PROCEEDINGS OF SCIENCE

High transverse momentum resonance production in pp, p–Pb and Pb–Pb collisions at LHC

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Resonance production in heavy-ion collisions is expected to be a sensitive probe to the properties of strongly interacting matter produced in such collisions. The production of resonances at high transverse momentum will help us to understand the mechanism of particle production and parton energy loss in the medium formed in ultra-relativistic heavy-ion collisions. We report the measurements of K^{*0} ($\tau \sim$4 fm/c) and ϕ ($\tau \sim$42 fm/c) production at high transverse momentum in pp, p–Pb and Pb–Pb collisions at LHC energies and nuclear modification factors. These measurements are compared to corresponding results for the other produced hadrons like charged kaons and protons. Some aspects of resonance production and particle production in general are discussed.

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†A footnote may follow.

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1. Introduction

$K^*(892)^0$ and $\phi(1020)$ resonances have been measured at the LHC by using the ALICE detector [1, 2], in proton-proton (pp) $\sqrt{s}$ = 2.76 TeV and 7 TeV, in proton-lead (p–Pb) collisions at $\sqrt{s_{NN}}$ = 5.02 TeV and in lead-lead (Pb–Pb) $\sqrt{s_{NN}}$ = 2.76 TeV. Throughout this report $K^*(892)^0$ and $\overline{K}^*(892)^0$ are averaged and denoted as K^{*0}, whereas $\phi(1020)$ is denoted as ϕ. Due to the short lifetimes of K^{*0} ($\tau \sim$4 fm/c) and ϕ ($\tau \sim$45 fm/c), they can be used as a probe for different stages of the evolution of the system formed in the relativistic heavy-ion collisions. The yields of stable particles are expected to be fixed at chemical freezeout. However, this is not the case for resonances : those resonances which decay in between chemical and kinetic freezeout may not be reconstructed when the decay daughters re-scatter in the hadronic medium. On the other hand, the yield of resonances may increase due to pseudo-elastic interaction leading to regeneration. The fraction of resonances that go undetected due to re-scattering depends on factors such as system size, time span between chemical and kinetic freezeout, phase space distribution of the resonance and the hadronic interaction cross section of the decay products. However, regeneration is mainly affected by the cross-section of the interacting hadrons to form a resonance. ALICE has measured resonance to stable particle yield ratios in order to gain more insight into these competing effects. Resonances can also be used for understanding particle production mechanisms, the effects that modify the shapes of particle p_T spectra and for the systematic study of nuclear modification factors.

2. Resonance reconstruction in ALICE

K^{*0} and ϕ are measured via invariant-mass reconstruction through their hadronic decay channels $K^{*0}(\overline{K}^{*0}) \rightarrow K^+\pi^-(K^-\pi^+)$ and $\phi \rightarrow K^+K^-$. In pp and Pb–Pb collision systems, resonances are measured in one unit of rapidity $|\, y \,| < 0.5$ in the centre-of-mass frame. However, in p–Pb collisions the measurement is restricted to $-0.5 < y < 0$, to ensure the best detector acceptance while keeping close to mid-rapidity in the center-of mass frame. The performance of the ALICE detector during the Run I of the LHC is described in [2]. Inner Tracking System (ITS) and Time-Projection Chamber (TPC) are used for tracking and determination of the primary collision vertex. There are two V0 detectors on both sides from the center of the ALICE detector. These are scintillation detectors covering $2.8 < \eta < 5.1$ (V0A) and $-3.7 < \eta < -1.7$ (V0C). These detectors are used for event triggering and the determination of centrality and multiplicity classes in Pb–Pb and p–Pb collisions, respectively. In the TPC, through specific ionization energy loss (d$E/$dx), the resonance decay products are selected among primary charged tracks. In p–Pb collisions, the Time-Of-Flight (TOF) information is also used for the identification of charged kaon and pion, leading to an improvement of the significance of the signal. The resonances are reconstructed by means of an invariant mass analysis. The uncorrelated combinatorial background is estimated using the event-mixing technique. After the combinatorial background subtraction, the resonance signal is fitted with a Breit-Wigner function for K^{*0} and a Breit-Wigner function convoluted with a Gaussian for ϕ along with a second order polynomial to describe the remaining residual background. The mass and width of K^{*0} and ϕ are found to be compatible in all collision systems and consistent with the

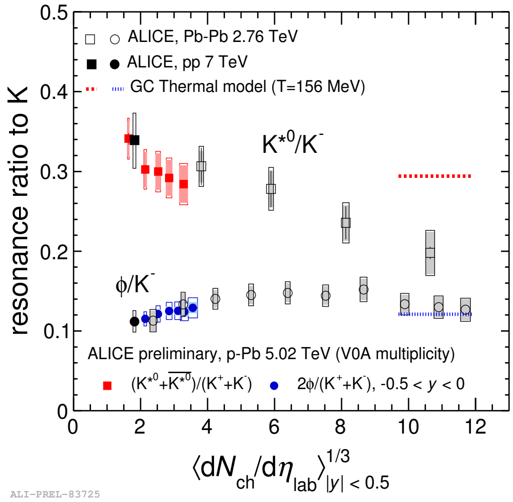

Figure 1: Resonances to charged kaons ratios measured in the three collision systems, as a function of the system size.

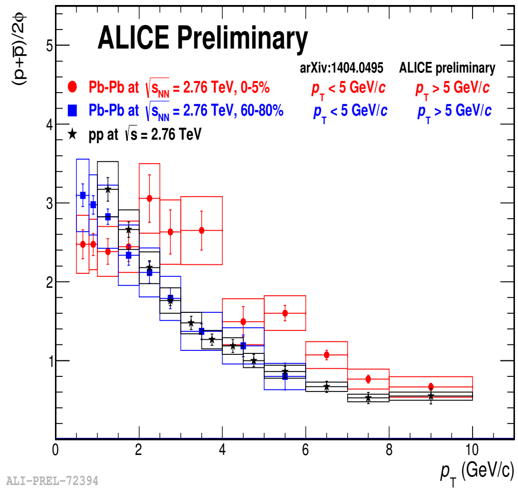

Figure 2: (p+p)/2ϕ ratio measured in 0-5% and 60-80% in Pb–Pb collisions compared to pp collisions.

vacuum values [3].

3. Results and discussion

The ALICE collaboration has published the measurement of K^{*0} and ϕ resonance production in pp and Pb–Pb collisions [3, 4]. Preliminary results on K^{*0} production in p–Pb collisions for different V0A multiplicity event classes have been reported in [5]. In Fig. 1, K^{*0}/K$^-$ and ϕ/K$^-$ ratios measured in p–Pb collisions are compared to the published measurements for pp [4] and Pb–Pb [3]. The K^{*0}/K$^-$ ratio shows decreasing trend towards most central (0-20%) Pb–Pb collisions and the measured value is about 60% of the thermal model prediction value with T_{chem} = 156 MeV [6]. However, ϕ/K$^-$ ratio remains unaltered irrespective of system size and is found to be consistent with the value predicted by a thermal model [6]. This can be explained by re-scattering effect which is dominant for $p_{\mathrm{T}} < 2$ GeV/c and more extensively discussed in [3]. In Fig. 2, the p_{T} differential ratio of (p+p̄)/2ϕ for the 0-5% and 60-80% centrality classes in Pb–Pb collisions is compared with pp collisions. This ratio is flat below 4 GeV/c for 0-5% centrality class in Pb–Pb collisions. The p_{T}-differential ratios p/π and ϕ/π have the same shape as a function of p_{T} [3], which suggests that the shape of p_{T} distribution is determined by particle masses in this p_{T} region. The (p+p̄)/2ϕ ratio in pp collisions consistently decreases with p_{T} and the trend is similar to peripheral Pb–Pb collisions. At high-p_{T}, these ratios have similar values for both the pp and Pb–Pb collison systems irrespective of centrality.

The nuclear modification factors for different collision systems, denoted by R_{AA} or R_{pPb}, are defined as the particle yield in heavy-ion collisions relative to that in elementary pp collisions scaled by the number of binary nucleon-nucleon collisions in Pb–Pb or p–Pb collisions,

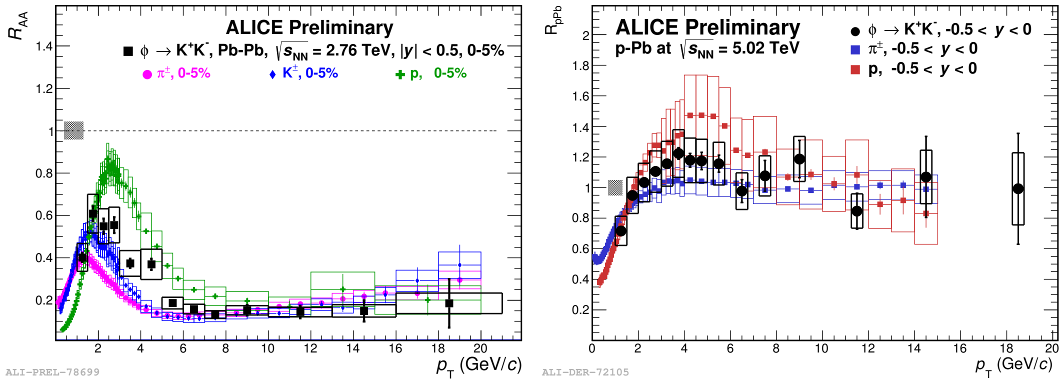

Figure 3: Resonance nuclear modification factor (R_{AA}) in 0-5% central Pb–Pb collisions (left panel) and in minimum bias p–Pb collisions, R_{pPb} (right panel), compared to that of identified stable hadrons.

$$R_{\mathrm{i}}(p_{\mathrm{T}}) = \frac{\mathrm{d}^2\mathrm{N_i}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{i}}\rangle \mathrm{d}^2\sigma^{pp}/\mathrm{d}y\mathrm{d}p_{\mathrm{T}}}, \tag{3.1}$$

where i = p–Pb, Pb–Pb collision systems, $\langle T_{\mathrm{i}}\rangle$ (= $\langle N_{\mathrm{coll}}\rangle$ / σ^{inel}) is the nuclear overlap function, $\langle N_{\mathrm{coll}}\rangle$ is the average number of binary nucleon-nucleon collisions and σ^{inel} is the inelastic pp cross section. Whenever $R_{\mathrm{i}}(p_{\mathrm{T}})$ is unity, the observed yields can be explained by a simple linear superposition of pp collisions, with any deviation from unity indicating an in-medium effect. The left panel of Fig. 3 shows the R_{AA} of ϕ in 0-5% centrality class which is measured up to p_{T} = 21 GeV/c. For the R_{AA}, the reference spectrum is measured in pp collisions at $\sqrt{s}$ = 2.76 TeV. At high-p_{T}, all hadron species are suppressed in the same way and therefore no flavour dependence of parton energy loss is observed. The right panel of Fig. 3 shows the nuclear modification factor for p-Pb, R_{pPb}, which is used to quantify initial nuclear matter effects. The reference spectrum for p–Pb at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV has been obtained by interpolation of the measured cross sections in pp collisions at $\sqrt{s}$ = 2.76 and 7 TeV by following the same approach as described in [7]. The R_{pPb} for pion is consistent with unity for $p_{\mathrm{T}} > 2.5$ GeV/c, and protons exhibit a moderate enhancement. At the intermediate and high-p_{T} R_{pPb} is consistent with unity for all hadrons.

4. Conclusion

The recent measurements of K^{*0} and ϕ resonance production in ALICE at LHC in pp, p–Pb, Pb–Pb collisions are reported here. The particle ratios of resonances to stable hadrons are measured in different collision systems as a function of system size. The $\mathrm{K}^{*0}/\mathrm{K}^-$ ratio shows a decrease as system size increases, suggesting that the K^{*0} decay daughters undergo re-scattering in central Pb–Pb collisions. ϕ/K^- ratio is constant as a function of system size. This shows that ϕ is not affected by re-scattering because of its long lifetime as compared to the fireball lifetime. Measurement of p_{T}-dependent p/ϕ ratio suggests that particle masses are the dominant factor in determining the shapes of p_T spectra in central Pb–Pb collisions. All particles are suppressed equally and no flavour dependence of parton energy loss is observed at high-p_T in Pb–Pb collisions.

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