Highly compact sandwich structure for a granular electromagnetic ECAL-P calorimeter

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Compact high density sampling calorimeter

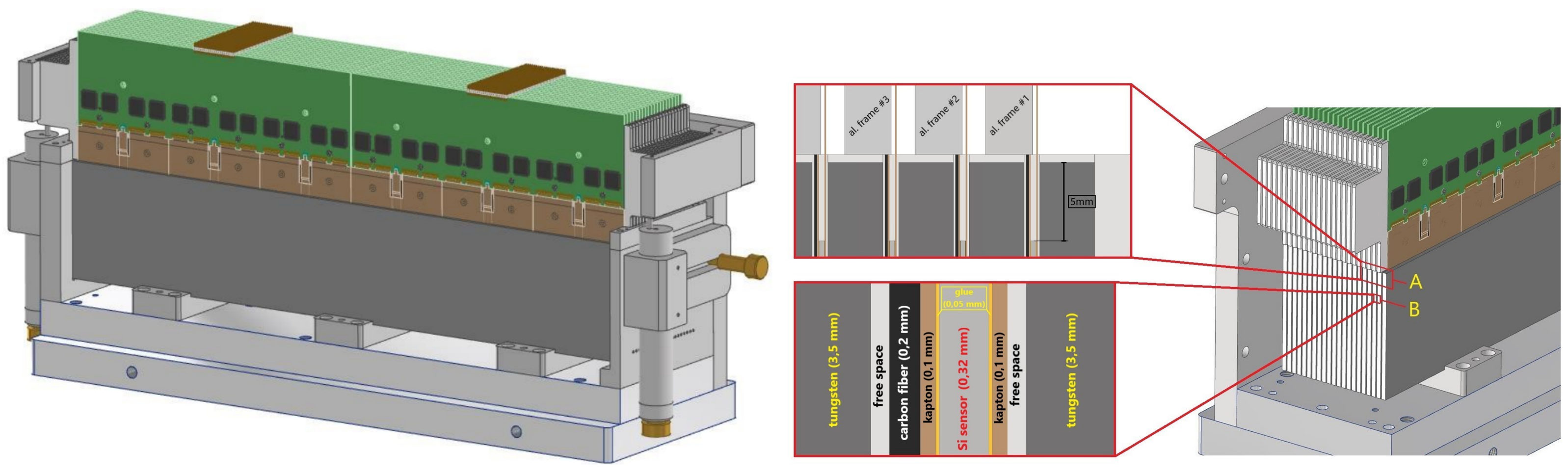


Fig. 1: ECAL-P baseline design and its sandwich structure

- 21 tungsten layers 3.5 mm $1X_0$ thick, 20 layers of 320 μm thick CALICE/Hamamatsu Silicon Sensors
- Six 9×9 cm^2 Si Sensors per layer subdivided into 16×16 (5.5×5.5 mm^2) pads inserted into 1 mm gaps
- Fiducial volume of the calorimeter (XYZ): $540 \times 90 \times 90$ mm^3
- Tungsten purity $99.95 - 99.98\%$, $\rho = 19.25$ g/cm^3, effective density of fiducial volume ~ 15 g/cm^3
- Kapton readout fan-outs and HV electrode attached to sensors with conductive silver glue
- Front End Electronics outside the active volume of the calorimeter

Mechanical structure

Fig. 2: Mechanical structure of ECAL-P prototype

- Duraluminum mechanical body, precision of CNC machining 10 μm, precision of assembly 100 μm
- Combs and ribs structure to hold the tungsten plates, 80 μm gap clearance w.r.t. the nominal thickness
- Precise T-Frames to support the Si Sensor sandwiches and FEBs electronics
- Pins on T-Frames define the precision of the Si Sensor alignment between the tungsten plates

Precision support for Silicon Sensors and FEBs

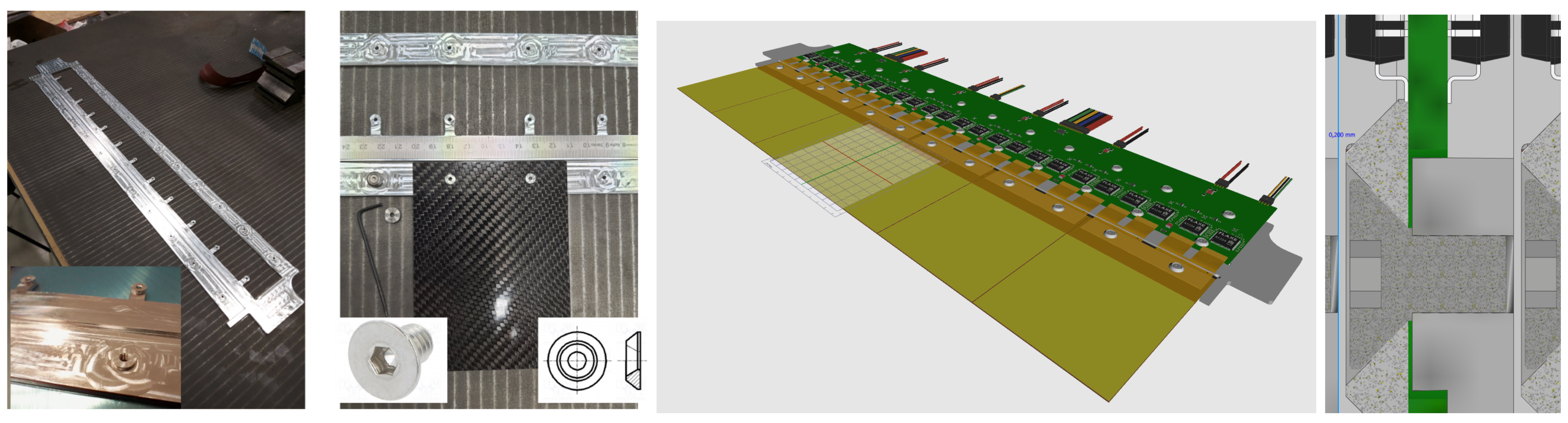


Fig. 3: Duraluminum T-Frame supporting Silicon Sensors and Front End Boards

- M2.5 mm screws used to fix all components to the T-Frames
- 250 μm thick Carbon Fiber (CF) plates to strengthen the Silicon Sandwich structure
- Nominal gap between neighbor CF plates: 200 μm
- Nominal gap between active area of neighbor Silicon Sensors: 1.7 mm
- Double sides chipset of FLAXE ASICs, 4.5 mm pitch, 200 μm clearance

Machining of duraluminum T-Frame

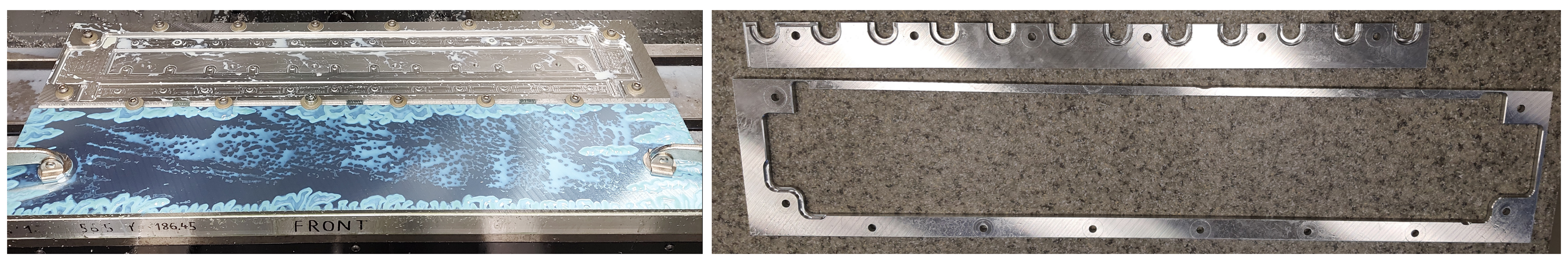
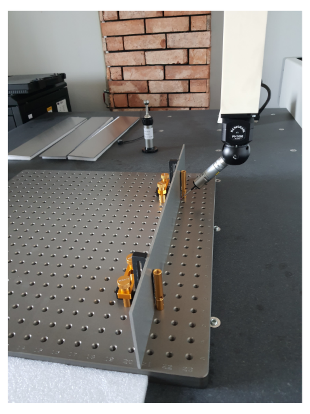


Fig. 4: T-Frame during machining and the remainder of the substrate plate

- Duraluminum: G.AL C330 precision milled plate, Alloy: EN AW-7021 [AlZn5,5Mg1,5]
- Machining on CNC table after leveling to 10 μm
- Two approaches: starting from 6 mm and 3 mm duraluminum plates
- T-Frame shape cut from the substrate after machining to minimize mechanical tension during fabrication
- Final afterprocesing by sandblasting to relax mechanical stress and improve the flatness

CMM metrology of tungsten plates



XYZ dimensions (mm)			
Plate	X	Y	Z
X1	555.1039	100.0907	3.5593
X2	555.1047	100.0864	3.5429
X3	555.1388	100.0964	3.5407
B1	555.0785	100.0640	3.5451
B2	555.0654	100.0458	3.5547
B3	555.0637	100.0366	3.5701
Nom	555.00±0.20	100.00±0.20	3.50±0.05

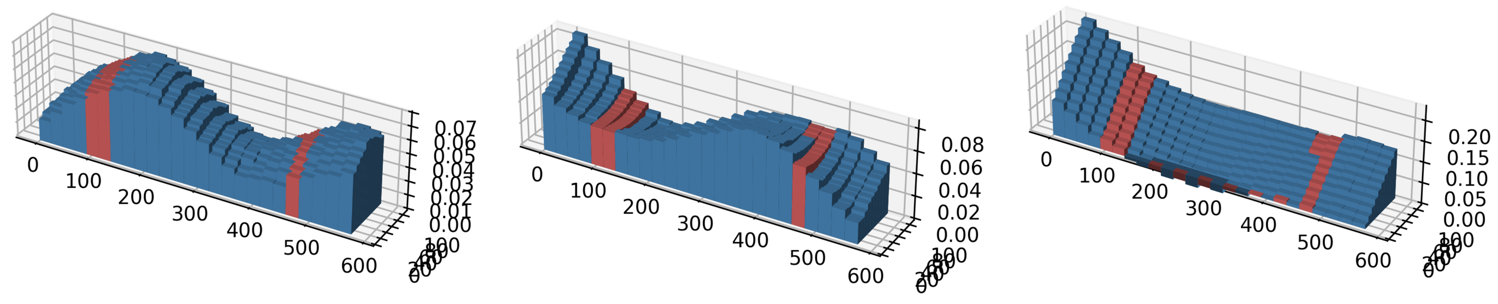


Fig. 5: Survey on CMM table, XYZ dimensions and example of thickness profiles, difference to nominal 3.5 (mm)

- Pilot orders: Xiamen Honglu Industry CO. LTD. and Beijing AT&M/CISRI
- XY dimensions within specification. Z profiles on average 50 μm thicker, flatness deviations $\sim 50 - 150$ μm

Tungsten plates inside ECAL-P mechanical frame

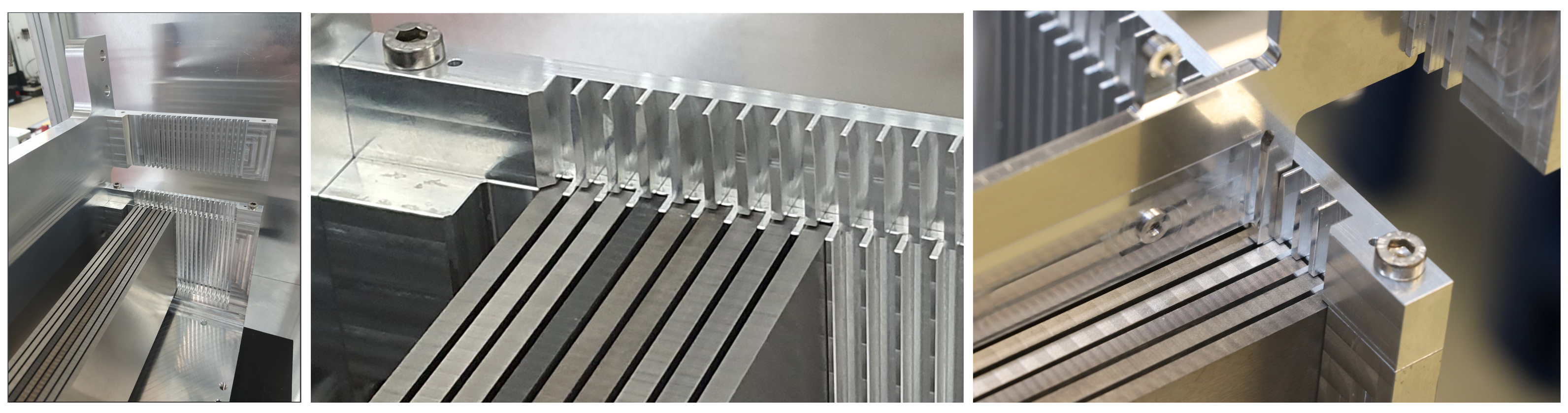


Fig. 6: Tungsten plates inserted into the combs

- Precise combs and ribs structure (bottom, side, middle and upper) to hold the tungsten plates and T-Frames
- After CMM survey the nominal spacing between tungsten plates increased from 1.0 mm to 1.2 mm

High granularity Silicon Sensors: precise tooling

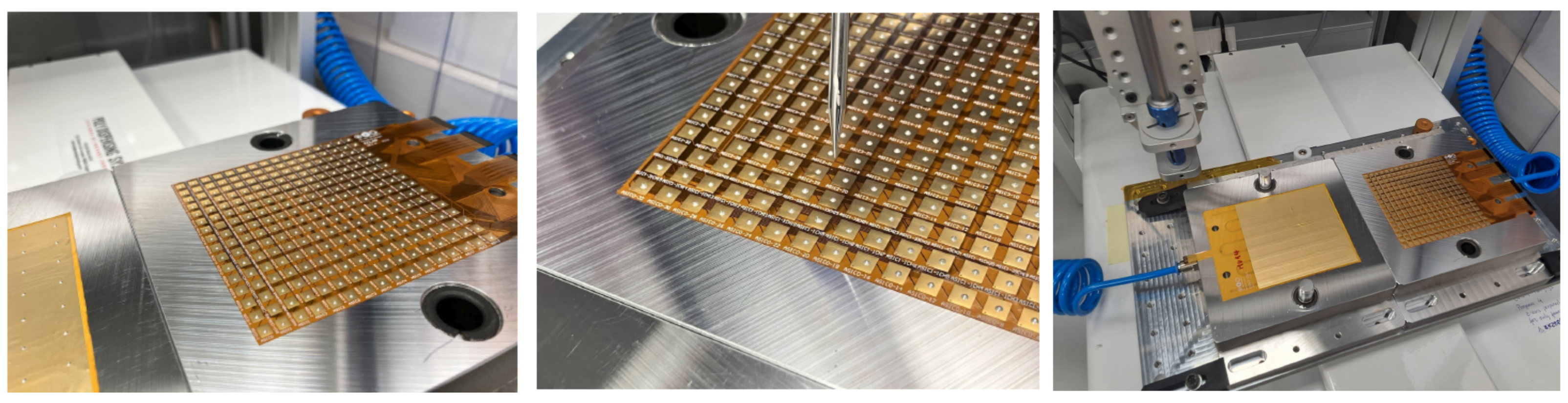


Fig. 7: Vacuum jigs for precise manufacture of Silicon sandwich at IFIC Valencia

- Multistep procedure: gluing of Si+Kaptons with conductive silver glue, curing in oven at 140 °C
- Next gluing Carbon Fiber, dedicated jigs to ensure the required precision, vacuum holders
- Robotic glue deposition, glue dots 50 μm, total thickness of all 20 test Si sandwiches below 900 μm

ECAL-P prototype at DESY Test Beam

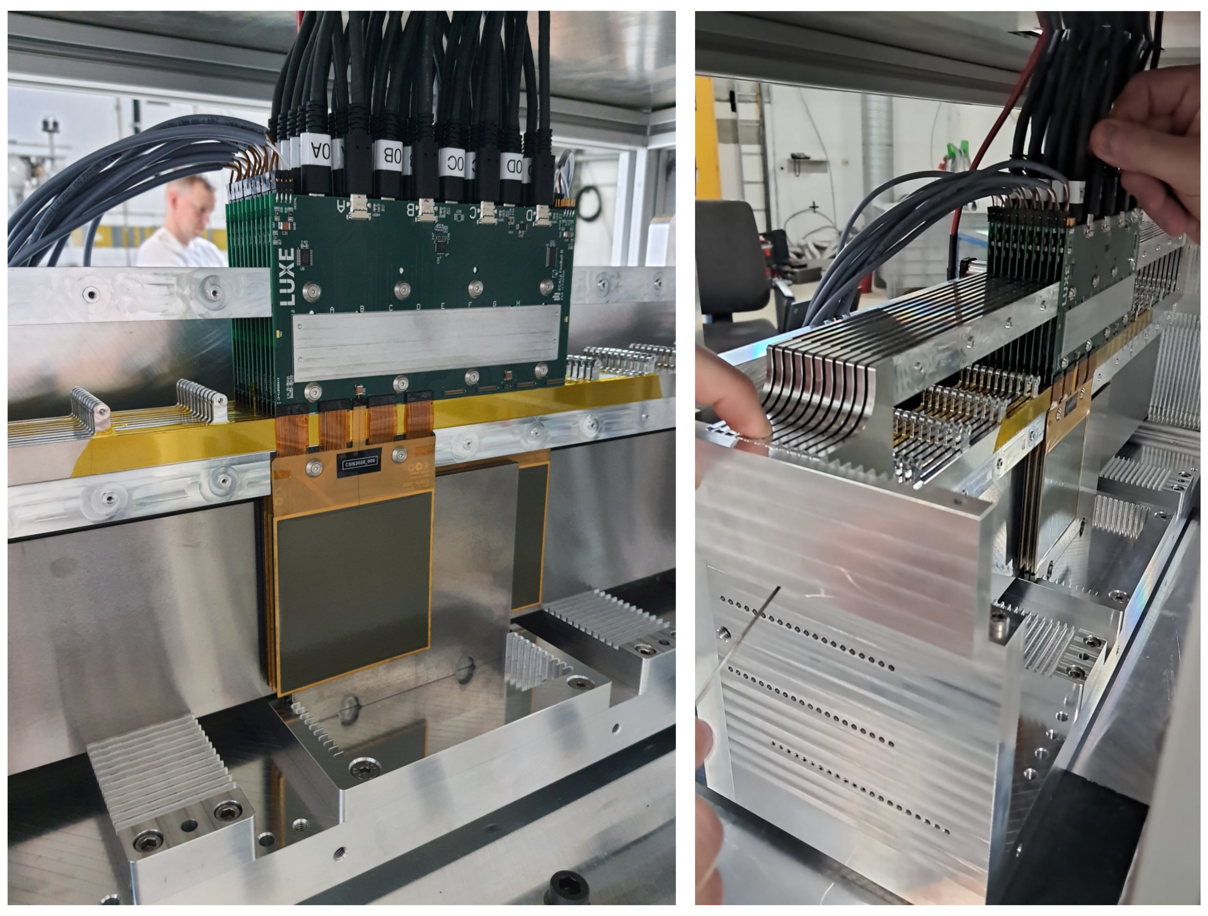


Fig. 8: ECAL-P prototype instrumented with two towers at DESY 5 GeV Test Beam in June 2025

- Silicon Sandwich before first tungsten plate as an "pre-shower" MIP detector
- Readout electronics: dedicated FLAME ASICs on FEBs developed for Test Beam by AGH Kraków

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