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

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Work in progress for the LUXE ECAL group
10/05/2024

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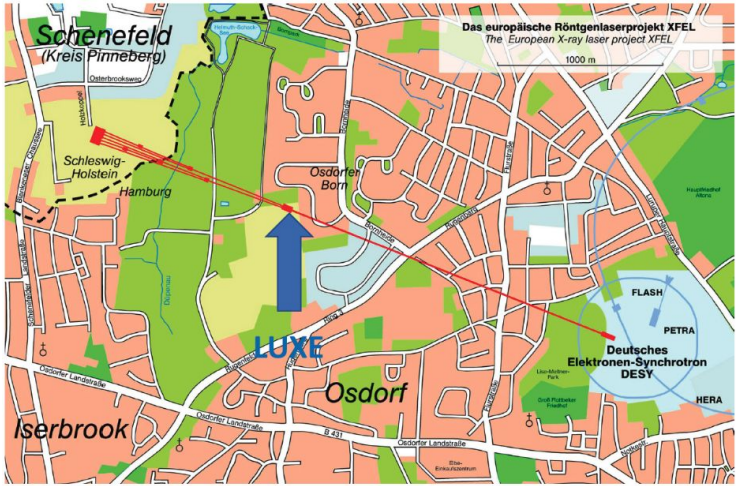
LUXE (Laser Und XFEL Experiment)

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

European XFEL + High-intensity laser



LOI (2019) [1909.00860]

CDR (2021) Eur. Phys. J. Spec. Top. 230, 2445–2560

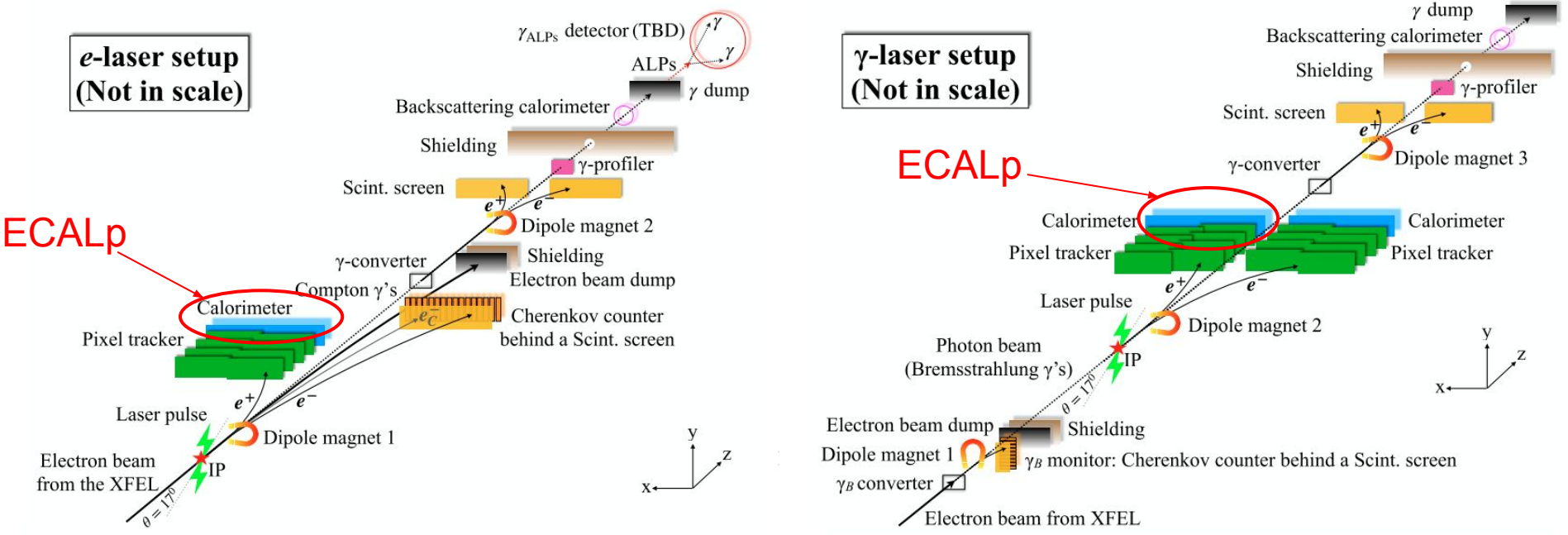
TDR 2023 [2308.00515] EPJST Accepted

European XFEL

DESY.

LUXE CDR (2021)

Two modes for the experiment



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The ECAL-P group

Participating institutes

DESY.

IFIC INSTITUT DE FÍSICA CORPUSCULAR

ISS

UNIVERSITAS VARSOVIENSIS

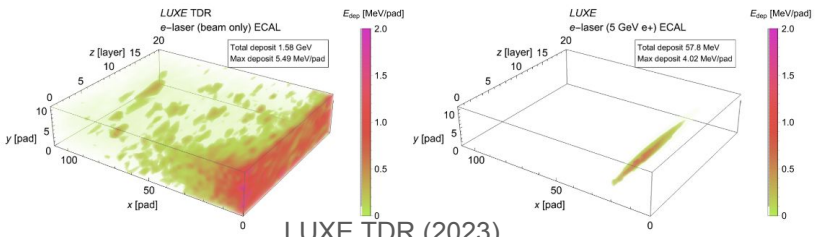
AGH UNIVERSITY OF KRAKOW

AGH

TEL AVIV UNIVERSITY אוניברסיטת תל אביב

Challenges

- Two modes with expected fluxes varying from 10^{-4} to 10^{5}
- EM shower overlap at high multiplicity
- Low multiplicity showers immersed in low energy widely spread background



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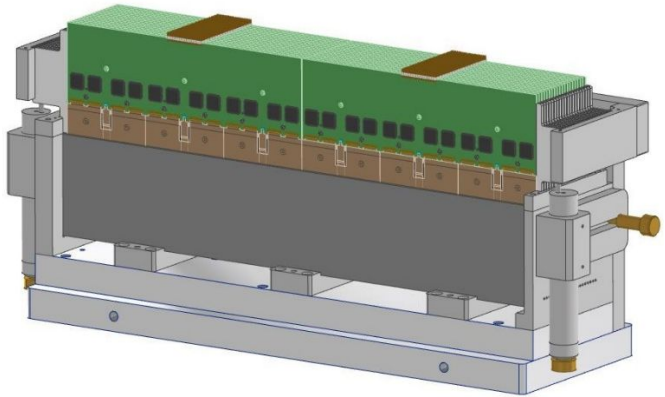
Solutions

- Compact sampling calorimeter
- Small Molière radius
- High granularity



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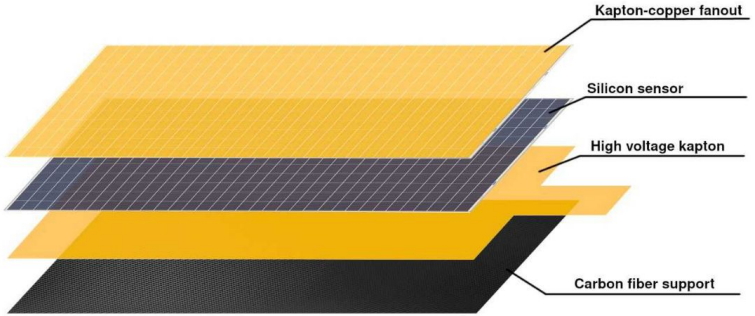
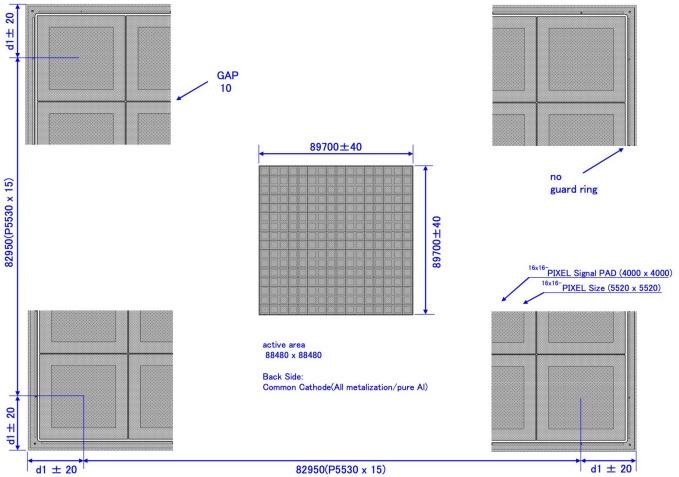
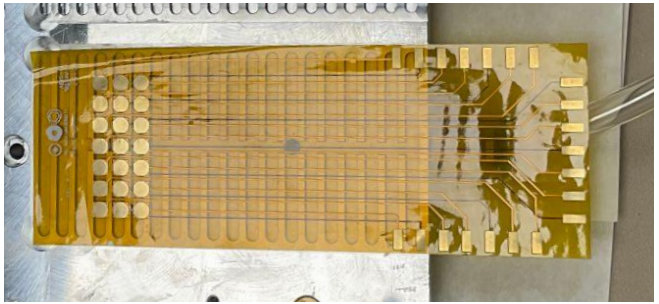
Sensors: Silicon

- The readout: Kapton fan-outs with copper traces connected to the sensor pads with conductive glue.
- 320/500 μm thick, 5.5 × 5.5 mm^2 pad
- Small gap of 0.01 mm between pads







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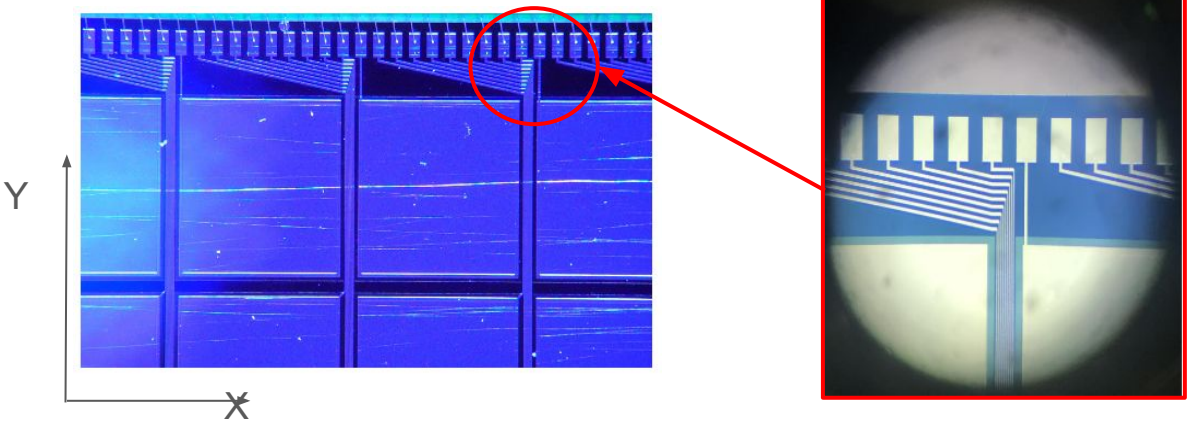
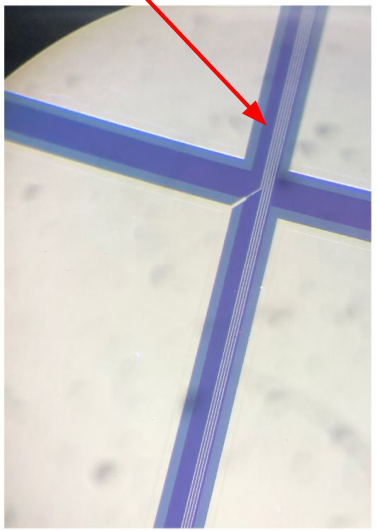
Flex Kapton PCB Example

Sensors: Gallium Arsenide

- Single GaAs crystals compensated with chromium.
- Pads are made of 0.05 μm vanadium layer
- Pad area of 4.7 × 4.7 mm^2
- 0.3 mm gap between pads
- Al traces in the gaps between pads.
- Sensor thickness of 500 μm.
- Tolerate higher radiation dose than silicon.

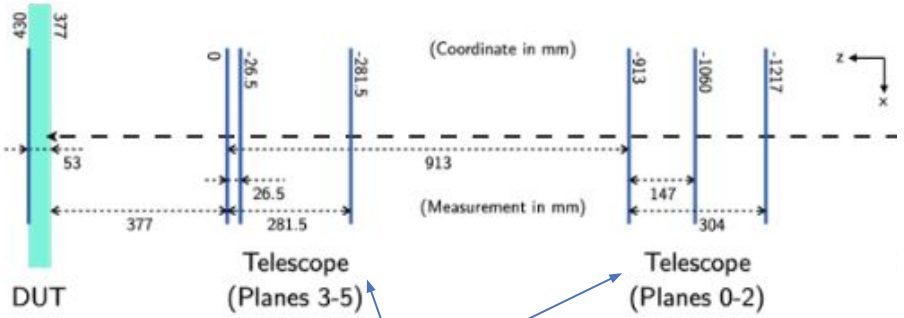




Credit: Dawid Pietruch (AGH University of Krakow)

Test beam 2022

Two 16 × 8 pad arrays of silicon sensors and two 15 × 10 pad arrays of GaAs sensors were tested in a 5 GeV electron beam at the DESY-II facility.



Measures the energy deposited by the particle

Gives a precise measurement of the path of electrons from beam.

Data for sensor homogeneity studies!

Testbeam prepared and operated by ECAL-P group before IFIC joined the project.

Homogeneity of individual pad response

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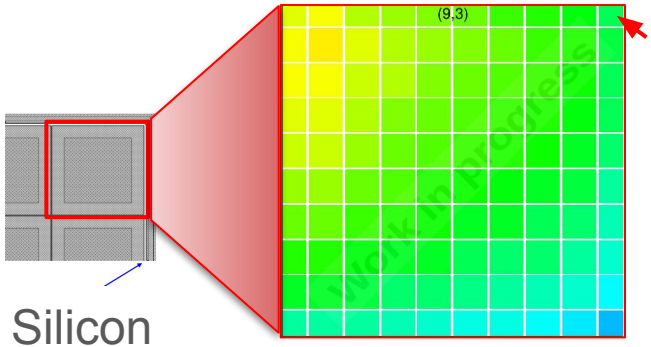
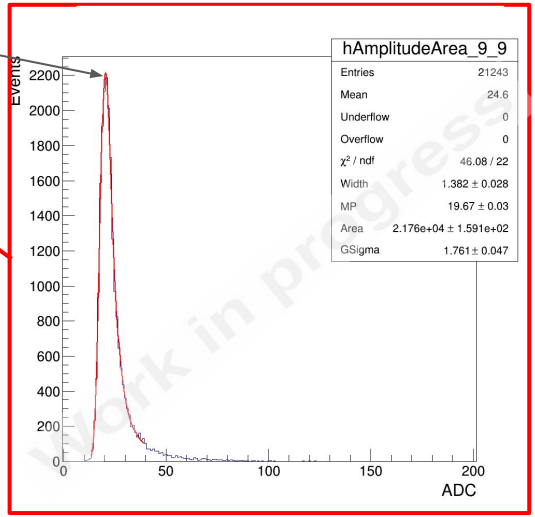
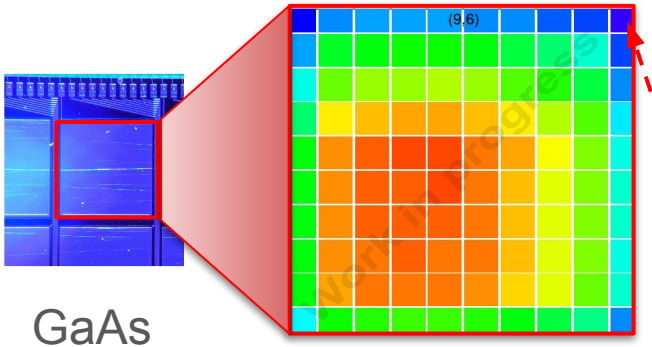
MPV=Most Probable Value

Subdivided pad into sections and plotted amplitude distribution of electrons in each section

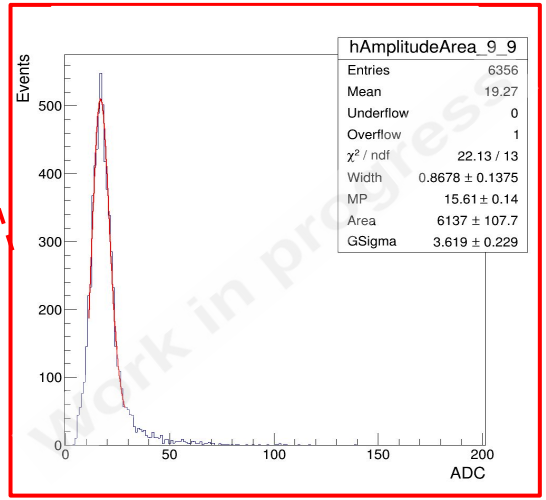


Silicon





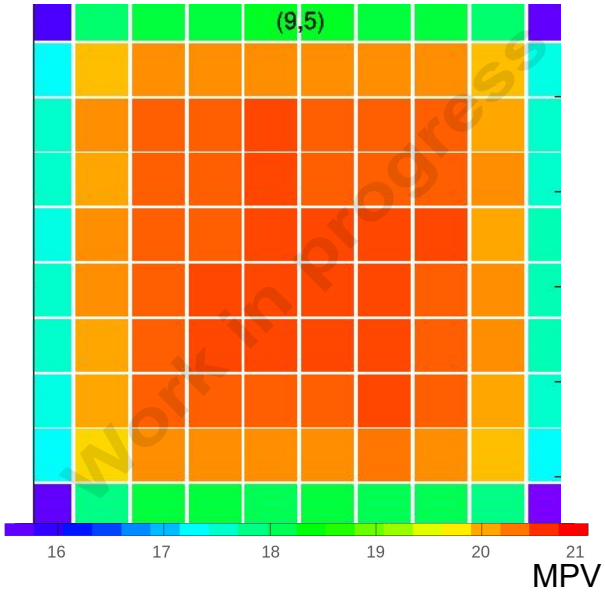
GaAs



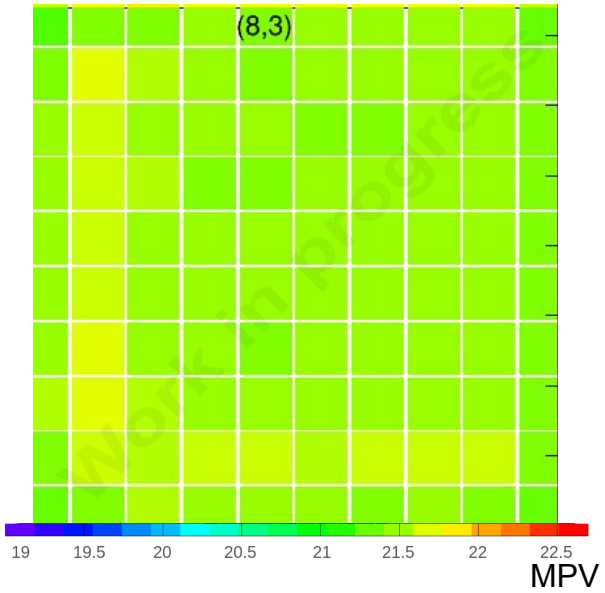
Z scale represents number of entries for the section

Examples of average response in pad sections

GaAs



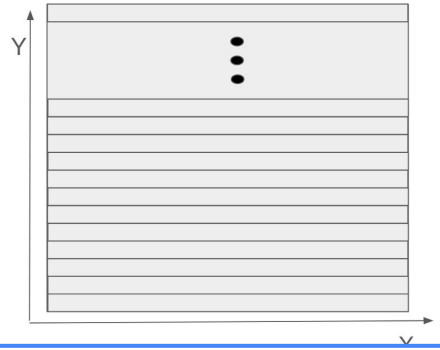
Silicon



- Drop in amplitude around edges for GaAs
- L-shaped higher amplitude area for silicon sensor.

Examples of average pad response near edges

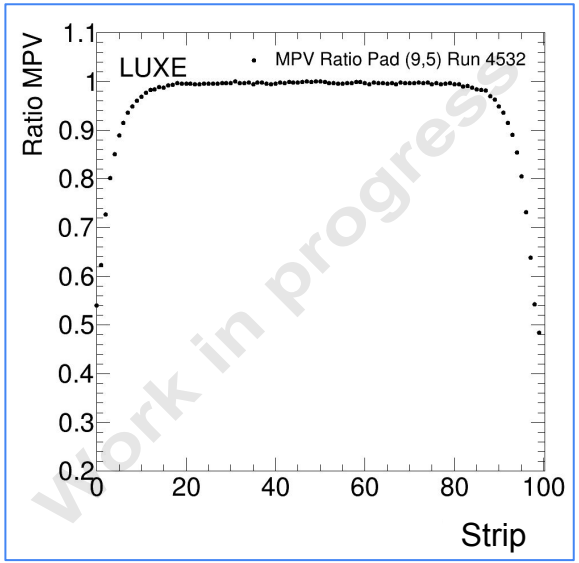
Subdivided pad into strip sections



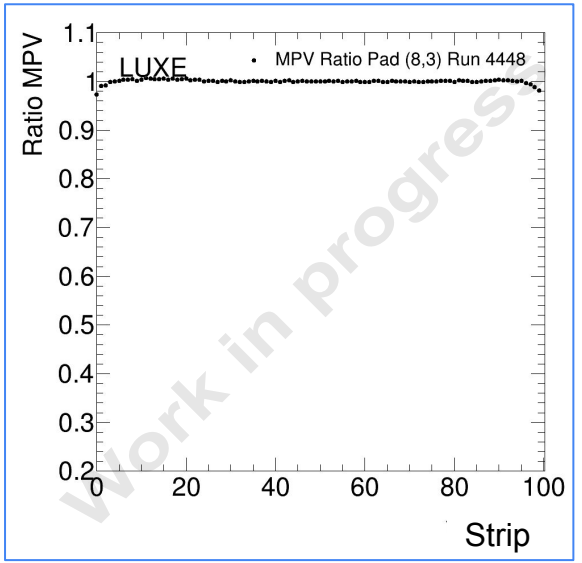
Calculated the MP amplitude of electrons in each strip

Normalized to MPV of center strip

GaAs

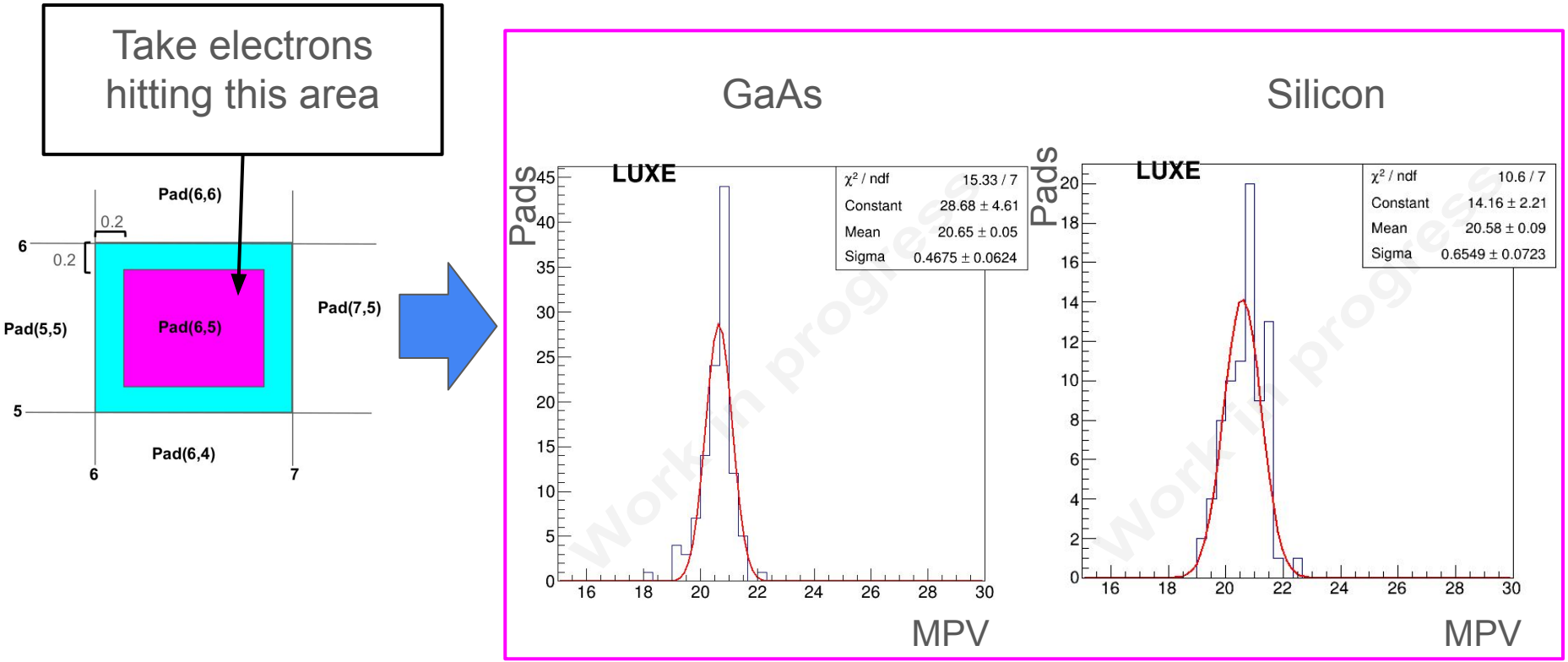


Silicon



- 50% drop in amplitude wrt center for edges of GaAs pads
- 2-3% drop in amplitude for silicon wrt center

Homogeneity of sensor response



- In GaAs sensor, the pads are more compatible with each other than in silicon

Conclusion

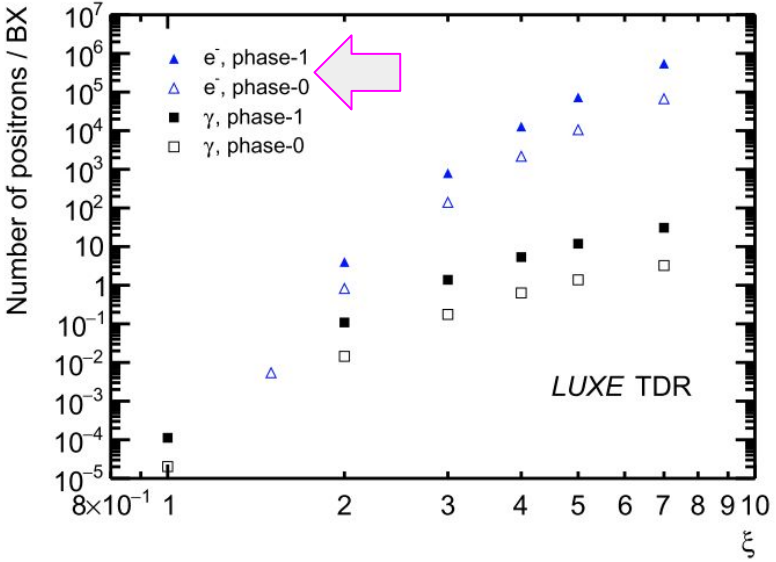
- Individual pad-response studies were possible with the help of the telescope
- The GaAs sensors present edge-effects involving a drop in the measured energy of electrons
- This effect is small for the tested silicon sensors
- The edge-effects from the GaAs sensors lower the mean response of the full sensor array

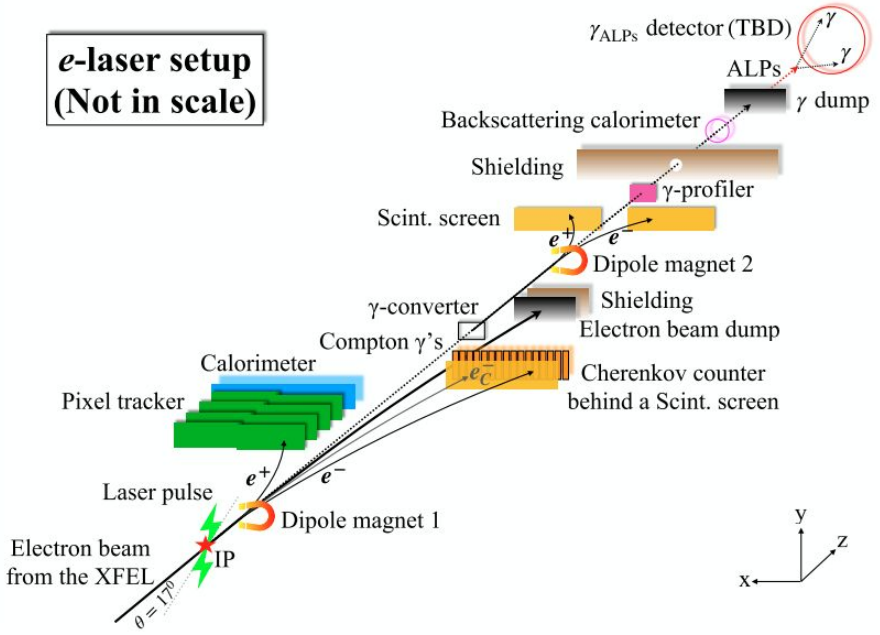
Backup

Main aims of LUXE

- Measure the interaction of real photons with electrons and photons at field strengths where the coupling to charges becomes non-perturbative
- Make precision measurements of electron-photon and photon-photon interactions in the transition from perturbative to the non-perturbative regime of QED.
- Use strong-field QED processes to design a sensitive search of new particles beyond the Standard Model that couple to photons.

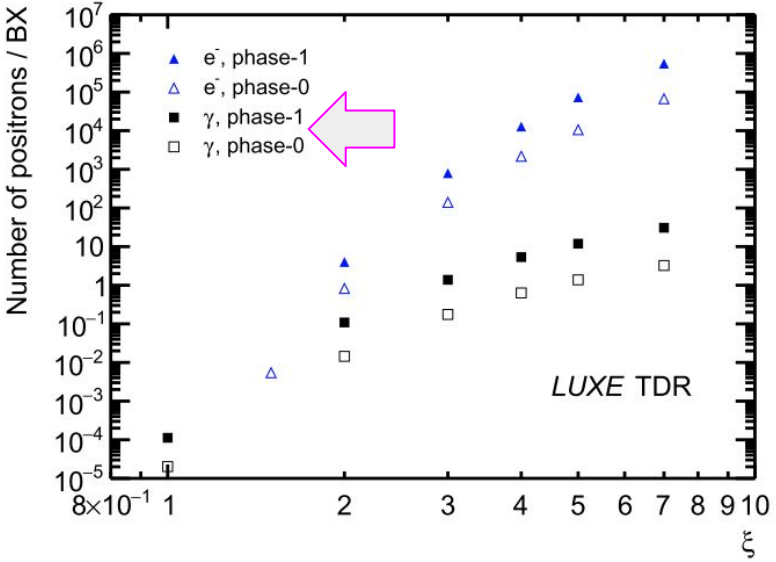
Initial mode for LUXE: e-laser

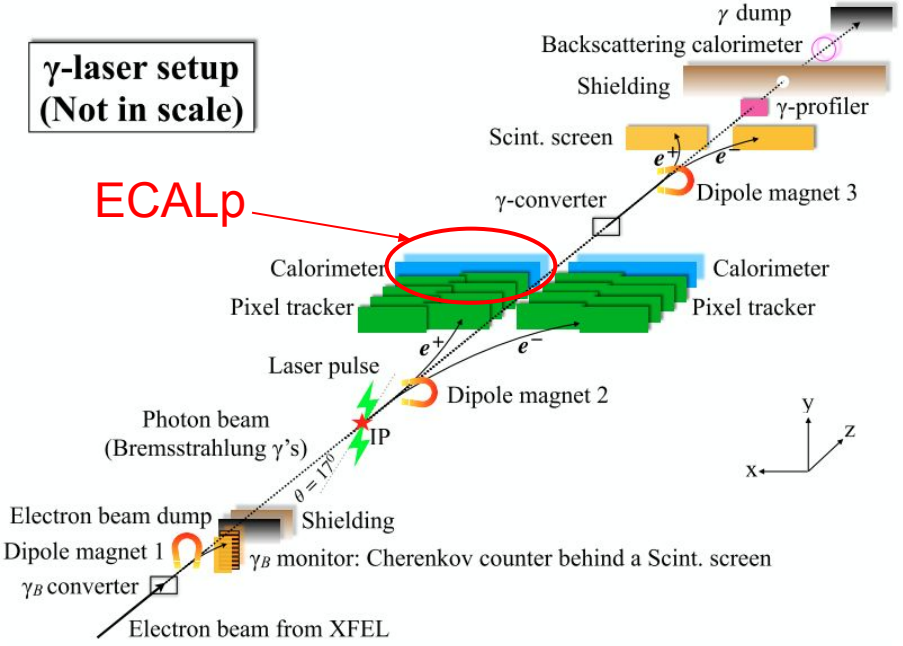




LUXE TDR (2023)

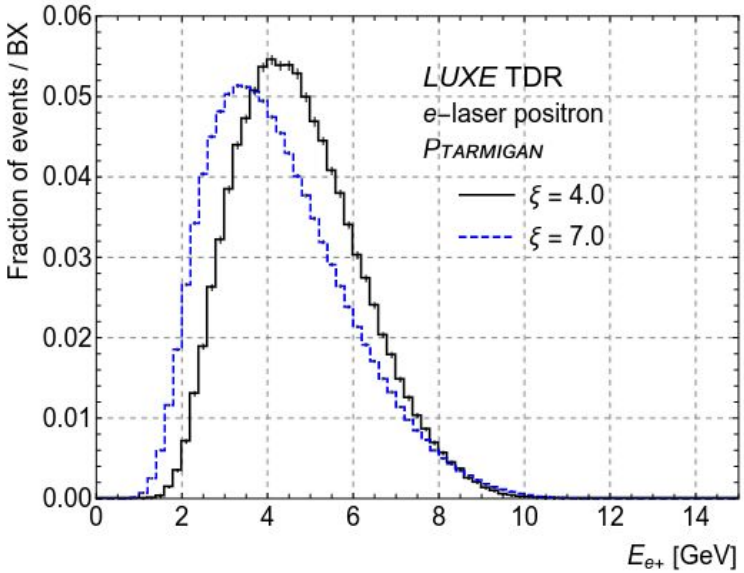
Second mode: γ-laser

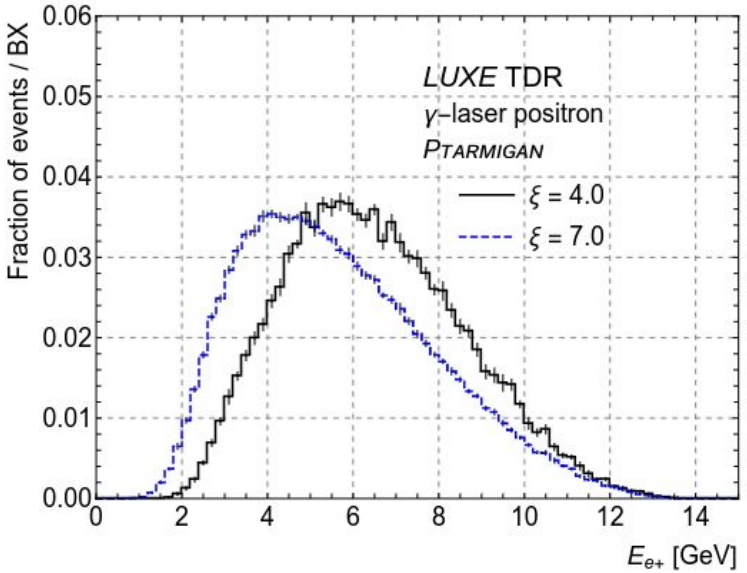




LUXE TDR (2023)

Expected positron energy spectra

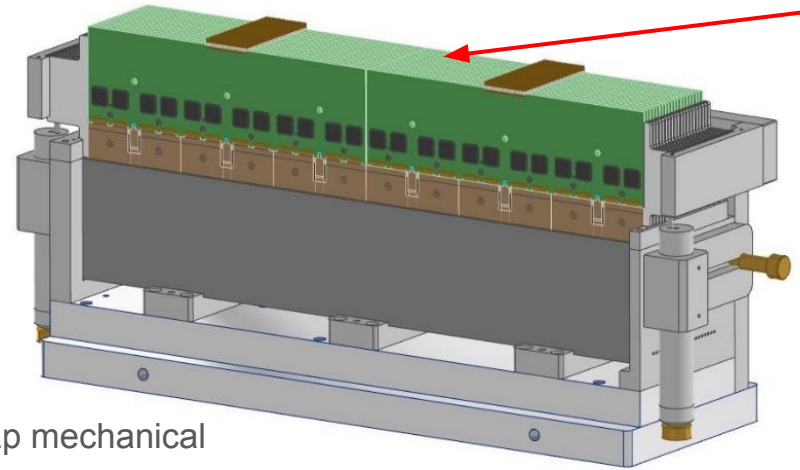




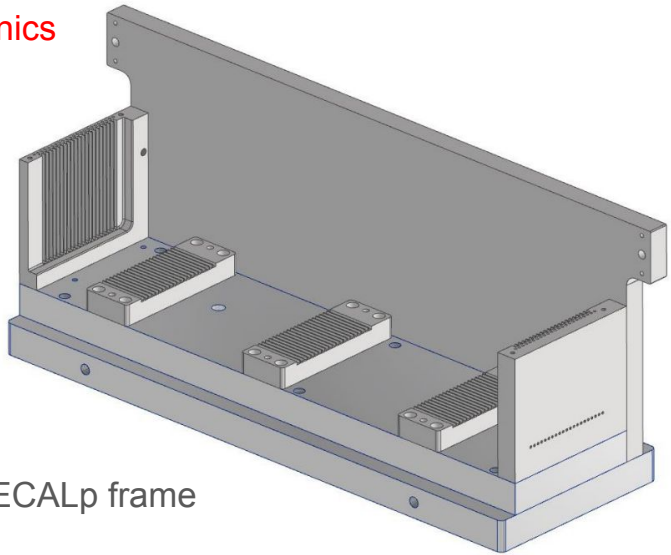
LUXE TDR (2023)

ECALp design

- Tungsten absorber: 21 layers of 3.5mm, Molière radius of 9.3mm
- Active layers including sensors and readout will be kept to less than 1mm in thickness.



ECALp mechanical structure



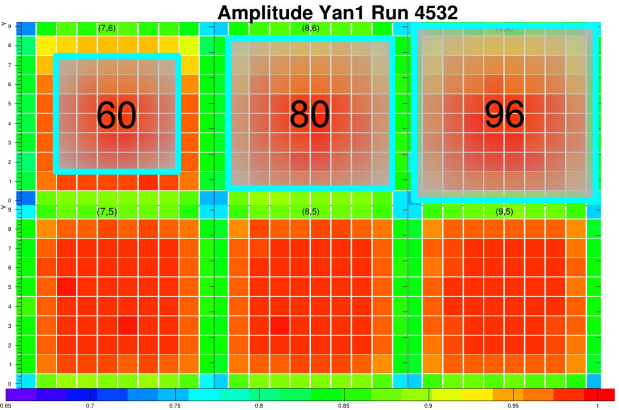
ECALp frame

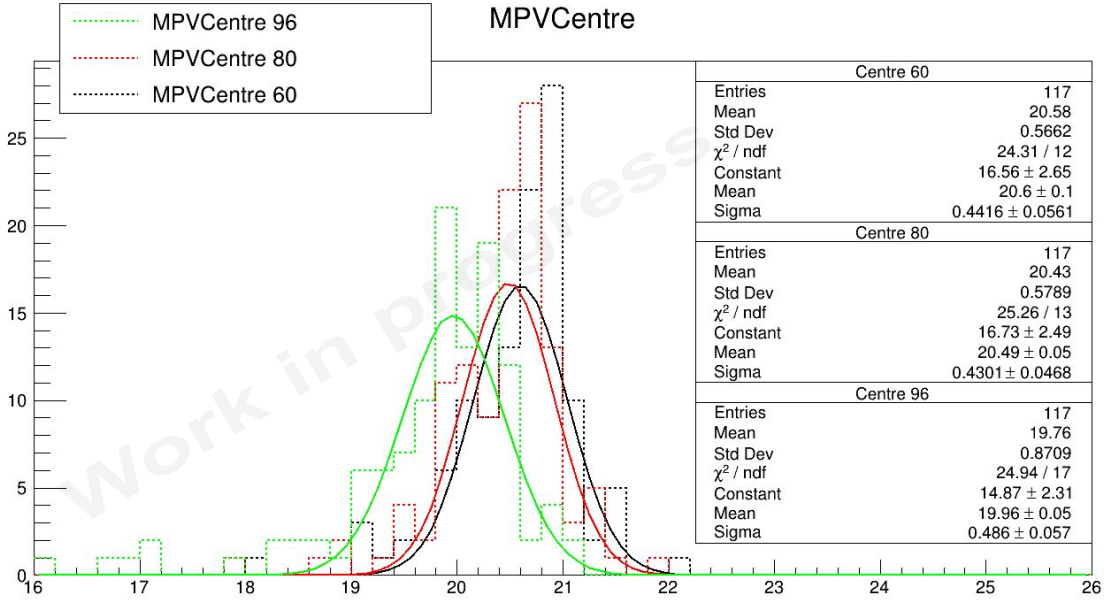
LUXE TDR (2023)

Edge-effects in homogeneity

Results on amplitude varying the centre area

The size of the remove edges are

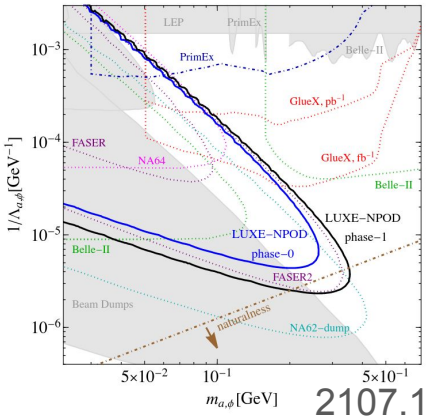




- Mean sensor amplitude drops by less than 1% from area 60 to 80, and by around 3% when taking area 96.

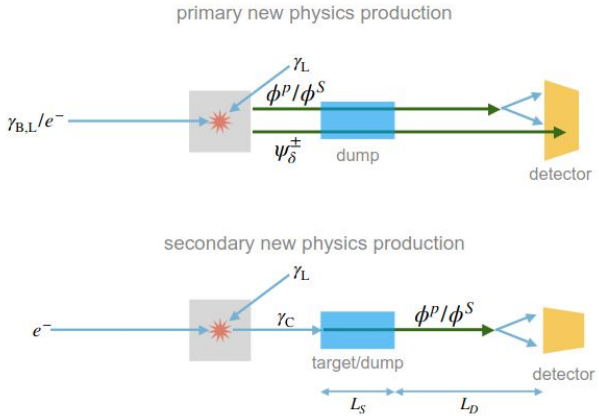
Probing physics Beyond the Standard Model at LUXE

The high photon rate from LUXE gives the opportunity to search for physics BSM



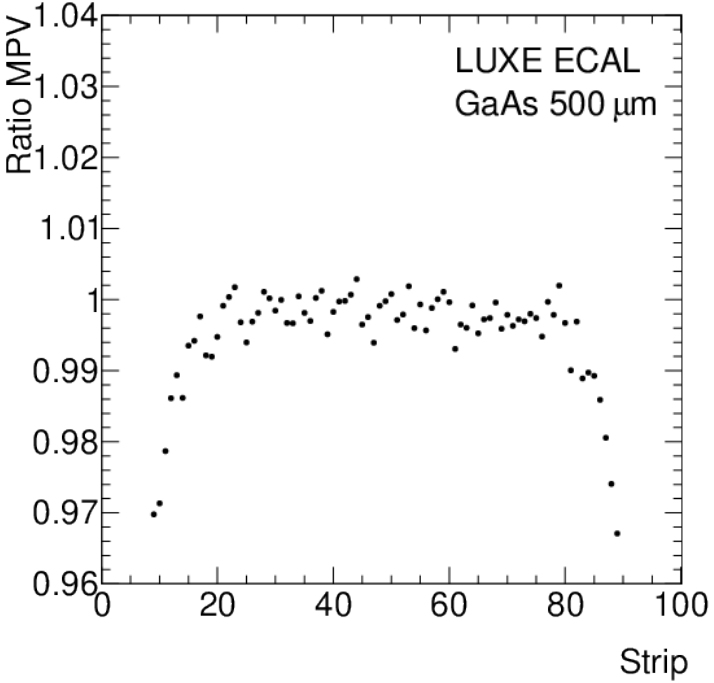
2107.13554

Two NP production modes for ALPs and scalars that couple to photons and electrons



Proposals to set a calorimeter at a fixed distance from photon dump to probe ALPs decays to two photons

LUXE CDR (2021)


LUXE ECAL
GaAs 500 µm
Ratio MPV
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0
20
40
60
80
100
Strip