A Preliminary Measurement of the $\bar{u}/\bar{d}$ Asymmetry in the Proton Sea

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Abstract. The NuSea (E866) experiment at Fermilab has been using Drell-Yan scattering to study the $\bar{u}/\bar{d}$ quark content of the proton by comparing of the yield between liquid hydrogen and liquid deuterium targets. A preliminary ratio of Drell-Yan yields, $\sigma^{pd}/2\sigma^{pp}$ as a function of x is shown. This data confirms the previous indications from the NMC and NA51 experiments that $\bar{u} \neq \bar{d}$.

Until recently it was assumed that the up-down quark content in the nucleon sea was flavor symmetric. The first evidence that this may not be the case was found using the Gottfried Sum Rule [1]. The Gottfried Sum is given by

$$I_{GS} = \int_0^1 \left[F_2^p(x) - F_2^n(x)\right] \frac{dx}{x}.$$

Here, $F_2^p(x)$ and $F_2^n(x)$ represent the proton and neutron structure functions and x represents the fraction of the proton's momentum carried by the struck parton. This expression can be expanded by substituting the parton distribution functions for the structure functions, $F_2(x) = \sum_i e_i^2 x\,(q_i(x) + \bar{q}_i(x))$, where the sum is over all the partons in the proton or neutron. With this substitution and the assumption of charge symmetry ($u_p(x) = d_n(x)$, $\bar{u}_n(x) = \bar{d}_p(x)$, etc.), the Gottfried Sum simplifies to

$$I_{GS} = \frac{1}{3} - \frac{2}{3}\int_0^1 \left[\bar{d}_p(x) - \bar{u}_p(x)\right] dx.$$

If the proton sea is flavor symmetric, the integral vanishes, and the Gottfried Sum reduces to 1/3.

Using deep inelastic scattering on hydrogen and deuterium targets, the NMC collaboration [2] was able to determine the F_2^p and F_2^n structure functions in the range of $0.004 \leq x \leq 0.8$. After extrapolating through the unmeasured regions, NMC found that

$$I_{GS} = 0.235 \pm 0.026 \neq \frac{1}{3}.$$

Several explanations have been proposed for the difference between the NMC result and 1/3. The extrapolation over the unmeasured region in x is subject to any anomalous behavior at small x. FNAL E665 extended NMC's measurements to smaller x and uncovered evidence for nuclear shadowing [3]. Such an effect would produce an even smaller value for I_{GS}. A violation of charge symmetry in the nucleon could also explain these results, but a violation at the level necessary to account for the difference has not been seen elsewhere. This leaves an up-down flavor asymmetry in the nucleon sea as the most likely explanation.

Since deep inelastic scattering measures the quark weighted sum of *all* of the quark distributions, it was suggested by Ellis and Stirling [4] that the Drell-Yan process be used to measure the up-down asymmetry of the sea. In the Drell-Yan process [5], a quark from the beam (or target) annihilates with an antiquark from the target (or beam) to produce a virtual photon, which decays into a lepton pair. By comparing the production rates of the lepton pairs from various nuclear targets, the antiquark sea is probed. This approach has been by the E772 collaboration at Fermilab [6] and by the NA51 collaboration [7]. E772 reanalyzed data which had been collected to study the nuclear dependence of the Drell-Yan process. Their results were consistent with a symmetric sea. NA51 measured Drell-Yan yields from protons incident on hydrogen and deuterium targets. The NA51 spectrometer had a limited range of kinematic acceptance, and so was only able to measure the $\bar{u}/\bar{d}$ ratio near $x = 0.18$ and $x_f = 0$. NA51 observed approximately 6000 events and found

$$\left.\frac{\bar{u}}{\bar{d}}\right|_{x=0.18} = 0.51 \pm 0.04 \pm 0.05.$$

This showed that the nucleon sea was not flavor symmetric. However, it did not determine the x dependence of this ratio.

The Fermilab E866 experiment used an 800 GeV extracted proton beam to measure Drell-Yan muon pair production from 50 cm long flasks of liquid hydrogen and liquid deuterium. An empty flask was also used for background determination. The experimental apparatus was the forward x_F spectrometer [8] shown in Fig. 1. The acceptance of the spectrometer was defined by the first two magnets (SM0 and SM12). Within the second magnet, the beam was intercepted by a copper beam dump. A large absorber wall, also located within the second magnet, removed scattered hadrons and allowed only muons to pass through the detection system. The muons passed through four tracking stations and a momentum analyzing magnet. The trigger was formed by a pair of triple hodoscope coincidences matching the topology of a muon pair produced at the target.

Data were collected over a six month period ending in March of 1997. More than 1.3×10^{17} protons were incident on the targets, and over 3.5×10^5 Drell-Yan events were recorded, as well as more than 2×10^4 Υ and 10^6 J/ψ events. Three spectrometer magnet settings were used in order to shift the peak acceptance of the spectrometer to low, intermediate and high mass muon pairs.

A preliminary analysis has been completed for each of the three data sets. The results presented here are based on only the high mass data set. This data set was chosen because it does not suffer from several systematic effects which are present in the other two data sets. The combined mass spectrum, as well as the mass spectrum for only the high mass data set is shown in Fig. 2. Also shown in Fig. 2 is the kinematic coverage of our data in terms of x_2, the fractional momentum carried by the target parton.

Based on only the high mass data set, a preliminary ratio of Drell-Yan yields from hydrogen and deuterium as a function of x_2 is shown in Fig. 3, along

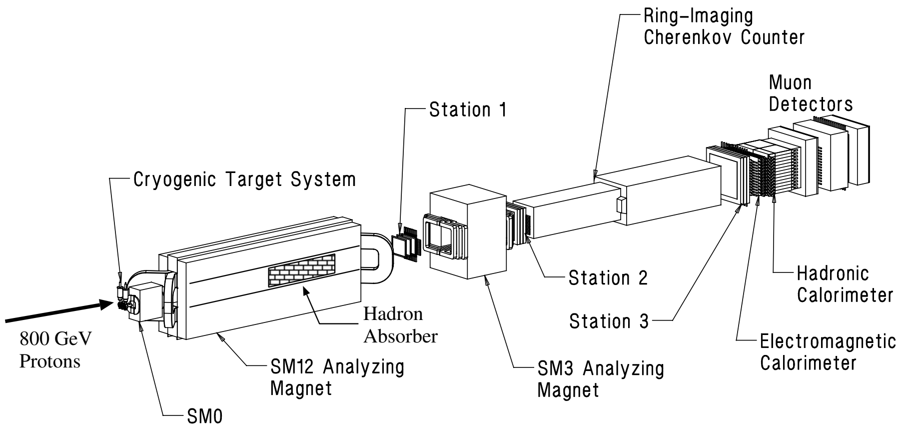

FIGURE 1. The Meson East spectrometer at Fermilab used by the E866 experiment. The detector was approximately 60 m long. The RICH and Calorimeters were not instrumented.

with the predictions from several common parameterizations of the proton, which have been weighted by the detector's acceptance. The "CTEQ4M ($\bar{u} = \bar{d}$)" curve needs special comment. For this curve, the CTEQ4M distribution functions [9] were modified to force $\bar{u} = \bar{d} = (\bar{u} + \bar{d})/2$ to simulate a totally flavor symmetric sea. Inspection of this plot reveals that for values of x_2 below approximately 0.2, the parameterizations which have $\bar{u} \neq \bar{d}$ match or are slightly above the data, but reflect the general trend of the data. For x_2 above 0.2, the data clearly tend toward a more flavor symmetric sea. Unfortunately, the statistical uncertainties are large in this region, but should improve after the analysis of the complete data set. While interesting, this region is perhaps better studied with a higher intensity, lower energy proton beam, such as the one soon to be available from the new Main Ring Injector nearing completion at Fermilab.

The extraction of $\bar{d}(x)/\bar{u}(x)$ from the ratio of cross sections is not a simple exercise. Simplifications may be made for $x_1 \gg x_2$, in which case

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_1 \gg x_2} \approx \frac{1}{2}\left[1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right].$$

This simplification is not applicable to all of our data, however. Thus, the full parton distribution functions, which themselves are established based on the large body of existing data, must be used. At present, a procedure, based

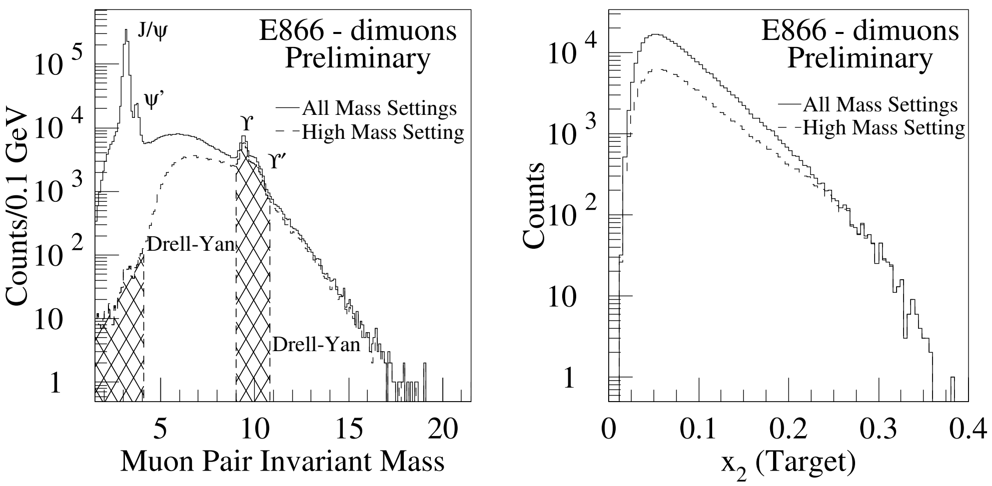

FIGURE 2. Reconstructed mass spectrum for muon pairs is shown on the left. The solid line represents the sum of all three spectrometer settings. The dashed line shows only the data obtained with the high mass settings. The cross hatched region was excluded from the analysis because of the ψ and Υ resonances. On the right is shown the distribution in x_2 of the data. Again, the solid line represents the sum of all data sets and the dashed line is only the high mass data set. The events in the hashed region of the mass plot have been excluded in producing the x_2 plot.

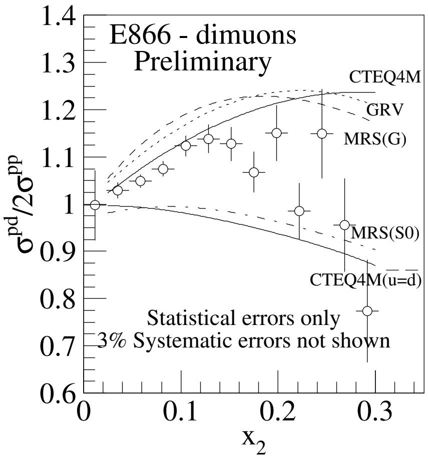

FIGURE 3. The Drell-Yan cross section ratio for $\sigma_{p+d}/2\sigma_{p+p}$ as a function of x_2. Also shown is this ratio for several common parameterizations of the proton. For the CTEQ4M $(\bar{u} = \bar{d})$ curve, we have set $\bar{u} = \bar{d} = \left[\left(\bar{u} + \bar{d}\right)/2\right]_{CTEQ4M}$.

on the CTEQ4M parameterization, which modifies the $\bar{d}(x)/\bar{u}(x)$ ratio while requiring the sum $\bar{d}(x) + \bar{u}(x)$ to remain constant, is being developed. Using this procedure, work is currently underway to extract the $\bar{d}(x)/\bar{u}(x)$ ratio.

In conclusion, the preliminary results from FNAL E866 are consistent with a violation of the Gottfried Sum rule as first observed by NMC, and confirm the NA51 result that $\bar{u} \neq \bar{d}$. For $x < 0.2$ the data are consistent with common parameterizations of the proton. At larger x, the data tend toward a more flavor symmetric sea. After full analysis of all of the data collected, we expect to achieve our goal of 1% systematic error on $\sigma^{pd}/2\sigma^{pp}$ for $0.03 < x_2 < 0.15$ and will extract the $\int \left(\bar{d}(x) - \bar{u}(x)\right) dx$ portion of the Gottfried Sum over the measured x_2 region. This work was supported in part by the U. S. Department of Energy and the National Science Foundation.

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