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Recent results from MICE on multiple Coulomb scattering and energy loss

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Multiple coulomb scattering and energy loss are well known phenomena experienced by charged particles as they traverse a material. This is of particular interest to the Muon Ionization Cooling Experiment (MICE) collaboration which has the goal of measuring the reduction of the emittance of a muon beam induced by energy loss in low Z absorbers. MICE took data without magnetic field suitable for multiple scattering measurements in the spring of 2016 using a lithium hydride absorber. The scattering data are compared with the predictions of various models, including the default GEANT4 model.

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1. Introduction

Results from atmospheric neutrinos at Super-Kamiokande [1] and from solar neutrinos at the Sudbury Neutrino Observatory [2] conclusively demonstrated that neutrinos have a non-zero mass and oscillate between different flavours. A facility promising precision measurement of neutrino oscillations parameters is the Neutrino Factory [3], where neutrinos would be produced via muon decay rings. Before the muons are injected into the storage ring the phase-space volume of the beam must be reduced. The only cooling technique which can act within the lifetime of the muon is ionization cooling. It has been shown with simulation that a reduction of the phase-space volume of the beam by a factor of 100,000 [4, 5, 6] may be obtained. MICE Step IV is current taking data to provide the first measurement of ionization cooling. This demonstration is an essential part of the worldwide research effort towards building a Neutrino Factory. A Neutrino Factory is the proposed facility with the capability to measure the CP violation phase, $\delta_{\rm CP}$, with the highest accuracy.

2. MICE Beam Line and Experiment

The MICE experiment is located at the Rutherford Appleton Laboratory (RAL) in the UK and operates parasitically on the ISIS proton accelerator [7], producing beam for the newly built MICE Muon Beam (MMB) by the insertion of an internal pion-production target. MICE is a novel single particle experiment designed to perform high precision measurements of normalized emittance both upstream and downstream of the ionization cooling equipment. The MMB is composed of three quadrupole triplets, two dipole magnets, which select the momentum, and a decay solenoid (DS), which increases the number of muons in the beam. It consists of an Absorber Focus Coil (AFC) located between two measurement stations. These stations are composed of particle identification suites including a total of three time-of-flight detectors (TOFs) [8], two Cherenkov detectors (Ckova and Ckovb) [9], a KLOE-type sampling calorimeter (KL) [10] and an Electron Muon Ranger (EMR) [11]. Each station has a Tracker with five planes of scintillating fibres inside a 4 T Spectrometer Solenoid (SS) to measure track and momentum information (x, y, p_x and p_y), so as to reconstruct the emittance before and after cooling. In MICE Step IV an AFC module, which houses a liquid hydrogen or lithium hydride absorber within a focusing coil, is located between the two measurement stations.

3. Deconvolution of Raw Scattering Data

The scattering in the absorber material is the physical quantity of interest. To extract this information the effects of scattering in non-absorber materials and those of detector resolution must be deconvolved from the measured scattering distribution. A deconvolution algorithm using Bayesian statistics [12] has been used based on the implementation contained in the RooUnfold package [13]. This method uses the simulation to provide a probability of observing a given scattering angle from the trackers for a given true scattering angle in the absorber, $P(\Delta\Theta_j^{\rm tracker}|\Delta\Theta_i^{\rm abs})$.

The estimate is refined through multiple applications of the algorithm by updating the prior probability by letting $P_0(\theta_i^{abs}) = n(\theta_i^{abs})/\sum_{i=1}^{n_c} n(\theta_i^{abs})$ in iterations subsequent to the initial calculation in which a flat prior is used. The conditional probability $P(\theta_j^{tracker}|\theta_i^{abs})$ is derived from the

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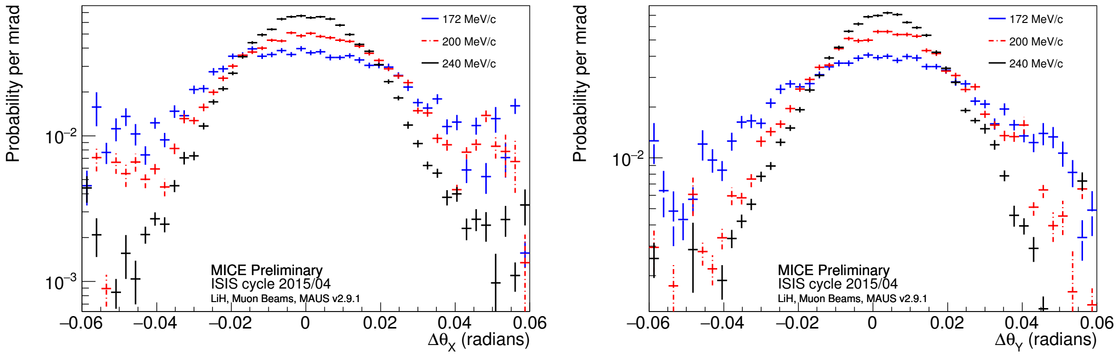

Figure 1: The results of the scattering analysis using data from all three nominal beam settings. Scattering widths are reported after application of deconvolution.

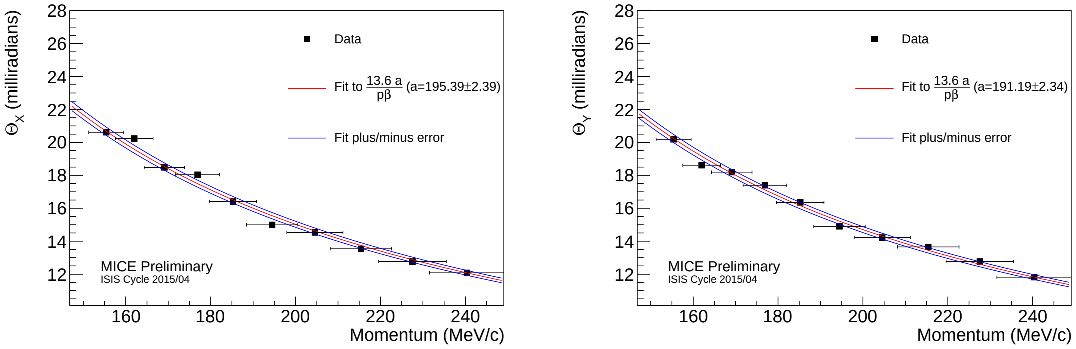

Figure 2: The results of the scattering analysis using data from all three nominal beam settings. Scattering widths are reported after application of deconvolution.

convolution where $\theta^{tracker}$ is drawn from the sum of the reconstructed scattering angle in the empty absorber data and the scattering angle in the absorber data from the convolution model, and θ_i^{abs} is the scattering angle in the absorber alone. The final scattering distributions at each of the nominal momentum points are shown in figure 1 and over the full momentum range in figure 2.

4. Conclusion

MICE has measured multiple Coulomb scattering off a lithium hydride target for muons with momentum between 140 and 240 MeV/c. These data have been compared to popular simulation packages such as GEANT4 and other relevant models such as Moliere and Carlisle-Cobb. A study of the systematics is in progress with a MICE publication currently being prepared. Future work will including a measurement of multiple Coulomb scattering off liquid hydrogen, a measurement of scattering with magnetic field in the cooling channel and an energy loss measurement.

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