Muon Ionization Cooling Experiment (MICE) Results & Prospects

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Introduction

- Present accelerators/colliders: electron, proton and ion beams
- Future proposed accelerators have huge footprint (FCC, ILC, CLIC)

- Growing interest in using muons
  - Muon collider
  - Neutrino factory
- Technological challenges
  - Ionization cooling one of the many

Muon cooling

- Low synchrotron radiation wrt to e ($m_\mu \sim 207\ m_e$)
- Relatively easy muon production
- Tertiary production from
  - Proton beam on target
  - Pion decay
- Large phase-space volume
- Short lifetime (~2.2 μs at rest)

Muons through an absorber:
- Ionization energy loss: **cooling**
- Multiple scattering: **heating**

ε_N = normalized transverse emittance
β_t = transverse betatron function
E_μ = muon energy
<dE/ds> = mean energy loss
βc = velocity
m_μ = muon mass
X_0 = radiation length

Cooling equation:

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

Cooling   Heating

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

$$\mathcal{C} = \begin{pmatrix} \sigma_{xx} & \sigma_{xp_x} & \sigma_{xy} & \sigma_{xp_y} \\ \sigma_{xp_x} & \sigma_{p_xp_x} & \sigma_{yp_x} & \sigma_{p_xp_y} \\ \sigma_{xy} & \sigma_{yp_x} & \sigma_{yy} & \sigma_{yp_y} \\ \sigma_{xp_y} & \sigma_{p_xp_y} & \sigma_{yp_y} & \sigma_{p_yp_y} \end{pmatrix}$$

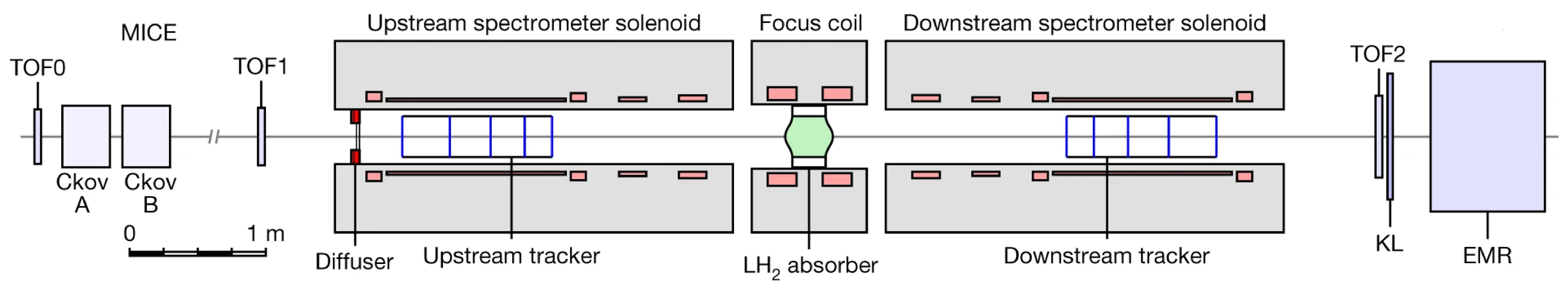

Fig. 1: MICE apparatus, with the various PID detectors, the liquid hydrogen absorber and the superconducting magnets surrounding the tracking detectors. Muons are coming from the left.

MICE

Production: pions production from protons hitting a titanium target

Transport: beam line collecting muons from the pion decays

Diffuser: choice of the incident beam emittance

PID: fully instrumented beamline
- *TOF* detectors for particle velocity
- *Scintillating fibre trackers* in magnetic field: position and momentum reconstruction before and after passing through an absorber
- *Cherenkov* detectors for pion/muon separation
- *EMR* for muon/electron separation

Energy absorbers:
- Empty channel (for comparison)
- 22 l *liquid hydrogen* vessel (LH2)
- 65 mm *lithium hydride* disk (LiH)
- *Polyethylene wedge*

Muons were measured one by one, creating an ensemble ("beam") of particles. Beams were selected with various initial emittances and momenta (e.g. "3-140" is a 3 mm, 140 MeV/c beam). GEANT4 based simulation was used to model the experiment.

Results

Transverse amplitude measurement before and after an absorber

Beam through an empty absorber: no increase of the core density

"6-140" and "10-140" beams through LH2 and LiH:
- Increase the density of the downstream beam core
- ratio of the amplitude distributions above 1
- → **cooling signal**

Prospects

- MICE data analysis is ongoing (different momenta and focusing properties)
- studies for follow-up experiments
- lattices with enhanced cooling at lower emittances
- wedge-shaped absorber to exchange of emittance between longitudinal and transverse
- "6D" cooling may be achieved
- muon source studies (nuSTORM)

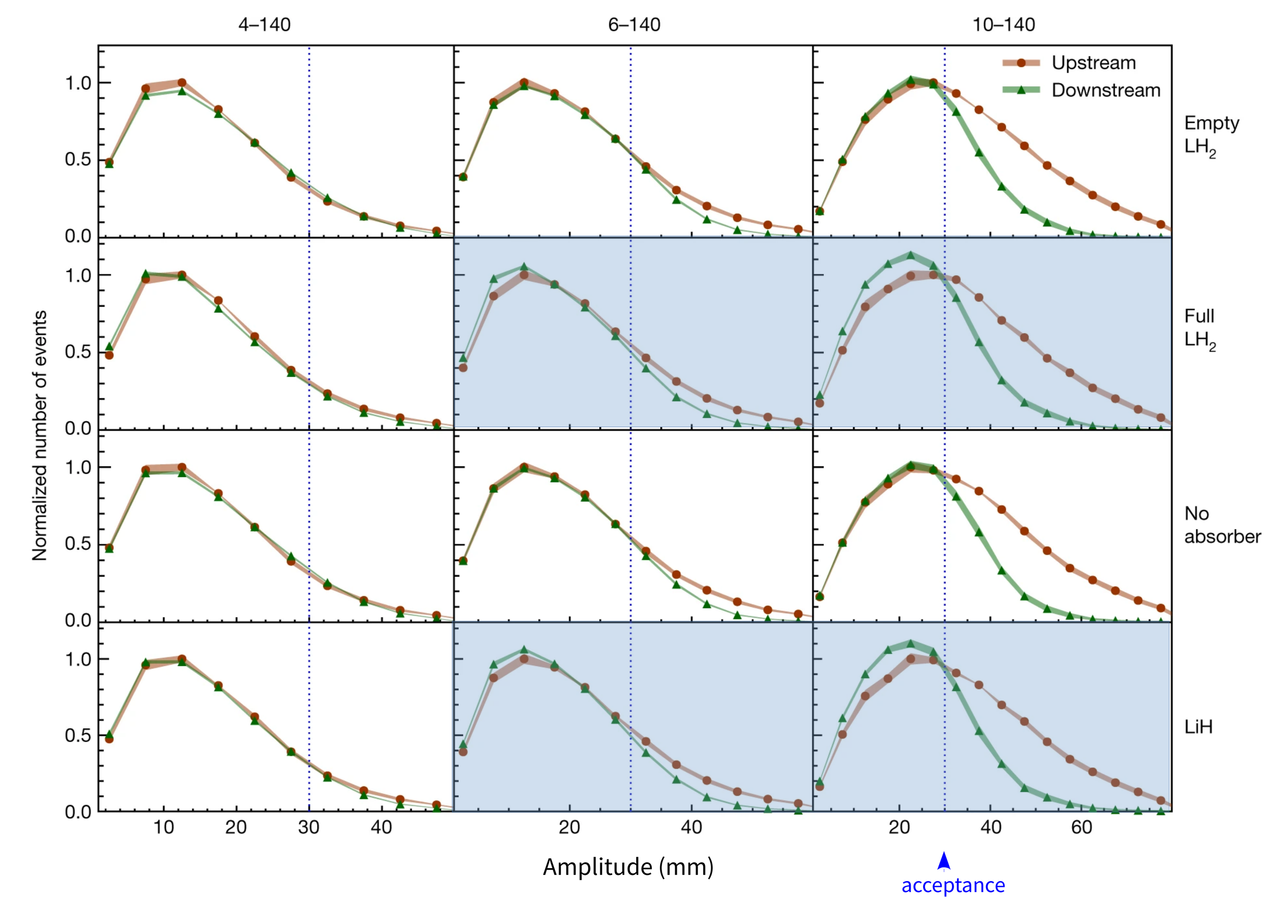

Fig. 2: Muon amplitudes for various beam configurations

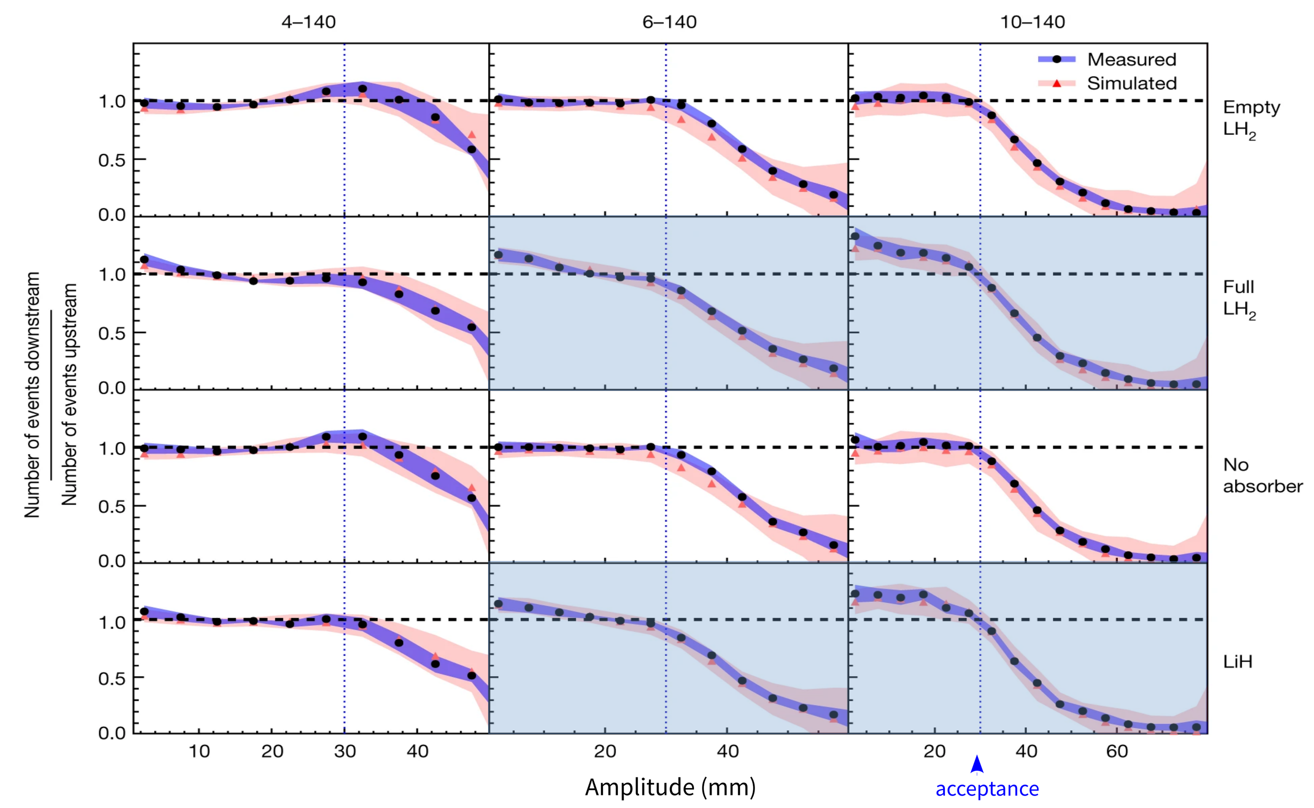

Fig. 3: Downstream to up stream ratio of events of each amplitude, for different beams and configurations

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