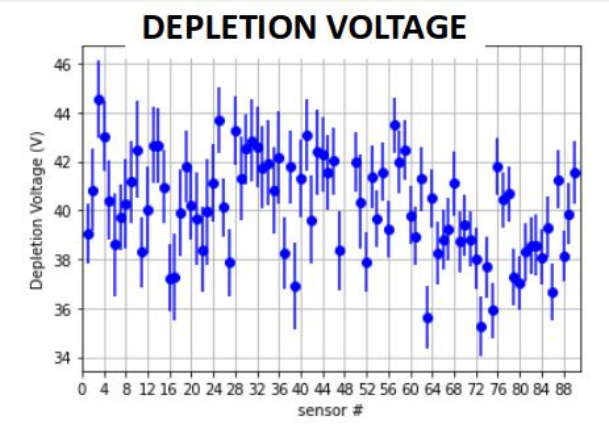


Characterization of sensors

- **Two manual probe stations: at TAU and at IFIC**
- **CERN Developed switch card**
- Automatic IV and CV measurements of Hamamatsu silicon sensors: pad-by-pad
- Exchangeable probe card for different sensor geometries
- Measurements performed before and after hybridization
- **90 Sensors tested at TAU, all passed specifications**

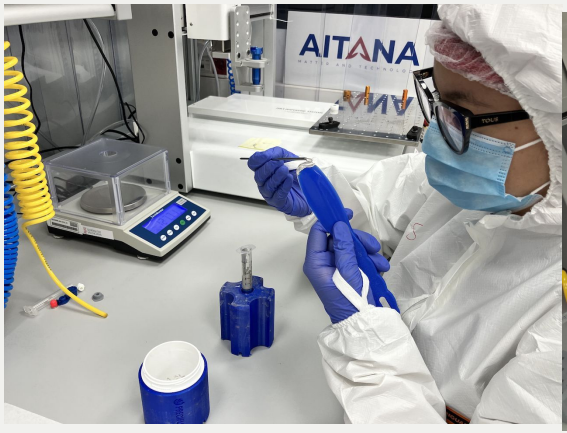


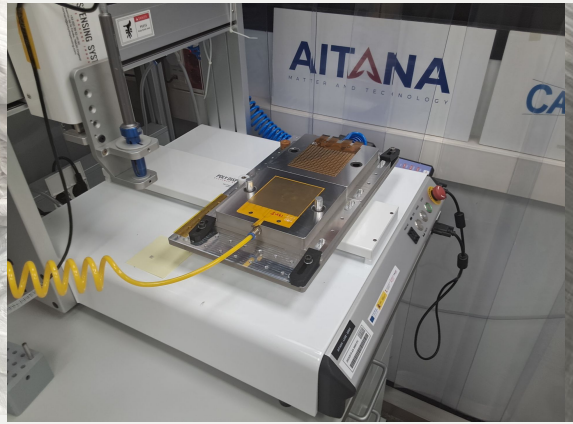


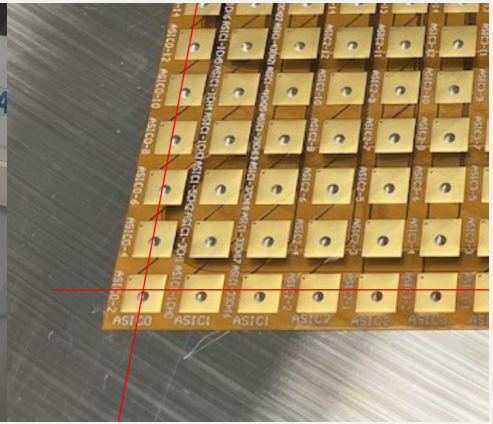


The TARDIS LAB at IFIC - Glue deposition

- Programmable 3D positioning of glue depositing robot and volumetric dispenser
- Standardized procedures for mixing and depositing two types of conductive epoxy glue
  - H20E – from EPOTEK (Two-component)
  - TDS-9410 – from MG-Chemicals (monocomponent)





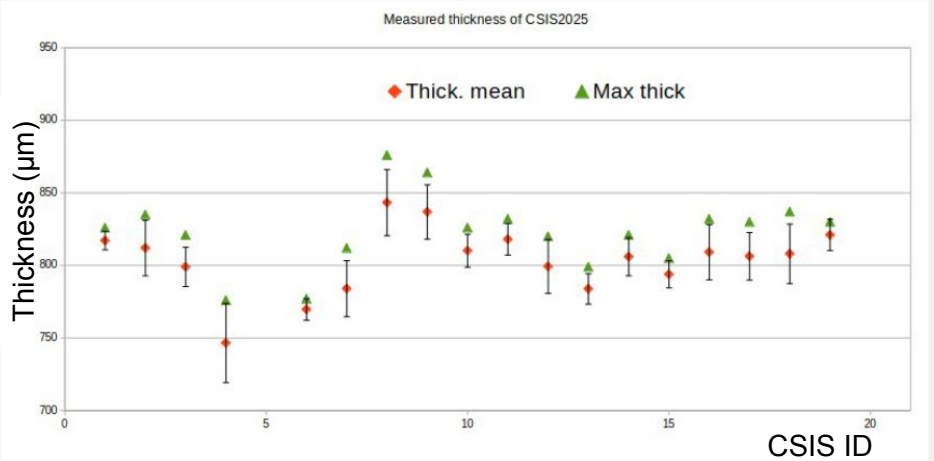


Active plane thickness results

- Expected: ~870-960 μm
  - Most variation in CF Thickness

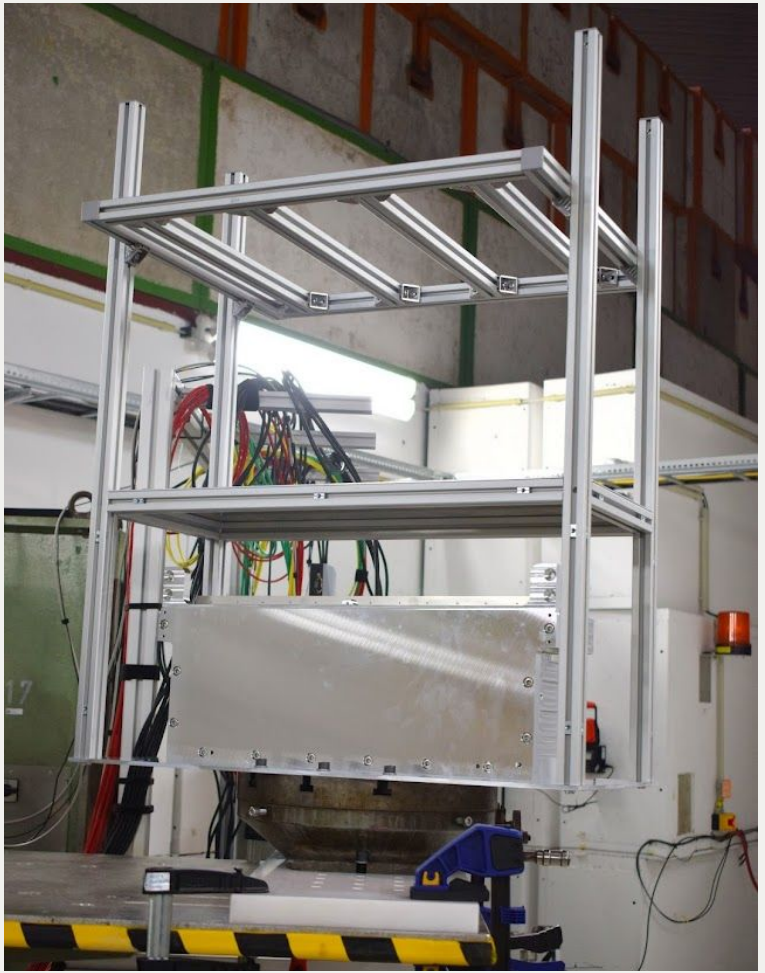


- Achieved: ~750-870 μm
  - 4 combinations of conductive and non-conductive glue
  - 4 missing glue dots out of 6400 total



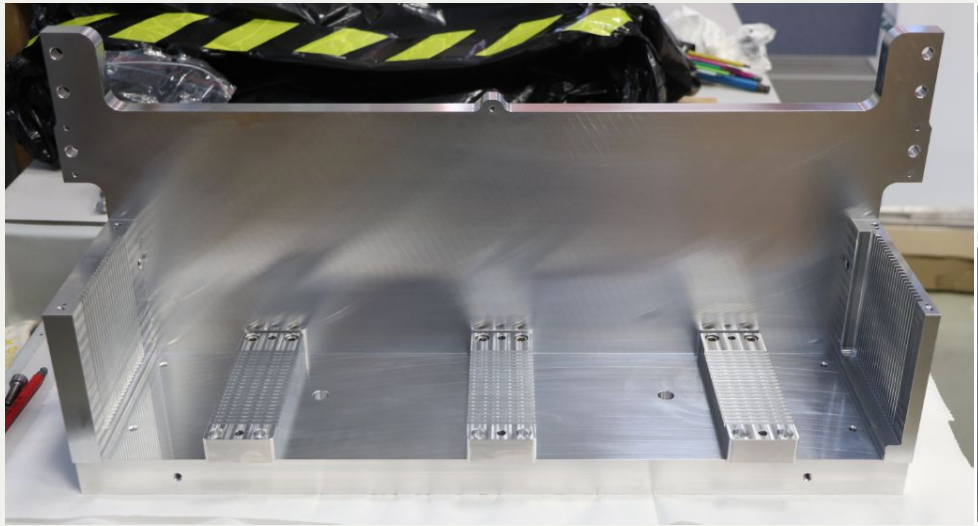
2025_001	DOWSIL+H20E	2025_011	DOWSIL+H20E
2025_002	DOWSIL+H20E	2025_012	DOWSIL+H20E
2025_003	DOWSIL+H20E	2025_013	DOWSIL+H20E
2025_004	3MDST+H20E	2025_014	DOWSIL+H20E
2025_005	3MDST+H20E	2025_015	DOWSIL+H20E
2025_006	3MDST+H20E	2025_016	DOWSIL+H20E
2025_007	3MDST+MG9410	2025_017	DOWSIL+H20E
2025_008	DOWSIL+MG9410	2025_018	DOWSIL+H20E
2025_009	DOWSIL+MG9410	2025_019	DOWSIL+H20E
2025_010	DOWSIL+H20E	2025_020	DOWSIL+H20E

Mechanics



Mechanical frame

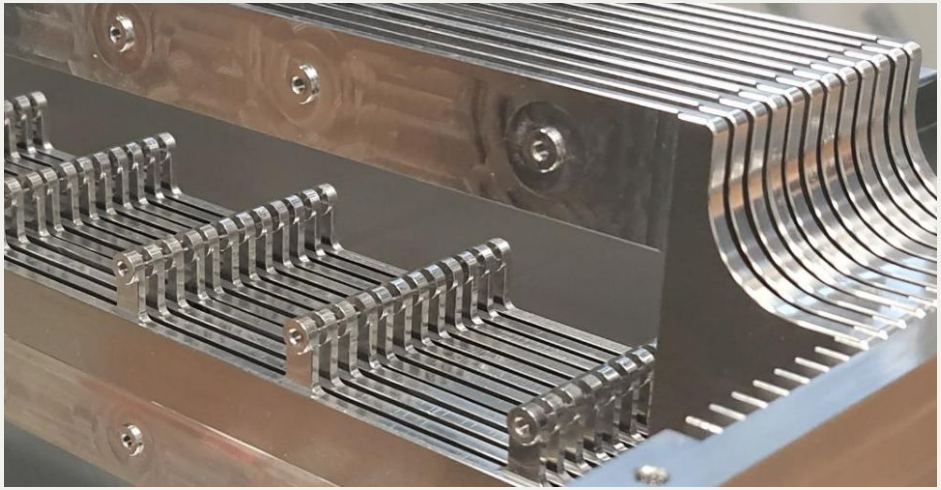
- Aluminum frame
- Designed and manufactured at University of Warsaw
- Combs and ribs structure for the insertion of tungsten plates
- Sensor gap of 1.2mm for TB2025

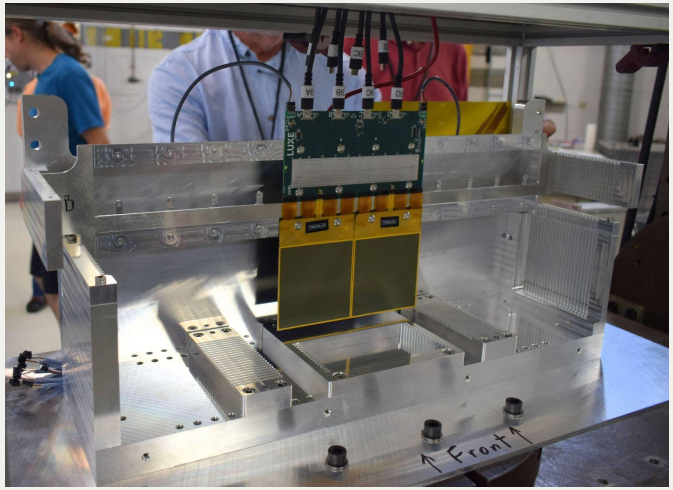




Mechanical frame

- “T-Frames” supports for FEBs and sensor planes
- Designed for alignment of sensor planes



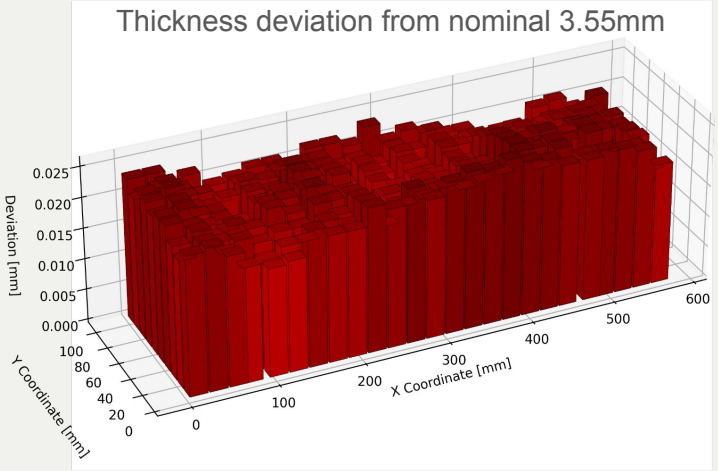


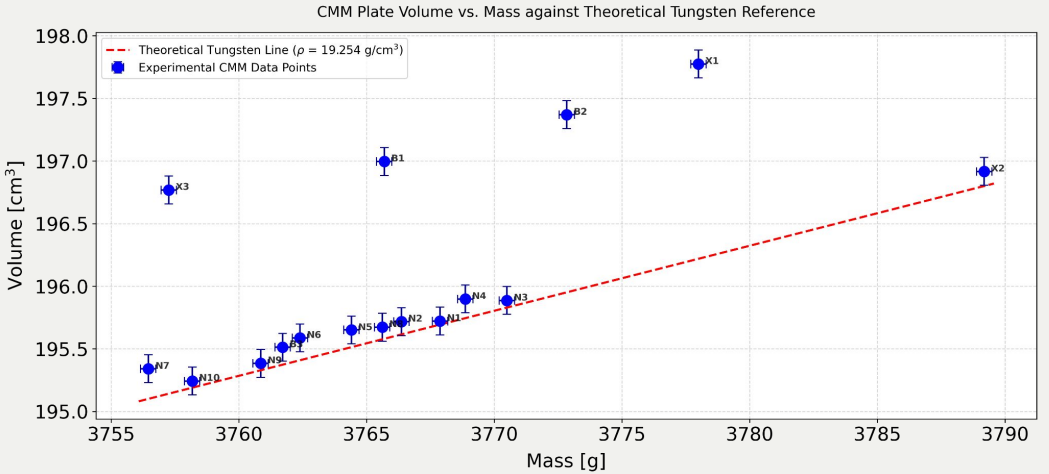
- All elements machined to 10μm
- Precision of whole assembly ~100μm

Tungsten plates

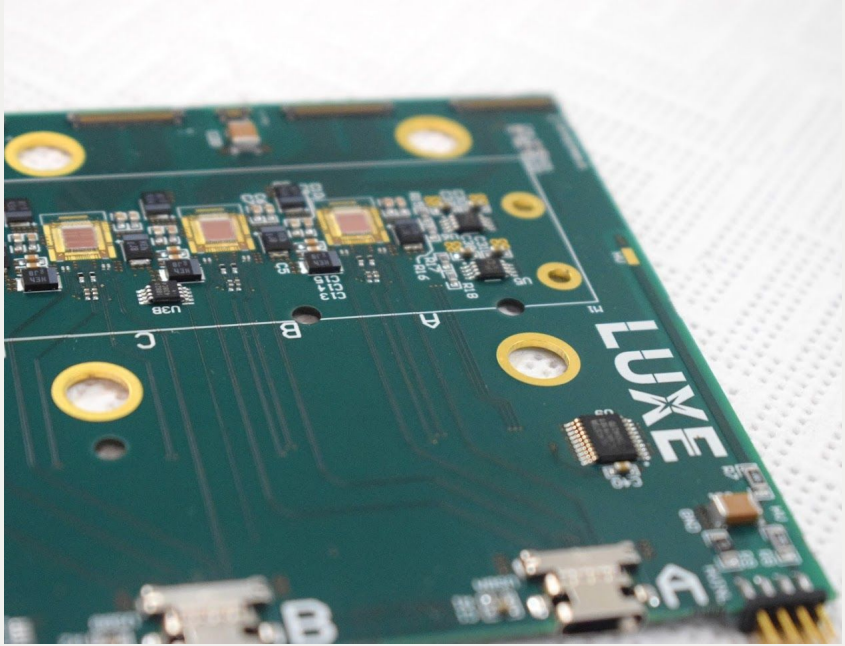


- 16 plates size 55cm x 10cm x 3.55mm
  - 6 plates from two Chinese companies (B1-B3, X1-X3)
  - 10 plates from German company (N1-N10)
- CMM measurements on all plates results
  - Planarity deviations ± 100 µm
  - Thickness deviations below 50 µm for all plates
- During TB2025: 9 plates (B,X,N1-N3) fit properly into the combs



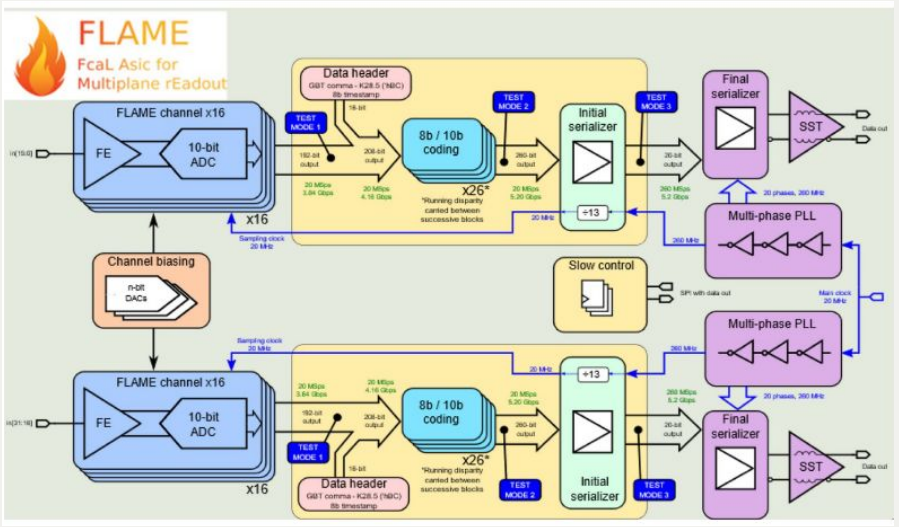


FE and FPGA



Front-end and FPGA

- FLAME ASIC was developed for luminometers at future Higgs factories
- FLAME Main features
  - 32 channels
  - Analog front end in each channel. CR-RC shaper of 50ns
  - 10 bit ADC at 20 MHz in each channel
  - High speed serializer



- FEB developed specifically for TB 2025 with FLAME
  - Limited amount of available FLAME ASICs and FPGAs for the readout.
- Read out with dedicated system based on commercial Trenz TE0808 FPGA.
  - Developed at AGH University of Krakow
- Special FLAXE ASIC developed for SF-QED Low rates

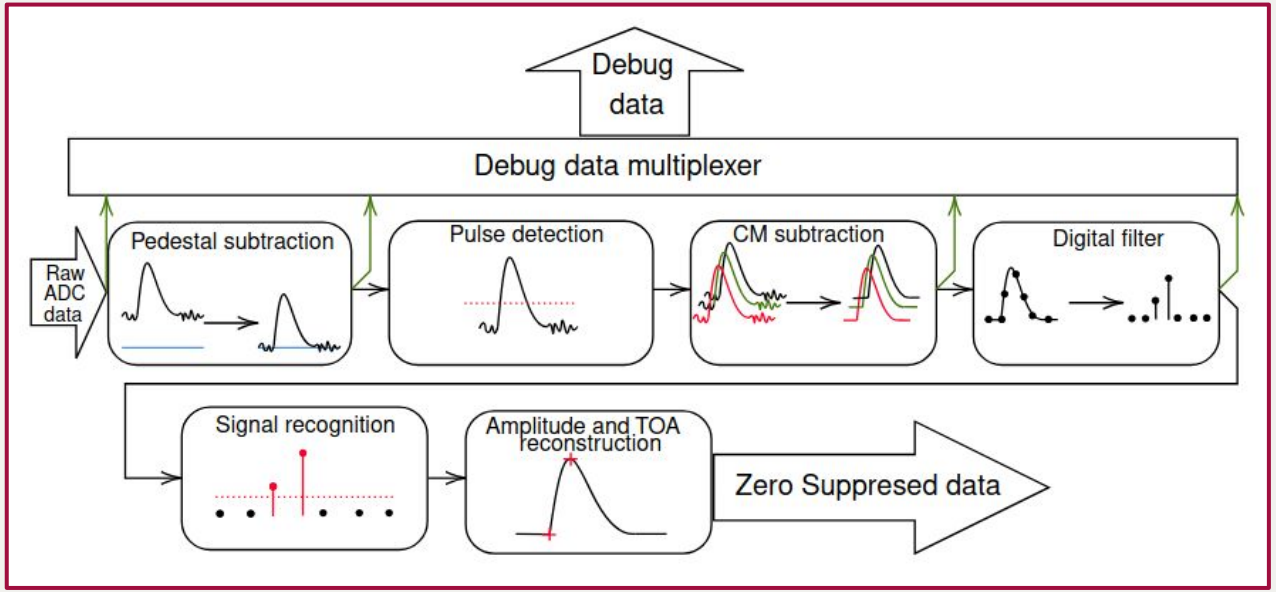
DAQ and data storage for TB2025

Raw ADC samples of all channels:

For detailed offline reconstruction and analyses

Zero Suppressed data:

calculated signal amplitude and time of arrival, crucial for online monitoring system



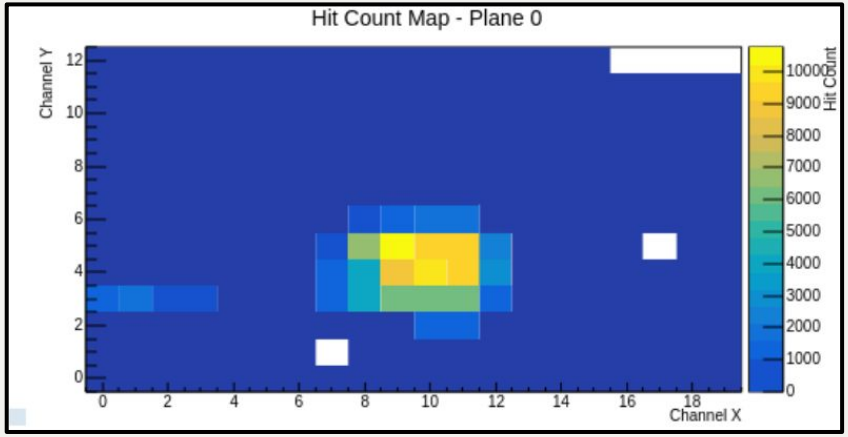
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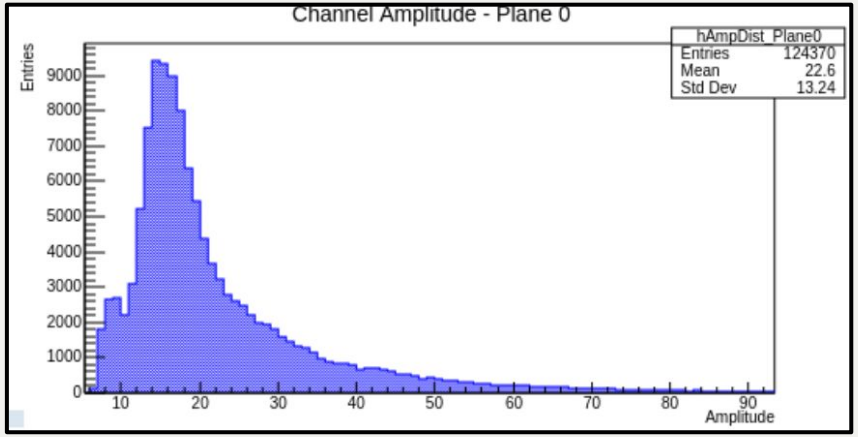
- The DAQ operated without any issues at event rates of up to 2 kHz.
- Total of 2616 instrumented channels
  - Approximately 2.1% of the channels do not show a signal, while 4% are qualified as noisy.

From all geometries → 70.7 days of combined FPGA uptime

DAQ: On-line monitoring

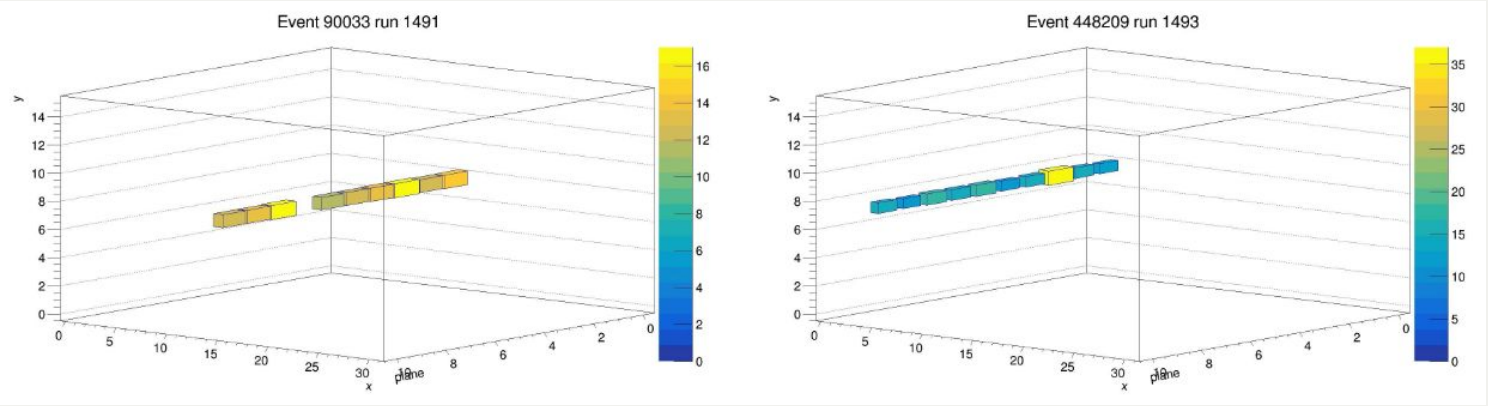
Real-time interactive detector monitoring of system performance and data quality via web interface



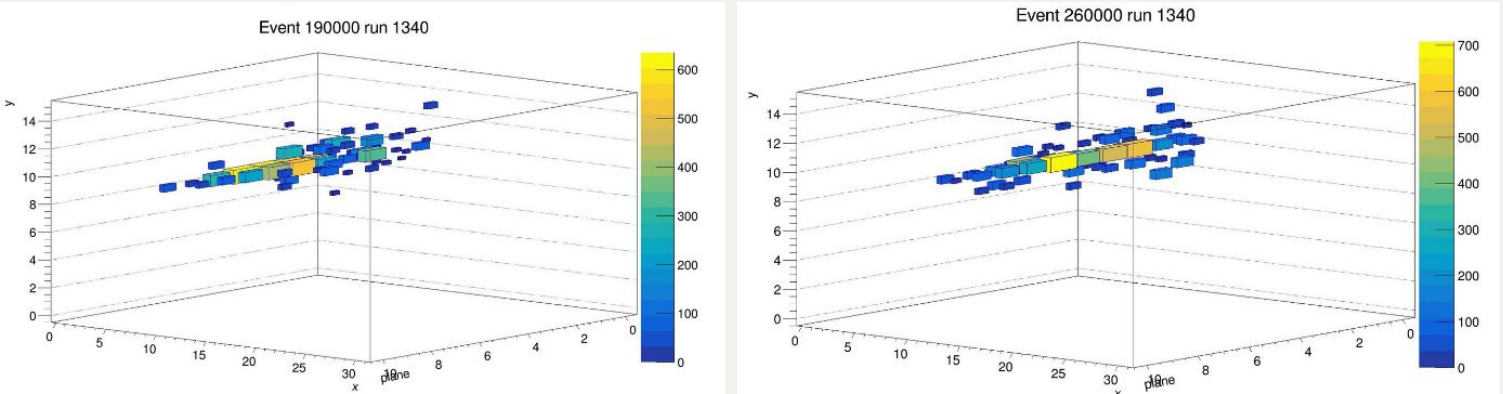


- Allows remote access for any device in DESY network
- JSROOT interactive plots and histograms
- GUI for DAQ control and configuration

Online reconstructed data: Event displays



MIP Tracks



5 GeV Showers

Conclusions

- The main components of the highly compact ECAL-P prototype have been successfully developed and integrated.
- Silicon sensor characterization and active plane assembly procedures have been established and validated.
- The mechanical structure demonstrated the required precision.
- The FLAME-based readout and DAQ system operated reliably, reaching event rates of up to 2 kHz with 2616 instrumented channels.
- The 2025 DESY test beam successfully demonstrated the operation of the detector, including online monitoring.
- The experience gained provides a solid basis for further detector integration, optimization and future test-beam campaigns.

Calorimeter system alignment
By Bartek Brudnowski

Performance Analysis
By Yan Benhammou

Adaptation for dark-sector experiments
By Adrián Irles

Thank you for your attention!



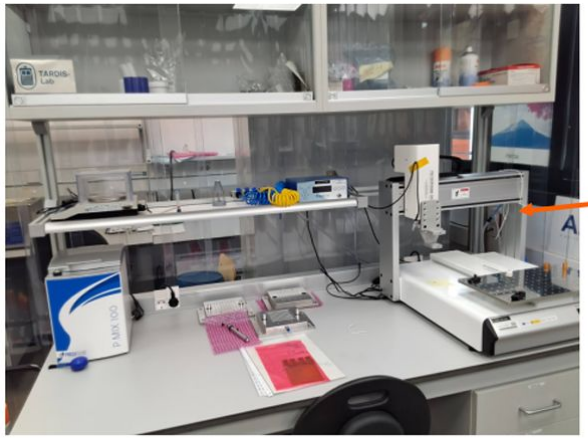


Back up

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TARDIS-Lab

- Facility for the characterization and hybridization of silicon
- ISO 7 Clean-room + dry cabinet + curing oven
- Glue depositing 3D Robot + Probe station



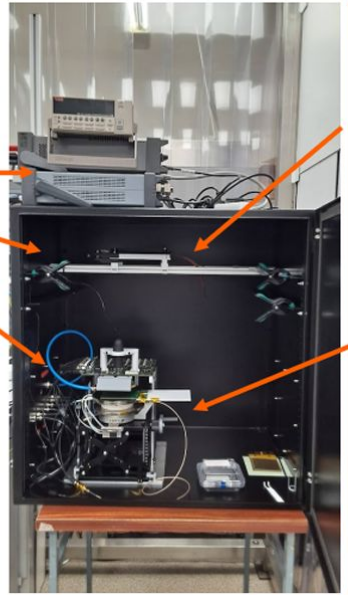
Programmable 3D robot (PDS-400-3) for positioning and control of volumetric deposition (PreciFluid). Planetary Mixer and degassing P.MIX100

Usual epoxy-silver glues: epotek H20E, MGChem 9410



Work area and control PC: probe-station; PDS-400-3, readout modules for sensor commissioning.

Slow control monitoring (humidity, temperature)



Single module set-up with radiactive sources (Sr90 8kBq) and cosmic rays

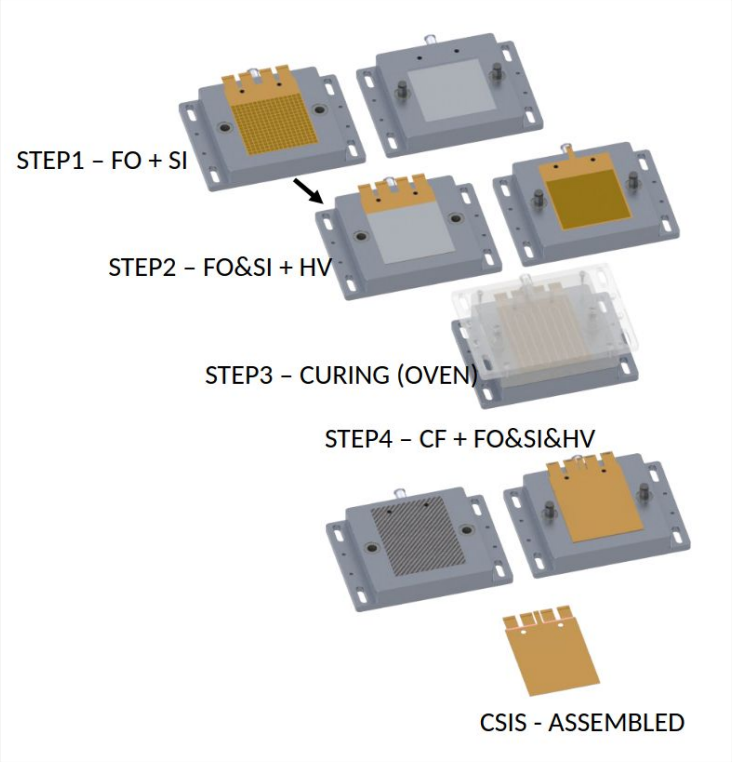
Probe-station with dedicated electronics to characterize **CALICE-Hamamatsu sensors with IV/CV**

- ARRAY HGC Sensor - Switching matrix
- CALICE 6-inc Probe Card
- Keithley 6487
- Keysight E4980A/AL
- Keithley 2470

Nozzles for N_2 injection.
WIP: temperature control

Active plane: assembly

- Methodology for 2025 production



- Precision machined alignment jigs for all sublayers of a sensor plane
- Sandwiched jig place in oven for curing
- Two non-conductive glue types (CF to FO)
  - Silicone
  - 5 μm thick Double sided tape
- 2025 production experience
  - Procedure mastered by the group (IFIC)
  - No major problems
    - 4 missing glue dots out of 6400 total

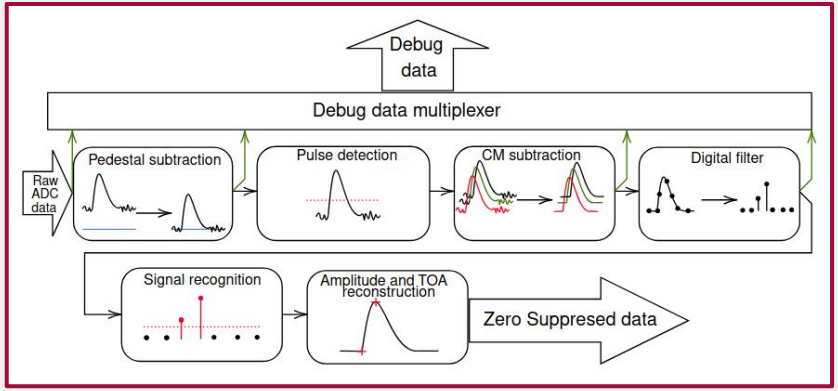
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