Limit on the $\bar{d}/\bar{u}$ Asymmetry of the Nucleon Sea from Drell-Yan Production

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Abstract

We present an analysis of 800 GeV proton-induced Drell-Yan production data from isoscalar (IS) targets ^2H and C, and from W, which has a large neutron excess. The ratio of cross sections per nucleon, $R = \sigma_W/\sigma_{IS}$, is sensitive to the difference between the $\bar{d}(x)$ and $\bar{u}(x)$ structure functions of the proton. We find that R is close to unity in the range $0.04 \leq x \leq 0.27$, allowing upper limits to be set on the $\bar{d} - \bar{u}$ asymmetry. Additionally, the shape of differential cross section, $m^3 d^2\sigma/dx_F dm$, for ^2H at $x_F \approx 0$ shows no evidence of an asymmetric sea in the proton. We examine the implications of these data for various models of the violation of the Gottfried sum rule in deep-inelastic lepton scattering.

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Recent precise measurements, by the New Muon Collaboration (NMC)[1], of the F_2 structure function in deep-inelastic muon scattering (DIS) from hydrogen and deuterium targets show that,

$$G_{0.004}^{0.8} \equiv \int_{0.004}^{0.8} (F_2^p - F_2^n)\frac{dx}{x} = 0.227 \pm 0.007 \pm 0.014.$$

When the integration is extended from zero to one the theoretical result $G_0^1 = \frac{1}{3}$ is known as the Gottfried Sum Rule (GSR)[2]. Assuming charge symmetry, its violation implies $\bar{d}(x) \neq \bar{u}(x)$ in the sea of the proton. The NMC result has led to many analyses[3-10] of the nucleon sea. For the purposes of the present paper we separate them into three groups: 1) modified structure functions[3-5] which reconcile the NMC data with the more conventional $SU(2)$-symmetric structure function analyses by allowing $\bar{d}(x) \neq \bar{u}(x)$, 2) explicit calculation of the up-down asymmetry in the sea arising from virtual mesons [5-9], and 3) a structure function analysis[10] which presumes an $SU(2)$ symmetric sea and utilizes the NMC data to constrain the experimentally unobserved region $x \leq 0.004$.

It is well established that the proton-induced Drell-Yan (DY) process in the Feynman-x range $x_F \geq 0.1$ is sensitive to the antiquark distribution of the target nucleons, due to dominance of the term $u_{beam}\bar{u}_{target}$. Under these conditions proton bombardment of free proton and neutron targets could be used to extract the ratio,

$$R(x) = \frac{\sigma_{pn}(x)}{\sigma_{pp}(x)} \approx \frac{\bar{u}_n(x)}{\bar{u}_p(x)} \approx \frac{\bar{d}_p(x)}{\bar{u}_p(x)}. \tag{1}$$

A comparison of DY production from ^1H and ^2H is the best approximation to this ideal. Comparison of nuclear targets with different neutron excesses is less sensitive, but still very relevant to the issue of asymmetry in the nucleon antiquark sea. An approximation valid to ≤ 0.02 for the range of the present experiment is,

$$R_A(x) \equiv \frac{\sigma_A(x)}{\sigma_{IS}(x)} \approx 1 + \frac{(N-Z)}{A} \times \frac{\bar{d}(x) - \bar{u}(x)}{\bar{d}(x) + \bar{u}(x)} = 1 + \frac{(N-Z)}{A}\Delta(x), \tag{2}$$

where σ is the cross section per nucleon, IS stands for isoscalar, and N, Z and A refer to a heavy target with a neutron excess. Unlike DIS studies of the GSR which determine an integral quantity, the DY process yields information about $\bar{q}(x)$.

The above equation presumes that effects due to next-to-leading order quantum-chromodynamic corrections cancel in the ratio. A recent analysis of the pion-induced DY process aimed at extracting the ratio of sea-quark to valence-quark distribution in the proton[11] demonstates that this approximation is valid at the few percent level.

We report here a new analysis from Fermilab Experiment E772, a precision study of the A-dependence of dimuon production from 800 GeV proton bombardment of nuclear targets[12-14]. We compare Drell-Yan production data from isoscalar targets, ^2H and C, to W which has a large neutron excess. From Eq. 2 one has $R_W(x) \approx 1 + 0.183\Delta(x)$. The ratio shown in Fig. 1 was determined from sets of runs in which the three targets were alternately inserted in the beam at intervals of a few minutes. Relative normalization errors dominated by differences in rate dependence are less than 2%. Table 1 gives the mean values of mass and x_F corresponding to each x bin.

It is now well established from DIS that nuclear shadowing occurs in the range $x \leq 0.1$ when comparing low-A and high-A targets[15,16]. Evidence for shadowing has also been reported in the DY process from the present experiment[12]. Because W is significantly heavier than ^2H and C, the targets used to obtain σ_{IS}, we have corrected the two smallest-x points of $R_W(x)$ for shadowing by the following procedure. First, consistent with the functional dependence observed in DIS[15,16] an A-dependent shadowing factor, α_{SH}, was determined from the isoscalar targets ^2H, C, and Ca. Next, for $x \leq 0.1$, the pure shadowing contribution to R_W was calculated using $\sigma_A = \sigma_N \times A^{\alpha_{SH}}$. This value was subtracted from the experimental ratio to yield R_W plotted in Fig. 1 as solid points at small x above the open points (no shadowing correction).

Also shown in Fig. 1 are calculated values of the DY ratio using several published models of the GSR violation. The exact expression for the ratio is evaluated using the full DY formula, not the approximation of Eq. 2. The structure functions of Ellis and Stirling[3] (ES), and of Eichten, Hinchliffe, and Quigg[5] (EHQ) have $\bar{d}(x) \neq \bar{u}(x)$, the flavor asymmetry being determined from the NMC data. The Kumano-Londergan[8] (KL), calculation is based on virtual pion contributions which naturally lead to flavor asymmetry. It should be noted that KL account for only 47% of the GSR violation via sea-quark contributions. All calculations were performed at the mean kinematic values given in Table 1, simulating the acceptance of the E772 spectrometer. Structure function evolution with Q^2 is small[17] in the range of the present data and was not taken into account.

The ES and EHQ structure functions yield an asymmetry which is entirely inconsistent with R_W in the range $x \leq 0.15$. The KL calculation exhibits a smaller asymmetry in the sea and is consistent with the present data. Similarly the parton distributions of Martin, Stirling, and Roberts[10], where $\bar{d}(x) = \bar{u}(x)$ is assumed, yield $R \sim 1$ in agreement with the data (calculation not shown). One can use R_W in conjunction with Eq. 2 to set upper limits on $\Delta(x)$. These values (Table 1), which include the 2% normalization error and an estimate of the calculational error from Eq. 2, are determined at the 2σ statistical error level.

A different and complimentary sensitivity of the DY process to the $\bar{d}/\bar{u}$ asymmetry has been applied to earlier data[18,3]. Here one uses the shape of the differential cross section versus x_F for a single target as evidence of differences between $p-p$ and $p-n$ DY production. The $p-p$ process is symmetric around $x_F = 0$ whereas the $p-n$ process is not, leading to an x_F asymmetry even for isoscalar targets. This allows the use of ^2H, hence avoiding unforeseen nuclear effects which could complicate the previous analysis. Figure 2 compares $m^3 d^2\sigma/dx_F dm$ for the ^2H data at a mean mass of 8.15 GeV with two versions of the ES structure functions, with and without the term which gives the $\bar{d}/\bar{u}$ asymmetry. The calculations were normalized to the large-x data with a K factor of 1.45. At $x_F = 0$ one is sensitive to the $\bar{d}/\bar{u}$ asymmetry at $x \approx 0.21$. Again there is no evidence for the suppression of the $x_F \leq 0$ cross section predicted by the ES structure functions with $\bar{d} \neq \bar{u}$. Based on the quality of the fits of Fig. 2 an upper limit for the $\bar{d}/\bar{u}$ asymmetry is given in Table 1.

In conclusion, from studies of the DY process we find no indication of a large SU(2) asymmetry in the antiquark sea of the nucleon. Clearly more precise proton-induced DY data are needed particularly to explore the region $x \geq 0.15$. Direct comparisons of hydrogen and deuterium targets would maximize the sensitivity to $\bar{d}/\bar{u}$ and minimize possible complications due to nuclear effects.

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Table 1. Mean values of kinematic variables at each x bin of Fig. 1 as determined by the acceptance of the E772 spectrometer and the Drell-Yan cross section. The far right column gives the upper limit of $\Delta(x)$ at the 2σ statistical error level.

x	x_F	Mass	$\Delta_{UL}(x)$
0.040	0.370	4.94	0.19
0.072	0.295	6.24	0.27
0.120	0.155	7.32	0.22
0.168	0.115	8.36	0.77
0.215	0.152	10.9	≈ 1
0.267	0.162	13.1	≈ 1
$\approx$0.21	$\approx$0	8.15	0.4

Figure Captions.

Figure 1. The ratio $R_W \equiv \sigma_W/\sigma_{IS}$ versus x_{target}. The open circles at small x are the ratio before correction for shadowing as described in the text. The curves are calculations described in the text; Ellis and Stirling (dashed), Eichten, Hinchliffe, and Quigg (dot-dashed), and Kumano and Londergan (solid).

Figure 2. Differential cross section $m^3 d^2\sigma/dx_F dm(GeV^2 \times nb)$ for ^2H. The curves are calculations with the ES structure functions with (solid) and without (dashed) $\bar{d}/\bar{u}$ asymmetry.