Analysis of Multiple Coulomb Scattering of Muons in the MICE Liquid Hydrogen Absorber

Gavriil Chatzitheodoridis[a,b,c]

On behalf of the MICE collaboration

[a] University of Strathclyde, Department of Physics, 107 Rottenrow East, Glasgow UK, G4 0NG
[b] University of Glasgow, School of Physics and Astronomy, Kelvin Building, University Avenue, Glasgow UK, G12 8QQ
[c] Cockcroft Institute, Daresbury Laboratory, Sci-Tech Daresbury, Daresbury, Warrington UK, WA44AD

Introduction

- **M**ultiple **C**oulomb **S**cattering: multiple elastic collisions a charged particle undergoes when crossing a material.
- Accurate **MCS** predictions are key in enabling design of such ionization cooling systems
- **MCS** causes emittance growth, the effect is mitigated by using a low-Z absorber at a magnetic focus point.

The cooling equation[2] (for normalised transverse emittance)**:**

$$\frac{d\epsilon_{n\perp}}{dz} \approx -\frac{\epsilon_\perp}{\beta^2 E_\mu}\left\langle\frac{dE_\mu}{dz}\right\rangle + \frac{\beta_\perp (13.6MeV/c)^2}{2\beta^3 E_\mu m_\mu X_0}$$

- Liquid hydrogen has been shown experimentally to be the most effective[1]
- Experiments (172MeV/c muons in liq. H_2) have shown scattering behaviour diverging from theoretical models:
  - Moliere MCS model
  - GEANT4 v4.7.0p01
- The **aim** is to assess the latest GEANT4 simulation and Moliere's mathematical MCS model in a field-off setting (straight tracks)

[1] MICE collaboration., Bogomilov, M., Tsenov, R. et al. Nature 578, 53–59 (2020)
[2] D. Neuffer, Part. Accel.14 75–90 (1983)
[3] Muscat collaboration, Nucl. Instrum. Meth. Sec. A, vol. 83, pp. 492–504, (2005)

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COOLING **HEATING**

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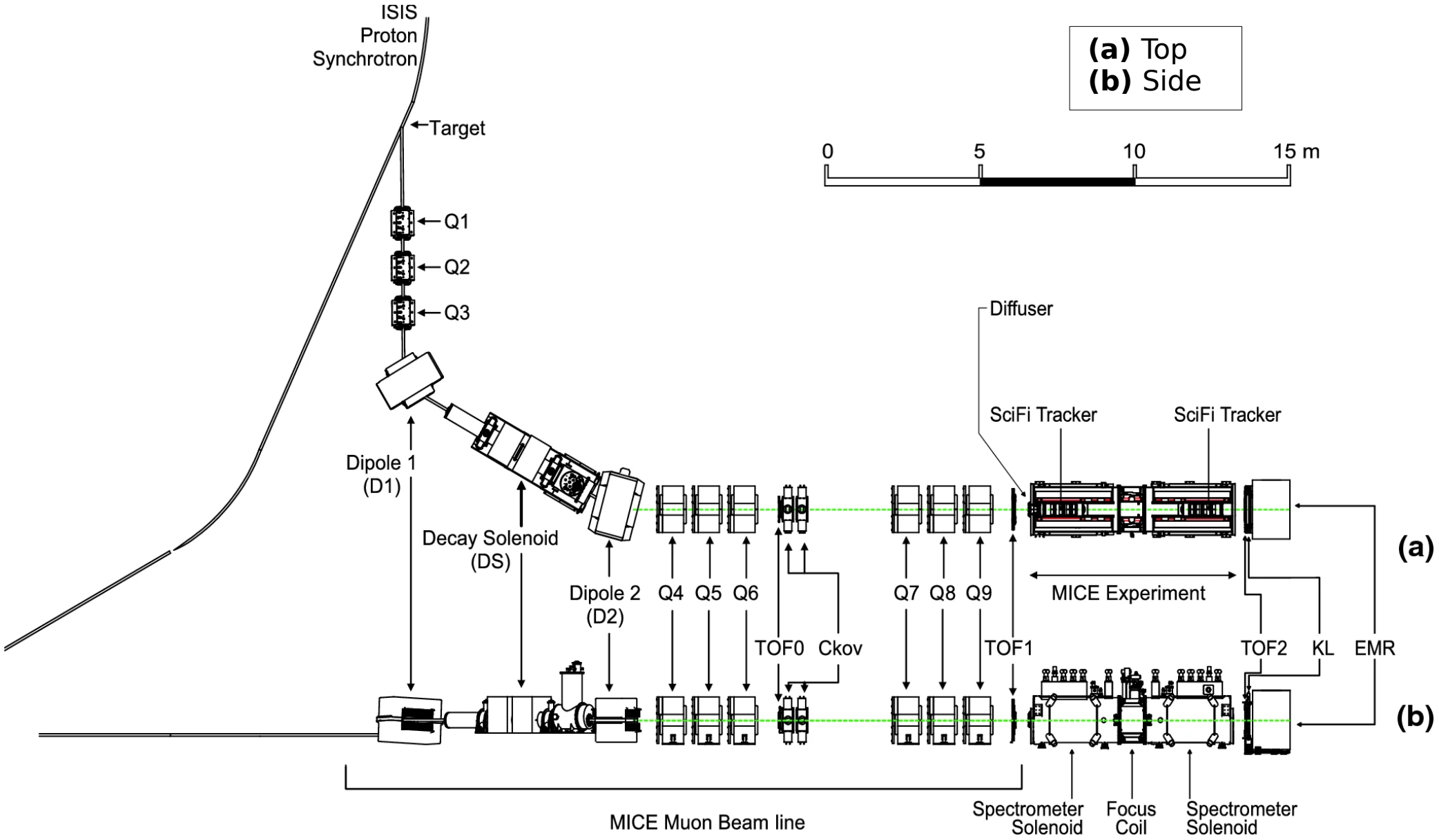
The Muon Ionization Cooling Experiment



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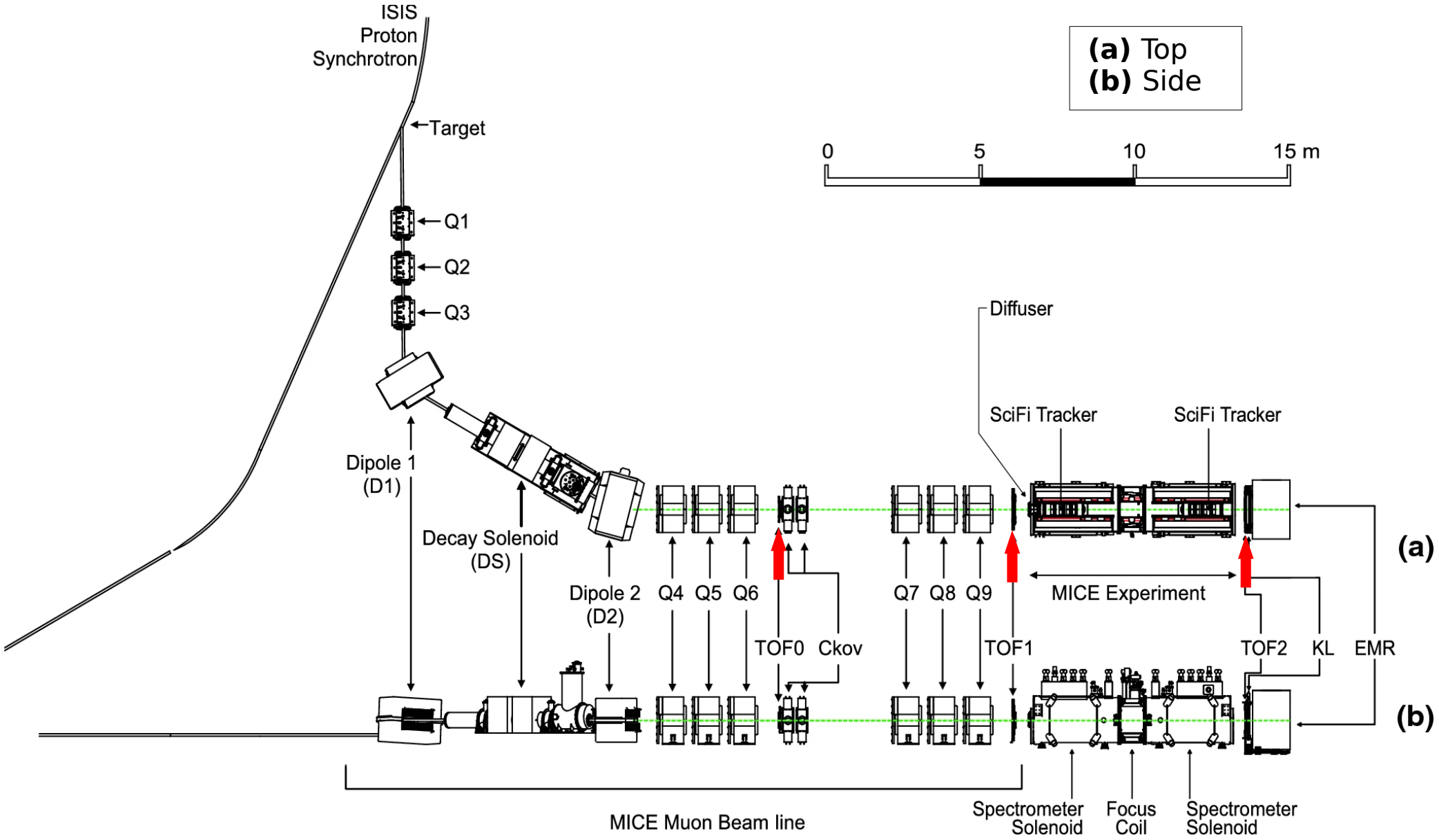

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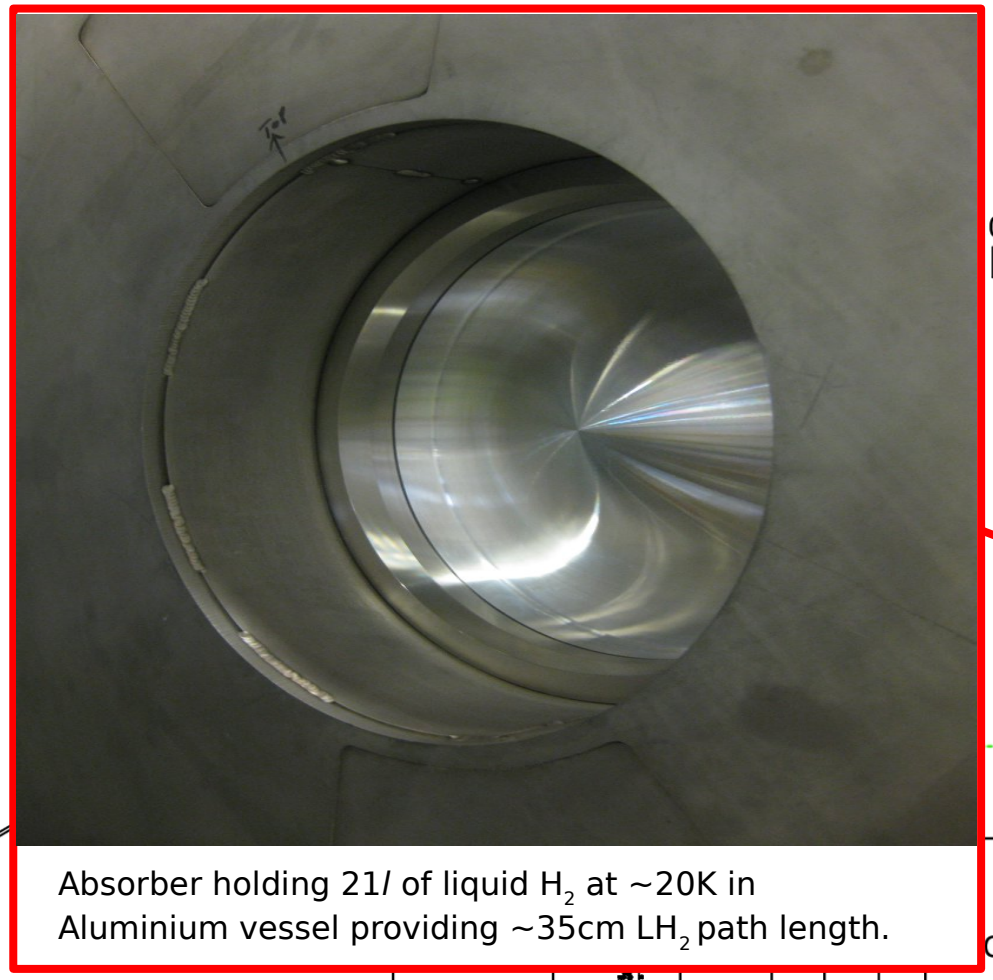

Absorber holding 21/ of liquid H_2 at ~20K in
Aluminium vessel providing ~35cm LH_2 path length.

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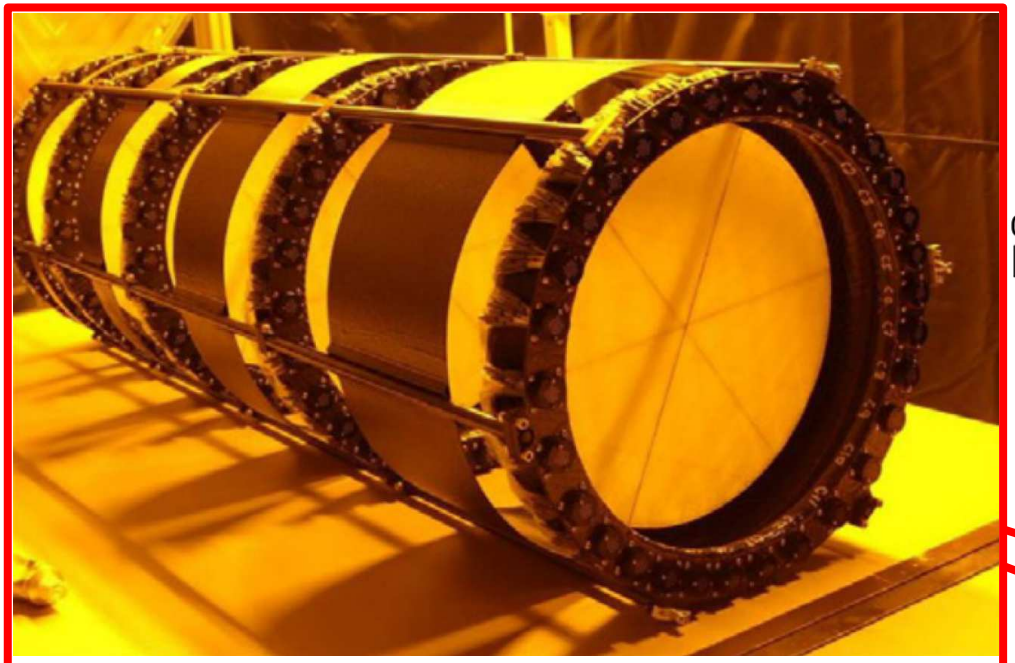
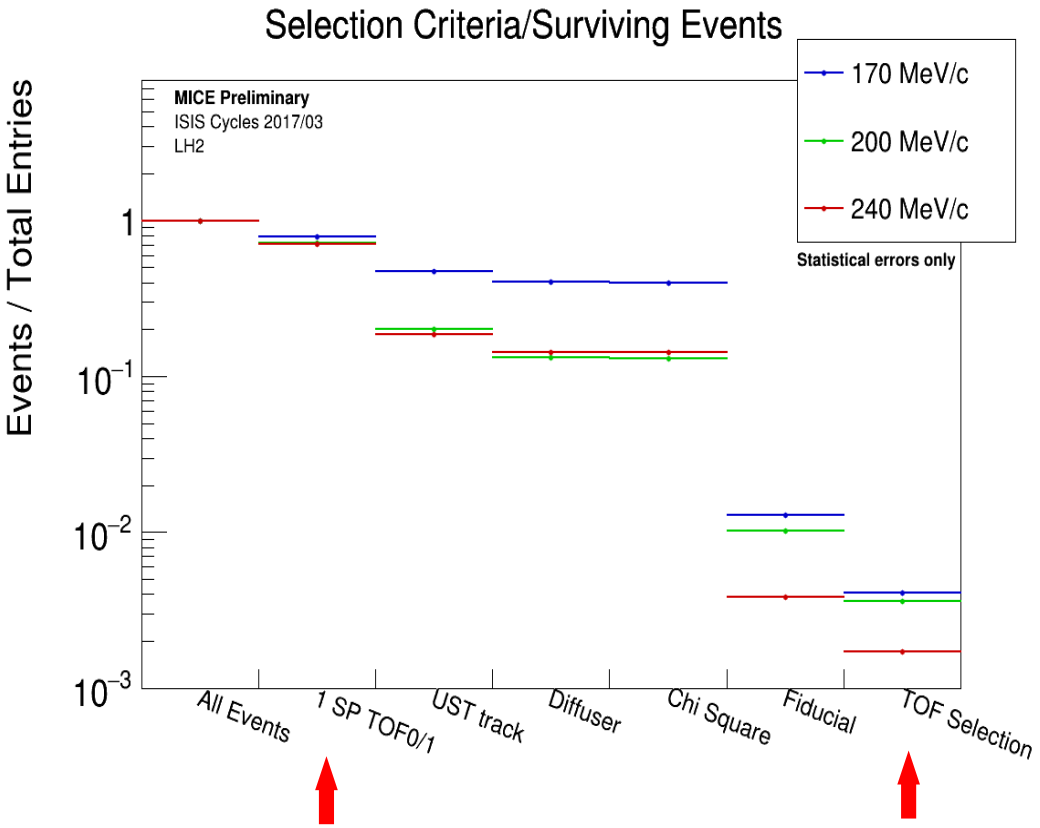


MICE scintillating fibre tracker. 5 stations with 3 layers each. Each layer is rotated 120° to each other and is composed of fibres with diameter 350 nm. Total tracker length 1.9 m

Selection for MCS Measurement



Selection criteria

- US TOF space-points required for:
  - Velocity selection
  - Particle identification
- Particles with US Track
  - Particle has passed clear of preceding high-Z structure (Diffuser ring)
  - DS track expected to be within tracking volume of homogenous efficiency

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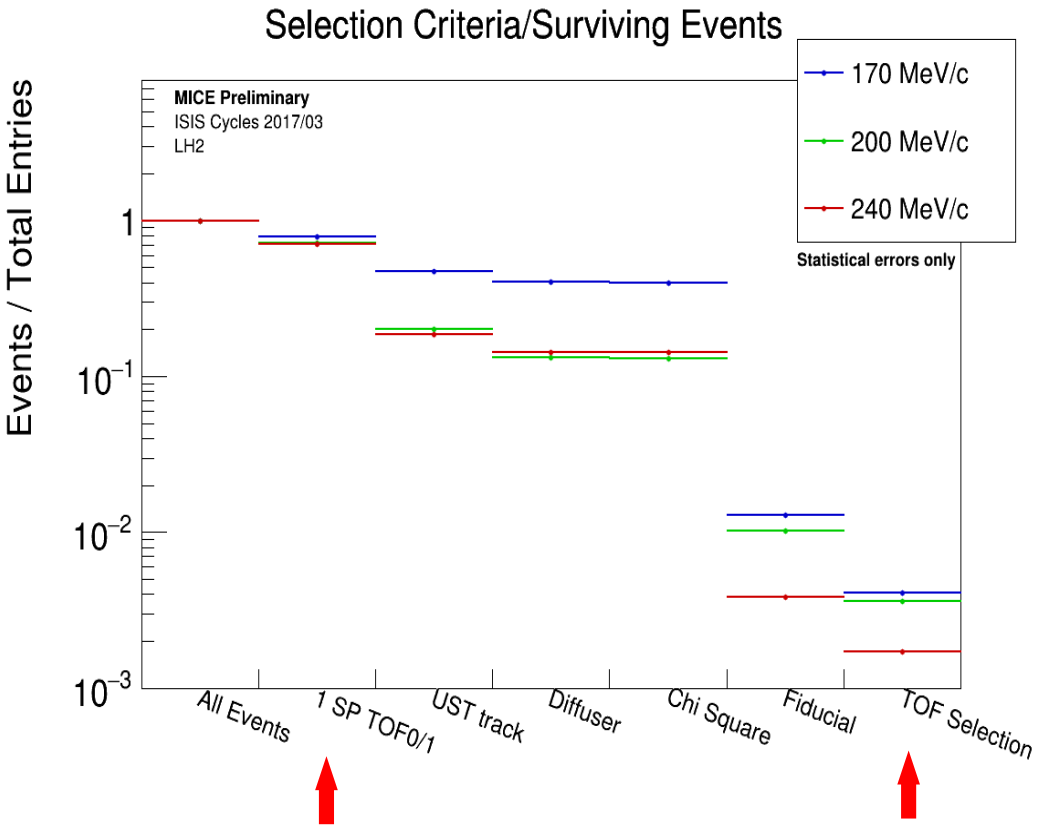

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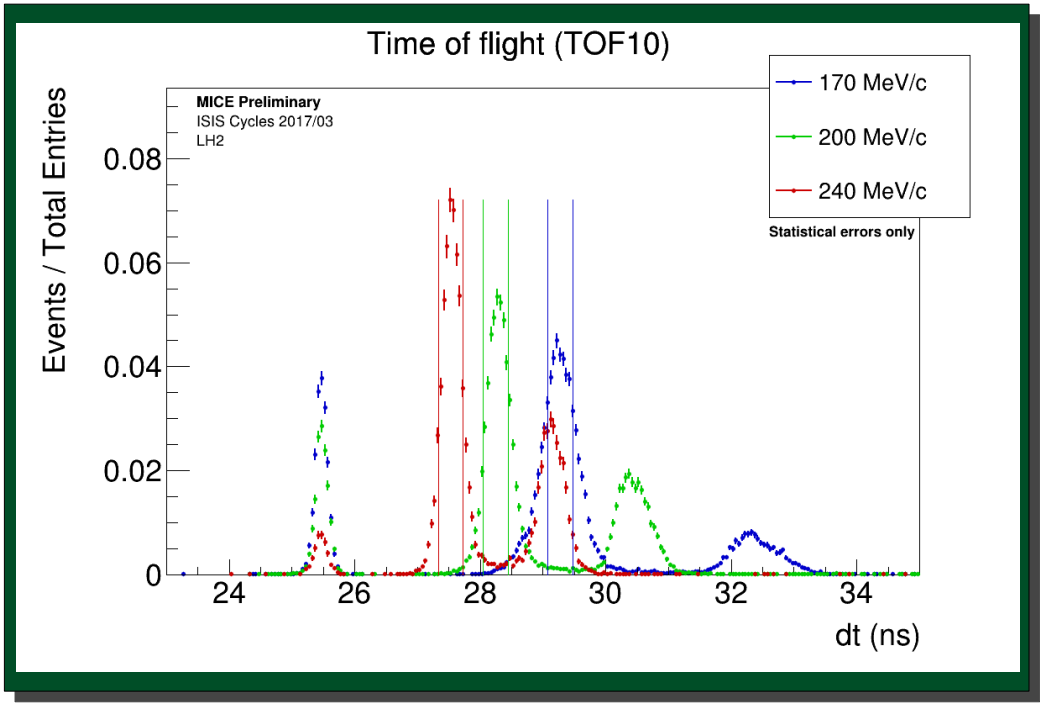
Beam-setting (MeV/c)	TOF interval (ns)	
170	29.07	29.47
200	28.05	28.45
240	27.33	27.73



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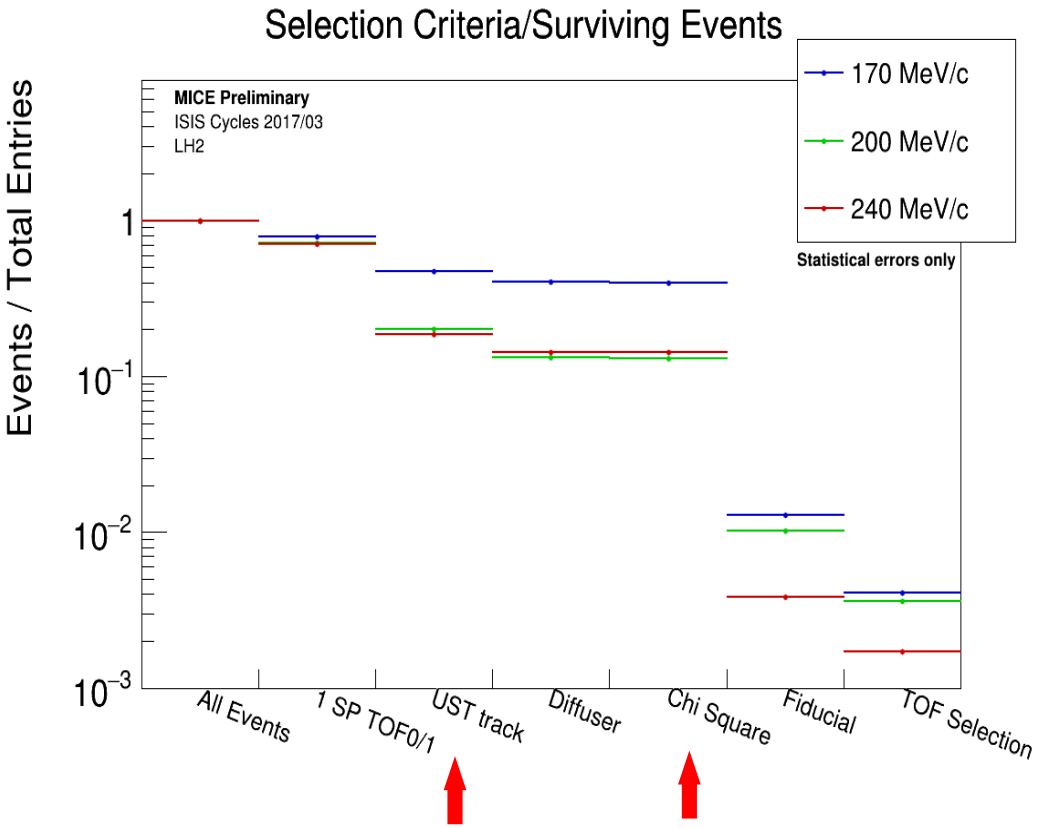

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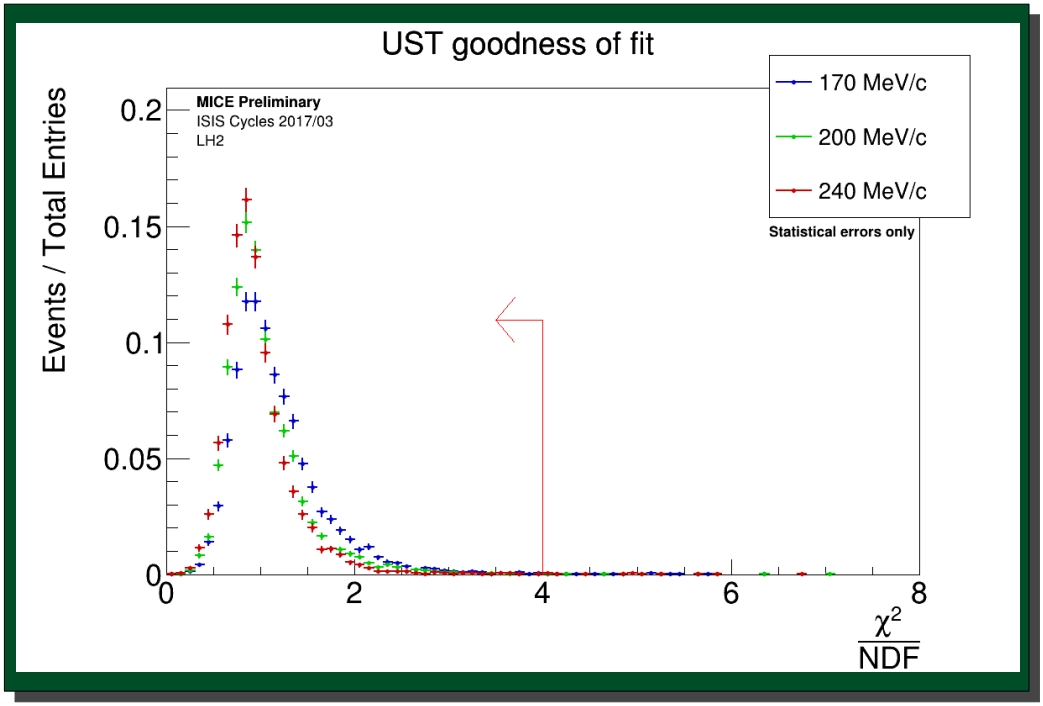

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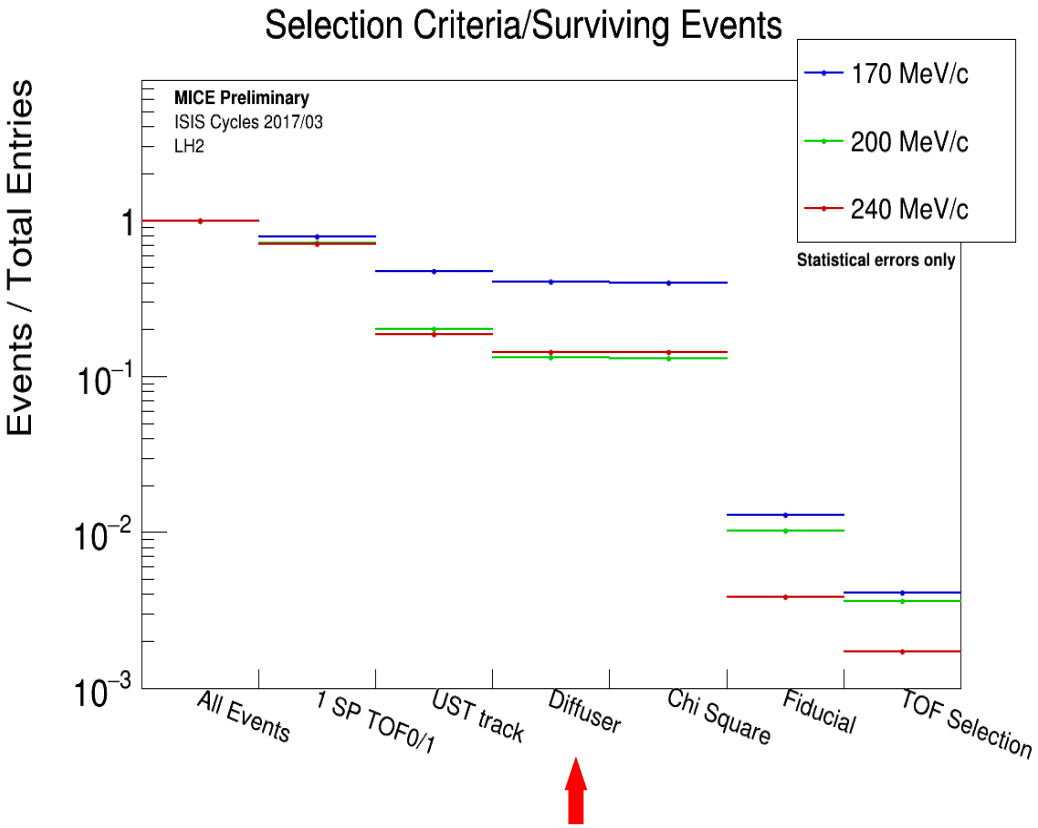

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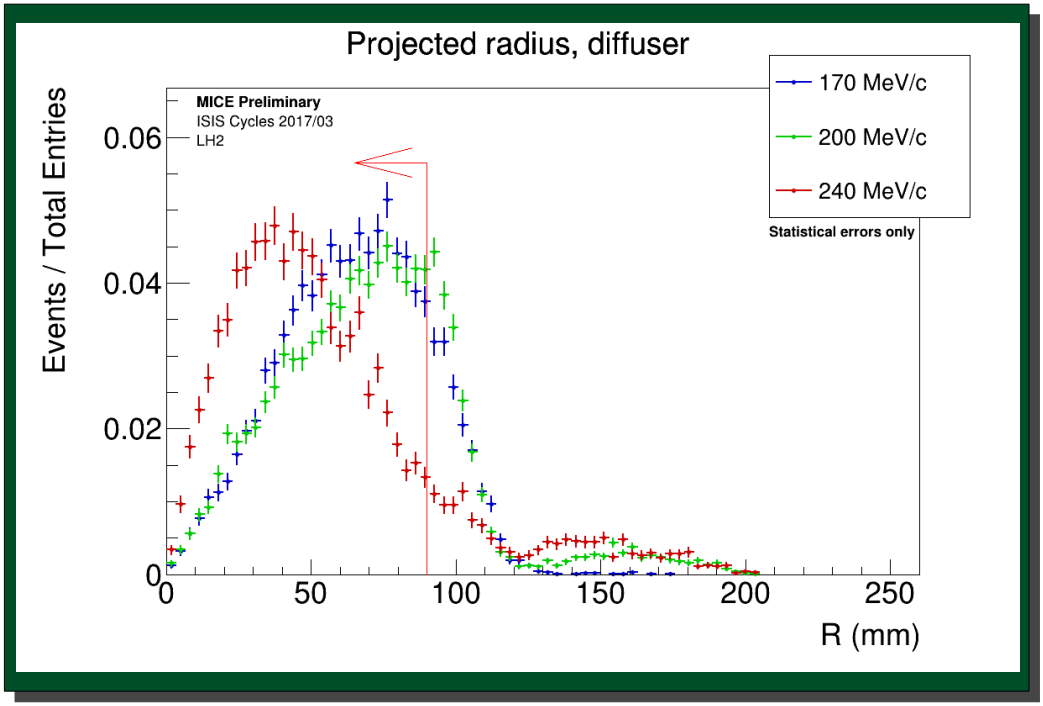

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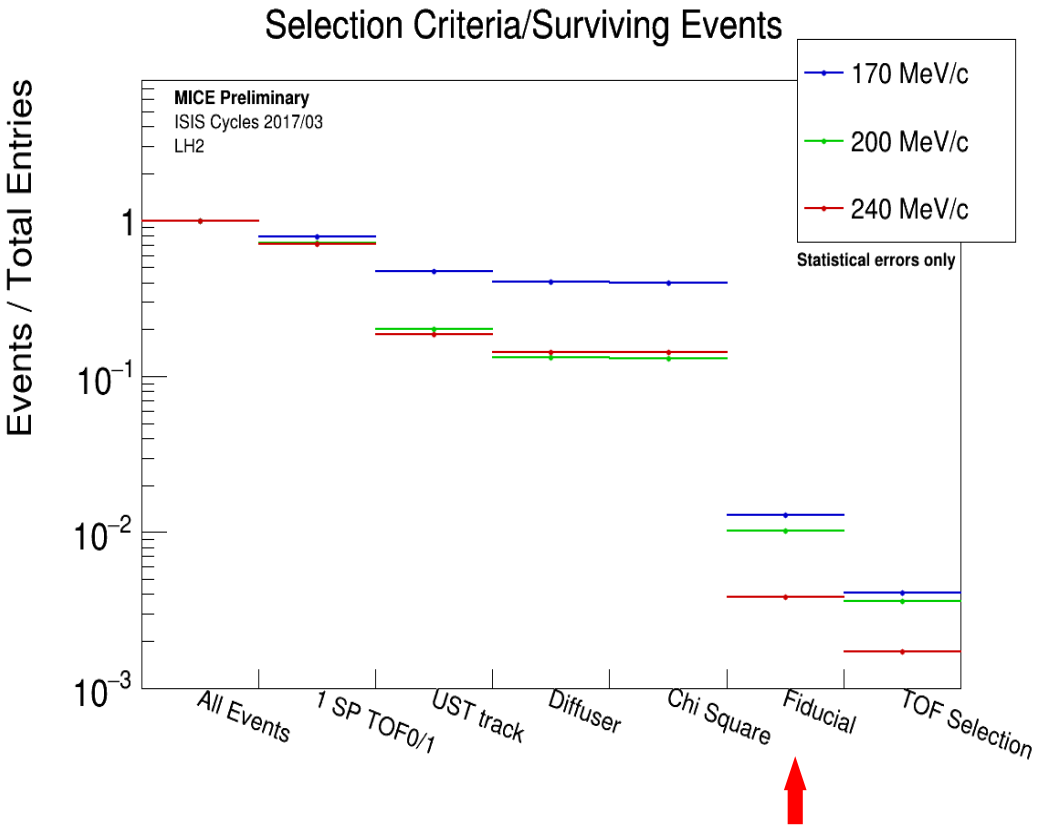

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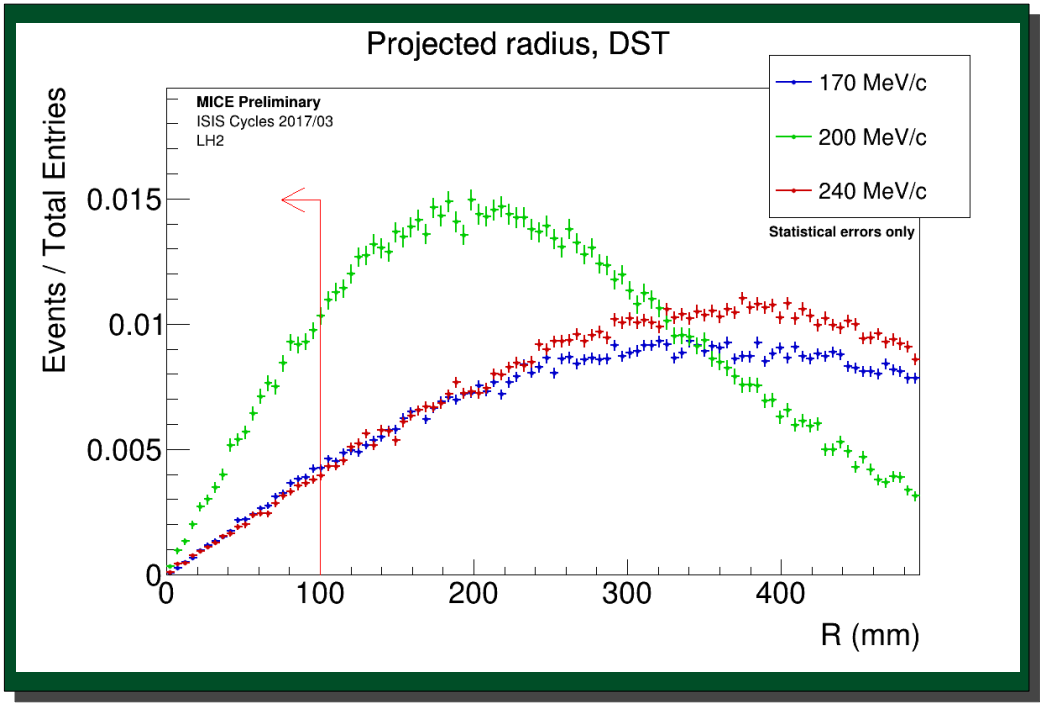


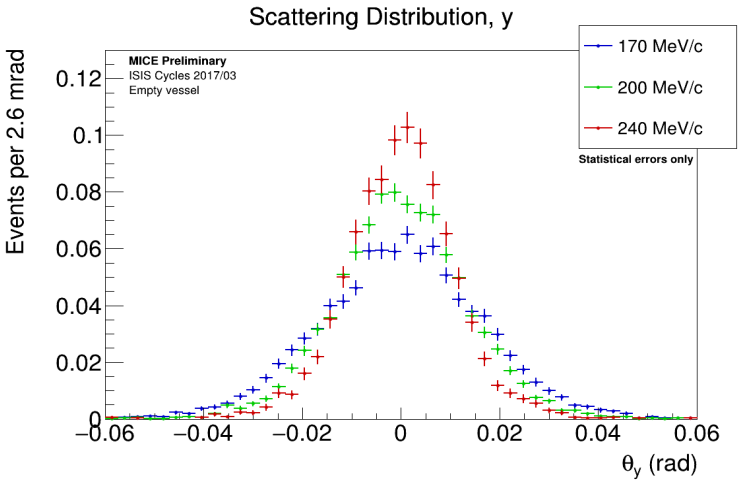
Results - MCS measurement

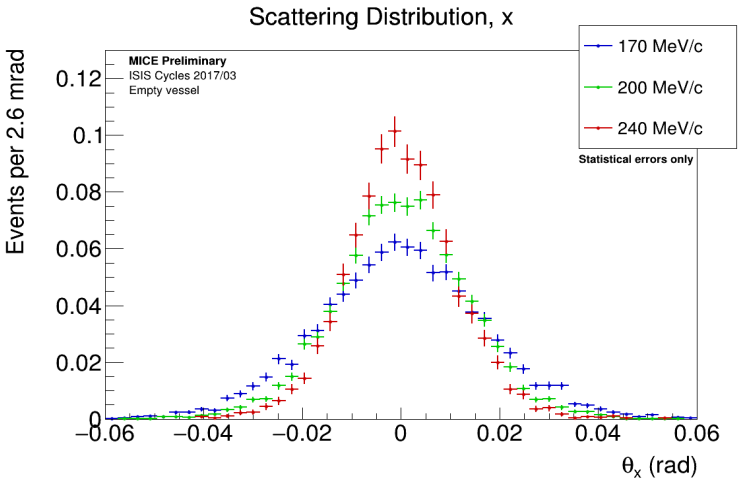
2D Projected angles

Results are expressed as angles between US and DS track vectors when projected unto orthogonal planes

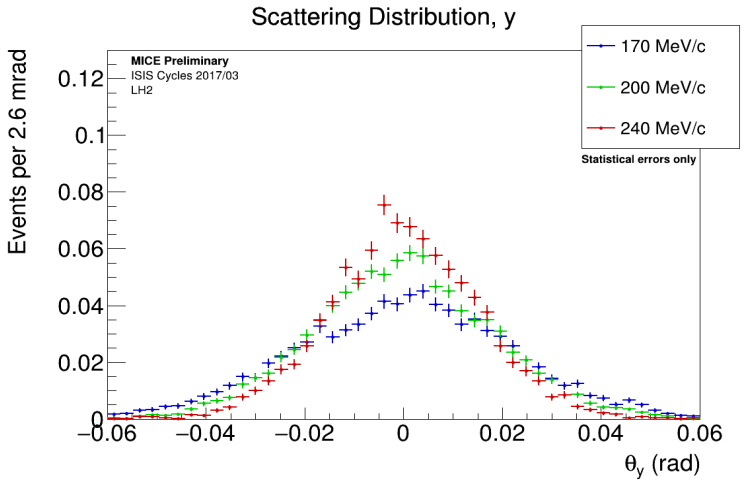
- θ_y : On plane defined by US vector and y-axis
- θ_x : On plane defined by US vector and orthogonality to above

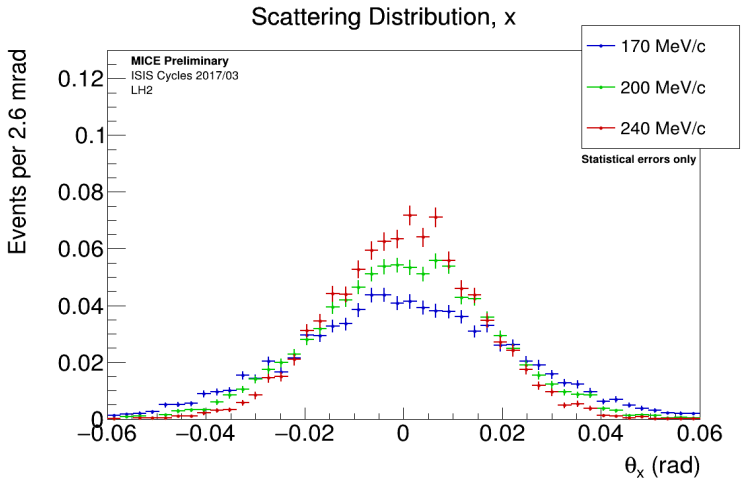
Empty vessel





Liq. H_2





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Summary

- MCS measurement using experimental data of the MICE muon beam crossing ~35cm of LH_2
- For ~170, 200, 240 MeV/c beam momenta
- Observations on results:
  - Projected angle distribution width decreases as beam momentum increases
  - Liquid H_2 on beam path increases width
- Only statistical errors are shown

Future work

- Systematic uncertainty calculation
- Momentum dependent comparison with predictions from:
  - GEANT4 MC simulation
  - Moliere MCS model with convolution analysis:
    - Experimental empty vessel distribution convoluted with predicted liq. H_2 and compared with experimental full absorber distribution.