Field Off Scattering Studies: Current Status

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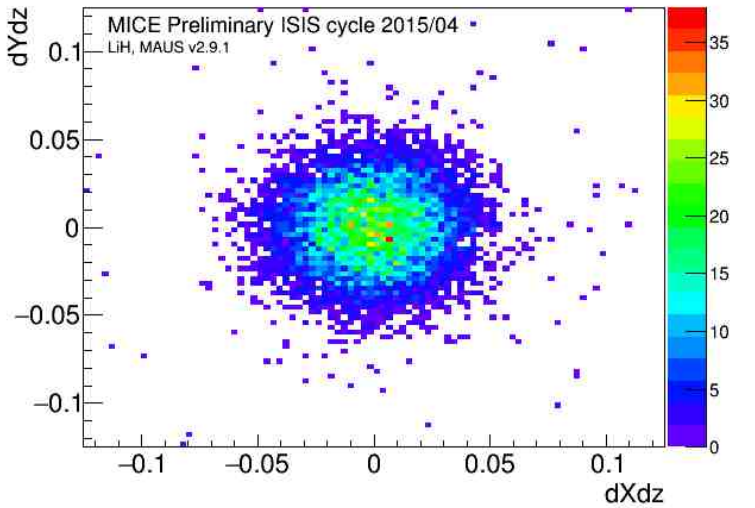
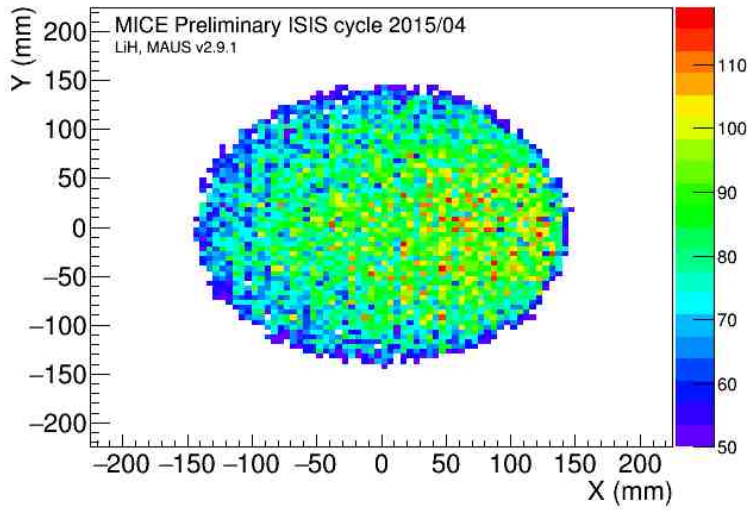
Job List

- Number of comments at CM
- Requested boost to MC statistics (✓)
- Pulled all LH2 data from latest cycle (✓)
- Investigating fiducial selection (✓)
- Rotating vector definitions to cross-check (✓)
- P correction by Bethe-Bloch (✓)
- Impact parameter plot (✓)
- Include tracker acceptance into analysis (✓)
- Update all plots and tables (✓)

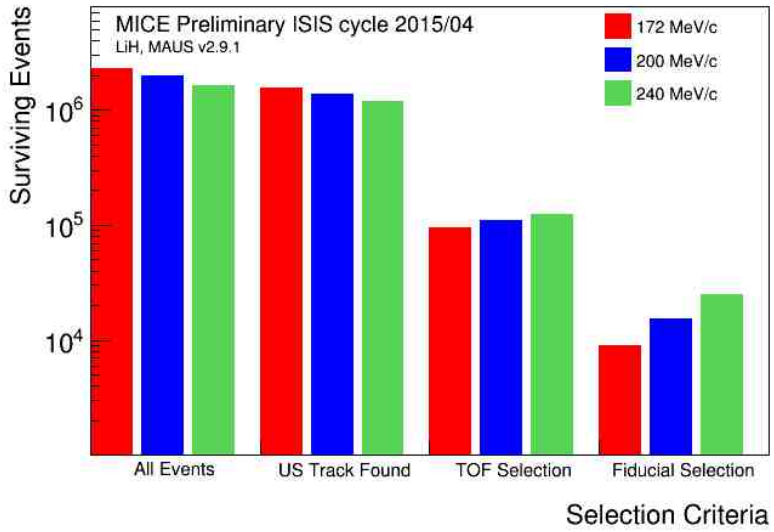
Scattering Data

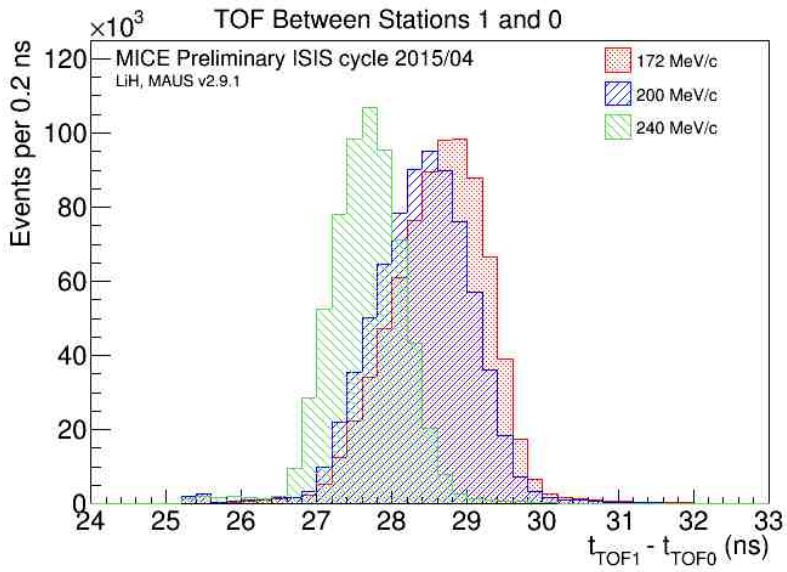
- Field off data sets were collected in ISIS run periods 2015/03 and 2015/04
- A momentum dependent multiple scattering measurement is made
  - Measure empty channel scattering
  - Convolved with physics model of scattering in absorber - prediction.
  - Measure absorber scattering
  - A Bayesian deconvolution algorithm unfolds absorber scattering distribution
  - χ^2 comparison between data and prediction
  - Width of scattering distribution: Θ as a function of P





Selection





Only minor changes to selection

- Require a US track. If a DS track not extant, statistics are set to overflow values.
- Analysis done in 200 ps bins, as shown in TOF plot
- Require projection of US tracks to appear, when 12 mrad radial angle is added, within central 140 mm radius of DS trkr plane 5

Momentum Calculation

1. Momentum is measured with

$$p = \frac{m}{\sqrt{\frac{t_\mu^2}{t_e^2} - 1}} \tag{1}$$

2. If there is a hit in TOF2 this is done with TOF1+2 information
3. If there is no hit in TOF2 this is done with TOF0+1
4. Only in the case of TOF0+1 is a correction applied to account for the energy loss in the channel.

Momentum Correction

- Developed analytic formula for momentum correction over the summer - works fine
- For greater transparency now use Bethe-Bloch most probable energy loss for known material budget in channel

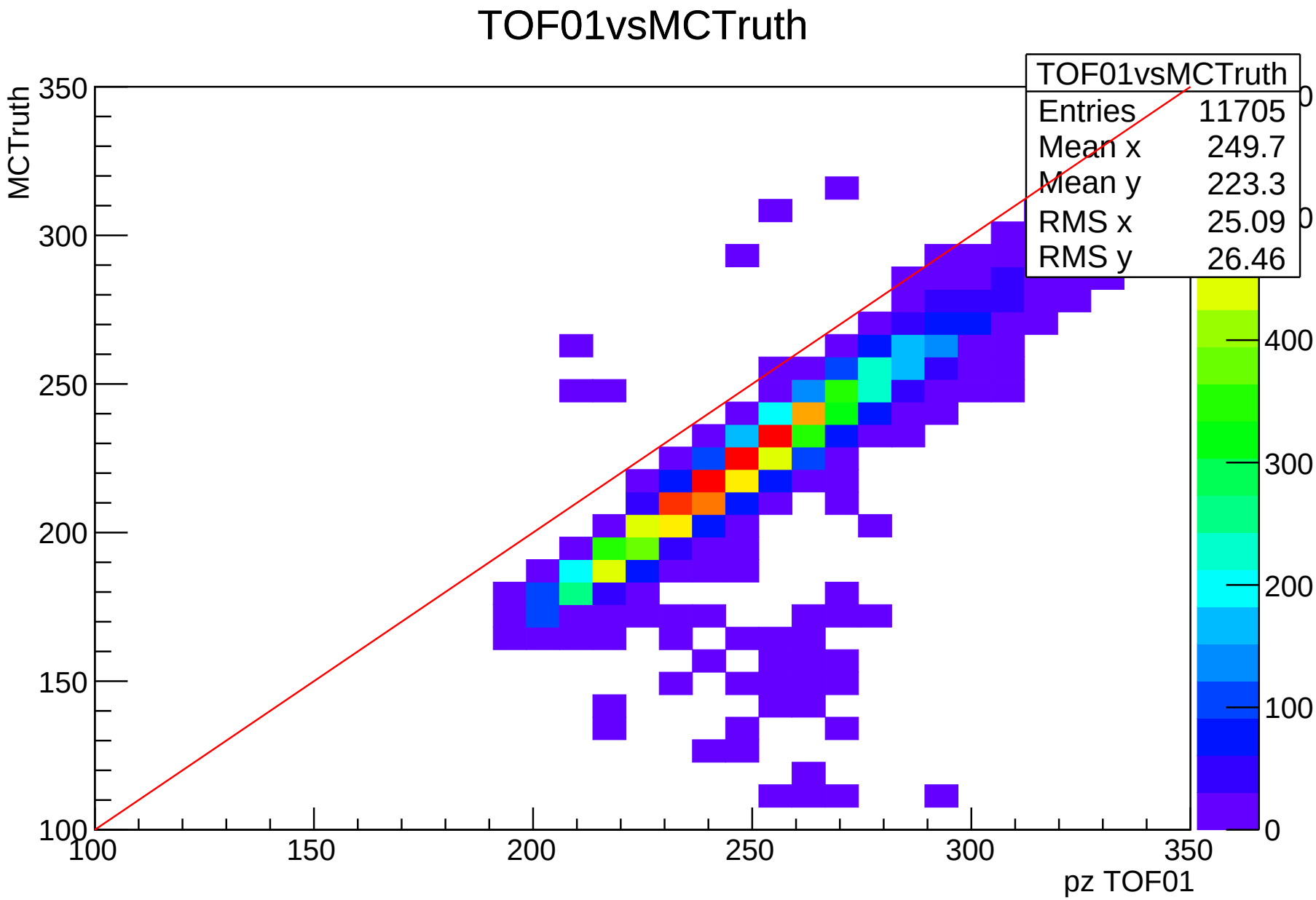
$$\Delta_p = \xi \left[\ln \frac{2mc^2\beta^2\gamma^2}{I} + \ln \frac{\xi}{I} + j - \beta^2 - \delta(\beta\gamma) \right] \tag{2}$$

where

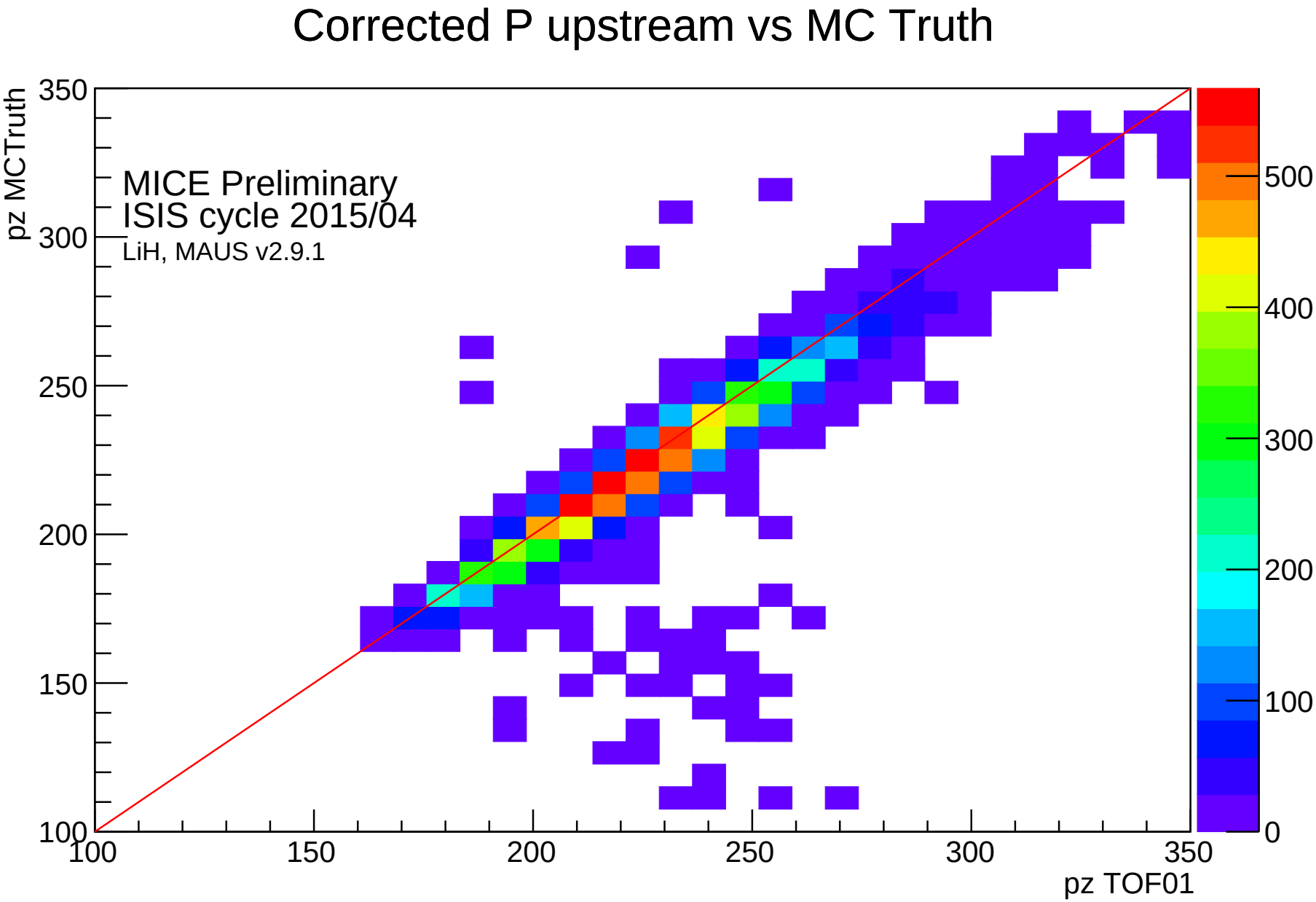
$$\begin{aligned} \xi &= (K/2)\langle Z/A \rangle z^2 (x/B^2) \\ I &= \text{mean excitation energy} \\ j &= 0.2 \end{aligned} \tag{3}$$

- Tracks crossing the diffuser ring are cut

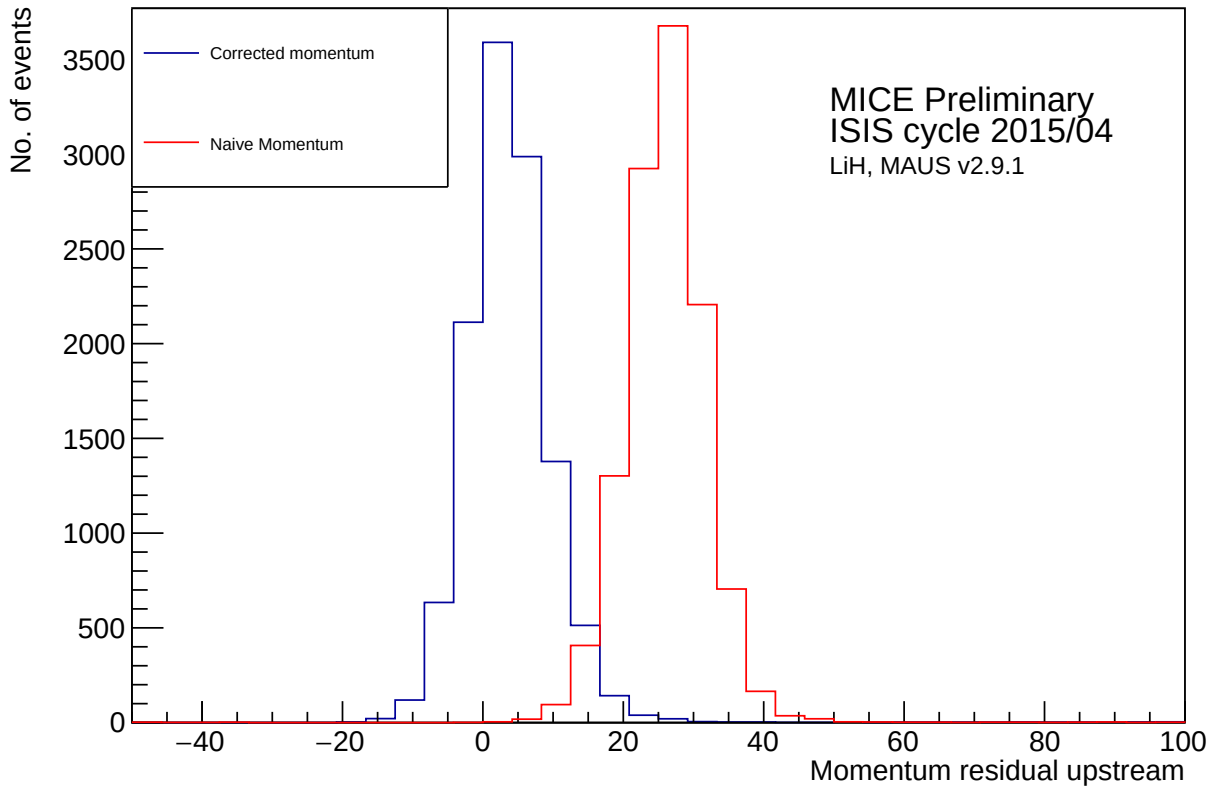
Compare Before Correction with MC



Compare Bethe Bloch Correction with MC



Before After Correction Residuals



Scattering Data

- Define projection angles

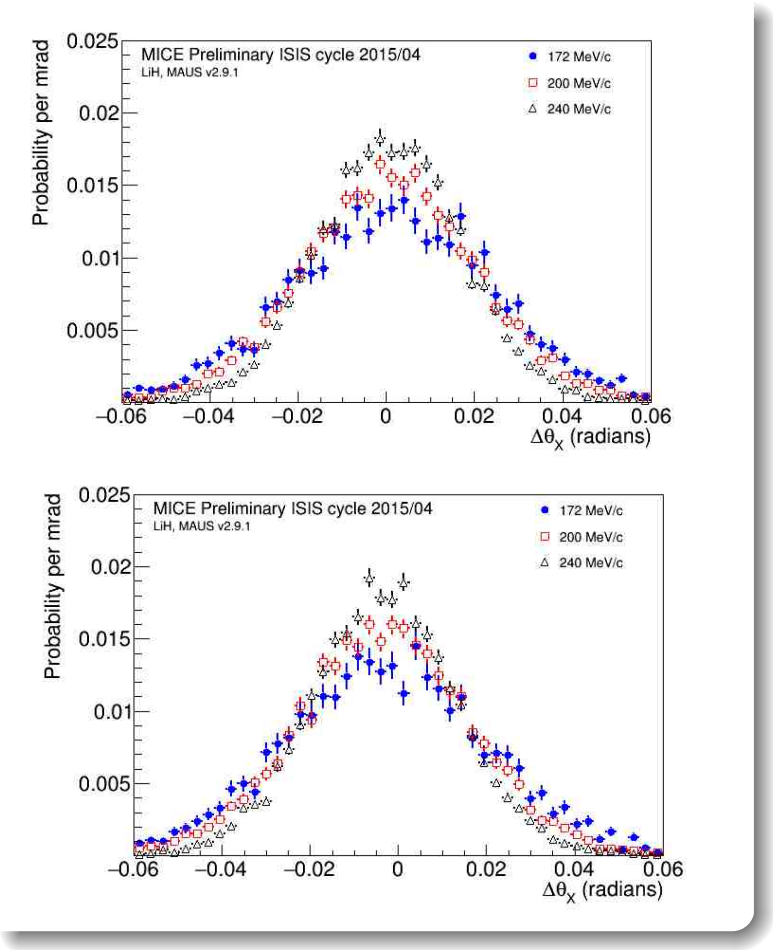
$$\theta_y = \text{atan}\left(\frac{p_{DS} \cdot (\hat{y} \times p_{US})}{|\hat{y} \times p_{US}||p_{DS}|}\right) \quad (4)$$

and

$$\theta_x = \text{atan}\left(\frac{p_{DS} \cdot (p_{US} \times (\hat{y} \times p_{US})}{|p_{US} \times (\hat{y} \times p_{US})||p_{DS}|}\right) \quad (5)$$

- Where $\theta_x^2 + \theta_y^2 \approx \theta_{scatt}^2$ with

$$\cos\,\theta_{scatt} = \frac{p_{US} \cdot p_{DS}}{|p_{US}||p_{DS}|} \quad (6)$$



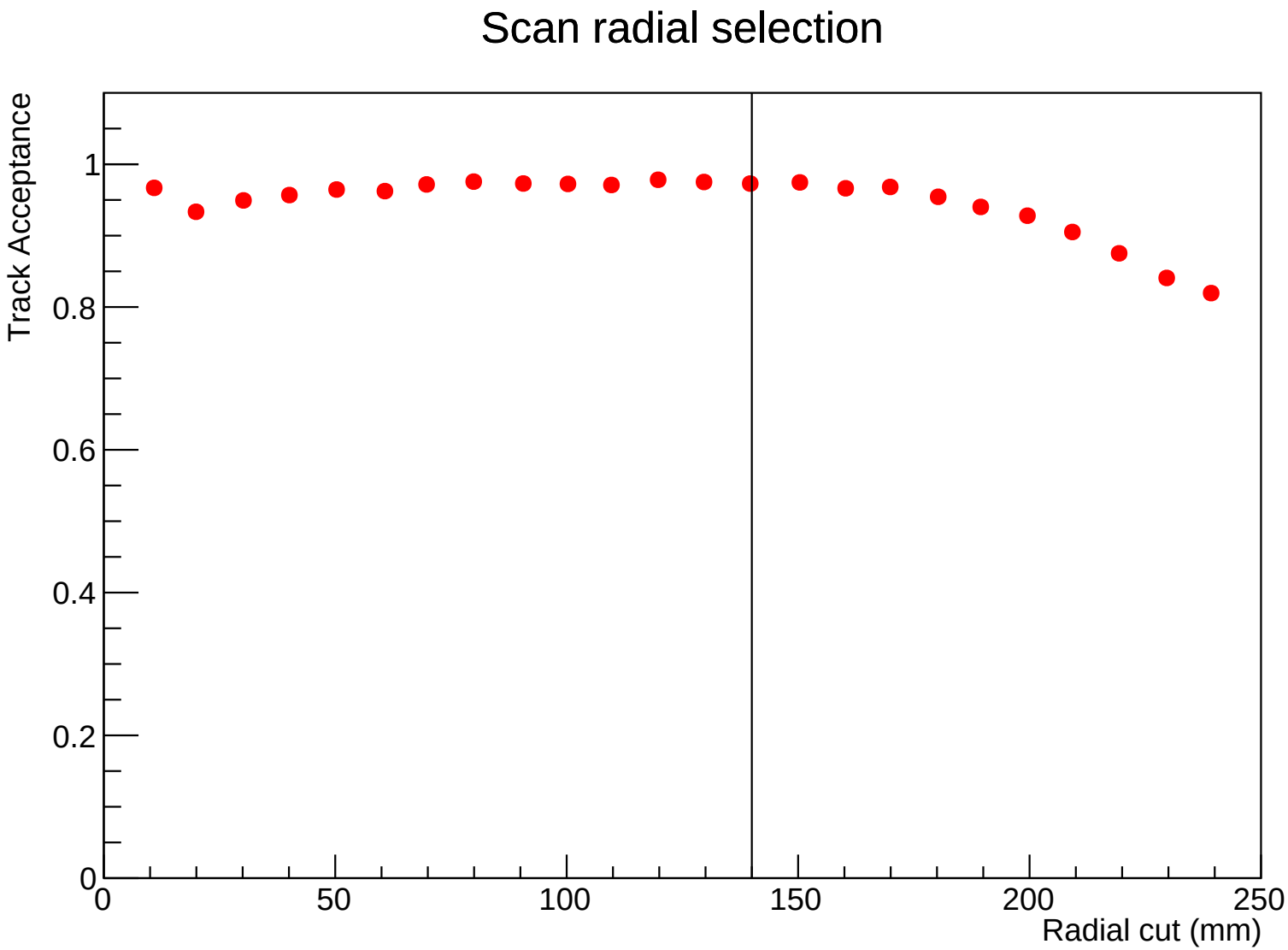
Fiducial Scan

- Ultimately want bin by bin correction for acceptance in θ
- $\therefore$ MC must be used, takes into account the efficiency, tracker resolution + selection. MC is treated in idential manner to data.

$$\frac{\text{No. of tracks in } \theta \text{ bin MC Truth that are reconstructed}}{\text{No. of tracks in } \theta \text{ bin MC Truth}} \tag{7}$$

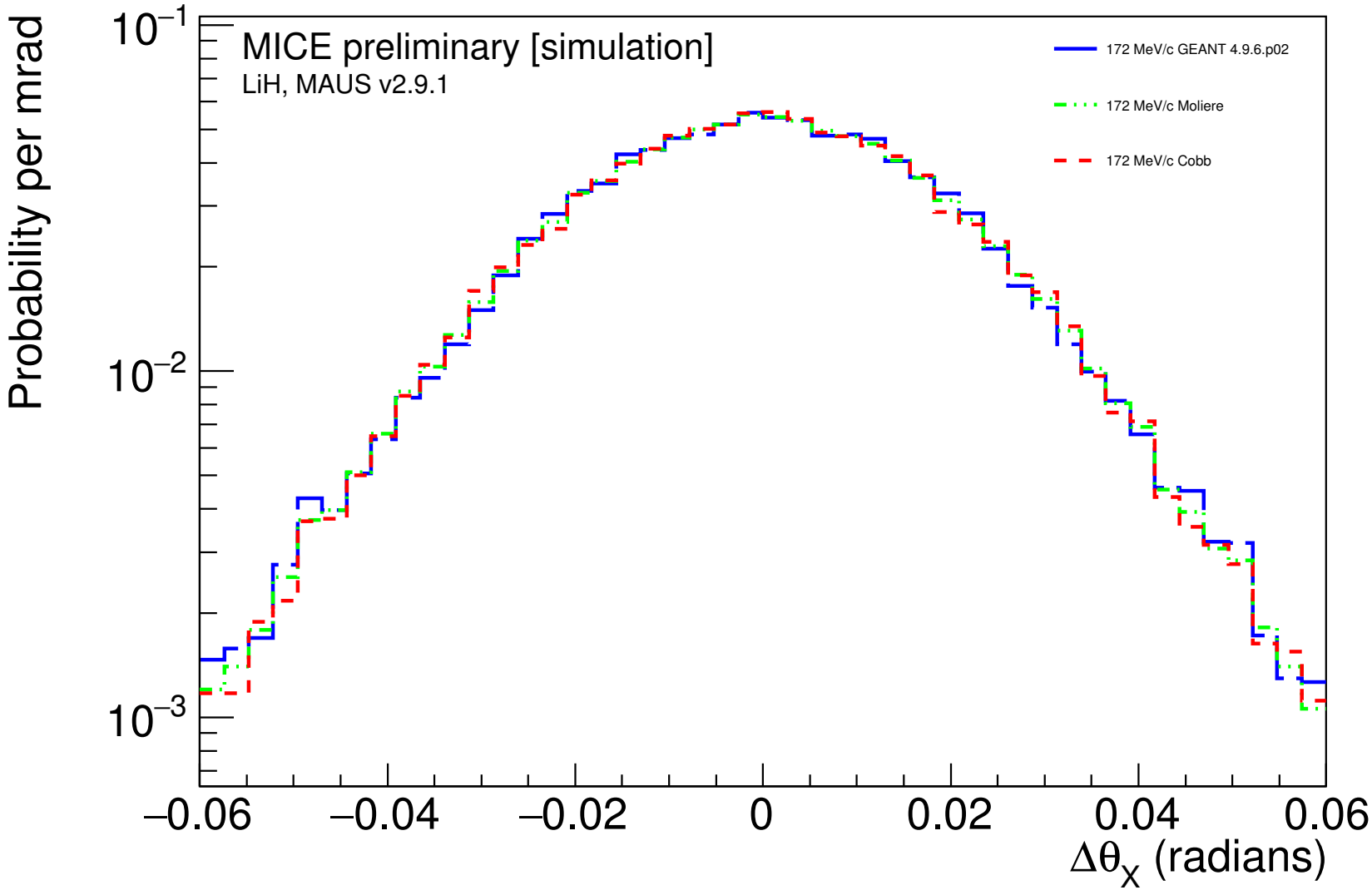
- Detector efficiency know to be $\sim 100\%$ $\therefore$ selection acceptance must be $\sim 100\%$. If not then there is geometric acceptance effect which is a bias in scattering measurement
- Track upstream is propagated to most downstream plane in DSS, nominal scattering fixed 40 mrad.
- Scan cut applied to analysis and calculate track acceptance
- Justify cuts based on acceptance scan

Fiducial Scan



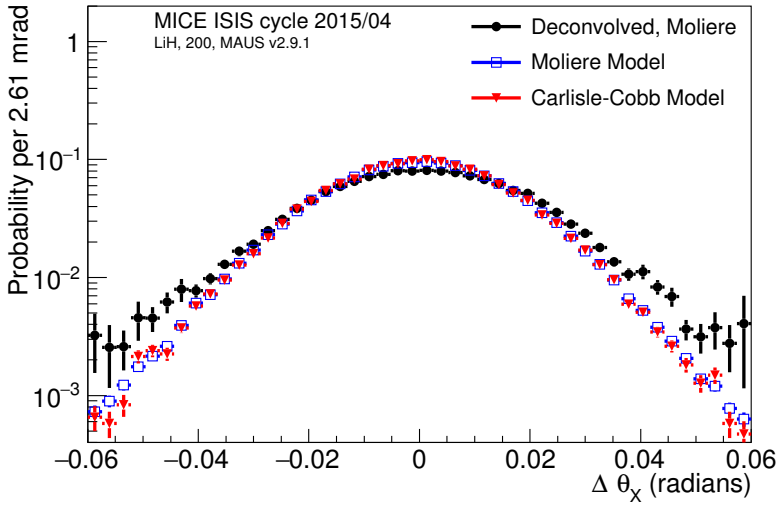
Physics Model

Three different physics models are used to make the scattering prediction, GEANT4, Carlisle-Cobb & Moliere



Deconvolution of Raw Scattering Data

- Use a iterative algorithm that uses the conditional probability to characterize the response of the reconstructed scattering angle to the true scattering angle

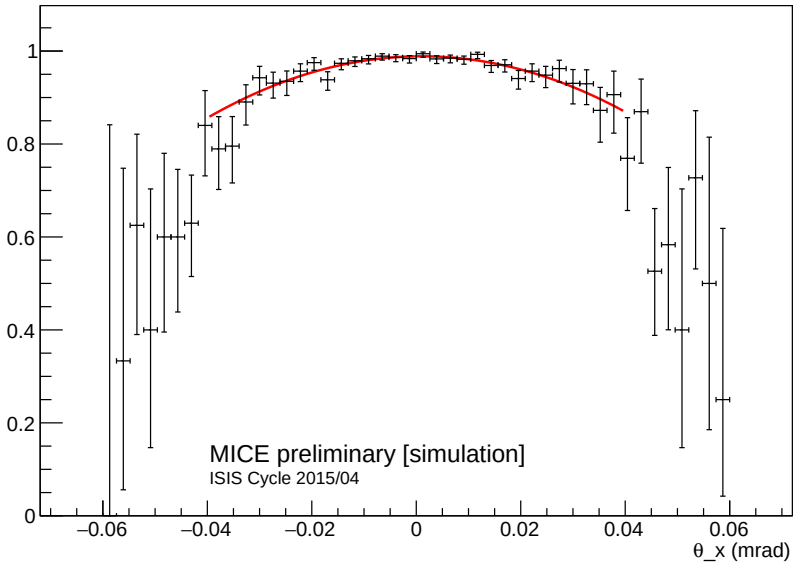


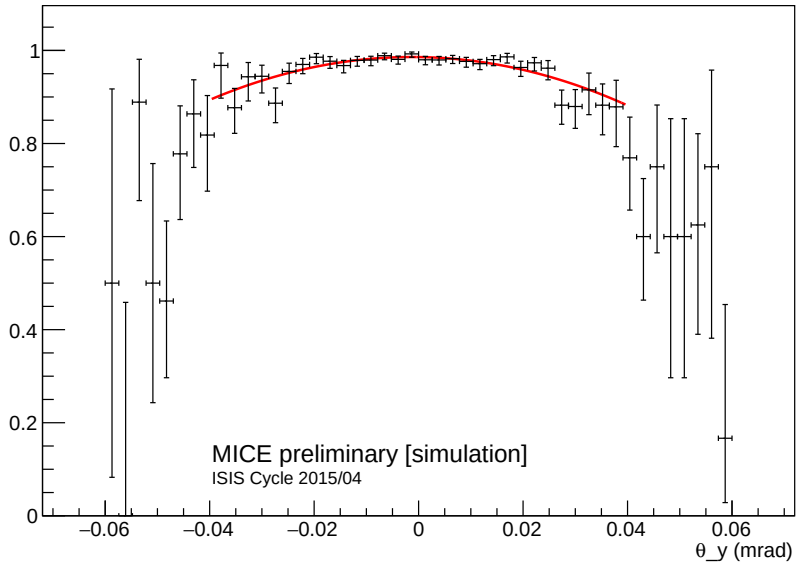
Bayes Theorem

$$P(C_i|E_j) = \frac{P(E_j|C_i)P_0(C_i)}{\sum_{l=1}^{n_c} P(E_j|C_l)P_0(C_l)}$$

- We want $C_i = \Delta\theta_Y^{abs}$ the deflection angle in the absorber material.
- We measure $E_j = \Delta\theta_Y^{tracker}$ the deflection angle measured at the first tracker plane.

Tracker Acceptance





- 200 MeV/c case
- Match track upstream and downstream
- TOF selection
- Calculate angle θ as per analysis
- Downstream acceptance is defined

$$\frac{\text{No. of tracks in } \theta \text{ bin MC Truth that are reconstructed}}{\text{No. of tracks in } \theta \text{ bin MC Truth}} \quad (8)$$

Systematic Errors

- Several sources have been considered
  - Material thickness uncertainties
  - Alignment uncertainties
  - TOF uncertainties
  - Fiducial volume uncertainties
- TOF systematic affects the momentum scale and is the dominant systematic
- All systematics are combined and included in final result

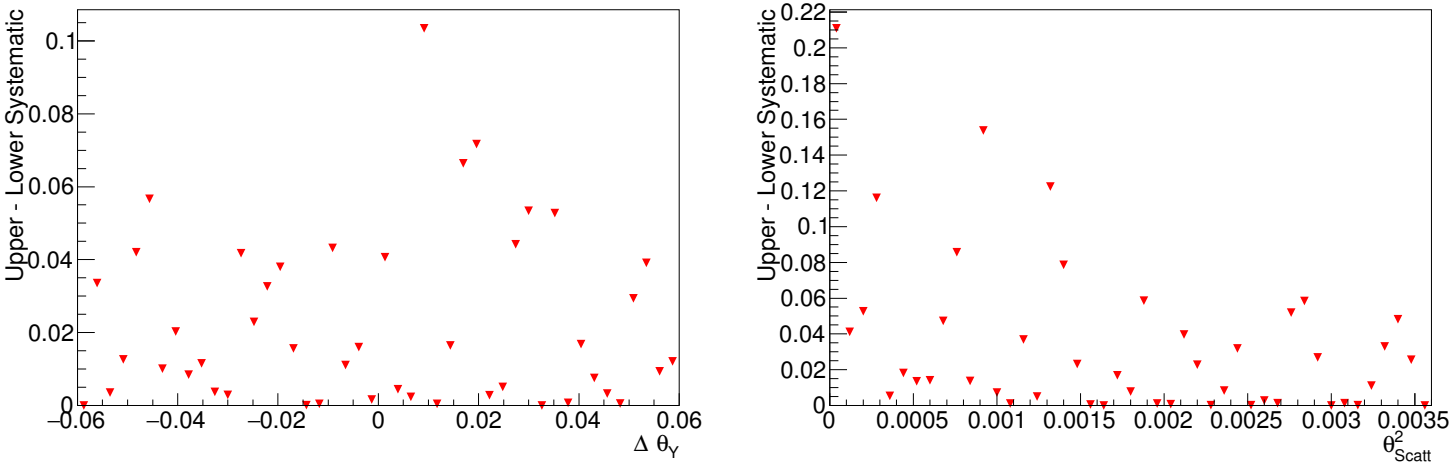
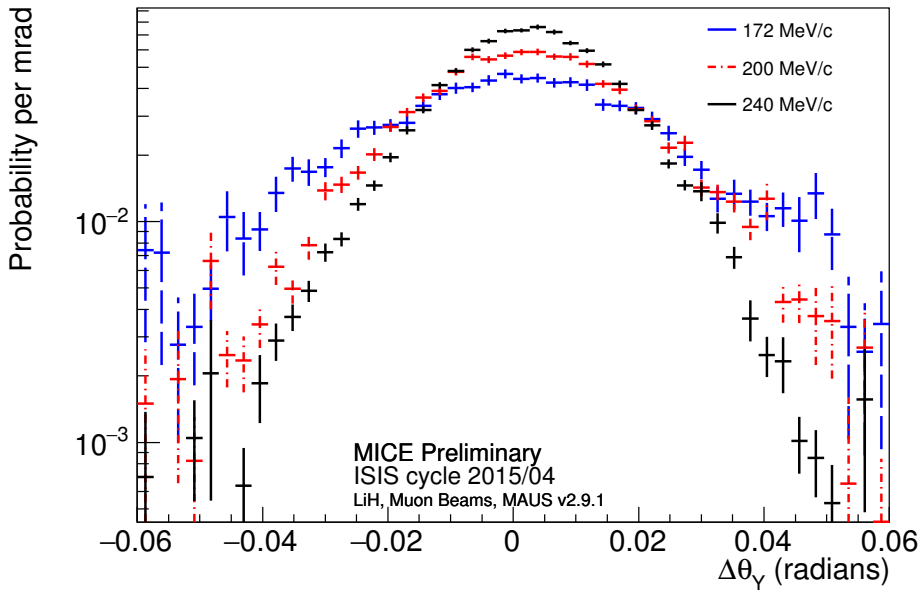
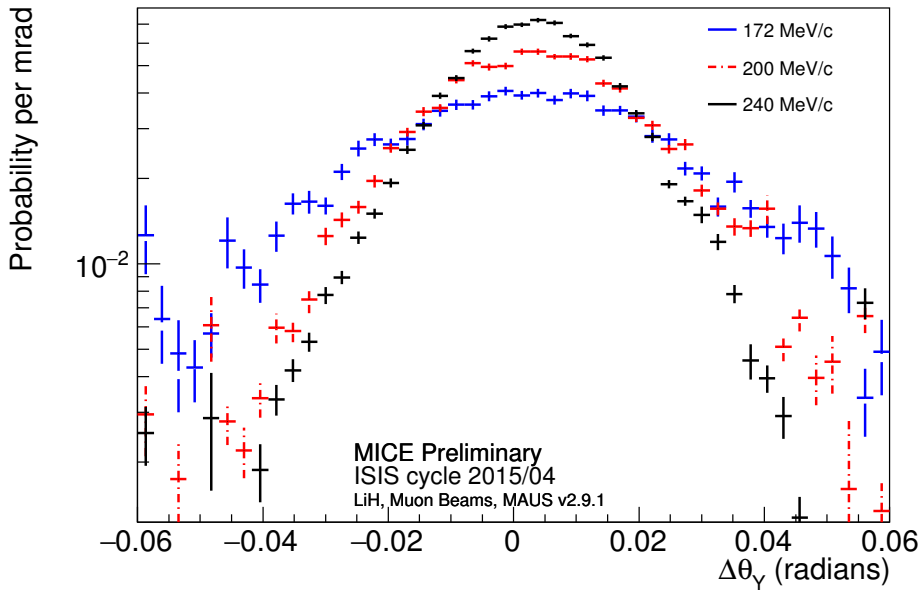


Figure: TOF systematic in $\Delta\theta_X$ & θ^2_{Scatt}

Results slide - deconvolution

Preliminary MICE result



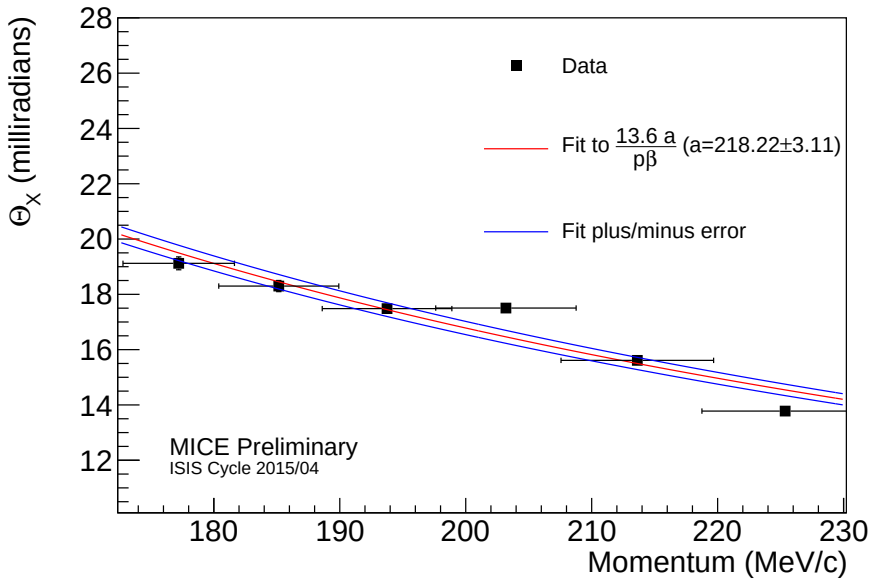


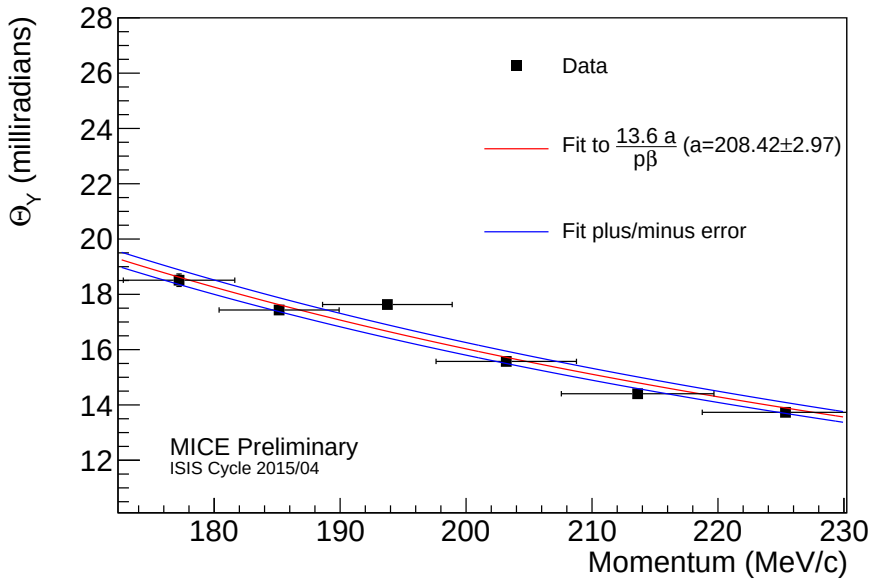
- Measurement of scattering at each nominal momentum point following the deconvolution proceedure - final value is a Gaussian fit to the central -40 to +40 mrad

Results - deconvolution

p (MeV/c)		Meas. (mrad)	G4 Pred.	χ^2/DoF	CC Pred.	χ^2/DoF
171.89±0.07	thetaX	22.82±0.33±0.54	19.27±0.1	1074.5 / 34	19.45±0.1	963.8 / 34
171.89±0.07	thetaY	23.13±0.39±0.61	19.05±0.1	1657.4 / 34	19.18±0.1	1475.5 / 34
199.3±0.06	thetaX	18.7±0.18±0.46	16.61±0.07	1306.3 / 34	16.21±0.07	1635.8 / 34
199.3±0.06	thetaY	17.91±0.17±0.76	16.39±0.07	1825.9 / 34	16.04±0.07	1885.4 / 34
243.73±0.08	thetaX	14.33±0.08±0.49	13.29±0.04	1327.3 / 34	13.06±0.03	1617.4 / 34
243.73±0.08	thetaY	14.4±0.09±0.5	13.1±0.04	4064.4 / 34	13.03±0.03	3297.5 / 34
171.89±0.07	theta2Scatt	32.92±1.23±0.25	26.91±0.23	2647.9 / 46	27.17±0.23	2744.9 / 46
199.3±0.06	theta2Scatt	25.34±0.52±0.69	23.19±0.15	1011.5 / 46	22.71±0.15	1154.8 / 46
243.73±0.08	theta2Scatt	20.14±0.2±0.72	18.61±0.07	1338.1 / 46	18.42±0.07	1394.5 / 46

Θ as a Function of Momentum





- Scan across the entire momentum range and measure scattering in both projections in each bin
- Comparison with PDG formula is made and the fit is made for $a = \sqrt{\frac{z}{X_0}}(1 + 0.038 \ln \frac{z}{X_0})$

Job List

- Note has been updated
- MC/data comparison done but needs to be updated and incorporated into Note
- Update plots colour scheme/format etc
- Incorporate LH2, Neon & Xenon into analysis

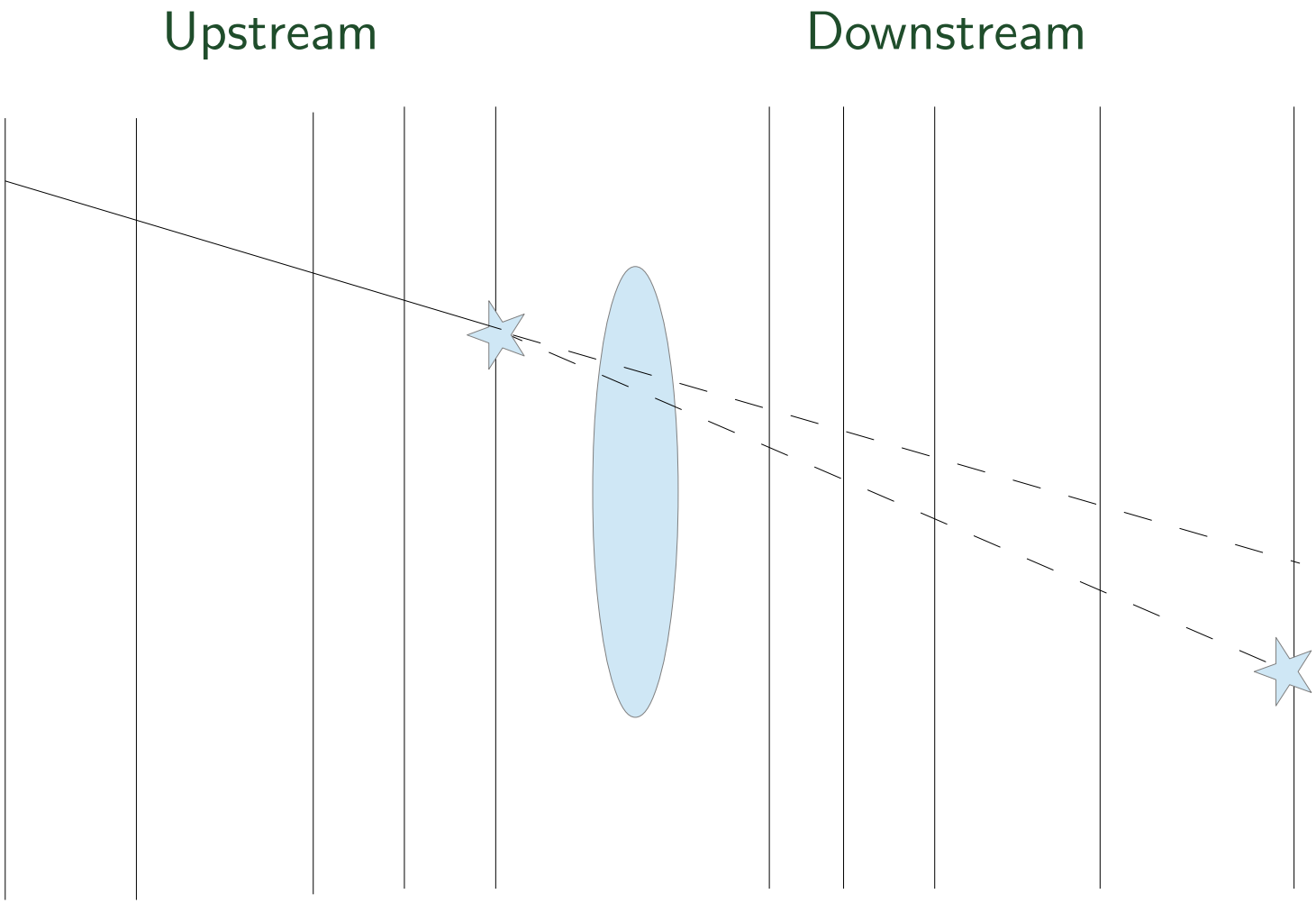
Selection

Selection	Description	μ Beams, LiH abs. 172	200	240	π Beam 240
TOF1 trigger	At least two raw TOF slab hits exist and at least one in each TOF plane.	1.	1.	1.	1.
Upstream track selection	There is one US track and at most one track in the DS tracker (If is are no DS track $\theta_X = \theta_Y = 45°$).	66.8%	68.4%	74.1%	59.0%
TOF timing selection	Select muons from run at the target momentum.	3.8%	5.4%	7.5%	35.0%
Fiducial selection	For projected US tracks $\sqrt{x^2+y^2} < r_0$ at DS ref plane, where $x = x_0 + (\frac{dx}{dz} + a_0 \cos\phi)\Delta z$, $y = y_0 + (\frac{dy}{dz} + a_0 \sin\phi)\Delta z$, and $\phi = \tan^{-1}\frac{dy/dz}{dx/dz}$. $r_0 = 150$ mm and $a_0 = 0.012$ assumed.	0.3%	0.5%	0.8%	2%

[1]

[1] Taken from MCSNote

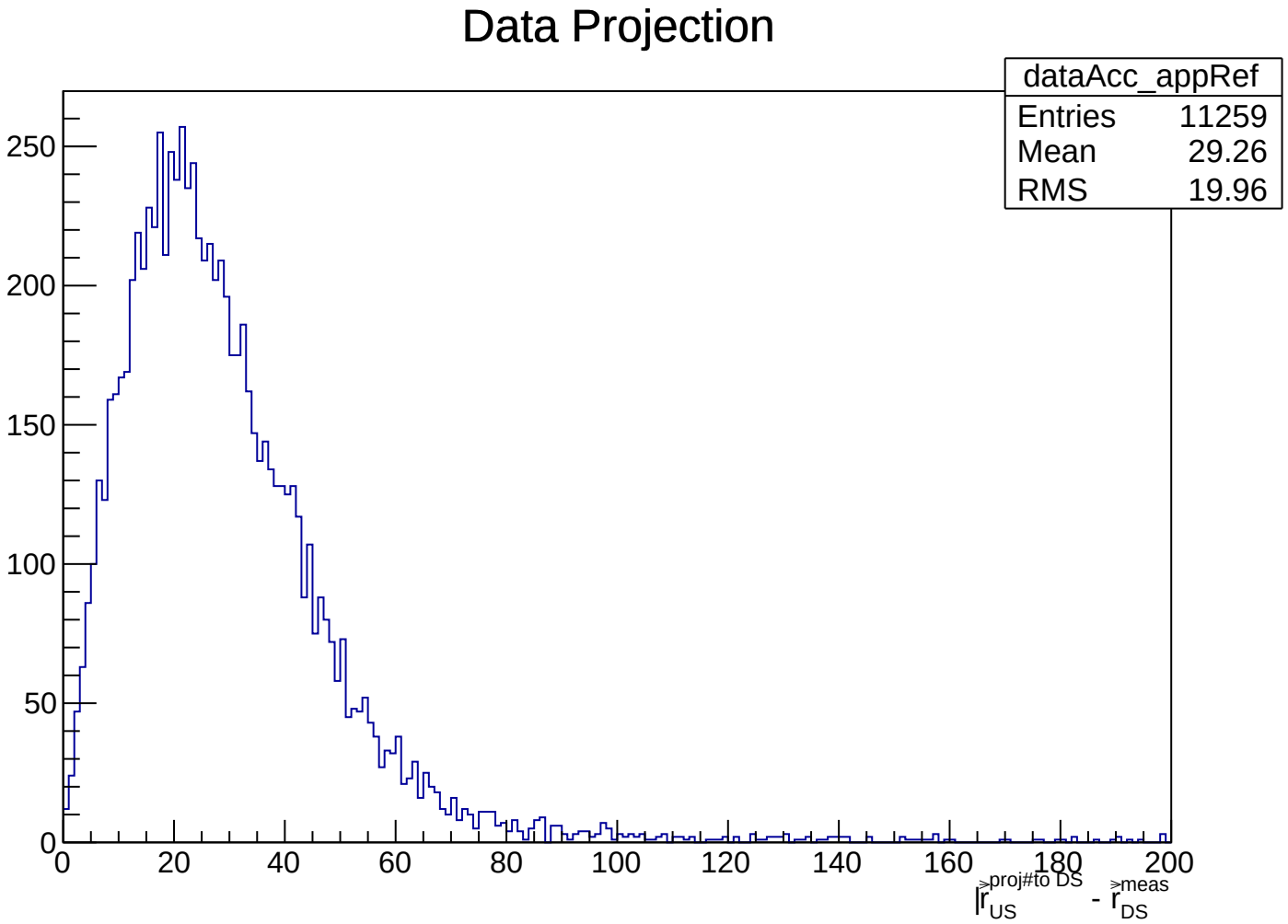
Selection



Transverse Distance at Absorber

Request to understand distance between projected tracks at absorber centre

Project tracks to centre of absorber and calculate transverse distance



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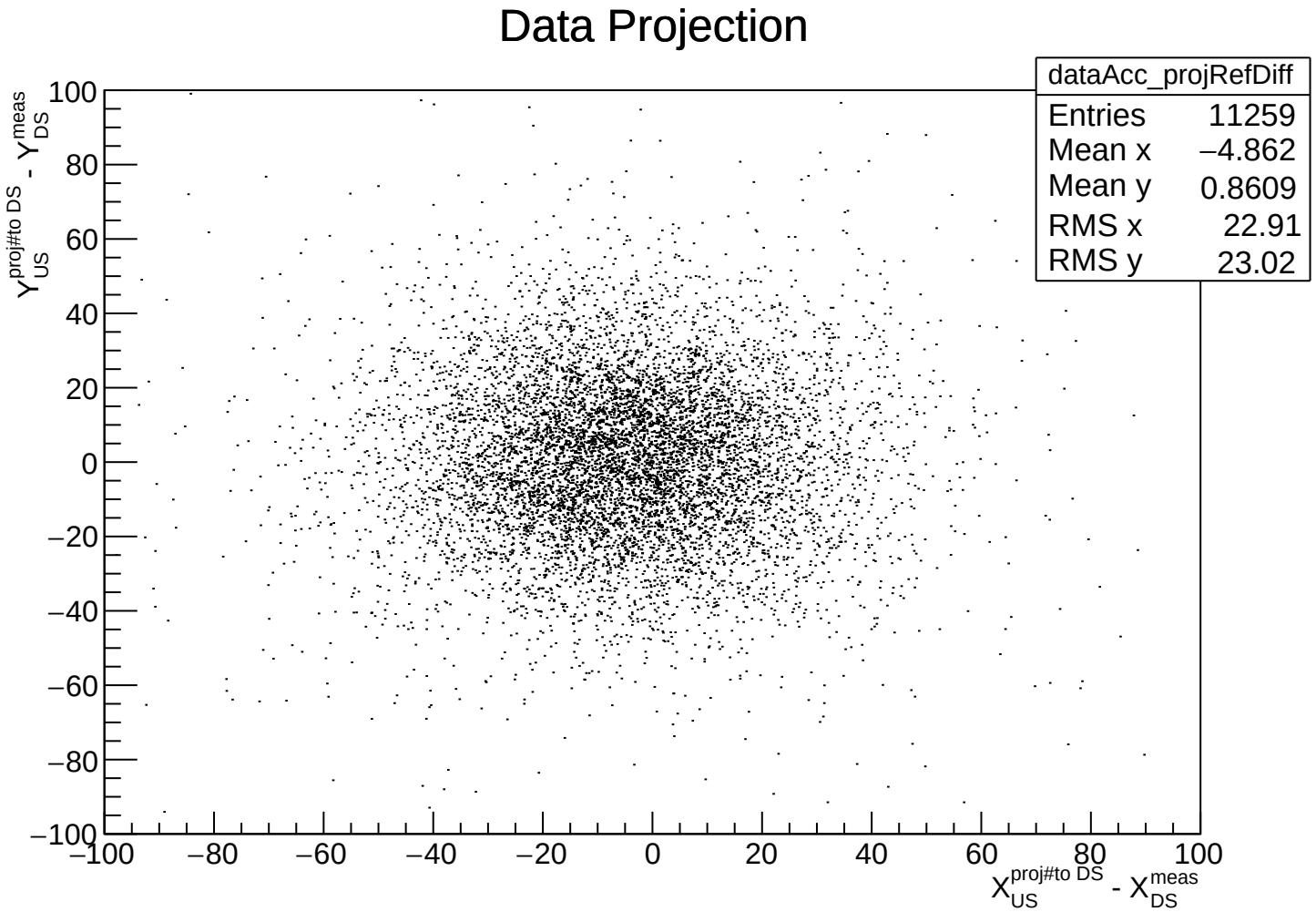


Rotate Angle Definitions

Definition of scattering angles comes from Cobb Note

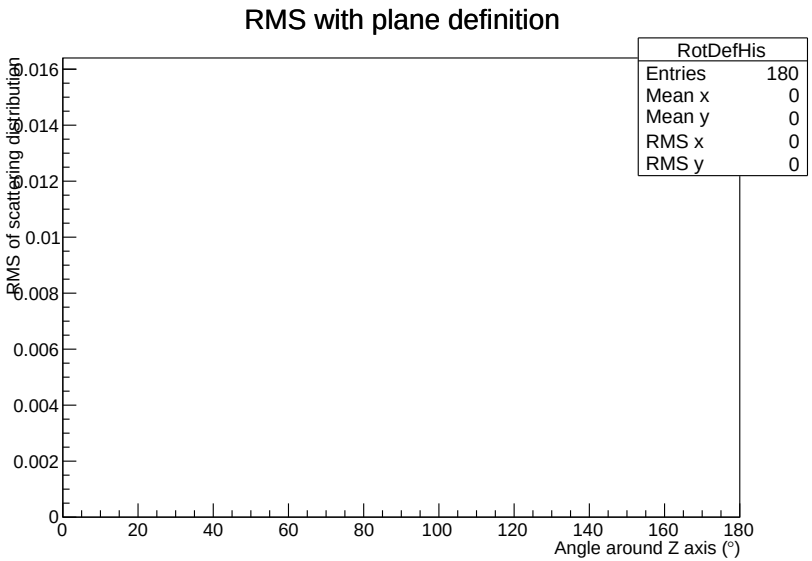
$$\tan\theta_p = \frac{\vec{d}\cdot\vec{v'}}{\vec{d}\cdot\vec{u}} \tag{9}$$

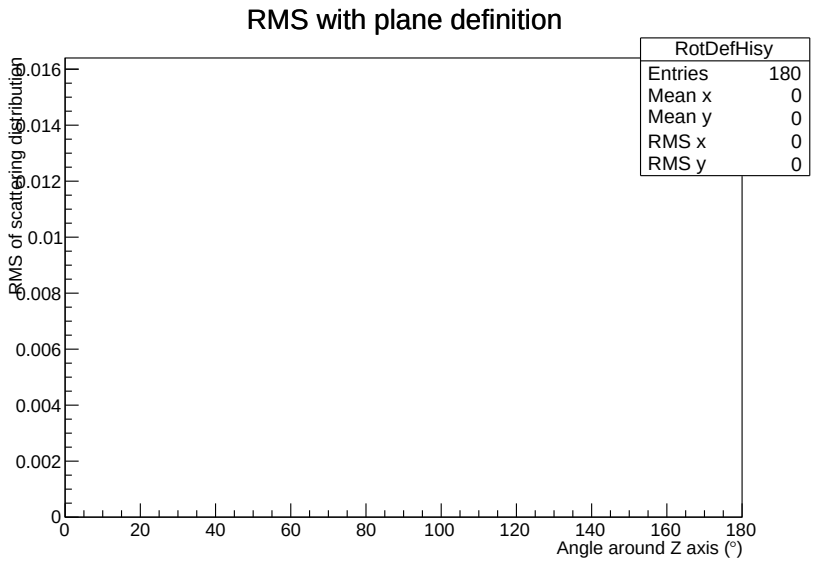
where

$$\vec{v} = \vec{s}\times\vec{u} \tag{10}$$

where $\vec{s}$ is arbitrary defined as $\vec{s} = (0, -1, 0)$
Test that this definition is arbitrary by rotating around the z-axis and plot RMS of scattering distribution

Rotate Angle Definitions



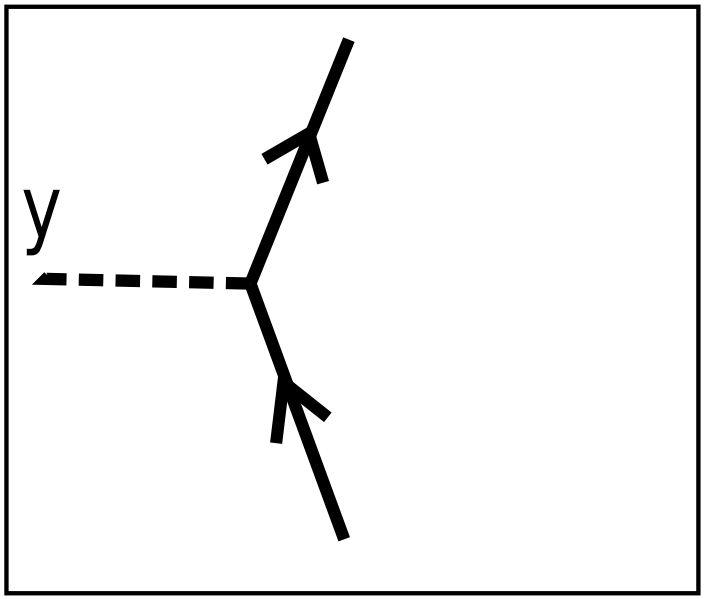


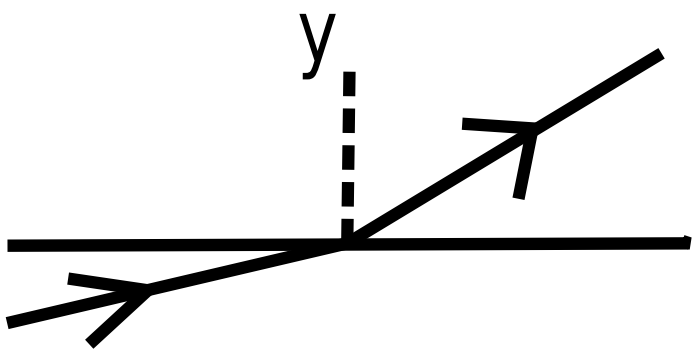
Left: θ"$_x$" Right: θ"$_y$"

Scattering Data

Scattering Angle Definitions

- In the top diagram both the solid vectors are in the plane of the square i.e. the plain of the board. The y-axis is coming out of the board
- If both the up- and downstream vector were in the same plane then the subtraction of the simple projected angle would be sufficient
- The bottom figure is a side on view of the top figure. If the up- and downstream vectors are in two different planes then a more consider apporach is required as detailed in `http://www.ppe.gla.ac.uk/~jnugent/Projected-angles.pdf` by John Cobb





MC Truth After Deconvolution

- Want to correct absorber scattering distribution bin by bin in the θ_{scat}
- Bin by bin correction can not be done in data, if the track is not measured down stream then we never measure the scattering angle
- Can only be done in MC truth
- $\therefore$ correction must be done on final deconvolved distribution, raw distributions include tracker resolution + interstitial material
- We calculate the acceptance of the tracker system (Up+down)
- MC selection == data selection
- Apply acceptance correction to final deconvolved scattering distributions