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Jet energy redistribution and broadening using hadron+jet measurements in pp and Pb–Pb collisions with ALICE

Jaime Norman[1,*], on behalf of the ALICE Collaboration

[1]Oliver Lodge Laboratory, Oxford St, Liverpool L69 7ZE

Abstract. In this contribution we present measurements of the semi-inclusive distributions of charged jets recoiling from a trigger hadron (hadron+jet) in pp and Pb–Pb collisions, which provide unique probes of medium-induced modification of jet production. We observe that the jet yield at low p_{T} and at large azimuthal angle between the trigger hadron and jet is significantly enhanced in Pb–Pb collisions with respect to pp collisions, which we interpret through comparisons to model calculations.

1 Introduction

Jet acoplanarity (deviation from coplanar dijet production) provides important information about the production and evolution of jets. In vacuum, the jet acoplanarity distribution is broadened by gluon emission (Sudakov broadening) [1], while in heavy-ion collisions the distribution may be additionally broadened through jet-medium scattering. Multiple in-medium soft scattering is parameterised by the jet transport coefficient $\hat{q}$ which the acoplanarity distribution gives direct access to [2]. In addition, it is expected that single-hard, large-angle scatters occur rarely - their observation would provide the possibility to resolve the weakly-interacting scattering centers, and therefore the quasiparticle nature of the QGP [3], and the acoplanarity distribution may be sensitive to this effect.

This contribution presents the recent publications [4, 5] of the semi-inclusive measurement of hadron+jet production in pp and central (0–10%) Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV, using Run 2 LHC data recorded with the ALICE detector. This follows on from the first ALICE measurement with Run 1 data [6], utilising techniques developed here to correct for the large uncorrelated background present in heavy-ion collisions in a data-driven way, which enables measurements of low transverse momentum (p_{T}), large R jets.

2 Analysis

Events are selected requiring the presence of a high-p_{T} charged-hadron trigger particle ('trigger track') in a defined p_{T} interval, $p_{\mathrm{T,low}} < p_{\mathrm{T}}^{\mathrm{trig}} < p_{\mathrm{T,high}}$ GeV/c, denoted TT$\{p_{\mathrm{T,low}}, p_{\mathrm{T,high}}\}$. Jets are reconstructed with charged-particle tracks using the anti-k_{T} algorithm and boost-invariant p_{T} recombination scheme. The event-wise median background energy density ρ is subtracted from these jets. The quantity we then measure is the **trigger-normalised yield**

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[*] e-mail: jaime.norman@cern.ch

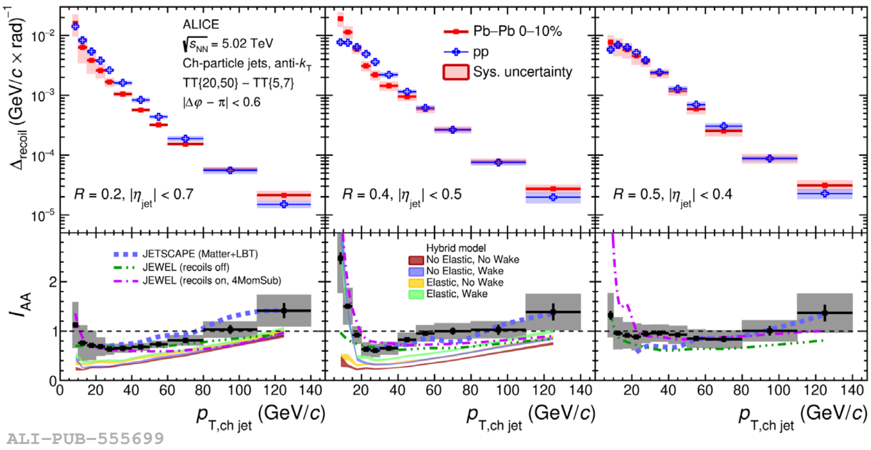

Figure 1. $\Delta_{recoil}(p_{T,jet})$ distributions for $R = 0.2$, $R = 0.4$, and $R = 0.5$ recoil jets in pp and central Pb–Pb collisions (upper panels), and $I_{AA}(p_{T,ch\ jet})$ with comparisons to theoretical calculations (lower panels).

of charged-particle jets recoiling from a high-p_T trigger hadron, as a function of the recoil jet transverse momentum $p_{T,jet}$ and the the trigger–recoil jet azimuthal separation $\Delta\varphi$. In particular, we define an observable Δ_{recoil} as

$$\Delta_{recoil}(p_{T,jet}, \Delta\varphi) = \frac{1}{N_{trig}} \frac{d^2 N_{jet}}{dp_{T,jet} d\Delta\varphi}\bigg|_{p_T^{trig} \in TT_{sig}} - c_{Ref} \times \frac{1}{N_{trig}} \frac{d^2 N_{jet}}{dp_{T,jet} d\Delta\varphi}\bigg|_{p_T^{trig} \in TT_{ref}}, \qquad (1)$$

i.e. the difference between the trigger-normalised jet yield measured in two exclusive trigger track intervals, $TT_{sig}(TT\{20, 50\})$ and $TT_{ref}(TT\{5, 7\})$. By taking into account that by definition, the trigger-normalised uncorrelated jet yield is independent of p_T^{trig}, this observable removes all uncorrelated background. For precise subtraction, the reference distribution is scaled by a normalisation factor c_{Ref} to account for conservation of jet density. To align the background energy density, in reference-classed events ρ is also scaled by a constant value which brings the ρ distribution into agreement with that in signal-classed events. Both corrections are described in detail in [4]. The Δ_{recoil} distributions are fully corrected for residual background fluctuations and detector effects using Iterative Bayesian Unfolding.

3 Results

The fully-corrected $\Delta_{recoil}(p_{T,jet})$ distributions in pp and Pb–Pb collisions are shown in the top panels of Fig. 1, for $R = 0.2$ (left), $R = 0.4$ (middle), and $R = 0.5$ (right) jets. It is notable that the uncorrelated background subtraction technique allows the measurement of jets down to $p_{T,jet} \sim 7$ GeV/c – among the lowest p_T for jets at the LHC. The ratios $I_{AA} = \Delta^{PbPb}_{recoil}/\Delta^{pp}_{recoil}$ are shown in the bottom panels of Fig. 1.

For $p_{T,jet} > 20$ GeV/c, for $R = 0.2$ and $R = 0.4$ the I_{AA} is below 1 which indicates jet suppression, and gradually increases such that I_{AA} is consistent with or above 1. This increase may indicate an evolution in the geometric bias of vertices which generate the recoil event as the trigger p_T and jet $p_{T,jet}$ become less balanced. This increasing trend is reproduced by both JETSCAPE [7] and the Hybrid model [8], while JEWEL [9] predicts a flatter trend, underestimating the data at high $p_{T,jet}$. For $R = 0.5$, the I_{AA} is consistent with 1 for this full $p_{T,jet}$

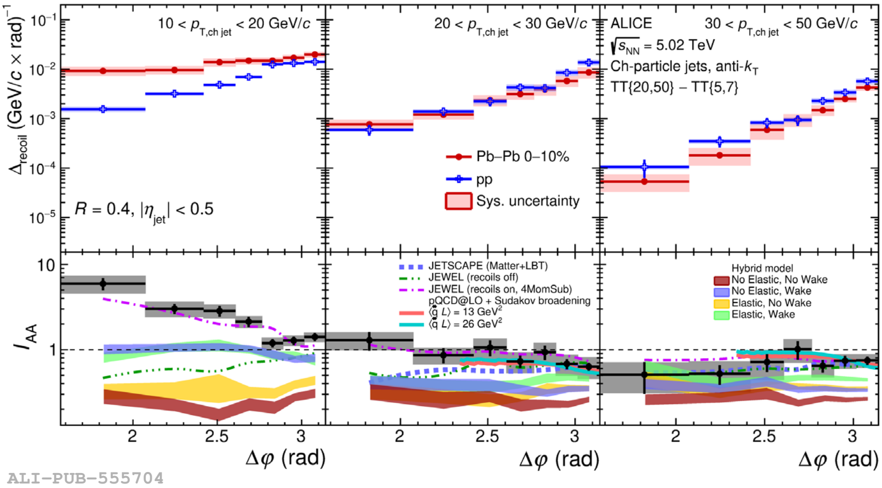

Figure 2. $\Delta_{\mathrm{recoil}}(\Delta\varphi)$ distributions for recoil jets with $R = 0.4$ in pp and central Pb–Pb collisions (upper panels) in $p_{\mathrm{T,ch\ jet}}$ intervals [10,20], [20,30], and [30,50] GeV/c (upper panels), and $I_{\mathrm{AA}}(\Delta\varphi)$ with comparisons to theoretical calculations (lower panels).

range, suggesting larger R jets are less suppressed, potentially due to the recovery of energy within a cone radius of ~ 0.5. This is in contrast to an ALICE measurement of inclusive jet production [10] where medium-induced narrowing is measured, however due to the different jet populations they cannot be compared directly. JEWEL (recoils on, which simulates medium response effects) qualitatively reproduces the increase in I_{AA} with increasing jet R.

For $p_{\mathrm{T,jet}} < 20$ GeV/c, a significant increase in I_{AA} is seen for $R = 0.4$ with decreasing $p_{\mathrm{T,jet}}$, which is reproduced by both the Hybrid model and JEWEL when medium response effects (‘wake’ in Hybrid model) are switched on. This suggests that the energy of ‘quenched’ jets at high $p_{\mathrm{T,jet}}$ is transferred to the medium and recovered at low $p_{\mathrm{T,jet}}$. This rise is however absent in the data for $R = 0.5$ jets at low $p_{\mathrm{T,jet}}$ within the experimental uncertainties.

The fully-corrected $\Delta_{\mathrm{recoil}}(\Delta\varphi)$ distributions in pp and Pb–Pb collisions are shown in the top panels of Fig. 2 for $R = 0.4$, in $p_{\mathrm{T,jet}}$ intervals from 10 GeV/c to 50 GeV/c. $I_{\mathrm{AA}}(\Delta\varphi)$ is shown in the bottom panels. In the lowest $p_{\mathrm{T,jet}}$ interval, a marked broadening of the $\Delta\varphi$ distribution is observed in Pb–Pb collisions (the I_{AA} has a slope inconsistent with 0 at a level of 4.7σ). This is the first observation of acoplanarity broadening in heavy-ion collisions.

JETSCAPE describes the peak but predicts a slight narrowing of the $I_{\mathrm{AA}}(\Delta\varphi)$ distributions which displays moderate tension with data. A LO pQCD calculation incorporating transverse broadening [2] displays slight broadening for two $\hat{q}$ values, though the data are not yet precise enough to resolve the difference. The Hybrid model reproduces the yield enhancement but not the magnitude of the broadening in the data when wake is switched on. Elastic scattering effects in this model do not generate broadening effects. JEWEL, on the other hand, reproduces quantitatively all features of the data when recoils are switched on.

The R dependence of the acoplanarity broadening is investigated in Fig. 3, where the $I_{\mathrm{AA}}(\Delta\varphi)$ distributions for $R = 0.2, 0.4$ and 0.5 are shown for the same $p_{\mathrm{T,jet}}$ intervals. Broadening of the distributions is seen in the [10,20] GeV/c $p_{\mathrm{T,jet}}$ interval for $R = 0.4$ and 0.5 jets, while narrower, $R = 0.2$ jets exhibit no broadening. JEWEL (recoils on) describes all of these data within uncertainties. While jet-medium scattering could result in broadening of the $\Delta\varphi$

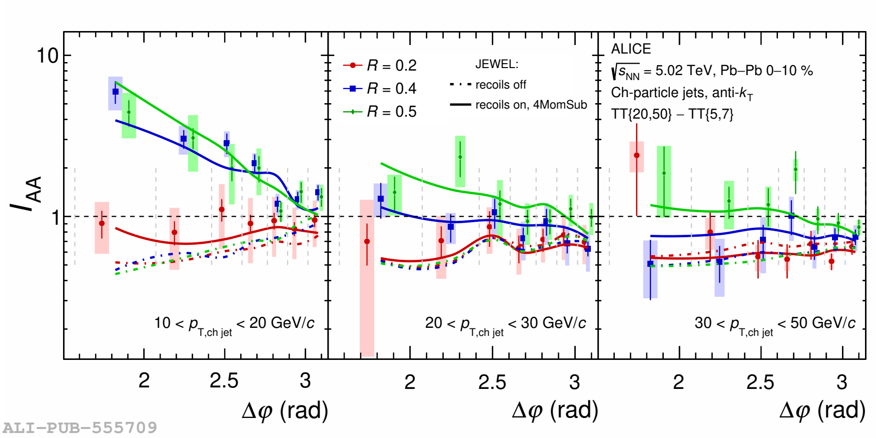

Figure 3. $I_{AA}(\Delta\varphi)$ for recoil jets with $R = 0.2$, $R = 0.4$, and $R = 0.5$, in $p_{T,ch\ jet}$ intervals [10,20], [20,30], and [30,50] GeV/c with comparisons to JEWEL.

distribution, the R-dependence suggests that the broadening is predominantly due to more soft and diffuse radiation (such as medium-induced wake effects), which may scale with the jet area and thus generate a rapid transition in the broadening effects from low to high R jets. The model comparisons also back up this picture.

4 Summary

The first observation of medium-induced jet yield excess and acoplanarity broadening has been presented. The data favour scenarios where the enhancement arises from the response of the QGP medium to jets, rather than large-angle jet scattering. This conclusion is also supported by model comparisons, although there is no model that describes all data, and future measurements and comparisons to theoretical calculations through global analyses will help constrain these new phenomena.

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