Incident angle effect analysis with the SDHCAL

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on behalf of the SDHCAL group

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cfp CIEMAT física de partículas

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Context & Setup

The objective is to check the effect of the incident angle of the particles in the efficiency, multiplicity, energy reconstruction, etc. using the SDHCal as detector.

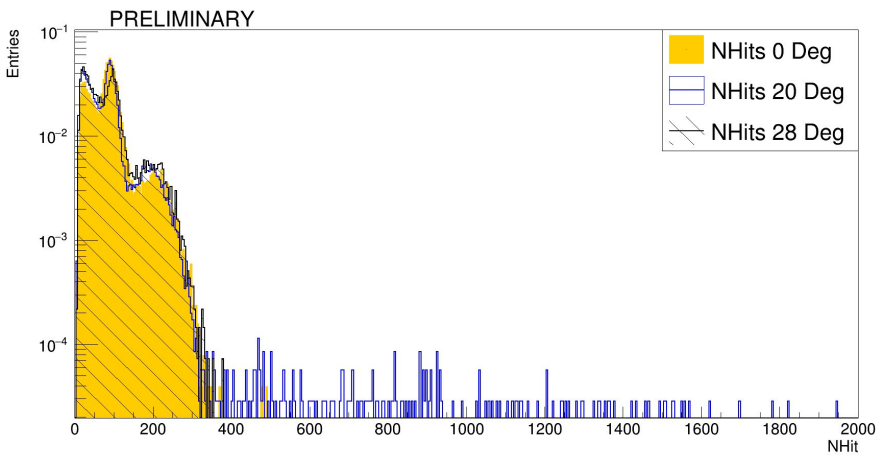
Data taking was during two test beam in the SPS (May 2015) and PS (June 2015):

- Wide range of energies: 1 - 10 Gev (PS) and 10 - 70 GeV (SPS).
- Several rotation angles: 0º, 20º and 22º (Later computed with muons).

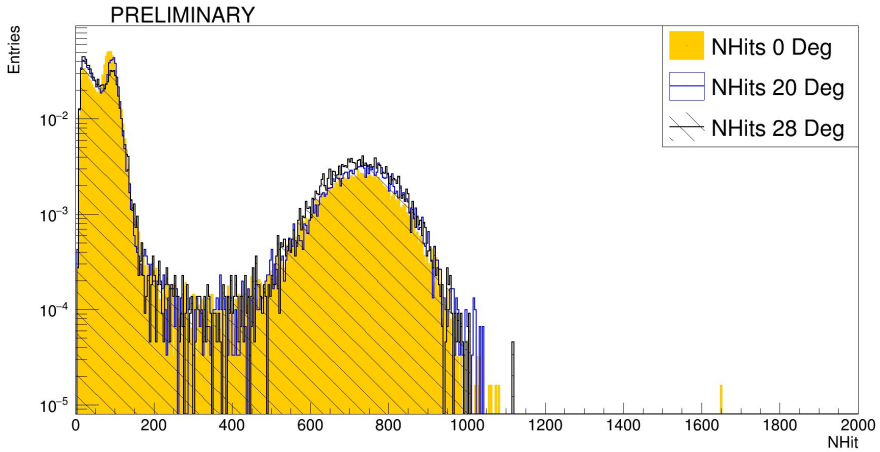
The SDHCal had 49 GRPC layers installed (multigap and other chambers excluded from the analysis).

Beam NHit distributions, example 40GeV

10 GeV Pion runs



40 GeV Pion runs



Particles selection variables

Density: $\rho = \frac{nHit}{nLayers}$

nHit → total number of hits in the detector

nLayers→ number of layers with signal

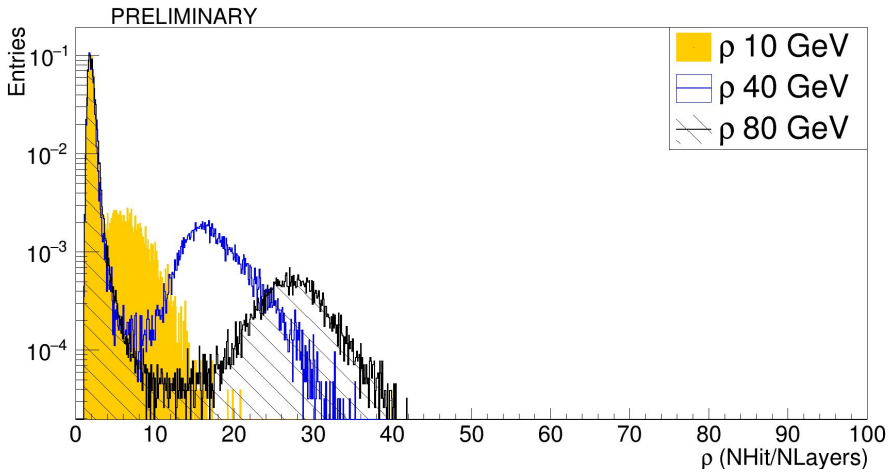
Second maximum of hits in a single layer: Hit_{Max2}

Penetrability Condition (P.C.):

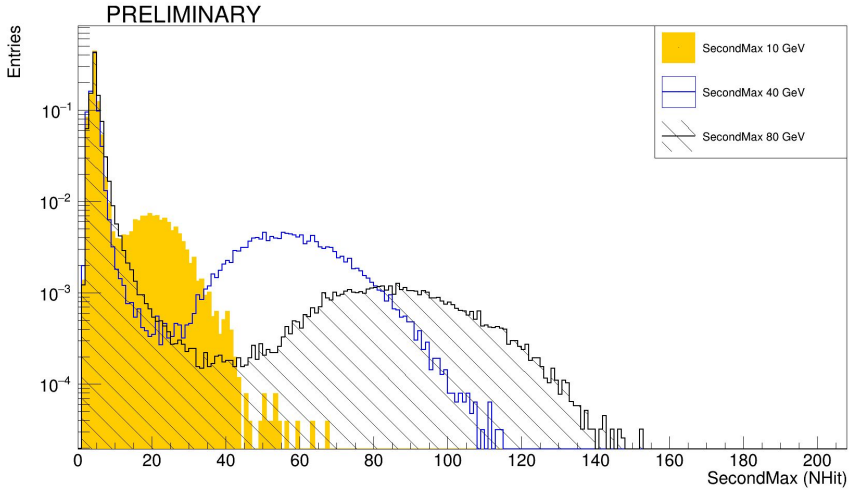
- Layers 00-11: at least 9 with signal
- Layers 12-23: at least 9 with signal
- Layers 24-35: at least 9 with signal
- Layers 36-48: at least 9 with signal

Particle selection variables

40 GeV Density 22º



40 GeV SecondMax 22º



Selected cuts: Muons/Cosmics →(density < 2.2 or SecondMax < 6) and P.C. separates cosmics and muons
Showers → All events that not fall in the above selection

Track reconstruction

Steps for the reconstruction of the track:

- A first approximation by taking the mean value of all clusters in each layer.
- This approximation is fitted to a straight line.
- Then the closest cluster with a distance less than 20.8 mm in X and Y to the previous approximation is selected for each layer. (It is possible that a layer has no cluster selected)
- The final track is the set of selected clusters fitted to a straight line
- Tracks with less than 5 layers with clusters selected are discarded

Finally the following cuts to the slope in the Y axis are applied:

$$|\alpha| < 0.05$$

Angle computing

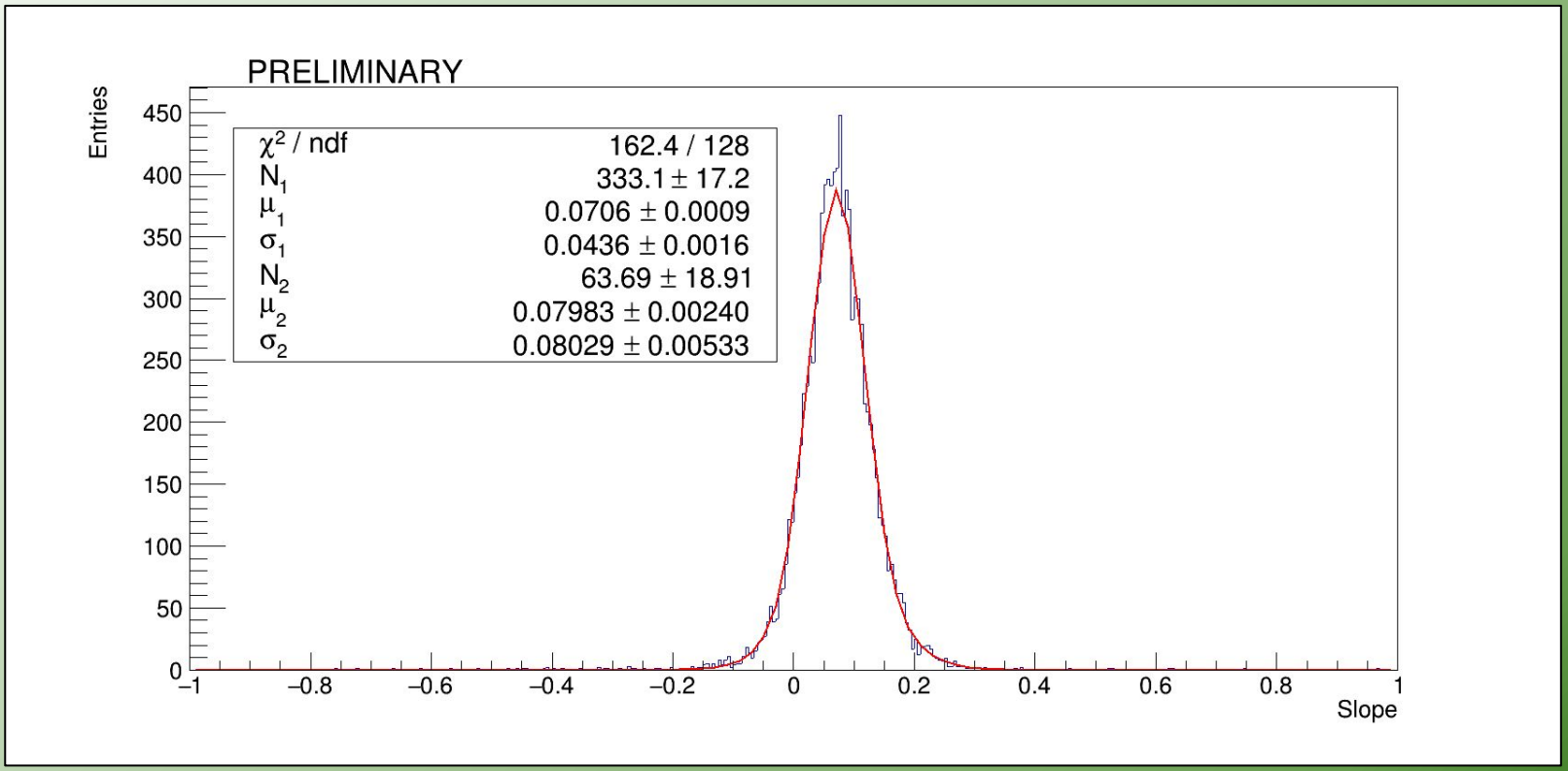
So far the angle of the data have been approximated from measurements during the test beam. However, we will compute a more precise value of the incident angle in the X axis from the tracks of the muons.

The distributions of the slopes are fitted to sum of two Gaussians to take into account the background of tracks not properly reconstructed.

$$Gauss(x) = Ne^{-\frac{(\mu-x)^2}{2\sigma^2}}$$

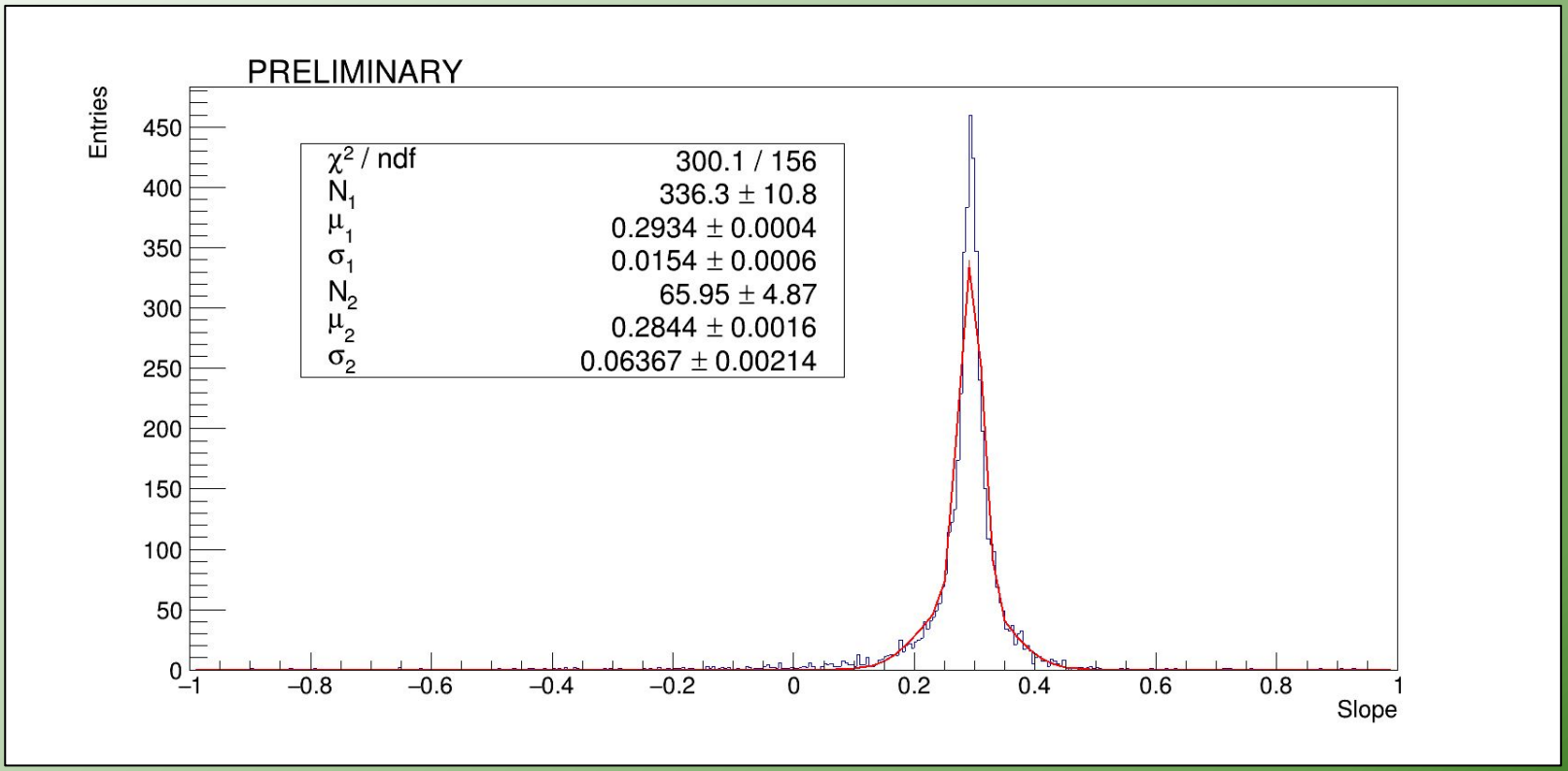
$$f(x) = Gauss_1(x) + Gauss_2(x)$$

Angle computing - 0º PS



$$\theta_X = 4.04$$

Angle computing - 20º SPS

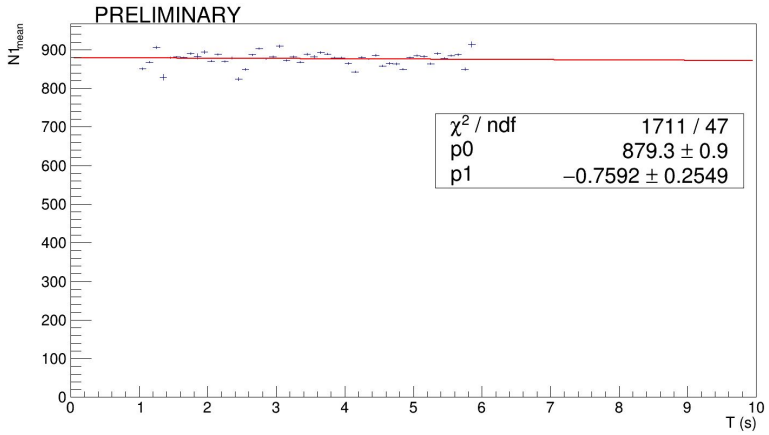


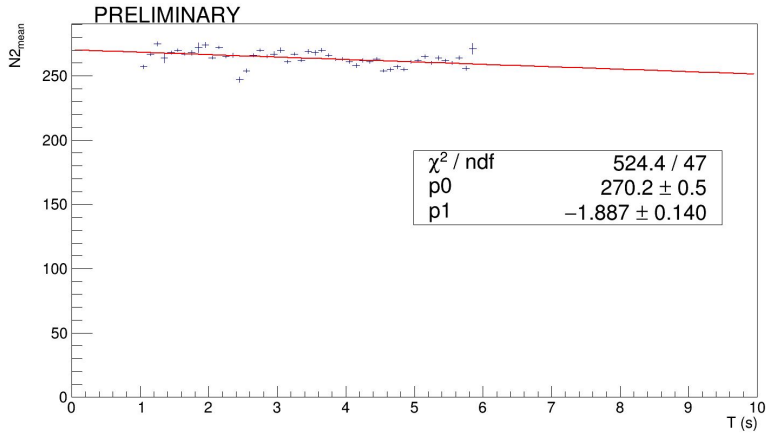
$$\theta_X = 16.35$$

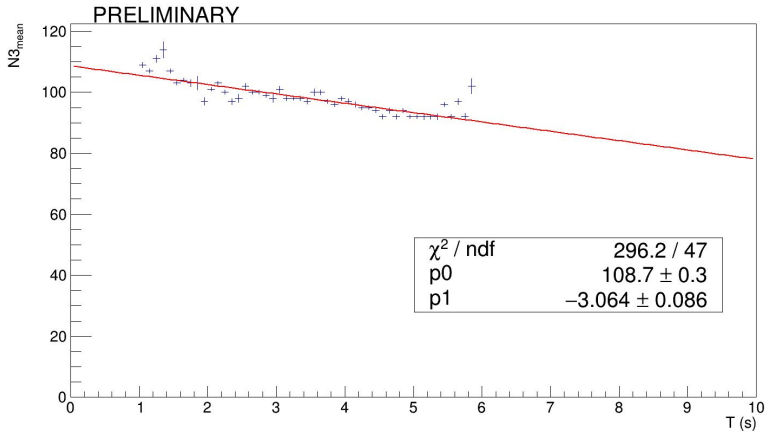
Saturations 80GeV - 0 Deg

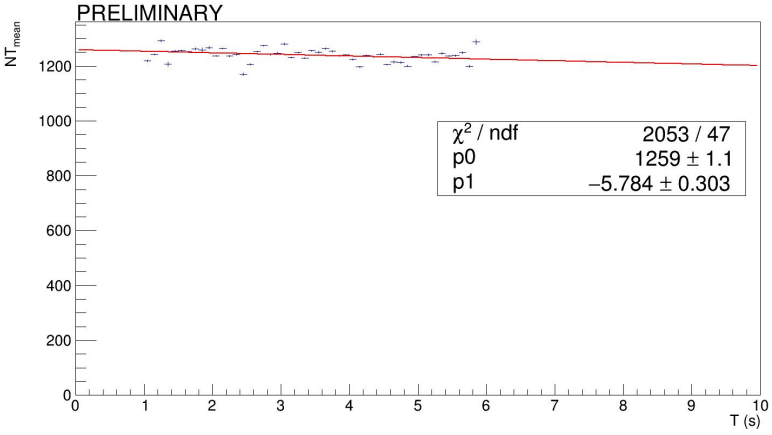
$$N_j = N_j - \lambda_j T$$

$$\Delta Bin = \sqrt{\frac{Bin_C}{N_{Entries}}}$$









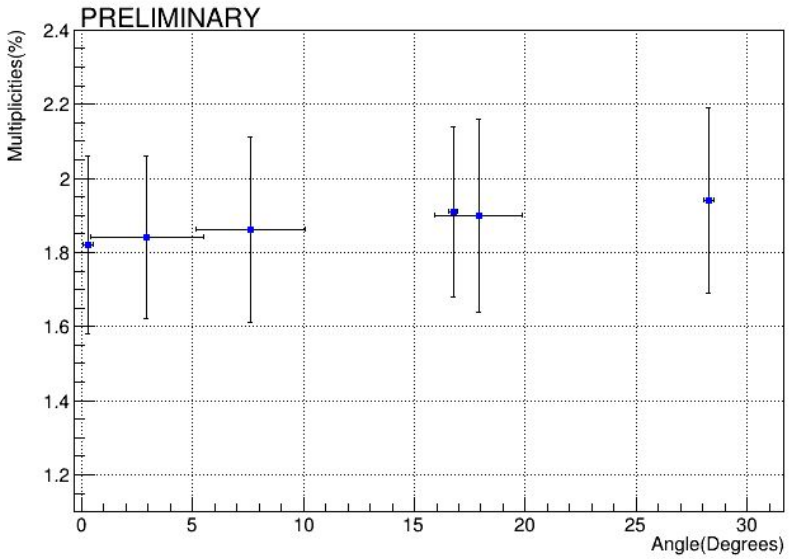
Muons analysis

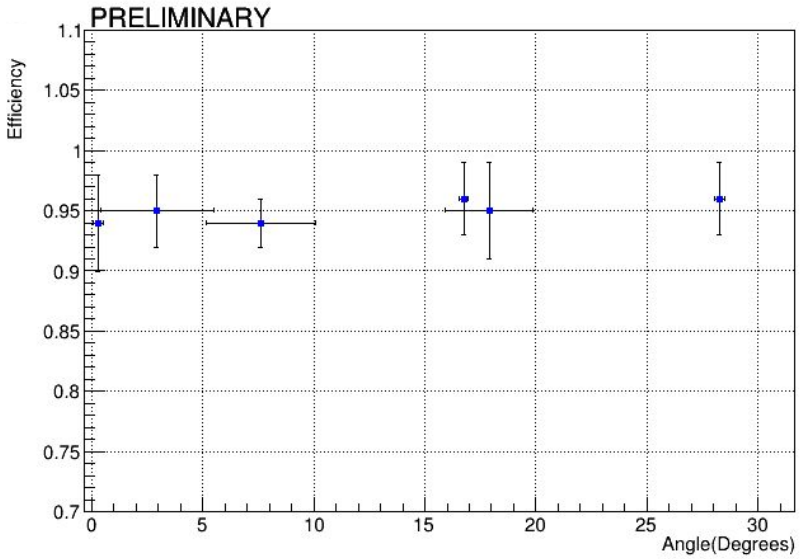
We can use the track of muons to compute the efficiency and multiplicity of each GRPC layer in the prototype. First we recompute the track of the muon using all the chambers but the one we are going to study then:

Efficiency → The layer is efficient if it has a cluster of hits closer than 3 cm in X and Y. The final efficiency is the sum of times the layer has been efficient divided by the total number of muons analyzed.

Multiplicity → If the layer is efficient then the multiplicity is the size of the cluster found Then we take the mean by all muons analyzed.

Analysis results all angles





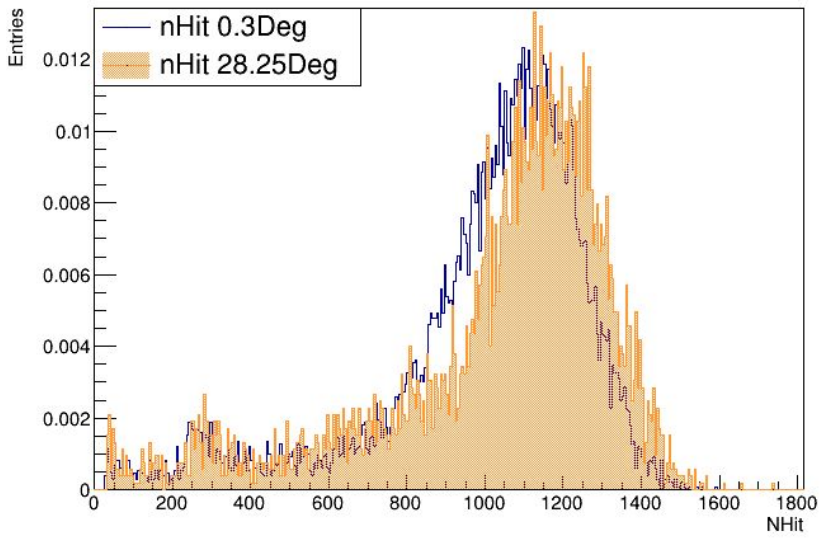
$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

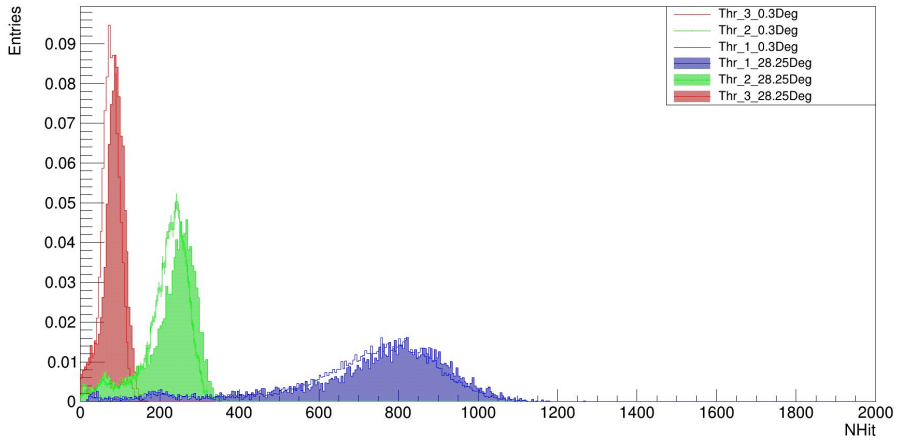
Hit distributions comparison

The effect of the incident angle is also present in the hit distributions and it translates into an effect in the energy reconstruction.

Total nHits distribution



Threshold distributions



Energy parametrization

Energy is parametrized as a function of the number of hits per threshold.

$$E_{Reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$

$$\alpha = \alpha_0 + \alpha_1 N_T + \alpha_2 N_T^2$$

$$\beta = \beta_0 + \beta_1 N_T + \beta_2 N_T^2$$

$$\gamma = \gamma_0 + \gamma_1 N_T + \gamma_2 N_T^2$$

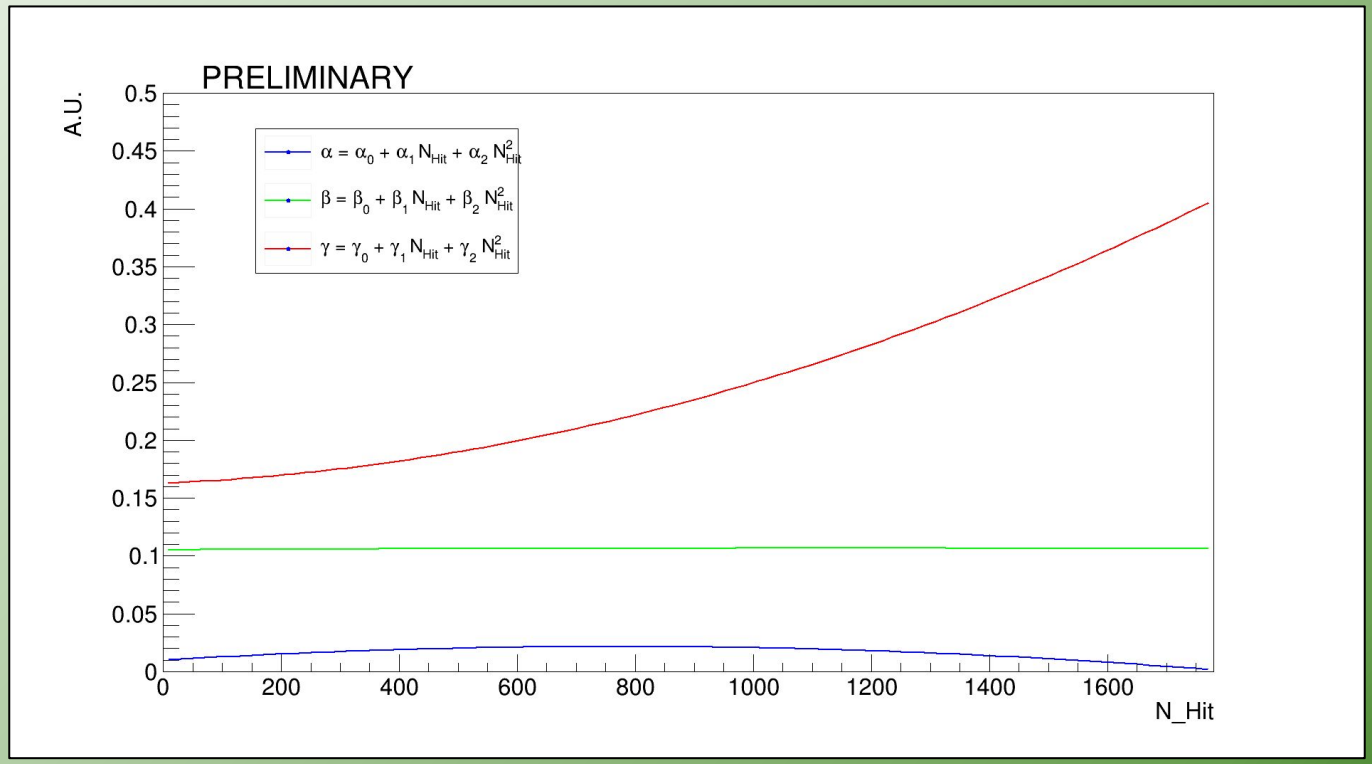
$$N_T = N_1 + N_2 + N_3$$

The set of optimal parameters are obtained from minimizing:

$$\chi^2 = \sum_{i=1}^{N} \frac{\left(E^i_{Beam} - E^i_{Reco}\right)^2}{\sqrt{E^i_{Beam}}}$$

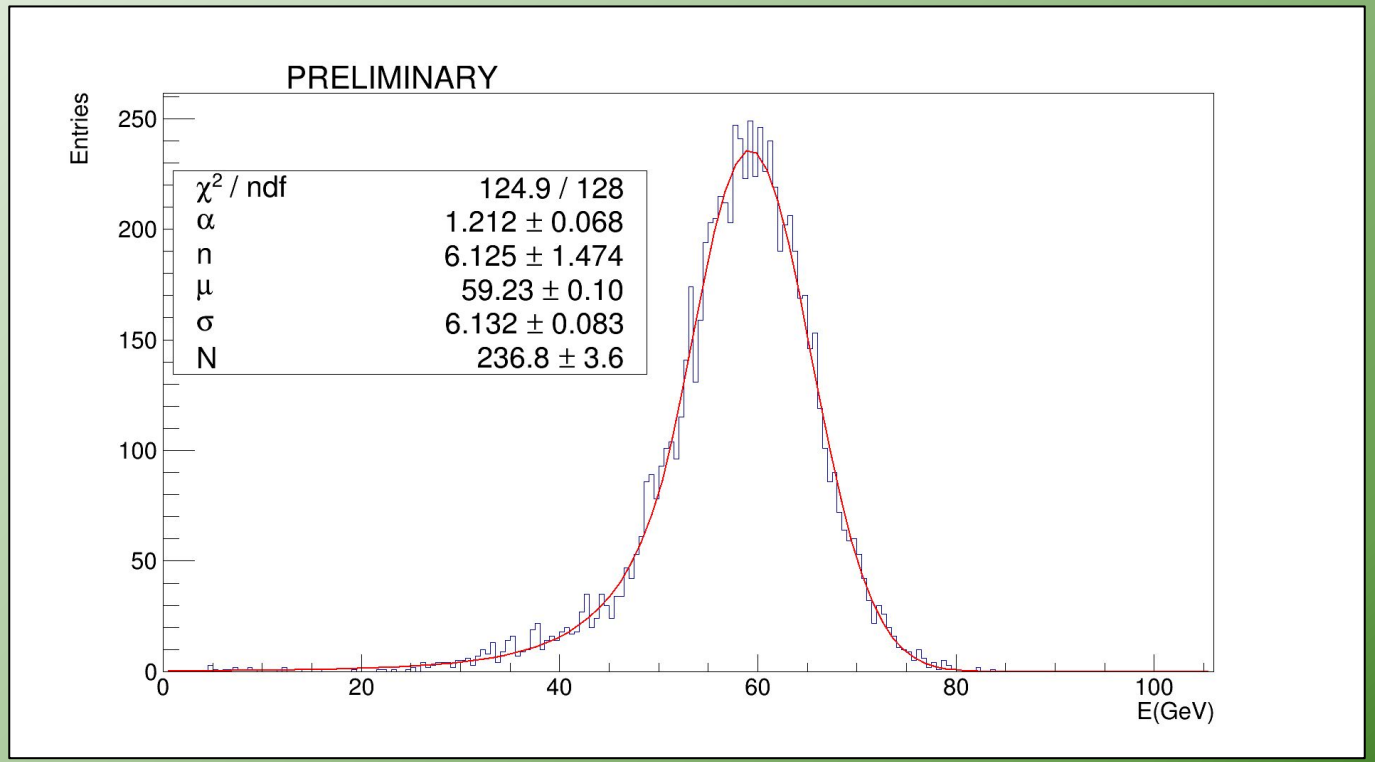
EReco parameters used in all angles

α, β *and* γ



EReco 60 GeV - 0º

The energy distributions are fitted to a CB function to obtain the final value of the energy for the run.



Linearity, resolution and deviations.

Linearity is computed as a fit to a straight line of $E_{Reco}\ vs\ E_{Beam}$ where $\Delta E_{Reco} = \sigma$

Deviations from linearity are relative differences of the previous plot:

$$Dev = (E_{Beam} - E_{Reco})/E_{Reco}$$

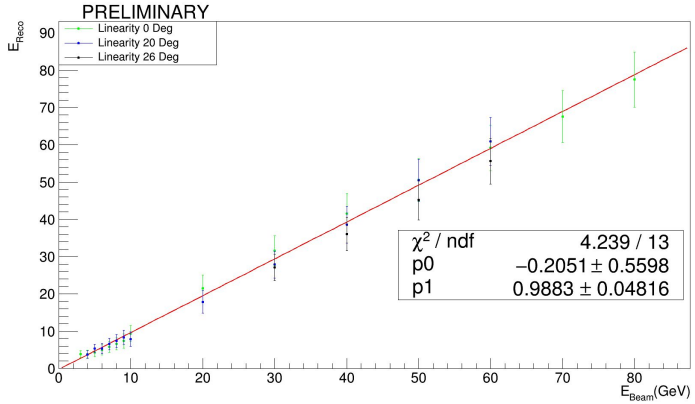
$$\Delta Dev = |Dev|\sqrt{(\frac{\sigma}{E_{Beam}-E_{Reco}})^2 + (\frac{\sigma}{E_{Reco}})^2}$$

Resolution is computed as follows:

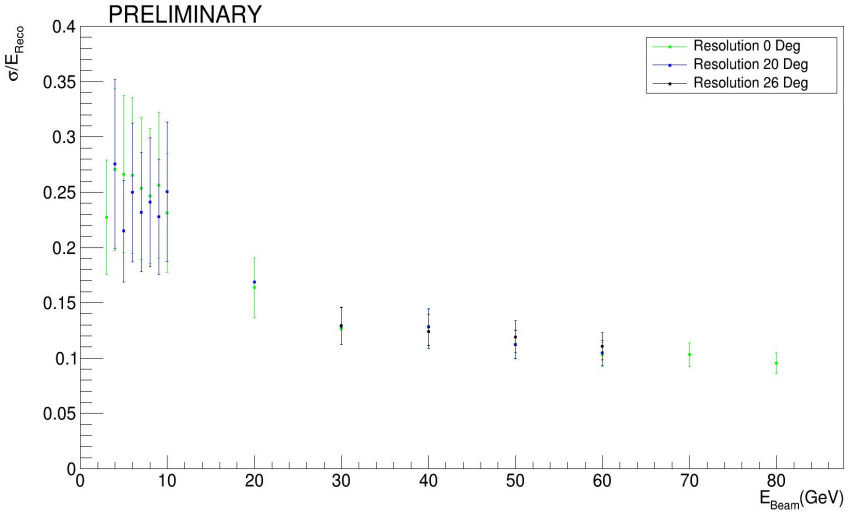
$$Res = \frac{\sigma}{E_{Reco}}$$

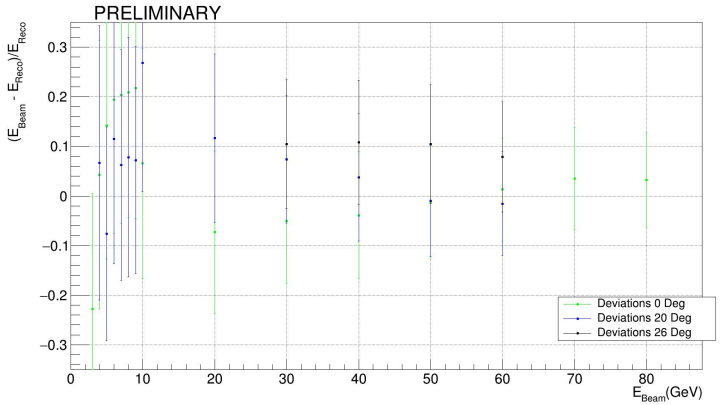
$\Delta Res = |Res|\sqrt{(\frac{\Delta\sigma}{\sigma})^2 + (\frac{\sigma}{E_{Reco}})^2}$ where $\Delta\sigma$ is taken from the energy fit

Linearity and resolution. All angles



$$N_j = N_j cos(\theta_X)$$





Summary

- There is a shift in the energy reconstructed depending on the incident angle of the particle.
- This effect can be taken into account and corrected to use the same set of parameters.
- An analysis note is being prepared about this topic.

$$N_j = N_j cos(\theta_X)$$

Backup

Raw Stream-Out & Trivent

Raw *.slcio* byte collections are converted into CalorimeterHits then Trivent does the time event reconstruction and encoding of the hits.

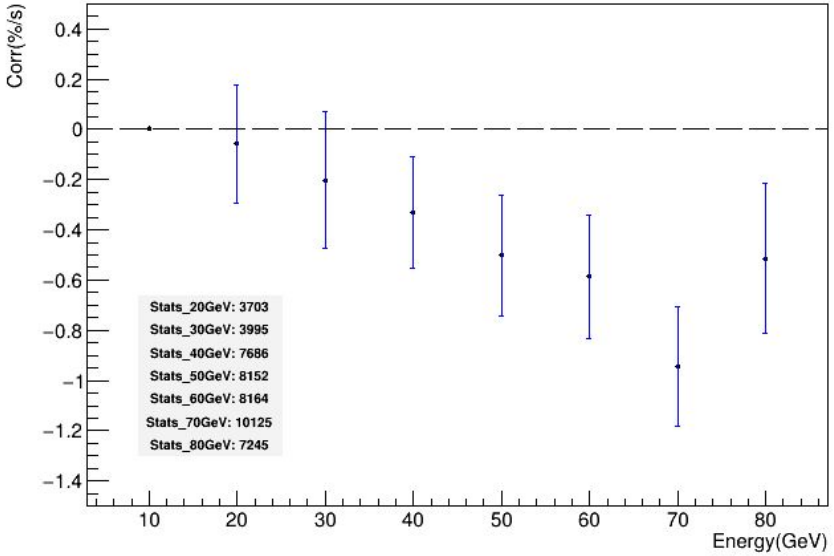
The raw data from 2015 had a DIF header size of 24 bytes and the Slow Control data was not extracted. Before Trivent all the hits from ASICs firing all 64 pad were removed.

Cuts to the reconstructed events:

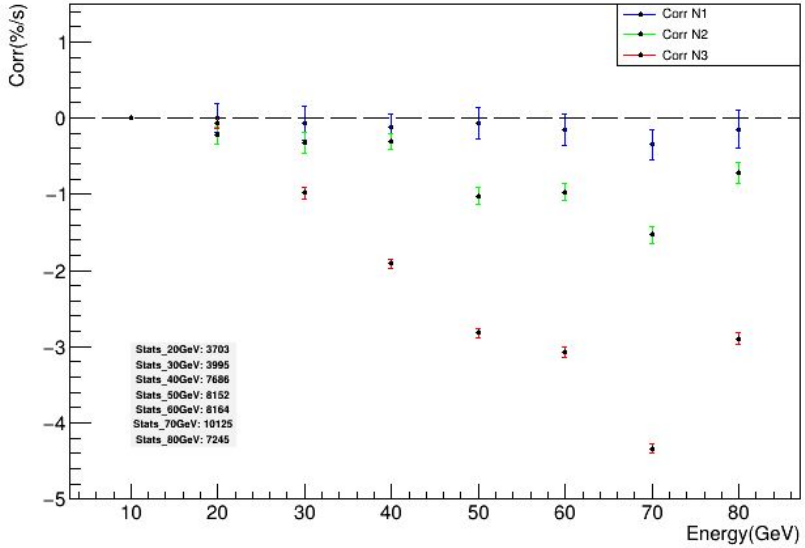
- Total NHit < 200000 in readout (remove electronic noise)
- NHit > 7 in the main bin to start time reconstruction
- NLayers with signal > 7 (removes noise in a single layer)
- NClose GRPCs with signal >= 5 (To be able to reconstruct tracks)
- NHit in the first 10 layers >= 4 & 6 layers >= 3 (This ensures the particle comes from the beam)

Saturation correction 0 Deg

Total Correction

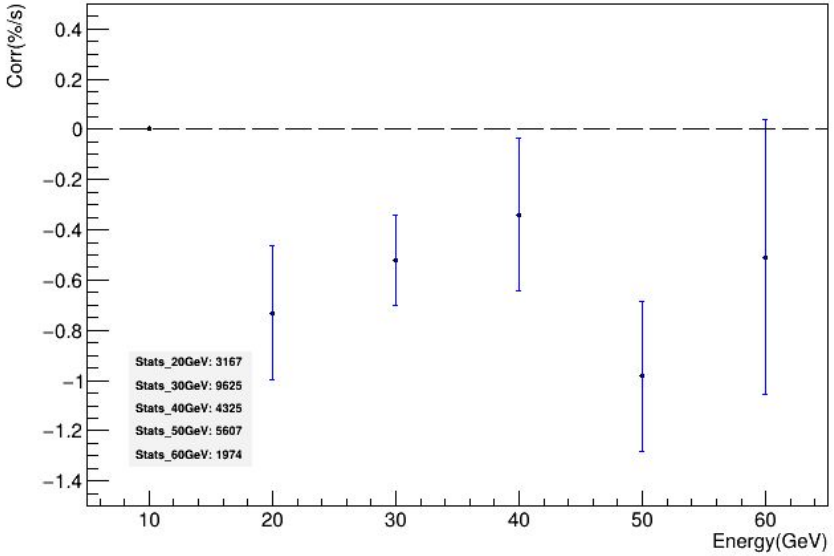


Per threshold correction

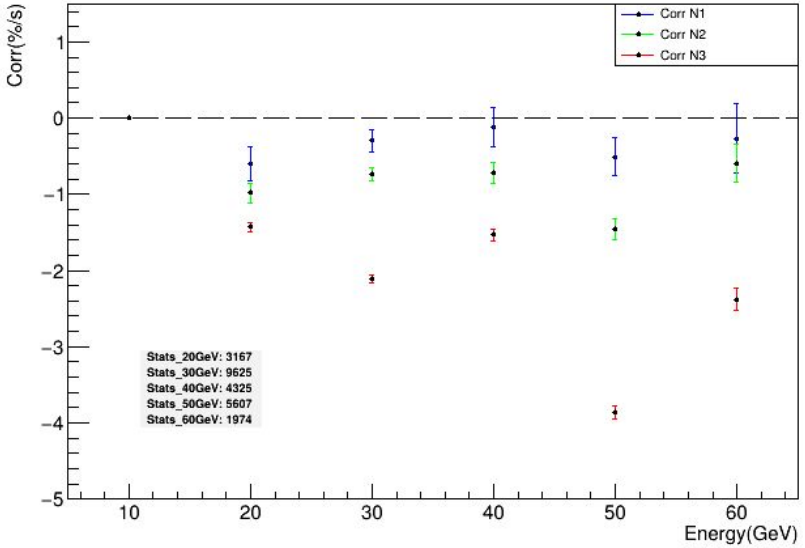


Saturation correction 20 Deg

Total Correction

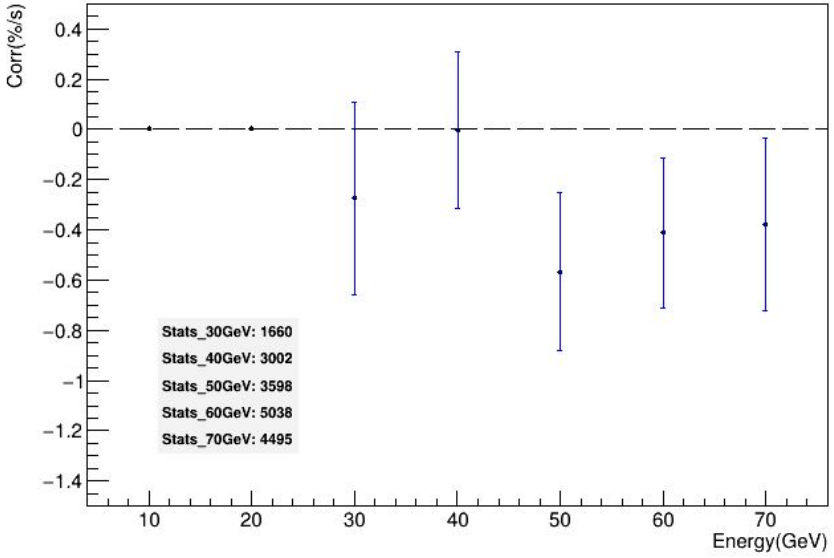


Per threshold correction

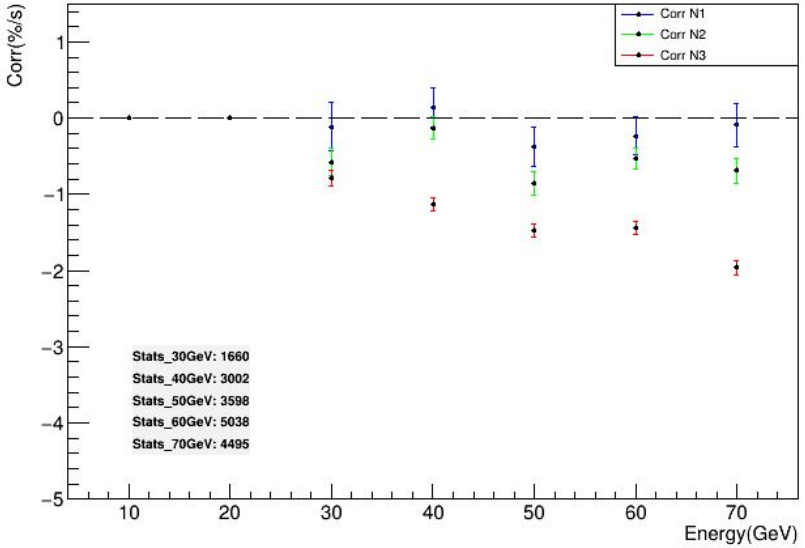


Saturation correction 22 Deg

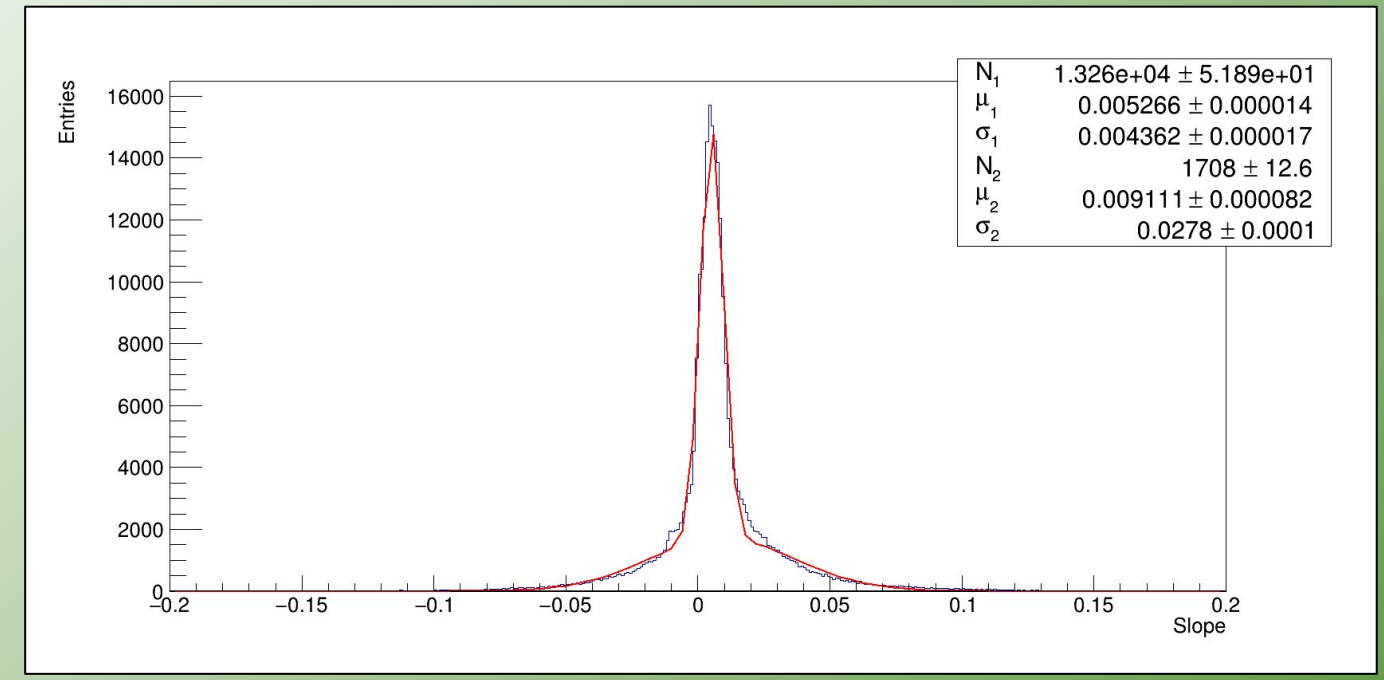
Total Correction



Per threshold correction

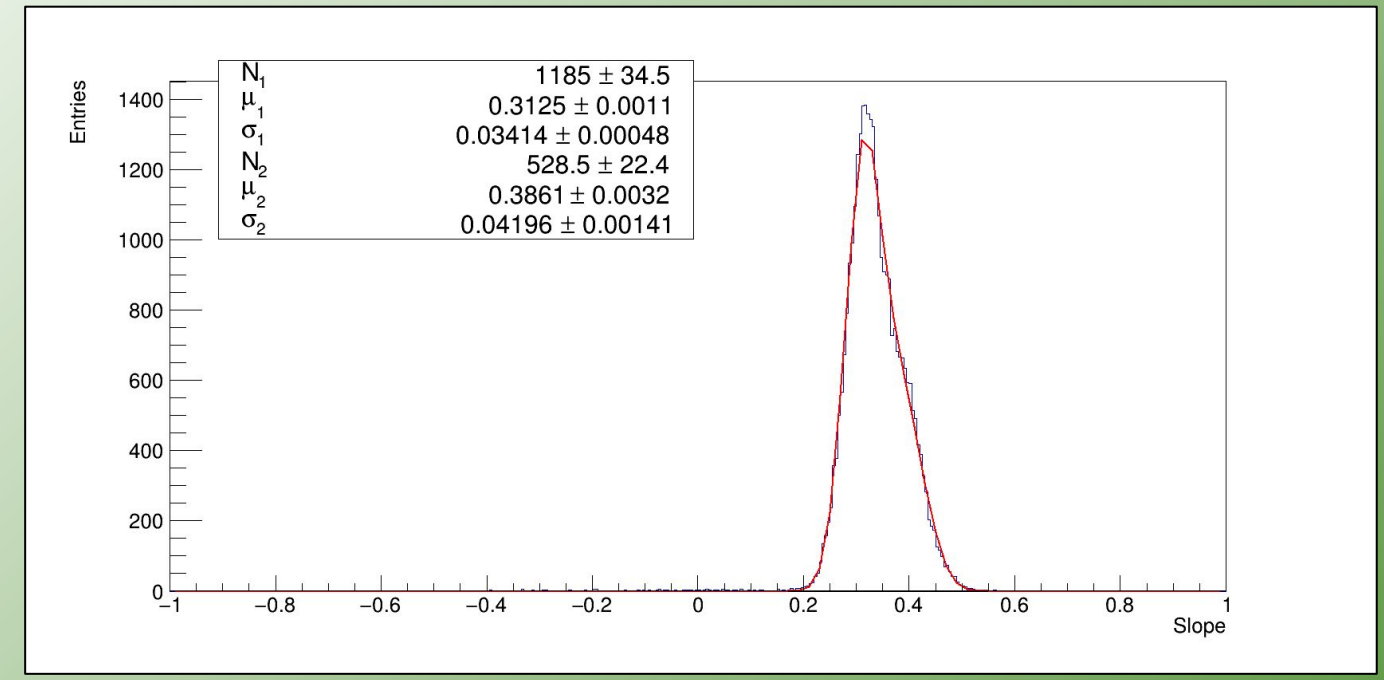


Angle computing - 0º SPS



$$\theta_X = 0.30 \pm 0.25$$

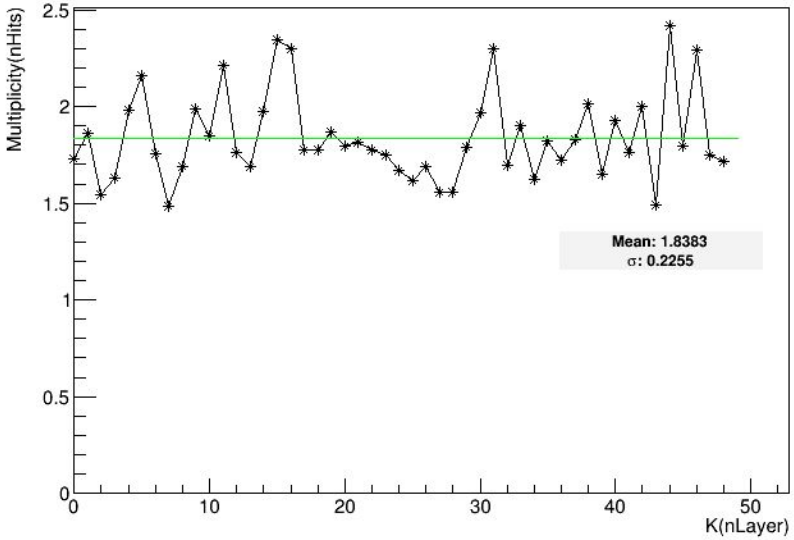
Angle computing - 20º PS



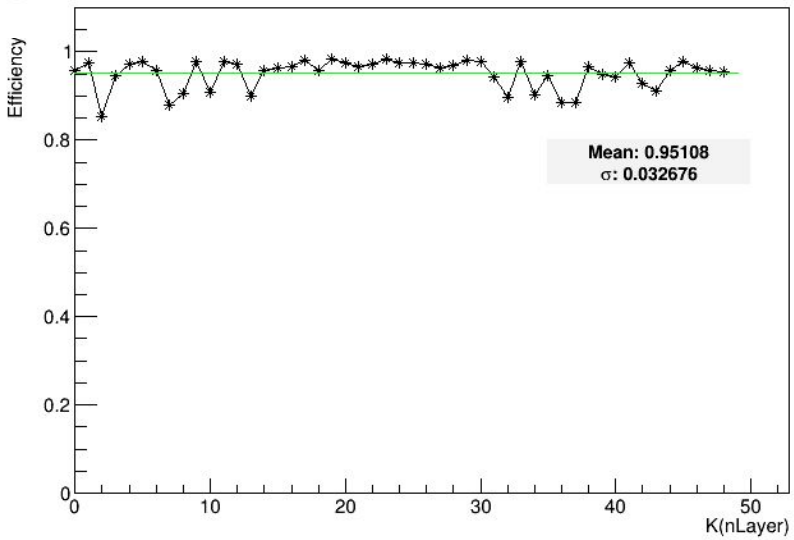
$$\theta_X = 17.90 \pm 1.96$$

Analysis results 0.3º SPS

Multiplicity



Efficiency

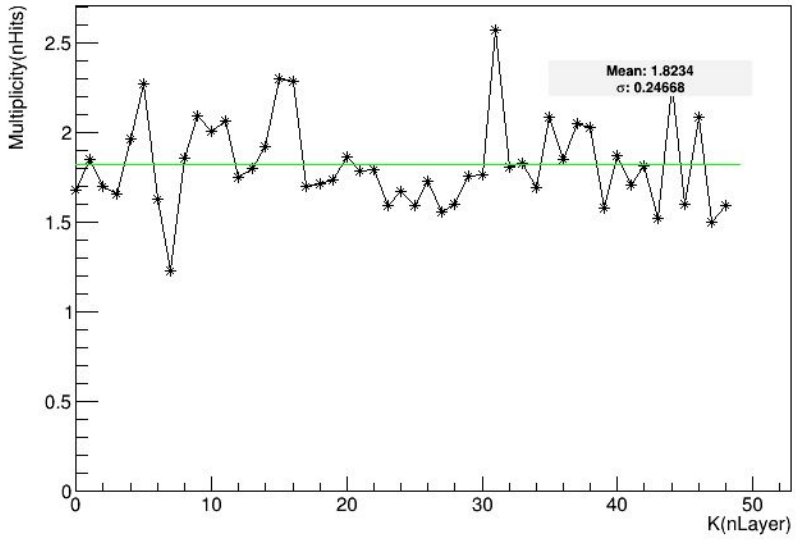


$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

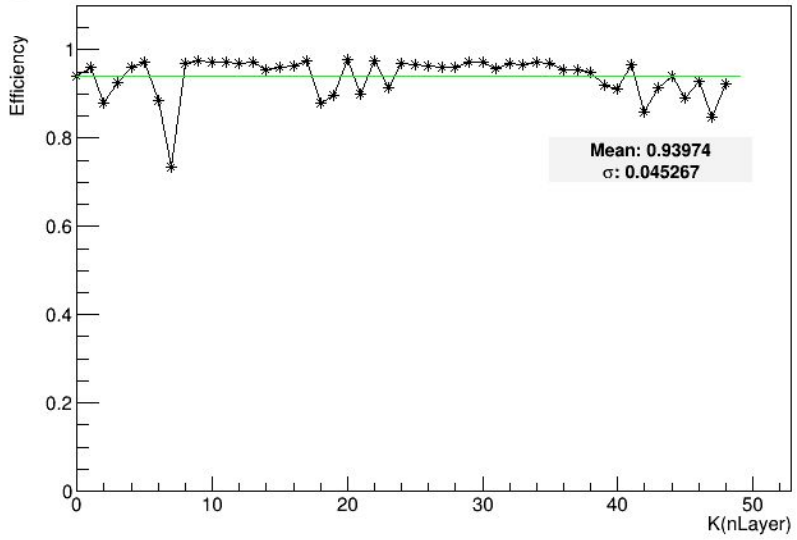
$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

Analysis results 4.04º PS

Multiplicity



Efficiency

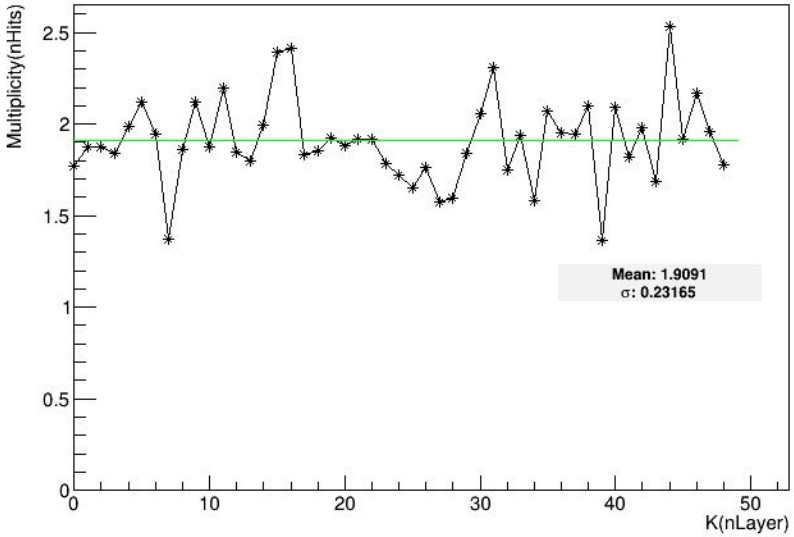


$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

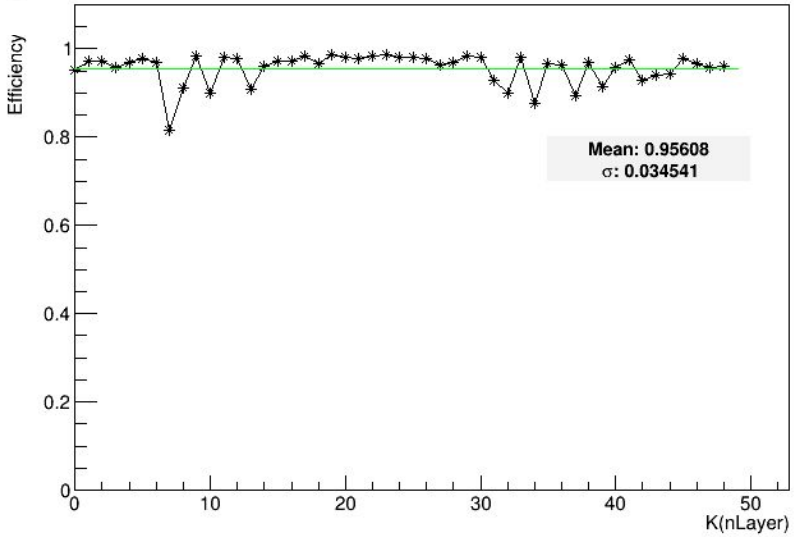
$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

Analysis results 16.75º SPS

Multiplicity



Efficiency

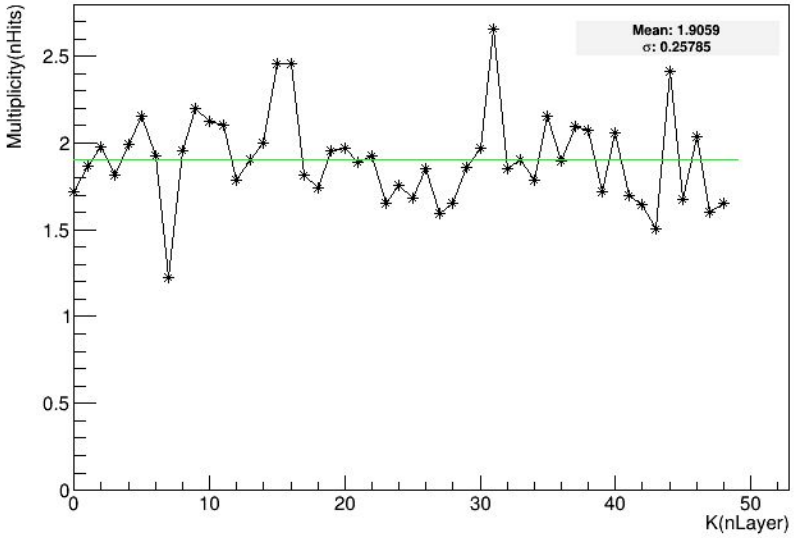


$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

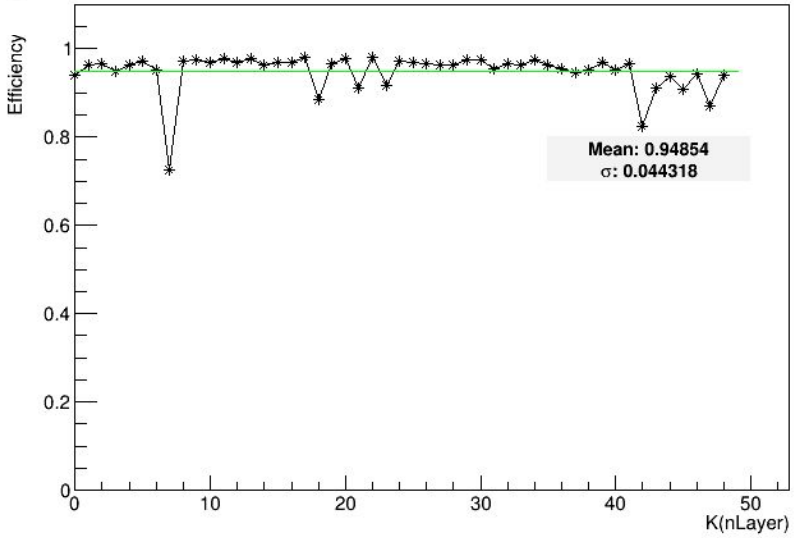
$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

Analysis results 17.90º PS

Multiplicity



Efficiency

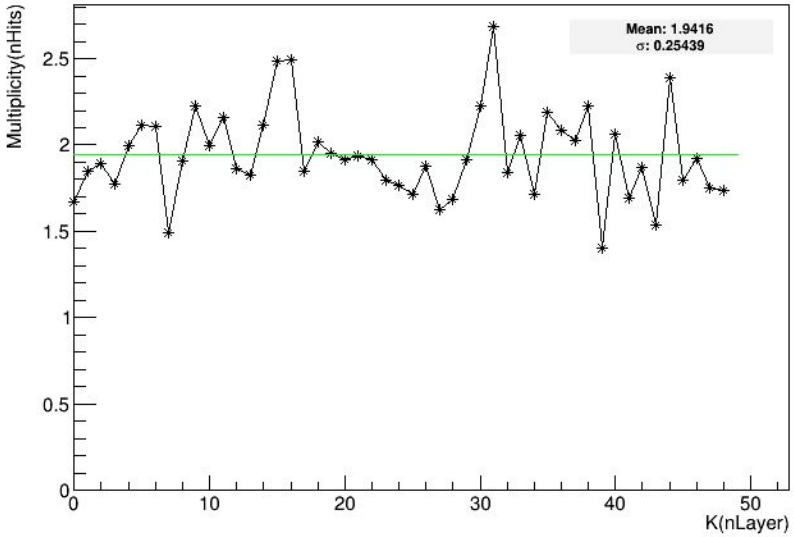


$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

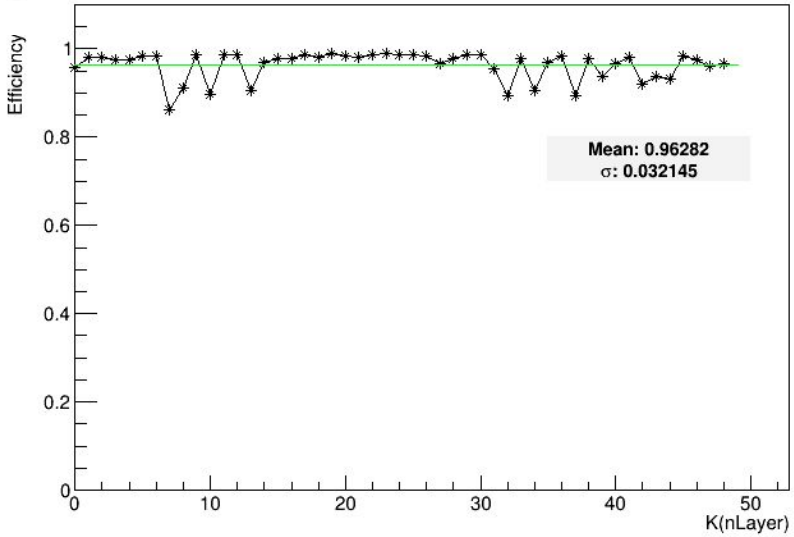
$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

Analysis results 26.35º

Multiplicity



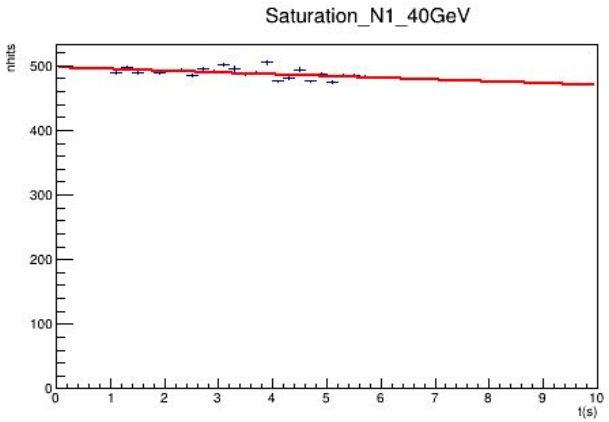
Efficiency

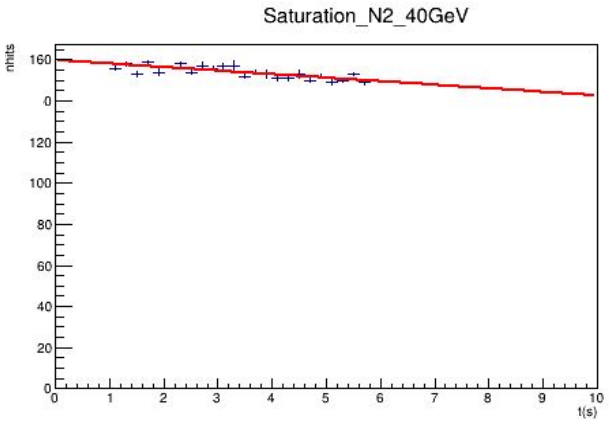


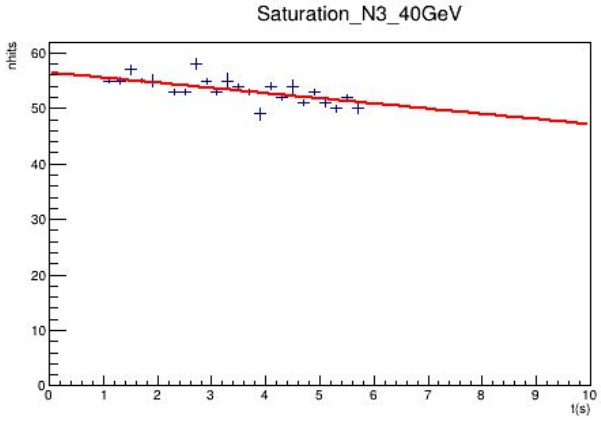
$$\sigma_{Mult} = \frac{1}{nLayers} \sum_{i=1}^{nLayers} (Mean - Mult_i)^2$$

$$\sigma_{Eff} = \frac{1}{nLayers} \sqrt{Mean(1 - Mean/nLayers)}$$

Saturations 40GeV 26.35 Deg



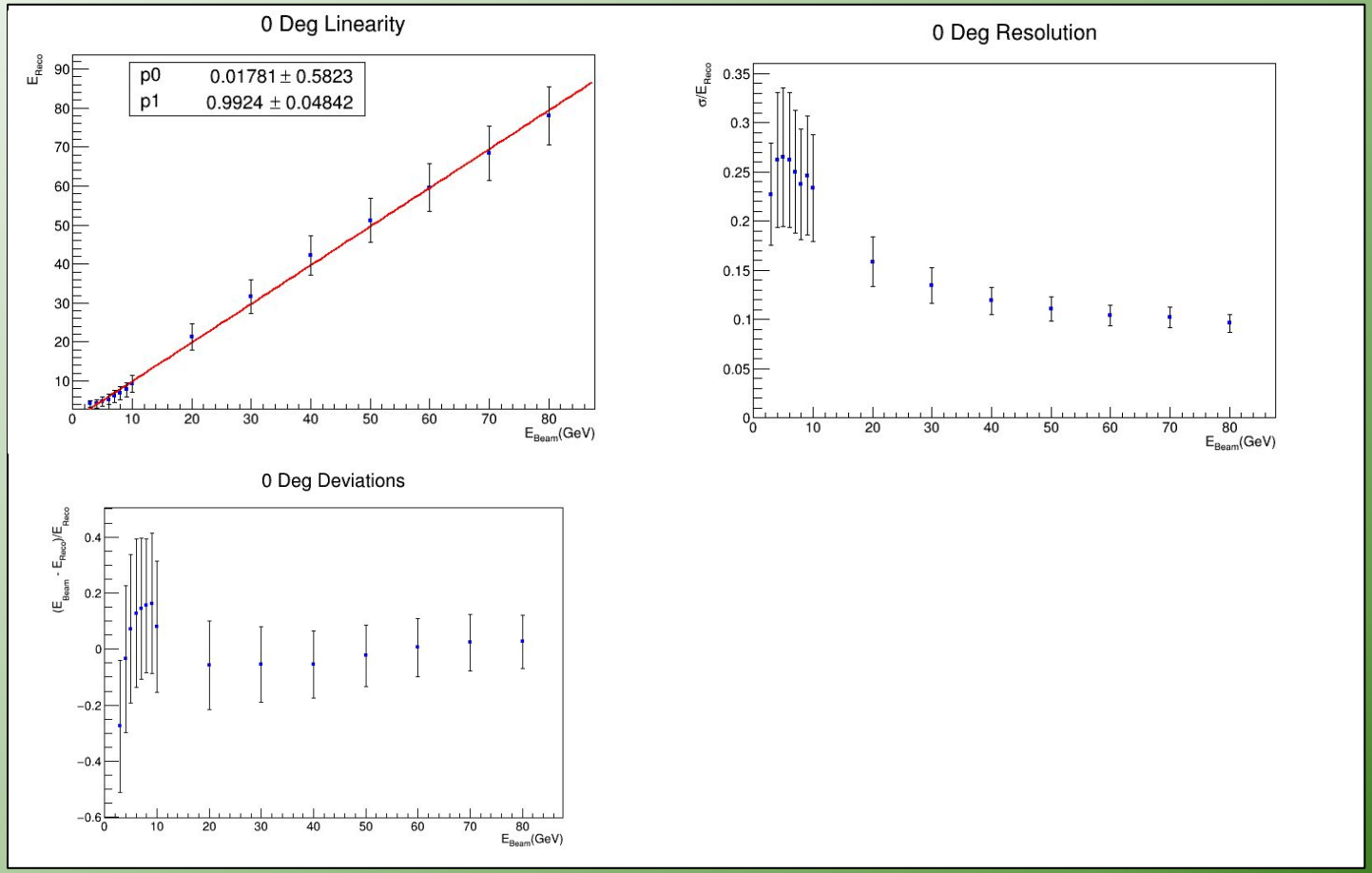




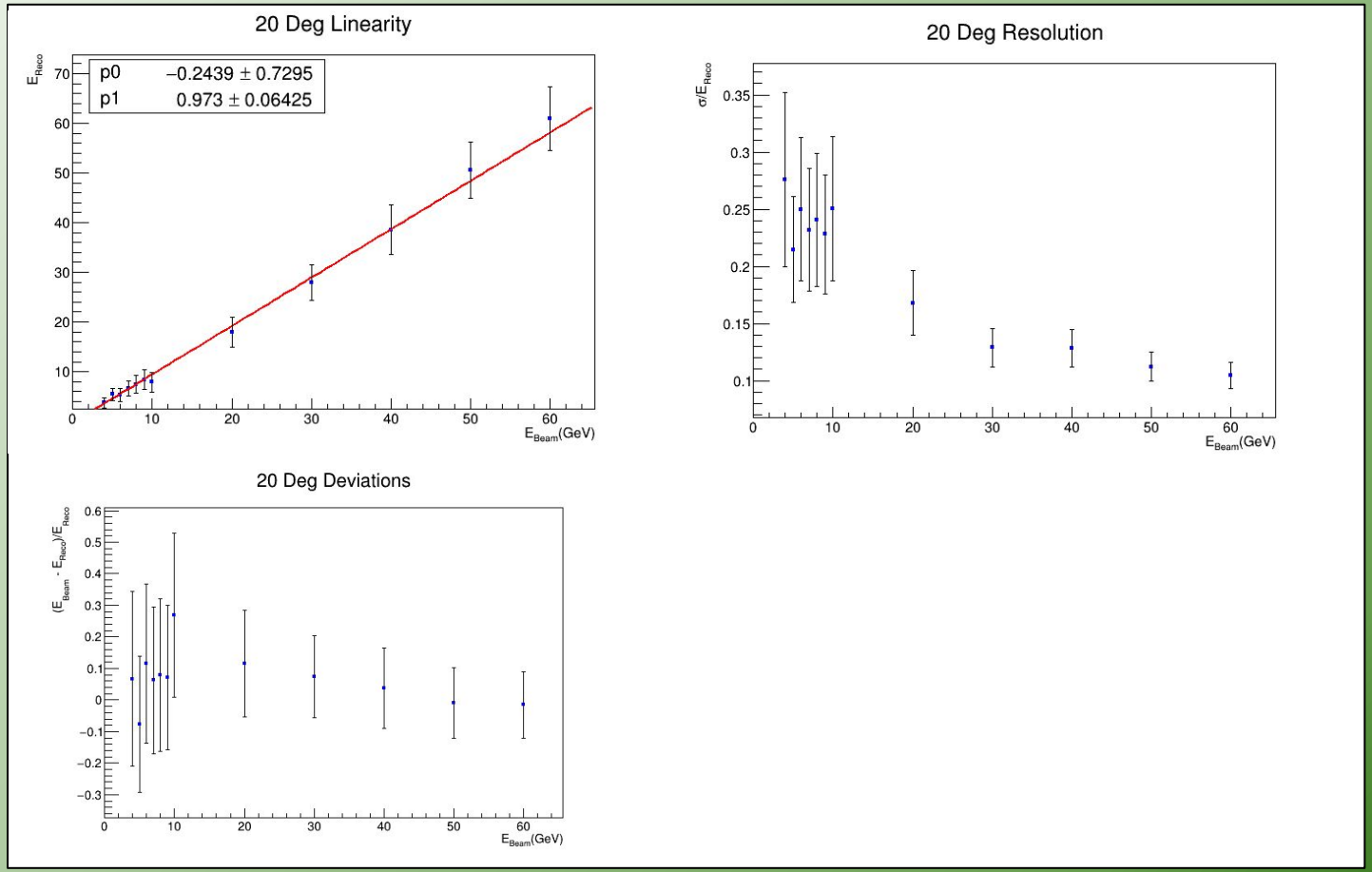
$$\Delta Bin = \sqrt{\frac{Bin_C}{N_{Entries}}}$$

$$\Lambda_{N1} = -2.7358 \pm 0.260475$$
$$\Lambda_{N2} = -1.71823 \pm 0.146358$$
$$\Lambda_{N3} = -0.931567 \pm 0.0860312$$

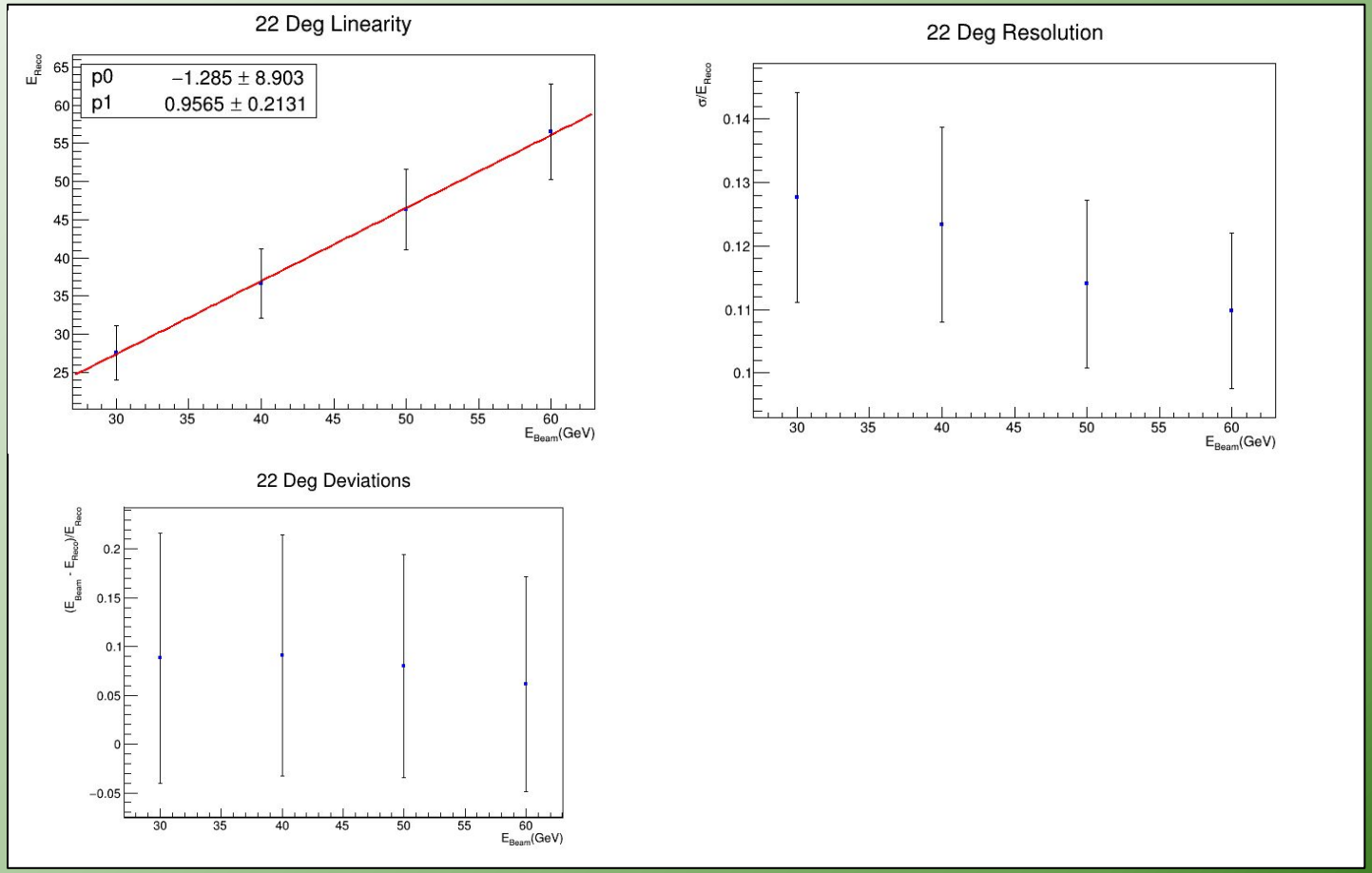
Linearity and resolution 0 Deg



Linearity and resolution 20 Deg



Linearity and resolution 22 Deg



Profiles 0.3º SPS

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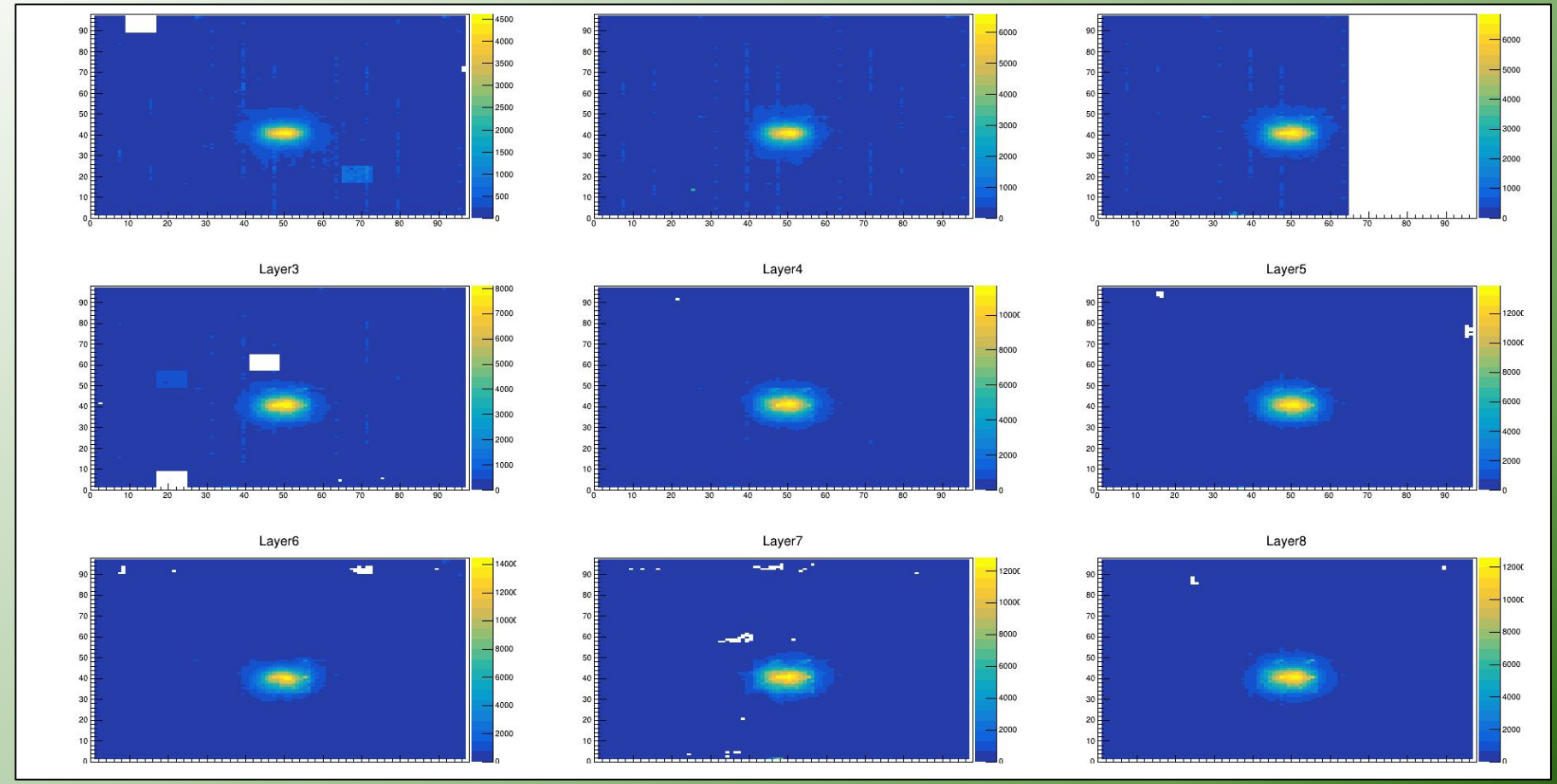
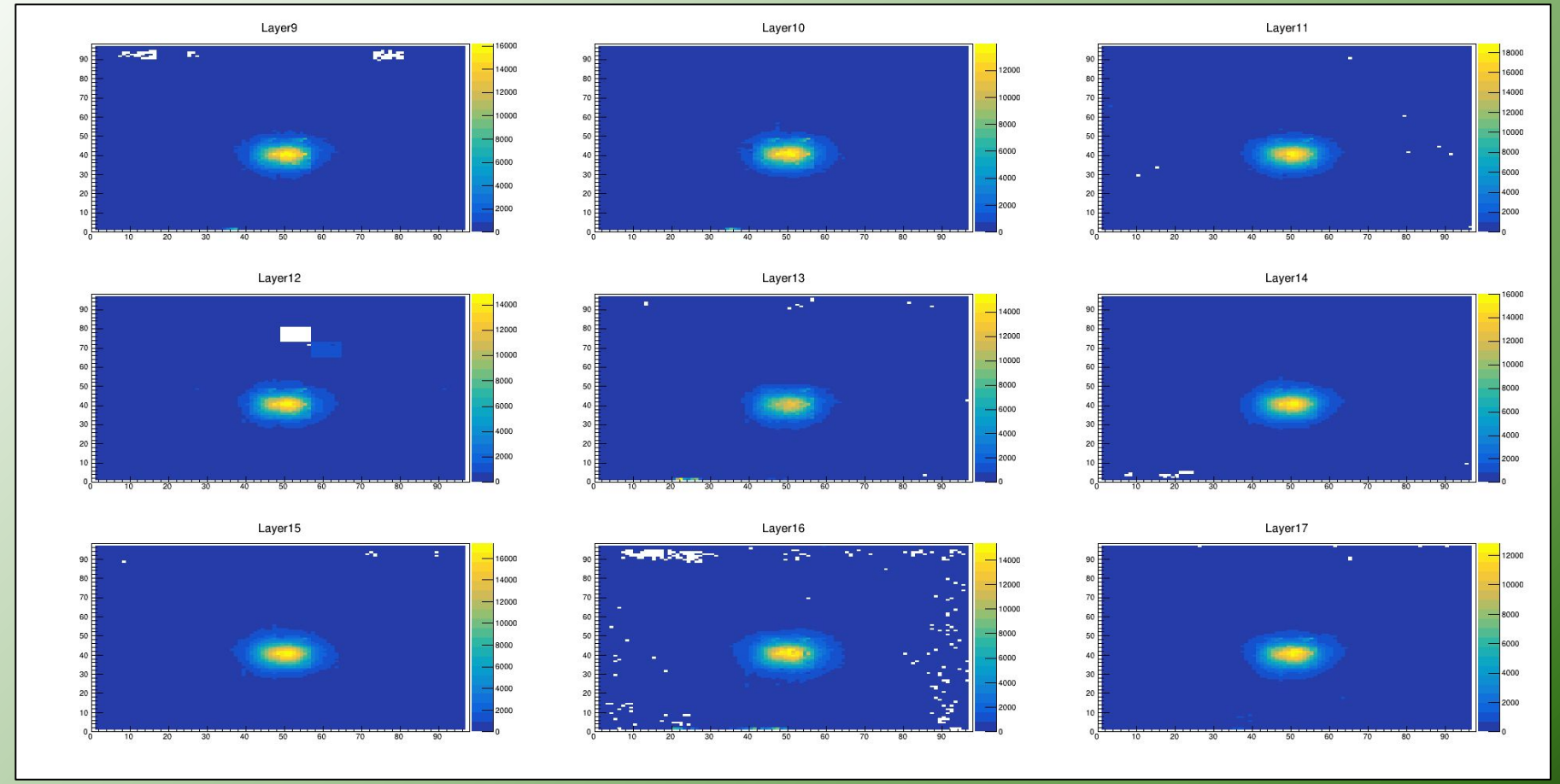


Profiles 0.3º SPS



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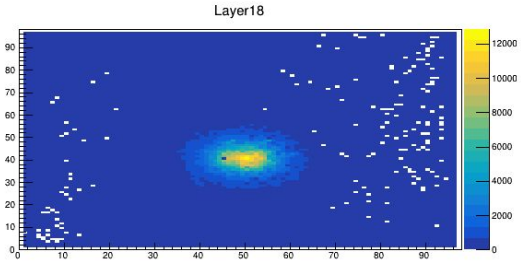

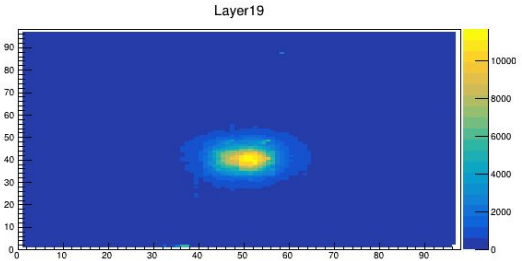

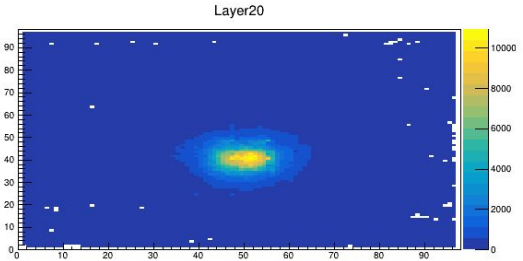

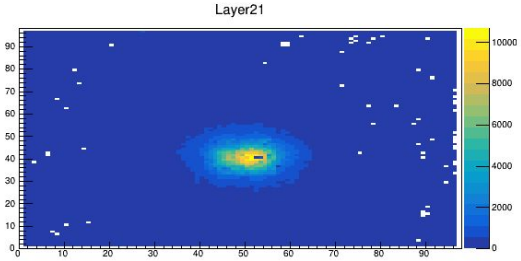

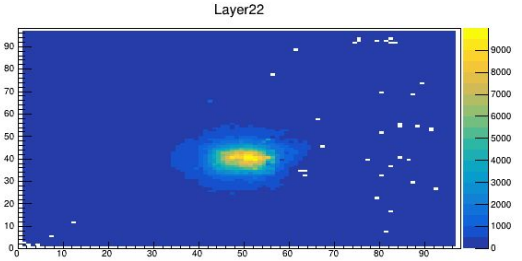

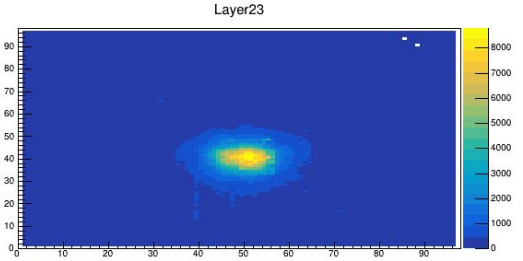

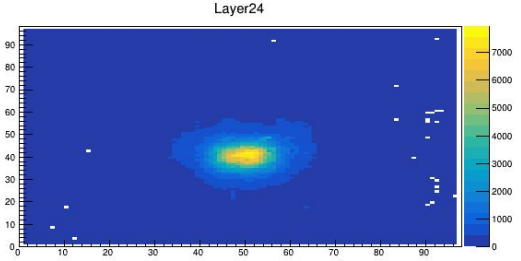

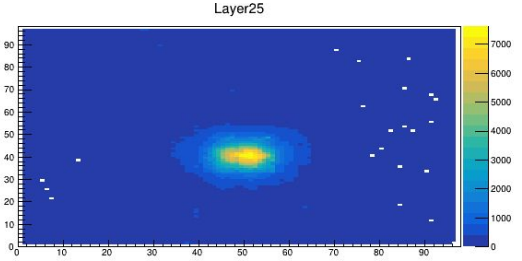

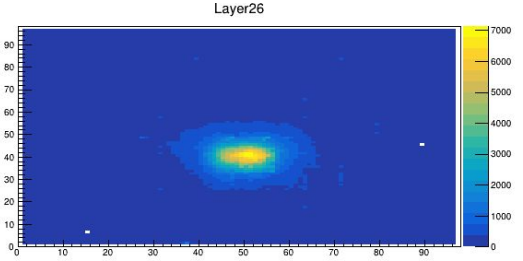

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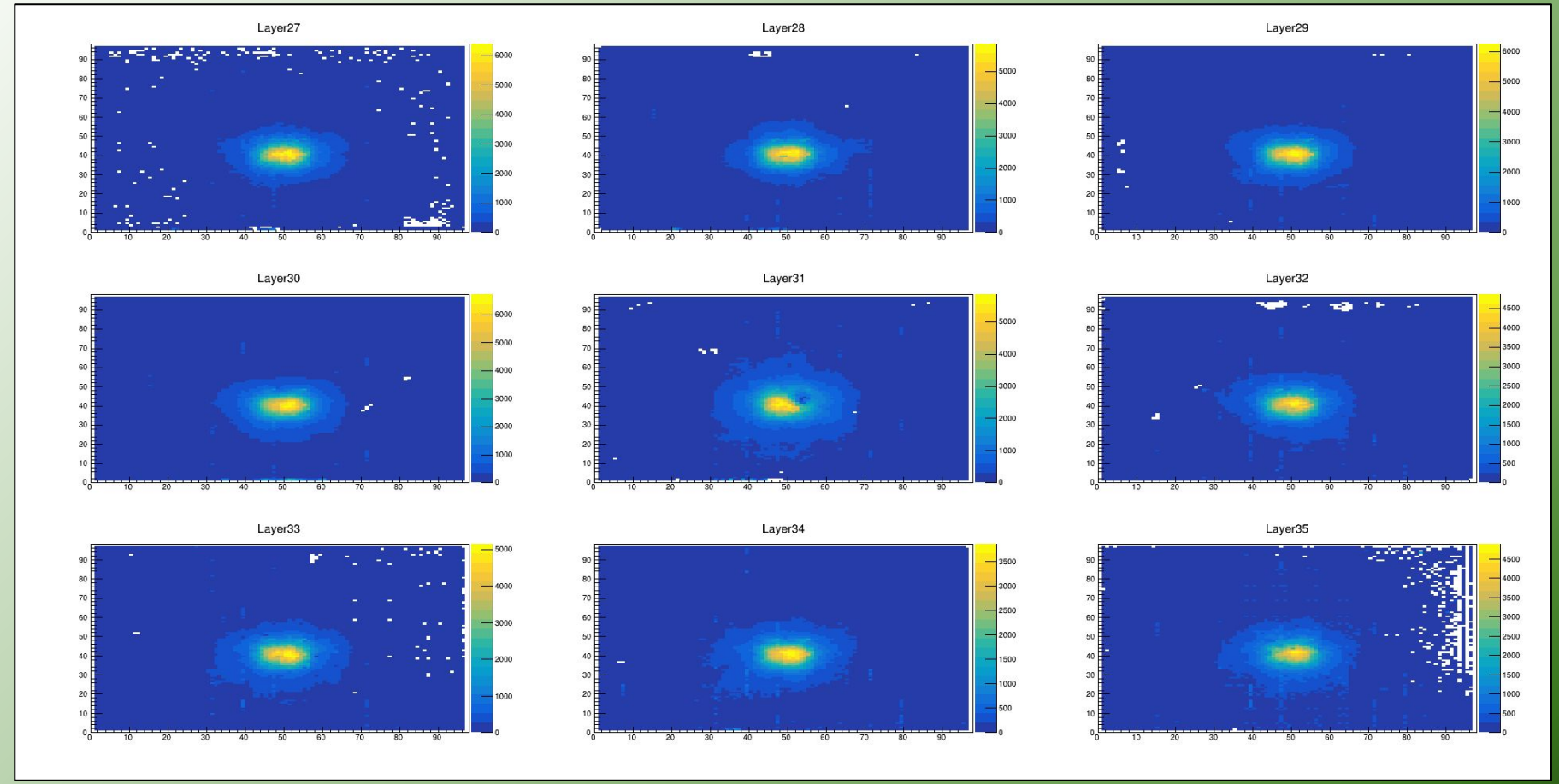

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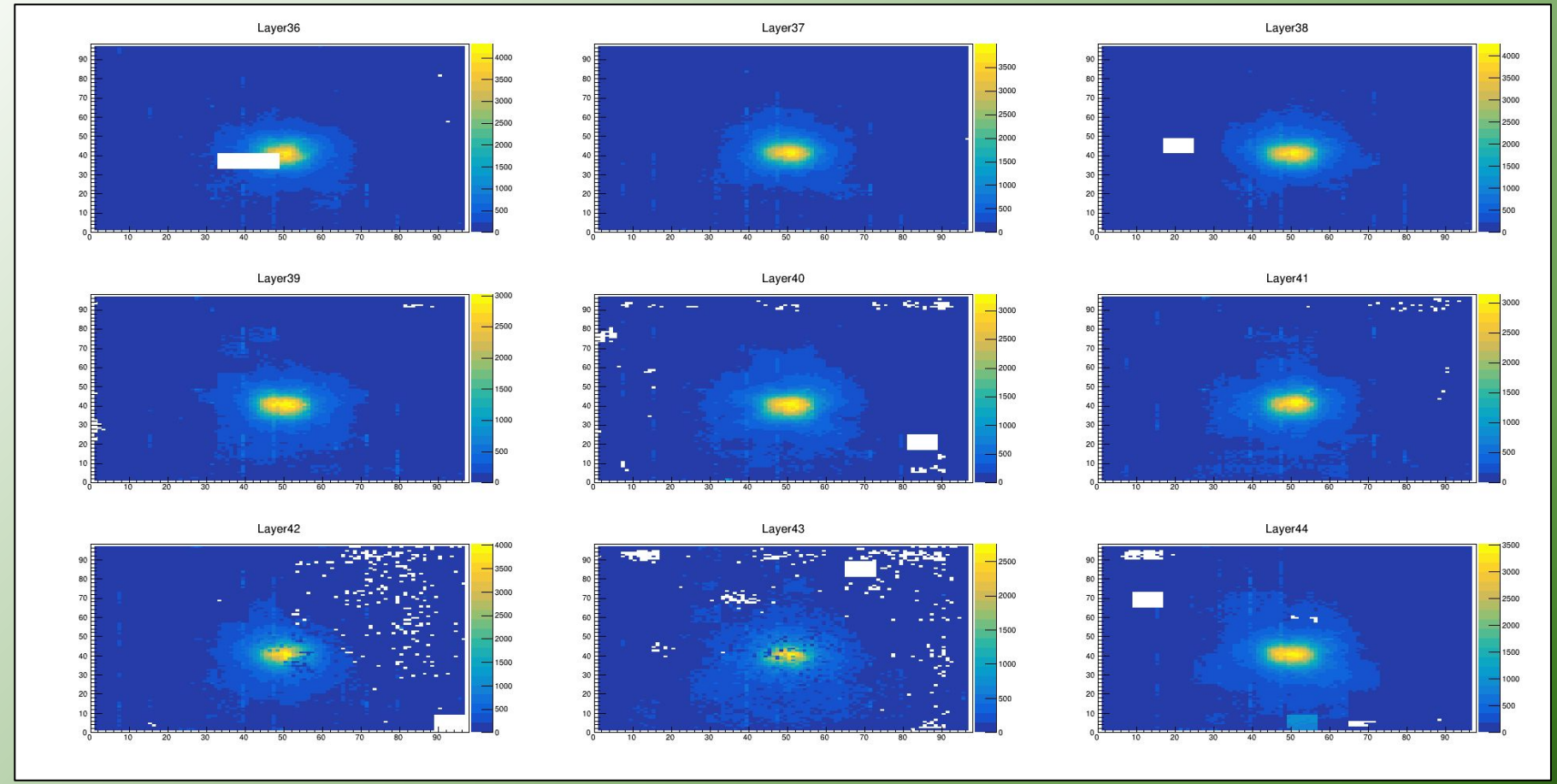

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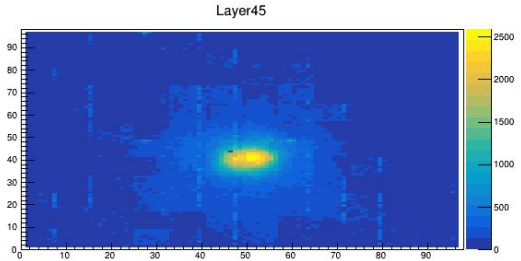

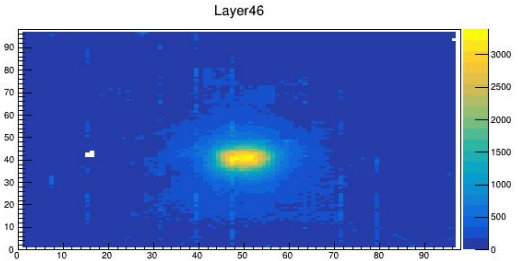

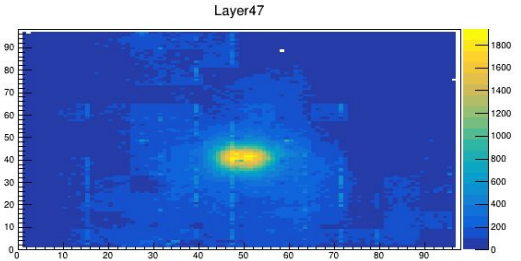

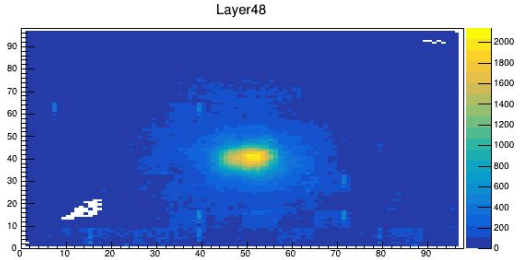

Profiles 2.95° PS

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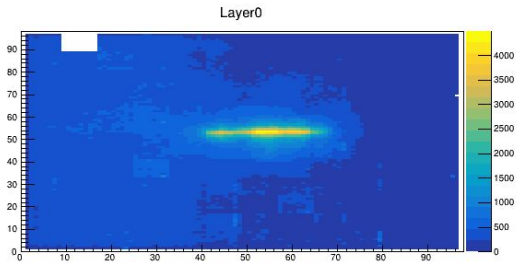
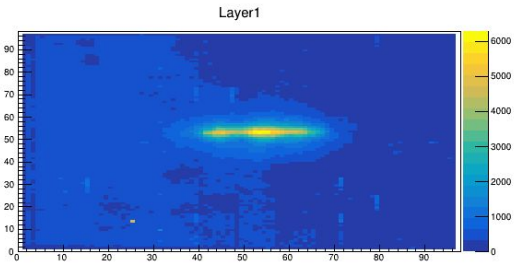
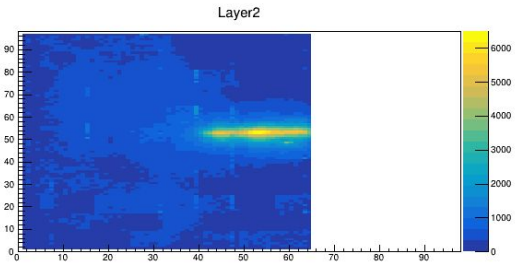
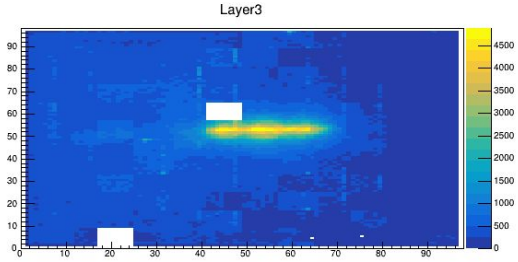
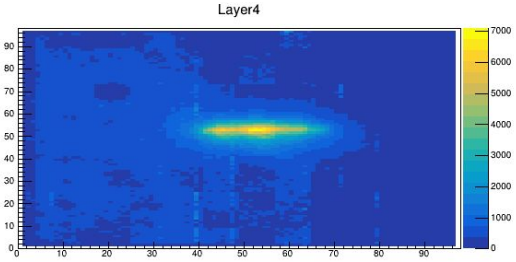
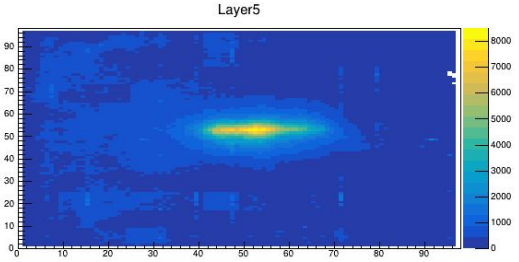


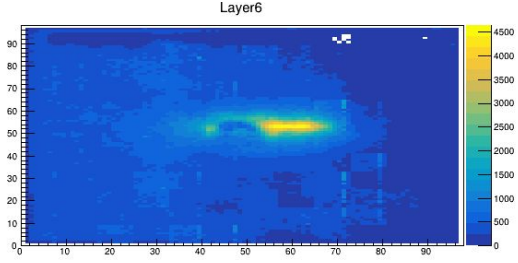


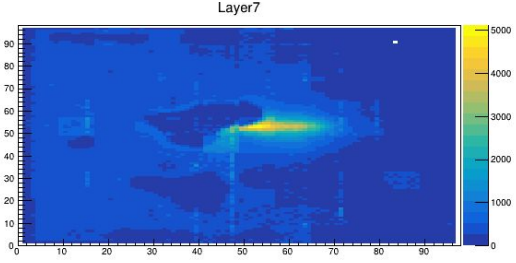


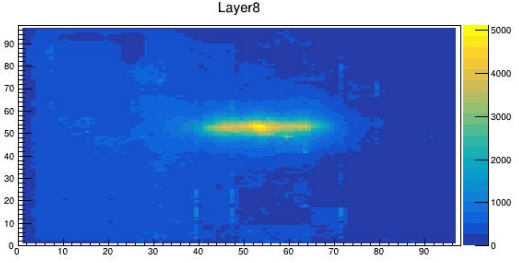




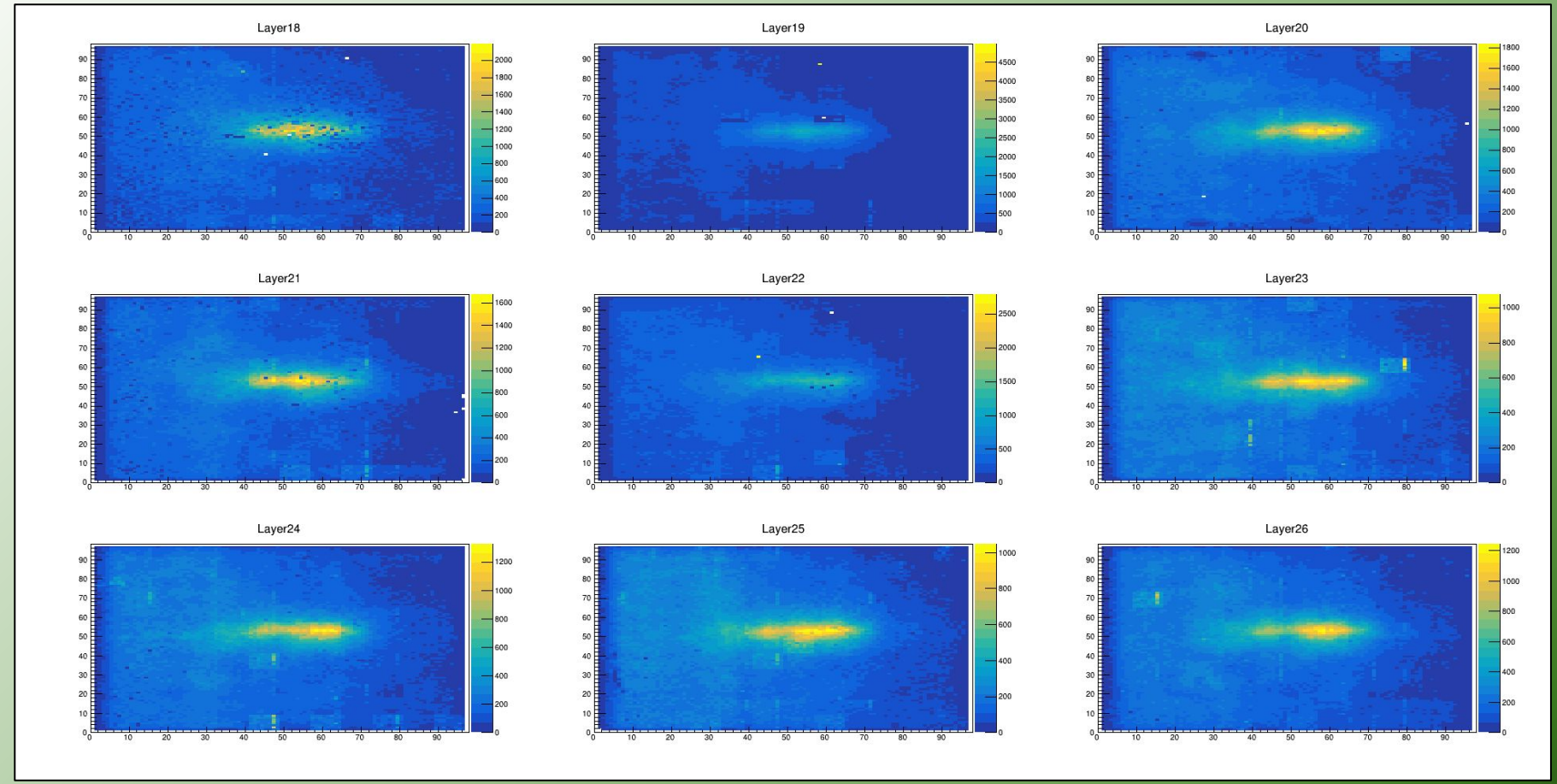








Profiles 2.95º PS



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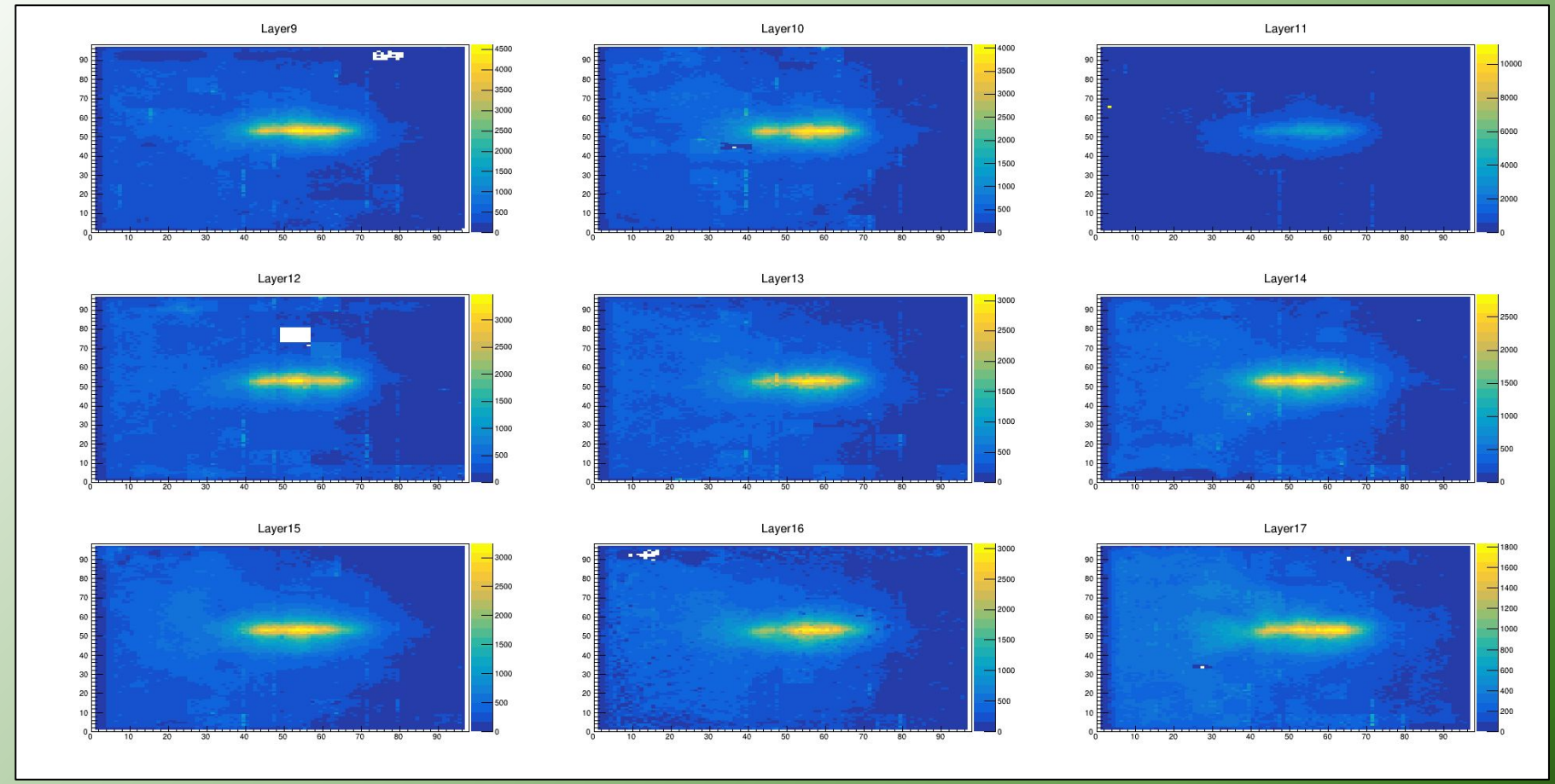

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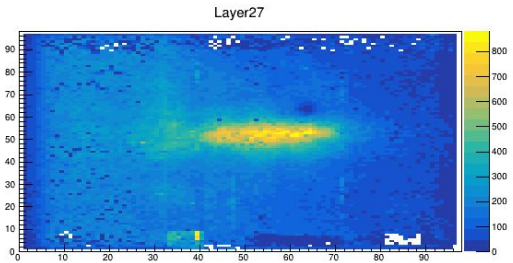

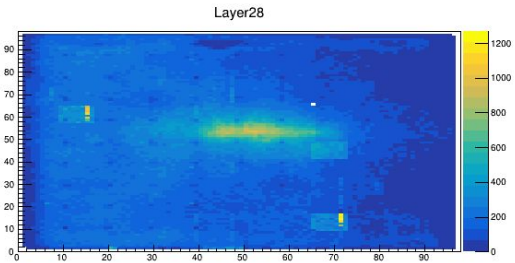

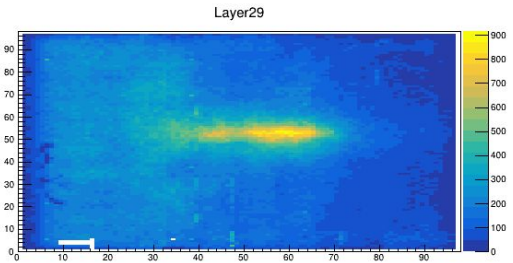

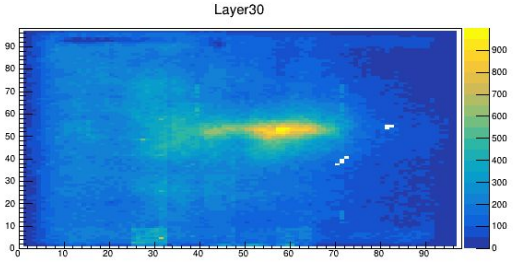

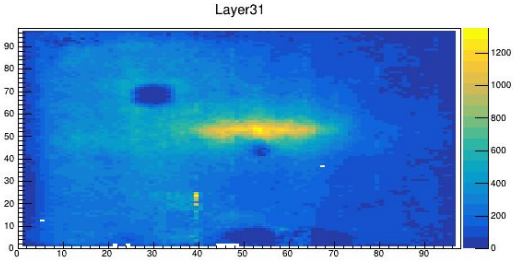

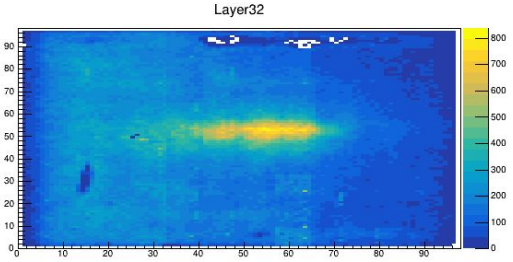

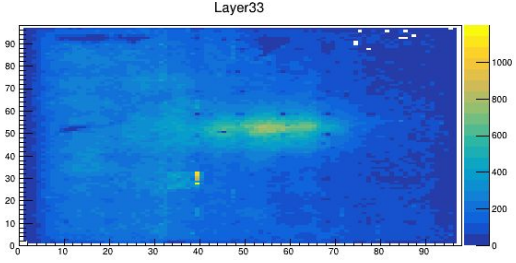

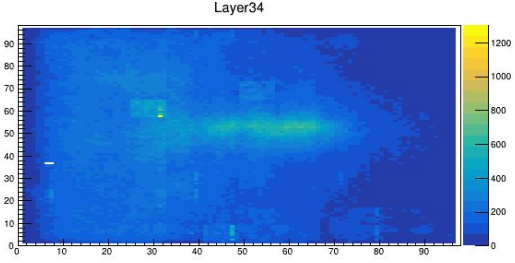

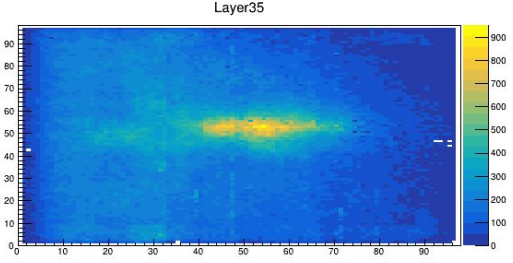

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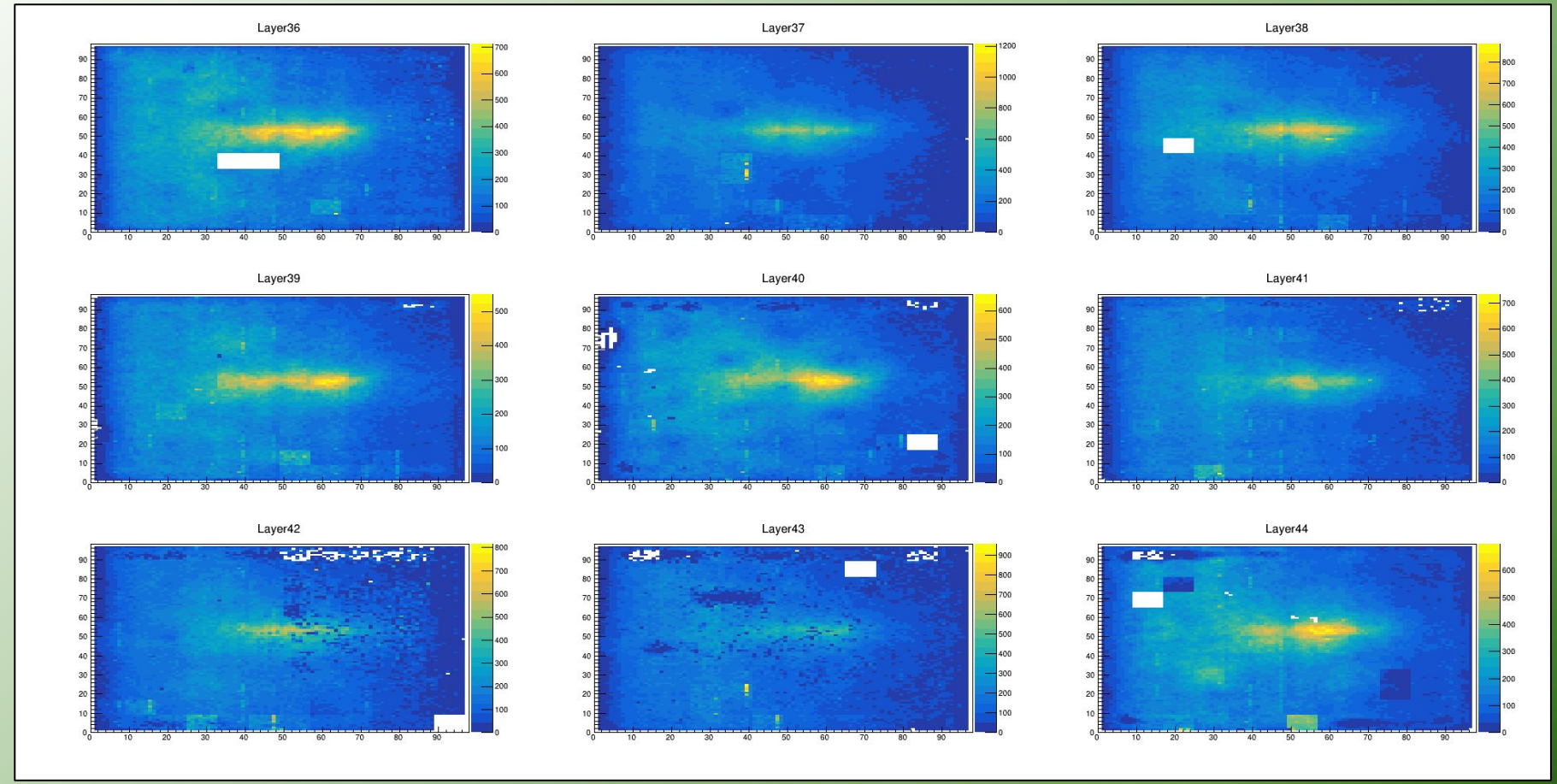

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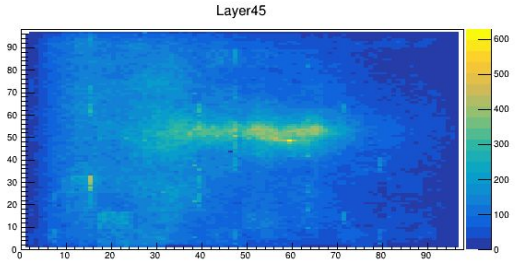
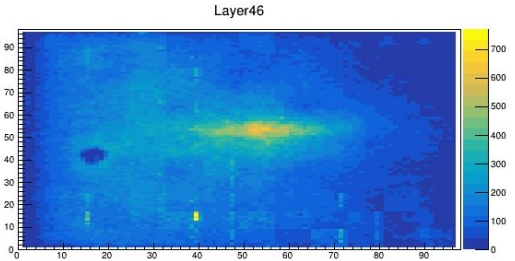
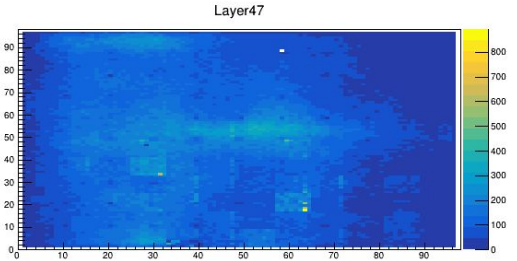
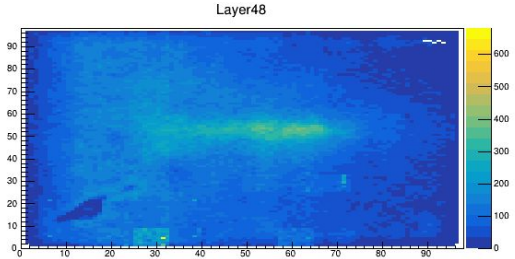
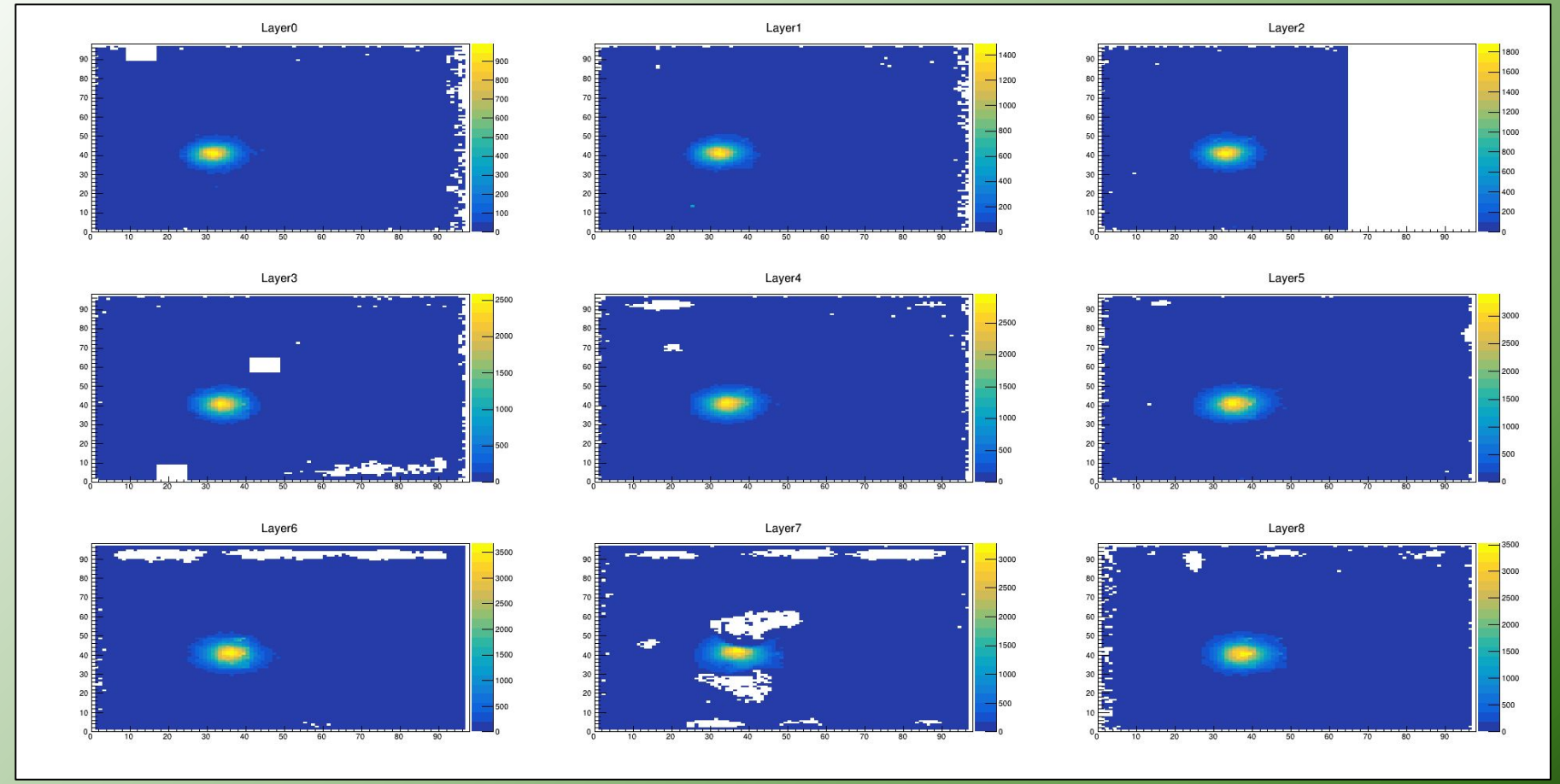








Profiles 16.75º SPS



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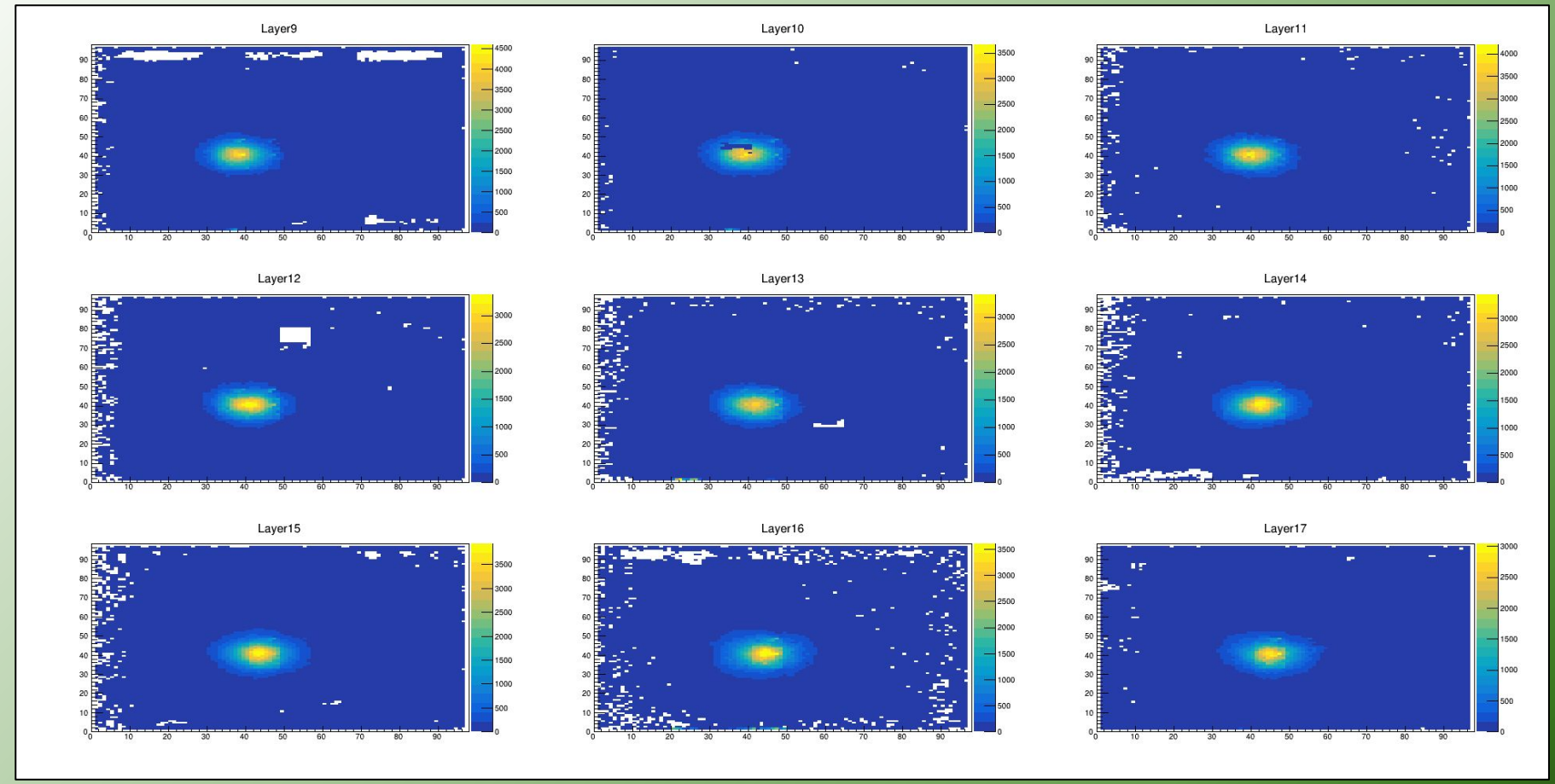

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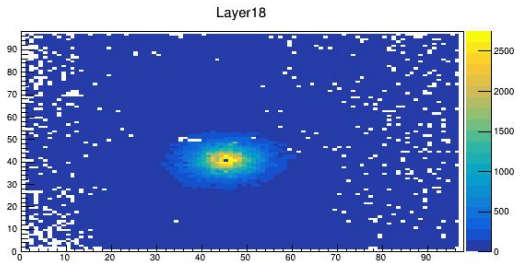

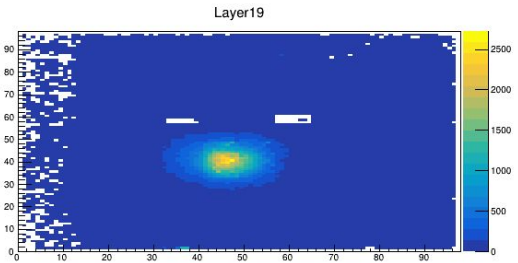

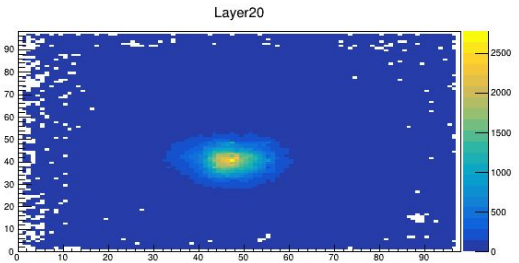

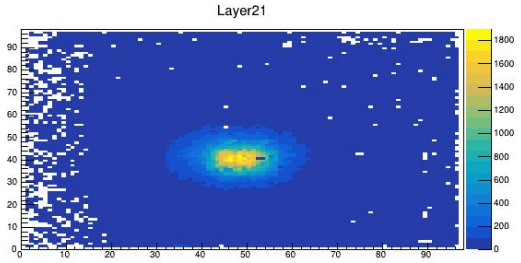

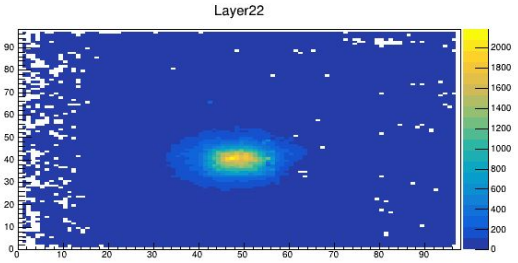

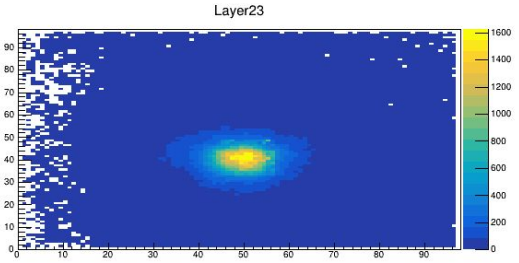

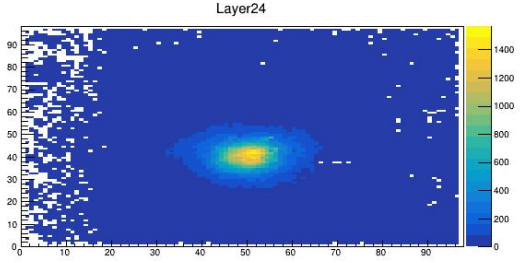

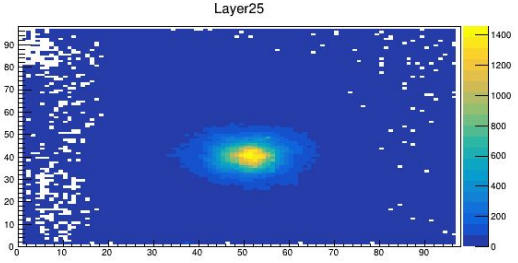

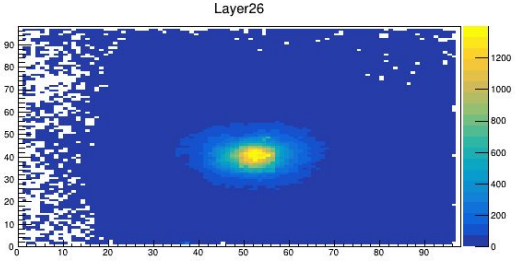

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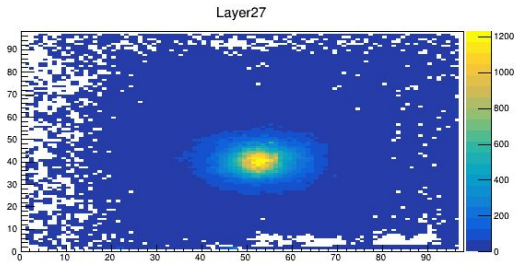
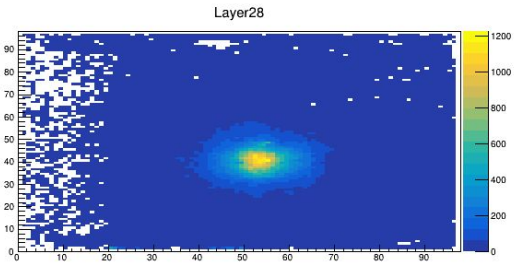
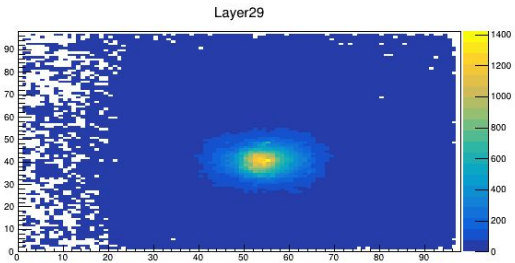
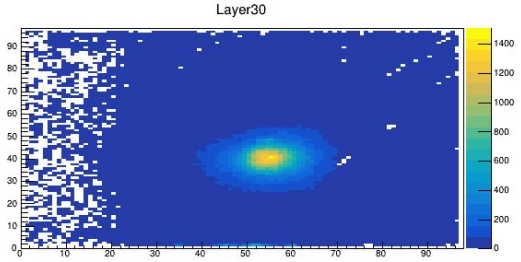
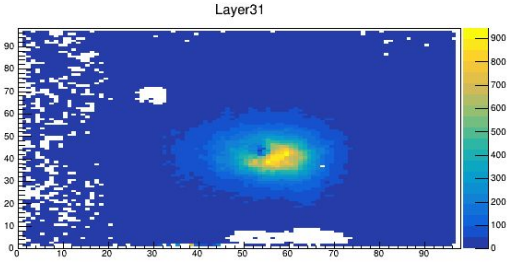
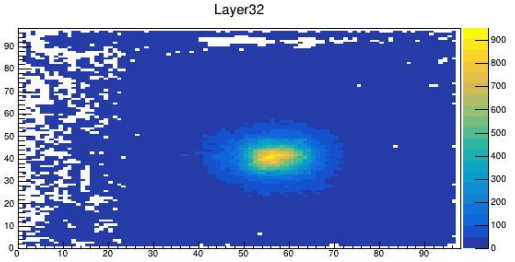


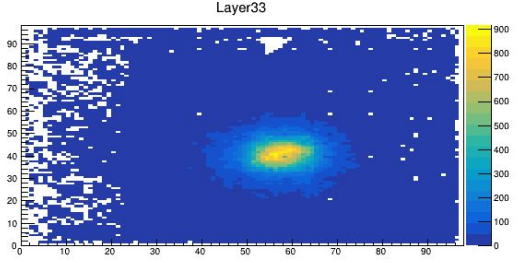


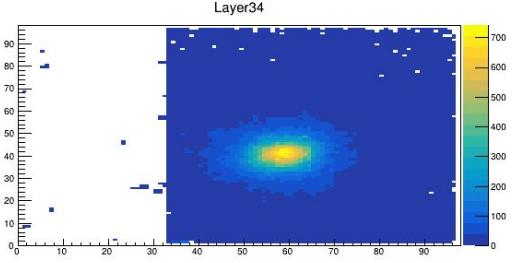


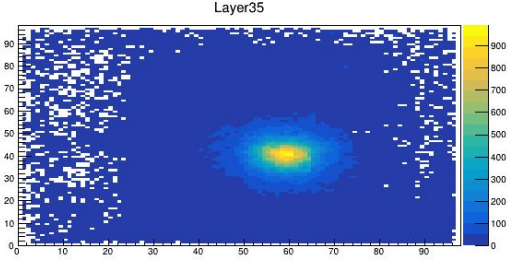




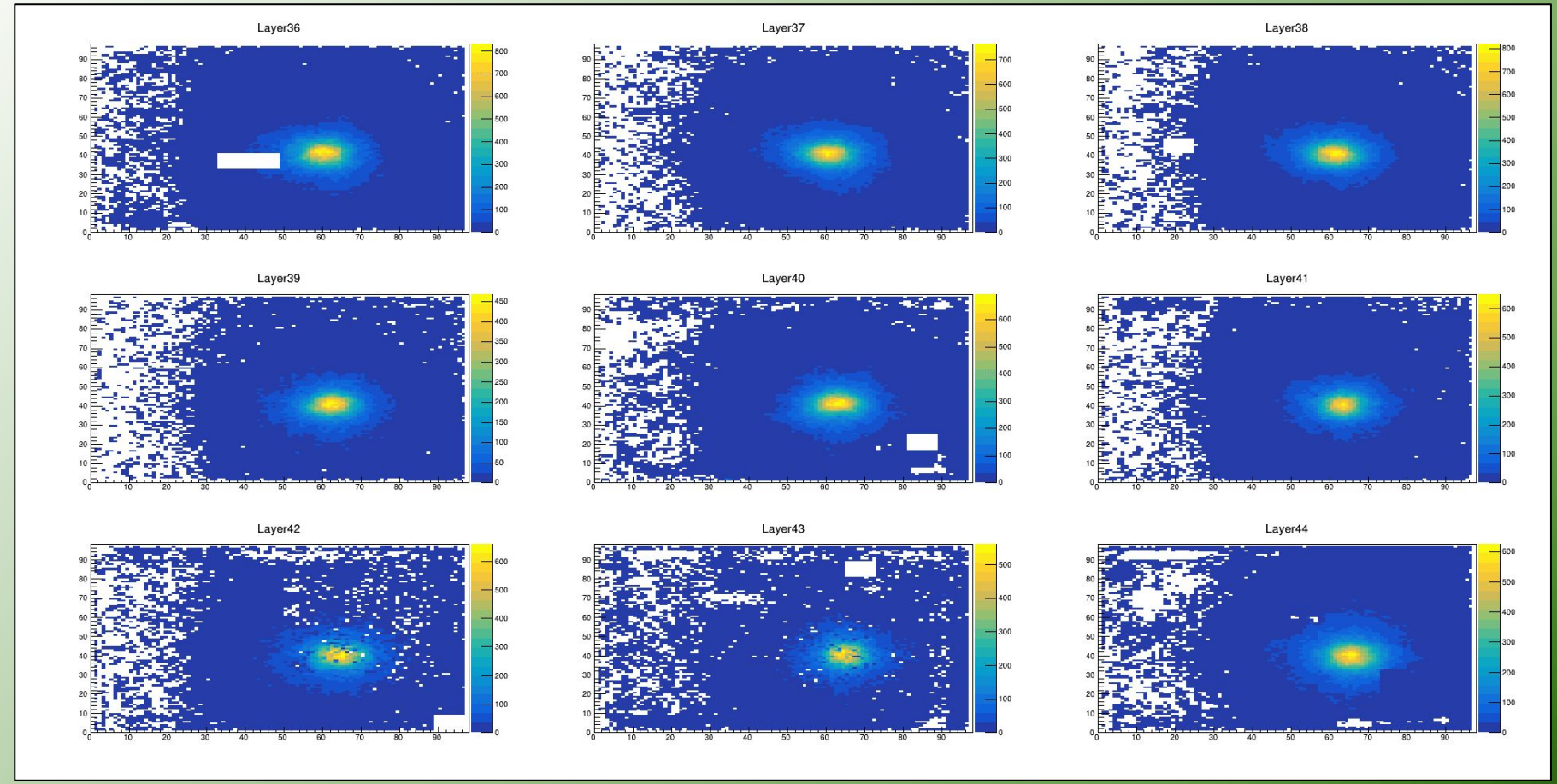




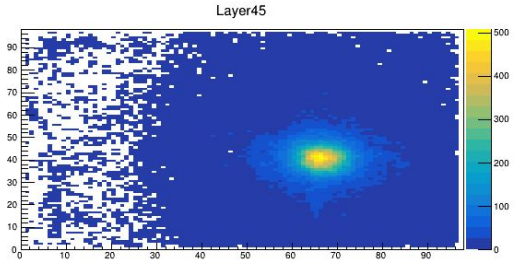


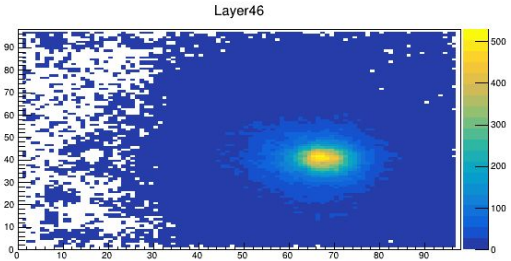


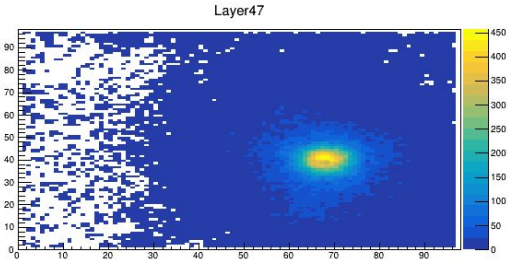
Profiles 16.75º SPS

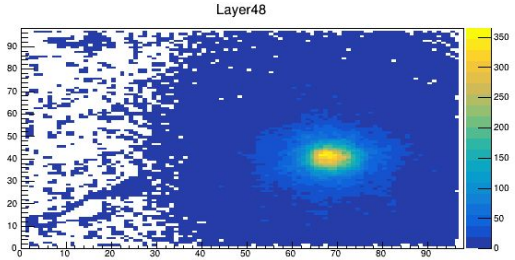


Profiles 16.75º SPS



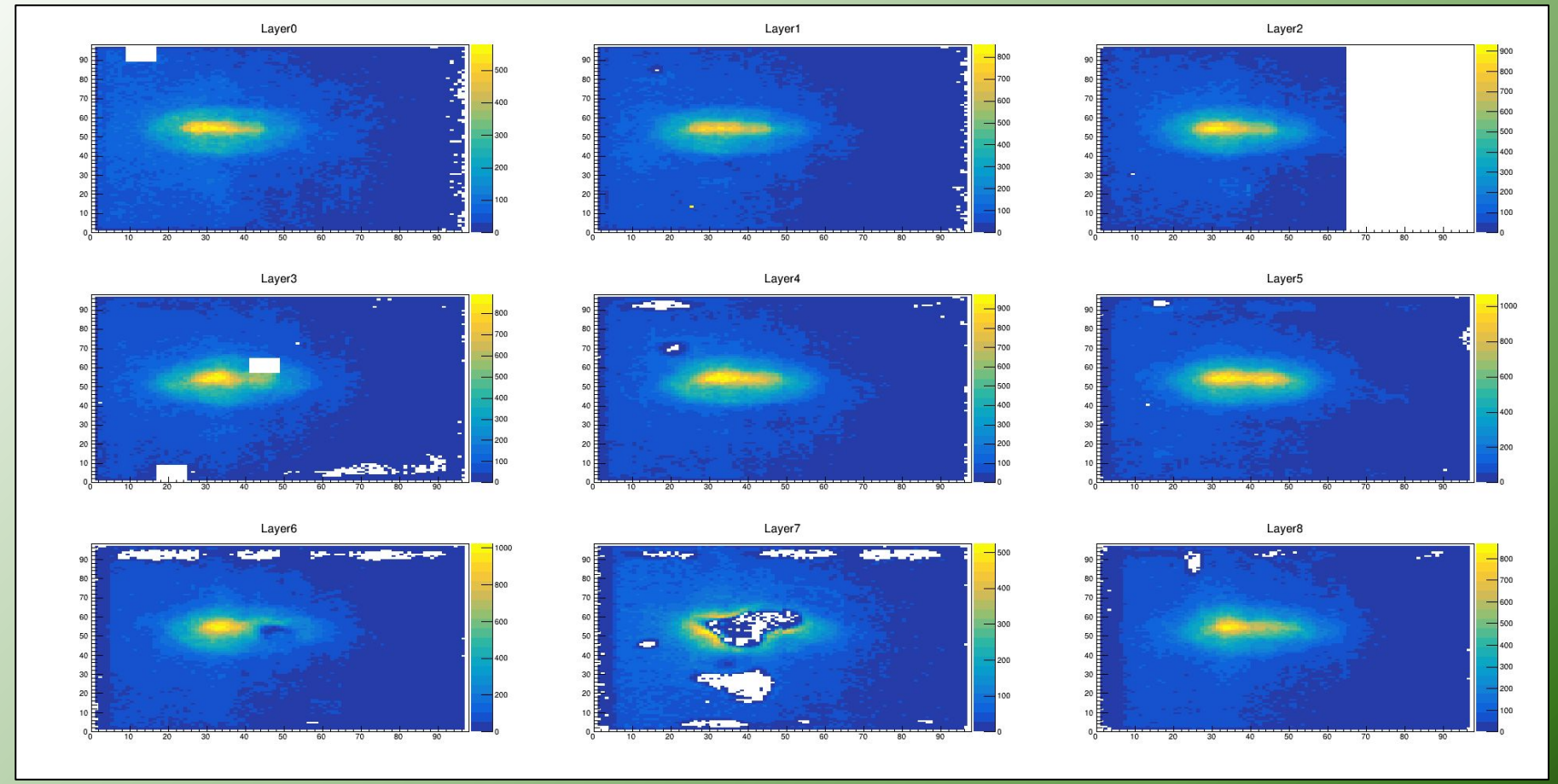




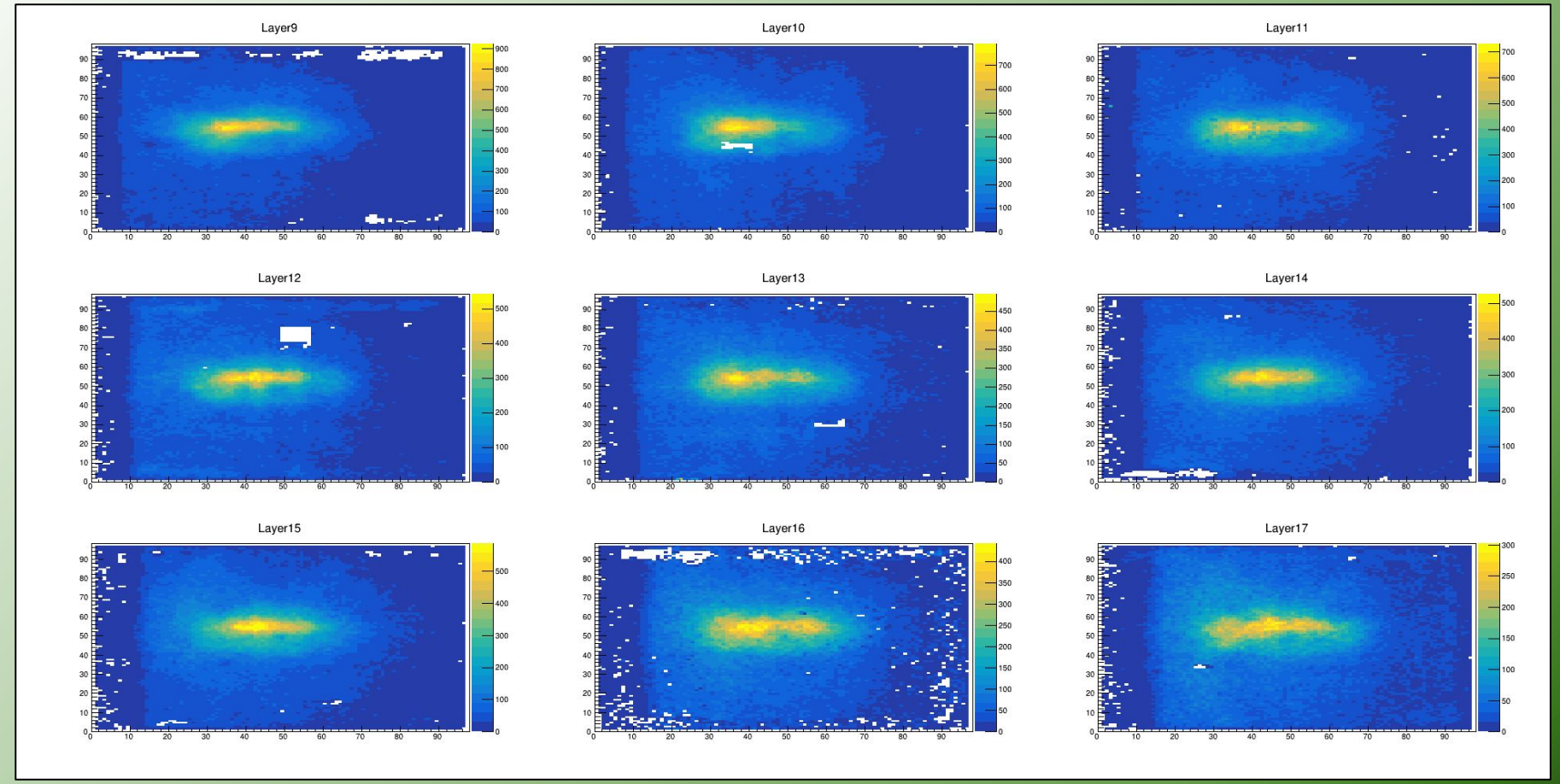


Profiles 17.90º PS

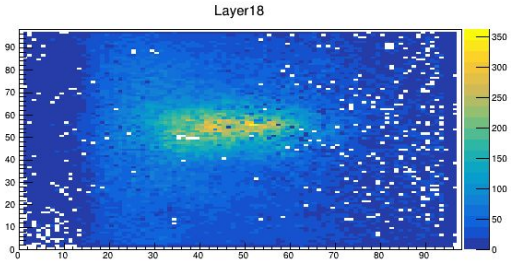
Profiles 17.90º PS

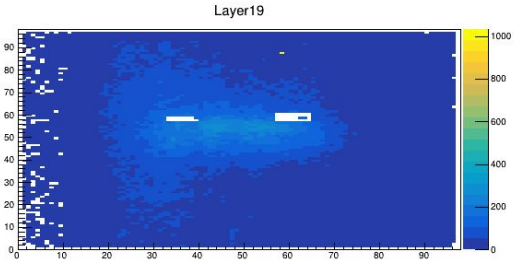


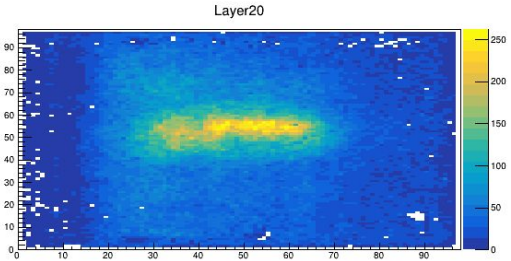
Profiles 17.90º PS

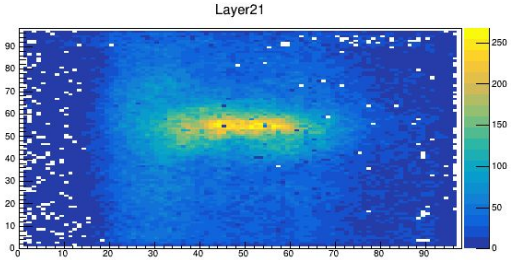


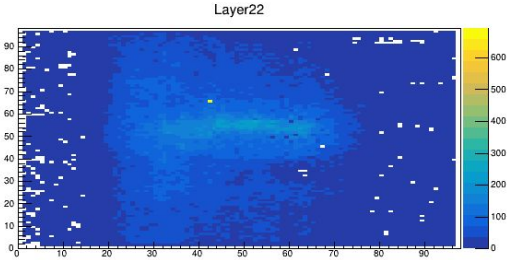
Profiles 17.90º PS

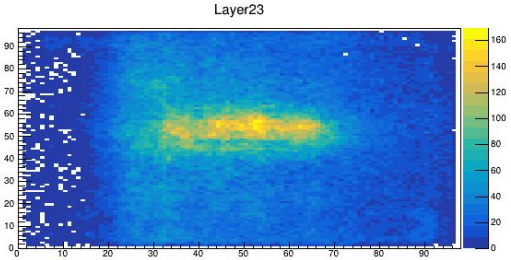


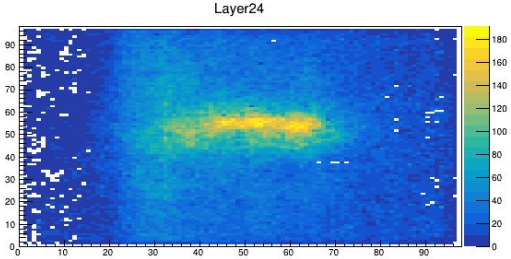


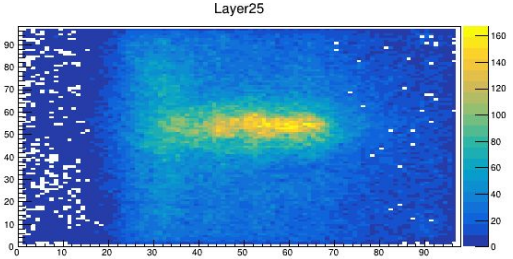


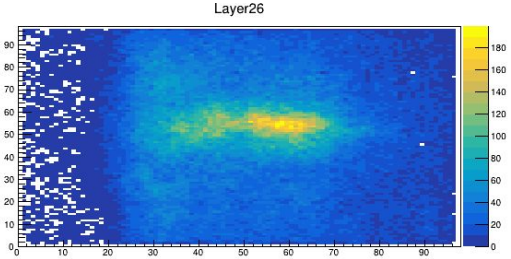




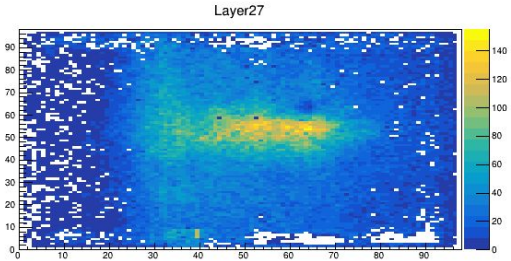


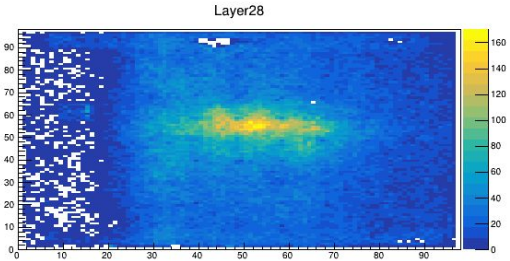


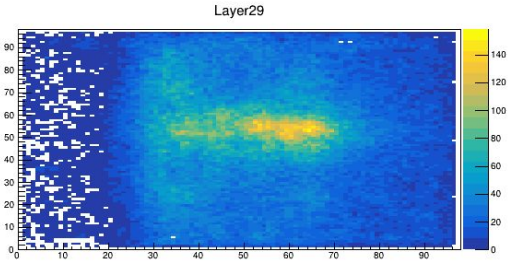


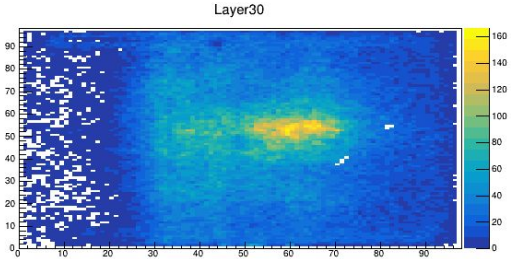


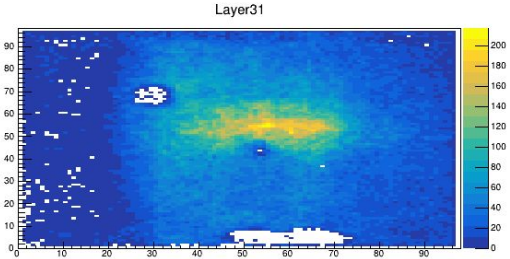
Profiles 17.90º PS

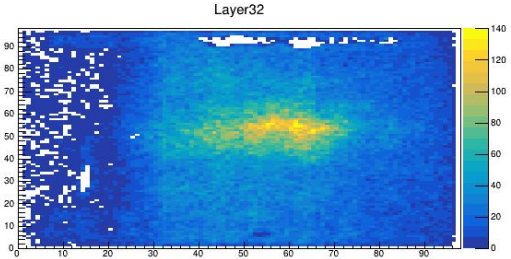


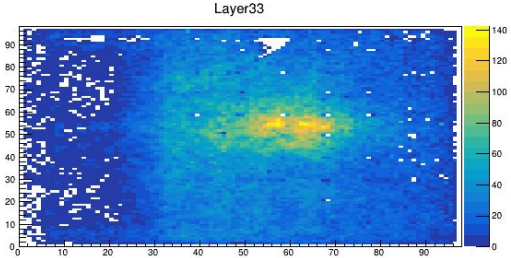


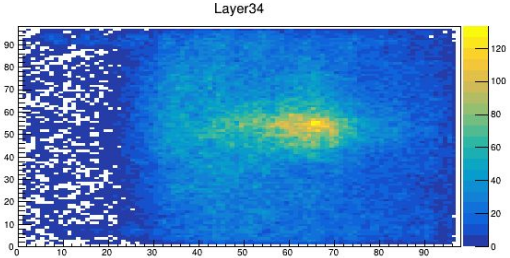


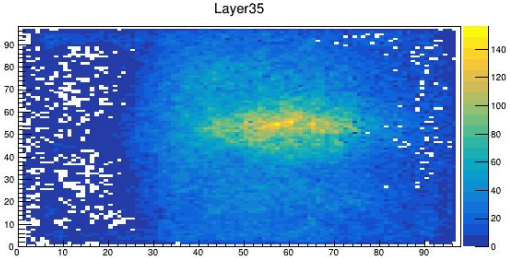




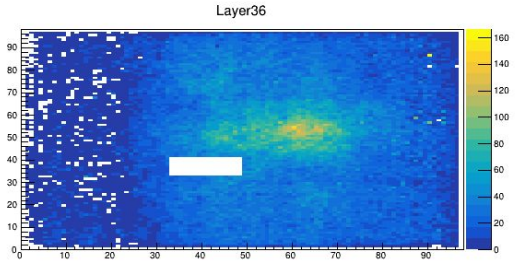


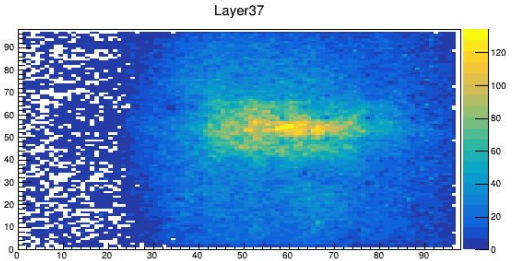


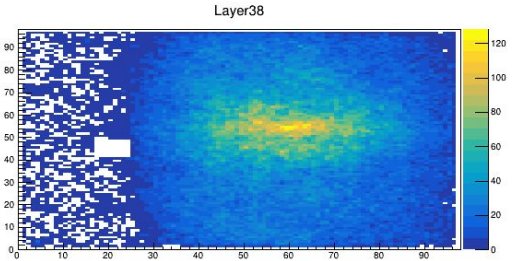


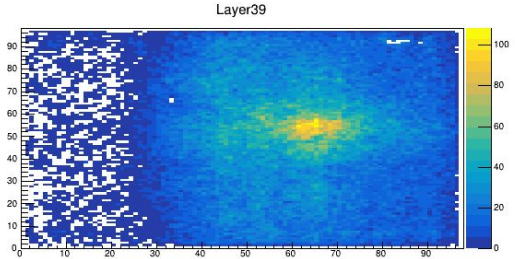


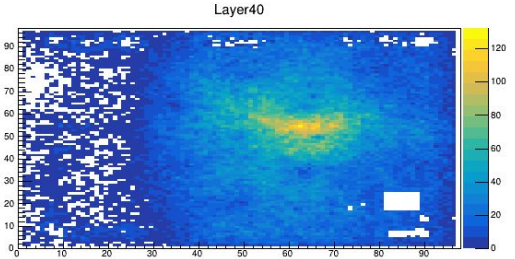
Profiles 17.90º PS

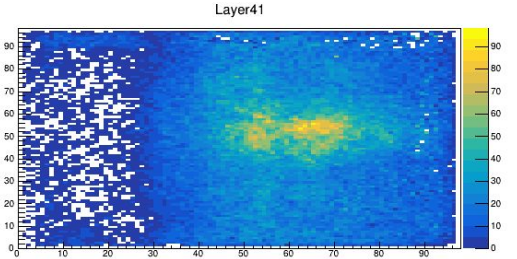


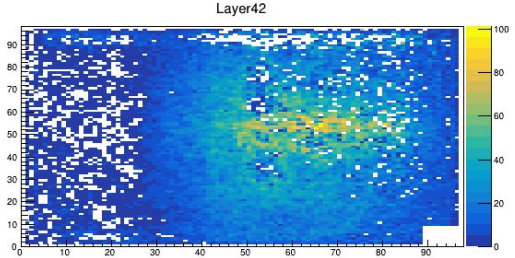


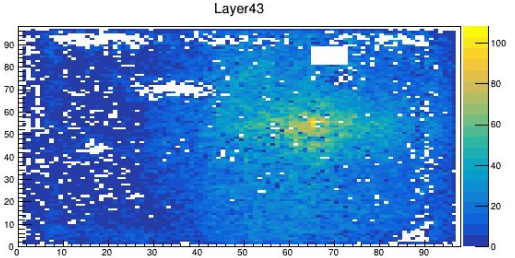


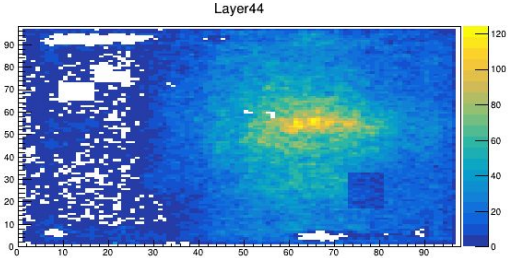












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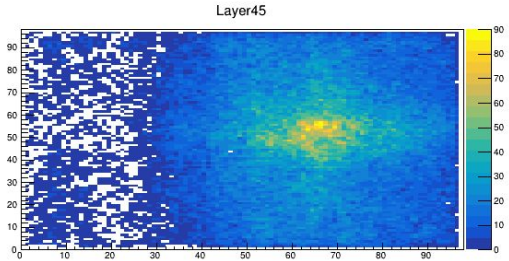
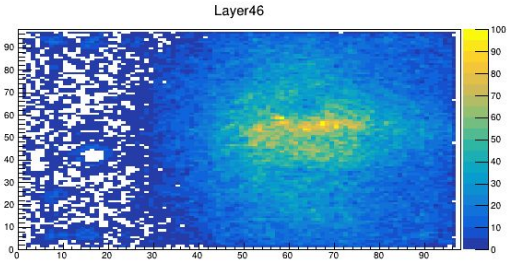
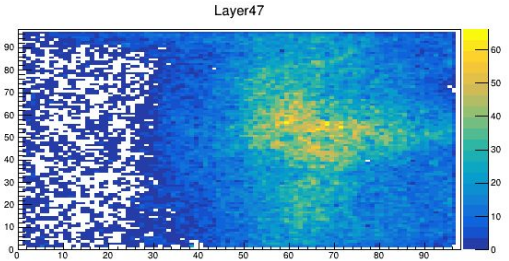
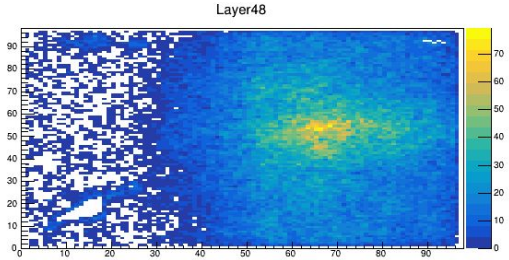


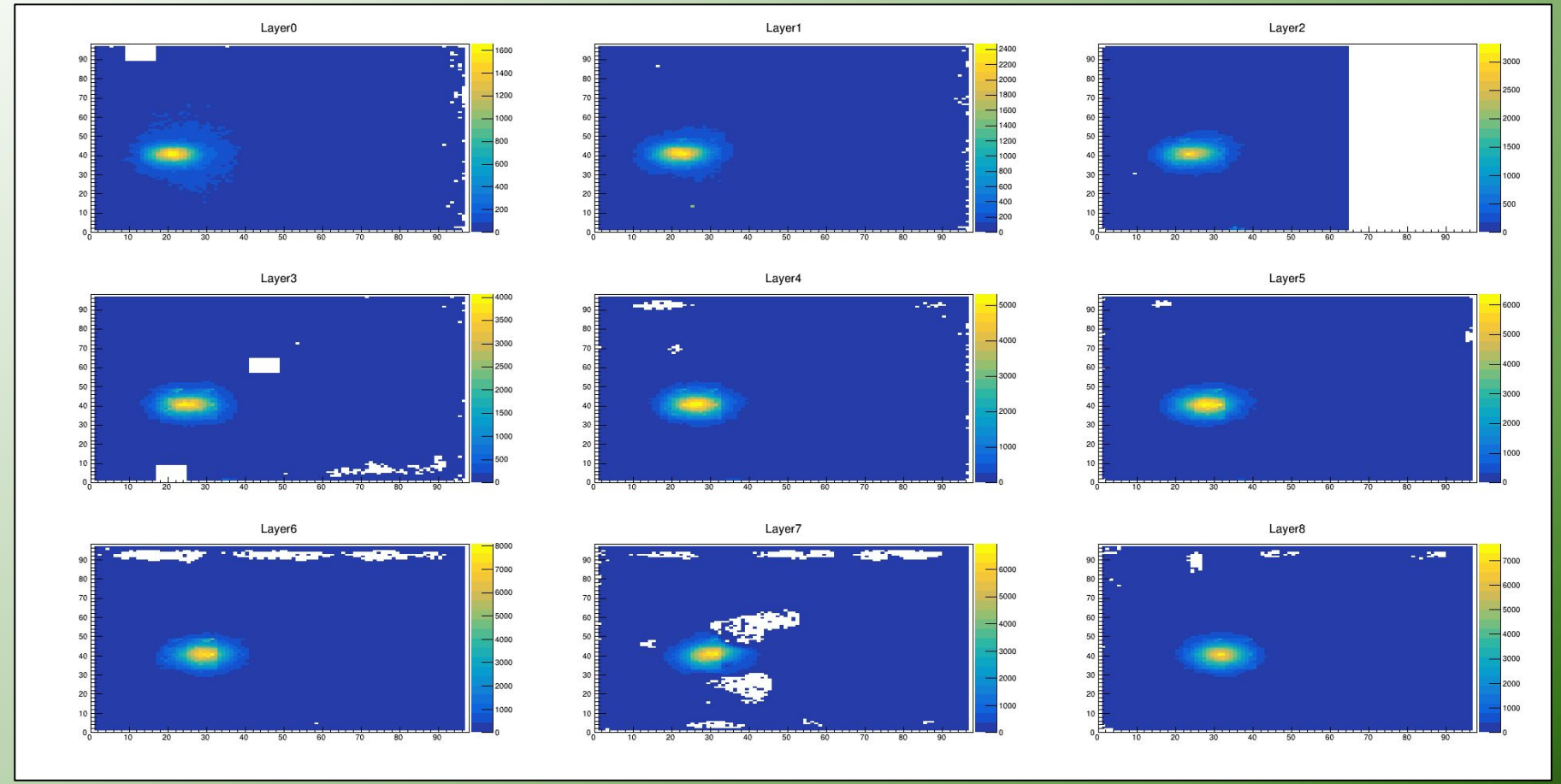




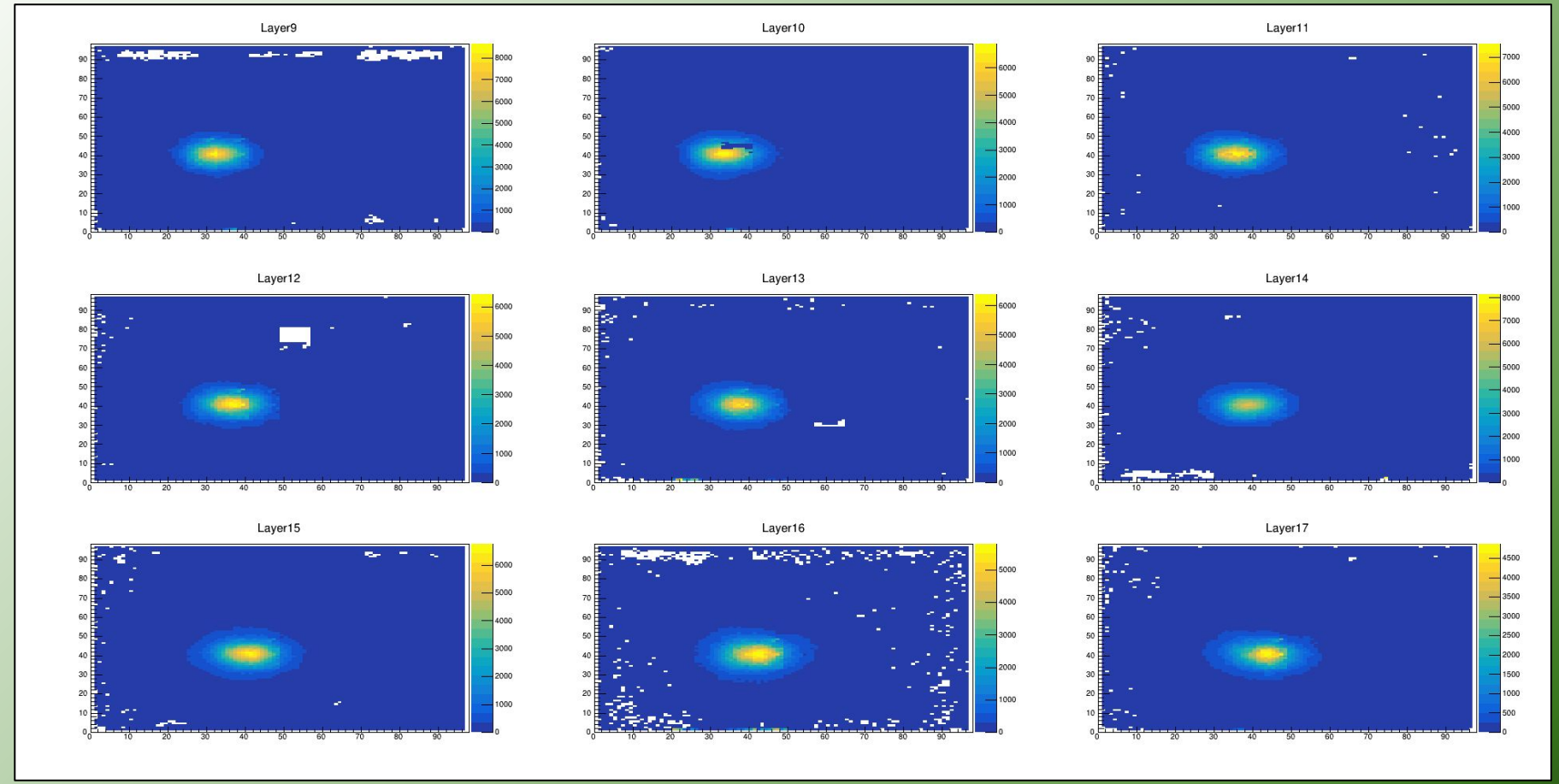


Profiles 28.25°

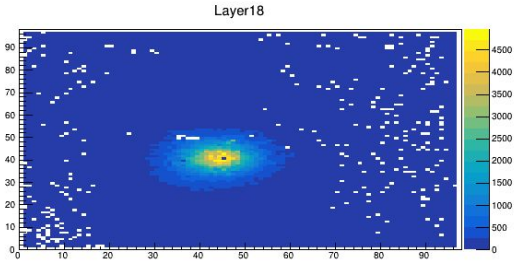
Profiles 28.25º

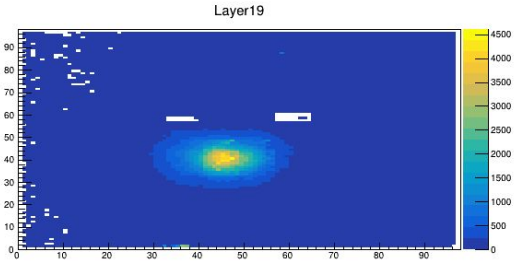


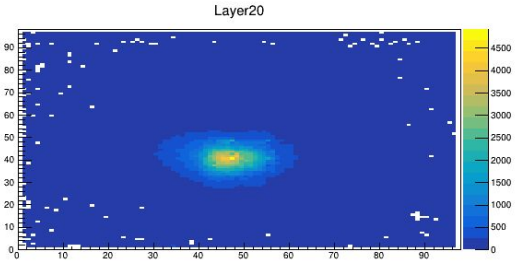
Profiles 28.25º

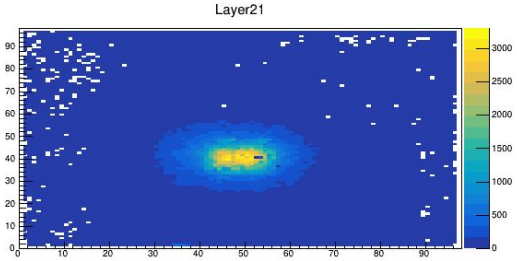


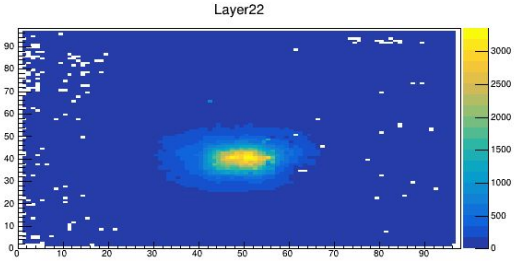
Profiles 28.25º

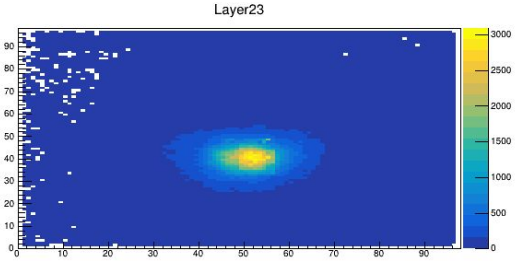


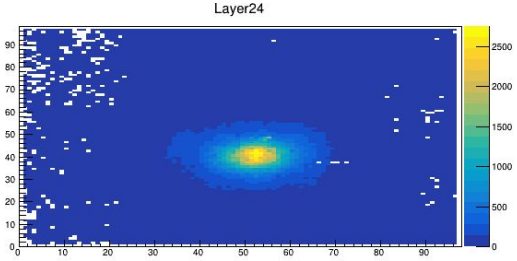


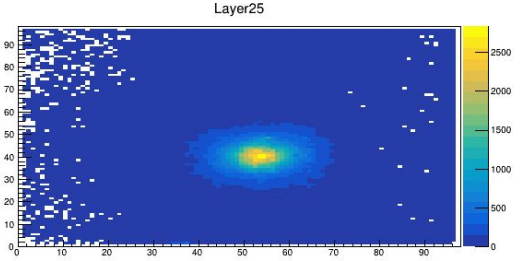


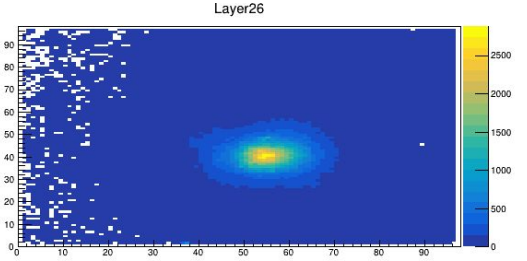




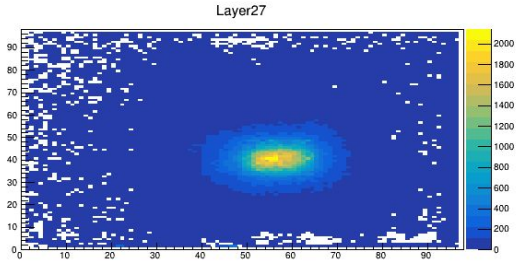


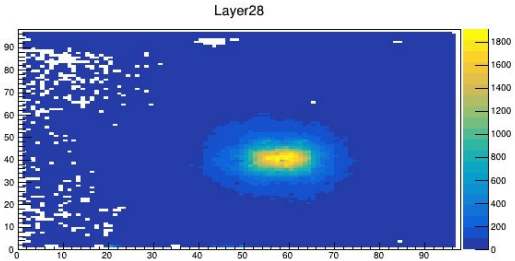


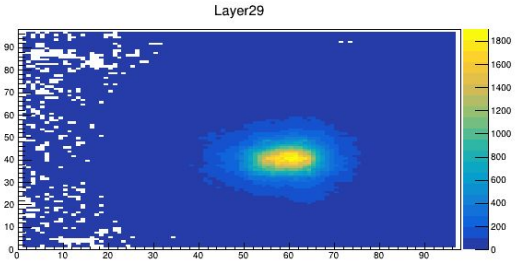


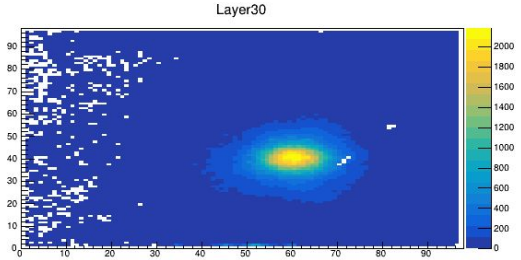


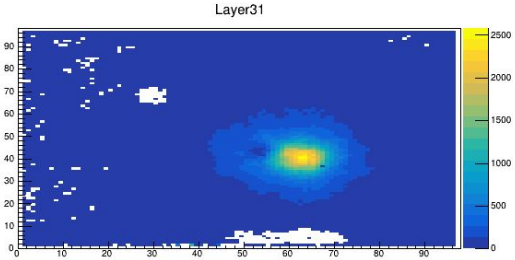
Profiles 28.25º

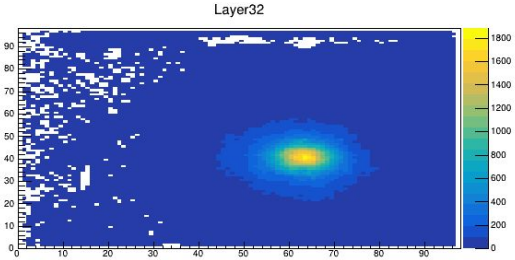


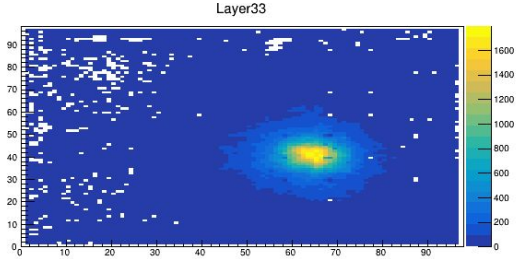


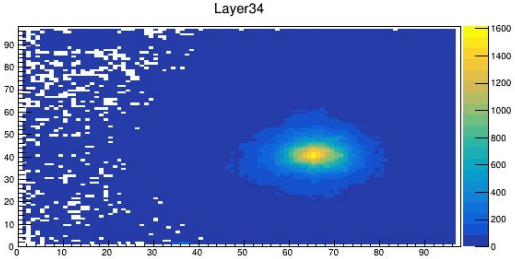


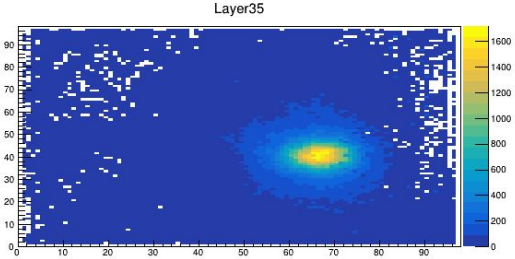




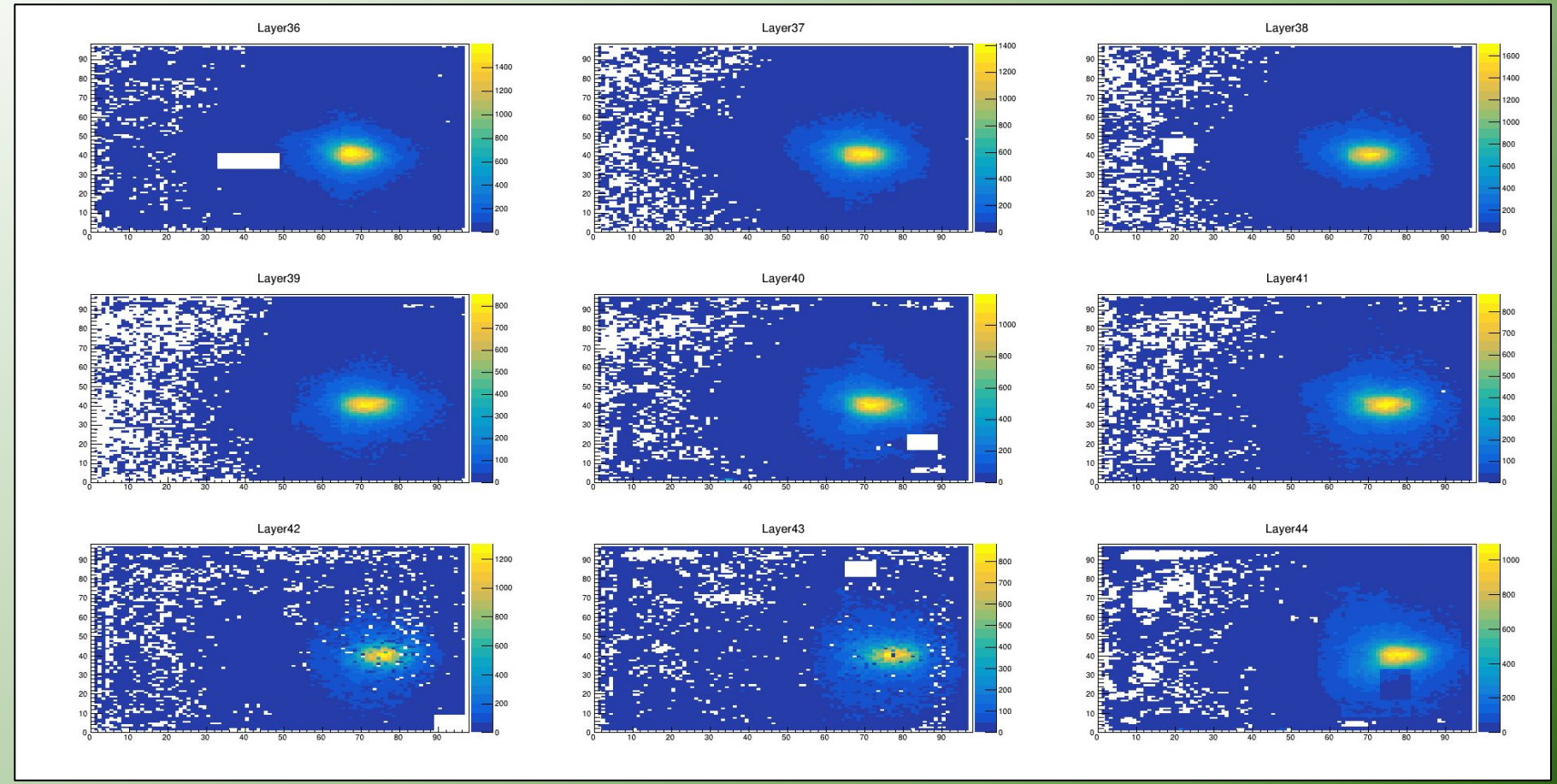








Profiles 28.25º



Profiles 28.25º