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Jet Substructure through Splitting Functions And Mass in pp and PbPb collisions at 5.02 TeV with CMS

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Abstract

We present recent results on measurements of jet substructures using grooming techniques with pp and PbPb data collected with the CMS detector at a center-of-mass energy of 5.02 TeV per nucleon pair. The grooming technique is used to focus on the hard structure of the jet by extracting the two subjets corresponding to the hardest parton splitting. This allows us to study medium-induced gluon emission properties and the evolution of partons through dense QCD matter. The hard jet structure is sensitive to the virtuality evolution of a parton in the medium, as well as the role of (de)coherent gluon emitters. Results and prospects on the transverse momentum balance, mass and angular difference of the two hard subjets over a wide range of jet transverse momentum and various collision centrality selections are discussed.

Keywords: Jet, Heavy Ion Collision, QCD, QGP

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1. Introduction

In heavy ion collisions, hard scattering of partons occurs early in the process. The scattered parton would then travel through a hot and dense QCD medium created by interaction between other nucleons in the collision. The jet quenching [1, 2] effect where the scattered partons interact with the medium and lose energy has been observed first at RHIC [3, 4, 5, 6, 7] and later at the LHC experiments [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18]. The effect can be used as a probe to understand the mechanism with which the parton interacts with the dense QCD medium.

Interaction with the QCD medium could temporarily increase the virtuality of the parton which leads to a different gluon emission probability [19, 20, 21, 22]. It could lead to a modification of the parton splitting function compared to that in vacuum. The scattered parton will in general decrease in virtuality and lose energy while traveling through the medium [23]. The lost energy manifest itself in large angle soft radiation around the jet direction, as well as in the medium.

The use of jet grooming algorithms [24, 25, 26, 27, 28] allows us to remove the contributions from large angle soft radiation of the jet and underlying event activities, and to focus on the hard structure of the jet. We employ the soft drop algorithm [28, 29]. The constituents of each jet are used to build an angular-ordered tree, similar to that of the Cambridge-Aachen jet clustering algorithm [30]. From the root node of the tree

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we examine if the momentum sharing, z_g, between the two sub-jets satisfies the soft drop condition:

$$z_g \equiv \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}} \geq z_{\rm cut}\theta^{\beta},$$

where $p_{T,1}(p_{T,2})$ denote the transverse momentum of the first (second) subjet, and θ is the angular separation between the two subjets. $z_{\rm cut}$ and β are free parameters we can choose for different types of jet grooming. If the soft drop condition is not met, the smaller of the two subjets is discarded and the two subjets of the leading subjet are examined. The algorithm terminates when the condition is met. The angle-independent version of the soft drop algorithm ($\beta = 0$) is used here which has the advantage of being largely insensitive to higher order QCD corrections and allows us to measure the first hard splitting of the jet. The z_g distribution is measured both in PbPb collisions and in pp collisions at the same nucleon pair energy and compared with each other.

2. Analysis and Results

The study is based on 25 $\rm pb^{-1}$ of pp collisions at 5.02 TeV collected in November 2015 and 404 $\mu\rm b^{-1}$ of PbPb collision data at the same nucleon pair energy collected at the end of 2015 by the CMS detector [31]. The average number of collisions per bunch crossing ("pileup") is estimated to be around 1.4 in the pp data set and has a negligible effect on the measurement presented here.

Events are selected using high $p_{\rm T}$ jet triggers. In pp collisions, these triggers are based on jets reconstructed from particle-flow candidates [32, 33]. An unprescaled trigger with a jet $p_{\rm T}$ threshold of $p_{\rm T,jet} = 80$ GeV is used. In PbPb collisions, triggers are based on jets reconstructed from calorimeter deposits including a subtraction of the uncorrelated underlying event. The threshold for these triggers is $p_{\rm T,jet} = 100$ GeV. For both the analysis in pp and PbPb, the anti-$k_{\rm T}$ algorithm [34, 35] with resolution parameter $R = 0.4$ is used.

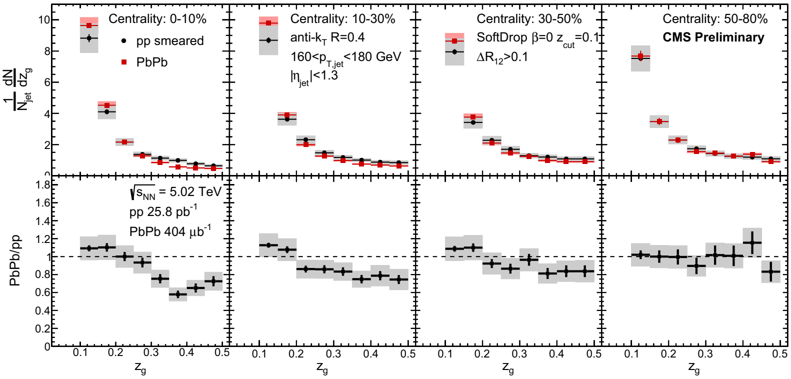

Fig. 1. Splitting function in PbPb for $160 < p_{\rm T,jet} < 180$ GeV in several centrality ranges compared to pp data [36]. For this comparison the resolution of the pp data is deteriorated to the same resolution as the PbPb measurement for each centrality selection. The shaded area around the data points indicates the systematic uncertainty while the vertical lines represent the statistical uncertainty.

In order to remove contributions from the underlying event activity, the "constituent subtraction" [37] algorithm is performed for each jet. The algorithm takes the per-event background energy density as input and performs a particle-based background subtraction. The average event activity is estimated following methods described in Ref. [38]. To compare results from pp collisions to those from PbPb collisions, additional fluctuations are introduced ("smearing") in the pp result to bring the effective resolution to the same level as that found in PbPb events. These corrections are derived by comparing fully simulated and reconstructed PYTHIA [39] events with PYTHIA events embedded in HYDJET [40] background.