Recent hadronic resonance measurements at ALICE

A G Knospe (for the ALICE Collaboration)

Department of Physics, The University of Houston, Houston, TX, USA

E-mail: anders.knospe@cern.ch

Abstract. In heavy-ion physics, measurements of short-lived hadronic resonances allow the properties of the hadronic phase of the collision to be studied. In addition, resonances can be used along with stable hadrons to study parton energy loss in the quark-gluon plasma and the mechanisms that shape hadron p_{T} spectra at intermediate transverse momenta. Resonance measurements in small systems serve as a reference for heavy-ion collisions and contribute to searches for collective effects. An overview of recent results on hadronic resonance production measured in ALICE is presented. These results include the p_{T} spectra and yields of the $\rho(770)^0$, $\mathrm{K}^*(892)^0$, and $\phi(1020)$ mesons in pp, p–Pb, and Pb–Pb collisions at different energies as well as the $\Sigma(1385)^{\pm}$ and $\Xi(1530)^0$ baryons in pp and p–Pb collisions.

Hadronic resonances, along with stable hadrons, allow the study of properties of heavy-ion collisions, both in the early (quark-gluon plasma) and late (hadronic) stages of their evolution. Energy loss of partons in nuclear matter can be studied by measuring the nuclear modification factors R_{AA} and R_{pPb}. The yields of resonances may be modified even after chemical freeze-out by re-scattering and regeneration, which are (pseudo-)elastic scattering processes expected to have their greatest strength at low p_{T} ($\lesssim 2$ GeV/c) [1, 2, 3]. Measurements of resonance and stable-hadron yields can be used along with theoretical models [2, 4, 5] to estimate the properties (temperature and lifetime) of the hadronic phase of heavy-ion collisions. The various mechanisms that may determine the shapes of particle p_{T} spectra, including vacuum fragmentation, quark recombination, hydrodynamic flow, re-scattering, and regeneration, can be studied through comparison of different measurements of multiple particle species (including hadronic resonances) with differing masses and quark content. These proceedings present measurements from the ALICE experiment that are related to these topics.

The $\rho(770)^0$, $\mathrm{K}^*(892)^0$, and $\phi(1020)$ mesons (hereafter ρ^0, K^{*0}, and ϕ) and the $\Sigma(1385)^{\pm}$ and $\Xi(1530)^0$ baryons are measured using invariant-mass analyses to reconstruct their hadronic decays ($\rho^0 \rightarrow \pi^-\pi^+$, $\mathrm{K}^{*0} \rightarrow \pi^{\pm}\mathrm{K}^{\mp}$, $\phi \rightarrow \mathrm{K}^-\mathrm{K}^+$, $\Sigma(1385)^{\pm} \rightarrow \Lambda\pi^{\pm}$, and $\Xi(1530)^0 \rightarrow \Xi^-\pi^+$). For the baryonic resonances, the intermediate decay daughters Λ and Ξ^- are identified through selections based on their masses and decay topologies. Combinatorial backgrounds, constructed using either like-charge pairs or event mixing, are subtracted from the distributions of unlike-charge pairs for multiple p_{T} and centrality/multiplicity intervals. The resulting invariant-mass distributions are then fitted. For the ρ^0, a cocktail is used, including a smooth function to describe a continuum residual background, plus peaks accounting for the contributions of the K^0_{S}, $\omega(782)$, K^{*0}, $\mathrm{f}_0(980)$, and $\mathrm{f}_2(1270)$. The shape of the ρ^0 peak is described by the product of a relativistic p-wave Breit-Wigner function, a phase-space factor, a mass-dependent reconstruction efficiency, and a Söding interference term [12]. For the other resonances, the background-subtracted invariant-mass distributions are fitted using Breit-Wigner or Voigtian peaks added

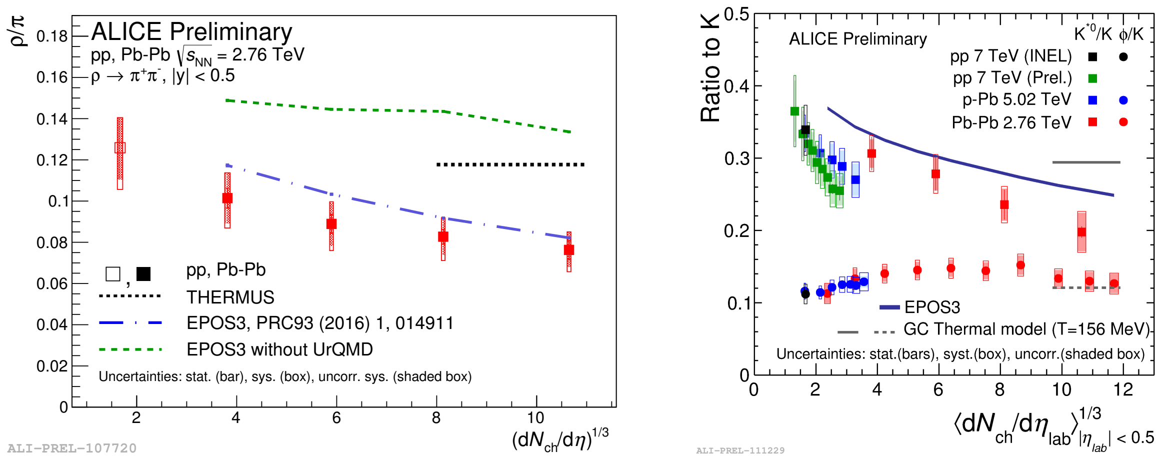

Figure 1. Ratios $\rho^0/\langle\pi^\pm\rangle$, K^{*0}/K, and ϕ/K [6, 7, 8] as functions of $\langle dN_{ch}/d\eta\rangle^{1/3}$ for various collision systems, with grand-canonical thermal-model [9, 10] and EPOS [11] calculations.

to first- or second-order polynomials to describe the residual backgrounds; see [6, 13] for further details. The p_T spectra, which are corrected for efficiency, acceptance, and branching ratios, are fitted using Lévy-Tsallis functions (for pp and p–Pb collisions) or Boltzmann-Gibbs blast-wave functions (for Pb–Pb collisions) so that the total integrated yields and mean transverse momenta $\langle p_T\rangle$ can be extracted. The p_T spectra and yields of the ρ^0 have 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 $\Sigma(1385)^\pm$ and $\Xi(1530)^0$ have been measured in pp collisions at $\sqrt{s} = 7$ TeV and in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV.

Figure 1 shows the ratios of integrated yields $\rho^0/\langle\pi^\pm\rangle$, K^{*0}/K, and ϕ/K for the various collision systems [6, 7, 8]. A centrality-dependent suppression of the $\rho^0/\langle\pi^\pm\rangle$ and K^{*0}/K ratios has been observed in Pb–Pb collisions. These ratios in central Pb–Pb collisions are also suppressed with respect to grand-canonical thermal-model calculations [9, 10] with a chemical freeze-out temperature of 156 MeV. This suppression may be the result of re-scattering of the ρ^0 and K^{*0} decay products in the hadronic phase of the medium (re-scattering being dominant over regeneration of these resonances) and is at least qualitatively reproduced by calculations using the EPOS model [11]. In contrast, the ϕ lives 10 times longer than the K^{*0} and 35 times longer than the ρ^0; it decays predominantly after the end of the hadronic phase and is not significantly affected by re-scattering or regeneration. Furthermore, an apparent multiplicity-dependent suppression of the K^{*0}/K ratio has been observed in pp and p–Pb collisions, which might be an indication of a hadron-gas phase with non-zero lifetime in high-multiplicity pp and p–Pb collisions. The K^{*0} and ϕ mesons have also been measured in inelastic pp collisions at $\sqrt{s} = 13$ TeV. No energy evolution in the p_T-integrated K^{*0}/K and ϕ/K ratios is observed from RHIC to the top LHC energy. Furthermore, the $\Sigma(1385)^\pm/\Lambda$ and $\Xi(1530)^0/\Xi^-$ ratios in p–Pb collisions are consistent with the value previously measured by ALICE in minimum-bias pp collisions at $\sqrt{s} = 7$ TeV [13]. No multiplicity dependence is observed for these ratios in p–Pb collisions. This implies that the $\Sigma(1385)^\pm/\pi$ ratio has the same evolution with multiplicity as the Λ/π ratio, and similarly that $\Xi(1530)^0/\pi$ evolves like the Ξ^-/π ratio. The Λ/π and Ξ^-/π ratios are enhanced as functions of multiplicity in p–Pb collisions [14]; the evolution of the $\Sigma(1385)^\pm/\pi$ and $\Xi(1530)^0/\pi$ suggests that the enhancement depends on their strangeness content and not on their masses.

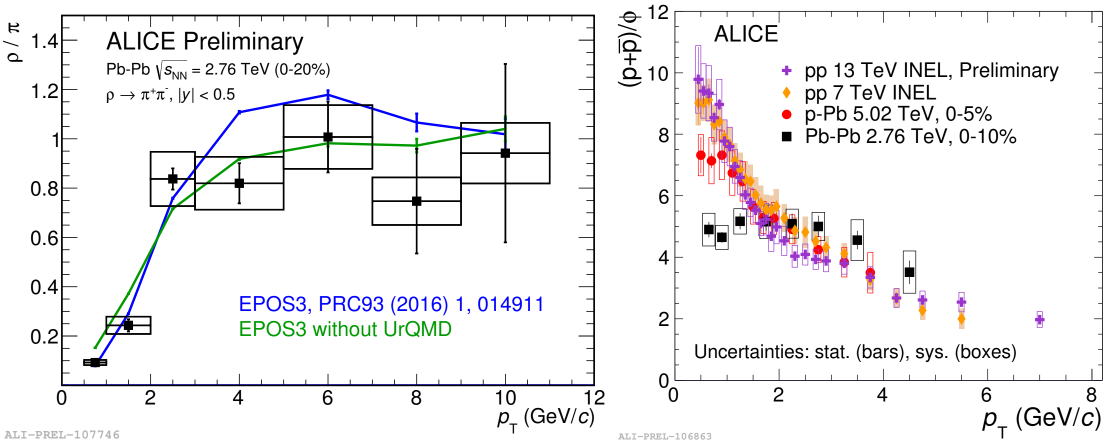

Figure 2. Ratios ρ^0/π and p/ϕ as functions of p_{T} for various collision systems [6, 7, 8]. EPOS calculations [11] of the ρ^0/π ratio are also shown.

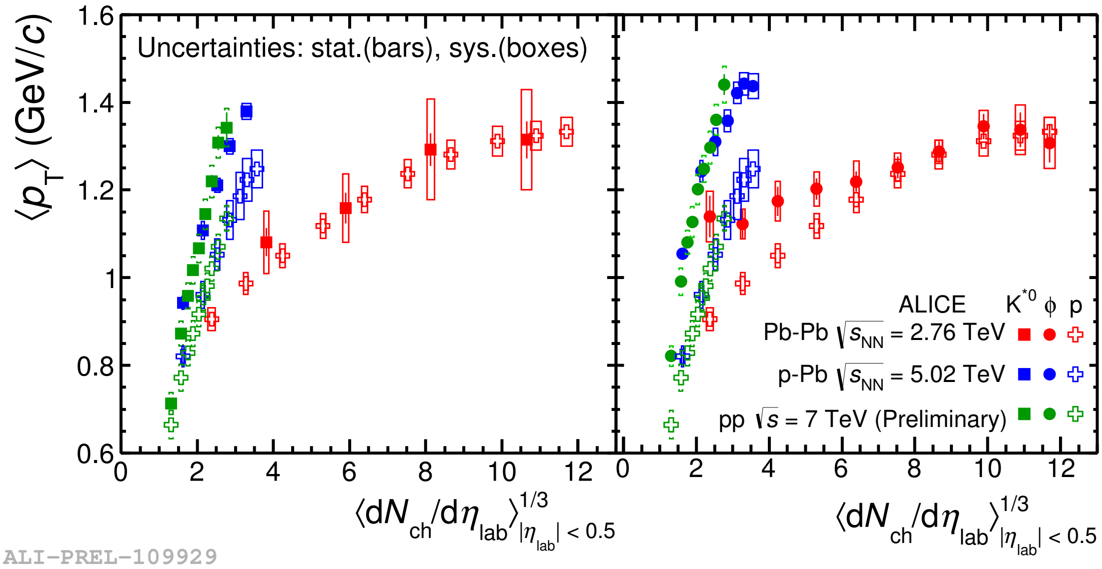

Figure 3. Mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ values of K^{*0}, p, and ϕ in various collision systems [6, 7, 15, 16].

The p_{T} dependent ρ^0/π ratio has also been calculated in Pb–Pb collisions, see Fig. 2(a). In central collisions, this ratio is fairly well described by EPOS [11] with its UrQMD module turned on, but is overestimated by at least 30% for $p_{\mathrm{T}} < 2$ GeV/c if UrQMD is turned off. Both EPOS calculations describe the ratio in peripheral Pb–Pb collisions well. This suggests that the hadronic phase, which includes re-scattering effects in UrQMD, may indeed be responsible for the observed suppression of the ρ^0 yield in central Pb–Pb collisions.

Baryon-to-meson ratios (*e.g.*, p/π and Λ/K^0_S) have been observed to be enhanced in Pb–Pb collisions with respect to pp collisions at intermediate p_{T} ($1.5 \lesssim p_{\mathrm{T}} \lesssim 6$ GeV/c) [15, 17]. This enhancement may be attributed to hadronization by recombination [18, 19] or to hydrodynamic flow that modifies the particle p_{T} spectra [20, 21, 22]. The p/ϕ ratio, in which the baryon numerator and meson denominator particles have very similar masses, can be used to further study these effects. This ratio is constant in central Pb–Pb collisions for $p_{\mathrm{T}} < 4$ GeV/c [6], but becomes sloped for peripheral Pb–Pb, p–Pb, and pp collisions, as shown in Fig. 2(b).

The constant behavior in central Pb–Pb collisions is consistent with the basic hydrodynamic assumption, although the behavior is also reproduced by some recombination models [23].

The dependence of the shapes of p_{T} spectra on mass and quark content can also be studied using the mean transverse momentum $\langle p_{\mathrm{T}} \rangle$. The $\langle p_{\mathrm{T}} \rangle$ values of the K^{*0}, p, and ϕ (which all have similar masses) are shown in Fig. 3 for different collision systems [6]. For central Pb–Pb collisions, the $\langle p_{\mathrm{T}} \rangle$ values for these three particles are consistent. This suggests that the shapes of the p_{T} spectra are determined primarily by the particle masses, which would be expected for hydrodynamic behavior. However, this behavior is not observed for smaller collision systems, where the proton is observed to have lower $\langle p_{\mathrm{T}} \rangle$ values than the two mesonic resonances. The $\langle p_{\mathrm{T}} \rangle$ values in pp and p–Pb collisions also follow different trends and rise faster with multiplicity than in Pb–Pb collisions. In pp and p–Pb collisions, the $\langle p_{\mathrm{T}} \rangle$ values approach or even exceed the values measured in central Pb–Pb collisions.

In summary, the short lifetimes of hadronic resonances make them useful probes for the study of the hadronic phase of heavy-ion collisions. Resonances can also be used along with stable hadrons in studies of the mass and quark-content dependence of mechanisms that influence the shapes of particle p_{T} spectra. The ALICE Collaboration has measured a centrality-dependent suppression of the ρ^0/π and $\mathrm{K}^{*0}/\mathrm{K}$ ratios in Pb–Pb collisions which can be described by EPOS calculations with UrQMD. Multiplicity-dependent suppression of the $\mathrm{K}^{*0}/\mathrm{K}$ ratio is also observed in pp and p–Pb collisions. In contrast, the ϕ/K ratio does not exhibit a centrality- or multiplicity-dependent suppression. This behavior may be due to the loss of the ρ^0 and K^{*0} signals caused by re-scattering of their decay products in the hadronic phase, while the ϕ decays mostly after the hadronic phase and is not affected. The $\Sigma(1385)^{\pm}/\Lambda$ and $\Xi(1530)^0/\Xi^-$ ratios are not observed to depend on system size or activity in pp and p–Pb collisions. Comparisons of resonance and proton $\langle p_{\mathrm{T}} \rangle$ values suggest that hydrodynamics can describe the p_{T} spectra of those particle in central Pb–Pb collisions, while other effects may be necessary to describe the p_{T} spectra in smaller collision systems. The ALICE Collaboration is currently extending these measurements to higher energies, other resonances ($\Lambda(1520)$ and $K^*(892)^{\pm}$), and other collision systems (*e.g.*, baryonic resonances in Pb–Pb collisions).

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