Measurements of jets in ALICE

Christine Nattrass for the ALICE collaboration

1408 Circle Drive, Knoxville, TN 37996, USA

E-mail: christine.nattrass@utk.edu

Abstract. Partonic energy loss in the medium formed in heavy ion collisions results in significant modifications of jet spectra. Quantitative understanding of these modifications can constrain models for partonic energy loss in heavy ion collisions. The ALICE detector is capable of unique measurements of jets due to its low momentum tracking and particle identification capabilities. The ALICE Electromagnetic Calorimeter (EMCAL) is a key element for the measurement of fully reconstructed jets in ALICE due to its measurement of neutral particles and its triggering capabilities. Measurements of fully reconstructed jet spectra and the nuclear modification factor, R_{AA} , in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are presented.

1. Introduction

Jets, the collimated sprays of particles created from a fragmenting parton, are an ideal probe of the hot, dense medium formed in high-energy heavy-ion collisions because hard parton scattering occurs early in the collision and therefore the scattered partons can interact with the medium. The production of jets is well understood in the absence of a medium, for example in pp collisions, and calculable in pQCD. Jets may be modified by the medium by parton energy loss through gluon brehmsstralung, collisional energy loss, or modification of fragmentation and hadronization. Studies of jets in heavy ion collisions at both the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC) have indicated that high momentum colored probes interact strongly with the Quark Gluon Plasma (QGP). The effects of parton interactions with the QGP have already been observed [1–6].

The ALICE detector provides unique capabilities due to its low momentum acceptance ($p_T > 150 \text{ MeV}/c$). This means that measurements of jets with the ALICE detector are less sensitive to corrections that are dependent on the shape of the fragmentation functions at low momenta in heavy ion collisions. The particle identification capabilities of the ALICE detector will also enable novel measurements of jets in heavy ion collisions.

2. The ALICE detector

The ALICE detector [7], shown in Figure 1, is designed for measurements of events with high track densities with precision detectors focused on studies around midrapidity ($|\eta| < 0.9$). The central detectors are in a 0.5 T magnetic field. The primary detectors used for the reconstruction of jets are the Inner Tracking System (ITS), the Time Projection Chamber (TPC), and the Electromagnetic Calorimeter (EMCAL) [8]. The TPC extends from a radius of approximately 85 cm to 250 cm from the beam pipe and when combined with the ITS provides tracking within $|\eta| < 0.9$ with momentum resolution $\Delta p_T/p_T$ ranging from approximately 1% below 10 GeV/c to 5% at 100 GeV/c for tracks completely contained in the TPC acceptance. The ITS surrounds



Figure 1. The ALICE detector.

the beam pipe and consists of a Silicon Strip Detector (SSD), Silicon Drift Detector (SDD), and Silicon Pixel Detector (SPD). The EMCAL is a lead scintillator sampling calorimeter covering $|\eta| < 0.7$ and 107° in azimuth optimized for studies of jets and capable of triggering on jets.

3. Measurements of jets

There are three steps in the jet reconstruction procedure: identification of jet candidates, background subtraction, and corrections for energy resolution and energy scale. Jet candidates are reconstructed using the anti- k_T algorithm in FastJet [9, 10]. ALICE reconstructs jets in two ways, using tracks only [6] and using information from the tracking detectors and from the EMCAL [11]. The former are called "charged jets" and the latter "full jets." For full jet reconstruction, tracks reconstructed using the TPC and ITS with $p_T > 150 \text{ MeV}/c$ and calorimeter clusters from the EMCAL with $E_{\text{cluster}} > 300 \text{ MeV}/c$ are used as input for the jetfinding algorithm. The boost-invariant p_T recombination scheme [9] is used, meaning that jet momentum $p_{T,jet}$ is the scalar sum of the constituent momenta. Charged particles will deposit some energy into the EMCAL. This energy needs to be removed to prevent double counting. Tracks are extrapolated to the EMCAL and then geometrically matched to clusters. The track momentum is subtracted from the matched clusters, and clusters that fall below 300 MeV after this correction are discarded. Jet candidates are required to be at least $R = \sqrt{\Delta \phi^2 + \Delta \eta^2}$ away from the EMCAL boundaries. For R=0.2 this corresponds to an acceptance of $\eta < 0.5$ in pseudorapidity and $1.60 < \phi < 2.94$ in azimuth.

The background subtracted jet p_T is given by

$$p_{T,jet} = p_{T,jet}^{rec} - \rho A_{jet} \tag{1}$$

where $p_{T,jet}^{rec}$ is the p_T reconstructed from the jet finder, ρ is the average energy density per unit area and A_{jet} is the area of the jet. For jet finding algorithms such as anti- k_T which reconstruct jets in cone symmetric in ϕ and η , $A_{jet} = \pi \mathbb{R}^2$. Due to the restricted acceptance for full jets, ρ is calculated from the background from charged jets, ρ_{ch} . Charged jets are reconstructed using a random cone, the two jets with the highest p_T are excluded, and the median value of $p_{T,jet}^{rec}/A_{jet}$ is used to determine ρ_{ch} [5]. This is done event-by-event. To calculate ρ from ρ_{ch} , the ρ_{ch} is scaled up by a factor s, $\rho = \rho_{ch} * s$. This centrality-dependent factor is the ratio of the charged plus neutral energy to the charged energy in the event averaged over the event class determined from data.

The $p_{T,jet}$ from Eq.(1) still needs to be corrected for detector effects and smearing due to the fluctuations in the background. The response matrix which describes these effects and is used in unfolding is separated into a component due to background fluctuations and a component due to detector effects such as finite track reconstruction efficiency. The response matrix for detector effects is determined from simulated PYTHIA events run through GEANT. Particle level jets from the raw PYTHIA events are correlated with detector level jets from PYTHIA+GEANT and form the detector response matrix [12]. The fluctuations in the background are determined by the difference between the reconstructed energy and the average background energy given by

$$\delta p_T = p_{T,RC}^{rec} - \rho \pi R^2 \tag{2}$$

where $R = \sqrt{\Delta \phi^2 + \Delta \eta^2}$ is the radius of the random cone. The δp_T distribution is calculated by placing cones randomly in the event, and summing up the energy within them, and subtracting the average energy that should be contained in a cone of that size. The width of this distribution indicates the size of the background fluctuations. This distribution is used to create the background response matrix. Unfolding is done using the Bayesian method in the RooUnfold package [13]. The uncertainty is dominanted by the uncertainty due to the tracking efficiency and the unfolding algorithm.



Figure 2. Inclusive p_T spectrum of fully reconstructed jets in pp collisions at $\sqrt{s} = 2.76$ TeV for the anti- k_T algorithm with R=0.2 compared to NLO calculations [11].

Measurements of full jets in pp collisions are consistent with pQCD calculations including hadronization for both R=0.2, show in figure 2, and R=0.4 [11], indicating that the measurement is well understood theoretically in pp collisions.

To reduce the background in heavy ion collisions, the jet candidate sample is biased by requiring at least one track with $p_T > 5 \text{ GeV}/c$. For calculations of the nuclear modification factor, R_{AA} , this bias is also used in pp collisions.

Full jet spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are shown in figure 3 for R=0.2. The nuclear modification factor, R_{AA} , is shown in figure 4. Substantial suppression is observed, decreasing with p_T . These results are consistent with measurements from CMS [3], which were measured using a similar method, in the kinematic region where the results overlap. These results are also consistent with the charged particle spectra at the same momenta [14].



Figure 3. Inclusive spectrum of fully reconstructed jets in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV for the anti- k_T algorithm with R=0.2.



Figure 4. Inclusive spectrum of fully reconstructed jet R_{AA} in Pb-Pb collisions at $\sqrt{s} = 2.76$ TeV for the anti- k_T algorithm with R=0.2.

Future studies will incorporate the Di-jet Calorimeter (DCAL) [15] that is being installed 180° from the EMCAL and will cover $|\eta| < 0.7$ and 67° in azimuth. This will enable triggering on jets opposite to an energetic deposit such as that expected from a photon or high energy electron from a heavy flavor decay.

- [1] Aad G et al. (ATLAS Collaboration) 2013 Phys.Lett. B719 220-241 (Preprint 1208.1967)
- [2] Aad G et al. (ATLAS Collaboration) 2010 Phys. Rev. Lett. 105 252303 (Preprint 1011.6182)
- [3] Chatrchyan S et al. (CMS Collaboration) 2012 Eur. Phys. J. C72 1945 (Preprint 1202.2554)
- [4] Chatrchyan S et al. (CMS Collaboration) 2013 (Preprint 1310.0878)
- [5] Abelev B et al. (ALICE Collaboration) 2012 JHEP 1203 053 (Preprint 1201.2423)
- [6] Verweij M (ALICE Collaboration, Marta Verweij collaboration) 2012 (Preprint 1208.6169)
- [7] Aamodt K et al. (ALICE Collaboration) 2008 JINST **3** S08002
- [8] Cortese P et al. (ALICE Collaboration) 2008 ALICE Electromagnetic Calorimeter Technical Design Report Tech. Rep. CERN-LHCC-2008-014. ALICE-TDR-14 CERN Geneva
- [9] Cacciari M, Salam G P and Soyez G 2012 Eur. Phys. J. C72 1896 (Preprint 1111.6097)
- [10] Cacciari M and Salam G P 2006 Phys.Lett. B641 57-61 (Preprint hep-ph/0512210)
- [11] Abelev B et al. (ALICE Collaboration) 2013 Phys.Lett. B722 262–272 (Preprint 1301.3475)
- [12] Aiola S (ALICE) 2013 J.Phys.Conf.Ser. 446 012005 (Preprint 1304.6668)
- [13] Adye T 2011 6 p comments: 6 pages, 5 figures, presented at PHYSTAT 2011, CERN, Geneva, Switzerland, January 2011, to be published in a CERN Yellow Report
- [14] Aamodt K et al. (ALICE Collaboration) 2011 Phys.Lett. B696 30-39 (Preprint 1012.1004)
- [15] Allen J et al. 2010 ALICE DCal: An Addendum to the EMCal Technical Design Report Di-Jet and Hadron-Jet correlation measurements in ALICE Tech. Rep. CERN-LHCC-2010-011. ALICE-TDR-14-add-1 CERN Geneva