New Results from Fermilab E866 (NuSea) for $\bar{d}/\bar{u}$

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The Fermilab dimuon experiment 866/NuSea measured Drell-Yan yields from an 800 GeV/c proton beam incident on liquid hydrogen and deuterium targets. Over 370,000 Drell-Yan muon pairs were recorded. From these data, the ratio of anti-down ($\bar{d}$) to anti-up ($\bar{u}$) quark distributions in the proton sea is determined over a wide range in Bjorken-x. A strong x dependence is observed in the ratio $\bar{d}/\bar{u}$, showing substantial enhancement of $\bar{d}$ with respect to $\bar{u}$ for $x < 0.2$. The results presented here for the full data sets confirm previously published results from E866 and are compared with parametrizations of parton distribution functions calculated both before and after the publication of the high-mass E866 data.

1. FLAVOR ASYMMETRY IN THE NUCLEON SEA

Recent measurements [1–4] provide strong evidence of a large asymmetry in the distributions of up and down anti-quarks. While no known symmetry requires $\bar{u}$ to equal $\bar{d}$, a large $\bar{d}/\bar{u}$ asymmetry was not anticipated. The usual assumption was that the sea of q-$\bar{q}$ pairs is produced from gluon splitting. Since the mass difference of the up and down quark is small compared to the nucleon mass, nearly equal numbers of up and down pairs should result. Thus a large $\bar{d}/\bar{u}$ asymmetry requires a non-perturbative origin for an appreciable fraction of these light antiquarks.

The data from experiment E866 [3] at Fermilab were the first to demonstrate a strong Bjorken-x dependence of the $\bar{d}/\bar{u}$ ratio. In that earlier work, only a limited set of data at fairly large dimuon mass was available. In this paper we present all three data sets, which cover a larger range of mass and Bjorken-x. Averaging all of the data provides more accurate measurements of $\bar{d}/\bar{u}$ and the integral of $\bar{d} - \bar{u}$.

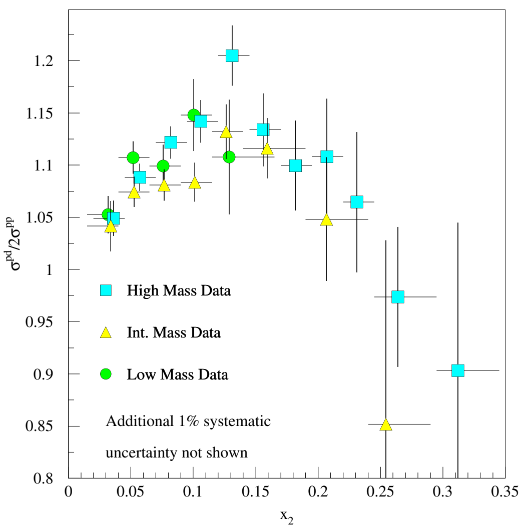

Figure 1. The Drell-Yan cross section ratio versus x of the target parton. The results from all three mass settings are shown. The error bars represent the statistical uncertainty. An additional one percent systematic uncertainty is common to all points within a mass setting.

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2. DATA

Fermilab experiment 866 (E866) measured the Drell-Yan muon pair yield from 800 GeV/c proton bombardment of liquid hydrogen and deuterium targets. From these data, $\bar{d}/\bar{u}$ and $\bar{d}-\bar{u}$ in the proton over the range $0.015 < x < 0.345$ are extracted. A significant difference between the $\bar{d}$ and $\bar{u}$ distributions is found.

E866 used a modified version of the 3-dipole spectrometer [5] employed in previous experiments E605, E772, and E789. The non-interacting beam protons were stopped in an internal beam dump. Immediately after the beam dump was an absorber wall which removed hadrons produced in the target and the dump. The detection system consisted of four tracking stations and a momentum analyzing magnet.

Some kinematic quantities commonly used to describe Drell-Yan events are the Feynman-x (x_F) and the dilepton mass (M) which are defined as :

$$x_F = \frac{p_{||}^{\gamma}}{p^{\gamma,max}} \approx \frac{p_{||}^{\gamma}}{\sqrt{s}/2} = x_1 - x_2 \tag{1}$$

and

$$M^2 = Q^2 \approx x_1 x_2 s \tag{2}$$

where $p_{||}^{\gamma}$ is the center of mass longitudinal momentum of the virtual photon, $p^{\gamma,max}$ is its maximum possible value, and s is the total four momentum squared of the initial nucleons. The proton-deuterium cross section is

$$\sigma^{pd} \approx \sigma^{pp} + \sigma^{pn} \tag{3}$$

which ignores the small nuclear effects inside the deuterium nucleus. Using this approximation, the cross section ratio for DY produced in deuterium and hydrogen targets can be used to determine the ratio of $\bar{d}/\bar{u}$.

Over 370,000 Drell-Yan events were recorded, using three different spectrometer settings which were optimized for low, intermediate and high mass muon pairs. The data collected with the low and intermediate mass settings are reported here for the first time in combination with the high mass data previously published [3]. The data from the two lower mass settings required careful analysis to correct for rate dependences, which were smaller in the high mass data due to the greatly reduced rates in the tracking chambers. The percentage correction for rate dependence in the low, intermediate and high mass samples respectively were 5.45%, 1.06%, and 1.76%.

In addition to corrections for rate dependence, the data were also corrected for random coincidences between two unrelated, oppositely charged muons, background events from the target flask and beam line windows, differences in beam attenuation in the targets, differences in the target density, and a small hydrogen contamination in the deuterium target. The total systematic error in the cross section ratio is less than $\pm 1\%$.

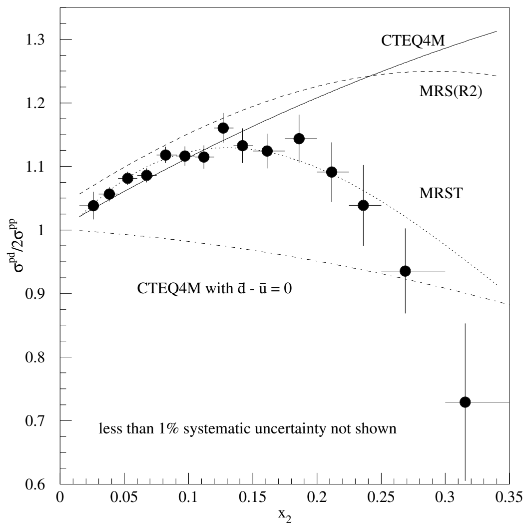

Figure 2. Combined Drell-Yan cross section ratio versus x of the target parton. Statistical uncertainties are shown. An additional one percent systematic uncertainty is common to all points. The curves are the calculated cross section ratios using CTEQ4M, MRS(R2), and MRST. The bottom curve is calculated using CTEQ4M where $\bar{d}-\bar{u}$ has been forced to zero.

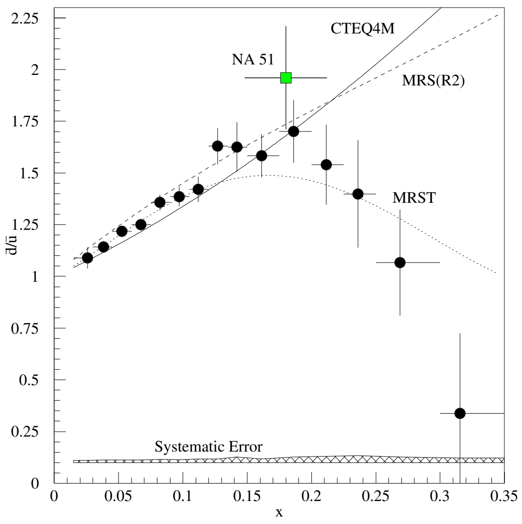

Figure 3. $\bar{d}(x)/\bar{u}(x)$ versus x. The combined result from all three mass settings is shown along with three parameterizations. The NA51 data point is also shown.

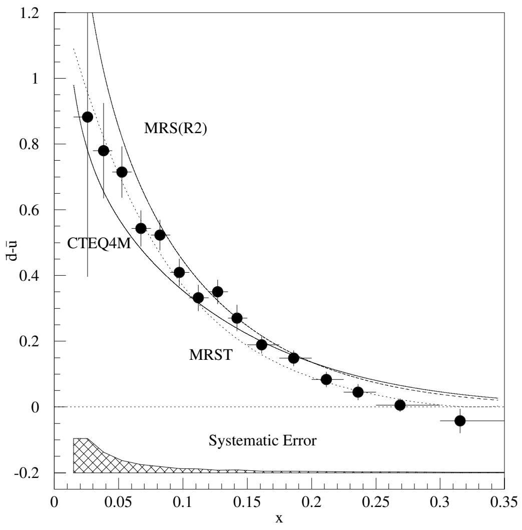

Figure 4. $\bar{d}(x) - \bar{u}(x)$ versus x. The combined result from all three mass settings is shown along with three parameterizations.

3. CROSS-SECTION RATIOS FOR $p + d$ TO $p + p$

The resulting ratio of the Drell-Yan cross section per nucleon for $p + d$ to that for $p + p$ is shown in Fig. 1 as a function of x_2, the momentum fraction (Bjorken-x) of the target quark in the parton model. (The Bjorken-x of the beam parton is denoted by x_1.) To eliminate contributions from the J/ψ and Υ resonance families a cut on the muon pair mass, $M_{\mu^+\mu^-}$, was used. The data clearly show that the Drell-Yan cross section per nucleon for $p+d$ exceeds $p+p$ over an appreciable range in x_2. The result of averaging all of the mass settings is shown in Fig. 2

4. $\bar{d}/\bar{u}$ EXTRACTION

The ratio $\bar{d}/\bar{u}$ was extracted iteratively by calculating the leading order Drell-Yan cross section ratio using a set of parton distribution functions (PDF) as input and adjusting $\bar{d}/\bar{u}$ until the calculated cross section ratio agreed with the measured value from data. The extracted $\bar{d}/\bar{u}$ ratio is shown in Fig. 3 along with the CTEQ4M [6] parameterization. A qualitative feature of the data, not seen in either CTEQ4M or MRS(R2) [7], is the rapid decrease towards unity of the $\bar{d}/\bar{u}$ ratio beyond $x = 0.2$. At $x = 0.18$, the extracted $\bar{d}/\bar{u}$ ratio is somewhat smaller than the value obtained by NA51. Such a large $\bar{d}/\bar{u}$ asymmetry cannot arise from perturbative effects [8]. Since the publication of the high mass results, the MRS and CTEQ calculations have been updated [9,10] (only MRST is shown).

5. $\bar{d} - \bar{u}$ EXTRACTION

To address the GSR violation observed by NMC, our extracted $\bar{d}/\bar{u}$ ratio is used together with the CTEQ4M value of $\bar{d} + \bar{u}$ to obtain $\bar{d} - \bar{u}$. Based on this, the integral of $\bar{d} - \bar{u}$ between 0.015 and 0.345 is calculated. Results for $\bar{d} - \bar{u}$ are shown in Fig. 4 and the results for

$\int_{0.015}^{0.345} (\bar{d}-\bar{u})\, dx$ are shown in Fig. 5. The integral reaches a value of $0.082 \pm 0.010(stat) \pm 0.008(syst)$ at $x^{\min} = 0.015$. This may be compared with the CTEQ4M and MRS(R2) parameterizations which have values of 0.082 and 0.108, respectively, for the integral over the same region. Over the range $10^{-4} < x < 1$, CTEQ4M gives a value of 0.109 for the integral, and MRS(R2) gives 0.166. Using the CTEQ4M parameterization to extend our measurements over the full range from 0 to 1, we obtain a value for the integral to be 0.100 ± 0.018. Above $x = 0.345$, it is unlikely there are significant contributions to the $\bar{d}-\bar{u}$ integral since the sea is relatively small in this region. It is clear, however, that significant contributions to the integral arise in the unmeasured region below $x = 0.015$. The addition of the low and intermediate data sets is the major difference between these results and those shown at DIS98 [12].

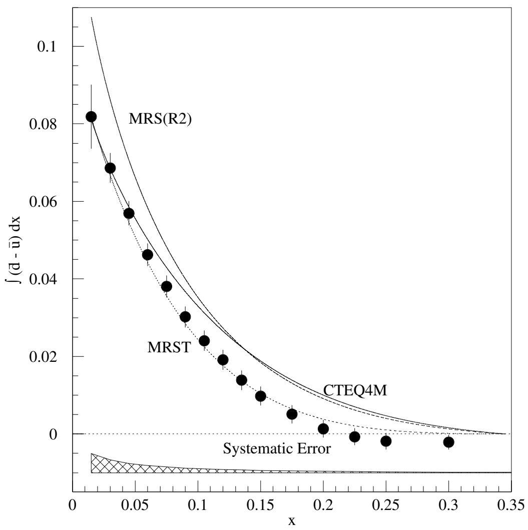

Figure 5. $\int_x^{0.35} (\bar{d}(x) - \bar{u}(x))dx'$ versus x. The curves are from three different parameterizations.

6. CONCLUSION

The possible production mechanisms that can account for the sea of quark-antiquark pairs in the nucleon can be categorized as either perturbative or nonperturbative. While gluon splitting is a source of quark-antiquark pairs in the nucleon, it can not be the source of the large observed flavor asymmetry. Thus, some other non-perturbative processes must be responsible. As these nonperturbative mechanisms are considered, it is important to remember that they act in addition to the perturbative sources, which tends to dilute their effect. In effect the non-perturbative sources must be even stronger to account for the large asymmetries shown here. Models which explicitly include pions in the proton wavefunction are relatively successful at reproducing the observed flavor asymmetry [11].

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