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STATUS AND PLANNED EXPERIMENTS OF THE HIRADMAT PULSED BEAM MATERIAL TEST FACILITY AT CERN SPS*

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Abstract

HiRadMat (High Irradiation to Materials) is a facility at CERN designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies (e.g. vacuum windows, shock tests on high power targets, collimators) can be tested. The beam parameters (SPS 440 GeV protons with a pulse energy of up to 3.4 MJ, or alternatively lead/argon ions at the proton equivalent energy) can be tuned to match the needs of each experiment. It is a test area designed to perform single pulse experiments to evaluate the effect of high-intensity pulsed beams on materials in a dedicated environment, excluding long-time irradiation studies. The facility is designed for a maximum number of 10^{16} protons per year, in order to limit the activation of the irradiated samples to acceptable levels for human intervention. This paper will demonstrate the possibilities for research using this facility and go through examples of upcoming experiments scheduled in the beam period 2015/2016.

INTRODUCTION

In the new era of high-brightness accelerators, the power of the circulating beam can be destructive during its interaction with the machine equipment (collimators, magnets, beam dumps). To avoid any possibly destructive incident that will compromise the operation of the accelerator, it is preferred that an experimental verification of the beam interaction with the equipment and materials is performed beforehand. Apart from the accelerator design itself, in the targetry applications, where a high-energy beam impinges on a target material for producing secondary particles, as is the case of Neutrino Beam facilities [1] or Muon Collider, where the flux of secondary particles requires a MW or even multi-MW power of the primary beam, the need of experimentally verifying the behaviour of the target material is imperative. HiRadMat (High Radiation to Materials) is a unique facility providing a pulsed, high-energy beam, available for tests in a controlled and safe way.

EXPERIMENTS IN HIRADMAT

The facility was commissioned in 2011. During 2012-2013, nine experiments were approved by the facility's scientific and technical boards and completed the data taking successfully [2]. Those experiments covered a broad spectrum of research topics, from a fully assembled LHC collimator and a SPS magnet septum, to high-power targetry investigating the effect of the proton beam on a tungsten powder target.

Depending on the scientific scope of each experiment online and/or offline (post -irradiation) analysis was used. Although rather challenging, online measurements are very interesting as they provide information on the dynamics of the beam impact. The main systems used for online measurements covered the following techniques: Doppler-laser-vibrometry measuring instantaneous deformations (up to 24 m/s at 2.5 MHz sampling), a fast camera (few kHz frame rate) for optical observations, accelerometers to measure the propagation of shock waves, temperature and acoustic measurements, and pressure gauges. The challenge in online instrumentation comes from the radiation field in the cavern that prohibits any installation of active electronics nearby unless specifically designed.

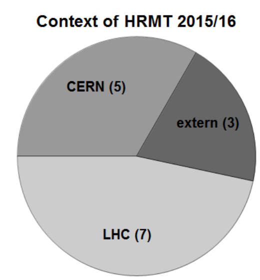

Figure 1: The context of the approved experiments for the beam period 2015-2016.

Following the start-up of the CERN accelerators after the LS1, for the period 2015-2016, fifteen experiments have already submitted their requests for beam time in the facility. The context of the experiments is shown in Fig. 1: seven experiments are directly related to accelerator operation for LHC (e.g. collimator materials), five have a general CERN oriented context (e.g. target development for the AD facility), and 3 experiments are proposed from international collaborations external to CERN (high-power targetry, optical microphones as beam loss monitor and testing the strength limits of beryllium windows for vacuum applications). For 2015, seven of these experiments are approved and scheduled. The current schedule of the experiments along with the cumulative proton budget can be seen in Fig 2.

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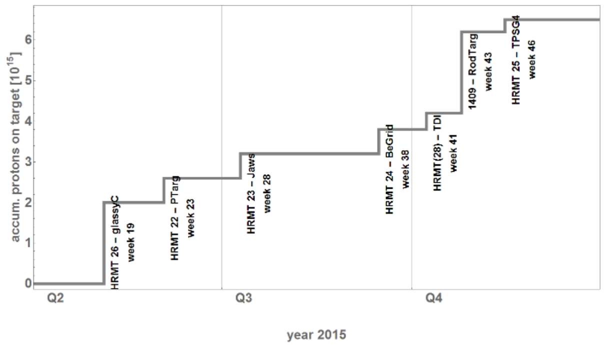

Figure 2: The cumulative number of protons to the facility for the experiments scheduled in 2015.

One of the main aims of HiRadMat is the validation test of collimator systems suitable for CERN accelerator operation within HL-LHC. This includes the validation of the TPSG4 (HiRadMat test HRMT25), which is the protection collimator for the SPS extraction septum blade and also concerns collimators in the transfer lines and in the LHC itself. The development of the LHC collimator jaw materials is a multi-stage test in the HiRadMat facility. Already in 2012 an array of candidate materials was tested (HRMT14) in the HiRadMat facility, which will be followed by an upgraded test in 2015 (HRMT23) with full scale jaws of the three most promising materials. It is also planned that HiRadMat will host the collimator assembly for final validation in the course of 2016.

Two HiRadMat experiments during 2015 focus on the structural strength of vacuum windows for high power proton beams. In an international collaboration between FNAL, RAL and CERN (HRMT24), the tested window material is Beryllium. The primary purpose is the proton beam line for the neutrino production at FNAL, but test results will extend to other high-intensity applications. The second window material is glassy carbon, a material obtained through pyrolysis at high temperature of a highly reticulated resin. This experiment, HRMT26, is conducted by CERN TE/VSC group.

The scheduled proton budget for the 2015 experiments raises to about 6×10^{15} protons, well within the annual intensity budget allocated to the facility of 10^{16} protons per year. This annual limit is rational since HiRadMat is not designed as an irradiation facility were large doses on equipment can be accumulated.

BEAM FOCUS AT EXPERIMENT

The primary proton beam from SPS, offers a variety of possible beam sizes at the experimental area that can be tuned according to needs. The proton beam parameters at the focal points in the experimental HiRadMat target area were defined at the commissioning in 2011 [3]. Since then the SPS has changed to Q20 optics [4], so the extraction has to be adapted accordingly for HiRadMat operation from 2015 onwards. The baseline of the normalized transverse emittance is defined by the LIU project as 2.5 µm [5] for a 25 ns bunch spacing. The proton momentum to HiRadMat remains 440 GeV/c. Figure 3 and 4 show the 1-σ beam size at the three experimental positions (vertical grey lines).

The usage of beam radii below 0.5 mm at the target is restricted by the need to maintain focal point positions that yield beam sizes larger than 0.5 mm at the vacuum window (position 403 m, see Fig. 3).

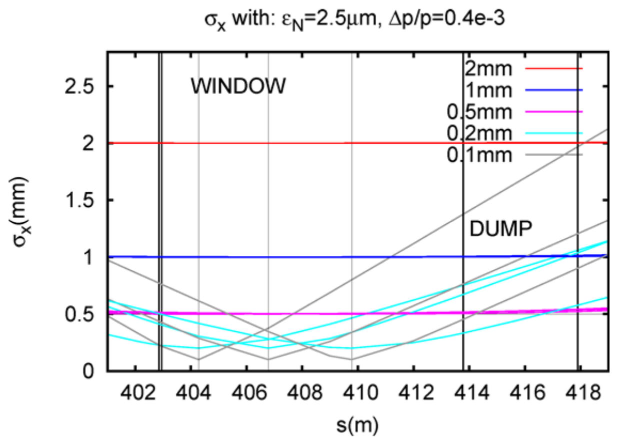

Figure 3: Calculation of the horizontal beam size of a proton beam with nominal emittance as a function of the longitudinal position in the region of the experimental area for different focal point positions and for different focal spot sizes.

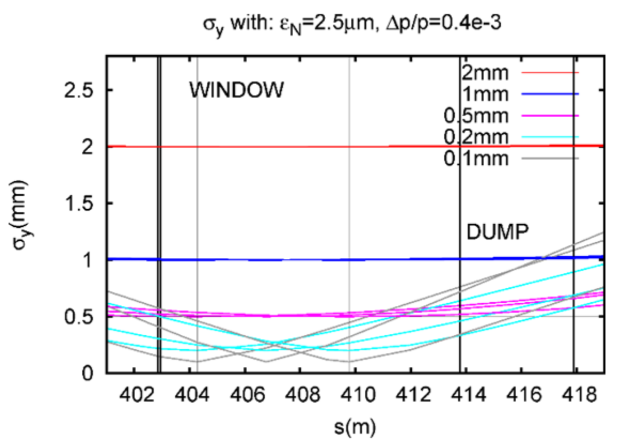

Figure 4: Calculation of the vertical beam size of a proton beam similar to Fig. 3.

RECENT FACILITY UPGRADES

Three major upgrades were conducted during the CERN shutdown of 2013/2014: a location for radiation sensitive electronics at a "cable" distance of less than 10 m from the target area; additional patch cabling for HQ signals and high voltage dedicated for experiment use; and the development of a beam position monitoring system adaptable to experiments.

During HiRadMat operation in 2012, several experiments operated for the first time numerous sensors for strain/temperature measurements and optical observations based on a high-speed camera and laser-Doppler vibrometry. In all cases, the sensitive electronics had to be installed in a dedicated concrete bunker at a "cable" distance of about 40 m from the target area. This positioning reduced the prompt radiation to levels acceptable for off-the-shelf electronics, and no failure of electronics due to radiation was observed. However, the long cable distance caused difficulties to the experiments for the readout and data acquisition systems. Also, the adjustment of the optical observation over a distance of 40 m required lengthy installation delays. Last, for electric signals the distance caused undesired distortions of high frequency signals and background noise in the same range as the low level signals from strain gauges. For these reasons a setup location of read-out electronics and equipment installation closer to the target position was requested in a nearby tunnel. The TT61 tunnel, next to the target area of HiRadMat, was adapted with civil-engineering modifications and additional shielding.

Figure 5 shows a representative integration study of an experiment scheduled for 2015 in HiRadMat. The experimental target box is positioned on the HiRadMat beam line in the TNC tunnel. The sensitive electronics (e.g. laser-Doppler vibrometer) are placed in the neighbouring tunnel TT61. A feedthrough in the separating concrete wall allows an optical path and passage of cables to the experiment setup, reducing the viewing distance and the cable length to below 10 m.

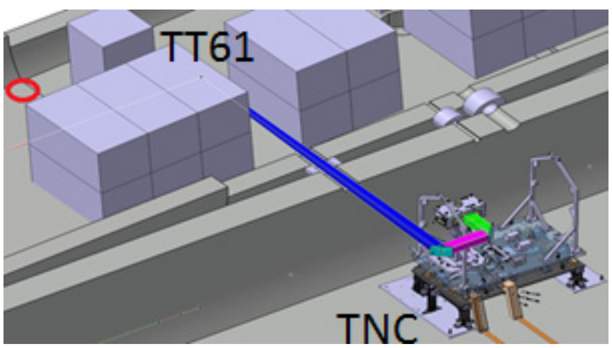

Figure 5: Integration study of a HiRadMat experiment placed on the position B. The adjacent tunnel TT61 hosts the sensitive electronics e.g. of the high-speed cameras, where the optical path passes through the recently installed feed-throughs.

Based on FLUKA simulations [6-7], additional shielding placed in TT61 was defined in order to reduce the prompt radiation (Fig. 6) to levels similar to the previous electronics location in TJ7.

The beam position monitors used during 2012 are limited in measurement precision at the location of the experiment, as they are placed several meters just upstream of the experimental tables. A dedicated system is being provided, which will allow installation on individual experimental setups. It is composed of two types of beam monitor, a beam screen and a BPKG monitor, which both operate in air: The beam screen, which can be retracted for high intensity pulses, will allow the calibration of the BPKG, which is a stripline pick-up already successfully used in CNGS [8].

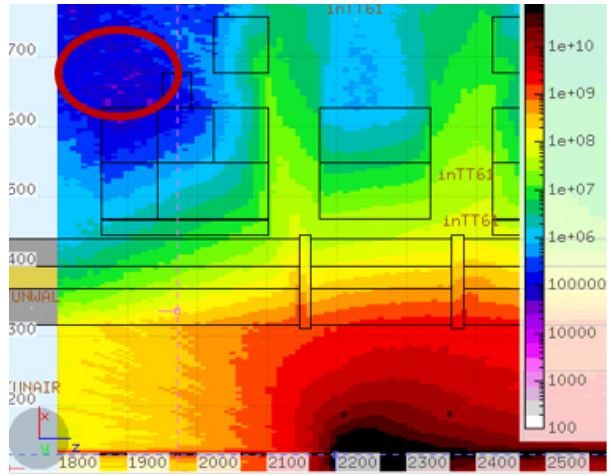

Figure 6: Prompt radiation levels around the target area and the proposed electronics positions in TT61 (red circle). The radiation levels are shown in fluence/cm2 (hadrons > 20 MeV) and for 3.7 x 10^{12} protons impinging on a thick target.

The BPKG can be then used over the full range of the proton beam intensity, with a measurement precision better than 0.1 mm, with respect to the experimental setup. This monitor system is provided by the CERN BE/BI group.

CONCLUSION

After its successful installation and start-up in 2012, with nine experiments completed, the HiRadMat facility will restart operations in 2015 with seven new experiments covering a broad spectrum of R&D areas. The facility thus confirms its unique place for performing state-of-the-art experiments on the impact of pulsed high-intensity beams on material subjects. The HiRadMat facility is also registered under EuCard-2 as HiRadMat@SPS Transnational Access where financial support is available for the users. For more information visit http://www.cern.ch/hiradmat.

ACKNOWLEDGMENT

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