Initial Scattering Studies

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Experimental
Particle Physics

Outline

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

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

- RMS scattering width recommended by the Particle Data Group is

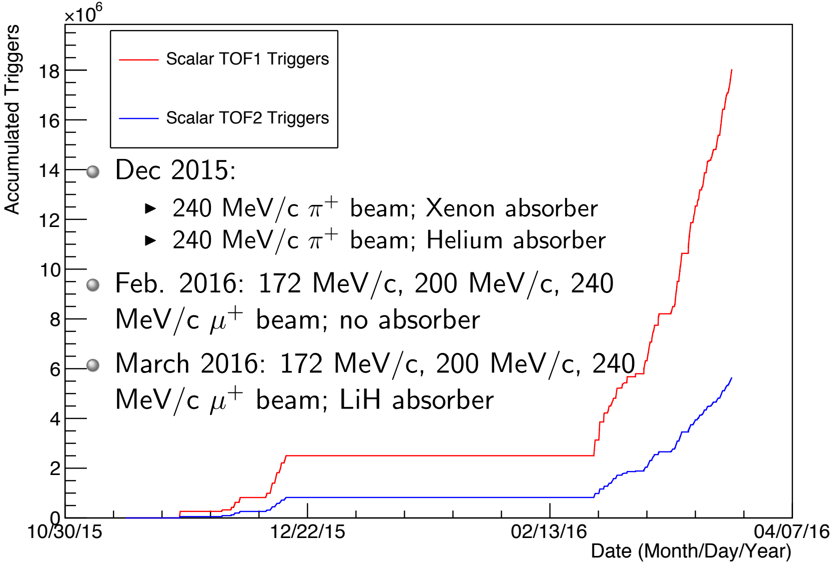
$$\theta_0 = \frac{13.6\ \mathrm{MeV/c}}{p_\mu \beta}\sqrt{\frac{x}{X_0}}\left(1 + 0.0038 \ln \frac{x}{X_0}\right)$$

- 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

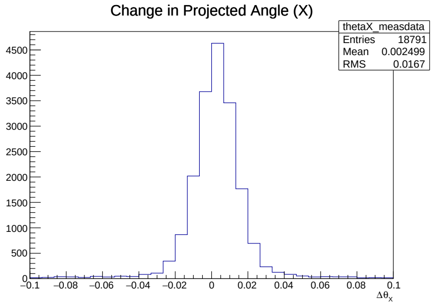
- Particles follow straight paths through spectrometers.
- Scatter off of materials along its path.
  - Need to identify scattering from absorber material only.
- Use TOFs to measure momentum.
  - Consider scattering as a function of momentum.
- Define scattering angles for trajectories
  - $\Delta\theta_x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

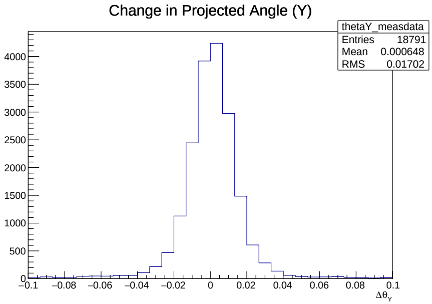
Field Off Scattering Data Collected by MICE



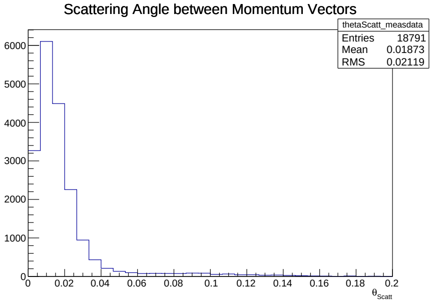
- Dec 2015:
  - 240 MeV/c π^+ beam; Xenon absorber
  - 240 MeV/c π^+ beam; Helium absorber
- Feb. 2016: 172 MeV/c, 200 MeV/c, 240 MeV/c μ^+ beam; no absorber
- March 2016: 172 MeV/c, 200 MeV/c, 240 MeV/c μ^+ beam; LiH absorber

Control Data Sets

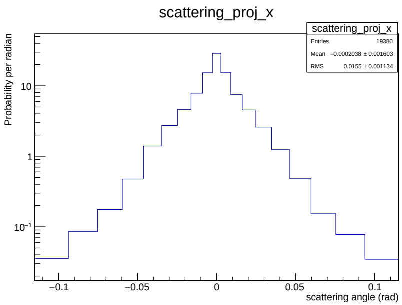


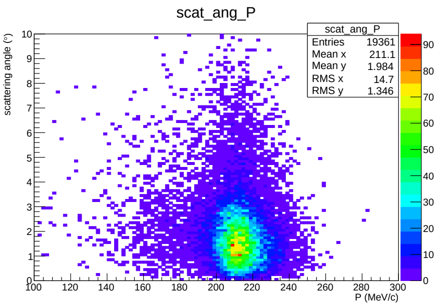


- Two controls taken
  - He filled absorber
  - Empty Focus Coil
- Evaluate scattering with windows independent of absorber
- Empty focus coil shown.

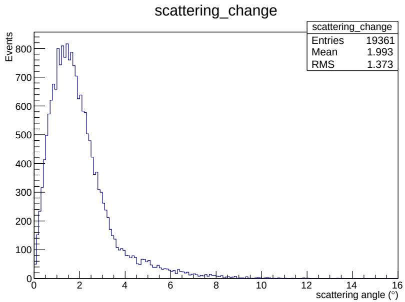


Scattering Distributions in Xenon

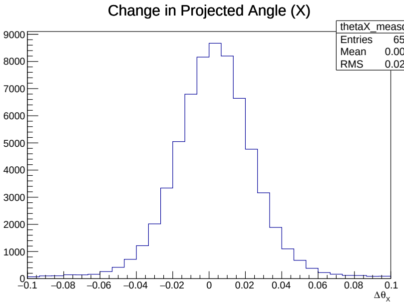


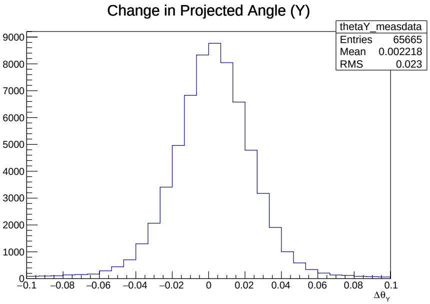


- Official MICE reconstruction used for analysis
- We believe scattering in GEANT for this material.
- Taken to develop and confirm analysis methods.

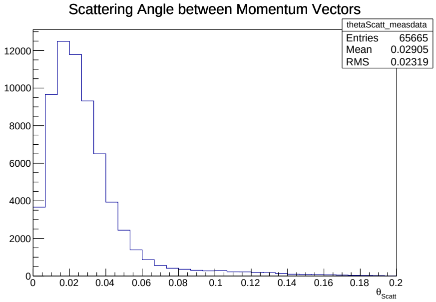


Scattering in Lithium Hydride





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

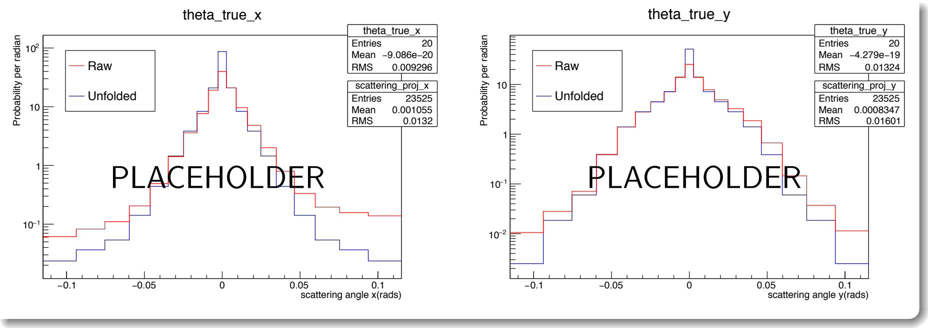


Detector Unfolding

- MuScat unpacking uses expression : $D_j = B_j + R_{ij}\epsilon_{ii}\theta_i$
- $D_j \rightarrow$ 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
- $\epsilon_{ii} \rightarrow$ 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 Minuit convergence.

Bayesian Deconvolution[1]

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

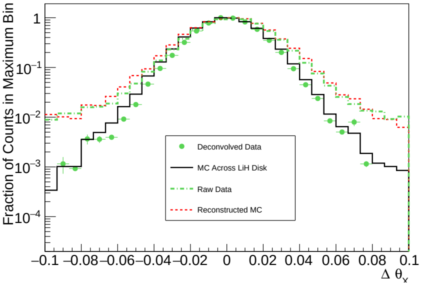
$$n(C_i) = \sum_{j=1}^{n_E} n(E_j)P(C_i|E_j)$$

- 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.
  - A prior distribution for the scattering angle at the absorber.
- Virtual planes added to the absorber to provide $P(E_j|C_i)$.
- Use RooUnfold package (see `http://arxiv.org/abs/1105.1160`)
- Iterates P_0 based on $n(C_i)$ until $n(C_i)$ converges.

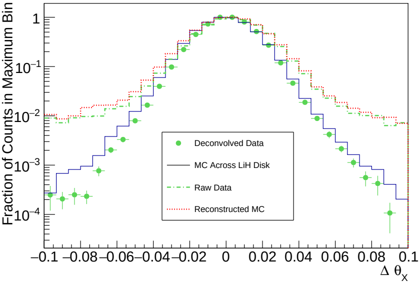
[1] NIM A 362 (1995) 487-498

Deconvolution in Lithium Hydride

Preliminary Distribution: 200 MeV/c



Preliminary Distribution: 240 MeV/c



- Removed the effect of the windows and measurement resolution
- Differences between simulation and data visible before and after deconvolution.

An Alternative Model for Scattering

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

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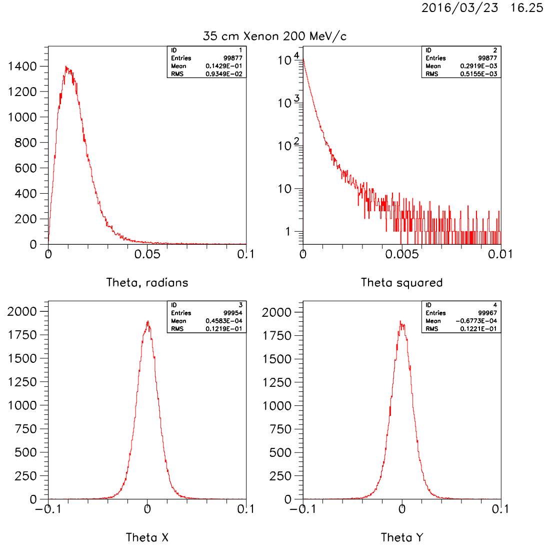
[a]T. Carlisle (2013), Thesis DPhil, University of Oxford, `http://ora.ox.ac.uk/objects/uuid:a2f17fc5-c61b-4f9e-bb7f-cadc2f1 datastreams/ATTACHMENT01`



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.