PROCEEDINGS OF SCIENCE

Neutral mesons production measured with the ALICE experiment

Adam Matyja[*†]
The Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences
ul. Radzikowskiego 152, 31-342 Kraków, Poland
E-mail: adam.tomasz.matyja@cern.ch

Inclusive neutral meson production spectra have been measured in a wide p_{T} range at mid-rapidity by the ALICE experiment in pp collisions from $\sqrt{s}$ = 0.9 to 13 TeV, p-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 and 8.16 TeV, as well as Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 and 5.02 TeV. π^0 and η mesons are reconstructed by their two photon decay channels using the invariant mass technique. The photons are detected with two complementary methods: photons converted to e^+e^- pairs in the central barrel detectors' material or directly registered in the ALICE electromagnetic calorimeters, EMCal and PHOS. An overview of the recent results from ALICE on mesons production in pp, p-Pb and Pb-Pb collisions is presented.

13th International Workshop in High pT Physics in the RHIC and LHC Era (High-pT2019)
19-22 March 2019
Knoxville, Tennessee, USA

[*]Speaker.
[†]On behalf of the ALICE collaboration.

PoS(High-pT2019)002

1. Introduction

The ALICE experiment has been designed to study the Quark-Gluon Plasma (QGP) which is formed in heavy-ion (HI) collisions at the LHC. To disentangle ordinary nuclear effects from effects of a QGP one needs to refer to proton-proton or proton-nucleus collisions, which serve as a reference. The measurement of the differential production cross-section of neutral mesons is important for various reasons. At sufficiently large momentum, the calculation of the cross section can be factorized into short distance (perturbative) and long distance (non-perturbative) terms. Thus the measurement gives a chance to test NLO or NNLO pQCD calculations and to constrain parton distributions as well as fragmentation functions. Because the meson production is so well understood in pp collisions, neutral mesons can be used as precision probes also in HI collisions to study the QGP and possibly distinguish between different effects. The measurement of the neutral meson spectra constrains mechanisms of parton energy loss in dense systems via studies of the nuclear modification factor. In addition, looking into the cross-section ratio allows studying the m_{T} scaling, which is particularly important in the low-p_{T} regime.

2. Neutral meson reconstruction

Photons are detected in two ALICE electromagnetic calorimeters, EMCal and PHOS. They are also reconstructed by combining e^+e^- pairs produced when photons convert in the material of the central barrel detectors (called Photon Conversion Method). The π^0 and η mesons are reconstructed via invariant mass technique of two photons using any of the three methods ($M_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\alpha)}$, where E_1 and E_2 are photon candidates energies and α is an opening angle between them) or via the shower shape of two overlapped electromagnetic cascades in EMCal in the case of the decay of a high energy π^0. The neutral meson differential production cross-section $E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3}$ (or the invariant yield $E\frac{\mathrm{d}^3N}{\mathrm{d}p^3}$, when the trigger cross-section is not known) can be written in the form, $E\frac{\mathrm{d}^3\sigma}{\mathrm{d}p^3} = \frac{1}{2\pi p_{\mathrm{T}}}\frac{1}{L}\frac{1}{BR}\frac{1}{\varepsilon_{\mathrm{eff}}}\frac{N_{\mathrm{meson}}}{\Delta p_{\mathrm{T}}\Delta y}$, where the luminosity $L = N_{\mathrm{evt}}R_{\mathrm{trig}}/\sigma_{\mathrm{MB}}$ is expressed in terms of the number of events N_{evt}, the trigger rejection factor R_{trig} and the minimum bias trigger cross-section σ_{MB}, and BR is the double photonic branching ratio, $\varepsilon_{\mathrm{eff}}$ is the efficiency for reconstructing the meson in the considered detector acceptance and N_{meson} is the feed-down corrected neutral meson yield in the transverse momentum interval Δp_{T} and rapidity interval Δy. The spectra measured with these different techniques are in good agreement and are presented as a combined result, taking into account the correlated uncertainties for the combination using the BLUE method [3].

3. Neutral mesons in pp, p-Pb and Pb-Pb collisions

Neutral meson spectra. ALICE has published the π^0 meson differential production cross-section in pp collisions at $\sqrt{s} = 0.9$ [4, 5], 2.76 [6, 7], 5 [8, 9], 7 [4] and 8 [10] TeV as well as the invariant yield in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV [11, 12] and Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ [6, 13] and 5.02 TeV [8] in several centrality classes. Figure 1 shows preliminary high precision π^0 meson production spectra in pp (left) and Pb-Pb (right) at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV compared to NLO pQCD and various model predictions. The pp spectra are reasonably described by the NLO pQCD calculations, where agreement is within 20-40% depending on p_{T} and predictions with a

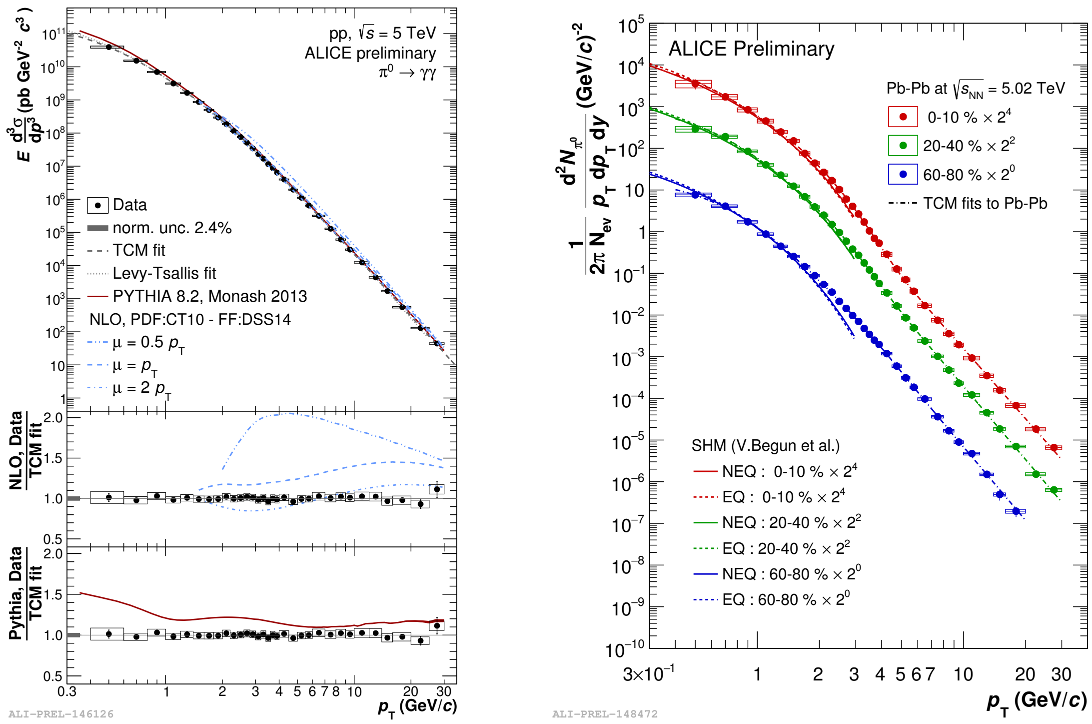

Figure 1: Left: The π^0 meson spectrum versus p_{T} in pp collisions at $\sqrt{s} = 5.02$ TeV is shown in top panel. Result is compared to the PYTHIA 8 Monte Carlo [14] generator (red solid curve) and NLO pQCD predictions for three scales (blue curves). Corresponding ratios are shown in bottom panels. Right: The π^0 meson spectra for 0-10 % (red dots), 20-40% (green dots) and 60-80% (blue dots) Pb-Pb collsions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV compared to EQ and NEQ versions of SHM [15] model.

higher factorization and renormalization scale describe pp data better. The PYTHIA 8 generator (Monash 2013 tune [14]) overpredicts pp data in the whole p_{T} range up to 40%. For $p_{\mathrm{T}} < 2$ GeV/c, the Pb-Pb spectra in centrality classes are well reproduced by the hydro inspired SHM [15] model.

η/π^0 cross-section ratio. ALICE has measured the η/π^0 cross-section ratios for systems and energies where the η meson spectrum was measured. The η/π^0 ratio in pp collisions [10] at $\sqrt{s} = 2.76$, 7 and 8 TeV, in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and in the most central Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV [13] is shown in Fig. 2. The η/π^0 ratio grows with increasing p_{T} and then levels off at ~ 0.5 above $p_{\mathrm{T}} \sim 3$ GeV/c. Results show the universal character among collision energies and systems, and agree within uncertainties with the world data [4]. The significant (above 6σ for pp collisions at $\sqrt{s} = 8$ TeV) deviation from m_{T} scaling prediction at low-p_{T} is visible in pp collsions as seen also for other mesons at LHC energies [16]. The origin is most likely from additional contributions to light mesons from heavier resonance decays. A similar behavior is seen in p-Pb and Pb-Pb collisions. An additional effect coming from the onset of flow may result in an enhancement between $p_{\mathrm{T}} \approx 1-3$ GeV/c as in the $K^{\pm}/\pi^{\pm}$ ratio for the most central p-Pb collisions. There is no clear onset seen yet in the η/π^0 ratio due to the larger uncertainties. However, a hint of enhancement is seen in Pb-Pb collisions, which are well reproduced by models including flow (SHM [15] or EPOS [20]).

Nuclear modification factor. The nuclear modification factor R_{AA} (or Q_{pA} for p-Pb collisions

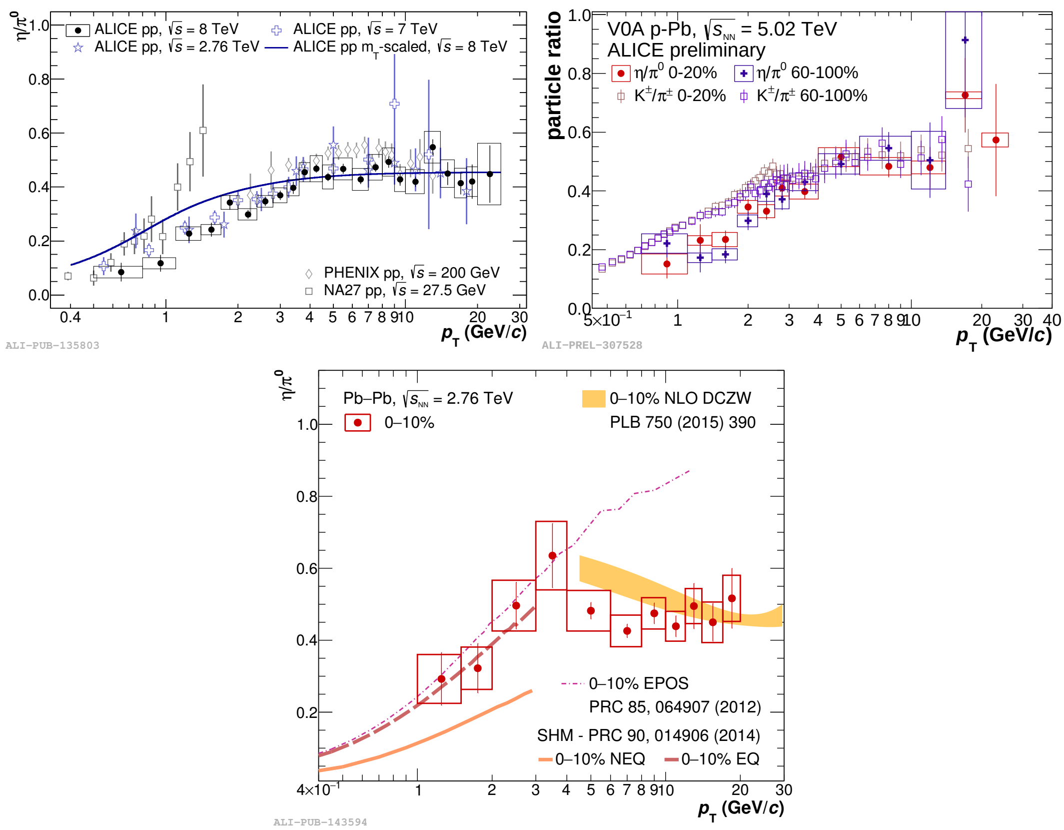

Figure 2: The η/π^0 cross-section ratio in pp [10] at $\sqrt{s} = 2.76$, 7 and 8 TeV compared to m_{T} scaling predictions and lower energy experiments [17, 18] (top left), p-Pb (top right) for most central and peripheral collisions compared to $K^{\pm}/\pi^{\pm}$ ratios at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV and Pb-Pb (bottom) collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV [13] compared to NLO pQCD calculations [19] or SHM [15] and EPOS [20] models.

to differenciate between different centrality estimators) quantifies the effect in nuclear collisions in comparison to pp collisions, $R_{\mathrm{AA}}(p_{\mathrm{T}}) = \frac{\mathrm{d}^2N/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y|_{\mathrm{AA}}}{<T_{\mathrm{AA}}>\times \mathrm{d}^2\sigma/\mathrm{d}p_{\mathrm{T}}\mathrm{d}y|_{\mathrm{pp}}}$, where the numerator represents the differential yield in AA collisions, while the denominator is the differential cross-section in pp collisions scaled by $< T_{\mathrm{AA}} >$, the nuclear overlap factor. There are several methods to determine centrality in p-Pb collisions [21] due to large fluctuations and possible correlations between the multiplicity estimator and the measured spectrum. The CL1 estimator is based on tracklets in the pseudo-rapidity range $|\eta| < 1.4$, the V0A estimator covers the $2 < \eta < 5.1$ range and the ZNA measures neutral energy on the Pb-side in the Zero Degree Calorimeter in the $|\eta| > 8.7$ range. The ZNA estimator is the least biased [21]. The apparent "suppression" of the yield for the most peripheral class for CL1 and V0A estimators in p-Pb collisions can lead to incorrect conclusions. One should be very cautious with interpretation of the results.

The neutral pion Q_{pA} for different centrality classes measured with different estimators in p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV are shown in Fig. 3. There is no centrality dependence for ZNA (the largest rapidity gap), while V0A and CL1 show strong and similar dependence (smaller rapidity gap). The Q_{pA} for π^0, η and D^0 meson as well as for charged hadrons in the most central p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV are shown in the top left plot in Fig. 4. Agreement within

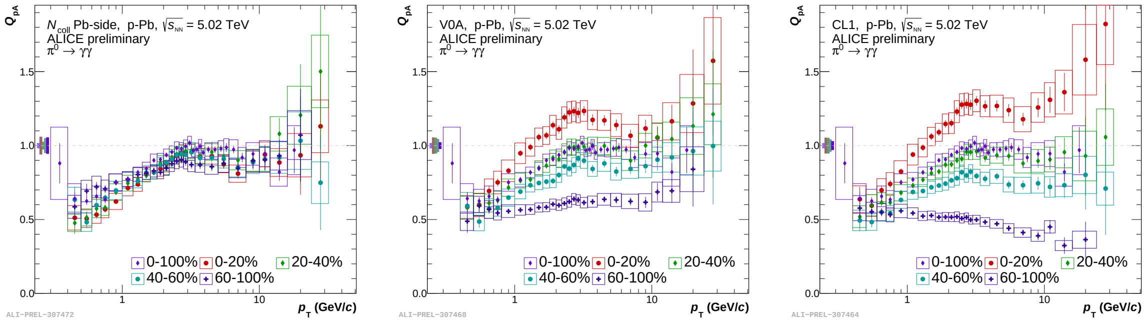

Figure 3: $Q_{\rm pA}$ vs $p_{\rm T}$ in p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV in centrality classes measured via ZNA (left), V0A (middle) and CL1 (right) estimators.

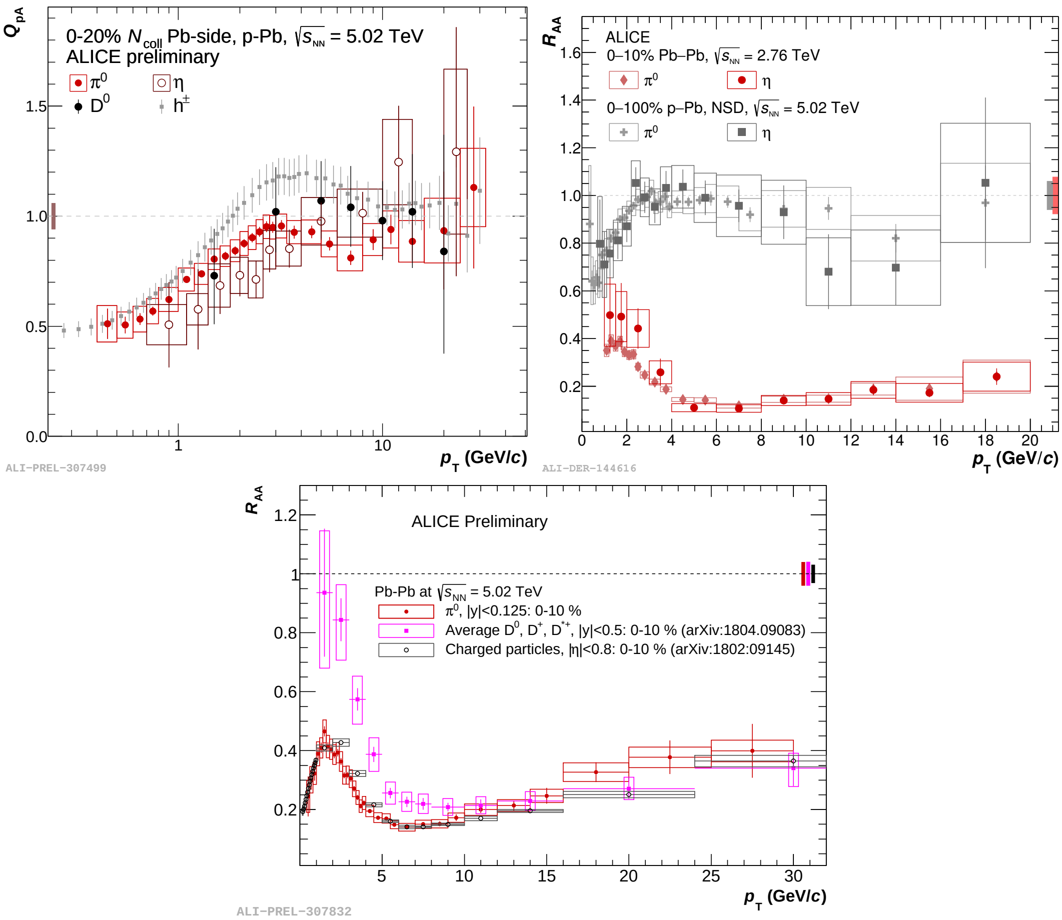

Figure 4: The nuclear modification factor versus $p_{\rm T}$. Top left: The π^0 (red dots) and η (open brown circles) mesons in the most central 0-20% p-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV are compared to charged hadrons (gray squares) and D^0 mesons (black dots). Top right: The π^0 (diamonds) and η (dots) mesons in 0-10% most central Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeVcompared to non-single diffractive p-Pb collsions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV for the π^0 (crosses) and η (squares) mesons. Bottom: The π^0 (red dots) in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 5.02 TeV are compared to average D mesons (pink squares) and charged particles (open black circles) at the same energy and centrality.

uncertainties is visible for each identified meson Q_{pA}. The bump around $p_{\mathrm{T}} \sim 3$ GeV/c visible for unidentified hadrons is probably caused by protons [21]. The R_{AA} for π^0 and η mesons in 0-10% central Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV are compared to MB (0-100%) p-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV in the top right plot of Fig. 4. No suppression in p-Pb collisions and strong suppression of meson yield in Pb-Pb collisions indicates that this suppression is due to a final state effect. The similar suppression pattern above $p_{\mathrm{T}} = 4$ GeV/c for both mesons indicates that suppression occurs at the partonic level. The suppression of different particle species in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV is shown in the bottom plot of Fig. 4. The similar suppression above $p_{\mathrm{T}} \approx 10$ GeV/c is visible for all the considered particles. Below this value π^0 and charged particles show the same amount of suppression while D-mesons show less suppression. Different masses, flow, quark content or recombination pattern can be the potential source of this hierarchy, which still remains to be further disentangled.

4. Summary

The ALICE experiment has measured π^0 and η meson production spectra, their ratios and nuclear modification factors in pp, p-Pb and Pb-Pb collisions at LHC energies. A theoretical description of measured observables is far from fully satisfactory. However, calculations and MC generator predictions agree with measured quantities in some p_{T} regions well. There is still a lot of room for improvements. The observed m_{T} scaling violation at low p_{T} in every collision system and a hint of flow in Pb-Pb collisions indicate the need for more precise measurements. The nuclear modification factor in p-Pb collisions is very sensitive to the used centrality estimator. One needs to carrefully interpret the results. There is no difference within uncertainties between light neutral mesons and D mesons Q_{pA} in p-Pb collisions while a hierarchy ($R_{\mathrm{AA}}(D) < R_{\mathrm{AA}}(\pi^0)$) is seen at $p_{\mathrm{T}} < 10$ GeV/c in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV.

Acknowledgments

We would like to thank the Ministry of Science and Higher Education and the National Science Centre, Poland for the supporting grants.

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PoS(High-pT2019)002