Incident angle effect analysis with the SDHCAL

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CALICE Collaboration meeting at Valencia
22 - 04 - 2022

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Contents

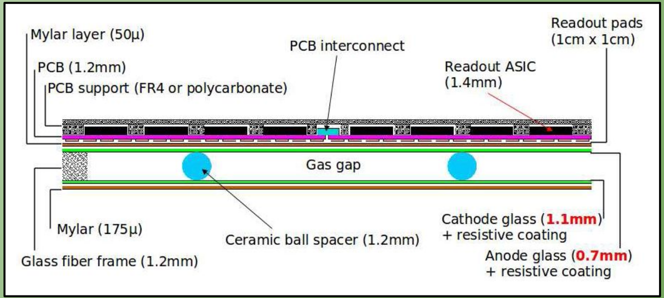
Context & Setup

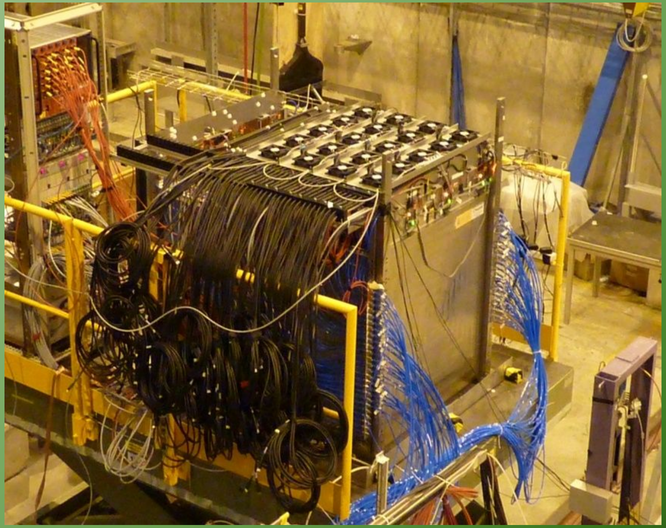
The objective is to check the effect of the incident angle of the particles in the efficiency, multiplicity, energy reconstruction, etc. using the SDHCal as detector.

Data taking was during two test beam in the SPS (May 2015) at CERN:

- Wide range of energies: 10 - 70 GeV .
- Several rotation angles: 0º, 20º and 22º data sets.

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

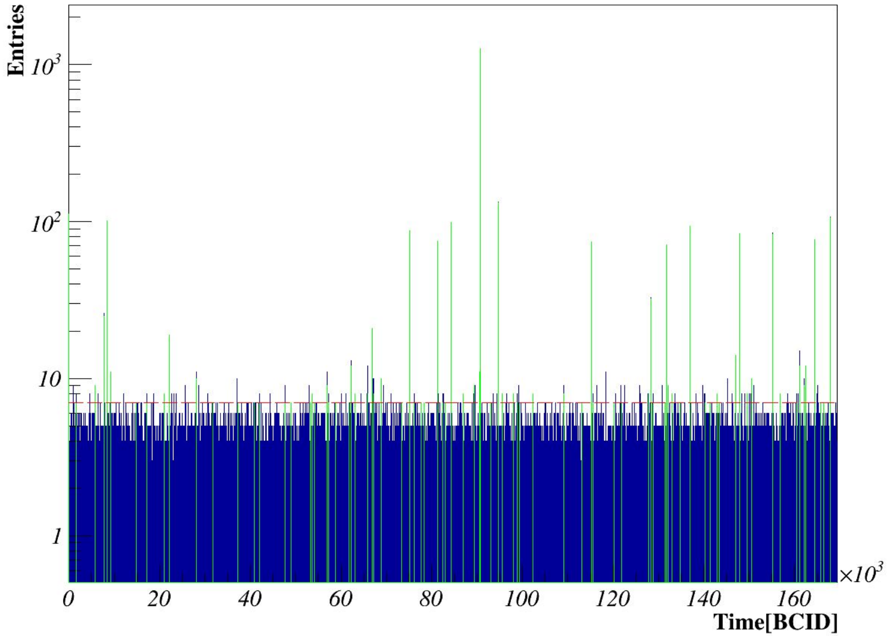




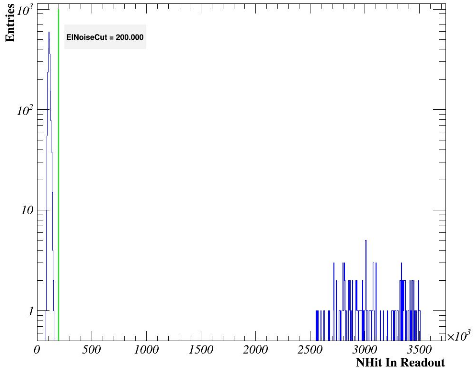
Event building

First, the time clustering algorithm takes care of event building, grouping hits belonging to neighbour time bins with a peak above the noise cut. Also the noisy readouts are removed and overlapping hits are merged.

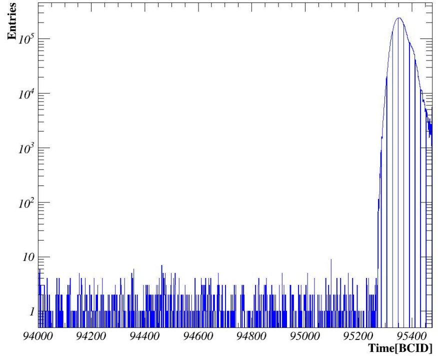
Readout with reconstructed events



Cut to the total hits in a readout

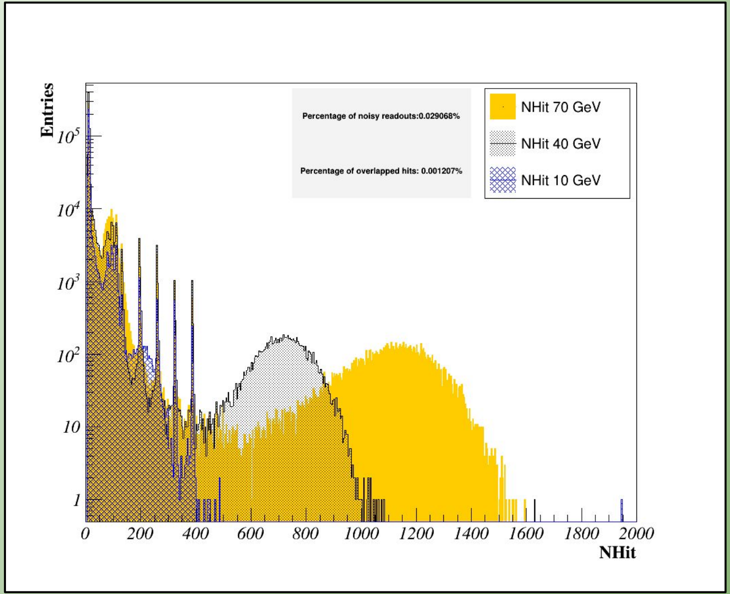


Noisy readout

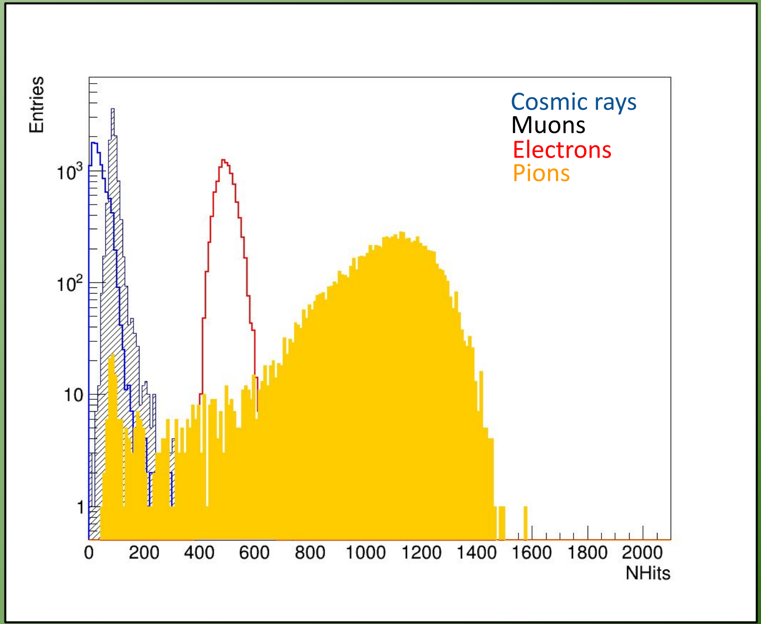


NHit distributions

Each TB run after the event building process is a combination of muons, pions, electrons. cosmic rays and electronic issues. The first step in the analysis is to use the topological properties of each particle to create a clean sample of pions.



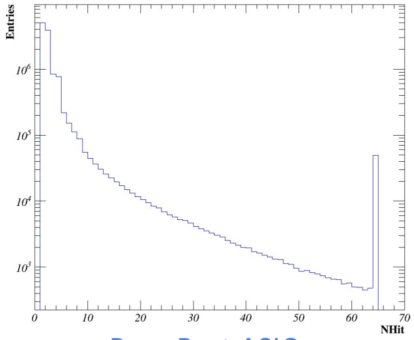
MC simulations of the prototype were available to use as guide to find and improve the selection variables used However the final cut values were chosen in the context of the data.



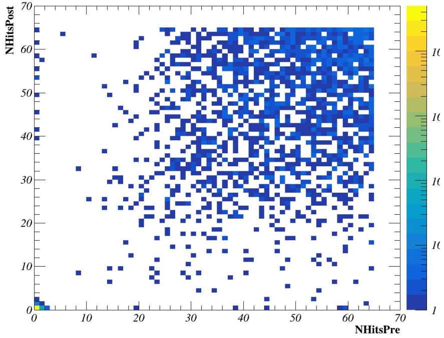
Electronic noise cleanup

The 4 energy independent peaks between 200 - 400 hits are produced by noisy ASICs and DIFs that are cleaned in this step. First the noisy ASICs are selected if they have > 40 hits, if they are not between two ASICs with similar number of hits they are removed.

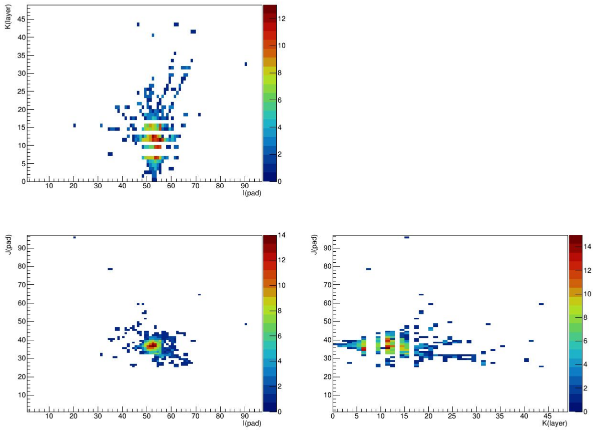
NHits Per ASIC



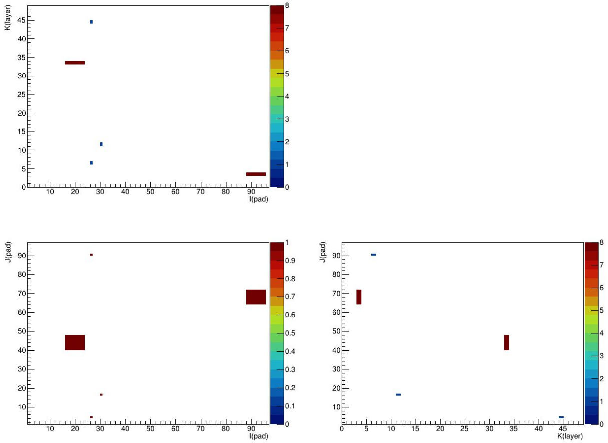
Pre - Post ASICs



Layer issues



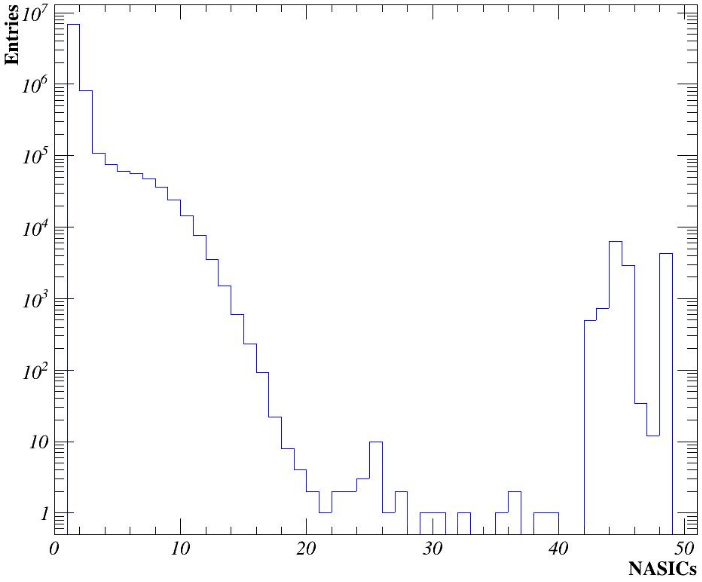
Noisy ASIC



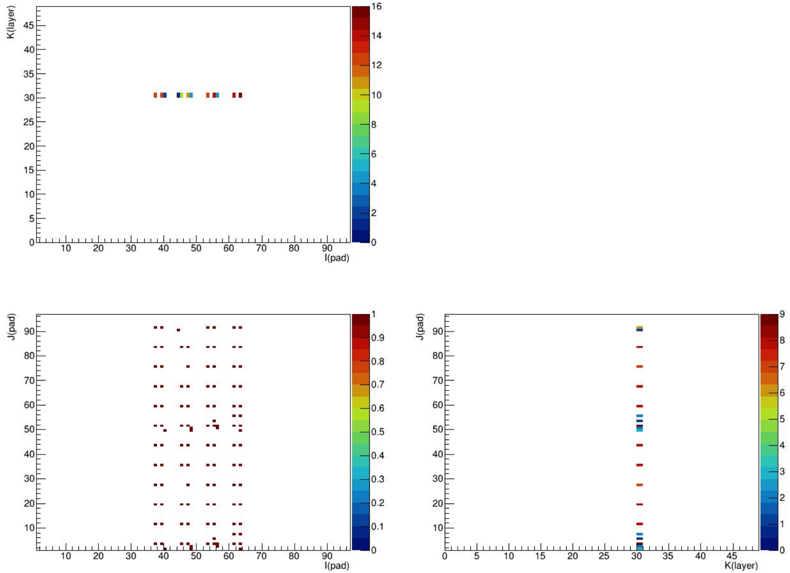
Electronic noise cleanup

The 4 energy independent peaks between 200 - 400 hits are produced by noisy ASICs and DIFs that are cleaned in this step. Noisy DIFs produce a wide area of hits through most of its ASICs. A DIF is removed if it has more than 20 ASICs firing at once.

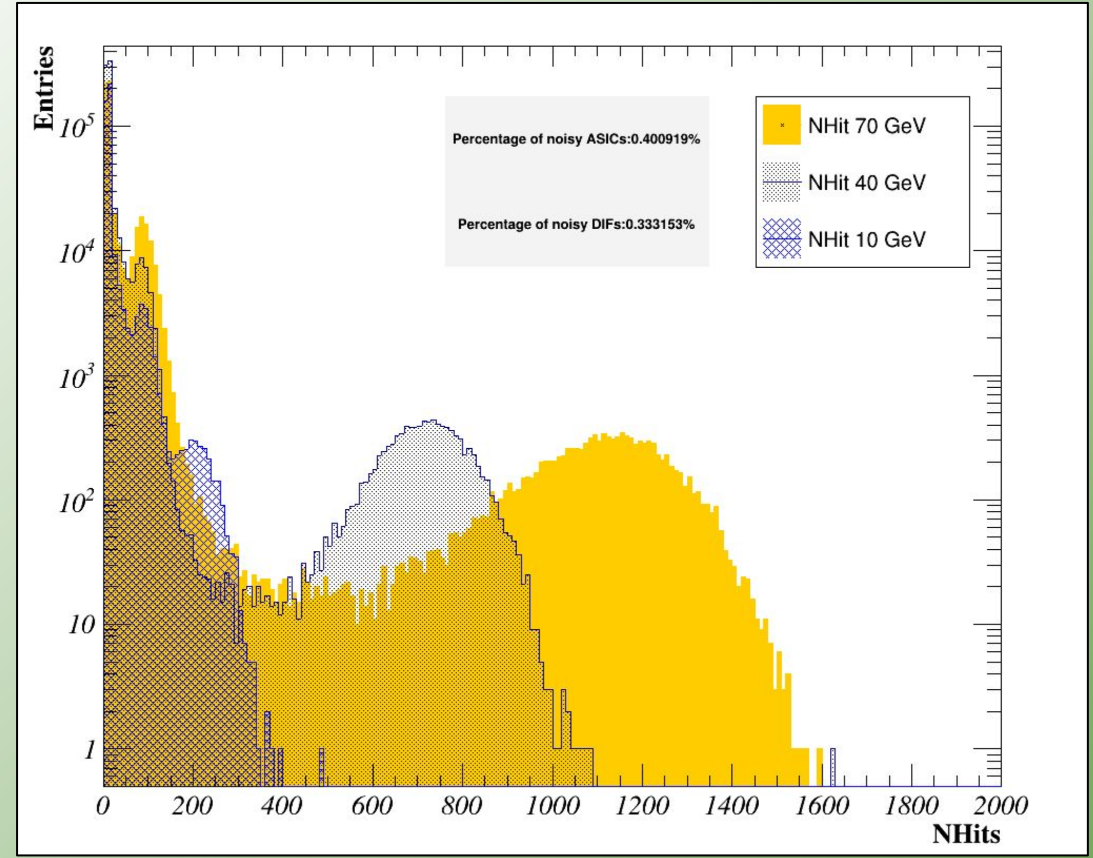
NASICs per DIF

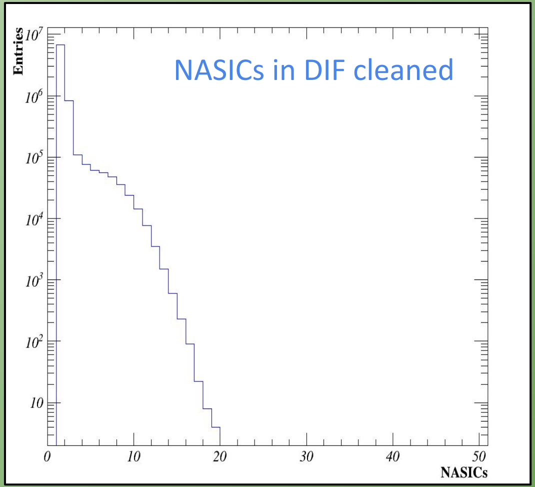


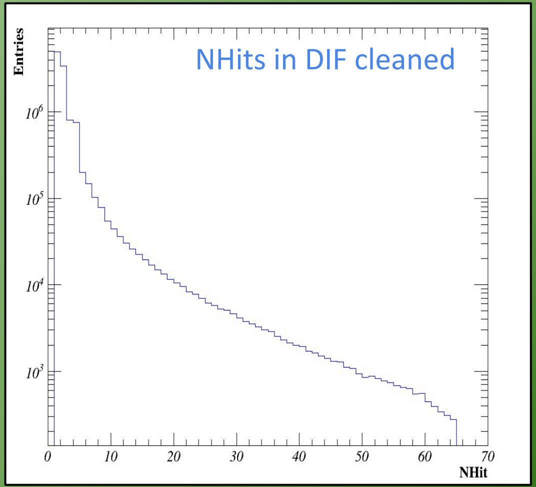
Noisy DIF



Electronic noise cleanup - Results

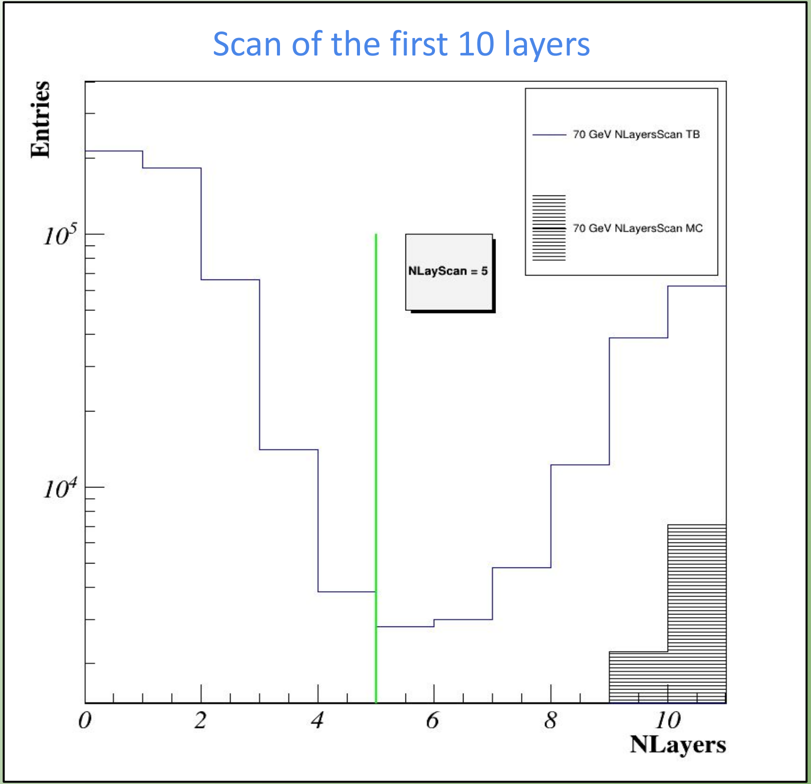


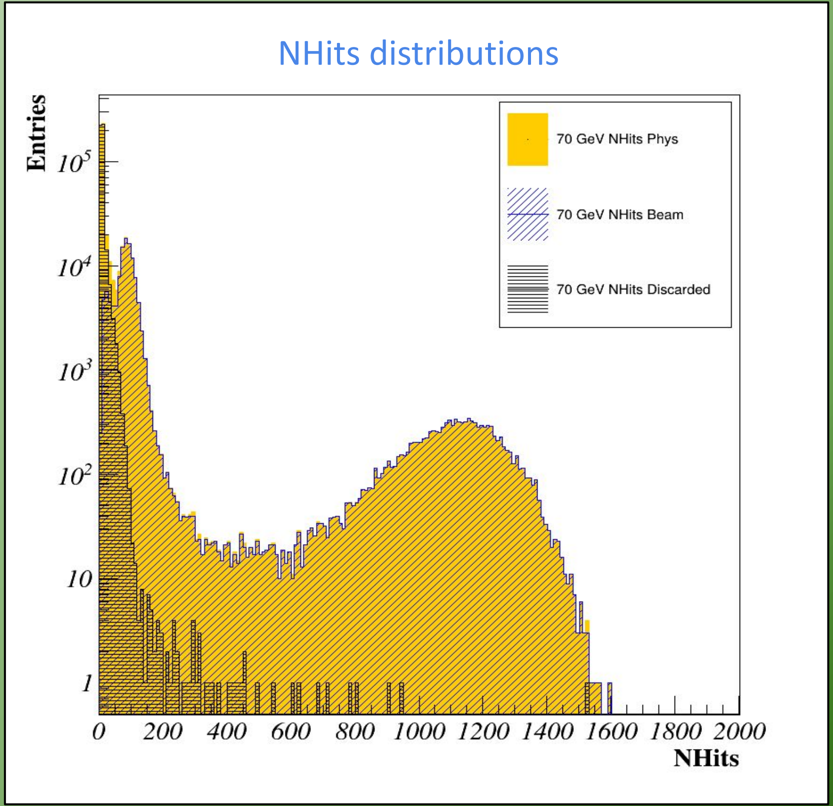




Beam selection

To select the beam particles a scan of the first 10 layers is performed (1 interaction length). The cut to select it as a beam particle has been set to at least 5 layers with signal.





Particles identification variables

Penetrability Condition (P.C.). it is computed relatively to the track length. Taking into account entry and exit points of the particle:

- FirstQuarter = 25%: at least 20% with signal
- SecondQuarter = 30%: at least 25% with signal
- ThirdQuarter = 30%: at least 25% with signal
- LastQuarter = 15%: at least 10% with signal

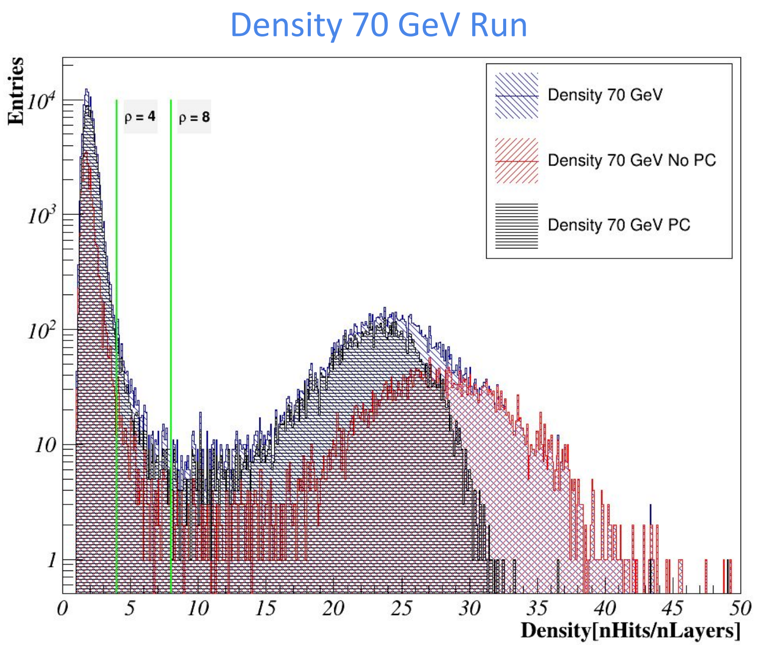
Density: $\rho = \frac{nHit}{nLayers}$

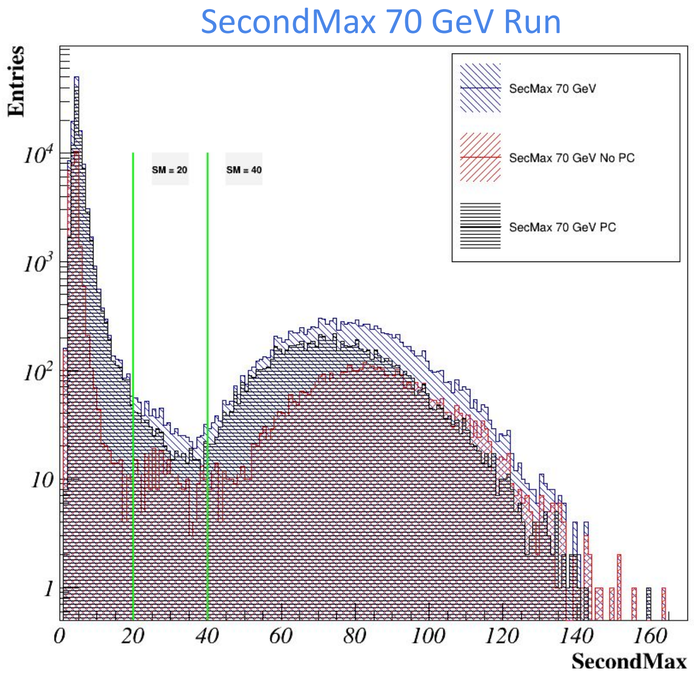
nHit → total number of hits in the detector

nLayers→ number of layers with signal

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

Muon selection



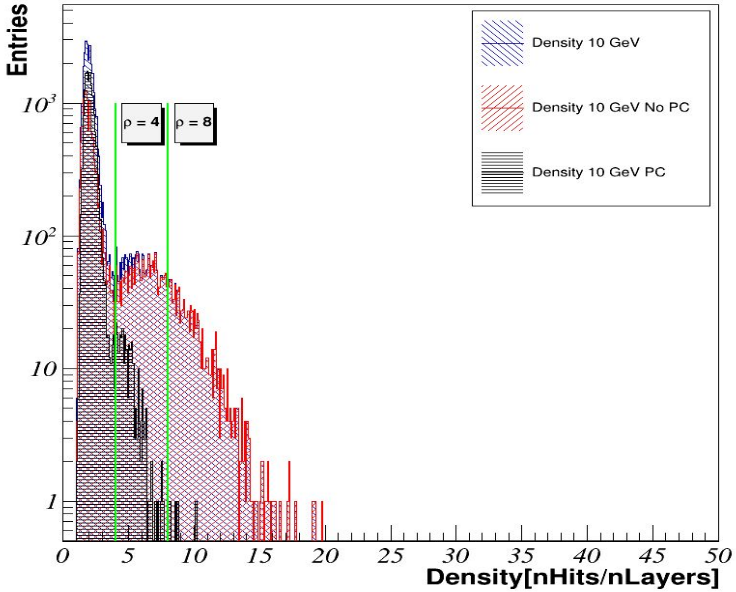


Selected cuts:

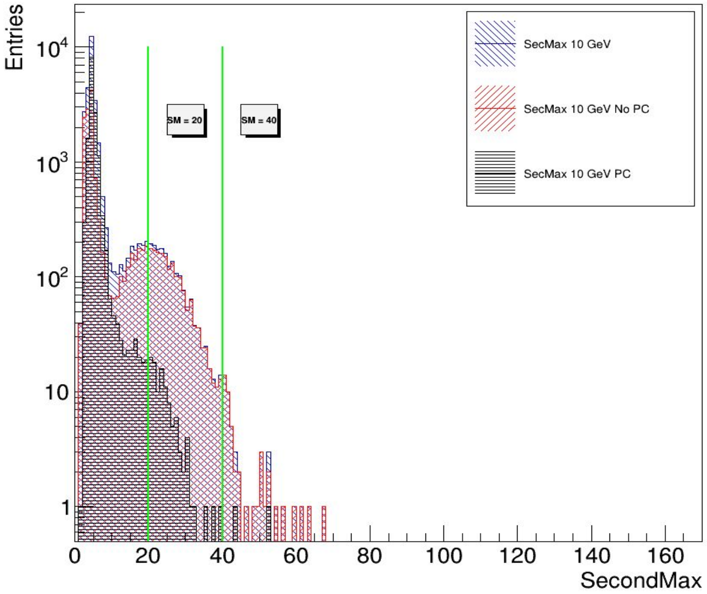
- PC is powerful enough to separate most of the muons and late showers is requested first. If PC is true then $\rho < 8$ and SecondMax < 40 cut selects MIP like particles, muons showering and late showers.
- The events with no PC are a combination of showers and cosmics. Cosmics are selected as $\rho < 4$ and SecondMax < 20.

Muon selection

Density 10 GeV Run



SecondMax 10 GeV Run



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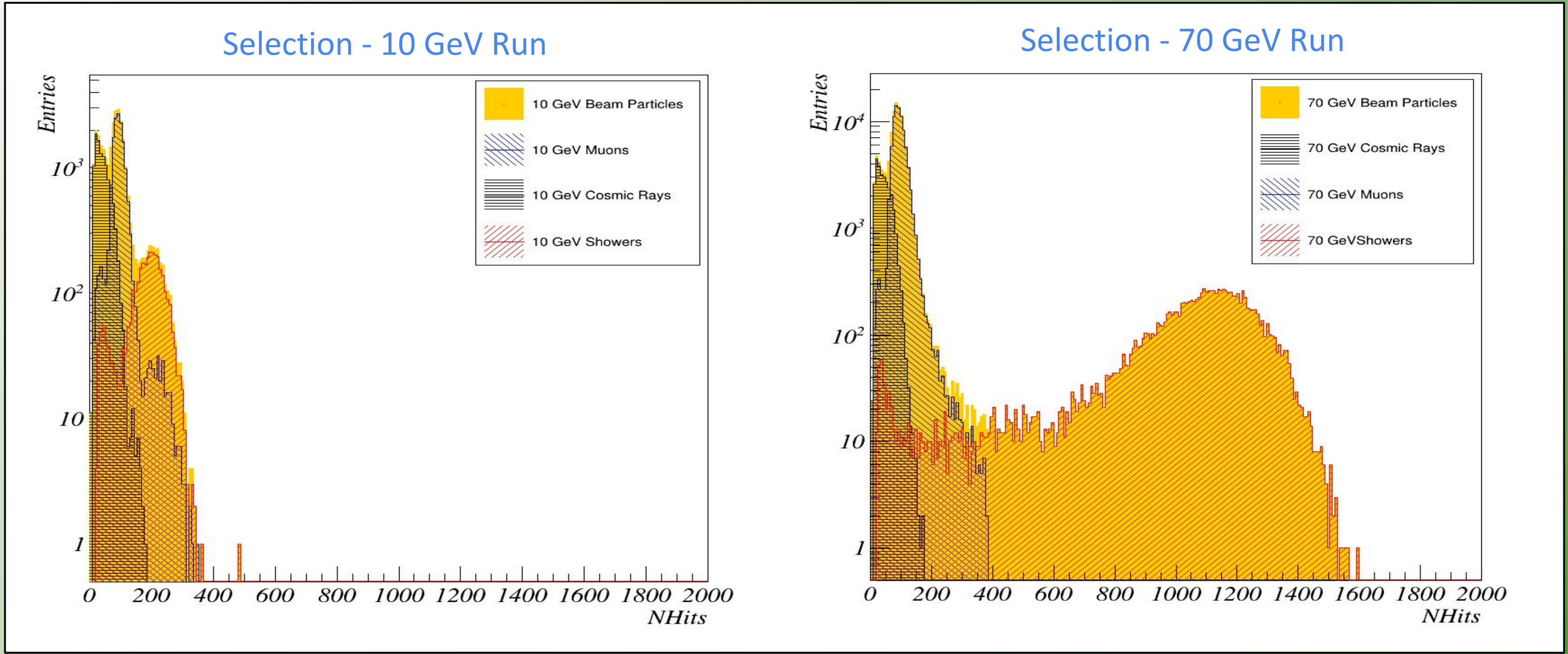
Muon selection - Result



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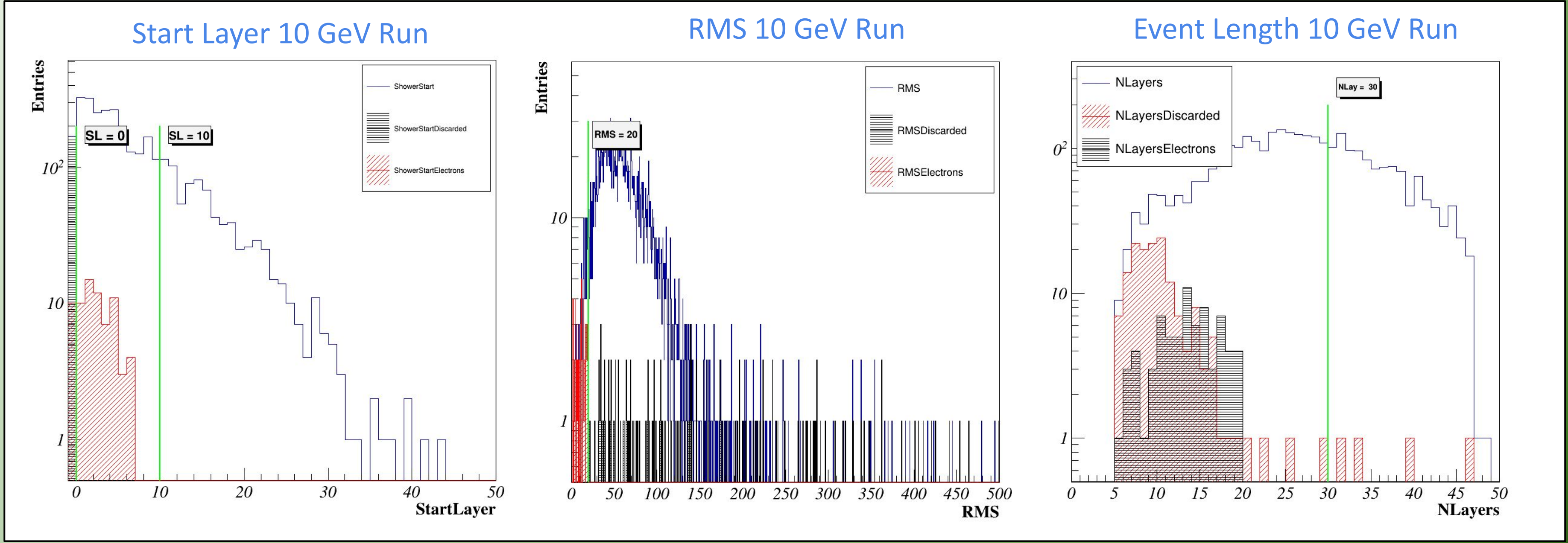
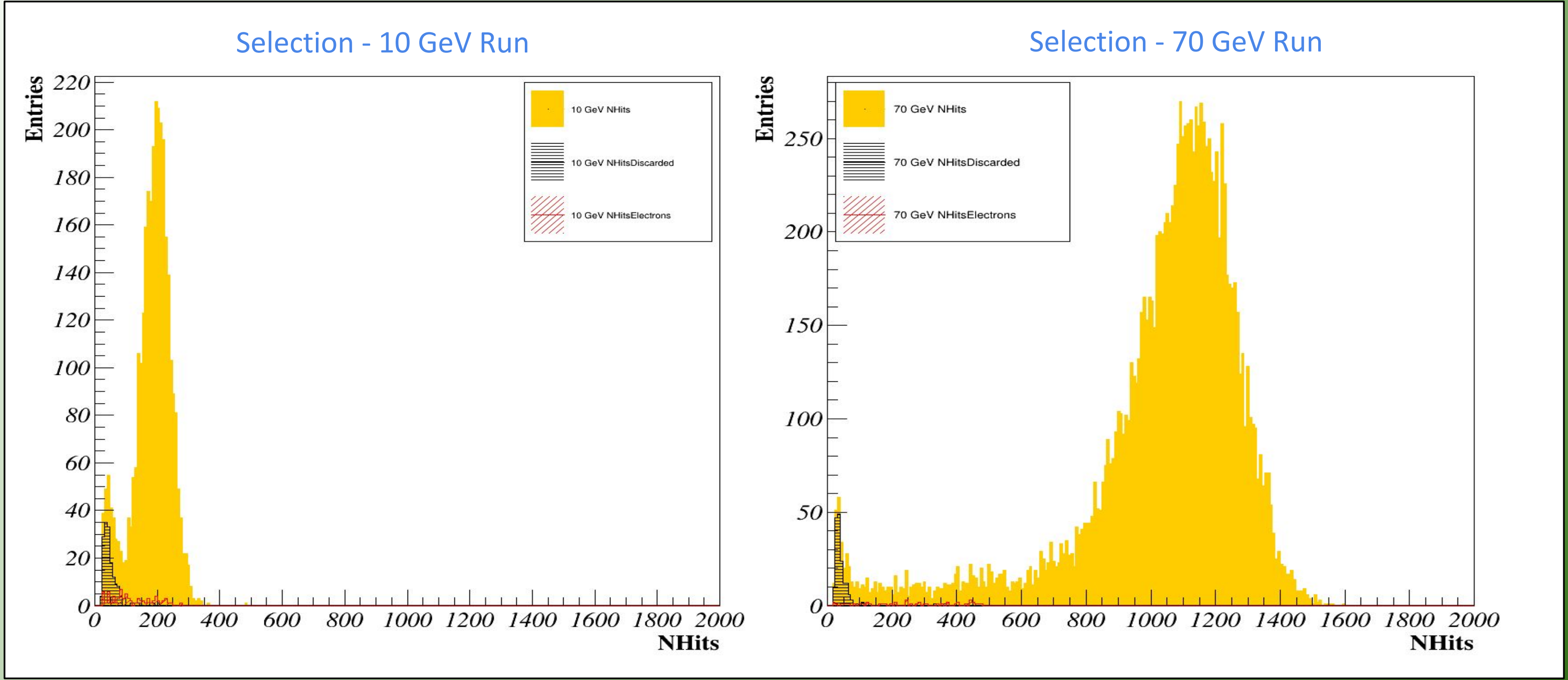
Pion selection

The current data sets contain pions, electron (although very low contamination is expected) and some remaining low number of hits events.

A combination of cuts to the shower start layer, the RMS of the hits and the event length are enough to make the final selection. The value of the cuts were guided by the simulations.



Pion selection - Result



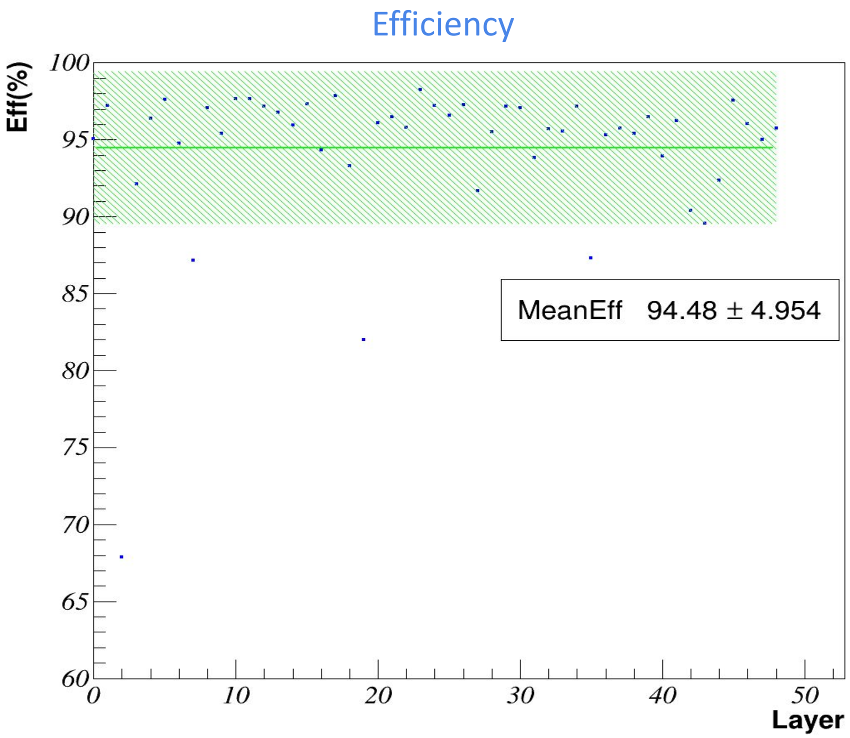
Muons analysis

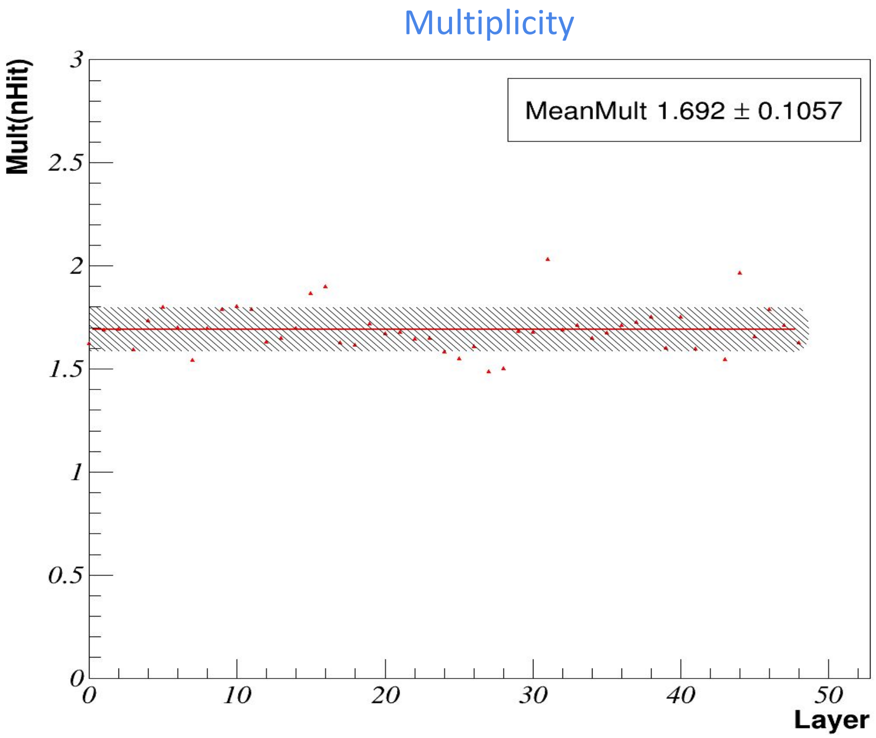
We can use the track of muons to compute the efficiency and multiplicity of each GRPC layer in the prototype. First we recompute the track of the muon using all the chambers but the one we are going to study then:

Efficiency → The layer is efficient if it has a cluster of hits closer than 5 pads 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.

Detector performance. Efficiency and multiplicities - 0 Deg DataSet



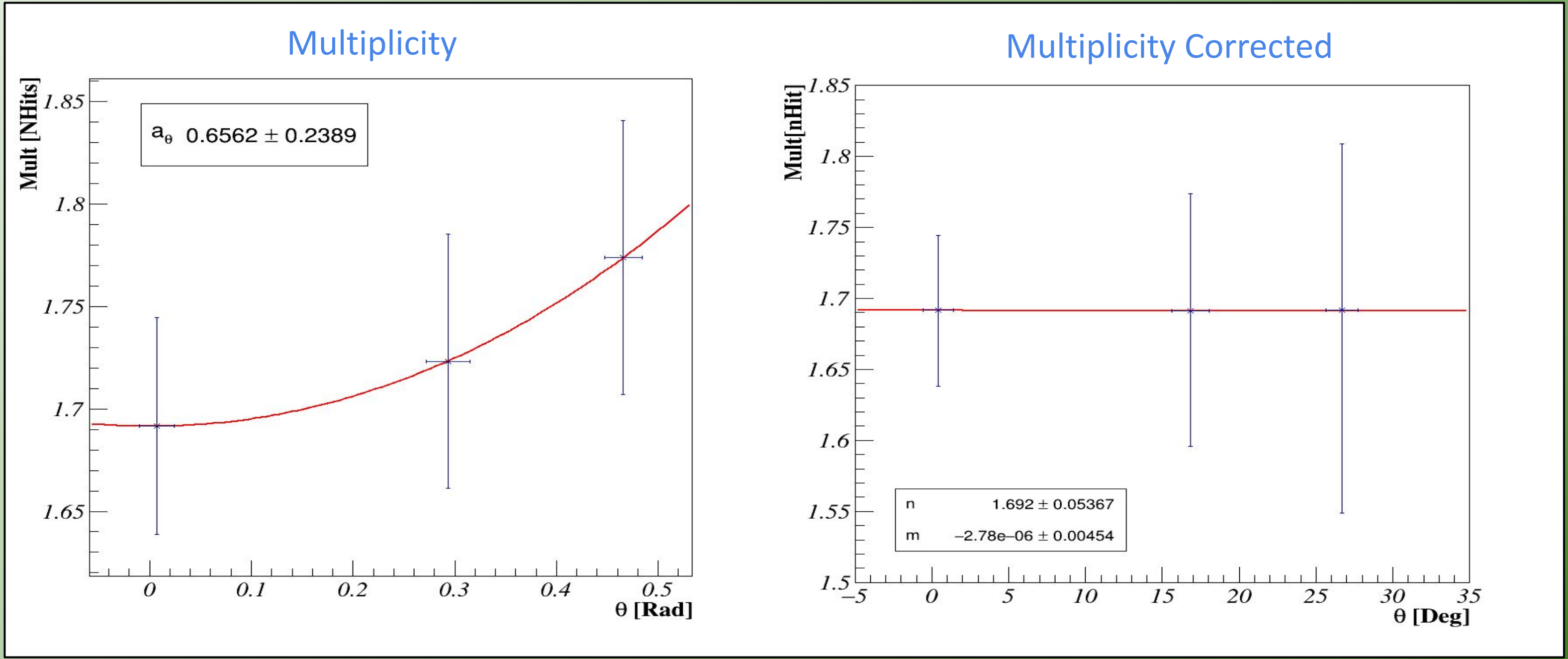


$$\sigma = \frac{1}{NLayers} \sum_{i=1}^{NLayers} (Mean - Value_i)^2$$

Detector performance. Angle effect

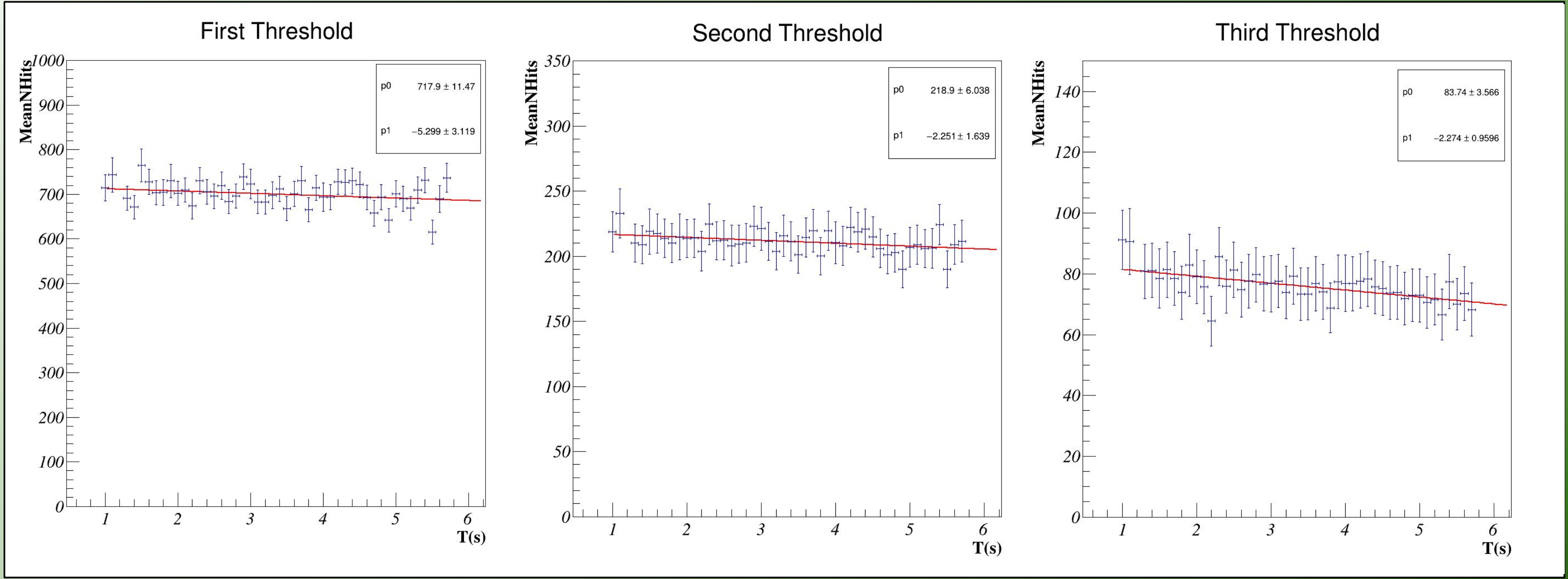
The multiplicity increases with the angle as the particle crosses more active area. This angle effect has in impact degrading the energy reconstruction as the number of hits changes. It can be accounted by correcting the number of hits as a function of the angle: $N'_{Hit} = N_{Hit} \cdot cos(a\theta_{Rad})$

The correction parameter 'a' can be obtained by fitting the multiplicity to the function: $$M = \frac{M_0}{cos(a\theta)}$$



Detector performance. Intensity effect

At the end of spills the intensity increases saturating the detector producing a loss of hits. This effect is of different magnitude per threshold and it is corrected with the expression: $N_j = N_j - \lambda_j T$



Energy parametrization

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

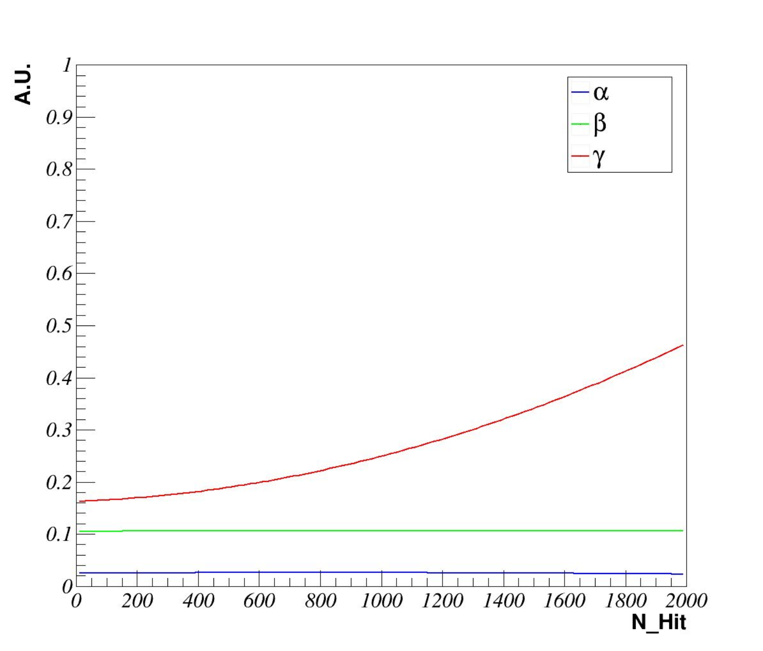
$$E_{Reco} = \alpha N_1 + \beta N_2 + \gamma N_3$$

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

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

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

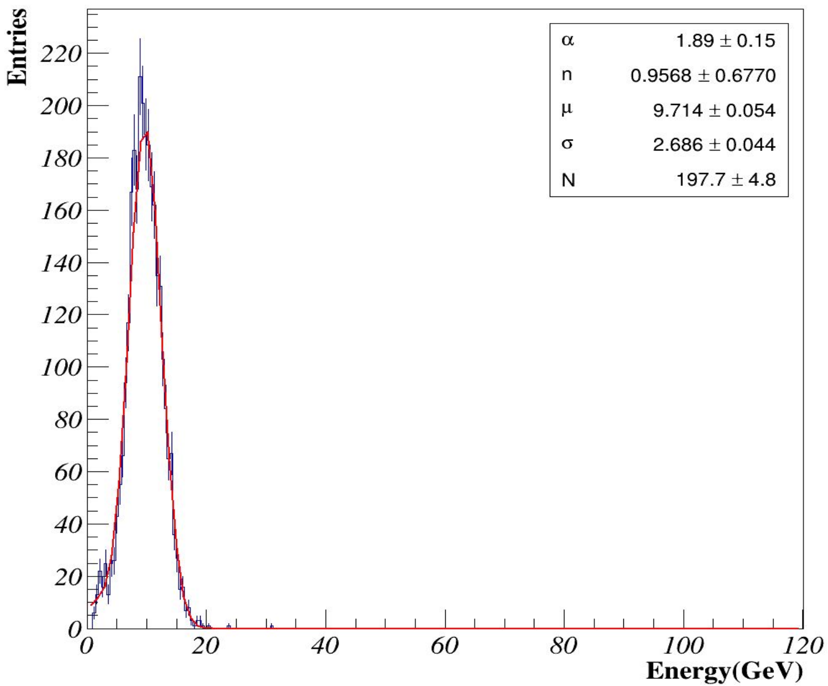
$$N_T = N_1 + N_2 + N_3$$



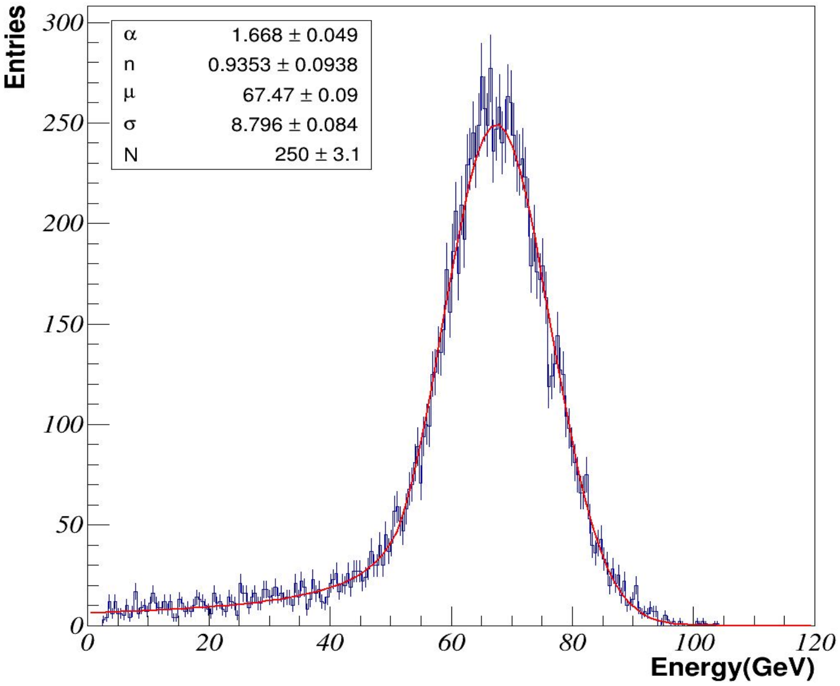
The set of optimal parameters are obtained from minimizing: $\chi^2 = \sum_{i=1}^{N} \frac{(E^i_{Beam} - E^i_{Reco})^2}{\sqrt{E^i_{Beam}}}$

Energy Reconstruction

10 GeV Pions - 0 Deg DataSet



70 GeV Pions - 0 Deg DataSet

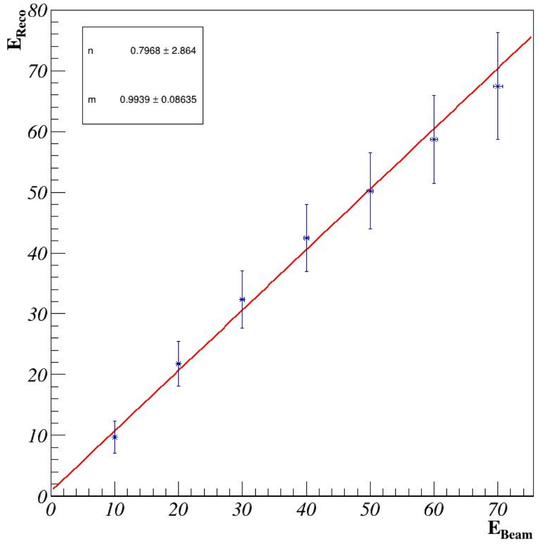


Linearity and resolutions - 0 Deg DataSet

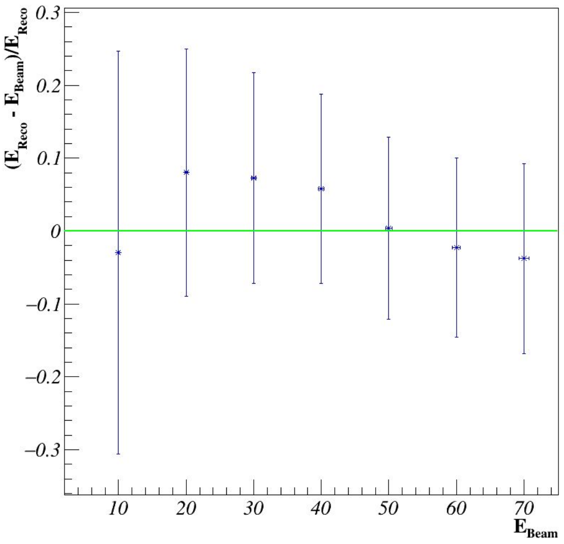
The values from the fit of the energy distribution are used to compute the linearity and resolutions.

$$\Delta E_{Reco} = \sigma \qquad Dev = (E_{Beam} - E_{Reco})/E_{Reco} \qquad Res = \frac{\sigma}{E_{Reco}}$$

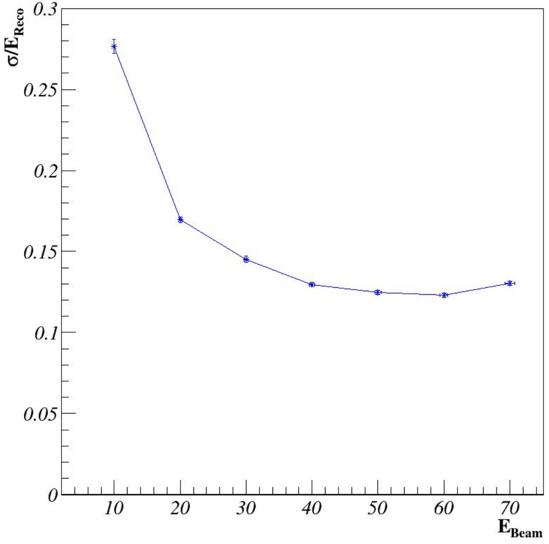
Linearity



Deviations



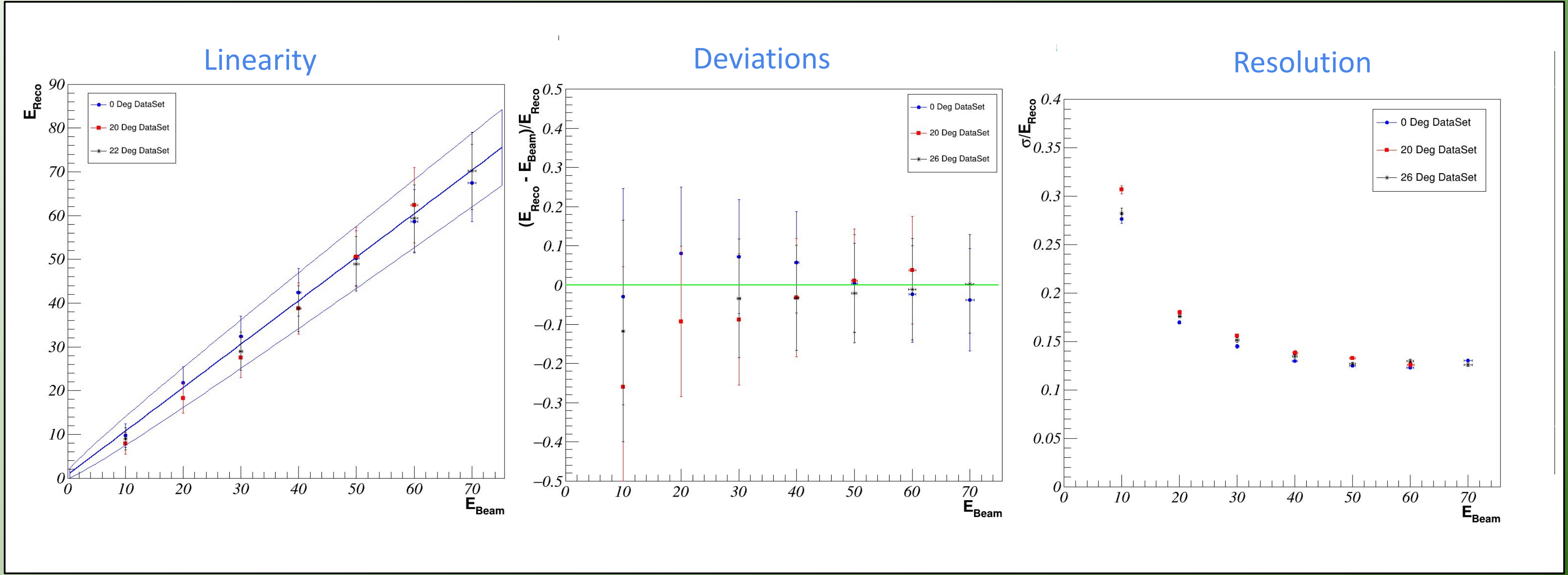
Resolution



Linearity and resolutions - All Degrees

Results from all DataSets are compatible using the same parametrization.

$$\Delta E_{Reco} = \sigma \qquad Dev = (E_{Beam} - E_{Reco})/E_{Reco} \qquad Res = \frac{\sigma}{E_{Reco}}$$



Conclusion

The effect of the incident angle of the particles has been identified, accounted and corrected to be able to use the standard 0Deg calibrated parametrization only using geometrical properties.

The results include statistical and an estimation of the systematics errors, by applying a ~ +-10% variation to each cut consecutively and propagated to the end results.

This kind of analysis can be easily extended to wider energy ranges or even other prototypes of similar granularity.

A paper of this analysis has been prepared and will be shared to revision soon.

?

Backup

Raw Stream-Out & Trivent - Backup

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

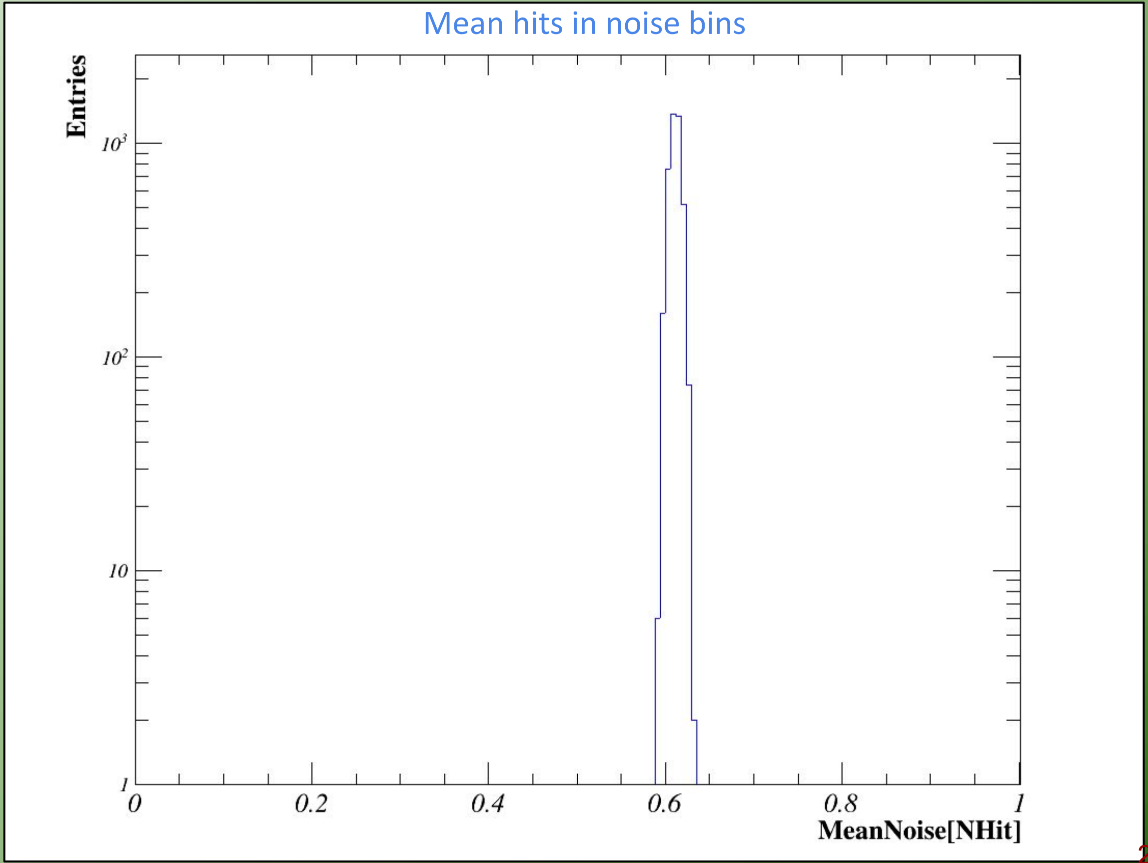
The raw data from 2015 had a DIF header size of 24 bytes and the Slow Control data was not extracted.

Cuts to the reconstructed events:

- Total NHit < 200000 in readout (remove electronic noise)
- NHit > 7 in the main bin to start time reconstruction

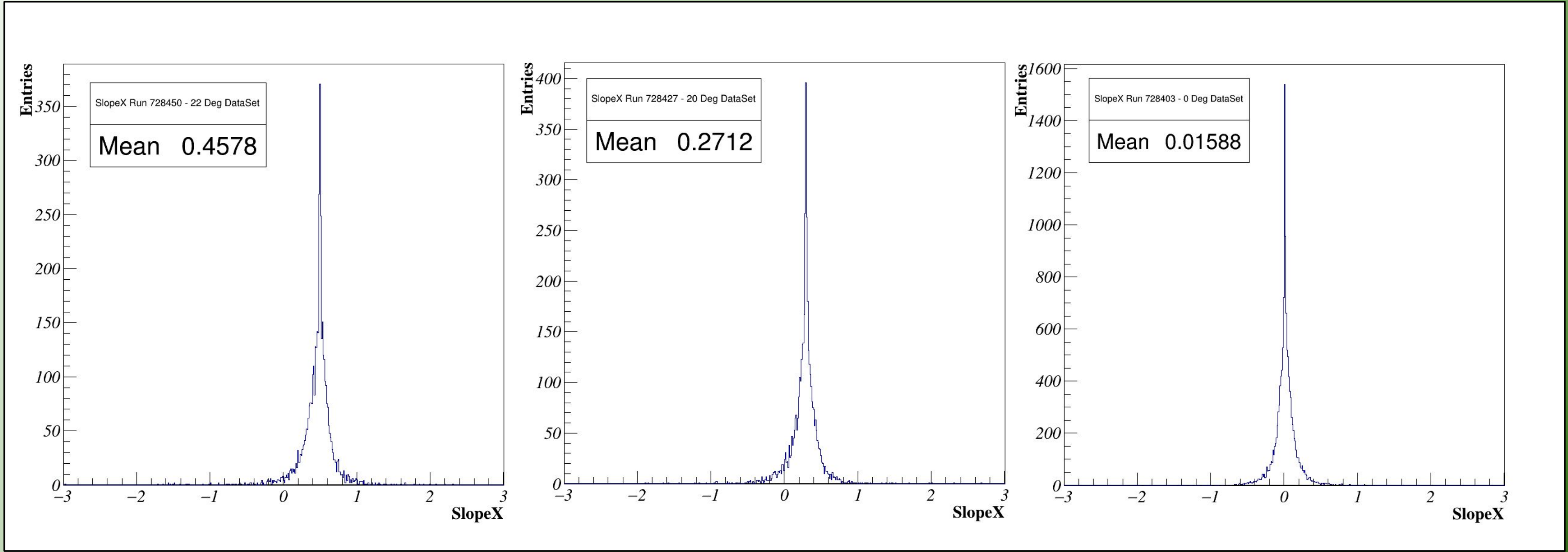
Event building - Backup

After selecting the physical events it is possible to compute the mean noise hits per bin in the rest of the readout. This multiplied to the last bin should be the mean number of hits expected in a readout plus the physical events, which is always less than 200.000 hits.

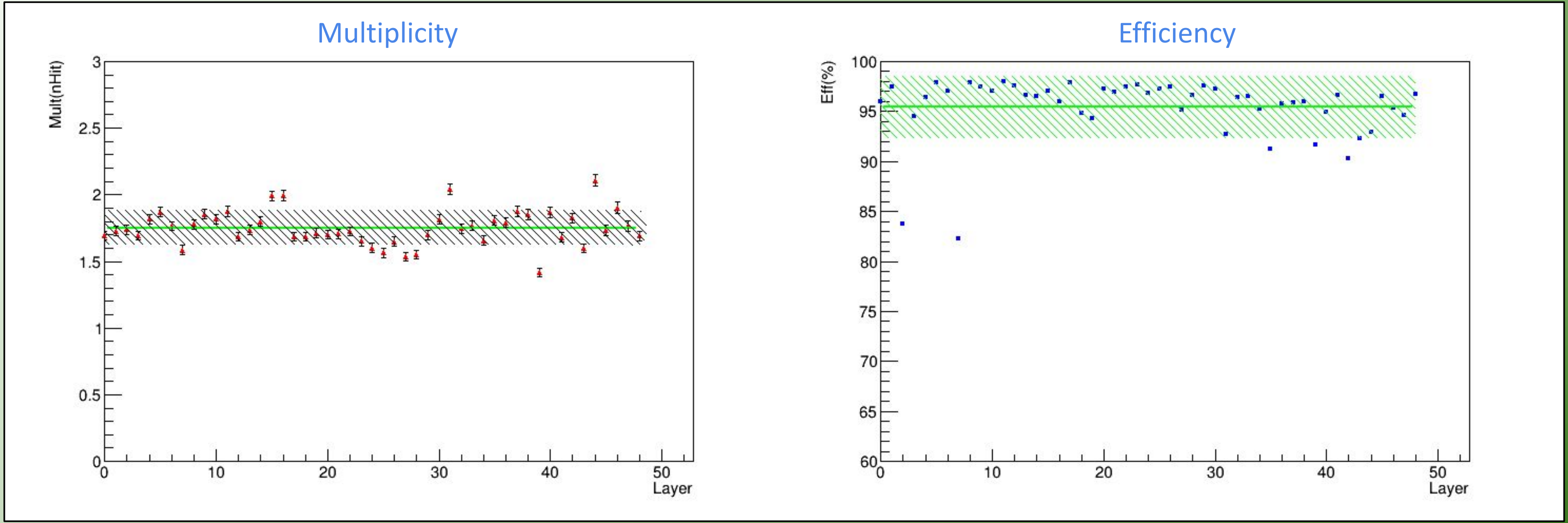


Slopes - Backup

The slopes are obtained from the track using the first 10 layers of the prototype where the particles will behave most likely as a MIP.



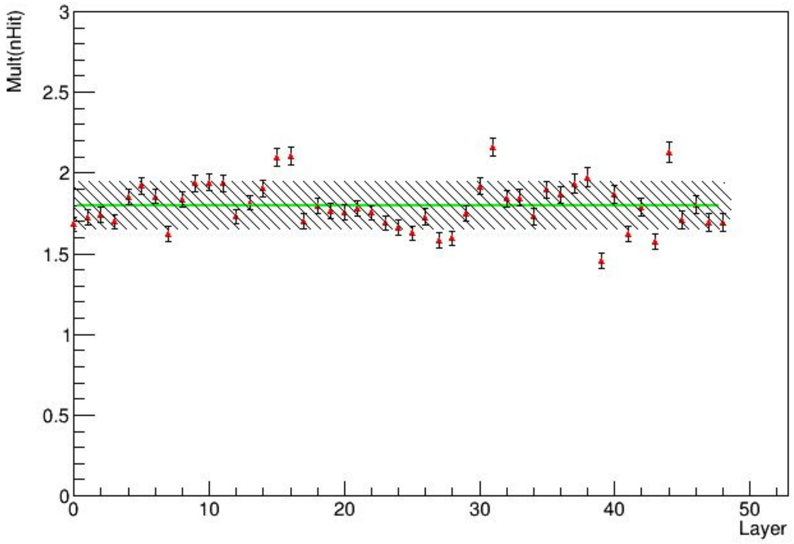
Detector performance. Efficiency and multiplicities (20 Deg Data) - Backup



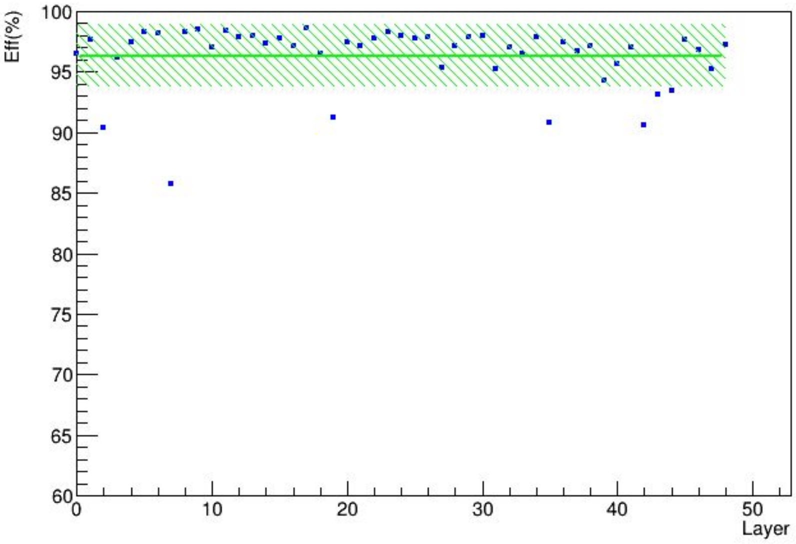
$$\sigma = \frac{1}{NLayers} \sum_{i=1}^{NLayers} (Mean - Value_i)^2$$

Detector performance. Efficiency and multiplicities (26 Deg Data) - Backup

Multiplicity

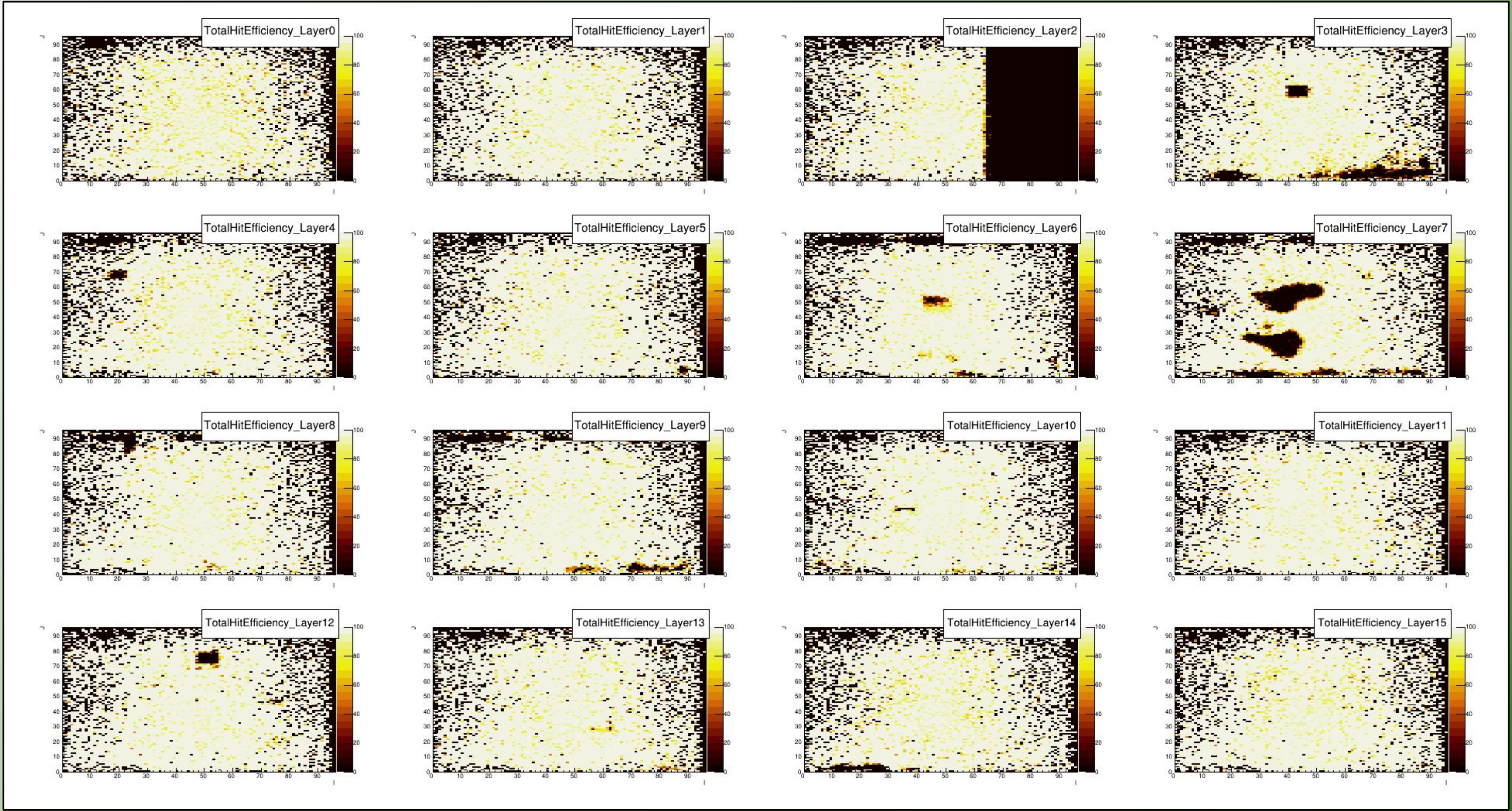


Efficiency

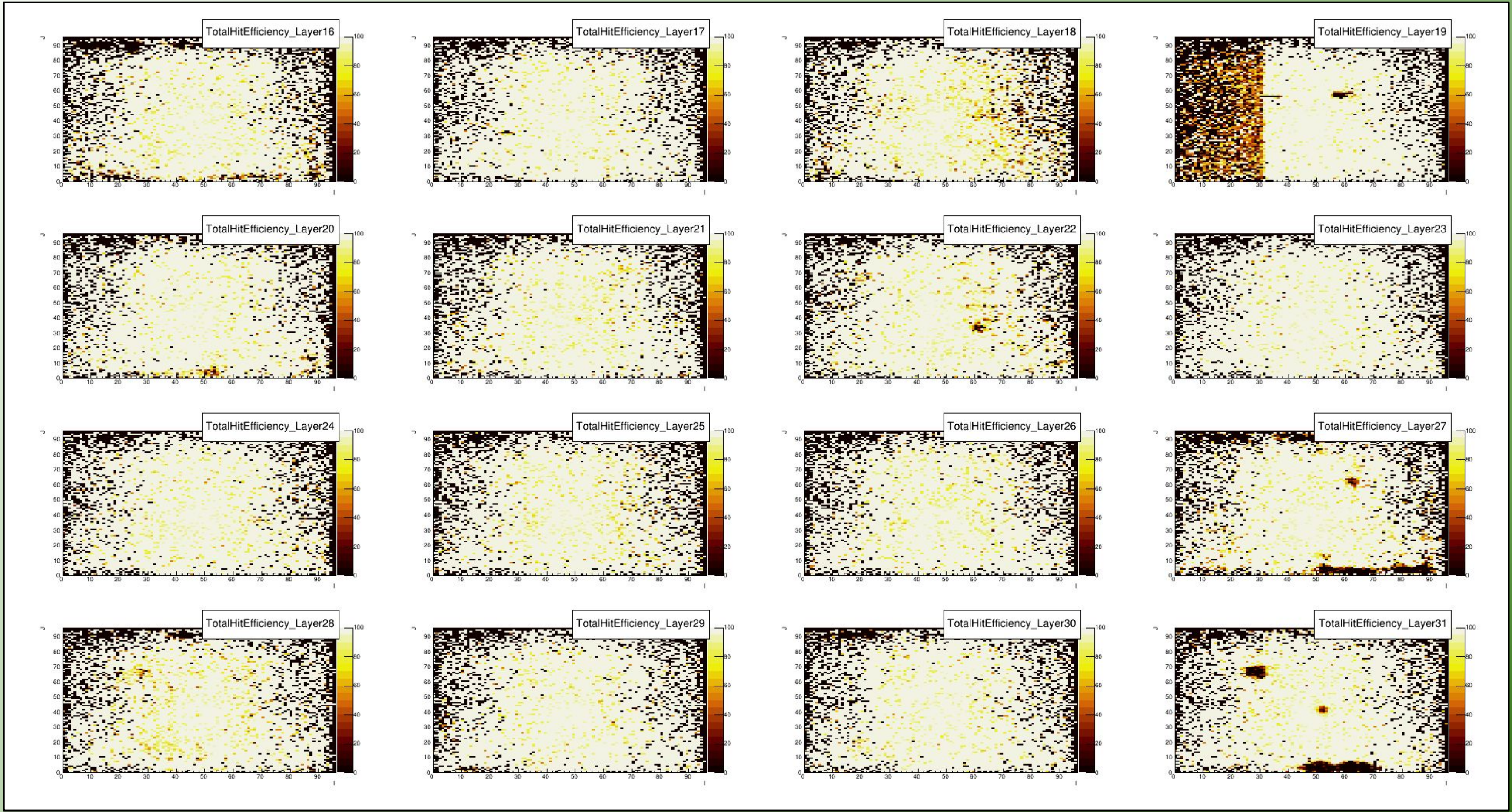


$$\sigma = \frac{1}{NLayers} \sum_{i=1}^{NLayers} (Mean - Value_i)^2$$

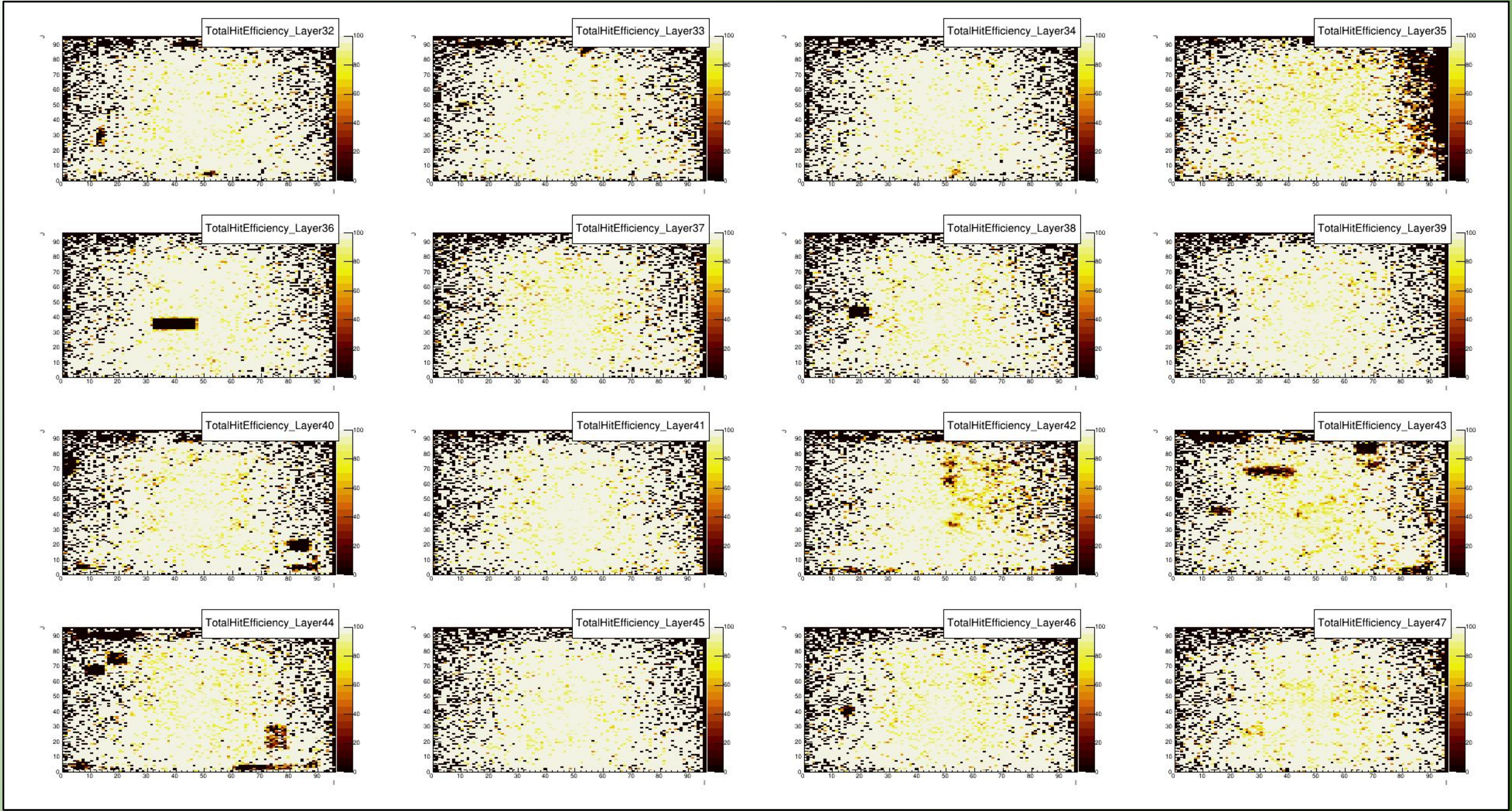
Detector performance. Hit Efficiencies - Backup



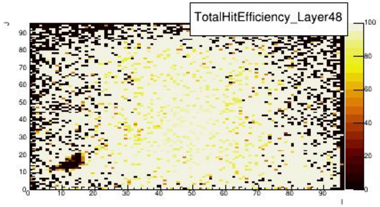
Detector performance. Hit Efficiencies - Backup



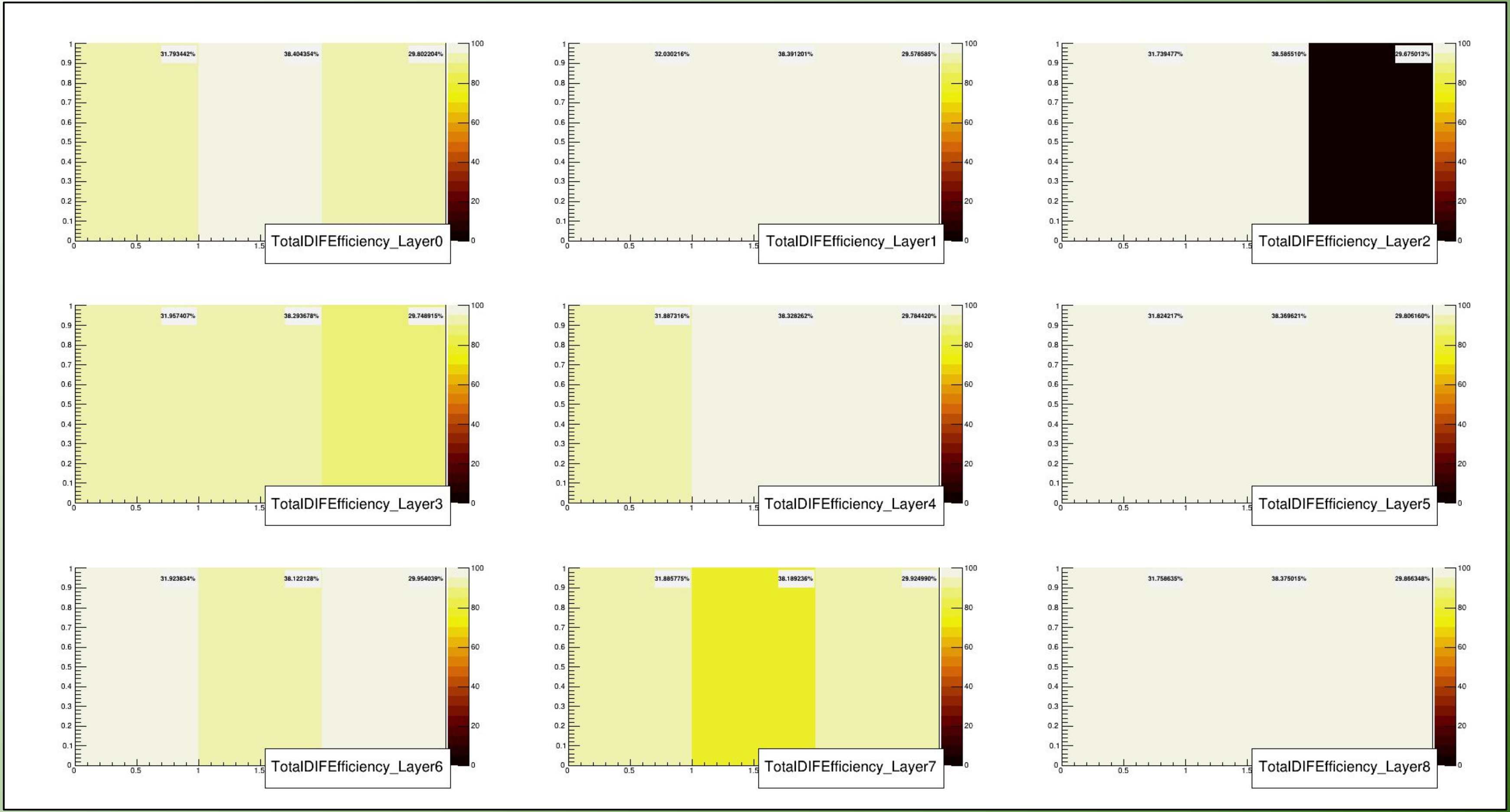
Detector performance. Hit Efficiencies - Backup



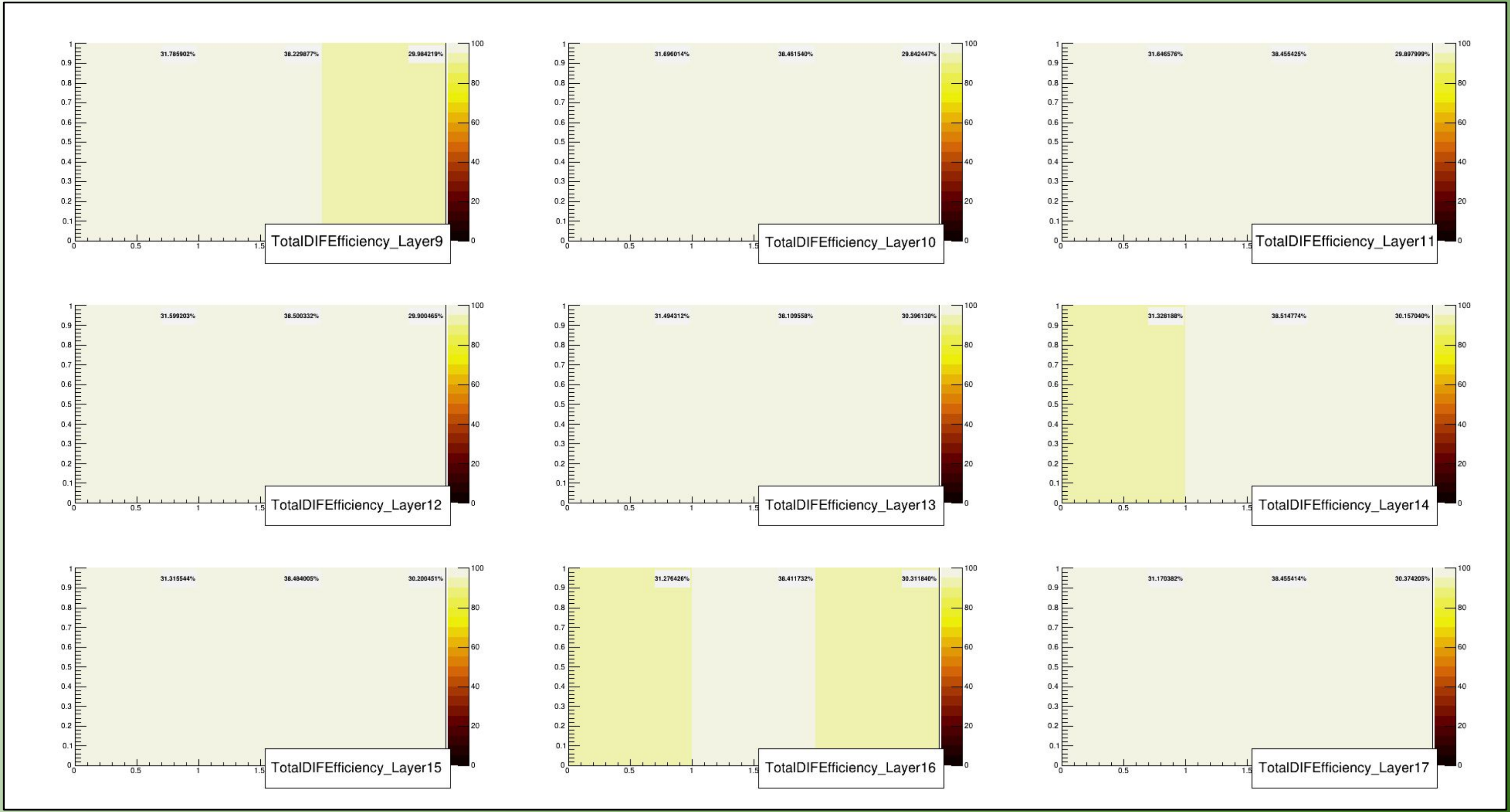
Detector performance. Hit Efficiencies - Backup



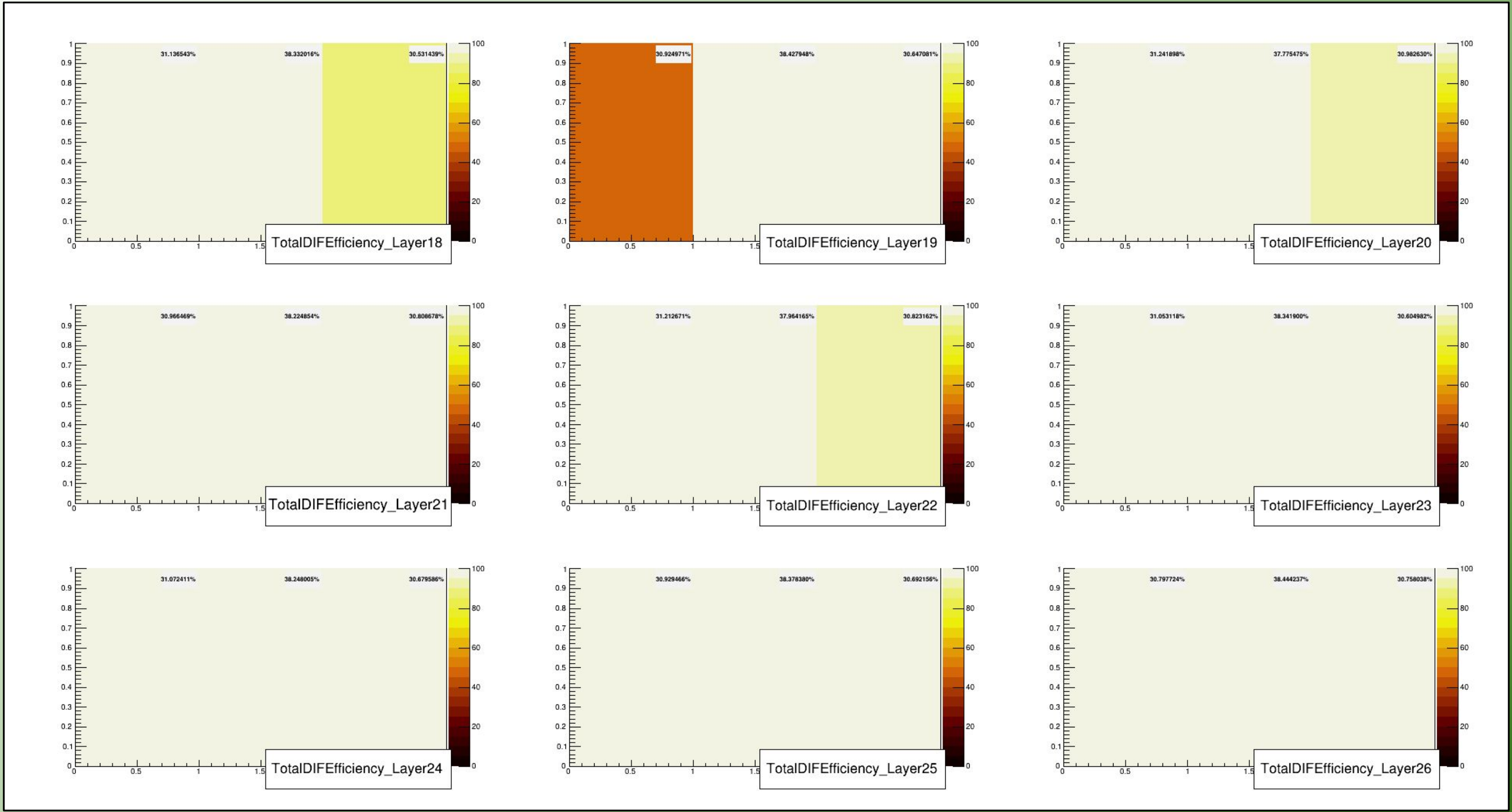
Detector performance. DIF Efficiencies - Backup



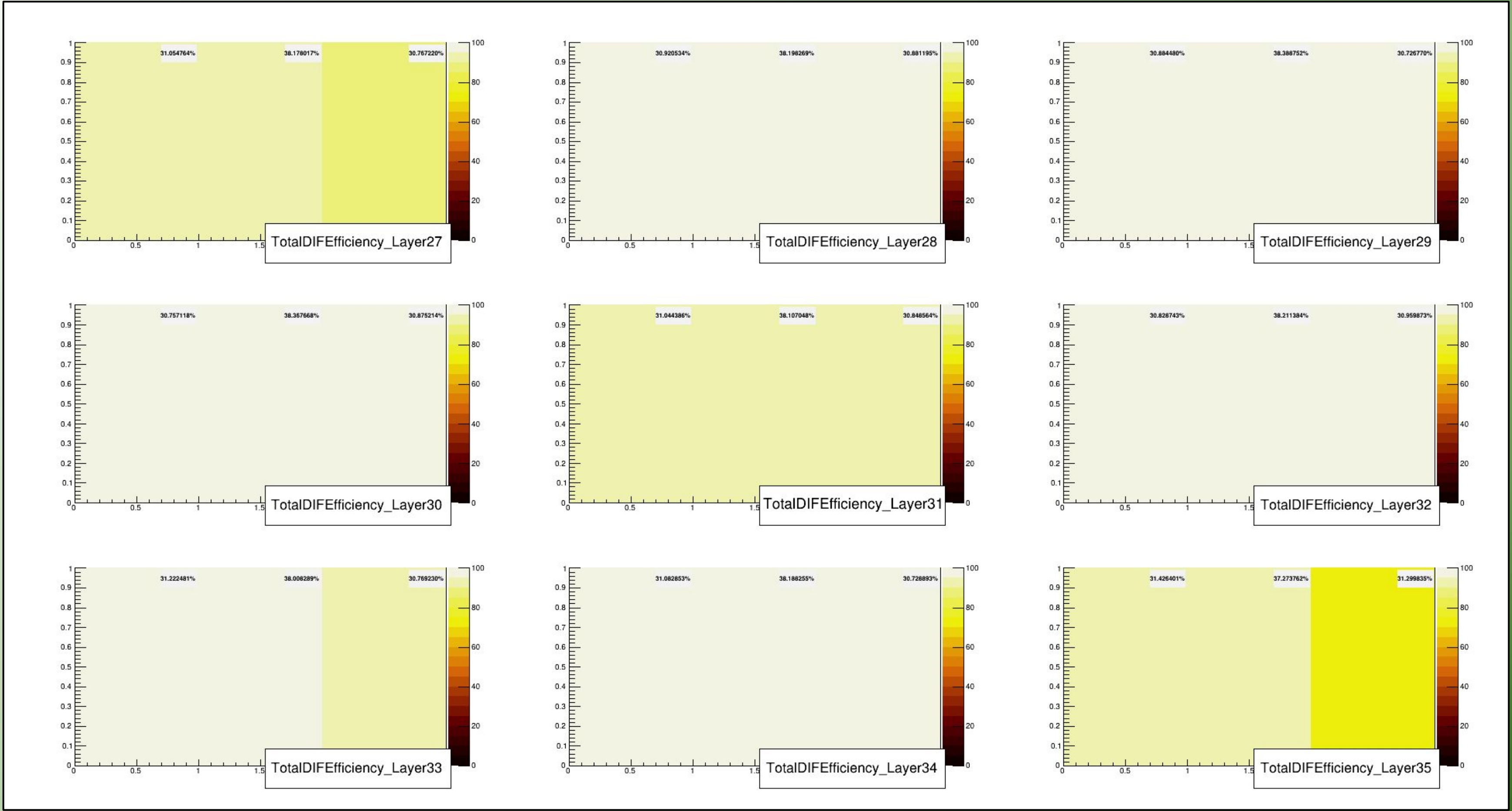
Detector performance. DIF Efficiencies - Backup



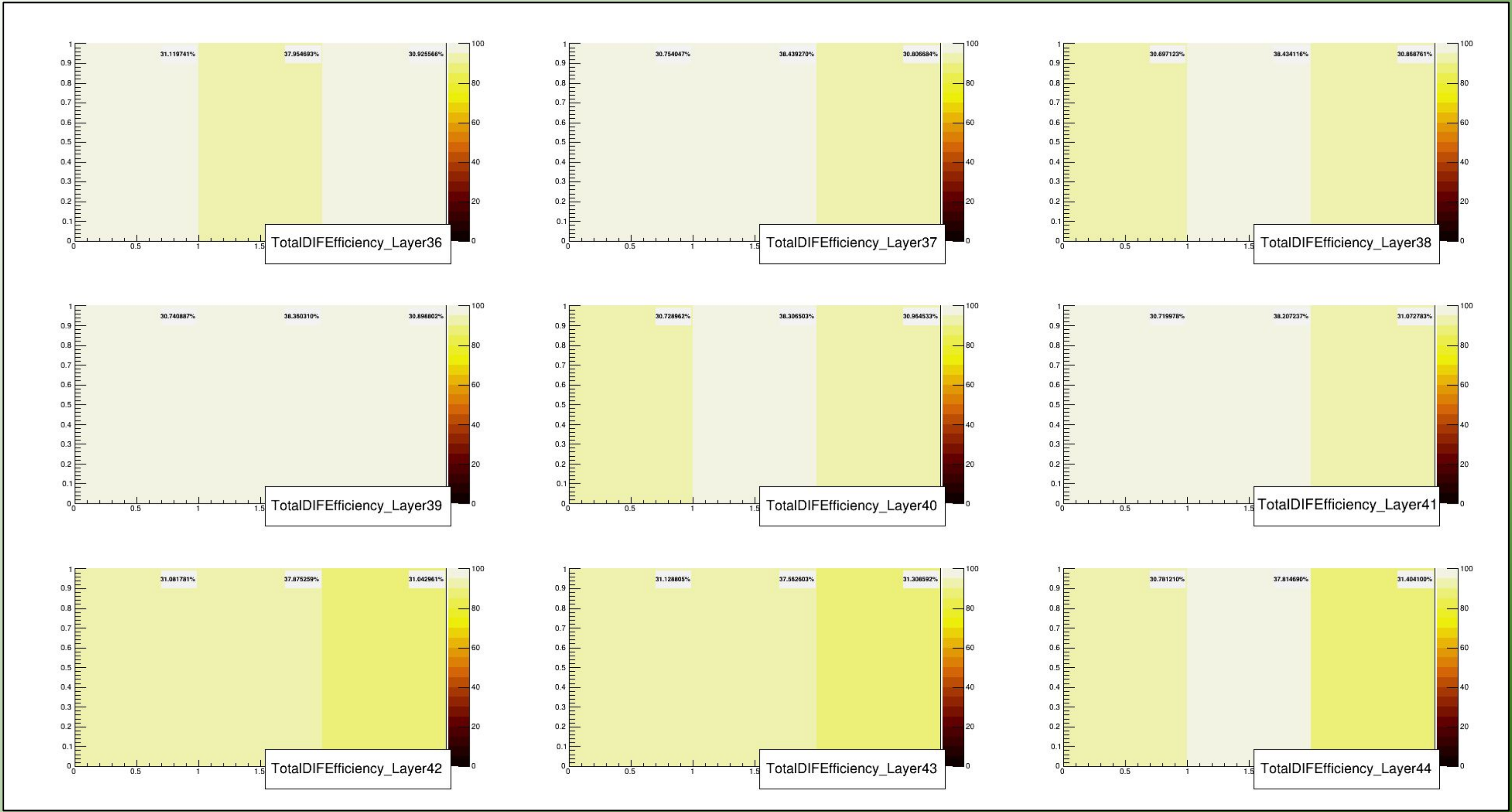
Detector performance. DIF Efficiencies - Backup



Detector performance. DIF Efficiencies - Backup



Detector performance. DIF Efficiencies - Backup



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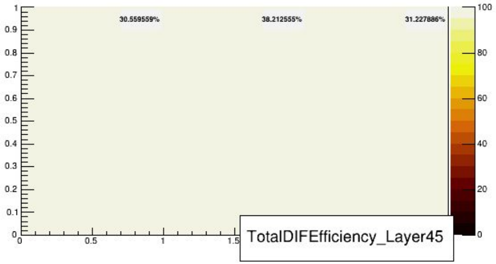

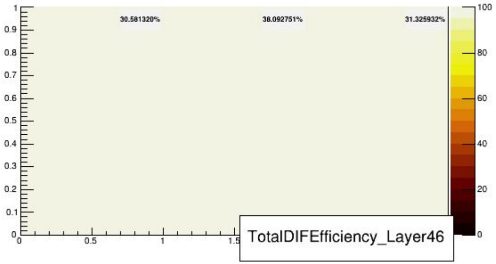

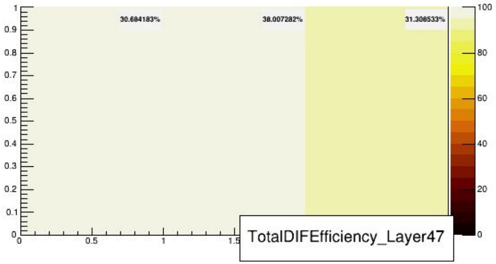

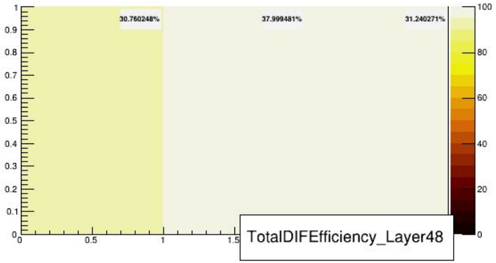

Linearity, resolution and deviations. - Backup

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

Systematic errors - Backup

For each cut and correction the systematic error has been estimated as the difference of the NHits distribution with the results with the cuts +-10%, where each bin has an error associated as a percentage of the bin entry value $(\%^U, \%^D)$.

The propagation of the percentage errors has the following formula, to keep the constraints $\%^U \in [0, \%_{Init}]$, $\%^D \in [0, 1]$

$$\%_F^U = \prod(1 + \%_i^U) - 1$$
$$\%_F^D = 1 - \prod(1 - \%_i^D)$$