Heavy flavored jet modification in CMS

Kurt Eduard Jung for the CMS Collaboration

Abstract

The energy loss of jets in heavy-ion collisions is expected to depend on the flavor of the fragmenting parton. Thus, measurements of jet quenching as a function of flavor place powerful constraints on the thermodynamical and transport properties of the hot and dense medium. Measurements of the nuclear modification factors of the heavy-flavor-tagged jets (from charm and bottom quarks) in both PbPb and pPb collisions can quantify such energy loss effects. Specifically, pPb measurements provide crucial insights into the behavior of the cold nuclear matter effect, which is required to fully understand the hot and dense medium effects on jets in PbPb collisions. In this talk, we present the heavy flavor jet spectra and measurements of the nuclear modification factors in both PbPb and pPb as a function of transverse momentum and pseudorapidity, using the high statistics pp, pPb and PbPb data taken in 2011 and 2013. Finally, we also will present a proposal for c-jet tagging methodology to be used for the upcoming high-statistics heavy-ion run in late 2015 at the LHC.

Presented at QM2015 Quark Matter 2015, XXV INTERNATIONAL CONFERENCE ON ULTRA-RELATIVISTIC NUCLEUS-NUCLEUS COLLISIONS
Heavy Flavored Jet Modification at CMS

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Abstract

The energy loss of jets in heavy-ion collisions is expected to depend on the flavor of the fragmenting parton. Thus, measurements of jet quenching as a function of flavor place powerful constraints on the thermodynamical and transport properties of the hot and dense medium. Specifically, p\textsubscript{Pb} measurements provide crucial insights into the behavior of the cold nuclear matter effect, which is required to fully understand the hot and dense medium effects on jets in PbPb collisions. In these proceedings, we present the heavy flavor jet spectra and measurements of the nuclear modification factors of b jets in both PbPb and p\textsubscript{Pb} as a function of transverse momentum and pseudorapidity, at $\sqrt{s_{\text{NN}}}=2.76$ and 5.02 TeV, respectively. In addition, we present the first ever measurement of charm-tagged jets in a heavy-ion environment, including cross-sections and comparisons to PYTHIA in both p\textsubscript{Pb} and pp.

Keywords: QGP, b jets, c jets, heavy flavor, energy-loss

1. Introduction

In relativistic collisions of heavy nuclei, experiments at both the RHIC BNL and CERN LHC have observed the phenomenon known as “jet quenching” [1, 2]. This suppression of inclusive high-$p_T$ hadrons and jets is thought to be due to collisional and radiative energy loss. When observed as a function of jet parton flavor, however, the energy loss mechanisms are less clear. Due to the additional color factors for gluon emission in the heavy quark sector and the large prevalence of gluon jets in a heavy flavored jet measurement, heavy flavored jets may quench in different ways than light flavored jets [3, 4].

While measurements of jet quenching in heavy collisions can quantify the jet-medium interaction strength, measurements of jet energy loss in proton-lead collisions allow for a factorization of initial-state or “cold nuclear matter” effects from the suppression effects seen in heavy collisions. Energy loss measurements as a function of collision species will allow for a visualization of the quenching power directly from the hot and dense medium, since it is expected that the QGP is not produced in proton-lead collisions.

These proceedings also present the first measurement of a charm jet cross-section [5]. In conjunction with the measurements of nuclear modification factor in p\textsubscript{Pb} for inclusive jets [6] and b-jets [7], a comprehensive picture of flavor-dependent energy loss can be obtained, from which mass-dependent effects may be observed.

\textsuperscript{1}A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.
2. Tagging Methodology

The procedure at CMS [8] for identifying b-jets makes use of the long lifetime of the b-jet and applies selections on displaced secondary vertices. This algorithm is known as the “simple secondary vertex” (SSV) tagger and applies a discriminator based on the three-dimensional vertex displacement divided by its uncertainty. Selections on this quantity enhance the relative b-jet fraction by roughly a factor of ten. After applying a selection on the SSV tagger, templates of secondary vertex mass are created in simulation, where the relative yields of light, charm, and bottom jets are allowed to float such that the fit to the distributions in data is maximized. An example of this fit is shown in Fig. 1 (left). From this procedure, the tagging purity is obtained. Then, tagging efficiency is found via simulation, but is cross-checked using an alternate tagging algorithm independent of secondary vertex mass [9]. The efficiency is calculated by taking the ratio of the purity of tagged jets to the purity of untagged jets, multiplied by the tagged jet fraction. This is done in each jet $p_T$ bin, after which the full $p_T$ spectra are unfolded to correct for detector resolution effects.

Charm jets are defined in these proceedings as any jet containing a charm quark within the jet cone, but ignoring charm quarks that stem from the $b$–$c$ cascade. In principle, charm jets can be identified from their displacement from the primary vertex, but in practice, the $c_T$ of these displacements is only on the order of 100 µm, so this tagging is difficult. At CMS, the presence of a silicon tracker close to the interaction point allows for the possibility to resolve features at these length scales and is crucial for this analysis.

The c-tagging strategy used here is similar to that used to tag b-jets, but with some important differences. Charm jets are again tagged using displaced vertices, but a requirement of at least three associated tracks is placed on the vertex. The inclusion of the third associated track reduces the light-jet contamination to the sample by an additional factor of three while still maintaining the charm-jet and b-jet tagging efficiencies. With a reduced light-jet component, the charm jets begin to dominate the sample in small regions of kinematic phase space which is crucial to constrain the template fits used to extract the relative fractions of bottom, charm, and light jets.

The second distinction is the use of the so-called “corrected” secondary vertex mass ($M_{corr}$), defined in Eq. (1), where $M$ is the standard secondary vertex mass, $p$ is the jet momentum, and $\theta$ is the angle between the secondary vertex displacement vector and the vector sum of the particles associated with the vertex.

$$M_{corr} = \sqrt{M^2 + p^2 \sin^2 \theta + p \sin \theta}$$

This tool was developed by the experiments at the LEP collider [10] and is currently used by the LHCb Collaboration [11]. Essentially, the variable corrects for any angular discrepancy between the final state particle momenta and the displacement vector of the secondary vertex due to neutral or invisible particles.
With the presence of a decay neutrino, for example, the direction of the vector sum of all reconstructed particles in the vertex may not match the expectation based on the displacement vector of the secondary vertex. In this case, one can assume that there must be missing energy associated to the vertex, and can add additional mass-energy to correct for this effect.

Templates of $M_{\text{corr}}$ are built in simulation, where, as in b-jet tagging, the relative contributions of each jet flavor are allowed to float independently such that the fit to the $M_{\text{corr}}$ distribution in data is maximized. An example template fit is shown in Fig. 1 (right). A visual comparison of the templates of secondary vertex mass and corrected secondary vertex mass shows a clear difference in b-tagged jet template shape, leading to a more robust calculation of charm-jet purity. As in the b-jet methodology, the efficiency is found via simulation and is cross-checked using a tagger independent of secondary vertex reconstruction.

3. Results and Conclusions

The b-jet nuclear modification factors $R_{pA}$ (in PbPb, relative to pp data) and $R^{\text{PYTHIA}}_{pA}$ (in pPb, relative to a PYTHIA simulation using the Z2 tune) are shown in Fig. 2. While the PbPb results show clear suppression in central events, the pPb cross-section is consistent with that from a PYTHIA simulation using the Z2 tune. In addition, both the pPb and PbPb results are consistent with suppression factors of inclusive jets [7, 9], indicating that mass-dependent effects are small, at least at high-$p_T$. Both panels in the figure also show a comparison to a theoretical model, described in Refs. [12] and [13], based on primarily collisional and radiative energy loss using perturbative QCD. While the PbPb suppression is predicted very well when a stronger gluon-to-medium coupling parameter is used, the relative enhancement seen in pPb is not anticipated by the model. However, this is expected due to the fact that initial state effects are not included in the models, so the observation in data that initial state enhancement dominates any energy loss effects in pPb is compatible with the theoretical interpretation.

The c-jet spectrum in pPb and pp is compared to PYTHIA simulations at 5.02 and 2.76 TeV, respectively. After scaling the pPb results by the Glauber nuclear overlap factor, we observe relative consistency with the PYTHIA simulations. Charm jet spectra from data and PYTHIA are shown in Fig. 3 in pPb (left) and pp collisions (right).

Fitting a constant to the data/PYTHIA ratios gives $1.00 \pm 0.19$ (stat.+syst.) in pPb and $1.15 \pm 0.27$ (stat.+syst.) in pp. These values indicate that charm jet energy is not significantly modified in pPb or
In summary, we present the first measurement of charm-tagged jets in a heavy ion environment, along with studies of b-tagged jets, in proton-proton, proton-lead and lead-lead collisions. Significant modification of b-jets is observed in PbPb collisions, while such effects are consistent with PYTHIA simulations in pPb collisions, both for charm and bottom jets. The proven viability of the charm tagging methodology described in these proceedings is indicative that a measurement of charm jet energy modification in PbPb may be possible using the data from upcoming LHC run periods.

References