Measurement of jet quenching with I_{CP} and $I_{AA,Pythia}$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$ with ALICE

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This paper discusses the measurement of I_{CP} and $I_{AA,Pythia}$ with ALICE (A Large Ion Collider Experiment). An away-side suppression is found expected from in-medium energy loss. Further, and unexpected, a near-side enhancement is seen which has not been reported by previous experiments at lower energies.

The objective of the study of ultra-relativistic heavy ion-collisions is the characterization of the quark–gluon plasma, the deconfined state of quarks and gluons. Recent measurements by ALICE indicate that in central Pb-Pb collisions at the LHC unprecedented color charge densities are reached. For example, the suppression of charged hadrons in central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76\,\text{TeV}$ expressed as the nuclear modification factor $R_{\rm AA}$ as a function of transverse momentum (p_T) reaches a value as low as 0.14.[1]

Di-hadron correlations allow for the further study of in-medium energy because for most pairs of partons scattered in opposite directions, one will have a longer path through the medium than the other. Thus, two-particle correlations can be used to study medium effects without the need of jet reconstruction. In such studies the near-side (particles found close to each other in azimuthal angle) and the away-side (particles found at azimuthal angles different by about π) yields are compared between central and peripheral events (I_{CP}) or studied with respect to a pp reference (I_{AA}). Previous measurements at RHIC have shown a significant suppression of the away-side yield consistent with a strongly interacting medium.[2,3] On the near-side no significant modifications have been observed at high p_T. Such analysis usually require the subtraction of non-jet correlations, e.g. flow, which are present in A+A collisions but not in pp collisions and therefore have influence on the extracted yields. This analysis chooses a p_T-region where the jet peak is the dominant correlated signal and thus the influence of non-jet correlations is small.

1 Detector and Data Sample

The ALICE detector is described in detail elsewhere.[4] For the present analysis the Inner Tracking System (ITS) and the Time Projection Chamber (TPC) are used for vertex finding and tracking. The TPC has a uniform acceptance in azimuthal angle and a pseudorapidity coverage of $|\eta| < 0.9$. The uniform acceptance results in only small required acceptance corrections. Forward scintillators (V0) are used to determine the centrality of the collisions.

About 12 million minimum-bias events recorded in fall 2010 have been used in the analysis. Good-quality tracks are selected by requiring at least 70 (out of 159) associated clusters in the TPC, and a χ^2 per space point of the momentum fit smaller than 4. In addition, tracks are required to originate from within $2 - 3\,\text{cm}$ of the primary vertex.

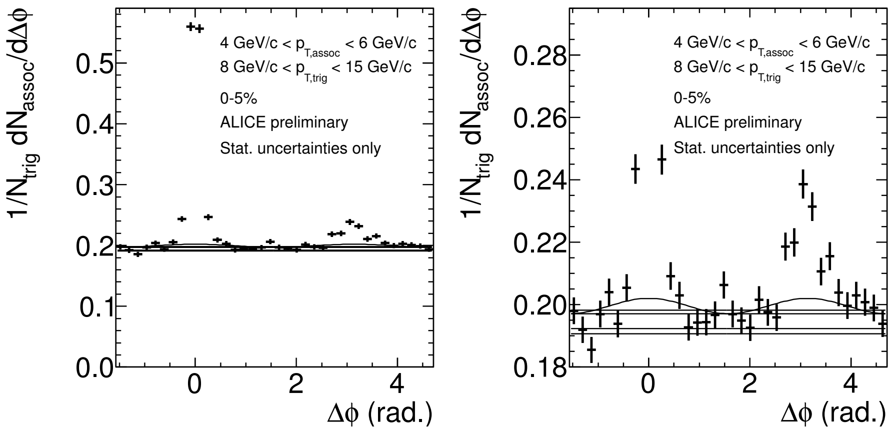

Figure 1: Per-trigger yield in an example bin: the right panel shows a zoom of the left panel. Indicated are the determined pedestal values (horizontal lines) and the v_2 component ($\cos 2\Delta\phi$ term). For details see text.

2 Analysis

The quantity which is obtained in this analysis is the associated per-trigger yield as function of the azimuthal angle difference:

$$\frac{dN}{d\Delta\phi}(\Delta\phi) = \frac{1}{N_{\mathrm{trig}}}\frac{dN_{\mathrm{assoc}}}{d\Delta\phi} \tag{1}$$

where N_{trig} is the number of trigger particles to which N_{assoc} particles are associated at $\Delta\phi = \phi_{\mathrm{trig}} - \phi_{\mathrm{assoc}}$. We measure this quantity for all pairs of particles where $p_{T,\mathrm{assoc}} < p_{T,\mathrm{trig}}$ within $|\eta| < 0.8$ and normalize by $\Delta\eta = 1.6$. Due to the flat acceptance in ϕ no mixed-event correction is needed. The per-trigger yield is extracted in bins of $p_{T,\mathrm{trig}}$ and $p_{T,\mathrm{assoc}}$.

Pedestal Subtraction To remove uncorrelated background from the associated yield, the pedestal value needs to be determined. This is done by fitting the region close to the minimum of the $\Delta\phi$ distribution ($\Delta\phi \approx \pm\frac{\pi}{2}$) with a constant and using this value as pedestal (zero yield at minimum – ZYAM). One cannot exclude a correlated contribution in this region (e.g. from 3-jet events), and we do not claim that we only remove uncorrelated background. Instead we measure a yield with the prescription given here. To estimate the uncertainty on the pedestal determination, we use four different approaches (different fit regions as well as averaging over a number of bins with the smallest content). Fig. 1 shows the per-trigger yield for an example bin. The horizontal lines indicate the determined pedestal values; their spread gives an idea of the uncertainty. Also indicated is a background shape considering v_2. The v_2 values are taken from an independent measurement (a measurement of v_2 at high p_T similar to [5]. For the centrality class $60-90\%$ no v_2 measurement was available, therefore, as an upper limit, v_2 is taken from the $40-50\%$ centrality class as it is expected to reduce towards peripheral collisions). For a given bin the v_2 background is $2\langle v_{2,\mathrm{trig}}\rangle\langle v_{2,\mathrm{assoc}}\rangle \cos 2\Delta\phi$ where the $\langle ...\rangle$ is calculated taking into account the p_T distribution of the trigger and associated particles. The yields are then calculated with and without removing the v_2 component. Subsequently to the pedestal (and optionally v_2) subtraction, the near and away side yields are integrated within $\Delta\phi$ of ± 0.7 and $\pi \pm 0.7$, respectively.

Systematic Uncertainties The influence of the following effects has been studied and considered for the systematic uncertainty on the extracted yields: detector efficiency and two-track effects, uncertainties in the centrality determination, p_T resolution, the size of the integration window for the near and away-side yield as well as uncertainties in the pedestal determination.

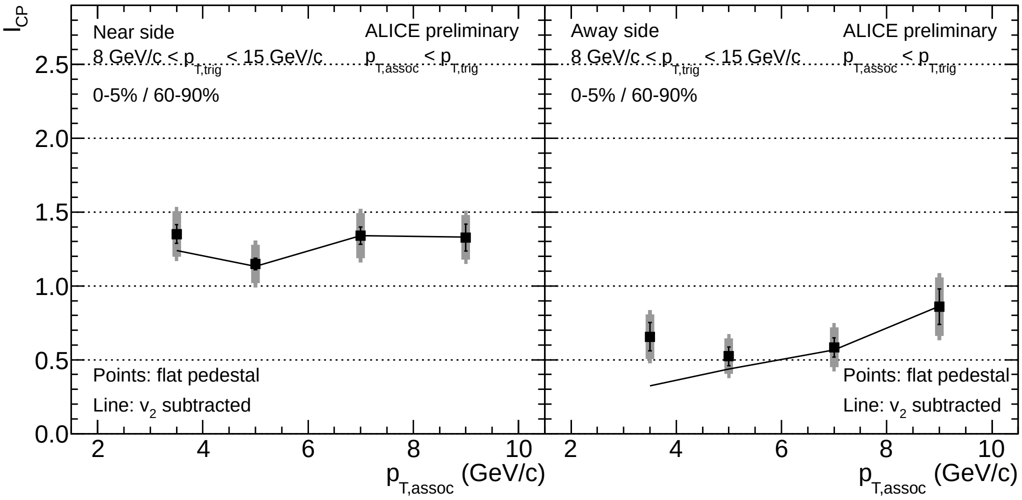

Figure 2: I_{CP}: the data points are calculated with a flat pedestal; the line is based on v_2 subtracted yields.

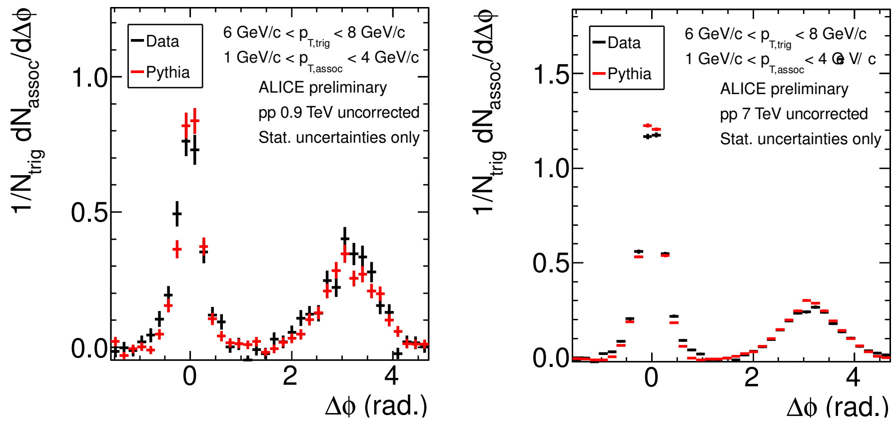

Figure 3: Uncorrected pedestal-subtracted per-trigger yields from pp collisions at 0.9 (left) and 7 TeV (right) are compared to a scaled MC (Pythia 6.4 with the tune Perugia-0).

The last mentioned item has the largest contribution (7-20%) to the systematic uncertainties on I_{CP} and $I_{AA,Pythia}$.

Results To quantify the effect of the in-medium energy loss, ratios of central to peripheral yields are calculated $I_{CP} = Y_{\mathrm{central}}/Y_{\mathrm{peripheral}}$ where Y_{central} ($Y_{\mathrm{peripheral}}$) is the yield in central (peripheral) collisions, respectively. Fig. 2 shows I_{CP} using the flat pedestal (data points) and v_2 subtracted yields (lines). That the only significant difference is in the lowest bin of $p_{T,\mathrm{assoc}}$ confirms the small influence of flow in this p_T region. It should be noted that we only consider v_2 here, although the v_3 contribution might be of the same order, particularly for central events. The away-side suppression from in-medium energy loss is seen, as expected. Moreover, there is an unexpected enhancement above unity on the near-side.

To study this further, and in particular if the enhancement is due to using peripheral events in the denominator, it is interesting to calculate $I_{AA} = Y_{\mathrm{Pb-Pb}}/Y_{\mathrm{pp}}$ where $Y_{\mathrm{Pb-Pb}}$ (Y_{pp}) is the yield in Pb-Pb (pp) collisions, respectively. No pp collisions at the same center-of-mass energy than the recorded Pb-Pb collisions had been produced yet at the time of this analysis. Therefore the option of using a MC as reference has been investigated. Fig. 3 compares uncorrected pedestal-subtracted per-trigger yields of pp collisions taken with ALICE to Pythia[6] 6.4 with the tune Perugia-0[7] at $\sqrt{s} = 0.9$ and 7 TeV. The MC has been scaled such that the yields on the near side agree with each other. The required scaling factor is $0.8 - 1$ depending on p_T. One can see

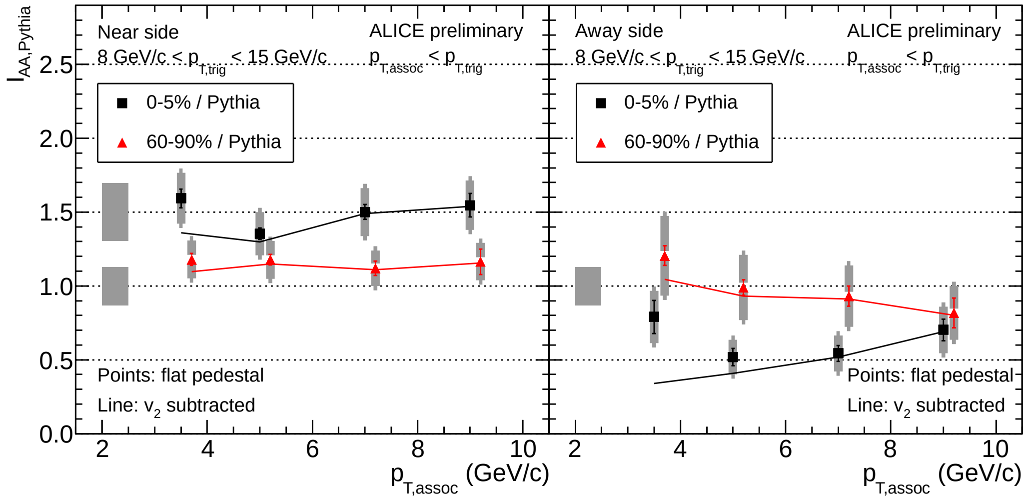

Figure 4: $I_{AA,Pythia}$: the data points are calculated with a flat pedestal; the line is based on v_2 subtracted yields.

that the away side is described well without applying an additional scaling. The scaling factor interpolated to the Pb-Pb energy of 2.76 TeV is then found to be $0.93 \pm 13\%$.

Yields extracted from Pythia 6.4 Perugia-0 with the mentioned scaling factor are used to measure $I_{AA,Pythia}$, shown in Fig. 4. As before the data points use the flat pedestal subtraction and the lines use the v_2 subtraction. The difference is rather small and only in the smallest $p_{T,\mathrm{assoc}}$ bins. $I_{AA,Pythia}$ in peripheral events is consistent with unity, but the near side is slightly higher than the away side. This could indicate a slightly different description of the near and away side in the MC. The qualitative behavior of $I_{AA,Pythia}$ in central events is consistent with I_{CP}. The away side is suppressed and the near side significantly enhanced. Such an enhancement has not been reported at lower energies. E.g. STAR measured a near-side I_{AA} consistent with unity[3].

Near-Side Enhancement A near-side enhancement at LHC was predicted albeit for larger $p_{T,\mathrm{trig}}$: an enhancement of $10-20\%$ is reported and attributed to the enhanced relative abundance of quarks w.r.t. gluons escaping the medium.[8] Gluons couple stronger to the medium due to their different color charge and their abundance is reduced. The quarks fragment harder and thus produce an enhanced associated yield. Furthermore, a near-side enhancement can be understood if one assumes that the near-side parton is also quenched. Then trigger particles with similar p_T stem from partons with higher p_T in Pb-Pb collisions than in pp collisions. Consequently, more energy is available for particle production on near and away side.

It should be stressed that a MC was used as a reference for $I_{AA,Pythia}$ and it will be interesting to study if I_{AA} using pp collisions shows the same behavior. Such a study is ongoing using newly taken data of pp collisions provided by the LHC in the week after this conference.

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