ND280 HA-TPC ANALYSIS

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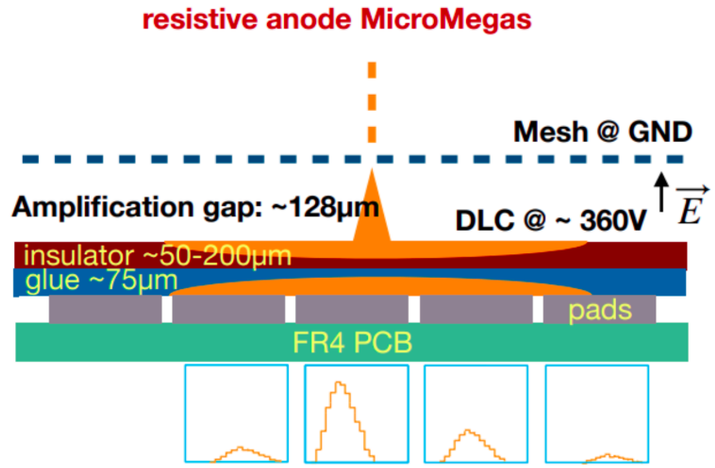
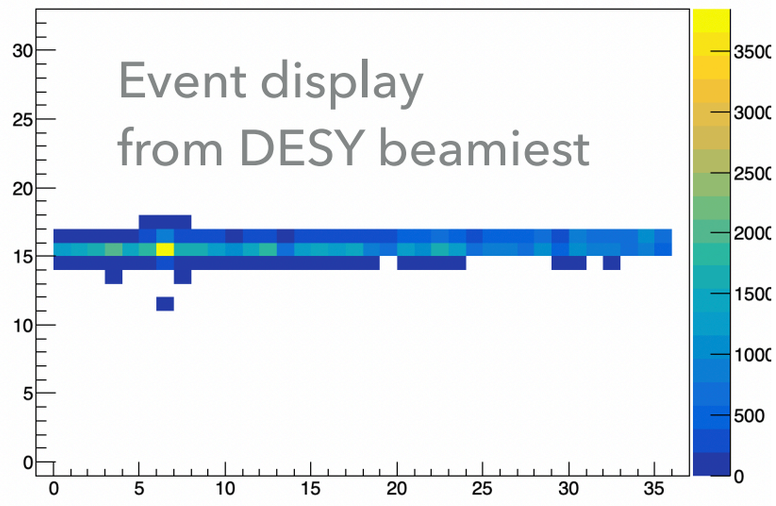
OUTLINE

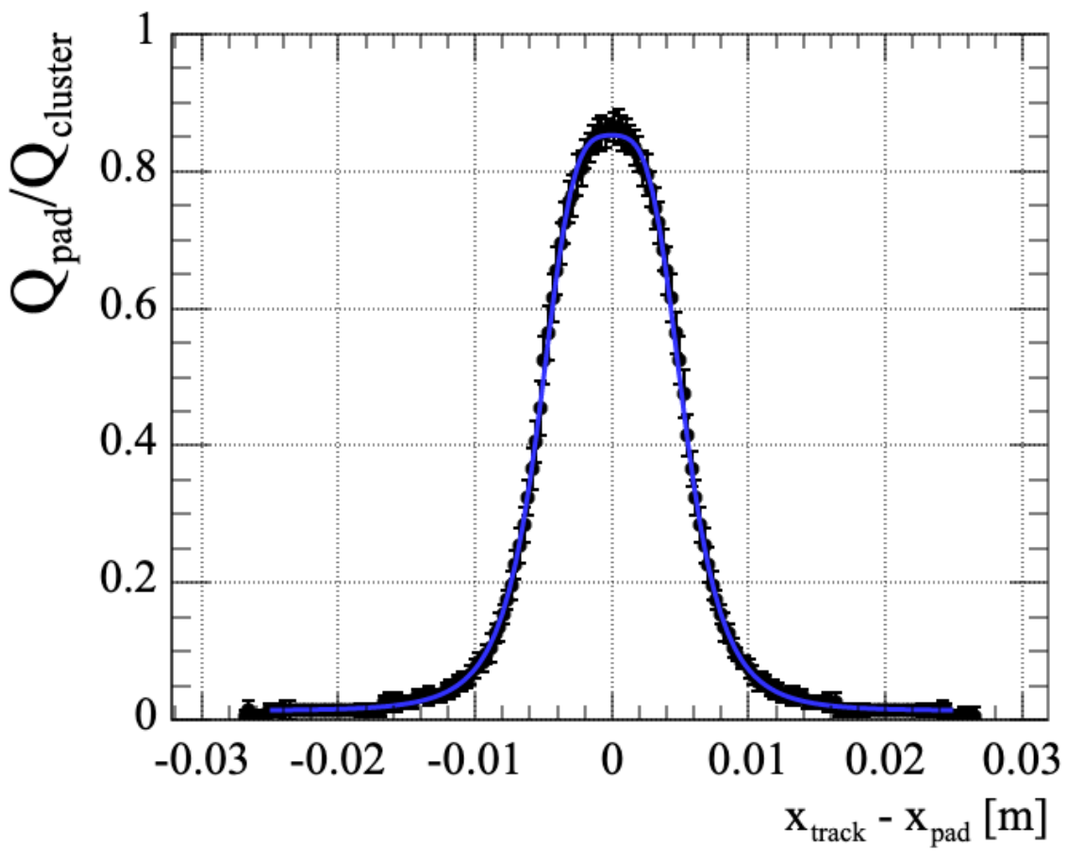
- Spatial resolution analysis of the prototype and beyond
  - Method improvements
  - Inclined tracks fitting
- dE/dx measurements anomalies
- Results of the recent prototype analysis
  - Anomalies in the Saclay prototype tests
- HA-TPC reconstruction work

SPATIAL RESOLUTION ANALYSIS

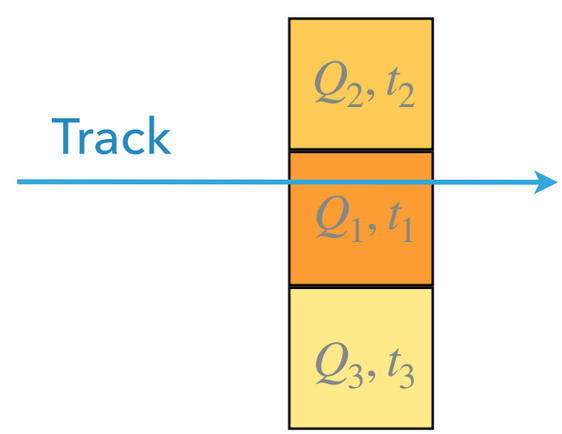
- Analysis of the prototype data was one of the main part of my thesis
- I've implemented a track resolution procedure based on the Pad Response Function (PRF)
- PRF describes charge fraction $Q_{pad}/Q_{cluster}$ over the track position w.r.t. pad
- PRF was used to reconstruct track position based on the measured charge fractions





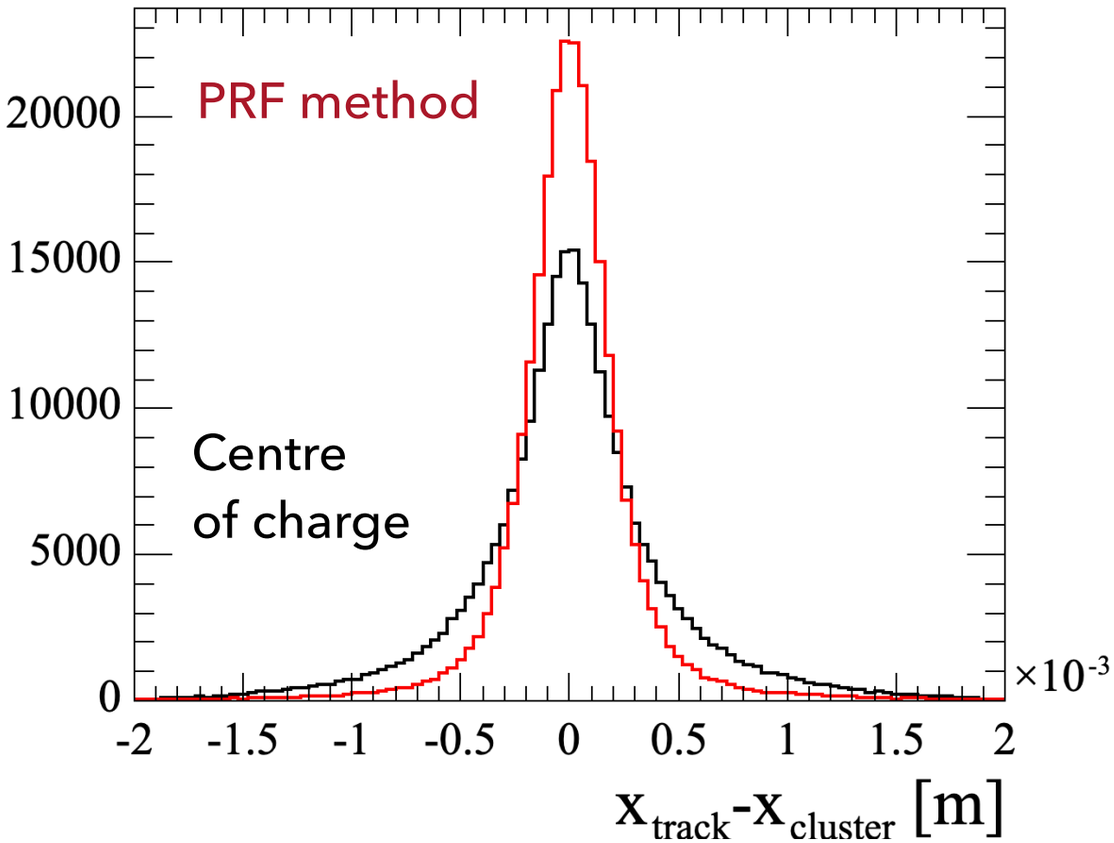


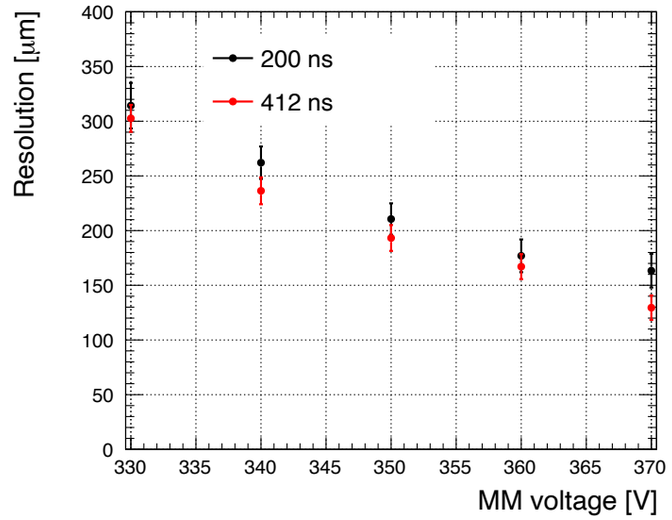
Charge sharing
in a cluster:

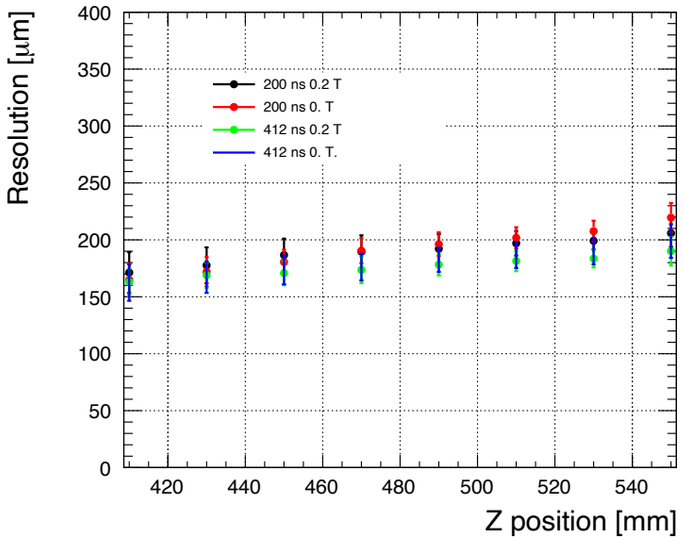


SPATIAL RESOLUTION ANALYSIS

- Based on known PRF the track position in the cluster is extracted
- All the clusters are fit together to form a track
- The difference between the global fit result and fit in the particular cluster gives residuals
- The sigma of the residual defines the resolution



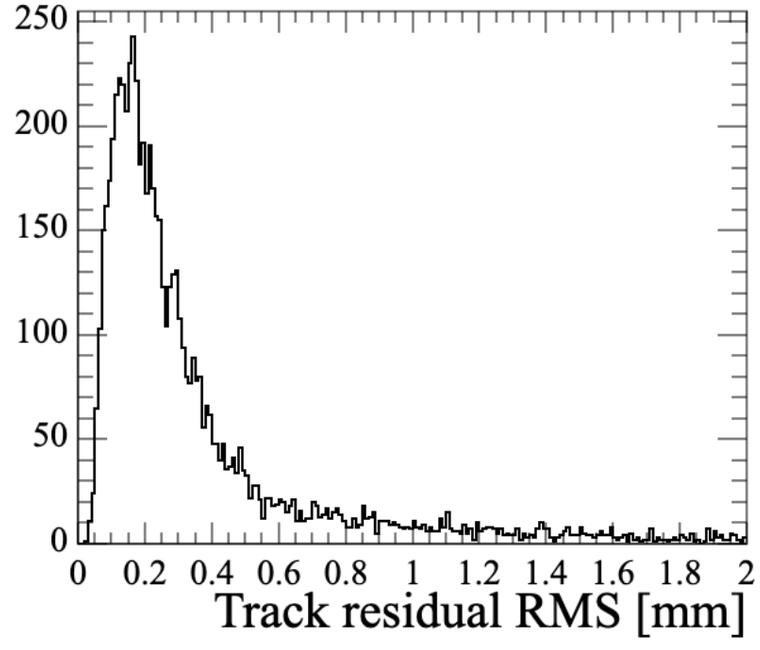




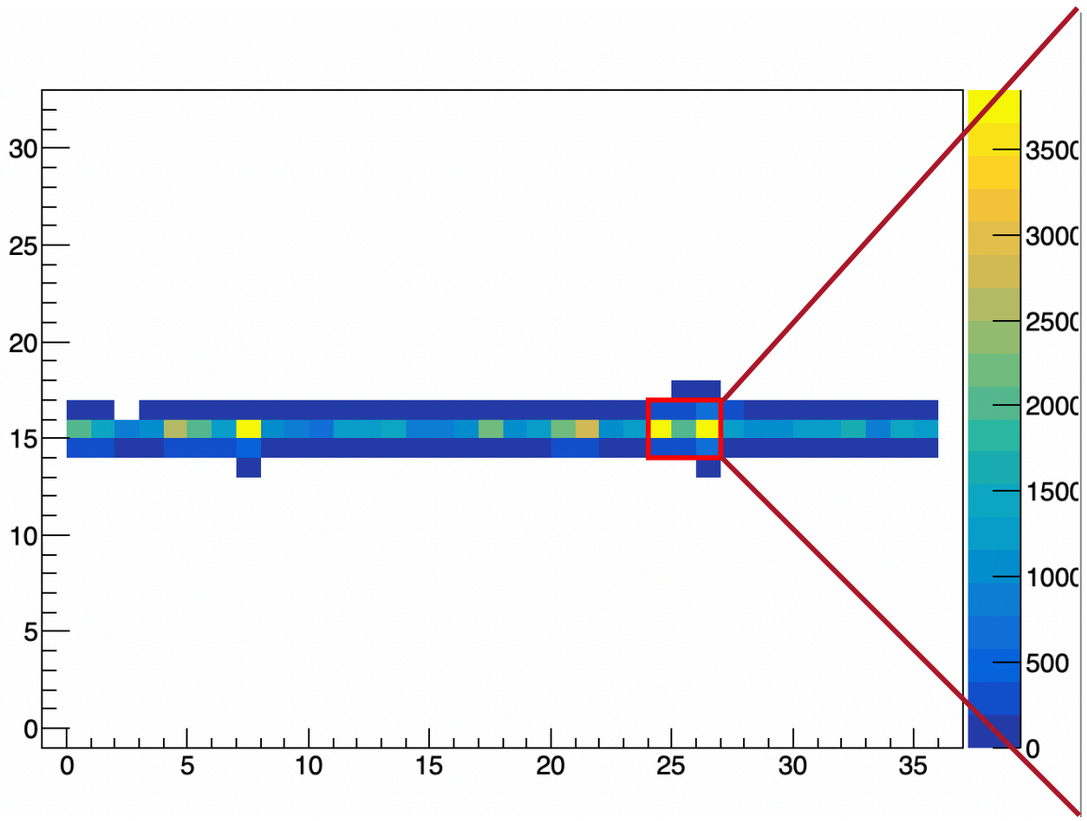
- PRF method was proved to improve the precision

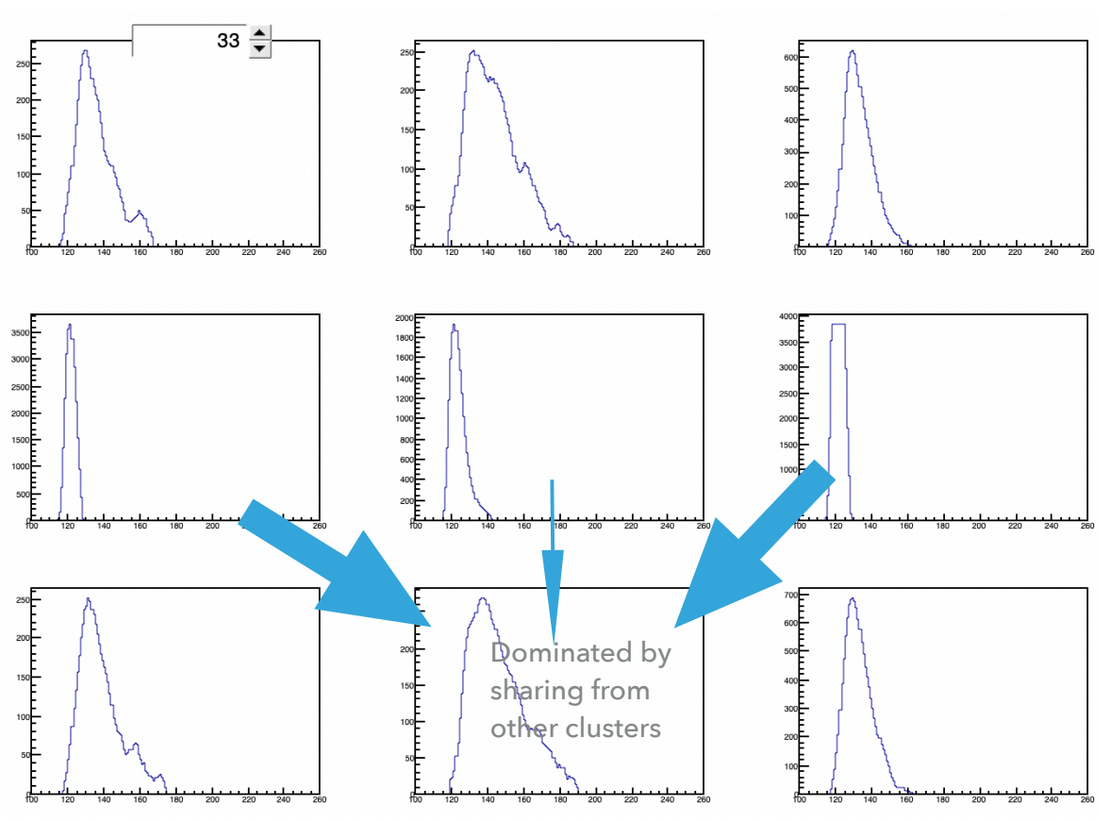
SPATIAL RESOLUTION. RECENT FINDINGS.

- Different method of the resolution estimation was proposed
  - Take an RMS of 36 residuals per track
  - Tails towards high RMS values were observed
  - Inspired to look in details at “suspicious” tracks
  - Many of them were a subject of charge fluctuations (delta)
- Perform the analysis with omitting of:
  - Some fraction of high energetic clusters
  - Clusters above the certain threshold



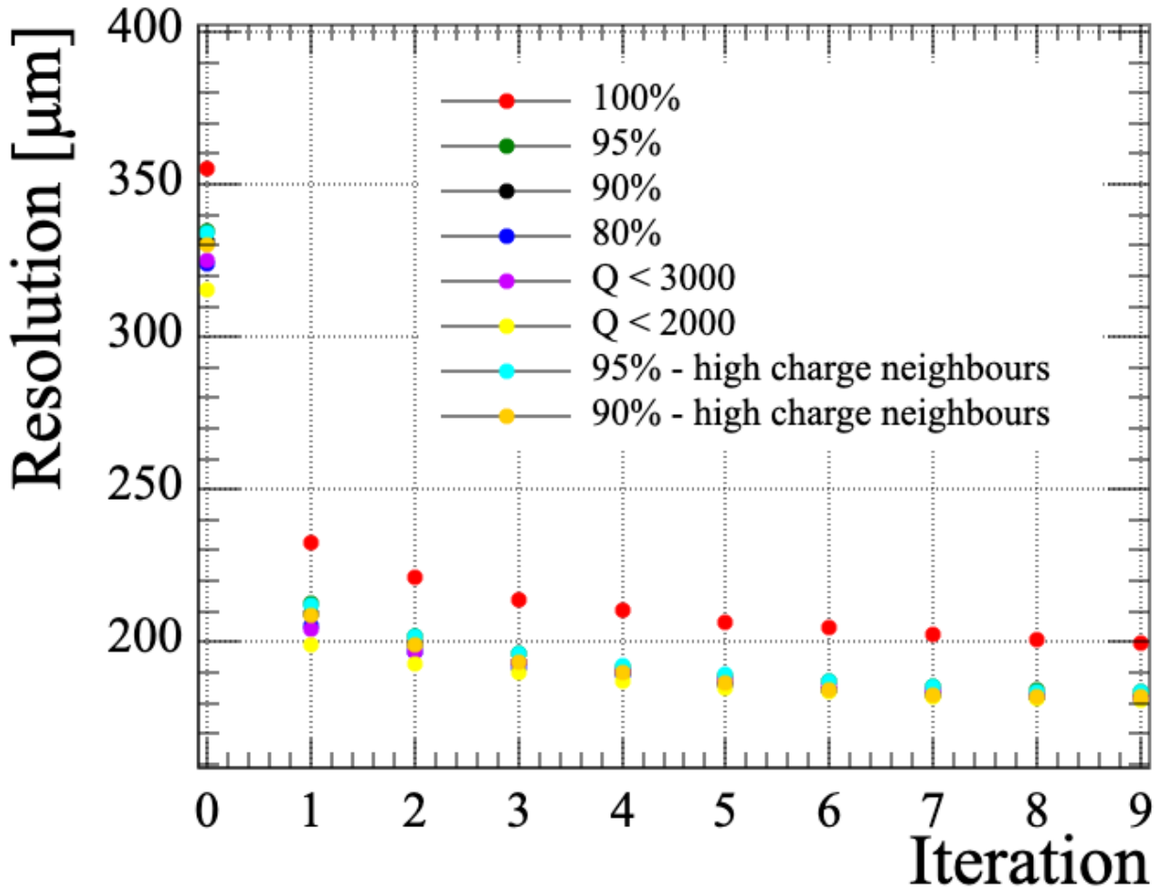
- Example of charge fluctuations that affects nearby pads:





SPATIAL RESOLUTION. RECENT FINDINGS.

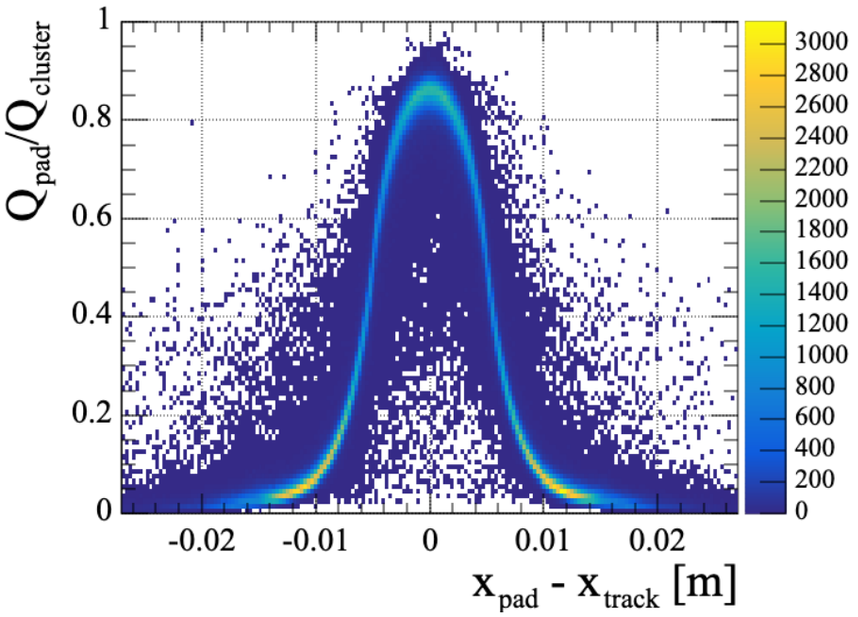
- Truncate the clusters with high charge
  - Tested truncation with:
    1. *Fraction of clusters, e.g. 90%*
    2. *Charge in the cluster, e.g. Q < 2000 c.u.*
    3. *Fraction 90% + neighbours of the large charge deposition*
  - Omitting just 1-2 clusters gives the same result as omitting ~30% of clusters
  - Results with different cut converges
  - Further improvements may be limited by method/detector



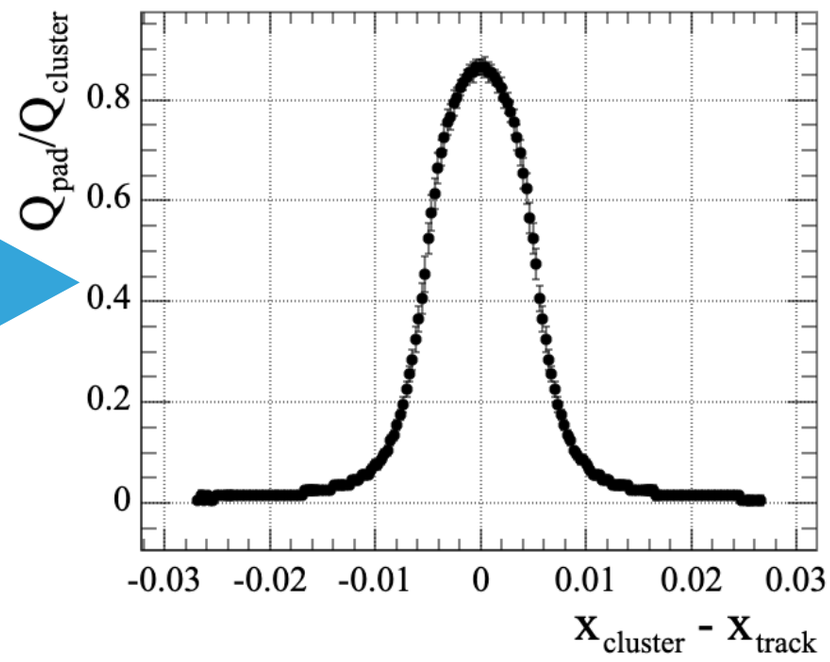
SPATIAL RESOLUTION. IMPROVEMENTS

- How the PRF is used:

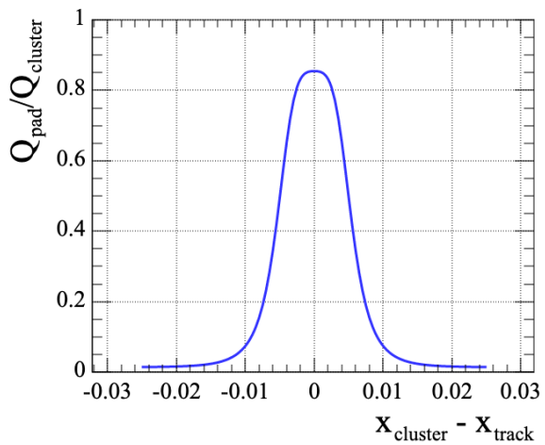
The scatter plot is filled based on baricentrical method



Scatter plot is profiled along Y with maximum and FWHM as an error



Analytical function fit the PRF



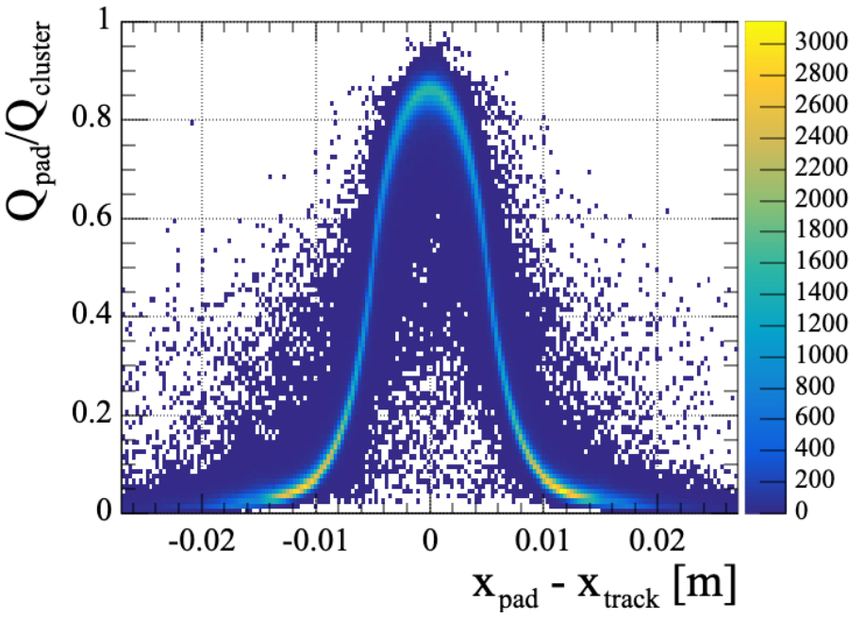
- Track position win the cluster is obtained from χ^2 fit

$$\chi^2_{cluster} = \sum_{row} \left[\frac{Q_{pad}/Q_{cluster} - PRF\left(X_{pad} - X_{cluster}\right)}{\sigma_{Q_{pad}}} \right]^2 \qquad \sigma_Q = \sqrt{Q}$$

SPATIAL RESOLUTION. PROBLEMS?

- Uncertainties of the scatter plot are not propagated to the track fit

The scatter plot is filled based on baricentrical method



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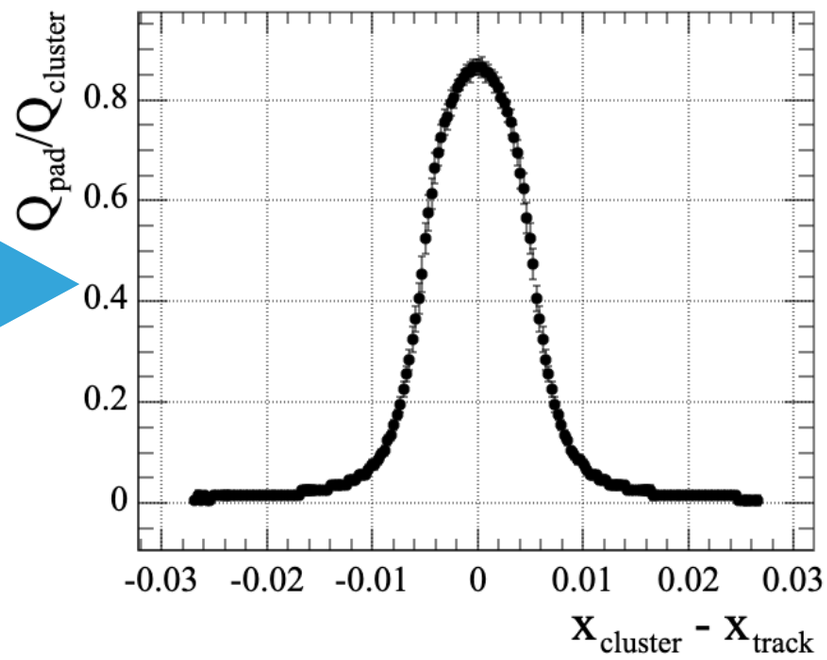
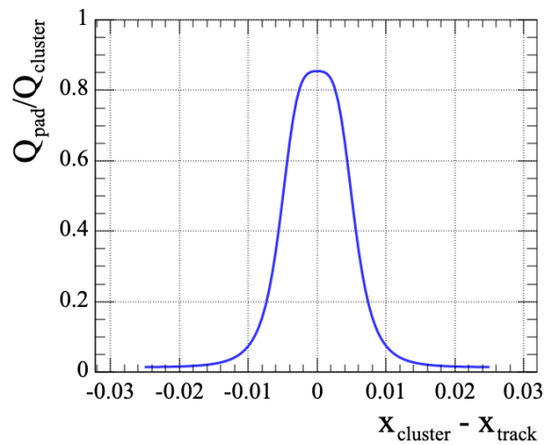


Analytical function fit the PRF

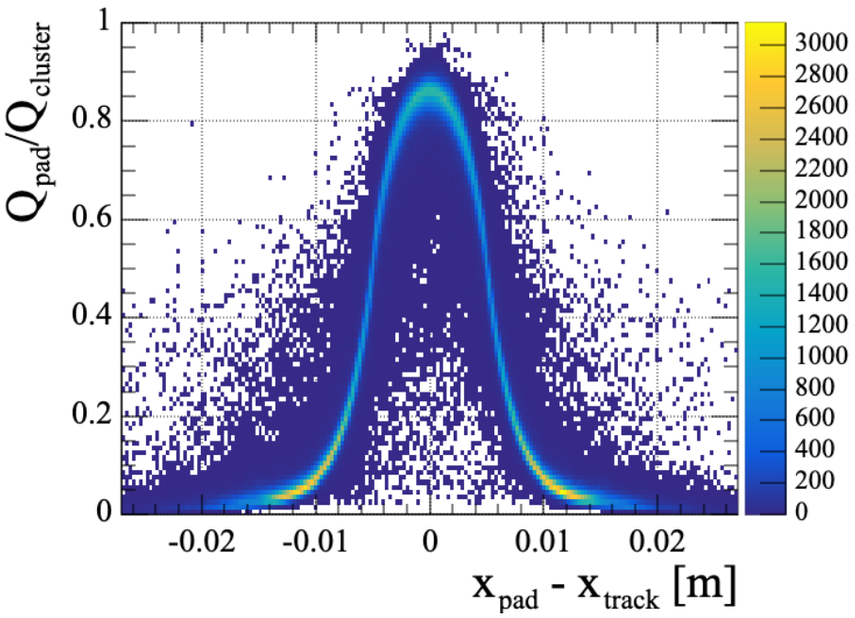


- Uncertainties of the scatter plot are used for the fit with analytical function but are not used in the track position fit

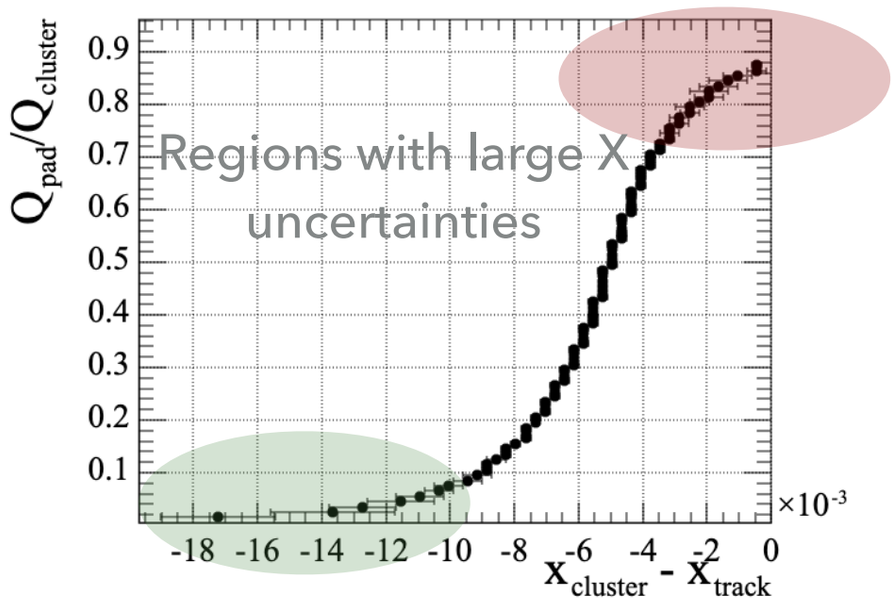
$$\chi^2_{cluster} = \sum_{row} \left[\frac{Q_{pad}/Q_{cluster} - PRF\left(X_{pad} - X_{cluster}\right)}{\sigma_{Q_{pad}}} \right]^2 \qquad \sigma_Q = \sqrt{Q}$$

SPATIAL RESOLUTION. PROBLEMS?

- Uncertainties of the scatter plot are not propagated to the track fit



Why is ti important?



Green region corresponds to low Q and is considered not reliable with $\sigma_Q = \sqrt{Q}$

Red region is supposed to be VERY reliable as Q is large

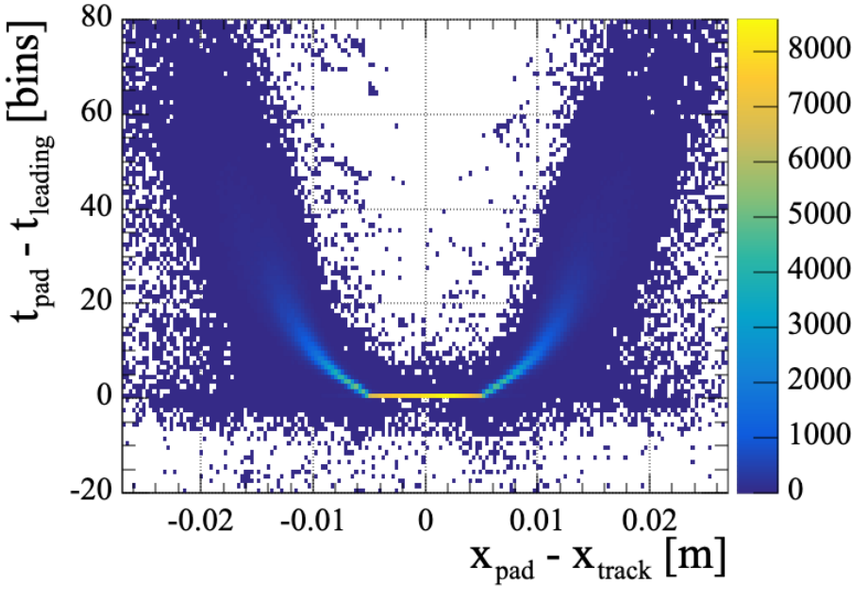
- Uncertainties of the scatter plot are used for the fit with analytical function but are not used in the track position fit

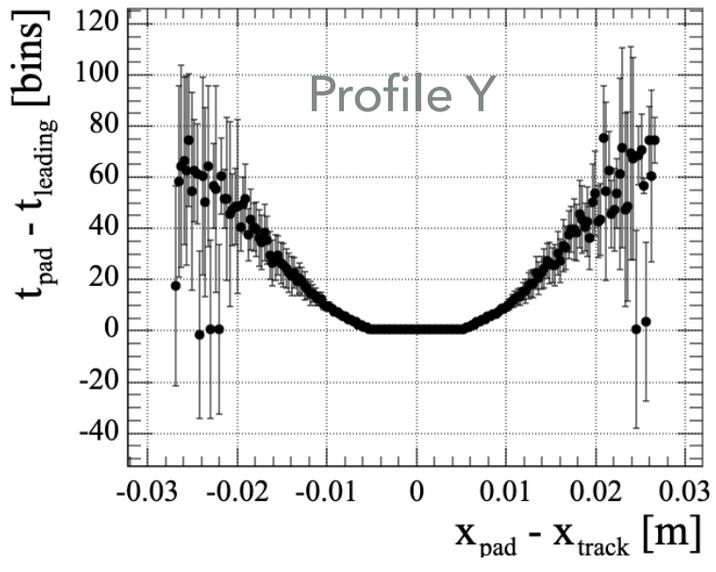
$$\chi^2_{cluster} = \sum_{row} \left[\frac{Q_{pad}/Q_{cluster} - PRF\left(X_{pad} - X_{cluster}\right)}{\sigma_{Q_{pad}}} \right]^2 \qquad \sigma_Q = \sqrt{Q}$$

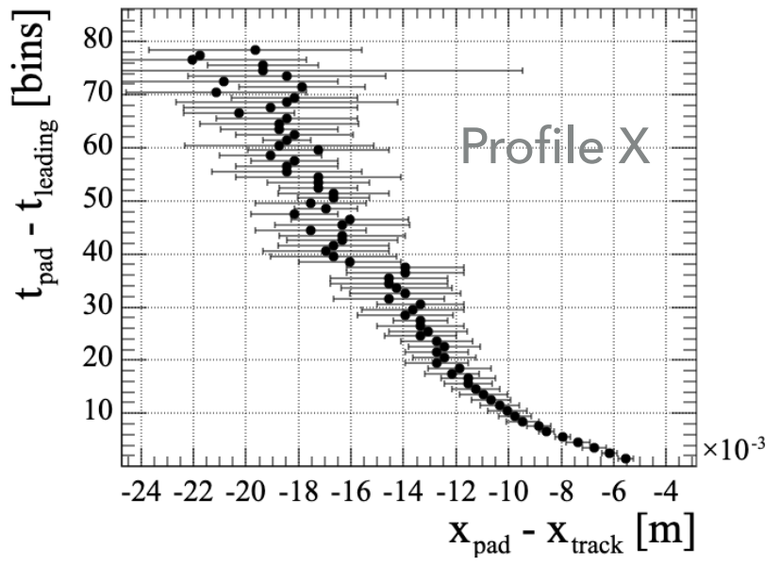
- A better error treatment of the uncertainties in the track fit are possible

SPATIAL RESOLUTION. IMPROVEMENTS

- Besides charge we have also a time information



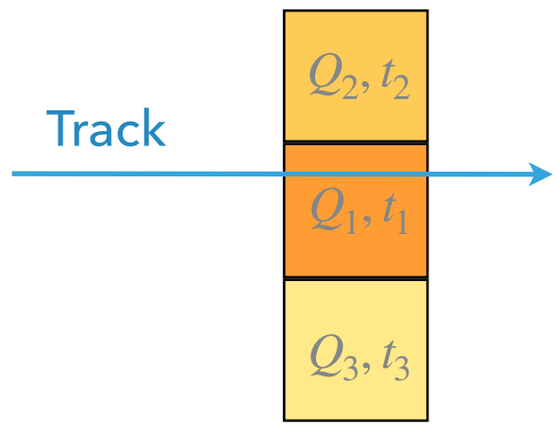




- An additional χ^2 term may be implemented

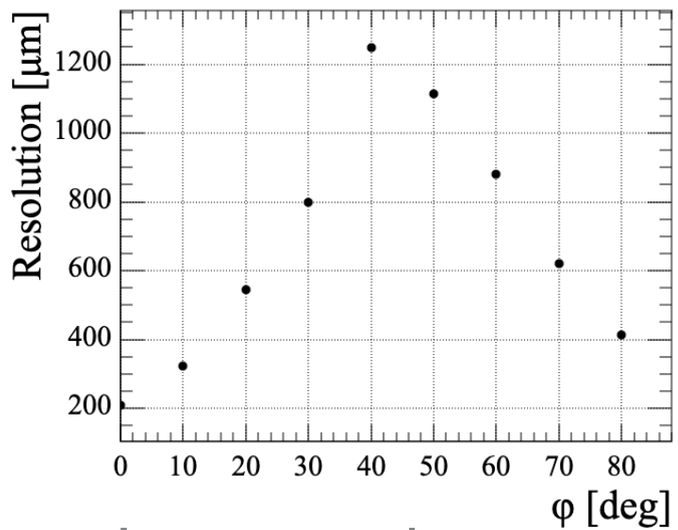
$$\chi^2_{cluster} = \sum_{row} \left[\frac{Q_{pad}/Q_{cluster} - PRF\left(X_{pad} - X_{cluster}\right)}{\sigma_{Q_{pad}}} \right]^2 + \sum_{row} \left[\frac{X_{cluster} - X(dt)}{\sigma_X} \right]^2$$

Charge sharing in a cluster:

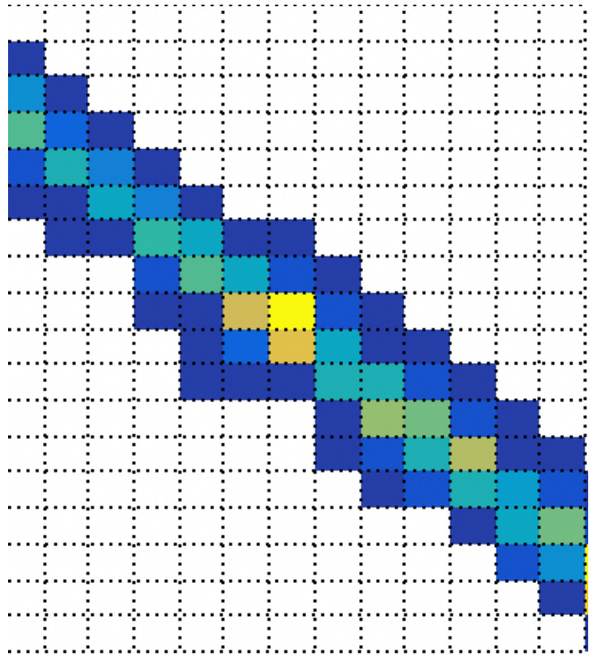


SPATIAL RESOLUTION. INCLINED TRACKS

- PRF method can be applied to the inclined tracks
- For each cluster it's decided if it's vertical or horizontal and the proper cluster is fit
- Conservative limit on the oblique tracks was set

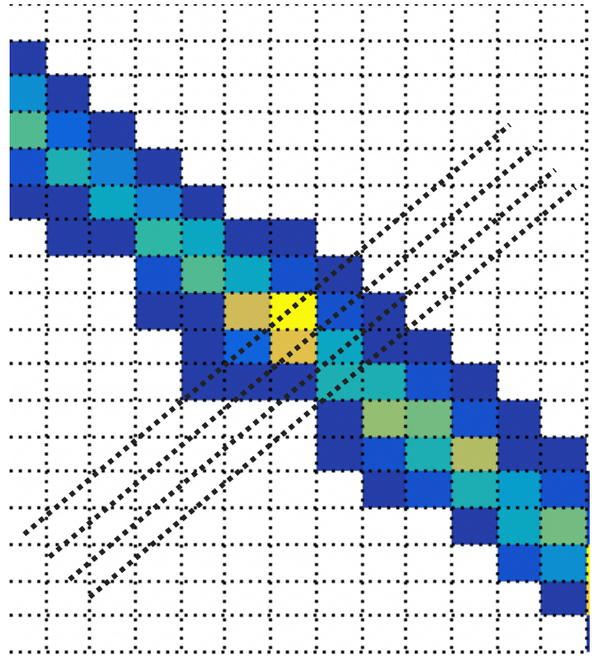


- The problem:
  - For horizontal track only transverse spreading was used
    charge deposition fluctuation is not affecting measurements
  - For oblique tracks longitudinal fluctuations charge fluctuation start play an important role
  - Fluctuations in oblique tracks affects both rows and columns

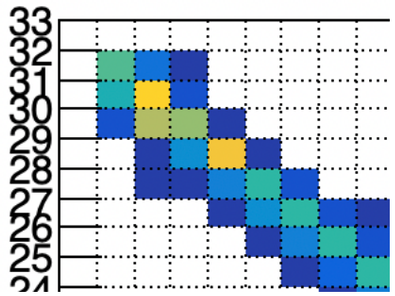


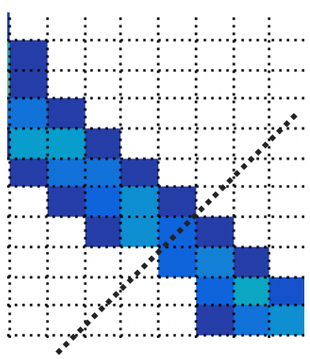
SPATIAL RESOLUTION. INCLINED TRACKS

- Study them with diagonal (idea from Pierre)
  - Diagonals provide the information only about charge spreading
  - not affected by charge fluctuations
  - PRF method can still be used!

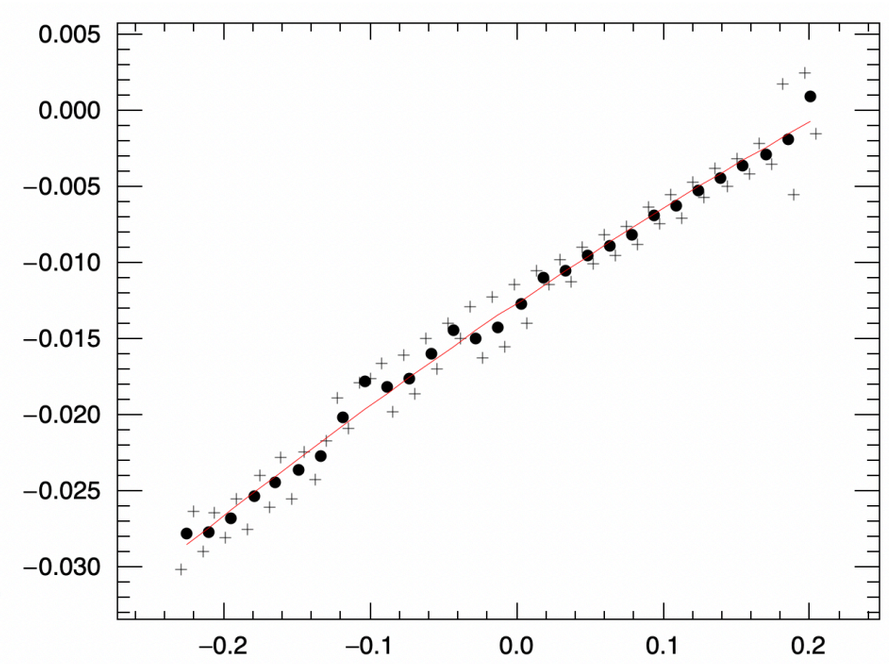


- What was done?
  - Analysis framework adapted to work with diagonal clusters
  - 1st and last rows/columns are omitted as usual
    in addition 1st and last diagonals are omitted as the contain only one pad
  - Diagonals are found to alternate position around the track
    - *Use the average position from 2 diagonals in a row*
    - *Position is averaged with the different uncertainties for 1 and > 1 pad in a cluster*





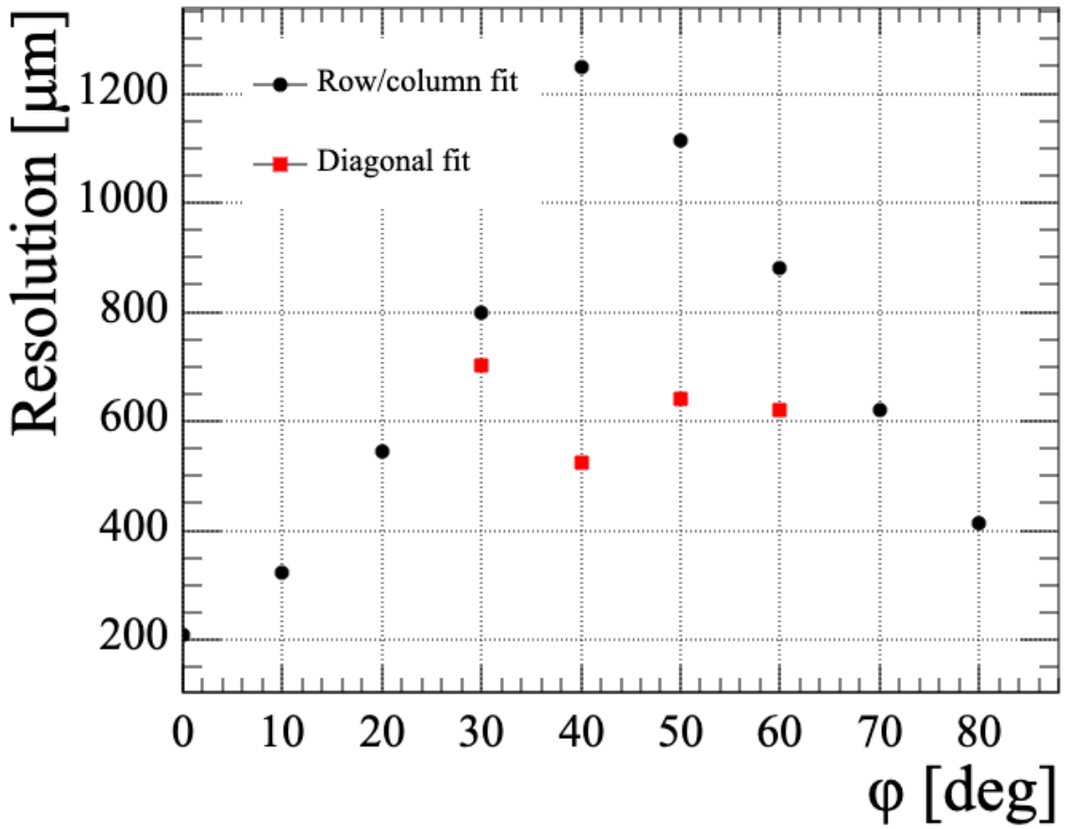
+ – diagonal position
● – average of 2 diagonals in a row
– track fit



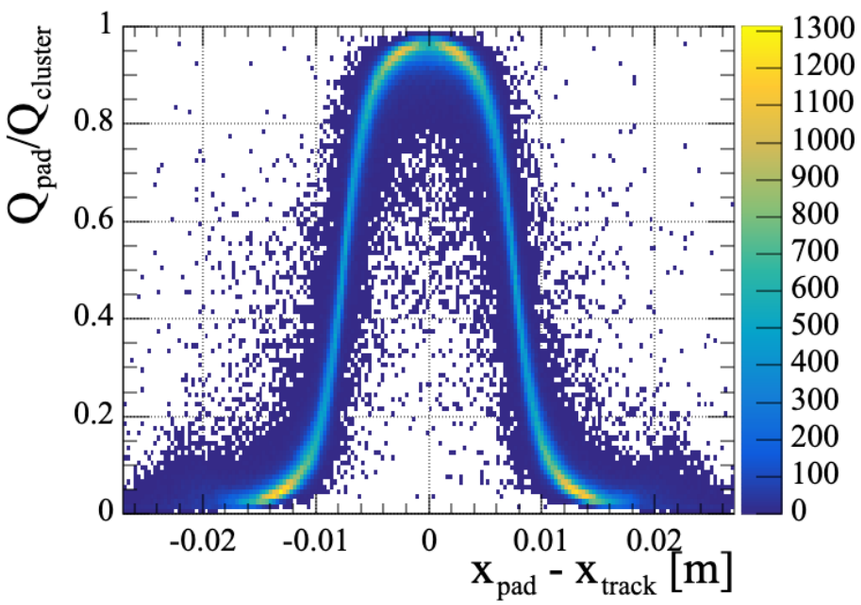
SPATIAL RESOLUTION. INCLINED TRACKS

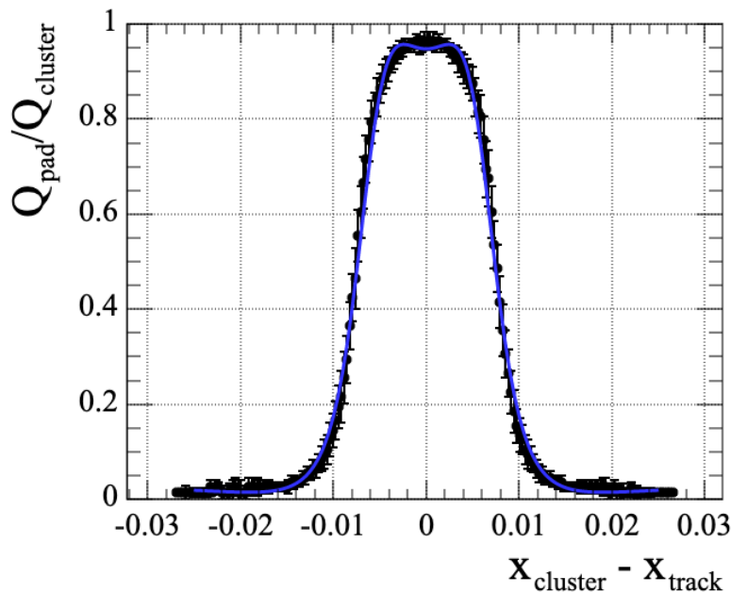
- Significant improvement was observed

- Why 40° sample is so different?
  - If fact it was wrongly logged/set up
  - The tracks are found mostly at 45°
  - That's why it is very bad with columns and much better with diagonals



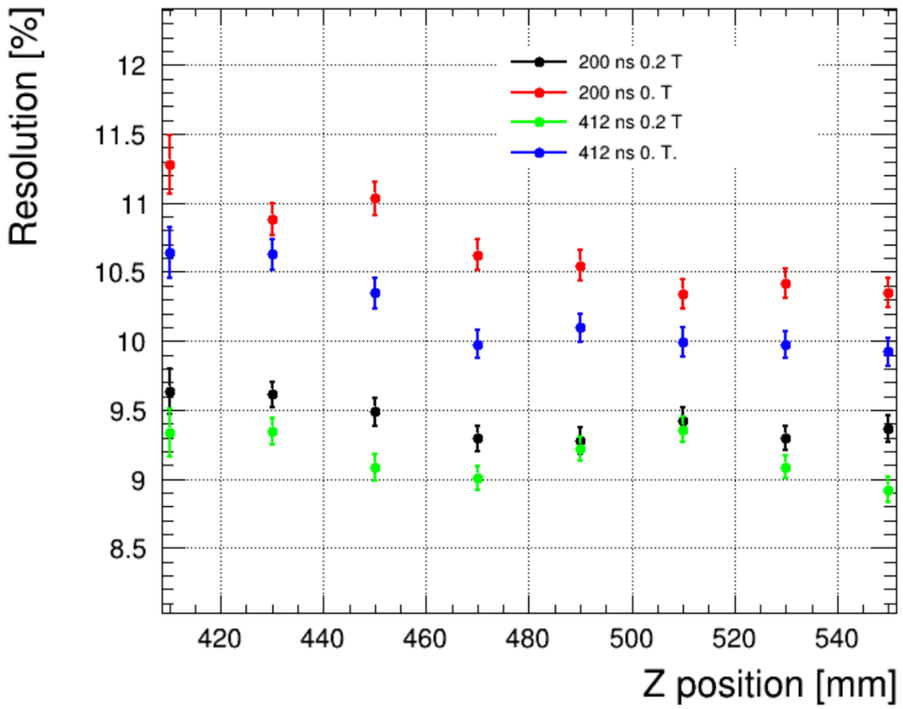
- PRF is more step-like
  - As expected as effective pad size is $\sqrt{2}$ times larger

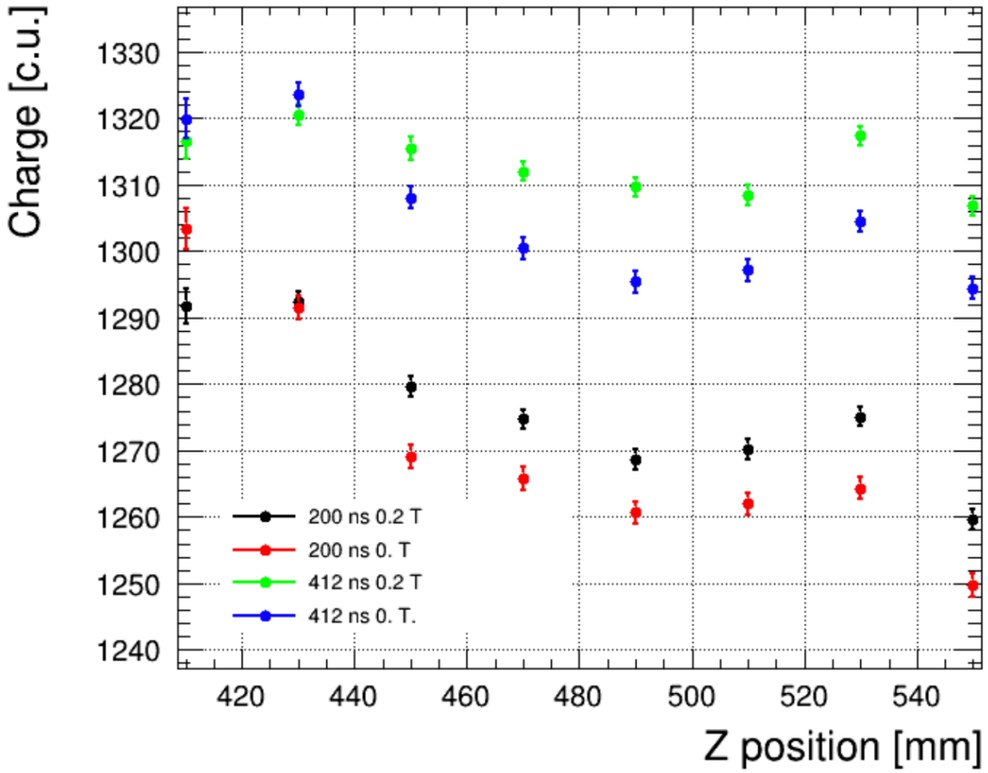




DE/DX ANOMALIES

- Problem is ~one year old

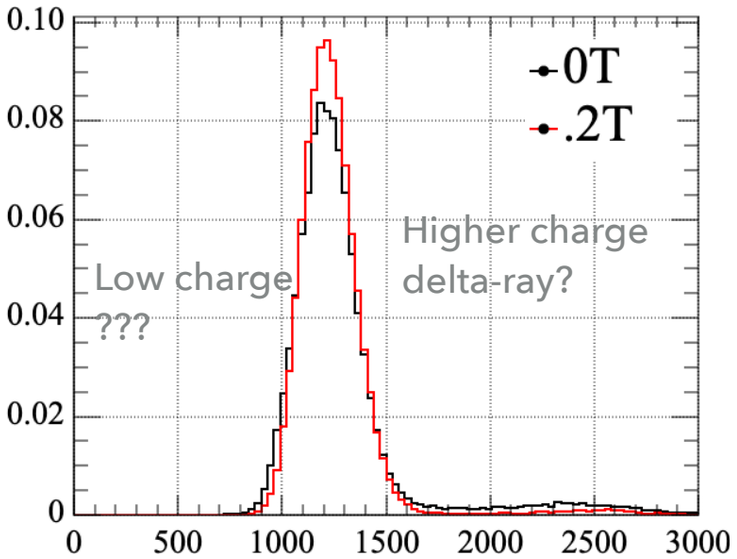


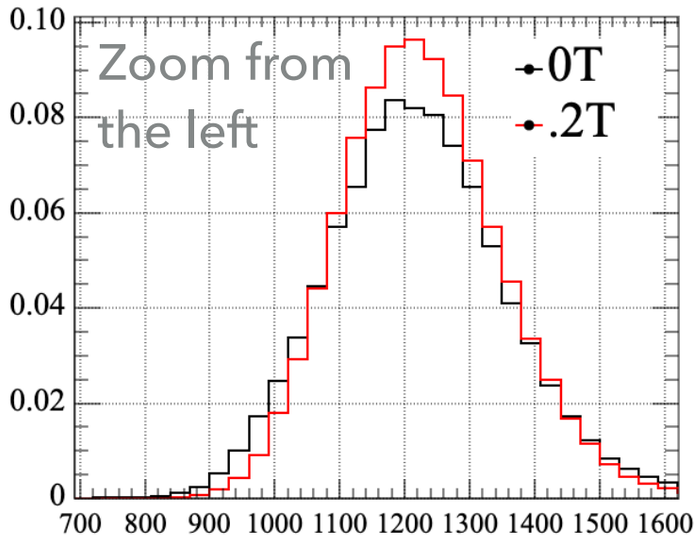


- The dE/dx resolution is not expected to improve with magnetic field
  - But it does

DE/DX ANOMALIES. INVESTIGATION

- Together with Claudio and Vlada we are investigating the difference
- Delta-rays w/o magnetic field are not banded and they may more affect charge measurements
  - We tested different truncation coefficient, but it's not reducing the difference
  - One more interesting observation is that the dE/dx is wider not only in high charge tail (delta-ray?) but in a low charge edge as well





- If the upper bound of fit is set away from the tail (1500 c.u.) the worsening of the resolution is caused by the low charge tracks!

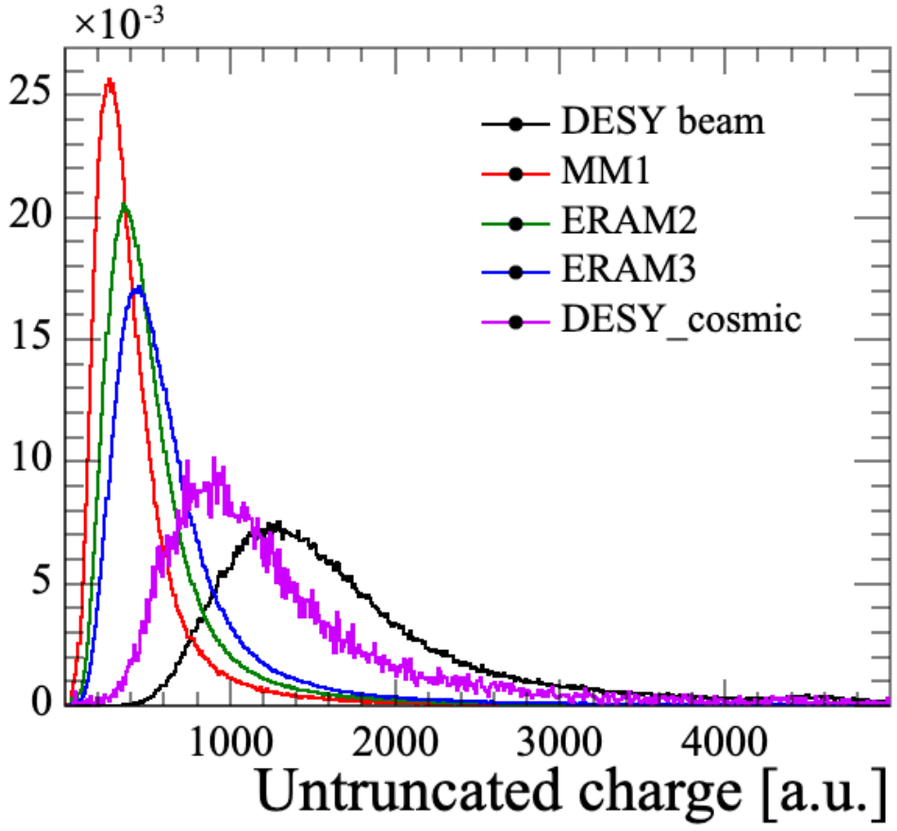
  .0T 10.56% +- 0.04

  .2T 9.48% +- 0.03

- These difference is under investigation

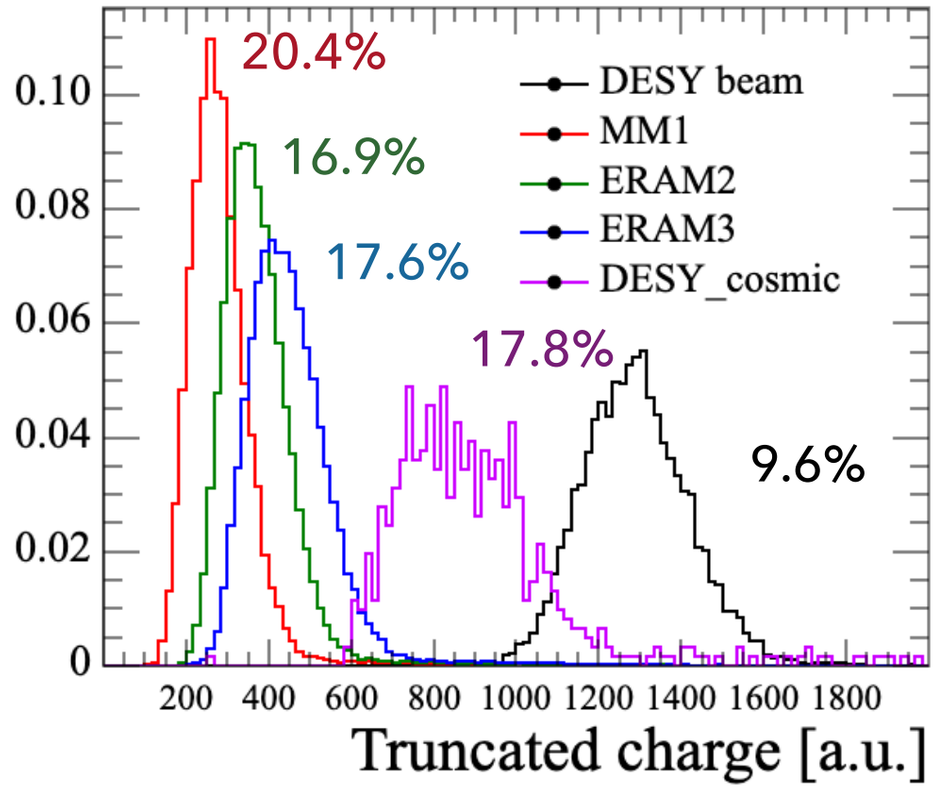
SACLAY PROTOTYPES

- Since DESY test beam new detectors (ERAM) with larger spreading were produced and studied at Saclay with cosmic
- Few anomalies were found in the data
- The charge significantly lower comparing to DESY test
  - Charge from MIP and electrons is consistent in DESY
  - Signal from MIP in Saclay is dramatically lower
  - May be a subject of low gas quality. Low charge will affect dE/dx and spatial resolution



360V
Area
norm to 1

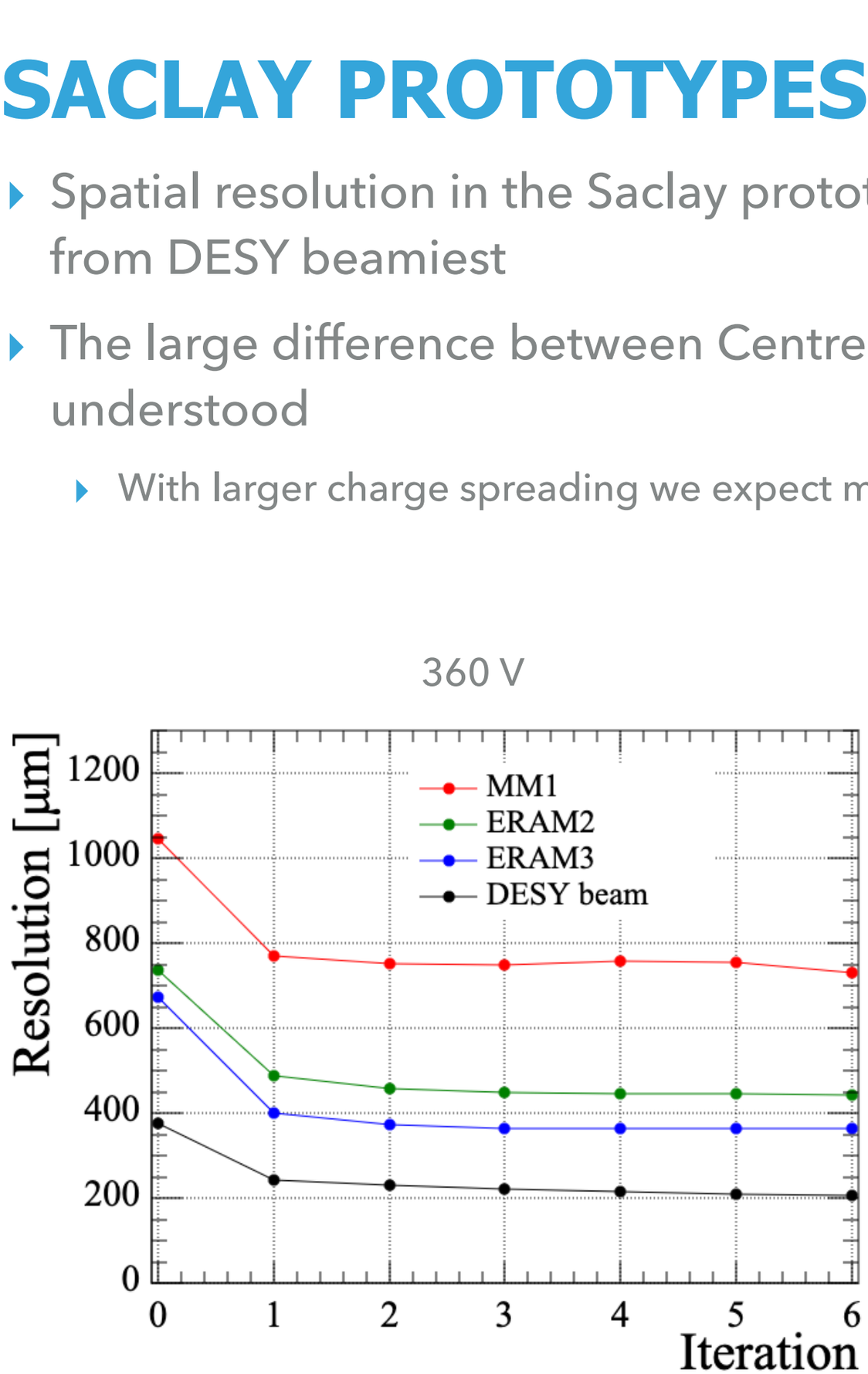
dE/dx resolution



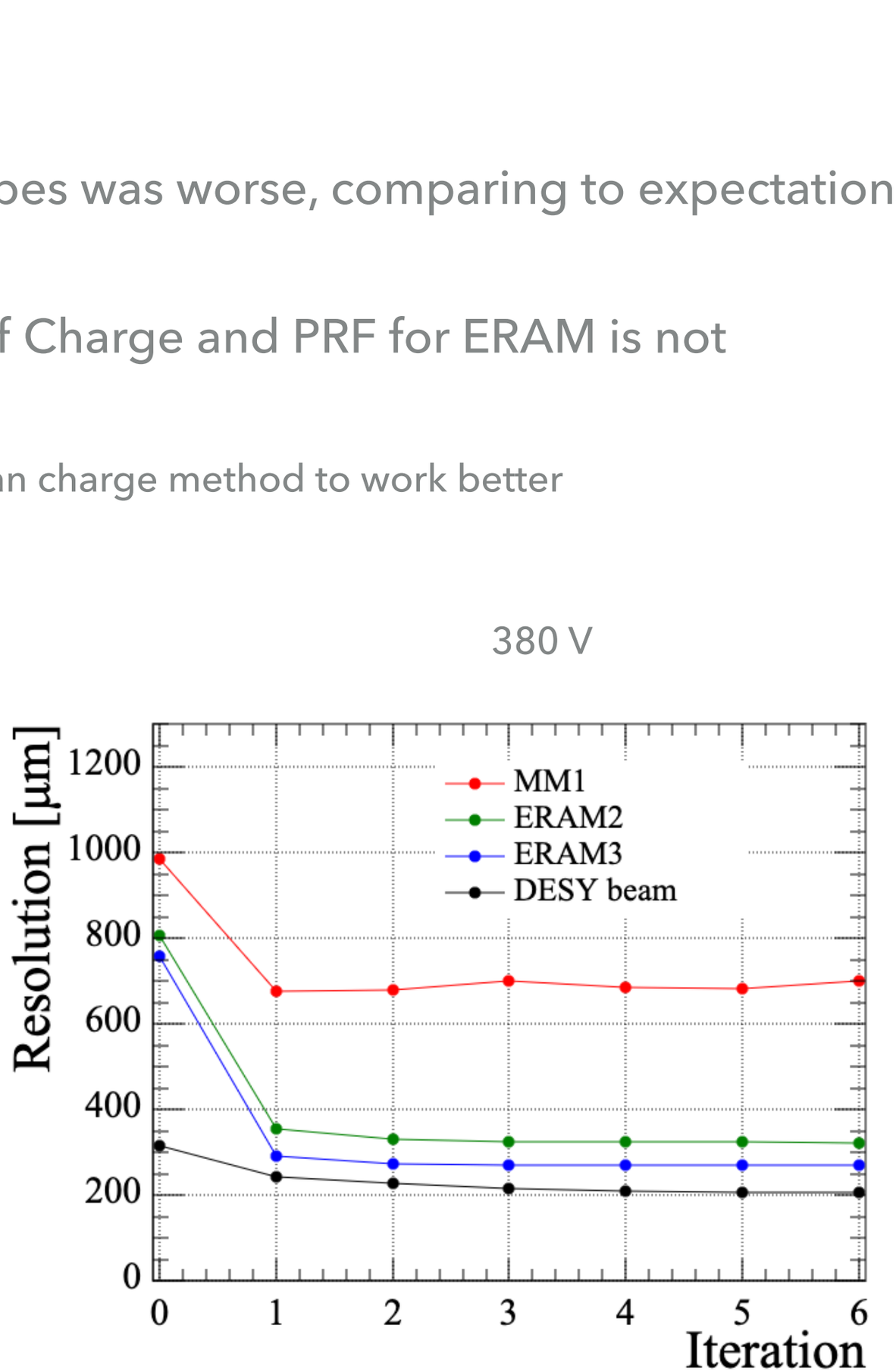
SACLAY PROTOTYPES

- Spatial resolution in the Saclay prototypes was worse, comparing to expectations from DESY beamiest
- The large difference between Centre of Charge and PRF for ERAM is not understood
  - With larger charge spreading we expect mean charge method to work better

360 V

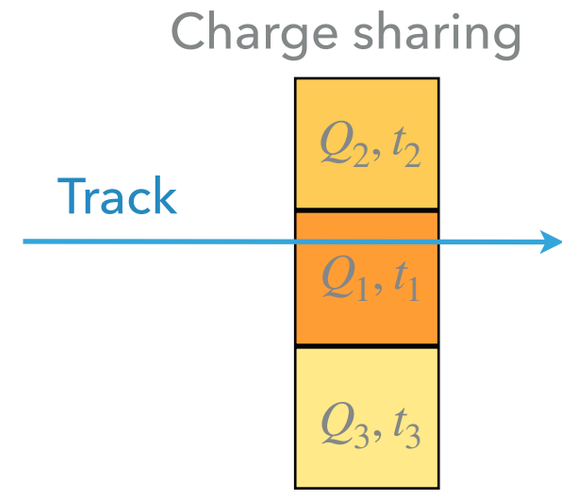


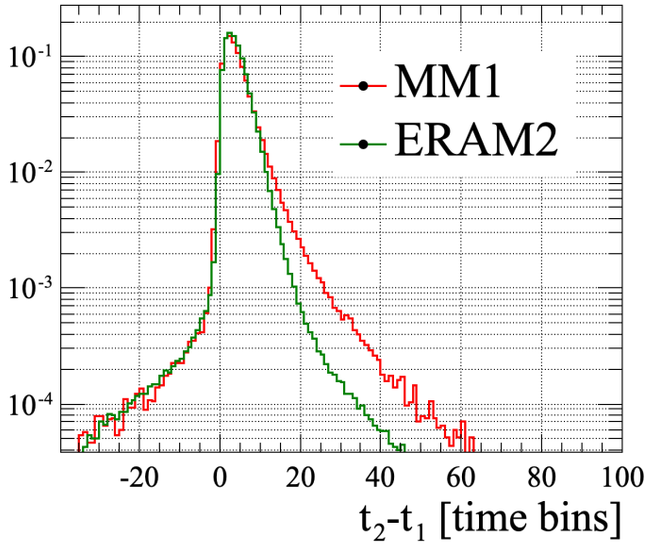
380 V

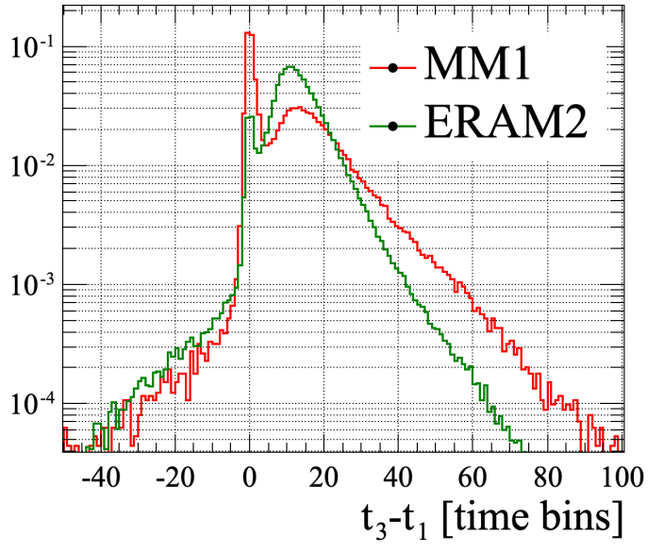


SACLAY PROTOTYPES

- The other anomaly in time measurements was observed
  - The 3rd pad is not expected to receive a charge at the same time as a leading pad
  - The possible explanations are: induction in pads, electronics cross-talk, …
  - The effect on the Spatial resolution is very small, but detector behaviour need to be understood



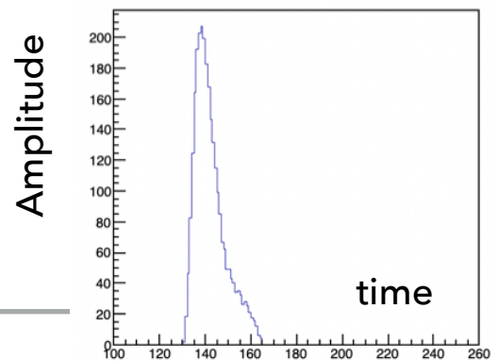




Reference points:

- $t_2 - t_1 < 0$ wrong reco (3%)
- $t_2 - t_1 = 0$ track over pad border
- $t_3 - t_1 \leq 0$ should never happen

Waveform example:



HA-TPC RECONSTRUCTION

- The analysis goal is to use data from prototypes to test the reconstruction algorithms within ND280 software
- Successfully converted DESY beamiest data into ND280 data format

- Implemented the prototype analysis algorithm in to the ND280 software:
  - We used DBSCAN for pattern recognition and PRF for extracting track position
  - At the moment ND280 use TREx (based on A*)

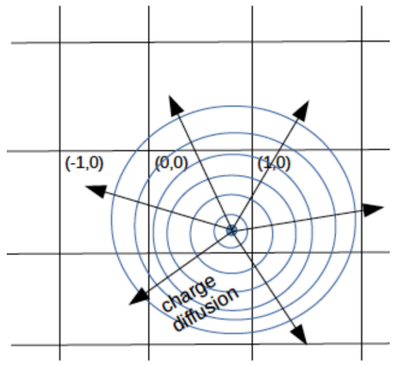
- Having both algorithms will allow to test their performance and to chose the best one for the final reconstruction

- Still working on obtaining the similar results as with the prototype analysis software

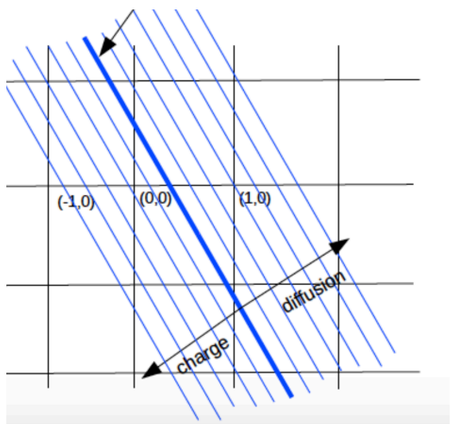
BU

SPATIAL RESOLUTION. INCLINED TRACKS

- Few approaches were considered:
  - Use time information instead/in addition to charge,
    time delay is not affected by fluctuation as charge
    not easy to extract a precise time measurement from a waveform
  - Use a likelihood based approach for 3x3 or 5x5 pads regions
    analytical solution for charge spreading is known
    electronics contribution to signal need to be understood in this approach



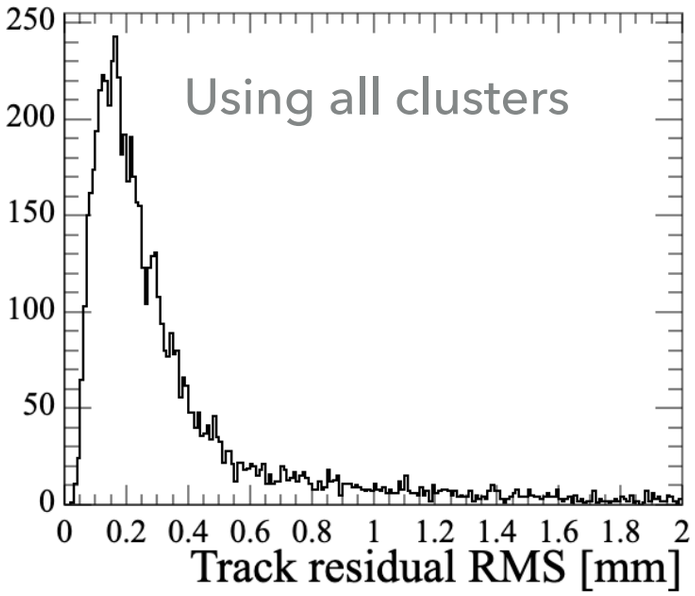
$$Q(r,t) = \frac{RC}{2t} e^{-\frac{r^2 RC}{4t}}$$

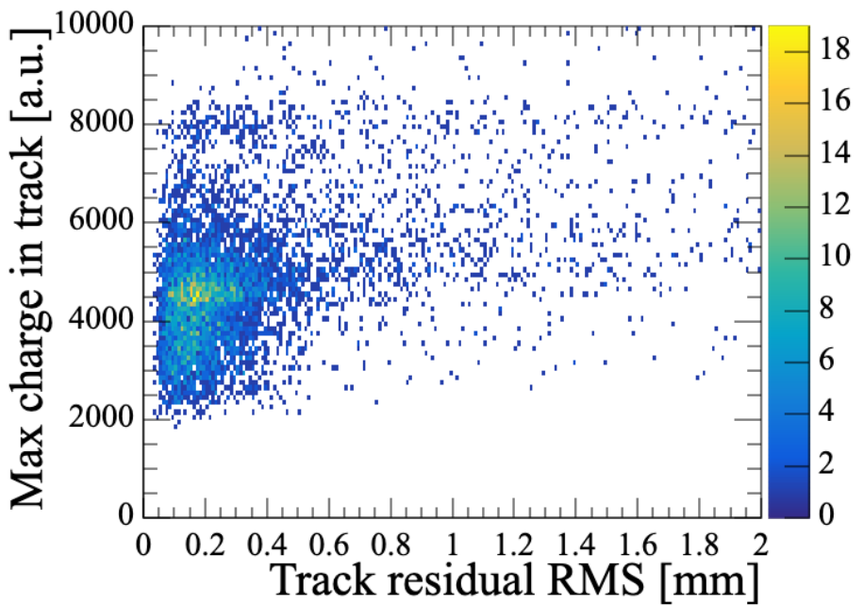


$$Q(x,t) = \sqrt{\frac{RC}{4\pi t}} e^{-\frac{x^2 RC}{4t}}$$

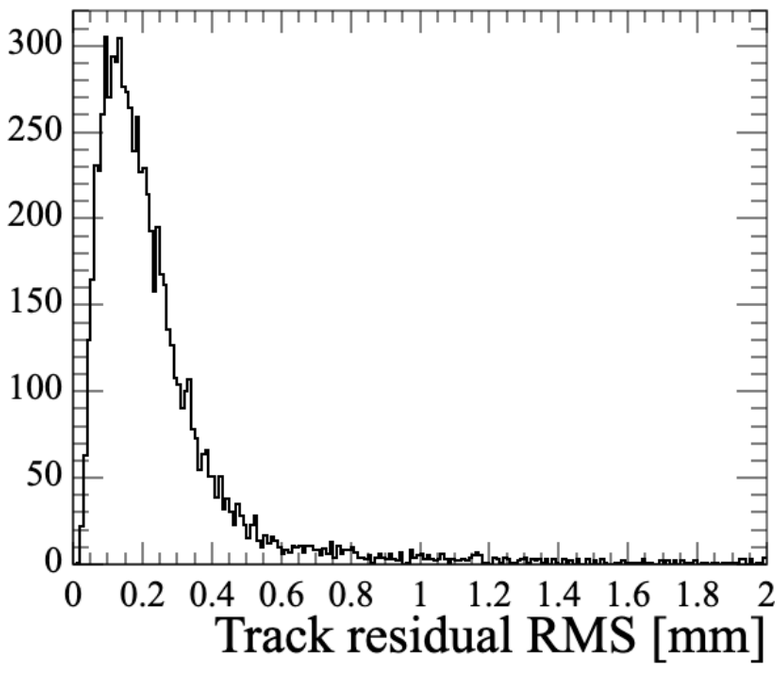
- Other possible corrections procedures are under discussion with Pierre

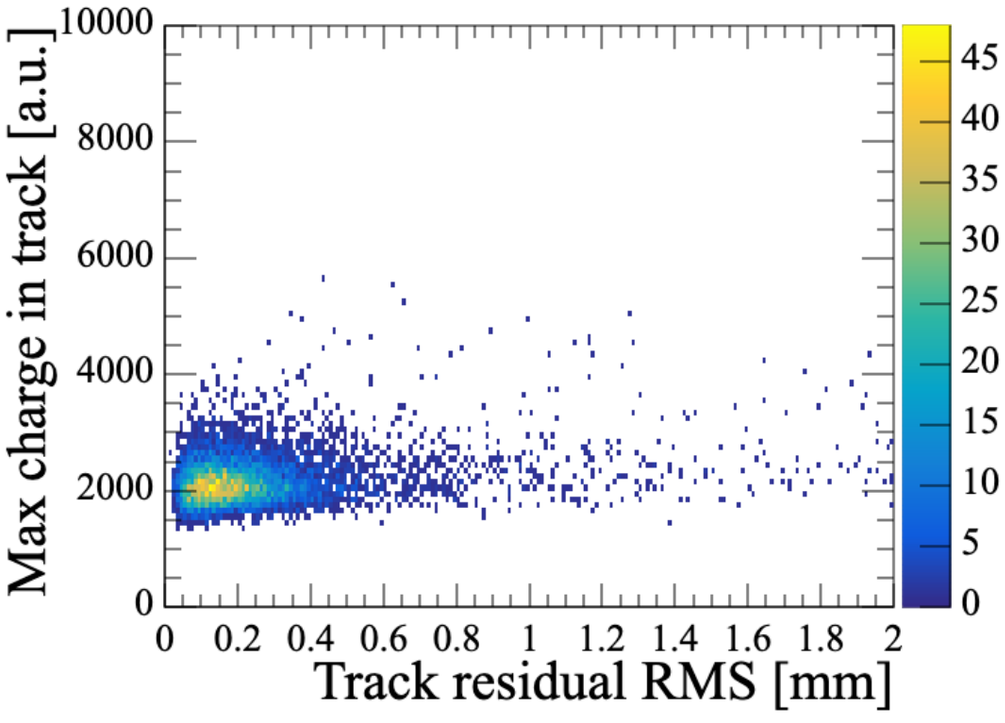
- Tail in the track residual RMS distribution => some tracks has a large residual RMS
  - Is it caused by few wrong reconstructed clusters with large energy deposition?





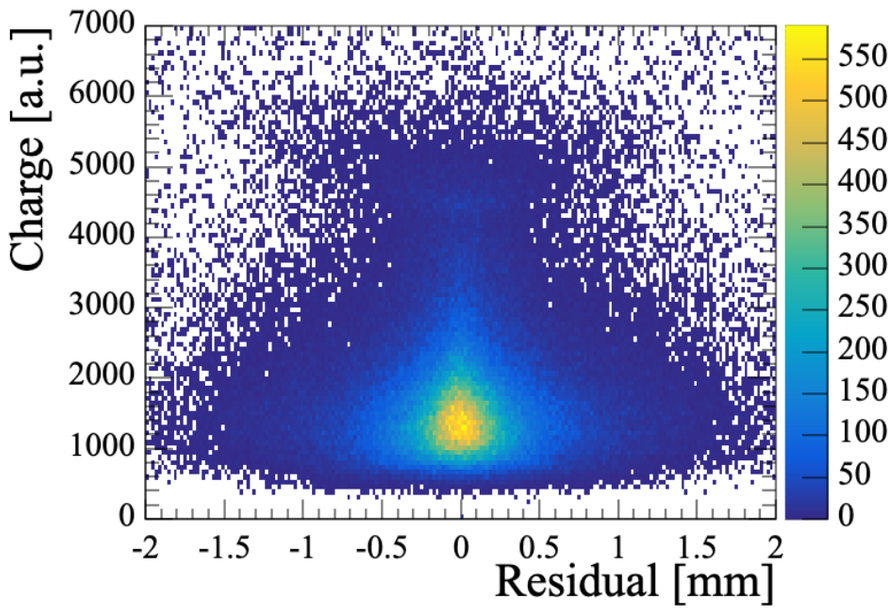
- 80% of low energy clusters used:



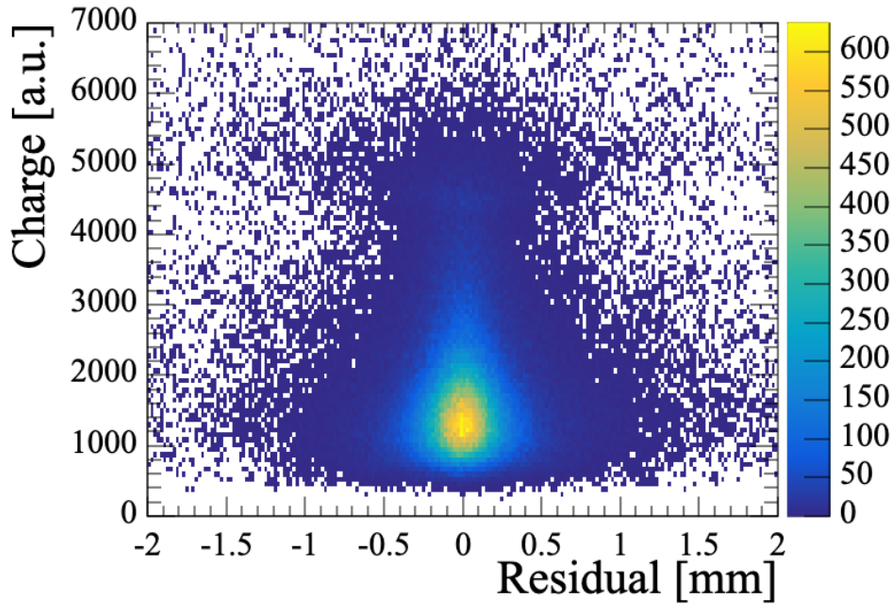


Text

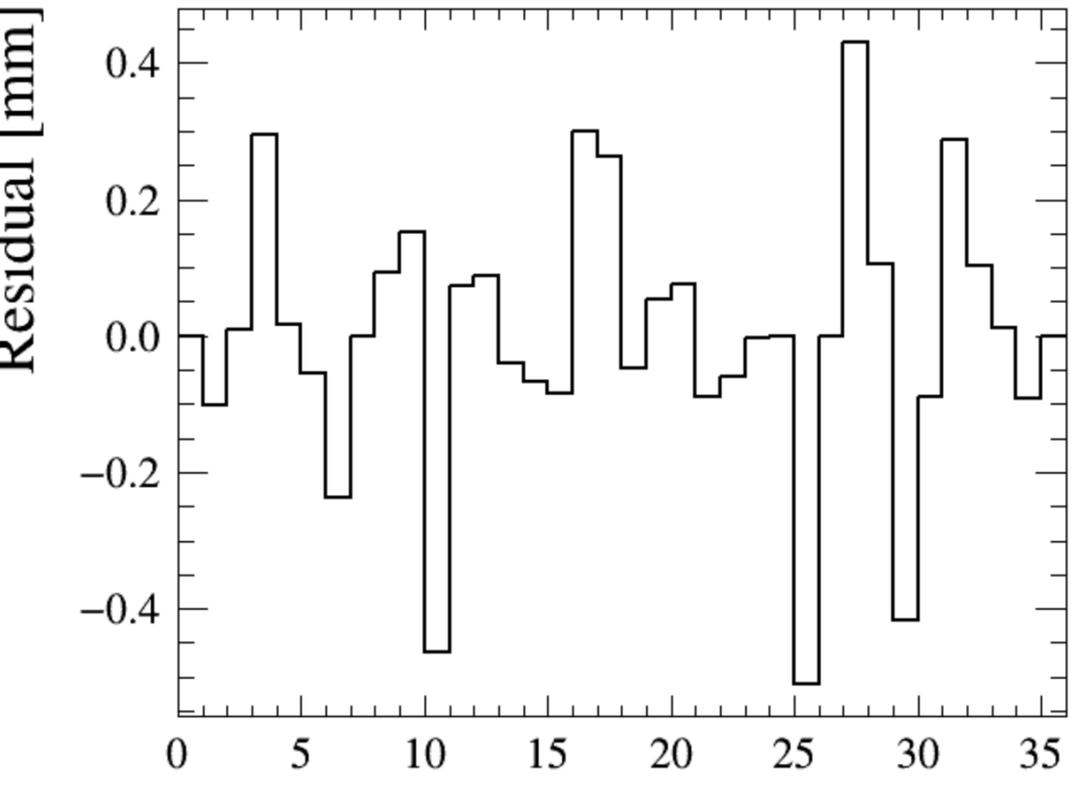
- All the plots are for 360V 200 ns DESY beam events
- CoC:

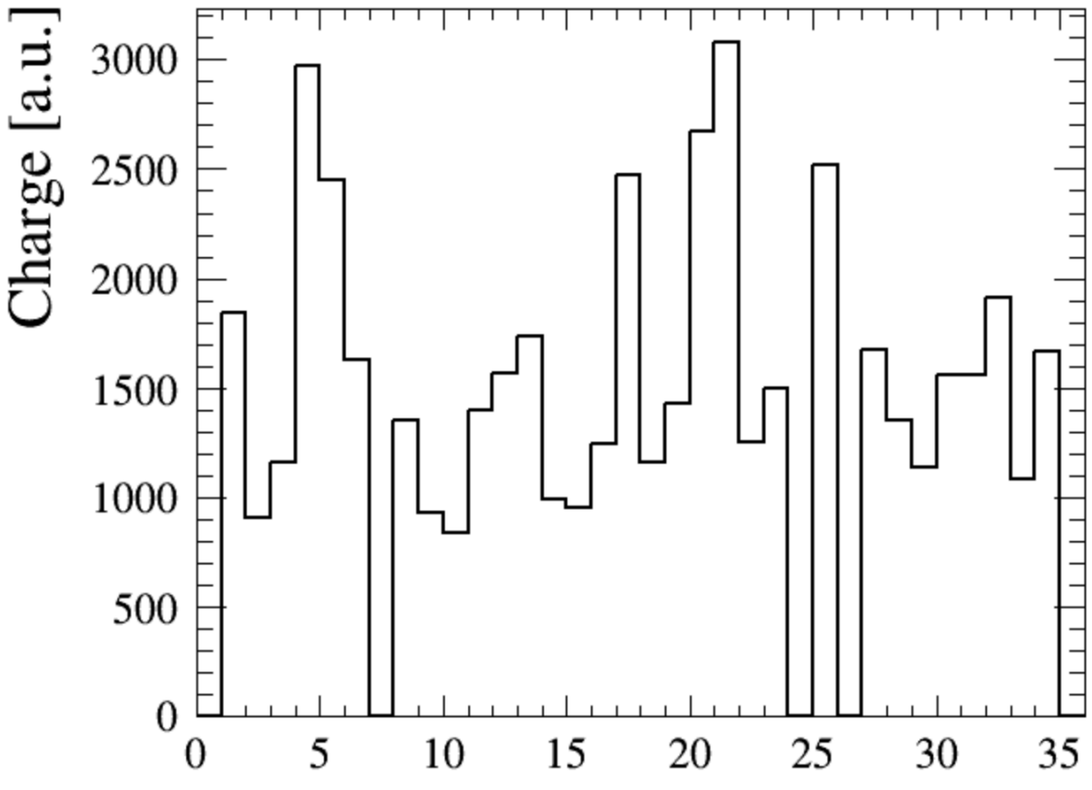


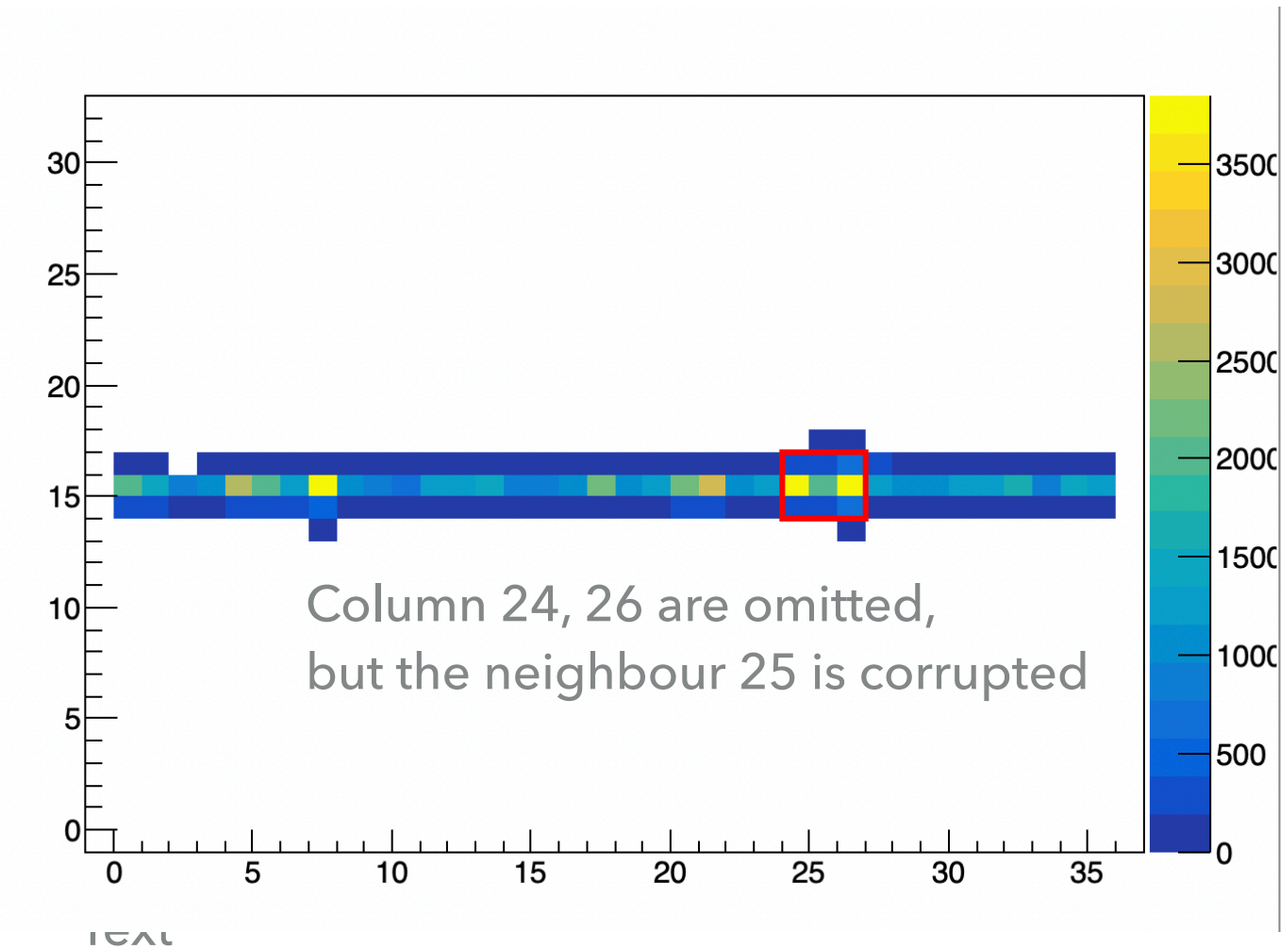
- PRF iter 9:

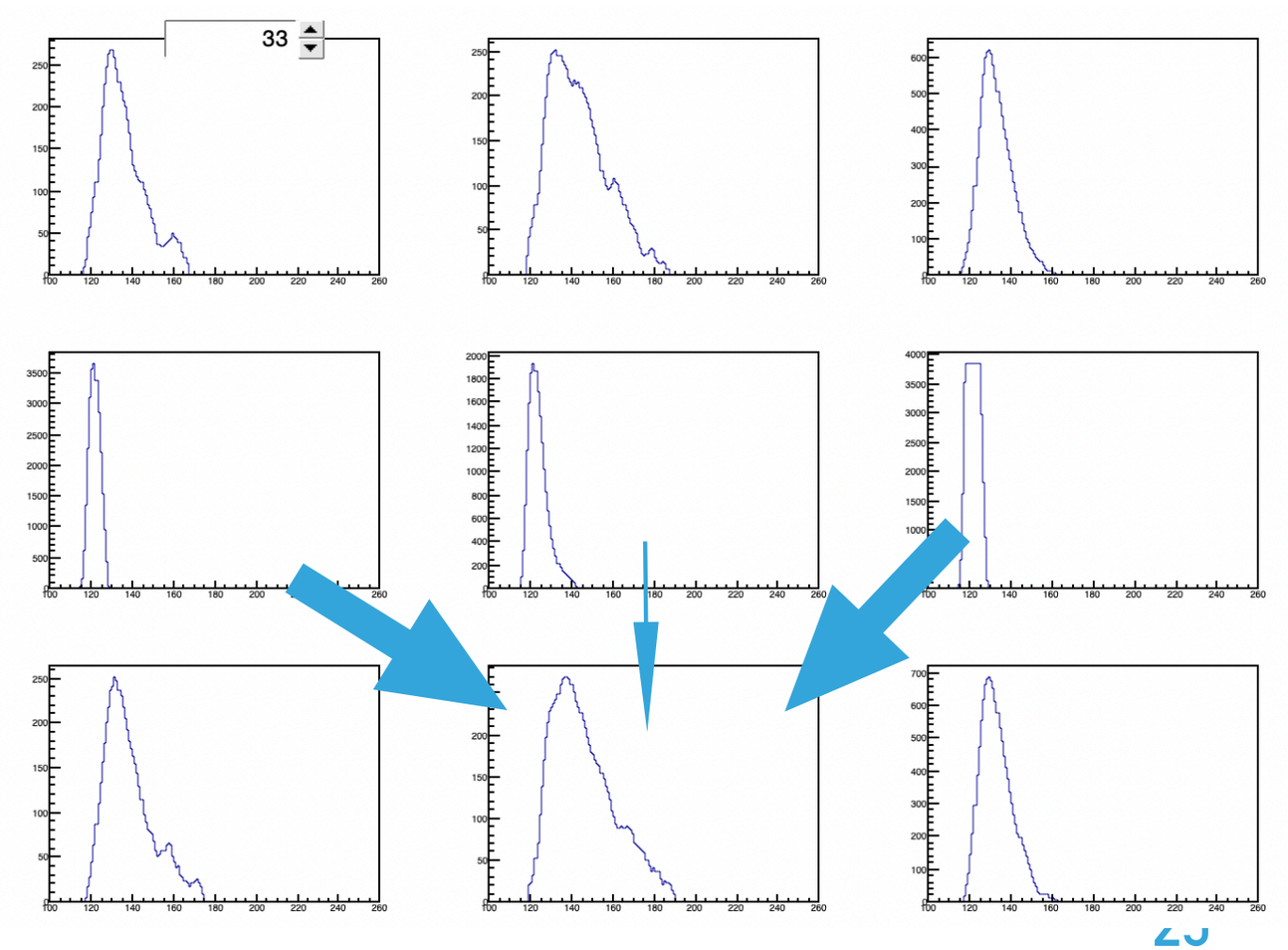


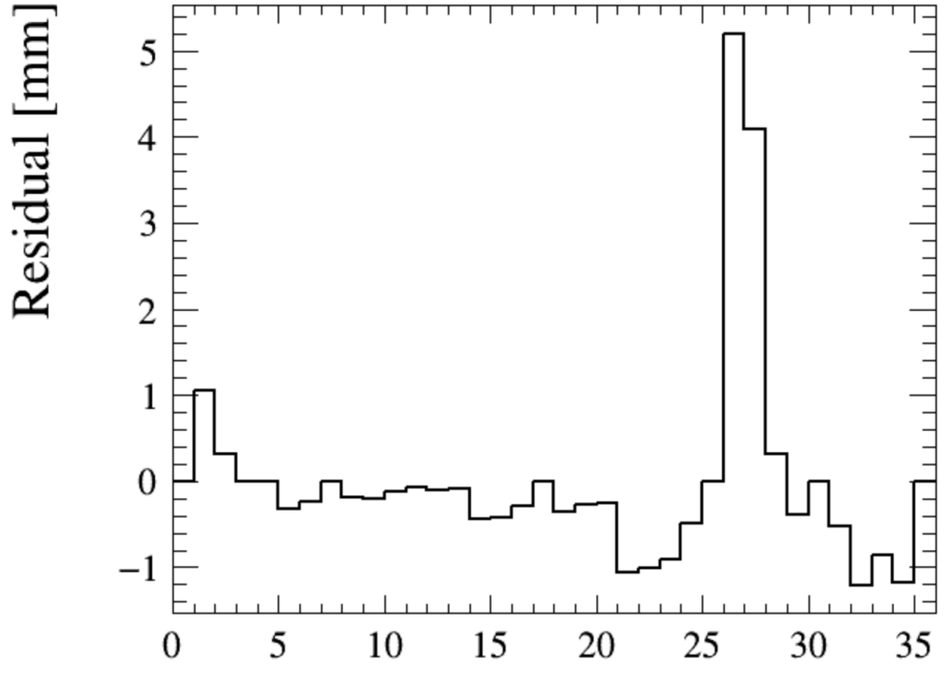
- Clusters with more charge **don't** systematically cause larger residual spread

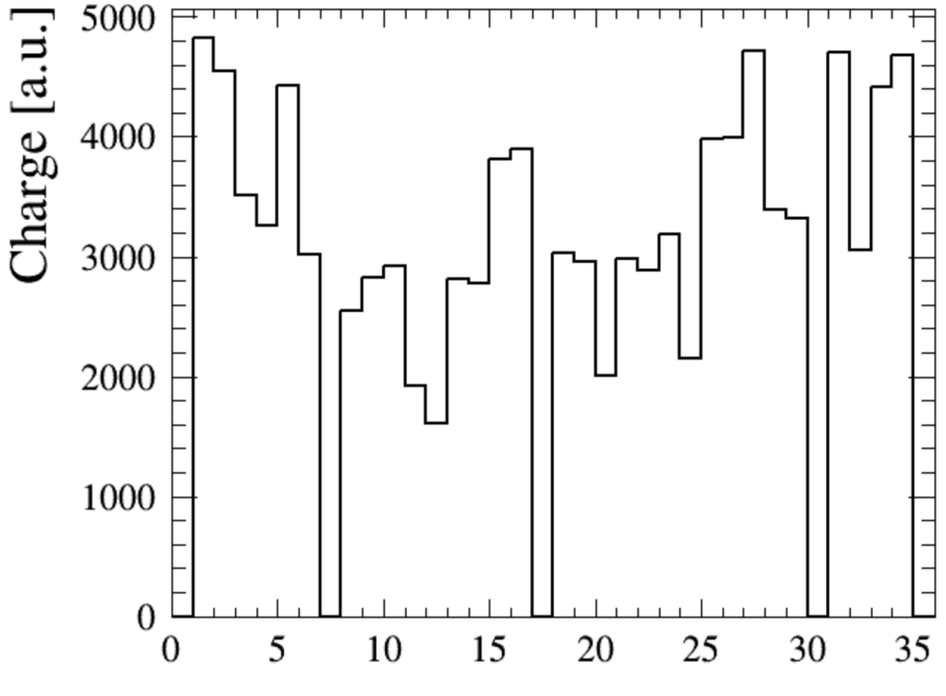

Residual [mm]
0.4
0.2
0.0
−0.2
−0.4
0
5
10
15
20
25
30
35

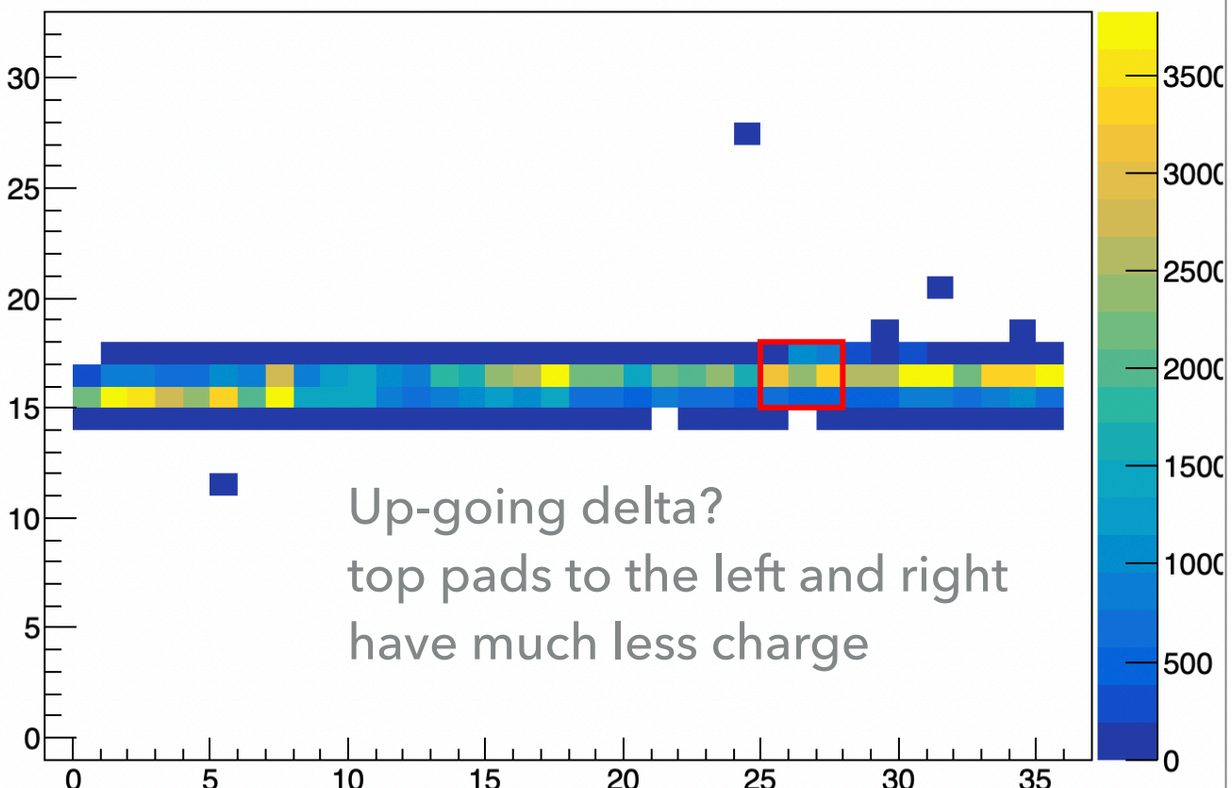

Charge [a.u.]
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35

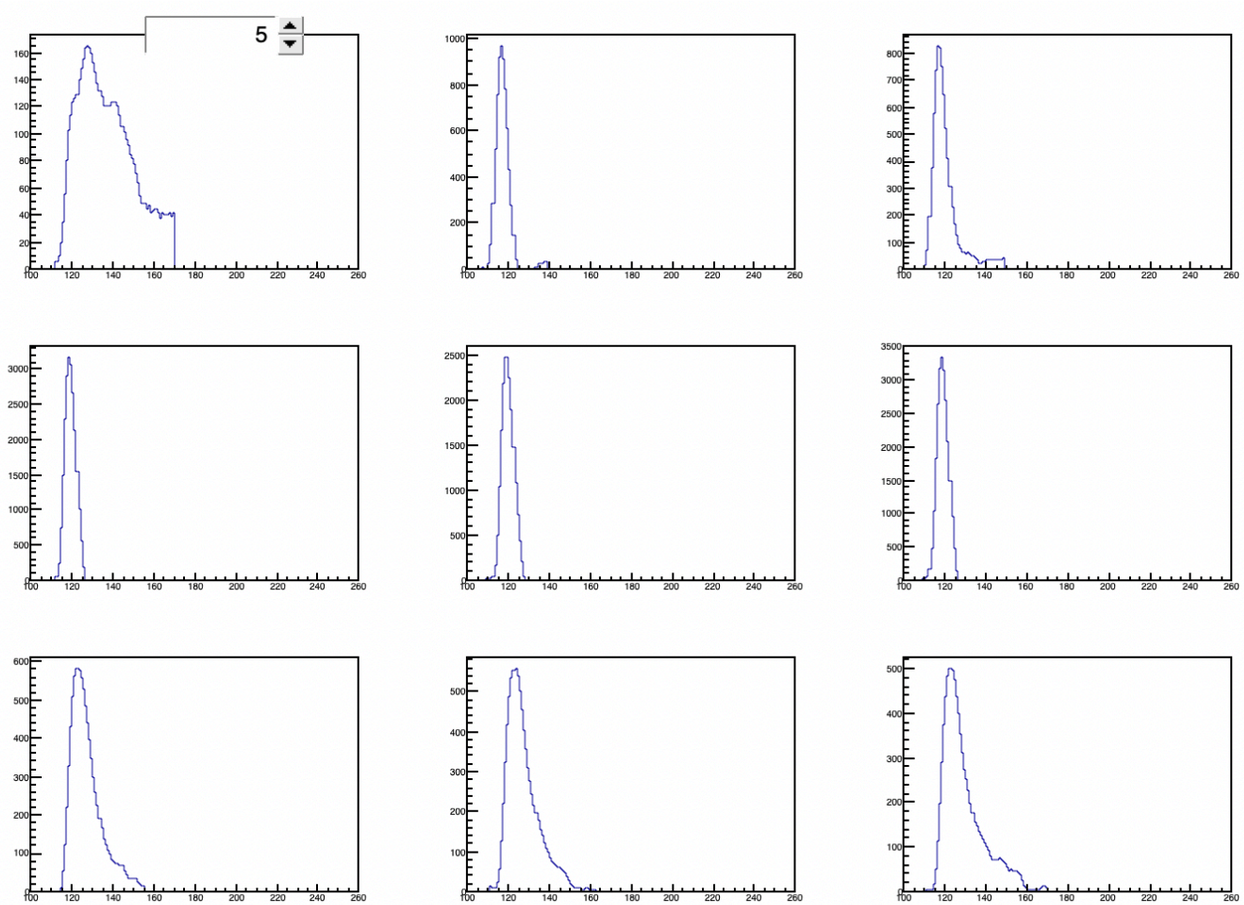

Column 24, 26 are omitted,
but the neighbour 25 is corrupted


33

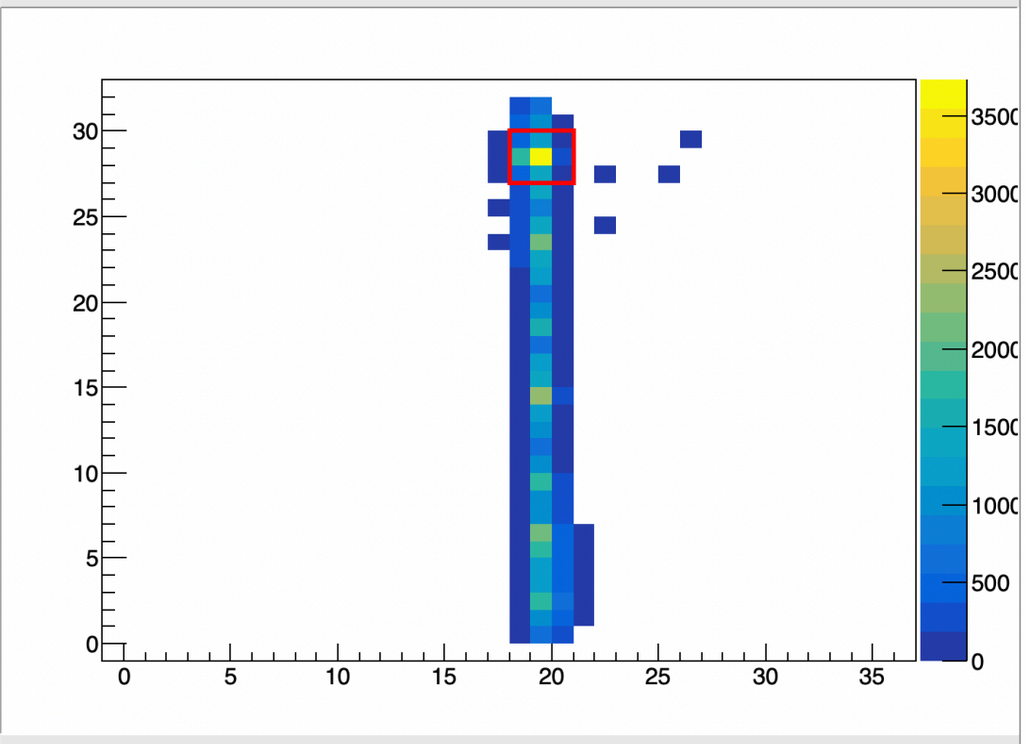

Residual [mm]
5
4
3
2
1
0
−1
0
5
10
15
20
25
30
35

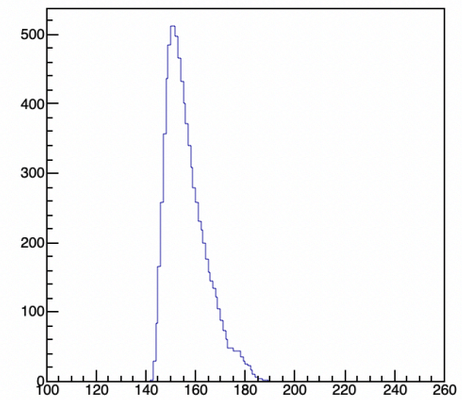

Charge [a.u.]
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
35

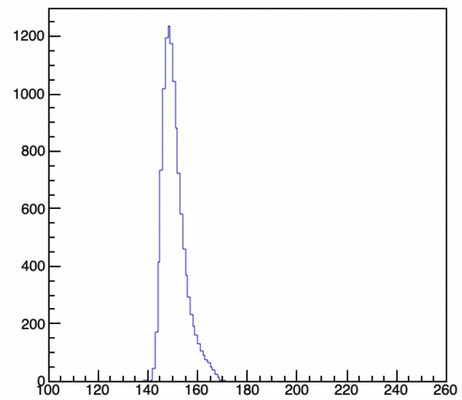

30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
3500
3000
2500
2000
1500
1000
500
0
Up-going delta?
top pads to the left and right
have much less charge

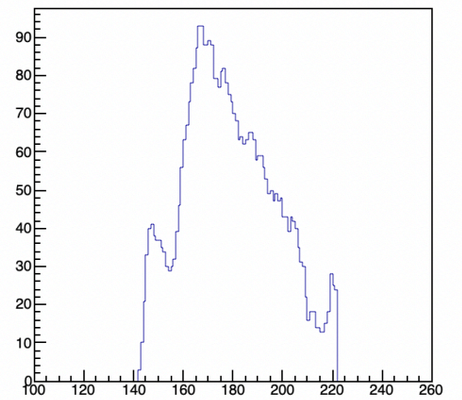

5

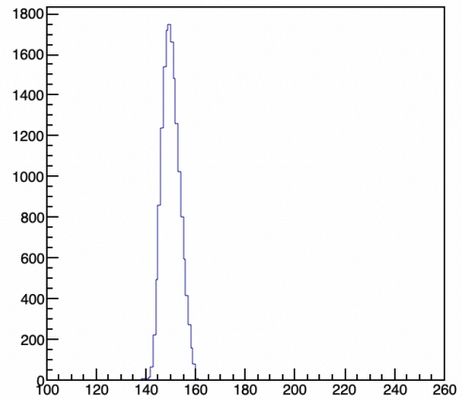
Text


0
5
10
15
20
25
30
35
3500
3000
2500
2000
1500
1000
500
0


0
100
200
300
400
500
100
120
140
160
180
200
220
240
260


0
200
400
600
800
1000
1200
100
120
140
160
180
200
220
240
260


0
10
20
30
40
50
60
70
80
90
100
120
140
160
180
200
220
240
260


0
200
400
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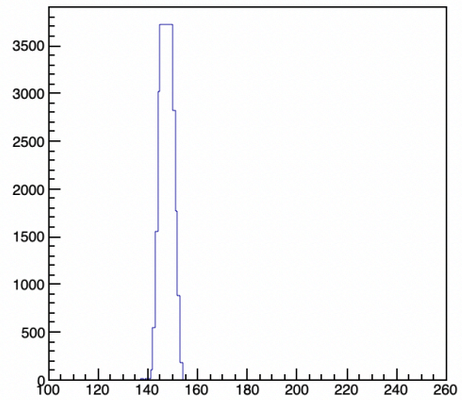
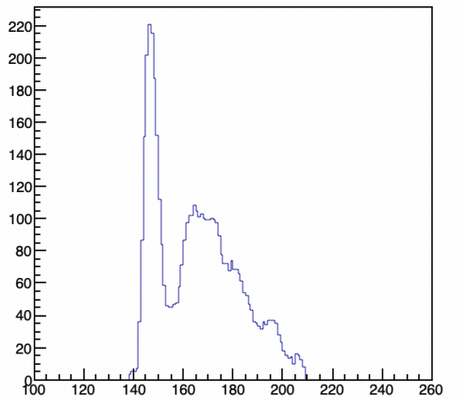
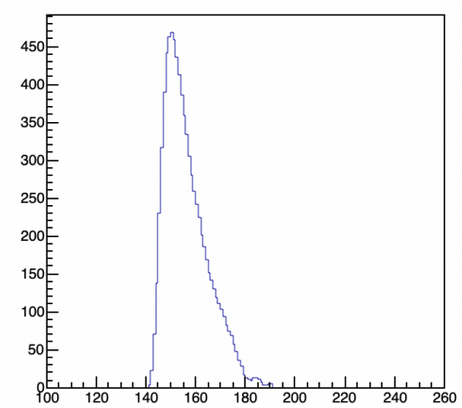
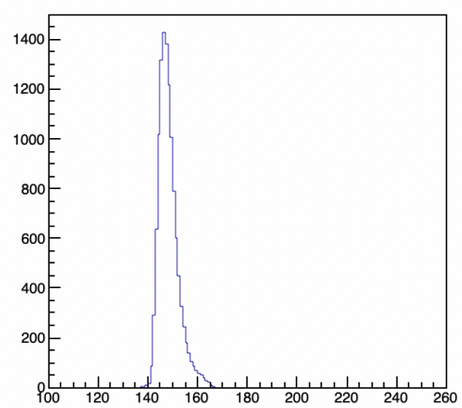
800
1000
1200
1400
1600
1800
100
120
140
160
180
200
220
240
260


0
500
1000
1500
2000
2500
3000
3500
100
120
140
160
180
200
220
240
260


0
20
40
60
80
100
120
140
160
180
200
220
240
260


0
50
100
150
200
250
300
350
400
450
100
120
140
160
180
200
220
240
260


0
200
400
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1200
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100
120
140
160
180
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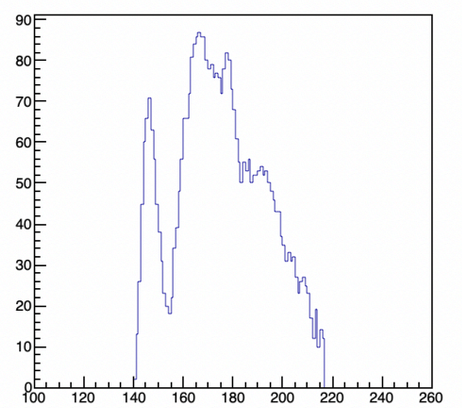
220
240
260


0
10
20
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40
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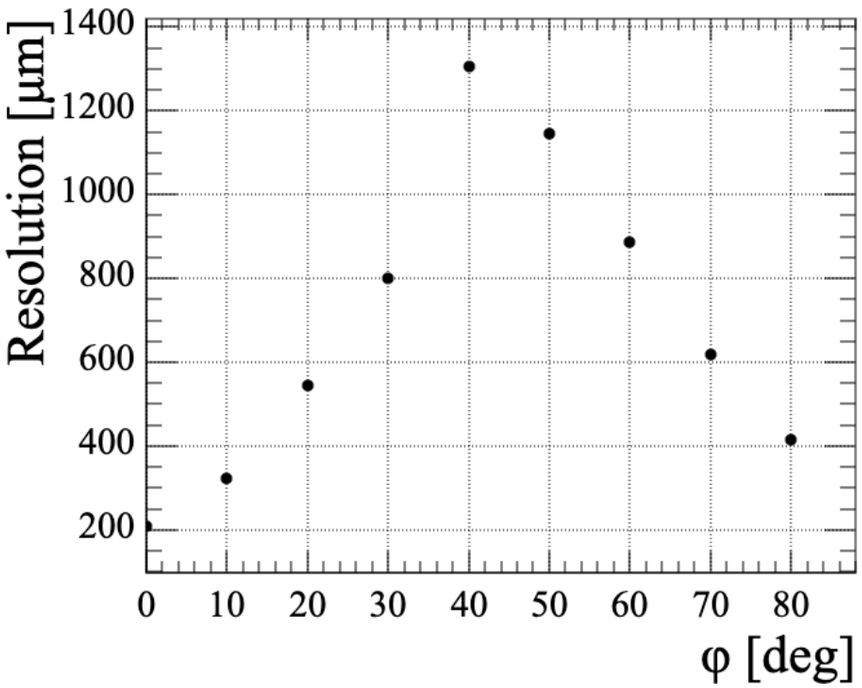
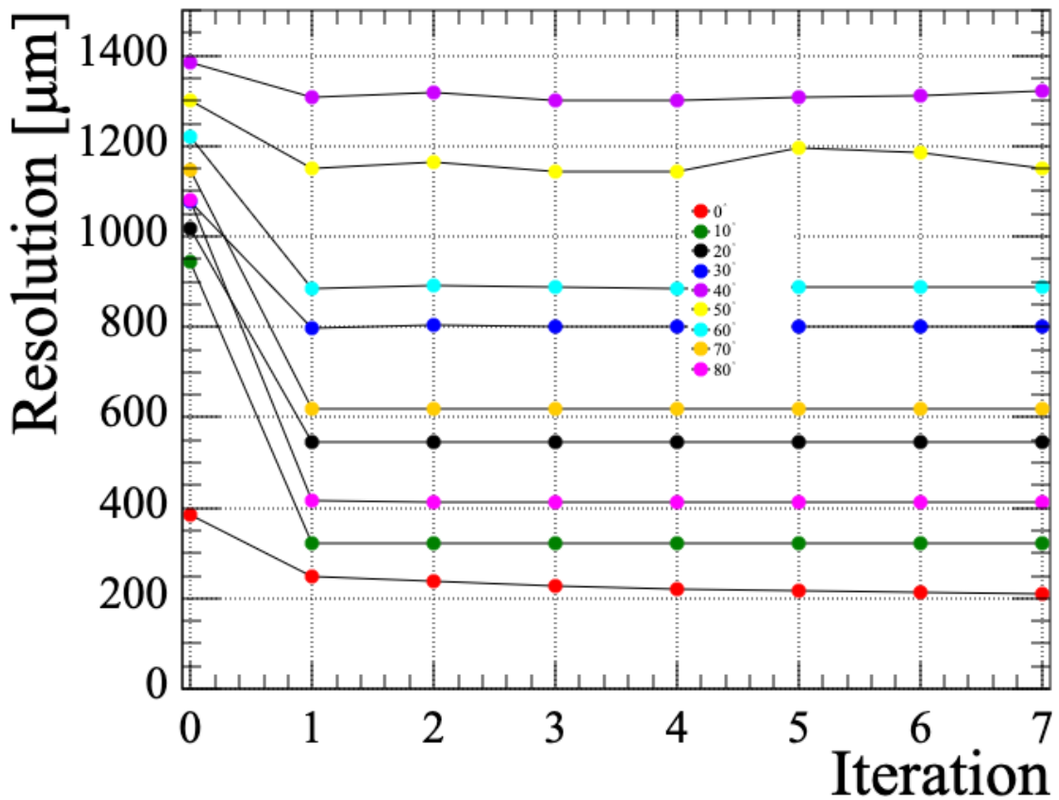
60
70
80
90
100
120
140
160
180
200
220
240
260


Resolution [μm]
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
φ [deg]


Resolution [μm]
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
Iteration
0°
10°
20°
30°
40°
50°
60°
70°
80°