Measurement of jet quenching with $I_{CP}$ and $I_{AA,Pythia}$ in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ 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 $\sqrt{s_{NN}} = 2.76$ TeV expressed as the nuclear modification factor $R_{AA}$ 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 $\pi$) 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 $\chi^2$ per space point of the momentum fit smaller than 4. In addition, tracks are required to originate from within $2 - 3$ 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:

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

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

**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. 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 [6]). 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 $2\langle v_{2,\text{trig}} \rangle \langle v_{2,\text{assoc}} \rangle \cos 2\Delta \phi$ 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 $\pm 0.7$ 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.
The last mentioned item has the largest contribution (7-20\%) to the systematic uncertainties on $I_{CP}$ and $I_{AA,P_{Pythia}}$.

**Results** To quantify the effect of the in-medium energy loss, ratios of central to peripheral yields are calculated $I_{CP} = Y_{\text{central}} / Y_{\text{peripheral}}$ where $Y_{\text{central}}$ ($Y_{\text{peripheral}}$) 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 $p_T$, 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 $I_{AA} = Y_{\text{Pb-Pb}} / Y_{\text{pp}}$ where $Y_{\text{Pb-Pb}}$ ($Y_{\text{pp}}$) 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 6.4 with the tune Perugia-0 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...
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 $p_T,assoc$ 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.

Near-Side Enhancement A near-side enhancement at LHC was predicted albeit for larger $p_T, trig$: an enhancement of $10 - 20\%$ is reported and attributed to the enhanced relative abundance of quarks w.r.t. gluons escaping the medium. 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.

References

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