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Probing the medium with jets in ALICE

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Abstract. Among the different hard probes, jet results have been here selected to present a unique insight into the nature of the hot QCD matter. Jets are reconstructed from charged particles using the anti-$k_T$ algorithm with the ALICE detector at the LHC in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in a momentum range down to 0.150 GeV and in a pseudorapidity range $|\eta| < 0.9$. We report inclusive jet spectra and ratios as a function of the jet transverse momenta ($p_T$) for different centrality classes and jet radii. Strong suppression of the inclusive jet spectrum has been observed in the most central collisions. Comparison with theory puts more stringent constraints on modeling jet modification and energy loss in dense matter.

1. Introduction
In the study of the Quark Gluon Plasma (QGP), the hard probes are commonly considered the direct probes able to resolve the sub-hadronic scales and distinguish confined and deconfined media in the different steps of the fragmentation. Jets with large transverse momentum play an essential role in the space-time tomography study of the relativistic heavy-ion collisions and of the QGP. This is because, being produced in the early stage of the reaction, prior to the formation of the hot medium, jets interact with the traversed dense matter through elastic and inelastic collisions loosing some of their initial energy, quenching [1], in the process.

In this proceeding, ALICE preliminary results on charged jet reconstruction, in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, are discussed. Single inclusive charged jet cross sections for different radii are presented. Jet suppression and jet broadening are explored.

The jet momenta contamination from soft production and the remaining influence of underlying event fluctuations are the largest contribution to the uncertainty in the jet energy. They are treated event by event and by an embedding procedure [2] while the final reconstructed transverse momenta are corrected by unfolding.

2. Dataset and unfolding
For this analysis, data collected in the heavy-ion runs of 2010 are used. For the jet reconstruction the anti-$k_T$ algorithm from the FastJet package [3] with resolution parameters R=0.2 and R=0.3 is used. Since the electromagnetic calorimeter has only been fully installed in the beginning of 2011, jets use only charged tracks with $p_T > 0.150$ GeV and their 4-momentum vector is calculated using the boost invariant $p_T$ recombination scheme. The Time Projection Chamber (TPC) and the Inner Tracking System (ITS) are the main detectors to measure the charged particle momenta in the pseudorapidity range $|\eta| < 0.9$. 

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In the Pb-Pb collisions, the background from the Underlying Event (UE) contribution plays a very important role and must be subtracted from the reconstructed jet $p_T$. The summed transverse momentum from the UE is calculated as the product of the mean momentum density $\rho = \text{median}(p_{jet}^{T}/A_{jet}^{}}$ and the jet area $A_{jet}$.

The smearing introduced by the UE energy fluctuation can be evaluated by $\delta p_T = (p_{rec}^{T} - \rho A_{jet}^{T}) - p_{true}^{T}$ which give the difference between the UE corrected summed $p_T$ and the true jet. The embedding method to determine $\delta p_T$ is described in [2].

Moreover, background fluctuations have a large impact on the measured jet spectrum due to the tail to upwards fluctuations in the $\delta p_T$ distribution. These fluctuations are corrected for by unfolding [4]. A response matrix $RM_{\delta p_T}$ containing the $p_T$ smearing due to background fluctuations is constructed from the measured $\delta p_T$ distribution.

Detector effects affecting the jet energy resolution have been studied with the detector simulation using PYTHIA and HIJING. The magnitude of these corrections results in a 10% shift in the jet energy scale which corresponds to 40% on the jet yield. The uncertainty on the exact knowledge of the tracking efficiency results in a 3% uncertainty on the jet energy scale reported in the systematic uncertainty of the measurement.

The two response matrices from background fluctuations and detector effects are combined to obtain the response matrix which will be used in the unfolding procedure: $M = RM_{\delta p_T} \cdot RM_{det} \cdot T$ in which $M$ is the measured jet yield and $T$ is the true jet yield.

Jet spectra are unfolded using a $\chi^2$ minimization method. Using this method the number of jets is always conserved. The $\chi^2$ function to be minimized indicates how well the unfolded distribution convoluted with the response matrix (the refolded spectrum) describes the measured spectrum. The $\chi^2$ function used in this analysis is:

$$\chi^2 = \sum_{\text{refolded}} \left( \frac{y_{\text{refolded}} - y_{\text{measured}}}{\sigma_{\text{measured}}} \right)^2 + \beta \sum_{\text{unfolded}} \left( \frac{d^2 \log y_{\text{unfolded}}}{d \log p_T^2} \right)^2.$$ (1)

The first summation term of equation 1 gives the $\chi^2$ between the refolded spectrum and the measured jet spectrum. The second summation term of equation 1 is the penalty term which is used to regularize the unfolded solution and favors a local power law. Regularization is necessary to avoid heavily fluctuating solutions. The strength of the applied regularization $\beta$ is tuned so as to make sure the regularization term is not dominant. In case the regularization is dominant the penalty term is equal to or larger than the $\chi^2$ between the refolded and measured spectrum. In this case the refolded spectrum does not describe the measured spectrum. In case the regularization is too weak or too strong off-diagonal correlations in the Pearson coefficients extracted from the covariance matrix are observed.

The regularization adds a systematic uncertainty of $\sim$ 10% for central events and $\sim$ 4% for peripheral events to the unfolded yield.

3. Results
Fig.1 shows the charged jet yields as a function of $p_T$ normalised by the number of collisions with a resolution parameter $R=0.3$. Comparing jet spectra for different centrality classes, a sizable suppression increasing with centrality can be observed.

In order to study the modification of the Pb-Pb spectra with respect to an incoherent superposition of binary nucleon-nucleon collision, the jet nuclear modification factor $R_{\text{Pythia}}^{Pb-Pb}$ is shown in Fig.2. As a reference, we use the jet spectrum from PYTHIA-Perugia0 [5] simulated at the same centre of mass energy. A strong jet suppression is observed for central events similar to the $R_{AA}$ of inclusive charged particles.

These results show that the full jet energy is not contained in jets with radii $R=0.2$ or $R=0.3$ for the heavy-ion collisions. In Fig.3, the ratio $R_{CP}$, central to peripheral for $R=0.3$, shows the jet yield measured with respect to 50-80% centrality, used as a reference.
Another important observable to measure is the ratio between the jet spectra for radii $R=0.2$ and $R=0.3$, as plotted in Fig.4. The result shows a jet production consistent with the one in vacuum for central to peripheral highlighting no significant jet broadening in the cross section ratio. A possible rise with $p_T$ is shown due to the fact that higher $p_T$ jets are more collimated. The data points are also in agreement with the pQCD and PYTHIA$^8$ [6] calculation.

In Fig.5 and Fig.6, the charged jet results are compared to the JEWEL jet quenching MC.
A good agreement is observed between the energy loss implementation of JEWEL and the charged jet results from ALICE.

**Figure 5.** Comparison between JEWEL and measured charged jet $R_{AA}$ for jet radius $R = 0.3$.

4. Conclusions

Important steps in the understanding of the heavy-ion collisions and the QGP physics have been achieved by ALICE. A strong suppression of the inclusive jet yield, in central collisions with respect to a PYTHIA $pp$ reference, is observed. The measured suppression amounts to 0.20-0.35 in the momentum range 30-100 GeV. Measuring the ratio of jet yields at different resolutions, there is no indication of energy redistribution within the experimental uncertainties. These results are in qualitative agreement with models and are able to constrain or to exclude other models and calculations.

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