VECTOR MESON PRODUCTION AND NUCLEAR EFFECTS IN FNAL E866

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Fermilab E866/NUSEA is a fixed-target experiment which has made a number of measurements of the production of vector mesons by 800 GeV protons. The nuclear dependence results include measurements for J/ψ, ψ' and ϕ production over very broad ranges in x_F and p_T, and the J/ψ decay angular distribution at very large x_F. Preliminary results from measurements on Be, Fe and W targets are presented and discussed in the context of nuclear effects such as energy loss and multiple scattering of the partons, absorption of the produced $c\bar{c}$ pairs, and shadowing. Production mechanisms involving color-singlet or color-octet states for the $c\bar{c}$ pair which eventually forms a J/ψ or ψ' have implications on the strength of absorption in the nucleus and on the angular distribution of the decay muons. Our preliminary results on the angular distributions versus x_F and p_T indicate some transverse polarization of the J/ψ as predicted by models of production through the color octet state. Our measurements of dimuons in the 1 to 3 GeV region explore the nuclear dependence of the ϕ meson and also the composition of the continuum between the ϕ and the J/ψ. These studies of vector meson production and it's nuclear dependence are critical in furthering our understanding of these processes towards future measurements at RHIC and new results from NA50 at CERN, where J/ψ suppression is predicted to be an important signature of the creation of quark-gluon plasma in heavy-ion collisions.

1 Introduction

Here I present results from the E866/NUSEA experiment, an 800 GeV/c proton fixed-target experiment done at Fermilab in 1996 and 1997. The primary goal of this experiment was a measurement of the $\bar{d}/\bar{u}$ asymmetry in the nucleon sea, but other results include the nuclear suppression of J/ψ, ψ' and ϕ in p-A collisions and the decay angular distributions for the J/ψ. The $\bar{d}/\bar{u}$ results, which will not be discussed here, are already published[1]. All of the other results are preliminary, and are expected to change in detail, but not qualitatively, as the analysis of the data progresses. The E866/NUSEA collaboration includes physicists from Abilene Christian, Argonne, Fermilab, Georgia State, Illinois Institute of Technology, Los Alamos, Louisiana State, New Mexico State, Oak Ridge, Texas A&M, and Valparaiso.

2 FNAL Meson East Spectrometer

E866 used a 3-dipole magnet pair spectrometer employed in previous experiments (E605, E772, and E789)[2], modified by the addition of new drift chambers and hodoscopes with larger acceptance at the first tracking chamber and a new trigger system[3]. An 800 GeV/c extracted proton beam of up to 2×10^{12} protons per 20 s spill bombarded one of the many targets used in these measurements. After passing through the target, the remaining beam was absorbed in a copper beam dump located inside the large second magnet. The beam dump itself was used as a target for some of the measurements. However, for most of the measurements thin solid targets in a rotating wheel located upstream of the first magnet were used. These included Be, Fe, Cu and W targets with thicknesses corresponding to between 10 and 15% of an interaction length. Following the beam dump was a 13.4 interaction length absorber wall which filled the entire aperture of the magnet and helped stop hadrons and assured that only muons traversed the spectrometer's detectors. These muons were then tracked through a series of detector stations composed of drift chambers and hodoscopes. Because of improvements in the trigger system, the coverage in p_T was much broader than in previous experiments on this spectrometer (e.g. E772) and reached out to over 4 GeV/c. Beam intensity was monitored using secondary-emission detectors.

3 Nuclear Dependence of J/ψ Production

The suppression of J/ψ production in nuclei is probably a result of many different effects including absorption on nucleons or on co-moving light quarks or hadrons, energy loss in the initial state, and shadowing and other nuclear effects on the gluon structure function. Also the question of whether the $c\bar{c}$ pairs are produced in color-singlet or octet states has an important implication on the strength of the absorption since an octet state will be more readily absorbed than a singlet state. The production through octet states will also be discussed below in the context of the angular distributions of the produced J/ψ. In order to distinguish these different sources of suppression it is important to have data over broad ranges in x_F and p_T, and on several different vector mesons. The data presented here broadens the range in these kinematic variables and increases the statistics over previous measurements in p-A collisions. A thorough understanding of this physics is also essential towards future studies at RHIC where the suppression of vector meson production in heavy-ion collisions is thought to be an important signature for the formation of the quark-gluon plasma.

Over three million J/ψ's and 100 thousand ψ''s have been observed over

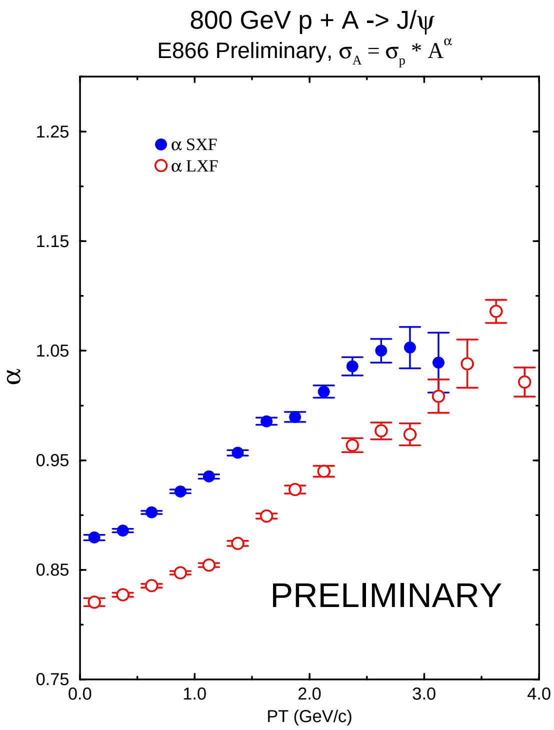

Figure 1: Preliminary results from E866 for α versus p_T for J/ψ production by 800 GeV/c protons. Results are shown for two ranges in x_F: $-0.15 \leq x_F \leq 0.3$ (SXF) and $0.3 \leq x_F \leq 0.95$ (LXF).

a range in x_F of -0.15 to 0.95 and p_T up to more than 4 GeV/c. The nuclear dependence of this production is obtained from data on Beryllium, Iron, and Tungsten targets. For convenience in comparing the suppression of J/ψ's on different nuclei I will present it in terms of α, where α is defined by, $\sigma_A = \sigma_p * A^\alpha$. In this representation a value of $\alpha = 1$ means that there is no suppression (or enhancement) of the J/ψ cross section per nucleon in a heavy nucleus compared to a light nucleus. The results, of course, can also be presented in terms of simple ratios between a heavy and light nucleus, but I will not include these here.

The p_T dependence of α is shown in Fig. 1 for two portions of our data. Two different spectrometer magnet settings were used to obtain data over

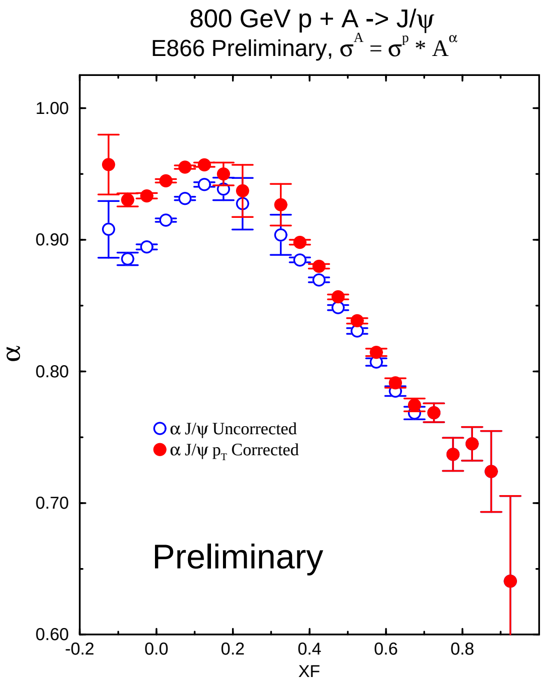

Figure 2: Preliminary values of α versus x_F for J/ψ production with and without a correction for the p_T acceptance, as described in the text.

the measured x_F range. The small-x_F (SXF) data in Fig. 1 has a smaller suppression than the large-x_F (LXF) data because of the strong decrease of α for larger values of x_F. But it is important to note that the shapes versus p_T are approximately the same for the two regions of x_F. The general increase in α with p_T is a typical nuclear effect in production processes such as this and in the Drell-Yan process. This increase is thought to be a result of multiple scattering of the incident parton and, in the case of resonance production, the resonance or nascent resonance in the final state.

Previous experiments such as E772 have had a limited acceptance in p_T which varied with x_F. Since the value of α depends strongly on p_T this can cause a distortion of the apparent shape of α versus x_F. In E866, because of a more open trigger, our p_T acceptance is much broader than in the older

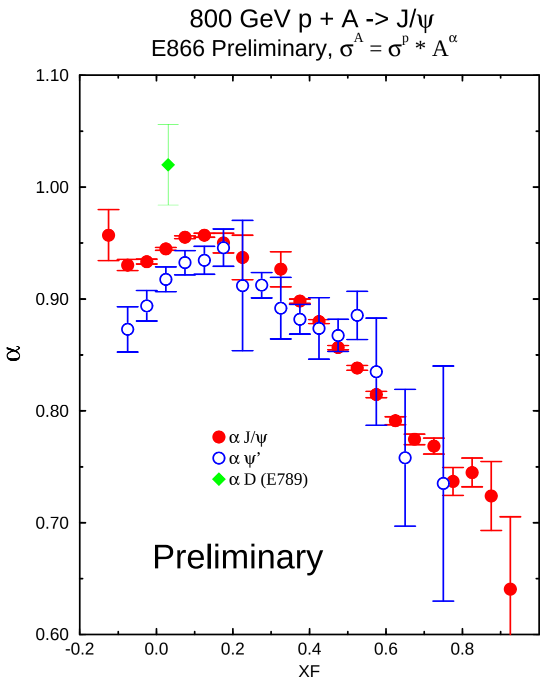

Figure 3: Preliminary values of α from E866 versus x_F for production of J/ψ and ψ' by 800 GeV/c protons. Also shown is the results from E789 for the D meson.

experiments. However, at the lowest values of x_F for each spectrometer setting we still have a narrow p_T acceptance. So, in order to try to remove the bias caused by our still incomplete p_T coverage we have corrected the α values which will be shown versus x_F using the known p_T acceptance for each x_F bin and the universal shape of α versus p_T. The results are shown in Fig. 2 along with the uncorrected α values. The correction is quite important for values of x_F below about 0.15 and near 0.37 where our p_T range is limited. It makes little difference elsewhere.

When we compare the E866 results to those of E772 we have to take into account two important effects. One is the x_F dependent p_T acceptance discussed above, and the other is that the E772 results were obtained by taking ratios of heavy nuclear targets to those for deuterium. The latter assumes that

Table 1: Comparison of Vector Mesons expected for Phenix Muon with those measured in the E772 and E866 Fermilab Fixed Target Experiments.

	E772	E866	PHENIX Muon
ϕ	—	63k	57k
J/ψ	100k	2.8M	1.3M
ψ'	12k	90k	23k
Υ	17k	—	710
$\sqrt{s}(GeV)$	40	40	200
x_F	0 to 0.6	-0.15 to 0.9	-0.3 to 0.3
x_2	0.03 to 0.27	0.005 to 0.16	$\sim 10^{-4}$ to 0.2
p_T (GeV/c)	0 to 2.5	0 to 4	0 to 10

in E772 the deuterium cross section follows the systematics of A^α. But, in fact, this is a poor assumption. Other measurements of J/ψ's on deuterium and hydrogen targets made as part of our $\bar{d}/\bar{u}$ asymmetry study show that for J/ψ's the cross section per nucleon is almost identical for deuterium and hydrogen. Indeed this result does not follow the systematics seen for heavy nuclei which would predict about a 5% decrease for deuterium. If we plot instead the E772 results obtained from the ratio of W to C and also make a correction for the p_T acceptance of E772 then we get quite good agreement between E772 and the new E866 results, where the latter are obtained from ratios of W to Be. This means that deuterium is not really a nucleus for the purposes of these comparisons, but rather is more like an isolated proton and isolated neutron.

We have also extracted the x_F dependence of α for the ψ'. Since the ψ' peak is much smaller than that for the J/ψ much more care in extracting the yield must be taken. At this time we are still working to improve our fitting techniques, but already the general features seem stable. These are shown in Fig. 3, where one sees that the ψ' is suppressed about the same as the J/ψ for positive values of x_F but for x_F below zero the ψ' is more strongly suppressed. This is the first time that a stronger suppression of ψ' has been seen in p-A production, but it is not completely unexpected. It is natural to expect that for large x_F, where the J/ψ and ψ' are not hadronized in the nucleus but rather are a nascent $c\bar{c}$ pair, their absorption would be the same. But for a small enough x_F one would expect them to become physical, in which case the ψ' would be absorbed more strongly than the J/ψ since it's size is larger and it's binding energy smaller.

Also in Fig. 3 is the α obtained in E789 for the production of D mesons [4], which illustrates that, at least near $x_F = 0$, the mechanism that causes the suppression of the vector mesons does not affect open charm. This probably

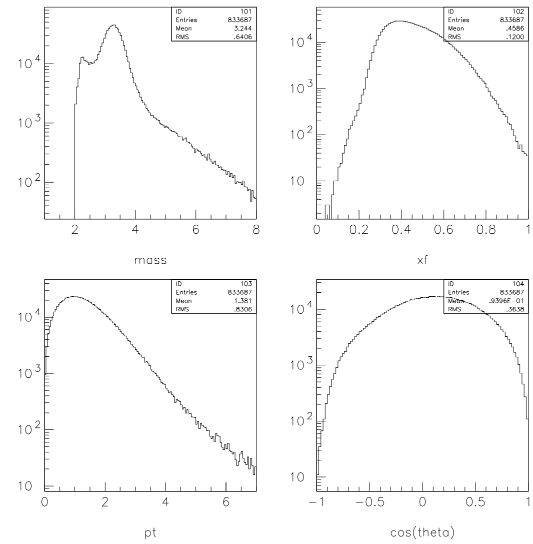

Figure 4: Kinematic distributions for about 5% of the E866 data where the copper dump is used as a target.

means that absorption effects are the main source of the suppression of the vector mesons near $x_F = 0$. However, the increasing suppression for larger values of x_F is probably due to other effects such as energy loss [5] or coherence lengths [6].

Another interesting comparison to make for this data is to similar data expected from the PHENIX detector at RHIC. Table 1 compares the expected vector meson yields and coverage of the muon arms of the PHENIX detector to those obtained from E866 and E772 [7]. The PHENIX muon numbers are for min-bias Au-Au collisions for one RHIC year at blue-book luminosity, i.e. 3000 hours at an integrated luminosity of $2 \times 10^{26} cm^{-2}$. One can see that the PHENIX muon measurements can be expected to have similar statistics for min-bias events for the lighter resonances. These statistics should allow for ample binning in the interesting kinematic variables in order to try to isolate different mechanisms for the suppression of these resonances.

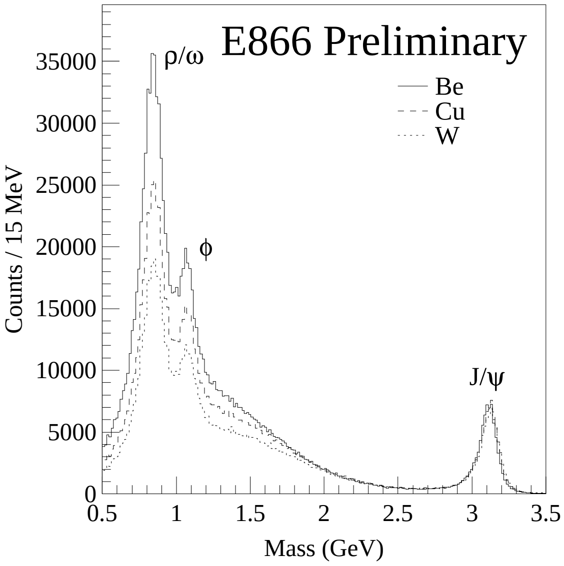

Figure 5: Preliminary dimuon mass spectra in the $\sim$ 0.5 to 3.2 GeV/c^2 region. In addition to Drell-Yan and open-charm muon pairs, the continuum contains random pairs which have not yet been subtracted. The ρ/ω, ϕ, and J/ψ peaks are also seen on top of the continuum.

4 J/ψ Decay Angular Distributions

In recent years calculations of J/ψ production cross sections using the color-singlet model have been found to underpredict the observed cross sections by large factors, especially for the CDF measurements where ψ' predictions were close to a factor of 30 too small. However, model calculations where the J/ψ is produced in a color-octet state have been found to give a reasonable description of these cross sections [8]. Another implication of the production through color-octet states is that the produced J/ψ's should be transversely polarized [9] and therefore would be observed with a decay angular distribution that goes as $1 + cos^2(\theta)$. However feeddown from higher states and higher twist at large x_F will tend to wash out or change this polarization [10] in some regions of x_F or p_T.

We have observed over 8 million J/ψ's, using our beam dump as a target, in order to measure the decay angular distribution over a broad range in x_F and p_T. The kinematic distributions of a portion of this data are shown in Fig. 4. About 40 thousand of these J/ψ's have an x_F above 0.8 and one hundred thousand have a p_T above 4 GeV/c. The reliable extraction of the angular distribution requires careful attention to the asymmetries in the spectrometer, so current results are preliminary and will not be shown in this writeup. (The effect of these asymmetries can be seen in the plot of the raw $cos(\theta)$ distribution in Fig. 4.) However these results, after many of the asymmetry effects have already been studied and accounted for, indicate some transverse polarization, especially at lower values of x_F, in the 0.2 to 0.5 range. We expect to have final results for this data by the end of 1998.

5 Low mass Nuclear Dependence and the ϕ

Near the end of our data taking period we made measurements of the nuclear dependence in the 1 to 3 GeV dimuon mass region for the first time on this spectrometer. Approximately 63 thousand ϕ's and over 100 thousand J/ψ's were collected from beryllium, copper, and tungsten targets. Some representative mass spectra are shown in Fig. 5. Initial results indicate that these ϕ's have a much stronger nuclear dependence than that for the J/ψ. However the kinematic coverage of the ϕ may be different than that for the J/ψ and is currently being studied. The data also contain a large number of muon pairs in the continuum between the ϕ and the J/ψ. In order to extract useful information from this continuum region the random pairs must first be extracted. Once the random pairs are eliminated, we will study the nuclear dependence of the remaining dimuons. These are expected to be composed of Drell-Yan and of open-charm semileptonic decay pairs. Previous results for the nuclear dependence of Drell-Yan at larger masses [11] and of open-charm production [4] suggest that there may be little or no change in the cross section per nucleon for the continuum pairs between light and heavy nuclei.

We have also analyzed the ϕ with tighter cuts to obtain a much better mass resolution in order to check for any mass shift between light and heavy nuclei. Initial results over the covered kinematic range indicate a mass shift between beryllium and tungsten targets of 6 MeV or less.

Acknowledgments

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