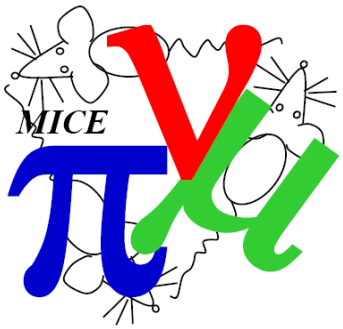


University of Glasgow

MICE 4D Cooling Programme

Proton Accelerators for Science and Innovation Workshop

Fermilab, 12-14 January 2012

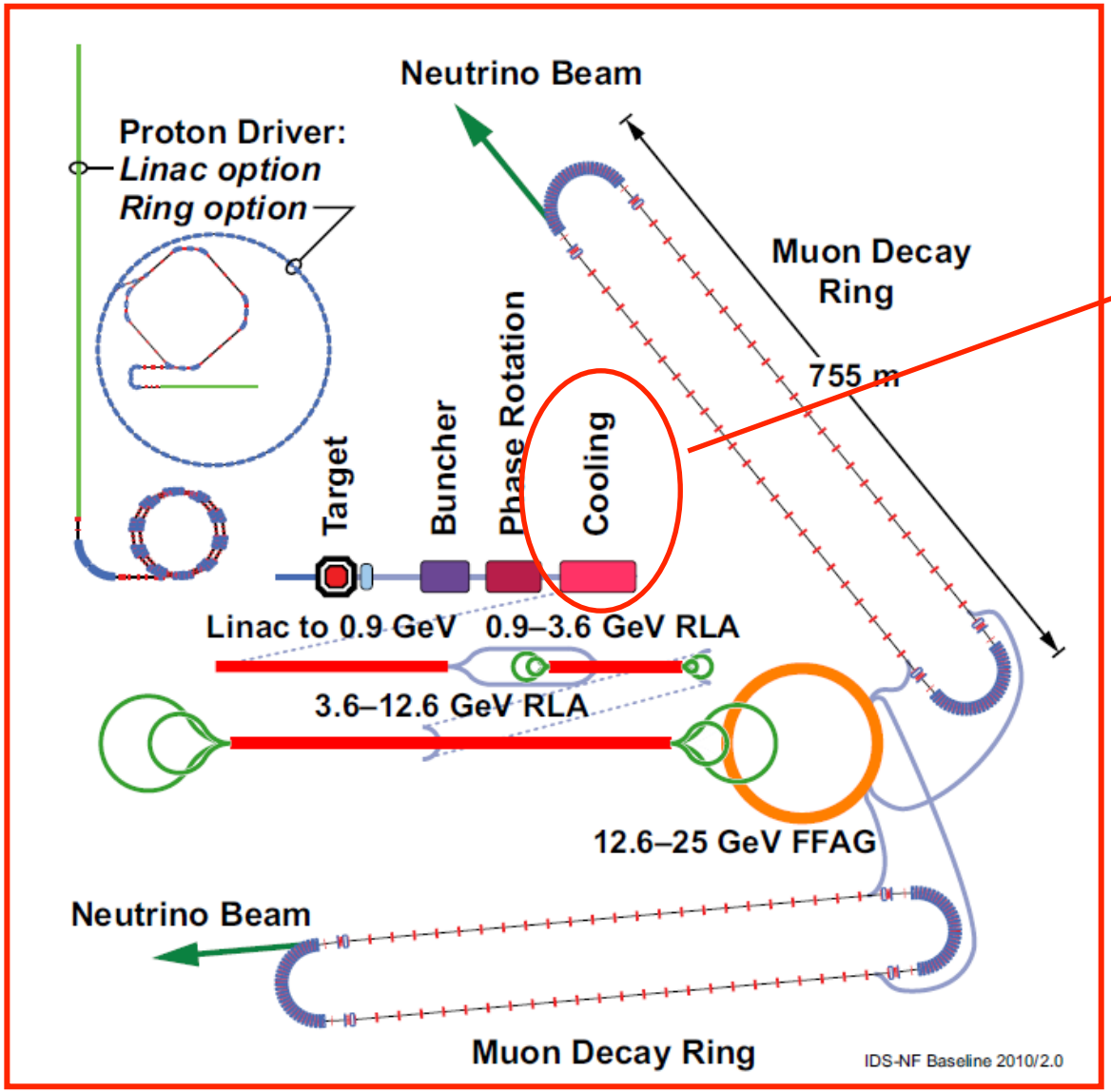
Paul Soler

on behalf of the MICE Collaboration

Contents

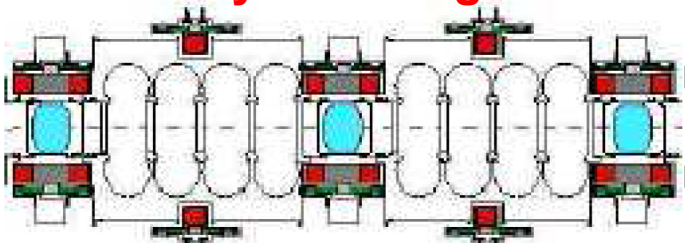
1. Motivation for MICE: Neutrino Factory and Muon Collider
2. MICE aims
3. Ionization cooling
4. Description of MICE
5. MICE achievements
6. MICE Step IV, V and VI preparations

Neutrino Factory



4D muon ionization cooling essential for 10^{21} μ/year

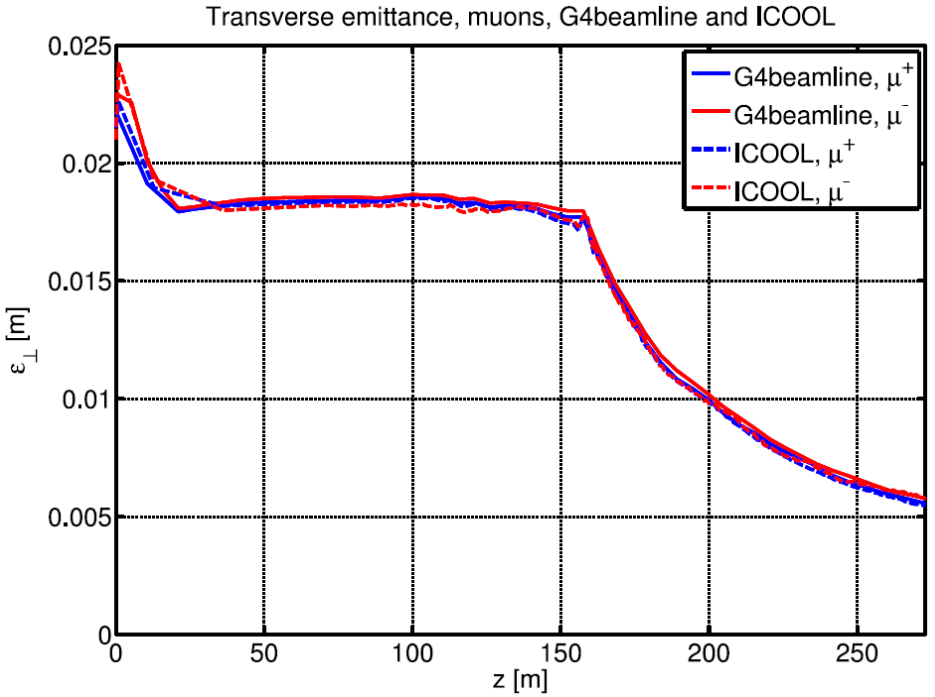
Study II cooling cell

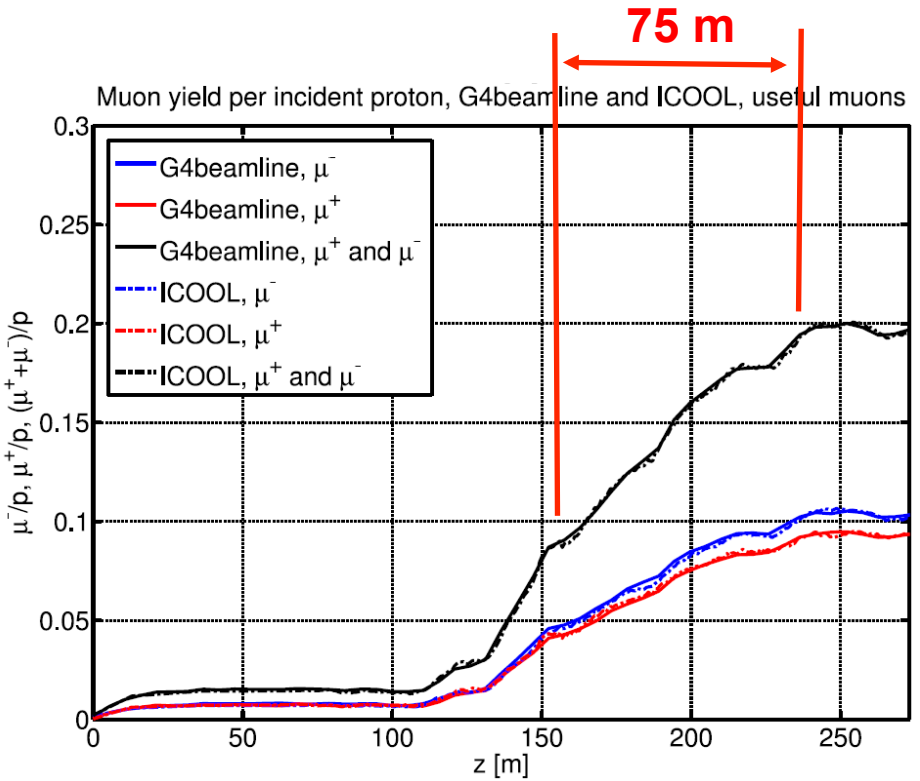


International Design Study for a Neutrino Factory Interim Design Report IDS-NF-020

Neutrino Factory

- Cooling essential to deliver Neutrino Factory performance



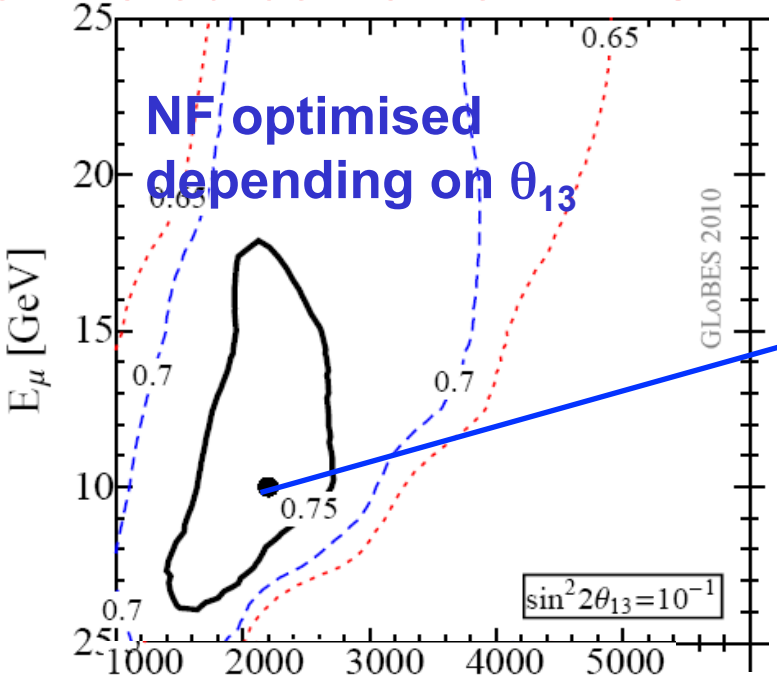


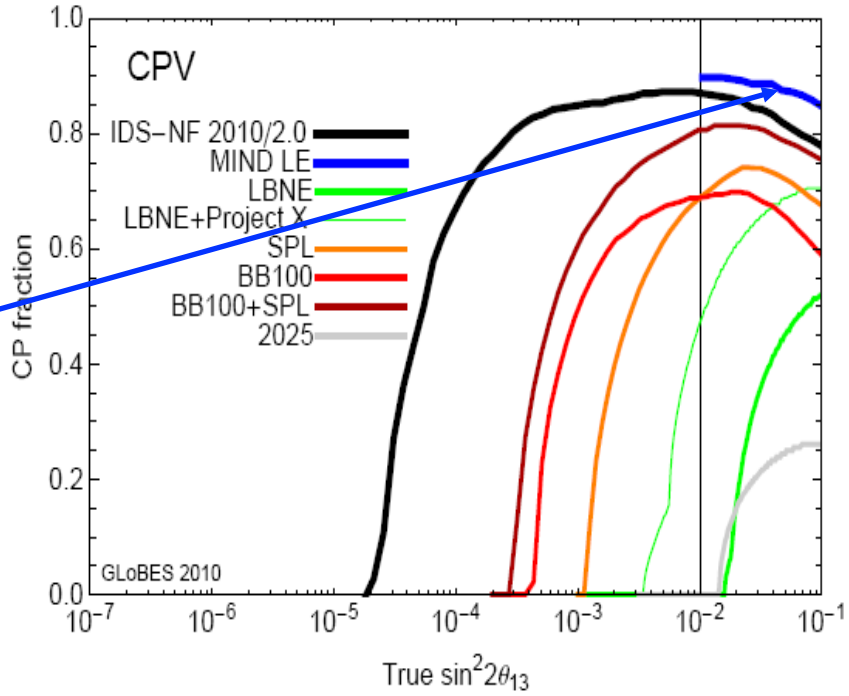
Emittance: 18 mm rad→7.5 mm rad **Muon yield: 0.08 μ/prot→0.19 μ/prot**

Increase in performance: 2.4

Neutrino Factory

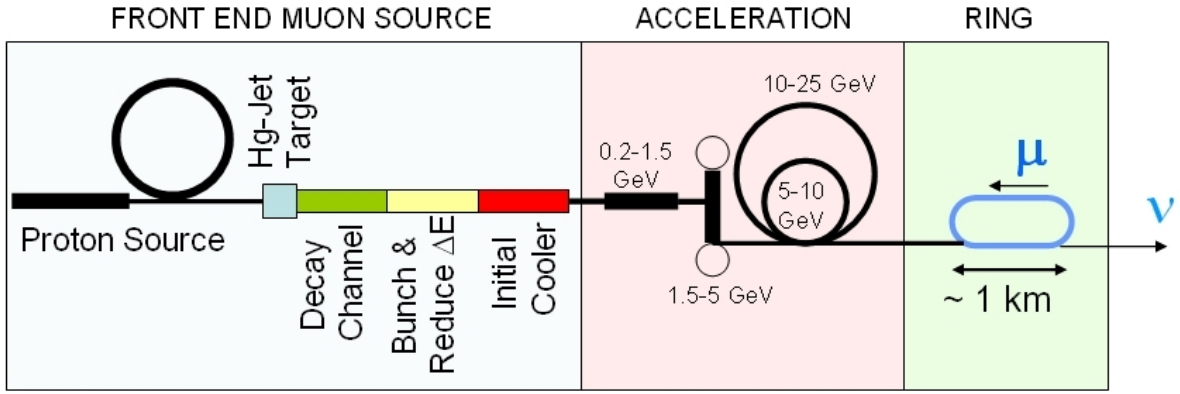
- Neutrino Factory optimisation depends on value of θ_{13}
- At $\sin^2 2\theta_{13}$~0.1 optimum is ~10 GeV NF with ~2000 km baseline
- Neutrino Factory offers best sensitivity and smallest $\Delta\delta_{CP}$ ~ 5º out of all future facilities, regardless of value of θ_{13}
- Consensus from NUFACT11 summary talks (de Gouvea): physics of NF (CP violation and LFV) unique regardless of the outcome from LHC



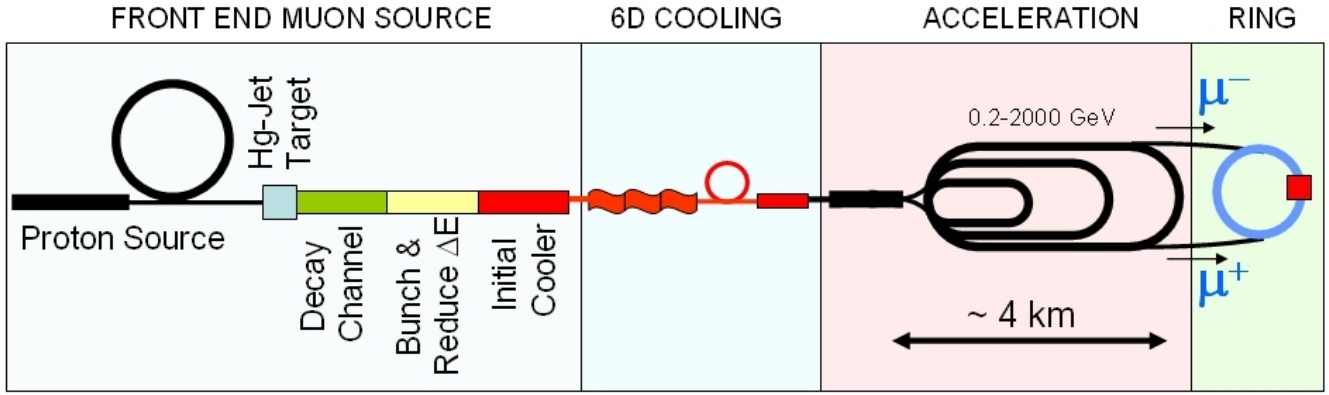


Muon Collider

- At the energy frontier, a multi-TeV muon collider fits inside most major laboratories, has better energy resolution than e^+e^- linear colliders and has enhanced coupling to the Higgs
  - A Muon Collider requires 6D ionization cooling
  - A Neutrino Factory is the first step towards a Muon Collider



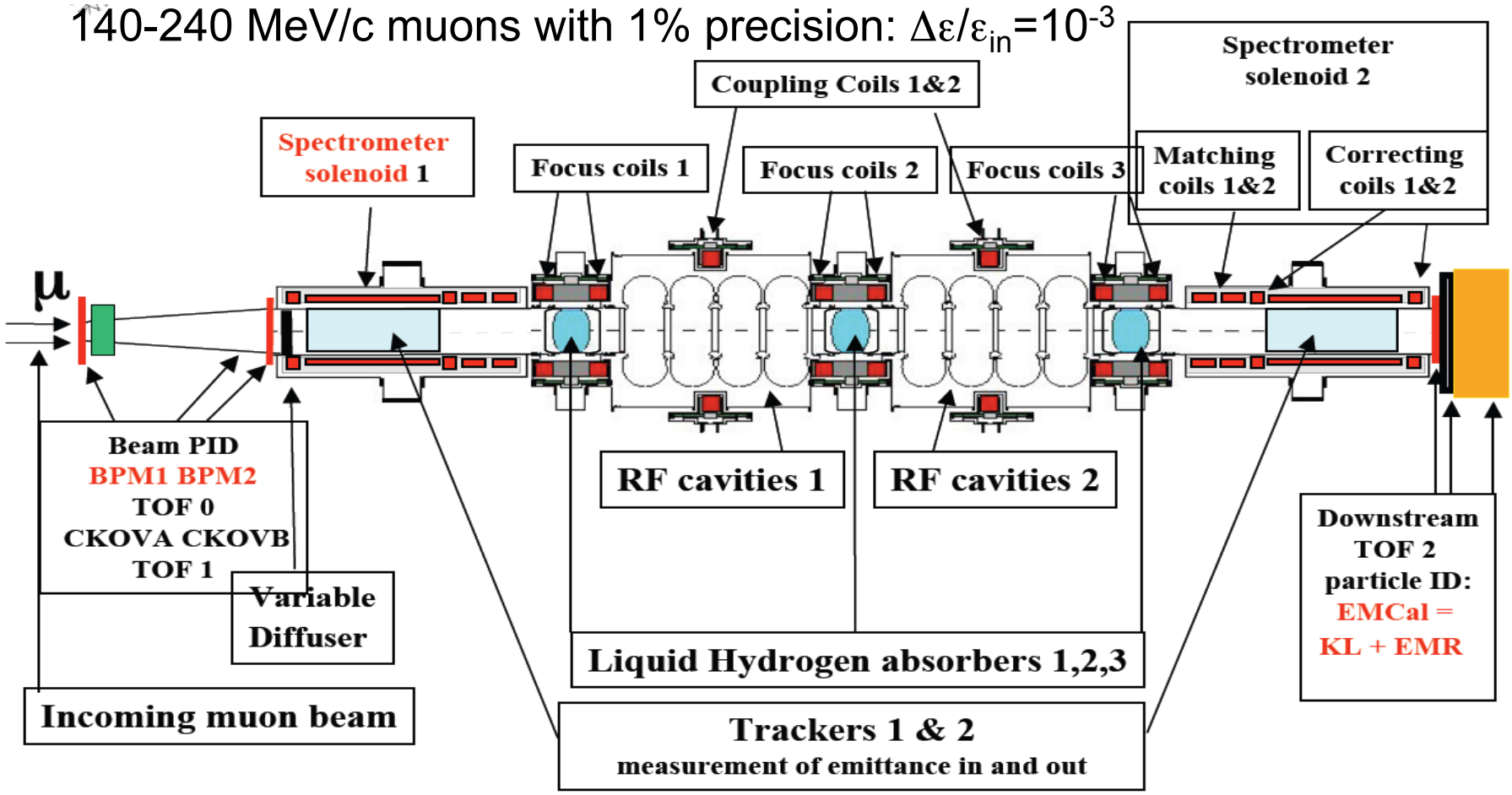
NEUTRINO FACTORY



MUON COLLIDER

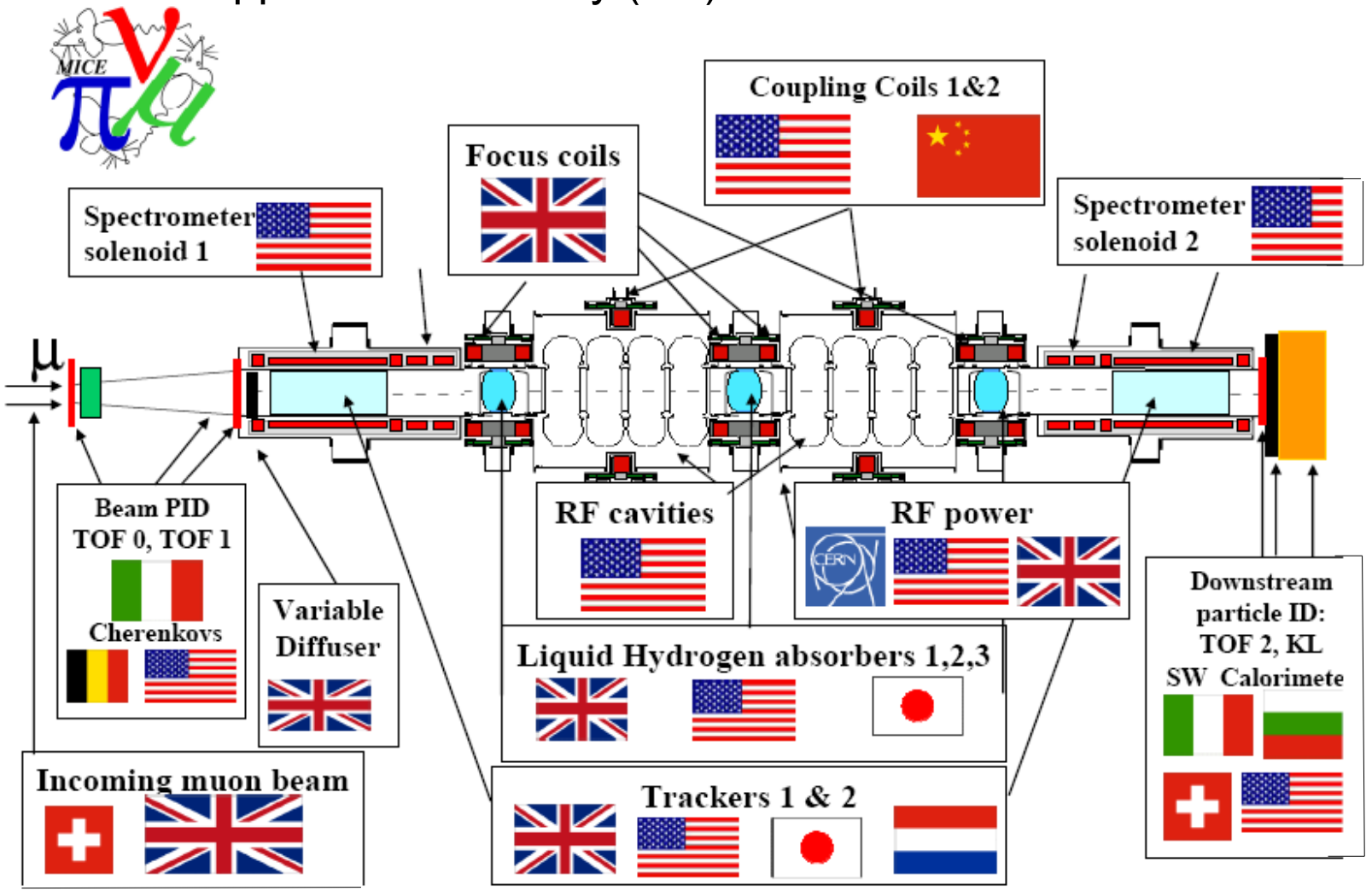
MICE aims

- The Muon Ionization Cooling Experiment (MICE) is a UNIQUE facility at RAL to measure muon ionization cooling in a cell of the NF Study II design
- Absorbers: liquid hydrogen and other low Z absorbers (LiH).
- The aim of MICE is to measure ~10% emittance reduction (cooling) from 140-240 MeV/c muons with 1% precision: $\Delta\varepsilon/\varepsilon_{in}=10^{-3}$



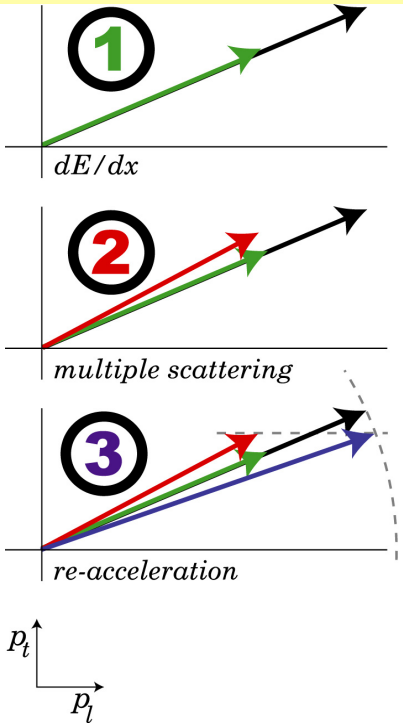
MICE Collaboration

- International Muon Ionization Cooling Experiment (MICE): Belgium, Bulgaria, China, Holland, Italy, Japan, Switzerland, UK, USA based at Rutherford Appleton Laboratory (UK): ~150 collaborators

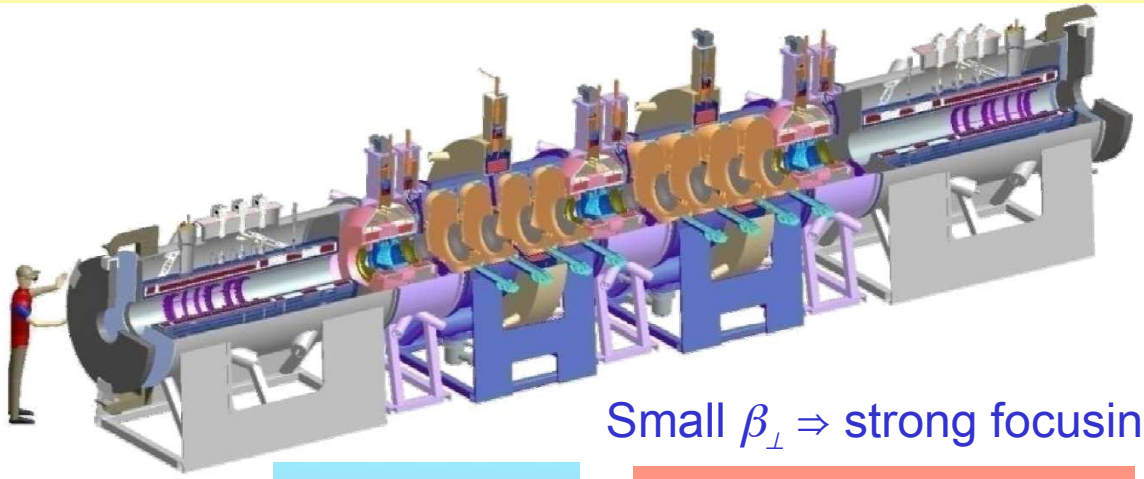


Ionization Cooling

Principle



Practice



Small $\beta_\perp \Rightarrow$ strong focusing

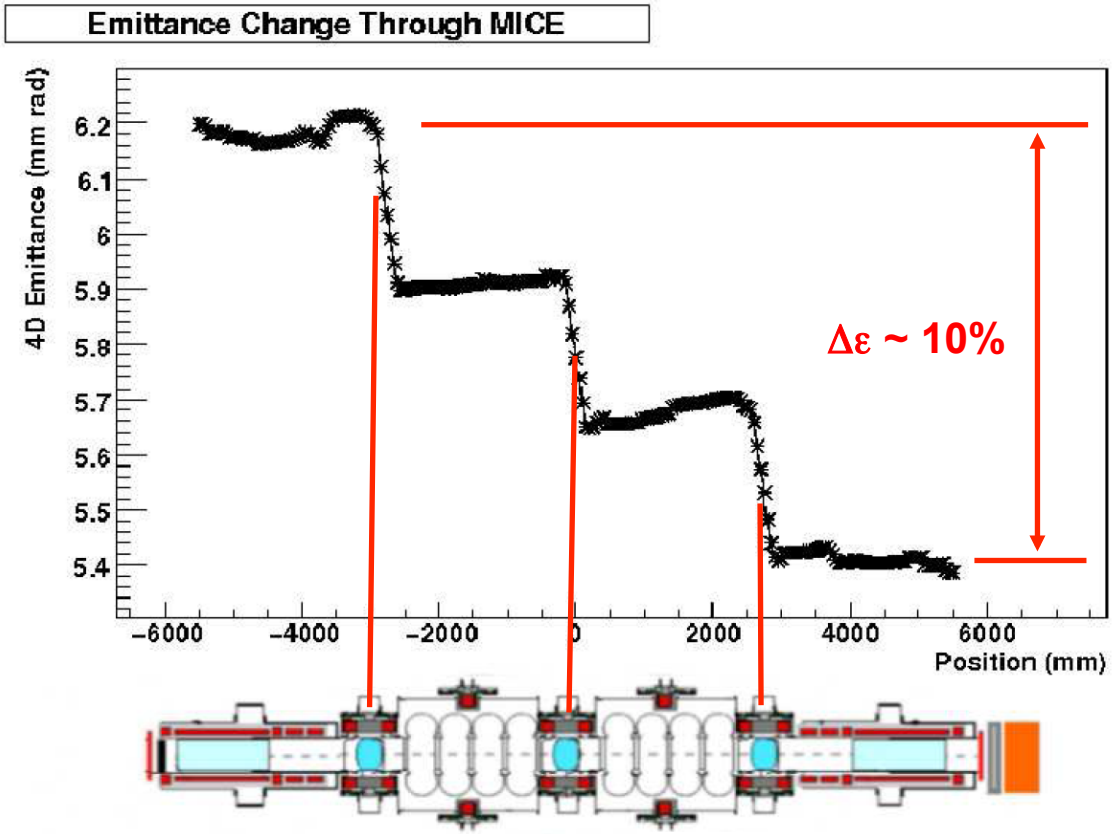
$$\frac{d\varepsilon}{dz} \approx -\frac{\varepsilon}{E_\mu \beta^2}\frac{dE_\mu}{dz} + \frac{\beta_\perp}{2m\beta^3}\frac{(13.6\,MeV)^2}{E_\mu X_0}$$

Ionization: cooling term

Multiple scattering: heating term

- Goals of MICE:
  - design, engineer, and build a section of cooling channel
  - measure performance under different beam conditions
  - show that design tools (simulation codes) agree with experiment
  - demonstrate operation LH_2 close to high gradient RF in high B fields

Expected cooling performance

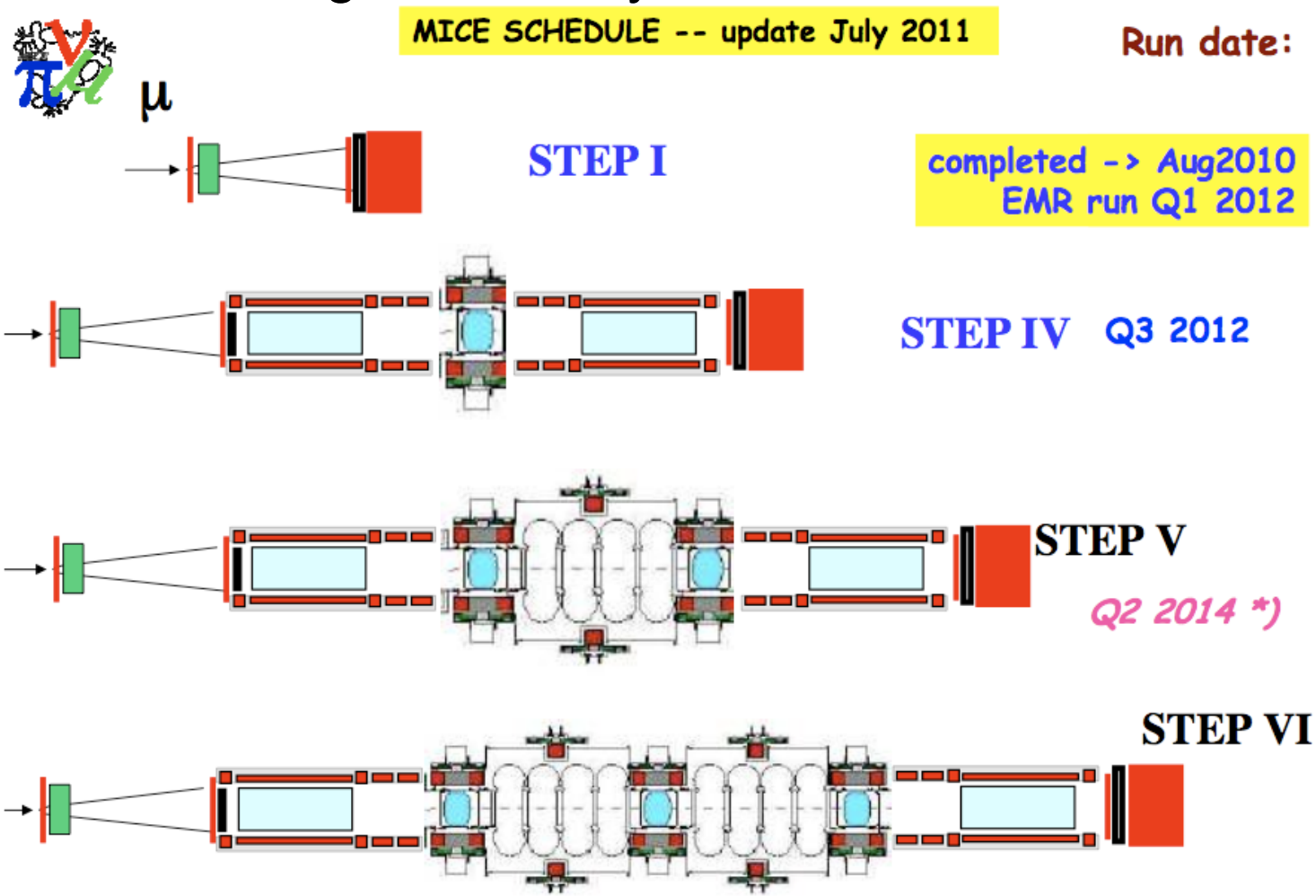


Change in emittance at absorber: $\frac{\Delta\varepsilon}{\varepsilon} = -\frac{\Delta p}{p}\left(1 - \frac{\varepsilon_0}{\varepsilon}\right)$

Equilibrium emittance for H_2: $\varepsilon_0 \sim 2.5$ mm-radians

MICE

- MICE schedule agreed at July 2011 collaboration meeting:

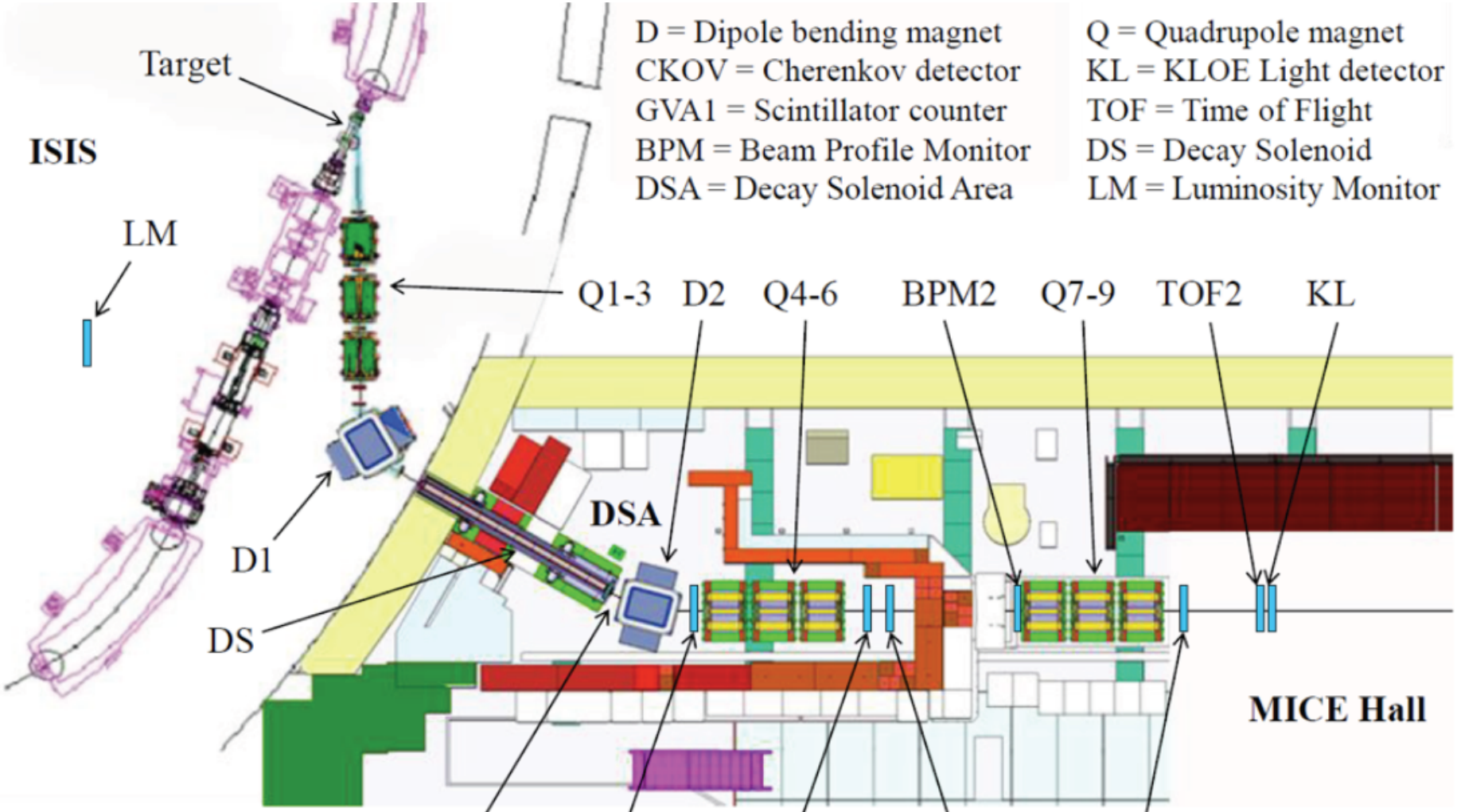


*) target date, necessary to run step V before long ISIS shut-down Aug.2014-Feb.2015

Skip steps II, III/III.1

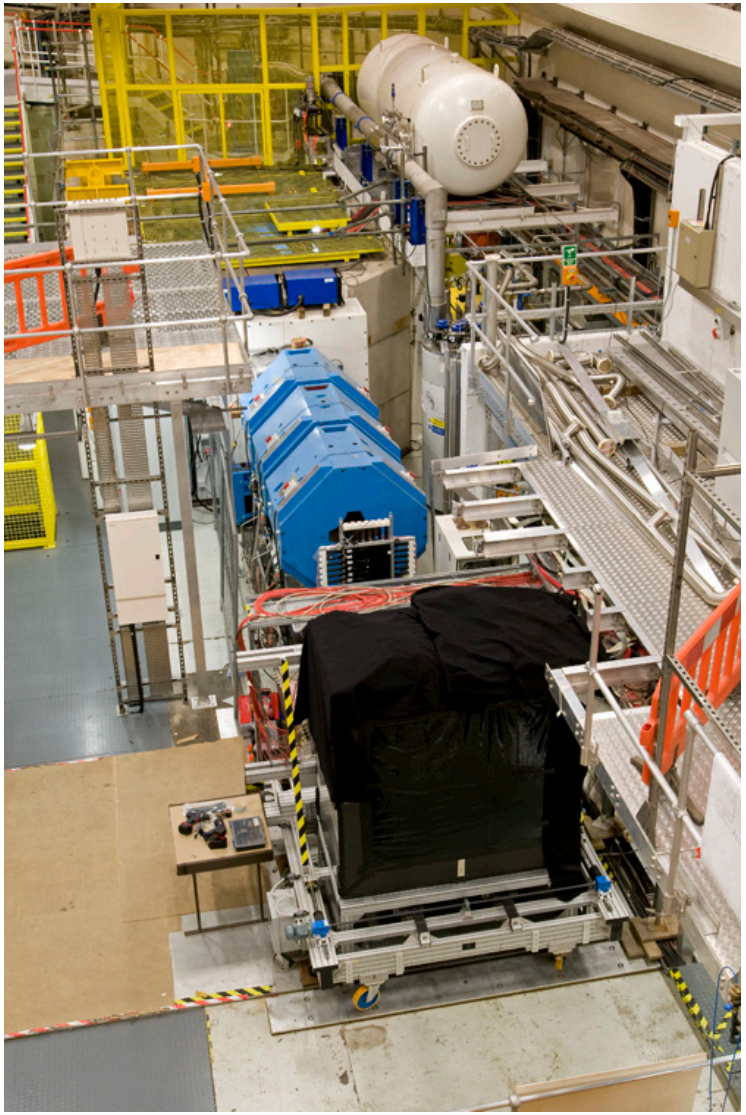
MICE achievements

- MICE beam and instrumentation fully constructed and operational



MICE beam line

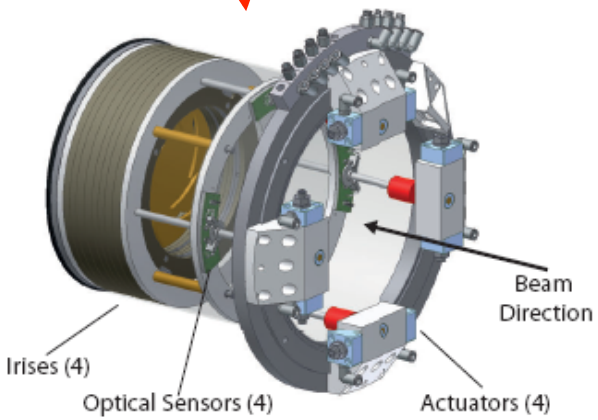
MICE achievements

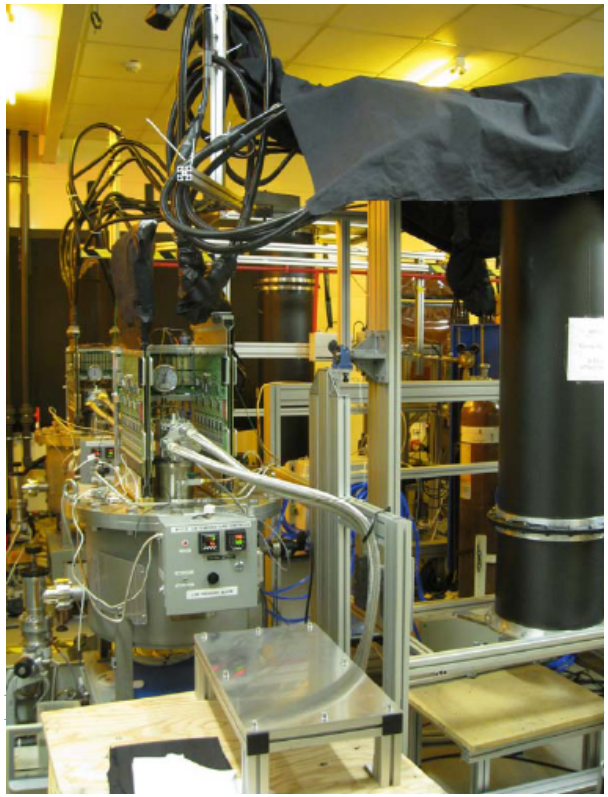


MICE beam line (UK)

MICE achievements

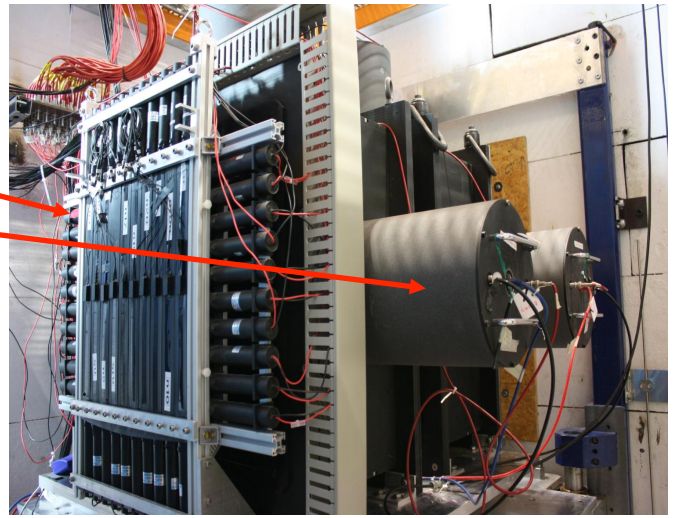
- Further achievements (UK):
  - MICE infrastructure and beam line
  - MICE target and target mechanism →
  - Luminosity monitor
  - Scintillating fibre tracker (UK/USA/Japan)
  - Diffuser

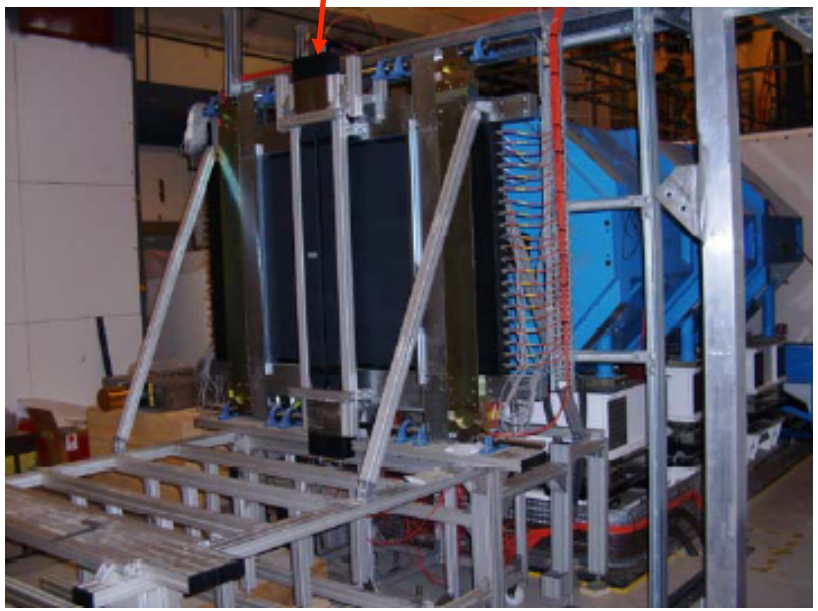


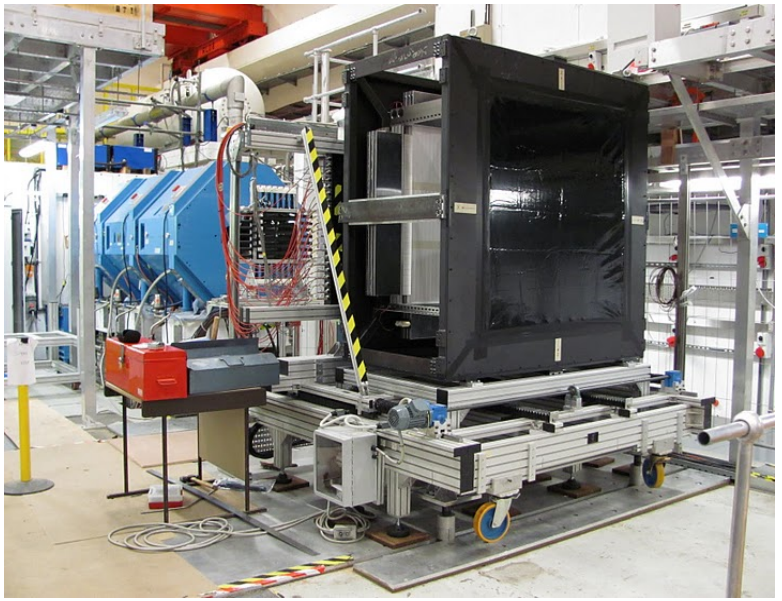


MICE achievements

- Instrumentation MICE beam line:
  - Time of flight counters (TOF0,1,2) - Italy
  - Cherenkov counters (CKOV) - USA
  - Kloe-light (KL) – preshower detector (Italy)
  - Beam position monitors (USA)
  - Electron-Muon Ranger – Geneva/USA

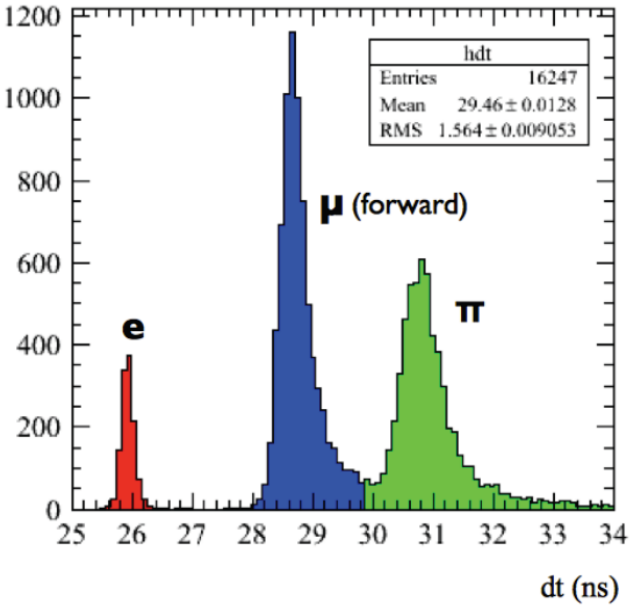


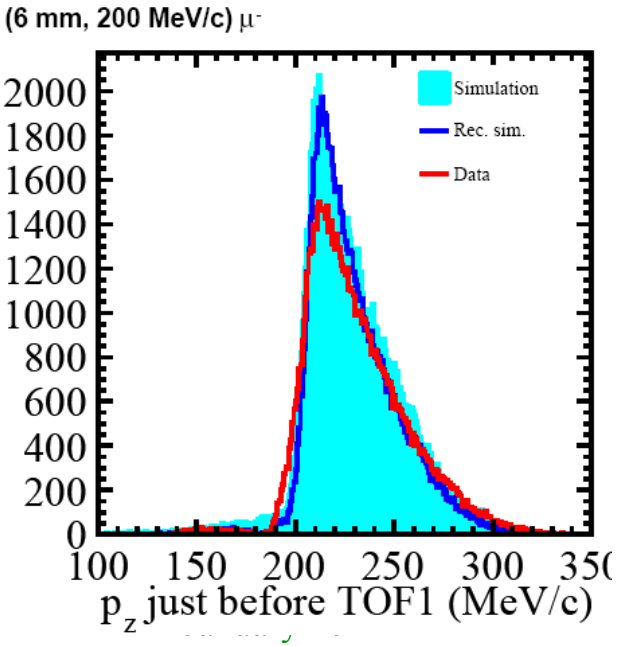


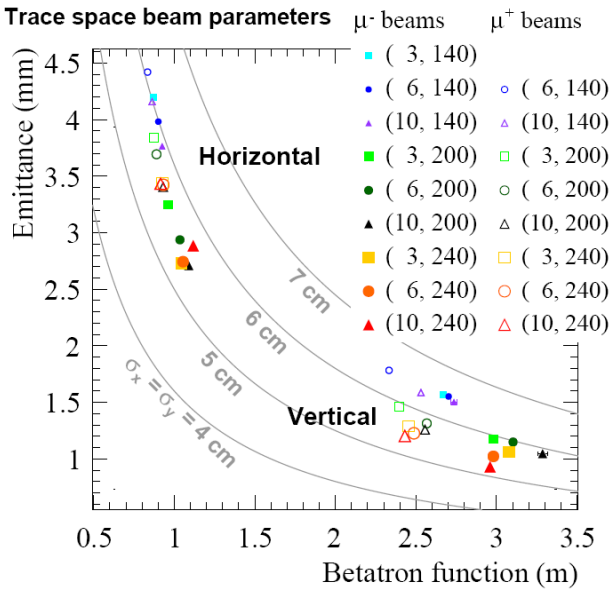


MICE achievements

- UK leadership in physics analyses for Step I:
  - Developed novel method to measure emittance using TOF
  - Measured nine elements of (ε,p) matrix for positive and negative particles (ε = 3, 6, 10 mm rad; p = 140, 200, 240 MeV/c)
- MICE Step I completed: two papers in preparation
  - **The Beam Line and Instrumentation of the Muon Ionization Cooling Experiment at ISIS**
  - A First Measurement of the Emittance of the MICE Muon Beam







MICE achievements

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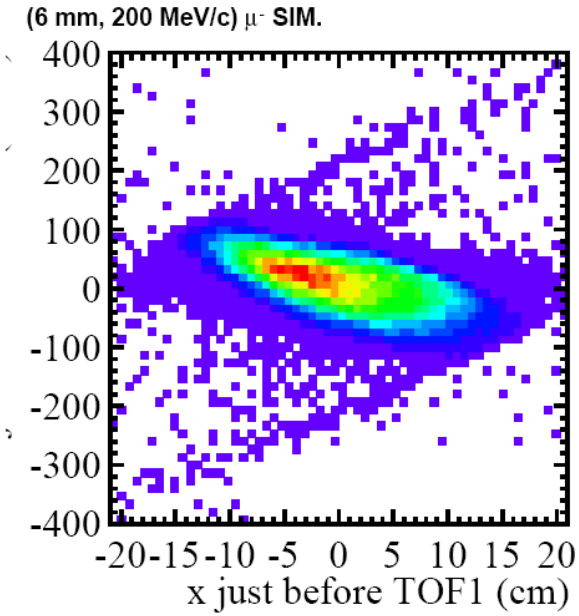
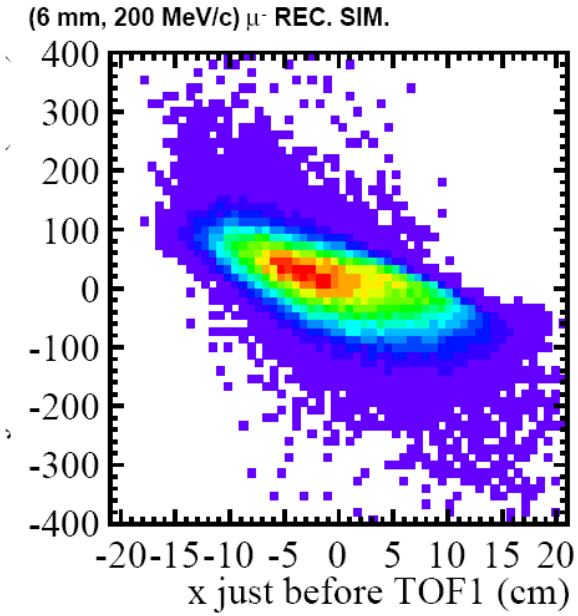
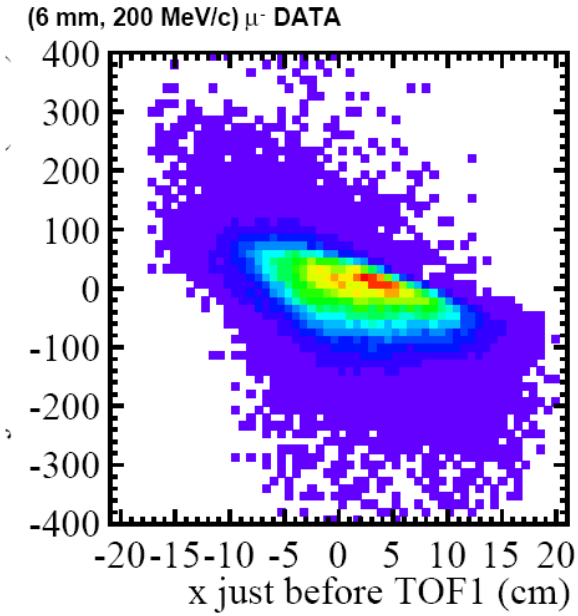
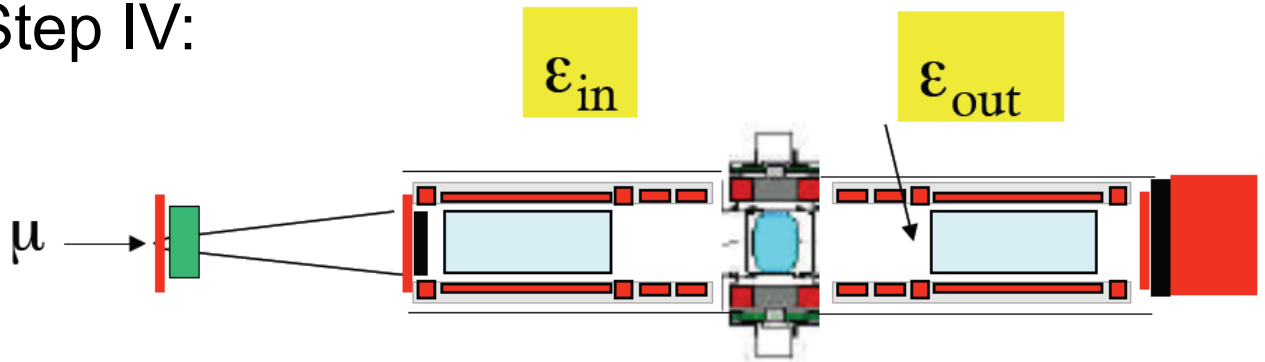




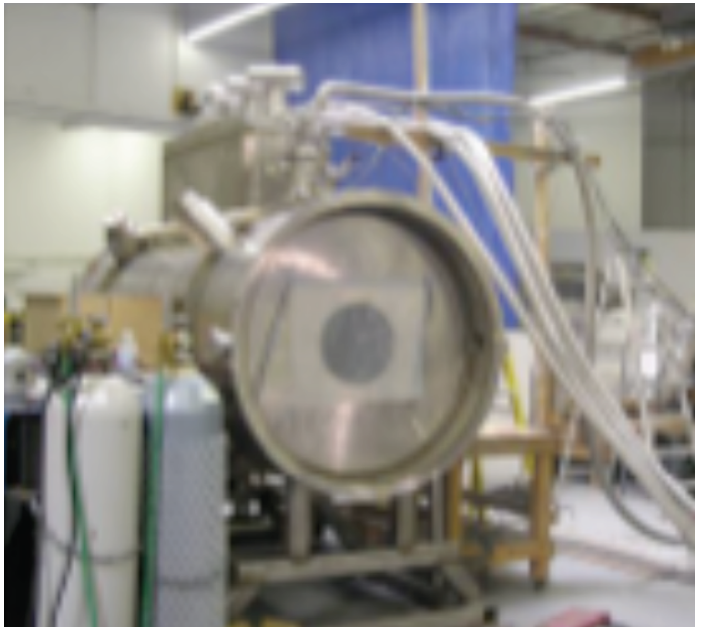


MICE Step IV Preparations

- MICE Step IV:



  - Install spectrometer solenoids, trackers and absorber by Q4 2012
  - Problems with design and manufacture of spectrometer solenoids: could not sustain temp quenched before achieving design current
  - Re-scoping of solenoid project under leadership of S. Gourlay (LBNL, Accelerator and Fusion Research Division)
  - Collaboration LBNL, FNAL, Wang NMR, STFC – UK/USA collaboration
  - Good progress in rebuilding spectrometer solenoids



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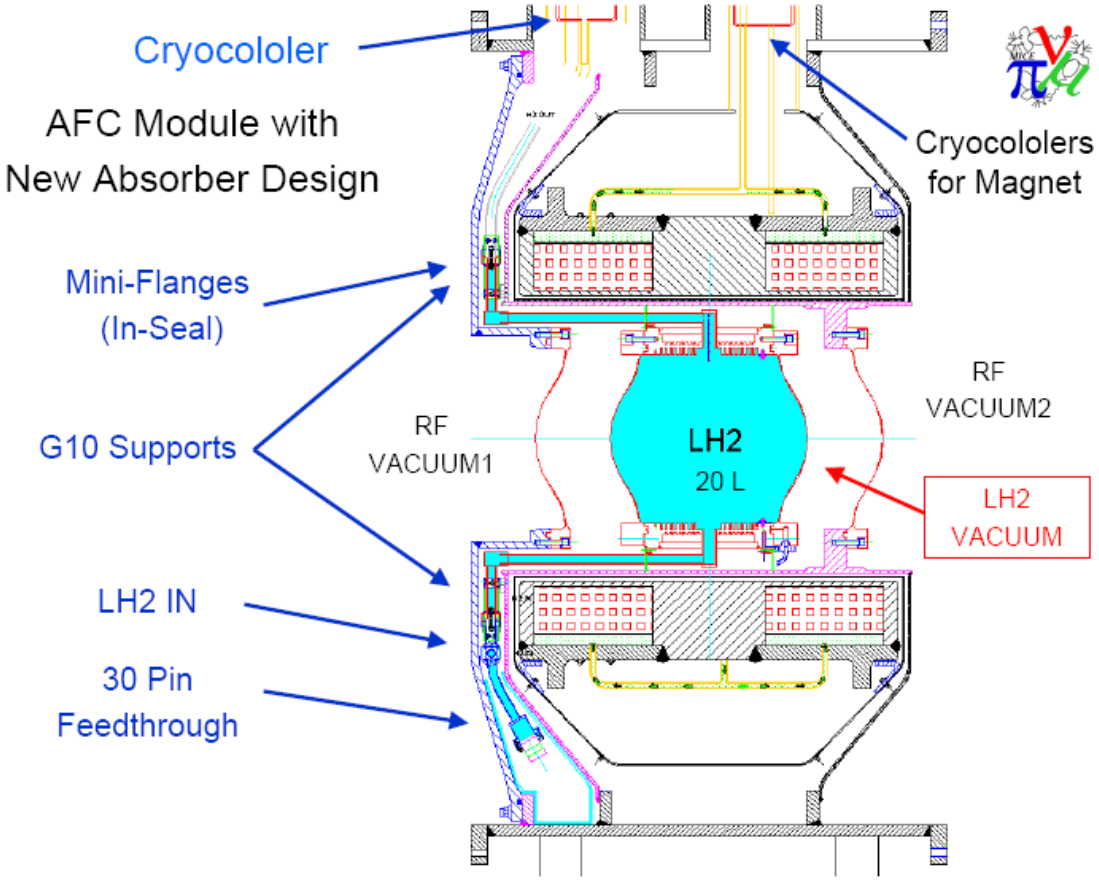
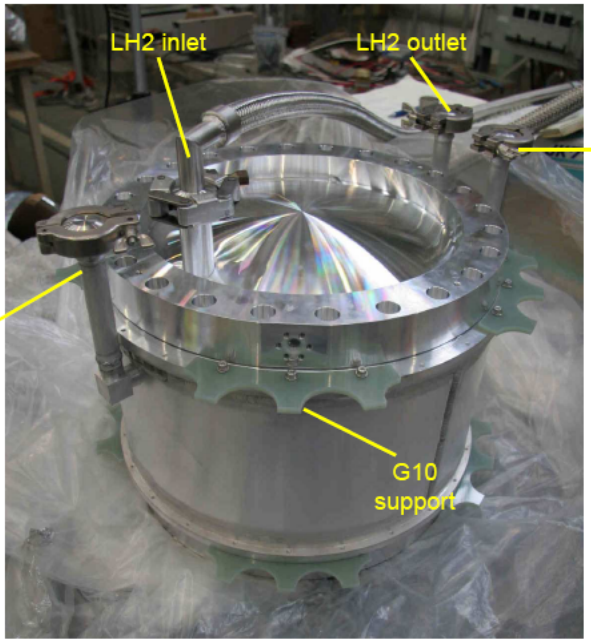
MICE Step IV Preparations

- Absorber Focus Coil (AFC) module (UK/Japan/USA):
  - Design AFC, thin windows, LH_2 system and magnet design





LH_2 absorber vessel

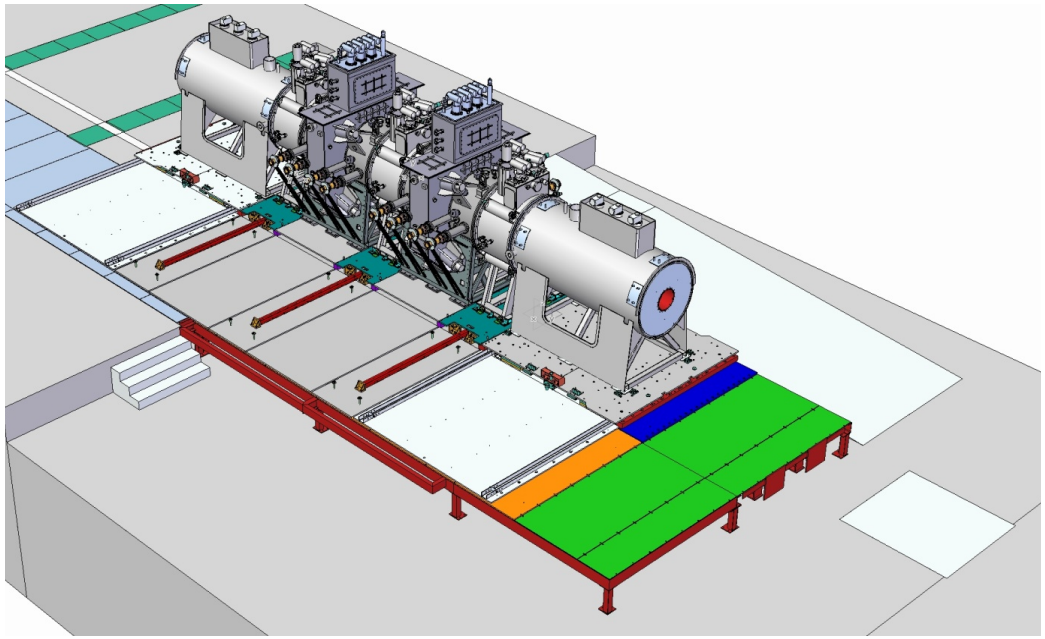
MICE Step IV Preparations

- Absorber Focus Coil (AFC) module (UK/Japan/USA):
  - Design AFC, thin windows, LH_2 system and magnet design
- Focus coil module plans
  - Three focus coil modules required for Step VI
  - Supplier: Tesla Engineering (Sussex)
  - Two modules by Q1 2013
  - Third module (option at Tesla)
  - Magnet and power supplies
  - Commissioning and tests
  - Field map: CERN

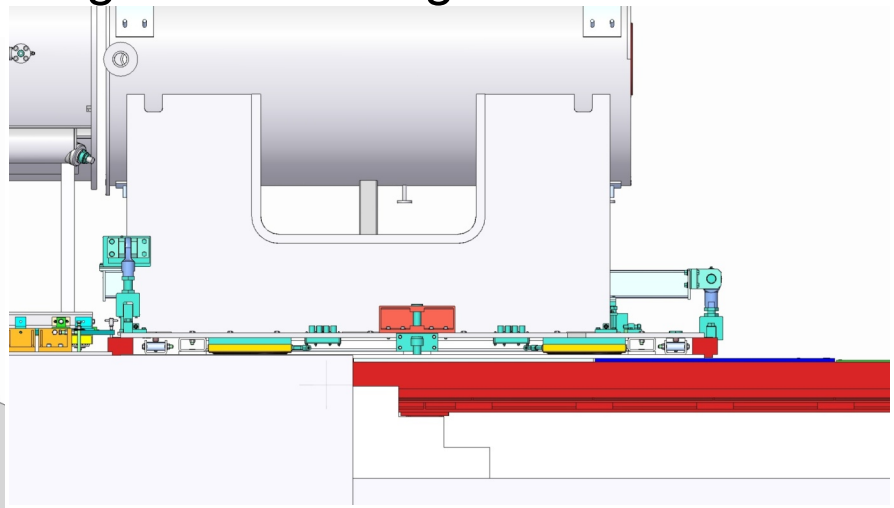
Focus coil being wound at Tesla Engineering

MICE Step IV Preparations

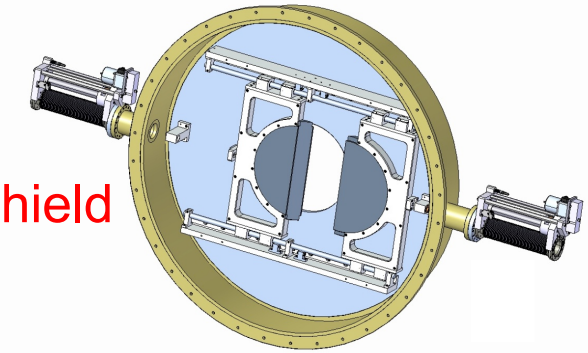
- Mechanical integration
  - Services, civil, mechanical, electrical and structural engineering
  - Radiation shield, vacuum window, magnetic shielding



Step VI cooling channel mechanical design



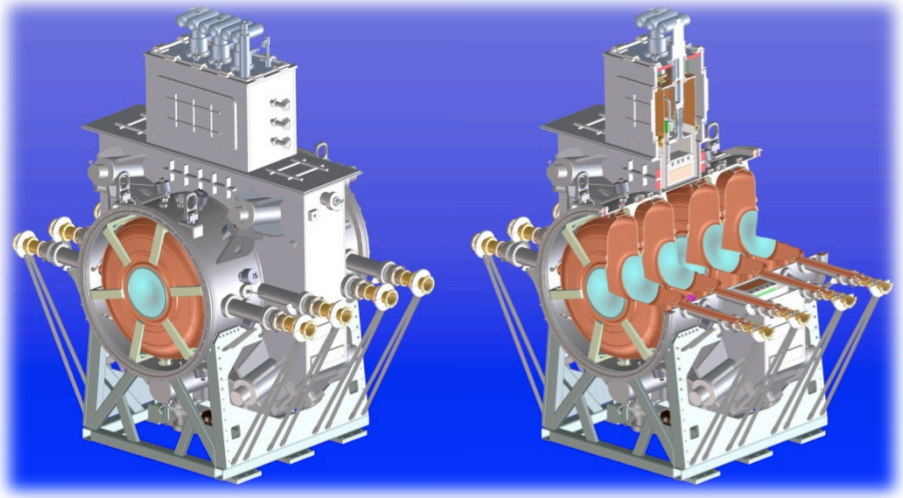
MICE Step IV floor plates



Radiation shield

MICE Step V and VI preparations

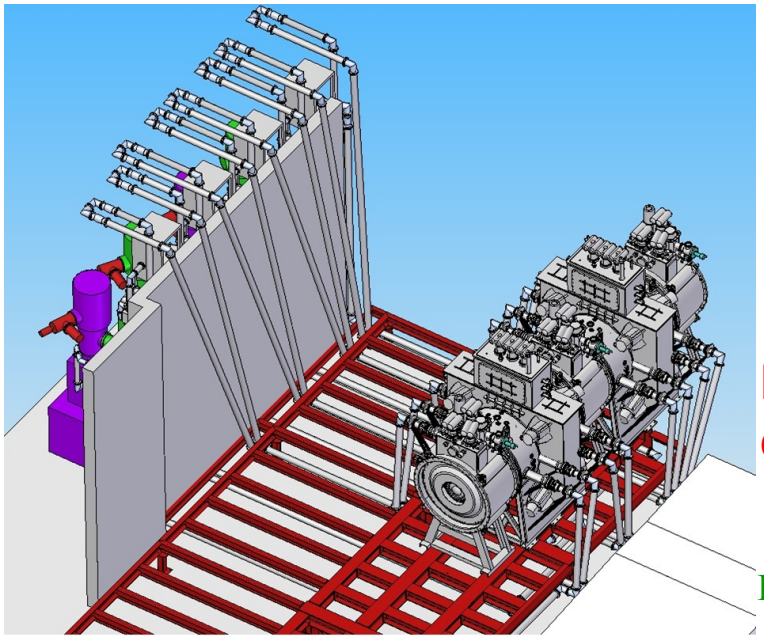
- Four 201.25 MHz copper cavities per RFCC module:
  10 cavities already constructed (USA)
  - Thin Be window design (UK)



- Coupling coils to be built and integrated in RFCC
  (USA/China)

MICE Step V and VI preparations

- RF Power distribution system (UK/USA)
  - 8 MW RF power at 201 MHz
  - Four amplifiers
  - Each amplifier:
    - 4 kW solid state amp
    - Burle 4616 tetrode 250 kW
    - TH116 amp 2 MW
  - Power splitting using cavity couplers



Layout of RF power distribution in MICE Hall

P. Soler, PASI Workshop, FNAL, 12-14 January 2012

2 MW amplifier under test conditions at Daresbury Lab

Conclusions

- MICE aims to perform the first measurement of ionization cooling
- MICE is a unique contribution to the Neutrino Factory and Muon Collider R&D activities
- MICE Step I has been successfully delivered and first papers are being completed
- Preparations for MICE Steps IV, V and VI are well underway, with renewed funding by international collaborators
- This remains an excellent example of a very successful US/UK collaboration and an essential step towards a Neutrino Factory and Muon Collider