A method based on transverse energy balance of jets for selection of direct photons and fragmentation photons in high energy pp collisions

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Abstract

Direct photons are important probes in high energy collisions. They play an important role in determining the parton distribution function directly inside a proton as well as the nature of the matter formed in heavy ion collisions. However fragmentation photons play the role of prominent background in identifying the direct photons. In the present work we developed a new method based on the transverse energy balance of jets for enrichment of direct photon candidates in pp collisions. This method can reject 35% of the background photons (fragmentation) which can not be suppressed by isolation. Efficiency of detection of direct photon decrease by 10% in the method.

Key words: fragmentation photon, direct photon, isolation cut

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1 Introduction

Direct photons in p-p collisions are very important in determining the parton distribution function inside a nucleus. Since it gives direct control to the parton kinematics, precise measurement of intrinsic transverse momentum of partons can be made. Measurements of yields of direct photons can also be used to compare with the pQCD predictions. When one considers the detection of direct photons, the task at high energies e.g, RHIC and LHC become
quite difficult due to the presence of other sources of photons, acting as background to the direct photons. Direct photons, originated from two basic interactions e.g., $q\bar{q} \rightarrow g\gamma$ and $qg \rightarrow q\gamma$ are very important observables in high energy collisions (1). Main sources of background photons are from hadronic decays and the fragmentation of partons. Some of the processes giving fragmentation photons are $qg \rightarrow g(q\gamma)$ and $qg \rightarrow q(g\gamma)$, even dominating in higher order due to collinear singularity. It has been shown that the yields of these photons are significant at relatively large $\sqrt{s}$. e.g., at $\sqrt{s} = 540$ GeV (2)(3), at RHIC energies and at LHC energies (4)(5). However, theoretically there are rather large uncertainty in the estimation of the yield of fragmentation photons (6), thereby making the measurement of fragmentation photons at pp collisions very important. This will enable to set a reference for AA collisions, where direct photons can be used to calibrate the jets and thereby allowing more precise analysis of jet quenching. Recently at RHIC, efforts are made to measure fragmentation photons (7).

For the measurement of direct photons, various methods (e.g., shower shape) are employed to identify and estimate decay photons (e.g., for $\pi^0$, $\eta$). Apart from these, the method being used extensively for identifying the direct photons is by the use of isolation cuts, since unlike direct photons, the fragmented photons carry charge particles as a part of jet. Hence the isolation cut is quite effective in rejecting the decay and fragmentation photons for most of the cases. But this cut is not very effective in rejecting fragmentation photons when they share most of the parton’s energy and appear like direct photons. It has been demonstrated extensively for the case of ALICE experiment (8) that all the methods mentioned earlier will enrich the photon sample. However no special effort is made for the rejection of fragmentation photons. It has been found that the fragmentation photons at LHC energies can be removed at best by 55% by the method of isolation.

In this letter we are presenting a technique based on the transverse energy of the away side jets relative to the detected photon for discrimination of direct and fragmentation photons. For fragmentation photons, the ratio of the photons transverse energy to the jet transverse energy likely to differ from the ratio obtained for direct photons. In the present method this property is used for the enrichment of photon samples.

The paper is organized as follows, in section-2, we discuss the methods in detail, simulation procedure, data set used and results are discussed in section-3. In section-4 we discuss the applicability of the method.
2 Method based on transverse energy balance of jets

Direct photons originate from two basic processes: (i) annihilation of quarks \( f \bar{f} \rightarrow g \gamma \) and by (ii) Compton scattering \( fg \rightarrow f\gamma \) (where \( f \) may be u, d, c, s, t, b and their anti-pairs). On the other hand fragmentation photons are originated by the process of fragmentation of partons into colorless particles (iii) \( f_1 f \rightarrow (f, \gamma_{frag}) f \), where \( \gamma_{frag} \) is the fragmentation photon originating from the parton \( f_1 \).

For the cases (i) and (ii), the transverse energy of the photon is equal to that of the other parton (\( f/g \)), i.e., \( E_{T,\gamma_{dir}} = E_{T,f/g} \). In contrary, for the case (iii), the transverse energy of photon is always less than that of the parton \( f \), i.e., \( E_{T,\gamma_{frag}} < E_{T,f} \). From the experiments we do not get the partons but the jets of particles fragmented from the parton. Hence in present method we have calculated \( E_T \) of jet by summing over all charged particles around the leading hadron within a specific phase space in \( \eta \) and \( \phi \). After studying the jet topology on transverse plane, we have found that jets fragments, on away side may not have unidirectional structure in a cone, it might even be visualized as two jets as shown in Fig.1. It should be noted that, as this is obtained from a limited phase space, calculated \( E_T \) here might not represent the total jet energy, but the parameter based on this \( E_T \), discussed later has the property of discrimination of direct and fragmentation photons. In case of pp collisions, it is expected that the background underlying the jet is not significant compared to heavy ion collisions.

For this work, we have used PYTHIA (6.214) as event generator. Current study is performed for the LHC energy (pp at \( \sqrt{s} = 14 \) TeV). We have generated direct and fragmentation photon samples in the \( p_T \) ranges 10 - 500 GeV. Two sources of photons are studied separately keeping the spectra as obtained from the event generator. No weightings are done for relative contribution of two sources of photons. We have taken a coverage of photon detector as \( |\eta| \geq 0.12 \).
and $220 \leq \phi \leq 340$, and charge particle detector as $|\eta| \leq 1$ with full azimuthal coverage. This coverage is used for the detectors in ALICE for the detection of photons and charge particles (9). In the definition of away-side regions we have taken two leading hadrons $h_1, h_2$ (Fig.1) such that $|\phi_{h_1} - \phi_{h_2}| > 1$ rad. We calculated summed transverse energies as follows:

$$E_{T_1} = \sum_{i=\pi^\pm(\phi>\phi_{h_1}+1rad)}^{\phi<\phi_{h_1}+1rad} E_{T_i}$$

(1)

$$E_{T_2} = \sum_{i=\pi^\pm(\phi>\phi_{h_2}+1rad)}^{\phi<\phi_{h_2}+1rad} E_{T_i}$$

(2)

If $E_{T_1} > E_{T_2}$, we used $E_T = E_{T_1}$, else we have assigned $E_T = E_{T_2}$. We then extracted the discriminating parameter, ‘f’ = $E_{T,\gamma}/E_T$. It is expected that ‘f’ > 1 for direct $\gamma$ and ‘f’ < 1 for fragmentation photons. Fig.2 shows the distribution of ‘f’ for the direct photons and the fragmentation photons clearly demonstrating the possibilities of using this variable for discriminating two sources of photons. There are cases where deviations occur from this expectation because it might not be possible to collect significant amount of away-side jet energy since the jet energy may spread beyond $|\eta| \leq 1$ and background from the underlying events might play a role. For the results presented here, we use ‘f’ as the parameter for enrichment of direct photon samples. It should be noted that by increasing the coverage of photon detectors, we can increase the statistics, but discriminating power will not change significantly.

Fig. 2. Distribution of ‘f’ for direct and fragmentation photons.
3 Simulation and results

In current approach we present the fractions of direct and fragmentation photons rejected after the application of isolation cut and f-cut, first separately and then both applied sequentially. Simulated data samples consists of direct photons ($\gamma$− jet) events, fragmentation photons from jet-jet in the detector coverage mentioned earlier. Other set of criteria e.g. shower shape, are not studied here as it depends strongly on detector properties. It is expected that, these will enrich the photon samples even further.

Events are passed through varying isolation radii, $R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$ with various thresholds in transverse momentum ($p_T$) on associated particles, where $\Delta \eta$ and $\Delta \phi$ are the separation of charged particles from the triggered photon in $\eta$ and $\phi$ respectively. The results of isolation alone for fragmentation and

![Fraction of fragmentation photons rejected after isolation cut.](image1)

![Fraction of direct photons rejected after isolation cut.](image2)
direct photons are shown in Fig.3 and in Fig.4 respectively. We have plotted the fraction of fragmented and direct photons rejected for different isolation radii and for different $p_T$ thresholds on associated particles. It is seen that for $\Delta R=0.4$ and $p_{T,\text{threshold}}$ (associated particles) = 1 GeV, $\sim 55\%$ of the fragmentation photons are rejected and $\sim 10\%$ of the direct photons are lost due to the isolation criteria.

The results for the application of ‘f’ cut alone is shown in fig.5 by solid line. The dashed lines show the result on ‘f’ cuts on the photons which can not be rejected by isolation cuts. The percentage of rejection for both the cases with the variation of ‘f’ values are as follows:

1. The solid curve shows that only ‘f’ cut alone can reject fragmentation photons in the range of 50-80%.
2. The curve with filled points shows the direct photon rejection vary from 10-60%.
3. The curve with open cross marks shows the rejection efficiency of the fragmentation photons which can not be removed by isolation cuts. We have applied ‘f’ cuts for R=0.4 and $p_{T,\text{associated}} > 1$ GeV. As shown in the dashed curve (cross markers) upto 70% of non-isolated fragmentation photon can be rejected by this cut.

The rejection of direct photons is always less compared to that of the the fragmentation photons. Above some ‘f’ value, two cases become parallel, suggesting little increase in purity of direct photon samples, while not rejecting direct photons appreciably. For $f = 1$ cut, $\sim 35\%$ of the non-isolated fragmen-

Fig. 5. Fraction of non-isolated fragmentation (open cross markers) and direct (filled rectangular markers) photons rejected with $p_{T,\text{associated}} > 1$ GeV and for various ‘f’ values after isolation cut. Solid curve shows the rejection fraction for incident fragmentation photons with ‘f-cut’ alone.
tation photons can be removed in the new approach at the cost of 10% loss of the direct photons. The performance of ‘f’ cut is dependent on the fraction of jet energy carried by the fragmentation photon. The study has been made at $\sqrt{s} = 200$ GeV with $p_T$ of fragmentation photons above 4 GeV and jet $p_T \geq 10$ GeV. In Fig.6 we show the variation of rejection efficiency in isolation method and f-cut method with varying fraction of jet energy carried by the fragmentation photon. It is clear from Fig.6 that for the fragmentation photons carrying larger fraction of jet energy, identification efficiency decreases and any of the methods perform similarly for direct and fragmentation photons.

![Graph](image_url)

Fig. 6. Rejection efficiency of fragmentation photons as a function of the fraction of jet energy carried by the fragmentation photon.

4 Summary and Discussions

Based on the differences in jet topology for direct photons and fragmentation photons, we have developed a method to enrich direct photon sample further to the result obtained for isolation cut. The method is based on the transverse energy balance of near and away side jets for two sources of photons. If we consider the role of the fragmentation photon in deciding the purity of direct photon detection assuming that the decay photons are completely rejected, the ratio of yields of direct to fragmentation plays an important role. At LHC energy, for pp collisions, if we take the ratio as 1 in the $p_T$ region we are looking for we obtain $\sim 50\%$ fragmentation photons rejected due to isolation cut and 40% non-isolated fragmented photon rejected by ‘f’ cut at the cost of 10% direct photon loss. We can estimate that the overall purity of direct
photon increases from 66% to 75%.

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