MEASURING THE $\bar{u}/\bar{d}$ ASYMMETRY IN THE PROTON SEA: FERMILAB E866

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Abstract

Experiment E866, conducted at the Fermi National Accelerator Laboratory, is a high statistics experiment to measure $\bar{u}(x)/\bar{d}(x)$ in the proton over a wide range of x. A review of the current evidence for $\bar{u}(x) \neq \bar{d}(x)$ in the proton is given and is followed by a short description of the spectrometer and the experimental procedures used in E866. Preliminary results are shown for the ratio of the Drell-Yan cross sections $\sigma^{pd}/2\sigma^{pp}$. Our preliminary results confirm the conclusions of both the NMC and NA51 collaborations that there is an $\bar{u}(x)/\bar{d}(x)$ asymmetry in the proton sea.

1 Review of Asymmetry Measurements

1.1 Gottfried Sum Rule:

The first indication of an asymmetry in the quark sea of the proton was found by using the Gottfried Sum Rule[1] to interpret the DIS data taken by the NMC Collaboration[2]. The Gottfried Sum Rule (I_{GSR}) is

$$I_{GSR} = \int_0^1 (F_2^p - F_2^n) \frac{dx}{x} \tag{1}$$

which can rewritten in terms of parton distribution functions to give

$$I_{GSR} = \int_0^1 \sum_i e_i^2 \left[(q_i^p(x) + \bar{q}_i^p(x)) - (q_i^n(x) + \bar{q}_i^n(x)) \right] dx. \tag{2}$$

If isospin is assumed to be a good symmetry, then $u_p(x) = d_n(x)$ and $d_p(x) = u_n(x)$ etc., so I_{GSR} can be simplified to

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

Therefore $I_{GSR} = 1/3$ if the proton sea is flavor symmetric with respect to the up and down quark flavors.

The NMC Collaboration measured deep inelastic muon scattering on hydrogen and deuterium targets in the range of 0.004≤x≤0.8. After doing an extrapolation to cover the full range of x they determined[3]

$$I_{GSR}(0 < x < 1) = 0.235 \pm 0.026. \tag{4}$$

There are several possible explanations why the NMC result differs from the expected I_{GSR} value of 1/3. The extrapolation NMC did for the I_{GSR} integral to cover the full range of x is highly model dependent due to nuclear shadowing at low x. Any unexpected behavior in the structure functions at low x could cause the discrepancy between the NMC result and the expected value for a symmetric nucleon sea. In addition, either isospin symmetry breaking and/or flavor symmetry breaking in the nucleon sea, could explain the NMC result. However, isospin symmetry has been rigorously tested in other experiments, and has been found to be a good symmetry to within a few tenths of a percent. Therefore, the most likely explanation for the NMC result is an up, down flavor asymmetry in the proton sea.

1.2 Drell-Yan:

Dimuon production via the Drell-Yan mechanism can be used to investigate the question of flavor asymmetry in the nucleon sea. The proton-nucleon Drell-Yan cross section can be written in terms of parton distribution functions as

$$\sigma^{pN} \propto \sum_i e_i^2 \left[q_i(x_1)\bar{q}_i(x_2) + q_i(x_2)\bar{q}_i(x_1) \right] \tag{5}$$

with the subscripts 1 and 2 denoting the beam and target parton respectively.

The NA51 collaboration[4] compared the Drell-Yan yields from protons incident on hydrogen and deuterium targets to find the proton - neutron Drell-Yan cross section asymmetry which they define as

$$A_{DY} = \frac{\sigma^{pp} - \sigma^{pn}}{\sigma^{pp} + \sigma^{pn}}. \tag{6}$$

The spectrometer used by NA51 had a narrow x_F acceptance, and was centered at $x_F = 0$, where x_F is defined as $x_F = x_1 - x_2$. In a simplistic version of NA51's analysis, an assumption can be made that $x_1 = x_2 = x$, which, in addition to using Eq. 5 and Eq. 6, allows $\bar{u}/\bar{d}$ to be written as

$$\frac{\bar{u}(x)}{\bar{d}(x)} = \frac{-(2+5\lambda_V)A_{DY} + (2-5\lambda_V)}{(5+8\lambda_V)A_{DY} + (5-8\lambda_V)}, \tag{7}$$

where λ_V is the ratio of the valence distributions, $u_V(x)/d_V(x)$. From their measurements NA51 determined $\bar{u}/\bar{d}$ for only a single average value of x.

$$\frac{\bar{u}(x)}{\bar{d}(x)} = 0.51 \pm 0.04 \pm 0.05 \text{ at x} = 0.18 \tag{8}$$

This was the first definitive observation of an asymmetry in the proton sea.

2 Fermilab E866

The goal of the E866 experiment is to measure the ratio of Drell-Yan cross sections $\sigma^{pd}/2\sigma^{pp}$ to the order of 1% accuracy for $0.05 \leq x \leq 0.15$ and with lesser statistical accuracy out to $x \simeq 0.3$. Furthermore, it is our goal to then use this measurement to determine $\bar{u}(x)/\bar{d}(x)$ over this range of x.

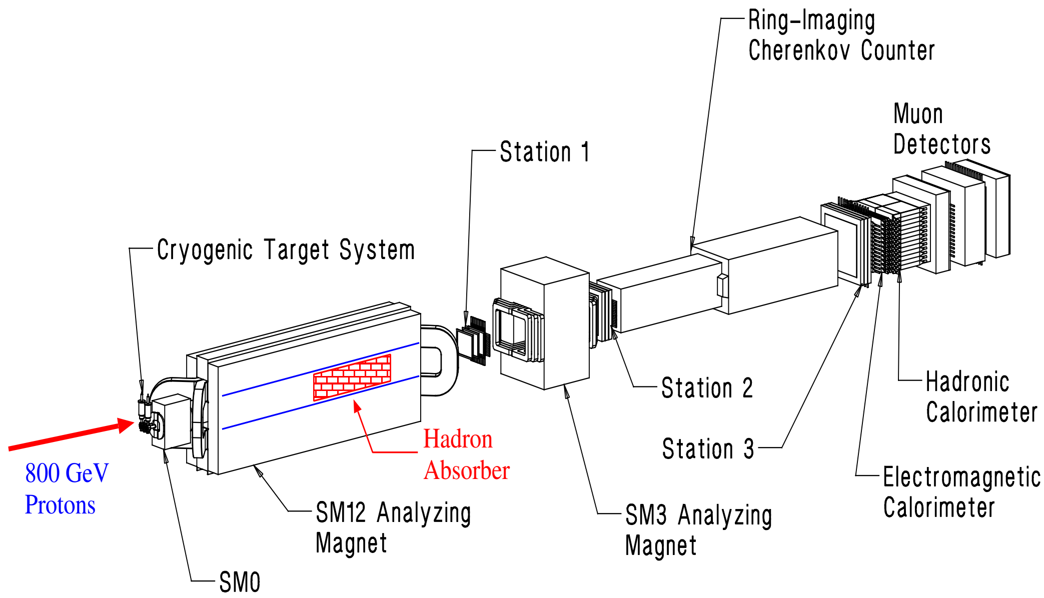

Figure 1: The E605/E772/E789/E866 Spectrometer[5)]. The ring-imaging cherenkov counter and the two calorimeters were not used to provide data for the experiment.

E866 is the fourth experiment to use this spectrometer (shown in figure 1), which is located in the Meson East experimental hall at Fermilab. The spectrometer is a forward x_F, high mass dimuon spectrometer. Dimuon yields were measured from 800 GeV protons interacting with liquid hydrogen, liquid deuterium and empty flask targets. Protons not interacting in the target are absorbed in an internal beam dump located inside the aperture of the SM12 analyzing magnet. A thick absorber wall filling the magnet aperture directly behind the beam dump makes muon identification possible by absorbing all of the hadrons produced in the target or beam dump. The acceptance of the spectrometer is defined by the first two magnets (SM0 and

SM12). A third analyzing magnet (SM3) is used to measure the muon momenta as the muons are tracked through the four detector stations. Each of the first 3 detector stations contains scintillation hodoscopes for triggering purposes, and six drift chamber planes. Station four (the muon detectors) contains three proportional tube planes, as well as scintillation hodoscopes.

Data was taken over a six month period ending in March, 1997. Three different current settings were used for SM0 and SM12 in order to shift the acceptance of the spectrometer to record data in low, intermediate, and high mass regions. In the three mass settings combined, E866 received a total of more than 1.3×10^{17} 800 GeV protons incident on the targets, as well as recording over 350,000 Drell-Yan, 20,000 Υ, and one million J/ψ events.

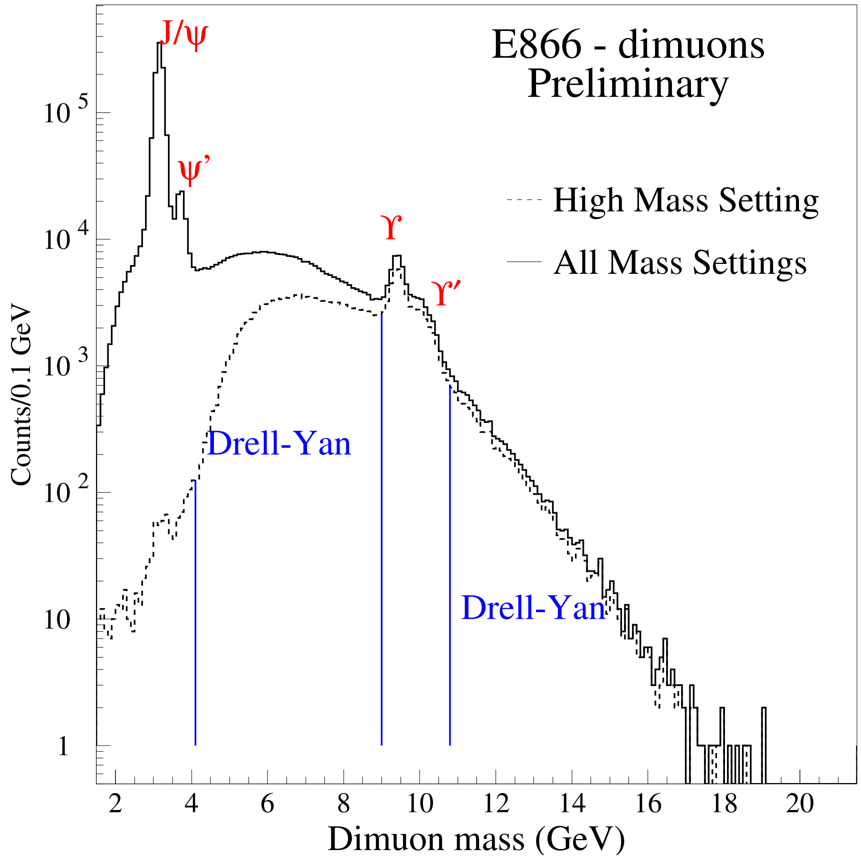

Figure 2: Preliminary dimuon mass spectra from the $\bar{u}/\bar{d}$ run. The upper solid line shows the mass distribution for the sum of all three data sets while the lower dashed curve shows the high mass data set only.

3 Preliminary Results

A preliminary analysis of each of the three data sets has been completed, and the ratio of the deuterium to hydrogen Drell-Yan cross sections has been computed for the high mass data set. The high mass data set was chosen for this analysis since it does not suffer from several systematic effects that still need to be corrected in the intermediate and low mass data sets. Figure 2 shows the mass spectra of all three data sets as well as the high mass data set alone.

An examination of the mass spectra shows clear signals for the J/ψ, ψ' and Υ resonances in the combined data set. To extract only the Drell-Yan events, cuts were made in the mass spectra, as shown in figure 2, to exclude the quarkonia resonances.

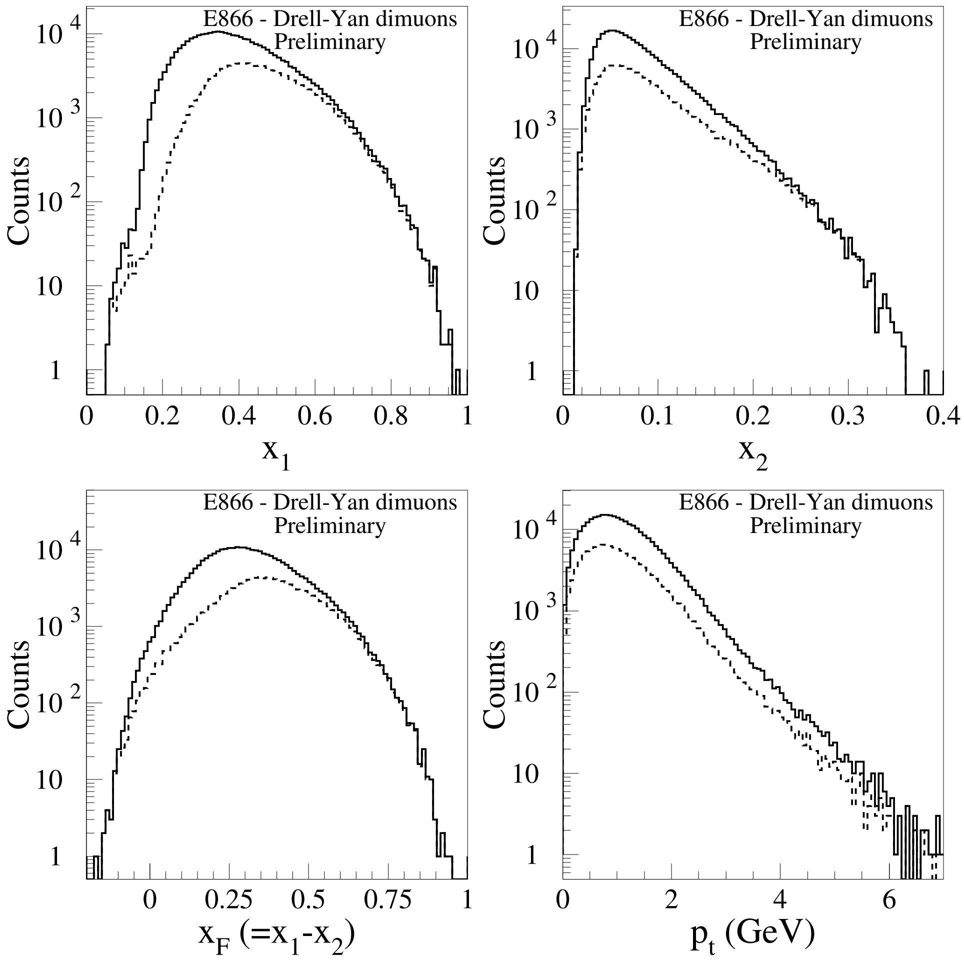

Figure 3: Spectra of the kinematic quantities x_1, x_2, x_F, and p_t for dimuons recorded from all mass settings (solid) and from the high mass setting (dashed).

The kinematic coverage of the Drell-Yan data is shown in figure 3. Again the upper solid lines represent all three data sets while the lower dashed lines are from the high mass data set only. The x_F coverage extends well beyond the NA51 measurement at $x_F \simeq 0$. With this extended coverage equation 7 is not appropriate for our $\bar{u}/\bar{d}$ analysis. Instead, if we assume that $x_F \gg 0$ then Eq. 5 yields a simple approximation to $\bar{u}/\bar{d}$.

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_F \gg 0} \approx \frac{1}{2}\left(1 + \frac{\bar{d}(x)}{\bar{u}(x)}\right) \tag{9}$$

However, as seen in figure 3, a significant portion of the data is near $x_F = 0$, and so calculating $\bar{u}/\bar{d}$ is not as simple as shown above, and has not been done at this time. Also, as seen from figure 3, we will be able extract the $\bar{u}/\bar{d}$ ratio as a function of x_2 rather than at one specific point.

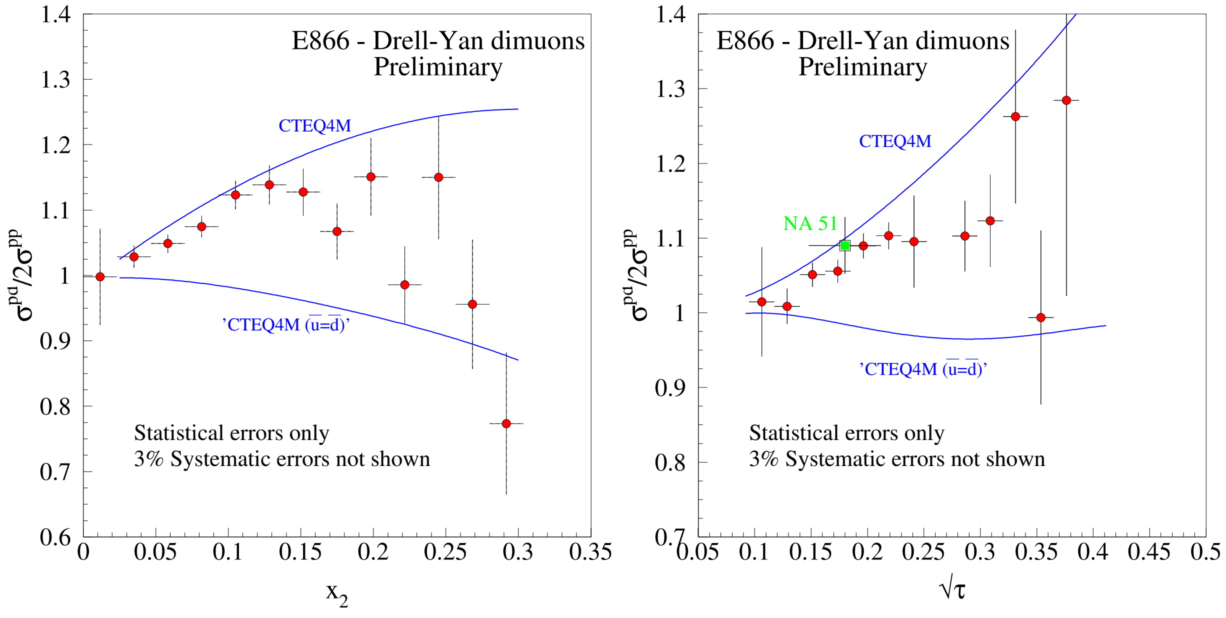

Figure 4: Preliminary results for $\sigma^{pd}/2\sigma^{pp}$ versus x_2 and $\sqrt{\tau}$.

Based on the high mass data, preliminary ratios of Drell-Yan yields from the two targets have been computed. These are shown in figure 4 as a function of x_2 and $\sqrt{\tau} \equiv m/\sqrt{s}$. In both plots our data points are compared with the CTEQ4M[6] parameterization of the proton weighted by the acceptance of our spectrometer. Also plotted is a curve based on CTEQ4M, where we have modified the parameterization to force $\bar{u}_p = \bar{d}_p \equiv (\bar{u}_p + \bar{d}_p)/2$. The error bars show only the statistical uncertainty; an additional systematic uncertainty of about 3% is not shown. From these two graphs it is apparent that our results agree well with CTEQ4M for small values of x_2, but at high values of x_2 our data drop towards the $\bar{u}_p = \bar{d}_p$ curve. The NA51 result is also shown in figure 4. Our data agree with their result, however it is important to note that NA51's measurement is at a much lower Q^2 value.

4 Conclusion

The goal of E866 should be achieved after a full analysis of the data. The preliminary results from FNAL E866 confirm both the NMC evidence that $\bar{u}_p \neq \bar{d}_p$ and the NA51 result that $\bar{d}_p > \bar{u}_p$. Our data for $x > 0.2$ do not agree with the present CTEQ4M parameterization of the proton.

References

1. K. Gottfried, Phys. Rev. Lett **18**, 1174 (1967).
2. P. Amaudruz, et. al., Phys. Rev. Lett. **66**, 2712 (1991).
3. M. Arneodo, et. al., Phys. Rev. **D50**, R1 (1994).
4. A. Baldit, et. al., Phys. Lett. **B332**, 244 (1994).
5. G. Moreno, et. al., Phys. Rev. **D43**, 2815 (1991).
6. H. L. Lai, et. al., Phys. Rev. **D55**, 1280 (1997).