PROCEEDINGS OF SCIENCE

Current and future measurements of semi-inclusive hadron+jet distributions with ALICE

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The measurement of jets recoiling from a trigger hadron in heavy-ion collisions can be used to understand the properties of the Quark Gluon Plasma. Jet-medium interactions cause jets to lose energy in the medium and may modify the jet structure. Jet deflection towards large angles due to scattering off of quasi-particles in the Quark-Gluon Plasma may also occur, which can be studied through a measurement of the hadron-jet acoplanarity. These phenomena can be studied through the semi-inclusive distribution of track-based jets recoiling from a trigger hadron. This contribution presents the latest measurements and prospects of semi-inclusive hadron+jet distributions with ALICE. Constraints on energy loss in p–Pb collisions and future prospects to measure energy loss in smaller systems are shown. A jet shape measurement of N-subjettiness using recoil jets is outlined. Finally, prospects for hadron+jet acoplanarity measurements with ALICE are presented.

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1. Introduction

Measurements of jets created in ultrarelativistic heavy-ion collisions provide unique probes to characterise the hot and dense QCD medium created in these collisions. The measurement of inclusive jets (see e.g. [1] for recent ALICE results) show a significant suppression in heavy-ion collisions with respect to pp collisions, indicating that partons lose energy while travelling through and interacting with the QCD medium.

The measurement of jets recoiling from a trigger hadron is being employed to further study jet quenching effects. ALICE has measured the trigger-normalised semi-inclusive yield of jets recoiling from a trigger hadron $\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}$, differential in jet transverse momentum $p^{\mathrm{ch}}_{\mathrm{T,jet}}$. A variable Δ_{recoil} is then defined as the difference between the trigger-normalised recoil jet distributions in 'reference' and 'signal' trigger track p_{T} intervals TT_{ref} and TT_{sig} [2]:

$$\Delta_{\mathrm{recoil}} = \left.\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\right|_{TT_{\mathrm{sig}}} - c_{\mathrm{ref}}\cdot\left.\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}^2N_{\mathrm{jet}}}{\mathrm{d}p^{\mathrm{ch}}_{\mathrm{T,jet}}\mathrm{d}\eta_{\mathrm{jet}}}\right|_{TT_{\mathrm{ref}}} \tag{1.1}$$

where c_{ref} accounts for the combined effects of invariance of total jet yield with trigger track p_{T}. With this observable one removes entirely the background from uncorrelated reconstructed jets, giving the possibility of extending jet measurements to low-p_{T} and high jet resolution parameter R. The jet population measured with this technique is not biased in terms of jet fragmentation pattern. As a trigger-normalised and semi-inclusive quantity one can also avoid model-dependent assumptions to relate event activity to event geometry, leading to greater systematic sensitivity to jet quenching effects in small systems [3]. It is noted that the measurements shown here use jets reconstructed from charged tracks only, i.e. 'track-based jets'.

2. Constraints on jet quenching in smaller systems

The measurement of the trigger-normalised recoil jet distributions in Pb–Pb collisions indicates that jets lose a significant amount of energy in Pb–Pb collisions, and that this energy is predominantly radiated to angles greater than $R = 0.5$ [2]. A similar analysis was performed in p–Pb collisions in different event-activity classes, defined using the signal magintude in the V0A detectors of ALICE, to test whether jets are quenched in smaller systems [3]. Figure 1 (left) shows the Δ_{recoil} ratio in high/low event activity classes for recoil jets with $R = 0.4$ from $15-50$ GeV/c. The ratio is consistent with unity, indicating minimal jet quenching in p–Pb collisions, and a limit of < 0.4 GeV out-of-cone energy loss for jets in this p_{T} range is set (90% CL).

The sensitivity to jet quenching in small systems in Run 3/4 of the LHC has also been assessed, based on PYTHIA simulations to estimate the expected number of charged hadron triggers and trigger normalised recoil jet spectrum for a given integrated luminosity. Figure 1 (right) shows the projection of the same observable for $R = 0.4$ jets in pp collisions at $\sqrt{s} = 14$ TeV with an integrated luminosity of 200 $\mathrm{p\,barn}^{-1}$, where the ratio of 'central' and 'peripheral' events corresponds to the 0–0.1% centrality percentile and 50–100% centrality percentile respectively. Here no event-activity shift is included, and the statistical limit (90% CL) on a measurement of out-of-cone energy loss is 175 MeV for this system. For p–Pb collisions where the high-EA is set to the 0–5% percentile, this

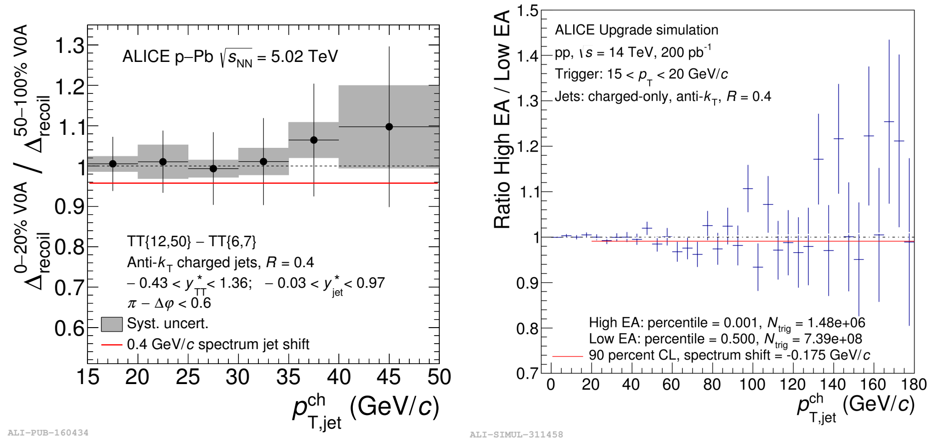

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Figure 1: Left: The ratio of Δ_{recoil} in high/low event activity classes in p–Pb collision at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV. Right: Projection of the ratio of Δ_{recoil} in high/low event activity classes in pp collisions at $\sqrt{s} = 14$ TeV in Run 3/4 of the LHC. The red line in both figures corresponds to the 90% CL spectrum shift.

limit is 70 MeV. While the corresponding systematic uncertainties are not estimated, it is noted that the statistical uncertainties were dominant in the Run 1 measurement.

3. Substructure of recoil jets

The measurement of jet shapes and their modification in heavy-ion collisions can give further insight into jet quenching mechanisms. For example, the role of colour coherence [4] can be probed by studying how 2-pronged jets are modified in heavy-ion collisions. The N-prongness of jets is measured through the N-subjettiness observable τ_N. For this observable, jets are reclustered using an exclusive clustering algorithm, and 'subjet' axes are found by unwinding the last clustering step. τ_N is then defined as

$$\tau_N = \frac{\sum_{i=1}^{N} p_{\mathrm{T,i}} \mathrm{min}(\Delta R_{\mathrm{i,1}}, \Delta R_{\mathrm{i,2}}, ..., \Delta R_{\mathrm{i,N}})}{R_0 \sum_{i=1}^{N} (p_{\mathrm{T,i}})} \tag{3.1}$$

where $\Delta R_{\mathrm{i,j}}$ is the $\phi - \eta$ distance between track i and subjet j, $p_{\mathrm{T,i}}$ is the p_{T} of the i-th jet constituent and R_0 is the jet resolution parameter. The ratio τ_2/τ_1 is a measure of how 2-pronged a jet is.

In order to get a combinatorial background-free distribution of low-p_{T} jets with low fragmentation bias, a similar technique as described in Section 1 is used. As shown in figure 2 (left) a 'reference' trigger track recoil jet distribution is subtracted from a 'signal' trigger track distribution to obtain the τ_2/τ_1 distribution of true jets, free from fragmentation bias. Figure 2 (right) shows the τ_2/τ_1 distribution in Pb–Pb collisions in comparison with the same distribution in PYTHIA. No modification of two-prongness with respect to PYTHIA is seen within the experimental uncertainties. Different reclustering algorithms are also explored which are sensitive to different properties of the jet splitting, see [5] for more information.

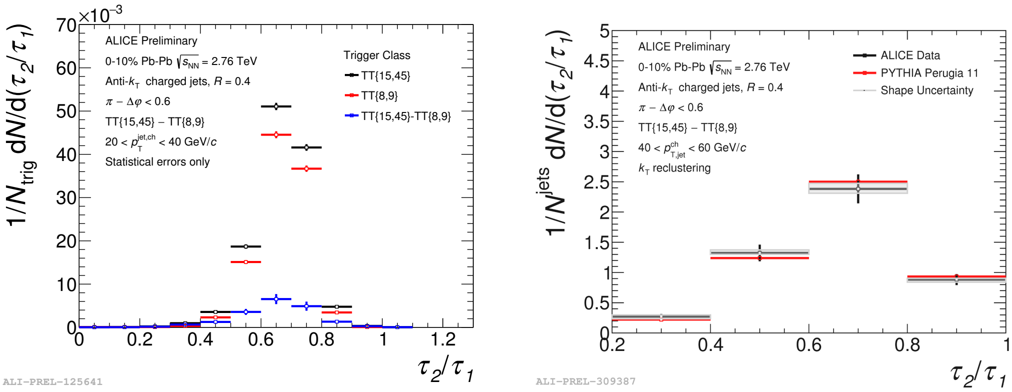

Figure 2: Left: The trigger-normalised τ_2/τ_1 distributions in a signal and reference class, and the difference between the two. Right: The trigger-normalised τ_2/τ_1 distribution in Pb–Pb collisions compared to a PYTHIA reference.

4. Di-jet azimuthal correlations

The interaction of jets with the Quark-Gluon Plasma can be further studied by measuring the azimuthal correlation of dijets, or in this case, the azimuthal correlation between a trigger hadron and a corresponding recoiling jet. This is measured by the angle between the trigger hadron and recoiling jet, denoted $\Delta\varphi$. The motivation for studying this observable is two-fold:

1. The broadening of the peak of the away side distribution (at $\Delta\varphi \sim \pi$) with respect to vacuum expectation is sensitive to soft multiple scattering in-medium. Since the angular deflection can be related to the change in the momentum transverse to the direction of the initial parton, this could give direct constrains to the transport coefficicent $\hat{q}$ [6].

2. The shape of the tails of the distribution at large angles away from π can be used to study the rate of large angle scattering in the QGP. This can arise from resolving the weak degrees of freedom in the Quark-Gluon Plasma, and evidence of large angle scattering could give evidence of a quasiparticle nature of the plasma [7].

The background-subtracted hadron+jet azimuthal distribution was measured in Pb–Pb collisions at ALICE with Run 1 data [2]. The rate of large angle scattering showed no deviation from the vacuum expectation within the experimental uncertainties, though this measurement was statistically limited. Recent theoretical work (see e.g. [7, 8]) has suggested that low-p_T jets are most sensitive to such effects and additional, higher statistics measurements are underway.

The reach of a hadron+jet measurement in Run 3/4 of the LHC has been assessed. Central Pb–Pb and pp collisions are simulated with the JEWEL model [9]. Figure 3 (left) shows the background-corrected azimuthal distribution of jets recoiling from a high-p_T trigger hadron, with the expected statistics of Run 3/4. The difference between the large-angle recoil jet yield in pp and Pb–Pb collisions is then studied by integrating this distribution at large angles away from π, between $\pi/2$ and a theshold angle $\Delta\varphi_{threshold}$, defining $\Sigma(\Delta\varphi_{thresh}) = \int_{\pi/2}^{\pi-\Delta\varphi_{thresh}} d\Delta\varphi[\Phi(\Delta\varphi)]$.

Figure 3 (right) shows the $\Sigma(\Delta\varphi_{\text{thresh}})$ distribution in Pb–Pb and pp collisions in JEWEL, and the ratio between the two systems. The statistical precision of the ratio at $\Delta\varphi_{\text{threshold}}$ is around 5% (dominated by the uncertainty of the pp reference), so a deviation in the large-angle yield from vacuum will be able to be resolved to approximately this accuracy. Theoretical calculations predict deviations of similar magnitude [8], so a measurement in Run 3/4 promises to resolve different pictures of the micro-structure of the medium.

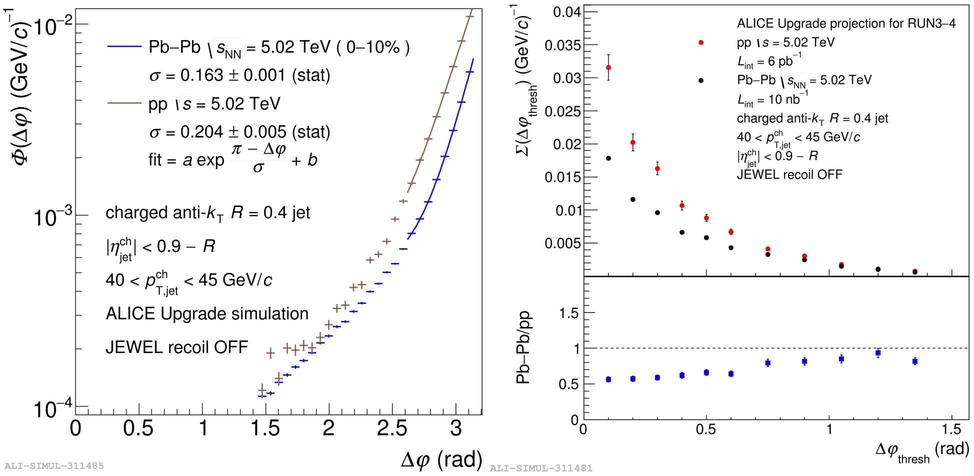

Figure 3: Left: Projection of the background-corrected azimuthal hadron-jet distribution in pp and Pb–Pb collisions in Run 3/4. Right: The integral of this distribution at large angles as a function of the threshold angle of integration $\Delta\varphi_{\text{thresh}}$, and its ratio in Pb–Pb and pp collisions.

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