Sophie Middleton

MICE: The International Muon Ionisation Cooling Experiment

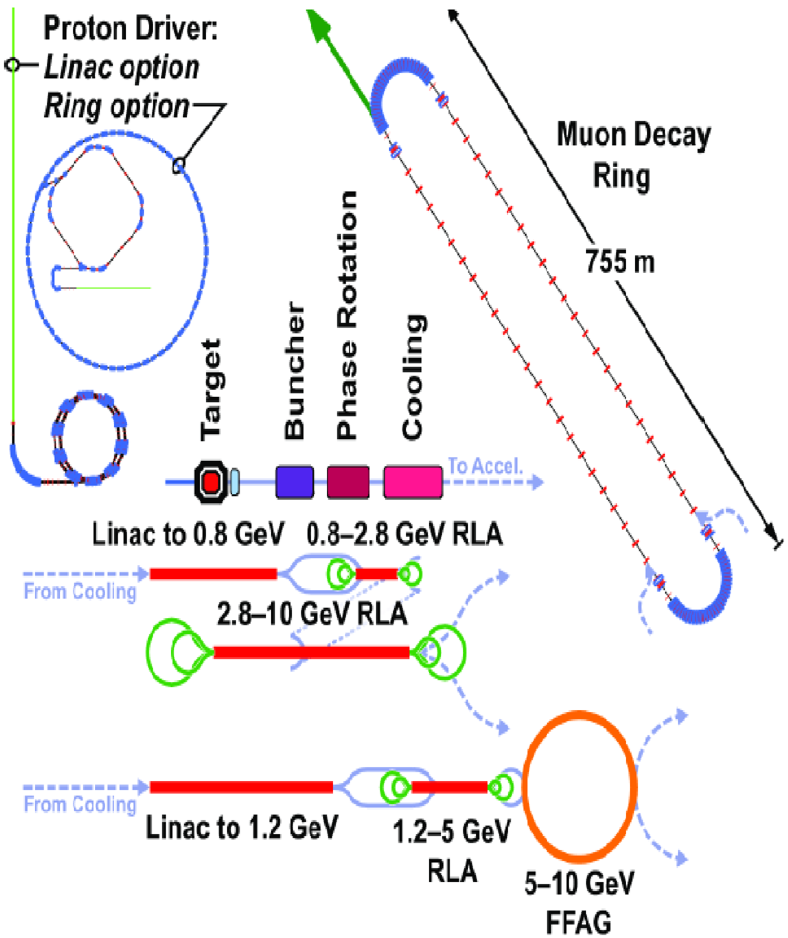
The Experiment , its Motivations and the Importance of Studying Muon Multiple Scattering

1. Introduction: Motivations

Introduction

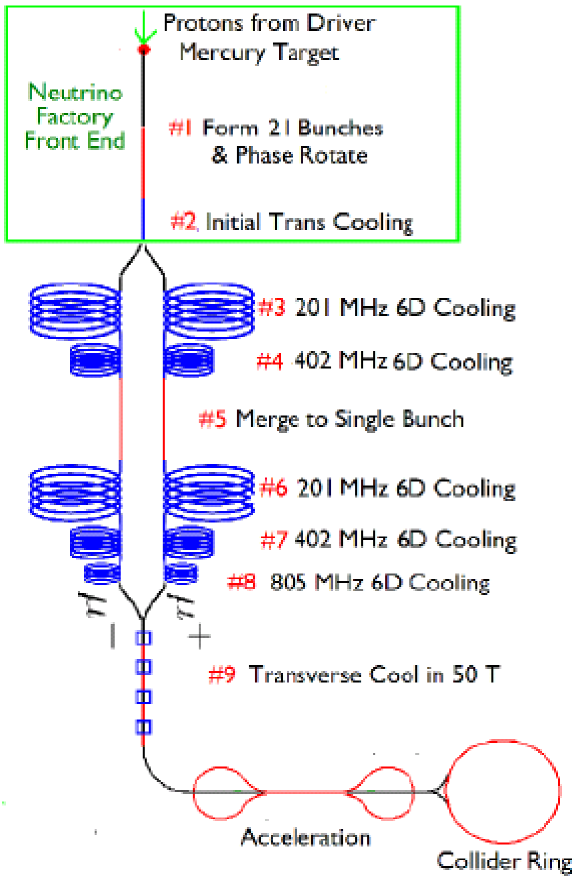
- Future Accelerator projects include neutrino factories and even further into the future muon colliders - both require muon acceleration
- Difficult due to the large transverse emittance of muon beams
- Only viable way to reduce emittance is through ionisation cooling
- MICE is a proof of principle prototype machine and aims to make the first measurements of this ionisation cooling
- MICE aims to observe reduction of transverse emittance of 10% for muons of momenta 140-240MeV/c

The Neutrino Factory



- Investigate mass hierarchy and CP-violation in the lepton sector
- High energy protons produced: H- source and strip electrons
- Impact Hg target and pions produced- decay to muons
- Muon beam bunched and phase rotation before cooling required
- Muons accelerated to final energy of 10GeV
- Muons decay and produce neutrinos

Muon Colliders



- Advantages:
  - Would provide finely tuned, high centre of mass energy lepton collisions
  - Unlike in hadron collider, the interaction would not be convoluted by parton distribution function
  - Unlike e+e- colliders would not suffer from synchrotron radiation losses
- Require s more cooling than the neutrino factory in order to achieve high luminosity.

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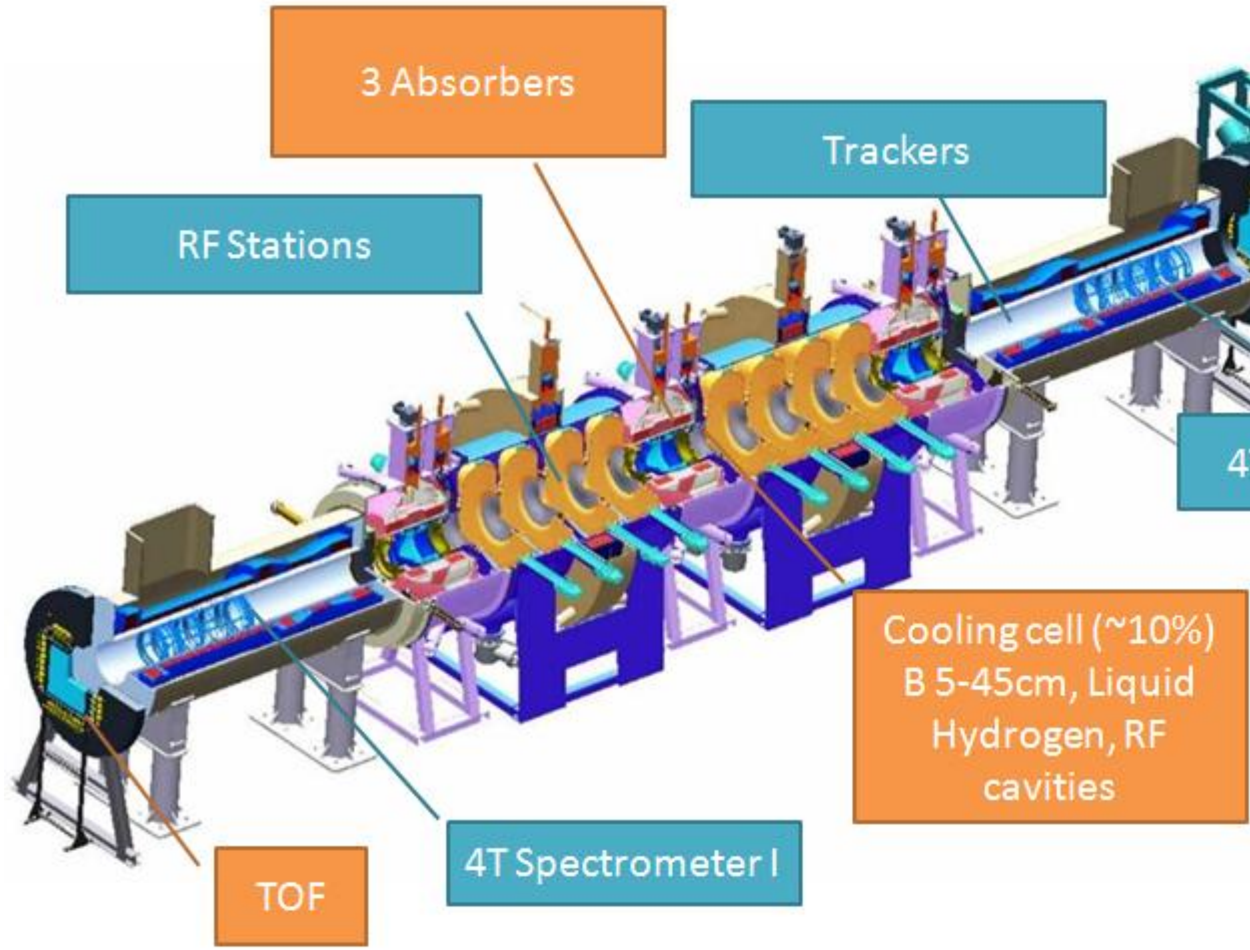
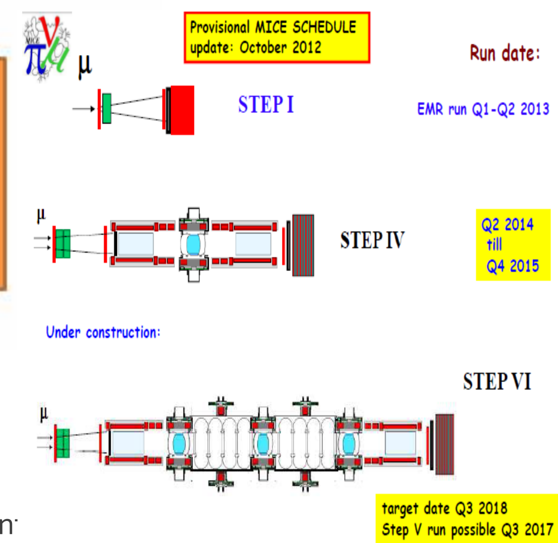
2. The Experiment

The Layout of Final Cooling Channel

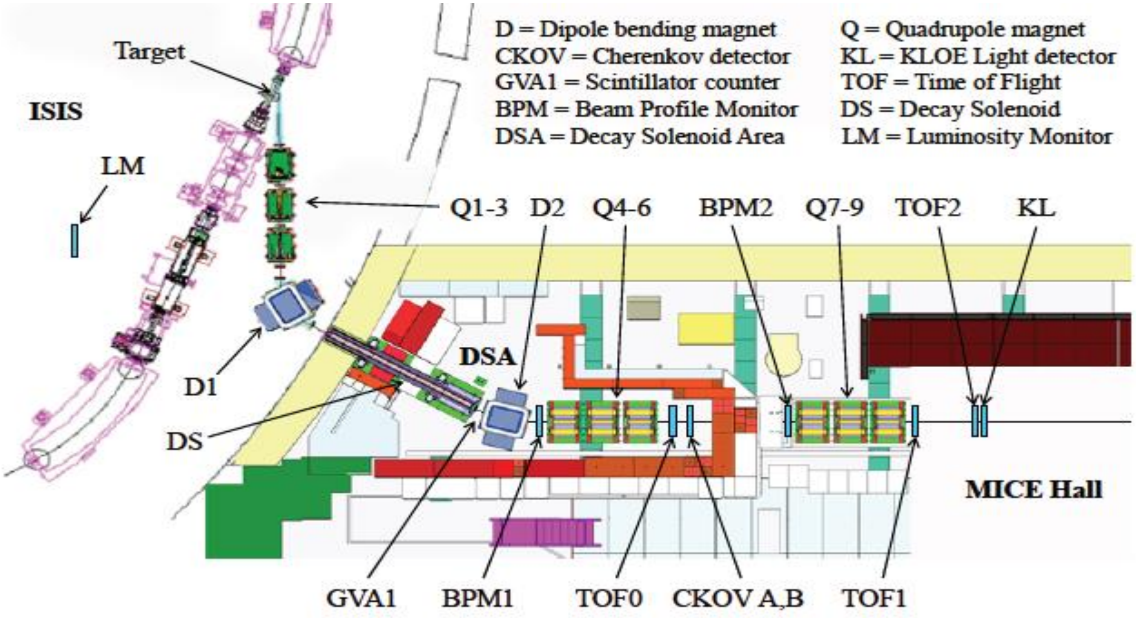




The Beam Line

1. <u>**Beam Production**</u>

- 800MeV proton beam provided by ISIS synchrotron
- Titanium target dipped in beam at frequency of 1Hz - pions produced these decay in flight to muons



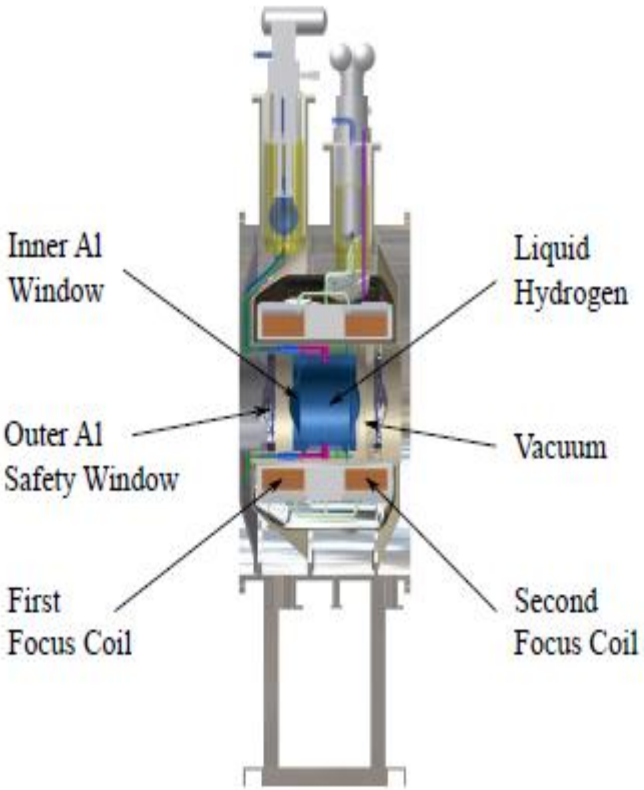
MICE: Description of Components

2. Absorbers and Cooling

- Muons impact an absorber and loss energy reduces emittance

- Interchangeable absorbers: LH2, solid Lithium Hydride, Aluminium, Copper and Beryllium

- Al windows at ends of absorber module allowing entry and exit of the beam

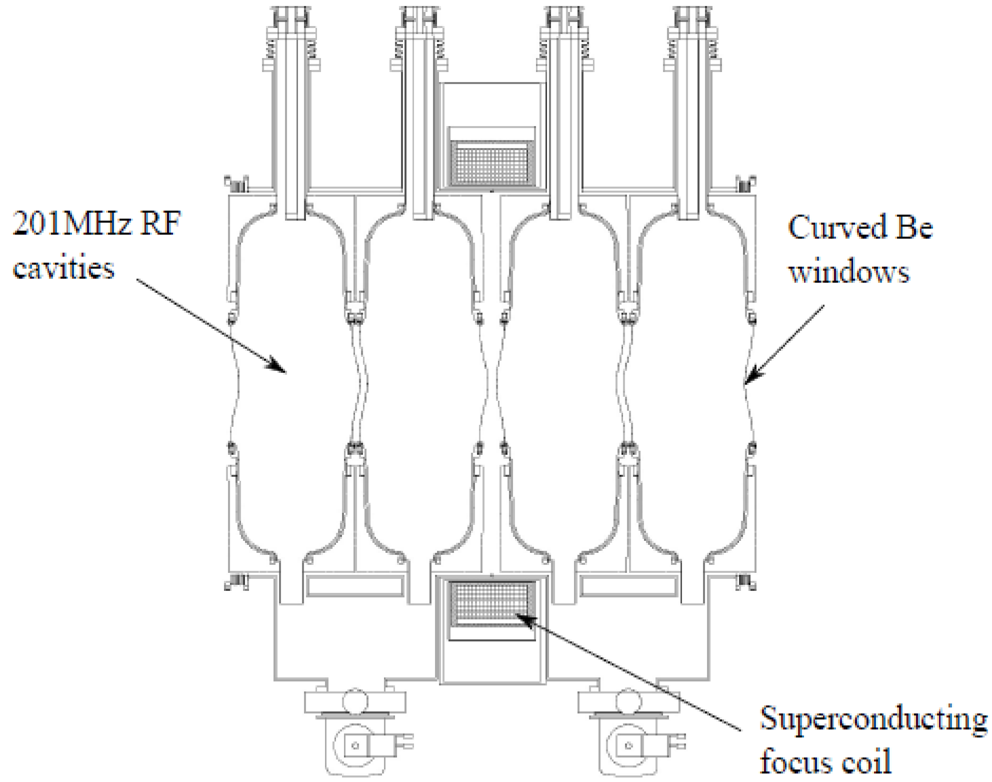


Absorber module from A. Dobbs thesis (Imperial, 2011)

MICE: Decription of Components

3. **RF Cavities**

- The ionisation cooling will reduce emittance in all directions
- Need to boost the longitudinal direction
- MICE has 2 RFCC modules
- Each with 4 201MHz RF cavities and one super-conducting coil.
- Gradient of 8MV/m



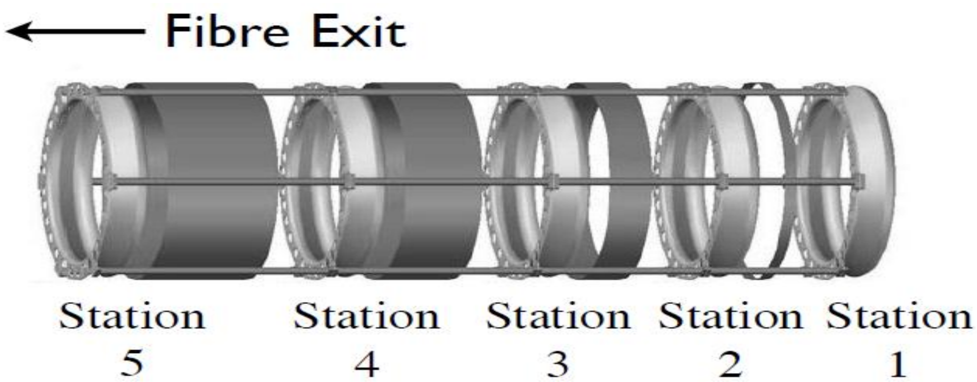
RF: A RF station with 4 cavities from A. Dobbs thesis (Imperial, 2011)

MICE: Decription of Components

4 . **Tracker**

- Scintillating fibre trackers within 4T SC solonoid → measure emittance before and after cooling

- Tracker has 5 30cm diameter stations each with 3 layers of 350 µm scintillating fibre

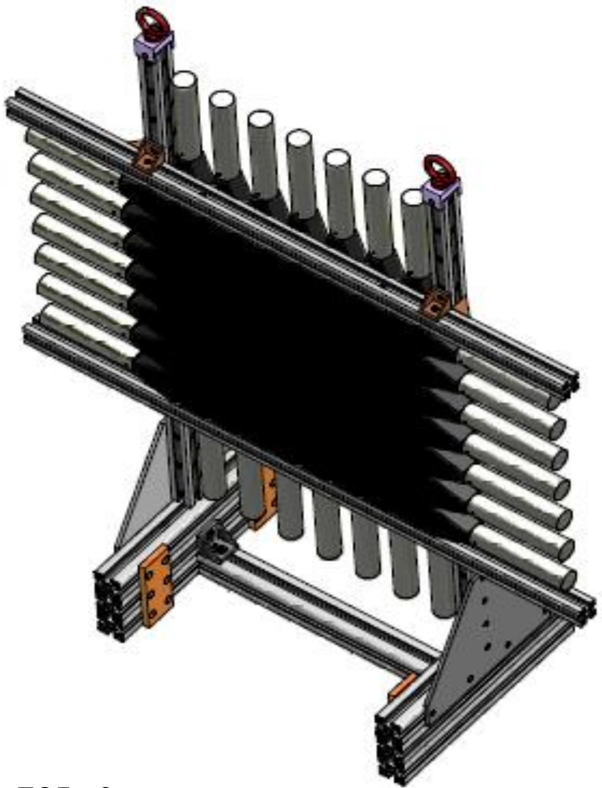


- The trackers are readout by Visible Photon Light Counters (VLPCs) and are designed to measure x, y,px, py, the transverse coordinates to the beam and E the muon energy

MICE:Description of Components

5. **Particle ID**

- **Upstream:** TOF0/TOF1 calculate mass allowing the particle to be identified.
- Also,2 Cerenkov counters (CKOVA/CKOVB), a rate counter and 2 beam-profile monitors
- **Downstream :** TOF2 along with a KLOE-Light (KL) detector.
- Works with electron-muon ranger (EMR) forming downstream ECAL



TOF1: 6 cm×42 cm×
2.5 cm scintillator slabs-Taken from Mark Rayner's thesis (Oxford U.,2011)

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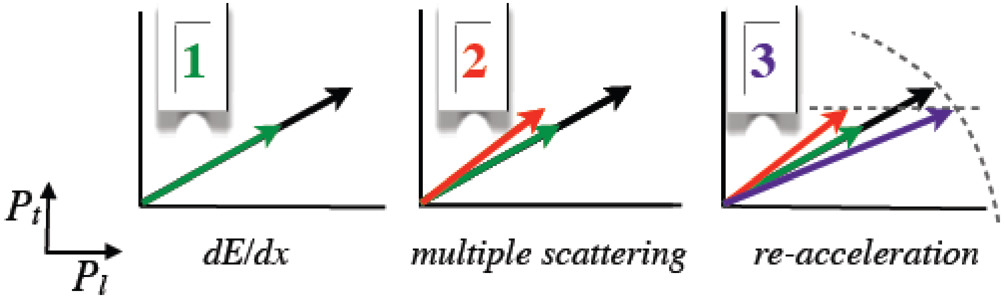
3. Multiple Scattering Studies

Muon Ionisation Cooling

- Cooling Equation:

$$\frac{d\epsilon_n}{dz} = \frac{-\epsilon_n}{\beta^2 E}\langle\frac{dE}{dz}\rangle + \frac{\beta_\perp (14MeV)^2}{2\beta^3 E m_\mu X_0}$$

- Cooling term and heating term (due to multiple scattering)
- Cool by passing through absorber then boost back in longitudinal direction using RF cavities



Multiple Scattering

- Before any measurements of cooling we need to understand heating effect i.e. multiple scattering

- Muons will be deflected by small angles when traversing absorber. PDG gives the expression for the RMS angle as:

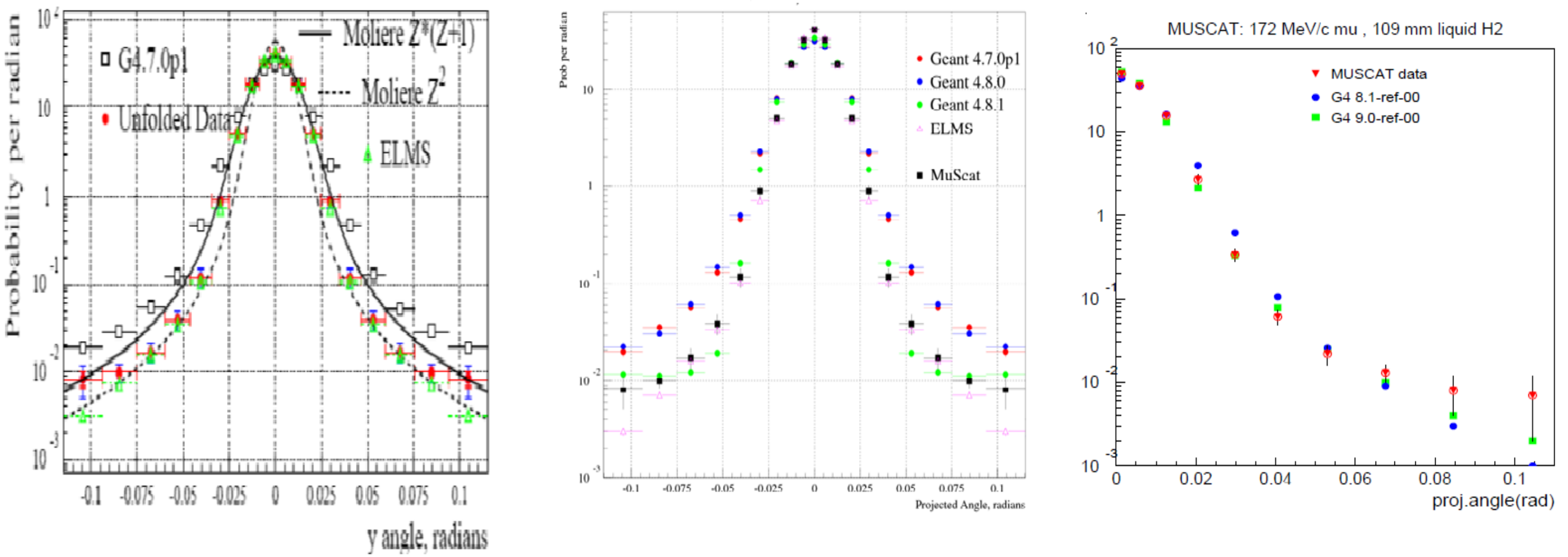
- Where:

$$\theta_0 = \theta_{plane}^{rms} = \frac{1}{\sqrt{2}}\theta_{space}^{rms}$$

$$\theta_{plane}^{rms} = \frac{13.6MeV}{\beta cp}\sqrt{\Delta z/X_0}[1 + 0.038ln(\Delta z/X_0)]$$

- However, recent studies from MuScat have suggested a better understanding at high scattering angles is needed

MuScat results



- Above plots for 15.9cm LH2 (first two) and 10.9cm LH2 (end)
- Above figures show that Moliere based theories don't successfully describe the tails of the distribution
- GEANT4.9.0 and ELMS better at describing this distribution at high angles but still not great at larger angles!

MuScat results

- W. Allison's ELMS program generates MC for thin absorbers. The method uses double differential cross sections and splits muon collisons into coulomb collisions with nuclei and electrons and collisions with the atom as a whole.

- The last version of the expression for scattering angle used in the 2007 analysis has a central part given by-same as in latest version of GEANT4:

$$\theta_0 = \frac{13.6MeV}{\beta cp} z[\frac{x}{X_0}]^{0.5}[1 + 0.105ln(\frac{x}{X_0}) + 0.0035ln(\frac{x}{X_0})^2]^{0.5}$$

- The tail has the functional form:

$$\frac{1}{(b - cos\theta)^c}$$

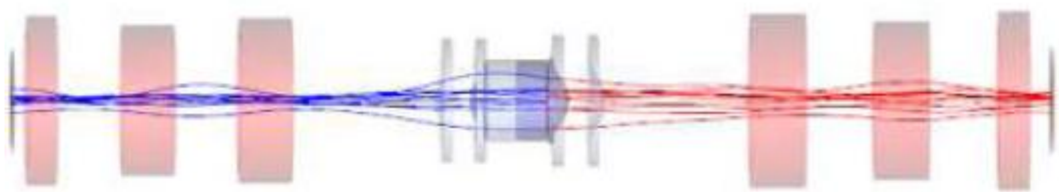
- Where :

$$c = 2.40 - 0.027Z^{2/3}$$

Multiple Scattering and MICE

- Simulations again show 20% deviation from PDG-Step IV of MICE will allow direct measure of multiple scattering of muons

$$\cos\theta^{space}_{rms} = \frac{\vec{p}.\vec{q}}{|p||q|}.$$



- **"Multiple Scattering Measurements in the MICE Experiment"**

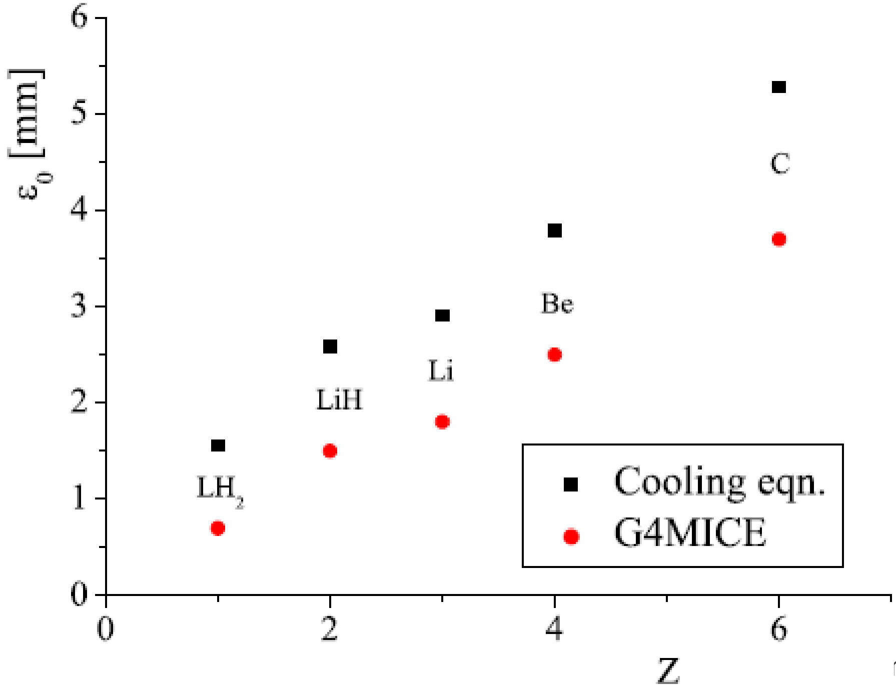
T. Carlisle, J. Cobb, Department of Physics, Oxford University, Oxford, UK

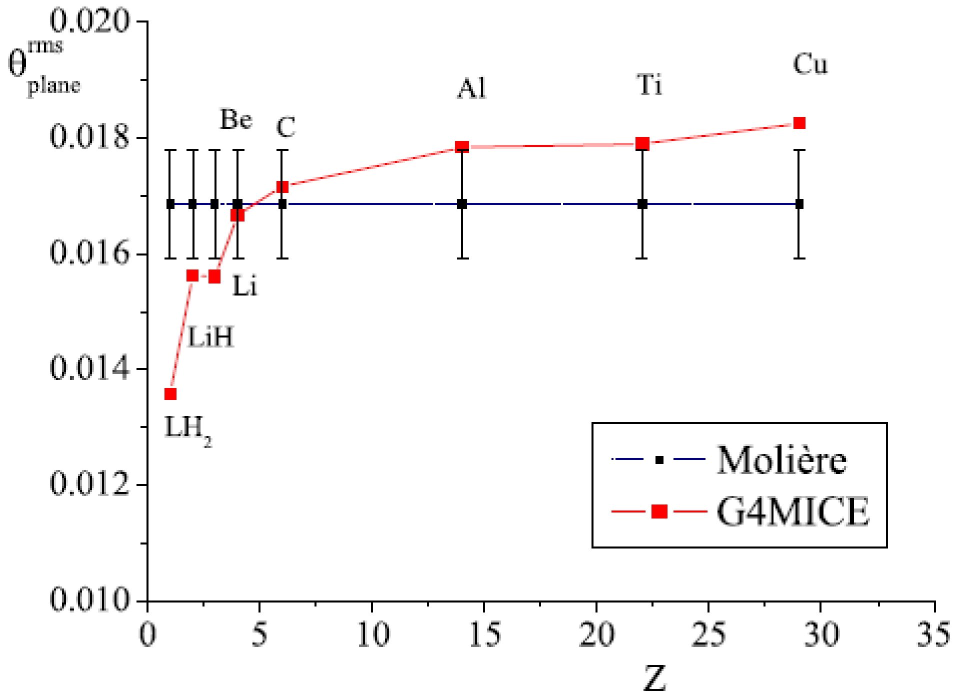
- Note shows that the trackers were considered able to directly measure multiple scattering in the LH2 and LiH absorbers in step IV

Multiple Scattering and MICE

- Scattering predictions at Z < 5 ***were significantly greater than measured in*** G4MICE

- Moliere predictions appear to significantly overestimate eqm emittance when compared to GEANT4





MICE simulation compared with predictions from Moliere's theory of multiple (J. Cobb, T . Carlisle)

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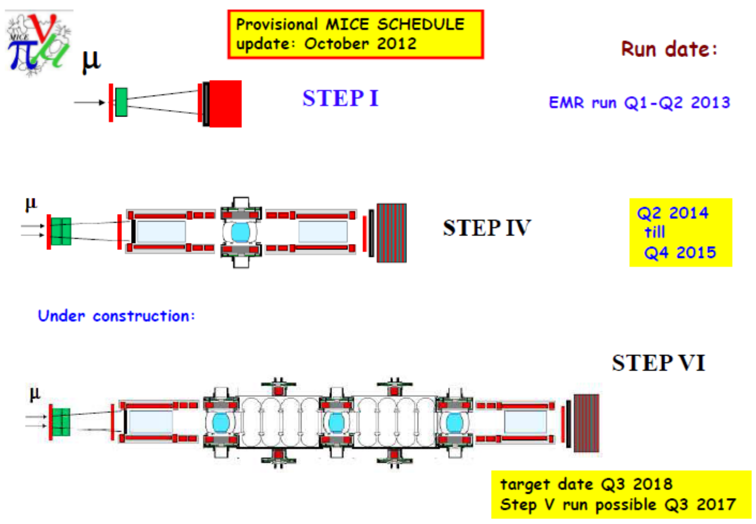
4. Current Status

Current Status and My work

- Current Schedule:



- For the first year or so of my PhD I will be making further studies of multiple scattering using simulation and in 2014 (summer) will start analysing data from Step IV.