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Hadronic resonance production in small collision systems with ALICE at the LHC

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Short-lived hadronic resonances are good probes to investigate the late-stage evolution of ultra-relativistic heavy ion collisions. Since they have lifetimes comparable to that of the system created after the collision, the measured yields may be affected by the competing rescattering and regeneration processes during the hadronic phase, which modify the particle's momentum distributions after hadronization. Measurements of the production of resonances characterized by different lifetimes, masses, quark content, and quantum numbers can be used to explore the different mechanisms that influence the shape of particle momentum spectra, the dynamical evolution and lifetime of the hadronic phase, strangeness production, and collective effects. Furthermore, multiplicity dependent analyses of resonance production in pp and p–Pb collisions contribute to the investigation of collective effects and their onset in small collision systems. The ALICE experiment has collected data from several collision systems at LHC energies and the latest results on hadronic resonance production in pp and p–Pb collisions are presented here.

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1. Introduction

Hadronic resonances are useful tools to characterize the late-stage evolution (hadronic phase) of the system created in heavy-ion collisions at ultrarelativistic energies. In such collisions the critical values of temperature ($T_c \sim$ 155-160 MeV) and energy density ($\epsilon_c \sim$ 0.3-0.5 Gev/fm^3) can be reached with the consequent formation of a deconfined state of quasi-free quarks and gluons, known as quark–gluon plasma (QGP). Resonances with a lifetime comparable to that of the fireball ($\approx$ 1-10 fm/c at Large Hadron Collider (LHC) energies) may be sensitive to the competitive rescattering and regeneration mechanisms that could lead to a suppression or an enhancement of the resonance measured yield, respectively. The suitable conditions for QGP formation are expected to be reached only in heavy-ion collisions, with data from small systems (pp and p–Pb) collected only as a baseline. However recent studies of pp and p–Pb collisions at the LHC for events with high charged-particle multiplicities have shown patterns that are reminiscent of phenomena observed in A–A collisions. For example the strangeness enhancement [1], the hardening of the p_T spectra with increasing multiplicity and a shift in the maximum of the distributions to larger p_T that depends on the hadron mass (more pronounced for heavier particles) [2–5], long-range multiparticle azimuthal correlations [6], and the hint of suppression with increasing multiplicity of the ratios of short-lived resonances to long-lived hadrons [5] have been observed even in small collision systems. The presence of typical features of heavy-ion collisions in pp and p–Pb collisions is an intriguing observation whose interpretation could lead to new perspectives in the theoretical foundations behind QGP formation and to a better understanding of the particle production mechanisms involved.

2. Methodology

ALICE [7] is one of the large experiments installed at the LHC at CERN. A complete description of the ALICE apparatus and its performance can be found in [7, 8]. The main sub-detectors involved in resonance analyses are the Inner Tracking System (ITS), the Time Projection Chamber (TPC), the Time-Of-Flight detector (TOF), and the V0A and V0C scintillators. The ITS and the TPC are used for primary vertex determination, tracking and particle identification (PID) via the measurement of the particle specific energy loss. The TOF detector is designed for PID measuring the particle time of flight, and the V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$) hodoscopes are used for triggering and selecting events based on the charged-particle multiplicity at forward rapidities. Resonances are reconstructed by reconstructing their invariant mass after the identification of the decay products. The shape of the uncorrelated background is estimated by the event-mixing or like-sign technique. After combinatorial background subtraction, the invariant mass distribution is then fitted with a polynomial function to describe the residual background and with a Breit-Wigner, a Voigtian or a Gaussian function to describe the signal. Corrective factors as geometrical acceptance and detector efficiency, branching ratio, trigger selection efficiency, and signal-loss factor are applied to the raw yields in order to estimate the yields.

3. Results and discussion

ALICE has measured the production at midrapidity ($|y| < 0.5$) of a large set of hadronic resonances in several collision systems at different LHC energies [5, 9–16]. The latest results from the multiplicity ($\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$) dependent analyses of $K^*(892)^\pm$ in pp collisions at $\sqrt{s}$ = 13 TeV, $\Lambda(1520)$ in pp collisions at $\sqrt{s}$ = 5.02 and 13 TeV, and of $\Xi(1530)$ in pp collisions at $\sqrt{s}$ = 13 TeV are discussed here. The p_T-differential distributions of $K^{*\pm}$, $\Lambda(1520)$, and $\Xi(1530)$ get harder for $p_T \lesssim 5$ GeV/c going from low to high multiplicity events. The trend is qualitatively similar to the behaviour observed in Pb–Pb collisions that is usually attributed to a collective radial expansion of the system (radial flow) following QGP formation. However in small collision systems the collectivity-like signals could be mimicked by the colour reconnection mechanism, reproducing a boost effect similar to the one observed in the case of collective flow but due to a different process [17].

Figure 1 shows the $\Lambda(1520)$ and $\Xi(1530)$ p_T-integrated yields as a function of the charged-particle multiplicity density. The yields exhibit a linear increase with increasing multiplicity and results for different energies and collision systems at the same multiplicity are consistent within systematic uncertainties. Therefore, as observed also for other hadron species [2, 5], the particle production rate is independent of collision energy or system and scales with the event multiplicity.

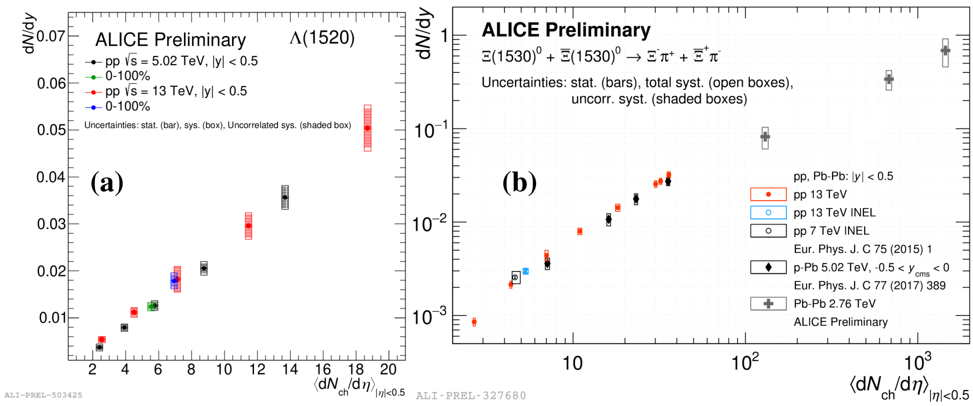

Figure 1: The p_T-integrated yields of $\Lambda(1520)$ **(a)** and $\Xi(1530)$ **(b)** as a function of $\langle dN_{ch}/d\eta \rangle_{|\eta|<0.5}$.

Figure 2 shows the ratios of $K^{*\pm}$ and K^{*0} to K^0_S in pp collisions at $\sqrt{s}$ = 13 TeV. The ratio of resonance p_T-integrated yields to the production of their ground states, is an important tool to verify the presence of a suppression in resonances production and its dependence on the system size. An intriguing suppression of the $K^{*\pm}/K^0_S$ ratio is observed from low to high multiplicity pp collisions, which is significant at the 7σ level taking into account the fraction of systematic uncertainties uncorrelated with multiplicity. The latest measurement confirms and improves the precision of previous K^{*0} results [5] due to lower systematic uncertainties. The measured values are compared with several model calculations. Among them, EPOS-LHC [18] without the UrQMD hadronic afterburner provides the best description, reproducing the decreasing trend. The right panel of Fig. 2 shows the p_T-dependent $K^{*\pm}/K^0_S$ ratios in high and low-multiplicity events as well as the former divided by the latter (double ratio) showed in the lower panel. The double ratio is consistent with unity for $p_T \gtrsim 2.5$ GeV/c while for $p_T \lesssim 2.5$ GeV/c is suppressed at more than 3σ level. Since in heavy-ion collisions a suppression at low p_T is considered as a signature of re-scattering effects in the late hadron gas stage, this evidence could be a hint of the presence of a hadronic phase in small collision systems too.

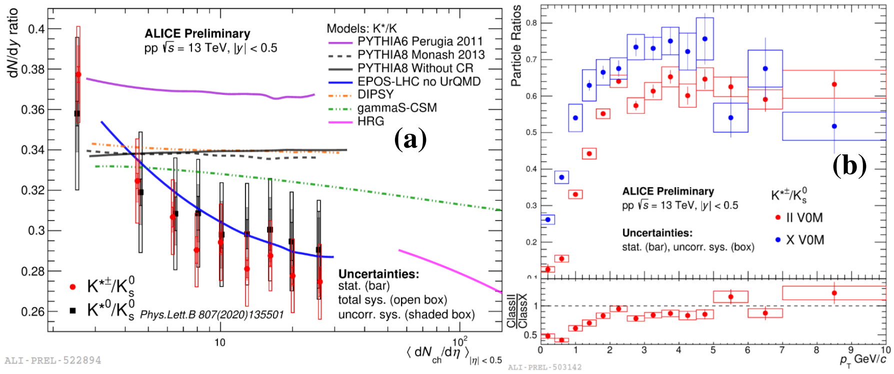

Figure 2: **(a)** Ratios of $p_{\rm T}$-integrated yields of $\rm K^{*\pm}/K^0_S$ in pp at $\sqrt{s}$ = 13 TeV as a function of multiplicity compared with $\rm K^{*0}/K^0_S$ data [5] and predictions from event generators [18–24]. **(b)** Ratios of $\rm K^{*\pm}/K^0_S$ $p_{\rm T}$ spectra for low (X) and high (II) multiplicity classes. The high multiplicity $\rm K^{*\pm}/K^0_S$ $p_{\rm T}$ spectrum divided by the low multiplicity one (double ratio) is reported in the lower panel.

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