MICE BRIEFING

Daniel M. Kaplan

ILLINOIS INSTITUTE OF TECHNOLOGY
Transforming Lives. Inventing the Future. www.iit.edu

MICE

National Science Foundation
Arlington, VA
Jan. 7, 2015

MICE BRIEFING: NSF-supported activities

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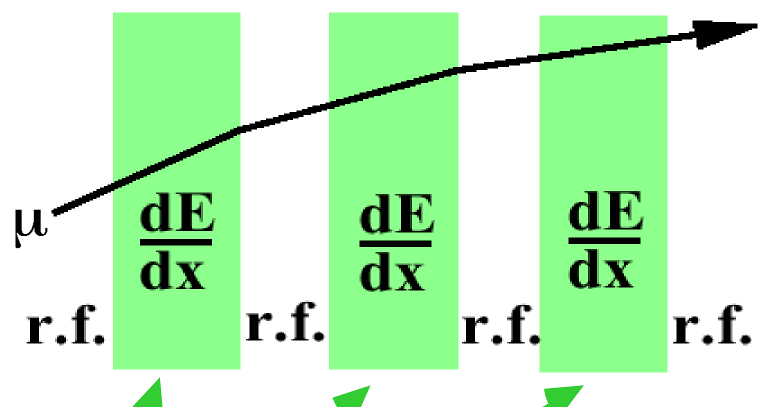
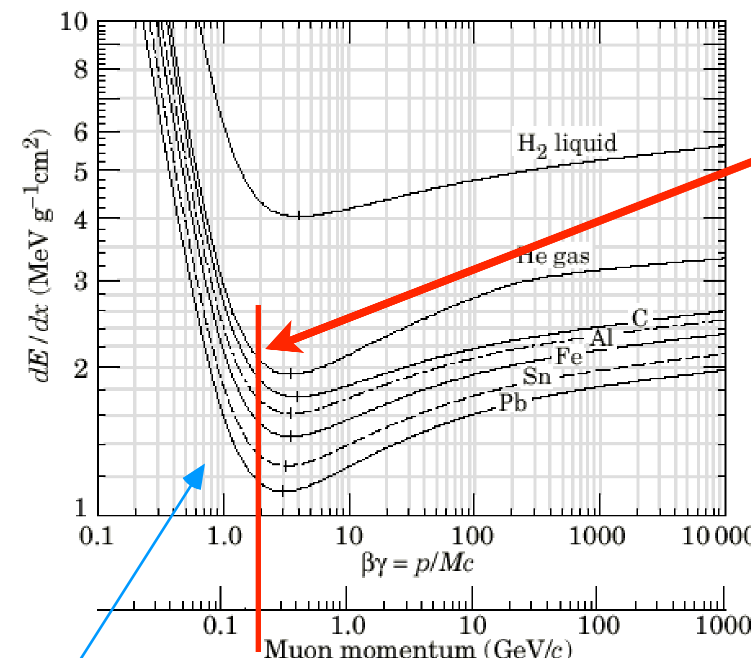
Outline

- Experimental Matters
- NSF-supported Collaborators and Activities
- Conclusions & Questions

Ionization Cooling

- Muons cool via dE/dx in low-Z medium:





- optimal working point is ≈ ionization minimum

  – Absorbers:

$$\begin{cases} E \to E - \left\langle \frac{dE}{dx} \right\rangle \Delta s \\ \theta \to \theta + \theta^{rms}_{space} \end{cases}$$

ionization energy loss

multiple Coulomb scattering

- 2 competing effects
  ⇒ equilibrium emittance:
  $\varepsilon_0 \propto \beta_\perp / \langle dE/ds \rangle \; X_0$

  – RF cavities between absorbers replace ΔE

  – Net effect: reduction in $p_\perp$ at constant $p_\parallel$, i.e., transverse cooling

$$\frac{d\epsilon_N}{ds} \approx -\frac{1}{\beta^2}\left\langle \frac{dE_\mu}{ds} \right\rangle \frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$$

(emittance change per unit length)

- Challenging engineering ⇒ need demonstration

Principle of the Measurement

- E.g., Step IV:

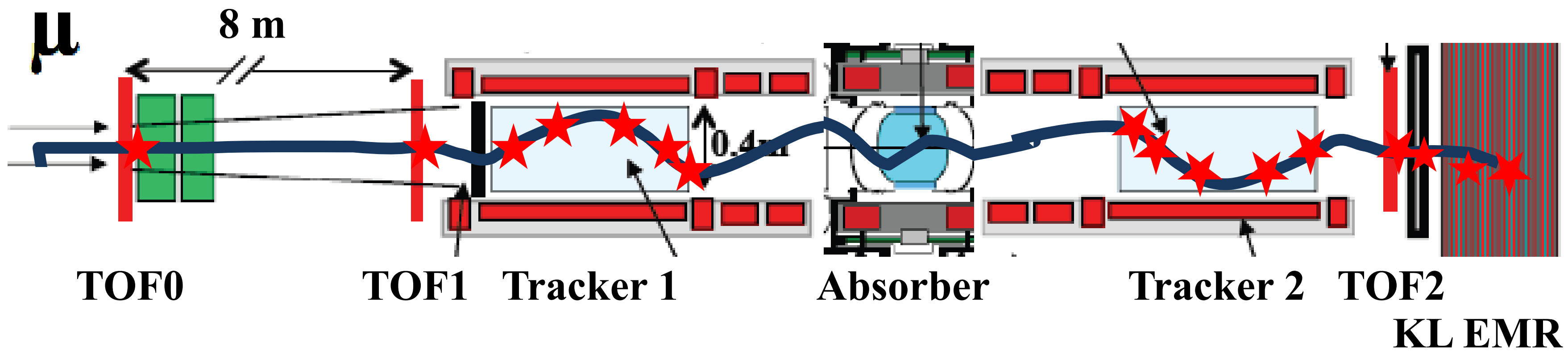
Measure input particle $x, x', y, y', t, t' = E/P_z$

→ input emittance ε^{in}

→ Cooling Section →

Measure output particle $x, x', y, y', t, t' = E/P_z$

→ output emittance ε^{out}



Particle by particle measurement, then accumulate few 10^5 muons

→ $\Delta[(\varepsilon^{in} - \varepsilon^{out})/\varepsilon^{in}] \approx 10^{-3}$

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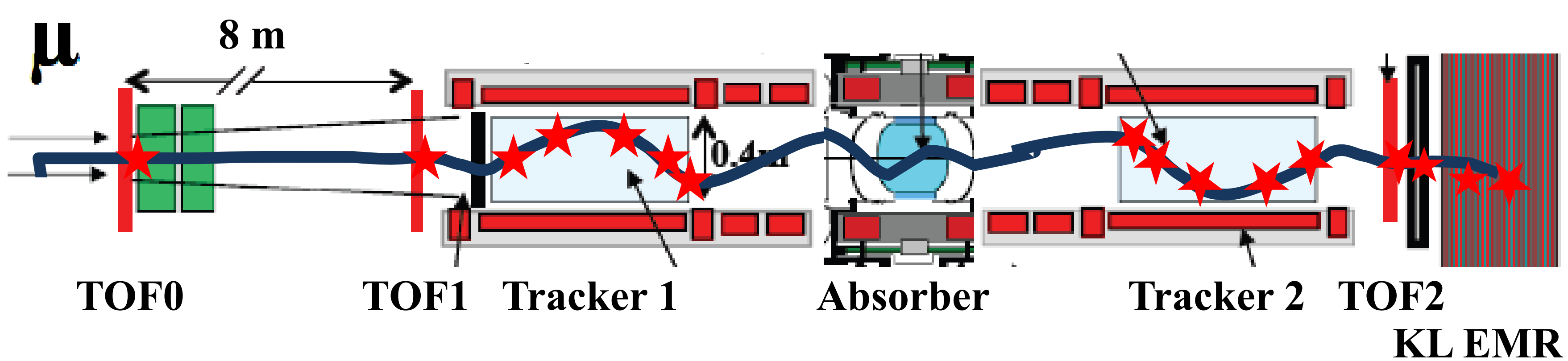

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PID to provide 99.9% muon purity

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Measure input particle x,x',y,y', t, t'=E/Pz
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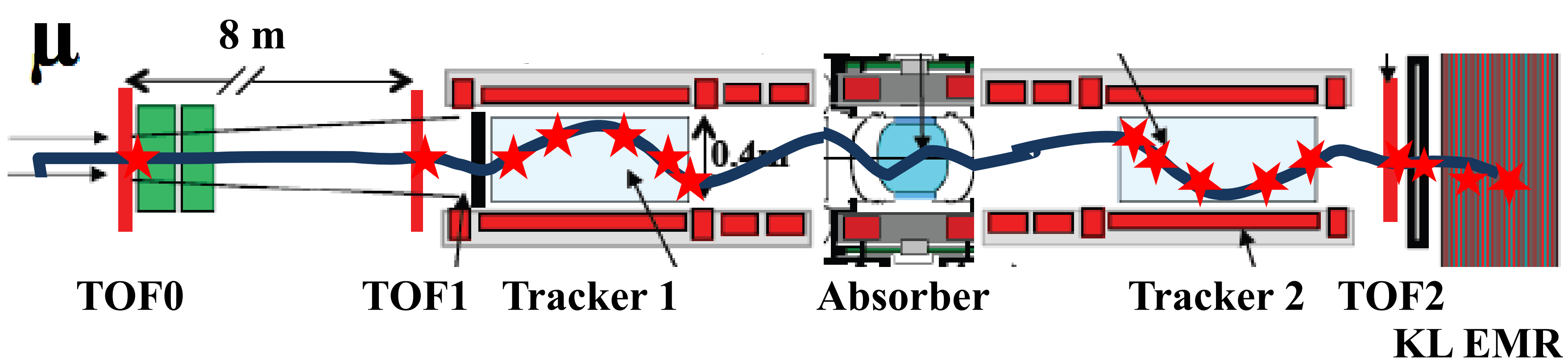


PID to provide 99.9% muon purity

Particle by particle measurement, then accumulate few 10^5 muons
➔ $\Delta[(\varepsilon^{in} - \varepsilon^{out})/\varepsilon^{in}] \approx 10^{-3}$

& detector calibrations to provide $<10^{-3}$ systematics

Detectors

MICE Particle ID

- Need to suppress (to < 10^{-3} level) undecayed π in beam & decay electrons

- Performed using

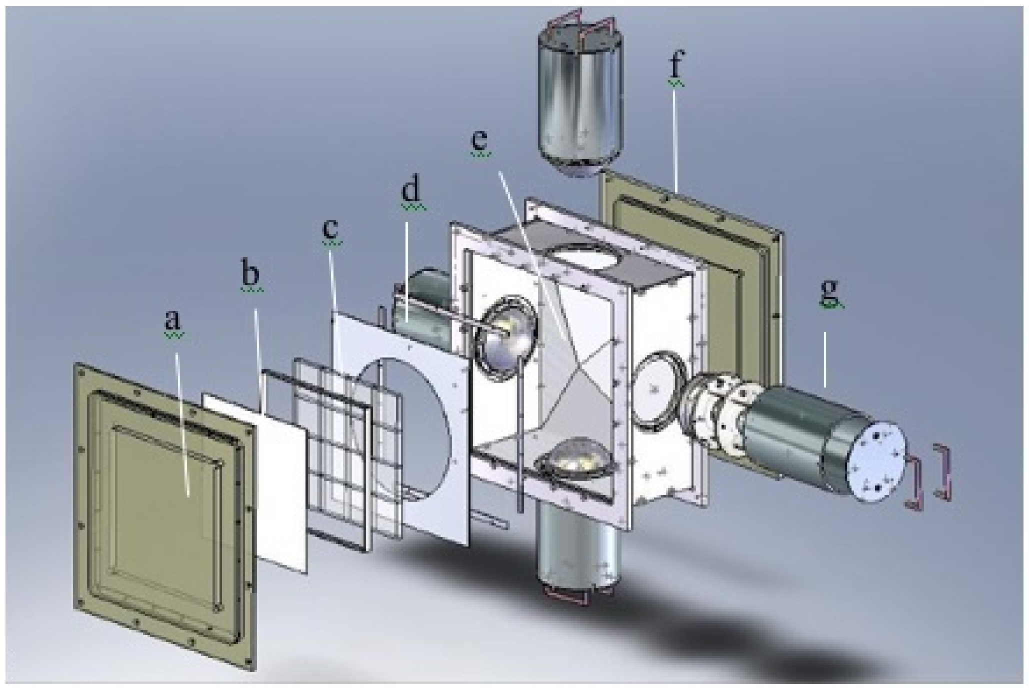
In and working?

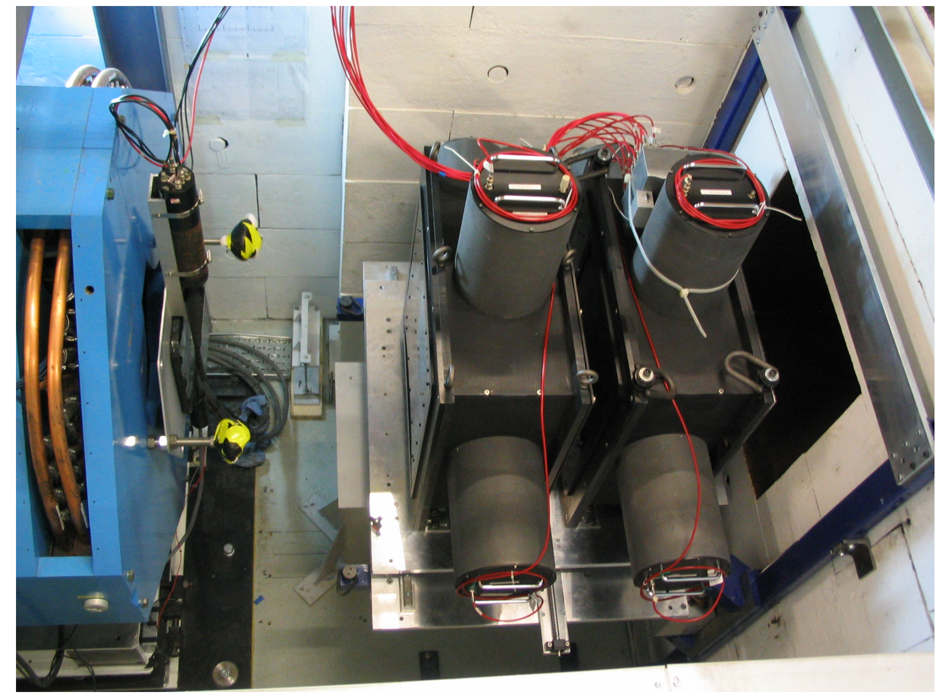
  - 3 sets of TOF counters (Milan/Pavia/Geneva/Sofia) √
  - 2 Cherenkov counters (U Miss/IIT/U Iowa) √
  - KL sampling EM Calorimeter (Roma III), and √
  - Electron-Muon Ranger (Geneva/FNAL/Trieste/Como) √

Cherenkov Counters

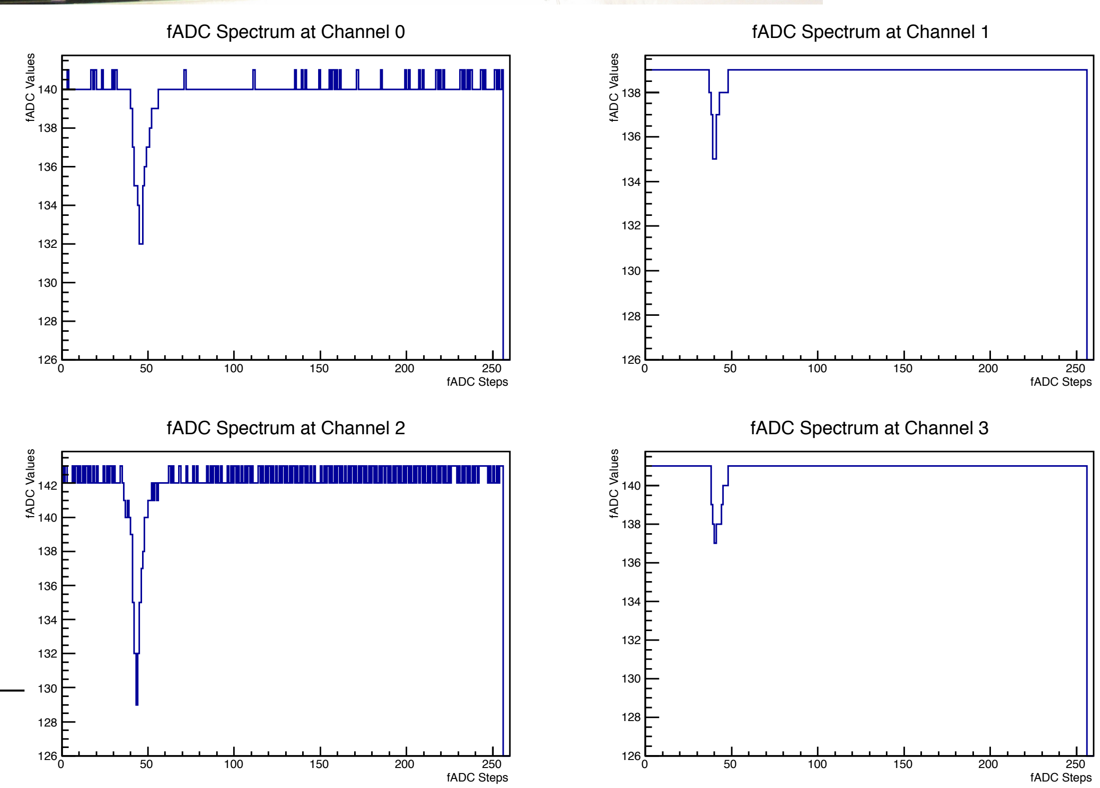
[U Miss, IIT, U Iowa]

- 2 Cherenkov counters with high-*n* aerogel radiators:





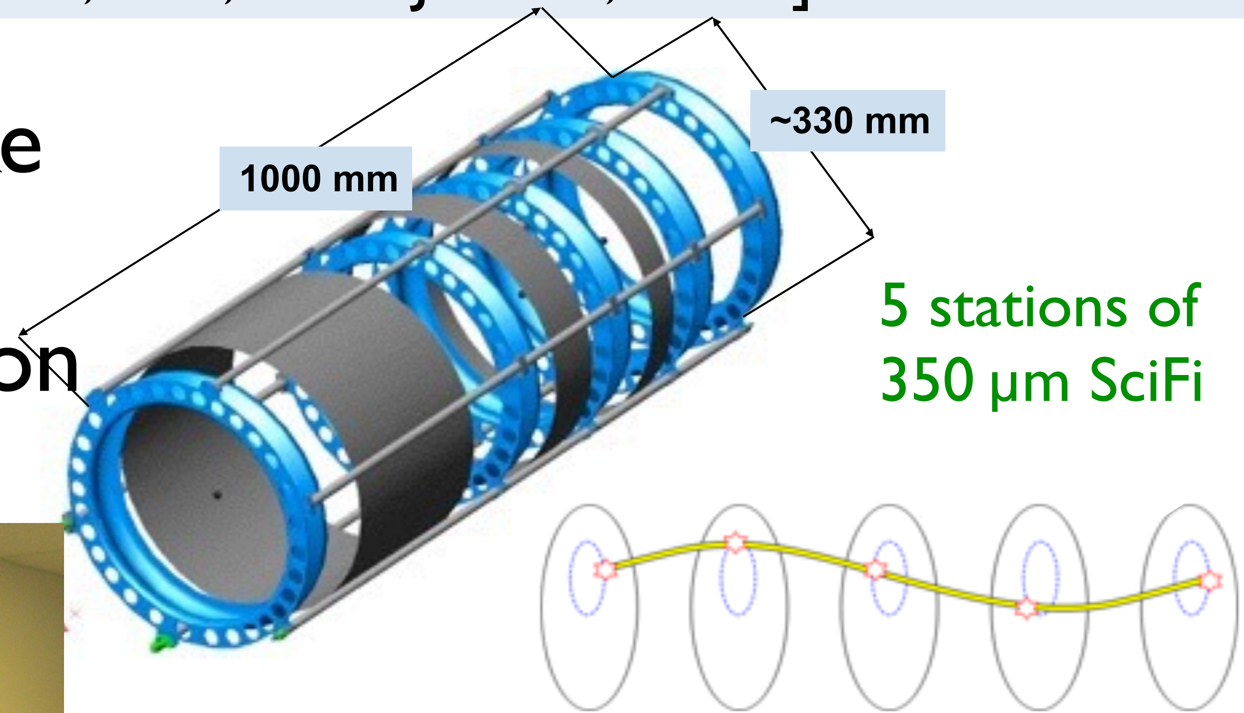
- Located in DSA, downstream of Q9 & TOF0
- 1 GS/s FADC readout
- MAUS reconstruction software done; MC in progress



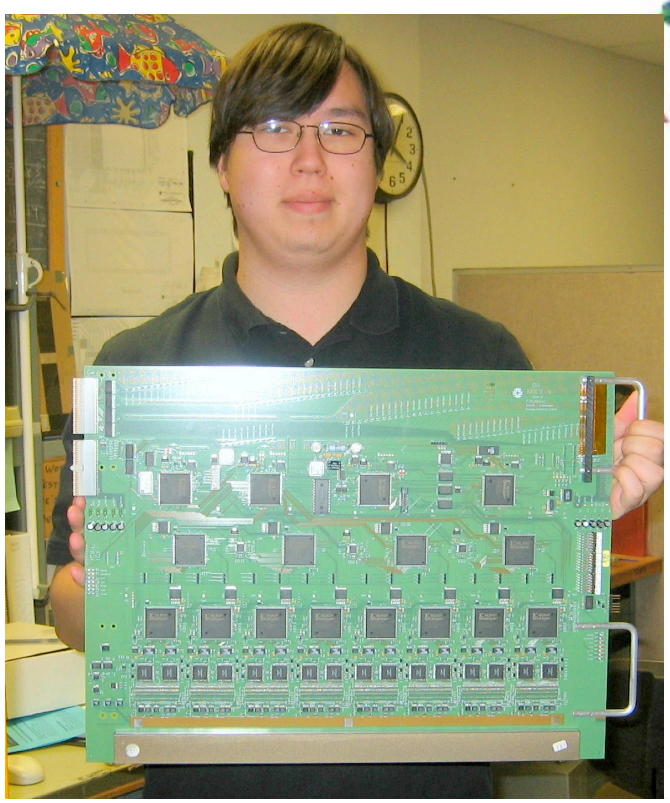
SciFi Spectrometers

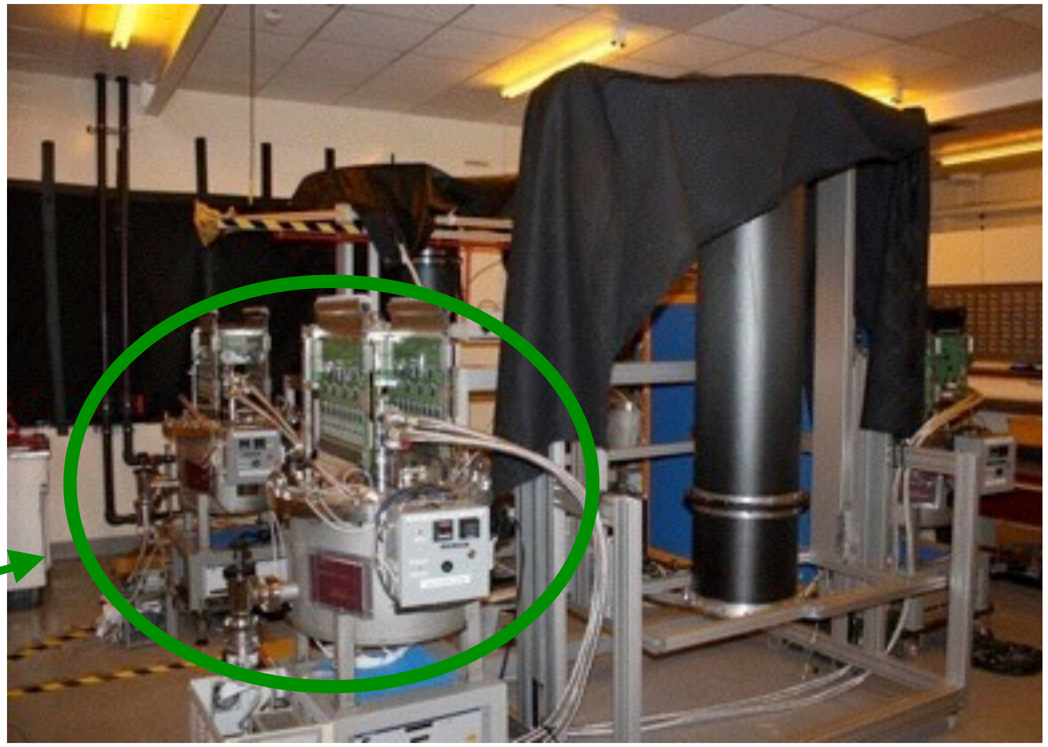
[US: FNAL, IIT, UCLA, UCR / UK: ICL, BrU, ULiv, RAL / JP: KEK, Osaka]

- The SciFi trackers in 4 T field make the precise track measurements needed for 10^{-3} emittance precision
- Tracker DAQ a complex system
  - its maintenance a US responsibility
  - calibrations, cryogenics, μcode mods as needed…



5 stations of 350 μm SciFi





Cryogenic VLPC readout (from DØ)

Cosmic test setup

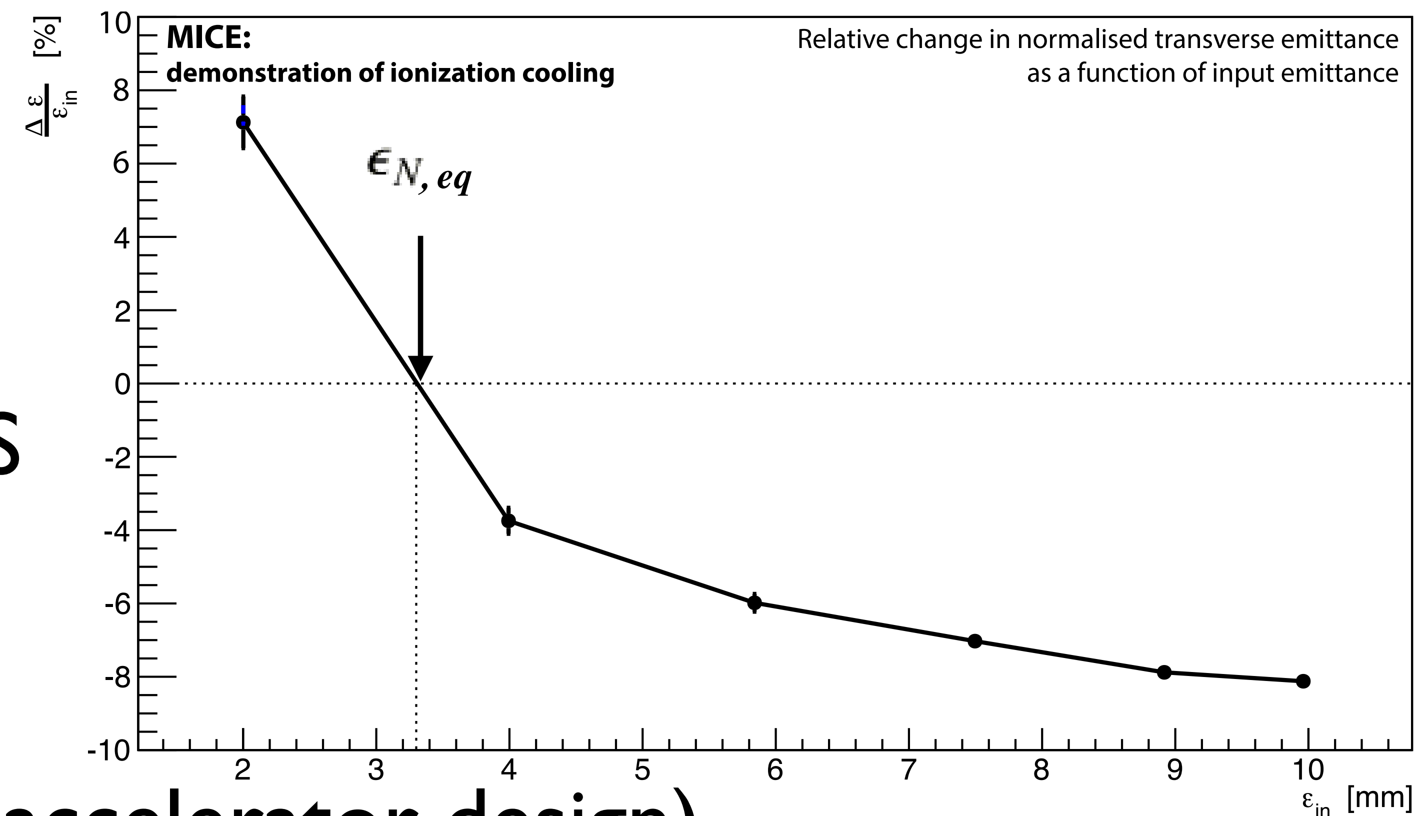
M. Ellis et al., “The design, construction and performance of the MICE scintillating fibre trackers,” NIM A **659** (2010) 136

Measurements & Datasets

Needed Measurements

- Key is cooling "equation": $\frac{d\epsilon_N}{ds} \approx -\frac{1}{\beta^2}\left\langle\frac{dE_\mu}{ds}\right\rangle\frac{\epsilon_N}{E_\mu} + \frac{\beta_\perp (0.014\ \mathrm{GeV})^2}{2\beta^3 E_\mu m_\mu X_0}$
  - cooling rate depends on E_μ, $\beta_\perp$, absorber material, and details of *dE*/*dx* and MCS

  $\Rightarrow$ (inter alia) ∃ equilibrium emittance $\epsilon_{\perp,eq}$ reflecting *interplay* of *dE*/*dx* and MCS



    - note that large muon emittance ⇒ *very* non-"paraxial" beam (novel in accelerator design)

  - all these features are measurable

  & *need* to be measured in order to complete validation of models

MICE Datasets: Step IV

- Goal: demonstrate in detail that energy loss, multiple scattering, and non-paraxial, nonlinear, beam optics behave as expected (match simulations)

$\Longrightarrow$ vary p, absorber material, μ polarity, input emittance, and optics focal length $\beta_\perp$

- 3 nominal momenta: p = 140, 200, 240 MeV/c
- 3 (or 4) absorbers: empty, LH_2, LiH, (possibly) plastic disk or wedge
- 3 nominal emittance settings: 3, 6, 10 mm·rad
- 10 optics settings: {flip, solenoid} × 5 $\beta_\perp$ values
- 2 polarities: $\mu^\pm$
  - need 10^5 "good" muons per setting ⇒ 2(20) hr/setting for μ^+(μ^-)

- Note $3^3 \times 2^2 \times 5 > 500$ potential run settings!

⇒ will have to take an intelligent subset! (+ setup time + calibration runs…)

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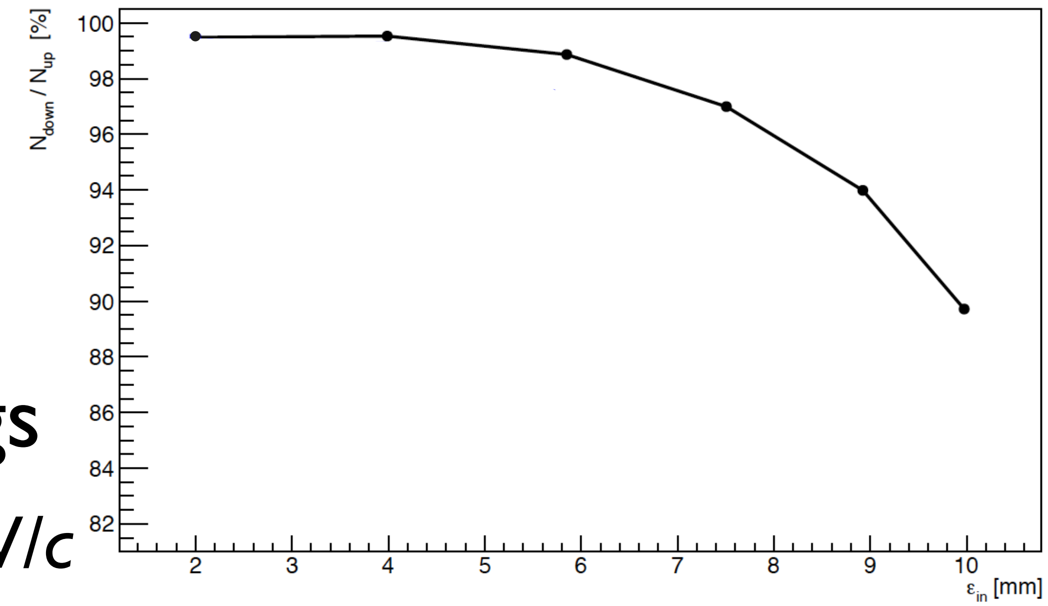

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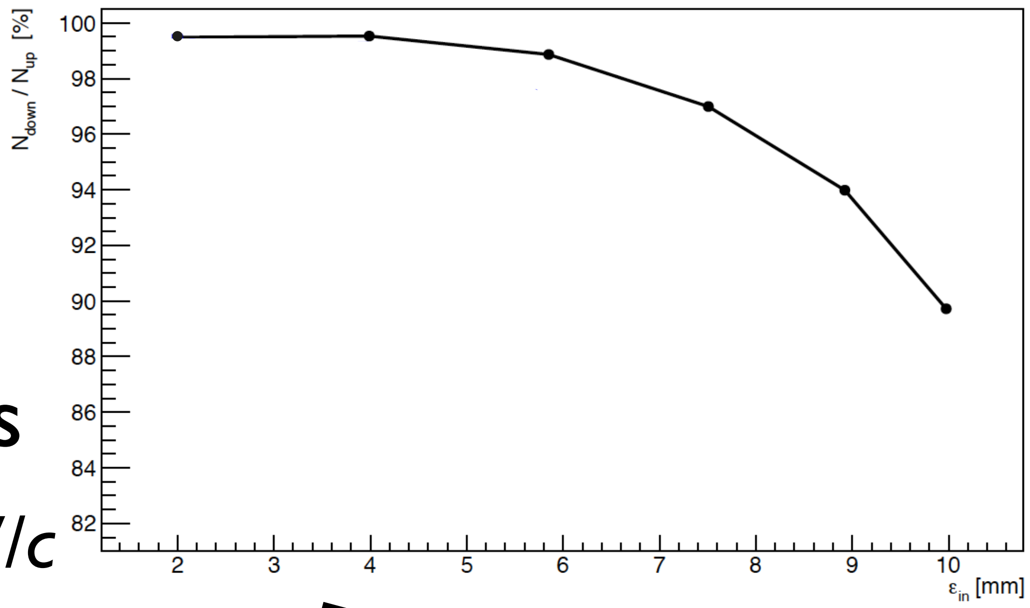

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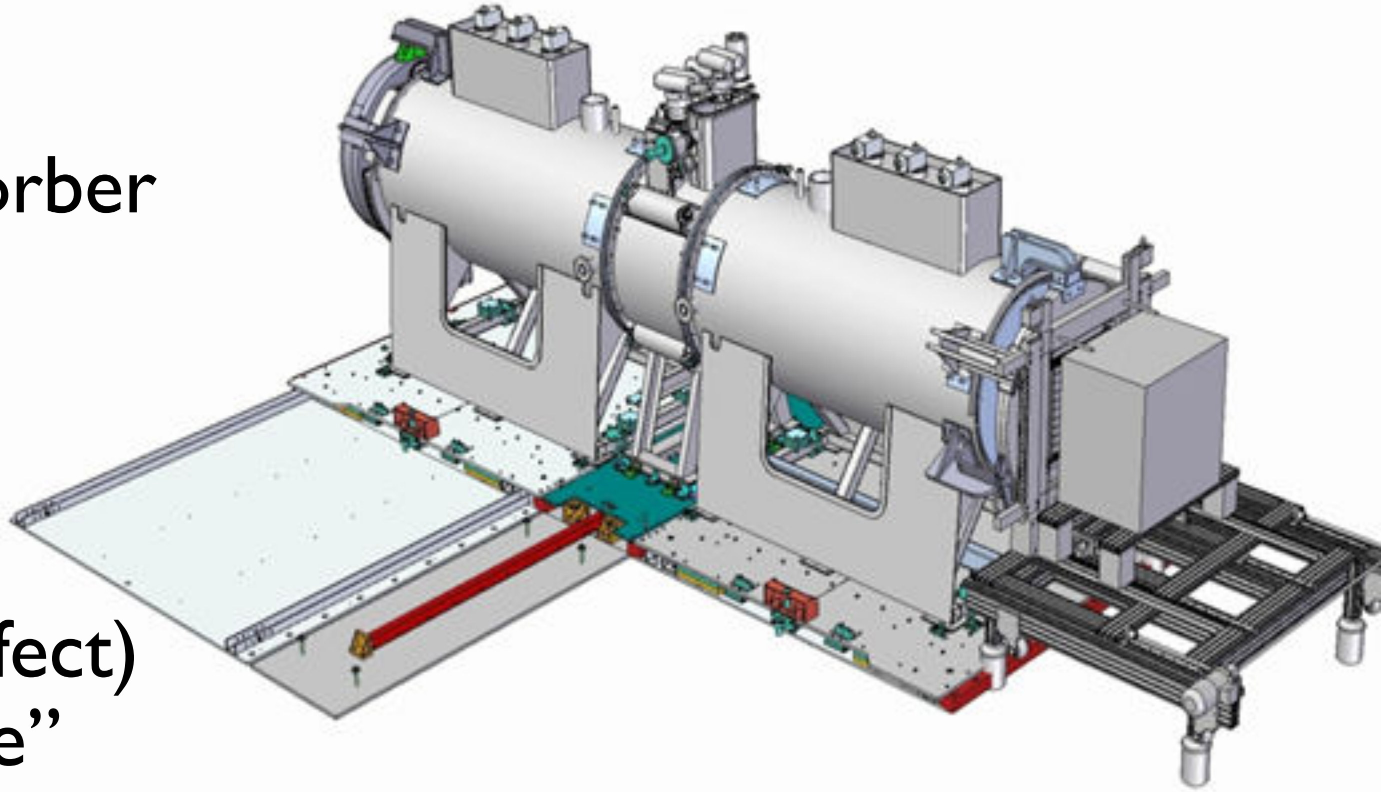
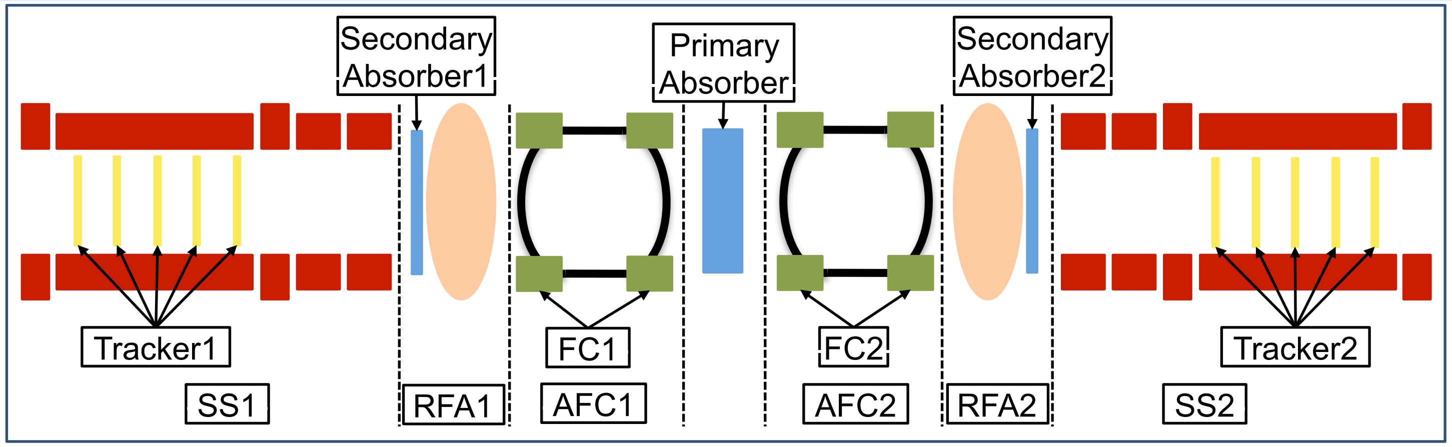
MICE Step IV

- Deliverables:
  - establish safe and routine LH_2 absorber operation
  - engineering test of beamline made of several magnetically coupled components
  - understand propagation of (imperfect) beam through the "magnetic bottle"
  - calibration of emittance measurement to 10^{-3}
  - measurement of emittance change (normalized-emittance cooling)
  - precision validation of simulation codes and physics models
  - precision measurements of correlated multiple scattering and energy-loss straggling



- And desirable, if possible:
  - first test of emittance exchange (wedge absorbers, time permitting)

MICE Ionization Cooling Demo



- Deliverables:
  - routine and safe operation of RF in *B* field
  - significant and measurable longitudinal heating
  - precise measurement of equilibrium emittance of various optical and absorber configurations
  - detailed and precise verification of simulation codes
  - benchmark for many future cooling-channel options
- And desirable, if possible:
  - cooling cell allowing multiple optics configurations: flip, non-flip, etc…
  - exact replenishment of energy (possible only with supplementary funding for extended running & more RF power)

NSF-supported collaborators and activities

History of NSF MICE Support

		Amt	Duration
2000.	IIT NSF funding (via Cornell subcontract)	150k	3y
	• T. Roberts invents G4beamline to simulate MICE beam		
2005.	MICE consortium grant (IIT/UCR/UMiss)	300k	3y
2005.	MRI grant (IIT)	750k	3y
	• SS conductor & cryocoolers, SciFi planes & readout, Ckovs		
2007.	MICE grant (UCR)	436k	3y
2008.	MICE consortium grant (IIT/UCR/UMiss)	252k	3y
2010.	MICE collab'tive grant (UCR/IIT/Iowa/UMiss/UNH)	1,051k	3y
	• important contribs to Tracker, PID, online, C&M, operations		
2010.	MRI grant (UMiss)	1,632k	3y
	• MICE RF equipment		
2013.	MICE collaborative grant (UCR/IIT), terminal	230k	1y
	total ≈	4,800k	

Future MAP–NSF balance

- During 3-year ramp-down, MAP will continue to support MICE participation by those scientists crucial to apparatus installation & commissioning

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  - these include:
    - P. Hanlet, IIT: MICE Integration Physicist/C&M head
    - D. Rajaram, IIT: MICE Software head
    - Y. Torun, IIT: MTA Lead Scientist

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    - which are ongoing US responsibilities to int'l MICE Collaboration

Proposed NSF University Support

(guidance sought on this…)

- IIT
  - PI summer salary (2 mo)
  - postdoc
  - grad student
  - travel & incidentals
- U Mississippi
  - PI & Co-PI summer salary (1 mo ea)
  - staff scientist (1 mo)
  - postdoc
  - part-time undergrads
  - travel & incidentals
- U Iowa
  - PI summer salary (2 mo)
  - adjunct fac. summer salaries (2 mo)
  - grad student & part-time undergrads
  - travel & incidentals
- NYIT (new)
  - PI summer salary (2 mo)
  - postdoc
  - travel & incidentals

Proposed NSF University Support

(guidance sought on this…)

- IIT
  - D. Kaplan, PI (2 mo)
  - P. Snopok, Fac. Assoc.
  - Y. Torun, Fac. Assoc.
  - P. Hanlet, Rsch. Faculty
    - MICE Integration Physicist/C&M head
  - D. Rajaram, Rsch. Faculty
    - MICE Software head
  - postdoc
  - grad & undergrad students
- U Iowa
  - J. Nachtman, PI (2 mo)
  - Y. Onel, Fac. Assoc.
  - U. Akgun (Coe Coll.), Adjunct (1 mo)
  - R. Rahmat (Mid-America Chr. U), Adjunct (1 mo)
  - grad & undergrad students
- U Mississippi
  - D. Summers, PI (1 mo)
  - L. Cremaldi, Co-PI (1 mo)
  - D. Sanders, Rsch. Faculty (1 mo)
  - postdoc
  - undergrads
- NYIT (new)
  - D. Adey PI (2 mo)
  - postdoc

* desired NSF salary support

Proposed NSF-MICE Activities

- IIT
  - Tracker calibration & support
  - Software development
  - Operations & analysis
- U Mississippi
  - Particle ID calibration & support
  - Absorber windows
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2. **To succeed, MICE requires full intellectual engagement (not just equipment) from *all* collaborating regions—not least the U.S.**

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☛ **NSF university personnel can play a crucial role, leading key analysis efforts**

Budget Estimate

- Broad-brush-estimate (since each univ. slightly different), fully loaded:

postdoc	90 k
GRA	50 k
2 fac. summer mo.	20 k
travel+incidentals	50 k
Total/institute:	≈ 200 k

$\Rightarrow$ 4-university consortium ≈ 700k/yr

Conclusions

- MICE is substantial international effort to achieve:
  1. a thorough demonstration that ionization cooling is well understood and works as expected
  2. calibration and validation of Monte Carlo models used to design and characterize ionization cooling channels
  3. a major step on the way to Neutrino Factories and Muon Colliders!
- Major equipment built with DOE + NSF MRI funds
- To succeed, need sufficient US personnel for experimental support, data-taking, and analysis
  - Great training ground for young HEP & accelerator physicists
  - Great opportunity for NSF-supported university groups

Questions

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  - U Miss requests minimal (1 mo.) partial Staff Sci. support

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➡ We solicit your guidance on how to proceed…