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THE MERIT(nTOF-11) HIGH INTENSITY LIQUID MERCURY TARGET EXPERIMENT AT THE CERN PS

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Abstract

The MERIT(nTOF-11) experiment is a proof-ofprinciple test of a target system for a high power proton beam to be used as front-end for a neutrino factory 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 30 × 10^{12} per pulse. The target system, based on a free mercury jet, is capable of intercepting a 4-MW proton beam inside a 15-T magnetic field required to capture the low energy secondary pions as the source for intense muon beams. Partice detectors installed around the target setup measure the secondary particle flux out of the target and can probe cavitation effects in the mercury jet when excited by an intense proton beam.Preliminary results of the data analysis will be presented here.

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The MERIT(nTOF-11) experiment is a proof-of-principle test of a target system for a high power proton beam to be used as front-end for a neutrino factory 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 30×10^{12} per pulse. The target system, based on a free mercury jet, is capable of intercepting a 4-MW proton beam inside a 15-T magnetic field required to capture the low energy secondary pions as the source for intense muon beams. Partice detectors installed around the target setup measure the secondary particle flux out of the target and can probe cavitation effects in the mercury jet when excited by an intense proton beam.Preliminary results of the data analysis will be presented here.

INTRODUCTION

The MERIT experiment represents an important milestone in the R&D program of high-power targetry for a future neutrino factory or muon collider [1]. It comes as a continuation of previous studies with encouraging results done at BNL [2] and CERN [3], combining for the first time a free mercury jet and a focusing/capturing solenoid for secondary pions or muons as proposed in design studies for future facilities [4]. The focus of the experiment is the study of the impact of intense single proton pulses. 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 addresses with results presented here.

THE EXPERIMENTAL SETUP

The MERIT experiment was installed in the TT2 extraction line of CERN PS (see Fig. 1). The experiment comprises of two major components: the 1-m long 15-cm bore diameter solenoid capable of delivering a 15-T field [5], and the mercury loop system that generates a 1-cm diameter free mercury jet moving with velocities up to 20 m/s [6].The jet delivery system is inserted from the downstream side inside the solenoid bore and the whole assembly is tilted by 67 mrad relative to the horizontal direction. The free jet is generated upstream and intercepts the beam axis at the center of the solenoid at an angle close to 50 mrad. 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.

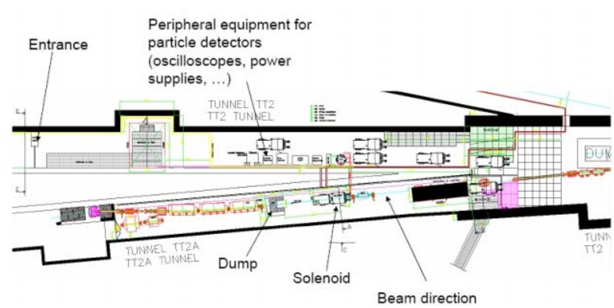

Figure 1: The TT2/TT2A tunnels of CERN PS showing the experimental setup. The experimental apparatus is installed upstream of the nTOF target shown at the left.

To observe the mercury jet/beam interaction, special optical diagnostics with high-speed cameras were developed [7] capable of taking photos at four locations along the mercury jet inside the solenoid bore. Particle flux detectors were placed at six locations around the target assembly and behind the thick beam attenuator that stops the non-interacting proton beam as shown in Fig. 2. At each location an Aluminum Cathode Electron Multiplier (ACEM) detector, and a Polycrystaline Chemical Vapour Deposition diamond (pCVD) detector were mounted. The pCVD diamond detectors [8] are of a similar type as those used as beam loss monitors around the interaction regions of the LHC. They are known to be radiation hard and capable of

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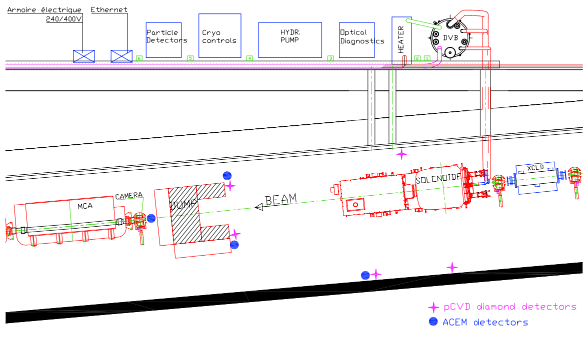

Figure 2: The experimental layout indicating the location of the particle flux detector assemblies.

measuring high particle fluxes such as those expected close to the MERIT target. The ACEM detectors are extensively used as beam loss monitors in the CERN accelerator complex and are also tested to high fluxes [9] similar to those expected at MERIT. They were installed as a backup system having the additional advantage of being able to regulate the output signal by lowering the HV of the photomultiplier. The detector assembly with both the ACEM and pCVD detectors is shown ing Fig. 3.

Figure 3: Photo showing the assembly of one detector.

THE EXPERIMENTAL RESULTS

For the needs of the experiment the last part of the TT2A beam line that normaly delivers beam to the nTOF facility was modified with the magnetic elements reconfigured such to provide a small beam spot at the MERIT target. Beam optics calculations predict beam spot sizes on the target to be of the order of 12 mm^2 and 6 mm^2 for the 14 GeV/c and 24 GeV/c beams respectively for the maximum beam intensity of 30×10^{12} protons. The resulting energy deposition on the target can reach 160 J/gr matching the value in future neutrino beam facilities. The maximum extracted intensity of 30×10^{12} protons at 24 GeV/c to the MERIT expriment corresponds to a new record for the PS machine.

The MERIT experiment is a single pulse experiment, with the PS beam extracted upon request at variable intensity and timing structure. For most of the pulses the PS machine was configured to harminic 16, i.e. filled with up to 16 bunches spaced at 131 ns while other configurations of harminic 8 and harmonic 4 were used. A special configuration of the PS machine allowed to extract part of the circulating bunches in the PS ring at variable timing after the first extraction within the same or following turns up to a maximum separation of 1000 μs. Note that one turn of the PS ring corresponds to 2.2 μs. This important feature permitted an examination of the target disruption as a function of the beam structure as shown in Fig. 4.

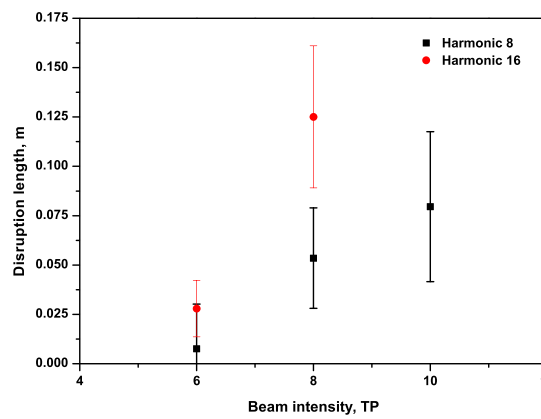

Figure 4: Target disruption length vs beam intensity for different harmonic configurations of the PS machine.At harmonic-16(8) the bunches have a time separation of 131(262) ns.

The data indicate that the disruption length decreases when the same intensity is delivered by fewer bunches spaced further apart. This and other experimental results reported elsewhere [10] will allow to determine a set of design and beam parameters for accelerator facilities involving high-power target systems.

Fig. 5 shows the linearity of the pCVD diamond detectors signal with increased beam intensity in the target for different settings of the solenoid magnet. The detector signals were directly, without additional signal amplification, connected to a fast sampling digital oscilloscopes synchronized with the beam timing. The detector response time is in order of nano-seconds, which allows a clear separation of individual beam bunches separated by 131 ns. According to simulations for the detectors the charged particle flux can reach up to 5×10^7 particles/cm^2/bunch which creates a current of 1.6 A in the $0.75 \times 0.75\,\mathrm{mm}^2$ diamond detectors. The integrated charge per bunch is then corrected for the variations of the beam intensity measured with current transformers along the beam line.

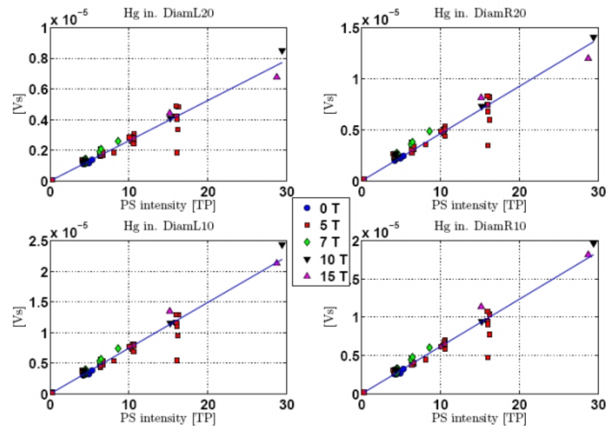

Figure 5: The response linearity of the pCVD diamond detectors for increased beam intensity.

In Fig. 6 the signal from the four particle detectors located at different angles around the target is plotted, showing good agreeement with the MARS [11] simulation predictions. The relatively small ratio between the target-in and target-out case can be attributed to the material from beam windows in the beam line. These results represent our present understanding of the target, beam shape and particle detector response. Extensive studies are ongoing in to include effects like the variations in the mercury jet shape, the effect of gravity or misalignment erros as well as improved calibration and beam intensity corrections for the paricle detector response.

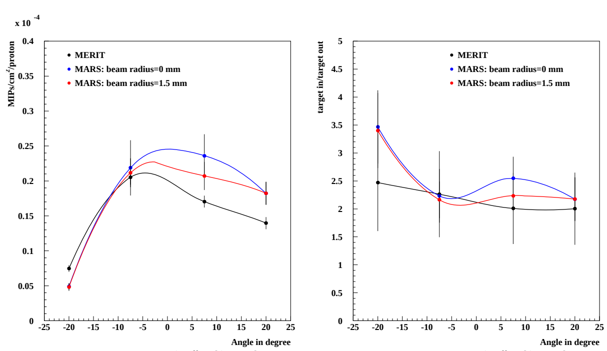

Figure 6: Left: The response of the pCVD diamond detectors installed at different angles around the mercury target for a 14 GeV/c proton beam compared to MARS simulation predictions. Right: The ratio of the response with and without the mercury jet for experimental data and simulations. The MARS simulation was done for a pencil like proton beam and for a beam with radius of 1.5 mm.

SUMMARY

The MERIT experiment successfully took data in the autumn of 2007 at the CERN PS. The successful operation of the experiment during the three weeks of the experiment combining for the first time a free mercury jet inside a strong magnetic field for a total of about 700 pulses (100 with high-intensity beam) demonstrate the validity of the principle as proposed for future accelerator facilities. The observations of the mercury jet disruption at the impact of the high-intensity beam support its use for multi-MW target systems and provide an important feedback in the design parameters for future applications. The first analysis results of the particle flux detectors provide useful imput in understand the mercury jet-beam interaction, while the rest of the analysis is ongoing and further results will be reported at a future occasion.

ACKNOWLEDGEMENTS

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