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Hadronic resonance production measured by ALICE at the LHC

F. Bellini for the ALICE Collaboration [1]

Dipartimento di Fisica dell'Università, Via Irnerio 46, 40126 Bologna, Italy

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Abstract

Hadronic resonances constitute a valuable probe for the properties of the medium formed in heavy-ion collisions. In particular, they provide information on particle-formation mechanisms, the properties of the hadronic medium at freeze-out, and they contribute to the systematic study of energy loss and recombination. The study of resonance production in other collision systems such as pp and p–Pb forms a necessary baseline to disentangle initial-state effects from genuine medium-induced effects. The production of the $K^*(892)^0$ and $\phi(1020)$ resonances has been measured at mid-rapidity in different collision systems at LHC energies using the ALICE detector. Resonances are reconstructed via their hadronic decay in a wide momentum range, by exploiting the excellent particle-identification capabilities of the Time-Projection Chamber and the Time-Of-Flight system. First results on $K^*(892)^0$ and $\phi(1020)$ production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV at the LHC are presented. The resonance transverse momentum spectra and yields are measured as a function of the multiplicity of p–Pb collision. Ratios of resonance to long lived hadron production in Pb–Pb are compared with the same quantities measured in pp and p–Pb, in order to investigate rescattering effects. The ratio of ϕ to protons and pions as a function of p_T suggests that in central Pb–Pb collisions it is the mass which drives the spectra shapes at low and intermediate p_T, as in a hydrodynamically-evolving system. The nuclear modification factors (R_{AA}, R_{pPb}), recently measured up to high p_T for resonances, are consistent with those of the stable hadrons.

Keywords: Quark–gluon plasma; p–Pb collisions; Resonances; Phi; K^{*0}

[1] A list of members of the ALICE Collaboration and acknowledgements can be found at the end of this issue.

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1. Introduction

$K^*(892)^0$ and $\phi(1020)$ resonance[2] production has been measured at the LHC using the ALICE detector [1,2] in pp collisions at $\sqrt{s} = 2.76$ TeV and 7 TeV [3] and in Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [4]. The first measurement of K^{*0} and ϕ in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV has been presented at this conference. Due to their short lifetimes, K^{*0} ($\tau \sim 4$ fm/c) and ϕ ($\tau \sim 45$ fm/c) are sensitive probes for different phases of the evolution of the medium produced in heavy-ion collisions. Information on particle formation mechanisms can be derived from the comparison of resonance production with that of long lived hadrons with similar mass but different baryon number and strangeness content. Particle ratios to stable hadrons provide information about the competing effects, rescattering and regeneration, that may affect the measurable resonance yield. Resonances that decay before kinetic freeze-out may not be reconstructed due to the rescattering of their daughter particles, the fraction of "undetected" particles depending on the time lapse between chemical and kinetic freeze-out, the system size, the resonance phase space distribution and the hadronic interaction cross section of the decay products. Resonances can be regenerated by pseudo-elastic interactions in the hadronic medium, a process driven by the cross-section of the interacting hadrons. In Pb–Pb, the measurement of resonance production at high p_T, and in particular that of ϕ with its hidden strangeness content, also contributes to the systematic study of in-medium parton energy loss and its flavor dependence. Their measurement in pp and p–Pb collision systems provides further insight into the measurement in heavy-ion collisions.

2. Resonance reconstruction

Resonances are reconstructed through their decay into charged hadrons: $K^{*0} \to K^+\pi^-$ ($\overline{K^{*0}} \to K^-\pi^+$) and $\phi \to K^+K^-$. In pp and Pb–Pb resonances are measured in one unit of rapidity $|y| < 0.5$ in the centre-of-mass reference frame, while in p–Pb the measurement is restricted to $-0.5 < y < 0$, in order to ensure the best detector acceptance with the shifted center of mass of the system. The primary vertex of the collision is reconstructed in the Inner Tracking System (ITS) and Time-Projection Chamber (TPC). The V0 detectors, a pair of scintillation hodoscopes covering $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C), were used for event triggering and the definition of centrality and multiplicity classes, respectively in Pb–Pb [5] and p–Pb [6] collisions. The resonance decay products are selected among primary charged tracks that satisfy good reconstruction quality criteria and are identified via the measurement of the specific ionization energy loss (dE/dx) in the TPC. The information of the Time-Of-Flight (TOF) is used as a veto on charged K and π identification in p–Pb, leading to an improvement of the significance of the signal. Resonances are identified by means of an invariant mass analysis, as described extensively in [3,4]. The mass and width of ϕ (K^{*0}) are found to be compatible in all collision systems and consistent with the values from Monte Carlo simulations.

3. Results and discussion

The results on K^{*0} and ϕ production in Pb–Pb have been recently published in [4]. A sample of 9×10^7 minimum bias events from the 2013 LHC runs has been analyzed to extract K^{*0} (ϕ)

[2] $K^*(892)^0$ and $\phi(1020)$ will be indicated as K^{*0} and ϕ, respectively.

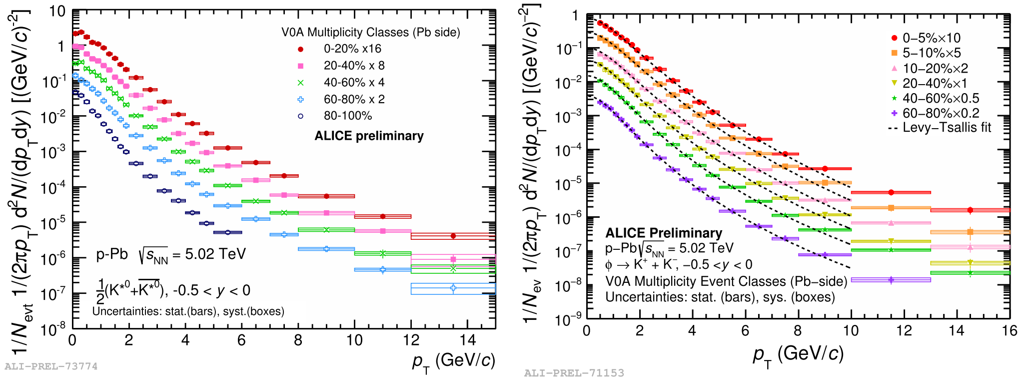

Fig. 1. K^{*0} (left panel) and ϕ (right panel) invariant transverse momentum spectra in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in different V0A multiplicity event classes. Bars and boxes represent statistical and systematic uncertainties, respectively.

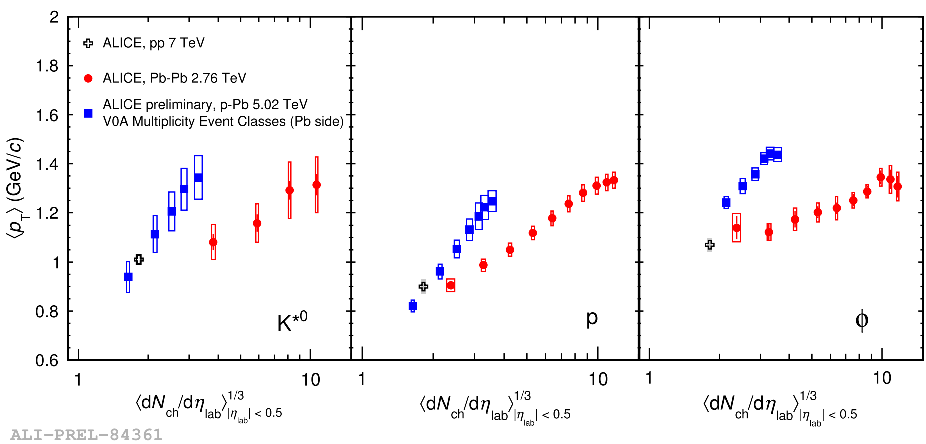

Fig. 2. System size dependence of the mean transverse momentum of K^{*0}, p and ϕ. The system size is defined as the cubic root of the average charged particle multiplicity density measured in the V0 detector in pp at $\sqrt{s} = 7$ TeV (black hollow cross), p–Pb at $\sqrt{s_{NN}} = 5.02$ TeV (blue full square) and Pb–Pb at $\sqrt{s_{NN}} = 2.76$ TeV (red full circle). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

in p–Pb collisions in the p_T range [0, 15] GeV/c ([0.3, 16] GeV/c) for different V0A multiplicity event classes. The preliminary p_T spectra in p–Pb collisions are shown in Fig. 1. In order to extract the particle yields and mean p_T, the spectra are fitted using a Levy–Tsallis parameterization [7]: the yields are calculated by integrating the corrected spectra in the measured p_T region and extrapolating using the fit outside this region. It may be noted that for K^{*0} in p–Pb the extrapolated region covers a fraction of the total yield lower than 0.1%, therefore the systematic uncertainty associated to the fit function is negligible. The mean p_T of K^{*0} and ϕ is shown in Fig. 2 in the three collision systems as a function of the system size. It is observed that particles with similar mass as K^{*0}, p [8] and ϕ have similar $\langle p_T \rangle$ in the most central Pb–Pb collisions. This observation agrees well with the fact that all particles undergo radial flow. Also in p–Pb collisions the $\langle p_T \rangle$ of resonances increases as a function of the average charged particle multiplicity density, as for other hadrons. However, while $\langle p_T \rangle$ of long lived hadrons follows mass ordering

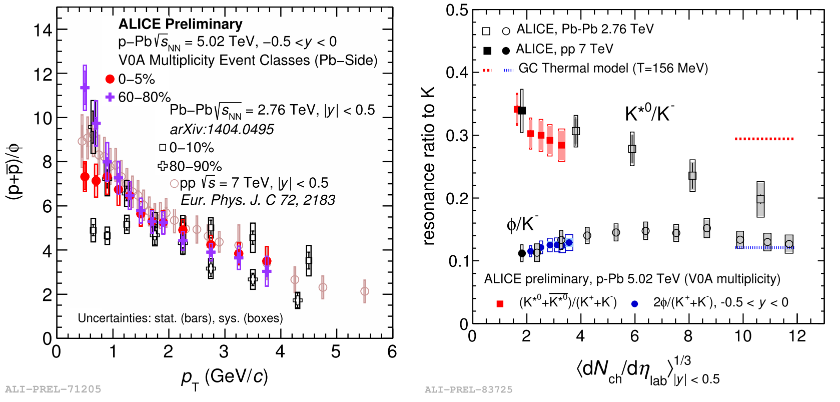

Fig. 3. Left panel: $(p + \bar{p})/\phi$ ratio measured in p–Pb in 0–5% (red full cross) and 60–80% (purple full cross) V0A multiplicity classes, compared to pp (hollow pink circle), 0–5% (black hollow squares) and 60–80% (black hollow cross) Pb–Pb collisions. Right panel: ratio of resonances to charged kaons measured in the three collision systems, as a function of the system size. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

($\langle p_T \rangle_\Lambda > \langle p_T \rangle_p > \langle p_T \rangle_{K^\pm, K^0_s} > \langle p_T \rangle_{\pi^\pm}$, [9]), the $\langle p_T \rangle$ of K^{*0} and ϕ is found to be larger than that of protons. $\langle p_T \rangle$ of ϕ is also larger than $\langle p_T \rangle_\Lambda$. A similar trend is observed in pp collisions at 7 TeV, where $\langle p_T \rangle_\phi > \langle p_T \rangle_{K^{*0}} > \langle p_T \rangle_p$. The question remains open whether the mesonic resonances deviate from mass ordering or the baryons, namely p and Λ, do instead. The $\langle p_T \rangle$ in p–Pb shows a steeper increase with multiplicity than in Pb–Pb, as also observed for unidentified charged particles and discussed in [10].

The $(p + \bar{p})/\phi$ ratio is shown in the left panel of Fig. 3. In 0–10% central Pb–Pb collisions this ratio is flat below 3 GeV/c. The fact that the p/π and ϕ/π have the same shape as a function of p_T [4] suggests that the shapes of the p_T distributions of the p and ϕ in this momentum range are determined by the particle masses. In peripheral p–Pb and pp collisions the $(p + \bar{p})/\phi$ ratio is quantitatively consistent and below 5 GeV/c it decreases steeply with p_T, with a trend similar to peripheral Pb–Pb collisions. In central p–Pb collisions, namely for the 0–5% V0A multiplicity event class, the ratio shows a hint of flattening for $p_T < 1.5$ GeV/c. It is interesting to note that the ratio is similar to 60–80% peripheral Pb–Pb collisions. The ratios ϕ/K and K^{*0}/K measured in p–Pb collisions have been compared to the published measurements for pp [3] and Pb–Pb [4], and are shown in the right panel of Fig. 3. While the ϕ/K ratio is nearly flat and reaches the value predicted by a grand-canonical thermal model with $T = 156$ MeV [11], the K^{*0}/K ratio exhibits a decreasing trend towards more central Pb–Pb, where the measured ratio is about 60% of the thermal model value. As more extensively discussed in [4], this can be explained in terms of rescattering effects, dominating for $p_T < 2$ GeV/c.

The production of resonances at high transverse momentum in different collision systems is studied through the nuclear modification factors, R_{AA} and R_{pPb}. The measurements of the p_T spectra in Pb–Pb and the new measurement of the reference spectrum in pp collisions at $\sqrt{s} = 2.76$ TeV allowed the existing results on R_{AA} of ϕ [12] to be extended up to 21 GeV/c and to measure the R_{AA} of K^{*0} up to 10 GeV/c. The nuclear modification factors for ϕ are shown in Fig. 4. High-p_T K^{*0} and ϕ resonances are strongly suppressed in most central Pb–Pb collisions with respect to pp collisions. The suppression is consistent with that measured for the stable hadrons, thus supporting once more the observation of the flavour-independence of par-

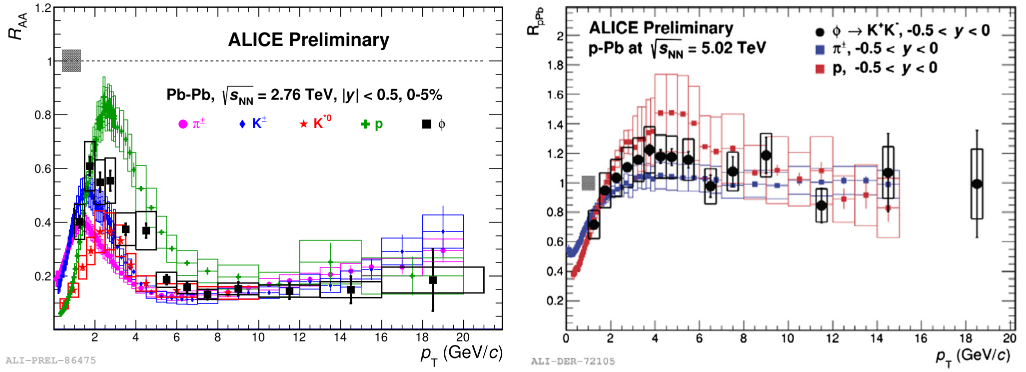

Fig. 4. Nuclear modification factor of resonances in 0–5% central Pb–Pb collisions (R_{AA}, left panel) and in minimum bias p–Pb collisions (R_{pPb}, right panel), compared to that of identified stable hadrons.

tonic energy loss in the medium. The production of ϕ in miminum bias p–Pb and pp collisions are compared by computing the R_{pPb}, shown in the right panel of Fig. 4. The reference pp spectrum at $\sqrt{s} = 5.02$ TeV has been obtained from an interpolation of the spectra measured in pp at 2.76 TeV and 7 TeV, following the same procedure described in [13] for identified charged hadrons. No suppression is seen at high-p_T in p–Pb collisions compared to pp.

4. Conclusions

The most recent results on ϕ and K^{*0} resonance production at the LHC shown at this conference include the first measurement in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV in several event multiplicity classes. The mean p_T of ϕ in Pb–Pb is found to be compatible to that of the proton, while in p–Pb it does not follow the same mass ordering as other long lived particles. Finally, the ratios of resonances to stable hadrons have been measured and compared in different collision systems. The K^{*0}/K ratio suggests that in central Pb–Pb collisions, K^{*0} suffer from rescattering due to the short lifetime, while compared to it, ϕ behaves as a long lived particle.

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