Neutral pion and eta meson measurements with the ALICE detector

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Abstract. The ALICE experiment at the LHC is optimized to study the quark-gluon plasma (QGP), created in heavy-ion collisions. The medium-induced energy loss of particles can be investigated via the measurement of neutral meson spectra in heavy-ion collisions as well as via neutral meson-hadron correlations. Neutral mesons are identified from decay photon pairs via the invariant mass technique. Photons are measured in ALICE directly in the two electromagnetic calorimeters (PHOS and EMCal), as well as via the method of photon conversion (PCM) into electron-positon pairs, where the latter are measured in the inner tracking system (ITS) and the time projection chamber (TPC). Results obtained from EMCal, PHOS and PCM are consistent and allow measurements of spectra with high precision over a wide kinematical range. Suppression of the high-p_T meson production is observed through the mesasurement of nuclear modification factor (R_{AA}), which decreases with increasing the centrality of the collision. The suppression of the per-trigger yield on the away side in high-p_T π^0 hadron correlations as measured by the modification factor (I_{AA}) also shows evidence for parton energy loss in the medium.

1. Introduction

Neutral π^0 and η mesons are produced via parton fragmentation in pp collisions. The meson production differential cross section is a convolution of parton distribution functions (PDF) in the proton, fragmentation functions (FF) of the parton into a meson, and the inclusive cross section of partons production. Studies of neutral meson production constrain both the PDF and FF. The dense environment created in heavy-ion collisions allows observation of modification of the PDF or FF via linear and non-linear recombination effects caused by the dense matter [1]. Insight into modification can be quantified with particle ratio comparisons between ultra-relativistic heavy-ion collisions and pp collisions. Light mesons are mostly produced in gluon fragmentation at LHC energies. Due to the different color factor, gluons will suffer a larger energy loss in the medium than quarks. Both this and a different relative contribution of gluons and quarks to neutral meson production may lead to differences in the suppression pattern of π^0 and η mesons [2, 3]. High-p_T meson production spectra give information about the energy loss of the scattered parton in the dense medium.

 Two-particle angular correlations between high-p_T particles and associated particles are also used to study jet-quenching phenomena. They provide information about the amount and

distribution of the partonic energy loss in medium. Remnants of the radiated energy and the medium response to the initial parton can be studied in a soft and hard regime.

2. Neutral meson measurement

Photons were measured with two methods in the ALICE detector [4] at the LHC [5]. The first is via the measurement of the energy deposited by photons in the sensitive material on the EMCal [6] or PHOS [7] electromagnetic calorimeters. The second is based on the conversion of photons into e^+e^- pairs in the detector material (called the photon conversion method, PCM). Charged particles created by γ conversion are measured in the six layers of the silicon inner tracking system (ITS) and the gaseous time projection chamber (TPC). Neutral mesons are combined from photon pairs via the invariant mass technique.

ALICE has measured π^0 production spectra for four center-of-mass energies $\sqrt{s} = 0.9$ [8], 2.76 [9], 7 [8] and 8 TeV [10] in pp collisions. The p_T distributions presented in Fig. 1 are described by PYTHIA8 event generator and compared to the next-to-leading order perturbative QCD (NLO pQCD) calculations for two renormalization and factorization scales. The MSTW PDF and DSS14 FF [11] used in predictions describe the measured spectra better than previously used calculations [8]. Models describe data quite well for lower collision energies. A disagreement for higher energies starts at medium p_T and growing with p_T reaching almost factor two.
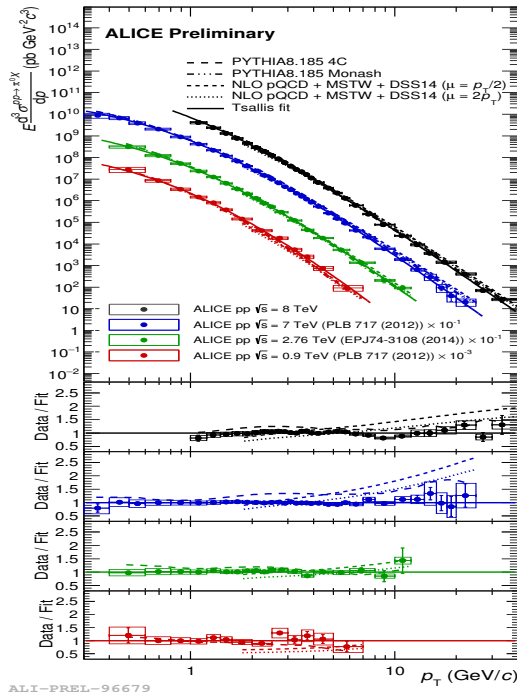

Figure 1: (On the left) π^0 production spectra in pp collisions for energies $\sqrt{s} = 0.9$, 2.76, 7 and 8 TeV compared to PYTHIA, NLO pQCD calculations and described by Tsalis fit.
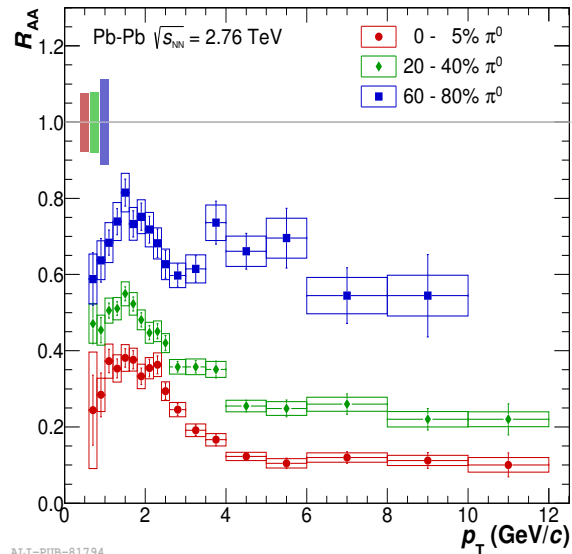

Figure 2: (Above) Neutral pion nuclear modification factor R_{AA} for three centrality classes in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [9].

ALICE also measured p_T spectra for six centrality classes in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [9]. Comparison of the data to theory predictions and Monte Carlo (MC) models can be found in [9]. Nuclear effects are quantified via the nuclear modification factor R_{AA} defined as: $R_{AA}(p_T) = \frac{1}{N_{coll}} \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$, where dN/dp_T is the yield in nuclear and pp collisions scaled by the number of binary nucleon-nucleon collisions, N_{coll}, obtained from Glauber Monte Carlo simulations [12, 13]. The interplay of the initial and the final state effects contribute to the nuclear modification factor. There is no impact of medium when $R_{AA} = 1$. Figure 2 shows the p_T dependence of R_{AA} for three centrality classes [9]. The largest suppression is observed for the most central Pb-Pb collisions with a value of $R_{AA} \sim 0.1$ above $p_T \approx 4$ GeV/c.

The increase of the integrated luminosity for [9] by a factor of 10 extended the p_T range of π^0 spectrum up to 20 GeV/c and allowed η meson p_T spectra measurements for the first time [10]

in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The η meson spectrum for pp and Pb-Pb collisions is shown in Fig. 3. The NLO pQCD prediction [11] is compatible with pp result. The same prediction scaled by N_{coll} compared to Pb-Pb results indicates a suppression of the yield.
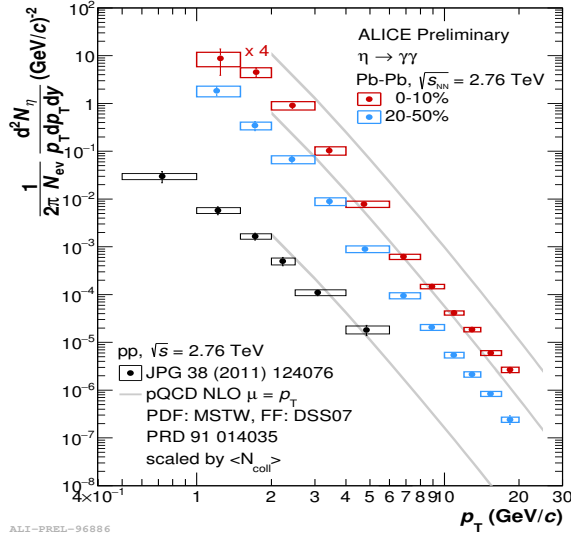

Figure 3: η meson production spectra in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for two centrality classes compared to pp data and NLO pQCD predictions scaled by N_{coll}.
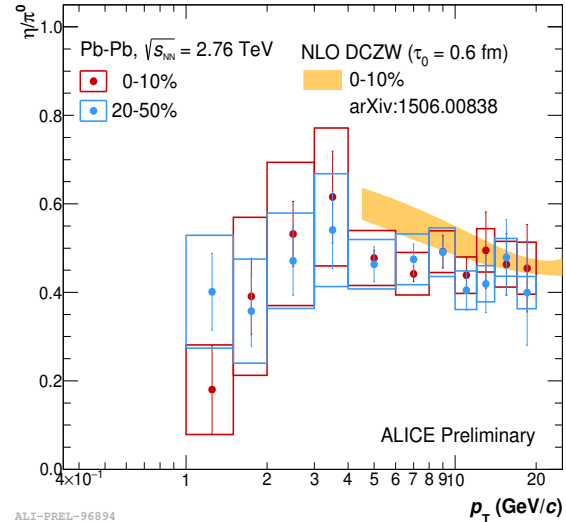
Figure 4: The η to π^0 meson production ratio in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV for two centrality classes compared to NLO theoretical calculation with quenching.

The measured η/π^0 production ratios in Pb-Pb collisions for two centrality classes compared to a theory prediction based on NLO and jet quenching [2] are shown in Fig. 4. The η/π^0 ratio is flat above $p_T = 4$ GeV/c. An agreement with pQCD predictions within uncertainties is visible. A comparison to the pp result at $\sqrt{s} = 7$ TeV [8] and $K^\pm/\pi^\pm$ result [14] in Pb-Pb collisions for the same centrality classes indicates no significant differences within uncertainties. A comparison to the K/π ratio is of interest, even if strangeness content is different, because the kaon has approximately the same mass as the η meson.

3. π^0 - hadron correlations

Two particle correlations between high-p_T ($8 < p_T < 16$ GeV/c) π^0 mesons and charged hadrons have been studied in the ALICE experiment in pp and central Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [15]. There are two jet origin structures in the azimuthal correlation $\Delta\varphi = \varphi^{\text{trig}} - \varphi^{\text{assoc}}$ of the trigger particle and associated particles. The near and away side peaks appear at $\Delta\varphi = 0$ and $\Delta\varphi = \pi$, respectively. The effect of medium is quantified with the medium induced per-trigger yield modification factor $I_{\text{AA}}(p_T^{\pi^0}, p_T^{h^\pm}) = \frac{Y^{\text{AA}}(p_T^{\pi^0}, p_T^{h^\pm})}{Y^{\text{pp}}(p_T^{\pi^0}, p_T^{h^\pm})}$, where $Y^{\text{AA(pp)}}(p_T^{\pi^0}, p_T^{h^\pm})$ is the per-trigger yield for given trigger particle $p_T^{\pi^0}$ and the associated particle $p_T^{h^\pm}$ in A-A (pp) collisions. The per-trigger yield modification factor for the near and away side are shown in the left and right hand side of Fig. 5, respectively. The enhancement on the near side ($1.2 < I_{\text{AA}} < 1.8$) can be interpreted as the modification of the fragmentation function, quark jet to gluon jet ratio modification, or bias in the parton p_T due to the energy loss. A suppression is observed on the away side ($I_{\text{AA}} \approx 0.6$) above $p_T^{assoc} = 3$ GeV/c, which is a manifestation of energy loss in medium. The enhancement visible at low p_T^{assoc} may arise from k_T broadening, medium excitation or fragments from radiated gluons. Results are compared to different models. JEWEL [16] and NLO pQCD [17] models describe only suppression on the away side. AMPT [18] describes low-p_T part (quantitatively) and overpredicts high-p_T region. The π^0-hadron I_{AA} are compatible with the charged di-hadron correlation measurements in ALICE [19].
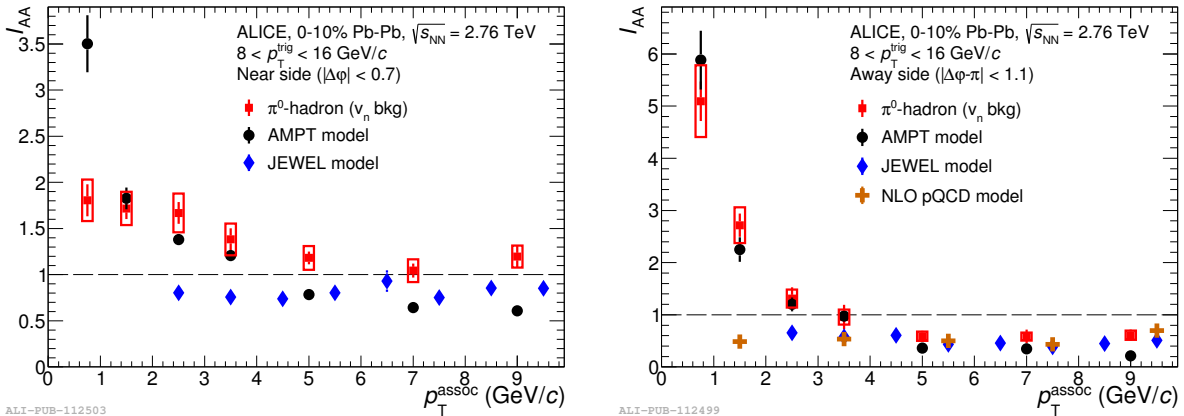
Figure 5: Per trigger yield ratio for the near side (left) and the away side (right) for π^0 - hadron correlations compared to several Monte Carlo predictions [15].

4. Summary

We presented measurements of the invariant π^0 yields for pp collisions at $\sqrt{s} = 0.9$, 2.76, 7 and 8 TeV as well as for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV over a wide p_T range. The NLO pQCD predictions describe pp results at lower energies quite well while there is an increasing discrepancy at high p_T for the highest energies. The nuclear modification factor R_{AA} for Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV indicates a strong and p_T dependent π^0 suppression. The first η meson measurement at LHC in heavy-ion collisions has been shown. The η/π^0 ratio is rising towards $p_T = 4$ GeV/c and then remaining essentially constant at 0.45 for higher p_T values. The π^0-hadron correlations have been measured in pp and the most central Pb-Pb collisions. The observed away side high-p_T suppression and low-p_T enhancement is partially described by different MC generators. Results constrain perturbative QCD inspired models, parametrization of parton distribution and fragmentation functions as well as phenomena governing the quark-gluon medium.

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