MICE MUON BEAMLINE PARTICLE RATE AND RELATED BEAM LOSS IN THE ISIS SYNCHROTRON

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Abstract

The international Muon Ionization Cooling Experiment (MICE) will provide a proof of principle of ionization cooling, the reduction of muon beam phase space, which will be needed at a future Neutrino Factory and Muon Collider[1]. The MICE muon beam begins with the decay of pions produced by a cylindrical titanium target dipped into the proton beam of the 800 MeV ISIS synchrotron at the Rutherford Appleton Laboratory, U.K. Studies of the particle rate in the MICE beamline and correlations with induced beam loss in ISIS are described, including the most recent data taken in the summer of 2010, representing some of the highest loss and rate conditions achieved to date. Ideally, a high rate of muons in the MICE beamline is desired. However, impact on the host accelerator equipment must also be minimized. The implications of the observed beam loss and particle rate levels for MICE and ISIS are discussed.

THE MICE MUON BEAMLINE

The MICE Muon Beamline has been in operation since the spring of 2008. A schematic of the beamline is shown in Fig 1. A cylindrical titanium target is pulsed into the circulating ISIS proton beam close to the end of the injection - extraction cycle. Hadronic interactions between the protons and the titanium nuclei generate a pion shower. Part of this shower is captured by a quadrupole triplet and transported down the MICE beamline toward the MICE Hall. A 5 T superconducting solenoid is used to extend the pion path length, increasing the purity of the muon beam downstream.

Various beam diagnostic detectors are positioned along the MICE beamline including a scintillator counter (GVA1), two beam profile monitors (BPM1 and BPM2), three 50 - 60 ps resolution time-of-flight (TOF) detectors (TOF0, TOF1 and TOF2)[2], two threshold Cherenkov detectors, and a KLOE-Light (KL) electron-shower calorimeter. A luminosity monitor positioned inside of the ISIS enclosure is used to provide a measure of the pion flux. GVA1, both BPMs, and the TOF detectors all measure the particle rate in the beamline, although the TOF detectors' primary function is to allow for particle identification. The Cherenkov detectors remain in the commissioning phase and the KL is not used in this study.

The cooling channel itself remains under construction and is to be placed between TOF1 and TOF2 in the MICE Hall.

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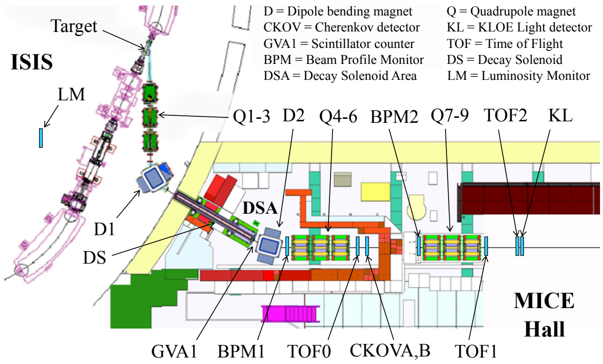

Figure 1: The MICE Beamline. Previously published in [3] (©2011IEEE).

ISIS AND MICE TARGET INDUCED BEAM LOSS

The action of the MICE target not only generates the pion shower used by the MICE beamline but also raises the beam loss levels present in the ISIS accelerator. Beam loss refers to protons which are lost from the ISIS beam and go on to interact with equipment such as the beam pipe and accelerator components. While this happens during all ISIS operation, interaction of the MICE target with the proton beam significantly alters the pattern and amount lost. At this facility, beam loss is measured using 39 wire ionisation chambers filled with argon gas and positioned around the inside of the ring.

ISIS is split into 10 repeating super periods or sectors, with the MICE target being positioned at the beginning of sector 7, as illustrated in Fig. 2. Most of the observed beam loss due to the action of the target occurs just downstream of the target in sectors 7 and 8, or at the ISIS collimator system in sector 1. Therefore, the total beam loss recorded in sector 7 is used to provide a measure of the beam loss induced by the MICE target. Although the target typically enters the proton beam in the last 2 ms of the cycle, this signal is integrated over the full 10 ms ISIS injection-acceleration-extraction period. The level of induced beam loss is then controlled by the depth the target enters the ISIS beam, characterised by the Beam Centre Distance (BCD). The BCD is defined as the distance of the target tip from the nominal ISIS beam centre, at the time of the maximum target excursion into the beam. Hence smaller values of the target BCD lead to greater values of the induced sector 7 beam loss.

Increased beam loss levels are undesirable as they can lead to disruption for other ISIS users and increased ac-

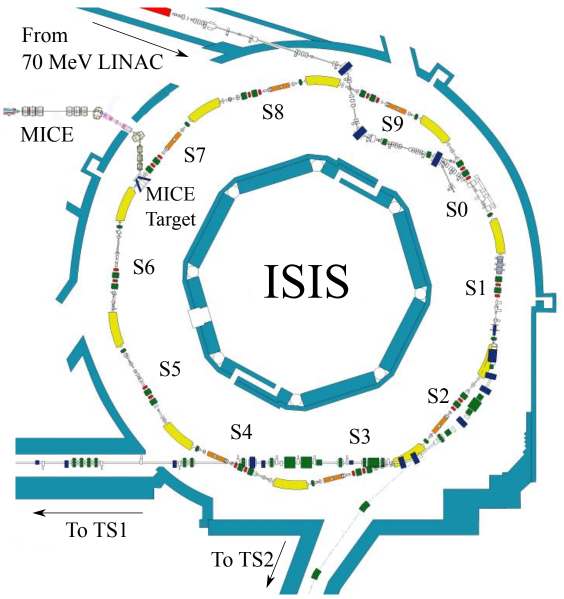

Figure 2: The ISIS proton synchrotron. Previously published in [3] (©2011IEEE).

tivation levels within the vault, making hands-on maintenance more difficult. At the same time, it is necessary for MICE to maximize the available particle rate in the beamline in order to be able to complete cooling measurements in a timely fashion. Hence a systematic study of the effect of the MICE target, under various working conditions, on both the induced ISIS beam loss and MICE particle rate is necessary. This paper reports on the results of a series of dedicated studies on this effect, performed during 2010.

METHODOLOGY

Experimental Methodology

This paper presents data from studies conducted on the 15th and 16th of July 2010. On the 15th, a beamline set for *negative* pion-to-muon transport was used,while on the 16th a *positive* pion-to-muon beam was used. For the 15th, the data acquisition (DAQ) spill gate, the period for each target pulse during which data is collected, was set to 3.2 ms. For the 16th, this DAQ window had to be lowered to 1 ms as the rates in the beamline were too high for the DAQ to successfully process.

A series of runs were taken on each day (where a run is defined as a collection of typically consecutive target pulses), each run represented a particular value of induced beam loss, set by altering the target BCD. Approximately 400 target pulses, or dips into the ISIS beam, were used per run. Each run then provided a data point on a plot of the particle rate in the various MICE detectors as a function of the induced ISIS beam loss.

Analysis

Scaler hits, representing simple coincidences of photomultiplier tubes (PMTs) firing, were recorded by all of the detectors used here, giving a measure of the raw particle rate from all species present in the beam. In order to specifically measure the muon rate in the MICE beamline, it is necessary to do particle identification (PID) using the TOF detectors. In this study, the time-of-flight between TOF0 and TOF1 provides the muon identification using software which reconstructs TOF tracks from the Time-to-Digital-Conversion (TDC) data recorded by both detectors. In contrast to scaler hits, TOF tracks are only recorded following a trigger, that is, within 1.28 μs of a scaler hit in TOF1.

A sample reconstructed TOF track spectrum between TOF0 and TOF1 is shown in Fig. 3. A small positron peak is visible on the left, while a large peak consisting primarily of (anti-)muons is present on the right. Monte Carlo studies have shown that the pion background remaining in the muon peak is $< 1\%$. Cuts on the TOF spectrum of 26.2 ns $<$ dt $<$ 32 ns are used to isolate the muon tracks. These are then used to provide a measure of the number of muons present in the beamline.

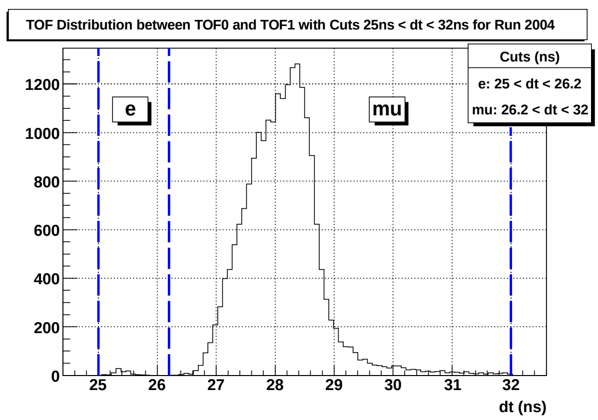

Figure 3: TOF spectrum between the TOF0 and TOF1 for a beamline optimised for positive pion-to-muon transport.

PARTICLE RATE AND BEAM LOSS

The rate of scaler hits for the negative beamline (15th June) study is shown in Fig. 4 for three beamline detectors. A linear relationship is plainly visible in both TOF detectors and BPM2. GVA1 also exhibits a linear relationship but is not shown as it dominates the scale, while BPM1 data was not available.

Fig. 5 shows the equivalent scaler rates for the positive beamline study (16th June 2010). Again the linear relationship is clearly visible for all detector rates shown.

The equivalent reconstructed muon TOF track rates for negative and positive beams are shown in Figs. 6 and 7 respectively. As was the case for the scaler hits, a linear relationship is plainly visible for both beam polarites.

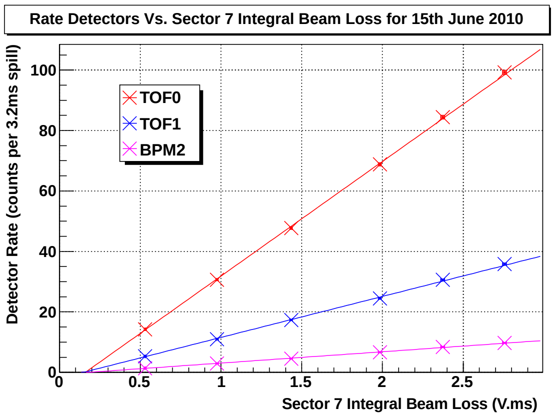

Figure 4: Scaler hits as a function of induced beam loss for the negative muon beam study(15th June 2010). Previously published in [3] (©2011IEEE).

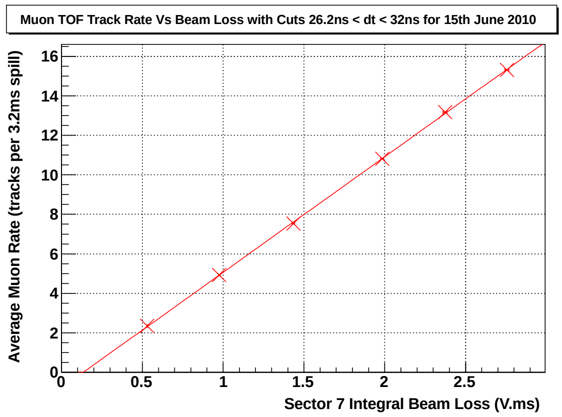

Figure 6: Reconstructed muon TOF tracks as a function of induced beam loss for the negative muon beam study (15th June 2010).

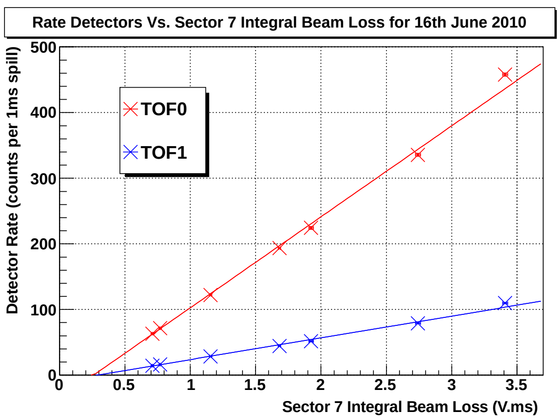

Figure 5: Scaler hits as a function of induced beam loss for the positive muon beam study (16th June 2010). Previously published in [3] (©2011IEEE).

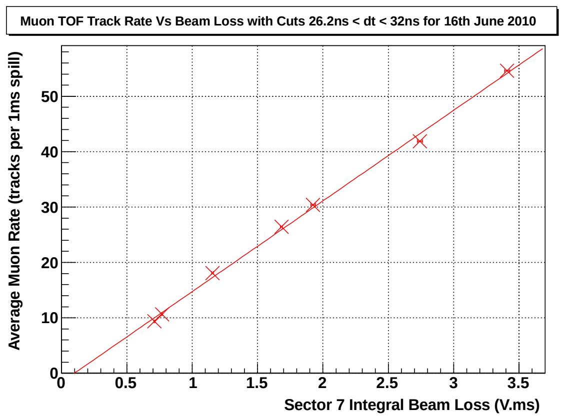

Figure 7: Reconstructed muon TOF tracks as a function of induced beam loss for the positive muon beam study (16th June 2010).

Using the fits present for each plot, it is possible to produce an estimate for the number of scaler hits and muon tracks present per V.ms beam loss per spill gate time. For the negative muon beam, this produces 13.6 scaler hits per V.ms per 3.2 ms spill gate, and 5.85 muon tracks per V.ms beam loss per 3.2 ms spill gate. For the positive muon beam, the estimate rises dramatically to 33.1 scalers hits per V.ms per 1 ms spill gate are observed, and 31.1 muon tracks per V.ms per 1 ms spill gate. It should be borne in mind that because the spill gates used in each study are different, and particle rates across the spill are not linear, the results for each study are not directly comparable. In can be asserted; however, that higher rates are present for a positive beamline than for a negative.

CONCLUSION

The need to produce a significant number of muons, particularly μ^-, to facilitate efficient ionization cooling measurements in MICE conflicts with the desire for zero-impact operation within the ISIS accelerator. Clearly a compromise must be found which satisfies, to some degree, both requirements. In order to find such a solution, the relationship between muon production and proton loss in ISIS must be well-understood. This systematic study of both positive and negative muon beam production in MICE has created a quantitative measurement of this relationship. This, in combination with periodic radiation surveys in ISIS to check for activation, provides crucial information needed to develop a plan to increase the MICE muon rate.

REFERENCES

[1] Steve Geer. Muon Colliders and Neutrino Factories. *Annual Review of Nuclear and Particle Science*, 59:345 – 367, 2009.

[2] R. Bertoni et al. The design and commissioning of the MICE upstream time-of-flight system. *Nucl. Instr. and Meth.*, A615:14 – 26, 2010.

[3] A. Dobbs, K. Long, and A. Alekou. The MICE muon beamline and induced host accelerator beam loss. In *Proceedings of PAC11*, 2011. MOP021.