Goals and Status of MICE

the international

Muon Ionization Cooling Experiment

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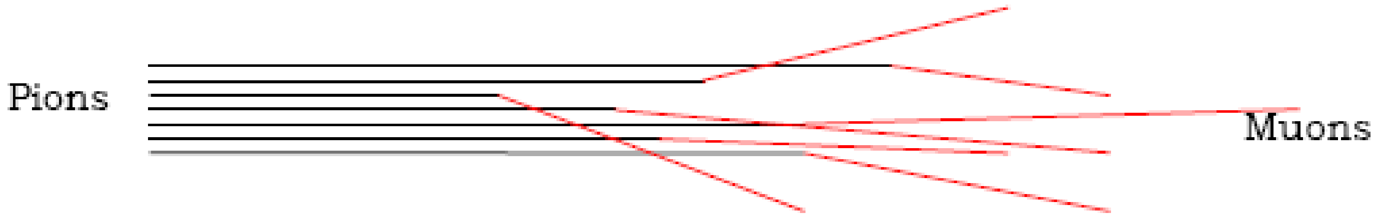
(Brunel University)

mis-representing the MICE Collaboration
(http://mice.iit.edu/)

The Intro...

Both the Muon Collider and Neutrino Factory concepts depend on high-quality muon beams.

Unfortunately, there is no convenient point-source of muons available – have to start from a decay process:



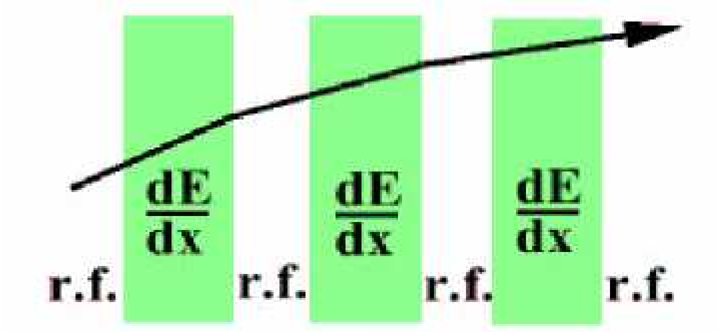
No correlation between transverse position and angle so have muons with various momenta and directions – thus a large, low-density beam.

Accelerating such a beam requires a machine with large magnetic aperture – expensive! – but the collision rate for a given size of target will be poor.

Need to convert it into a small, high-density beam. "Cooling" means "reducing the range of random transverse momenta".

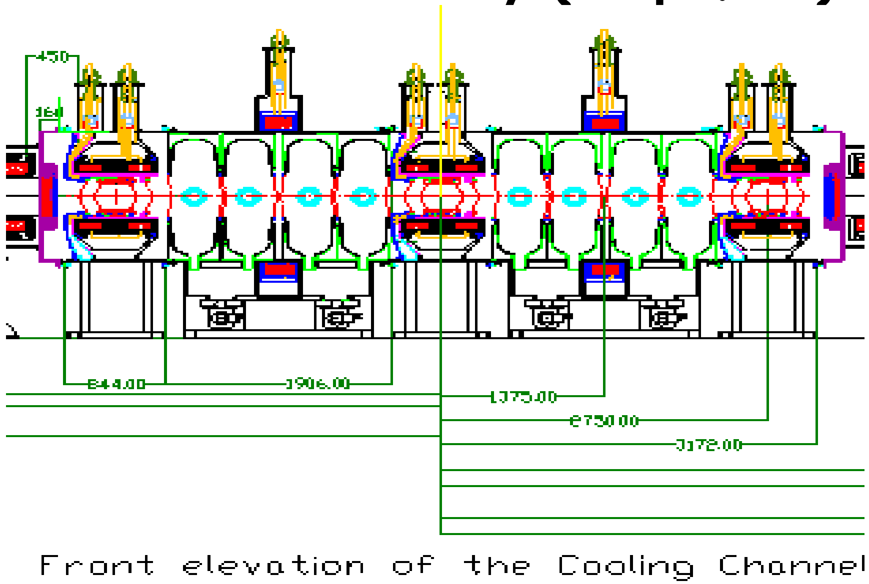
Ionisation Cooling

principle:



this will surely work..!

reality (simplified)



….maybe…

The muons will ionise material as they pass through it and thus lose energy. We replace this by accelerating them only along the desired beam direction to restore linear momentum.

Of course the material will also try to scatter the muons, "heating" the beam. Need to choose one that allows the first effect to dominate, such as hydrogen...

MICE Goals

The aim of MICE is to demonstrate the principle of ionisation cooling in practice, i.e.

- to build a realistic prototype of a cooling channel
- to verify that it cools a beam (at all)
- to evaluate performance

Accelerator physicists would produce a set of suitable muon beams and see how they cool, but this is expensive and inconclusive, as an affordable prototype of cooling section only cools beam by 10% while standard emittance measurements barely achieve this precision.

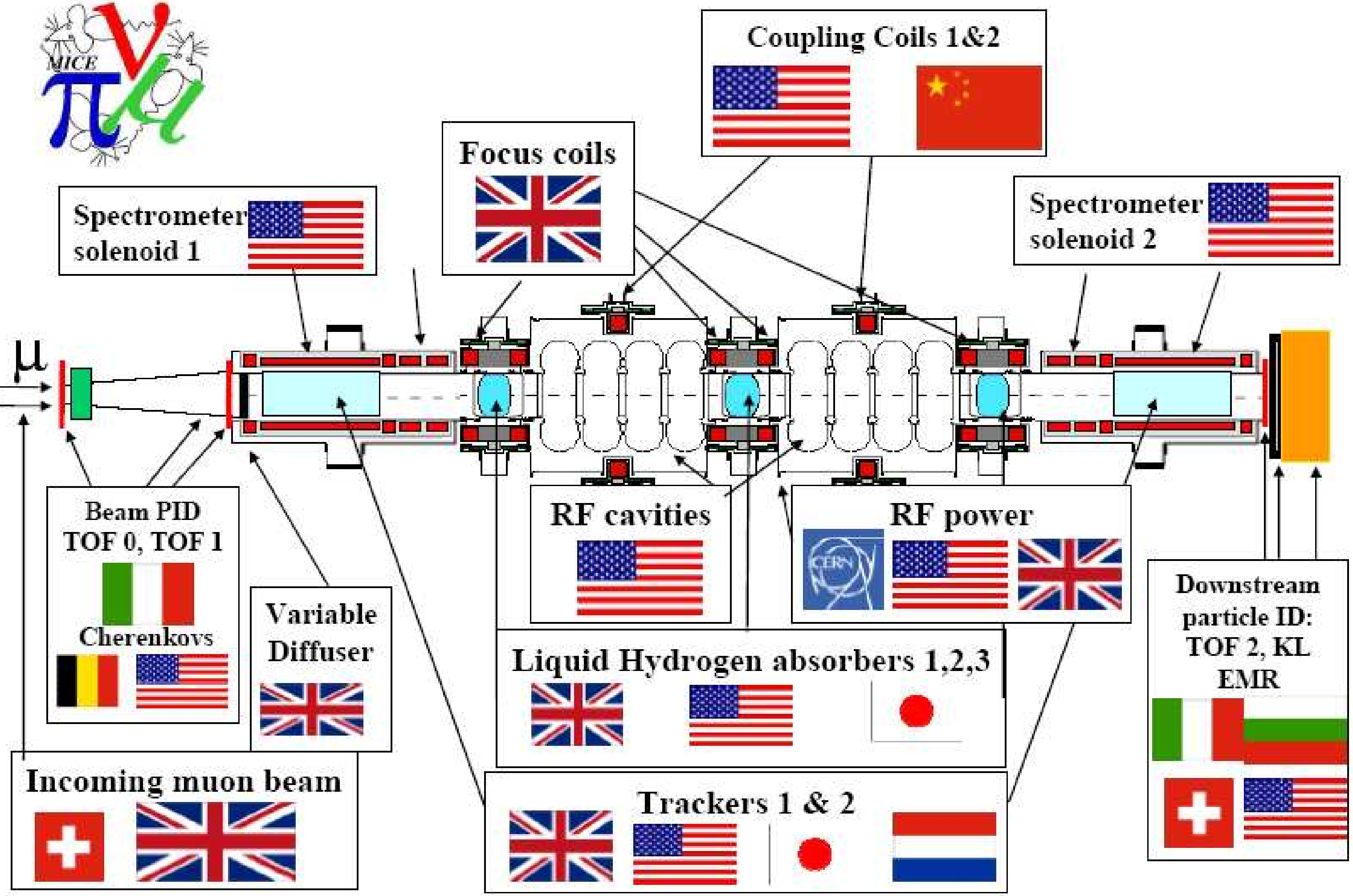
We are therefore doing a single-particle experiment: the momentum and position of each particle are measured before and then after it passes through the cooling channel.

Thus state-of-the-art particle physics instrumentation will test state-of-the-art accelerator technology.

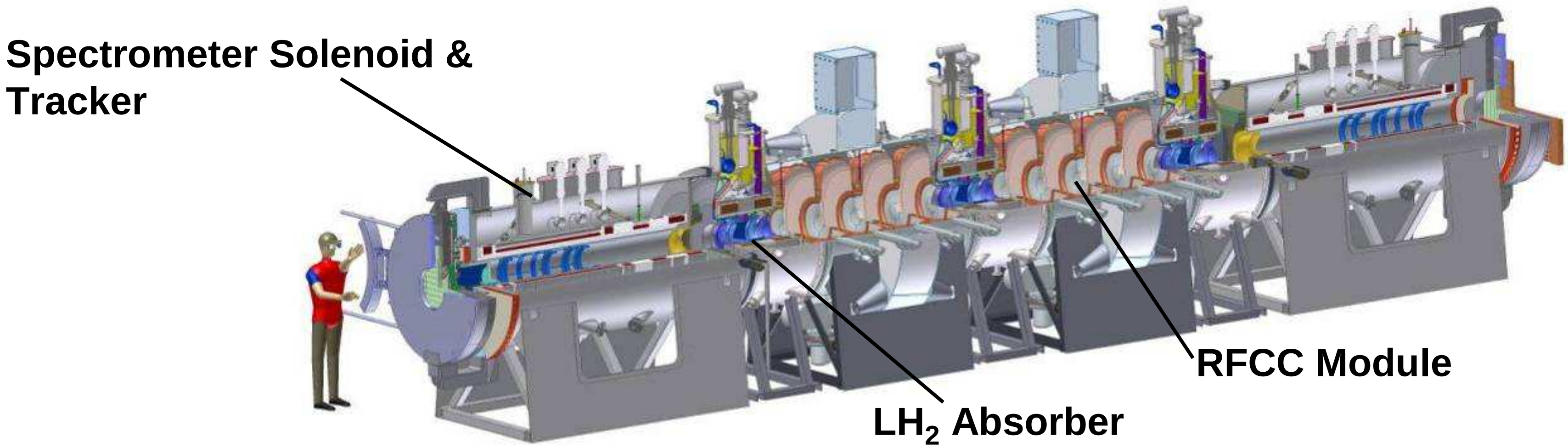
MICE – a global collaboration

Brunel UNIVERSITY WEST LONDON

Protons from ISIS synchrotron at RAL



MICE



MICE:

Design, build, commission and operate a realistic section of cooling channel

Measure its performance in a variety of modes of operation and beam conditions …

… results will be used to optimize Neutrino Factory & Muon Collider designs

MICE: Design

- *MICE designed to produce a 10% cooling effect on the muon beam*
- *Uses particle detectors to measure cooling effect to ~1%*
- *Measurements will be done with muon beams having momentum of 140 MeV/c – 240 MeV/c*
- Method:
  - Create beam of muons
  - Identify muons (TOF) and measure E,P (EMR); reject background
  - Measure single particle parameters x, p_x, y, p_y, p_z (Spectrometers)
  - Cool muons in absorber
  - Restore longitudinal momentum component with RF cavities
  - Measure single particle parameters x, p_x, y, p_y, p_z
  - Identify outgoing particles to reject electrons from muon decay
  - Create virtual beam of any emittance, by combining a subset of real single muons

MICE development

- *Proceeding in stages*

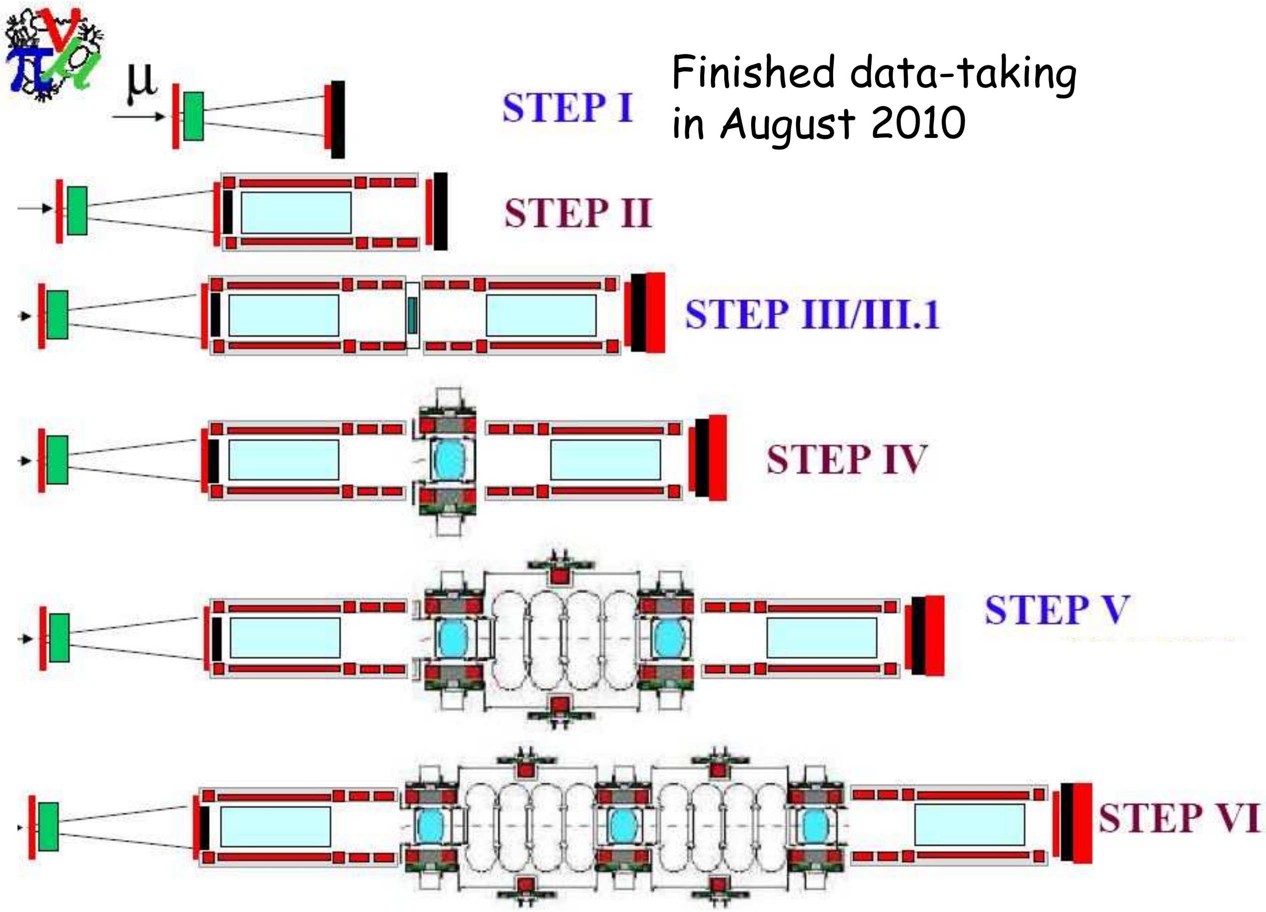
Commission beam line & detectors

Precisely measure incoming emittance & compare trackers

Precisely measure muon cooling

Test sustainable cooling

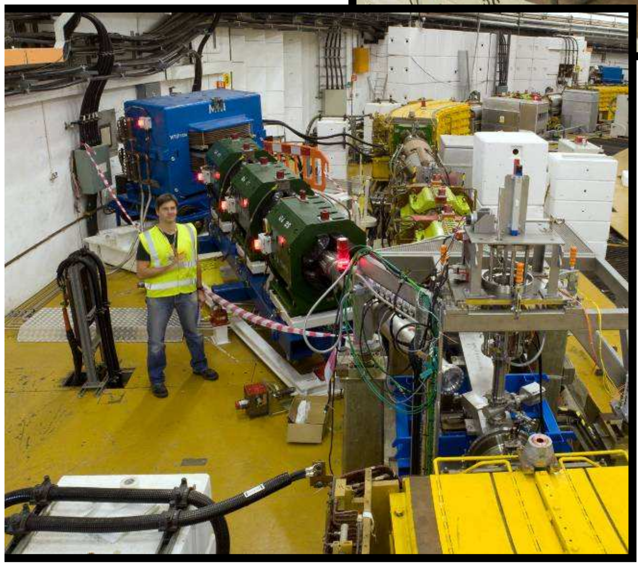
Ultimate MICE goal: operate full cooling channel

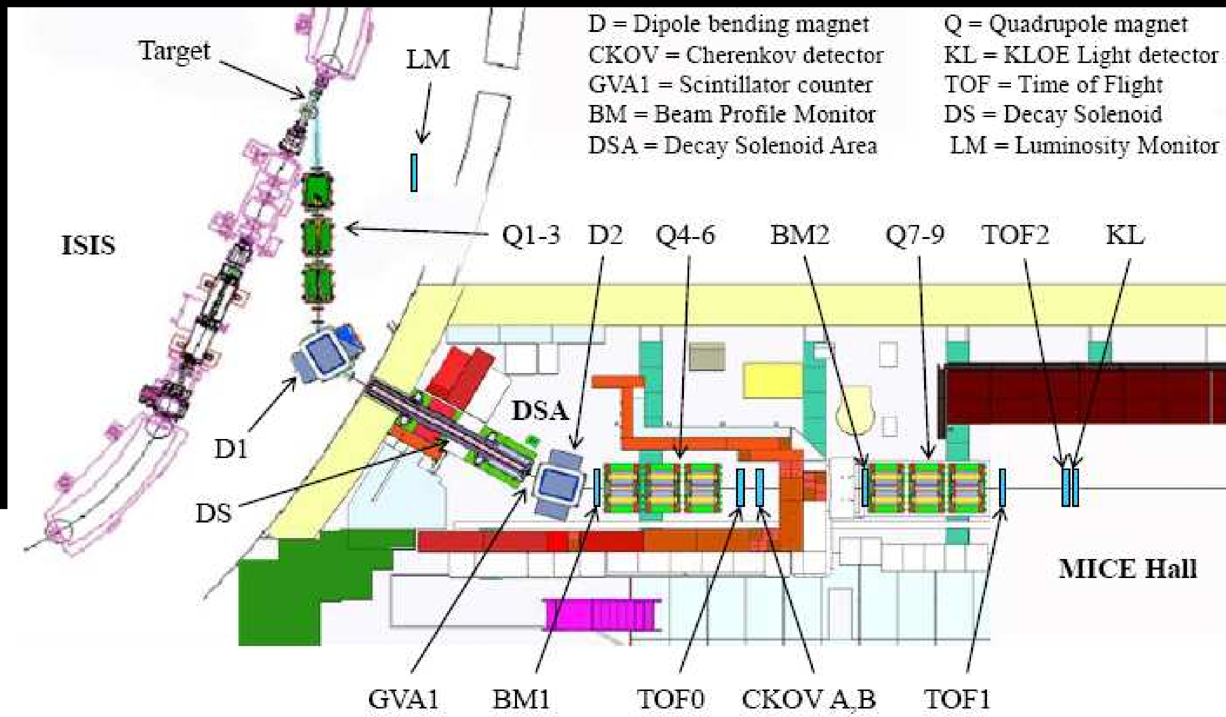


Added features

- at step III, a spool piece allows easy insertion of slabs of solid materials to measure precisely their effect on beam emittance
- will test materials relevant to neutrino factory: LiH, Carbon, Aluminum Titanium etc…(and simply plastic)
- at step IV and above, optics in FC can be explored to allow smaller beta functions (down to 5cm at 140 MeV/c) to test flip vs non-flip mode
- at step IV a wedge absorber can be tested in place of a flat piece to study effect
- at step V and VI can test cavities with LN2 cooling to allow higher gradient (X V2) with same power

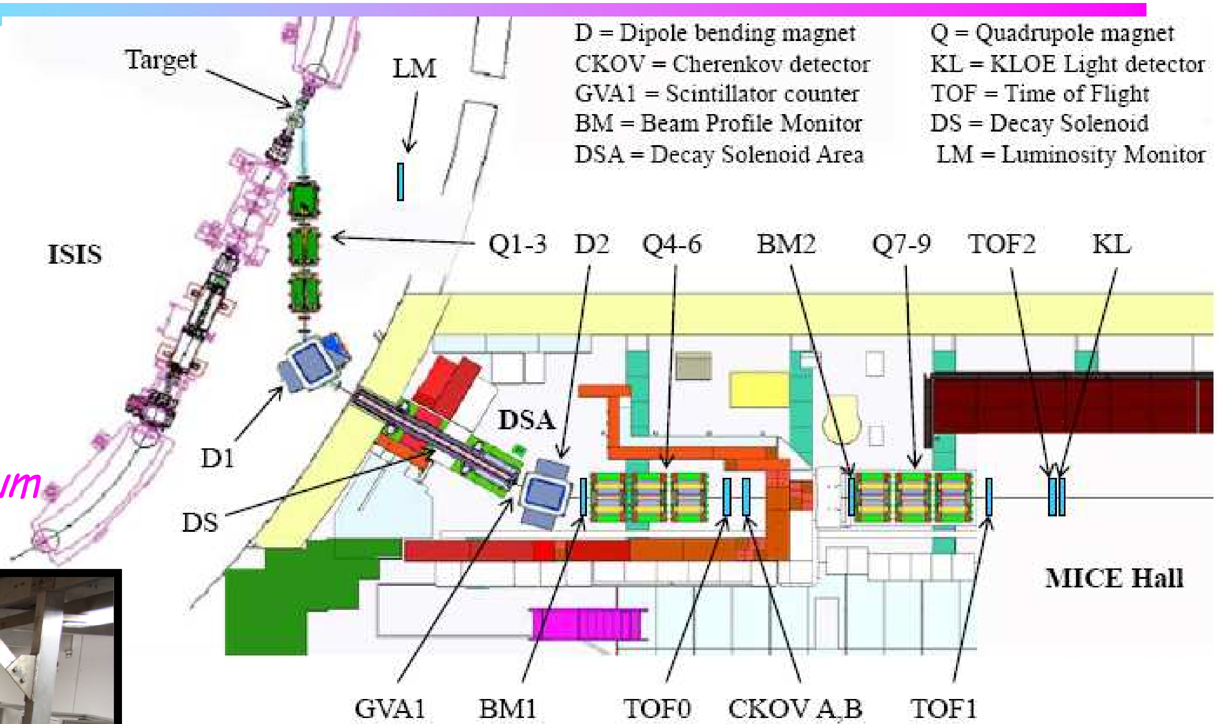
MICE Beam Line





Muon Beam Line

- *ISIS 800 MeV proton synchrotron at RAL*
- *Titanium target*
- *Quad Triplet*
  - *Captures pions*
- *First Dipole*
  - *Selects pion momentum*



- *Superconducting Decay Solenoid*
  - *Contains π and decay muons*
  - *5 T, 5 m long*
- *Second dipole*
  - *Selects muon momentum*
- *Two Quad Triplets follow for transport*

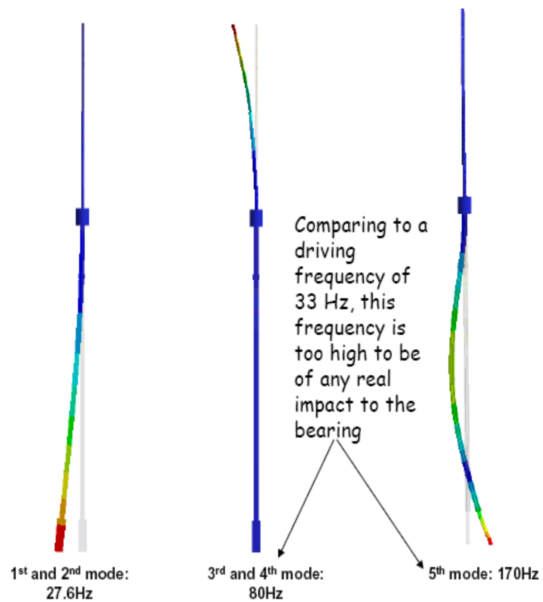
MICE Target

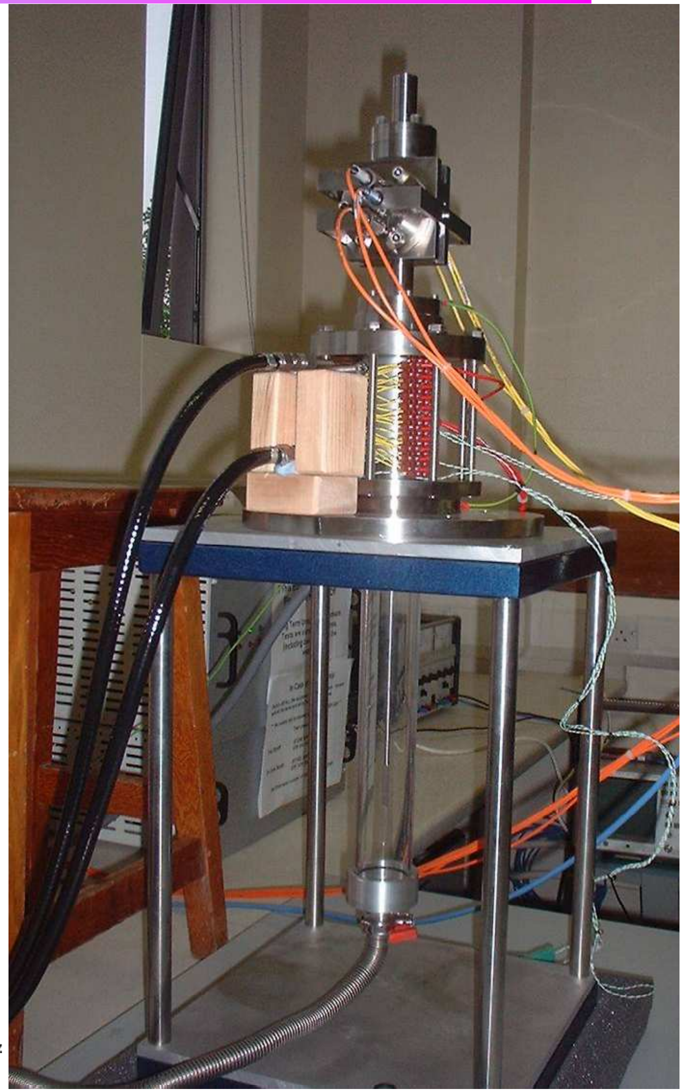
ISIS runs at 50Hz ~10ms beam on and acceleration + 10ms beam off

The target will run at 1Hz intercepting just 1 in 50 of the ISIS pulses

We need to intersect the last ~2ms of a given ISIS pulse without causing beam loss at any other time

Required Target Trajectory ~80g Acceleration





Target Status

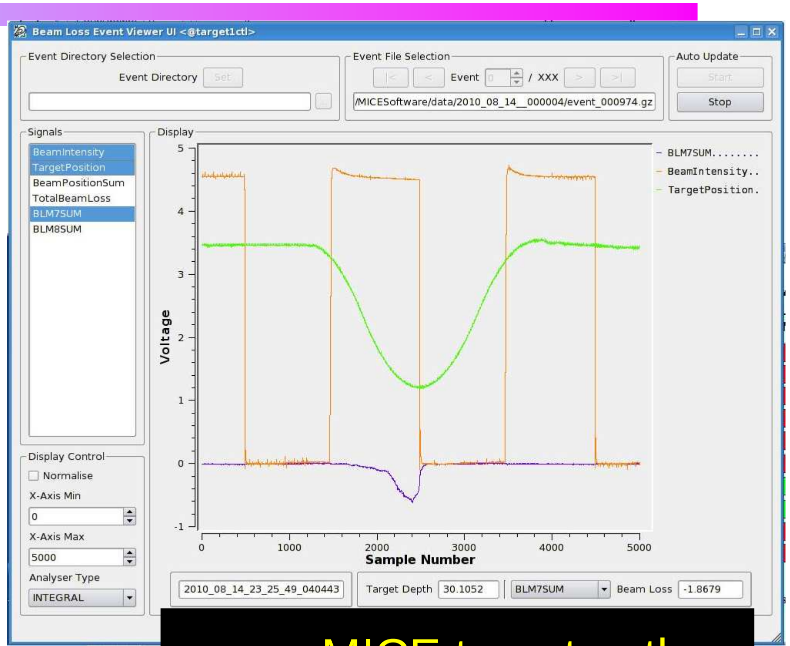
- *MICE target installed in ISIS August 2009*
  - *Run at base rate & 50 Hz (Normal User Run)*

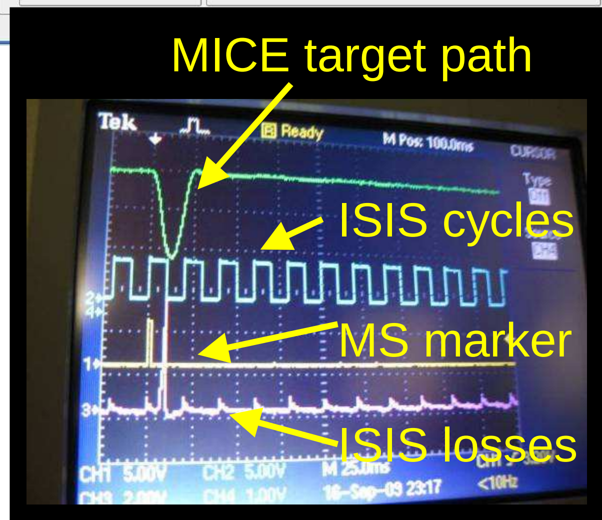
- *Target is working beautifully*

- *Target stability checked every 10,000 pulses*
  - *Process to monitor target behavior agreed upon with ISIS*
  - *Target timing monitored*

- *Target Operation:*
  - *570,000 pulses to date in ISIS*
  - *Offline target ran 2.15 M actuations*

- *Need online & offline working targets*
  - *T3 under construction*
  - *Two target system fall 2010*

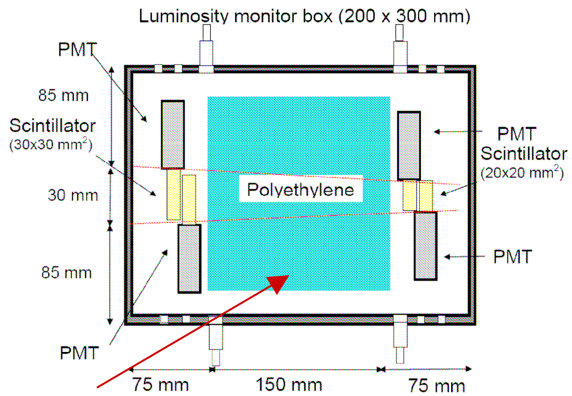




Luminosity Monitor

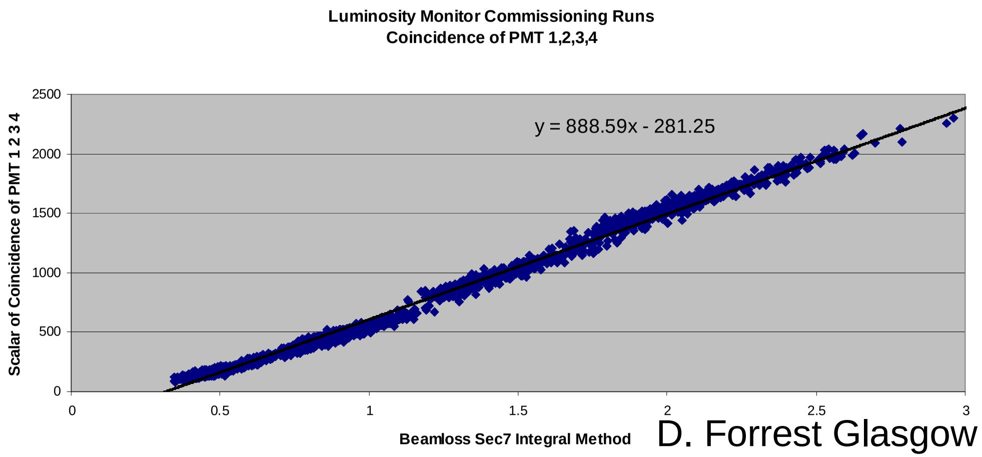
- *Determines particle rate close to target*
- *Extract protons on target as function of depth*
  - *independent of beam loss monitors.*
- *Installed in the ISIS vault & commissioned (Glasgow)*
  - *Coincidence between 4 scintillators with plastic filter to reduce low energy protons*
  - *Data scales well with beam loss*

Working well with info available online during running



Cuts off: protons ~500 MeV/c;

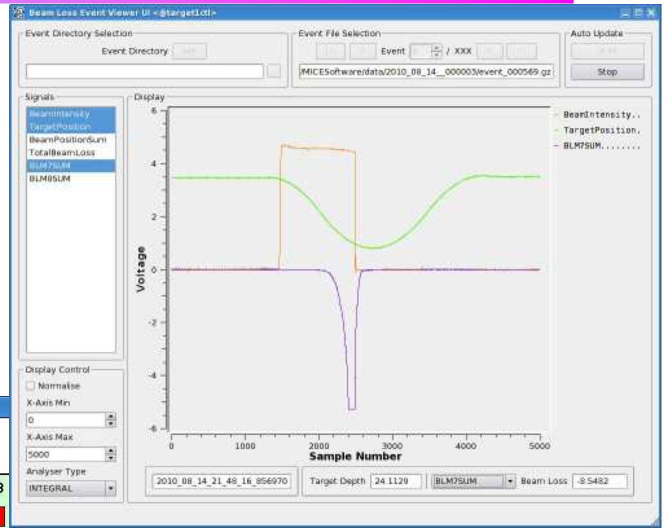
pions ~150 MeV/c

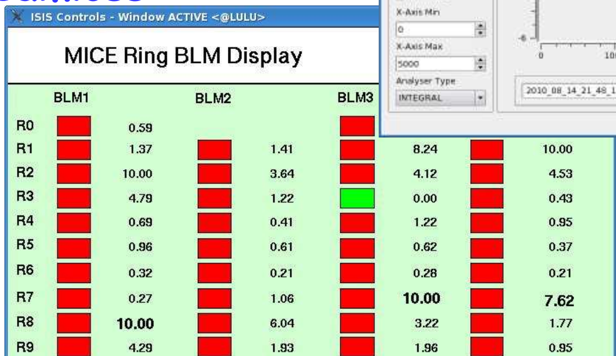


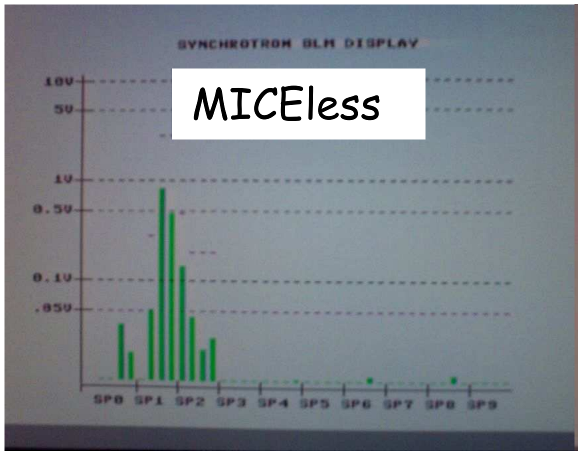
D. Forrest Glasgow

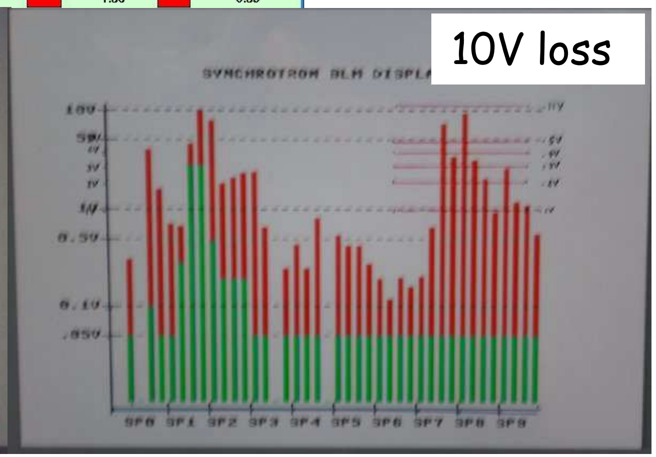
High Beamloss Tests

- The MICE beamline replaces an earlier muon beamline that ran at a 2V ISIS beam loss.
- MICE target nominally run at similar loss level. Higher losses would let us gather data faster, but may affect stability of ISIS beam and activation of components.
- Tests have been made up to a 10V beamloss – full scale.



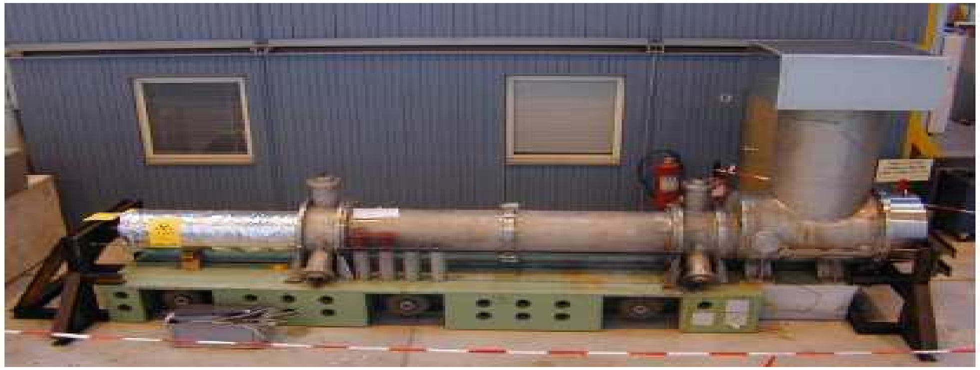






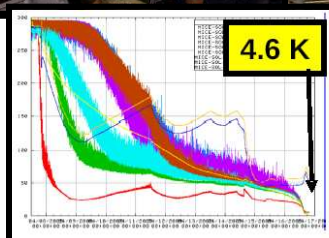
Beam Line Status

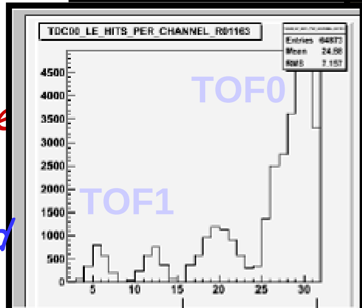
- *Conventional Magnets*
  - *All operational and working well*
  - *Current reliably stable during User Run*
- *Decay Solenoid (PSI/RAL)*
  - *5 T superconducting solenoid magnet*
  - *Increases downstream particle flux by factor of ~5*



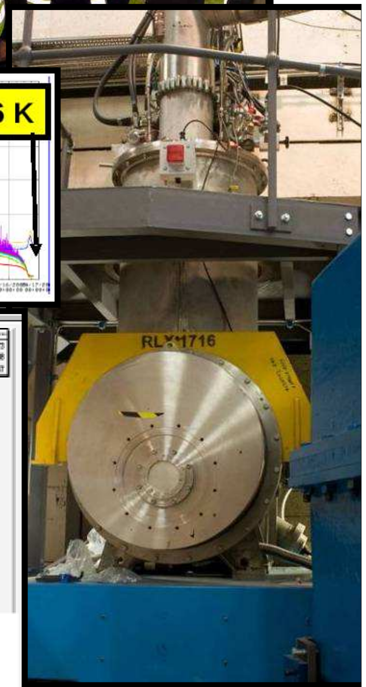
Decay Solenoid cold, stable, and operational for entire User Run June - August 2010

- *Proton Absorber installed downstream of Decay Solenoid*
  - *15, 29, 49, 54mm*
  - *Successfully eliminated proton contamination in positive μ beams*

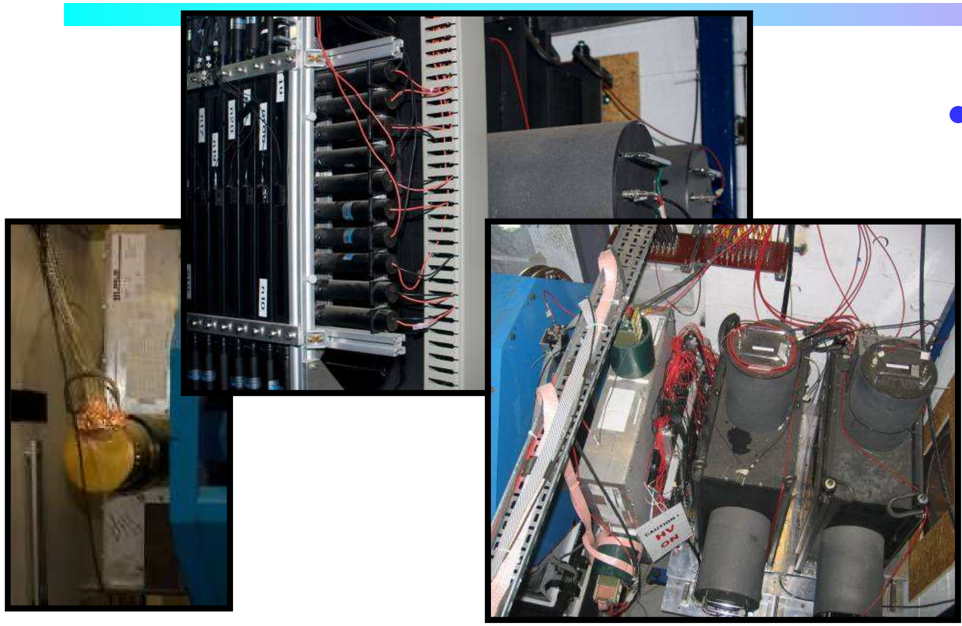




Proton contamination ranges out



Particle Identification Detectors



- *Upstream PID:*
  discriminate p, π, μ
  - *Beam Profile Monitors (FNAL)*
  - *Threshold Cerenkov (UMiss/Belgium)*
  - *Time of Flight - TOF0 & TOF1 (Italy/Bulgaria)*

- *Downstream PID:*
  reject decay electrons
  - *Time of Flight - TOF2 (Italy/Bulgaria)*
  - *Kloe-Light Calorimeter - KL (Italy)*
  - *Electron-Muon Ranger - EMR (UGeneva)*

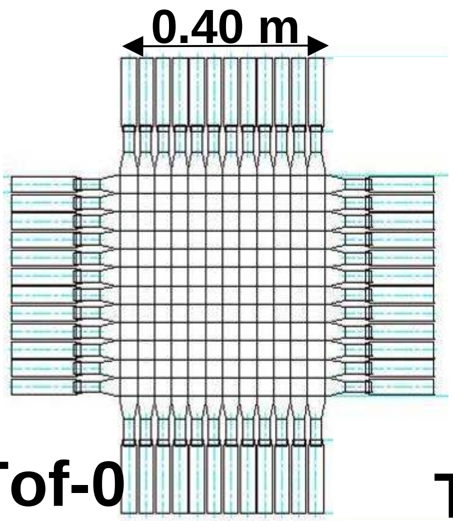
Step I: Running

- *Goals*
  - *Commission and calibrate beam line detectors*
    - *Luminosity Monitor*
    - *TOF0, TOF1, TOF2, CKOVs, KL*
    - *FNAL beam profile monitors*
  - *Commission beam line magnets*
  - *Take data for each point in ε-p matrix*
    - *MICE beam designed to be tunable*
    - *Understand beam parameters for each configuration*
  - *Compare data to simulation of beam line*
  - *Prepare for Steps with cooling*
- *Method*
  - *Dedicated data-taking run from June 22 - August 12*
  - *Special Machine Physics study periods*

Step I:
TOF Detector Commissioning

- *TOF0, TOF1, TOF2 are in beam line*
- *Two planes of 1 inch orthogonal scintillator slabs in x and y*
  - *Timing information & beam profile data*
  - *2D grid provides spatial information*

- *Essential in beam line commissioning*

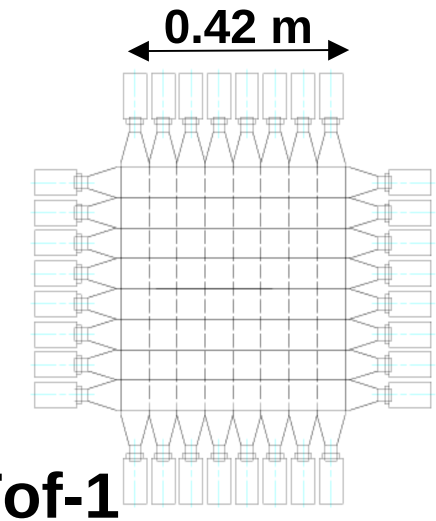


Tof-0

10 x 4cm scintillator bars

σ_x = 1.15 cm

σ_t = 50 ps

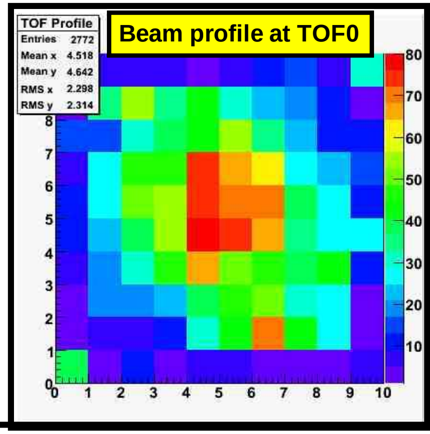


Tof-1

7 x 6cm scintillator bars

σ_x = 1.73 cm

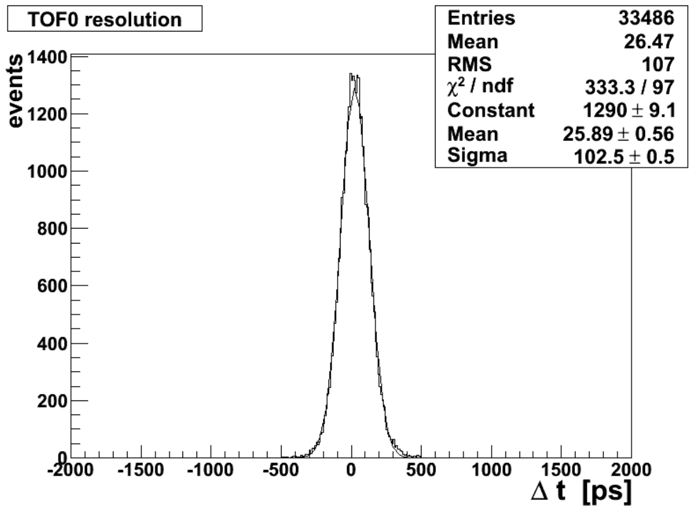
σ_t = 50 ps

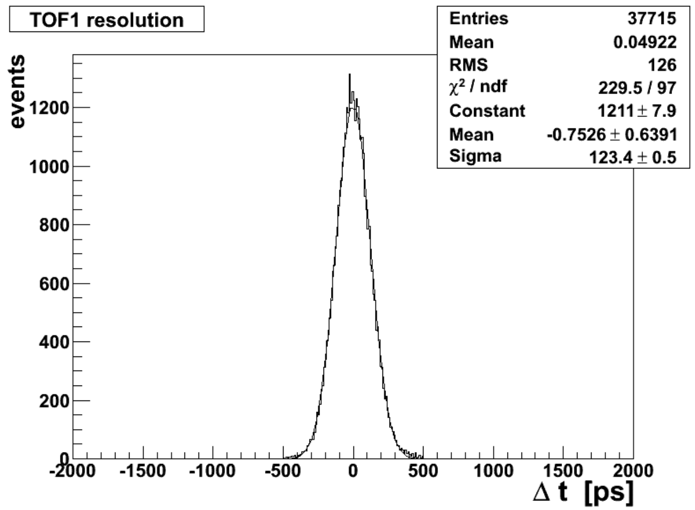


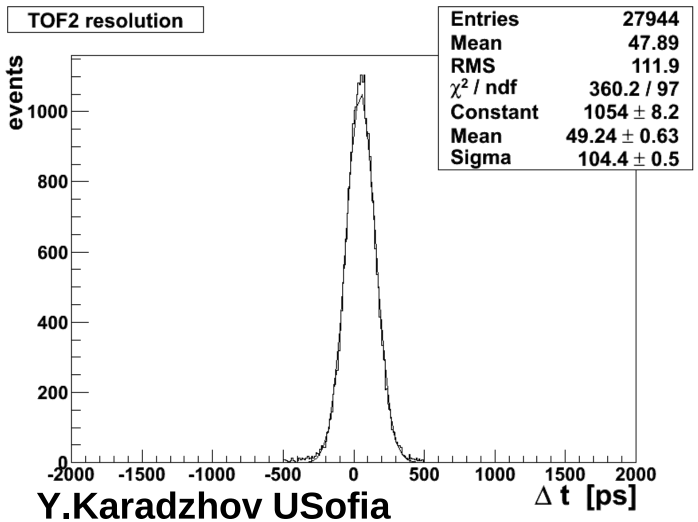
TOF Detectors Used to Calculate Beam Optics Parameters

- ***Define good muon sample with timing***
- ***Find muon (x,y) from TOF0 & TOF1 spatial information***

Step I: TOF Detector Commissioning







Y.Karadzhov USofia

- *Time resolution after calibration:*
- *TOF0 – 51ps*
- *TOF1 – 62ps*
- *TOF2 – 52ps*
- *Resolution meets design goals for TOFs*

Step I Running: Data Summary

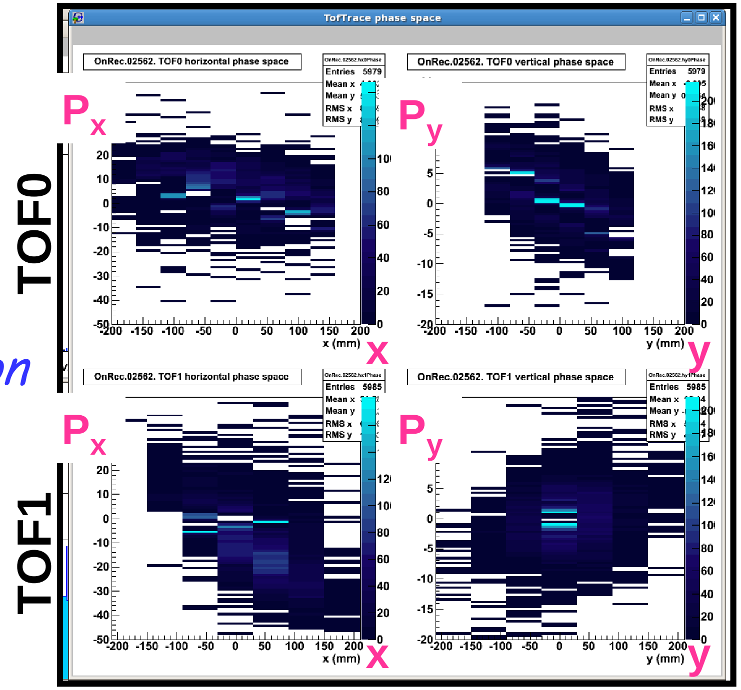
- *Record amount of data taken this summer*
  - *Over 335,000 dips of target into ISIS*
  - *Over 13,000,000 particle triggers*

- *Emittance-momentum matrix scan*
- *Beam line studies:*
  - *Quad scans*
  - *Dipole scans*
  - *DS scan*
  - *Neutrals*

- *Online tuning of beam with online reconstruction using beam optics parameters*

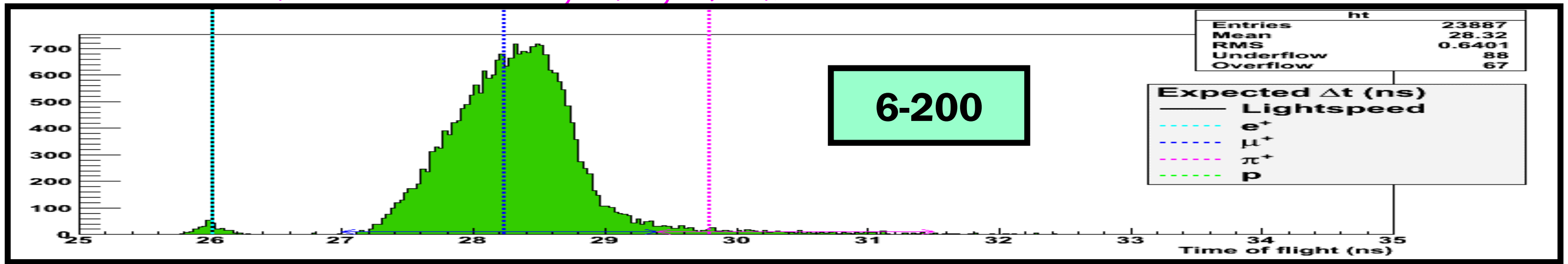
- *Reference run each day*
  - *400 pulses 6-200 (ε-p)*
- *Target test run each day*
- *All hardware found to be stable*

Muon Beam Online Phase Space



Step I: Beam Studies

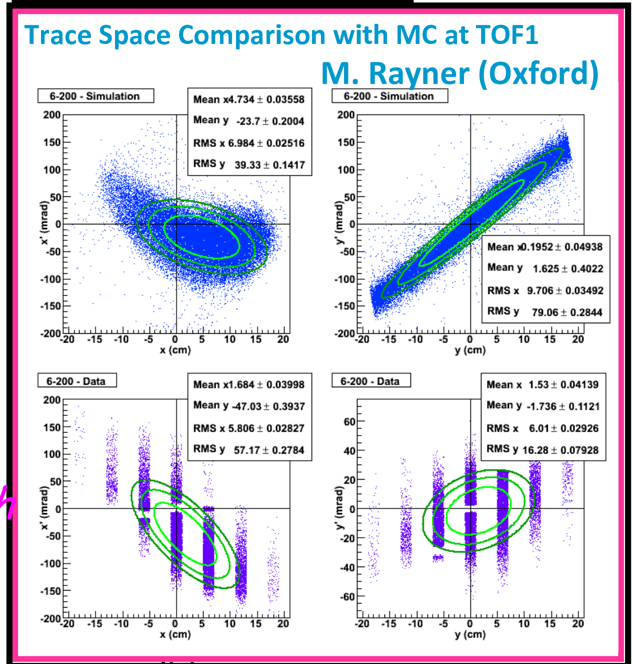
- *First emittance measurement using TOF detectors*
  - *Good muons selected using timing information*



- *Use TOF0 & TOF1 as (x,y) stations*

- *Initial path length assumed given beam line transfer matrix*
- *Each particle tracked through Q789*
- *Momentum estimated*

- *Infer x', y' → (x,x') (y,y')*
- *Phase space parameters calculated*
- *Iterated until true position/momentum known for each muon*



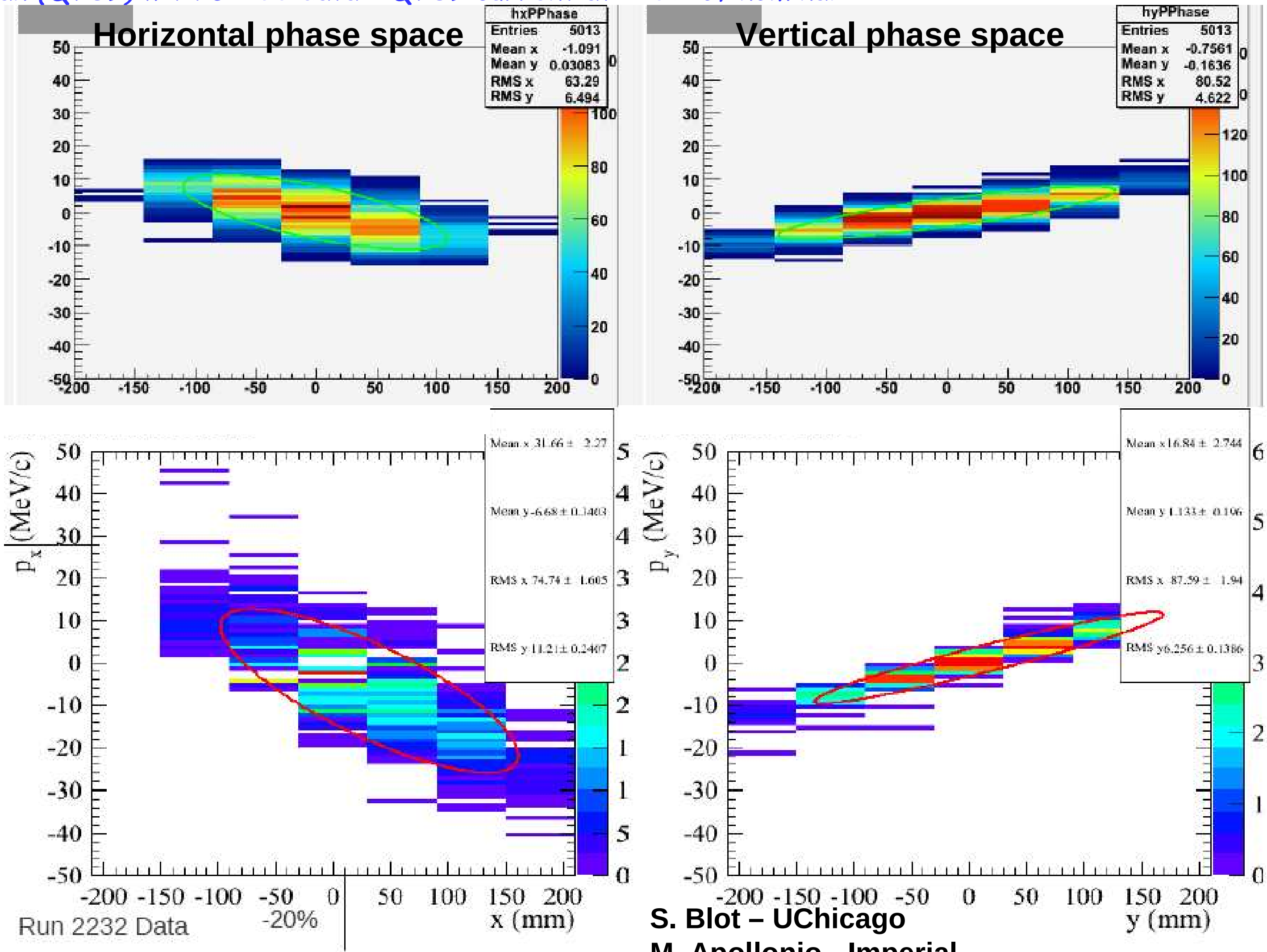
- *Compared to MC – reasonable agreement*

Step I: Data vs MC Comparison

- *Analyzing recent data*
- *Quad scan (Q789) with 6-200 data – Q789 current at -20% of nominal*

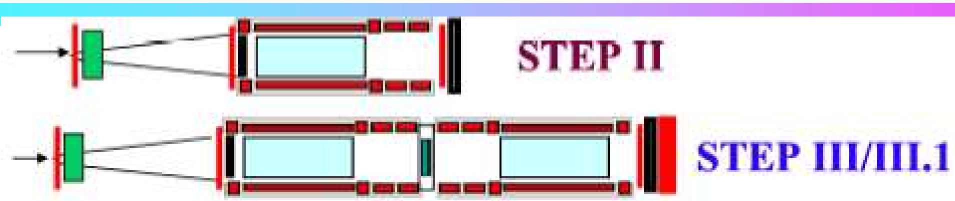
MC

Data



S. Blot – UChicago
M. Apollonio - Imperial

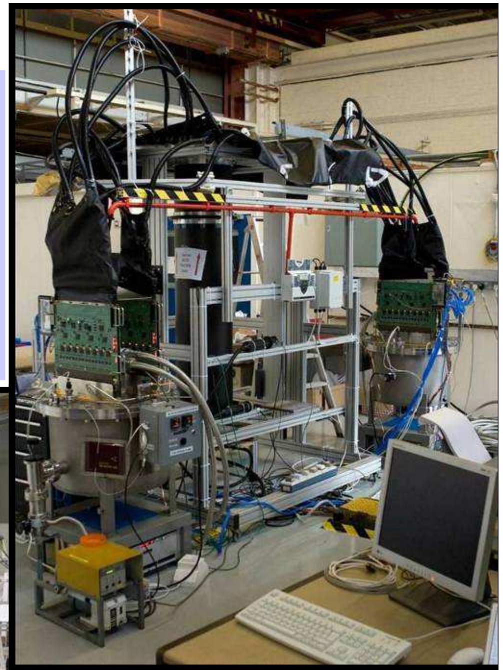
Cooling Channel Components

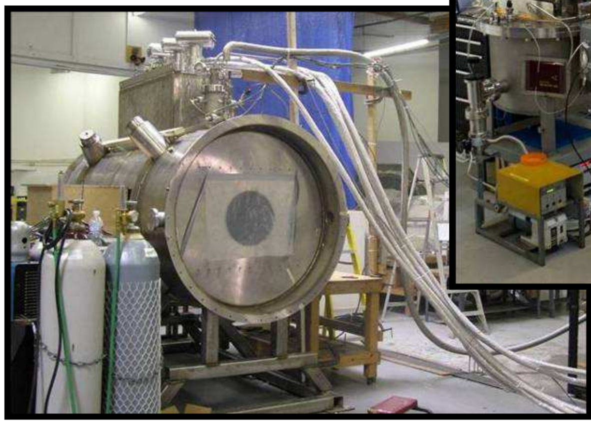


- *Steps II/III, and beyond, require spectrometers for precise emittance measurements*

- *Tracker (US, UK, Japan)*
  - *Both trackers ready and tested with cosmic rays*
  - *Resolution, Light Yield & Efficiency all exceed design goals*
  - *NIM paper submission In progress*

- *Spectrometer Solenoids (US)*
  - *Trackers sit inside solenoids*
  - *4 T superconducting*
  - *5 coils: 1 main tracker coil*
    - *2 end coils, 2 matching coils*

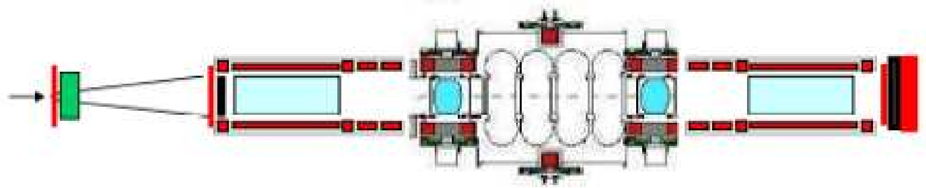


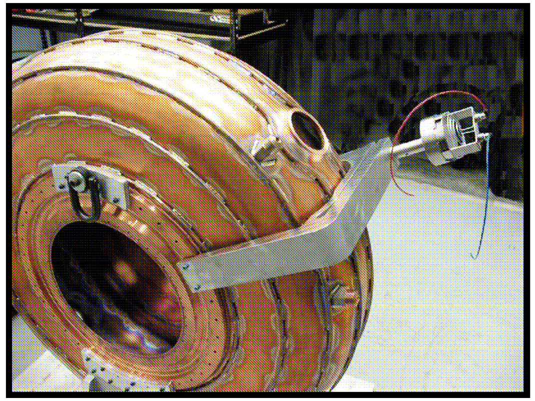


Absorber - AFC

- Absorber-Focusing Coil – AFC
  - LH_2 absorbers inside Absorber-Focus-Coil (AFC) module with superconducting coils to provide strong focus for muon cooling
  - 3 modules by Step VI
- LH2 Absorber (KEK)
  - 20.7 liters LH2
  - LiH absorber will also be tested
  - 35 cm long on beam axis
  - 15 cm radius
- Focusing Coils (UK)
  - 2 coils
  - 26.3 cm inner radius
  - 4 T in solenoid mode

RF cavities & RFCC

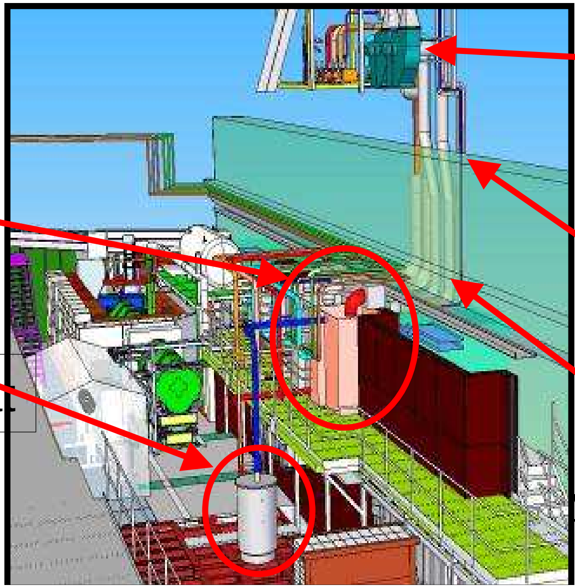




- *Step V requires RFCC module for replenishing longitudinal component of momentum*
- *RF Cavities*
  - *Provides magnetic field to guide muons through cooling cell*
  - *Restore longitudinal momentum after absorbers*
  - *Production and measurement proceeding well*
- *RF Coupling Coils*
  - *Fabrication in progress*
- *First RFCC module at RAL Oct 2012*

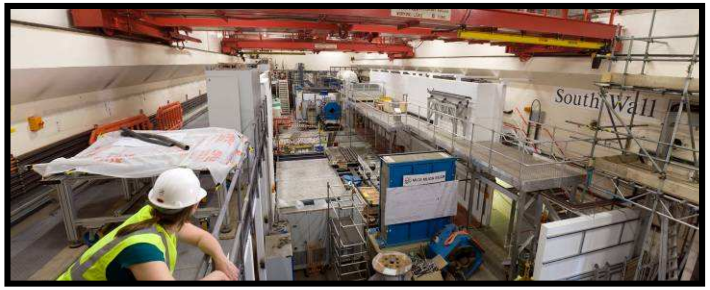
Preparation for Next Steps

- *Infrastructure projects have been reordered to take into account delay in spectrometer solenoids*
  - *Advance work on LH2 infrastructure*
    - *Vent system, Civil engineering, Pipe/valve & gas panel work*
    - *Control & safety engineering*
  - *RF power work (UK, UMiss - NSF)*
    - *Design of waveguide/power/cooling infrastructure, placement of amplifiers*
    - *Waveguide infrastructure*
    - *Specification and procurement of hardware*
  - *RF amplifiers (LBNL, CERN)*
    - *2 being reconditioned at Daresbury – one complete – second waiting*
    - *Very large (4m tall, 1 ton) and must fit four in confined space in MICE Hall*



…The Outro

- *Muons routinely observed at MICE*
- *Beam line and associated detectors fully operational*
- *Step I data-taking complete!*
- *Data analysis under way*



- *Absorber and RF cavities near delivery*
- *Infrastructure complete for Step II, III*

- *Spectrometer solenoid – plan for completion in place*
- *Infrastructure projects reordered – preparing for cooling steps*
- *Focusing coil – fabrication in progress*
- *Coupling coil – fabrication in progress*

MICE whom I've stole slides from, in order of appearance:
Paul Kyberd
Alain Blondel
Linda Coney
Paul Smith
Chris Booth