ANL/PHY/CP-99361

RECEIVED
OCT 13 1999
OSTI

Measurement of the Light Quark Flavor Asymmetry in the Nucleon Sea.

B.A. Mueller[b,#], T.C. Awes[i], M.E. Beddo[h], C.N. Brown[c], J.D. Bush[a], T.A. Carey[f], T.H. Chang[h], W.E. Cooper[c], C.A. Gagliardi[j], G.T. Garvey[f], D.F. Geesaman[b], E.A. Hawker[j,f], X.C. He[d], L.D. Isenhower[a], S.B. Kaufman[b], D.M. Kaplan[e], P.N. Kirk[g], D.D. Koetke[k], G. Kyle[h], D.M. Lee[f], W.M. Lee[d], M.J. Leitch[f], N. Makins[b,*], P.L. McGaughey[f], J.M. Moss[f], P.M. Nord[k], B.K. Park[f], V. Papavassiliou[h], J.C. Peng[f], G. Petitt[d], P.E. Reimer[f], M.E. Sadler[a], J. Selden[h], P.W. Stankus[i], W.E. Sondheim[f], T.N. Thompson[f], R.S. Towell[a,†], R.E. Tribble[j], M.A. Vasiliev[j,‡], Y.C. Wang[g], Z.F. Wang[g], J.C. Webb[h], J.L. Willis[a], D.K. Wise[a], G.R. Young[i]

(FNAL E866/NuSea Collaboration)

[a] *Abilene Christian University, Abilene, TX 79699*
[b] *Argonne National Laboratory, Argonne, IL 60439*
[c] *Fermi National Accelerator Laboratory, Batavia, IL 60510*
[d] *Georgia State University, Atlanta, GA 30303*
[e] *Illinois Institute of Technology, Chicago, IL 60616*
[f] *Los Alamos National Laboratory, Los Alamos, NM 87545*
[g] *Louisiana State University, Baton Rouge, LA 70803*
[h] *New Mexico State University, Las Cruces, NM, 88003*
[i] *Oak Ridge National Laboratory, Oak Ridge, TN 37831*
[j] *Texas A & M University, College Station, TX 77843*
[k] *Valparaiso University, Valparaiso, IN 46383*
[#] *Email address: mueller@cedar.phy.anl.gov*

Fermilab experiment E866 has performed a precision measurement of the ratio of Drell-Yan yields from 800 GeV/c protons incident on deuterium and hydrogen targets. The measurement is used to determine the ratio of down antiquarks($\overline{d}$) to up antiquarks($\overline{u}$) in the proton over a broad range in the fraction of the proton momentum carried by the antiquark, $0.02 < x < 0.345$. For $x < 0.15$, the data is in reasonable agreement with pre-existing parton distributions while for $x > 0.20$ the data is much closer to unity than these parton functions had indicated. The light quark asymmetry provides valuable information on the relative role perturbative and non-perturbative mechanisms play in generating the nucleon sea. A proposal to extend the Drell-Yan measurement to higher values of x using 120 GeV protons from the Fermilab main injector will be discussed.

No known symmetry requires $\bar{d}(x) = \bar{u}(x)$, i.e., that the up and down antiquark distributions of the proton are equal. The degree to which $\bar{d}$ and $\bar{u}$ differ may depend on the mechanism which generates the sea. If the light sea is gen-

DISCLAIMER

DISCLAIMER

erated primarily by gluons splitting into $q\bar{q}$ pairs, it is likely that $\bar{d}(x) \equiv \bar{u}(x)$, since the up and down quark masses are small relative to the confinement scale. Indeed, a theoretical investigation[1] concluded that perturbative processes cannot yield an asymmetry in the light sea which is larger than 1%. On the other hand, an excess of $\bar{d}$ to $\bar{u}$ is quite natural if the sea quarks interact with the surrounding partons before annihilating back into the vacuum, for example[2] fluctuating into a neutron and π^+. Since the π^+ contains a valence $\bar{d}$ and since there is no similar diagram to generate a $\bar{u}$, this diagram naturally leads to an excess of $\bar{d}$ in the proton. Ultimately, both perturbative and non-perturbative mechanisms may play important roles in generating the sea. For simplicity and for the lack of anything better, however, the light antiquark distributions were assumed to be the same until experimental evidence showed that this assumption was false.

In 1991 the New Muon Collaboration(NMC)[3] presented the first experimental evidence that the up and down sea distributions were not identical. NMC measured the Gottfried sum[4], the integral over x of the difference between the proton and neutron inelastic structure functions:

$$I_{GS} = \int_0^1 \left[F_2^{P,\mu}(x) - F_2^{N,\mu}(x)\right] \frac{dx}{x} = \frac{1}{3} + \frac{2}{3}\int_0^1 \left[\bar{u}^P(x) - \bar{d}^P(x)\right] dx. \quad (1)$$

NMC determined that $I_{GS} = 0.234 \pm 0.026 \neq \frac{1}{3}$, implying that on average the proton contains 0.147 more down antiquarks than up antiquarks.

Following publication of the NMC result, the use of the Drell-Yan process[5] was suggested[6] as a means to probe the light antiquark content of the proton. When two hadrons collide a quark or antiquark in the projectile can annihilate with an antiquark or quark in the target, forming a virtual photon. This photon can then decay into a pair of oppositely charged muons (a dimuon). In leading order, the cross section for such a reaction can be factorized into:

$$\sigma = \sum_i \sigma^i(x_1, x_2, Q^2)\left[q^i(x_1, Q^2)\bar{q}^i(x_2, Q^2) + \bar{q}^i(x_1, Q^2)q^i(x_2, Q^2)\right] \quad (2)$$

where $x_1(x_2)$ is the momentum fraction of the beam(target) parton, Q^2 is the virtuality of the annihilation photon, $\sigma^i(x_1, x_2, Q^2)$ are the annihilation cross sections for each quark type($i \in u, d, s, \ldots$), and $q^i(x, Q^2)$ are the parton distribution functions(PDF), the probability of finding a quark of type i in the beam(target) with a Bjorken x value of $x_1(x_2)$. The $\sigma^i(x_1, x_2, Q^2)$ are calculable perturbatively using electroweak theory. No one has yet figured out how to calculate the $q^i(x, Q^2)$ directly from QCD. Instead, groups such as CTEQ[7,8], MRST[9,10], and GRV[11,12] perform phenomenological fits to the world's deep inelastic scattering and hadron/hadron collision data to extract the PDFs.

A measurement of the ratio of proton induced Drell-Yan yield from deuterium to hydrogen, $\sigma_{pd}^{DY}/2\sigma_{pp}^{DY}$, provides a particularly powerful method for probing the ratio of light antiquarks in the proton, $\bar{d}/\bar{u}$. This is most clearly seen in the limit when $x_1 \gg x_2$, where in leading order the cross section ratio is given by:

$$\left.\frac{\sigma^{pd}}{2\sigma^{pp}}\right|_{x_1 \gg x_2} \approx \frac{1}{2}\frac{\left(1+\frac{1}{4}\frac{d_1}{u_1}\right)}{\left(1+\frac{1}{4}\frac{d_1}{u_1}\frac{\bar{d}_2}{\bar{u}_2}\right)}\left(1+\frac{\bar{d}_2}{\bar{u}_2}\right) \tag{3}$$

where the explicit Q^2 dependence of the parton distribution has been suppressed and where the shorthand notation $\bar{u}(x_2) \equiv \bar{u}_2, \ldots$ has been employed. NA51 [13] was the first experiment to exploit proton induced Drell-Yan production from hydrogen and deuterium to extract information about the $\bar{d}(x)/\bar{u}(x)$ ratio in the proton, reporting a value of:

$$\left.\frac{\bar{u}_p}{\bar{d}_p}\right|_{\langle x\rangle=0.18} = 0.51 \pm 0.04 \pm 0.05. \tag{4}$$

While the NMC and NA51 experiments provide compelling evidence for an asymmetry in the light antiquark sea, understanding the mechanism which causes such a large difference requires a determination of this difference over a broad range in x. A recent review article by Kumano [14] presents an extensive discussion on this subject.

The NuSea collaboration recently completed Fermilab experiment E866, performing a precision measurement of the ratio of proton induced Drell-Yan muon pairs produced from liquid deuterium and hydrogen targets [15,16]. In this experiment an 800 GeV/c beam of protons extracted from the Fermilab Tevatron bombarded liquid hydrogen or deuterium targets. Dimuon events were detected by an upgraded version of the same spectrometer used in three previous experiments (E605, E772, E789) [17]. A total of more than 330,000 Drell-Yan dimuon events generated from the deuterium or hydrogen targets were recorded during runs with three magnet settings, favoring dimuon events with either low, intermediate, or high invariant mass. The high mass data is relatively free of certain systematic errors which makes the analysis more simple; the data presented in this paper consists solely of the 140,000 Drell-Yan events from this data sample.

Figure 1 shows the measured ratio of Drell-Yan cross sections per nucleon for $p+d$ to that for $p+p$ versus x_2. Also shown are experimental acceptance weighted leading order (dotted) and next-to-leading-order(NLO) (solid)

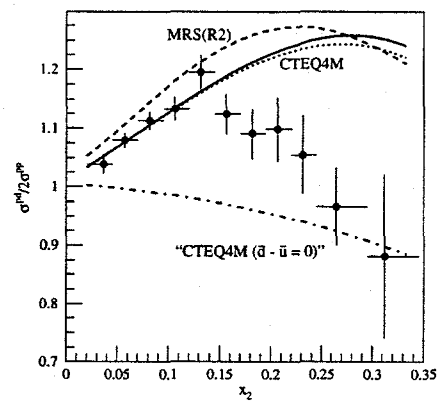

Figure 1: The E866 measurement of the Drell-Yan cross section ratio, $\sigma_{pd}/2\sigma_{pp}$. Calculations based on the CTEQ4M and MRS(R2) PDFs are also shown and are described in the text.

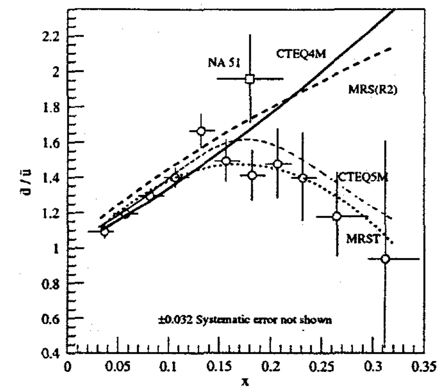

Figure 2: The ratio $\bar{d}/\bar{u}$ vs x extracted from the cross section ratio shown in figure 1. An addition ±3.2% systematic uncertainty is not shown in the plot. The curves are from various parton distribution functions mentioned in the text.

calculations for the cross section ratio using the CTEQ4M [7] PDF and a NLO calculation using the MRS(R2) [9] (dashed) PDF. The calculations are in reasonable agreement with the ratio for low $x(< 0.15)$, but clearly over estimate the ratio at large x. The lower curve (dot-dashed) displays the calculated ratio for a modified version of CTEQ4M with $\bar{d}_p(x) \equiv \bar{u}_p(x)$ while $\bar{d}_p(x) + \bar{u}_p(x)$ and the other parton distributions are kept fixed.

Equation 3 is an approximation which is not valid for the data with large x_2. E866 used an iterative procedure to extract $\bar{d}/\bar{u}$ from the data. In this procedure the parton distribution for the valance, $\bar{d} + \bar{u}$, and heavy flavor distributions were fixed while the $\bar{d}/\bar{u}$ value was varied until the calculated cross section ratio converged with the measured value. Negligible differences were seen in the extracted $\bar{d}/\bar{u}$ result when the CTEQ4M and MRS(R2) PDFs were used in this procedure. Figure 2 shows the extracted $\bar{d}/\bar{u}$ ratio compared to both pre-E866 PDFs(MRS(R2) and CTEQ4M) and PDFs which incorporate E866 data into the fits (MRST(1) and CTEQ5M). The square point is the NA51 value for $x = 0.18$.

The $\bar{d} - \bar{u}$ distribution is extracted from the E866 $\bar{d}/\bar{u}$ result by combining the data with one of the PDF values for $\bar{d}+\bar{u}$. This quantity is directly sensitive to the nonperturbative mechanisms which generate the sea since perturbative processes cancel in the subtraction [18]. Figure 3 shows the E866 result compared to PDF predictions and the recent result from the Hermes collaboration [19].

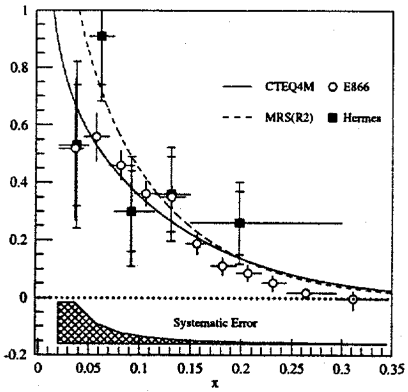

Figure 3: The E866 and Hermes values for $\bar{d} - \bar{u}$. The curves show the CTEQ4M and MRS(R2) values for this quantity.

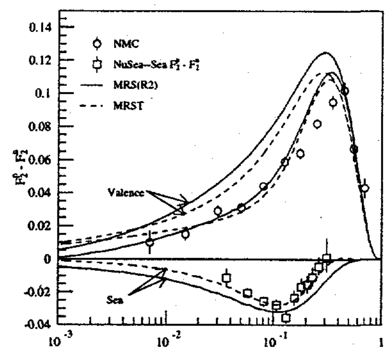

Figure 4: The NMC measurement of $F_2^P - F_2^N$(circles) at $Q = 2$ GeV. Also shown are the E866(squares) results, evolved to $Q = 2$ GeV, for the sea contribution to $F_2^P - F_2^N$. The solid(dashed) curves show the MRS-R2(MRST-1) values for $F_2^P - F_2^N$(middle) and the contributions from the valence(top) and sea(bottom) distributions.

Hermes extracted the x dependence of $\bar{d} - \bar{u}$ from a relationship between semi-inclusive deep-inelastic scattering yields of the π^+ and π^- from unpolarized hydrogen and deuterium targets. This type of experiment may be possible at the EPIC facility.

The E866 $\bar{d} - \bar{u}$ result can be used to extract a value for the Gottfried sum. By integrating the result and using the CTEQ4M parton distribution to estimate the contribution from the unmeasured region, E866 obtains: [15]

$$\int_0^1 \left[\bar{d}^P(x) - \bar{u}^P(x)\right] dx = 0.100 \pm 0.007 \pm 0.017 \qquad (5)$$

compared to the NMC value of 0.147 ± 0.39

The E866 measurement of $\bar{d}(x) - \bar{u}(x)$ and the NMC measurement of $F_2^P(x) - F_2^N(x)$ provide a precision measurement of the difference between the valence distributions in the proton, $u_V - d_V$, through the differential version of equation 1. Figure 4 shows the impact E866 has had on the determination of the sea, valence, and $F_2^P(x) - F_2^N(x)$ distribution by comparing a pre-E866(solid, MRS-R2) fit to a fit including E866(dashed, MRST).

The next issue is the origin of the $\bar{d}/\bar{u}$ asymmetry [16]. The large difference measured in the light quark sea most likely results from non-perturbative

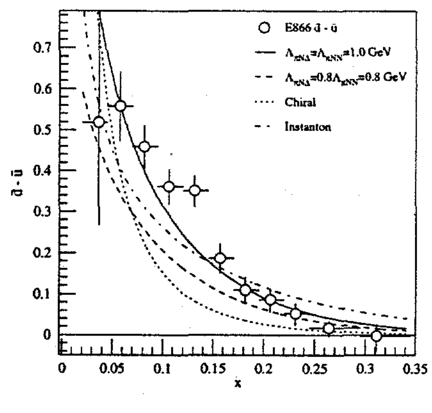

Figure 5: Comparison between the E866 value for $\bar{d} - \bar{u}$ and model calculations from a meson-baryon model, a chiral model, and an instanton model described in the text.

effects [1], although this is not universally accepted in the literature [20]. Several classes of models have been proposed which hope to explain the measured asymmetry in the light quark sea: meson-baryon models [21], chiral models [22], and instanton models [23]. Figure 5 displays the agreement between the E866 data and representative examples of each of these models,

The meson-baryon model uses the notion that the physical proton (p) may be expanded in a sum of products of its virtual meson-baryon (MB) states, with $p = (1-\alpha)p_0 + \alpha MB$, where α is the probability of the proton being in virtual states MB and p_0 is a proton configuration with a symmetric sea. It is easy to show [25] that

$$\int_0^1 \left[\bar{d}(x, Q^2) - \bar{u}(x, Q^2)\right] dx = (2a - b)/3 \tag{6}$$

where a is the probability of the virtual state πN and b the probability for $\pi\Delta$. These two configurations are the dominant intermediate MB states contributing to the asymmetry [24].

In the framework of chiral perturbation theory, the relevant degrees of freedom are the constituent quarks, gluons, and Goldstone bosons. In this model, a portion of the sea comes from the couplings of Goldstone bosons to the constituent quarks, such as $u \to d\pi^+$ and $d \to u\pi^-$. The excess of $\bar{d}$ over $\bar{u}$ is then simply due to the greater number of up valence quarks in the proton.

A third non-perturbative process which can produce a $\bar{d}$, $\bar{u}$ asymmetry is the coupling of instantons to the valence quarks. An earlier publication [23] proposed that the asymmetry observed in the NMC experiment was due to instantons but parameterized their result in terms of the observed asymmetry

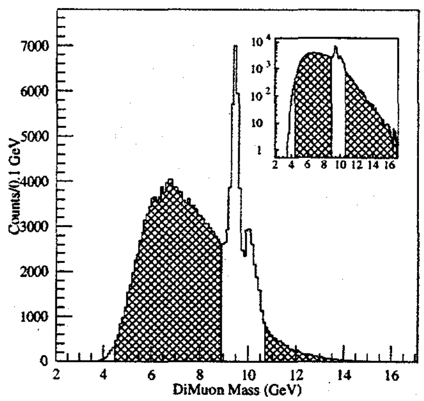

Figure 6: The dimuon mass distribution for the high mass setting. The crosshatched region shows the events used in the $\bar{d}/\bar{u}$ analysis; the remaining regions contain a mixture of Drell-Yan and dimuon decays of heavy resonance production and were excluded in the $\bar{d}/\bar{u}$ analysis.

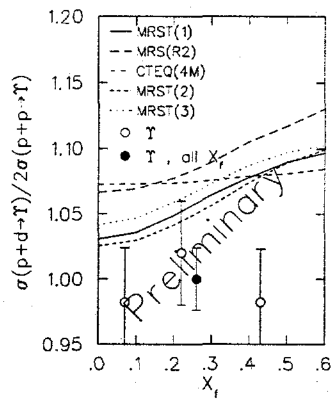

Figure 7: The ratio of upsilon production cross sections for 800 GeV protons incident on deuterium and hydrogen targets. The curves show CEM calculations of the ratio using several different PDFs.

so this calculation has no independent predictive power.

The meson-baryon calculation is performed following the prescription of Kumano [14]. Two curves are shown in figure 5; one curve uses a dipole form with Λ=1.0 GeV for both πNN and $\pi N\Delta$ while the other curve uses a reduced value for $\pi N\Delta$ of 0.8 GeV. Good agreement is obtained between the latter calculation and the data. As for the chiral model, the formulation of Szczurek *et al.* [22] is used to calculate $\bar{d}(x) - \bar{u}(x)$ at $Q = 0.5$ GeV which is then evolved to the Q of E866. The chiral model prediction for $\bar{d} - \bar{u}$ occurs at considerably smaller x than for the meson-baryon models. This difference reflects the fact that the pions are softer in the chiral model, since they are coupled to the constituent quarks which on average carry only 1/3 of the nucleon momentum. The x dependence of the E866 data favors the virtual-pion model over the chiral model predictions, suggesting that correlations between the chiral constituents need to be taken into account.

Several additional physics results will come from the data collected by E866 to measure $\bar{d}/\bar{u}$. These include Drell-Yan absolute cross sections for hydrogen and deuterium which should influence fits to the parton distributions. In addition, absolute cross sections and cross section ratios for Υ and J/ψ production from deuterium and hydrogen are being determined and preliminary results are reported here. E866 is sensitive to Υ and J/ψ production through the dimuon decay of these particles. Figure 6 shows the mass distribution for the E866 high mass set; the Υ production peak is clearly seen at $m = 9.46$ GeV. Drell-Yan and resonance dimuons in the same mass region have similar topology and it is therefore impossible to determine the parentage of a particular dimuon event. This forced E866 to exclude events near the Υ mass (the unhatched region in figure 6) from the $\bar{d}/\bar{u}$ analysis since, unlike the electromagnetically produced Drell-Yan events, the Υ and J/ψ are produced via the strong interaction. The Υ and J/ψ cross sections can be extracted from the data by performing a Monte Carlo simulation of the experiment to extract the mass shapes for Drell-Yan, Υ, Υ' and Υ'' dimuons; these shapes are then used in a four parameter fit to the data mass distribution.

There are two processes which significantly contribute to the production of heavy quark pairs($c\bar{c}$ and $b\bar{b}$): quark-antiquark annihilation and gluon-gluon fusion. The differential cross section for heavy quark production of a specific invariant mass m^2 can be factorized[27,28] into a form similar to equation 2:

$$\frac{d^2\sigma}{dx_f dm^2} = \frac{G(x_1)G(x_2)\sigma_{GG} + \sum_{i=u,d,...}\left[q^i(x_1)\bar{q}^i(x_2) + \bar{q}^i(x_1)q^i(x_2)\right]\sigma^i_{q\bar{q}}}{\sqrt{x_f^2 s^2 + 4m^2 s}} \quad (7)$$

where $G(x)$ is the gluon distribution of the proton, $\sigma(q\bar{q} \to Q\bar{Q}; m^2)$ and $\sigma(g\bar{g} \to Q\bar{Q}; m^2)$ are the calculable cross sections for the specific QCD subprocesses [30], $x_f = x_1 - x_2$ is the Feynman x of the interaction, $\sqrt{s}$ is the proton-nucleon center of mass energy, and x_1, x_2, q^i, and $\bar{q}^i$ are as defined in equation 2.

The hadronization of the heavy quark pair into a bound meson state is a complicated process which has not yet been directly calculated from QCD. There are several models for hardonization in the literature, however. One such model is the Local/Dual or Color Evaporation Model(CEM) [31]. The CEM cross section for Υ production, for example, is given by[27,28,29]:

$$\frac{d\sigma^\Upsilon}{dx_f} = F \times \int_{2M_b}^{2M_{B^+}} 2m dm \frac{d^2\sigma^{b\bar{b}}}{dx_f dm^2} \quad (8)$$

where $M_b(M_{B^+})$ the mass of the bottom quark(meson) and F is the (unknown) probability the $b\bar{b}$ state will hadronize into the physical Υ meson. Although this model is very simple, it is surprisingly good at reproducing the x_f shape of absolute cross sections for Υ and J/ψ production[27]. For the E866 hydrogen and deuterium data sets, J/ψ production is mostly from gluon fusion. The situation in the Υ case, however, is much less clear. CEM calculations using MRS(R2) indicate that Υ production is mostly gluon-gluon fusion for low x_f, is equal for $x_f \approx 0.25$, and is dominated by quark annihilation for large x_f. For the more recent MRST set, however, the CEM calculation of the gluon fusion fraction of the $p+p$ yield depends on which MRST set is used. When the CEM calculation is performed using the MRST preferred set (MRST(1)) or the soft gluon set (MRST(2)), the quark annihilation contribution is larger than the gluon piece for all x_f. When hard gluon set (MRST(3)) is used, however, gluon fusion generates a larger contribution at $x_f \approx 0$. The major cause for the change in the MRS(R2) and MRST gluon distributions and the cause of the variance in the MRST(1-3) gluon distributions is the theoretical uncertainty in the treatment of the prompt photon data[10]. The gluon distribution at large $x \sim 0.3-0.5$ is still fairly uncertain and the parton fitters could clearly benefit from additional measurements sensitive to the high x gluon distribution.

The cross section ratio for proton induced Υ production from deuterium to hydrogen is particularly sensitive to the parton distributions since the unknown scaling factor F cancels in the ratio. If gluon fusion dominates the $q\bar{q}$ cross section, the ratio should be nearly unity since the gluon distributions in the proton and neutron are expected to be the same. On the other hand, if the cross section is dominated by quark annihilation, the ratio should be > 1 for the x_f range where $\bar{d}(x_2) > \bar{u}(x_2)$. Figure 7 shows the preliminary E866 measurement of $\sigma(p+d \rightarrow \Upsilon)/2\sigma(p+p \rightarrow \Upsilon)$ compared to CEM calculations based on a variety of PDFs. The ratio extracted from the data is consistent with unity and is inconsistent with the CEM calculations, even when MRST(3) is used in the calculation. There are several possibilities for the difference between the data and the CEM calculation. First, the calculation might be too simplistic. A more sophisticated calculation would certainly be welcomed. Second, it is possible that nuclear effects suppress the $\sigma(p+d \rightarrow \Upsilon)$ cross section. E772[32] measured the ratio of proton induced Υ production from deuterium and heavy targets, and found $\sigma_A/\sigma_D \approx (A/2)^{0.96}$ for $x_f > 0$. A literal interpretation of this nuclear dependence implies a 3% suppression in the deuterium to hydrogen ratio, and if this correction was applied to the CEM calculations, they would be in better agreement with the data. Since the nucleon density in deuterium is much lower than in a heavy nucleus, however, it is difficult to believe that deuterium nuclear effects would be this large. Indeed, preliminary results from E866 for $\sigma(p+d \rightarrow J/\psi)/2\sigma(p+p \rightarrow J/\psi)$ find a value which is consistent with unity with an uncertainty of 1%, while the E772[33] nuclear dependence result finds $\sigma_A/\sigma_D \approx (A/2)^{0.92}$. If this nuclear dependence was applied literally to J/ψ production, it would imply a $\approx 5\%$ suppression which is not seen in the preliminary results. A final possibility is that the $x \sim 0.3-0.5$ part of the gluon distribution is underestimated in the PDFs, implying that Υ production is also dominated by gluon fusion for the E866 kinematics.

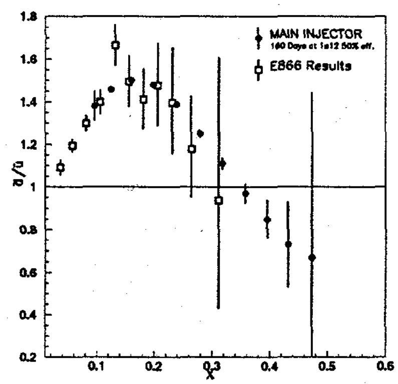

Figure 8: Comparison between the extracted value of $\bar{d}/\bar{u}$ for the E866 results and the projected results for a 160 day main injector run with 50% efficiency at 10^{12} protons per pulse.

As to the future, a proposal[34] has been submitted to the Fermilab PAC to use 120 GeV protons from the Fermilab main injector to measure $\sigma_{pd}^{DY}/2\sigma_{pp}^{DY}$ and extract $\bar{d}(x)/\bar{u}(x)$ for $0.1 < x < 0.45$. The event rate in the main injector experiment will be ≈ 50 times higher than for E866 for two reasons. First, the Drell-Yan cross section falls as $1/E_{\rm BEAM}$. Second, the experiment should be able to handle 7 times more protons per second since the singles rate should scale with beam power. Figure 8 shows the statistical uncertainties for a 160 day main injector measurement with 1×10^{12} protons per spill at 50% efficiency.

In summary, E866 has provided the first determination of $\bar{d}/\bar{u}$, $\bar{d}-\bar{u}$, and the integral of $\bar{d}-\bar{u}$ over the range $0.02 \le x \le 0.345$. It provides an independent confirmation of the violation of the Gottfried Sum Rule reported from DIS experiments. The magnitude of the integral of $\bar{d}-\bar{u}$ over the region $0.02 \le x \le 0.345$ is smaller than obtained from the parameterizations of some current PDFs. Together with the NMC data, the E866 results impose stringent constraints on both sea and valence quark distributions. The good agreement between the E866 $\bar{d}-\bar{u}$ data and the meson-baryon model indicates that virtual meson-baryon components play an important role in determining non-singlet structure functions of the nucleon. Future experiments extending the measurements of $\bar{d}/\bar{u}$ to different x and Q^2 regions can further illuminate the interplay between the perturbative and non-perturbative elements of the nucleon sea.

Acknowledgments

This work is supported in part by the U.S. Department of Energy.

[*] Present address: University of Illinois, Urbana, IL 61801.
[†] Also with University of Texas, Austin, Tx 78712.
[‡] On leave from Kurchatov Institute, Moscow 123182, Russia.

References

1. D. A. Ross and C. T. Sachrajda, Nucl. Phys. B **149**, 497 (1979).
2. A. W. Thomas, Phys. Lett. **126B**, 97 (1983).
3. P. Amaudruz *et al.*, Phys. Rev. Lett. **66**, 2712 (1991); M. Arneodo *et al.*, Phys. Rev. D **55**, R1 (1994).
4. K. Gottfried, Phys. Rev. Lett. **18**, 1174 (1967).
5. S. D. Drell and T. M. Yan, Ann. Phys. (NY) **66**, 578 (1971).
6. S. D. Ellis and W. J. Stirling, Phys. Lett. B **256**, 258 (1991).
7. H. L. Lai *et al.*, Phys. Rev. D **55**, 1280 (1997).
8. H. L. Lai *et al.*, hep-ph/9903282.
9. A. D. Martin, R. G. Roberts and W. J. Stirling, Phys. Lett. B **419**, 1280 (1997).
10. A. D. Martin, R. G. Roberts, W. J. Sterling and R. S. Thorne, Eur. Phys. J. **C4**, 463 (1998).
11. M. Gluck, E. Reya and A. Vogt, Z. Phys. C **67**, 433 (1995).
12. M. Gluck, E. Reya and A. Vogt, Eur. Phys. J. **C5**, 461 (1998).
13. A. Baldit *et al.*, Phys. Lett. B **332**, 244 (1994).
14. S. Kumano, Phys. Reports. 303 (1998) 183.
15. E. A. Hawker *et al.*, Phys. Rev. Lett, **80** 3715 (1998).
16. E866 Collaboration, J.-C. Peng *et al.*, Phys. Rev. D **58**, 092004 (1998).
17. G. Moreno *et al.*, Phys. Rev. D **43**, 2815 (1991).
18. A. D. Martin, W. J. Stirling and R. G. Roberts, Phys. Lett. B **252**, 653 (1990).
19. K. Ackerstaff *et al.*, Phys. Rev. Lett. **81**, 5519 (1998).
20. W. Melnitchouk, J. Speth, and A. W. Thomas, Phys. Rev. D **59**, 014033 (1999).
21. S. Kumano, Phys. Rev. D **43**, 3067 (1991); **43**, 59 (1991); S. Kumano and J. T. Londergan, Phys. Rev. D **44**, 717, (1991).
22. A. Szczurek, A. Buchmans and A. Faessler, J. Phys. C **22**, 1741 (1996)
23. A. E. Dorokhov and N. I. Kochelev, Phys. Lett. B **304**, 157 (1993).
24. A. Szczurek, J. Speth and G. T. Garvey, Nucl. Phys. A **570**, 765 (1994).
25. S. Kumano, Phys. Rev. D **43**, 3067 (1991); **43**, 59 (1991); S. Kumano

and J. T. Londergan, *ibid.* **44**, 717 (1991).
26. J. F. Owens, Phys. Lett. **266B**, (1991) 126.
27. J. C. Peng, D. M. Jansen, Y. C. Chen, Phys. Lett. B **344**, 1, (1995).
28. V. Barger, W. Y. Keung and R. N. Philips, Z. Phys. **C6**, 169, (1980).
29. R. Vogt, to be published.
30. B. L. Combridge, Nucl. Phys. **B151**, (1979) 429.
31. H. Fritzsch, Phys. Lett. **67B**, (1977) 217.
32. D. M. Alde *et al.*, Phys. Rev. Lett, **66** 2285 (1991).
33. D. M. Alde *et al.*, Phys. Rev. Lett, **66** 133 (1991).
34. Fermlab proposal P906 (Donald Geesaman, spokesperson).