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First results of the machine induced background estimation for the forward physics detectors in the IR5 of the LHC

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Summary

In this note we present first results of the machine induced background simulation in the IR5 of the LHC for the location of forward physics detectors.

Introduction

The experimental programme of the Large Hadron Collider at CERN includes the TOTEM experiment for the measurement of elastic scattering, total cross-section and diffractive dissociation. The physics program of TOTEM requires the measurement of the elastic scattering in the p-p interaction down to the four-momentum transfer of $-t \sim 10^{-3}\,\mathrm{GeV}^2$ ([1], p.2). To achieve this goal a set of detectors will be located in the insertion region IR5 along the beam line inside the LHC tunnel symmetrically on both sides of the interaction point IP5. Positioning the detecting stations extremely close to the beam at the distance of $\sim 10\,\sigma$ ([1], p.17) makes the estimation of the machine induced background in the region of the detectors one of the important issues in the evaluation of the experiment's performance.

To estimate the particle fluxes in the IR5 forward physics areas, the correct identification of machine background sources in the region of study is necessary. The general sources of background of this type include proton losses in the elastic and inelastic scattering of beam particles on the residual gas nuclei inside the LHC vacuum chamber, proton interactions with

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the material of experimental insertions due to the cleaning inefficiency and the p-p collisions in the experimental regions [2]. For the locations of TOTEM detectors, positioned along the beam outcoming from the interaction point IP5, several assumptions can be made in order to prioritize the study of the sources which have different nature, based on the current understanding of the background formation in the LHC [4].

The symmetry of the detector locations with respect to the interaction point and the overall symmetry of the LHC allows to make the estimations for the losses along LHC Beam 1 which will with just a few limitations be valid for the opposite side of the collision point and LHC Beam 2. Each side of the IP5 is featured by the presence of strong fields in the inner triplet quadrupoles, heavy shielding and the TAS passive absorber with a small mechanical aperture ([3], p.32, 504). This fact allows an assumption that the background particles generated in for example the left part of the straight section, along the Beam 1 coming to the interaction point, will be smeared and absorbed by this combination of magnetic and shielding elements and will not affect the detectors, located at the opposite right side. So for the detectors on Beam 1 only those proton losses that occur due to the interactions of beam particles with the residual gas on the machine length between upstream TAS and the rightmost TOTEM station need be taken into account. This assumption also leaves the distant sources of proton losses due to the elastic scattering in the cold elements of sectors 34 and 45 and cleaning inefficiency out of consideration since the accounting for these sources of background requires a specific study of machine operation.

The simulation of proton scattering on the residual gas nuclei and the transport of the subsequent cascade particles was performed using the methodical approach developed by the IHEP Radiation Physics Group for the solution of the radiation problems in the LHC [2]. In this approach the estimations of residual gas composition and density are used to simulate proton losses along the studied section of the LHC. The products of these losses are then transported through the machine elements and the subsequent secondary cascades are simulated with correct accounting for the magnetic and mechanical structure of the machine. The background particles are stopped as they cross the imaginary infinite 'scoring' plane at the location of the detectors and particle coordinates are recorded there for future analysis. Below we briefly describe optics parameters, details of the mechanical layout and residual gas density profiles which were used to build a model and to provide input data for simulations, and present first results for the estimations of particle fluxes and spectra at the location of forward physics detectors.

1 IR5 optics for the operation of TOTEM

One of the requirements for the study of elastic and diffractive proton scattering at the LHC energies is the possibility to measure rather small, of several μrads, scattering angles. To fulfill this requirement, a specific option of parallel-to-point optics was designed for the TOTEM operation in the IR5 of the LHC ([1], p.2). A feature of this optics solution is the phase advance of $\pi/2$ at the location of the detectors. This characteristic allows the position of the scattered proton in the detector to be obtained independently of its transverse position at the interaction point ([1], p.15). The required phase advance is at a distance of 220 m from the IP5 in both vertical and horizontal planes that increases the detector efficiency, enabling proton tracks to be processed in both planes by a single detector and also maximizes the effective distance of the detector from the interaction point.

Optics functions for this solution of the optics for the IR5 are given in Figure 1. The minimal detectable angle is inversely proportional to $\sqrt{\beta_y^*}$ ([1], p.16) so a value of β^* greater than 1000 m is required for the measurements in the desired angular range. With the increase of the upstream Q6 quadrupole gradient to 3.4 % above the nominal, a higher value of $\beta^* = 1540$ m can be obtained. This option is considered as a basic one because in this case good resolution in the t and φ measurement is achieved ([1], p.183). Since this high-β^* optics differs significantly from the standard optics for high luminosity insertions, the formation of the machine induced background in the IR5 during TOTEM operation will be different from the one for the high luminosity insertion at the nominal machine running scenario [5]. It has also to be mentioned that the B-field of CMS spectrometer itself was assumed to be switched off in the simulations.

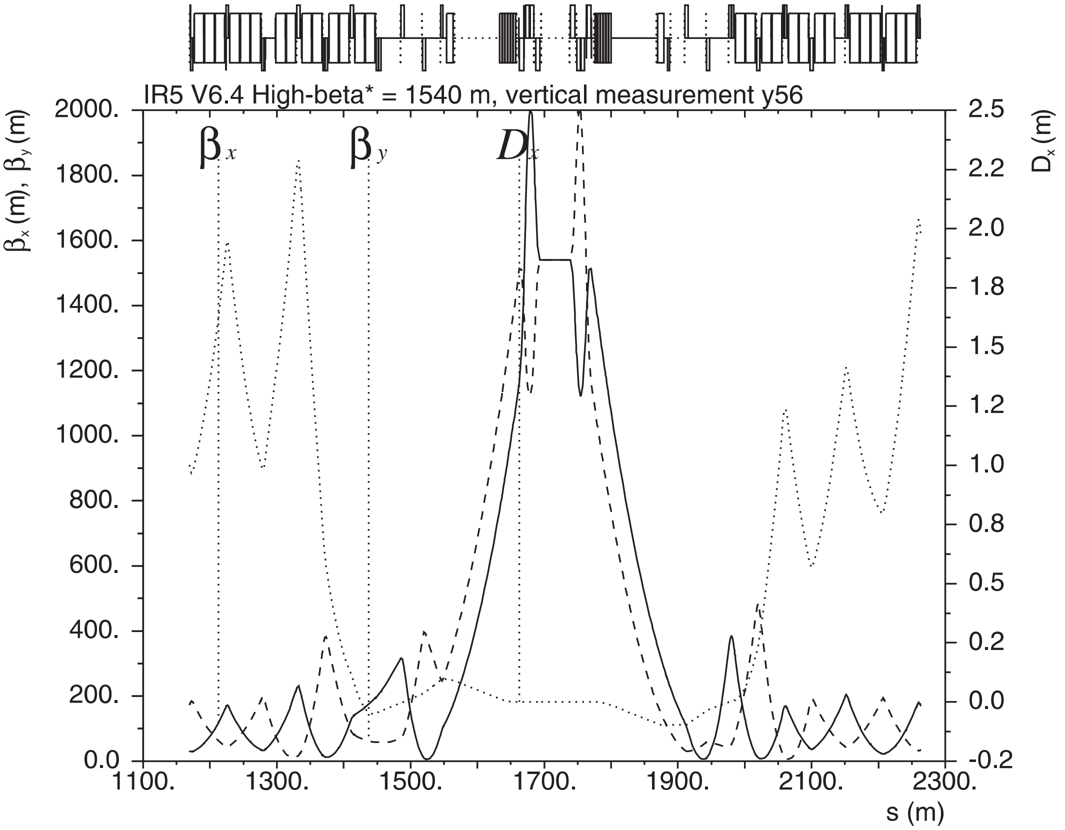

Figure 1: Optics functions for IR5 high-β^* optics option of LHC Ring 1 ([1], p.16).

2 Mechanical layout of IR5

The material budget in IR5 was accounted for according to the insertion layout in the LHC optics version 6.402. The nominal beam screen orientations and their dimensions, as well as the cold bore dimensions for both cryogenic and warm elements were taken at their operating temperature [6]. The other dimensions of the LHC magnetic elements were taken from the EDMS Magnet Catalogue, and the value for the magnetic length was used for the length of elements in the geometry model for the simulations. The presence of TCLP absorbers was not taken into account in the calculations since these elements are supposed to be open during high-β^* runs because they are not required for luminosities smaller than $5\times10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ [7]. The TCT collimators were not implemented in the model of simulations either since these details were not defined at the moment of study. They will also be unnecessary during TOTEM tuns at low luminosity.

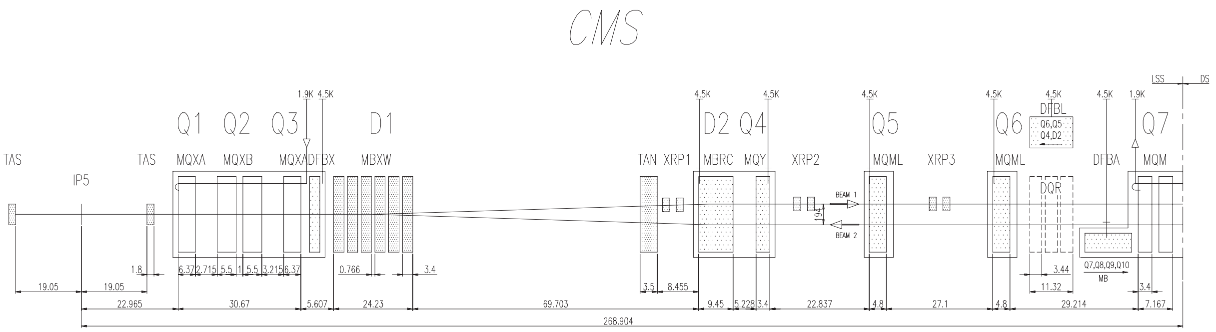

Figure 2: Mechanical layout of IR5 right straight section part.

The mechanical layout of the right part of IR5 long straight section is shown in Figure 2. Three locations marked on the scheme as XRP1–3 are foreseen for TOTEM detecting stations with their positions in IR5 determined by the conditions of TOTEM high-β^* optics and by the requirements of integration with other LHC components. Each station is composed of two units, separated by a distance of 4 m, with each unit consisting of two pots that move vertically and one that moves horizontally ([1], p.23). The third station XRP3 will be located at a distance of 220 m from the interaction point where the phase advance of $\pi/2$ is achieved in both planes. The first station XRP1 will be positioned at 147 m from IP5 while the second station XRP2 is foreseen to be installed at 180 m at a later stage of TOTEM operation. The estimations of machine induced background will be presented below for the background source scoring plane positioned at 220 m from the IP5, in the region of the third station XRP3.

3 Residual gas density profile in the IR5

The density of gas components is one of the parameters that define the rate of particle losses in the machine elements due to the interactions of beam protons with the nuclei of residual gas [8]. Gas density distributions along the length of LHC experimental insertions were calculated for the latest design of LHC vacuum chamber and pumping system [9]. This data was recently supplemented by the residual gas density profiles for the different machine filling schemes and various periods of operation [10]. The estimations of gas component densities for the machine start-up period will be used below as the input parameters, with 156 bunches and 1.15×10^{11} protons/bunch as the machine filling scheme. This gives the value of 35 mA for the beam current. These conditions result in a pessimistic estimation for the case when TOTEM runs for physics in the early days of LHC operation.

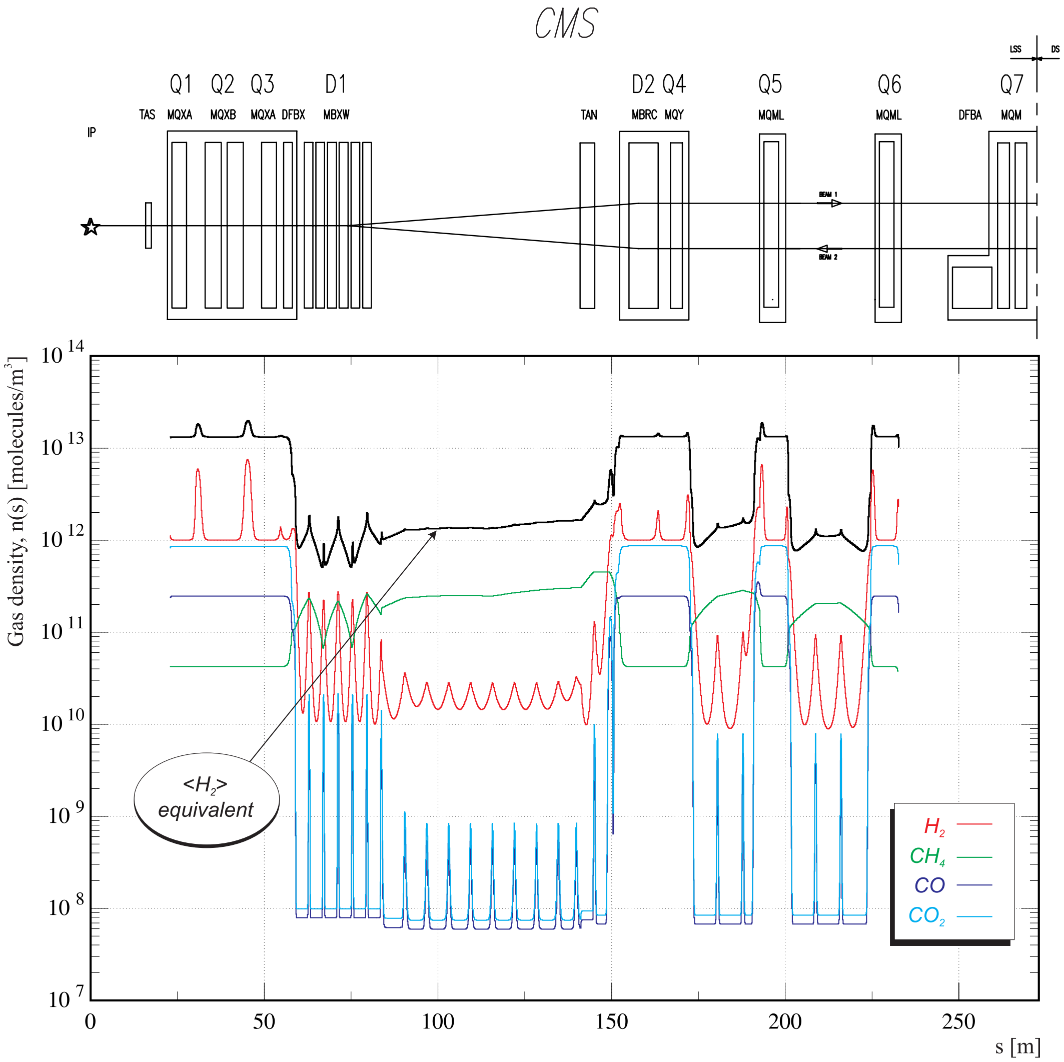

Figure 3: Density profiles of residual gas components in the IR5 for the period of machine start-up with nominal intensity and 156 bunches [10].

The density profiles for different residual gas components in the right-hand straight section part of IR5 for the considered period of LHC operation are given on Figure 3. These distributions reflect specific features of the insertion layout and residual gas dynamics. As can be seen from Figure 2, the mechanical layout of the IR5 includes elements operating at both cryogenic and room temperatures. The vacuum chamber inside the cold mass of the magnets will be thermalized down to 1.9 or 4.5 K while in the interconnections between the magnets the cold bore will operate at 10 K. Because of this a high pressure of hydrogen is predicted along these sections represented by the spikes of the H_2 curve in Figure 3 since this gas component will not be pumped onto the surface of the cold bore in these regions. The relatively high density of other gas components there is determined by higher desorption yields from the unbaked surfaces [10].

For most parts of the room temperature beam pipe a copper chamber with 80 mm inner diameter will be used except for the D1–TAN region where the use of a wide (∼ 200 mm) chamber is foreseen. Room temperature parts will have a few μm of TiZrV sputter NEG coating and will be baked to activate the surface [9]. Due to the fact that NEG coating does not pump the methane the CH_4 curve on the Figure 3 shows that it is the dominant component in the room temperature regions. The peaks in other distributions show the locations of uncoated and unbaked elements of vacuum chamber such as stainless steel bellows and pumping ports. The solid curve at the top of Figure 3 gives the distribution of the hydrogen equivalent gas density calculated from the profiles of the gas components using the estimations of relative nuclear scattering cross-sections [11]. This curve reveals the sections of the IR5 where most of the particle losses due to the beam-gas interactions will occur. For the detectors located between Q5 and Q6 quadrupoles the region of D2–Q4 and Q5 will probably be the most critical although the possible contribution from the particles elastically scattered in the inner triplet and then successfully transported to the detector area can not be neglected.

The profile of the residual gas density in the experimental pipe of IP5 was also taken into account in the simulations, together with the thickness and material of the experimental vacuum chamber [10]. It should be noted that such elements as TCT and TCLP absorbers as well as the TOTEM detectors themselves were not taken into account in the present estimations of the residual gas density in IR5.

4 Particle fluxes and spectra in the region of XRP3

The methodical approach applied for the simulation of machine induced background in the insertion region IR5 allows to study the recorded source of particles using various selection criteria and different representations of secondary particle flux. Figure 4 presents the spectra and the radial distribution of particle flux density for several components of the background, namely $\pi^{\pm}$, protons and neutrons. At the current stage of studies only the transport of hadrons with a kinetic energy above 20 MeV was simulated. In the present analysis only those particles were accounted that cross the scoring plane inside the room temperature vacuum chamber in the XRP3 region, at a radius of less than 40 mm distance from the beam line.

All four distributions of particle flux density are very steep and have a distinct peak at the position of the beam. It has to be noted that the recorded source of particles included only those produced in the interactions with the residual gas or in the subsequent cascades in IR5. Concerning the proton flux, this criteria excludes the unperturbed primary beam particles. The peak value at the center of the beam is a few kHz/cm^2 for all components while pions start to dominate in the background flux at high radii and at a distance of 30–40 mm from the beam line the density of $\pi^{\pm}$ flux exceeds the flux density of protons and neutrons by about an order of magnitude. At these radii the value for the density of π^{+} flux is ∼ 20 % above the π^{-} flux density. This is a reflection of the proton-oriented optics of the LHC. At the same time the flux density for all components at the XRP3 vacuum chamber inner radius of 40 mm is more than two orders of magnitude lower than the peak value at the beam line.

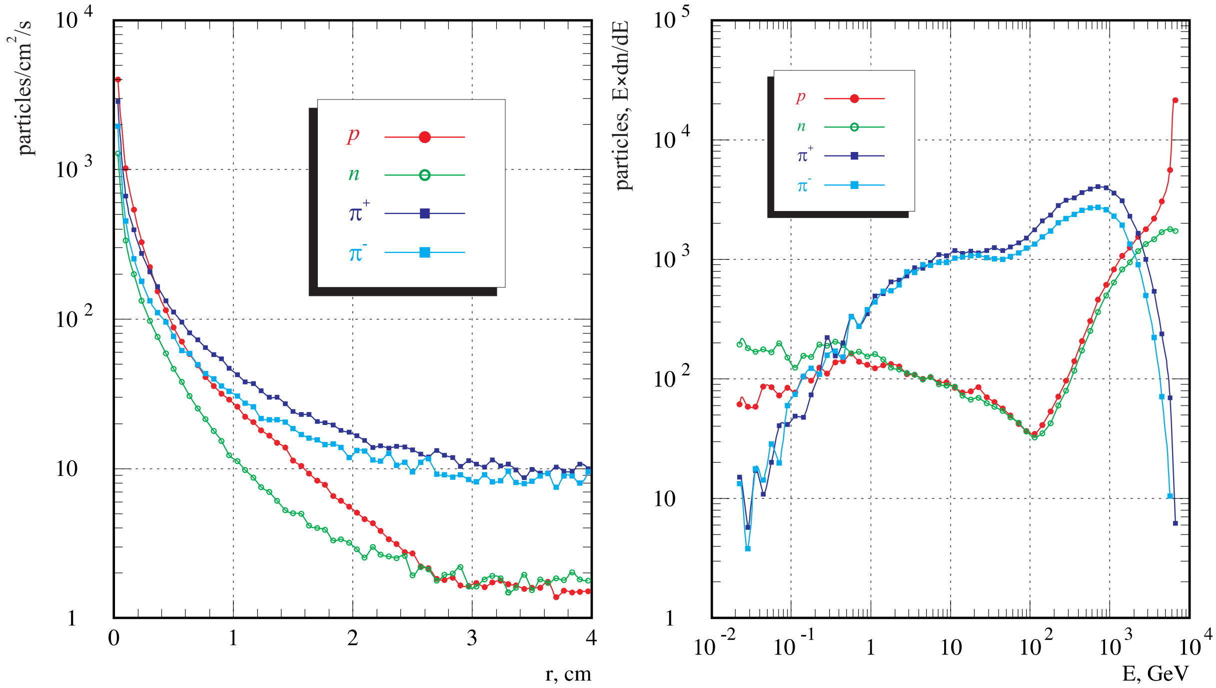

Figure 4: Particle flux density and spectra calculated for the region of XRP3 station.

The energy distribution of protons is featured by the elastic peak at an energy close to the nominal 7 TeV energy of the LHC beam. Another peak in the energy distribution for protons and neutrons associated with the secondary cascade particles is located in the region of a few hundred MeV. Both proton and especially neutron spectra do not fall down at the energy close to the 20 MeV transport threshold that indicates that lowering this threshold will probably be necessary to avoid an underestimation of the background flux. The pion spectra are clearly dominated by the first generation particles which are produced directly in the primary proton-nucleus interaction and have a resulting energy of $\sim$1 TeV. Taking into account that $\pi^{\pm}$ also dominate in the radial distribution of particle flux this high energy component can be considered as the most important part of the machine induced background at the location of TOTEM station XRP3.

Conclusion

These first results estimate the machine background in IR5 induced by the proton losses along the LHC Beam 1, for the case of TOTEM operation with high-β^* optics and 156 bunches of nominal intensity. Elastic and inelastic interactions of beam particles with the nuclei of residual gas were simulated inside the LHC vacuum chamber over the machine length between the left TAS absorber and the rightmost TOTEM station, using the most recent data on residual gas pressure and composition. The secondary particles produced in the initiated cascades were transported down to the location of the XRP3 station where their properties were recorded. The analysis of the background source gave the peak value of 2–4 kHz/cm^2 for the hadron components of background, with $\pi^{\pm}$ dominating at large distances from the beam and also in the particle spectra at relatively high 10^3 GeV energies.

Finally, it has to be noted that in the present paper the contribution from only one source of the background was analyzed while the study is continued to evaluate the other sources of secondary particle fluxes in the region of TOTEM detectors.

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