FIRST YEAR OF OPERATIONS IN THE HIRADMAT IRRADIATION FACILITY AT CERN

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Abstract

HiRadMat (High Irradiation to Materials) is a new facility at CERN constructed in 2011, designed to provide high-intensity pulsed beams to an irradiation area where material samples as well as accelerator component assemblies can be tested. The facility uses a 440 GeV proton beam extracted from the CERN SPS with a pulse length of up to 7.2 μs, to a maximum pulse energy of 3.4 MJ. For 2012, the first year of operations of the facility, nine experiments were scheduled and completed data-taking successfully. The experience gained in operating this unique facility, along with highlights of the experiments and the instrumentation developed for online measurements are reported.

INTRODUCTION

The HiRadMat facility [1] is designed to provide a test area where the effect of high-intensity pulsed beams on materials or accelerator component assemblies can be studied. The facility is not designed for long-term irradiation studies but rather for single pulse experiments to study the onset of material damage. The designed target is ten experiments per year, with 10^{15} protons or about 30 high-intensity pulses per experiment, thus a total of 10^{16} protons per year for the whole facility. It is judged that for the majority of the experiments a small number of high-intensity pulses would be sufficient in order to investigate the damage to the test samples whilst keeping the activation levels reasonably low such that post-irradiation tests could be performed after a reasonable cool-down period. The HiRadMat facility is situated in the former West Area Neutrino Facility (WANF) target tunnel and is about 35 m below ground. It takes the fast extracted beam from the long straight section LSS6 of SPS, the same used for the TI2 injection line to LHC.

The construction of the facility was completed in 2011. Two commissioning periods, one with low-intensity beams in May 2011 and one with high-intensity beams (with intensities up to the 10^{13} protons/pulse) in summer 2011 were successfully completed [2]. The online documentation for the facility is available at: http://cern.ch/hiradmat.

EXPERIMENTS IN 2012

In the initial call for experiments, sixteen proposals were submitted, nine of which advanced to full experimental proposals, approved for beam time by the facility Scientific and Technical boards. Figure 1 shows the timeline of the experiments. All the experiments completed the irradiation time successfully. The safety pre-cautions and procedures defined in agreement with the CERN safety units for the operation of the facility were followed, resulting in no safety incident during HiRadMat operation.

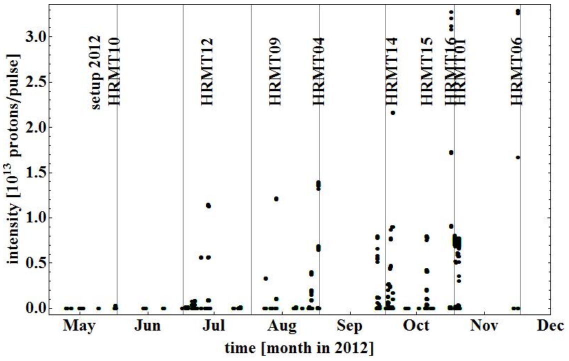

Figure 1: 2012 time-line of the HiRadMat experiments. The labels indicate the nine experiments of the year following the initial setup period. The maximum pulse intensity of 3.3 10^{13} protons was achieved.

The nine experiments in 2012 covered a broad spectrum of topics from LHC collimation to material testing, targetry and radiation monitoring.

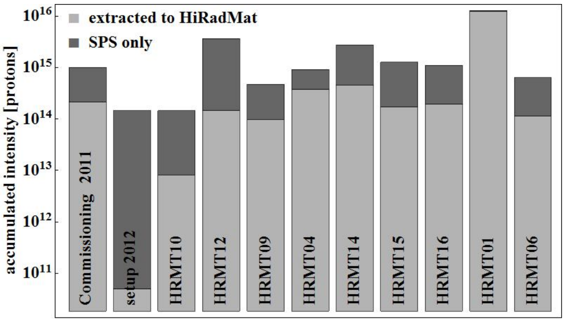

Figure 2: Integrated proton intensity per experiment. In total 1.4 10^{16} protons were delivered to the facility.

Three robustness tests experiments were performed related to **LHC collimation system**, the initial proponents for the facility:

- on a fully assembled LHC phase-II collimator, looking in particular to qualify the setup against beam shock impact [3],

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- on a UA9 crystal assembly [4] , required to validate the device before its installation in the LHC machine, and last
- on protecting collimator (TPSG4) for the SPS magnet septum (MSE), using beam pulses at the highest possible beam intensity.

Figure 3: The TPSG experimental setup. The beam arrives from the left of the picture, the beam dump is in the background. The exact configuration of the TPSG4 and MSE was reproduced, using two separate vacuum tanks spanning over the full length of the experimental facility (9 m).

On the **LHC machine protection**, an experiment [5] investigated the impact of a loss of the full LHC beam on solid materials. Solid copper cylinders were exposed to the SPS proton beam investigating the beam tunnelling effects and benchmarking of numerical models, using sequences of high-intensity ($1.2\,10^{13}$) protons.

On the **material evaluation**, two experiments were performed:

- on the first twelve different candidate materials for beam intercepting devices like collimators, in a fully instrumented setup using fast photography, laser doppler vibrometer and strain gauges measurements, in order to compare the online measurements with advanced numerical models [6], and
- in the second experiment target elements and structural materials used in ion source units to produce secondary radioactive ion beams at future CERN-HIE-ISOLDE and in general for Isotope Mass-Separation OnLine (ISOL) facilities were tested. The goal of the experiment was to study micro-structure evolution (ageing) under proton pulsed beams by performing post-irradiation microscopic analysis. The experiment took data over 48 hours using the highest possible beam intensity accumulating in total $\sim 1.1\,10^{16}$ protons.

For the **high-power targetry** R&D, the WTHIMBLE experiment investigated the exposure of a Tungsten powder target to a proton beam. The test aimed to validate the potential application of such granular target concepts in future high-power proton beam facilities [7].

Beyond the "conventional" use of the HiRadMat beam, two experiments used the beam impact on the dump and the generated **radiation field**. The first to test and calibrate new types of beam loss monitors (BLM) designed to extend the dynamic range to higher radiation fluxes, particularly interested for the LHC upgrades. The second exposed five radiation detector types to the generated neutron field for inter calibration but also to compare their performance and capacity to detect high-intensity radiation bursts [8].

Registered as HiRadMat@SPS open facility with Transnational Access in the EUCARD FP7/EC funded R&D (contract agreement 225759), several experimental teams received funds in support of their activities at CERN.

BEAM OPERATION

For the HiRadMat experiments, the interesting beam parameters are the intensity, spot-size and repetition rate for the beam pulses. The beam intensity is measured for each pulse(integral) and per bunch using current transformers in the line. The spot size at the target is determined by the beam optics, validated during the commissioning tests, while the beam position and intensity are quite stable from pulse-to-pulse (see Fig. 4). For the beam cycle, HiRadMat uses different cycle schemes of the SPS depending on the requested pulse intensity (1-8 injections from the PS). For up to 72 bunches or $8.0\,10^{12}$ protons where a single injection from the PS is required, the cycle length is 7.2 s. For higher intensities up to the maximum of 288 bunches or $3.3\,10^{13}$ protons, multiple injections from PS are required to fill the SPS and the cycle length varies between $15.6 \div 21.6$ s. The SPS super-cycle length depends on the exact configuration of the machine with the other users. In 2012 the short HiRadMat cycle was used in parallel to other users of SPS like LHC, CNGS and Fixed Target physics. The integrated beam time for all HiRadMat experiments in sums up to 48 hours, with 75% of it in "'parasitic'" mode cycles, without affecting the other physics program of SPS.

ONLINE INSTRUMENTATION

Depending on the scientific scope of each experiment online or offline (post -irradiation) analysis will be required. 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: secondary particle flux measurement using pCVD diamond detector technology [9], Doppler-laser-vibrometry measuring instantaneous deformations (up to 24 m/s at 2.5 MHz), 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

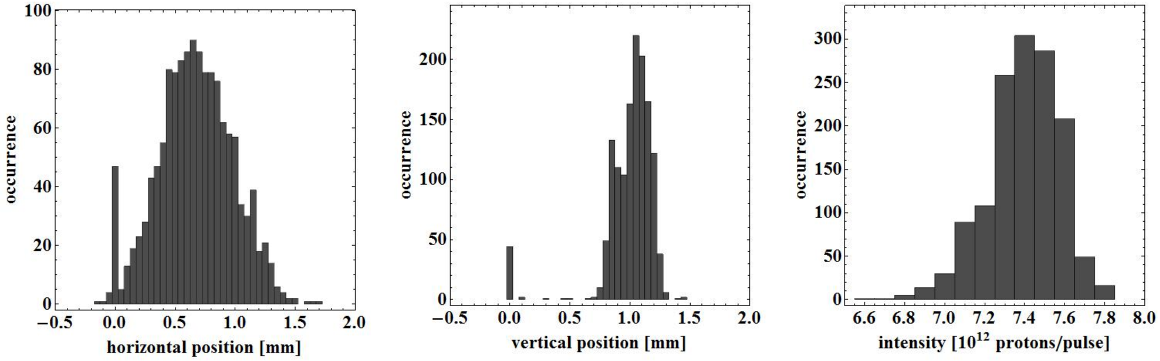

Figure 4: Beam position and pulse intensity stability during a 48 hour run (1500 extractions) for the HRMT01 experiment. The beam position has a σ of 0.3(0.1) mm in the horizontal(vertical) plane, and the beam intensity is stable to 1% level.

any installation of active electronics nearby unless specially designed. In the facility a special shielded area was prepared where all the electronics instruments and computers could be safely stored, readout and controlled remotely from the surface. For the fast photography and laser vibrometry special setup using high-reflectivity mirrors (see Fig. 5) was developed and using special setups with mirrors had to be developed to be able from a far distance to take measurements of the samples.

Figure 5: The HRMT10 setup with the side mounted mirror used for the fast photography and laser vibrometry from a 40 m distance where the camera and laser control box are located.

Specially developed sensitive microphones were deployed for the collimator test around the experimental setup to record the sound at beam impact. From careful analysis of the recorded signals an immediate classification of the damage levels cloud be obtained [10]. Timing and fast trigger signals from the beam line instrumentation are available used to mark the beam passage to ns precision, and all the beam properties (intensity, position and spot size just upstream of the irradiation area, beam structure) are monitored for each pulse individually and are available to experiments for offline analysis.

What found missing in terms of infrastructure was additional cabling for AC power near the experimental area and additional cables for vacuum system installation and control. These will be installed during the present shutdown as well as a permanent beam monitor (position and intensity) using pCVD diamond detectors.

CONCLUSION

Following the successful installation and commissioning in 2011, the HiRadMat facility was extensively used in 2012. A total of nine experiments fully used the available budget of integrated proton beam intensity. The facility concept was proven, for beam performance and also for the operation in experimental mode including the installation procedures, the infrastructure layout and the online observation equipment. The HiRadMat facility will be available again for future experiments with the SPS restart in autumn 2014, and as part of EUCARD-2 the HiRadMat@SPS Transnational Access will also be available to provide financial support to the users.

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