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NUCLEAR PHYSICS A

Nuclear Physics A 904–905 (2013) 1015c–1018c

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# Measurement of jet spectra with charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}$=2.76 TeV with the ALICE detector

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**Abstract**

We report a measurement of transverse momentum spectra of jets detected with the ALICE detector in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Jets are reconstructed from charged particles using the anti-$k_{\rm T}$ jet algorithm. The transverse momentum of tracks is measured down to 150 MeV/$c$ which gives access to the low $p_{\rm T}$ fragments of the jet. The background from soft particle production is determined for each event and subtracted. The remaining influence of underlying event fluctuations is quantified by embedding different probes into heavy-ion data. The reconstructed transverse momentum spectrum is corrected for background fluctuations by unfolding. We observe a strong suppression in central events of inclusive jets reconstructed with radii of 0.2 and 0.3. The fragmentation bias on jets introduced by requiring a high $p_{\rm T}$ leading particle which rejects jets with a soft fragmentation pattern is equivalent for central and peripheral events.

*Keywords:* jet quenching, hard probes, Quark Matter

Jets are a powerful tool to study the properties of the medium created in heavy-ion collisions. The kinematic properties of the jets reflect the kinematic properties of the original hard partons from the hard process. It is expected that the kinematic properties of jets are modified in the presence of a medium. The challenge in heavy-ion collisions is to disentangle the jet fragments originating from hard scatterings from the very large background due to soft processes.

This analysis uses data collected by the ALICE experiment in the heavy-ion run of the LHC in the fall of 2010 with an energy $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Jets are clustered from charged particles measured in the central tracking detectors: Inner Tracking System (ITS) and Time Projection Chamber (TPC). This ensures a uniform acceptance in full azimuth and $|\eta| < 0.9$ with high tracking efficiency.

For the clustering of jet candidates the anti-$k_{\rm T}$ algorithm [1] with resolution parameters $R = 0.2$ and $R = 0.3$ is used. We subtract from each jet candidate event-by-event the average background. The minimum $p_{\rm T}$ of the jet constituents is 0.15 GeV/$c$. All jets with a jet axis within $|\eta| < 0.5$ are considered for this analysis. The $k_{\rm T}$ algorithm [2] is used to obtain a collection of background clusters in each event from which the average transverse momentum per unit area $\rho$ is calculated by taking the median of $(p_{\rm T,j}/A_{\rm j})$ (where $A_j$ is the area of the background cluster) of all $k_{\rm T}$ clusters. To reduce the contribution from true hard jets the two leading $k_{\rm T}$ clusters are excluded from the calculation of $\rho$. The estimated background momentum $\rho \cdot A$ is subtracted from the reconstructed $p_{\rm T}$ of each anti-$k_{\rm T}$ jet candidate in the event [3, 4].

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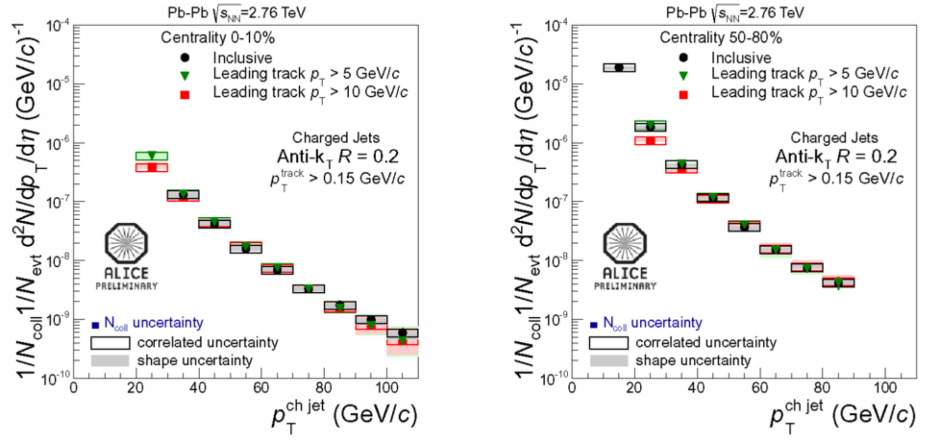
http://dx.doi.org/10.1016/j.nuclphysa.2013.02.187

Point-to-point fluctuations of the background are quantified by placing random cones in the measured Pb–Pb events and by embedding high $p_{\rm T}$ probes [5]. The reconstructed transverse momentum $p_{\rm T}^{\rm rec}$ of the embedded probe in the heavy-ion environment is compared to the embedded transverse momentum $p_{\rm T}^{\rm probe}$ by calculating the difference: $\delta p_{\rm T} = p_{\rm T}^{\rm rec} - \rho \cdot A_{\rm jet} - p_{\rm T}^{\rm probe}$. Fluctuations of the background depend strongly on the multiplicity, jet area (or radius) and minimum $p_{\rm T}$ of the jet constituents $p_{\rm T}^{\rm const}$. Background fluctuations have a large impact on the measured jet spectrum due to the finite probability for large positive flucuations. The width of the background fluctuations, $\sigma(\delta p_{\rm T})$, for 10% most central events and $p_{\rm T}^{\rm const} > 0.15$ GeV/$c$ is 4.47 GeV/$c$ for $R = 0.2$ jets and 7.15 GeV/$c$ for $R = 0.3$ jets. Background fluctuations are corrected for statistically via unfolding. Combinatorial jets consisting of a random collection of particles which do not originate from a hard process are removed in the unfolding by not constraining the region below $p_{\rm T}^{\rm measured} = 30$ GeV/$c$ with measured data. In addition, jet spectra are also extracted by requiring a minimum $p_{\rm T}$ of the leading track in the jet. The requirement of a high $p_{\rm T}$ leading track removes a large part of the combinatorial jets in the sample while introducing a bias to harder fragmentation. Jets with a soft fragmentation pattern are removed from the sample when a high $p_{\rm T}$ leading track is required.

## Results




(b) Centrality 50 – 80%

Figure 1: Inclusive jet spectra with no requirement on the leading track and jets with a leading track of at least 5 and 10 GeV/$c$.

Jet spectra are unfolded using a $\chi^2$ minimization method which minimizes the difference between the unfolded spectrum convoluted with the response matrix (the refolded spectrum) and the measured spectrum. The $\chi^2$ function used in this analysis is:

$$\chi^2 = \sum_{\rm refolded} \left( \frac{y_{\rm refolded} - y_{\rm measured}}{\sigma_{\rm measured}} \right)^2 + \beta \sum_{\rm unfolded} \left( \frac{{\rm d}^2 \log y_{\rm unfolded}}{{\rm d} \log p_{\rm T}^2} \right)^2 , \quad (1)$$

in which $y$ is the yield of the refolded, measured, or unfolded jet spectrum and $\sigma_{\rm measured}$ the statistical uncertainty on the measured jet spectrum. The first summation term of equation 1 gives the $\chi^2$ between the refolded spectrum and the measured jet spectrum and the second summation term regularizes the unfolded solution favoring a local power law.

The response matrix includes the smearing of the measured background fluctuations and detector effects which are determined from event and detector simulations [6]. When a leading track in the jets is required, a small bias due to collective flow is introduced: the average $p_{\mathrm{T}}$ density $\rho$ of the full Pb–Pb events is at maximum 3 GeV/$c$ smaller than the local $p_{\mathrm{T}}$ density in the region of the event where a jet with a high $p_{\mathrm{T}}$ track is present. For the cross-section of jets with radius $R = 0.2$ this effect is negligible and no extra correction is required. For central events the correction applied on the jet yield is a factor 1–2.

The corrected jet spectra with jet radius $R = 0.2$ are presented in Figure 1 for central (0-10%) and peripheral collisions (50-80%) [7]. For both centrality classes the unbiased and leading track $p_{\mathrm{T}}$ biased spectra are shown. Requiring a leading high $p_{\mathrm{T}}$ track in the jet does not modify the jet sample at high $p_{\mathrm{T}}$ while, as expected, at low $p_{\mathrm{T}}$ the jet yield is reduced.

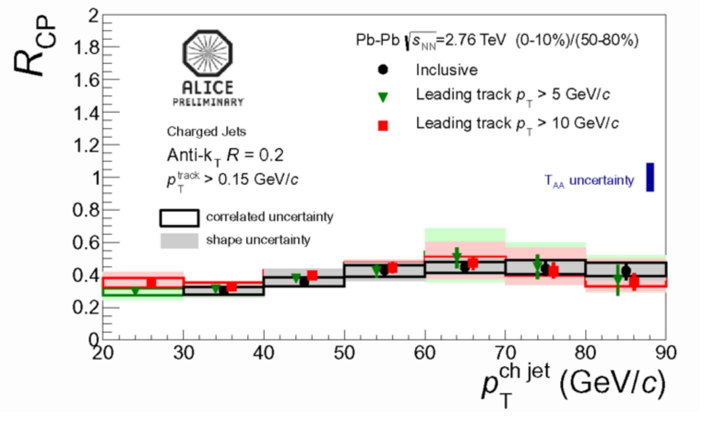



Figure 2: Jet nuclear modification factor $R_{\mathrm{CP}}$ for inclusive jet spectra with no requirement on the leading track and jets with a leading track of at least 5 and 10 GeV/$c$.

Figure 2 shows the nuclear modification factor of jets, $R_{\mathrm{CP}}$, in central collisions with respect to peripheral collisions. A strong suppression which does not depend on the leading track requirement is observed. The fragmentation bias due to the leading track requirement of $p_{\mathrm{T}} > 5$ and $p_{\mathrm{T}} > 10$ GeV/$c$ is observed to be similar in central and peripheral collisions for $p^{\mathrm{ch}}_{\mathrm{T,jet}} > 30$ GeV/$c$. The strong jet suppression, $R_{\mathrm{CP}} \simeq 0.4$, implies that the full jet energy is not captured by jet reconstruction in heavy-ion events. This is consistent with out-of-cone radiation induced by the interaction of the parton with the dense medium.

Figure 3 shows that the ratio between the measured jet spectra without a leading track requirement for radii of $R = 0.2$ and $R = 0.3$ is consistent with jet production in vacuum for central and peripheral events. No sign of a modified jet structure is observed between radii of 0.2 and 0.3 in the ratio of the cross sections. The measured ratio of cross sections in Pb–Pb collisions is compared to the JEWEL jet quenching MC [9, 10] in Figure 4. A good agreement is observed between the energy loss implementation of JEWEL and the charged jet results from ALICE.

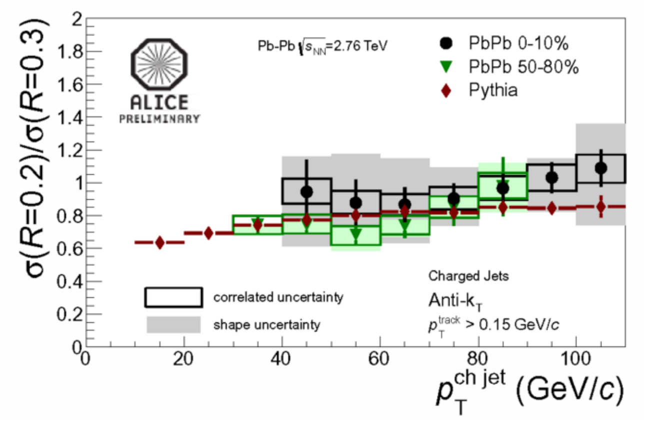



Figure 3: Ratio between measured cross-sections with radii $R$ = 0.2 and $R$ = 0.3 in Pb–Pb collisions for central and peripheral events compared to generator level PYTHIA [8]

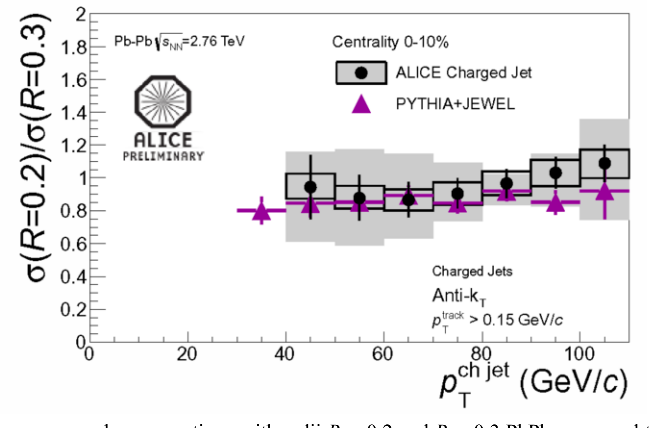



Figure 4: Ratio between measured cross-sections with radii $R$ = 0.2 and $R$ = 0.3 PbPb compared to JEWEL energy loss MC.

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