R2E applications of Timepix3

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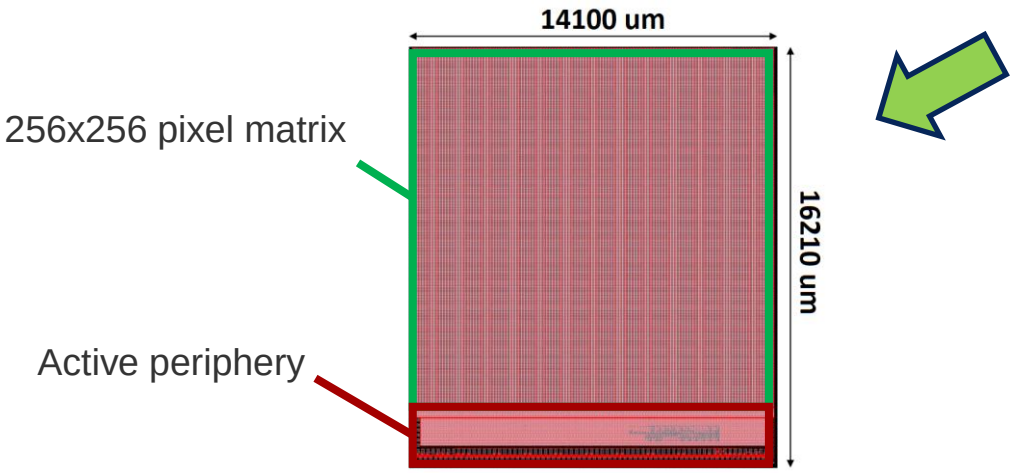
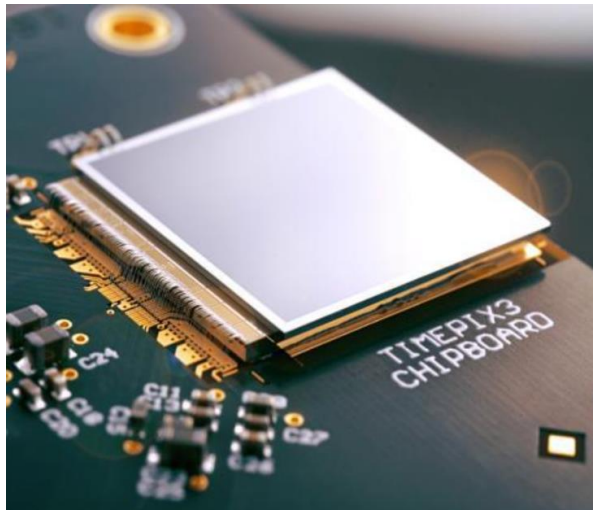
R2E Annual Meeting – 1-2 March, 2022
https://indico.cern.ch/event/1116677/

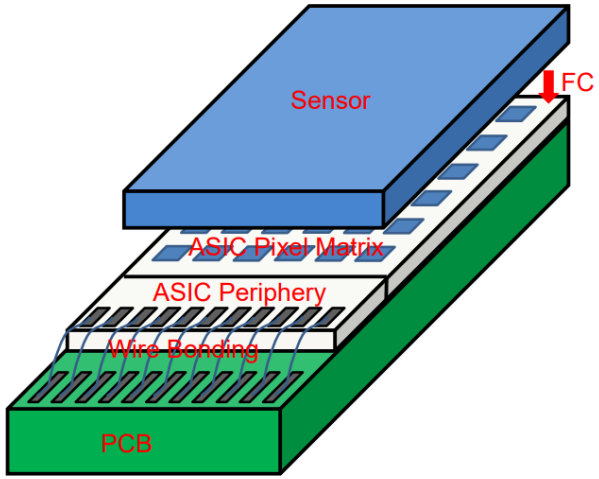
Timepix3 detector

- 55µm x 55µm x 300µm pixel size (P-on-N type)
- 256x256 pixels
- Minimum detectable charge: 500e-
- Time resolution: 25 ns (**ToA**, 40 MHz clock) or 1,56 ns (**fToA**, 640 MHz clock from local VCO)
- **ToT** resolution: 10 bits
- Maximum event rate: 1,3 kHz per pixel (85 MHz per device)





Source: Levasseur S., Development of a Hybrid Pixel Detector Based Transverse Profile Monitor for the CERN Proton Synchrotron, PhD thesis

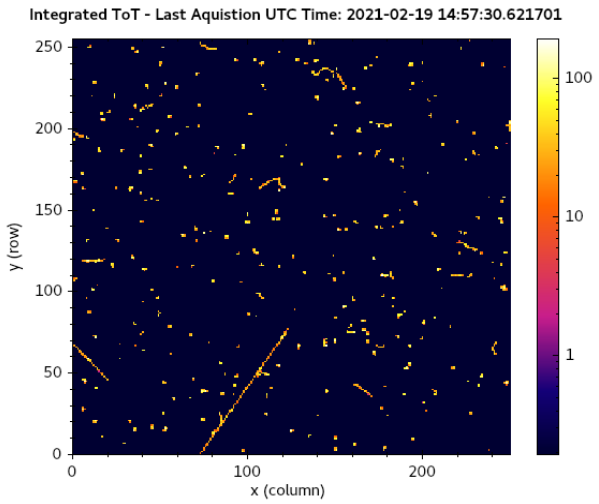


Source: Llopart X., The TimePix Chip Family, presentation, 20th Anniversary Symposium on Medipix and Timepix, 18 September 2019

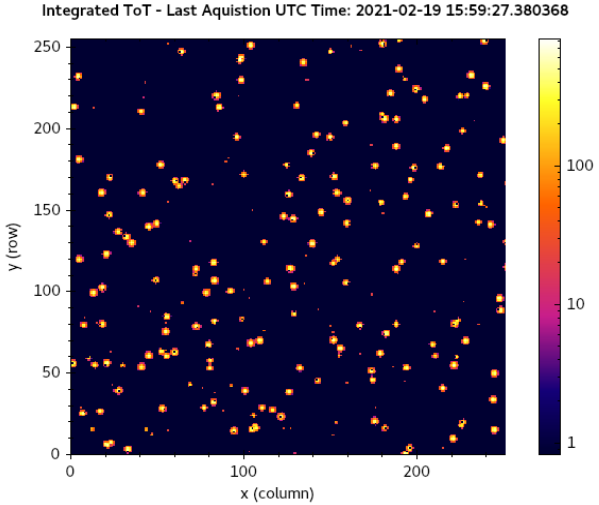
Timepix3 as an R2E monitor

- Radiation field assessment, interchangably with the Si diode detector
  - spectrometry
  - possible particle type distinguishing based on the impact area (pixel cluster) shape
- beam profile monitoring at the irradiation facilities (CHARM, CHIMERA, etc.)
- beam loss monitoring

300 µm P-on-N Timepix3 module as a part of the BGI Pixel setup

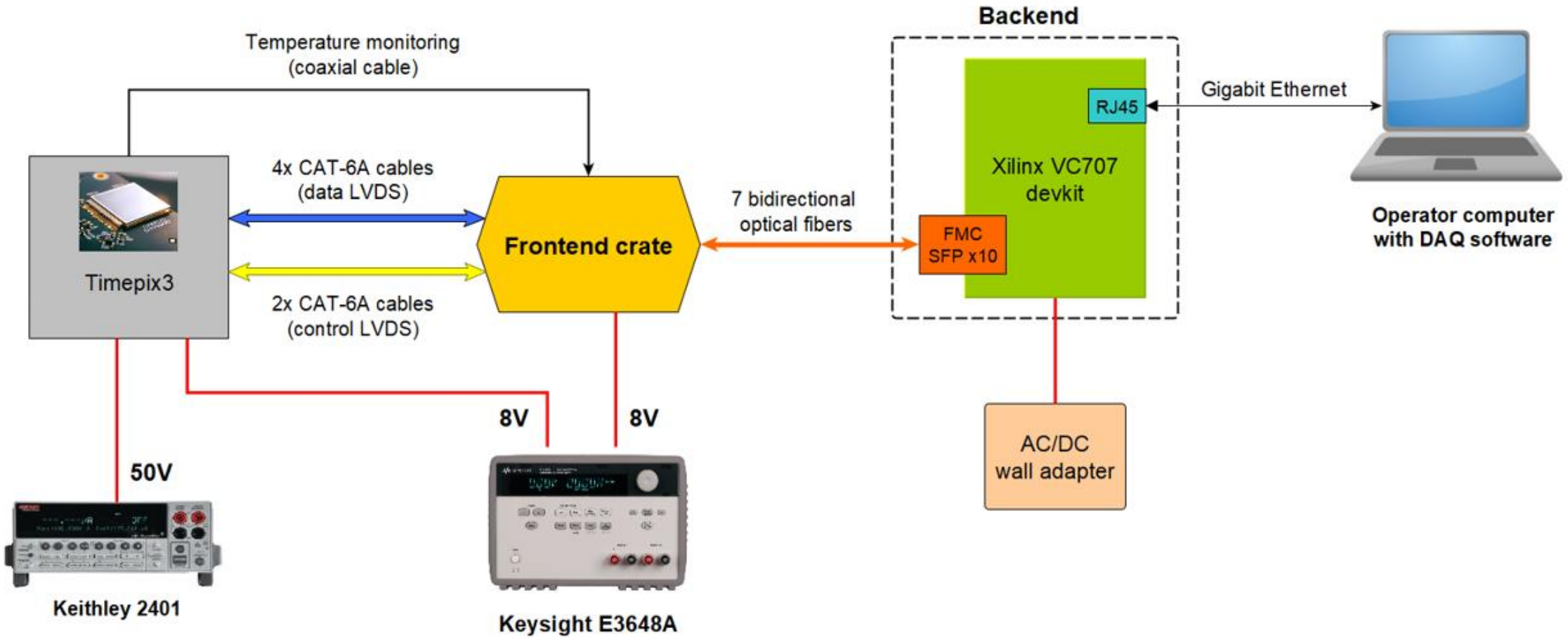


Co-60 2.1 kBq (3982RP) 1.17 MeV, 1.33 MeV γ
Distance from the detector: 100 mm (300 sec)



Am-241 39 kBq (4276RP) 5.49 MeV, 5.44 MeV α
Distance from the detector: 20 mm (60 sec)

BGI Pixel setup: block diagram



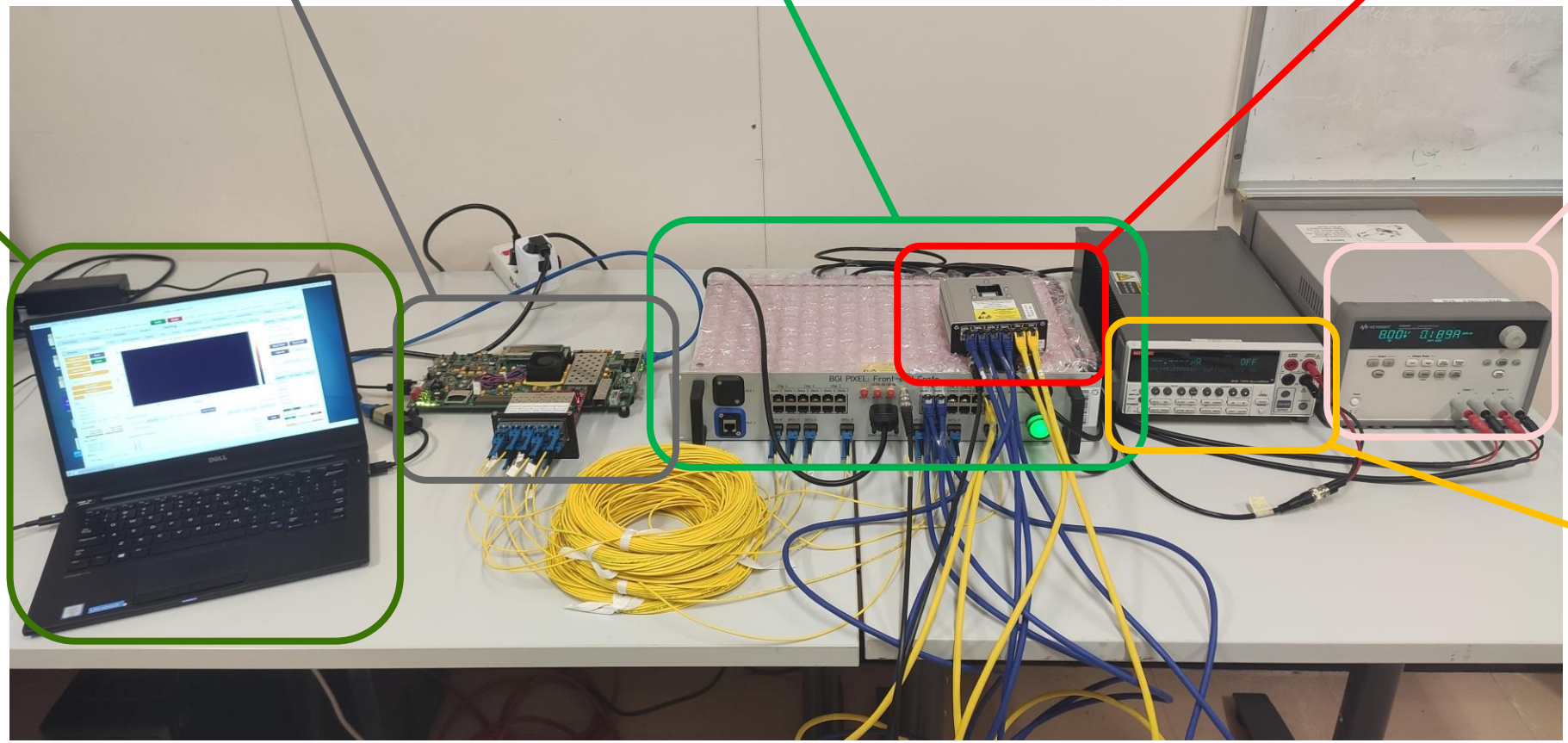
BGI Pixel setup

Laptop with BIPXL software running

Back-end electronics

Front-end electronics

Timepix3 module



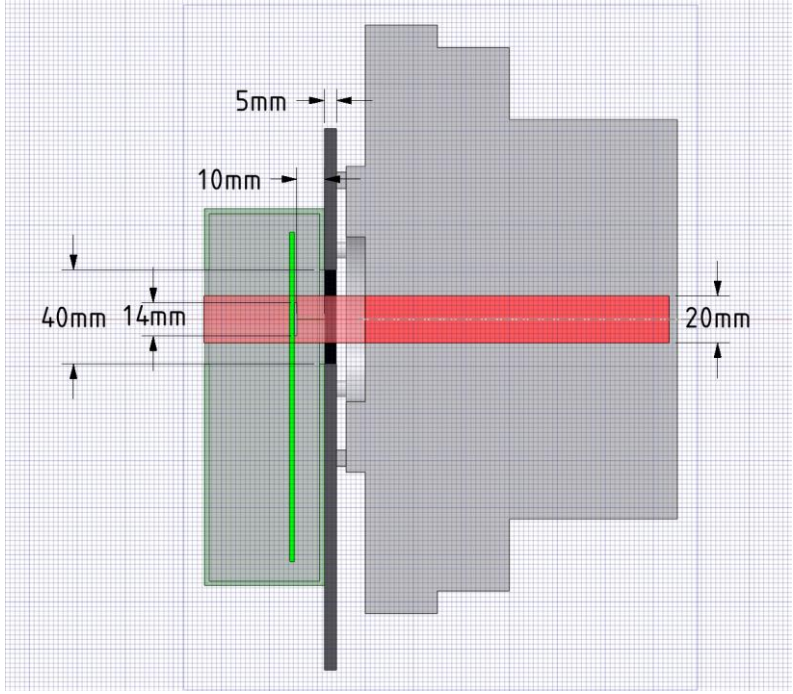
Timepix3 + frontend crate power supply (2 x 8V)

Timepix3 detector power supply (+50V)

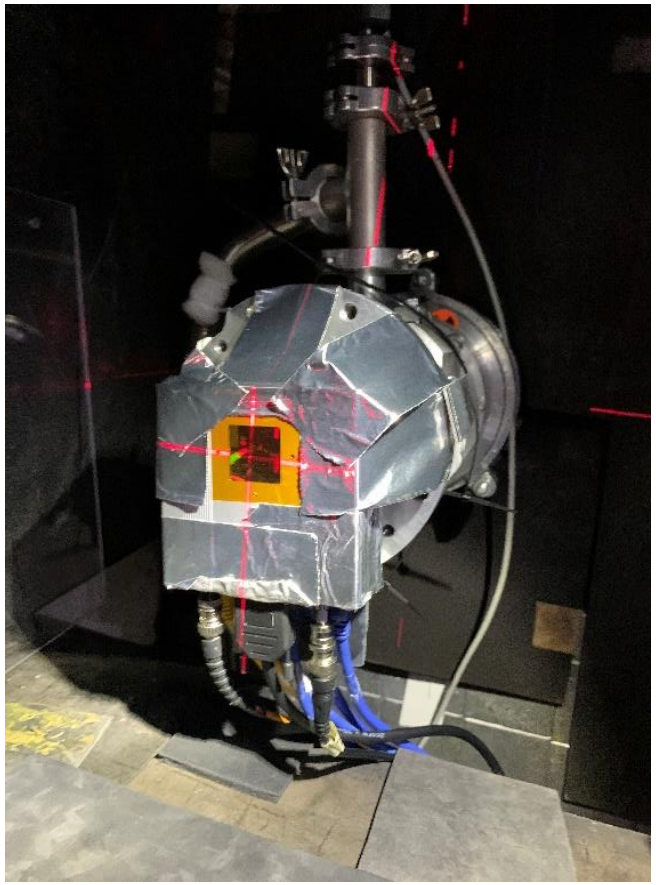
February 2021: ILL (PF1b instrument) test campaign

Objectives:

- verify the beam profile monitoring capabilities;
- assess the detector's response to monoenergetic cold neutrons: ~6,68 meV, $2 \cdot 10^9$ n/cm^2/s, ø2 cm;
- assess the detector's response to the alpha particles as a product of the Li(n,α)T reaction.

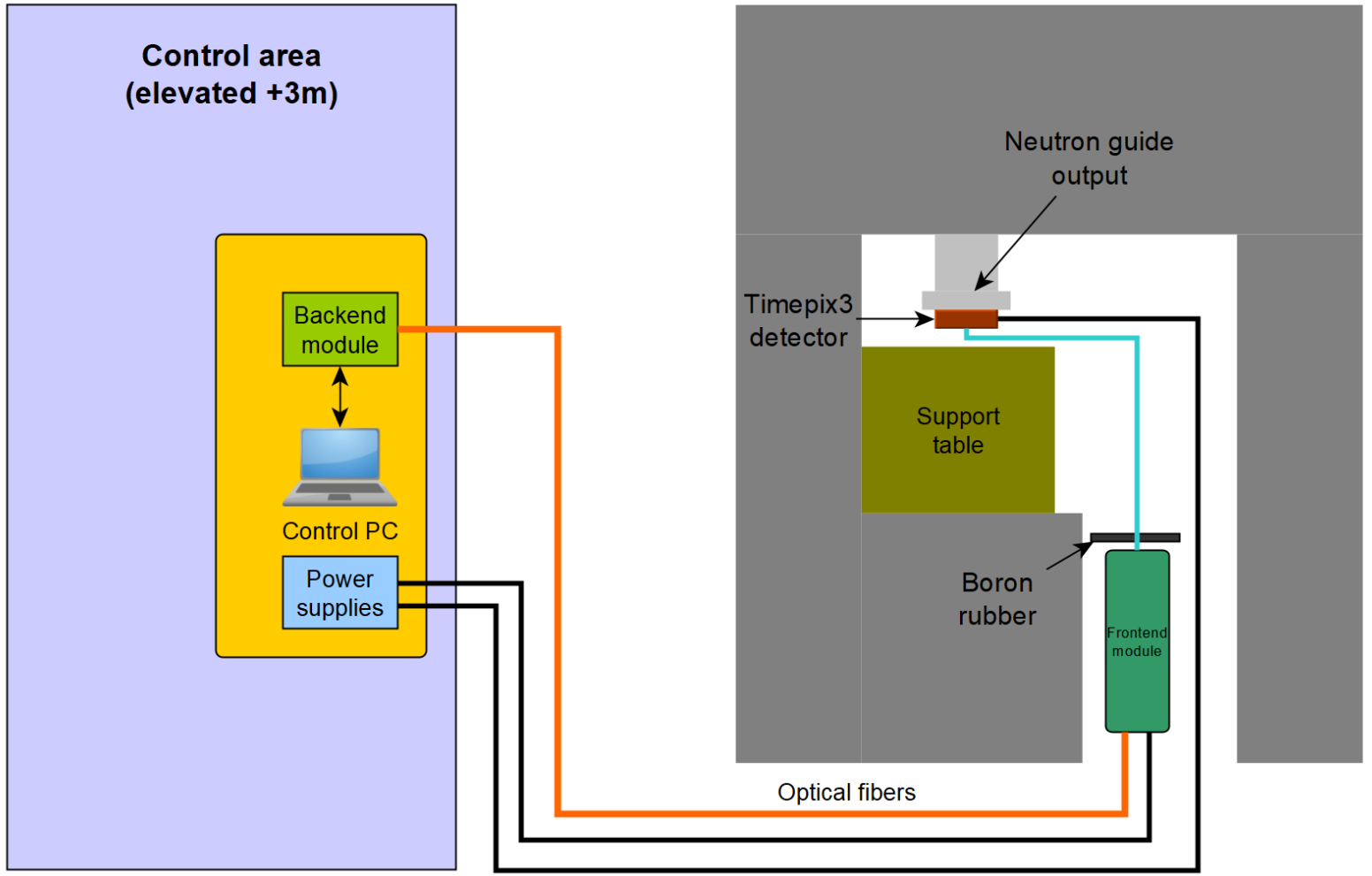


Drawing of Timepix3 BLM attached to the neutron guide output (cross-section)

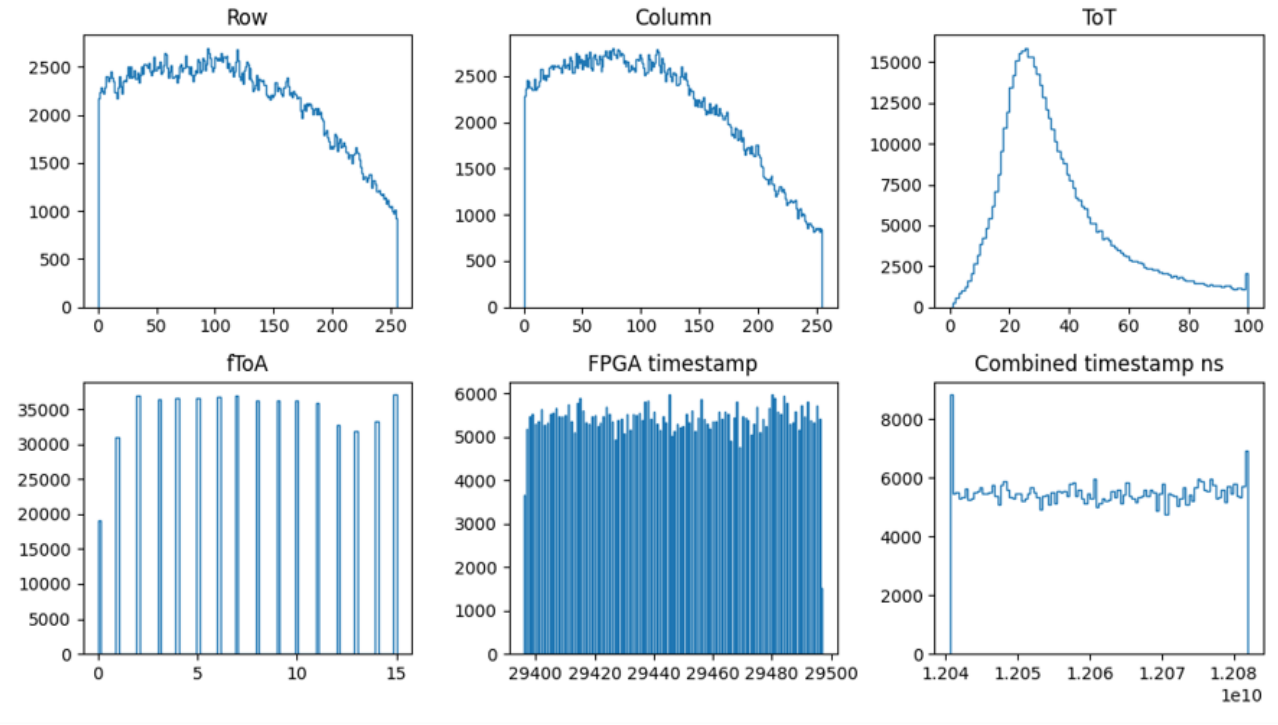


Timepix3 BLM attached to the neutron guide output

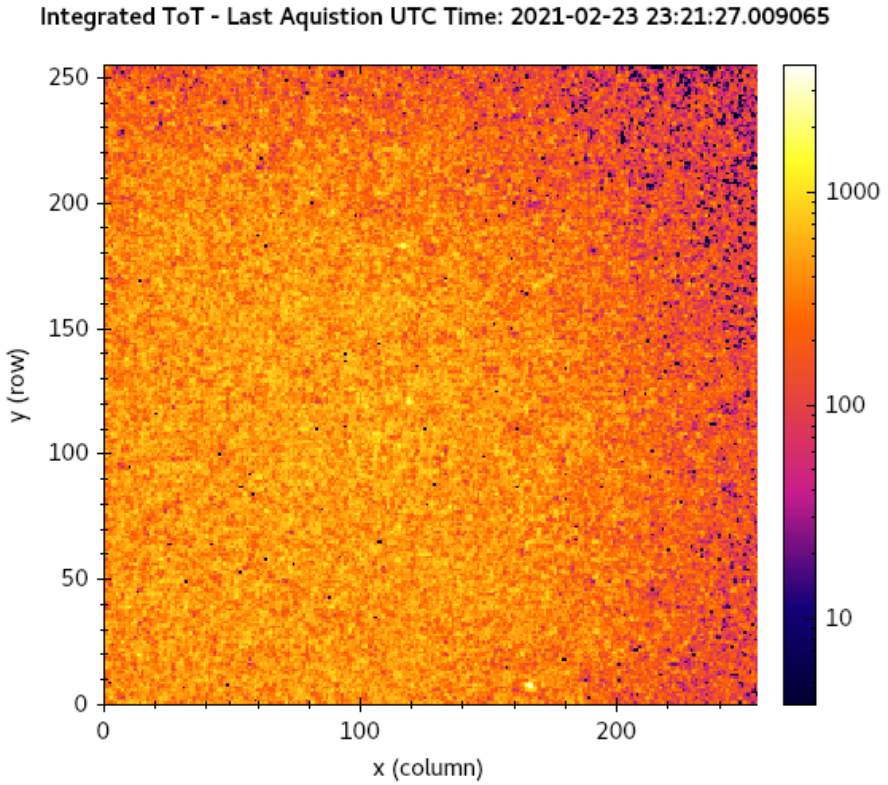
ILL Test campaign: setup layout



ILL Test campaign: detector readouts



Statistical representation of the detector readout (Run 65, ~ 5s exposure)



Beam profile captured by the detector (cumulative ToT view)

Detector energy calibration (July 2021 – present)

General procedure of calibration:

- Calculating the detector ToT response involving pixel clustering with the selected α radioactive sources (several MeV range).
- Monte Carlo particle transport simulations of irradiation tests to obtain the deposited energy values during each test.
- Combining the results to determine the ToT(E) dependency.

Alternative procedure:

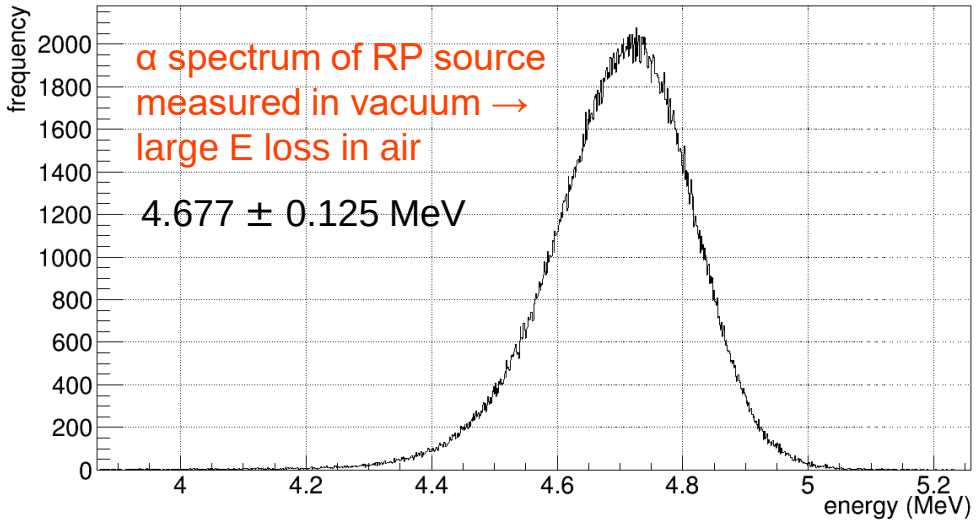
- Pixel preamplifier characterization ToT(U_{in}) – requires test pulse input
- ToT → U_{in} → Q_{in} (based on C_{in}) → E_{in} (assuming 3.6 eV/e^-)

Energy calibration: radioactive sources at CALLAB

Am-241 (α energies: 5.486 MeV (85%) and 5.441 MeV (13%) + some 59.5 keV γ)

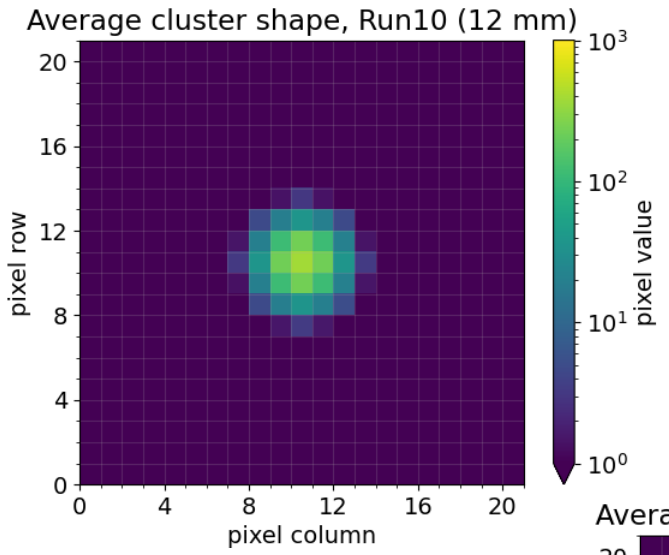
Big statistics (~1-3M events) measurements performed at 12 mm, 16 mm, 20 mm, 24 mm

→ calibration based on deposited energy dependency on the distance from the source

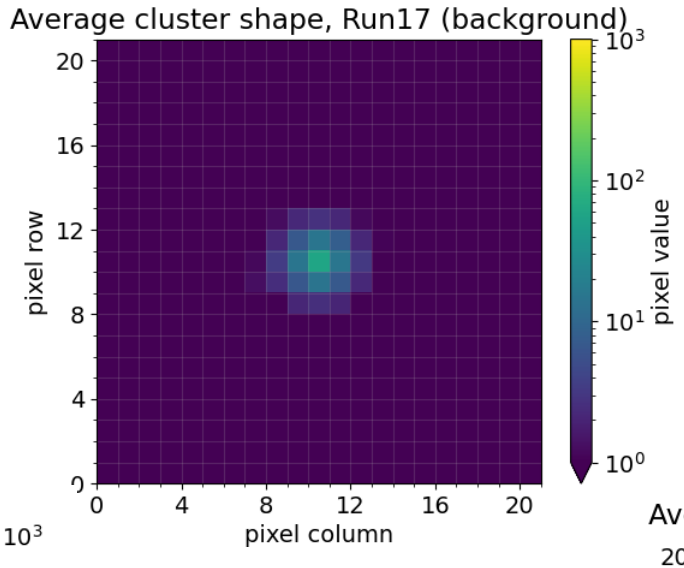


+ similar tests with **Co-60** (1.17 MeV and 1.33 MeV γ)

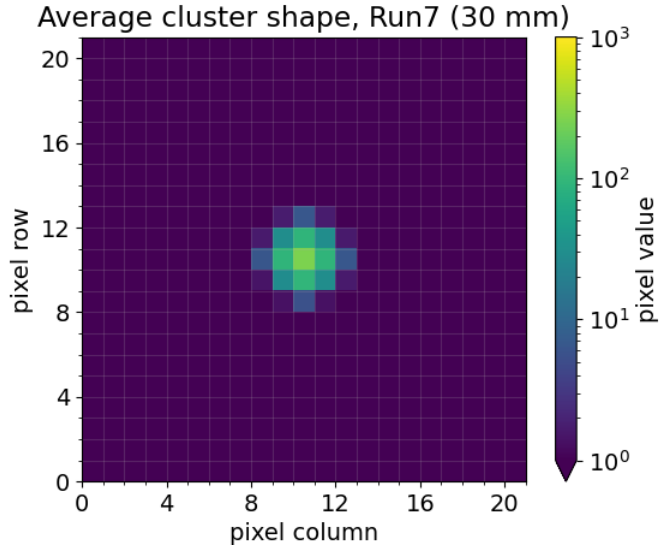
Cluster analysis: average cluster shapes



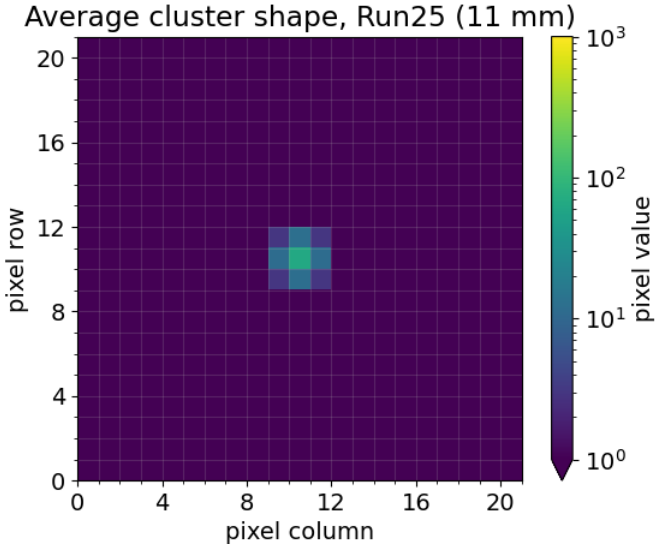
^{241}Am alpha 12 mm



Cosmic background (mostly muons)



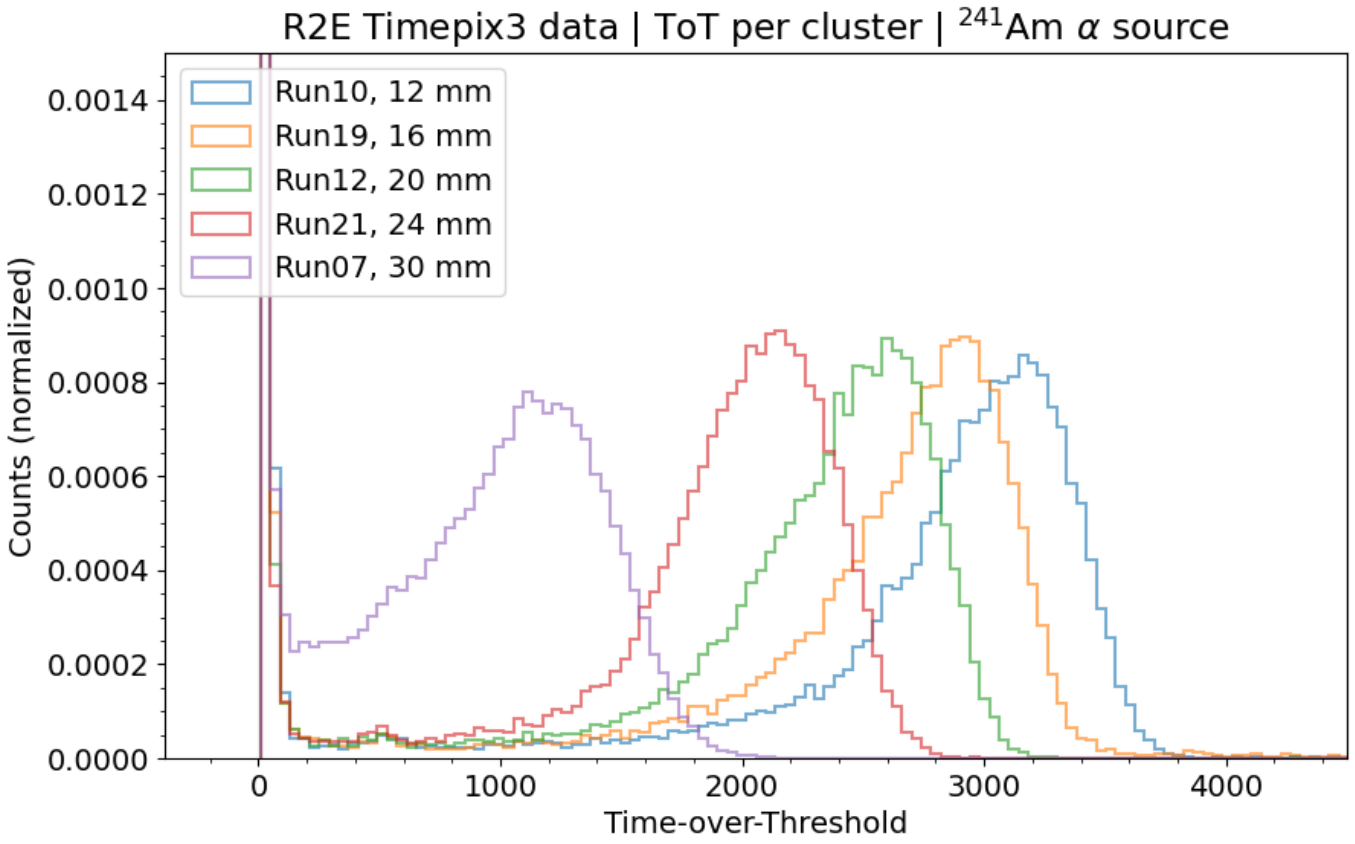
^{241}Am alpha 30 mm

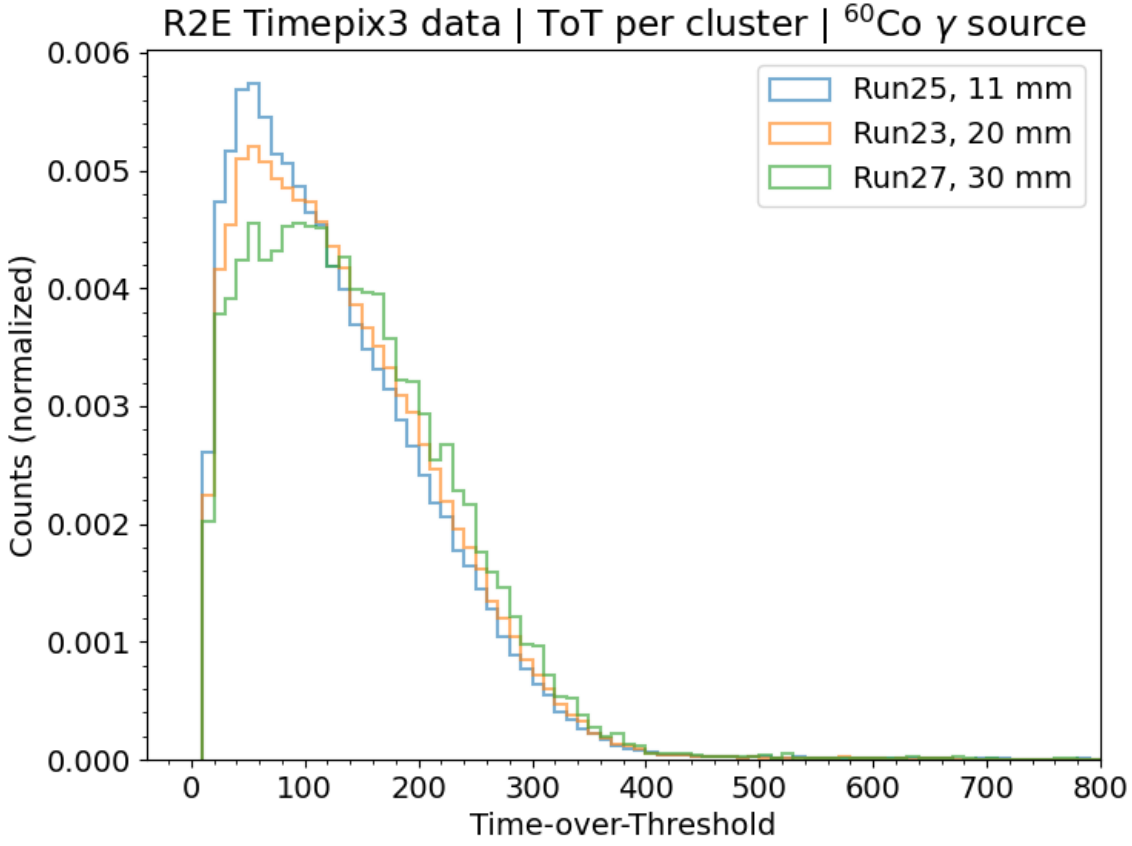


^{60}Co gamma 11 mm

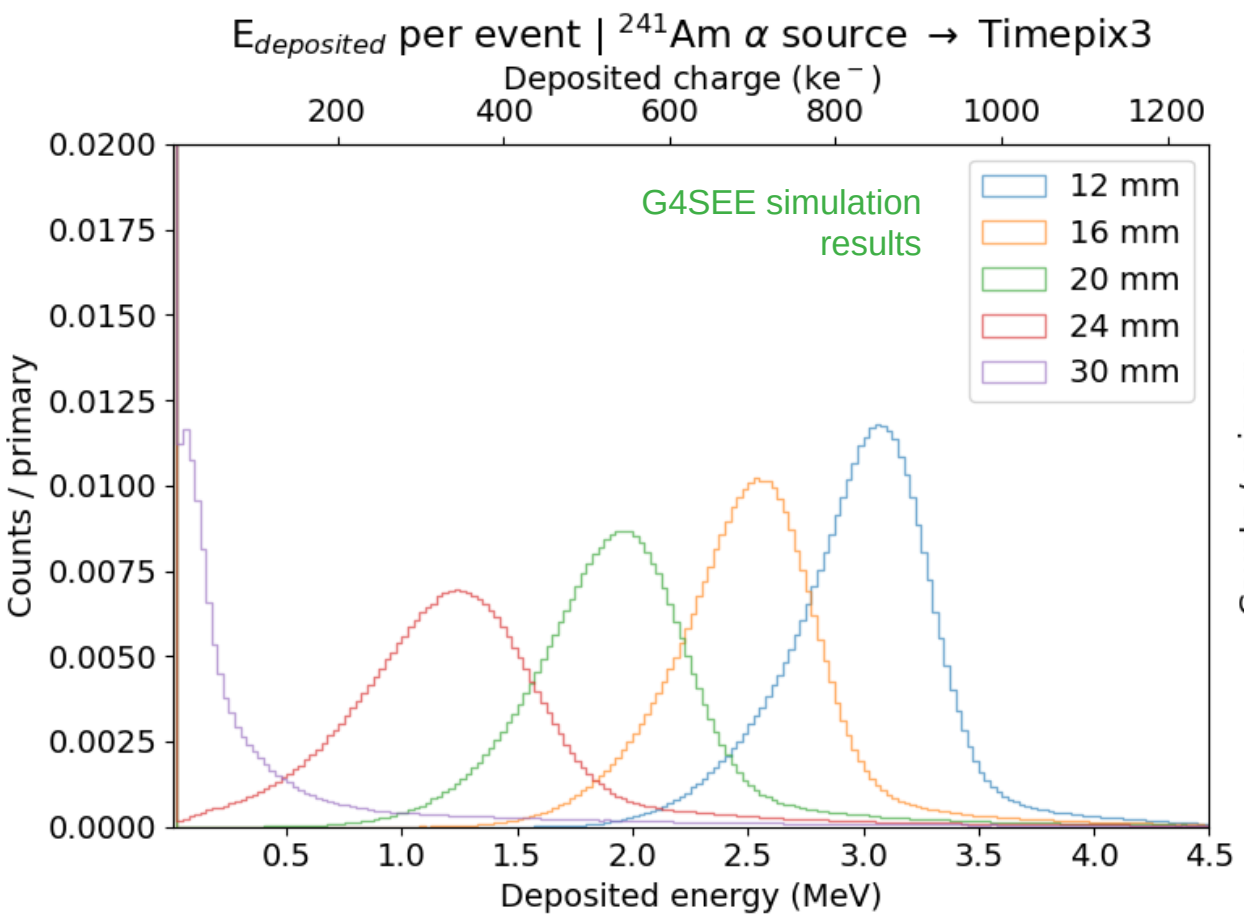
Energy calibration: ^{241}Am (α) & ^{60}Co (γ) ToT spectra

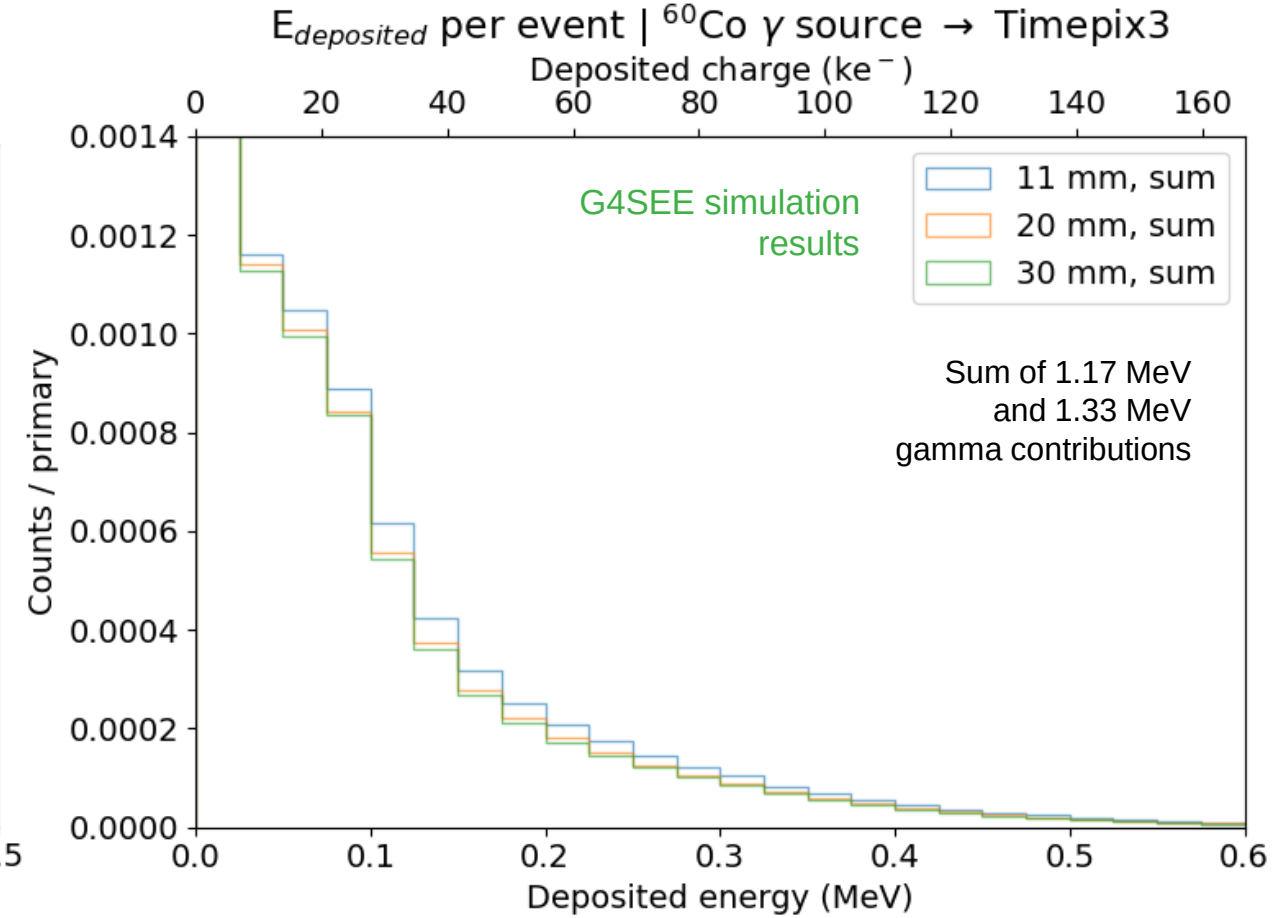
The equivalent of the energy deposited by each one of the hits is the ToT data integrated over each recorded cluster.



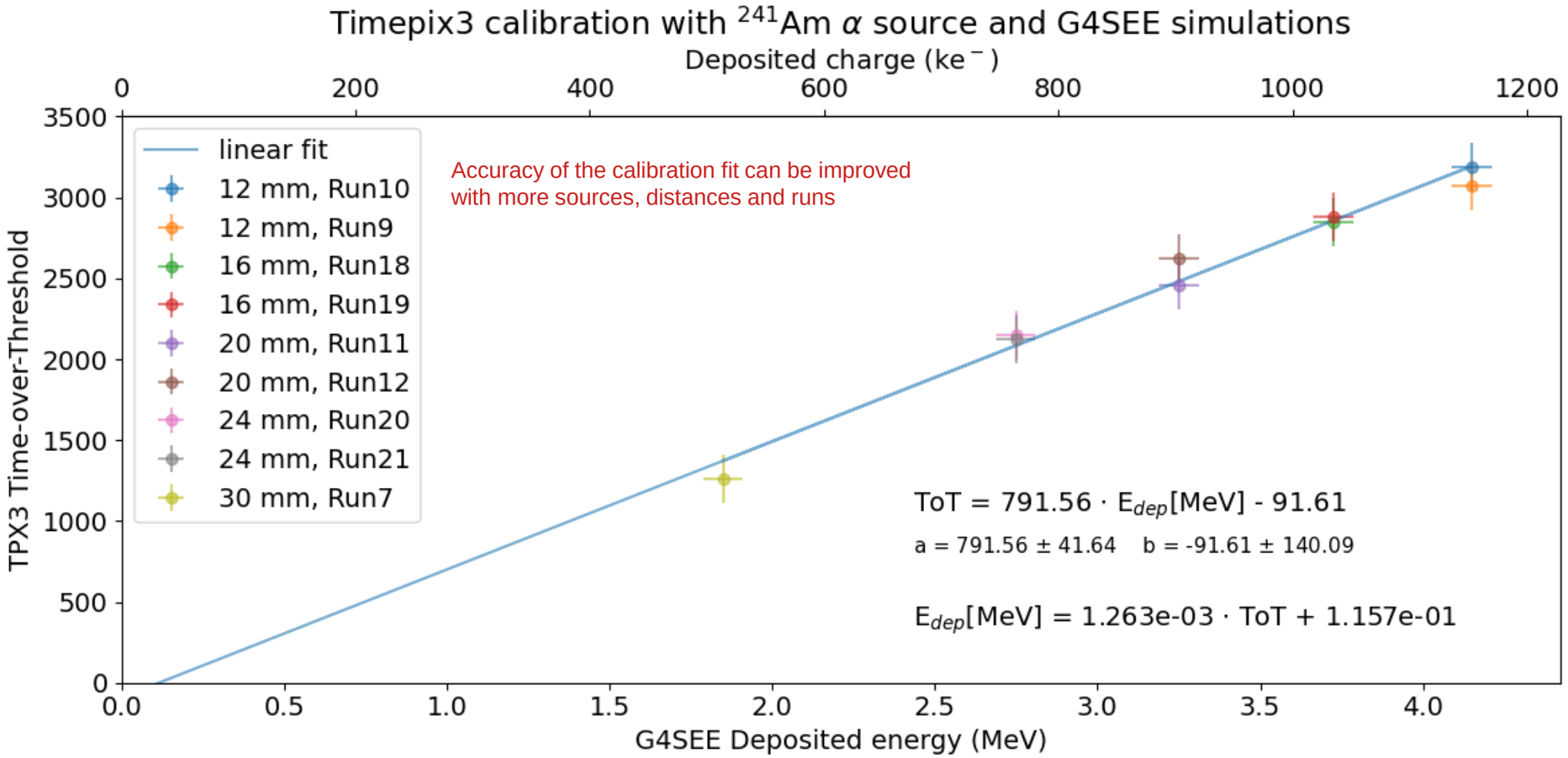


Energy calibration: MC simulations





Energy calibration: earlier results [WIP]



Am-Be test campaign (February 2022)

Measurement of Am-Be neutron emission spectrum and particle flux depending on:

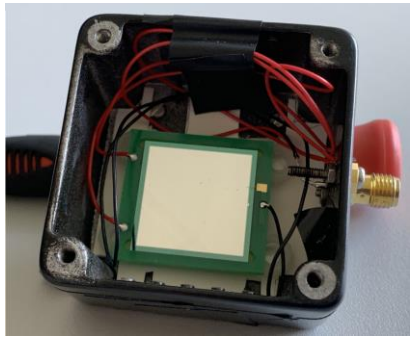
- Distance from source (20 cm / 59 cm)
- Neutron thermalization
  (~6 cm thick PE cylinder as moderator)

Detectors used:

- Timepix3
- PLWS (image sensors)
- Silicon Diode
- SRAM tester

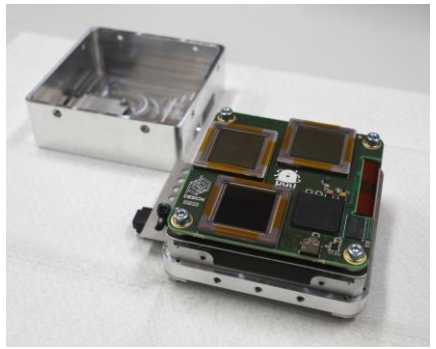
Energy spectrum and flux

Flux

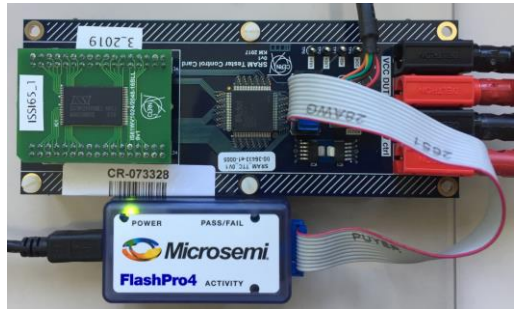


Micron MSX04 “Carlo”
300 µm Si diode

300 µm P-on-N Timepix3



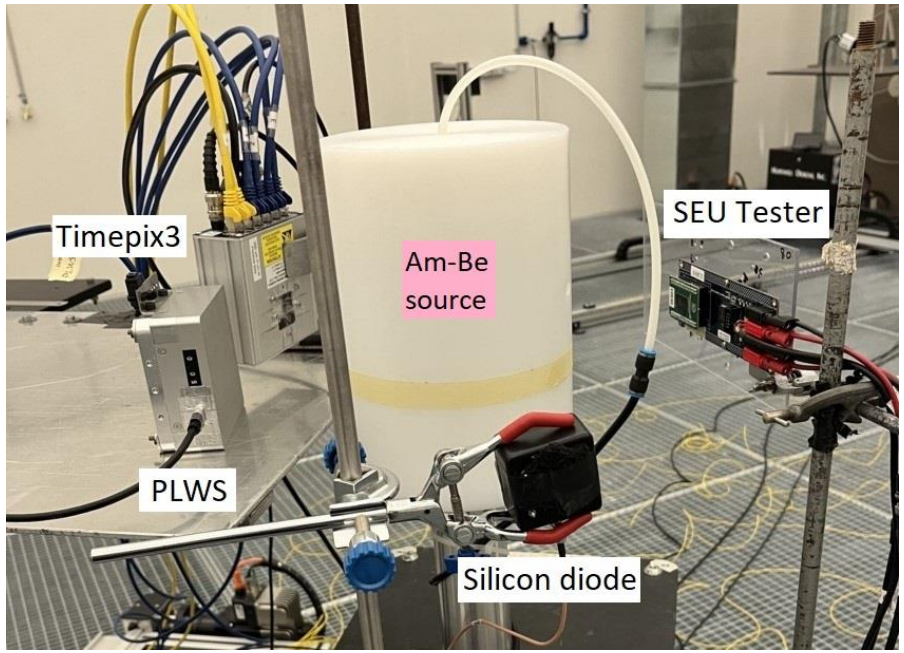
PLWS with 2 neutron sensitive + 1 reference CMOS image sensors



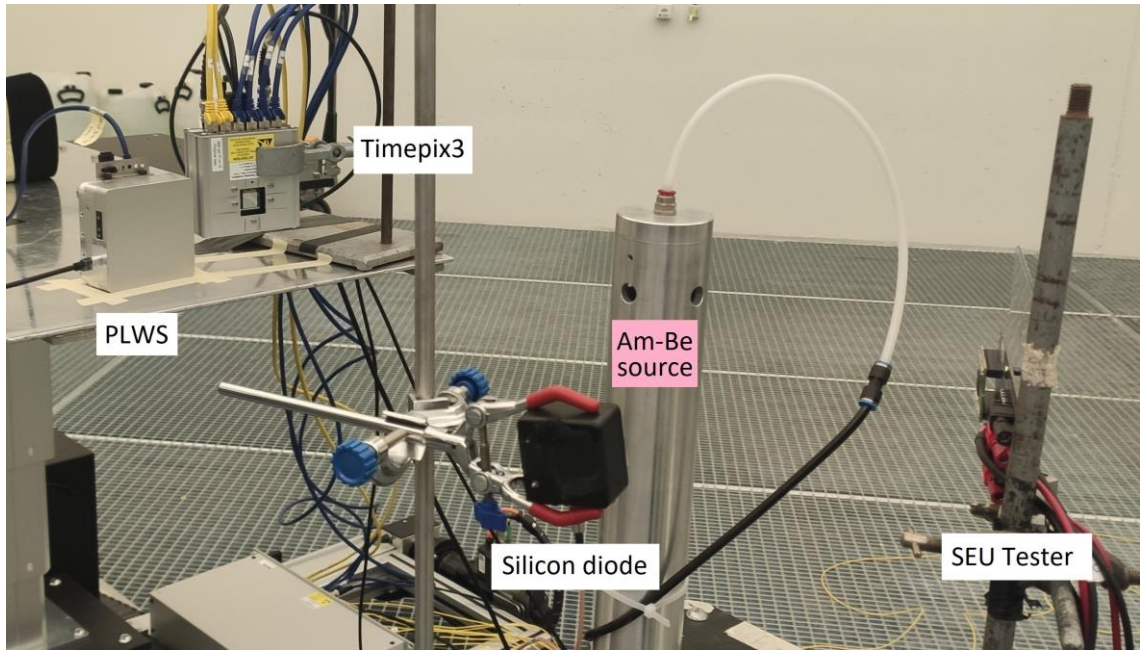
SEU Tester with ISSI SRAM (IS61WV204816BLL-10TLI)

Am-Be test campaign: setups

All detectors positioned at 20 cm distance from the neutron source with PE moderator cylinder on top

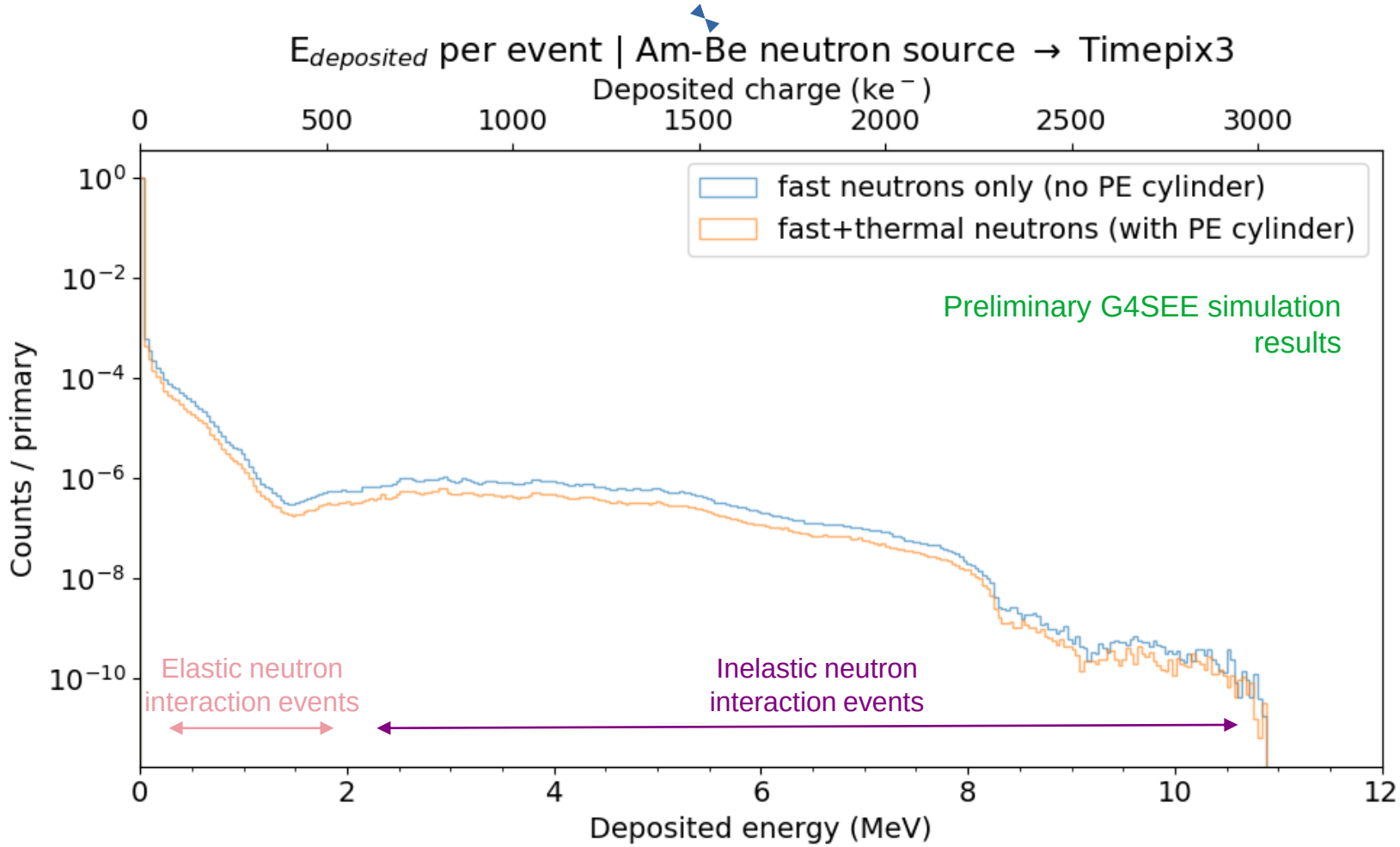


Timepix3 and PLWS detectors positioned at 59 cm distance from the neutron source, w/o PE cylinder



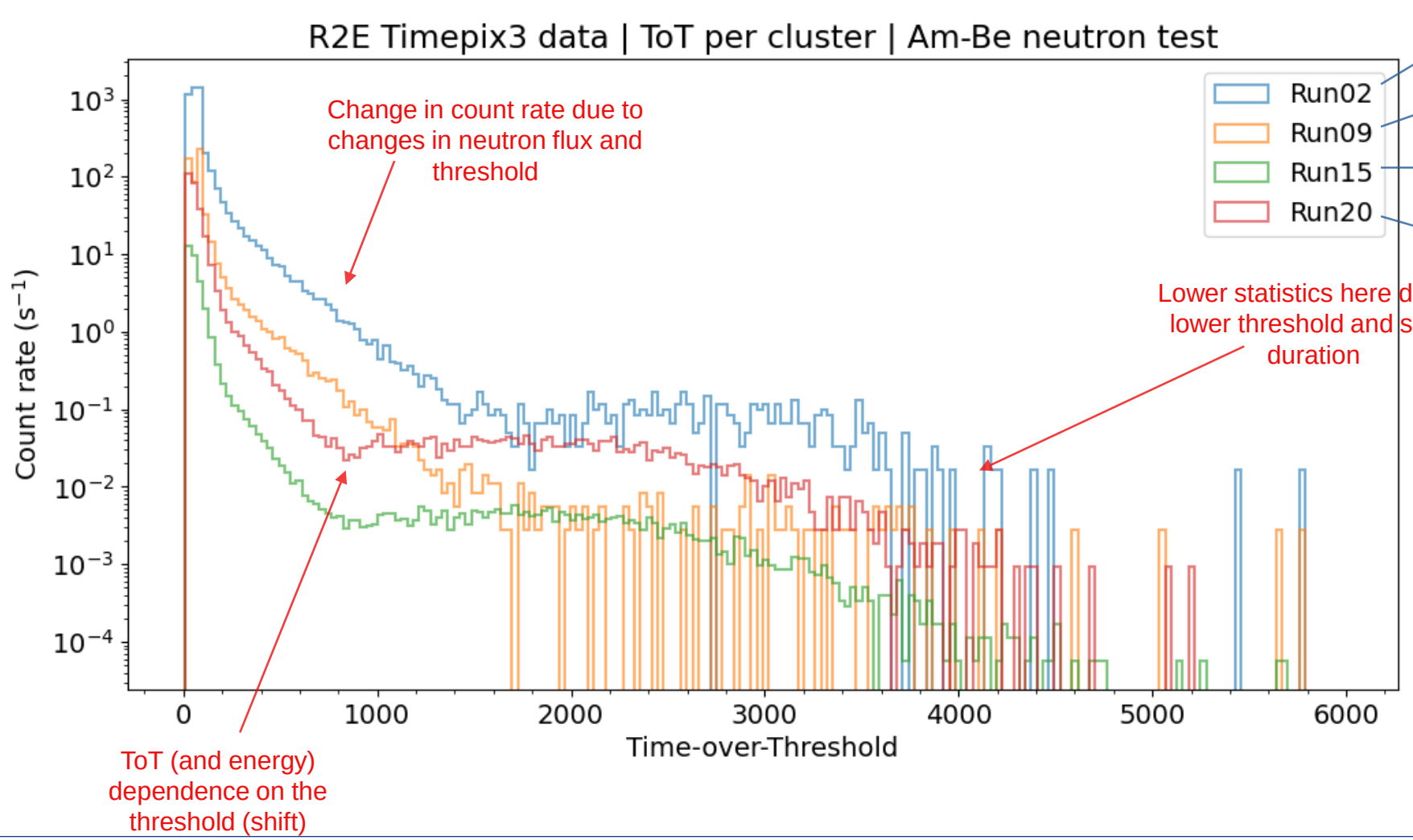
Timepix3 threshold was eventually increased to bring the event rate to a value comparable with other detectors and increase statistics on the higher energy part of the spectrum.

Am-Be test campaign: MC simulations



Am-Be test campaign: Timepix3 data

Preliminary results!



These will be compared with similar spectra of the Si diode and PLWS

To be checked if these ToT spectra could be also used for energy calibration combined with previous G4SEE simulations

R2E Timepix3 setup: future work

- Comparison of detector response with Si diode and PLWS setups
- Test campaign in CNA (Seville, Spain) in April-May 2022: inside vacuum chamber, irradiated with 500 keV – 5 MeV protons
- Possible vacuum chamber energy calibration at CERN (adaptation of the setup developed by HSE-RP-SP) with the radioactive sources available at RP
- Additional tests in CALLAB using other α radioactive sources (U, Th, Ra, etc.)
- Assembly of a second Timepix3 module with same thickness and opposite polarity (N-on-P) sensor: evaluation of doping influence on degradation and sensitivity
- Development of data processing and analysis codes

Thank you for
your attention!

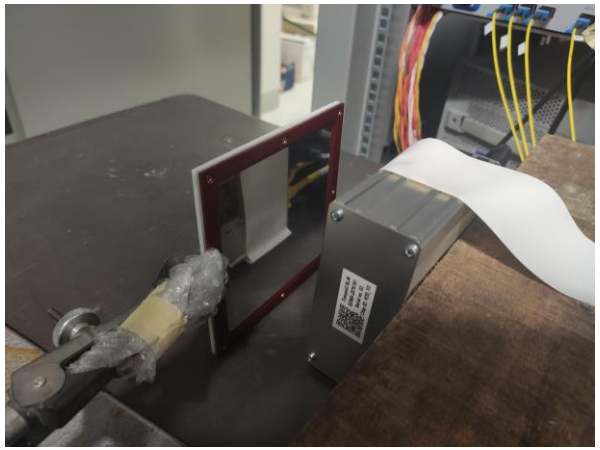
CERN SY STI R2E

Backup slides

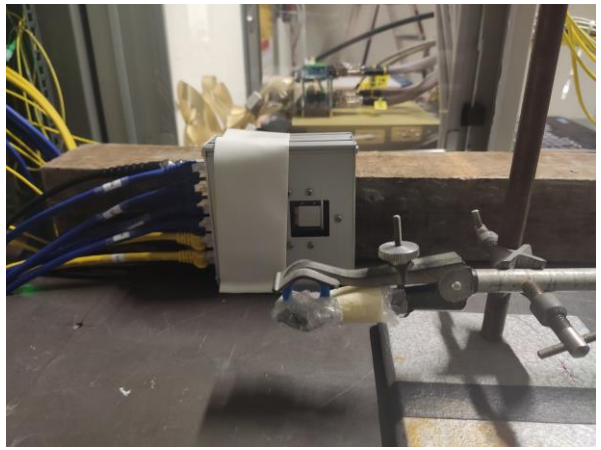
February 2021: pixel equalization

Software updated to v3.4 allowed for the implementation of pixel equalization (noise floor Medipix-style procedure)

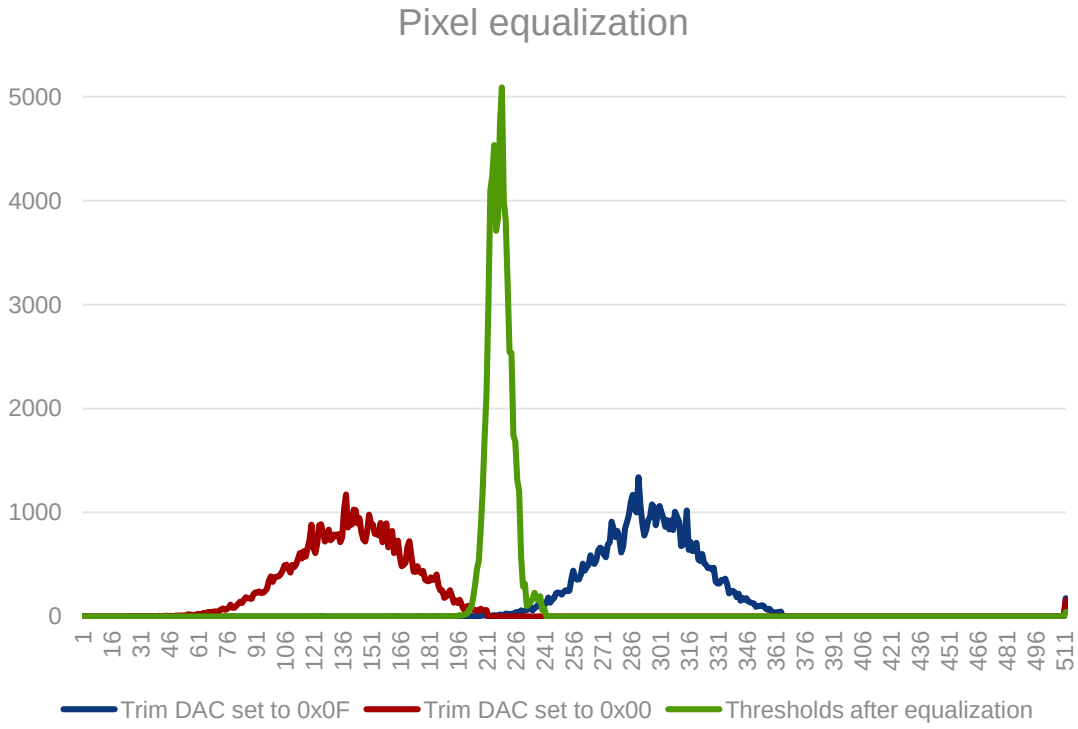
First tests in CALLAB (19.02.2021)



Co-60 668 Bq (4248RP)



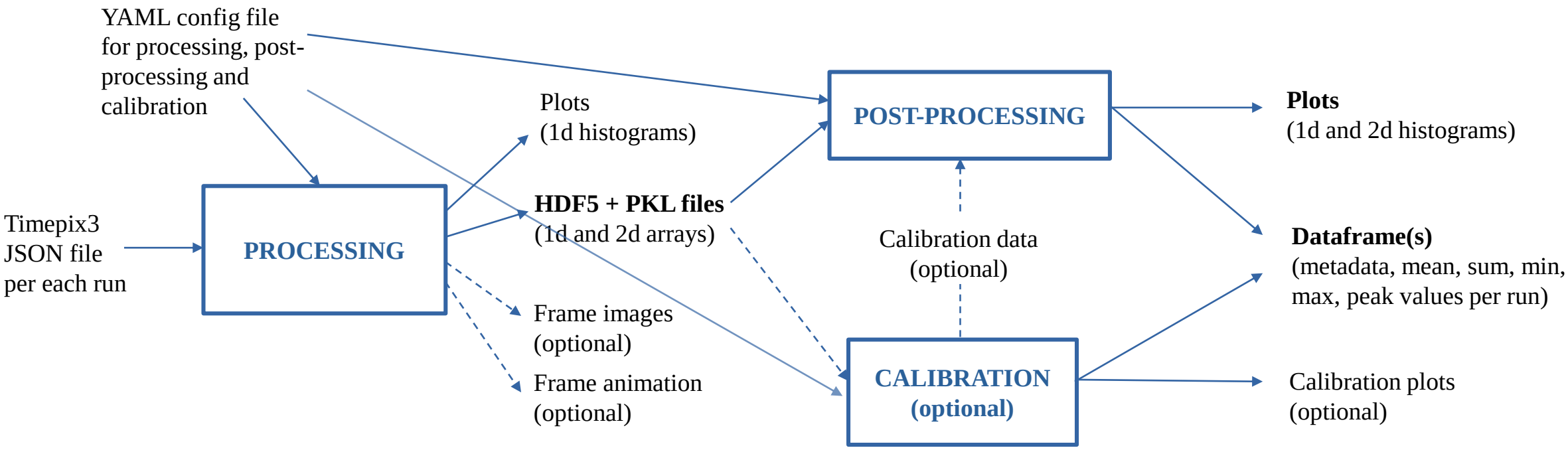
Co-60 2.1 kBq (3982RP)



X axis: Threshold setting; Y axis: number of pixels

Data processing – Architecture & pipeline

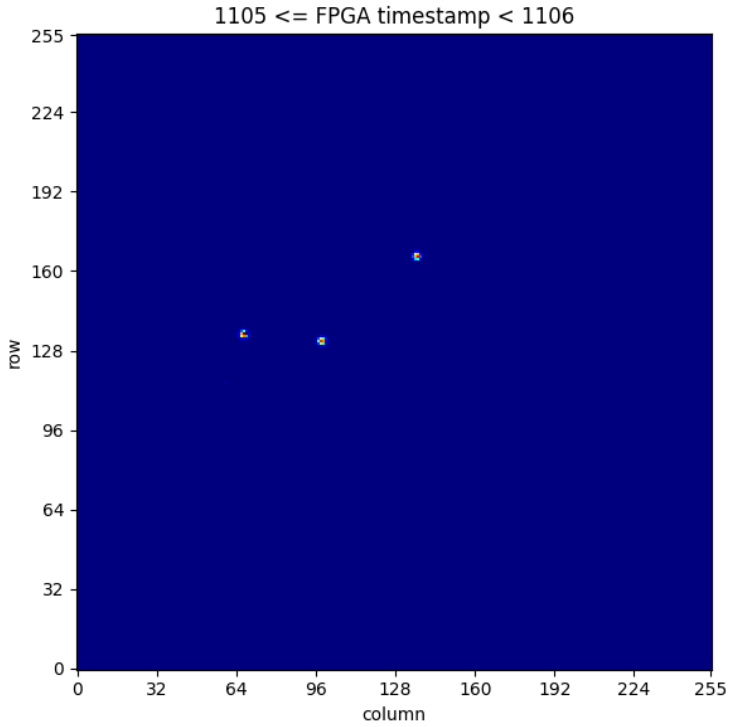
- Data processing code consists of 3 separate, independent submodules



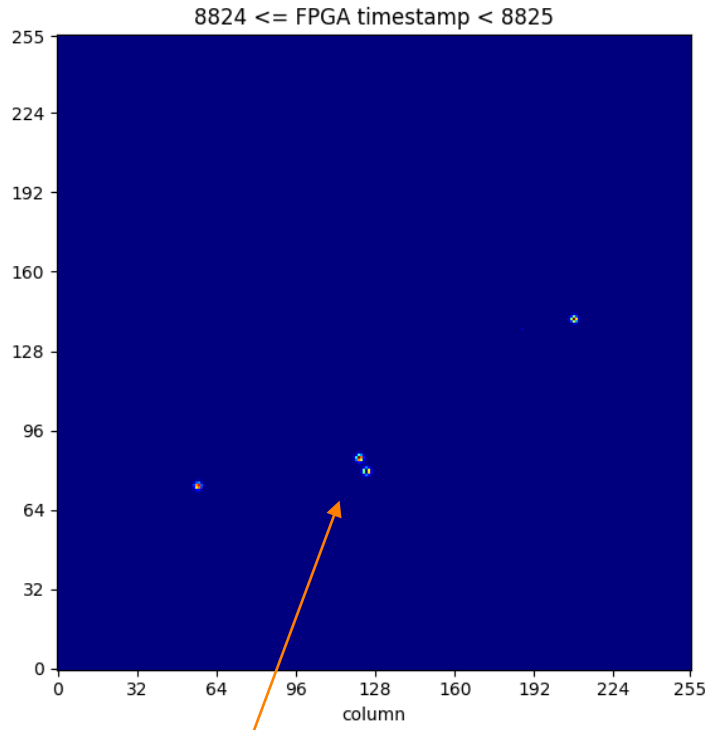
Timepix3 data processing code: https://gitlab.cern.ch/r2e-bmi/timepix3/timepix3-data-processing

Processing raw data

Separate pixel events have to be grouped both in time and space!
→ Create frames (temporal grouping using FPGA timestamp data)
→ Find pixel clusters (spatial grouping using DBSCAN algorithm)

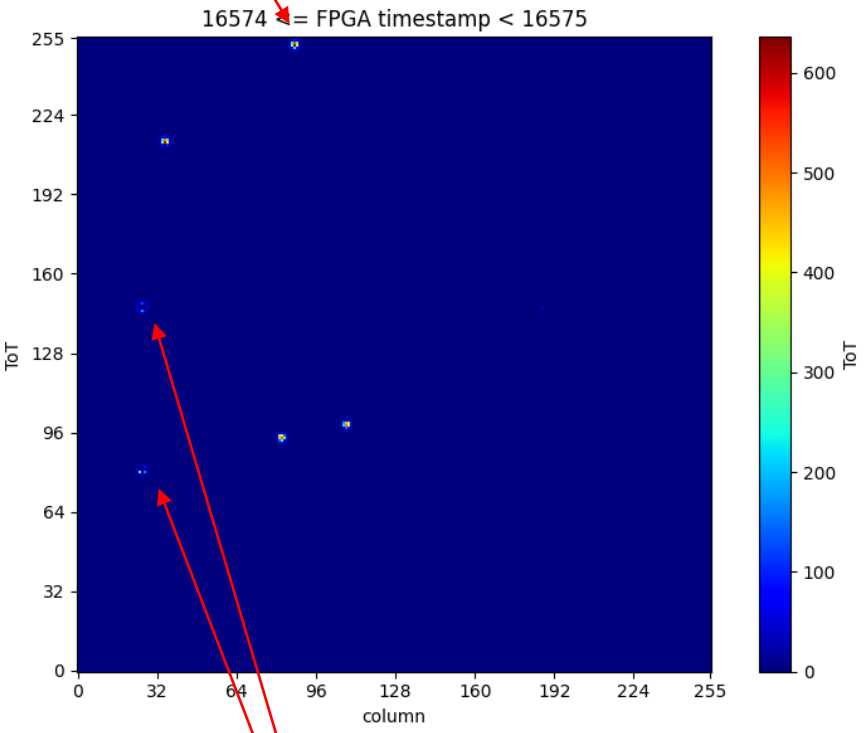


A "well-behaving" normal frame based on FPGA timestamps (majority of the frames)



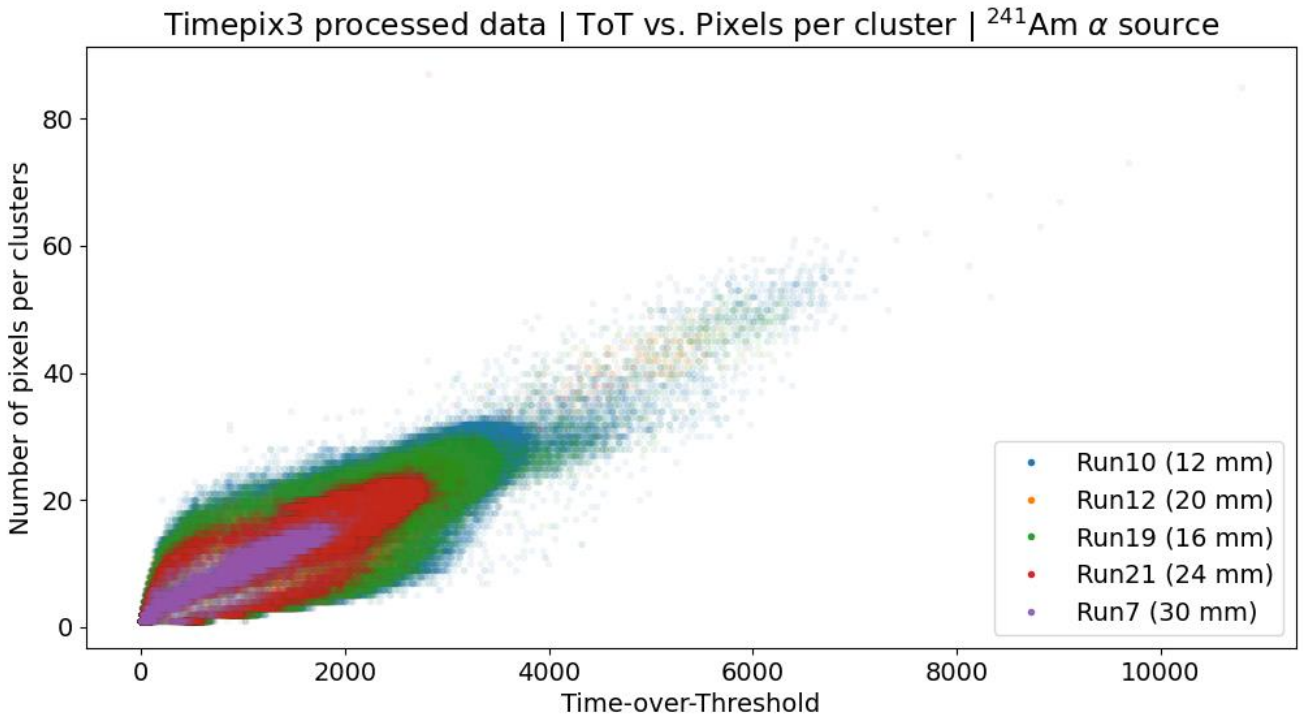
Close hits and too large clusters
→ pile-up events could occur

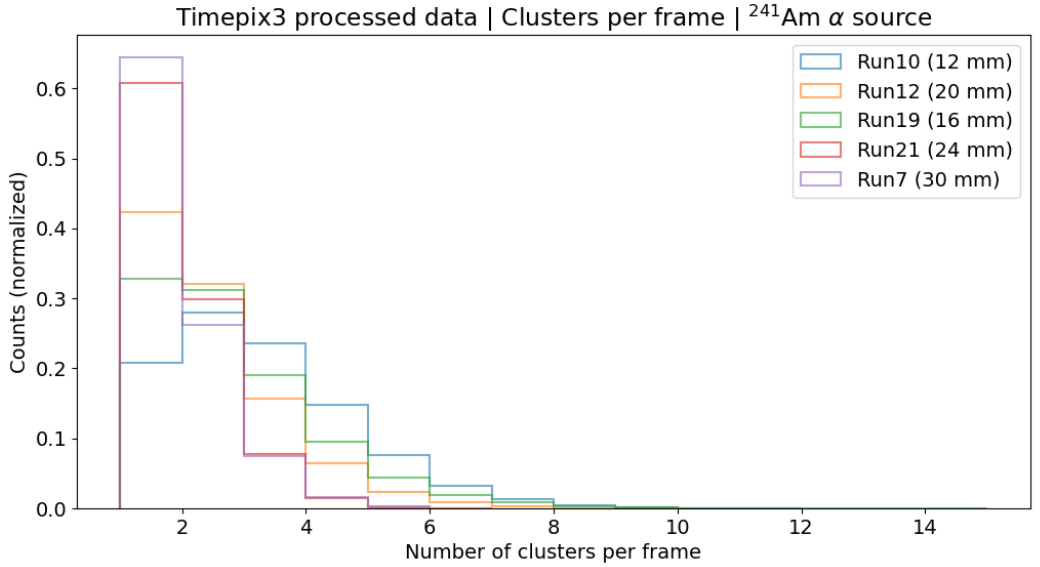
Particle hits on the sensor edge
→ potential missing deposited energy

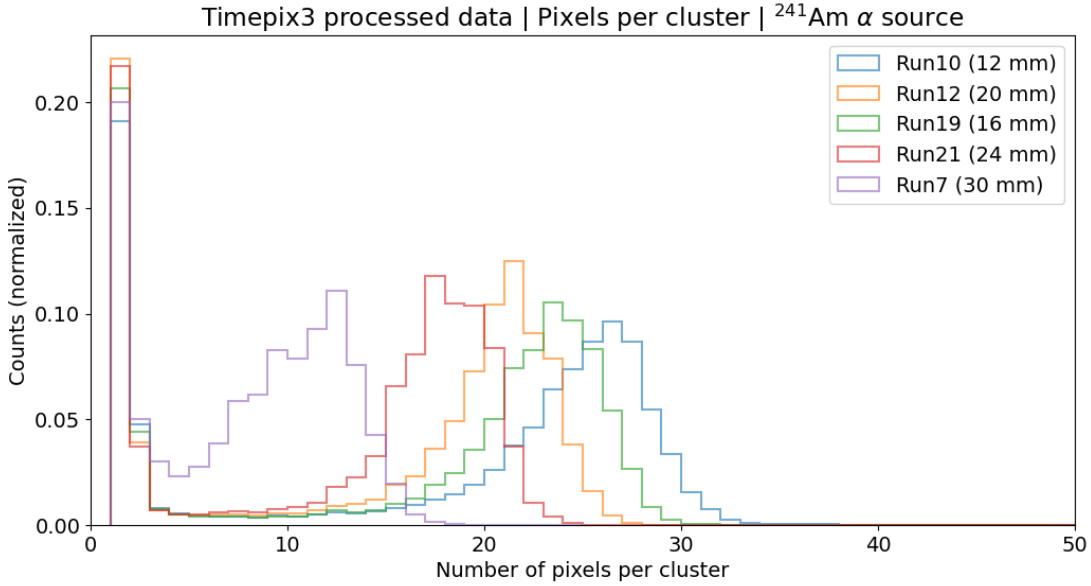


Timepix "Halo effect"
→ False hits or delayed/partial readout of pixel hits

Processed data plots

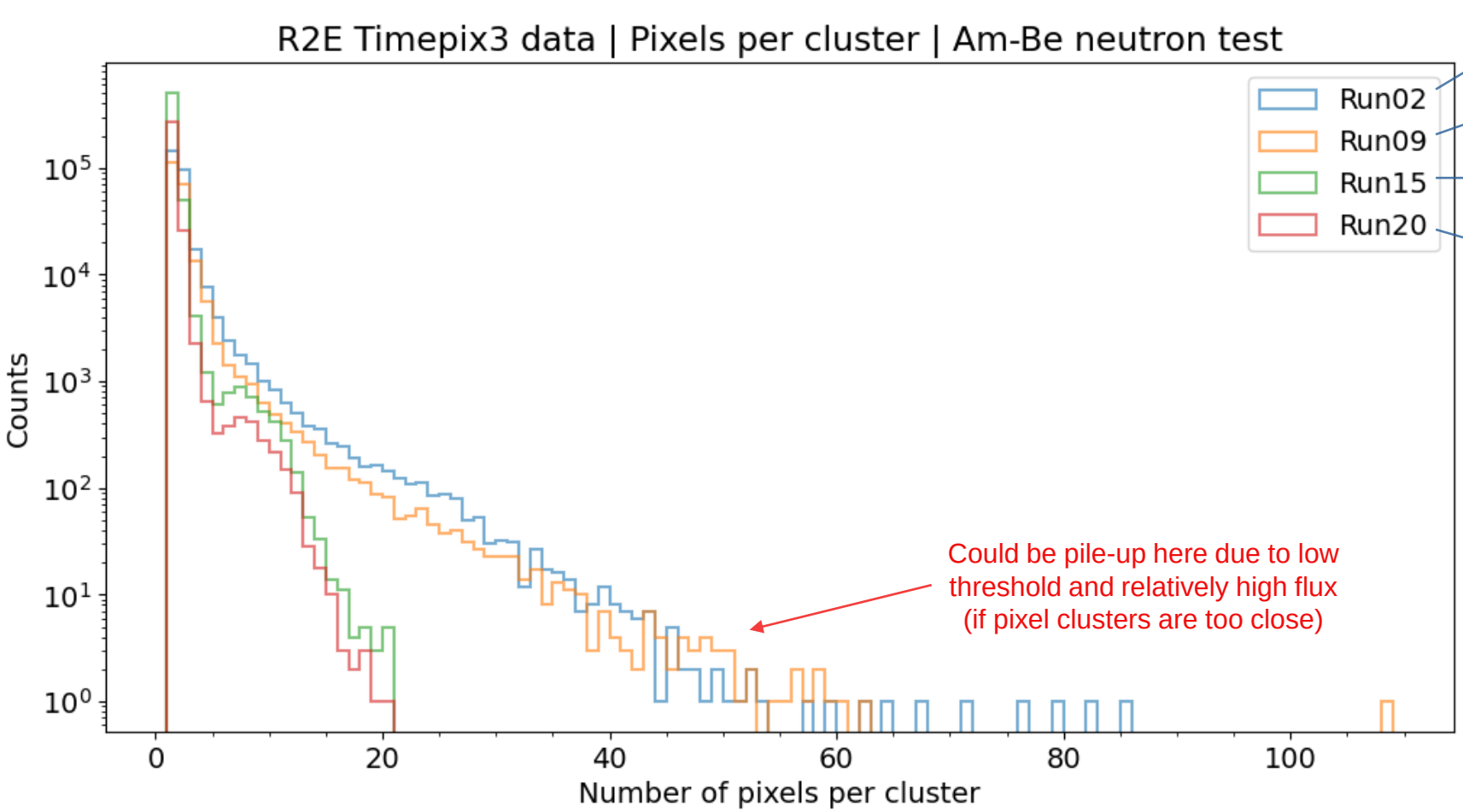






Am-Be test campaign: Timepix3 data

Preliminary results!



20cm, PE cylinder ON, low threshold, 10min

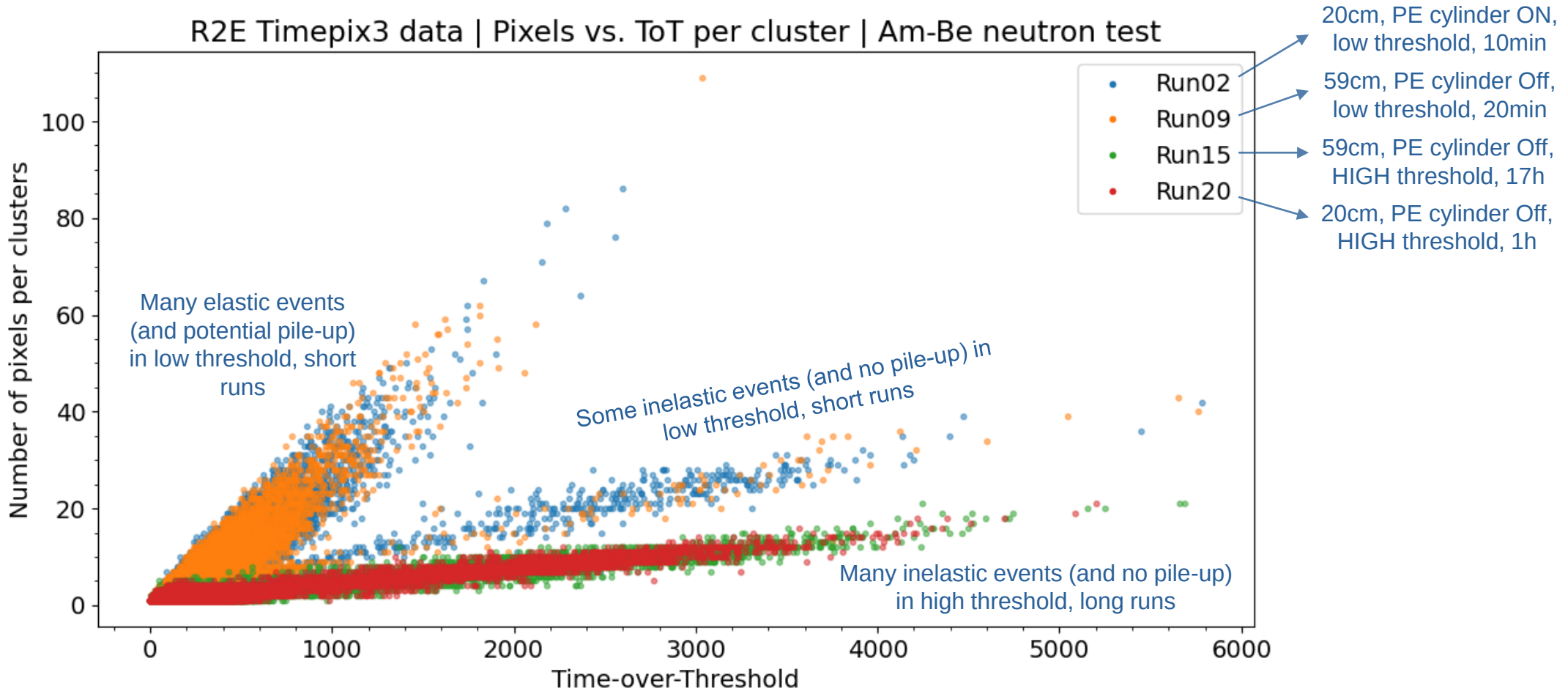
59cm, PE cylinder Off, low threshold, 20min

59cm, PE cylinder Off, HIGH threshold, 17h

20cm, PE cylinder Off, HIGH threshold, 1h

Am-Be test campaign: Timepix3 data

Preliminary results!



Energy calibration: to be done

At least two more tests with the sources which need to be moved to CALLAB from the CERN radiation sources service:

U-238 (4.151 MeV α (21%), 4.198 MeV α (79%) (or U-235 or U-233)

Th-232 (3.947 MeV α (21.7%), 4.012 MeV α (78.2%)) (or Th-228)

Ra-226 (4.601 MeV α (5.6%), 4.784 MeV α (94.5%))

Energy calibration: issues

- High energy loss and short range of alpha particles in air (2-4 cm) → potential future tests in vaccum ✓
- Lacking accurate information (geometry) on RP sources → solved: α spectrum in vacuum ✓
- Memory, CPU and cluster related data processing issues → WIP
- Challenges of histogram fitting → WIP
- Unknowns and uncertiainities about Timepix3 sensor during MC simulation (dead layer thickness)
- Bug found in Geant4 v10.7 affecting simulations of α particles in air
- Source-Sensor distance measurement uncertainities
- Special Timepix3 effects (Halo effect, Edge effect, Pile-up, etc.)