# Proton Spin Structure Study with PHENIX Detector at RHIC

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Acceleration of polarized protons in Relativistic Heavy Ion Collider (RHIC) will provide unique tool to study the spin structure of the nucleon, covering the $\sqrt{s}$ region from 50 GeV to 500 GeV with proton polarization of 70%. PHENIX, one of the major detector systems at RHIC, is going to investigate poorly known gluon and flavor identified sea quark polarization in the proton. Overview of the PHENIX spin program is presented and sensitivities of the measurements are discussed.

## 1. Introduction

Spin is one of the most fundamental properties of the elementary particles. The spin of the proton had been believed to be carried by the valence quarks for long years. The amazing result from polarized deep-inelastic scattering experiments (polarized-DIS) is that on average only about 1/4 to 1/3 of the proton spin is carried by the quarks and antiquarks in the proton [1]. Therefore, the spin of the proton appears to be mainly carried by the gluons and orbital angular momentum. It may also be the evidence that the sea quark polarization is large and anti-parallel to the proton spin. Since gluon doesn't couple directly to the photon and photon couples to the quark and antiquark in a same way, gluon and antiquark polarization cannot be directly measured in polarized-DIS experiments. In the case of *pp* collisions, there are several processes where gluons participate directly, such as prompt photon production and heavy quark production. Flavor decomposition of quark and antiquark polarization can be done using *W*-production.

## 2. Acceleration of Polarized Protons at RHIC

The primary purpose of Relativistic Heavy Ion Collider (RHIC) is a search for a new hadronic state, quark-gluon plasma (QGP), in heavy ion collisions. In addition to the heavy ion physics program, RHIC will be also used to collide polarized proton beams for exploration of the spin of the proton.

Polarized protons will be generated by an optically pumped polarized ion source and then accelerated in a chain of accelerators to 22 GeV. Individual bunches of $2\times10^{11}$ protons with 70% polarization will be transferred to the RHIC rings. This will be repeated 120 times for each ring at RHIC. The polarized protons will be then accelerated to up to 250 GeV in each ring for collisions at each of 6 intersection regions. We expect RHIC to provide the integral luminosity of 320 $pb^{-1}$ at $\sqrt{s}=200$ GeV and 800 $pb^{-1}$ at $\sqrt{s}=500$ GeV (100 day runs with full luminosity and 50% efficiency).

To maintain the proton polarization through acceleration RHIC will be equipped with a set of four helical dipole magnets (Siberian Snakes), which rotate the proton spin $180^0$ around horizontal axis each time the beam passes. This will help to eliminate the major spin resonances at RHIC. The spin of the beam particle will be rotated to the demanded direction before colliding points by spin rotators, which will be located before and after the experimental halls. The particles produced in the reaction will be detected by two major detector systems, PHENIX and STAR.

### 3. PHENIX Detector

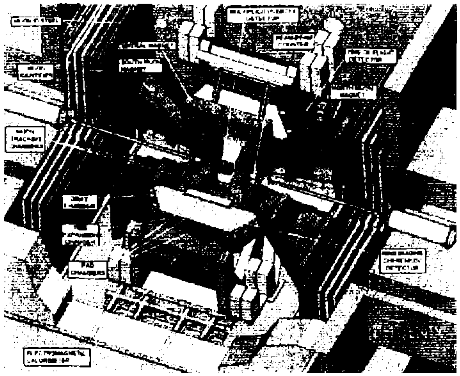

Fig 1. The PHENIX detector system.

PHENIX detector system [2] is shown on Fig 1 It comprises four parts: two Central Arms ($|\eta| < 0.35$, $\eta$ - pseudorapidity) and North and South Muon Arms ($1.2 < |\eta| < 2.4$). The Central spectrometer consists of two arms, West and East, each of which covers $\Delta\varphi=\pi/2$ in azimuth. It provides charged particle tracking and momentum measurements (with Drift Chambers, Pad Chambers and Time Expansion Chambers) in the axial magnetic field of Central Magnet, electron and photon energy and position measurements (with Electromagnetic Calorimeter) and particle identification (with Electromagnetic Calorimeter, Time of Flight walls and Ring Imaging Cherenkov Detector). The finely granulated Electromagnetic Calorimeter provides a clear discrimination between single $\gamma$ and $\pi^0$ up to $p_t$=25 GeV/c (Fig.2), using parameterized transverse electromagnetic shower profile and taking into account energy correlations in cluster towers. A 50% discrimination efficiency is reached for $p_t(\pi^0)$ = 50 GeV/c (minimal distance between two photons $d_{min}$~0.5 EMCal cells) for the particles with normal impact.

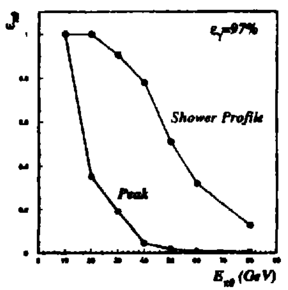


Fig.2 Two photon from $\pi^0$ separation efficiency in PHENIX EMCal (orthogonal impact), solid points – by distinguishing two peaks (local maxima) in EMCal, open points – by shower profile analysis

Muon identification, tracking and momentum measurements will be done in Muon Arms. They include muon magnets, muon identifier with 5 iron-detector layers and three tracking stations. Longitudinal momentum resolution is about 2% at 10 GeV/c.

### 4. Measurements of Gluon Polarization

#### 4.1. Prompt Photon and High $p_t$ $\pi^0$ Production

One of the promising methods to probe the gluon helicity distribution is the asymmetry measurements for prompt photon production with high transverse momentum. In $pp$ collisions the production is dominated by the gluon Compton process $gq \to \gamma q$ (~85-90%) and annihilation process $q\bar{q} \to \gamma g$ (~10-15%). Thus the cross section is quite sensitive to the gluon distribution in the proton. To extract helicity dependent structure functions one can measure double longitudinal spin asymmetry:

$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}},$$

$\sigma^{++}$ and $\sigma^{+-}$ are helicity dependent cross sections for parallel and anti-parallel proton spin direction. $A_{LL}$ is a product of gluon and quark helicity distributions. For example for Compton process the asymmetry can be written at the leading order (LO) as [3]:

$$A_{LL} = \frac{\Delta G(x_1)}{G(x_1)} A_1^p(x_2) \cdot \hat{a}_{LL}(gq \to \gamma q) + (1 \leftrightarrow 2), \quad A_1^p(x) = \frac{\sum_{i=u,d,s} e_i^2 \Delta q_i(x)}{\sum_{i=u,d,s} e_i^2 q_i(x)},$$

here $G$ and $\Delta G$ are gluon distribution function and polarized gluon distribution function respectively, $q_i$ and $\Delta q_i$ are quark and polarized quark distribution functions, $\hat{a}_{LL}$ represents the double longitudinal spin asymmetry for elementary process $gq \to \gamma q$. Since the asymmetry $A_1^p$ had been measured in pol-DIS experiments [4], $\hat{a}_{LL}$ is calculable in QCD [5], $\Delta G/G$ can be extracted from the measured $A_{LL}$. Fig.3 shows the expected sensitivities of this channel. Three models on $\Delta G$ proposed by Gehrmann and Stirling [6] will be clearly distinguished by the data from 320 pb$^{-1}$.

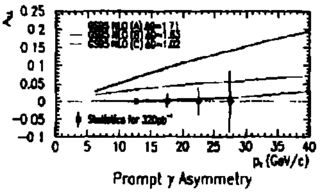


Fig.3. The sensitivity of the prompt photon measurements to $A_{LL}$ for 320 pb$^{-1}$. The curves are three different $\Delta G$ assumptions by Gerhmann and Stirling [6].

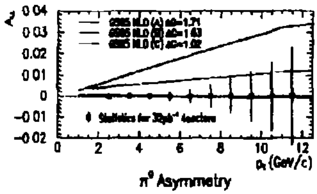


Fig.4. The sensitivity of the $\pi^0$ measurements to $A_{LL}$ for 32 pb$^{-1}$. The curves are three different $\Delta G$ assumptions by Gerhmann and Stirling [6].

The main background for prompt photon reconstruction comes from $\pi^0$ and $\eta$ meson decays. Two-photon invariant mass reconstruction considerably suppresses this source of background. Shower profile measurement in the Electromagnetic Calorimeter of PHENIX is extremely important for $\pi^0$ rejection with $p_t$ >15 GeV/c (Fig.2). The discrimination between $\pi^0/\gamma$ at high $p_t$ is considerably improved by taking into account energy correlations in cluster towers. Additional background suppression is provided by an isolation cut. After these cuts the expected residual background to reconstructed prompt photons is about 7-10% [7].

The measurement of asymmetry of high $p_t$ $\pi^0$ production is important to extract $A_{LL}$ in prompt photon production. On the other hand, since $\pi^0$ production is given by an admixture of partonic interactions ($qq$, $qg$, $gg$), $\pi^0$ itself can give an access to the gluon polarization. Fig.4 shows the expected asymmetry in $\pi^0$ production and our sensitivities.

## 4.2. Heavy Quark Production

High $p_t$ leptons are a good tag for heavy quark production. In the RHIC energy the major channel is gluon fusion $gg \to q\bar{q}$, thus gluon polarization is accessible

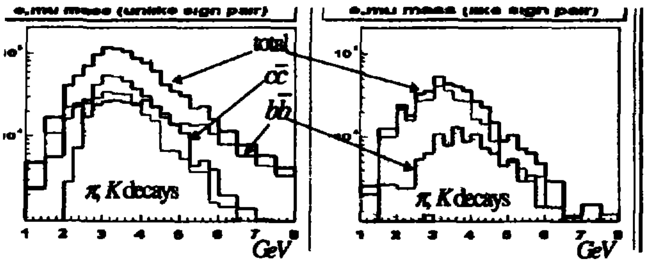


Fig.5. Mass distribution of unlike-sign $e\mu$ pairs (left) and like sign pairs (right). The hatched areas are the background from pion and kaon decays

with high $p_t$ leptons. The double longitudinal spin asymmetry for the open heavy quark production can be formulated as

$$A_{LL} = \frac{\Delta G}{G}\frac{\Delta G}{G}\,\hat{a}_{LL}(gg \to q\bar{q}).$$

The expected asymmetry of $e\mu$ pairs production (from $b\bar{b}$) and our sensitivities are shown on Fig.6. The coincidence requirement suppresses the decay background and enhances the leptons from $q\bar{q}$ (Fig.5). Like-sign pairs will give the estimate of the yield and asymmetry of background. From one-year run we expect to get 120k $e\mu$ pairs from $b\bar{b}$ and 100k from $c\bar{c}$, with about 10-20% of background. Bottom contribution dominates in the high mass region where the pair mass is above 5 GeV.

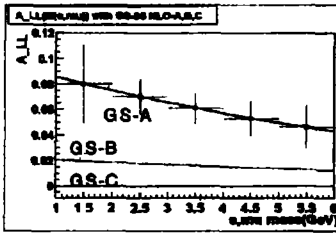


Fig.6. The sensitivity of the $b\bar{b} \to e\mu$ measurements to $A_{LL}$ for 320 pb$^{-1}$. The curves are three different $\Delta G$ assumptions by Gerhmann and Stirling [6]

## 5. Measurements of Anti-quark Polarization

Detailed flavor analysis is possible with $W^{\pm}$ production measurements, since the flavors participating in the reaction are almost fixed: $u\bar{d} \to W^{+}$, $d\bar{u} \to W^{-}$. In the case of $W^{-}$ the parity violating asymmetries can be described as

$$A_L^{pp\to W X} = \frac{\Delta d(x_1)\bar{u}(x_2) - \Delta\bar{u}(x_1)d(x_2)}{\Delta d(x_1)\bar{u}(x_2) + \Delta\bar{u}(x_1)d(x_2)}.$$

At large $x_2$ where $\bar{u}$ is small, $A_L^{W^-}$ simply becomes $-\Delta\bar{u}/\bar{u}$, and at large $x_1$ $A_L^{W^-}$ is $\Delta d/d$. Likewise from $W^+$, $\Delta\bar{d}/\bar{d}$ and $\Delta u/u$ can be extracted.

In Central Arms $W^{\pm}$ are identified as a Jacobian peak in the $p_t$ spectrum of electrons and positrons. In Muon Arms the $p_t$ spectrum of muons is dominated with ones from $W$ decays at the $p_t$ region above 20 GeV/c. The main background in this $p_t$ region comes from $Z^0$ decays. The yield and asymmetry measurements of $Z^0$ production will help to minimize the systematic errors. In proton-proton collisions at $\sqrt{s}$=500 GeV with 800 pb$^{-1}$ integral luminosity (100 day run with 50% efficiency) we expect to get about 8000 $W^+$ and 8000 $W^-$ in muon arms. Fig.7 shows the expected sensitivities from $\Delta f(x)/f(x)$, with $f = u, d, \bar{u}, \bar{d}$, for PHENIX muon data.

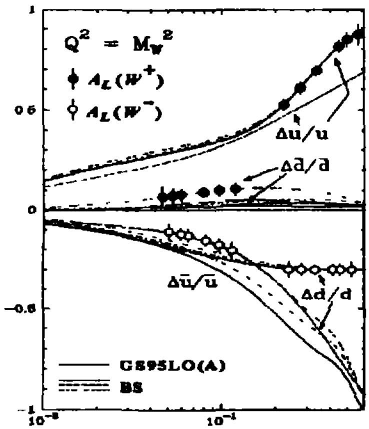


Fig.7 Sensitivities for the flavor decomposed asymmetry plotted with model prediction [8].

## 6. Summary

The acceleration of the polarized protons at RHIC will open a new era of the high energy spin physics. The first experimental data is expected in 2001. The PHENIX detector is suited to the spin program by its high rate capability and its powerful particle identification. The gluon helicity distribution will be measured via high $p_t$ prompt photon and $\pi^0$ production. Heavy quark production measurements will be helpful to further studies of gluon polarization in the proton. $W$ production will provide tool for flavor decomposition of anti-quark and quark helicity distributions.

## References


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