On the Physics Potential of Polarized Nucleon–Nucleon Collisions at HERA

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Abstract: The physics of polarized nucleon–nucleon collisions originating from an internal polarized target in the HERA proton beam is investigated. Based on 240 pb^{-1} integrated luminosity at 40 GeV c.m. energy, statistical sensitivities are given over a wide (x_F, p_T)–range for a variety of inclusive and exclusive final states. By measuring single spin asymmetries unique information can be obtained on higher twist contributions and their p_T-dependence. From double spin asymmetries in both photon and J/ψ production it appears possible to measure the polarized gluon distribution in the range $0.1 \leq x_{gluon} \leq 0.4$ with a good statistical accuracy.

1 Introduction

There is a widespread general consensus, much grown in the last years and based both on surprising experimental results and intense theoretical activity, that the spin structure and the spin dynamical properties of nucleons and hadrons in general are far from being understood; a satisfactory knowledge of hadronic structure and dynamics and their correct description in terms of constituents cannot ignore the spin subtleties and more experimental information is badly required.

An experiment ('*HERA–*$\vec{N}$' [1]) utilising an internal polarized nucleon target in the 820 GeV HERA proton beam would constitute a natural extension of the studies of the nucleon spin structure in progress at DESY with the *HERMES* experiment [2]. Conceivably, this would be the only place where to study high energy nucleon–nucleon spin physics besides the dedicated RHIC spin program at BNL [3] supposed to start early in the next decade.

An internal polarized nucleon target offering unique features such as polarization above 80% and no or small dilution, can be safely operated in a proton ring at high densities up to 10^{14} atoms/cm^2 [4]. As long as the polarized target is used in conjunction with an unpolarized proton beam, the physics scope of *HERA–*$\vec{N}$ would be focused to 'phase I', i.e. measurements of single spin asymmetries. Once later polarized protons should become available, the same set-up would be readily available to measure a variety of double spin asymmetries. These 'phase II' measurements would constitute an alternative – fixed target – approach to similar physics which will be accessible to the collider experiments *STAR* and *PHENIX* at the low end of the RHIC energy scale ($\sqrt{s} \simeq 50$ GeV) [6].

We shall briefly discuss here the physics motivations to measure single and double spin asymmetries in several $p\vec{N}$ inclusive and exclusive processes; more details and further discussions, together with a complete list of references, which we cannot give here for lack of space, can be found in Ref. [5]. We recall that the integrated luminosity calculation is based upon realistic

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figures. For the average beam and target polarisation $P_B = 0.6$ and $P_T = 0.8$ are assumed, respectively. A combined trigger and reconstruction efficiency of $C \simeq 50\%$ is anticipated. Using $\bar{I}_B = 80$ mA $= 0.5 \cdot 10^{18}\ s^{-1}$ for the average HERA proton beam current (50% of the design value) and a rather conservative polarized target density of $n_T = 3 \cdot 10^{13}$ atoms/cm^2 the projected integrated luminosity becomes $\mathcal{L} \cdot T = 240\ pb^{-1}$ when for the total running time T an equivalent of $T = 1.6 \cdot 10^7\ s$ at 100 % efficiency is assumed. This corresponds to about 3 real years under present HERA conditions. However, proton currents much higher than the original HERA design value of 160 mA are envisaged in the HERA luminosity upgrade program. In addition, experience from UA6 running at CERN shows that after having gained some practical running experience it presumably becomes feasible to operate the polarized gas target at about 3 times higher density without seriously affecting the proton beam lifetime. Hence in a few years 500 pb^{-1} *per year* will presumably become a realistic figure.
We note that, except in the case of single spin asymmetries, we took into account major acceptance limitations and jet detection efficiencies. Hence it can be anticipated that the sensitivities shown in the rest of the paper are realistic for an about one year's running of a future polarized nucleon–nucleon scattering experiment at HERA. Any better estimate requires considerably intensified efforts to be invested along many different directions, like machine and target limitations, detector capabilities versus rate, acceptance, costs etc.

2 Single Spin Asymmetries

Single spin asymmetries in large p_T inclusive production, both in proton-nucleon and lepton-nucleon interactions, have recently received much attention (for references see [5]). The naive expectation that they should be zero in perturbative QCD has been proven to be false, both experimentally and theoretically. It is now clear that higher twist effects are responsible for these asymmetries, which should be zero only in leading twist-2 perturbative QCD.
Several models and theoretical analyses suggest possible higher twist effects: there might be twist-3 dynamical contributions, which we shall denote as hard scattering higher twists; there might also be intrinsic $k_\perp$ effects, both in the quark fragmentation process and in the quark distribution functions. The latter are not by themselves higher twist contributions - they are rather non-perturbative universal nucleon properties - but give rise to twist-3 contributions when convoluted with the hard scattering cross sections. The dynamical contributions result from a short distance part calculable in perturbative QCD with slightly modified Feynman rules, combined with a long distance part related to quark-gluon correlations.
An intrinsic $k_\perp$ effect in the quark fragmentation is known as Collins or sheared jet effect; it simply amounts to say that the number of hadrons h (say, pions) resulting from the fragmentation of a transversely polarized quark, with longitudinal momentum fraction z and transverse momentum $\boldsymbol{k}_\perp$, depends on the quark spin orientation. That is, one expects the *quark fragmentation analysing power* $A_q(\boldsymbol{k}_\perp)$ to be different from zero:

$$A_q(\boldsymbol{k}_\perp) \equiv \frac{D_{h/q^\uparrow}(z, \boldsymbol{k}_\perp) - D_{h/q^\downarrow}(z, \boldsymbol{k}_\perp)}{D_{h/q^\uparrow}(z, \boldsymbol{k}_\perp) + D_{h/q^\downarrow}(z, \boldsymbol{k}_\perp)} \neq 0 \tag{1}$$

where, by parity invariance, the quark spin should be orthogonal to the $q - h$ plane. Notice also that time reversal invariance does not forbid such quantity to be $\neq 0$ because of the (necessary) soft interactions of the fragmenting quark with external strong fields, i.e. because of final state interactions. This idea has been applied to the computation of the single spin asymmetries observed in $pp^\uparrow \to \pi X$ [7].
A similar idea applies to the distribution functions, provided soft gluon interactions between initial state partons are present and taken into account, which most certainly is the case for

hadron-hadron interactions. That is, one can expect that the number of quarks with longitudinal momentum fraction x and transverse intrinsic motion $\boldsymbol{k}_\perp$ depends on the transerve spin direction of the parent nucleon, so that the *quark distribution analysing power* $N_q(\boldsymbol{k}_\perp)$ can be different from zero:

$$N_q(\boldsymbol{k}_\perp) \equiv \frac{f_{q/N^\uparrow}(x,\boldsymbol{k}_\perp) - f_{q/N^\downarrow}(x,\boldsymbol{k}_\perp)}{f_{q/N^\uparrow}(x,\boldsymbol{k}_\perp) + f_{q/N^\downarrow}(x,\boldsymbol{k}_\perp)} \neq 0 \tag{2}$$

This effect also has been used to explain the single spin asymmetries observed in $pp^\uparrow \to \pi X$ [8].

Note that both $A_q(\boldsymbol{k}_\perp)$ and $N_q(\boldsymbol{k}_\perp)$ are leading twist quantities which, when convoluted with the elementary cross-sections and integrated over $\boldsymbol{k}_\perp$, give twist-3 contributions to the single spin asymmetries.

Each of the above mechanisms might be present and might be important in understanding twist-3 contributions; in particular the quark fragmentation or distribution analysing powers look like new non-perturbative universal quantities, crucial in clarifying the spin structure of nucleons. It is then of great importance to study possible ways of disentangling these different contributions in order to be able to assess the importance of each of them. We propose here to measure the single spin asymmetry

$$\frac{d\sigma^{AB^\uparrow \to CX} - d\sigma^{AB^\downarrow \to CX}}{d\sigma^{AB^\uparrow \to CX} + d\sigma^{AB^\downarrow \to CX}} \tag{3}$$

in several different processes $AB^\uparrow \to CX$ which should allow to fulfil such a task. To obtain a complete picture we need to consider nucleon-nucleon interactions together with other processes, like lepton-nucleon scattering, which might add valuable information. For each of them we discuss the possible sources of higher twist contributions, distinguishing, according to the above discussion, between those originating from the hard scattering and those originating either from the quark fragmentation or distribution analysing power.

- $pN^\uparrow \to hX$. In this process all kinds of higher twist contributions may be present; this asymmetry *alone* could not help in evaluating the relative importance of the different terms.

- $pN^\uparrow \to \gamma X$, $pN^\uparrow \to \mu^+\mu^- X$, $pN^\uparrow \to jets + X$. Here there is no fragmentation process, and we remain with possible sources of non-zero single spin asymmetries in the hard scattering or the quark distribution analysing power.

- $lN^\uparrow \to hX$. In such a process the single spin asymmetry can originate either from hard scattering or from $k_\perp$ effects in the fragmentation function, but not in the distribution functions, as soft initial state interactions are suppressed by powers of α_{em}. Moreover, this process allows, in principle, a direct measurement of the Collins effect, i.e. of the quark fragmentation analysing power, via a measurement of the leading-twist difference of cross sections for the production of two identical particles inside the same jet, with opposite $\boldsymbol{k}_\perp$.

- $lN^\uparrow \to \gamma X$, $\gamma N^\uparrow \to \gamma X$, $lN^\uparrow \to \mu^+\mu^- X$, $lN^\uparrow \to jets + X$. Each of these processes yields a single spin asymmetry which cannot originate from distribution or fragmentation $k_\perp$ effects; it may only be due to higher-twist hard scattering effects, which would thus be isolated.

It is clear from the above discussion that a careful and complete study of single spin asymmetries in several processes might be a unique way of understanding the origin and importance of higher twist contributions in inclusive hadronic interactions; not only, but it might also allow a determination of fundamental non-perturbative properties of quarks inside polarized nucleons and of polarized quark fragmentations. Such properties should be of universal value and applicability and their knowledge might be as important as the knowledge of unpolarized distribution and fragmentation functions.
In the following we discuss the capability of HERA-$\vec{N}$ to investigate some of these processes.

Inclusive pion production $p^{\uparrow}p \to \pi^{0\pm}X$ at 200 GeV exhibits surprisingly large single spin asymmetries, as it was measured a few years ago by the E704 Collaboration using a transversely polarized beam [9]. For any kind of pions the asymmetry A_N shows a considerable rise above

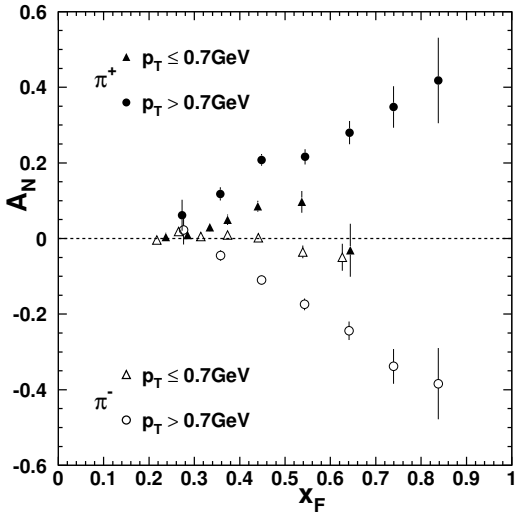

Figure 1: *Single spin asymmetry in inclusive pion production* $p^{\uparrow} + p \to \pi^{0\pm} + X$ *measured by the E704 Collaboration [9] and shown for two subregions of* p_T.

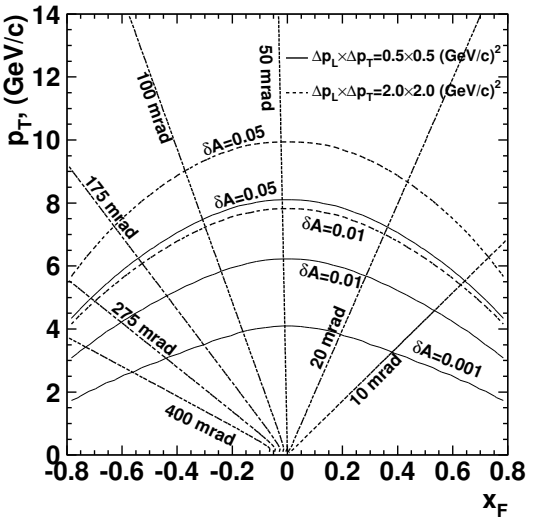

Figure 2: *Contours of the asymmetry sensitivity levels for* π^+ *production in the* (p_T, x_F) *plane. Lines of constant laboratory angles of the pion are shown.*

$x_F > 0.3$, i.e. in the fragmentation region of the polarized nucleon. It is positive for both π^+ and π^0 mesons, while it has the opposite sign for π^- mesons. The charged pion data taken in the $0.2 < p_T < 2$ GeV range were split into two samples at $p_T = 0.7$ GeV/c; the observed rise is stronger for the high p_T sample, as can be seen from fig. 1. Contours characterizing different HERA-$\vec{N}$ sensitivity levels ($\delta A_N = 0.001$, 0.01 and 0.05) for an asymmetry measurements in the reaction $pp^{\uparrow} \to \pi^+ X$ are shown in fig. 2. Note that in the large p_T region the contours calculated with big $\Delta p_L \times \Delta p_T$ bins are appropriate, since usually a larger bin size is chosen where the statistics starts to decrease. We can conclude that the accessible p_T values are significantly larger than those E704 had; the combined p_T dependence of all involved higher-twist effects can be measured with good accuracy ($\delta A_N \le 0.05$) up to transverse momenta of about 10 GeV/c in the central region $|x_F| < 0.2$ and up to 6 GeV/c in the target fragmentation region. This corresponds to an almost one order of magnitude extension in the p_T range in comparison to E704. The capability of HERA-$\vec{N}$ to really prove a predicted p_T dependence is shown in fig. 3, where the curve was obtained assuming a non–zero quark distribution analysing power (cf. eq. 2) according to Ref. [8].

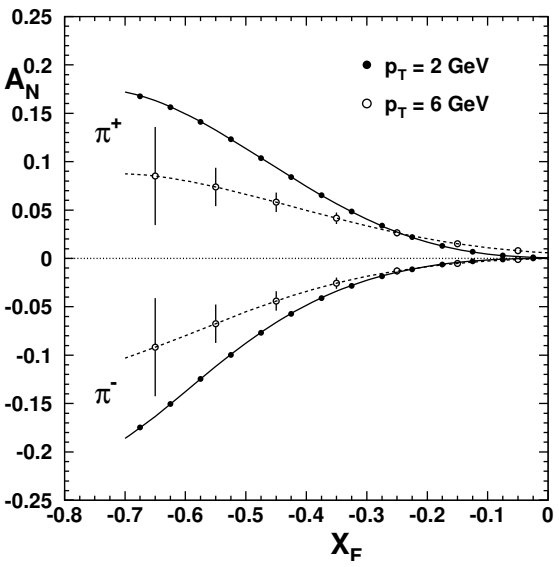

Figure 3: *Capability of HERA-*$\vec{N}$ *to discriminate predictions for different* p_T.

Inclusive direct photon production, $pp^{\uparrow} \to \gamma X$, proceeds without fragmentation, i.e. the photon carries directly the information from the hard scattering process. Hence this process

measures a combination of initial $\boldsymbol{k}_\perp$ effects and hard scattering twist–3 processes. The first and only results up to now were obtained by E704 Collaboration [10] showing an asymmetry compatible with zero within large errors for $2.5 < p_T < 3.1$ GeV/c in the central region $|x_F| \lesssim 0.15$. The experimental sensitivity of HERA-$\vec{N}$ was determined using PYTHIA 5.7 by simultaneous simulation of the two dominant hard subprocesses contributing to direct photon production, i.e. gluon–Compton scattering ($qg \to \gamma q$) and quark–antiquark annihilation ($q\bar{q} \to \gamma g$), and of background photons that originate mainly from π^0 and η decays. It turns out that a good sensitivity (about 0.05) can be maintained up to $p_T \leq 8$ GeV/c. For increasing transverse momentum the annihilation subprocess and the background photons are becoming less essential; we expect to be able to detect a clear dependence on p_T, of the direct photon single spin asymmetry.
Inclusive J/ψ production was calculated in the framework of the colour singlet model [11]. Our calculations at HERA-$\vec{N}$ energies [5] show an asymmetry less than 0.01 in the region $|x_F| < 0.6$, i.e. the effect is practically unobservable.

3 Double Spin Asymmetries

Perturbative QCD allows sizeable lowest order double spin asymmetries for various 2→2 partonic subprocesses. Relying on the factorization theorem a rich spectrum of asymmetries at the hadronic level can be predicted which constitute the backbone of the RHIC spin physics program. When both incoming particles are longitudinally polarized, the insufficient knowledge of the polarized gluon distribution makes the predictions for double spin asymmetries A_{LL} to some extent uncertain. Conversely, the measurement of A_{LL} in certain final states seems to be one of the most valuable tools to measure the polarized gluon distribution function in the nucleon. The presently most accurate way to do so is the study of those processes which can be calculated in the framework of perturbative QCD, i.e. for which the involved production cross sections and subprocess asymmetries can be predicted. Both *direct photon (plus jet)* and *J/ψ (plus jet)* production are most suited because there are only small uncertainties due to fragmentation.
In the following we discuss the corresponding capabilities of HERA–$\vec{N}$, operated in doubly polarized mode ('Phase II'), to perform such measurements.
Inclusive photon production with HERA–$\vec{N}$ was the subject of a very recent study [12]. Basing on a NLO calculation rather firm predictions were obtained including an assessment of their theoretical uncertainties; the latter turned out to be of rather moderate size. In fig. 4 three different predictions for the asymmetry are shown in dependence on p_T and pseudorapidity η, in conjunction with the attainable statistical uncertainty of HERA–$\vec{N}$. We note that the dashed line is rather close to the prediction of Ref. [14], set A. As can be seen, there is sufficient statistical accuracy up to transverse momenta of about 8 GeV/c to discriminate between different polarized gluon distribution functions (cf. fig 4a). At $p_T = 6$ GeV/c there is sufficient accuracy to check the asymmetry prediction for photon pseudorapidities between -1.5 and 1.5 (cf. fig 4b).
In **photon plus jet production** the away-side jet is measured as well and the complete kinematics of the 2→2 subprocess can be reconstructed. In this case the asymmetry A_{LL} can be directly related to the polarized gluon distribution if a certain subprocess can be selected. Using this approach *photon plus jet* production was discussed in Ref. [5] as a tool to directly measure ΔG/G. The quark–antiquark annihilation subprocess is suppressed relatively to quark-gluon Compton scattering because of the lower density of antiquarks (of the polarized sea) compared to gluons (polarized gluons). The absolute statistical error of $\Delta G(x_g)/G(x_g)$ was obtained as

$$\delta[\frac{\Delta G(x_g)}{G(x_g)}] = \frac{\delta A_{LL}}{A_{DIS} \cdot \hat{a}_{LL}}. \qquad (4)$$

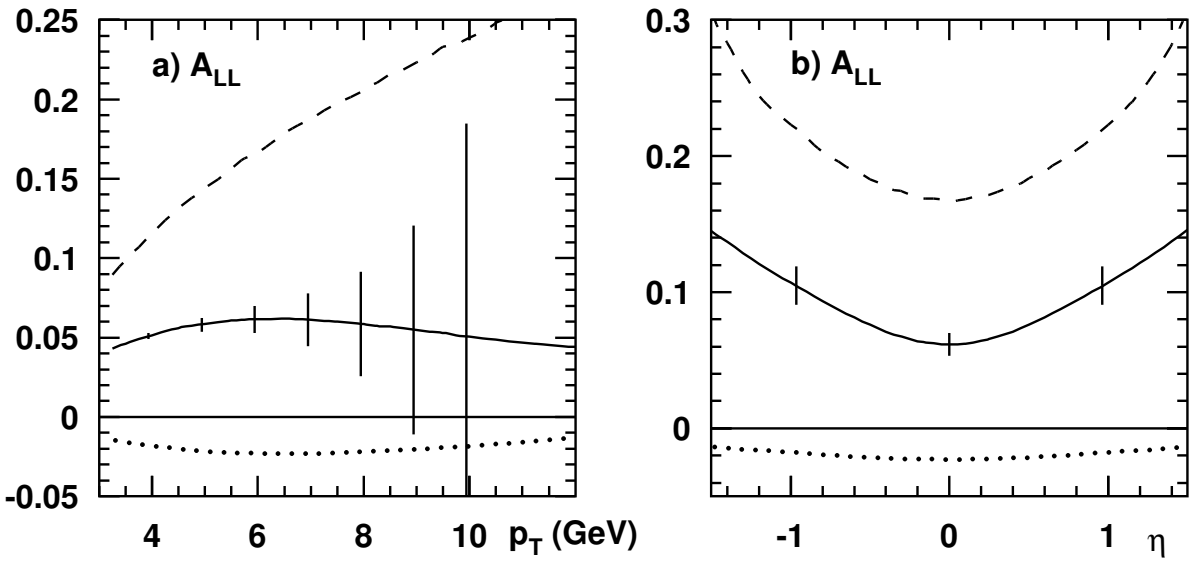

Figure 4: *Inclusive photon production: Double spin asymmetry vs. a) p_T and b) η for the NLO 'valence set' of Ref. [12] (full line), shown in conjunction with the HERA–$\vec{N}$ statistical sensitivity. The dotted line corresponds to set C of Ref. [13] and the dashed line is close to set A of Ref. [14]*

Here A_{DIS} and $\hat{a}_{LL}$ are to be taken at the appropriate values of x_F and x_g, respectively. In calculating the r.h.s. of eq. 4 we had to take into account the influence of the acceptance, as described in [5].

In fig. 5 the calculated HERA–$\vec{N}$ statistical sensitivity, on the present level of understanding, is shown vs. x_{gluon} in conjunction with predicted errors for *STAR* running at RHIC at 200 GeV c.m. energy [15]. The errors demonstrate clearly that in the region $0.1 \leq x_g \leq 0.4$ a significant result can be expected. This statement will very probably remain valid if once the systematic errors will have been estimated. As can be seen, the measurement of $\Delta G/G$ from *photon plus jet* production in doubly polarized nucleon-nucleon collisions at HERA can be presumably performed with an accuracy being about competitive to that predicted for RHIC.

At this point we note that the HERA–$\vec{N}$ fixed target kinematics causes additional problems for the jet reconstruction when compared to a collider experiment. As obtained from rather preliminary investigations [5], the number of photon events accompanied by a successfully reconstructed jet decreases considerably when approaching lower values of p_T and, correspondingly, of x_{gluon}. To have a more realistic statistical significance than that shown in Ref. [5] we now include these preliminary jet reconstruction efficiencies. As a result, the statistical error bars became somewhat larger for smaller transverse momenta.

J/ψ Production. Compared to direct photon production the production of quarkonium states below the open charm threshold is a similarly clean tool to measure the polarized gluon distribution. Hence many statements made in the previous section apply here, as well, and the principle of analysis is very similar. Because of the relatively large quark mass the $c\bar{c}$ production cross section and the expected asymmetry are supposed to be calculable perturbatively.

Quarkonium production has traditionally been calculated in the color-singlet model (CSM) [16] where the quark-antiquark pair is produced in a color-singlet state with the quantum numbers

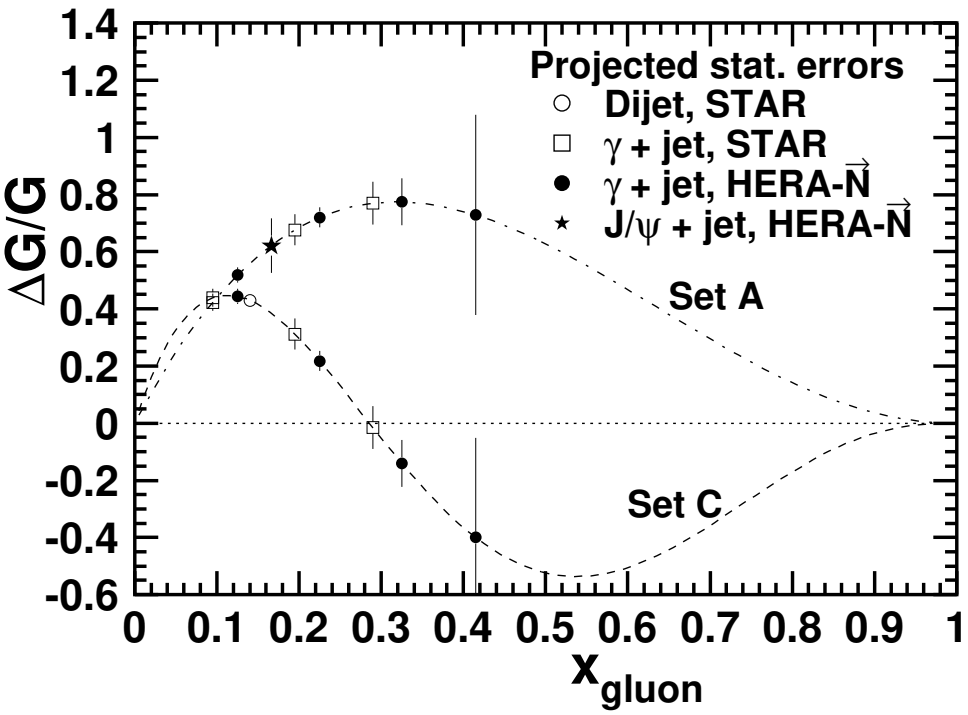

Figure 5: *Typical predictions for the polarized gluon distribution confronted with the projected statistical errors expected for HERA-$\vec{N}$ and RHIC experiments.*

of the corresponding hadron. This heavy mass pair then creates the hadronic state with a probability determined by the appropriate quarkonium wave function at the origin. It is assumed that for heavy quarks soft gluon emission is negligible, as also other non-perturbative effects like higher twist contributions. While this model gives a reasonable description of J/ψ production cross section shapes over p_T and x_F, it completely fails in the explanation of the integrated cross section; a K factor of $7 \div 10$ is needed to explain the data. The anomalously large cross section [17] for J/ψ production at large transverse momenta found at the Tevatron reveals another bad feature of the CSM; it is not able to explain the large ψ' and direct J/ψ production rates at CDF. All these observations led to the understanding that fragmentation and hadronization of color-octet [18] $q\bar{q}$ pairs are essential in the heavy quarkonium production process.

Within the framework of the color-octet mechanism the quarkonium production process can be separated, according to the factorization hypothesis, into a short and a long distance part. The former describes the quark-antiquark pair production at small distances and can be computed perturbatively. The latter is responsible for the creation of a particular hadronic state from the quark-antiquark pair; its matrix elements can not be calculated perturbatively.

The shapes of the p_T distribution of short distance matrix elements calculated within the color-octet model indicate that the new mechanism seems to be able to explain the Tevatron data for direct J/ψ and ψ' production at large p_T [19]. We note that unlike color-singlet matrix elements being connected to the subsequent hadronic non-relativistic wave functions at the origin, color-octet long distance matrix elements are unknown and have to be extracted from the experiment. As it was shown recently [20, 21] the color-octet mechanism gives the dominant contribution in J/ψ-production at HERA–$\vec{N}$ energies. This concerns not only the total cross section [20], but also J/ψ production at non-zero p_T, i.e. at those values of transverse momenta which are not due to internal motion of partons inside the colliding hadrons, $p_T \gtrsim 1.5$ GeV/c [21].

For inclusive J/ψ production we calculated the double spin-asymmetry within the framework of the color-octet model using the value of the color-octet matrix elements from [21]. It is interesting to note that the magnitude of the asymmetry does almost not depend on the choice of the color-octet matrix elements, if one assumes that the transition matrix elements of octet ${}^3P_J$-states into J/ψ are negligible compared to those of the ${}^1S_0$ state. This is the most likely scenario since only in this case it is possible to establish a consistence between different combinations of the above two matrix elements, as extracted from CDF data [19] and photo- [22] or hadroproduction [20] data. We underline that the measurement of the double spin asymmetry in J/ψ production would allow to extract information about the color-octet matrix elements *separately*, whereas from unpolarized experiments it is only possible to extract combinations of them. In fig. 6a we present the expected asymmetry versus p_T for two different sets of polarized gluon

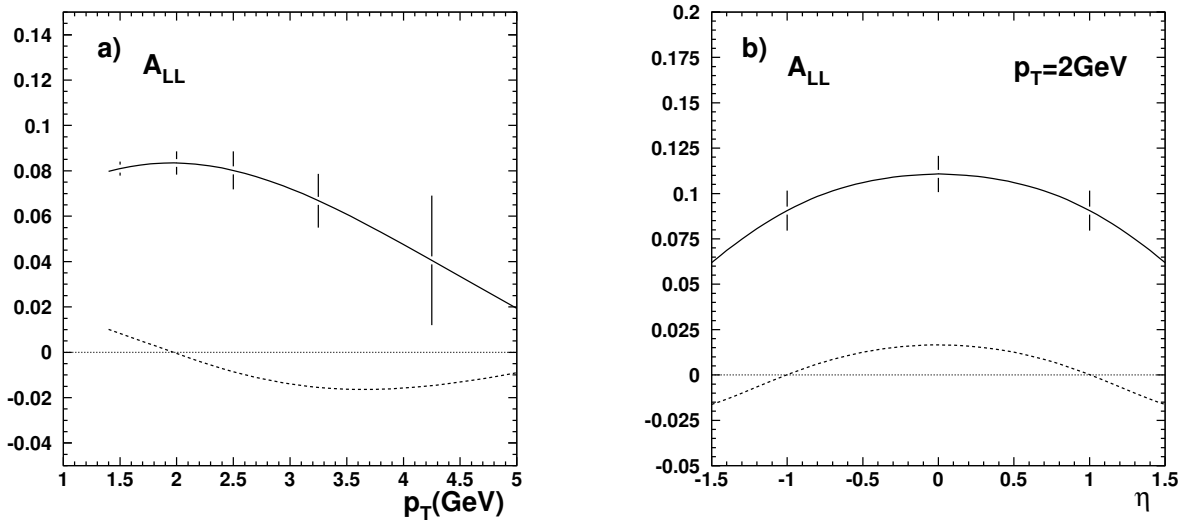

Figure 6: *Inclusive J/ψ production: Double spin asymmetry vs. a) p_T and b) η for the LO set A (full line) and the set C (dotted line) of Ref. [14], shown in conjunction with the HERA-$\vec{N}$ statistical sensitivity.*

distributions taken from [14]; the solid curve corresponds to set A and the dashed one to set C. For set A the asymmetry appears sufficiently large to be observed and its measurement would allow to extract information about the polarized gluon distribution function in the nucleon. As can be seen from fig. 6b, a very good discrimination between set A and set C is possible over the whole HERA-$\vec{N}$ pseudorapidity interval. For the mass of the charm quark we chose $m_c = 1.5$ GeV/c^2, as it was used for extraction of the color-octet matrix elements from experimental data [19, 20]. We found that unlike the J/ψ production cross section the asymmetry does practically not depend on the charm quark mass; if we vary the charm quark mass from 1.35 to 1.7 GeV/c^2 the magnitude of the asymmetry changes by about $3 \div 5\%$ over the whole considered p_T region. **In J/ψ plus jet production** the study of the double spin asymmetry would allow to access directly the polarized gluon distribution function, similar to the case of *photon plus jet* production. For the absolute statistical error of $\Delta G(x_g)/G(x_g)$ an expression similar to eq. 4 is obtained:

$$\delta[\frac{\Delta G(x_g)}{G(x_g)}] = \frac{\delta A_{LL}}{[\Delta G/G] \cdot \hat{a}_{LL}} \tag{5}$$

with

$$\hat{a}_{LL} = \frac{\Delta\hat{\sigma}(gg \to J/\psi\ g)}{\hat{\sigma}(gg \to J/\psi\ g) + [q(x)/G(x)] \cdot \hat{\sigma}(gq \to J/\psi\ q)}. \tag{6}$$

Here the quark-gluon subprocess was neglected, since its contribution to $\hat{a}_{LL}$ amounts only to about 10% compared to the gluon-gluon fusion subprocess.

Unfortunately, taking into account the acceptance limitations as it was done for *photon plus jet* production, the J/ψ production cross section for HERA-$\vec{N}$ decreases significantly. Following the same principle of analysis as in Ref. [5], it turns out that the measurement of $\Delta G(x)/G(x)$ in J/ψ *plus jet* production is feasible only for $x_g = 0.1 \div 0.2$, i.e. for J/ψ transverse momenta of about 2.5 GeV/c. This prediction is shown as an additional entry in fig. 5. Although being a single point only, we underline that this is a very important measurement, because the lowest lying point from *photon plus jet* production is obtained for rather small values of p_T where perturbative QCD is not expected to give reliable predictions. We note that the nature of the gluon-gluon subprocess has rather similar consequences for *jet plus jet* production at RHIC; the prediction [15] consists of only one single point at a similar value of x_g, as well (cf. fig. 5).

4 Elastic Scattering

Large unexpected spin effects in singly polarized proton-proton elastic scattering $p + p^{\uparrow} \rightarrow p + p$ have been discovered many years ago and remain unexplained up to now. The single spin asymmetry A_N was found significantly different from zero in the region $1 \lesssim p_T^2 \lesssim 7$ (GeV/c)^2 as it is shown in fig. 7 in conjunction with the HERA-$\vec{N}$ statistical errors.

At HERA-$\vec{N}$ energies the detection of the recoil proton for p_T^2 values in the range $5 \div 12$ (GeV/c)^2 requires a very large angular acceptance (up to 40 degrees) [5]. The forward protons for the same interval in p_T^2 have laboratory angles of the order of a few milliradians and require a dedicated detector very close to the beam pipe. Note that although the accessible p_T^2 range would be similar to the range explored at low energies the c.m. scattering angle detected amounts to a few degrees at HERA–$\vec{N}$ energies, only.

The transverse single-spin asymmetry A_N in elastic pp scattering at HERA-$\vec{N}$ and RHIC energies has been calculated in a dynamical model that leads to spin-dependent pomeron couplings [23]. The predicted asymmetry is about 0.1 for $p_T^2 = 4 \div 5$ (GeV/c)^2 with an expected statistical error of $0.01 \div 0.02$ for HERA-$\vec{N}$, i.e. a significant measurement of the asymmetry A_N can be performed to test the spin dependence of elastic pp scattering at high energies.

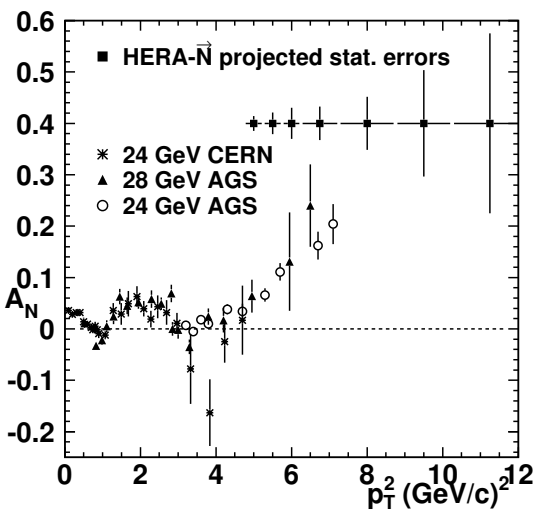

Figure 7: *Compilation of experimental data on the asymmetry in elastic proton-proton scattering as a function of p_T^2. In addition the projected statistical errors attainable with HERA-$\vec{N}$ are shown.*

5 Conclusions

The physics potential of polarized nucleon-nucleon collisions originating from an internal target in the 820 GeV HERA proton beam has been investigated. Single spin asymmetries, accessible already with the existing unpolarized beam, are found to be an almost unique and powerful tool to study the nature and physical origin of twist-3 effects; even more so when taken in conjunction with results of other experiments at HERA. When measuring the polarized gluon distribution through double spin asymmetries in *photon (plus jet)* and *J/ψ (plus jet)* production – requiring a polarized HERA proton beam – the projected statistical accuracies are found to be comparable to those predicted for the spin physics program at RHIC. In addition, significant results can be obtained on the long-standing unexplained spin asymmetries in elastic scattering.

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