hep-ph/9905511
STAR NOTE # SN0406
19 July, 1999

Asymmetry of prompt photon production in $\vec{p}-\vec{p}$ collisions at RHIC

G. P. Škoro[1],

Institute of Nuclear Sciences "Vinča",
Faculty of Physics, University of Belgrade,
Belgrade, Yugoslavia

M. Zupan[2],

Institute of Nuclear Sciences "Vinča",
Belgrade, Yugoslavia

M. V. Tokarev[3]

Laboratory of High Energies,
Joint Institute for Nuclear Research,
141980, Dubna, Moscow region, Russia

Summary.– *The prompt photon production in $\vec{p}-\vec{p}$ collisions at high energies is studied. Double-spin asymmetry A_{LL} of the process is calculated by using Monte Carlo code SPHINX. A possibility to discriminate the spin-dependent gluon distributions and to determine sign of ΔG is discussed. Detailed study of expected background, such as π^0 production and decay, is given. The predictions for the longitudinal asymmetry A_{LL} of the prompt photons and π^0-meson production in the $\vec{p}-\vec{p}$ collisions at RHIC energies have been made.*

[1]goran@rudjer.ff.bg.ac.yu
[2]mzupan@rt270.vin.bg.ac.yu
[3]tokarev@sunhe.jinr.ru

1 – Introduction

One of the actual problems of high energy spin physics is the measurement of the spin-dependent gluon distribution $\Delta G(x, Q^2)$. This would allow the determination of gluon and moreover of quark contribution to the spin of the proton. Although spin-dependent quark distributions were obtained from deep-inelastic lepton-nucleon scattering, this information was not sufficient to determine the various parton contributions to the proton spin (see [1] and references therein).

Consequently the preparation of many experiments is well under way. These experiments are to take place on colliders that are presently under construction, such as RHIC [2], HERA [3] and LHC (see [4] and references therein). These colliders will provide high-energy polarized proton beams necessary for the study of the asymmetry of jet and/or prompt photon production which can be used as a measure of $\Delta G(x, Q^2)$. In a recent paper [5], we analyzed asymmetry of jet and dijets production at RHIC by means of Monte Carlo simulations and found that the asymmetry A_{LL}^{jet} is sensitive for ΔG and can give us the information about the sign and shape of spin-dependent gluon distribution. In this paper we study prompt photon production and the asymmetry of the production with respect to the parallel and anti-parallel orientation of the longitudinally oriented spins of the colliding protons.

The processes responsible for prompt photon production are the Compton $qg \to q\gamma$ scattering and the annihilation process $q\bar{q} \to g\gamma$. The asymmetry of prompt photon production will therefore be dependent on the convolution of spin-dependent distributions of quarks and gluons. The set of possible distributions is subject to very few constraints. Additional ones must be arrived at theoretically or empirically, or both. For example, the sign of the gluon spin contribution is subject to speculation. Although there are indications that it should be positive, the possibility that it may be negative also exists. Both positive and negative values of the sign of $\Delta G(x, Q^2)$ were considered in [6]. The possibility to draw conclusions on the sign of the spin-dependent gluon distribution, $\Delta G(x, Q^2)$, from existing polarized DIS data have been studied in [7]. Other speculations deal with the relative magnitude of the gluon contribution, models are proposed in which ΔG is large compared to other contributions, others where it is small compared to other contributions.

All this points to the necessity of measurement of $\Delta G(x, Q^2)$, and consequently ΔG. The goal of this paper is to study the asymmetry of prompt photon production in proton-proton collisions for positive and negative $\Delta G(x, Q^2)$ and to predict the magnitude of the effect when observed by the STAR detector at RHIC [8]. Moreover, the paper is intent on presenting some of the considerations involved in the selection of the kinematical region which is optimal for the observation of the effect. Finally some consideration was made of the expected background giving a prediction of the asymmetry signal that would actually be observed in the experiment.

2 – Spin-dependent gluon distribution

A phenomenological spin-dependent distributions [6] were used in the calculation of the prompt photon production asymmetry. The distributions [6] were arrived at empirically,

including some constraints on the signs of valence and sea quark distributions, taking into account the axial gluon anomaly and utilizing results on integral quark contributions to the nucleon spin. Based on the analysis of experimental deep inelastic scattering data for the structure function g_1 the parametrizations of spin-dependent parton distributions for both positive and negative sign of ΔG have been constructed. We would like to note that both sets of distributions describe experimental data very well. We shall denote $\Delta G^{>0}$ and $\Delta G^{<0}$ sets of spin-dependent parton distributions obtained in [6] with positive and negative sign of ΔG, respectively. It was shown in [9] that the constructed spin-dependent parton distributions for positive sign of ΔG reproduce the main features of the NLO QCD Q^2-evolution of proton, deuteron and neutron structure function g_1.

Figure 1 shows the dependence of the ratio $\Delta G(x,Q^2)/G(x,Q^2)$ on x at $Q^2 = 100\ (GeV)^2$ for gluon distributions $\Delta G^{>0}$ and $\Delta G^{<0}$ [6]. In the case of positive $\Delta G(x,Q^2)$ we see a monotonically increasing curve corresponding to the behaviour $\Delta G/G \sim x^{\alpha}$ as $x \to 1$. For $\Delta G^{<0}$ we see a monotonically decreasing curve behaving almost exactly as $\Delta G/G \sim -x^{1/2}$, as $x \to 1$. Figure 2 shows the dependence of the ratio $\Delta q(x,Q^2)/q^R(x,Q^2)$ on x at $Q^2 = 100\ (GeV)^2$ for u-quark (a) and d-quark (b). We would like to note that $q^R(x,Q^2)$ represents the renormalised parton distribution as given in [6].

3 – Asymmetry of prompt photon production

There are two principal processes that produce prompt photons: the Compton process $qg \to q\gamma$ scattering and the annihilation process $q\bar{q} \to g\gamma$. However for large gluon polarisations the contribution of the annihilation process can be neglected.

The longitudinal, double spin asymmetry is defined as the difference of cross-sections for prompt photon production when the longitudinally oriented spins of the colliding protons are antiparallel ($\uparrow\downarrow$) and parallel ($\uparrow\uparrow$):

$$A_{LL} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} = \frac{1}{P^2} \cdot \frac{N_\gamma^{\uparrow\downarrow} - N_\gamma^{\uparrow\uparrow}}{N_\gamma^{\uparrow\downarrow} + N_\gamma^{\uparrow\uparrow}}, \tag{1}$$

where N_γ represents the number of prompt photons. The statistical error is calculated as:

$$\delta A_{LL} \simeq \frac{1}{P^2} \cdot \frac{1}{\sqrt{N_\gamma^{\uparrow\downarrow} + N_\gamma^{\uparrow\uparrow}}}. \tag{2}$$

The calculation of prompt photon production asymmetry was done using Monte Carlo code SPHINX [10] which is a 'polarized' version of PYTHIA [11]. Calculations of asymmetry were made for center-of-mass energies $\sqrt{s} = 200\ GeV$ and $\sqrt{s} = 500\ GeV$ which are part of the design specifications of RHIC. The STAR detector is designed to cover full space in azimuth and pseudorapity region $-1 < \eta < 2$, so this was taken into account in calculating the asymmetry of prompt photon production.

The rate and asymmetry of prompt photon production was estimated using the assumed RHIC integrated luminosity 320 pb^{-1} at $\sqrt{s} = 200\ GeV$ and 800 pb^{-1} at $\sqrt{s} = 500\ GeV$ and a fixed beam polarization of P = 0.7.

4 – Results and discussions

The asymmetry of prompt photon production was calculated from simulations for both $\Delta G^{>0}$ and $\Delta G^{<0}$ sets of spin dependent PDF [6]. Figure 3 shows the dependence of A_{LL} on the photon transverse momentum p_T at $\sqrt{s} = 200\ GeV$. For $\Delta G^{>0}$ the asymmetry increases from about 1.5% at $p_T = 6\ GeV/c$ to 13% at $p_T = 24\ GeV/c$. For $\Delta G^{<0}$ the asymmetry drops from zero at $p_T = 6\ GeV/c$ to -17% at $p_T = 24\ GeV/c$. The errors shown are statistical. Figure 4 shows the asymmetry of prompt photon as a function of prompt photons transverse momentum p_T at $\sqrt{s} = 500\ GeV$. This asymmetry is much smaller than the one at $\sqrt{s} = 200\ GeV$. It is practically equal to zero for p_T up to about $14 GeV/c$. Beyond $p_T = 14\ GeV/c$ it rises slowly for $\Delta G^{>0}$ and drops for $\Delta G^{<0}$.

This means that the energy of $\sqrt{s} = 200\ GeV$ will be more preferable for determination of ΔG from prompt photon production. Note that higher colliding energy $\sqrt{s} = 500\ GeV$ is preferable for extracting ΔG from jets asymmetry [5]. Figure 5 shows estimated rates of prompt photon production with above mentioned conditions at $\sqrt{s} = 200\ GeV$ and $\sqrt{s} = 500\ GeV$.

The rate of prompt photon production decreases with increasing p_T due largely to the decrease in the distribution of gluons at high x, keeping in mind the approximate relation $x = p_T/(2\sqrt{s})$. At the same time the asymmetry effect increases with p_T. Consequently the successful measurement of the asymmetry in prompt photon production depends largely on reconciling the magnitude of the effect with the statistical reliability of the measurement. For example, at $\sqrt{s} = 200\ GeV$ only the asymmetry values up to $p_T \simeq 25\ GeV/c$ will have acceptable statistical significance. The problem of experimental errors have to be analyzed in the light of corresponding background processes, too.

The main source of background, in this case, is the production of π^0 mesons because the π^0's general mode of decay $\pi^0 \rightarrow 2\gamma$ significantly affects prompt photon detection. High-energy π^0's decay into photons diverging mostly at an angle θ, given by $sin(\theta/2) = m_{\pi^0}/E_{\pi^0}$, small enough to be collected by a single cell of the Electro-Magnetic Calorimeter and counted as a high-p_T prompt photon. Also the possibility of one of the decay photons escaping detection causes the one which is detected to be considered a prompt photon.

Also, the processes responsible for π^0-meson production are $q-q$, $q-g$ and $g-g$ scattering, so in the polarized pp collisions non-zero values of π^0 asymmetry can be expected. Figure 6 shows the asymmetry of π^0-meson production as a function of transverse momentum p_T at $\sqrt{s} = 200\ GeV$. The asymmetry is positive and increase with p_T for $\Delta G^{>0}$ and practically equal to zero for $\Delta G^{<0}$. Such a behaviour will reflect on the expected experimental prompt photon asymmetry. Also, we can see in Figure 7 that the average cross-section of π^0-meson production is higher than average cross-section of prompt photon production by an order of magnitude in the whole kinematical region. To provide an adequate prediction of the asymmetry measured in the experiment, the production of π^0's has to be taken into account in the calculation of A_{LL}. Also, in order to reduce such a high background, the optimal method for the so-called "π^0/γ separation" should be performed. The very important part of the EM Calorimeter at STAR is Shower Maximum Detector which can be used for the purpose [12]. The method described in Ref. [12] is based on the different shapes of the EM showers induced by gammas and pions. The experimental asymmetry was calculated by substituting:

$$N_{\rm exp}^{\uparrow\uparrow} = a \cdot N_{\gamma}^{\uparrow\uparrow} + b \cdot N_{\pi^0}^{\uparrow\uparrow}, \tag{3}$$

for $N_{\gamma}^{\uparrow\uparrow}$ into (1), and by an analogous substitution for $N_{\gamma}^{\uparrow\downarrow}$. The quantity $N_{\pi^0}^{\uparrow\uparrow}$ is the number of produced pions and a and b are constants determined by the gamma detection efficiency and the percent of misidentified pions , respectively. These constants were taken to be: $a = 0.9$ reflecting a 90% photon detection efficiency and $b = 0.35$ reflecting a 65% efficiency in π^0-meson rejection from the signal as shown in [12].

Figure 8 shows the 'experimental' prompt photon asymmetry obtained by taking into account all conditions described above. The experimental asymmetry is different for different signs of ΔG implying that it will be a clear signal at least for the sign of ΔG.

5 – Conclusions

Monte Carlo simulations of prompt photon production in polarized proton collisions at high energies were made, taking into account parameters of the STAR detector at RHIC. The dependence of asymmetry of prompt photon production on the transverse momentum of photons was studied for positive and negative values of ΔG at colliding energies of $\sqrt{s} = 200\ GeV$ and $\sqrt{s} = 500\ GeV$. The results show that a stronger asymmetry signal with a clear indication of the sign of ΔG will be at $\sqrt{s} = 200\ GeV$. At that energy the asymmetry A_{LL} ranges from 1.5% to 13% for the p_T range of 6 GeV/c to 24 GeV/c. The asymmetry effect is larger at higher p_T values but at the same time the number of prompt photons produced at high p_T is smaller. The measurement of the asymmetry will need to reconcile the visibility of the effect and the statistical reliability of the measurement. The decay of π^0 mesons was considered as a source of background. It was found that the number of photons from π^0 decay can exceed the number of prompt photons by an order of magnitude. Taking into account the results on π^0/γ separation achievable at STAR, it was shown that the experimental asymmetry will also give a clear signal as to the sign of ΔG.

Acknowledgments One of the authors (M.T.) would like to thank T.Hallman for the support of the present work and organization of the visit to BNL.

References

[1] M.Anselmino, A.Efremov, E.Leader, Phys.Rep. **261** (1995) 1.

[2] RSC Collaboration, Proposal on Spin Physics using the RHIC Polarized Collider, August 1992.

[3] Proceedings of the Workshop "Prospects of SPIN PHYSICS at HERA", DESY-Zeuthen, Germany, 28-31 August, 1995, DESY95-200, ed. by J.Blumlein, W.-D.Nowak

[4] A. Penzo et al., Proc. VI Workshop on High Energy Spin Physics, p.238, Protvino, 1996.

[5] G.P.Škoro, M.V.Tokarev, Nuov. Cim. **A111** (1998) 353.

[6] M.V.Tokarev, Preprint JINR, E2-96-304, Dubna, 1996.

[7] W.-D.Nowak, A.V.Sidorov, M.V.Tokarev, Preprint JINR, E2-96-315, Dubna, 1996; Nuov. Cim. **A110** (1997) 757.

[8] G.Bunce et al., Particle World, vol.3, (1992) p.1.

[9] W.-D.Nowak, A.V.Sidorov, M.V.Tokarev, In: Proc. International workshop SPIN'97, July 7-12, 1997, Dubna, p.99.

[10] St.Gullenstern et al., Nucl. Phys. **A560** (1993) 494.

[11] T.Sjostrand, Computer Physics Commun. **82** (1994) 74.

[12] G.S. Averichev et al, JINR Rapid Comm. 6(74)-95, p. 95, 1995.

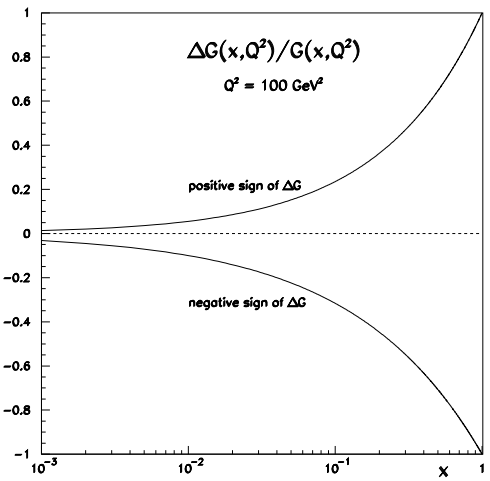
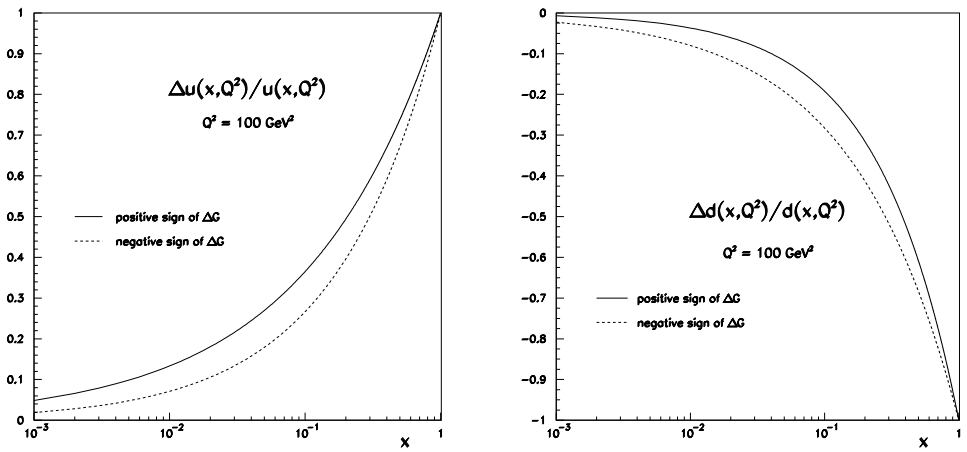


Figure 1

The ratio of polarized and unpolarized gluon distributions as a function of x for two different parametrizations $\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6] at Q^2=100 GeV^2.



a) b)

Figure 2

The ratio of polarized and unpolarized u-quark (a) and d-quark (b) distributions as a function of x for two different parametrizations $\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6] at Q^2=100 GeV^2.

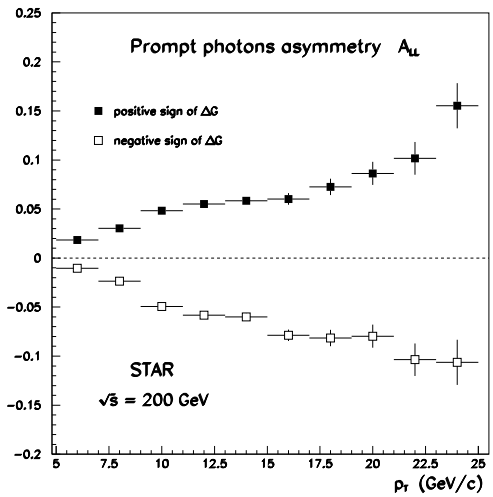


Figure 3.

Asymmetry of prompt photon production A_{LL} in polarized pp collisions at $\sqrt{s}$ = 200 GeV for two different sets of spin-dependent PDFs ($\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6]) as a function of photon transverse momentum p_T. The errors indicated are statistical only.

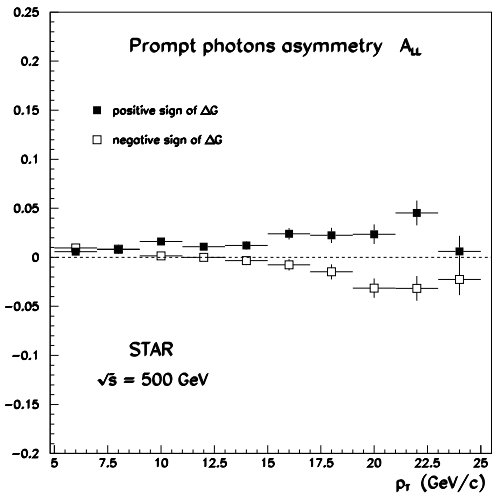


Figure 4.

Asymmetry of prompt photon production A_{LL} in polarized pp collisions at $\sqrt{s}$ = 500 GeV for two different sets of spin-dependent PDFs ($\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6]) as a function of photon transverse momentum p_T. The errors indicated are statistical only.

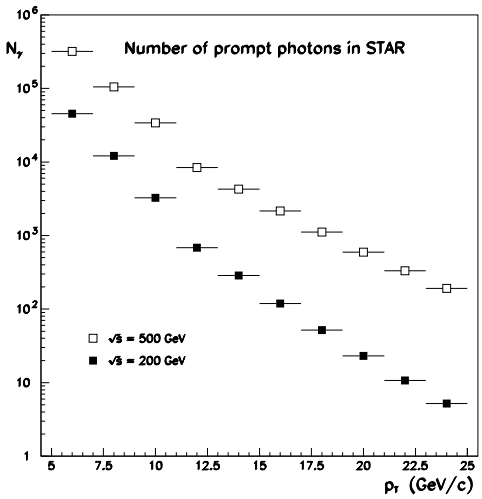


Figure 5.

Estimated rates of prompt photon production A_{LL} in polarized pp collisions at $\sqrt{s} =$ 200 GeV and $\sqrt{s} = 500$ GeV as a function of photon transverse momentum p_T. The rates are based on the expected luminosity of RHIC and the properties of the STAR detector.

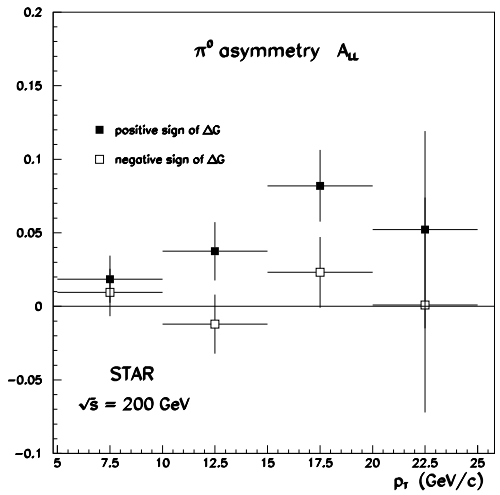


Figure 6.

Asymmetry of π^0 production A_{LL} in polarized pp collisions at $\sqrt{s} = 200$ GeV for two different sets of spin-dependent PDFs ($\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6]) as a function of π^0 transverse momentum p_T. The errors indicated are statistical only.

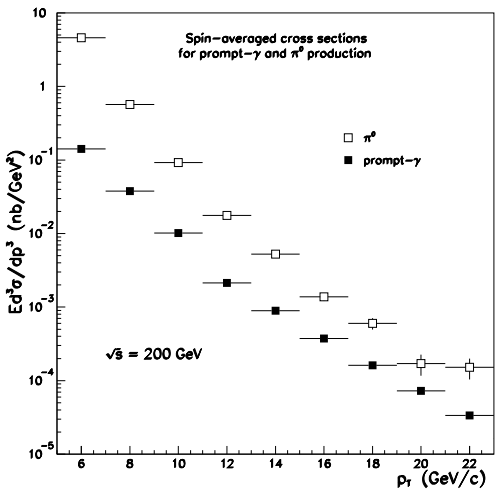


Figure 7.

Comparison of prompt photon and π^0 cross-sections in polarized pp collisions at $\sqrt{s} =$ 200 GeV as a function of transverse momentum p_T.

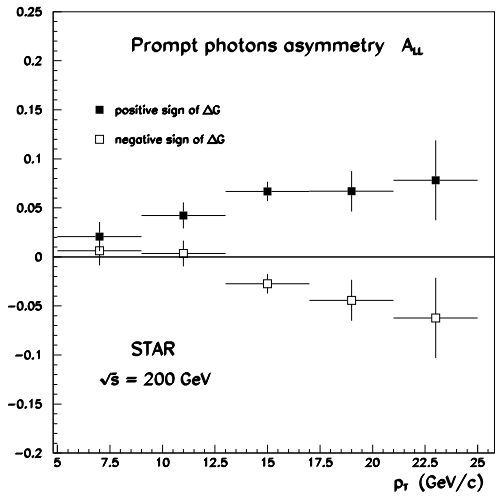


Figure 8.

Experimental asymmetry of prompt photon production A_{LL} in polarized pp collisions at $\sqrt{s} = 200$ GeV for two different sets of spin-dependent PDFs ($\Delta G^{>0}$ [6] and $\Delta G^{<0}$ [6]) as a function of photon transverse momentum p_T.