Position Sensitive Detectors 14 (PSD14)

1 – 4 September 2026 | Queen Mary University of London, London, UK

Design and Beam-Test Performance of a Highly Compact Si-W Electromagnetic Calorimeter

Veta Ghenescu (Institute of Space Science - INFLPR Subsidiary, Romania)

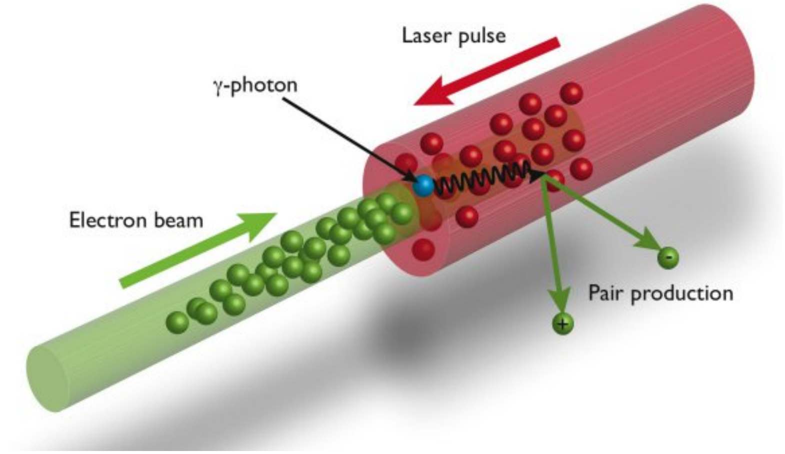
[on behalf of the ***FCAL Collaboration***]

DESY. INSTITUTE OF SPACE SCIENCE INFLPR SUBSIDIARY TEL AVIV UNIVERSITY אוניברסיטת תל אביב IFIC AGH UNIVERSITY OF WARSAW

Outline

- Motivation
- Concept & ECAL-P design
- Ultra Compact ECAL-P prototype performance
- Conclusions & Future steps

Motivation – LUXE experiment

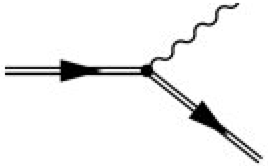


- Low energy experiment based at ***DESY-XFEL***
- Collisions of ***EuXFEL e^- beam*** with high-power ***LASER***
- Synergy between particle physics and LASER physics
- ***LUXE*** will study the behavior of ***QED*** in the strong-field regime

Main process of interest:

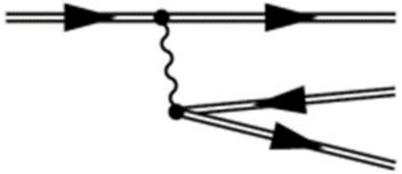
- Non-linear Compton scattering:

$$e^- + n\omega_L \rightarrow e^- + \gamma$$



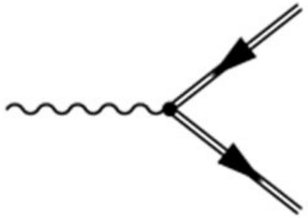
- Non-linear trident process:

$$e^- + n\omega_L \rightarrow e^- + e^+ e^-$$



- Non-linear Breit-Wheeler process:

$$\gamma + n\omega_L \rightarrow e^+ + e^-$$



EuXFEL electron beam:

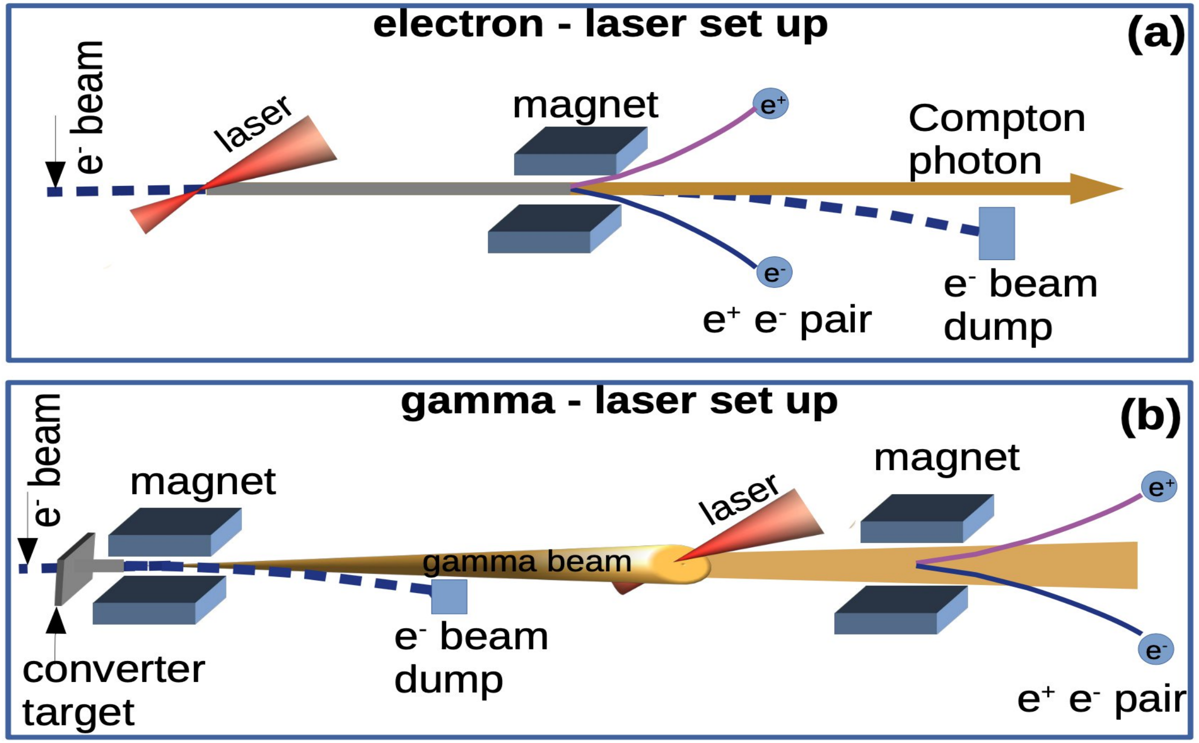
- 16.5 GeV @10 Hz bunch trains
- $1.5\text{x}10^9$ e^-/bunch
- 1 out of 2700 for LUXE

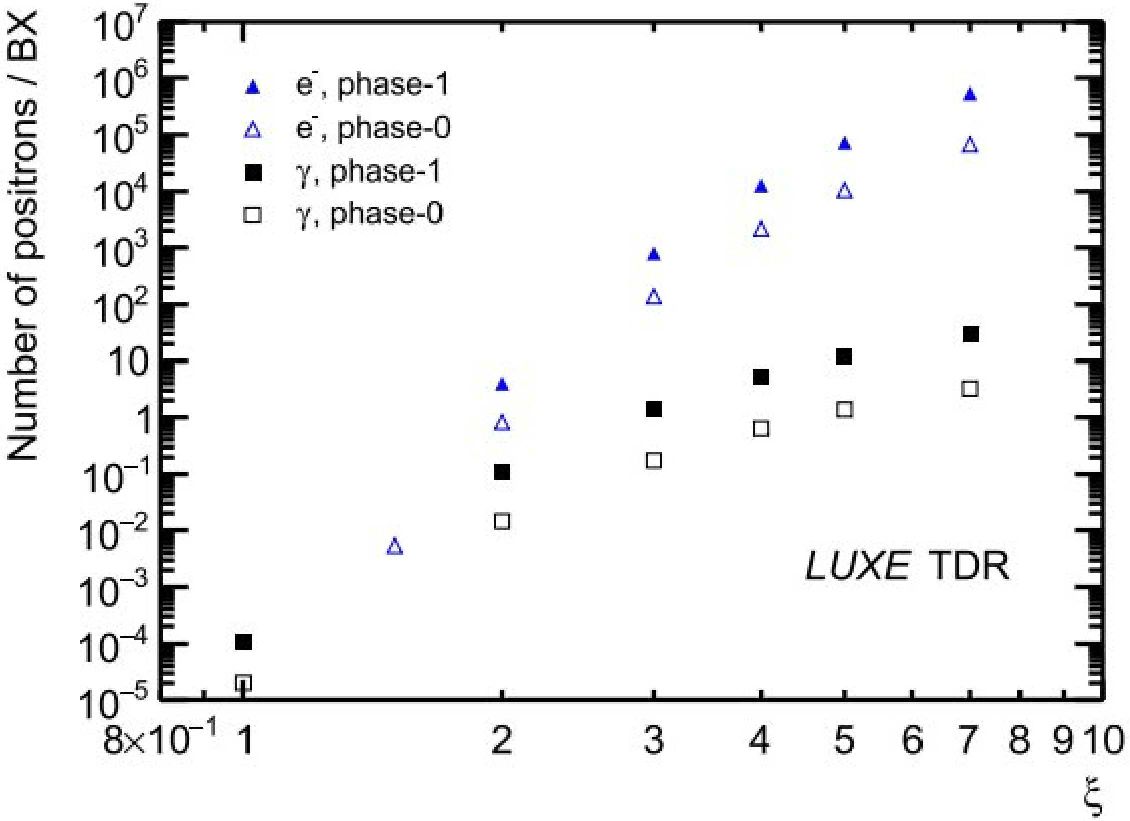
Laser system:

- Ti:Sa laser with 800 nm @ 1 Hz repetition rate
- Power:
  - ✓ Phase 0: **40 TW**, focal spot size: 3 or 8 µm ($\xi < 7.9$);
  - ✓ Phase 1: **350 TW**, focal spot size: 3 µm ($\xi < 23.6$);

LUXE TDR: Eur. Phys. J. Spec. Top. 233 (2024) 10, 1709-1974
LUXE website: https://luxe.desy.de

Motivation – LUXE experiment





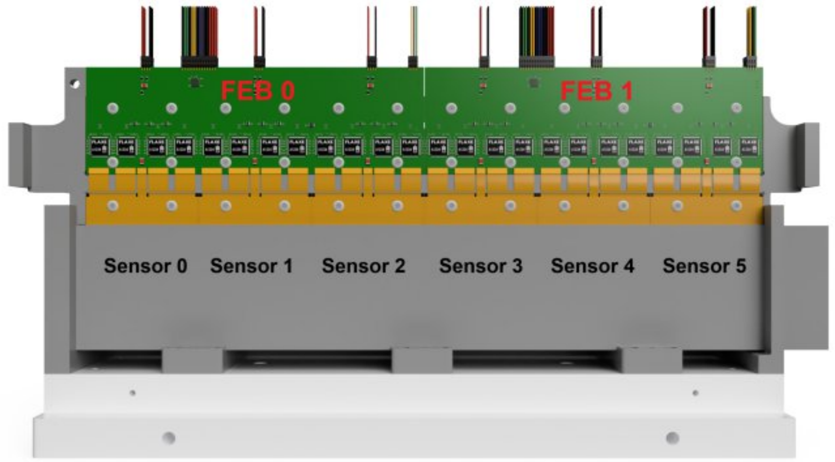
Expected production rate as a function of ξ parameter

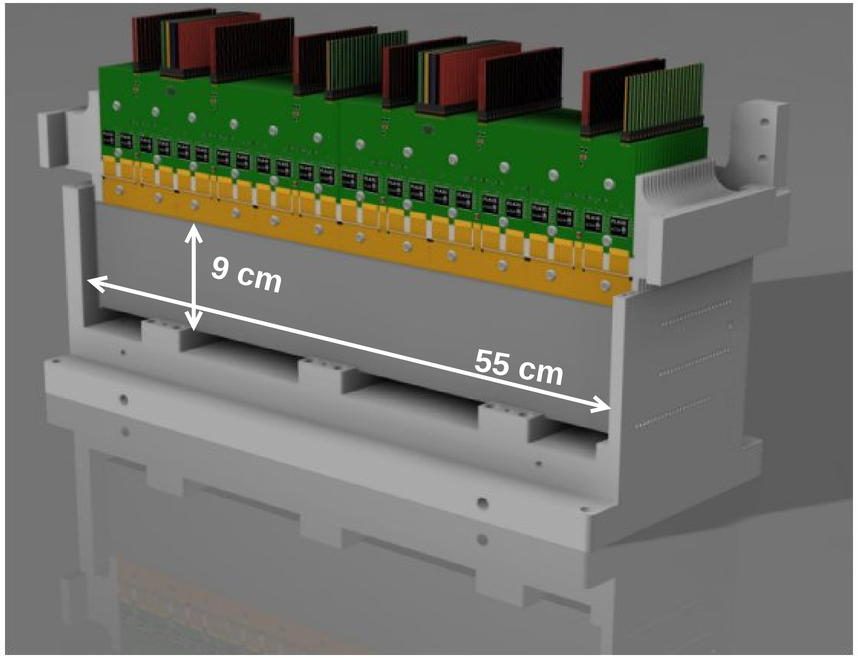
Operation modes

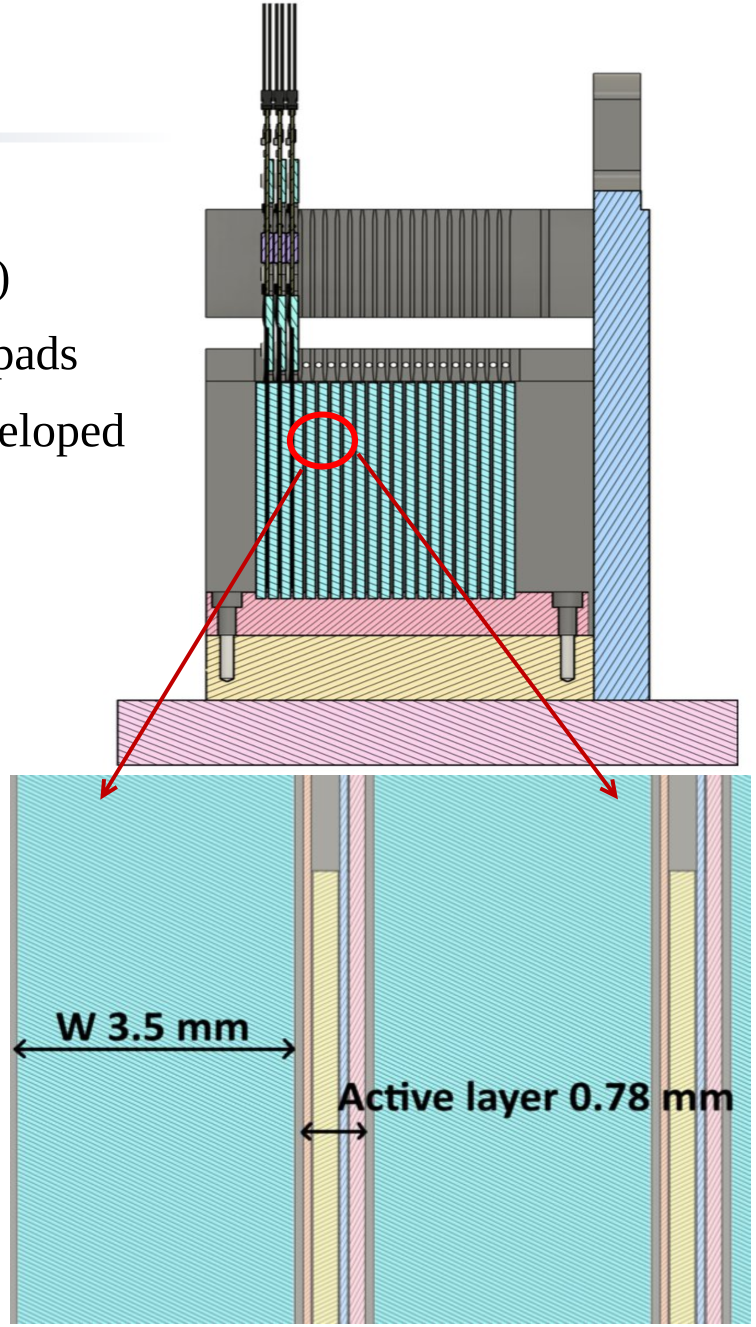
- **electron-laser**:
    - Up to 10^9 photons and electrons per pulse ⇒ dedicated instruments needed for precise spectra and flux measurement.
        - 10^{-3} – 10^5 e+ per pulse ⇒ "standard" high precision tracking and compact high-density calorimeter
- **gamma-laser:**
    - Up to 10^9 photons per pulse and
    - 10^{-5} – 10 e+ e − pairs ⇒ high precision tracking and calorimetry also for electron spectra measurement.

ECAL-P prototype: design

- 21 tungsten plates, 3.5 mm (1 X_0) thick
- 1mm gaps between W plates for minimal transverse size (effective Molière radius)
- 6 silicon sensors (Hamamatsu/CALICE) per layer, each 90 x 90 mm^2 with 16x16 pads
- Front-end boards above the sensors, with dedicated readout ASICs (FLAXE) developed for LUXE.
- Very compact sampling calorimeter: 54 x 9 x 9 cm^3

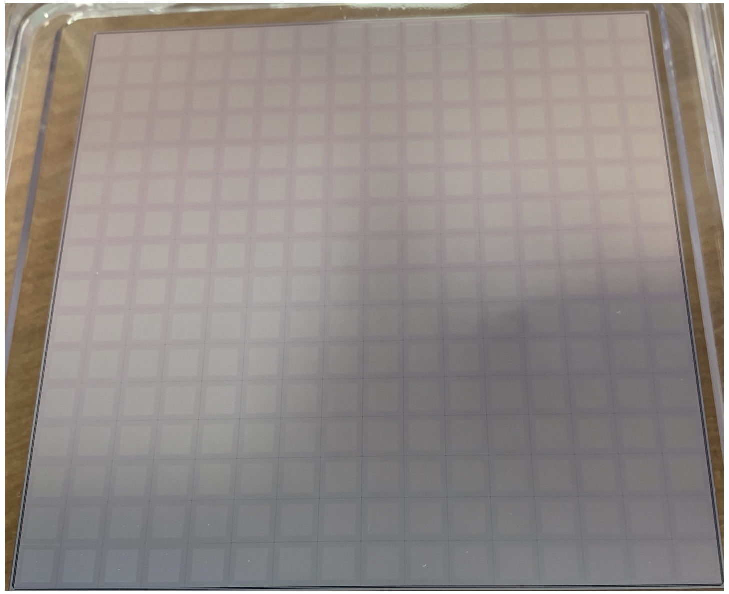




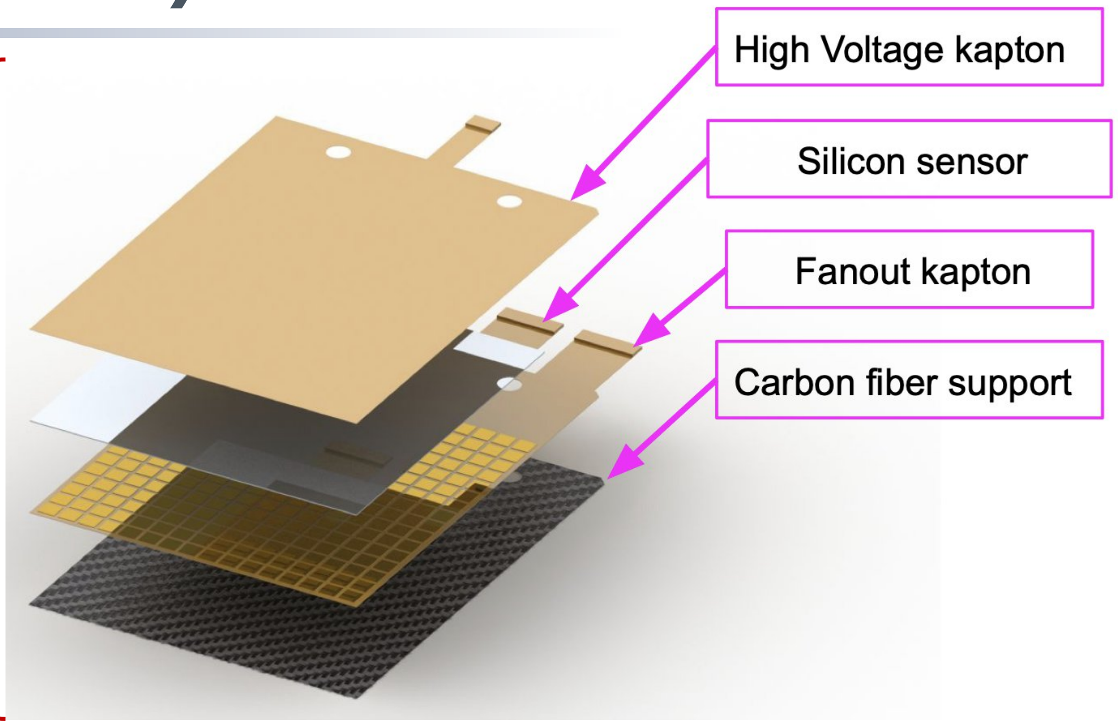


Compact Silicon Sandwich (CSIS) module

Silicon sensor



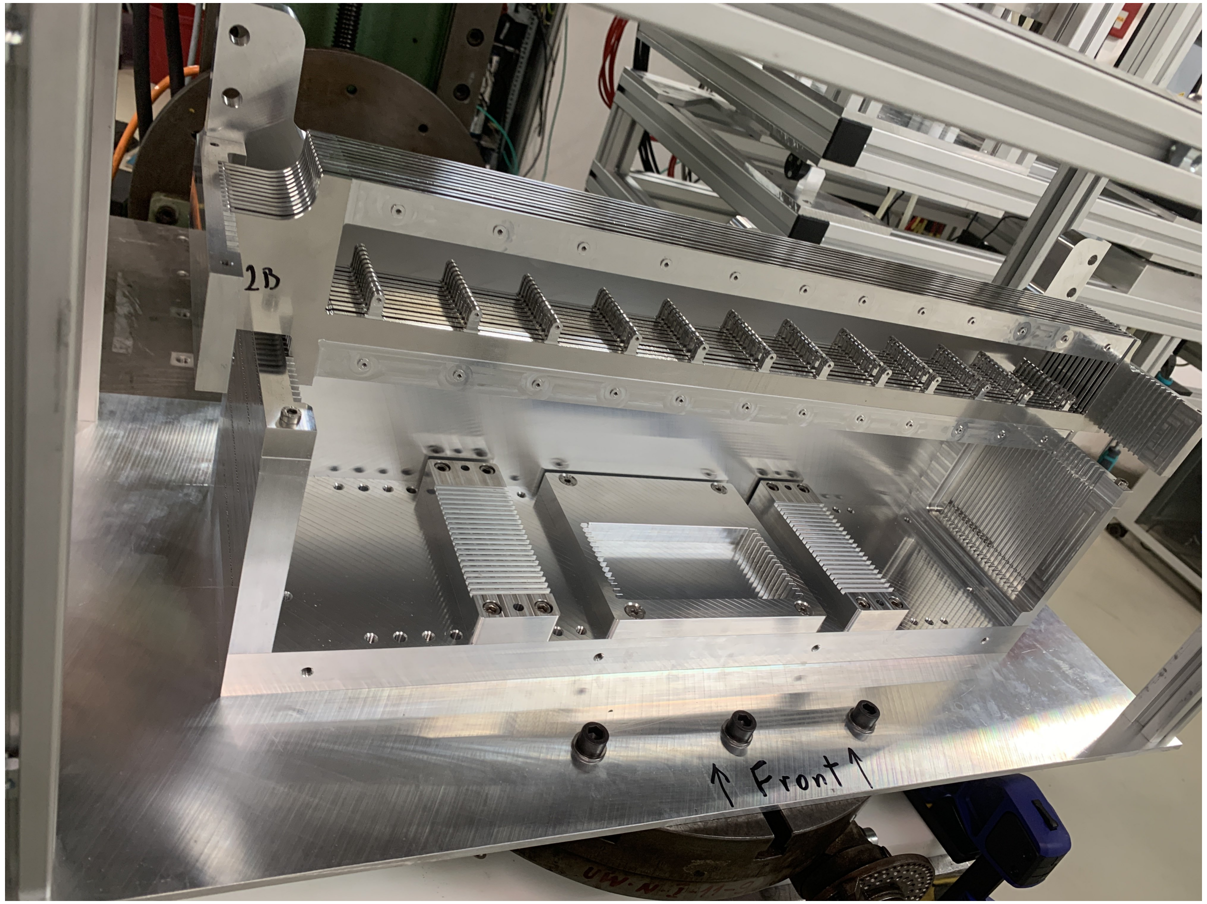
Thickness ~ 850 µm
(including glue layers)



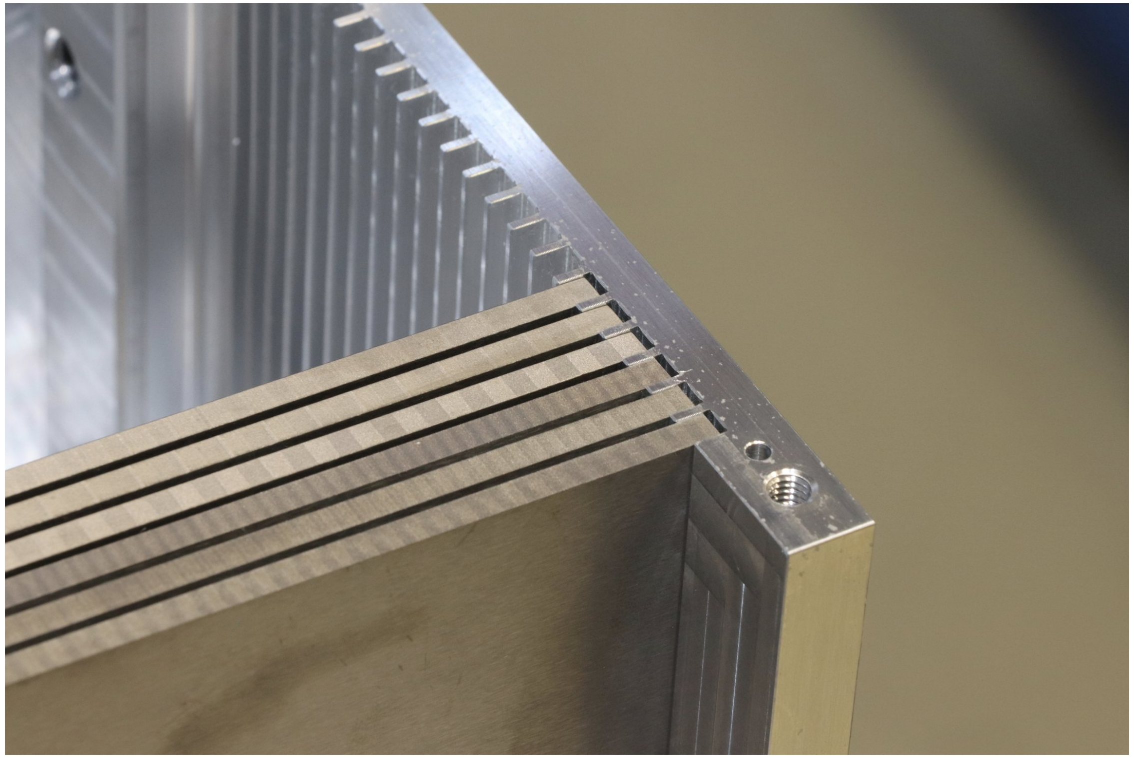
- Array of 16x16 pads of 5.5x5.5 mm^2
- Thickness 320µm
- 10µm between pads
- p^+ on n substrate, produced by Hamamatsu

Mechanical framework

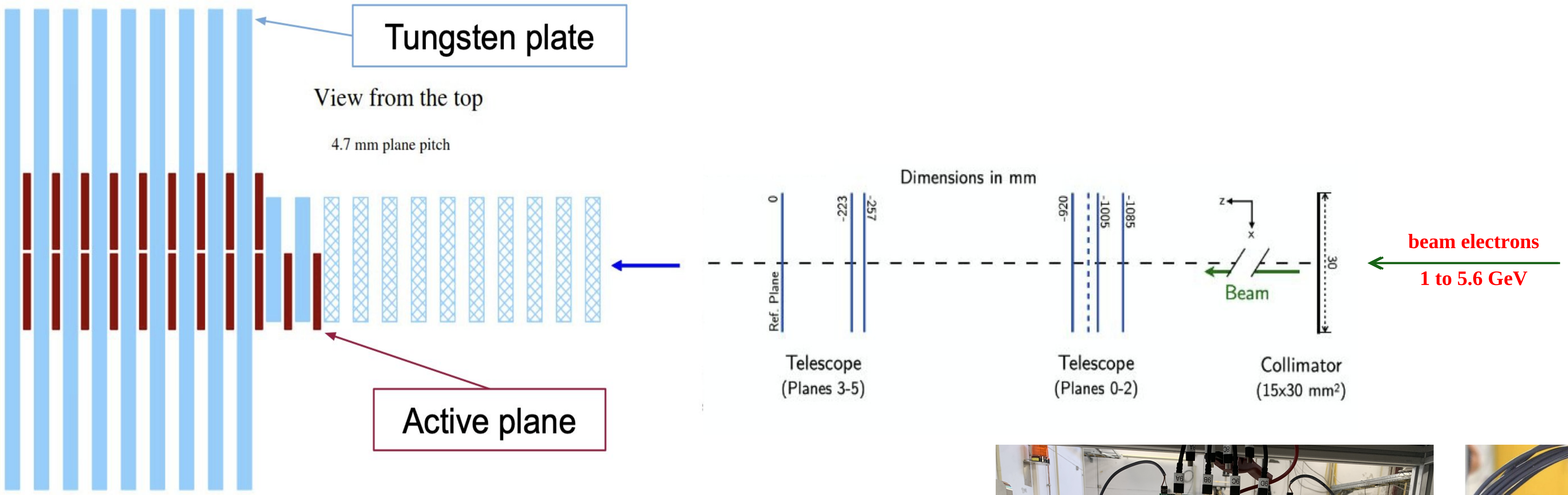
- **Final detector frame with supports for the electronics boards**

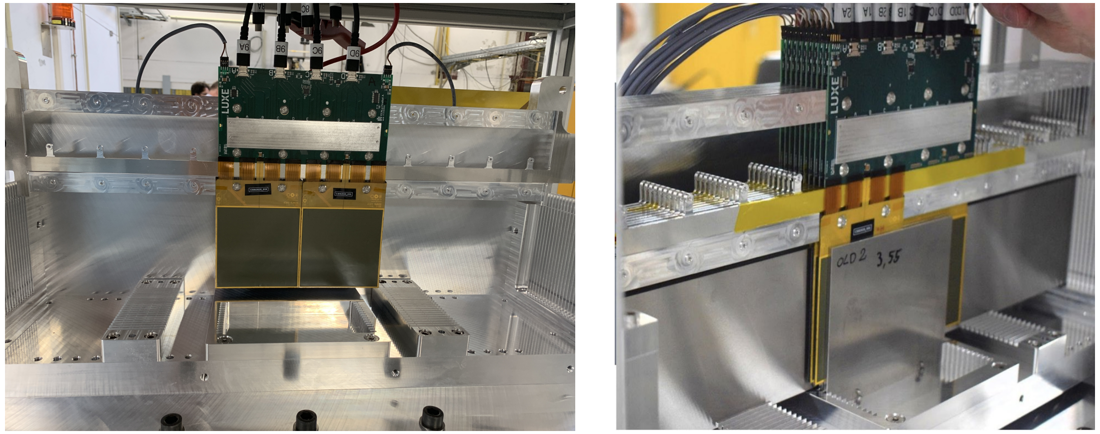


- **6 tungsten plates inserted**



ECAL-P prototype: TB campaign – June 2025

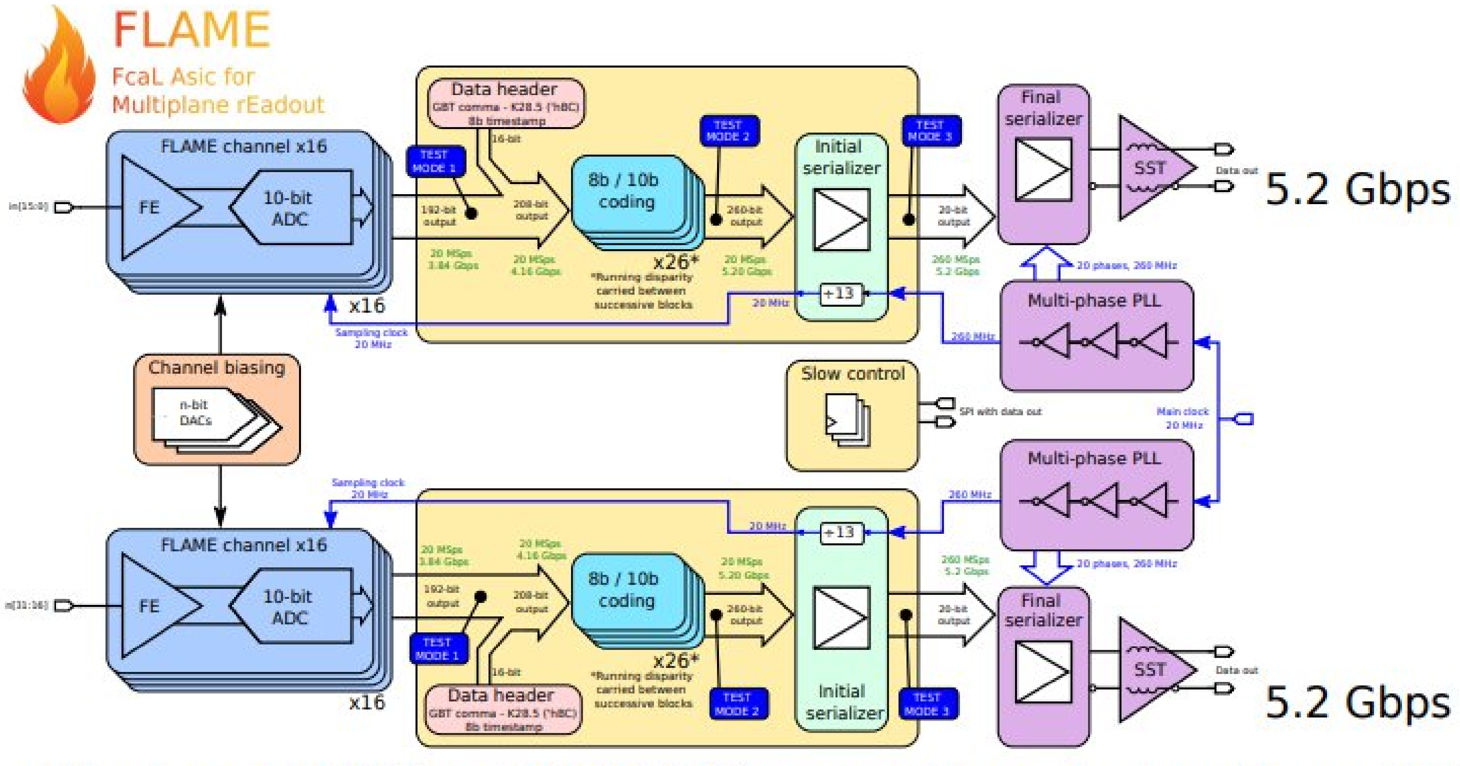




- Electron energies: 1 to 5.6 GeV
- Telescope based on ALPIDE sensors (6 planes)
- 20 CSIS modules over 11 layers w/ or w/o tungsten absorbers
- Runs with 4 to 10 additional W absorbers in front of the active layers
- Scans of the electron incidence angle from -15° to +15°, in 5°step
- Each run contains ~1 million events
- High statistics allow analysis of rare effects (e.g. charge sharing, double showers, effect of sensor gaps on shower/energy resolution)

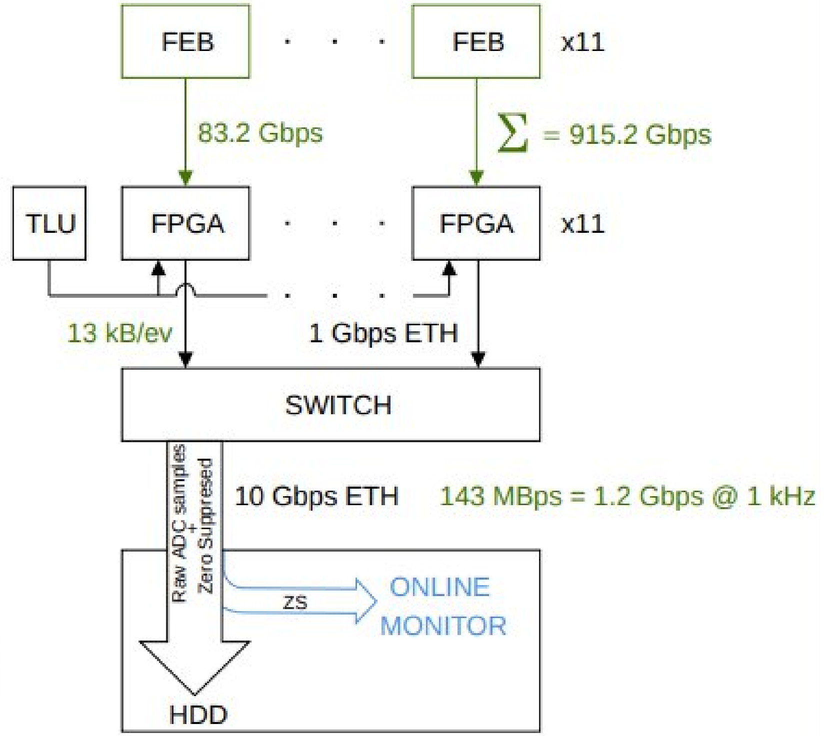
Readout electronics and DAQ

- **FLAME readout ASIC:**



- Two 16-channel blocks, common biasing & slow control;
- Analog front-end with CR_RC shaping T_{peak} = 50ns & 20 MS/s
- 10 -bit SAR ADC in each channel
- Two 5.2 Gbps serializer&transmitters per ASIC, one per each 16-channel block

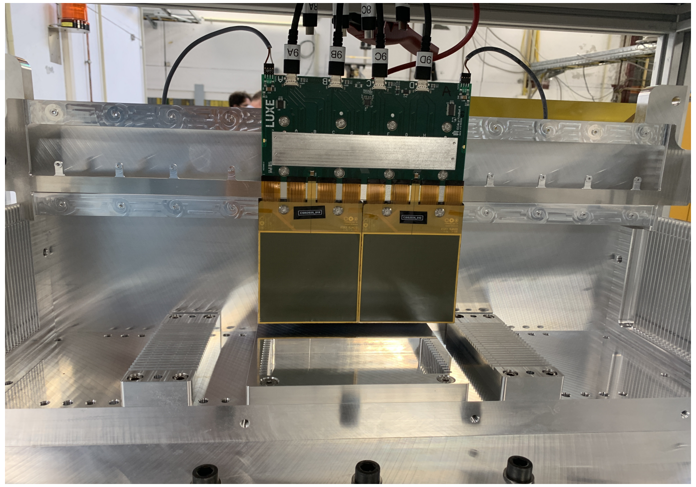
- **Back-end electronics and DAQ**



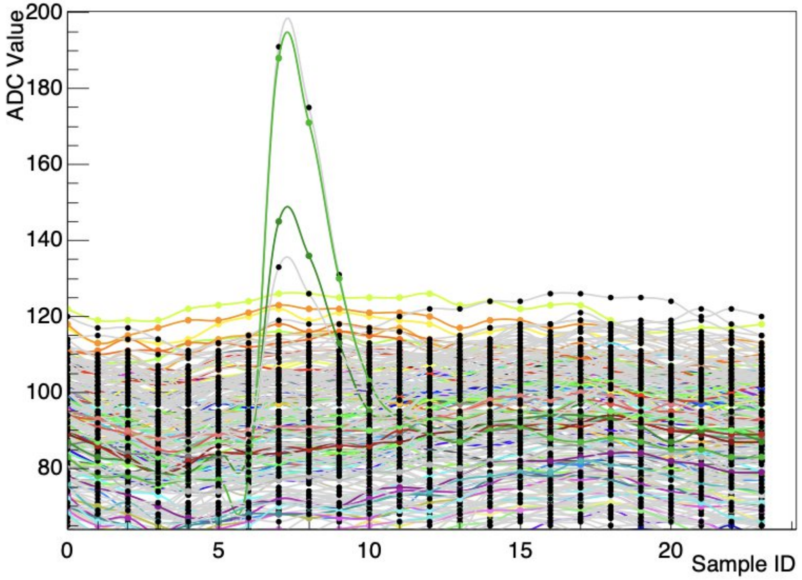
Readout with Zynq architecture:

- FEB contains 8 FLAMEs (256 channels)
- FPGA back-end
- Embedded Linux on ARM processor

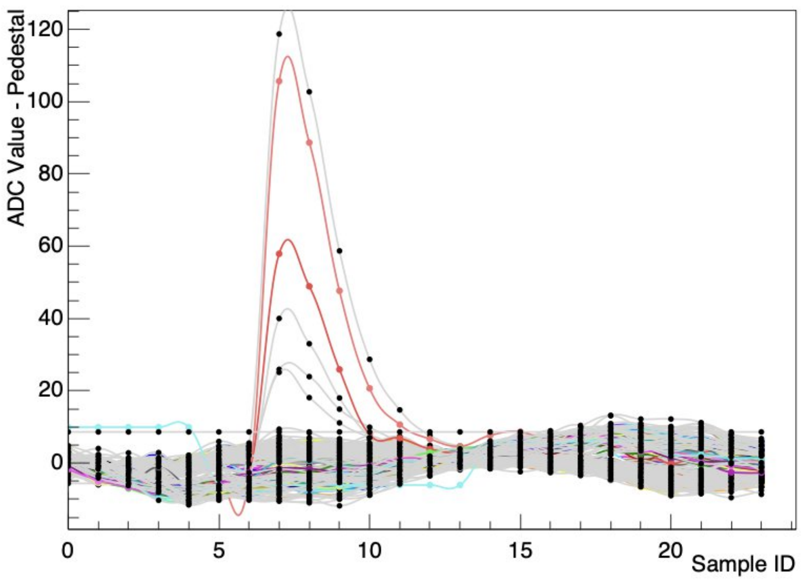
Signal processing and calibration



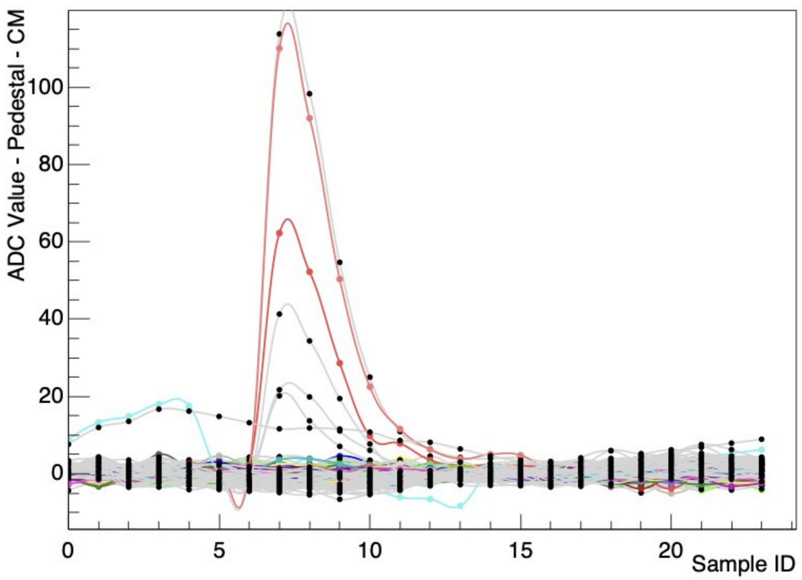
- Important work has been done to process the raw data and calibrate the detector signal
- To calibrate the detector, data have been collected without tungsten plates: **MIP particle**



RAW ADC Data



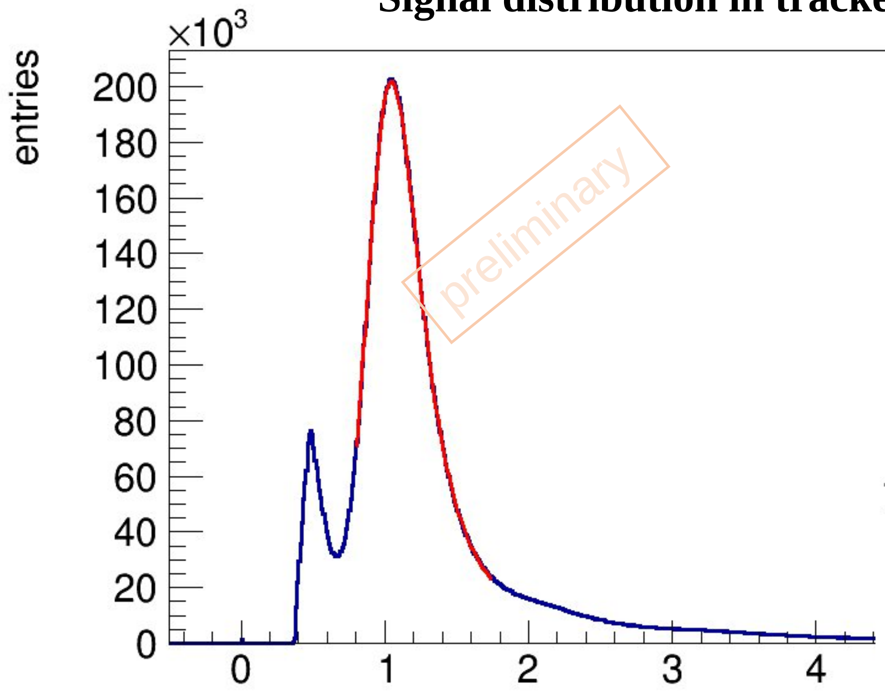
Pedestal subtracted



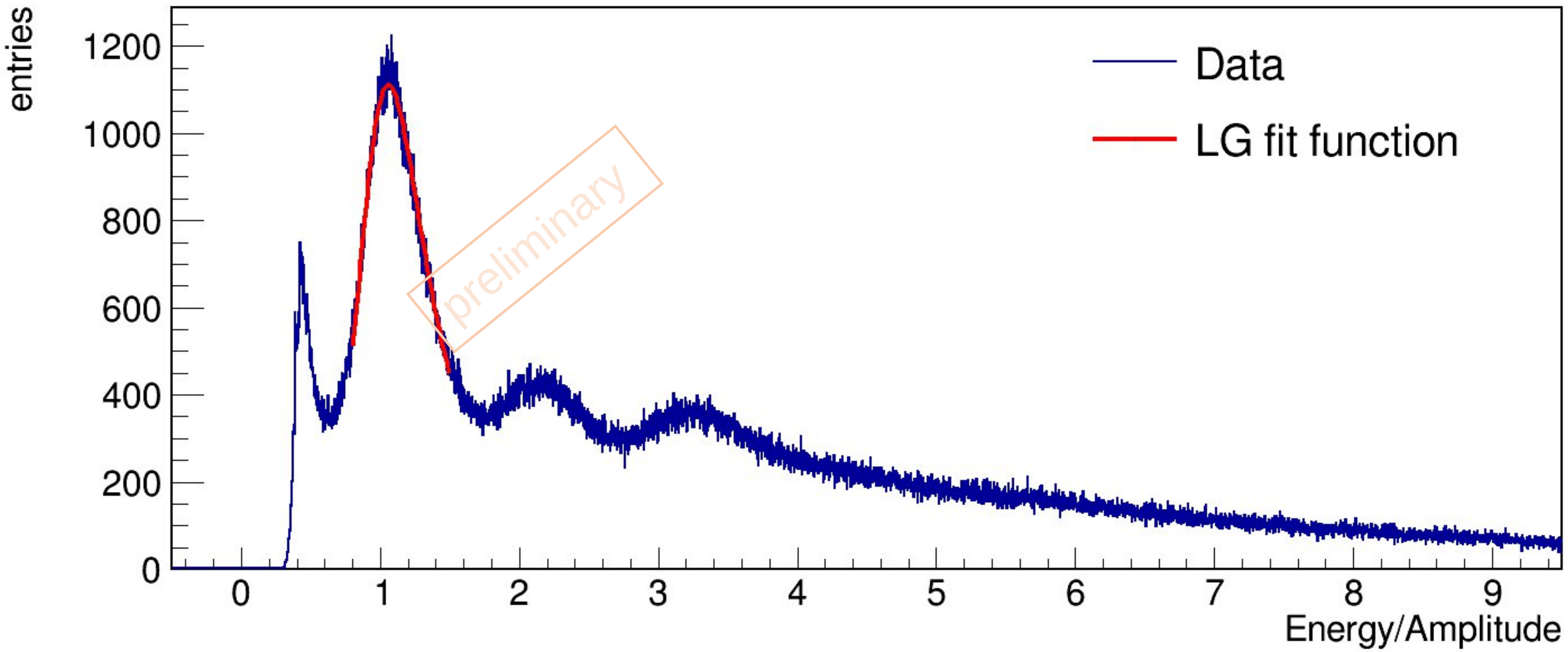
Pedestal and Common Noise subtracted

Signal processing and calibration

Signal distribution in tracker mode

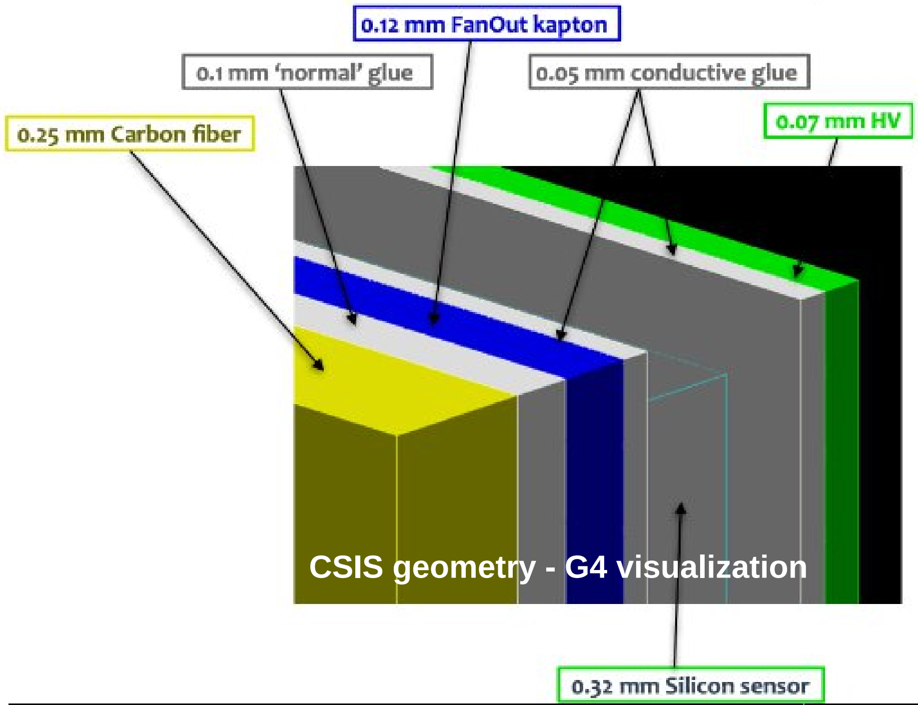


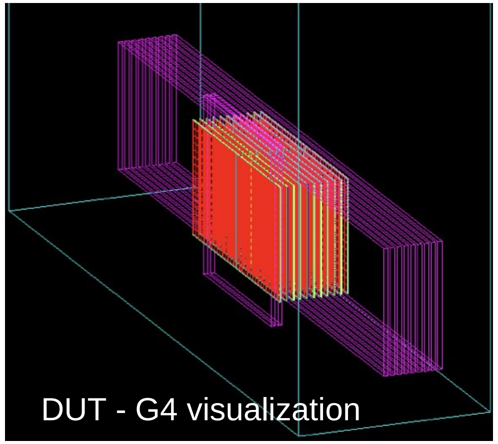
Signal distribution w/ tungsten plate

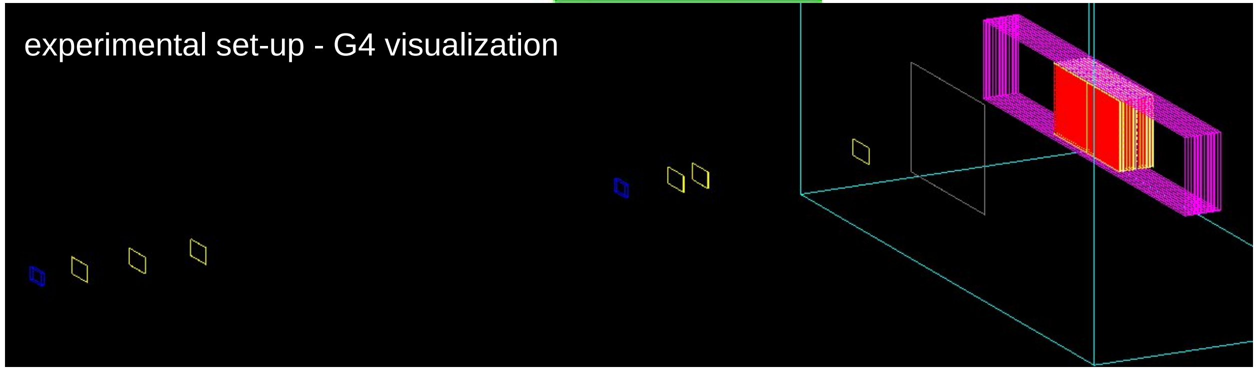


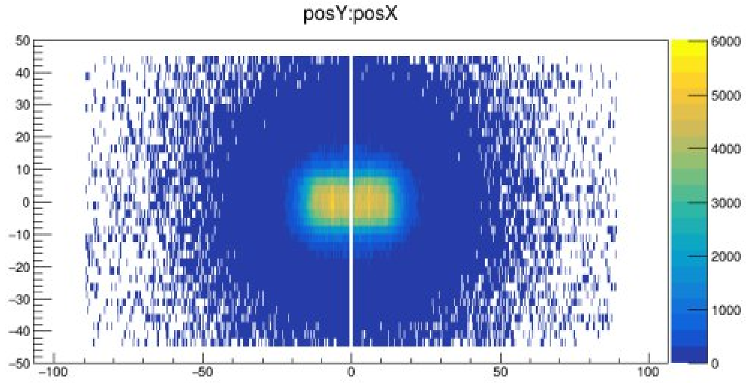
ECAL-P prototype: simulation studies

- A full and detailed ***Geant4*** simulation of the test beam has been created

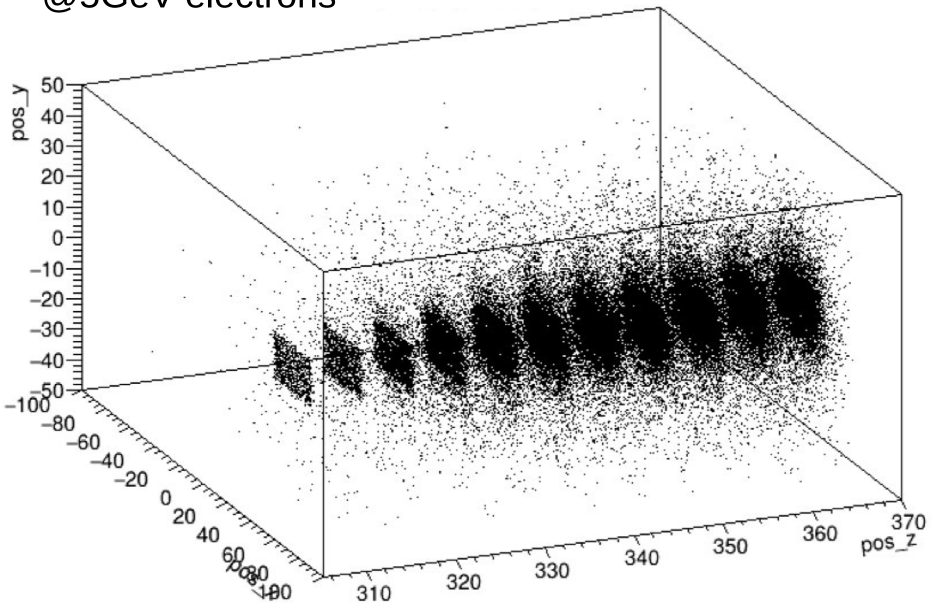






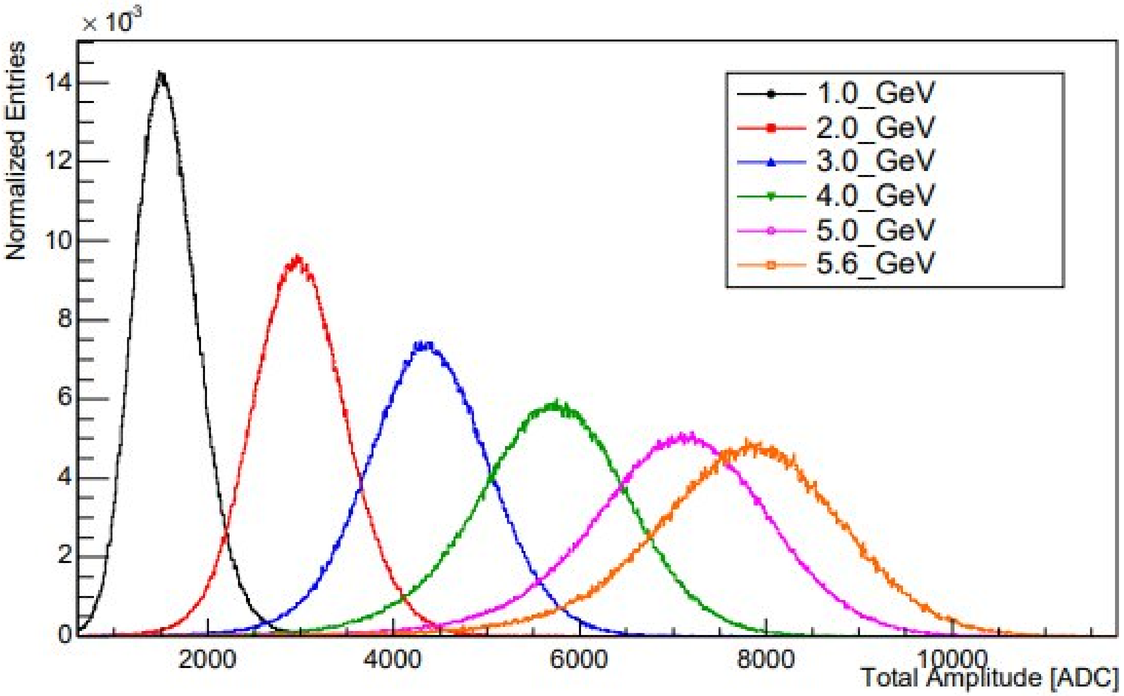


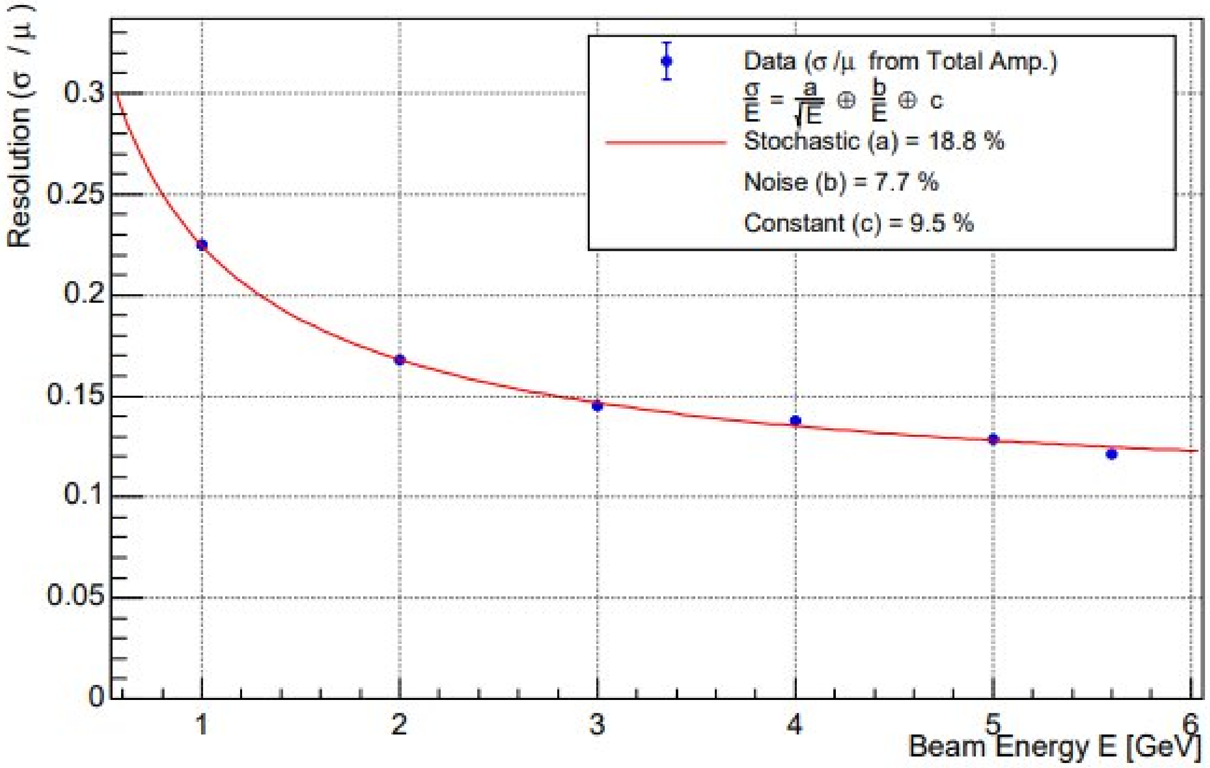
Hits in silicon sensors
@5GeV electrons



Preliminary results: energy distribution & resolution

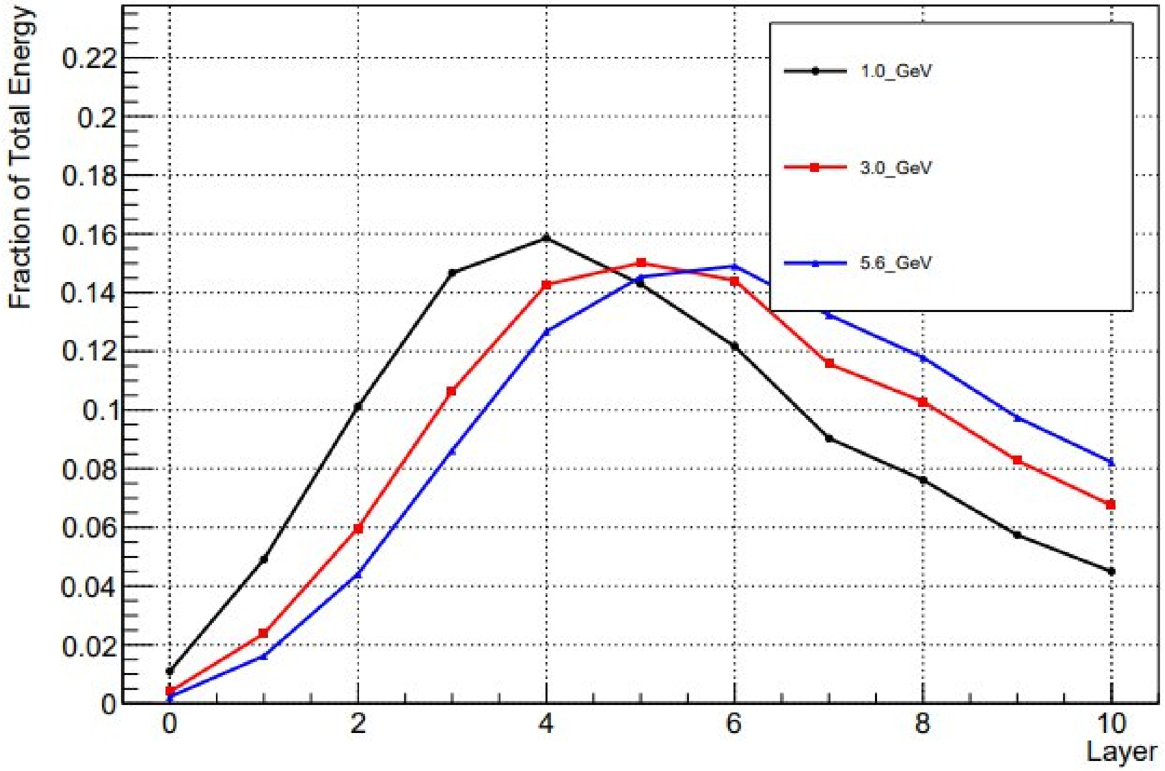
- Distribution of deposited energy for different beam energies;
- For higher energies, part of the shower energy escapes longitudinally;

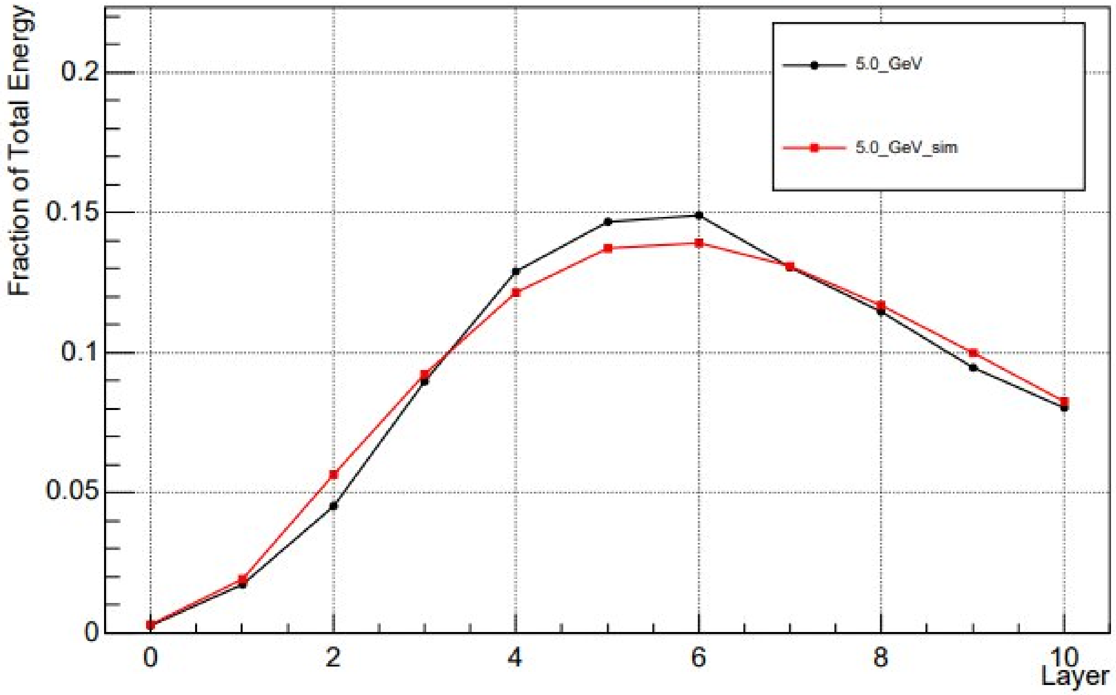




Preliminary results: longitudinal shower development

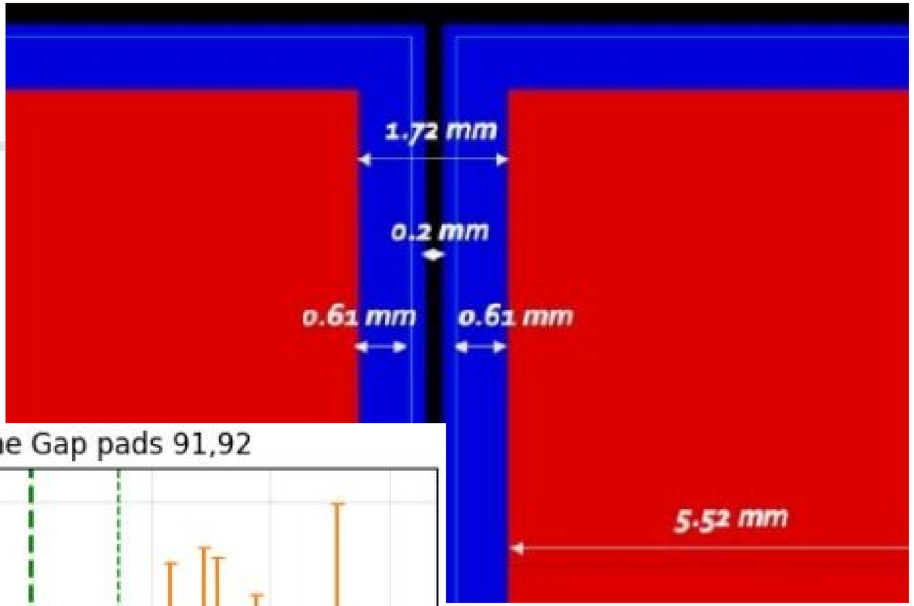
- Maximum shower deposition moves from 4th to 6th layer with increasing beam energy.



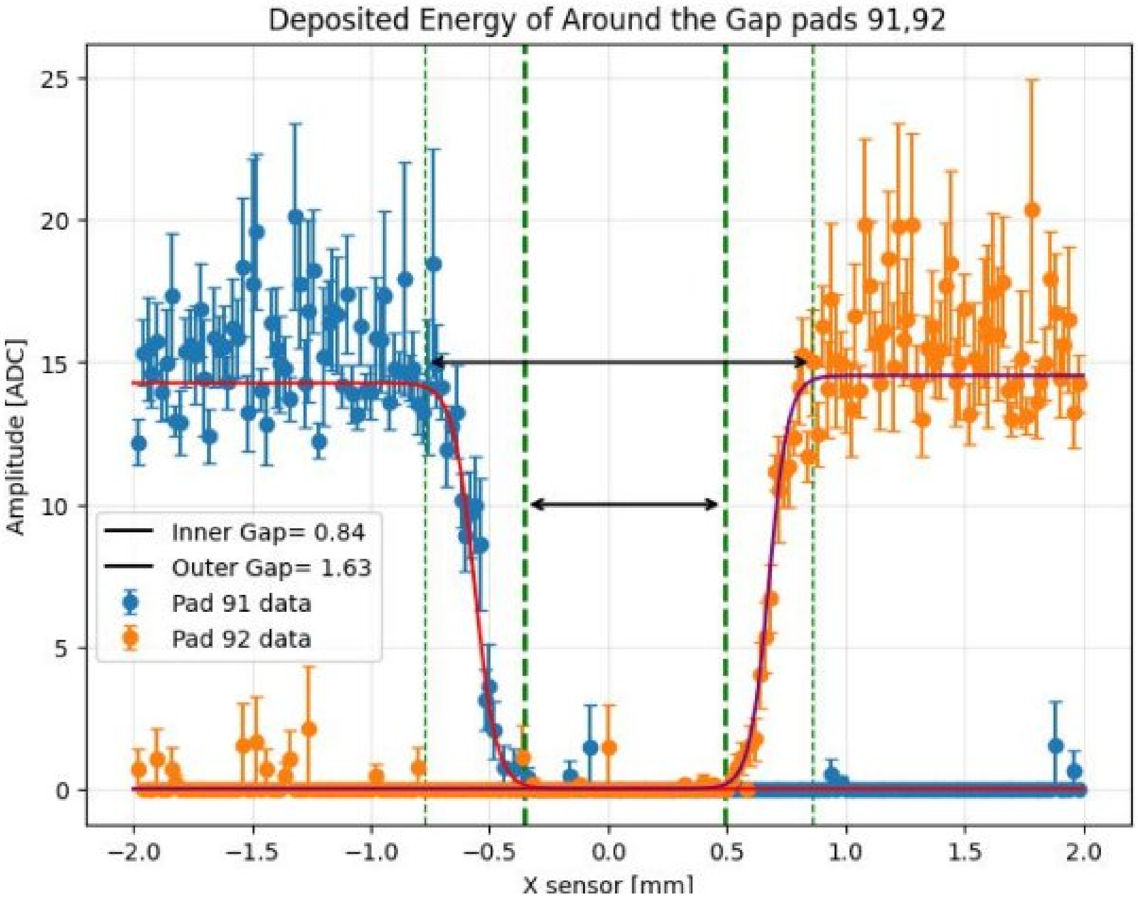


Preliminary results: inter-gap sensors

- 11 Si sensor layers w/o tungsten plates
- 5 GeV electron beam
- Average sensor response in the inter-sensor gap region



- Bold Green: 1% of the energy
- Light Green: 99% of the energy
- Inner Gap: fully blind zone
- Outer Gap: partial efficiency



Preliminary results: inter-gap sensors

- 8 Si-W layers sandwich
- 5 GeV electron beam
- Signal loss up to **~ 50%**

$$f(x) = c - Ae^{-\left(\frac{|x-\mu|}{\sigma}\right)^{\beta}}$$

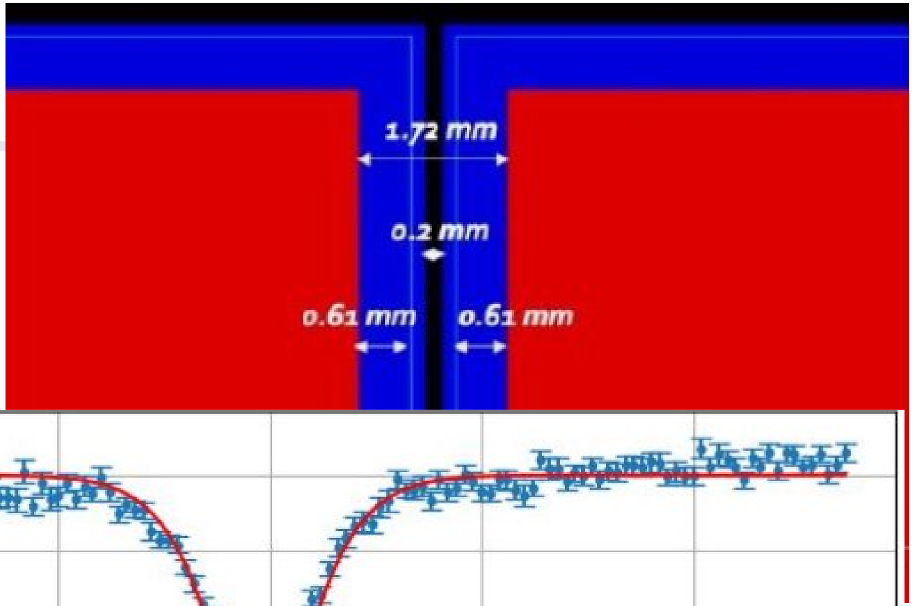
A - Maximum signal loss [MIP]

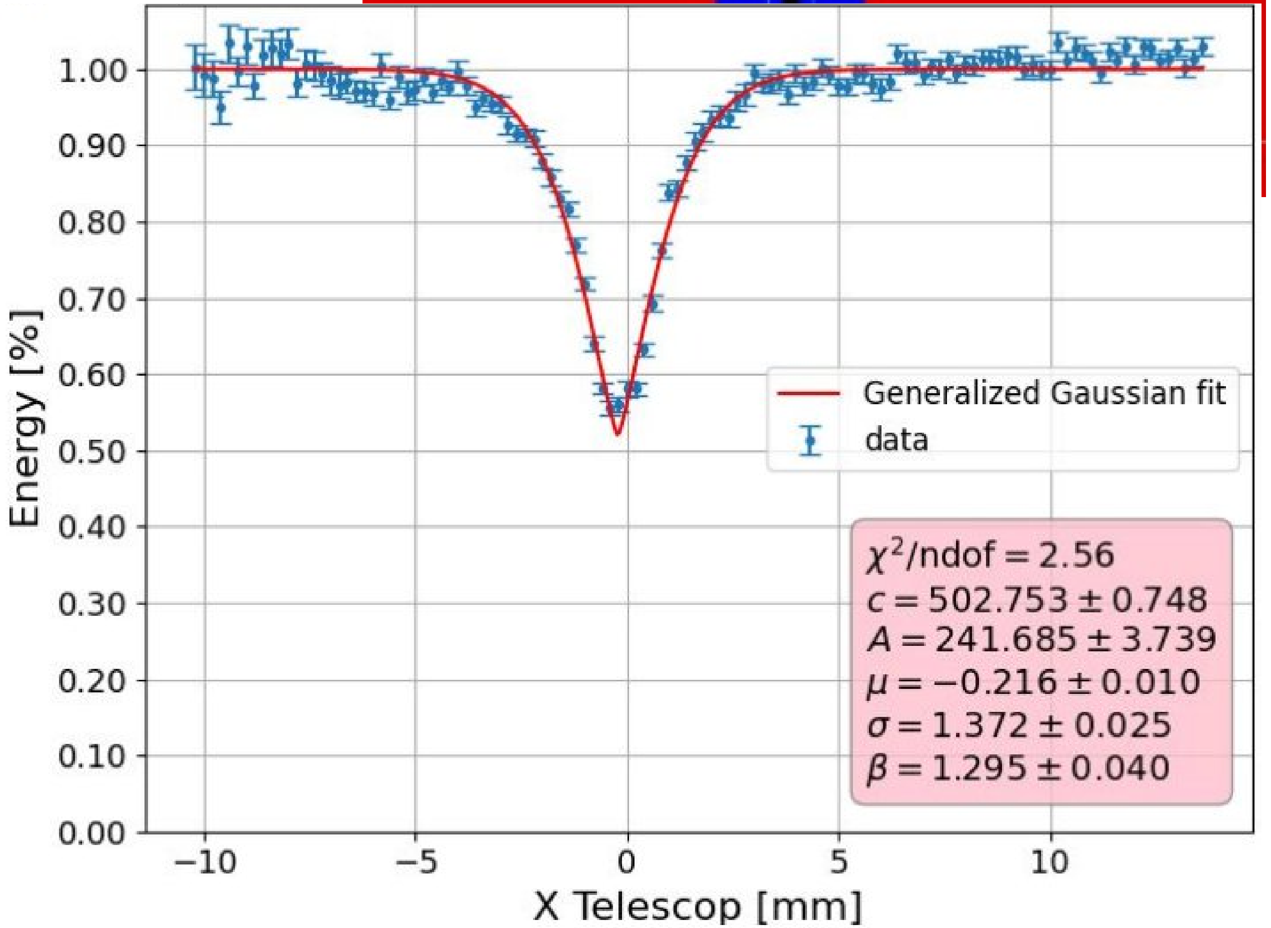
c - Signal outside the gap [MIP]

μ - *Center of gap [mm]*

σ - *Gaussian spread [mm]*

β - *Rate of signal loss*





Summary and Plans

- Analyses of **2025 test-beam data** for different detector/beam configurations are advancing:
- Monte Carlo simulations were initiated to compare them with data and better understand the results
- Energy depositions per plane between MC and Data are in a good agreement
- Shower parameters: Mean total energy, longitudinal profile show small differences between MC and data, the effect of bad channels will be studied.
- We lose up to ~50% of the deposited energy from showers initiating around the gap
- Works on design and construction of final ECAL-P calorimeter for LUXE experiment are proceeding in parallel

Acknowledgment

- National Science Centre, Poland, under grant no. 2021/43/B/ST2/01107
- European Union's Horizon 2020 Research and Innovation programme 3309 under GA no. 101004761
- Weissfeld Family Charitable Foundation, the Israeli PAZY Foundation (ID 318)
- Spanish MICIU/AEI and European Union/FEDER via the grant PID2024-158190NBC21 the Generalitat Valenciana (GV) via PlanGenT program with the grant number CIDEGENT/2020/021
- University of Warsaw Excellence Initiative IDUB grant no. SP-501-D113-20-0001380
- Institute of Atomic Physics through the CERN-RO Project No.005/2024.

The measurements leading to these results have been performed at the Test BeamFacility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

THANK YOU FOR YOUR ATTENTION