Angular and momentum distribution of vector mesons produced in proton-proton and heavy-ion collisions at LHC energies

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Introduction

The spin-orbit coupling causes fine structure in atomic physics and shell structure in nuclear physics, and is a key ingredient in the field of spintronics in materials sciences. In non-central heavy-ion collisions a large initial angular momentum ($O(10^7)$ $\hbar$) is expected to be created perpendicular to the reaction plane (subtended by the beam axis and impact parameter direction). In the presence of a large initial angular momentum produced in heavy-ion collisions, the quarks can be polarized due to the spin-orbital angular momentum interaction of QCD. This leads to the preferential alignment of the intrinsic angular momentum (spin) of vector mesons, formed by hadronization of quarks, along the direction of angular momentum. Spin alignment of vector meson is quantified by measuring the spin density matrix element ρ_{00} which is the probability of finding a vector meson in spin state 0 out of 3 possible spin states. In the absence of spin alignment all 3 spin states (-1, 0, 1) are equally probable which makes $\rho_{00} = 1/3$. The ρ_{00} will deviate from 1/3 in the presence of spin-orbital angular momentum interactions. Experimentally, the ρ_{00} can be measured by studying the angular distribution of the decay daughter of vector meson with respect to the direction of angular momentum [1]. We report the first evidence of significant spin alignment effect for vector mesons (K^{*0} and ϕ) in heavy-ion collisions. The measurements are carried out as a function of transverse momentum (p_{T}) and collision centrality with the ALICE detector using the particles produced at mid-rapidity ($|y| < 0.5$) in Pb–Pb collisions at a center-of-mass energy ($\sqrt{s_{\mathrm{NN}}}$) of 2.76 TeV. The initial angular momentum due to the extended size of the nuclei and the finite impact parameter in non-central heavy-ion collisions is missing in proton-proton collisions. Determination of ρ_{00} for vector mesons produced in pp collisions and for spin zero K^0_S produced in heavy-ion collisions provide a null test for spin alignment of vector mesons measured in the present work.

On the other hand, short lifetimes of hadronic resonances (eg. K^{*0}) compared to other stable hadrons are comparable to the time taken by the dense nuclear matter to evolve to its final state. This can be exploited to investigate the properties of the hadronic phase produced in heavy-ion collisions. K^{*0} yields are expected to be modified due to the interaction of their decay daughters within the hadronic medium. In order to find the possible presence of hadronic phase effect in small collisions system, K^{*0} production as a function of charged particle multiplicity in pp collisions at $\sqrt{s} = 13$ TeV are also presented.

Results and discussion

We have observed for the first time a significant spin alignment effect (3σ level for K^{*0} and 2σ level for ϕ) for vector mesons in heavy-ion collisions [1] . The ρ_{00} values for K^{*0} mesons are found to deviate from 1/3 at low transverse momentum (p_{T}) in mid-central Pb–Pb collisions, whereas at high p_{T} the ρ_{00} values are consistent with 1/3 (see the left panel of Fig. 1). A number of systematic tests such as ρ_{00} measurements for K^0_S (meson with spin zero) in Pb–Pb collisions, ρ_{00} measurements for vector mesons with respect to a random direction and ρ_{00} measurements for

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vector mesons in pp collisions are carried out in order to verify the results. All these control measurements yield $\rho_{00} = 1/3$, indicating no spin alignment which is as per the expectation. The observed p_{T} dependence of ρ_{00} is qualitatively consistent with the expectation from the hadronization of polarized quarks via recombination mechanism in presence of initial angular momentum. At low p_{T}, maximum deviation of ρ_{00} from 1/3 occurs in mid-central collisions whereas in central and peripheral collisions, the measurements are consistent with 1/3 (see the right panel of Fig. 1). The centrality dependence of ρ_{00} is consistent with the impact parameter dependence of initial angular momentum.

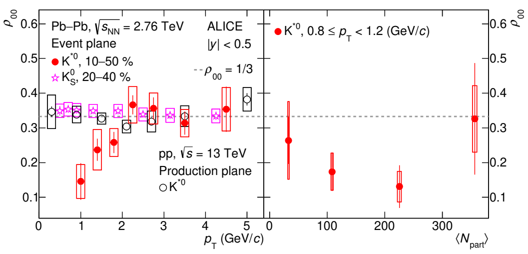

FIG. 1: Left panel: ρ_{00} as a function of p_{T} for K^{*0} in Pb–Pb and pp collisions, and for K^0_S in Pb–Pb collisions. Right panel: Centrality dependence of ρ_{00} for K^{*0} mesons in Pb–Pb collisions. Bars represent statistical uncertainties and open boxes represent total systematic uncertainties

Figure 2 shows p_{T} integrated K^{*0}/K and ϕ/K ratio as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ [2]. K^{*0}/K ratio shows a decreasing trend with increasing $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ in all the collision systems. The decrease in K^{*0}/K ratio in central A–A collisions has been attributed to a re-scattering effect of K^{*0} decay daughters inside the hadronic medium. For pp collisions at $\sqrt{s} = 13$ TeV, the K^{*0}/K ratio in the highest multiplicity class is smaller compared to the lowest multiplicity class at a 2.3 σ level (considering only the multiplicity uncorrelated uncertainties). Observed decreasing trend of K^{*0}/K ratio with increasing $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ indicates a possible presence of hadronic re-scattering in small collision system. The K^{*0}/K ratio in pp collisions at $\sqrt{s} = 13$ TeV is well described by EPOS–LHC model which includes hadronic re-scattering. The ϕ/K ratio in all collision systems is fairly constant as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$. Due to large lifetime (10 times more than K^{*0}) of the ϕ meson, it decays outside the hadronic medium. Hence, decay daughters of ϕ meson do not re-scatter inside the hadronic phase.

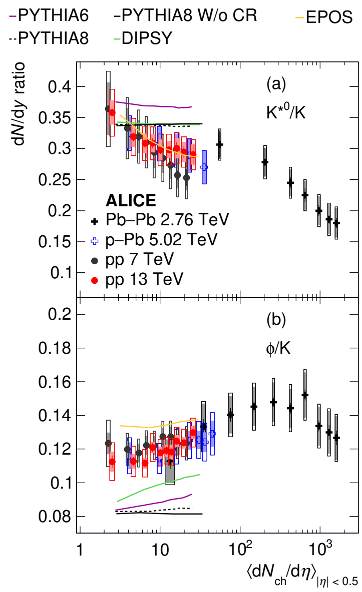

FIG. 2: The K^{*0}/K (panel (a)) and ϕ/K (panel (b)) ratio as a function of $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$ in pp, p-Pb and Pb–Pb collisions. Bars represent statistical uncertainties, open boxes represent total systematic uncertainties, and shaded boxes show the systematic uncertainties that are uncorrelated between multiplicity classes.

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References

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