Recent Results from MICE on Multiple Coulomb Scattering and Energy Loss

Author: J. C. Nugent, Presenter:J. Tang (IHEP) on behalf of the MICE collaboration

School of Physics and Astronomy, University of Glasgow

Outline

The International Muon Ionisation Cooling Experiment (MICE) aims to give the first demonstration of ionisation cooling. MICE is a stepping stone to a neutrino factory or muon collider.

Basic Concepts

- Ionisation cooling uses a low Z absorber encased in a focusing coil to reduce the momentum of the muon beam.
- A high gradient radio frequency cavity then restores the longitudinal momentum of the muon beam.

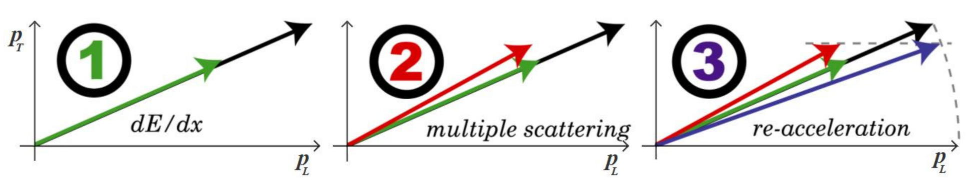


Figure: Reduction of phase-space volume of muon beam.

Ionisation Cooling

- The rate of change of normalised emittance due to ionisation cooling is:

$$\frac{d\varepsilon_N}{dX} \approx -\frac{\varepsilon_N}{\beta^2 E_\mu}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_\perp (0.014 \text{ GeV})^2}{2\beta^3 E_\mu m_\mu X_0}; \quad (1)$$

The emittance of the beam at equilibrium is:

$$\varepsilon_{eq} \approx \frac{\beta_\perp (0.014(GeV))^2}{2\beta m_\mu X_0}\left\langle\frac{dE}{dX}\right\rangle^{-1}. \quad (2)$$

- The lower the equilibrium emittance the better the cooling channel. To achieve this β_t should be minimised which requires strong focusing at the absorber and $X_0\langle\frac{dE}{dX}\rangle$ should be maximised suggesting a low Z material should used as the absorber material.

MICE Status

- The MICE data taking campign concluded in the December of 2017 at the Rutherford-Appleton Laboratory (RAL).
- More than 300 million particle triggers were collected over the data taking campaign.

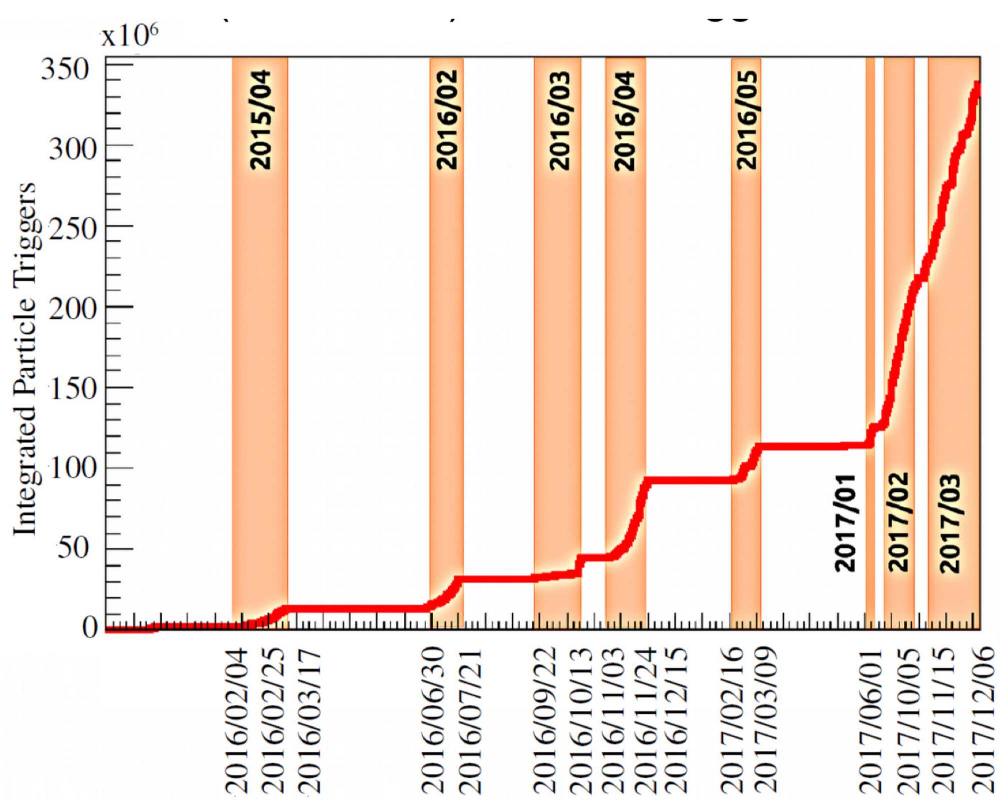


Figure: Number of particle triggers collected as a function of time over the MICE data taking campaign.

MICE Step IV

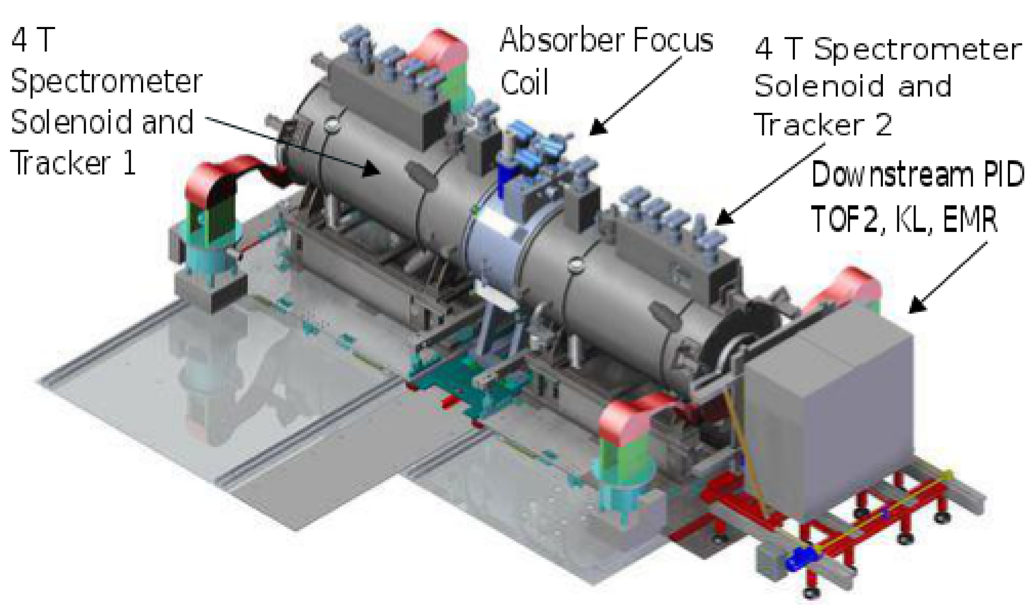
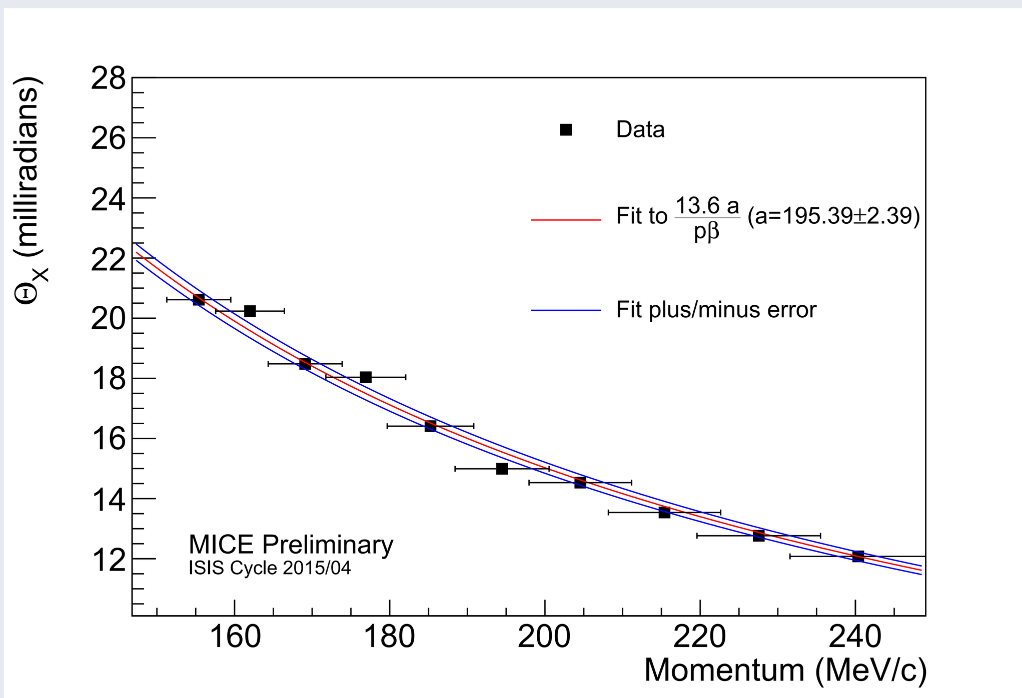


Figure: MICE Step IV cooling channel

- Step IV uses an absorber focus coil module, placed between the two scintillating fibre trackers, to house liquid hydrogen or solid absorbers.
- Trackers within 4 T solenoids make single particle measurements at each end of the cooling channel. Each tracker consists of five scintillating-fibre planes, measuring x, y, p_x, p_y and E.
- A pair of match coils in each spectrometer tune the magnetic optics to match the muon beam into and out of the cooling lattice.

Measurement of Multiple Coulomb Scattering

Step IV collected data measuring multiple Coulomb scattering.



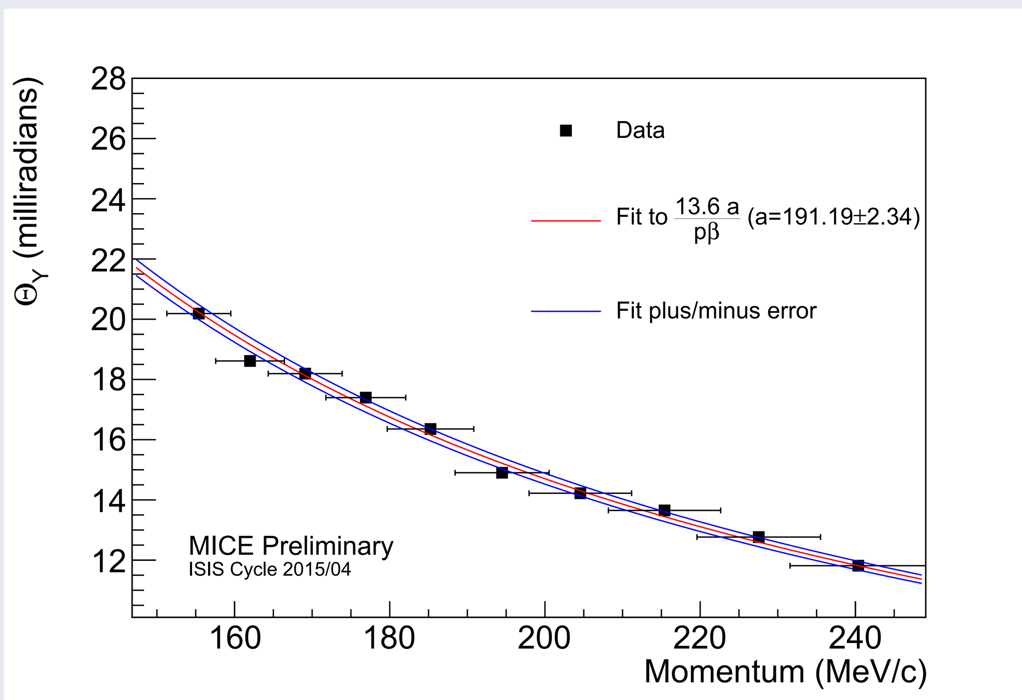


Figure: The results of the scattering analysis using data from all three nominal beam settings. Scattering widths are reported after application of deconvolution.

- The PDG recommends this formula, based on work by Lynch and Dahl incorporating path length effects (accurate to ~11%)

$$\theta_0 = \frac{13.6\,\text{MeV}}{p_\mu c\beta_{\text{rel}}} Z\sqrt{\frac{\Delta z}{X_0}}\left[1 + 0.038\ln\left(\frac{Z^2\Delta z}{\beta_{\text{rel}}^2 X_0}\right)\right] \quad (3)$$

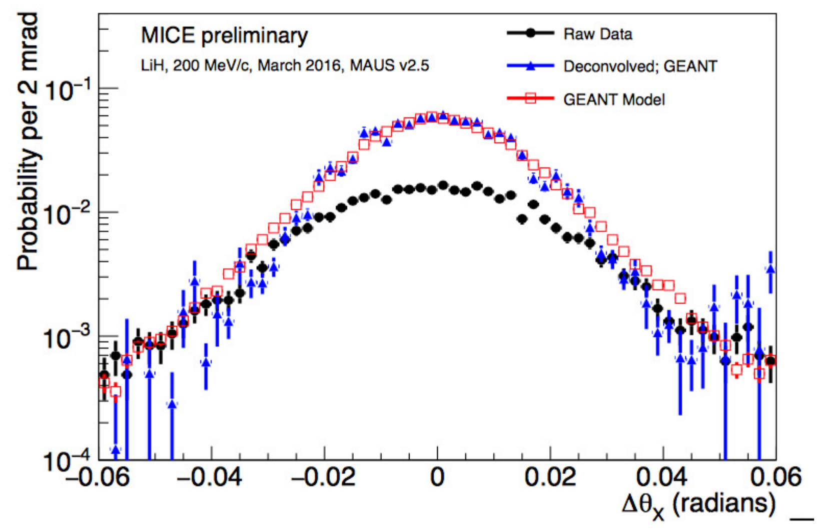
- The resulting distribution is non-Gaussian with the shape dependant on the thickness of the absorber
- Goal of MICE is to measure $d\varepsilon_n/dz$ to precision of 0.1% - more precise measurement of multiple Coulomb scattering is required
- MUSCAT showed poor agreement between GEANT simulations and low Z material scattering data
  - LiH composition: 81% ^{6}Li, 4% ^{7}Li, 14% ^{1}H (trace of C, O, and Ca)

dE/dX

Analysis measuring energy loss is ongoing

- Need confidence on muon collider luminosity to better than factor-of-2 level
- MICE has taken data for a number of different materials

Deconvolution of raw scattering data



- Use an iterative algorithm from RooUnfold that uses the Bayesian conditional probability to characterize the response of the reconstructed scattering angle to the true scattering angle

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

- 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

Absorber Material

Step IV is designed to study cooling in different materials.

Absorbers in the MICE Step IV program

Material	X_0	dE/dX	ρ	Δz
	gcm^{-2}	MeVg^{-1}cm^2	gcm^{-3}	cm
LH$_2$	63.04	4.103	0.07	35
LiH	79.62	1.897	0.82	6.3

Longitudinal emittance reduction via emittance exchange was also demonstrated.

- Achieved with solid plastic wedge absorber in Step IV
- Muons with higher energy pass through more material and experience greater momentum loss.

Acknowledgements

- This research was supported by grants from the Science and Technology Facilities Council (UK) and their support is gratefully acknowledged.

References

- G. D'Agostini, *A Multidimensional unfolding method based on Bayes' theorem*, Nucl. Instrum. Meth., A362:487â498, 1995.
- D.Attwood et al., *The scattering of muons in low Z materials*, Nucl. Instrum. Meth., B251:41â55, 2006.

john.nugent@glasgow.ac.uk