Photon reconstruction and identification in heavy ion collisions with the CMS detector

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Abstract. Measurement of isolated photon gives possibility to constrain the nuclear parton distribution functions (nPDF). Isolated photon is also the clear tag in photon-jet channel for studying in-medium modifications of fragmentation functions of parton initiated jets. The performance of isolated photon reconstruction and identification has been studied in PbPb collisions at $\sqrt{s}$ = 5.02 TeV. Trigger, reconstruction and isolation efficiencies are measured in PYTHIA+HYDJET Monte-Carlo simulation. We describe signal template method to determine the purity of isolated photons.

1 Introduction

Prompt photons coming from the primary vertex of the high energy hadron collisions are unaffected by the strongly interacting medium produced in the reaction. Prompt photons are the 'clean' probes of the initial state of the collision and play key roles in better understanding the Quark-Gluon Plasma (QGP). Isolated photons includes prompt photons and collinear fragmentation photons of a parton producing large transverse momentum. The performance of reconstruction and identification of isolated photons has been studied at 5.02 TeV centre of mass energy with 2015 heavy ion collisions data collected by the CMS detector and PYTHIA+HYDJET Monte Carlo simulation. In this analysis, isolted photon performances has been studied with respect to its transverse momentum and centrality, which is defined by the impact parameter b. Experimentally, centrality is expressed as a percentage of the total nuclear interaction cross-section.

2 Efficiency

2.1 Trigger Efficiency

Figure 1 shows trigger efficiency for different photon threshold(left) and reconstructed photon spectra coming from all the photon trigger combination without isolation condition(right). All trigger efficiencies are over 99 % and have sharp turn-on feature for each threshold.

2.2 Reconstruction Efficiency

Reconstruction efficiency is the fraction of reconstructed photons in generated photons without isolation condition as shown in Figure 2 left panel. There is no centrality dependence for the reconstruction efficiency for all p_T region. Reconstruction efficiency is over 98 % in all centrality and p_T region.
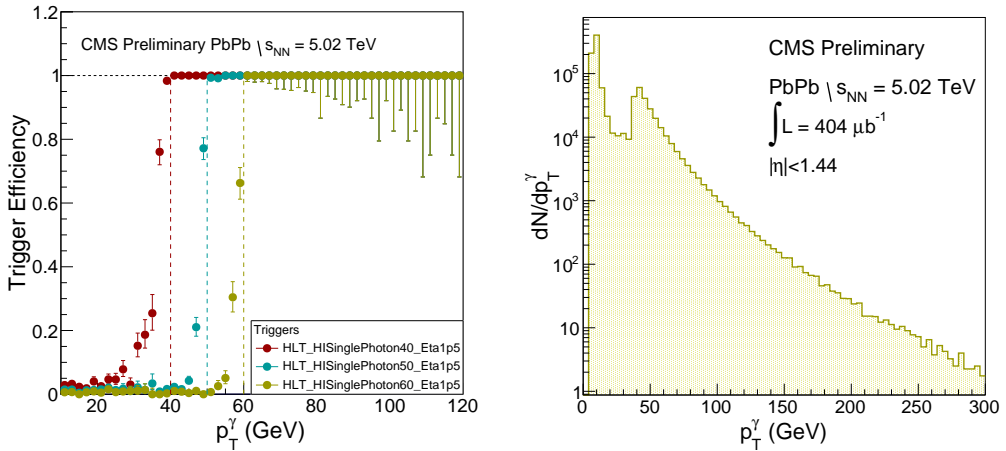
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Figure 1. Photon trigger efficiency in PbPb data as a function of the reconstructed E_T (left), computed using a minimum bias data sample. It shows that for photons with an $E_T > 40$ GeV/c the trigger was nearly 100% efficient. Reconstructed photon spectra as a function of p_T (right) have been measured without isolation condition.

2.3 Isolation Efficiency

Isolation Efficiency is defined as reconstructed photons passing isolation selection in all reconstructed photons. Table 1 summarizes the isolated photon selections.

Isolation variable 'sumIso' is defined as energy sum in an R=0.4 cone around photon candidates, which is tracker E_T + ecal E_T + hcal E_T. SumIso condition selects isolated photons.

The H/E ratio is defined as the fraction of hadronic energy to the electromagnetic energy inside a cone of $\Delta R = 0.15$ which is computed from the energy deposition in ECAL and HCAL. This variable is used to reject candidates originating from jets, which carry not only electromagnetic energy but also hadronic energy. In this analysis, the H/E ratio of the photon candidates is required to be smaller than 0.1 in order to reject candidates originating from jets.

The $\sigma_{\eta\eta}$ characterizes the shower shape in the η direction which is defined as:

$$\sigma^2_{i\eta i\eta} = \frac{\sum_i^{5\times5} w_i(\eta_i - \eta_{5\times5})^2}{\sum_i^{5\times5} w_i}, w_i = \max(0, c + \ln\frac{E_i}{E_{5\times5}}),$$ (1)

where E_i and η_i are the energy and pseudorapidity of the ith crystal within the 5×5 electromagnetic cluster. $E_{5\times5}$ and $\eta_{5\times5}$ are the energy and averaged η of the 5×5 crystals. The value of c is a constant which was set to 4.7 in the pp studies and is effectively a cutoff on the crystal energy. The isolated photon candidates tend to have smaller $\sigma_{i\eta i\eta}$ while hadrons and decay photon from π^0s tend to have larger $\sigma_{i\eta i\eta}$.[1]

Isolation efficiency for the signal and the background are shown in Figure 2 right panel for different centrality bins. Over 80 % to 95 % of background photons are rejected by isolation condition according to photon p_T. These background photons are mainly decay photons from neutral meson such as π^0 and η and also non-isolated prompt and fragmentation photons such as jets. Isolation efficiency for the signal depends on centrality. It decreases with increasing centrality and decreasing p_T. But, isolation efficiency for the background has no strong dependence on the centrality.

Table 1. Isolated photon selection

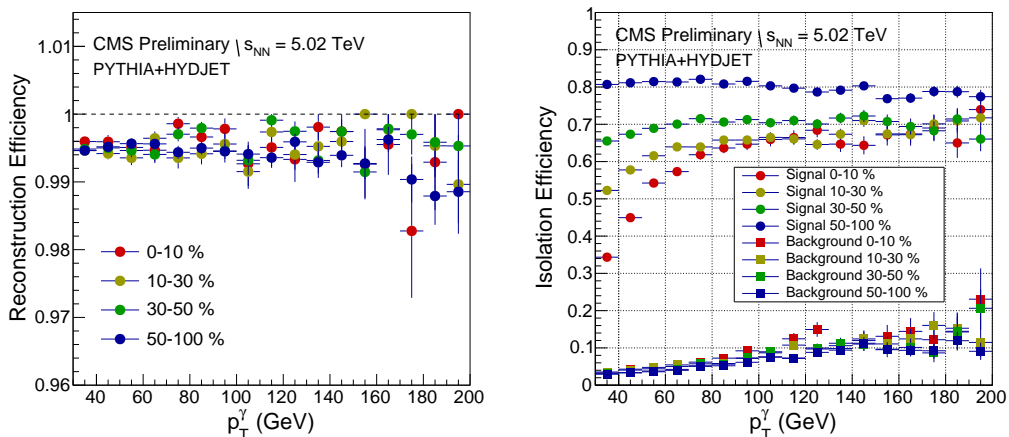| Isolated photon selection |
|---|
| H/E < 0.1 |
| SumIso < 1 GeV |
| $\sigma_{i\eta i\eta} < 0.01$ |

Figure 2. Reconstruction efficiency (left) and isolation efficiency (right) as a function of reconstructed photon p_T measured with PYTHIA+HYDJET samples. Different colors represent different centrality range.

3 Purity

The selection criteria described above yield a relatively pure sample of isolated photons. Yet, there are still non-prompt photons, such as those from an isolated π^0 carrying a large fraction of the parent fragmenting parton energy, which can pass the isolation cuts. The fraction of those remaining backgrounds are statistically calculated using a two-component fit of the shape of the electromagnetic shower in ECAL ($\sigma_{i\eta i\eta}$), called the Template method.

A template is defined as the probability distribution function of $\sigma_{i\eta i\eta}$ of either pure photons (signal template) or pure background (e.g. π^0, η) (background template). The signal template was obtained from MC photon samples (PYTHIA+HYDJET for PbPb or PYTHIA for pp), and the background template was obtained from data in a sumIso sideband (10 GeV< SumIso < 20 GeV) where the background is enriched. The yield of signal photons is estimated with a binned maximum likelihood fit to the $\sigma_{i\eta i\eta}$ distribution of data with the signal and background templates. The purity is defined as the fraction of photons with $\sigma_{i\eta i\eta} < 0.01$ (chosen to maximize the purity value) which are accounted for by the signal template.[1]

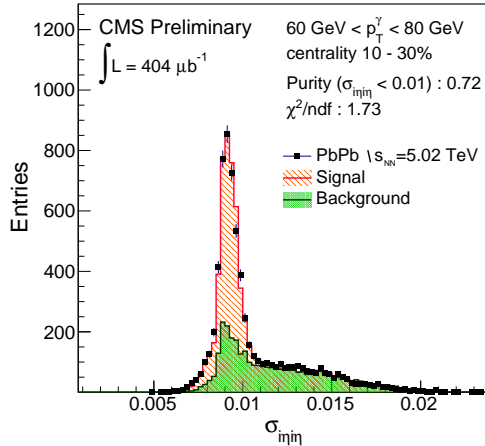An example of the template fitting method is shown in Figure 3

Figure 3. The shower shape variable ($\sigma_{i\eta i\eta}$) of photons from mid-central (10-30%) PbPb collisions. The black points are PbPb data, the red histogram is the signal template from PYTHIA+HYDJET, and the green histogram is the background template from a non-isolated data sideband. The purity is defined as the fraction of isolated photons in the signal region $\sigma_{i\eta i\eta}$< 0.01.

4 Summary

Reconstruction and identification of isolated photons have been developed in heavy ion collisions from the data collected during run 2 CMS experiment and PYTHIA+HYDJET Monte-carlo simulation. We presented high trigger and reconstruction efficiencies. Isolation condition is optimized to maximize the yield of prompt photon and to reject background photons from neutral meson decay. Isolated photon measurement will give a better understanding of strongly interacting medium in heavy ion collisions.

References

[1] CMS collaboration, "Photon-Jet correlations in PbPb and pp collisions at center of mass energy 5.02 TeV", CMS Physics Analysis Summary CMS-PAS-HIN-16-002, CERN (2016)