Progress in the construction of the MICE cooling channel and first measurements

Adam Dobbs, EPS-HEP, 23rd July 2011

Outline

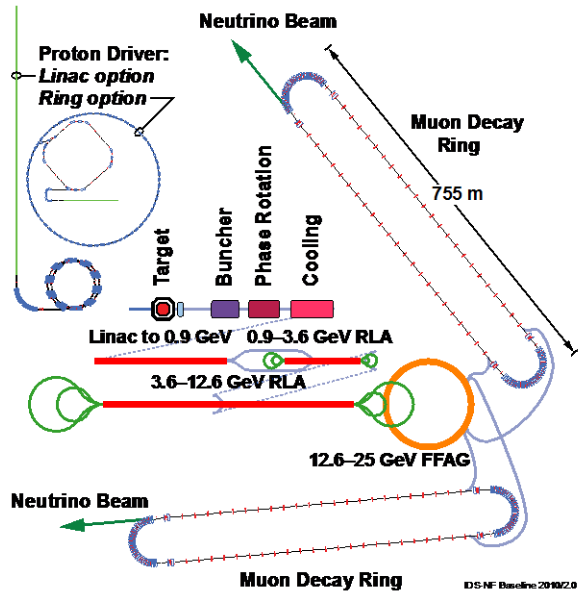
I. Motivation: Neutrino Factory and Muon Collider
II. Ionisation Cooling
III. The MICE Experiment
IV. The Beamline – rate and emittance measurements
V. Cooling channel status
VI. Conclusion

Motivation

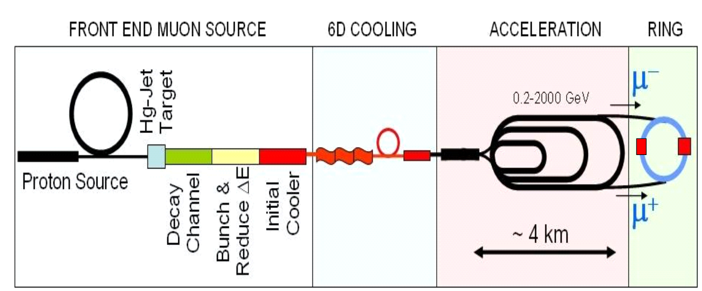
- Neutrino Factory: Best coverage of the oscillation parameter space of any proposed next generation oscillation experiment.
- Muon Collider: route to multi – TeV lepton – anti-lepton collisions.
- Both types of muon accelerator with technology synergies:
  - Intense proton driver
  - Complex target
  - Muons from pion decay → Large initial emittance

→ **Muon Cooling**

Neutrino Factory



Muon Collider



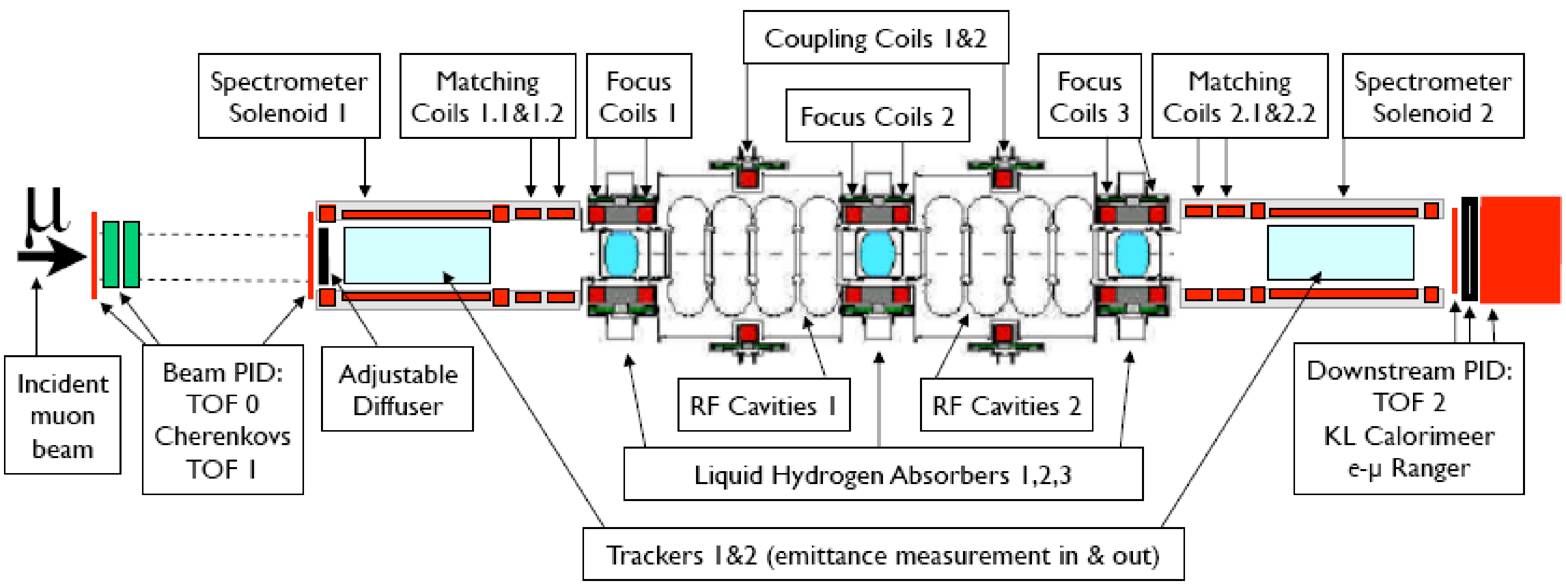
Muon Ionisation Cooling

- Traditional beam cooling techniques are too slow due to the short muon lifetime (2.2 μs at rest)
- Leads to concept of ionisation cooling
- Beam momentum is reduced in all directions by passing beam through an absorber (cooling)
- Beam is re-accelerated in longitudinal direction (sustainable cooling)

→ **Emittance reduction**

The MICE Experiment

- The international **Muon Ionisation Cooling Experiment**
- Demonstrate muon ionisation cooling for application to a Neutrino Factory or Muon Collider
- Produce a 10% emittance reduction, measured to1% accuracy (hence requiring an absolute emittance measurement of 0.1%)

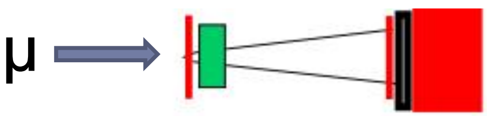


Location (Mousehole)

Hosted at the Rutherford Appleton Laboratory, U.K.

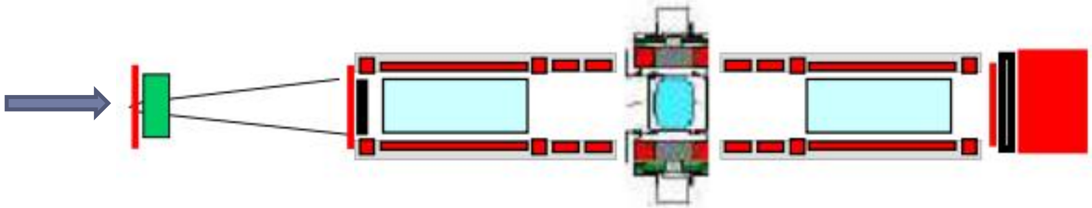
Proton driver provided by the ISIS 800MeV proton synchrotron

MICE Steps



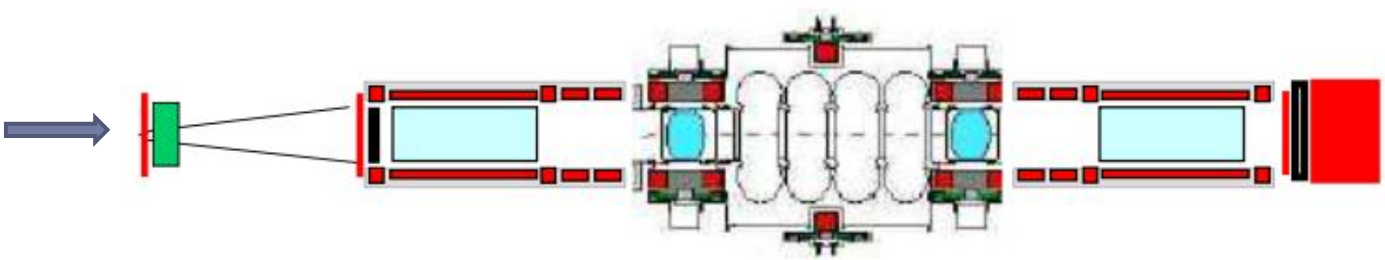
Step I **Commission beam line & detectors**

- achieved!



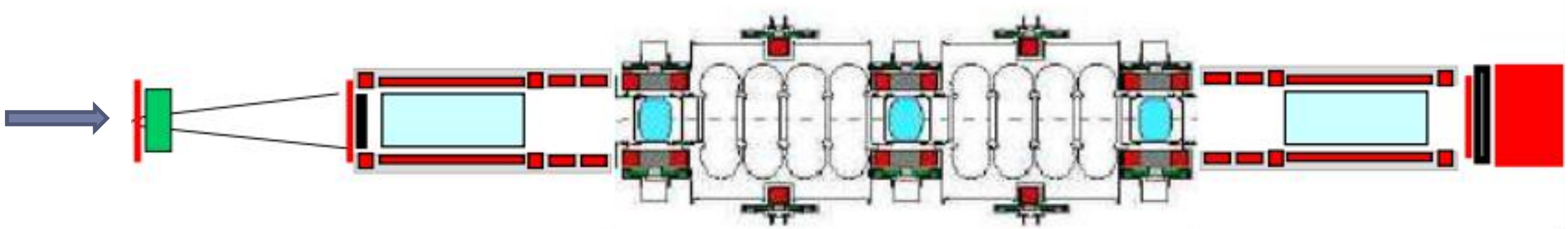
Step IV **Precisely measure emittance reduction**

- Q3 2012



Step V
Sustainable cooling

- Q2 2014*



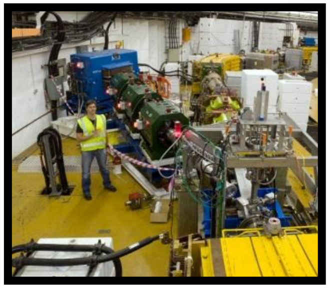
Step VI
Full cooling channel

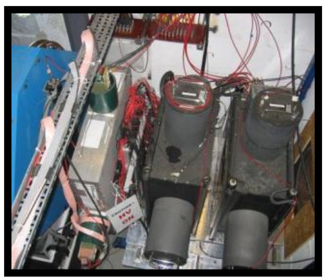
*** Target date to run Step V before ISIS long shutdown from Aug 2014 – Feb 2015**

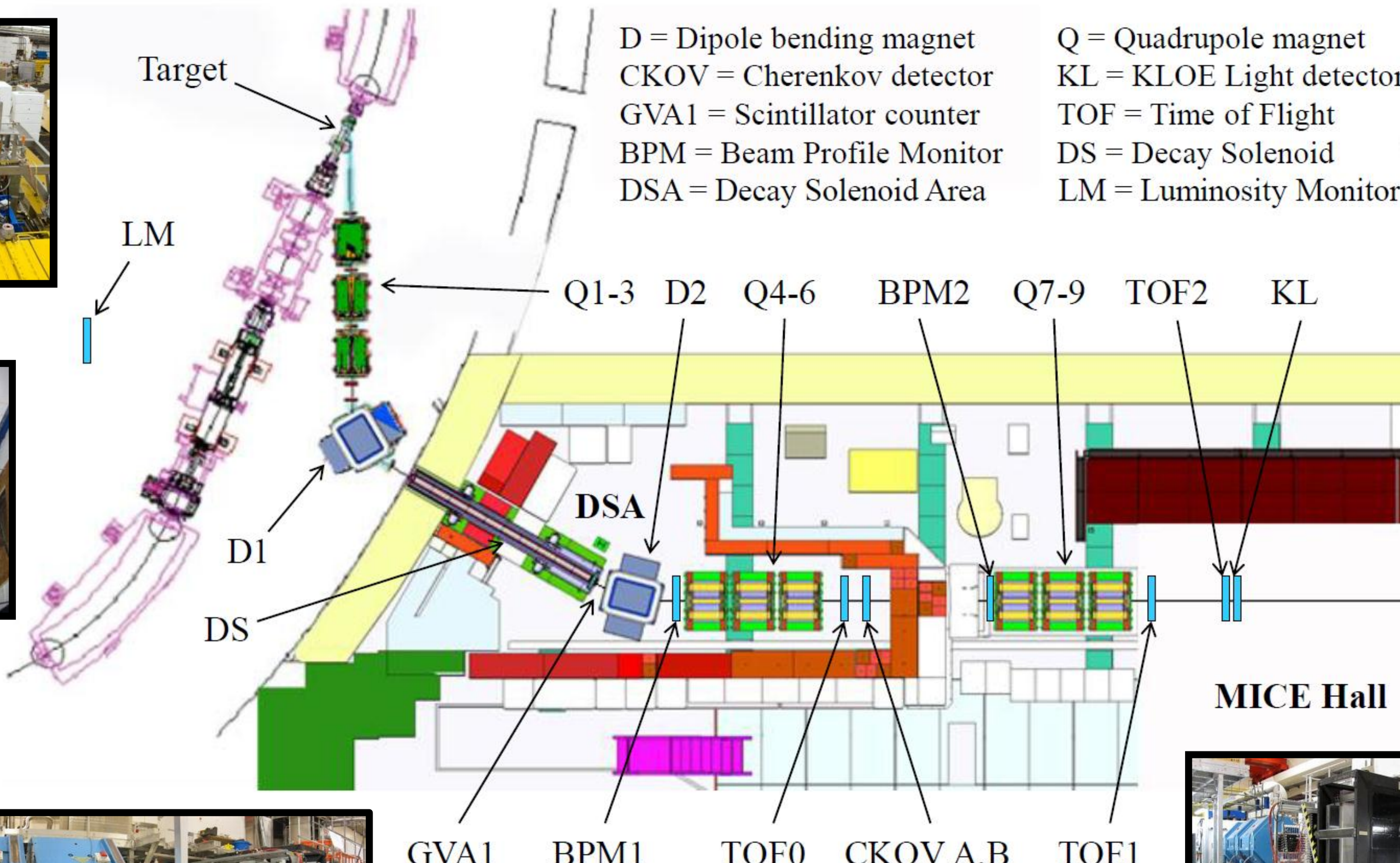
Beamline status

- **Step I achieved** – MICE Muon Beamline producing beam since Spring 2008
- Target: cylindrical titanium target pulsed into ISIS using stator drive
- Magnets: 3 quadrupole triplets and 2 dipoles installed and operational
- Decay Solenoid (DS): 5T superconducting DS installed and operational
- Time-Of-Flight (TOF): 3 TOF stations commissioned and performing well
- Luminosity monitor: commissioned and performing well
- CKOVs, Electron Muon Ranger (EMR) and KLOE-Light (KL) undergoing commissioning

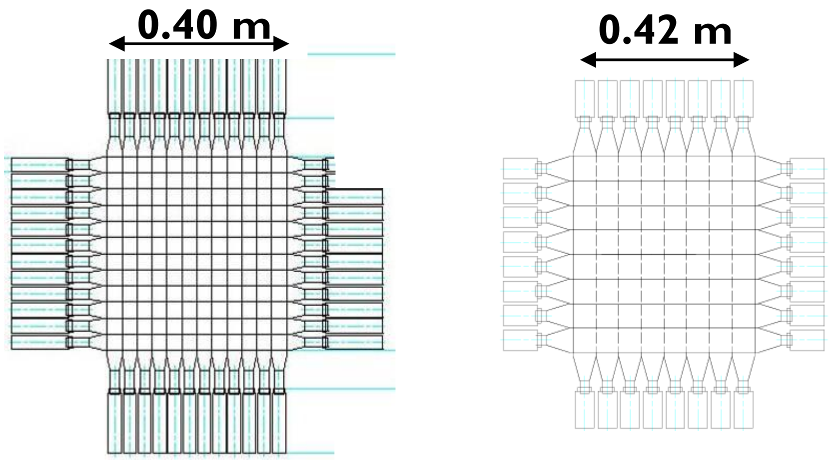
The MICE Beamline







TOF Detectors



TOF0

10 x 40mm scint. bars

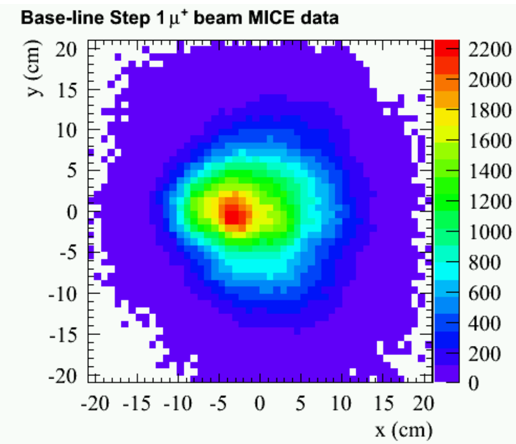
σ_x = 11.5mm

TOF1

7 x 60mm bars

σ_x = 17.3mm

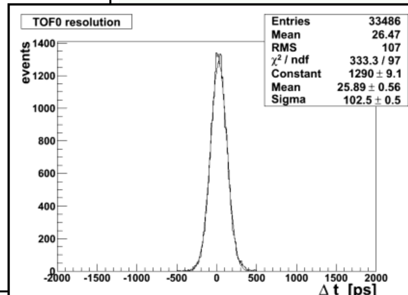
(Spatial res. can be increased by use of timing information)

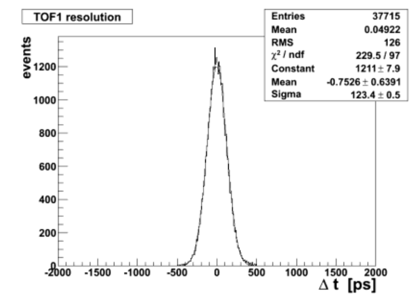


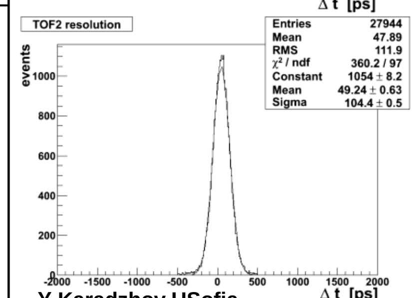
Beam profile using TOF station

[The design and commissioning of the MICE upstream time-of-flight system, *R. Bertoni et al.* , NIM-A 615 (2010) 14-26]

- 3 stations, each with 2 orthogonal layers of scintillator bars
- Provides spatial as well as timing information



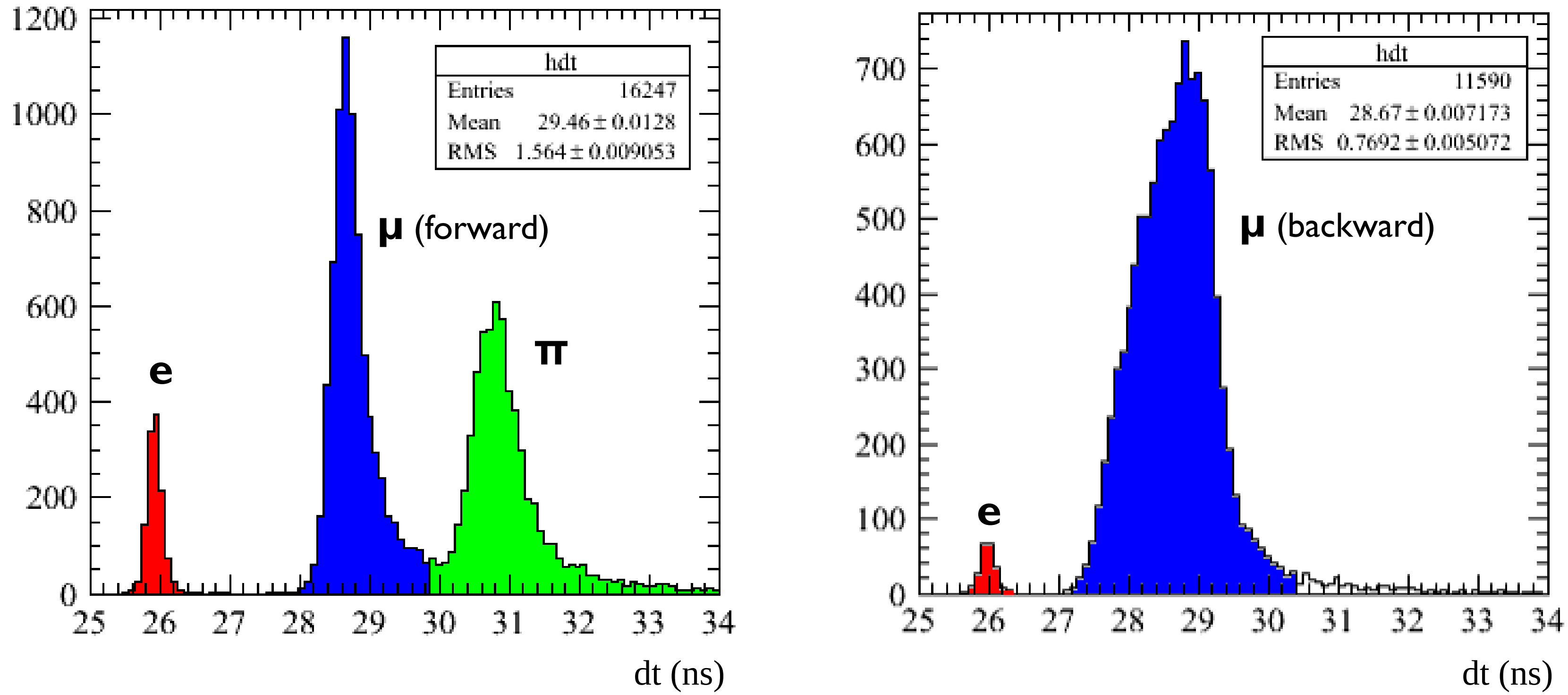




Y.Karadzhov USofia

- ***Time resolution after calibration:***
- ***TOF0 – 51ps***
- ***TOF1 – 58ps***
- ***TOF2 – 52ps***
- ***Resolution meets design goals for TOFs***

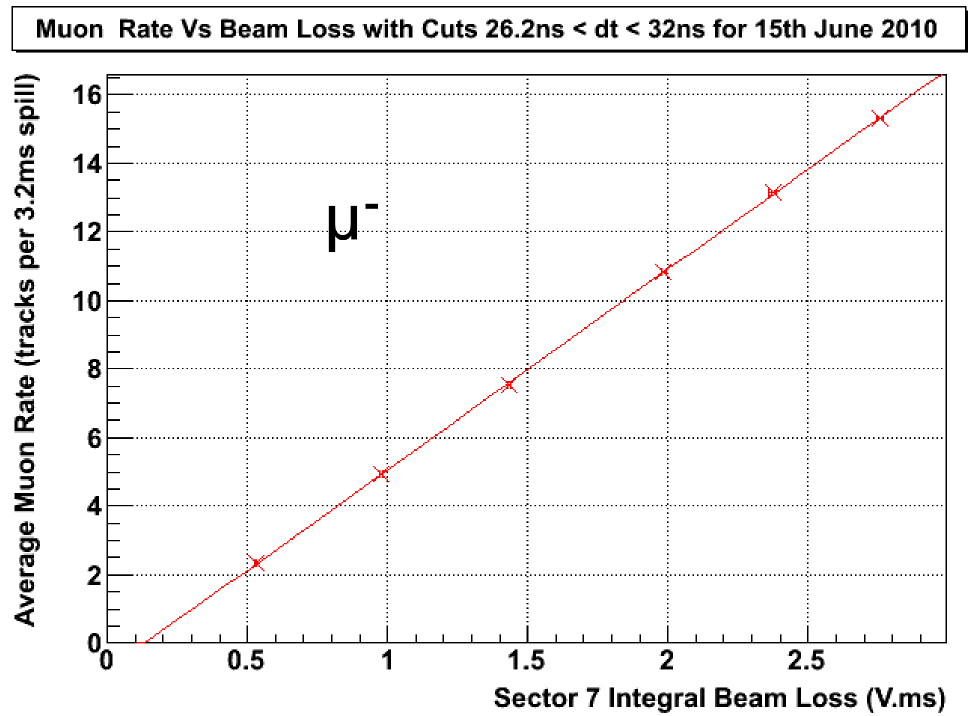
Particle Identification



- Particle Identification (PID) from TOF
- Good clean muon beam achieved when optics set for $\pi \rightarrow \mu$ transport (right histogram) – exploits emitted muon direction with dipoles to remove pions
- Additional π, μ separation using CKOVs and Electron – Muon Ranger (in commissioning)

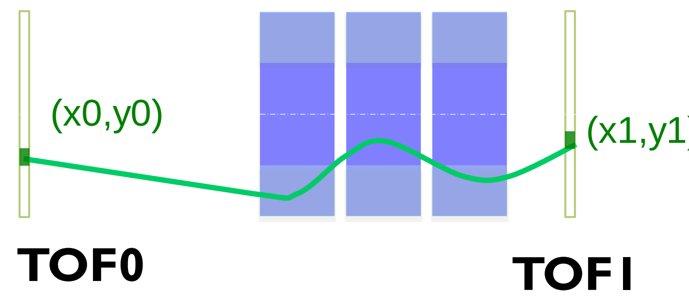
Particle Rates

- Systematically study ISIS beam loss induce by MICE target and subsequent particle rate
- Observe linear increase of particle rate with beam loss
- Observe ~10 per 3.2ms spill at 2V.ms beam loss in μ- (typical current running point)
- Dependent on beam optics



Emittance measurement technique

- Emittance normally measured using three beam profile measurements
- As transfer matrix $M_{ij} = M_{ij}(p_z)$ this is not possible on MICE due to large p_z spread
- New technique developed on MICE (M. Rayner) to measure emittance using two TOF stations while waiting for the trackers:
  - Measure x, y, t at both TOF0 and TOF1
  - Identify muons using time-of-flight
  - Momentum-dependent transfer matrices map particle motion from TOF0 to TOF1 through drifts and quads
  - Make initial estimate of path length and p_z, then use p_z and transfer map to improve path length estimate, then recalculate p_z. Iterate until converges.
  - Calculate $x' = p_x/p_z$ and $y' = p_y/p_z$ at TOF0 and TOF1
- Compare with simulation



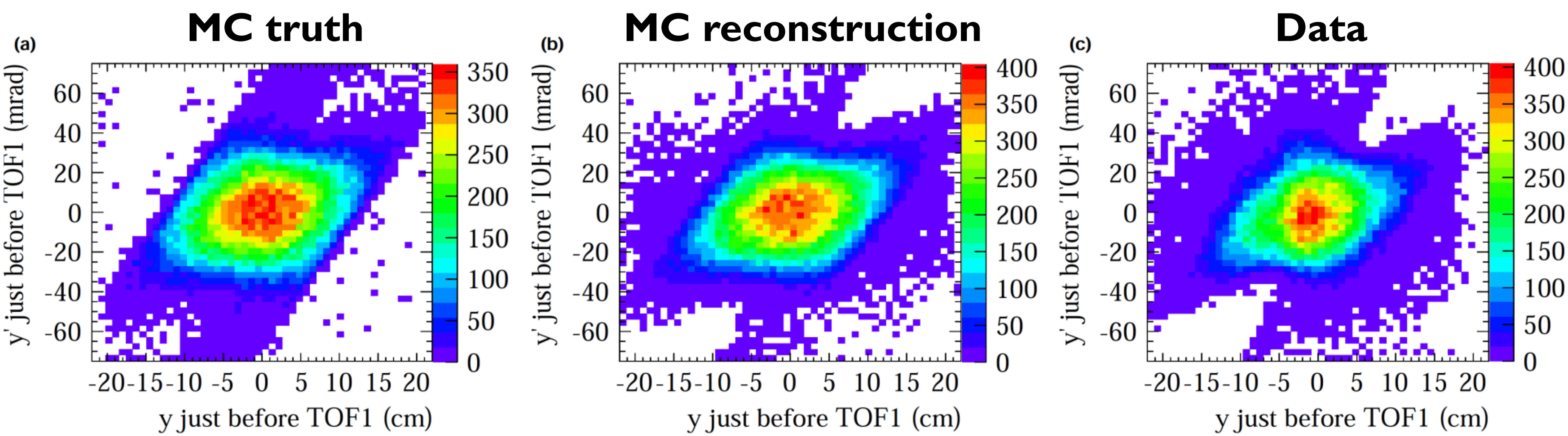
$$\begin{pmatrix} x_1 \\ x'_1 \end{pmatrix} = \begin{pmatrix} \mathcal{M}_{11} & \mathcal{M}_{12} \\ \mathcal{M}_{21} & \mathcal{M}_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ x'_0 \end{pmatrix}$$

$$\begin{pmatrix} x'_0 \\ x'_1 \end{pmatrix} = \frac{1}{\mathcal{M}_{12}} \begin{pmatrix} -\mathcal{M}_{11} & +1 \\ -1 & \mathcal{M}_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ x_1 \end{pmatrix}$$

[Upcoming MICE Step I paper will describe technique in detail]

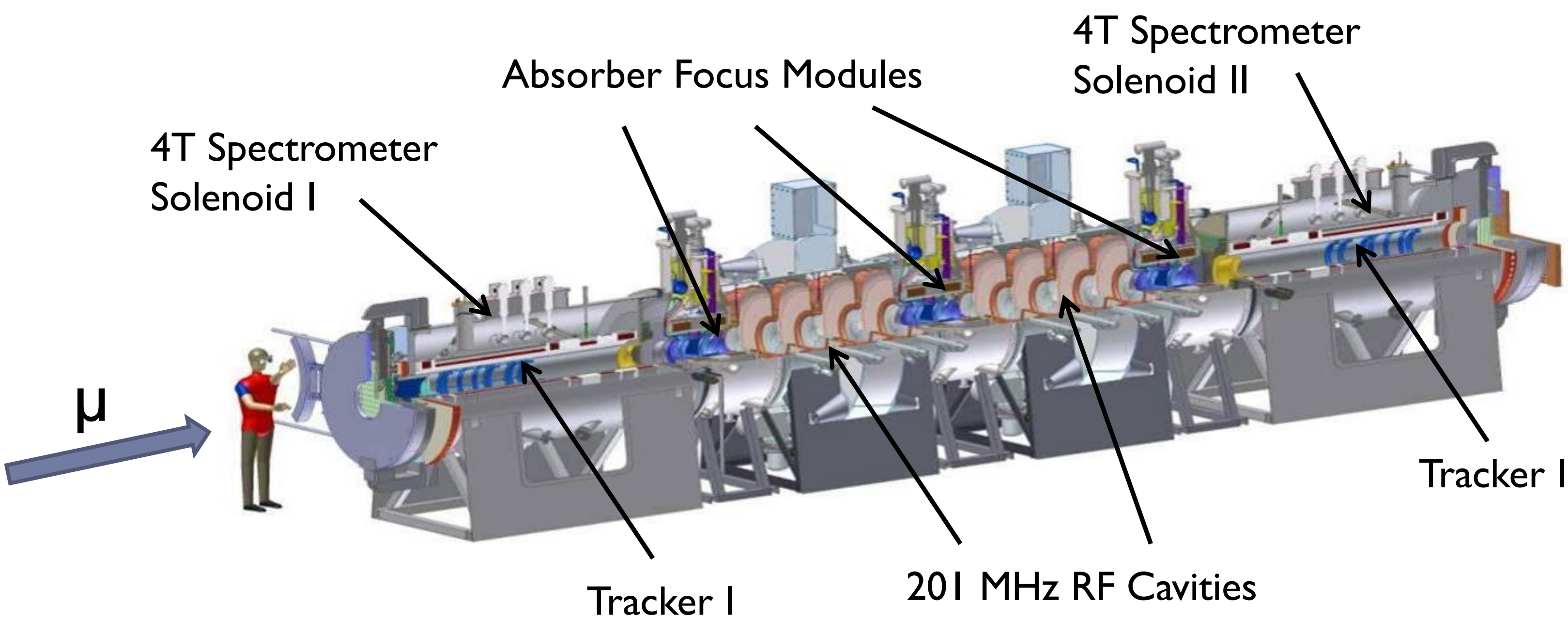
Emittance Results

- Using a standard (6mm, 200 MeV/c) μ^- beam:



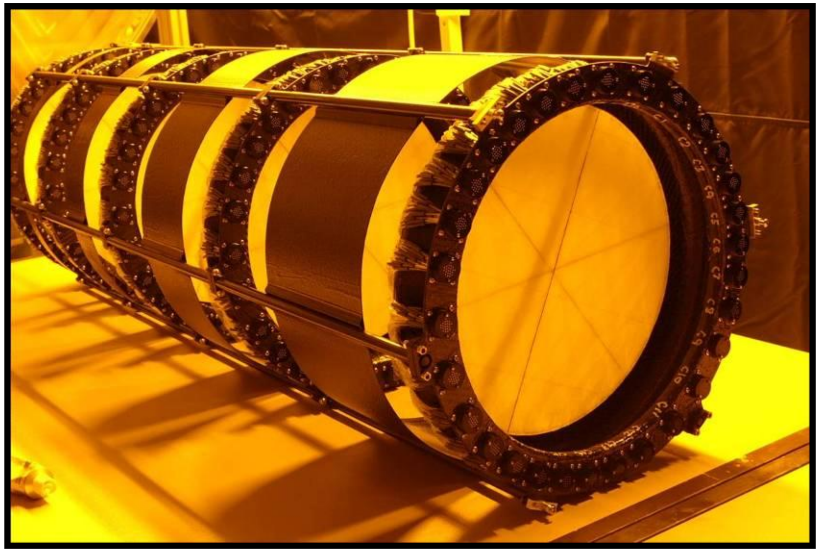
- Measure ε_x = 2.94mm and ε_y = 1.15mm for this beam. Transverse normalised emittance is then given approximately by $\epsilon_n \approx \frac{p_z}{m_\mu}\sqrt{\epsilon_x \epsilon_y}$
- Numerous other beams (generated by beamline optics) measured covering MICE emittance – momentum matrix, giving emittance and twiss parameters
- Results to be published in upcoming MICE Step I paper

Cooling channel status



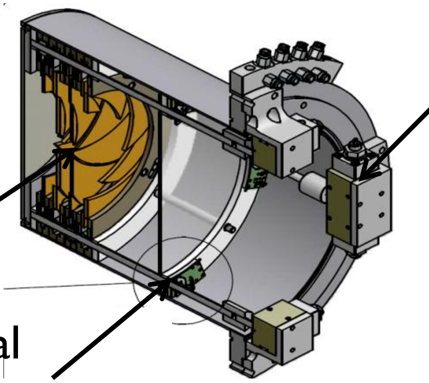
- Scintillating fibre trackers built and taking cosmic data
- Spectrometer solenoids, absorbers and RF cavities under construction

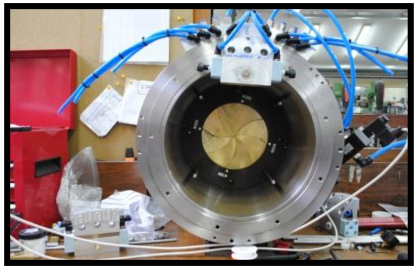
Trackers and Diffuser



- 2 trackers, 5 stations per tracker, 3 planes of 350μm scintillating fibres per plane
- Measures x, x', y, y', p_z
- Measured track residual 650μm with 470μm point resolution (c.f. TOFs)
- Constructed & ready taking cosmic data
- 4T superconducting spectrometer solenoids still in production for Step IV

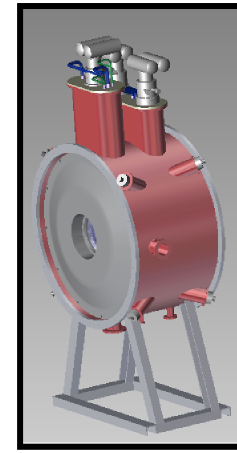
- Diffuser used to expand beam emittance prior to cooling
- 4 stacked disks of varying thickness
- Camera iris design

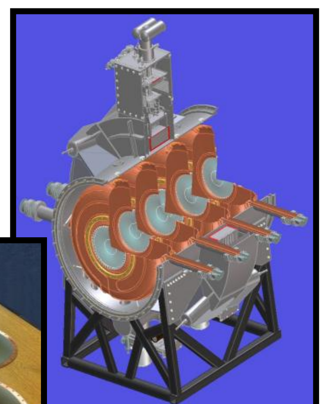




Absorbers and RF Coupling Coils

- 3 Absorber Focus Modules
- Use LH2 as absorber and also LiH (plastic also possible later)
- Use magnetic field to guide muons (4T in solenoid mode)





- 2 RFCC stations
- Produce a 7.8T magnetic field to guide muons
- Curved beryllium windows
- Restores longitudinal momentum lost in absorbers, via 201.25 MHz 8 MV/m RF field

Summary

- Ionisation cooling a necessary technology for any future Neutrino Factory or Muon Collider – MICE to demonstrate the technique
- MICE Muon Beamline successfully commissioned – **Step I of MICE achieved**
- **First preliminary measurements of emittance performed** using the excellent TOF detectors
- Progress continues on fabrication of cooling channel components
- Goal to measure **muon cooling in 2012** and **sustainable muon cooling in 2014**


Thanks for your attention.
MUON
BEAM ON
Questions?