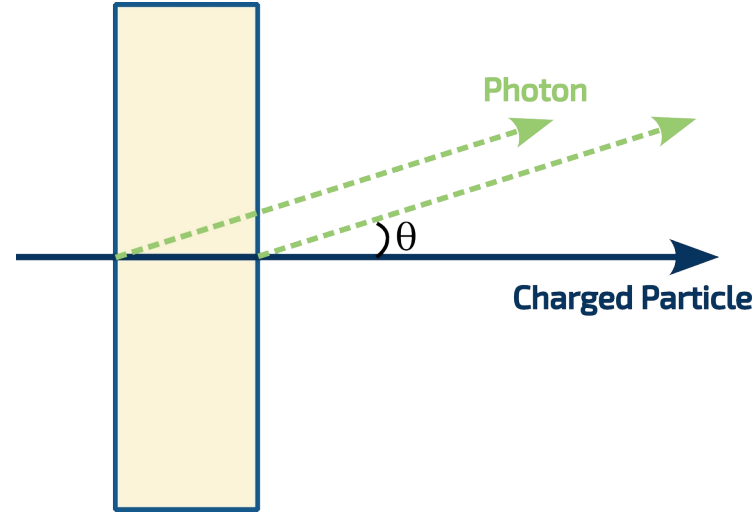
PARTICLE PHYSICS SEMINAR

PRAGMATIC TRANSITION RADIATION TARGETS: BL4S 2025 RESULTS FROM TEAM XTREME AT ELSA

Rasmus Partzsch, Philip Bechtle, Christian Bespin, Klaus Desch, Frank Frommberger, Avin Gupta, Saime Gürbüz, Sebastian Laudage, Chuming Li, Ryan Antony Pius, Dennis Proft, Wei Yee Pua, Sanjana Rajaram, Kristof Schmieden, Justin Thomas Szela

Transition Radiation

- *Transition radiation is produced by charged particles when they cross the interface of two media of different dielectric constants*
- Investigated previously
  - Silicon pixel matrices (DEPFET structures) by S. Furletov, J. Furletova in 2010 (SILAB)
  - Similar setup from a previous BL4S team (EXTRA-BL4S) at DESY test beam by using Timepix3



EXTRA-BL4S (2023)
arXiv:2301.11247

Julia Furletova, Sergey Furletov (2011)
https://doi.org/10.1016/j.nima.2010.06.342

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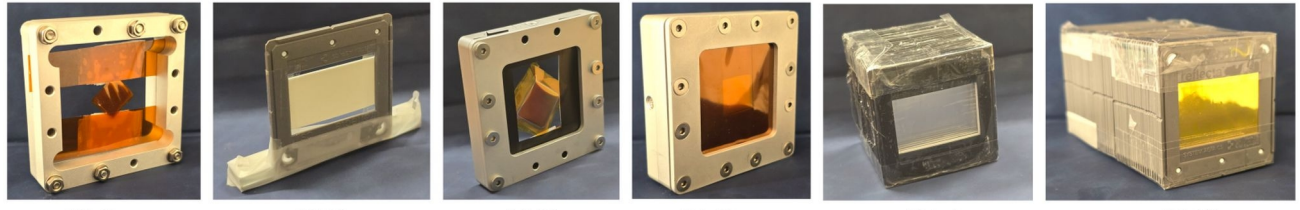
Experimental Setup

Targets

Our Multilayer Target Combinations

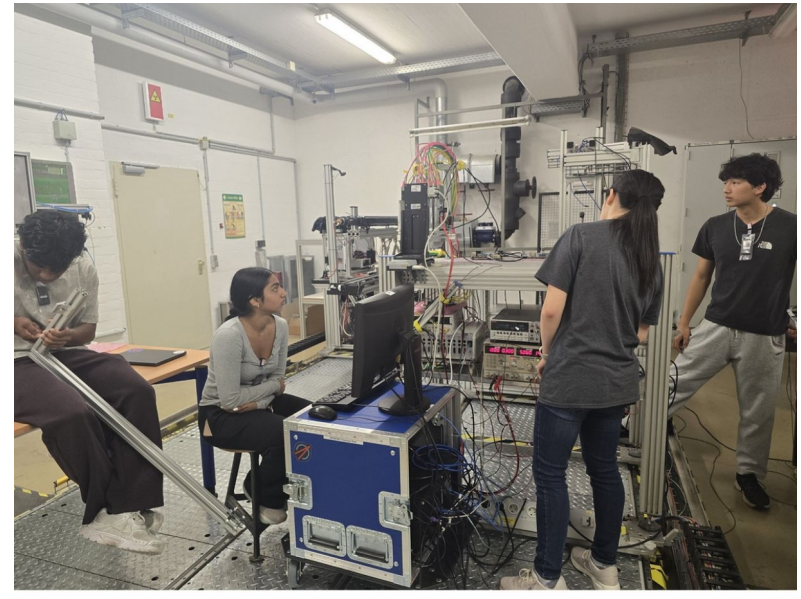
1. Kapton [6] - *Control*
2. Polyethylene [1] - *Control*
3. Ta_2O_5 & SiO_2 [102]
4. Kapton & Air [51]
5. Polyethylene & Air [51]
6. Polyester with Aluminum Coating (Space Blanket) & Air [51]



#1 **#2** **#3** **#4** **#5** **#6**

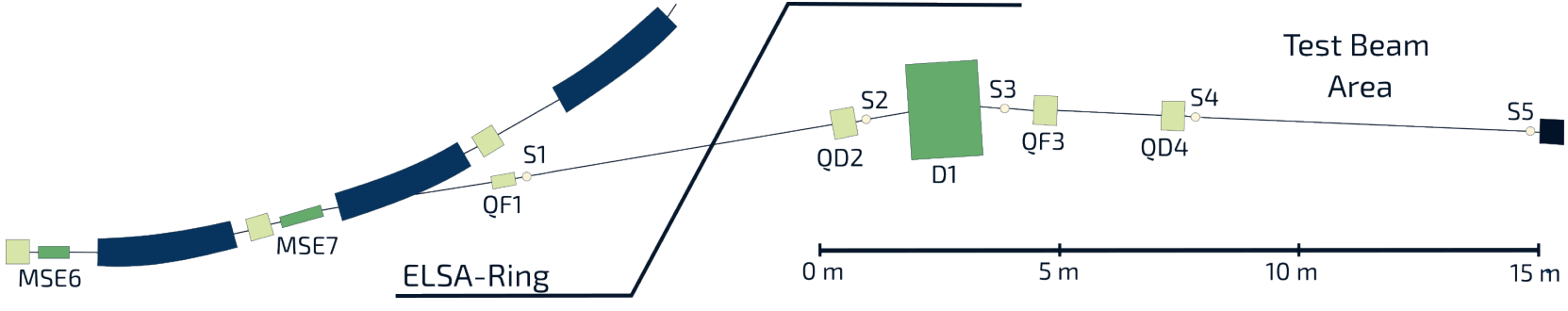
→ Investigate TR photon production of different targets

ELSA Test Beam



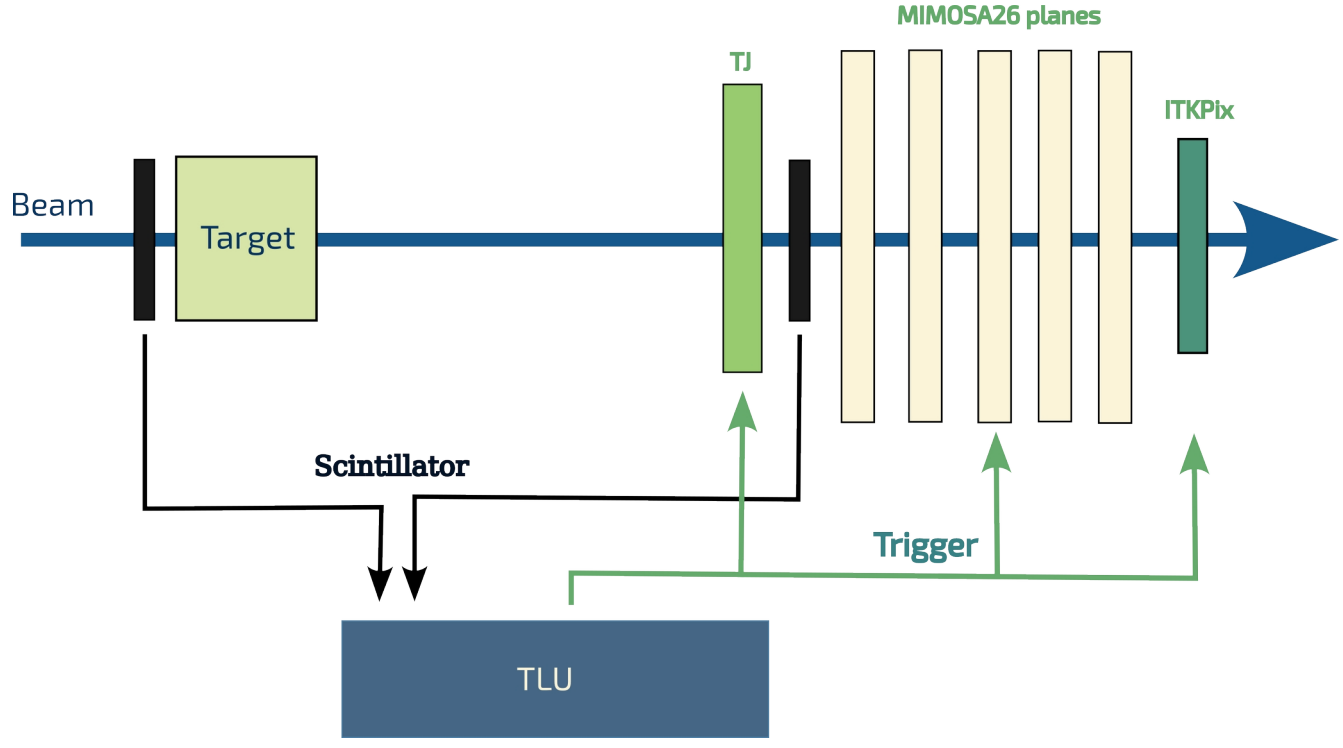
Test beam area E3

- Primary beam
- Variable beam spot
- Particle rate (~kHz - MHz)
- Energy (< 3.2 GeV)



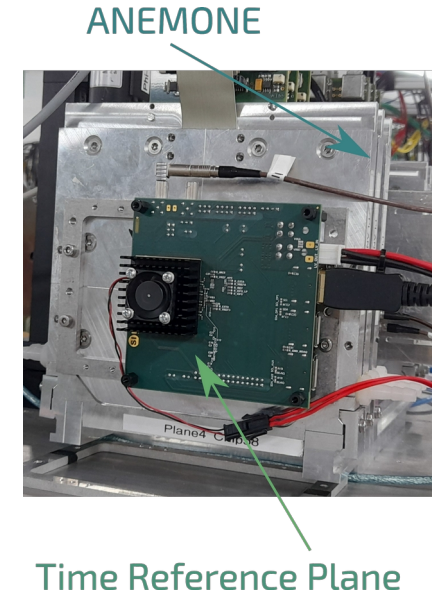
Nikolas Heurich (2017)
https://hdl.handle.net/20.500.11811/7310

Test Beam Setup

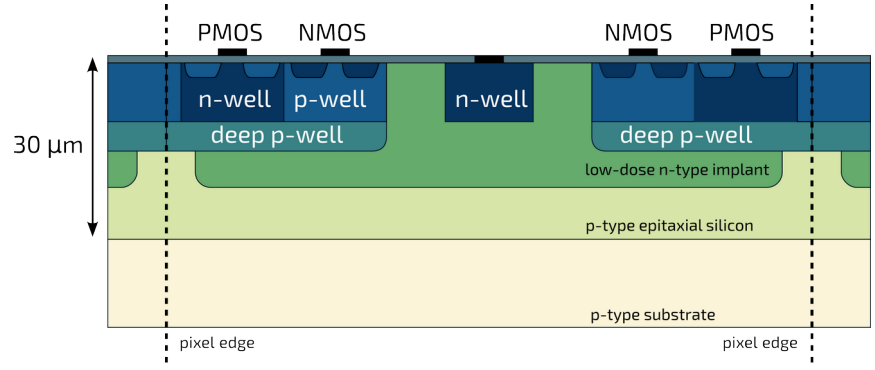


ANEMONE: A Nice EUDET Mimosa Bonn Telescope

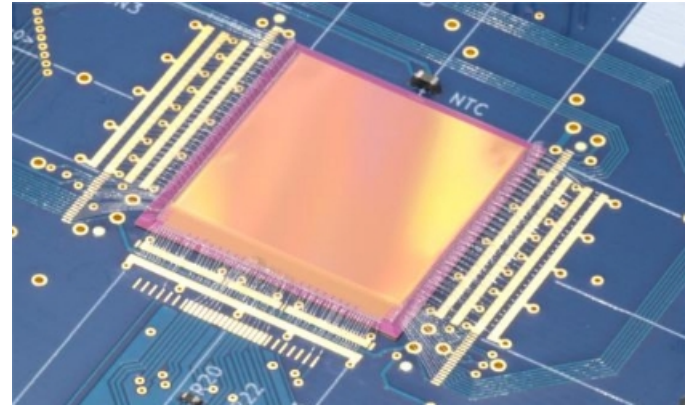
- Scintillator for trigger generation
- MIMOSA26 high spatial resolution planes
  - Pixel size: 18.4 x 18.4 µm²
  - 115.2 µs readout time
- Time reference plane (ITkPix)
  - Pixel size: 50 x 50 µm²
  - 25 ns time stamping
- 2-4 µm track resolution with 25 ns time stamps



TJ-Monopix2



- Depleted Monolithic Active Pixel Sensor (DMAPS)
  - 180nm TowerSemi CMOS
- Large scale 2x2 cm² chip with 33 x 33 µm² pixel pitch
- TJ-Monopix2 is the baseline for a new detector Optimised BELle II monolithic pIXel (OBELIX)
  - VTX inner tracker upgrade of BELLE 2
- Also interest in OBELIX/TJ2 from proposed ELSA experiments



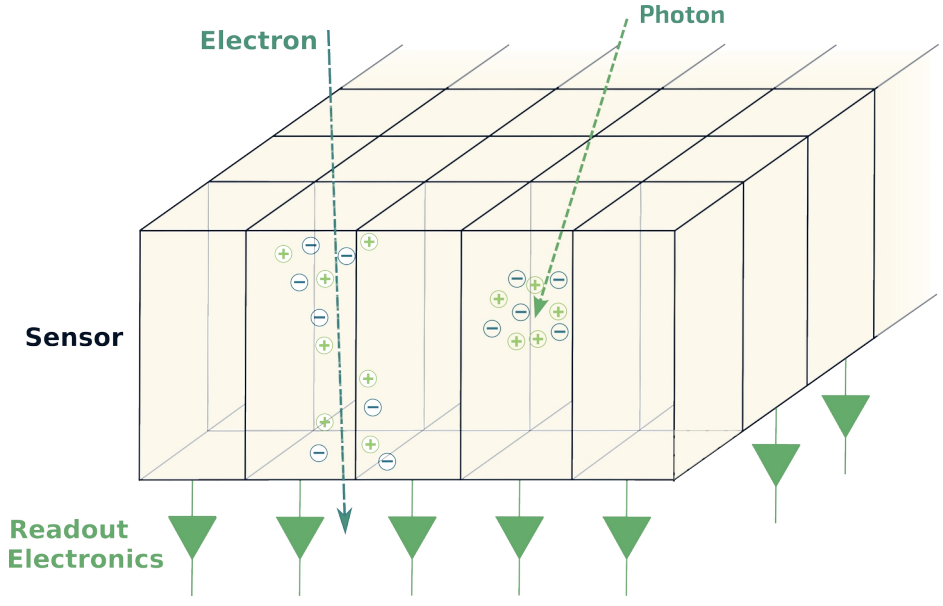
Bespin Valero, Christian (2024)
https://doi.org/10.48565/bonndoc-427

Ivan Caicedo., et al. (2024)
https://doi.org/10.7566/JPSCP.42.011021

Signal Generation

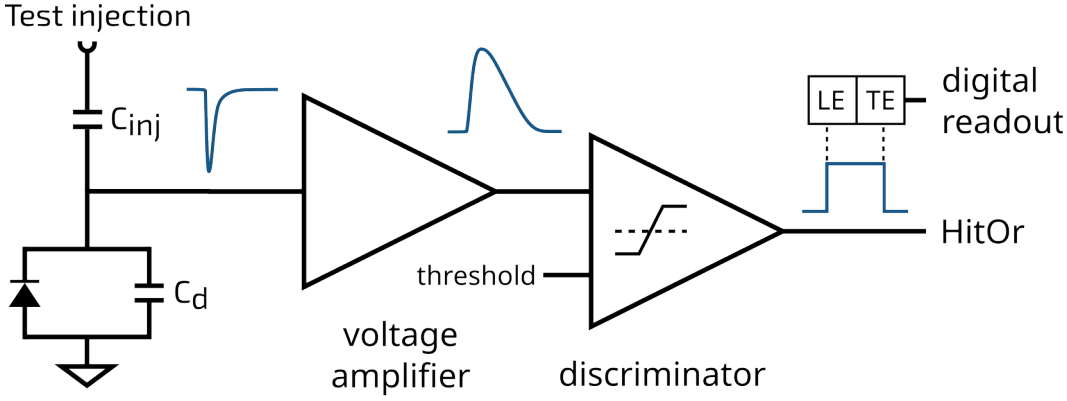
- Sensitive volume (depleted silicon)
- Ionizing particles create charge cloud
- Measured photons are fully absorbed
- Electrons lose energy along path
- Charge can be shared between pixels

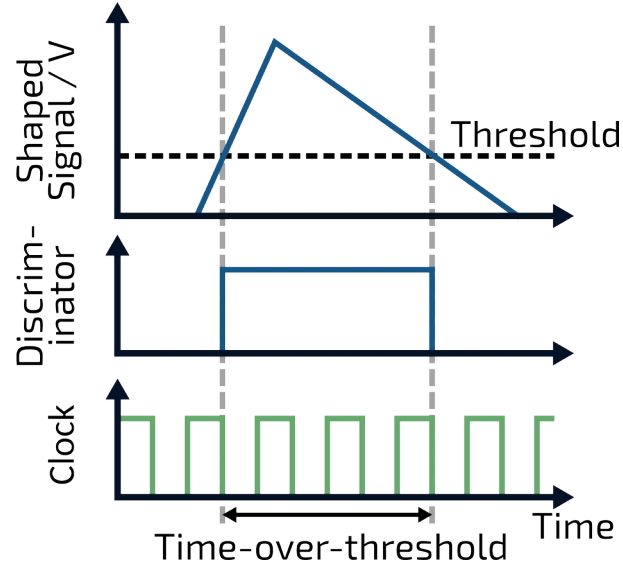
  → Cluster



Signal Processing: Readout Electronics

- Signal is amplified, digitized (charge to time converter)
- Length of digital signal (TE – LE) contains deposited charge information
- Time over Threshold (TOT) is sampled

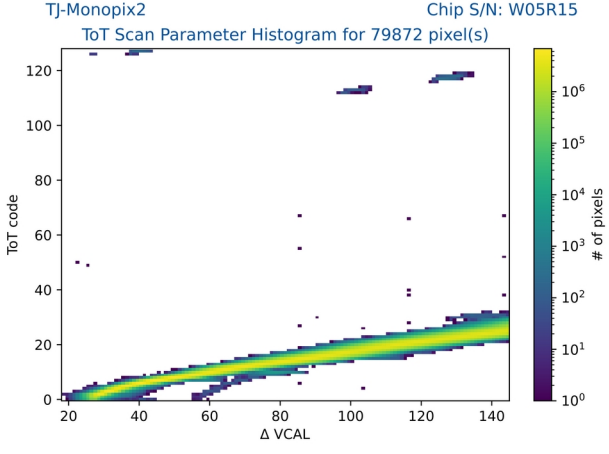


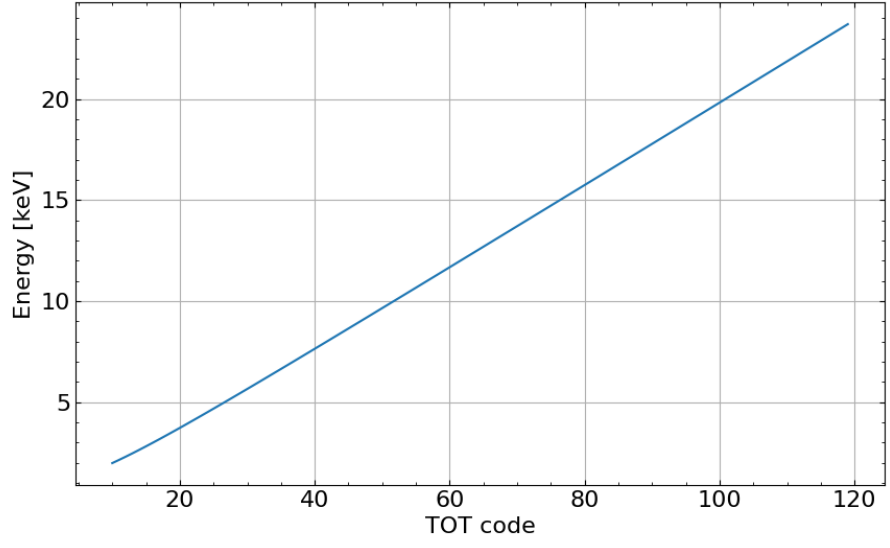


Christian, Bespin Valero, Lars Schall

Energy Calibration

- Convert ToT code to energy
- Injecting known charges (ΔVCAL) into each pixel
- Comparing Time over Threshold (ToT)





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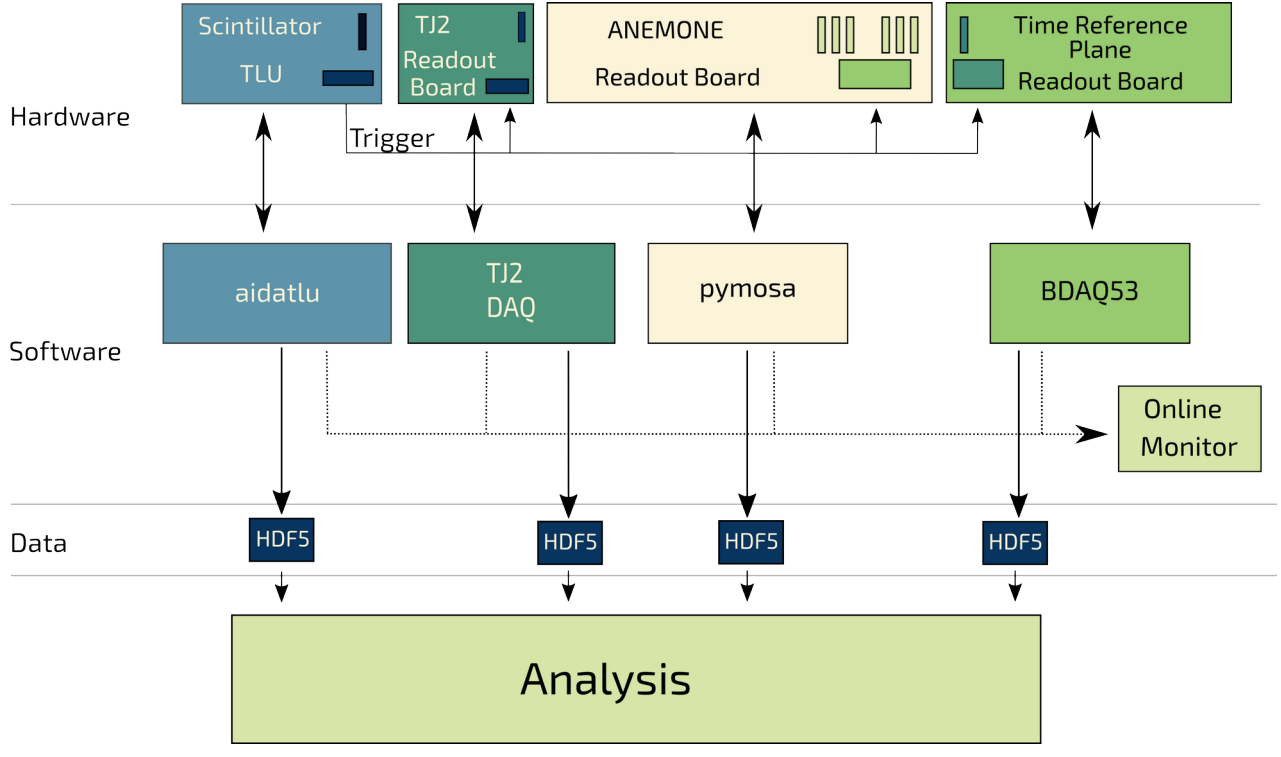
Data Acquisition

Control Software

- Modular software framework
- Individual readout board with Python-based control software
- Individual HDF5 data output files
- Data files are merged in analysis (Corryvreckan)



Dieter, Yannick Manuel (2022)
https://hdl.handle.net/20.500.11811/10346

Constellation: Slow Control

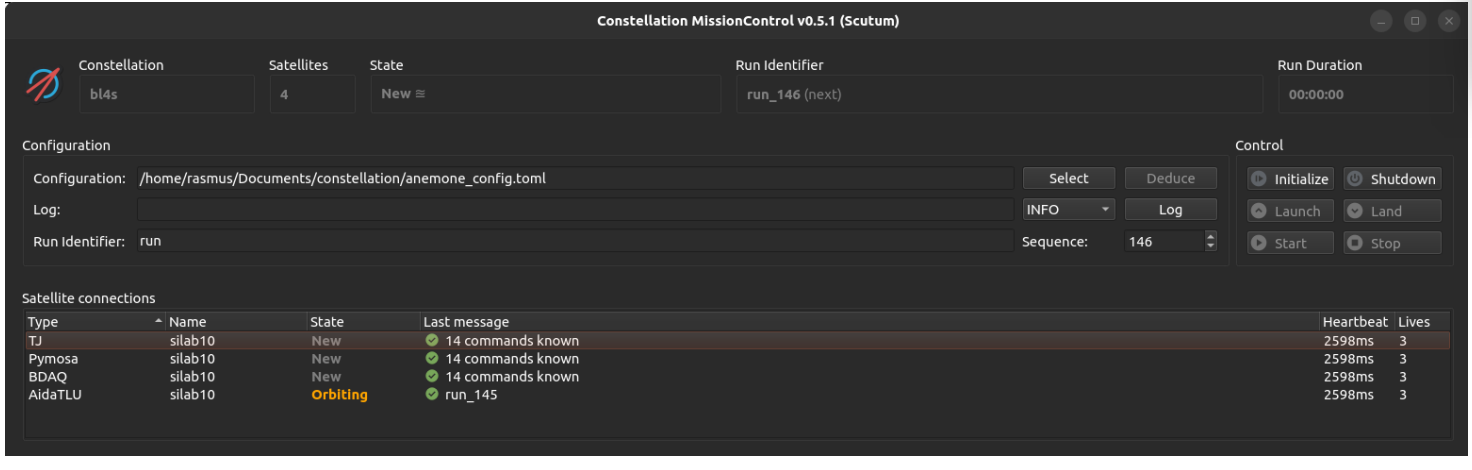
- Constellation: Control and DAQ system for dynamic experimental setups
- Integration of hardware into common system
- Unified
  - Logging
  - Configuration
  - Data taking

https://constellation.pages.desy.de/

Constellation: ANEMONE

- Implemented ANEMONE readout into Constellation
- Enabled independent operation of the complete test beam setup by high school students.

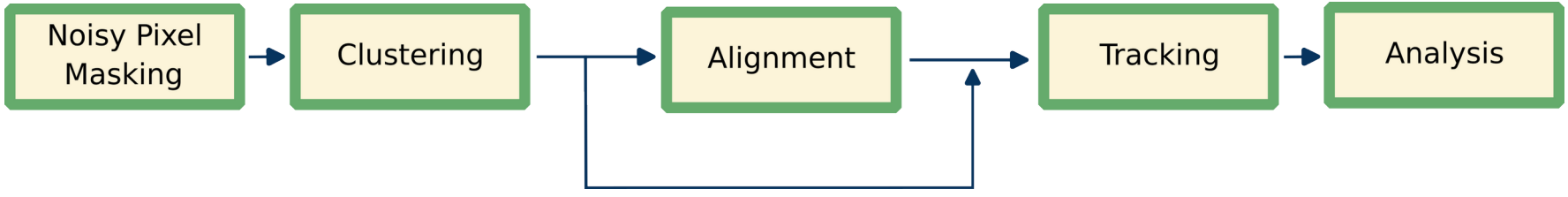
```
[satellites]
Number of Triggers

[satellites.AidaTLU]
Trigger Logic
DUT Triggering Mode

[satellites.Pymosa]
Enabled Planes

[satellites.ITkTimeref]
Enabled Matrix
Tuning Configuration

[satellites.TJ2]
Enabled Matrix
Tuning Configuration
```



https://constellation.pages.desy.de/

Analysis Software: Corryvreckan

- Flexible software framework for test beam analysis
- Modular structure developed for detector characterization
- Adapted for BL4S TR analysis



https://gitlab.cern.ch/corryvreckan/corryvreckan

D. Dannheim et. al.(2021)
10.1088/1748-0221/16/03/P03008

Measurement Procedure

Energy (cluster charge)

- Electrons
  - Coulomb interaction
- Photons
  - Photoelectric effect
  - Compton scattering
- Electrons lose continuously lose energy in matter

→ Analyze cluster charge

Spatial distribution (cluster position)

- Separate electron and photon
  - Angular distribution of TR (target at a distance)
  - Magnetic field (not used here)

→ Measure electron and photon position

→ Both methods are used in the following

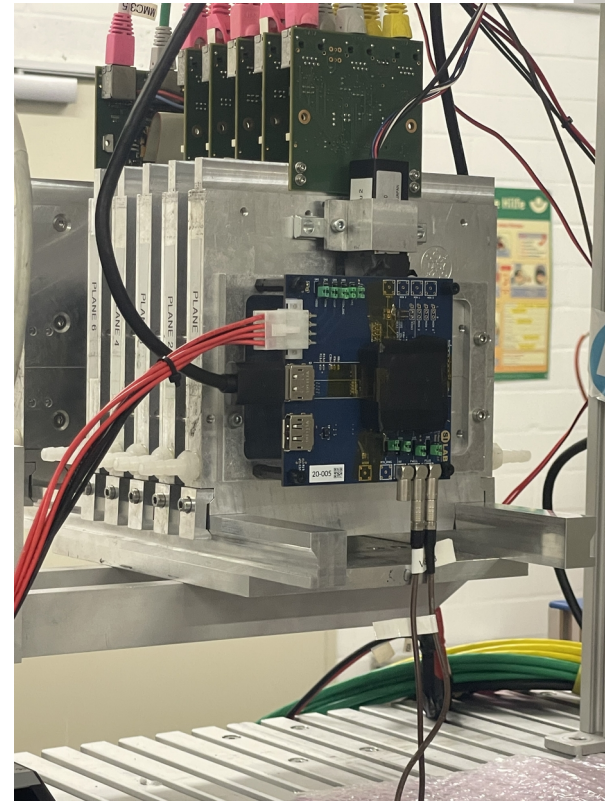
Boris Dolgoshein (1993)
https://doi.org/10.1016/0168-9002(93)90846-A

Measurement Procedure

- All shown data from 2.5 GeV electrons with rates around 5 kHz
- Runs with target at 50 cm distance recorded 15M triggers

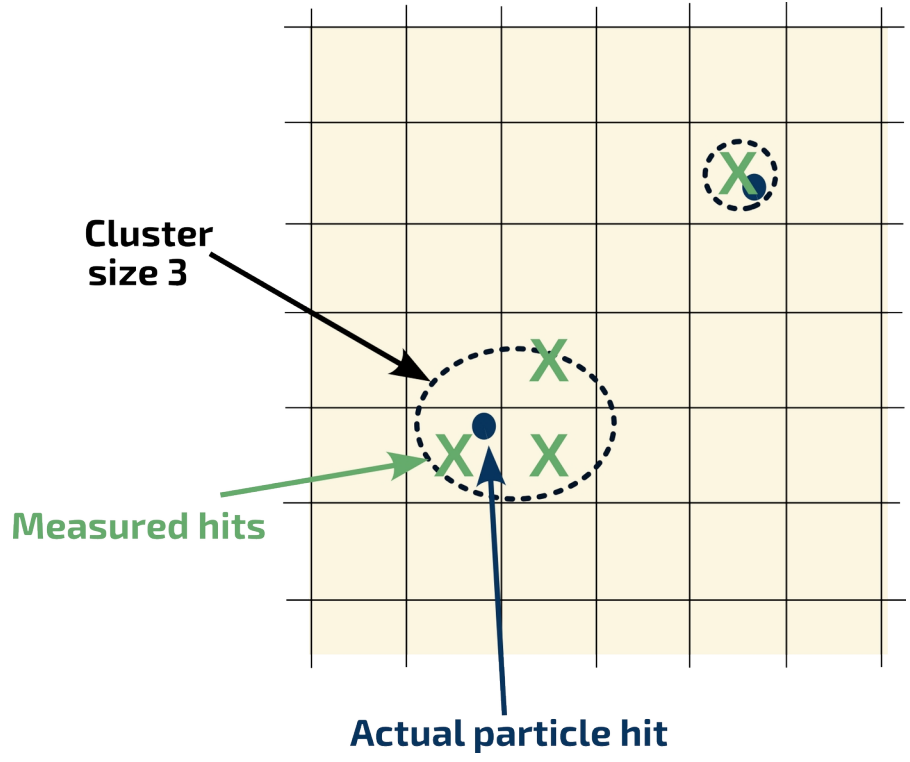
  → around 7M clean electron tracks
- Analysis focuses on
  - Multi-layer Polyethylene
  - Single layer Polyethylene
  - Background (no target)

  for comparative reasons



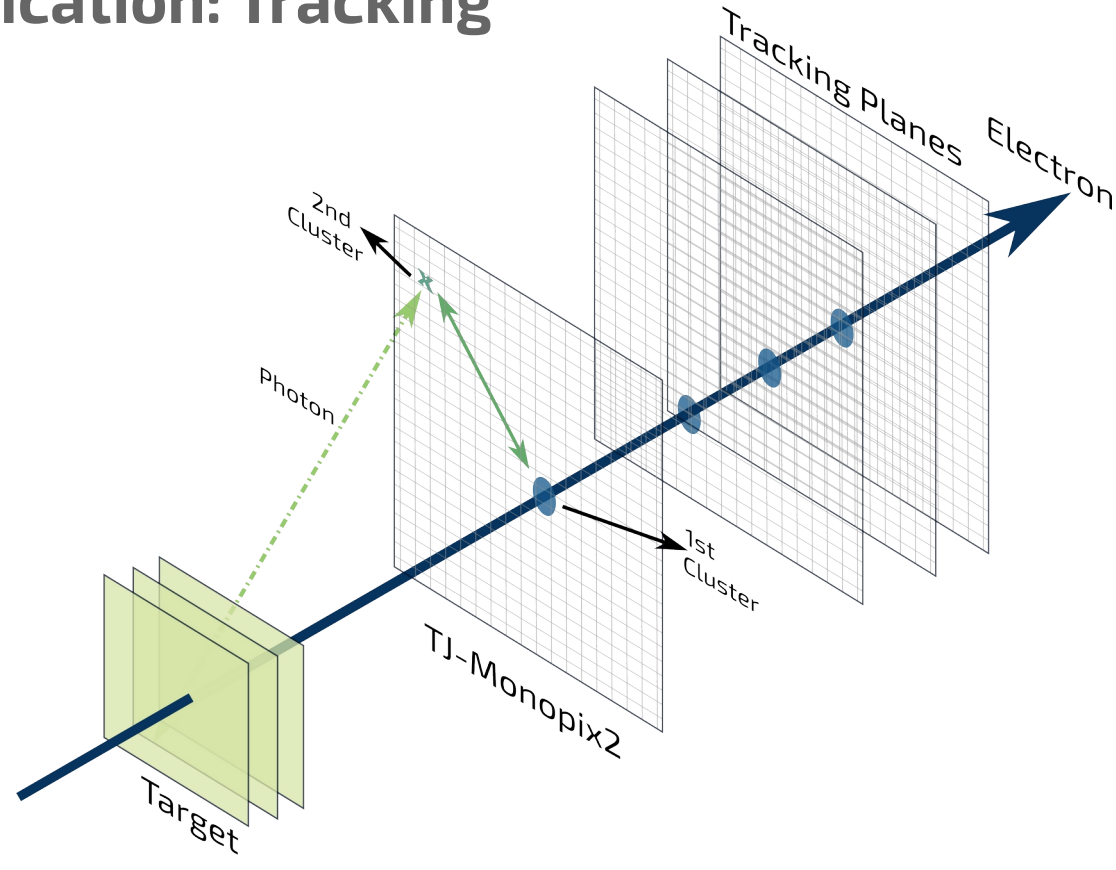
TR Identification: Clustering

- Particle hits share charge to neighboring pixels
- Measured hits are grouped together to clusters
- Photon clusters on average smaller than electron clusters
- Select only clusters with size 1 for analysis



TR Identification: Tracking

- Identify electron track from tracking planes
- Track extrapolation onto TJ-Monopix2
  - Discarding closest cluster to track (electron)
  - Left with photon clusters
- Primary (1st) cluster from electron
- Secondary (2nd) cluster from photon



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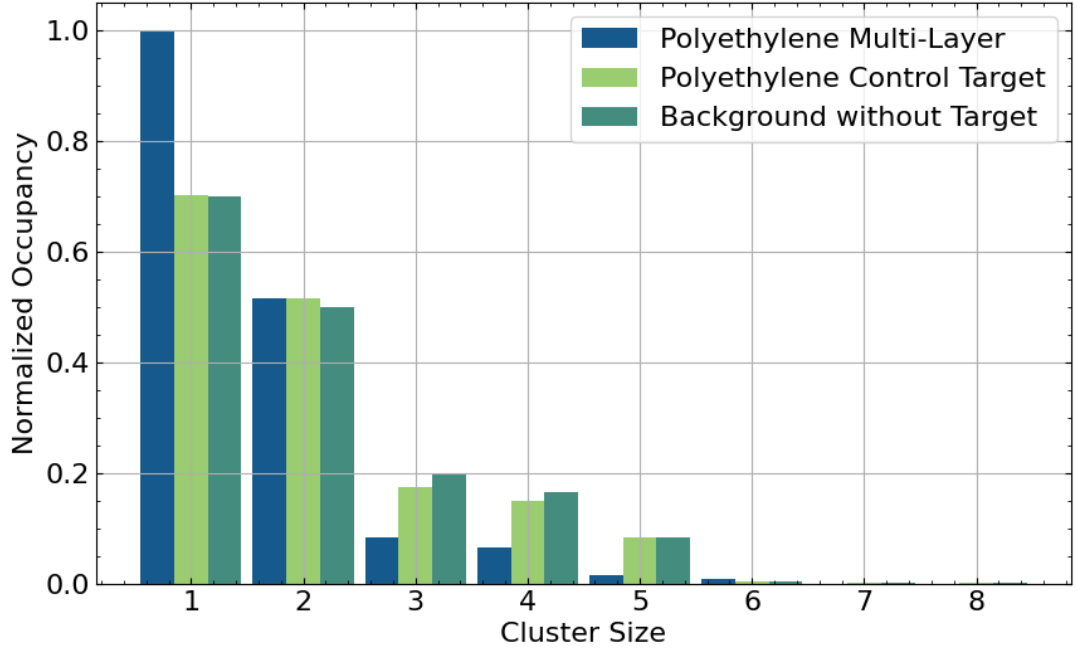
Charge Analysis

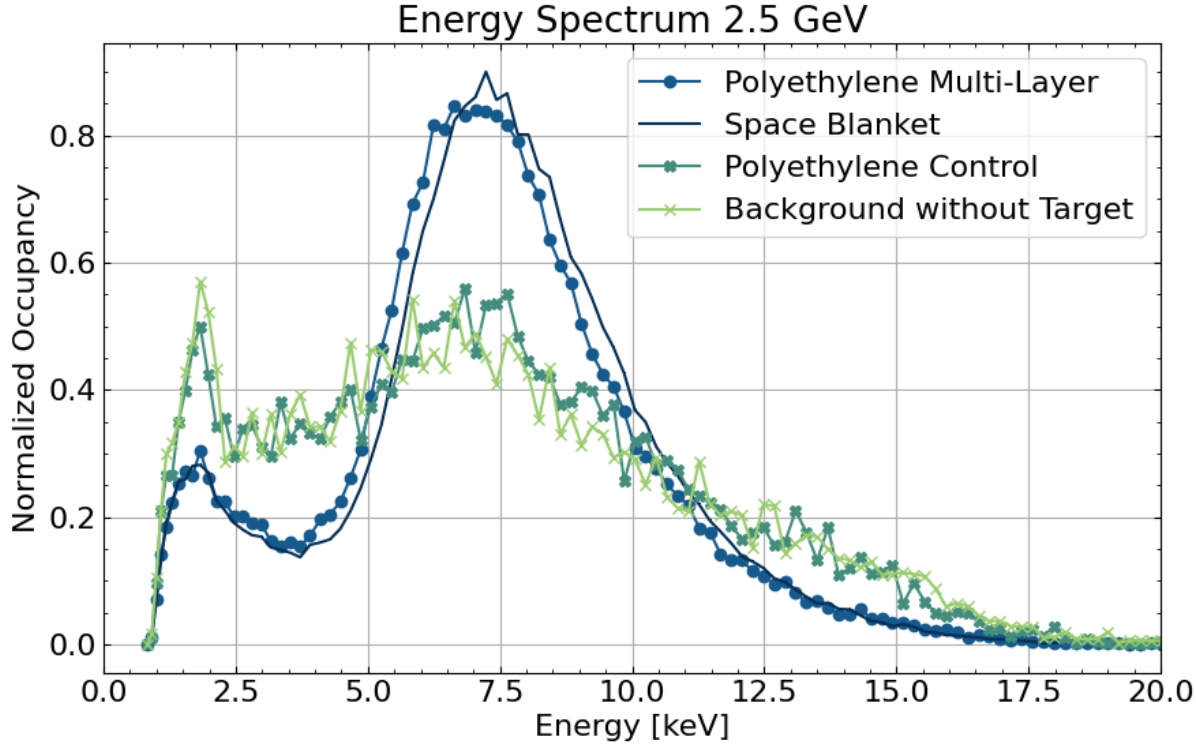
Cluster Sizes

- Cluster sizes of secondary clusters
- Multi-layer Polyethylene target creates many small cluster
- Control target and background runs show no significant number of small clusters



Energy Spectra

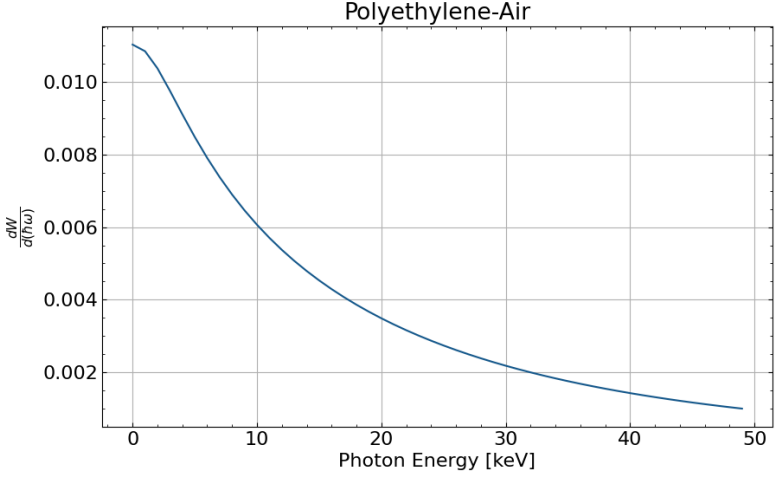
- Energy spectra of secondary clusters
- Only cluster size 1
- Similar charge spectrum in Background and control target runs
- TR photon peak in Polyethylene multi-layer target and space blanket target



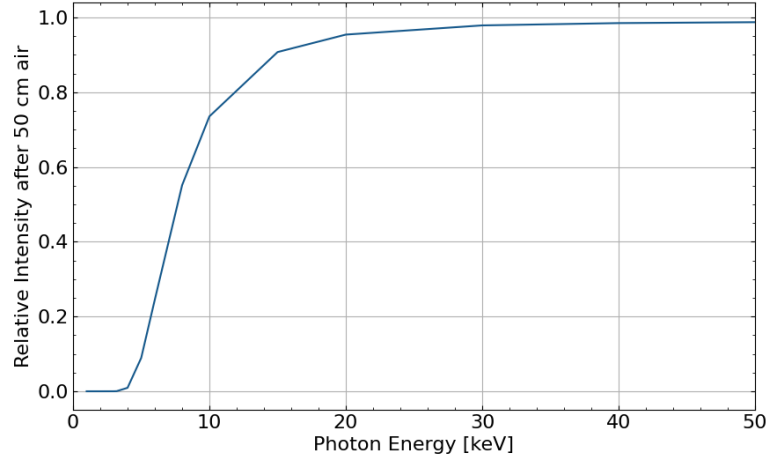
Energy Distribution

- Compare measured charge spectra with simplified prediction
- Identify most important contributions to charge spectra

Transition radiation spectra



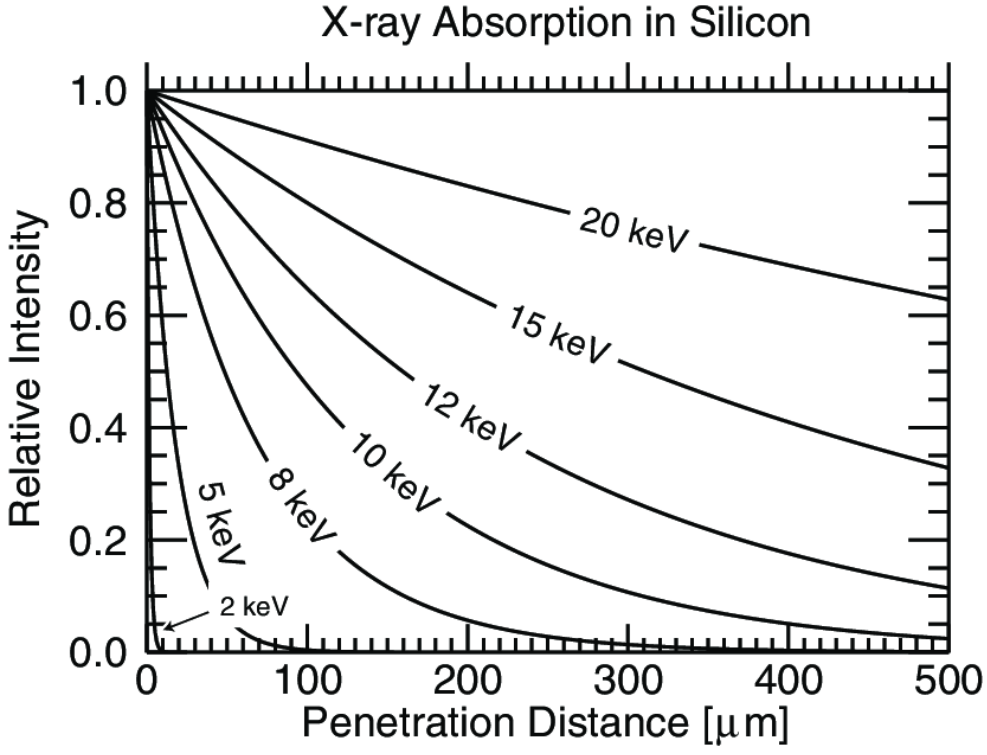
Transmission of X-ray photons in 50 cm air



Boris Dolgoshein (1993)
https://doi.org/10.1016/0168-9002(93)90846-A

https://physics.nist.gov/PhysRefData/XrayMassCoef/ComTab/air.html

Energy Distribution

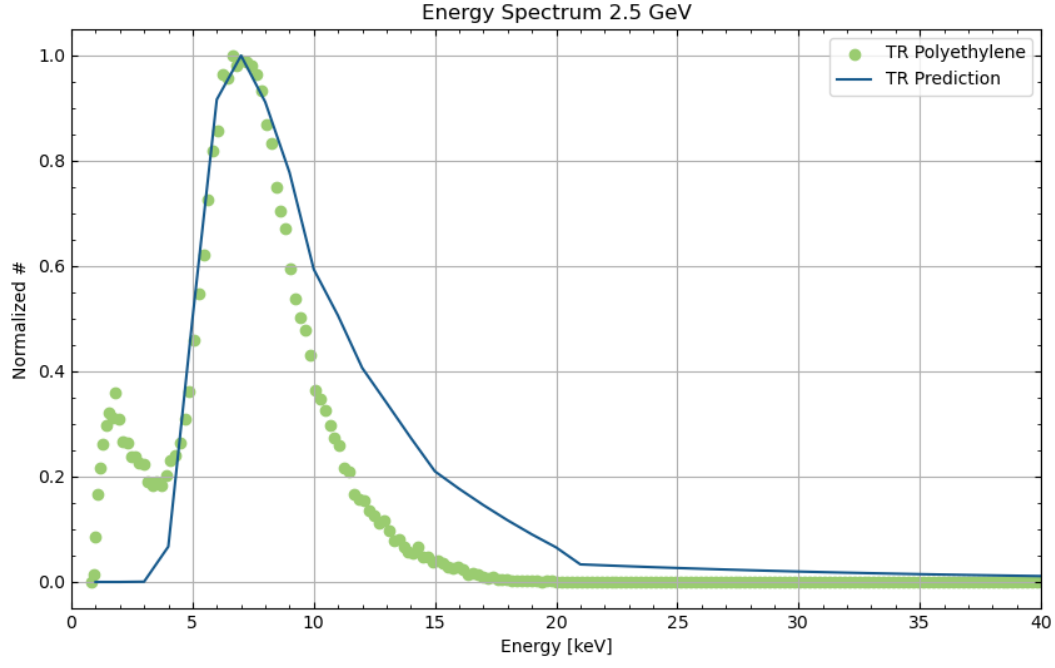


- Absorption probability of different X-ray energies in silicon
- Around 25 um thick sensitive volume

Hornberger, Benjamin (2007)
2007PhDT.....212H

Energy Distribution

- Greatly simplified model
- Agreement of peak position and shape
- Difference at higher photon energies
  - Absorption of photons in target
  - Data shows only energy distribution of cluster size 1 which suppresses clusters with higher charge
  - Assumed linear ToT at higher energies



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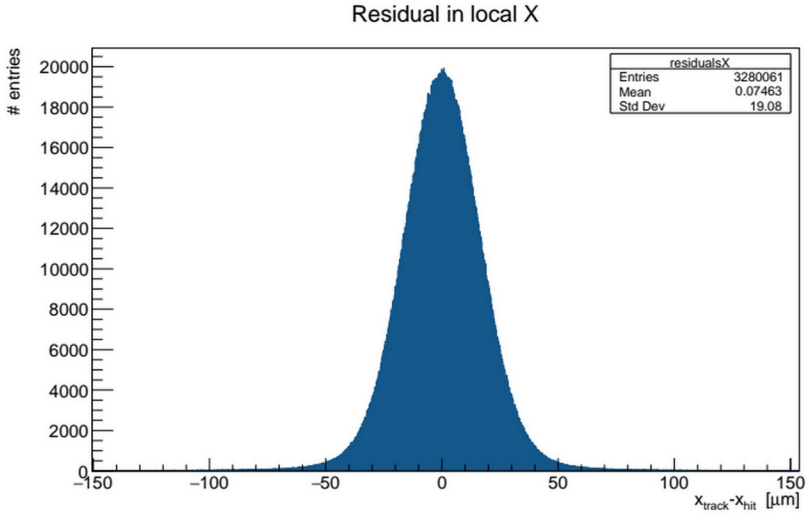
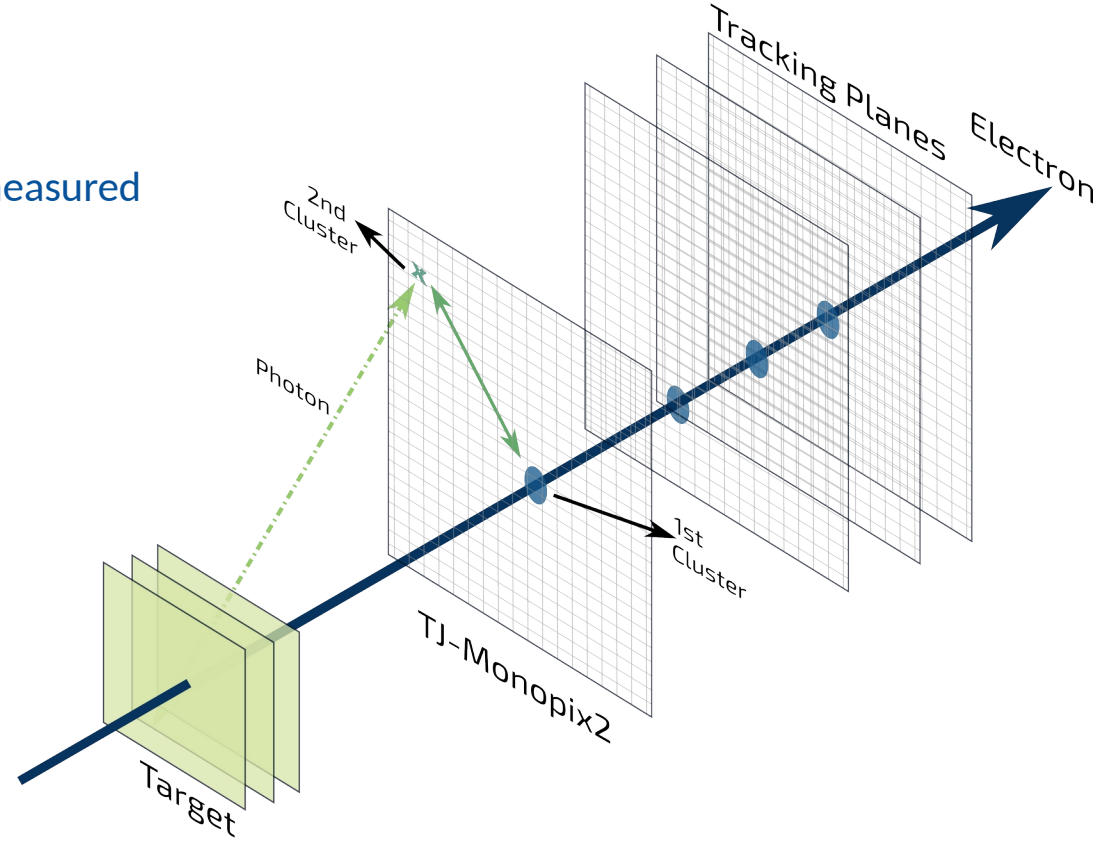
Spatial Distribution

Residuals

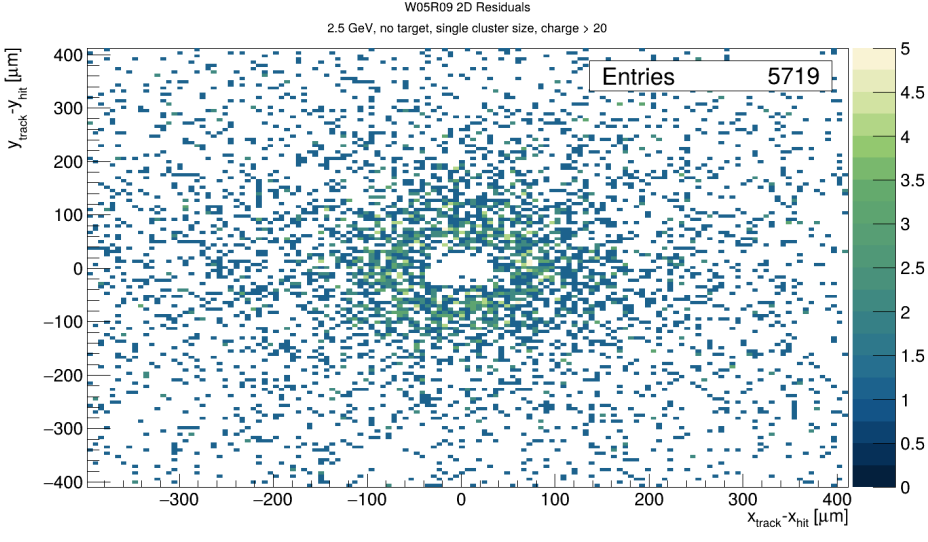
Distance between interpolated track and measured hit on TJ-Monopix2



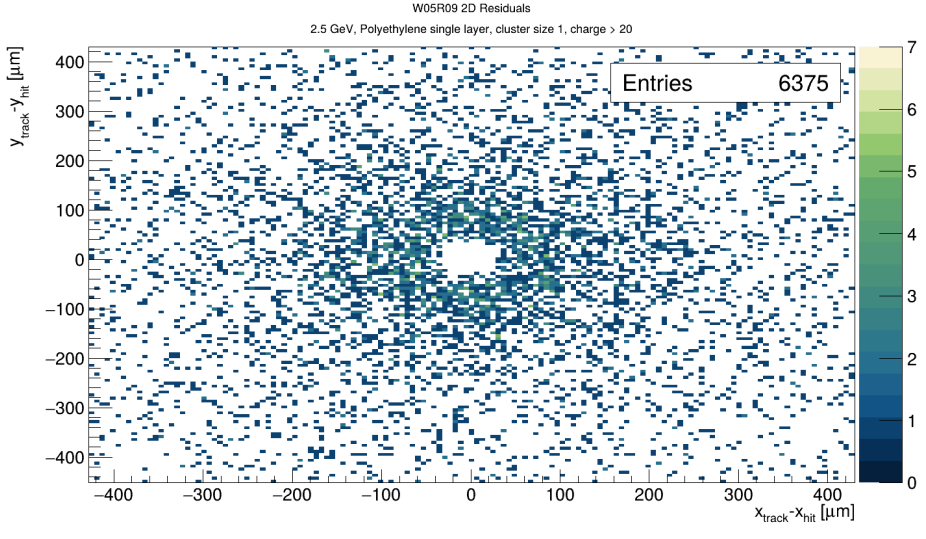


2D Residuals of 2nd Clusters

Background run: without target



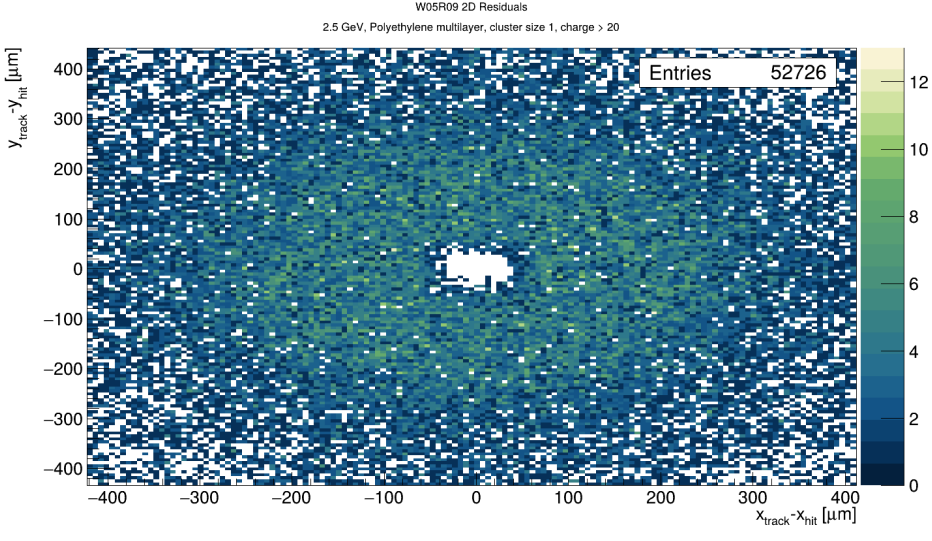
Single layer Polyethylene control target



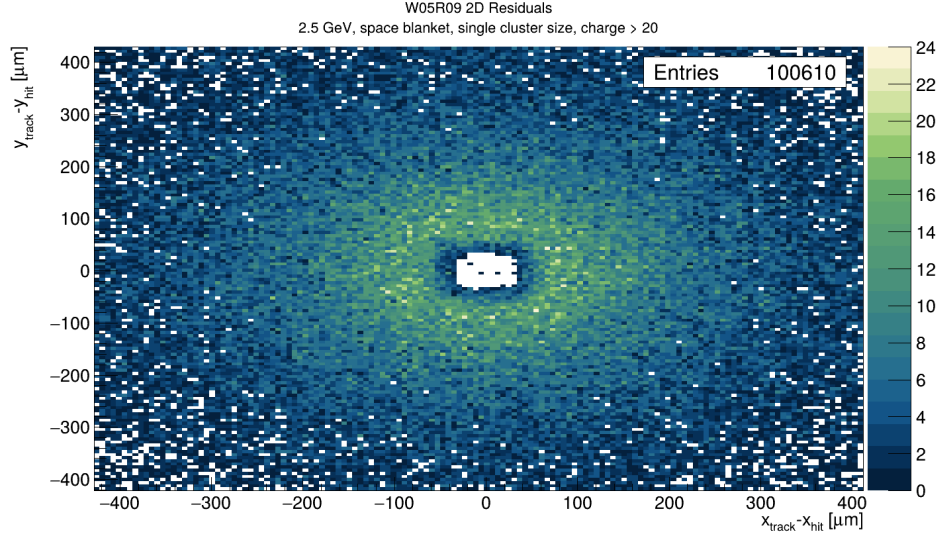
Same number of tracks (~7M)

2D Residuals of 2nd Clusters

Multi layer Polyethylene target



Space blanket target

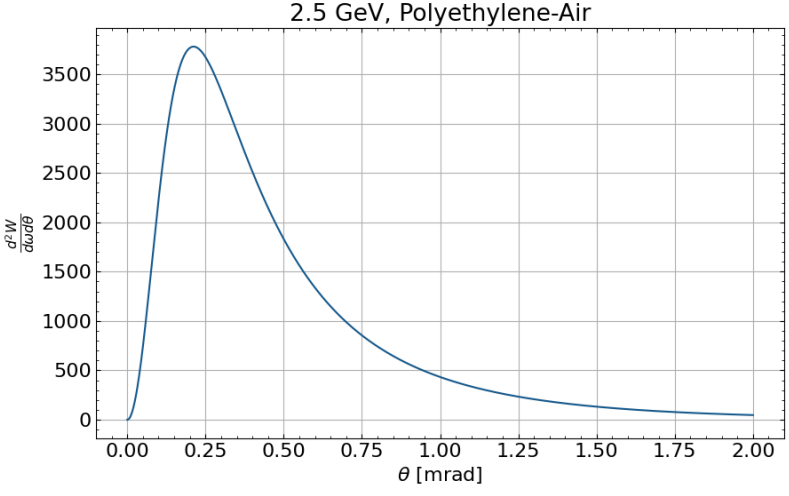


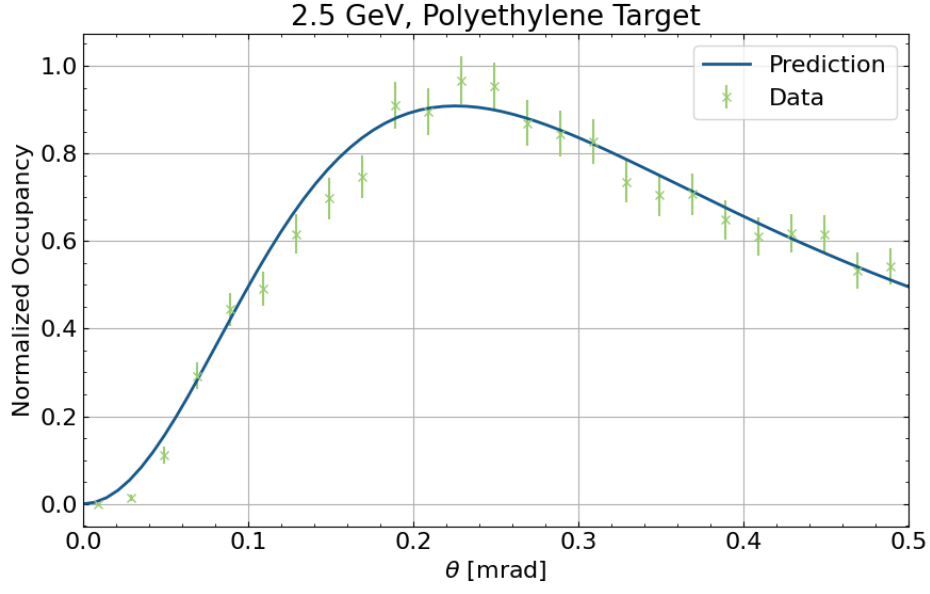
Same number of tracks (~7M)

Angular Distribution

- Comparison of angular distribution with prediction
- Extract angular distribution from 2D residual plots

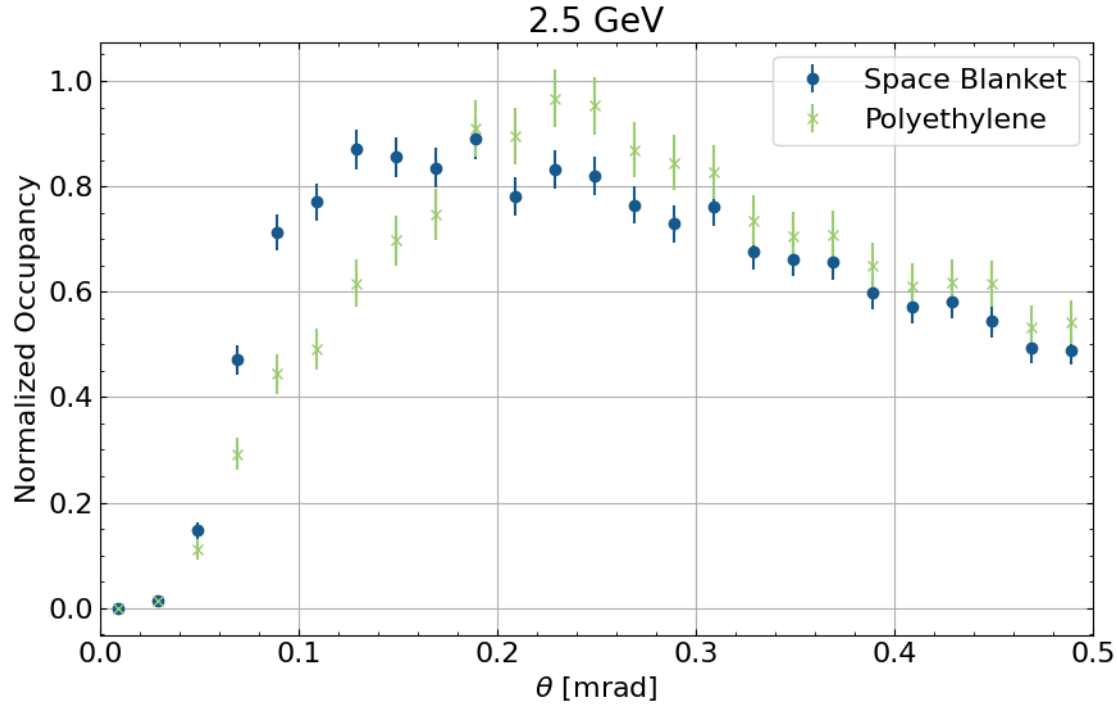
Predicted angular distribution of TR photons





Angular Distribution

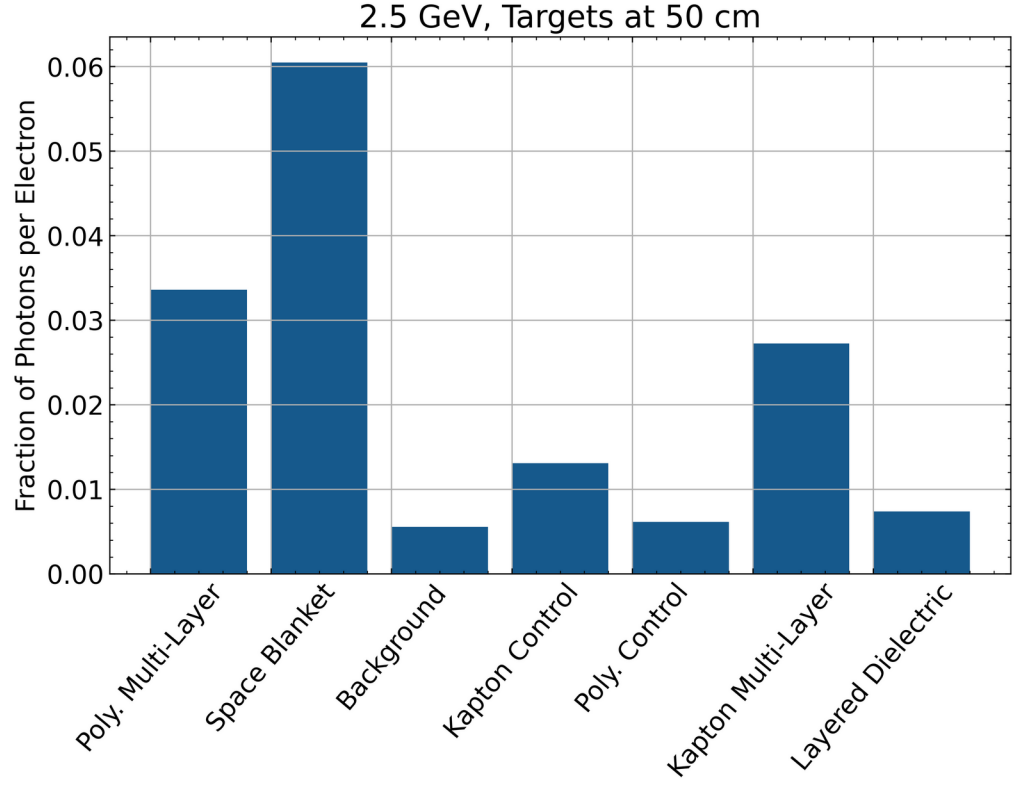
- Angular distribution for space blanket target is different
- More complex layer structure than Polyethylene multi-layer target



TR Photon Production Rates

Ranking TR target efficiencies:

1) Space blanket
2) Polyethylene
3) Kapton-Air
4) Kapton
5) Layered dielectric target
6) Single layer Polyethylene (control target)
7) Background (no target)



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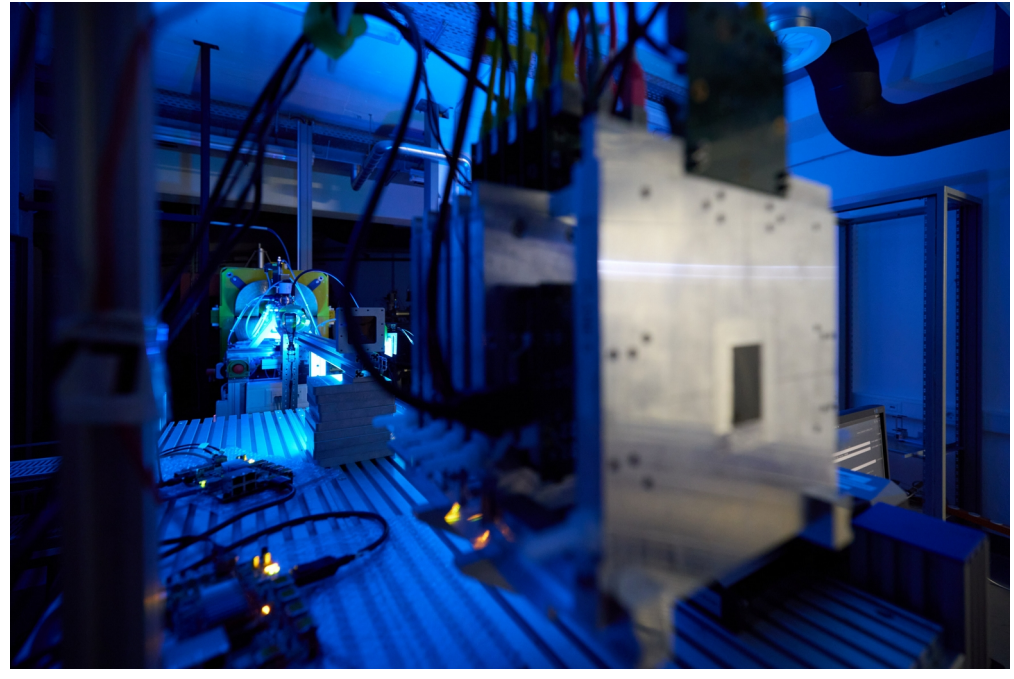
Conclusion

- Successful full small-scale particle physics experiment with high school students
  - Setup, DAQ, analysis
- Comparisons of angular and energy distribution with prediction models
- Estimation of photon production rate of different targets made from “simple” materials



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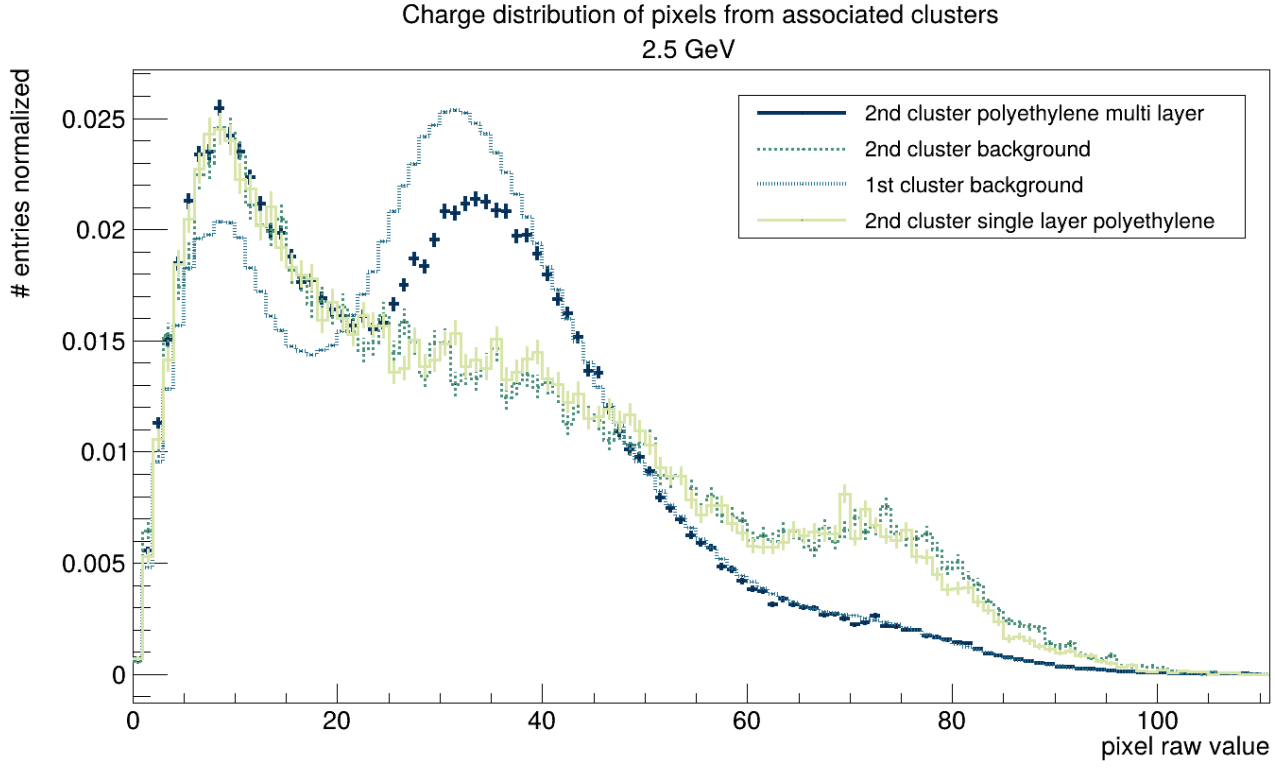
Backup

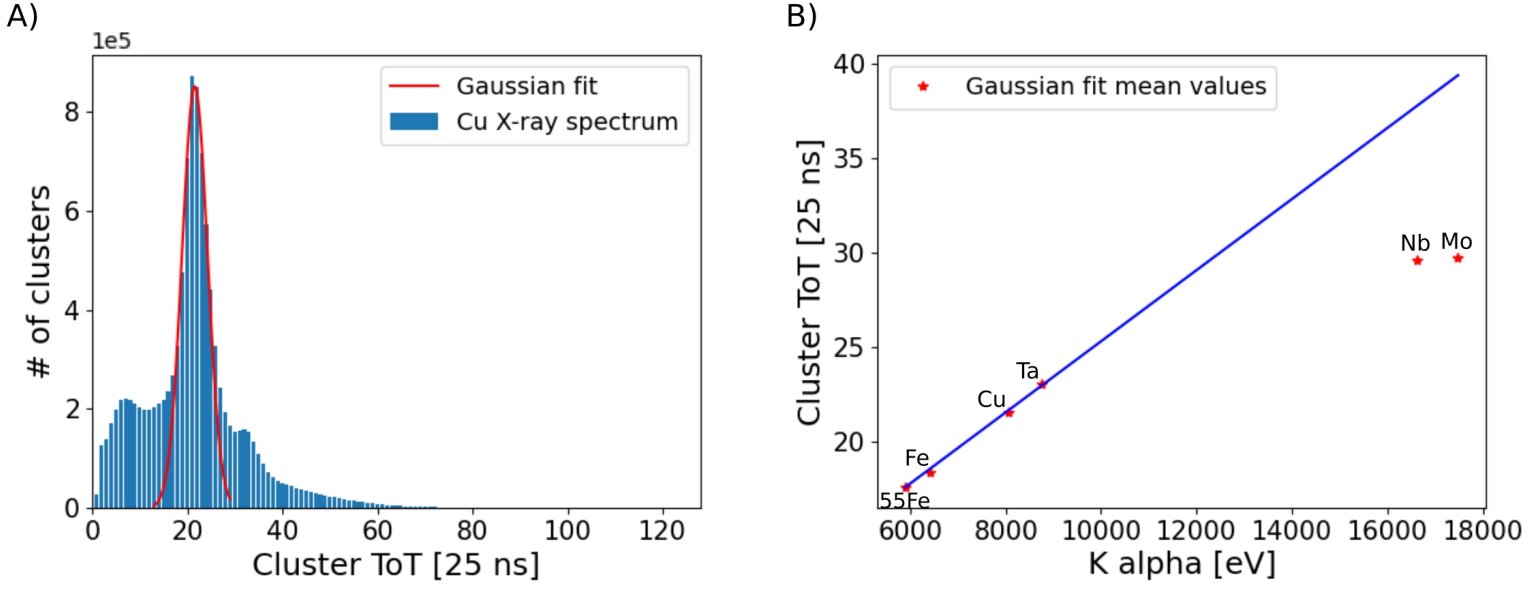
Pixel Charge Distribution

- Charge distribution of each pixel normalized by the area under the curve
- All cluster sizes
- Control and background runs very similar distribution



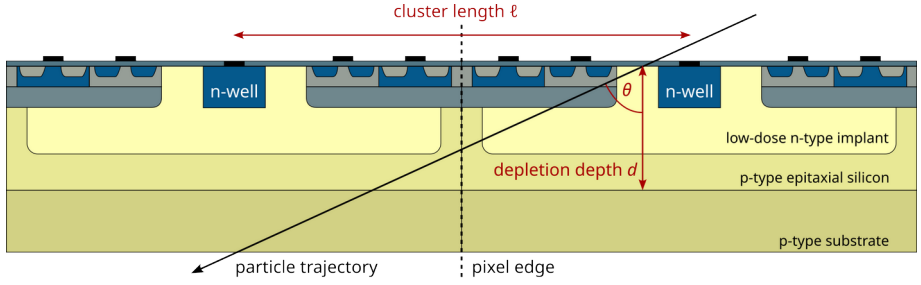
Energy Calibration

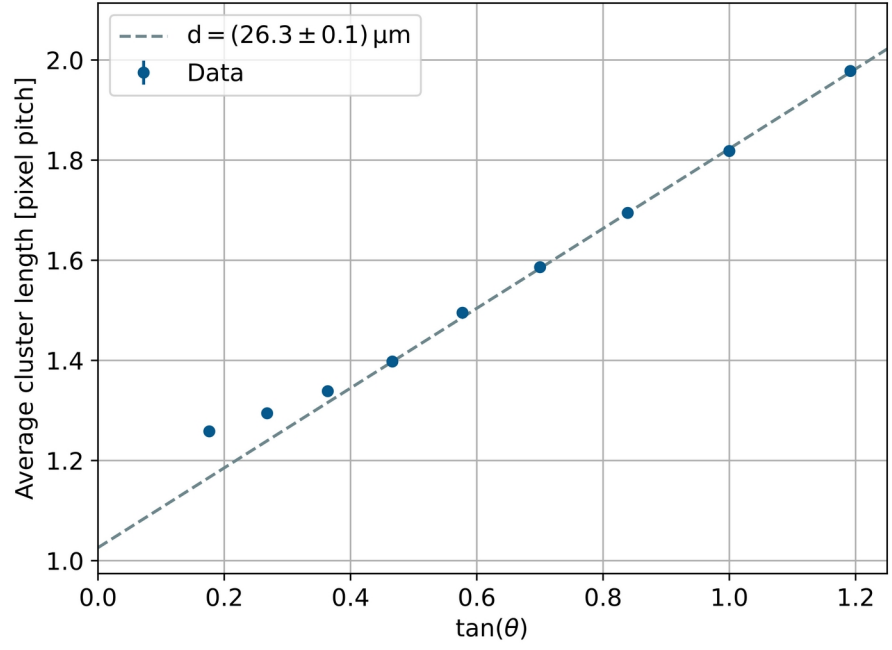
- Injection capacitance (conversion factor between ΔVCAL and eV) is measured with X-rays



Corradino, Thomas
https://hdl.handle.net/11572/402529

Sensitive Volume: Depletion depth





Grazing angle method

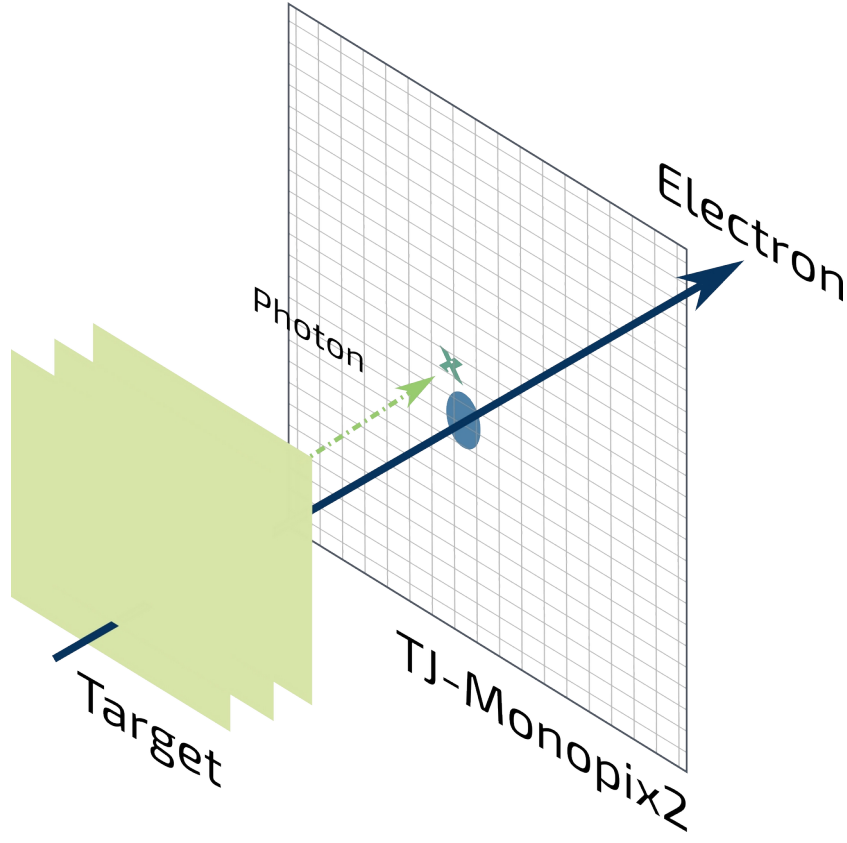
- Rotate TJ-Monopix2 in beam (w.r.t. beam axis) therefore elongate cluster size
- Measured in previous test beam campaigns

Bespin Valero, Christian (2024)
https://doi.org/10.48565/bonndoc-427

Charge Analysis

Energy/Charge

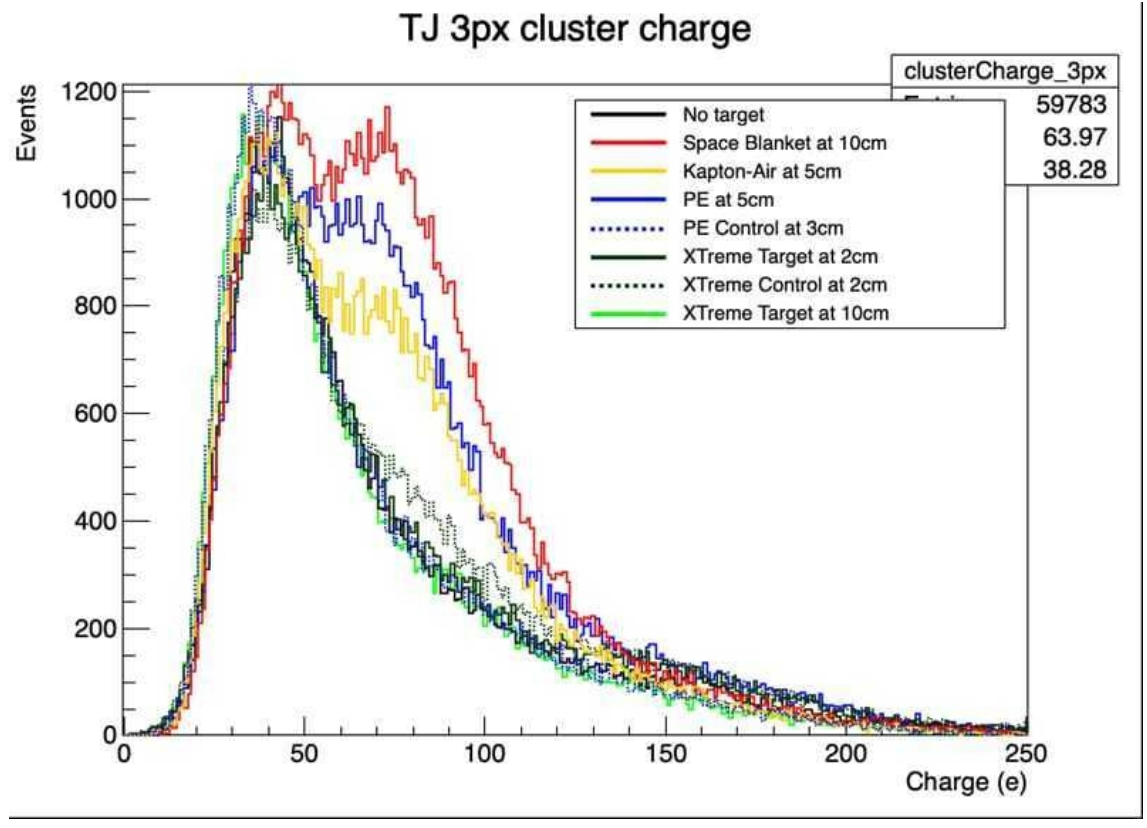
- **Small Distance between target and TJ (~5 cm)**
- Close distance between electron and photon
- Two peaks in total cluster charge
  - Single electron events
  - Electron + photon events



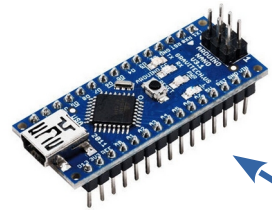
Charge Distribution

- Order of target efficiencies
  1. Space blanket
  2. PE
  3. Kapton-air
  4. Control and background targets

- 80 MPV → 14.8 keV photon + e^-
  - 7 keV photon energy



Satellites



basil

Satellite A

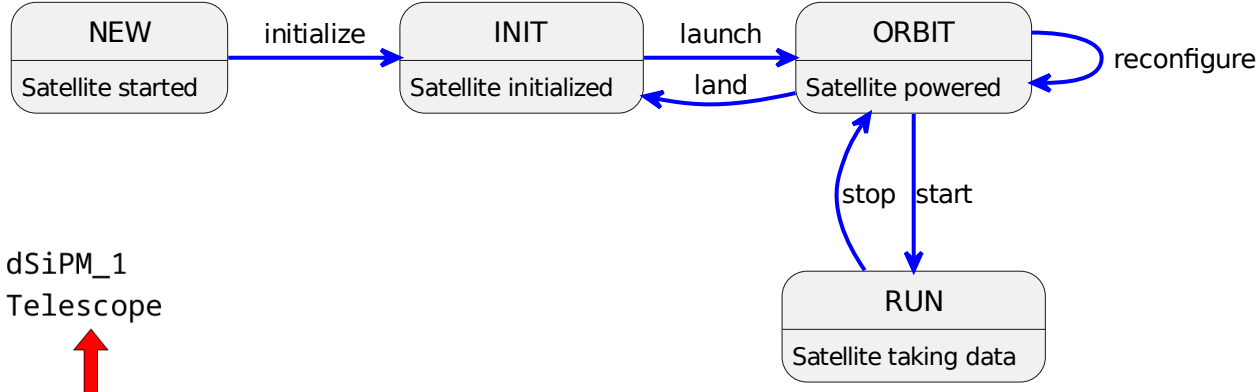
Satellite B

Controller

BDAQ53

Satellite C

Satellites




```
Satellite -t Caribou -g tb22 -n dSiPM_1
Satellite -t Adenium -g tb22 -n Telescope
```

Satellite type

Group name

Satellite name

```
stephan@slthinkpad: ~
[Constellation] stephan@slthinkpad:~$ Satellite -t Adenium -g tb22 -n Telescope
|2025-05-13 14:48:10.724|   STATUS [DEFAULT] Constellation v0.4 (Circinus)
|2025-05-13 14:48:10.728|     INFO [CMDP] Starting to log on port 37783
|2025-05-13 14:48:10.728|   STATUS [DEFAULT] Starting satellite Adenium.Telescope
|2025-05-13 14:48:10.731|     INFO [CSCP] Starting to listen to commands on port 37437
|2025-05-13 14:48:10.732|     INFO [CDTP] Data will be sent on port 34983
```

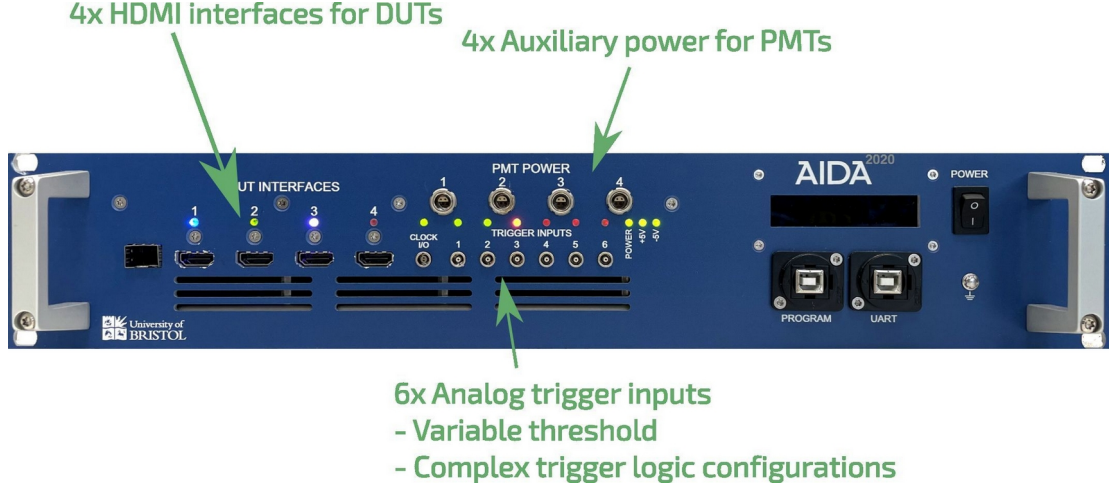
- Well defined Satellite states for each hardware
- Satellite sent heartbeat for status

https://constellation.pages.desy.de/

The AIDA-2020 Trigger Logic Unit

Synchronization of test beam devices with flexible operating modes

– Event building with synchronous time stamp or synchronous trigger number



P. Baesso, D. Cussans, J. Goldstein
https://doi.org/10.48550/arXiv.2005.00310