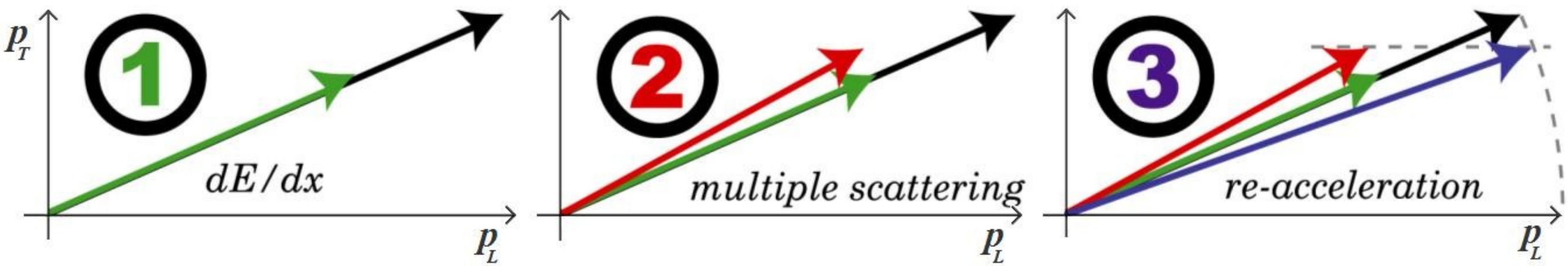
Status, Recent Results and Prospects of the International Muon Ionization Cooling Experiment (MICE)

C. T. Rogers on behalf of the MICE collaboration,
ASTeC Intense Beams Group
STFC Rutherford Appleton Laboratory

Cooling for Muon Accelerators

- There is a compelling case to build high energy muon accelerators
  - How can we get muon beams so that we can accelerate them?
  - Ionisation Cooling!
- How can we demonstrate that such a principle can work in reality?
- **The international Muon Ionisation Cooling Experiment**
  - Situated next to ISIS synchrotron at RAL

Ionisation Cooling

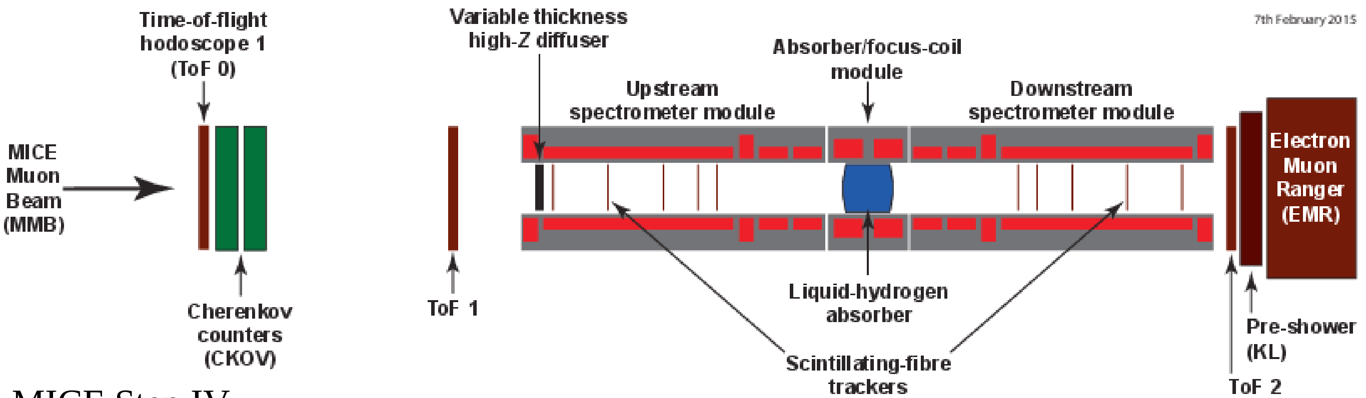


- Cooling achieved by ionisation energy loss
  - Absorber removes momentum in all directions
  - RF cavity replaces momentum only in longitudinal direction
  - End up with beam that is less divergent
- Stochastic effects limit cooling
  - Multiple Coulomb Scattering increases transverse emittance
- Tight focus reduces relative effect of scattering
- Low Z material reduces scattering
  - E.g. lithium hydride or liquid hydrogen
- Equilibrium emittance where the two effects balance

Questions

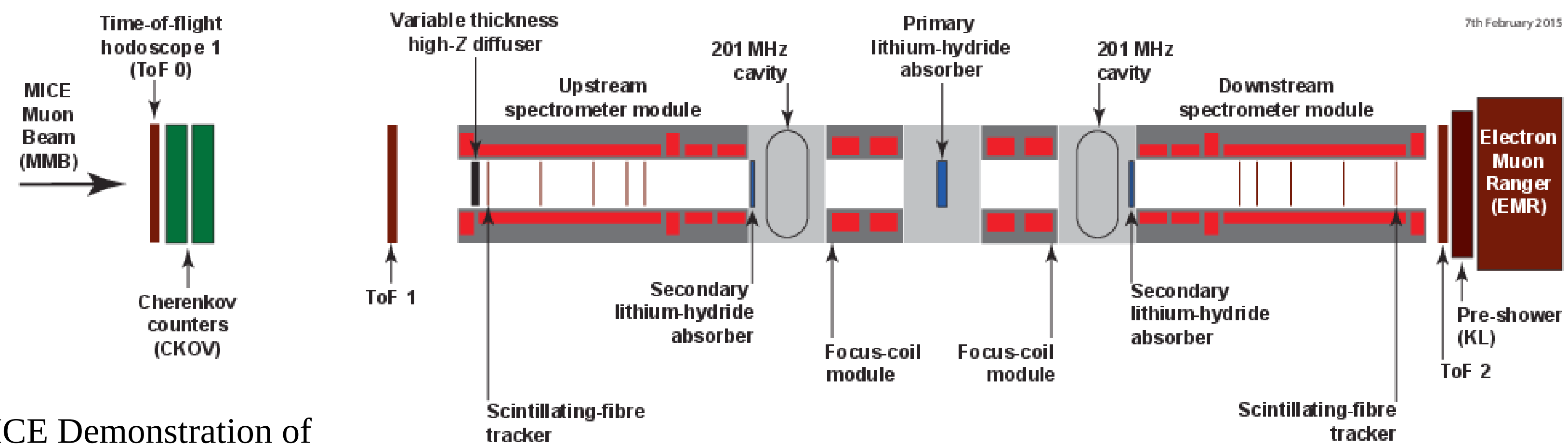
- Can we safely operate liquid hydrogen absorbers?
- Can we operate such a tightly packed lattice?
- Do we see the expected emittance change?
- Do we see the expected transmission?

The answer - MICE



2015/2016

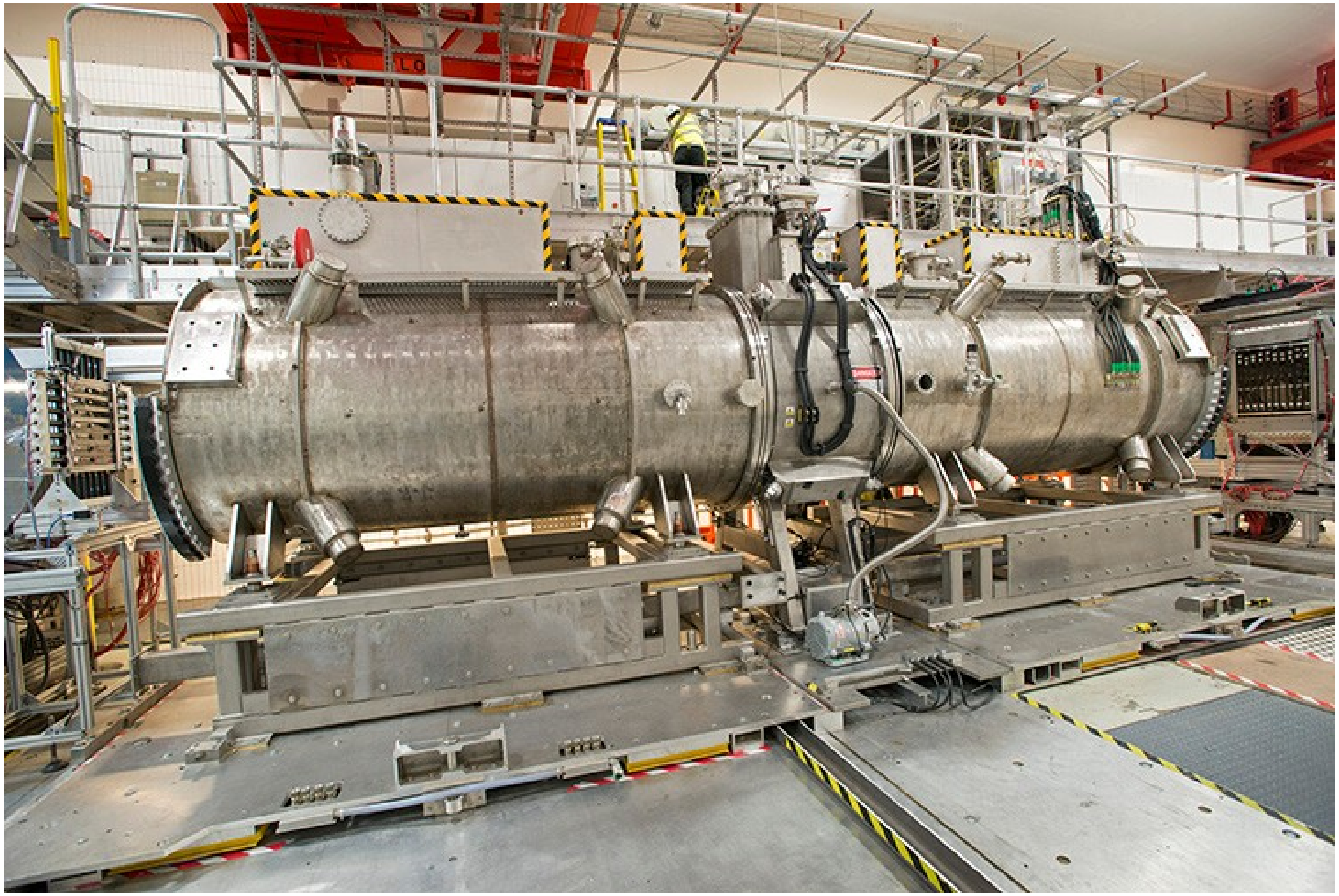
MICE Step IV



2017

MICE Demonstration of Ionisation Cooling

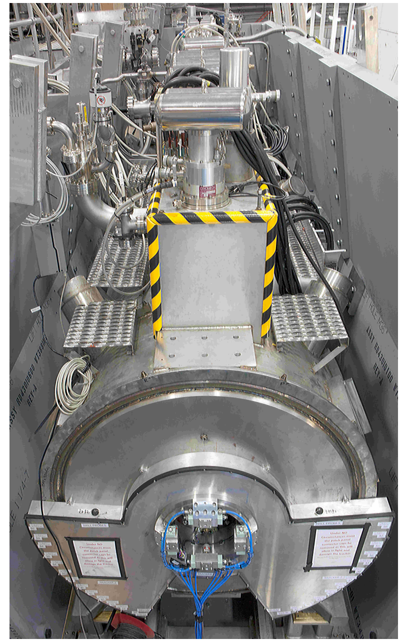
The answer - MICE



MICE Highlights and Challenges

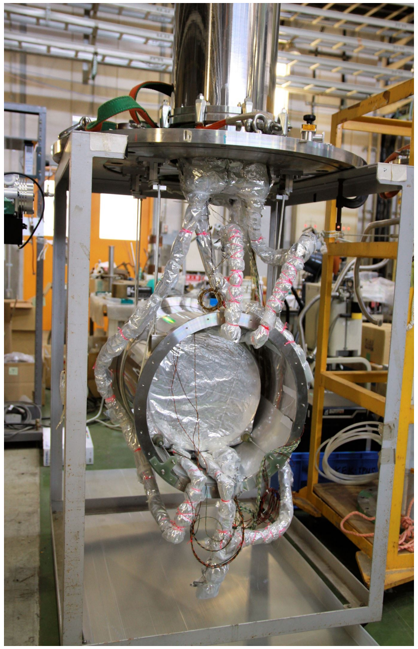
- High resolution particle-by-particle diagnostics
  - Measure individual particle's position and momentum to get fully correlated beam measurements
  - Reject beam impurities
- High aperture superconducting magnets
  - Upstream and Downstream Spectrometer Solenoids (SSU and SSD)
  - Focus coils (FC)
  - Magnetically coupled – mutually induced quench
- High gradient RF cavities
  - Two 10 MV/m, 201.25 MHz RF cavities
  - 4 MW peak RF power
  - Particle-by-particle phase measurement
- Liquid hydrogen and lithium hydride absorbers
  - 21 litres lH_2 in 150 micron thick containment vessel
  - 65 mm thick lithium hydride disk

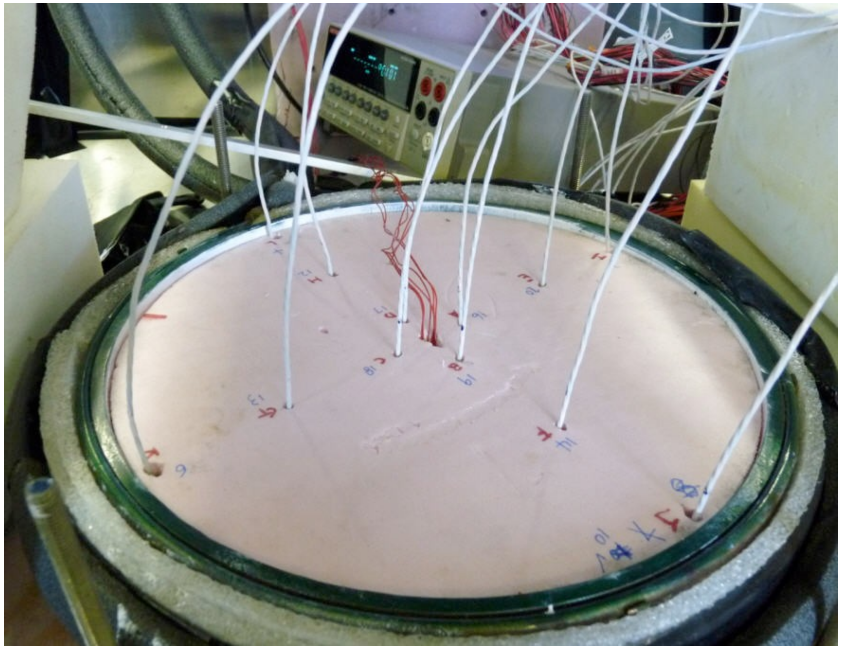
Superconducting Magnets



- Focus Coil on the beamline and cooling down
- SSU fully trained to operating field; awaiting soak test
- SSD retraining in-situ in progress
- Failure of LTS lead on MatchCoil1 in SSD
  - Key physics measurements still available
  - Repair plan in preparation after Step IV

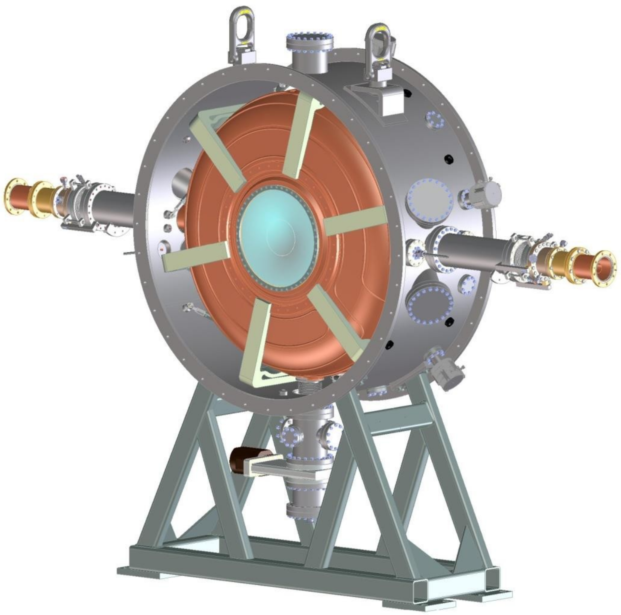
Absorber

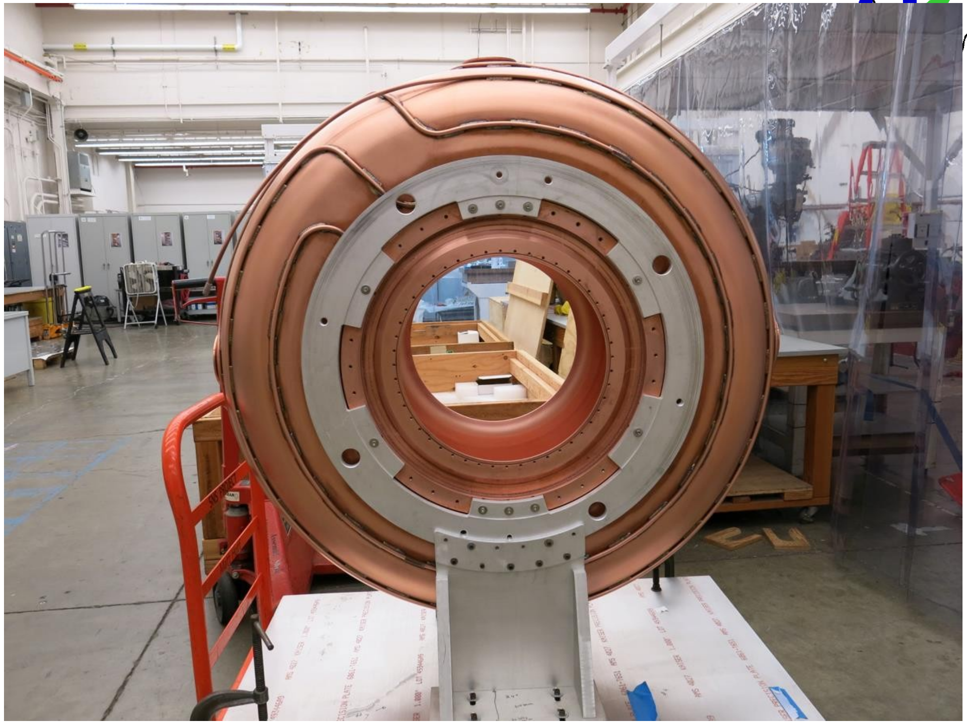




- 350 mm thick liquid hydrogen absorber
  - 21 litres
  - Enclosed by four 150 micron windows
  - Installed
- 65 mm lithium hydride absorber
  - Will be installed, replacing lH_2 absorber, early in 2016 for Step IV

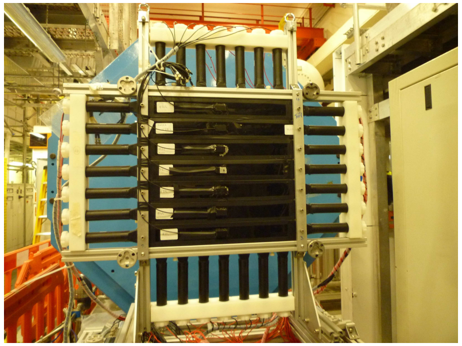
RF

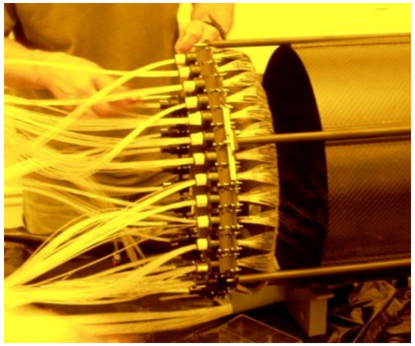


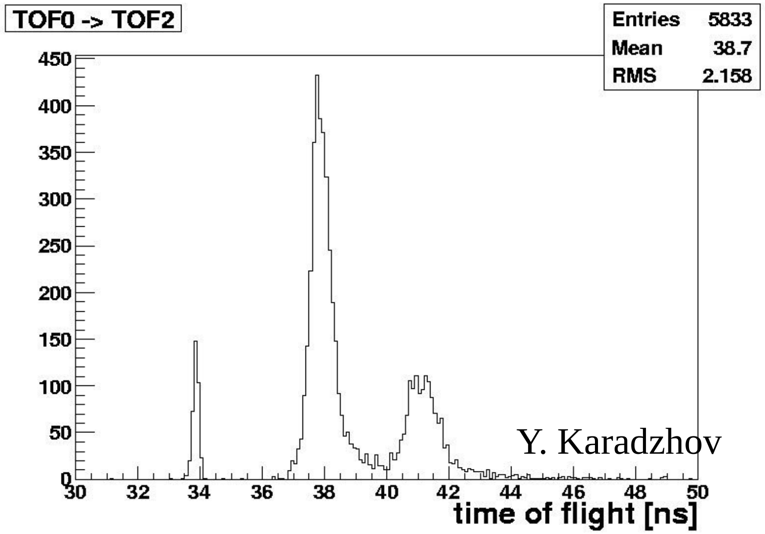


- Two normal conducting RF cavities
- 201.25 MHz, 10 MV/m
- Beryllium windows provide enhanced on-axis fields
- Successful operation in magnetic field in 2015 at MTA
- Installed 2016-2017, following Step IV

Diagnostics





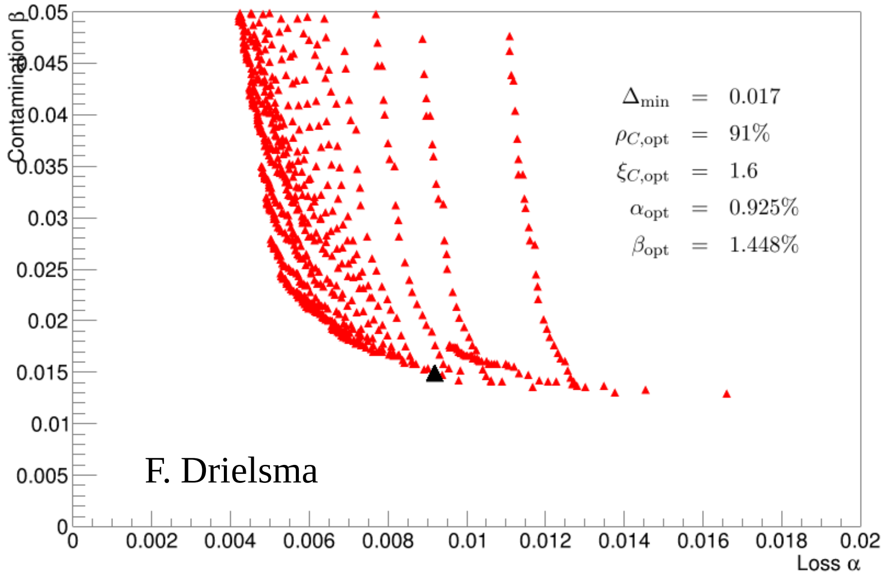


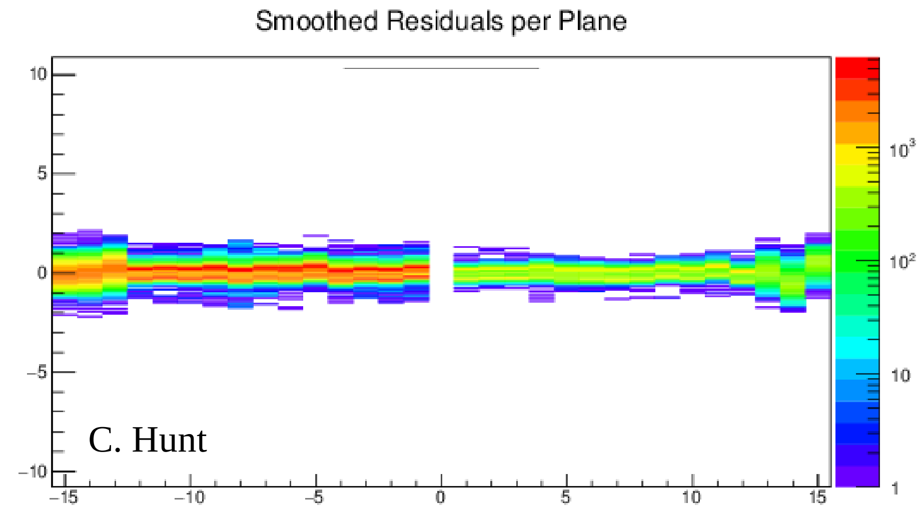
- Three scintillating TOF stations
  - Time resolution ~ 50 ps
  - Commissioned in 2009
- Two Scintillating Fibre Trackers
  - Position resolution ~ 0.7 mm
  - Simulated momentum resolution ~ 2 MeV/c
- Threshold Cerenkov counter
- KL pre-shower detector
- Electron-muon ranger

Beam Measurement Status

- Commission PID Detectors - **done**
- Commission trackers – **95 % complete**
- Beam-based alignment **– 20 % complete**
- Demonstration of beam transport/optics **– 0 % complete**
- Normalised transverse emittance reduction **– 0 % complete**
- Material physics measurements **– 0 % complete**

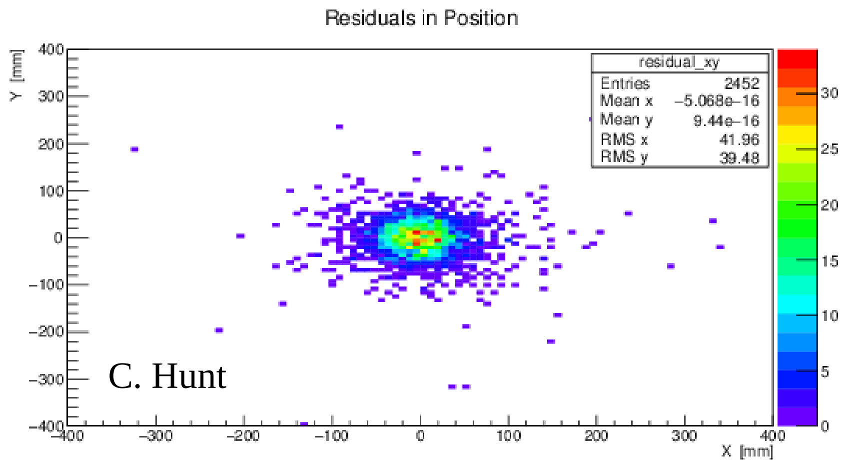
Detector Commissioning

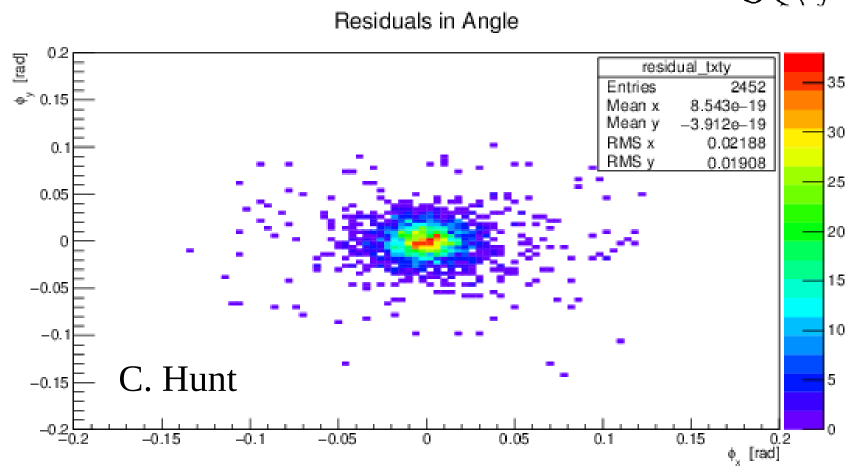




- PID detectors commissioned 2010-2013
  - EMR last PID detector to be commissioned in 2013
- Tracker commissioned June 2015
  - Awaits final push to improve efficiency

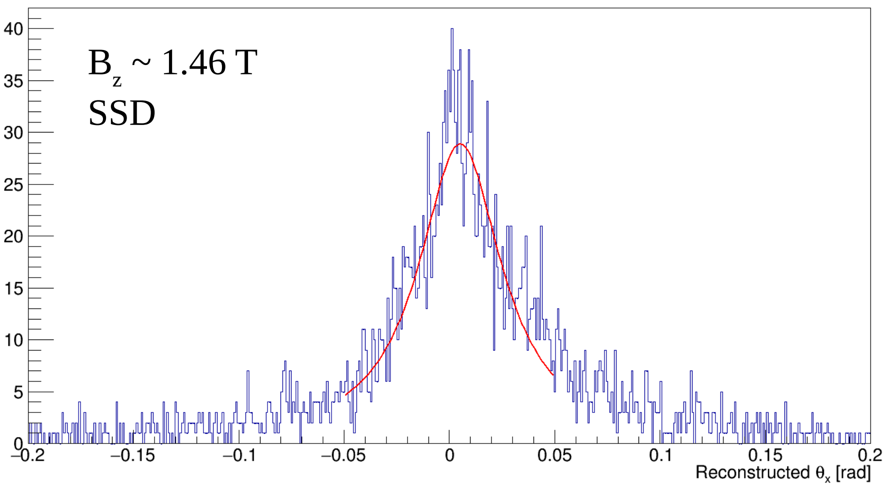
Beam-based Detector Alignment

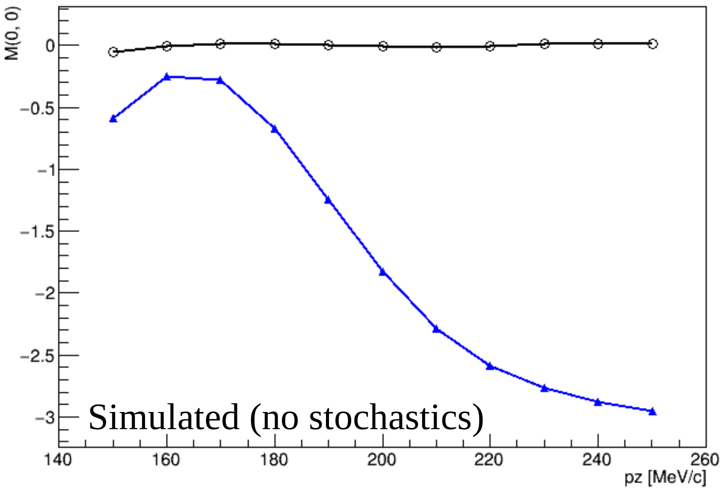




- Beam based alignment of detectors
  - Project measured tracks between detectors with magnets off
  - Compare position of tracks with expected position
    - Spread in positions due to scattering in windows
  - Alignments at (expected) mm/mrad level
    - Final numbers await error analysis

Beam-based Magnet Alignment



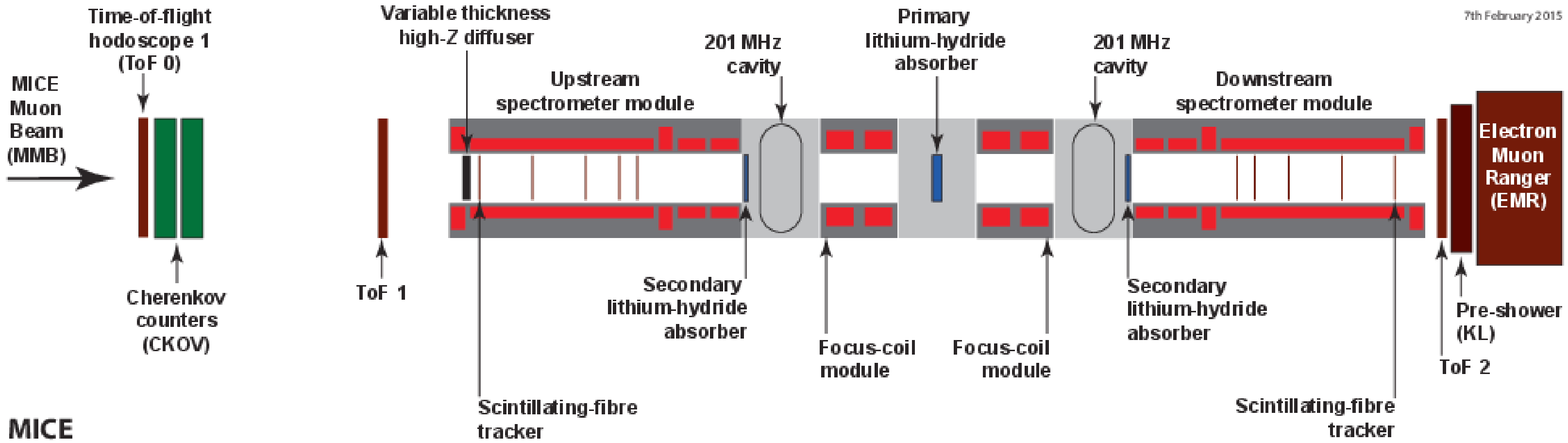


- Beam-based alignment of solenoid tilt to tracker
  - Examine alignment of helix formed by each particle
  - Find “best fit tilt”
  - Systematic errors which we are working on
- Beam-based alignment of trackers to magnets
  - Project particles from tracker to tracker, with magnets on
  - Calculate transfer matrix; compare with expected transfer matrix

Step IV Plans

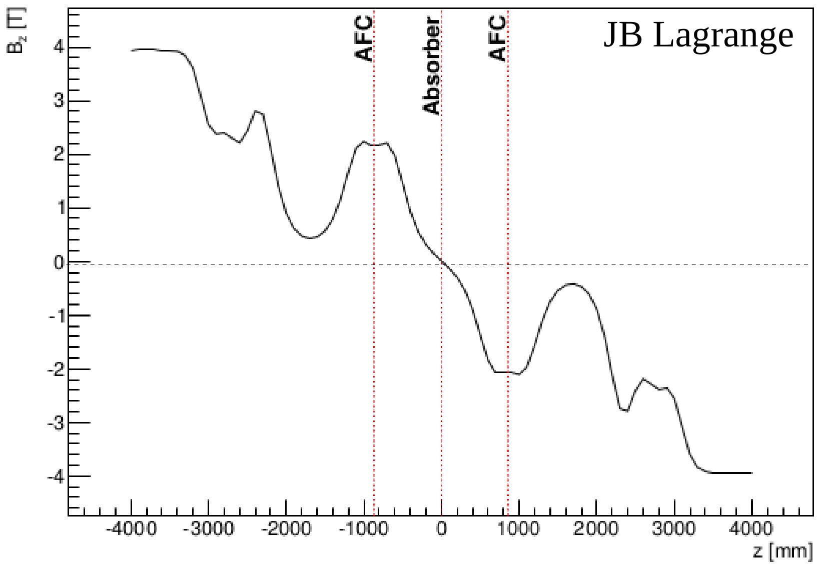
- Continue beam based alignment
  - Alignment with solenoids at full fields (4 T)
- Characterise diagnostics
  - Rejection of beam impurities
  - Resolution of phase space variables
- Demonstrate beam optics
  - Linear and non-linear optics
  - Material budget in the beamline
  - Emittance change in the absence of an absorber
- Study normalised emittance reduction
  - Under a variety of beam conditions
- Characterise absorber
  - Energy loss
  - Multiple Coulomb scattering

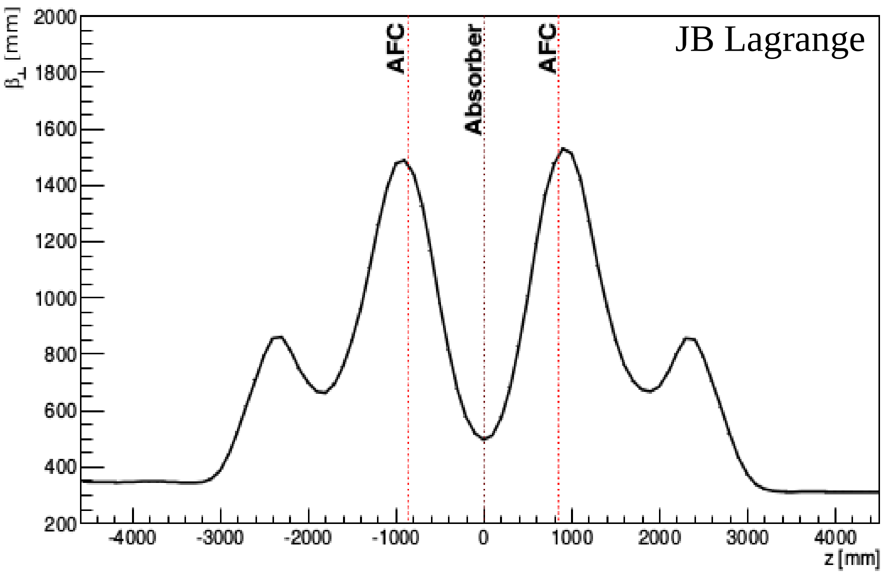
Demonstration of Ionisation Cooling



- MICE "Demonstration of Ionisation Cooling"
  - Redesign of MICE Step VI given lessons learnt during Step IV construction
  - Includes a full cooling half-cell
  - Includes RF cavities
- Shows geometric emittance reduction including reacceleration

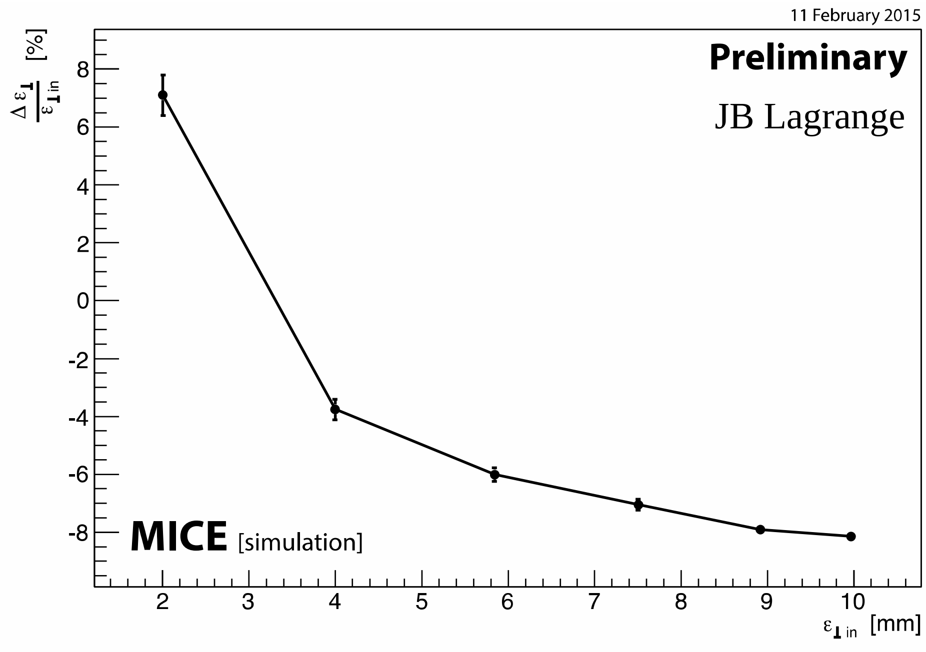
Demonstration of Ionisation Cooling





- Two Focus coil modules
- Lithium hydride absorber and two secondary absorbers
- Two RF cavities

Performance



- Equilibrium emittance around 3 mm – to be measured
- Acceptance around 10 mm – to be measured

Conclusions

- Muon accelerators have the potential to:
  - Make definitive measurements of neutrino oscillations at the Neutrino Factory
  - Make detailed measurements as a Higgs factory
  - Provide multi-TeV lepton-antilepton collisions at the Muon Collider
- Ionisation cooling is critical enabling technique for muon accelerators
- MICE Step IV is in final stages of commissioning
  - Will demonstrate normalised emittance reduction
- MICE Demonstration of Ionisation Cooling is in final design stage
  - Will demonstrate emittance reduction and reacceleration
  - Construction commences summer 2016