J/ψ and ψ' Suppression in p-A Collisions at 800 GeV/c

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Strong suppression of the yield per nucleon of heavy vector mesons produced in heavy nuclei relative to light nuclei has been observed in proton and pion-nucleus collisions [1,2]. Similar suppression has also been observed in heavy-ion collisions [3]. The kinematic dependencies are strong, especially with Feynman-x (x_F) and transverse momentum (p_T), and broad coverage in these kinematic variables is essential towards unraveling the sources of the suppression. Since suppression of vector mesons in heavy-ion collisions is predicted to be an important signature for the formation of the quark-gluon plasma, it is important to understand all the mechanisms that already contribute in the absence of a quark-gluon plasma as seen in proton-nucleus collisions. Also important in understanding these mechanisms is to contrast suppression of vector meson production with similar studies of the Drell-Yan process and open charm production. In the Drell-Yan process shadowing, energy loss and multiple scattering in the initial state should play a role but no final-state effects should enter. However open-charm production should be similar to vector meson production except that absorption mechanisms in the final state should be much weaker. Finally, comparisons of J/ψ and ψ' suppression, especially at small or negative x_F should yield information about the formation time of these resonances.

Here we report measurements made in Fermilab E866/NuSea of the nuclear dependence of J/ψ and ψ' production for proton-nucleus collisions on Be, Fe, and W targets over broad ranges in the kinematic variables. Over three million J/ψ's and 100,000 ψ''s with x_F between -0.15 and 0.95 and p_T up to 4 GeV/c were observed. Previous measurements in E772 [1] and E789 [4] have suffered from limited p_T acceptance and limited statistics at larger values of x_F, both of which are improved dramatically in this new data.

E866/NuSea uses a 3-dipole magnet pair spectrometer employed in previous experiments (E605[5], E772, and E789), modified by the addition of new drift chambers and hodoscopes with larger acceptance at the first tracking chamber and a new trigger sys-

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tem [6]. This spectrometer was also used for other measurements in E866/NuSea [7,8]. An 800 GeV/c extracted proton beam of up to 2×10^{12} protons per 20 s spill bombarded solid targets of Be, Fe, and W with thicknesses between 3 and 19% of an interaction length. The remaining beam was absorbed in a copper beam dump located inside the large second magnet. Following the beam dump was a 13.4 interaction length absorber wall which filled the entire aperture of the magnet, eliminated hadrons, and assured that only muons were tracked through a series of detector stations composed of drift chambers and hodoscopes.

Two magnetic field settings were used to span the full range in x_F, small-x_F (SXF) and large-x_F (LXF). Detailed Monte Carlo simulation of the J/ψ and ψ' peaks and of the Drell-Yan continuum were used to generate lineshapes which were used to fit the mass spectra for each bin in x_F and p_T. A maximum-likelihood method was used that takes into account the statistics of both the data and the Monte Carlo shapes[9]. In addition, a detailed construction of random muon pairs using single-muon events was used to account for the smooth random background underneath the peaks.

We present our results in terms of α, where α is obtained by fitting the cross section dependence on nuclear mass, A, to the form $\sigma_A = \sigma_p \times A^{\alpha}$. Figure 1 shows the α values obtained from our measurements versus p_T for the J/ψ and ψ' for both the small- and the large-x_F parts of the data. The same characteristic increase of α due to multiple scattering with p_T is seen for the J/ψ and ψ' in both x_F ranges.

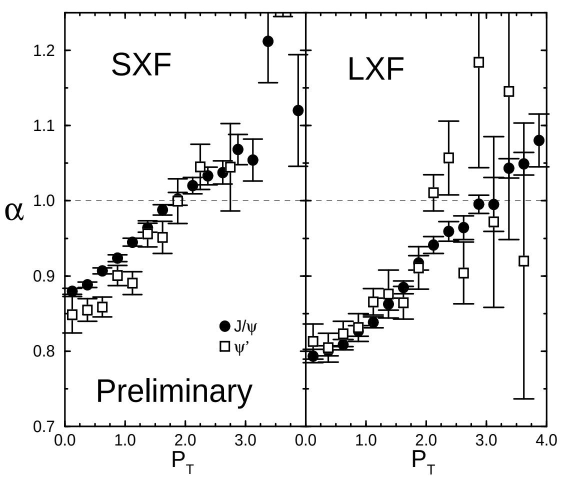

Figure 1. α versus p_T for J/ψ and ψ' production by 800 GeV/c protons. Results are shown for $-0.15 \leq x_F \leq 0.3$ (SXF) and $0.3 \leq x_F \leq 0.95$ (LXF).

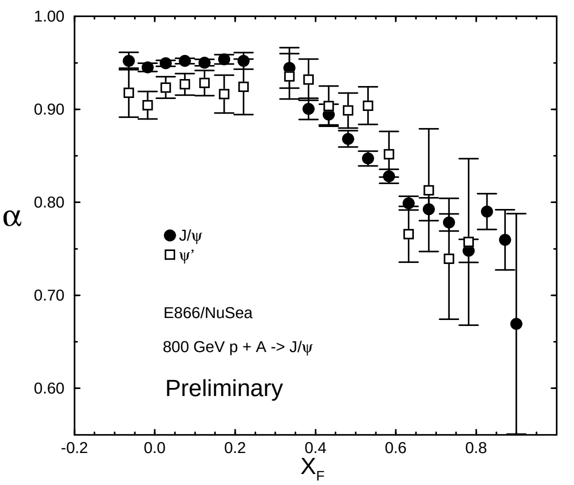

Figure 2. α versus x_F for J/ψ and ψ' production by 800 GeV/c protons. Values are corrected for the p_T acceptance, as discussed in the text.

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/NuSea, because of improvements in the trigger, our acceptance is much broader than in the earlier measurements. However, at the lowest values of x_F for each spectrometer setting, our p_T acceptance still narrows somewhat. For the results presented here we have corrected the values of α using a detailed simulation of our acceptance and a differential cross section shape versus p_T derived from our data.

The resulting dependence of α on x_F is shown in Fig. 2. The J/ψ experiences its weakest suppression at values of x_F of 0.2 and below but has strongly increasing suppression at larger values of x_F. The ψ' experiences the same suppression for positive values of x_F above about 0.2 but shows somewhat more suppression than the J/ψ at lower values of x_F. At smaller values of x_F the nascent $c\bar{c}$ pair is going much slower and may tend to hadronize more readily while still in the nucleus. If this is so, then since the ψ' has a larger size and smaller binding energy than the J/ψ, it would naturally be absorbed more strongly. On the other hand, for the $c\bar{c}$ pairs that are at larger x_F, they would experience the same absorption, whether they eventually become (outside the nucleus) a J/ψ or a ψ'. This absorption is thought of as just a dissociation of the nascent $c\bar{c}$ that would otherwise have hadronized into a J/ψ or ψ' by interactions with the nucleus or with comovers[10]. Comparison of these results with the lack of suppression seen for D mesons[11], where this dissociation mechanism is not available, support this picture.

Another critical issue in understanding the absorption is whether the initial $c\bar{c}$ object is formed in a color-octet or -singlet state[12]. If it is formed in a colored state then its interactions will be much stronger and should yield both stronger absorption and stronger multiple-scattering and energy-loss effects. Also if the octet state emits a gluon and becomes a singlet state after a color-neutralization time then the lifetime of the octet state and thus the amount of absorption would increase with x_F since the lifetime in the laboratory frame would increase due to Lorenz dilation at larger x_F values[13]. Shadowing of the initial gluon distributions is also thought to play a role in the observed suppression, but current estimates[14,10] only predict a few percent drop in α due to shadowing at the larger x_F values. Potentially more important is the energy-loss of the $c\bar{c}$ as it exits the nucleus.

A comparison of our results with earlier results from E772's previous measurements at 800 GeV/c[1] and also with NA3's measurements at 200 GeV/c[16] is shown in Figs. 3 and 4 and illustrates that the bulk of the suppression seen for J/ψ production scales with x_F and not with x_2. This means that we should not look for explanations of this suppression from effects which are properties of the initial parton distributions, e.g. structure function modifications in nuclei such as shadowing. Rather, we should look for the source of the suppression in effects such as absorption, energy-loss, and multiple scattering as discussed above.

In conclusion, we have presented new data for the suppression of J/ψ and ψ' production in heavy versus light nuclei for 800 GeV/c proton-nucleus collisions which surpasses that of previous experiments in kinematic range and statistics. The smallest suppression, corresponding to $\alpha = 0.95$, is seen at about $x_F = 0.2$ with nearly constant suppression for smaller values of x_F but strongly increasing suppression for larger x_F. For $x_F > 0.2$ the ψ' and J/ψ are equally suppressed, but for smaller values of x_F the ψ' is suppressed more strongly. The dominant source of the observed suppression is probably absorption. For smaller x_F values, where the resonance may start to become physical within the nucleus, the ψ' may be absorbed more strongly due to its larger size and smaller binding energy compared to the J/ψ. At larger values of x_F the resonances pass through the nucleus as $c\bar{c}$ states and are absorbed equally. The strongly increasing suppression towards large x_F may be caused by some combination of shadowing, parton energy loss, and color neutralization times for produced color-octet $c\bar{c}$ states.

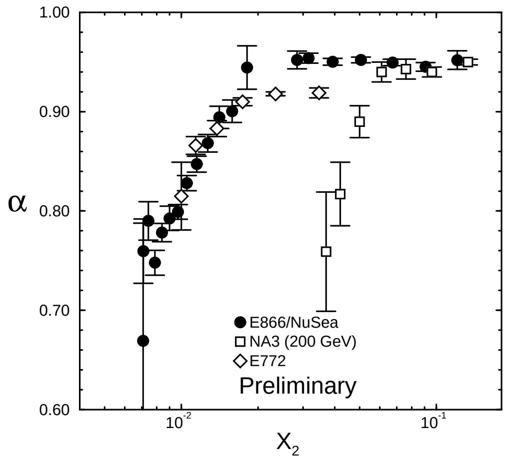

Figure 3. α versus x_2 for J/ψ from E866/NuSea (800 GeV/c) compared to E772 and NA3 (200 GeV/c) showing the non-scaling of the suppression versus x_2.

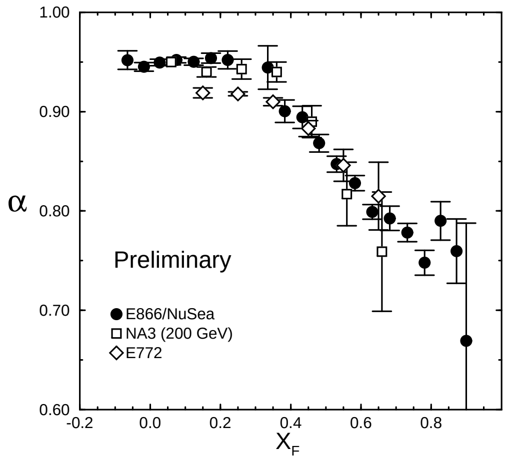

Figure 4. α versus x_F for J/ψ from E866/NuSea (800 GeV/c) compared to E772 and NA3 (200 GeV/c) showing the scaling versus x_F.

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