

Initial Scattering Studies

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Experimental
Particle Physics

- 1 Motivation For Scattering Studies
- 2 Data Collected for Field Off Studies
- 3 Unfolding and Deconvolution Methods

Multiple Coulomb Scattering in MICE

- Cooling performance in the channel given by

$$\frac{d\epsilon_n}{dz} = -\frac{\epsilon}{p_\mu\beta} \left\langle \frac{dE_\mu}{dz} \right\rangle + \frac{\beta_\perp p_\mu}{2m} \frac{d\theta_0^2}{dz}$$

- RMS scattering width recommended by the Particle Data Group is

$$\theta_0 = \frac{13.6 \text{ MeV}/c}{p_\mu\beta} \sqrt{\frac{x}{X_0}} \left(1 + 0.0038 \ln \frac{x}{X_0} \right)$$

- Theory developed by Rossi and Greisen, Moliere, and Bethe
- GEANT4 uses a Legendre polynomial expansion implemented by Urban.
 - ▶ Theories do not agree with measurements of muon scattering in low Z materials (see MuScat <http://arxiv.org/pdf/hep-ex/0512005.pdf>)

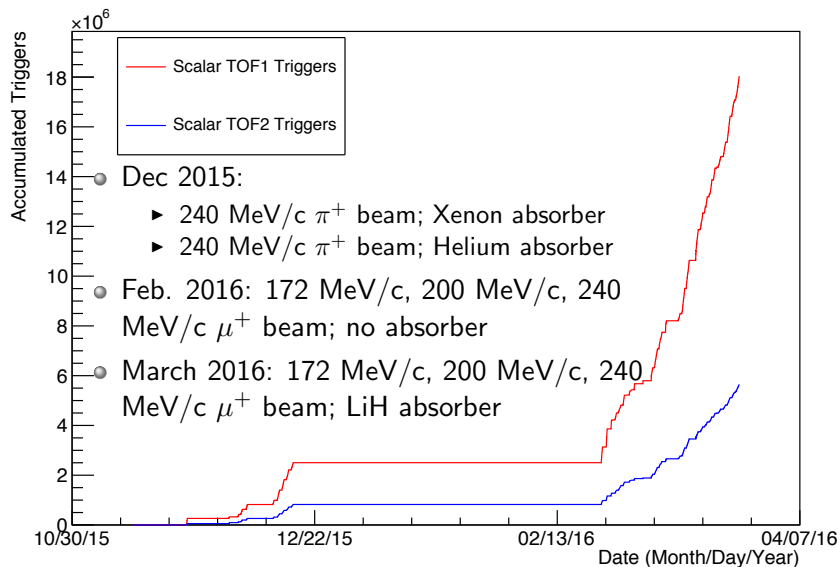
MCS in MICE With Field Off

7th February 2015

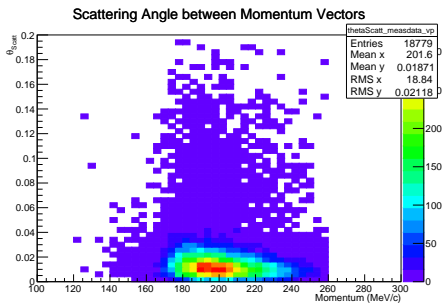
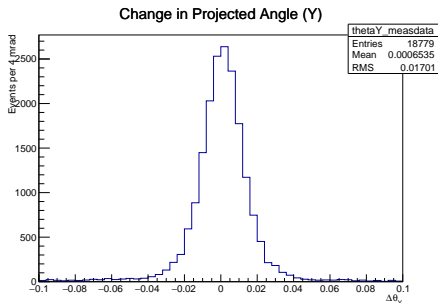


- Particles follow straight paths through spectrometers.
- Scatter off of materials along its path.
 - ▶ Need to identify scattering from absorber material only.
- Use TOFs to measure momentum.
 - ▶ Consider scattering as a function of momentum.
- Define scattering angles for trajectories
 - ▶ $\Delta\theta_x = \text{atan}\left(\frac{dy}{dz}\right)_{US} - \text{atan}\left(\frac{dy}{dz}\right)_{DS}$
 - ▶ $\Delta\theta_y = \text{atan}\left(\frac{dx}{dz}\right)_{US} - \text{atan}\left(\frac{dx}{dz}\right)_{DS}$
 - ▶ $\theta_{scatt} = \text{acos}\left(\frac{\mathbf{p}_u \cdot \mathbf{p}_d}{|\mathbf{p}_u| |\mathbf{p}_d|}\right)$

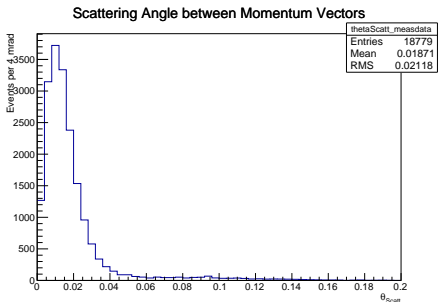
Field Off Scattering Data Collected by MICE



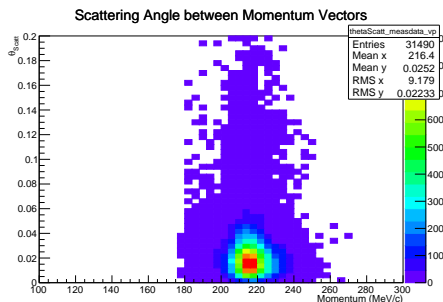
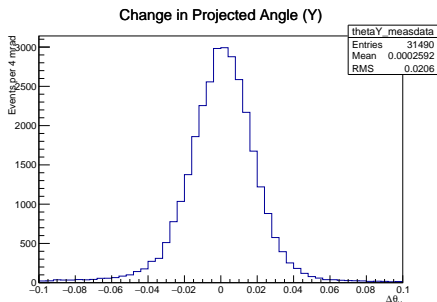
Control Data Sets



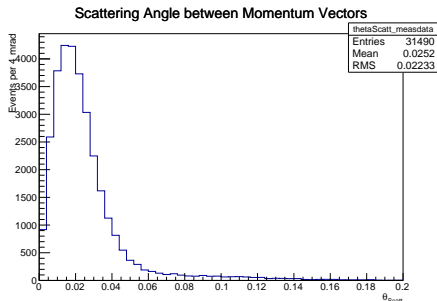
- Two controls taken
 - ▶ He filled absorber
 - ▶ Empty Focus Coil
- Evaluate scattering with windows independent of absorber
- Empty focus coil shown.



Scattering Distributions in Xenon

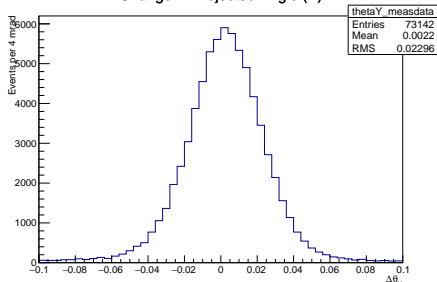


- Official MICE reconstruction used for analysis
- We believe scattering in GEANT for this material.
- Taken to develop and confirm analysis methods.



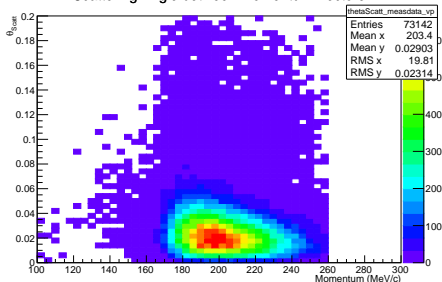
Scattering in Lithium Hydride

Change in Projected Angle (Y)

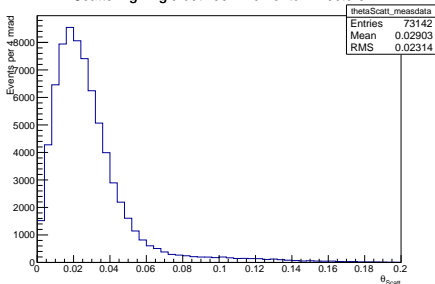


- Physics measurement.
- Must compare to new models in addition to GEANT4.
- Raw distribution shown

Scattering Angle between Momentum Vectors



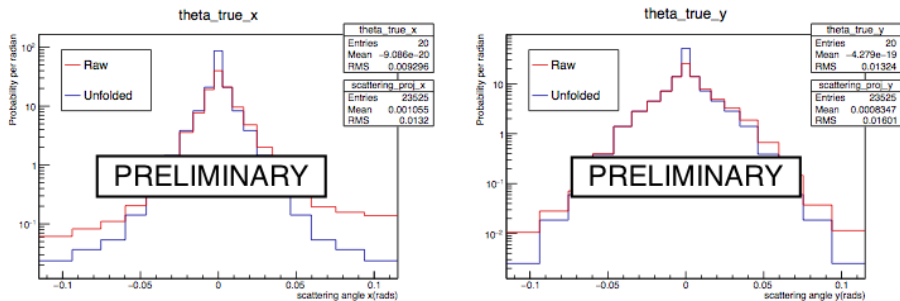
Scattering Angle between Momentum Vectors



Detector Unfolding

- MuScat unpacking uses expression : $D_j = B_j + R_{ij}\epsilon_{ij}\theta_i$
 - $D_j \rightarrow$ data vector of no. of counts per position bin
 - $B_j \rightarrow$ background vector of no. of counts per position bin PID != 13, primarily electron contamination
 - $R_{ij} \rightarrow$ matrix of no. of counts per position bin j for angular bin i normalised by row
 - $\epsilon_{ij} \rightarrow$ matrix is
$$\frac{\text{No. of counts angular bin recon}}{\text{No. of counts angular bin truth}}$$
 - $\theta_i \rightarrow$ vector of no. of counts per angular bin of true scattering angle
-
- Use Minuit to minimise $\chi^2 = \sum \frac{(D_{measured} - D_{calculated})^2}{D_{measured}}$
 - Migrad varies θ_i entries for each iteration tests the gradient at each point until optimum is found
 - χ^2 calculated for every D_{true} entry and minimised globally

Preliminary Unfolding in Xenon



- Early results look promising but full Monte Carlo only recently prepared.
- Effects due to detector resolution and scattering in trackers removed.
- Unfolded distributions symmetric about zero
 - ▶ Requirement for Minit convergence.

Bayesian Deconvolution¹

Bayes Theorem

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

The number of events for process

$$n(C_i) = \sum_{j=1}^{n_E} n(E_j)P(C_i|E_j)$$

- 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.
- Depend on the simulation for
 - ▶ A conditional probability of observing an angle in the trackers given a scattering angle at the absorber;

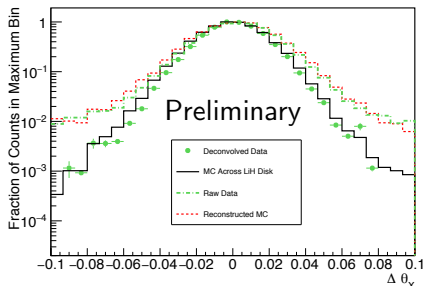
$$P(E_j|C_i) = P(\Delta\theta_j^{tracker}|\Delta\theta_i^{abs})$$

- Use RooUnfold package (see <http://arxiv.org/abs/1105.1160>)
- Iterates $P(\Delta\theta_i^{abs})$ based on $n(\Delta\theta_i^{abs})$ until convergence.

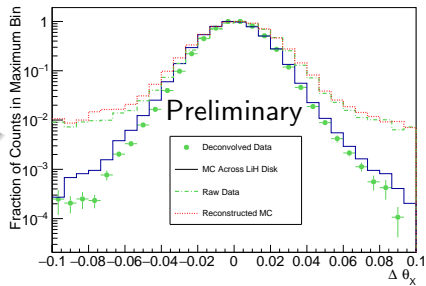
¹NIM A 362 (1995) 487-498

Deconvolution in Lithium Hydride

Preliminary Analysis: 200 MeV/c



Preliminary Analysis: 240 MeV/c



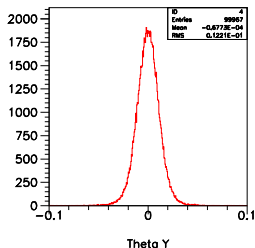
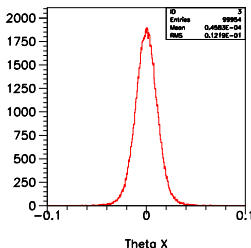
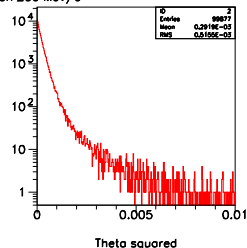
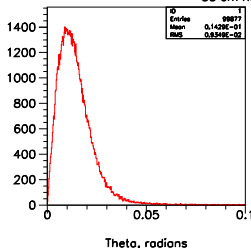
- A first (hot off the press) look at a subset of available data.
- Removed the effect of the windows and measurement resolution
- Differences between simulation and data visible before and after deconvolution.

An Alternative Model for Scattering

2016/03/23 16.25

- An alternative model for coulomb interactions proposed by Carlisle and Cobb^a
- Would like to compare to LiH data.

35 cm Xenon 200 MeV/c



^aT. Carlisle (2013), Thesis DPhil, University of Oxford, <http://ora.ox.ac.uk/objects/uuid:a2f17fc5-c61b-4f9e-bb7f-cadc2f1datastreams/ATTACHMENT01>

Summary

- Collected field off scattering data Dec. 2015 and Feb.- March 2016
- Analysis development is well underway.
- Two complementary analyses considered
 - ▶ Direct unfolding of data to confront detector effects
 - ▶ Bayes deconvolution to infer scattering in absorber material.
- There is a plan to integrate the two methods.
- Need to evaluate alternative models in comparison to data.