Spin alignment measurements of vector mesons with ALICE at the LHC

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Introduction

In non-central heavy-ion collisions a large initial angular momentum is expected to be created. A theoretical study predicts the magnitude of the angular momentum to be $\sim 10^5 \hbar$ [1]. In presence of large initial angular momentum, vector mesons (spin = 1) can be polarized due to the spin-orbital interaction of quantum chromodynamics. Polarization/spin alignment measurements of vector meson provide a unique opportunity to probe this initial condition in heavy-ion collisions. Spin alignments can be studied by measuring the angular distributions of the decay daughters of vector mesons with respect to the quantization axis. The quantization axis can be perpendicular to the production plane, defined by the momentum of the vector meson and the beam axis or it can be perpendicular to the reaction plane, subtended by the impact parameter and the beam axis. In the experiment the event plane is used as a proxy of the reaction plane (as the impact parameter direction is not directly measured) and the results are further corrected for the event plane resolution. The angular distribution is expressed as [2],

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto [1 - \rho_{00} + \cos^2\theta^*(3\rho_{00} - 1)]. \quad (1)$$

where θ^* is the angle made by the decay daughter of vector meson with the quantization axis in the rest frame of the vector meson. N_0 is the normalization constant. ρ_{00} is the second diagonal element of the 3×3 hermitian spin density matrix. ρ_{00} corresponds to the probability of finding a vector meson in spin state 0, where vector mesons can occupy 3 spin states –1, 0 and 1. In absence of spin alignment all spin states are equally probable which makes $\rho_{00} = 1/3$ and leads to a flat angular distribution. Deviation of ρ_{00} from 1/3 would lead to a non-uniform angular distribution which is the experimental evidence of the presence of large initial angular momentum, followed by the spin alignment of vector mesons.

We present the recent ALICE measurements of transverse momentum (p_{T}) and centrality dependence of ρ_{00} for K^{*0} and ϕ vector mesons in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV. Measurements are also compared with the results from pp collisions where we do not expect the presence of initial angular momentum and with the spin zero hadron $\mathrm{K}^0_{\mathrm{S}}$ in Pb–Pb collisions as a null test.

Analysis details

This analysis is carried out by analyzing 14 million and 43 million minimum bias Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV and pp collisions at $\sqrt{s} = 13$ TeV, respectively. The measurements are performed at midrapidity ($|y| < 0.5$). Details about the ALICE detector, event selection, trigger logic, track reconstruction, centrality determination and 2nd order event plane estimation using the V0 detectors are discussed in [3, 4]. The K^{*0} and ϕ vector mesons are reconstructed from the invariant mass distribution of oppositely charged Kπ and KK pairs, respectively as discussed in [4, 5]. Whereas, the $\mathrm{K}^0_{\mathrm{S}}$ are reconstructed from the invariant mass distribution of oppositely charged $\pi\pi$ pairs, where the $\pi\pi$ pairs are selected by using V0 decay topology [6]. Charged π and K mesons are identified by using two particle identification techniques: the specific energy loss measured in the Time Pro-

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jection Chamber (TPC) and the velocity measured by the Time-Of-Flight (TOF) detector. The K^{*0}, ϕ and K^0_S signals are extracted for various p_T and $\cos\theta^*$ bins in different centrality classes and corrected for detector acceptance $\times$ efficiency to get the corrected yields. The efficiency and acceptance corrected $\cos\theta^*$ distributions [5] are fitted with Eq.1 to extract ρ_{00} values for each studied p_T interval in the different centrality classes.

Results

The extracted ρ_{00} values for K^{*0} as a function of p_T in 10–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV are shown in Fig. 1. The results are compared with the measurements from pp collisions at $\sqrt{s}$ = 13 TeV and with K^0_S measurements in 20–40% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The extracted ρ_{00} values for K^{*0} in pp collisions and for K^0_S in Pb–Pb collisions are consistent with 1/3 through out the whole measured p_T intervals. Whereas, the ρ_{00} values for K^{*0} in Pb–Pb collisions show a deviation from 1/3 at $p_T < 2$ GeV/c. Figure 2 shows ρ_{00} vs. $\langle N_{part}\rangle$ for K^{*0} and ϕ mesons in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The ρ_{00} values for vector mesons in Pb–Pb collisions show a clear centrality dependence. Maximum deviation from 1/3 occurs at mid-central collisions. In peripheral and central collisions the measurements are consistent with 1/3 within uncertainty. The centrality dependence of the extracted ρ_{00} values are similar to the centrality dependence of the angular momentum [1].

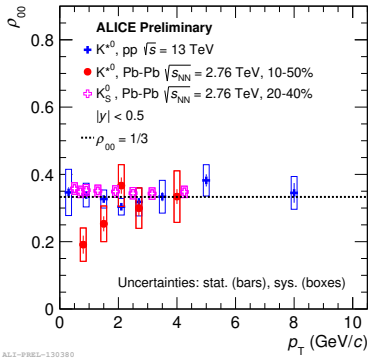

FIG. 1: (Color online) ρ_{00} vs. p_T for K^{*0} in 10–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV, along with the results for K^{*0} in pp collisions at $\sqrt{s}$ = 13 TeV and for K^0_S in 20–40% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

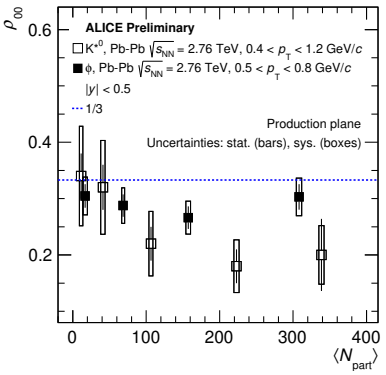

FIG. 2: (Color online) ρ_{00} vs. $\langle N_{part}\rangle$ for K^{*0} and ϕ mesons in 10–50% Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

Summary

A first observation of the spin alignment of vector mesons in high energy heavy-ion collisions is presented. The extracted ρ_{00} values for vector mesons in heavy-ion collisions deviate from 1/3 at $p_T < 2$ GeV/c. The deviation from 1/3 is largest at mid-central collisions which is expected from the presence of a large initial angular momentum at mid-central collisions.

References

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