NEAR BEAM-GAS BACKGROUND FOR LHCb AT 3.5 TeV

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Abstract

We consider the machine induced backgrounds for LHCb arising from collisions of the beam with residual gas in the long straight sections of the LHC close to the experiment. We concentrate on the background particle fluxes initiated by inelastic beam-gas interactions with a direct line of sight to the experiment, with the potential impact on the experiment increasing for larger beam currents and changing gas pressures. In this paper we calculate the background rates for parameters foreseen with LHC running in 2011, using realistic residual pressure profiles. We also discuss the effect of using a pressure profile formulated in terms of equivalent hydrogen, through weighting of other residual gases by their cross section, upon the radial fluxes from the machine and the detector response. We present the expected rates and the error introduced through this approximation.

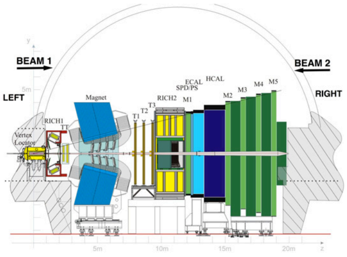

Figure 1: LHCb detector schematic.

THE LHCb EXPERIMENT

The LHCb experiment [1] (see Fig. 1) at the LHC is a single arm spectrometer, orientated in the beam1 direction, designed to investigate CP-violation and rare decays, mainly in the b-meson sector. In this paper we discuss the simulation and observation of particle flux produced from the beam-gas in the long straight section as seen by the LHCb Vertex Locator (VeLo). The LHCb VeLo [2] is a silicon strip detector surrounding the Interaction Point (IP).

Backgrounds relevant to LHCb

A machine induced background (MIB) is described as the particle flux that results from the proton beam interacting with matter in the machine that arrives at the cavern. Discussion of this can be found in [3]. Beam-gas background originates from the beam colliding with residual gas in the beam pipe and can be categorized as:

- Beam-gas through the whole of the LHC beam pipe, that leads to beam emittance growth and losses in the next restrictive aperture.
- Long straight section (LSS) beam-gas, from the 270 m either side of the IP, which has direct line of sight with the experiment.
- Experimental beam-gas, which take place in the beam pipe within the LHCb detector. This is used for luminosity measurements[4] and not part of this study.

The LSS beam-gas is considered to be the most relevant for the 2010 and 2011 conditions of LHCb. With higher current and luminosity cross-talk and distant beam-gas may become an issue.

BEAM-GAS SIMULATION - MACHINE TO EXPERIMENT BOUNDARY

We define left side as the beam1 direction into the detector and right as beam1 leaving the detector as indicated in Fig.1. The simulation is based upon recent simulated pressure profiles produced by the LHC vacuum group; these consider the densities of H_2, CH_4, CO_2 and CO [5]. The gas pressures peak in the warm sections of the machine[6]. The final triplet (Q1, Q2 and Q3) and the aperture separating dipole (D1) have lower gas pressures as they are cryogenically cooled. The LSS has a significant broad peak at 80 m caused by the injection collimator.

A proton loss is considered to be an event where a proton collides with a gas particle (see Fig. 2). From this, a nuclear interaction will occur with particle showers through the machine with some resulting particles reaching the interface plane (IRPLANE) and these are then passed on to the detector simulation. The IRPLANEs are 2.1 m and 19.9 m from the IP for the left and right sides respectively. The proton losses resulting in secondaries at the IRPLANE decrease with distance from the IP, this is due to greater dispersion leading to loss in the next restrictive aperture in the LSS. The total loss rate is far greater for the left than for the right side due to the difference in position of IRPLANE (see Tab. 1). The event generator is called in the simulation and models a 3.5 TeV proton colliding with a hydrogen atom. The choice of using hydrogen is partially because proton-proton interactions are better understood than

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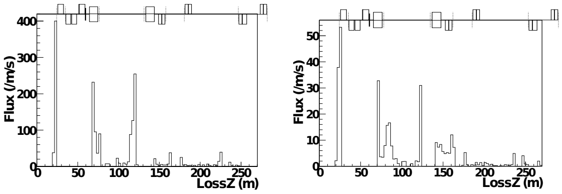


(a) Left side (b) Right side

Figure 2: The proton losses resulting in secondaries at the IRPLANE with beamline elements overlaid. (I = 0.049 A)

proton-neutron at these energies. The generator used was DPMJET-III [7].

FLUKA model

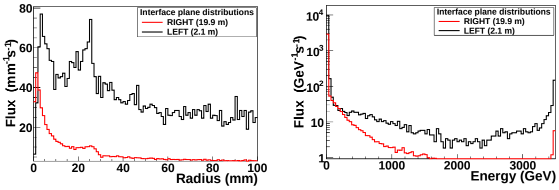
A model based on the long straight sections of the LHC has been produced for carrying out background studies [8] with the FLUKA particle transport code [9]. This detailed model was set for the running conditions of 13^{th} April 2011 in which a run was taken with no collisions in the LHCb IP and with a very loose trigger, allowing for dedicated background studies. The β^* was set to 3 m, with 228 bunches at 50 ns spacing per beam. The collimators were also adjusted accordingly for this run and the experiment dipole and correction magnets off. The event generator models a proton gas collision and creates daughter particles which are then passed into the model. The position of these collisions is determined by a Monte Carlo based upon the pressure distribution. Only particles greater than 20 MeV in energy are tracked.

Table 1: Loss rates and particle fluxes reaching IRPLANEs from the LSS (I = 0.049 A, E = 3.5 TeV). (Where region not designated rate is taken across the whole of the IRPLANE.)

	Left	Right
Proton losses in LSS (/s)	4.2E3	0.6E3
reaching IRPLANE (/s)	1.7E3	0.3E3
Charged hadrons (/s)	1.1E4	0.3E4
Charged hadrons (/proton)	2.60	4.75
on axis / 100 mm radius (/mm^2/s)	1.7 / 0.35	10.1 / 0.27
Muons (/s)	1.0E3	0.3E3
Muons (/proton)	0.25	0.47

Fluxes at the experiment-machine interface.

A first analysis of the MIB can be carried out at the IRPLANE between the accelerator and the experimental cavern. The charged hadron radial distribution has two peaks (see Fig. 3(a)). The closest peak to the axis results from secondaries from beam-gas collisions, while the second peak is a result of more distant beam-gas sources undergoing showering with materials in the machine. It can be noticed that the relative height of the two peaks for the left side differs compared with the right suggesting greater distant proton losses from showering reaching the IRPLANE. This is caused by a pressure bump next to the IRPLANE for the right side (see Fig. 2(b)).



(a) Radial distribution (b) Energy distribution

Figure 3: Charged hadron distributions at the IRPLANEs (Energy cut at 20 MeV).

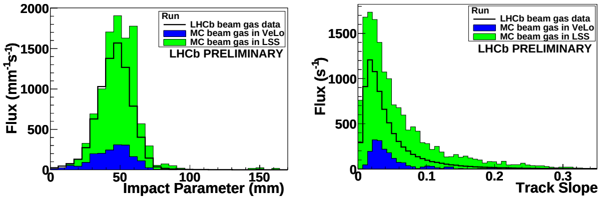
The energy distribution (see Fig. 3(b)) also clearly shows that there are a number of protons close to beam energy that have undergone diffractive processes off the beam-gas reaching the IRPLANE. For total rates see table 1.

ANALYSIS OF BEAM GAS BACKGROUND IN THE LHCb DETECTOR

The data from the interface plane is passed into the LHCb simulation framework [3], modelling the detector response and trigger. The signal is then reconstructed by interpolating between signals in VeLo sensors using a non standard reconstruction, which doesn't force the reconstructed vertex to being close to the IP [10]. Two variables of the tracks reconstructed with the VeLo have been considered. The impact parameter (see Fig. 4(a)) which is the radial track distance at the IP, is expected to be peaked due to showering from the beam screen. The track slope (see Fig. 4(b)), defined as change in radius with optical path, which is expected to be low due to the particle source being distant leading to flat tracks compared with a collision at the IP. The data collected for background studies has the VeLo in an open position (radius 29 mm at nominal IP) compared with the 8 mm closed position for physics data, hence the result will be different to that in physics runs. Also a very loose trigger is applied to the data compared with that during physics runs. To compare with the data collected, the beam-gas in the VeLo is also simulated. Comparing the two tracks' variables between the simulation and the data it can be observed that the shapes of the distributions are rather similar and the total rate from beam gas in the LSS and in experimental area is within a factor of 1.6 of the one observed in the data. Significant differences are still present, suggesting corrections are needed to be made to the simulation. Possible contributions come from the vacuum profile, gas species choice and particle interaction errors.

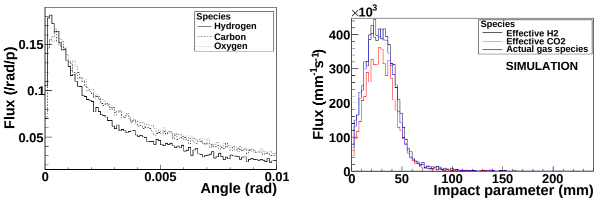
EFFECTIVE GAS

An effective gas is where one gas species is chosen to represent all other gasses as a sum of their pressures



(a) Impact parameter (b) Track slope

Figure 4: Track rates from beam-gas simulation and data as collected in special run (preliminary result). The MC are stacked.



(a) Angular distributions of outgoing charged hadrons from collisions of 3.5 TeV protons with H, C and O atoms[7]

(b) Impact parameter from LHCb simulation (VeLo closed) from a simulation using the unscrubbed pressure profile.

Figure 5: Effective gas study.

weighted by their relative total cross sections,

$$P_{eH_2} = \sum_i \frac{\sigma_{p-A_i}}{\sigma_{p-H_2}} P_{A_i}, \qquad (1)$$

where P_{A_i} is the pressure of a given species A_i, weighted by a the total collision cross section σ_{p-A_i}, for a proton with the species. The angular distributions (see Fig. 5(a)) resulting from the event generator for a 3.5 TeV proton colliding with either a H, C or O atom show that hydrogen with a lower mass nucleus results in a more forward shower but fewer products. For a simulated pressure profile it can be seen that the most common specie is H_2 however in terms of collisions CO_2 is dominant due to a higher cross section(see Tab. 2).

Table 2: Simulated relative pressures and collision rates from the unscrubbed pressure profile.[5]

Gas species	**CO_2**	**H_2**	**CO**	**CH_4**
Pressure	61	11	13	14
Collisions	21	60	7	12

The choice of gas species appears to have a very limited effect on the distributions of impact parameters of tracks as reconstructed with the VeLo detector (see Fig. 5(b)). Though it may be noted more collisions occur with CO_2 in the machine, the actual track rates are closer to that of effective H_2 whose daughter products are more forward, therefore more likely to reach the VeLo directly. Further study will be made for other detectors at larger radius were the situation may be different.

CONCLUSION

A method for simulation and data analysis for LSS beam-gas background for LHCb has been commissioned with the further intention to investigate effects of the background on physics searches. The backgrounds from the long straight section have distinguishing features that the left side has a more dispersed and higher current background particle flux compared with the right side caused by the proximity of the interface planes to pressure bumps. It has been observed that the simulation agrees with the data for the shape of the track distributions in the VeLo. Furthermore the choice of gas species appears to be a minor contribution to the errors in calculation of simulated rates and hence we conclude the effect of choosing any low Z species on the final detector response to be minimal for detectors at low radii.

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