Gamma-jet physics with the Electro-Magnetic Calorimeter in the ALICE experiment at LHC

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Abstract. The Electro-Magnetic Calorimeter (EMCal) will be fully installed for the first LHC heavy ion beam in order to improve the ALICE experiment performances in detection of high transverse momentum particles and in particular in reconstruction of γ-jet events. These events appear to be very interesting to probe the strongly interacting matter created in ultra-relativistic heavy ion collisions and the eventual Quark Gluon Plasma (QGP) state. Indeed, they may give information on the degree of medium opacity which induces the jet-quenching phenomenon: measuring the energy of the γ and comparing it to that of the associated jet may provide a unique way to quantify the jet energy loss in the dense matter. The interest of γ-jet studies in the framework of the quark gluon plasma physics will be discussed. A particular highlight will be stressed on the EMCal calorimeter. The detection of the γ-jet events will be then presented using this new ALICE detector.

1. Introduction

After four years of research on the QGP at RHIC [1–4], the notion of perfect liquid emerged to describe the medium formed in ultra-relativistic heavy ion collisions. Some of the most interesting observations were based on the suppression of particles going through the medium (jet quenching, see [5] for an overview): the hard probes appear to be of prime interest in this context. Those observations were most significant compared to the previous ones at CERN/SPS. The LHC will be the most powerful accelerator ever built. The hard processes will be dominant and will provide an access to higher p_T jets with more statistics. The dedicated heavy-ion experiment ALICE, whose design has been decided before the appearance of RHIC first results, calls for dedicated detectors for high p_T and hard probes. This is the goal of EMCal [6]: a large acceptance Electro-Magnetic Calorimeter. This detector, coupled with the central tracking system, will provide the possibility to reconstruct jets event by event. Moreover, the reconstruction of γ-jet correlation will be possible, using the calorimeter and the central tracking system of ALICE.

2. Jet quenching and γ-jet main features

2.1. Jet quenching observation

The jet-quenching effect has been discovered at RHIC [5]: a large suppression in high p_T hadron production was observed in $Au + Au$ collisions compared to the production in proton-proton collisions. This effect is explained by the interaction of high energy partons in the dense colored medium formed in $A+A$ collisions. Energy loss is due to radiations of gluons (Gluon strahlung).

The distribution of the energy in the jet is modified: a depletion of the yield of high energy particles and an increase of number of the low energy particles is expected in the final jet, by comparing heavy ion to proton-proton collisions. A proper observation of such a phenomenon needs to reconstruct the full jet event by events, to estimate the jet energy, and its particle composition. For such a measurement, ALICE presents noticeable assets.

2.2. Gamma-jet reconstruction at LHC energies

ALICE will allow the reconstruction of the full jet event by event. Its central tracking system allows the reconstruction of particles with an energy $0.1\ \mathrm{GeV}/c < p_T < 100\ \mathrm{GeV}/c$. The TPC (Time Projection Chamber) has a high geometrical acceptance ($\Delta\eta = \pm 0.9; \Delta\phi = 360°$) and provides particle identification capabilities at relatively high p_T. ALICE will be completed by EMCal [6], a large acceptance Electro-Magnetic Calorimeter ($\Delta\eta = \pm 0.7; \Delta\phi = 110°$) with an energy resolution of $\sigma_E/E \simeq 15\%/\sqrt{E}$. It gives the possibility to reconstruct neutral mesons and photons. Even with this experimental system, observing the modification of the energy distribution in the jet is a challenge. The global jet energy cannot be obtained by summing the energy of all the detected particles in the jet, a part of the energy is not deposited in the detectors (like neutrons). An alternative solution is to use the rare γ-jet events (γ-jets). The parton hadronizes in a jet which will be detected and reconstructed. The γ detected almost back to back gives directly the energy of the initial jet, and then a satisfying study of the quenching effect on the fragmentation is possible. The production rate of γ-jet events at LHC, with the photon in the EMCal acceptance and an energy higher than 30 GeV, will be about 10000 events by years [7]. The number of jet-jet events (two partons emitted back to back in the center of mass coordinate, giving two jets) is three order of magnitude higher. So they will be an important part of the background in the γ-jet study. The background from heavy ions collisions will also present a challenge. In order to avoid a maximum of background photons in the γ selection, the γ candidates must have an energy higher than 30 GeV.

2.3. Fragmentation function

The fragmentation function is the event distribution as a function of x, defined as $x = p_T(particle)/p_T(jet)$ for each particle in the jet. A modification of this function is expected if the fragmentation occurs in a dense, hot and colored medium: a depletion of high p_T particles (high x values) is expected due to interaction of the scattered partons in the medium. This energy loss is due to the gluon strahlung, so the radiated gluons will enhance the number of low p_T particles (low x values) in the jet. The redistribution of the jet energy modifies the fragmentation function, and to observe easily this change, the hump-backed plateau (HBP) distribution [8] is used, being the distribution of ξ defined as: $\xi = \ln(1/x)$. The fragmentation functions and the HBP distributions are presented in figure 1, where a modification of energy distribution due to the quenching effect is observed.

2.4. γ-jet reconstruction

An algorithm has been developed to perform the γ jet reconstruction in AliRoot Framework [9]. The procedure is the following:

- Detection of the γ in EMCal: the particle must have a PID value larger than 0.6. The PID is a criterion for γ discrimination deduced from a shower shape analysis [10] and a Bayesian method [11]);
- Selection of the γ with an energy higher than 30 GeV to avoid most of the photons from the background (decay, thermal...);
- Selection of the γ with an isolation cut method;

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- Detection of the back-to-back leading particle of the jet, i.e., the particle that carries most of the jet energy. The jet is emitted back to back in the rapidity angle, and the azimuthal angle has a selection range about 0.1 radian; Selection of the leading particle with an energy higher than 10 % of the γ energy to avoid fake jet reconstruction;
- Jet cone algorithm: a cone of a determined radius is opened around the leading particle. The jet axis is computed iteratively by considering the barycenter of the particles energy;
- The jet energy is compared to the γ energy and the following condition must be fulfilled: $0.2 \times E_\gamma < E_{jet} < E_\gamma$;

If all the conditions are verified, the γ-jet is accepted and used to obtain the fragmentation function and the HBP distribution.

3. Testing the hump-backed plateau with simulated data

To reconstruct the HBP distribution, three samples of 10000 events of 30 GeV γ-jets have been used, with a full GEANT [12] simulation, using the AliRoot framework:

- A first sample is composed of events generated in proton-proton collisions at 14 TeV, within the AliRoot Framework, using PYTHIA [13], forcing the γ-jet production. No quenching is considered. This sample is representative of the jet topology independently of the available energy of the collision.
- A second sample was generated with the same parameters, but the events are quenched with PYQUEN [14] whose parameters and initial conditions are selected according to an estimation for LHC heavy ion energies ($\Gamma_0 = 0.1$ fm/c; $T_0 = 1$ GeV/c – corresponding to a value of $\hat{q}$ about 30 GeV^2/fm).
- A last sample, which is a merging of the second sample simulation (quenched), with a background from heavy ion collisions, obtained with HIJING [15] computations for most central collisions.

The reconstruction efficiency is about 71 % of γ particles found. If the γ is detected, 72 % of the jets are detected and correctly reconstructed.

Figure 1 shows the simulated fragmentation function and the associated deduced HBP distribution for the three samples of events. In the comparison between unquenched and quenched events without background, a modification of the HBP is observed: the depletion at high p_T particles is seen for $\xi < 2$. The increase at low energy is not yet correctly determined and visible due to the errors induced by energy and position reconstructions.

For the sample incorporating the background contaminations, the HBP distribution is totally dominated at $\xi > 2.5$ by the contributions of the low energy particles produced in the heavy ion collisions. The ratio *signal/background* is about 1% in this region. A background subtraction is needed: the actual solution is to compute a "background hump-backed plateau" collecting particles outside the jet, in an area with the same surface as the jet area, and to subtract it from the "in cone" HBP. The study of this method is in progress and needs more investigation and tests.

4. Summary

The large Electro-Magnetic Calorimeter (EMCal) will improve direct photon and jet detection capabilities of ALICE. This complement is of keen interest in the study of the Quark & Gluons Plasma, notably in the understanding of the jet quenching effect. In this context γ-jet investigation will give access to the characteristics of the redistribution of jet energy. The key words are the fragmentation function and the HBP distribution. They will serve to observe the depletion of high energy particles in the jet composition and correlatively an enhancement of

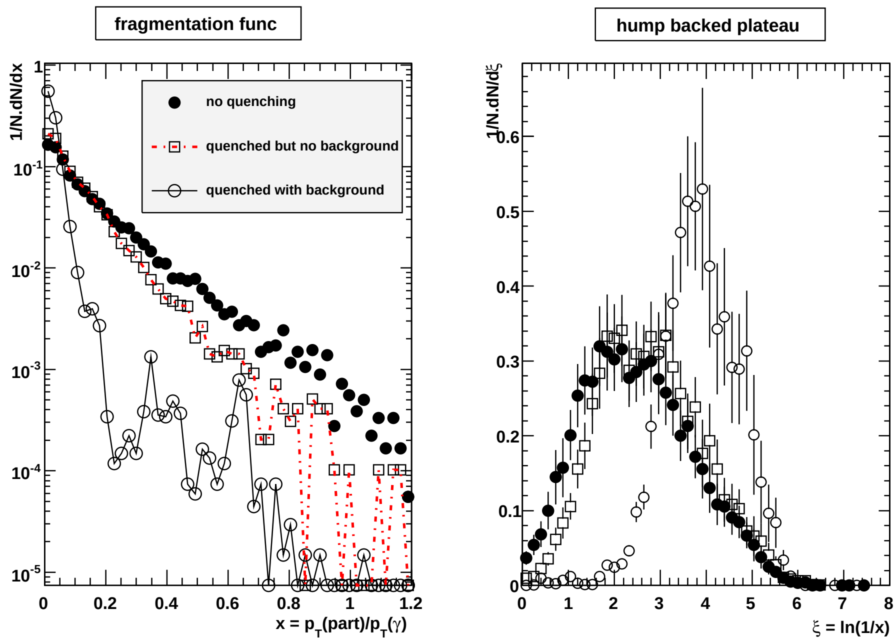

Figure 1. Fragmentation functions and Hump-backed Plateau distributions, computed from simulated events within the AliRoot Framework

the low p_T particle yield. Such an effect has still to be investigated with an efficient background subtraction in ALICE.

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