The Physics Programme of MICE Step IV

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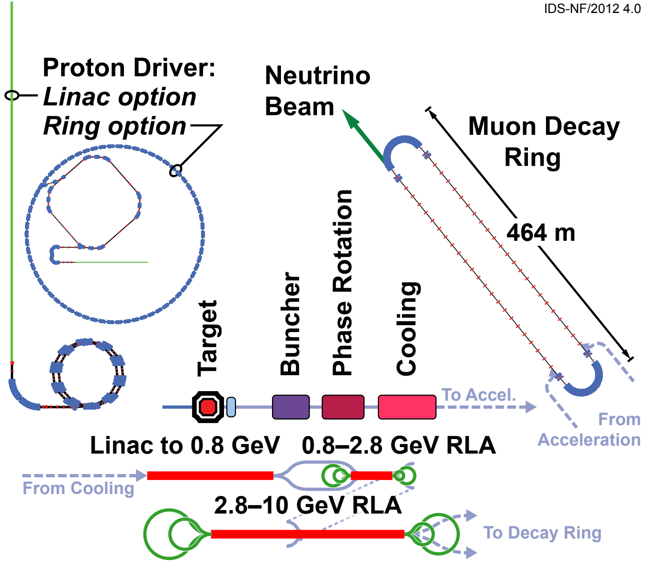
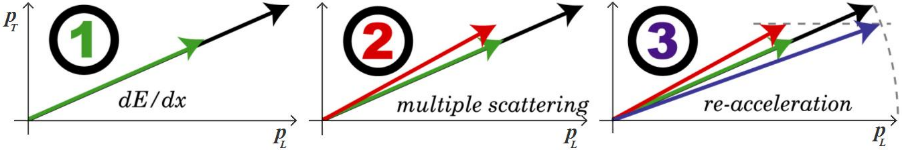
Outline

Cooling at a Neutrino Factory



- Muon beam must be cooled in transverse direction during acceleration.
- Increase the rate of the muon beam in the channel.
- Preferred method is cooling through ionization energy loss.

Ionization Cooling



- Reduce the beam momentum in absorber material
- Change in beam emittance described by;

$$\frac{d\epsilon}{ds} = \frac{-\epsilon_n}{\beta^2 E}\langle\frac{dE}{dX}\rangle + \frac{\beta_t(13.6\mathrm{MeV})^2}{2\beta^3 E m_\mu X_0}$$

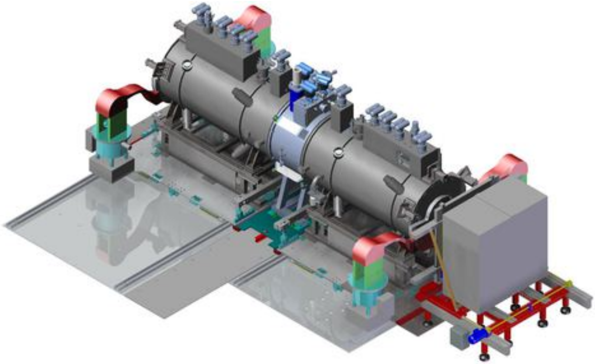
- Re-acceleration results in sustained transverse beam cooling.

Measurements of MICE

	Step IV	Step $\frac{3\pi}{2}$
Study of properties that determine cooling performance		
Material properties of LH_2 and LiH	**Yes**	LH_2 and/or LiH
Observation of $\epsilon_{\perp}^{n}$ reduction	**Yes**	Yes
Demonstration of sustainable ionization cooling		
Observation of $\epsilon_{\perp}$ reduction with re-acceleration		**Yes**
Observation of $\epsilon_{\perp}$ reduction and $\epsilon_{\parallel}$ evolution		**Yes**
Observation of $\epsilon_{\perp}$ reduction and $\epsilon_{\parallel}$ and angular momentum		Yes [a]

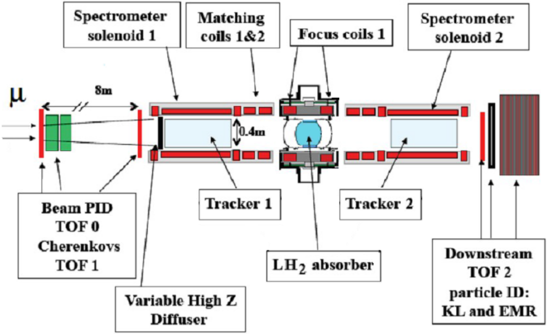
[a] Requires systematic study of "flip" optics

MICE Step IV Cooling Channel



- Detectors provide independent upstream and downstream measurements of
  - the momentum ($\Delta p/p < 0.1\%$).
  - the PID ($N_\pi/N_\mu < 0.1\%$).
  - Produce a $< 1\%$ emittance measurement.

MICE Step IV Cooling Channel



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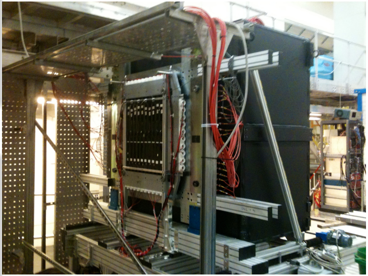
MICE Detector Capabilities

Cherenkov detectors

- Two different velocity threshold measurement.
- Aerogel volumes with PMT counters; two refractive indices.

TOF (Time of flight)

- Measures particle velocity
- Composed of scintillator slabs; ≈50 ps precision



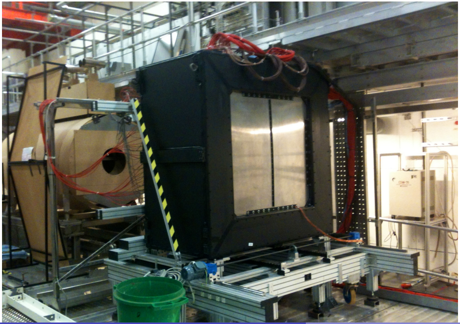
KL (Kloe Light)

- Scintillating fibres sandwiched between lead foils.
- Induce pion showers.
- Energy deposition: $\sigma_E/E = 7\%/\sqrt{E}$

MICE Detector Capabilities

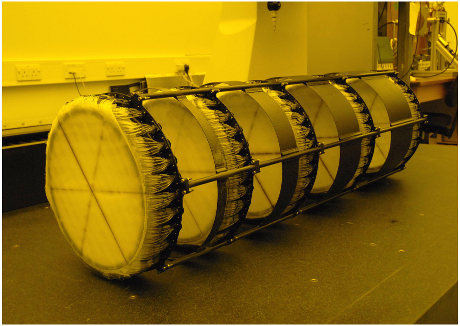
EMR (Electron Muon Ranger)

- 48 alternating x and y planes of 59 triangular scintillating bars.
- 33 mm base $\times$ 17 mm height $\times$ 1 m length for each bar .



Trackers

- Scintillating fibre tracker in 4 T solenoids.
- 470 μm position resolution



Channel Settings

- Will test transport through absorber at various momenta and initial emittance

3π 140 MeV/c	6π 140 MeV/c	10π 140 MeV/c
3π 200 MeV/c	6π 200 MeV/c	10π 200 MeV/c
3π 240 MeV/c	6π 240 MeV/c	10π 240 MeV/c

- Manipulate momentum with magnet lattice.
  - Matching conventional beam line to super conducting magnets.
- Manipulate initial emittance with diffuser.

- Absorber material may also be changed
  - Liquid hydrogen and lithium hydride disk absorbers available.
  - Polystyrene wedge absorber also under consideration.

Beam Cooling

Change of emittance for muons

$$\frac{d\epsilon}{ds} = \frac{-\epsilon_n}{\beta^2 E}\langle\frac{dE}{dX}\rangle + \frac{\beta_t(13.6\mathrm{MeV})^2}{2\beta^3 E m_\mu X_0}$$

Physics measurements that directly impact MICE result

- Precision of measurement of emittance: ϵ.
- Energy loss in material $\langle\frac{dE}{dx}\rangle$.
  - Using liquid hydrogen and lithium hydride.
- Multiple scattering.
- Background identification.

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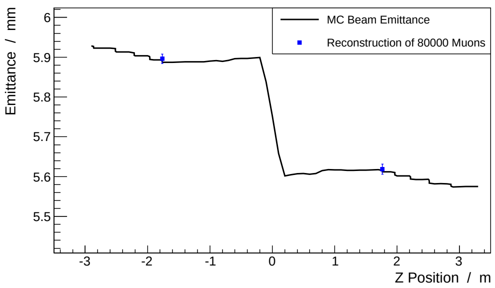
Emittance Measurement

Preliminary results by Chris Hunt



- Compiled from single muon tracks.
- Emittance evolves continuously but,
- Only a single measurement from each tracker.

- Initially calculated with

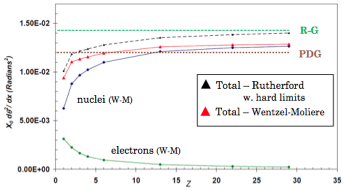
$$\epsilon_n = \frac{\sqrt{V(x, p_x, y, p_y)}}{m}$$

- Correction applied to variance to match for correlations.
  - Matches measured emittance to the true emittance within errors.

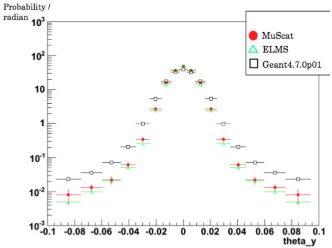
Multiple Scattering

- Heating term in cooling equation.
- Poorly understood in low Z targets.
- GEANT4 by default uses Urban MCS model for scattering.
- Will be tested directly from matching upstream and downstream muon trajectories

Comparison of formulae (produced by Tim Carlisle)



Scattering distributions in liquid hydrogen (produced by Tim Carlisle)



MICE Schedule for Step IV

- Step IV
  - Begin: May 2015
  - Possible decommissioning: Sept. 2015
- Recent DOE review of MAP/MICE recommends:
  - Demonstration of ionization cooling with re-acceleration.
  - Equipment required to make demonstration must be in experimental hall by end of Sept. 2017.
  - Decommissioning time prior to delivery motivates a short data collection period.

Summary

- Preliminary steps of MICE complete.
- Physics program of MICE step IV provides tests of material properties necessary for ionization cooling.
  - Will test the reduction of emittance with no acceleration.
- Includes an integral measurement of muon scattering in low Z materials.
  - Can provide new data with which to validate models.
- An intensive data collection period planned to take advantage of this opportunity.