

HIRADMAT: A FACILITY BEYOND THE REALMS OF MATERIALS TESTING

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Abstract

The ever-expanding requirements of high-power targets and accelerator equipment has highlighted the need for facilities capable of accommodating experiments with a diverse range of objectives. HiRadMat, a **High Radiation to Materials** testing facility at CERN has, throughout operation, established itself as a global user facility capable of going beyond its initial design goals. Pulsed high energy, high intensity, proton beams have been delivered to experiments ranging from materials testing, detector's prototype validation, radiation to electronics assessment and beam instrumentation. A 440 GeV/c proton beam is provided directly from the CERN SPS. Up to 288 bunches/pulse at a maximum pulse intensity of 3.5×10^{13} protons/pulse can be delivered. Through collaborative efforts, HiRadMat has developed into a state-of-the-art facility with improved in situ measurement routines, beam diagnostic systems and data acquisition techniques, offered to all users. This contribution summarises the recent experimental achievements, highlights previous facility enhancements and discusses potential future upgrades with particular focus on HiRadMat as a facility open to novel experiments.

INTRODUCTION

Establishing an irradiation facility capable of researching high-energy, high-power proton (or ion) beam effects on materials was envisaged as part of the LHC Collimation Project [1]. The initial mandate was the construction of a facility capable of investigating damage thresholds of accelerator machine components, as well as creating a facility that had global outreach to researchers investigating beam-induced thermal shock waves. Since its commissioning in 2011 the facility has a proven track record of providing research capabilities to a range of R&D concepts, including accelerator component devices [2], beam monitoring and diagnostic systems [3,4], proton beam induced effects [5,6] and materials investigations [7–9]. Details on the design phases, commissioning and first years of operation (2012–2016) have already been reported [10–12].

HIRADMAT FACILITY OVERVIEW

Comprehensive details of the facility layout have been reported elsewhere [13]. In brief, HiRadMat is located in the former West Area Neutrino Facility (WANF) tunnel, approximately 35 m underground, and can receive proton (and equivalent ion) beams similar to those delivered to the

Transfer Injection Line of the LHC (specifically TI2) from the Super Proton Synchrotron (SPS). Figure 1 highlights the location of the HiRadMat facility within the CERN accelerator complex and Figure 2 is a schematic of the HiRadMat injection line, where the experimental area (TNC) and the adjacent tunnel for shielded electronic/readout systems (TT61) are shown.

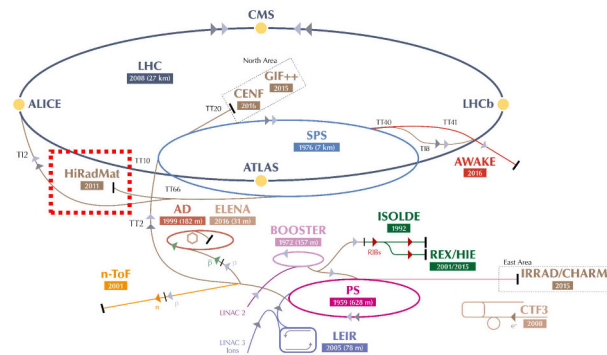


Figure 1: The location of HiRadMat in the CERN Accelerator Complex is highlighted in red [14].

HiRadMat was designed to receive up to 1.7×10^{11} protons/bunch (i.e. a maximum pulse intensity of approximately 4.9×10^{13} protons) [13]. Since operation, this maximum has not been achievable due to hardware limitations in the SPS accelerator. However, after the CERN Long Shutdown (LS2), from 2019-2020, the HiRadMat design maximum should be obtainable.

Presently, due to the infrastructure of the beam line, HiRadMat is not suitable for High Luminosity LHC (HL-LHC) type beams due to the type of beam dump and beam windows installed. If, however, there was sufficient interest in testing HiRadMat experiments at these HL-LHC type beams a feasibility study to upgrade would be completed.

Table 1 highlights the parameters used during the current HiRadMat runs (2017-2018). A cap of 1.0×10^{16} protons per year delivered to the facility has been imposed for two reasons; firstly, to keep the accumulated dose in the facility to a reasonable level and secondly, to normalise the beam time amongst users of the facility to an average of 1.0×10^{15} protons per experiment. It is important to note that HiRadMat is not an irradiation facility where large doses on equipment can be accumulated.

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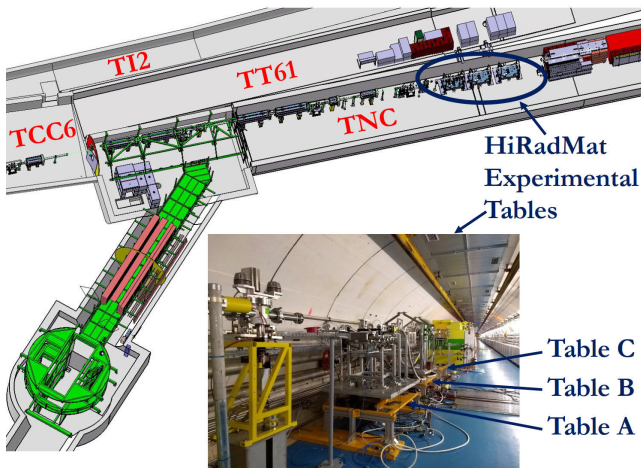


Figure 2: 3D schematic of the HiRadMat irradiation area. The HiRadMat injection line within TNC with the three experimental tables (A, B, C respectively from left to right) are shown. The TT61 area with the feed-throughs for electrical cables and equipment is visible.

Table 1: HiRadMat Proton Beam Specifications

Parameter	Proton Beam
Beam Momentum	440 GeV/c
Max. Pulse Energy	2.4 MJ
Min. Bunch Int.	5.0×10^9 protons
Max. Bunch Int.	1.2×10^{11} protons
No. Bunches (Range)	1-288 bunches/pulse
Max. Pulse Length	7.95 μ s
1 σ r.m.s. beam radius	0.25 - 4 mm ²
Total Allocated Protons/year	1.0×10^{16} protons

2017/2018 EXPERIMENTAL CAMPAIGN

The 2017/2018 experimental campaign was highly successful. A total of 18 experiments were completed from 16 individual projects. Approximately 40% of these projects completed benefited from Transnational Access support through ARIES [15]; highlighting a high number of external collaborators undertaking experiments at HiRadMat. During this period many "standard" experiments (i.e. covering the initial design remit of the facility) were performed. HRMT36 ("MultiMat") investigated the dynamic behaviour of an array of materials subjected to high-energy proton beams for use in collimators and beam intercepting devices [16]. HRMT42 ("TaScat") investigated the dynamic response induced by proton beam on a prototype design for the CERNs Antiproton Decelerator Production Target, which was composed of a tantalum target encased in a compressed expanded graphite [17, 18]. Also, HRMT19 ("BLM2") which has, since 2015, thoroughly studied and compared the signal linearity, the response, calibration and saturation of different beam loss monitors; equipment which

has been used throughout CERN and other institutes including the European Spallation Source in Sweden [19].

However, new experimental concepts were also investigated for the first time. During 2018 the first cryogenic experiment was completed, namely HRMT37 ("SextSc") which investigated the damage induced by high-energy proton beams on superconducting magnet components at cryogenic temperatures. HRMT21 ("ROTCOL") tested a newly designed rotatable collimator to study the surface damage caused by proton beam, evaluate the re-usability of the rotating system and to determine the impact of multiple high-energy, high-intensity proton beam pulses on the electronic and cooling systems of the device. HRMT41 ("ATLASPixel") investigated the effects of accidental beam loss scenarios on ATLAS tracking detectors, using the full bunch range offered [20]. HRMT43 ("BeGrid2") explored different materials used for accelerator beam windows and secondary particle production targets, by studying the thermal shock response of a range of irradiated and non-irradiated materials, investigating the failure mechanisms and limits of the array of materials and comparing their response. These examples highlight the adaptability of HiRadMat to new scientific areas of research for an array of R&D applications.

FACILITY ENHANCEMENTS

The general experimental procedures for HiRadMat users have been reported previously [13]. HiRadMat uses various SPS operation diagnostic systems to gather additional beam information, for example, the stability of the beam trajectory is monitored via the beam position monitors (BPM), the intensity of the proton pulses at the point of extraction is determined using the SPS Quality Control application and the transverse emittance measurements for each pulse is measured by applying a wire scanner. However, changes in beam dynamics can have a profound effect on the experimental results. For example, an unexpected increase of the beam spot size delivered to an experiment will have an impact on the energy deposition of the proton beam at the location. This, in turn, has consequences on the desired tests. Therefore, in situ monitoring of the beam is essential to ensure the correct parameters are being delivered to the experimental users. A summary of the available instrumentation and analysis software is provided in the next subsections.

Dedicated HiRadMat Beam Instrumentation

To measure the beam conditions a special beam monitoring table was allocated, upstream of the experiments, in the HiRadMat beamline, (i.e. Table A, see Figure 2 for details on location). A fixed Beam observation TV monitor (BTV), a Beam Position Monitor of the Beam PicKup Gold type (BPKG) and a Polycrystalline Chemical Vapor Deposition Diamond Detector (pCVD Diamond Detector) were installed by the end of the 2018 experimental campaign and are shown in Figure 3.

The BTV was developed in collaboration with CERNs Beam Instrumentation Group. Specifications and design

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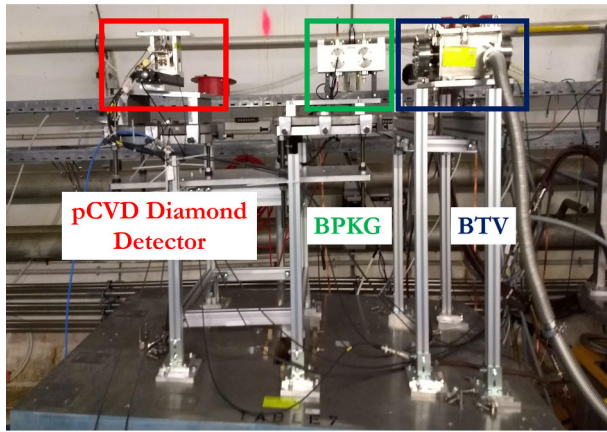


Figure 3: Side view of the Beam Instrumentation Table in the HiRadMat experimental area. The pCVD Diamond Detector, BPKG and BTV are all indicated.

similar to the BTV have been reported elsewhere [21]. The HiRadMat BTV, however, is under vacuum to minimise the parasitic Cherenkov radiation produced in air, the beam profile is read through a camera located in the TT61 area in order to be protected from stray radiation and the SIGRADUR® G (Glassy Carbon) [22] screen is selected as it has shown excellent resilience and usability over the full pulse range. Real-time beam profile information across the whole intensity range delivered to HiRadMat can be obtained (see Table 1 for details). Firstly, during alignment, the theoretical central position of the beam to the experiment can be determined and a replicable beam position can be achieved and cross-checked during several days of beam time. Similarly, any drift in beam trajectory or changes in the beam spot size can be monitored in situ. Figure 4 shows an example of the beam spot size obtained from the BTV.

The BPKG provides complimentary information to the BTV to enable further details of the bunch-to-bunch beam behaviour. Details on the development and use of the BPKG set-up can be found elsewhere [23,24]. The pCVD Diamond Detector provides additional information regarding the beam intensity and structure (see ref. [3] for details). The current set-up now mounted in a fixed way on the beam instrumentation table enables consistent measurements to be applicable for future experiments.

Data Logging and Scripts for Analysis

All BTV data recorded in situ is logged in the CERN accelerator logging database (CALs) and is accessed via the TIMBER application [25]. Developed python scripts, available to all users, enables raw data extraction of all pulses from TIMBER, as well as post-beam analysis of the profiles using standard Gaussian fitting parameters. Thus, the beam spot position and beam sigma for every pulse extracted into HiRadMat can be obtained by the users and remains available after the experiment.

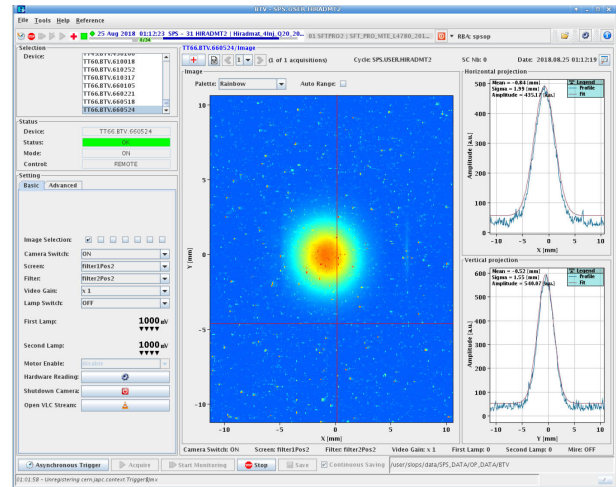


Figure 4: Profile for 288 bunch pulse at 1.2×10^{11} protons/bunch. The central beam position and spot size is estimated in situ with Gaussian fitting curves to the projected image received.

FUTURE STRATEGY

With an increasing interest in HiRadMat and the variability of experiments the future strategy of the facility is under discussion. Studies are being performed on possible improvements to the current infrastructures (e.g. surface laboratory, beam line upgrades for HL-LHC) and to measurements, beam diagnostic techniques and software. Similarly, improvements to all facility procedures including experimental design, installation and beam time allocation is foreseen. The prospective use of HiRadMat goes beyond the accelerator physics community and a workshop is being organised [26] to address user requirements for experiments from other scientific fields, including condensed matter and fusion physics.

CONCLUSIONS

HiRadMat fulfils the fundamental missions of CERN [27] and is currently evaluating requirements for a user facility open to a multitude of scientific endeavours from global researchers using its unique parameters available.

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