IST performance study with cosmic data

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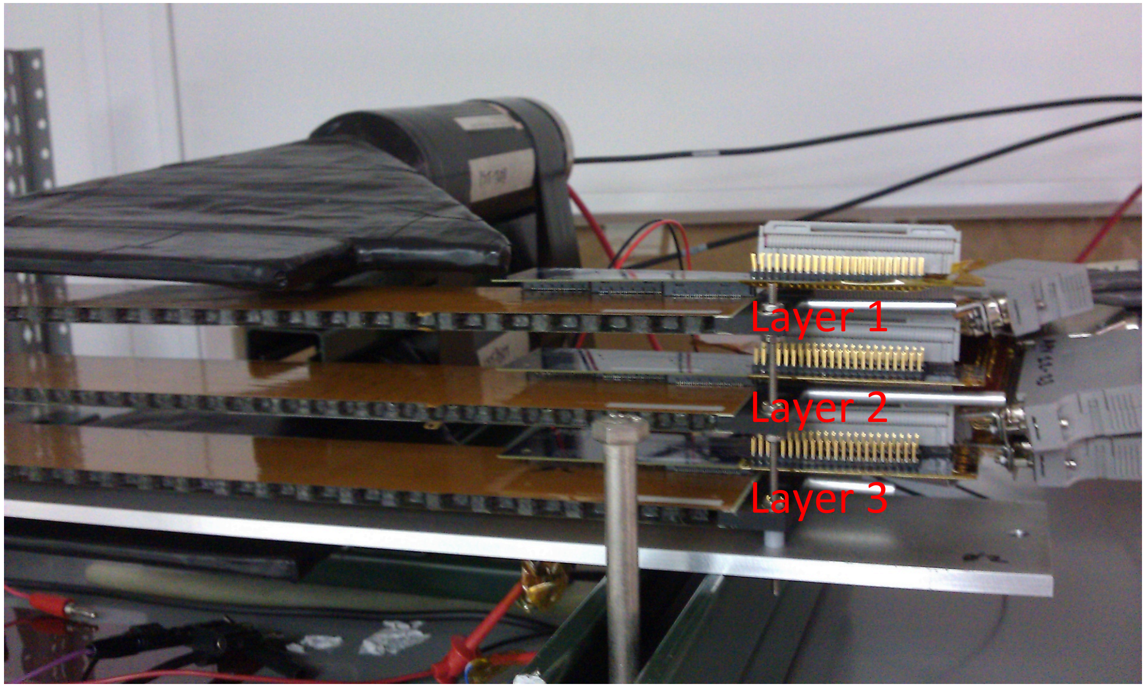
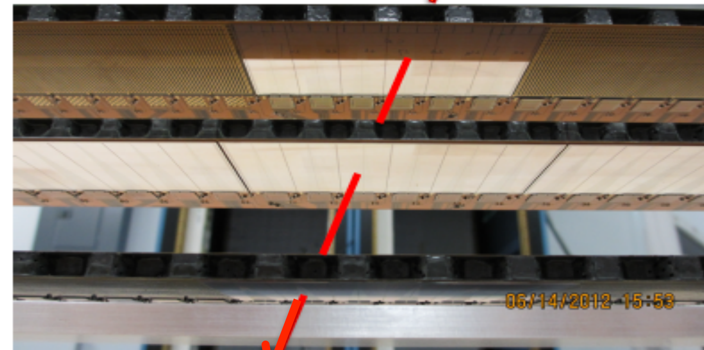
Outline

- Data set and mapping structure
- Pedestal and noise
- Pedestal subtract
- Clustering
- Cluster ADC sum spectrum
- Cluster size
- Residual
- Efficiency

Cosmic data set





Layer 1: 12 APVs, 1 bonded sensor
Layer 2: 36 APVs, 6 bonded sensor
Layer 3: 36 APVs, 1 bonded sensor

Distance between two layers is 37 mm.

Data taken by Gerrit at BNL:

Old cosmic data are available at RCF (~ 500,000 events):
/star/institutions/mit/nieuwhzs/IST_TESTING/IST_PROTOTYPE_STACK_02-03-04/COSMICS

Latest cosmic data (run 3002 to 3032) are available at RCF (~ 400, 000 events):
/star/institutions/mit/nieuwhzs/IST_TESTING/IST_PROTOTYPE_STACK_02-03-04/COSMICS_Sep2012

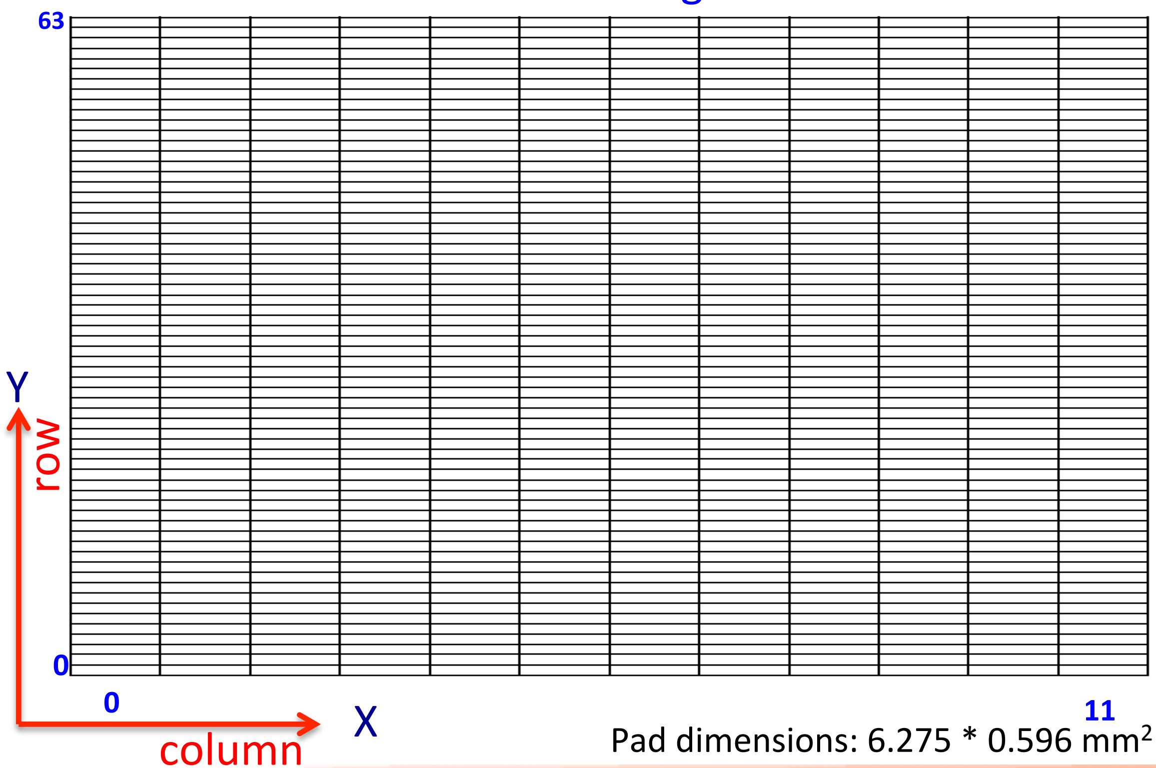
400,000 events (latest cosmic data run 3002 to 3032) are used for the following analysis.

Mapping structure

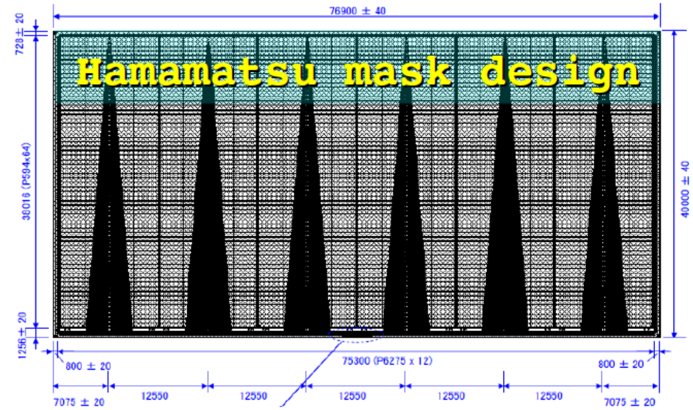
Readout numbering scheme

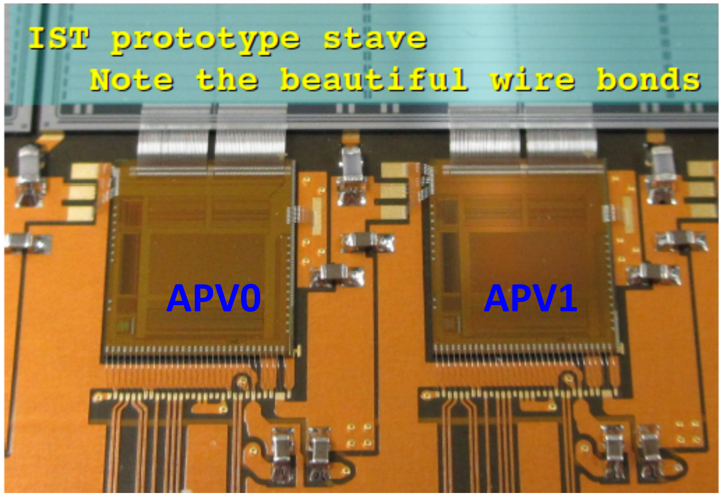
4	123	4	123	4	123	4	123	4	123	4	123
3	124	3	124	3	124	3	124	3	124	3	124
2	125	2	125	2	125	2	125	2	125	2	125
1	126	1	126	1	126	1	126	1	126	1	126
0	127	0	127	0	127	0	127	0	127	0	127
APV0		**APV1**		**APV2**		**APV3**		**APV4**		**APV5**	

Offline numbering scheme



Pad dimensions: 6.275 * 0.596 mm^2





- Each sensor consists of 768 pads, which are organized in 12 columns * 64 rows.
- Readout of each pad is done by the APV chip which digitizes signal into 25 ns bins.
- Each APV chip covers 128 pads (2 columns * 64 rows)

Pedestal and noise

Readout of each IST pad is done by the APV chip which digitizes the signal into 25 ns bins. Time bins number is set to 7.

- The pedestal of each pad: mean pulse height excluding signals
- The rms noise on each pad: average variation of the pulse heights about the pedestal, excluding signals
- The common mode noise of each chip (per APV): rms variation from event to event of the common-mode offset per APV. Here the common-mode offset is defined as the mean pulse height (pedestal subtracted) on all pads (belong to the same APC chip) in an event, excluding those with signals.

Pedestal calculation:

1) calculate pedestals including signals and calculate their Means and Sigmas
2) calculate pedestals excluding signal which are out of range (Mean±PEDCUT*Sigma)

Common mode noise calculation:

1) Get the pedestal subtracted signals (128 channels) coming from the same APV chip;
2) Exclude the channels which are particle-related signal (w/ big ADC counts)
3) Calculate the mean value from the left channels

$$N'_{cm} = \frac{1}{n}\sum_{i=0}^{n} S_i$$

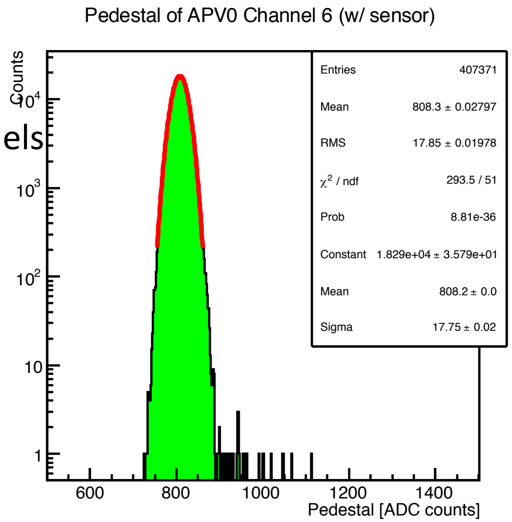
(N'_{cm}: common mode noise per one APV chip)
(S_i: pedestal subtracted signal from i^{th} channel)

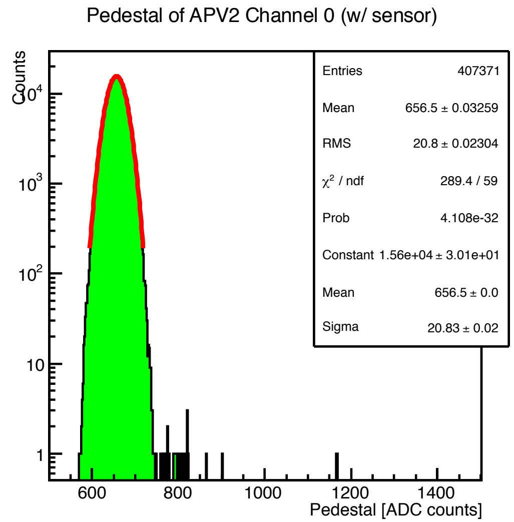
4) Loop over all events and fill N'_{cm} into a histogram.
5) Estimate its RMS or Sigma by Gaussian fit.

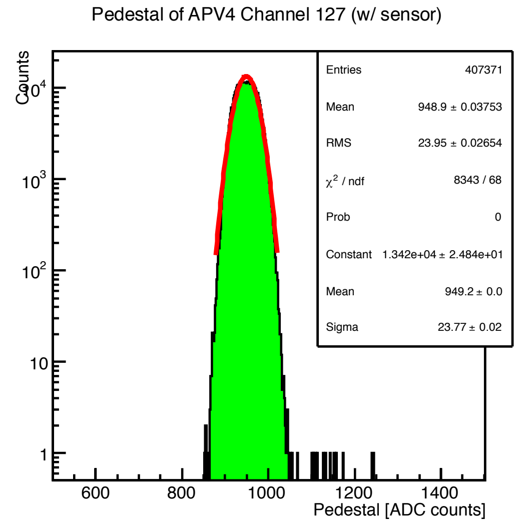
Pedestal shape

Pedestal shapes at time bin 0 (fitted with Gaussian function):

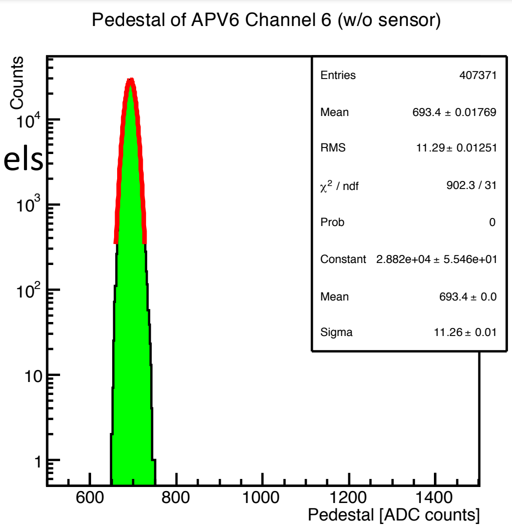
Three channels w/ sensor connected

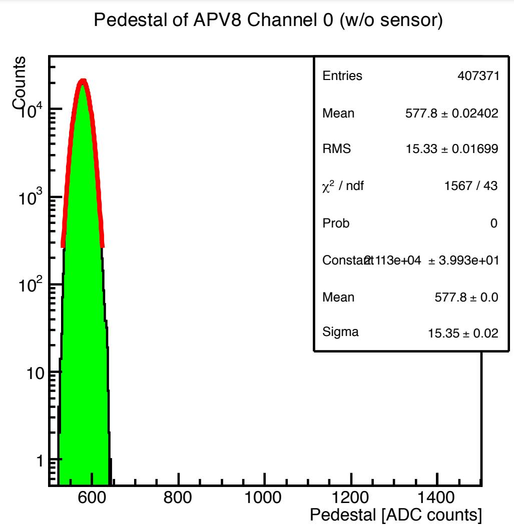


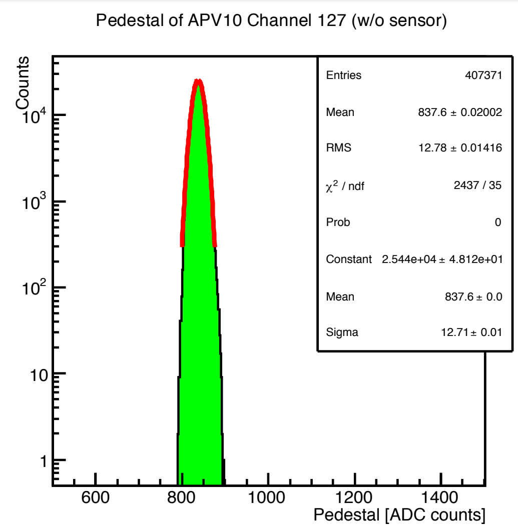




Three channels w/o sensor connected

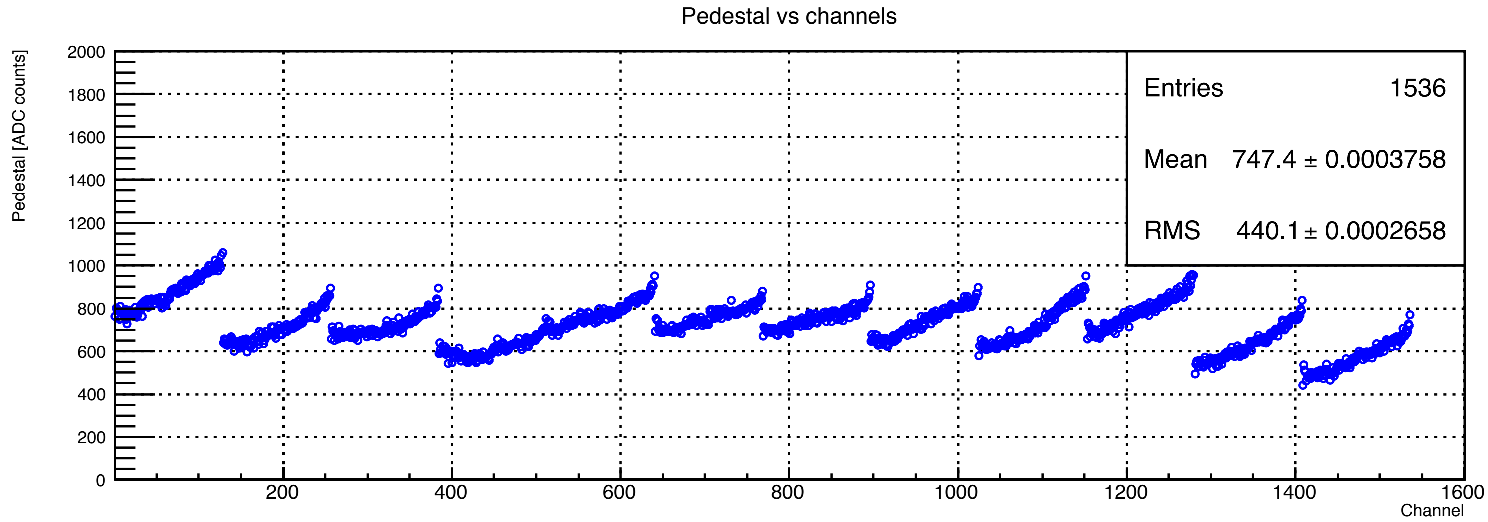


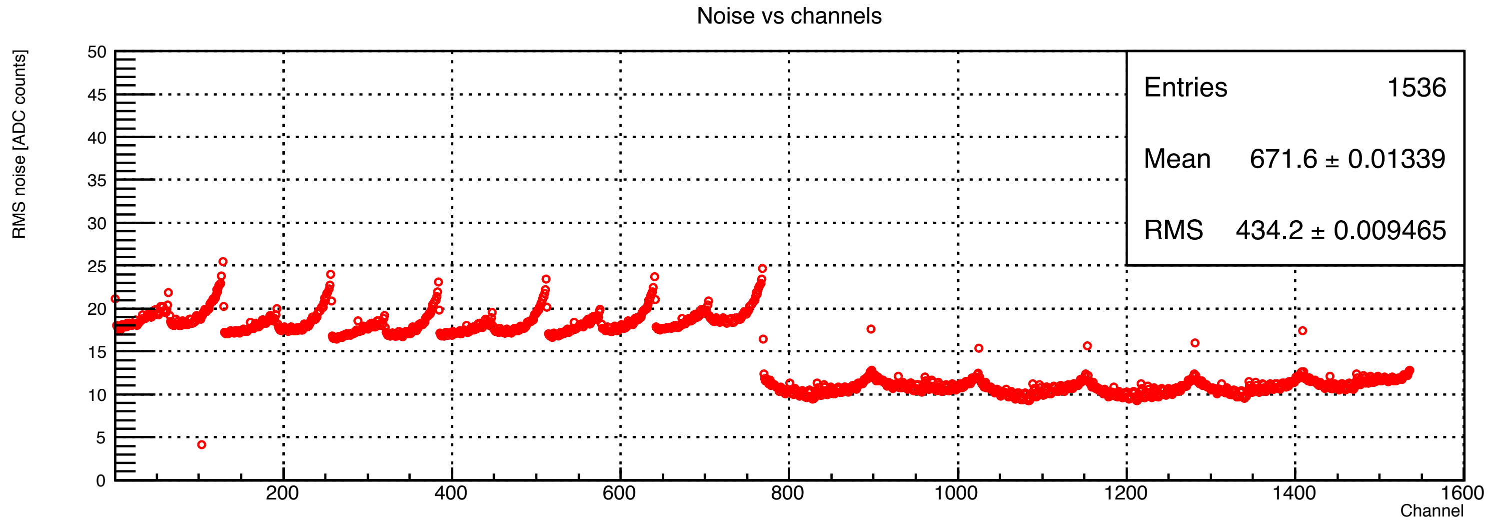




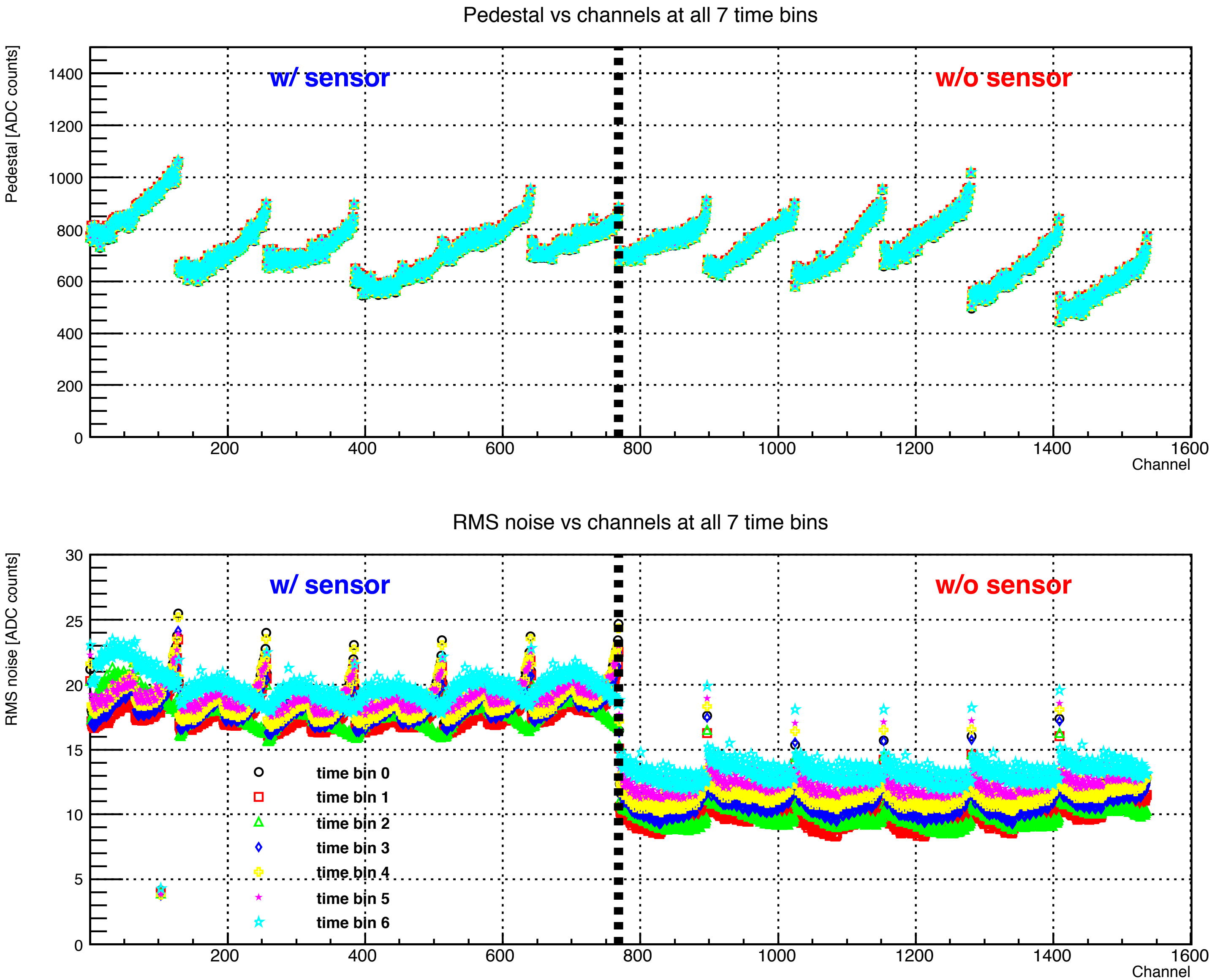
Pedestal & RMS noise

Pedestal and rms noise at time bin 0:

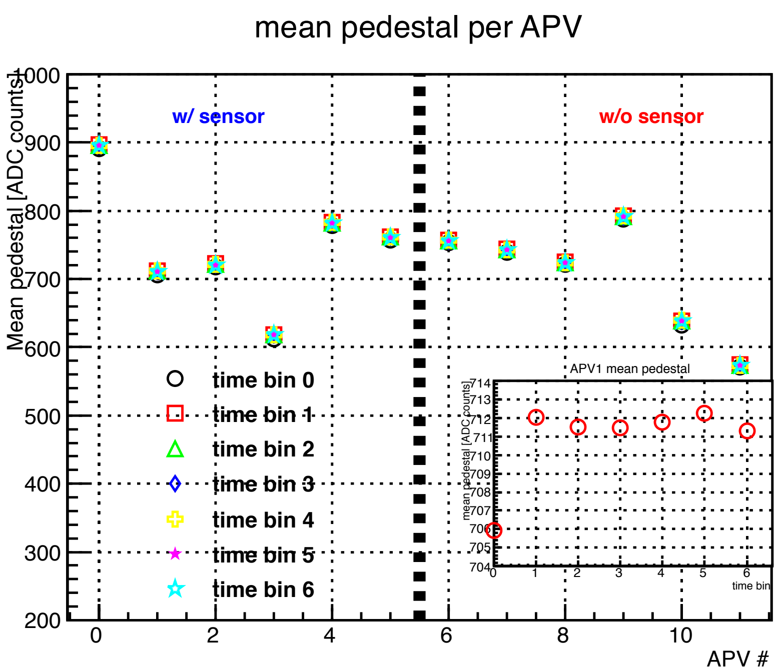


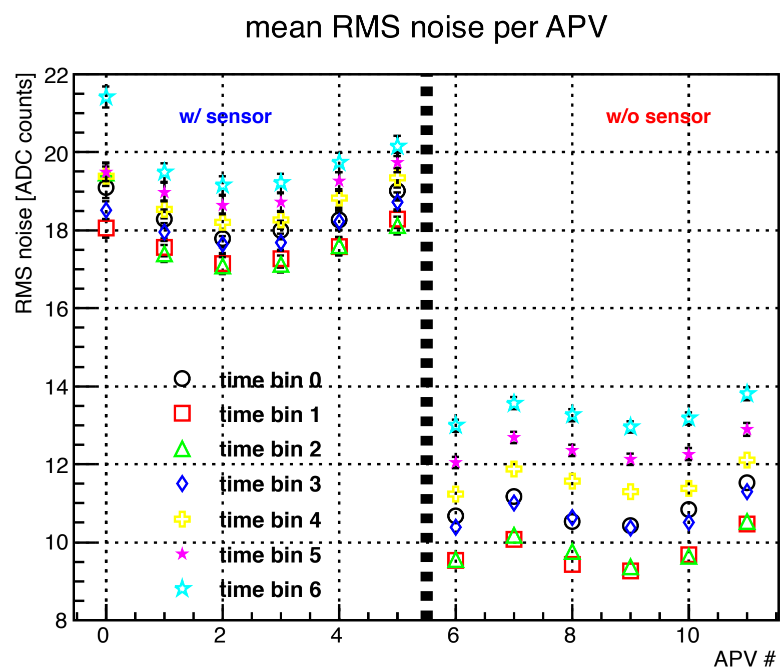


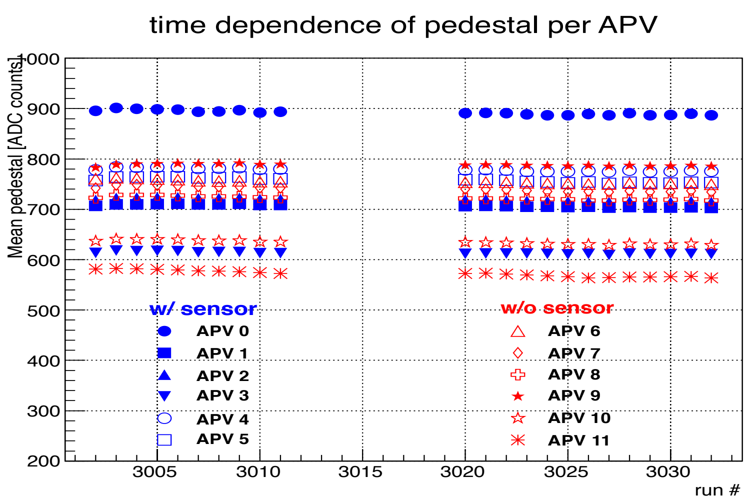
Pedestal & RMS noise vs. time bin



Pedestal & RMS noise per APV

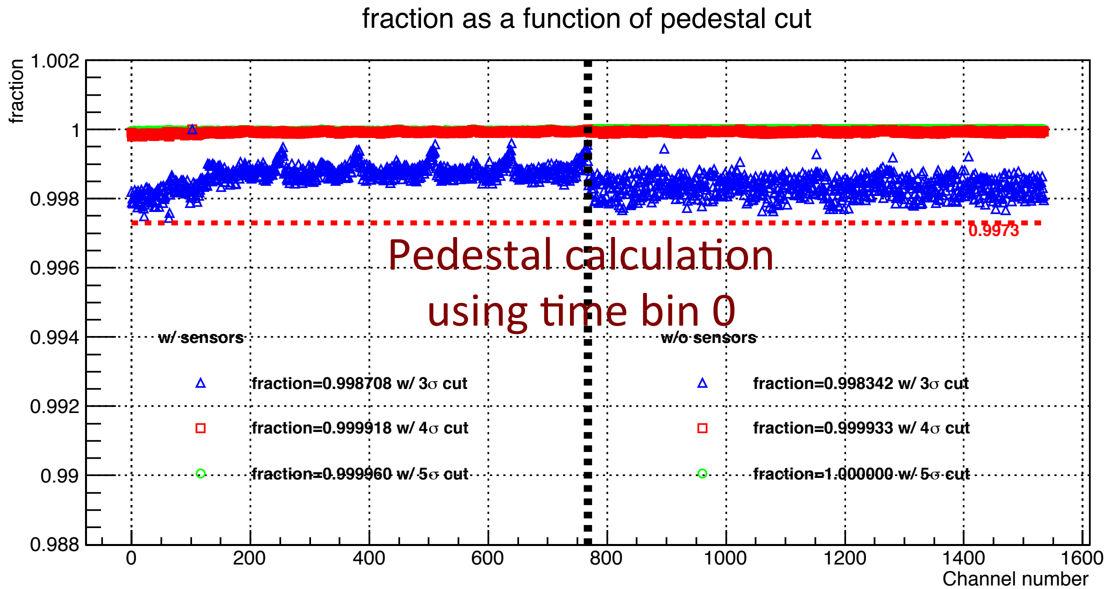


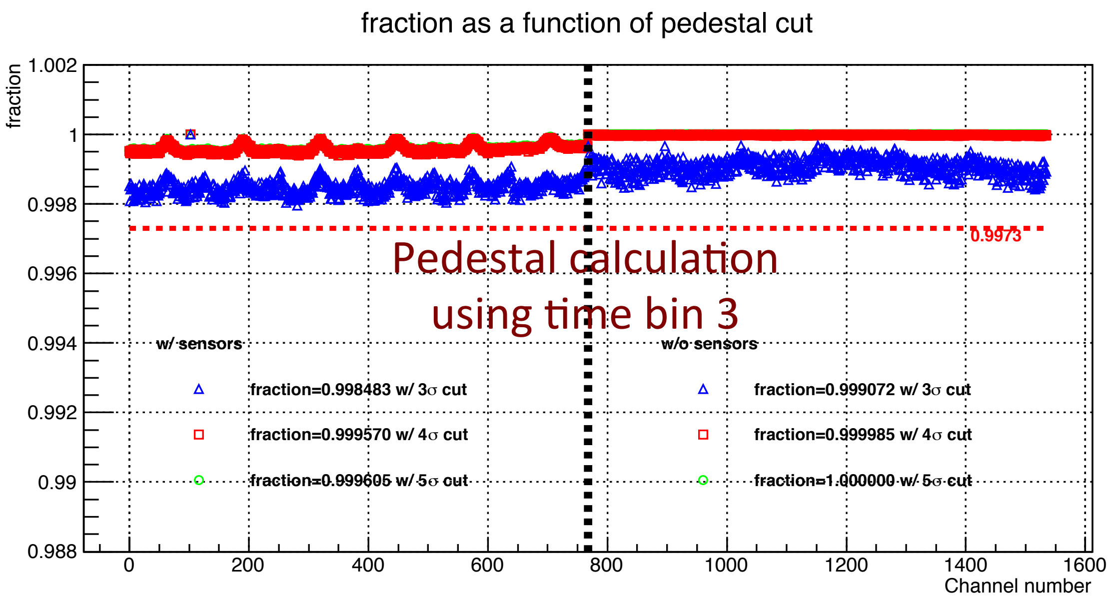




1. The pedestal is not sensitive to the time bin change except for time bin 0
2. RMS noise of most APVs increases as time bin increases except for time bin 0.
3. The pedestal level is stable within ±5 ADC during the whole runs.

Pedestal calculation cut -- PEDCUT





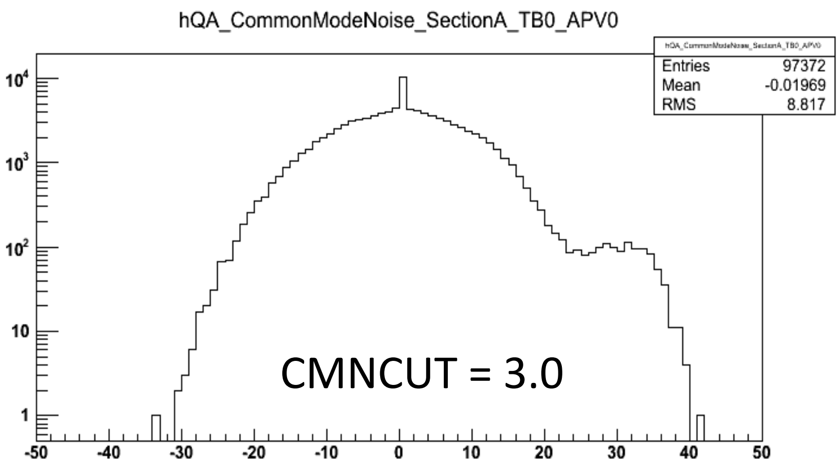
To estimate the detector occupancy, the fraction of entries which locates in range of (0, Mean + PEDCUT*Sigma) over the total entries was calculated for each channel, as shown in left plots.

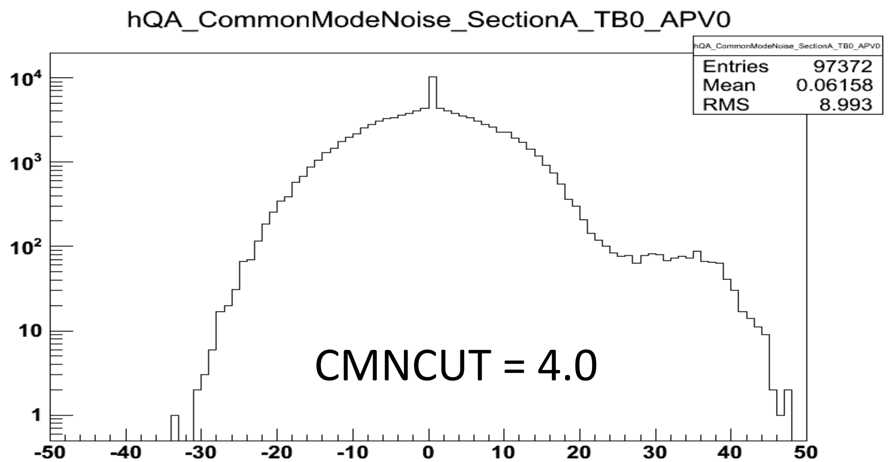
To do:
occupancy per chip vs. PEDCUT

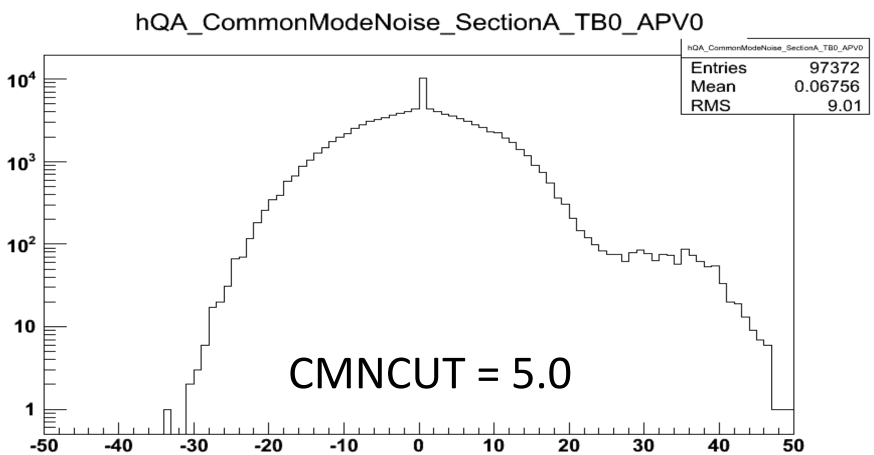
PEDCUT was set to 3.0

Common mode noise per APV

During the common mode noise calculation, a cut was set to exclude channel which are particle-related signal (its pedestal subtracted ADC absolute value > CMNCUT*RMS noise)

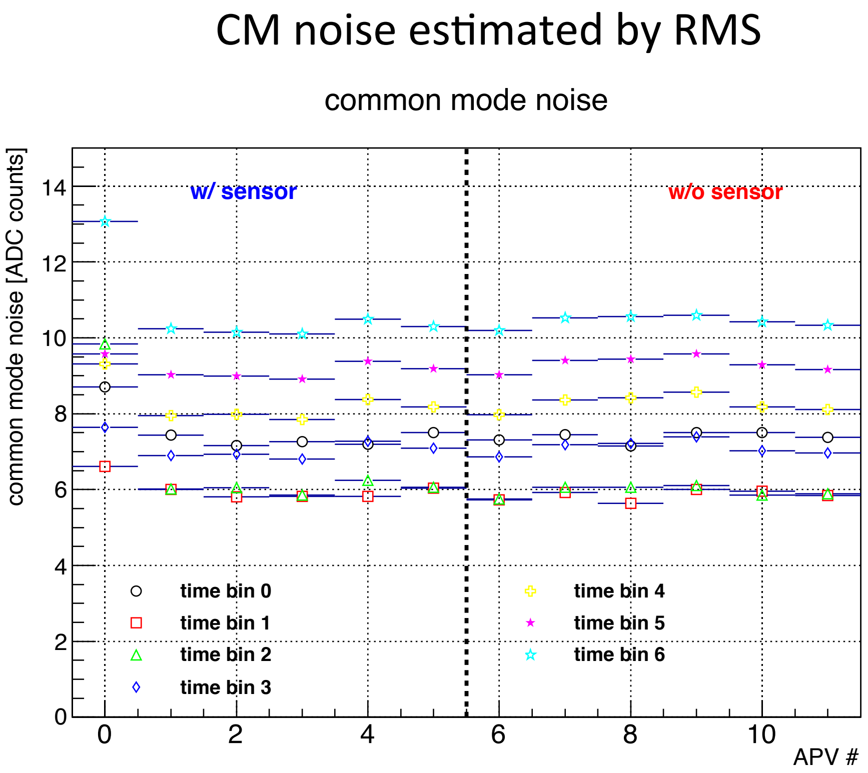


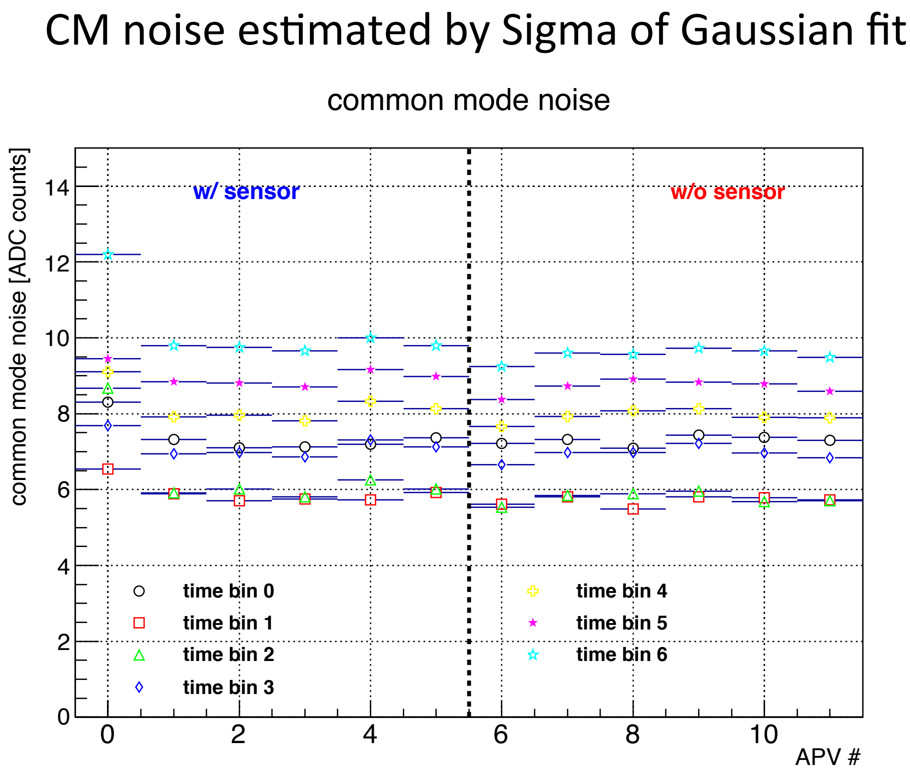




CMNCUT was set to 3.0

Common mode noise per APV





Compared with the RMS noise, the contribution from common mode noise to the RMS noise is around 10%.

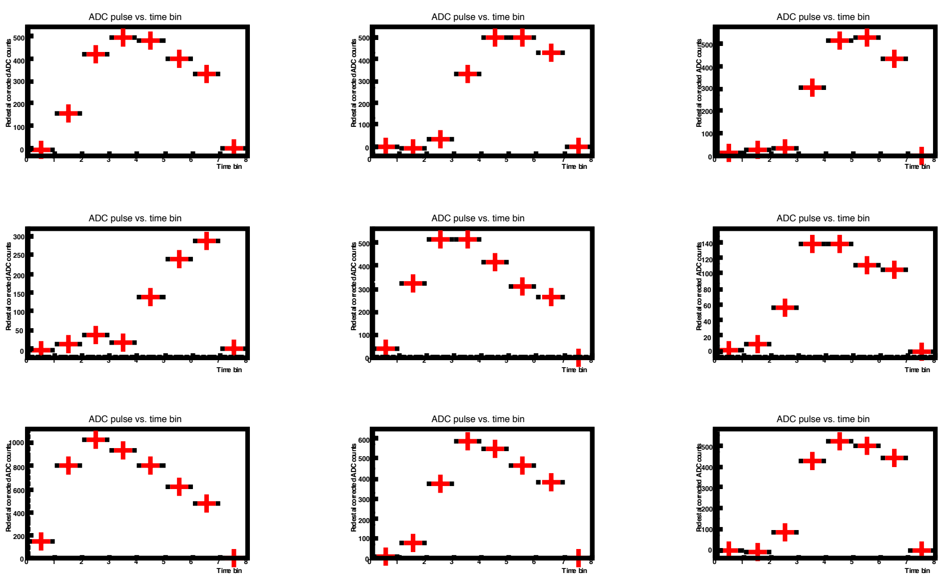
Pedestal subtracted signal

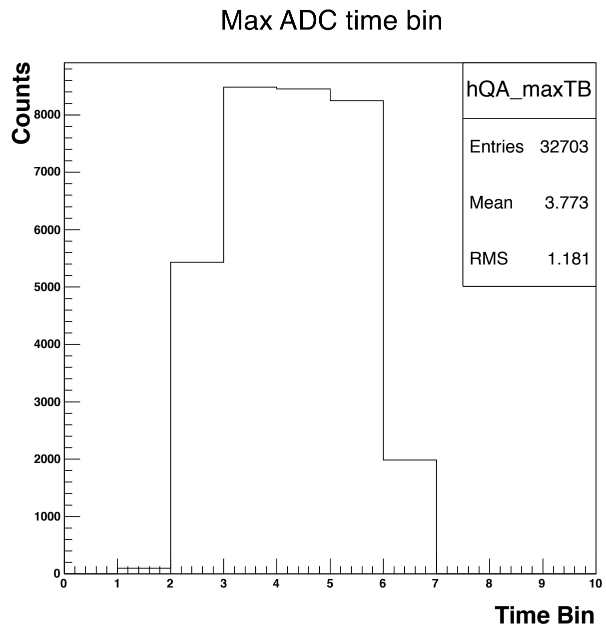
In the cosmic analysis, a raw hit cut (HITCUT) was applied: Signal to Noise ratio (S/N)

Pedestal subtracted ADC values above (HITCUT * Sigma) are accepted as a hit

Algorithm (based on Gerrit's ARMdisplay.C):

1. Loop over all 7 time bins of the pedestal subtracted ADC pulse
2. Raw hit decision: (To do: find a new/better algorithm?)
   (1) Pedestal subtracted ADC values of 3 consequential time bins exceed threshold cut (HITCUT)
   (2) Pedestal subtracted ADC value of time bin 0 is smaller than the one of time bin 3
   (3) Calculated rms noise of the current pad should be larger than minimum noise (12 ADC counts)
3. Find the maximum ADC of all 7 time bins and store as the raw hit's value





Cluster finding

Cluster finding algorithm:

(0) Sort hits by pad ID increasing order (pad ID = row + column*64) for the 3 hit lists

(1) Regard the 1st raw hit of a hit list as the 1st cluster and tag it with ID index = 0

(2) Loop every left raw hit of the hit list, and compare its row/column with all hit elements of the existed clusters.

if hitList[i].row == clusterList[j].row && hitList[i].column == clusterList[j].column + 1 (same row) or
hitList[i].column == clusterList[j].column&& hitList[i].row== clusterList[j].row+ 1 (same column),
Regard the hit as member of the cluster, and calculate weighted row/column/ADC sum for the cluster.
else create a new cluster and tag it with ID index++

Cluster information:

1) Cluster size N_{pads}
2) Cluster local position ($x_{cluster}$, $y_{cluster}$)
3) Cluster ADC sum ($ADC_{cluster}$)
4) Cluster noise ($\sigma_{cluster}$)

$$x_{cluster} = \sum_{i=1}^{N_{pads}} x_i \cdot w_i$$

$$y_{cluster} = \sum_{i=1}^{N_{pads}} y_i \cdot w_i$$

$$w_i = ADC_i / \sum_{i=1}^{N_{pads}} ADC_i$$

$$ADC_{cluster} = \sum_{i=1}^{N_{pads}} ADC_i$$

$$\sigma_{cluster} = \sqrt{\sum_{i=1}^{N_{pads}} \sigma_i^2 / N_{pads}}$$

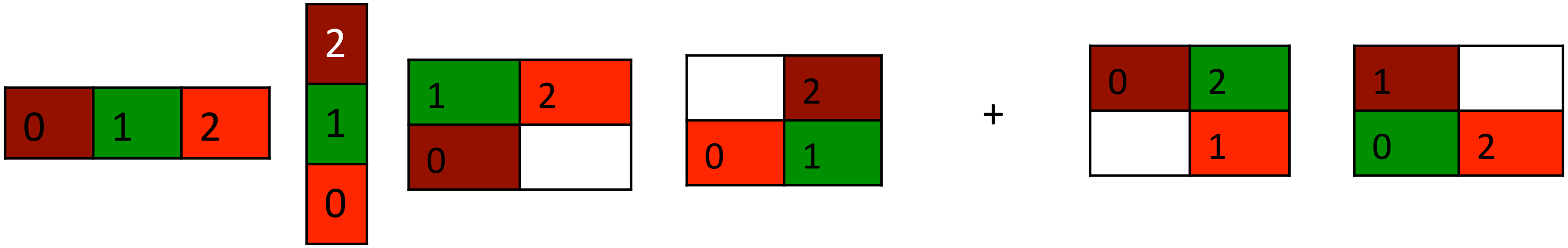
ADC_i, σ_i, x_i and *y_i* mean ADC, rms noise, local position x and y of the i^{th} fired pad's

Cluster splitting

Currently, only clusters w/ size = 3/4 are taken into account splitting:

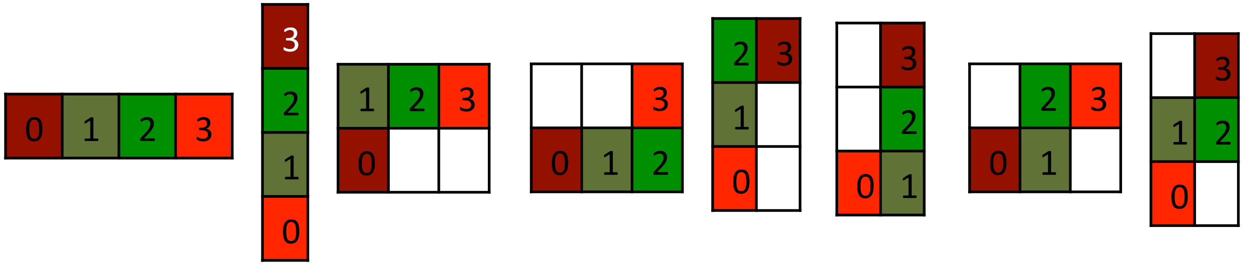
Cluster size = 3

(1) Find the fired pad which has the minimum ADC in the cluster
(2) Check whether the minimum pad locates in the position marked in green as below.
If yes, split the cluster into two clusters and re-calculate cluster information
If not, do not split.



Cluster size = 4 (for 8 simple cases)

(1) Find the fired pad which has the minimum ADC in the cluster
(2) Check whether the minimum pad locates in the position marked in green/brown as below.
If yes, split the cluster into two clusters and re-calculate cluster information
If not, do not split.



Cluster splitting

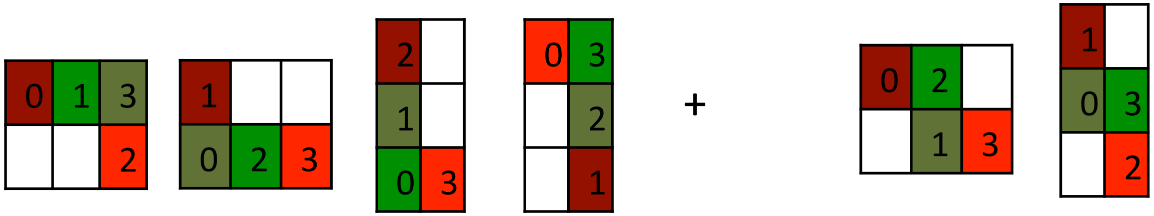
Cluster size = 4 (additional 6 cases)

(1) Find the fired pad which has the minimum ADC in the cluster

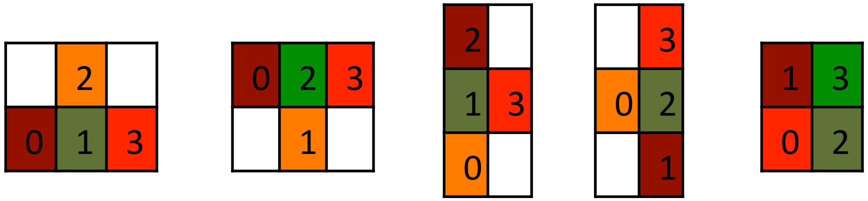
(2) Check whether the minimum pad locates in the position marked in green/brown as below.

If yes, split the cluster into two clusters and re-calculate cluster information

If not, do not split.



Cluster size = 4 (The following 5 cases are not splitted)



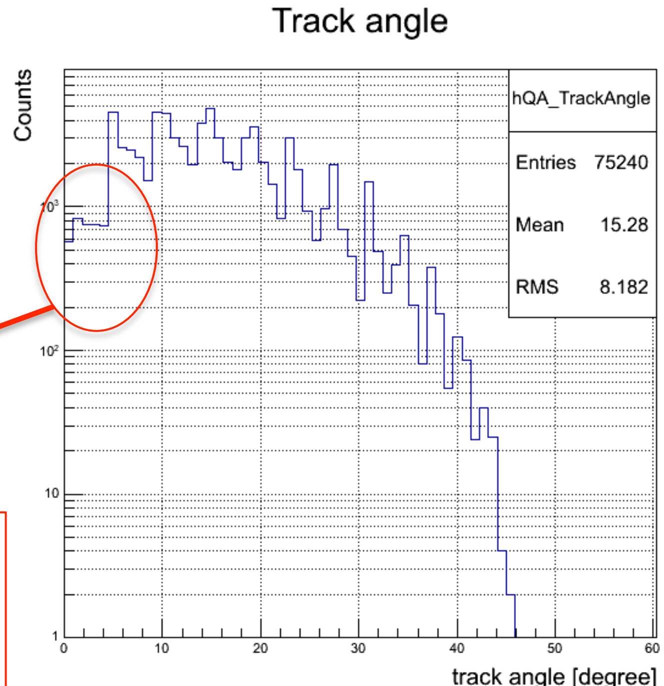
Analysis cuts

PEDCUT = 3 fixed for pedestal/noise calculation

HITCUT = 10 fixed for layer 1 and layer 3

To study the HITCUT dependence of cluster size/residual/efficiency, the HITCUT varies from 3.0 to 21.0 for layer 2.
HITCUT = 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 12.0, 15.0, 18.0 for layer 2

To study the track angle dependence of the IST performance, 10 angle windows are set:
Track angle bin = 4.5^{o}
Angle window = (0, 4.5), (4.5, 9.0), (9.0, 13.5), (13.5, 18.0), (18.0, 22.5), (22.5, 27.0), (27.0, 31.5), (31.5, 36.0), (36.0, 40.5), (40.5, 45)

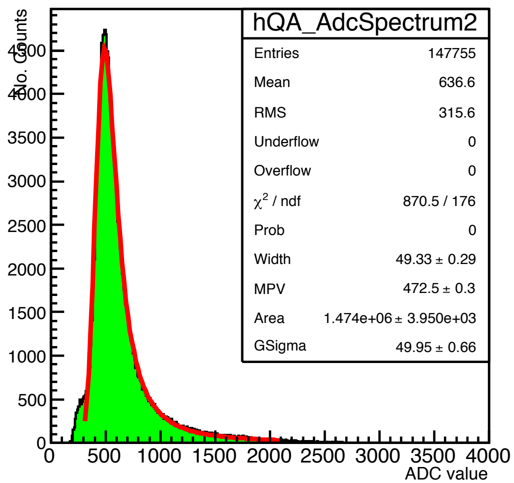


Currently I can not explain why the entries in the first angle window is much smaller than the others.

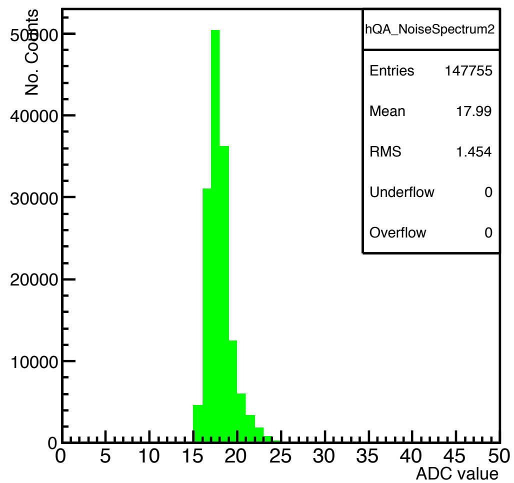
Cluster ADC spectrum – Layer 2 (HITCUT = 5)

Single pad ADC spectrum (No clustering and no track angle correction)

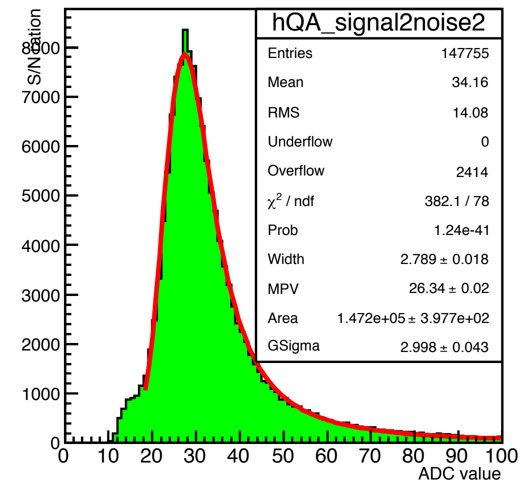
Layer 2: single pad ADC spectrum



Layer 2: single pad noise spectrum

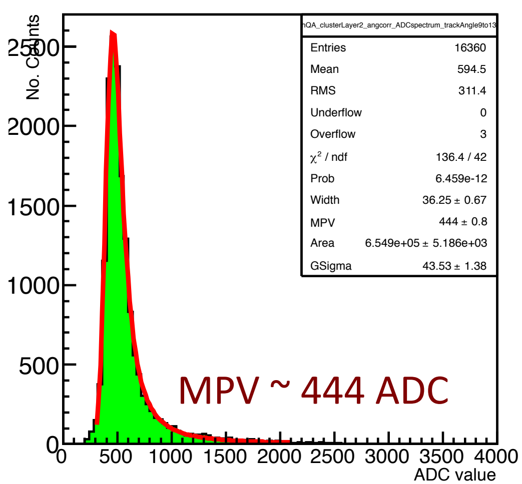


Layer 2: single pad S/N spectrum

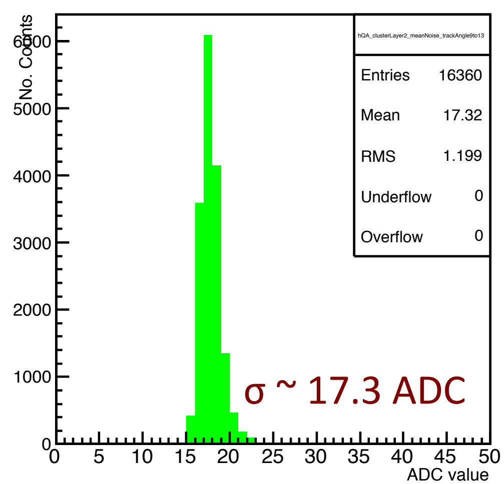


The cluster ADC spectrum (9.0 < θ_{track} < 13.5 degree) was corrected by track angle.

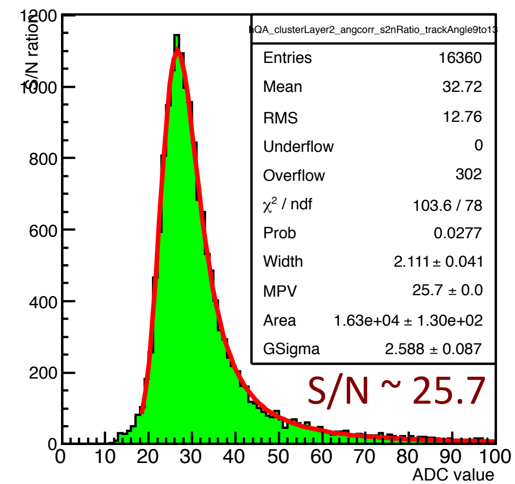
Layer 2: cluster ADC spectrum



Layer 2: cluster noise spectrum

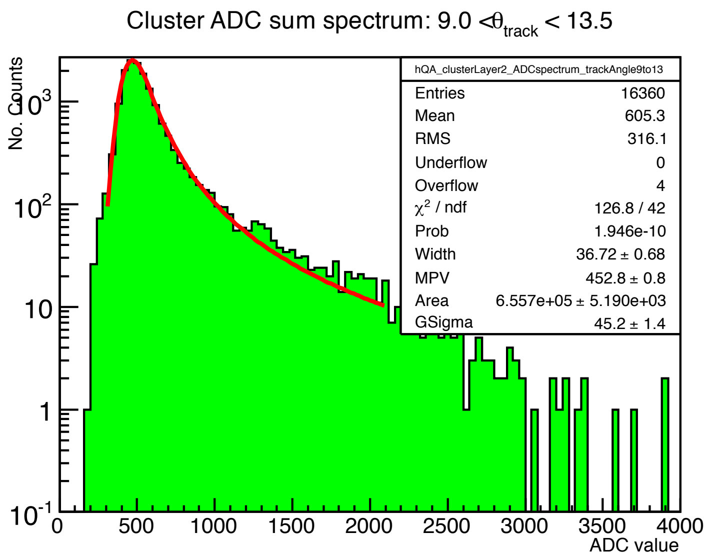


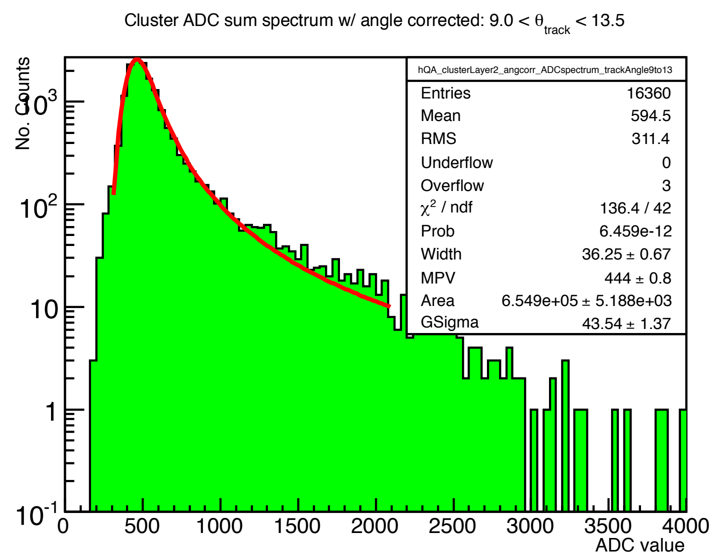
Layer 2: cluster S/N spectrum

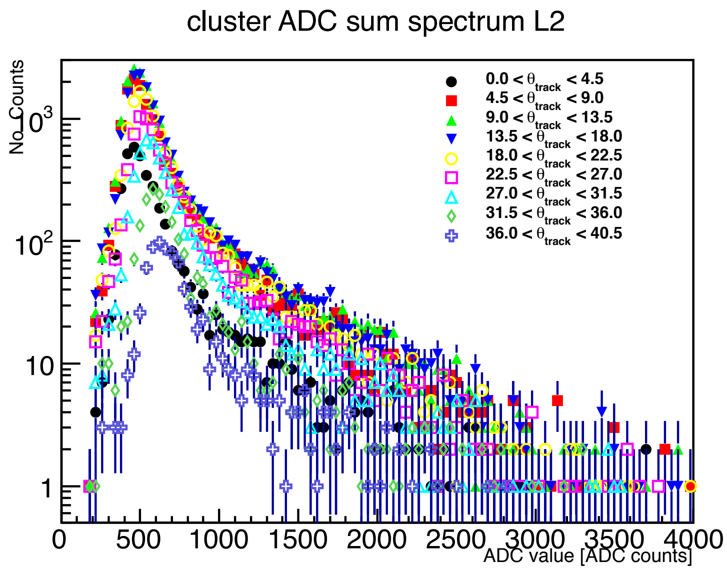


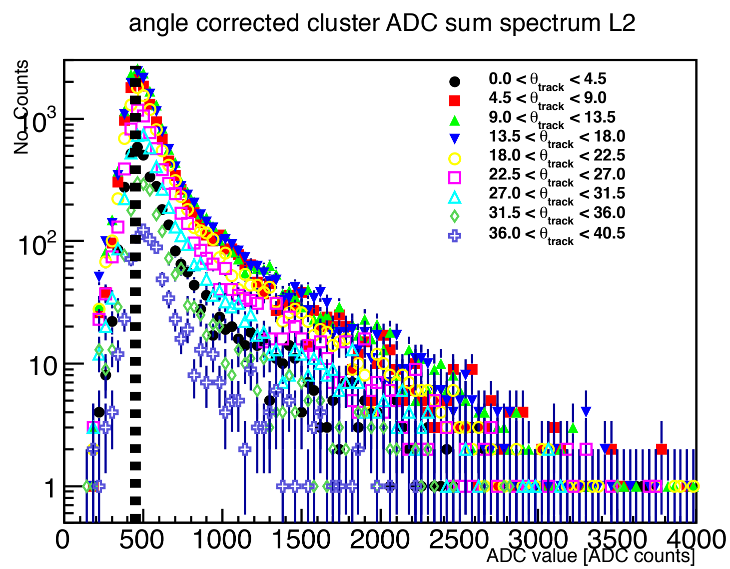
Cluster ADC spectrum – Layer 2 (HITCUT = 5)

Cluster ADC spectrum were fitted with convoluted Landau and Gaussian fitting function.



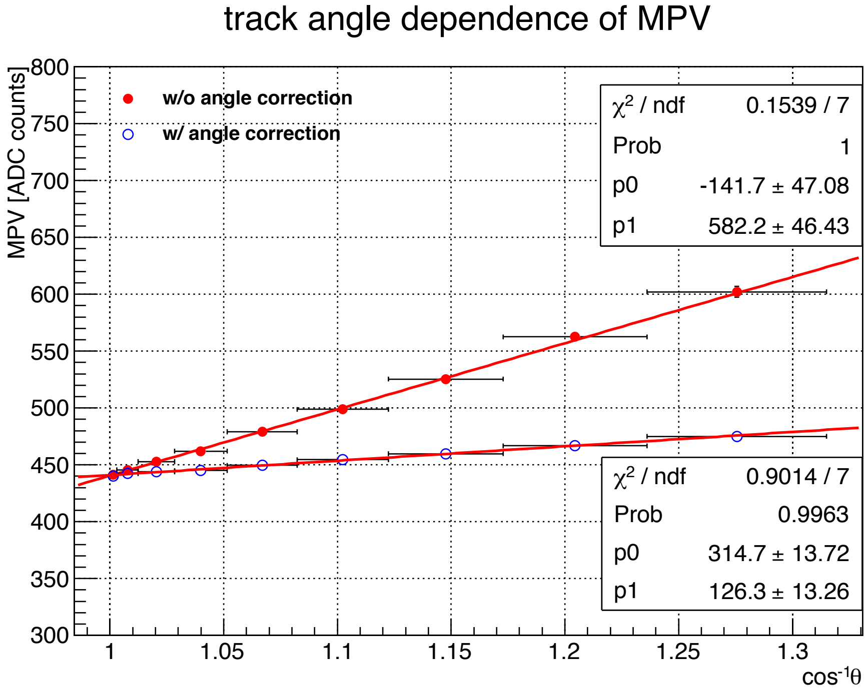


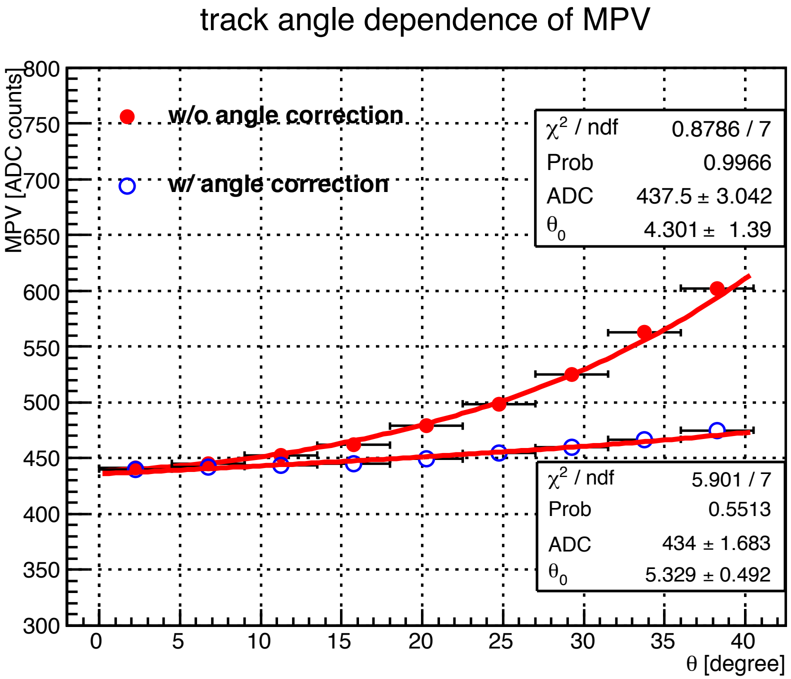




Cluster ADC spectrum – Layer 2 (HITCUT = 5)

Cluster ADCs with/without path-length correction (track angle correction) can be obtained by the convoluted Landau and Gaussian fitting function (MPV).





$$MPV = p0 + p1 \cdot \cos^{-1}\theta$$

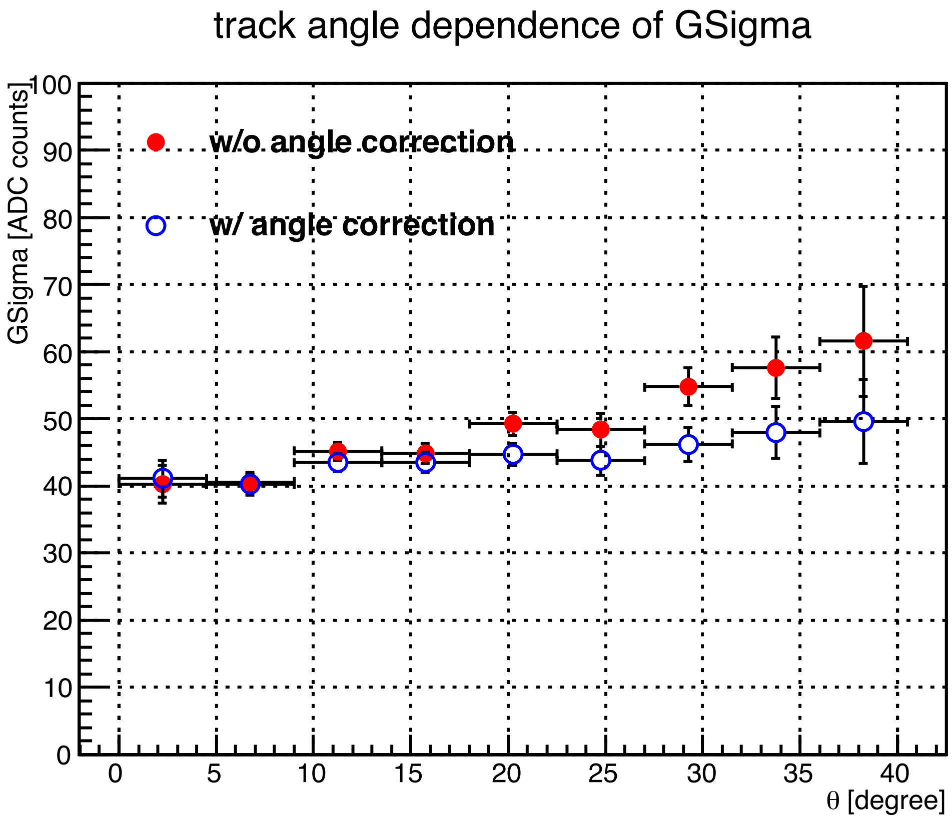
$$\mathrm{MPV} = \mathrm{ADC}/\cos(\theta_{trk} + \theta_0), \quad \text{w/o track angle correction}$$

$$\mathrm{MPV}_{corr} = \mathrm{ADC} \times \cos\theta_{trk} / \cos(\theta_{trk} + \theta_0), \quad \text{w/ track angle correction}$$

- The MPV shows a linear relation with the $\cos^{-1}\theta$ as expected
- w/ track angle correction, MPV vs. $\cos^{-1}\theta$ is not flat due to stack alignments
- The predicted MPV is ~ 441 ADC
- The rotation shift θ_0 ~ 5 degree

Cluster ADC sum spectrum – Layer 2 (HITCUT = 5)

Cluster overall noise with/without path-length correction (track angle correction) can be obtained by the convoluted Landau and Gaussian fitting function (GSigma).



GSigma reflects overall noise (weighted value ~ 43 ADC w/ track angle correction), and includes contributions from:

1) Cluster rms noise ~18 ADC

2) Angular resolution ~16 ADC

~sqrt(2)*6.275mm/sqrt(12)/74mm * MPV ~ 15.3 ADC

3) Non-uniform gain (plus others?) ~ 35 ADC

Based on these noise estimations, it shows that the IST detector energy resolution is better than 10%.

Additional Cuts for cluster size/residual/efficiency study

For cluster size/residual/efficiency study, events which has only one track passing through the stack and fired only one pad on both Layer 1 and Layer 3 (cluster number = 1 && cluster size = 1 for Layer 1 and Layer 3).

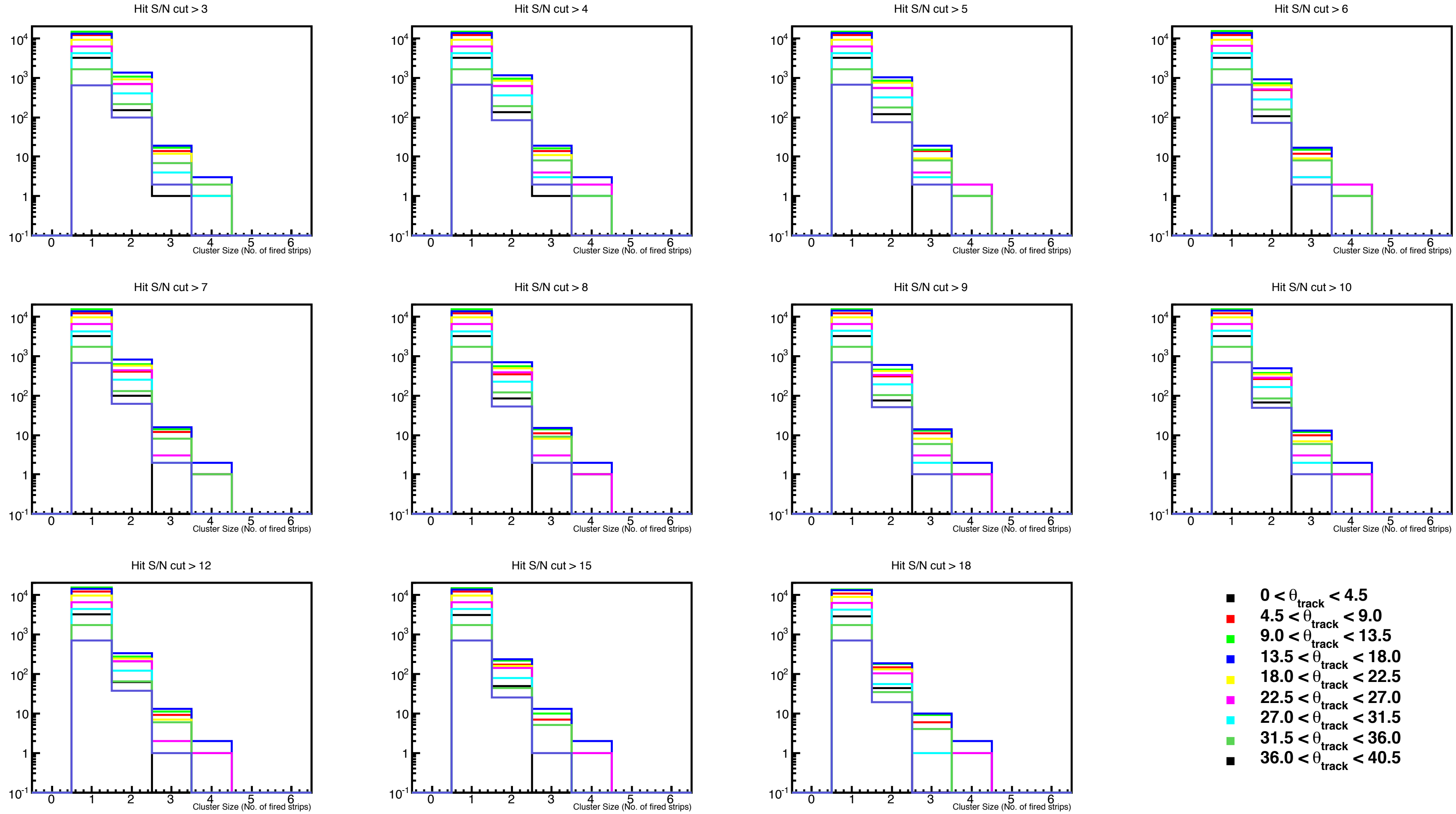
1) Find the cluster on Layer 2 which has the minimum residual ($= \sqrt{(X_{residual} * X_{residual} + Y_{residual} * Y_{residual})}$).
Here $X_{residual} = X_{measured} - X_{projected}$ and $Y_{residual} = Y_{measured} - Y_{projected}$
$X_{projected} = (X_1 + X_3)/2$, $Y_{projected} = (Y_1 + Y_3)/2$

2) If its $X_{residual}$ is in range of (Mean $X_{residual}$ ± TRKMATCHCUT* RMS $X_{residual}$) and its $Y_{residual}$ is in range of (Mean $Y_{residual}$ ± TRKMATCHCUT* RMS $Y_{residual}$), we call the found cluster is belong to the track.

TRKMATCHCUT was set to 3 for cluster size study.

TRKMATCHCUT was set to to 2.5, 3.0, 3.5, 4.0, 4.5 or 5.0 to estimate the influences on efficiency by this cut.

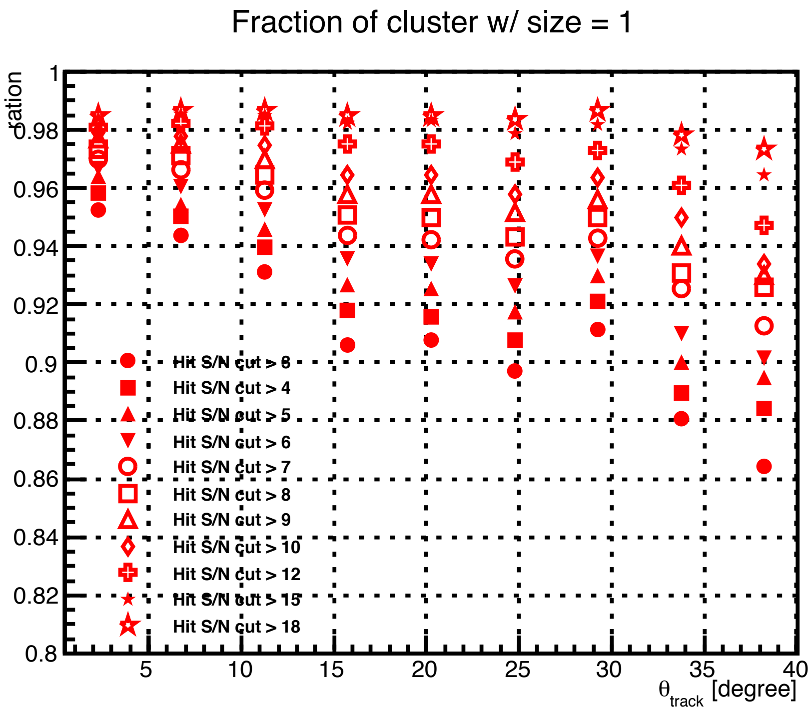
Cluster size – Layer 2

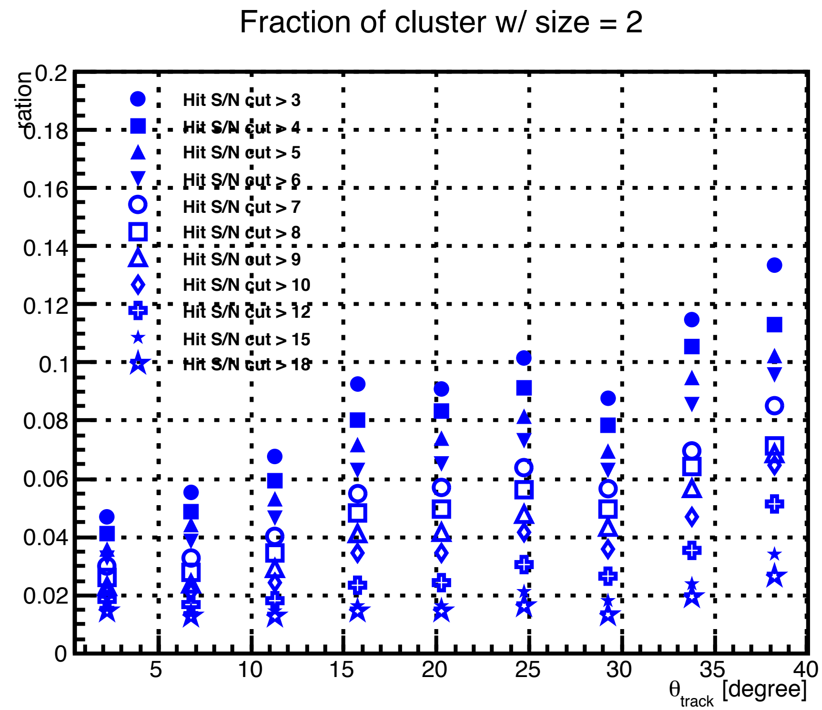


Cluster size – Layer 2

To describe cluster size correlations with track angle, here fraction of clusters with size N in all found clusters was used.

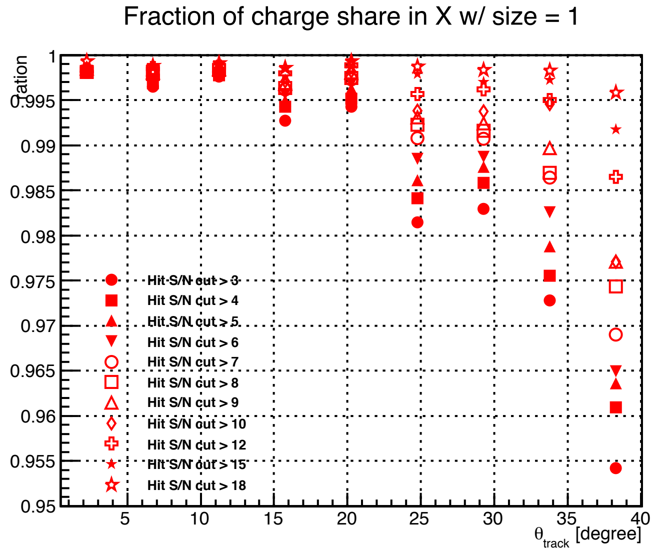
IST silicon sensor pad dimensions in X (6.275 mm) and Y (0.596 mm)

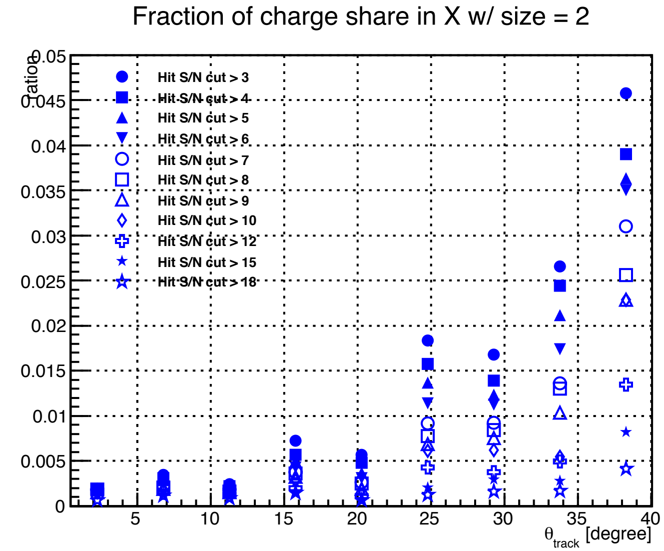




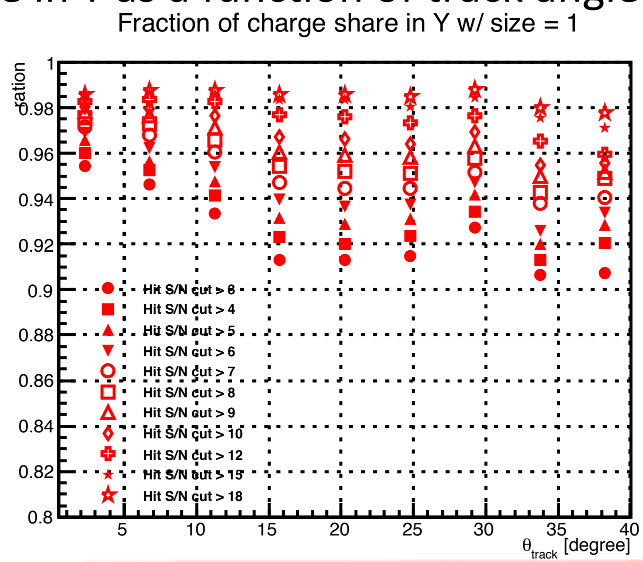
Cluster size – Layer 2

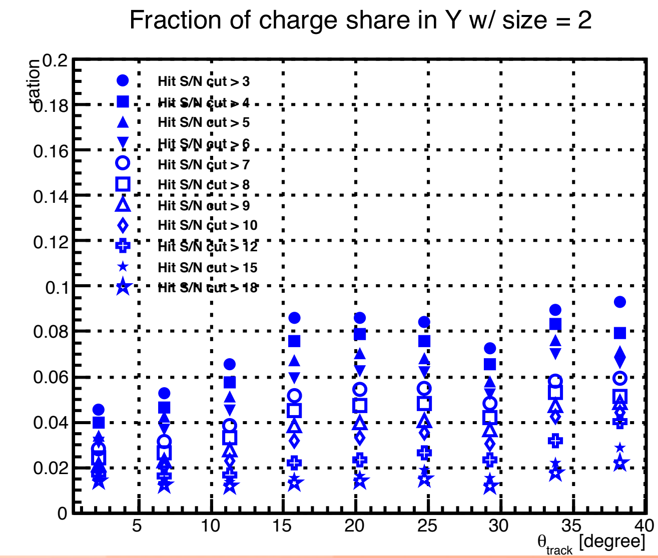
Cluster size in X as a function of track angle.





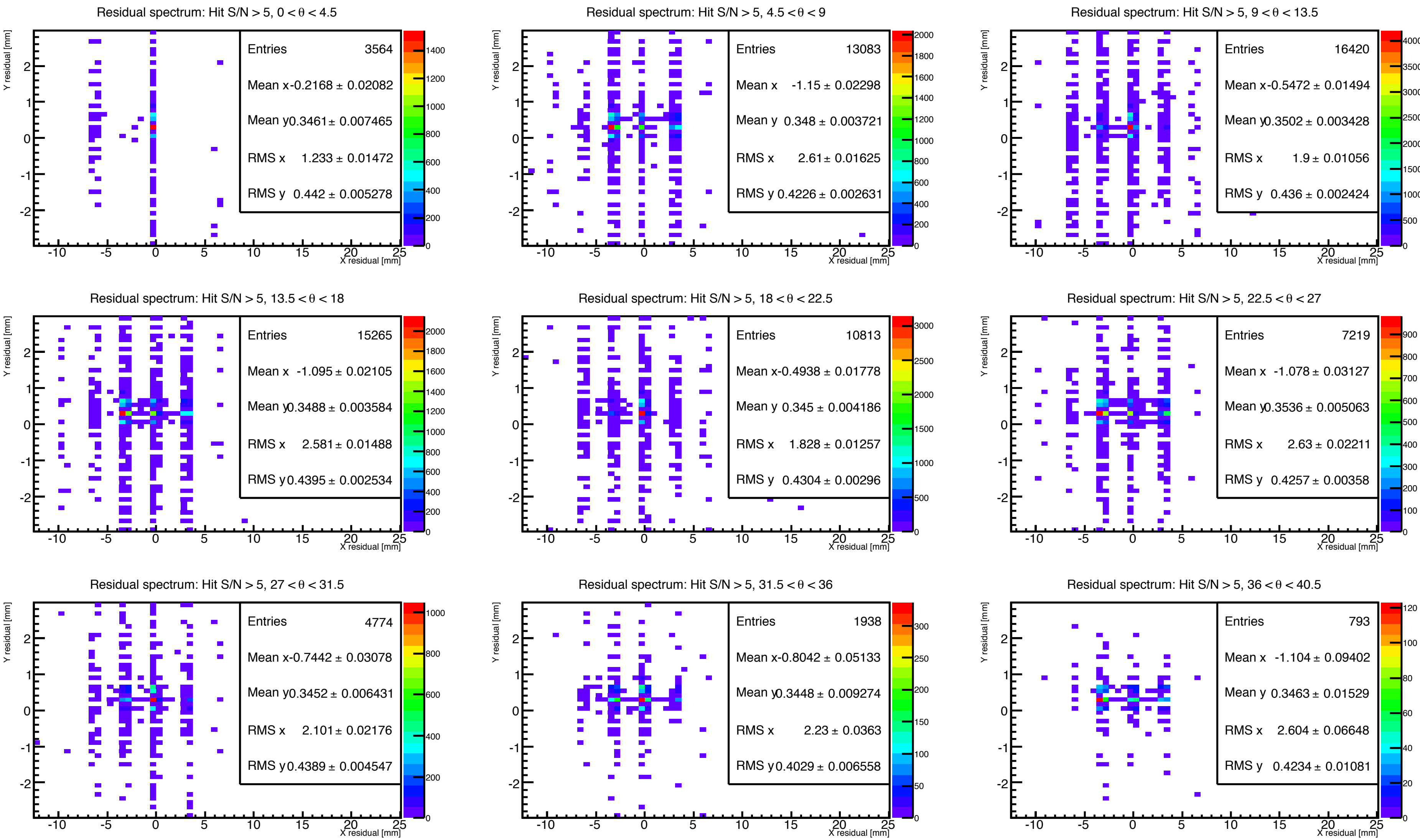
Cluster size in Y as a function of track angle.





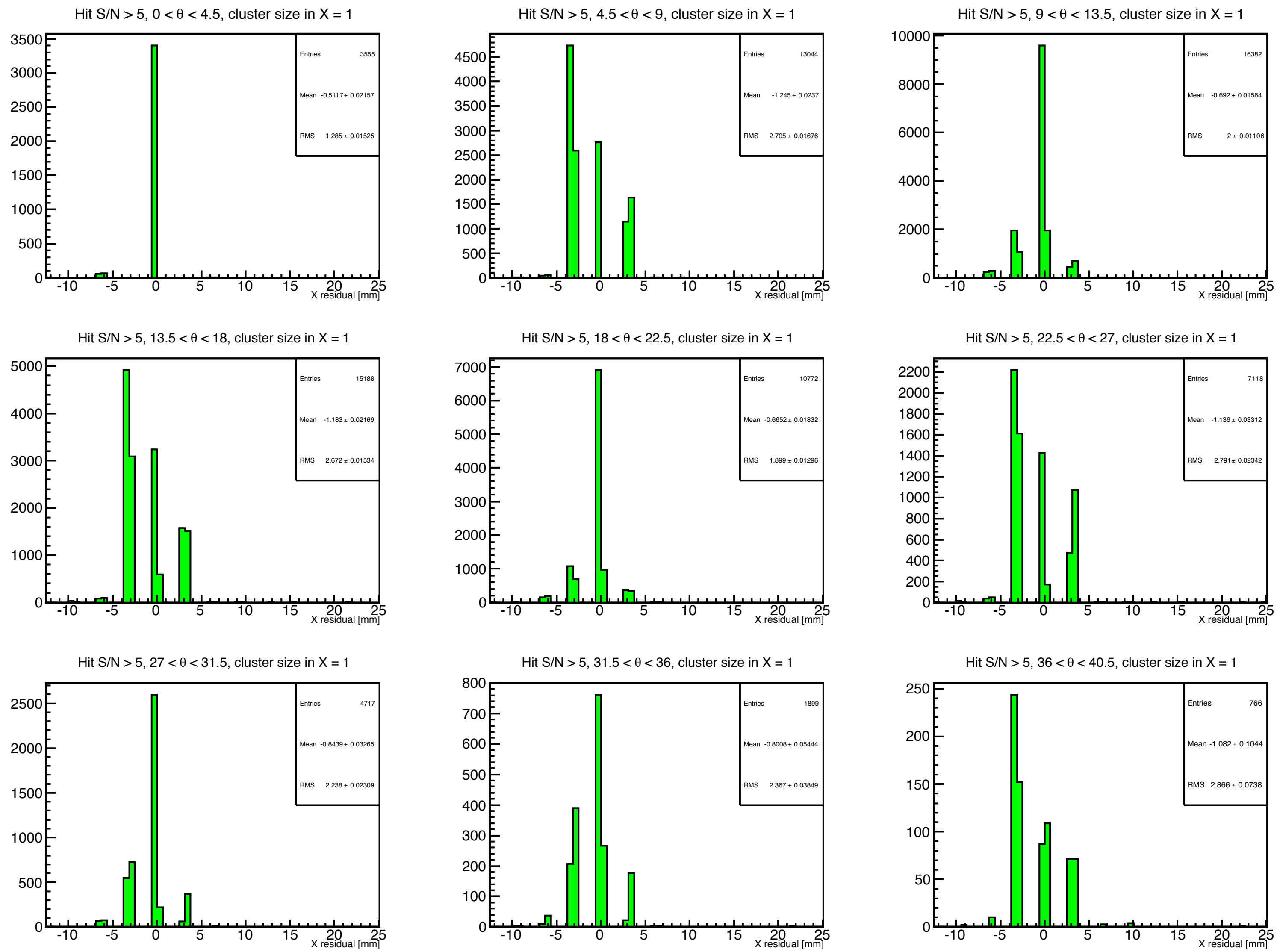
Residual – Layer 2 (HITCUT = 5)

Residual distribution (w/ all cluster sizes) in different track angle windows.

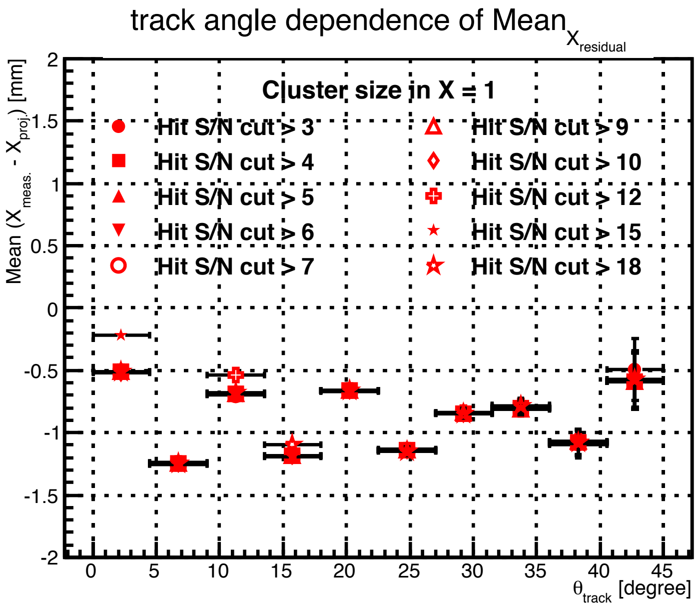


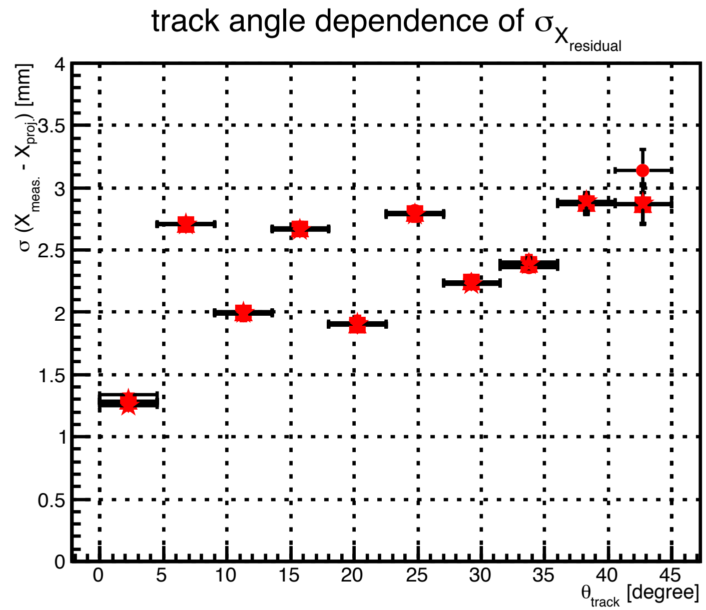
Residual in X – Layer 2 (HITCUT = 5)

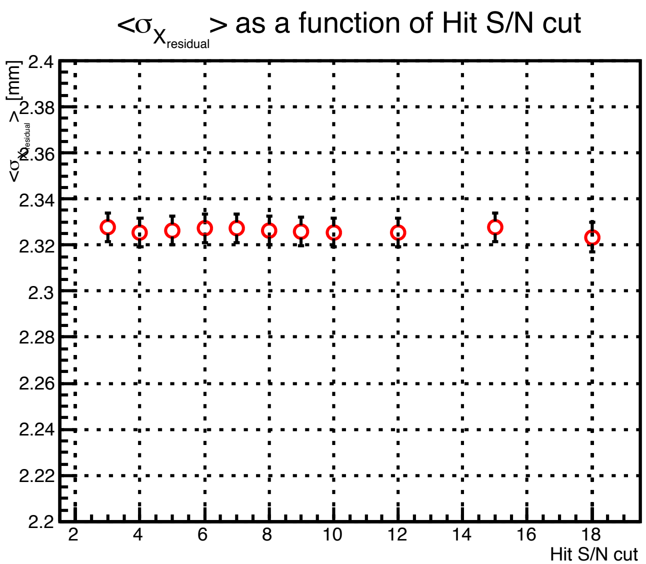
Residual distribution in X (w/ cluster size = 1 in X) in different track angle windows.



Residual in X – Layer 2





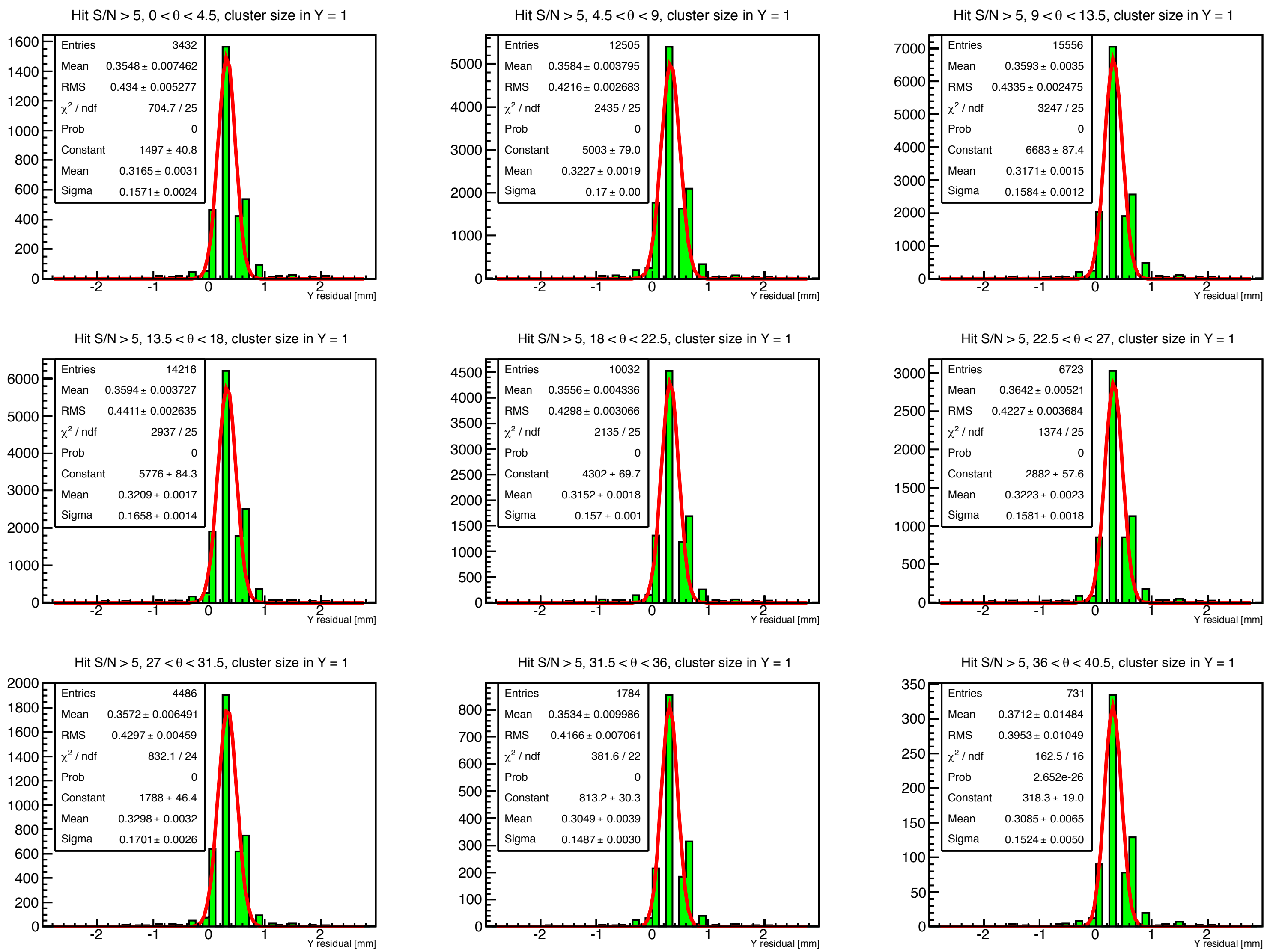


Weighted $<\sigma_{residual}>$ in X is ~ 2.325 mm

Expected residual resolution in X is 2.218 mm
(= sqrt(3/2)*6.275mm/sqrt(12))

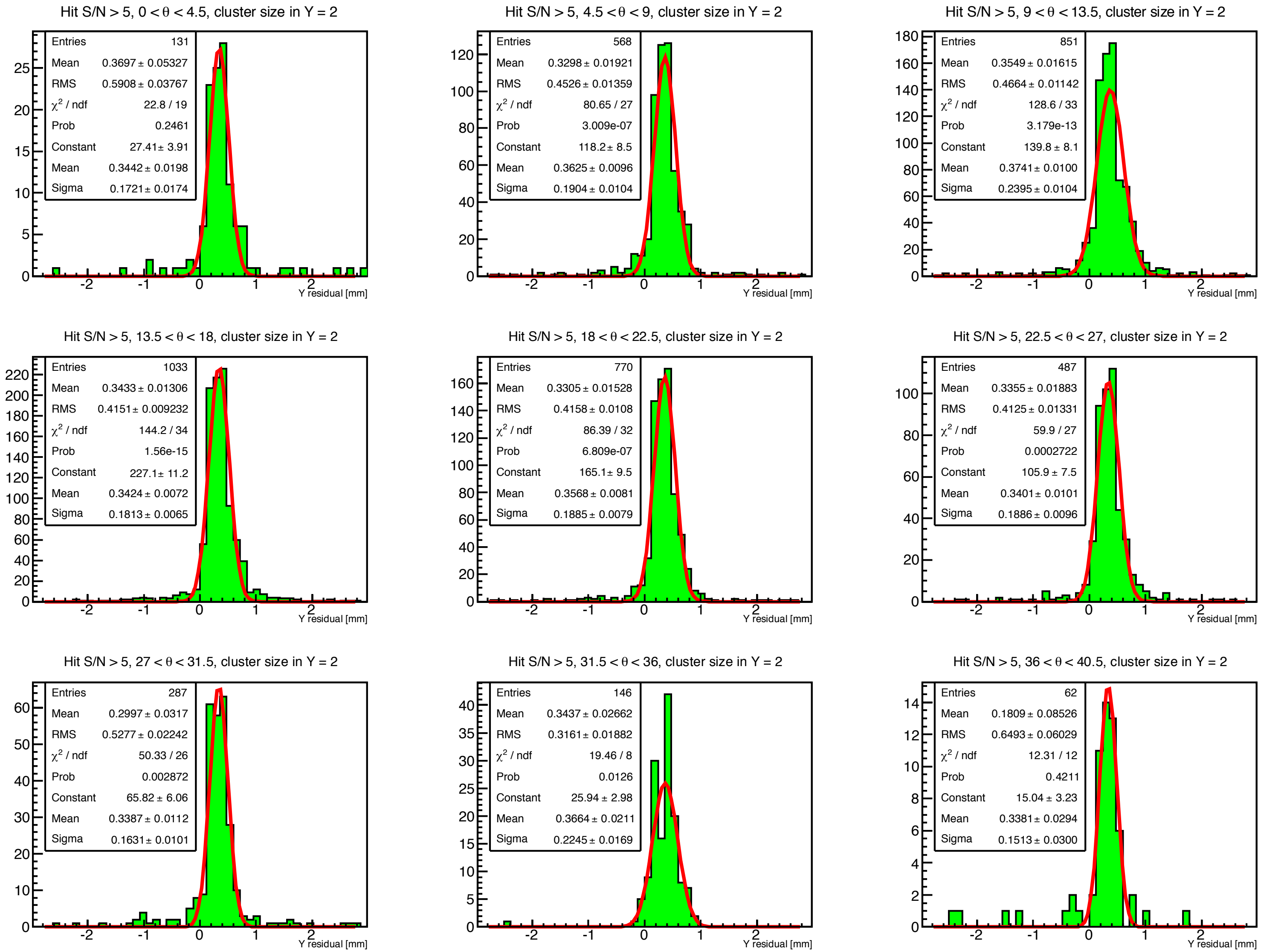
Residual in Y – Layer 2 (HITCUT = 5)

Residual distribution in Y (w/ cluster size = 1 in Y) in different track angle windows.

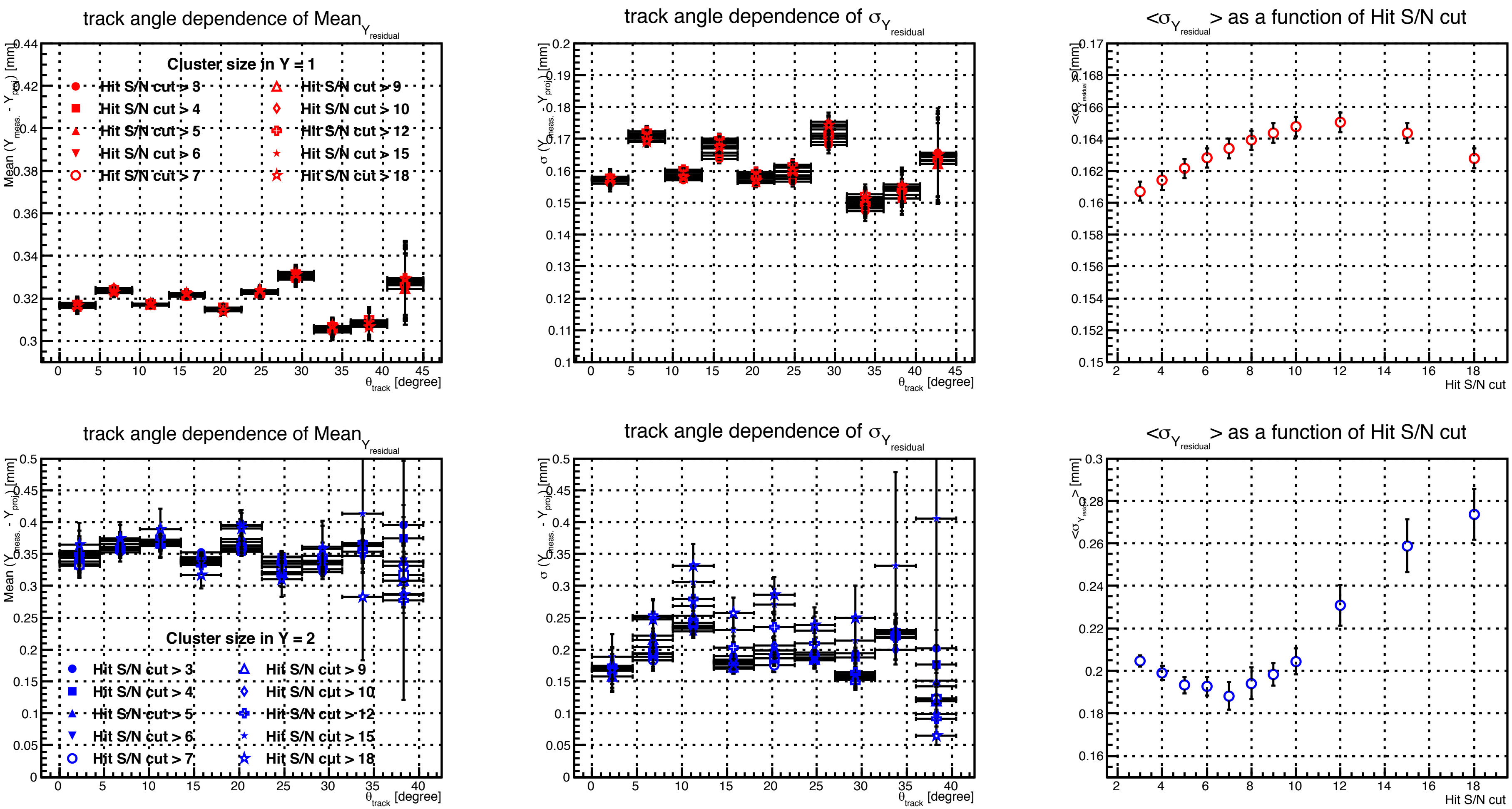


Residual in Y – Layer 2 (HITCUT = 5)

Residual distribution in Y (w/ cluster size = 2 in Y) in different track angle windows.

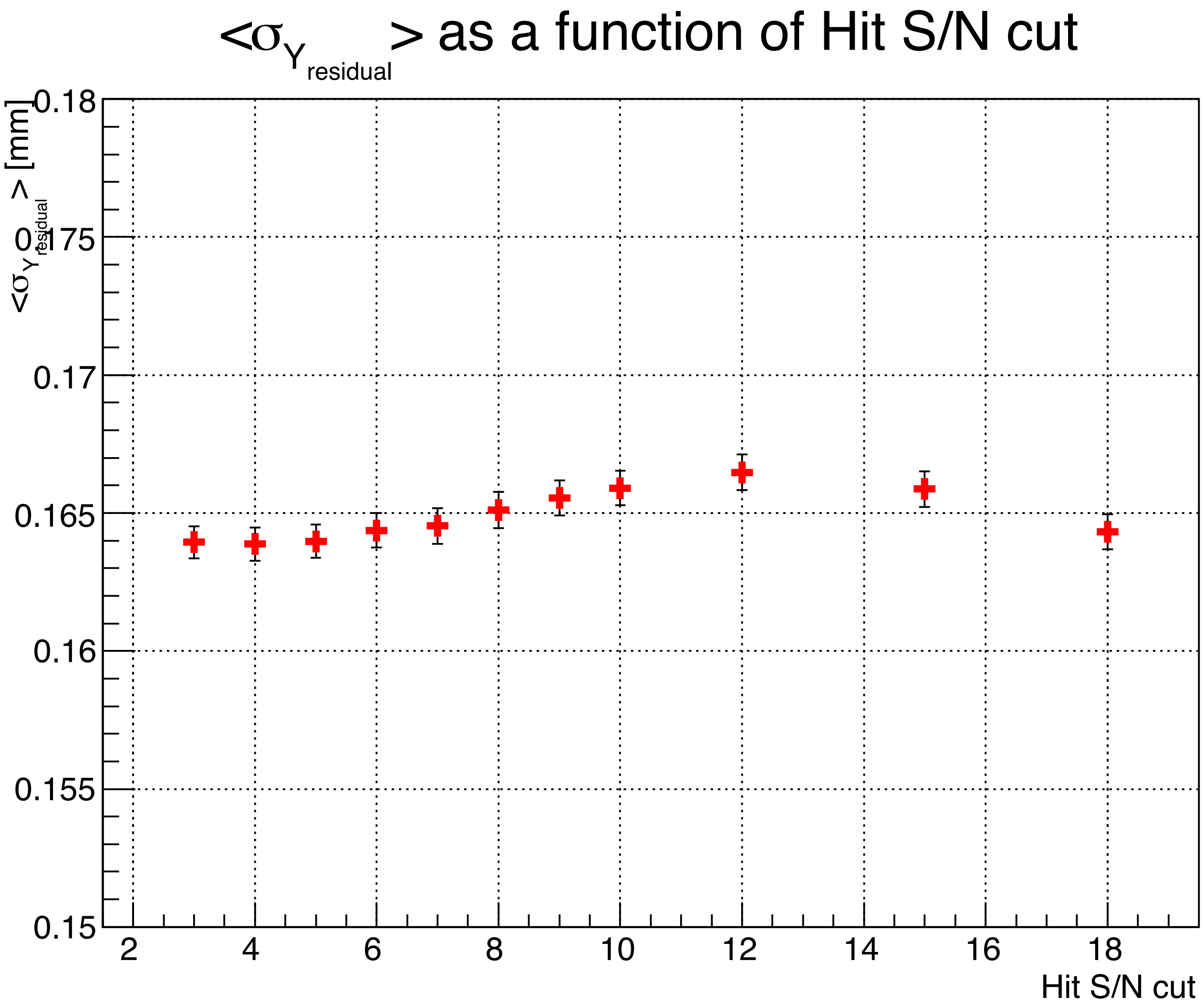


Residual in Y – Layer 2



Weighted <$\sigma_{residual}$> in Y is ~ 0.163 mm (cluster size = 1) and ~ 0.22 mm (cluster size = 2)

Residual in Y – Layer 2

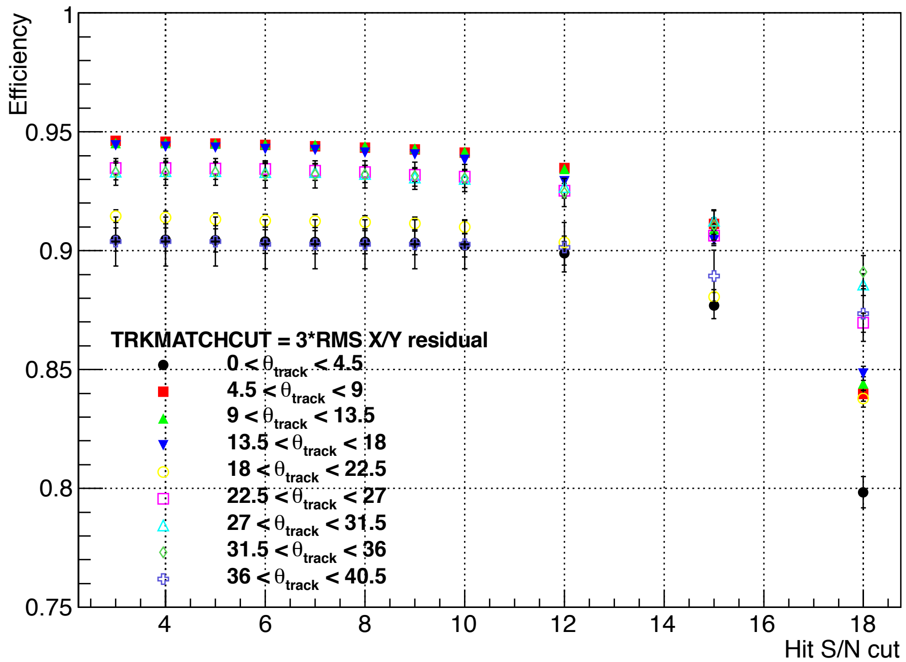


Combined $<\sigma_{residual}>$ in Y is ~ 0.165 mm (combined cluster size = 1 and =2)

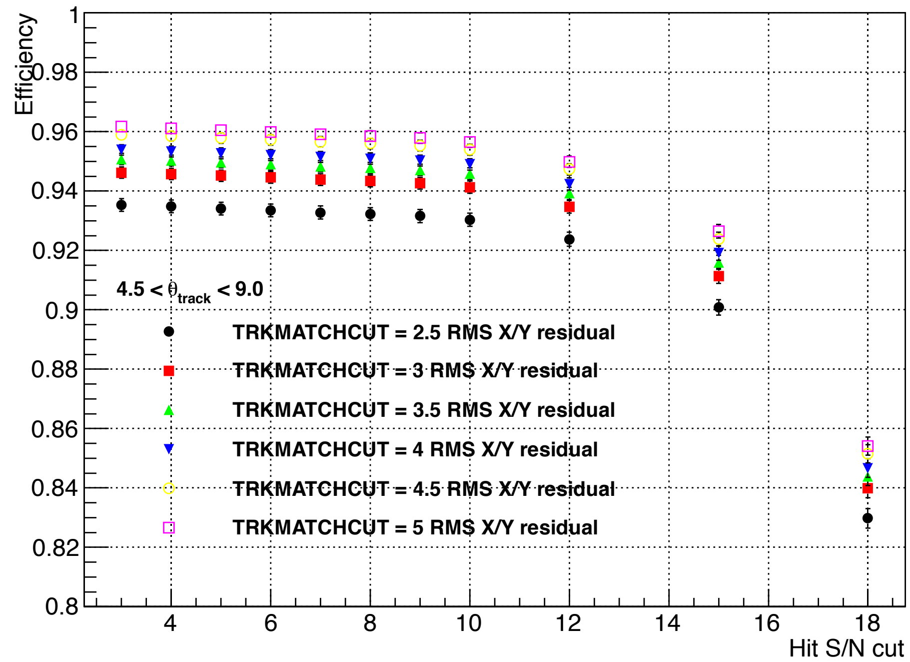
Expected residual resolution in Y is 0.2107 mm (= sqrt(3/2)*0.596mm/sqrt(12))

Efficiency – Layer 2

Hit S/N cut dependence of efficiency



track matching cut dependence of efficiency



Calculation of the integrated efficiency:

$$\varepsilon = N_{found}/N_{total}$$

- Efficiency decreases as HITCUT increases, which behaviors as expected.
- The efficiency is around 94% for most track angle windows when HITCUT is less than 10.

Efficiency vs. track matching cut

About two percent efficiency lose while using strict cut (2.5 RMS) instead of the loose cut (5 RMS).

To do

- Alignment (ongoing)
- Test validity of the cluster splitting (ongoing)
- Apply new cut for the efficiency calculation, like using IST silicon pad dimensions instead of RMS residual cuts (data run is done, plots not available yet)