MACHINE INDUCED BACKGROUND IN THE HIGH LUMINOSITY EXPERIMENTAL INSERTION OF THE LHC PROJECT

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Abstract

The methodical approach, developed for the solution of the radiation problems in the LHC project, is used for the estimation of the machine induced background in the high luminosity experimental insertion IR1. The results of the cascade simulations are presented for the cases of the proton losses in the cold and warm parts of the collider. The formation of the machine induced background in the interaction region is discussed.

INTRODUCTION

The interactions of the beam particles with the nuclei of the residual gas in the LHC vacuum chamber are the main origin of the *machine induced background* — secondary particle flux that reaches the regions of the LHC insertion points from the machine tunnel [1]. The LHC layout [2] includes four experimental insertions, with the interaction point where the beams cross in the middle of each insertion. The calculation of the machine induced background, made for the insertions IR2 and 8 with low luminosity in the interaction point [3] showed the dependence of the resulting particle fluxes on the optics, the mechanical layout and the residual gas dynamics in the machine. Below we present the results of the machine induced background simulation for the high luminosity insertion of the interaction point IP1 and analyze the formation of the background in the considered region of the machine structure.

SETUP OF THE SIMULATIONS

The parameters of the simulation that define the machine layout are given in Table 1 below. The choice of the LHC structure length considered in this study is based on the current understanding of the beam loss formation in the machine. As it was noted in [1], the primary collimators of the cleaning insertion in the IR7 isolate quite well the downstream interaction points from all losses, except those that occur in the machine structure between the cleaning and the interaction point. For the LHC beam one and the insertion IR1 this part of the machine consists of the two LHC sectors 78 and 81, so we estimate the machine background, which is induced in these sectors and reaches the entrance of the underground cavern UX15 of the interaction point IP1.

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LHC optics version	6.4
β^* in IP1 at collision	0.5 m
E_{kin} transport threshold	20 MeV
Circulating beam current	0.54 A

Table 1: Paramaters of the cascade simulations.

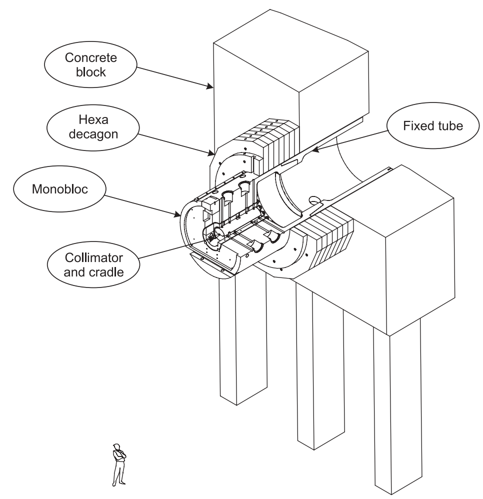

Figure 1: The section of the UX15 inner shielding together with its concrete block and the fixed tube part.

The cascade numerical simulation was performed using one of the methodical approaches, developed by IHEP Radiation Physics Group for the solution of the radiation problems in the LHC project [4]. In this approach the proton losses are simulated along the considered LHC length, and the resulting secondary particles are transported through the machine structure up to the entrance to the IP1 cavern, where the coordinates of the particle track crossings with some imaginary 'scoring' plane are recorded for future analysis [3]. For the IR1 case, the *s* position of this fictitious plane at 23 m from the IP1 was chosen to include the whole length of the IR1 inner triplet [5]. The model of the simulations had also to take into account the IP1 inner shielding layout, an illustration of which is given in Figure 1. As can be seen from the next Figure 2, this chosen plane cuts the fixed tube of the inner shielding, so this element together with the concrete block was introduced in the standard model of the simulations. This model consisted of the machine structure elements with all the necessary details of the beam line structure, such as the beam screen inside the magnets and the layout of the interconnections, and LHC tunnel, surrounding the magnet line.

The values for the residual gas composition and density, which are one of the important parameters of the machine background simulations, were taken according to the estimations of these quantities for the different regions of the LHC structure [6]. As it was shown in [5], for the IR1 these values are lower at least for a couple of important locations than the estimations used in the study for the LHC low luminosity insertions [3]. The assumed decreased values for the matching and separation section elements determine the lower contribution from the straight section in IR1 to the total particle flux. Together with the assumed very low value of 4×10^{12} mol/m^3 for the gas density in the dispersion suppressor and arc elements this fact allows one to presume that, with these estimations, the absolute value of the machine induced background in IR1 will be even lower than for IR2 & 8.

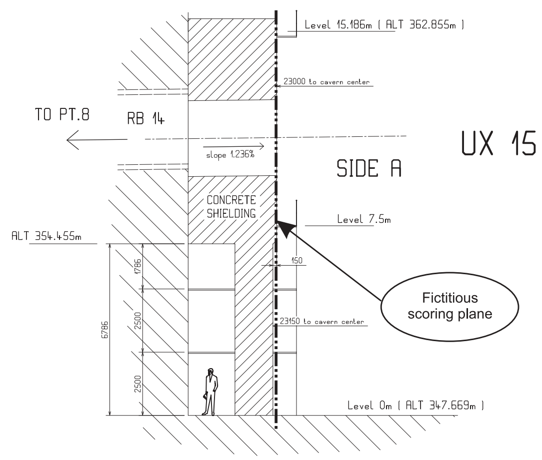

Figure 2: The tunnel opening into the UX15 cavern and the position of the plane, where particles were recorded.

PARTICLE FLUX FORMATION IN THE STRAIGHT SECTION OF IR1

Most of the secondary particles, seen at the entrance to the UX15 cavern, are produced in the straight section SS of IR1. An analysis of the formation of this background component is illustrated by the Figures 3 and 4. On these figures the dashed curves give the number of hadrons and muons, produced in the proton-nuclei interactions along the length of the different machine elements in the SS of IR1, as a function of the distance to the IP1. These curves show the locations in the SS where most of the primary beam-gas interactions occur, which determine the secondary flux occur through the subsequent cascades in the straight section.

For both hadrons and muons these two curves are different for the regions located close to IP1 and those farther away. Both hadron and muon distributions have a central peak in the D2 region, which reflects the high value of the gas pressure there. Downstream of D2, in the D1 and inner triplet section, the contribution to hadrons from the different elements increases with the decrease of the distance to the IP1. The observed oscillations in the region of Q1–DFBX reflect the assumed profile for the gas pressure in these elements, where for the cold interconnections in the inner triplet the values are about 20 times higher than for the magnets they connect.

For the muons downstream of D2, the closer to the IP1, the less is the relative role of the particular structure element, since the process of muon production requires an open space for the parent pion to decay to a muon. So the beam-gas interactions directly inside the inner triplet give less contribution to the muon final flux than for the hadrons. Upstream of D2, in the matching section, the source of muons consists of the interactions on the warm vacuum chamber with a subsequent decay in the length between the quadrupoles.

HIGH-MOMENTUM BACKGROUND COMPONENT

It has to be noted that the values on Figures 3 and 4 are given at the position of the ‘scoring’ plane. According to the second Section of the present report, the position of the scoring plane was defined so that it crossed the shielding of IP1. This means that the secondary particles, recorded at that location, will be additionally attenuated by the material of the downstream shielding elements before they reach the experimental area of IR1 itself. The fraction of the secondary particles, which is within the radius of the inner shielding fixed tube, will encounter in addition the material of the collimator, the cradle and monobloc [5]. The particles beyond this radius, up to a distance of 2.6 m from the beam line, will have to pass through the ≈ 2 m thick iron plates that make up the hexadecagon of the shielding (see Figure 1).

Only the high-momentum muons and the products of the cascades, initiated by the high energy hadrons, will be able to survive in this shielding and give a signal in the experimental detectors. In a special second stage of the simulations the high-momentum background component was considered by increasing the transport threshold of the particle kinetic energy. For this second stage, on the basis of the previous particle spectra analysis [7], this value was set to 1 GeV, which effectively rejects the low energy part of the hadron background.

The results of the second stage simulations are given in Figures 3 and 4 by a solid line. The relative contribution to the high momentum part of the hadron and muon background from the SS region upstream from D2 appears larger than for the D1–D2 drift or inner triplet. Although the triplet region is the closest region to the scoring plane, and hence an important one, the main part of the particles, produced there, have low energy and can be absorbed by the inner shielding of IP1.

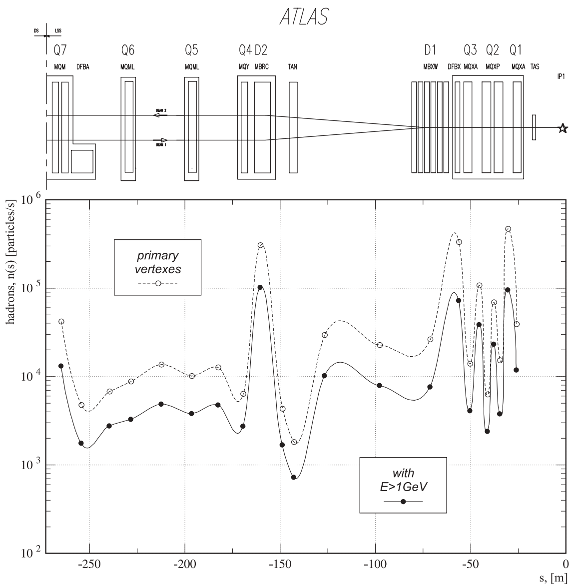

Figure 3: Number of hadrons at UX15 entrance as a function of primary proton-nucleus interaction distance to IP1.

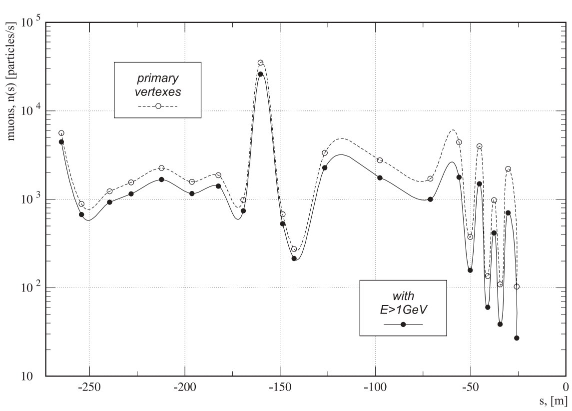

Figure 4: Number of muons at UX15 entrance as a function of primary proton-nucleus interaction distance to IP1.

SECONDARY PARTICLE FLUX AT THE UX15 ENTRANCE

The absolute values for hadron and muon fluxes, obtained by the sum of the numbers from Figures 3 and 4, are given in Table 2. The relative ratio between hadrons and muons appears to be of about an order of magnitude which is the same as for the low luminosity insertions, and the absolute flux values are comparable to those for IR2 & 8, assuming the nominal value of the gas density for the TDI region [3]. Table 2 gives also the fraction of hadrons and muons, produced in the secondary cascades from the interactions in the straight section only. The difference between these two values is the contribution from the dispersion suppressor and the cold arcs.

For muons the contribution from the straight section alone is decreased with regard to the fluxes in the IR2 & 8 because of the absence in IR1 of the two cold elements with the highest estimated values for the gas density [5]. At the same time the role of the cold DS and arc sections is increased significantly for muons. Previously for IR2 & 8 with the new data for the residual gas density [6] the contribution to the background from the cryogenic parts of the LHC was estimated as negligible. So the straight section of the IR2 & 8 alone was considered as the length of the machine structure, which allowed a rather complete study of the machine induced background problem in these insertion regions [8]. It appears not to be the case for the high luminosity IR1 where even for the assumed very low gas density the proton losses in the dispersion suppressor and arcs determine significant fraction of the total muon flux. This fact is the reflection of a more demanding optical structure of IR1, which collects more particles from the upstream elastic proton-nucleus interactions.

	Total	**SS**	**Ratio**
Hadrons	1.77×10^6	1.57×10^6	89 %
E > 1 GeV	5.06×10^5	4.24×10^5	84 %
	29 %	27 %	
Muons	1.04×10^5	6.77×10^4	65 %
E > 1 GeV	6.67×10^4	4.81×10^4	72 %
	64 %	71 %	

Table 2: Fluxes [particles/s], total and from straight section SS only, their fraction with $E_{kin} > 1$ GeV, and their ratio.

The results show that the machine background in IR1 is determined by the pressure level in the cryogenic elements, of which separation dipole D2 and inner triplet box DFBX are the most important ones. At the same time, even with the very low gas density for the dispersion suppressor and cold arc elements, the distant regions of the machine contribute 11% of hadrons and 35% of the total muon flux. Thus considering this part in the estimation of the machine background appears to be still an important issue for the high luminosity insertions.

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