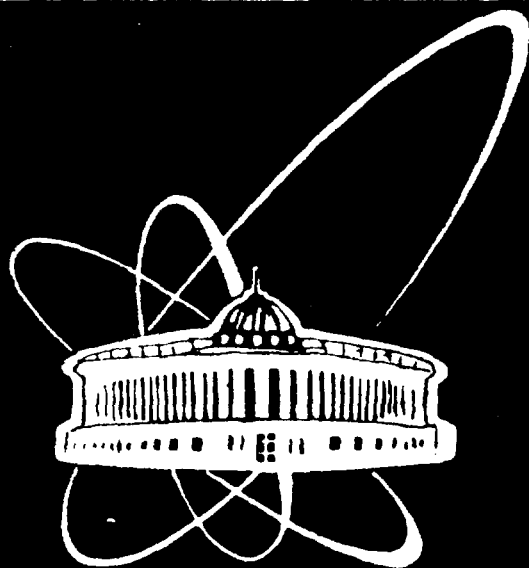




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DOUBLE-SPIN ASYMMETRY OF  $J/\psi$  PRODUCTION  
IN POLARIZED  $pp$ -COLLISIONS AT HERA- $\vec{N}$

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# 1 Introduction

The presently most accurate way to measure the polarized gluon distribution function in the nucleon is to study those processes which can be calculated in the framework of perturbative QCD (PQCD), i.e. for which the involved production cross sections and subprocess asymmetries can be predicted. One of the cleanest ways to probe QCD is to investigate heavy quarkonia production processes. Heavy quark pair production processes can be controlled perturbatively due to large mass of constituents. On the other hand, heavy quark systems are mainly produced in gluon fusion processes and therefore, asymmetries are expected to be sensitive to the polarized gluon distribution in the nucleon. Investigation of heavy quarkonia production processes in polarized experiments would also yield additional information about the quark-antiquark pair hadronization phase.

The two-spin asymmetry in  $J/\psi$  production has been studied in the framework of the so called color singlet model (CSM) [1] by Morii and collaborators [2]. But as was shown in the last years, the color singlet model does not describe satisfactorily the heavy quarkonium hadroproduction at Tevatron and also at fixed target energies. While the CSM gives a reasonable description of the  $J/\psi$  production cross section distribution shapes over  $p_T$  or  $x_F$  at fixed target energies, it completely fails in the explanation of the integrated cross section (a K factor 7-10 is needed to explain experimental data) [3]. The anomalously large cross section [4] of the  $J/\psi$  production at large transverse momenta at the Tevatron revealed another negative feature of the CSM. Within the framework of the CSM it is impossible to explain the anomalously large  $\psi$  [5] and direct  $J/\psi$  production [6] in the CDF experiment at the Tevatron.

The CSM is a nonrelativistic model where the relative velocity between the heavy constituents in the bound state is neglected. But discrepancies between experimental data and the CSM predictions hint that  $O(v)$  corrections as well as other mechanisms of quarkonium production, which do not appear in the leading order in  $v$ , should be considered. Expansion of quarkonium cross sections and decay widths in powers of relative velocity  $v$  of heavy quarks in a bound state has recently been realized in terms of Nonrelativistic QCD (NRQCD) [7]. This formalism implies not only color-singlet processes but the new color-octet mechanism, when a quark-antiquark pair is produced on small time scales in color octet states and evolves into a hadron by emission of soft gluons. The color octet mechanism takes into account the complete structure of the quarkonium Fock space while in the CSM only the dominant Fock state is considered, which consists of a color singlet quark antiquark pair in the definite angular-momentum state (higher order Fock states are suppressed by powers of  $v$ ). According to the factorization approach based on the NRQCD, the production cross section for a quarkonium state  $H$  in the process

$$A + B \rightarrow H + X \tag{1}$$

can be written as

$$\sigma_{ij} = \sum_{i,j} \int_0^1 dx_1 dx_2 f_{i/A}(x_1) f_{j/B}(x_2) \hat{\sigma}(ij \rightarrow H) \quad (2)$$

$$\hat{\sigma}(ij \rightarrow H) = \sum_n C^{ij}[n] \langle 0 | \mathcal{O}^H[n] | 0 \rangle$$

where  $f_{i/A}$  is the distribution function of the parton  $i$  in the hadron  $A$ . The subprocess cross section is separated into two parts: short distance ( $C^{ij}[n]$ ) coefficients and long distance matrix elements  $\langle 0 | \mathcal{O}^H[n] | 0 \rangle$ . The  $C^{ij}[n]$  is the production cross section of a heavy quark-antiquark pair in the  $i$  and  $j$  parton fusion. It should be calculated in the framework of pQCD. The  $[n]$  state can be either a color singlet or a color octet state. The  $\langle 0 | \mathcal{O}^H[n] | 0 \rangle$  describes the evolution of a quark-antiquark pair into a hadronic state. These matrix elements cannot be computed perturbatively. But the relative importance of long distance matrix elements in powers of velocity  $v$  can be estimated by using the NRQCD velocity scaling rules [8].

Shapes of the  $p_T$  distribution of short distance color-octet matrix elements indicate that the new mechanism can explain the Tevatron data of direct  $J/\psi$  and  $\psi'$  production at large  $p_T$  [9]. But unlike color-singlet matrix elements connected with the subsequent hadronic nonrelativistic wave functions at the origin, color octet long distance matrix elements are unknown and should be extracted from experimental data. The color octet contribution to the  $J/\psi$  photoproduction has been analyzed in the papers [10, 11]. Recently, the  $J/\psi$  hadroproduction at fixed target energies has been studied by including the color-octet mechanism [12, 13]. Large discrepancies between experimental data and the CSM predictions for the total cross section of the  $J/\psi$  hadroproduction were explained. The color octet contribution is dominant in the  $J/\psi$  hadroproduction at energies  $\sqrt{s} \simeq 30 - 60$  GeV. The analyses carried out in these papers [10, 11, 12, 13] demonstrate that fitting the photoproduction and hadroproduction data at low energies requires smaller values than those extracted from prompt  $J/\psi$  production at CDF at the Tevatron [9]. Possible reasons for such discrepancies have recently been analyzed in the papers [13, 14]. The extraction of color-octet long distance matrix elements from the quarkonium production properties in polarized experiments would be an additional test of universality.

In the present letter we consider the color octet contribution to the double spin asymmetry of  $J/\psi$  hadroproduction. Unlike the previous calculations [16] we consider  $(c\bar{c})$  color octet and color singlet pair production in  $2 \rightarrow 2$  subprocesses to obtain asymmetries at nonzero transverse momenta ( $p_T > 1.5$  GeV). Such values of  $p_T$  can not be caused by internal motion of partons in the nucleon and hence transverse momentum distributions of production cross section and asymmetries are calculable perturbatively. The double spin asymmetries in parton collisions are presented in section 2. Since heavy quarkonium is mainly produced in the gluon-gluon fusion subprocesses, the  $J/\psi$  production asymmetry should be sensitive to the polarized gluon distribution function in the proton. We have calculated the expected asymmetry of

$J/\psi$  production at HERA- $\vec{N}$ , one of the future options of HERA [15]; an experiment utilizing an internal polarized nucleon target in the polarized HERA beam with energy 820 GeV would yield  $\sqrt{s} \simeq 39$  GeV. For comparison, we also considered the expected asymmetry of  $J/\psi$  production in similar spin physics experiments at much higher energies at the RHIC collider [17].

## 2 Double Spin Asymmetries at Subprocess Level

Let us discuss the two-spin asymmetry  $A_{LL}$  for the inclusive  $J/\psi$  production which is defined as

$$A_{LL}^{J/\psi}(pp) = \frac{d\sigma(p_+p_+ \rightarrow J/\psi) - d\sigma(p_+p_- \rightarrow J/\psi)}{d\sigma(p_+p_+ \rightarrow J/\psi) + d\sigma(p_+p_- \rightarrow J/\psi)} = \frac{Ed\Delta\sigma/d^3p}{Ed\sigma/d^3p}. \quad (3)$$

where  $p_+(p_-)$  denotes helicity projection sign on the proton momentum direction.

The cross section of  $J/\psi$  production can be written as

$$\sigma_{J/\psi} = \sigma(J/\psi)_{dir} + \sum_{J=0,1,2} Br(\chi_{cJ} \rightarrow J/\psi X) \sigma_{\chi_{cJ}} + Br(\psi' \rightarrow J/\psi X) \sigma_{\psi'}, \quad (4)$$

where  $Br((c\bar{c}) \rightarrow J/\psi X)$  denotes the branching ratio of the corresponding  $(c\bar{c})$  state into  $J/\psi$ . The production of each state of quarkonium is contributed by both color octet and color singlet states, as in the case of direct  $J/\psi$  production

$$\sigma(J/\psi)_{dir} = \sigma_{J/\psi}^{singl} + \sigma_{J/\psi}^8 = \sigma(J/\psi)^{singl} + \sum \sigma(Q\bar{Q} [^{2s+1}L_J^8] \langle 0 | O_8^{J/\psi} (^{2s+1}L_J | 0 \rangle) \quad (5)$$

where the sum is over the states  $^3P_{0,1,2}^8$ ,  $^1S_0^8$  and  $^3S_1^8$ . We consider only the dominant sets of color octet states by the NRQCD velocity expansion for the direct  $S$  and  $P$  state charmonium production.

In a recent paper [16] was considered asymmetry of  $J/\psi$  hadroproduction in the color octet model exploiting only the lowest order subprocesses ( $2 \rightarrow (c\bar{c})$ ) over the QCD coupling constant. Subprocesses  $2 \rightarrow 1$  contribute only to the production of a quarkonium state at zero transverse momentum with respect to the beam axis. Transverse momentum distributions of  $(c\bar{c})$  states and, consequently, the  $J/\psi$  meson are not calculable in the  $p_T < \Lambda_{QCD}$  region. To deal with the experimentally observable quantities (taking into account the kinematic restriction on the angle with respect to the beam axis at HERA- $\vec{N}$  and at collider experiments), we consider the subprocess  $2 \rightarrow 2$  which gives the leading contribution to the quarkonium production with  $p_T$  greater than 1.5 GeV. Such large transverse momenta cannot be caused by internal motion of partons in the nucleon and, respectively, subprocesses  $2 \rightarrow 1$  should not contribute to the production of quarkonia with  $p_T > 1.5$  GeV. For calculating the expected asymmetries we consider only the following subprocesses:

$$\begin{aligned} g + g &\rightarrow (c\bar{c}) + g \\ g + q &\rightarrow (c\bar{c}) + q \end{aligned} \quad (6)$$

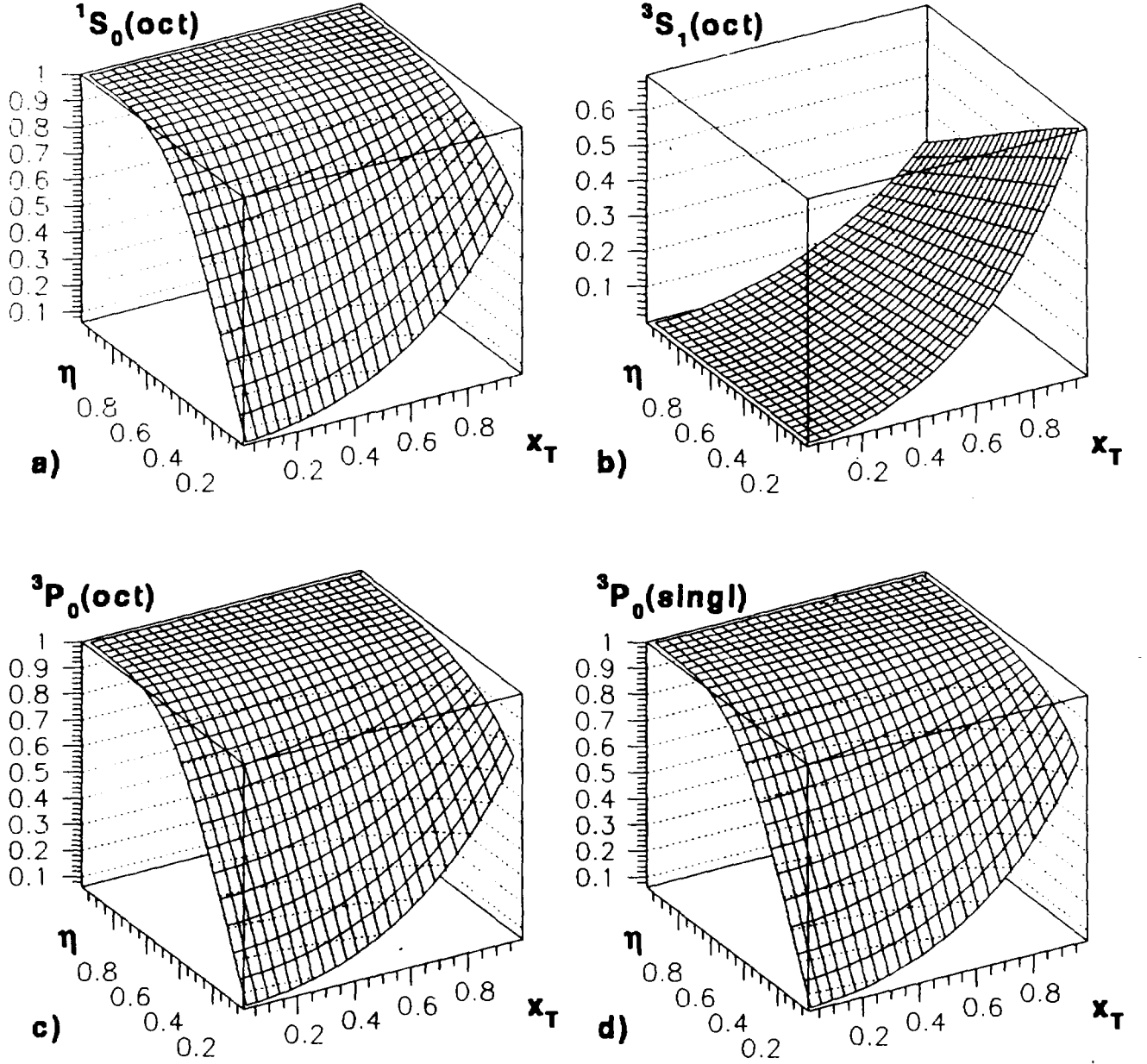


Figure 1. Partonic level double spin asymmetries for  $^1S_0$  and  $^3S_1$  color octet and  $^3P_0$  color octet and singlet states versus  $\eta$  and  $x_T$ .

for the color octet and singlet states of a  $(c\bar{c})$ -pair. The quark-antiquark collision subprocesses are not taken into account, because of small sea quark polarization in the proton.

Using the symbolic manipulation program FORM [18], we have calculated the  $(c\bar{c})$ -states production cross sections for different helicity states of colliding partons. For the color octet states total cross sections have been calculated by Cho and Leibovich [9]. The total cross sections for color singlet states are presented in [19, 20]. The latter results served for checking our calculations.

Figs.1 and 2 present the values of the subprocess level asymmetries for the color octet and color singlet states production of a  $(c\bar{c})$ -pair depending on the two dimensionless quantities:  $\eta = 4m_c^2/\hat{s}^2$  and  $x_T = p_T/p_{max}$ , where  $p_{max}$  is the maximum

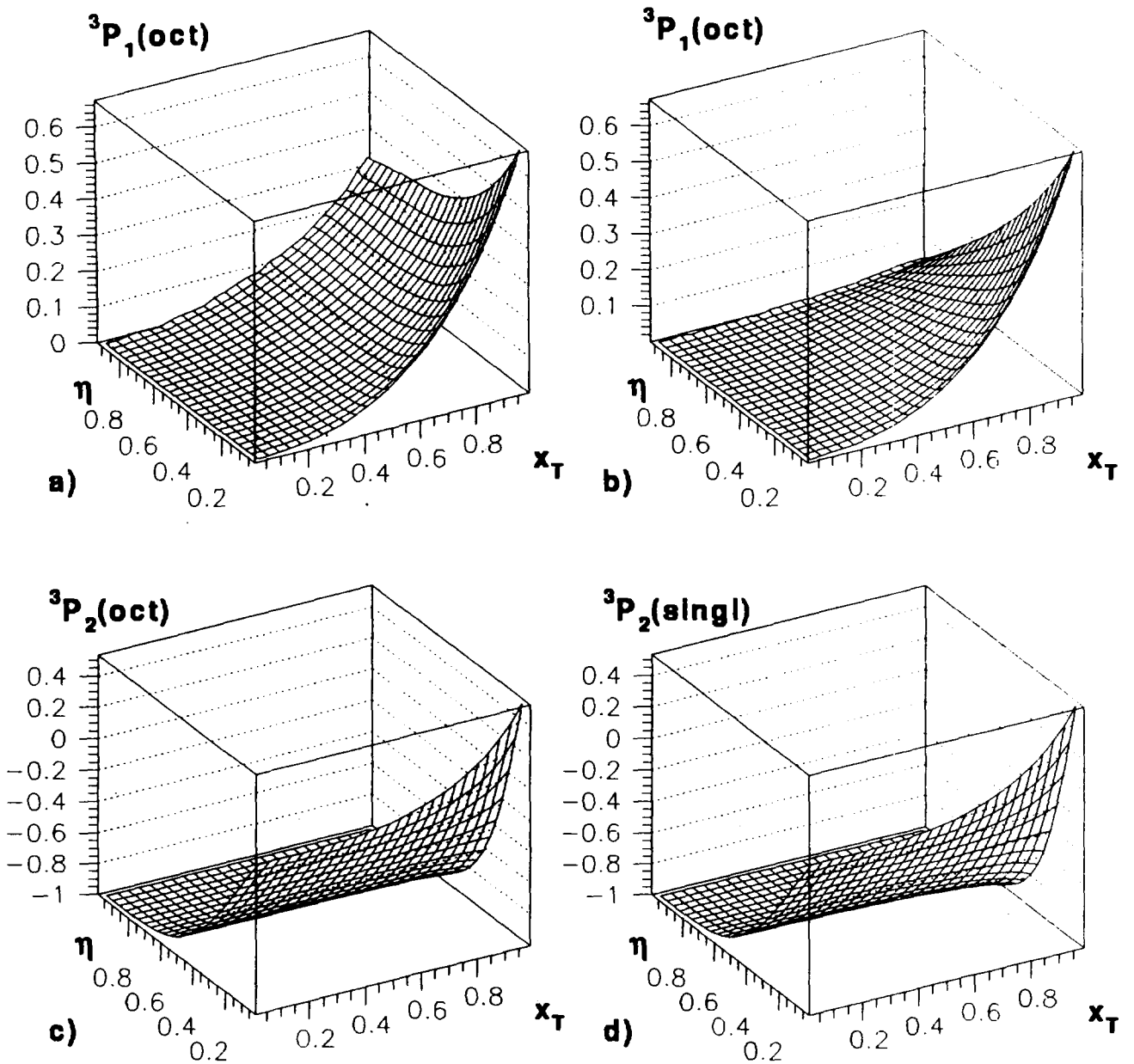


Figure 2. Partonic level double spin asymmetries for  ${}^3P_1$  and  ${}^3P_2$  color octet and singlet states versus  $\eta$  and  $x_T$ .

momentum of the produced state in the subprocess. In Figs.1 and 2 are shown only the gluon fusion subprocess asymmetries because they give the main contribution to the hadronic level asymmetry. The cases of  ${}^1S_0$  and  ${}^3S_1$  singlet states are omitted in figs.1 and 2. The  ${}^1S_0$  state does not contribute to  $J/\psi$  production and analytical expressions for the corresponding cross sections for the  ${}^3S_1$  state are given in [2].

As can be seen from figs.1 and 2, the asymmetries are very similar for color octet and color singlet states with the same spin-orbital quantum numbers. It is worth mentioning that in the limit  $4m_c^2/s \rightarrow 1$  (i.e. at the threshold of heavy quark pair production)  $\hat{a}_{LL}$  for the scalar and tensor states tends to 1 and -1, respectively. The limit  $4m_c^2 \rightarrow s$  means that the emitted gluon in the  $2 \rightarrow 2$  subprocess ( $gg \rightarrow (c\bar{c})g$ ) becomes soft and the helicity properties of the amplitude should be the same as

those of the amplitude of the  $2 \rightarrow 1$  process ( $gg \rightarrow (c\bar{c})^1$ ). It is easy to show that the asymmetries for the process  $2 \rightarrow 1$  for scalar and tensor states are 1 and -1, respectively. The existence of such limits serves as an additional test for our analytical calculations of cross sections  $\Delta\hat{\sigma}$ . for scalar and tensor states are 1 and -1, respectively. The existence of such limits serves as an additional test for our analytical calculations of cross sections  $\Delta\hat{\sigma}$ .

### 3 Matrix Elements

For the calculation of the hadronic level asymmetries of  $J/\psi$  production we used the long distance matrix elements fitted from various experimental data. All color singlet matrix elements are related to the radial quarkonium wave functions at the origin and their derivatives. As in paper [9] for this purpose we used the Buchmüller-Tye wave functions values at the origin tabulated in ref.[13]. The color octet matrix elements were fitted from the  $J/\psi$  and higher charmonium state production data in various experiments. Unfortunately, there are some discrepancies between the values of color octet matrix elements extracted from different experiments.

The number of color octet long distance matrix elements should be reduced by using the NRQCD spin symmetry relations:

$$\langle 0 | \mathcal{O}_8^H(^3P_J) | 0 \rangle = (2J + 1) \langle 0 | \mathcal{O}_8^H(^3P_0) | 0 \rangle, \quad (7)$$

$$\langle 0 | \mathcal{O}_8^{x_{cJ}}(^3S_1) | 0 \rangle = (2J + 1) \langle 0 | \mathcal{O}_8^{x_{c0}}(^3S_1) | 0 \rangle. \quad (8)$$

These relations are accurate up to  $v^2$ .

After using these relations we have only four independent matrix elements  $\langle \mathcal{O}_8^{J/\psi}(^3S_1) \rangle$ ,  $\langle \mathcal{O}_8^{x_{c1}}(^3S_1) \rangle$ ,  $\langle \mathcal{O}_8^{J/\psi}(^3P_0) \rangle$  and  $\langle \mathcal{O}_8^{J/\psi}(^1S_0) \rangle$ , which give the main contributions to the  $J/\psi$  hadroproduction cross section. For the first two parameters we used the values extracted from Tevatron data by Cho and Leibovich [9]. The other parameters, connected with the  $\psi'$  production, were also taken from [9]. As concerns the parameters  $\langle \mathcal{O}_8^{J/\psi}(^1S_0) \rangle$  and  $\langle \mathcal{O}_8^{J/\psi}(^3P_0) \rangle$ , it is possible to extract only their combination from direct  $J/\psi$  production data at Tevatron [9]:

$$\langle 0 | \mathcal{O}_8^{J/\psi}(^1S_0) | 0 \rangle + \frac{3}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}(^3P_0) | 0 \rangle = 6.6 \cdot 10^{-2} GeV^3. \quad (9)$$

Values for the other combinations are extracted from the  $J/\psi$  photoproduction and fixed target hadroproduction data [10, 11, 12, 13]

$$\begin{aligned} \langle 0 | \mathcal{O}_8^{J/\psi}(^1S_0) | 0 \rangle + \frac{7}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}(^3P_0) | 0 \rangle &= 2 \cdot 10^{-2} GeV^3 [13], \\ \langle 0 | \mathcal{O}_8^{J/\psi}(^1S_0) | 0 \rangle + \frac{7}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}(^3P_0) | 0 \rangle &= 3 \cdot 10^{-2} GeV^3 [10, 11]. \end{aligned} \quad (10)$$

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<sup>1</sup>The same reason makes the asymmetry less sensitive to the radiative corrections, than spin-averaged cross section, as K-factor is dominated by the contributions of virtual, soft and collinear gluons

If one assumes that  $\langle 0|\mathcal{O}_8^{J/\psi}(^1S_0)|0\rangle = \langle 0|\mathcal{O}_8^{J/\psi}(^3P_0)|0\rangle/m_c^2$  the photoproduction and fixed target hadroproduction values ('low energy' values) are an order smaller than the Tevatron value ('high energy' value). The possible sources for such a discrepancy are discussed in [13, 14]. In paper [13] it is mentioned that the mass of the produced hadronic final state (or intermediate color octet state) must be higher than that of the  $J/\psi$  meson –  $M_{J/\psi} = 2m_c$ , because the intermediate octet state emits gluons with energy  $2m_c v^2$  before transition into a color singlet state. But a charmonium is not a truly nonrelativistic system, the average relative velocity of constituents in  $J/\psi$  is not very small —  $v^2 \simeq 0.23 - 0.3$  and emitted gluons in the  $c\bar{c}$  pair hadronization phase have the energy  $0.7 \div \text{GeV}$ . Therefore the mass of the hadronic final state is about 4 GeV. At fixed target energies, increasing the mass of the produced hadronic state leads to a reduced partonic luminosity because of a steeply falling gluon distribution function. Consequently, the production cross section of the  $(c\bar{c})$  color octet state should be smaller. So, the 'true' color octet long distance matrix elements must be larger, than those extracted by using  $M_{J/\psi}$  as mass of the intermediate octet state [13].

Another possible source was mentioned in the paper [14] and should be an uncertainty connected with the choice of different parametrizations for the gluon distribution function in fitting the direct  $J/\psi$  production data at CDF [9]. Cho and Leibovich used in their calculations the MRSD0 parametrization for parton distribution functions. At small values of  $p_T \simeq 5 \text{ GeV}$ , using a more reliable parametrization for small partonic  $x$  (GRV LO or GRV HO[21]) leads to 1.5  $\div$  1.6 times higher cross sections for the  $^3P_0$  and  $^1S_0$  color octet state production than those obtained by using MRSD0 parametrization [9]. Hence the fitted value of combination (9) should be approximately 1.5  $\div$  1.6 times smaller:

$$\langle 0|\mathcal{O}_8^{J/\psi}(^1S_0)|0\rangle + \frac{3}{m_c^2}\langle 0|\mathcal{O}_8^{J/\psi}(^3P_0)|0\rangle = 4 \div 4.4 \cdot 10^{-2} \text{GeV}^3 [14]. \quad (11)$$

At large  $p_T \simeq 10 \div 15 \text{ GeV}$  all parametrizations give practically the same magnitude for the color octet states cross sections. Hence if we use the new combination (11) one needs a larger value of the parameter  $\langle 0|\mathcal{O}_8^{J/\psi}(^3S_1)|0\rangle$  to explain the experimental data for the  $J/\psi$  cross section at  $p_T \simeq 10 \div 15 \text{ GeV}$ :

$$\langle 0|\mathcal{O}_8^{J/\psi}(^3S_1)|0\rangle \simeq 10 \cdot 10^{-3} \text{GeV}^3. \quad (12)$$

Practically the same values for these parameters were obtained by Beneke and Krämer in a recent paper by fitting the CDF data of direct  $J/\psi$  production and using the GRV LO (1994) parametrization [22]:

$$\langle 0|\mathcal{O}_8^{J/\psi}(^3S_1)|0\rangle = 1.06 \pm 0.14_{-0.59}^{+1.06} \cdot 10^{-2} \text{GeV}^3, \quad (13)$$

$$\langle 0|\mathcal{O}_8^{J/\psi}(^1S_0)|0\rangle + \frac{3.5}{m_c^2}\langle 0|\mathcal{O}_8^{J/\psi}(^3P_0)|0\rangle = 3.9 \pm 1.15_{-1.07}^{+1.46} \cdot 10^{-2} \text{GeV}^3. \quad (14)$$



For calculations of the hadronic level asymmetries we use three different sets for the three long-distance color octet matrix elements

$$\begin{aligned}
A) \quad & -\langle 0 | \mathcal{O}_8^{J/\psi}({}^3S_1) | 0 \rangle = 6.6 \cdot 10^{-3} \text{GeV}^{-3} [9], \\
& \langle 0 | \mathcal{O}_8^{J/\psi}({}^1S_0) | 0 \rangle + \frac{3}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}({}^3P_0) | 0 \rangle = 6.6 \cdot 10^{-2} \text{GeV}^3 \quad [9]; \\
B) \quad & -\langle 0 | \mathcal{O}_8^{J/\psi}({}^3S_1) | 0 \rangle = 6.6 \cdot 10^{-3} \text{GeV}^{-3} [9], \\
& \langle 0 | \mathcal{O}_8^{J/\psi}({}^1S_0) | 0 \rangle + \frac{3}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}({}^3P_0) | 0 \rangle = 3 \cdot 10^{-2} \text{GeV}^3 \quad [13]; \\
C) \quad & -\langle 0 | \mathcal{O}_8^{J/\psi}({}^3S_1) | 0 \rangle = 10 \cdot 10^{-3} \text{GeV}^{-3} [14], \\
& \langle 0 | \mathcal{O}_8^{J/\psi}({}^1S_0) | 0 \rangle + \frac{3}{m_c^2} \langle 0 | \mathcal{O}_8^{J/\psi}({}^3P_0) | 0 \rangle = 4 \cdot 10^{-2} \text{GeV}^3 \quad (11);
\end{aligned}$$

As has been mentioned above, values for the other color octet parameters were taken from [9]. For the calculations of the expected asymmetries we assume that the leading term in the combination (11) is the parameter  $\langle \mathcal{O}_8^{J/\psi}({}^1S_0) \rangle$  (or  $\langle \mathcal{O}_8^{J/\psi}({}^3P_0) \rangle = 0$ ). Only with such a radical choice the values of 'high' and 'low' energy parameters should be consistent to each other.

## 4 Results and Discussion

Fig. 3a presents the expected asymmetries for the three sets of color octet parameters in the case when the parameter  $\langle \mathcal{O}_8^{J/\psi}({}^3P_0) \rangle$  tends to zero ( $\langle \mathcal{O}_8^{J/\psi}({}^1S_0) \rangle$  is the leading term in the combinations (9),(10),(11)). Fig. 3b represents the other radical choice, when the second parameter  $\langle \mathcal{O}_8^{J/\psi}({}^1S_0) \rangle$  is zero. For the calculations of hadronic level asymmetries we used the GRV LO parametrization for unpolarized distribution functions [21] and a parametrization proposed by Gehrmann and Stirling for the polarized parton distribution function (set A) [23]. For the mass of the charm quark the value  $m_c = 1.48 \text{ GeV}$  was taken. As we can see from Fig.3, the magnitude of the asymmetry is more sensitive to the choice of the leading term in the combinations than to the choice of the particular set of the octet matrix elements. Recently the color octet matrix elements  $\langle \mathcal{O}_8^{J/\psi}({}^3P_0) \rangle$  and  $\langle \mathcal{O}_8^{J/\psi}({}^1S_0) \rangle$  have been extracted separately from the  $J/\psi$  electroproduction data [24].

$$\begin{aligned}
\langle 0 | \mathcal{O}_8^{J/\psi}({}^1S_0) | 0 \rangle &= 4 \cdot 10^{-2} \text{GeV}^3, \\
\frac{\langle 0 | \mathcal{O}_8^{J/\psi}({}^3P_0) | 0 \rangle}{m_c^2} &= -0.3 \cdot 10^{-2} \text{GeV}^3.
\end{aligned} \tag{15}$$

These values confirm our assumption that the leading term in the combinations is the parameter  $\langle \mathcal{O}_8^{J/\psi}({}^1S_0) \rangle$ . In fig.3a, the dotted-dashed curve corresponds to the

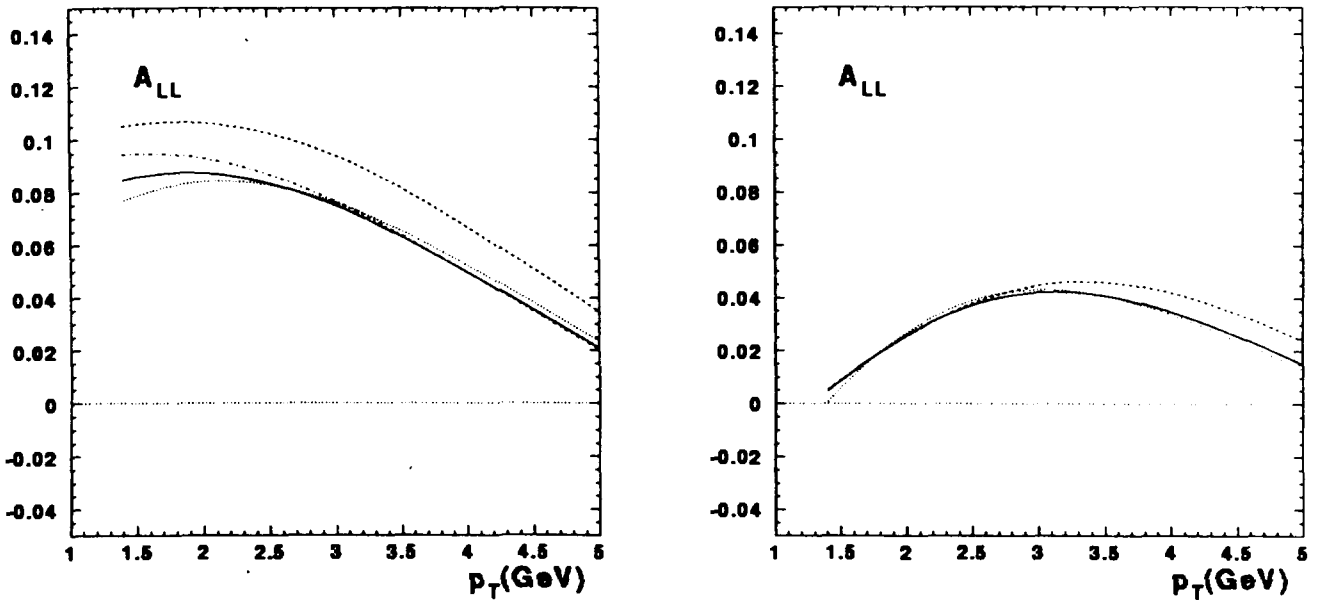


Figure 3. The double spin asymmetries for different sets of color-octet long distance parameters. Solid line corresponds to set C, dashed line – set A, dotted line – set B; (a) for the case when  $\langle 0_{8}^{J/\psi}(^3P_0) \rangle = 0$ , (b) for  $-\langle 0_{8}^{J/\psi}(^1S_0) \rangle = 0$ . Dot-dashed line in Fig.a corresponds to asymmetry calculated by using values of parameters from [24].

asymmetry calculated by using the values of the long-distance parameters (15). For the parameter  $\langle 0_{8}^{J/\psi}(^3S_1) \rangle$  a value from set C was used. As one can see from fig.3a, the expected asymmetries calculated by using set C of parameters and the values extracted from the  $J/\psi$  electroproduction data are practically the same. In the following calculations we shall use the set C for the values of the parameters, assuming  $\langle 0 | \mathcal{O}_{8}^{J/\psi}(^3P_0) | 0 \rangle = 0$ . Fig.4a shows the expected double spin asymmetries at HERA- $\vec{N}$  energies as functions of transverse momentum  $J/\psi$  in the c.m.s. The solid curve corresponds to the Gehrman and Stirling parametrization for polarized distribution functions, set A; the dashed curve, to set C [23]. In fig.4a we also display the expected statistical errors  $\delta A_{LL}$  at HERA- $\vec{N}$  which can be estimated from [15]

$$\delta A_{LL} = 0.17 / \sqrt{\sigma(pb)}. \quad (16)$$

This relation has been determined by assuming an integrated luminosity of  $240 \text{ pb}^{-1}$  and beam and target polarizations  $P_B = 0.6$ ,  $P_T = 0.8$  [15]. The error bars are obtained by using integrated cross sections over bins  $\Delta p_T = 0.5 \text{ GeV}$  (for the first three points) and  $\Delta p_T = 1 \text{ GeV}$  (for the other two ones). The  $J/\psi$  decay branching ratio into the  $e^+e^-$  mode is also included. The magnitude of asymmetries and expected errors allows one to distinguish between different parametrizations of polarized parton distribution functions. Fig.4b shows expected asymmetries depending on the pseudorapidity of  $J/\psi$  at  $p_T = 2 \text{ GeV}$ . Statistical error bars correspond to the integrated cross section over bins  $\Delta \eta = 1$  and  $\Delta P_T = 0.5 \text{ GeV}$ . As in the previous case, the errors are small in a wide range of pseudorapidity interval and give

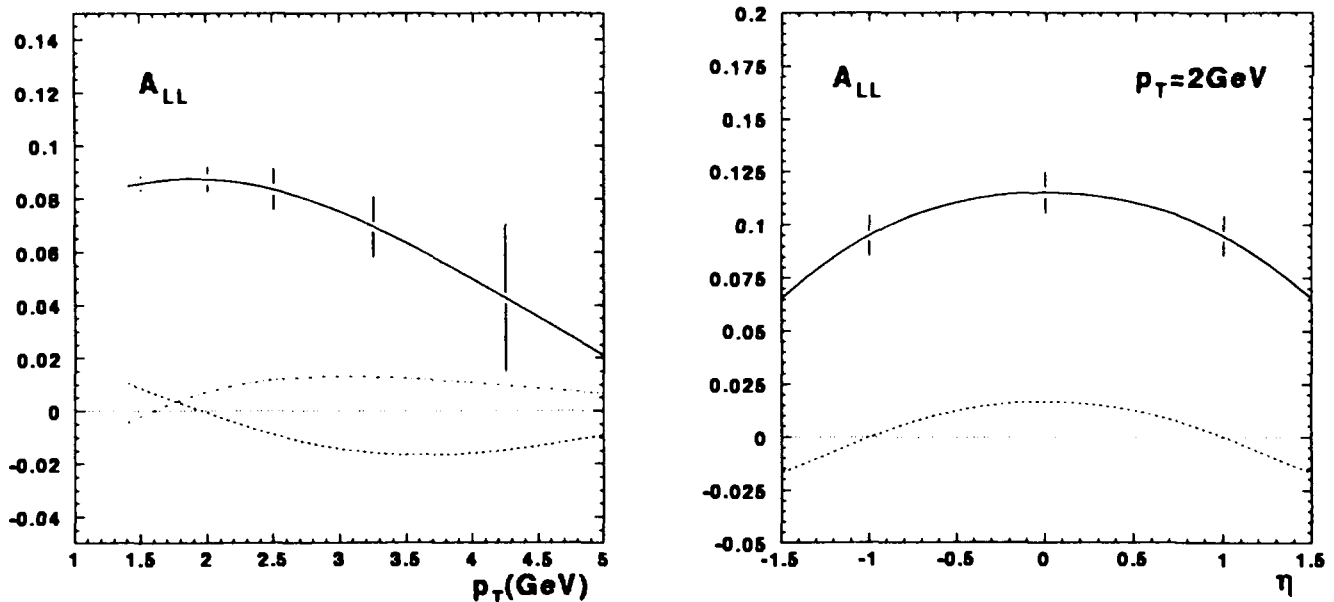


Figure 4. The expected asymmetries at  $\sqrt{s} = 39$  GeV. Solid line corresponds Gehrman-Stirling polarized parton parametrization, set A; dashed line, set C [23]. (a) expected asymmetries versus transverse momentum, (b) versus pseudorapidity of  $J/\psi$ . Dot-dashed curve in the fig.a corresponds to the color-singlet contribution to asymmetry.

a possibility to distinguish between different parametrizations for  $\Delta g(x)$ . It is worth mentioning that gluon-quark collision subprocesses give about  $5 \div 10\%$  in  $\Delta\sigma$ . The dot-dashed curve in fig.4a represents the color-singlet contribution to the asymmetry for the parametrization set A. It is clear that the color octet contribution dominates in the expected asymmetries of  $J/\psi$  production. One may ask, where the such a difference is coming from, as the subprocess asymmetries are not sensitive to colour structure. The main reason for this is the large matrix element  $\langle 0|O_8^{J/\psi}(^1S_0)|0\rangle$ . The production of such a state has a large asymmetry  $A \sim 1$  (at  $\eta \sim 1$ , which is not far from the reality for the considered  $p_T$ ), providing the smooth transition to  $2 \rightarrow 1$  process, discussed above. As such a state is absent in CSM, the large asymmetry itself is already a sign of a presence of colour-octet contribution.

One of main parameters of the model is the mass of the charm quark. Fig.5 shows the asymmetries of  $J/\psi$  production depending on  $m_c$  for two values of  $p_T$  for a large set of polarized parton parametrizations (set A). As displayed in fig.5, the expected asymmetries are practically insensitive to the quark mass above  $m_c = 1.5$  GeV. Therefore, the double spin asymmetry of  $J/\psi$  production, unlike the cross section, should be free from uncertainties caused by a unknown mass of the intermediate color octet states.

For comparison we have also calculated the expected double-spin asymmetries of  $J/\psi$  production at RHIC energies. The results are given in Fig.6 for two different values of energy. The expected statistical errors are calculated with the anticipated the integrated luminosities at the corresponding energies. As we can see from Fig.6,

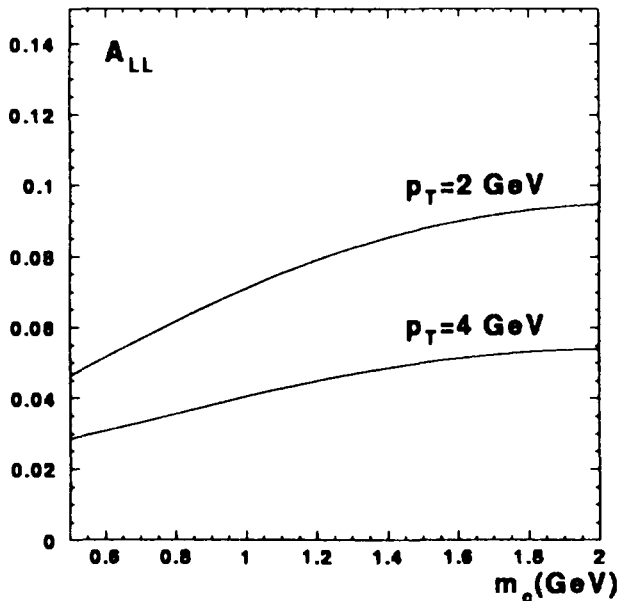


Figure 5. Expected double-spin asymmetries at  $\sqrt{s} = 39$  GeV versus mass of charm quark.

the expected asymmetry decreases with increasing c.m.s. energy. The statistical errors are calculated by integration over  $p_T$  with bins  $\Delta p_T = 0.5$  GeV of the differential cross sections.

## 5 Conclusions

In this paper we investigated the expected double spin asymmetries of heavy quarkonium hadroproduction at HERA- $\vec{N}$ . To deal with experimentally observed quantities, we considered  $J/\psi$  meson production at nonzero transverse momenta,  $p_T > 1.5$  GeV. Unlike the calculations of [16], where only the lowest order subprocesses were taken into account ( $2 \rightarrow 1$ ), we considered  $J/\psi$  production in the subprocesses  $2 \rightarrow 2$  because large values of  $p_T$  can not be caused by internal motion of partons. We have calculated the heavy quark pair color octet and color singlet  $S$  and  $P$  states production cross sections for different helicities of colliding partons. The FORTRAN codes for calculated cross sections are available by E-mail. For calculation of the expected hadronic asymmetries we used more reliable values for the color-octet long distance matrix elements, which are in good agreement with those extracted from the  $J/\psi$  electroproduction data [24].

The magnitude of expected asymmetries and statistical errors at HERA- $\vec{N}$  allows one to distinguish between different parametrizations for polarized parton distribution functions (Gehrmann and Stirling, set A and C). On the other hand, measuring the asymmetry would give a possibility to extract information about the color-octet long distance matrix elements and to check universality of factorization. We also calculated the  $J/\psi$  production asymmetries at RHIC energies. By comparing the magnitudes of

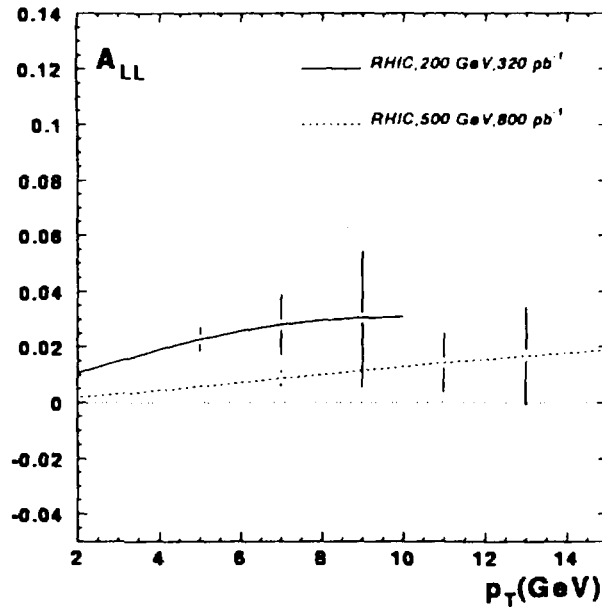


Figure 6. Expected asymmetries and statistical errors at the RHIC for two different energies.

the expected asymmetries at HERA- $\vec{N}$  and STAR, it becomes clear that the energy of the fixed target experiment is more preferable for the investigation of the charmonium production asymmetry.

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Двухспиновые асимметрии при образовании  $J/\psi$ -мезона  
в поляризованных  $pp$ -соударениях на установке HERA- $\vec{N}$

Исследованы двухспиновые асимметрии для образования чармония в протон-протонных соударениях. Показано, что вклад октетного механизма — доминирующий в ожидаемой асимметрии. Уровень асимметрии и ожидаемых статистических ошибок на установке HERA- $\vec{N}$  позволит извлечь информацию о распределении поляризованных глюонов в протоне  $-\Delta g(x)$ . Показано, что наиболее подходящими для наблюдения двухспиновых асимметрий при образовании  $J/\psi$ -мезона являются энергии фиксированной мишени ( $\sqrt{s} = 39$  ГэВ для HERA- $\vec{N}$ ).

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Double-Spin Asymmetry of  $J/\psi$  Production  
in Polarized  $pp$ -Collisions at HERA- $\vec{N}$

We calculated the color-octet contribution to the double spin asymmetry of  $J/\psi$  hadroproduction with nonzero transverse momenta at fixed target energies  $\sqrt{s} \simeq 40$  GeV. It is shown that color-octet contribution is dominant in the asymmetries. The expected asymmetries and statistical errors in a future option of HERA with longitudinally polarized protons at  $\sqrt{s} = 39$  GeV (HERA- $\vec{N}$ ) should allow one to distinguish between different parametrizations for polarized gluon distribution in proton.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

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