Analysis of Timepix3 Test Beam Data

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Contents

1) Introduction - Pixel Detector

- Timepix3 readout chip bump bonded to a thick silicon layer (675µm).
- Charge drift time information can be used to reconstruct the track angle, just like a time projection chamber, using only a single layer. The Timepix3 time binning is 1.56ns.
- Timepix3 is a possibility for the CLIC tracker. It would be useful for track finding and background rejection.

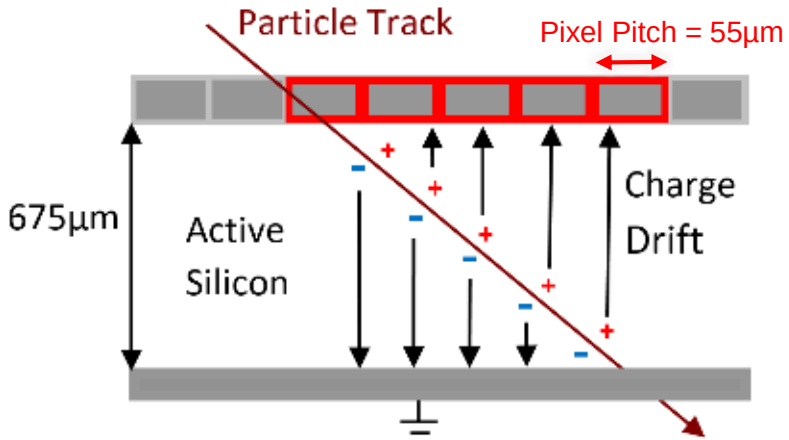


Diagram illustrating the charge drift time information from the thick Timepix3

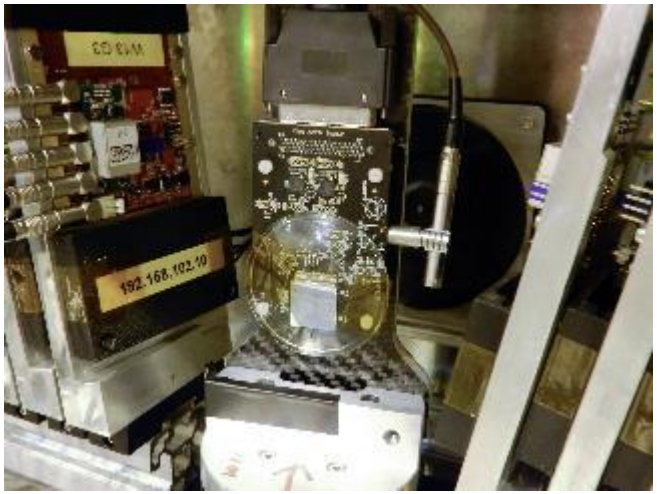


Image of the Timepix3 with a thick silicon layer of 675µm.

Test Beam Set Up

- Aim was to study the accuracy and precision of the detector's track angle measurement.
- Timepix3 DUT inserted at different angles to the beam to test this principle.
- Larger angles should lead to larger clusters and hence better resolution.

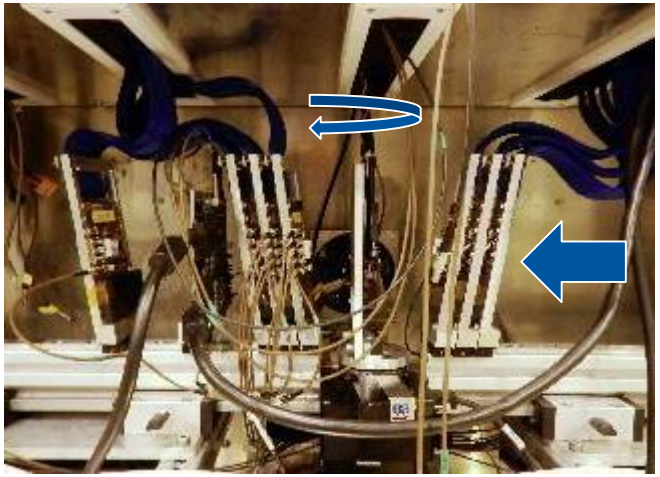
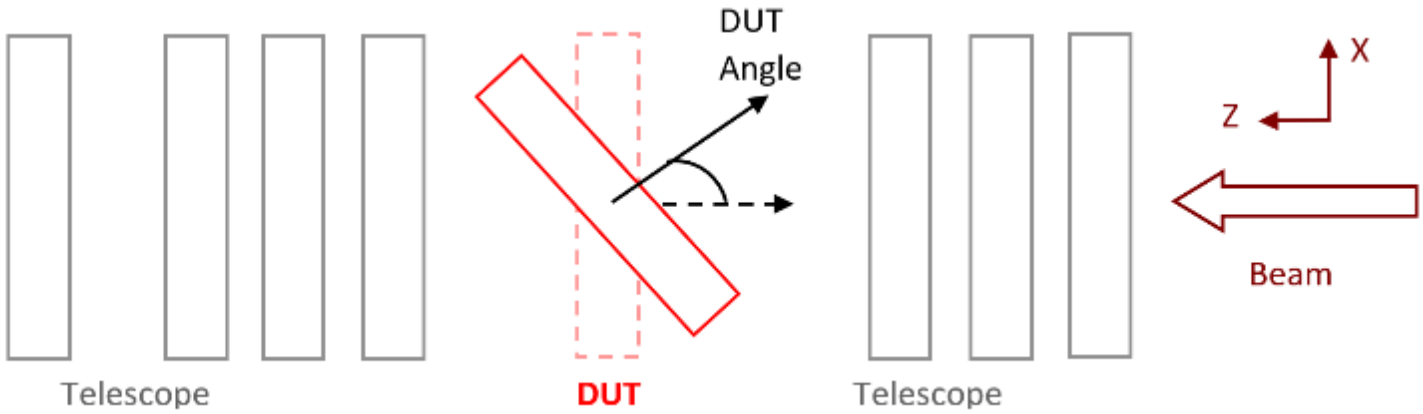


Image of the CLIC Timepix3 telescope set up in the North Area, beam from SPS. Positive x axis into the page and beam from right to left.

Diagram (top-down view) of the test beam telescope set up with the DUT rotated at different angles to the beam along the x axis.



Raw data to Timing data

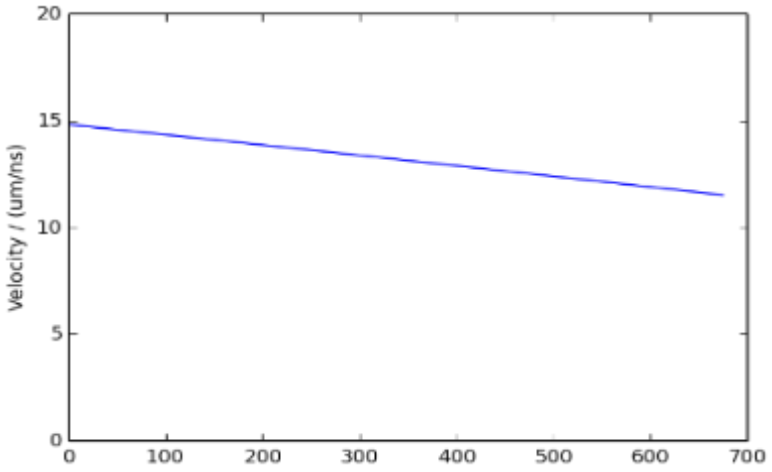
- Need the depletion voltage, so this was calculated from the data of the bias scan runs (0° and differing bias V).

- The electric field was calculated for the voltage's active thickness using the equation below:

$$E(z) = \frac{U_{Bias} - U_{Depletion}}{d} + \frac{2U_{Depletion}\,\frac{1-z}{d}}{d}$$

- From this and the mobility of holes we obtain a drift velocity curve.

- The timing then can be calculated using an integration stepping method under this curve.



Graph of the charge drift velocity of the holes in the sensor for a bias voltage of 200V vs. the readout time.

2) Analysis

- Aim: to calculate the DUT angle from the data and compare this to the set angle from the alignment.

- Used data from October 2015 and June 2016.

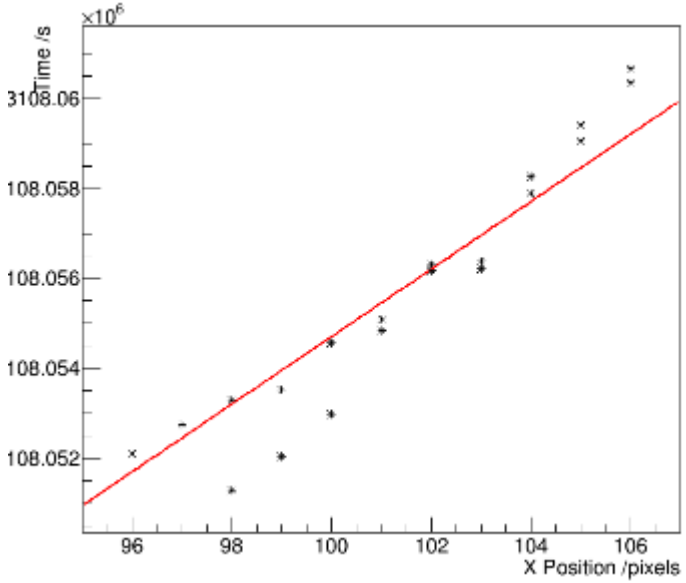
- Two methods were used:
  - A) Timing Information Analysis
  - B) Multivariate Analysis

A. Timing Information Analysis

- Using October 2015 data with a DUT bias of 200V.

For each cluster:

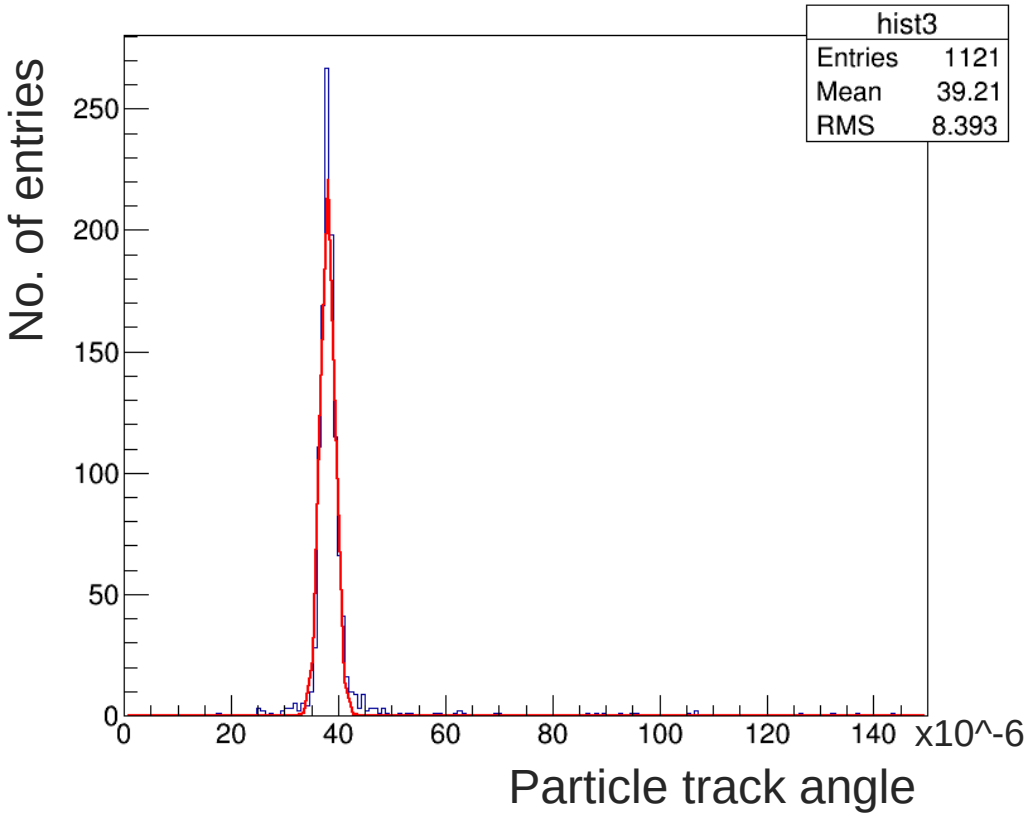
- From charge arrival times and drift velocity, the depths of the charges in the cluster were calculated.
- Plotted these depths vs. x position and saved the linear fit gradient.
- Using the slope the angle of the tracks for each cluster were calculated using trigonometry.



Graph of time of arrival vs. x position, showing the charge drift inside the thick silicon layer.

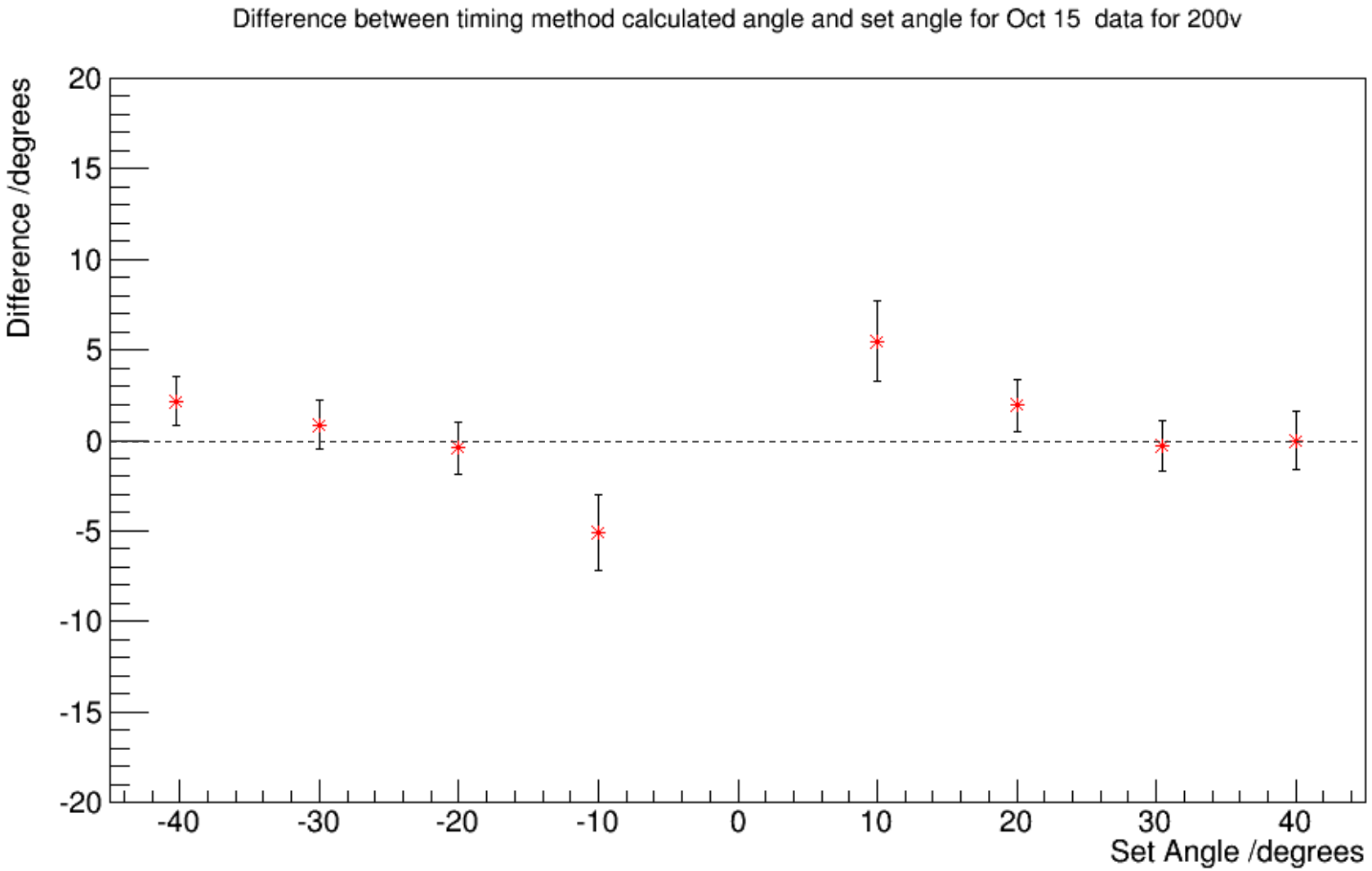
For each run:

- These angles were added to a histogram and fitted with a Gaussian to get the overall mean angle of the DUT for the run.



Histogram of the DUT angles calculated for each cluster to give the mean calculated angle for the run. Example is for run 1254, -40º DUT set angle wit a bias voltage of 200V.

October 2015 data, 200V. Note the error bars are the sigma values of the Gaussian fits.



B. Multivariate Analysis

- Aim was to use all possible information to make a decision on the DUT angle value.

- Using a multivariate analysis technique (TMVA) to determine the track angle from multiple inputs:
  - ToT weighted x cluster size
  - Total ToT
  - Depth vs. x position graph slope
  - Time vs. x position graph slope

- Values inputted for each cluster in the run.

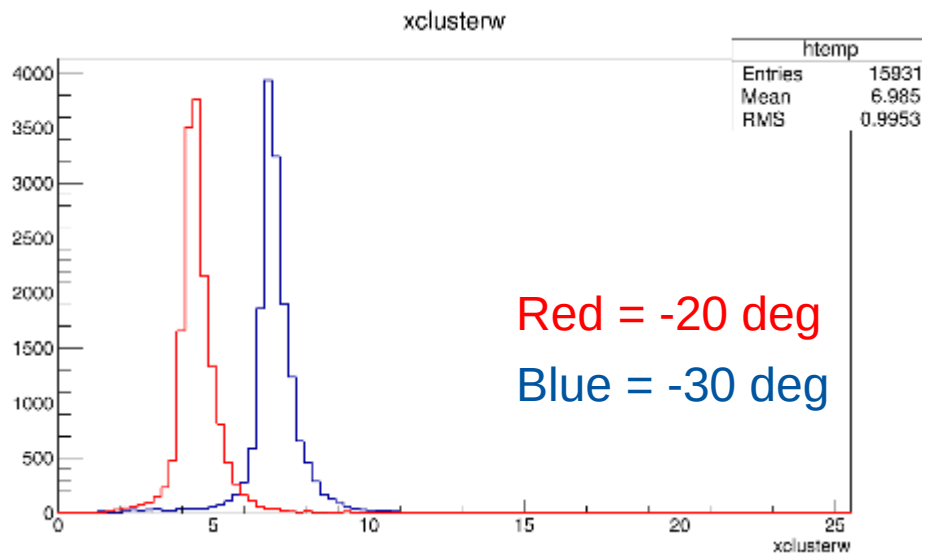
Training with ToT weighting

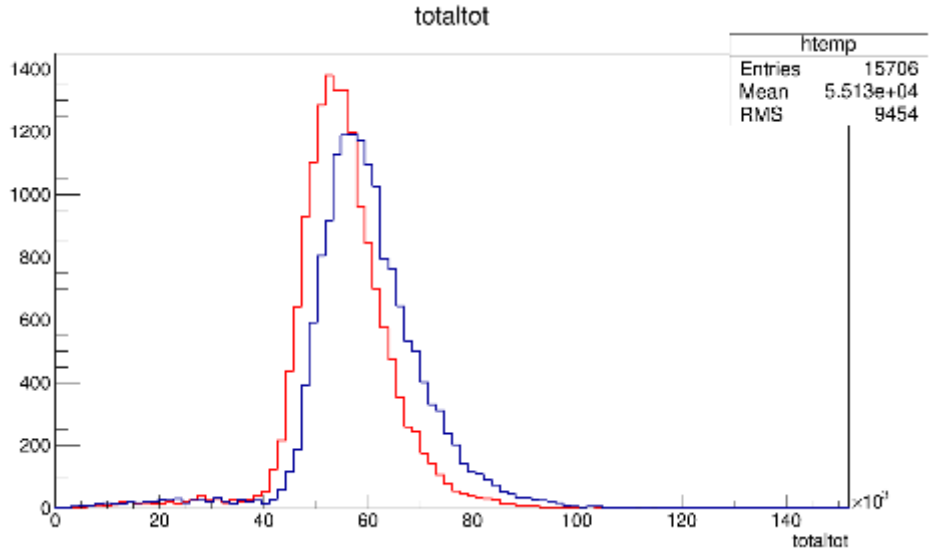
- Only for clusters with size in x of > 2 pixels.
- Training the network with integer cluster sizes causes multiple peaks in the calculated angle histogram.
- Weight the outside pixels by the mean ToT of the inner pixels, taking into account if there are more than one pixel in the y direction.
- Gives equivalent fraction of the outer pixels hit and makes the cluster size a floating point value.

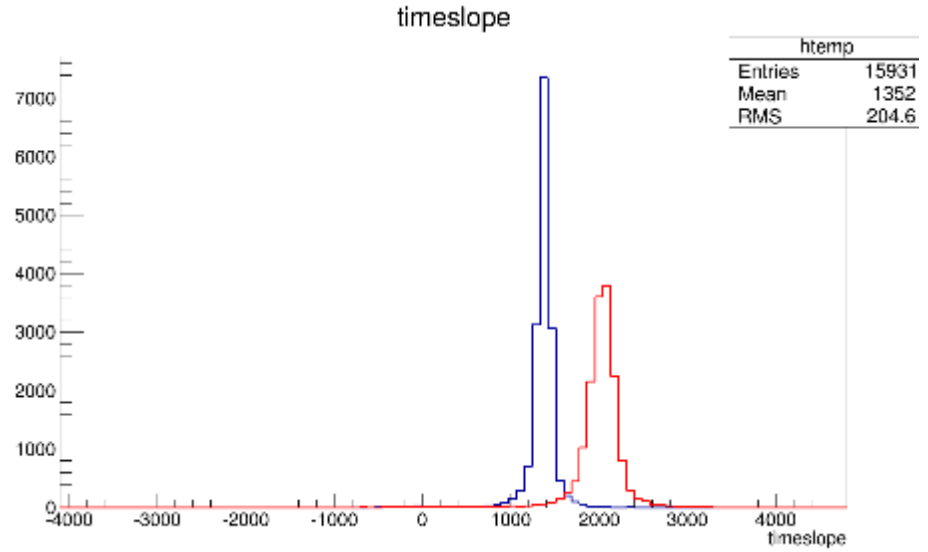
Outer Pixels:
fraction = tot/mean tot of inner pixels

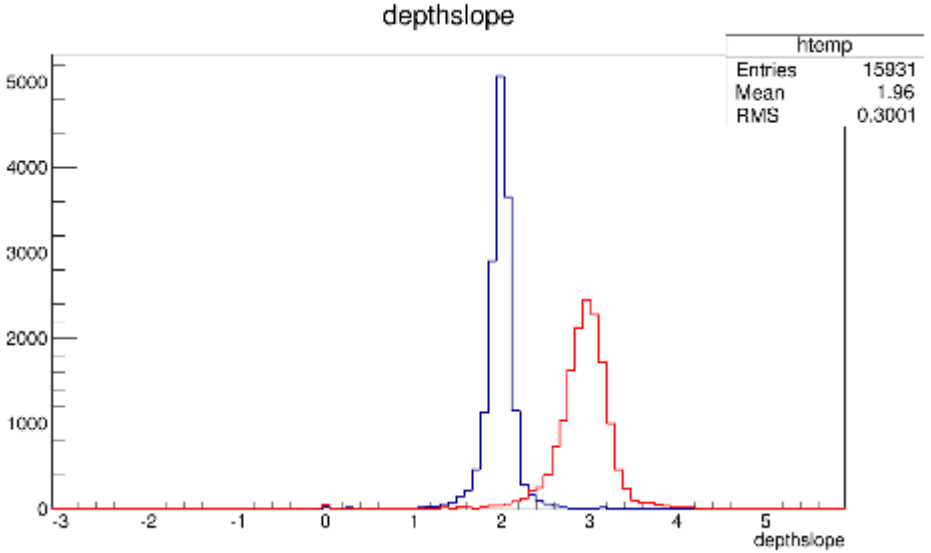
Inner Pixels: find mean tot value

Diagram of a simple example cluster along the x axis, showing the ToT weighting idea of using the mean tot of the inner pixels (blue) to find the fractional pixel values of the outer pixels (red).









Histograms showing the inputted values into the network. Red denotes run 8174, DUT angle -20; Blue denotes run 8164, DUT angle -30.

MVA Steps:

- Two steps: training and testing. Fraction of the total events used for each step.

Step	Set angle known?	Set angle given to network?	Used to:
Training	Yes	Yes	Train the network to recognise different DUT angle data
Testing	Yes	No	Compares the set and TMVA calculated angles to determine the network's performance

Methods:

- PDE Foam – Probability Density Estimation
- FDA Minuit – Function Discrimination Analysis
- BFGS on an MLP neural network – MultiLayer Perceptron
- BDTG - Boosted Decision Tree with Gradient boosting

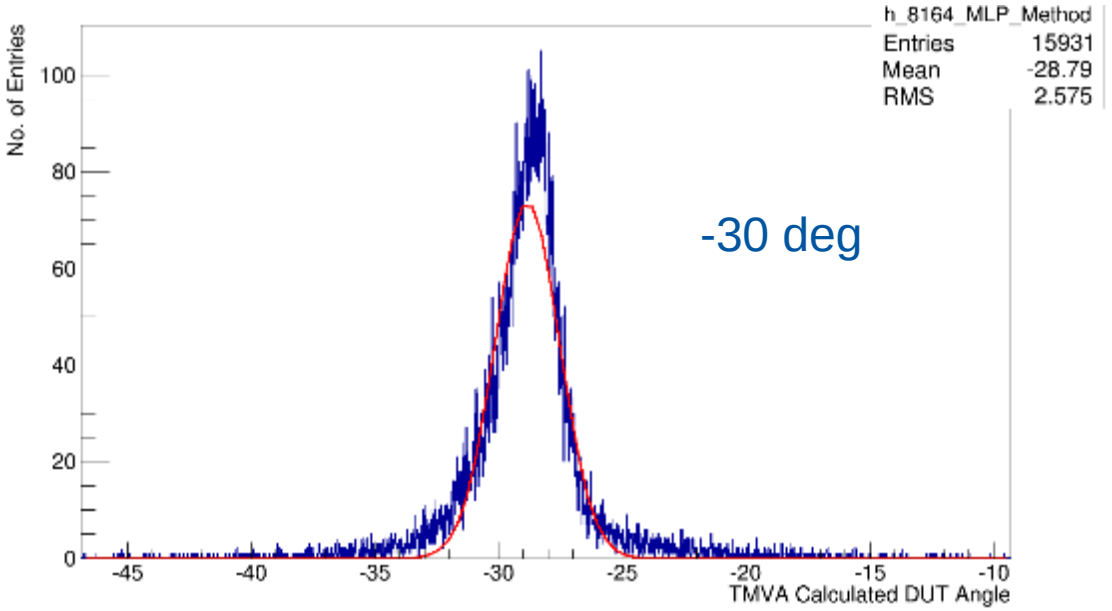
- TMVA methods tried are regression methods, as the aim is to obtain a value for the calculated angle.

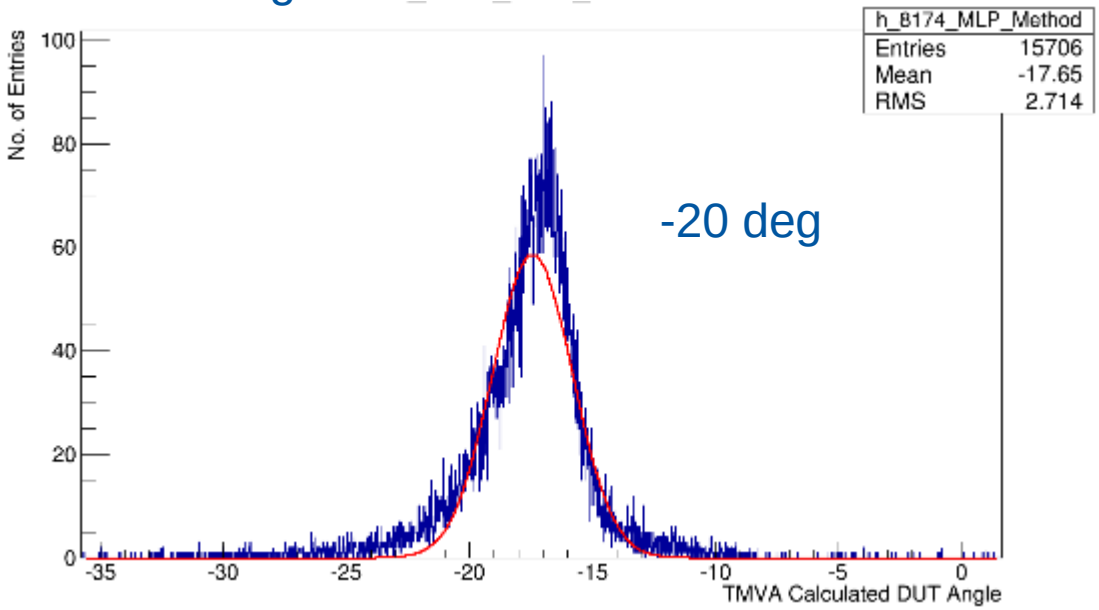
- Found latter two to be the most appropriate from the testing results; found BFGS to give the best performance from the analysis results.

- Note: method parameters were not optimised.

Gauss Fits:

- Fit a Gaussian to the TMVA calculated angle histograms.
- Take the mean and sigma values and plot these against the set angle from the alignment.

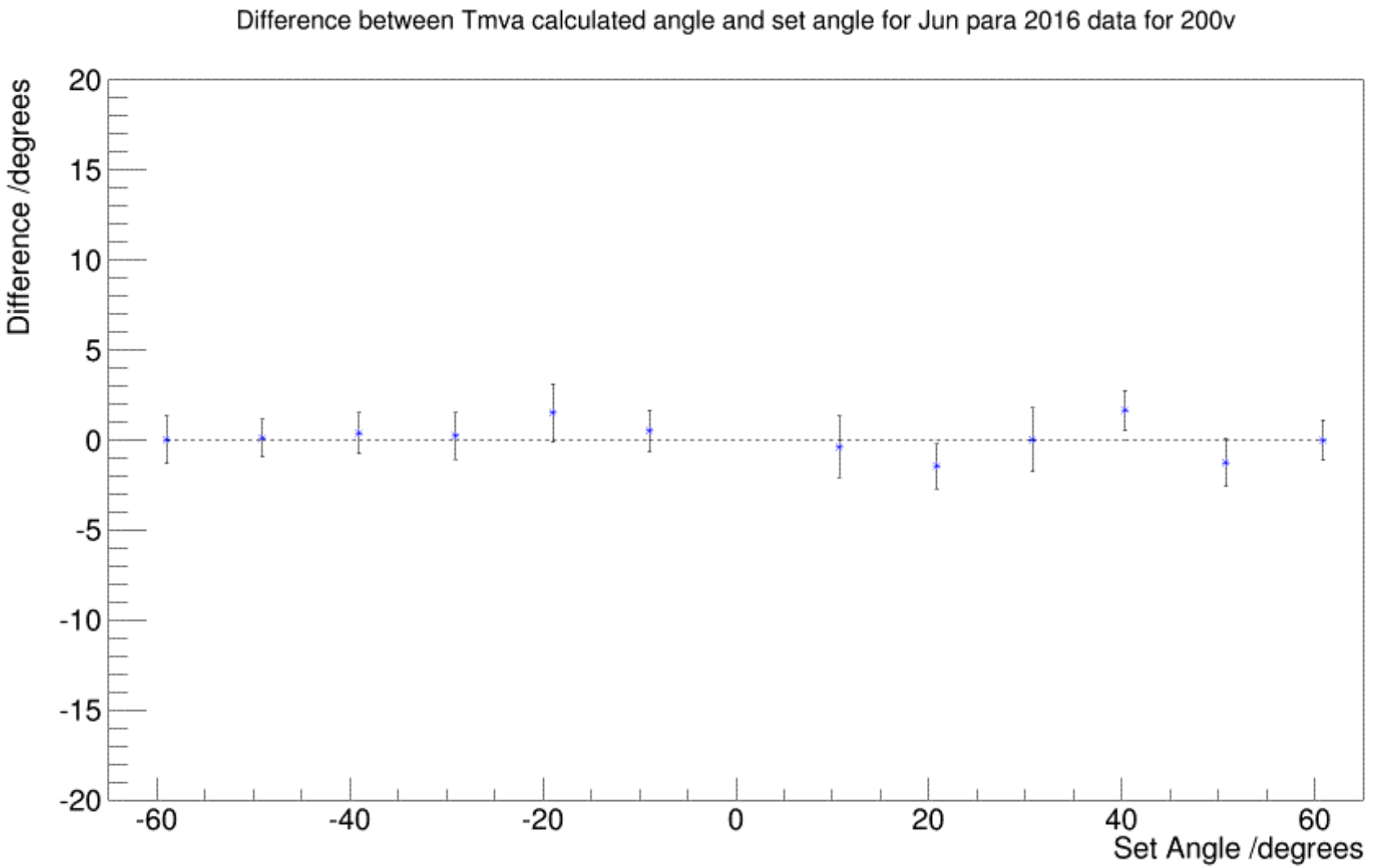




Histograms of the calculated DUT angle from the MVA method.

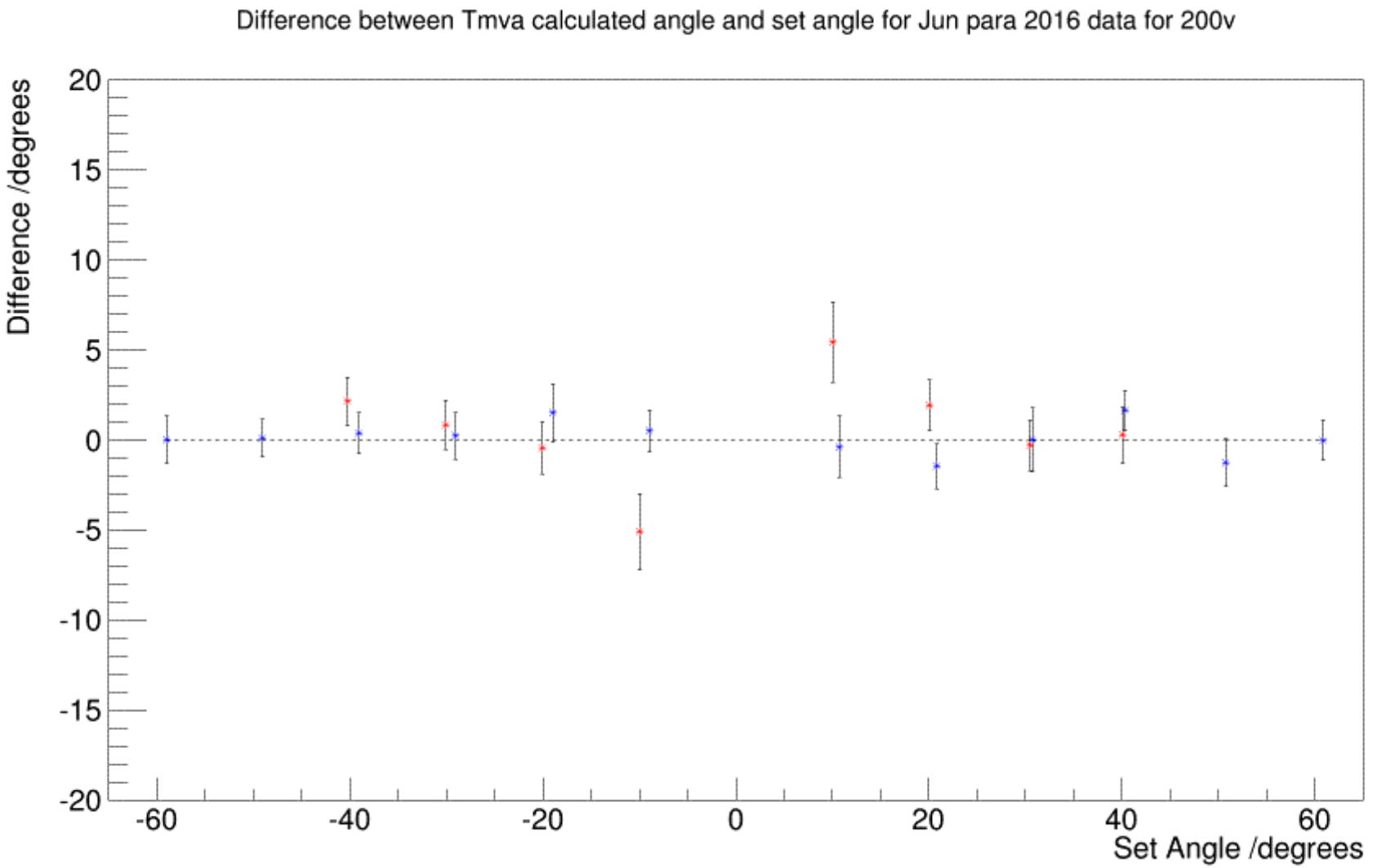
Top, right: for run 8164, DUT angle of -30 degrees.
Bottom, left: for run 8174, DUT angle of -20 degrees.

June 2016 data, 200V. Note the error bars are the sigma values of the Gaussian fits.



Blue – June 2016 TMVA data

Red – October 2015 timing analysis data



3) Next Steps

- Possibly input the difference in time between the earliest and latest point into the training.
- Investigate the effect of cluster splitting.
- Train network with higher statistics with new test beam data and/or simulated data.
- Train and compare calculated angle's produced for different bias voltages.
- Analyse new data with the 300µm thick Timepix3.

4) Summary

- Working with a Timepix3 chip with a thick silicon layer.
- Reconstructed test beam data to study the accuracy and precision of the sensor's track angle measurement.
- Two forms of analysis used: A) timing information analysis and B) multivariate analysis.
- The MVA method was found to give much better results, especially for smaller angles, than the 1st method.
- Now we will try to obtain timing information from a thinner sensor.

Thank you for your attention.

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References

1. Rossi, Fischer, Rohe and Wermes, Pixel Detectors: From fundamentals to applications, Heidelberg: Springer, 2006.

2. Poikela, Plosila, Westerlund, Campbell, Gaspari, Llopart, Gromov, Kluit, v. Beuzekom and Zappon, “Timepix3: a 65k channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout”, *Journal of Instrumentation*, vol.9, 2014.

3. Hoecker, Speckmayer, Stelzer, Therhaag, von. Toerne and Voss, “TMVA 4: Toolkit for Multivariate Data Analysis with ROOT”, *Proceedings of Science*, vol. ACAT, 2007.


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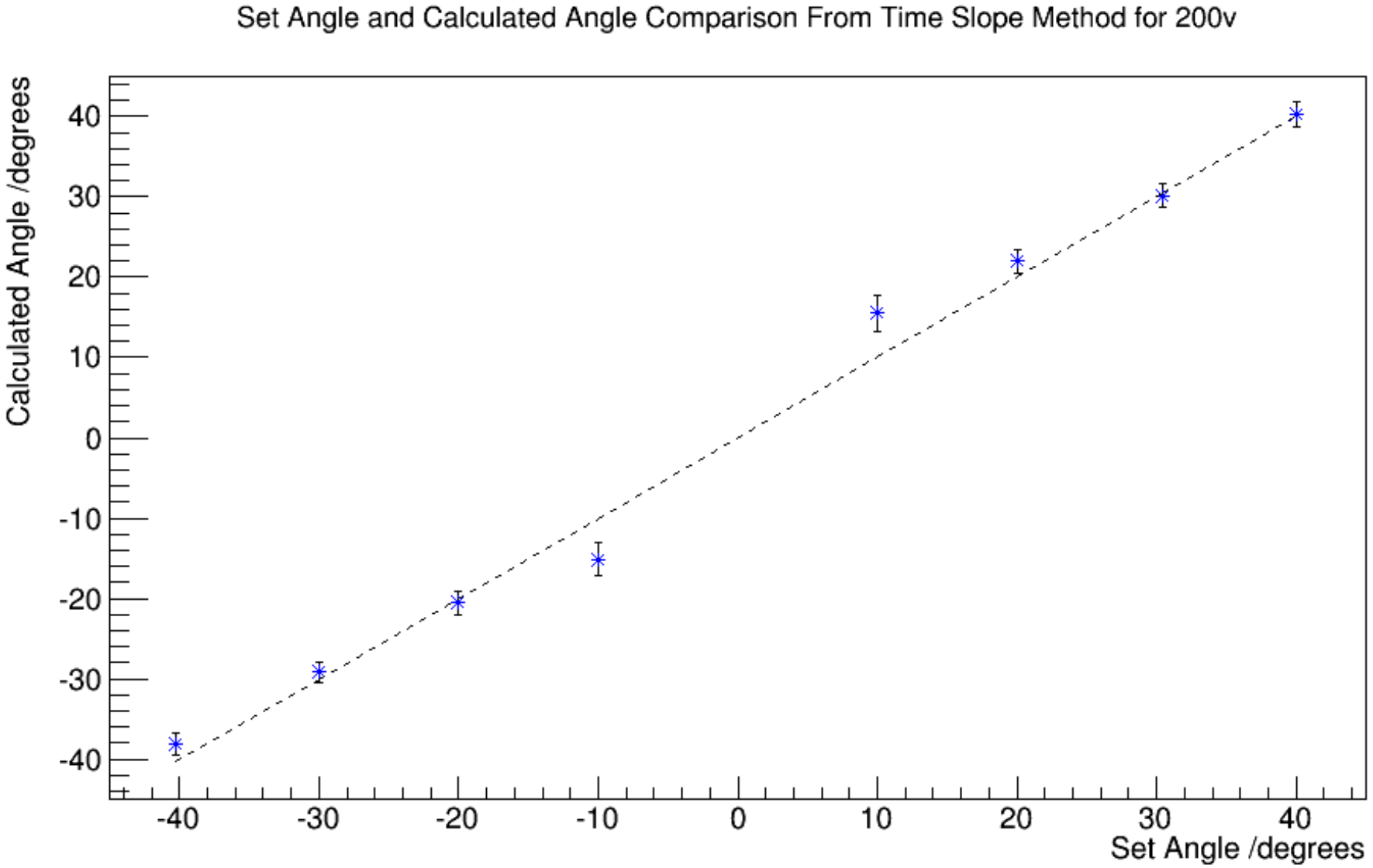
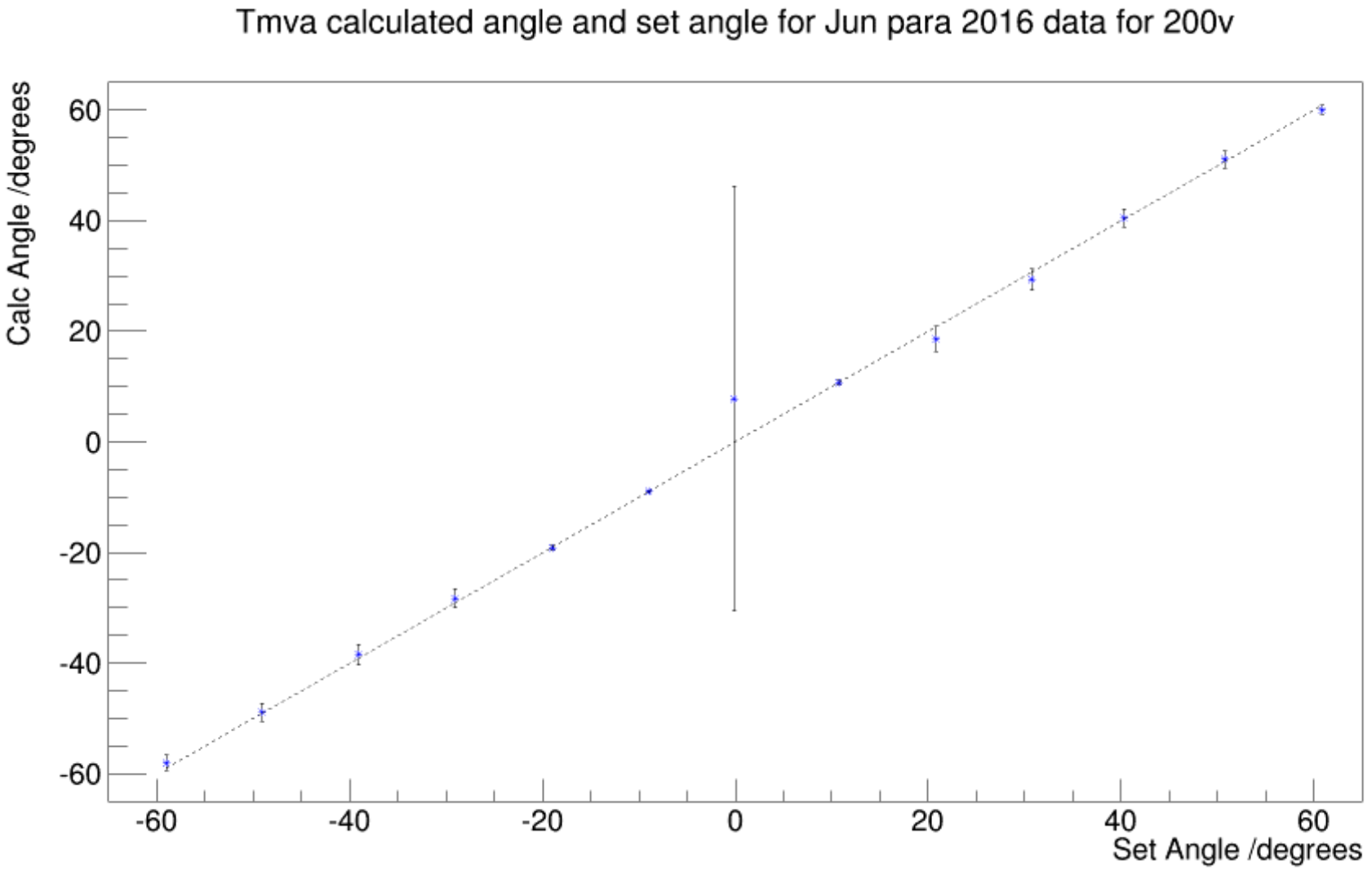
Backup slides

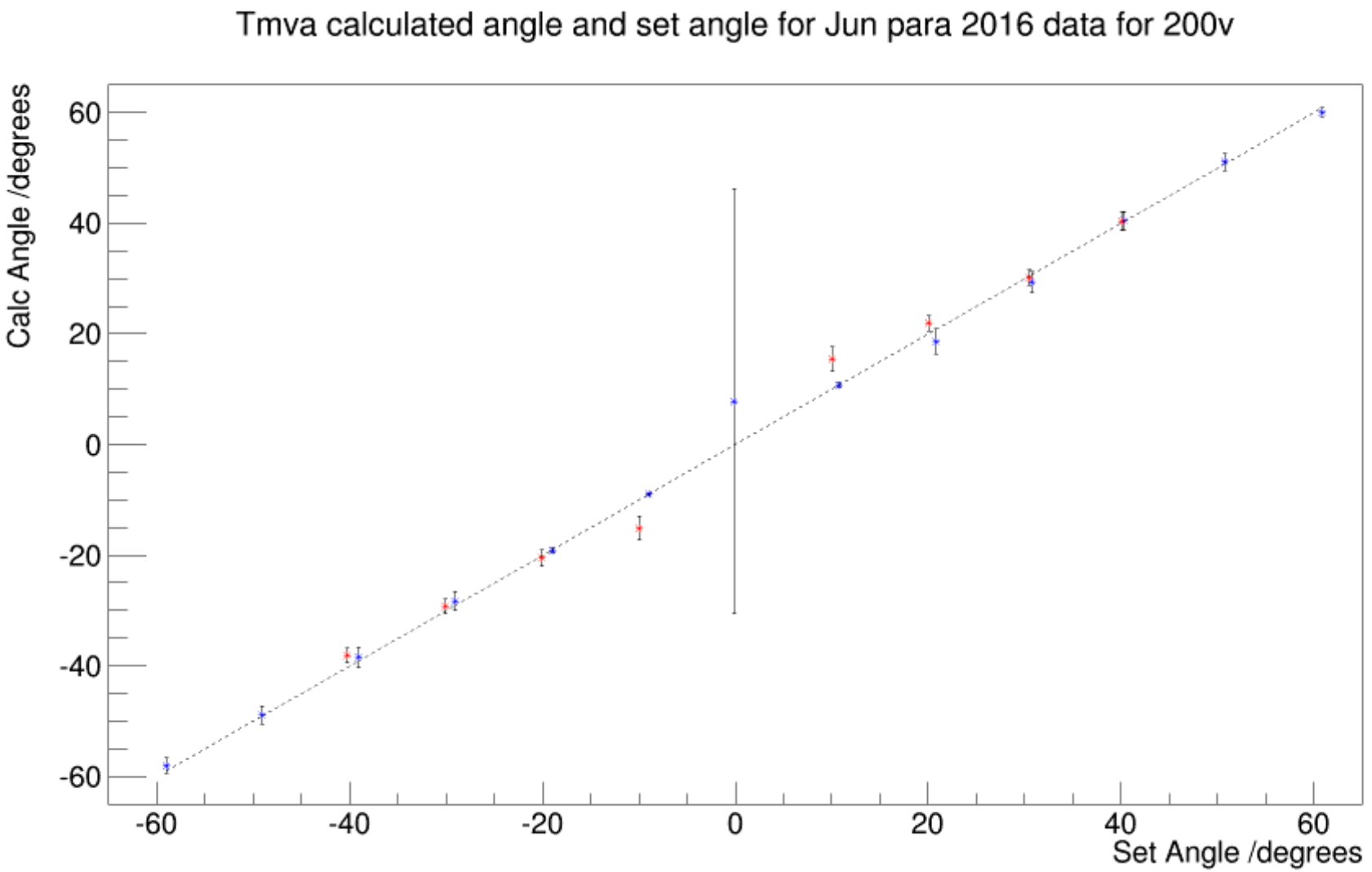
October 2015 data, 200V. Note the error bars are the sigma values of the Gaussian fits.



Note: with tot weighted cluster size in the



Blue – June 2016 TMVA data Red – October 2015 timing analysis data



TimePix3

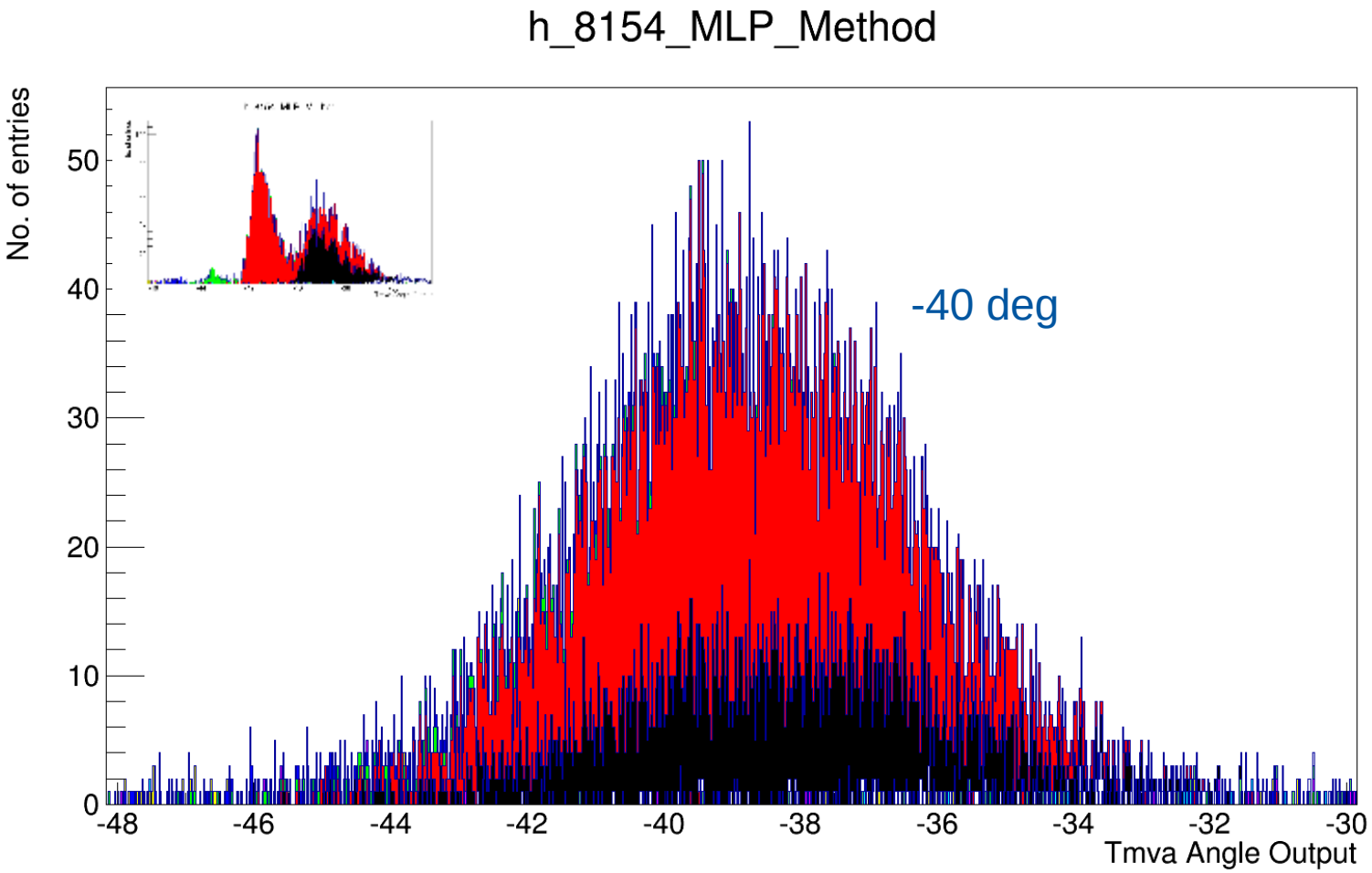
- 256x256 pixel readout chip, pixel size 55x55µm.
- Can record ToA and ToT information simultaneously.
- Continuous readout to reduce pixel dead time.
- Operates in two other modes: only ToA, and event count and integral ToT.
- Suited for readout of semiconductor and gas-filled detectors.
- Timing accuracy ?? Eneryg accuracy ???

- For further information on Timepix3:

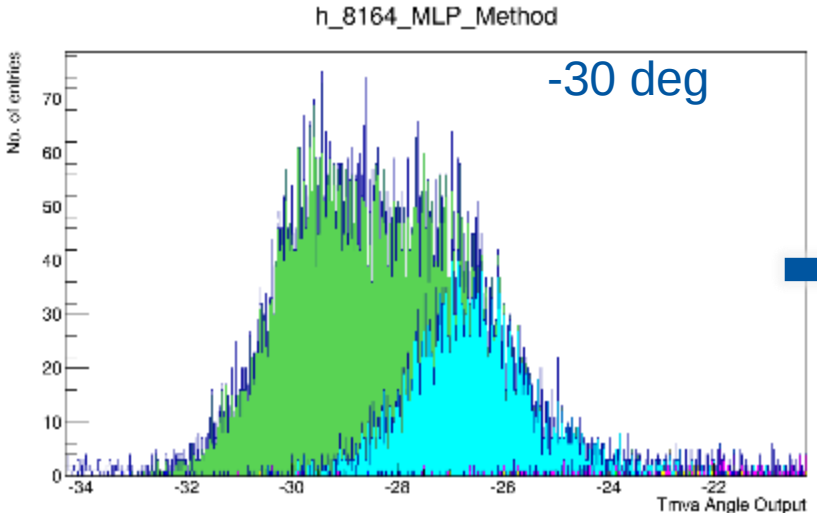
  - “Development and Applications of the Timepix3 Readout Chip”; Gromov et. al.; proceedings of 20th Anniversary International Workshop on Vertex Detectors, Austria, June 2011.

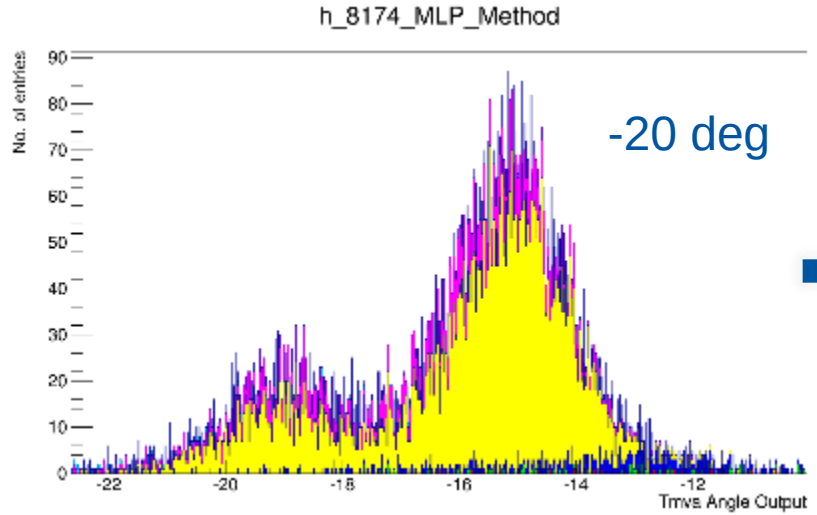
  - “Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout”; Poikela et. al.; 15th International Workshop on Radiation Imaging Detectors, France, June 2013.

Training without Cluster Size:

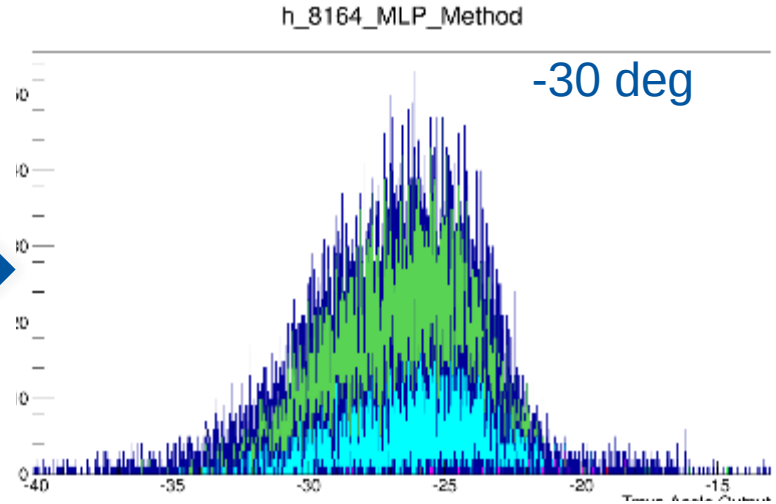


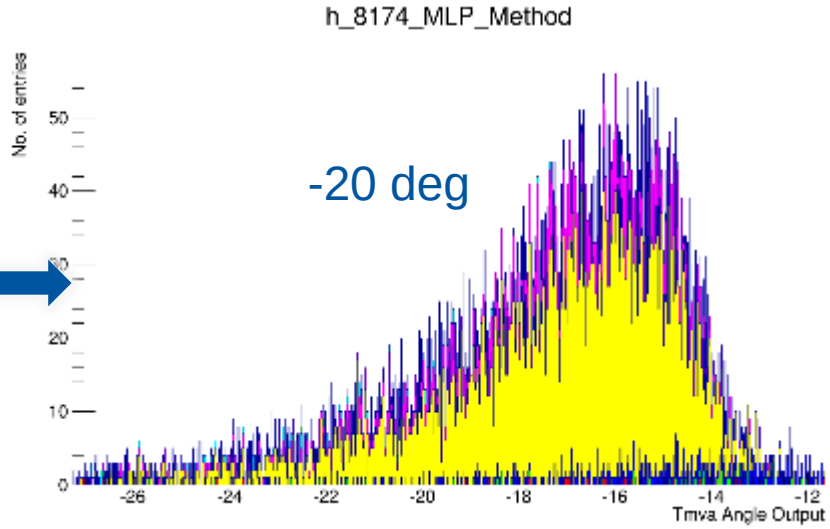
With cluster sizes in training:





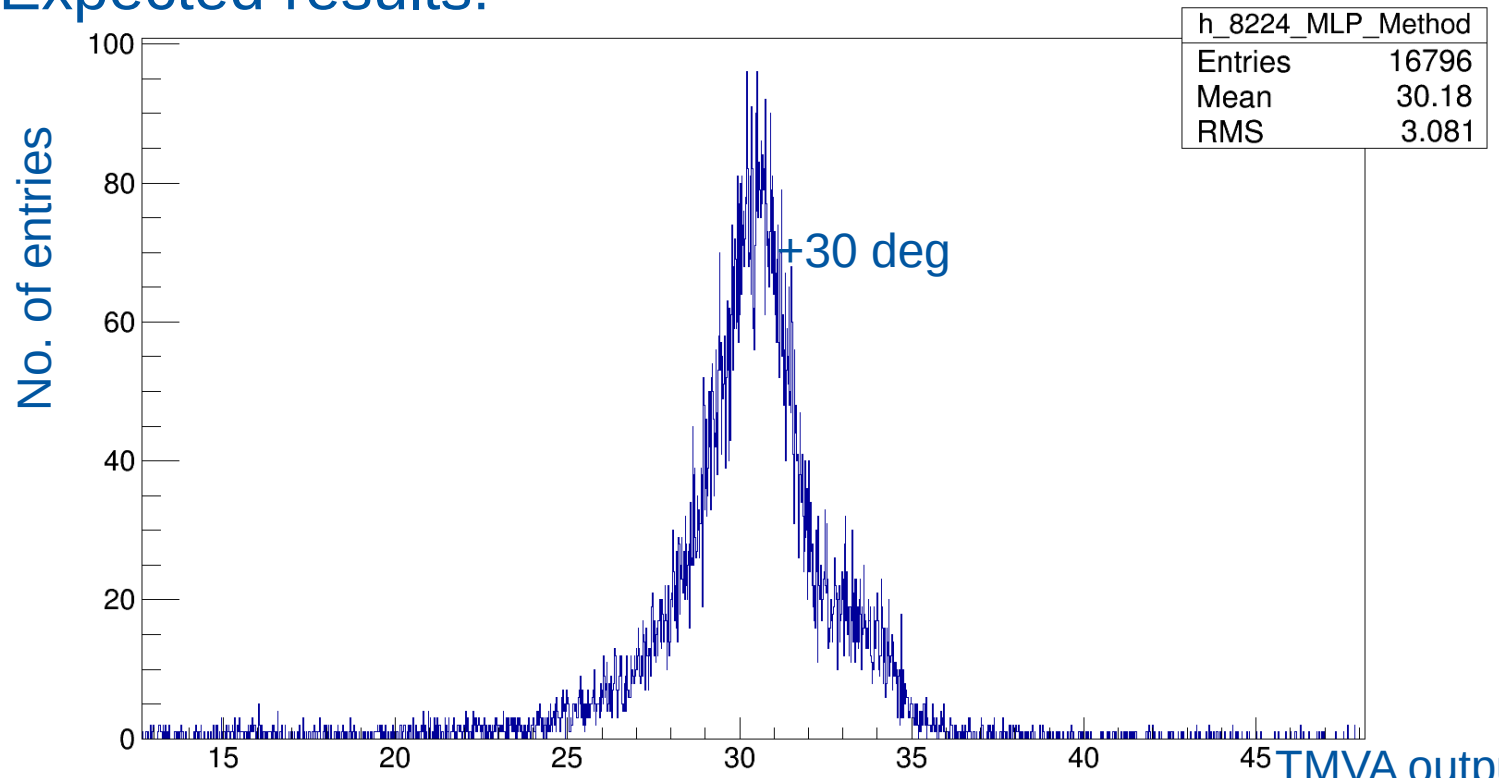
Without cluster sizes in training:



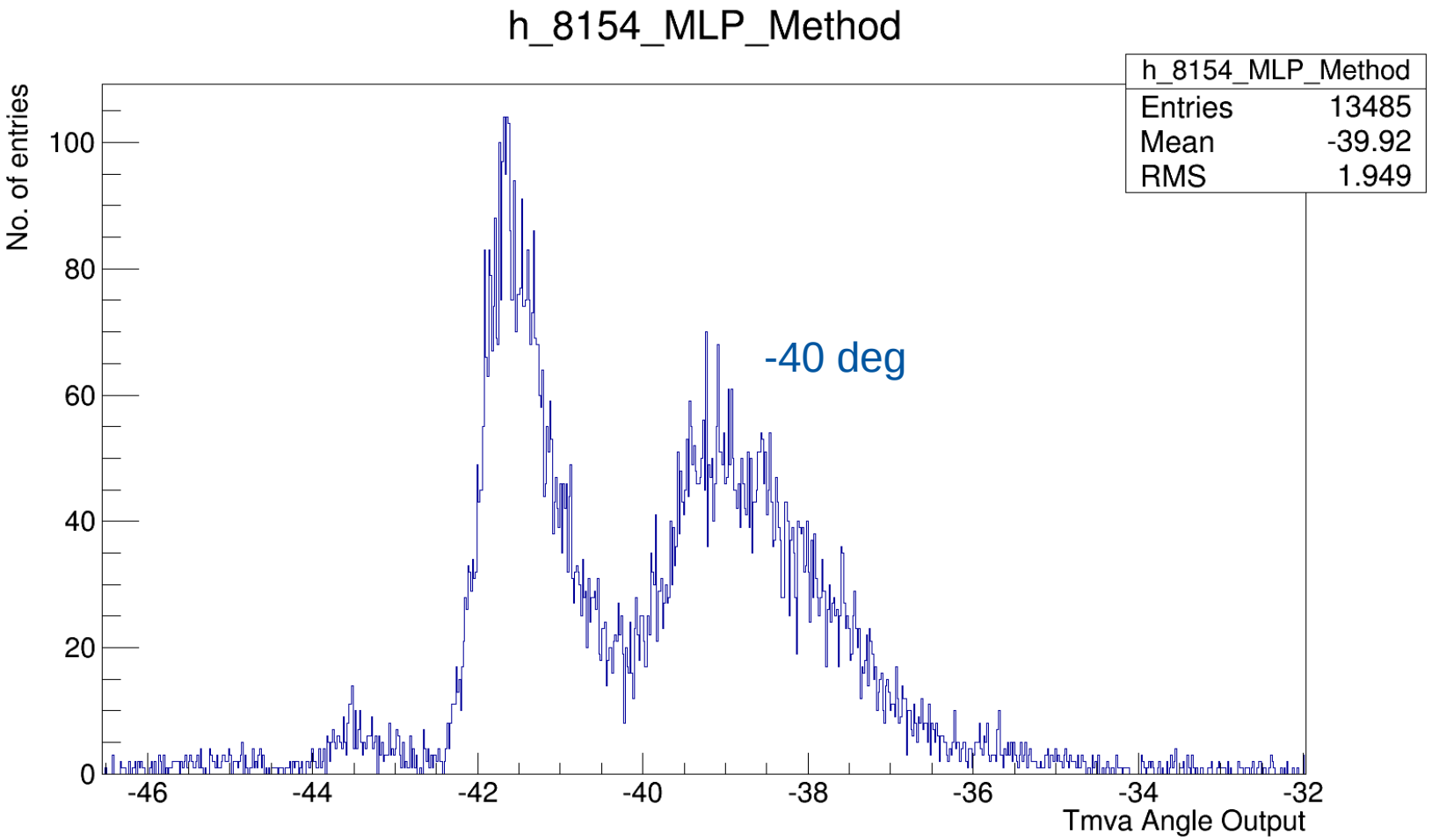


MLP with integer cluster size :

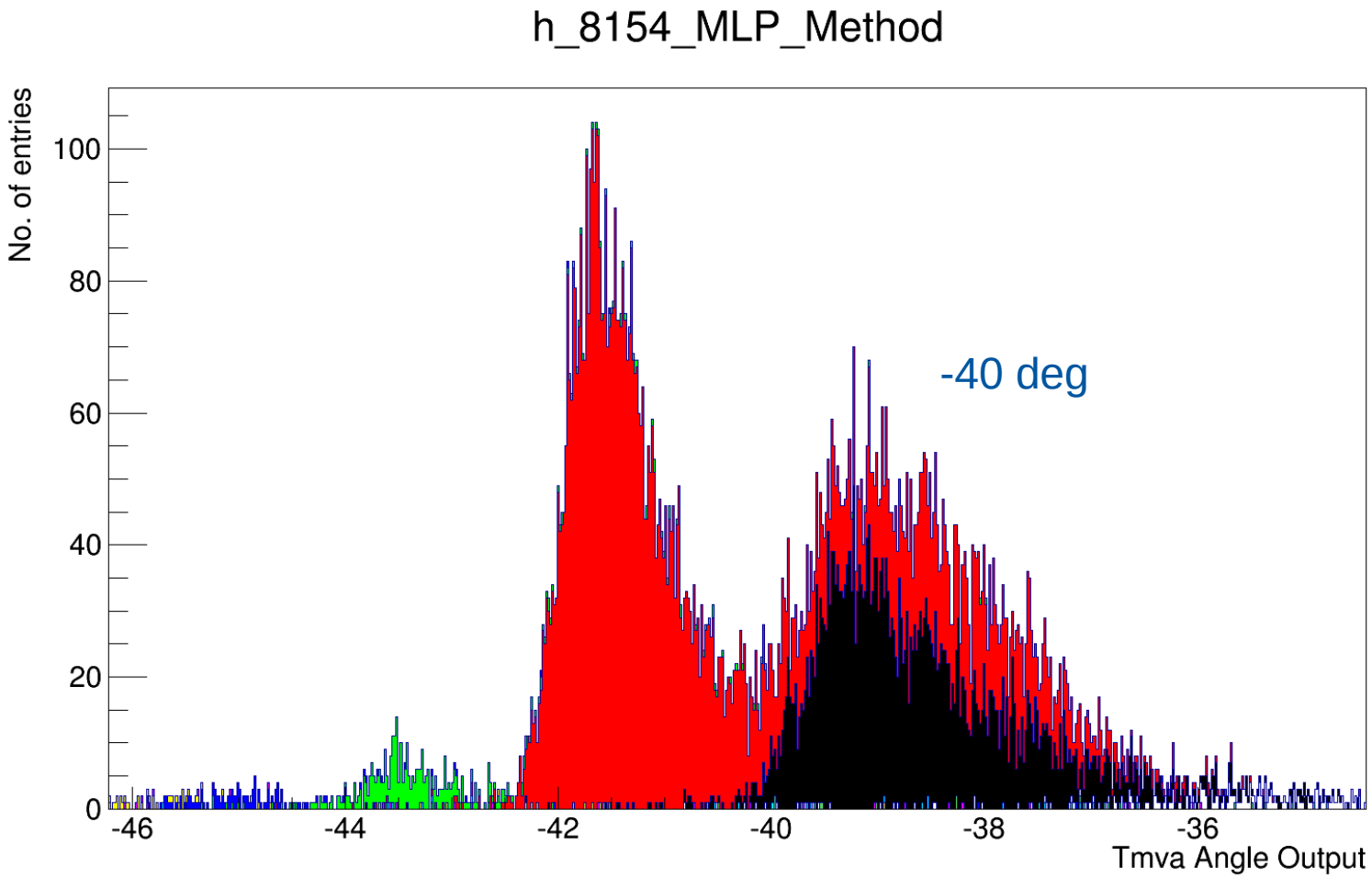
- June 2016 parasitic data: 200v, angles -60 to +60º in steps of 10.
- Expected results:

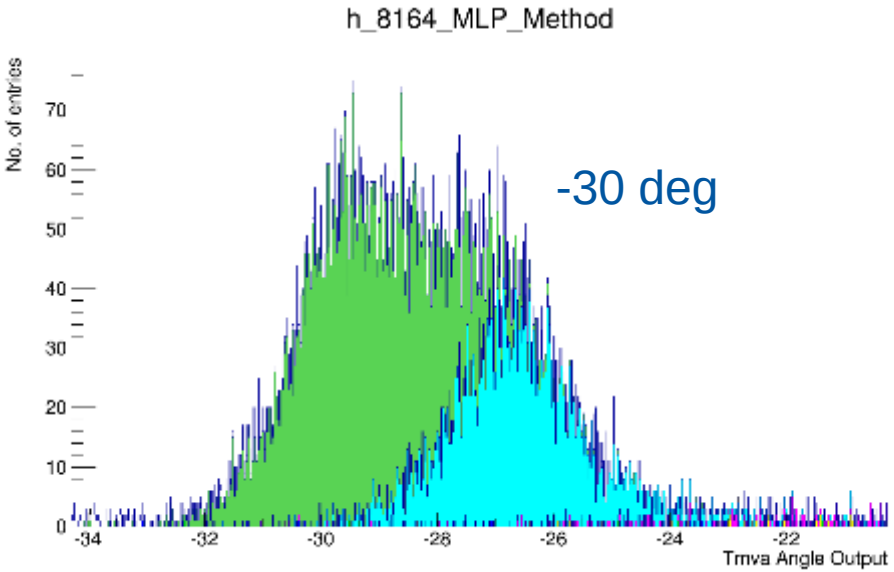


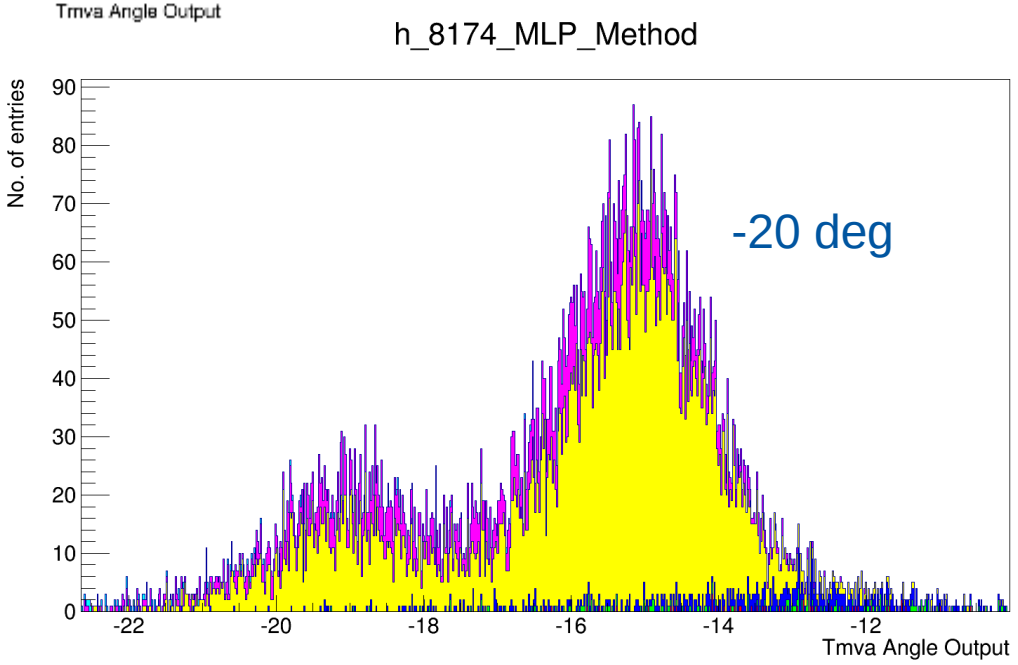
Unexpected results:



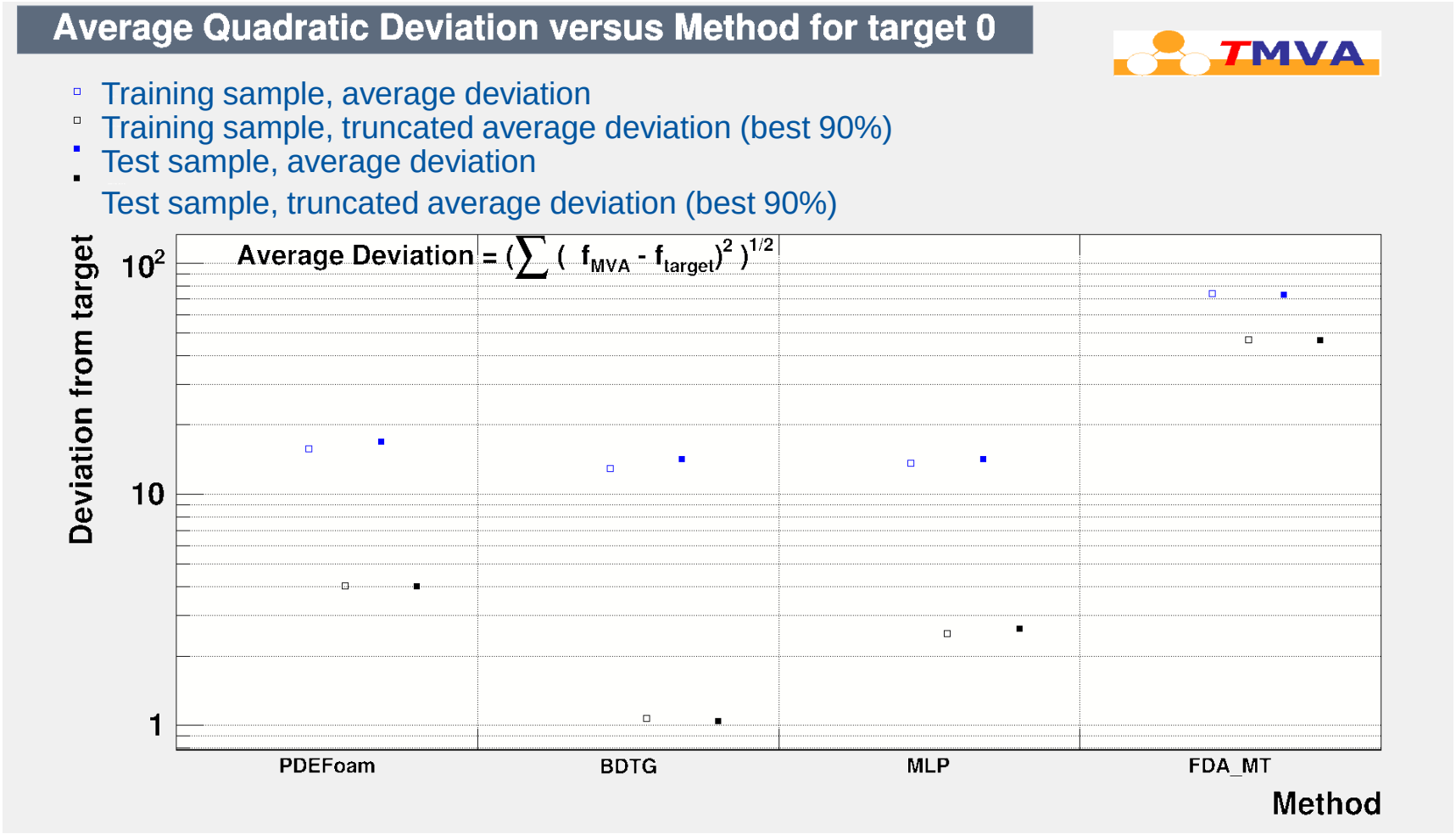
Looking into Cluster Sizes:

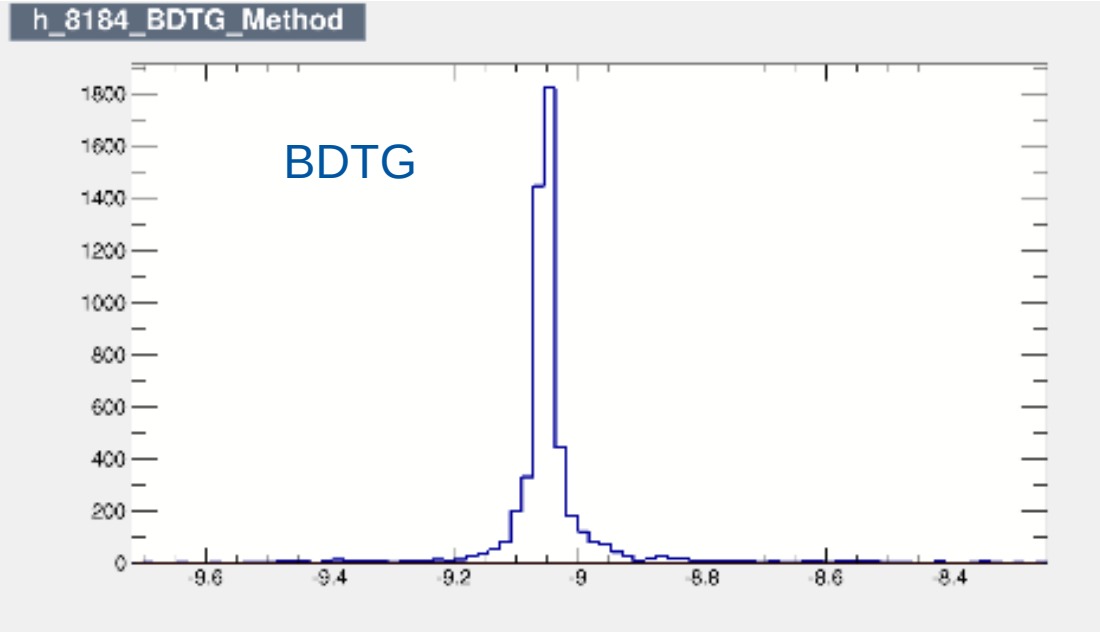


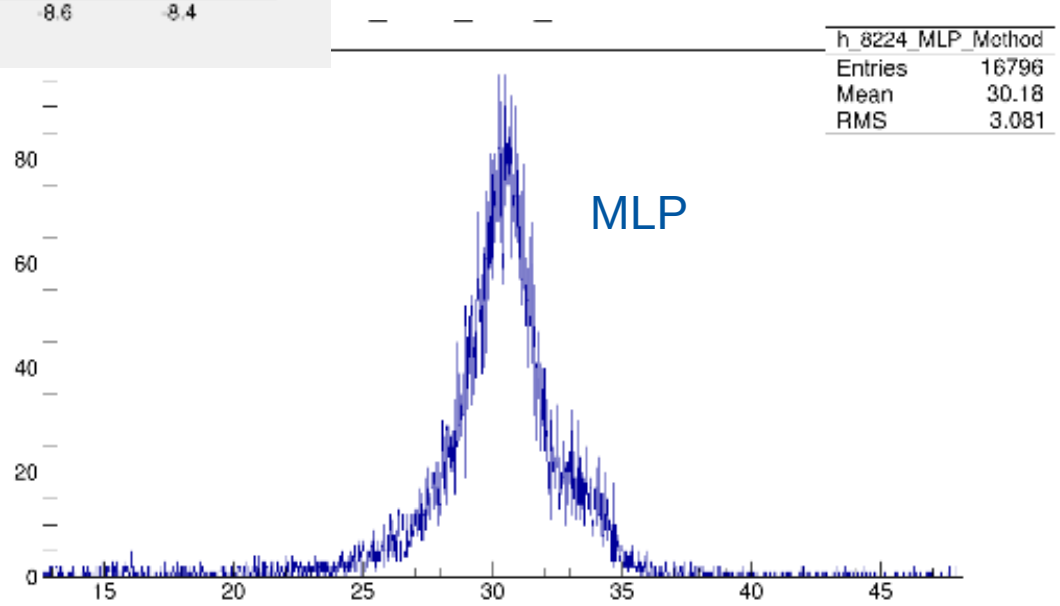

h_8164_MLP_Method
No. of entries
70
60
50
40
30
20
10
0
-34
-32
-30
-28
-26
-24
-22
Tmva Angle Output
-30 deg


h_8174_MLP_Method
No. of entries
90
80
70
60
50
40
30
20
10
0
-22
-20
-18
-16
-14
-12
Tmva Angle Output
-20 deg

Testing performance:

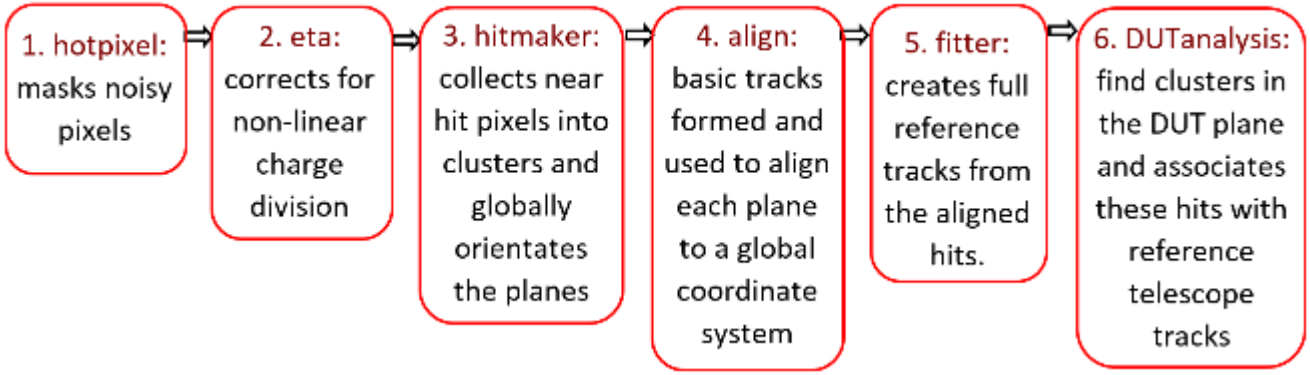



h_8184_BDTG_Method
BDTG
1800
1600
1400
1200
1000
800
600
400
200
0
-9.6
-9.4
-9.2
-9
-8.8
-8.6
-8.4


h_8224_MLP_Method
Entries 16796
Mean 30.18
RMS 3.081
MLP
80
60
40
20
0
15
20
25
30
35
40
45

Reconstruction

- Reconstructed runs with 50V Telescope bias and DUT THL ~600e.
- Differing DUT angles: 10º steps, from -40 to 40º in October 2015 and -80 to 80º in June 2016.
- Bias Voltages between 5V and 200V, 10 in total.
- Larger angles should lead to larger clusters and hence better resolution.



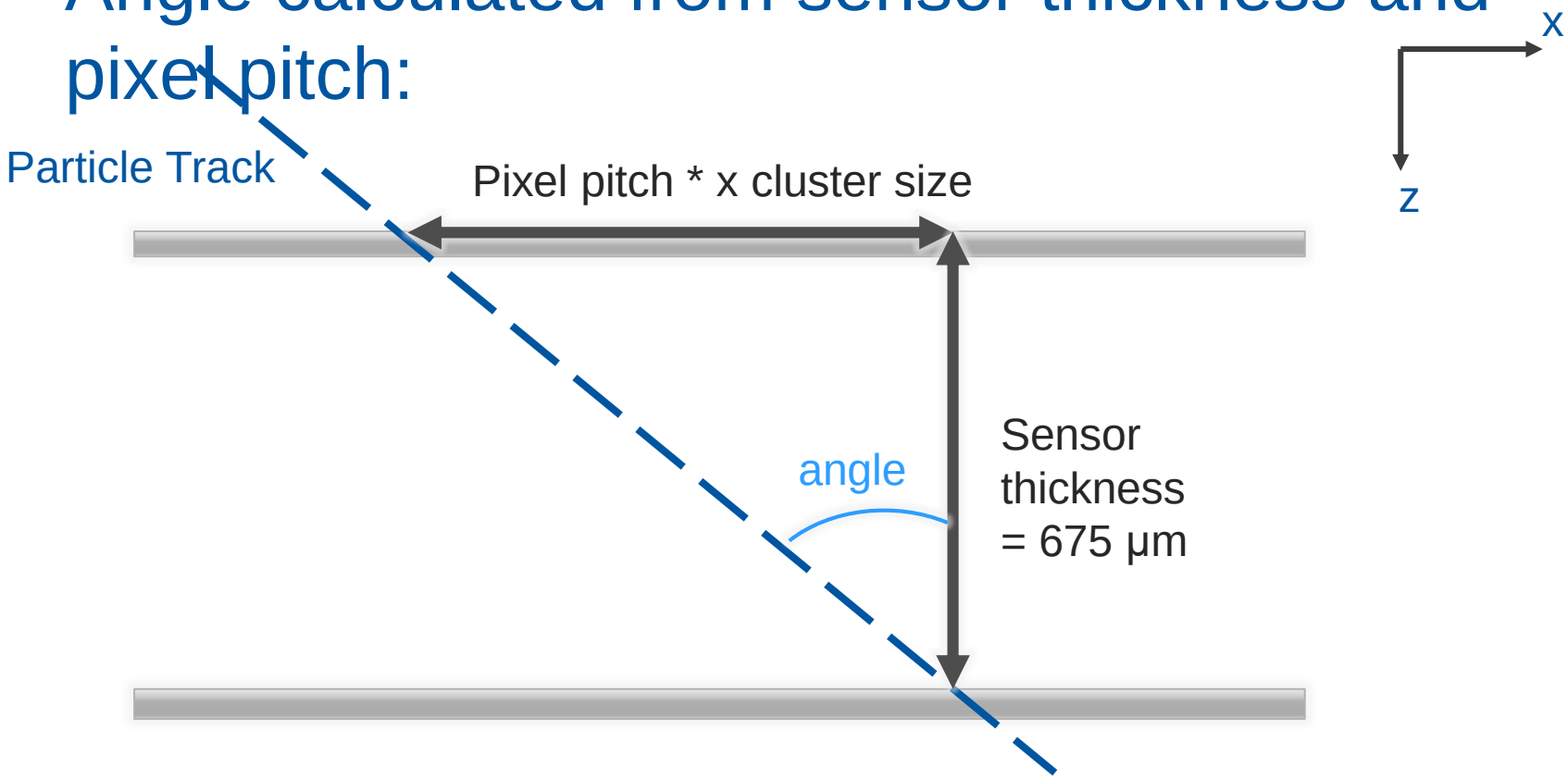
Outline of the EUTelescope processors used for reconstruction.

Summary of Cluster size and timing analysis

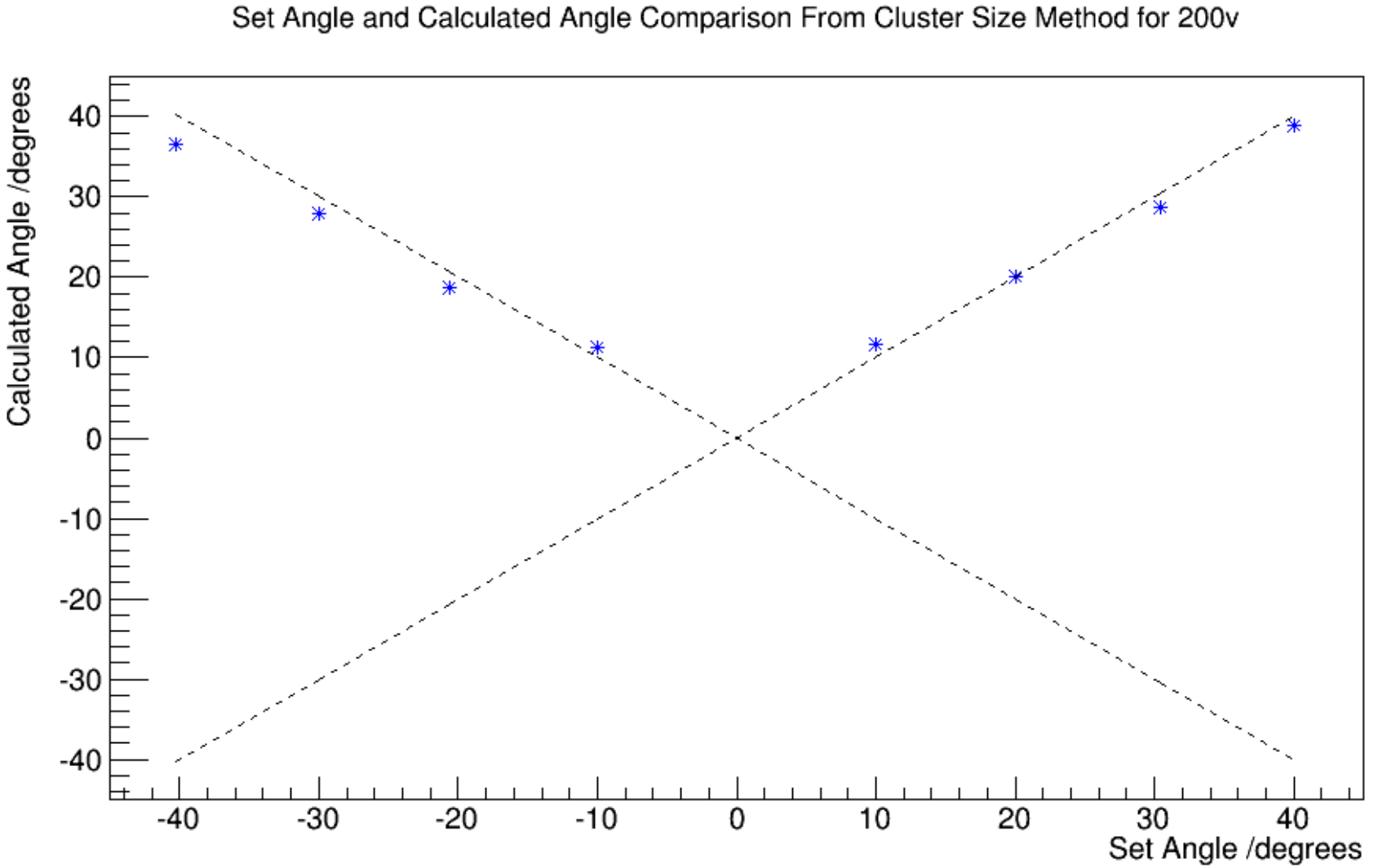
- Reconstructed tracks through Timepix3 with a thick silicon layer (675µm) for different DUT angles.
- Aim was to calculate the DUT angle from the data.
- Used 2 methods to compare the calculated and set DUT angles: one using only the cluster size information, and one using the timing information.
- Found the 2nd method to have angle magnitudes closer to the set values and gives the right angle sign. This is because it uses more information.
- Found the voltage effects the calculated angle but an optimum was not found.

Cluster size method:

- Angle calculated from sensor thickness and pixel pitch:



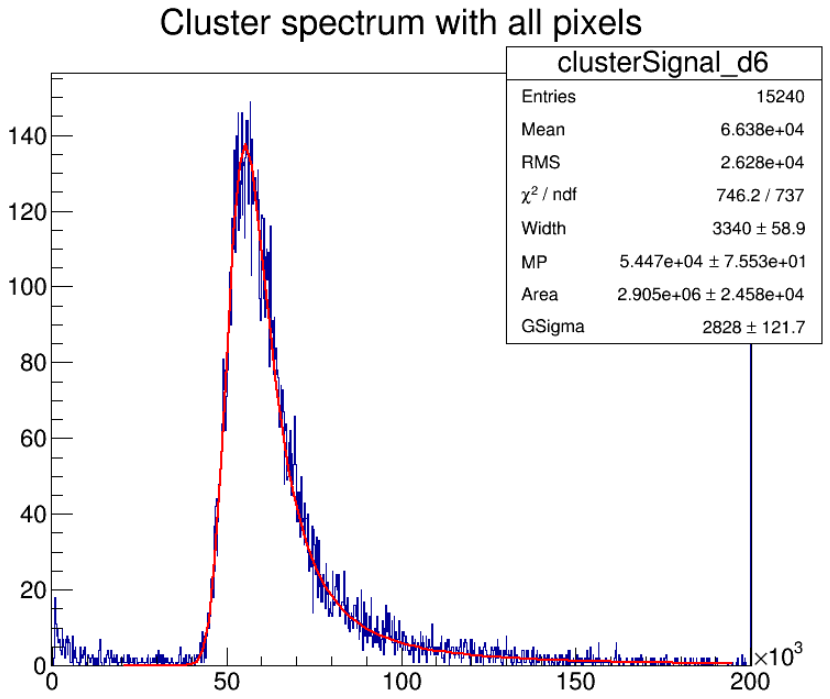
- Note: From this method you cannot extract the sign of the angle.


Set Angle and Calculated Angle Comparison From Cluster Size Method for 200v
Calculated Angle /degrees
40
30
20
10
0
-10
-20
-30
-40
-40
-30
-20
-10
0
10
20
30
40
Set Angle /degrees

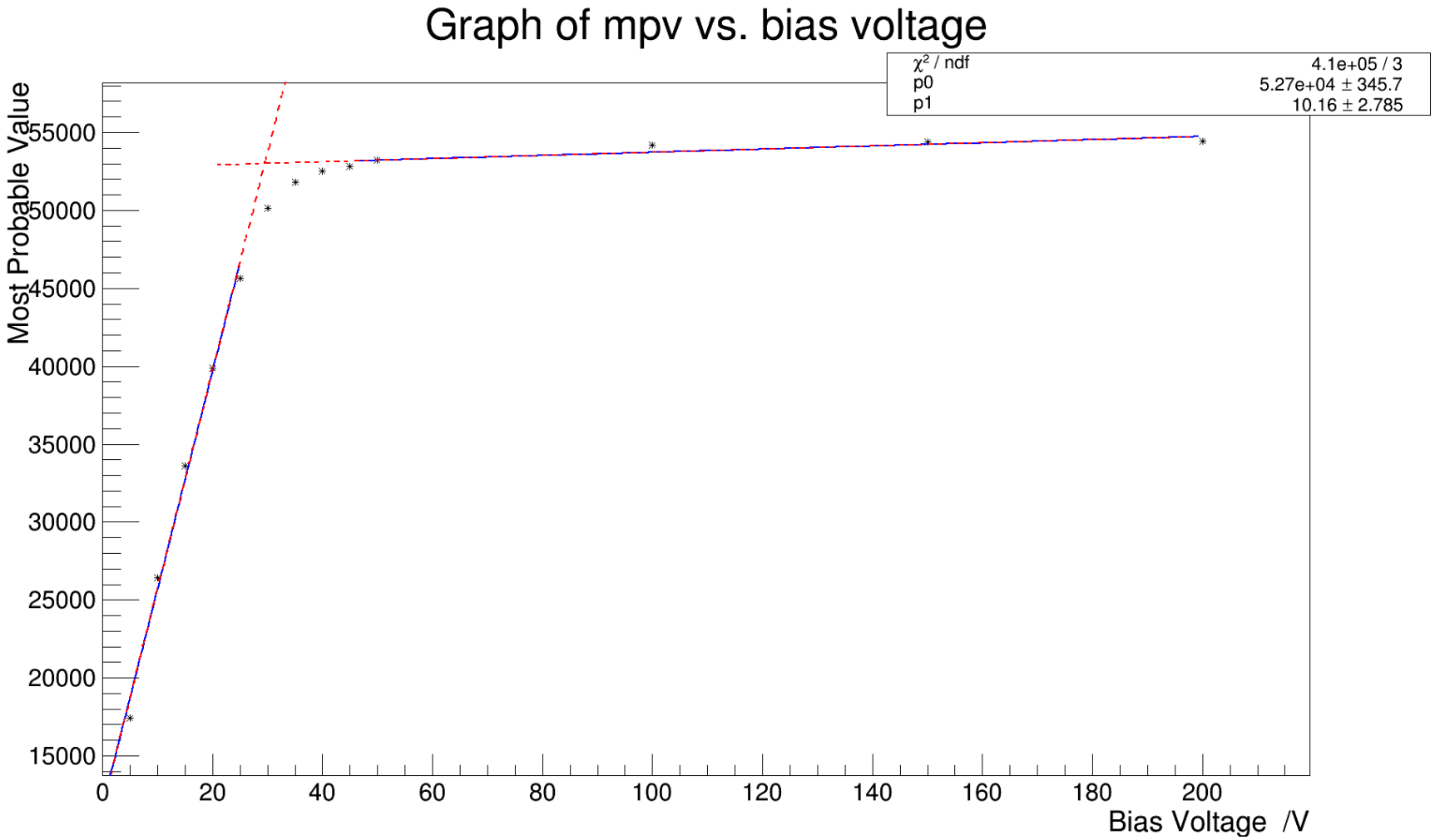
Finding depletion voltage:

- Looked at bias scan runs. Plotted cluster signal for each voltage. Fitted a Landau-Gauss convolution to each histogram as it's a mixture of signal and noise.

Graph for 200V, 0 degrees



- Extracted M.P.V. from fit and plotted this value for each bias voltage to find the point of full depletion.



A) Timing Information Analysis

- Using October 2015 data with a DUT bias of 200V,

Initial Calculations to obtain timing information:

- Method needs depletion voltage, so this was calculated from the data of the bias scan runs (0° and differing bias V).

- The electric field was calculated for the voltage's active thickness using the equation below:

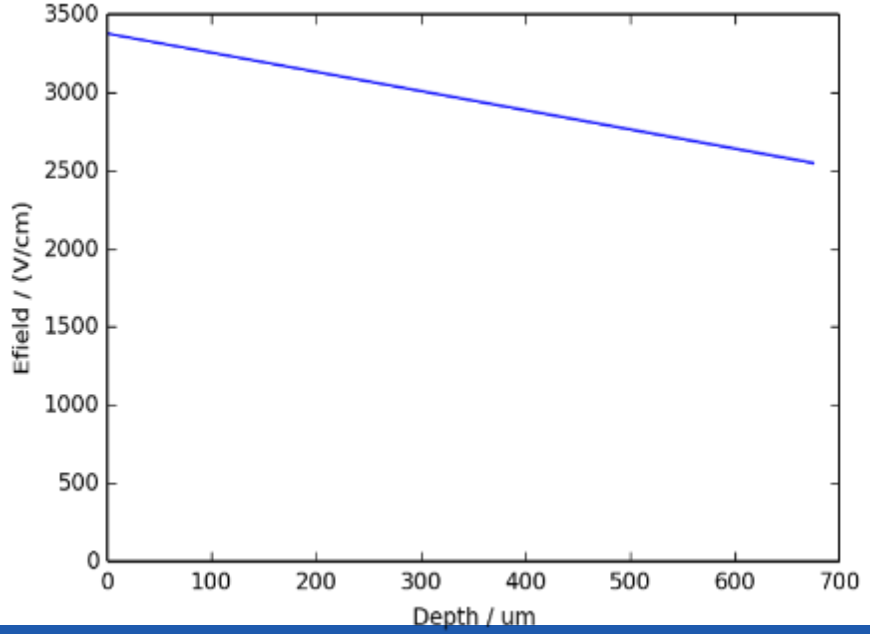
$$E(z) = \frac{U_{Bias} - U_{Depletion}}{d} + \frac{2U_{Depletion}\,\frac{1-z}{d}}{d}$$

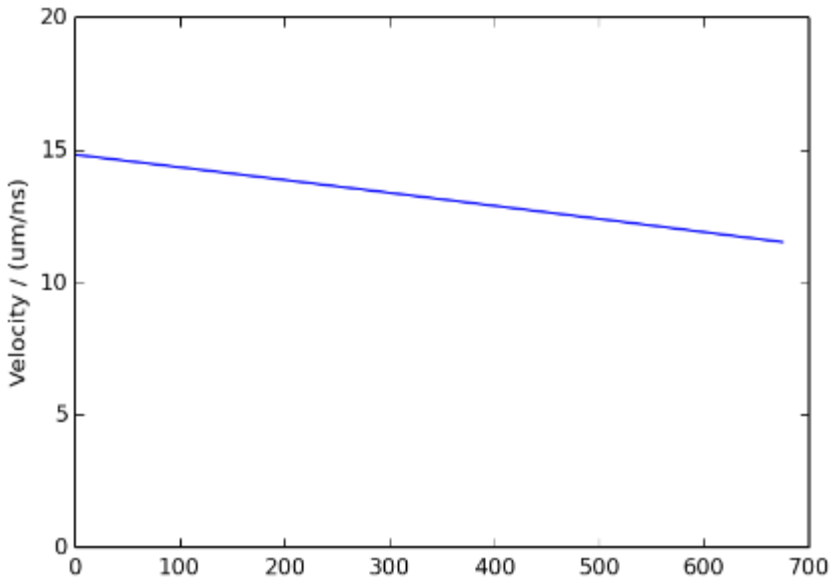
- From this we obtain a drift velocity curve and hence the timing information for the cluster.

- Calculate the electric field for the voltages' active thickness:

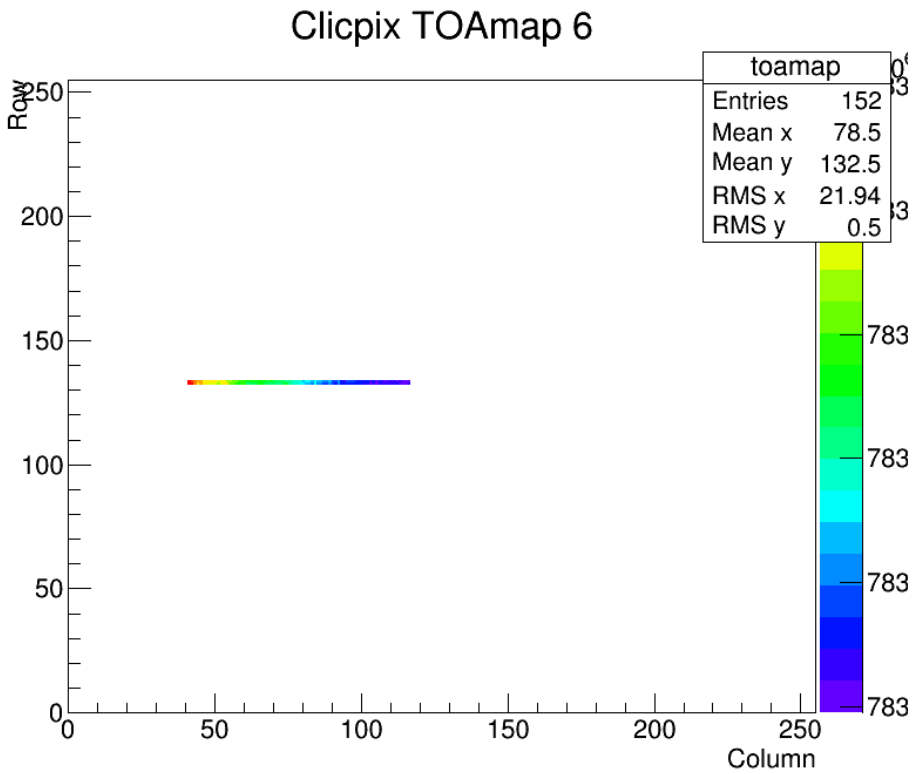
$$E(z) = \frac{U_{bias} - U_{depl}}{d} + \frac{2U_{depl}}{d}\left(1 - \frac{z}{d}\right)$$

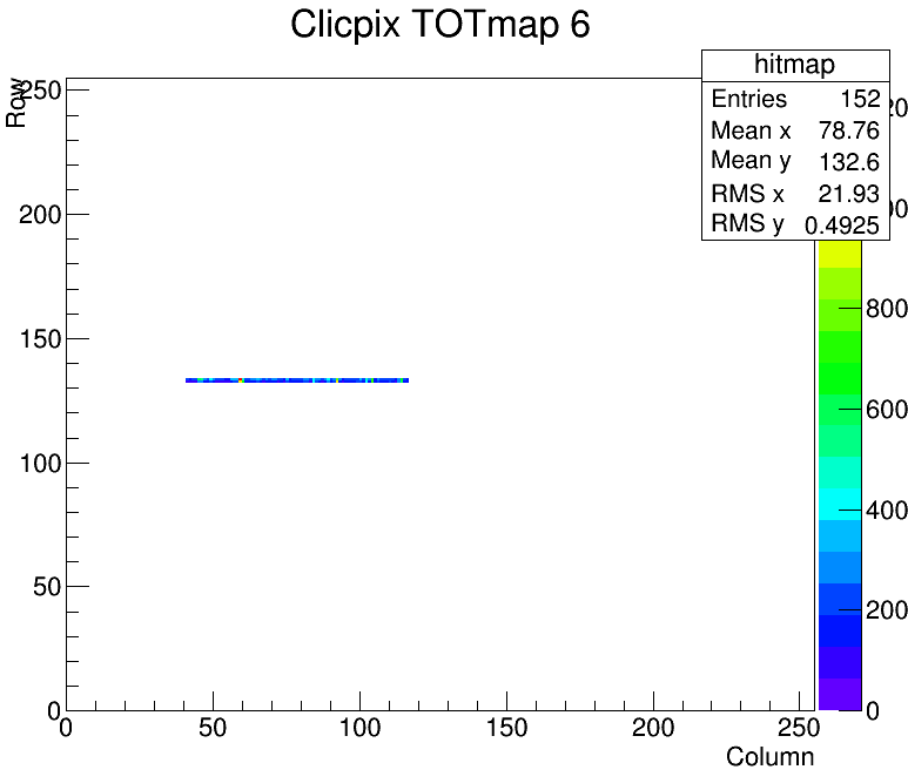
- From this we obtain a drift velocity curve and hence the timing.



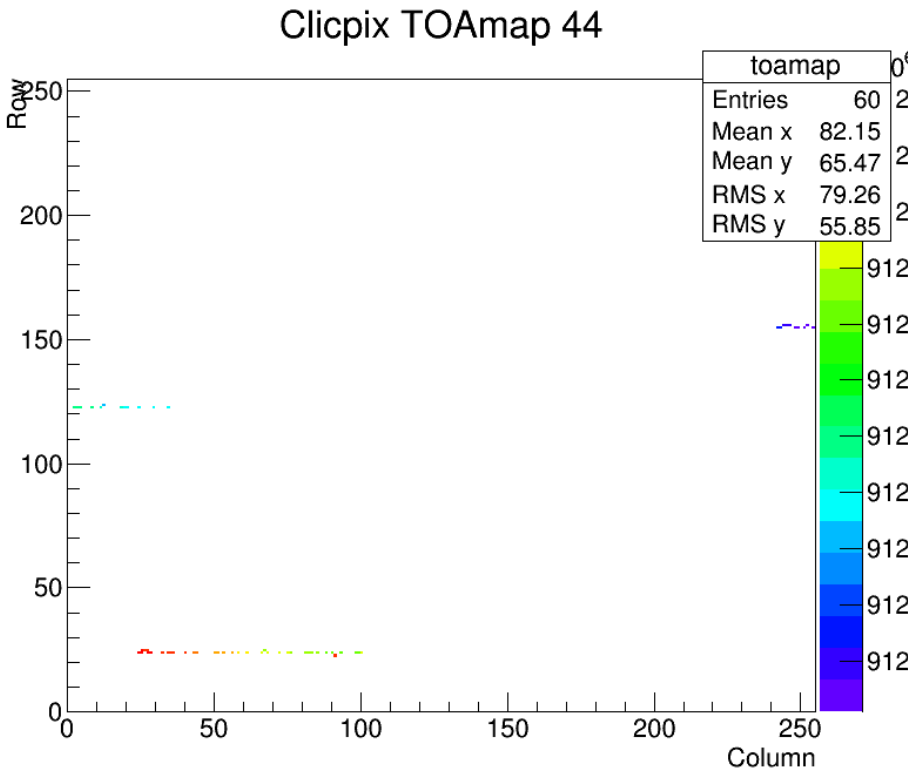


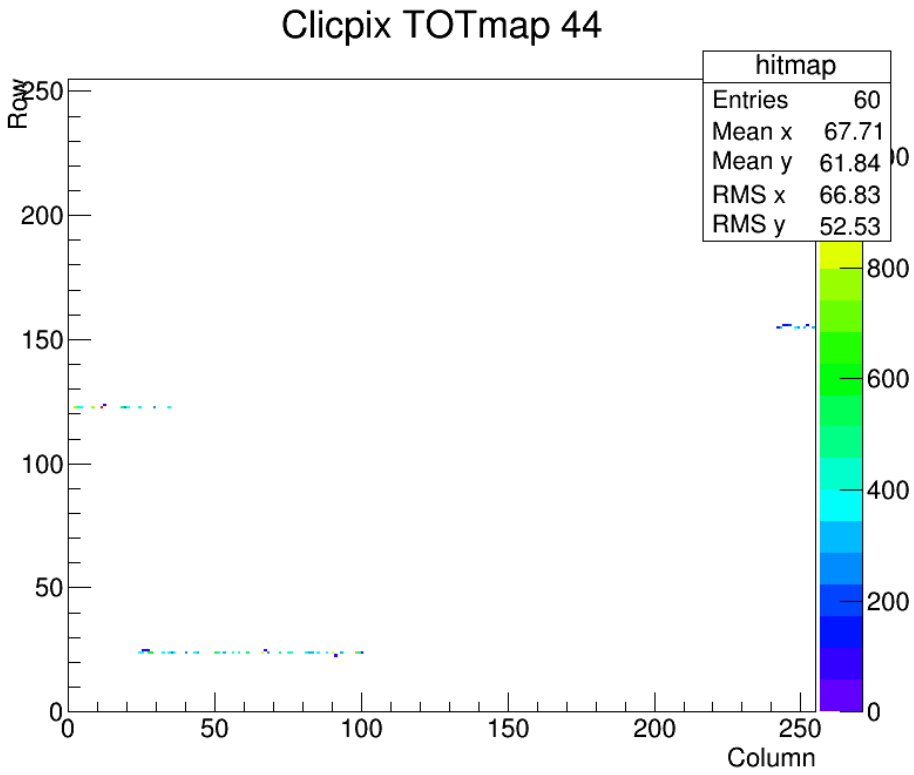
Example TOA, TOT Graphs for +80 Degree Run (Jun 2016)



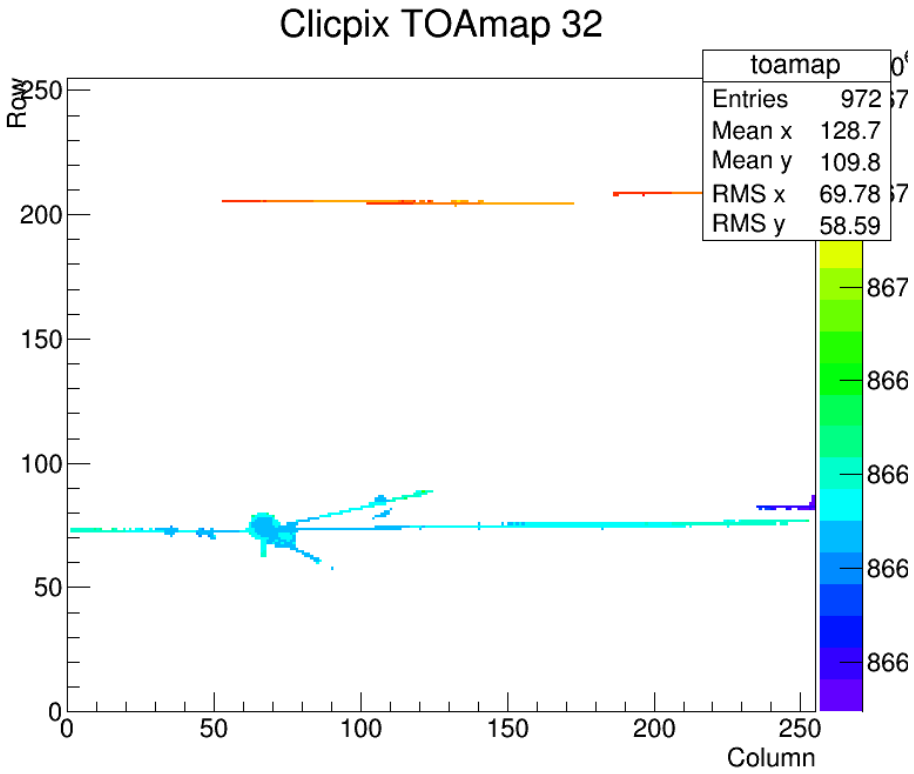


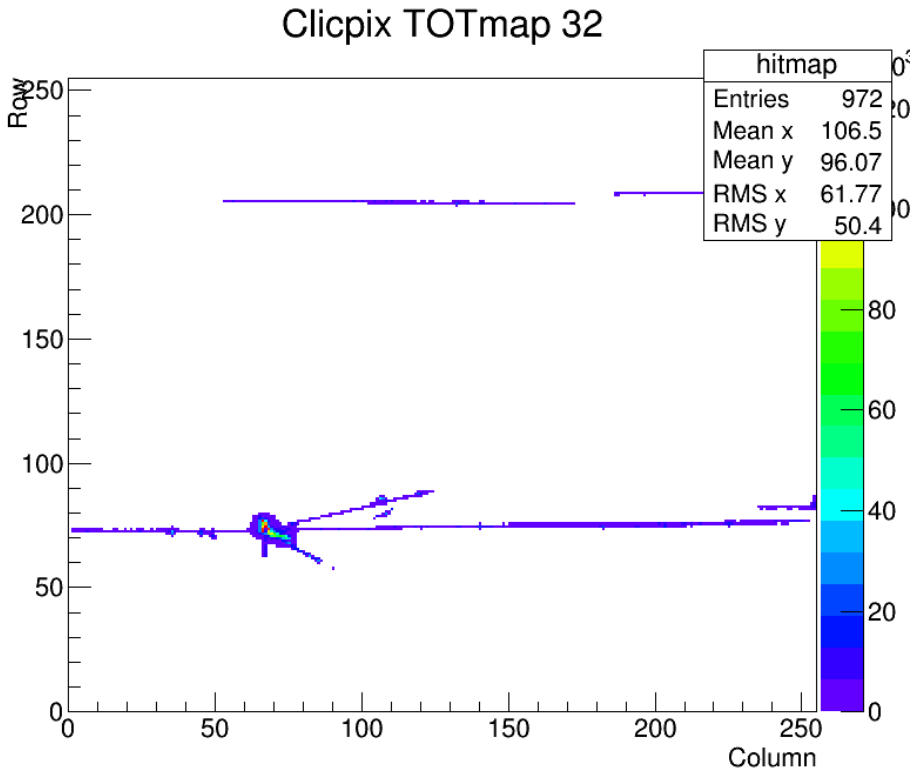
Example TOA, TOT Graphs for +80 Degree Run: Anomalies



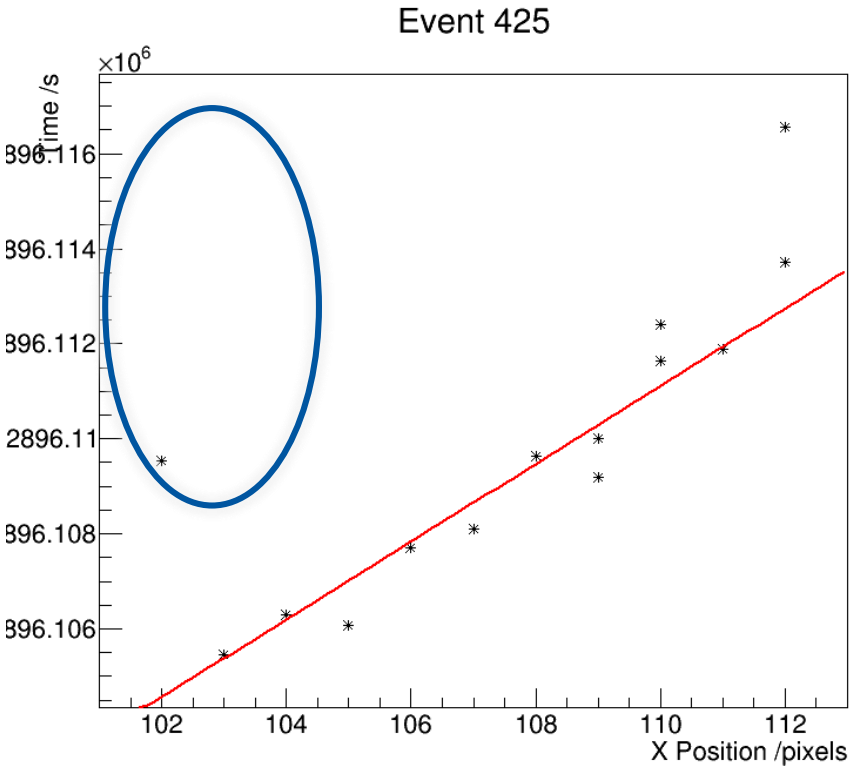


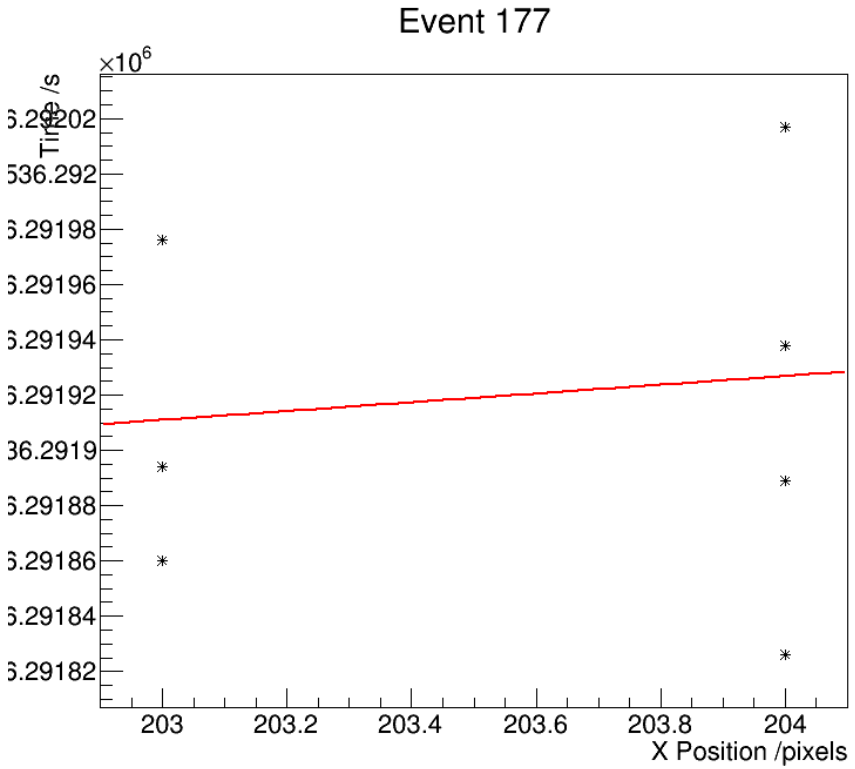
Example TOA, TOT Graphs for +80 Degree Run: Anomalies





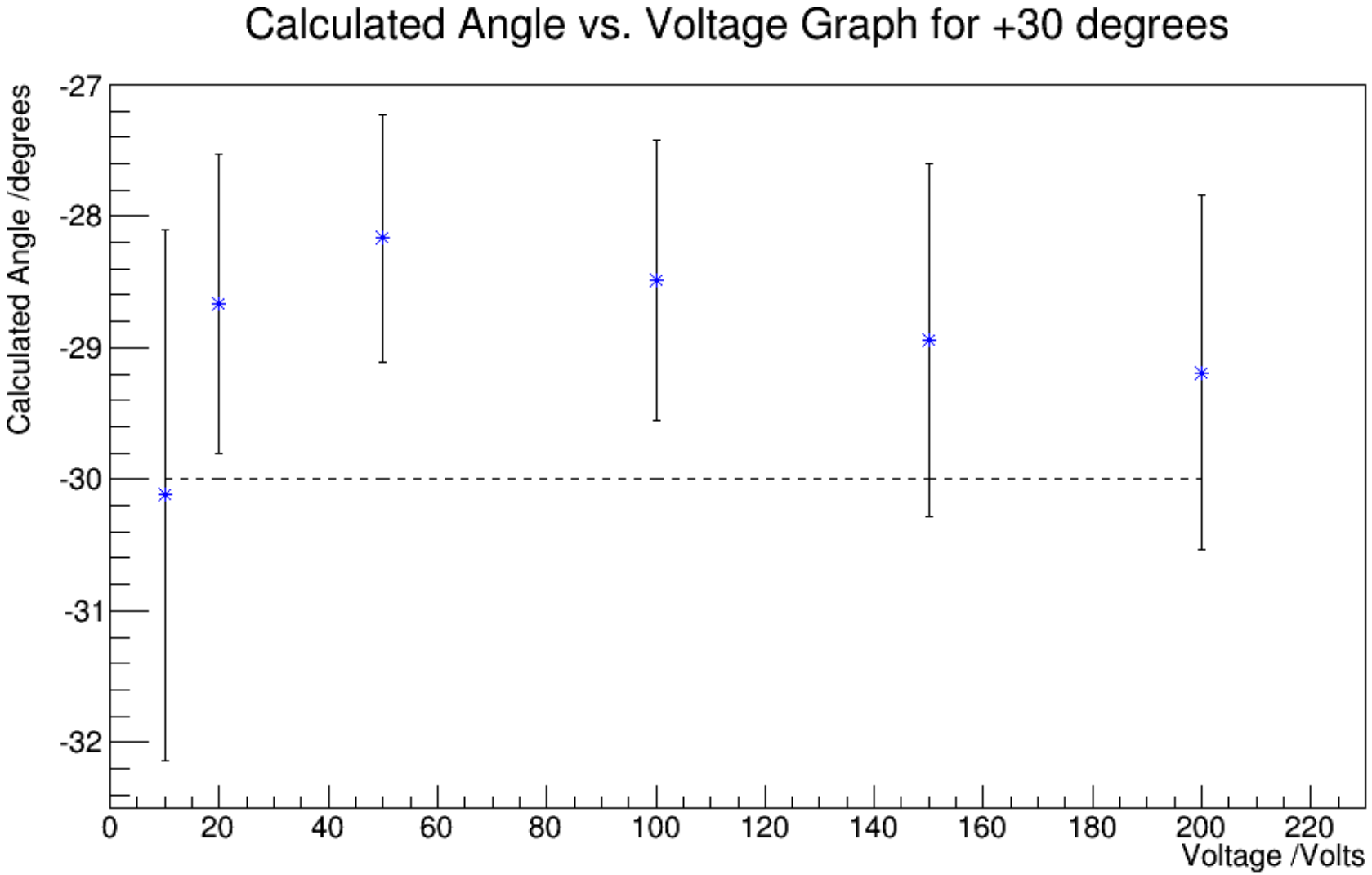
Example Timing Graphs for -40 Degree Run: Anomalies



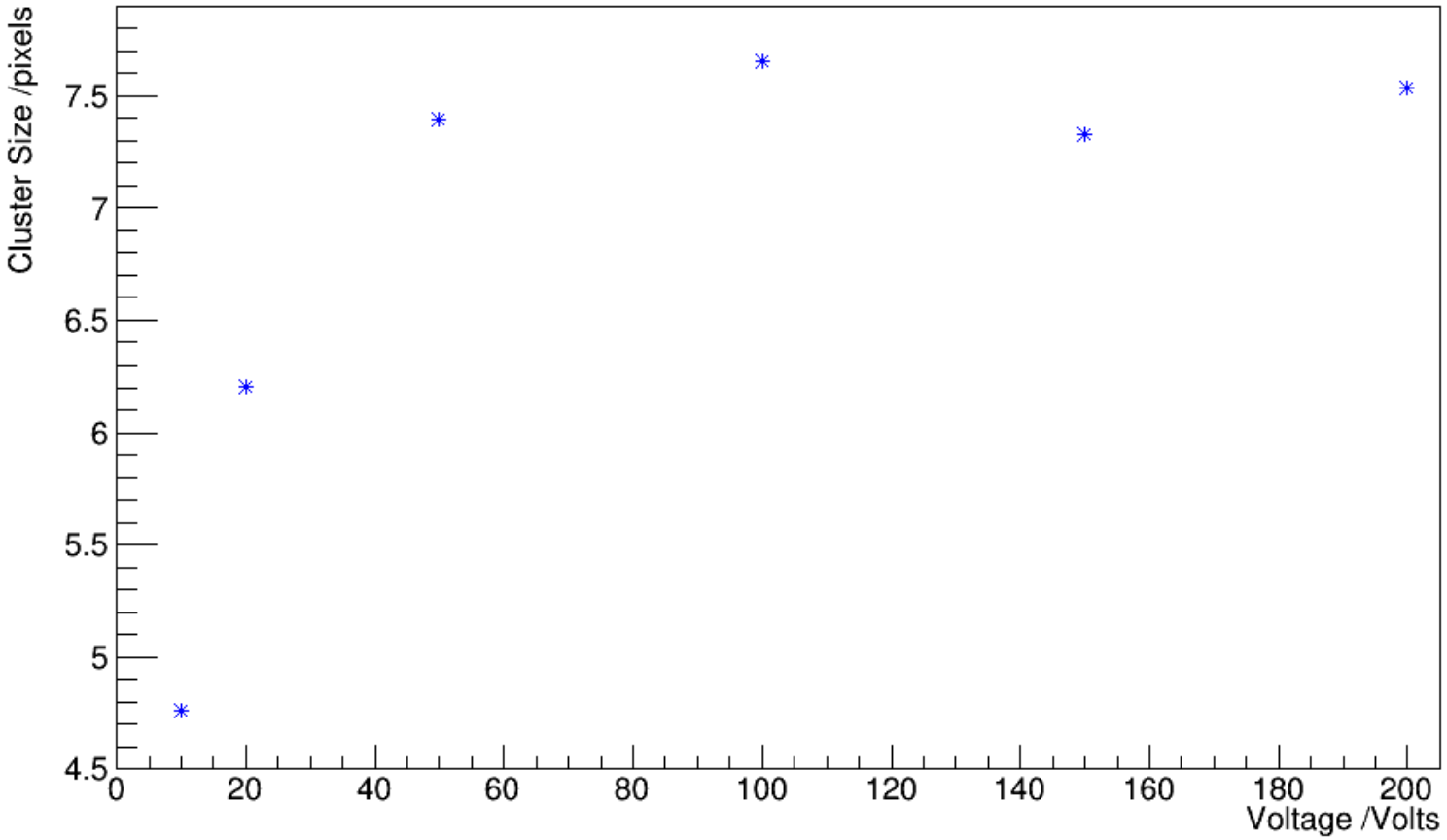


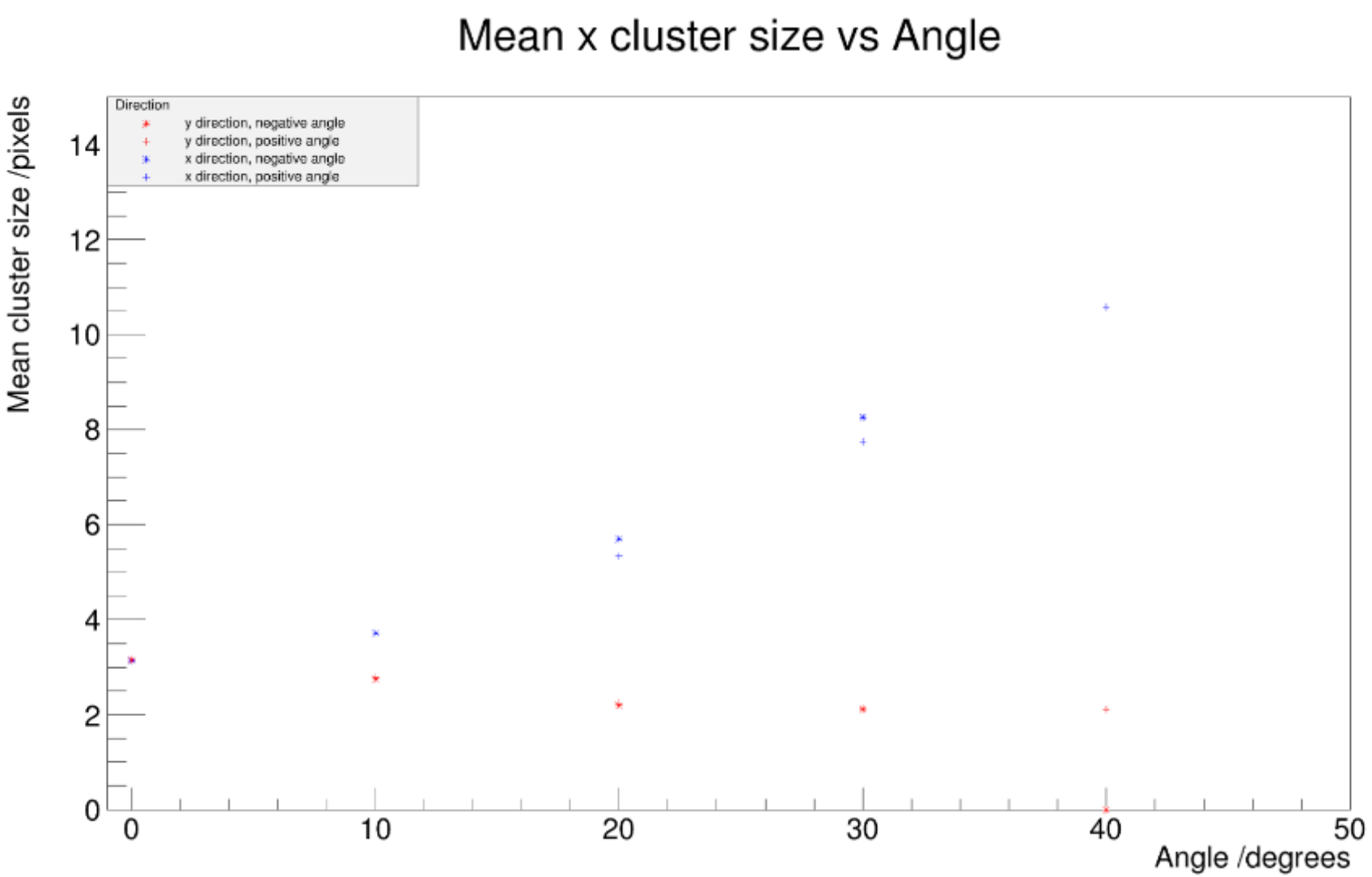
Voltage Analysis

- Reconstructed runs for -30 degrees for different DUT bias voltage.
- Wanted to find out the effect of the voltage on the calculated angle and x cluster size.
- Used the timing method to calculate the DUT angle (see previous section 2b).

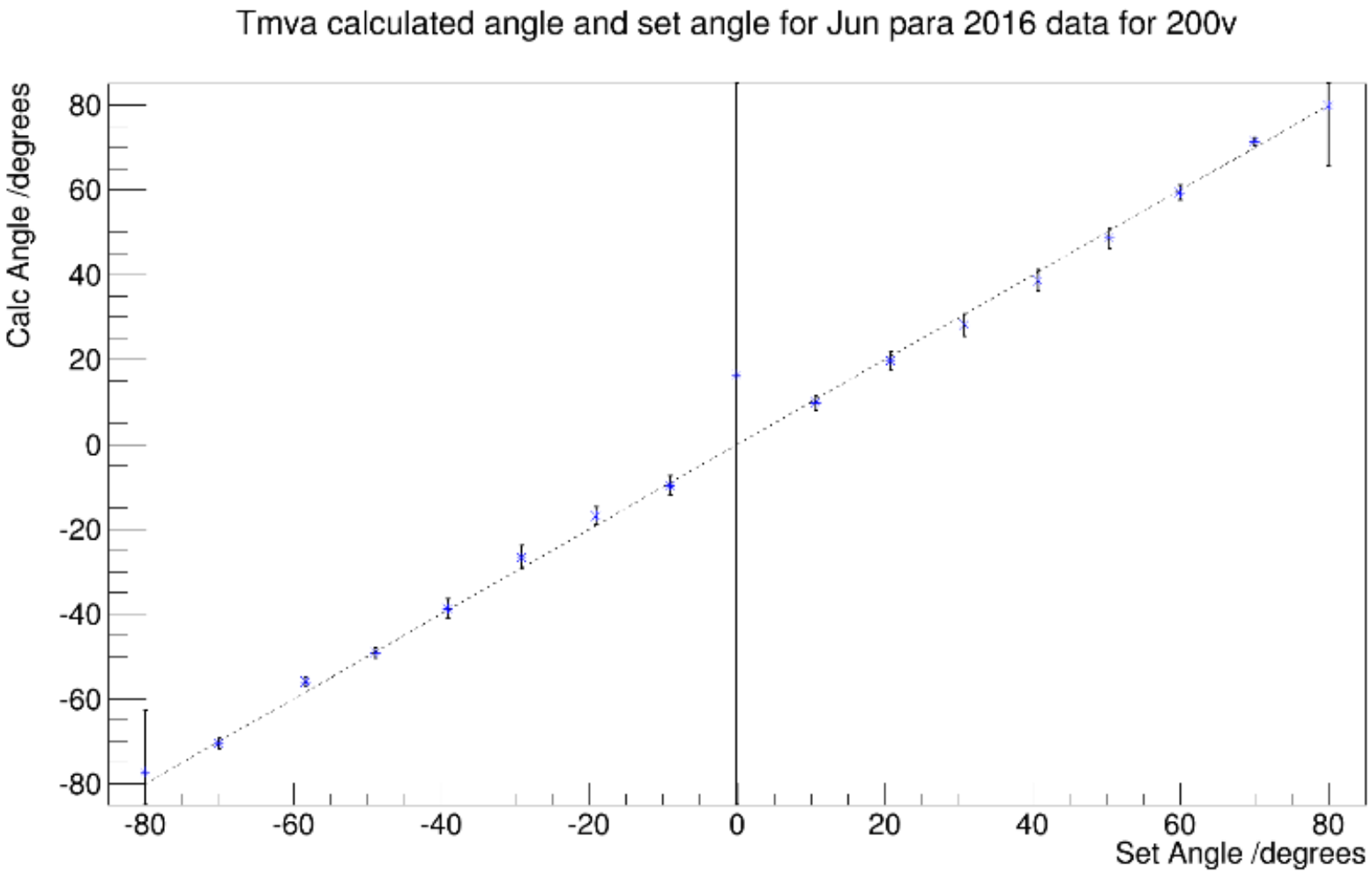

Calculated Angle vs. Voltage Graph for +30 degrees
Calculated Angle /degrees
-27
-28
-29
-30
-31
-32
0
20
40
60
80
100
120
140
160
180
200
220
Voltage /Volts

X Cluster Size for Different Voltages for -30 deg

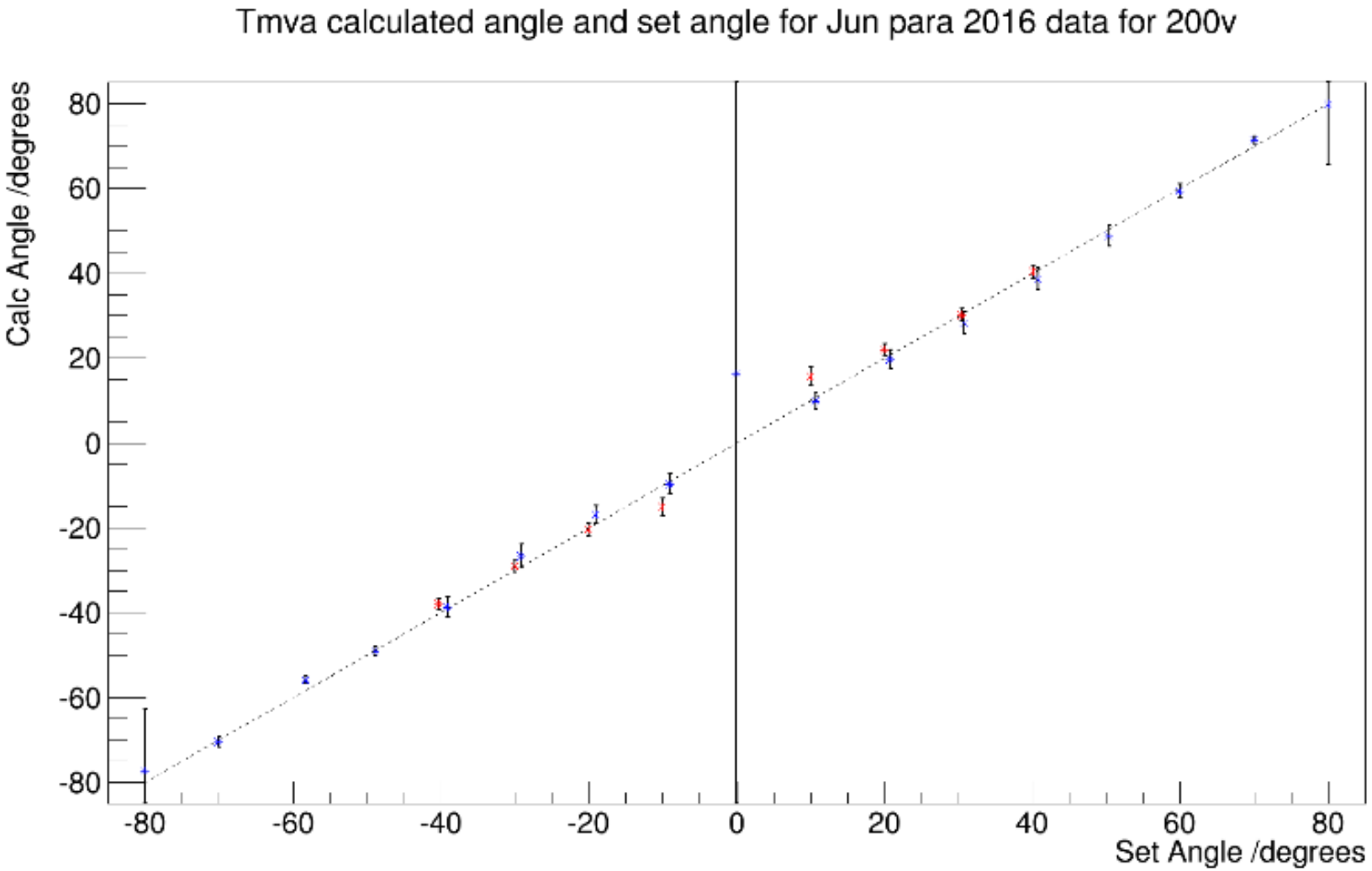



Mean x cluster size vs Angle
Direction
y direction, negative angle
y direction, positive angle
x direction, negative angle
x direction, positive angle
Mean cluster size /pixels
0
2
4
6
8
10
12
14
0
10
20
30
40
50
Angle /degrees

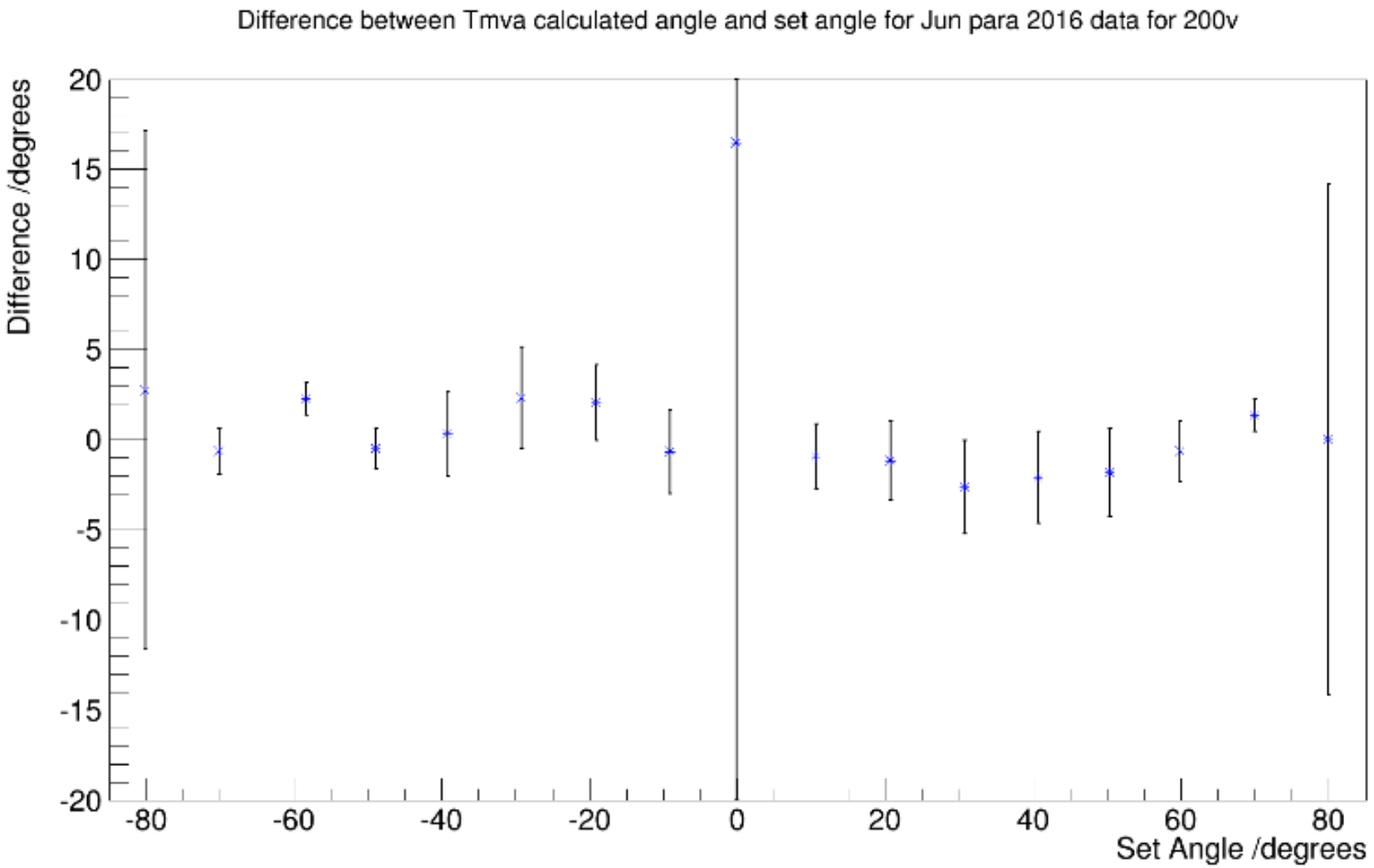
Note: without cluster size in the training



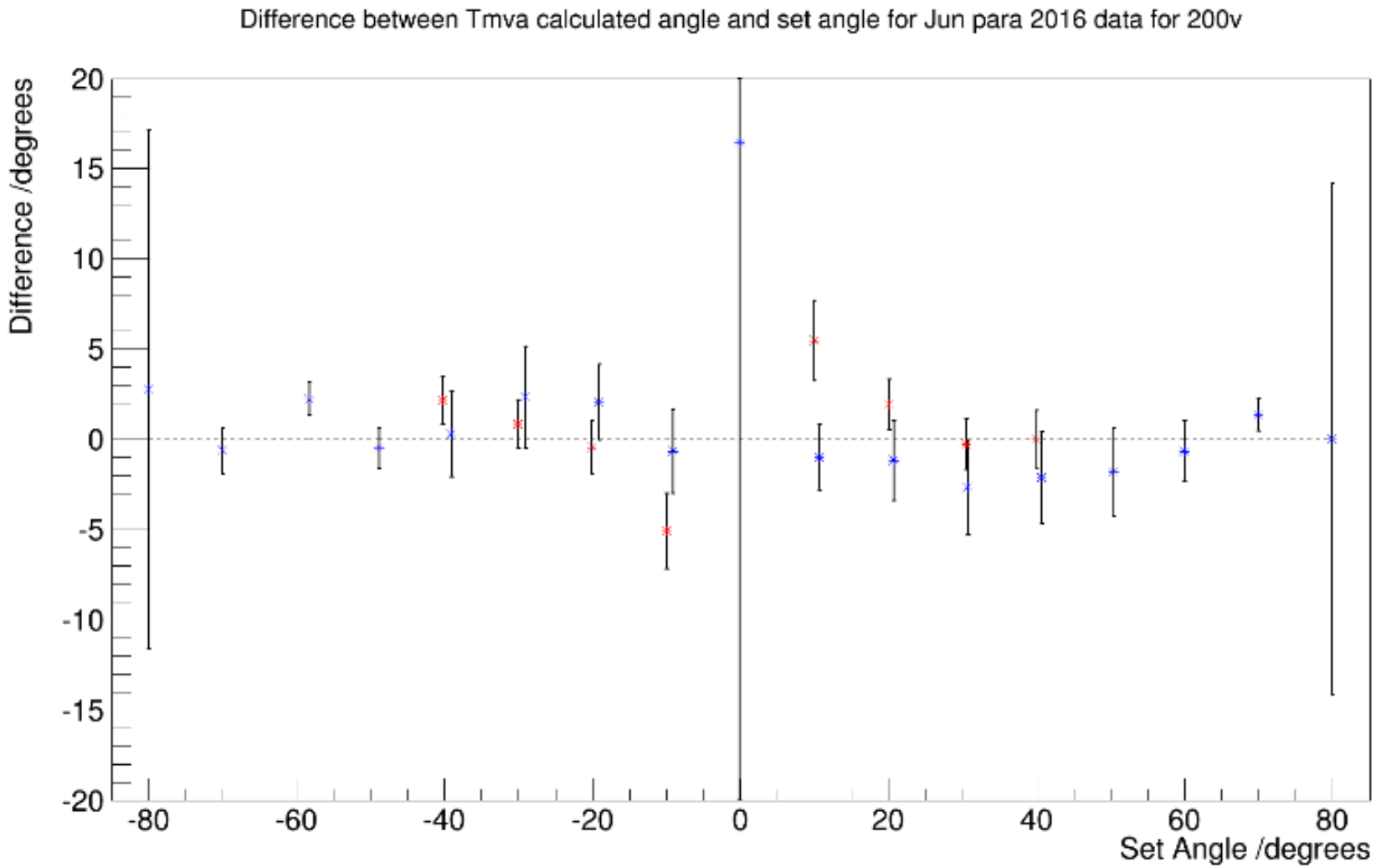
Blue – June 2016 TMVA data Red – October 2015 timing analysis data



Note: without cluster size in the training



Blue – June 2016 TMVA data Red – October 2015 timing analysis data

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