Measurement of the Absolute Drell-Yan Dimuon Cross Sections in 800 GeV/c pp and pd Collisions

C.A. Gagliardi[j], T.C. Awes[i], M.E. Beddo[h], M.L. Brooks[f], C.N. Brown[c], J.D. Bush[a], T.A. Carey[f], T.H. Chang[h*], W.E. Cooper[c], G.T. Garvey[f], D.F. Geesaman[b], E.A. Hawker[j,f], X.C. He[d], L.D. Isenhower[a], D.M. Kaplan[e], S.B. Kaufman[b], 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], B.A. Mueller[b], P.M. Nord[k], V. Papavassiliou[h], B.K. Park[f], J.C. Peng[f], G. Petitt[d], P.E. Reimer[f,b], M.E. Sadler[a], W.E. Sondheim[f], P.W. Stankus[i], T.N. Thompson[f], R.S. Towell[a,f], 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; [b] Argonne National Laboratory; [c] Fermi National Accelerator Laboratory; [d] Georgia State University; [e] Illinois Institute of Technology; [f] Los Alamos National Laboratory; [g] Louisiana State University; [h] New Mexico State University; [i] Oak Ridge National Laboratory; [j] Texas A&M University; [k] Valparaiso University

Fermilab experiment 866 has measured the Drell-Yan dimuon cross sections in 800 GeV/c pp and pd collisions. This represents the first measurement of the Drell-Yan cross section in pp collisions over a broad kinematic region and the most extensive study to date of the Drell-Yan cross section in pd collisions. The results are compared to previous measurements and to predictions based on various global parton distribution function fits. The implications for future parton distribution fits are discussed.

Fermilab experiment E866/NuSea has measured the Drell-Yan cross sections in 800 GeV/c pp and pd collisions over a broad kinematic range. In leading order, the Drell-Yan dimuon cross section for $AB \to \mu^+\mu^- X$ is given by

$$M^3 \frac{d^2\sigma}{dM\, dx_F} = \frac{8\pi\alpha^2}{9} \frac{x_1 x_2}{x_1+x_2} \sum_q e_q^2 \left[q_A(x_1)\bar{q}_B(x_2) + \bar{q}_A(x_1)q_B(x_2)\right]. \quad (1)$$

In this expression, M is the invariant mass of the muon pair, $x_F = 2p_L/\sqrt{s}$ where p_L is the dimuon longitudinal momentum, and the sum is over all quark flavors. x_1 and x_2, the momentum fractions of the beam and target partons, are given in leading order by $x_F = x_1 - x_2$ and $M^2 = x_1 x_2 s$. Drell-Yan dimuon production distinguishes between quarks

*Present address: University of Illinois, Urbana, IL.
†On leave from Kurchatov Institute, Moscow 123182, Russia.
‡This work was supported in part by the U.S. Department of Energy.

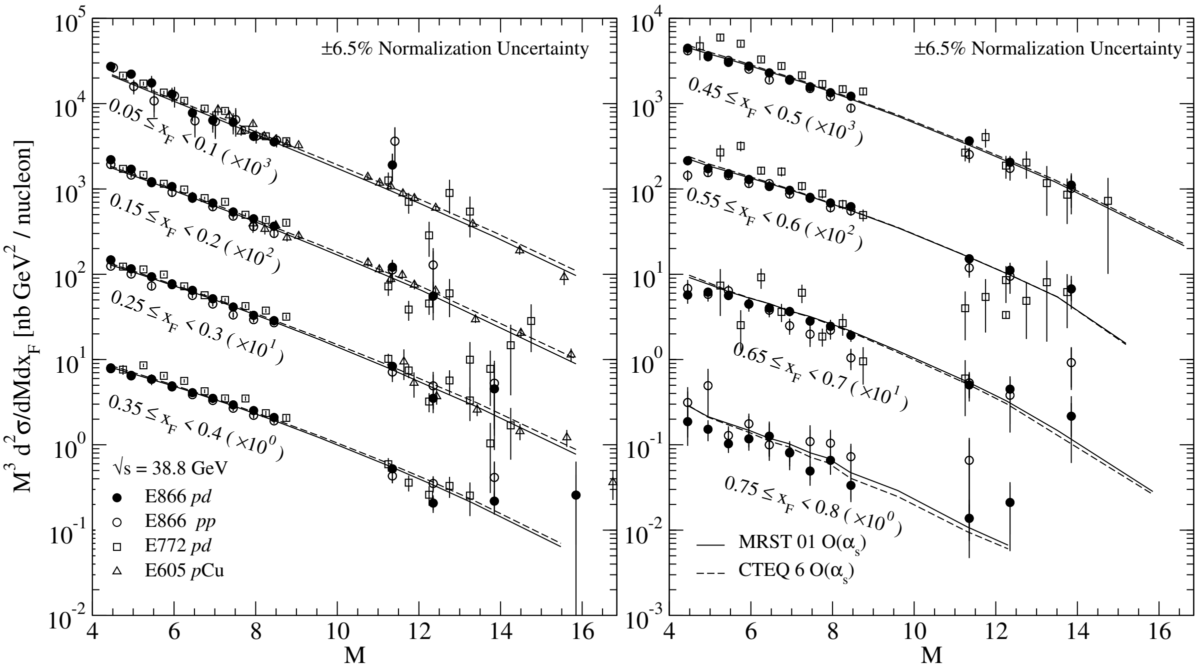

Figure 1. Preliminary FNAL E866 Drell-Yan pp and pd invariant cross sections, compared to previous results from E605 [8] and E772 [10], and to NLO predictions based on the CTEQ6 [4] and MRST2001 [6] PDFs. The error bars on the E866 results show the sum of the statistical and point-to-point systematic errors. There is an additional $\pm 6.5\%$ normalization uncertainty that is common to all points.

and antiquarks, so it provides valuable information about parton distribution functions (PDF) that is complementary to deep-inelastic scattering studies. Previous publications [1,2] have described the E866 measurement of the $\bar{d}/\bar{u}$ ratio in the proton as a function of x, based on the observed ratio of the Drell-Yan cross sections $\sigma^{pd}/2\sigma^{pp}$, and those results have been included in recent global PDF fits [3–7]. Here we describe absolute measurements of the Drell-Yan dimuon cross sections and discuss their implications.

E866 used a 3-dipole magnet spectrometer [8] employed previously in experiments E605, E772 and E789, modified by the addition of new detectors with larger acceptance at the first tracking station. An 800 GeV/c proton beam bombarded identical 50.8-cm long target flasks containing liquid hydrogen, liquid deuterium and vacuum that were alternated every few minutes. After passing through the target, the remaining beam was intercepted by a copper beam dump. The beam dump was followed by a thick absorber which removed hadrons produced in the target and the dump, ensuring that only muons traversed the spectrometer's detectors, consisting of four tracking stations and a momentum analyzing magnet. Drell-Yan events were recorded using three different spectrometer settings which focused low-, intermediate- and high-mass muon pairs and provided good acceptance from below the J/ψ to above 15 GeV. A detailed description of the experiment may be found in Ref. [2].

The present analysis used 55,000 pp and 120,000 pd Drell-Yan events in the ranges $4.2 < M < 16.85$ GeV and $-0.05 < x_F < 0.8$. This represents approximately half the

Table 1
K' factors obtained with various PDFs [3–7], where $K' = \sigma^{\rm exp}/\sigma^{\rm NLO}$. The χ^2 values include the statistical and point-to-point systematic uncertainties in the experimental cross sections, but not the $\pm 6.5\%$ global normalization uncertainty. The K' fits have 183 and 190 degrees of freedom (dof) for the pp and pd reactions, respectively.

	pp		pd	
PDF	K'	χ^2/dof	K'	χ^2/dof
CTEQ5	0.975	1.47	0.963	2.56
CTEQ6	1.015	1.44	1.000	2.62
MRST98	0.973	1.43	0.960	2.42
MRST2001	0.980	1.50	0.966	2.48
GRV98	0.811	2.11	0.808	4.24

statistics of the E866 $\bar{d}/\bar{u}$ study [2], because cuts were imposed to retain only those data sets and events for which the *absolute* acceptance of the spectrometer could be determined. Several improvements were made to the event reconstruction and Monte Carlo simulation that led to a more precise reconstruction of the dimuon kinematics and a better match between the real and simulated events. The spectrometer acceptance was determined from a detailed study of 10^6 Monte Carlo events, which were thrown with realistic kinematic distributions, then reweighted to provide a precise match to the experimental results. A detailed study was performed of the overall and point-to-point systematic uncertainties in the measured cross sections. The former is dominated by the integrated proton beam intensity, while the latter is dominated by the absolute field strength of the spectrometer magnets. See Ref. [9] for additional details.

Figure 1 shows the preliminary Drell-Yan pp and pd invariant cross sections for selected x_F bins. The results agree with previous 800 GeV/c Drell-Yan cross section measurements in p-Cu collisions by E605 [8]. They also agree with previous measurements in pd collisions by E772 [10] for $x_F < 0.3$. At larger x_F and small M, the E772 cross sections are systematically larger than the present results. E772 quoted a larger systematic uncertainty in this kinematic region, but the results of the two experiments differ by more than the combined systematic uncertainties would predict. The largest differences are in the region $0.4 < x_F < 0.6$ and $4.2 < M < 7$ GeV, where inconsistencies between the E772 results and expectations from global PDF fits were noted previously [5]. This region was studied during E866 by both the low- and high-mass spectrometer settings. The measurements, which involve very different acceptances, are consistent.

Figure 1 also shows the results of next-to-leading-order (NLO) predictions of the Drell-Yan cross sections from the MRST2001 [6] and CTEQ6 [4] global PDF fits. The agreement with the global fits is seen to be very good over the entire kinematic region measured. This agreement is also demonstrated in Table 1. The K' factors show that, with the exception of GRV98, all of the recent PDF fits predict the absolute magnitude of the Drell-Yan cross sections to within the $\pm 6.5\%$ overall normalization uncertainty.

While the overall normalization is well reproduced, there are systematic deviations between the measurements and the predictions that are reflected in the large χ^2 values in Table 1. To elucidate these deviations, it is useful to examine the experimental cross

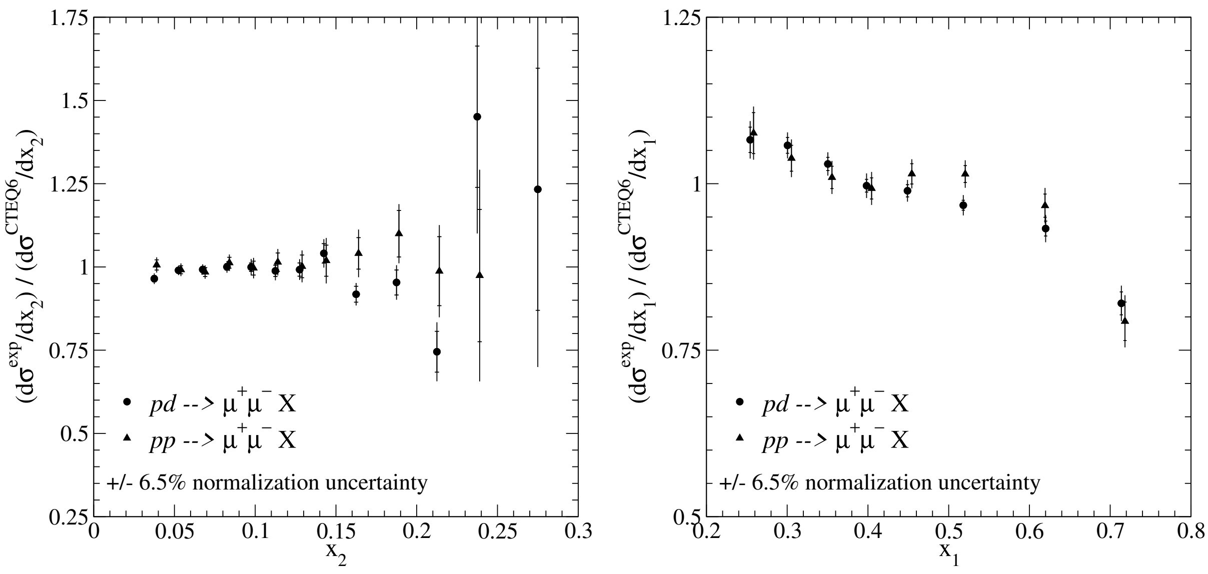

Figure 2. Preliminary ratios of the measured Drell-Yan *pp* and *pd* cross sections to NLO predictions based on CTEQ6 [4] *vs.* x_2 (left panel) and *vs.* x_1 (right panel).

sections separately as functions of x_1 and x_2. Most of the events have $x_1 >> x_2$, which implies the x_1 dependence is primarily sensitive to the valence quarks in the proton beam and the x_2 dependence measures the antiquarks in the target. Figure 2 shows the ratios of the experimental cross sections to NLO predictions using CTEQ6, as functions of x_2 and x_1. CTEQ6 provides a good description of the x_2 dependence, indicating that it is a reliable model for the $\bar{u}$ and $\bar{d}$ distributions for $0.02 < x < 0.3$. In contrast, CTEQ6 overestimates the Drell-Yan cross section at large x_1. This implies that the u quark distribution in CTEQ6 is overestimated as $x \to 1$. Similar results are obtained if the measured cross sections are compared to predictions from MRST2001. This discrepancy, while substantial, is within the quoted uncertainty on the u quark distribution in the current PDFs [4]. Therefore, future global PDF fits that include these new results should provide a much better description of the E866 Drell-Yan cross sections without significant degradation to the quality of the fit for the rest of the world's current data.

REFERENCES

1. E.A. Hawker et al. (FNAL E866/NuSea), Phys. Rev. Lett. 80 (1998) 3715.
2. R.S. Towell et al. (FNAL E866/NuSea), Phys. Rev. D 64 (2001) 052002.
3. H.L. Lai et al., Eur. Phys. J. C 12 (2000) 375.
4. J. Pumplin et al., JHEP 0207 (2002) 012.
5. A.D. Martin et al. Eur. Phys. J. C 4 (1998) 463.
6. A.D. Martin et al., Eur. Phys. J. C 23 (2002) 73.
7. M. Gluck, E. Reya, and A. Vogt, Eur. Phys. J. C 5 (1998) 461.
8. G. Moreno et al. (FNAL E605), Phys. Rev. D 43 (1991) 2815.
9. J.C. Webb, Ph.D. thesis, New Mexico State University (2002).
10. P.L. McGaughey et al. (FNAL E772), Phys. Rev. D 50 (1994) 3038; 60 (1999) 119903.