Two particle correlations: a probe of the LHC QCD medium

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Abstract. The properties of $\gamma$–jet pairs emitted in heavy-ion collisions provide an accurate mean to perform a tomographic measurement of the medium created in the collision through the study of the medium modified jet properties. The idea is to measure the distribution of hadrons emitted on the opposite side of the direct photon. The feasibility of such measurements is studied by applying the approach on the simulation data, we have demonstrated that this method allows us to measure, with a good approximation, both the jet fragmentation and the back-to-back azimuthal alignment of the direct photon and the jet. Comparing these two observables measured in pp collisions with the ones measured in AA collisions reveals the modifications induced by the medium on the jet structure and consequently allows us to infer the medium properties. In this contribution, we discuss a first attempt of such measurements applied to real proton-proton data from the ALICE experiment.

1. Introduction

Quantum ChromoDynamics (QCD) [1] is a theory of the strong interaction, the fundamental force describing the interactions of quarks and gluons making up hadrons. The QCD calculations performed on a lattice, indicate that a phase transition from normal hadronic matter to partonic matter, the Quark-Gluon Plasma (QGP), will occur beyond a critical temperature of $T_c \sim 170$ MeV [2]. By colliding heavy ions at ultra relativistic energies, this new state of matter can be created and its properties, such as the equation of state, the degrees of freedom and the transport properties can be measured.

The phase diagram has been explored in various regions with heavy-ion collisions at continuously increasing kinetic energies. Experiments at CERN's Super Proton Synchrotron (SPS) [3] concluded on the indirect evidence of a "new state of matter". Current experiments at Brookhaven National Laboratory’s Relativistic Heavy Ion Collider (RHIC) [4] have found that matter does not behave as an ideal gas of free quarks and gluons predicted by theory, but, rather, as an almost perfect fluid. The new experiment ALICE [5] at CERN’s Large Hadron Collider (LHC), will push further the study of the QCD medium. Thanks to the huge step in collision energy ($\sqrt{s_{NN}} = 5.5$ TeV in Pb-Pb collisions), LHC will open new avenues for the exploration of matter under extreme conditions of temperature and density. Since the hot QCD medium will be formed at higher temperatures than at RHIC, the deconfined phase will last longer and more readily modify our experimental probes, allowing for a more accurate study of this new state matter.
Hard scattered partons produced in initial stage of the collisions, have been identified as a valuable probe of the medium. Indeed, medium properties can be inferred from the modifications experienced by the partonic shower inside the medium. Partons are only observed indirectly, as a collimated jet of hadrons coming from the fragmentation of the partonic shower [6]. Comparing the measurements of the jet fragmentation in proton-proton and heavy-ion collisions will reveal the modifications produced by the medium on the hard scattered partons. Ideally, one needs to know the 4-momentum of the parton when it has been produced in the hard scattering and after it has been modified by the medium. This can be achieved by selecting particular hard processes in which there is a photon in the final state. Since the photon does not interact with the medium, its 4-momentum is not modified and thus provides a measure of the hard scattered parton emitted back-to-back with the photon. Measuring the hadrons opposite to the photon is thus a promising way to measure the jet fragmentation and misalignment between photon and hadrons to quantify the modifications due to the medium.

2. Approach Validation with Monte-Carlo Data

The experimental technique consists in tagging events with a well identified high energy direct photon and measuring the distribution of hadrons emitted oppositely to the photon as a function of the parameter $x_E = -\vec{p}_T \cdot \vec{p}_T / |\vec{p}_T|^2$. Such a measurement requires an excellent direct photon identification and the measurement of charged and neutral hadrons with good $p_T$ resolution. In ALICE, the electromagnetic calorimeters, PHOS ($|\Delta \eta| < 0.12$ and $\Delta \phi = 100^\circ$) and EMCal ($|\Delta \eta| < 0.7$ and $\Delta \phi = 100^\circ$) [7, 8], are capable to measure photons with high efficiency and resolution [9]. The central tracking system (ITS and TPC), covers the pseudorapidity $-0.9 \leq \eta \leq +0.9$ and the full azimuth, is helpful for direct photon extraction with the isolation technique.

We have first established the feasibility of $\gamma$–hadrons correlation measurement with ALICE detectors using Monte-Carlo data. As a first result [11] of this study, PYTHIA [10] generator is used to simulate $pp$ collisions at $\sqrt{s} = 14$ TeV containing a 2→2 process with a direct photon inside PHOS acceptance. we have demonstrated that this measurement allows us to determine, both the jet fragmentation distribution and the back-to-back azimuthal alignment of the direct photon and the jet. However because of the limited acceptance covered by the calorimeters, the measurement is restricted by statistics to photon with energies below 50 GeV. This kinematic region is particularly interesting because jets of such low energy loose a large fraction of their energy while traversing the medium, rendering the medium modification most visible. In addition, because jets with energy below 50 GeV can hardly be reconstructed in the heavy-ion environment, the photon tagging technique provides a sensitive measurement of jets in this kinematic range. Systematic errors due to the improper identification of direct photons remain, within this kinematic range, lower than statistical errors from our study [11].

To quantify the medium modification, the photon–hadrons correlation distribution has been studied with events generated in $pp$ collisions at $\sqrt{s} = 5.5$ TeV containing a 2→2 process with a direct photon inside ECal acceptance. They have been generated by PYTHIA [10] generator and qPYTHIA, which includes a parton energy loss model [12] with the medium transport parameter $\hat{q} = 50$ GeV$^2$/fm for photon energies between 5 and 200 GeV. At this stage of the study, the heavy-ion collision background has not yet been taken into account. Direct photons are identified with the isolation technique requiring no hadronic activity around the direct photon candidate inside a given cone size [13]. Hadrons detected in the azimuthal range $\pi/2 < \Delta \phi < 3\pi/2$ relative to the photon were used to construct the correlation function. The contribution of hadrons from the underlying event was calculated from the hadrons emitted in the same azimuthal hemisphere as the photon.

The relative azimuthal angle, $\Delta \phi = \phi_\gamma - \phi_h$, between the direct photon and charged hadrons is strongly peaked at $\pi$ as expected for the 2→2 process (Fig. 1). When medium effects are
simulated (qPYTHIA), the Δφ distribution becomes broader. The broadening can be related to the medium transport parameter ˆq. However, the effect is quite small which will make the measurement in the heavy-ion environment quite challenging. A stronger signal is expected to be observed in the photon–hadrons distribution from heavy-ion collisions when compared to the distribution from pp collisions. The resulting photon-triggered hadrons distributions, after subtraction of underlying events, are shown in Fig. 2, normalized to the number of trigger particles found in corresponding generation. The statistical errors are estimated from the annual yield of photon events with pT larger than 30 GeV we anticipate to collect during one PbPb run at nominal luminosity [5]. The distribution exhibits the expected suppression at high xE, due to the energy loss of the hard scattered parton and the enhancement at low xE due to the fragmentation of soft gluons radiated in the medium.

### Figure 1. Relative azimuthal angle distribution Δφ = φγ − φhadron for γ-jet events in pp collisions at √s = 5.5 TeV.

### Figure 2. γ-hadron correlation distributions in quenched and unquenched PYTHIA events as a function of ln(1/xE).

3. Two Particle Correlations in pp@7TeV

Minimum bias data have been collected in pp collisions at center of mass √s = 7 TeV. We have analyzed about 35 million events in a first attempt to measure γ-hadrons correlations. The trigger particle is selected as the one with the highest transverse momentum measured either in the central tracking system or in the electromagnetic calorimeters. In the calorimeters, electromagnetic particles are detected as clusters of hit calorimeter cells. Roughly we have identified π0 candidate as a pair of clusters which invariant mass matches the π0 mass range, 135 ± 15 MeV, and single clusters (which do no pair with another cluster) as direct photon candidates. No particle identification has been applied yet so that the single cluster sample contains a sizable fraction of charged particles which develop a shower in the calorimeters.

The azimuthal correlation between the trigger particle (charged particle, π0 candidate, single cluster) and the charged hadrons are shown in Fig. 3. The near side (Δφ = 0) and away side (Δφ = π) peak are clearly observed. Note, however, that these distributions have not been corrected for efficiency. It is interesting to remark that at this very preliminary stage of the analysis we find that the underlying event background level, outside the peaks region, is independent of the type of trigger particles, giving some confidence in the measurement. By applying an isolation selection on the trigger candidate, where hadron activity carries less than 30 % transverse momentum of the trigger candidate inside a cone with size R = 0.4 required,
the probability of direct photon or single particle jets in the sample enhances. Comparing the azimuthal correlation with and without isolation selection, obviously, a suppression of the near side peak is observed, but the away side peak is almost unaffected, as expected (Fig. 4). However, this preliminary analysis does not allow to draw any conclusion other that these results indicate the expected behaviour. The isolation parameters are not well adjusted and especially in our case only charged tracks are considered in our isolation cone due to the limited calorimeter acceptance (40% EMCAL and 60% PHOS have been installed so far).

Figure 3. Relative azimuthal angle distribution $\Delta \phi = \phi_{\text{trigger}} - \phi_{\text{hadron}}$ in pp collisions at $\sqrt{s} = 7$ TeV.

Figure 4. Azimuthal correlation distributions before and after isolation cut (IC) on the trigger particles with $p_T > 5$ GeV/c.

4. Summary and outlook
The feasibility to measure $\gamma$–hadrons correlation in pp collisions and medium modification effect in PbPb collisions with ALICE has been evaluated. Such a measurement provides an exclusive observable sensitive to the properties of the medium formed in heavy-ion collisions. So far only a preliminary analysis has been performed on a small fraction of the data collected by ALICE. Exciting physics will certainly come with the final analysis of large statistics with well calibrated detectors.

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