ψ(2S) polarization in pp collisions at $\sqrt{s}$ = 13 TeV with ALICE

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Introduction

Polarization refers to the degree of alignment of a particle's spin with respect to a specified direction. Investigating quarkonium production and polarization is crucial for extracting valuable insights about the quark-gluon plasma (QGP) produced during Pb–Pb collisions in the early stages of the collision process. In proton-proton (pp) collisions, studying quarkonium polarization, along with the production cross section, is vital for constraining their production mechanisms, as different theoretical models offer varying predictions for polarization observables. However, in heavy-ion collisions, quarkonium polarization may be influenced by the strong magnetic field generated by the rapid motion of the two colliding charged ions in non-central collisions. Additionally, polarization might be modified by the rotating fluid with significant vorticity. Quarkonium polarization can also serve as a probe for regeneration effects in the QGP by comparing the polarization measured in Pb–Pb and pp collisions in both the Helicity (HE) and Collins-Soper (CS) frames. In the HE frame, the quantization axis is the quarkonium momentum direction in the collision's center-of-mass system. In contrast, in the CS frame, the quantization axis is the bisector of the angle formed by the two colliding beams in the quarkonium rest frame. The polarization of the ψ(2S) can be measured through the study of the angular distribution of the leptons produced in the $\psi(2S) \rightarrow \mu^+ \mu^-$ decay [1]:

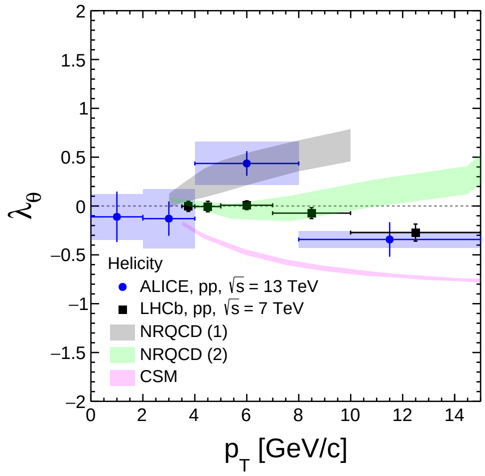

FIG. 1: λ_θ as a function of transverse momentum in the helicity frame for pp collisions at $\sqrt{s_{\rm NN}}$ = 13 TeV in ALICE [2].

$$W(cos\theta, \phi) \propto \frac{1}{3+\lambda_\theta}(1 + \lambda_\theta\ cos^2\theta +$$

$$\lambda_\phi\ sin^2\theta\ cos2\phi + \lambda_{\theta\phi}\ sin2\theta\ cos\phi) \qquad (1)$$

where λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ are the ψ(2S) polarization parameters. The combinations of these parameters can give us information about the polarization of the particle; the values of (λ_θ, λ_ϕ, $\lambda_{\theta\phi}$) = (0,0,0) means there is no polarization, (-1,0,0) suggests pure longitudinal polarization and (+1,0,0) suggests pure transverse polarization. Alternatively, one can also take a one-dimensional approach and fit the angular distributions integrated over $cos\theta$ and ϕ.

The muon spectrometer is used for the quarkonia detection in this analysis, which is

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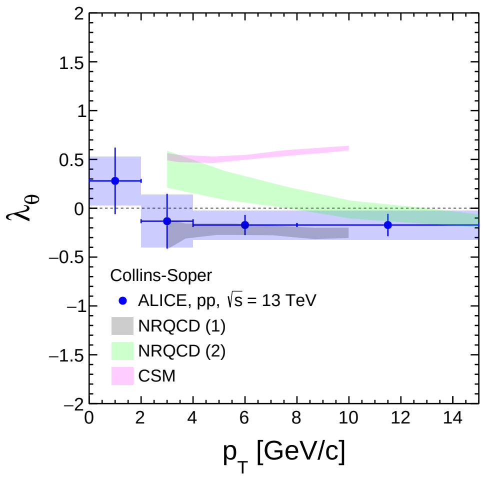

FIG. 2: λ_θ as a function of transverse momentum in the Collin-Soper frame for pp collisions at $\sqrt{s_{\mathrm{NN}}}$ = 13 TeV in ALICE [2].

situated in the forward part od the ALICE detector (4¡ ¡2.5). For this analysis, the dataset considered corresponds to the data samples collected from 2016 to 2018 for *pp* collisions at $\sqrt{s} = 13$ TeV. The standard event selection and track selection cuts are used, which can be seen in Ref. [2].

Results and discussion

We have fitted the corrected $\psi(2S)$ angular distributions and obtained the polarization parameters. The fits are converged and show reasonable χ^2/ndf values. The extracted polarization parameters are then studied as functions of transverse momentum. We have done the same analysis for different combinations of signal and background functions. For the signal, we have taken the double crystal ball function (DCB) and NA60 function, and for the background, we have taken the variable width gaussian (VWG) and the double exponential function. The acceptance times efficiency is also estimated by fitting the MC simulated data with both DCB and NA60 functions for their respective cases. The estimation from different signal and background functions will contribute to the systematic uncertainties of the polarization parameters.

In Fig. 1, we have compared our estimated λ_θ in the HE frame with that of the LHCb results for pp collisions at $\sqrt{s} = 7$ TeV. The bars represent the statistical uncertainties, whereas the shaded boxes represent the systematic uncertainties. We have also shown the estimations from various theoretical models. A good agreement can be observed between our results and the LHCb one, except for the 4.0 $\leq p_{\mathrm{T}} \geq 6.0$ GeV/c, where we get a substantial polarization. In addition, no theoretical estimations can explain our results for the whole p_{T} range. The prediction from the color singlet model [3] shows a longitudinal polarization, whereas the NRQCD 1 [3] and NRQCD 2 [4] predict slightly transverse polarization. This means one should study with better statistics and a higher center of mass energies, which can give a conclusive result. Moreover, given this, better theoretical studies have to be done which can explain both the production and polarization of charmonia in high-energy hadronic collisions.

Similarly, in fig. 2, we have shown our result for λ_θ in the CS frame and observed that all the polarization parameters are zero within uncertainties. Here also, the theoretical predictions don't match with our obtained result.

Summary

In summary, we have studied the polarization of $\psi(2S)$ in pp collisions at $\sqrt{s} = 13$ TeV, which is the first study of $\psi(2S)$ polarization within the ALICE collaboration. We have estimated the polarization parameters; λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ and studied them as functions of p_{T} in both helicity and Collin-Soper frames. We observe almost zero polarization within the uncertainties in both frames. However, the helicity frame observes a 1.58σ deviation from zero in $4.0 - 8.0$ p_{T} bin. Our results are almost in agreement with the LHCb results in pp collisions at $\sqrt{s} = 7$ TeV. In addition, no theoretical prediction which has been discussed matches with the experimental results for all p_{T} ranges.

References

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