Measurement of b-jet to inclusive jet ratio in PbPb and pp collisions at $\sqrt{s} = 2.76$ TeV with the CMS detector

Jorge A. Robles (for the CMS Collaboration)[1]

Rutgers University

Abstract

Modification to jets in high-energy heavy-ion collisions is expected to depend on the flavor of the fragmenting parton. To disentangle this flavor dependence, jets from heavy quark fragmentation are identified for the first time in heavy-ion collisions. Jets are first tagged by their secondary vertices and the contribution from bottom quarks is extracted using template fits to their secondary mass distribution. The bottom quark jet to inclusive jet ratio is measured with the CMS detector in PbPb and pp collisions at a center-of-mass energy of 2.76 TeV per nucleon. The b-jet fraction is measured in the range of 80 < jet p_T < 200 GeV/c in PbPb collisions and found to lie in the range of 2.9-3.5% ± 0.6-1.1% depending on jet p_T. The measured values for PbPb and pp are comparable, within uncertainties, to those predicted by simulation. The measurement is a promising method to study b-quark energy loss. Improved statistics should allow to make a more precise comparison between light and b-quark quenching.

1. Introduction

The quenching of jets in heavy-ion collisions is expected to depend on the flavor of the initiating parton, models [1] suggest that energy loss should depend on the mass of the parton. Collisional energy loss and gluon radiation are the main mechanisms through which fast partons loose energy. Gluon bremsstrahlung off a heavy quark is what is known as the 'dead cone effect'. The kinematics of the system restrict the phase-space in which the radiation of gluons from a heavy quark can occur. The suppression is along the direction of propagation. The reduction in the available phase-space for gluon radiation translates into a lesser quenching for jets originating from heavy quarks than for lighter quarks jets [2].

2. b-Tagging algorithm

The b-tagging algorithms in CMS rely mainly on the long lifetime, high mass and large momentum fraction of the b-hadrons produced in b-quark jets. The lifetime of the b-quark ($c\tau \sim 500\ \mu$m) is large enough to be used as a tag to identify b-jet events. The excellent spatial resolution of the inner tracker allows for clear identification of displaced vertices. The vertex resolution of the CMS tracker is on the order of 50 - 100 μm.

[1] A list of members of the CMS Collaboration and acknowledgements can be found at the end of this issue.

Preprint submitted to Nuclear Physics A *October 19, 2012*

3. b-Tagging Performance

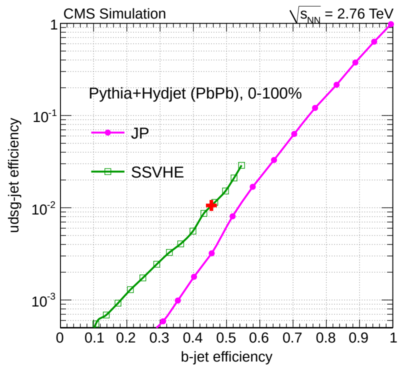

Figure 1: Light-jet mis-tag rate as a function of b-tagging efficiency for the SSVHE and JP taggers. The SSVHE performance is shown with open green squares and solid pink markers show the JP tagger.

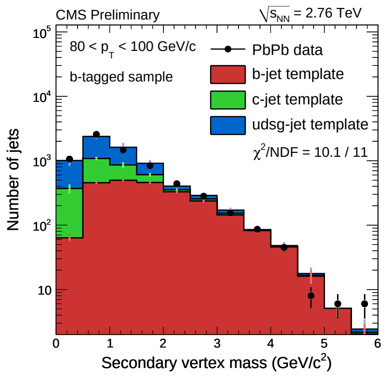

Figure 2: SV mass distributions of template fits from tagged sample compared to data. The stacked histogram shows the contribution of the usdg-jets (top) in blue, c-jets (middle) in green, and b-jets (bottom) in red.

The b-tagging sequence is initiated with the reconstruction of the primary vertex (PV) of the event. Once the PV is found, the tracks that are not compatible with it, are used in the search of secondary vertices (SV). Several tagging algorithms have been developed and used for b-identification in proton-proton collisions, more details can be found in [6]. From the aftermentioned algorithms, two are used in this analysis, the Simple Secondary Vertex High Efficiency (SSVHE) and the Jet Probability (JP) algorithm. The SSVHE is a simple and robust algorithm that relies on the 3D decay length significance, which is the distance between the PV and the SV normalized by its uncertainty. The JP is used as a cross check, it is a more efficient and complex algorithm which is based on large impact parameter tracks. The performance of a tagger can be studied by comparing the b-jet tagging efficiency with the light-jet rejection power. Figure 1 shows the performance of the SSVHE tagger in green (open squares) and JP in pink (solid circles) in a PYTHIA + HYDJET [3, 4] simulation. The working point for this analysis is marked with the red cross, it is set to have a light-jet rejection of 1/100 which yields a b-jet tagging efficiency of ∼45 %.

4. Template fits

The b-jet contribution is obtained from template fits of the tagged sample. The fits are done to the SV mass distributions. The SV mass is calculated as the invariant mass of all the charged tracks pointing to the displaced vertex, using a pion mass assumption. Figure 2 shows the SV mass distribution of the tagged sample for the $80 <$ jet $p_T < 100$ GeV/c range. The data is shown in black (solid circles), the b-jet contribution is shown in the red histogram, the c-jet in green and the light-jet in blue, each with statistical error bars. Using maximum log likelihood fits the contribution from b-jet and non-b-jets is obtained. The ratio of jets originating from charm to jets originating from light quarks is set by input simulations. The χ^2/NDF indicates a good agreement between data and the template fits.

The SSVHE b-tagging efficiency is obtained with a data-driven method using the template fits and making use of the JP tagger, which has a tagging efficiency of ~98 %. The SSVHE tagging purity, estimated to be ~30 %, is also calculated with a data-driven method, and cross-checked directly with simulation, further details can be found in [5].

5. Results

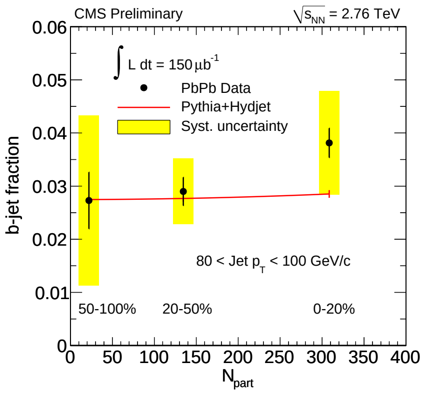

Figure 3: b-jet fraction as a function of number of participants compared to a PYTHIA + HYDJET simulation

The b-jet fraction is defined as the ratio of the number of b-jets to the number of inclusive jets, and is found to be ~3%. Figure 3 shows the b-jet fraction as a function of number of participants (N_{part}). The data is shown in black markers (solid circles), with statistical error bars. The systematic uncertainties are shown as yellow boxes. The expectation from a PYTHIA + HYDJET simulation is shown with a red line. The data agrees, within uncertainties, with simulation as a function of centrality.

The b-jet fraction is also shown as a function of jet p_T in Fig. 4 for the pp case. Figure 5 shows the b-jet fraction as a function of p_T in PbPb collisions. In both cases the data is shown in black markers (solid circles) with statistical error bars and systematics uncertainties in yellow boxes. The simulations for pp (PbPb) are obtained from PYTHIA (PYTHIA + HYDJET) and are shown with a red line. In both cases the simulations agree with data, with no dependence as a function of jet p_T.

The main systematic uncertainties arise from the estimation of the tagging efficiency, the estimation of the charm-to-light ratio, the uncertainties in the template shape from the fits, the variation of the working point and the estimation of the jet energy scale. Some of the systematic uncertainties are calculated with data-driven methods which makes some of these quantities dependent on the limited statistics of the pp sample.

$$\text{b-jet } R_{AA} = \frac{PbPb \text{ b-jet fraction}}{pp \text{ b-jet fraction}} \times \text{Inclusive jet } R_{AA} \tag{1}$$

The inclusive nuclear modification factor R_{AA} for b-jets is obtained with Eq. 1. The inclusive jet R_{AA} measured by CMS can be found in [7]. The b-jet R_{AA} is found to be 0.48 ± 0.09 (stat.) ± 0.18 (syst.) for 100 < jet p_T < 120 GeV/c. This results favors a scenario in which jets originating

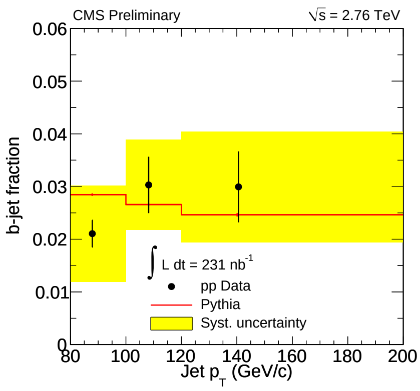

Figure 4: b-jet fraction as a function of jet p_T in pp collisions compared to a PYTHIA simulation

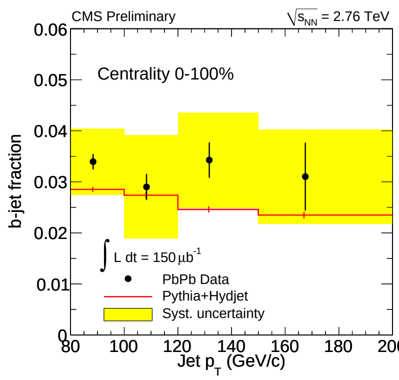

Figure 5: b-jet fraction as a function of jet p_T in PbPb collisions, compared to a PYTHIA + HYDJET simulation

from b-quarks exhibit the same parton energy loss as light jets, hence making the mass a lesser factor in this p_T regime.

6. Summary

The identification of b-jets has been performed for the first time in heavy-ion collisions. The b-jet fraction has been found to be consistent with simulation as a function of jet p_T for pp an PbPb, also as a function of N_{part} for the PbPb case. The nuclear modification factor for jets originating from b-quarks agrees with the one measured for inclusive jets in the 100-120 GeV/c transverse momentum regime.

References

[1] W. Horowitz. Heavy quark production and energy loss, plenary talk. These proceedings.
[2] Y. L. Dokshitzer and D. Kharzeev, Heavy quark colorimetry of QCD matter, Phys. Lett. B 519 (2001) 199206, doi:10.1016/S0370-2693(01)01130-3, arXiv:hep-ph/0106202.193
[3] T. Sjostrand, S. Mrenna and P. Z. Skands, JHEP 0605, 026 (2006) [hep-ph/0603175].
[4] I. P. Lokhtin and A. M. Snigirev, Eur. Phys. J. C 45, 211 (2006) [hep-ph/0506189].
[5] CMS Collaboration, Measurement of b-jet to inclusive jet ratio in *PbPb* and *pp* collisions at sNN = 2.76 TeV with the CMS detector, CMS Physics Analysis Summary CMS-PAS-HIN-12-003, (2012).
[6] CMS Collaboration, b-Jet Identification in the CMS Experiment, CMS Physics Analysis Summary CMS-PAS-BTV-11-004, (2012).
[7] CMS Collaboration, Nuclear modification factor of jets at high p_T in *PbPb* collisions $\sqrt{s_{NN}}$ = 2.76 TeV, CMS Physics Analysis Summary CMS-HIN-12-004, CMS, (2012).