TIME STRUCTURE OF PARTICLE PRODUCTION IN THE MERIT HIGH-POWER TARGET EXPERIMENT

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Abstract

The MERIT experiment is a proof-of-principle test of a target system for high power proton beam to be used as front-end for a neutrino factory complex or a muon collider. The experiment took data in autumn 2007 with the fast extracted beam from the CERN Proton Synchrotron (PS) to a maximum intensity of about 30×10^{12} protons per pulse. We report results from the portion of the MERIT experiment in which separated beam pulses were delivered to a free mercury jet target with time intervals between pulses varying from 2 to 700 μs. The analysis is based on the responses of particle detectors placed along side and downstream of the target.

INTRODUCTION

The MERIT experiment was proposed as a proof-of-principle demonstrator of a target system based on a free mercury jet, including magnetic focusing/capture of secondary pions/muons, suitable for generating intense muon beams as source for future Muon Collider or Neutrino Factory facilities [1]. The experiment was installed in one of the extraction lines of the CERN PS machine and took data for few weeks in Fall 2007. The experiment was designed to study the impact of intense single proton pulses to the high-Z liquid metal mercury jet which intercepts the beam at the center of a high-field (15-20 T) solenoid. The observation of the jet target dispersal by the mechanical shock and sudden energy deposition accompanied with material vaporization and cavitation formation and how much such effects are influenced by the strong magnetic field are important scientific questions that the experiment addressed. The concept and preliminary results of this experiment have been previously reported [2] [3].

In this paper the results from the particle flux detectors that monitor the secondary particle production from the target will be reported. In particular, the analysis is focused on the time evolution of the detector response after the beam impact as a probe for the onset of cavitation formation.

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THE EXPERIMENTAL SETUP

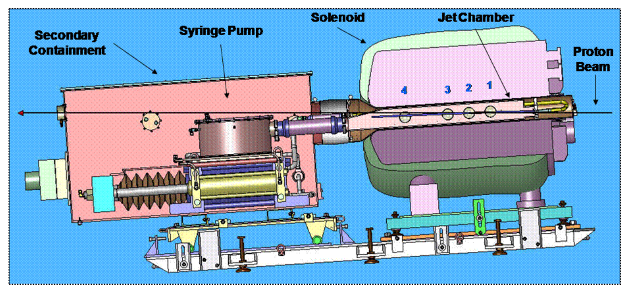

Figure 1: Cut-away view of the experimental apparatus.

The MERIT experiment was installed in the TT2 extraction line of CERN PS. Fig. 1 shows the experimental apparatus with its two major components: the 1-m long 15-cm bore diameter LN_2 cooled solenoid capable of delivering a 15-T field [4], and the mercury loop system that generates a 1-cm diameter free mercury jet moving with velocities up to 20 m/s [5]. Both systems are pulsed, capable of maintaining the desired field and mercury jet for few seconds, synchronized with the beam. The whole assembly is tilted to produce an angle of 67 mrad with respect to the beam needed to maximize the collection of soft pions that later decay into muons. For the nominal mercury jet diameter, the beam interaction region is about 30 cm and varies with the jet speed and shape which is also affected by the magnetic field.

The instrumentation of the experiment includes special optical diagnostics with high-speed cameras capable of taking photos at four locations along the Hg jet inside the solenoid bore [6] and particle flux detectors placed at six locations around the target assembly as shown in Fig. 2 to do a relative measurement and monitoring of the secondary particle flux out of the target.

Upon request, pulses from the PS machine were extracted to the experiment, with each pulse corresponding to a different setup of jet speed, magnetic field, beam intensity and time structure. At 15 T, the magnet had to be cooled down at each shot making an overall cycle of

Figure 2: The experimental setup in the TT2A tunnel. The yellow circles indicate the location of four of the six detectors: the two in the forward direction are at 10 deg. angle from the target, and the other two at 20 and 90 degrees respectively. A fifth detector is located behind the beam attenuator and the sixth at 20 deg. on the beam-right behind the experimental setup.

about 30 min. Typically the PS machine was configured to harmonic-16 mode with 16 bunches in the machine interspaced by 131 ns. Few pulses were also taken at harmonic-8 (262 ns interbunch spacing) and harmonic-4 (524 ns interbunch spacing). The beam intensity was varied (either by varying the intensity per bunch or by leaving empty slots in the ring) from 0.20 to 30×10^{12} protons per pulse, and the energy between 14 and 24 GeV. 360 beam pulses were taken by the experiment for a total of 3×10^{15} protons. The pulse at 24 GeV with $30{\times}10^{12}$ protons (equivalent to 115 kJ of beam power) represents a new record for the CERN PS machine.

THE PARTICLE FLUX DETECTORS

To measure the high fluxes of particles coming out of the target, two types of detectors were used: Aluminum Cathode Electron Multiplier (ACEM) detectors, used in the past as beam loss monitors in the PS machine, and Polycrystaline Chemical Vapour Deposition diamond (pCVD) detectors, as those used as beam loss monitors around the interaction regions of the LHC. The detector assembly with both the ACEM and pCVD detectors is shown in Fig. 3. The pCVD detectors are known to be radiation hard and capable of measuring high particle fluxes such as those expected close to the MERIT target [7] and are the ones used in the analysis here. According to simulations, the charged particle flux for the detectors close to the target can reach up to 5×10^7 particles/cm ^{2}/bunch, which generates a current of 1.6 A in the 0.75×0.75 mm^2 diamond sensors.

Signal Reconstruction

The pCVD detectors were directly connected to a fast oscilloscope sampling the waveforms at 2.5 GHz (see Fig. 4.

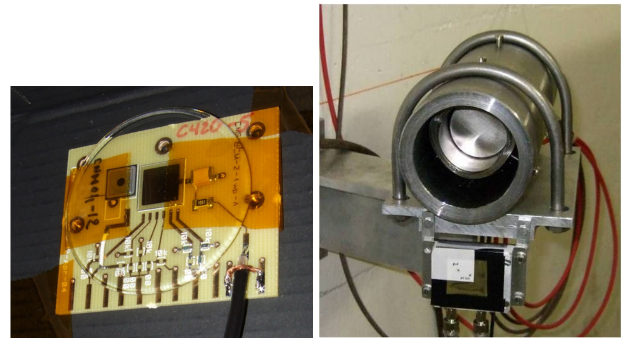

Figure 3: Left: the pCVD board with the detector sensor. Right: the detector assembly with the ACEM PMT on top in its shielding and the pCVD detector at the bottom.

A large 100 nF leak capacitor was added in the circuit to provide the necessary voltage and drain the sensors between bunches. However for the highest intensity pulses the capacitor was not sufficient and a dependence of the signal response with bunch number was observed. Since we are interested in only relative measurements this effect is corrected by applying an average correction to each bunch and normalizing tho the first bunch of the train.

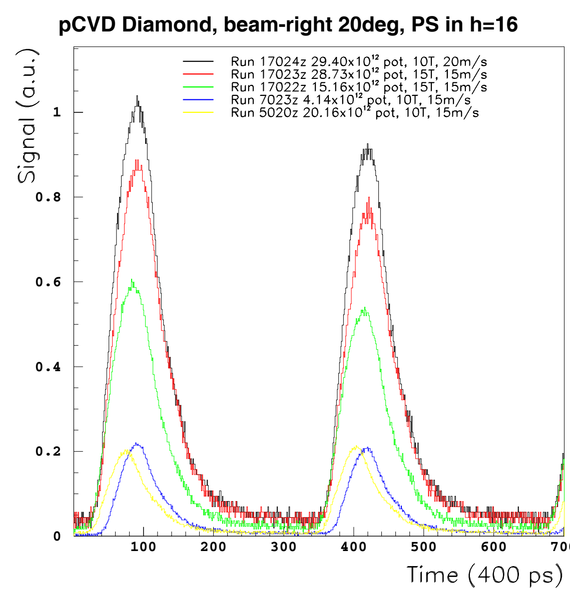

Figure 4: The response of a diamond detector at different beam intensities and target configurations.These traces correspond to the first two bunches out of 16 of a beam pulse.

THE EXPERIMENTAL RESULTS

Pump-Probe Studies

The effect of the mercury jet disruption to the production of secondary was studied using the “pump-probe” method profiting from the versatility of the PS machine. The concept of the pump-probe studies is illustrated in Fig. 5. Either 6 or 12 bunches of 14-GeV protons were first ejected from the CERN PS during one turn, and then the remaining 2 or 4 bunches were ejected during a subsequent turn, 40, 350 or 700 μs later. This could only be done with beams of energy up to 14 GeV, and the maximum delay was 1 ms.

The relative rates of secondary particles produced by these bunches as recorded by one of the diamond detectors is shown in Fig. 4. Data from both target-in and -out events showed a rapid reduction of sensitivity of the diamond detectors during a bunch train, with a recovery time of order several hundred μs. Hence, the effect of disruption of the mercury target by the pump bunches on the rate of particle production during the pump bunches was gauged by the following ratio

$$Ratio = \frac{\frac{Probe_{target} - Probe_{no-target}}{Pump_{target} - Pump_{no-target}}}{\frac{Probe_{no-target}}{Pump_{no-target}}} \qquad (1)$$

The observed values of this ratio, shown in Fig. 6, are consistent with no reduction in particle production for bunches 40 or 350 μs after a first set of bunches, and about 5a mercury jet target, although disrupted by intense proton bunches as shown in other studies [6], would remain fully effective in producing pions during a bunch train of up to 300 μs as may be desirable for operation of a 4-MW proton driver at a Neutrino Factory.

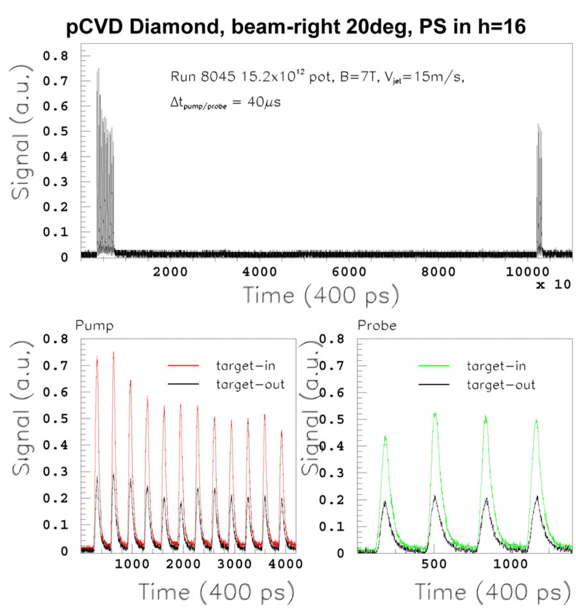

Figure 5: Response waveform of a diamond detector for a beam pulse with 12 pump bunches, followed by 4 probe bunches 40 μs later.

SUMMARY

The MERIT experiment successfully took data in the autumn of 2007 at the CERN PS, demonstrating the validity

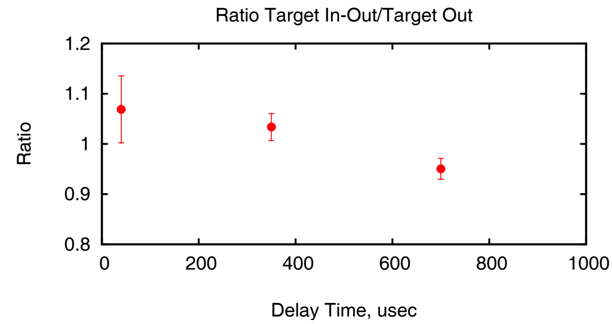

Figure 6: The probe/pump ratio for target-related particle production as a function of delay of the probe bunches.

of the free mercury jet target principle as proposed system for the generation of intense muon beams at interaction with megawatt proton beams. The temporal analysis of the particle production showed that despite the apparent disruption of the mercury jet on the scale of several ms, secondary particle production is little affected for several hundred μs after the arrival of the first bunches of a train.

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