# MCS in $LH_2$, Field-off

## Analysis Overview

- Selection process
- Final Sample tracker parameters
- Scattering distribution, comparison with GEANT4
- Future work

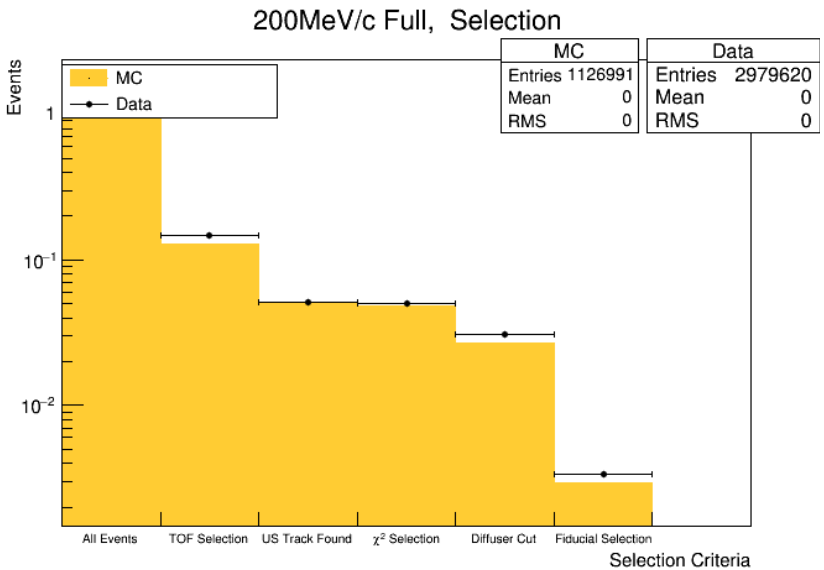
# Selection process

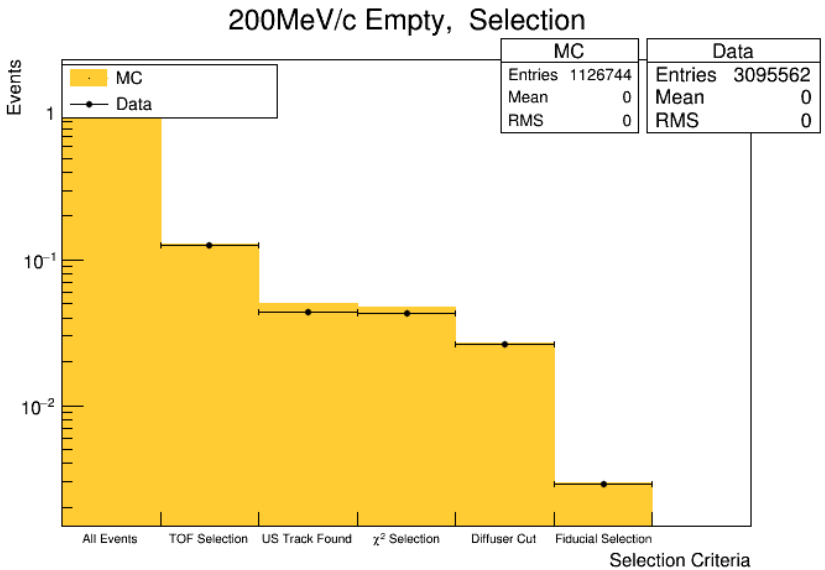
## Aim

The data sets are reduced through a set of selection criteria that aim at maximising particle tracks reconstructed after the the absorber while reducing the systematic uncertainties/biases of the measured sample and ensuring compatibility between full and empty absorber data sets.

## Criteria

- Single TOF0 & TOF1 SP. $dt_{TOF10}$ within 300ps (to be optimised) of muon peak.
- Single reconstructed US track
- US track $\chi^2/NDF < 4$.
- Track projection at diffuser pos. < 90mm radius.
- Track projection at DST st. 5 < 100mm radius.



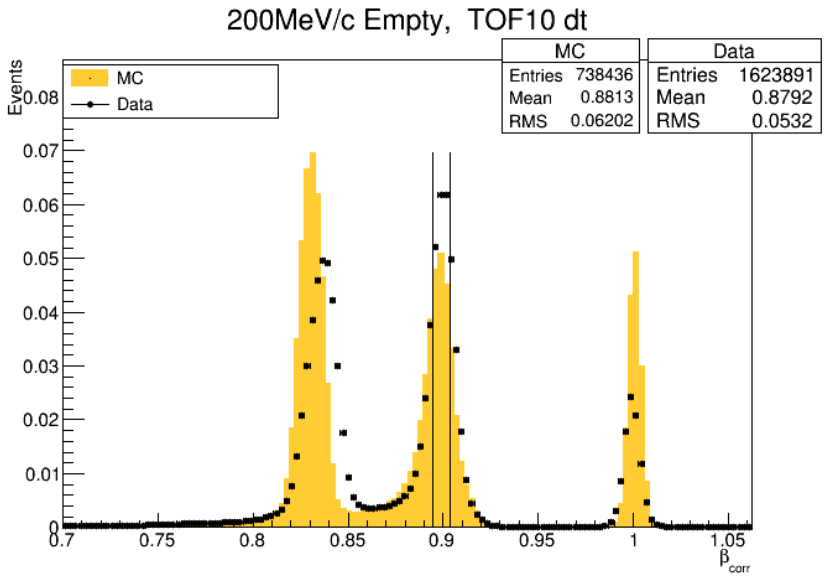



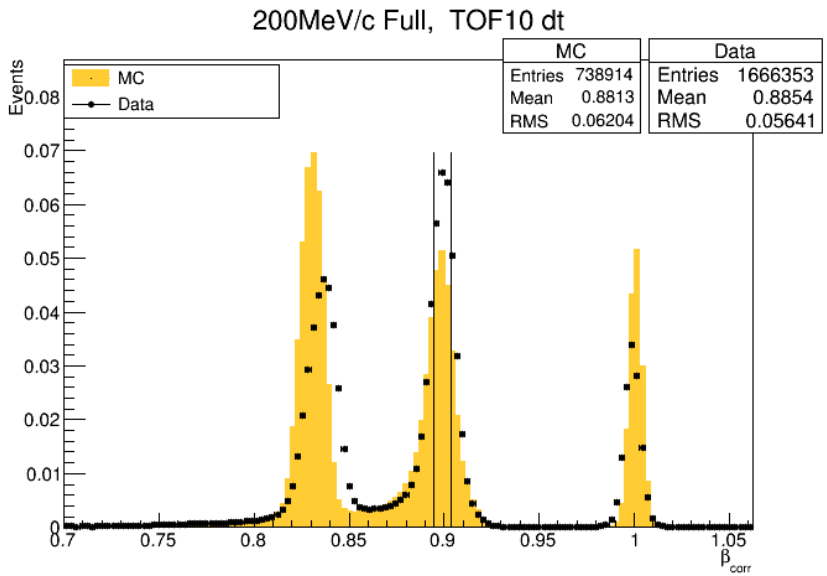
# TOF Selection

## Single TOF0 & TOF1 SP.

| | 0 SPs | 1 SPs | 2 SPs | 3 SPs |
|---|---|---|---|---|
| 200MeV/c Empty Data TOF0 | 251679.0 (0.1) | 1713508.0 (0.69) | 431045.0 (0.17) | 55572.0 (0.022) |
| 200MeV/c Empty MC TOF0 | 8488.0 (0.0095) | 829119.0 (0.92) | 56364.0 (0.063) | 654.0 (0.00073) |
| 200MeV/c Empty Data TOF1 | 74959.0 (0.03) | 2232688.0 (0.9) | 162215.0 (0.065) | 10690.0 (0.0043) |
| 200MeV/c Empty MC TOF1 | 5084.0 (0.0057) | 793904.0 (0.89) | 78913.0 (0.088) | 5078.0 (0.0057) |
| 200MeV/c Full Data TOF0 | 236088.0 (0.1) | 1742125.0 (0.75) | 294693.0 (0.13) | 27827.0 (0.012) |
| 200MeV/c Full MC TOF0 | 8499.0 (0.0095) | 829078.0 (0.93) | 56237.0 (0.063) | 646.0 (0.00072) |
| 200MeV/c Full Data TOF1 | 65396.0 (0.028) | 2122543.0 (0.91) | 118183.0 (0.051) | 7491.0 (0.0032) |
| 200MeV/c Full MC TOF1 | 5146.0 (0.0057) | 794271.0 (0.89) | 78414.0 (0.087) | 5046.0 (0.0056) |

## TOF10 dt within 300ps of muon peak



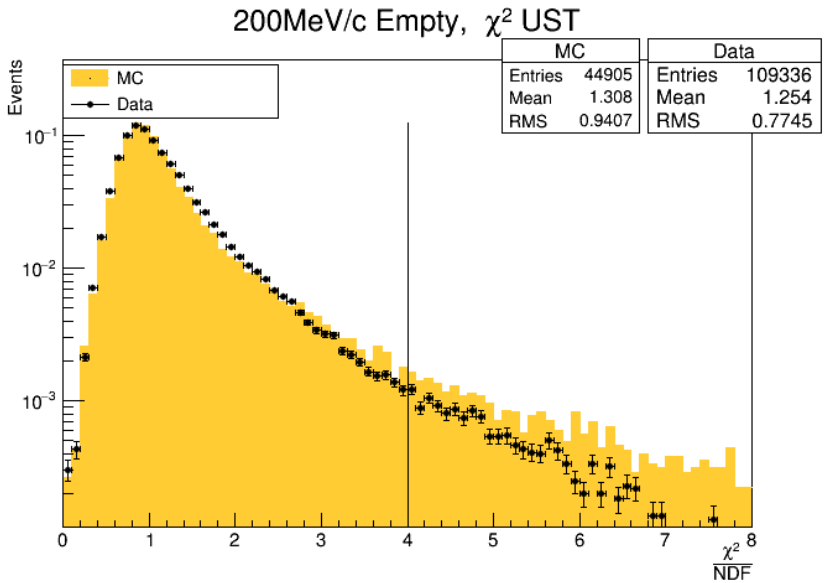



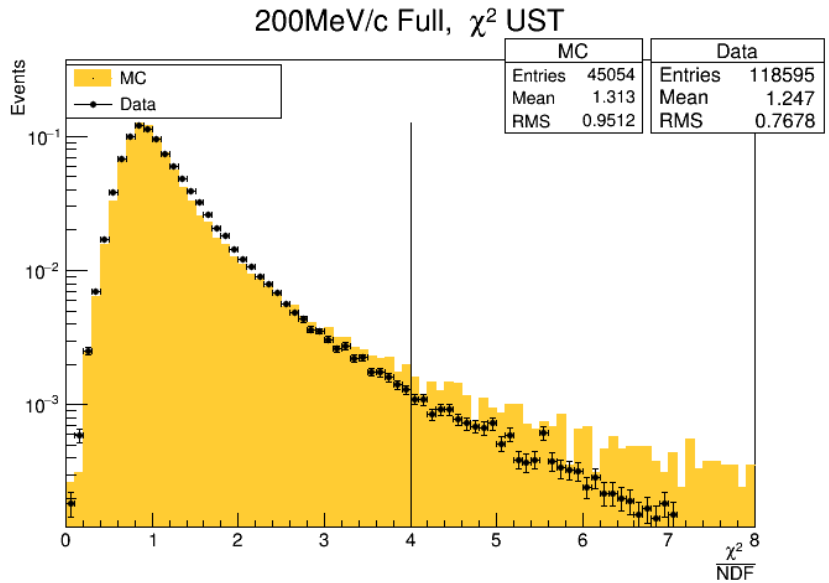
# UST Selection

## Single US track rec.

| | 0 Tracks | 1 Track | 2 Tracks |
|---|---|---|---|
| 200MeV/c Empty Data | 203492.0 (0.65) | 109248.0 (0.35) | 142.0 (0.00045) |
| 200MeV/c Empty MC | 71178.0 (0.61) | 44902.0 (0.39) | 3.0 (2.6e-05) |
| 200MeV/c Full Data | 221885.0 (0.65) | 118546.0 (0.35) | 90.0 (0.00026) |
| 200MeV/c Full MC | 71003.0 (0.61) | 45054.0 (0.39) | 1.0 (8.6e-06) |

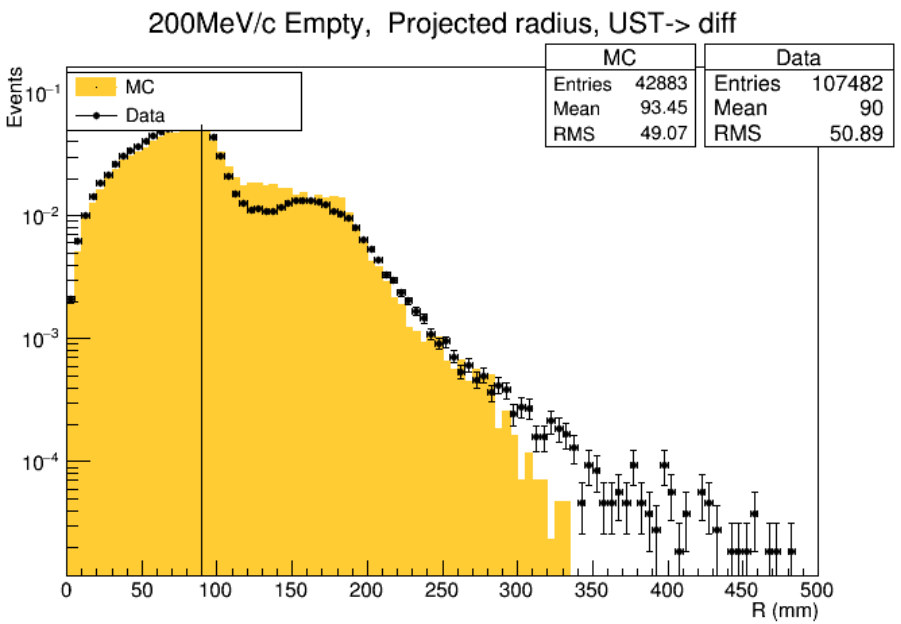
## $\chi^2/NDF$ goodness of fit $< 4$

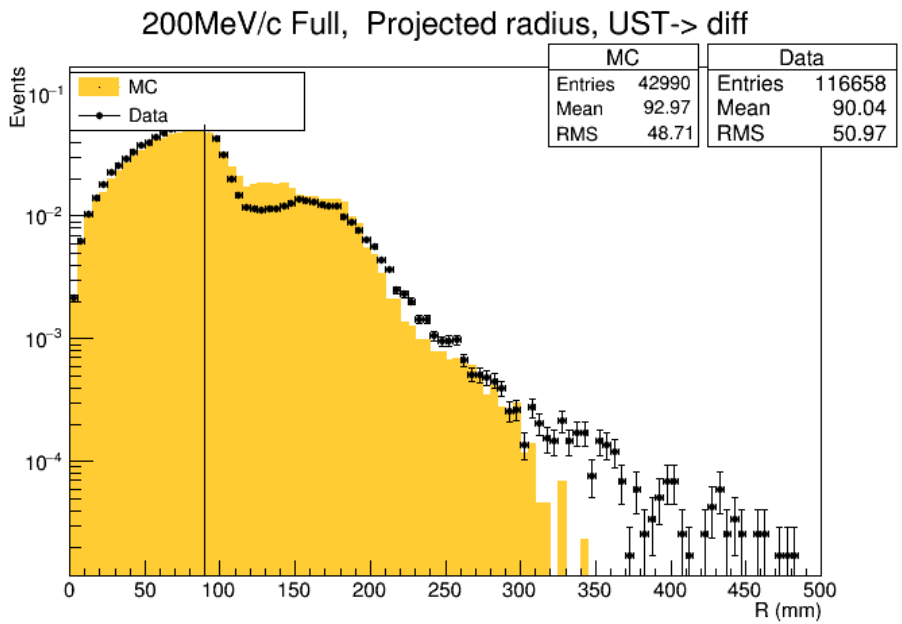


# Diffuser cut

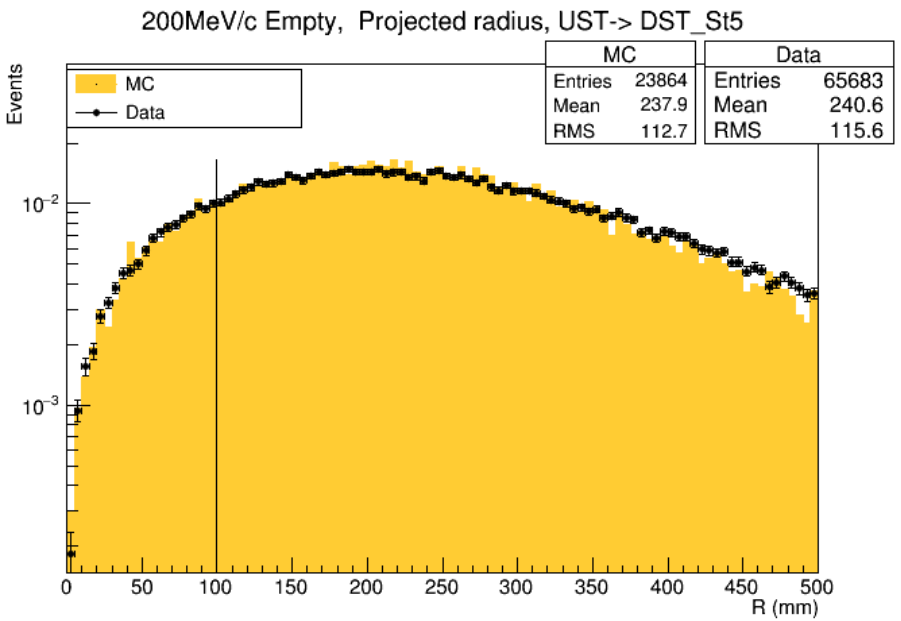
**Projected radius at diffuser < 90mm**

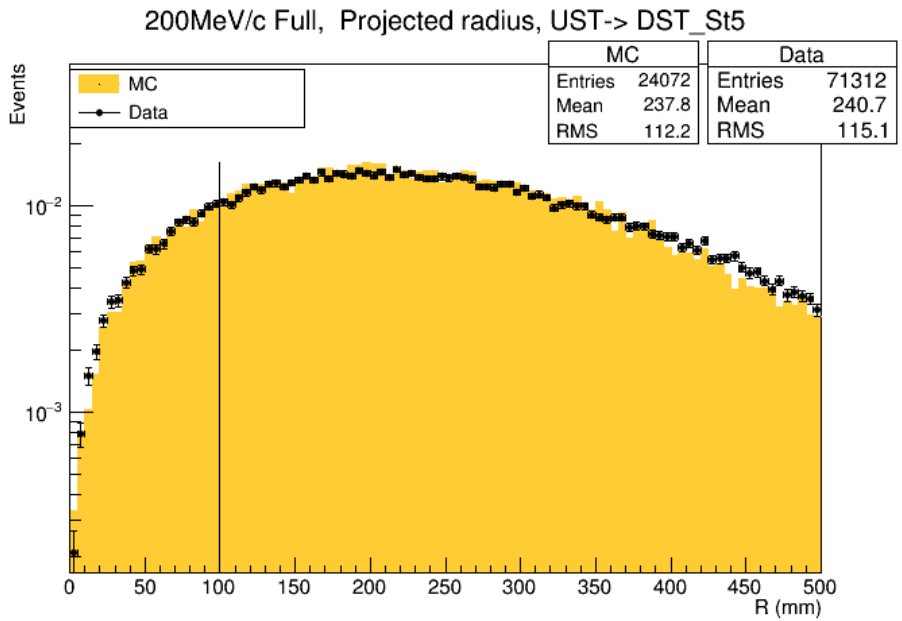


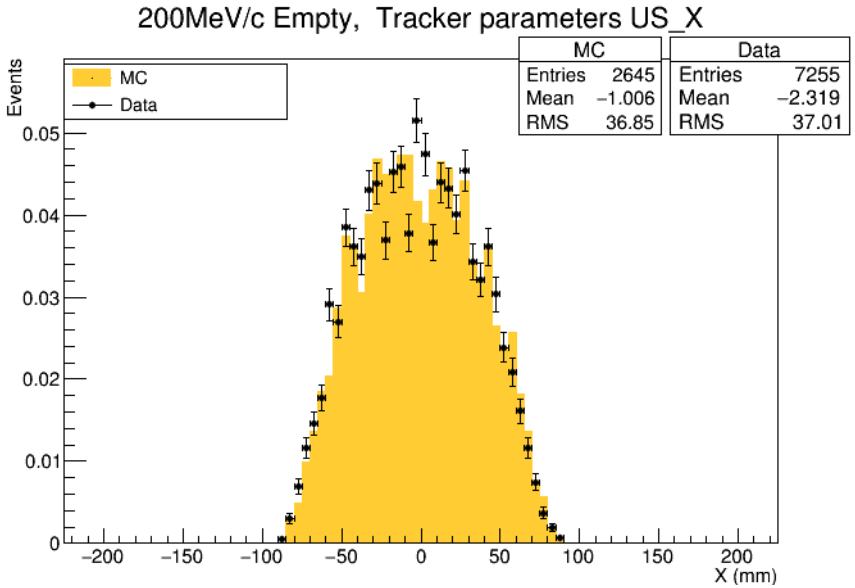
# Fiducial Selection

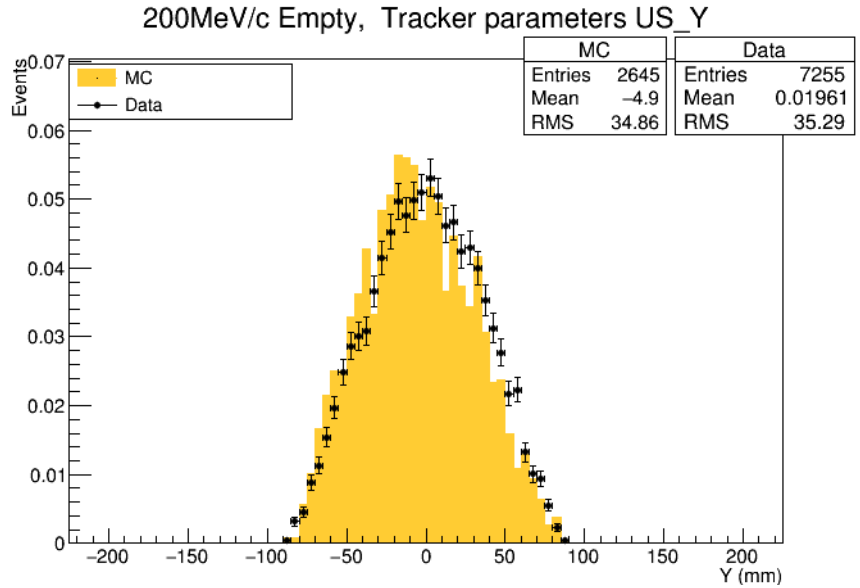
**Projected radius at DST st. 5 < 100mm**

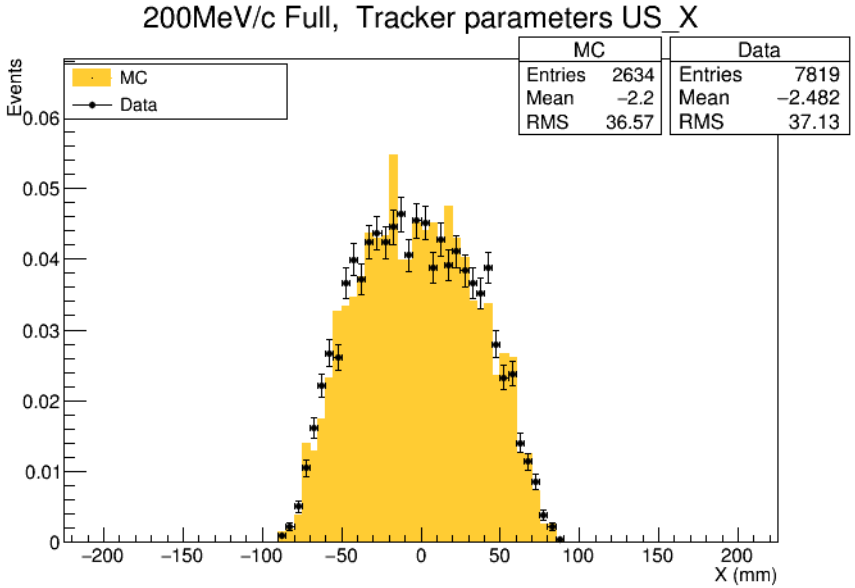


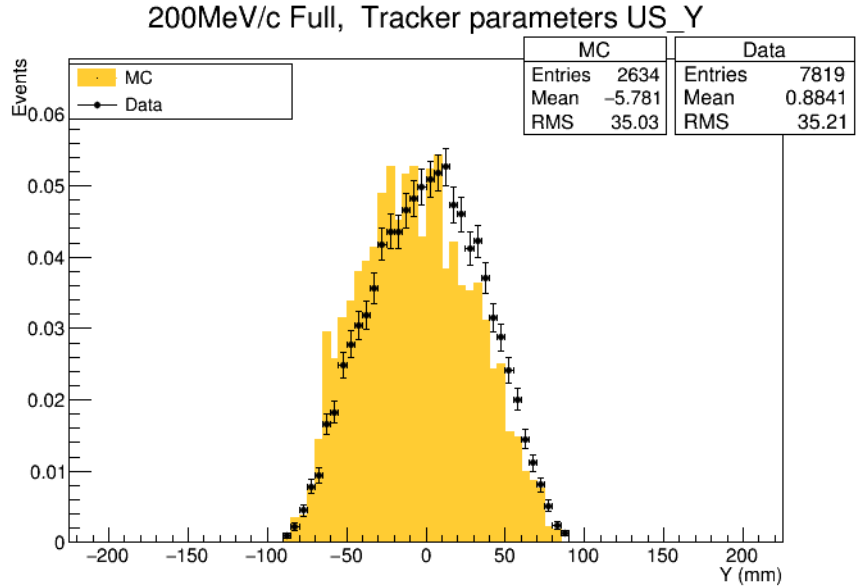



# Final Sample, UST St1 XY

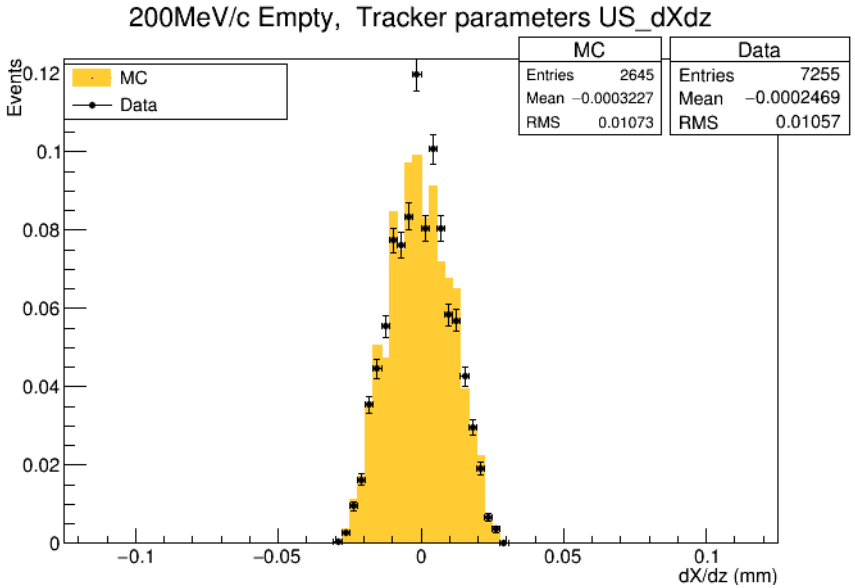


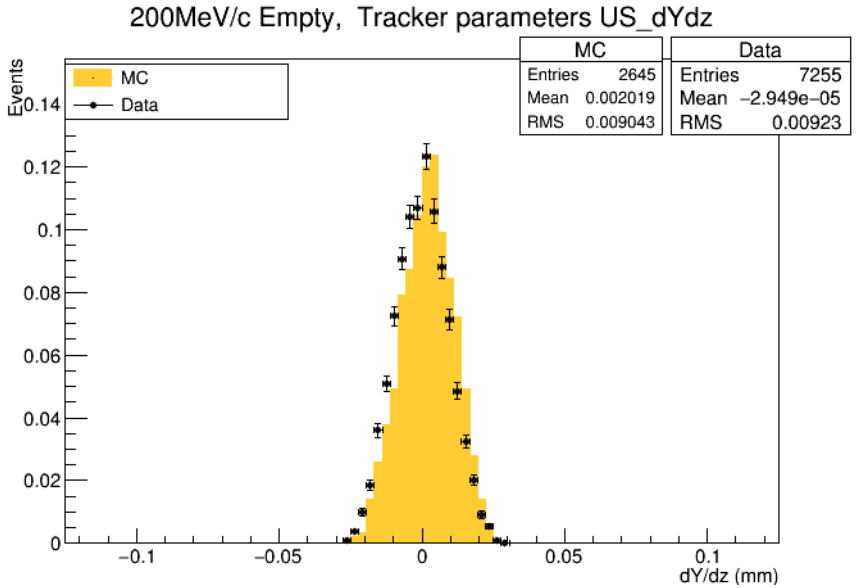



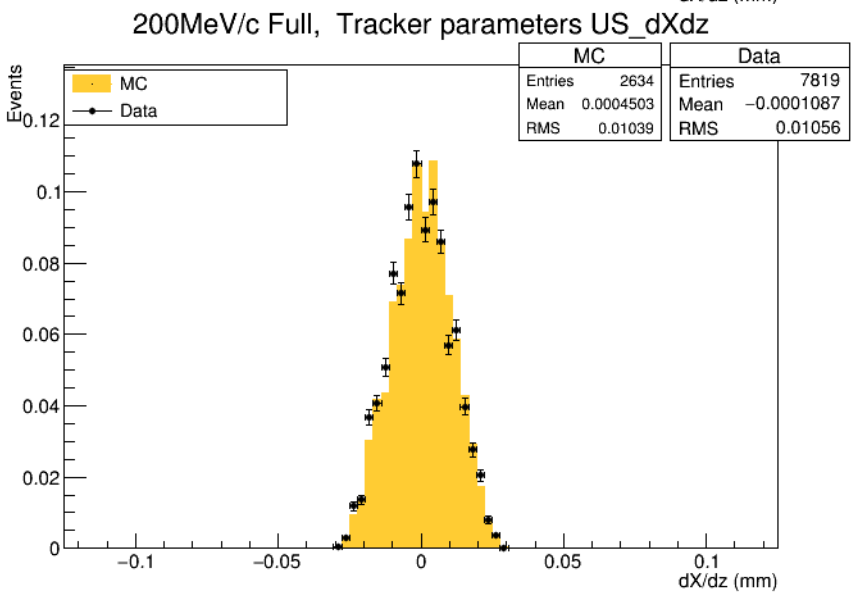



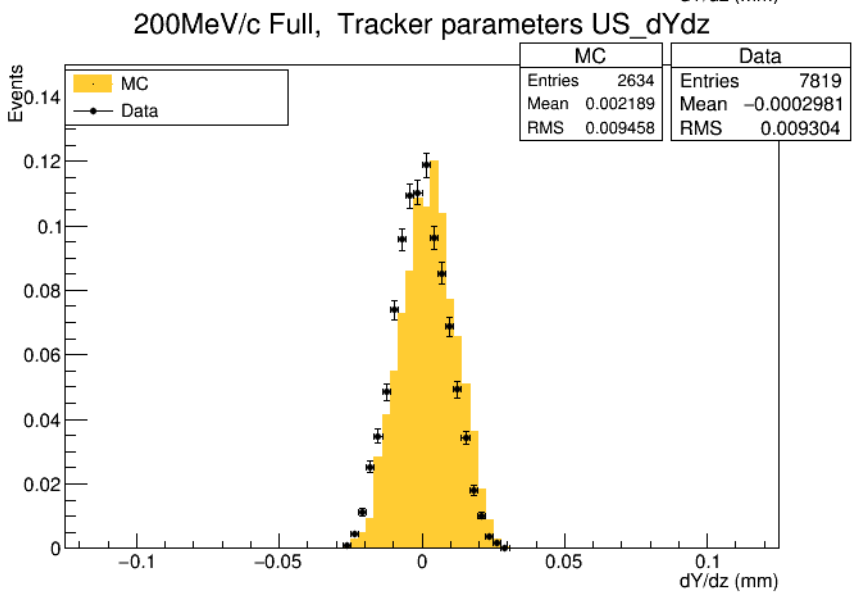



# Final Sample, UST St1 $\frac{dX}{dz}\frac{dY}{dz}$

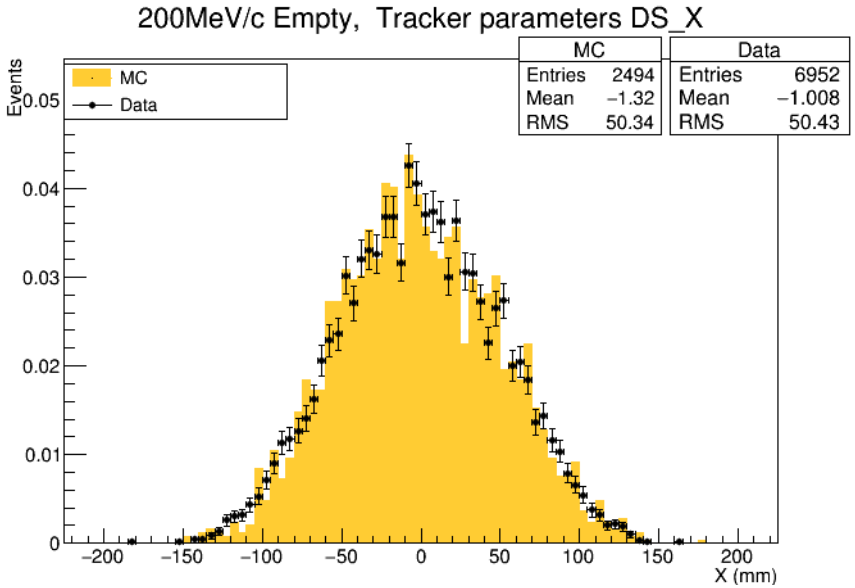


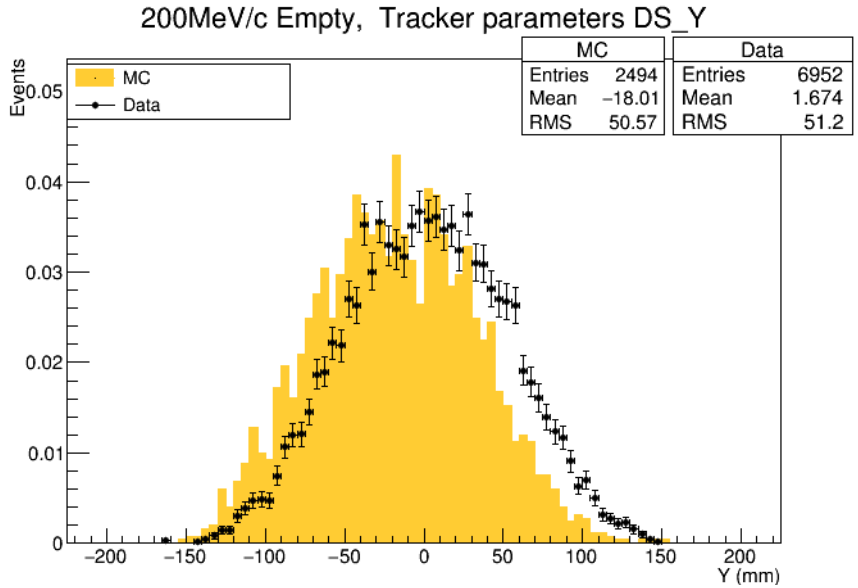



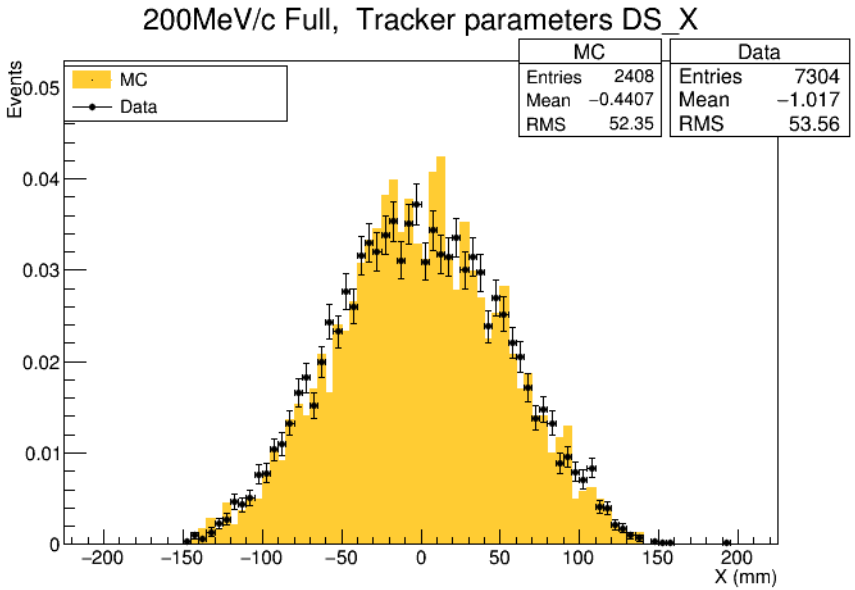



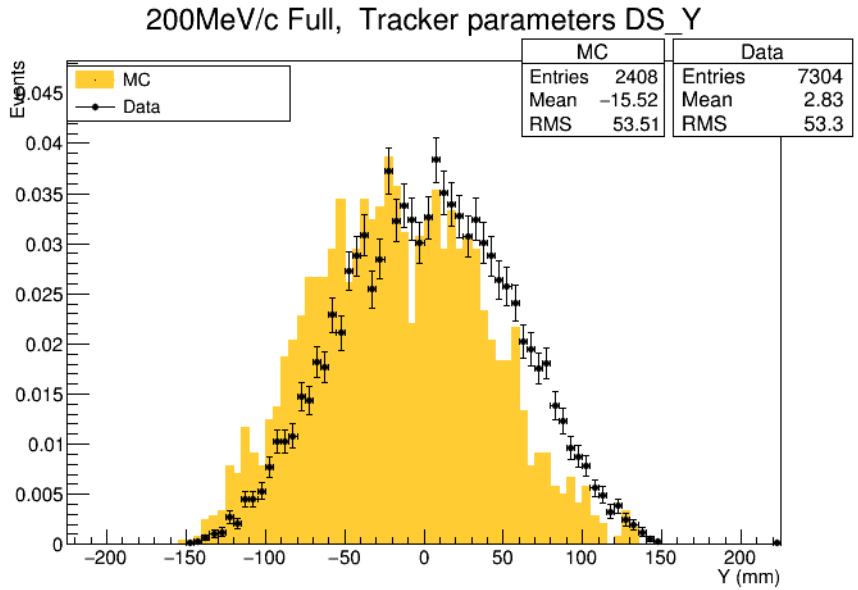



# Final Sample, DST St1 XY

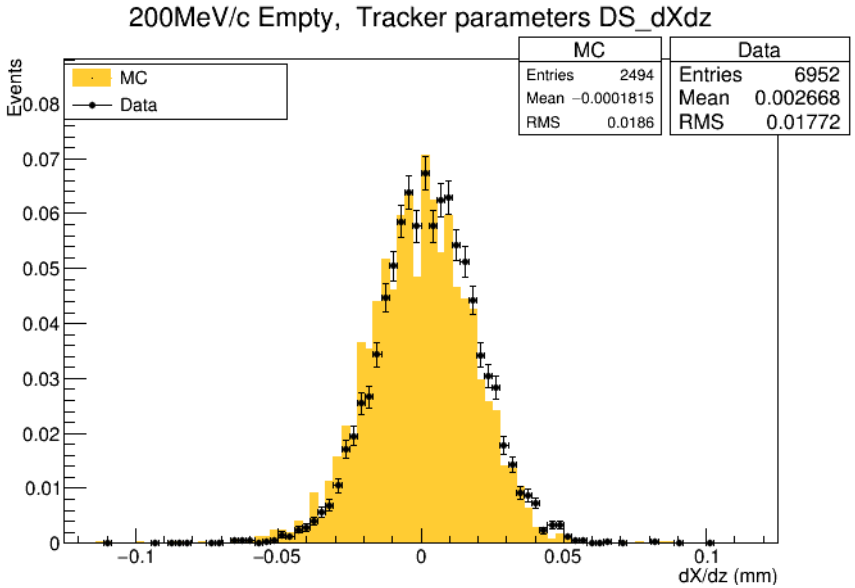


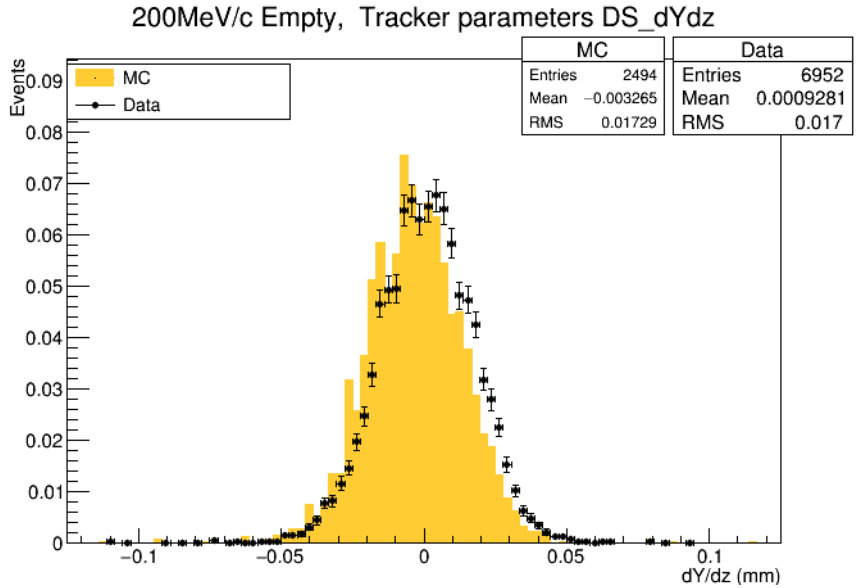



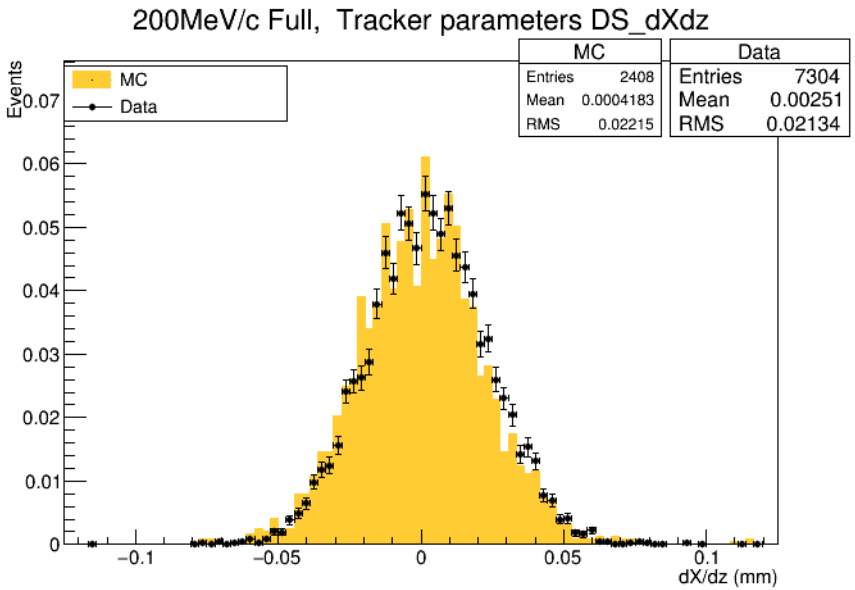



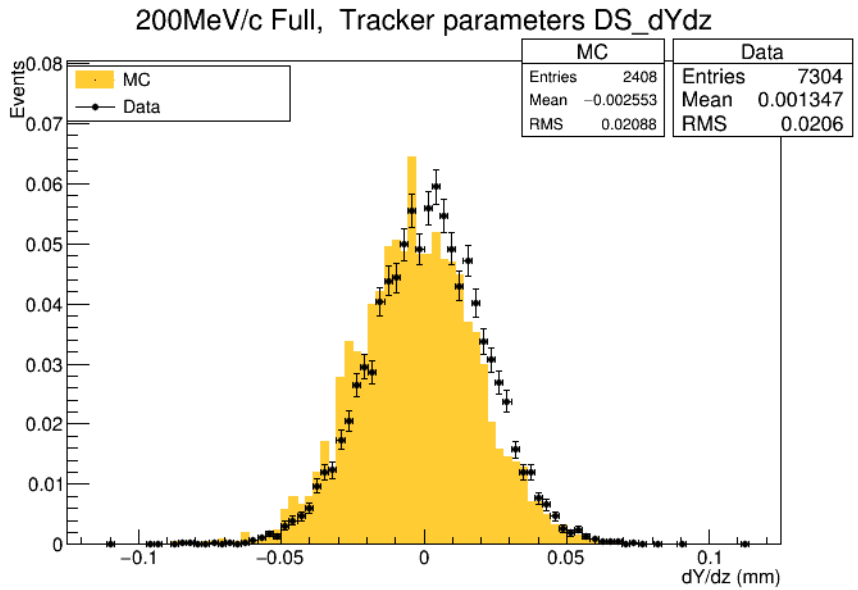



# Final Sample, DST St1 $\frac{dX}{dz}\frac{dY}{dz}$



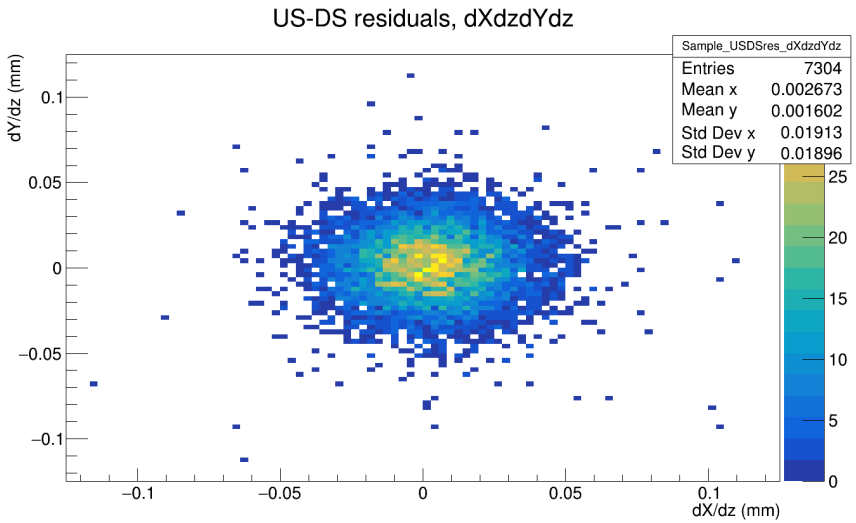



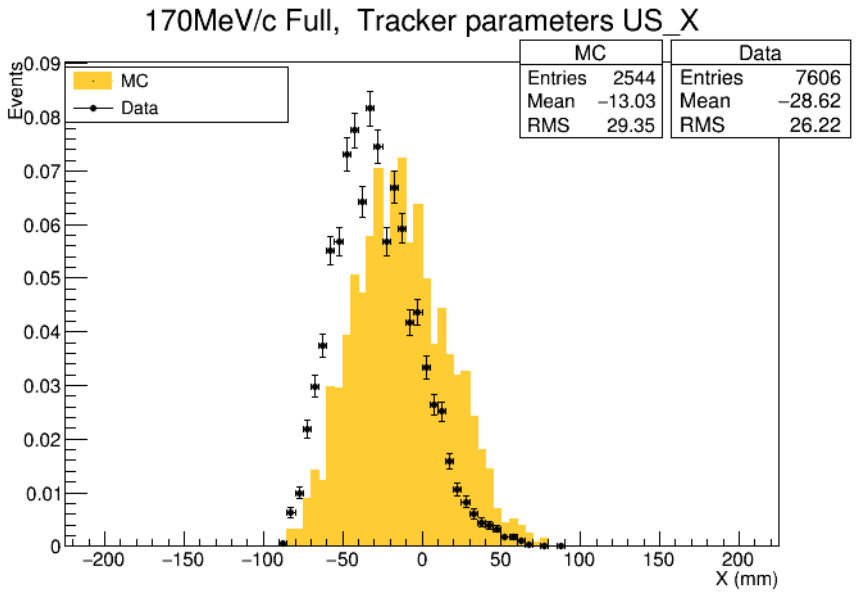



# Some observations

- In some cases, the position/direction of the beam in the UST is not compatible between data/MC, as seen in X position of 170MeV/c Full Data X UST (right plot).
  - ➤ Beamline magnet scaling (to do).
- Misalignment between UST and DST, as seen in US-DS directional residuals of 200MeV/c Full data (left plot).
  - ➤ Alignment correction by US track rotation.

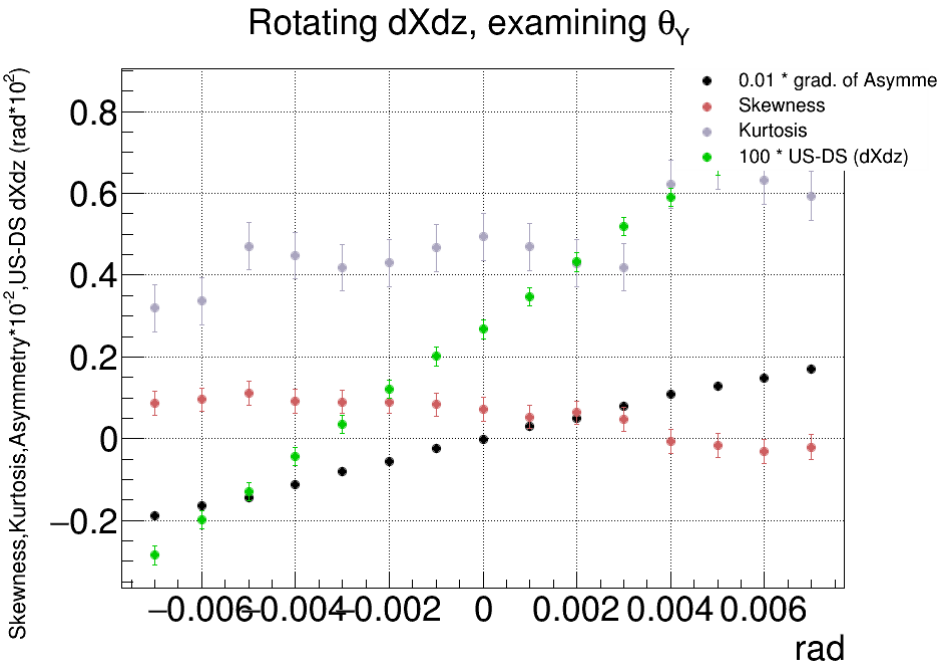


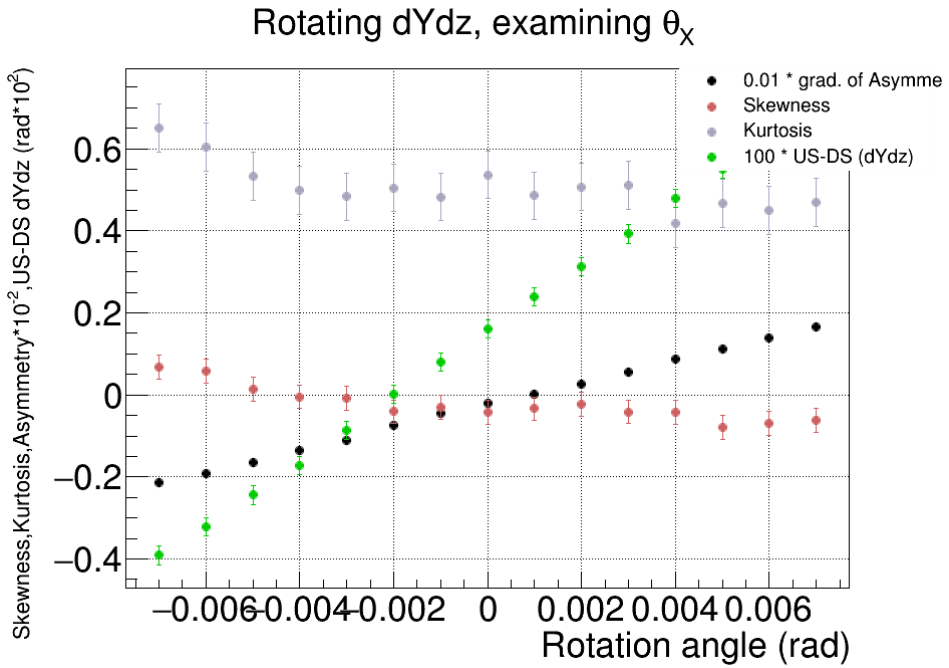



# Rotation scan, 200 Mev/c Full Data

## Method of alignment correction

Rotation angles (X-axis in below plots) of the US tracks are applied and alignment properties are assessed (green, black) in the scattering distribution. Skewness and kurtosis are shown for each rotation to examine any dependency. The correction angle is the one that zeros the US-DS directional residuals.



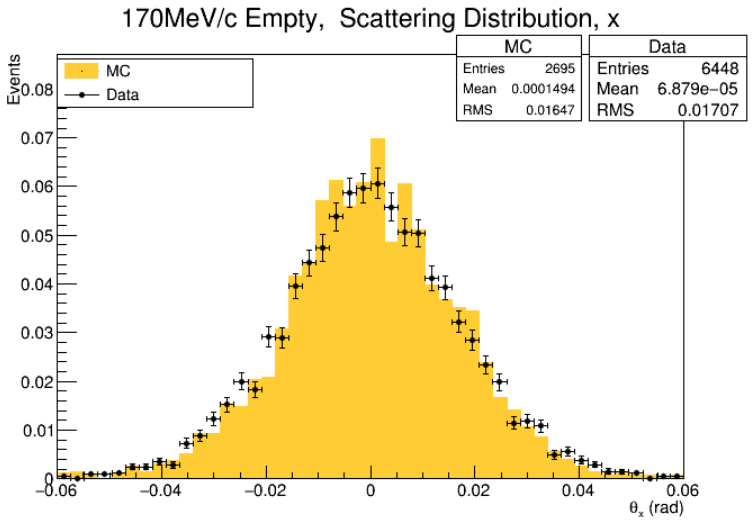



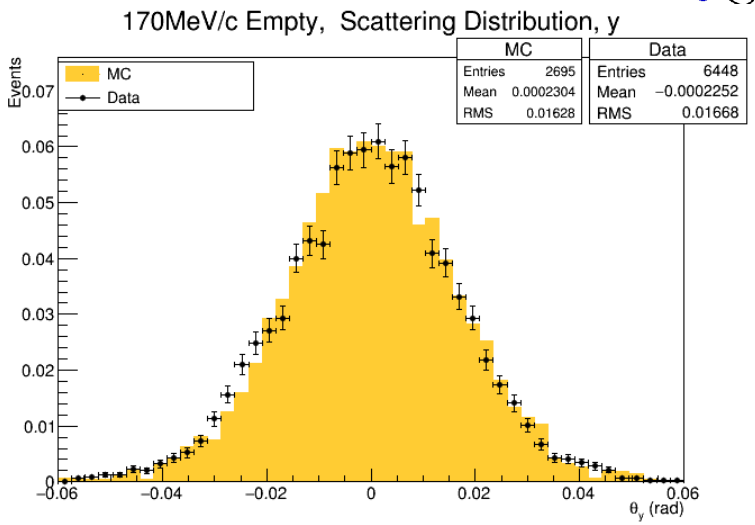
# Pion Contamination

- Contamination is assessed in MC for the final selected sample
  - ➤ PIDs are taken at TOF0 (where data-taking begins)
- This sets an upper limit to contamination in scattering distribution
  - ➤ Particle populations need to be checked for consistency between MC & Field-on data
  - ➤ Effect of decays on momentum measurement and reconstructed tracks need to be taken into account in systematic uncertainty calculation.

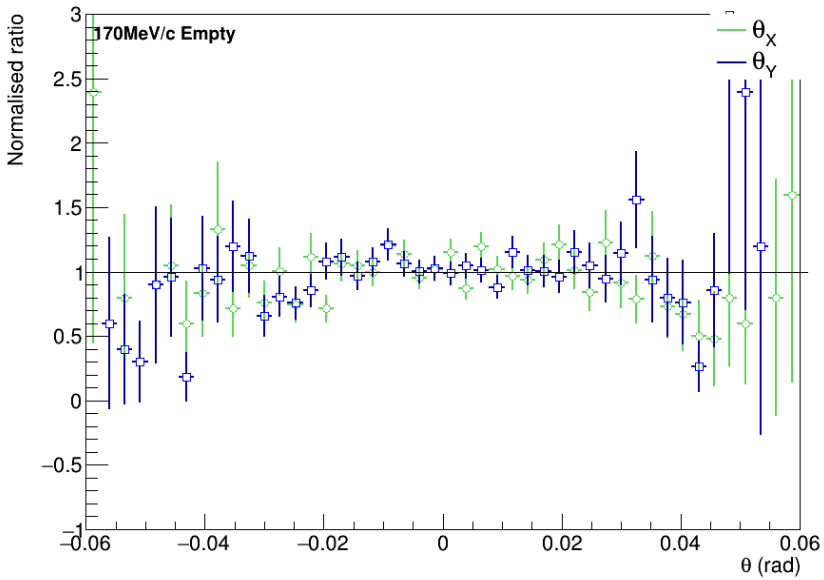
| Set | $N_\pi / N_\mu$ |
|---|---|
| 170MeV/c Empty MC | 0.85% |
| 170MeV/c Full MC | 0.99% |
| 200MeV/c Empty MC | 0.35% |
| 200MeV/c Full | 0.45% |
| 240MeV/c Empty | 1.6% |
| 240MeV/c Full | 1.5% |

# Scattering distribution, 170MeV/c Empty

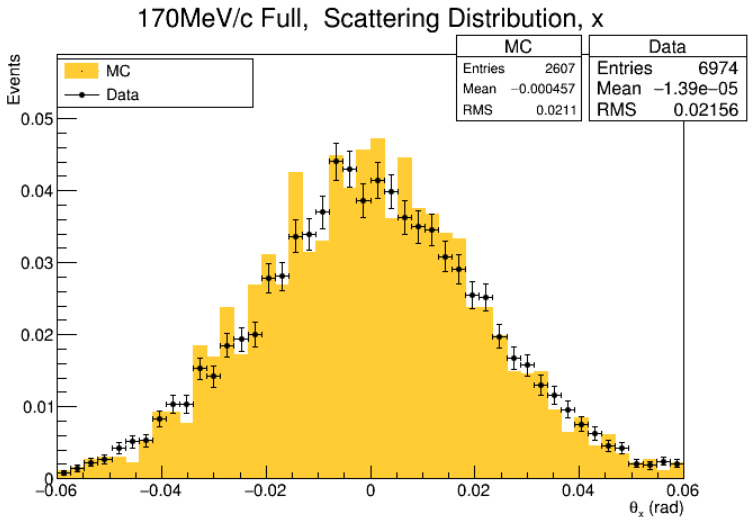


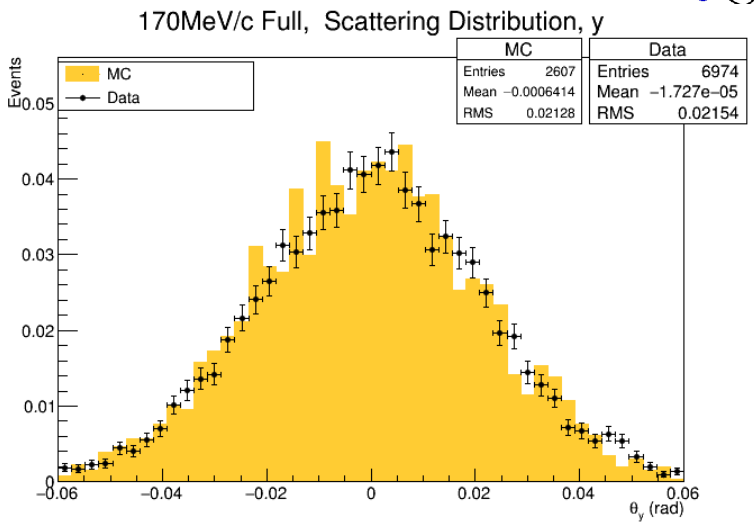




Normalized ratio MC/Data

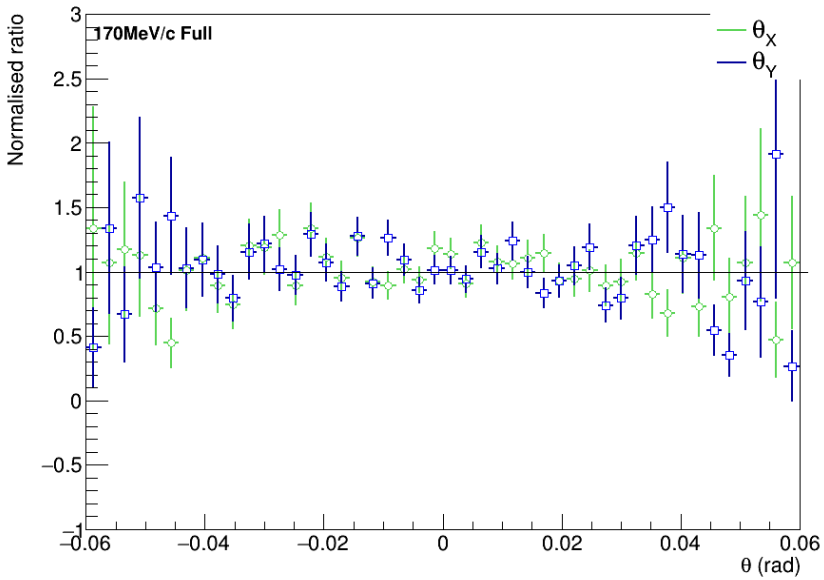


# Scattering distribution, 170MeV/c Full

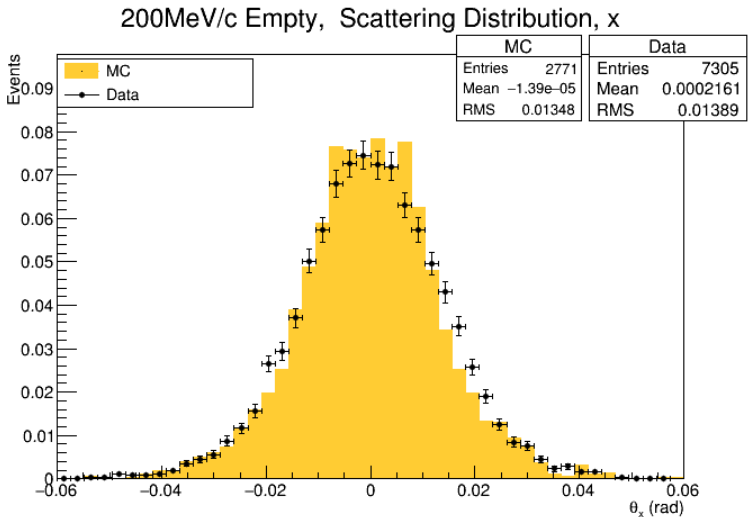


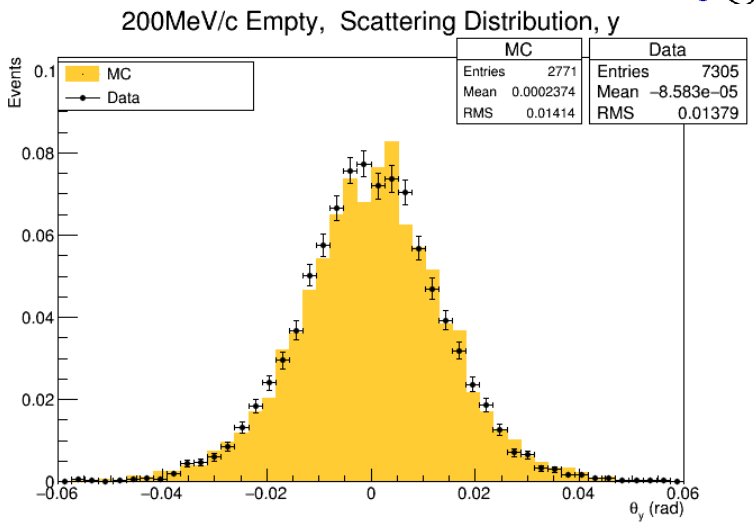




Normalized ratio MC/Data

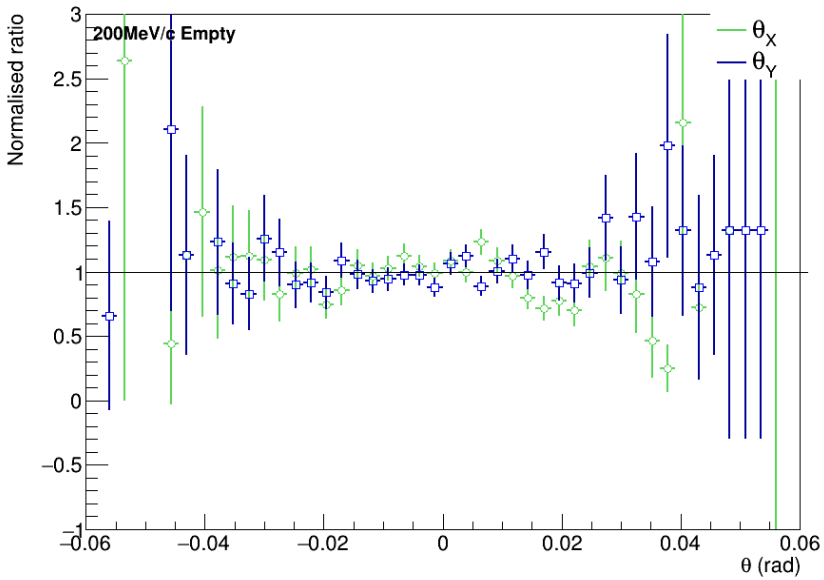


# Scattering distribution, 200MeV/c Empty

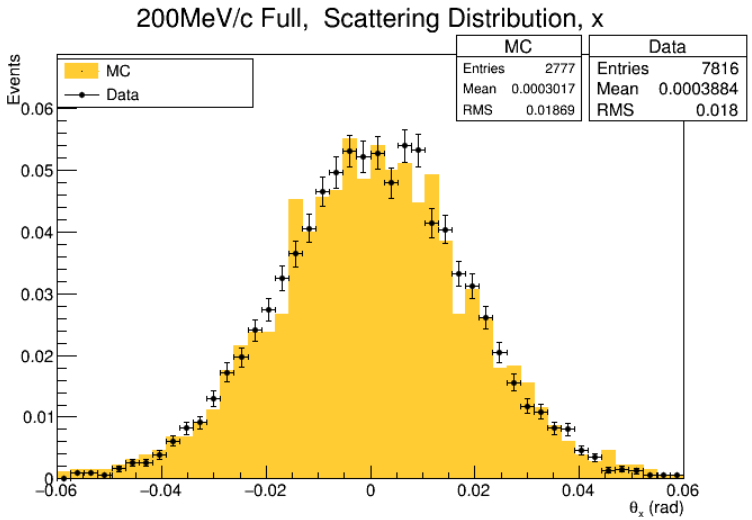


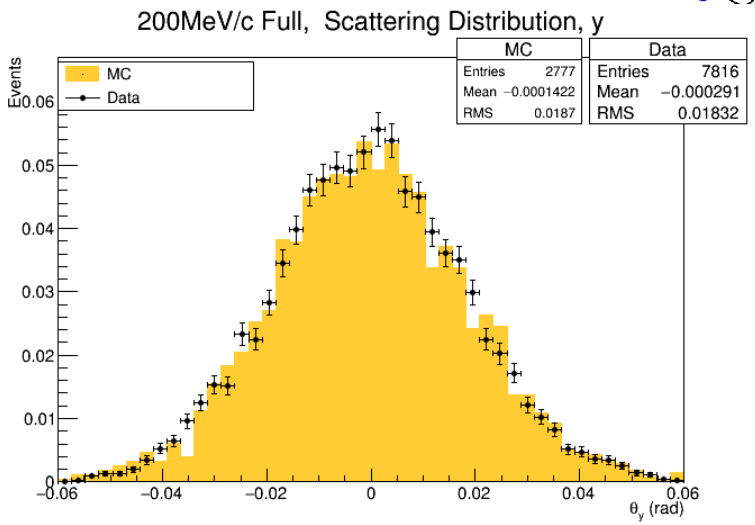




Normalized ratio MC/Data

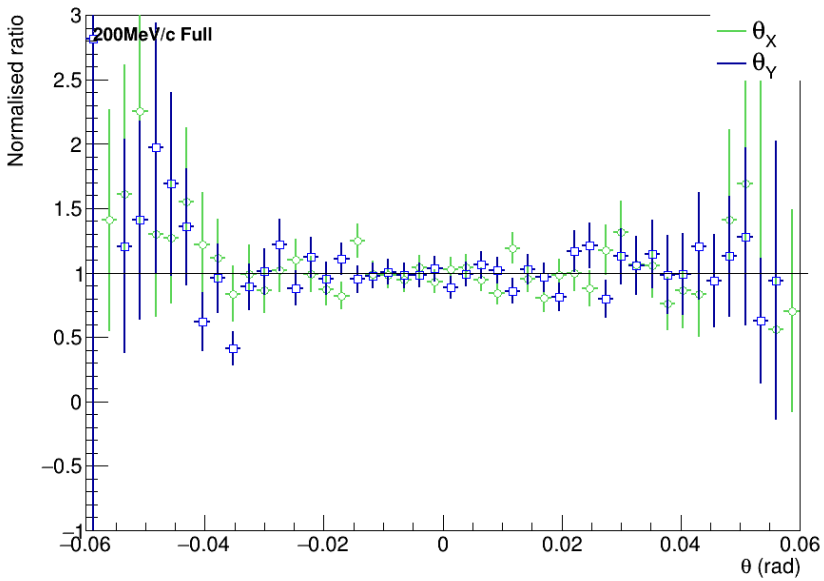


# Scattering distribution, 200MeV/c Full

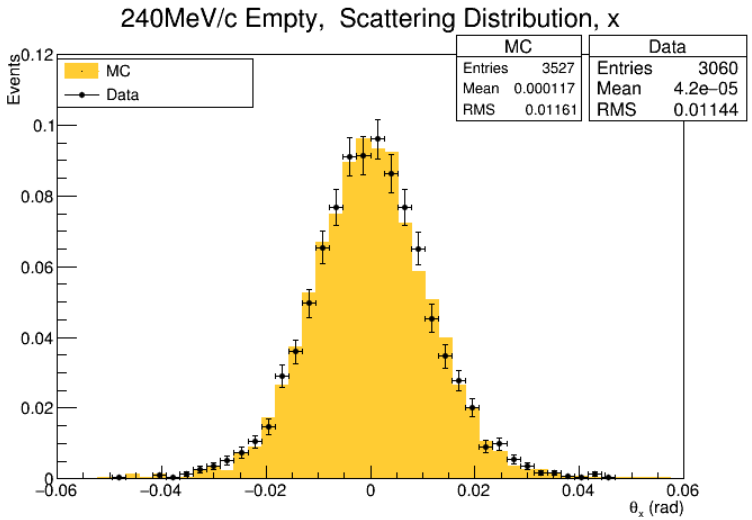


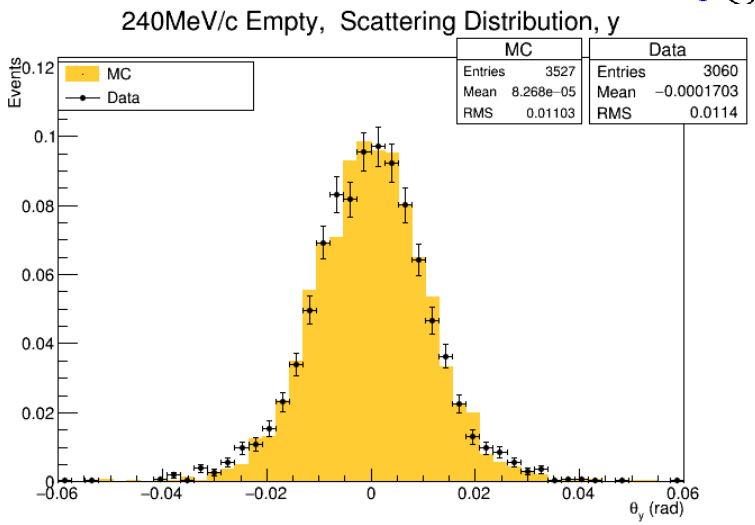




Normalized ratio MC/Data

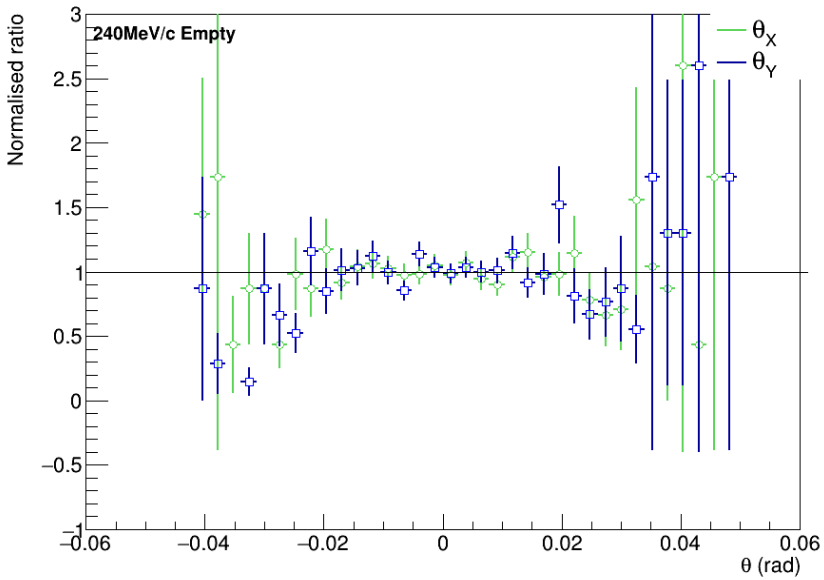


# Scattering distribution, 240MeV/c Empty

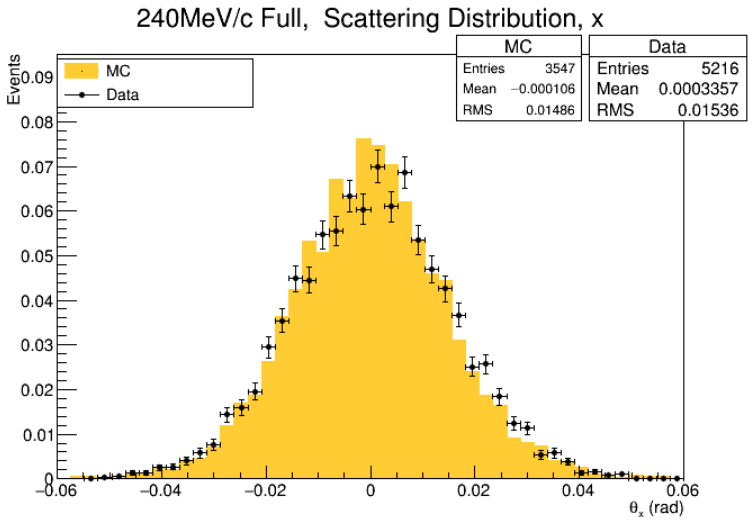


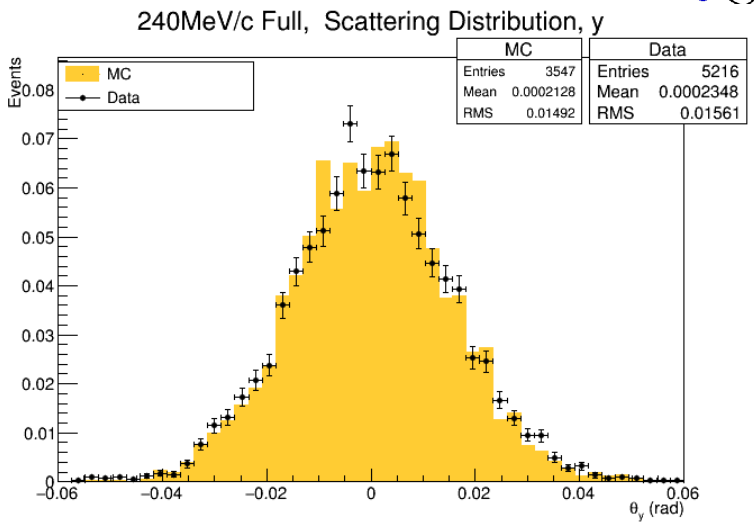




Normalized ratio MC/Data

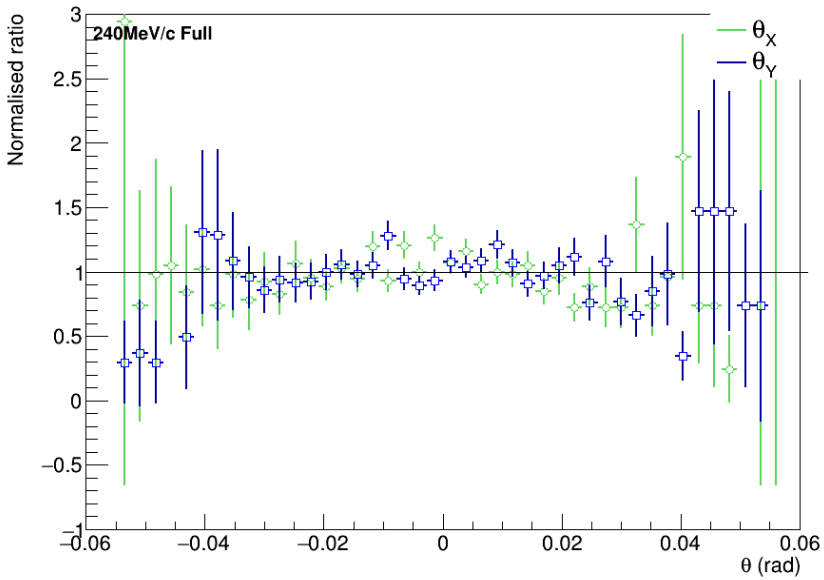


# Scattering distribution, 240MeV/c Full




Normalized ratio MC/Data



# MCS in $LH_2$, Field-off

## To do:

- Momentum measurement
  - TOF21 momentum measurement & TOF10 extrapolated momentum consistency.
- Beamline-magnet scaling to match MC/Data at the UST (priority).
- Pion contamination upper limit <1.6% in final sample (in MC).
  - Comparison with data field-on estimation is required.
  - Systematic effect in scattering distribution.
  - Decays between TOF measurements
- Remaining systematic uncertainty calculations