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Measurement of the Shared Momentum Fraction z_g using Jet Reconstruction in p+p and Au+Au Collisions with STAR

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Abstract

One key difference in current energy loss models lies in the treatment of the Altarelli-Parisi, AP, splitting functions. It has been shown that the *shared momentum fraction*, henceforth called *Jet Splitting Function* z_g as determined by the SoftDrop grooming process can be made a Sudakov-safe measurement of the symmetrized AP functions in p+p collisions. The STAR collaboration presents the first z_g measurements at $\sqrt{s_{NN}} = 200$ GeV in p+p and Au+Au collisions, where in Au+Au we use a set of di-jets with hard cores reconstructed with a 2 GeV/c constituent cut. For a jet resolution parameter of $R = 0.4$, these di-jet pairs were found to be significantly imbalanced with respect to p+p, yet regained balance when all soft constituents were included. We find that within uncertainties there are no signs of a modified Jet Splitting Function on trigger or recoil sides of this di-jet selection.

Keywords: Quark-gluon plasma, jets, SoftDrop, Shared Momentum Fraction

1. Introduction

Jet reconstruction algorithms and techniques used to correct for the underlying event have been primarily developed by the particle physics community as a robust tool to access parton kinematics from measured final-state hadrons. Modern approaches to extract information from the jet sub-structure pioneered by particle physics applications have recently found their way into the heavy-ion field, where the dramatically larger underlying event poses unique challenges. For an excellent review of the now ubiquitous class of infra-red and collinear safe sequential clustering algorithms (k_T, anti-k_T, Cambridge/Aachen(C/A)) and of the concepts used in this analysis, please refer to M. Cacciari's recent presentation at Hard Probes [1].

We focus on the groomed momentum fraction z_g, or *Jet Splitting Function*, that allows a direct measurement of a fundamental building block of pQCD in p+p collisions, the (symmetrized) Altarelli-Parisi splitting functions. It emerges as a "by-product" of the modified mass drop tagger or SoftDrop [2, 3] grooming algorithm, used to remove soft wide-angle radiation from a sequentially clustered jet. This is achieved by recursively declustering the jet's branching history and discarding subjets until the transverse momenta $p_{T,1}, p_{T,2}$ of the current pair of subjets fulfill the SoftDrop condition: $\frac{\min(p_{T,1},p_{T,2})}{p_{T,1}+p_{T,2}} > z_{\rm cut}\theta^{\beta}$, where θ is an additional measure of the relative distance between the two sub-jets. The current analysis disregards θ by setting $\beta = 0$, and we adopt the default choice $z_{\rm cut} = 0.1$ [3]. It was shown that for such a choice, and for a C/A clustering, the distribution of the resulting groomed momentum fraction, or *Jet Splitting Function*

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$z_g \equiv \frac{\min(p_{T,1},p_{T,2})}{p_{T,1}+p_{T,2}}$ converges to the vacuum AP splitting functions for $z > z_{\text{cut}}$ in a "Sudakov-safe" manner [4], i. e. independent of α_s in the UV limit. In A+A collisions, a modification of z_g could signify modification of the splitting kernel, a characteristic aspect in some classes of energy loss models, but it could also indicate changes due to quenching of the sub-jets after a vacuum-like split. Measurements of z_g can thus yield qualitatively new constraints for theoretical treatment.

Jets consisting of charged tracks and neutral towers are found using the anti-k_T algorithm from the FastJet package [5, 6] with resolution parameter $R = 0.4$. Data selection and detector setup are identical to Ref. [7]. The data were collected by the STAR detector in p+p and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV in 2006 and 2007, respectively. Charged tracks were reconstructed with the Time Projection Chamber (TPC) [8], and neutral hadrons with transverse energy E_T were measured in the Barrel Electromagnetic Calorimeter (BEMC) [9], with a so-called full hadronic correction scheme in which the transverse momentum of any charged track that extrapolates to a tower is subtracted from the transverse energy of that tower. Tower energies are not allowed to become negative via this correction. An online High Tower (HT) trigger required $E_T > 5.4$ GeV in at least one BEMC tower. All z_g spectra in this work are normalized to unity.

A p+p simulation at $\sqrt{s}$=200 GeV of leading jet z_g was conducted using PYTHIA 6.410 [10] with CTEQ5L pdfs [11] and PYTHIA 8.219 [12] with default settings. As an additional difference, the PYTHIA8 sample only contains stable particles in the final state while the PYTHIA6 sample also comprises short-lived and long-lived particles since the final decay happens at a later stage in the simulation of the STAR detector. Despite the differences, both lead to nearly identical z_g distributions (not shown) and qualitatively good agreement with the analytical solution.

2. Measurement in p+p HT

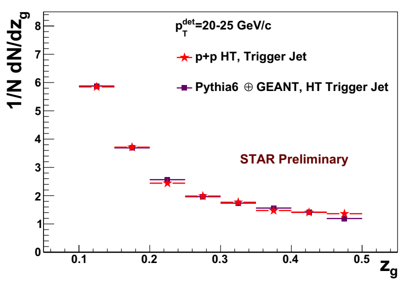

Fig. 1. Trigger jets for p+p HT compared to detector level PYTHIA predictions in one example p_T^{det} bin at detector level. Error bars are statistical only.

To estimate the fragmentation bias effect of a High Tower (HT) trigger in p+p, the PYTHIA8 simulation was first repeated with the additional requirement of a neutral 5.4 GeV/c particle in the trigger jet. In this analysis, we distinguish between "trigger" and "recoil" jets depending on which jet contains the HT that fulfilled the trigger requirement. Differences in the z_g distribution on the trigger side disappear around $p_T^{\text{Jet}} = 20 - 25$ GeV/c, whereas, as expected, we found no difference on the recoil side between triggered and untriggered events.

At the detector level, an example comparison (without efficiency or smearing corrections; p_T^{det}) of trigger jets between measured p+p HT and the above-mentioned PYTHIA6 data after detector simulation is shown in Fig 1. For both trigger and recoil, and for all p_T^{det} bins between 10 and 30 GeV/c, we observe excellent agreement between the measured data and PYTHIA6 when folded by the STAR detector simulation.

It is therefore appropriate to use a bin-by-bin correction as a first approach to correct for detector effects and the HT trigger bias. The corrected distributions are shown in Fig. 2 in p_T^{part} bins, where p_T^{part} refers to the value corrected to particle level. Measurements above 30 GeV/c only have reasonable statistics for trigger jets, and hence are omitted here. The overlaid dashed lines demonstrate the z_g agreement with PYTHIA8 on both trigger and recoil side for jets in p+p. The shaded bands in Fig. 2 represent the uncertainty due to the overall jet energy scale uncertainty of 4% [13]. Note that this scale uncertainty when applied to subjets cancels out in the calculation of z_g, hence we only consider p_T^{part} bin migration. Nevertheless, especially at lower jet p_T the presence of a High Tower leads to a significantly different neutral energy fraction in the trigger jet and thus in one of its subjets. An evaluation of the effect of tracking efficiency and tower scale uncertainty on individual subjets and their potential (anti-)correlation is underway.