Intrajet radiation study with the ALICE experiment at LHC

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Abstract. The ALICE collaboration is interested in measuring the $\xi = \ln(p_{\text{jet}}^T/p_{\text{hadron}}^T)$ distribution of hadrons in jets known as the Hump-backed plateau (HBP). After an introduction to color coherence effects responsible for the shape of the HBP, we discuss the ALICE capabilities to perform such a study. Preliminary results from ALICE for non corrected charged particle and jet spectra measurement in $p+p$ collisions at $\sqrt{s} = 900$ GeV and 7 TeV are presented. Finally, we show the results of a MC based analysis of intrajet radiations. It supports the idea of jet collimation which increases with increasing jet energy as expected from QCD and show the feasability of this study with ALICE.

1. Motivations for intrajet radiation study

Hard processes in QCD produce high energy initial partons which give birth to a cascade of radiated partons: the jet. The way partons radiate in the parton shower is constrained by color coherence effects \cite{1}. From one emission to the next one, the $\theta$ emission angle is always decreasing because of the color charge of the former emitted parton. The shower keeps evolving with emission of partons of momentum $k$ as long as $\theta > (k R)^{-1}$ (where $1/R \propto$ hadron mass at the end of the shower). Consequently, the sooner the shower is stopped, the heavier might be the mass of the resulting hadron at the end of the shower and the larger is the last emission angle \cite{2}. Both phenomena are responsible for the shape of the so-called hump-backed plateau (HBP) which summerizes how hadrons are distributed inside jets as a function of the $\xi = \ln(p_{\text{jet}}^T/p_{\text{hadron}}^T)$ variable. First, the so-called splitting function $P(z)$ favours low $p_T$ emission since it is proportional to $1/z$ ($z = p_{\text{hadron}}^T/p_{\text{jet}}^T$) resulting in an increase of the HBP with increasing $\xi$. Then, the combination of angular ordering and hadronization scale leads to the early suppression of soft emissions in the parton shower resulting in the depletion of the HBP in its high $\xi$ region.

One of the models predicting the shape of this HBP is the Modified Leading Logarithmic Approximation (MLLA) which contains two free parameters: a QCD scale and a scale stopping the evolution of the parton shower. Because partons eventually fragment in sprays of hadrons at the end of the shower, MLLA is usually supplemented by the Local Parton Hadron Duality (LPHD) hypothesis in order to describe the hadron $p_T$ distribution inside jets. The LPHD hypothesis assumes a one-to-one correspondence between a last emitted parton and a hadron so that the parton distributions at the end of the shower are directly reflected in the hadron distribution. The shape of the HBP has already been measured for instance in $e^+e^-$ collisions.
in TASSO and OPAL experiments for $\sqrt{s} = 14$ GeV and $\sqrt{s} = 192-209$ GeV respectively as well as in hadronic $p+\bar{p}$ collisions by the CDF collaboration at $\sqrt{s} = 1.8$ TeV [3]. All experimental results are in good agreement with the expected shape predicted by the MLLA+LPHD [4]. Figure 1 presents the non corrected HBP expected to be measured by the ALICE experiment in $p+p$ collisions at $\sqrt{s} = 10$ TeV. These results are based on PYTHIA jet simulations performed within the full simulation/reconstruction chain of ALICE using GEANT 3 to account for the transport of particles in the detectors. Jets have been reconstructed with a cone algorithm based on the UA1 jet finder running on charged particles only with a radius $R = \sqrt{\Delta \eta^2 + \Delta \phi^2} = 0.4$. The same set of data is used for the intrajet radiation studies in section 3. The shapes of the HBP for 10-20 (squares), 20-30 (stars), 30-40 (triangles) and 40-70 (points) GeV/c jets are presented. It seems the expected trends from MLLA+LPHD predictions are observed: a) At higher jet $p_T$, the phase space available for particle emissions is larger which results in an increase of the number of entries with increasing $\xi$. b) At large $\xi$ we observe a steeply falling shape. Nevertheless, it is not sufficient to prove the presence of coherence effects. Indeed, because of the small cone size used for jet reconstruction, fractions of intrajet radiations are missing, this could also explain the shape of the distributions. However, the moving position of the peak with increasing jet energy is a sign of the presence of color coherence effects [1]. The small cone size also induces a jet energy dependent bias and the Underlying Events lead to the presence of background in jets. These effects will have to be corrected in the future.

In the context of heavy ion collisions, the study of the HBP is of major interest to ALICE to investigate the properties of the dense partonic medium produced. The MLLA+LPHD predicts a distortion of the HBP in the presence of a dense partonic medium like the Quark-Gluon Plasma (QGP) where high energy initial partons are expected to loose their energy via gluon radiation leading to the suppression of the production of high $p_T$ hadrons [4, 5]. A shift of the maximum position of the peak of the distribution towards high $\xi$ values is expected. One should observe the enhancement of the amplitude of the distribution in the high $\xi$ region due to the production of more soft hadrons. On the contrary, a decrease of the population in the low $\xi$ region is expected as the result of the suppression of high $p_T$ hadron production [4]. We first concentrate on the HBP measurement in $p+p$ collisions in order to test ALICE capabilities to constrain pQCD but also to provide a baseline for future measurement in heavy ion collisions; our ultimate goal is to study and to extract properties of the QGP.

2. Track and jet reconstruction performances in the ALICE experiment

In ALICE, jets will be reconstructed at mid-rapidity with charged particle transverse momenta given by the tracking devices, the Inner Tracking System (ITS) and the Time Projection
Chamber (TPC), and neutral particle transverse energies measured by the Electromagnetic Calorimeter (EMCal). As the EMCal is not yet fully installed in the ALICE cavern (4/12 SuperModules are installed), jets are currently reconstructed from charged particle \( p_T \). ITS and TPC measurements endow ALICE with its excellent tracking capabilities from very low \( p_T \) (∼200 MeV/c) to higher values (∼100 GeV/c) with good efficiency (over 90%), good momentum resolution (still below 6% at 100 GeV/c in \( p+\bar{p} \) and \( Pb+Pb \) collisions according to the design values) and excellent PID [6]. In figure 2 (full lines), are shown the non corrected \( p_T \) spectra of the charged tracks coming from ∼1.95 M \( p+\bar{p} \) events at \( \sqrt{s} = 900 \) GeV (left plot) and ∼16.7 M \( p+\bar{p} \) events at 7 TeV (right plot) respectively. These plots show the large \( p_T \) range reachable from track measurement for the first data registered by ALICE. The figure 2 also presents the first measurements by the ALICE collaboration of the non corrected jet \( p_T \) spectra reconstructed from the same set of events collected in \( p+\bar{p} \) collisions at 900 GeV (left) and 7 TeV (right). Jets have been reconstructed with cones and sequentials algorithms available in the ALICE analysis framework [7]: UA1 (blue) and SISCone (green) which are cone algorithms, \( k_T \) (black) and anti-\( k_T \) (red) which are sequential algorithms [7]. Both cone and sequential jet finders have their advantages and drawbacks, nevertheless they are not perfect and introduce biases in the reconstructed jet energy because of the use of parameters. Moreover, detector effects, background, charged to neutral fluctuations also bias the reconstructed energy. This last contribution dominates in our case as jets have been reconstructed from charged particles \( p_T \) only. The presented spectra are not yet corrected for the track and jet reconstruction efficiency. It can be done by correcting individually each bias or by using unfolding methods [8, 9]. Nevertheless, we observe a good agreement between the jet finders except at low \( p_T \) where UA1 reconstructs less jets than the others. This is due to its seed parameter as jet reconstruction is started only from particles which pass a threshold in \( p_T \): the seed value. Figure 2, clearly shows that jet measurement can already be done over large \( p_T \) intervals which is promising for the study of the HBP over several bins of \( p_T \).

3. Preliminary studies on intrajet radiation
In this section, we show the preliminary studies on intrajet radiation based on PYTHIA+GEANT simulations in which angular ordering features have been modelized. The angle and transverse momentum distributions of hadrons inside jets have been observed. Figure 3 (left) shows the angle in three dimensions between the jet axis and the hadron transverse
momenta, $\theta$, distribution. We observe that the number of hadrons increases with the jet energy and particularly near the jet axis.

In figure 3 (right) is plotted the $p_T$ distribution of hadrons for jets of $p_T$ taken between 20 and 30 GeV/c and reconstructed with different radii. We notice that all high $p_T$ hadrons are recovered whatever the radius value. But more low $p_T$ hadrons are recovered when the radius increases. No corrections have been applied yet, nevertheless the features expected from QCD are observed: energetic jets contain more hadrons and particularly near their axis in agreement with the idea of collimation. Hard hadrons are emitted at small angles and when moving away from the jet axis toward larger angles, more soft hadrons can be found. But a lot of these soft hadrons come from the background which evolves in $R^2$. The background will have to be subtracted before going further in the interpretation of the data.

4. Summary

Color coherence effects constrain the way partons radiate inside a jet and are responsible for the shape of the HBP. The ALICE experiment is well-suited to perform such a study. Jets over a large $p_T$ domain have been reconstructed which is a very promising basis for fragmentation function studies. A preliminary work on simulated data with PYTHIA+GEANT containing angular ordering features supports the idea of jet collimation: the latter is stronger for higher energy jets, more particles are expected close to the jet axis and low $p_T$ hadrons are emitted with a larger probability at higher angles. This work shows that the intrajet measurement is feasible with ALICE.

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