Polarization of Anti-Lambda in $\sqrt{s}$=200GeV Polarized Proton-Proton Collision

HAN Ran[1] (for PHENIX Collaboration)

(School of Physics, Peking University, Beijing 100871, China)

Abstract We study the polarization of produced $\bar{\Lambda}$ in $\sqrt{s}$=200GeV polarized proton-proton collision at RHIC/PHENIX, and also the polarization as a function of its rapidity which may be sensitivity to the quark helicity distributions of the proton and to the polarized fragmentation functions of the quark into the baryon. For polarized data collected in 2003 a very clean $\bar{\Lambda}$ peak in $\bar{p}\pi^+$ invariant mass spectrum in the mid-rapidity($|\eta|<0.35$) is obtained. In this letter, we report the calculation process of $P_{\bar{\Lambda}}$ as extracted from the data.

Key words anti-lambda, polarization, fragmentation function

1 Introduction

The proton spin structure has attracted a considerable interest in the past few years. While most of these studies concern the spin structure of nucleons, it has become clear that similar measurements involving other baryons would provide helpful[1]. The $\Lambda/\bar{\Lambda}$ baryon plays a special role in this respect, it is an ideal testing ground for spin studies since it has a rather simple spin structure in the naive quark model. Furthermore, its self-analyzing decay makes polarization measurements experimentally feasible.

The result on Λ production reported from large electron-positron collide have demonstrated the experiment feasibility of successfully reconstructing the Λ spin[2]. Polarized deep inelastic scattering (DIS)experiments at CERN, DESY, JLab and SLAC will certainly continue helping us to gain some new insight into this problem, but we also expect a lot to be achieved by means of the Relativistic Heavy Ion Collider (RHIC) at BNL. With the advent of RHIC[3] the polarization of Λ can be studied for the first time in pp scattering at high center of mass system energies. By analyzing the longitudinal polarized proton-proton data collected by PHENIX experiment in 2003, we have successfully reconstructed about 90k $\bar{\Lambda}$s. Based on the sample of $\bar{\Lambda}$s, the polarization of $\bar{\Lambda}$ is extracted.

2 PHENIX experiment

The PHENIX Experiment is the largest of the four experiments currently taking data at the Relativistic Heavy Ion Collider (RHIC). It is an exploratory experiment for the investigation of high energy collisions of heavy ions and protons. The PHENIX detector consists of global detectors at very large pseudorapidity and four spectrometers. A pair of beam-beam counters (BBC) that cover the pseudo-rapidity range $3<|\eta|<4$ have been used for the minimum bias trigger as well as for the relative luminosity measurement. Two central arm spectrometers cover $-0.35<\eta<0.35$ in pesudo-rapidity, azimuthal angle of 180°, and have been used to measure charged parti-

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1) E-mail: hanran@hep.pku.edu.cn

cles and photons. The two muon spectrometers in the forward and backward directions measure high energy muons in pseudo-rapidity $1.2<|\eta|<2.4$ and cover full azimuthal angle. The stable spin direction of RHIC beam is transverse. Then it is rotated to get longitudinally polarized collisions just before the PHENIX interaction point. PHENIX local polarimetry[4] confirms that the beam is longitudinal by measuring A_N of forward neutrons.

3 The approaches to extract polarization

The polarization of $\bar{\Lambda}$ can be analyzed through its dominant decay channel $\bar{\Lambda}\rightarrow\bar{p}\pi^+$ with a branch ratio of 64%. The angular distribution of the decay proton in $\bar{\Lambda}$ rest frame can be written as

$$\frac{d\sigma}{d\Omega}=\frac{d\sigma^0}{d\Omega}(1+\beta P_{\bar{\Lambda}}\cos\Theta_{\bar{p}\bar{\Lambda}})\cdot a(\kappa,\cos\Theta_{\bar{p}\bar{\Lambda}}), \qquad (1)$$

where $d\sigma^0/d\Omega$ is the differential cross section for unpolarized $\bar{\Lambda}$ and $a(\kappa,\cos\Theta_{\bar{p}\bar{\Lambda}})$ is the acceptance correction function. $a(\kappa,\cos\Theta_{\bar{p}\bar{\Lambda}})$ depends on the $\bar{\Lambda}$ momentum, the position where it decays and other kinematic parameters which is denoted as κ for simplicity. $\Theta_{\bar{p}\bar{\Lambda}}$ is the angle between momentum of the decay antiproton and $\boldsymbol{e}_3$ in the $\bar{\Lambda}$ rest frame, where $\boldsymbol{e}_3$ is defined as the direction of the $\bar{\Lambda}$ momentum in the laboratory frame. $\beta=-0.642\pm0.013$ is the decay asymmetry in the $\bar{\Lambda}$ rest frame. $P_{\bar{\Lambda}}$ is the $\bar{\Lambda}$ polarization as $P_{\bar{\Lambda}}=P_B\cdot D_{LL}$, where D_{LL} is the spin transfer factor, the first "L" denote the initial longitudinal polarized proton and the second one means the longitudinal polarized $\bar{\Lambda}$ produced in the collision.

In this letter, we report the calculation process of $P_{\bar{\Lambda}}$ in pp collisions at a center of mass energy ($\sqrt{s}$) of 200GeV as extracted from the data collected during the 2002—2003 run period (Run-3) of RHIC/PHENIX with one polarization reach to 26%.

3.1 The reconstruction of $\bar{\Lambda}$

The $\bar{\Lambda}$s are reconstructed via it's weak decay $\bar{\Lambda}\rightarrow\bar{p}\pi^+$ with a branch ratio of 64%. Charged particles are reconstructed in the central arms of PHENIX using drift chambers, each with an azimuthal coverage of $\pi/2$ and one layer of multi-wire proportional chamber with pad readout (PC1). Particle identification via time of flight is done for both types of particles. The particle flight time are determined by PHENIX lead-scintillator electromagnetic calorimeter (EMCal) with time resolution around 500ns, which covers the whole west arm and half of east arm.

In general, at least two tracks, one should be identified as π^+ and another as $\bar{p}$, were required in an event. Then for the candidate of $\bar{\Lambda}$, its invariant mass and four momenta are reconstructed. For the event with more than one pair of $\bar{p}\pi^+$, we kept all of them in the analysis. The invariant mass spectrum is plotted in Fig. 1. The signal and background ration is about 1:2 in a 3σ mass window,1.107—1.125GeV/c^2.

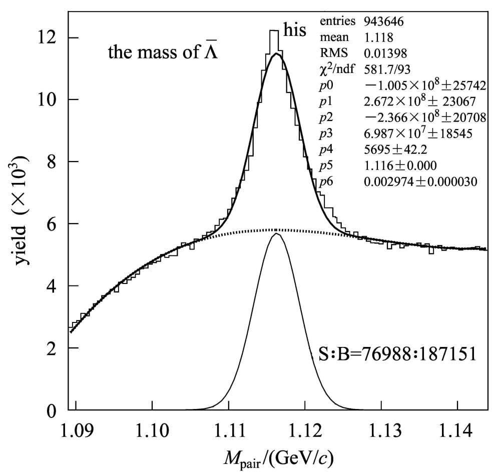

Fig. 1. The invariant mass of $\bar{\Lambda}$ from PHENIX Run-3 data.

3.2 The correction of acceptance

We can see that the acceptance cut by the detector system plays a dominant role on the asymmetry of $\cos\Theta_{\bar{p}\bar{\Lambda}}$ distribution. To get rid of the acceptance correction from Eq. (1), by assuming the integrated luminosity is L^+ and L^- for parallel and anti-parallel polarized beam, respectively, one can conveniently derive the single spin asymmetry from Eq. (1) with $dN/d\Omega=(d\sigma/d\Omega)\cdot L$

$$\left(\frac{dN^+}{d\Omega}\frac{1}{L^+}-\frac{dN^-}{d\Omega}\frac{1}{L^-}\right)\Big/\left(\frac{dN^+}{d\Omega}\frac{1}{L^+}+\frac{dN^-}{d\Omega}\frac{1}{L^-}\right)=\frac{\beta D_{LL}(P_B^+-P_B^-)\cos\Theta_{\bar{p}\bar{\Lambda}}}{2+\beta D_{LL}(P_B^++P_B^-)\cos\Theta_{\bar{p}\bar{\Lambda}}}, \qquad (2)$$

Where P_B^+ and P_B^- are the average polarization for parallel and anti-parallel polarized beams, respectively, in the region of $\cos\Theta_{\bar{p}\bar{\Lambda}}$ to $\cos\Theta_{\bar{p}\bar{\Lambda}}+d(\cos\Theta_{\bar{p}\bar{\Lambda}})$, and $D_{\rm LL}$ is the spin transfer factor. The $|P_{\rm B}^{+}+P_{\rm B}^{-}|\sim 0$ so one can safely simplify Eq. (2) to:

$$\frac{N_{\bar\Lambda}^{+}-RN_{\bar\Lambda}^{-}}{N_{\bar\Lambda}^{+}+RN_{\bar\Lambda}^{-}}=\beta P_{\bar\Lambda}\cos\Theta_{\bar{\rm p}\bar\Lambda},\quad R=L^{+}/L^{-}, \qquad (3)$$

Where $N_{\bar\Lambda}^{+}$, $N_{\bar\Lambda}^{-}$ stand for numbers of $\bar\Lambda$ in a $\cos\Theta_{\bar{\rm p}\bar\Lambda}$ bin with beam polarization parallel and anti-parallel to beam direction, respectively. We denote the left side of Eq. (3) as $\epsilon_{\rm L}$.

3.3 Approach to subtract the background influence

We can't distinguish the contribution of $\bar\Lambda$ from background in $\cos\Theta_{\bar{\rm p}\bar\Lambda}$ distribution. "background correction" is applied to subtract the background . The "background correction" could be described as below: in each $\cos\Theta_{\bar{\rm p}\bar\Lambda}$ bin, we corrected the $\epsilon_{\rm L}$ with the events of background (BG). We used counts adjacent to $\bar\Lambda$ peak: 1.084—1.102GeV/c^2 and 1.130—1.148GeV/c^2, on both sides from $\bar\Lambda$ peak.

$$\epsilon_{\rm L}^{\bar\Lambda}=\frac{\epsilon_{\rm L}^{\bar\Lambda+{\rm BG}}-r\epsilon_{\rm L}^{\rm BG}}{1-r},\quad \sigma_{\epsilon_{\rm L}^{\bar\Lambda}}=\frac{\sqrt{\sigma^2_{\epsilon_{\rm L}^{\bar\Lambda+{\rm BG}}}+r^2\sigma^2_{\epsilon_{\rm L}^{\rm BG}}}}{1-r}, \qquad (4)$$

r is background contribution to $\bar\Lambda$ yield (counted in 18MeV/c^2 mass range under $\bar\Lambda$ peak).

3.4 The consideration of mixed Kshort under the $\bar\Lambda$ peak

In the particle identification process, some π^- may be misidentified as $\bar{\rm p}$. This misidentification will mix some Kshorts into $\bar\Lambda$ candidates, since the Kshort decays to π^- and π^+. If that, those Kshorts will have influence on the polarization of $\bar\Lambda$. The way how to check is: In particle identification, we singled out the tracks which were identified as $\bar{\rm p}$ first, if those tracks were misidentified, then some of them may be π^-s. So in the reconstruction process, we applied the four momentum of π^-'s on those selected tracks, instead of anti-proton's. Then this track combine with a π^+ to see whether we can get Kshort or not. In PHENIX, after test, there is no Kshort in $\bar\Lambda$ candidates.

4 Summary

The longitudinal spin transfer to $\bar\Lambda$ in pp collisions at RHIC/PHENIX is studied in this letter. For data took with photon trigger in 2003, a very clean $\bar\Lambda$ peak in $\bar{\rm p}\pi^+$ invariant mass spectrum was obtained and about 90k $\bar\Lambda$ events are reconstructed with a signal/background level of 1:2.

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