Trigger and background study for the LHCf experiment

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***Abstract*. We studied the effects of background in the LHCf experiment by MC simulation. An important source of background is given by particles colliding with the inner wall of the beam pipe after they are generated in a proton-proton collision. Because the energies of these particles are less than 100 GeV, they can be reduced at the trigger level. The MC simulations have shown that a signal-to-noise ratio of 1.2 % can be achieved. These number can be reduced further in the analysis. Another source of the background is the particles generated in collisions between the beam and the residual gas in the beam pipe. Because the particles are emitted only in the direction of the beam, these backgrounds could be reduced with the coincidence of detectors at both sides of the interaction point. As the detection efficiency of a single calorimeter is only ∼15 %, the coincidence condition reduces the efficiency down to ∼3 %. It is the 20 % of events by single Arm calorimeter. To solve this problem, we developed additional detectors that have wide aperture and high detection efficiency, called Front Counter. By using the Front Counter signal in the coincidence condition, we can keep ∼60 % of the single side events but reduce the beam-gas background at the negligible level.**

***Keywords*: LHC, Background, Trigger**

I. Introduction

The uncertainties of the hadoron interaction model cause systematic errors of air shower simulations in high-energy region. To solve the problem, the LHCf experiment measures energies and transverse momenta of neutral particles emitted in the forward region of 7TeV+7TeV proton-proton collisions at LHC. Data taking of LHCf is planed at the very beginning of the LHC commissioning when the luminosity is below $10^{29}\,cm^{-2}s^{-1}$. With about 10^3 sec of operation, LHCf can provide sufficient statistics to discriminate between the hadron interaction models used in the air shower simulations.

The LHC beam pipe has two forks at both sides of interaction point IP1. The distance from IP1 to the forks is 140m, and it is covered by the TAN radiation absorver. The TAN has an instrumentation slot, where the LHCf detectors are installed as shown in Fig1. Two detectors are installed in the TANs on both sides of IP1. One side is called Arm1 and the other side is called Arm2. Each of the LHCf detector is composed of two sampling shower calorimeters of compact aperture because of the limited space and to avoid multi-particle incidence. The calorimeter has 16 layers of plastic scintillator, interleaved with 22 tungsten layers of total 44 radiation lengths. In addition, there are 4 layers of X-Y hodoscopes. The experimental target is to measure gamma-rays of >100 GeV and neutrons of >1 TeV. The detail of the LHCf experiment can be found in [1][2][3].

In the LHCf experiment, there are two major backgrounds. One is the particles generated by the collisions between the secondary particles of p-p collisions and the beam pipe inner wall. It is called the beam pipe background. The other background is the particles generated by the collisions between the proton beams and the molecules of residual gas in the beam pipe. It is called the beam&gas background. In these collisions, because the protons have high energies and the gases are almost at rest, the secondary particles are emitted along the beam direction. Therefore, these events will

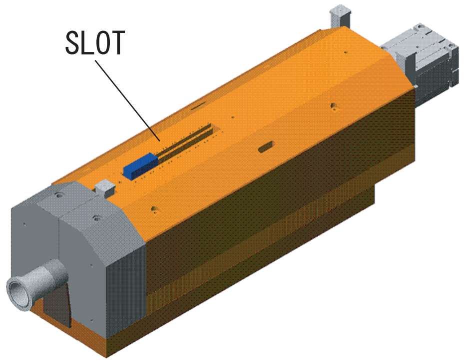

Fig. 1: The appearance of TAN absorber located 140 m from IP. It has an instrumentation slot 96 mm width.

not be detected at both sides. By taking coincidence between the Arm1 and Arm2 detectors, these background could be reduced. However, because the aperture of the calorimeters is limited, the efficiency for the coincidence events will be small and it will result a bias in the analysis. To solve the problem, we made additional detectors having larger aperture.

We studied these backgrounds by means of MC simulation. The software and the hadron interaction model used in this study are EPICS[4] and DPMJET3, respectively. The structure of the LHC beam pipe, the dipole magnets and the LHCf detectors are considered in the simulation. In this paper, we report the methods of the background rejection and the effects of background to the LHCf measurements.

II. Beam pipe background

The energy fluence of particles arriving at the LHCf detectors is shown in Fig.2. The fluence of beam pipe background peaks below 100 GeV and rapidly decreases over that energy while the gamma-rays from p-p interactions distribute above 100 GeV. Thus, by setting the threshold energy at 100 GeV, we can expect effective collection for the collision events and rejection for the background events.

The trigger is issued when more than 3 successive calorimeter layers record signals over a certain threshold level. In the LHCf operation, this threshold level is set at 150 MeV that realizes a sufficient efficiency for 100 GeV incident gamma-rays. We tested the background to signal ratio as a function of this threshold level as in Fig.3. At the threshold level of 150 MeV, the background to signal ratio is 1.2 %. This is a robust result for the fine tuning at the actual operation because the background to signal ratio has a weak dependence on the threshold level. Furthermore, because these background events concentrate in the lowest energy, the effect of the beam pipe background is negligible in the final LHCf analysis.

III. Beam&gas background

The particles from beam&gas collisions are difficult to be discriminated from the particles from the p-p collisions with only a single Arm detector. This is

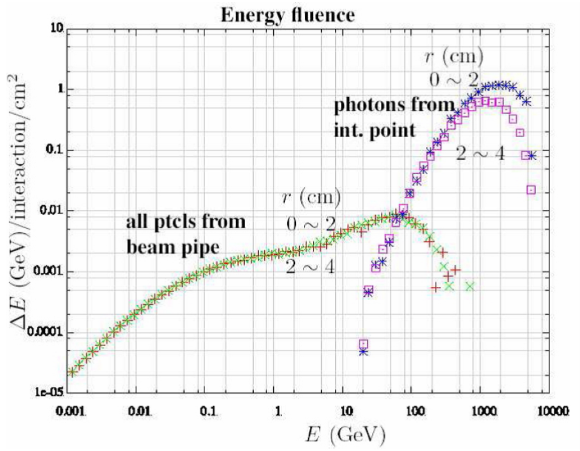

Fig. 2: The energy fluence of the beam pipe background and photons from IP at the calorimeter. Photons from IP dominate above 100 GeV while the background distribute below 100 GeV.

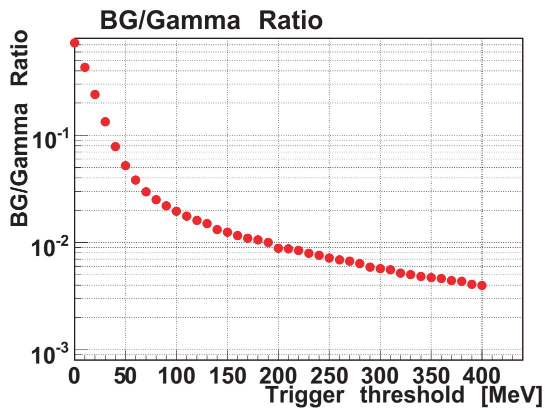

Fig. 3: The background to signal ratio as a function of the energy threshold of a calorimeter layer.

because the particle arrival timing of both origins at the detector is identical and energy spectra are very similar.

The difference between these two types of the particles are illustrated in Fig.4. The secondary particles are emitted only in the direction of the beam in the proton gas collisions. Therefore, these events can be rejected by the coincidence of the Arm1 and Arm2 calorimeters. Fig.5 shows the cross section around the detector perpendicular to the beam axis. The size of calorimeters are 20 mm × 20 mm and 40 mm × 40 mm at Arm1, 25 mm × 25 mm and 32 mm × 32mm at Arm2. The vertical lines show the inner wall of the TAN slot. The ellipses are the smallest limits of projection of the beam pipe at the detector plane. The apertures of the calorimeters in this region are ~12 cm^2 at Arm1 and ~16 cm^2 at Arm2.

The Front Counter is installed to enhance the detection efficiency of coincidence. The Front Counters have a thickness of 8 mm and are inserted in front of the Arm1 and Arm2 detectors. Two pairs of thin plastic scintillators (40 mm× 80 mm× 2.0 mm; Saint-Gobain Crystals

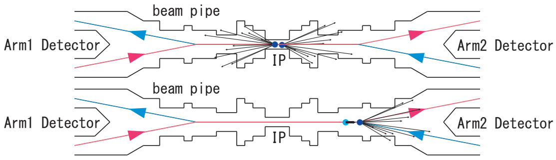

Fig. 4: Emissions of the secondary particles the pp collision (top) and the beam gas collision (bottom).

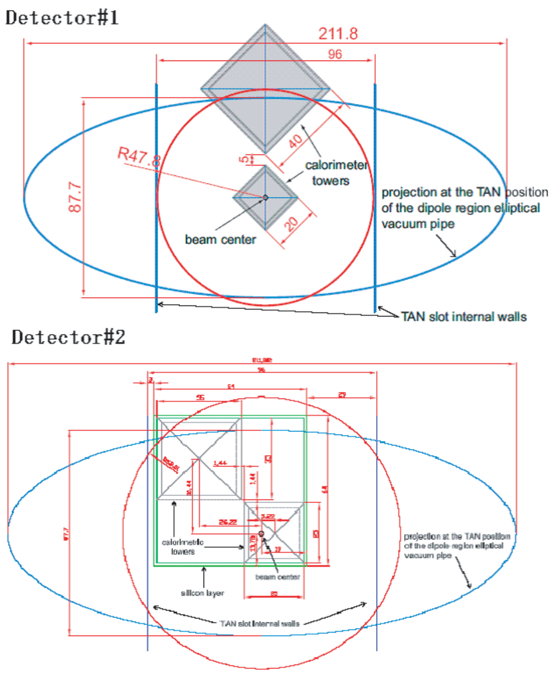

Fig. 5: The cross sections of the calorimeters. Top is the Arm1 calorimeter. Bottom is the Arm2 calorimeter.

BC404) are aligned in the vertical and horizontal directions to compose a double layer counter as shown in Fig.6. Between the two layers, a copper plate of 0.5mm thickness is inserted.

A. Simulation

We discuss about the detection efficiency with the LHCf calorimeters and the Front Counters for p-p collision event and the beam&gas background, separately in the following sections.

1) The detection efficiency of p-p collisions: We calculated the detection efficiency of each detector and coincidence condition by full MC simulation. The detection efficiency is defined as the fraction of the number of detected events with respect to the number of collisions. The definitions of detection are

- The calorimeters:
  the energy deposits exceed 150 MeV in any successive 3 layers.
- The Front Counters:
  the energy deposits exceed 0.302 MeV in both layers.

The results are shown in TABLE I. We found that the detection efficiency of the coincidence between the calorimeters is 2.6 % that is only 19 % and 13 % of events detected by single Arm1 and Arm2 calorimeters, respectively. On the other hand, the detection efficiencies of the coincidence between the calorimeter and Front Counter are enhanced to 8.8 % and 12.0 %, corresponding to 64 % and 58 % of single Arm events. By using the Front Counters in coincidence, 60 % of the single side events can survive and we can minimize the bias of coincidence in the analysis.

Fig. 6: A schematic view of The Front Counter. Two pairs of plastic scintillators segmented in vertical and horizontal directions. The size of a scintillator is 4×8 cm. A 8×8 cm copper plate of 0.5mm thickness is inserted between the pairs. The scintillator light outputs are fed to PMTs via an acrylic light guide and optical fibers.

TABLE I: The detection efficiencies

coincidence condition	Arm1	Arm2
without coincidence	13.7 %	20.7 %
Arm1 Calorimeter & Arm2 Calorimeter	2.6 %	2.6 %
Arm1 Calorimeter & Arm2 Front Counter	8.8 %	-
Arm1 Front Counetr & Arm2 Calorimeter	-	12.0 %

2) The reduction of beam&gas background: We estimated the detection efficiency of the coincidence between the calorimeter and the Front Counter for the beam&gas background. Because the density of residual gas is different in each section of the beam pipe and the phase of LHC start up and stable. To obtain the efficiency, density profiles of gas were considered. The profiles of H_2 equivalent density are shown in Fig.7 [5].

To consider the profile, the detection efficiency was calculated in each point of the beam pipe region. We generated 15,000 collisions at every 10m on axis of the beam in the simulation. The detection efficiencies of the single Arm and coincidence events are calculated for each position and phase.

At the same time, we calculated the collision rates of each collision point by the equation below.

There are some kinds of residual gas, H_2, CH_4, CO and etc. R_{pj} is the proton gas collision rate, where j is the kind of residual gas. Therefore the total collision

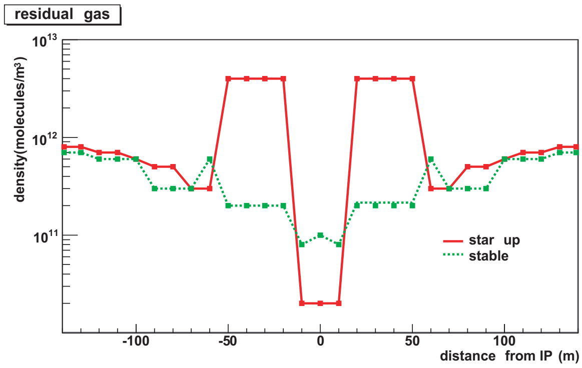

Fig. 7: The residual gas density profile H_2 equivalent in the region of ± 140 m from IP. The solid line shows start up phase and the dotted line shows stable phase of LHC running.

TABLE II: The list of constants

constant	define	value
f	revolution frequency	11.2×10^3 Hz
M	the number of bunch	43 bunch
N_b	the number of proton per bunch	1×10^{10} proton
D	the propagation distance of proton	10 m
σ_{pp}	the inelastic pp cross section	80 mb

rate is eq.(1), the constants are listed in TABLE II.

$$\sum_j R_{pj} = f M N_b D \sum_j n_j \sigma_{pj} \tag{1}$$

To make eq.(1) simpler, we used the H_2 equivalent gas density eq.(2).

$$n_{H_2,equiv} = \sum_j \frac{n_j \sigma_{pj}}{\sigma_{pp}} \tag{2}$$

Eq.(1) is transformed to eq.(3).

$$\sum_j R_{pj} = f M N_b D \sigma_{pp} n_{H_2,equiv} \tag{3}$$

The collision rates are calculated by eq.(3). The detection rate is obtained by multiplying the result of the detection efficiency and the result of the collision rate for each collision point. Finally, the total detection rate is calculated by summing them.

The ratio of the beam-gas rate to the p-p rate are $0.03\,\%$ in the start up phase, $0.7\,\%$ in the stable phase for the single detection. On the other hand, it is $0.004\,\%$ in start up phase, $0.0004\,\%$ in stable phase for the coincidence detection. By the results, we confirmed the coincidence detection can reduce the beam&gas background to $1/100$.

The beam&gas background is small enough even without coincidence. However, because the vacuum condition is not guaranteed, it is conservative to assume 100 times higher gas density. In this case, the ratio of the background to the p-p collision in the singe detection amounts to 3–7 %, while it is still below 1 % in the coincidence detection.

IV. SUMMARY

There are two major backgrounds in the LHCf experiment , these are the beam pipe background and the beam&gas background.

About the beam pipe background, these are reduced by the energy of the trigger threshold level. At the threshold level of 150MeV, the background to signal ratio can be reduced to $1.2\,\%$. Because these background events concentrate in the lowest energy, the effect of the beam pipe background is negligible in the final LHCf analysis. This is a robust result because the background to signal ratio has a weak dependence on the threshold level.

About the beam&gas background , We confirmed that it is reduced to $1/100$ by the coincidence detection between the calorimeter & the Front Counter. Additionally, by using the the Front Counters for coincidence, $60\,\%$ of the single side events can survive and we can minimize the bias of coincidence in the analysis.

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