Measurements of spin alignment of vector mesons and global polarization of hyperons with ALICE at the LHC

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Abstract. We present the measurements related to global polarization of Λ hyperons and spin alignment of K^{*0} vector mesons at mid-rapidity for Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV using the ALICE detector at the LHC. The global polarization measurements are carried out with respect to the first order event plane while the spin alignment measurements are carried out with respect to the production plane. No global polarization signal for Λ is observed for 5-15% and 15-50% central Pb-Pb collisions. The spin density matrix element ρ_{00} is found to have values slightly below 1/3 at low transverse momentum ($p_{\rm T}$) for K^{*0} mesons, while it is consistent with 1/3 (no spin alignment) at higher $p_{\rm T}$. No spin alignment is observed for K^{*0} in pp collisions at $\sqrt{s}$ = 13 TeV and for the spin zero hadron K^0_S in 20-40% Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV.

1 Introduction

Large magnetic field [1] and large angular momentum [2] are expected to be present in the initial stages of high energy heavy-ion collisions. One of the physics interests of the heavy-ion program using the ALICE detector at the LHC is to look for signatures of these effects. This can be achieved by studying the angular distributions of the decay daughters of hyperons and vector mesons [3–5]. The angular distributions are measured with respect to a quantization axis, which can either be perpendicular to the production plane of the hadron (for the spin alignment measurement), or normal to the reaction plane of the system (for the global polarization measurement). The production plane is defined by the momentum of the hadron under study and the beam direction, whereas the reaction plane is defined by the impact parameter and beam direction. The angle denoted as θ^* is that made by one of the decay daughters of the hadron in the rest frame of the hadron with respect to the quantization axis. In general, the angular distribution for vector mesons is expressed as [6],

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

while that for hyperons as [3],

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*} \propto [1+\alpha_{\rm H} P_{\rm H}\cos\theta^*]. \tag{2}$$

ρ_{00} is the zeroth element of the spin density matrix, $\alpha_{\rm H}$ is the decay parameter and $P_{\rm H}$ is the polarization. If initial conditions or the final hadronization process cause polarization effects in heavy-ion

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collisions, then the angular distributions as defined in Eq.1 and Eq.2 would become non uniform. This would lead to ρ_{00} values being different from 1/3 and/or non-zero values for P_{H}.

In this work we present the first results at LHC energies related to the spin alignment of K^{*0} vector mesons through the measurement of ρ_{00} in pp and Pb-Pb collisions with respect to the production plane. In addition, we report on the global polarization of Λ hyperons through measurement of P_{H} in Pb-Pb collisions with respect to the event plane using the ALICE detector [7].

2 Global polarization of Λ hyperons

The global polarization studies of Λ hyperons are carried out using 49 million minimum bias Pb-Pb events at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. The analysis is performed at mid-rapidity ($-0.5 < y < 0.5$) for 5-15% and 15-50% central collisions. The trigger and centrality selection use the V0 detectors [7]. Flow based techniques are used as discussed in [4, 8]. The information from the Time Projection Chamber (TPC) is used to reconstruct the Λ hyperons from their pπ decay channel. The measurements are done using the first order event plane reconstructed using the zero degree calorimeter [8]. The p_{T} integrated values of P_{H} for Λ hyperons in $-0.5 < y < 0.5$ are measured to be $P_{\mathrm{H}}(\Lambda) = -0.01 \pm 0.13$ (stat) $\pm$ 0.04 (syst) and $P_{\mathrm{H}}(\Lambda) = -0.08 \pm 0.10$ (stat) $\pm$ 0.04 (syst) for 5-15% and 15-50% central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV, respectively [8]. The corresponding values for $\bar{\Lambda}$ are $P_{\mathrm{H}}(\bar{\Lambda}) = -0.09 \pm 0.13$ (stat) $\pm$ 0.08 (syst) for 5-15% and $P_{\mathrm{H}}(\bar{\Lambda}) = 0.05 \pm 0.10$ (stat) $\pm$ 0.03 (syst) for 15-50% central Pb–Pb collisions [8]. The P_{H} values are consistent with zero.

3 Spin alignment of K^{*0} vector mesons

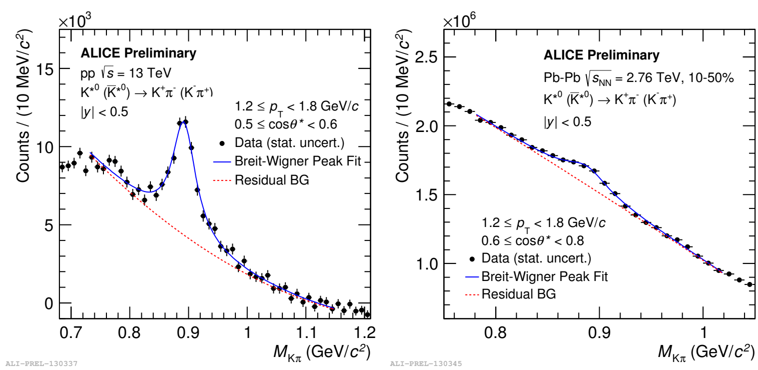

Figure 1. (Color online) Left Panel: Kaon-Pion invariant mass ($M_{\mathrm{K}\pi}$) distribution at mid-rapidity after mixed background subtraction in minimum bias pp collisions at $\sqrt{s}$ = 13 TeV. The data are fitted with a Breit-Wigner function and a 2^{nd} order polynomial function in $M_{\mathrm{K}\pi}$ reflecting the residual background. Right Panel: Same as left panel but for 10-50% central Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV.

The spin alignment studies for the spin one meson K^{*0} are carried out using 43 million minimum bias events in pp collisions at $\sqrt{s}$ = 13 TeV and 14 million minimum bias events in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV. The K^{*0} analysis in Pb–Pb collisions uses the data taken in year 2010 whereas the global polarization studies of Λ hyperons use both the data sets taken in 2010 and 2011. The measurements are performed at mid-rapidity for both pp and Pb–Pb collisions. Results for 10-50%

collision centrality in the Pb–Pb system are presented here. In order to study the null hypothesis, a similar analysis for 20-40% collision centrality using the spin zero meson K^0_S is also carried out. The K^{*0} are reconstructed via the decay into charged K and π while the K^0_S is reconstructed via its decay into $\pi\pi$. The ALICE TPC and TOF are used for identifying the decay products of the above hadrons and the signals are extracted via the invariant mass technique [9, 10]. The background, dominantly coming from combinatorics, is removed by constructing the invariant mass distributions using mixed event techniques [9, 10]. The mixed event background subtracted invariant mass $M_{K\pi}$ distributions for pp and Pb–Pb collisions are shown in Fig. 1. The results are shown for a particular p_T and $\cos\theta^*$ bin as a representative case, but the same procedure is followed for each p_T and $\cos\theta^*$ bin of the analysis. The distributions are then fitted with a Breit-Wigner function for the signal and 2^{nd} order polynomial for the residual background to extract the yields, which are then corrected for the corresponding reconstruction efficiency and acceptance in each $\cos\theta^*$ and p_T bin using Monte Carlo simulations of the ALICE detector and response [9, 10]. The efficiency and acceptance corrected $dN/d\cos\theta^*$ distributions at mid-rapidity for $1.2 \leq p_T < 1.8$ GeV/c in minimum bias pp collisions and for $0.4 \leq p_T < 1.2$ GeV/c in 10-50% central Pb-Pb collisions are shown in Fig. 2. These distributions are fitted with the functional form shown in Eq. 1 to extract the ρ_{00} values for each p_T bin. Figure 3

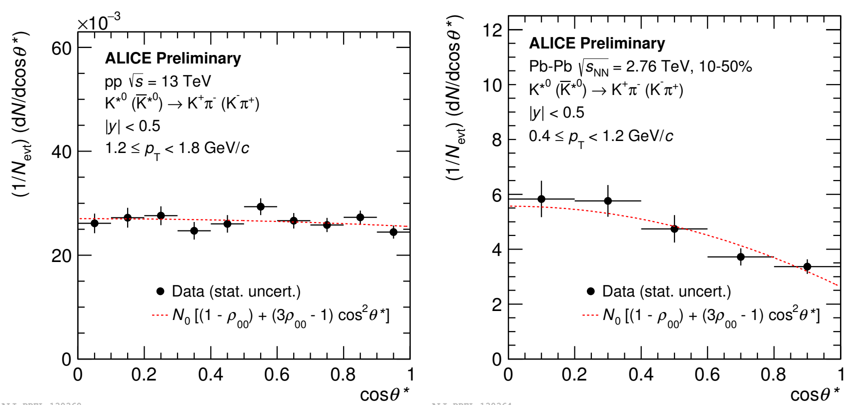

Figure 2. (Color online) Left Panel: $dN/d\cos\theta^*$ versus $\cos\theta^*$ at mid-rapidity for minimum bias pp collisions at $\sqrt{s}$ = 13 TeV. Right Panel: Same but for 10-50% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The error bars shown are statistical only. The angular distributions are obtained with respect to production plane.

shows the ρ_{00} values as a function of p_T for K^{*0} and K^0_S. The K^{*0} results for pp collisions at $\sqrt{s}$ = 13 TeV are consistent with no spin alignment ($\rho_{00} \sim 1/3$). The ρ_{00} values for K^{*0} at $0.4 \leq p_T < 1.2$ GeV/c is about 2.5 standard deviations (σ) lower than 1/3, about 1.4σ lower than 1/3 for the p_T bin 1.2 - 1.8 GeV/c and consistent with 1/3 for higher p_T values in 10-50% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The σ is calculated by adding the statistical and systematic uncertainties on ρ_{00} in quadrature. The ρ_{00} values are consistent with 1/3 for the whole p_T range studied for K^0_S in 20-40% central Pb–Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. The sources of systematic uncertainties on ρ_{00} include: reconstruction efficiency and acceptance, track selection conditions, particle identification procedure, signal extraction procedure, and material budget estimates [9, 10].

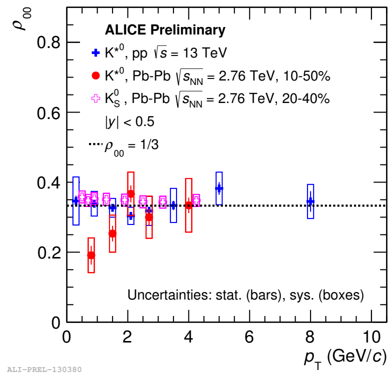

Figure 3. (Color online) ρ_{00} versus $p_{\rm T}$ extracted from the $\cos\theta^{*}$ distributions at mid-rapidity for K^{*0} vector meson in minimum bias pp collisions at $\sqrt{s}$ = 13 TeV and 10-50% central Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. Also shown are the corresponding results for spin zero K^0_S meson for 20-40% Pb–Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. The vertical lines on the data points are statistical errors and the boxes reflect the systematic uncertainties on ρ_{00}.

4 Summary and outlook

We have presented results related to the global polarization of Λ hyperons measured with respect to the reaction plane and those related to spin alignment of K^{*0} with respect to the production plane in Pb-Pb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. No polarization effect was observed for the Λ produced at mid-rapidity for 5-15% and 15-50% central collisions. The spin density matrix element ρ_{00} extracted from the angular distributions of the decay daughter of K^{*0} at mid-rapidity in 10-50% central Pb-Pb collisions was found to be slightly lower than 1/3 for $p_{\rm T}$ below 1.8 GeV/c. The ρ_{00} values are consistent with 1/3, namely indicating no spin alignment, for high $p_{\rm T}$ K^{*0} in Pb-Pb collisions, for the full $p_{\rm T}$ range studied in pp collisions and for spin zero K^0_S produced in 20-40% central Pb-Pb collisions.

The analysis of the centrality dependence of spin alignment for vector mesons with respect to both production and reaction planes is ongoing. Results with increased statistical precision are expected for both global polarization and spin alignment studies with the Pb-Pb data set at $\sqrt{s_{\rm NN}}$ = 5.02 TeV. This will help in clarifying the significance of the observed effects.

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