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NEUTRAL MESON AND DIRECT PHOTON MEASUREMENTS WITH THE ALICE EXPERIMENT

The ALICE experiment is designed to study the properties of the matter created in proton-proton and heavy-ion collisions at the LHC. Neutral mesons can be reconstructed in ALICE in a wide range of transverse momenta via two-photon decays. Neutral meson measurements in pp collisions give an opportunity to validate the NLO or NNLO pQCD calculations and to constrain the parton distribution functions and the parton fragmentation functions. Neutral meson spectra measured in pA and AA collisions allow us to test a modification of the parton distribution functions in nuclei and the parton energy loss in the hot matter created in AA collisions. The recent results from ALICE on direct photon measurements in the Pb–Pb, neutral pion and η meson productions in pp, p-Pb, and Pb–Pb collisions are presented.

Keywords: high-energy physics, neutral meson spectra, direct photons.

1. Introduction

ALICE experiment aims to explore properties of the hot ($T \sim 10^{12}$ K) and dense quark-gluon matter and to investigate the chiral symmetry restoration and the deconfinement mechanisms. The hard hadron production in pp collisions can be described by a convolution of the hard parton cross-section, parton distribution function (PDF), and fragmentation function (FF). The measurement of hadron spectra in a wide kinematic range for various collision energies provides a new input for PDF and FF parametrizations. The meson production in heavy-ion collisions allows studying several effects. The development of a collective flow can be studied at low $p_{\rm T}$ ($p_{\rm T} < 3$ GeV/c). The high-$p_{\rm T}$ ($p_{\rm T} > 5$ GeV/c) part of the spectra originates predominantly from the hard parton hadronization. At moderate $p_{\rm T}$, the π^0 and η mesons are mainly produced via the gluon fragmentation at LHC energies. As gluons show a larger energy loss in the medium than quarks, the comparison of the suppressions of the yields of light neutral mesons and heavier hadrons will provide an input for the understanding of the energy loss by the different partons. The difference in the suppression patterns of the π^0 and η meson yields can indicate the differences in the relative contributions of quarks and gluons. Neutral meson spectra also serve as an input for the direct photon analysis. Direct photons are defined as all photons that are not coming from the decays of particles. Photons do not interact strongly with the medium. They carry information on the properties of the matter at the space-time point of their emission. The high-$p_{\rm T}$ part of the direct photon spectrum is dominated by photons created in the hard scattering of the partons of incoming nucleons and can serve as a tool to constrain the models that describe the initial stage of a collision. The low-$p_{\rm T}$ part of the direct photon spectrum may contain photons from the thermal emission of the hot matter and probes its temperature and the velocity of the collective expansion.

2. Neutral Meson Measurements

The ALICE experiment is a general-purpose detector [1]. It consists of 17 separate subdetectors that are dedicated to specific goals. Neutral mesons are reconstructed via the two-photon decay channel. Photons in ALICE can be measured in an Electro-Magnetic Calorimeter (EMCal) [2] and a Photon Spectrometer (PHOS) [3] or by means of the Photon Conversion Method (PCM) based on the reconstruction of photons from e^+e^- pairs that are products of the photon conversion in the material of central barrel detectors [4].

The product the efficiency ε times the acceptance A for different methods of neutral meson reconstruction is shown in Fig. 1. The EMCal has the highest $A \cdot \varepsilon$

values, as it has a large acceptance and a high probability to measure photons. PHOS has a lower $A \cdot \varepsilon$ factor due to limited acceptance, but it has lower energy threshold for the signal and outperforms EMCal at low $p_{\rm T}$. It is possible to combine the photons reconstructed with EMCal and PCM to form pairs (PCM-EMC method). In this case, the $A \cdot \varepsilon$ factor is approximately 10 times smaller than that of EMCal due to the small conversion probability of a photon. This method makes it possible to extend the measurement up to high $p_{\rm T}$, because showers from different photons don't merge in a detector. The PCM efficiency is determined by the probability of the photon conversion, its $A \cdot \varepsilon$ factor is the lowest.

2.1. Transverse momentum spectra of neutral mesons in pp collisions

The ALICE experiment has measured π^0 and η meson spectra in pp collisions at several collision energies: $\sqrt{s} = 0.9, 2.76, 7, 8$ TeV [5–9], see Fig. 2. Neutral pion spectra were reconstructed up to $p_{\rm T} \sim 40$ GeV/c (for $\sqrt{s} = 2.76$ TeV). PYTHIA 8.2 [10] with Monash 2013 tune describes the data at high $p_{\rm T}$, but shows a deviation from the data at moderate $p_{\rm T}$ at the higher energies. The NLO calculations [11–13] predict a 20–60% higher yield, and the difference increases with $p_{\rm T}$. The situation with η meson is similar: PYTHIA 8.2 with Monash 2013 tune reproduces the data, whereas the NLO calculations predict a 50–100% higher yield at all colliding energies.

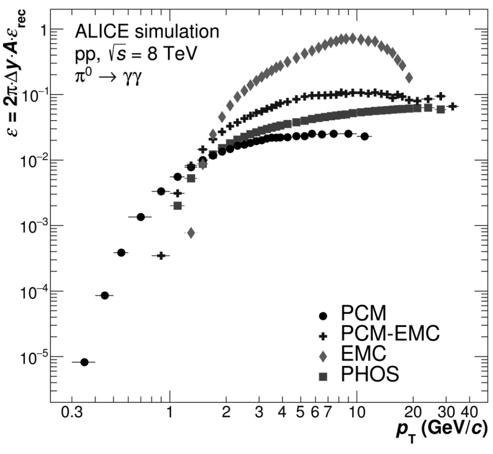


Fig. 1. Normalized correction factors ϵ for each reconstruction method for π^0 as a function of $p_{\rm T}$. The factors contain the reconstruction efficiencies and the detector acceptances normalized per unit rapidity and full azimuthal angle

2.2. Transverse momentum spectra of neutral mesons in p-Pb collisions

ALICE has recently measured the π^0 and η yields in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV [15]. Neutral pion and η spectra are well described by the Tsallis fits [16]. The NLO pQCD calculations [11, 17] scaled

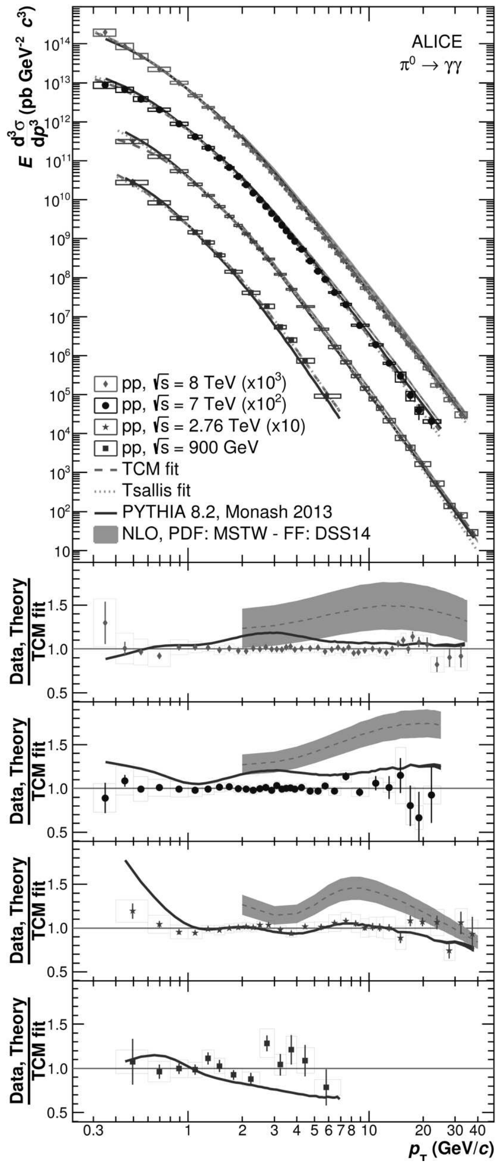


Fig. 2. Neutral pion spectrum at $\sqrt{s} = 0.9, 2.76, 7,$ and 8 TeV [5–9]. The spectrum is compared to the PYTHIA8 [10] event generator and NLO pQCD calculations. The ratios of data and predictions to the two-component model (TCM) fit [14] are shown on the bottom panels for each energy separately

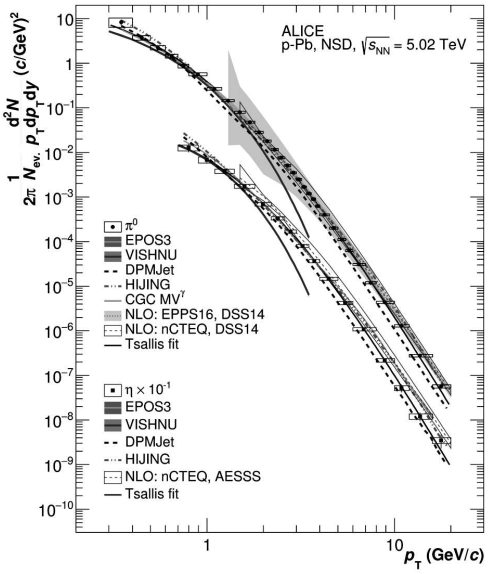


Fig. 3. Neutral pion and η spectra measured in p-Pb collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV [15]. The data are compared to the scaled NLO pQCD calculations [11, 17] and to DPMJET [19], VISHNU [20], HIJING [21], EPOS [18], CGC [22] models

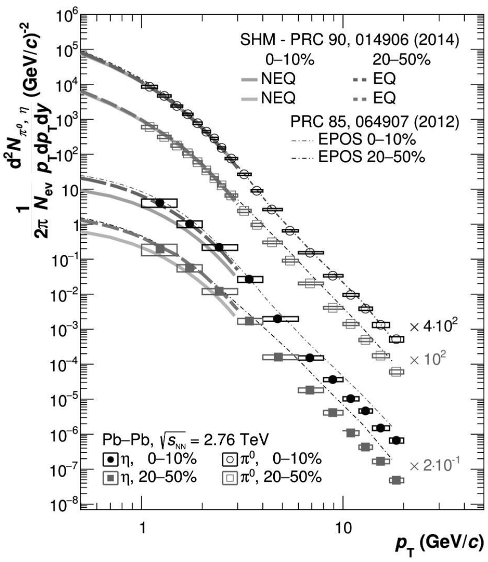


Fig. 4. Neutral pion and η spectra in two centrality classes measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV [6]

with the number of binary nucleon-nucleon collisions reproduce the π^0 spectrum in the entire $p_{\rm T}$ range and overpredict the η spectrum at high $p_{\rm T}$. EPOS [18] Monte-Carlo reproduces the π^0 spectrum and η spectrum below 3 GeV/c, but overpredicts it at high $p_{\rm T}$. The hydrodynamic model VISHNU[20] provides a good description at low $p_{\rm T}$. The HIJING[21] and DPMJET [19] models fail to reproduce data for $p_{\rm T}$ larger than 4 GeV/c.

2.3. Transverse momentum spectra of neutral mesons in Pb–Pb collisions

The data collected in 2010 allowed the measurement of the spectrum of π^0 in Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV in the range $0.6 < p_{\rm T} < 12$ GeV/c [6]. The neutral pion yield can be described by the Tsallis fits. Combining the datasets collected in 2010 and 2011 years allowed one to extend the range of the π^0 spectrum up to 20 GeV/c and to measure also the η meson spectra in narrower centrality classes [8], see Fig. 4. Two versions of the SHM model [23] reproduce the shape of the π^0 spectrum at low $p_{\rm T}$. For the η mesons, NEQ SHM underestimates the yield at the low-$p_{\rm T}$ region.

2.4. Nuclear modification factor in Pb–Pb collisions

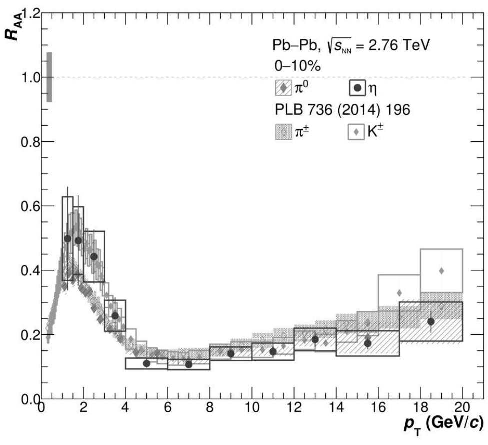
Figure 5 shows the nuclear modification factor defined as the meson yield in Pb–Pb collisions divided by the meson production cross-section in pp collisions at the same energy scaled with the nuclear overlap function. The value of $R_{\rm AA} = 1$ corresponds to the absence of medium effects. For Pb–Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV, $R_{\rm AA} \sim 0.1$ at $p_{\rm T} \sim 7$ GeV/c was observed reflecting a strong energy loss by partons in the hot quark-gluon matter. The $R_{\rm AA}$ increases with $p_{\rm T}$. The nuclear modification factors for π^0 and η agree with those for $\pi^\pm$ and $K^\pm$. The right plot of Fig. 5 shows the centrality dependence of the nuclear modification factor in Pb–Pb collisions. The $R_{\rm AA}$ decreases, as the centrality increases, indicating that the medium effects are most prominent in the central collisions.

3. Direct Photons Measurements

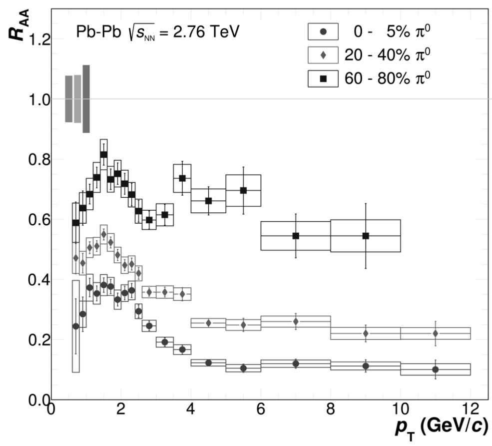
Direct photons are all photons that do not originate from the hadron decays. The yield can be calculated as

$$\gamma_{\rm \,direct} = \gamma_{\rm \,inc} - \gamma_{\rm \,decay} = (1 - 1/R_\gamma)\,\gamma_{\rm \,inc},$$

where $\gamma_{\rm \,inc}$ – the inclusive photon spectrum, $\gamma_{\rm \,decay}$ – the decay photon spectrum, $\gamma_{\rm \,direct}$ – the direct photon spectrum, and $R_\gamma = \gamma_{\rm \,inc}/\gamma_{\rm \,decay}$. It turns out that the ratio R_γ expressed as a double ratio $R_\gamma =$



a



b

Fig. 5. Nuclear modification factor of π^0, $\pi^\pm$, η, and $K^\pm$ mesons measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV in the centrality class 0–10% [8] (*a*). Centrality dependence of the π^0 nuclear modification factors in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV (*b*)

$= \frac{(N_{\gamma,\ \rm inc}/N_{\pi^0})_{\rm meas}}{(N_{\gamma\ \rm decay}/N_{\pi^0})_{\rm simulated}}$ cancels out the significant part of systematic uncertainties of the measurement. The value of R_γ greater than unity indicates the direct photon signal. The double ratio together with the direct photon spectrum were measured for three centrality classes in Pb–Pb at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [24], see Fig. 6. The pQCD calculations describe well the high $p_{\rm T}$ part [25]. There is a visible excess of direct photons compared to NLO pQCD predictions for $p_{\rm T} <$ < 4 GeV/c in the most central collisions, which can be attributed to the thermal emission of a hot matter. The low $p_{\rm T}$ part (below 2.2 GeV/c) of the spectrum was fitted with the exponential function. The inverse slope is found to be equal to $304 \pm 11^{\rm stat} \pm$ $\pm\, 40^{\rm sys}$ MeV. To convert the slope value to the temperature, however, one has to take the expansion of the system into account.

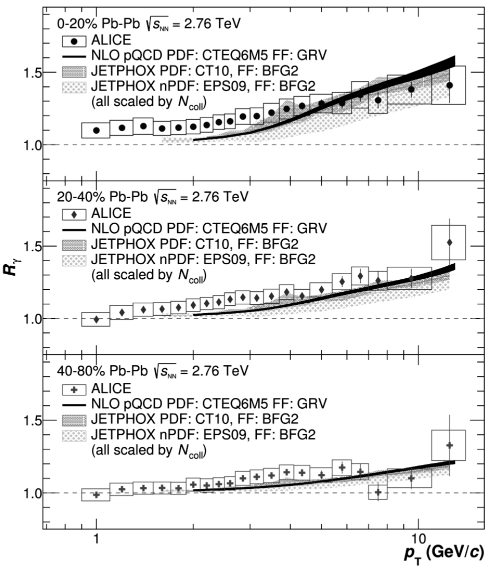


Fig. 6. The double ratio R_γ measured for three centrality classes in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [24] compared to NLO pQCD (for the direct photon yield in pp collisions) and JETPHOX [26] predictions with various PDFs and FFs scaled by the number of binary collisions

4. Summary

ALICE has measured the neutral meson spectra in a wide $p_{\rm T}$ range in pp collisions at $\sqrt{s}$ = 0.9, 2.76, 7, and 8 TeV. The NLO calculations systematically predict a higher yield, especially at the highest collision energies. The neutral meson spectra measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV were used to calculate nuclear modification factors. The nuclear modification factor measured in Pb–Pb shows the strong suppression of the π^0 yield related to the parton energy loss in a hot quark-gluon matter. That can be explained by the final-state effect, as p-Pb data are consistent with unity, showing the absence of cold nuclear matter effects. The direct photon spectrum and the double ratio R_γ were measured in Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV in three centrality classes. The double ratio R_γ in central Pb–Pb collisions exceeds the prompt photon pQCD predictions at $p_{\rm T} < 4$ GeV/c. The inverse slope of the direct photon spectrum in central Pb–Pb collisions is estimated to be $304 \pm 11^{\rm stat} \pm 40^{\rm sys}$ MeV.

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ВИМІРЮВАННЯ НЕЙТРАЛЬНИХ МЕЗОНІВ
ТА ПРЯМИХ ФОТОНІВ В ЕКСПЕРИМЕНТАХ ALICE

Р е з ю м е

Експеримент ALICE заплановано для вивчення властивостей речовини, що народжується в зіткненнях протонів та важких іонів на LHC. Нейтральні мезони можна відтворити в ALICE в широкому інтервалі поперечних імпульсів за допомогою двофотонних розпадів. Вимірювання нейтральних мезонів у зіткненнях протонів дають можливість перевірити пертурбативну КХД в NLO та NNLO наближеннях, а також уточнити функції розподілу та фрагментації партонів. Спектри нейтральних мезонів, виміряних у pA та AA зіткненнях, дозволяють перевірити модифікацію партонної функції розподілу в ядрі і втрату енергії партонів у гарячій речовині, що утворюється в AA зіткненнях. Нами представлено останні результати ALICE стосовно вимірювання прямих фотонів у Pb–Pb зіткненнях, продукування нейтральних піонів та η мезонів у зіткненнях pp, p-Pb та Pb–Pb.