IL NUOVO CIMENTO **44 C** (2021) 74
DOI 10.1393/ncc/i2021-21074-9

COMMUNICATIONS: SIF Congress 2020

Measurements of hadronic resonance production with ALICE

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received 15 January 2021

Summary. — Short-lived hadronic resonances are an important tool to characterize the system formed both in elementary and heavy-ion collisions. Since they have a lifetime comparable to the fireball one, resonance measured yields may be affected by re-scattering and regeneration processes. The ALICE experiment has collected data from several collision systems at LHC energies. The latest results on resonance production in pp, p-Pb and Pb-Pb collisions are reported; in particular $\langle p_{\mathrm{T}} \rangle$ and the ratios of p_{T}-integrated yields to long-lived particle ones will be discussed.

1. – Introduction

ALICE (A Large Ion Collider Experiment [1]) is one of the large experiments installed at the Large Hadron Collider (LHC) at CERN. The detector is mainly designed to study the physics of strongly interacting matter created in nucleus-nucleus (A-A) collisions at ultra-relativistic energies. In these extreme conditions of temperature and energy density, a deconfined state of free quarks and gluons, known as Quark-Gluon Plasma (QGP), is formed. Hadronic resonances are perfect probes to characterize the evolution of the late hadronic phase. Indeed, resonances with a lifetime comparable to the fireball one ($\sim$10 fm/c) may be sensitive to the competitive mechanisms of re-scattering and regeneration. When a resonance decays inside the hadronic medium, the decay products may interact with the other particles, leading to a suppression of the resonance measured yield. The process just described is known as re-scattering. On the contrary the regeneration mechanism occurs when the particles of the hadronic medium, as a consequence of pseudo-elastic collisions, regenerate a given resonance, resulting in an enhancement of the measured yield. Long-lived resonances, decaying mainly at the end of the hadronic phase, should not be affected by any of these processes. Besides heavy-ion collisions, data from small collision systems, like proton-proton (pp) and proton-lead (p-Pb) collisions, have been collected as a baseline for A-A collisions. Recent studies of pp and p-Pb collisions at the LHC with high charged-particle multiplicities have shown patterns that are reminiscent of phenomena observed in A-A collisions such as Pb-Pb and Xe-Xe. For

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TABLE I. – *Resonances studied by ALICE at different collision systems and energies. Lifetime (τ) and hadronic decay channel with the correspondent branching ratio (B.R.) are shown.*

Resonance	$\rho(770)^0$	$K^*(892)^0$	$\Sigma(1385)^{\pm}$	$\Lambda(1520)$	$\Xi(1530)^0$	$\phi(1020)$
τ(fm/c)	1.3	4.2	5-5.5	12.6	21.7	46.4
Decay	$\pi\pi$	Kπ	$\Lambda\pi$	pK	$\Xi\pi$	KK
B.R. (%)	100	66.6	87	22.5	66.7	48.9

example strangeness enhancement [2], double-ridge structure [3], hardening of hadron p_{T} spectra, and suppression of short-lived resonance production with increasing multiplicity [4] have been observed even in small collision systems. The presence of typical features of heavy-ion collisions also 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 mechanisms involved.

2. – Methodology

The ALICE apparatus and its performance are fully described in [1, 5]. The main sub-detectors involved in resonance analysis 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 TPC are used for particle identification (PID) by energy loss measurement, tracking, and primary vertex determination. The TOF detector is designed for PID measuring time of flight, and the V0A ($2.8 < \eta < 5.1$) and V0C ($-3.7 < \eta < -1.7$) counters are used for triggering and charged particle multiplicity estimation at forward rapidities. In table I the main hadronic resonances studied by ALICE in pp, p-Pb, Xe-Xe, and Pb-Pb collisions in the energy range $\sqrt{s_{\mathrm{NN}}} = 2.76$–$13\,\mathrm{TeV}$ are shown. Resonances are reconstructed via invariant mass distribution of the hadronic decay daughters (table I). 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 suitable function for the residual background and with a proper function for the resonance peak, like a Breit-Wigner function, a Voigtian or a Gaussian one. 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 final yields.

3. – Results

The ALICE experiment has collected data from several collision systems at different LHC energies, measuring the production of a large set of hadronic resonances [4, 6-9]. In pp collisions at $\sqrt{s} = 13\,\mathrm{TeV}$ [6] the hardening of the spectra of $K^*(892)^0$ and $\phi(1020)$ is observed for $p_{\mathrm{T}} < 4\,\mathrm{GeV}/c$, passing from peripheral to central collisions. This is qualitatively similar to the behaviour observed in Pb-Pb collisions that it is attributed to collective radial expansion. The origin of collective flow-like effect in small collision systems is not clear. However, some collective expansion models such as EPOS-LHC [10] or models like PYTHIA [11] or DIPSY [12] with the colour reconnection mechanism are able to mimic these collective effects in small collision systems. The shapes of the

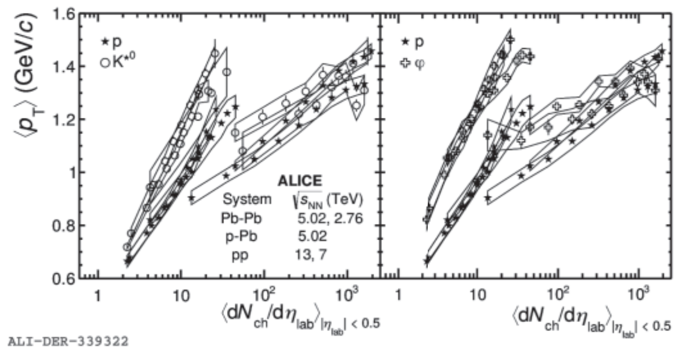

Fig. 1. – Mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ values of K^{*0}, ϕ, and p in pp at $\sqrt{s} = 7\,\mathrm{TeV}$ and $13\,\mathrm{TeV}$, in p-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$, and in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02\,\mathrm{TeV}$ and $2.76\,\mathrm{TeV}$ as a function of charged-particle multiplicity density at mid-rapidity.

spectra are the same for all multiplicity classes at high p_{T}. The results have many qualitative similarities to those reported for longer-lived hadrons in the same collision system [13-15] and are consistent with previous measurements [16] of K^{*0} and ϕ in pp collisions at $\sqrt{s} = 7\,\mathrm{TeV}$. The mean transverse momentum $\langle p_{\mathrm{T}} \rangle$ distributions of K^{*0}, ϕ, and p (which have similar masses) as a function of charged-particle multiplicity density, are shown in fig. 1. In central Pb-Pb collisions, mass ordering of $\langle p_{\mathrm{T}} \rangle$ values is observed: particles with similar mass have similar $\langle p_{\mathrm{T}} \rangle$, as expected by considering a collective expansion of the system. The mass ordering breaks down for peripheral Pb-Pb collisions, as well as for p-Pb and pp collisions. The ratio of resonance p_{T}-integrated yields to long-lived particle yields is an important tool to check for the presence of a suppression in resonances production and if it depends on system size. Figure 2 shows

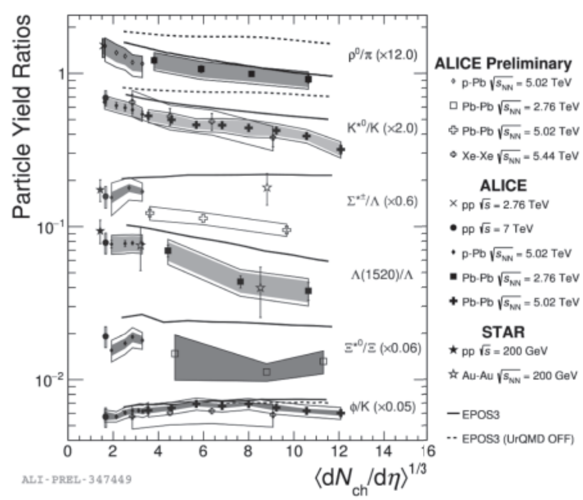

Fig. 2. – Ratios of p_{T}-integrated resonance yields to long-lived particle yields in increasing lifetime order: ρ^0/π [7], $\mathrm{K}^{*0}/\mathrm{K}$ [4, 6], $\Sigma^{*\pm}/\Lambda$ [9], $\Lambda(1520)/\Lambda$ [8], Ξ^{*0}/Ξ [9], and ϕ/K [4, 6] as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle^{1/3}$ for different collision systems. Data are compared to EPOS3 predictions with and without UrQMD [17], and to STAR results for $\Sigma^{*\pm}/\Lambda$ and $\Lambda(1520)/\Lambda$ [18].

the ratios ρ^0/π, K^{*0}/K, $\Sigma^{*\pm}/\Lambda$, $\Lambda(1520)/\Lambda$, Ξ^{*0}/Ξ, and ϕ/K as a function of the cubic root of the charged-particle multiplicity density ($\langle dN_{ch}/d\eta\rangle^{1/3}$) for the indicated collision systems and energies. Resonance lifetime increases from the top to bottom. For central Pb-Pb collisions the ratios ρ^0/π, K^{*0}/K, $\Sigma^{*\pm}/\Lambda$, and $\Lambda(1520)/\Lambda$ are suppressed with respect to peripheral Pb-Pb, pp and p-Pb collisions. This would indicate the dominance of re-scattering mechanisms compared to the regeneration ones. It is interesting to notice that ρ^0/π and K^{*0}/K ratios show a hint of suppression also in pp and p-Pb collisions, suggesting the presence of a hadron-gas phase even in these small systems. No centrality dependence across the different systems is observed for Ξ^{*0}/Ξ and ϕ/K, since Ξ^* and ϕ live longer than K^{*0} and ρ^0. They decay predominantly after the end of the hadronic phase and their yield should not be affected by regeneration and re-scattering effects.

4. – Discussion and conclusion

The latest results on resonance production obtained by ALICE in different collision systems have been here reported. The hardening of resonance p_T spectra with increasing multiplicity observed in A-A collisions and attributed to collective expansion is observed also in small collision systems. Comparable values of $\langle p_T\rangle$ have been measured for K^{*0}, ϕ, and p in central Pb-Pb collisions, as expected from the hydrodynamics of the system, since they have similar masses. However the observed mass ordering breaks down in pp and p-Pb collisions. The p_T-integrated yields ratios of short-lived resonances to their stable counterparts are suppressed in central heavy-ion collisions compared to peripheral and elementary collisions, suggesting dominance of re-scattering over regeneration. No suppression is noticed for long-lived resonances. A very interesting aspect is the hint of suppression for ρ^0/π and K^{*0}/K in high-multiplicity pp and p-Pb collisions. These results seem to suggest that in elementary collisions collective-like phenomena are at play and that the presence of a hadronic phase affects the measured resonance yields. In the near future more results will allow to investigate further and potentially help in improving our phenomenological interpretation of these intriguing observations.

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