

TARGET STUDIES WITH BNL E951 AT THE AGS

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Abstract

We report initial results of exposing low-Z solid and high-Z liquid targets to 150-ns, 4×10^{12} proton pulses with spot sizes on the order of 1 to 2 mm. The energy deposition density approached 100 J/g. Diagnostics included fiberoptic strain sensors on the solid target and high-speed photography of the liquid targets. This work is part of the R&D program of the Neutrino Factory and Muon Collider Collaboration.

1 INTRODUCTION

It has become apparent to high-energy physicists over the past few years that the physics opportunities available to the community provided by intense muon beams are significant. Recent examples include the concept of a machine based on $\mu^+\mu^-$ colliding beams and even more recently of an intense neutrino beam resulting from the decay of muons circulating in a storage ring. Each of these applications calls for a scenario [1] in which muons are generated from a beam of pions which are in turn generated by impinging an intense proton beam on a target.

Note that, for this scenario, the intensity of the resulting muon beam is directly proportional to the power of the proton beam which initiates the process. Questions arise about the viability of targets to withstand the high beam power required to generate the desired pions.

Considering that a high intensity proton beam is required in order to generate the required muons, the choice of the target material becomes a particularly important issue. One is confronted with conflicting demands, namely a target material and geometry capable of producing copious pions while mitigating their absorption once they are produced. Modeling studies point to high-Z materials being more efficient at producing pions of both signs, whereas low-Z materials are better in avoiding the absorption of the produced pions. This is illustrated in Fig. 1, in which we see that pion yields from a carbon target are insensitive to the radius of the target, whereas the yield from a mercury target noticeably peaks in the range of radii from 3 to 4 mm. Carbon

has the advantage of permitting larger target cross-sections and therefore larger beam spot sizes with a corresponding decrease in shock heating due to high peak energy depositions. The muon collider collaboration is considering another approach, however, which is to retain the pion production advantage from high-Z materials by utilizing a free liquid mercury jet. In this case, the jet can be conveniently replaced so that target integrity after exposure to the proton beam is not an issue.

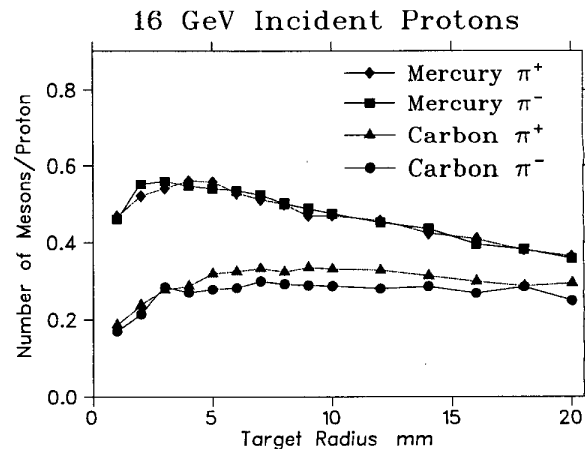


Figure 1: Pion production from 16 GeV protons

2 EXPERIMENTAL LAYOUT

Experiment E951 [2] has been approved for running at the Brookhaven Alternating Gradient Synchrotron (AGS). The A3 beam line [3] in the experimental hall has been configured for the transport of primary 24 GeV protons extracted from the AGS. All targets have been mounted inside a stainless steel vessel which prevents the potential dispersal of activated fragments which could be ejected from the tested target. This target system is placed on a translation table which has a target flag mounted to one side to facilitate the tuning of the proton beam prior to the target being moved into position. Measured beam rms

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spot sizes typically were on the order of $\sigma_x = 1.6$ mm and $\sigma_y = 0.9$ mm. Beam intensities were monitored by a series of beam transformers extending from the AGS extraction point to immediately preceding the target table. Intensities were adjustable from 0.5 to 4.0×10^{12} protons/pulse with full bunch beam lengths typically 150 ns.

The dispersal of the mercury was recorded with the use of two independent camera systems: 1) an Olympus Industrial, Encore PCI 8000S camera system capable of recording at a rate of 4 kHz with shutter settings for each frame set to $25 \mu\text{s}$; and 2) an SMD 64K1M camera capable of taking 16 frames at speeds of up to 1 MHz. The exposure time for the latter camera is 150 ns per frame.

Strain measurements were based on miniaturized Fabry-Perot interferometers provided by Fiso Technologies. Signals from the interferometers were then processed through a Veloce multi-channel system.

3 CARBON TARGETS

Two forms of solid carbon rods were exposed to the primary proton beam: 1) two ATJ carbon rods each 30 cm long by 16 mm diameter; and 2) two 12 cm long by 16 mm diameter rods made from an anisotropic carbon-carbon composite. The carbon composite is particularly interesting because its elastic modulus is unusually high while its coefficient of thermal expansion is nearly zero over a large temperature range. See Table 1 for the relevant properties. In Fig. 2, results of two strain measurements for both materials are shown. From the ATJ strain waveform we see clear evidence of a 100 kHz signal superimposed on a 4.5 kHz signal which has an initial peak-to-peak amplitude of $30 \mu\text{strains}$. Also clearly seen, before the arrival of the proton pulse, is the background noise level of the strain gauge which is $\sigma_{rms} = 0.7 \mu\text{strains}$. The 4.5 kHz signal corresponds well to the expected longitudinal propagation of reflected pressure waves. The 100 kHz signal is appropriate for radial reflections. For the carbon-carbon composite we observe a 34 kHz signal but with a much lower amplitude. This signal's initial peak-to-peak level is $3 \mu\text{strains}$ while the background noise level for this strain gauge is $\sigma_{rms} = 0.3 \mu\text{strains}$.

Table 1: Properties of carbon targets

	ATJ	Carbon-Carbon Composite	
		Z	(U,V)
Elastic Modulus, GPa	9.6	117	48
Exp. coefficient, $1/^\circ\text{C}$	2.46×10^{-6}	~ 0	~ 0

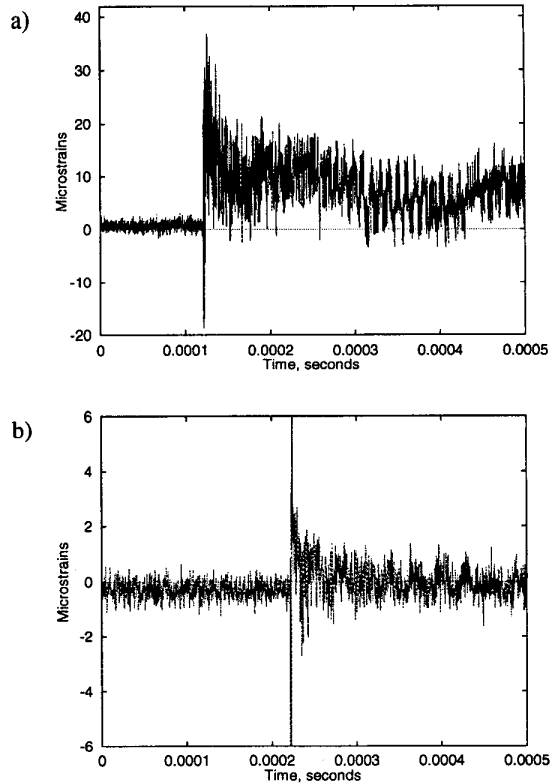


Figure 2: Strain gauge data from carbon targets: a) 3×10^{12} proton beam on ATJ carbon; b) 2×10^{12} proton beam on carbon-carbon composite

4 MERCURY TARGETS

Two separate mercury targets were exposed to the AGS proton beam. An initial test was made with a passive system in which a small well loaded with 1.9 cm^3 of mercury was placed into a container in which the dispersed mercury droplets could be collected and channeled back into the well. Five shots were delivered and the mercury dispersion recorded. The beam intensity for these shots varied from 0.65 to 4×10^{12} . In Fig. 3 we see three frames taken with the SMD 16K1M camera. The initial velocity of the ejected mercury was 70 m/s, however, this velocity was reduced to 40 m/s by the time the cloud of mercury has traveled 4 cm. This effect could be due to the presence of 1 atmosphere of air inside the chamber.

The mercury jet (Fig. 4) was formed by supplying a pneumatic pressure of 26 psi which forced the mercury out of a 1 cm diameter nozzle inclined at 18.5° . The resulting mercury stream travels 20 cm to its maximum height at which point the trajectory of the Hg jet overlaps with the proton beam for 19 cm. The average velocity of the jet was 2.5 m/s. The diameter of the jet at the interaction point fluctuated between 0.7 and 1.7 cm.

Dispersal of the mercury by energy deposition due to the

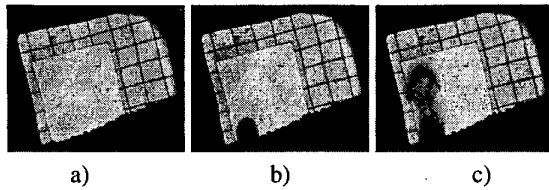


Figure 3: Hg interaction with 24 GeV, 4×10^{12} protons; $t =$ a) $0 \mu s$; b) $300 \mu s$; c) $800 \mu s$. The grid is $1 \text{ cm} \times 1 \text{ cm}$

interacting proton beam was observed directly by viewing prominences as they left the bulk of the mercury jet. We were also able to indirectly measure the velocity of Hg droplets, since their arrival at the quartz viewing ports was signaled by distinctive splashes. Directly measured bulk velocities range from 5 to 50 m/s while the velocities of the Hg droplets arriving at the quartz window varied from 1 to 10 m/s. In both cases we observe that the maximum velocities increase roughly proportionally to the intensity of the impinging proton beam.

Also of interest is the extent of the disruption of the mercury, and in particular whether this disruption extends forwards and backwards from the interaction region. It was observed that the region of disruption was confined largely to the volume of overlap with the proton beam with no evidence of jet dispersal propagating back to the nozzle. The maximum disruption length observed was 14 cm.

Finally, by utilizing the SMD 64K1M camera set in a fast frame mode (1 frame/ $10 \mu s$), we observed that the breakup of the mercury jet commenced after an elapsed time of $\sim 40 \mu s$. Observations with the camera set as fast as 18 frames per $18 \mu s$ showed no discernible disruptive motion in the jet.

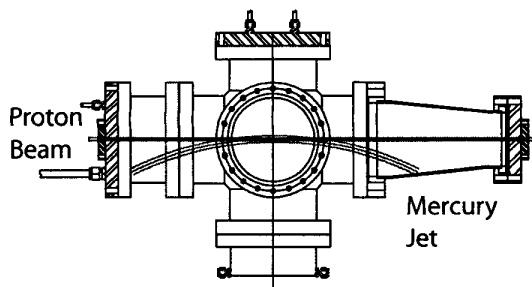


Figure 4: Elevation view of the Hg jet overlapping with the 24 GeV proton beam.

5 SUMMARY

This spring, the E951 collaboration began a series of measurements with the goal of providing observations needed to clarify the best technological path for the Neutrino Factory and Muon Collider Collaboration to proceed

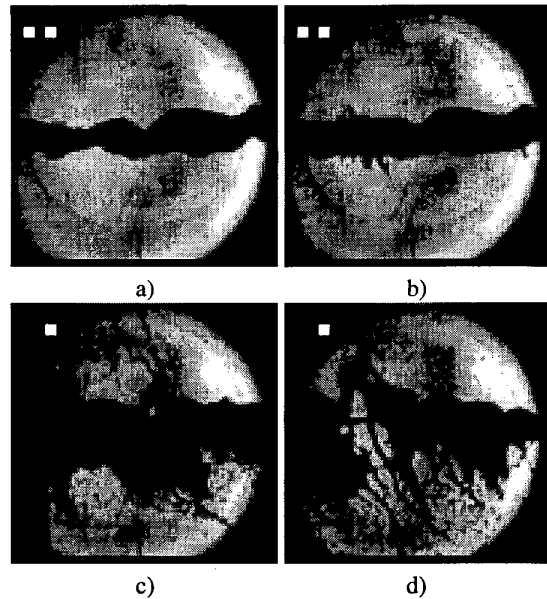


Figure 5: Hg jet interaction with 24 GeV 3.8×10^{12} protons; $t =$ a) 0 ms; b) 0.75 ms; c) 10 ms; d) 18 ms

in order to provide a future machine with a source of muons more intense than presently achievable. Among the initial results:

- The strain amplitudes for a cylinder made from an anisotropic carbon-carbon composite are substantially less (a factor of ~ 10) than those for ATJ carbon.
- Hg jet dispersal is mostly transversal. The jet disruption is confined mostly to the proton beam-Hg jet interception volume.
- For a 4×10^{12} proton beam, dispersed Hg droplet velocities are $< 10 \text{ m/s}$.
- Hg jet dispersal is delayed for $\sim 40 \mu s$.

6 REFERENCES

- [1] H.G. Kirk, *TARGETRY FOR A $\mu^+ \mu^-$ COLLIDER*, Proceedings of the 1999 Particle Accelerator Conference, New York, March 1999, p.3029.
- [2] James Alessi, et al., *An R&D Program for Targetry and Capture at a Muon-Collider Source*, Proposal submitted to Brookhaven National Laboratory, (Sept. 28, 1998).
- [3] K. Brown, *First Beam Tests of the Muon Collider Target Test Beam Line at the AGS*, Proceedings of the 2001 Particle Accelerator Conference, Chicago, IL, June 18-22, 2001.