# Progress report of SPD Zero Degree Calorimeter for the first stage


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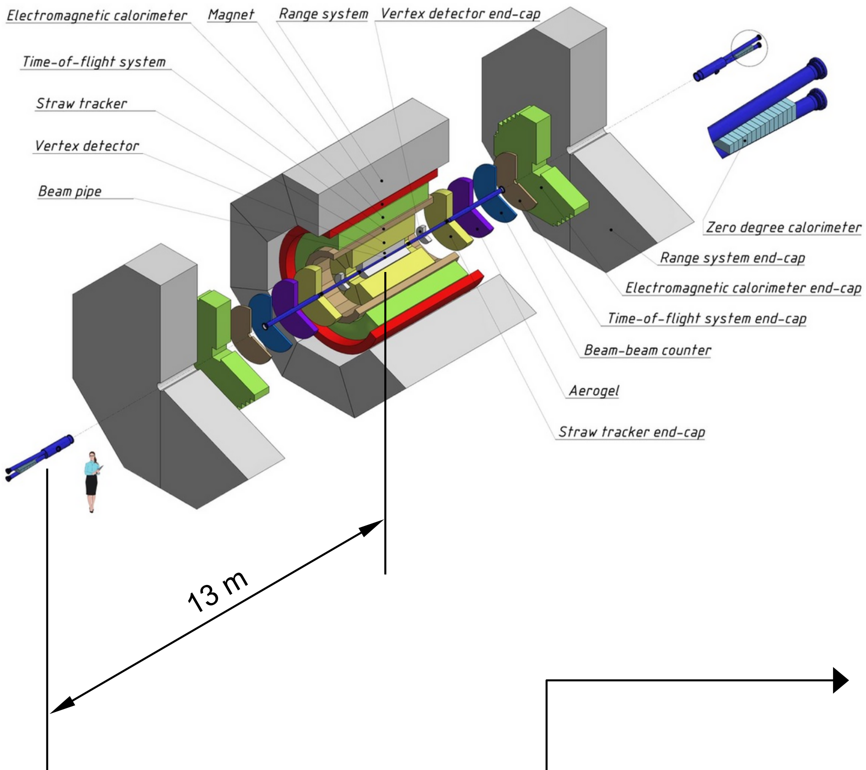
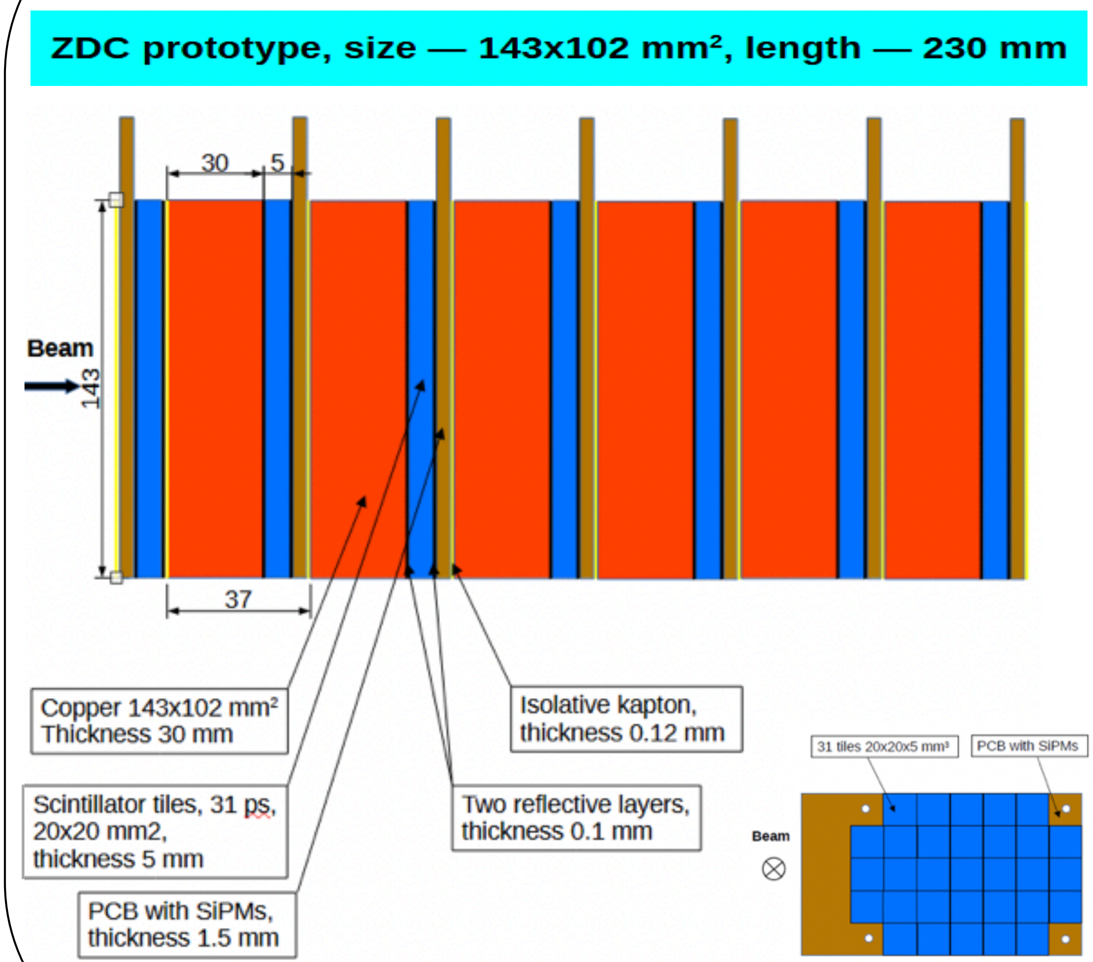
On behalf of ZDC team: JINR – ITEP – InsTEC


IX SPD Collaboration Meeting




Two such prototypes are planned

## Prototype for phase-0



Update since the last SPD Collaboration meeting:

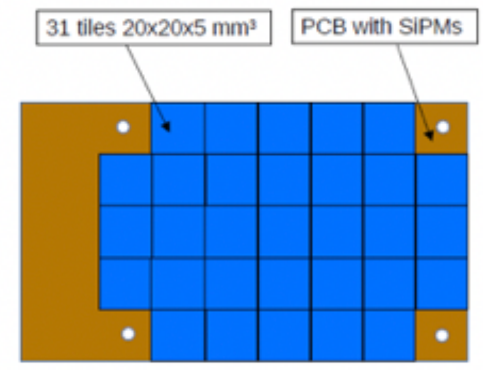
✓ Two boards with scintillator layers of 3 and 5 mm thickness were tested with cosmic muons.

✓ Six boards with SiPMs and scintillators layers were prepared by ITEP group and tested with cosmic muons (shown in Alexey Tishevsky's report)

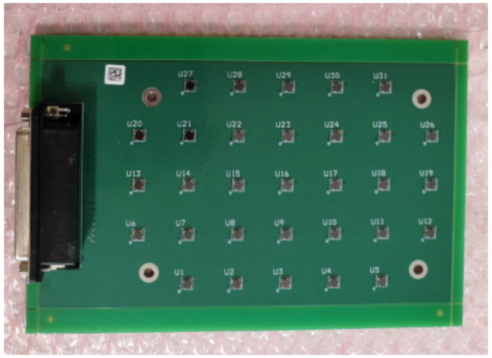
✓ **The first detector of this prototype was installed in the cryostat.**

✓ As for the second detector:

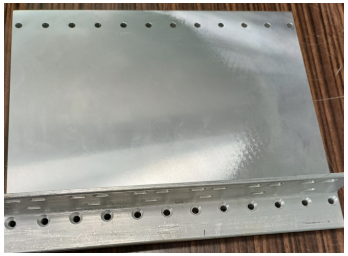
- Six boards with SiPMs have been ordered to REZONIT. It should be completed by the end of May/2025 and installed in June.
- Scintillator layers are being prepared by ITEP group.
- Sets of copper plates, substrates and corners are ready.
- Internal wiring cables are ready.




PCB with 31 SiPMs (thickness: 1.5 mm)

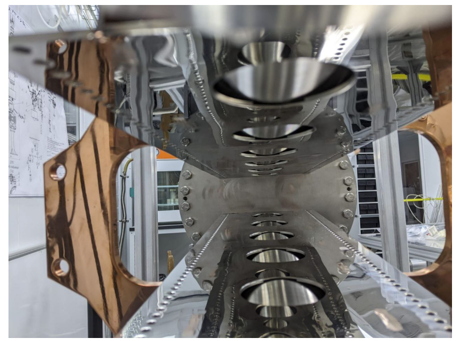


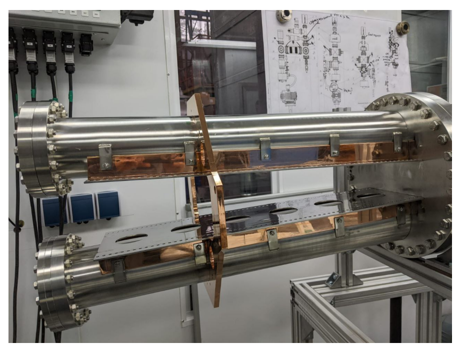
Cu radiators: 143 x 102 mm$^2$

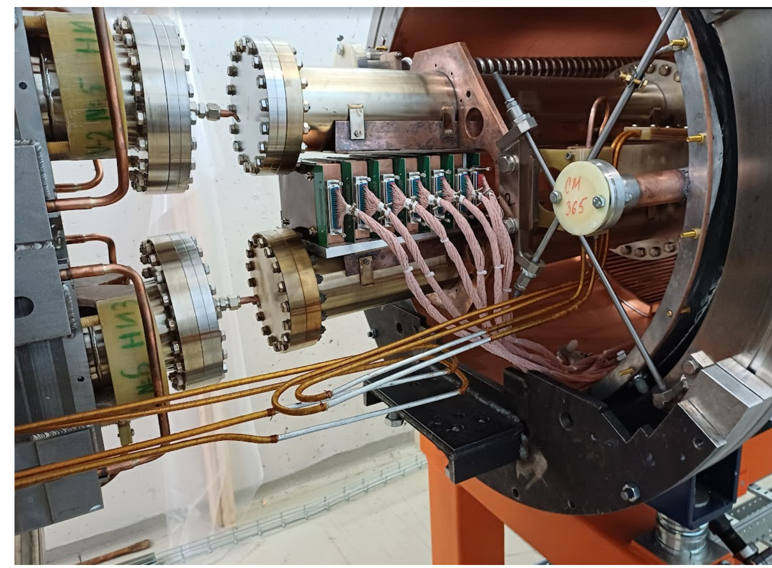


Update since the last SPD Collaboration meeting:

✓ One prototype is ready and placed in the supporting rails between the two beam pipes.

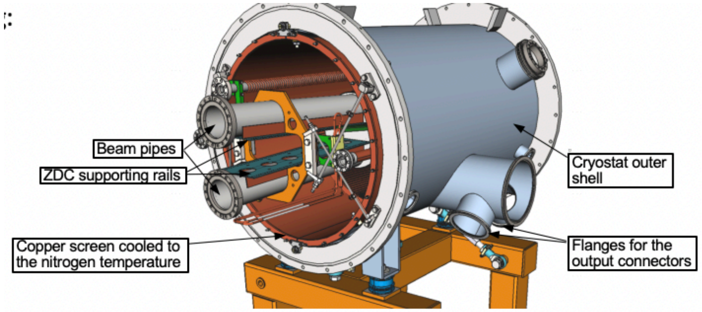




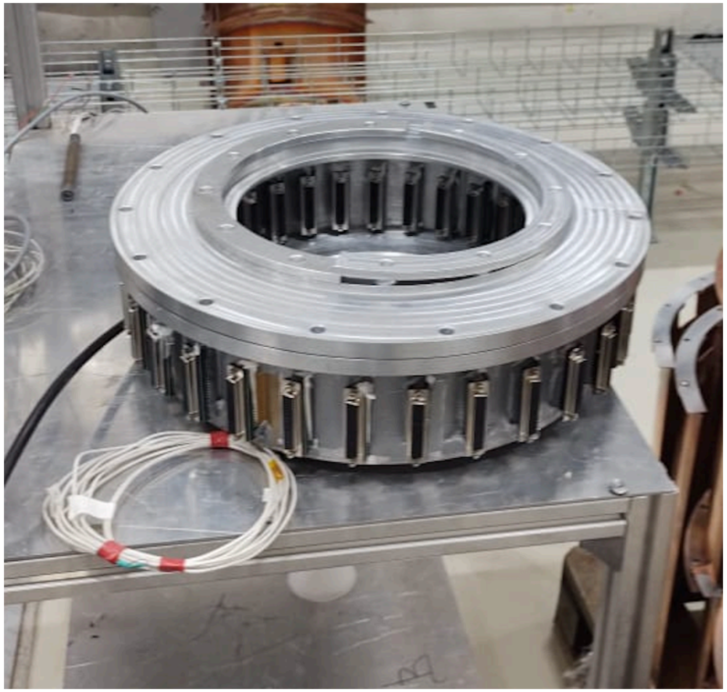


Update since the last SPD Collaboration meeting:

- ✓ Two barrels with print circuit boards (PCB) were completed, including connector soldering for the cables through the cryostat, hermetic sealing and vacuum testing.

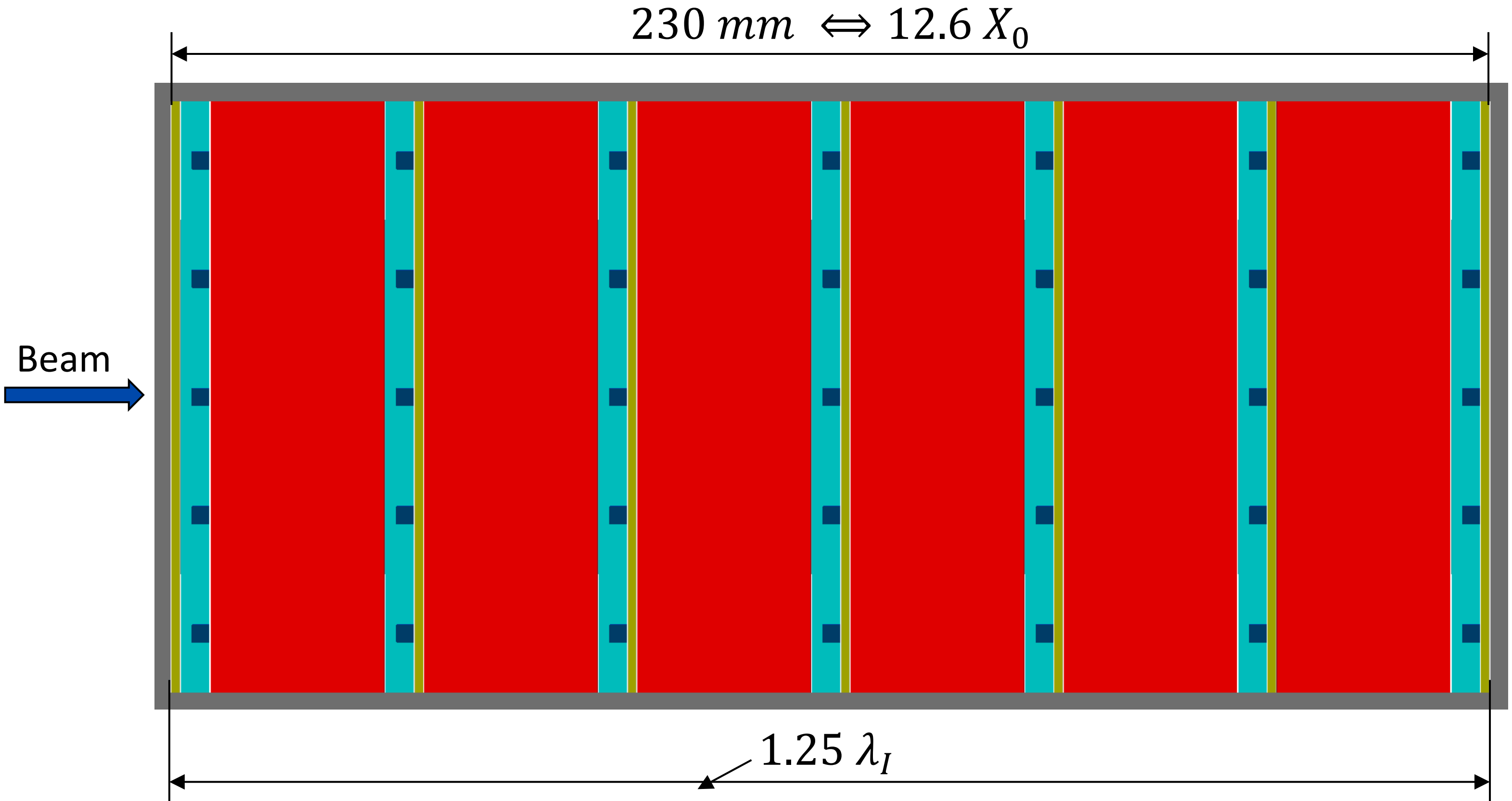


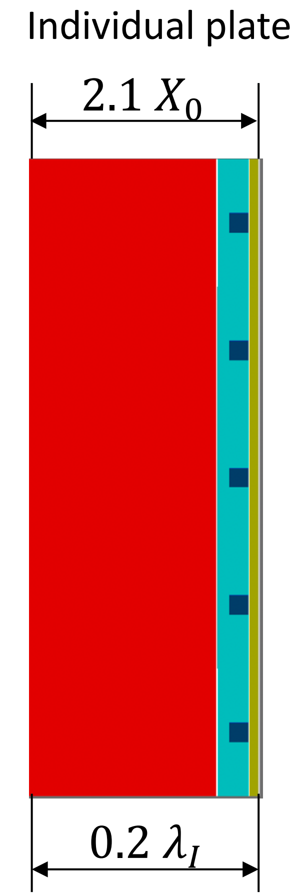

Barrel with PCB ready to be installed in the cryostat



- It only remains to complete the second prototype and install it.

- CAEN modules (FERS – DT5202) have already been received, on the basis of which digitization will be performed (CAEN modules are only for phase-0)



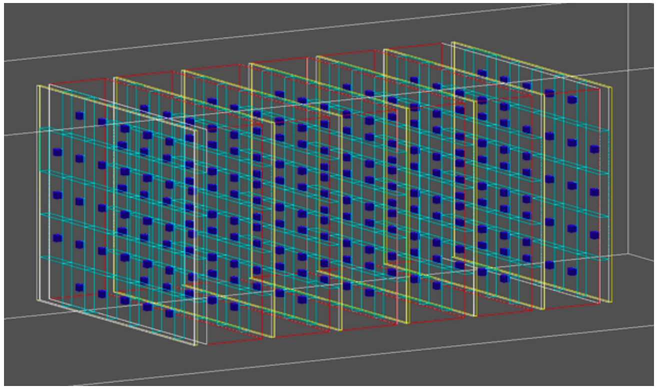




This thickness is enough to contain the hadron shower energy in 95% for only $E_{beam} \leq 1.2$ GeV

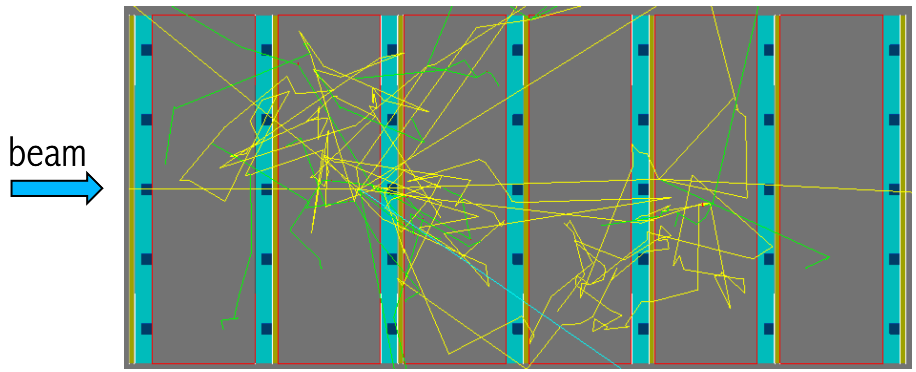
This prototype is not designed to capture as much energy from forward neutral spectators.

The electromagnetic shower maximum, $t_{max} \propto ln(E_0/E_c)$, should be created in the first three layers of Cu radiator. Some numbers:

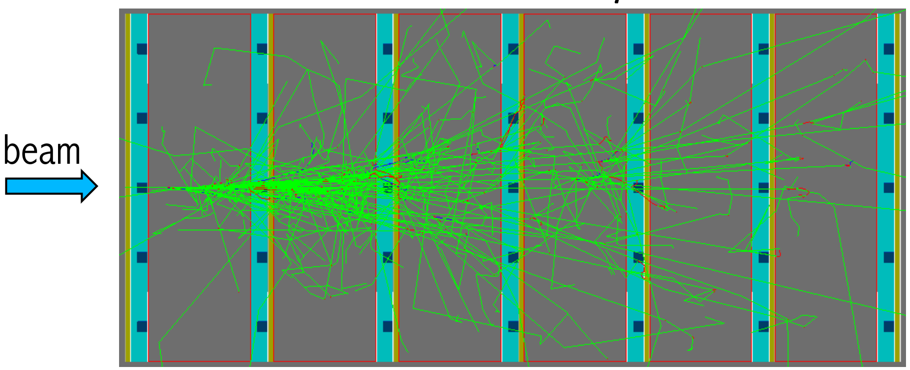
| $E_\gamma$(GeV) : | 1 | 2 | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|
| $t_{max}(X_0)$ : | 3.9 | 4.6 | 5.3 | 5.7 | 6.0 | 6.2 | 6.4 |



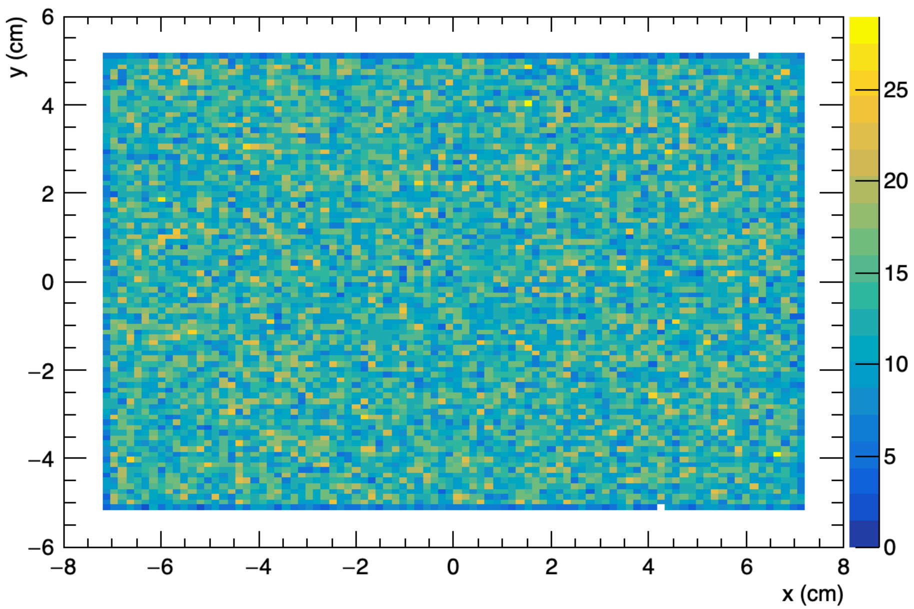
2 neutrons, $E_n = 1\ GeV$




1 gamma photon, $E_\gamma = 1\ GeV$




- Source particles where randomly generated with a uniform distribution in the first transverse plane of the detector, with momentum parallel to the beam axis.

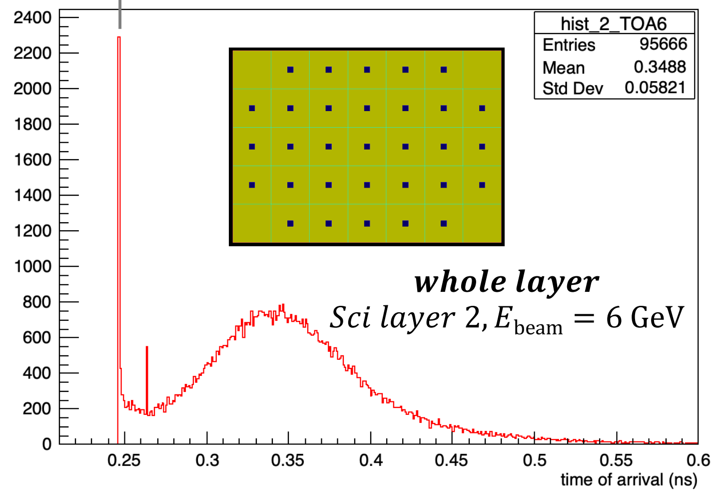


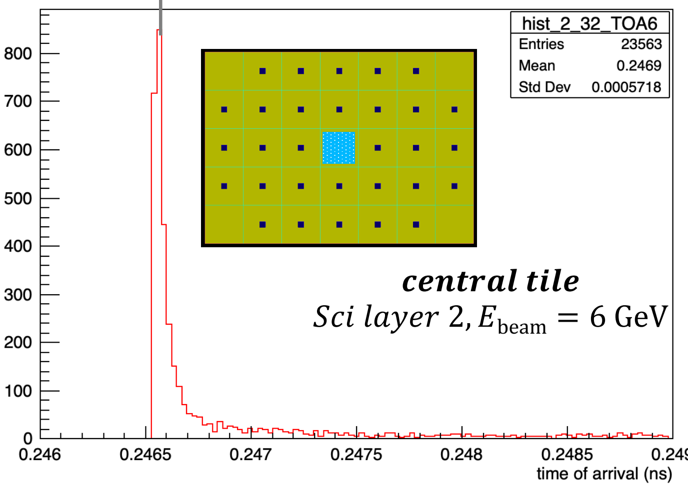

- Beam: n, $\gamma$: 1 – 12 GeV
- Physics: FTFP-BERT-EMZ → FTF parton, Bertini and pre-compound models for inelastic hadron-nucleus processes and the standard EM physics of GEANT4.
- Simple model with the following optical parameters of the scintillator:
  - Scintillator yield: 20 ph.e / MeV
  - Scintillator decay time: 2 ns
  - Measured time: arrival time of the first ph.e.

1. Collecting TOA in the whole Sci layer
2. Collecting TOA in only one tile in a layer

TOA ≈ 246 ps

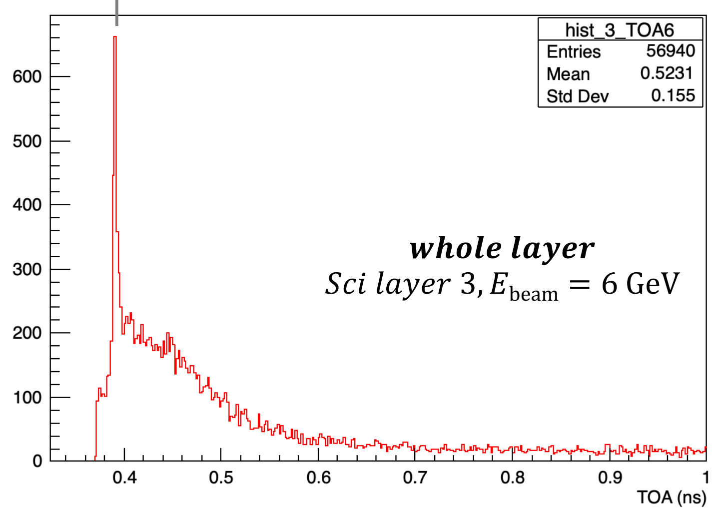
Photons

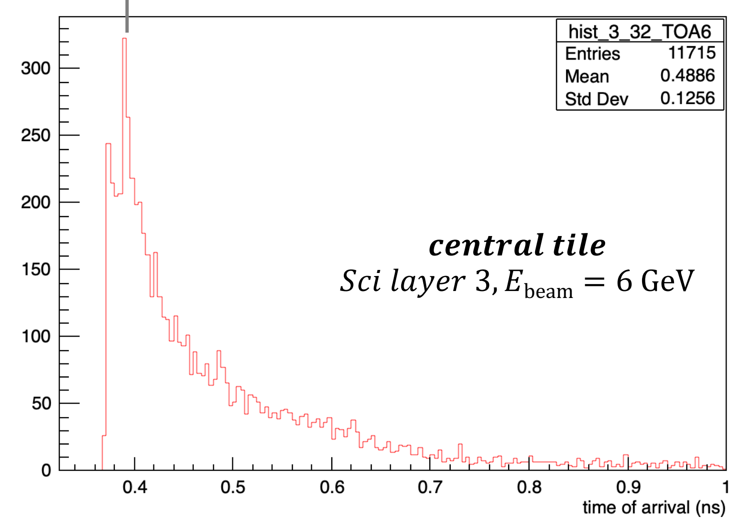



TOA ≈ 391 ps

Neutrons



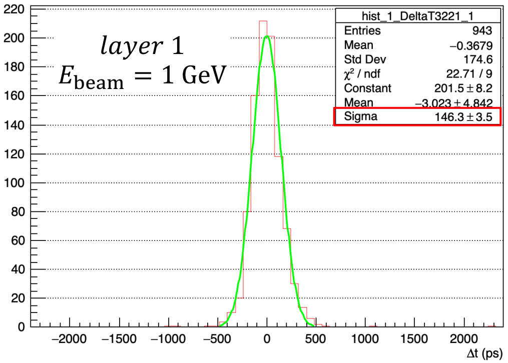




The time of arrival is the time of the energy deposit.
It means the time since the event in which the track belongs, was created.

## Time resolution in scintillator tiles (based on TOA)

Estimated as the standard deviation of Gaussian fit of the time interval between two hits (two different tiles in the same scintillator layer) by event

$$\sigma_{\Delta t} = \sigma(t_i - t_j)$$

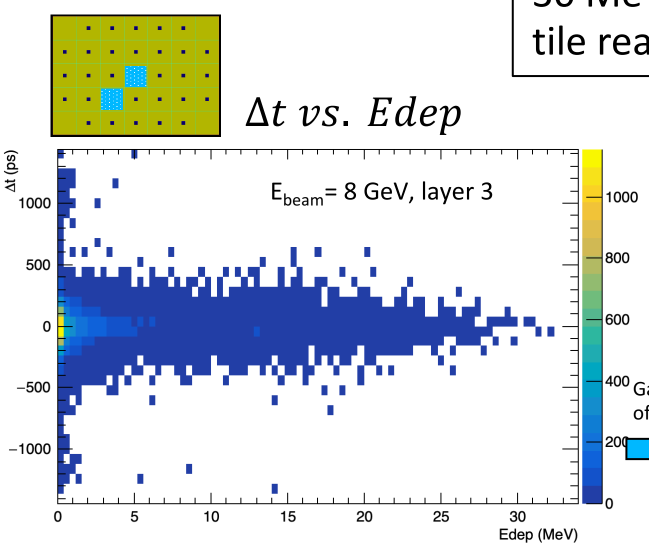



$time\ resolution\ of\ a\ tile = \sigma_{\Delta t}/\sqrt{2}$ (by weighting according to the fraction of hits)

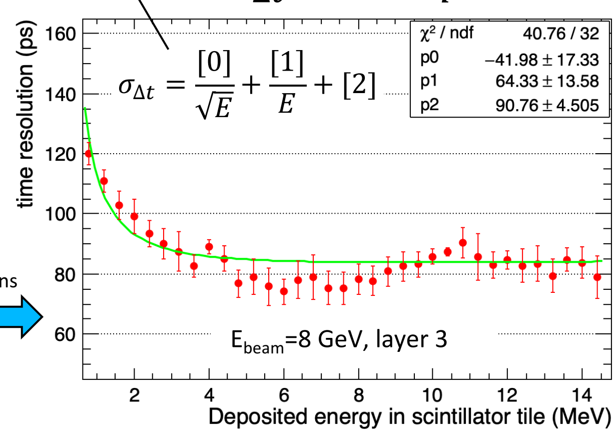
Time resolution of a single scintillator tile is not worse than $\sim\mathbf{300\ ps}$

30 MeV of energy deposit in a scintillator tile reaches ~85 $ps$ resolution

$\Delta t\ vs.\ Edep$

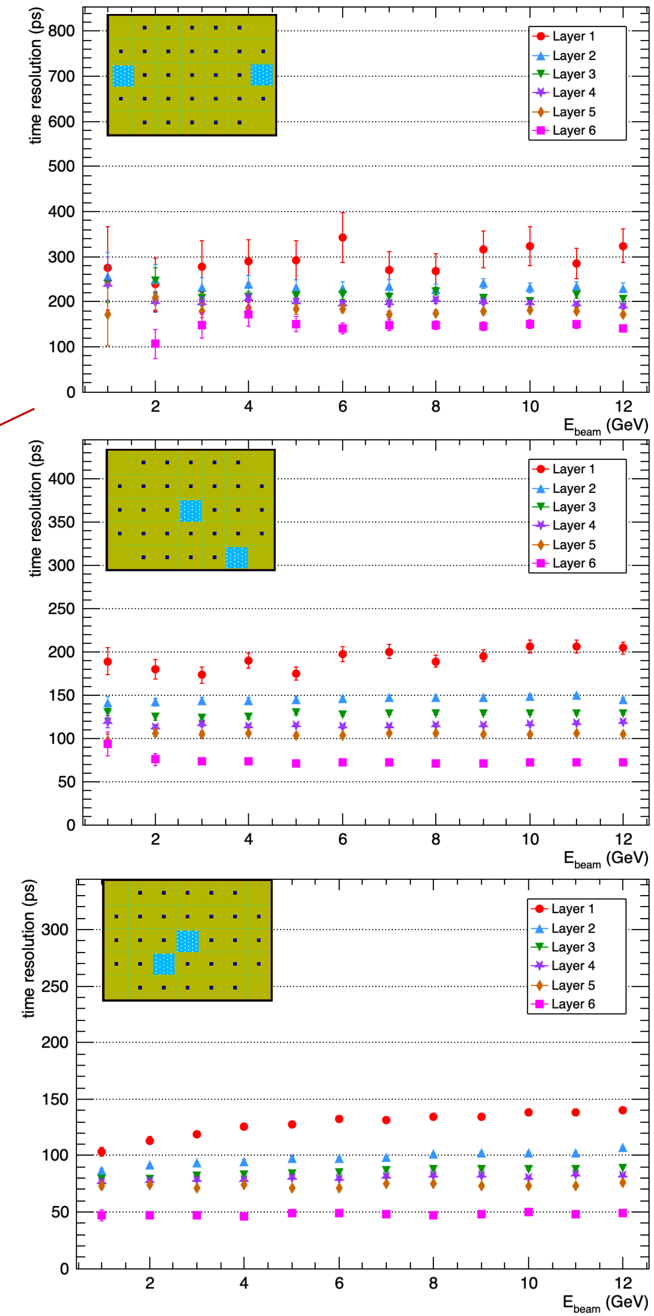



$\sigma_{\Delta t}\ vs.\ Edep$




**Time resolution for all layers**

Three combinations of tile pairs:



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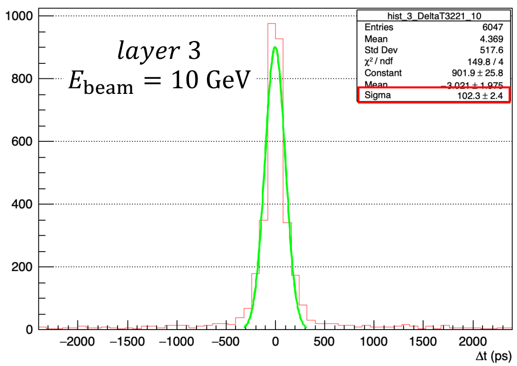
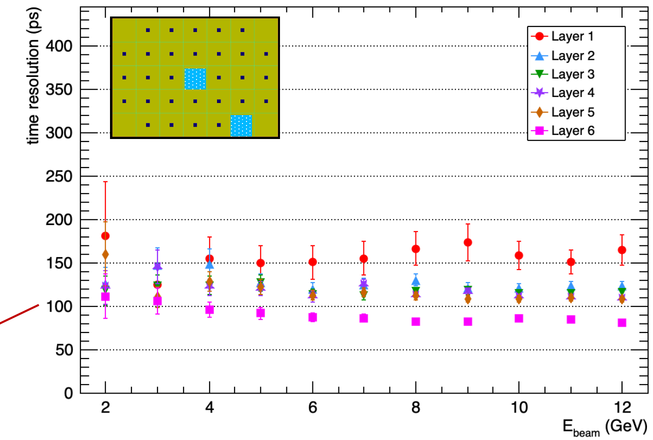


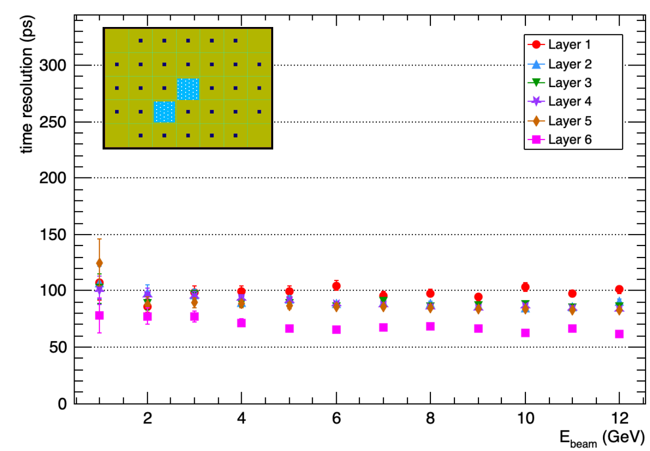

*time resolution of a tile* $= \sigma_{\Delta t}/\sqrt{2}$ (by weighting according to the fraction of hits)

Time resolution of a single Scintillator tile is not worse than $\sim$**170 *ps***

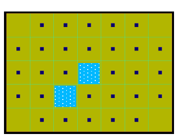
### Time resolution for all layers

Two combinations of tile pairs:

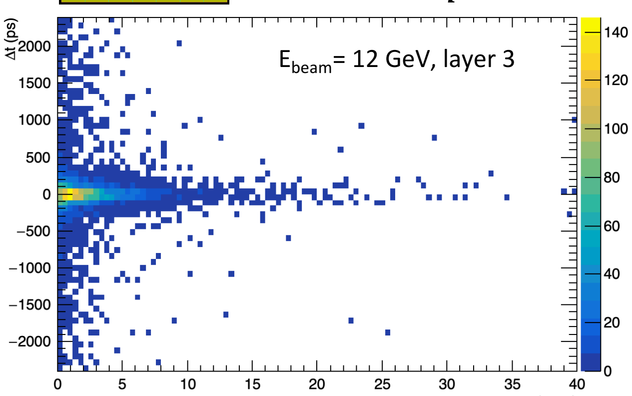



8 MeV of energy deposit in a scintillator tile reaches ~68 *ps* resolution

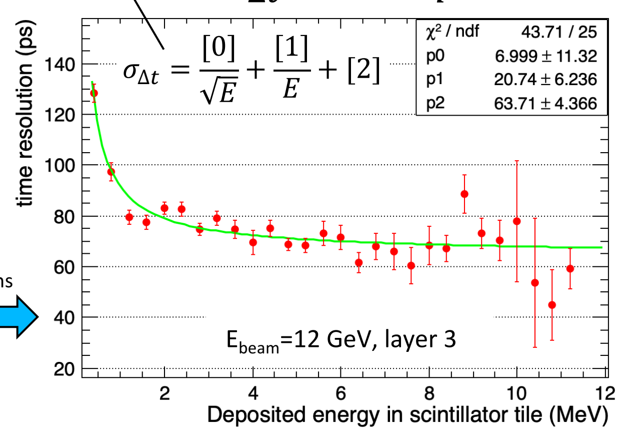


$\Delta t$ *vs. Edep*

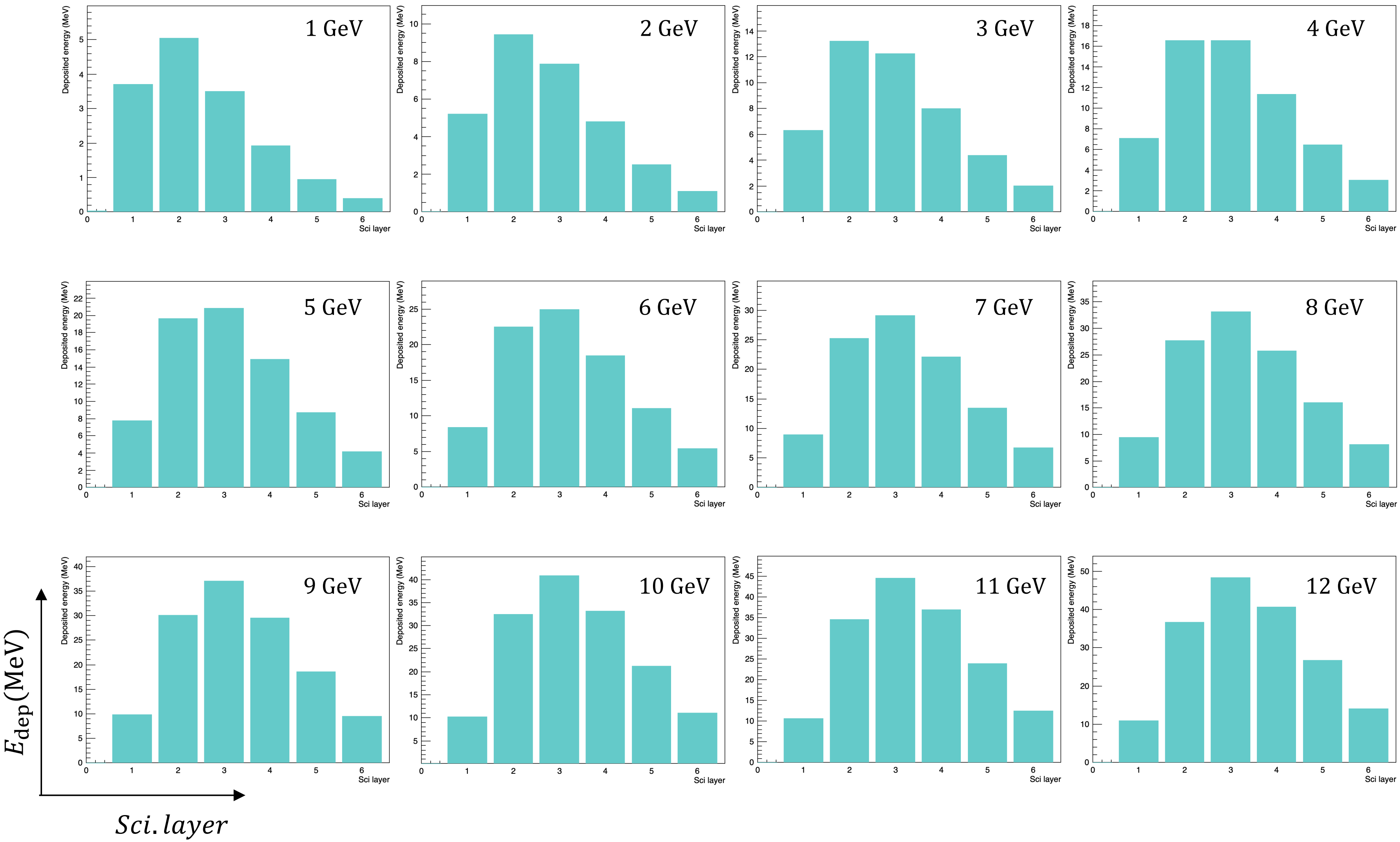



Gaussian fit of projections

$\sigma_{\Delta t}$ *vs. Edep*



## Longitudinal distribution of deposited energy in scintillator layers by event



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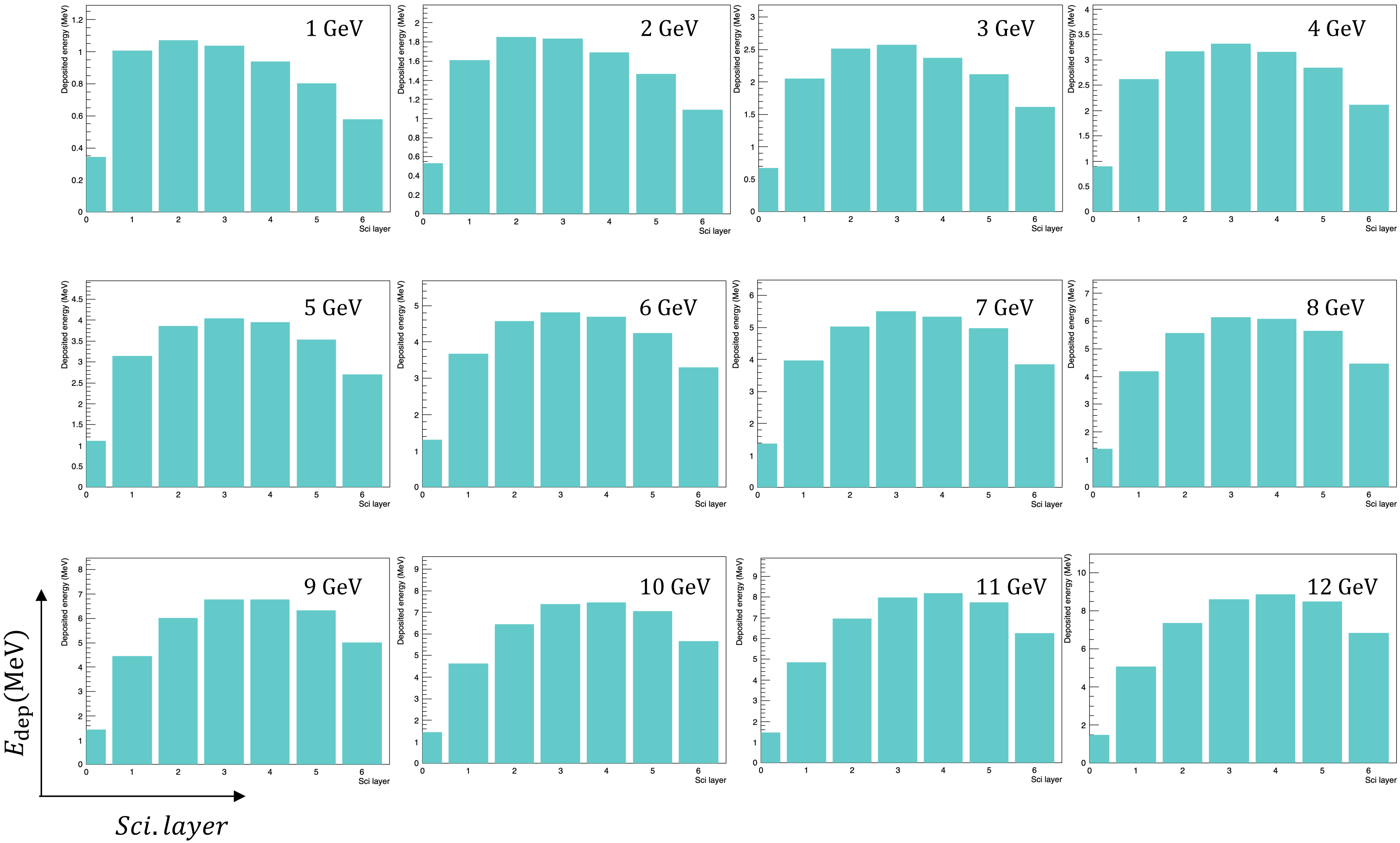
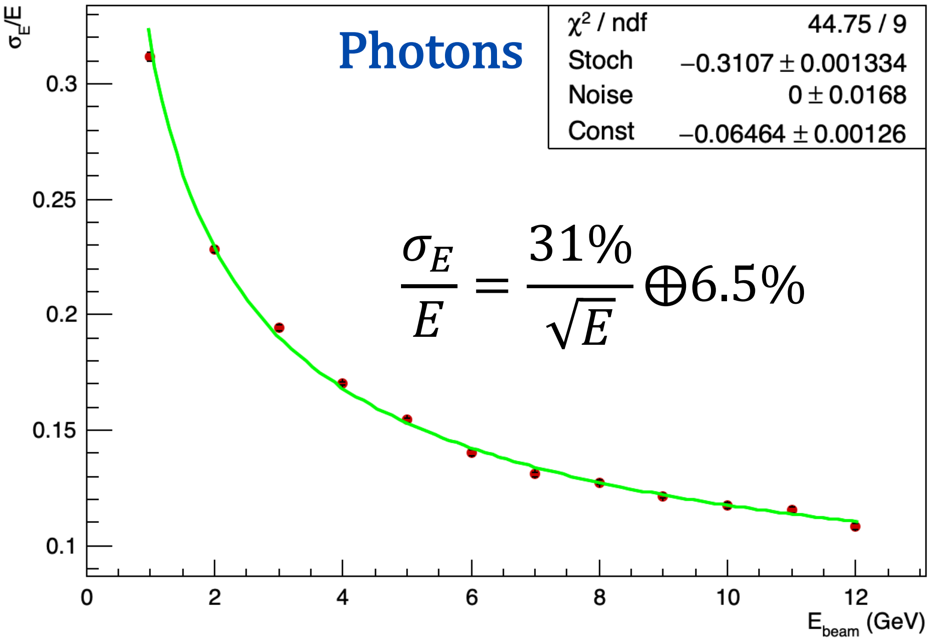
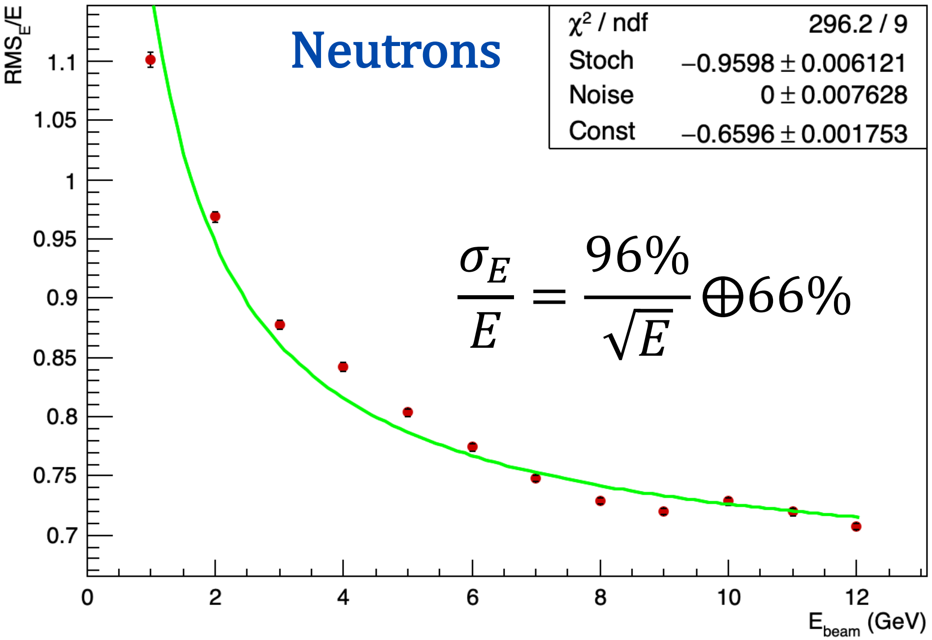





Mean number of tiles hit per event :

- ✓ Photons: $\approx 25$
- ✓ Neutrons: $\approx 6$

Mean energy deposit in scintillator layers per hit:

- ✓ 1 ÷ 4 MeV for photons
- ✓ 1 ÷ 2.5 MeV for neutrons.

## Installation

- ✓ One prototype is ready and placed in the supporting rails between the two beam pipes.

It consists of:

- plastic scintillator plastic tiles with direct SiPM readout and Copper absorber plates.
- 7 sensitive layers of 5 mm thickness (the first one is a charge particle veto) with 31 scintillator tiles each one.
- It is assembled from individual planes, each of which has a PCB with SiPMs 3x3 $mm^2$ (MicroFC-30050-SMT, produced by On Semiconductor), the scintillator tiles and the Copper absorber plate. The SiPMs and the tiles are organized into matrix 7x5. In this stage the plane sizes remain constant for all plates.

- ✓ The second prototype will be installed in June/2025
- ✓ The barrels with the PCB and connectors are ready, but not yet installed on the cryostat.

## Simulation

- ✓ The simulation of the $1^{th}$ stage detector was done within the GEANT4 framework.
- ✓ The resolution expected for photons is $\frac{31\%}{\sqrt{E}} \oplus 6.5\%$ and for neutrons $\frac{96\%}{\sqrt{E}} \oplus 66\%$.
- ✓ The mean number of tiles hit per event is ≈25 for photons and ≈6 for neutrons.
- ✓ The mean energy deposit in scintillator layers per hit is 1÷4 MeV for photons and 1÷2.5 MeV for neutrons.
- ✓ The time resolution of a single scintillator tile is better than 300 ps for photons and 170 ps for neutrons.
- ✓ The GeoModel code describing the geometry of ZDC for phase-0 is ready.

## Plan for the first collisions

- ✓ Test detector in the operating conditions of isolation vacuum and liquid Nitrogen temperature.
- ✓ Calibrate SiPMs at low temperature.
- ✓ Get statistics from beam collisions for gamma photons and neutrons.
- ✓ Compare to Monte Carlo simulations.
- ✓ Try to get luminosity measurements.

## TODO

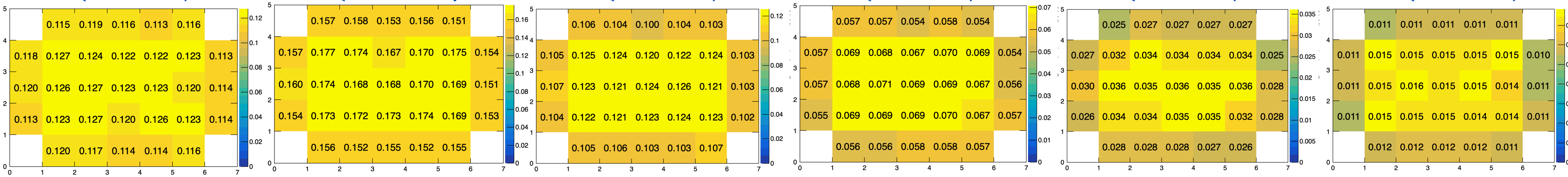
- ✓ Coding the geometry to be used in the SpdRoot framework.
- ✓ Complete the MC simulations to define the accuracy to which the neutrons can be detected in the first stage.

# BACKUP

## Map of energy deposit in the scintillator tiles per each layer

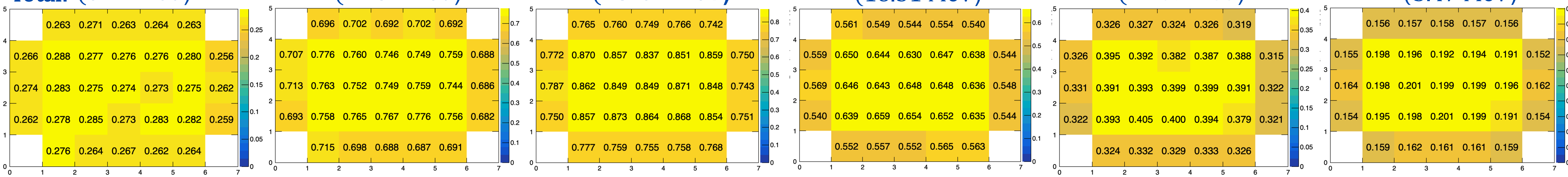
### 1 GeV

*Sci layer 1* **Total:** (3.71 MeV) | *Sci layer 2* **(5.05 MeV)** | *Sci layer 3* (3.51 MeV) | *Sci layer 4* (1.93 MeV) | *Sci layer 5* (0.95 MeV) | *Sci layer 6* (0.40 MeV)



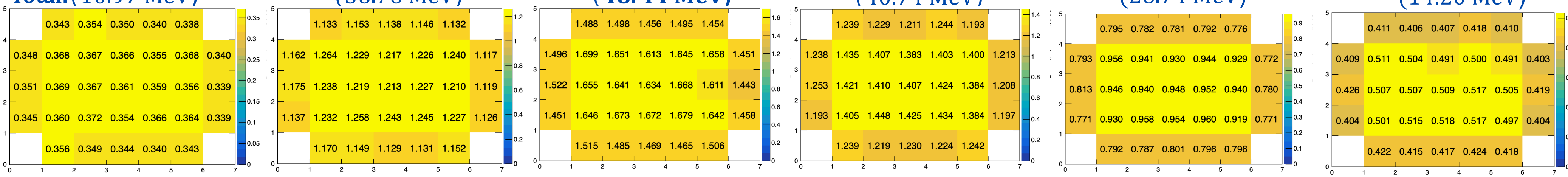

### 6 GeV

*Sci layer 1* **Total:** (8.42 MeV) | *Sci layer 2* (22.51 MeV) | *Sci layer 3* **(25.02 MeV)** | *Sci layer 4* (18.51 MeV) | *Sci layer 5* (11.09 MeV) | *Sci layer 6* (5.47 MeV)



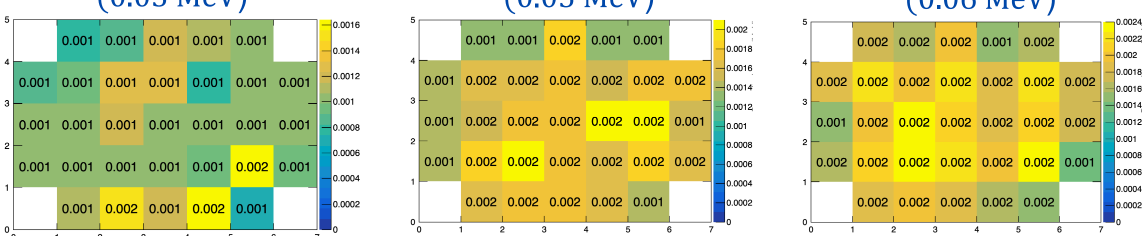

### 12 GeV

*Sci layer 1* **Total:** (10.97 MeV) | *Sci layer 2* (36.76 MeV) | *Sci layer 3* **(48.44 MeV)** | *Sci layer 4* (40.74 MeV) | *Sci layer 5* (26.74 MeV) | *Sci layer 6* (14.20 MeV)




***Sci layer 0***
Charged particle veto

1 GeV (0.03 MeV) | 6 GeV (0.05 MeV) | 12 GeV (0.06 MeV)

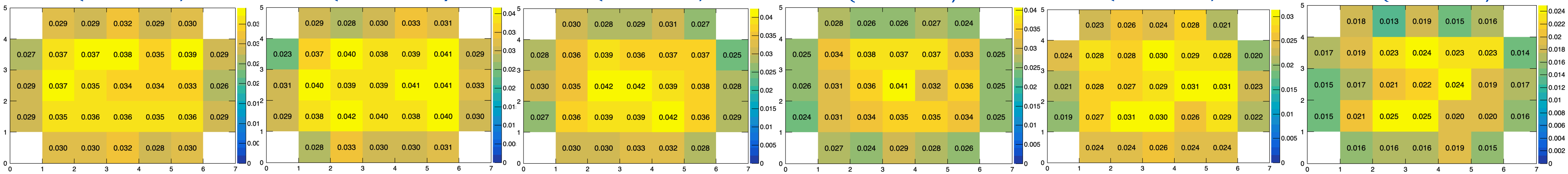


# Neutrons

## Map of energy deposit in the scintillator tiles per each layer

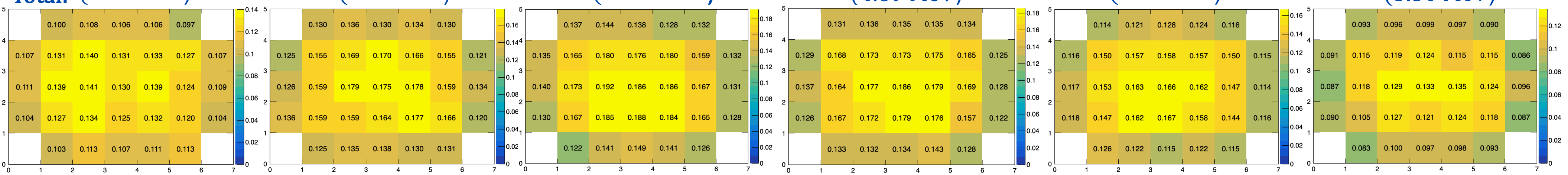
**1 GeV**

*Sci layer* 1 — **Total:** (1.00 MeV) | *Sci layer* 2 — **(1.07 MeV)** | *Sci layer* 3 — (1.04 MeV) | *Sci layer* 4 — (0.94 MeV) | *Sci layer* 5 — (0.80 MeV) | *Sci layer* 6 — (0.58 MeV)



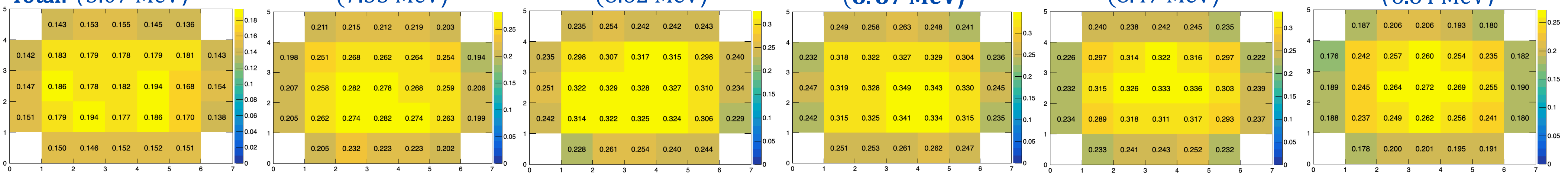
**6 GeV**

*Sci layer* 1 — **Total:** (3.68 MeV) | *Sci layer* 2 — (4.57 MeV) | *Sci layer* 3 — **(4.81 MeV)** | *Sci layer* 4 — (4.69 MeV) | *Sci layer* 5 — (4.24 MeV) | *Sci layer* 6 — (3.30 MeV)



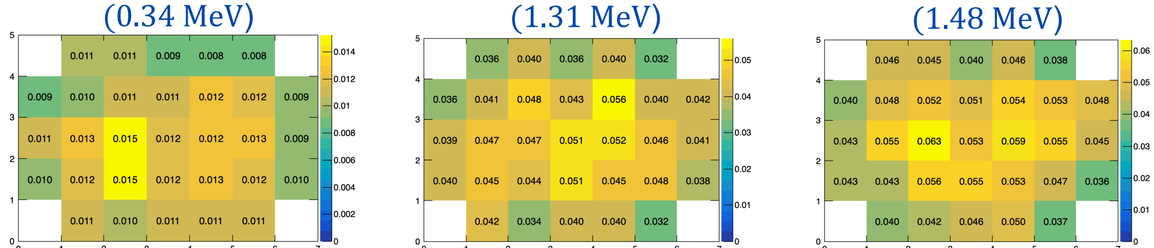
**12 GeV**

*Sci layer* 1 — **Total:** (5.07 MeV) | *Sci layer* 2 — (7.35 MeV) | *Sci layer* 3 — (8.62 MeV) | *Sci layer* 4 — **(8.87 MeV)** | *Sci layer* 5 — (8.47 MeV) | *Sci layer* 6 — (6.84 MeV)

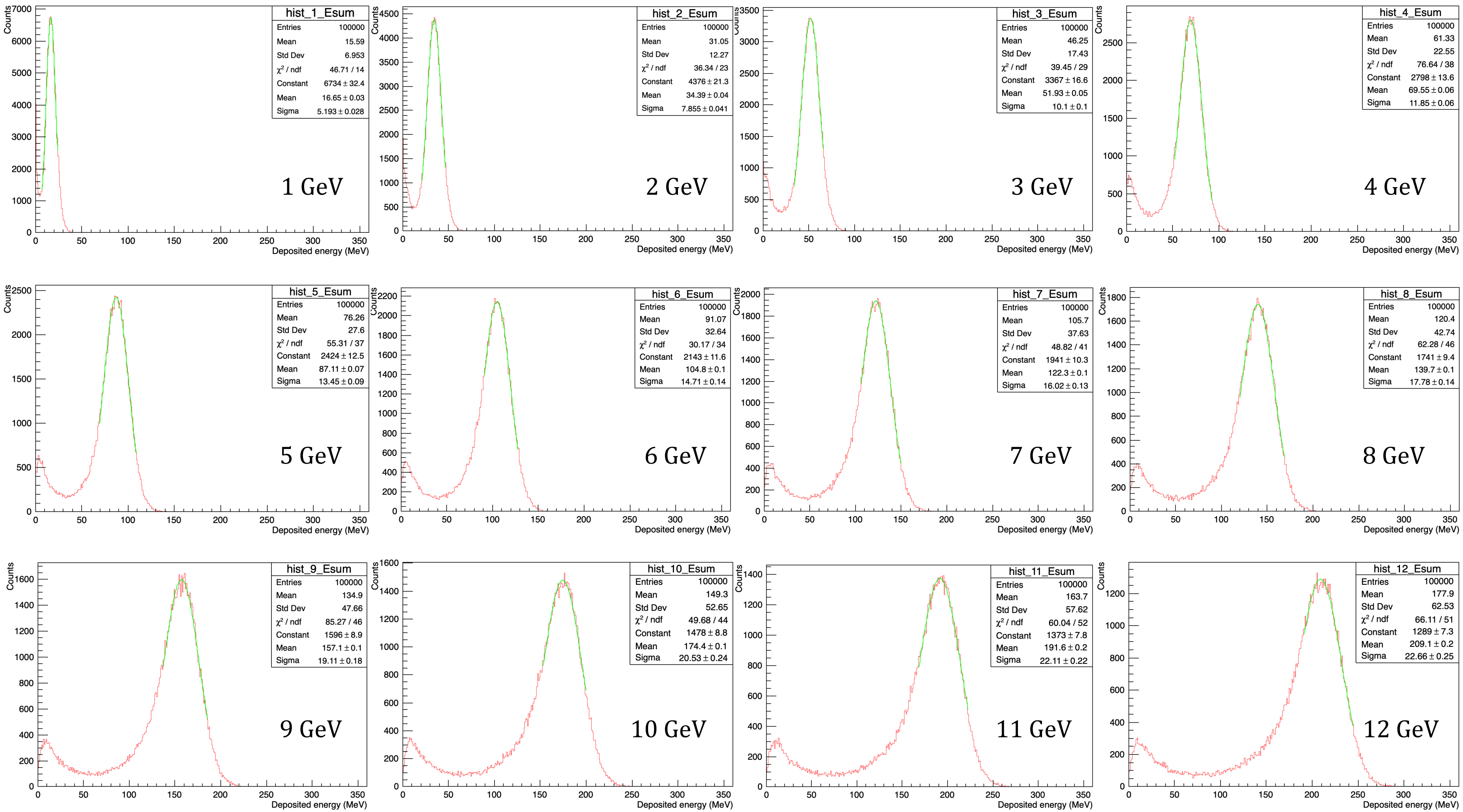


***Sci layer* 0**
Charged particle veto

1 GeV (0.34 MeV) | 6 GeV (1.31 MeV) | 12 GeV (1.48 MeV)



## Deposited energy distribution in scintillator layers (derived from each event)



## Deposited energy distribution in scintillator layers (derived from each event)

$E_{dep} > 1$ MeV