Studies of transition radiation using silicon on a TimePix3 chip: first results and plans

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on behalf of
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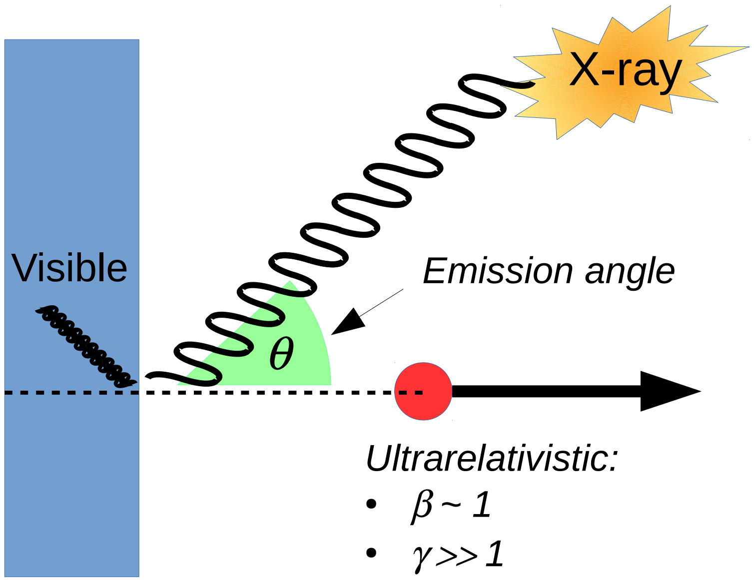
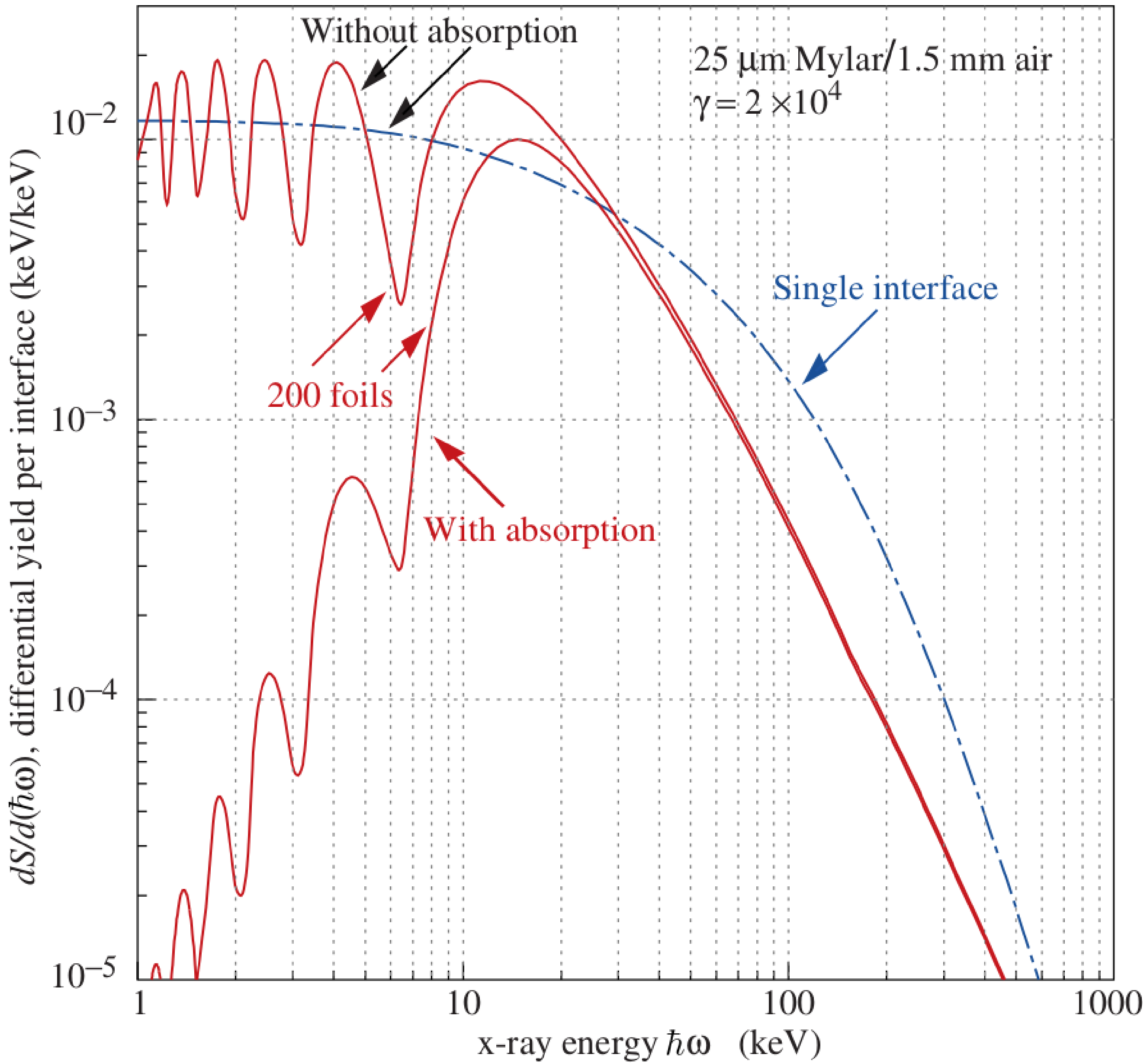
What is transition radiation?



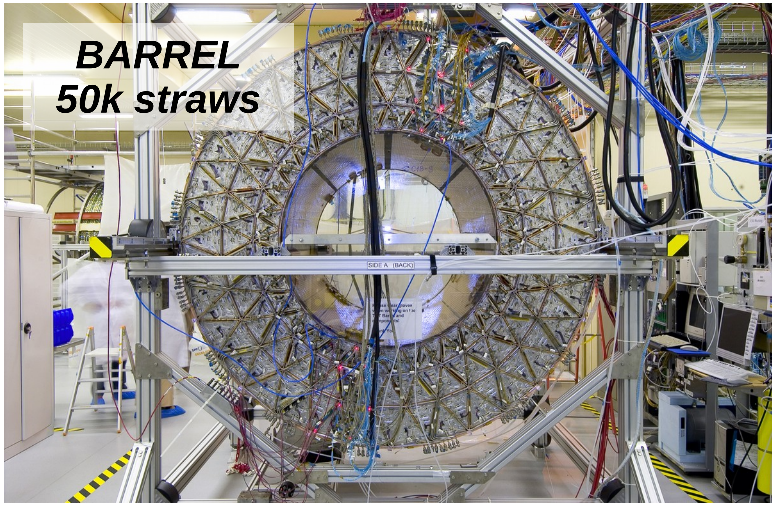
- Highly relativistic particle, gamma~10^3
- TR yield is low, ~1% → detectors are made of **multiple layers of radiators**
- TR is in the X-ray range (keV – few tens of keV)
- TR is emitted in the **forward** direction (few mrad)
- For a single boundary, intensity ~ gamma
- For multiple boundaries, **interference** puts a saturation limit at $\gamma_{sat} = 0.6\,\omega_1 \frac{\sqrt{l_1 l_2}}{c}$
- TR emission starts at a **threshold** $\gamma_{sat} = \frac{l_1 \omega_1}{c}$

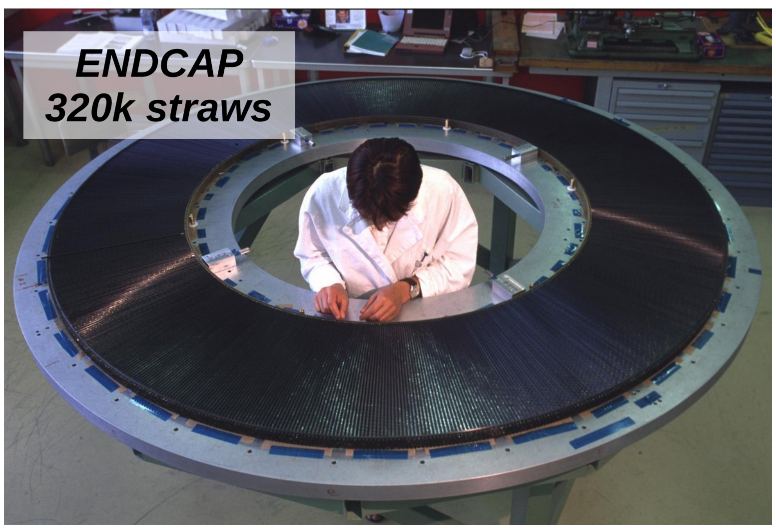
→ **Particle identification** in a given gamma range can be achieved by optimizing the radiator parameters

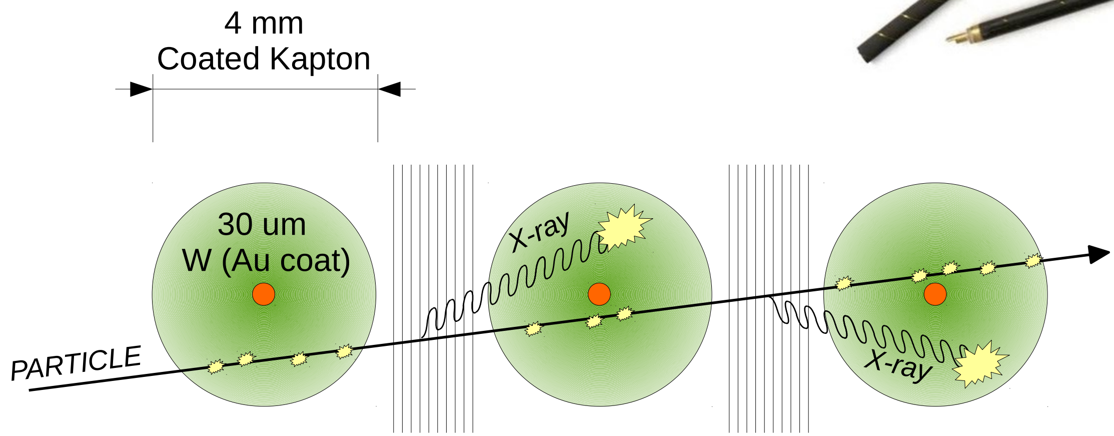
TR theoretical spectrum



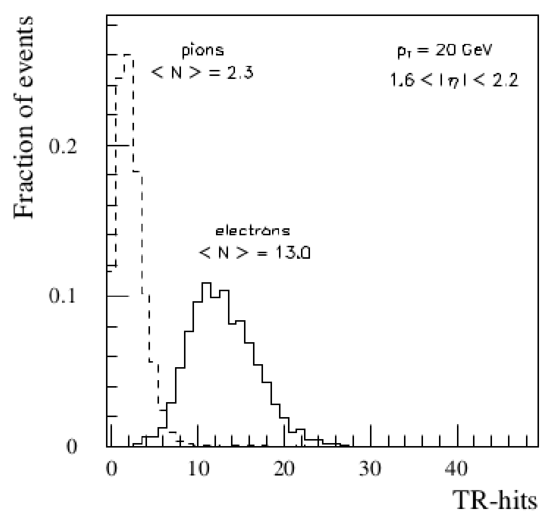
Example: the ATLAS Transition Radiation Tracker (TRT)

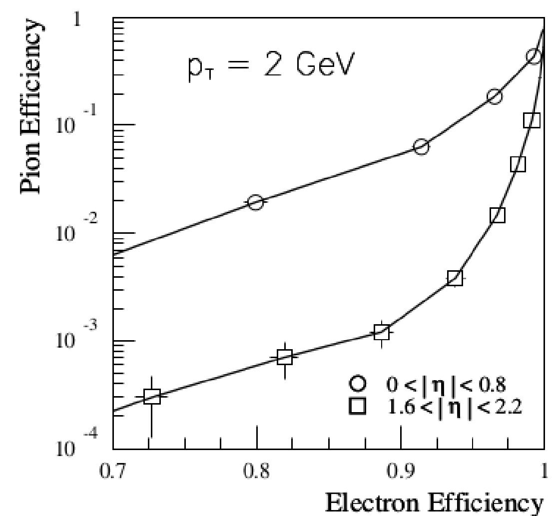






Low threshold → particle hits
High threshold → TR hits





Plots from reference [2]

Motivation for more studies

- Electron-hadron separation works only up to $\gamma \sim 500$. At higher values, the **TR yield** for hadrons approaches the one of electrons

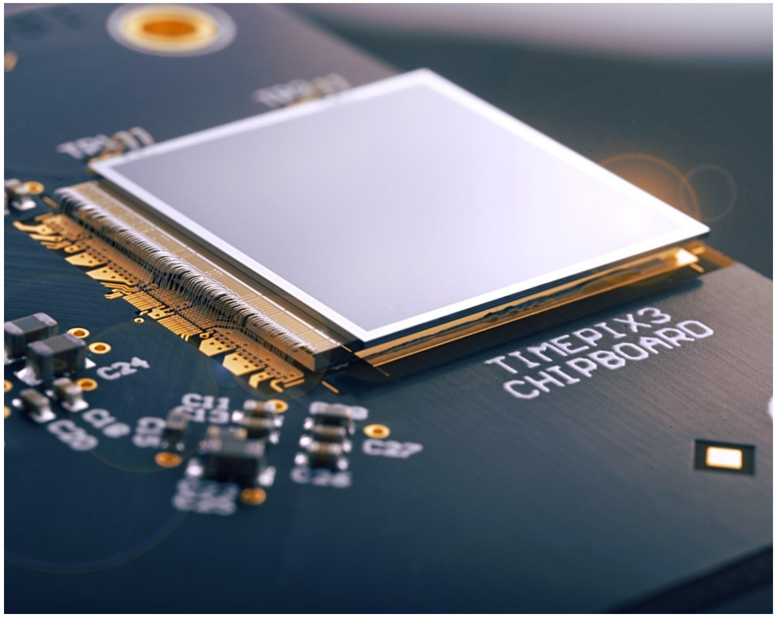
- At $\gamma \sim 3\text{x}10^3$, the TR yield **saturates** (need $\gamma \sim 10^5$ at future colliders and for cosmic rays)

- Gaseous detectors can be substituted by pixel detectors. These will allow to achieve particle identification by measuring **both energy and angular information** of TR photons

- E.g.: QCD measurements at the LHC
  - Hadrons produced as small angles
  - Need to **separate p, K and π** in the 1-6 TeV range

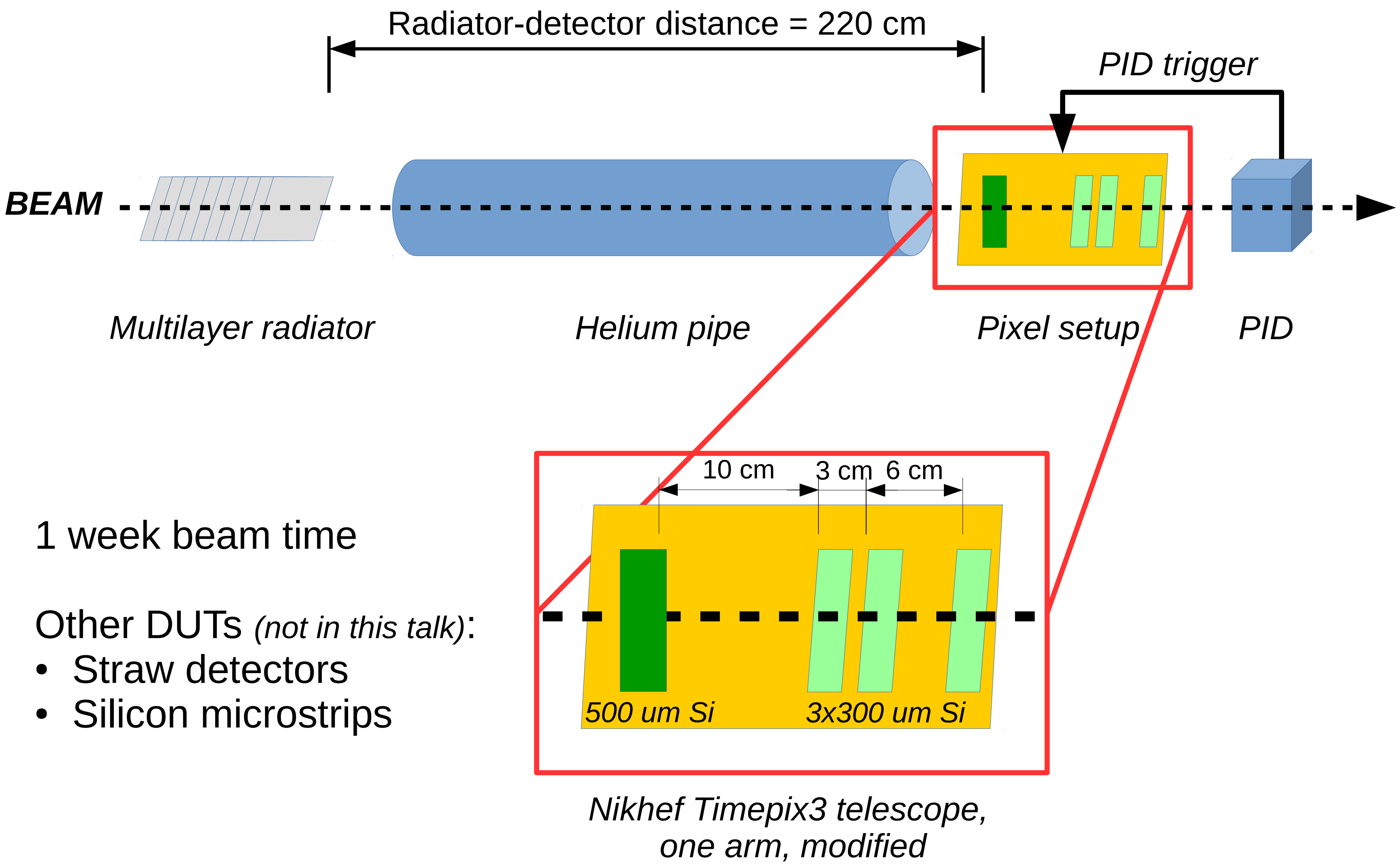
- E.g. 2: nuclear charge and energy identification in cosmic ray experiments

Timepix3



- Hybrid
- 1.4 cm x 1.4 cm
- 256 x 256 pixels
- 55 um x 55 um pixel size
- Single photon counting
- **Spectral sensitivity on single quanta**
- For this experiment, 500 um silicon sensor

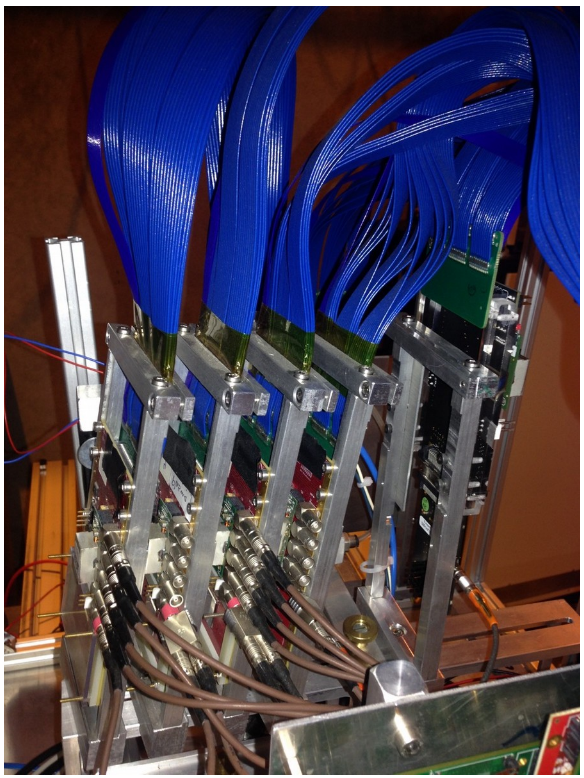
The SPS setup in June 2017



1 week beam time

Other DUTs *(not in this talk)*:
- Straw detectors
- Silicon microstrips

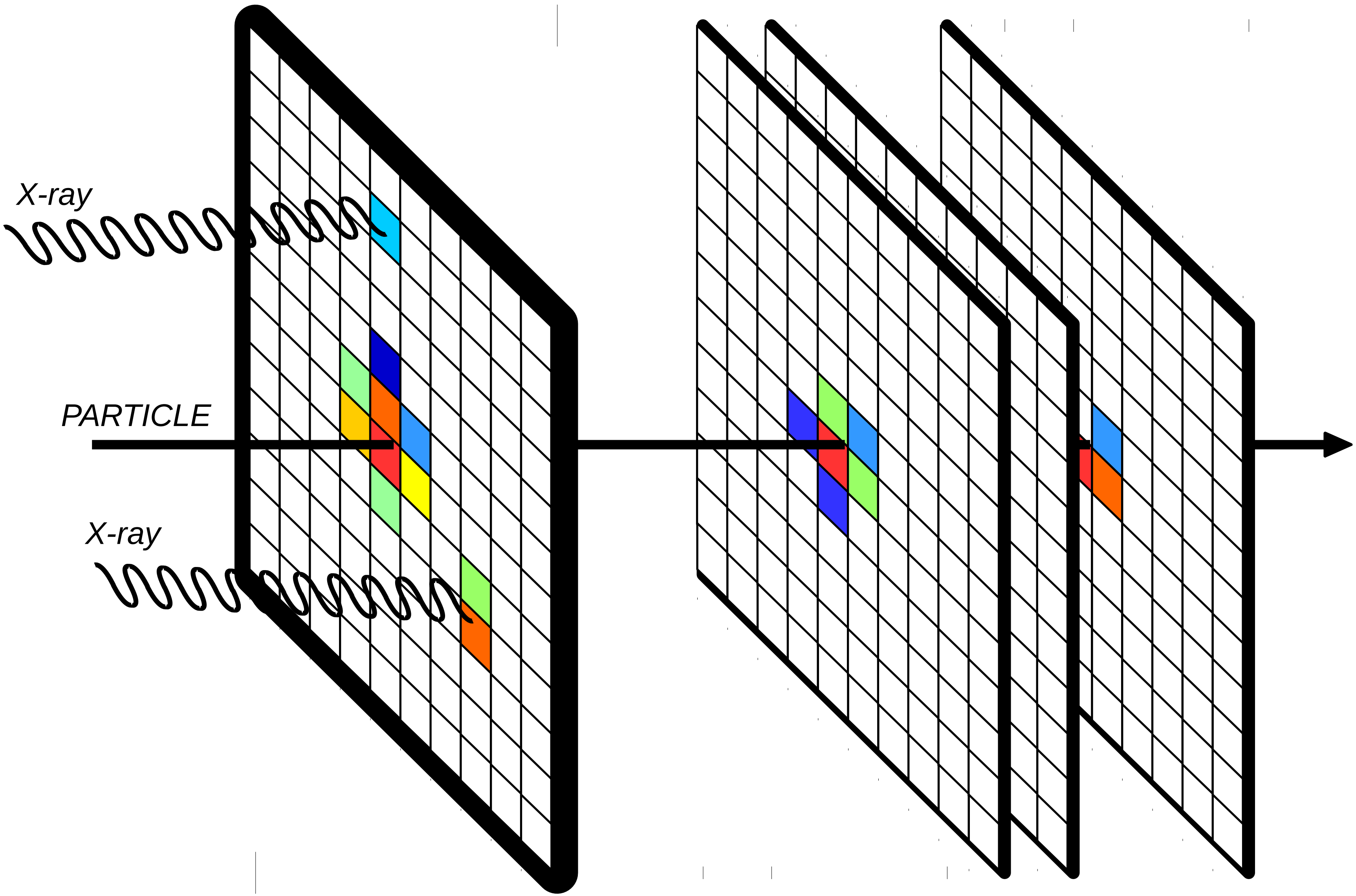
Some pictures



The Timepix3 telescope and DUT

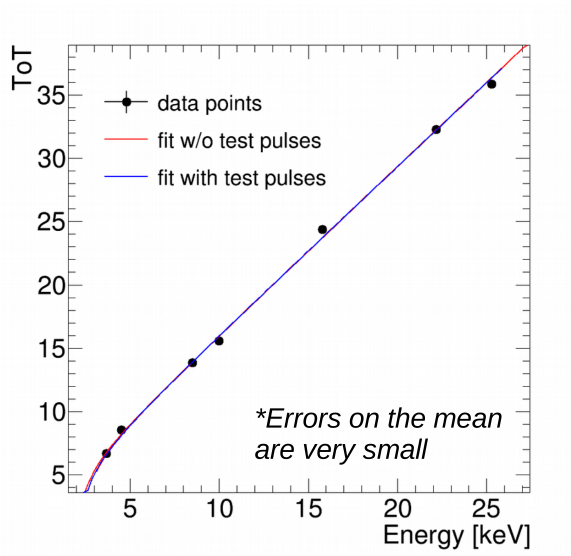
The whole setup, view from upstream

Concept

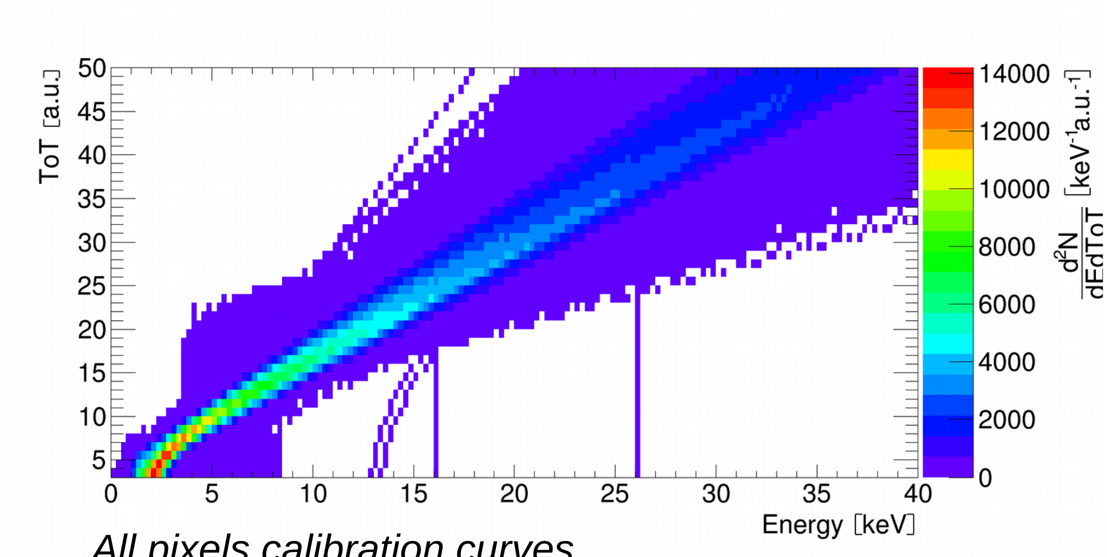


ToT calibration

Fluorescence (targets Ca, Cu, Zr, Ag) + test pulses

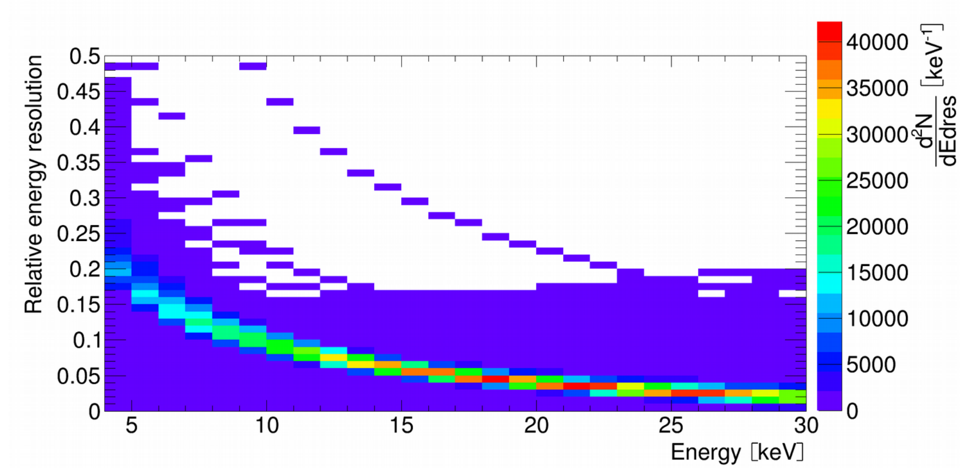


Single pixel calibration



All pixels calibration curves

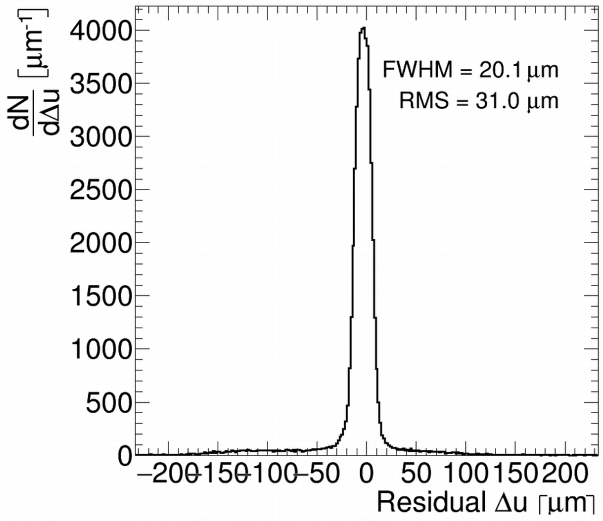
An additional Fe-55 point was taken during the test beam → rescale factor of ~8%

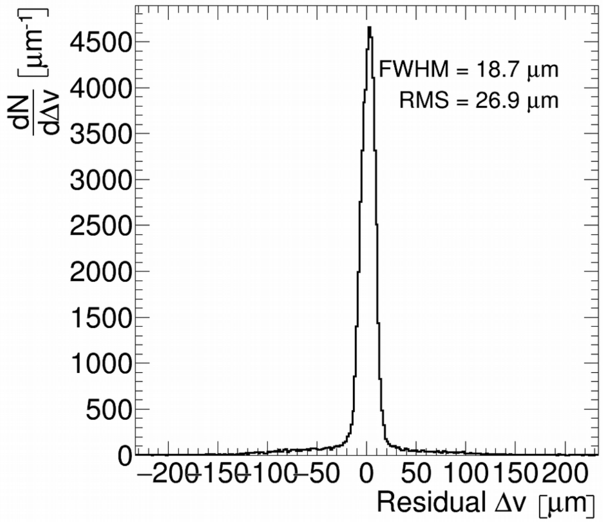


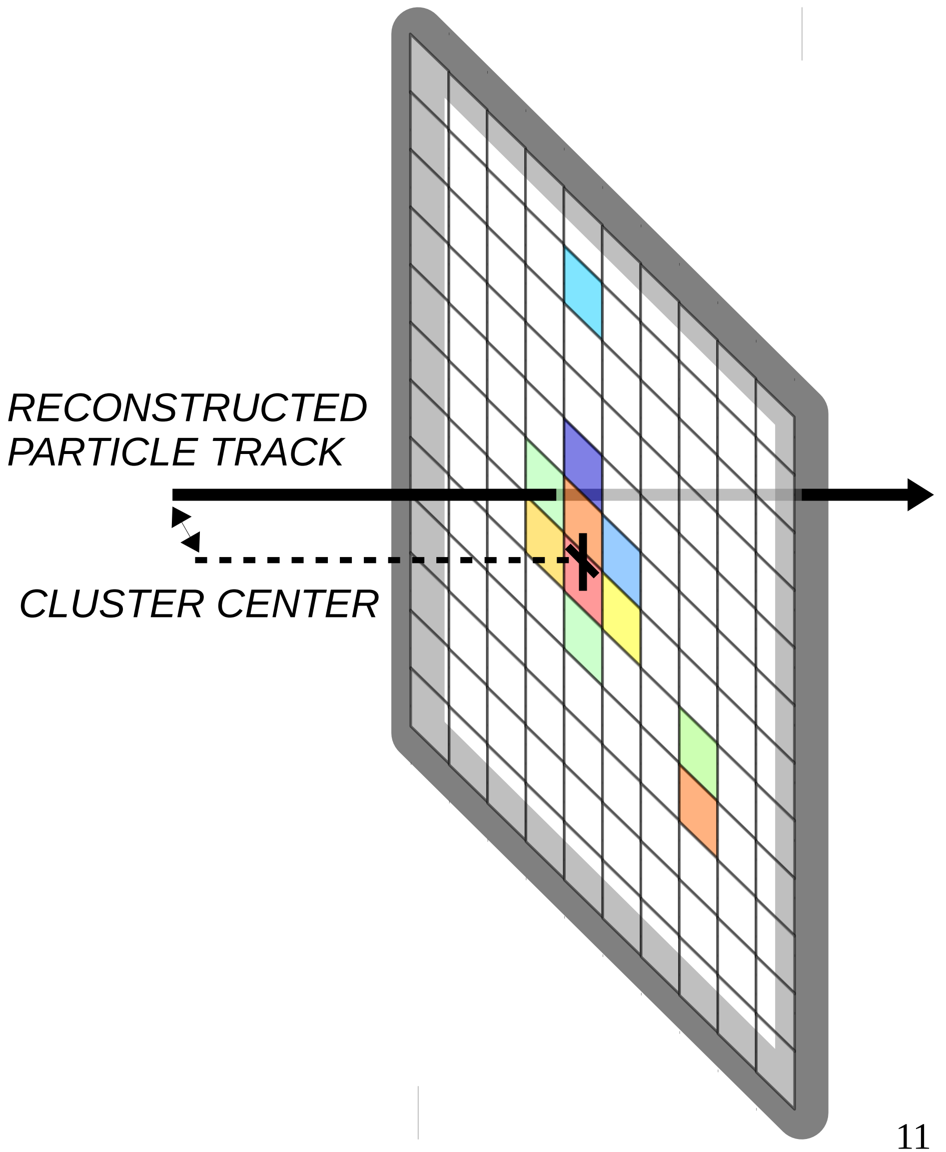
All pixels resolution curves

Alignment and tracking

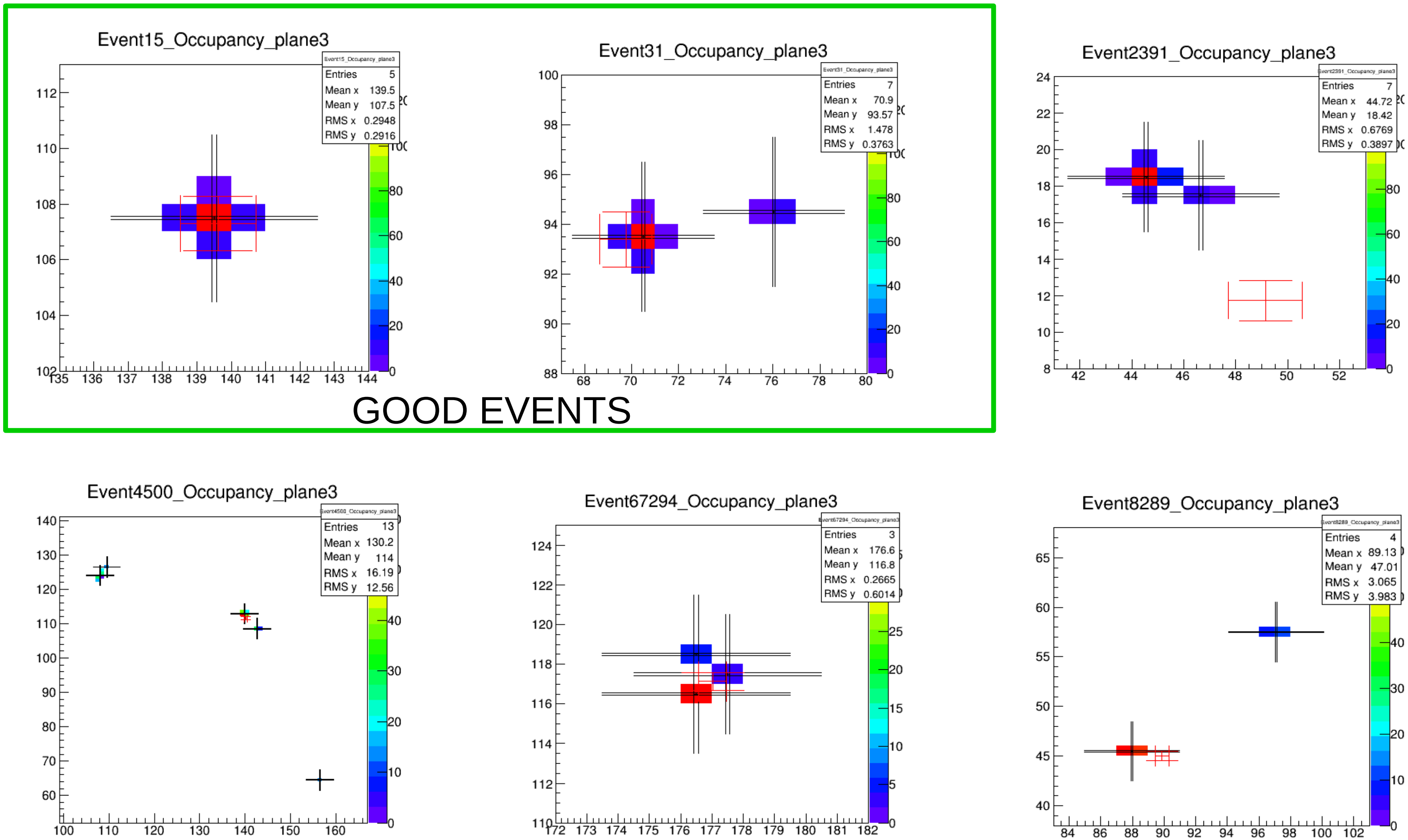
Alignment and tracking is done with the Proteus framework [3]. *Many thanks to M. Kiehn.*

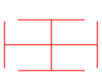




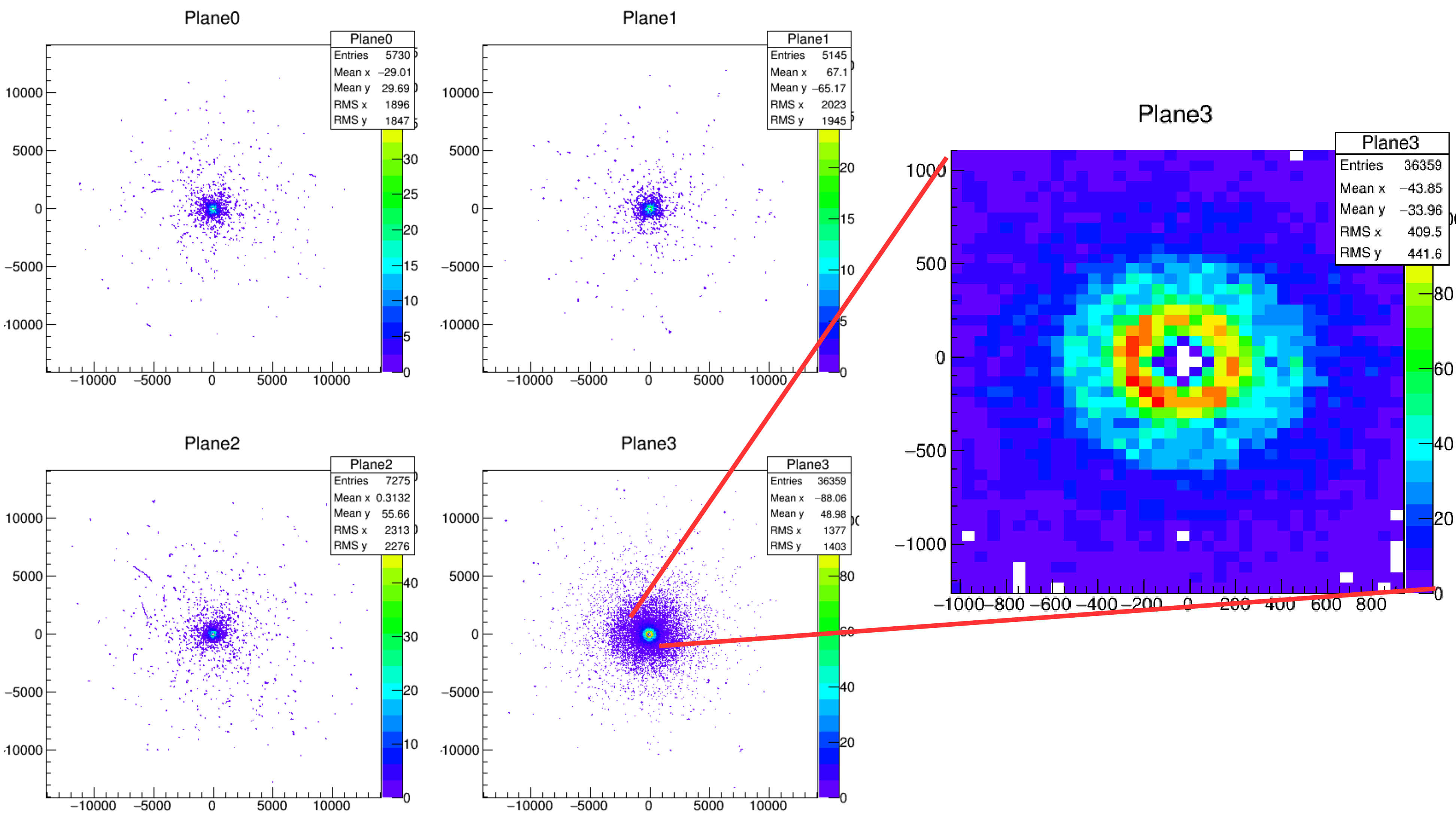


Event reconstruction

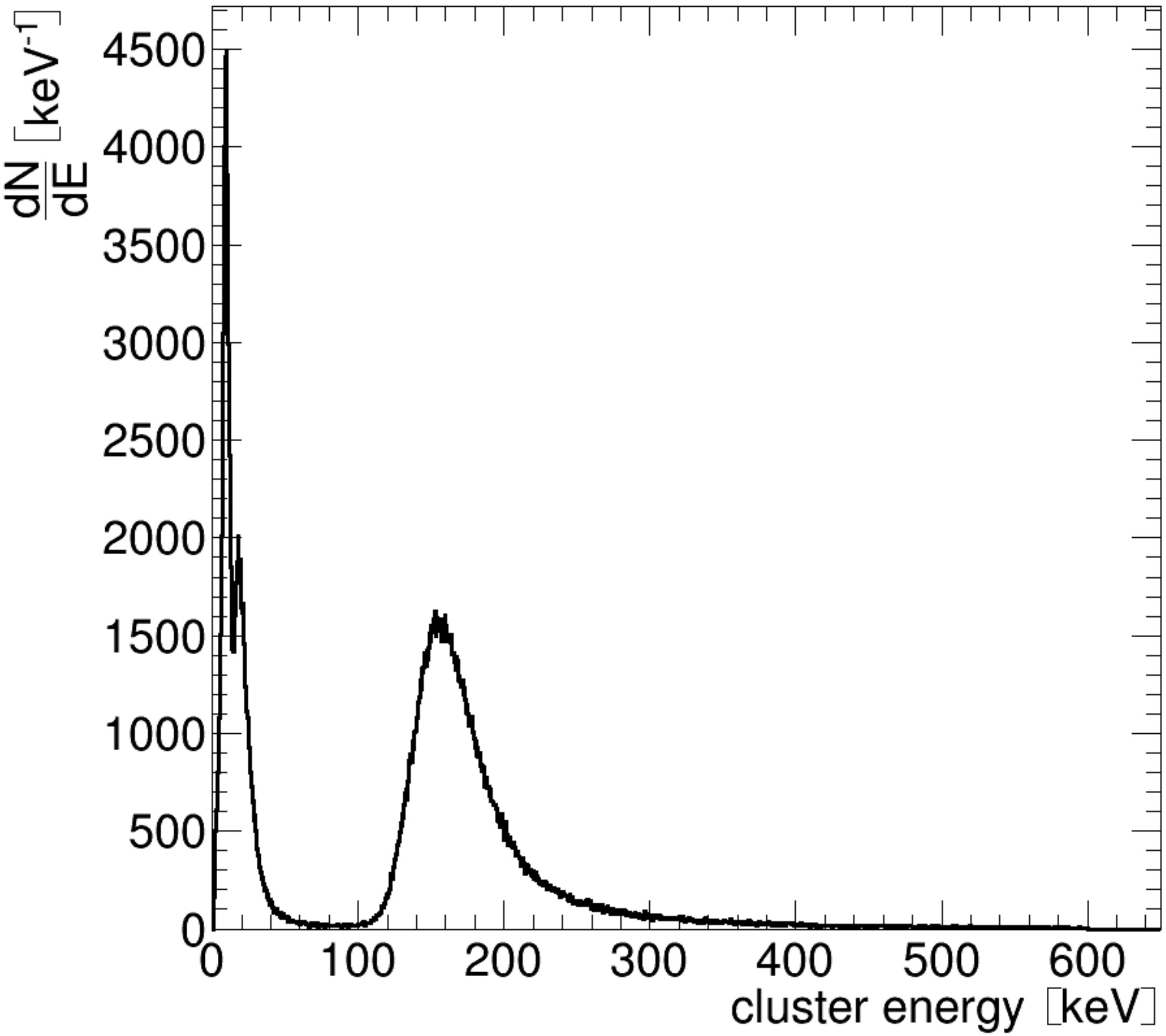


 = *track intercept*

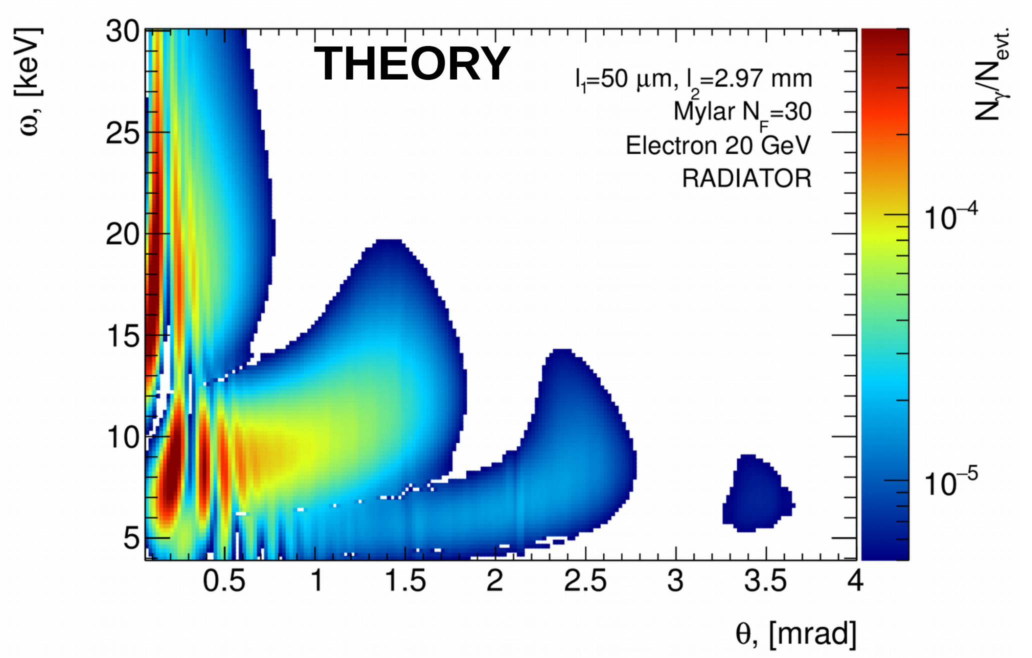
Quantum mechanics at its finest

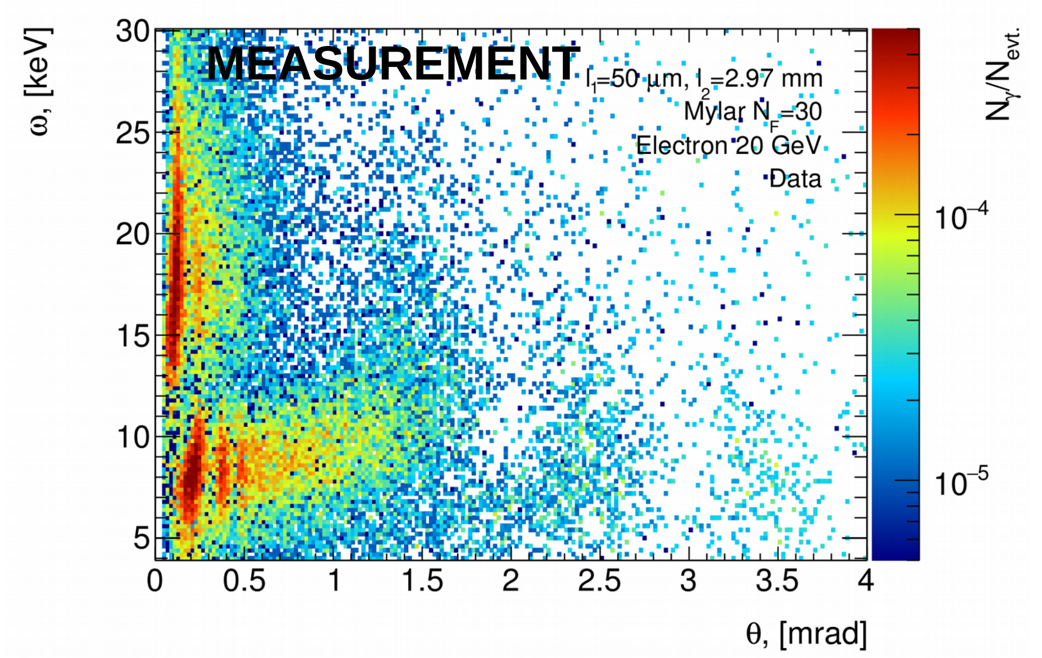


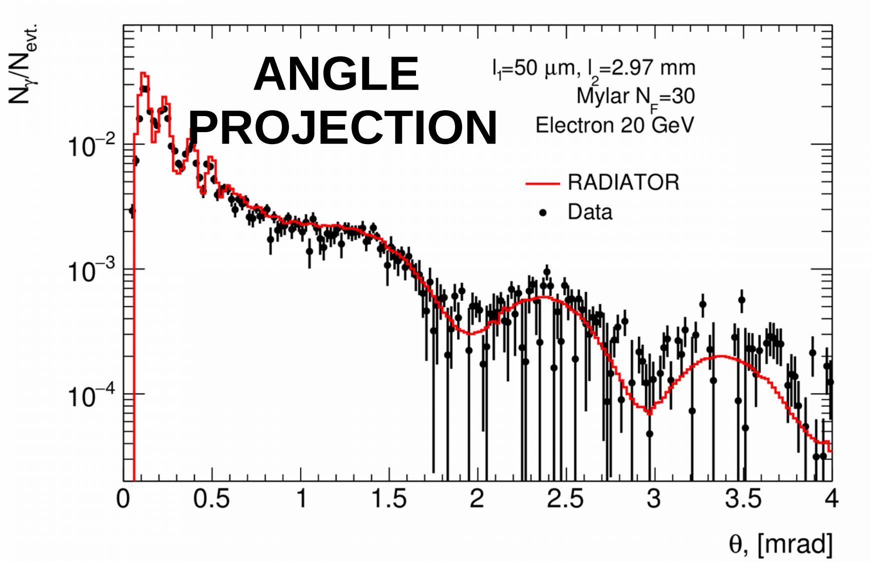
Outlook: tracking is not needed

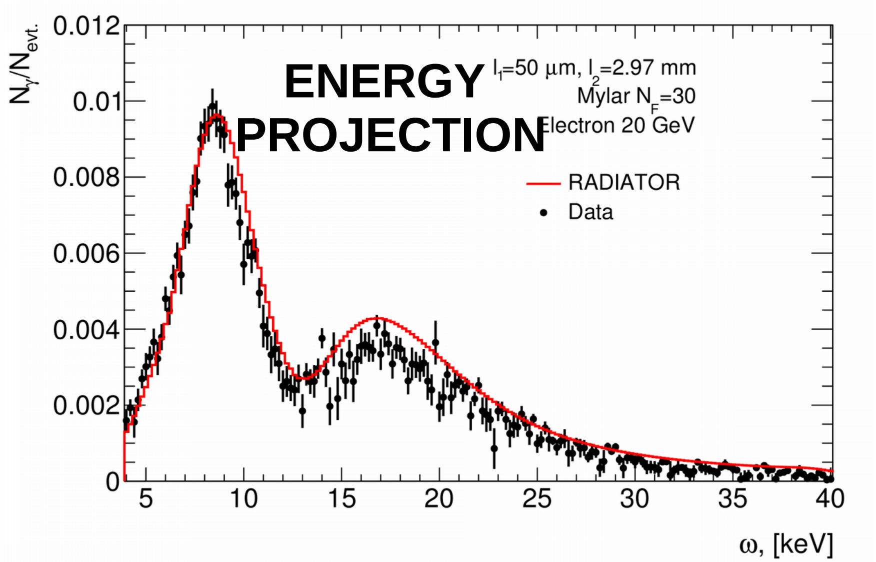


Very first results





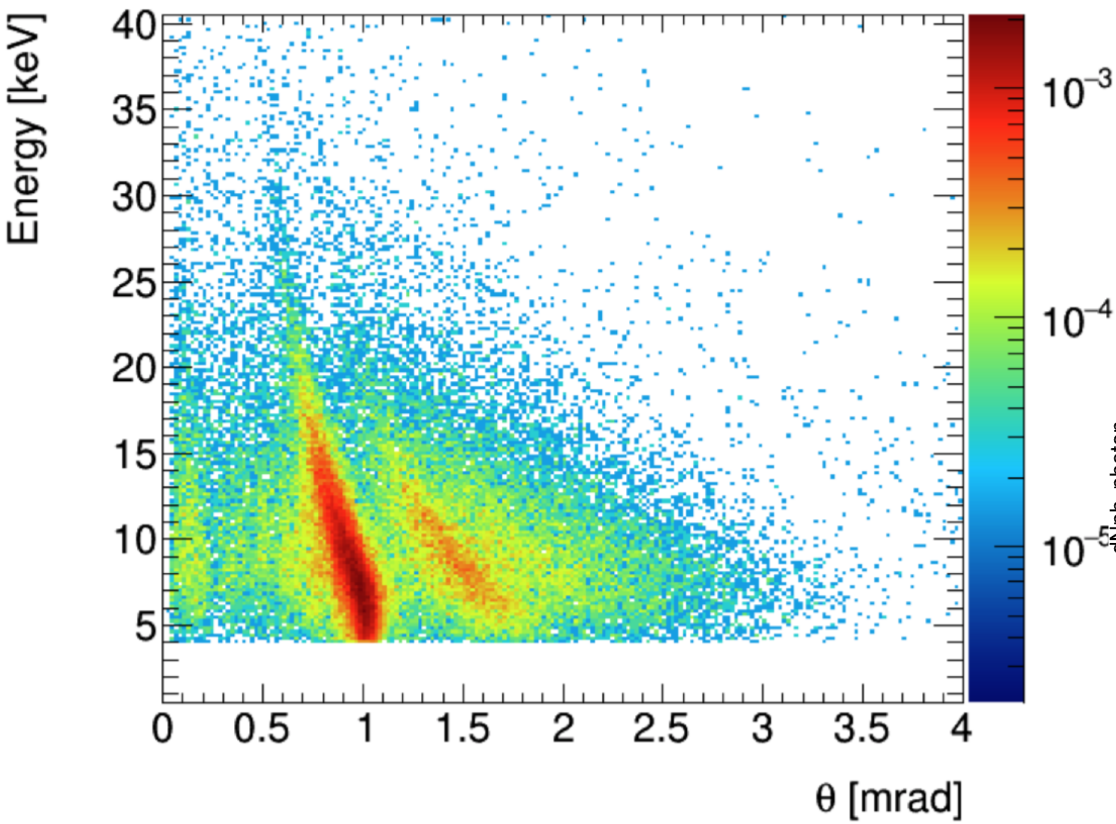


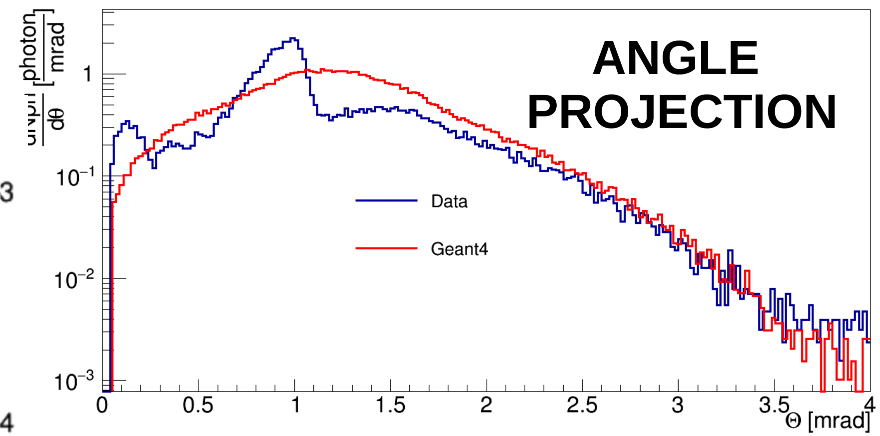


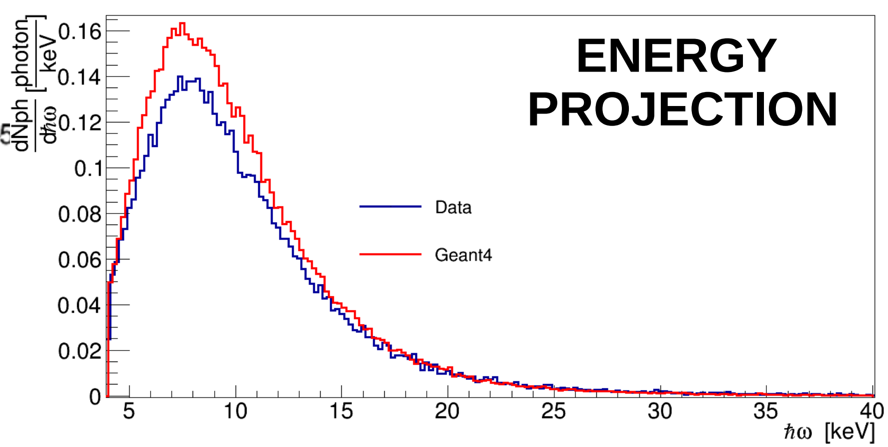
Credit: E. Shulga, Y. Smirnov, A. Savchenko

Another example

20 GeV electrons
Polypropylene 15 um







Ongoing effort to implement full differential TR spectrum in GEANT4

Credit: E. Shulga, Y. Smirnov, A. Savchenko

Conclusion and plans

- Transition Radiation Detectors are useful to achieve **particle identification**
- For future collider and cosmic ray experiments, TR **angular and spectral information** must be exploited
- First tests with a **Timepix3 pixel detector** have shown encouraging results
- The analysis of the 2017 data is being finalized, together with the implementation of **MC simulations**
- New beam time in June 2018
  - No need of a telescope
  - Will measure **GaAs sensor**, for better spectral sensitivity at high energy

References

[1] B. Dolgoshein, *Transition radiation detectors*, NIM A326 (1993) 434-469, http://ivanik3.narod.ru/Vacuum/DolgosheinNIMdet.pdf

[2] ATLAS Collaboration, *Inner Detector TDR, Vol. I*, 30 April 1997, https://cds.cern.ch/record/331063/files/ATLAS-TDR-4-Volume-I.pdf

[3] https://gitlab.cern.ch/unige-fei4tel/proteus/

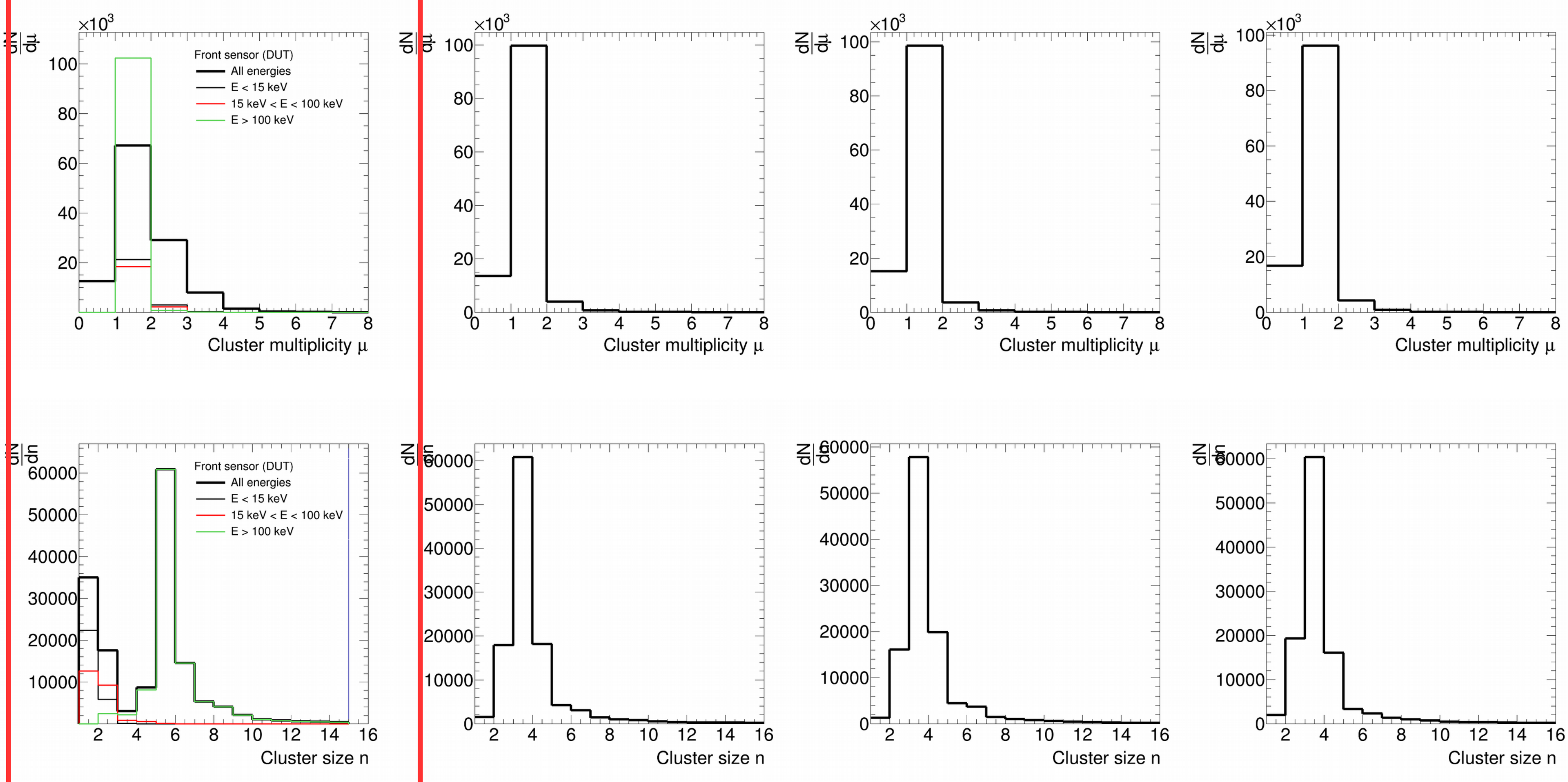
[4] N. Belyaev at al., *Measurements of angular distribution and spectrum of transition radiation with a GridPix detector, 2017* . Phys.: Conf. Ser. 934 012049, http://iopscience.iop.org/article/10.1088/1742-6596/934/1/012049/pdf

Datasets

Runs	Beam type	Beam energy	Run type	Radiator
18-22	pions+electrons	20 GeV	Phys	Mylar, 1 set, 2 or 3 or 4
23-27	pions+electrons	20 GeV	Phys	Mylar, 3 sets, 2,3,4
28-31	pions+electrons	20 GeV	Phys	Polyethylene, 3 sets
32-36	pions+electrons	20 GeV	Phys	Polypropylene, 15 µm
50-51	pions+electrons	20 GeV	Phys	Polypropylene, 62 µm 3 sets
52	pions+electrons	20 GeV	Phys	Dummy (2 pieces of plexiglass)
53	pions+electrons	20 GeV	Phys	Air, no radiator
76	pions+electrons	20 GeV	Phys	Fibre
77	pions+electrons	20 GeV	Phys	Dummy (2 pieces of plexiglass)
81	pions+electrons	20 GeV	Phys	Polypropylene, 62 µm, all (1,2,3,4,5)
49	Fe-55 source	6 keV	Calib	N/A
54/66	muons	180 GeV	Phys	Mylar, 1 set
55-56	muons	180 GeV	Phys	Mylar, 3 sets, 2,3,4
57	muons	180 GeV	Phys	Polyethylene, 1 set
58-59	muons	180 GeV	Phys	Polyethylene, 3 sets
60-61	muons	180 GeV	Phys	Polypropelene, 15 µm
62-63	muons	180 GeV	Phys	Polypropelene, 62 µm
64	muons	180 GeV	Phys	Air, no radiator
65/79	muons	180 GeV	Phys	Dummy (2 pieces of plexiglass)
78	muons	180 GeV	Phys	Fibre
80	muons	180 GeV	Phys	Polypropylene, 62 µm, all (1,2,3,4,5)
67	muons	120 GeV	Phys	Fibre
68	muons	120 GeV	Phys	Mylar, 1 set
69	muons	120 GeV	Phys	Mylar, 3 sets
70	muons	120 GeV	Phys	Polypropylene, 62 µm
71	muons	120 GeV	Phys	Polyethylene, 1 set
72	muons	120 GeV	Phys	Polyethylene, 3 sets
73	muons	120 GeV	Phys	Polypropylene, 15 µm
74	muons	120 GeV	Phys	Dummy (2 pieces of plexiglass)

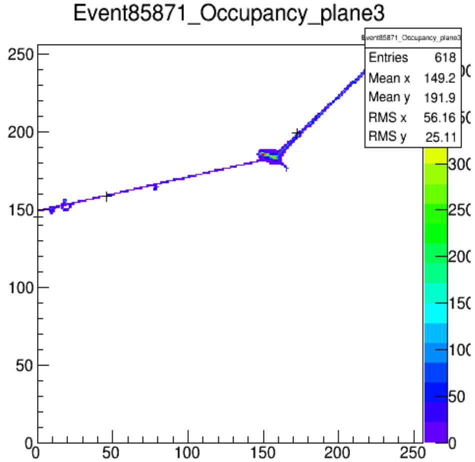
Clustering

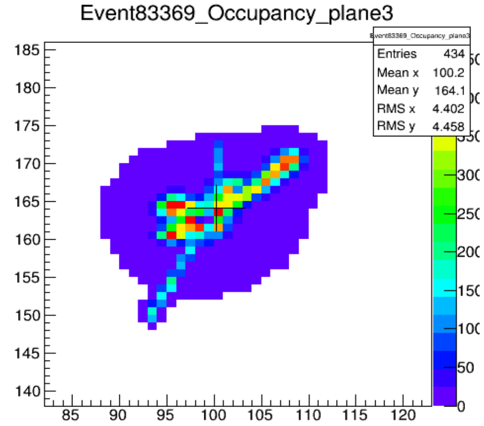
FRONT **PLANE 0** **PLANE 1** **PLANE 2**

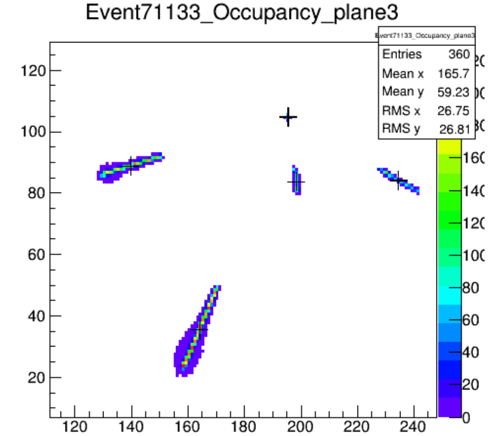


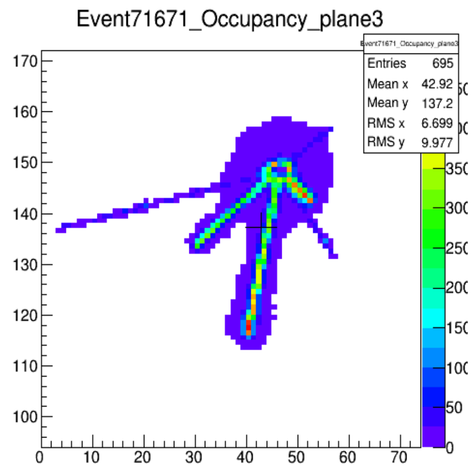
Clustering is done with the Proteus framework [3]. Many thanks to M. Kiehn.

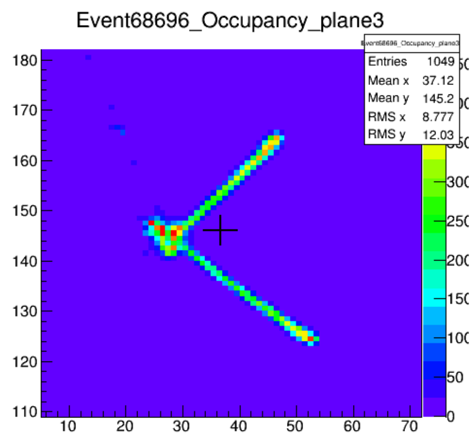
“Wtf” events (just for fun)

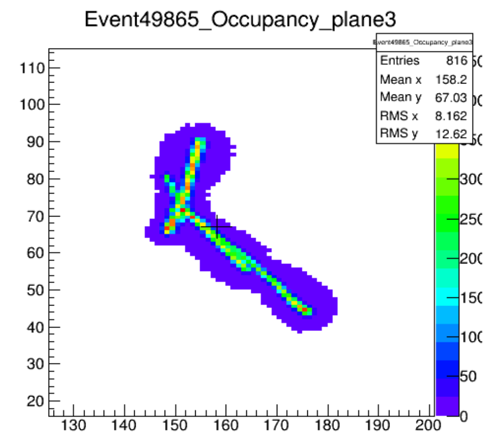


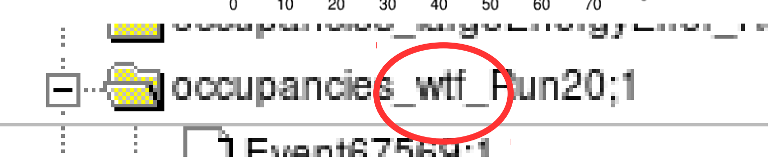




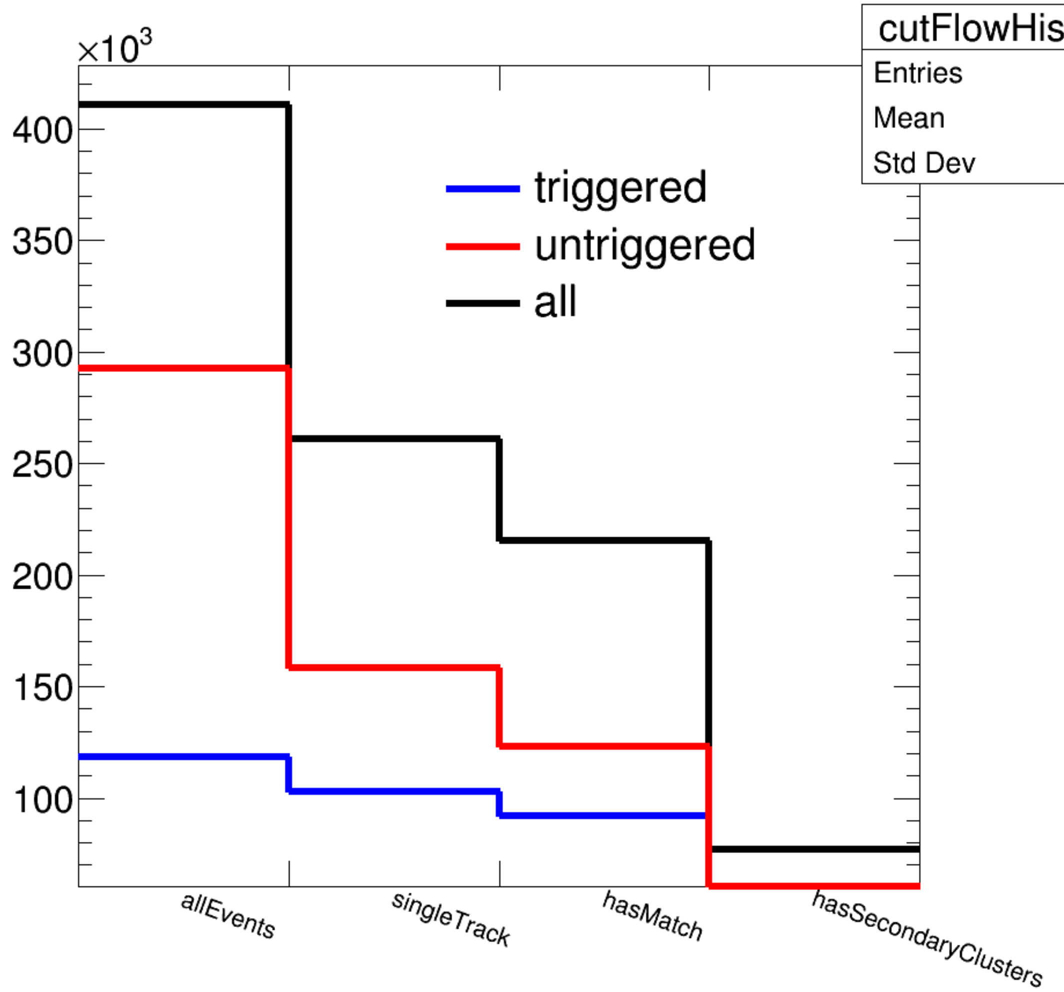




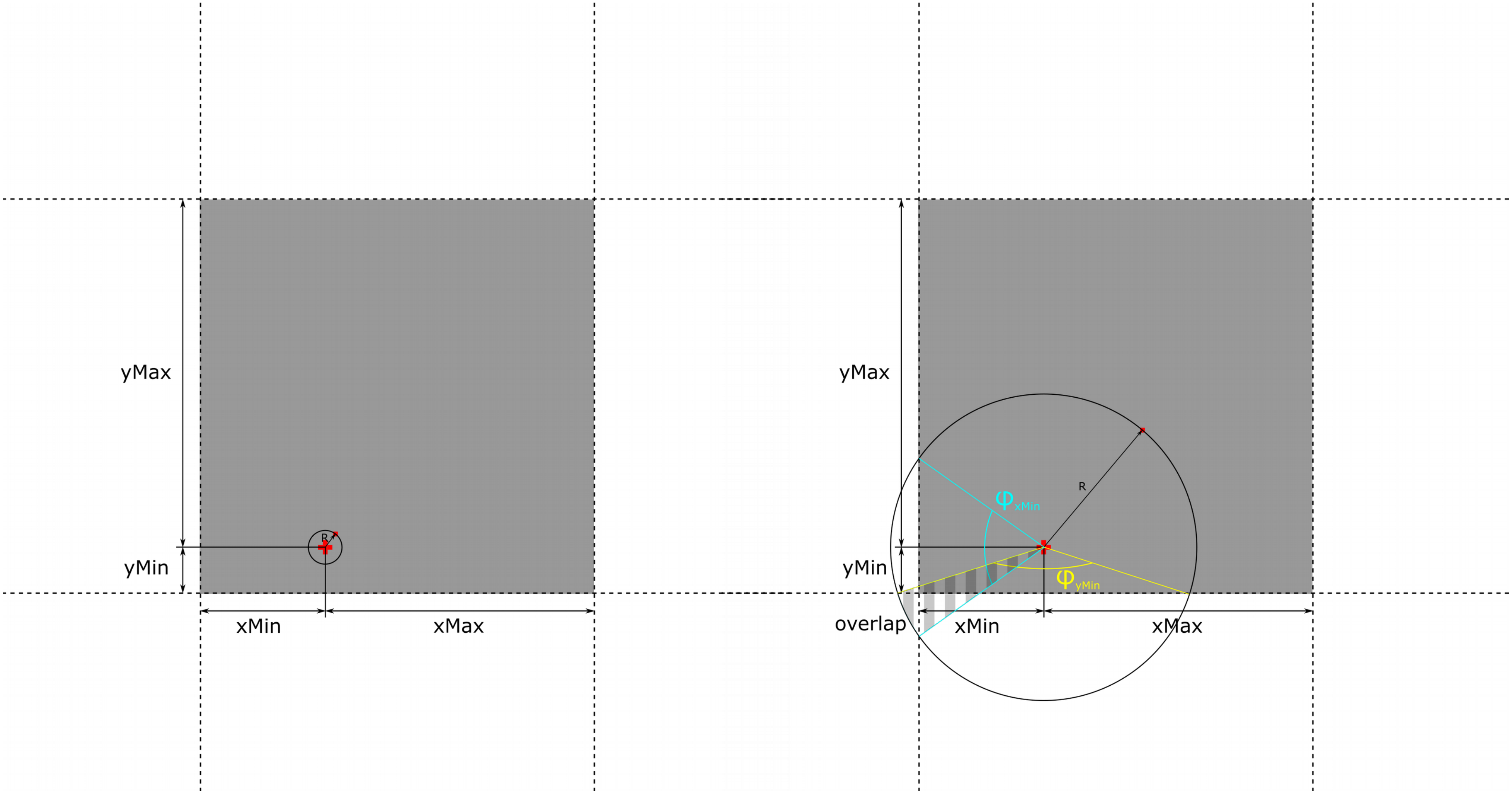




Event selection

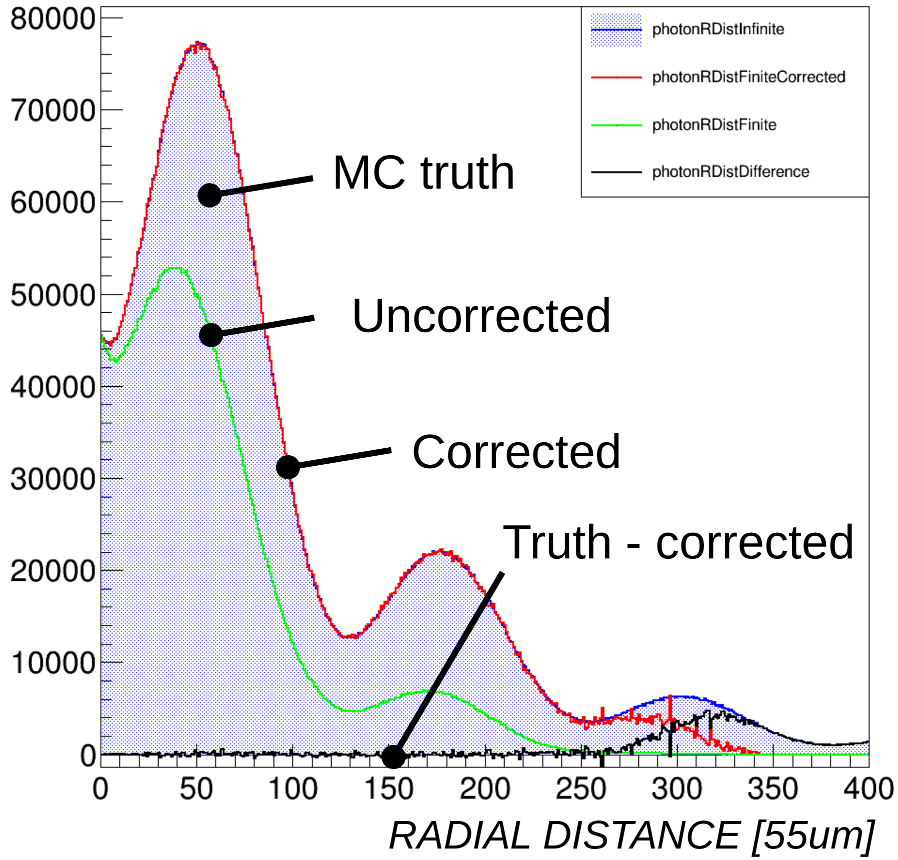


Fiducial volume correction



Effects of the correction

SIMULATION



DATA