Abstract

Longitudinal spin physics program at RHIC-PHENIX is introduced. Recent results of $\pi^0$ cross section and $A_{LL}$ are presented and discussed.

Key words: Proton spin structure
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1. Introduction

PHENIX[1] longitudinal spin program[2] has been launched to reveal the spin structure of proton. There exists wide efforts towards the understanding of the proton spin, mainly from polarized deep inelastic scattering (pDIS) so far. Many polarized parton distribution functions (pol. PDF) are suggested (e.g.[3][4]) based on pDIS data. But there has remained large uncertainty especially on $\Delta G$, the gluon spin contribution to the proton.

Since 2002, longitudinally polarized protons have been collided at RHIC, the world’s first polarized $pp$ collider. The experiment gives us unique opportunity to explore $\Delta G$ directly because gluon-gluon and quark-gluon scattering dominates in the measured $p_T$ range. $A_{LL}$ is defined as

$$A_{LL} = \frac{\sigma_{++} - \sigma_{--}}{\sigma_{++} + \sigma_{--}}$$

where $\sigma_{++(+-)}$ is the production cross-section in like (unlike) helicity collisions. Theory calculation based on factorized pertubative QCD (pQCD) with various pol. PDF models are available. Thus we can derive information on pol. PDF from $A_{LL}$. Since the argument is based on pQCD, we need to confirm pQCD applicability in the measured energy. Thus
our strategy is the following: We measure cross-section for pQCD confirmation, and then measure $A_{LL}$ to extract $\Delta G$.

Our figure of merit for $A_{LL}$ has grown dramatically due to the improvements in both luminosity and polarization (Table 1). In 2006, in addition to $\sqrt{s} = 200$GeV, we took data at $\sqrt{s} = 62.4$GeV which can probe higher Bjorken-$x$ at fixed $p_T$.

| Year | $\sqrt{s}$ (GeV) | Figure Of Merit (nb$^{-1}$) | Integrated Luminosity (pb$^{-1}$) | Polarization(%) |
|------|-------------------|-------------------------------|-----------------------------------|-----------------|
| 2003 | 200               | 2.6                           | 0.22                              | 35, 30          |
| 2004 | 200               | 2.9                           | 0.075                             | 45, 44          |
| 2005 | 200               | 170                           | 3.4                               | 47              |
| 2006 | 200               | 970                           | 7.5                               | 60              |
|      | 62.4              | 2.2 (for preliminary results) | 0.042                             | 48              |

Table 1
RHIC-PHENIX longitudinally polarized pp collision run history. Figure of merit (FOM) is defined as $P^4L$ where $P$ denotes polarization and $L$ integrated luminosity. Statistical uncertainty is proportional to $1/\sqrt{\text{FOM}}$.

2. Results and Discussions

We have published results of mid-rapidity $\pi^0$ and direct photon cross section at $\sqrt{s} = 200$GeV [5][6]. In addition, we present preliminary results for $\pi^0$ at $\sqrt{s} = 62.4$GeV in fig. 1. The results agree well with pQCD calculations at both energy within theoretical uncertainties. Thus we can discuss our $A_{LL}$ results based on pQCD.

The blue points in fig. 2 shows $\pi^0 A_{LL}$ published results in run 2005 at $\sqrt{s} = 200$GeV [5] as a function of $x_T = 2p_T/\sqrt{s}$. It is overlaid with pQCD calculation using two pol. PDF models [3]. More sophisticated comparison [5] with theory was performed as in fig. 3. The results reject large gluon polarization scenarios ($\Delta G = \pm G$) and prefer small $\Delta G$. Another independent analysis including our data likewise indicates $\Delta G$ is not large [4].

The red points in fig. 2 shows $\pi^0 A_{LL}$ preliminary results in run 2006 at $\sqrt{s} = 62.4$GeV [7]. Significant improvement can be seen in the large $x_T$ region. Probed Bjorken-$x$ roughly scales with $x_T$ thus the results can probe higher $x$, where we have large uncertainty [4].

In both cases, $\pi^0 A_{LL}$ is not sensitive to the sign of $\Delta G$ in the lower $x_T$ ($x_T < 0.05$) due to the dominance of gluon-gluon scattering. Measurement in higher $x_T$ where quark-gluon dominates, or measurement of direct photon, created by quark-gluon Compton scattering, or measurement of $\pi^\pm$ which have different fraction of subprocesses, are important for the sign determination. Other channels are also important for systematic study.

3. Summary and Outlook

PHENIX longitudinal spin physics program has been launched to investigate proton spin structure. PHENIX $\pi^0$ cross section agrees well with pQCD at both $\sqrt{s} = 200$GeV and $\sqrt{s} = 62.4$GeV within theoretical uncertainties. PHENIX $\pi^0 A_{LL}$ results at both $\sqrt{s} = 200$GeV and $\sqrt{s} = 62.4$GeV are also shown. They reject large $\Delta G$ scenarios. Detailed comparison with theory is on-going at $\sqrt{s} = 62.4$GeV. Results of $\pi^0 A_{LL}$ at $\sqrt{s} = 200$GeV in run 2006 will be available soon. To have better sensitivity for the sign of $\Delta G$, measurement of $\pi^0 A_{LL}$ at higher $x_T$, direct photon $A_{LL}$ and $\pi^\pm A_{LL}$ are important and...
Fig. 1. Preliminary results of $\pi^0$ production cross section in $pp$ collisions at $\sqrt{s} = 62.4$ GeV.

Fig. 2. PHENIX $A_{LL}(\pi^0)$ results. Red: Preliminary results at $\sqrt{s} = 62.4$ GeV in run 2006. Blue: Final results at $\sqrt{s} = 200$ GeV in 2005.

Fig. 3. The $\chi^2$ distribution of the measured $A_{LL}$ results at $\sqrt{s} = 200$ GeV in run 2005 versus the value of the first moment of the polarized gluon distribution (solid line) in the $x$ range from 0.02 to 0.3 for which the $\pi^0$ results are sensitive. Dotted and dashed curves correspond to polarization scale uncertainty of $\pm 9.4\%$. Arrows indicate four different polar. PDF models. Our results reject two large polarization scenarios ($\Delta G = \pm G$) and prefer small $\Delta G$. The two minima indicate the contribution from gluon-gluon scattering which hides the sign of $\Delta G$.

will be available in the future. Other channels are also important for systematic study. They together give us further information on proton spin.

References

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