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

Bedangadas Mohanty (for the ALICE collaboration)\textsuperscript{1,*}

\textsuperscript{1}National Institute of Science Education and Research, HBNI, Jatni 752050, India

Abstract. We present the measurements related to global polarization of $\Lambda$ 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 $\Lambda$ is observed for 5-15\% and 15-50\% central Pb-Pb collisions. The spin density matrix element $\rho_{00}$ is found to have values slightly below $1/3$ at low transverse momentum ($p_T$) for $K^{*0}$ mesons, while it is consistent with $1/3$ (no spin alignment) at higher $p_T$. 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 \cite{1} and large angular momentum \cite{2} are expected to be created 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 which can be looked into by studying the angular distributions of the decay daughters of hyperons and vector mesons \cite{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, or normal to the reaction plane of the system. 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 $\theta^*$ 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 \cite{6},

$$\frac{dN}{d\cos \theta^*} = N_0[1 - \rho_{00} + \cos^2 \theta^*(3\rho_{00} - 1)],$$

while that for hyperons as \cite{3},

$$\frac{dN}{d\cos \theta^*} = \frac{1}{2}[1 + \alpha_H P_H \cos \theta^*].$$

$N_0$ is a normalization constant, $\rho_{00}$ is the zeroth element of the spin density matrix, $\alpha_H$ is the decay parameter and $P_H$ is the polarization. If initial conditions or the final hadronization process cause

\*e-mail: bedanga@niser.ac.in
polarization effects in heavy-ion collisions, then the angular distributions as defined in Eq.1 and Eq.2 would become non uniform. This would lead to $\rho_{00}$ 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 $\rho_{00}$ in pp and Pb-Pb collisions with respect to the production plane. In addition, we report on the global polarization of $\Lambda$ 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 $\Lambda$ hyperons

The global polarization studies of $\Lambda$ hyperons are carried out using 49 million minimum bias Pb-Pb events at $\sqrt{s_{NN}} = 2.76$ 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 $\Lambda$ hyperons from their p and $\pi$ decay channels. 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 $\Lambda$ hyperons in -0.5 < $y$ < 0.5 are measured to be $P_H(\Lambda) = -0.01 \pm 0.13$ (stat) $\pm 0.04$ (syst) and $P_H(\bar{\Lambda}) = -0.09 \pm 0.13$ (stat) $\pm 0.08$ (syst) for 5-15% and 15-50% central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, respectively [8]. The corresponding values for $\bar{\Lambda}$ are $P_H(\bar{\Lambda}) = 0.05 \pm 0.10$ (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

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 $\sqrt{s_{NN}} = 2.76$ TeV. The $K^{*0}$ analysis in Pb–Pb collisions uses the data taken in year the 2010 whereas the global polarization studies of $\Lambda$ hyperons use both the data set taken in the year 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 $K_0^0$ is also carried out. The $K_0^0$ are reconstructed via the decay into charged K and π while the $K_S^0$ 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 $M_{\pi\pi}$ 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 2nd 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 $\rho_{00}$ values for each $p_T$ bin. Figure 3 shows the $\rho_{00}$ values as a function of $p_T$ for $K^{*0}$ and $K_S^0$. The $K^{*0}$ results for pp collisions at $\sqrt{s} = 13$ TeV are consistent with no spin alignment ($\rho_{00} \sim 1/3$). The $\rho_{00}$ values for $K^{0}$ at $0.4 \leq p_T < 1.2$ GeV/c is about 2.5 standard deviations ($\sigma$) lower than 1/3, about $1.4\sigma$ 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 $\sigma$ is calculated by adding the statistical and systematic uncertainties on $\rho_{00}$ in quadrature. The $\rho_{00}$ values are consistent with 1/3 for the whole $p_T$ range studied for $K_S^0$ in 20-40% central Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The sources of systematic uncertainties on $\rho_{00}$ include: reconstruction efficiency and acceptance, track selection conditions, particle identification procedure, signal extraction procedure, and material budget estimates \[9, 10\].

![Figure 2](image-url)

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.
Figure 3. (Color online) $\rho_{00}$ versus $p_T$ 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 $\sqrt{s_{NN}} = 2.76$ TeV. Also shown are the corresponding results for $K_0^0$ spin zero meson for 20-40% Pb–Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. The vertical lines on the data points are statistical errors and the boxes reflect the systematic uncertainties on $\rho_{00}$.

4 Summary and outlook

We have presented results related to the global polarization of $\Lambda$ 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 $\sqrt{s_{NN}} = 2.76$ TeV. No polarization effect was observed for the $\Lambda$ produced at mid-rapidity for 5-15% and 15-50% central collisions. The spin density matrix element $\rho_{00}$ 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 $p_T$ below 1.8 GeV/c. The $\rho_{00}$ values are consistent with 1/3, namely indicating no spin alignment, for high $p_T$ $K^{*0}$ in Pb-Pb collisions, for the full $p_T$ 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 $\sqrt{s_{NN}} = 5.02$ TeV. This will help in clarifying the significance of the observed effects.

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