COMMISSIONING STATUS OF THE MICE MUON BEAMLINE

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Abstract

It is planned to install a Muon Ionisation Cooling Experiment (MICE) at the ISIS facility at Rutherford Appleton Laboratory. This experiment will be the first demonstration of ionisation cooling as a means to reduce the large transverse emittances expected in the early stages of a Neutrino Factory. A new muon beamline has been installed on ISIS, in order to supply muons of characteristic energy and emittance to the experiment. This paper gives an overview of the goals and design of the beamline, the commissioning of its subsystems, and the results which have been obtained during its first operating periods with beam in 2008.

INTRODUCTION

A new muon beamline has been installed at the ISIS facility at Rutherford Appleton Laboratory, with the purpose of supplying muons to the MICE experiment [1]. This experiment will allow the first demonstration and exploration of muon ionisation cooling. The specifications for the muon beam to be produced from the beamline are listed below:-

Table 1: MICE Muon Beam Requirements

Normalised Emittance ε_n	~1π - 12 π mm rad
Reference momentum p_{ref}	140 – 240 MeV/c
Momentum Spread	± 10 %
Intensity	600 matched muons / ms / s
Purity	<0.1% non-muon contamination

The beamline design is based on a conventional pion-muon decay channel, similar to those used for condensed matter research [2], and to provide a source of pions, an internal target [3] has been designed and installed in the ISIS proton synchrotron. The optical design of the beamline has been described before [4], but in summary consists of three sections, governing pion capture, pion-muon decay, and a muon transport for selection and matching into the MICE experiment.

Use has been made of existing dipole and quadrupole magnets from RAL, together with a superconducting solenoid contributed by PSI in Switzerland. A number of diagnostic devices have been designed specifically for beamline tuning, and extensive use will be made of the MICE particle identification (PID) detectors which will sit in the downstream section.

The first beamline element was installed in July 2007, in the ISIS long shutdown, and since then all magnet systems have been positioned and aligned, together with a first set of diagnostics. First beam was achieved in March 2008.

This paper describes the installation, the progress with systems commissioning, and the first experience with beam since the report in [4]. An outline of future commissioning, optics studies and hardware upgrades will also be given.

BEAMLINE LAYOUT

The layout of the beamline is shown below in Figure 1.

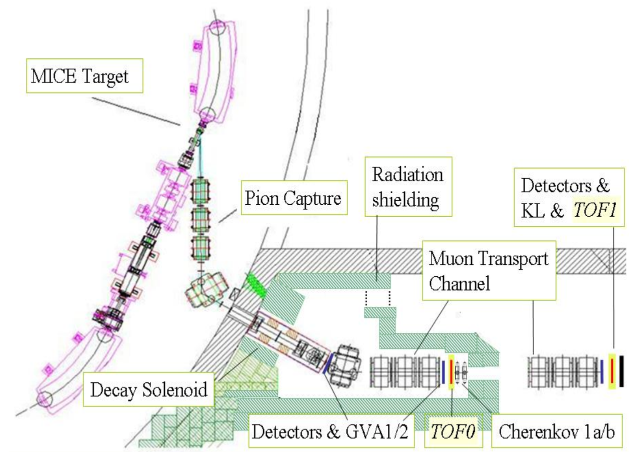

Figure 1. Layout of the MICE muon beamline

Beamline diagnostics are positioned at the exit of the solenoid and of each muon triplet, as shown in Fig. 1, and will be described in more detail below. The time-of-flight (TOF) system, highlighted in yellow, is due to be installed shortly. Once available, the layout will constitute 'Step I' of the MICE staging plan [5].

INSTALLATION AND SYSTEMS COMMISSIONING

Target

The MICE target is a thin titanium blade, and is driven in and out of the proton beam by an electromagnetic linear drive [3]. Extensive offline development and commissioning preceeded installation of the first version of the target mechanism in January 2008. Particular attention was paid to the choice of bearing materials, in order to minimise the chance of residual dust production in the ISIS accelerator, as well as work to establish means by which long term running and reliability could be easily monitored in situ.

A first operation, consisting of 700 actuations without beam, was made on the 31st of January 2008.

Conventional Magnets & Power Supplies

Field measurements and power tests were performed on the majority of the conventional magnets before installation. The upstream quadrupoles, and both dipoles had been in use in a previous beamline, and so only one of each class was tested before installation. The downstream large aperture quadrupoles had a less clear history and these required complete refurbishment. Coil integrity was checked through resistance testing, and once fully assembled, field and power checks were performed on each magnet. These confirmed field centres, as well as detailed excitation values and long term integrity. Only a small number of assembly changes were required to water and power connections before final installation.

Once installed and aligned, significant effort was extended to check all interlock circuits and performances with the final power supply and water systems. In the process, it was found necessary to rebalance the two dipole power supplies, as well as to make adjustments in other areas. Polarities and final fields were verified, and following commissioning of each individual system, a final 'String test' was undertaken to demonstrate full power operation, under remote control, of the whole beamline in May 2008.

Decay Solenoid & Linde Refrigerator

The decay solenoid was installed and aligned, following important vacuum system work and refurbishment, in January 2008. Together with the Linde Refrigerator, a 5% liquid Helium fill was achieved in April 2008. After some further modifications to the compressor, full cooling and power testing is anticipated in late summer of 2008.

Detectors & Beam Diagnostics

To enable early beam commissioning, a number of detectors have been installed within the downstream beamline. These include three 20x20cm^2 square, 10cm thick scintillators at the exits of the solenoid, the first and second muon triplets ('GVA1/2/3'). Two 20x20cm^2 scintillating tile detectors are stationed at the exits of the same triplets, to provide spatial information. Finally, two high spatial resolution scintillating fibre monitors are stationed at the exit of the decay solenoid, and of the first muon triplet. Both of the latter two types of devices are still undergoing careful commissioning.

The MICE PID Cherenkov detectors are also present, and can give pion/muon/electron discrimination from background. The electromagnetic calorimeter (KL), and the TOF system, will also be able to provide spatial information as well as supporting particle ID.

Vacuum System

The vacuum system extends from the first quadrupole in the ISIS vault to the upstream dipole, as well as internal to the superconducting solenoid. Its purpose is to maximise transmission of the parent pion beam. The vacuum system was installed and pumped down in March 2008. The downstream section is at atmosphere in view of the low muon-air interaction cross sections.

Shielding

Radiation shielding in the MICE hall consists of a layer of steel and an outer layer of concrete block, to protect against shine from accidental loss in the ISIS synchrotron. Calculations were made using MCNPX [6]. The shielding encloses all elements up to Q6 as shown in green in Figure 1. Shielding was installed in August 2007, with a temporary breach to install the solenoid in January 2008.

COMMISSIONING PROGRESS WITH BEAM

Target Operation with Beam

The first dedicated MICE physics shifts were granted on March 14th and 15th, and first operation of the target with beam was achieved on March 15th [7]. The target was run at ~0.5 Hz, and trials with varying insertion times and depths were performed, within a set beam loss limit.

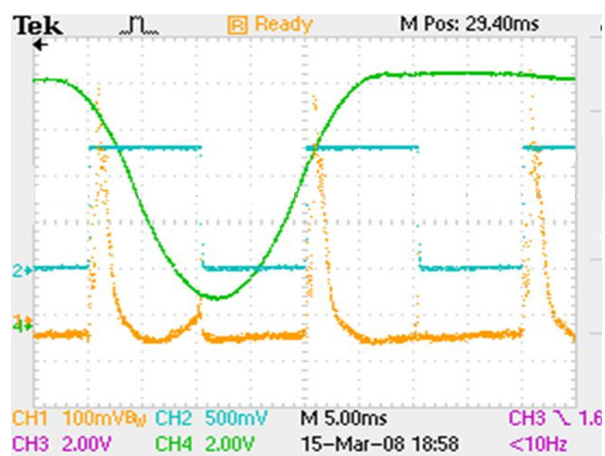

Figure 2. First operation of the MICE target with beam. The signals shown are the target trajectory (arb. units, green), circulating intensity in ISIS (blue) and the ISIS beamloss sum signal (yellow). The beamloss signal shows a rise at ~6-10ms as the MICE target is inserted. No interference is seen with subsequent ISIS pulses.

Full parasitic operation was demonstrated during the following ISIS user run on May 15th [8]. A clear 3ms window was demonstrated between the preferred target insertion time and the appearance of injection loss on the subsequent ISIS pulse.

Initial Operation of Beamline

Once the dipole systems were commissioned and available, beam was directed into the MICE hall for the first time on March 29th [7]. In view of estimated flux measurements from a prototype target test in 2006 [9], polarities were set to transmit positive particles, and initial magnet settings chosen to transmit the expected high intensity inelastically scattered proton beam from the target. Hits were recorded in GVA1, GVA2, the large scintillating fibre monitor, and the Cherenkov detectors.

Scanning of the second dipole showed the peak transmission to be at the expected setting, given energy losses along the beamline.

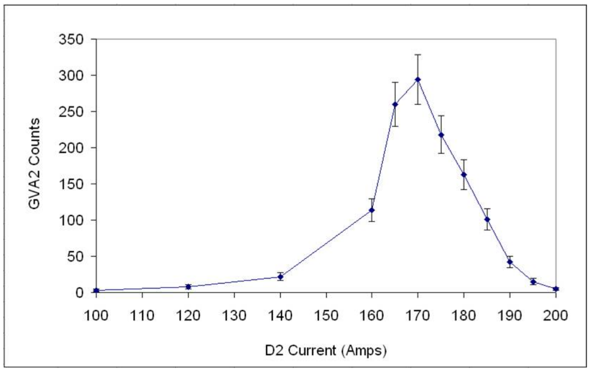

Figure 3. Recorded hits in detector GVA2 against current in second dipole.

This first measurement, giving the absolute intensity of protons at GVA2 from this simple beamline, was an important figure, as it enabled a direct estimate of primary proton interactions in the MICE target, and an estimate of particle production. This could then be used to estimate the corresponding pion source and muon flux in MICE, for a particular target depth and beamloss [10]. At standard ISIS loss limits, fluxes were estimated to be lower by some margin than required for the final MICE experiment, and experiments and discussions are underway to investigate means to raise this figure.

Following final commissioning of the conventional magnet systems, first operation with the quadrupoles was made on June 2nd and 3rd. These were again set to transmit the scattered proton beam, and rates were compared to the expected increase in flux. Beamsizes and alignment measurements will be made once position sensitive detectors are fully commissioned.

Radiation Surveys.

In parallel with first optics work, radiation surveys have been carried out at each new working point and when simulating particular modes of failure. These have the aim of enabling access to work in specific areas of the MICE hall whilst beam is present, thus permitting true parasitic running.

FUTURE WORK

In parallel with activities to increase the beam rates from the target, studies will continue to check the alignment and the basic optics against simulation. These will be strengthened by the addition of the MICE Step I detectors in late summer. To take full advantage of the detectors, it is envisaged to provide the first optimised pion beam with the beamline, as well as a β=1 electron beam for calibration and commissioning purposes.

The superconducting solenoid is anticipated to be functioning in late summer, and with the availability of this last magnetic element for the upstream section, setup and tuning of the pion and pion-muon decay sections can begin in earnest. At this stage, the focus is expected to turn more towards setting up the beamline for the optimum pion and muon optics. Tuning techniques are currently under development. The beamline will be complemented later in the autumn by the upstream MICE Tracker and spectrometer solenoid. These important devices will allow full particle ID to be performed, and together with the lead diffuser system, will allow precise measurement and manipulation of the emittance and match into the first MICE element [4].

Studies are ongoing into many other areas relevant to MICE needs. Work continues to derive the full range of emittance and momenta settings for provision into MICE, and collimation and steering schemes are being studied.

SUMMARY

Commissioning of the new MICE beamline, to supply muons to the MICE experiment has begun. Most hardware systems have now been commissioned, and first activities have taken place with beam. New detectors are being installed, and work is moving towards setting up the required muon beams for the MICE experiment.

ACKNOWLEDGEMENTS

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