THE MERIT HIGH-POWER TARGET EXPERIMENT AT THE CERN PS

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Abstract

The MERIT experiment was designed as a proof-of-principle test of a target system based on a free mercury jet inside a 15-T solenoid that is capable of sustaining proton beam powers of up to 4 MW. The experiment was run at CERN in the fall of 2007. We describe the results of the tests and their implications.

INTRODUCTION

Plans are being discussed for possible future machines which can deliver proton beams with multi-MW beam powers. A prominent application for these powerful beams will be to produce intense secondary beams suitable for investigating important physics issues. Examples include investigations of rare decay processes and neutrino oscillations. The Neutrino Factory and Muon Collider Collaboration [1] has proposed a target system [2, 3] which will be capable of supporting proton beam powers of 4 MW with the purpose of producing and collecting intense muon beams for eventual use in storage rings. The core of this proposed target system consists of a high-Z, free-flowing liquid mercury jet which intercepts the proton beam within the confines of a high-field (15-20 T) solenoid. An important attribute of this system is that the liquid jet target can be replaced for subsequent proton pulses. The experiment described in this paper was designed to provide a proof-of-principle demonstration of this concept. Preparations for this experiment have been previously reported [4].

EXPERIMENTAL LAYOUT

A major experimental component consists of a high-field pulsed solenoid [5] capable of reaching a peak field of 15 T in a 1-m-long, 15-cmthreeaperture bore. In addition, a mercury injection system [6] was constructed which allows for a 20-m/s free-flowing Hg jet to be injected within the bore of the solenoid (See Fig. 1). The proposed target system requires the jet/proton beam axis to be tilted relative to the axis of the solenoid [7] to maximize the collection efficiency of the produced soft pions. In the MERIT experiment we have tilted the mated solenoid/injection system by 67 mrad relative to the horizontal direction of the incoming proton beam. The vertical alignment of the experimental apparatus was set to have the beam line intercept the central axis of the solenoid at the axial center of the magnet.

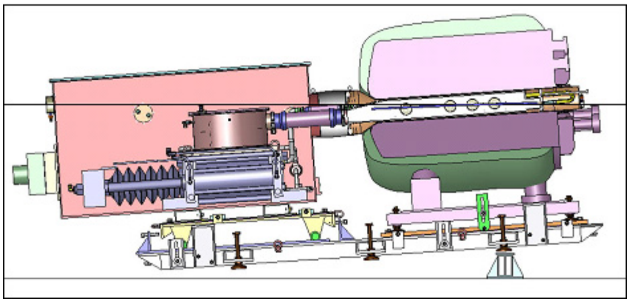

Figure 1: Cutaway view of the MERIT Hg injection system and with the pulsed 15-T solenoid. The entire system is tilted by 67 mrad relative to the incoming proton beam.

The operation of a liquid metal jet inside a strong magnetic field does, however, raise several magnetohydrodynamic issues as to possible deformation of the jet's shape and trajectory, as well as the effect of the magnetic field on the beam-induced dispersal of the jet. This experiment is designed to address these issues.

The experimental apparatus was installed in the TT2A area of the CERN PS complex (Fig. 2). The upstream magnetic elements allow for the transport of proton beams with energies up to 24 GeV. In addition, the PS is capable of multiple-turn extractions for beams of up to 14 GeV. We utilized this capability and ran the experiment at the two energies of 14 GeV and 24 GeV.

Diagnostics for the experiment were obtained mainly from two systems: 1) an optical diagnostics system with high-speed cameras observing the region of the Hg jet/proton beam interactions through four viewports installed on the primary containment vessel (Fig. 3), and 2) a series of charged-particle detectors placed downstream of the interaction region. Details of the optical diagnostics system has been previously reported [8], while the performance of the particle detection system is reported elsewhere [9]. The four optical viewports are aligned such that

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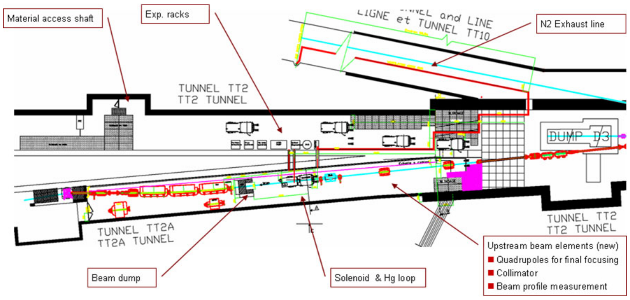

Figure 2: The TT2 area of the CERN PS complex showing the reconfiguration of the elements which normally deliver beam to the nTOF target.

the upstream three ports are set 15 cm apart with the second viewport located at the magnet axial center. The final viewport is displaced 45 cm downstream from the axial center.

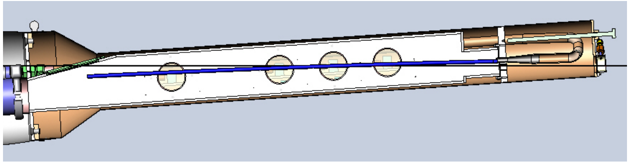

Figure 3: The primary containment region of the Hg injection system with four viewports situated along the axis of the solenoid allowing for viewing the Hg jet/proton beam interactions. The proton beam enters from the right.

EXPERIMENTAL RESULTS

For the MERIT experiment, the PS was typically run in a harmonic-16 mode (although several shots were also done with the proton beam in a harmonic-8 mode and a few with a harmonic-4 structure). The proton beam intensity was varied from 0.25 to 30×10^{12} protons (TP) per pulse. The field of the solenoid magnet was varied from 0 to 15 T. The mercury jet was typically injected with velocities of 15 or 20 m/s. Figure 4 shows images in viewport 2 of an interaction between a 15-m/s jet and a 24-GeV, 10×10^{12} proton pulse in a 10-T solenoid field. These images were taken with a 25-μs frame rate and an exposure time of 150 ns.

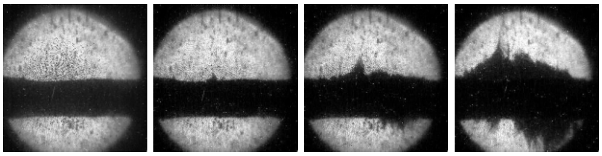

Figure 4: A 1-cm-diameter, 15-m/s Hg jet at 0, 75, 175, and 375 μs after interaction with 10×10^{12} 24-GeV protons in a 10-T solenoid field.

Complete dispersal of the Hg jet resulting from the impact of the proton beam is observed at the third viewport, located 15 cm downstream of the center of the solenoid. After the beam/jet impact, the full extent of the jet breakup can be observed as the jet streams past the viewport. Figs. 5 and 6 show the observed lengths of disruption of the Hg jet along its axis for proton beam energies of 14 and 24 GeV. A dependency of the jet breakup on the proton beam intensity and magnetic field strength is clearly seen. Strong magnetic fields reduce the extent of dispersal of the Hg jet at high beam intensities, as well as increasing the threshold for disruption at lower intensities.

These dispersal lengths can be compared to optimal beam/jet overlap length for particle production as calculated using the particle production code MARS [10]. We see in Fig. 7 that the optimal interaction length for the 14-GeV proton beam case is achieved near 30 cm which corresponds to roughly two interaction lengths for Hg (one interaction length in Hg is 14 cm). We note that for a 20-m/s jet velocity, replacing two interaction lengths will be done in 14 ms thus allowing for operations with a repetition rate of up to 70 Hz. We see in Figs. 5 and 6 that, for the extreme case of an incoming beam with 30×10^{12} protons and a solenoid field of 15 T, the extent of the Hg jet breakup is confined to less than 20 cm, thus permitting the 70-Hz beam rep-rate option. For the 24-GeV, 30×10^{12} proton pulse, the total energy content of the pulse is 115 kJ. For a 70-Hz beam rep-rate, this would correspond to a total beam power of 8 MW.

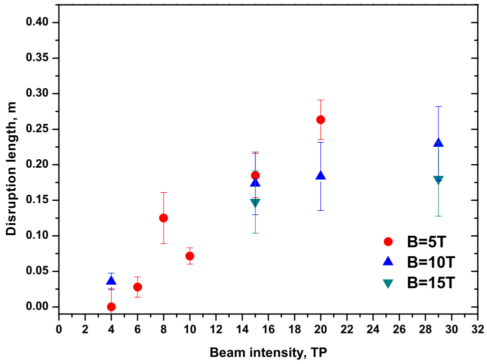

Figure 5: The observed disruption length of the Hg jet for various beam intensities and solenoid field strengths for an incoming proton beam energy of 14 GeV.

The magnetic field of the solenoid also affects the the time delay between the initial ejection of filaments from the Hg jet and the proton beam interaction, as shown in Fig. 8. For a 15-T magnetic field, this delay amounts to 150-200 μs, which permits use of proton bunch trains of at least this length without reduction in secondary pion production.

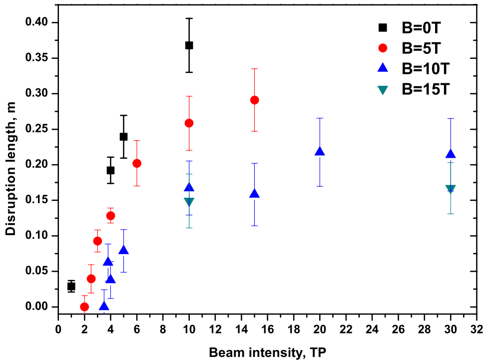

Figure 6: The observed disruption length of the Hg jet for various beam intensities and solenoid field strengths for an incoming proton beam energy of 24 GeV.

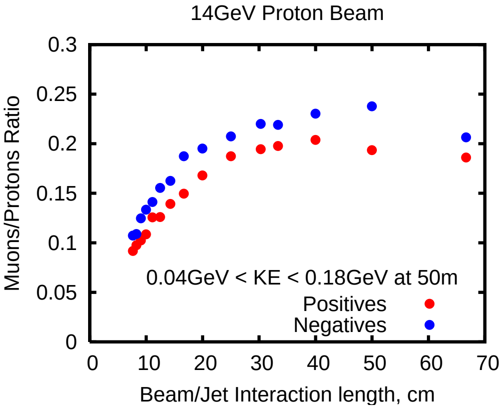

Figure 7: Results from MARS calculations predicting the efficiency of soft meson production ($0.04 < \mathrm{KE} < 0.18$ GeV) as determined after a 50-m drift.

CONCLUSIONS

The MERIT high-power target experiment was run in the Fall of 2007 at CERN. The experiment successfully established the proof-of-principle of a proposed system for generating an intense muon beam. A key result finds that mercury jet can be injected into a high-field solenoid field without serious consequences. The disruption of the mercury jet due to the impact of an intense proton beam is substantially mitigated by the presence of high magnetic field (15 T). Other effects of the magnetic field include an increase in the threshold for disruption, and a delay in the onset of observable jet breakup.

We have demonstrated a target system capable of supporting pulsed proton beams with powers of up to 8 MW.

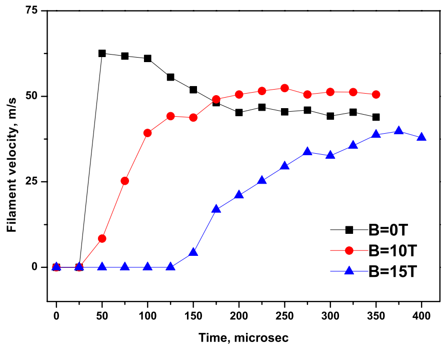

Figure 8: The observed time delay for material being ejected from the Hg jet after impact with a 24-GeV beam containing 10×10^{12} protons.

ACKNOWLEDGMENTS

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