PHYSICAL REVIEW D VOLUME 52, NUMBER 7 1 OCTOBER 1995

Nuclear dependence of J/ψ production by 800 GeV/c protons near $x_F = 0$

M. J. Leitch,[1] C. N. Brown,[2] T. A. Carey,[1] R. Childers,[3] W. E. Cooper,[2] C. W. Darden,[3] G. Gidal,[4] K. N. Gounder,[2,*] L. D. Isenhower,[5] D. M. Jansen,[1] R. G. Jeppesen,[1,†] D. M. Kaplan,[6,‡] J. S. Kapustinsky,[1] M. S. Kowitt,[4,§] D. W. Lane,[1,||] L. M. Lederman,[7,‡] J. W. Lillberg,[1] K. B. Luk,[4] V. M. Martin,[6,¶] P. L. McGaughey,[1] C. S. Mishra,[2] J. M. Moss,[1] J. C. Peng,[1] R. S. Preston,[6] J. Sa,[6] M. E. Sadler,[5] R. Schnathorst,[5,**] M. H. Schub,[7,††] V. Tanikella,[6] and P. K. Teng

[1] *Los Alamos National Laboratory, Los Alamos, New Mexico 87545*
[2] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[3] *University of South Carolina, Columbia, South Carolina 29208*
[4] *Lawrence Berkeley Laboratory and University of California, Berkeley, California 94720*
[5] *Abilene Christian University, Abilene, Texas 79699*
[6] *Northern Illinois University, DeKalb, Illinois 60115*
[7] *University of Chicago, Chicago, Illinois 60637*
[8] *Institute of Physics, Academia Sinica, Taipei, Taiwan*

(Received 17 March 1995)

The nuclear dependence for 800 GeV/c proton production of J/ψ's has been measured near $x_F = 0$. J/ψ's produced from beryllium, carbon, and tungsten targets were detected with the Fermilab E789 pair spectrometer. These data extend the results from E772 down to the range $x_F = -0.1$ to 0.1 and indicate a gradually increasing suppression as x_F falls below zero.

PACS number(s): 13.85.Ni, 14.40.Gx, 24.85.+p

A strong suppression of the production of heavy vector mesons in proton-nucleus collisions has been observed in heavy nuclei relative to light nuclei [1–5]. In heavy-ion collisions, a similar suppression is seen when comparing central to peripheral collisions [6]. A number of mechanisms for this suppression have been advanced including modification of the gluon structure functions in nuclei and dynamical effects such as multiple scattering and energy loss in the initial state or dissociation in the final state [7–12]. In order to obtain a clearer picture of these effects and determine which are most important, measurements are needed for various processes over a broad range of Feynman-x (x_F) and momentum fraction of the target parton (x_{target}) [13], since each mechanism should be most important in certain regions of kinematic space and for certain reactions. The effect of dissociation or absorption of the produced heavy-quark system by the nucleus or by comoving light partons should be most important near $x_F = 0$ and below, where the heavy-quark pairs which will form the vector mesons are moving more slowly and therefore have more chance to be dissociated. Recent results on open charm production near $x_F = 0$ [14], where this kind of absorption would be absent, have shown no nuclear dependence. This suggests that absorption may be the dominant cause of the J/ψ suppression at small x_F seen in E772 [1]. Here we report measurements from E789 for the nuclear dependence of J/ψ production at x_F values below those of E772, down to -0.1.

The measurements were made using the small-aperture pair spectrometer in the Fermilab Meson East beam line which has been described previously [1,2,14–17]. Useful acceptance for $J/\psi \to \mu^+\mu^-$ was obtained for x_F between -0.1 and 0.1. A rotating wheel of targets was placed 1.27 meters downstream of the usual target position in order to increase the acceptance near $x_F = 0$. The targets were 7.3-cm-diameter solid disks with thicknesses of 2.433 cm for beryllium, 2.032 cm for carbon, and 0.298 cm for tungsten. Target out measurements were used to check for backgrounds not originating in the target. A total per nucleon luminosity of about 0.15 pb^{-1} was accumulated alternating among these targets. The relative beam flux normalization was obtained from an ion chamber and a secondary-emission monitor upstream of the targets.

Dimuon mass spectra obtained for the three targets, integrated over x_F and p_T, are shown in Fig. 1. A clear peak is evident at the J/ψ mass of 3.097 GeV/c^2. The mass spectra binned in x_F and p_T were fitted by an

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*Present address: Department of Physics, University of Mississippi, University, MI 38677.

†Present address: Science Applications International Corp., 2950 Patrick Henry Drive, Santa Clara, CA 95054.

‡Present address: Department of Physics, Illinois Institute of Technology, Chicago, IL 60616.

§Present address: NASA/Goddard Space Flight Center, Greenbelt, MD 20771.

||Present address: Department of Physics, Iowa State University, Ames, IA 50011.

¶Present address: Department of Electrical Engineering and Computer Science, University of Illinois at Chicago, Chicago, IL 60607.

**Present address: Department of Physics, Purdue University, Lafayette, IN 47907.

††Present address: School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455.

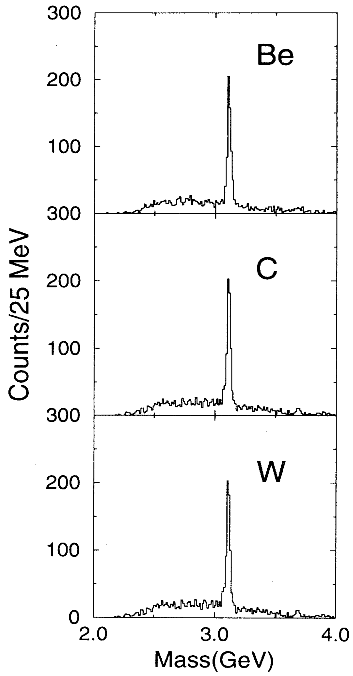

FIG. 1. Dimuon mass spectra for the three nuclear targets integrated over the other kinematic variables (not corrected for acceptance).

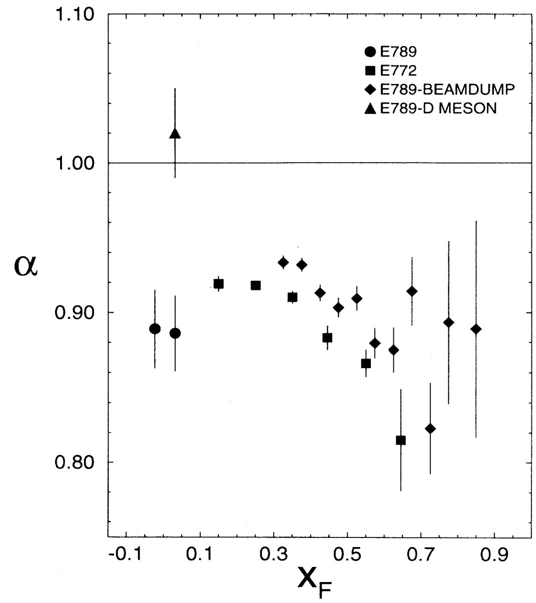

FIG. 2. x_F dependence of α for 800 GeV/c proton production of J/ψ's from this experiment (circles) compared to that from E772 [1] (squares). Also shown are the data from E789 for large x_F J/ψ's [2] (diamonds) and for neutral D production [14] (triangle).

asymmetric Gaussian plus a polynomial background to obtain the number of J/ψ's in each bin. The x_F- and p_T-dependent ratios of cross section per nucleon were obtained using the relative beam on each target, the target thicknesses, and the observed yields. Uncertainties are completely dominated by the J/ψ statistics. Since the singles rates in the tracking detectors were nearly identical for the three targets, no rate dependent corrections were necessary. Using the form $\sigma \propto A^{\alpha}$, where σ is the cross section and A is the nucleon number, the parameter α was obtained from a fit to the beryllium, carbon, and tungsten data points for bins in x_F, x_{target}, and p_T. The results are shown in Table I and in Figs. 2 and 3, along with previous results from E772 and E789.

The only previous J/ψ measurements in this region of x_F are for a π^- beam at 39.5 GeV/c with the Omega spectrometer [18]. Those measurements have uncertainties that are about a factor of 2 larger than ours. Although the pion data show an overall suppression that is less than observed in the present measurements, they do show a similar trend of increasing suppression with smaller x_F.

The x_F dependence of α for J/ψ production is shown in Fig. 2. The measurements of α reported here lie at values of x_F well below those of E772, and show an increasing suppression as x_F falls below 0.10. This trend is also

TABLE I. Dependence of α and R for J/ψ production on x_F, x_{target}, and p_T.

$\langle x_F \rangle$	R(C/Be)	R(W/Be)	α
-0.023	0.879±0.057	0.686±0.047	0.889±0.026
0.032	0.881±0.041	0.684±0.041	0.886±0.025
$\langle x_{\mathrm{target}} \rangle$			
0.061	0.947±0.055	0.717±0.043	0.893±0.019
0.086	0.842±0.043	0.659±0.035	0.880±0.019
$\langle p_T \rangle$ (GeV/c)			
0.16	0.782±0.081	0.743±0.074	0.932±0.026
0.40	0.929±0.044	0.725±0.038	0.903±0.013
0.77	0.928±0.063	0.709±0.050	0.890±0.018

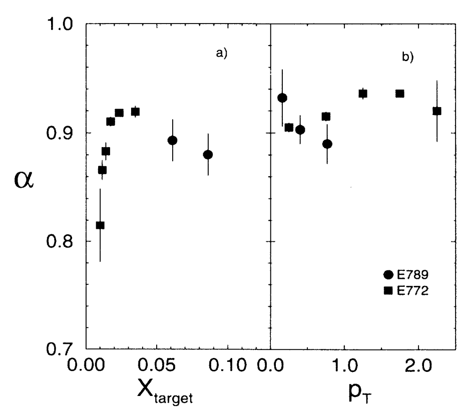

FIG. 3. x_{target} and p_T dependences of α for 800 GeV/c proton production of J/ψ's from this experiment (circles) compared to that from E772 (squares).

similar to that seen previously for the Υ [19]. The x_{target} dependence of our measurements, shown in Fig. 3(a), is consistent with that of E772 and shows a gradual falloff with larger x_{target}. The x_{target} range of our data, 0.05 to 0.09, is well above that of the earlier measurements and above the strongest part of the shadowing region [20]. The p_T distribution of α, shown in Fig. 3(b), is also consistent with the earlier measurements. Although our results suffer from low statistics relative to those of E772, they are adequate to indicate the increasing suppression at low x_F.

There is no generally accepted explanation for the nuclear dependence of J/ψ production. The increasing suppression of J/ψ production at negative x_F seen in these data may be explained qualitatively by dissociation effects from the comoving light partons [7], e.g., where the $c\bar{c}$ pair is dissociated into an open-charm pair ($D\bar{D}$) before it can form a J/ψ. This is also consistent with the linear nuclear dependence for D mesons [14] shown in Fig. 2, since a D would not experience these dissociation effects. The region of x_{target} covered by these data is probably too high for significant effects from shadowing [20] and is probably too low for the usual European Muon Collaboration (EMC) effects seen at larger x_{target} [20]. Initial state energy loss effects [10] would produce an opposite trend to that seen in these data, and an intrinsic charm effect [8], if any, is predicted to be important only at large x_F.

This work was supported by the U.S. Department of Energy and the National Science Foundation. K.B.L. was partially supported by the DOE OJI program and the Alfred P. Sloan Foundation. P.K.T. was supported by the National Science Council of the Republic of China. We thank the Fermilab staff for their support.

[1] D. M. Alde *et al.*, Phys. Rev. Lett. **66**, 133 (1991).
[2] M. S. Kowitt *et al.*, Phys. Rev. Lett. **72**, 1318 (1994).
[3] S. Kartik *et al.*, Phys. Rev. D **41**, 1 (1990).
[4] S. Katsanevas *et al.*, Phys. Rev. Lett. **60**, 2121 (1988).
[5] J. Badier *et al.*, Z. Phys. C **20**, 101 (1983).
[6] C. Baglin *et al.*, Phys. Lett. B **220**, 471 (1989); **255**, 459 (1991); *ibid.* **270**, 105 (1991).
[7] R. Vogt, S. J. Brodsky, and P. Hoyer, Nucl. Phys. **B360**, 67 (1991); **B383**, 643 (1992).
[8] Stanley J. Brodsky and Paul Hoyer, Phys. Rev. Lett. **63**, 1566 (1989).
[9] S. Gavin and R. Vogt, Nucl. Phys. **B345**, 104 (1990).
[10] S. Gavin and J. Milana, Brookhaven preprint BNL-46793 (unpublished).
[11] J.-P. Blaizot and J.-Y. Ollitrault, Phys. Lett. B **217**, 386 (1989).
[12] C. Gerschel and J. Hufner, Phys. Lett. B **207**, 253 (1988).
[13] See Ref. [1] for a more detailed discussion and definition of x_{target} (there called x_2).
[14] M. J. Leitch *et al.*, Phys. Rev. Lett. **72**, 2542 (1994).
[15] D. M. Alde *et al.*, Phys. Rev. Lett. **64**, 2479 (1990); P. L. McGaughey *et al.*, Phys. Rev. D **50**, 3038 (1994).
[16] J. A. Crittenden *et al.*, Phys. Rev. D **34**, 2584 (1986); G. Moreno *et al.*, *ibid.* **43**, 2815 (1991), and references therein.
[17] D. M. Jansen *et al.*, Phys. Rev. Lett. **74**, 3118 (1995).
[18] M. J. Corden *et al.*, Phys. Lett. **110B**, 415 (1982).
[19] D. M. Alde *et al.*, Phys. Rev. Lett. **66**, 2285 (1991).
[20] J. Ashman *et al.*, Phys. Lett. B **202**, 603 (1988).