Determination of $\gamma^{\text{direct}}/\pi^0$ using photon-charge particle correlation measurement in high energy heavy ion and pp collisions

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Abstract

A method has been proposed for the determination of $\gamma$ to $\pi^0$ ratio in high energy pp and nucleus-nucleus collisions at large transverse momentum ($p_T$). In photon measuring device, it is proposed that shower shape analysis is made to select only cases with wide showers. These candidates come mostly from $\pi^0$. Correlation is measured between those photon candidates as trigger particles and associated charged particles above selected $p_T$. The ratio of yields of near and far angle correlation peaks for $\pi^0$ events is compared with correlation peaks from other set of events where trigger particle contains photons for direct-photon jets alongwith $\pi^0$. The comparative study in reduction of yield of near angle peak is used to extract photon fraction.

Key words: correlation, photon, jets

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1 Introduction

In high energy heavy ion collisions photons play a very important role in understanding the created system. Special attentions are made to detect photons at various $p_T$ [1]. Depending on the physics requirement, energy and position resolution and energy reach of detected photons vary. At very high collision energy e.g at LHC a large fraction of photons are expected to be produced as $\gamma$-jet. Several observations are made at RHIC where leading particle spectra are found to be quenched in high energy heavy ion collision. One of the possible explanation is loss of energy of partons forming jets while passing through dense matter [2]. It is however impossible to reconstruct full jet in AA collisions because of large background due to soft particles. One of the ways calibration of jets can be done is by detecting photons from $\gamma$-jet events, where photons do not loose energy. There are several predictions made on the cross-section of produced large $p_T$ photons where the fraction of photons produced are expected to go up with increase in
collision energy. On the other hand with increase in photon $p_T$, the separation of photons from $\pi^0$ becomes difficult as the angular separation between the decay photons become small and likely to deposit energy in same detector cell. Efforts are made to reduce the cell-size of the detector, so that some handles can be made on photon-$\pi^0$ discrimination based on shower shape parameter. But even with reasonable granularity, photon samples contain good fraction of $\pi^0$ [3]. In these methods a threshold is applied on shower shape below which samples are rich in photons and at large shower-size the samples contain mostly $\pi^0$. These $\pi^0$-rich samples are usually ignored and efforts are made to reduce the fraction of $\pi^0$ contamination in photon-rich sample. It is however possible to take these $\pi^0$-rich sample as reference and some $\pi^0$-specific property can be used to estimate $\gamma$ to $\pi^0$ ratio in photon-rich sample. Overall $\gamma/\pi^0$ can be obtained taking $\gamma/\pi^0$ from various subset of events.

In this paper we propose photon-charged particle azimuthal correlation for $\pi^0$-rich events as a reference for such estimation. Decay photons from $\pi^0$ when correlated with associated charged particles give two peak structures characteristics of jets. However, direct photons coming out as a part of photon jet will have near angle peak absent and far-angle peak will look like those of $\pi^0$-jet for similar jet energy. This property can be used to estimate photon-$\pi^0$ relative population.

2 Proposal

We propose that we take photons with very large shower size as trigger particles where samples contain mostly $\pi^0$ events and find the azimuthal correlation with respect to the associated charged particles above some $p_T$. We then measure the ratio ($R_{\text{large}}$) of the yields of two characteristic correlation peaks by measuring the area under each correlation peak. Similar correlation functions are measured for photons samples with smaller shower size where data set contains $\gamma^{\text{direct}}$ with varying fraction. Here also we take the ratio of near and far angle yield ($R_{\text{small}}$). Comparison of $R_{\text{large}}$ with $R_{\text{small}}$ will give the estimate of $\gamma^{\text{direct}}/\pi^0$ for that set of events. This exercise can be carried out for different $p_T$ bins of trigger particles to obtain $p_T$ spectra of $\gamma/\pi^0$.

3 Simulation

Simulation is performed using HIJING [4] event generator in which hard-scattering has been implemented with detailed jet fragmentation. No particular detector configuration is used in this simulation, so it is implied that all particles produced in the events will be detected. We generated two types of events at LHC energy for pp collisions. One type of events select only those cases having at least one photon coming out from direct photon and other type of events contain at least one high-$p_T$ $\pi^0$ leading particle. Lowest threshold
of \( p_T \) for trigger photon used in this simulation is 8.5 GeV/c. Correlation function is then constructed taking photons as trigger particle and charged particles with \( p_T^{\text{associated}} > 1 \) GeV/c as associated particle. Fig.1 shows the correlation function for 'direct photon' events with \( p_T^{\text{associated}} > 1 \) GeV/c. Fig 2 shows similar correlation function for \( \pi^0 \) events. It is seen while in case of \( \pi^0 \) events two correlations peaks are clearly seen, in case of direct-photon events, near angle peak is absent. Large error bars in 'direct-photon' cases reflect lack of statistics. In all correlation functions we measure \((1/N_{\text{trig}})dN/d\phi\), where \( N_{\text{trig}} \) is the number of trigger particle and dN corresponds to number of pairs in various \( \Delta\phi \) bin. No correction is made on efficiency of associated charged particles.

Two peaks are then fitted with gaussian in the range of \( \delta\phi = -1 \) to 1 radians and \( \delta\phi \) from 2.0 to 4.5 radians and yields are determined by obtaining the area under each peak. In order to simulate correlation function where \( \pi^0 \)-jets are mixed with \( \gamma \)-jets, we superposed direct-photon correlation function with \( \pi^0 \)-correlation function with different \( \gamma/\pi^0 \) ratios. Proper weightage is taken to obtain the resultant correlation function. Fig. 3 shows the variation of (near angle yield)/(far angle yield) for various \( \gamma \)-jet fraction in mixed sample. It is seen when entire data sample contains \( \gamma \)-jet events, ratio becomes close to zero, and for various \( \pi^0 \) fraction ratio increases reaching a value which depends on mean transverse energy of jets and on associated particle threshold. It is clearly seen that this yield ratio is sensitive to \( \gamma \) to \( \pi^0 \) ratio. In order to simulate the sensitivity in case of PbPb collisions, we have taken one sample PbPb event generated from Hijing event generator. Two types of pp events are then

Fig. 1. Azimuthal correlation for direct-photon events in pp collision at LHC energy. Photons with highest \( p_T \) in the event is taken as trigger particle and charged particles with \( p_T^{\text{associated}} > 1 \) GeV/c is taken as associated particles.

Fig. 2. Azimuthal correlation for \( \pi^0 \) events in pp collision at LHC energy. Photons with highest \( p_T \) in the event is taken as trigger particle and charged particles with \( p_T^{\text{associated}} > 1 \) GeV/c is taken as associated particles.
Fig. 3. Ratio of near and far angle yield for various γ fraction in the event samples where correlation function for direct-photon events are mixed with correlation function of π⁰ leading particle events.

superposed on this PbPb event. Fig. 4 (top) shows the correlation function for the π⁰-jet events superposed on PbPb event for \( p_T^{\text{trigger}} > 8.5 \) GeV/c. As expected the background of the correlation function increases drastically in presence of PbPb event. We then estimated the background by taking average of correlation function in the region of \( \Delta \phi \) from 1 to 2 radians. Background was then subtracted to obtain final correlation function (fig. 4(bottom)) which was then fitted with gaussians to obtain near and far angle correlation function yield. The peak heights in background-subtracted correlation function differ compared to pp case. This can be attributed to the background in PbPb events where there are cases with large background not contributing to the correlation peak corresponding to the trigger particle. But the method based on relative yield ratio should not be affected by this background effect. We therefore made all further investigations using background-subtracted correlation function. Following the procedure as adopted for pp collision case, ratio is found for varying γ-fraction. It is observed that in case of correlation function in presence of heavy ion events also we can use this method to obtain \( \gamma/\pi^0 \). From the slope in two cases however it is seen that slope is steeper in pp case compared to PbPb case.


It is clearly seen from the results of the simulation that more the sample becomes rich in photon, better sensitive is the method in determining $\gamma/\pi^0$. Photon-rich samples can be obtained by two steps (a) using this currently proposed method after the use of all possible discriminatory properties available (b) we expect increase in photon fraction due to the quenching of $\pi^0$. There is however a possibility of mismatch for $\pi^0$-jet some fraction of energy going to the associated particle.

We have tried to estimate the effect of $p_T^{\text{associated}}$, as it might be necessary to use higher threshold on $p_T^{\text{associated}}$ for PbPb central events where background will be large. We have not made detailed estimation about the threshold of $E_T$ of trigger photons and corresponding $p_T^{\text{associated}}$ where correlation function can be meaningful, but we have taken events with $E_T$ of trigger particle as 45-55 GeV/c and studied with three different $p_T^{\text{associated}}$ e.g. 1GeV/c, 2GeV/c and 4 GeV/c. For this $E_T$ correlation peaks are clearly visible. Fig.6 shows the ratio with different $\pi^0$ fraction, normalized with the cases where photon fraction is absent. It is seen that for lower $p_T^{\text{associated}}$, the ratio changes faster compared to higher $p_T^{\text{associated}}$. One of the possible reasons could be with higher $p_T^{\text{associated}}$ full jet will not be accepted. So it might be suggested to use as low $p_T^{\text{threshold}}$ as far as possible.

This approach are expected to be useful in extracting the spectra of photons after the estimation of $\pi^0$ production using $\pi^0$-rich sample. This estimation of the sensitivity of the method however should be made using realistic photon production rate at LHC energies.

In summary, we have proposed a method for extraction of $\gamma/\pi^0$ for heavy ion collisions at LHC energies using photon-charged correlation. It
is seen that the yield ratio of near and far angle correlation peaks is sensitive to $\gamma/\pi^0$ in the sample of events. It is also seen that this method is more effective for lower $p_T^{\text{associated}}$.

References

[1] S. S. Adler et. al., nucl-ex/0503003

[2] K. Adcox et. al., Phy. Rev. Lett 88, 022301 (2002), C. Adler et. al., Phy. Rev. Lett 89, 0202301 (2002), S. S. Adler et. al., Phy. Rev. Lett 91, 072301 (2003)

[3] PHOS technical design Report, ALICE collaboration.

[4] X-N. Wang & M. Guylassy, Phys. Rev. D 44, 3501 (1991)