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Double Spin Asymmetries in Charmonium Hadroproduction at HERA-$\vec{N}$[1]

W.-D. NOWAK[a], O. TERYAEV[b], A. TKABLADZE[a,b]

[a] *DESY-IfH Zeuthen, Germany*

[b] *Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, Russia*

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Abstract

We discuss the double spin asymmetries in charmonium hadroproduction with nonzero transverse momenta at fixed target energies, $\sqrt{s} \simeq 40$ GeV, within the framework of the factorization approach. It is shown that the color octet contribution is dominant in the asymmetries. The size of the asymmetries and the projected statistical errors in a future option of HERA with longitudinally polarized protons scattering off a polarized target (HERA-$\vec{N}$) should allow to distinguish between different parametrizations for the polarized gluon distribution in the proton.

1 Introduction

The study of spin asymmetries in the production of heavy quarkonium states in polarized nucleon-nucleon collisions should provide important information about the proton spin structure. Heavy quark-antiquark production processes occur at small distances and the subprocess level cross sections can be calculated perturbatively. On one hand, charmonium production asymmetries are expected to be sensitive to the polarized gluon distribution function in the proton, since heavy quark systems are mainly produced in gluon-gluon fusion subprocesses. On the other hand, it is essential to investigate in more detail the heavy quark-antiquark pair hadronization phase. To this end, observation of charmonium production in polarized experiments is expected to provide additional tests for existing models.

The double spin asymmetry in J/ψ production has been studied in the framework of the so-called color singlet model (CSM) [1] by Morii and collaborators [2]. The CSM is a nonrelativistic model where the relative velocity, v, between the heavy constituents in a bound state is neglected. However, discrepancies between experimental data [3-10] and the CSM predictions indicate 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. Such an expansion of the quarkonium cross sections and decay widths has been realized in the last few years within the framework of the

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Factorization Approach (FA) based on Nonrelativistic QCD (NRQCD) [11]. Here the production cross section for a quarkonium state H in the process

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

can be written as

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

where $f_{i/A}$ is the distribution function of the parton i in the hadron A, and

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

the subprocess cross section, is separated into two parts: short distance coefficients, $C^{ij}[n]$, 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 by fusion of partons i and j. It can 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 using the NRQCD velocity scaling rules [12]. Unlike the color singlet long distance matrix elements, each connected with the subsequent hadronic nonrelativistic wave function at the origin, color octet long distance matrix elements are unknown and should be extracted from experimental data.

The new formalism implies that quark-antiquark color octet intermediate states are allowed to contribute to heavy quarkonium production and decay processes at higher order in the velocity expansion. Therefore, in the Color Octet Mechanism (COM) the complete structure of the quarkonium Fock space is taken into account while in the CSM only the dominant Fock state is considered, which consists of a color singlet quark-antiquark pair in a definite angular-momentum state of a final hadron (the leading term in the velocity expansion).

The shape of the p_T distribution of the ${}^3S_1^{(8)}$ octet state production cross section indicates that J/ψ and ψ' production at large p_T observed at the Tevatron (FNAL) can be explained in the FA [10, 13]. The color octet contribution to J/ψ photoproduction has been analyzed in papers [14, 15]. Recently, J/ψ hadroproduction at fixed target energies has been studied by including the color octet mechanism [16, 17, 18]. Large discrepancies between experimental data and the CSM predictions for the total cross section of J/ψ hadroproduction were explained. The color octet contribution is dominant in J/ψ hadroproduction at energies $\sqrt{s} \simeq 30 \div 60$ GeV. The COM prediction for the ratio $\sigma(J/\psi)_{dir}/\sigma(J/\psi) \simeq 0.6$ is also in a good agreement with experimental data [19].

Despite the obvious successes of the COM some problems remain unsolved. In particular, the theoretical predictions disagree with the J/ψ and ψ' polarization data at fixed target energies [17, 19] and the COM prediction for the yield ratio of χ_{c1} and χ_{c2} states remains too low [17]. These discrepancies indicate that higher twist corrections may give a significant contribution to low p_T production of charmonium states and should be added to the color octet contributions [20]. The color octet contribution underestimates the J/ψ photoproduction cross section at large values of z ($z = E_{J/\psi}/E_\gamma$ in the laboratory frame) [21].

The NRQCD factorization approach implies universality, i.e. the values of long distance matrix elements extracted from the different experimental data must be the same. However, due

to the presently rather large theoretical uncertainties, the existing experimental data does not allow to check the FA universality and therefore to test the COM.

This fact motivated us to look for other processes with less theoretical uncertainties to test the color octet mechanism. The observation of J/ψ asymmetries can be used for these purposes as well as measurements of the J/ψ polarization in unpolarized hadron-hadron collisions and electroproduction [20, 22, 23].

In this talk we consider the possibility of extracting information about the gluon polarization in the nucleon through spin asymmetries in charmonium production. And conversely, we investigate what can be learned from charmonium production asymmetries about color octet long distance matrix elements, if the polarized gluon distribution function should once be measured in other experiments.

Finally, we will present the results of our calculation of the expected spin asymmetries in production of J/ψ and χ_{cJ} states at HERA-$\vec{N}$, one of the future options of HERA [24]; an experiment utilizing an internal polarized nucleon target in the polarized HERA beam with energy 820 GeV would yield $\sqrt{s} \simeq 40$ GeV. To avoid the uncertainties coming from higher twist subprocesses [20] we considered J/ψ production at large enough p_T which can not be caused by internal motion of partons within the nucleon.

2 Matrix Elements

We consider the double spin asymmetry A_{LL} in inclusive charmonium state production defined as

$$A_{LL}^H(pp) = \frac{d\sigma(p_+p_+ \to H) - d\sigma(p_+p_- \to H)}{d\sigma(p_+p_+ \to H) + d\sigma(p_+p_- \to H} = \frac{Ed\Delta\sigma/d^3p}{Ed\sigma/d^3p}, \tag{3}$$

where $p_+(p_-)$ stands for the sign of the helicity projection onto the proton momentum direction and H denotes the particular charmonium state. The production of each quarkonium state receives contributions from both color singlet and color octet quark-antiquark pair states. We consider here only the dominant sets of color octet states in the NRQCD velocity expansion for direct S and P state charmonium production. Hence we calculated the production asymmetries for the color octet states ${}^3P_{0,1,2}^8$, ${}^1S_0^8$ and ${}^3S_1^8$ together with those for color singlet states.

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

$$\langle 0|\mathcal{O}_8^H({}^3P_J)|0\rangle = (2J+1)\langle 0|\mathcal{O}_8^H({}^3P_0)|0\rangle, \tag{4}$$

$$\langle 0|\mathcal{O}_8^{\chi_{cJ}}({}^3S_1)|0\rangle = (2J+1)\langle 0|\mathcal{O}_8^{\chi_{c0}}({}^3S_1)|0\rangle, \tag{5}$$

which are accurate up to v^2.

After having utilized these relations we remain with the three independent color octet matrix elements $\langle \mathcal{O}_8^{J/\psi}({}^3S_1)\rangle$, $\langle \mathcal{O}_8^{J/\psi}({}^3P_0)\rangle$, and $\langle \mathcal{O}_8^{J/\psi}({}^1S_0)\rangle$ which give the main contributions to the direct J/ψ hadroproduction cross section. There is only one color octet matrix element $\langle \mathcal{O}_8^{\chi_{c1}}({}^3S_1)\rangle$ which contributes to χ_{cJ} states production at lowest order.

As was mentioned above, the values of the matrix elements extracted from the fixed target experiment's data contain large theoretical uncertainties. In our further calculations we will use the following values for the three main matrix elements extracted from J/ψ production at CDF at the Tevatron using the GRV LO (1994) [25] parametrization for unpolarized parton densities

[22]:

$$\langle 0|\mathcal{O}_8^{J/\psi}(^3S_1)|0\rangle = 1.06 \pm 0.14^{+1.05}_{-0.59} \cdot 10^{-2} GeV^3, \quad (6)$$

$$\langle 0|\mathcal{O}_8^{J/\psi}(^1S_0)|0\rangle + \frac{3.5}{m_c^2}\langle 0|\mathcal{O}_8^{J/\psi}(^3P_0)|0\rangle = 3.9 \pm 1.15^{+1.46}_{-1.07} \cdot 10^{-2} GeV^3 \quad (7)$$

The second errors quoted in these expressions correspond to the variation of the factorization scale μ from $0.5\sqrt{p_T^2 + 4m_c^2}$ to $2\sqrt{p_T^2 + 4m_c^2}$. From the errors indicated in (6) and (7) it is obvious that the variation of the renormalization and/or factorization scale also leads to large uncertainties when fitting the color octet parameters.

The fit results for long distance color octet matrix elements can be affected also by higher v^2 corrections. In particular, large uncertainties emerge when the matrix element $\langle O_8^{J/\psi}(^3S_1)\rangle$ is extracted from the data on J/ψ production at large p_T at the Tevatron. In fitting the CDF data the energy of soft gluons emitted by a heavy quark-antiquark pair before transition into J/ψ is usually neglected [13, 22, 26] and, consequently, the fragmentation function of a gluon into J/ψ on the scale $2m_c$ has the form:

$$D_{g\to\psi}(z, 2m_c) = \frac{\pi\alpha_s(2m_c)}{24m_c^3}\delta(1-z)\langle O_8^{J/\psi}(^3S_1)\rangle. \quad (8)$$

Here the delta function implies that the J/ψ carries the whole energy of the fragmenting gluon. If the nonzero energy of the soft gluons (of order $m_c v^2$) is taken into account the fragmentation function becomes softer. Hence the realistic cross section is smaller at large p_T and the fit value of the $\langle O_8^{J/\psi}(^3S_1)\rangle$ matrix element appears about a factor of two larger [27, 28, 29, 30]. Therefore, care is required when using the value for this parameter extracted from CDF data at fixed target energies. Also, the uncertainty connected to the 'trigger bias' effect makes it impossible to use this value for testing the NRQCD universality.

For indirect J/ψ production via decay of the underlying ψ' state and for production of χ_{cJ} states we use the following values fitted from CDF data:

$$\langle \mathcal{O}_8^{\chi_{c1}}(^3S_1)\rangle = 9.8 \cdot 10^{-3} GeV^3 [13], \quad (9)$$

$$\langle \mathcal{O}_8^{\psi'}(^3S_1)\rangle = 0.46 \cdot 10^{-2} GeV^3 [22], \quad (10)$$

$$\langle \mathcal{O}_8^{\psi'}(^1S_0)\rangle + \frac{3.5}{m_c^2}\langle \mathcal{O}_8^{\psi'}(^3P_0)\rangle = 1.8 \cdot 10^{-2} GeV^3 [22]. \quad (11)$$

For the calculation of the expected asymmetries we assume that the first parameter is dominating in eq. (11). In this case the discrepancy between the COM predictions and experimental data on ψ' polarization appears to be smallest [19].

3 Results and Discussion

Asymmetries in production of quark-antiquark states. The characteristic value of the partonic x in the production of $(c\bar{c})$ pairs can be obtained from the relation $x_1 x_2 \simeq (4m_c^2 + p_T^2)/S$ ($\simeq 0.01$ at HERA-$\vec{N}$). This means that the typical values of x_{gluon} which can be probed by measuring the spin asymmetry in charmonium production is about $x_{gluon} \simeq 0.1$. We used three parametrizations for polarized parton distribution functions (PDF) that are different in the region $x \simeq 0.1$ to show the dependence of spin asymmetries in the production of various quark-antiquark pair states on the gluon polarization in the nucleon: the old

version of the Gehrmann-Stirling (GS) parametrization (set A) [31] (as example of a large gluon polarization) and the new version of the GS parametrizations in NLO and LO (both set A) [32] (as examples for moderate gluon polarizations peaking at different values of x_{gluon}).

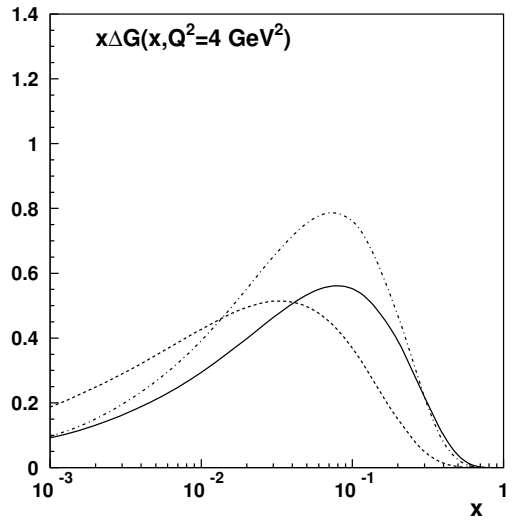

Figure 1: Different possible polarized gluon distributions in the nucleon, used in this paper at $Q^2 = 4$ GeV: new GS parametrization NLO set A (solid line), LO set A (dashed line) [32] and old GS parametrization (set A) (dash-dotted) [31].

In Fig.1 the polarized gluon densities from these parametrizations are shown at $Q^2 = 4$ GeV (note that the polarized gluon distribution functions of NLO set B and LO set A practically coincide at this value of Q^2). As can be seen from Fig.1, the three chosen sets exhibit different values for the polarized gluon distribution function for the partonic x near 0.1. We note that, although the calculations of subprocess level cross sections are performed in leading order, the NLO set of the parametrization was used to probe different shapes of the polarized gluon distribution function.

Fig.2 shows the expected asymmetries for different states of a heavy quark-antiquark pair at $\sqrt{s} = 40$ GeV (HERA-$\vec{N}$). The asymmetries for ${}^1S_0^{(8)}$ and ${}^3S_1^{(8)}$ octet states are represented by solid and dotted lines, respectively. The dashed lines correspond to combined asymmetries of ${}^3P_J$ octet states, $\sum_{J=0,1,2}(2J+1){}^3P_J^{(8)}$. The dash-dotted lines show asymmetries of J/ψ production in the CSM including J/ψ production through decays of higher charmonium states (ψ' and χ_{cJ}). For unpolarized parton distribution functions we used the GRV LO parametrization [25].

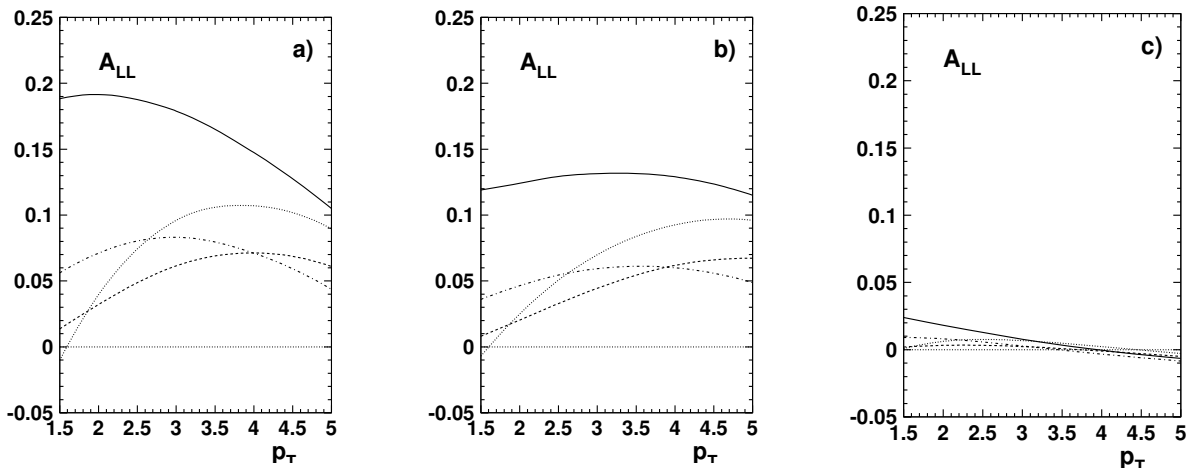

Figure 2: The expected asymmetries at HERA-$\vec{N}$ ($\sqrt{s} = 40$ GeV) for the production of different color octet states. Solid lines represent asymmetries for the ${}^1S_0^{(8)}$ state, dashed lines for the combination of ${}^3P_J^{(8)}$ states (see text), dash-dotted lines for the ${}^3S_1^{(8)}$ octet state, and dotted lines correspond to J/ψ production in the CSM. The three figures base upon different input distributions: a) old GS parametrization (set A) [31], new version of GS parametrization b) NLO set A, and c) LO set A [32].

In all three parametrizations for the polarized PDF the gluon-gluon fusion gives the dominant

contribution to $\Delta\sigma$; quark-gluon subprocesses contribute only to about 10% and the contribution of quark-antiquark annihilation subprocesses is less than 1%.

As can be seen from Fig.2, the expected asymmetries for all states strongly depend on the size of the polarized gluon distribution function in the region $x_{gluon} \simeq 0.1$.

Measurement of the inclusive J/ψ asymmetry. In the inclusive case the kinematics of the $2 \to 2$ subprocess cannot be reconstructed completely. Hence only indirect information on the gluon polarization in the nucleon can be obtained by measuring the spin asymmetry in inclusive J/ψ production.

Figure 3 shows the expected double spin asymmetries at HERA-$\vec{N}$ energy as a function of J/ψ transverse momentum. From now on we use the new GS parametrization, sets A,B, and C [32]. For the mass of the charm quark the value $m_c = 1.48$ GeV was taken and the parton distribution functions are evaluated on the factorization scale $\mu = \sqrt{p_T^2 + 4m_c^2}$. The strong coupling constant is calculated by the one-loop formula with 4 active flavors ($\Lambda_{QCD} = 200$ MeV).

Fig.3a corresponds to the case when the first parameter in the combination (7), $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$, is dominating, i.e. $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$=0. Fig.3b corresponds to the opposite case, $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$=0. In both cases we use for the third main parameter the value $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle = 20 \cdot 10^{-3} GeV^3$ (the sensitivity of asymmetries to the value of this parameter will be considered below). Figures 3a

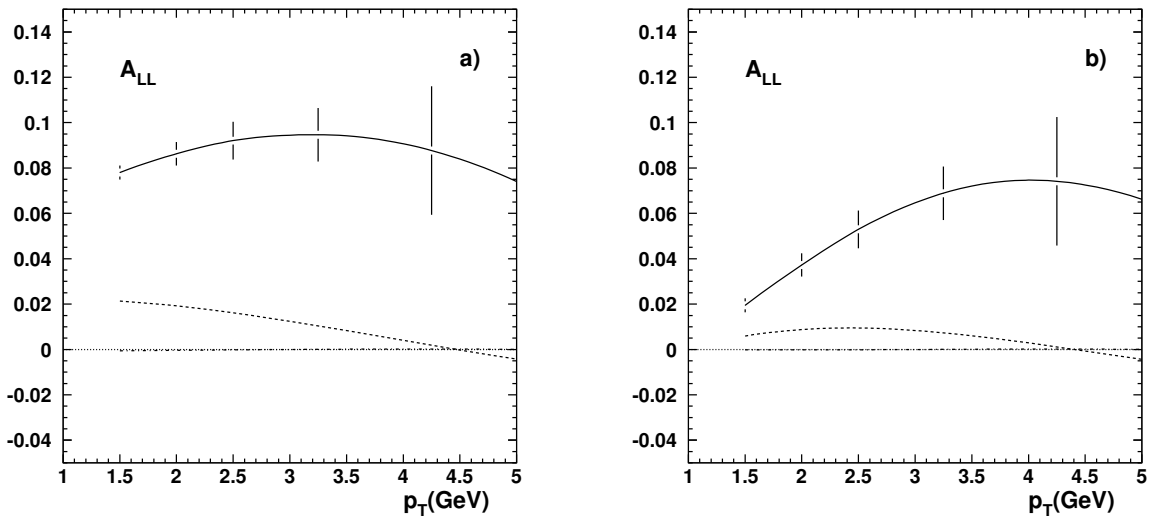

Figure 3: The expected asymmetries versus transverse momentum at $\sqrt{s} = 40$ GeV for the NLO set A (solid lines), set B (dashed lines) and set C (dash-dotted lines) of the new GS parametrization [32]; a) $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle = 0$, b) $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle = 0$.

and 3b also display the expected statistical errors. The statistical error δA_{LL} at HERA-$\vec{N}$ can be estimated from [24]

$$\delta A_{LL} = 0.17/\sqrt{\sigma(pb)}; \tag{12}$$

100% efficiency is assumed. This relation has been determined by assuming an integrated luminosity of 240 pb^{-1} and beam and target polarizations $P_B = 0.6$ and $P_T = 0.8$, respectively [24]. The error bars are obtained by using integrated cross sections over bins $\Delta p_T = 0.5$ GeV (for the first three points) and $\Delta p_T = 1$ GeV (for the other two ones). The J/ψ decay branching ratio into the e^+e^- mode is also included. As can be seen from Figs.3, the magnitude of asymmetries

and expected errors allows one to distinguish between different parametrizations of polarized parton distribution functions.

Production asymmetry of χ_{c1} and χ_{c2} states. In Figs.4a,b we show the production asymmetries of χ_1 and χ_2 states in conjunction with the projected HERA-$\vec{N}$ errors for the three different sets used for polarized PDF. Unlike direct J/ψ production the production asymmetries of χ states depend only on one color octet matrix element, namely $\langle \mathcal{O}_8^{\chi_{c1}}(^3S_1)\rangle$. The value of this parameter was extracted from Tevatron data at large p_T values, i.e. from the region where the NRQCD factorization mechanism is valid, and higher twist effects are expected to be small, i.e. of the order of Λ/p_T or even $(\Lambda/p_T)^2$. Hence the production asymmetries of χ states do not contain additional free parameters and enable us to probe the polarized gluon distribution function with less theoretical uncertainties. We note that the branching ratios of χ_J decay into J/ψ plus photon are taken into account in the calculations of the expected errors.

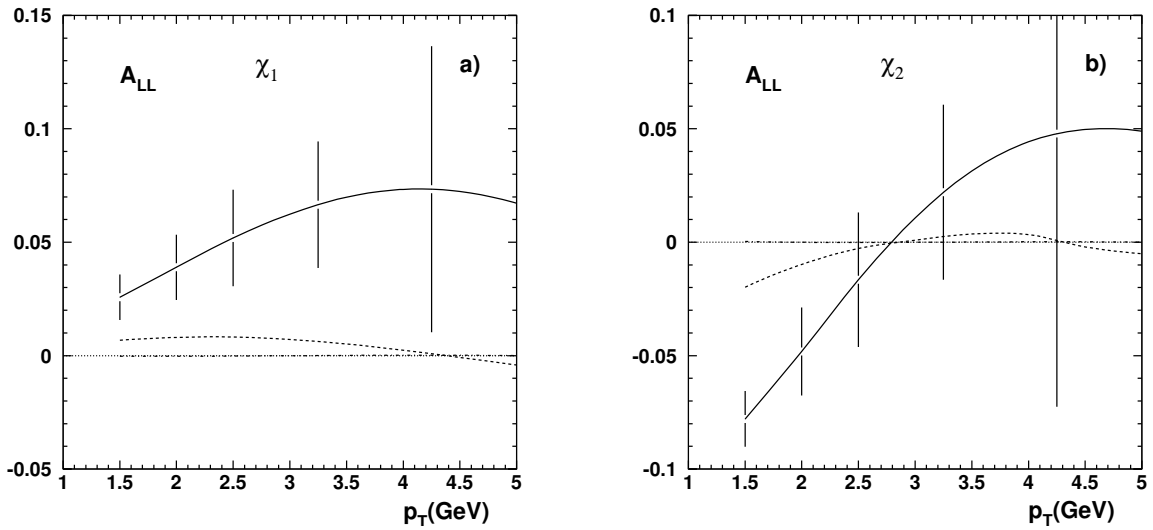

Figure 4: The χ_{cJ} production asymmetries versus transverse momentum at $\sqrt{s} = 40$ GeV for the NLO set A (solid lines), set B (dashed lines) and set C (dash-dotted lines) of the new GS parametrization [32]; a) χ_{c1}, b)χ_{c2}.

J/ψ plus jet production. Direct access to the ratio $\Delta G(x)/G(x)$ is possible only if the 'other jet' is detected (*photon+jet* or J/ψ+*jet*) [33], because the complete kinematics of the $2 \to 2$ subprocess can be reconstructed if the away-side jet in the production of J/ψ is measured, as well. If the values of the long distance matrix elements are established from experiments where the uncertainties connected with higher twist and other corrections are expected to be small (or negligible), the J/ψ+*jet* production asymmetry at HERA-$\vec{N}$ will serve as a good tool for the extraction of the $\Delta G(x)/G(x)$ value at $x \simeq 0.1$ [33].

Measurement of color octet matrix elements. As soon as the polarized gluon distribution function is extracted from other channels (e.g. *photon+jet*) at HERA-$\vec{N}$ [33] or RHIC [34], a measurement of the J/ψ asymmetry can be used for checking the NRQCD factorization scheme.

For further calculations and analysis we choose the new GS parametrization for polarized PDF (NLO, set A) [32]. In figures 5a and 5b we present the expected asymmetries in J/ψ production for two radical choices of $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$ and $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$. Figure 5a corresponds to the case when the parameter $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$ tends to zero, i.e. $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$ is the dominating term in

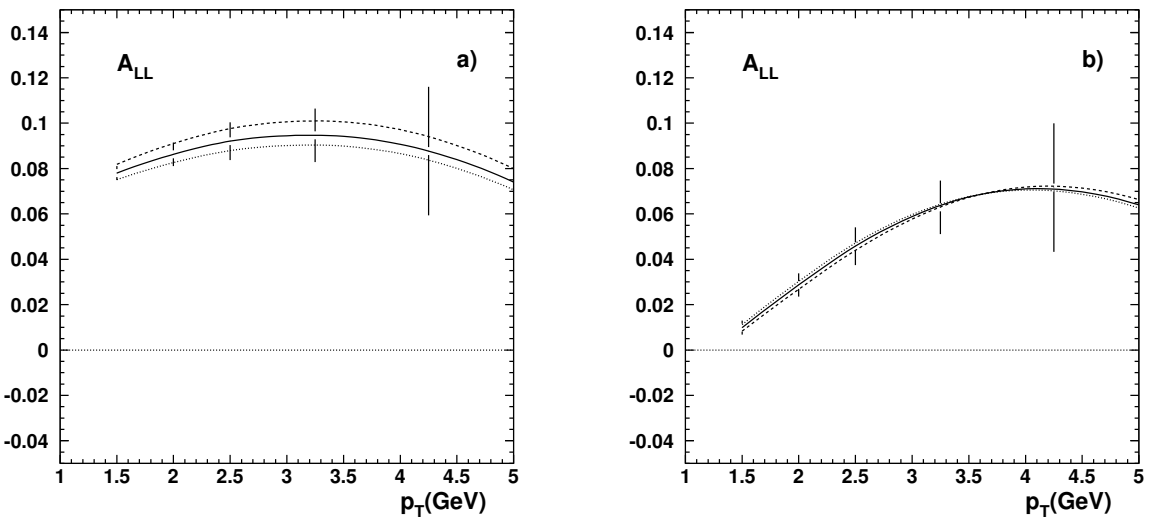

Figure 5: The expected asymmetries at HERA-$\vec{N}$ energy for different values of the long-distance parameter $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle$. The solid lines correspond to the value $20 \cdot 10^{-3}\ GeV^3$, the dashed lines to $10{\cdot}10^{-3}\ GeV^3$, and the dotted lines to $30{\cdot}10^{-3}\ GeV^3$; a) asymmetries for the case when $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle = 0$, b) for $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle = 0$.

the combination (7). Figure 5b represents the other radical choice, when the second parameter $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$ is zero. As already mentioned above, due to the 'trigger bias' effect the value of the third main parameter, $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle$, is underestimated about twice. To check the sensitivity of the expected asymmetries to the uncertainty caused by this effect, we used three different values for $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle$, $10{\cdot}10^{-3}$ GeV^3 from (6) (dashed lines in Figs.5), $20{\cdot}10^{-3}$ GeV^3 (solid lines) and $30{\cdot}10^{-3}$ GeV^3 (dash-dotted lines). From comparison of Figs.5a and b it can be seen that the asymmetries depend strongly on the relative values of the matrix elements $\langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle$ and $\langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$ and practically do not depend on the value of $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle$. Hence, independently of the value of the latter parameter and, consequently, independently of the 'trigger bias' effect, a measurement of the J/ψ production asymmetry can be used for an extraction of the ratio of the first two parameters.

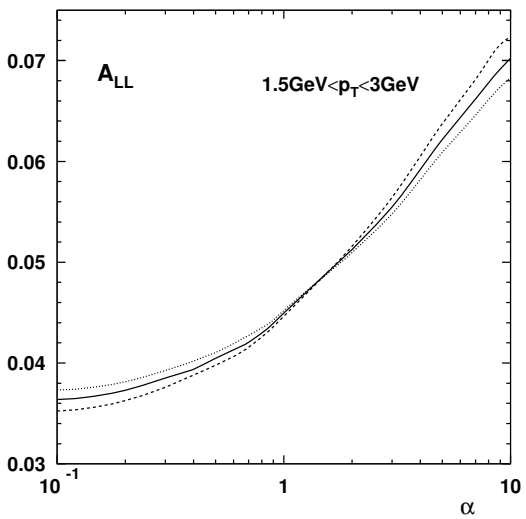

Figure 6: The integrated double spin asymmetry versus the ratio of color octet parameters, $\alpha = \langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle m_c^2 / \langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$. Solid line: $\langle \mathcal{O}_8^{J/\psi}(^3S_1)\rangle = 20 \cdot 10^{-3}\ GeV^3$, dashed line: $10 \cdot 10^{-3}\ GeV^3$, dotted line: $30 \cdot 10^{-3}\ GeV^3$.

In Fig.6 we plot the expected integrated asymmetry ($1.5 < p_T < 3$ GeV) versus the ratio $\alpha = m_c^2 \langle \mathcal{O}_8^{J/\psi}(^1S_0)\rangle / \langle \mathcal{O}_8^{J/\psi}(^3P_0)\rangle$ at HERA-$\vec{N}$ energy for the above presented three different values of the third parameter. The expected statistical error for the integrated asymmetry is about 0.002, i.e. it will be possible to determine the ratio α within about $\pm 15\%$ if α is larger than unity. With α being smaller the sensitivity is becoming worse.

Of course, this method requires that the polarized gluon distribution function is known

already and large enough to generate observable sizes of J/ψ production asymmetries.

One of the main parameters of the factorization approach is the mass of the charm quark. As was shown in [35], the expected asymmetries are practically insensitive to the value of the charm quark mass. Therefore, the double spin asymmetry in J/ψ production, unlike the cross section, should be free from uncertainties caused by the unknown mass of intermediate color octet states. We also note that the asymmetries do not depend strongly on the renormalization scale unlike the J/ψ production cross section [22].

Finally, we note that recently a possibility was shown to extract the ratio α of color octet long distance parameters from polarized J/ψ electroproduction data with reasonable errors [23].

4 Conclusions

We investigated the expected double spin asymmetries in heavy quarkonium hadroproduction in polarized proton proton collisions. To reduce the contribution from possible higher twist corrections [20] we considered J/ψ meson production at nonzero transverse momenta, $p_T > 1.5$ GeV. Unlike the calculations of [36], where only the lowest order subprocesses, $2 \to 1$, were taken into account, we considered J/ψ production in $2 \to 2$ subprocesses at large enough p_T to avoid uncertainties coming from higher twist corrections [20].

The size of the expected asymmetries in conjunction with the statistical errors at HERA-$\vec{N}$ allow to distinguish between different parametrizations for polarized PDF (GS, set A, B and C [32]). If, on the other hand, those were already known measuring the asymmetry would give a possibility to extract information about the color octet long distance matrix elements $\langle \mathcal{O}_8^{J/\psi}(^1S_0) \rangle$ and $\langle \mathcal{O}_8^{J/\psi}(^3P_0) \rangle$, separately. This would deliver useful information to check the universality of the factorization scheme.

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