2022 TestBeam - sneak peek on sensors for e^- calorimeter

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LUXE Collaboration Meeting – September 2023

2022 Test Beam @ DESY

Test Beam's primary goal

- Studies of sensor response of Si and GaAs pad sensors prototype, with up-to-date development of FLAXE FE and FPGA read-out, to electrons with energy in the range of 1 to 5 GeV in the DESY II electron beam

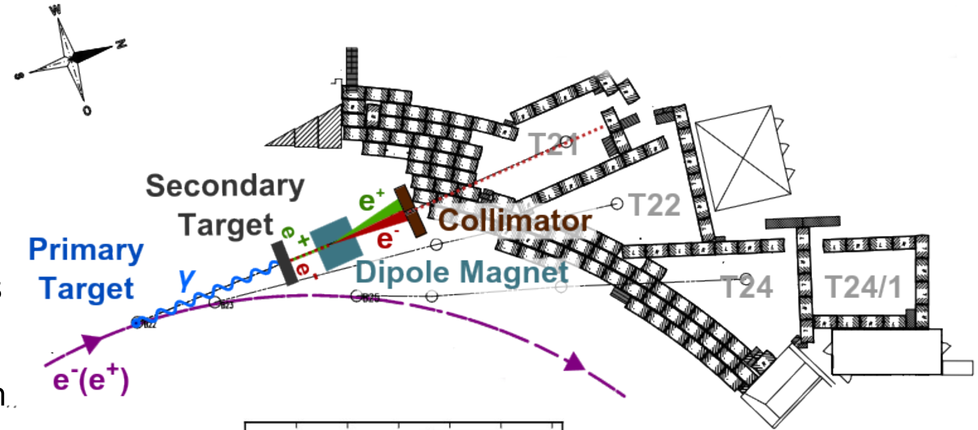
Test Beam's questions to be answered

- readout testing with various configurations
- homogeneity of the sensor response
- signal size and signal-to-noise ratio for several pads of each sensor type
- edge effects, response between pads
- response in the positions of the routing strips, cross talk
- cross-checking data with simulations results

Sept ‘22 – test beam conditions

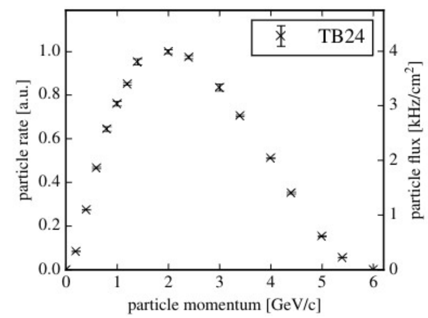
DESY Hamburg Facility

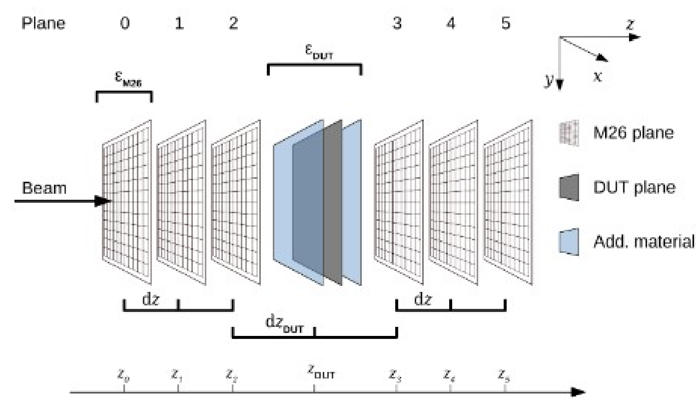
- electron beams of 1 - 6 GeV/c
- primary and secondary targets
- dipole magnet (DESY Typ MR)+
additional magnet (DESY Typ MB) for geometrical reasons
- a primary collimator (tungsten)
- test beam shutter – controlled by safety interlock system
- huts allowing user control of the corresponding beam line



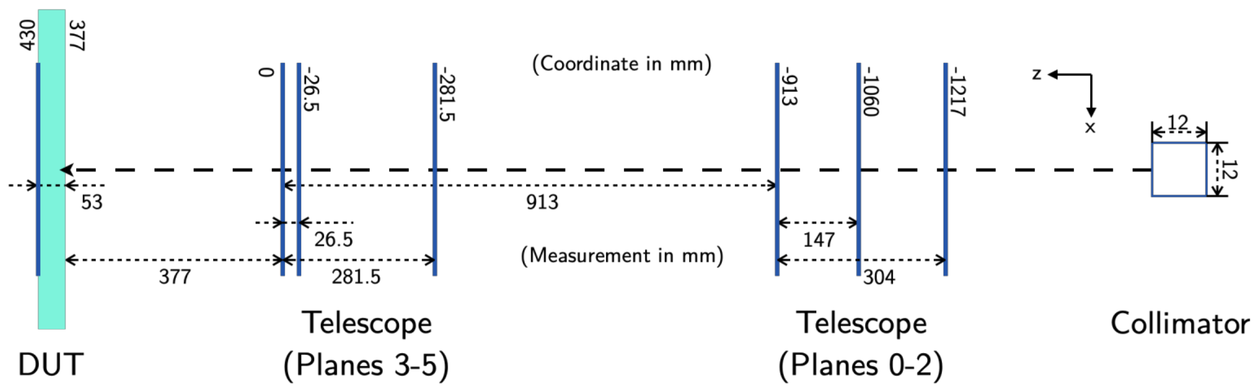
Test Beam Area TB24

- beam monitors – just after the evacuated beam pipe
- second collimator – lead insets of 5 x 5 mm² to 20 x 20 mm²
- EUDET-type pixel beam telescope – to track the test beam particles
  - 2 telescope arms with 3 planes each
  - each plane is a MIMOSA26 monolithic active pixel silicon sensor
- EUDAQ data acquisition framework consisting of:
  - a EUDET Trigger Logic Unit (TLU) – timestamp information on particle passage through 4 trigger devices in coincidence
  - MIMOSA26 DAQ & DUT DAQ
- a x-, y-, ϕ-stage system providing a µm-precision



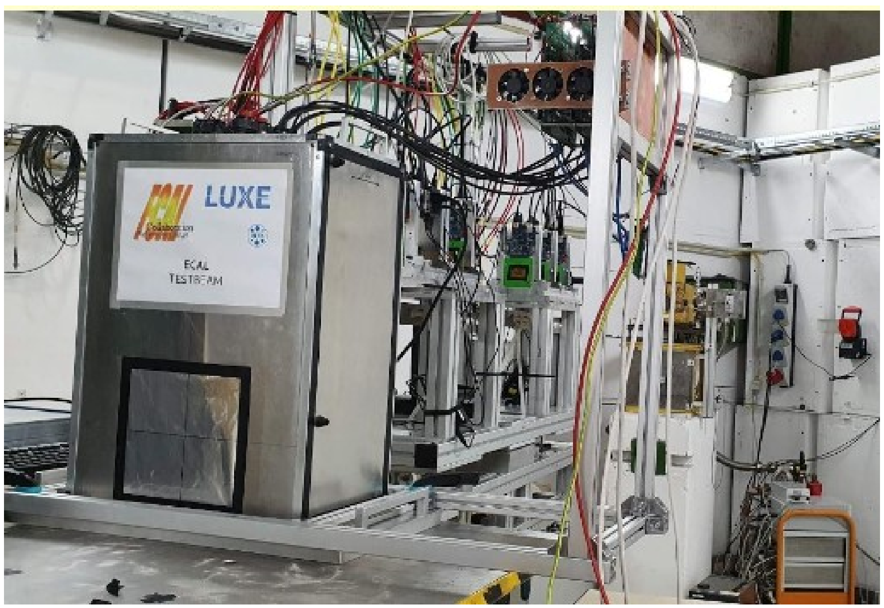


Experimental setup



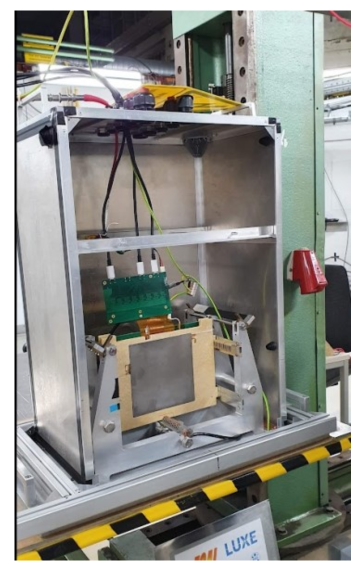
Test Beam Area TB24

- collimator – lead insets of 12 x 12 mm^2
- 6 Alpide Si telescope planes
  - 1 arm with 3 planes equally placed
  - 1 arm with 2 planes close to DUT
- data acquisition framework:
  - Trigger Logic Unit (TLU)
  - EUDAQ for telescope
  - FireDAQ for DUT / sensors
- DUT placed on x-, y-, ϕ-stage system

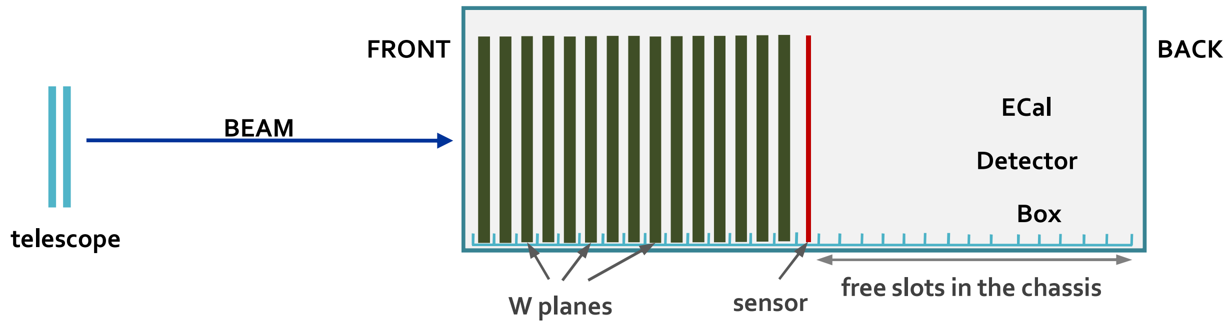


DUT components

- ECal Luxe TestBeam box frame
- components included in the DUT:
  - Al foil for entrance window
  - sensors of various types (3 Si & 2 GaAs)
  - W plates with different compositions / thickness
- electronics for the sensors
  - FLAME board
  - cables, FPGA card

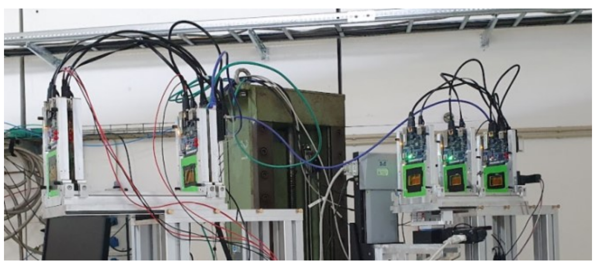


Setup components



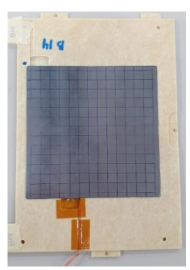
Telescope

- Alpide Si sensors:
  - Pixel pitch: 29.24 um x 26.88 um
  - Pixel number: 1024 x 512
  - Spatial resolution: 8.44 um x 7.76 um
  - Time resolution: 10.0 us



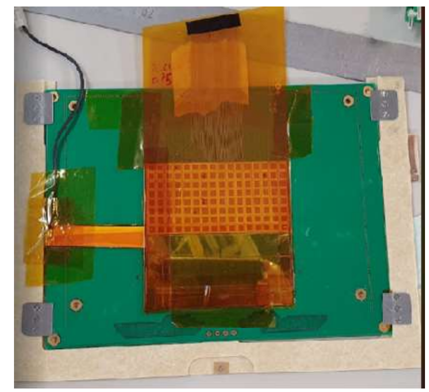
W plates

- 2 different compositions:
  - 7 with 93% W
  - 8 with 95% W
- Various thickness:
  - from 3.470 to 3.645 um

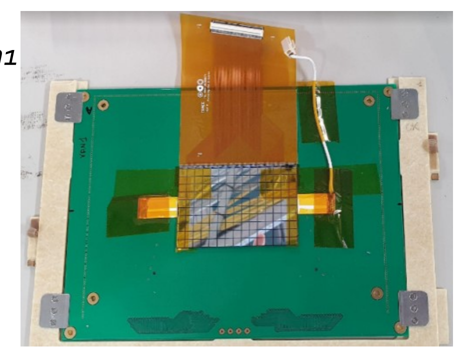


Sensors under test

- **Si sensors**:
  - 3 types , denoted *C72*, *C74* and *C75*
  - thickness: 320 um
  - dimensions: 9 cm x 4.5 cm
  - pad size: 5.5 mm x 5.5 mm
  - number of pads: 16 x 8



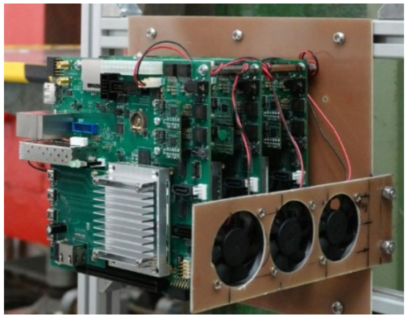
- **GaAs sensors**:
  - 2 types, denoted *Yan1* and *Anton1*
  - thickness: 500 um
  - dimensions: 74.7 mm x 49.7 mm
  - pad size: 4.7 mm x 4.7 mm
  - gap between pads: 0.3 mm
  - number of pads: 15 x 10



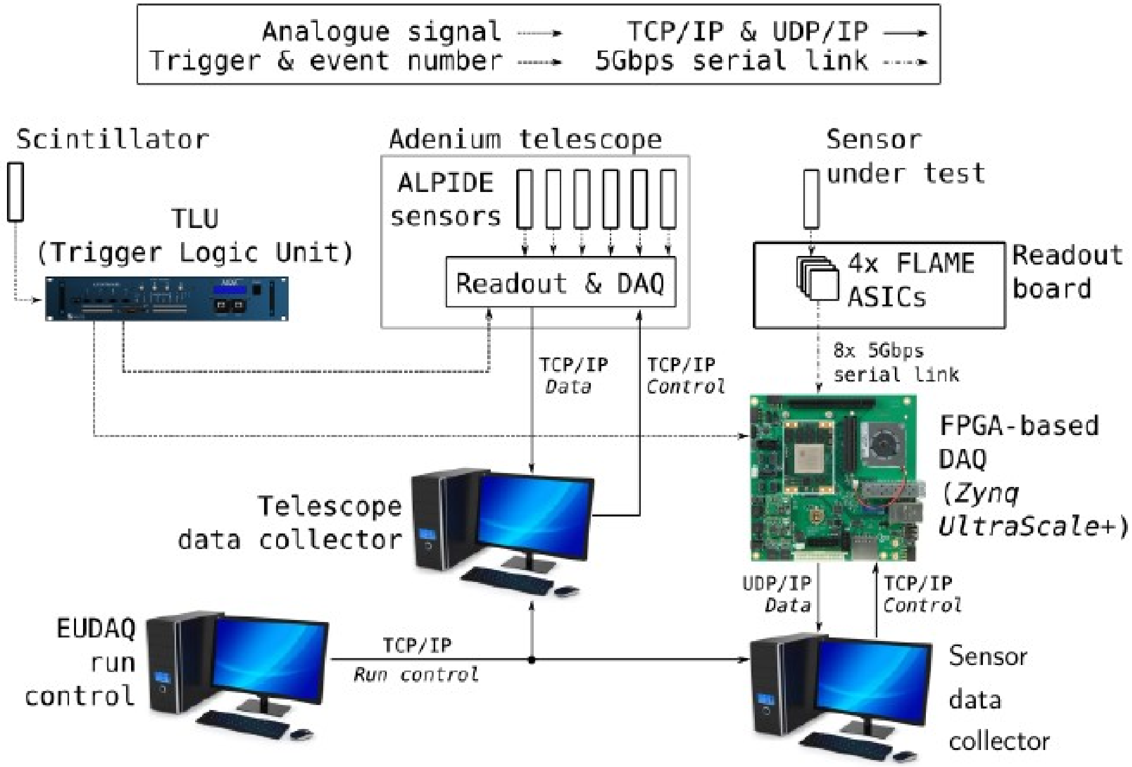
Electronics Configuration

Data processing

- There are no 'raw' data samples stored for Flame ASICs (except debug runs)
- Signal processing/extraction is made already on the FPGA level, which includes:
  - Pedestal subtraction
  - Common mode subtraction
  - Signal extraction
  - Zero suppression



- Output information corresponding to each single hit are:
  - Chanel number
  - Signal amplitude (in ADC units)
  - Time of Arrival
  - Chanel gain (constant during whole testbeam)



Credit: Jakub Moroń (AGH)

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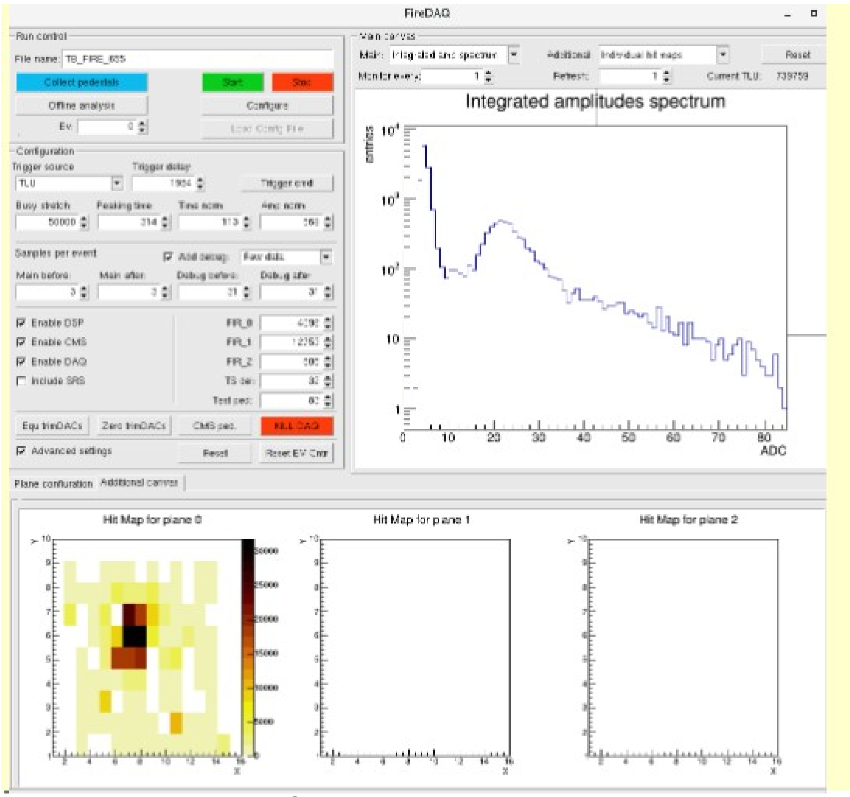
The integrated GUI

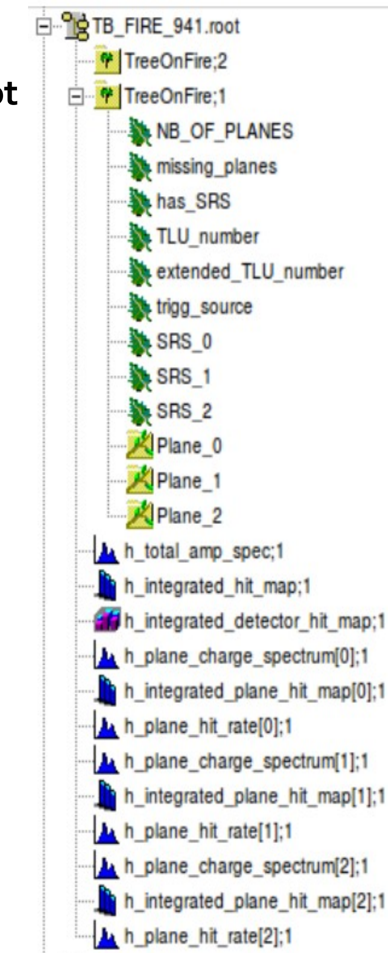


Number of triggers:

C74	18×10^6	scan over the sensor
	7×10^6	at position – 37,5, - 6.5
C75	27×10^6	scan over the sensor
	18×10^6	at position – 1.5, - 88.5
A1	46×10^6	scan over the sensor
Y1	44×10^6	scan over the sensor
	33×10^6	at position 1, - 94,4

FLAME data structure

- for each run a **TB_FIRE_#run_nb#.root** and **.log** files are created
  - **#run_nb#** is directly taken from the telescope run number
  - **.log** file contains the flame settings
- **flame data** are stored in a **.root** file
- one can easily browse the file through TBrowser
- each .root file contains:
  - Tree with „raw" data „TreeOnFire"
  - Several basic plots like:
    - Signal spectrum for each plane (*h_plane_charge_spectrum[x]*)
    - Hit map for each plane (*h_plane_hit_map[x]*)



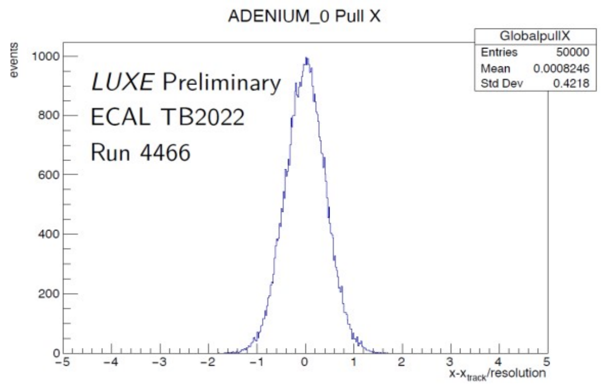
Telescope & sensors alignment

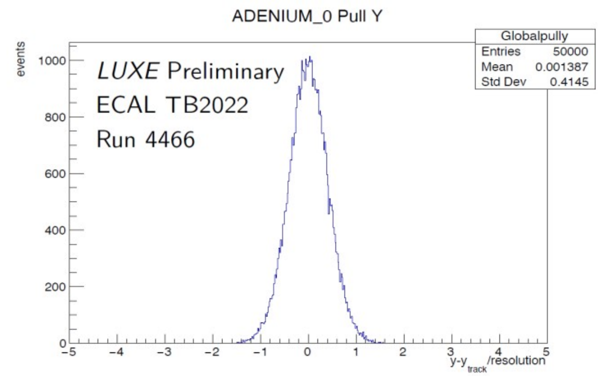
Alignment procedure with Corryvreckan

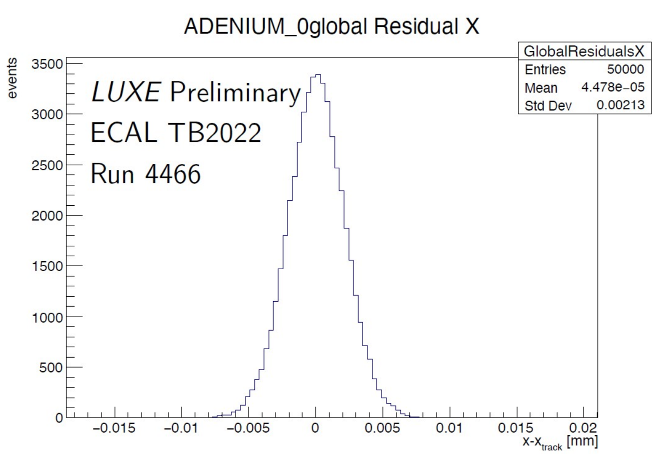
- **Four-step alignment**
  - Pre-alignment
  - Alignment on x-y
  - Alignment on rotation
  - Alignment on x-y and rotation

Alignment efficiency indicators

- **Pull function** - should be a normal dist. with μ = 0 and σ = 1
- **Residues** - smaller than 1 um
- χ^2/n_{DoF} - peaks at 1

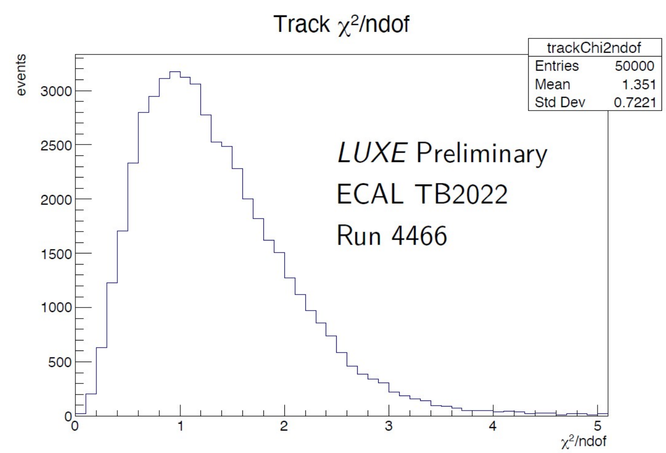






- **Tracking models:**
  - General broken line (GBL)
  - Simple straight line (SSL)

- **Credit : Shan Huang**

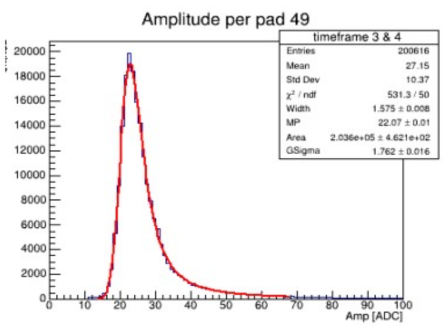


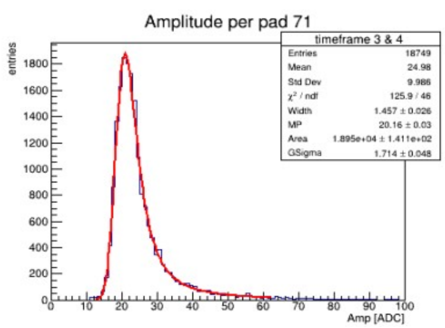
Sensors data analysis

Si sensors (C74, C75)

GaAs sensors (Yan1, Anton1)

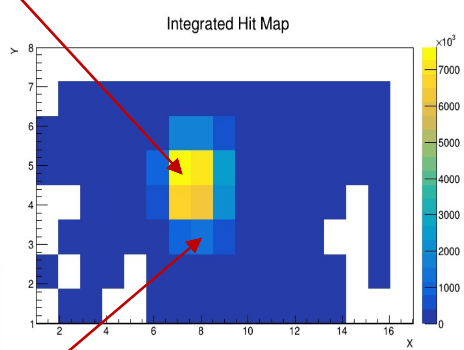
- channel by channel gain calibration can be done by looking on the response of sensor directly exposed on MIPs deposition in Si sensor
- for each pad a (Landau & Gauss) function was fitted to energy spectrum

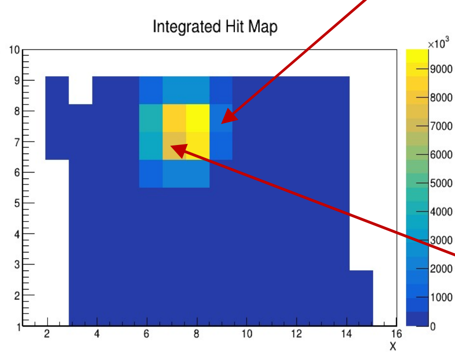


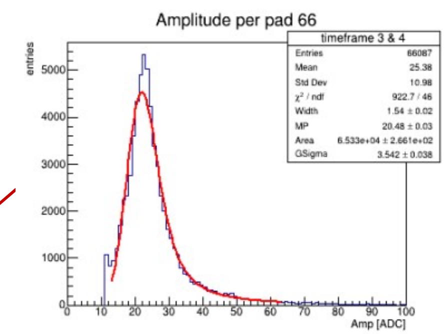


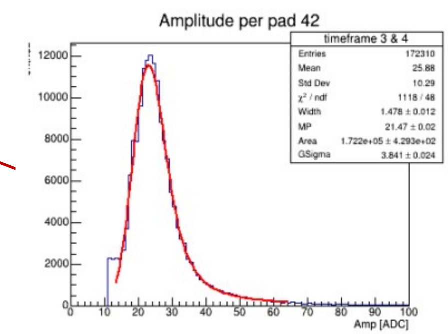
Analysis conditions

- kept all timeplanes
- dead channels masked
- cut on amplitude < 900
- Gauss&Landau fitted in range [12-64] ADC









- a lot of channels are dead or unresponsive
- for each pad a (Landau & Gauss) function was fitted to energy spectrum
- The analysis showed very small deviations from channel to channel

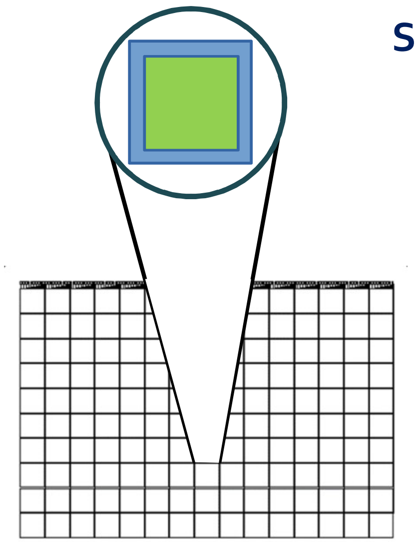
Data from run4436 – C75 sensor

- Beam on pads 49, 51, 59, 61

Data from run4484 – Anton1 sensor

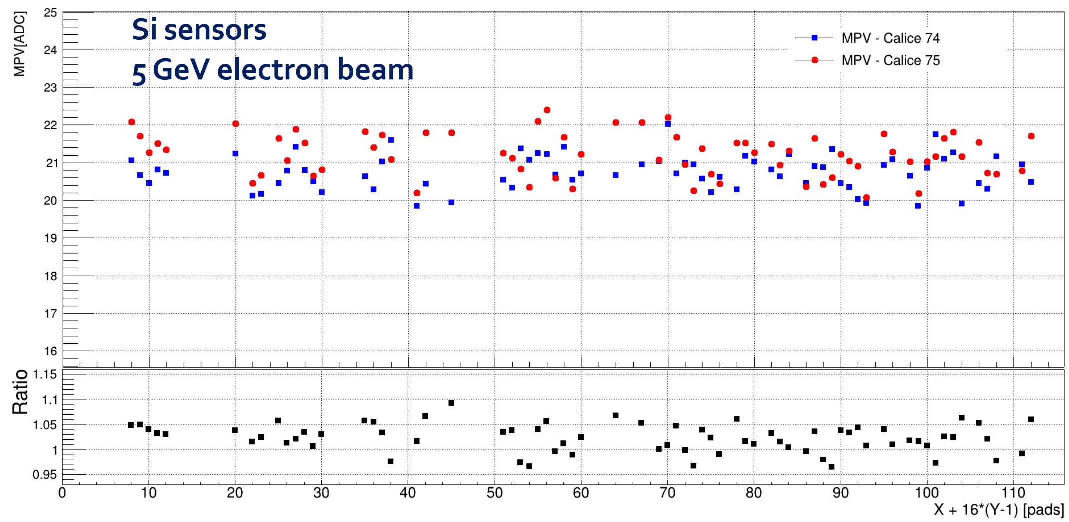
- Beam on pads 42,44,62,64

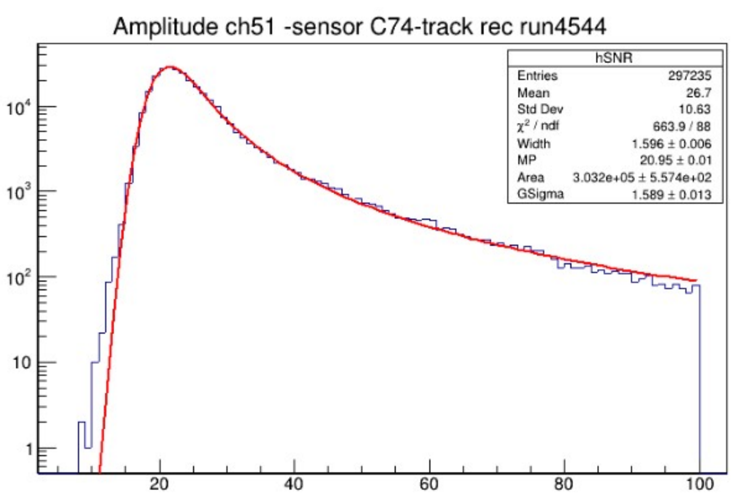
Sensors data analysis

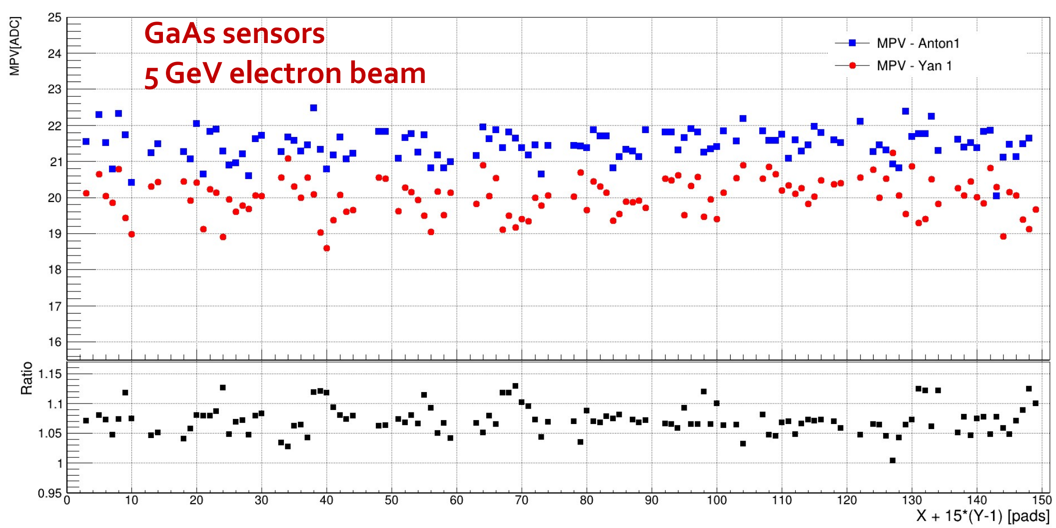


Sensors homogeneity

- **Si sensors** - ratio between C74 signal and C75 signal on each channel is less than 10% after removed bad channels;
- **GaAs sensors** - the ration between Yan1 and Anton1 signals is about 5 ÷ 15 percents.







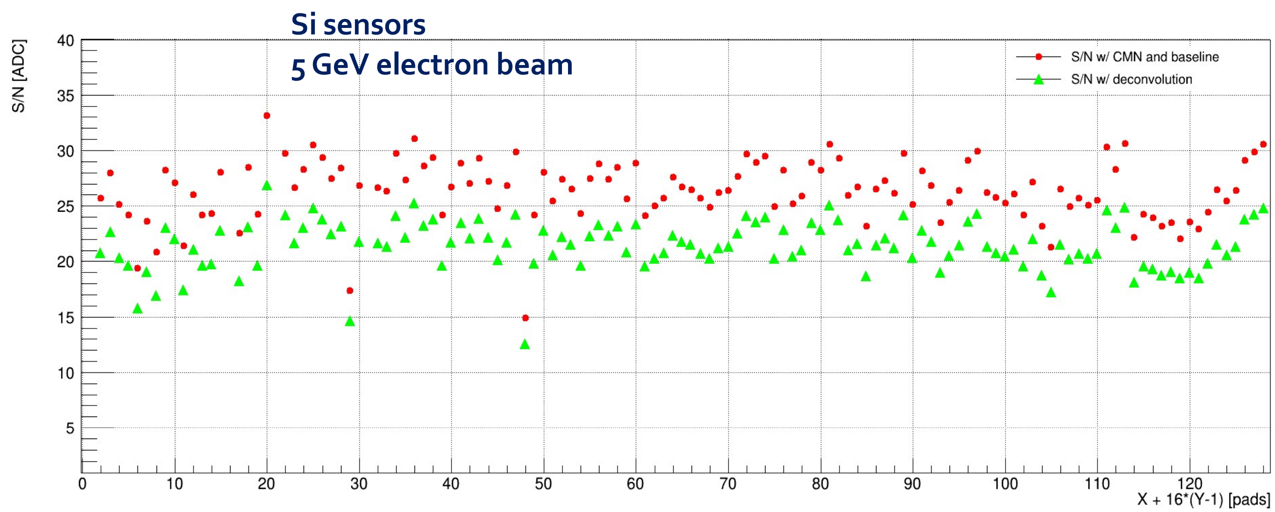
Sensors data analysis

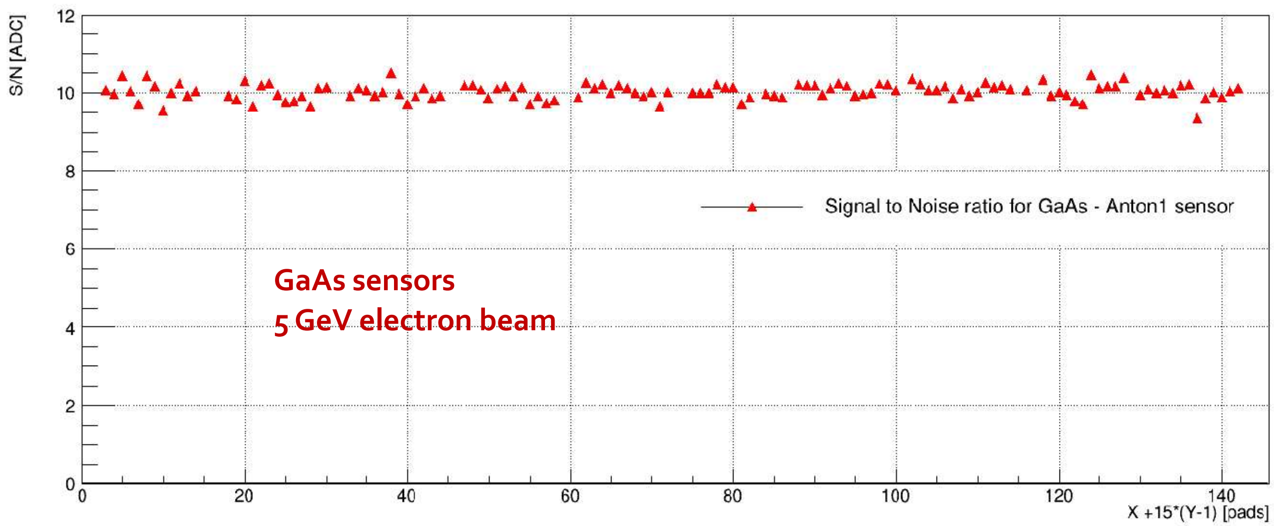
Signal to noise ratio

- Signal to noise ration for C74 silicon sensor and Anton1 GaAs sensor

$$S/_N = \frac{MPV_{signal}}{\sigma_{pedestal}}$$

- **Si sensor C74** - pedestal extracted using Common-Mean-Noise + baseline and deconvolution methods
  - s/n ratio on each channel is lower when using deconvolution
  - s/n ratio has a wide spread over 10 ADC
- **GaAs sensor Anton1** – signal-to-noise ratio in a narrow region (around 10 ADC)

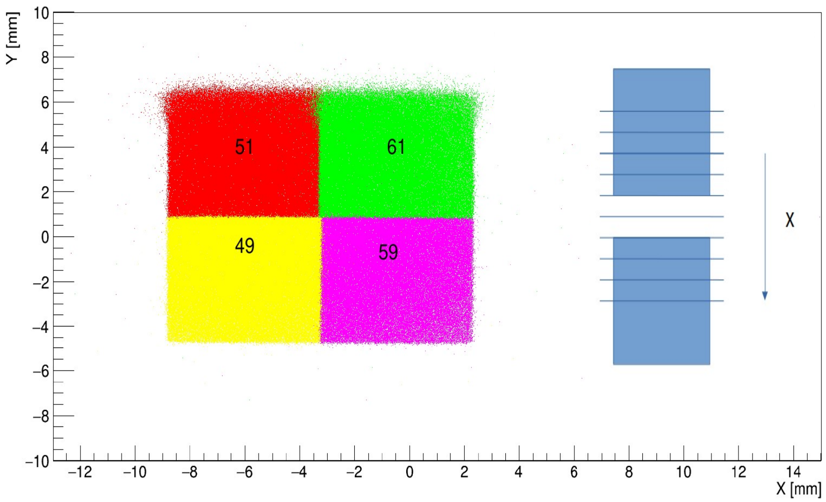


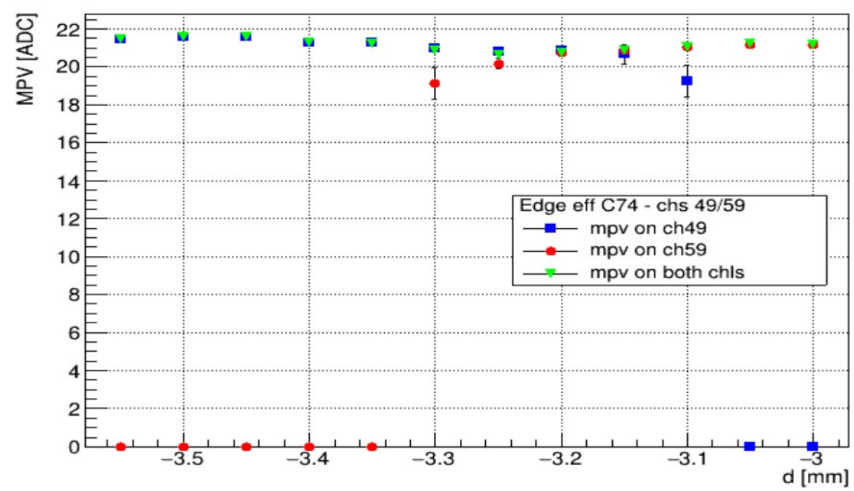


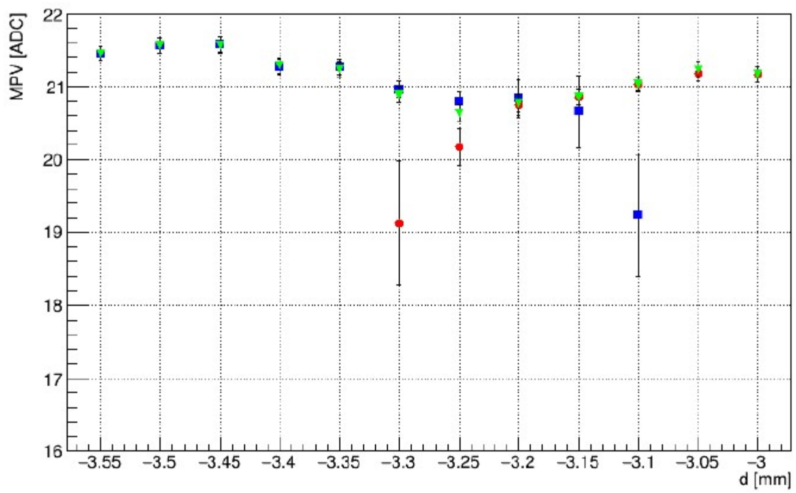
Sensors data analysis

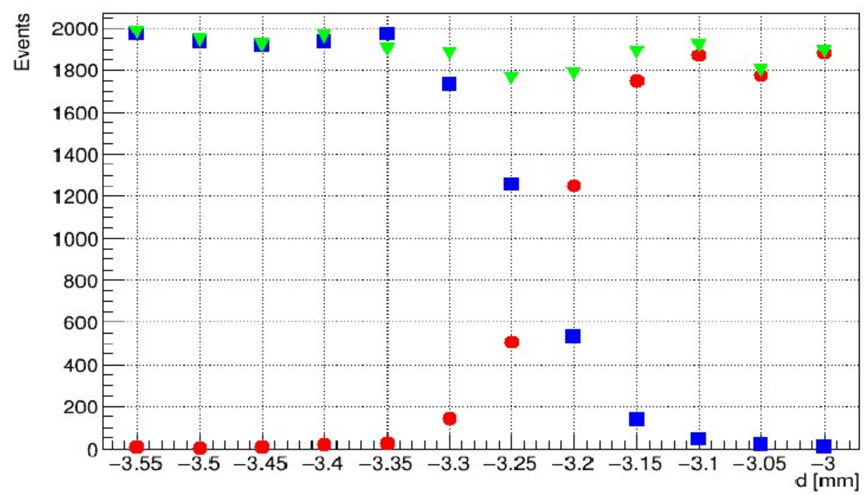
Performance near the edges of the pads

- Signal scan: pads 49 and 59 using 50 um slices





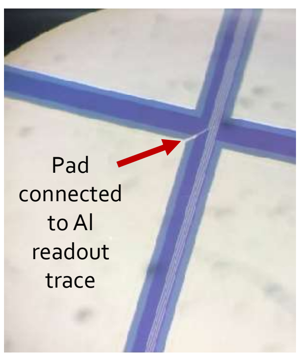


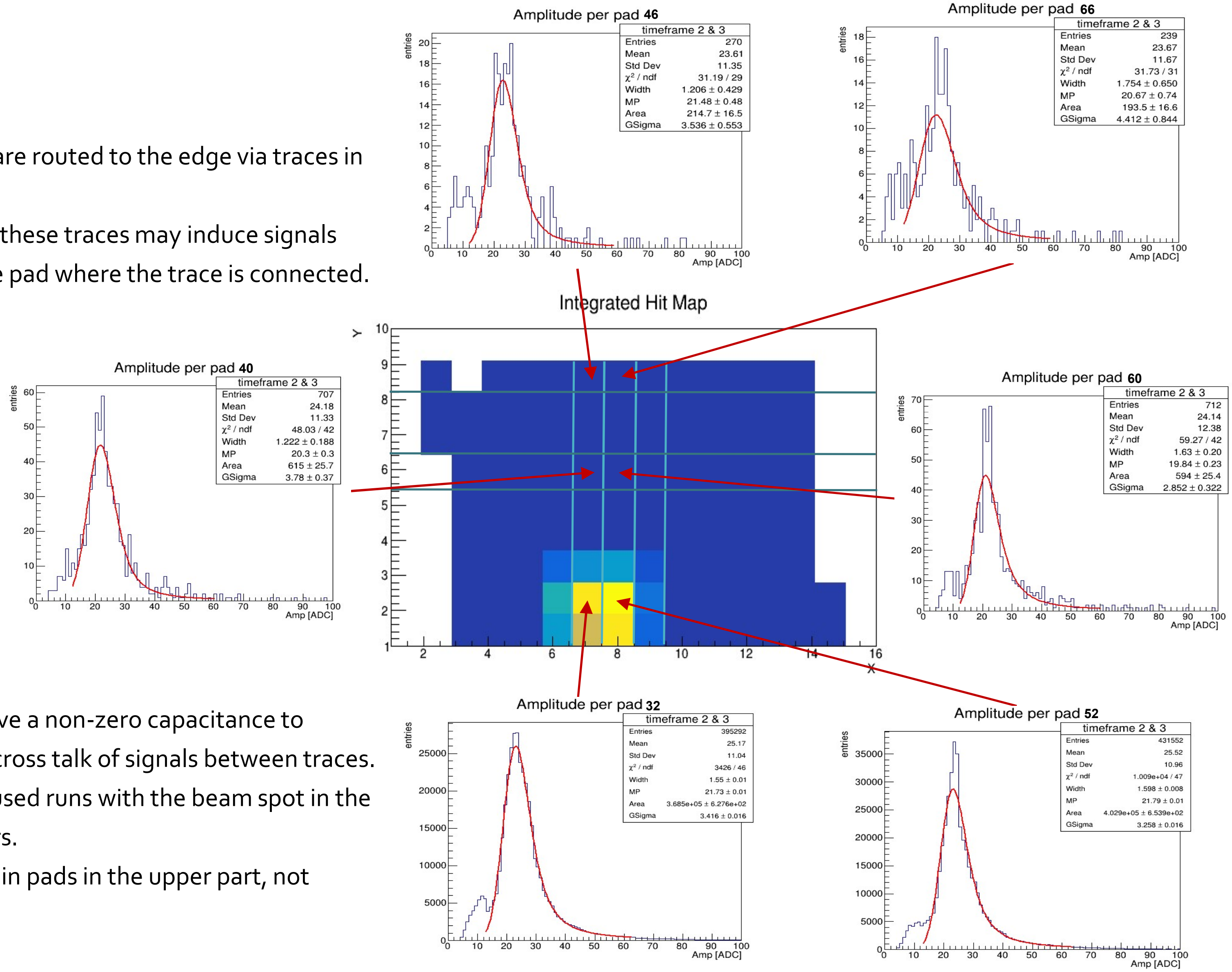


Sensors data analysis

Cross talk

- **GaAs sensors**
  - the signals of the pads are routed to the edge via traces in between the pads.
  - electrons impinging on these traces may induce signals assigned wrongly to the pad where the trace is connected.





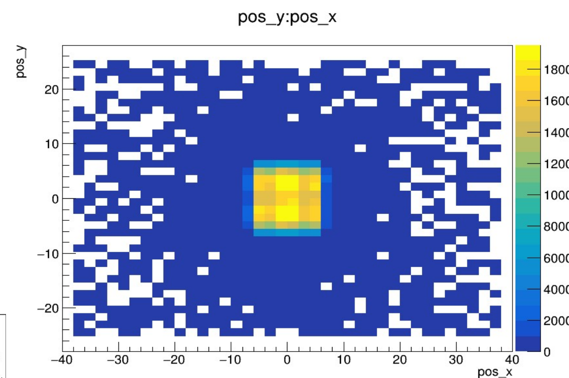
- **Si and GaAs sensors**
  - signal routing traces have a non-zero capacitance to neighbors, resulting in cross talk of signals between traces.
  - to study this effect we used runs with the beam spot in the lower part of the sensors.
  - we searched for signals in pads in the upper part, not covered by the beam

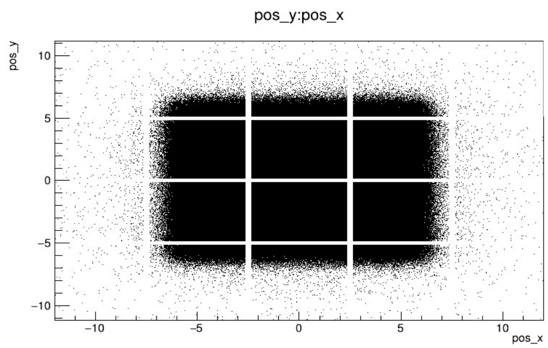
Simulations

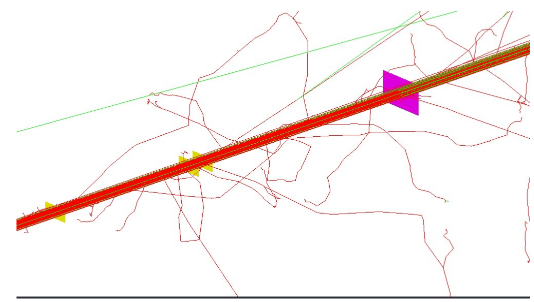
▪ GaAs sensor – Anton1

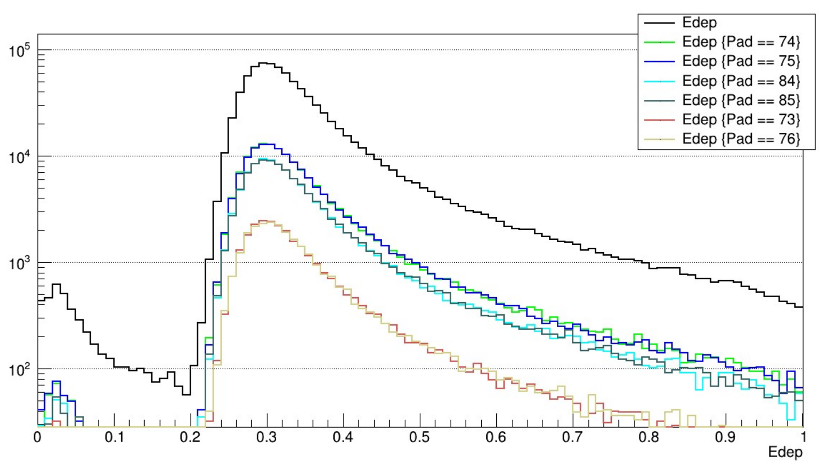
Simulation setup

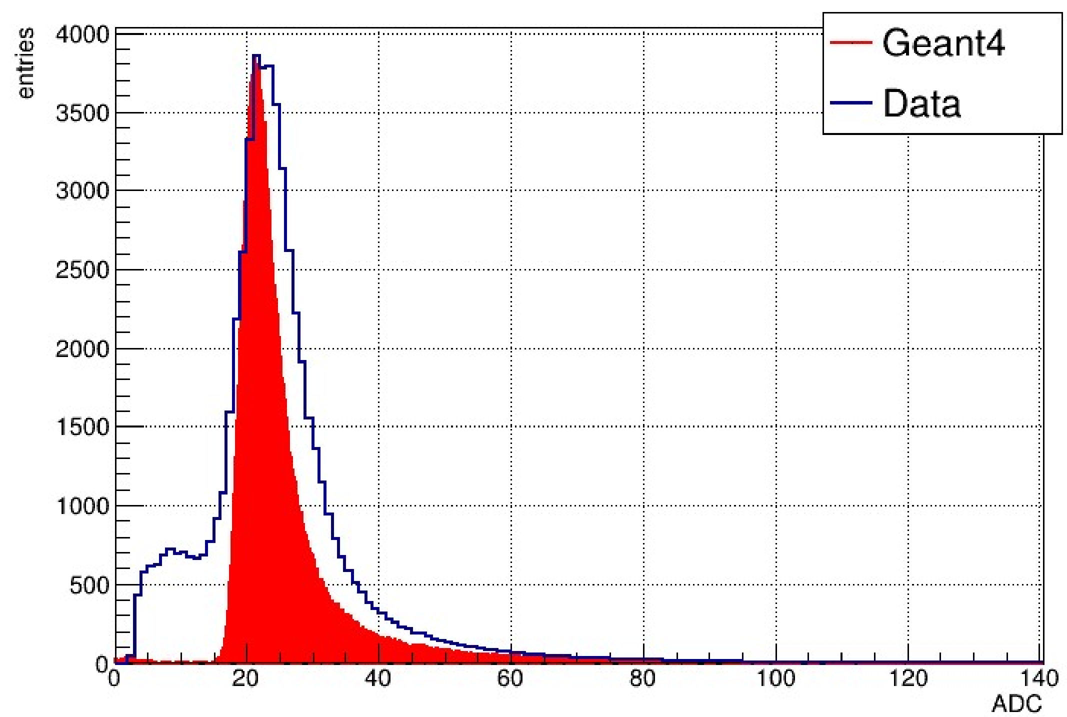
- e⁻ with 5GeV
- centered on pads 64, 65, 74, 75 , 84, 85
- source type: squared, 12 mm x 12 mm
- Number of simulated events: 1 000 000
- Similar with run4484









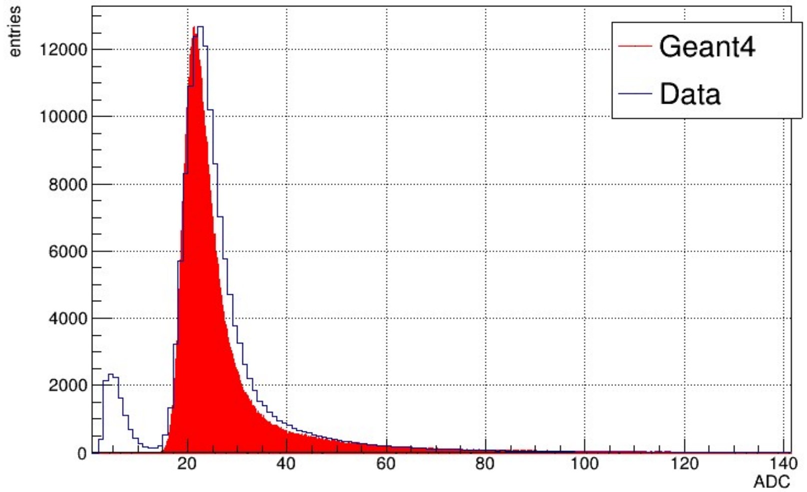


Simulations

▪ Si sensor – C74 & W

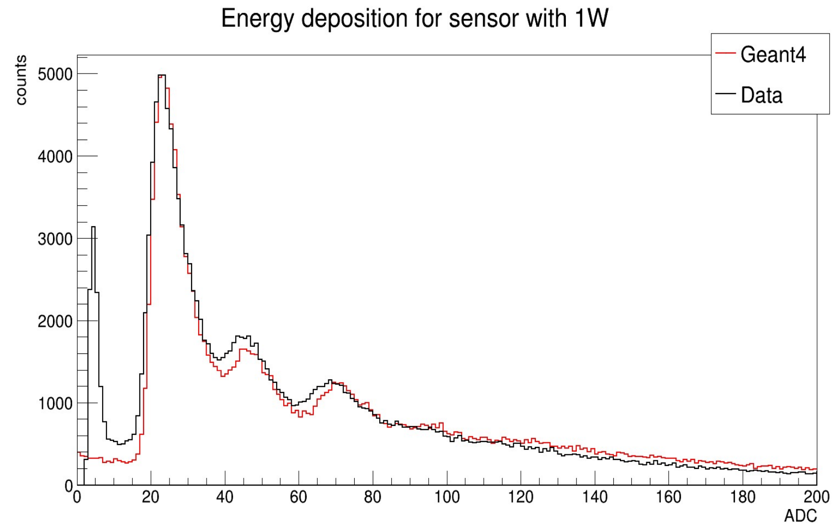
Data from *run4436*

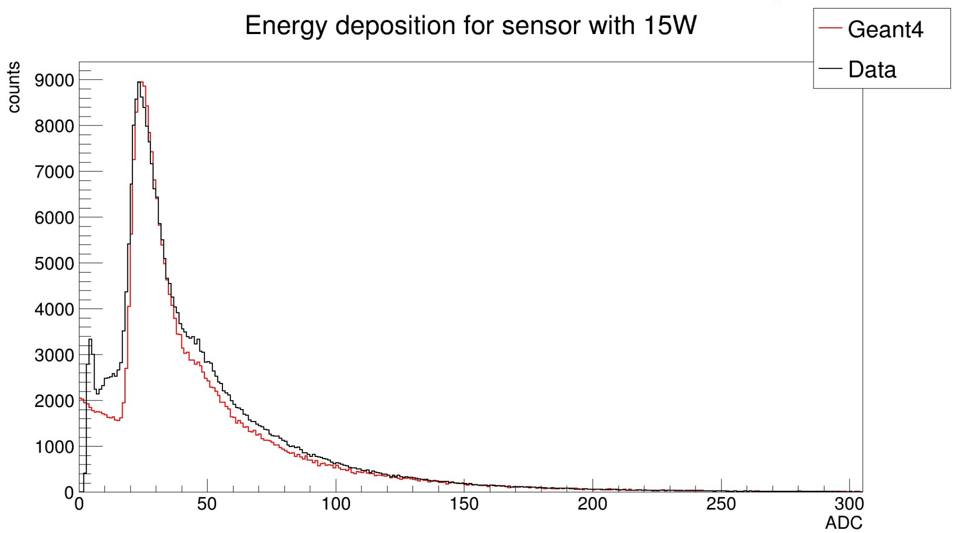
- Beam on pads 49, 51, 59, 61
- **MPV = 20.79 ± 1.07 [ADC]**

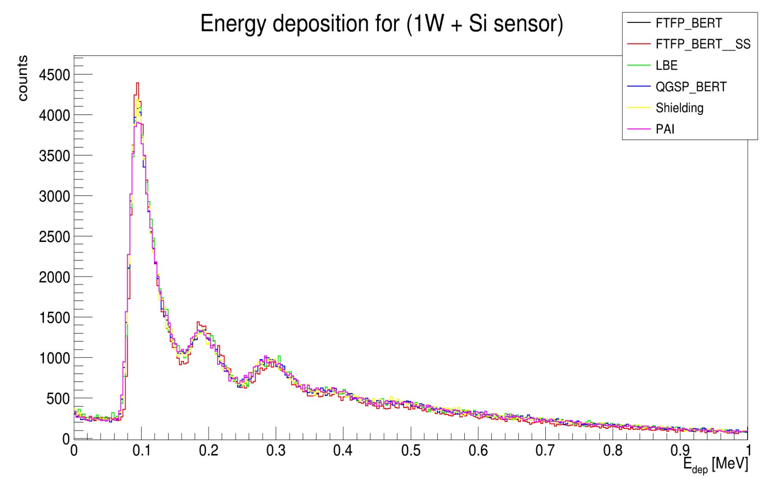


▪ Geant4: FTFP_BERT_EMZ

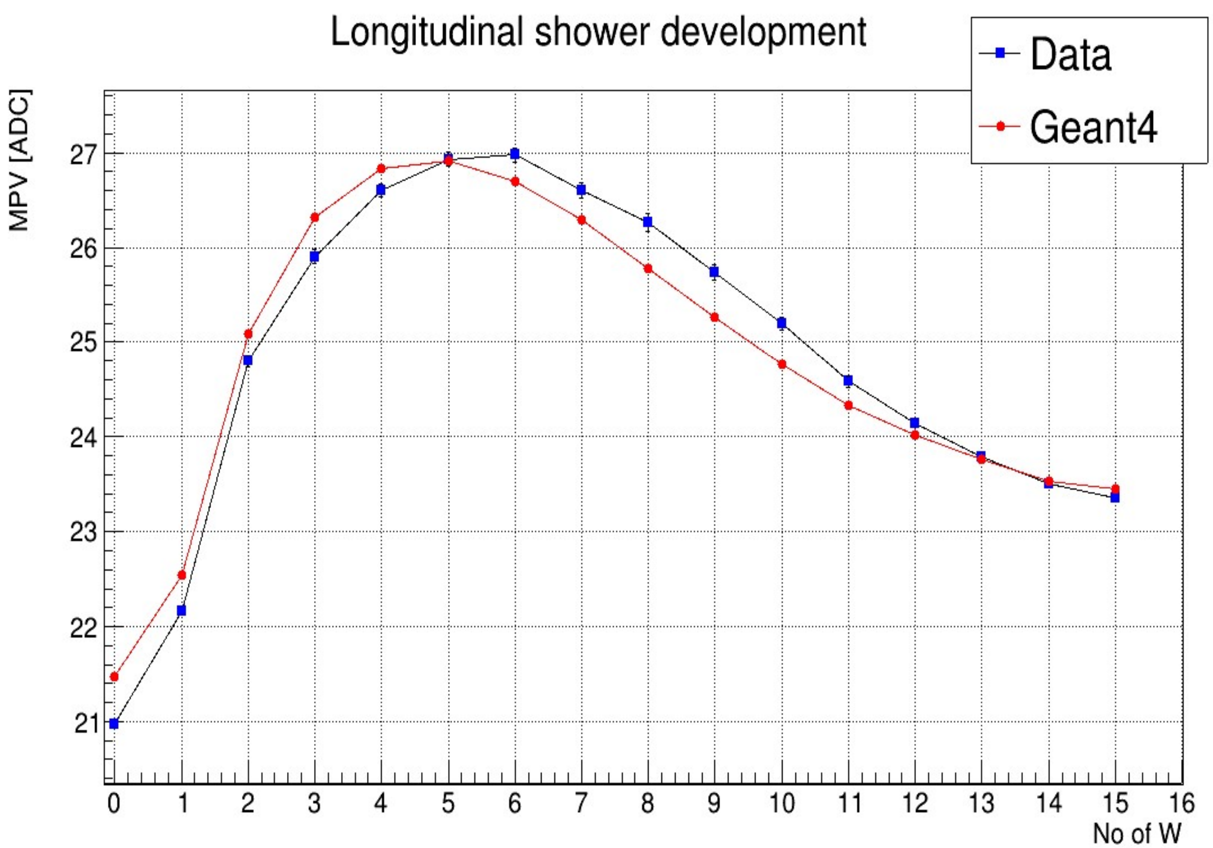
▪ **Data:** *run4749* – C74 sensor with 1 tungsten plate in front







Simulations vs Data



Geant4 implementation

- placed all tungsten plates in the same position as in test-beam taking into account that the plates where removed one by one starting with the one placed further of the sensor - **no noticeable influence!**
- checked the composition of each tungsten plate and implemented in Geant4 simulations – **no noticeable influence!**
- modified the beam profile using a Gaussian shape of the energy distribution for the incoming electrons - **no noticeable influence!**
- modify the physics list to include / exclude some process – *work in progress.*

Conclusions

Our beam tests were conducted on DESY-II TB24 for LUXE ECAL sensors

- successful alignment of 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
- studied 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
- proofs are found indicating different behaviors for sensors with and without traces
- differences found when compared simulations with data for GaAs sensors
- good agreement between data and simulations for Si sensors with and without W plates in front of it

THANK YOU!

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- *Romanian National Program FAIR-RO - contract no. FAIR_02/2020*