Quarkonium polarization in pp and Pb–Pb collisions

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Introduction

Polarization is the degree of a particle spin alignment with respect to a given direction. In order to obtain useful information about the quark-gluon plasma (QGP) produced in Pb–Pb collisions and the initial stages of the collision, the study of quarkonium production and polarization is extremely important. In pp collisions, the study of quarkonium polarization (and production cross section) is essential to constrain their production mechanism since various theoretical models provide different predictions for the polarization observables [1]. On the other hand, in heavy-ion collisions, quarkonium polarization can get affected by the magnetic field generated by the fast motion, in opposite direction, of the two colliding charged ions in non-central collisions. In addition, quarkonium polarization may be altered by the presence of the rotating fluid with a large vorticity. Quarkonium polarization can also be used to probe the regeneration effect in the QGP in Helicity (HE) and Collins-Soper (CS) frames by comparing polarization measured in Pb-Pb and pp collisions. For the HE frame, the quarkonium momentum direction in the center-of-mass of the collision is chosen as the quantization axis. On the other hand, for the CS frame, the quantization axis is the bisector of the angle formed by the two colliding beams in the quarkonium rest frame.

The quarkonium polarization can be measured by analyzing the angular distribution of their dilepton decay products, which obey the following functional shape,

$$W(\cos\vartheta,\varphi) \propto \frac{1}{(3+\lambda_\vartheta)}(1+\lambda_\vartheta\cos^2\vartheta + \lambda_\varphi\sin^2\vartheta\cos 2\varphi + \lambda_{\vartheta\varphi}\sin 2\vartheta\cos\varphi) \quad (1)$$

where ϑ and φ are the polar and azimuthal angles formed by the direction of the daughter particle and the quantization axis [2]. λ_ϑ, λ_φ and $\lambda_{\vartheta\varphi}$ are the polarization parameters. If all of them are zero, the angular distribution is isotropic. If λ_ϑ is equal to $+1$ or -1 (with $\lambda_\varphi, \lambda_{\vartheta\varphi} = 0$), the anisotropy of the distribution is maximum corresponding to the scenario of transverse or longitudinal polarization, respectively. The ALICE detector has a dedicated muon spectrometer to study the dimuon decay daughters from quarkonia at forward rapidity ($-2.5 < y < -4.0$), while the quarkonium measurements in the dielectron channel are performed in the central barrel ($|y| < 0.9$) [3].

Υ(1S) polarization in pp collisions

Recently, the ALICE Collaboration [3] has performed the first measurement of the Υ(1S) polarization in pp collisions at $\sqrt{s} = 13$ TeV. The analysis was performed using both HE and CS reference frames. As shown in Fig. 1, all the polarization parameters are compatible with zero within uncertainties. There is no clear trend as a function of the transverse momentum, p_{T}. The ALICE results are also compatible with the ones performed by the LHCb Collaboration in pp collisions at $\sqrt{s} = 8$ TeV [4]. No sizeable polarization is measured for the Υ(1S) regardless of the center-of-mass energy. In addition, these measurements are qualitatively in agreement with the theoretical expectations from NLO NRQCD [5].

J/ψ polarization in Pb–Pb collisions

ALICE has also measured the J/ψ polarization in Pb–Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV in the HE and CS reference frames [6]. Recently, a measurement has been carried out considering a reference frame where the quantization axis corresponds to the direction or-

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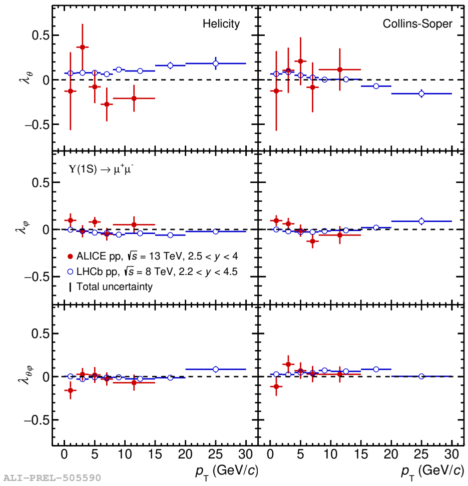

FIG. 1: Polarization parameters for $\Upsilon(1S)$ as a function of transverse momentum for HE and CS frames in pp collisions at $\sqrt{s}$ = 13 TeV. Comparison to LHCb results at $\sqrt{s}$ = 8 TeV are also shown [4].

thogonal to the event plane, the plane identified by the impact parameter of the collision and the beam axis [7]. Such analysis allows one to investigate potential effects related to the magnetic field and the large angular momentum produced in the collision. The results in Fig. 2 show a maximum deviation of 3.9σ with respect to $\lambda_\vartheta = 0$ in semi-central ($30 - 50\%$) collisions for $2 < p_T < 4$ GeV/c. This behavior is qualitatively in agreement with the one observed for light vector mesons [8]. However, the absence of theoretical predictions prevents us to draw a definitive conclusion on the mechanism responsible for the observed non-zero quarkonium polarization.

Summary

The ALICE Collaboration has measured $\Upsilon(1S)$ polarization in pp collisions at $\sqrt{s}$ = 13 TeV. The results are in agreement with the ones from the LHCb Collaboration. Polarization studies of J/ψ and $\psi(2S)$ are ongoing in pp collisions at $\sqrt{s}$ = 13 TeV. Moreover, ALICE has measured for the first time the J/ψ

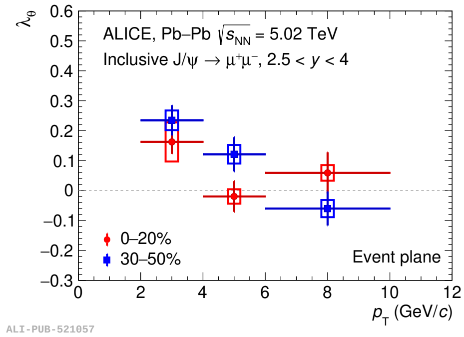

FIG. 2: λ_ϑ polarization parameter for J/ψ as a function of transverse momentum in the event plane frame, in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV [7].

polarization in Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV in the event plane frame. A finite polarization is observed in semi-central collisions at low transverse momentum.

References

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