Results from Step I of MICE and the Physics Plan for Step IV

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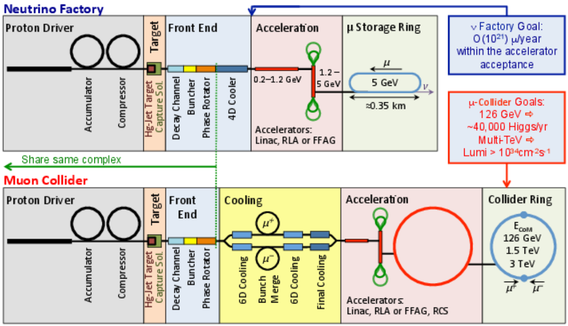
Motivation



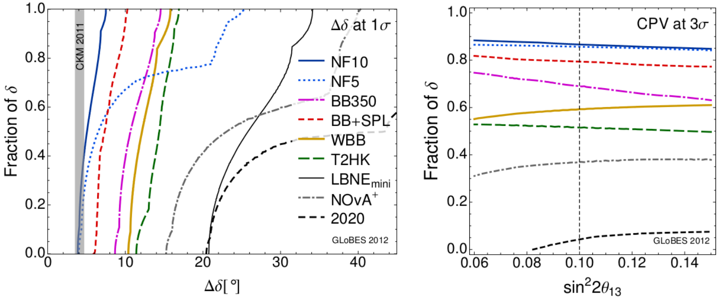
Neutrino Factory

- 10^{21} usable μ decays per year.
- Cooling may double μ flux.

Muon Collider

- 40k Higgs per year
- 6D cooling required for high luminosity ($> 10^{34}$ cm^{-2}s^{-1}).

Motivation

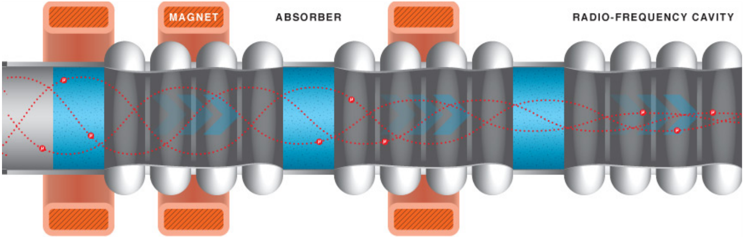


P. Coloma *et al.*, arXiv:1209.5973 (2012).

A comparative study of δ measurements at different facilities. "Fraction of δ" refers to the fraction of possible δ values for which a given precision ($\Delta\delta$) is obtainable.

Ionization Cooling

$\tau_\mu \approx 2.2\ \mu$s means stochastic, electron beam cooling approaches are not viable. Instead, we employ *ionization cooling*:



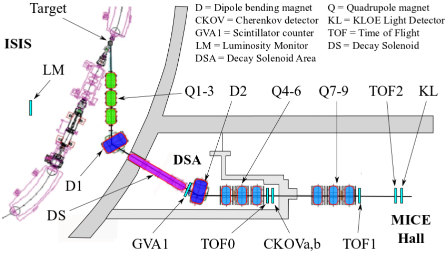
$$\frac{d\epsilon_{\mathrm{N}}}{dX} \approx -\frac{\epsilon_{\mathrm{N}}}{\beta^2 E_\mu}\left\langle\frac{dE}{dX}\right\rangle + \frac{\beta_t (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

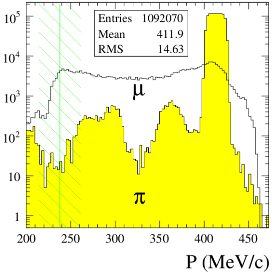
... a cooling term and a heating term from multiple scattering.

MICE, the Muon Ionization Cooling Experiment

1. ∼150 collaborators from 9 countries.
2. Hosted at Rutherford Appleton Laboratory in the UK.
3. 4D ionization cooling of 140-240 MeV/c muon beams.
4. Expected to demonstrate a 10% reduction in transverse emittance. We therefore require $\Delta\epsilon_{\mathrm{N}}/\epsilon_{\mathrm{N}} = 1\%$.

MICE and the ISIS Beamline

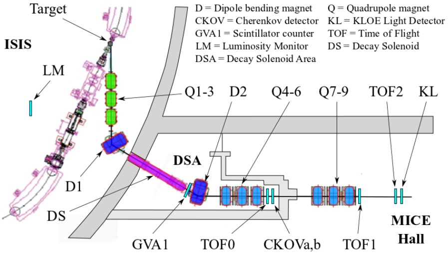


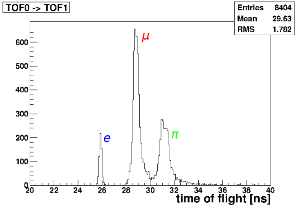


- 800 MeV protons → Ti target → pion "spill" → μ beam.
- $\epsilon_{\rm N} = 3, 6, 10\pi$ mm-rad.
- $p_z = 140, 200, 240$ MeV/c.
- D2 strength gives > 95% pure μ beam or "calibration beam".

Momentum spectra at D2. Select backwards-decaying μ's in π rest frame for best separation.

MICE and the ISIS Beamline





Calibration beam

- 800 MeV protons $\rightarrow$ Ti target $\rightarrow$ pion "spill" $\rightarrow$ μ beam.
- $\epsilon_N = 3, 6, 10\pi$ mm-rad.
- $p_z = 140, 200, 240$ MeV/c.
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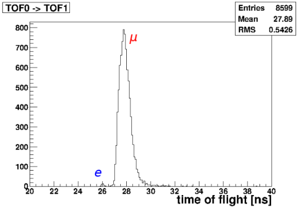
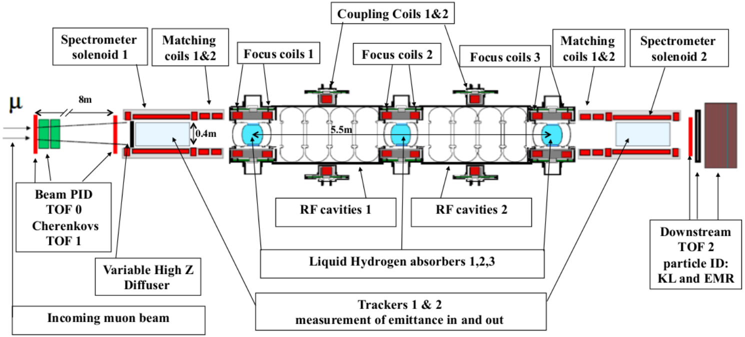
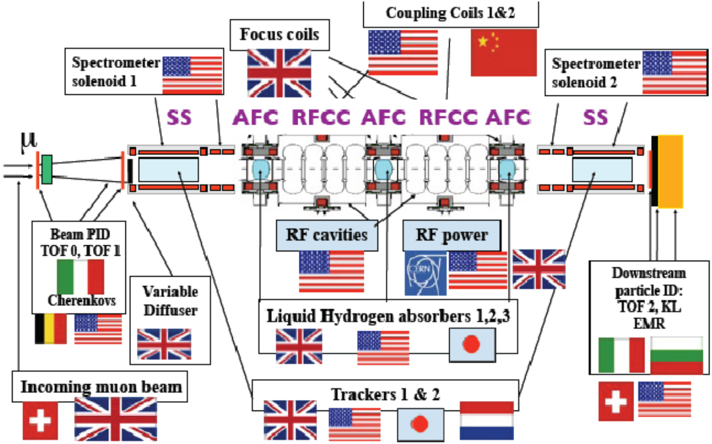


$> 95\%$ muons

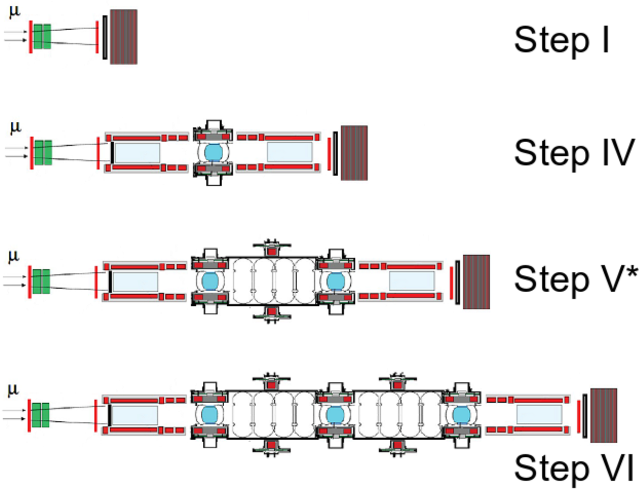
MICE is a *systems integration* study.



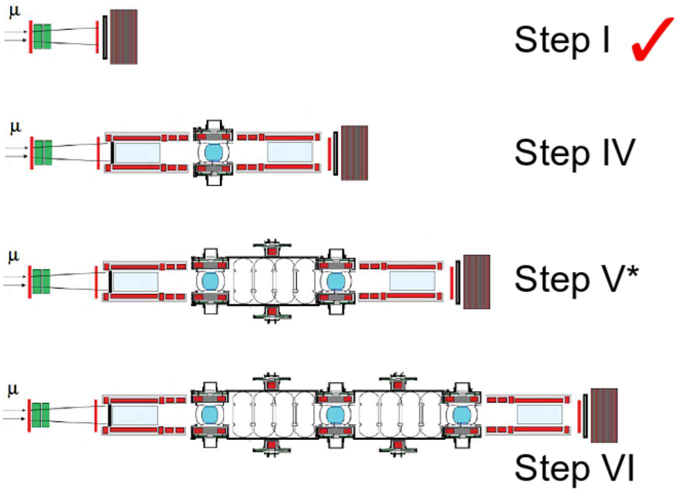
MICE is an international effort.



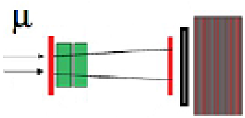
MICE Staging



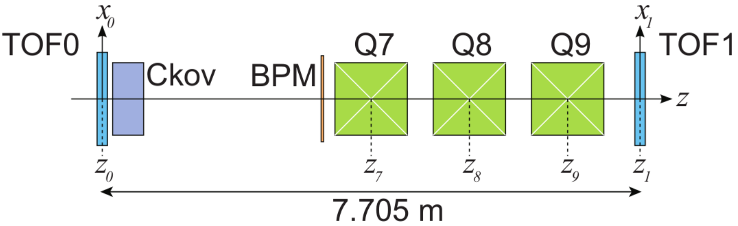
MICE Staging



MICE Step I

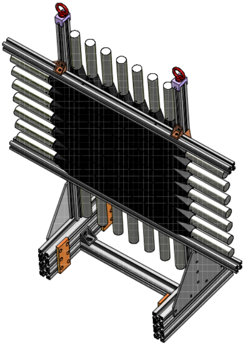


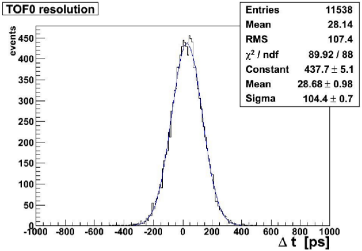
Goals of Step I



- Integrate various time-of-flight (TOF), particle ID systems.
- Large momentum spread $\rightarrow$ no single transfer matrix for MICE. Demonstrate single-particle beam reconstruction method.
- Characterize μ beams for next MICE steps.

Step I Components: TOF



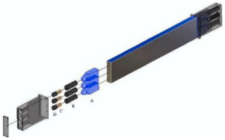


X/Y scintillator hodoscope.

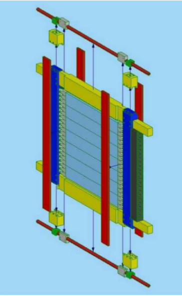
- Required for π rejection efficiency $> 99\%$.
- Determine RF phase to within 5°.

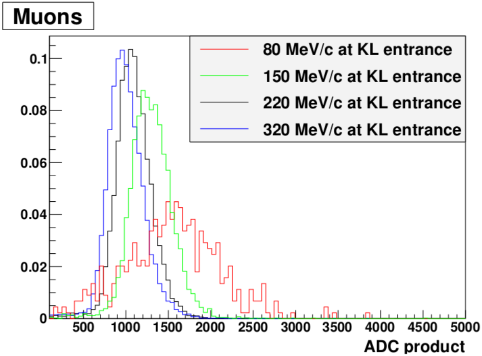
- $\sigma_t^{\mathrm{TOF0}} = 55$ ps
- $\sigma_t^{\mathrm{TOF1}} = 53$ ps
- $\sigma_x \approx 1$ cm

Step I Components: Calorimeter

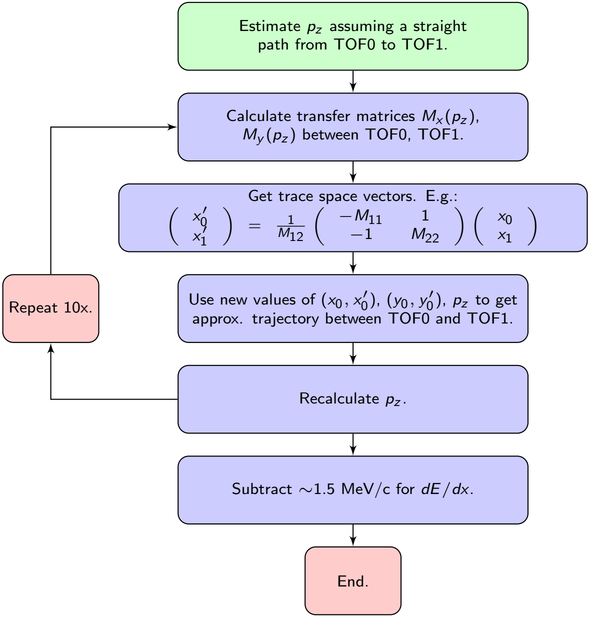


- "KLOE Light (KL)": KLOE-type sampling calorimeter
- 2:1 fiber/Pb ratio
- e^+/e^- tests at INFN-LNF: $\Delta t \approx 70\,\mathrm{ps}/\sqrt{E}$, and $\Delta E/E \approx 7\%/\sqrt{E}$.

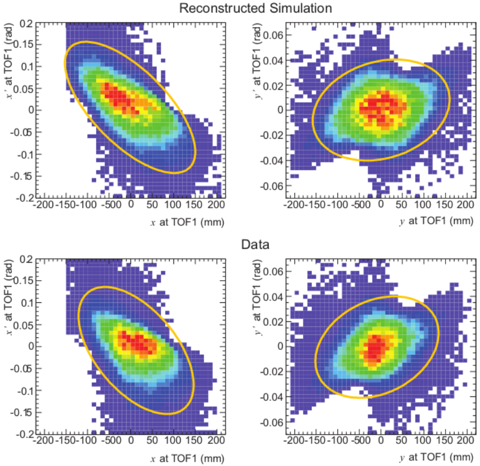




Single-particle tracking

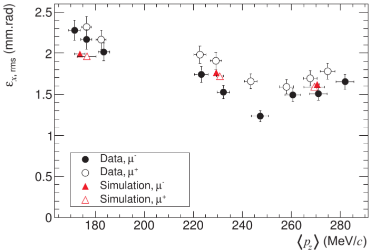


Step I Results: Trace space distributions

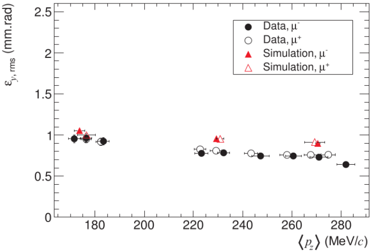


Reconstructed simulation & data for a 200 MeV/c, 6π mm-rad beam. Trace space distributions known to $\sim$5% at entrance to cooling channel.

Step I Results: $\epsilon_{x,y}$ MC vs. Data



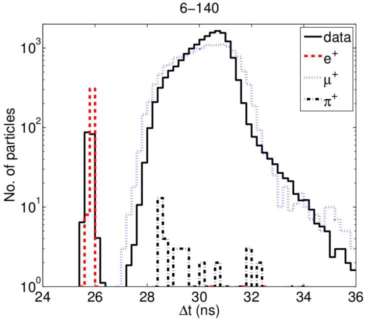
Horizontal Emittance



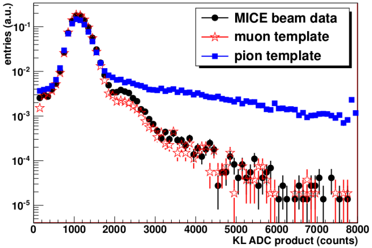
Vertical Emittance

- Error bars include systematic and statistical error.
- Largest contribution to error is effective c in TOF scintillators.

π contamination studies



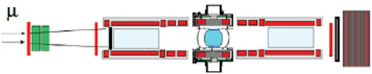
π contamination in 140 MeV/c, 6π mm-rad μ beam.



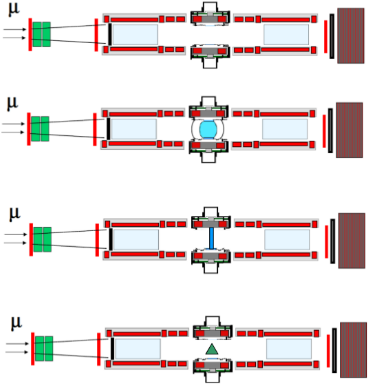
KL response for μ beam vs. calibration beam. Useful for statistical estimate of contamination.

Preliminary results indicate π contamination is $\mathcal{O}(\%)$.

MICE Step IV: Physics Plans

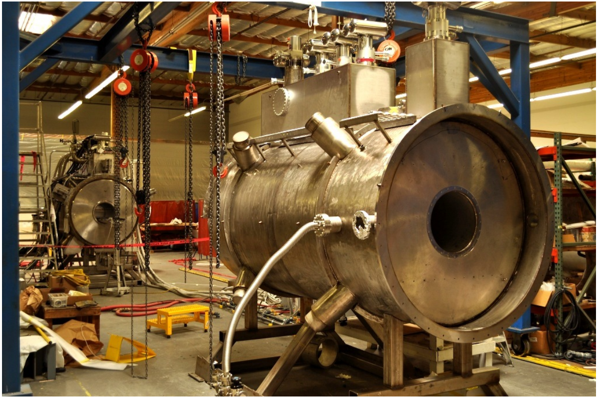


Step IV Physics Goals



1. No absorber: Alignment / optical studies.
2. LH_2 absorber: **Cooling**, scattering studies. Test empty & full.
3. Solid absorbers: LiH, plastic, C, Al, Cu.
4. LiH wedge for emittance exchange studies (6D cooling).

Step IV status: Spectrometer solenoids

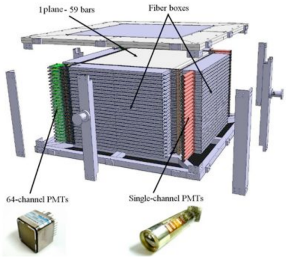


- First solenoid is ready, will be shipped to RAL in September.
- Magnet training, field mapping underway for second solenoid.

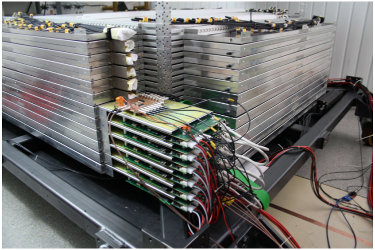
Step IV status: Focus coils

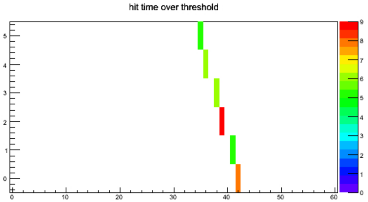
- LH_2, LiH absorbers fabricated. LH_2 system has been tested.
- First coil qualified in solenoid mode. Flip mode qualification is problematic.
- Second focus coil to be delivered this month.

Step IV status: Electron-muon ranger (EMR)



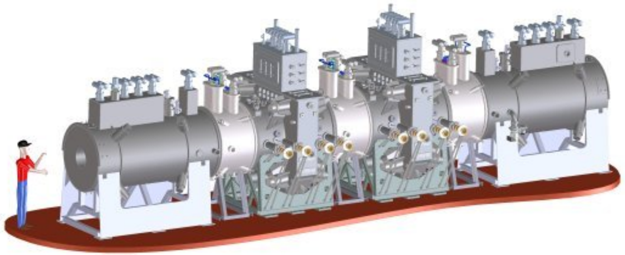
- Prototype already tested in MICE.
- Fabrication nearly complete.
- Delivery in September.
- Comissioning with beam in October.





First cosmic seen with EMR!

Conclusions



- MICE beamline commissioned, 1.3×10^7 triggers collected.
- Particle ID systems (TOF, KL, Ckov) are working well.
- 2013 will be an exciting year for MICE – lots of systems being completed, delivered, qualified!
- Step IV will start taking data in 2015.