ISSN 2616-7433 Vol. 1, Issue 07: 1-9, DOI: 10.25236/FSST.2019.010701

Study of jet quenching with isolated photon+jet correlations in pbpb and pp collisions at $\sqrt{S_{NN}}$ =5.02 tev

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ABSTRACT. *In pp and PbPb collisions, azimuthal angle and transverse momentum(PT) distributions of jetphoton pairs are recorded with the CMS detector at the CERN LHC at* $\sqrt{S_{NN}}$ *=5.02 TeV. The modeling technique is based on the Monte Carlo Glauber Model, in which the nucleons are randomlydistributed in the nuclei. Distribution of the ratio* p_T^{jet} / p_T^{γ} *is simulated at different centrality intervals, and the reconstructed jets have to pass the cut of* $\eta^{jet} < 1.6$ *and* $p_T^{jet} > 30$ *GeV/c. Centralitypercentile can be defined by binning the distribution with fractions regarding the total integral. The results from the simulation show that the Monte Carlo Glauber Model is consistent with the resultsof the CMS experimental data in PbPb and pp collisions at* $\sqrt{S_{NN}}$ *=5.02 TeV.*

KEYWORDS*: Quark Gluon Plasma; Jet quenching; Glauber Monte Carlo model*

1. Introduction

In relativistic heavy ion collisions, QGP(quark-gluon plasma), a state of matter predicted by QCD that exists at extremely high temperature and/or density is formed. Jets, which is a group of hadrons that come from the hadronization from quarks in heavy ion collisions, are produced in the collisions interact with the QGP and lose certain amount of energy since they are color charge carriers. This process, named “jet quenching”, provides a probe to determine properties of the hot and dense QGP,

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which has been observed through the measurements of hadrons with high transverse momentum and of jets.

Though electroweak bosons do not interact with the QGP directly, the jets produced can give insights to the properties of QGP since the electroweak boson p_T closelyreflects the initial energy of the associatedparton that fragments into the jet. The parton energy loss mechanisms can be understood through the study of correlations in boson-jet events. In this paper, energy loss ofPbPb collisions is studied by comparing Glauber MonteCarlo model and experimental data.

In this research, the isolated photon that is selectedby the CMS experiment is used. Prompt photon and associated jets are selected by reconstruction with a coneof specific value of radius. The correlations of isolatedphotons and jets in PbPb and pp collisions are measured at $\sqrt{S_{NN}}$ =5.02 TeV. The azimuthal angle difference $\Delta\phi_{j\gamma} = \left|\phi^{jet} - \phi^{\gamma}\right|$, the p_T ratio $x_{j\gamma} = p^{jet} / p^{\gamma}$ and the average number of associated jets per photon, $r_{j\gamma}$,are presented. In the end, the results from PbPb collisions are compared with those from pp collisions, withsmeared pp data serving as the reference.

2. Analysis methodology

2.1 Monte carlo glauber model

To calculate geometric quantities of ultra-relativistic heavy ion collisions, such as the impact parameter (b), number of participating nucleons (N_{part}) and number of binary nucleon-nucleon collisions (*Ncoll*), Glauber Models are developed to perform calculations on experimental data (for a complete review, see [2][3]). Basically, Glauber Models involves two approaches-the optical-limit approximation and the

Monte Carlo approach[3]. In this paper, the modeling technique is based on the Monte Carlo Glauber Model, in which the nucleons are randomly distributed in the nuclei.

The nucleons are stochastically distributed in three-dimensional coordinates. Then it is assumed that thenucleons move along straight trajectories, which indicatesthat the longitudinal coordinate is irrelevant to the calculations. The impact parameter b is randomly chosen from the distribution.

$$\frac{dN}{db} \propto \mathrm{b} \tag{1}$$

A nucleon-nucleon collision is counted when the distance d between the nucleons satisfies:

$$d \leq \sqrt{\sigma NN / \pi} \tag{2}$$

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where σ_{NN} is the total inelastic nucleon-nucleon cross-section. At CERN LHC, it is expected that σ_{NN} =68mb,corresponding to $\sqrt{S_{NN}}$ =5.02 TeV.[1]Fig.1 qualitativelyvisualizes one example of the collisions with impact parameter b=5fm.

The Glauber Model used in this paper is parametric,which means that the parameters in the model can be adjusted through many iterations to increase the correlationbetween the model and the experimental data. The output of the model is a statistical probability distribution ofrespective geometric parameters. Physical insights intoPbPb collisions can be interpreted from the distributionsthrough comparison with experimental data.

2.2 Centrality

In events with large b, i.e., peripheral collisions, weexpect large nuclear overlap and a large number of participants, whereas in events with small b, i.e., central

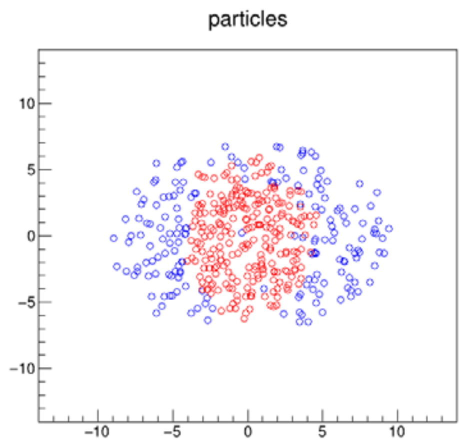

Figure.1 A illustrative example of the PbPb collision simulated in the Monte Carlo Glauber Model drawn in two-dimensional coordinate.

Collisions, we expect small nuclear overlap and a small number of participants. Therefore, it is assumed that the impact parameter b of the collisions is monotonically related to the number of participating nucleons [1]. From the distribution of N_{part} , centrality percentile can be defined by binning the distribution with fractions regarding the total integral[3]. The N_{part} distribution ofthe Glauber Model in this research is shown in Fig.2.

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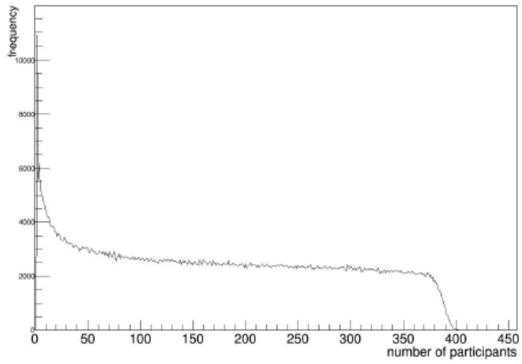

Figure. 2 The distribution of number of participants N_{part} . Impact parameter b used in each trial is randomly assigned.

After a large number (10000 in this case) of Monte Carlo trials, for each of the centrality intervals, the mean value of participants (i.e., $< N_{part} >$) is calculated (Tab.1).

Table 1 Average values of the number of participatingnucleons$< N_{part} >$for centrality intervals used in analysis ofthe paper

Centrality	$< N_{part} >$
0 - 10%	340-416
10-30%	249-340
30-50%	167-249
50-100%	0-167

2.3 Jet path length

In order to calculate the energy loss during jet-quenching, algorithm for jet path length is implemented

in the Glauber Model. In the algorithm, the paths in QGP are denoted by L_1 and L_2, which are calculatedas the number of participating nucleons of which the jetencounters in hard scattering, respectively.

The algorithm is aimed to show the distribution ofthe relationship of L_1 and L_2in PbPb collisions. Toachieve this outcome, the algorithm generates jets for every nucleon-nucleon collision with random azimuthalangle $\Delta\phi$, and the number of collided nucleons crossedby each of the jets is counted. The results for variouscentrality intervals are presented in Fig.3.

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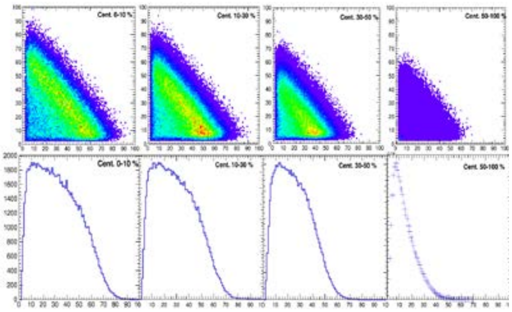

Figure.3 The centrality dependence of L_1 and L_2 for PbPbcollision(top). The color of the bins represents the density ofjets with respective path lengths.The centrality dependenceof the distribution of L_1 for PbPb collision(bottom)

Since the energy loss of the jets during interactionswith the QGP cannot be directly measured from the experiment, energy loss formula needs to be applied to themodel.

Certain parameters are considered to be related to theenergy loss in jet-quenching: and jet path length, as discussed above. Derivations from the order of magnitudeof the jet energy loss infer that the energy loss is proportional to the quadratic of jet path length L. For theGlauber Model used in this paper, the energy loss formula is given by

$$\Delta E = p_T^{jet} - 0.8 \times (\ln(\frac{p_T^{jet}}{p_0}))^2 \times (\frac{L_1}{L_0})^2 \quad (3)$$

Where ρ_0 and L_0 represent the mean value of jet transverse momentum p_T^{jet} and jet path length L, respectively.

Jet reconstruction is done by the CMS particle-flow(PF) algorithm and the anti-k_T algorithm.Reconstructed jets have to pass the cut of $|\eta^{jet}| < 1.6$ and $p_T^{jet} >$ 30*GeV/c*[1].

3. Result

3.1 Centrality dependence

By inputting the values of the several parameters intothe proposed energy loss formula, the centrality dependence of transverse momentum change(equivalent to energy change in magnitude) is calculated. After applyingthe simulated energy change to a set of pp collisions selected by the CMS detector[1], a histogram of PbPb momentum ratio $x_{j\gamma}$ (simulated) can be plotted togetherwith the $x_{j\gamma}$ ratio of

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the original photon-jet momentumfrom pp collision. We can obtain the centrality dependence of $x_{j\gamma}$ and compare it directly to the CMS experimental data [1].

By adjusting the parameters of the energy loss function, the model gradually approaches the experimentaldata. Fig.3 presents the calculations with energy lossformula of:

$$\Delta E = p_T^{jet} - 0.8 \times (\ln(\frac{p_T^{jet}}{10}))^2 \times (\frac{L_1}{12.2})^2 \tag{4}$$

In 50-100% centrality, i.e., the most peripheral collisions,the PbPb distribution corresponds with the pp reference data. As the collisions become more and morecentral(smaller centrality percentile), the PbPb distributions present lower values and smaller integrals. Thistrend is consistent with the Glauber Model expectationsthat as the jet path lengths become larger with morecentral collisions, the energy loss increases.

The $R_{j\gamma}$ distributions, the average number of associated jets per photon, as a function of centrality is shownin Fig.4 with p_T^{γ} interval($p_T^{\gamma} > 60 GeV/c$)In more central collisions, larger suppression of $R_{j\gamma}$ compared to thesmeared pp reference data is observed in p_T^{γ} selection,corresponding to larger energy loss due to interactionwith the QGP.

3.2 PHOTON+JET TRANSVERSE MOMENTUM IMBALANCE

Photon+jet transverse momentum imbalance is calculated with $x_{j\gamma} = p_T^{jet} / p_T^{\gamma}$. In order to subtract the background fluctuations [1], a selection cut of $\triangle\phi_{j\gamma} > 7 /$

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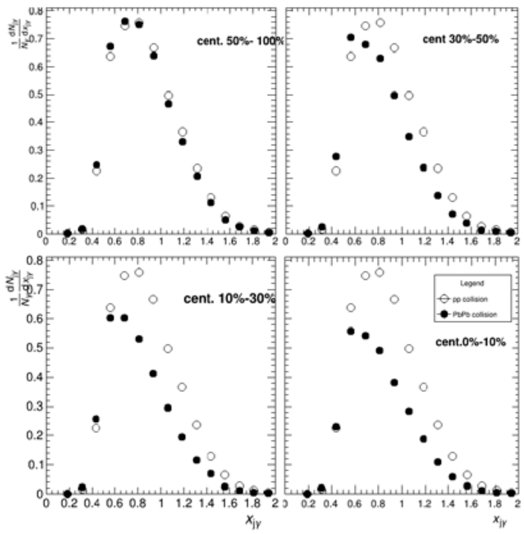

Figure.4 The centrality dependence of $x_{j\gamma}$ *of photon+jet pairs normalized by the number of photons for PbPb (full markers) and smeared pp (open markers) data. (Simulation)*

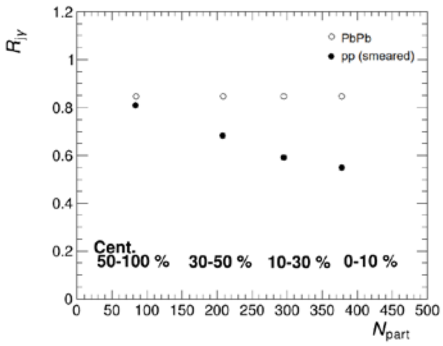

Figure.5 The distribution of $R_{j\gamma}$ *as a function of centrality for* p_T *>60GeV/c. Smeared pp collision data is implemented asreference.*

(8π) is applied. The distributions of $x_{j\gamma}$ with differentcentrality intervals (0-30% and 30-100%) and p_T^{γ} selection cuts in PbPb and pp collisions are shown in Fig.6.In 0-30% centrality, PbPb collisions present relativelystrong modifications with respect to the smeared pp collisions. The distributions shift towards smaller valuesof $x_{j\gamma}$ and smaller total integrals, whereas in less central collisions(30-100% centrality), distributions that are more consistent between PbPb and pp collisions are observed.

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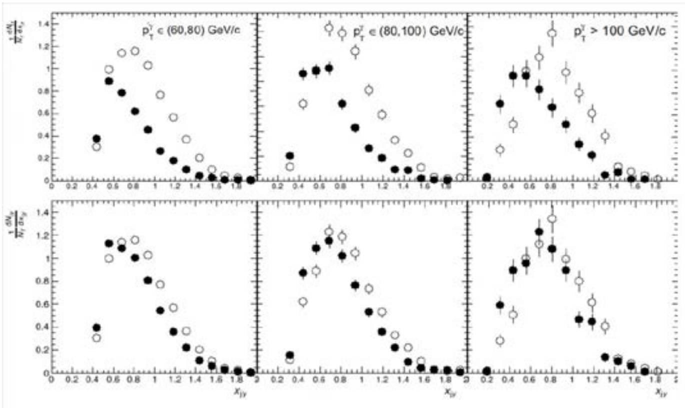

Figure.6 The $x_{j\gamma} = p_T^{jet} / p_T^{\gamma}$ *distributions of PbPb collisions(markers) in 0-30% (top) and 30-100% centrality(bottom) intervals and five* p_T^{γ} *intervals. Smeared pp collision data (markers) is implemented for comparison.*

4. Conclusions

This paper studied the correlations of isolated photons with $p_T^{\gamma} > 40GeV/c$ and $\left|\eta^{jet}\right| < 1.44$ and jets with p_T^{jet} $>30GeV/c$ and $\left|\eta^{jet}\right| < 1.6$ in pp and PbPb collisions at $\sqrt{S_{NN}}$ =5.02 TeV based on the data collected in the CMS experiment. Monte Carlo Glauber Model is used to compare simulation with experimental data and energy loss formula associated with jet path length is implemented. The $x_{j\gamma} = p_T^{jet} / p_T^{\gamma}, < x_{j\gamma} >$ and $Rj\gamma$ of pp and PbPb collisions is studied in different centrality

intervals and in different p_T^{γ} intervals. The difference between PbPb collision data and pp collision data increases as the collisions becomes more central. For intervals with $p_T^{\gamma} > 60GeV$, the values of $R_{j\gamma}$are observed to be lowerthan those of respective pp reference and PbPb collisionstend to have lower $x_{j\gamma}$ and smaller integrals. These results are consistent with the Monte Carlo Glauber Modeland previous study at $\sqrt{S_{NN}}$ =2.76TeV. The results provide new comparisons between Monte Carlo GlauberModel simulation and experimental data from the CMSexperiment with various centrality intervals and differentselection cuts of isolated-photon and jets.

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ISSN 2616-7433 Vol. 1, Issue 07: 1-9, DOI: 10.25236/FSST.2019.010701

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