Progress Towards Completion of the MICE Demonstration of Muon Ionization Cooling

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Muon Accelerator Program

ILLINOIS INSTITUTE OF TECHNOLOGY
Transforming Lives, Inventing the Future: www.iit.edu

MuTAC Review
Fermilab
16–17 March, 2006

NuFact 2013
IHEP Beijing
21 August 2013
Outline

• Brief MICE overview
• Magnets & other equipment
• Software & results
• Conclusions
MICE

- International **Muon Ionization Cooling Experiment** at UK’s Rutherford Appleton Laboratory (RAL)

- Has flexibility to test several absorber materials and optics schemes, incl. first 6D cooling demo

- **Nutshell:** under construction, program complete ~2020
Principle of MICE

MICE the Muon Ionization Cooling Experiment

Measure input particle \(x,x',y,y', t, t'=E/Pz\)
→ input emittance \(\varepsilon^{\text{in}}\)

Measure output particle \(x,x',y,y', t, t'=E/Pz\)
→ output emittance \(\varepsilon^{\text{out}}\)

Particle by particle measurement, then accumulate few \(10^5\) muons
\[ \Delta[ (\varepsilon^{\text{in}} - \varepsilon^{\text{out}})/\varepsilon^{\text{in}}] = 10^{-3} \]

• Plus PID to achieve 99.9% muon purity
MICE Collaboration

MICE Module Key:

- **Spectrometer Solenoid (SS)**
- **Absorber–Focus Coil (AFC)**
- **RF–Coupling Coil (RFCC)**
Steps of MICE

Provisional MICE SCHEDULE update: June 2013

STEP I

- Needed for Step IV: EMR, 2 spectrometers & 1 AFC module

STEP IV

- Needed for Step VI: above + 2 AFC + 2 RFCC modules

STEP VI

Target date Q3 2019
Step V run possible 2018

Under construction:

Run date:
EMR run Oct 2013

(possibly w/o field: Q2 2014)
Q1 2015 to Q1 2016

Electron–Muon Ranger
[Geneva, FNAL, Trieste/Como]

- Final MICE PID detector, under construction at U Geneva
  - totally active scintillator calorimeter in which muons range out
  - prototype already tested at MICE
  - to be installed in Sept., commissioned with beam in Oct.
SciFi Spectrometers
[US / UK / Japan]

- Trackers complete & tested with cosmic rays
  - installation awaiting Spectrometer Solenoid (SS) delivery

![Typical cosmic track](image)

- Light yield ≈ 10 p.e.

![Cosmic test setup](image)
**Diffuser**

[U Oxford]

- Need variable-thickness high-density material in 1st SS to generate required input emittances

- 4 irises with W or brass petals
- W petals have brass backing plate
- ready for installation
Superconducting Magnets: SS

[LBNL, FNAL]

- **Spectrometer Solenoids**
  - two 4 T magnets with 0.1% field quality, each with 5 NbTi coils
  - specified by LBNL, built by Wang NMR (CA)
  - initial cryogenic and superconducting-lead problems required significant repair and retrofit effort
  - 1st SS now trained & mapped (CERN), shipping soon
Superconducting Magnets: SS

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  - 2nd SS reassembled but requires further repair before training
Superconducting Magnets: FC
[U Oxford, RAL]

- Focus Coils
  - three 3 T solenoid pairs operable in both gradient (“flip”) and solenoid modes to provide low beta at absorbers
  - specified by U Oxford & RAL, build by Tesla Engineering (UK)
  - 1\textsuperscript{st} two delivered
    - one needed for Step IV
  - 1\textsuperscript{st} successfully trained in solenoid mode, flip-mode training going slowly
  - 2\textsuperscript{nd} FC nearly ready for training
LH2 Absorbers
[KEK]

- 35 cm long x 30 cm diameter
- 3 required (one for step IV)
  - 2 built so far
- Thin, tapered Al-alloy windows
  - designed by IIT & U Oxford
  - fabricated by U Miss
- Can also use LHe
LH2 System

[RAL]

- Liquid-hydrogen system successfully tested
  - uses hydride-bed H₂ storage
LiH Absorbers
[FNAL]

- Fabrication at Y12 (Oak Ridge)
  - both disks and wedges (6D test) ordered
  - disks done, awaiting approvals for delivery to RAL (CRADA with STFC)

- Other solid absorbers also under consideration:
  - C, Al, polyethylene,...
RFCC Modules
[LBNL, HIT, U Miss]

- One (2) needed for MICE Step V (VI)
- Modules designed, RF cavities built
  - 1st cavity at FNAL for tests
  - much work in progress on RF couplers, tuners & assembly procedure

- Coupling Coil fab in China (HIT, Qi Huan, SINAP) led by LBNL
  - 1st CC cold mass delivered, test in progress at FNAL STF
    - working on cryogenics issues
• More on cavities...

- novel Be cavity windows double the accelerating gradient for a given power level
- shown to work by MuCool

EP setup at LBNL
Coupler design
Be windows at LBNL
Tuner arms fabricated at FNAL
Tuner design
Wire EDM at FNAL

RFCC Modules
[LBNL, HIT, U Miss]
RF Power
[DL, LBNL, U Miss, U Strathclyde]

• 4 recycled 2 MW triode supplies
  - 2 from LBNL, 2 from CERN
  - refurbishment in progress at DL
  - 1st has been successfully tested at full power

• Installation plan devised
• LLRF design in progress
• “TIARA” test this year
RF Power
[DL, LBNL, U Miss, U Strathclyde]

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  - 2 from LBNL, 2 from CERN
  - refurbishment in progress at DL
  - 1st has been successfully tested

**NEWS FLASH!**

Begin forwarded message:
From: Andrew Moss <andrew.moss@STFC.AC.UK>
Subject: Re: Fwd: 1.5 Megawatt
Date: July 5, 2013 5:03:24 PM CDT
To: MICE-RF-POWER@JISCMAIL.AC.UK
Reply-To: MICE RF power distribution system <MICE-RF-POWER@JISCMAIL.AC.UK>

2MW from mice amplifier

Andy

Sent from my Windows Phone
RF Power
[DL, LBNL, U Miss, U Strathclyde]

• Conceptual layout:
Some details:

Typical layout of system using amplifier with DL/LBNL type output

System will be pressurized with N2 for voltage standoff and interlocking

4816 AUXILLUARY RACK  4816 HT  116 AUXILLUARY RACK  116 HT RACK & CAPACITOR BANK

DC = directional coupler= power measurement
B-Field Mitigation

- 2 concepts:
  - partial return yoke (PRY)
    - suppress the fringe field at its source
  - “local” shielding
    - shield (or move) each sensitive component

- PRY currently seems favored
  - local solution may be riskier: hard to identify all sensitive devices & assess their degree of sensitivity
  - SS delay leaves more time for PRY implementation
  - decision to be taken this fall
B-Field Mitigation

Concept

- Partial Return Yoke (a.k.a. “shield”, PRY?)
- Concept presented at MICE CM 2012
- Shielding plates
  - wall thickness >10 cm
  - weight: 35t
- Performance
  - Reduces stray field outside of shield to 5-10 Gauss

H Witte. Step IV & VI: Local Flux Return. MICE CM 34, October 2012.
(Note: not to scale)

• Engineering continues; review & decide in Sept.
- G4MICE developed initially by Y. Torun (IIT)
  - used for Step I analysis
MICE Software

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- Succeeded by MAUS (MICE Analysis User Software) framework
  - simplifies maintenance & use
  - strong emphasis on good documentation & thorough testing
  - making good progress, but much remains to be done
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Example of MAUS analysis output showing pion contamination is small.
Step IV Plans

- MICE Step IV “deliverables”:
  - complete particle detector system
  - establish safe and routine LH$_2$ absorber operation
  - engineering test of beamline made of several magnetically coupled components
  - understand propagation of (imperfect) beam through the “magnetic bottle”
  - calibration of emittance measurement to $10^{-3}$
  - measurement of 6D emittance change (normalized-emittance cooling)
  - first test of longitudinal cooling (with wedge absorbers)
  - precision validation of simulation codes and physics models
  - precision measurements of correlated multiple scattering and energy-loss straggling
Step VI Plans

• MICE Step VI “deliverables”:
  - operation of channel with all magnetic couplings in place
  - routine and safe operation of RF in B field near LH$_2$
  - full cooling cell allowing all optics configurations: flip, non-flip, etc...
  - exact replenishment of energy possible
  - significant and measurable longitudinal heating
  - precise measurement of equilibrium emittance of various optical and absorber configurations
  - detailed and precise verification of simulation codes
  - benchmark for many future cooling-channel options

• (Step V, with 1/2 lattice cell, possible as intermediate step, but not the current baseline)
Conclusions

- MICE is a major undertaking:
  - thorough demonstration that ionization cooling works as expected and is well understood
  - calibration and validation of Monte Carlo models used to design and characterize ionization cooling channels

- A major step on the way to Neutrino Factories and Muon Colliders

- Given adequate support we will accomplish this by 2020