Muon Ionization Cooling Demonstration by Normalized Transverse Emittance Reduction in MICE 'Flip' Mode

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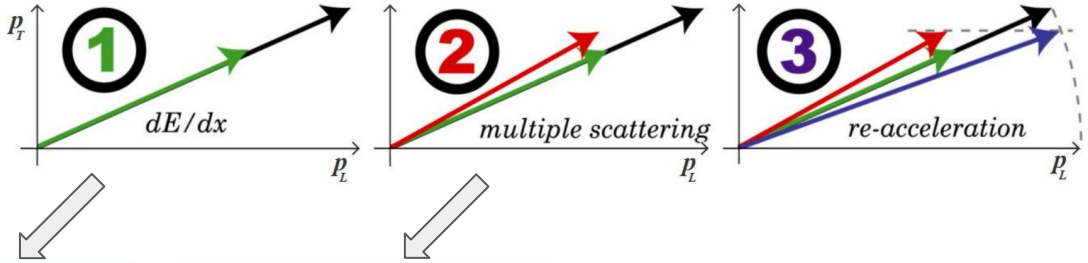
MICE

Ionization cooling

- High brightness muon beams essential for development of facilities such as Neutrino Factory and Muon Collider
- Muons typically produced via pion decay ➞ diffuse beam; difficult to characterize and manipulate
- IONIZATION COOLING: proposed technique to reduce muon beam phase-space volume (emittance)

- Beam momentum spread reduced via energy loss in an absorber material



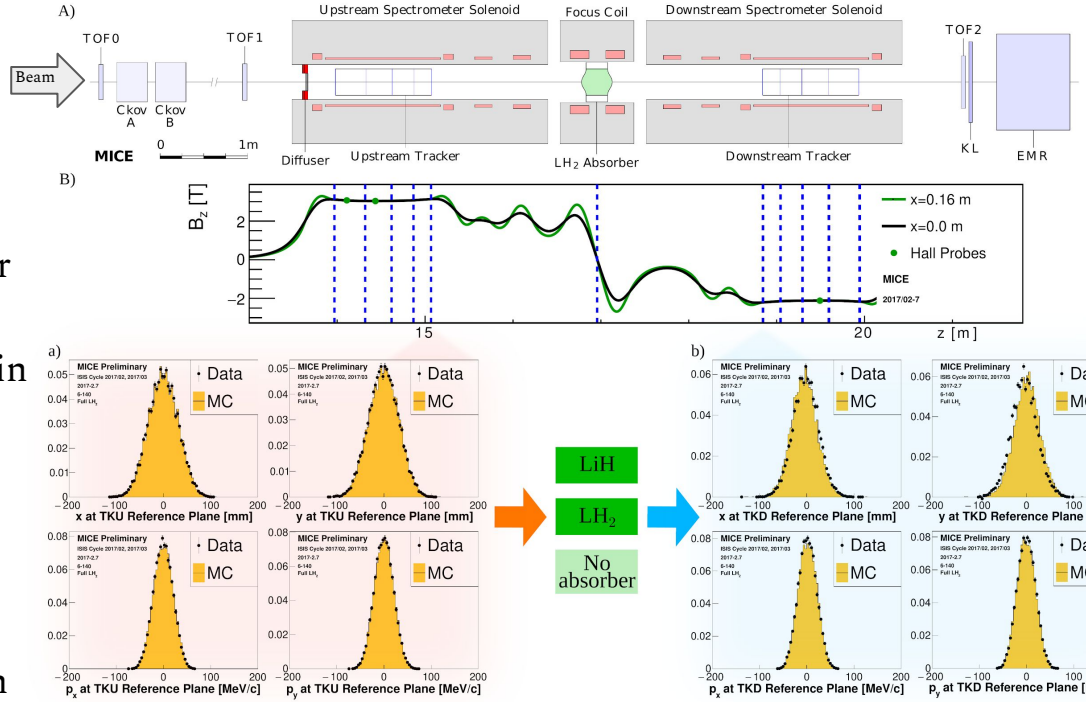
- Emittance evolution described by the cooling equation:

$$\frac{d\varepsilon_\perp}{dz} \simeq -\frac{1}{\beta^2}\frac{\varepsilon_\perp}{E_\mu}\left|\frac{dE_\mu}{dz}\right| + \frac{\beta_\perp (13.6\,\mathrm{MeV})^2}{2\beta^3 E_\mu m_\mu c^2}\frac{1}{X_0}. \qquad (1)$$

- The cooling performance increased by using low Z materials and tightly focusing the beam at the absorber

The Experiment

- A transfer line delivered the muon beam to the cooling apparatus
- Beam tightly focused using 12 superconducting solenoids
- Individual muon position and momentum measured before and after passing through an absorber by scintillating fiber trackers immersed in 3 T and -2 T uniform fields
- Muon beams crossed liquid hydrogen (LH_2) and lithium hydride (LiH) absorbers
- Field fliped polarity at absorber to prevent canonical angular momentum build-up



Emittance reduction

- Emittance change: $\Delta\varepsilon_\perp = \varepsilon_{\perp downstream} - \varepsilon_{\perp upstream}$
- $\Delta\varepsilon_\perp < 0$ → **COOLING**
- Rejection sampling used to obtain beam with optimized optics, reducing the heating term
- Data presented here taken using beams with 140 MeV/c nominal input momentum and 6 mm input normalized transverse emittance
- 'No absorber' - no significant emittance change
- 'Empty LH_2' - slight heating due to muon scattering in the vessel windows
- 'Full LH_2' and 'LiH' demonstrate emittance reduction, clear signal of ionization cooling
- Simulation and systematics - work in progress