Request for E866 Run Extension

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ABSTRACT

E866 has been measuring the ratio of $\bar{u}/\bar{d}$ in the proton via the Drell-Yan process since September 1996. The data obtained by the end of calendar year 1996 will achieve the goals stated in the E866 proposal. In addition to this work, the E866 spectrometer is capable of making several other important measurements. In this note, we present the physics motivation with supporting test data and Monte Carlo simulations to demonstrate the feasibility of the proposed measurements. To carry out this extended program we request that the Meson-East beam-line remain operational during the 1997 fixed-target run. A proton beam intensity of up to 2×10^{12} per spill is requested. Only very minor modifications of the spectrometer are needed.

I. Introduction

For the past 15 years a series of experiments, E605, E772, and E789, using the Meson-East spectrometer have provided high statistics dimuon data from proton-nucleus interactions. The reactions – Drell-Yan dimuon (DY), J/ψ, and Υ production – have impacted three areas: 1) Absolute differential cross sections yielded important constraints on parton structure and have been incorporated into global structure function analyses, 2) Nuclear dependence of DY production was found to be quite small, thereby eliminating many explanations of the EMC effect, and 3) Large nuclear dependencies observed in J/ψ, ψ', and Υ production have challenged conventional beliefs and inspired much more sophisticated approaches, particularly in connection with searches for quarkonia signatures of quark-gluon plasma formation in heavy-ion collisions.

The main goal of the current experiment, E866, is the determination of $\bar{u}(x)/\bar{d}(x)$ in the proton via a precision comparison of proton-induced Drell-Yan dimuon production from hydrogen and deuterium targets. E866 has been recording data since early September 1996. Approximately 300,000 DY events will have been recorded by the end of 1996. This will accomplish the goal stated in the E866 proposal, providing a precise measurement of the flavor asymmetry in the nucleon sea.

Seven months of fixed-target beam are scheduled in 1997 (January 15 to August 15). This may be the last chance to do proton-induced dimuon measurements at 800 GeV, and offers an excellent opportunity for E866 to obtain additional data. These data will extend the range in x of the $\bar{u}/\bar{d}$ ratio and advance other important issues in Drell-Yan and quarkonium physics. The additional measurements that E866 can perform are outlined as follows:

- Extended measurements of $\bar{u}(x)/\bar{d}(x)$ and $p+p$ Drell-Yan cross sections
- Polarization of Drell-Yan Pairs and Quarkonia
- Nuclear-Dependence of J/ψ and Low-Mass Drell-Yan Yields

These subjects are briefly discussed below.

II. Improved measurements of $\bar{u}(x)/\bar{d}(x)$ and high-statistics $p+p$ Drell-Yan cross sections

E866 measured dimuons produced by 800 GeV protons incident on 50-cm long liquid H_2 and D_2 targets. The data were obtained at three different spectrometer settings covering a wide range of dimuon mass. Figure 1 shows a preliminary mass spectra from $\sim 2/3$ of the low and medium-mass data. Good statistics are obtained from the J/ψ up to the Υ. The expected statistical accuracy of the E866 data from 1996 is illustrated in Figure 2. Predictions of the CTEQ4M structure functions[1] are plotted with statistical errors from the E866 data. Clearly, additional measurements of the D/H ratio at a high-mass spectrometer setting are needed to determine the $\bar{u}/\bar{d}$ ratios at large x.

We request a continuation of E866 at the high-mass setting for a period of two months with 2×10^{12} protons/spill. These data would triple the statistics at high-mass and large x_2 where the CTEQ fit shows a large sea asymmetry. Note that the CTEQ prediction for the asymmetry is unconstrained in this region.

Drell-Yan data play an important role in the determination of the light quark structure functions of the proton, particularly the sea for $x > 0.1$. Drell-Yan data for $p + Cu$ from E605[2] have been included by the CTEQ[1] and MRS[3] groups in their global fits. To take advantage of the greatly improved theoretical description of the Drell-Yan process and to eliminate any nuclear effects, it is important to use precision data from $p+p$ collisions. No such high statistics data exist yet, but E866 will provide them. Figure 3 shows $pp \rightarrow$ DY raw counts from the E866 1996 data versus x_1, x_2, and p_T, illustrating the large kinematic coverage. Additional $p+p$ and $p+d$ measurements in 1997 will improve the statistical accuracy at high mass where the cross section is small. These data may be obtained in parallel with the $\bar{u}(x)/\bar{d}(x)$ data.

III. Polarization of Drell-Yan Pairs and Quarkonia

High statistics pion-induced Drell-Yan[4, 5] and J/ψ[6] production data have been analyzed to study the decay angular distributions in θ_{CS} and ϕ_{CS} (Collins-Soper frame). Drell-Yan pairs were observed to be transversely polarized, as expected, except at very large x_F (> 0.8) where they became longitudinally polarized[4, 5]. This large x_F behavior was explained as a higher-twist effect[7]. The J/ψ was measured to be unpolarized except at large x_F where it also became longitudinally polarized[6, 8]. A detailed measurement of the decay angular distribution will also help investigate the role of the color-octet states in the production of charmonium[9], recently proposed to account for the unexpectedly large CDF ψ production cross sections[10]. Some models using color-octet intermediate states predict that the J/ψ and ψ' are strongly polarized at large p_T[11].

The literature contains no high statistics measurement of the polarization of proton-induced DY virtual photons. A recent analysis of beam-dump dimuons from E772[12] clearly demonstrates the feasibility of recording high statistics DY data even at large mass, large x_F, or large p_T where cross sections are small. A preliminary angular distribution of high-mass DY pairs is shown in Figure 4. About 50,000 DY dimuon pairs were recorded for masses above 11 GeV/c^2 in E772. Figure 5 shows a mass spectrum for beam-dump dimuons obtained by E866 in a 4-hr test run at low intensity. A large number of J/ψ and Drell-Yan events were obtained in a relatively short time. These beam-dump dimuons extend to large values of p_T and x_F and may reveal interesting aspects of the DY process. Angular distribution measurements in E866 are possible from the beam dump, which provides for the necessary combination of large angular acceptance and high luminosity.

We request two months of beam with 1×10^{11} protons/spill for the angular distribution measurements. Table 1 shows the expected number of Drell-Yan events ($4 \leq M_{\mu^+\mu^-} \leq 9$ GeV/c^2) as a function of x_F. The statistics are adequate for a detailed measurement of the decay-angle distributions. Table 2 shows the expected yields for the J/ψ.

IV. Nuclear-Dependence of J/ψ and Low-Mass Drell-Yan Yields

- *J/ψ and ψ' nuclear dependences*

The large nuclear dependencies found in hadronic production of quarkonium have inspired several explanations within the past few years. Parton energy loss, intrinsic heavy flavor, co-mover interactions, gluon shadowing, and color octet production are among the mechanisms proposed to explain the data. The yield of quarkonium in hadronic collisions is interesting not only in its own right, but is also advanced as one of the most important diagnostic tools for high-density nuclear matter created in heavy-ion collisions.

E866 can extend the systematic study of nuclear effects in J/ψ and ψ' production beyond what was achieved in E772 and E789[1]. The enhanced capacity of the E866 data acquisition and analysis systems exceeds that of E772 by a factor of 10. Furthermore the p_T acceptance of E772 was limited. The E866 acceptance allows a study of correlations in x_F versus p_T with very high statistics. As an example, in E866 one million J/ψ's were recorded from the hydrogen and deuterium targets in a two week run at low intensity (see Figure 1). Thin solid targets, Be and W, would be used in place of the cryogenic targets. Thin targets provide an improved mass resolution compared to the $20''$ long cryogenic targets, which aids in the ψ' measurement.

- *Low mass Drell-Yan production and nuclear shadowing.*

The NMC[13] and FNAL-E665[14] experiments have observed 'shadowing' in deep inelastic scattering (DIS) on nuclear targets. This suppression of sea-quarks in heavy nuclei occurs at $x \leq 0.05$ and appears to saturate at $x \sim 0.001$. Figure 6 shows the ratios of $F_2(x)$ for Ca/D from the NMC experiment. Also shown are the Drell-Yan ratios measured by E772[12]. Although there is evidence of shadowing in the E772 data, it is important to extend the measurements to smaller values of x. To reach lower x, DY masses less than 4 GeV/c^2 must be explored. It is of interest to compare shadowing in DIS and DY because the virtual photons involved are different, being spacelike and timelike, respectively. Secondly, the DY events are selected to arise from sea quarks in the nuclear target, while the DIS data measure a composite of valence and sea quarks.

E866 can obtain the dimuon continuum for $2 \leq M_{\mu^+\mu^-} \leq 4\ GeV/c^2$ in parallel with the J/ψ nuclear dependence described above (see Figure 7). Values of x_2 as low as 0.01 can be obtained for Drell-Yan events at 2 GeV. It is known from E772 that the low-mass dimuon continuum is subject to backgrounds originating from random coincidences of pion, kaon, and charm decays. However, we believe that higher p_T and x_F cuts will provide a large enhancement of the Drell-Yan signal relative to these backgrounds. Since the Drell-Yan cross section at low mass is large, it is not necessary to use high beam intensity. It will be possible to reduce the accidental background significantly at low intensity. A like-sign subtraction can be used to remove much of the remaining contamination from pion and kaon decays. The yield of high p_T dileptons ($p_T > 3GeV/c$) is also of interest, as it contains information

[1] E772 was the source of most of the quarkonium nuclear dependence data. The large x_F nuclear dependence data from E789 used a special Be beam dump insert. This configuration did not allow separation of the ψ'.

on the gluon structure function of the nucleon and should be interpretable in terms of $\alpha^2\alpha_s$ processes.

We request three months of beam for the nuclear dependence measurements. Intensities will vary from 1×10^{11} to 5×10^{11} protons/spill, depending on target location and x_F coverage. Beryllium and tungsten targets of $\sim 15\ g/cm^2$ will be used instead of the cryogenic targets. Physical removal of the cryogenic targets will not be required. Tables 3 and 4 list the expected J/ψ yields.

V. Summary of Requested Beam Time and Intensity

To carry out the measurements discussed in Sections II - IV, we request the following beam intensity and running time.

1. **Improved Measurement of $\bar{u}/\bar{d}$**

   2×10^{12} protons/spill for two months. Existing LH_2 and LD_2 targets will be used.

2. **Polarization of Drell-Yan Pairs and Quarkonia**

   1×10^{11} protons/spill for two months. The beam-dump (Cu) will be used as the target for this measurement.

3. **Nuclear-Dependence of J/ψ and Low-Mass Drell-Yan Yields**

   Up to 5×10^{11} protons/spill for three months. Two thin solid targets, Be and W, will be used.

   The total amount of beam requested for the measurements is 7 months.

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DY										
x_F	−0.2	−0.1	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
# of events $\times\ 10^3$	2.3	8.5	23.5	59.5	155.0	312.5	324.5	231.0	130.0	46.3
# of events $\times\ 10^3$ $p_T > 2.0\ GeV/c$	0.2	1.0	5.2	16.2	43.3	97.0	101.5	73.0	43.6	16.5

Table 1: Expected number of recorded Drell-Yan events from the beam-dump as a function of x_F for the $4 < M_{\mu^+\mu^-} < 9\ GeV/c^2$. The last row of numbers is for $p_T > 2.0\ GeV/c$, a region where NLO DY predicts sensitivity to the gluon content of the proton. The calculation is based on intensity of 1×10^{11} protons/spill and 2 months or running.

J/ψ								
x_F	.26	.31	.36	.41	.46	.51	.56	
# of events $\times\ 10^3$	280.	2900.	5700.	5800.	5200.	3700.	2800.	
x_F	.61	.66	.71	.76	.81	.86	.91	.96
# of events $\times\ 10^3$	1900.	1200.	650.	330.	140.	43.	7.	0.3

Table 2: Expected yield of high-x_F J/ψ's from 2 months of beam-dump data at 1×10^{11} protons/spill.

J/ψ						
x_F	−0.08	−0.04	0.00	0.04	0.08	0.12
# of events $\times\ 10^3$	24	186	470	468	236	20

Table 3: Expected yield of low-x_F J/ψ's for one month run on Be and W targets at 1×10^{11} protons/spill.

J/ψ												
x_F	0.48	0.52	0.56	0.60	0.64	0.68	0.72	0.76	0.80	0.84	0.88	0.92
# of events $\times\ 10^3$	88	220	232	232	196	144	88	50	26	9.6	2.8	0.5

Table 4: Expected yield of high-x_F J/ψ's for a two-month run on Be and W targets at 5×10^{11} protons/spill.

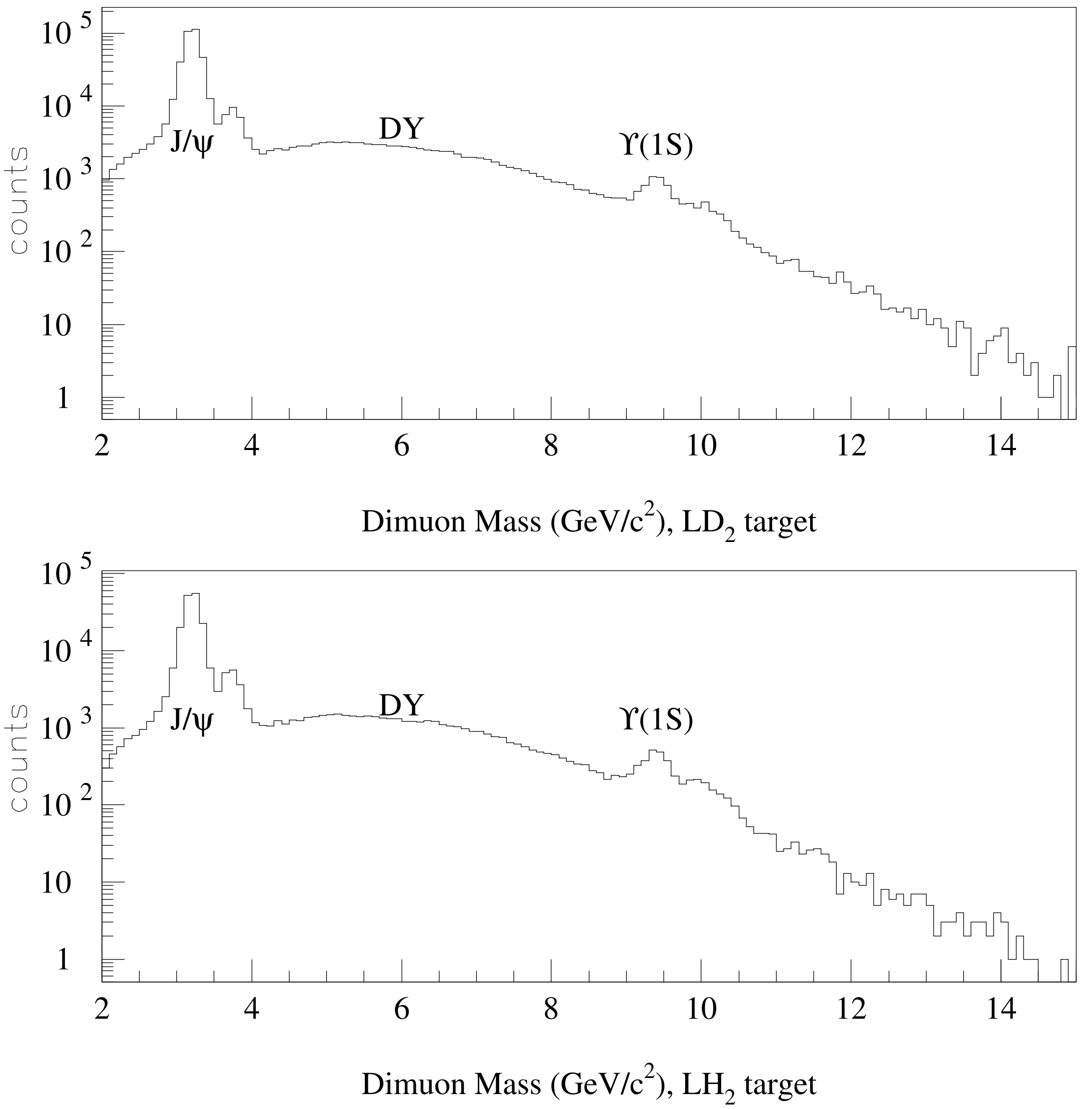

Figure 1: Preliminary dimuon mass spectra from $\sim$2/3 of the E866 low and medium-mass data. In this plot there are $\sim$ 200,000 observed DY dimuon pairs from $LD2$ target, and about half as many for the LH_2 target.

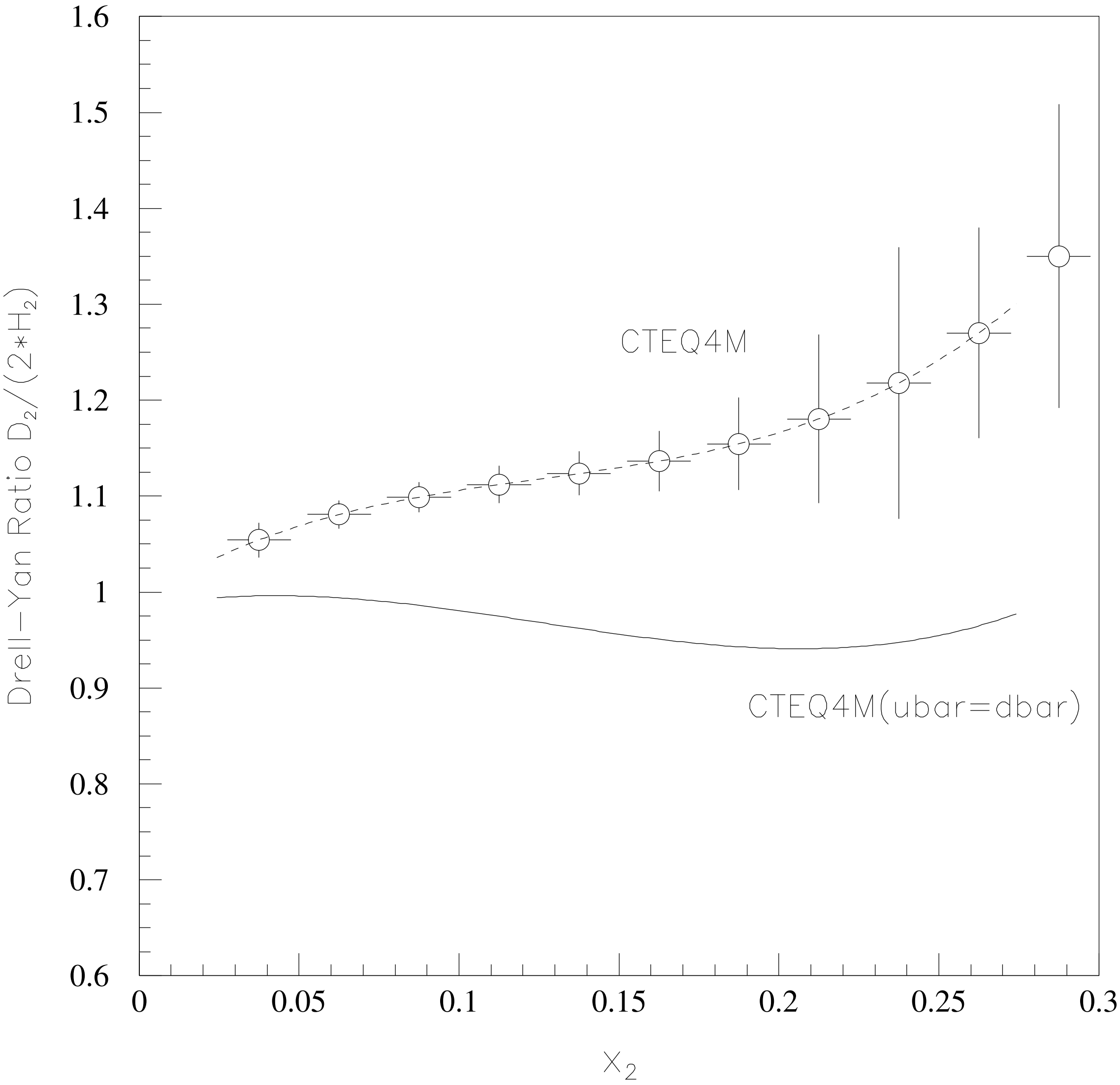

Figure 2: Expected statistical accuracy of the 1996 E866 data. For this plot, we have assumed that the results fall on the predictions of the CTEQ4M structure function.

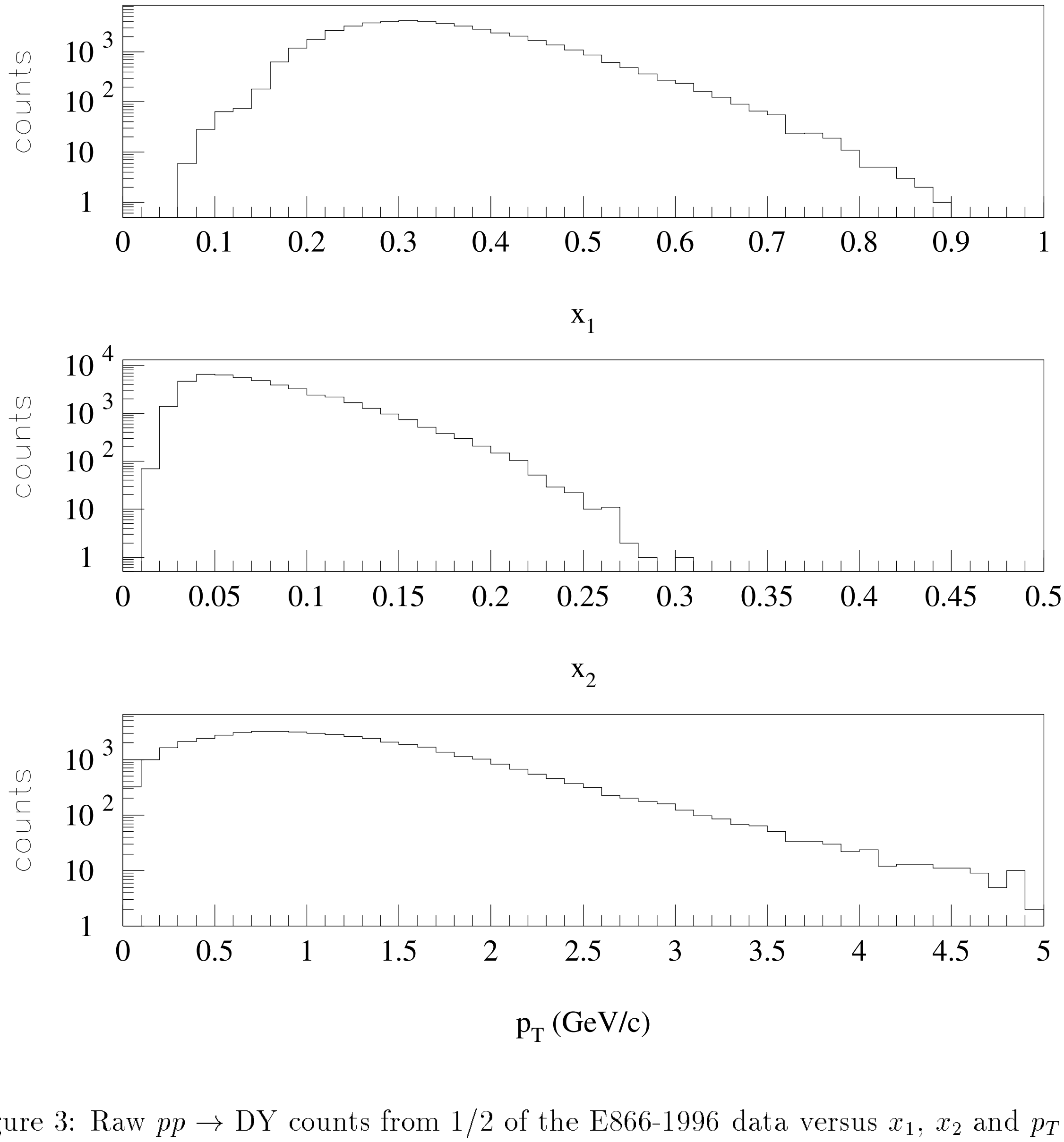

Figure 3: Raw $pp \to$ DY counts from 1/2 of the E866-1996 data versus x_1, x_2 and p_T.

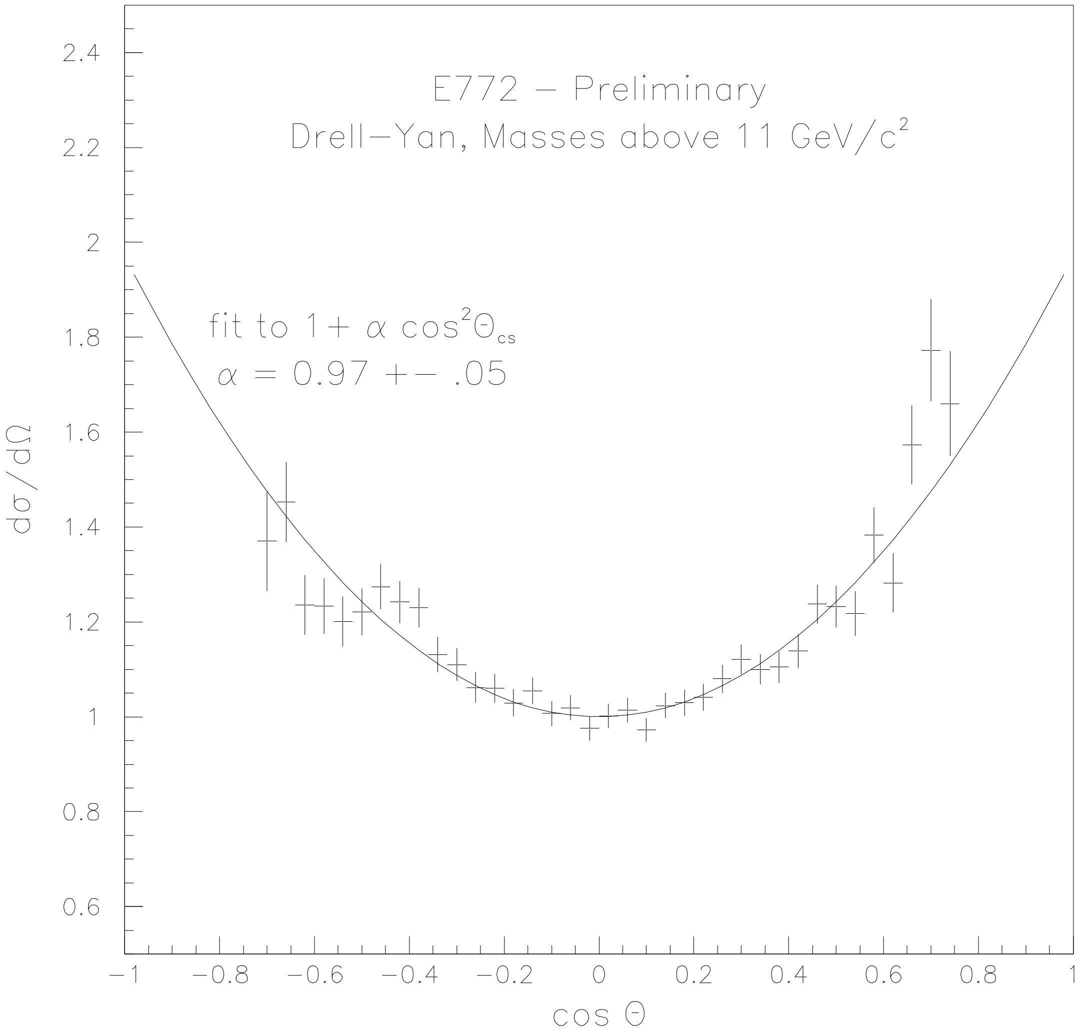

Figure 4: A preliminary angular distribution of high-mass DY pairs from E772 is shown.

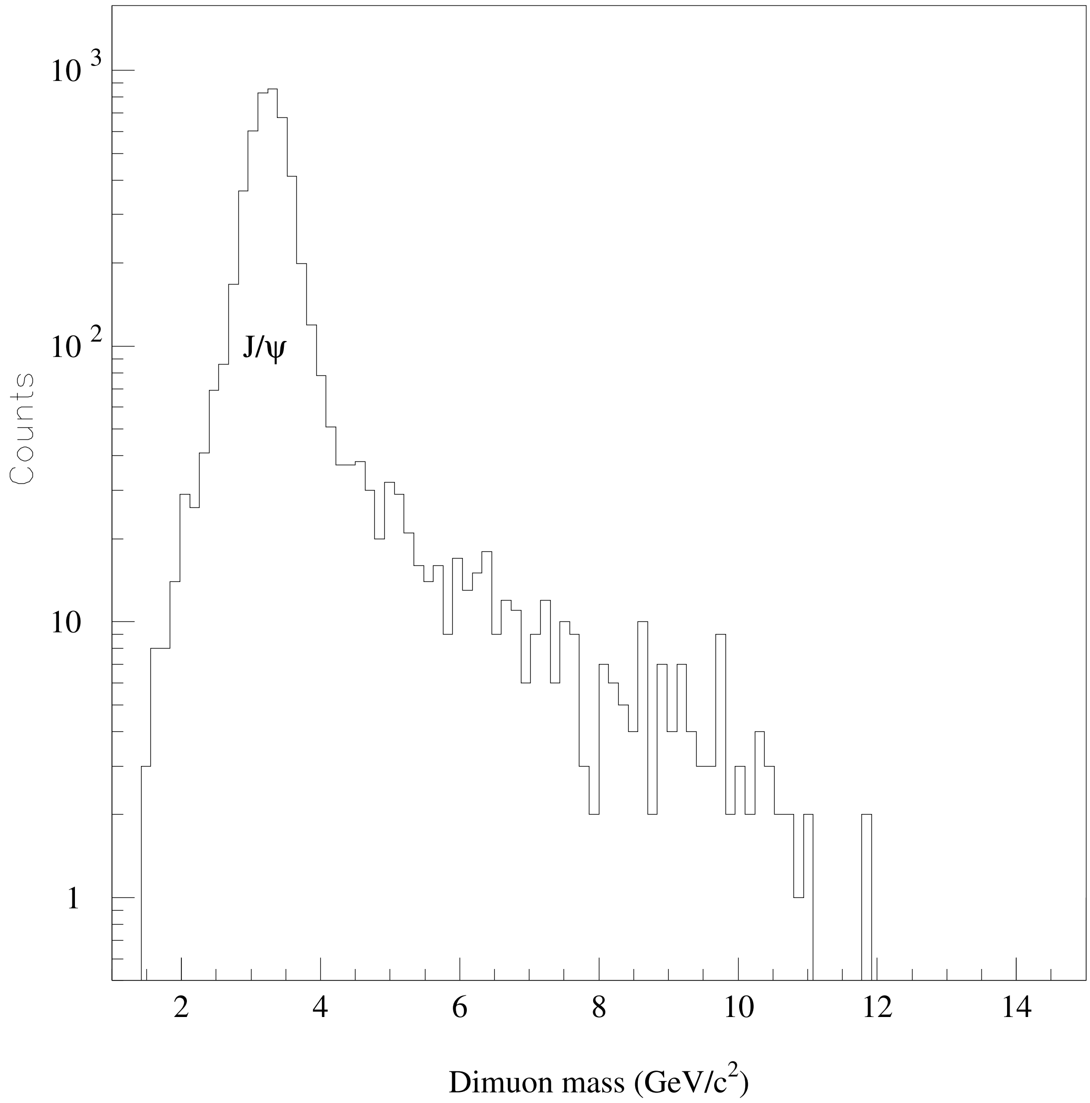

Figure 5: E866 beam-dump data taken in 4 hours at an intensity of 1×10^{10} protons/spill.

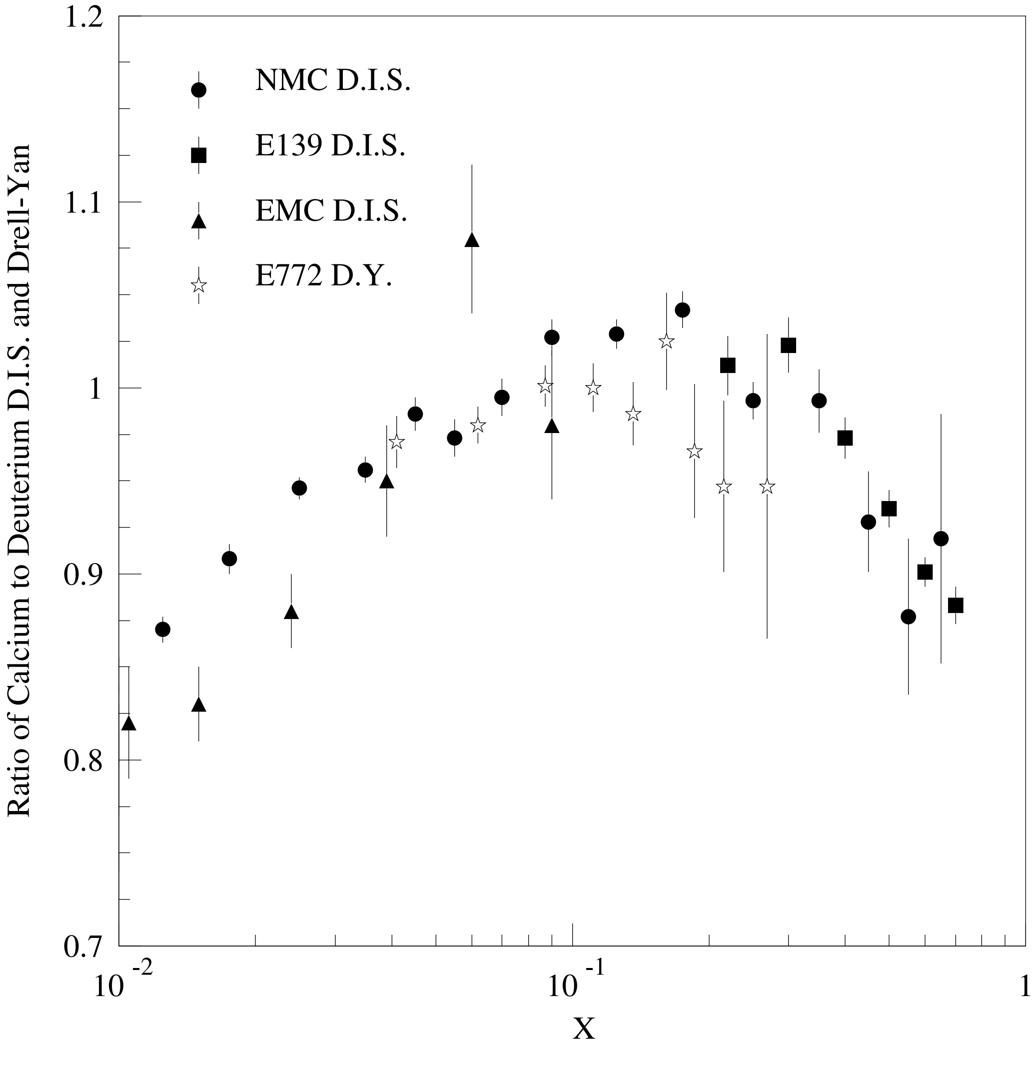

Figure 6: The ratios of $F_2(x)$ for Ca/D from various experiments. Also shown are the Drell-Yan ratios measured in E772.

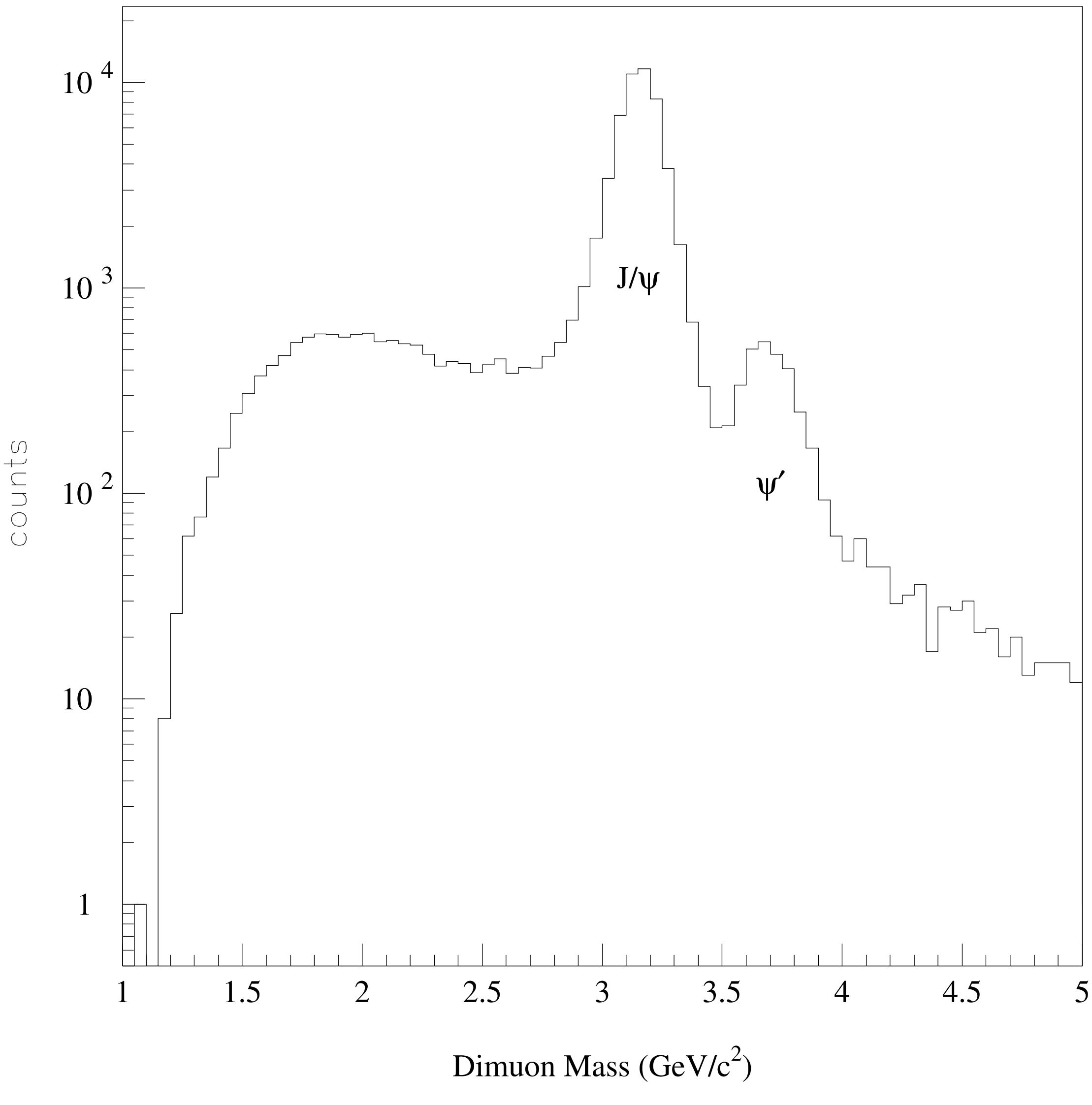

Figure 7: Result from a very-low-mass test-run that lasted 5 hours at 2×10^{11} protons/spill. The like-sign dimuon yield has been subtracted.