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QGP tomography with photon tagged jets in ALICE*

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Abstract γ+jet events provide a tomographic measurement of the medium formed in heavy ion collisions at LHC energies. Tagging events with a well identified high p_T direct photon and measuring the correlation distribution of hadrons emitted oppositely to the photon in ALICE, allows us to determine, with a good approximation, both the jet fragmentation function 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 will reveal the modifications of the jet structure induced by the medium formed in AA collisions and consequently will infer the medium properties.

Key words direct photon, QGP, jet structure, tomography, path length

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1 Introduction

The Large Hadron Collider (LHC) at CERN, will collide heavy-ions at unprecedented high energies, exceeding by a factor 30 the energy available at RHIC [1]. The main objective of ALICE (A Large Ion Collider Experiment) [2], is to study matter under extreme conditions of energy density to gain a better understanding of the fundamental properties of the strong interaction. In particular, ALICE will explore the Quark-Gluon Plasma (QGP), the state of deconfined matter predicted by QCD [3]. The medium formed in heavy-ion collisions can be best probed by hard scattered partons produced in 2→2 QCD processes at the leading order (LO) including in the final state a hard direct photon (Compton scattering: $q+g\rightarrow\gamma+q$ and quark annihilation: $q+\bar{q}\rightarrow\gamma+g$). On one hand, the 4-momentum of the scattered parton is modified while traversing the medium, whereas on the other hand, the scattered photon does not interact, thus providing a reference for the 4-momentum of the partner parton. Hence, from the modification experienced by the hard scattered partons, measured though photon tagged jets, the medium properties can be inferred. In particular, since these hard scattering processes sample the entire collision volume, the final state hadronic observables provide a real tomographic probe of the medium [4].

Several algorithms have been developed [5] to identify γ-jet events in p–p and Pb–Pb collisions, demonstrating the feasibility of such measurements with the ALICE detectors. However, the jet identification remains challenging in the heavy-ion environment in particular for energies $E_\gamma \sim$ 30 GeV where γ-jet events are measurable in ALICE with sufficient statistics. An equivalent approach is to measure direct-photon–hadrons correlation [6].

In the following, we have first established the intrinsic properties (k_T) of γ-jet events expected in pp collisions at LHC energies. Then we discuss the nucleus-nucleus (AA) collision case, in particular, we explore the possibility to select γ-jet events as a function of their localization in the medium to validate the tomographic approach.

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2 γ-hadron topology in pp collisions

At leading order perturbative QCD, a pair of hard-scattered partons emerges exactly back-to-back in the center of mass of the partonic system. Due to the finite size of the proton, however, it was found that each of the colliding parton carries initial transverse momentum with respect to the colliding axis, originally described as "intrinsic k_{T}". Beyond the leading order, initial and final state radiations (ISR/FSR) will generate additional transverse momentum. Therefore, the resulting total transverse momentum of the outgoing parton pair causes an acoplanarity and a momentum imbalance, $<k_{\mathrm{T}}>$ [7]. It is measured as the net transverse momentum of the outgoing parton-pair $<p_{\mathrm{T}}>_{\mathrm{pair}}=\sqrt{2}\cdot<k_{\mathrm{T}}>$. When the hard scattered parton traverses a color dense medium, it is anticipated that medium effects will generate additional transverse momentum resulting in a broadening of k_{T} . This transverse momentum broadening can be directly related to the transport parameter $\hat{q}$, which describes the transverse momentum transferred from the medium to the traversing parton [8].

Using the PYTHIA event generator [9], we have established the collision-energy dependence of $<k_{\mathrm{T}}>$ from γ-jet events, by taking available data from different experiments measurements [10] and extrapolate to the LHC energies. The resulting dependence is $<p_{\mathrm{T}}>_{\mathrm{pair}}=A\cdot\log(B\cdot\sqrt{s})$ with $A=2.064\pm0.171$ and $B=0.164\pm0.045$.

To study the dependence of $<k_{\mathrm{T}}>$ with the transverse momentum of the hard scattering, we have generated PYTHIA events triggered by 2→2 hard processes where the final state was either a γ-parton pair (γ-jet events) or a parton-parton pair (jet-jet events). Hard processes were generated in different p_{T} bins with collision energy 14 TeV, with the k_{T} setting predicted above and ISR/FSR switched on. The averaged $<p_{\mathrm{T}}>_{\mathrm{pair}}$ versus the transverse momentum, shows a weakly linear dependence.

3 Medium modification by heavy ion collisions

The tomography measurement can be performed by selecting γ-hadron pairs with different values of the parameter x_{E}=-$\vec{p}_{\mathrm{T}}^{\,\mathrm{h}}\cdot\vec{p}_{\mathrm{T}}^{\,\gamma}/\,|\,p_{\mathrm{T}}^{\gamma}\,|^2$. This criteria can effectively control hadron emission from different regions of the medium and therefore extract the corresponding jet modification parameters [4].

To simulate the medium induced energy loss, we used the Monte-Carlo model QPYTHIA [11], which combines an energy loss mechanism [12] and a realistic description of the collision geometry [13]. The HIJING [14] generator was used to simulate the underlying events of heavy-ion collisions and PYTHIA to simulate pp collisions. Three samples of γ-jet events were generated with photon energy larger than 20 GeV. A first sample of pp collisions at 5.5 TeV generated with PYTHIA provides the baseline. The second sample consists in similar events modified by QPYTHIA merged with central heavy ion collision events. The last sample is obtained by merging the PYTHIA events and peripheral heavy ion collision events.

Tagging events with a direct photon well identified [15] by the ALICE calorimeters and measuring the distribution of hadrons emitted oppositely to the photon as a function of x_{E}, allows us to determinate the jet fragmentation function [6]. The underlying event is subtracted by correlating the isolated photon with charged hadrons emitted on the same side as the photon, in the azimuthal range $-\pi/2<\Delta\phi<\pi/2$. To quantify the medium modification, I_{AA} is calculated (Fig. 1)

$$I_{\mathrm{AA}}(x_{\mathrm{E}})=\frac{CF_{\mathrm{AA}}}{CF_{\mathrm{pp}}} \qquad (1)$$

as the ratio of γ-hadrons correlation distribution measured in AA CF_{AA} and pp collisions CF_{pp}. The expected enhancement at low x_{E} and suppression at high x_{E} for central collision is observed, whereas, I_{AA} is equal to 1 for peripheral collisions, where quenching effects are absent.

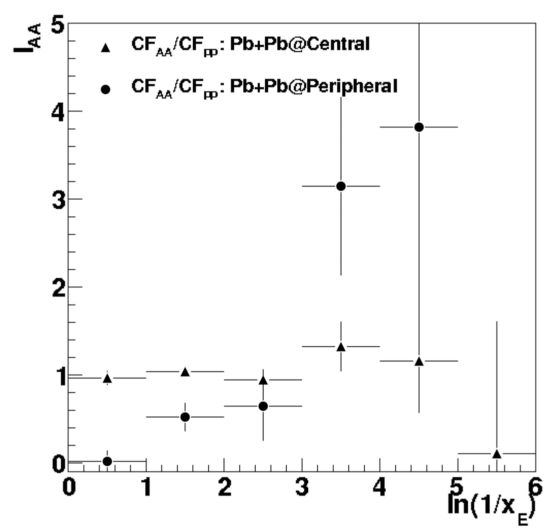

Fig. 1. The nuclear modification factor I_{AA} for γ-hadrons correlation distribution in central and peripheral Pb+Pb collisions at $\sqrt{s_{\mathrm{NN}}}=$ 5.5 TeV.

To illustrate the selectivity of the tomographic measurement, the length, L, the jet travels inside the medium is calculated. Fig. 2 indicates that most high $p_{\rm T}$ leading particles are preferentially produced at the surface (small L), while low $p_{\rm T}$ leading particles are produced inside the whole volume (large L), which demonstrates the L dependence of of the γ tagged charged hadron production for 2 different $x_{\rm E}$ regions.

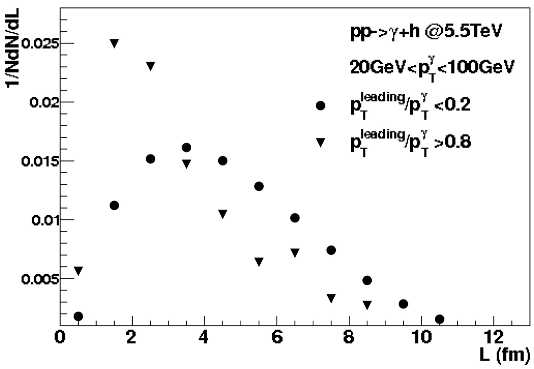

Fig. 2. The probability of the leading particles production as a function of medium length L.

We have then studied the L dependence of the medium modification factor $I_{\rm AA}$ (Fig. 3) by selecting different $x_{\rm E}$ regions. For large $x_{\rm E}$ particles, an obvious suppression is observed, and the suppression is stronger with increasing the medium length. For small $x_{\rm E}$, the opposite behavior is obtained as an enhancement ($I_{\rm AA} > 1$). This result implies that γ-hadrons correlation could be used to probe volume versus surface emission by selecting γ-jet events with different $x_{\rm E}$ values. However such L dependence will be challenging to measure in the experiments.

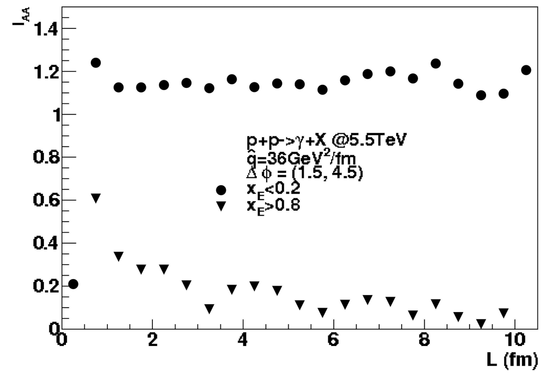

Fig. 3. The nuclear modification factor $I_{\rm AA}$ distribution as a function of medium length L by selecting different regions of $x_{\rm E}$ on correlation distribution.

4 Conclusions

γ+jet studies are widely recognized as a powerfull tool to characterize QGP. The "γ+jet tomography" study will enable us to extract jet quenching parameters in different regions of the dense medium via measurement of the nuclear modification factor of γ-hadrons correlation.

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