



The MICE Beam Line Instrumentation (Trackers and PID) for precise Emittance Measurement

ICHEP 2012 Melbourne, 7 July 2012

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Neutrino Factory





Neutrino Factory



- Neutrino Factory optimisation depends on value of θ_{13}
- At $sin^2 2\theta_{13} \sim 0.1$ optimum is ~10 GeV NF with ~2000 km baseline
- Neutrino Factory offers best sensitivity and smallest $\Delta\delta_{CP} \sim 5^{\circ}$ out of all future facilities



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Neutrino Factory



Cooling essential to deliver Neutrino Factory performance



Emittance: 18 mm rad \rightarrow 7.5 mm rad Muon yield: 0.08 µ/p.o.t. \rightarrow 0.19 µ/p.o.t.

Increase in performance: 2.4

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



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: $\Delta \epsilon / \epsilon_{in} = 10^{-3}$



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





- 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 LH₂ close to high gradient RF in high B fields
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Implementation in Steps



MICE beam line



MICE beam and instrumentation fully constructed and operational



MICE beam detectors



MICE: single particle spectrometer

□ Particle Identification:

- Time of flight counters (TOF0,1,2)
- Two aerogel threshold Cherenkov counters (CKOV)
 Pion/muon and muon/electron
- MICE Calorimeters: purity >99.9%
 - Kloe-light (KL) lead-scintillating fibre preshower
 - Electron-Muon Ranger: 1 m³ of extruded scintillator bars

Beamline under construction





Time-of-Flight



- □ Time-of-flight system:
 - X/Y scintillator hodoscopes
 - TOF0: σ_t =51 ps
 - TOF1: σ_t =53 ps^{*} ^{*}Faulty PMTs giving 58 ps for TOF1 were
 - TOF2: σ_t=52 ps
 - Magnetic field: $B_{\parallel} \sim 200 300 G$ $B_{\parallel} \sim 1 kG$
 - CAEN V1724 FADC
 - CAEN V1290 TDC







KL Preshower



Light guide

□ Calorimeters:

- KLOE-light (KL): lead extrusion with extruded scintillating fibres as in KLOE calorimeter but with lighter Pb to fibre ratio
- Performs electron-muon separation for 0.5% of muons that decay – requires electron rejection at 0.1% level

Assembly TOF2-KL



Pb-fibre



KL ADC product

Performance KL vs TOF



Electron Muon Ranger



□ MICE EMR:

- Electron-muon ranger: 1 m³ extruded scintillator bars with WLS fibre
- 24 X/Y modules (48 planes) with
 59 bars/plane: 2832 bars
- Electrons give EM showers and muons give tracks
- dE/dx also used to separate electrons from muons (constant energy loss)





- Prototype tested at RAL
- Full detector under construction for STEP IV

MICE Tracker

- □ Scintillating fibre tracker:
 - Performs emittance measurement: x, x', y, y'
 - 350 μ m scintillating fibre doublet layers
 - Two trackers: 5 stations per tracker, 3 planes per station
 - Inside 4 T superconducting solenoid
 - Trackers built, solenoids being commissioned



Resolution: 661 μm (inlcuding MS)







Yield: ~11 PE Efficiency = 99.8% Read out by VLPC 80% QE

25 30 Light Yield (PE)

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MICE reconstruction



□ Instrumentation used in physics analyses for Step I:

- Measured nine elements of (ϵ, p) matrix for positive and negative particles $(\epsilon = 3, 6, 10 \text{ mm rad}; p = 140, 200, 240 \text{ MeV/c})$
- □ MICE Step I completed: beam line paper completed
 - The Beam Line and Instrumentation of the Muon Ionization Cooling Experiment at ISIS
 JINST 7 (2012) P05009 (6 mm, 200 MeV/c) μ⁻



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MICE emittance measurement Step I

- □ Physics analyses for Step I:
 - Developed novel method to measure emittance using TOF detectors



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 detectors constructed and commissioned: TOF system (TOF0,1,2), two CKOVs and KL
- EMR is currently under construction
- Trackers completed but need to be integrated with tracker solenoids
- MICE Step I has been successfully delivered
- Preparations for MICE Steps IV and VI well underway.