PROCEEDINGS OF SCIENCE

First measurement of jet angularities with D^0-meson tagged jets with ALICE

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The properties of partonic fragmentation in QCD are dependent on the flavours of the partons involved in the 1→2 splitting processes underpinning parton showers. These flavour dependencies arise due both to the different Casimir factors of quarks and gluons, as well as the mass of heavy quarks. Heavy-flavour jets provide a unique experimental tool to probe these flavour dependencies, particularly at low and intermediate transverse momenta where mass effects are significant. Here we report the first measurement of the angularity of jets tagged with a reconstructed D^0 meson, in the jet transverse momentum interval of 10−20 GeV/c. Generalised angularities are a set of IRC-safe jet-substructure observables which can be tuned in their sensitivity to the partonic fragmentation and hadronisation processes. Comparisons to angularity measurements in a flavour-untagged jet sample will probe both the flavour depdendences due of the mass of the charm quark, as well as the high purity quark nature of the D^0-tagged jet sample. Further comparisons to different MC generators will assess the role of these flavour dependencies in different parton shower prescriptions.

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1. Introduction

In high-energy hadron collisions, heavy-flavor (charm and beauty) quarks are produced during the initial hard scattering at the partonic level. The production of these quarks, with masses much greater than the intrinsic scale of QCD ($\Lambda_{\rm QCD} \sim 200$ MeV), is well understood by perturbative quantum chromodynamics (pQCD) calculations [1–3].

Jets, which are collimated sprays of particles produced by hard-scattered partons, have been a crucial observable in high-energy particle physics. Reconstructed jets provides direct access to the initial parton initiating the shower. The properties of partonic fragmentation in QCD are dependent on the flavours of the partons involved in the $1 \rightarrow 2$ splitting processes underpinning parton showers. These flavour dependencies arise due to both the difference in Casimir color factors of quarks and gluons, as well as the mass of heavy quarks. In these proceedings, we present the study of these flavor dependencies using a jet substructure observable known as generalized jet angularities [4]. They are a special class of jet substructure observables which depends both on the $p_{\rm T}$ and angular distribution of constituents within the jet, individually weighted by the adjustable and continuous parameters κ and α, respectively:

$$\lambda_{\alpha}^{\kappa} \equiv \sum_{\rm i \in jet} \left(\frac{p_{\rm T,i}}{p_{\rm T,jet}} \right)^{\kappa} \left(\frac{\Delta R_{\rm jet,i}}{R} \right)^{\alpha} \equiv \sum_{\rm i \in jet} z_i^{\kappa} \theta_i^{\alpha} \tag{1}$$

where i runs over constituents in the jet, R is the jet resolution parameter, $p_{\rm T}$ is transverse momentum, and the relative rapidity and azimuthal angle determine $\Delta R_{\rm i} = \sqrt{(y_{\rm jet} - y_{\rm i})^2 + (\phi_{\rm jet} - \phi_{\rm i})^2}$. These observables are IRC safe in the case of $\kappa = 1$ and $\alpha > 0$. They can be tuned in their sensitivity, by varying α, to fragmentation and hadronization processes. Figure 1 shows the comparison of the angularity of quark-initiated, gluon-initiated and D^0-tagged jet obtained using PYTHIA 8 [5] simulations for two different values of α in $10 < p_{\rm T,ch\ jet} < 20$ GeV/c interval. The left figure shows the comparison for $\alpha = 1$, where the core of the jet is given higher weight. The distribution of quark-initiated jets have, on average, lower angularities than gluon-initiated jets. D^0-tagged jets, which are heavy-quark (charm)-enriched jets, have even lower angularities than quark-initiated jets. Whereas on the right, at higher $\alpha = 3$ (higher weight assigned to large angle radiation), the D^0-tagged jet and quark-initiated jet distributions become more similar. This modification as a function of α suggests that the jet angularities are sensitive to flavor dependencies of parton shower. To gain further insight into this modification, we present a study of the D^0-tagged jets angularities with ALICE data in pp collisions at $\sqrt{s} = 5.02$ TeV in these proceedings. These angularities are compared to those of semi-inclusive jets by systematically varying the angular parameter α. The semi-inclusive jets baseline is constructed by imposing a $p_{\rm T} > 5.33$ GeV/c cut on the leading track, corresponding to the transverse mass of a D^0-meson with $p_{\rm T} = 5$ GeV/c.

2. D^0-tagged jets reconstruction

Heavy flavor jets, originating from the charm quarks, are identified by the presence of a prompt D^0-meson among their constituents. For D^0-meson tagged jets, prior to jet finding, the reconstruction of D^0-meson candidate and its charge conjugates[1] in central rapidity region is performed via

[1]The analysis refers to both D^0 and $\bar{D}^0$ as a D^0

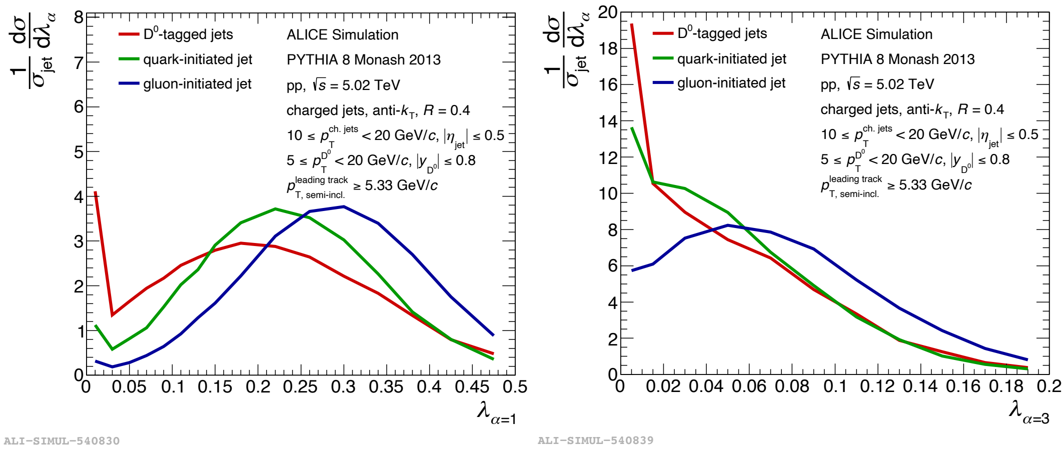

Figure 1: Angularity distributions of quark-initiated, gluon-initiated and D^0-tagged jets in PYTHIA 8 for R = 0.4 in 10 < $p_{\mathrm{T,ch\ jet}}$ < 20 GeV/c range.

its charged hadronic decay mode, D^0 $\rightarrow$ K$^-\pi^+$ (branching ratio, BR = 3.93 ± 0.04%). The reconstruction of D^0-meson is mainly done by applying topological selections where the reconstructed secondary vertex is required to be displaced by few hundreds of μm from the primary vertex and particle identification (PID). This technique removes a significant amount of combinatorial background due to uncorrelated tracks and improves the precision of D^0 signal extraction. Decay daughters of a D^0-meson candidate are then replaced by their 4-momentum vector sum (i.e the D^0-meson). This is done to mitigate against cases where the angle between the decay daughters is larger than the jet radius, as this would degrade the jet energy resolution. Thereafter, D^0-meson tagged jets are reconstructed using a track-based procedure with the anti-k_{T} algorithm [6] implemented in FastJet [7] with a resolution parameter R = 0.4, in the range of 2 < $p_{\mathrm{T,ch\ jet}}$ < 50 GeV/c. The jet containing the fully reconstructed D^0 candidate along with the other charged tracks is then selected.

After jet selection, invariant mass technique is used to extract the signal angularity distribution. In each $p_{\mathrm{T,D^0}}$ interval, the invariant mass of the D^0 candidates is fitted with a Gaussian function for the signal and an exponential function for the background. The signal angularity distribution is extracted within ±2σ region of the Gaussian peak and the background angularity contribution is estimated by totaling the distributions obtained from 4σ–9σ region in the side-bands on either side of the Gaussian peak. The side-bands are selected far enough away from the peak such that they are considered to be fully background dominated. The side-band angularity distribution is then subtracted from the signal angularity distribution to obtain a background subtracted angularity distribution. The subtracted distributions are then scaled by 1/0.9545 to account for the limited 2σ width of the signal region.

In the next step, the raw D^0-tagged jets angularity distribution are corrected for mainly three factors. Firstly, with the efficiency of D^0-tagged jet reconstruction within the detector acceptance. The analysis cuts used to identify the D^0-meson candidate from their decay products have a finite efficiency of successfully finding the D^0-meson present in an event. The raw D^0-tagged jet yields should be corrected for this efficiency. The efficiency is estimated using Monte Carlo simulations and is defined as the ratio of the matched detector level D^0-tagged jets that passed all the data analysis selection requirements to all generator level D^0-tagged jets within the acceptance. The raw distribution are corrected by the efficiency in $p_{\mathrm{T,D^0}}$ intervals and then final shape in a given jet p_{T} interval is obtained by summing over all $p_{\mathrm{T,D^0}}$ intervals. Secondly, the subtraction of the jets tagged with a D^0-meson coming from a B meson decay. This factor is estimated using the POWHEG [8] + PYTHIA 8 simulations. POWHEG is an NLO generator which can more accurately produce the required non-prompt D^0 cross section. PYTHIA 8 is used for the showering and hadronization processes. And thirdly, the impact of momentum smearing introduced by detector effects such as track momentum resolution, energy loss in the detector volume, and tracking inefficiencies.

3. Results

We report angularity (λ_α) using equation 1 as follows:

$$\frac{1}{\sigma_{\mathrm{jet}}(p_{\mathrm{T}}^{\mathrm{ch.\ jet}})}\frac{\mathrm{d}\sigma}{\mathrm{d}\lambda_\alpha}(p_{\mathrm{T}}^{\mathrm{ch.\ jet}}) = \frac{1}{N_{\mathrm{jet}}(p_{\mathrm{T}}^{\mathrm{ch.\ jet}})}\frac{\mathrm{d}N}{\mathrm{d}\lambda_\alpha}(p_{\mathrm{T}}^{\mathrm{ch.\ jet}}) \tag{2}$$

where $N_{\mathrm{jet}}(p_{\mathrm{T}}^{\mathrm{ch.\ jet}})$ is the number of charged jets with a given $p_{\mathrm{T}}^{\mathrm{ch.\ jet}}$. The final D^0-tagged jet angularity distributions are compared to semi-inclusive jets in pp collisions at $\sqrt{s}$ = 5.02 TeV data and PYTHIA 8 simulations in Figure 2.

The top panel of Figure 2 shows the comparison of D^0-tagged jet angularities to inclusive jets in the $10 < p_{\mathrm{T,ch\ jet}} < 20$ GeV/c range for increasing α values, ranging from 1 (top left) to 3 (bottom right). It indicates that at lower α values, the D^0-tagged jets have lower angularities compared to the semi-inclusive jets. This effect can be attributed to the smaller color charge of quarks when compared to gluons and the presence of the "dead cone" effect [9] around the charm quark.

The bottom panel illustrates the ratio of D^0-tagged to inclusive jet angularities. As α is increased or a higher weight is assigned to wide-angle radiation, the D^0-tagged jets and semi-inclusive jets angularities start to converge. This observation suggests that the largest differences lie in the core of the jet due to the "dead cone" effect, while cleaner sensitivity to Casimir color effects is achieved at larger values of α

4. Conclusions

ALICE has performed the first measurement of D^0-tagged jet angularities in pp collisions at $\sqrt{s}$ = 5.02 TeV. These results are compared with inclusive jets to probe the flavour dependences due to the mass of the charm quark as well as the high purity quark nature of the D^0-tagged jet sample. The results shows that the angularity is sensitive to both mass and Casimir color effects in the shower. Scanning the angular profile of jets with α parameters can control the impact of each of the flavor effects. At lower α, the D^0-tagged jets which are heavy-quark (charm) enriched jets have narrower angularities than semi-inclusive jets suggesting that the mass effects are more prominent. As higher weight is given to large-angle radiation, the D^0-tagged jets and semi-inclusive jets angularity distributions become more similar. This indicate that the impact of mass effects is reduced and there is a cleaner sensitivity to Casimir colour effects with higher α.

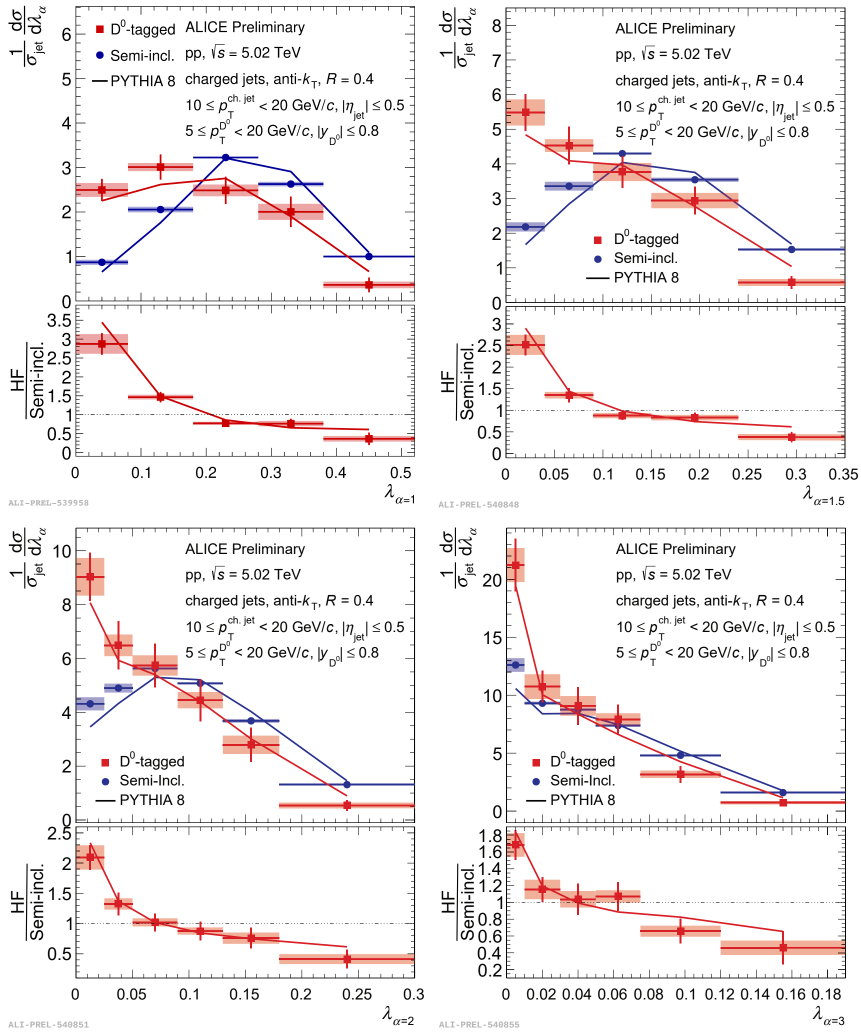

Figure 2: Jet angularity distributions of D^0-tagged jets compared to semi-inclusive jets and to PYTHIA 8 for α = 1 (top left), α = 1.5 (top right), α = 2 (bottom left) and α = 3 (bottom right) in $10 < p_{\mathrm{T,ch\ jet}} < 20$ GeV/c interval.

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