Hyperon Polarization in Heavy ion Collisions

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Abstract. The STAR collaboration has measured the Λ and anti-Λ polarizations in 200 GeV Au-Au collisions [1]. These results can be understood in terms of a model [2], [3], that we proposed recently, based on the hydrodynamical model, and taking into account the effect of the final-state interactions (that occur in the hadronic phase) between the hyperons and other produced particles. These final interactions are described in terms of chiral effective lagrangians, that consider many hadronic processes. This model describes quite well the antihyperon polarization data obtained in proton-nucleus collisions, and now we extended it to study nucleus-nucleus collisions, with a very good accord. Theoretical results obtained with other models will also be discussed. The perspectives of hyperon and antihyperon polarization at LHC is another subject of interest.

Since the discovery of significant polarization of the Λ particles produced in 100 GeV p-Be collisions by Bunce [4], hyperon polarization has been found to be a very challenging subject, as, at the time it was a totally surprising result. This fact, unexpected both experimentally and theoretically has been confirmed by further experiments, and this puzzle has been complicated when the polarizations of the other hyperons and antihyperons have been measured [5]-[12].

Hyperon polarization may be quite well described by parton-based models [13]-[15], but antihyperon polarization not. In [2], we proposed a model [2] that was able to describe successfully the antihyperon polarization in terms of final-state interactions that occur in the hadronic phase of such collisions, in a mechanism based in the hydrodynamics.

Recently, at RHIC, in 200 GeV Au-Au collisions, the Λ and $\overline{\Lambda}$ polarizations have been measured [1], as functions of the transverse momentum, in the range $0 < p_t < 5$ GeV, and as functions of the pseudorapidity, in the range $-1.5 < \eta < 1.5$. In this region, the final polarization for both particles may be considered consistent with zero. Some models deal with this problem [16]-[18]. Other models [19], [20] propose that some polarization should be produced due to the mechanical processes.

In this work, we show the results obtained in [3], with a model that we used to calculate antihyperon polarization in p-A collisions, now in the study of the Au-Au collisions performed at RHIC. This model is based in the hydrodynamical aspects of such collisions, and depends on the velocity distribution of the fluid formed during the collision. Then, we will use it in order to obtain the average polarization, taking into account the $\pi\Lambda$ and $\pi\overline{\Lambda}$ final interactions.

We will consider that the velocity distribution of such a fluid may be given by the expression

$$u^0 \frac{d\rho}{d^3u} = A \left[e^{-\beta(\alpha-\alpha_0)^2} + e^{-\beta(\alpha+\alpha_0)^2} \right] e^{-\beta_t \xi^2} \quad , \qquad (1)$$

that is written in terms of its longitudinal (α) and transversal (ξ) rapidities. That means that the formed fluid expands in the incident nuclei direction (α), and also in the transverse direction (ξ). We may visualize this fluid geometrically as a hot expanding cylinder. The constants β, β_t and α_0 are parameters that describe the shape of this distribution, and are determined by calculating the distributions of the produced particles, and, comparing them with the RHIC experimental data for the transverse momentum p_t [23] and pseudorapidity (η) distributions [24].

This objective may be achieved, making a convolution of the fluid velocity distribution (1) with the particle distribution inside these fluid elements, that may be considered a Bose distribution as most of the produced particles are pions. We will consider

$$\frac{dN}{d\vec{p}_0} = \frac{N_0}{\exp\left(E_0/T\right) - 1} \tag{2}$$

with the temperature $T \sim m_\pi$, and $\vec{p}_0$ and E_0 are the momentum and energy of the pions inside one fluid element. The observed distributions of particles are given by [21], [22]

$$E\frac{dN}{d\vec{p}} = C\int \left[e^{-\beta(\alpha-\alpha_0)^2} + e^{-\beta(\alpha+\alpha_0)^2}\right] \frac{e^{-\beta_t\xi^2} E_0(\alpha,\xi,\phi)}{\exp\left(E_0(\alpha,\xi,\phi)/T\right) - 1} \times \sinh\xi \ \cosh\xi \ \mathrm{d}\alpha \ \mathrm{d}\xi \ \mathrm{d}\phi \ , \tag{3}$$

where ϕ is the azimuthal angle. Fig. 1 and Fig. 2 show the resulting particle distributions compared with the experimental data.

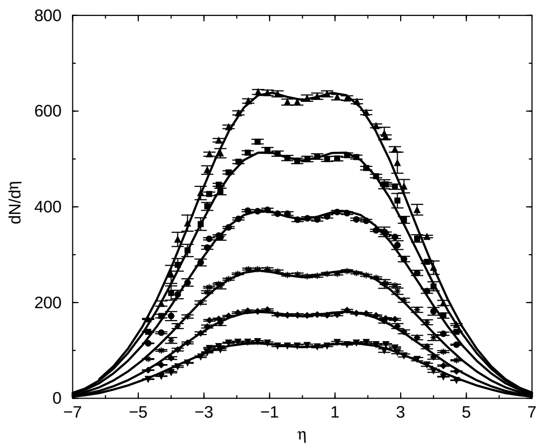

Figure 1. Distributions $dN/d\eta$, for many centralities. From the top, 0-5%, 5-10%, 10-20%, 20-30%, 30-40%, 40-50%. We compare our results (solid lines), with the experimental data from [24] (points).

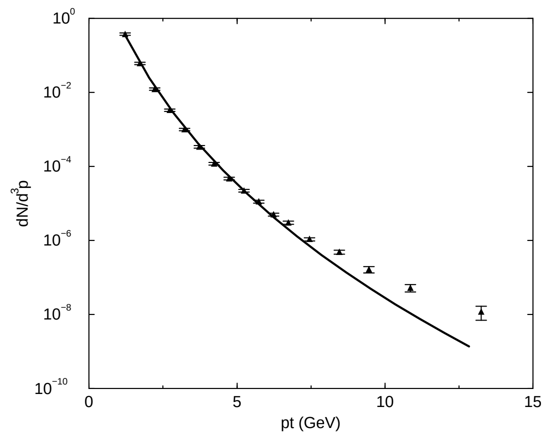

Figure 2. Comparison of the calculated distribution dN/d^3p as function of p_t with the experimental data from [23].

The final-state interactions may be described by effective chiral lagrangians, as was done in [25]-[27], where the resonance $\Sigma^*(1385)$ in the intermediate state is a key element.

With the knowledge of the velocities distribution and of the final interactions, we are able to calculate the average polarization of the produced particles in the same way as in [2]. The average polarization may be calculated by the expression [3], [2]

$$\langle\vec{P}\rangle = \frac{\int\left(\vec{P}' \ d\sigma/dt\right)\mathcal{G} \ d\alpha \ d\xi d\phi \ d\vec{\Lambda}_0' d\vec{\pi}_0'}{\int\left(d\sigma/dt\right)\mathcal{G} \ d\alpha \ d\xi d\phi \ d\vec{\Lambda}_0' d\vec{\pi}_0'} \ . \tag{4}$$

The factor $\mathcal{G}$ that appears in eq. (4) contains the statistical weighs of the production of the particles and the ones relative to the expansion of the fluid, and can be written as

$$\mathcal{G} = \frac{(d\rho/d^3u)\Lambda_0'^2\pi_0'^2}{(\exp{(E'_{\pi_0}/T)}-1)\,(\exp{(E'_0/T)}+1)} \times \delta\left(E'_0 + E'_{\pi_0} - E' - \sqrt{m_\pi^2 + (\vec{\pi}'_0 + \vec{\Lambda}'_0 - \vec{\Lambda}')^2}\right) \quad , \tag{5}$$

where $d\rho/d^3u$, is given by (1).

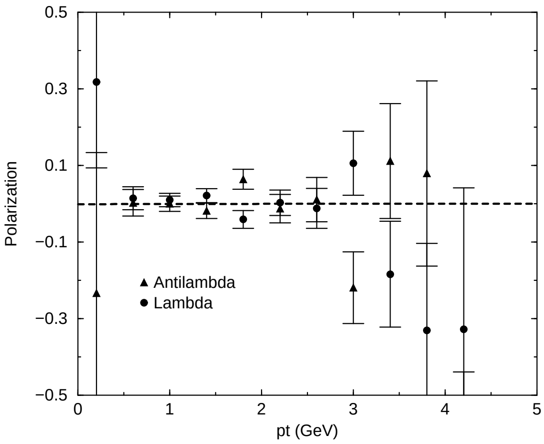

Figure 3. Calculated Λ and $\overline{\Lambda}$ polarizations as functions of the transverse momentum (dashed line) compared with the RHIC data [1].

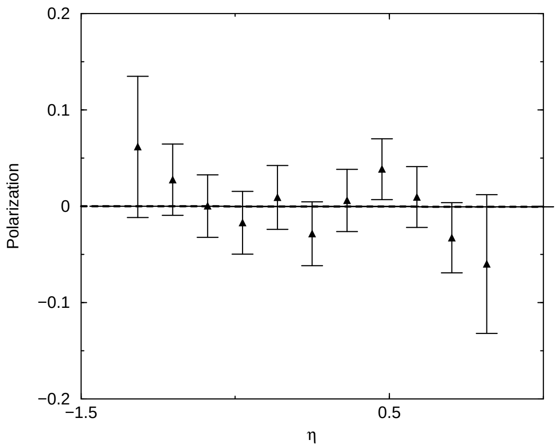

Figure 4. Calculated Λ and $\overline{\Lambda}$ polarizations as functions of η (solid line) compared with the RHIC data [1].

With this procedure we obtained the results shown in Fig. 3 and Fig. 4. As we can see, the resulting polarization is very small (smaller than 1%) for all values of the centrality, and are in good accord with the experimental data for both Λ and $\overline{\Lambda}$.

In view of these results, if the hyperon polarization were to be measured at LHC in heavy ion collisions, we expect that the effect due to the final state interactions will be totally washed out in average, for Λ, $\overline{\Lambda}$ and for the other hyperons, as the energy of the system is much higher. If some polarization effect could be found (averaging the data in a different way, for example) it would be due to global aspects of the system, in processes similar to the ones proposed in [19], [20] and [28].

Another intriguing possibility is the hyperon polarization in pA collisions at LHC. In this case we imagine that it is possible that some polarization could survive considering the final state interactions, but the exact results are not available yet.

Acknowledgments

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