PROCEEDINGS OF SCIENCE

Jet quenching in heavy-ion collisions with CMS

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The energy loss of fast partons traversing the strongly interacting matter produced in relativistic heavy-ion collisions is one of the most interesting observables to probe the nature of the produced medium. The collisional and radiative energy loss of the partons will modify the fragmentation functions depending on the path length in the medium. In this report, we present a detailed study of complete simulated γ-jet events by the CMS detector at LHC in view of the expected modification of jet fragmentation functions in central collisions at $\sqrt{s_{NN}} = 5.5$ TeV compared to the p+p case. Since the produced prompt photon does not interact strongly with the medium, the initial transverse energy of the fragmentation parton can be related to the photon transverse energy in γ-jet events. This enables us to make precision measurements of the modification of the fragmentation function.

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1. Introduction

One of the key results from the study of high-energy nuclear collisions at the Relativistic Heavy-Ion Collider (RHIC) is the observation of a strong suppression of hadron yields at transverse momenta $p_T > 4$ GeV/c, compared to expectations based on p+p and d+Au collisions at the same collision energies [1]. The extreme magnitude of the suppression effect (up to a factor of 5) makes a quantitative interpretation of the result difficult, as the observed remaining yield of high-p_T hadrons is dominated by emissions from the surface of the collision region and therefore carries little direct information about the medium and the mechanisms of collisional and radiative energy loss of the partons [2, 3]. At LHC energy ($\sqrt{s_{NN}} = 5.5$ TeV), the jet cross sections are large enough to copiously produce high-E_T jets that stick out of the underlying heavy-ion background, such that it will allow a much more detailed study of the jet quenching phenomenon. The collisional and radiative energy loss of the partons as they traverse the medium will modify the fragmentation functions, depending on the path length inside the medium. The boson-tagged (γ, Z)-jet production provides a unique opportunity to study the fragmentation function. Since the produced boson does not interact strongly with the medium, the initial transverse energy of the fragmentation parton (E_T^{jet}) can be related to the photon/Z transverse energy ($E_T^{\gamma/Z}$) in γ/Z-jet events. This will avoid the precise measurement of the absolute E_T^{jet}. Therefore, the jet fragmentation function $1/N_{\text{jets}} dN/d\xi$ can be approximated by using $\xi = \ln E_T^{\gamma/Z}/p_T$ for particles associated with the jet. [4, 5]

In this report, we present the measurement of the jet fragmentation functions for γ-jet events with $E_T^{\gamma} > 70$ GeV with a full simulation and reconstruction by the CMS detector for 0-10% central Pb+Pb collisions.

2. Event Simulation

The studies are performed in two different scenarios of the parton energy loss in Pb+Pb collisions. The "unquenched" scenario, using the PYTHIA event generator [6], assumes that there is no parton energy loss. The "quenched" scenario is generated with the PYQUEN [7] generator, which has been tuned based on the results seen at RHIC, to simulate the parton energy loss effect inside the medium. In both scenarios, the underlying heavy-ion event is modeled by the HYDJET generator [8]. For this study, the 0-10% most central Pb+Pb collisions are selected by the impact parameter of the lead nuclei, yielding an average mid-pseudorapidity density of about 2400 (2200) charged particles in the quenched (unquenched) case. 4000 γ-jet events in the CMS acceptance for $E_T^{\gamma} > 70$ GeV and $|\eta^{\gamma}| < 2$ with $\Delta\phi(\gamma, \text{jet}) > 172^{\circ}$ and about 40000 (125000) QCD background events for the quenched (unquenched) case are simulated. This corresponds to the expected yields for one year of Pb+Pb data taking with an integrated luminosity of 0.5nb^{-1}.

3. Event Reconstruction

Jet reconstruction in heavy-ion using electromagnetic (ECAL) and Hadronic (HCAL) calorimeters in CMS is performed by an iterative cone algorithm with a cone size of $R = 0.5$ in the $\eta - \phi$ plane modified to subtract the underlying soft background on an event-by-event basis [9, 10].

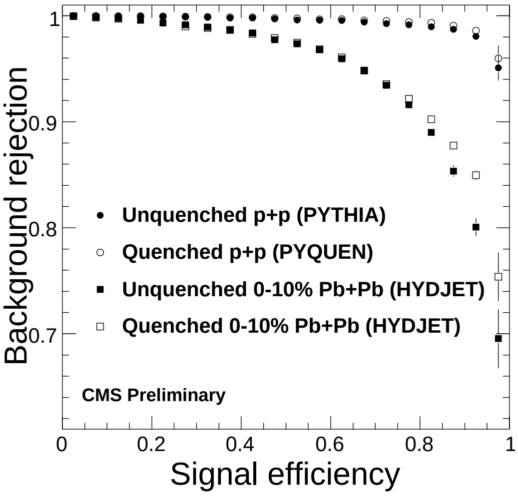

Figure 1: Background rejection versus signal efficiency for the identification of isolated photons in different systems.

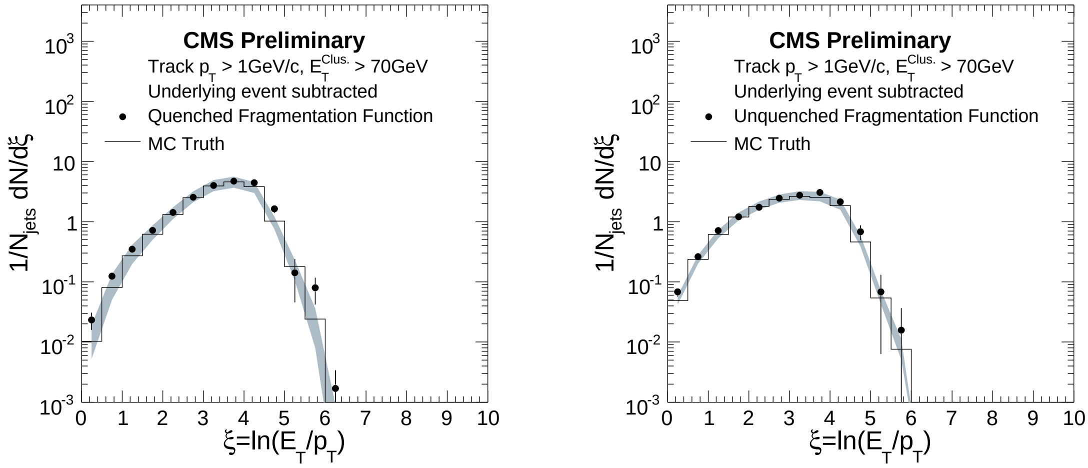

Figure 2: The left(right) panel is the reconstructed quenched(unquenched) fragmentation function compared with the corresponding MC truth fragmentation function.

Charged particles are reconstructed by CMS Silicon Tracking System [11, 13]. The reconstruction algorithm is an extension of the standard tracking algorithm used for p+p and seeds from the three dimensional hits of the silicon pixel detector (which has a geometrical acceptance of 80%) [14]. In the high-multiplicity environment, an algorithmic tracking efficiency of $\sim$ 70% is achieved near mid-rapidity with less than a few percent fake track rate for $P_T > 1$ GeV/c. High-E_T isolated photons are reconstructed from clusters of hits measured in the ECAL using the so-called "Island Clustering Algorithm" [12]. For each photon candidate, the information provided by ECAL cluster shape variables associated with the candidate is examined. Based on these ECAL photon-identification variables and the information from the HCAL and tracker, we determine if a given

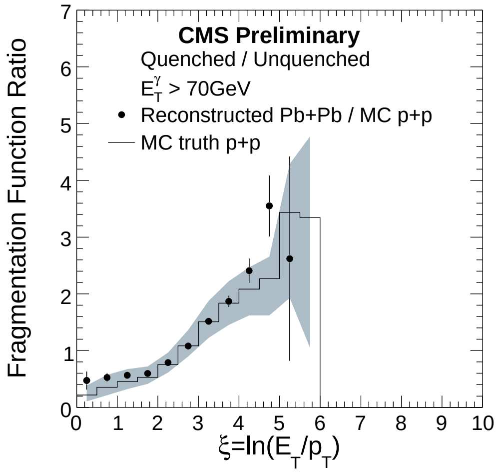

Figure 3: Ratio of the reconstructed quenched fragmentation function(symbols) and MC truth fragmentation functions(line) over unquenched MC truth. The estimated systematic error is represented as the shaded band.

photon candidate is an isolated photon. The combined information of these variables forms a three-dimensional space, in which optimal rectangular cuts are obtained (Fig. 1). We set a working point of 60% signal efficiency for this analysis, which leads to a background rejection of about 96.5% with a signal-to-background ratio of 4.5 for 0-10% central quenched Pb+Pb events. On average, for $E_T > 70$ GeV, the E_T resolution for isolated photon is about 4.5%, and the spatial resolution in η and ϕ is better than 0.005.

4. Results

To construct the fragmentation function, isolated photons with $E_T^\gamma > 70$GeV and $|\eta^\gamma| < 2$ are selected and correlated with the highest E_T^{jet} back-to-back calorimeter jets which $\Delta\phi(\gamma,\mathrm{jet}) > 172^\circ$ is fulfilled. Since we obtain the charged particle information from the tracker, the away-side jet ($R = 0.5$) associated with the photon needs to be contained in the tracker acceptance of $|\eta| < 2.5$. Therefore we require the reconstructed jet axis to be within $|\eta| < 2.0$ to avoid edge effects at the limit of the tracker acceptance. Also, a minimum E_T^{jet} cutoff of 30 GeV is applied in order to ensure that the reconstructed calorimeter jet corresponds to the away-side parton. For each selected γ-jet pair, reconstructed charged particles with $p_T > 1$ GeV/c that lie within the $R = 0.5$ cone size around the reconstructed jet axis are selected. The raw fragmentation function is obtained by using the transverse energy of the photon which is much more precise than the measurement of jet transverse energy. The contribution from the underlying event is estimated by using the momentum distribution of the tracks within a $R = 0.5$ cone perpendicular in the ϕ direction to the reconstructed jet axis and subtracted from the raw distribution. The reconstructed fragmentation functions are compared with the MC truth determined at generator level using the true parton E_T and the direction for the selected particles (Fig. 2). There are four main sources of systematic differences between the reconstructed and true fragmentation functions which are listed below:

1. Photon selection and background contamination (15%)
2. Track finding efficiency correction (10%)
3. Wrong/fake jet matches (10%)
4. Jet finder bias (10-30%, largest contribution in quenched case)

The overall capability to measure the medium-induced modification of jet fragmentation functions in the γ-jet channel can be illustrated by measuring the ratio of the reconstructed quenched fragmentation function to the unquenched fragmentation function(Fig. 3).

In summary, we have demonstrated that γ-jet events can be used to study quantitatively the fragmentation function functions of high-p_T partons inside the medium. For a data set corresponding to one nominal year of CMS Pb+Pb running, the expected statistical and systematic uncertainties should be small enough such that the measurements will be sensitive to the foreseeable changes in the fragmentation functions relative to parton fragmentation in vacuum.

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