BEAM LINE DESIGN FOR THE CERN HIRADMAT TEST FACILITY

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Abstract

The LHC phase II collimation project requires beam shock and impact tests of materials used for beam intercepting devices. Similar tests are also of great interest for other accelerator components such as beam entrance/exit windows and protection devices. For this purpose a dedicated High Radiation Material test facility (HiRadMat) is under study. This facility may be installed at CERN at the location of a former beam line. This paper describes the associated beam line which is foreseen to deliver a 450 GeV proton beam from the SPS with an intensity of up to 3×10^{13} protons per shot. Different beam line designs will be compared and the choice of the beam steering and diagnostic elements will be discussed, as well as operational issues.

INTRODUCTION

A characteristic of the LHC is its large stored energy of 360 MJ per beam. In case of an incident, the energy deposition on accelerator components can exceed by far the damage threshold of the most robust materials. Thereby, damage created by thermal shock waves could occur much below the melting point. Damaged components like e.g. vacuum vessels or evaporated collimator materials can severely disturb the LHC operation and must therefore be avoided. In view of the planned LHC intensity upgrade this will even be a greater challenge.

Therefore, tests of near-beam components with LHC type high-intensity beams must be performed prior to their installation. This includes materials and complete accelerator components such as collimators [1], absorbers, windows and dumps. Furthermore, for the first time, the effect of thermal shock waves on superconducting magnets at cryogenic temperatures could be measured.

In the past, beam shock impact experiments have been performed in TT40 [2]. As TT40 is part of the transfer lines to the LHC and CNGS [3] it must provide a constant and reliable operation, excluding any further tests in this location. Therefore, a dedicated irradiation facility for beam shock impact experiments – the HiRadMat facility – has been proposed [4]. In this paper different possible designs of its primary beam line are presented.

PROPERTIES OF THE FACILITY

Beam Parameters

The HiRadMat facility is foreseen to provide an LHC type beam with the parameters listed in Table 1. It is planned to operate with both proton and lead ion beams up to the SPS end energy of 450 GeV and 177.4 GeV per nucleon respectively. The transverse beam sizes at the target should be controllable in order to reproduce conditions as they can be encountered in the LHC and its injectors. The optics design must thus be flexible within the ranges defined in Table 1.

Table 1: Beam Parameters of the HiRadMat Facility

Parameter	Proton beam	Lead ion beam
Beam energy [GeV]	450	36.9×10^3 (177.4 GeV/n)
Bunch intensity [particles]	5×10^9 – 1.15×10^{11}	5×10^9 – 4.1×10^{10}
Bunch length [cm]	11.2	11.2
Number of bunches	1 – 288	1 – 592
Bunch spacing [ns]	25	≥ 25
Pulse energy [MJ]	2.4	28×10^{-3}
Pulse length [μs]	7.2	7.2
Peak power [GW]	340	2.3
Normalized emittance (1σ) [μm]	3.5	1.4
$\sigma_x \times \sigma_y$ at exp. (baseline) [mm^2]	1.0	1.0
$\sigma_x \times \sigma_y$ at exp. (request) [mm^2]	0.25 – 4.0	0.25 – 4.0

Location

Three different possible locations for the HiRadMat test facility have been identified. They are all situated near the upstream part of the TI 2 transfer line, the so-called TT60 transfer line. In particular the following locations shown in Fig. 1 have been studied:

- Former West Area Neutrino Facility (WANF) [5] near the T9 target position;
- Former T1 target area;
- TT61 tunnel, further downstream of the T1 target area.

All of these locations fulfil the above mentioned requirement of safe LHC operation and have different advantages and disadvantages [6]. The WANF e.g. is already equipped with an overhead crane and a closed loop ventilation system. However, the radiation background is rather high due to its former use as neutrino factory.

BEAM LINE LAYOUT

The beam line layouts shown in Fig. 2 have been studied for the three different locations of HiRadMat. For

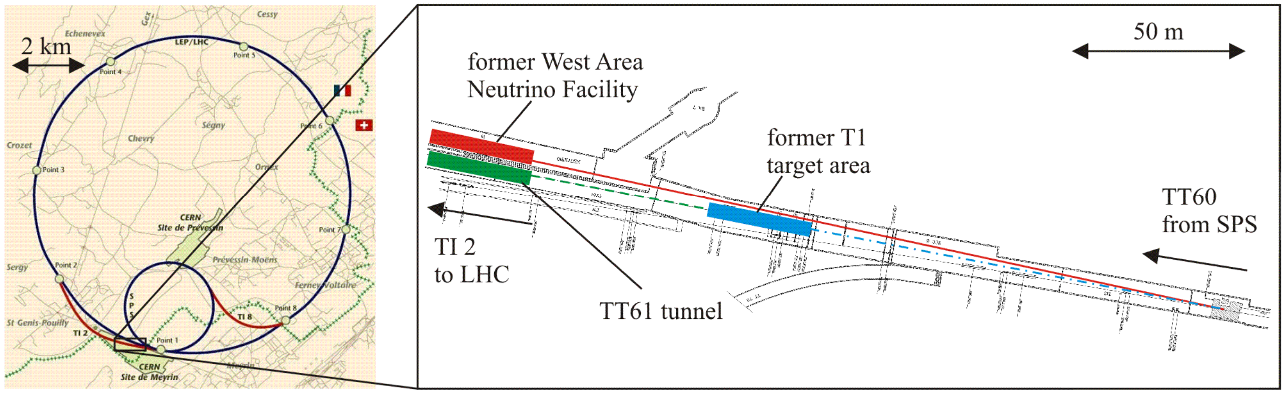

Figure 1: Possible locations of HiRadMat: The former West Area Neutrino Facility (red), the former T1 target area (blue) and the TT61 tunnel (green).

the T9 and T1 solutions the beam line layouts are based on the former operating beam lines. The TT61 solution is a modified version of the T9 solution. For each version, the beam line starts at the extraction point of the SPS, uses 200 m of existing TT60 beam line – in common with the TI 2 transfer line – and branches off to a new 200 m long beam line towards the test stand.

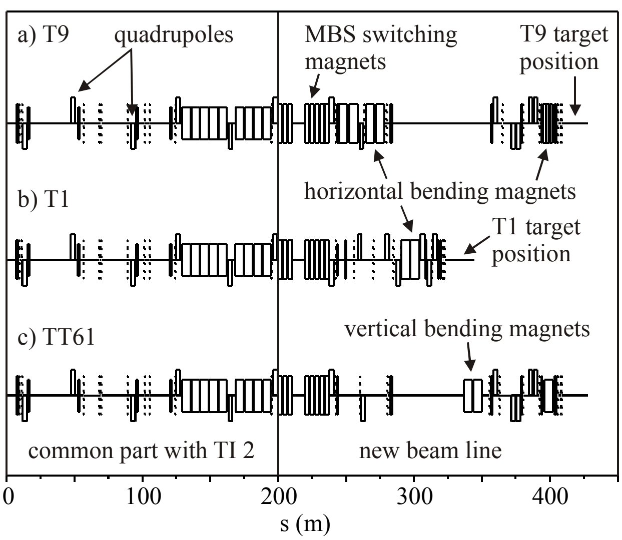

Figure 2: Layouts of the three different beam line versions.

To minimise the costs, the beam line designs were optimised in order to recuperate equipment like magnets, power convertors and cables wherever possible. Care was taken to use only magnet types which are available in sufficient spare quantities. To reduce the number of MBS type switching magnets, eight units were replaced by the more abundant SPS-MBB type bending magnets.

OPTICS SIMULATIONS

For each beam line design, detailed optics simulations have been carried out for a wide range of beam sizes at the target using MAD-X [7]. The required maximum beam radius at the target of 2 mm has been achieved and the minimum beam radius even reached values of 0.15 mm for the T1 solution and 0.1 mm for the T9 and TT61 solutions. Furthermore, the lattice has been optimized to minimize the dispersion at the target position. The simulated beta and dispersion functions are shown in Fig. 3 to 5.

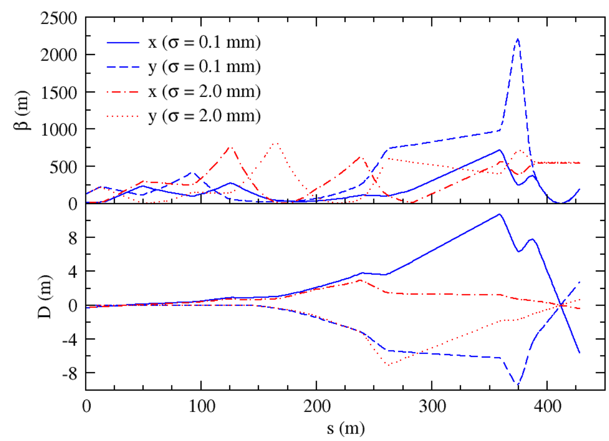

Figure 3: Simulated beta and dispersion functions for the T9 solution for beam radii of 0.1 and 2.0 mm at the target.

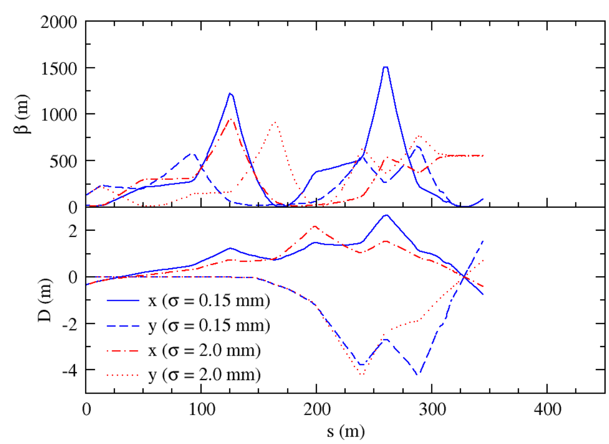

Figure 4: Simulated beta and dispersion functions for the T1 solution for beam radii of 0.15 and 2.0 mm at the target.

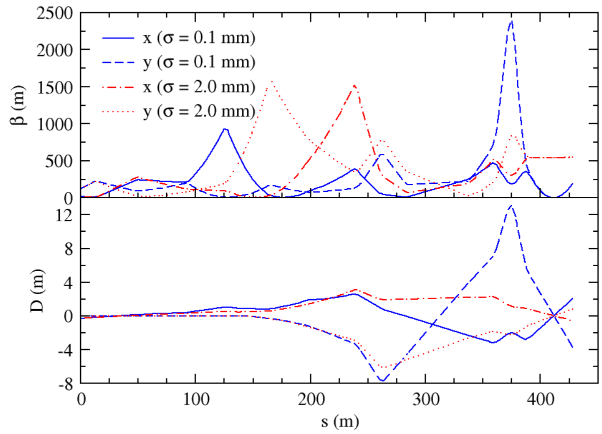

Figure 5: Simulated beta and dispersion functions for the TT61 solution for beam radii of 0.1 and 2.0 mm at the target.

APERTURE MODEL

The beta function values for small beam sizes at the target are large. However, aperture calculations, which were carried out for all simulated beam sizes, show that the beam envelopes fit within the aperture of the beam line components. As an illustration, Fig. 6 shows the beam envelope and the aperture of the beam line elements for the T9 solution, with a beam radius of 0.1 mm at the target.

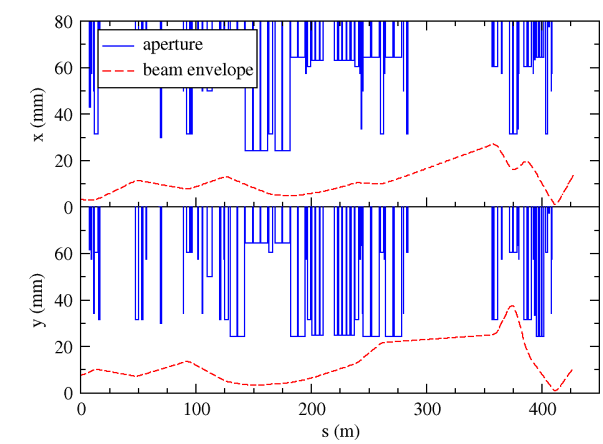

Figure 6: Calculated beam envelope for the T9 solution (σ = 0.1 mm at the target) compared with the half aperture of the beam line elements.

The beam envelopes were calculated using the equation

$$x, y = N\cdot\sigma\cdot 1.1 + |D|\cdot\frac{\Delta p}{p}\cdot 1.1 + co\cdot\sqrt{\frac{\beta}{\beta_{max}}},$$

where σ is the r.m.s. beam size, D and β the dispersion and beta function, $\Delta p/p$ the momentum error and *co* the maximum allowed trajectory excursion. For the calculations, a 6σ beam envelope, a 5 mm trajectory excursion and $\Delta p/p$=0.0006 have been assumed.

BEAM INSTRUMENTATION

It is foreseen to equip the beam line with beam position monitors of the same type as used in the CNGS primary beam line which provide a sufficient large aperture and a large dynamic range. It would allow an upgrade of the facility to a bunch spacing of 12.5 ns at a later stage. The location of the beam position monitors has been chosen in order to be able to perform orthogonal steering on the target with a range of ±5 mm in both planes with the foreseen corrector magnets. The beam instrumentation scheme will be completed with optical transition radiation monitors and a beam current monitor.

CONCLUSION

All three presented beam line designs fulfil the requirements of the facility and could even provide smaller beam sizes at the target. Since it is foreseen to mainly use recuperated equipment, each beam line design will be cost effective. Due to their similar primary beam line characteristics, there is no restriction on the choice of the location for HiRadMat from the beam line point of view. The location can thus be solely determined by the facility's needs. With HiRadMat, a facility with world-wide unique beam characteristics for beam-induced shock wave experiments would become available to the scientific community.

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REFERENCES

[1] R. Assmann et al., "Accelerator Physics Concept for Upgraded LHC Collimation Performance", these proceedings.

[2] V. Kain et al., "Material Damage Test with 450GeV LHC-type beam". CERN-LHC-Project-Report-822 (2005).

[3] K. Elsener (Ed.), "The CERN Neutrino Beam to Gran Sasso: Conceptual Technical Design", CERN 98-02 (1998).

[4] R. Assmann et al., "Specification for a Test Facility with High Power LHC Type Beam", CERN-AB-2009 (2009).

[5] G. Acquistapace et al., "The West Area Neutrino Facility for CHORUS and NOMAD Experiments", CERN-ECP/95-014 (1995).

[6] http://lhc-collimation-project.web.cern.ch/lhc-collimation-project/HiRadMat.htm.

[7] www.cern.ch/mad.