Jet structure in 2.76 TeV Pb–Pb collisions at ALICE

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Abstract

We present the analysis of the semi-inclusive distribution of reconstructed charged particle jets recoiling from a high $p_{\rm T}$ hadron trigger in central Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV. We measure, subtract and unfold the large underlying event background in such collisions, utilizing a novel technique that does not impose fragmentation bias on the measured jet population. The Pb–Pb measurements are compared to a pp PYTHIA reference distribution generated at the same $\sqrt{s}$. Modification of the jet structure due to quenching is explored by varying the cone radius R (0.2, 0.4) and the lower $p_{\rm T}$ cutoff of the charged particle constituents (0.15, 2.0 GeV/c).

The radiation pattern of jets produced in heavy ion collisions is expected to be modified with respect to vacuum fragmentation, due to interaction with the medium. Measurement of fully reconstructed jets aims to capture the full dynamics of jet quenching, to understand the mechanisms of in-medium jet energy loss and to infer the transport properties of the medium itself. In these proceedings, the structure of jets in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is studied and compared to vacuum fragmentation, as given by a PYTHIA calculation at the same energy. The measurement is based on the semi-inclusive distribution of reconstructed charged particle jets (anti-$k_{\rm T}$, $R = 0.2$ and 0.4) recoiling from a high $p_{\rm T}$ trigger hadron ("h+jet"). The h+jet coincidence measurement enables full correction for the large underlying event background without imposing bias on jet fragmentation, down to low jet $p_{\rm T}$.

The measurements are carried out using Pb–Pb collision data recorded by ALICE in 2010. Jets are reconstructed using the FastJet anti-$k_{\rm T}$ algorithm [1] with resolution parameter $R = 0.2$ and $R = 0.4$, and with input consisting of all charged tracks reconstructed in the ALICE central barrel acceptance ($|\eta| < 0.9$, $p_{\rm T}> 0.15$ GeV/c). Jet reconstruction utilizing tracks with $p_{\rm T}> 2.0$ GeV/c was also considered, to study the contribution of soft particles to the jet energy. All jets with jet axis lying within $|\eta(\rm jet)| < 0.5$ are accepted for further analysis. The 20% most central Pb–Pb collisions are selected. In each event, the charged hadron with the largest $p_{\rm T}$ is designated the "trigger" hadron, with momentum $p_{\rm T}^{\rm trig}$. The semi-inclusive distribution of recoil jets is measured by counting the number of jets in the event population within the recoil azimuth relative to the trigger direction, $|\varphi(\rm trig) - \varphi(\rm jet)| < \pi - 0.6$, binned differentially in both $p_{\rm T}^{\rm trig}$ and $p_{\rm T,jet}^{\rm ch}$ and normalized to the corresponding number of triggers. Hadron triggers are considered only for $p_{\rm T}> 10$ GeV/c. The probability of two such triggers occuring in a central Pb–Pb event is negligible. Such triggers, therefore, isolate a single hard process in the collision, for which we aim to measure the recoil jet distribution. Hadrons are prefered to jet triggers in this analysis, since measurement of high $p_{\rm T}$ hadrons in both pp and Pb–Pb collisions can be carried

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

out accurately without having to correct the measured $p_{\rm T}$ for underlying event effects, allowing a more precise comparison of the two systems.

The effects on the recoil jets of the large underlying event in central Pb–Pb collisions are addressed in two distinct steps, correcting separately for the median background level and for its fluctuations. The first step, carried out on an event-by-event and jet-by-jet basis, estimates the median momentum density ρ [6] and subtracts $\rho \times A$ from each jet, where A is the jet area [2]. The ρ calculation excludes the two hardest clusters in the event, to reduce the influence of the true signal on the background estimate.

Since ρ is calculated as the median of $p_{\rm T}/A$ for all $k_{\rm T}$ clusters in the event, about half of the reconstructed jet population will in practice have $p^{\rm ch}_{\rm T,jet} < 0$ after subtraction of $\rho \times A$. A large fraction of these negative energy "jets" is due to the recombination of hadrons that are nearby in phasespace but have been generated by multiple incoherent processes ("combinatorial jets"). This component of the jet spectrum contains valuable information about the fluctuation structure of the events, which also distorts the measurement of true, hard coincidence jets. We therefore retain this noise component until a late stage in the analysis, utilizing it to correct the effect of fluctuations without imposing bias on the hard jet population.

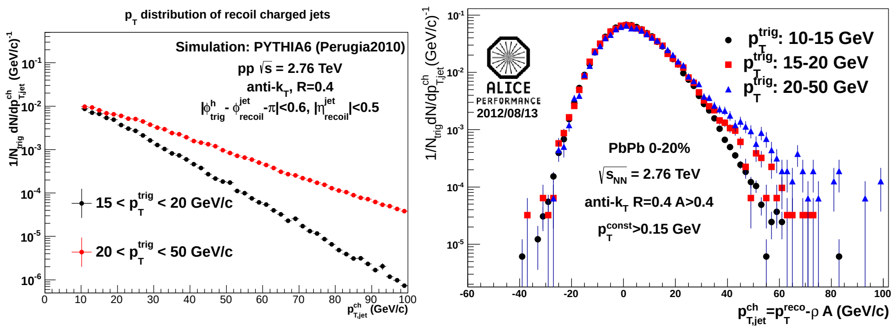

Figure 1: Recoil jet distributions for a pp PYTHIA calculation at 2.76 TeV (left), and the same observable measured in 0-20% central Pb–Pb collisions(right)

Fig. 1 (left) shows a PYTHIA calculation (Perugia10 tune [4]) of the semi-inclusive recoil jet spectrum in 2.76 TeV pp collisions for two different $p_{\rm T}^{\rm trig}$intervals. The recoil jet distribution is seen to depend strongly on $p_{\rm T}^{\rm trig}$, as expected, since a harder hadron trigger biases towards higher Q^2 processes on average.

Model studies show that a high $p_{\rm T}$ hadron trigger induces a geometrical bias, towards jets generated on the surface of the fireball and directed outward. The jet population recoiling from such a trigger is therefore biased towards larger in-medium path length compared to the inclusive population or the population recoiling from a jet trigger [5]. The hadron trigger imposes a low $p_{\rm T}$ suppression on the recoil jet spectrum: at LO the hadron $p_{\rm T}$ provides the strict lower bound for recoil jet $p_{\rm T}$, though there are higher-order and non-perturbative effects that smear this threshold in practice. There are additional biases induced by the hadron trigger, in event centrality, reaction plane orientation, and nuclear $k_{\rm T}$ effects. However, for the high p_T range of hadron triggers considered in this analysis, all such effects have only weak, if any, dependence on hadron $p_{\rm T}$, and their effects are to a large extent removed by the differential spectrum technique described below.

In this analysis we apply a new approach to suppress the combinatorial background for the h+jet measurement [3]. We observe that the distribution of combinatorial background jets is, by definition, *uncorrelated* with trigger p_{T}, and its shape is observed to be identical for all choices of trigger p_{T}. This raises the possibility of a purely data-driven elimination of the combinatorial jet population, by considering the measurement of the *difference* of two measured jet distributions with hadron triggers in different p_{T} intervals:

$$\Delta_{\mathrm{recoil}}((p_{\mathrm{T}}^{\mathrm{trig},1}\text{-}p_{\mathrm{T}}^{\mathrm{trig},2})-(p_{\mathrm{T}}^{\mathrm{trig},3}\text{-}p_{\mathrm{T}}^{\mathrm{trig},4})) = \frac{1}{\mathrm{N_{trig}}}\frac{\mathrm{dN}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}(p_{\mathrm{T}}^{\mathrm{trig},2}<p_{\mathrm{T}}^{\mathrm{trig}}<p_{\mathrm{T}}^{\mathrm{trig},1})-c\frac{1}{\mathrm{N_{trig}}}\frac{\mathrm{dN}}{\mathrm{d}p_{\mathrm{T,jet}}^{\mathrm{ch}}}(p_{\mathrm{T}}^{\mathrm{trig},4}<p_{\mathrm{T}}^{\mathrm{trig}}<p_{\mathrm{T}}^{\mathrm{trig},3})$$

Scaling of the lower p_T^{trig} distribution is applied to account for the observed strict conservation of jet density in the experimental acceptance, which results in increasing displacement of combinatorial jets by true, hard coincidence jets as p_T^{trig} increases. The scaling factor, c, is measured in the region $p_{\mathrm{T,jet}}^{\mathrm{ch}} < 0$ where the combinatorial contribution dominates, and differs from unity by about 5%.

The remaining distribution in this difference observable, is therefore not due to combinatoric jets. It represents the *evolution* of the true recoil jet distribution from the same hard interaction as the trigger, as the trigger p_{T} evolves from the lower p_{T} trigger interval ("reference") to the higher p_{T} trigger interval ("signal"). This observable, while uncommon, is nevertheless perturbatively well-defined.

Monte Carlo calculations of this observable require, in addition to perturbative processes, an accurate description of inclusive particle production to model the trigger. Comparison to these data then tests the modeling of the recoil (quenched) jet. We note that the analysis procedure removes the combinatorial jet component from the measured jet distribution without imposing any bias on jet fragmentation.

Correction of the measured jet p_{T} for fluctuations utilizes a response matrix based on the random cone technique [6], while the detector response is simulated using PYTHIA-generated jets. We unfold using two different iterative methods, based on χ^2 minimization and on Bayes's Theorem. Their difference contributes to the anti-correlated shape uncertainty in the figures.

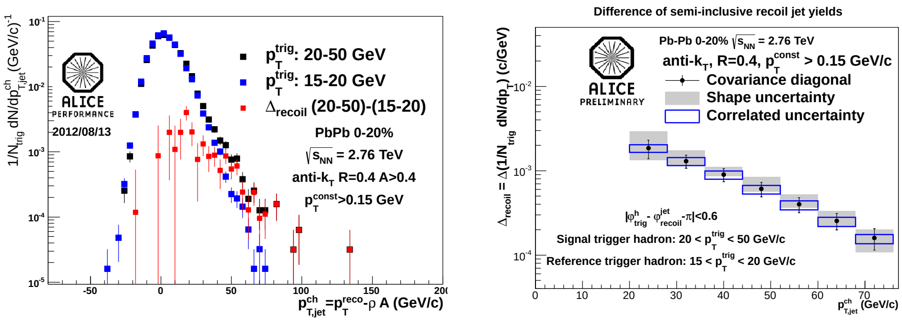

Figure 2: Δ_{recoil}((20-50)-(15-20)) raw (left) and corrected (right) distribution for R = 0.4 and p_T^{const}=0.15 GeV

Fig.1 right, shows the h+jet recoil distribution for R = 0.4, and for three exclusive intervals of trigger p_{T}. For $p_{\mathrm{T,jet}}^{\mathrm{ch}}$< 20 GeV/$c$ the distributions are uncorrelated with the trigger p_{T} and are seen to be very similar, consistent with dominance by the combinatorial jet contribution. In contrast, at larger $p_{\mathrm{T,jet}}^{\mathrm{ch}}$ the distributions are correlated with trigger p_{T} , consistent with dominance

by hard jets from the same hard scattering as the trigger.
In Fig.2 (left) the recoil jet distribution for two trigger classes as well as their difference Δ_{recoil}((20-50) − (15-20)) are plotted. Note the exponential shape of the distributions, indicating that the unfolding of background fluctuations and detector effects will be a small correction. The plot on the right shows the corrected Δ_{recoil} for the same choice of trigger classes.

To explore the energy redistribution within the recoil jets, we consider the ratio for the measured Δ_{recoil} distribution over the same observable calculated with PYTHIA, $\Delta_{\text{IAA}}^{\text{PYTHIA}}$. This ratio is presented in Fig.3 for $R = 0.4$ and $p_{\text{T}}^{\text{const}} > 0.15$ GeV, for $R = 0.2$ and $p_{\text{T}}^{\text{const}} > 0.15$ GeV and for $R = 0.4$ and $p_{\text{T}}^{\text{const}} > 2$ GeV. Comparison of these distributions does not indicate a large energy redistribution, relative to PYTHIA, either transverse to the jet axis, or towards lower p_{T} of constituents, though more precise statements will be possible with reduced systematic uncertainties and higher statistics data.

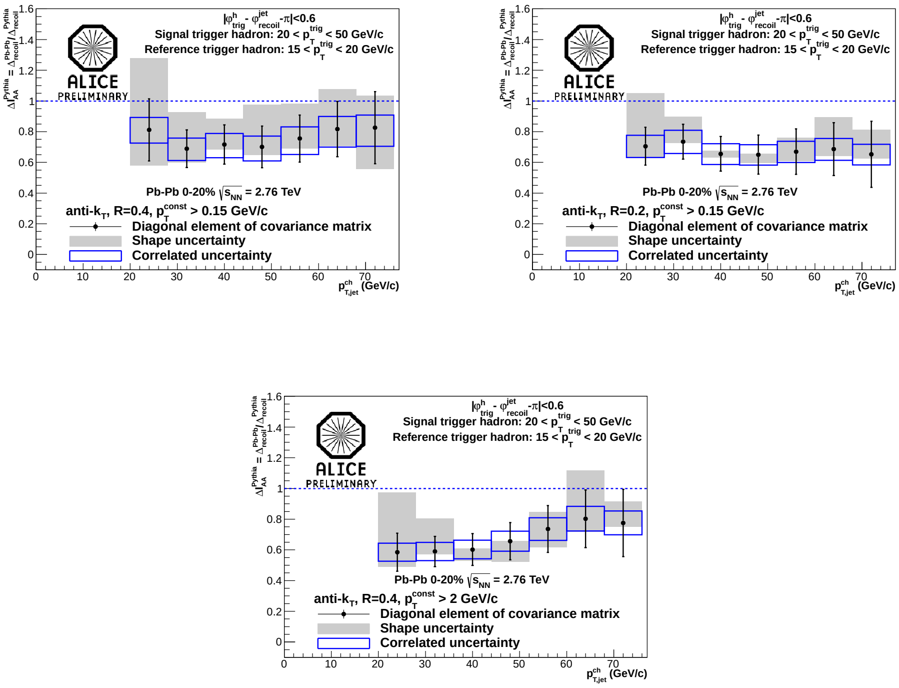

Figure 3: Δ_{IAA}^{PYTHIA} distributions for different radius and minimum constituent cut selections.

References

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