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Hadronic resonance production with ALICE at the LHC

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Abstract. Recent results on short-lived hadronic resonances obtained by the ALICE experiment in pp, p-Pb and Pb-Pb collisions at the LHC energies are presented. Transverse momentum spectra, yields, ratios to long-lived particles and nuclear modification factors are discussed. The results are compared with model predictions and measurements at lower energies.

1 Introduction

Hadronic resonance production plays an important role both in elementary and in heavy-ion collisions. In heavy-ion collisions, the medium at high density and/or high temperature can modify the properties of short-lived resonances such as their masses, widths and spectral shapes [1]. Moreover, since the lifetimes of short-lived resonances are comparable with the time span of the late hadronic phase, regeneration and rescattering effects become important and resonance ratios to longer lived particles can be used to estimate the time interval between the chemical and kinetic freeze-out [2]. The measurements in pp and p-Pb collisions constitute a reference for nuclear collisions and provide information for tuning event generators inspired by Quantum Chromodynamics. Recent results on short-lived mesonic $\rho(770)^0$, $K^*(892)^0$, $\phi(1020)$ and baryonic $\Sigma(1385)^{*\pm}$, $\Xi(1530)^{*0}$ resonances (hereafter ρ^0, K^{*0}, ϕ, $\Sigma^{*\pm}$, Ξ^{*0}) obtained by the ALICE experiment are presented here. The ρ^0 has been measured in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The K^{*0} and ϕ have been measured in pp, p–Pb, and Pb–Pb collisions at various energies in different multiplicity or centrality intervals. The $\Sigma^{*\pm}$ and Ξ^{*0} have been measured in pp collisions at $\sqrt{s} = 7$ TeV and in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

2 The ALICE detector

The ALICE detector [3, 4] at the LHC is designed to study Pb–Pb, p–Pb and pp collisions at TeV-scale center of mass energies. The components of the ALICE detector most directly related to the results presented here are described briefly. The Inner Tracking System (ITS) is a six-layers silicon-based detector that surrounds the interaction point and covers the pseudorapidity region $|\eta| < 0.9$. It is used to reconstruct the collision vertex and provides tracking and particle identification. Particle tracking is mainly provided by the Time Projection Chamber (TPC). The TPC also allows particles to be identified through their energy loss. The Time-of-Flight Detector (TOF) sits externally to the TPC and measures the time-of-flight of the particles, allowing for additional identification. Both the TPC and the TOF cover the central pseudorapidity region $|\eta| < 0.9$ and the full azimuthal angle. A pair

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of scintillation hodoscopes, covering $2.8 < \eta < 5.1$ (VZERO-A) and $-3.7 < \eta < -1.7$ (VZERO-B), were used for event triggering and the determination of the event multiplicity (pp, p–Pb) and centrality (Pb–Pb).

3 Analysis procedure

Resonances have been reconstructed via their main hadronic decay channels: $\rho^0 \rightarrow \pi^- + \pi^+$ (B.R.=1.00), $K^{*0} \rightarrow \pi^\pm + K^\mp$ (B.R.=0.67), $\phi \rightarrow K^+ + K^-$ (B.R.=0.49), $\Sigma^{*\pm} \rightarrow \Lambda + \pi^\pm$ (B.R.=0.87), $\Xi^{*0} \rightarrow \Xi^- + \pi^+$ (B.R.=0.67). For the baryonic resonances, the intermediate decay products, Λ and Ξ^-, are identified through selections based on their decay topology. Due to the short lifetimes of these resonances, their decay products cannot be distinguished from the particles coming from the primary vertex, and their yield can only be measured by first computing the invariant mass spectrum of all primary track pairs and then subtracting the combinatorial background. The combinatorial background is evaluated using the event-mixing technique or the like-sign technique. The resulting invariant mass distributions are then fitted. For the ρ^0 a cocktail is used, including a smooth function to describe the continuum residual background, plus peaks accounting for the contributions from K^0_S, $\omega(782)$, K^{*0}, $f_0(980)$ and $f_2(1270)$. The shape of the ρ^0 peak is described by the product of a p-wave relativistic Breit-Wigner function, a phase-space factor, a mass-dependent reconstruction efficiency and a Söding interference term [5]. For the other resonances, the background-subtracted invariant mass distributions are fitted using a Breit-Wigner function or a Voigtian function (convolution of Breit-Wigner and Gaussian which accounts for the detector resolution) plus a polynomial for the residual background, see [6–9] for details. After the signal is extracted, the raw yield is evaluated. The raw yields extracted in different p_T bins are corrected for efficiency and acceptance and the differential transverse momentum spectra are obtained. The corrected spectra are fitted with a Levy-Tsallis function [10] (pp and p–Pb collisions) or with a Blast Wave function [11] (Pb–Pb collisions), for extrapolation in the region where the spectra are not measured.

4 Results

Figure 1 presents the transverse momentum spectra for ρ^0 in pp and Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, $\Sigma^{*\pm}$ and Ξ^{*0} in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The transverse momentum spectrum of the ρ^0 meson in pp collisions has been compared to a number of PYTHIA [12] tunes and the PHOJET [13] event generators. None of them gives a fully satisfactory description of the data.

Figure 2 shows the $\langle p_T \rangle$ of K^{*0}, ϕ and p (which have similar masses) as a function of the cubic root of the average charged-particle multiplicity density, $\langle dN_{ch}/d\eta \rangle^{1/3}$, in the three collision systems pp, p–Pb and Pb–Pb [9]. The $\langle p_T \rangle$ values follow a similar trend with the system size in pp and p–Pb collisions, where they rise faster with multiplicity than in Pb–Pb collisions. An analogous behavior has been observed in [14] for charged particles and can be understood as the effect of color reconnection between strings produced in multi-parton interactions. In central Pb–Pb collisions, the $\langle p_T \rangle$ values for these three particles are consistent within uncertainties, as it is expected in presence of a common radial flow. However in pp and p–Pb collisions the $\langle p_T \rangle$ values for the K^{*0} and ϕ resonances are higher than for p. The mass ordering observed in central Pb–Pb collisions, where particle with similar mass has similar $\langle p_T \rangle$, is not observed in pp and p–Pb collisions.

Figure 3 presents the particle ratios ρ^0/π [15], K^{*0}/K and ϕ/K [7, 9] as a function of $\langle dN_{ch}/d\eta \rangle^{1/3}$ for various collision systems together with THERMUS [16] and grand-canonical [17] thermal models, and EPOS [18] calculations. The ρ^0/π and K^{*0}/K ratios exhibit a decreasing trend towards more central Pb–Pb collisions, where the measured ratios are about 60% of the thermal model predictions.

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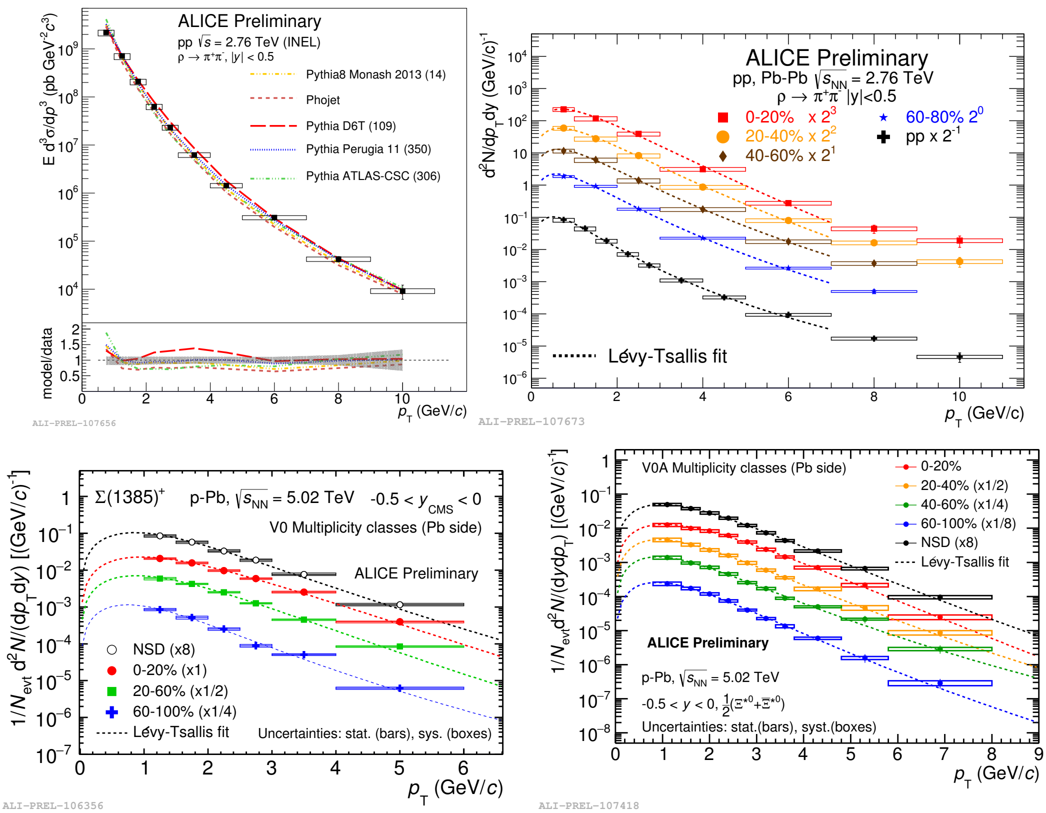

Figure 1. (color online) Transverse momentum spectra for ρ^0 in pp (top left) and Pb–Pb (top right) collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, $\Sigma(1385)^{\pm}$ (bottom left) and $\Xi(1530)^0$ (bottom right) in p–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

This suppression is consistent with rescattering of ρ^0 and K^{*0} daughters in the hadronic phase of central collisions as the dominant effect and is at least qualitatively reproduced by calculations using the EPOS model with UrQMD [18]. As described in [7], the K^{*0}/K ratio measured in central Pb–Pb collisions can be used along with predictions from a thermal model and modelling of rescattering after hadronization [2] to obtain an estimate of 2 fm/c for the lower limit of the time between chemical and kinetic freeze-outs. Results on the K^{*0}/K ratio in pp and p–Pb collisions have large uncertainties, but they hint to a multiplicity-dependent suppression, which leaves the door open for the possibility of a hadron-gas phase with non-zero lifetime in high-multiplicity pp and p–Pb collisions. In Pb–Pb collisions, the ϕ/K ratio is nearly flat and agrees with the prediction of the thermal model. This suggests that rescattering effects are not important for ϕ, which has 10 times longer lifetime than K^{*0} and decays mainly after the end of the hadronic phase.

The particle ratios for baryonic resonances $\Sigma^{*\pm}/\Lambda$ and Ξ^{*0}/Ξ are shown in figure 4 for p–Pb collisions as a function of $\langle dN_{ch}/d\eta \rangle$ and for pp collisions. For the $\Sigma^{*\pm}/\Lambda$ ratio no strong dependence on energy or system size is observed. The measured $\Sigma^{*\pm}/\Lambda$ values are consistent with thermal model [16, 17] and PYTHIA8 [20] predictions but higher than the DPMJET [21] value for p–Pb collisions. The Ξ^{*0}/Ξ ratio also does not depend on multiplicity at the LHC. However the measured Ξ^{*0}/Ξ

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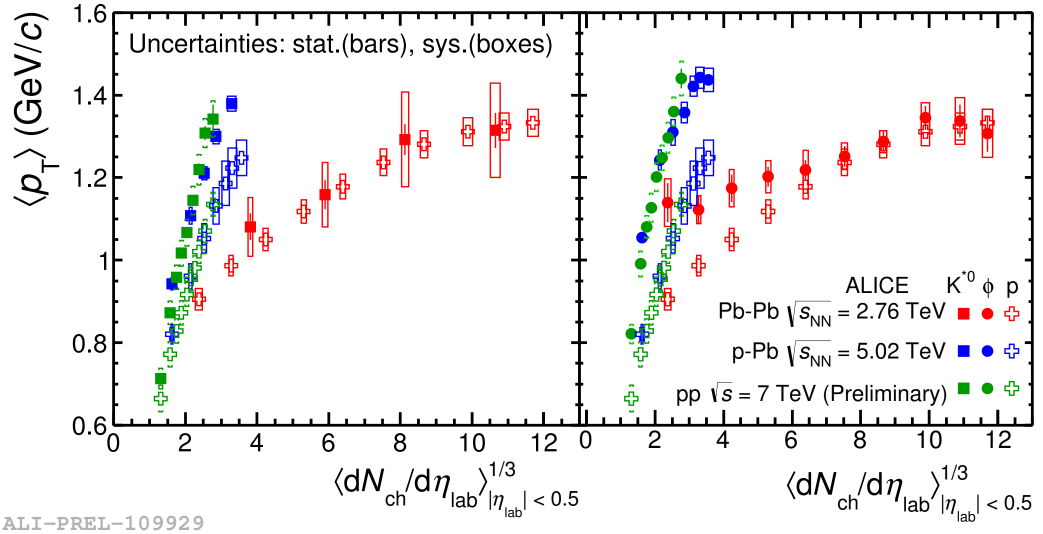

Figure 2. (color online) The mean transverse momentum as a function of $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle^{1/3}$ for K^{*0} (left) and ϕ (right) compared to p (same data in both panels).

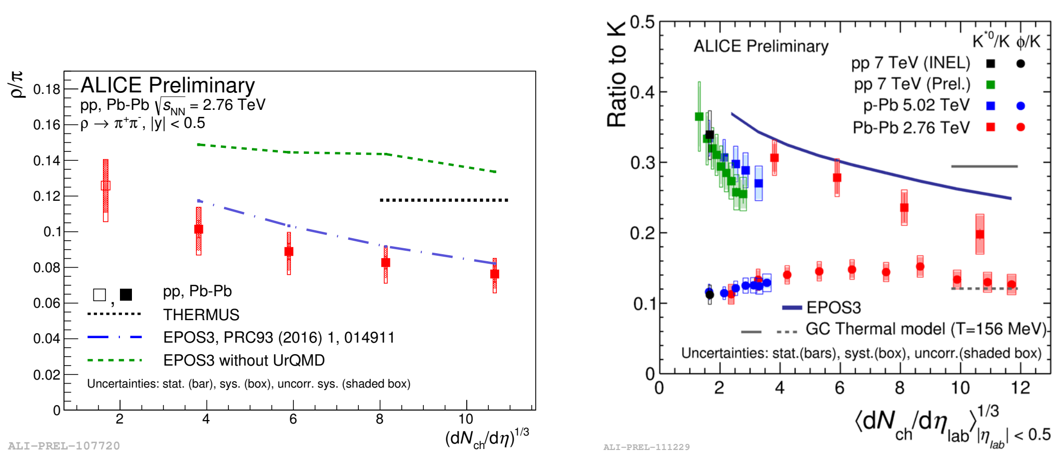

Figure 3. (color online) Ratios ρ^0/π (left), $\mathrm{K}^{*0}/\mathrm{K}$ and ϕ/K (right) as a function of $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle^{1/3}$ for various collision systems. The measurements are also compared to model [16–18] predictions.

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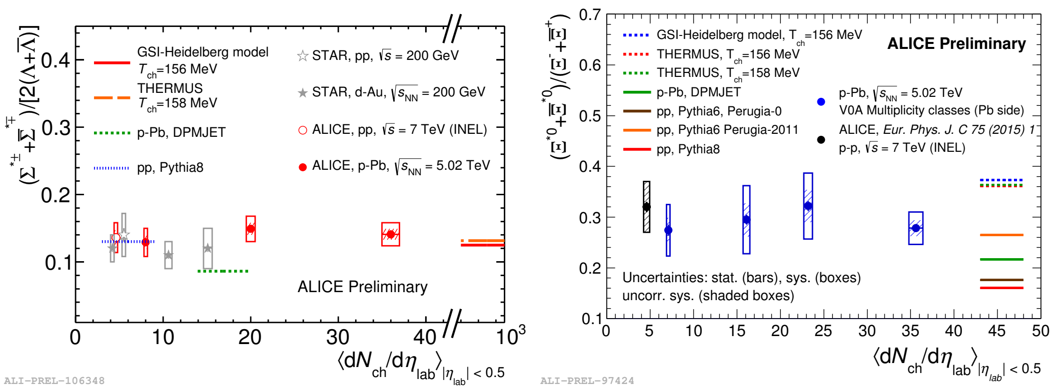

Figure 4. (color online) The particle ratios $\Sigma^{*\pm}/\Lambda$ (left) and Ξ^{*0}/Ξ (right) as a function of $\langle dN_{ch}/d\eta\rangle$ for various collision systems. STAR data are from [19].

values are lower than thermal model [16, 17] predictions and higher than the PYTHIA8 and DPMJET values. Since these ratios are flat, the $\Sigma^{*\pm}$ and Ξ^{*0} are enhanced relative to pions by the same amounts as the Λ and Ξ [22]. Therefore the enhancement of these strange baryons is driven by their strangeness content and not by their masses.

Figure 5 presents the nuclear modification factor of the ρ^0 resonance and stable hadrons as a function of p_T for central and peripheral Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. At high p_T, ρ^0 is

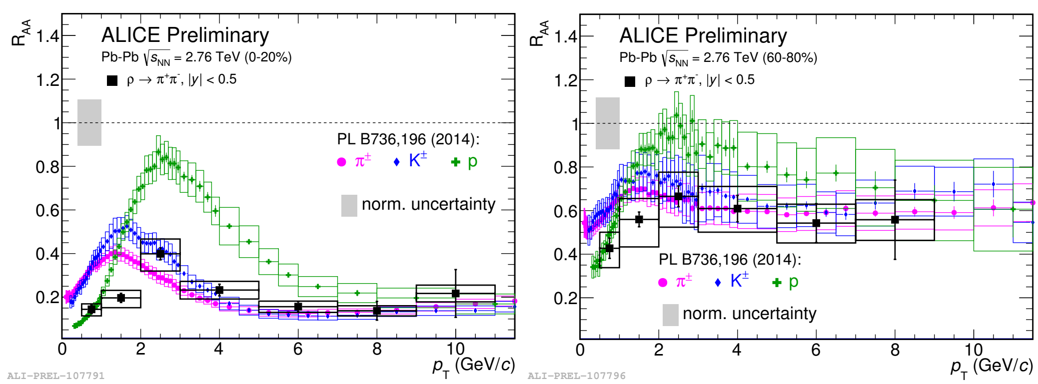

Figure 5. (color online) Nuclear modification factor of the ρ^0 resonance and stable hadrons as a function of transverse momentum for central (left) and peripheral (right) Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

strongly suppressed for central collisions, $R_{AA} \approx 0.15$ - 0.2. The suppression is consistent with that measured for the stable hadrons. For peripheral collisions there is a moderate suppression close to the values for the stable hadrons. At low p_T, $p_T < 2$ GeV/c, the ρ^0 is more suppressed than charged hadrons, which would be consistent with the hypothesis that rescattering effects are important.

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5 Conclusions

Recent results on short-lived hadronic resonances obtained by the ALICE experiment in pp, p-Pb and Pb-Pb collisions at the LHC energies have been presented. In pp and p–Pb collisions the $\langle p_{\mathrm{T}} \rangle$ values for the K^{*0} and ϕ resonances rise faster with multiplicity than in Pb–Pb collisions. One possible explanation could be the effect of color reconnection between strings produced in multi-parton interactions. The mass ordering observed in central Pb–Pb collisions, where particles with similar masses (K^{*0}, ϕ and p) have similar $\langle p_{\mathrm{T}} \rangle$, is not observed in pp and p–Pb collisions. The ρ^0/π and $\mathrm{K}^{*0}/\mathrm{K}$ ratios exhibit a significant suppression going from peripheral to central Pb–Pb collisions, consistent with rescattering of the decay products of the short-lived ρ^0 and K^{*0} in the hadronic phase. The ϕ/K ratio is not suppressed due to the longer lifetime of the ϕ. The $\Sigma^{*\pm}/\Lambda$ ratio, measured in pp and p–Pb collisions, does not show a variation neither with the collision energy, nor with the system size. The Ξ^{*0}/Ξ ratios are higher than predicted by event generators in pp and p–Pb. In Pb–Pb collisions the nuclear modification factor of the ρ^0 resonance is consistent with that for other light hadrons at high p_{T}, where high momentum particle production is suppressed due to parton energy loss in the hot and dense medium created in the collision.

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