A Possible Fixed Target Programme for the Polarized HERA Proton Ring

V.A. Korotkov[a,b], W.-D. Nowak[a]

[a] *DESY-IfH Zeuthen, D-15735 Zeuthen, Germany*

[b] *IHEP, RU-142284 Protvino, Russia*

Abstract

The physics programme for a possible fixed target polarized nucleon-nucleon collision experiment aiming at studying the nucleon spin structure at HERA is described. The experiment named HERA-$\vec{N}$ could be realized using an internal polarized gas target in the HERA polarized/unpolarized proton beam. Single spin asymmetry measurements could provide unique information on higher twist contributions. Once the HERA proton beam is polarized measurements of the polarized gluon distribution using double longitudinal spin asymmetries in both photon and J/ψ production appear possible. A study of the Drell-Yan process for different relative orientation of beam and target polarization can provide information on a variety of still not or badly measured polarized structure functions. The experiment would constitute a fixed target complement to the RHIC spin physics program with competitive statistical accuracy.

1 Introduction

Past experiments studying collisions of polarized particles have reached quite some progress, still the present picture of the nucleon spin structure is essentially incomplete. A number of new experiments at CERN, SLAC, DESY, BNL was proposed to investigate in more detail polarized particle interactions and to measure with good accuracy polarized parton distributions. Up to now polarized deep inelastic scattering experiments have measured only the longitudinal twist-2 spin structure function $g_1(x)$ and set an upper limit on the structure function $g_2(x)$ which contains a twist-3 contribution. Polarized hadron-hadron experiments measured large single spin asymmetries in inclusive production of different particles (π, η, K, p, $\bar{p}$) and in elastic pp-scattering which are all expected to be zero in perturbative QCD. No measurements of the polarized gluon distribution, ΔG, and of chiral odd quark distributions have been accomplished up to now.

The experiment 'HERA–$\vec{N}$' [1]-[4] 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 [5]. 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. The estimate of the integrated luminosity which could be accumulated in the experiment is based upon realistic 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 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 $T = 1.6 \cdot 10^7\ s$ is assumed. This corresponds to about 3 real years under present HERA conditions. One may argue, however, that at the time the experiment would run (>2005) even 500 pb^{-1} *per year* might presumably become a realistic figure [3] and the luminosity to be accumulated over the lifetime of the experiment might be considerably higher.
As long as the polarized target would be used in conjunction with the unpolarized HERA proton beam, the physics programme of HERA-$\vec{N}$ could be started and focused to measurements of single spin asymmetries. Once having available a polarized proton beam at HERA, all combinations of beam and target polarization (LL, TT, LT) could be possible and correspondingly double spin asymmetries A_{LL}, A_{TT} and A_{LT} would be accessible at HERA-$\vec{N}$.
We note that single spin asymmetries might also be investigated in the polarized HERA proton beam using an unpolarized gas target. This approach would have a number of advantages, e.g.: i) unpolarized targets can deliver higher densities (up to a limit given by the lifetime of the stored proton beam), ii) the fragmentation region of the polarized nucleon lies at much smaller laboratory angles which allows to use a forward oriented spectrometer. Another possibility is to get the single spin asymmetries as a by-product of the doubly polarized transverse-transverse collisions study whose importance will be shown in section 3. Generally speaking, the physics prospects considered in the section on the single spin asymmetries are rather independent on whether beam or target is polarized.
The sensitivities shown in the rest of the paper are all calculated based upon the above derived, rather conservative estimate of 240 pb^{-1} for the expected luminosity.
This paper intends to present a summary of the activities undertaken so far to later propose a physics programme for an experiment with an internal polarized gas target in the (polarized) HERA proton ring. Any discussion of a possible lay-out of the experiment and its location in the HERA ring is beyond the scope of this paper.

2 Single Spin Asymmetries

A study of single spin asymmetries in inclusive particle production is considered now as a way to investigate higher twist effects: there might be twist-3 dynamical contributions or hard scattering higher twists; there might also be intrinsic $\boldsymbol{k}_\perp$ effects, both in the quark fragmentation process and in the quark distribution functions. The contributions of the different effects are process dependent and therefore a comparative study of single spin asymmetries in different processes might be a unique way of understanding the origin and the importance of higher twist contributions in large p_T inclusive production.
There exists no consistent theoretical understanding yet of the role of higher twist contributions in single spin asymmetries. Existing phenomenological models predict a size of these asymmetries ranging from a few to tens of percent. Higher twist contributions should die out with increasing p_T and the asymmetries should approach zero as $A_N \sim m/p_T$. There is, however, another approach in which single spin asymmetries are associated with the manifestation of non-perturbative dynamics and the asymmetries would be large even at high p_T [6]. Among them, instantons are becoming increasingly interesting as possible sources for single spin asymmetries [7].
In the following we discuss the capability of HERA-$\vec{N}$ to investigate single spin asymmetries.

Inclusive pion production $p^{\uparrow}p \to \pi^{0\pm}X$ exhibits surprisingly large single spin asymmetries at large values of x_F, as it was measured a few years ago by the E704 Collaboration using a transversely polarized 200 GeV beam [8]. For any kind of pions the asymmetry A_N (fig. 1) shows a considerable rise above $x_F > 0.3$, 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 range $0.2 < p_T < 2$ GeV were split into two samples at $p_T = 0.7$ GeV/c; the observed rise is stronger for the high p_T sample.

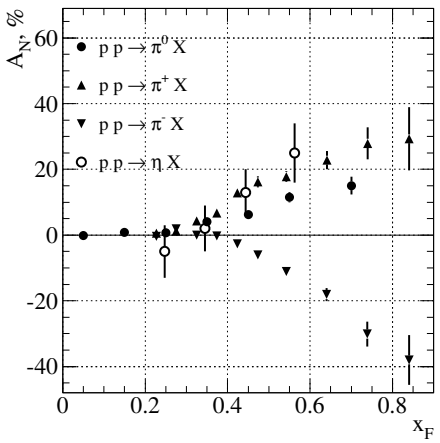

Figure 1: *Single spin asymmetry in inclusive production of $\pi^{0\pm}$ [8] and η mesons [9].*

New results on the asymmetry in η meson production were presented recently [9]. The asymmetry is positive and the behaviour is compatible with the one observed in π^0 and π^+ production (cf. fig.1).

There exist many results on asymmetry measurements in inclusive particle production at smaller energies. Recently, a new experiment with a 40 GeV polarized proton beam published data on the p_T dependence in the range $0.7 \leq p_T \leq 3.4$ GeV/c, of the single spin asymmetry in $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ production in the central region ($0.02 \leq x_F \leq 0.10$) [10]. The p_T dependence measured for the π^+ asymmetry is compatible with older data obtained at beam energies of 13.3 and 18.5 GeV/c [11] if plotted as a function of $x_T = 2p_T/\sqrt{s}$. This appears to be in some contrast to the E704 data on the π^0 asymmetry in the central region which shows a result compatible with zero up to p_T of about 4 GeV/c [12].

The p_T values accessible with HERA-$\vec{N}$ would be significantly larger than in all experiments performed up to now. The sensitivity δA_N of the asymmetry measurement in inclusive production of different particles at HERA-$\vec{N}$ was calculated using the inclusive differential cross-sections obtained with the Monte-Carlo program PYTHIA 5.6 [13]. The results are shown in fig. 2 in the (x_F, p_T) plane as contours characterizing the sensitivity level $\delta A_N = 0.05$ in a bin of $\Delta p_L \times \Delta p_T = 2 \times 2$ (GeV/c)^2. For produced particles lines of constant polar angle in the laboratory system are shown; they are given for pions, but represent also a good approximation for heavier particles.

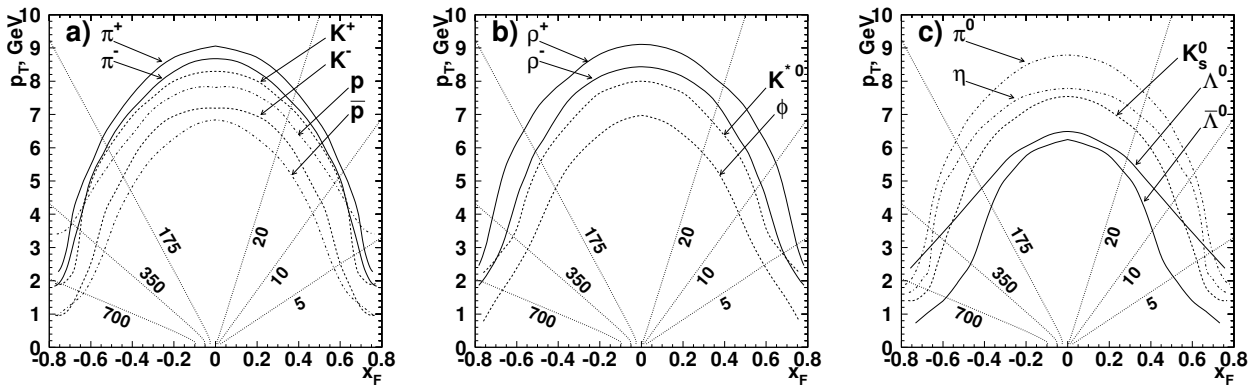

Figure 2: *Contours of the asymmetry sensitivity level $\delta A_N = 0.05$ for inclusive production of different particles in the (x_F, p_T) plane. Only the following decay modes are taken into account: $K^{*0} \to K^+\pi^-$, $\phi \to K^+K^-$, $\eta \to \gamma\gamma$, $K^0_s \to \pi^+\pi^-$, $\Lambda^0 \to p\pi^-$, $\bar{\Lambda}^0 \to \bar{p}\pi^+$. Lines of constant laboratory angles of the particles are shown and marked with their values in units of mrad.*

Experimentally, it is not a simple task to measure single spin asymmetries in the fragmentation region of the polarized nucleon in a fixed target experiment at 820 GeV. This region lies either at very large laboratory angles (a few tens of degrees) if a combination of polarized target and unpolarized beam is used, or it is at very small angles (a few mrad) for the other combination, unpolarized target and polarized beam (see fig. 2). The question how close to the HERA proton beam particles can be measured deserves a special study.

As can be seen from fig. 2, the combined p_T dependence of all involved higher-twist effects can be measured with good accuracy ($\delta A_N \leq 0.05$) up to transverse momenta of about 8÷10 GeV/c in the central region $|x_F| < 0.2$ and up to 5÷6 GeV/c in the target fragmentation region. Hence the p_T-range where higher twist effects are expected to be essential would be well covered. The capability of HERA-$\vec{N}$ to really prove a p_T dependence in the fragmentation region of the polarized nucleon is shown in fig. 3, where the curves were obtained [3] assuming a non–zero quark distribution analysing power, $N_q(\boldsymbol{k}_\perp)$, according to Ref. [14]. The curves and the projected statistical errors in fig. 3 are drawn for the combination of polarized proton beam and unpolarized target and the minimal pion detection angle was assumed to be 5 mrad.

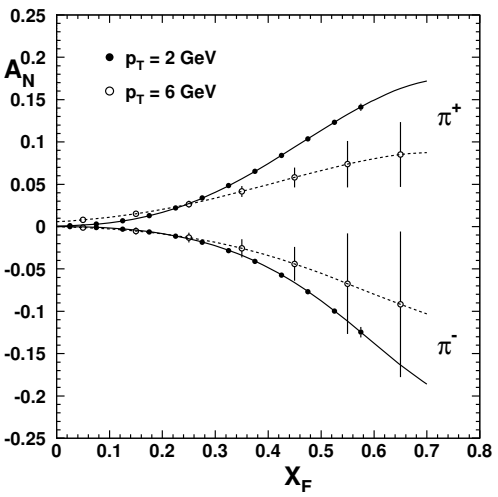

Figure 3: *Capability of HERA-$\vec{N}$ to discriminate predictions [14] for different p_T.*

A measurement of the asymmetry in the inclusive production of particles with different quark contents may allow to study a flavour dependence of the higher twist contributions. In particular, it would be interesting to compare the asymmetry for pions and kaons what appears possible at HERA-$\vec{N}$ (see fig. 2a,c).

A sizeable **inclusive production of Λ^0 and $\bar{\Lambda}^0$ hyperons** would allow to study the asymmetry in their production up to p_T of about 5÷6 GeV/c (fig. 2c). The measurement of the final-state Λ polarization via its decay would allow to study the polarization spin transfer coefficient, D_{NN}. A recent study by E704 [15] at moderate values of p_T (0.1÷1.5 GeV/c) showed a sizeable (up to 30%) spin transfer from the incident polarized proton to the outgoing Λ^0.

The study of polarization asymmetries in **inclusive vector meson production** is especially attractive as these particles are produced 'more directly' in comparison to pions which are mainly decay products of heavier particles. Comparing asymmetries in vector and pseudoscalar meson production can provide information on the magnitude of the asymmetry in quark scattering [16]. If the asymmetry is generated only during the fragmentation of polarized quarks, the asymmetry of ρ mesons is expected to be opposite in sign to that of pions, $R_{\rho/\pi} = A_N^\rho / A_N^\pi \simeq -\frac{1}{3}$. On the contrary, if the quark scattering asymmetry were the dominating one, the asymmetries of pseudoscalar and vector mesons would not differ substantially.

The statistical sensitivity of HERA-$\vec{N}$ for measuring single spin asymmetries in inclusive production of ρ, K^{*0}, and ϕ vector mesons are presented in fig. 2b. The sensitivity for ρ production is at a level comparable to that for pions (fig. 2a), while for K^{*0} and ϕ mesons the reachable p_T values are lower. On the other hand, a study of the asymmetry in K^{*0} and ϕ production using the decay channels $K^{*0} \to K^\pm\pi^\mp$ and $\phi \to K^+K^-$ could be easier since the level of the expected combinatorial background is smaller. Also, the asymmetry in ϕ meson production could be useful for a study of the strange quark polarization in a nucleon [6].

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 the E704 Collaboration [17] 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 cross-section calculations for the two dominant hard subprocesses, 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.

There is an interesting possibility [18, 19] to extract the third twist-2 quark distribution function (quark transversity distribution, $\delta q(x)$ or $h_1(x)$) using **inclusive production of two pions** on the transversely polarized nucleon, $p + p^{\uparrow} \to \pi^+ + \pi^- + X$. This structure function describing basically the fraction of transverse polarization of the proton carried by its quarks is totally unknown at present. In inclusive lepton DIS its contribution is suppressed by a quark mass whereas it is in principle accessible in semi-inclusive DIS [5, 19, 20]. The asymmetry in inclusive two-pion production would be studied as a function of the angle of the normal of the two-pion plane, $\vec{k}_+ \times \vec{k}_-$, with respect to the polarization vector, $\vec{S}_{\perp}$, of the nucleon. The statistical sensitivity of HERA-$\vec{N}$ remains to be calculated.

The single spin asymmetries in **inclusive J/ψ production** [2] and in **Drell-Yan production**, $p + p^{\uparrow} \to l\bar{l} + X$, at small transverse momenta [21], were estimated at HERA-$\vec{N}$ energy to be of the order of $0.01 \div 0.02$. Nevertheless, one may expect larger asymmetries as the calculations might still not be complete. The projected level of sensitivity can be taken from the section on double spin asymmetries as it is the same for both cases if the beam polarization is accounted for in case of A_{LL}.

Large spin effects in **proton-proton elastic scattering**, $p + p^{\uparrow} \to p + p$, have been discovered many years ago. The single spin asymmetry A_N was found significantly different from zero. At HERA-$\vec{N}$ energy one can measure the asymmetry in the range of $p_T^2 = 5 \div 12$ (GeV/c)^2 (see ref.[2, 3]).

3 Double Spin Asymmetries

The measurement of double spin asymmetries in certain final states seems to be the most valuable tool to measure polarized gluon and quark distribution functions in the nucleon. The most accurate way to do so is the study of those processes which can be calculated in the framework of perturbative QCD. Production of *direct photon (plus jet)*, *J/ψ (plus jet)*, and *Drell-Yan pair* final states are most suited because there are only small uncertainties due to fragmentation.
In the following we discuss the capabilities of HERA-$\vec{N}$, operated in doubly polarized mode, to perform such measurements.

3.1 $\frac{\Delta G}{G}(x)$ Measurement

Prospects for the polarized gluon distribution measurements with HERA-$\vec{N}$ are presented in other contributions [22, 23] to these proceedings. Here only a brief summary is given.

Direct photon production in pp interactions is dominated by the quark-gluon Compton subprocess, $q(x_1)+g(x_2) \rightarrow \gamma+q$ and the asymmetry A_{LL} is directly sensitive to the polarized gluon distribution. Indeed, the NLO calculation [24] of prospects for the **inclusive photon production** study with HERA-$\vec{N}$ showed a sufficient statistical accuracy of HERA-$\vec{N}$ to discriminate between different polarized gluon distribution functions.

The production of $c\bar{c}$ quarkonium states, in particular **inclusive J/ψ production**, is a similarly clean tool to measure the polarized gluon distribution. For the production of quarkonia with p_T above 1.5 GeV the $2 \rightarrow 2$ subprocess $g(x_1) + g(x_2) \rightarrow (c\bar{c}) + g$ provides the main contribution. Because of the relatively large quark mass the $c\bar{c}$ production cross section and the expected asymmetry are supposed to be calculable perturbatively. The expected asymmetry is proportional to $(\Delta G(x)/G(x))^2$ and the projected statistical accuracy of HERA-$\vec{N}$ allows for a very good discrimination between different parametrizations of $\Delta G(x)$ [3].
The expected double spin asymmetry for J/ψ production at RHIC energies is much smaller. In fig. 4 predictions at HERA-$\vec{N}$ and two different RHIC energies are shown with projected statistical errors. In the statistically accessible p_T interval the asymmetry ranges between 0.08 and 0.10 at HERA-$\vec{N}$, but only between 0.01 and 0.03 at RHIC energies. It is likely that the fixed target experiment at HERA might accomplish a more significant measurement of the charmonium production asymmetry.

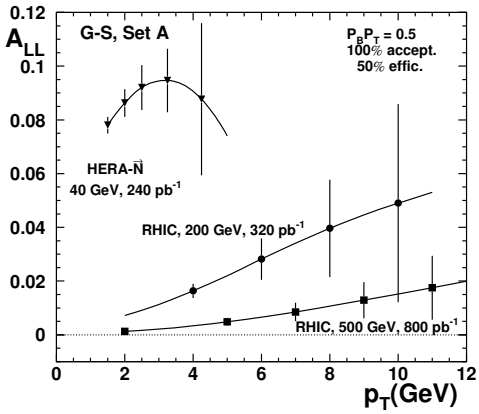

Figure 4: *The asymmetry and projected statistical errors for J/ψ production at HERA-$\vec{N}$ and two different energies at RHIC as a function of p_T.*

The inclusive **two-jet production** involves several hard subprocesses (gg, gq, qq scattering) with gluons. The extraction of the two-jet production cross-section at the given HERA-$\vec{N}$ fixed target kinematics is problematic, as was described in some more detail in ref. [2].
As a possible way out one may presumably replace the two jets by two correlated high p_T hadrons opposite in azimuth.
The asymmetry in **open charm production** could possibly be measured using as a tag a high p_T single muon or electron-muon pairs from charm decays. This option, as well as two-jet production, needs further study.

The complete kinematics of the underlying hard $2 \rightarrow 2$ subprocess can be reconstructed if the away-side jet in the production of photon or J/ψ is measured, as well. In this case the asymmetry A_{LL} can be directly related to the polarized gluon distribution [2]. Using this approach **photon plus jet** production was discussed in Ref. [3] as a tool to directly measure ΔG/G. In fig. 5 the projected statistical sensitivity of HERA-$\vec{N}$ for the $\Delta G(x)/G(x)$ measurement, 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 [26]. The errors demonstrate clearly that in the region $0.1 \leq x_g \leq 0.4$ a significant result from *photon plus jet production* can be expected from HERA-$\vec{N}$ with an accuracy being about competitive to that predicted for RHIC.

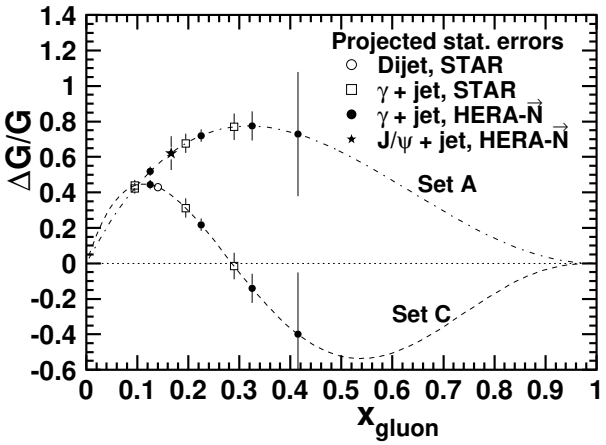

Figure 5: *Typical predictions for the polarized gluon distribution (LO calculations from Ref. [27]) confronted to the projected statistical errors expected for HERA-$\vec{N}$ and RHIC experiments.*

In J/ψ **plus jet** production the quark-gluon subprocess contributes only about 10% to the asymmetry compared to the gluon-gluon fusion subprocess. The prospect of a $\Delta G(x)/G(x)$ measurement at HERA-$\vec{N}$ is shown as an additional entry in fig. 5. Although the x_{gluon} interval $(0.1 \div 0.4)$ explored by both HERA-$\vec{N}$ and RHIC is quite comparable, the different transverse momentum ranges accessed (2...8 GeV at HERA-$\vec{N}$; 10...40 GeV at RHIC) make both measurements indeed complementary; $\frac{\Delta G}{G}$ would be studied by HERA-$\vec{N}$ in the pQCD onset region whereas the RHIC experiments will explore $\frac{\Delta G}{G}$ in the deep perturbative region.

3.2 Study of the Doubly Polarized Drell-Yan Process

The production of **Drell-Yan pairs** in polarized nucleon-nucleon collisions can provide information on a variety of polarized structure functions in dependence on the relative orientation of the beam and target polarization directions.

The **longitudinal** double spin asymmetry turns out to be well suited to extract the polarized light sea-quark distribution

$$A_{LL}^{DY} = -\frac{\sum_i e_i^2[\Delta q_i(x_1)\Delta\bar{q}_i(x_2) + (1 \leftrightarrow 2)]}{\sum_i e_i^2[q_i(x_1)\bar{q}_i(x_2) + (1 \leftrightarrow 2)]}. \quad (1)$$

The prospects for such a measurement at HERA-$\vec{N}$ were calculated in ref. [28] at next-to-leading order QCD. The spread of the predictions (see fig. 6a,c) reflects the insufficient present knowledge on the polarized sea quark distributions in the region $x > 0.1$; not even the sign of the asymmetry at large M is predicted. Since the asymmetry is the weighted sum of $\Delta\bar{u}$ and $\Delta\bar{d}$ quarks with the strange quark contribution assumed to be small and the weight of $\Delta\bar{u}$ is higher than that of $\Delta\bar{d}$ due to its abundance in the proton and the electric charge, the asymmetry measured in pp collisions provides mainly information on $\Delta\bar{u}$, i.e. on the u sea quark polarization. The flavour contributions are slightly different for pn collisions; this results in an asymmetry being much smaller (fig. 6c) than in the pp case. Since the total unpolarized cross-sections for the Drell-Yan process in pp and pn collisons are practically the same (see fig. 6d) much larger luminosity is required in pn collisons to obtain a reasonable statistical sensitivity. Nevertheless, it is very important as it could be used to decompose the flavour structure of the polarized sea

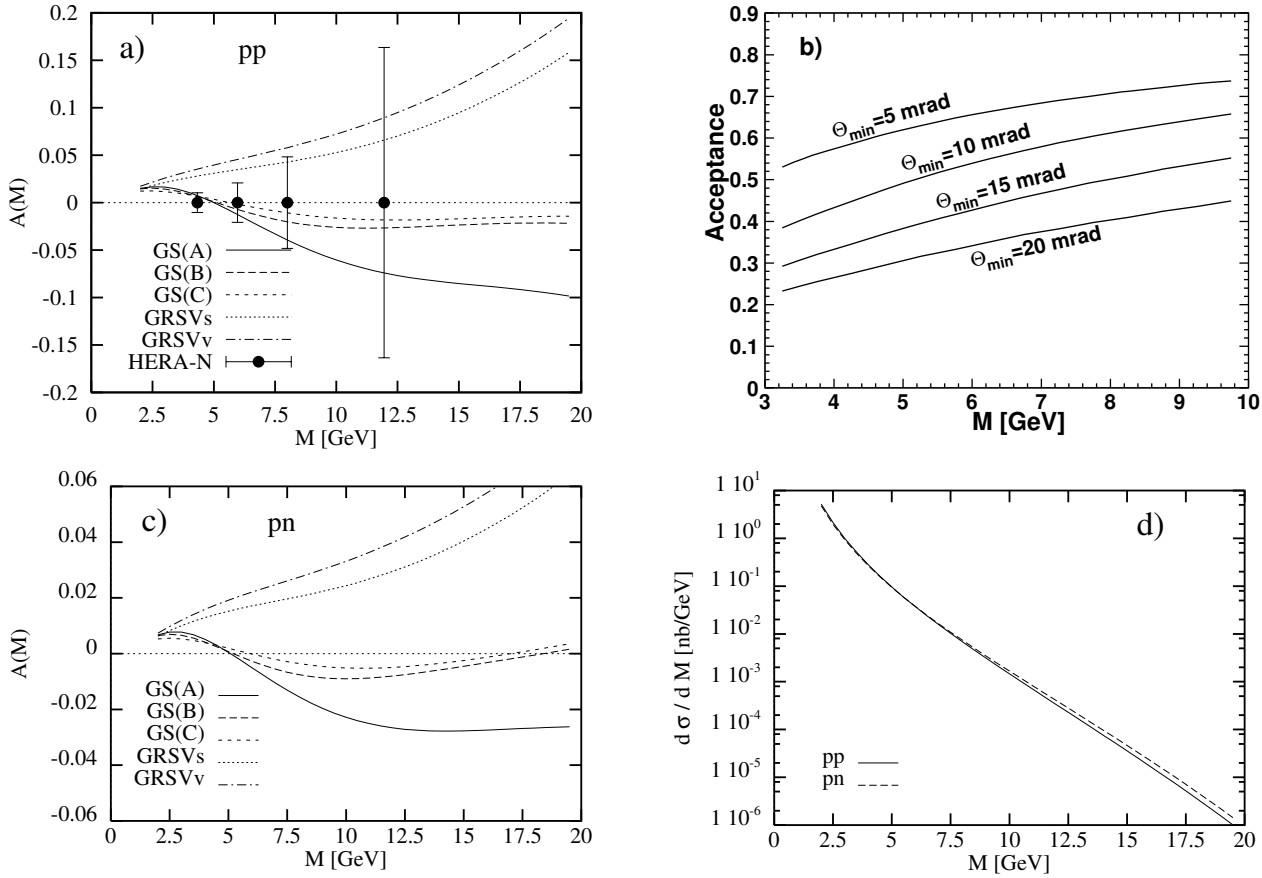

Figure 6: *Expected longitudinal double spin asymmetries in the polarized Drell-Yan process for a) pp and c) pn collisions ($\sqrt{s} = 40$ GeV) from Ref. [28] confronted to the projected statistical errors expected for HERA-$\vec{N}$. b) the acceptance for lepton pair registration in a particular detector with minimal registration angle Θ_{min}. d) the unpolarized cross-section of the Drell-Yan process for pp and pn collisions [28].*

which is practically unknown at present.
Also, with a larger luminosity more information could be obtained from measuring the differential lepton pair distributions in dependence on x_F or η [28, 29], the predictions for the x_F dependence are shown in fig. 7.
We note that the acceptance for lepton pair detection was not taken into account in the calculations [28] as it depends on the particular detector. The acceptance (integrated over kinematical parameters of produced pairs) depends mainly on the minimal accepted lepton angle in the detector (see fig. 6b); a value of about 50% may be realistic. In this case the projected statistical sensitivity values, shown in fig. 6a, would be larger by a factor of $\sqrt{2}$.

Drell-Yan pair production with **transverse polarization** of both beam and target can provide a measurement of the transversity distribution, $\delta q(x)$. The transverse double spin asymmetry in nucleon-nucleon Drell-Yan production can be schematically written in the form [30]

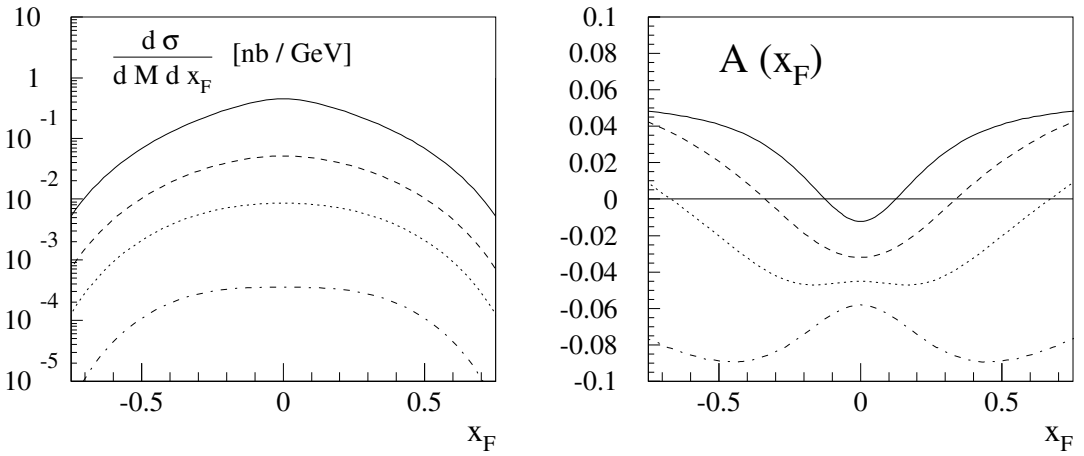

Figure 7: *The unpolarized Drell-Yan cross-section and the asymmetry in pp collisions for the polarized GS(A) parton distributions. Curves are for different invariant masses M: solid - 4 GeV; dashed - 6 GeV; dotted - 8 GeV; dot-dashed - 12 GeV. The figures are from Ref. [29]).*

$$A_{TT}^{DY} = \frac{\sin^2\theta\cos 2\phi}{1+\cos^2\theta}\frac{\sum_i e_i^2[\delta q_i(x_1)\delta\bar{q}_i(x_2)+(1\leftrightarrow 2)]}{\sum_i e_i^2[q_i(x_1)\bar{q}_i(x_2)+(1\leftrightarrow 2)]}, \tag{2}$$

where θ is the polar angle of one lepton in the virtual photon rest frame and ϕ is the angle between the direction of polarization and the normal to the dilepton decay plane. An estimate of the asymmetry for HERA-$\vec{N}$ energy was given recently [31] from both LO and NLO calculations. One should stress, however, that the anticipated asymmetry level strongly depends on the actual size of the transversity distributions, which are totally unknown at present. Although in the non-relativistic quark model the relation $\delta q(x) = \Delta q(x)$ holds, in reality differences between both distributions are expected to be caused by dynamical effects. Due to the lack of any information on the transversity distribution, the maximally possible value of the asymmetry was estimated [31]; the corresponding results on LO and NLO polarized Drell-Yan cross-section and asymmetry are presented at fig. 8. The projected statistical errors for a measurement of A_{TT} at HERA-$\vec{N}$ are also shown. The maximal value of A_{TT} at an invariant mass of $M = 4$ GeV was found to be approximately 4% with an expected statistical error of about 1%. The expected value of the asymmetry at RHIC energies is smaller but the statistical errors become relatively smaller at $\sqrt{s} = 500$ GeV due to the higher luminosity of $\mathcal{L} = 800$ pb^{-1} [31].
The calculations [31] do not account for the acceptance of the lepton pair in the detector. The same discussion as above for the LL case applies here.

We note that there exist another potentially interesting possibility, the study of the **longitudinal-transverse** double spin asymmetry, A_{LT}^{DY}. This asymmetry was calculated in ref. [30] and depends in a rather complicated fashion on both twist-2 ($\Delta q(x)$ and $\delta q(x)$) and twist-3 ($g_T(x)$ and $h_L(x)$) polarized structure functions. In contrast to A_{LL}^{DY} and A_{TT}^{DY} the asymmetry A_{LT}^{DY} decreases as $M/\sqrt{Q^2}$. The expected level of the asymmetry A_{LT}^{DY} at HERA-$\vec{N}$ energy has not been calculated yet, the expected level of sensitivity as a function of the lepton pair mass can be taken from fig. 6.

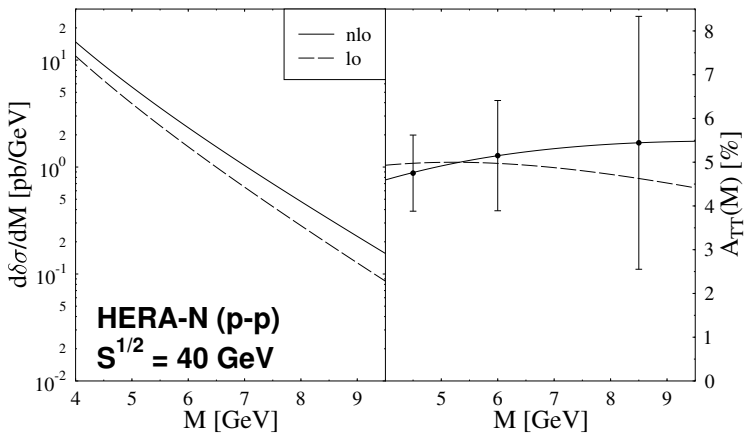

Figure 8: *Maximal polarized Drell-Yan cross-section (left figure) and the asymmetry (right figure) in double transverse polarized collisions as a function of the invariant mass. The results are shown for both LO and NLO calculations [31]. The projected statistical errors for HERA-$\vec{N}$ are shown, as well.*

4 Conclusions

A physics programme for a possible fixed target polarized nucleon-nucleon collision experiment utilizing an internal target in the 820 GeV HERA proton beam has been presented. Single spin asymmetries, accessible already with the existing unpolarized beam, are found to be a powerful tool to study the nature and physical origin of higher twist effects and a possible manifestation of non-perturbative dynamics. For that the study of asymmetries over a sufficiently large p_T-range is essential; HERA-$\vec{N}$ would be able to provide data up to p_T =10 GeV/c in the central region and up to 5÷6 GeV/c in the fragmentation region of the polarized nucleon. 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. Although both measurements explore the same x_{gluon} range they are complementary due to the different p_T ranges accessible. A measurement of Drell-Yan pair production with both beam and target longitudinally polarized can improve our knowledge on the polarized light sea quark distributions. A study of double transverse and/or longitudinal-transverse Drell-Yan spin asymmetries as well as a study of the single spin asymmetry in inclusive two-pion production might open first access to the quark transversity distribution. The existence of a polarized internal gas target in HERA-$\vec{N}$ would allow to study polarized pn and $pA(D,^3He,...)$ collisions, which are harder to be realized at RHIC. In addition, there is a potential to obtain significant results on the long-standing unexplained spin asymmetries in elastic scattering.

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