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Measurement of neutral mesons and direct photons with ALICE at the LHC

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Abstract

The recent ALICE results on neutral meson production in pp collisions at the energies $\sqrt{s} = 2.76$ and 8 TeV are summarized. They are compared to previously published results at $\sqrt{s} = 0.9$ and 7 TeV and to theoretical predictions. Neutral pion production in p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV, in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV and spectra of direct photons measured in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV are discussed.

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1. Introduction

Measurements of direct photon and neutral pion production in heavy-ion collisions provide a comprehensive set of observables characterizing properties of the hot QCD medium [1]. Unlike hadrons, direct photons are produced in all stages of a nucleus-nucleus collision and therefore probe the initial state of the collision as well as the space-time evolution of the produced medium. Prompt direct photons provide means to control the initial stage of the collision and test whether the yield suppression of hard hadrons and, in particular neutral pions in Pb-Pb collision is a final-state effect and should be attributed to the parton energy loss in the hot medium. To investigate and understand the properties of this hot and dense partonic medium, the analysis of pp and p-Pb collisions is crucial. Measurements of neutral meson spectra in pp collisions serve as a reference for heavy-ion collisions, and also provide valuable data for confronting with perturbative QCD calculations and for studying scaling properties of hadron production at the LHC energies. In the frame of perturbative QCD, the production of neutral mesons in pp collisions is described by a convolution of parton distribution functions (PDF), cross-section of parton scattering and fragmentation function (FF), see e.g. [2]. Neutral mesons, in particular π^0 and η mesons, can be measured and identified in very wide range of transverse momenta and thus impose restrictions on PDFs and FFs in a wide kinematic region.

2. Neutral meson spectra in pp collisions

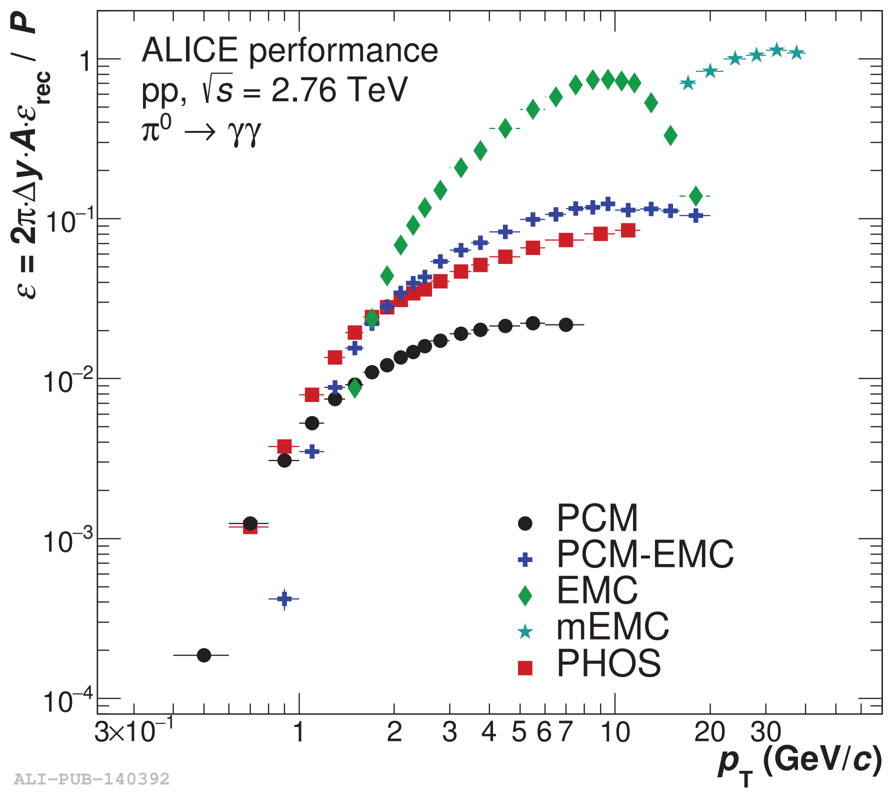

Figure 1: Normalized efficiency, defined as a product of acceptance A, reconstruction efficiency ε_{rec} divided by purity P, for five different methods of neutral pion reconstruction in the ALICE experiment.

The ALICE experiment at LHC measures neutral pions and eta-mesons using their two-photon decays. Photons in ALICE are reconstructed via several complementary methods: either using electromagnetic calorimeters PHOS [3] and EMCAL [4] or by the Photon Conversion Method (PCM) – by identifying photons converted to e^+e^- pairs and reconstructed with the Inner Tracking System (ITS) [5] and the Time Projection Chamber (TPC) [6]. Combination of these approaches uses the respective advantages of the detectors, that is the excellent momentum resolution of tracking system in measurement of conversion photons down to very low transverse momenta and the high reconstruction efficiency, triggering capability and good energy resolutions of calorimeters at high p_T thus allowing measurement of neutral meson spectra in a wide range of transverse momenta with very good precision.

The PCM method uses the central tracking system and therefore large acceptance ($\Delta\phi = 360^\circ$, $|\eta| < 0.9$), however it is efficient only when the photon conversion takes place up to the middle of the TPC. The integrated material budget of the beam pipe, the ITS and the TPC for $r < 1.8$ m corresponds to (11.4 ± 0.5)% of a radiation length X_0, resulting in a photon conversion probability that saturates at about 8.5% for $p_T > 2$

GeV/c. The photon spectrometer PHOS has fine granularity (cell size $2.2 \times 2.2 \times 18$ cm^3, installed at a distance to the Interaction Point 460 cm) but limited acceptance ($\Delta\phi = 60^{\circ}$, $|\eta| < 0.125$). The electromagnetic calorimeter EMCAL has coarser granularity ($5.5 \times 5.5 \times 24.6$ cm^3, installed at a distance 428 cm from IP) but large acceptance ($\Delta\phi = 107^{\circ}$, $|\eta| < 0.7$). To reconstruct π^0, two-photon invariant mass distributions are constructed. However, in the EMCAL case starting from $p_T \sim 10$ GeV/c a considerable part of photons from the same π^0 start to merge in one cluster reducing the efficiency of invariant mass analysis, see fig. 1. Two overcome this, two approaches are used: the first is the invariant mass analysis of combined pairs when one photon is converted and reconstructed by the PCM method while the second is reconstructed in EMCAL. This allows to extend efficiency of π^0 reconstruction to high p_T, see line PCM-EMC (blue crosses) in fig. 1. This advantage does not yet show up completely in the efficiency in fig. 1 because of statistical limitations of the data and corresponding Monte-Carlo samples. The second approach, denoted as mEMC in fig. 1, is to look at the shape of merged clusters and separate them from hadron and single-photon clusters. Quantitatively, it is done by comparing the eigen values of the dispersion matrix of the clusters. Summarizing the comparison of products of efficiency and acceptance of different methods shown in fig. 1, we find that the largest acceptance and high efficiency has the EMC method, but it starts to decrease at $p_T \sim 10$ GeV/c because of cluster merging. PHOS has smaller acceptance and smaller granularity so its normalized efficiency is ~ 7 times smaller but start to decrease only at $p_T \sim 30$ GeV/c. The combined PCM-EMC approach has similar $A \cdot \varepsilon$ to PHOS. And finally, the conversion method has the smallest normalized efficiency because of small material budget of inner ALICE detectors.

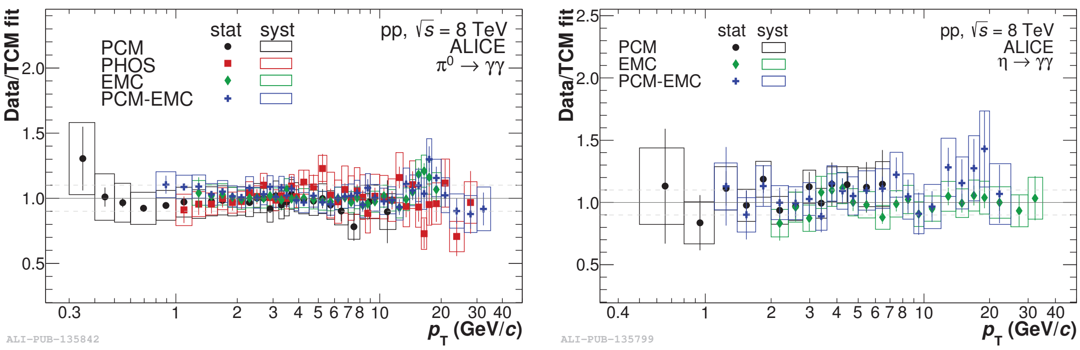

Figure 2: Comparison of the individual measurements in their respective measured transverse momentum ranges relative to the two-component model fits of the final spectra.

Neutral meson spectra in pp collisions at each colliding energy were measured with several methods. We carefully checked the consistency of individual measurements and then calculated the combined spectrum. Examples of the ratios of individual measurements of π^0 and η yields to the Two-Component Model (TCM) [7] fit to the combined spectrum in pp collisions at $\sqrt{s} = 8$ TeV are shown in fig. 2. We find good agreement within statistical and systematic uncertainties. A special method was developed to calculate the combined spectrum, which takes into account possible correlations between systematic uncertainties of different methods. These correlations are small between e.g. PHOS and PCM methods but considerable between EMC, PCM-EMC and PCM methods.

Invariant π^0 spectra in pp collisions at four LHC energies $\sqrt{s} = 0.9$ and 7 TeV [8], 2.76 TeV [9] and 8 TeV [10] are shown in the fig. 3. We find that shapes are pretty well reproduced with TCM fits and with Tsallis [11] parameterization. To perform a detailed comparison with theoretical calculations we divide both data and theoretical calculations by the TCM fit to data, see fig. 3, right plot. Pythia 8.2 with Monash tune reproduces π^0 spectra within few units of uncertainties in all four energies. In contrast, the state of the art NLO pQCD calculations [12] with recent MSTW parton distribution functions and DSS14 fragmentation functions over-predict yields approximately by 30-50%.

One can get more information about the reason of the difference between pQCD NLO calculations and data by looking at another meson. ALICE measured differential cross-sections of the η-meson production at four energies [8–10]. Similar to neutral pions, detailed comparison with NLO pQCD calculations shows that the latter over-predict eta yield at all four energies by a similar amount. It is instructive to construct η/π^0 ratio because some systematic uncertainties cancel in this ratio both in data and in theoretical calculations. The η/π^0 ratio in pp collisions at the energy $\sqrt{s} = 8$ TeV is shown in fig. 4 and compared to the Pythia 8.2 and pQCD NLO calculations. NLO pQCD calculations reproduce η/π^0 ratio pretty well even though they do not reproduce the individual spectra. As expected, Pythia 8.2 reproduces the η/π^0 ratio well with two popular tunes, Monash 2013 and Tune 4C. In addition, we compared the η/π^0 ratio in pp collisions at different $\sqrt{s}$ and confirm its universality first observed at lower energies [10].

3. Neutral meson and direct photon spectra in pPb and Pb-Pb collisions

ALICE collaboration measured neutral pion and eta-meson spectra in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV [14] and compared with spectra of the same mesons in pp collisions at the same energy, obtained by interpolation of spectra, measured at other LHC

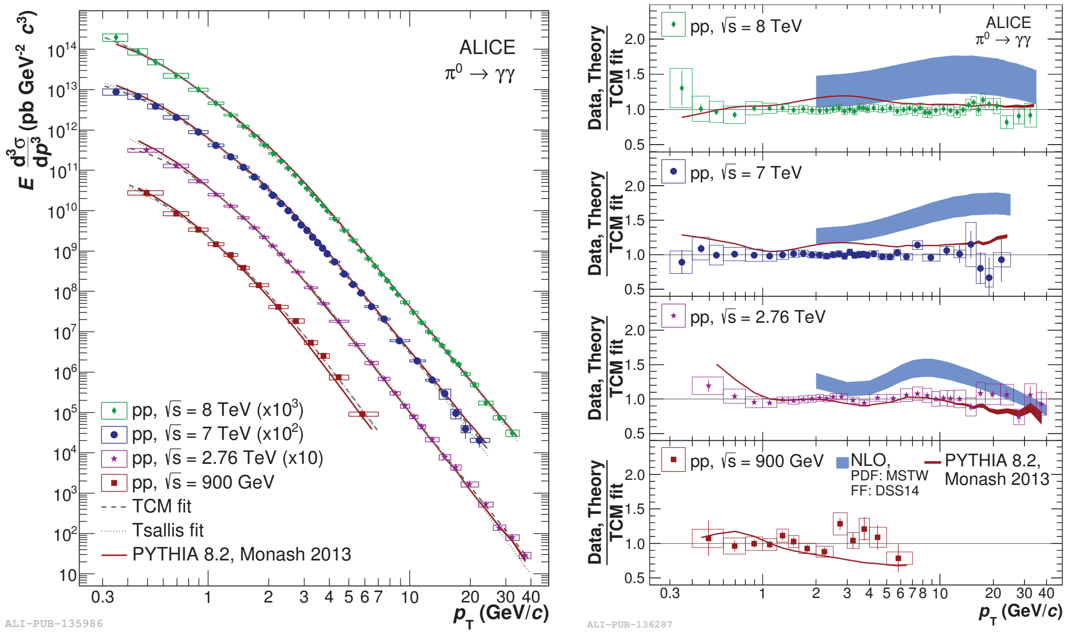

Figure 3: Invariant differential cross section of the π^0 for pp collisions at four energies. The data are compared to Pythia 8.2 [13] generator-level simulations using the Monash 2013 tune as well as recent NLO pQCD calculations [12]. Right plot: the ratios of the data and the calculations to the respective two-component model fits to the data. The error bars denote statistical, the boxes systematic uncertainties.

energies. We found that at high $p_T > 2$ GeV/c these spectra scale with the number of binary nucleon-nucleon collisions so that the nuclear modification factor R_{pPb}, defined as the ratio of the spectrum in p-Pb collisions to the spectrum in the pp collisions at the same colliding energy and scaled with the number of binary collisions, does not show deviations from unity within uncertainties. Apparently, no significant cold nuclear matter effects are seen in neutral meson production.

In Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV in contrast we find strong suppression of the yield of neutral pions [15]. The nuclear modification factor R_{PbPb} shows suppression by up to a factor ~ 10 in central collisions, which is in agreement with other measurements of the yield of identified and non-identified hadrons and even jets. This suppression is consistent with energy loss of partons in hot quark-gluon matter.

Finally, ALICE collaboration measured spectra of direct photons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [1]. Direct photons are the photons created in the collisions of charged particles in hot matter and not in decays of final hadrons. Unlike hadrons, direct photons are produced at all stages of the collision and escape from the hot nuclear matter basically unaffected, delivering direct information on the conditions at the time of production: *prompt* direct photons produced in hard scatterings of incoming partons provide information on parton distributions in nuclei; deconfined quark-gluon matter as well as hadronic matter created in the course of the collision emit *thermal* direct photons, carrying information about the temperature, collective flow and space-time evolution of the medium. Collisions of partons lead to power-law spectrum of direct photons and thus *prompt* photons dominate at high p_T. Thermal emission has almost an exponential spectrum and is important at low p_T. ALICE measurements agree with NLO pQCD predictions of prompt photon yield at high $p_T > 3-4$ GeV/c, which means that there is no considerable modification of the PDFs in nuclei and suppression of hadrons is a final state effect. At low $p_T < 2-3$ GeV/c an excess of direct photons compared to prompt photon predictions is observed which corresponds to thermal emission of hot quark-gluon matter.

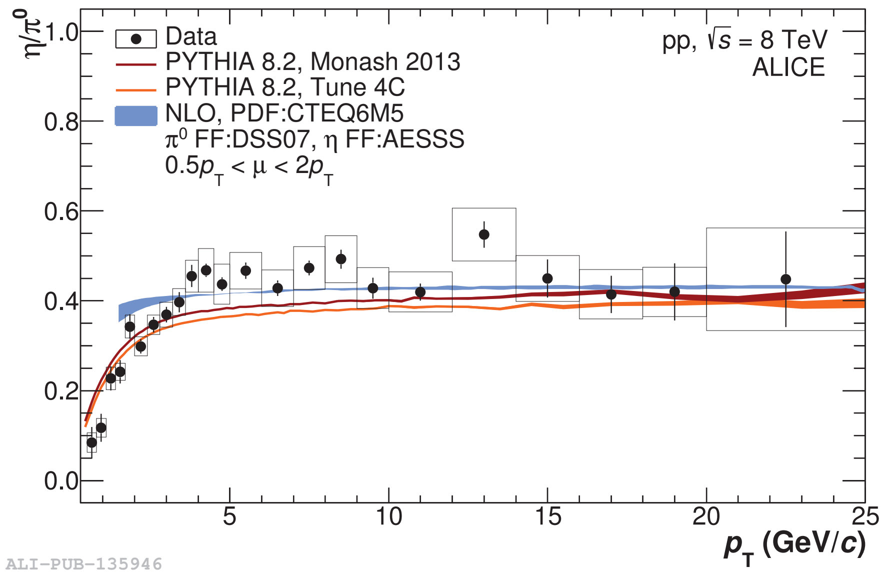

Figure 4: Measured η/π^0 ratio in pp collisions at $\sqrt{s}$ = 8 TeV compared to NLO pQCD calculations [16, 17] and Pythia 8.2 [18] generator-level simulations using the Monash 2013 tune. The horizontal error bars denote statistical, the boxes systematic uncertainties.

To conclude, ALICE collaboration performed precise measurement of neutral meson spectra in wide p_T range in pp collisions at four LHC energies. At all energies the data are well reproduced by Pythia 8.2 calculations, but pQCD NLO calculations systematically predict $\sim 30-40\%$ higher yield. In p-Pb collisions at high p_T we do not observe deviations from binary scaled interpolated spectrum in pp collisions, which corresponds to the absence of cold nuclear effects within uncertainties. In Pb-Pb collisions we observe strong suppression in yield of neutral pions but absence of suppression of direct photon yield at high p_T.

Acknowledgements

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