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High pt and photon physics with ALICE at LHC*

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Abstract ALICE, A Large Ion Collider Experiment, is dedicated to study the QCD matter at extreme high temperature and density to understand the Quark Gluon Plasma (QGP) and phase transition. High-transverse-momentum photons and neutral mesons from the initial hard scattering of partons can be measured with ALICE calorimeters, PHOS (PHOton Spectrometer) and EMCAL (ElectroMagnetic CALorimeter). Combing the additional central tracking detectors, the γ-jet and π^0-jet measurements thus can be accessed. These measurements offer us a sensitive tomography probe of the hot-dense medium generated in the heavy ion collisions. In this paper, high p_{T} and photon physics is discussed and the ALICE calorimeters capabilities of high-transverse-momentum neutral mesons and γ-jet measurements are presented.

Key words ALICE experiment, PHOS, EMCAL, Jet quenching, γ-jet measurement

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1 Introduction

Lattice QCD predicts the new matter QGP would be formed in an extreme condition of temperature and density. In order to understand its phase transition from confined matter, and the thermodynamic properties, heavy ion project ALICE [1, 2] at LHC is going well towards the lead-lead collisions at $\sqrt{S_{\mathrm{NN}}}=$ 5.5 TeV. Among the observations, photon measurement can be employed as a prominent probe for it carries ample information of the collision evolution. The soft photons will explore the thermodynamic property from hot dense matter and hot hadron gas. The direct photon with high-transverse-momentum from hard processes could be used to diagnose the formation of QGP, also benefit us to investigate the medium effect and γ-jet study. The neutral mesons spectra π^0, η and ω(782) can be reconstructed the decay channels of $\pi^0(\eta)\rightarrow 2\gamma$, $\eta(\omega(782))\rightarrow 3\pi$, $\omega(782)\rightarrow \pi^0\gamma$ to jet quenching from proton-proton to A-A collisions [3–7].

2 ALICE calorimeters, PHOS and EMCAL

ALICE calorimeters (Fig. 1), PHOS [8] and EMCAL [9], are sophisticated on hard electromagnetic probe. PHOS is placed at 460 cm distance from the interaction point which is a high resolution electromagnetic calorimeter segmented by CPV (Charged Particle Veto) and $PbWO_4$ (lead tungsten crystals). The PHOS consists of 5 identical modules and covers an azimuthal range from 220° to 320°, and a central rapidity of $|\Delta\eta|<0.12$. Each module is made of

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$56{\times}64$ $PbWO_4$ crystals with $22{\times}22{\times}180$ mm^3 corresponding to a fine granularity of $\Delta\phi{\times}\Delta\eta = 4.8{\cdot}10^{-3}{\times}4.3\cdot10^{-3}$ to allow us separate electromagnetic showers under high multiplicity environment with momentum range from 0.1 GeV/c to 100 GeV/c to fulfill the physics demand.

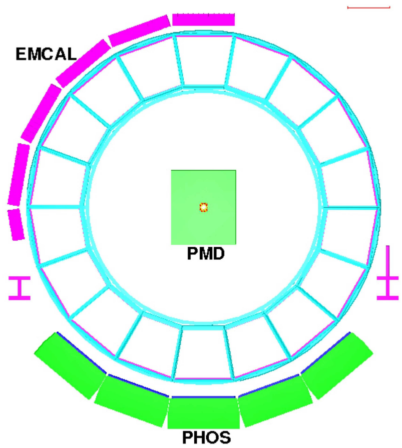

Fig. 1. (color online). ALICE calorimeters: PHOS and EMCAL.

The EMCAL is a lead-scintillator sampling electromagnetic calorimeter with a larger geometrical acceptance of azimuthal angle range from 70° to 180° and a rapidity of $|\Delta\eta| < 0.7$. Combing with the ALICE excellent capabilities to track and identify particles in a very wide momentum range, EMCAL would enhance the jet measurement and jet quenching study. Especially, the EMCAL can afford efficient and unbiased fast level L0 and L1 trigger on high energy jets. In addition, from simulation and cosmic test, the EMCAL energy resolution is of the order of $11\%/\sqrt{E(\mathrm{GeV})}\oplus 1.7\%$, which is sufficient for its physics motivation.

3 Direct photon and neutral mesons measurement

Photons produced with collision evolution are generally divided into two classes of direct (prompt) photons and decay photons [10]. The dominant process are Compton scattering ($\mathrm{q}(\overline{\mathrm{q}})+\mathrm{g}\rightarrow\gamma+\mathrm{g}$) and annihilation ($\mathrm{q}+\overline{\mathrm{q}}\rightarrow\gamma+\mathrm{g}$), thermal photon radiation and fragmentation photon produced in heavy ion collisions. The direct photon with high-transverse-momentum could be accessible through statistical method [11] or γ-tagged jet [12]. With the latter method, the jet tomography (jet shape, jet heating and fragmentation function) also can be determined [13], thus well employed in current analysis. However, due to huge background coming from neutral pion decays, especially at high p_{T} range ($p_{\mathrm{T}}^{\pi^0} > 40$ GeV/c), the open angle between the two decayed photons is too small to be distinguished. These two photons are then identified as a single photon cluster, hence the γ/π^0 separation is challenging in the real life. Shower shape analysis, time of flight and charged particle exclusion (track matching) are combined for photon identification. Additional isolation cut method is used for direct photon identification and γ/π^0 separation [14–16]. And the neutral mesons spectra π^0, η and $\omega(782)$ can be extracted by invariant mass analysis based on the decay channels of $\pi^0(\eta)\rightarrow2\gamma$, $\eta(\omega(782))\rightarrow\pi^0\pi^+\pi^-$, $\omega(782)\rightarrow\pi^0\gamma\rightarrow3\gamma$.

We first estimate the direct photon and neutral meson production rate by using next-leading-order package INCLNLO [17] and leading order generator PYTHIA [18]. For the first pp collision at $\sqrt{S} = 10$ TeV, π^0 with momentum range from 25 to 50 GeV/c, η at 20~40 GeV/c, $\omega(782)$ at 15~30 GeV/c and direct photon at 15~20 GeV/c are expected depending on the different run scenarios [19].

To validate the analysis algorithm and the detector response, we simulate proton-proton collisions at $\sqrt{S} = 10$ TeV [20] in the framework of AliRoot [21]. In our first analysis, the π^0 extraction is at high priority for detector calibration. The Fig. 2 and Fig. 3 show the π^0 invariant mass distribution with PHOS and EMCAL at $5.5 < p_T < 6.5$ GeV/c. The peak is fitted by a polynomial plus a gaussian function. The fitted mass peak positions agree well with the π^0 nominal mass, while the fitted mass resolutions ($\sigma_{\mathrm{m}_{2\gamma}}$) of π^0 are about 4.7 MeV/c^2 for PHOS and 10 MeV/c^2 for EMCAL. These results are in good accordance with the original design.

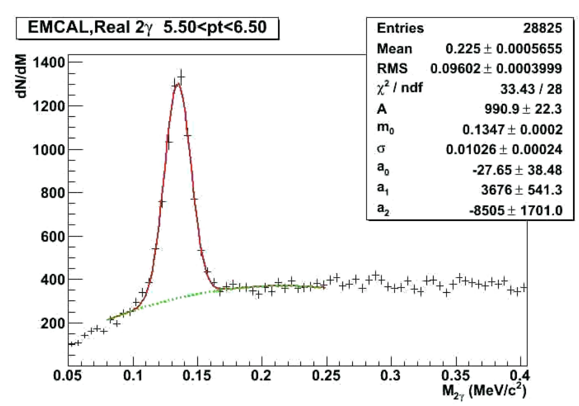

Fig. 2. (color online). π^0 signal with $5.5 < p_{\mathrm{T}} < 6.5$ GeV/c in EMCAL, and the peak is fitted by pol2+gaussian with simulation of pp at 10 TeV. The dot line is fitted by pol2 for the background subtraction.

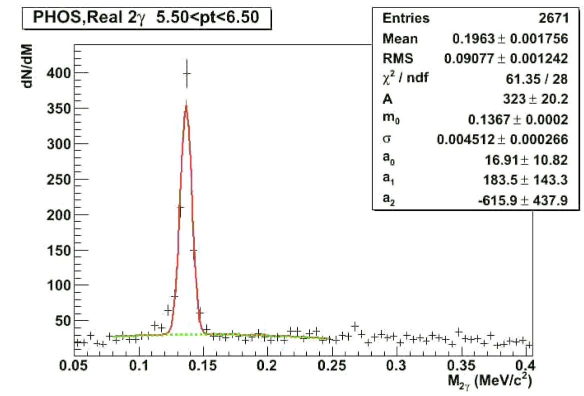

Fig. 3. (color online). π^0 signal with $5.5 < p_{\rm T} < 6.5$ GeV/c in PHOS, and the peak is fitted by pol2+gaussian with simulation of pp at 10 TeV. The dot line is fitted by pol2 for the background subtraction.

The $\omega(782)$ reconstruction starts from π^0 candidate selection, then loop it with the third photon or $\pi^+\pi^-$ to get its invariant mass. For $\omega(782) \rightarrow 3\gamma$, three types of backgrounds are considered to fully subtract the correlated background. While the 3π channel is for the reconstruction of η and $\omega(782)$, the sophisticated cuts for track selection require further optimization to minimize the background. All these spectra measurements in proton-proton collisions would be used as a baseline for further PbPb collisions to study the jet quenching by a nuclear modification factor ($R_{\rm AA}$).

4 Jet reconstruction

$\gamma -$jet pairs emitted in heavy-ion collisions provide a unique way to perform a tomographic measurement of the medium created in the collision through study of the medium modified jet properties. The γ is detected by PHOS detector, while the jet is reconstructed in its opposite. The jet reconstruction in ALICE takes an alternative method, which uses the high resolution charged particle tracking detector to measure the hadronic momentum, and employs EMCAL for electromagnetic particle detection. To avoid double counting of the hadronic energy deposition in EMCAL, the track matching method is used to remove its contribution. We use the UA1-type cone algorithm [22] to simplify the uncorrelated background reduction.

Due to a large fraction of the jet energy within a forward cone $R = \sqrt{\Delta\phi^2 + \Delta\eta^2}$, the R can be optimized to constrain the jet resolution at a reasonable level. For instance, with a cone size $R = 0.3$ and $p_{\rm T} > 2$ GeV/c the energy resolution for 100 GeV jets is about 30%. Without the EMCAL, the resolution would deteriorate to 45% which is mainly caused by charged-to-neutral fluctuation [9].

Jet measurements in heavy ion collisions must contend with the large background of soft hadrons in the underlying event, which makes the measurement in the real life more difficult, therefore Relativistic Heavy Ion Collider (RHIC) concentrated until recently mainly on high $p_{\rm T}$ hadrons and their correlations.

5 Fragmentation function calculation by γ-jet measurement

To detect how the kinematical properties of hard scattered partons (quarks or gluons) are modified when they traverse the hot QCD medium formed in heavy ion collisions, the probe selected for the study is the correlated direct photon and parton emitted back-to-back after initial hard collision. The fragmentation function of parton tagged by photon will be observed, where the hard scattering parton will experience additional medium induced energy loss in AA collision compared to pp collision as described previously, hence the fragmentation function will be modified [23]. As it is demonstrated, γ-hadrons correlation measurement is the unique approach to study jet fragmentation function where a full jet reconstruction can not be done due to the limited detector acceptance in experiments. The measurement of back-to-back γ-hadrons correlation in elementary collisions directly determines the fragmentation function of the recoil jet since $x_{\rm E} = -\vec{p}_{\rm T_h} \cdot \vec{p}_{\rm T_\gamma} / \left|p_{\rm T_\gamma}\right|^2 \approx p_{\rm T}^{\rm h}/p_{\rm T}^{\gamma} \approx p_{\rm T}^{\rm h}/p_{\rm T}^{\rm jet}$.

To quantify this medium modification of γ-hadrons correlation distribution in heavy ion collisions relative to pp collisions, one defines the medium modification factor $I_{\rm AA}$,

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

for γ-hadrons correlation distribution.

The relative azimuthal angle, $\Delta\phi = \phi_\gamma - \phi_{\rm h}$, between the direct photon and charged hadrons is strongly peaked at π radian for γ–jet events as shown in Fig. 4. The $\Delta\phi$ distribution between the photon trigger and the charged hadrons broadens the far side peak when quenching effects are introduced in heavy ion collisions. The broadening is small, however, and the background of an underlying heavy ion event might shadow this difference which makes the observation a challenging task.

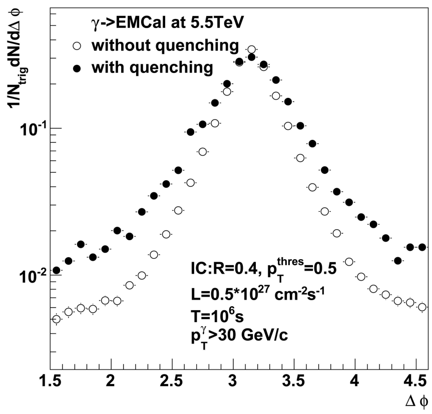

Fig. 4. Relative azimuthal angle distribution $\Delta\phi = \phi_{\gamma} - \phi_{\text{hadron}}$ for γ–jet events at $\sqrt{s}$=5.5 TeV. Photons with $p_{\text{T},\gamma}$ >30 GeV/c are measured and isolated in EMCAL. Associated hadrons have $p_{\text{T,hadron}}$ >2 GeV/c. Distributions are normalized to the total number of isolated photons.

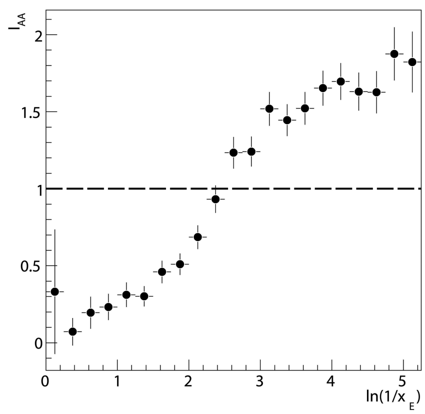

Fig. 5. The ratio of the photon-triggered conditional hadron yields.

The ratio of the correlations, labeled I_{AA} as a function of $\ln(1/x_E)$, is shown in Fig. 5. The statistical errors are based on the achievable annual yield of hadrons correlated with photons with p_{T} larger than 30 GeV/c. An enhancement at low x_{E} and a suppression at high x_{E} can be observed. These distributions have to be folded with realistic background distributions in order to obtain final statistical and systematic uncertainties for the heavy-ion environment.

6 Conclusion

ALICE is a new generation detector to open the new energy domain to explore the hot QCD matter and the phase transition from confined matter to QGP. Hard electromagnetic probe of high p_{T} direct photon and neutral mesons is provided by use of PHOS and EMCAL detectors, and jet reconstruction resolution is improved by about 50% especially by combining the EMCAL and high resolution central tracking detectors. High p_{T} direct photons and neutral mesons, as well as γ-jet can be precisely measured in ALICE. We also demonstrate the feasibility of fragmentation function calculation with γ-hadron correlation measurement.

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