PROCEEDINGS OF SCIENCE

Measurement of Λ hyperon spin-spin correlations in p+p collisions by the STAR experiment

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The Λ^0 hyperons have an interesting property that they can be produced polarized in collisions of unpolarized particles, as was discovered in Femilab in the 70's. Since then, the Λ^0 polarization has been measured in a variety of collision systems, including e^++e^-. Most of the measurements indicate that the polarization originates from final state effects, such as fragmentation and hadronization. It is therefore important to investigate if there is any contribution of initial state effects to the polarization, such as spin-spin correlation of initial state partons. This is possible utilizing a newly proposed experimental method which measures spin-spin correlations of Λ^0 hyperon pairs.

In these proceedings, we present preliminary results from the first experimental measurement of spin-spin correlations of $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$ pairs in p+p collisions at $\sqrt{s}$ = 200 GeV measured by the STAR experiment. The spin-spin correlation is measured to be consistent with zero for all three Λ^0 hyperon pair combinations, within the uncertainties. This measurement provides the first limit on the Λ^0 hyperon pair spin-spin correlations in p+p collisions at $\sqrt{s}$ = 200 GeV.

31st International Workshop on Deep Inelastic Scattering (DIS2024)
8–12 April 2024
Grenoble, France

*Speaker

1. Introduction

In the 70's, an interesting discovery has been made at Fermilab. It was observed that Λ^0 hyperons are produced polarized in collisions of proton beam on beryllium target [1], as shown in Fig. 1. This result was surprising, as neither the 300 GeV proton beam, nor the beryllium target was polarized in this experiment.

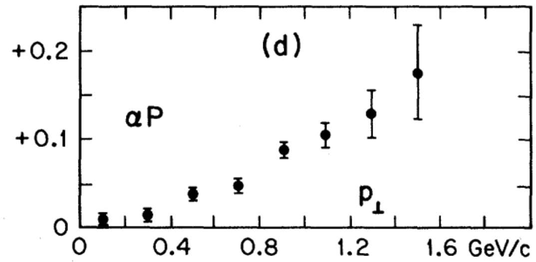

Figure 1: Polarization of Λ^0 hyperons as a function of transverse momentum p_T measured by Fermilab in p+Be collisions. Taken from Ref. [1].

Since its discovery, the Λ^0 hyperon polarization has been measured in a variety of collision systems such as p+p, e+p, or e^++e^- collisions. These measurements revealed more surprises. One interesting observation is that the measured polarization does not heavily depend on the collision energy or the collision system, but rather on x_F which is defined as:

$$x_\mathrm{F} = \frac{p_{z,\Lambda}}{p_\mathrm{beam}}, \tag{1}$$

where $p_{z,\Lambda}$ is the component of the Λ^0 hyperon momentum along the beam axis and p_beam is the beam momentum. The polarization increases with larger x_F which is well summarized in Ref. [2]. Another important observation is that the polarization is present also in e^++e^- collisions, as measured by the BELLE Collaboration [3]. This result suggests that the polarization is generated by final state effects, such as fragmentation or hadronization, as there are no partons in the initial stage that could affect the Λ^0 hyperon polarization in the final state.

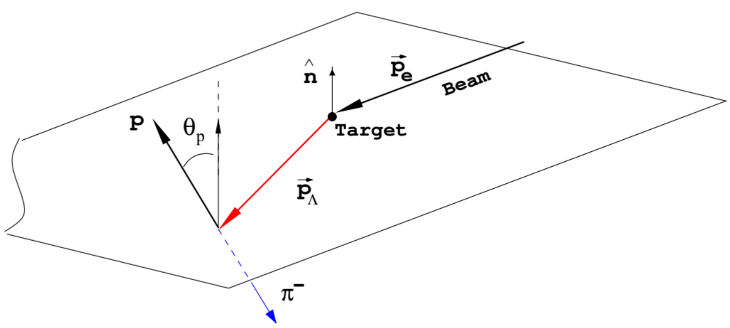

Figure 2: Cartoon illustrating definition of the production plane in measurement of Λ^0 hyperon polarization. Taken from Ref. [4].

What the aforementioned results have in common is the experimental method. The Λ^0 hyperons are reconstructed via hadronic decay channel $\Lambda^0 \to p\pi^-$. The polarization is then measured with respect to a vector $\hat{n}$ normal to the production plane, defined as $\hat{n} = \vec{p}_{\mathrm{beam}} \times \vec{p}_\Lambda$, as shown in Fig. 2. What is then experimentally measured is an angle $\theta^\star$ (sometimes θ_p) between vector $\hat{n}$ and the decay proton momentum boosted into the Λ^0 hyperon rest frame. The distribution of such boosted protons then follows the formula:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^\star} = 1 + \alpha P_\Lambda \cos\theta^\star \tag{2}$$

where α is the weak decay constant of the Λ^0 hyperon and P_Λ is the polarization.

2. Λ^0 hyperon spin-spin correlations

The measurements mentioned in the previous section generally aim to measure and explain the origin of a single Λ^0 hyperon polarization. Recently, it was proposed to investigate the Λ^0 hyperon polarization puzzle from a slightly different perspective, that aims to determine if there is any spin-spin correlation of $s\bar{s}$ quark pair produced in the hard partonic scattering. This is possible through measurement of $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$ hyperon pair spin-spin correlations [5, 6].

The experimental method for this new approach is similar to the standard one described earlier. The two key differences are that it is necessary to identify events containing at least one Λ^0 hyperon pair (any combination), rather than single hyperons, and the reference direction used for measurement of angle $\theta^\star$ is different. In this case, the angle $\theta^\star$ is measured between the momenta of the decay (anti-)protons boosted into rest frame of their mother. The distribution of such (anti-)proton pairs then follows:

$$\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^\star} = 1 + \alpha_1\alpha_2 P_{\Lambda_1\Lambda_2} \cos\theta^\star \tag{3}$$

where α_1 and α_2 are the weak decay constants of Λ^0 or $\bar{\Lambda}^0$ and $P_{\Lambda_1\Lambda_2}$ is the spin-spin correlation of the hyperon pair. In case $P_{\Lambda_1\Lambda_2} \neq 0$, the spins of the Λ^0 ($\bar{\Lambda}^0$) in the pair are correlated.

3. Results

The dataset used in this analysis are p+p collisions at $\sqrt{s} = 200\,\mathrm{GeV}$ collected by the STAR experiment in 2012, which contains a total of 400 million minimum bias events. The Λ^0 and $\bar{\Lambda}^0$ hyperons are reconstructed at mid-rapidity ($|y| < 1$) and in transverse momentum range of $0.5 < p_\mathrm{T} < 5.0\,\mathrm{GeV}$.

As described earlier, the Λ^0 and $\bar{\Lambda}^0$ are reconstructed via their hadronic decay $\Lambda^0 \to p\pi^-$ (and charge conjugate for $\bar{\Lambda}^0$). The (anti-)protons and charged pions, identified utilizing STAR Time Projection Chamber, are paired based on their charge into unlike-sign (US) pairs ($p\pi^-$, $\bar{p}\pi^+$) and like-sign (LS) pairs ($p\pi^+$, $\bar{p}\pi^-$). These pairs are subsequently combined into US-US Λ^0 hyperon candidate pairs, containing signal and combinatorial background. The background is estimated using US-LS pair combination.

The signal Λ^0 hyperon pairs are selected from a 2D invariant mass (M_inv) distribution of the Λ^0 hyperon pairs. First the combinatorial background (US-LS) M_inv distribution is subtracted from the US-US $M_{\rm inv}$ distribution. The $M_{\rm inv}$ distribution after background subtraction is then fitted with a 2D Gaussian distribution. The signal is extracted based on parameters of the fit within $\mu \pm 3\sigma$.

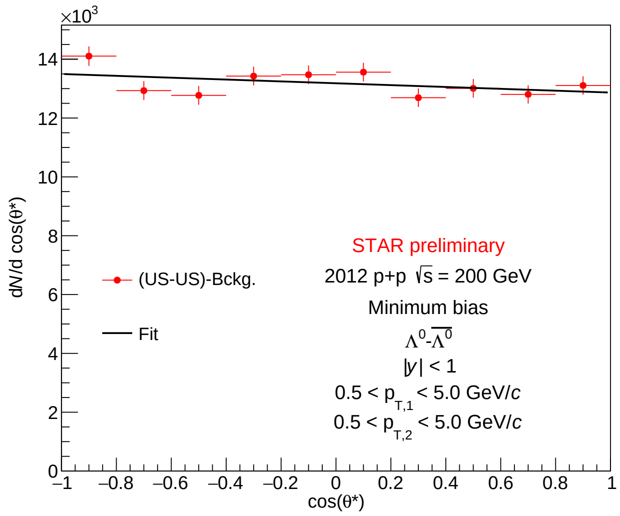

Figure 3: $\mathrm{d}N/\mathrm{d}\cos\theta^\star$ distribution of $\Lambda^0\bar{\Lambda}^0$ after acceptance effect correction and background subtraction. The data are fitted according to Eq. 3.

In the next step, the $\mathrm{d}N/\mathrm{d}\cos\theta^\star$ distributions of the selected Λ^0 hyperon pairs are filled for both US-US and US-LS charge combinations and all three possible Λ^0 ($\bar{\Lambda}^0$) pair combinations. These measured distributions are corrected for acceptance using mixed-event (ME) $\mathrm{d}N/\mathrm{d}\cos\theta^\star$ distributions, separately for US-US and US-LS. After the acceptance correction, the background (US-LS) distribution is subtracted from US-US distribution. The background subtracted distribution is then fitted according to Eq. 3 and the spin-spin correlation $P_{\Lambda_1\Lambda_2}$ is extracted. The $\mathrm{d}N/\mathrm{d}\cos\theta^\star$ distribution of $\Lambda^0\bar{\Lambda}^0$ after acceptance effect correction and background subtraction is shown in Fig. 3.

The spin-spin correlations of $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$ pairs at mid-rapidity ($|y| < 1$), with transverse momentum $0.5 < p_{\rm T} < 5.0$ GeV, measured in p+p collisions at $\sqrt{s} = 200$ GeV are shown in Fig. 4. The spin-spin correlations are consistent with zero for all three Λ^0 hyperon pair combinations, within the uncertainties. This measurement provides the first limit on the Λ^0 hyperon pair spin-spin correlations in p+p collisions at $\sqrt{s} = 200$ GeV.

4. Summary

The Λ^0 hyperons can be produced polarized in collisions of unpolarized particles, as was discovered in the 70's at Fermilab. Various experimental techniques and theoretical models have been developed over the last 50 years in the aim to explain the Λ^0 hyperon polarization puzzle. One such method, that was recently proposed, is the measurement of Λ^0 hyperon pair spin-spin correlations that is able to determine if there is any spin-spin correlation of the initial state $s\bar{s}$ quark pairs [5, 6]. In these proceedings, we have presented the first experimental measurement of the Λ^0 hyperon pair spin-spin correlations by the STAR experiment, in p+p collisions at $\sqrt{s} = 200$ GeV.

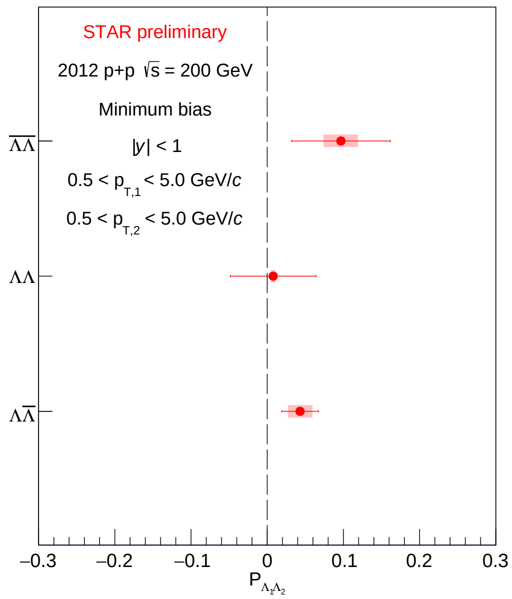

Figure 4: Spin-spin correlations of $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$ pairs measured in p+p collisions at $\sqrt{s}$ = 200 GeV.

The spin-spin correlation of the $\Lambda^0\bar{\Lambda}^0$, $\Lambda^0\Lambda^0$, and $\bar{\Lambda}^0\bar{\Lambda}^0$, measured at mid-rapidity ($|y| < 1$), with transverse momentum $0.5 < p_{\mathrm{T}} < 5.0\,\mathrm{GeV}$ is found to be consistent with zero for all three Λ^0 hyperon pair combinations, within the corresponding uncertainties. This measurement provides the first limit on the Λ^0 hyperon pair spin-spin correlations in p+p collisions at $\sqrt{s} = 200\,\mathrm{GeV}$.

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