Drell–Yan asymmetries at HERA-$\vec{\mathrm{N}}$

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Abstract: The production of Drell–Yan pairs in the double polarized mode of HERA-$\vec{\mathrm{N}}$ is studied at next–to–leading order in QCD. It is found that a measurement of this observable could yield vital information on the polarization of the light quark sea in the nucleon.

1 Introduction

Structure functions measured in deep inelastic lepton–nucleon scattering probe a particular combination of quark distributions in the nucleon. The mere knowledge of these structure functions is therefore insufficient for a distinction between valence and sea quarks and for a further decomposition of the light quark sea into different flavours. These are only possible if additional information from other experimental observables is taken into account.

Fits of unpolarized parton distributions (see for example [1]) obtain this information from two sources. The weak structure functions measured in neutrino–nucleon scattering probe different combinations of parton distributions than their electromagnetic counterparts. The inclusion of these structure functions in a global fit can therefore constrain the flavour structure of the unpolarized sea. A direct probe of the antiquark distributions in the nucleon is given by the production of lepton pairs in hadron–hadron collisions [2], the Drell–Yan process. It is in fact the inclusion of data from *both* processes in the global fits that leads to a precise determination of the distribution of antiquarks and its flavour decomposition.

Recent fits of polarized parton distributions [3, 4] have to rely entirely on the available data on the polarized structure function $g_1^{p,d,n}(x,Q^2)$. The distinction of valence and sea quark contributions to this structure function is possible to a certain extent if additional information from sum rules is taken into account. The flavour structure of the polarized sea is, however, completely unknown at present. It seems rather doubtful that more precise measurements of this structure function will be able to provide more information on these two issues.

Polarized neutrino–nucleon scattering experiments will not be feasible in the foreseeable future, although a measurement of polarized weak structure functions may be possible from charged current interactions at HERA [5] if polarization in the collider mode can be achieved.

An experimental study of the polarized Drell–Yan cross section would be possible with the HERA-$\vec{\mathrm{N}}$ experiment [6], operated with a polarized proton beam on a polarized nucleon target. We will examine the prospects of such a measurement in this article.

2 The polarized Drell–Yan process

The production of lepton pairs in hadronic collisions can be understood as annihilation of a quark–antiquark pair to a virtual photon, which decays into a lepton pair of invariant mass M^2. The polarized and unpolarized cross sections for this process are conventionally defined to be [7]

$$\mathrm{d}\Delta\sigma \equiv \frac{1}{2}\left(\mathrm{d}\sigma^{++} - \mathrm{d}\sigma^{+-}\right), \qquad \mathrm{d}\sigma \equiv \frac{1}{2}\left(\mathrm{d}\sigma^{++} + \mathrm{d}\sigma^{+-}\right),$$

where $(++)$ and $(+-)$ denote the configurations of aligned and antialigned hadron spins.

In the QCD–corrected parton model, these hadronic cross sections can be expressed as a convolution of parton–level coefficient functions with the appropriate parton distributions:

$$\begin{aligned}\frac{\mathrm{d}[\Delta]\sigma}{\mathrm{d}M^2} = \frac{4\pi\alpha}{9sM^2}\int_0^1 \mathrm{d}x_1\mathrm{d}x_2\mathrm{d}z\;\delta(x_1x_2z-\tau)\sum_q e_q^2 \\ \left\{\left\{\,[\Delta]q_1(x_1,M^2)\,[\Delta]\bar{q}_2(x_2,M^2) + (1\leftrightarrow 2)\,\right\}\left([-]\delta(1-z) + \frac{\alpha_s(M^2)}{2\pi}[\Delta]c_q^{DY}(z)\right)\right. \\ \left. + \left\{\left(\,[\Delta]q_1(x_1,M^2) + [\Delta]\bar{q}_1(x_1,M^2)\right)\;[\Delta]G_2(x_2,M^2) + (1\leftrightarrow 2)\,\right\}\frac{\alpha_s(M^2)}{2\pi}[\Delta]c_G^{DY}(z)\right\}, \quad (1)\end{aligned}$$

with the scaling variable $\tau = M^2/s$. The parton distributions in the (not necessarily identical) hadrons are denoted by $f_{1,2}(x_i, M^2)$.

The next–to–leading order corrections to the unpolarized coefficient functions have been calculated in [8], and the polarized corrections are given in [7, 9]. It turns out that inclusion of these corrections is crucial at fixed–target energies, as they contribute about 30% of the total cross section. A fully consistent study of the Drell–Yan process at next–to–leading order was until now only possible in the unpolarized case, as the polarized parton distributions could only be determined to leading accuracy. With the recently calculated polarized two–loop splitting functions [10], the polarized distributions can now be determined to next–to–leading order from fits to structure function data [3, 4].

Using these distributions in combination with the unpolarized distributions (set A′) from [1], we have calculated the total Drell–Yan cross section $\mathrm{d}\sigma/\mathrm{d}M$ and the expected asymmetry

$$A(M) \equiv \frac{\mathrm{d}\Delta\sigma/\mathrm{d}M}{\mathrm{d}\sigma/\mathrm{d}M}$$

for proton and (idealized) neutron targets at centre–of–mass energies $\sqrt{s} = 40$ GeV (HERA–$\vec{\mathrm{N}}$) and $\sqrt{s} = 25$ GeV. The latter could be achieved by operating HERA-$\vec{\mathrm{N}}$ with a proton beam energy of about 330 GeV. Figure 1 shows the unpolarized Drell–Yan production cross section as a function of the invariant mass of the lepton pair. It should be noted that invariant masses $M \leq 4$ GeV and 9 GeV $\leq M \leq 11$ GeV must be excluded from the experimental measurement, as lepton pair production in these mass regions is dominated by the decay of quarkonium resonances. An experiment with $\sqrt{s} = 25$ GeV will clearly be restricted to the invariant mass range 4 GeV $< M <$ 9 GeV; depending on the available luminosity, a measurement for $M >$ 11 GeV could be possible at $\sqrt{s} = 40$ GeV.

The Drell–Yan cross section at HERA–$\vec{\mathrm{N}}$ ($\sqrt{s} = 40$ GeV) is about two orders of magnitude larger than at RHIC–SPIN ($\sqrt{s} = 200$ GeV) when evaluated at fixed τ.

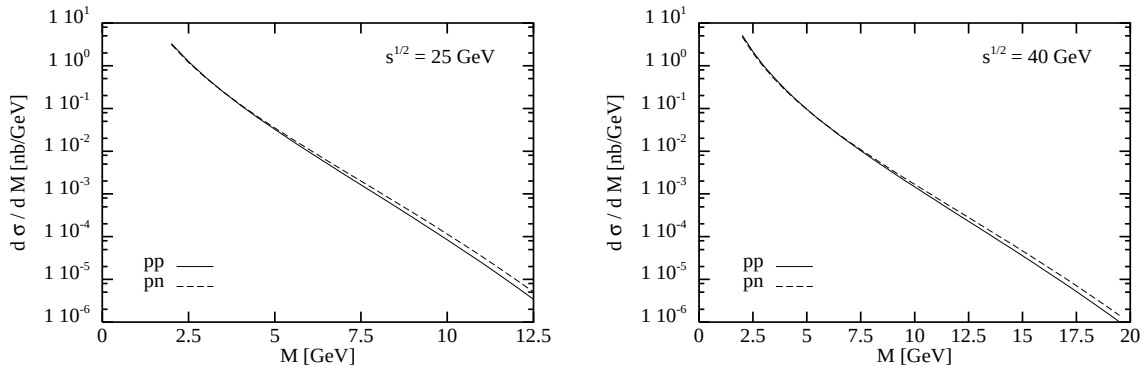

Figure 1: *Unpolarized Drell–Yan cross sections in proton–proton and proton–neutron collisions.*

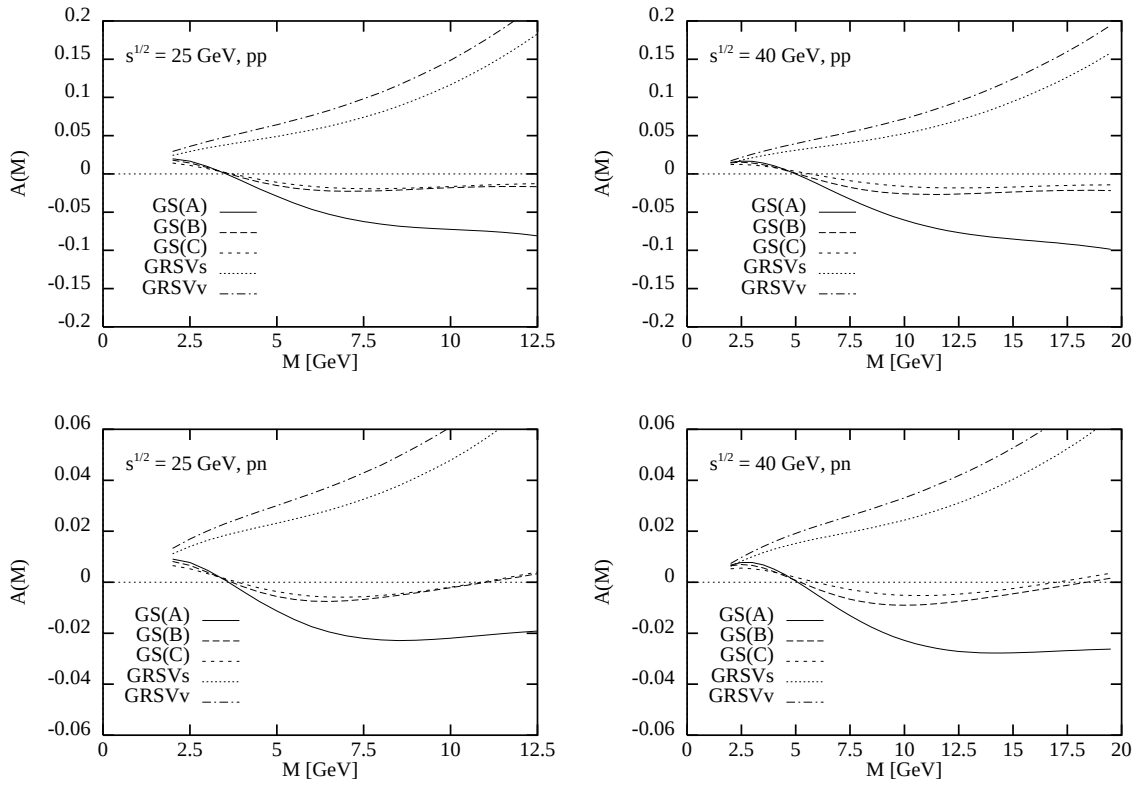

Figure 2: *Expected asymmetries in the polarized Drell–Yan process.*

Figure 2 shows the asymmetries obtained with the polarized NLO parton distributions of [3] (GS(A,B,C)) and [4] (GRSVs,v). The spread in these predictions reflects the present lack of knowledge on the behaviour of polarized sea quark distributions in the region $x > 0.1$. Not even the sign of the asymmetry at large M is predicted. A sizable asymmetry of more than $\pm 10\%$ can be expected in proton–proton collisions; the asymmetry in proton–neutron collisions is considerably smaller.

We have checked the perturbative stability of these results by varying the mass factorization scale; we find that the absolute value of the asymmetry is decreased (increased) by a maximum of 1.5% if we take $\mu_F = 2M$ ($\mu_F = M/2$). This variation is significantly smaller than the

difference between the different parton distribution functions.

3 Conclusions and Outlook

A measurement of the polarized Drell–Yan cross section in the double polarized mode of HERA-$\vec{\text{N}}$ appears feasible, given the anticipated luminosity of 240 pb^{-1} [6]. Such a measurement would provide important information on the polarization of the light quark sea at large x, a region which cannot be probed with measurements of polarized weak structure functions. Such a measurement would be unique to HERA-$\vec{\text{N}}$, as the polarized Drell–Yan process cannot be studied at the RHIC. Furthermore, HERA-$\vec{\text{N}}$ could measure Drell–Yan asymmetries off different targets, which could in principle be used to infer the flavour structure of the polarized sea. Such a measurement would however require much higher luminosity due to the small asymmetries on the (idealized) neutron target.

In this study we have only examined the invariant mass distribution of the Drell–Yan pairs, which is already able to discriminate different parametrizations for the polarized sea quark distributions. Even more information can be gained from more differential distributions (e.g. in the lepton–pair rapidity), which could be obtained with higher luminosity.

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