# Summary of pre-2008 Machine Induced Background Estimates for the LHCb Experiment

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# Abstract

This document summarizes the pre-2008 estimates of particle flux arriving at the LHCb experiment from machine (LHC) related background sources. These particles arrive in the form of showers from both beam-gas interactions in the dispersion suppression and long straight section of IR8 and from proton losses on the IR8 tertiary collimators due to betatron cleaning inefficiencies, momentum cleaning inefficiencies and elastic beam-gas interactions along the LHC beam orbit.

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# 1 Introduction

Due to various effects a certain amount of protons accompany the LHC beams in the form of a beam halo. The majority of such protons are stopped and lost at the momentum cleaning at IR3 and betatron cleaning at IR7. Due to, amongst others, inefficiencies in these system a comparatively small amount of halo protons survive this procedure and is eligible to strike other aperture limitations.

The tertiary collimators (TCTs) located close to the LHCb experiment (IR8) provide such an aperture restriction. Particle showers from these proton impacts can reach the LHCb cavern, interfering with the experiment. Such particles are referred to as the machine induced background (MIB) in this note.

Halo protons that interact with the TCTs can originate from several sources. In this document three such sources will be considered and treated independently:

a.) Betatron cleaning inefficiency. (Section 2)

b.) Momentum cleaning inefficiency. (section 3)

c.) Elastic beam-gas interactions in the arcs. (Section 4)

In addition beam-gas interactions close to the experiment can result in showers able to reach the LHCb cavern. As this source is not related to the TCTs, it will be treated separately in section 5.

Three shielding configuration have been investigated for the background estimates. The shields in question are concrete and iron walls located upstream of the experiment[1, 2]. The configurations involve variations in the beam 1 shielding and are as follows:

a.) Unshielded, where no shield walls are present.

b.) Full shielding, where an 80 cm concrete wall begins at 2.5 m upstream of the IP as well as a dual concrete (120 cm) and iron (80 cm) wall at 10.5 m.

c.) Staged shielding, where the concrete shields are installed, and only part of the iron shield close to the beam line.

Depending on the shielding configuration of the experiment the proton losses results in different particle distributions and flux into the cavern. This information can be imported into the LHCb software suite in order to simulate the effect on the experiment. Throughout this document "estimate" is used to indicate the investigation of MIB particles up to the LHCb experiment.

This document provides a summary of the various background rates, both in the form of loss rate on the TCTs as well as expected particle fluxes into the LHCb cavern. The numbers presented are all taken from pre-2008 estimates, and can be used as comparison for the currently ongoing background estimate production. Until the new estimates have been updated, these values also provide the current best background knowledge.

In the case of the particle flux into the cavern originating from proton losses on the TCTs, estimates only exist for beam 1 betatron cleaning. For the others sources only the proton loss rate at the TCTs is known. In order to attain an idea of the expected particle flux rates at the LHCb from these sources, the beam 1 betatron cleaning result has been reused and rescaled for each of the other sources. For example if a given source has a loss rate on a TCT twice that of the betatron cleaning, the particle flux at the LHCb for this source is set to twice that of the betatron cleaning flux. However, this assumes equal kinematic properties for all sources, and as such should only be regarded as a crude estimate.

All estimates assume $1.15 \times 10^{11}$ 7 TeV protons per bunch and 2808 filled bunches per beam.

# 2 Betatron Cleaning

Betatron cleaning, designed to clean the horizontal and vertical phase space of the beam is performed with primary and secondary collimators at IR7, just upstream of LHCb w.r.t. beam 1. Thus the effect on LHCb of inefficiencies in this cleaning is expected to be greater for beam 1 than for beam 2. For these estimates a proton loss rate of $2.8 \times 10^9$ p/s in the primary collimator has been assumed, which corresponds to a 30h collimation beam lifetime[3].

The beam halo reaching the TCTs have been divided into two components: Vertical and horizontal halo. For each of these components, the losses on the vertical (TCTV) and horizontal (TCTH) collimators are estimated.

The proton losses on the TCTs for both horizontal and vertical halo are shown in table 1. The values for the horizontal and vertical halo are not additive. They are extreme case estimates where the halo consists of only a vertical or horizontal component at the primary collimators in IR7. The real values will be in the region somewhere between these two extremes.

| | Beam 1 (p/s) | Beam 2 (p/s) |
|---|---|---|
| V.Halo, TCTV | $2.346 \times 10^6$ | $7.82 \times 10^5$ |
| V.Halo, TCTH | $6.12 \times 10^5$ | $6.12 \times 10^4$ |
| H.Halo, TCTV | $9.5 \times 10^3$ | $3.2 \times 10^3$ |
| H.Halo, TCTH | $8.44 \times 10^5$ | $8.44 \times 10^4$ |

**Table 1** Proton losses in TCTs due to betatron cleaning. The rate indicates the number of protons lost on the TCT per second.

In order to assess the resulting particle flux into the experiment, the worst case scenario, i.e. a totally vertical halo, is used. The particle showers originating from the interaction of the proton halo with the TCTs material are transported from the TCTs to the LHCb cavern where the surviving particles are saved for analysis and further processing. Separate particle files exist for the hadronic and muonic MIB, for non-, staged- and complete shielding for beam 1 betatron cleaning. These can be imported into the LHCb simulation application, Gauss, using the specifically written LbMIB package as generator in order to estimate their effect on the experiment[4].

The fraction of particles from the losses on TCTs entering the LHCb cavern depend on the shield configuration. In table 2 we give the particle flux for the different scenarios [5]. This value is given in particles per second arriving at an imagined infinite vertical interface plane 1 meter upstream of the IP for beam 1 and 19.9 meter downstream for beam 2. It can be seen that proton losses on the TCTH cause a lower flux in the cavern per lost proton than losses on the TCTV, due to the fact that the TCTV is located closer (73 m from IP) to the experiment than the TCTH (118 m from IP) [6]. The beam 2 results are rescaled from the beam 1 results, assuming a similar position and momentum distribution. It should be noted that the shielding configuration seen by beam 2 differs from that of beam 1. This must be kept in mind when considering the beam 2 shielded results.

| **Beam 1** | non-shielded | staged shield | full shield |
|---|---|---|---|
| muonic TCTV | $1.7 \times 10^6$ | $7.5 \times 10^5$ | $4.9 \times 10^5$ |
| muonic TCTH | $4.7 \times 10^4$ | $2.5 \times 10^4$ | $2.1 \times 10^4$ |
| hadronic TCTV | $5.7 \times 10^6$ | $8.0 \times 10^5$ | $5.8 \times 10^4$ |
| hadronic TCTH | $8.3 \times 10^4$ | $1.1 \times 10^4$ | $1.0 \times 10^3$ |
| **Beam 2** | non-shielded | staged shield | full shield |
| muonic TCTV | $5.7 \times 10^5$ | $2.5 \times 10^5$ | $1.6 \times 10^5$ |
| muonic TCTH | $4.7 \times 10^3$ | $2.5 \times 10^3$ | $2.1 \times 10^3$ |
| hadronic TCTV | $1.9 \times 10^6$ | $2.7 \times 10^5$ | $1.9 \times 10^4$ |
| hadronic TCTH | $8.3 \times 10^3$ | $1.1 \times 10^3$ | $1.0 \times 10^2$ |

**Table 2** Particle fluxes in the LHCb due to betatron cleaning. The fluxes are in particles per second. All values are scaled from beam 1 betatron cleaning.

# 3 Momentum Cleaning

The cleaning of off-momentum protons is performed at IR3 and contributes to the beam halo reaching the TCTs. The proton losses on the aperture restrictions for nominal machine and for a cleaning rate of $4.3 \times 10^8$ p/s, corresponding to a beam lifetime of 195 hours have been calculated by I. Baishev[7].

As can be seen from table 3, the rates for beam 2 are higher than those of beam 1 due to the different distance the two beams have to travel going from IR3 to IR8. However the rates are in general lower than for the betatron cleaning. Unlike for the case of the betatron cleaning inefficiency, no separation were done between the vertical and horizontal halo.

The losses in the TCTH for beam 2 is quite high, however as the amount of resulting flux into the cavern per proton lost in TCT is a factor 20 lower for TCTH than TCTV, the resulting flux is not dramatic. Additionally, as LHCb is a single arm spectrometer, background particles arriving with beam 2 are off-time w.r.t. the physics signal, and thus less likely to interfere with trigger and reconstruction.

| | Beam 1 (p/s) | Beam 2 (p/s) |
|---|---|---|
| TCTV | $4.95 \times 10^4$ | $9.89 \times 10^4$ |
| TCTH | $3.78 \times 10^4$ | $2.50 \times 10^6$ |

**Table 3** Proton losses in TCTs due to momentum cleaning. The rate indicates the number of protons lost on the TCT per second.

| **Beam 1** | non-shielded | staged shield | full shield |
|---|---|---|---|
| muonic TCTV | $3.6 \times 10^4$ | $1.6 \times 10^4$ | $1.0 \times 10^4$ |
| muonic TCTH | $2.9 \times 10^3$ | $1.5 \times 10^3$ | $1.3 \times 10^3$ |
| hadronic TCTV | $1.2 \times 10^5$ | $1.7 \times 10^4$ | $1.2 \times 10^3$ |
| hadronic TCTH | $5.1 \times 10^3$ | $6.8 \times 10^2$ | $6.2 \times 10^1$ |
| **Beam 2** | non-shielded | staged shield | full shield |
| muonic TCTV | $7.2 \times 10^4$ | $3.2 \times 10^4$ | $2.1 \times 10^4$ |
| muonic TCTH | $1.9 \times 10^5$ | $1.0 \times 10^5$ | $8.6 \times 10^4$ |
| hadronic TCTV | $2.4 \times 10^5$ | $3.4 \times 10^4$ | $2.4 \times 10^3$ |
| hadronic TCTH | $3.4 \times 10^5$ | $4.5 \times 10^4$ | $4.1 \times 10^3$ |

**Table 4** Particle fluxes in the LHCb due to momentum cleaning. The fluxes are in particles per second. All values are scaled from beam 1 betatron cleaning.

Table 4 shows the expected particle fluxes into the LHCb cavern due to momentum cleaning inefficiencies. The numbers are rescaled from the betatron cleaning results, thus assuming a similar position and momentum distribution for these sources. As mentioned for the betatron cleaning, the shielding seen by beam 2 also differs from that of beam 1.

# 4 Elastic Beam-Gas Interactions

An additional source of proton losses on the TCTs is due to elastic beam-gas interactions with the residual gas in the arcs and dispersion suppressors. Assuming a beam-gas interaction lifetime of 100h, representing the minimum requirement of the LHC design, there are about $8.89 \times 10^8$ p/s lost in elastics beam gas interactions. The estimates provided by I. Baishev[8] give resulting losses in the TCTs as reported in table 5. It must be mentioned that this beam lifetime is rather pessimistic, representing the lower limit.

Comparing the rates from the three backgrounds investigated it can be concluded that the elastic beam-gas interactions with the given lifetime constitute the dominant source of losses on the TCTs.

| | Beam 1 (p/s) | Beam 2 (p/s) |
|---|---|---|
| TCTV | $5.12 \times 10^6$ | $8.52 \times 10^6$ |
| TCTH | $6.99 \times 10^6$ | $7.76 \times 10^6$ |

**Table 5** Proton losses in TCTs due to elastic beam-gas interactions. The rate indicates the number of protons lost on the TCT per second.

Table 6 shows the expected particle fluxes into the LHCb cavern due to elastic beam-gas interactions. The numbers are rescaled from the betatron cleaning results, thus assuming similar kinematic distributions for these sources. As for the other sources, the beam 2 shielded results do not take the differences in beam 1 and beam 2 shielding into account.

| **Beam 1** | non-shielded | staged shield | full shield |
|---|---|---|---|
| muonic TCTV | $3.7 \times 10^6$ | $1.6 \times 10^6$ | $1.1 \times 10^6$ |
| muonic TCTH | $5.4 \times 10^5$ | $2.9 \times 10^5$ | $2.4 \times 10^5$ |
| hadronic TCTV | $1.2 \times 10^7$ | $1.7 \times 10^6$ | $1.3 \times 10^5$ |
| hadronic TCTH | $9.5 \times 10^5$ | $1.3 \times 10^5$ | $1.1 \times 10^4$ |
| **Beam 2** | non-shielded | staged shield | full shield |
| muonic TCTV | $6.2 \times 10^6$ | $2.7 \times 10^6$ | $1.8 \times 10^6$ |
| muonic TCTH | $6.0 \times 10^5$ | $3.2 \times 10^5$ | $2.7 \times 10^5$ |
| hadronic TCTV | $2.1 \times 10^7$ | $2.9 \times 10^6$ | $2.1 \times 10^5$ |
| hadronic TCTH | $1.1 \times 10^6$ | $1.4 \times 10^5$ | $1.3 \times 10^4$ |

**Table 6** Particle fluxes in the LHCb due to elastic beam-gas interactions. The fluxes are in particles per second. All values are scaled from beam 1 betatron cleaning.

# 5 Local Beam-Gas Interactions

Unlike the aforementioned sources, the local beam-gas interactions do not originate from what can be considered a fixed point like the TCTs, but are rather distributed over a few hundred meters close to the experiment. Beam particles interacting with gas residue in the beam pipe give rise to a particle shower resulting in a certain particle flux at LHCb [9].

The area included in these estimates are the closest long straight section (LSS), dispersion suppression (DS) and arc.

The estimates of these background sources are from 2001[10, 11, 12], and thus only exist for the unshielded configuration. In order to improve on the estimates they have been rescaled with gas profiles calculated in 2006[13, 14]. These studies have been performed with a proper gas mixture, not hydrogen equivalent.

| **Beam 1** | $\beta^* = 1$, Startup | $\beta^* = 10$, Startup | $\beta^* = 10$, Scrubbed |
|---|---|---|---|
| muonic | $4.8 \times 10^5$ | $3.8 \times 10^5$ | $7.3 \times 10^4$ |
| hadronic | $6.9 \times 10^6$ | $6.0 \times 10^6$ | $8.6 \times 10^5$ |
| **Beam 2** | $\beta^* = 1$, Startup | $\beta^* = 10$, Startup | $\beta^* = 10$, Scrubbed |
| muonic | $7.8 \times 10^5$ | $6.0 \times 10^5$ | $3.4 \times 10^5$ |
| hadronic | $1.8 \times 10^7$ | $1.2 \times 10^7$ | $4.3 \times 10^6$ |

**Table 7** Particle fluxes in the LHCb due to local beam-gas interactions. The fluxes are in particles per second assuming full machine current and no shielding.

# 6 Conclusion

Considering the estimates presented we can conclude that the strongest contribution to machine induced background from the tertiary collimators is expected to be due to elastic beam-gas scattering in the arcs, followed by the betatron cleaning. The momentum cleaning, as expected, only brings a very low background particle flux. Again it has to be noted, that the beam lifetime for elastic beam-gas scattering is very pessimistic.

Although the local beam-gas source is very old and lacks shielding, when comparing with the unshielded result of the other sources one can see that it is a source that even for the scrubbed gas profile should not be neglected. Additionally, as the local beam-gas interactions result in a stronger peak at low radius compared the other sources, the shielding is expected to be somewhat less efficient against particles from this source.

The summary table 8 shows the sum of the rates presented in this document, excluding the local beam-gas source, while table 9 gives the relative contribution from the various sources. It can seen that, in particular for the hadronic background, the amount of the shielding has a dramatic effect on the rate. The muonic background, though reduced by a factor 3, still remains at the MHz level. It is also clear that the beam-gas elastic interactions dominate, particularly for beam 2.

Comparing the shielded background flux ( 2 MHz) to the actual bunch crossing rate (31.6 MHz) one sees that less than one background particle per bunch is expected on average. However, the correlations between the background particles is not recorded in these studies. It is expected that the background will not be a flat distribution of single particles but rather sporadic showers where multiple particles arrive in the same event. Further studies have been initiated where this effect is taken into account so that the implications on, amongst others, the trigger system can be investigated.

| **Beam 1** | non-shielded | staged shield | full shield |
|---|---|---|---|
| muonic | $6.0 \times 10^6$ | $2.7 \times 10^6$ | $1.9 \times 10^6$ |
| hadronic | $1.9 \times 10^7$ | $2.7 \times 10^6$ | $2.0 \times 10^5$ |
| **Beam 2** | non-shielded | staged shield | full shield |
| muonic | $7.6 \times 10^6$ | $3.4 \times 10^6$ | $2.3 \times 10^6$ |
| hadronic | $2.5 \times 10^7$ | $3.4 \times 10^6$ | $2.5 \times 10^5$ |

**Table 8** Particle fluxes in the LHCb summary. The fluxes are in particles per second. Contributions from TCTV and TCTH are combined. Local beam-gas interactions are not taken into account.

| **Beam 1**, muonic | non-shielded | staged shield | full shield |
|---|---|---|---|
| Betatron Cleaning | 29.0% | 28.9% | 27.4% |
| Momentum Cleaning | 0.6% | 0.6% | 0.6% |
| Beam-Gas Elastics | 70.4% | 70.5% | 72.0% |
| **Beam 1**, hadronic | non-shielded | staged shield | full shield |
| Betatron Cleaning | 30.7% | 30.5% | 29.3% |
| Momentum Cleaning | 0.6% | 0.7% | 0.6% |
| Beam-Gas Elastics | 68.7% | 68.8% | 70.1% |
| **Beam 2**, muonic | non-shielded | staged shield | full shield |
| Betatron Cleaning | 7.5% | 7.4% | 6.9% |
| Momentum Cleaning | 3.4% | 3.9% | 4.6% |
| Beam-Gas Elastics | 89.1% | 88.7% | 88.5% |
| **Beam 2**, hadronic | non-shielded | staged shield | full shield |
| Betatron Cleaning | 7.8% | 8.0% | 7.7% |
| Momentum Cleaning | 2.3% | 2.3% | 2.6% |
| Beam-Gas Elastics | 89.9% | 89.7% | 89.7% |

**Table 9** Relative contribution from various sources. For beam 1 the about 30% comes from the betatron cleaning inefficiencies while the rest is from the beam-gas elastic interactions. Momentum cleaning contributes less than 1%. For beam 2 the beam-gas elastic contribution dominates.

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