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MICE Video Conference 193

First Results from MICE Step IV

4^{th} May 2017

WARWICK
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MICE

Overview

- Measurement of scattering distribution (*Ryan*)
- Measurement of energy loss (*Scott*)
- Direct measurement of MICE muon beam emittance (*Victoria*)

- Material for *IPAC 2017* (due to 10th May)
  - poster
  - three-pages proceeding

Measurement of scattering distribution

- The cooling formula in the **heating term** uses the PDG approximation for the Multiple Coulomb Scattering

$$\frac{d\varepsilon_N}{ds} \simeq -\frac{\varepsilon_N}{\beta^2 E_\mu}\left\langle \frac{dE}{ds} \right\rangle + \frac{\beta_t (13.6\ [\mathrm{MeV}])^2}{2\beta^3 E_\mu m_\mu X_0}$$

- Measuring the MCS is necessary for the cooling predictions

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

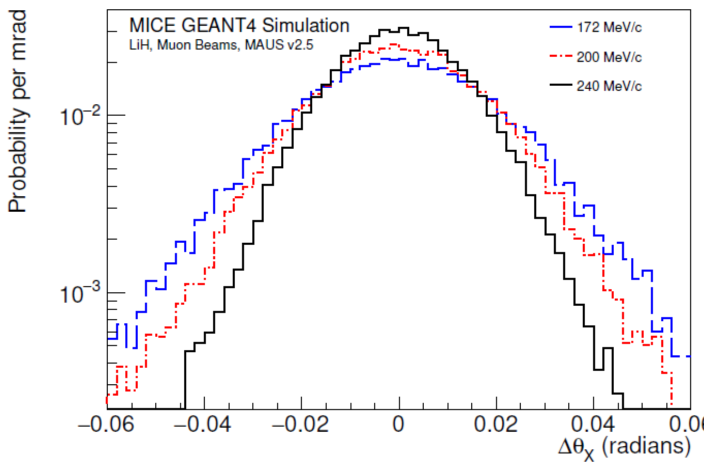
  - MCS not well modelled for low Z absorbers
  - GEANT overestimates the scattering (MuScatt)

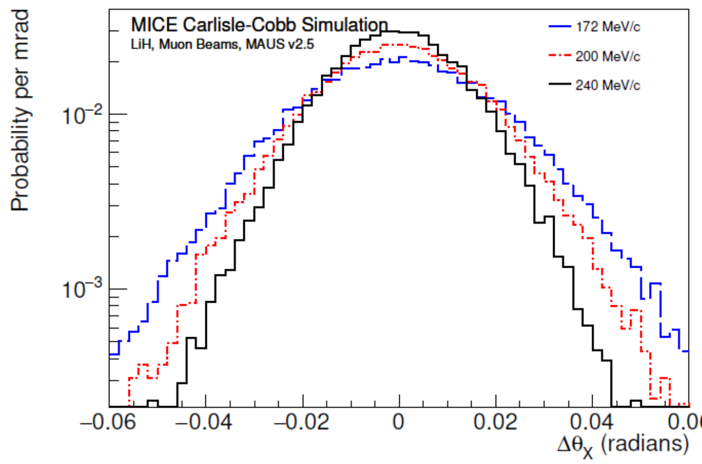
Measurement of scattering distribution

Scattering models

- **GEANT 4** model: Wentzel VI model, using a scattering distribution over steps of material
- **Carisle-Cobb** model: Wentzel model, simulating single separate interactions within the material

Lithium hydride

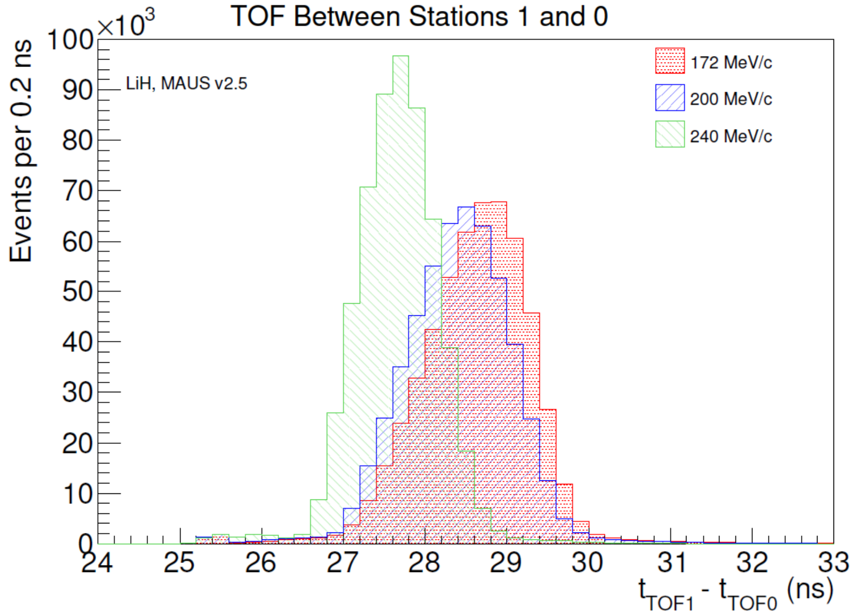




Measurement of scattering distribution

Data available

- ISIS user cycles 2016/03 and 2016/04
- 172 MeV/c, 200 MeV/c and 240 MeV/c momenta
- Empty absorber data
- Xenon, Lithium hydride and Helium
- No field in the cooling channel



Measurement of scattering distribution

Technique

- Scattering angle is, for each track, the deflection US vs DS

$$\theta_{Scatt} = \text{acos}\left(\frac{\mathbf{p}_{US} \cdot \mathbf{p}_{DS}}{|\mathbf{p}_{US}||\mathbf{p}_{DS}|}\right)$$

- TOFs are used to
  - select the muons
  - measure the momentum since the absence of field

Measurement of scattering distribution

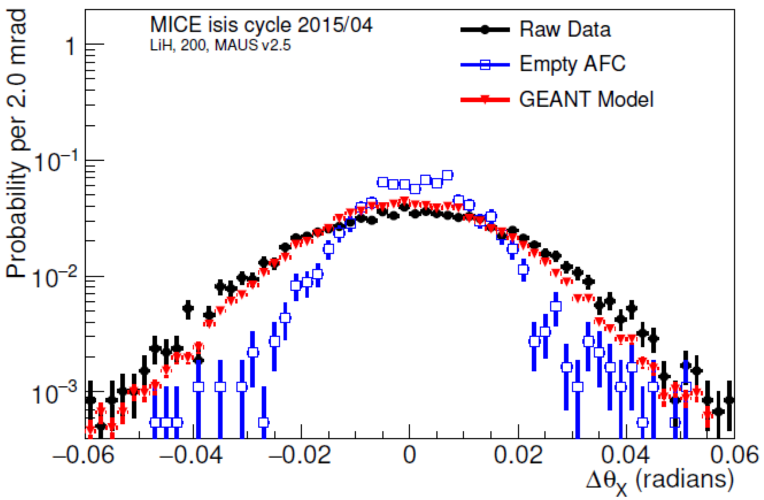
Selection

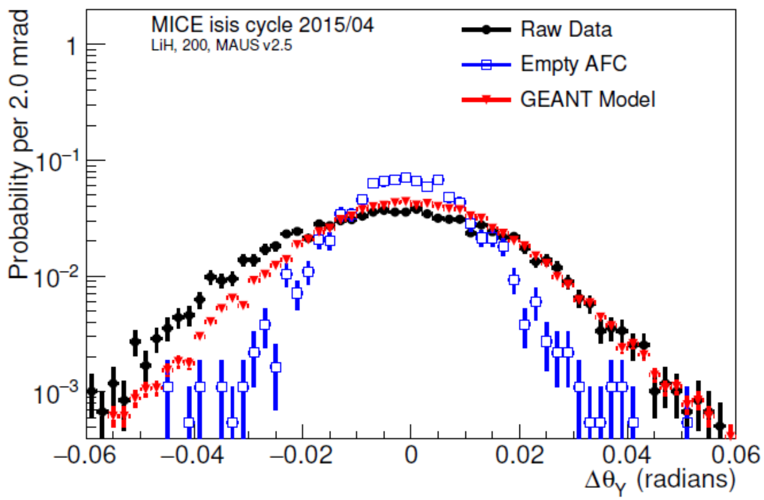
- A space point in TOFs
- Track in the upstream tracker (if not in the downstream, Θ=45º)
- TOF selection in 200 ps intervals
- Fiducial selection: projected US tracks at DS reference plane + 12mrad with radius < 150 mm

Measurement of scattering distribution

<u>Technique</u>

- Convolution: zero abs data ⋆ scattering model
  - Comparison <u>data</u> vs <u>simulation</u>
  - Raw data RMS width wider than the scattering models



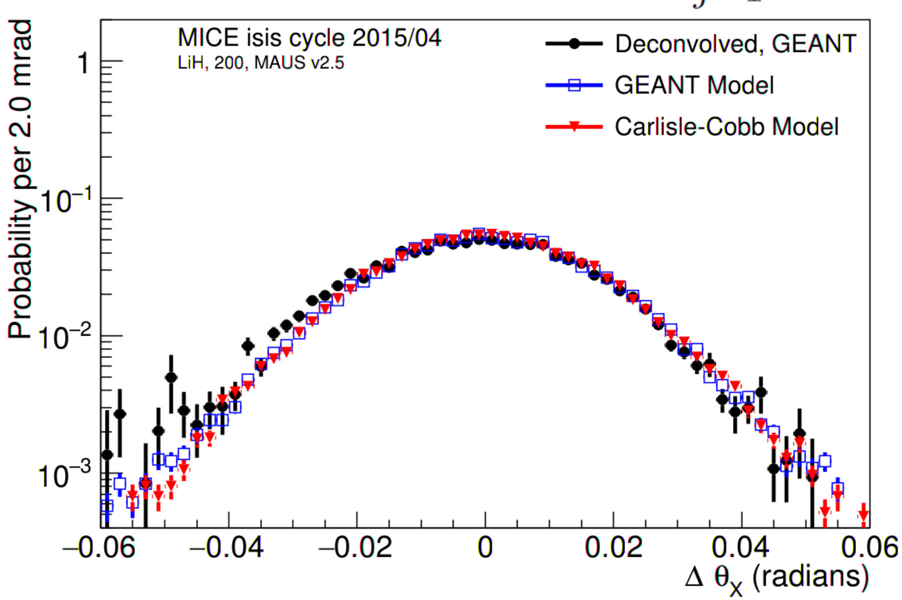


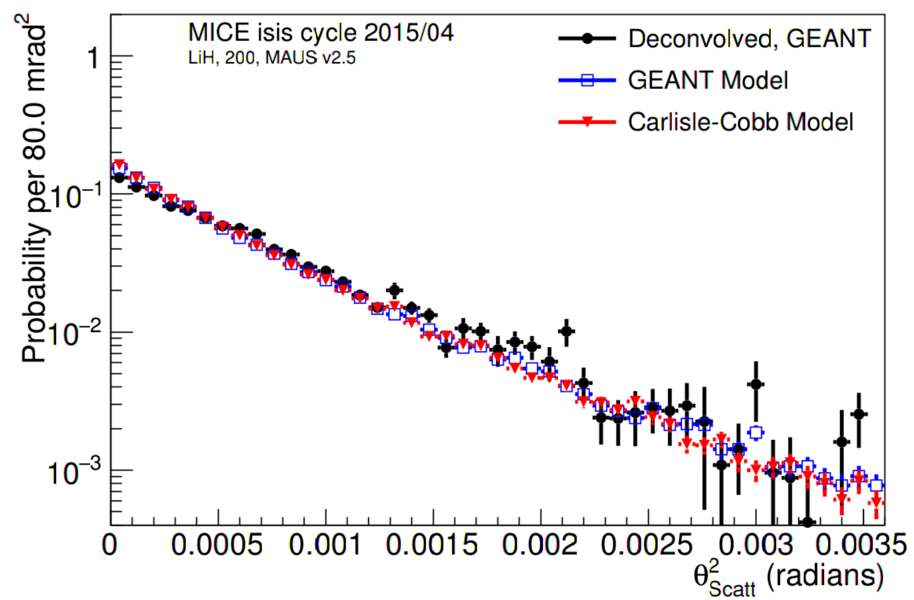
Measurement of scattering distribution

Results

- Bayesian deconvolution to extract the pure absorber scattering
- Iterations to refine the prior probability

$$n(\theta_i^{abs}) = \sum_{j=1}^{n_E} n(\theta_j^{tracker}) P(\theta_i^{abs} | \theta_j^{tracker})$$





Measurement of scattering distribution

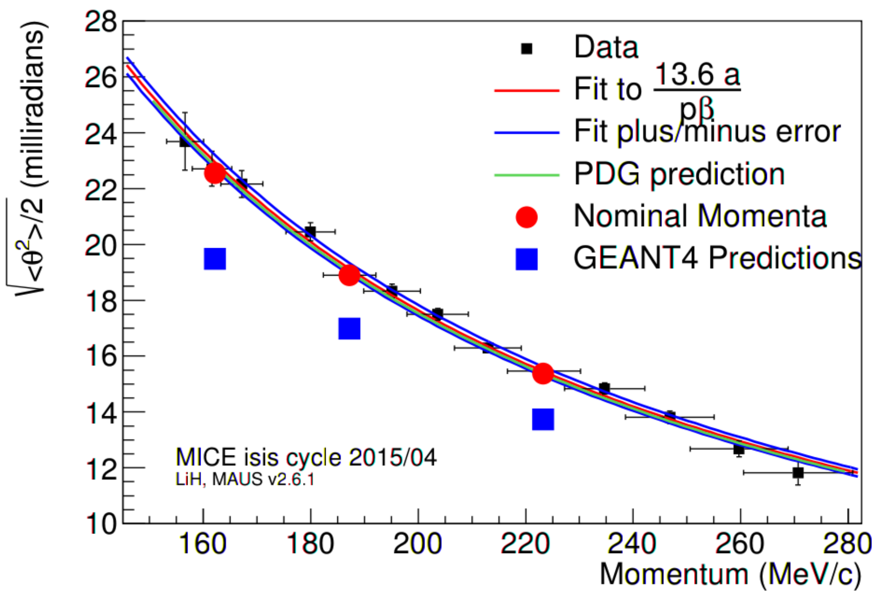
Systematic errors

- Absorber thickness → negligible
- Alignment → negligible
- Fiducial cuts → generally small, biasing the 200 MeV/c
- Time of flight → dominant, affects the momentum selection

Measurement of scattering distribution

Momentum dependence of the MCS

- General agreement within the PDG prediction for the RMS 3D scattering angle (underestimated by GEANT4)
- X, Y projections are not as good



Measurement of energy loss

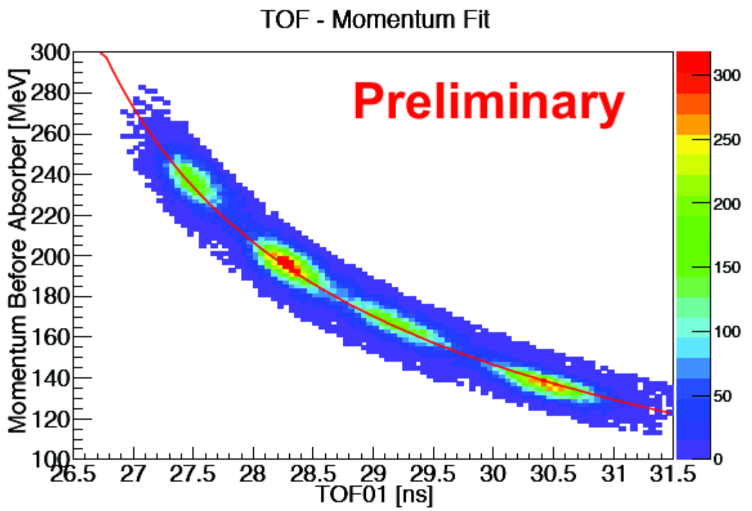
- The energy loss used in the cooling formula in the **cooling term** is given by the “Bethe” formula

$$-\left\langle \frac{dE}{dX} \right\rangle = Kz^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 W_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

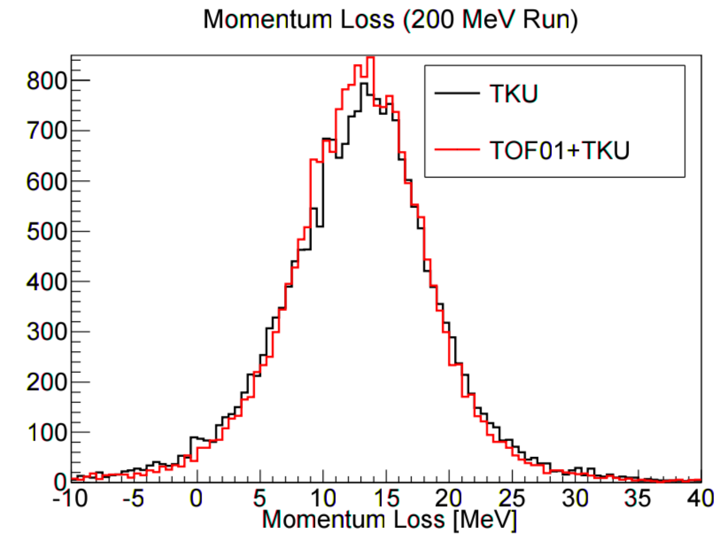
- Excitation energy *I* in H2 is known to about 5%
- Energy loss has never been measured in lithium hydride (LiH) or in liquid hydrogen (LH2)

Measurement of energy loss

- Field on data in lithium hydride
- Particles selection:
  - 1 helical track US and DS
  - TOF01 vs P(TKU) to select muons
  - good p_T measurement: $p_T/p > 0.1$

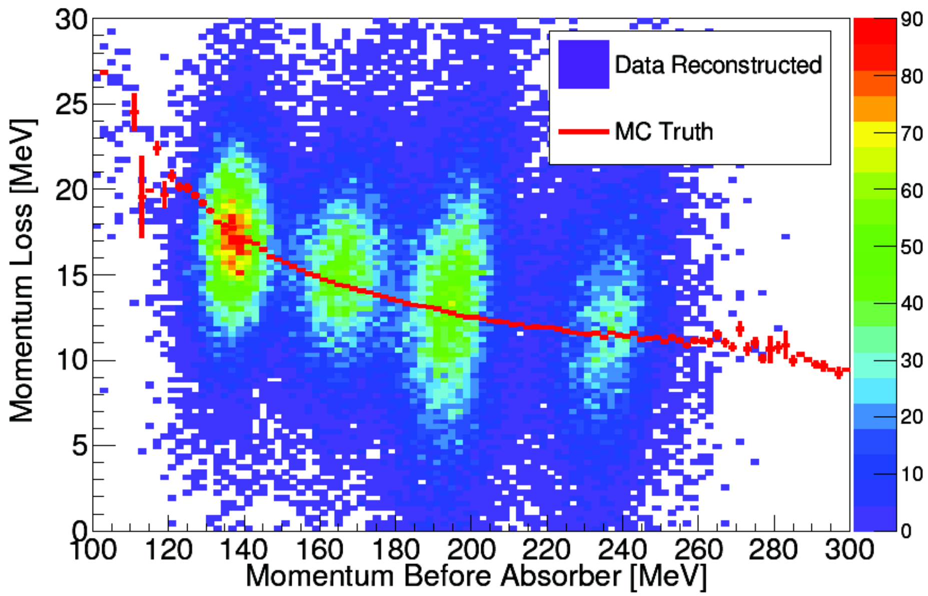


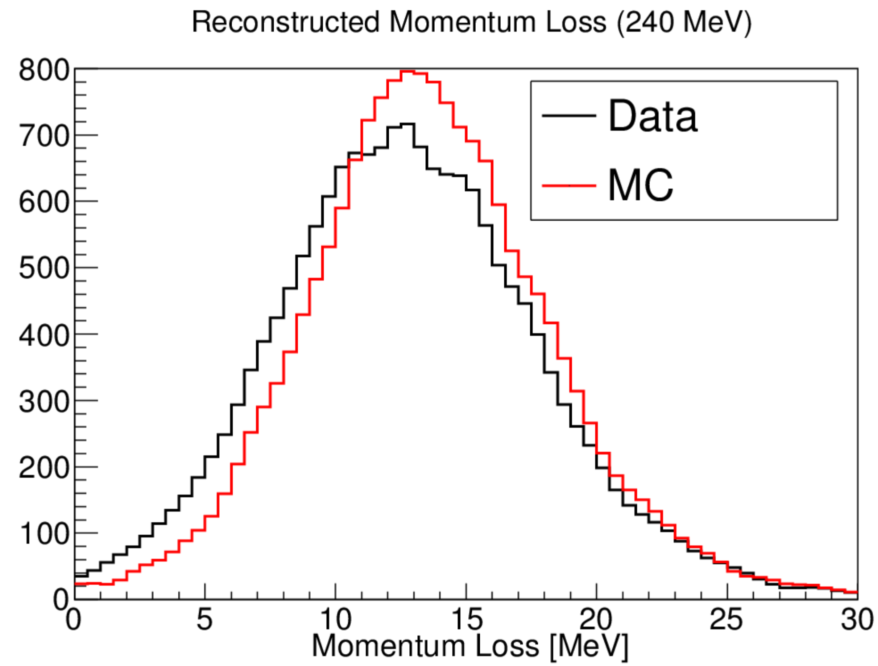
- TOF0→1 contributed to improve the momentum loss resolution



Measurement of energy loss

- Mean momentum loss agreement between reconstructed MC and data
- **Δp = 13.3 ± 5.9 MeV/c** (while MC is 12.8 ± 5.3 MeV/c)





Measurement of energy loss

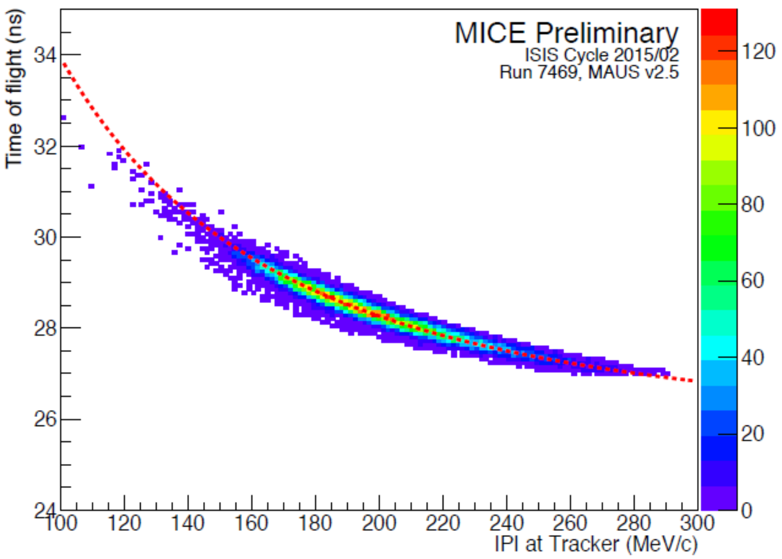
- The real measurement, deconvolved energy loss (empty absorber wrt absorber data) is not ready to be made public

- Final study: correlation of energy loss with multiple scattering

Direct measurement of MICE muon beam emittance

- First run with 4T in SSU, October 2015
- 3mm - 200 MeV/c muon beam
- Set of cuts to obtain a pure reconstructed muon sample

Successful TOF0 and TOF1 momentum reconstruction
$26.47 \leq t_{01} \leq 40\,\mathrm{ns}$
One spacepoint at TOF0
One spacepoint at TOF1
One track at Tracker
Particle triggered TOF0, TOF1 and all Tracker stations
P-value of track ≥ 0.01
$5 \leq P_{\mathrm{loss}} \leq 43\,\mathrm{MeV}/c$



- 19'076 selected events
- 8 MeV/c sub-samples in P_z

Direct measurement of MICE muon beam emittance

- Transverse normalized 4D emittance for each sub-sample defined as

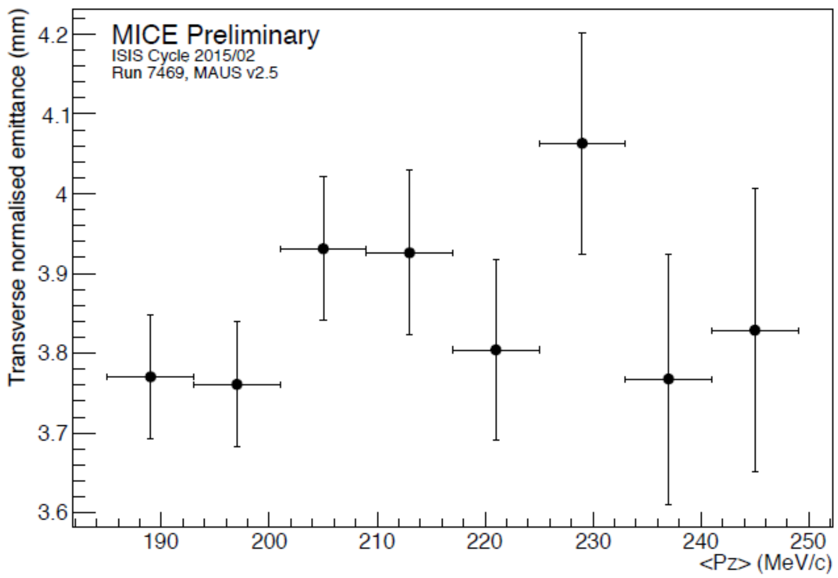
$$\varepsilon_N = \frac{1}{m_\mu}\sqrt[4]{\det\Sigma}$$

where

$$\Sigma = \begin{pmatrix} \sigma_{xx} & \sigma_{xy} & \sigma_{xPx} & \sigma_{xPy} \\ \sigma_{xy} & \sigma_{yy} & \sigma_{yPx} & \sigma_{yPy} \\ \sigma_{xPx} & \sigma_{yPx} & \sigma_{PxPx} & \sigma_{PxPy} \\ \sigma_{xPy} & \sigma_{yPy} & \sigma_{PxPy} & \sigma_{PyPy} \end{pmatrix} \qquad \sigma_{a,b} = \langle ab \rangle - \langle a \rangle \langle b \rangle$$

Direct measurement of MICE muon beam emittance

- Transverse normalized emittance in 8 MeV/c samples
- Approximately flat across the samples
- Statistically dominated errors



- Data – MC comparison, detector performance

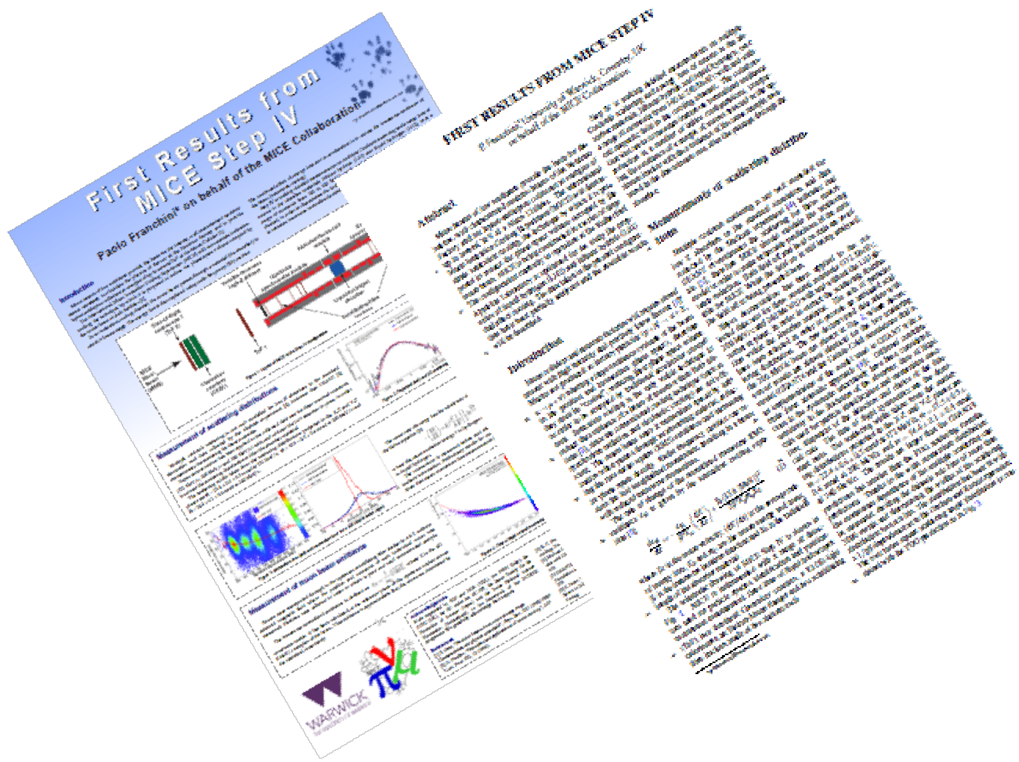
Conclusions

- Multiple Coulomb Scattering and Energy Loss measurements necessary to define the cooling equation

- Input emittance measurement necessary for characterise the beam and validate the trackers

Contributions

- Proceeding and poster will be circulated by the end of this week for the wide scrutiny
- Referee is Durga (thanks!)



References

- MICE note #497
- MICE note #498
- P. Soler talk for MICE Project Board March 2017
- Analysis meetings