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Measurement of quarkonium polarization in Pb–Pb collisions at the LHC with ALICE

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Polarization measurements represent an important tool for understanding the particle production mechanisms occurring in proton-proton collisions. In particular, for quarkonium states, the very small polarization measured at the LHC represents a long-lasting challenge for theoretical models. When considering heavy-ion collisions, particle polarization could also be used to investigate the characteristics of the hot and dense medium (Quark–Gluon Plasma, QGP) created at LHC energies. Recently, it has been hypothesized that quarkonium states could be polarized by the strong magnetic field generated in the early phase of the evolution of the system. In ALICE, the quarkonium polarization is extracted by measuring the anisotropies in the angular distribution of the muons coming from the quarkonium state decay. In this contribution, results on J/ψ and $\Upsilon(1S)$ polarization in Pb–Pb collisions at a center of mass energy per nucleon pair of $\sqrt{s_{NN}}$ =5.02 TeV will be presented [3]. The p_T-differential measurement was done at forward rapidity ($2.5 < y < 4$) and the results will be shown in two different reference frames. The results will be also compared with previous measurements from pp collisions. Finally, the status of the analysis dedicated to measure the J/ψ polarization as a function of the collision centrality will be discussed.

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1. Introduction

The study of quarkonium polarization represents an excellent tool to test the current knowledge of quantum chromodynamics (QCD) [1]. This observable measures the degree to which the spin of a particle is aligned with respect to a chosen direction, defined from now on as quantization or polarization axis. In a two-body decay this can be measured through the study of the anisotropies in the angular distributions of the decay products. The latter can be expressed as a two-dimensional distribution

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

where θ and ϕ are the polar and azimuthal angles, formed by the direction of the positive lepton and the quantization axis [1]. This distribution, which is the same for different choices of the quantization axis, depends on the polarization parameters λ_θ,λ_ϕ and $\lambda_{\theta\phi}$. If all of them are null the angular distribution is isotropic. If λ_θ is equal to +1 or -1 ($\lambda_\phi, \lambda_{\theta\phi} = 0$), it corresponds to the scenario of transverse or longitudinal polarization respectively. The interest in studying quarkonium polarization is related to the understanding of the J/ψ production mechanism, which still represents an open issue in the high energy physics. In proton-proton collisions many measurements were carried out by all the LHC experiments, but in contrast to the predictions of both the NLO NRQCD and NLO Color Singlet model [4], the measured polarization was compatible with zero. On the other hand in nucleus-nucleus collisions, polarization can be used to study QGP properties in an alternative way [2]. The formation of a deconfined, strongly interacting medium impacts the various quarkonium resonances differently, inducing a larger suppression on the less bound excited states (ψ(2S) and χ_C) and modifying their feed-down fractions into the ground state (J/ψ). This effect may lead to a modification of the overall polarization, since the various quarkonium states are expected to be produced with a different polarization. In addition, the J/ψ regeneration via a recombination mechanism of the uncorrelated heavy quark pairs in the plasma [6] may further affect the estimate of the original polarization.

2. Data analysis

The ALICE detector design and performance are described in details in [7] and [8]. The J/ψ and Υ(S) are measured via their decay into a muon pair and for this reason the muon spectrometer plays a crucial role. It is composed of a system of passive absorbers, a dipole magnet, a muon tracker, a passive iron wall and a muon trigger system. In addition, the V0 detector is used for the determination of the collision centrality [9]. Events are selected when there is an opposite sign muon pair, with muons above transverse momentum threshold $p_T > 1$ GeV/c. The angular variables θ and ϕ are evaluated in two different reference frames, the helicity, for which the quantization axis is chosen as the quarkonium momentum direction in the laboratory, and the Collins-Soper [10] where the bisector of the angle formed by the colliding beams in the quarkonium rest frame is selected. The extraction of the polarization parameters is performed in three steps. First of all the J/ψ and Υ(S) raw yields are obtained as a function of the angular variables fitting the dimuon invariant mass distribution with a combination of signal and background functions. This number is corrected with the product of the geometrical acceptance and the reconstruction efficiency which is evaluated via a Monte-Carlo simulation, where J/ψ and $\Upsilon(1S)$ are generated according the p_T and y distributions tuned to the data. Finally the polarization parameters are extracted fitting the corrected angular distributions with Eq. 1. More details on the data analysis procedure can be found in [3].

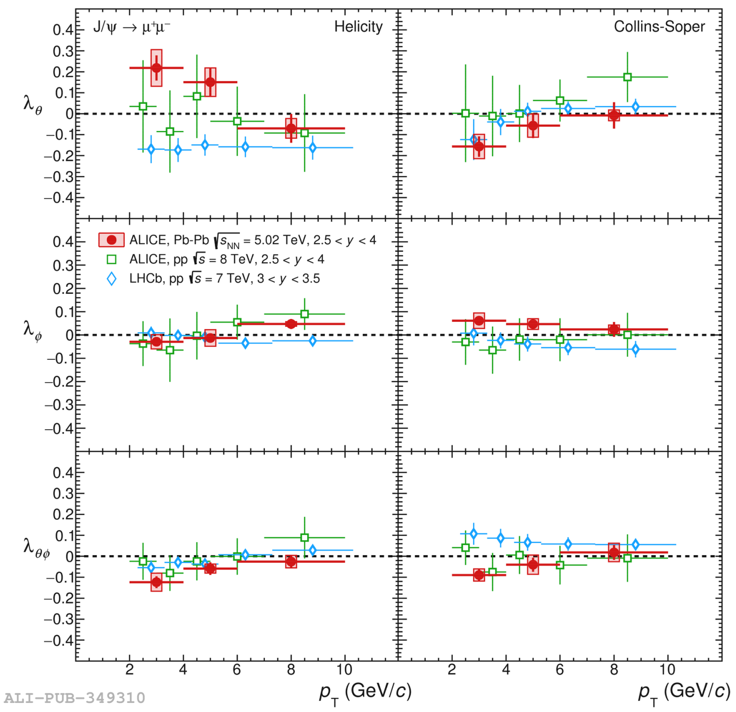

Figure 1: J/ψ polarization parameters as a function of p_T for Pb–Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV. The results are compared with the ALICE inclusive measurement at $\sqrt{s}$ = 8 TeV [11] and the LHCb result for prompt J/ψ at $\sqrt{s}$ = 7 TeV [12] in proton-proton collisions.

3. Results and conclusions

The extraction of the J/ψ and $\Upsilon(1S)$ polarization parameters is performed exploiting the full Run 2 Pb–Pb data sample collected at $\sqrt{s_{NN}}$ = 5.02 TeV in 2015 and 2018. The J/ψ polarization parameters are measured as a function of the transverse momentum in three p_T bins, as shown in Fig. 1. In this case, λ_θ, λ_ϕ and $\lambda_{\theta\phi}$ are found to be all close to zero, with a maximum difference of 2 standard deviations in $2 < p_T < 4$ GeV/c for λ_θ. This effect represents a small hint of transverse and longitudinal polarization in the helicity and Collins-Soper reference frames respectively. This result is compatible within the uncertainties with the ALICE measurement at $\sqrt{s}$ = 8 TeV in pp collisions [11], while interestingly it exhibits a significant difference with respect to the LHCb result obtained at $\sqrt{s}$ = 7 TeV [12] for prompt J/ψ. Moreover, it is possible to perform the analysis of the J/ψ polarization parameters as a function of collision centrality and, as shown in the top panel of Fig. 2, no clear dependence as a function of this observable is observed. The polarization parameters are also extracted for the rarer $\Upsilon(1S)$ (bottom panel of Fig. 2) for $p_T < 15$ GeV/c in a single p_T bin and they are all compatible with zero within the uncertainties.

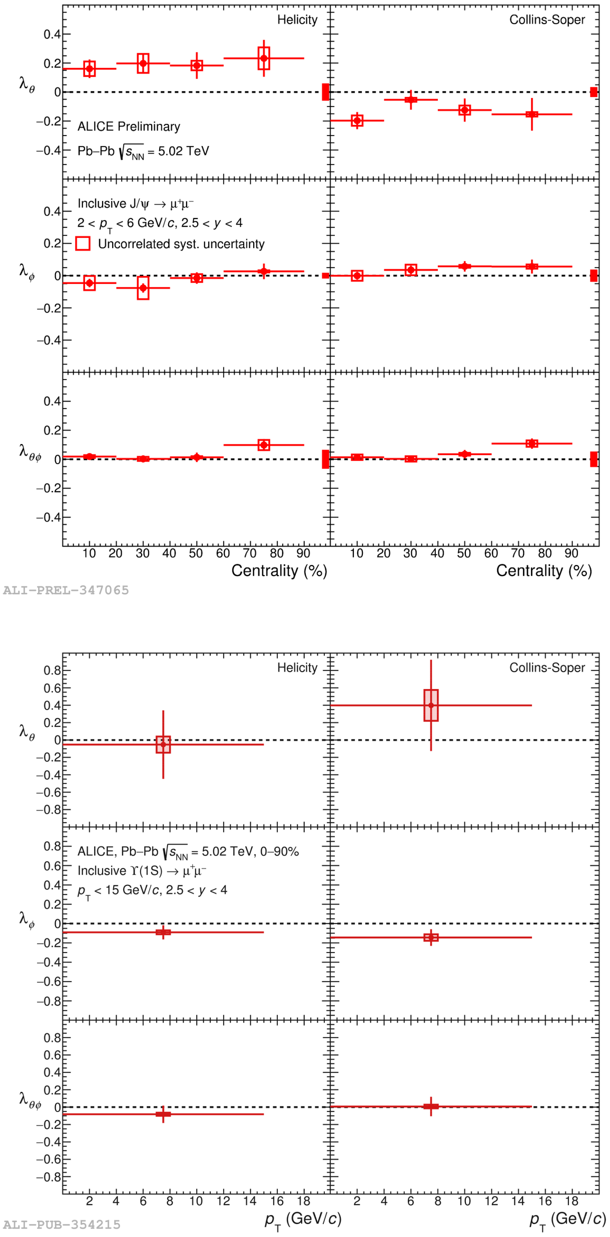

Figure 2: Top panel: J/ψ polarization parameters as a function of centrality for $2 < p_T < 6$ GeV/c. Bottom panel: $\Upsilon(1S)$ polarization parameters as a function of p_T.

In conclusion, this set of results represents a first step towards future studies to connect this observable to the well known mechanisms present in heavy-ion collisions. Moreover, these measurements will benefit the detector upgrades and the increase of luminosity expected in the LHC Run 3, leading to a higher statistical precision and allowing to perform more differential studies.

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PoS(HardProbes2020)095