The performance of the MICE muon beam line

A preliminary look at the Step 1 data

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NuFact10, 21 October 2010
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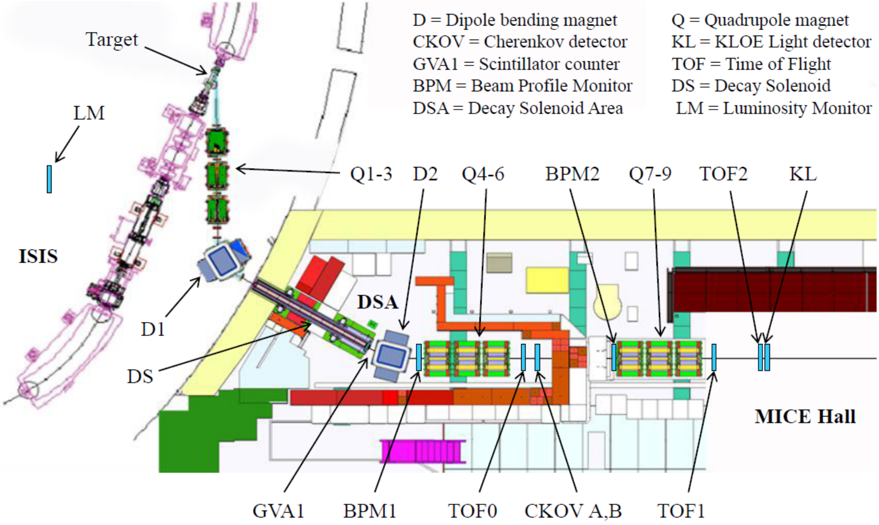
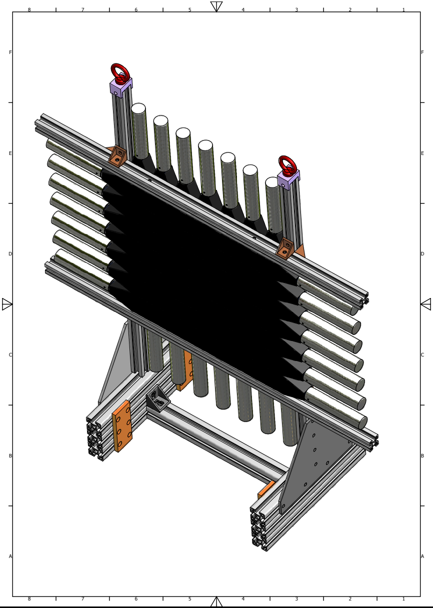
The MICE beam line



The time of flight detectors



Timing resolution of a station

After a time walk correction,

$$t_{\text{PMT}} \sim \text{N}(0, 100 \text{ ps})$$

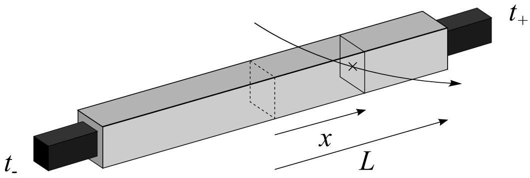
$$t = \frac{t_{\text{Top}} + t_{\text{Bottom}} + t_{\text{East}} + t_{\text{West}}}{4}$$

$$\sigma_t = \frac{\sigma_{\text{PMT}}}{2} \approx 50 \text{ ps}$$

Particle identification

Time of flight between TOF0 and TOF1 may then be measured with resolution 71 ps

Time difference position measurement



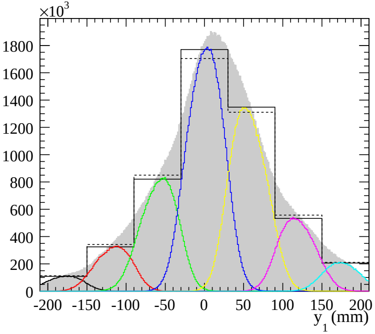
Position resolution of a slab

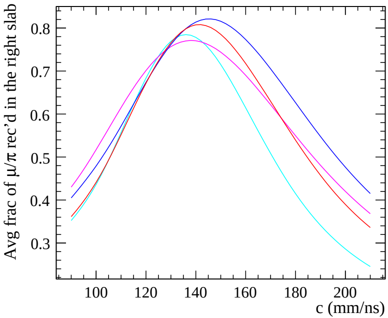
$$x = \frac{-c_{\text{eff}}(t_+ - t_-)}{2}$$

$$\sigma_x = \frac{c_{\text{eff}}\sigma_{\text{PMT}}}{\sqrt{2}}$$

Time difference position measurement

The effective propogation speed of light signals in the slabs may be measured by comparing $(t_+ - t_-)$ with the knowledge of which perpendicular slab was lit.

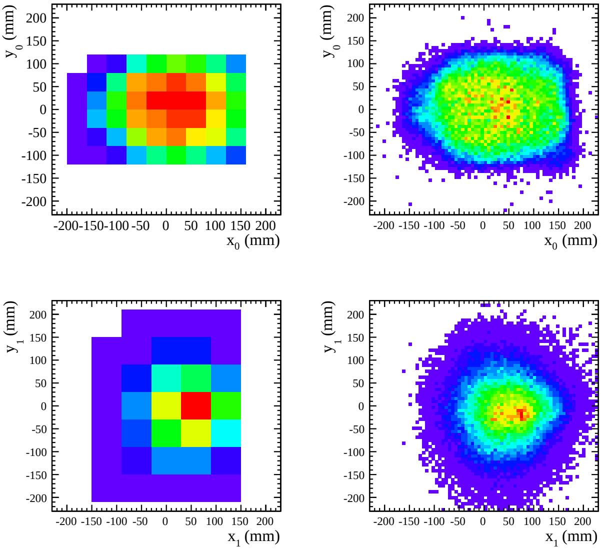




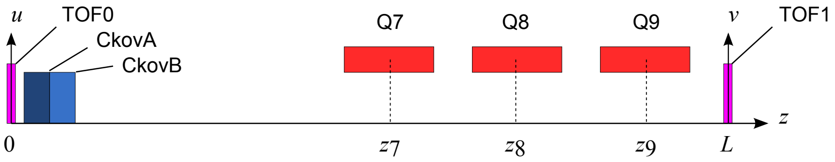
$c_{\text{eff}} = 140.5$ mm/ns

$$\sigma_x = \frac{c_{\text{eff}}\sigma_{\text{PMT}}}{\sqrt{2}} \approx 1.0 \text{ cm}$$

Illumination of the TOF detectors



Reconstruction technique

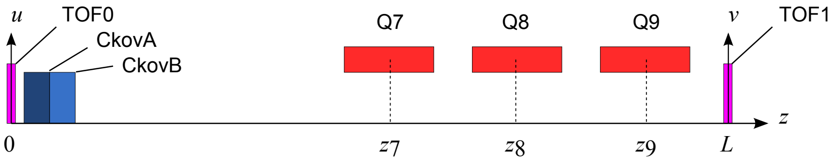


A transfer matrix $\mathbf{M}(p_z)$ maps trace space from TOF0 to TOF1

$$\begin{pmatrix} v \\ v' \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} u \\ u' \end{pmatrix}$$

where, $\det \mathbf{M} \equiv 1$.

Reconstruction technique



A transfer matrix $\mathbf{M}(p_z)$ maps trace space from TOF0 to TOF1

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where, $\det \mathbf{M} \equiv 1$.

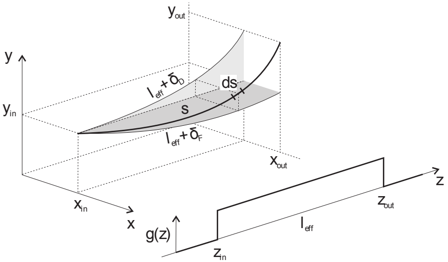
The angles may be deduced from the positions

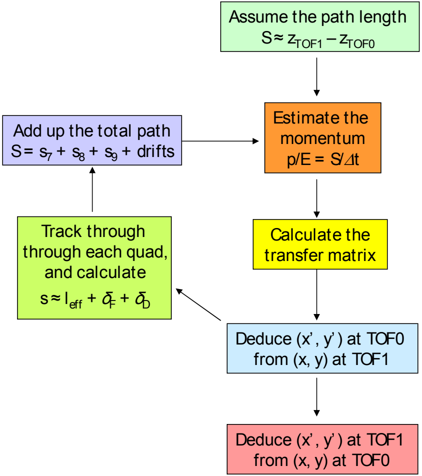
$$\begin{pmatrix} u' \\ v' \end{pmatrix} = \frac{1}{M_{12}} \begin{pmatrix} -M_{11} & 1 \\ -1 & M_{22} \end{pmatrix} \begin{pmatrix} u \\ v \end{pmatrix}$$

Phase space reconstruction technique

An iterative method is used to remove path length bias

Particles are tracked using a thick edge quadrupole model



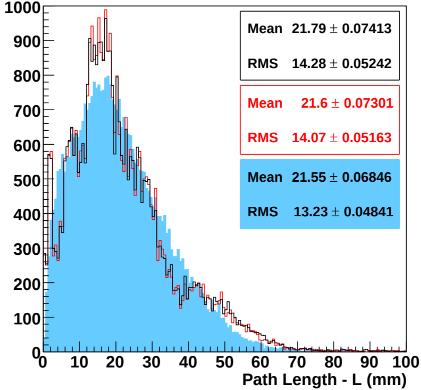


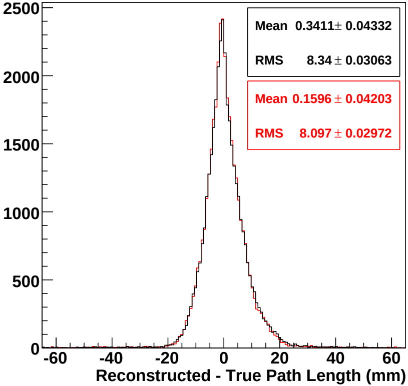
(i) Estimate the true path length by tracking

- True path length $-L$

Reconstructed path length $-L$

Assuming perfect timing





Bias

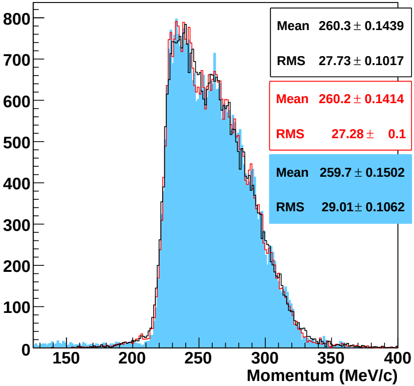
$$\frac{\Delta p}{p} = \frac{E^2}{m_0^2}\left(\frac{\Delta s}{s} - \frac{\Delta t}{t}\right)$$

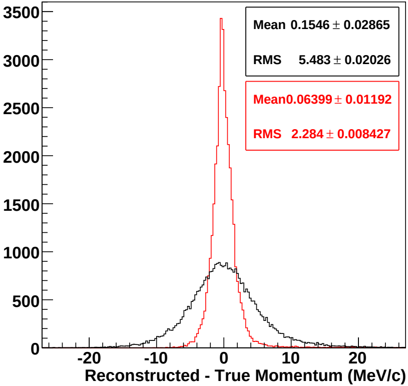
(ii) Use the path length estimate to measure p_z

True p_z

Reconstructed p_z

Assuming perfect timing



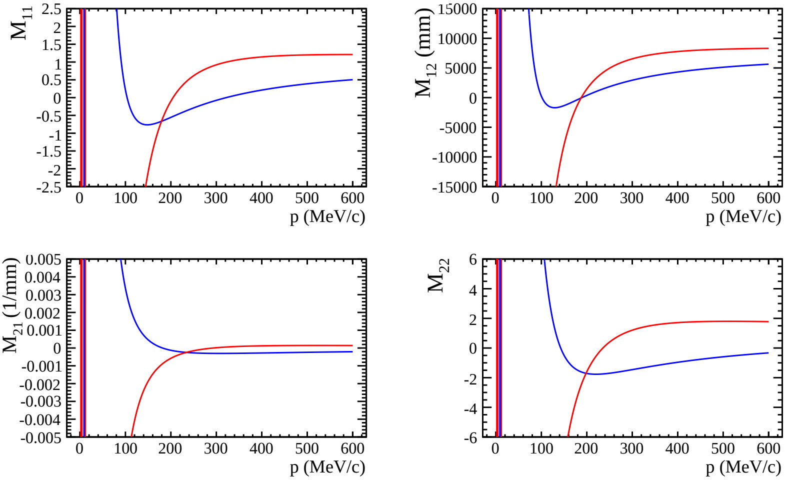


Error

$$\frac{\sigma_p}{p} = \frac{E^2}{m_0^2}\sqrt{\left(\frac{\sigma_t}{t}\right)^2 + \left(\frac{\sigma_s}{s}\right)^2}$$

The transfer matrix M is a function of p_z

The **horizontal** and **vertical** trace space transfer matrices

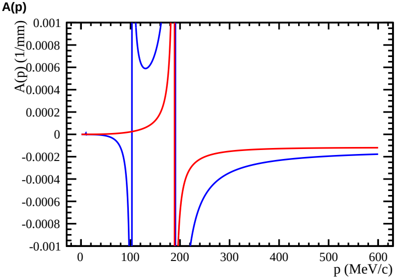


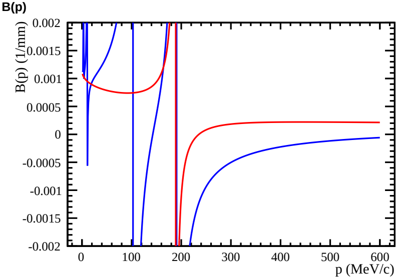
(central μ^- "M0" optics)

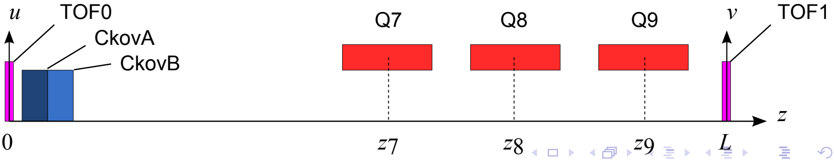
At certain p, v' depends strongly on p

When $u \approx v$ it is difficult to reconstruct the angle v'

$$v' = A(p)u + B(p)v$$

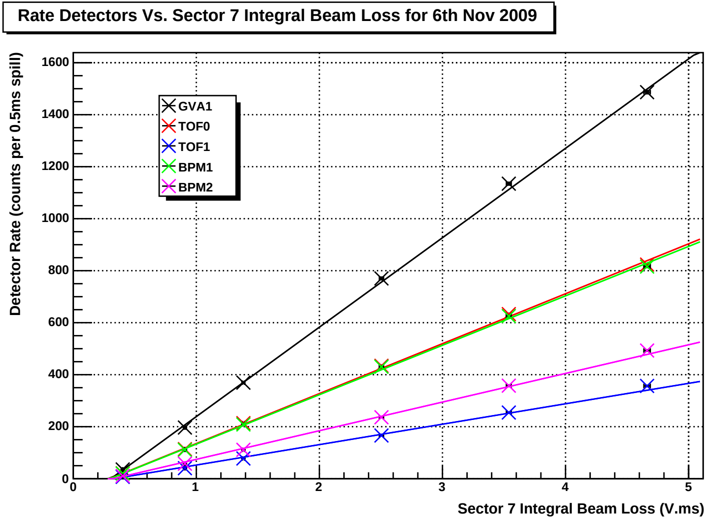






Particle rate

Particle rate increases linearly with beam loss (<4.7 V ms)



Particle rate

$\pi^- \rightarrow \mu^-$ optics at 2 V ms beam loss, 3.2 ms gate (15th June 2010)

- TOF1 hits: 26.0 hits
- TOF0–TOF1 tracks: 11.0 hits

$\pi^+ \rightarrow \mu^+$ optics at 2 V ms beam loss, 1 ms gate (16th June 2010)

- TOF1 hits: 56.5
- TOF0–TOF1 tracks: 30.5

Note: Rate across the spill gate is not linear; beware extrapolating

Inefficiencies

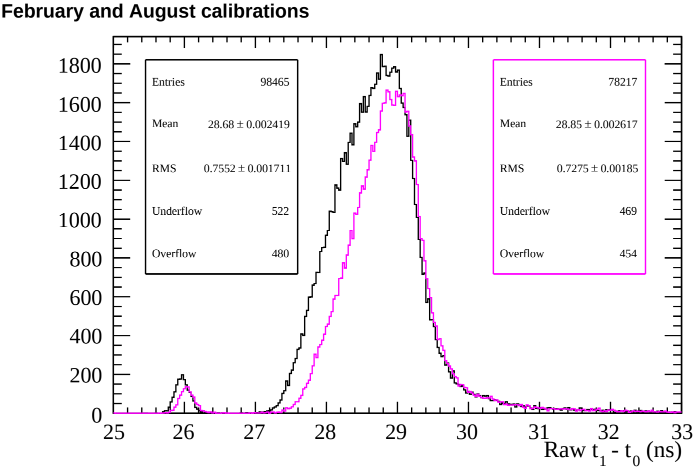
Reconstruction method, the presence of neutral particles, and a $1.28\ \mu s$ dead time

Numbers and plot: A. Dobbs, Imperial

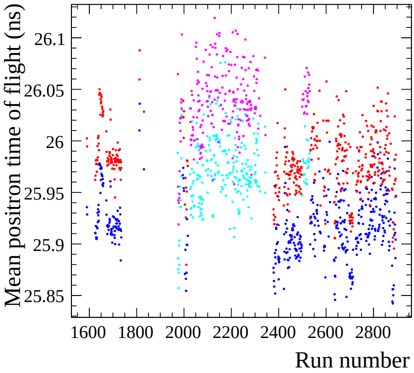
Time of flight for a $\pi^- \rightarrow \mu^-$ decay beam line

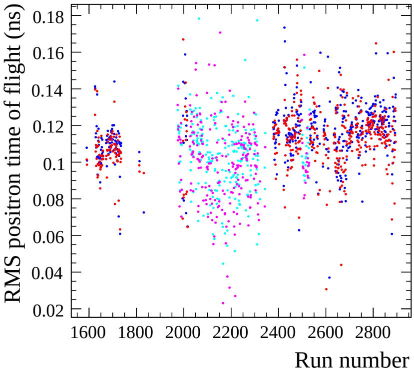
Time of flight using

- the **February calibration**, and
- the **August calibration**



Stability of the calibration

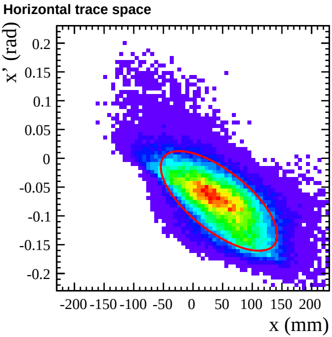


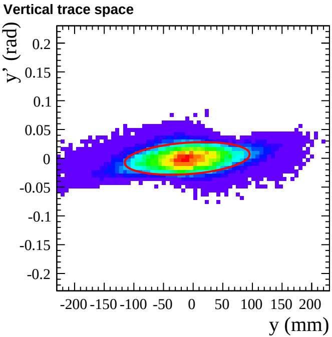


Legend

February calibration: **electrons** **positrons**
August calibration: **electrons** **positrons**

The analysis of trace space



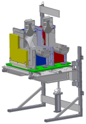


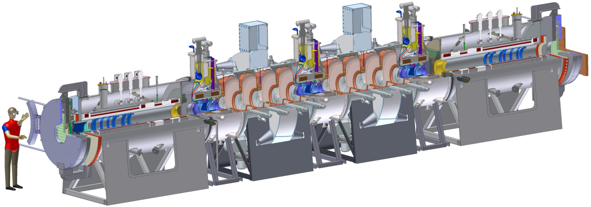
Work in progress

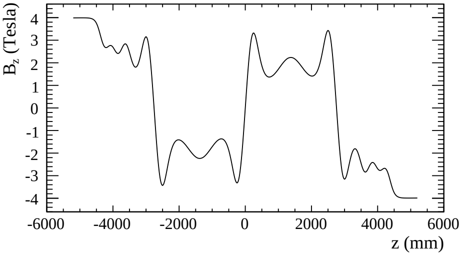
- Understanding the stability of the calibration
- Tuning Geant4 simulations to match and understand the data
- Removing bias on optical functions due to detector resolution

The agreement with Monte Carlo looks promising

How will the measured beam perform?





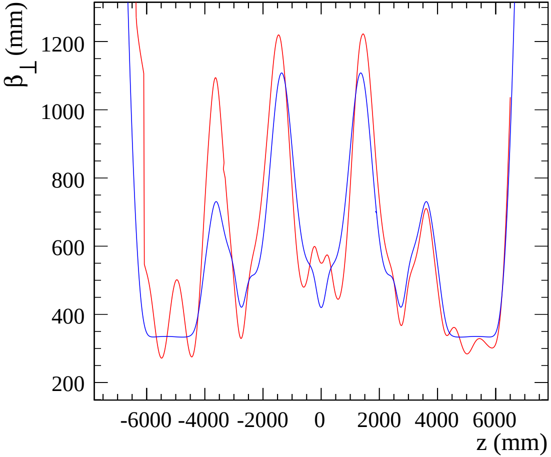


Evolution of the beam envelope preliminary

Matched beam, $\kappa = qB_z/(2p_z)$

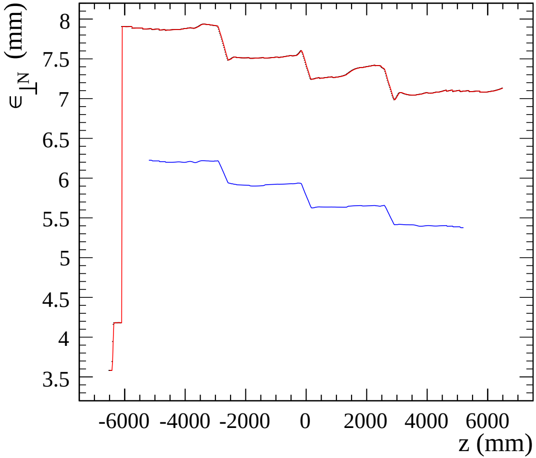
$$2\beta\beta'' - (\beta')^2 + 4\beta^2\kappa^2 - 4 = 0$$

A Geant4 simulation of evolution of the **measured beam**



Evolution of normalized 4D beam emittance preliminary

- Non-linear emittance growth is negligible
- A thinner Pb diffuser could generate a the required emittance



Conclusion

1. A highly successful data taking campaign took place in late 2009/early 2010
2. Timing detectors have been calibrated to a resolution approaching 50 ps, and confirm the generation of beams dominated by muons at the required momenta
3. The trace space of individual muons has been reconstructed and promising agreement is observed with Geant4 simulations
4. The trace space measurement has been used to simulate the progess of a real beam through the final Step 6 cooling channel; the beam is relatively well matched, and tuning magnet currents and diffuser thickness should be sufficient to generate a well matched beam