Test-beam measurements of instrumented sensor planes for the LUXE ECAL - a highly compact and granular electromagnetic calorimeter

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LUXE ECAL P



10⁻³-10⁶ positrons per bunch crossing, depending on ξ





LUXE ECAL



FE ASICs attached to the sensors on top of the calorimeter (FEB PCBs)

Tungsten-silicon sandwich

- 21 layers of 3.5 mm tungsten plates (1X0)
- Gap for sensors: ~1mm
- Small Moliere radius (pure W: 9.5 mm)
- Sensitive front area: 54 x 9 cm²



Sensors

Gallium Arsenid GaAs (produced by Tomsk State University)



- Single crystals compensated with Cromium.
- 15 x 10 pads, 4.7 x.4.7 mm², 0.3 mm gap.
- Aluminum traces between pads.
- Thickness 500 μm.

Silicon (produced by Hamamatsu)



- p+ on n substrate pad diodes,
- 16 x 16 pads, 5.5 x.5.5 mm², 0.01 mm gap.
- Kapton PCB with copper traces on top of the sensor.
- Thickness 320 μm (500 μm in the test-beam)

FE electronics, FLAME

 32 channel ASIC of ultra-low power (5 mW/channel), CMOS 130 nm. Developed within FCAL

- Fast sampling (20MSps) 10-bit ADC converter in each channel.
- Shaping time 50 ns.
- Two swichable gains.
- ENOB > 9.5 .

Dedicated adaption for LUXE: FLAXE

ASSOCIATION





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Test-beam scheme



- Six telescope planes for reconstruction of the electron trajectory.
- Scintillator counters upstream and downstream of the telescope to form a trigger.
- More than 100 x 10⁶ events recorded, distributed over nearly the full (GaAs) or half (silicon) sensor.





DAQ and Trigger



For several runs also raw data mode, i.e. recording 64 ADC samples per trigger.



Calibration of the read-out chain

Feeding in a known test-charge via a capacitor- resistor network each read-out channel is calibrated





Alignment Telescope planes

- 50 k at the beginning of each run used.
- Reconstruction of electron tracks with corryvreckan package.

Alignment telescope-sensor

- Use signals above a predefined threshold.
- Predict the impact point on the sensor using the reconstructed trajectory in the telescope (resolution 35 μm).
- Maximise the number of hits predicted on a given pad.
- More sophisticated: Hough transform .

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Response of a single pad and comparison to simulation



- Energy deposition from GEANT4 (QCSP_BERT physics list).
- Energy to create an electron-hole pair: 3.6 eV.
- 3.47 ADC counts per fC.
- Scale factor 1.05.

Fit with a Landau distribution convoluted with a Gaussian.

Determination of the "most probable value" MPV, here MPV = 21.9 ADC counts



Response as a function on the local pad coordinate



Pronounced signal drop at the edges of the pads on the GaAs sensor

Response as a function on the local pad coordinate



"Fine structure" on the silicon sensor

Response covering the gaps between pads



- No drop of the sum of signals for silicon (gap 10 μ m).
- 42 % drop of the sum of signals for GaAs (gap 300 μm, and aluminum traces).

Signals from electrons hitting the traces

- Using electrons with predicted impact points in the trace area.
- Looking for signals assigned to pads connected to the traces in the red area.





The Ratio of the integral of these depositions to the integral of depositions in a pad near the red area is 2×10^{-4} .

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Homogeneity of the response over the sensor area



Summary

- Two types of planar pad sensors, silicon and GaAs, are studied in a 5 GeV electron beam.
- Signals are routed to the edge of the sensor via copper traces on Kapton PCB (silicon) or aluminum traces embedded on the sensor (GaAs) to obtain thin sensor planes.
- A dedicated front-end (CMOS 130 nm) and back-end (FPGA) electronics (almost as foreseen for LUXE) is used.
- The distribution of the signal size is nicely reproduced by a GEANT simulation.
- Signal drop near the edges is more pronounced in GaAs sensors than in silicon sensors (larger gap, aluminum traces in the gap for GaAs).
- Signals on the traces are visible but negligible compared to depositions on the pads.
- The homogeneity over the sensor area is estimated to be about 3 %.





Test-beam crew







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Recent hardware progress

Sensors (Tel Aviv)

- 90 sensors delivered.
- More than half tested and match quality criteria.
- Kapton PCB designed.

ASICS (Cracow)

- 1200 ASICS produced.
- Currently in the packaging process.
- Characterisation PCB produced.
- FEB design ready.





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Recent hardware progress

Mechanics (Warsaw)

- 6 tungsten plates delivered (two vendors).
- Thickness and flatness measurements show satisfactory results.
- Prototype of the mechanical frame in production. Test with sensor mock-ups in September.

Sensor Planes (IFIC Valencia)

- Probe station installed.
- Gluing robot and metrology tests ongoing.
- Prototypes of carbon fibre plates under survey.





Next steps

Next steps:

- Mounting of (mock-up) sensor planes in September
- Working Group meeting in Cracow end of September
- Test-beam with FLAXE FE ASIC in spring 2025



backup

Sensors and characterisation











backup

Sensor plane





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