Beam test of sensors for a compact ECAL

Shan Huang (Tel Aviv University)

work in progress for the LUXE ECAL group

The 11th BTTB @ DESY Hamburg

20 April 2023

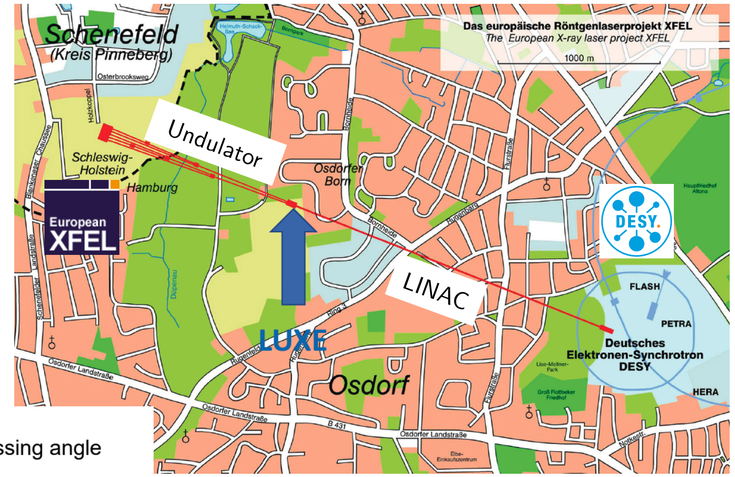
LUXE Overview

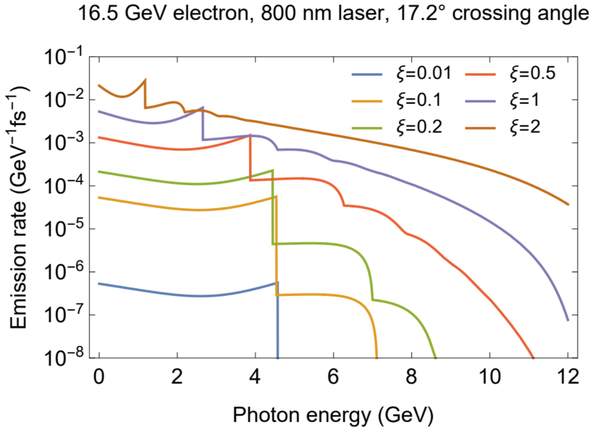
LUXE: ***Laser und XFEL Experiment***

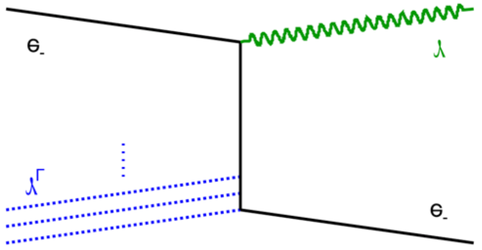
- A "laser collider" (with 16.5 GeV electron or photon)
- High energy density photon beam by laser
- About to release its technical design report

Physical goal: non-perturbative QED

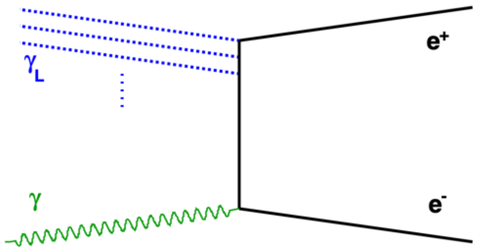
- Observables departure from perturbative prediction
  - Compton photon spectrum (edge moving)
  - Breit–Wheeler e^+e^- pair spectrum
- Challenges on positron detecting system:
  - high precision to verify the departure
  - large dynamic range
    (positron number/BX: 10^{-4} to 10^{6})







A key measurement!



Photons from Compton scattering or Bremsstrahlung

LUXE CDR, EPJ ST 230 2445 (2021)

LUXE ECAL Overview

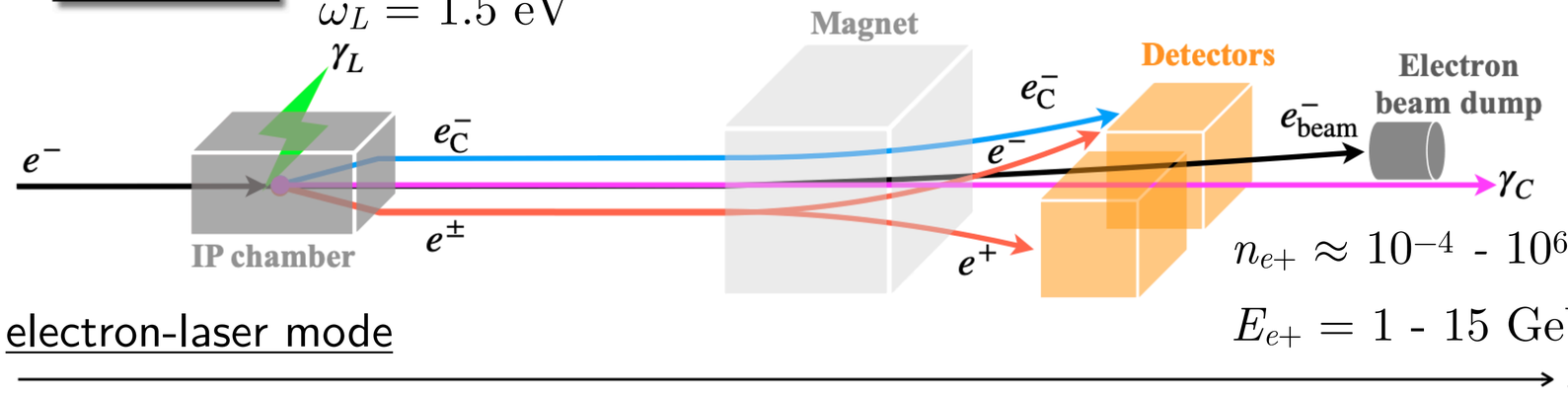
LUXE SFQED (not to scale)

$I_L \approx 10^{18}$ - 10^{21} W cm^{-2}

$\omega_L = 1.5$ eV

$\mathrm{BX} = 1.5\times10^{9}$

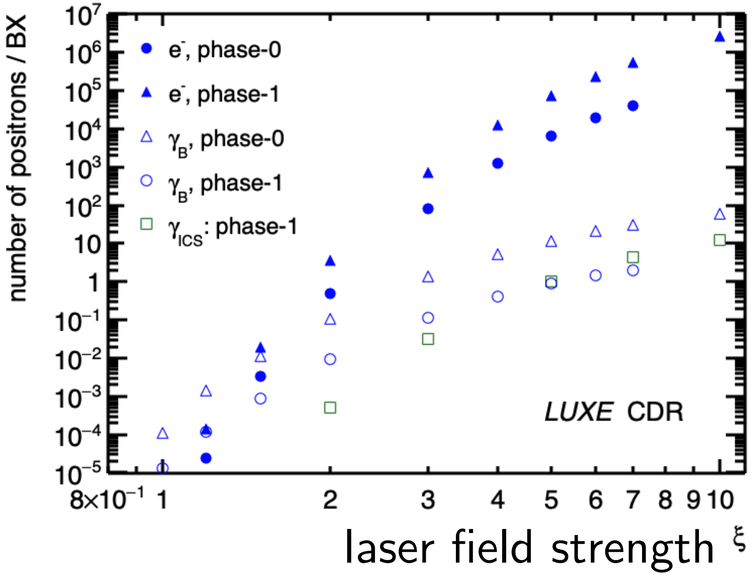
$E_e = 16.5$ GeV

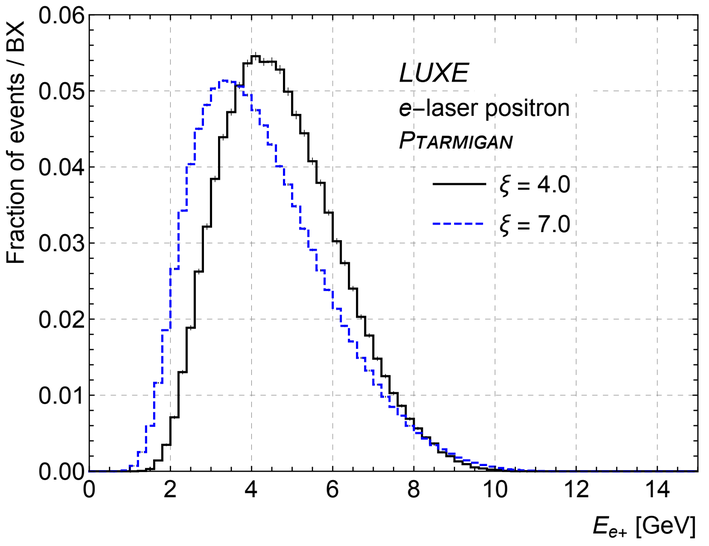


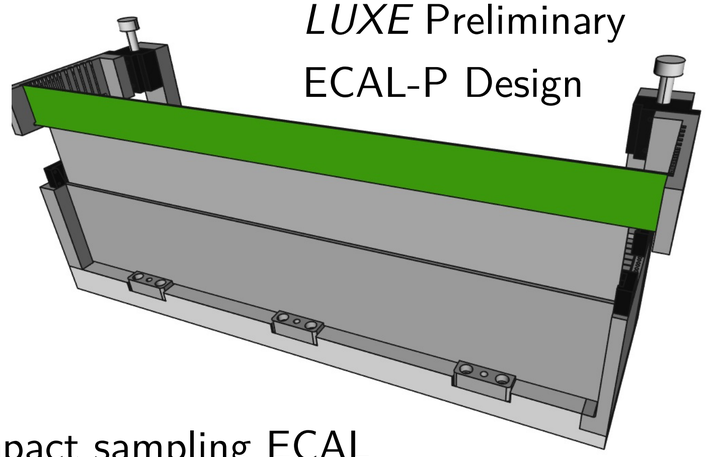
$n_{e+} \approx 10^{-4}$ - 10^{6} BX^{-1}

$E_{e+} = 1$ - 15 GeV

Detectors for e^+:
8 Tracker staves
1 Compact ECAL





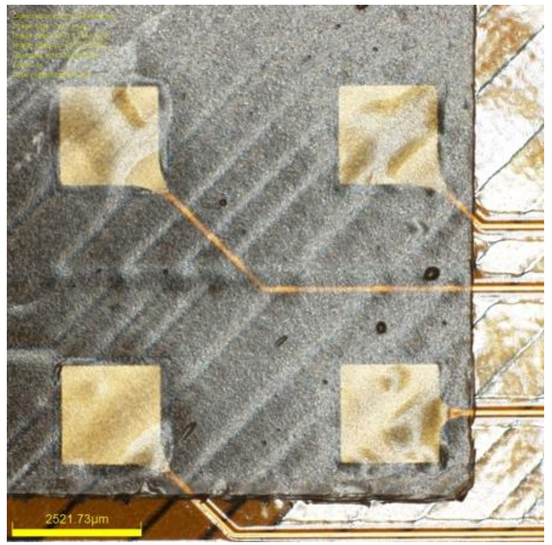


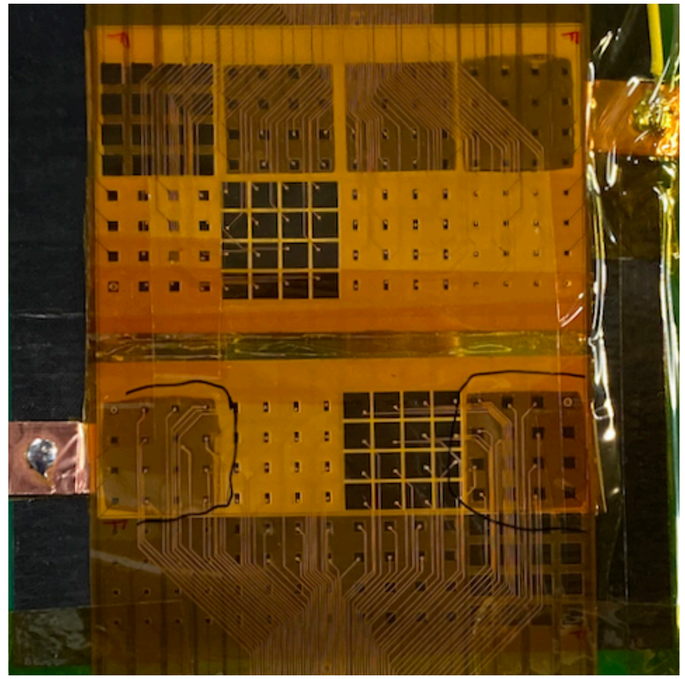
Compact sampling ECAL

55 x 5.5 x 9 cm^3; 20X_0

Compactness

- Small effective Molière radius
- On z direction, only 1 mm per layer space left for passive material and all other things including physical contact
- To replace bonding, which is fragile and needs space, several options are considered including:
  - anisotropic conducting film
  - implanted traces



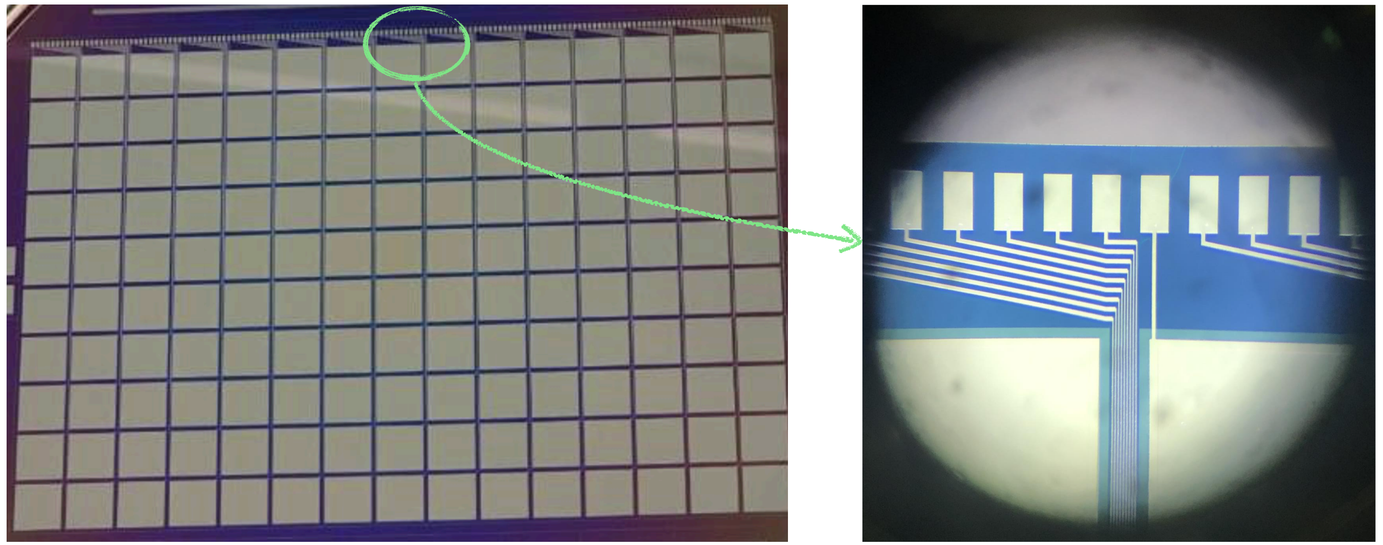


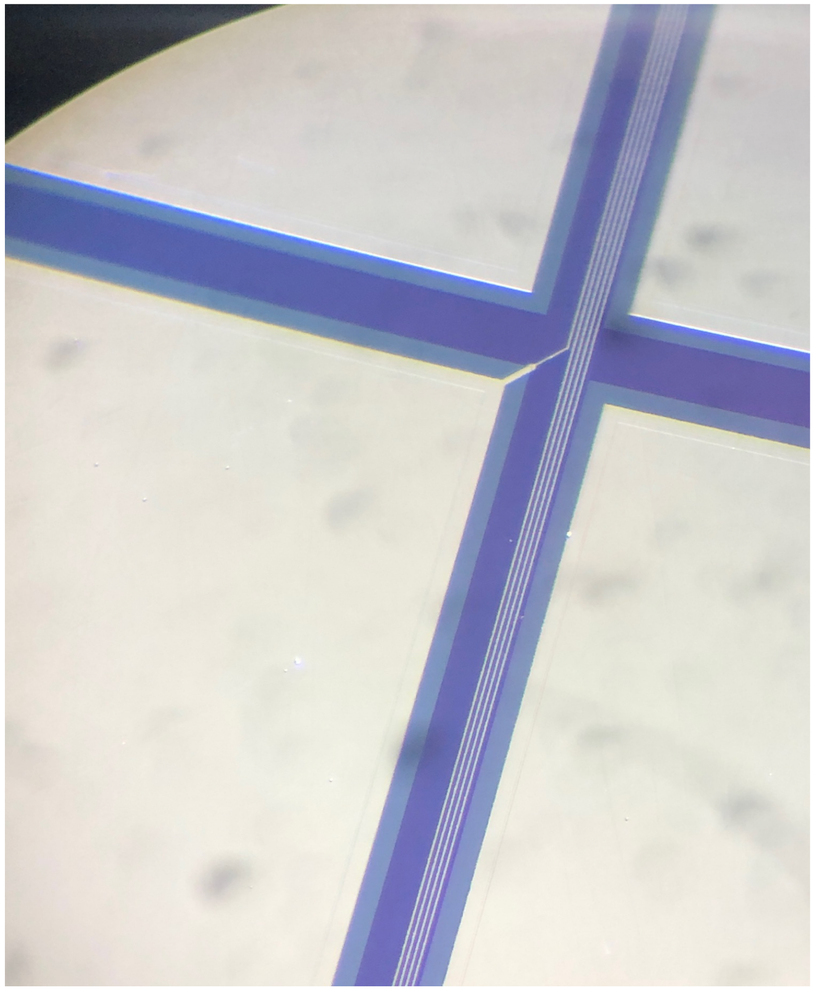
Back side of silicon sensor for test manufactured by Hamamatsu, connected with copper traces and conductive glue

Yan Benhammou (TAU)

Implanted traces

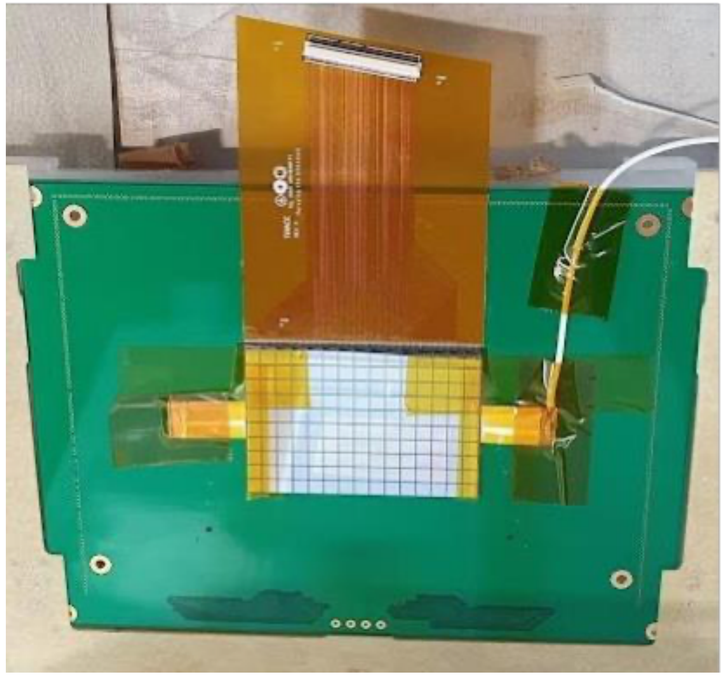
- Implanted aluminium traces, a new method to connect pads with the readout frontend, are used on GaAs sensor to make the sensor more compact
- The traces are bunched along *y*-direction and it is possible that fake signals could be induced in between traces





Trace bunches along *y* direction

Sensors under test



Front side of silicon sensor for test manufactured by Hamamatsu, “Calice Standard”

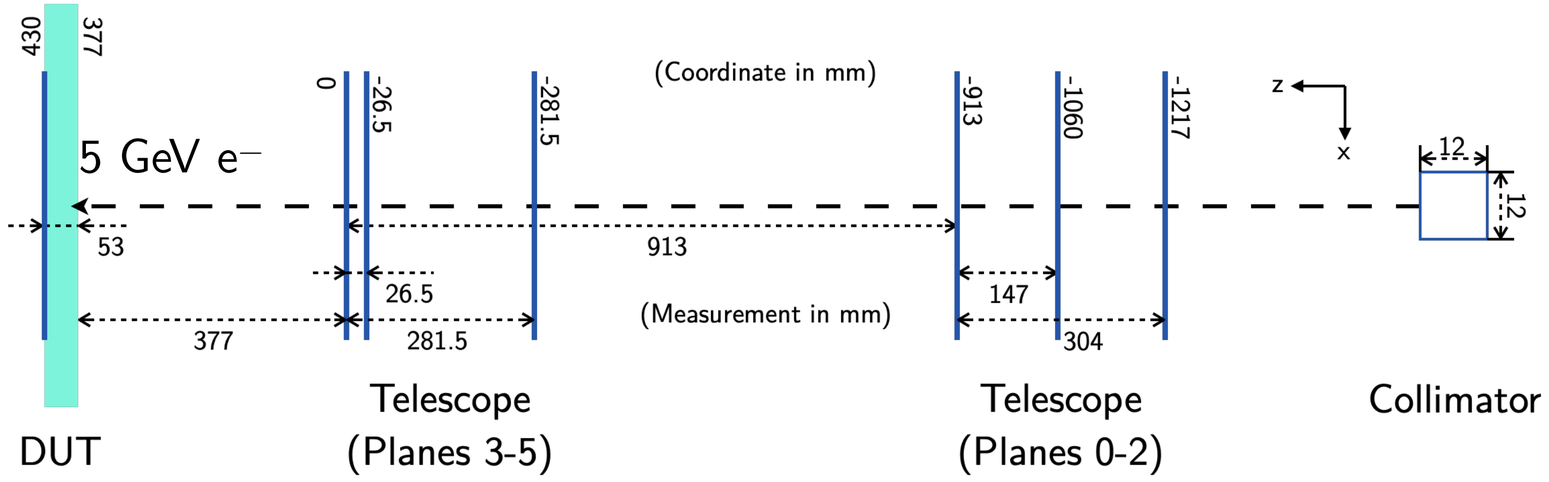
Questions to be answered by beam test:

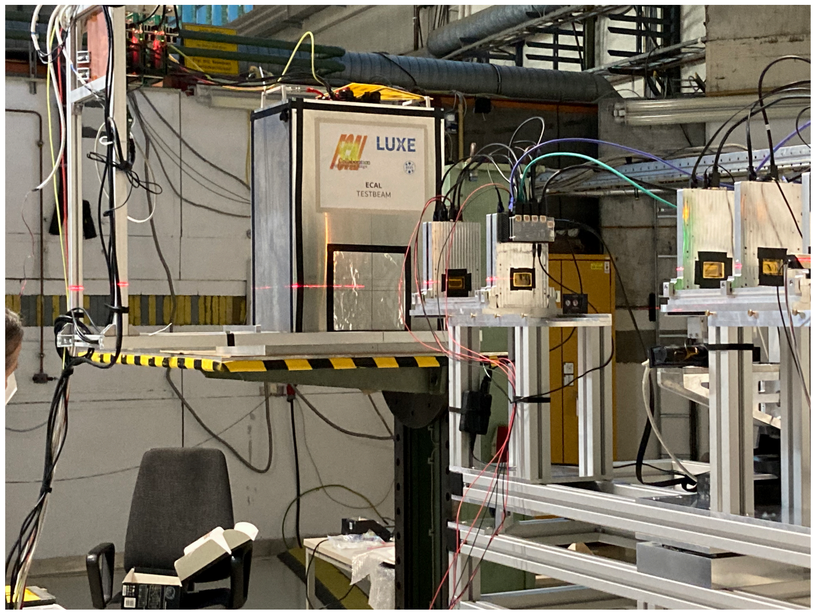
- How do different sensors response to the electron beam/shower?
- Do different pads on a sensor perform homogeneously?
- What happens when the electron comes in between two pads?
- Is there cross talk between read out channels?
- How to calibrate the Monte Carlo simulation?

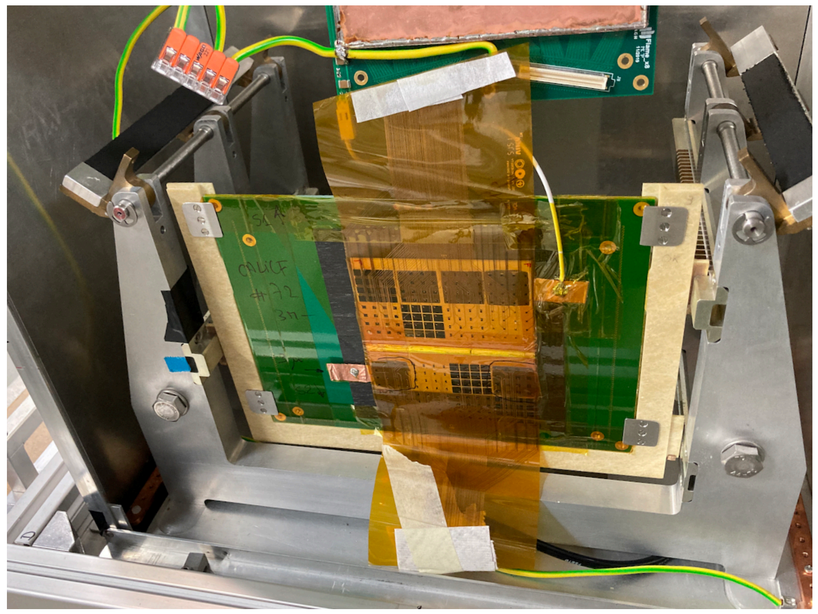
... and other questions need input from the telescope!

	Silicon	GaAs	Tungsten
Pad size [mm]	5.5×5.5	5.0×5.0	
Pad number	16×16	15×11	
Thickness [um]	320	500	3,500
Samples under test	4	2	

Test layout



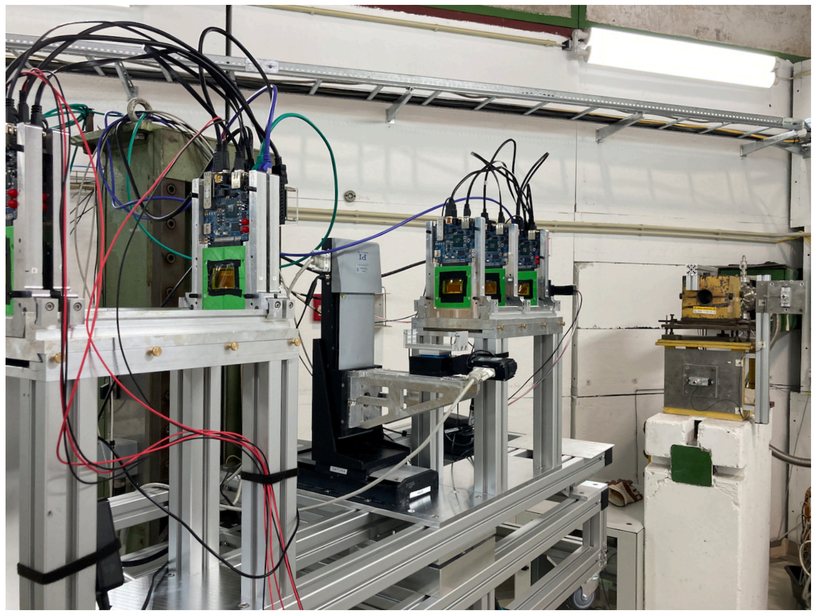


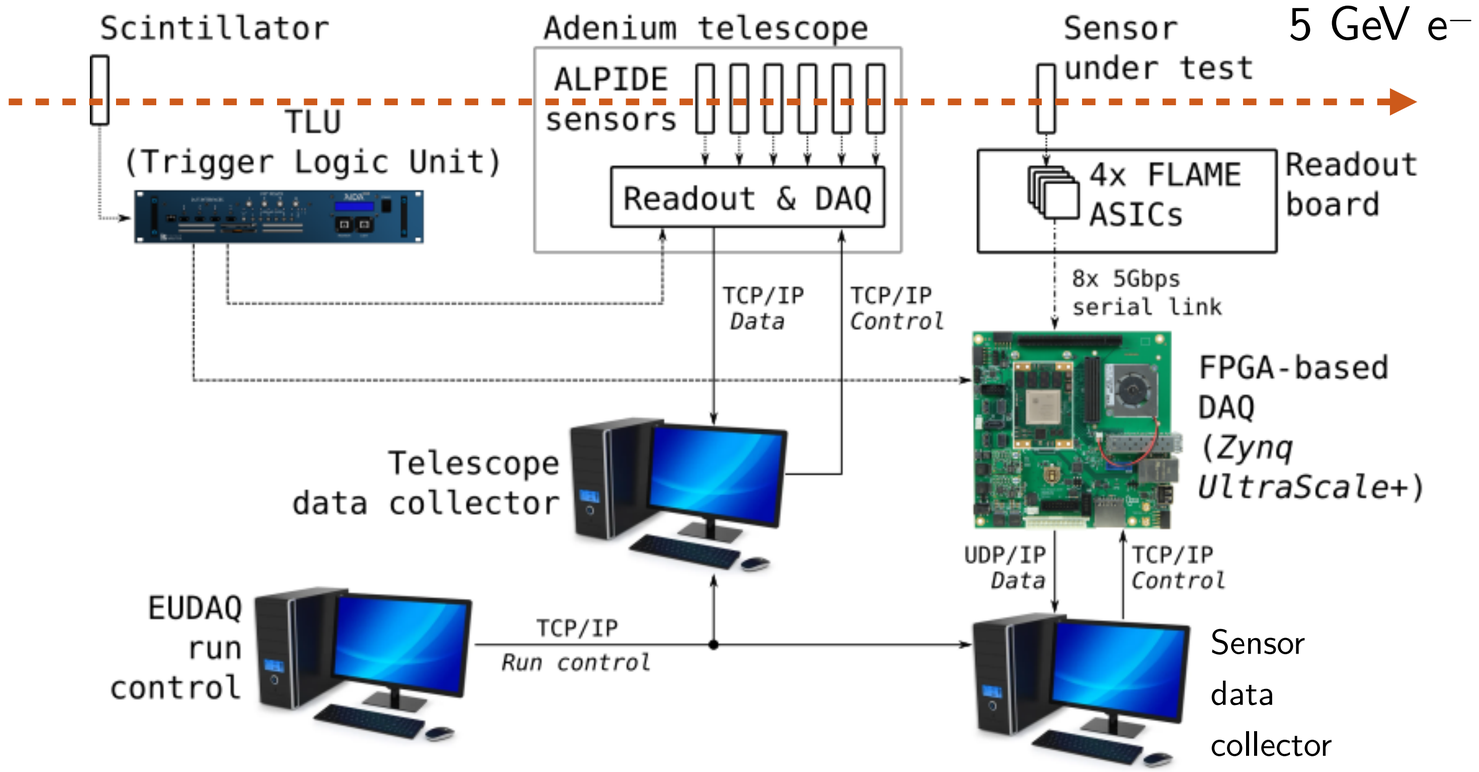


- Two planes close to DUT
- Hardware:
  - 6 Adenium planes
  - Sensors with or w/o W plates
- DAQ control:
  - EUDAQ/FireDAQ
- Alignment:
  - Corryvreckan
  - Extrapolation of broken lines
  - Telescope-sensor synchron./ alignment is done separately

Data acquisition

- DAQ is orchestrated by the TLU
  - Possible trigger ID drifting
- ASIC keeps reading out data and stores ± 150 ns when gets trigger
- FPGA deconvolutes and reconstruct signal's amplitude

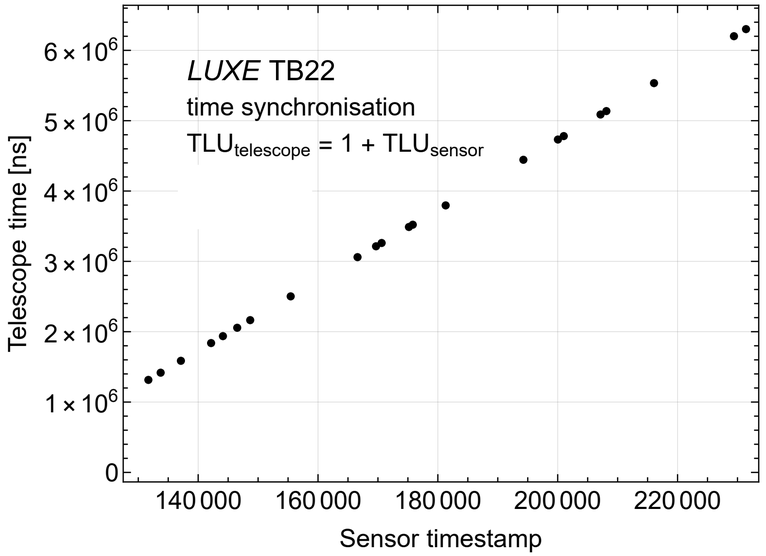


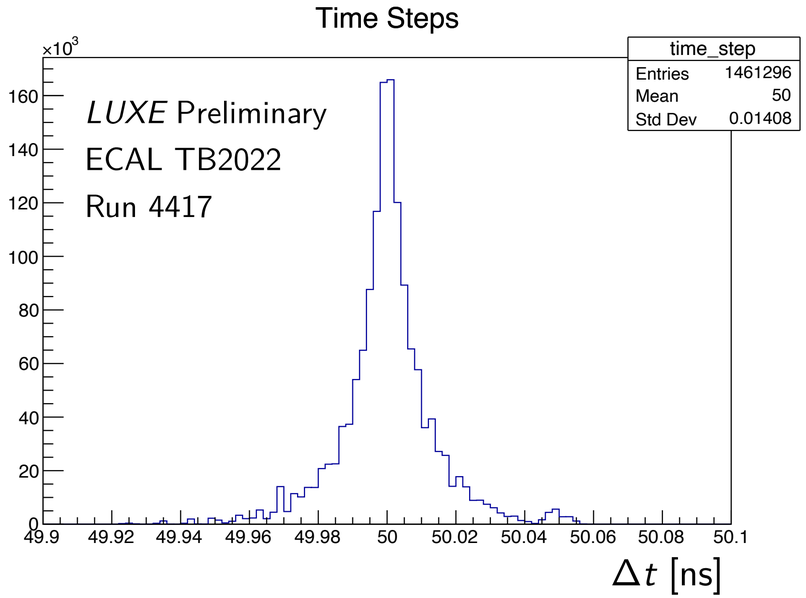


Credit: Jakub Moroń (AGH)

Synchronisation check

- Telescope's DAQ and the sensor's DAQ use different time "recorder"
  - telescope: time in ns
  - sensor: timestamp, one stands for 50 ns
- Events are labelled with TLU IDs, but they can be shifted in different DAQs
- The shift may be drifting over time

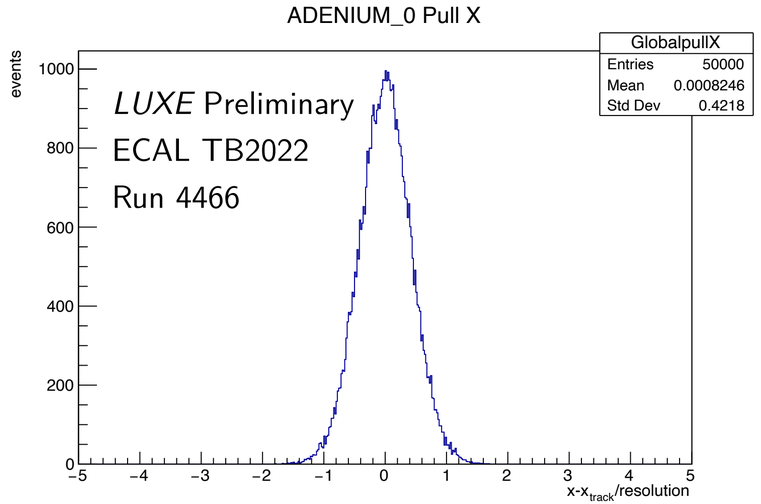


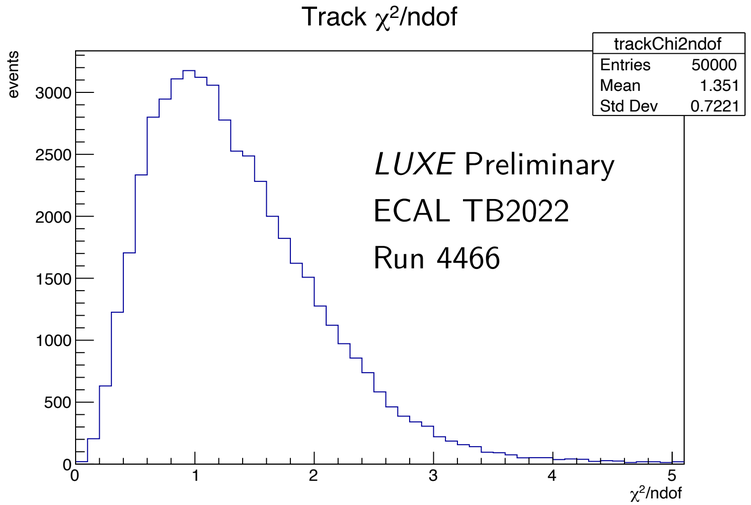


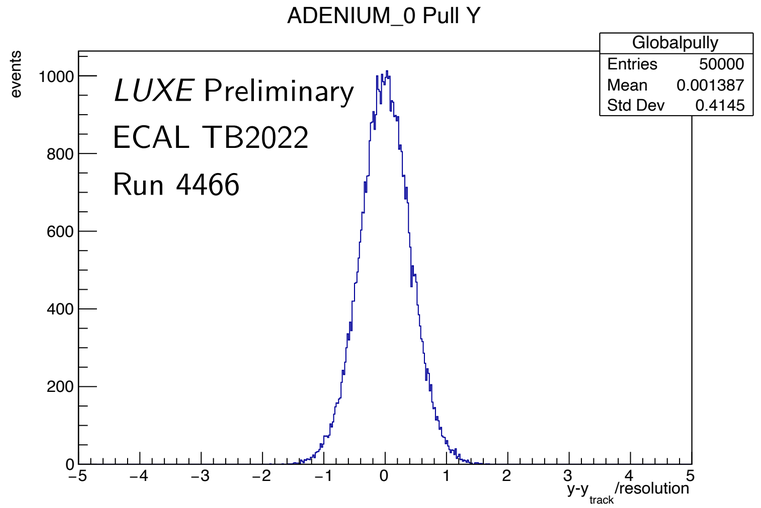
- In the most runs, the trigger ID shift is 1
- The time interval between neighbouring events in the two DAQs should be proportional if they are synchronised
- In some rare cases, these intervals are not proportional: the shift is drifting away

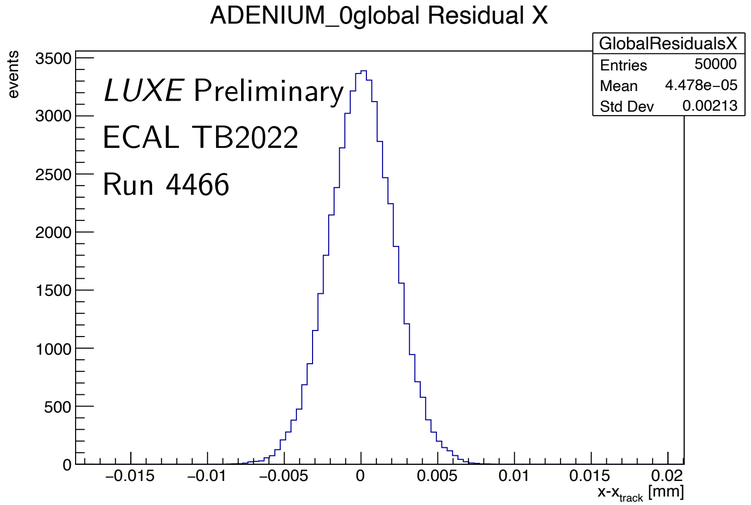
Telescope alignment

- Procedure of alignment
  - Conducted by Corryvreckan
  - Pre-alignment
  - Alignment with the best tracks
- Tracking models:
  - General broken line (GBL)
- Tracking efficiency near 90%
- Indicators of a good alignment
  - Pull function
  - Residues smaller than 1 um
  - χ^2/n_{DoF} close to 1
- Extrapolation to the DUT using the last three planes





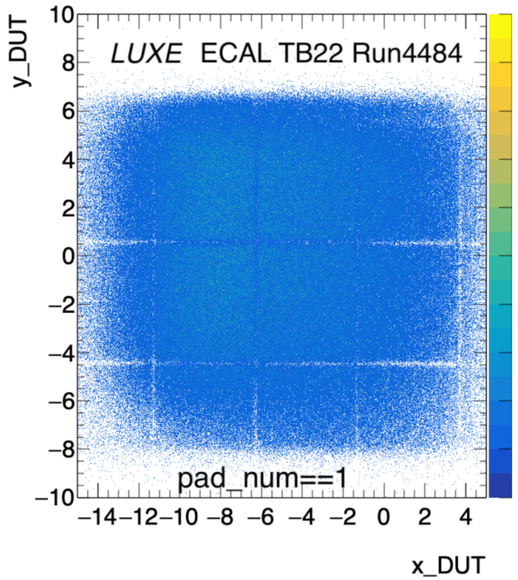


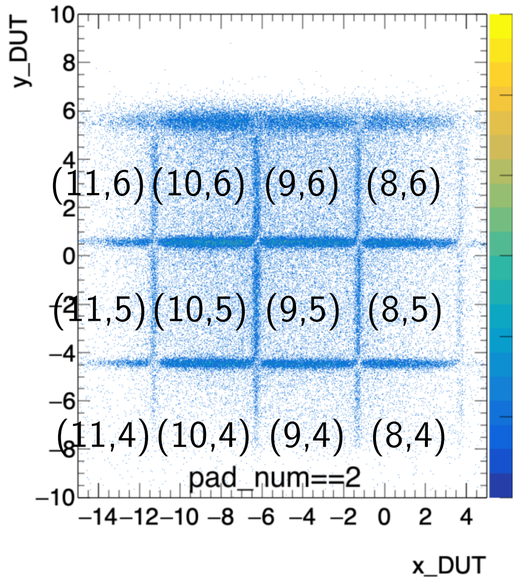


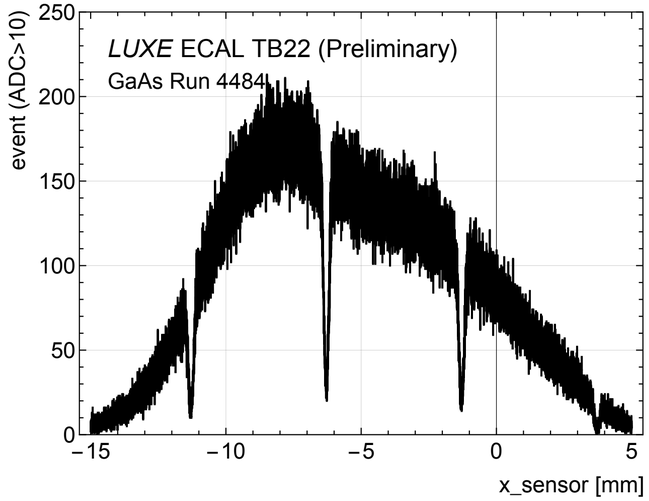
Residue on the furthest plane

Sensor alignment

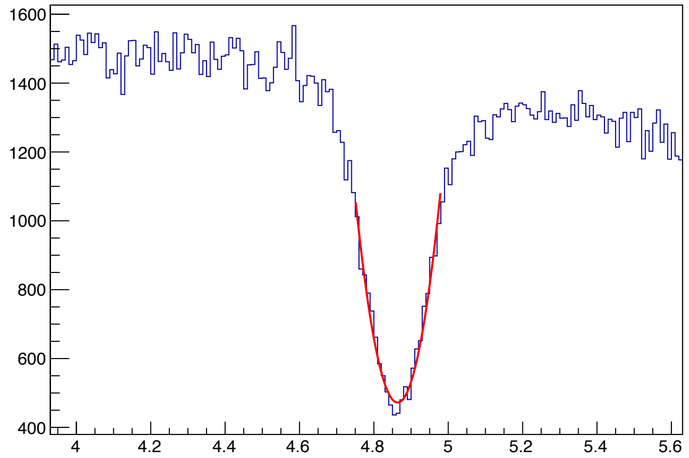
- When one electron hits on the sensor, there should be only one sensor pad having signal readout
- When the electron comes in between two pads, the sensor either has no readout (“dead” area) or has multiple readouts (signal sharing area), resulting in a dip
- The dips become clearer when applying amplitude cut
- The pad boundaries are fitted with the dips to a precision better than 100 um





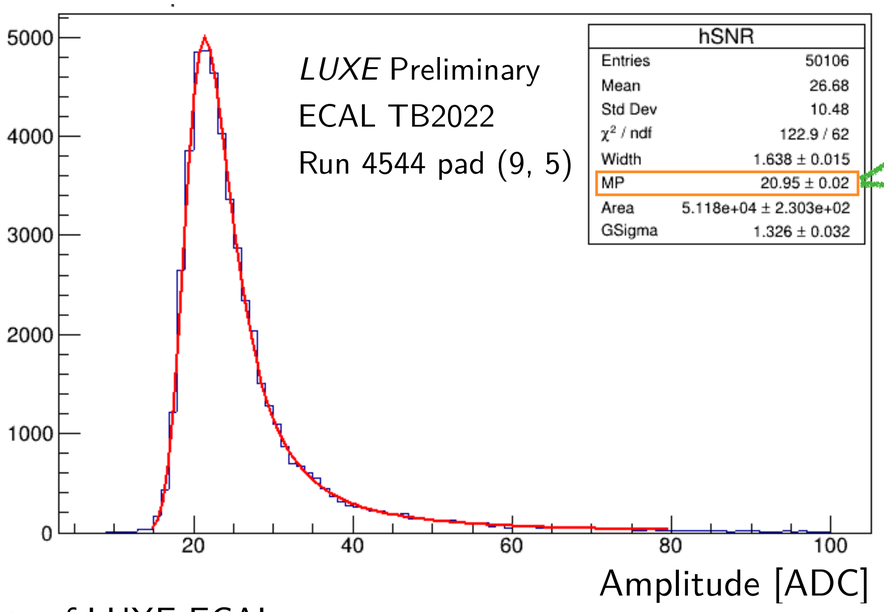


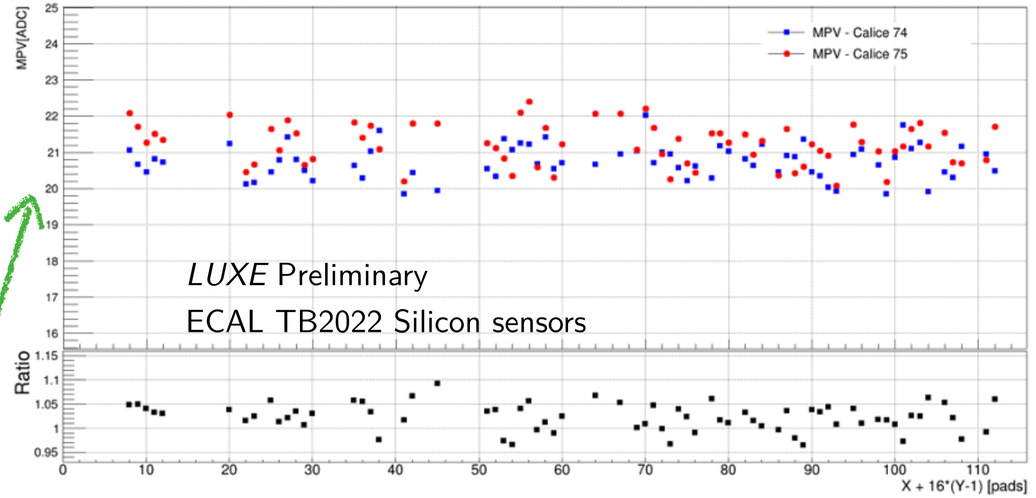
y projection

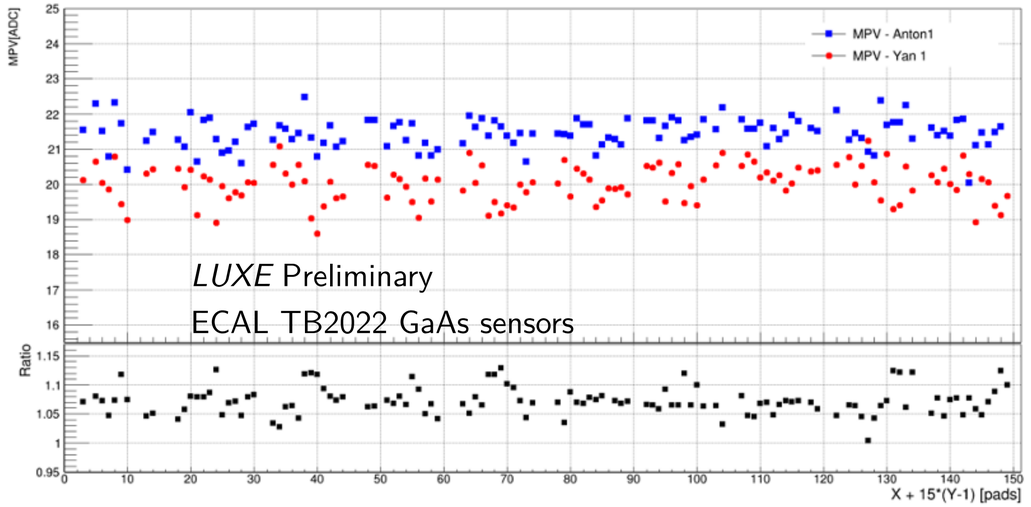


Homogeneity

- Select the events with one electron and one pad response at the corresponding area
- Amplitude distribution fitted into a Landau-Gaussian convoluted function
- Amplitude (MPV) fluctuates over 1 ADC count







Credit: Veta Ghenescu (Romanian ISS)

Homogeneity

- Select the events with one electron and one pad response at the corresponding area
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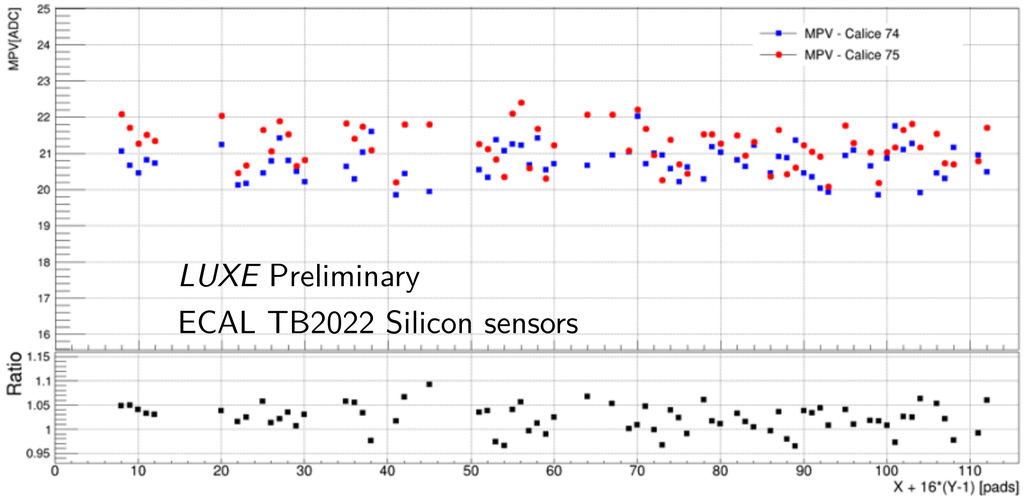
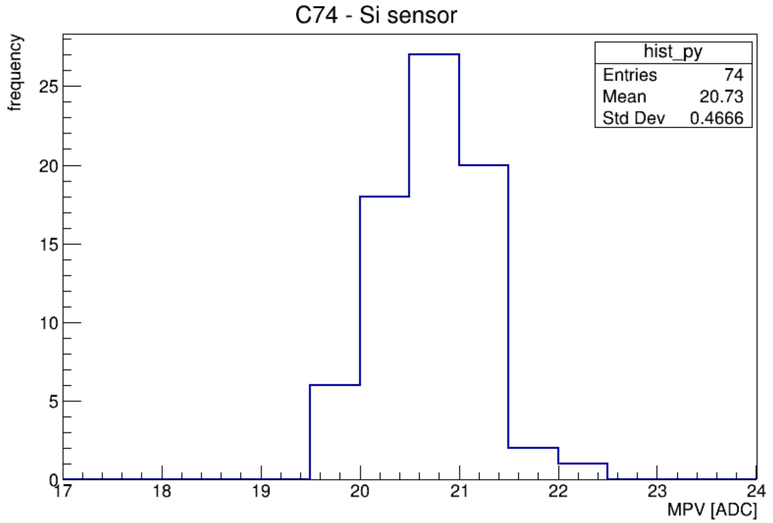
  - Silicon sensors have similar fluctuation, with different average responses at about half ADC count (2%)





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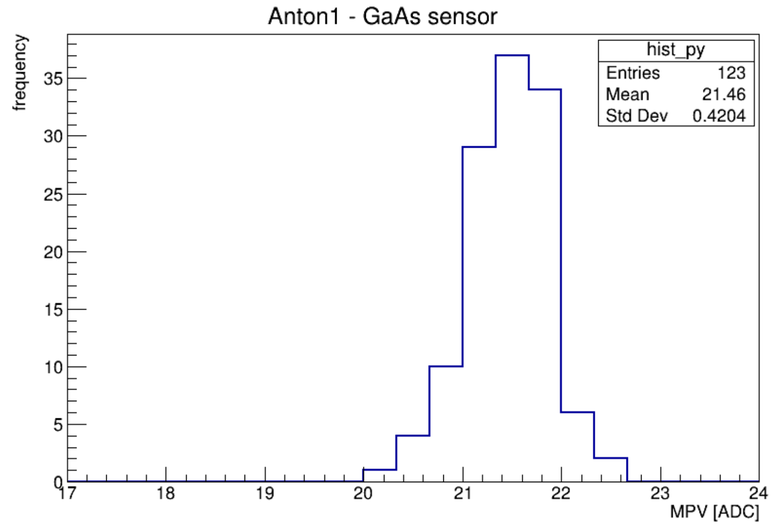
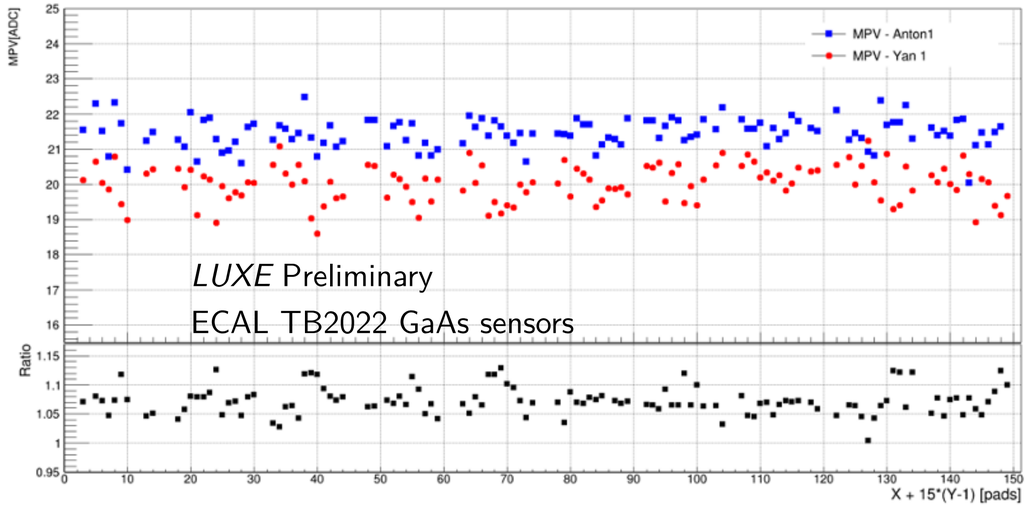
- Amplitude distribution fitted into a Landau-Gaussian convoluted function
- Amplitude (MPV) fluctuates over 1 ADC count
  - Silicon sensors have similar fluctuation, with different average responses at about half ADC count (2.5%)
  - GaAs sensors have different fluctuation sizes, and with different average responses at near 1.5 ADC counts (7.5%)





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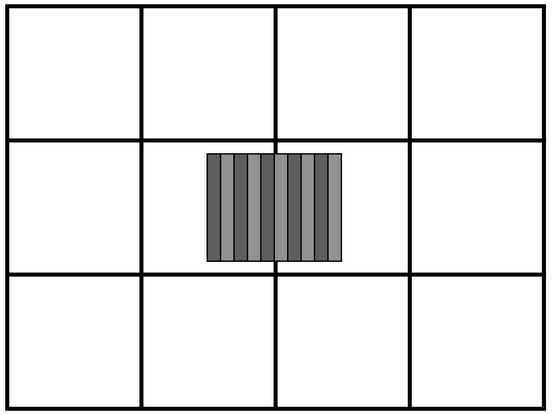
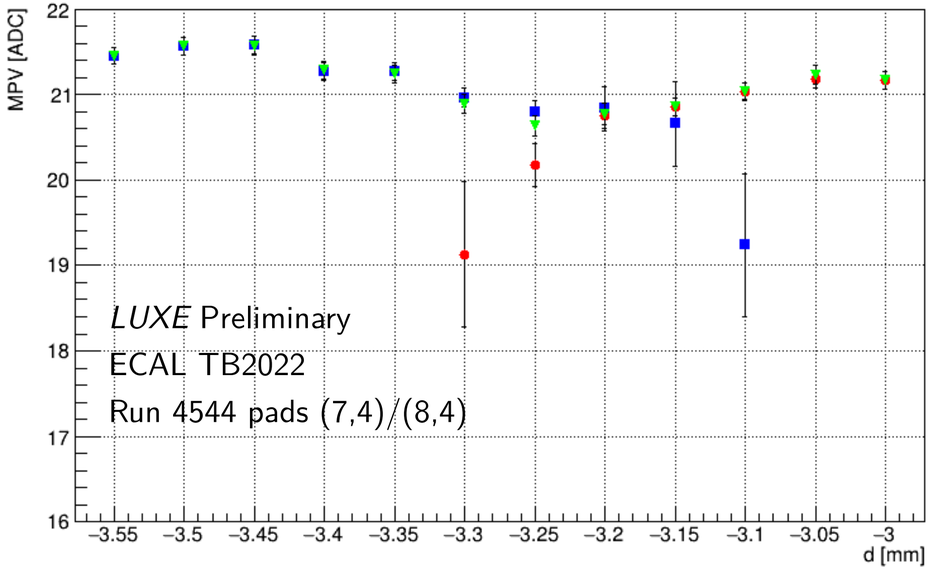
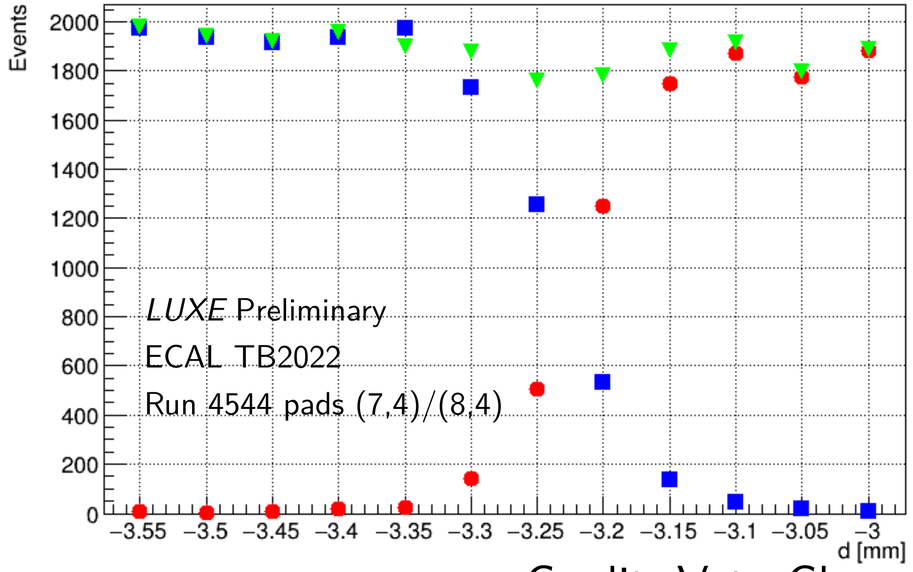
Signal sharing

- When an electron comes in between two pads, it is possible that the sensor has multiple readouts from both pads
- Select the events with one electron that hits on a specific stripe area
- Scan through two neighbouring pads and check signal amplitude
- Sum of the shared signal amplitude has almost no lost



Step: 50 um; Pad size: 5.5 mm





Blue: left pad

Red: right pad

Green: sum of two pads

Credit: Veta Ghenescu (Romanian ISS)

Summary

- On beam tests are conducted on DESY-II TB24 for LUXE ECAL sensors
- We have successfully synchronised and aligned the telescope with the sensors under test
  - Multiple scattering considered (general-broken-line model) except the last two planes
  - Small residues, nice pull functions and χ^2/n_{DoF} distribution
- We are able to study the sensor's properties with the help of the telescope
  - Pads in one sensor are generally homogeneous
  - Signal sharing is observed near the boundary of two pads (around 250 um)
  - ~~Indication of different behaviours for sensors with and without traces~~
- Some useful software tools in GitHub
  - Corryvreckan LUXE-ECAL configures: https://github.com/shan-yamabuki/TBTelescope-Configure/tree/TB22
  - Corryvreckan module for data dumping: https://github.com/LUXEsoftware/TBTelescope-TrackingInfo
  - Telescope resolution: https://github.com/eutelescope/eutelescope/tree/master/processors/include/legacy
- **Many thanks to the most kind and helpful DESY testbeam crew!**

Thank you for your attention!

Back Up

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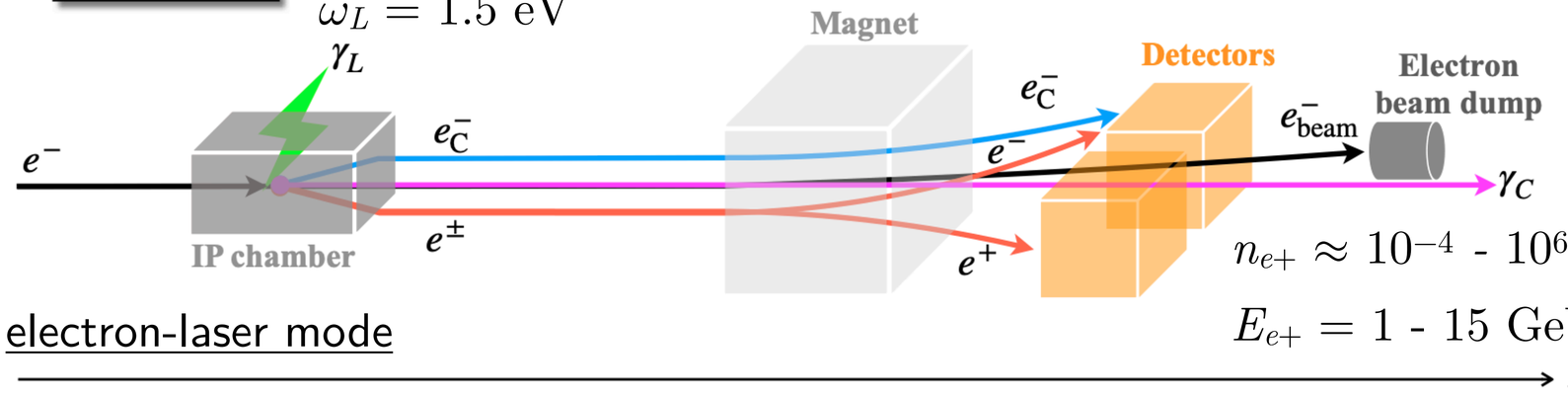

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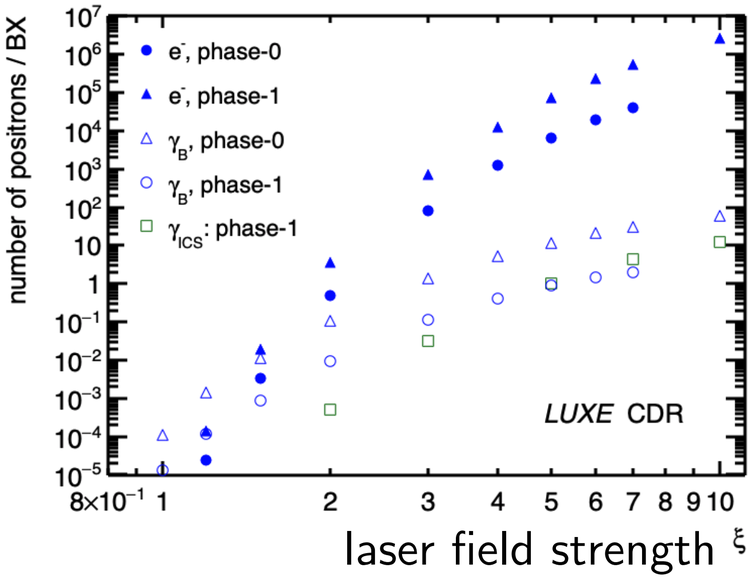
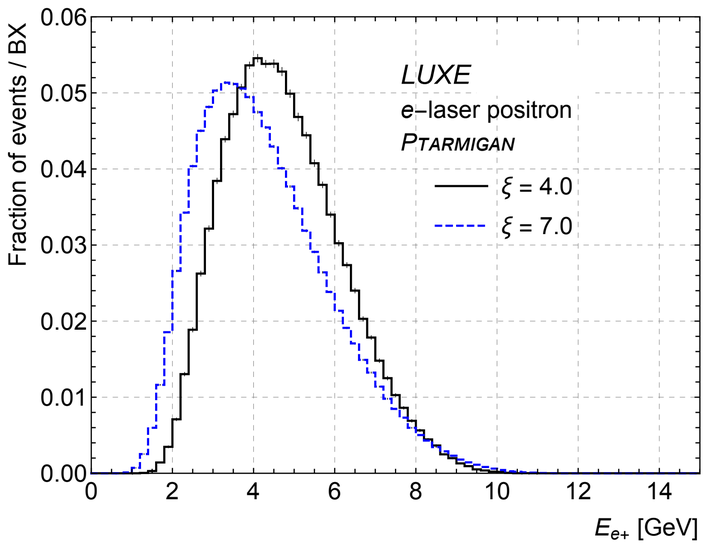
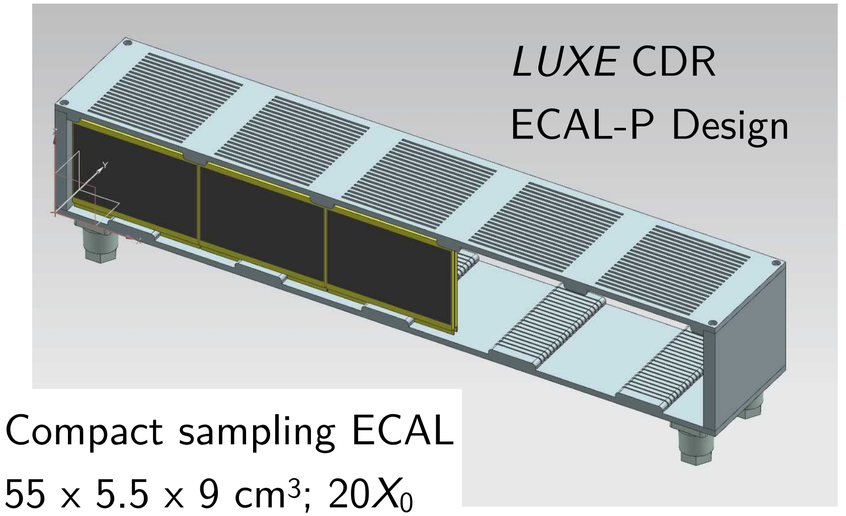






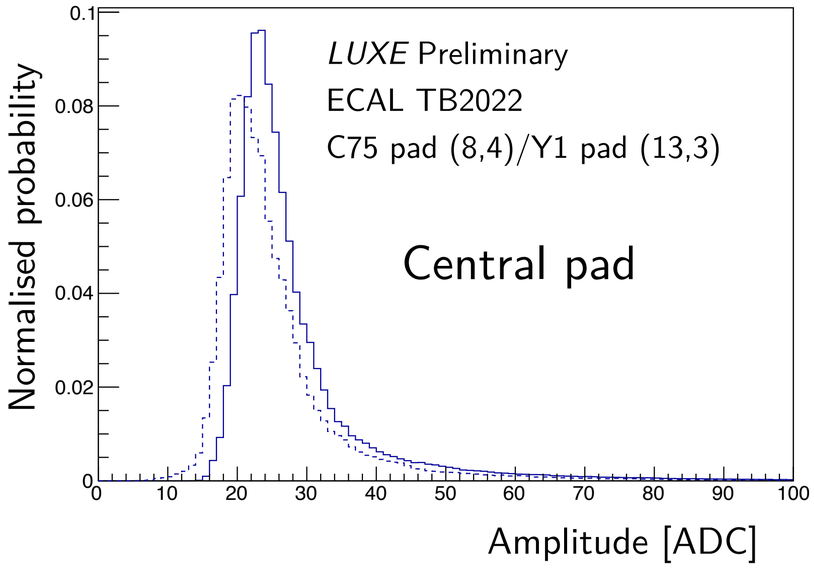
Compact sampling ECAL

55 x 5.5 x 9 cm^3; 20X_0

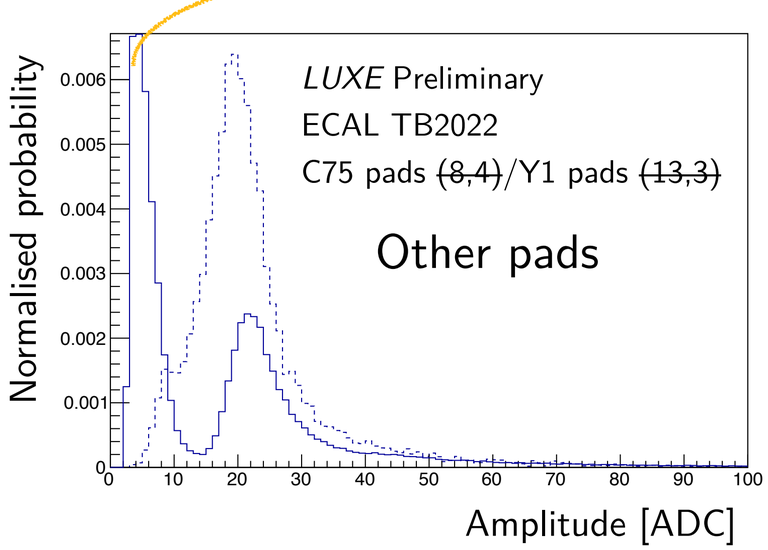
LUXE CDR, EPJ ST 230 2445 (2021)

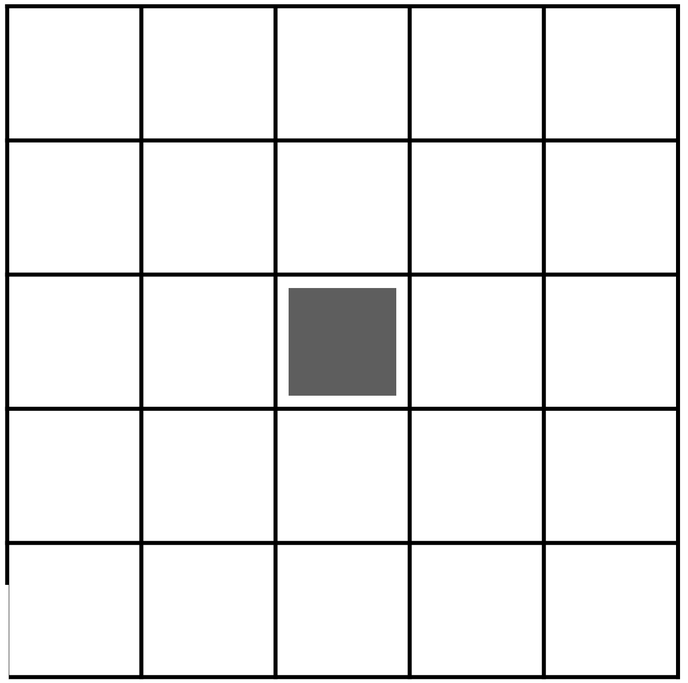
Difference between two kinds of sensors

- Aluminium traces, a new method to connect pads with the readout frontend, are used on GaAs sensor to make the sensor more compact
- The traces are bunched along *y*-direction and it is theoretically possible that fake signals could be induced in between traces
- Select the events with one electron that hits on a specific pad centre
- Check the response of this particular pad (left)
- Check the response of all other pads (right)



Noise in channels





Silicon sensor (>1 means multi. pads):
- On-pad response: 99.7%
- Off-pad response: <6.20% (noise)

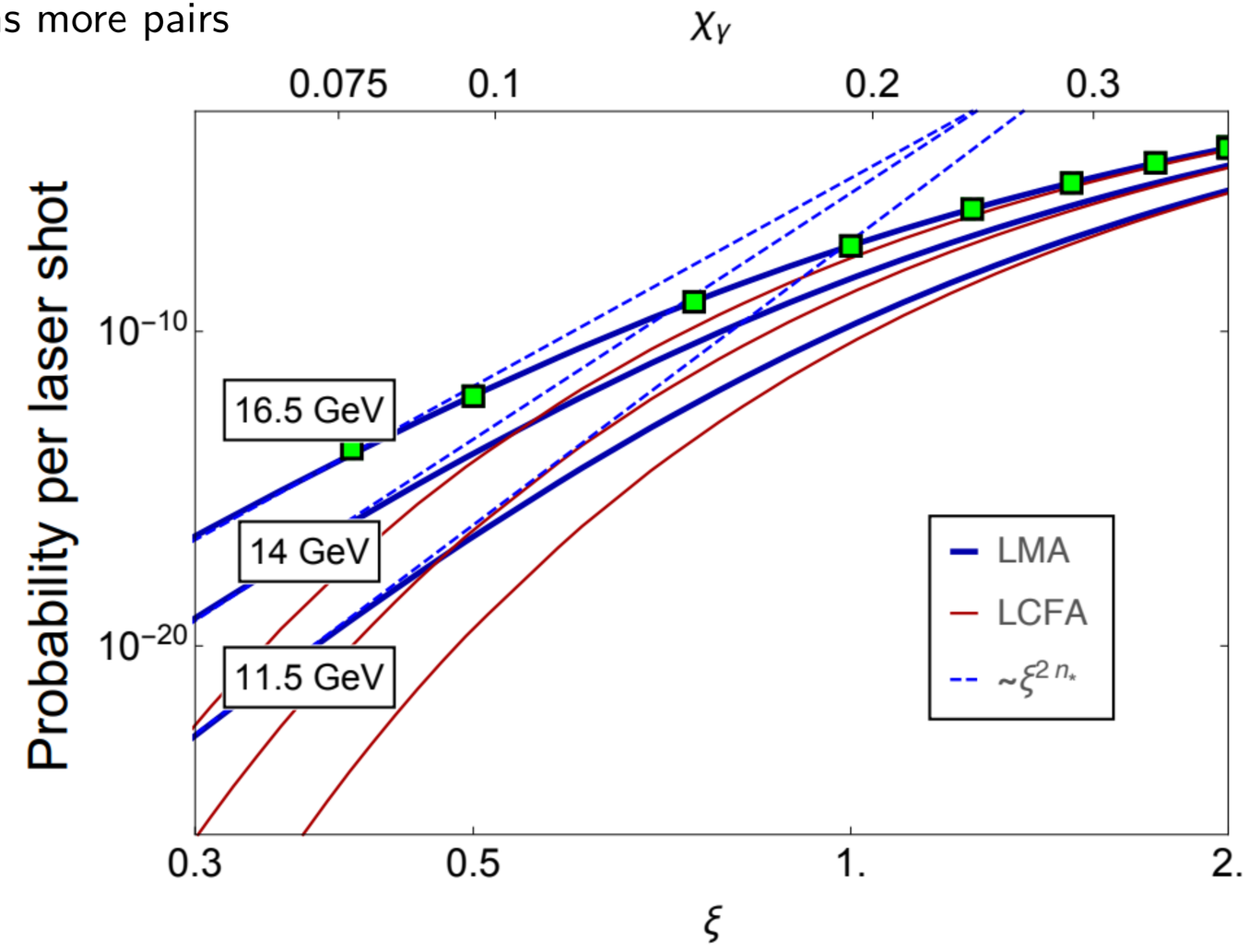
GaAs sensor:
- On-pad response: 94.4%
- Off-pad response: 8.65%

Silicon: solid lines

GaAs: dashed lines

Perturbative prediction:

More photons more pairs



Nonperturbative prediction:

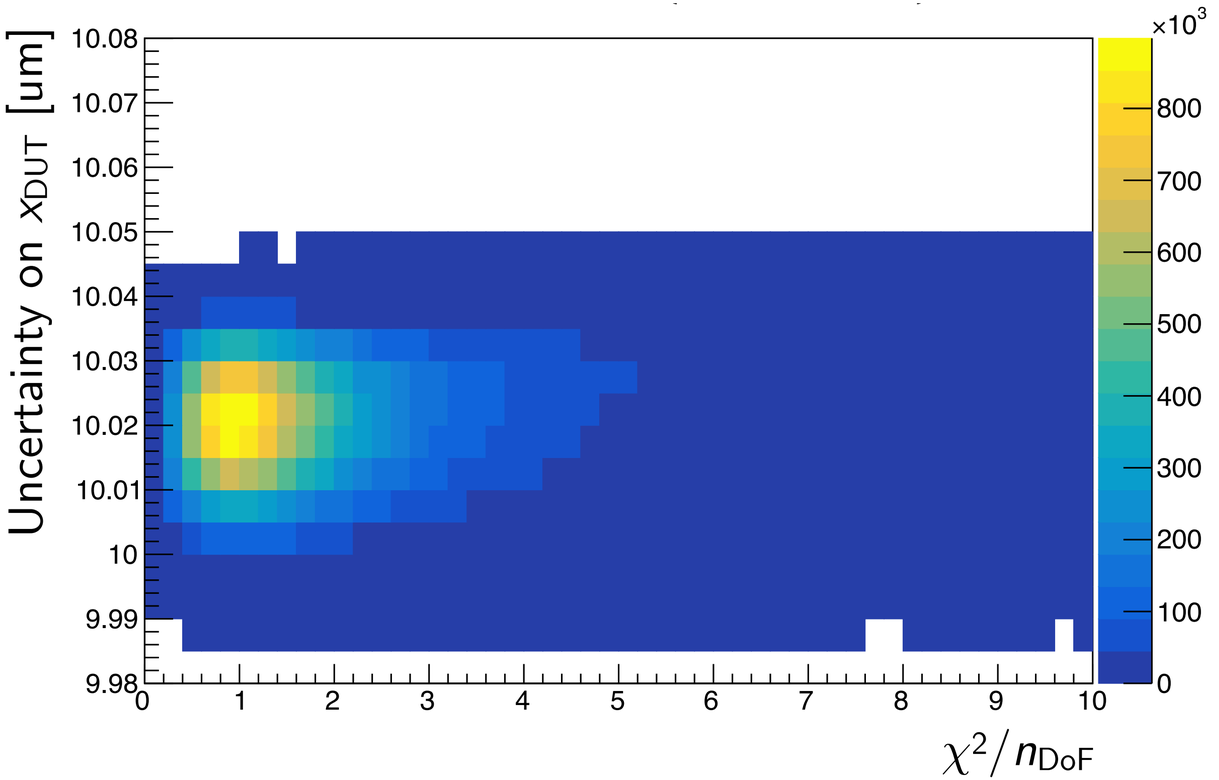
Fewer pairs (more photons) due to strong field

LUXE CDR, EPJ ST 230 2445 (2021)

Uncertainty

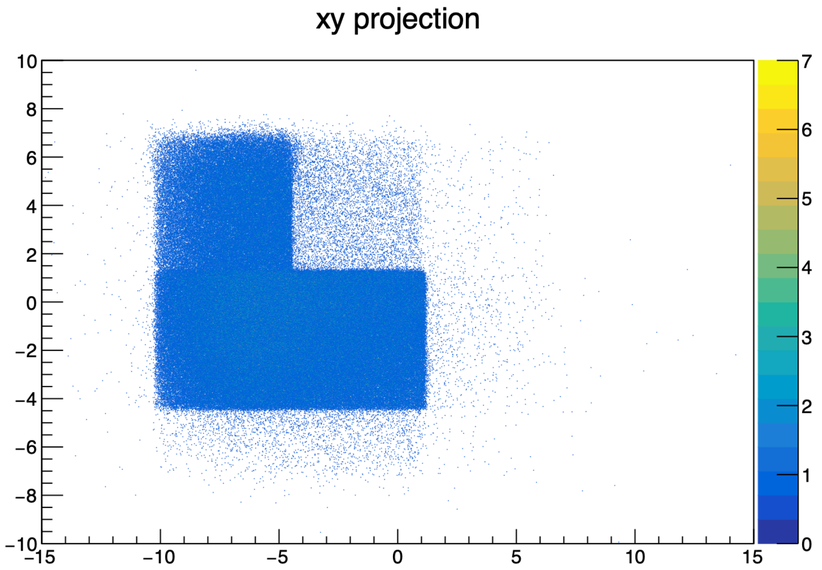
- Quality cut
  - $\chi^2/n_{\mathrm{DoF}} > 5$
  - Propagated uncertainties do not consider the scattering at the last two telescope planes
- Uncertainty estimated by another code

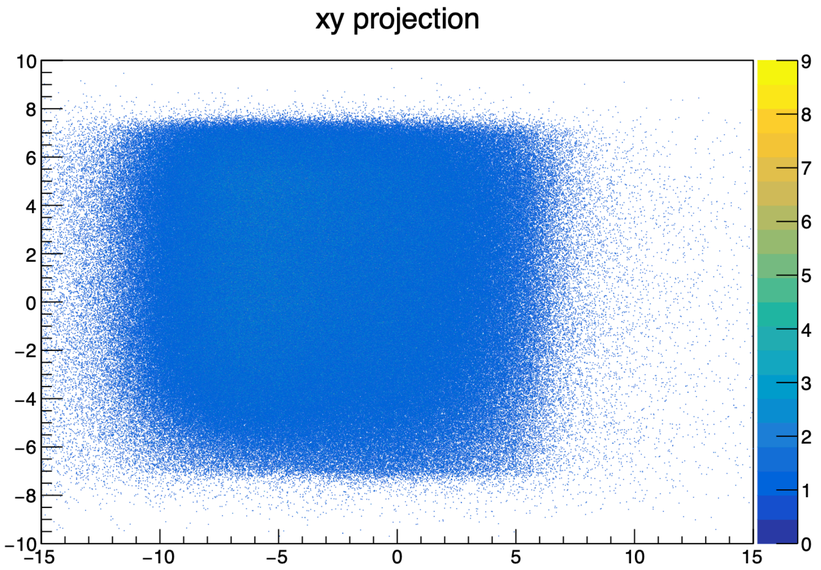
Configuration		TB21	TB22
Vacuum	1 GeV	96.3 μm	129.3 μm
	3 GeV	39.5 μm	48.1 μm
	5 GeV	27.7 μm	31.0 μm
Air	1 GeV	119.9 μm	151.9 μm
	3 GeV	47.4 μm	56.5 μm
	5 GeV	32.9 μm	36.8 μm



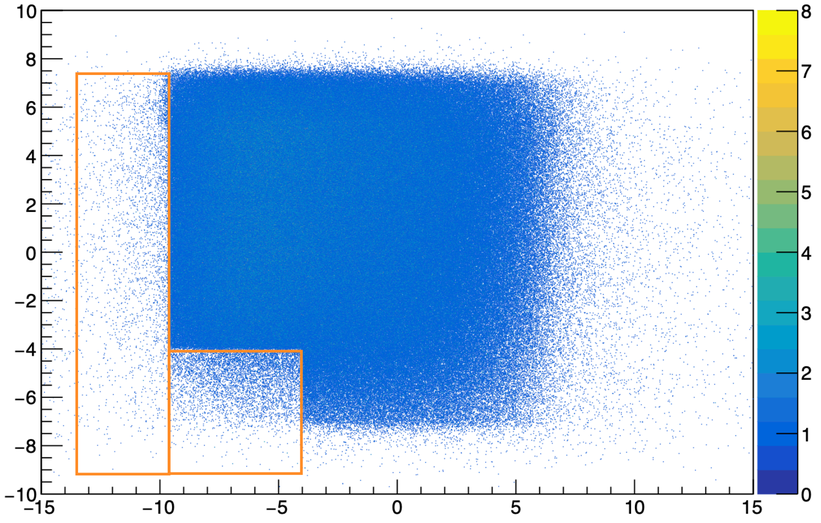
EUTelescope code for calculating uncertainty for a layout
https://github.com/eutelescope/eutelescope/tree/master/processors/include/legacy

Findings by the telescope





Left-Top: Electron profile with pad (2, 1) having response, showing the three pads are connected for readout



Right-Top: Telescope electron profile

Bottom: Electron profile with sensor response, showing a dead area on the sensor

Possible effect from traces

Run 4484: GaAs sensor “A1”

- Tops: electron x/y-distributions with response from only one pad
- Bottoms: same distributions with strong response from only one pad
- Asymmetry can be easily observed on x and y directions: no dip on y-distribution without amplitude cut
- Possible cause: traces are bunched along y direction