PROCEEDINGS OF SCIENCE

Jet measurements in proton-proton and Pb-Pb collisions with the ALICE experiment at LHC

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Abstract

Jets are an important tool in testing QCD and probing the hot and dense nuclear matter created in high energy heavy-ion collisions. They can be used to study hard scatterings, fragmentation and hadronisation and how these processes differ from baseline vacuum measurements in the presence of a partonic medium. Vacuum measurements are obtained from proton-proton collisions.

Data taken by the ALICE detector system in proton-proton collisions at $\sqrt{s}$ = 7 TeV and in heavy ion collisions at $\sqrt{s}$ = 2.76 TeV have been analyzed and results for jet p_T spectra, R_{CP} and longitudinal fragment distributions are presented. The procedures used to reconstruct jets and to extract them from a background are described.

LHC on the March - IHEP-LHC
20-22 November 2012
Institute for High Energy Physics, Protvino,Moscow region, Russia

PoS(IHEP-LHC)022

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Introduction

Jets can be a powerful tool in studying properties of the medium created in heavy-ion collisions. Originating from high-p_T quarks and gluons produced in hard scatterings during the very early phase of the reaction, jets propagate through the hot and dense matter, losing energy by elastic scatterings and gluon radiation. This process is generally called jet quenching [1] and is expected to manifests itself as a broadening of the jet cone, back-to-back energy imbalance in di-jets events, modification of the fragmentation function and the angular redistribution of energy with respect to the jet axis. One can see these modifications by comparing jets reconstructed in heavy-ion collisions and jets from more elementary proton-proton (pp) events. Also, since kinematic properties of the jet reflect the kinematic properties of the original parton, they can be used in studies of parton properties both in proton-proton and heavy-ion events.

With the fully installed EMCal calorimeter ALICE is capable to reconstruct full jets with both charged and neutral (photons from π^0 decays) constituents. Here we present full jet spectra and fragmentation functions from pp and charged jet spectra from PbPb collisions.

Jets in ALICE

Full jet reconstruction is based on combined information from charged and neutral (mostly π^0 decays fragments) particle measurements. Tracks are reconstructed at mid-rapidity ($|\eta| < 0.9$) within the full azimuth using the central tracking detectors: The Inner Tracking System (ITS) and Time Projection Chamber (TPC). Neutral particles are reconstructed by the ALICE electromagnetic calorimeter, a Pb-scintillator sampling calorimeter which covers mid-rapidity ($|\eta| < 0.7$) and partial azimuth ($\Delta\varphi = 100°$). A full description of the ALICE experiment is available in Ref. [2].

For jet reconstruction the anti-k_T algorithm from the FastJet package [3] with resolution parameters R varying between 0.2 and 0.4 is used. For proton-proton data the resolution parameter R can be as high as 0.7, since background is much smaller than in PbPb collisions. To reduce the contribution from the background in heavy-ion collisions, a commonly used value of the radius parameter is 0.4. This value is also used in pp collisions for comparison with heavy-ion collisions [4]. All jets taken for analysis have their jet axis within $|\eta| < 0.5$.

The input for charged jets are tracks with $p_T > 150$ MeV/c. The input for fully reconstructed jets are charged jets with additional EMCal clusters energy corrected for charged particles contribution. These jets are required to be entirely contained within the EMCal acceptance. The transverse cluster energy E_T is required to be more than 300 MeV.

p-p results

In the beginning of 2011 the first measurements with a fully installed EMCal calorimeter were made during a short reference proton-proton run at $\sqrt{s}$ = 2.76 TeV. Figure 1 shows the jet p_T spectrum reconstructed with the resolution parameter R = 0.4. The jet energy scale uncertainty is 4% and is mainly contributed by uncertainties of the missing neutral energy, the tracking efficiency and energy double counting. The jet p_T resolution $\sigma(\Delta p_T)/p_T$ equals to 20% and is dominated by jet energy scale fluctuations, while the effects of momentum resolution in the tracking and EMCal energy resolution are small. Efficiency and resolution effects on the jet spectrum have been taken into account by applying a bin-by-bin correction [9]. The measured spectrum is compared to NLO pQCD calculations [5, 6]. A good agreement is observed. The measurement itself represents an import reference for our PbPb measurements.

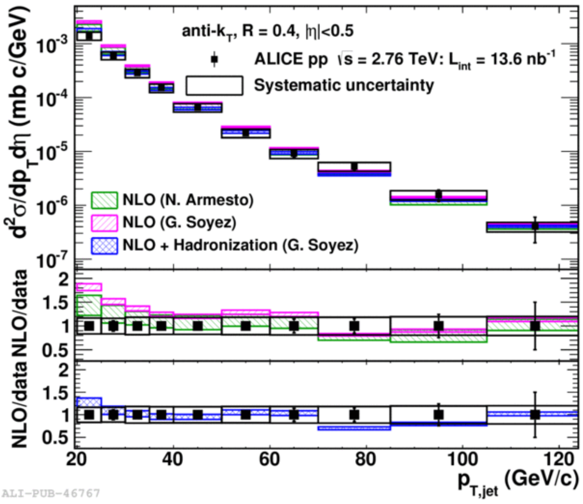

Figure 1: Upper panel: inclusive differential jet cross sections of fully reconstructed jets in pp collisions at √s = 2.76 TeV compared to NLO [5, 6] (for R = 0.4). Vertical bars show the statistical error, while boxes show the systematic uncertainty. The bands show the NLO pQCD calculations. Lower panels: ratio of NLO pQCD calculations to data [9].

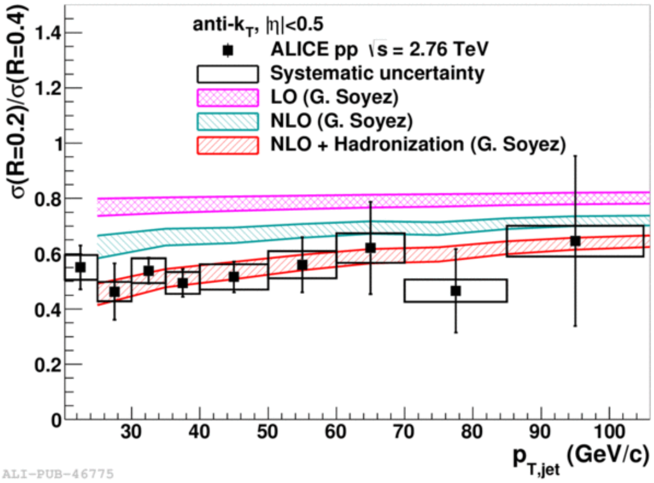

Figure 2: Ratio of jet cross sections reconstructed with R = 0.2 and R = 0.4 in pp collisions at √s = 2.76 TeV compared NLO pQCD from [5, 6].

In order to get information about energy distribution within a jet one can look at the ratios of differential cross-sections measured with different R, which is shown on Figure 2 for R values 0.2 and 0.4. A rise (data are consistent with a constant ratio) of the ratio with jet p_T is expected due to the fact that hard jets are more collimated. The NLO calculation of the ratio agrees within uncertainties with the measurement if hadronization effects are taken into account, indicating that the distribution of radiation within the jet is well-described by the calculation [9].

Measurements of the jet spectra in pp collisions at $\sqrt{s}$ = 7 TeV have been compared to results from other LHC experiments. We can see a good agreement between the ALICE and ATLAS results for charged jet spectrum measured at $\sqrt{s}$ = 7 TeV [10]. This comparison is shown on Figure 3.

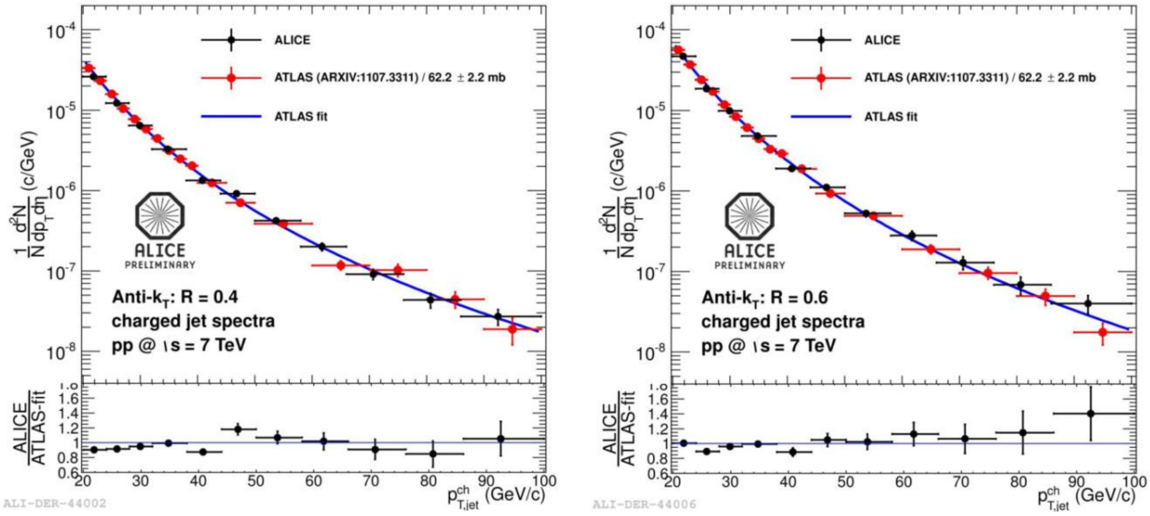

Figure 3: Charged jet spectra in pp events at $\sqrt{s}$ = 7 TeV for R = 0.4 (left) and R = 0.6 (right). Comparison to ATLAS results [10].

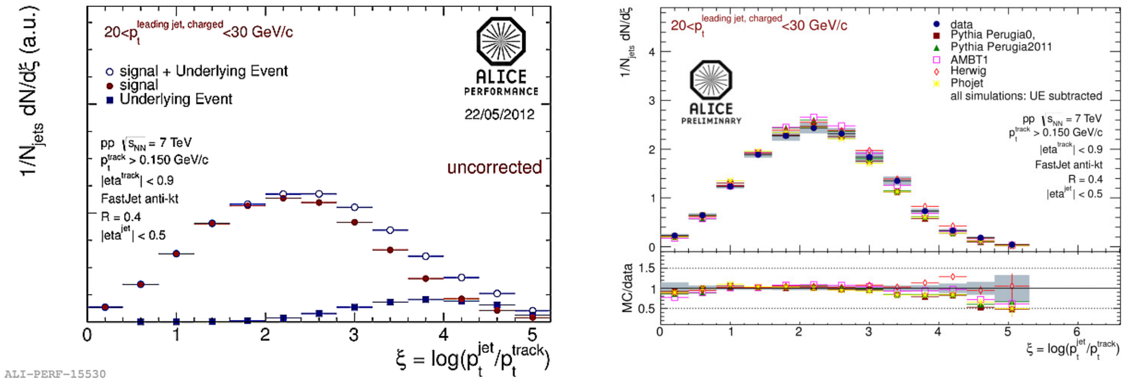

Figure 4: Momentum distributions of tracks in charged jets. Left: Effect of the underlying event subtraction for leading jets with 20 < p_T < 30 GeV/c. Right: Comparison data to different simulations. All with underlying event subtracted.

Figure 4 shows the longitudinal momentum distribution of jet fragments for jets with p_T in range 20 - 30 GeV/c in pp collisions at $\sqrt{s} = 7$ TeV. The Underlying Events (UE) in pp collisions mostly consist of soft particles that are produced in processes that are not correlated with the hard scattering. Those particles can be picked up as jet constituents by the jet-finding algorithms. To estimate the contribution of UE to the jet energy we are looking at the cone perpendicular to the jet axis with the same resolution parameter. The effect of the UE on the yield of low momentum fragments in jet constituents shown in the left panel of Figure 4 and comparison to different simulations on the right. One can see that UE contribution becomes significant at $\xi > 3.5$.

Background estimation in Pb-Pb

In PbPb collisions background subtraction is one of the most challenging and important steps in jet reconstruction. In the context of heavy-ion collisions one has to take into account the significant contribution of the uncorrelated background into the reconstructed jet momentum, which can be reduced e.g. by a p_T or energy threshold of the input particles to the jet finders and by a reduced distance parameter R. All of these introduce additional biases on the fragmentation pattern of the reconstructed jets and do not take into account that background fluctuates from region-to-region within the event. In ALICE the global background density is evaluated by applying the k_T-algorithm from FastJet [8] to the whole event. This provides a list of reconstructed clusters with transverse momentum $p^{rec}_{T,i}$, area A^{rec}_i in the (η,φ) plane, and a momentum density is calculated as $\rho^{rec}_i = p^{rec}_{T,i}/A^{rec}_i$. The global background ρ of the event is defined as the median of these background clusters: $\rho := \text{median}(\rho^{rec}_i) = \text{median}(p^{rec}_{T,i}/A^{rec}_i)$. The estimated background contribution $\rho \cdot A_{jet}$ is subtracted from the reconstructed jet momentum p^{rec}_T : $p_T = p^{rec}_T - \rho \cdot A_{jet}$.
The smearing of the jet energy due to background fluctuations is corrected through unfolding.
Some of the methods used to investigate the event background p_T fluctuations are Random Cones and embedding well known probes (single tracks, fully simulated proton-proton jets) into the heavy-ion event. A detailed description of these procedures can be found in Ref. [4].

Pb-Pb results

Figure 5 (left) shows the charged jet yields as a function of p_T normalized by the number of collisions (resolution parameters R = 0.3). The systematic uncertainties are dominated by the presence of combinatorial (fake) jets (~ 4%) and the jet energy scale corrections (4 - 10%). The right panel of Figure 4 shows the nuclear modification factor, R_{CP}, in central collisions with respect to peripheral collisions. We observe a strong suppression ($R_{CP} \approx 0.4$) of the inclusive charged jet yield in central PbPb collisions, while for more peripheral events the suppression is less ($R_{CP} \approx 0.8$). Strong suppression indicates that the reconstructed jets do not capture the full energy of the jet. This is in agreement with a scenario in which part of the energy of the jet is radiated by gluons out of the jet cone by interactions of the parton with the medium [11].

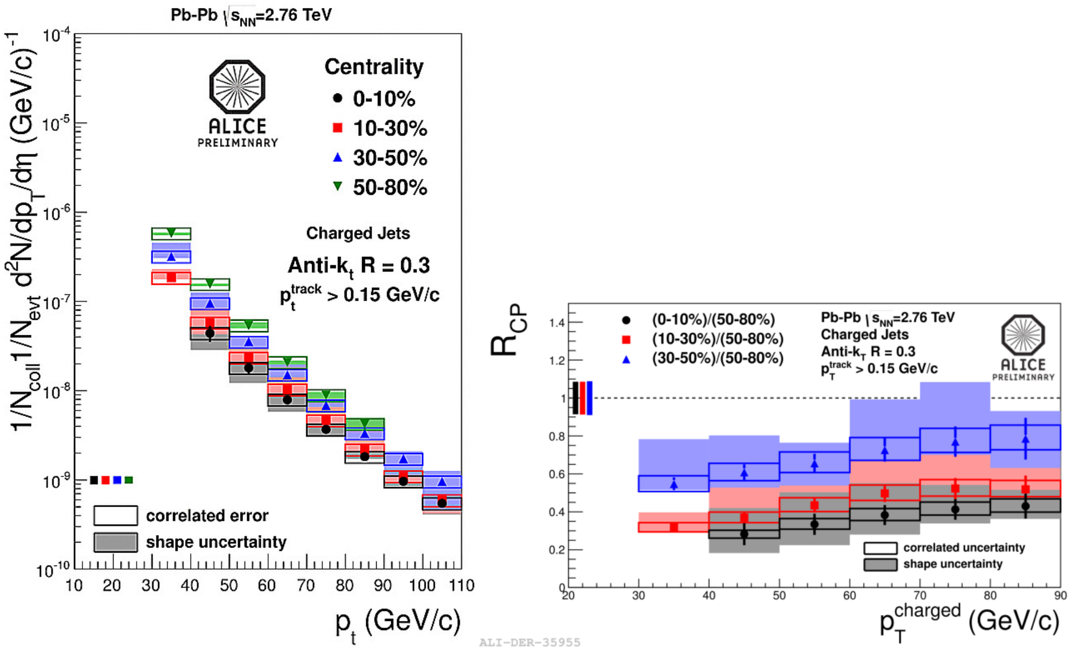

Figure 5: Left: Corrected jet spectrum with charged tracks for jet radius R = 0.3.
Right: Nuclear modification factor for charged jets reconstructed in central and peripheral Pb–Pb collisions.

Summary

We presented results of jet studies from proton-proton and PbPb data collected by the ALICE experiment. Full and charged jet spectra in pp are shown for energies $\sqrt{s} = 2.76$ TeV and $\sqrt{s} = 7$ TeV respectively. NLO pQCD calculations with hadronization agree well with both inclusive jet cross section measurements at R = 0.2 and R = 0.4, as well as their ratio. We observe a strong suppression of the inclusive charged jet yield in central PbPb collisions at $\sqrt{s} = 2.76$ TeV. The nuclear modification factor, R_{CP}, for charged jets is about 0.4 and has a small rise as a function of p_T at low jet energies and remains constant at high p_T.

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