Field Off Scattering Studies: Current Status

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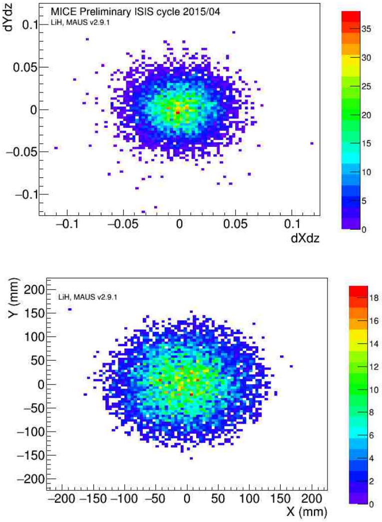
Job List

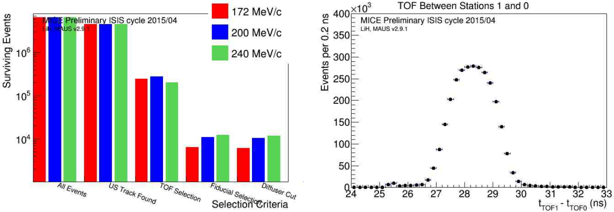
- Actions from referees at CM50 (✓)
- Requested boost to MC statistics (In progress)
- All plots shown use MC v2.9.1
  - There are known issues with geometry in this version
- All plots shown use data v3.1.2-V2
  - Myself and Durga indepedantly found bug in v3.1.2 field off data
- Misalignment/Impact parameter plot (✓)
- Systematic error due to angle definition, pion contamination and tracker acceptance added (✓)

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



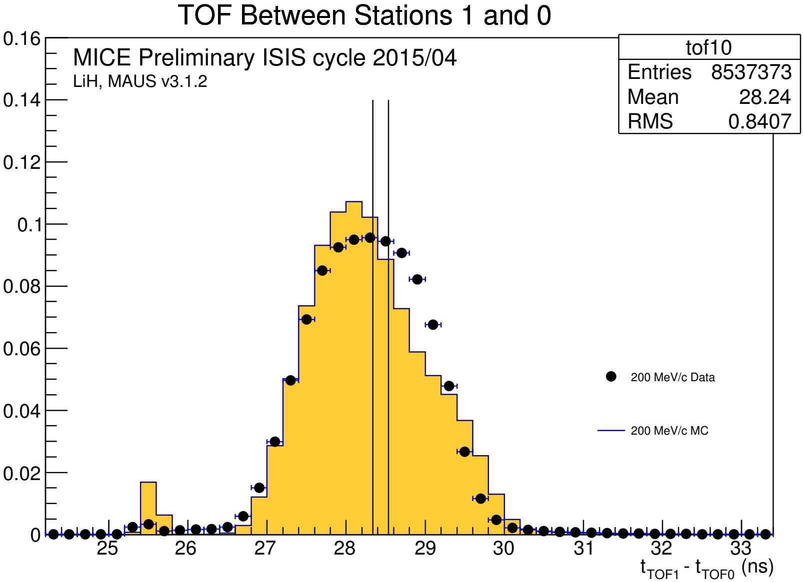
Selection



Only minor changes to selection

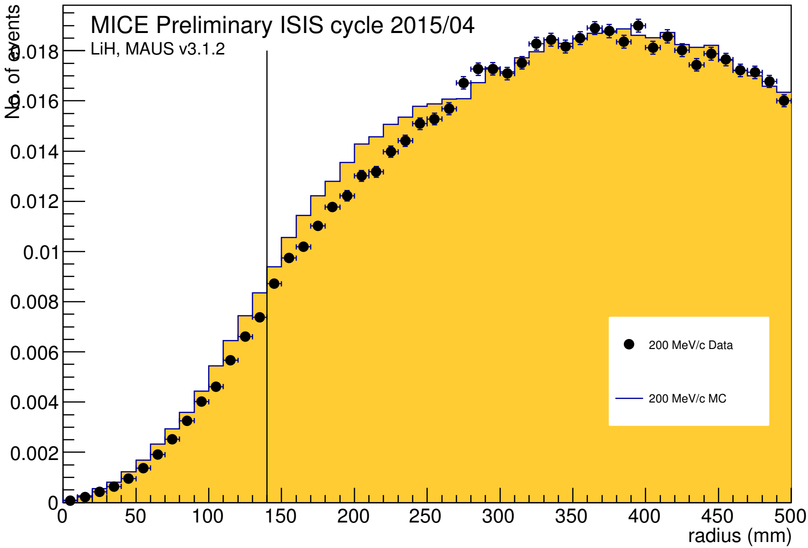
- Require a US track. If a DS track not extant, statistics are set to overflow values.
- Analysis done in 200 ps bins, as shown in TOF plot
- Require projection of US tracks to appear, when 12 mrad radial angle is added, within central 140 mm radius of DS trkr plane 5
- Tracks are projected to the upstream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

Cut plot

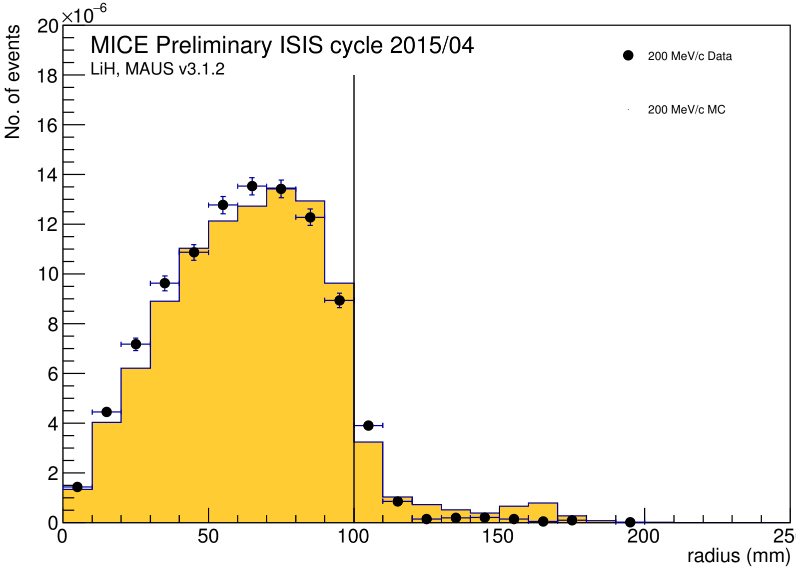


TOF Between Stations 1 and 0
MICE Preliminary ISIS cycle 2015/04
LiH, MAUS v3.1.2
tof10
Entries 8537373
Mean 28.24
RMS 0.8407
200 MeV/c Data
200 MeV/c MC
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
25
26
27
28
29
30
31
32
33
t_TOF1 - t_TOF0 (ns)

Cut plot

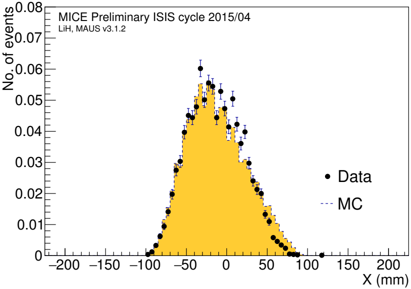

MICE Preliminary ISIS cycle 2015/04
LiH, MAUS v3.1.2
No. of events
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
50
100
150
200
250
300
350
400
450
500
radius (mm)
200 MeV/c Data
200 MeV/c MC

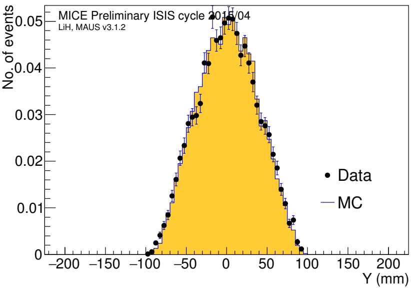
Cut plot



MICE Preliminary ISIS cycle 2015/04
LiH, MAUS v3.1.2
200 MeV/c Data
200 MeV/c MC
No. of events
×10^−6
0
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
radius (mm)

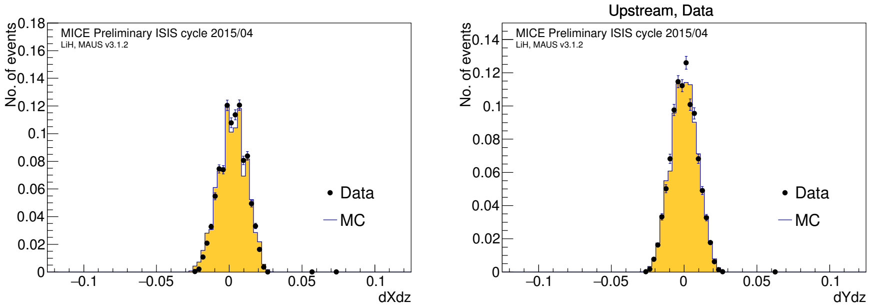
MC Data comparison





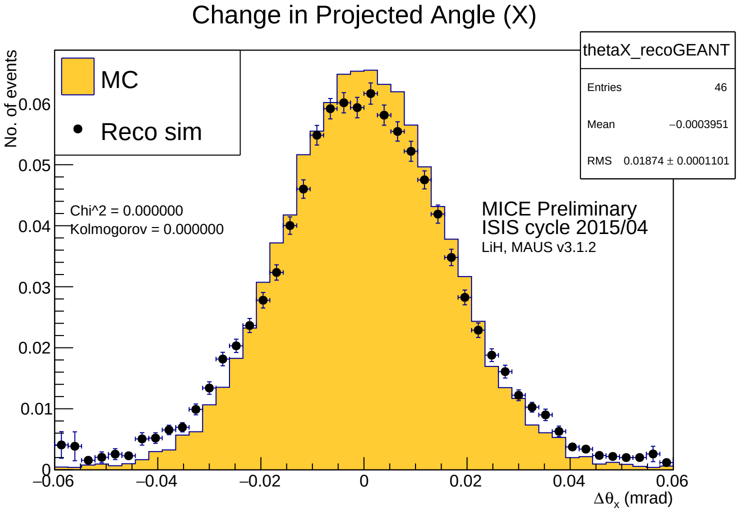
- 200 MeV/c case
- Compare MC recon and data

MC Data comparison



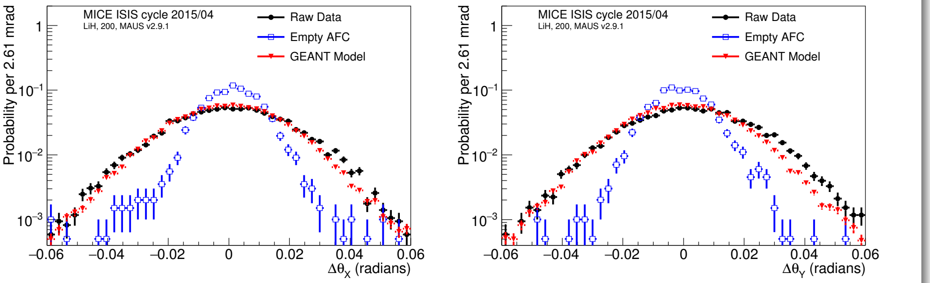
- 200 MeV/c case
- Compare MC recon and data

MC Data comparison



- 200 MeV/c case
- Compare MC recon and data

Forward convolution

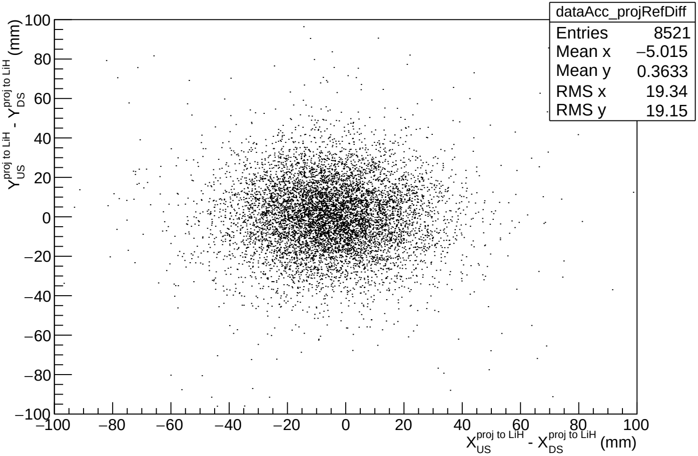


- Geometry fix gives much improved agreement
- Impact parameter plots on next slide

Transverse Distance at Absorber

Request to understand distance between projected tracks at absorber centre

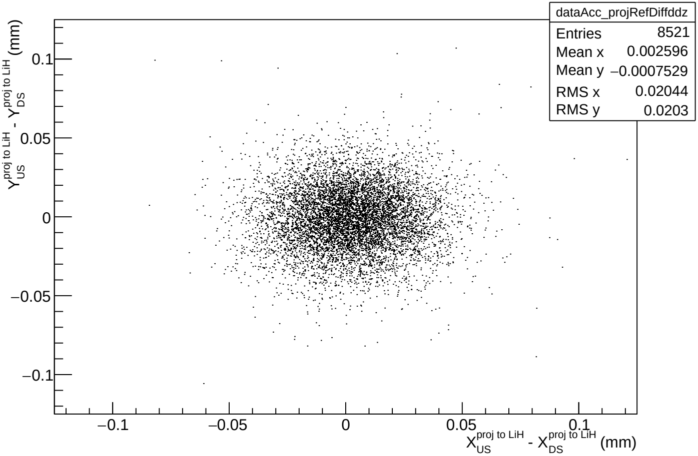
Project tracks to centre of absorber and calculate transverse distance



Transverse Distance at Absorber

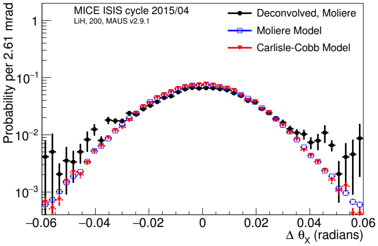
Request to understand distance between projected tracks at absorber centre

Project tracks to centre of absorber and calculate angle difference



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

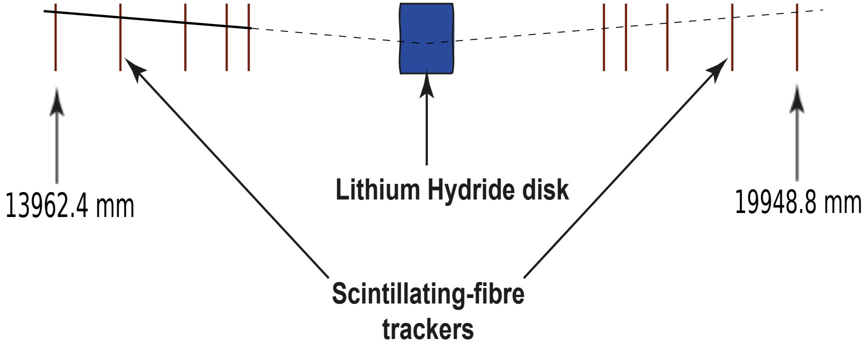
$$P(C_i|E_j) = \frac{P(E_j|C_i)P_0(C_i)}{\sum_{l=1}^{n_c} P(E_j|C_l)P_0(C_l)}$$

- 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.

Systematic Errors

- Several sources have been considered
  - Material thickness uncertainties
  - Alignment uncertainties
  - TOF uncertainties
  - Fiducial volume uncertainties
    - pion contamation - studied in MC
    - Angle defintion
    - Tracker acceptance - also studied in MC
- TOF systematic affects the momentum scale and is the dominant systematic
- All systematics are combined and included in final result

Acceptance Systematic



- Measurement made with reference planes for empty + LiH
- Repeat measurement at reference plane for LiH
  - Measure empty at virtual planes at absorber
- Difference is systematic error due to acceptance

Rotate Angle Definitions

Definition of scattering angles comes from Cobb Note

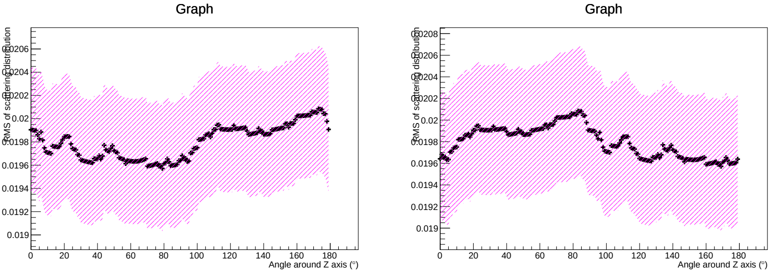
$$\tan\theta_p = \frac{\vec{d}\cdot\vec{v'}}{\vec{d}\cdot\vec{u}} \quad (1)$$

where

$$\vec{v} = \vec{s}\times\vec{u} \quad (2)$$

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

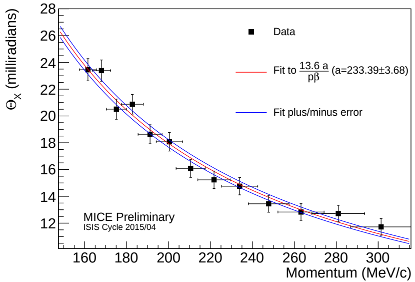


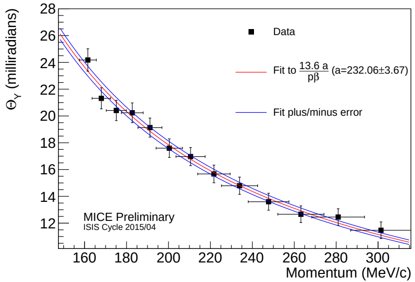
Left: $\theta_{"x"}$ Right: $\theta_{"y"}$

Results - deconvolution

p (MeV/c)		Meas. (mrad)	G4 Pred.	χ^2/DoF	CC Pred.	χ^2/DoF
172.08±0.03	θ_X	22.23±0.63±2.7	19.61±0.12	713.6 / 34	19.79±0.13	737.8 / 34
172.08±0.03	θ_Y	24.76±0.95±3.38	19.53±0.12	1648.9 / 34	19.67±0.13	1446.8 / 34
200.01±0.03	θ_X	17.95±0.3±2.01	17.05±0.08	2125.1 / 34	16.7±0.07	1642.4 / 34
200.01±0.03	θ_Y	19.24±0.34±2.09	16.96±0.08	2152.9 / 34	16.52±0.07	2412.0 / 34
239.72±0.04	θ_X	14.85±0.18±1.95	13.86±0.06	3381.8 / 34	13.62±0.05	2543.1 / 34
239.72±0.04	θ_Y	14.85±0.2±2.05	13.75±0.06	2071.2 / 34	13.54±0.05	1240.9 / 34
172.08±0.03	θ^2_{Scatt}	30.65±2.1±0.69	27.65±0.29	5540.8 / 46	27.85±0.3	4991.1 / 46
200.01±0.03	θ^2_{Scatt}	25.57±1.06±2.25	23.99±0.17	2839.7 / 46	23.48±0.16	2793.8 / 46
239.72±0.04	θ^2_{Scatt}	20.98±0.52±1.98	19.48±0.11	1711.2 / 46	19.19±0.11	1928.9 / 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

- Collect new MC, update Note

Selection

Selection	Description	μ Beams, LiH abs. 172	200	240
TOF1 trigger	At least two raw TOF slab hits exist and at least one in each TOF plane.	1.	1.	1.
Upstream track selection	There is one US track and at most one track in the DS tracker (If there is no DS track $\theta_X = \theta_Y = 45°$).	66.84 %	68.05 %	74.15%
TOF timing selection	Select muons from run at the target momentum.	4.1 %	5.42 %	7.77 %
Fiducial selection	For projected US tracks $\sqrt{x^2+y^2} < r_0$ at plane 5 of DS tracker, 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.	0.09 %	0.19 %	0.41 %
Diffuser cut	US tracks are projected to the diffuser position any track within the radius of the diffuser annulus is rejected	0.07 %	0.16 %	0.36 %

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