LICEO SCIENTIFICO STATALE "Arcangelo Scacchi"

INFN

Test beam results of the Electron X-ray Transition Radiation (EXTRA) experiment at DESY

BL4S 2021

beamline for schools
cern.ch/bl4s
powered by CERN & DESY

EXTRA

10th edition of the Beam Telescopes and Test Beams Workshop Lecce, Italy 20/06 - 24/06/2022

Outline

- BL4S competition
- EXTRA experimental setup
- Data analysis
- Conclusions

Beamline for school Competition

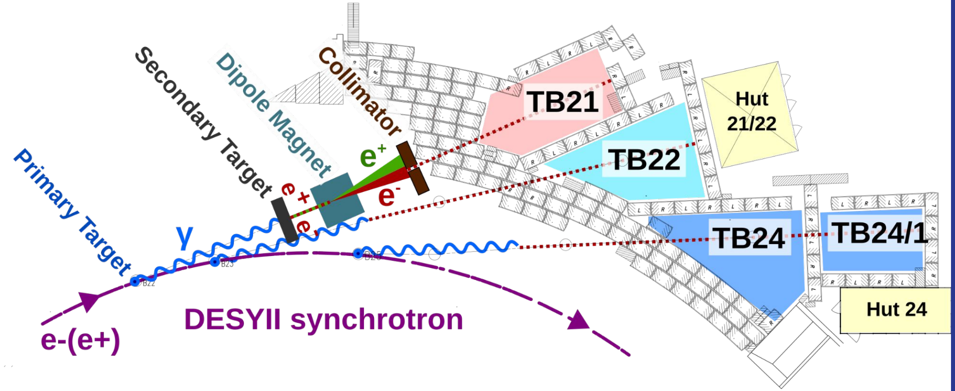
https://beamlineforschools.cern/

- **Beamline for Schools (BL4S)** is a competition in particle physics for high school students from all around the globe, organised by CERN.

- Each participating team proposes a fixed target experiment that can be performed at the available test beam facilities, making use of the available infrastructure and detectors.

- In 2021 the experiments were performed at one of beam lines of electron/positron synchrotron DESY II

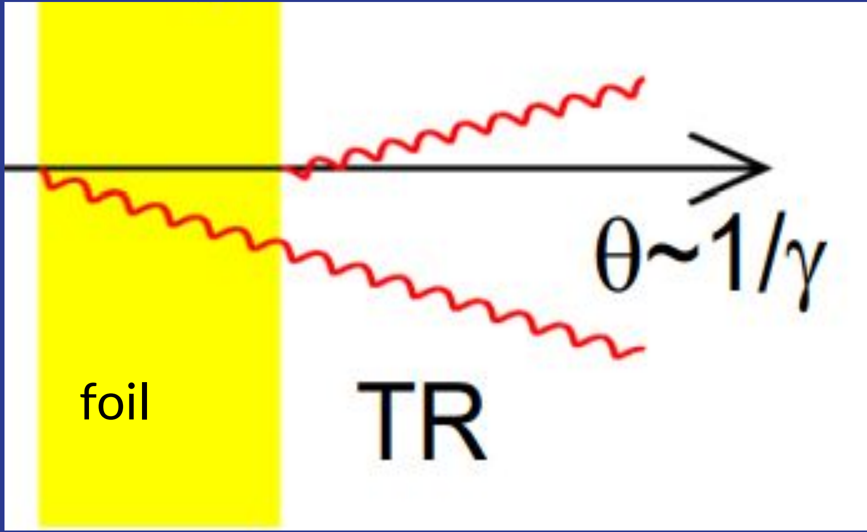
The DESY II Test Beam



- A bremsstrahlung beam is generated by a primary target in the circulating beam of the electron/positron synchrotron DESY II
- The produced photons are converted to electron/positron pairs via a metal plate target (secondary target)
- Momenta in the range 1 – 6 GeV/c
- Particle rate < 50 kHz (energy dependent)

The EXTRA experiment

The aim of EXTRA (Electron X-ray Transition RAdiation) is to study the transition radiation (TR) emitted by fast electrons crossing a multilayer radiator, using the DESY beam line in the TB21 area.



Timeline

Experimental Setup → **Measurements** → **Data analysis**

Experimental Setup

Alignment and Calibration

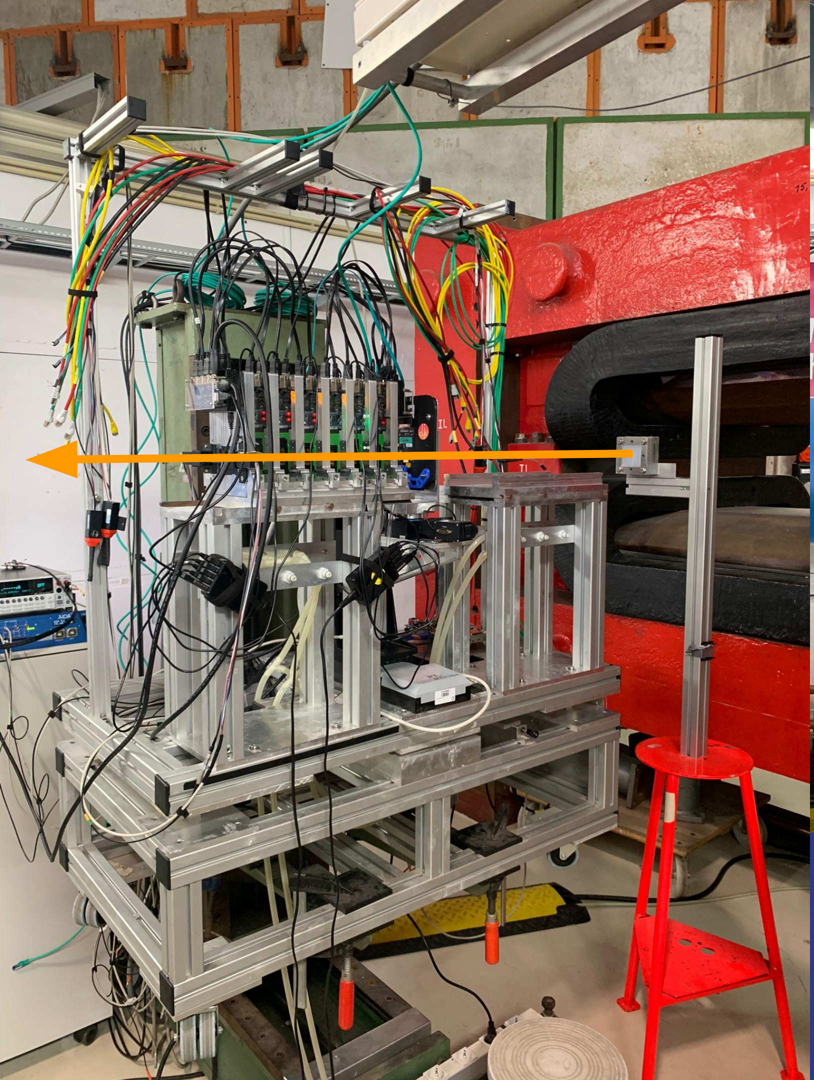
Measurements

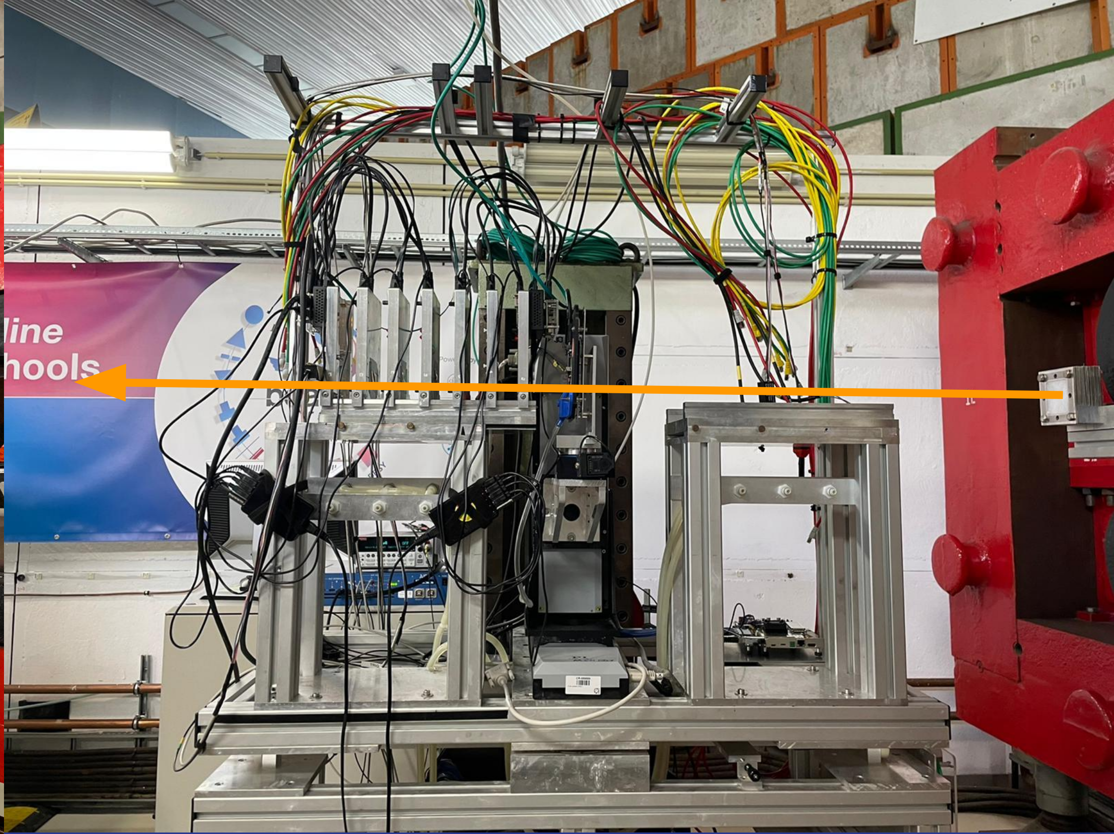
Setting different parameters to be changed for each run

- Electron beam energy
- Radiator
- Distance (from the back of the radiator-to the back of silicon sensor)

Data analysis

Raw files converted to root files were analyzed in order to check the alignment and study the energy spectra and the angular distributions of the TR X-rays

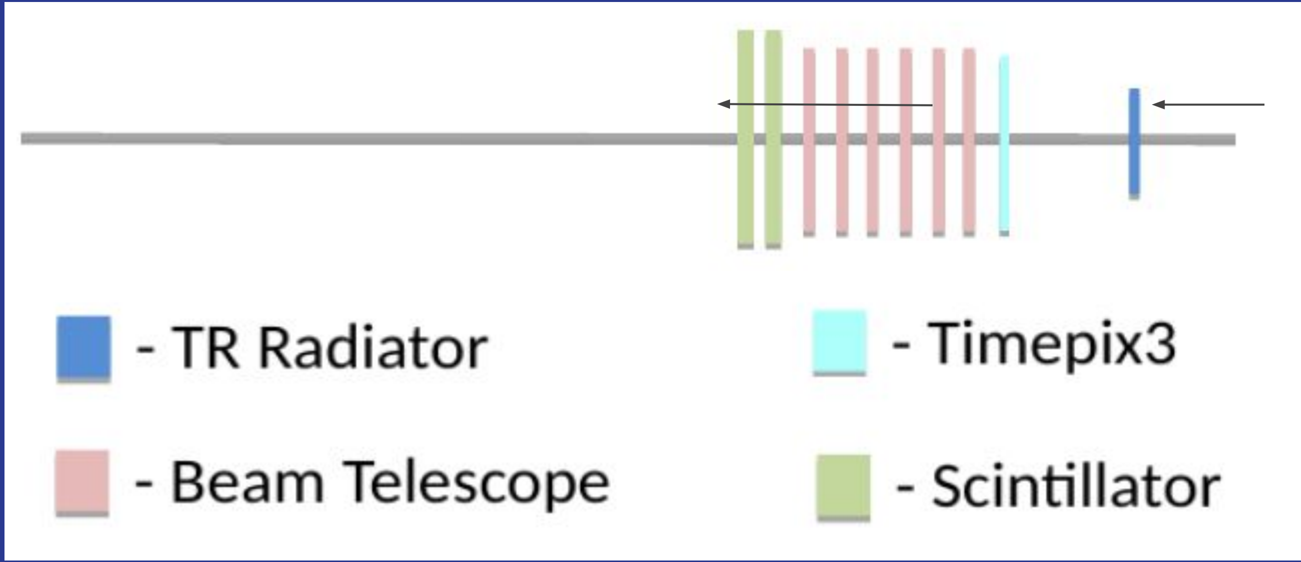




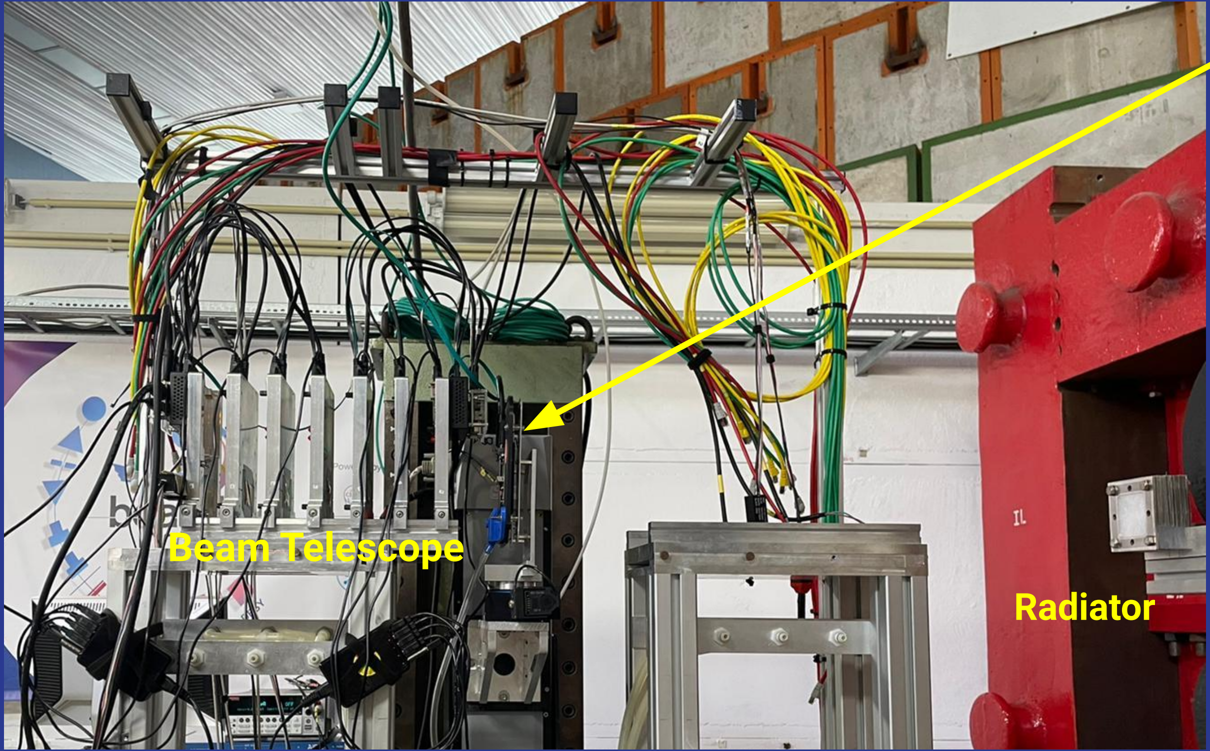
EXPERIMENTAL SET UP

EXTRA experiment - a sketch of our setup

Electron X-ray Transition RAdiation



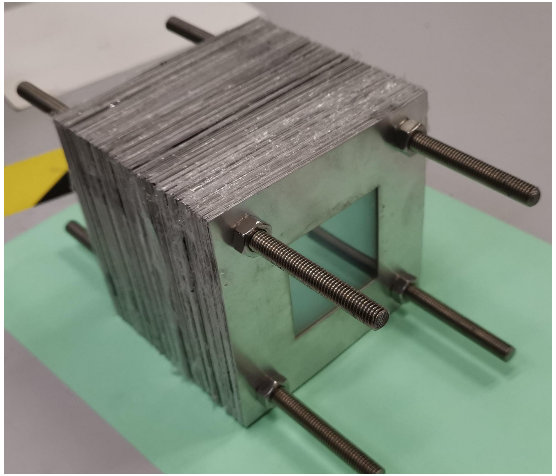
EXPERIMENTAL SET UP

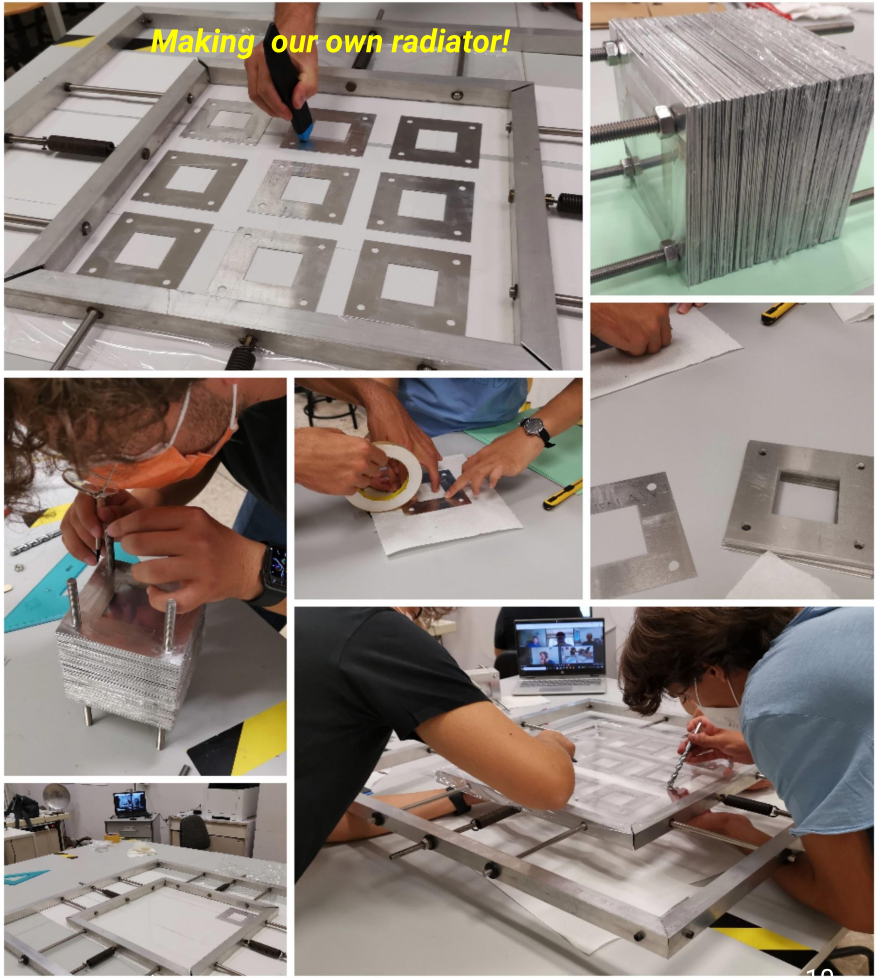


Timepix3

Multilayer Radiator

A radiator is a device composed of alternating layers of different materials with different dielectric constants, through which TR can be produced. In our case, several radiators were used for the data acquisition, one made by the EXTRA team.





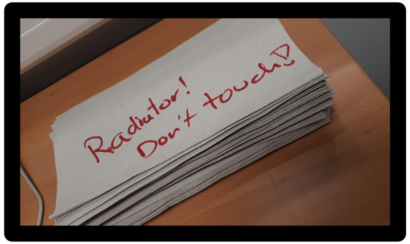
Parameters of multilayer regular radiators used in the test beam:

$\mathbf{d_1}$ and $\mathbf{d_2}$ are the thickness of the foils and of the gaps respectively

N is the number of foils

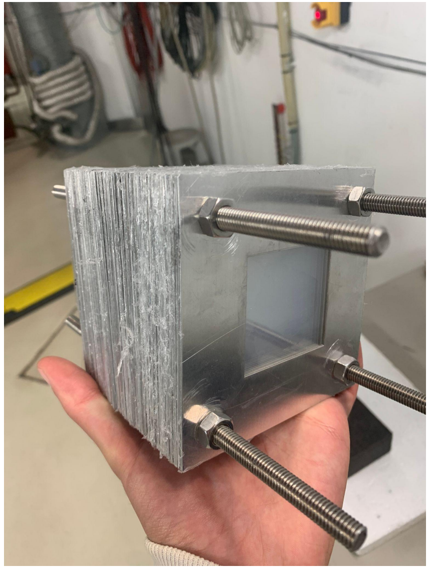
Radiator	*Foil /gap material*	$d_1(\mu m)$	$d_2(\mu m)$	*N*
EXTRA	polyethylene/air	23	500	150
INFN	polyethylene/air	25	300	155
CERN	polyethylene/air	25	240	190

Radiators overview



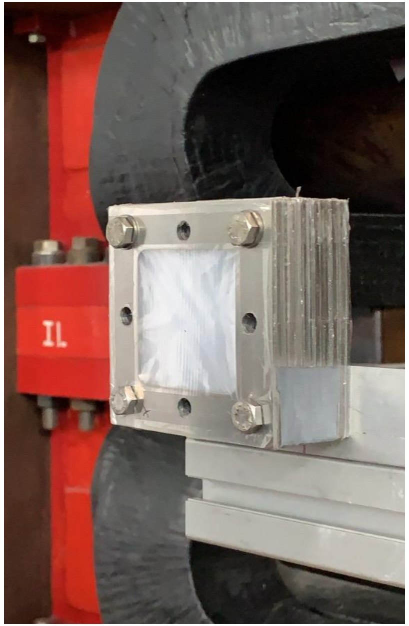
Sponge

EXTRA radiator



CERN radiator

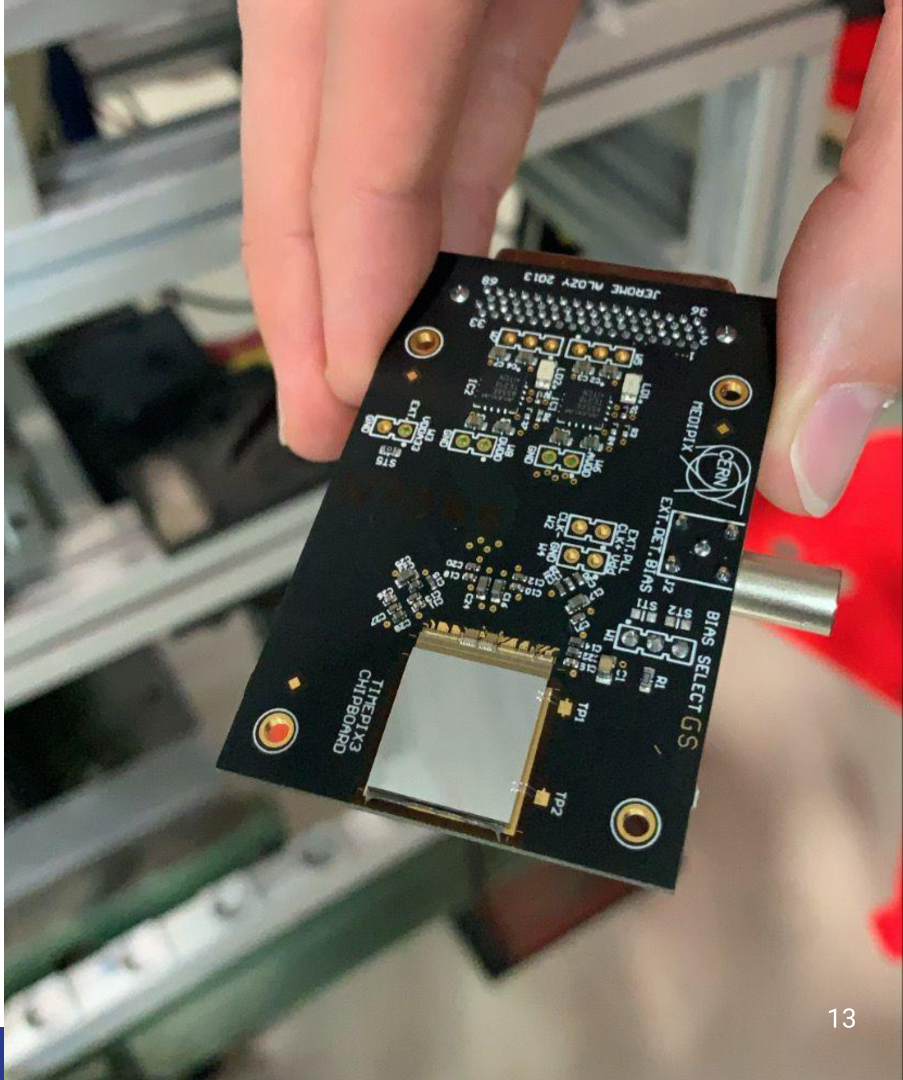
INFN radiator

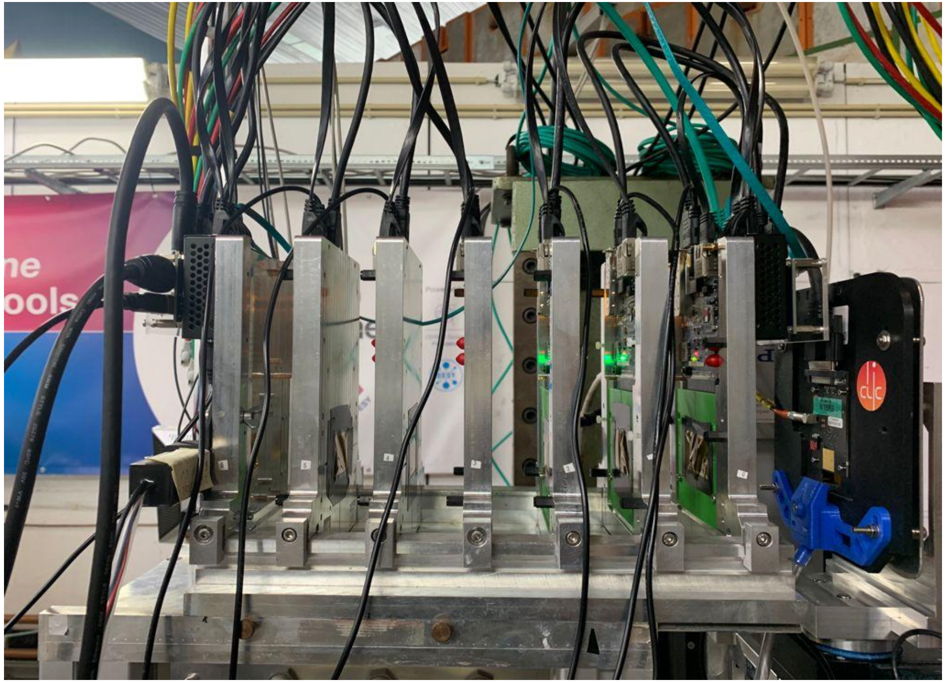


Towels

Timepix3

A silicon detector based on a Timepix3 chip.
Pixel pitch of 55 x 55 µm
Pixel matrix consists of 256 x 256 pixels.
In our case the silicon sensor
is 100 µm thick.

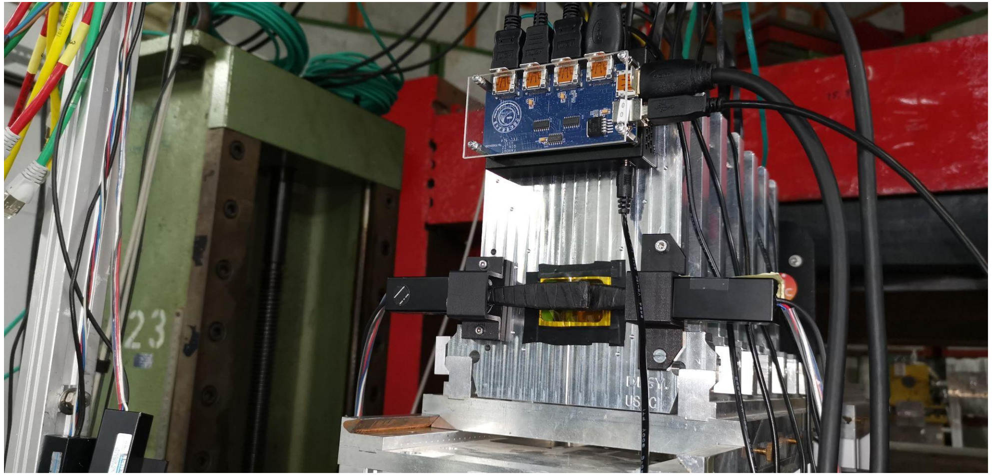




Beam Telescope

It consists of an array of six silicon pixel detectors, regularly spaced at distance of 5 cm.
Pixel pitch of 29.24 µm x 26.88 µm
Pixel matrix consists of 1024 x 512 pixels.

Scintillators



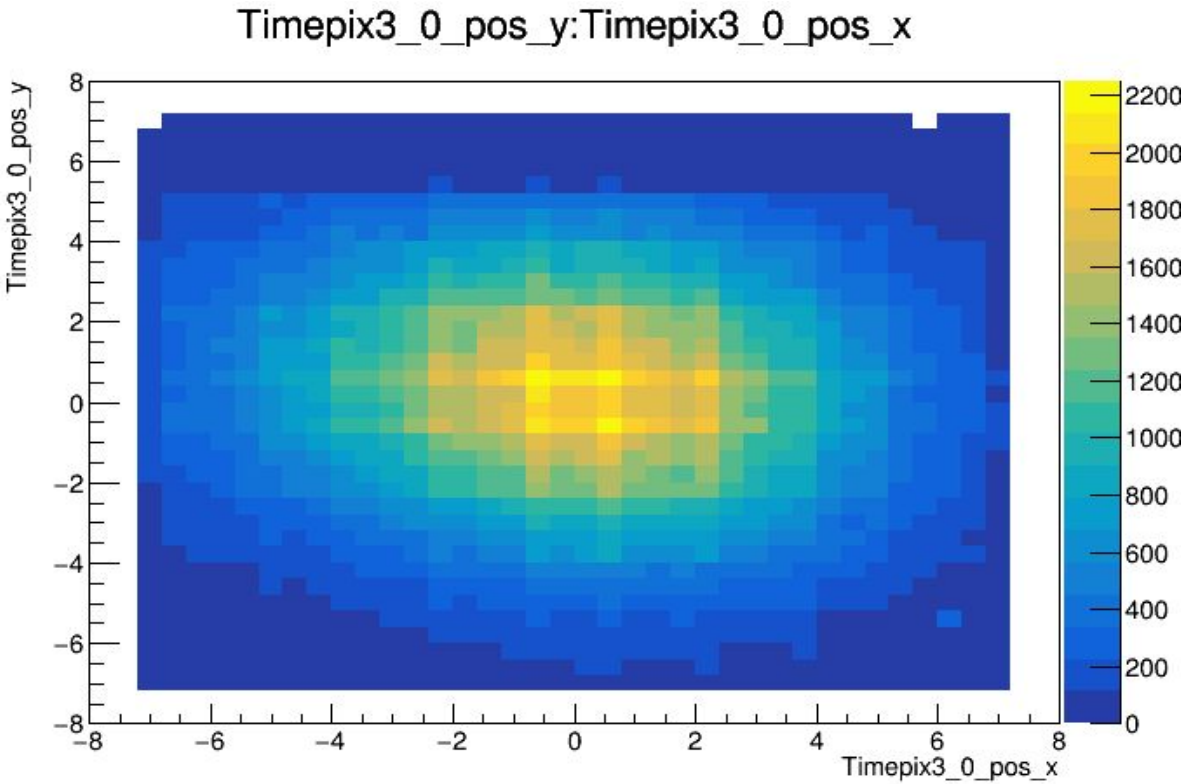
Placed at the end of the beam line, are used to select the beam particles and for triggering purposes.

Detector alignment and calibration

Our first aim was to align the silicon detectors with respect to the beam, and we held some trial runs, at first without the radiator, which we successively added to complete the calibration.

Through the help of a couple of lasers, the position of the Beam Telescope was checked and modified accordingly to the Beam trajectory.

Hit map calibration Timepix3 (100μm thickness)



Data taking

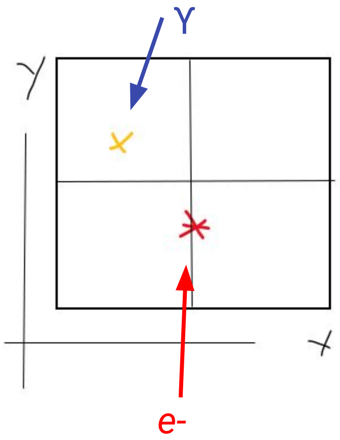
Several runs in different configurations have been taken, by changing the beam momentum, the radiator and its distance from the silicon pixel detector.

The X-rays are mainly absorbed by the front sensor, the charged particle continue its path and leaves a track in the following six detectors, which is reconstructed offline.

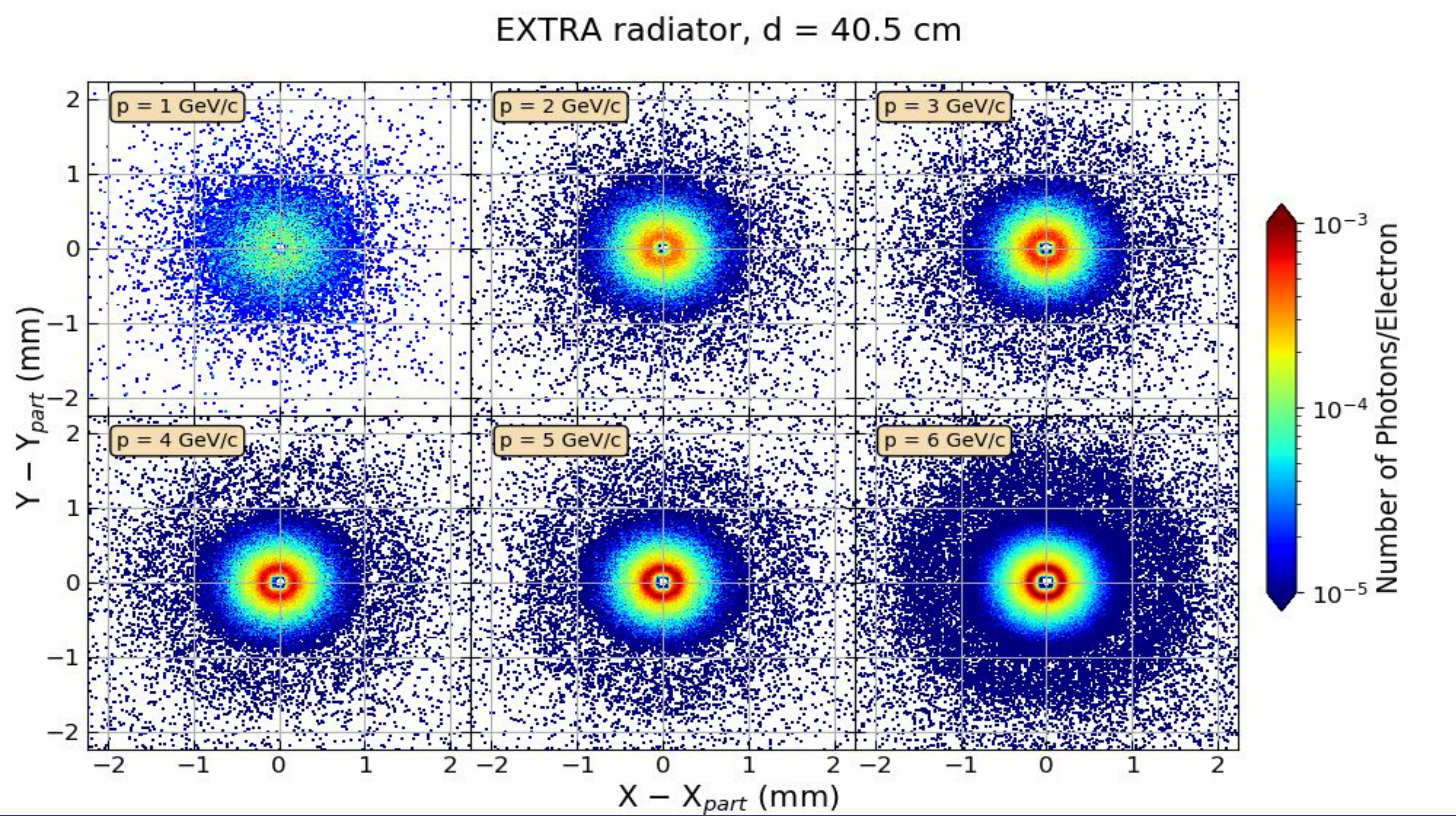
X-rays traversing the silicon detector can liberate electron-hole pairs. Holes and electrons drift towards the electrodes of the sensor. The charge collected is converted in energy by the Timepix3 redout chip.

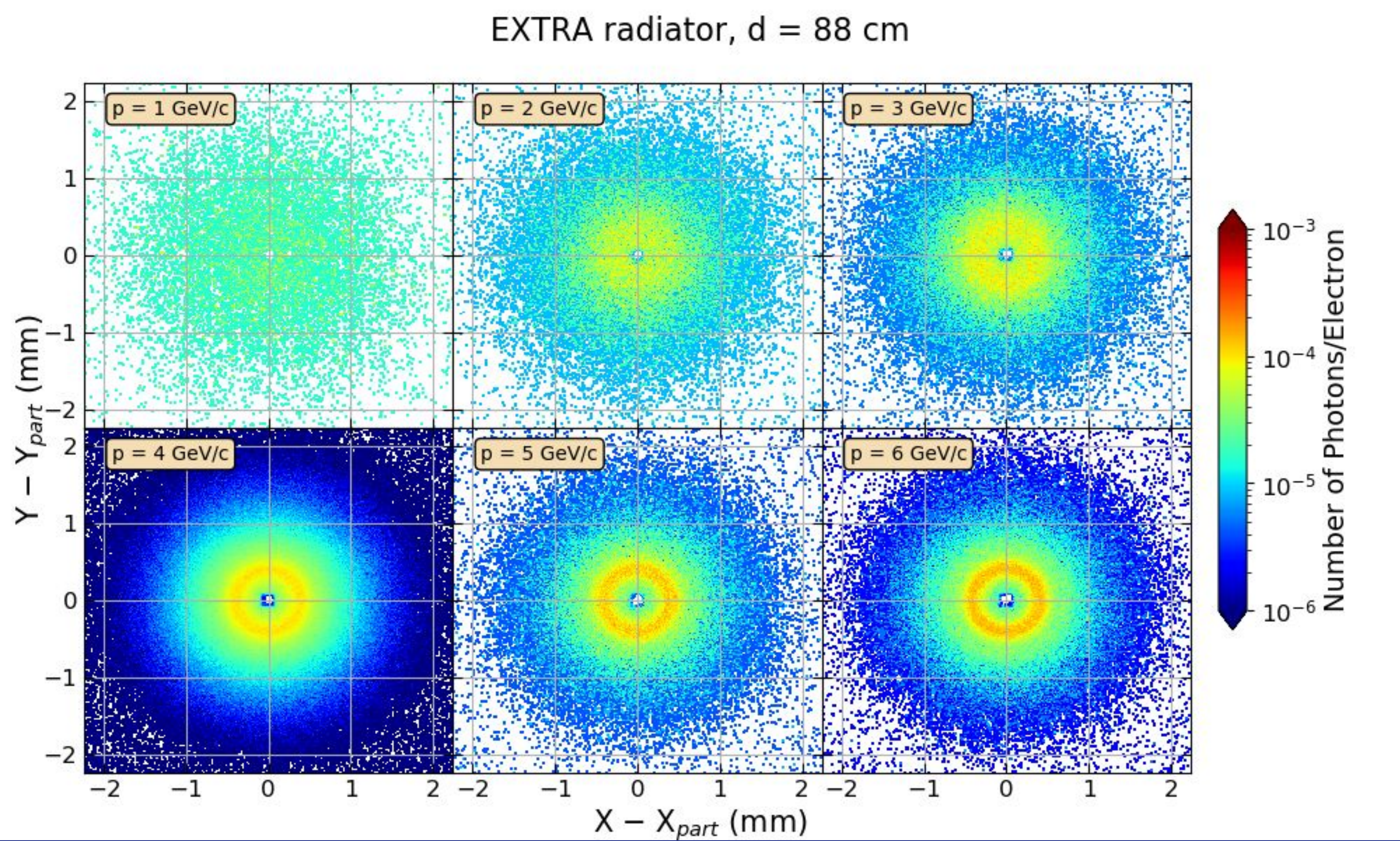
Clustering and tracking

- Clustering:
  - Hit pixels surrounded by empty pixels are grouped in clusters
  - Cluster energies are evaluated by summing up the energies of all pixels in the cluster
- In each run we have selected events with:
  - at least one cluster in the Timepix3
  - at least 3 clusters in different detectors of beam telescope
- The electron track is reconstructed fitting the positions of the clusters of the beam telescope with a straight line
- The cluster in the Timepix3 closest to the track is associated to the electron ("particle cluster")
- Other clusters are associated to TR X-rays being absorbed in the Timepix3 detector ("X-ray clusters")

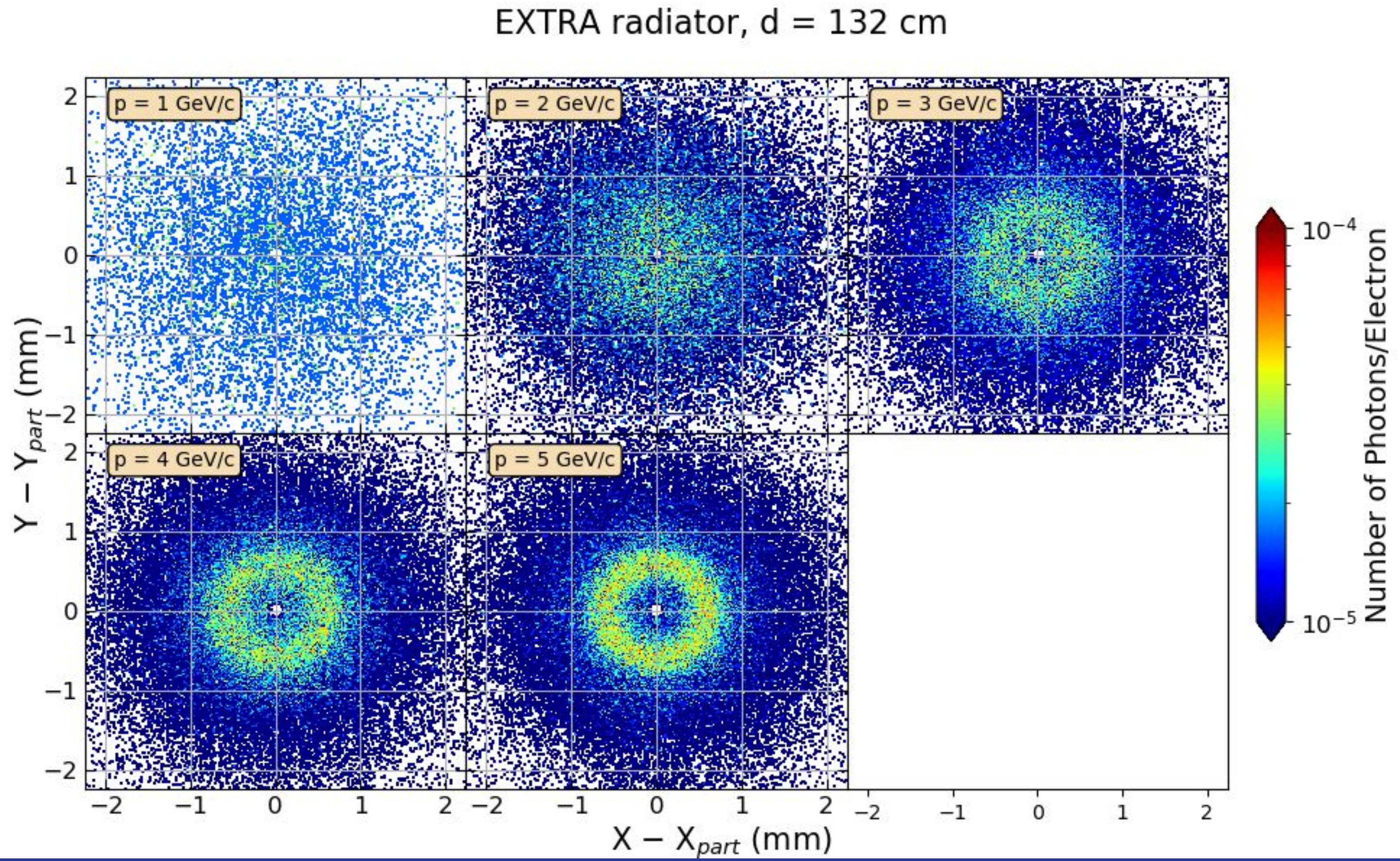


Relative position of the X-ray clusters with respect to the particle clusters

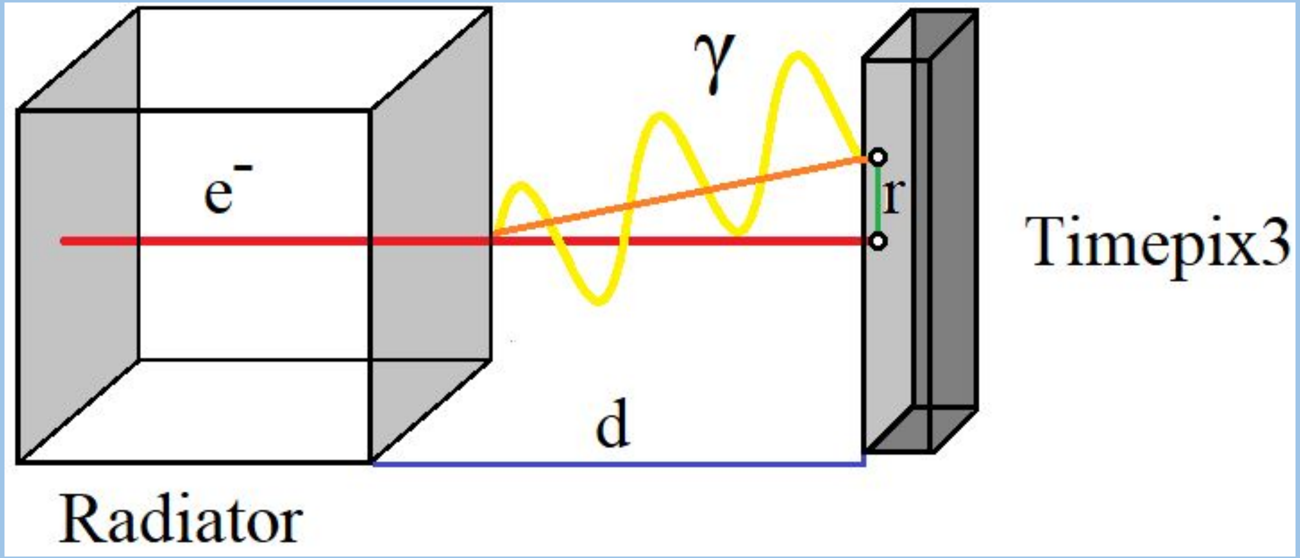




EXTRA radiator, d = 88 cm
p = 1 GeV/c
p = 2 GeV/c
p = 3 GeV/c
p = 4 GeV/c
p = 5 GeV/c
p = 6 GeV/c
$Y - Y_{part}$ (mm)
$X - X_{part}$ (mm)
Number of Photons/Electron
10^{-3}
10^{-4}
10^{-5}
10^{-6}


EXTRA radiator, d = 132 cm
p = 1 GeV/c
p = 2 GeV/c
p = 3 GeV/c
p = 4 GeV/c
p = 5 GeV/c
Y − Y_part (mm)
X − X_part (mm)
Number of Photons/Electron
10^−4
10^−5

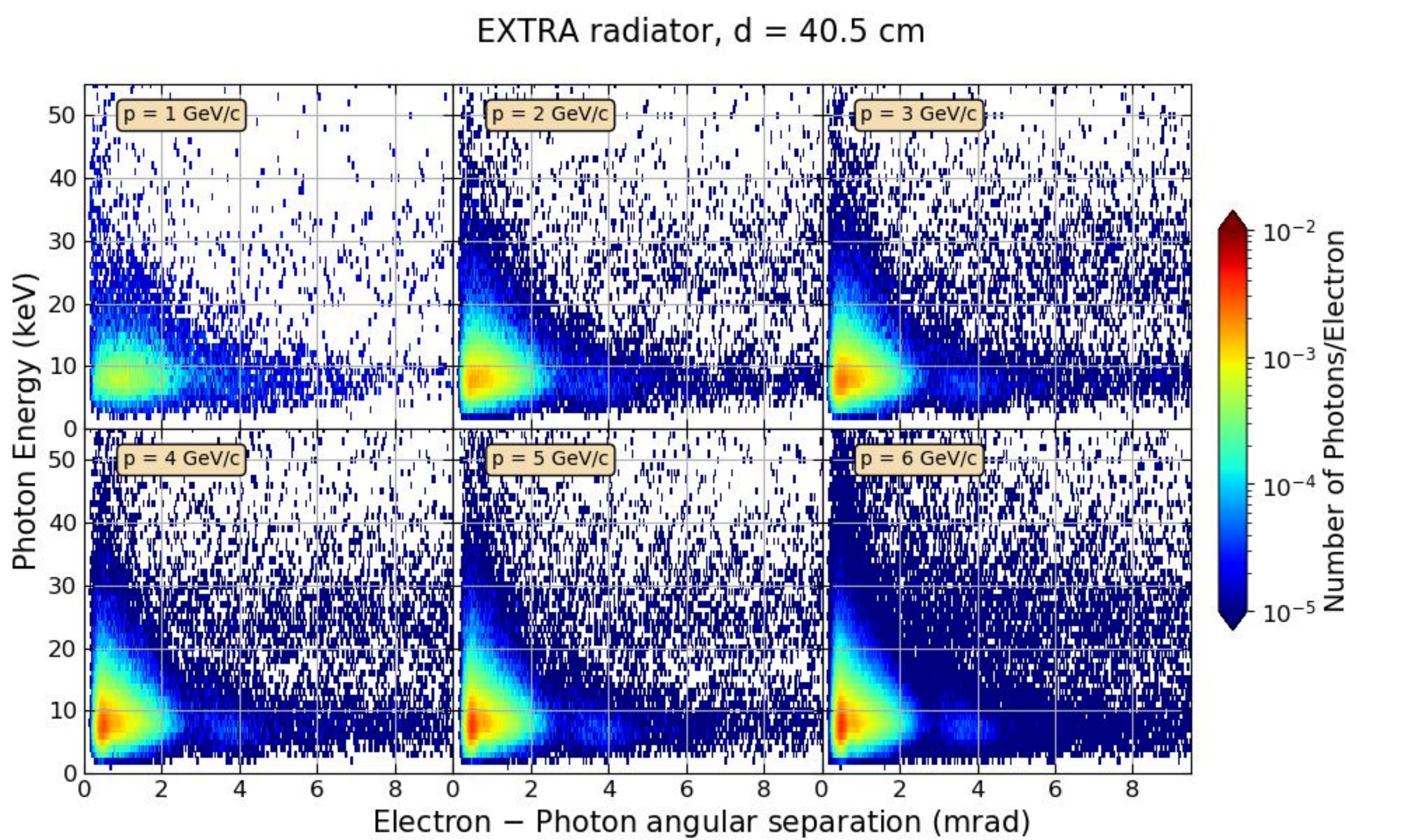
What about angular distribution?

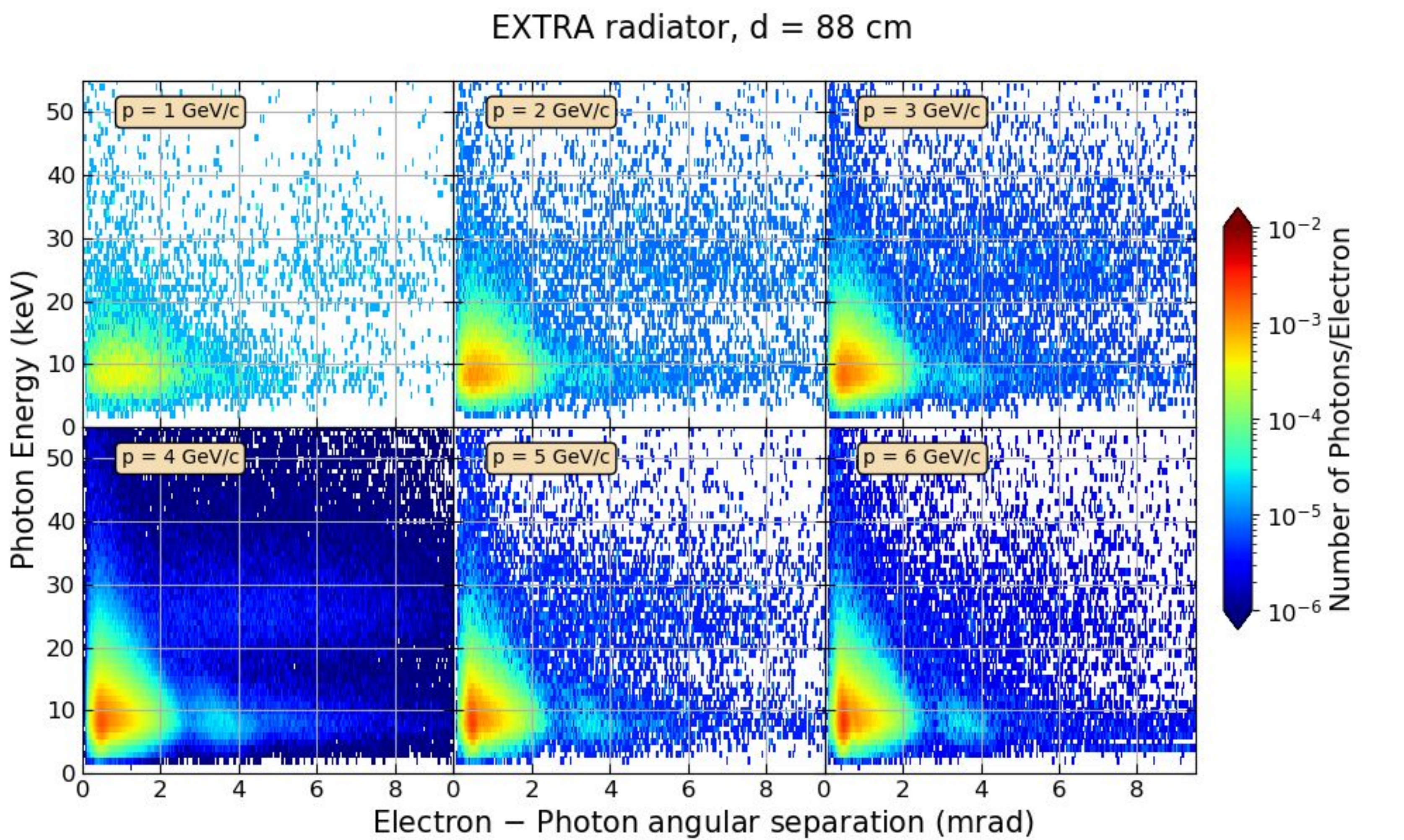


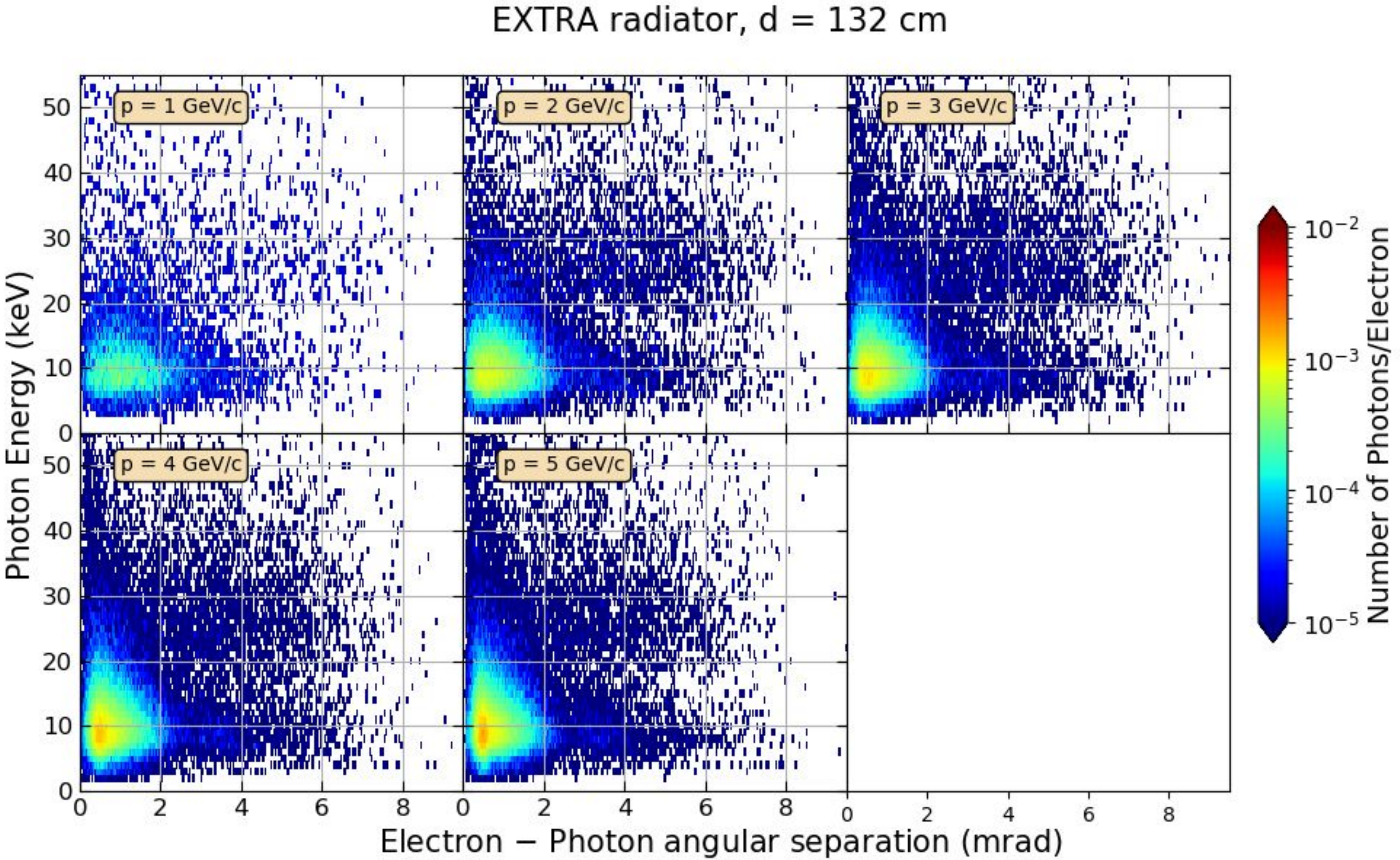
The angular separation of TR X-rays from the direction of the electron is:

$$\theta \sim \frac{r}{d}$$

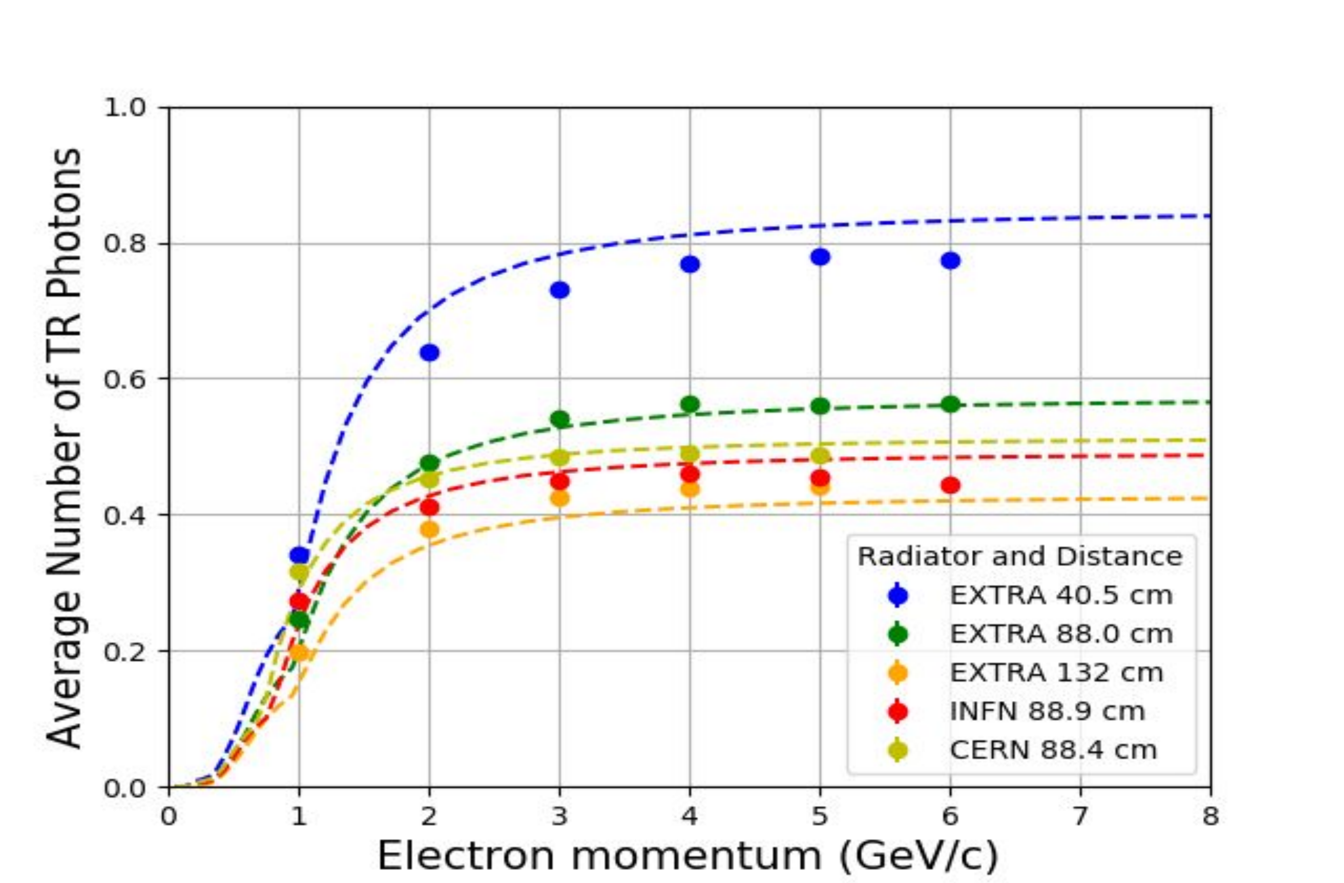
Two dimensional distribution of photon energy versus angular separation




EXTRA radiator, d = 88 cm
p = 1 GeV/c
p = 2 GeV/c
p = 3 GeV/c
p = 4 GeV/c
p = 5 GeV/c
p = 6 GeV/c
Photon Energy (keV)
Electron − Photon angular separation (mrad)
Number of Photons/Electron
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}


EXTRA radiator, d = 132 cm
p = 1 GeV/c
p = 2 GeV/c
p = 3 GeV/c
p = 4 GeV/c
p = 5 GeV/c
Photon Energy (keV)
Electron − Photon angular separation (mrad)
Number of Photons/Electron
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
10
20
30
40
50
0
2
4
6
8

TR photons vs electron momentum



Conclusions

Data Analysis:

- ❖ The intensity of detected TR depends on the distance between the radiator and the detector due to X-ray absorption in air
- ❖ The number of detected TR photons increases with the Lorentz factor as expected
- ❖ The distribution of angular separations of TR photons with respect to the beam particles depends on the Lorentz factor
  - ➢ TR photons are emitted mainly at angles < 1 mrad
  - ➢ As the Lorentz factor increases, peaks at larger angles become more clear

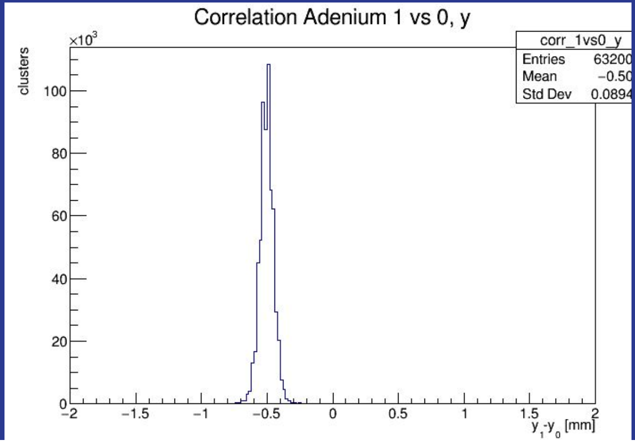
What we had brought back home:

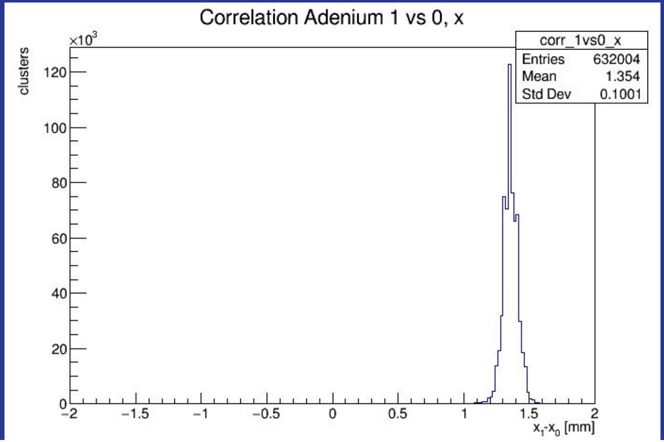
- ❖ The experience at DESY has given us the opportunity to live two weeks as real researchers!
- ❖ We are now much more aware of the method and the mindset needed to have a scientific approach not only with experiments, but also in our everyday lives and challenges.
- ❖ We have met so many wonderful people that showed us their unconditional love towards science and physics and we couldn't help but be drawn in this spiral of passion and self dedication.

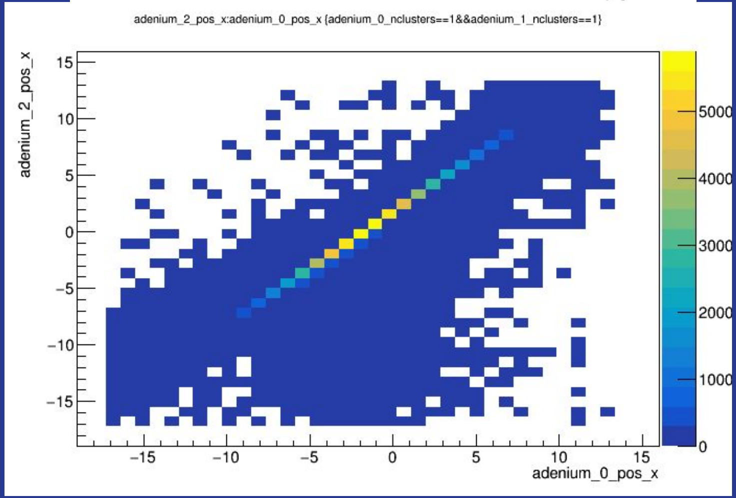
Thanks for your attention

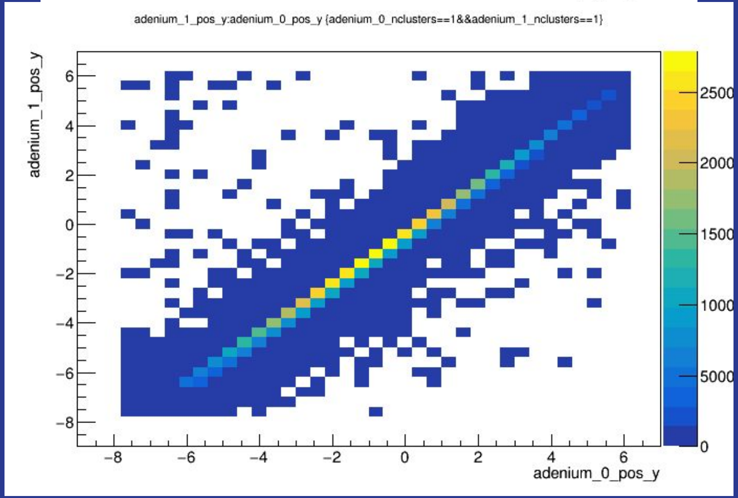

CABEZAS MONTIEL
Luis Eduardo

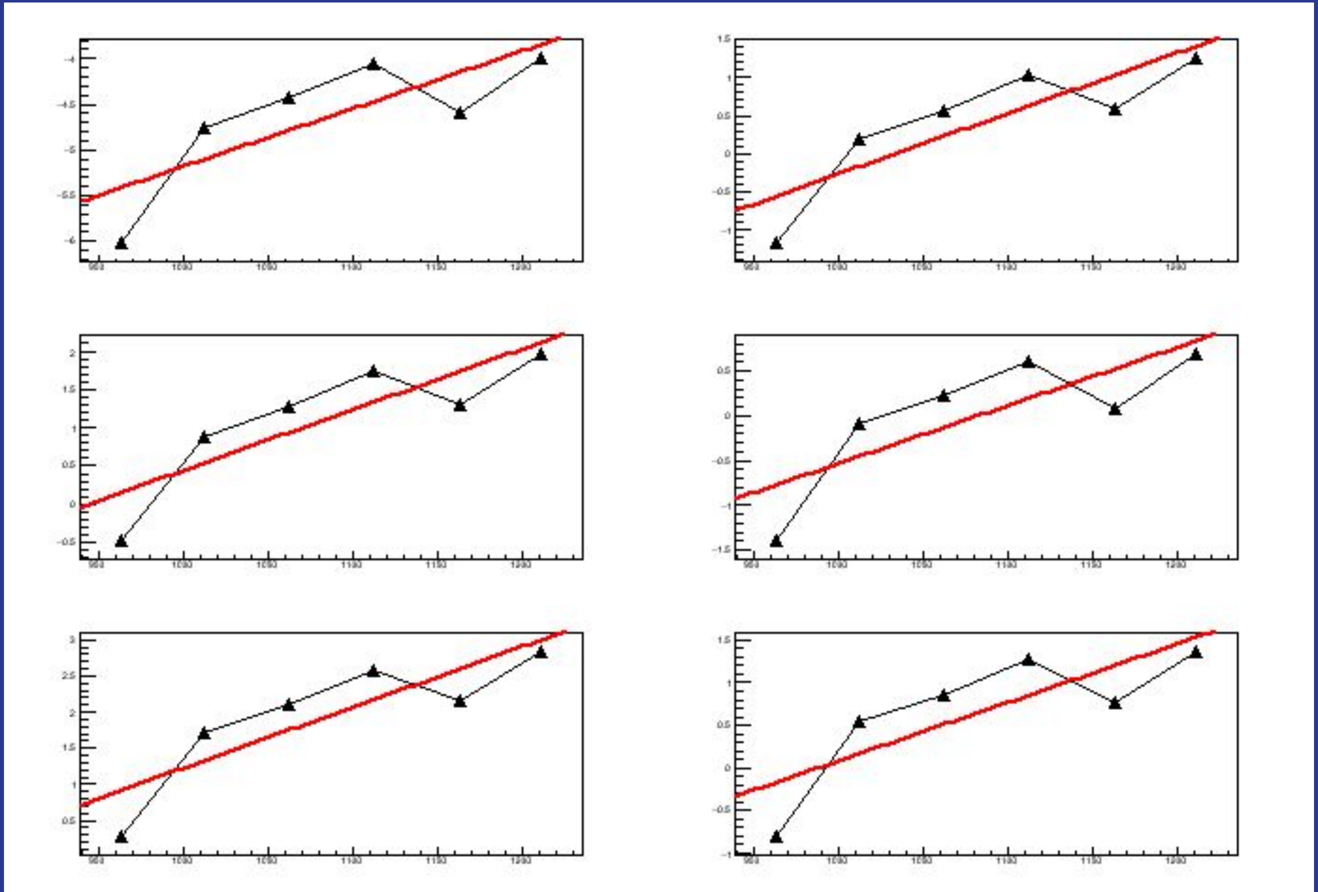
Samples of calibration plots







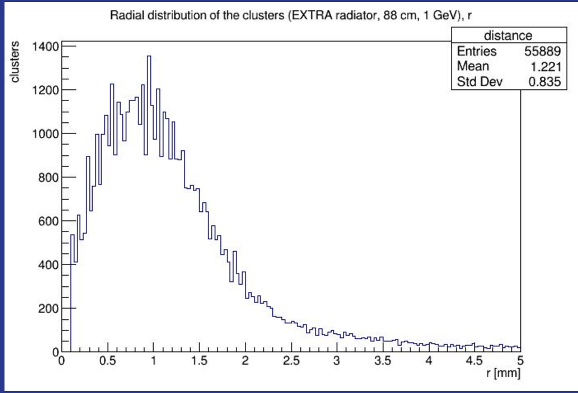


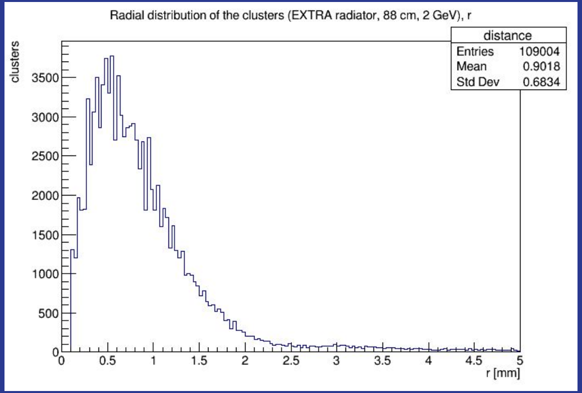


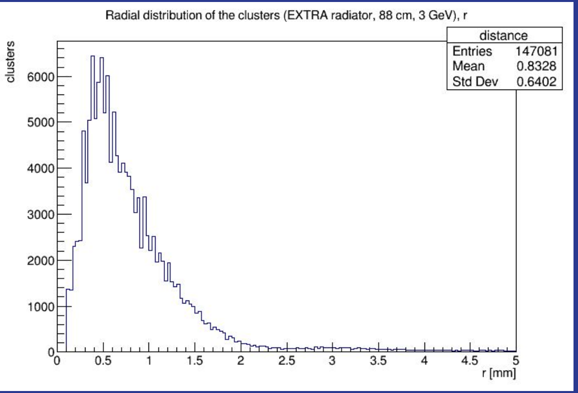
Track plots single hit cluster events (sample plots) for Adenium 0 to 5.

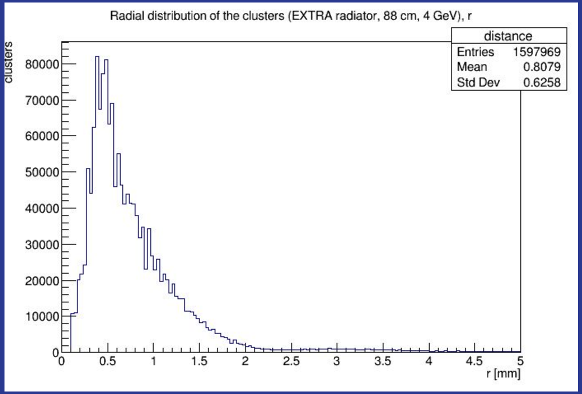
X axis _vs_ Z axis

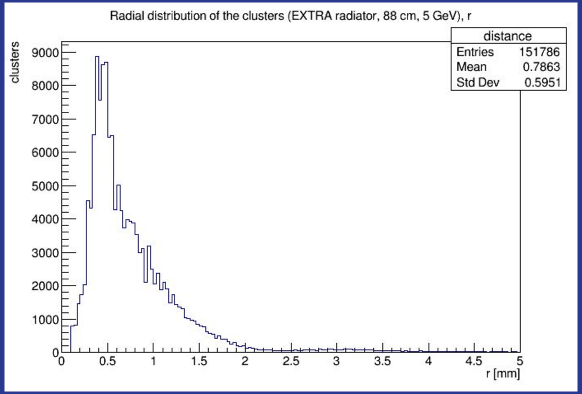
EXTRA radiator@ 88 cm Radial Distribution

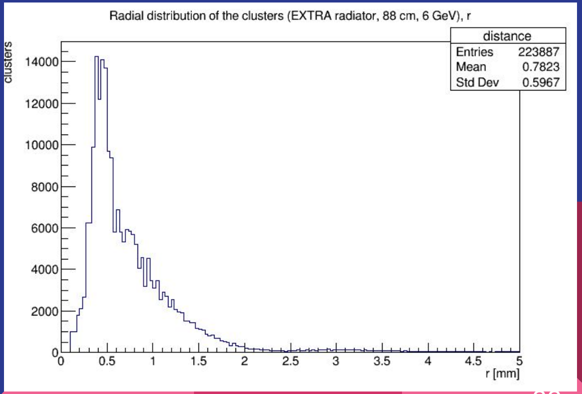












Summary Table

γ (Lorentz factor)	E (GeV)	Distance (cm)		
		40.5	88	132
2000	1	EXTRA	EXTRA, INFN, CERN	EXTRA
4000	2	EXTRA	EXTRA, INFN, CERN	EXTRA
6000	3	EXTRA	EXTRA, INFN, CERN	EXTRA
8000	4	EXTRA	EXTRA, INFN, CERN	EXTRA
10000	5	EXTRA	EXTRA, INFN, CERN	EXTRA
12000	6	EXTRA	EXTRA, INFN, SPONGE, PAPER	

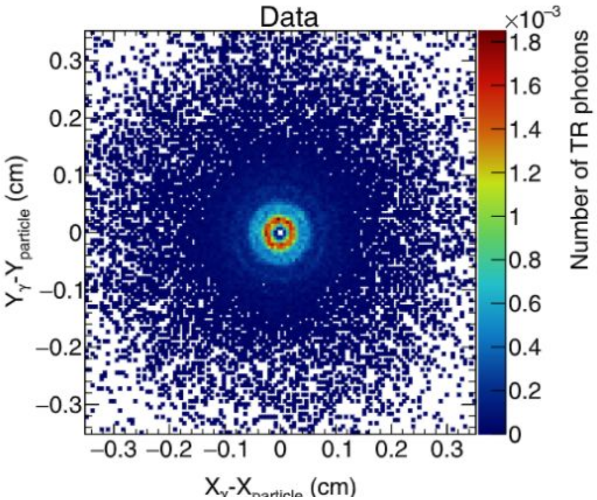
Radial distribution of the X-rays

In order to observe the distribution of the distance between the two clusters taken in consideration, we used the distance formula of two points in 2D.

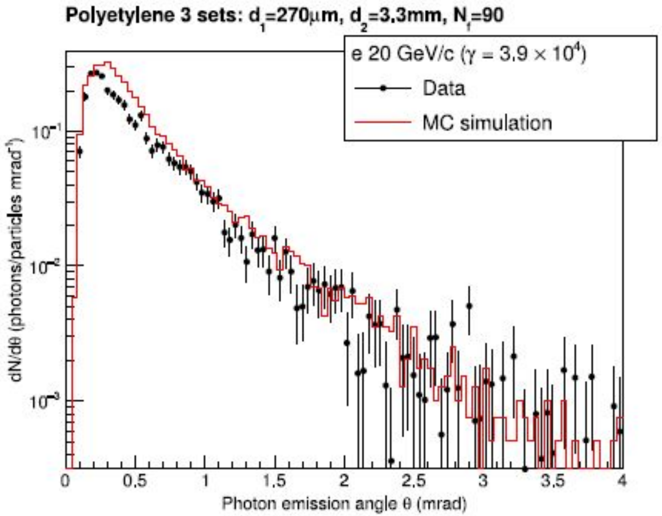
$$r = \sqrt{(x_\gamma - x_e)^2 + (y_\gamma - y_e)^2}$$

```
rootfile_51 = ROOT.TFile("/nfs/dust/fhlabs/group/BL4S/convertedData/EXTRA/converted_000051.root","READ")
Clusters51 = rootfile_51.Get("Clusters")
c1 = ROOT.TCanvas()
distance = ROOT.TH1D("distance","Radial distribution of the clusters (EXTRA radiator, 88 cm, 2 GeV), r;r [mm];clusters",150,0,3)
Clusters51.Draw("((Timepix3_0_pos_x[1]-Timepix3_0_pos_x[0])**2+(Timepix3_0_pos_y[1]-Timepix3_0_pos_y[0])**2)**(1/2) >> distance","Timepix3_0_nclusters==2","colz'
distance.Draw()
c1.Draw()
c1.SaveAs("Radial distribution of the clusters.pdf")
```

Some references



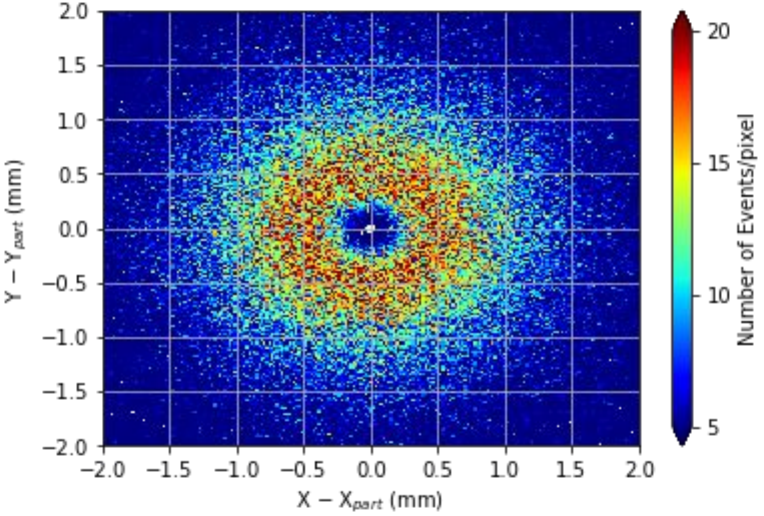
Relative position of identified TR photon clusters with respect to the particle clusters for 20 GeV electrons crossing the 30 foil Mylar radiator.



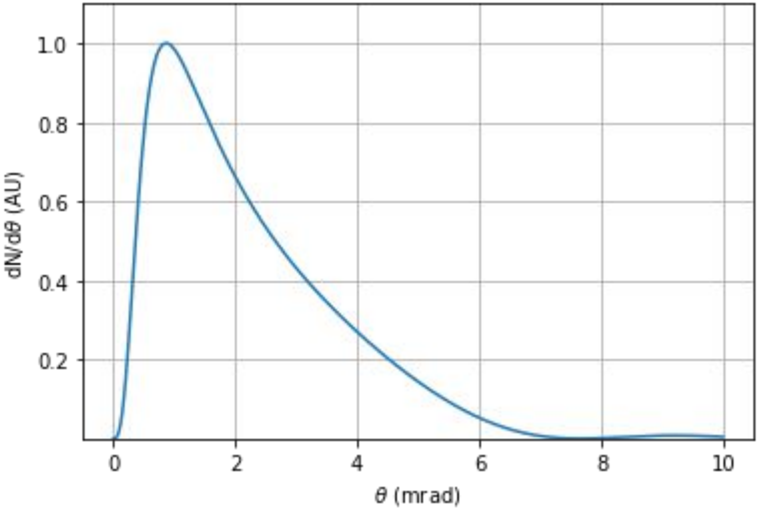
Comparison between the measured and simulated TR differential energy and angular spectra

J. Alozy et al. Identification of particles with Lorentz factor up to 104 with Transition Radiation Detectors based on micro-strip silicon detectors. Nucl. Instrum. Meth. A, 2019.

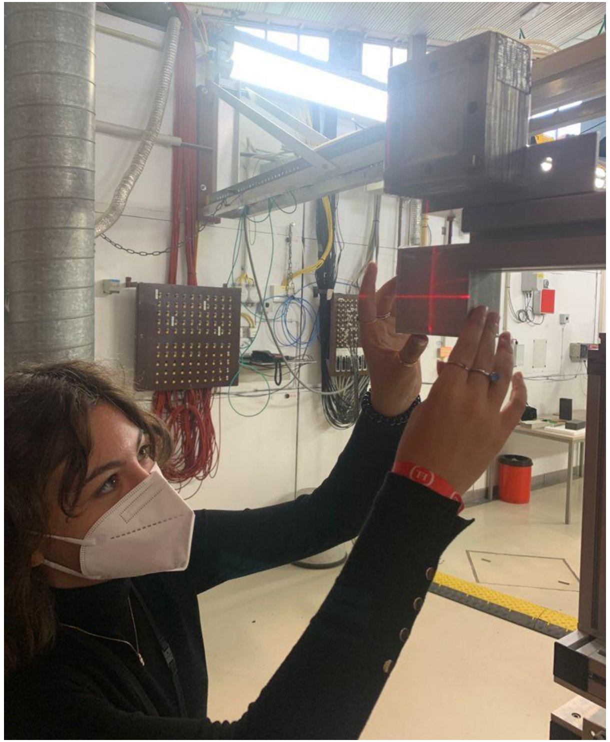
Simulated data



Single foil emission (20 um thick)



Angular distribution

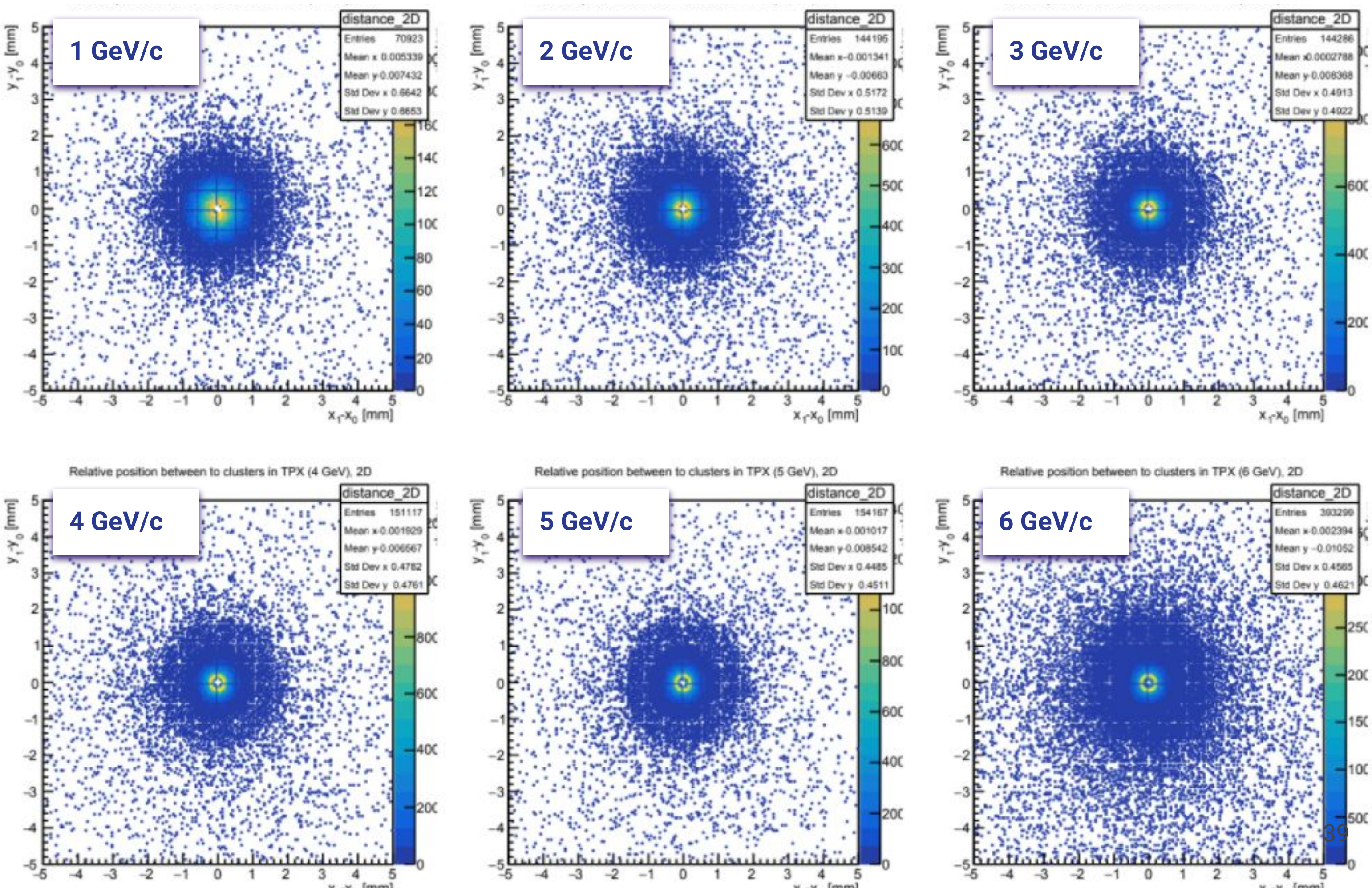


Through the help of a couple of lasers, the position of the Beam Telescope was checked and modified accordingly to the Beam trajectory. The six adeniums, in fact, were moved from a value of 5.7 mm to one of -4.5 mm towards east direction, and from 1.4 mm to -4.9 mm upwards. Afterwards, a calibration run has been carried out: the alignment resulted satisfactory and the detector ready to use.

Same goes for the Timepix3 detector.

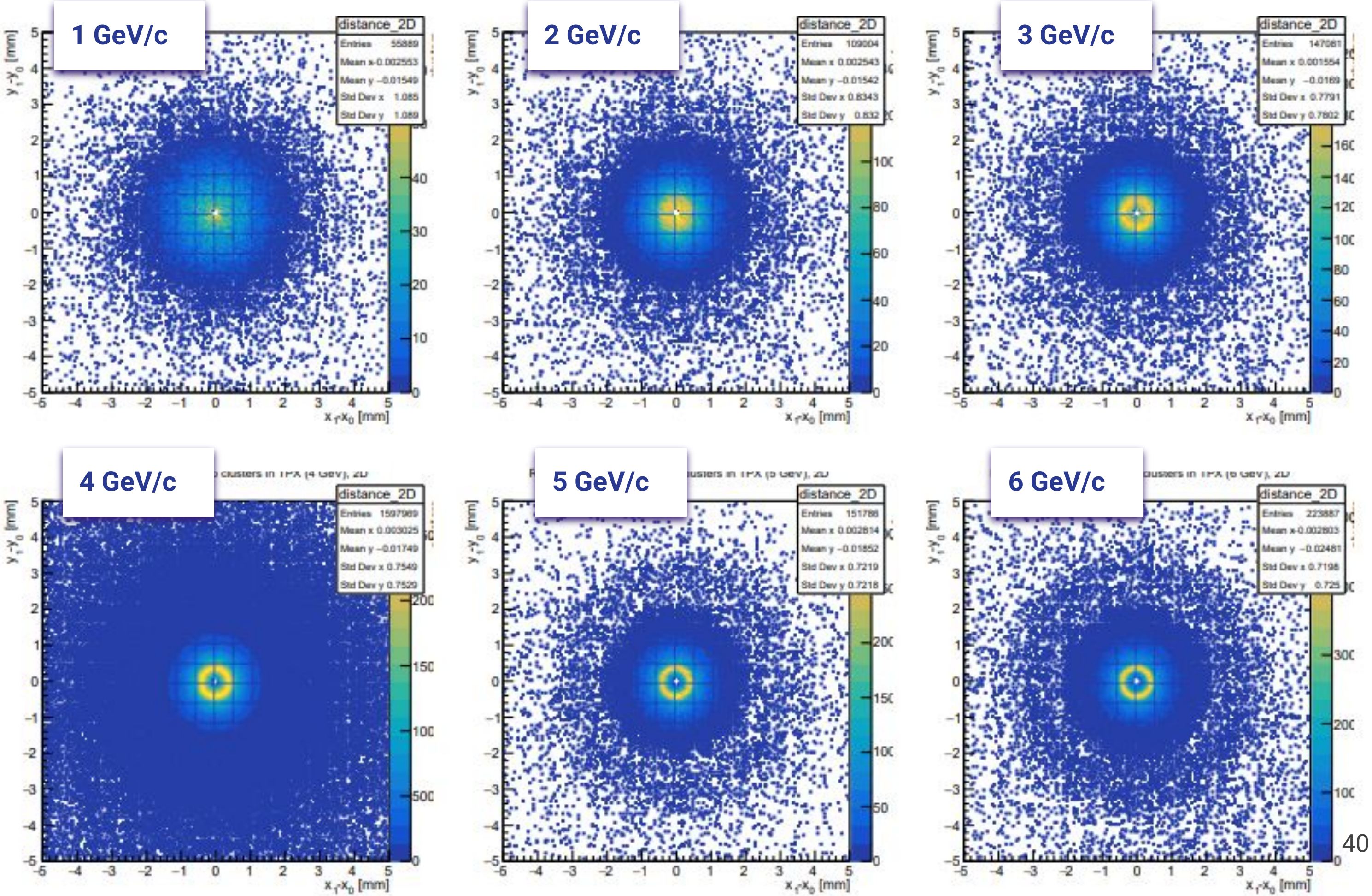
Hitmap: relative position between two clusters in Timepix3

EXTRA radiator@ 40.5cm

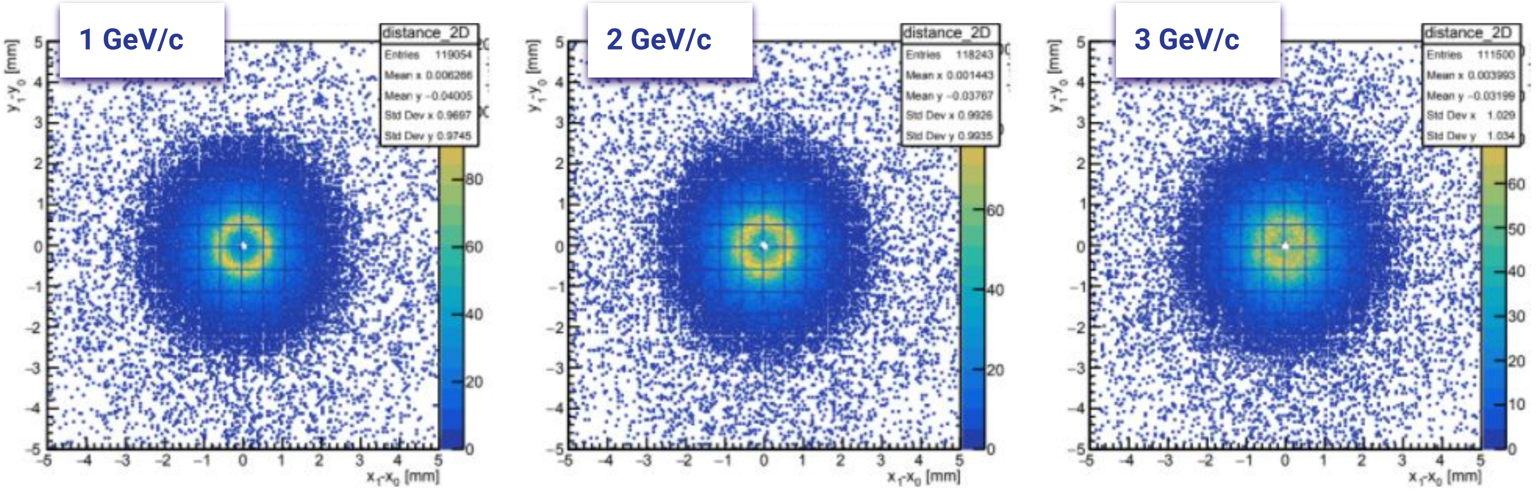


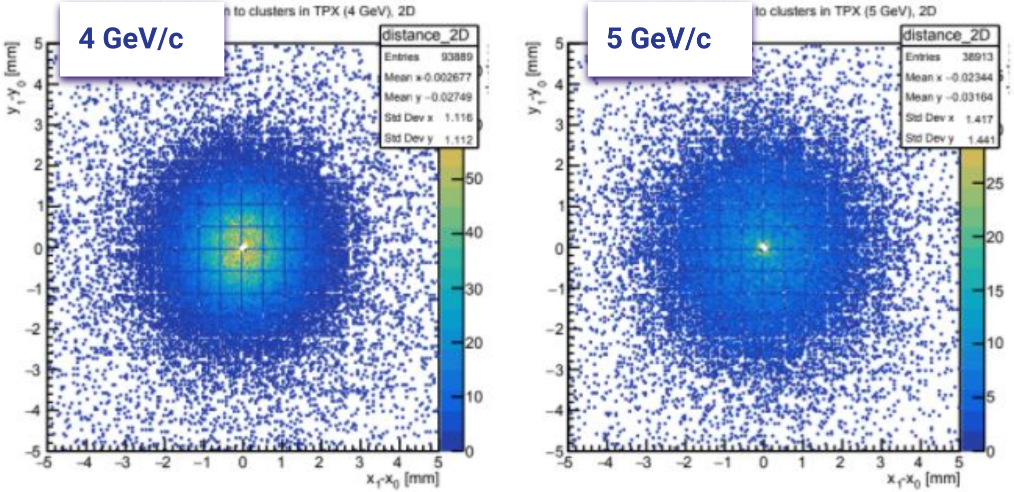
Hitmap: relative position between two clusters in Timepix3

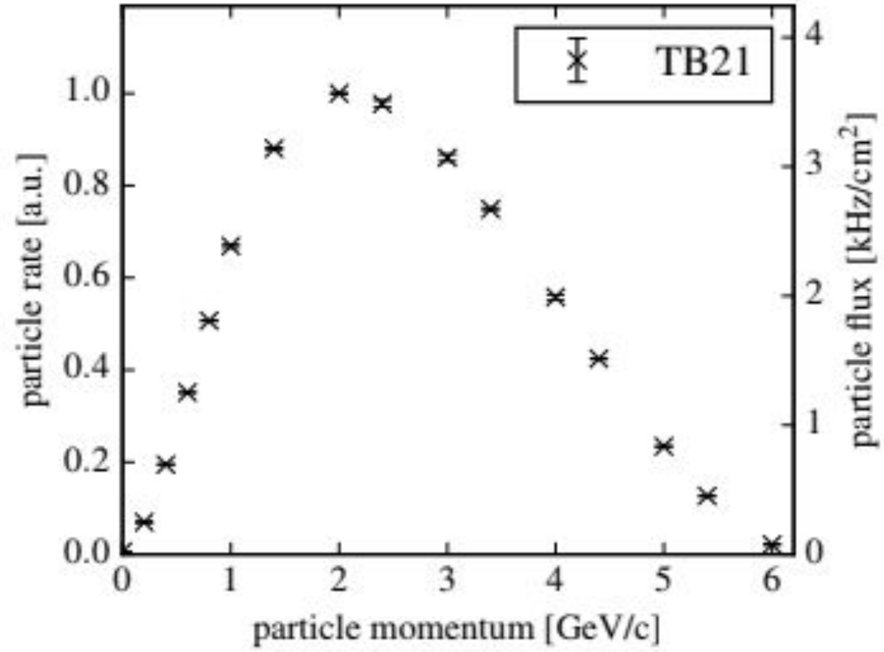
EXTRA radiator @88cm



EXTRA radiator @132cm







Dependence of the beam rate on the selected momentum measured in area TB21.
The rates is normalized to a maximum of 1.0.