MACHINE INDUCED BACKGROUNDS FOR FP420*

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Abstract

The LHC FP420 R&D project is assessing the feasibility of installing forward proton detectors at 420m from the ATLAS and/or CMS interaction points. Such detectors aim at measuring diffracted protons, which have lost less than 2% of their longitudinal momentum. The success of this measurement requires a very good understanding of the charged and neutral particle environment in the detector region in order to avoid the signal being swamped as well as for detector survivability. This background receives contributions from beam-gas interactions, halo particles surviving from the betatron and momentum cleaning systems and secondary showers produced by particles from the 14 TeV collision region striking the beampipe upstream of the FP420 detectors. In this paper, such background sources are reviewed, and the expected background rates calculated.

INTRODUCTION TO FP420

The FP420 R&D project [1] aims at exploring the immense amount of LHC physics potential by instrumenting with detectors the forward regions starting at about 420 m from IP1 and IP5. The tag on one or both of the forward protons can provide information on the mass of the central system in the detector and allowing measurements of quantities like the mass and quantum numbers of the Higgs Boson. This experimental programme would add considerable depth and potential to the main detector experimental programmes. The proposed detectors consist of tracking and timing stations, mounted on movable beam pipes, approaching the beam as close as allowed by LHC protection/ beam stability and as required by the experiment acceptance studies. The present proposed setup is at a horizontal distance of 5mm from the beam.

CLASSIFICATIONS OF BACKGROUND

The charged and neutral particle backgrounds at 420m can be classified according to the origin of the particle flux:
1) At the interaction point, the colliding beams produce many final state protons dominantly in the forward direction with a large coverage of phase space. These particles may be transported down the beamline and irradiate the 420m region. This contribution to the background is referred to as interaction point (IP) particles.
2) Elastic and inelastic proton-nucleus collisions between the beam and residual gas molecules resulting in protons with large scattering angles represent a direct background when the collisions occur close to the FP420 detector stations. This is referred to as the near beam-gas background.
3) Beam halo consists of protons in the distribution tails that can circulate for many turns and constitute the beam halo background. The primary halo is populated by various beam instabilities including distant beam-gas interactions resulting in small scattering angle protons. The consequent beam losses on both the betatron and momentum cleaning collimation systems produce secondary and tertiary halos.
4) Particles transported down the beam line arising from proton-proton interactions at the IP, near beam-gas collisions or any other beam-halo, can interact, and subsequently shower, with elements of the machine or detector. These processes create secondary showers which can irradiate the detector region at 420m with large charged and neutral particle fluxes. This background is known as secondary interactions.

In this paper, the present status of each background source at 420m is reviewed and the possible impact on the detector assessed.

IMPACT OF BACKGROUND SOURCES

Near Beam-gas Interactions

The near beam-gas contribution arises from the interaction of beam particles with residual gas in the beam pipe region immediately before 420 m, and study of this background requires a detailed model of the beam line, coupled with gas pressure profiles and computation of proton/gas interactions. However, an estimate of the number of beam-gas interactions per bunch in the 420 m detector region can be extracted by scaling results obtained for the straight section [2]. These simulations give a charged hadron rate for particles lost after scattering with the gas nuclei and secondary particles as $\mathrm{np}_{240\ \mathrm{m}} = 2.4\,\mathrm{s}^{-1}$, at a location 240m from IP1. The Hydrogen equivalent pressure is taken to be [2, 3] $\rho_{240\ \mathrm{m}} = 3.4 \cdot 10^{11}\,\mathrm{molecules} \cdot \mathrm{m}^{-3}$. The synchrotron radiation at 420m implies that the dynamic pressure is higher than the straight sections and, as a conservative upper limit, we consider a hydrogen density of $\rho_{420\ \mathrm{m}} = 1 \cdot 10^{15}\,\mathrm{molecules} \cdot \mathrm{m}^{-3}$ This corresponds to a beam-gas lifetime of 100 hours. The resulting total number of expected hadrons per bunch, due to near beam-gas events, is around

$$np_{420\ m} = \frac{np_{240\ m}}{N_{bs}} \cdot \frac{\rho_{420\ m}}{\rho_{240\ m}} = 1.8 \cdot 10^{-4}, \qquad (1)$$

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where $\mathrm{N_{bs}} = 4 \cdot 10^7$ is the number of bunches per second. Such a background rate is very low.

Beam Halo Backgrounds

The LHC cleaning system consists of a multi-stage process that aims at intercepting the primary beam halo by means of primary collimators located in IR3 (momentum cleaning) and IR7 (betatron cleaning). A large amount of the impacting protons will be scattered by the collimators and will circulate for many turns before being lost. Concerning on-momentum beam halo protons, the FP420 detectors (nominal position at $15\,\sigma_x$) will be well in the shadow of the betatron cleaning system. On the contrary, the off-momentum protons can potentially perturb the operation of the FP420 detectors, located in the high dispersion region. For this reason, a series of simulations using STRUCT [4] has been carried out in order to characterize the beam halo populated by such protons and the effect of the cleaning system settings on the FP420 background. The simulations have as input $\mathrm{N_0} = 2 \cdot 10^6$ protons belonging to the primary halo hitting the momentum cleaning primary collimators in IR3. A multi-turn tracking routine follows the protons emerging from the collimator surface until they are absorbed by the cleaning system or lost in other aperture limitations of the machine (not including the FP420 detectors). At each turn, the proton distribution is recorded at the 420 m locations. In order to estimate the absolute background level the distributions must be normalized for the number of protons that will interact with the momentum cleaning collimators during normal LHC operation.

If we assume: the nominal LHC beam intensity for high luminosity runs $I_0 = 3.2 \cdot 10^{14}$ protons, an exponential decay of the beam current due to off-momentum proton losses $I(t) = I_0 \cdot e^{-t/\tau}$, and a beam lifetime accounting for losses of off-momentum particles $\tau = 150$ hours, then the corresponding maximum proton loss rate is:

$$r(t=0) = -\left.\frac{dI}{dt}\right|_{t=0} = \frac{I_0}{\tau} \approx 5.9 \cdot 10^8\ [p \cdot s^{-1}]. \qquad (2)$$

Hence, the loss rate at FP420 as a function of transverse position can be calculated by normalizing the simulation results of protons per bin ($\mathrm{N_p}$) according to:

$$r(t, \Delta x) \quad = \quad \frac{N_p}{\Delta x} \cdot \frac{r(t_0)}{N_0} [\mathrm{p \cdot s^{-1} mm^{-1}}] \qquad (3)$$

where Δx is the bin width.

Another component contributing to the build up of a beam halo is the elastic and inelastic scattering between 7 TeV protons with residual gas nuclei, known as distance beam-gas. When the resulting proton momentum loss and scattering angle are small, the protons remain within the machine momentum and transverse acceptance and circulate for several turns. Therefore elastic or inelastic scattering can contribute to the halo.

STRUCT [4] has been used to simulate $1 \cdot 10^7$ protons, which were generated at the location of the collimator labelled as TCP.6L3 (177 m upstream of IP3), with momentum equal to 7 TeV and distributed according to the nominal transverse phase space. These protons were tracked around the LHC ring, to simulate the proton phase space distribution at 420 m by assuming a uniform gas density in the LHC arcs and dispersion suppressor regions, and are either lost or rescattered from a collimator after a proton-gas interaction. These simulation results must be normalized for the expected beam gas life time, and in the results presented here, we considered 500 h as a reasonable value for the LHC high luminosity runs.

The horizontal distribution of the beam halo protons at FP420, recorded for all protons in the simulation with horizontal position $|x| > 7\sigma_x$ and vertical position $|y| > 7\sigma_y$, is shown in figure 1 which is normalised for the number of protons per millimeter, and per bunch crossing.

Figure 2 shows the total number of beam halo protons that will enter the 420 m regions, for different horizontal positioning of the detectors (i.e. the number of protons integrated from the outer beam halo edge to the detectors inner edge).

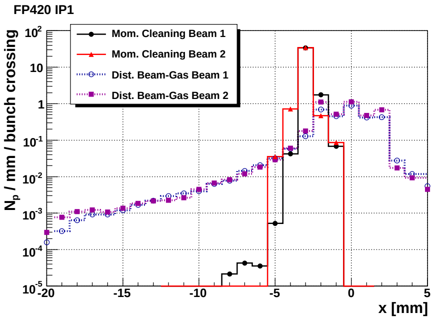

Figure 1: Horizontal beam halo distribution per bunch crossing at FP420 around IP1. Similar calculations have been done for IP5 [1].

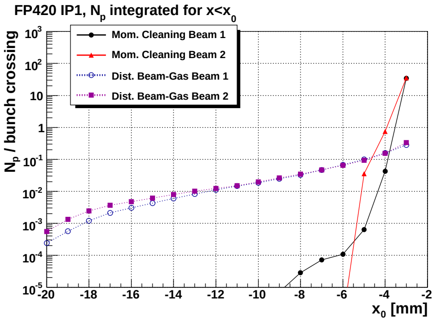

Figure 2: Total amount of beam halo protons predicted at the 420 m regions around IP1 for different FP420 detector horizontal positions. Similar calculations have been done for IP5 [1].

The peak of the beam-halo distribution is determined by the LHC momentum cleaning collimator settings. For nominal collimator settings, positioning the FP420 detectors at 5 mm from the beam would locate them well away from this peak. To operate closer than 5 mm an adjustment of the collimator positions would likely be required. Furthermore, for detector distances greater than 5 mm, this background is dominated by distant beam gas and the background rate is low.

Secondary Interaction Backgrounds

The proton-proton interactions at the IP result in final state proton distributions with a long momentum tail. The subsequent transport of this phase space distribution down the beamline will result in the interaction of the protons with the material of the machine and the detector, due to limited aperture and the high dispersion. The protons will become lost from the beam and results in electromagnetic and hadronic showers, causing deposited energy and the production of background particle species. The calculation of the resulting shower particle distribution requires coupling of a beam line and detector model with an initial particle phase space distribution.

To obtain a full simulation of secondary production along the beam line the simulation tool STRUCT has been used [2] to calculate the proton distribution on the dipole immediately preceding FP420. The showers in this dipole are then computed using MARS. Preliminary results are shown in Fig. 3.

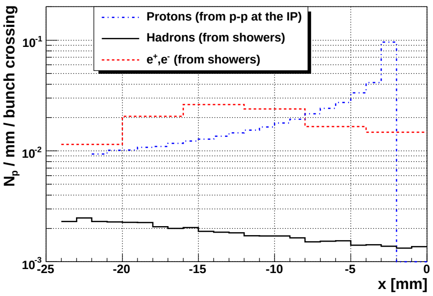

Figure 3: Secondary particles flux at the entrance of the 420 m region downstream IP5 (preliminary results). The shower source is IP protons, generated with loss on the last dipole magnet before FP420.

BDSIM [5] (Beam Delivery System Simulation) has been used to crosscheck the STRUCT-MARS results and to estimate the neutrons flux level. The code combines vacuum tracking of particles in the beam pipe with GEANT4 [6], which models the interaction of beam particles with matter and is used whenever particles leave the beampipe and enter solid parts of the machine. The BDSIM calculations were done using DPMJET [7] calculation of the protons at the interaction point, for which the LHC total proton-proton cross section gives about 35 proton-proton collisions per bunch crossing. Approximately 1/3 of these give forward protons. The loss map calculated with BDSIM has been crosschecked with the LHC machine tracking code MADX [8], as shown in Fig. 4. The BDSIM estimation of the neutron rate is 0.11 neutrons per bunch crossing at 420 m. This is equivalent to an integrated rate of $44.4 \cdot 10^3$ neutrons per $\mathrm{cm}^2 \cdot \mathrm{s}$. Showers from near beam gas and beam halo are expected to be negligible compared to showers arising from IP protons.

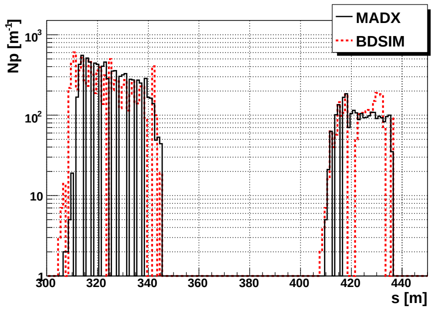

Figure 4: Loss maps produced for the IP5 beamline with a DPMJET phase space sample using MADX and BDSIM.

The detector region has also been simulated with GEANT4 [6]. The results of these studies are described in [1], where their impact on the design of the layout of the detector region is discussed. The aim is integration into the beamline models and a complete start-to-end simulation.

CONCLUSIONS AND OUTLOOK

The machine induced background in the LHC forward experiments at 420 m from IP1 and IP5 will be dominated by IP proton losses in the beam line, distant beam-gas and momentum cleaning collimators beam halo. The last two of these contributions give a proton background, which is described by a peak determined by the momentum cleaning collimator settings, and a tail dominated by far beam-gas halo protons. At detector transverse distance of 5 mm or greater, the expected integrated number of protons from beam halo is expected to be less than 1 per bunch crossing. All particle losses occurring immediately upstream of 420m produce showers of charged and neutral particles that have been (or are in the process of being quantified. All background contributions need to be combined with detailed detector and signal studies to understand the impact on the FP420 experiment.

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