Wedge Absorber

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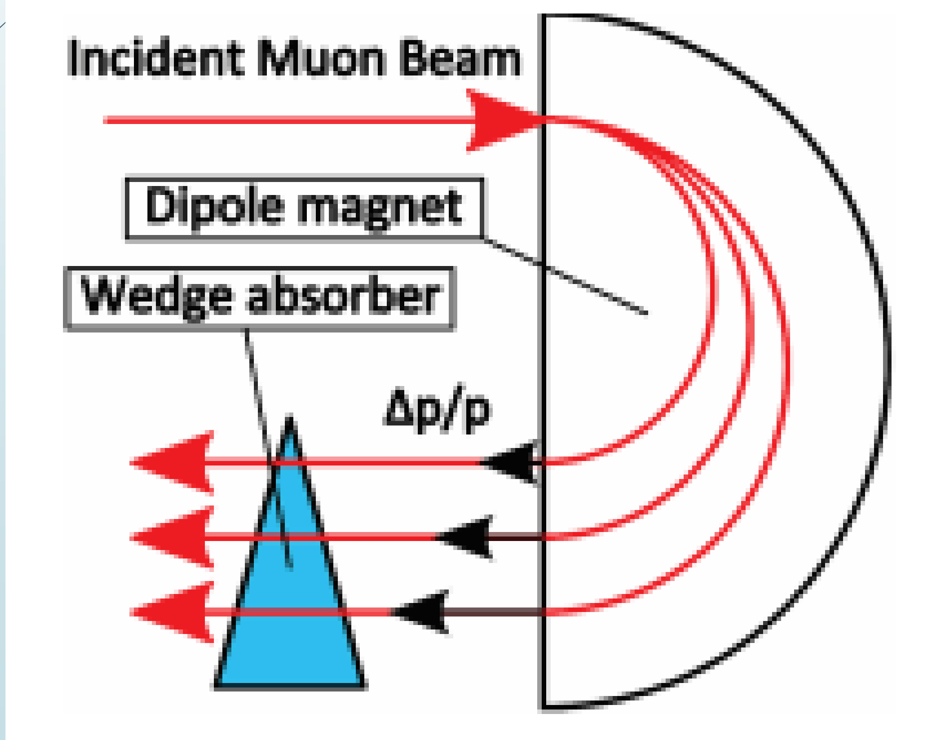
Aims

- Demonstrate Emittance Exchange in the Wedge using MICE data
- Number of techniques: KDE, KNN, Voronoi Tessellations, etc.
- Use beam reweighing techniques



Weighting by beam moment EPAC08 – Chris Rogers

- Input Distribution $f(\vec{x})$
- Desired Output Distribution $g(\vec{x})$
- Multidimensional phase-space vector $\vec{x}$
- Polynomial weighting function $w(\vec{x})$, where

$$w(\vec{x}) = 1 + \sum a_{i1}(x_{i1}) + \sum a_{i1i2}(x_{i1}x_{i2}) + \sum a_{i1i2i3}(x_{i1}x_{i2}x_{i3}) + \cdots$$

Such that

$$g(\vec{x}) = N\left(1 + \sum a_{i1}(x_{i1}) + \sum a_{i1i2}(x_{i1}x_{i2}) + \sum a_{i1i2i3}(x_{i1}x_{i2}x_{i3}) + \cdots\right) f(\vec{x})$$

- Denote moments of distribution $f(\vec{x})$, $< x_{i1}x_{i2} \ldots x_{in} >$ by $V^{f}_{i1i2\ldots in}$

Weighting by beam moment EPAC08 – Chris Rogers

- Denote moments of distribution $f(\vec{x})$, $< x_{i1}x_{i2} \ldots x_{in} >$ by $V^f_{i1i2\ldots in}$
- The n^th moment of the function $g(\vec{x})$, $V^g_{j1j2\ldots jn}$ can be written as

$$\frac{V^f_{j1\ldots jn} + \sum a_{i1}\left(V^f_{i1j1\ldots jn}\right) + \sum a_{i1i2}(V^f_{i1i2j1\ldots jn}) + \cdots}{1 + \sum a_{i1}\left(V^f_{j1\ldots jn}\right) + \sum a_{i1i2}\left(V^f_{j1\ldots jn}\right) + \cdots}$$

- Rearranging

$$V^g_{j1\ldots jn} - V^f_{j1\ldots jn} = \sum_{i1\ldots im} a_{i1\ldots im}\,(V^f_{i1\ldots imj1\ldots jn} - V^f_{i1\ldots im}V^g_{j1\ldots jn})$$

- Define $u_i = V^g_{j1\ldots jn} - V^f_{j1\ldots jn}$, $a_i = a_{i1\ldots im}$ and $M_{ij} = (V^f_{i1\ldots imj1\ldots jn} - V^f_{i1\ldots im}V^g_{j1\ldots jn})$

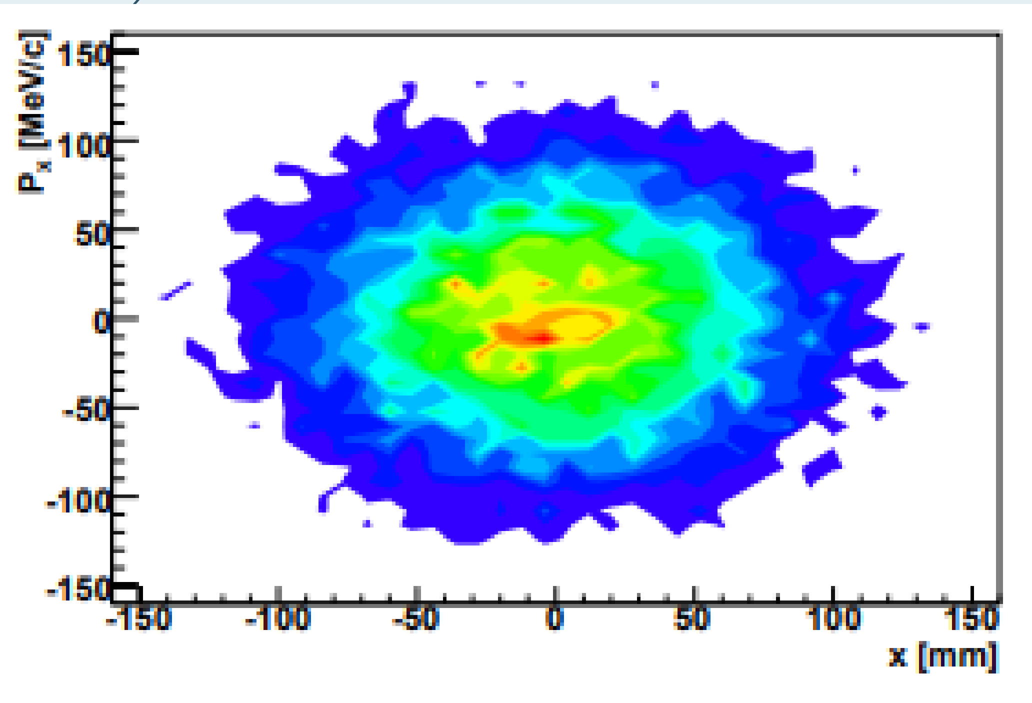
- Linear problem: $\boldsymbol{M}\vec{a} = \vec{u}$
- Which can be solved for polynomial coefficients $a_{i1\ldots in}$

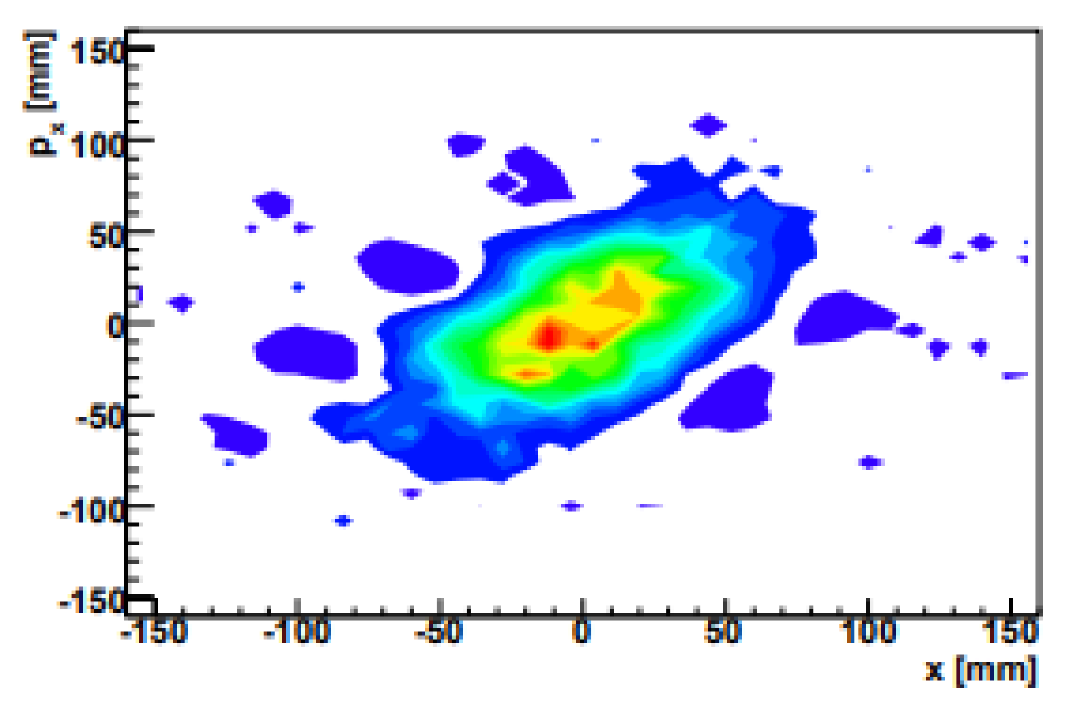
Weighting by beam moment EPAC08 – Chris Rogers

- 10000 particles sampled from Gaussian Distribution (left)
- Statistical weighting applied (right)

Initial: $\epsilon_x = 15mm,\ \beta_x = 334mm,\ \ \alpha_x = 0$

Final: $\epsilon_x = 4.2mm,\ \beta_x = 260mm,\ \ \alpha_x = -0.75$





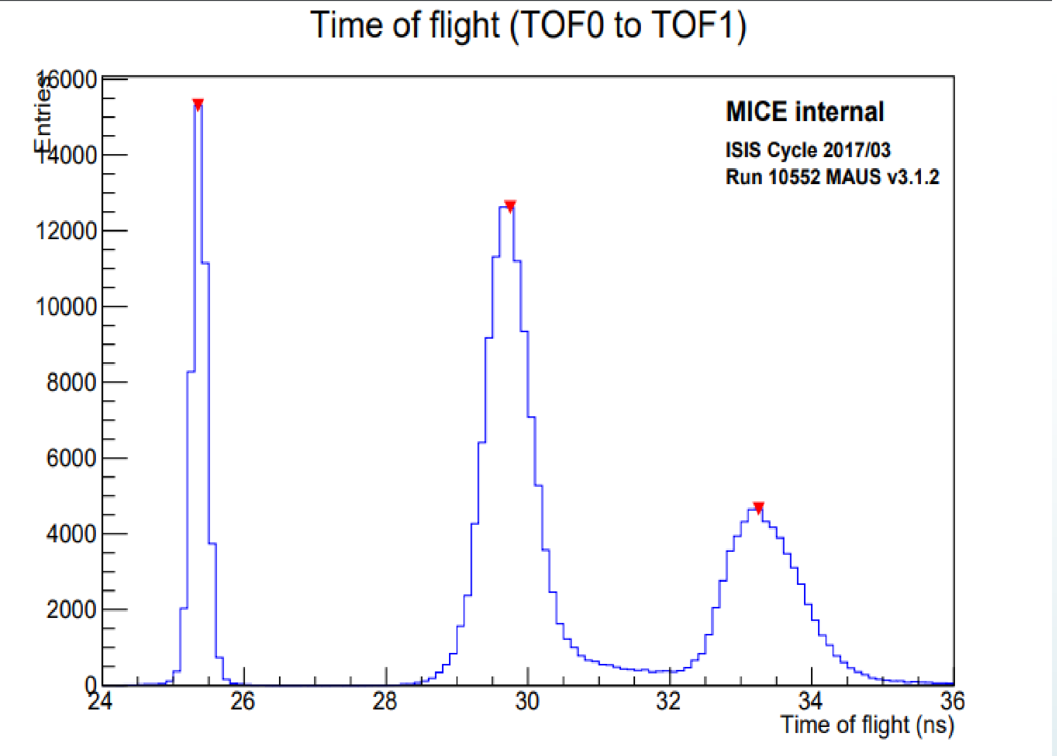
Beam Moments through the Wedge

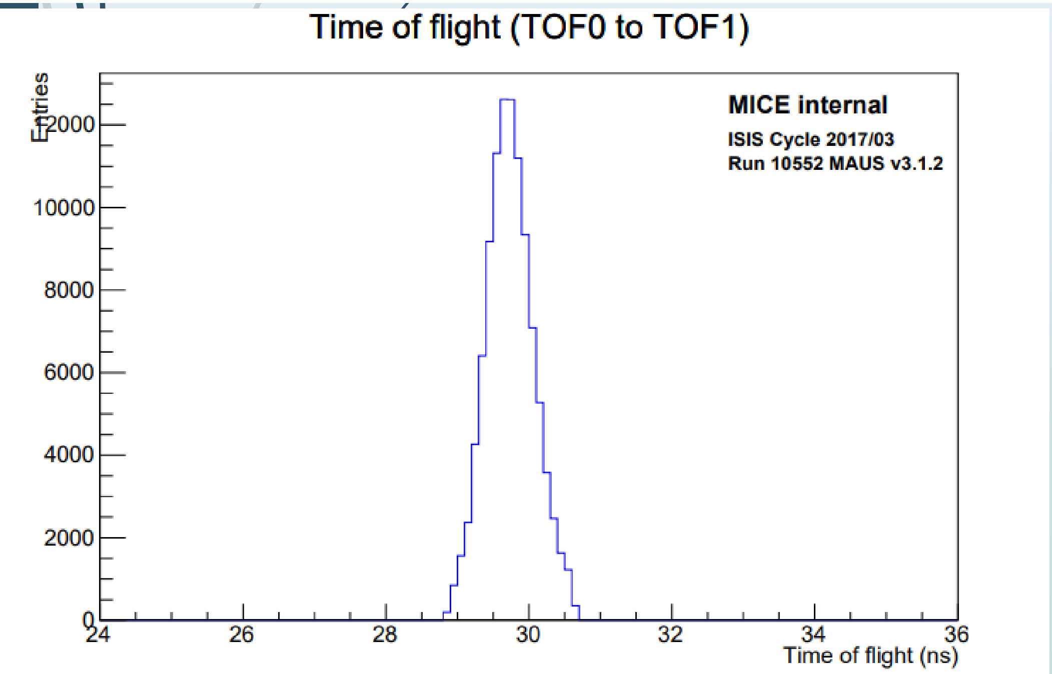
- Measurements at TKU and TKD reference plane
- Run Monte Carlo with Wedge and insert virtual planes
- See Evolution through Wedge and compare at TKD

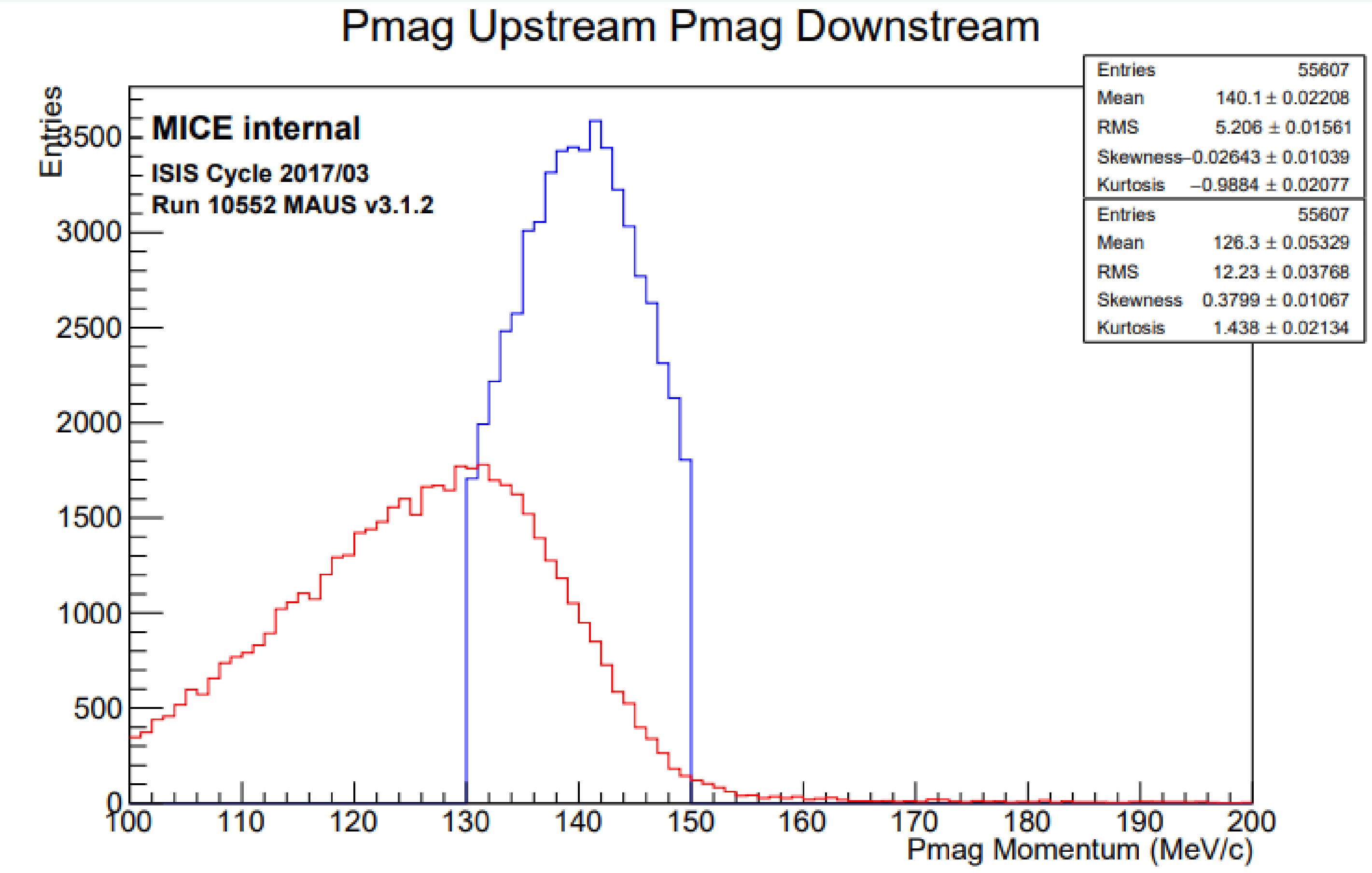
- Measurements after cuts are made at TKU used as input for MC
- TOF cut for muons
- TKU momentum cut 130 – 150 MeV/c
- Radius Cut upstream and downstream < 150 mm

- TKD momentum cut added (< 200MeV/c) to prevent incorrectly reconstructed particles skewing the calculated moments

TOF and momentum cut







Beam Moments through the Wedge

- Use Scipy to calculate the moments, where E is the expectation operator:

$$\mu_n = E[(X - E[X])^n] = \int_{-\infty}^{+\infty} (x-\mu)^n f(x)dx$$

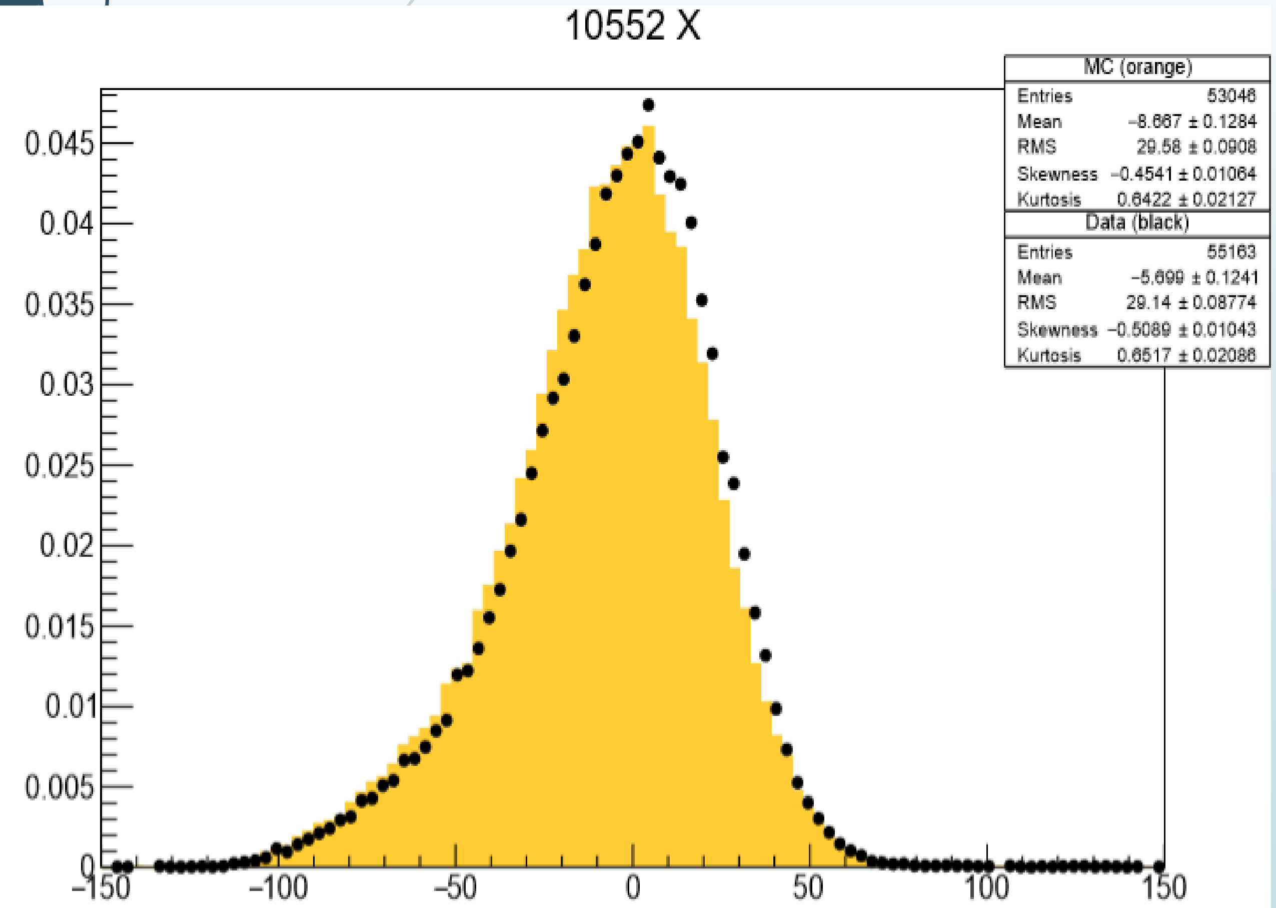
- Will display data in terms of Mean, RMS, Skew and Kurtosis, where the coefficients of Skewness and Kurtosis are given by:

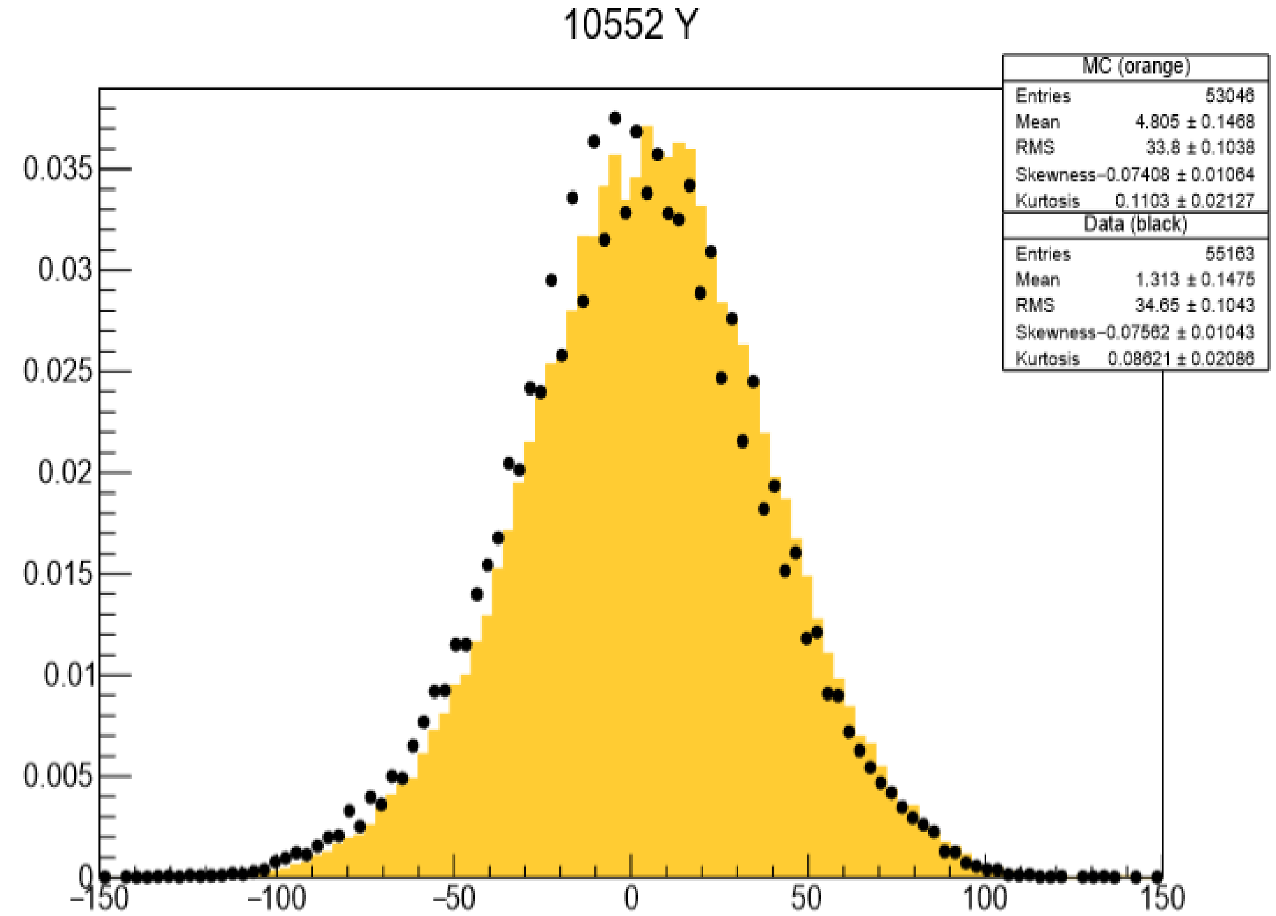
$$\gamma_1 = \frac{\mu_3}{\mu_2^{3/2}}$$

$$\gamma_2 = \frac{\mu_4}{\mu_2^2} - 3$$

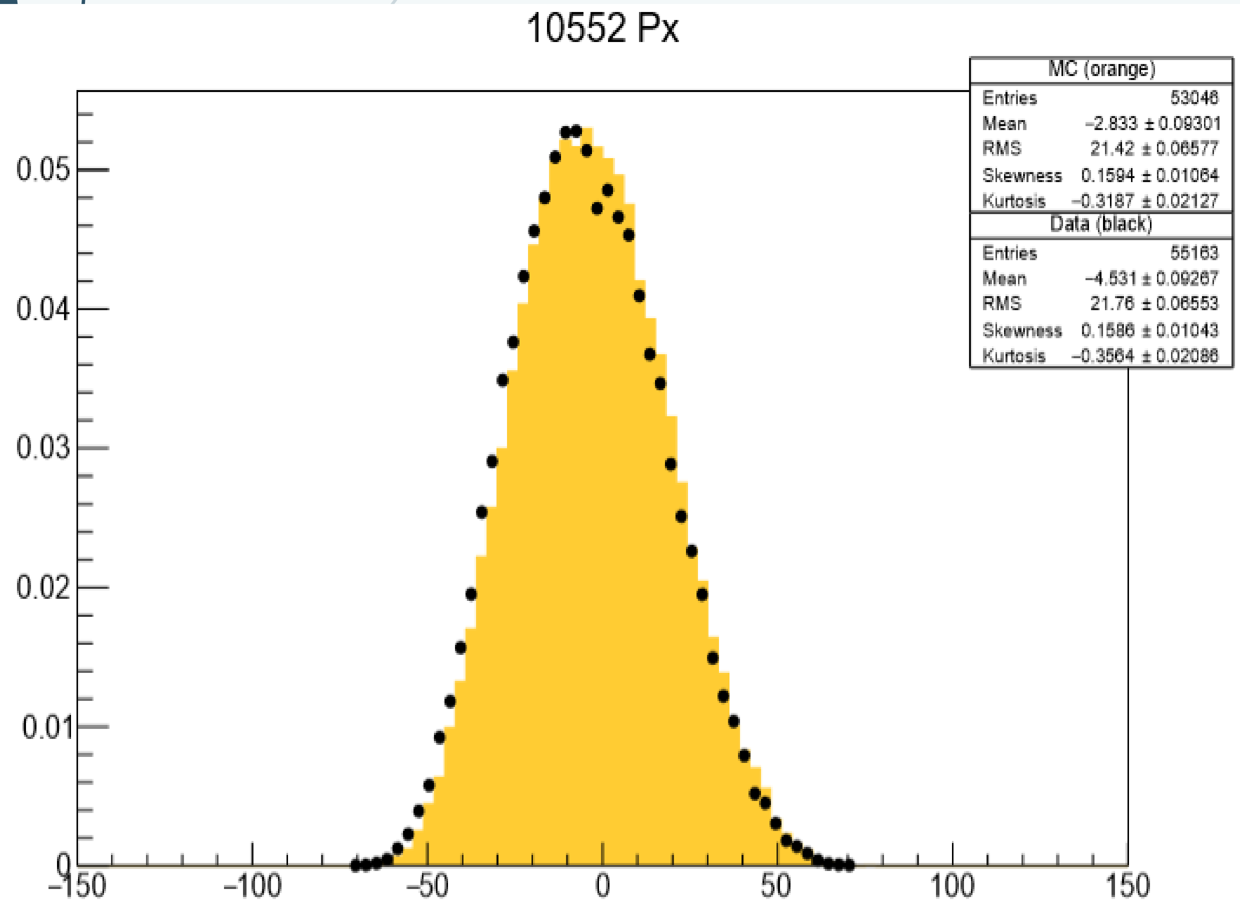
- For Gaussian distribution $\gamma_1 = 0$ and $\gamma_2 = 0$

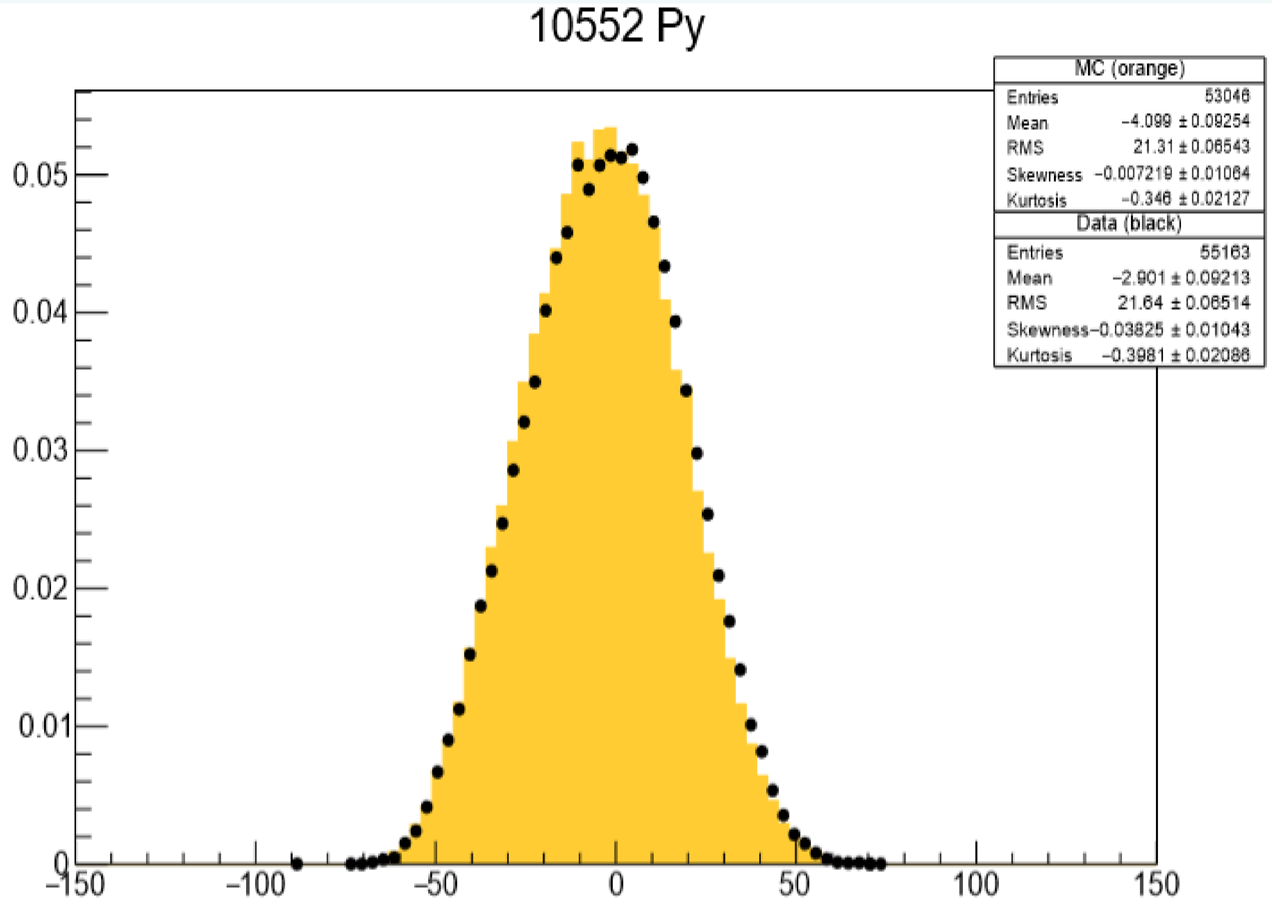
6 – 140 beam TKD MC vs Data 10552

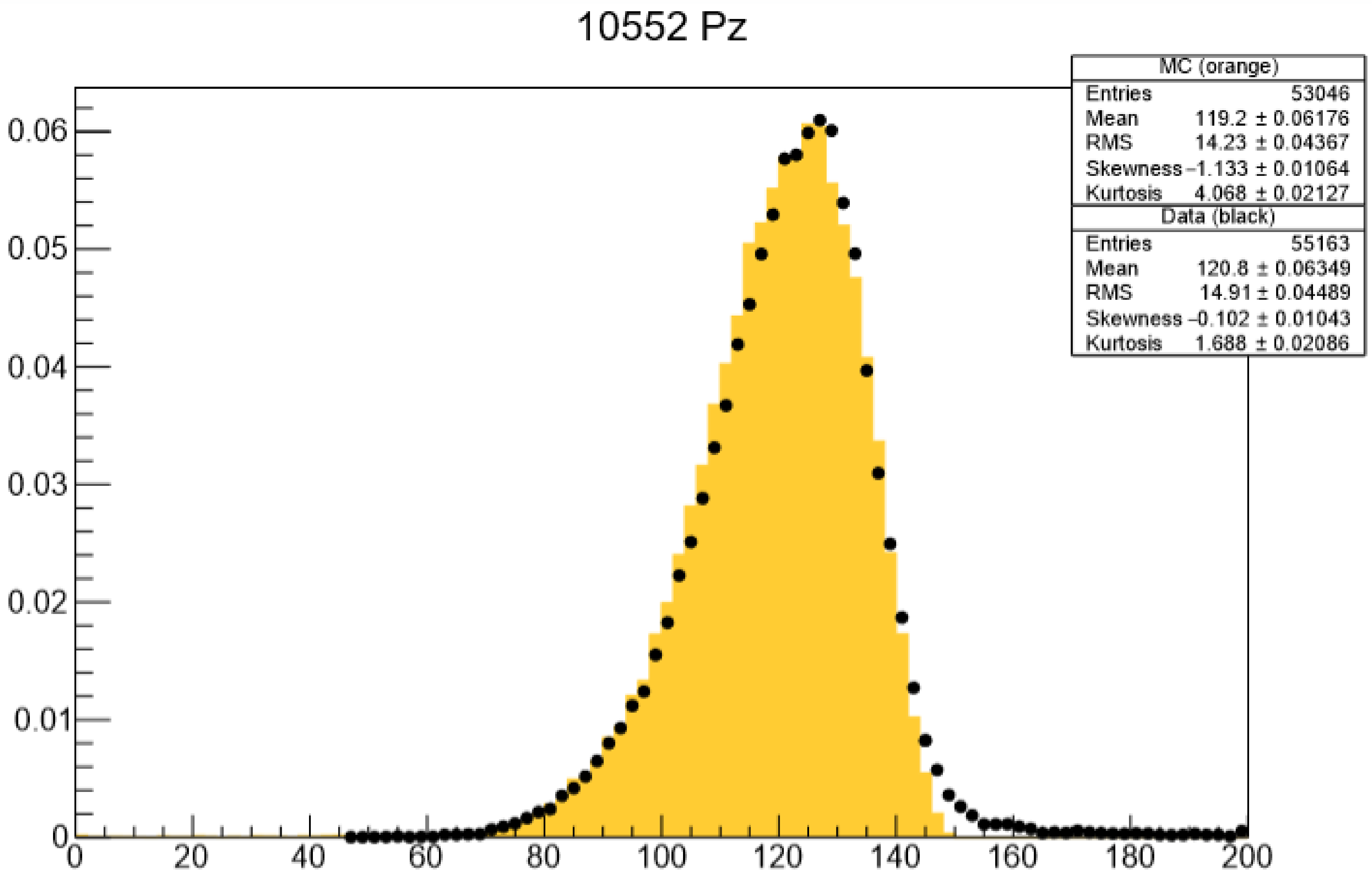


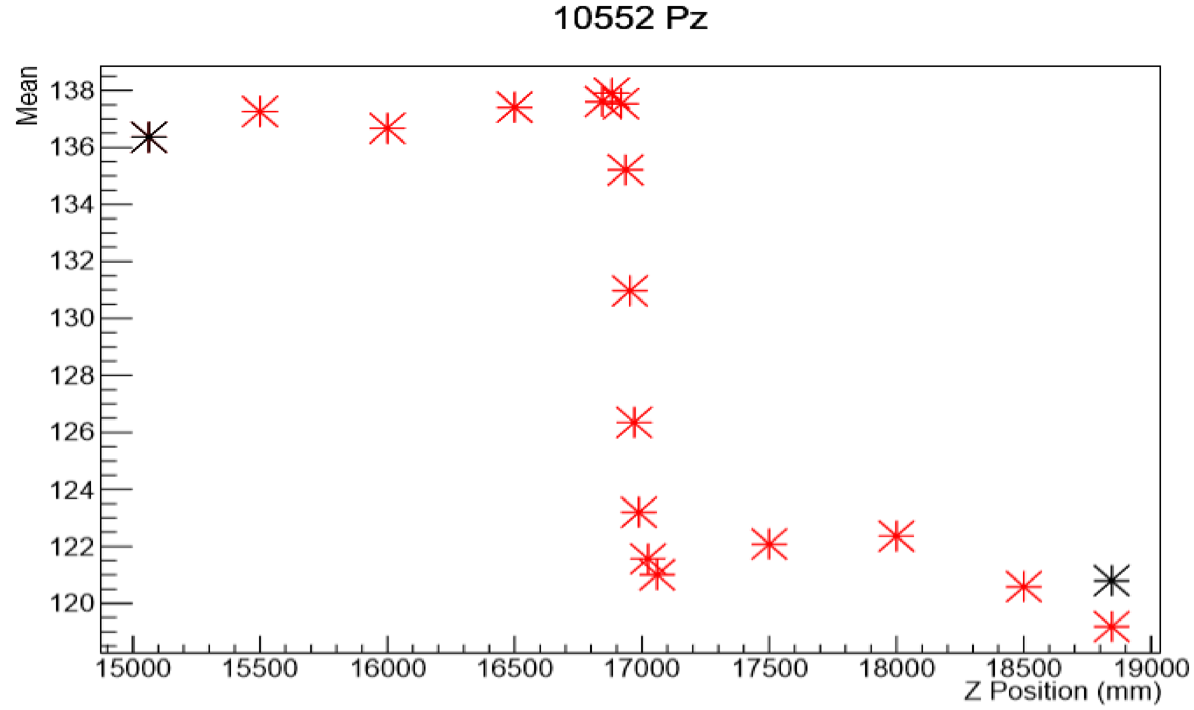


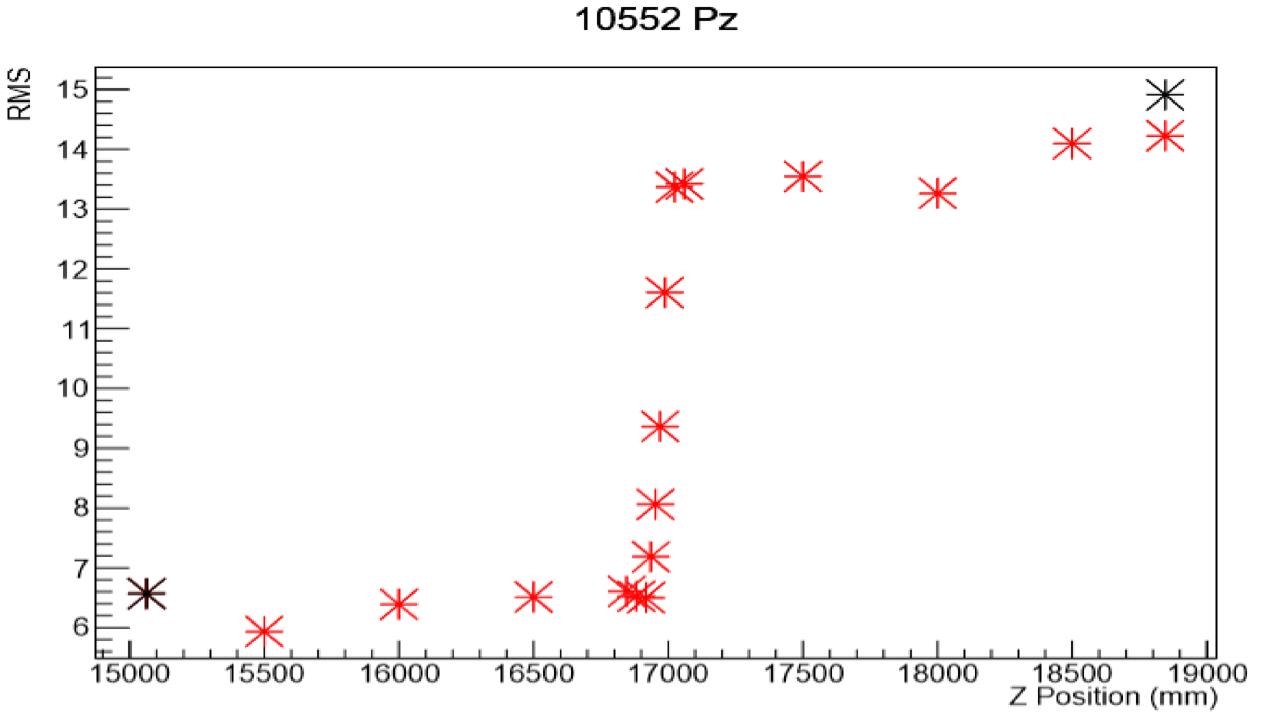
6 – 140 beam TKD MC vs Data 10552

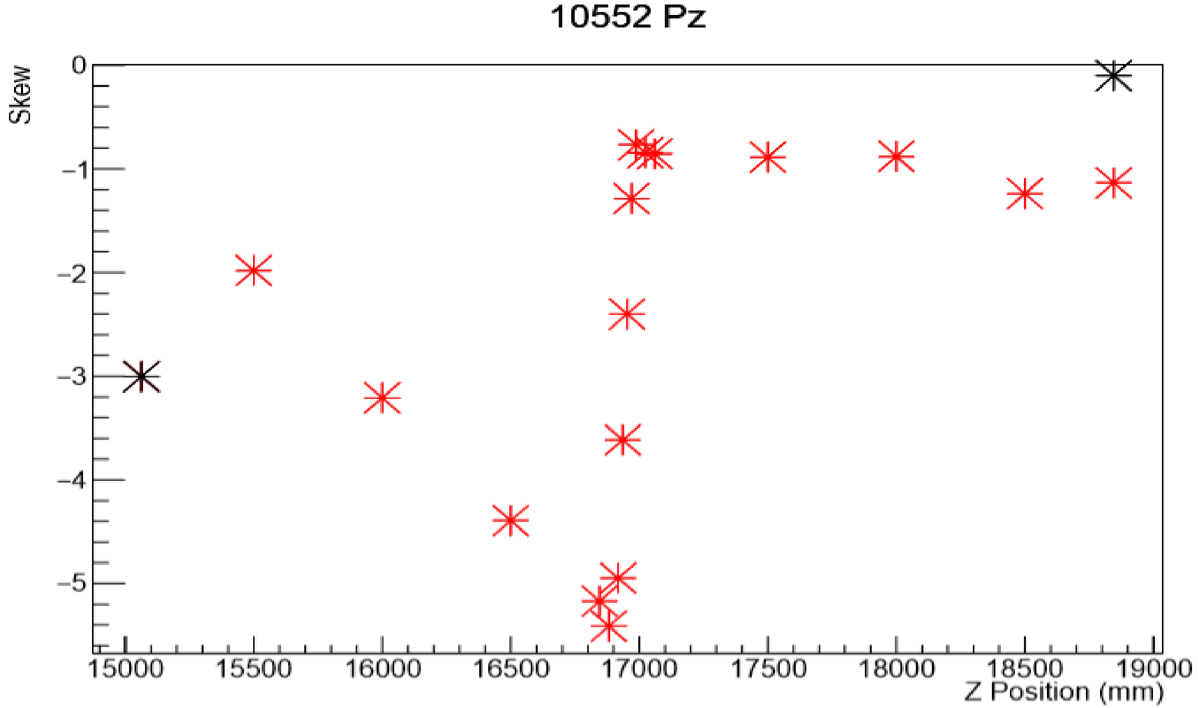


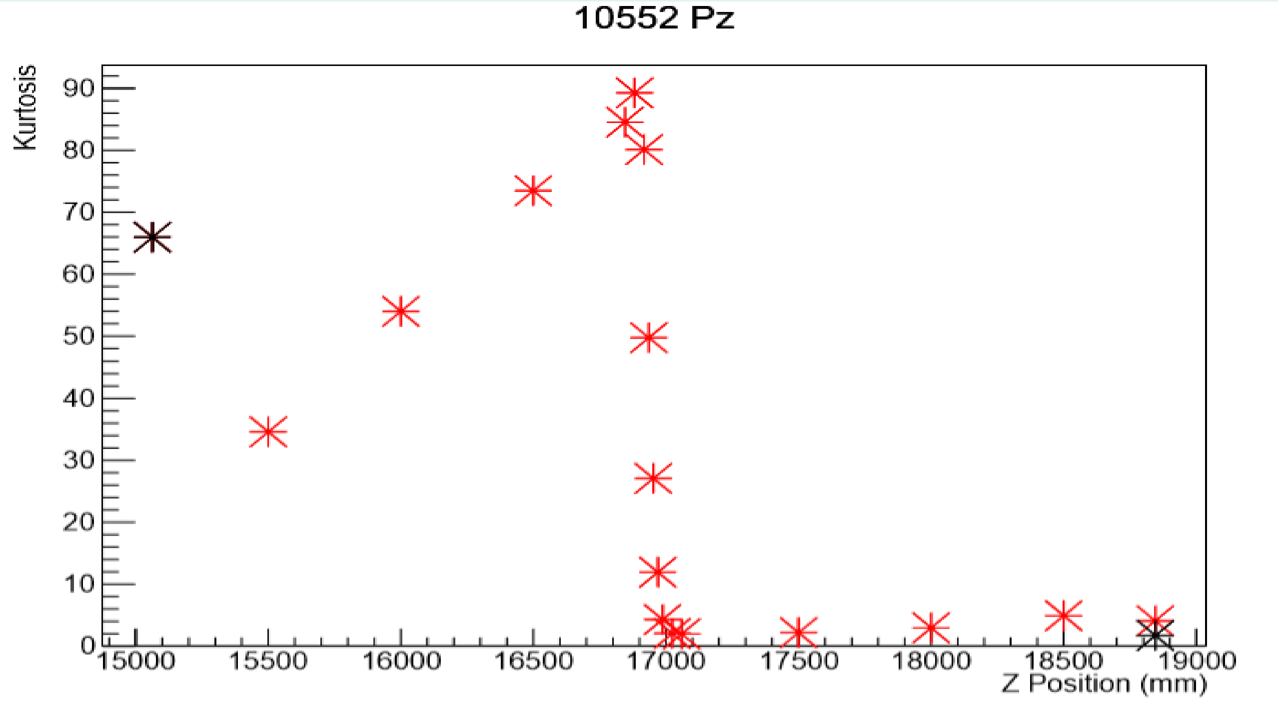


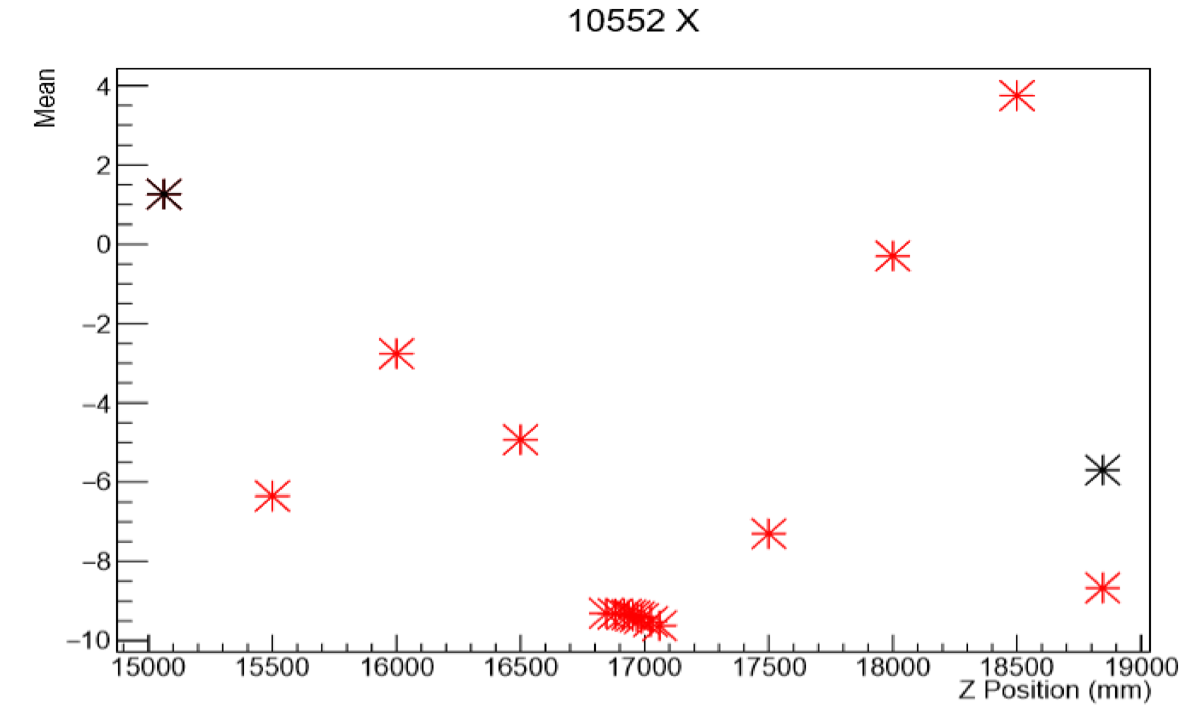

10552 Pz
MC (orange)
Entries 53046
Mean 119.2 ± 0.06176
RMS 14.23 ± 0.04367
Skewness −1.133 ± 0.01064
Kurtosis 4.068 ± 0.02127
Data (black)
Entries 55163
Mean 120.8 ± 0.06349
RMS 14.91 ± 0.04489
Skewness −0.102 ± 0.01043
Kurtosis 1.688 ± 0.02086
0.06
0.05
0.04
0.03
0.02
0.01
0
0 20 40 60 80 100 120 140 160 180 200

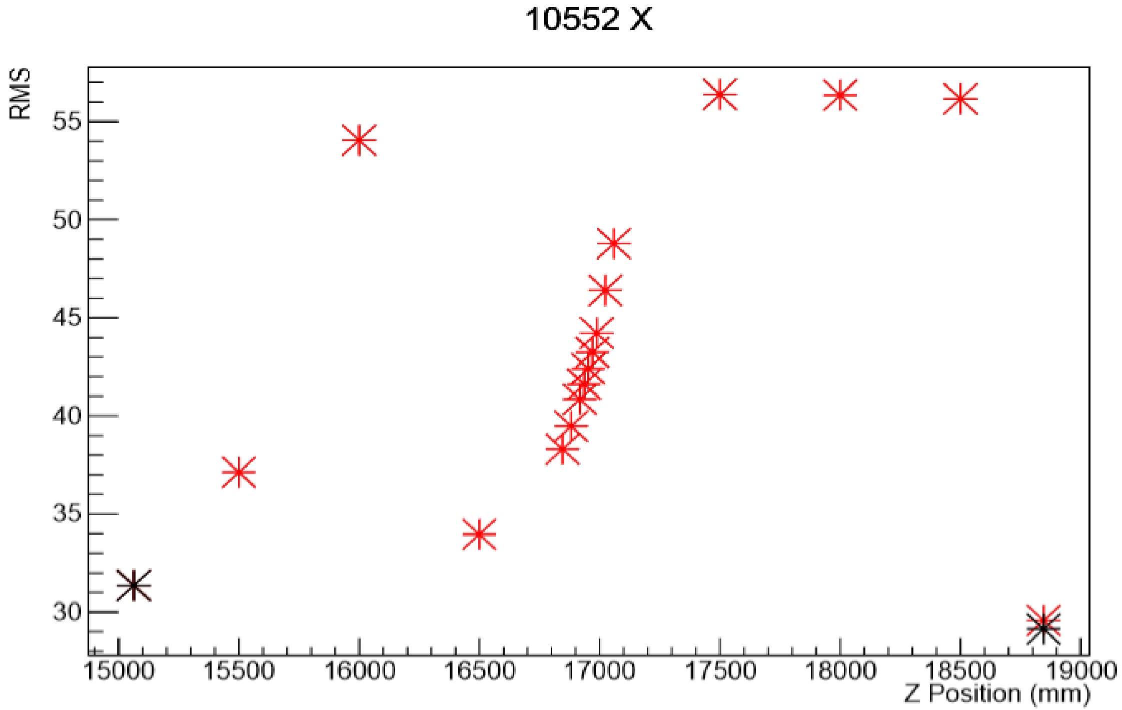

10552 Pz
Mean
138
136
134
132
130
128
126
124
122
120
15000
15500
16000
16500
17000
17500
18000
18500
19000
Z Position (mm)

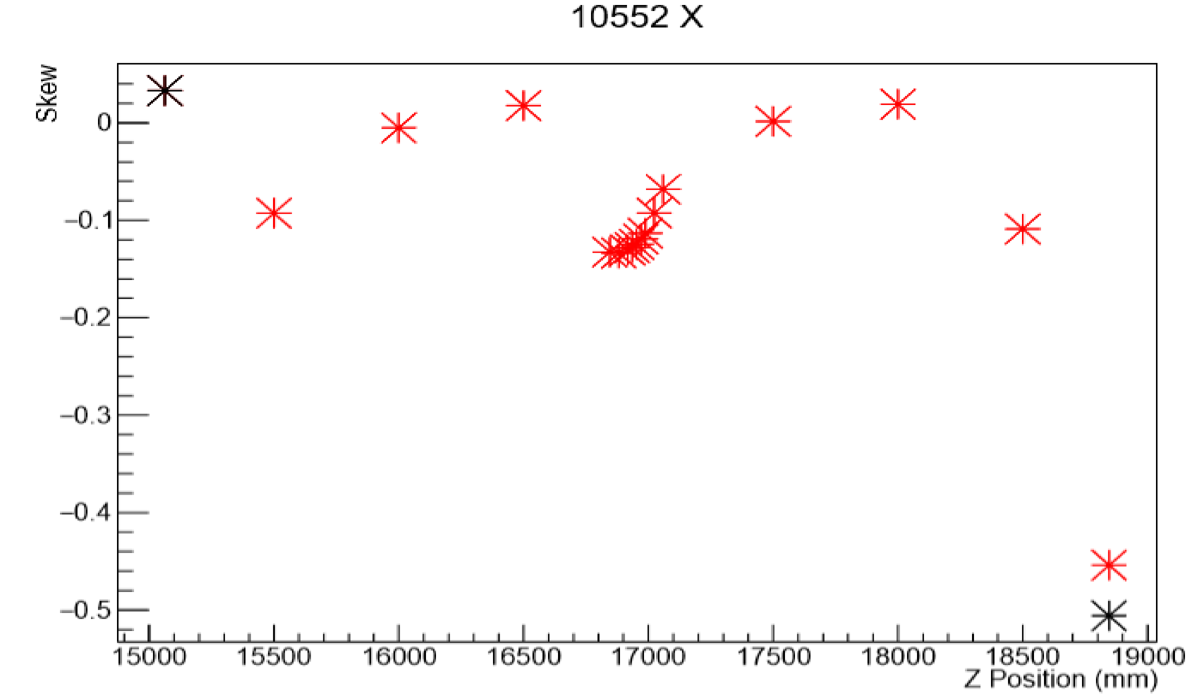

10552 Pz
RMS
15
14
13
12
11
10
9
8
7
6
15000
15500
16000
16500
17000
17500
18000
18500
19000
Z Position (mm)

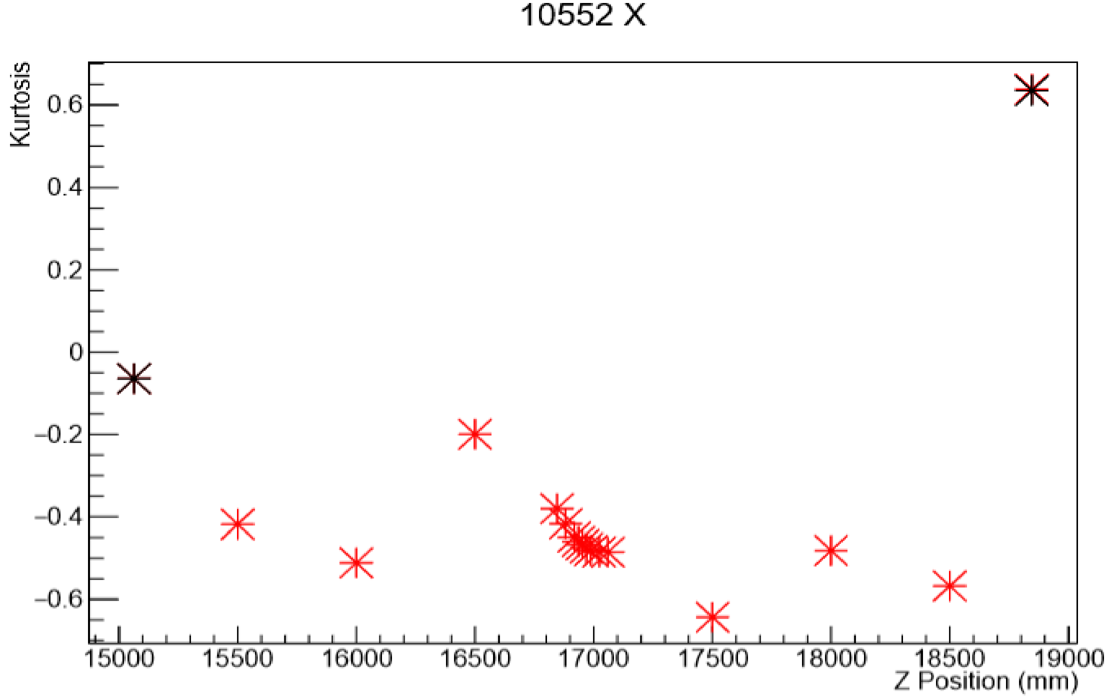

10552 Pz
Skew
0
−1
−2
−3
−4
−5
15000
15500
16000
16500
17000
17500
18000
18500
19000
Z Position (mm)

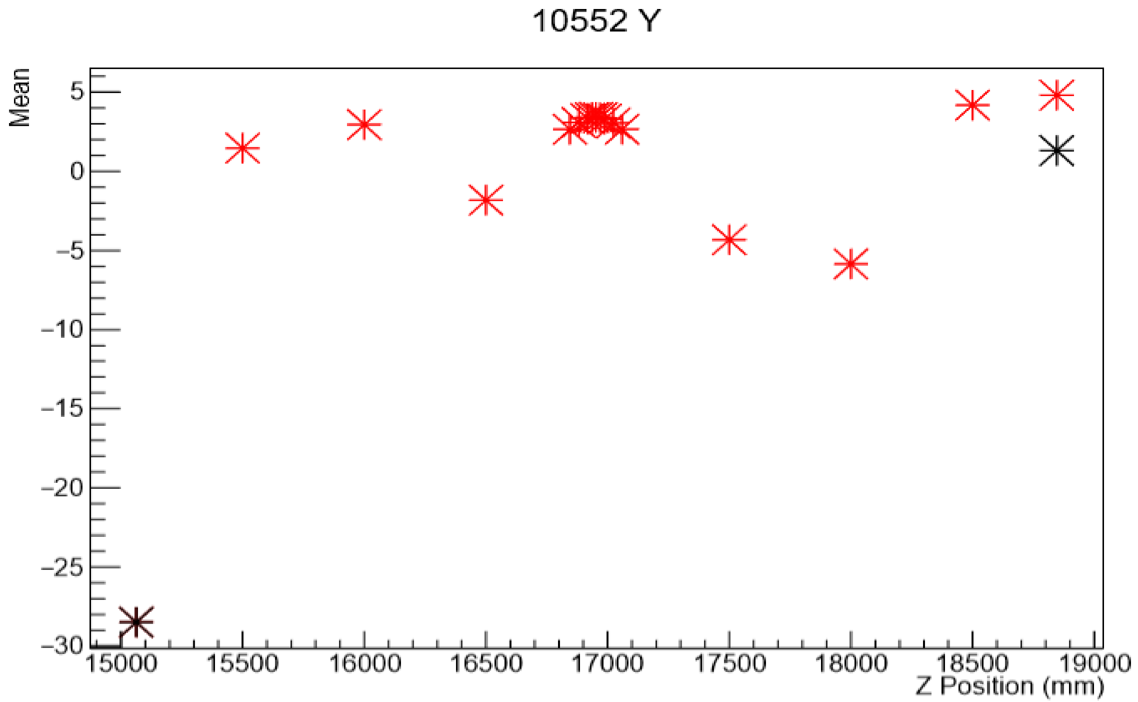

10552 Pz
Kurtosis
90
80
70
60
50
40
30
20
10
0
15000
15500
16000
16500
17000
17500
18000
18500
19000
Z Position (mm)

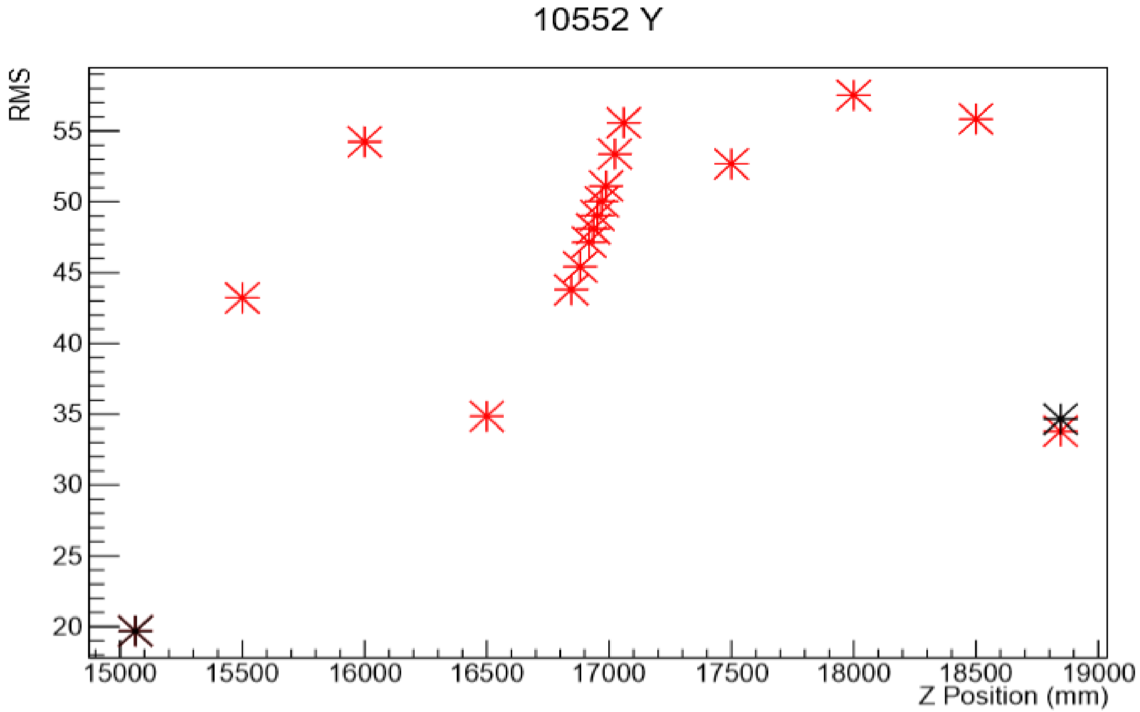

10552 X
Mean
Z Position (mm)

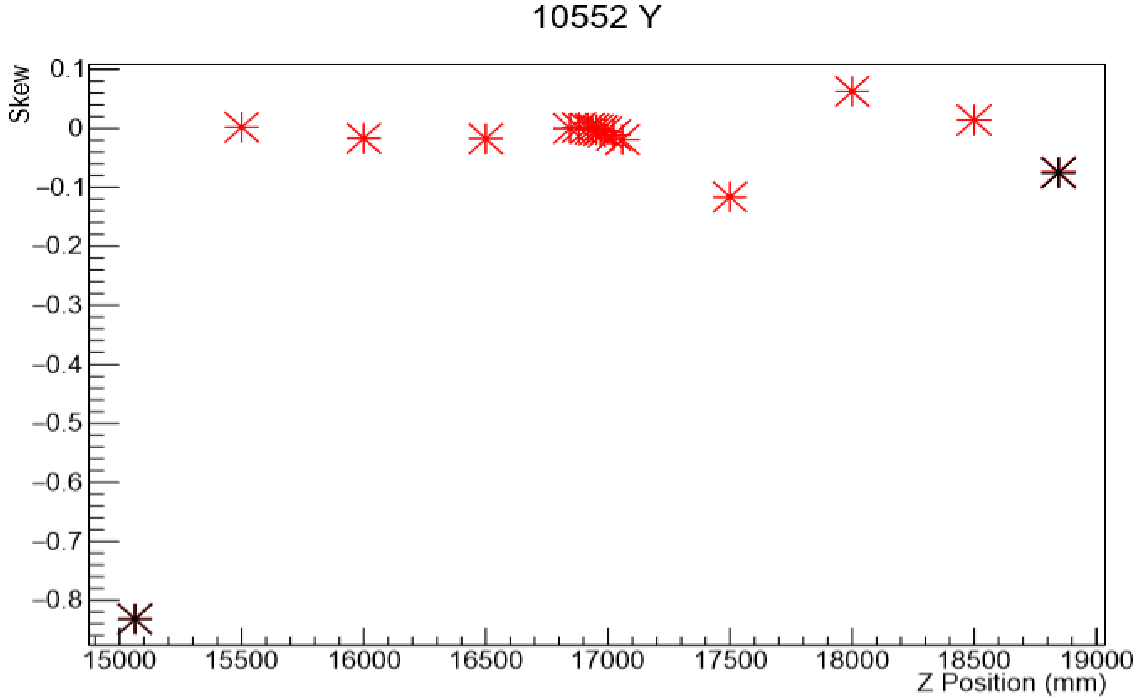

10552 X
RMS
Z Position (mm)

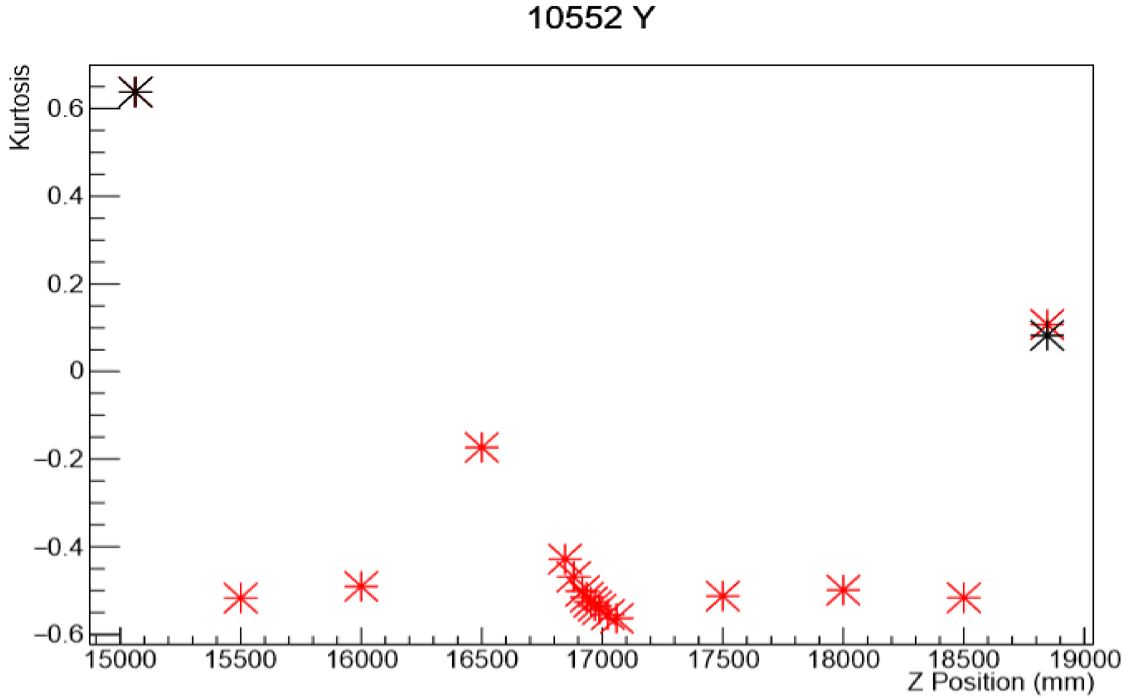

10552 X
Skew
Z Position (mm)

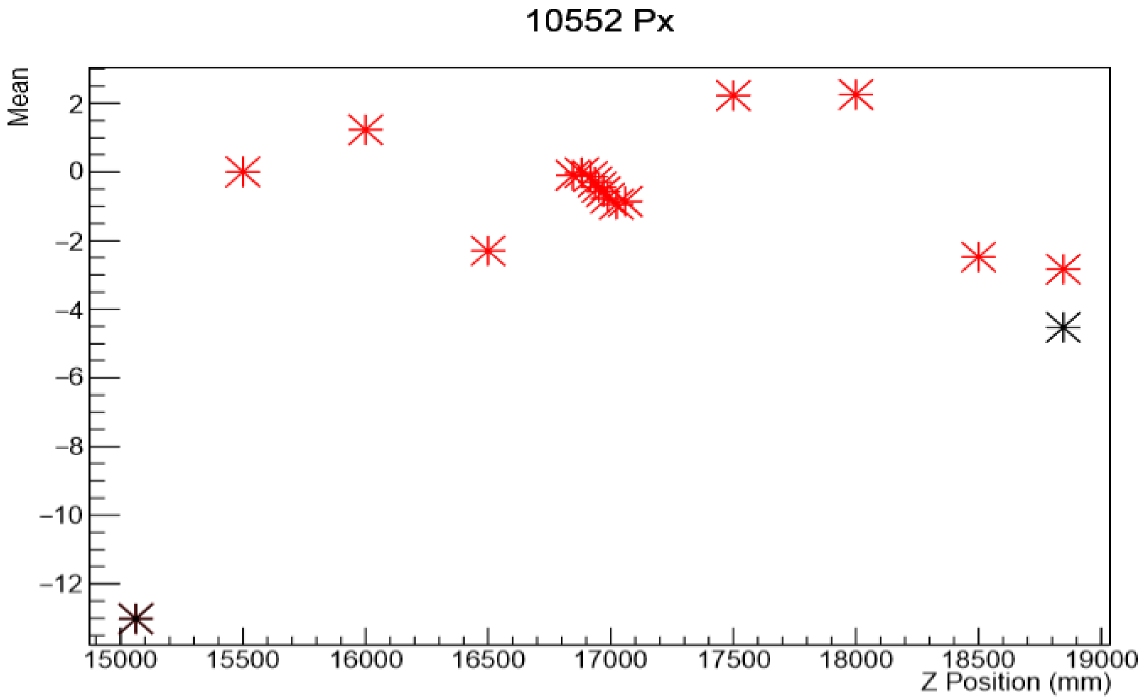

10552 X
Kurtosis
Z Position (mm)

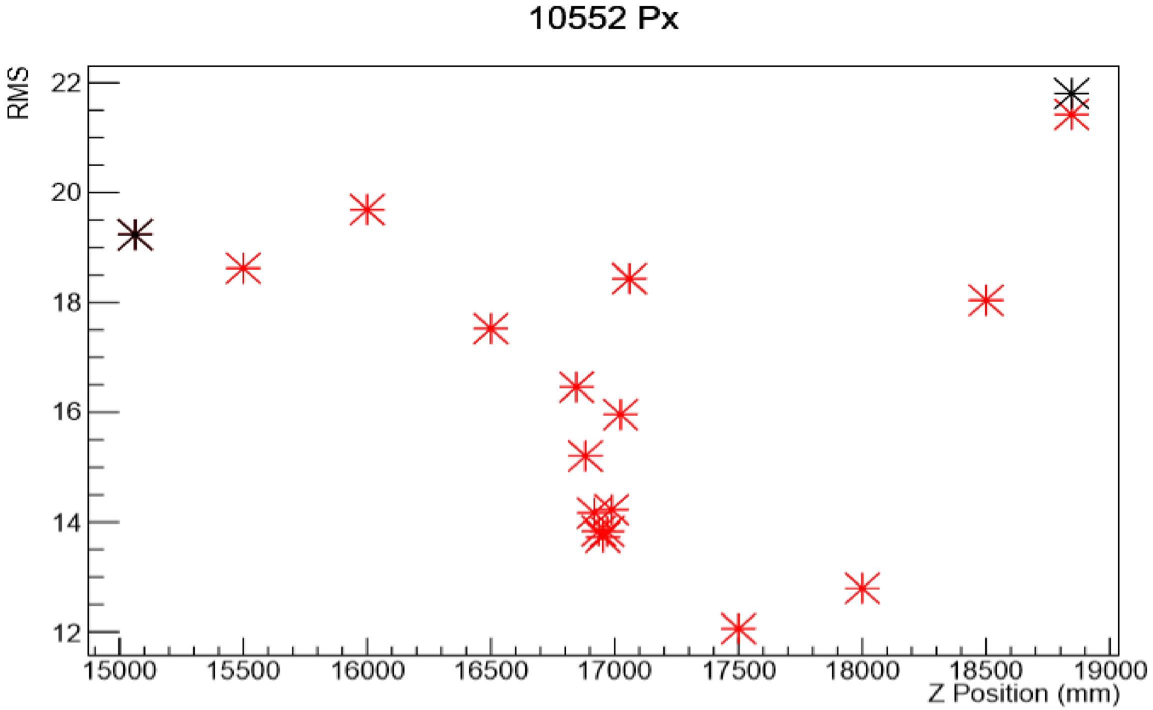

10552 Y
Mean
Z Position (mm)

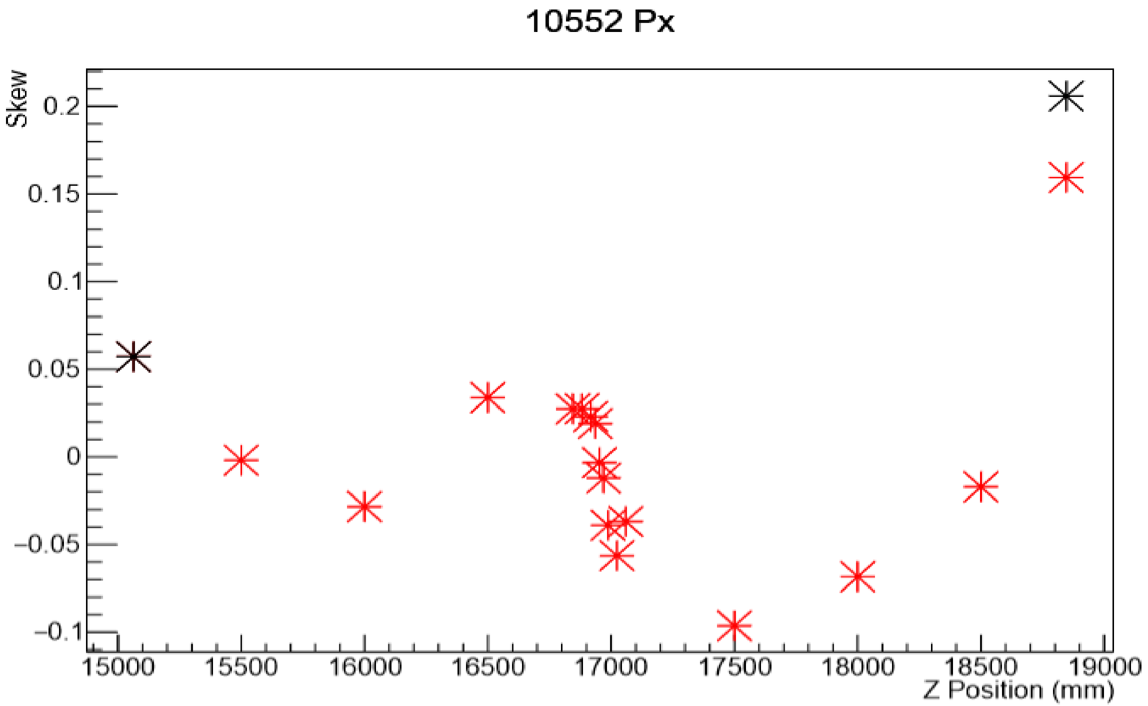

10552 Y
RMS
Z Position (mm)

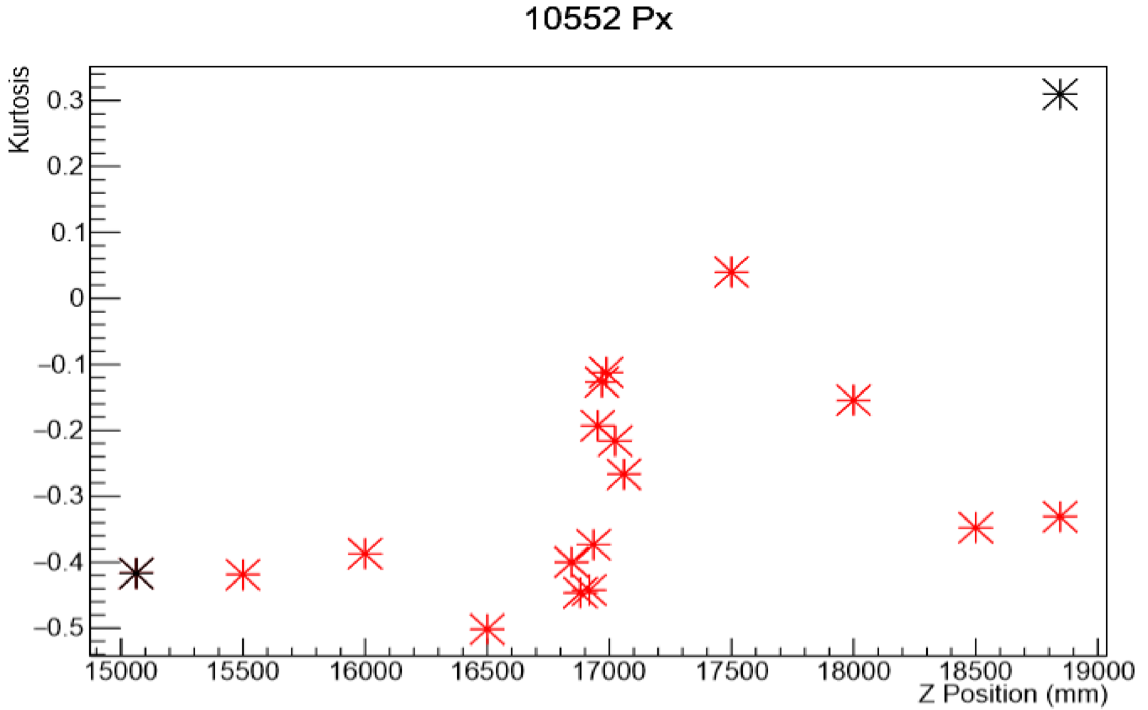

10552 Y
Skew
Z Position (mm)

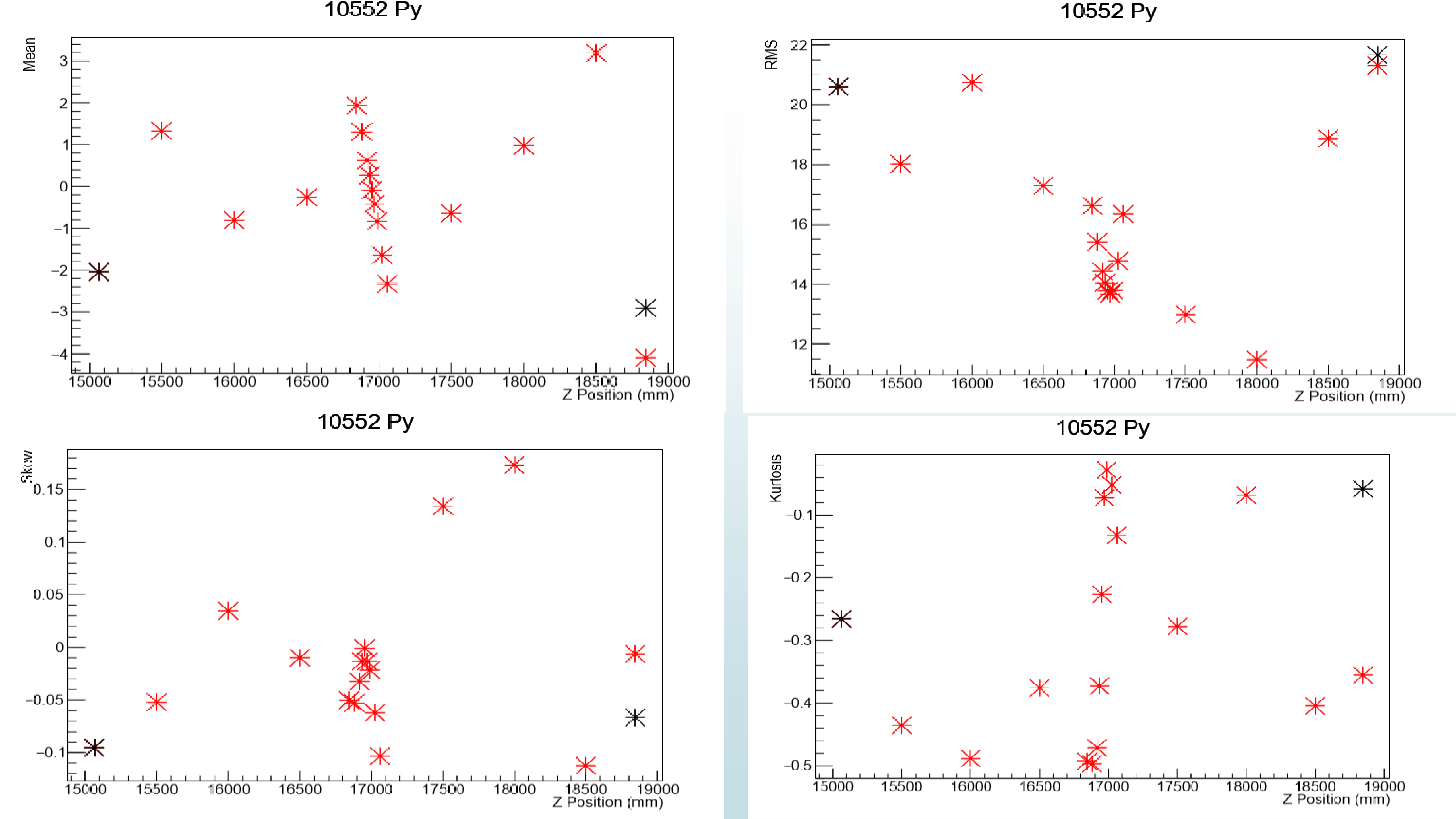

10552 Y
Kurtosis
Z Position (mm)


10552 Px
Mean
Z Position (mm)


10552 Px
RMS
Z Position (mm)

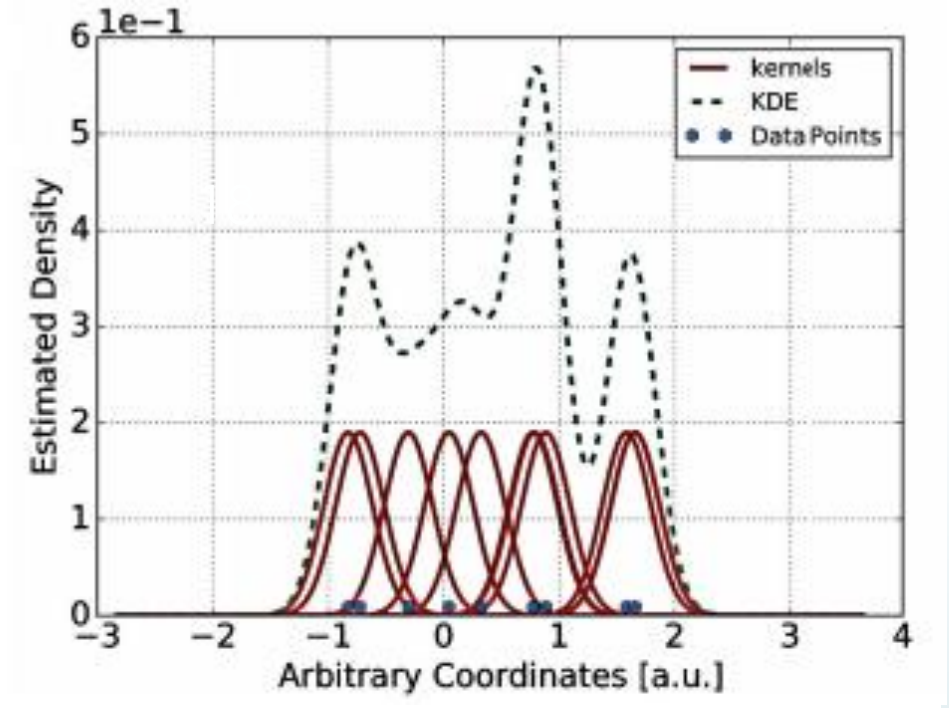

10552 Px
Skew
Z Position (mm)

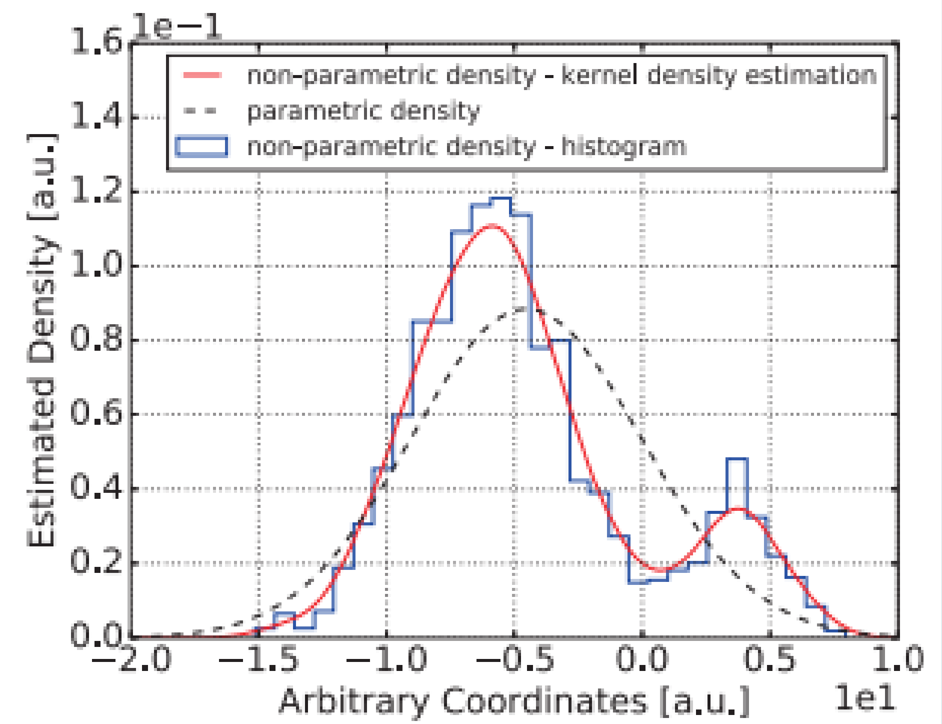

10552 Px
Kurtosis
Z Position (mm)


10552 Py
Mean
Z Position (mm)
10552 Py
RMS
Z Position (mm)
10552 Py
Skew
Z Position (mm)
10552 Py
Kurtosis
Z Position (mm)

Beam Weighting: Next Steps

- Beam Moments look reasonable through cooling channel at TKD
- Will look at beam Selection
- Beam has imperfections => Selection routine
- Select an ideal distribution from the data using a weighted algorithm at either TKU or absorber and see the results at TKD





Kernel Density Estimation (KDE) Tanaz – IPAC 2018

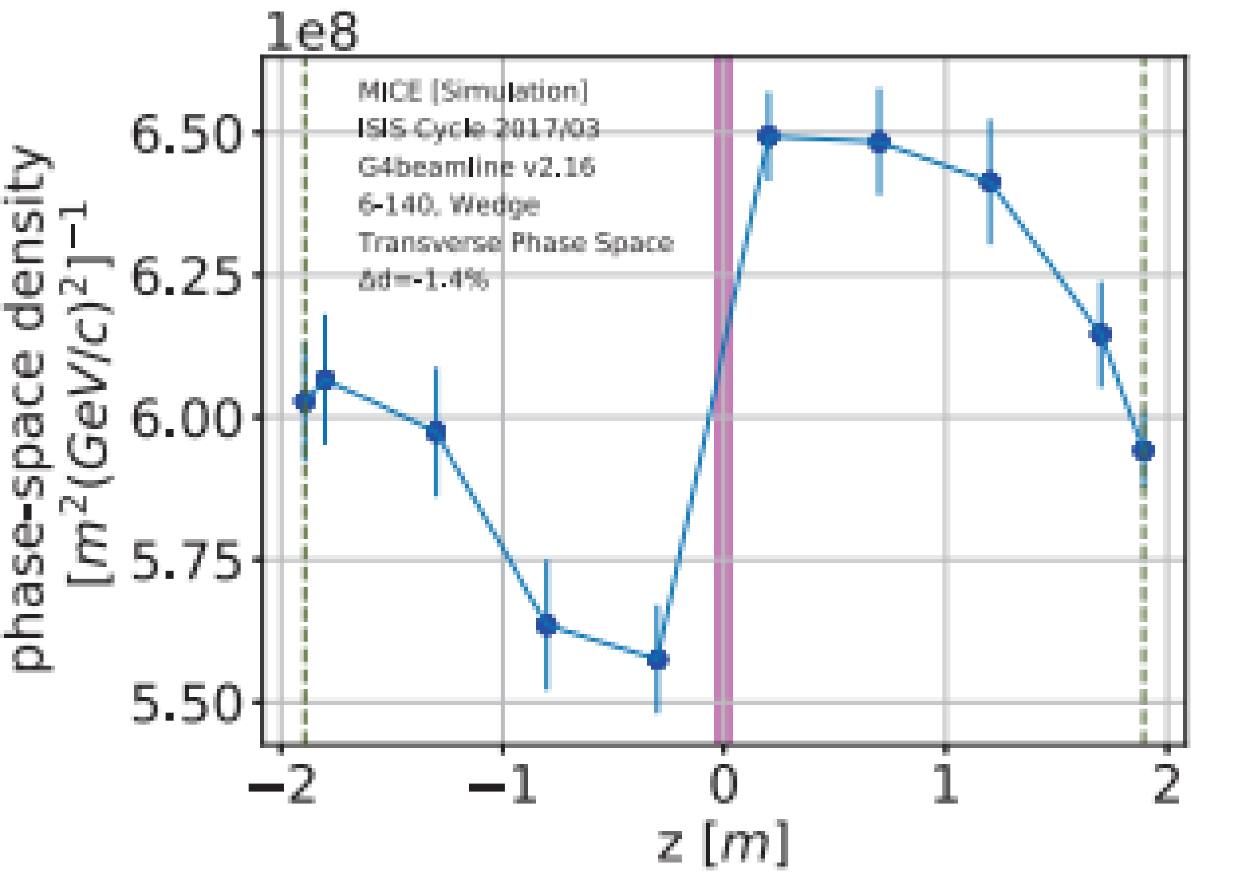
- Calculate the kernel, a multivariate Gaussian for each data point
- Sum all the kernels to get the KDE

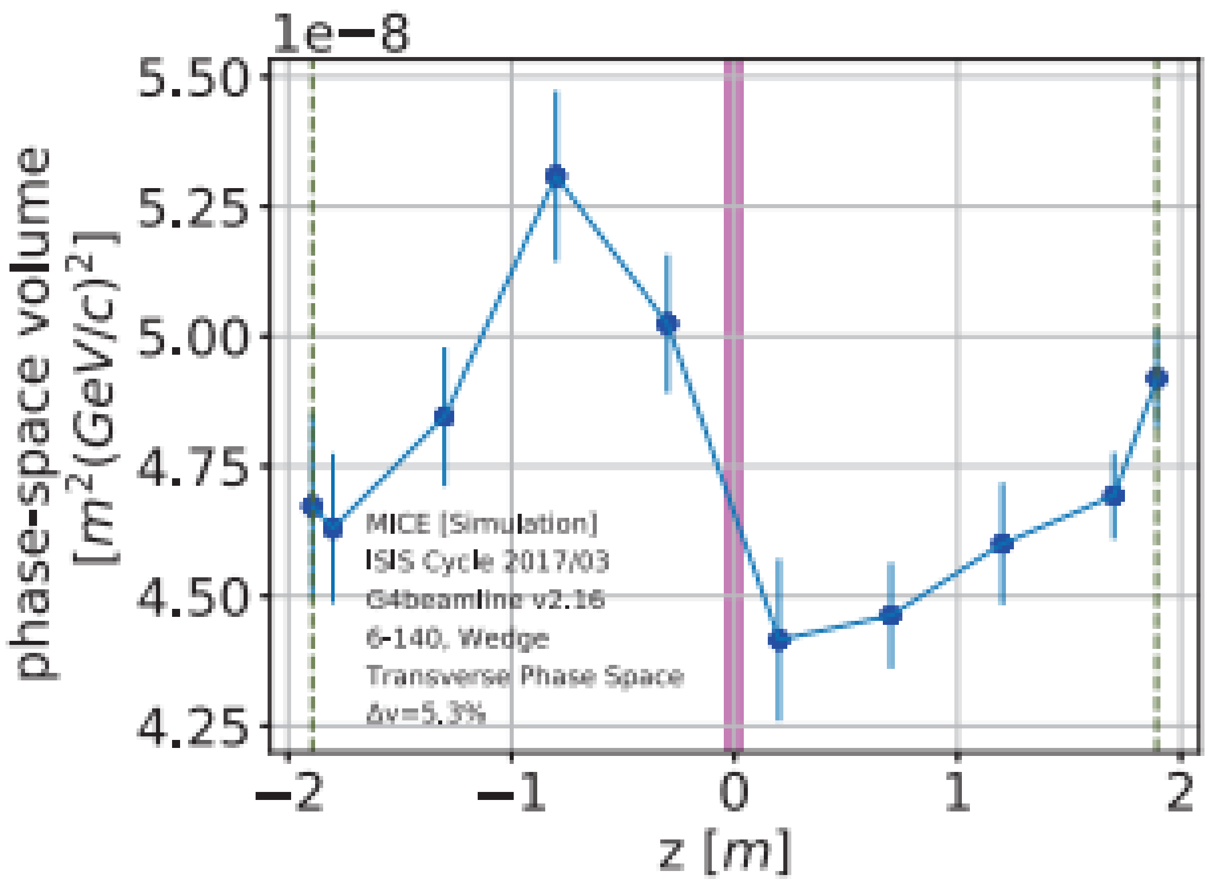
$$\hat{f}(\vec{x}) = \frac{1}{nh^d\sqrt{2\pi}} \sum_{i=1}^{n} k\left(\frac{-\left|\vec{x}-\vec{X}_i\right|^2}{2h^2}\right)$$

- Bottom left: Comparison between KDE, Histogram and a parametric approach

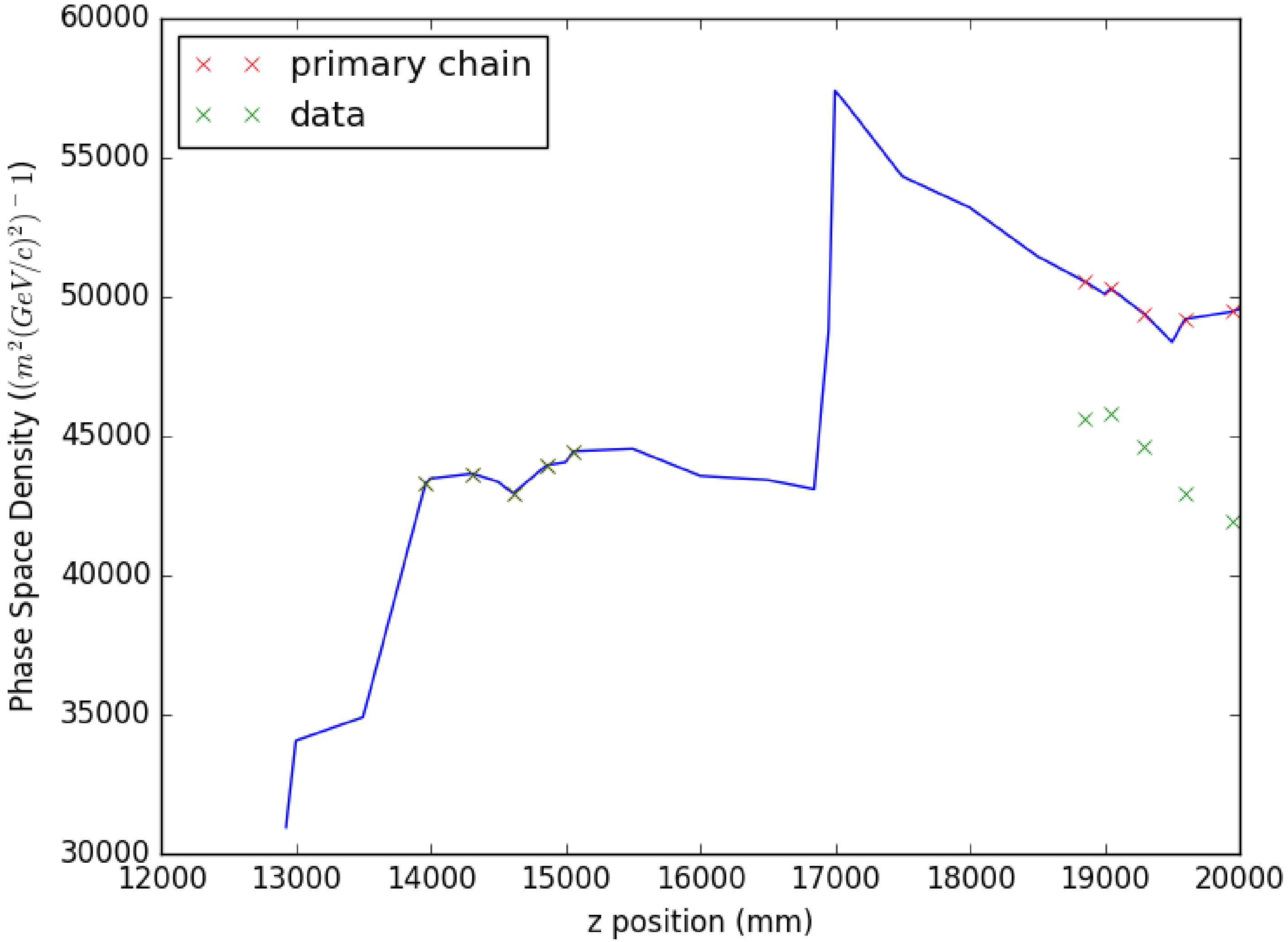
Parametric methods make an assumption of the underlying distribution

Tanaz's 6-140 transverse 4D results – IPAC2018





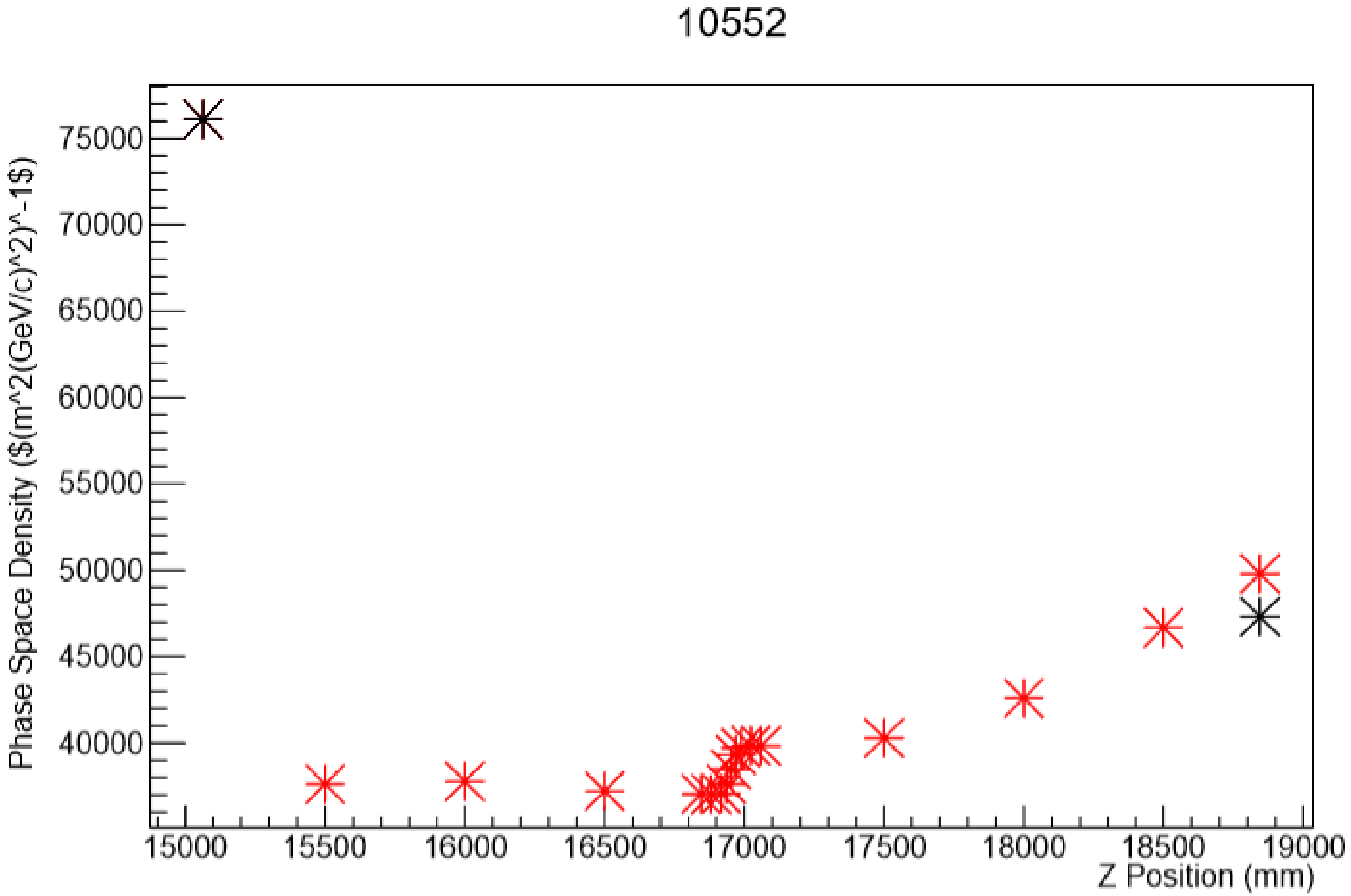
Try to recreate Tanaz's results (Analysis Workshop)



Problems

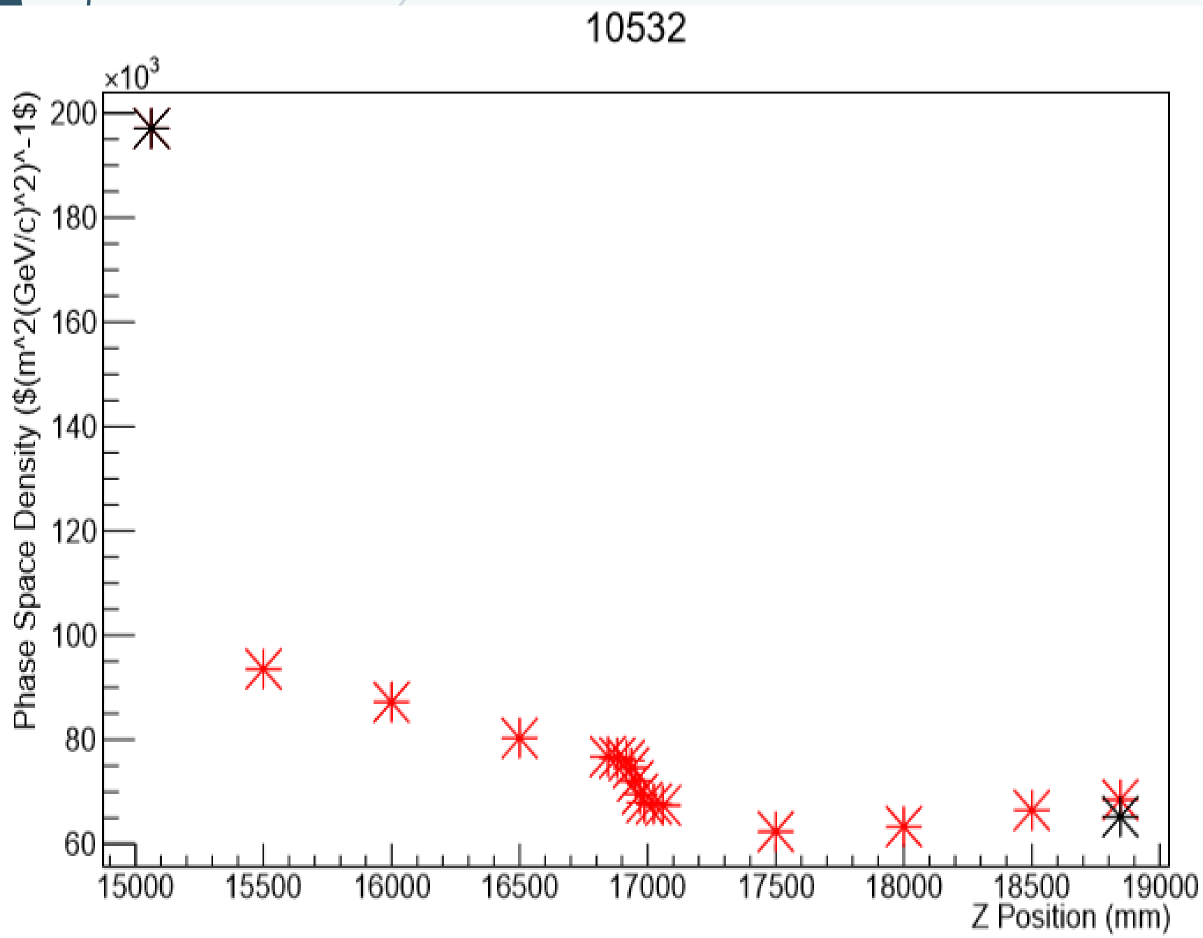
- Only started looking at Tanaz's work, so I have likely made some mistakes
- Axial look-up, cylinder not very Wedge shaped, primary chain extrapolation doesn't reflect Wedge
- Need to run extrapolation with Wedge geometry
- I am off by a factor of >10^4
- No Cuts on data
- Only require a matched upstream track to a downstream track

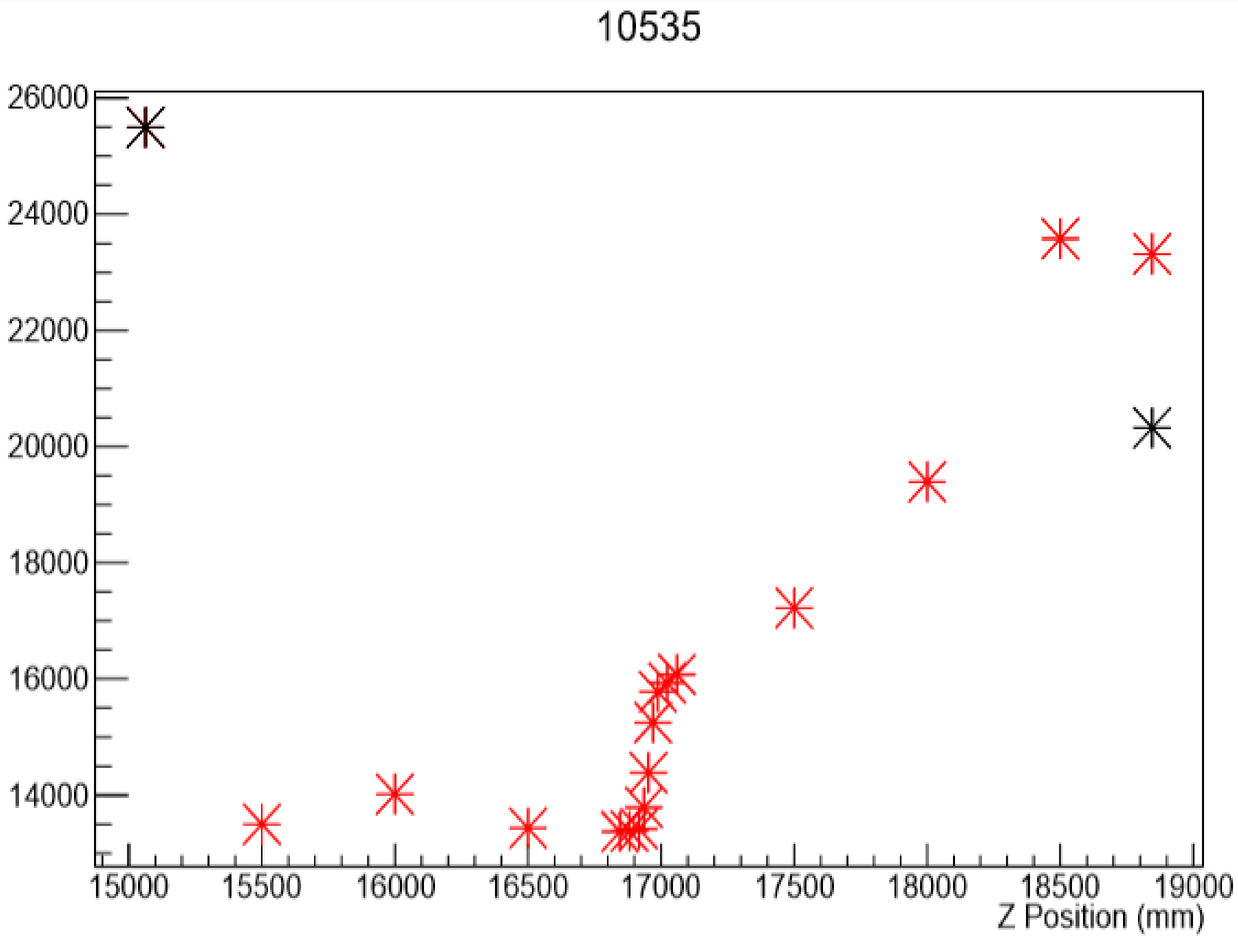
Try to recreate Tanaz's results (Full MC)



- Phase Space Density from TKU to TKD
- Includes cuts
- Not convinced what I have is correct
- Think big dip is due to mean and RMS (x, px, y, py) varying significantly between those two points
- Going to try to find newer plots by Tanaz/ ask her to run data sample
- Write Independent KDE code

3-140 (left) and 10-140 (right)





Summary

- Beam moment evolution through cooling channel looks reasonable
- Will use Chris Rogers beam weighing algorithm to select a smooth distribution
- Use that as input to calculate KDE
- KDE analysis needs more work
- Will try to get further clarifications from Tanaz, and how she arrived at her results, I believe I am missing something
- Write own code to compare with Tanaz's results

The End