Fermi National Accelerator Laboratory

FERMILAB-Pub-87/57-E
[E-537]

Nuclear Target Effects in J/ψ Production in 125 GeV/c Antiproton and π^- Interactions*

S. Katsanevas, C. Kourkoumelis, A. Markou,
L. K. Resvanis, S. Tzamarias[1], G. Voulgaris
University of Athens
Athens, Greece

M. Binkley, B. Cox, J. Enagonio[2], C. Hojvat, D. Judd[3],
R. D. Kephart, P. K. Malhotra[4], P. O. Mazur, C. T. Murphy
F. Turkot, R. L. Wagner, D. E. Wagoner[3], W. Yang
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

H. Areti[5], S. Conetti, P. Lebrun[5], D. Ryan
T. Ryan[6], W. Schappert[7], D. G. Stairs
McGill University
Montreal, H3A 2T8, Canada

C. Akerlof, P. Kraushaar[8], D. Nitz, R. Thun
University of Michigan
Ann Arbor, Michigan 48109

He Mao, Zhang Nai-jian
Shandong University
Jinan, PRC

November 1987

*Submitted to Phys. Rev. Lett.

Operated by Universities Research Association Inc. under contract with the United States Department of Energy

Nuclear Target Effects in J/ψ Production in 125 GeV/c Antiproton and π^- Interactions

S. Katsanevas, C. Kourkoumelis, A. Markou,
L.K. Resvanis, S. Tzamarias[1] , G. Voulgaris,
University of Athens, Athens, Greece

M. Binkley, B. Cox, J. Enagonio[2], C. Hojvat, D. Judd[3],
R.D. Kephart, P.K. Malhotra[4] , P.O. Mazur, C.T. Murphy,
F. Turkot, R.L. Wagner, D.E. Wagoner[3], W. Yang
Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*

H. Areti[5], S. Conetti, P. Lebrun[5], D. Ryan,
T. Ryan[6], W. Schappert[7], D.G. Stairs
McGill University, Montreal, H3A 2T8, Canada

C. Akerlof, P. Kraushaar[8], D. Nitz, R. Thun
University of Michigan, Ann Arbor, Michigan 48109, USA

He Mao, Zhang Nai-jian
Shandong University, Jinan, PRC
November, 1987

Abstract

The production of the J/ψ resonance in 125 GeV/c $\bar{p}$ and π^- interactions with Be, Cu and W targets has been measured. The cross section per nucleon for J/ψ production is suppressed in W interactions relative to the cross sections measured with lighter targets. This effect, which is especially pronounced for $x_F > 0.5$, is opposite to the one expected from the various explanations of the EMC effect observed in deep inelastic lepton scattering. Models incorporating modifications of the gluon structure functions in heavy targets show qualitative agreement with the data.

*Operated by Universities Research Association Inc. under contract with the United States Department of Energy.

Heavy target effects observed in deep inelastic scattering of electrons and muons from heavy nuclei[1,2] have been interpreted to be due to the distortions of the free nucleon quark structure functions by the presence of neighboring nucleons in the target nucleus. The production of the J/ψ resonance, in contrast to deep inelastic lepton scattering, should have a large component which proceeds via the interactions of gluons[3,15]. Observation of heavy target effects in J/ψ production offers the opportunity to infer modifications of the gluon structure function in heavy targets in a manner analogous to the inference of the quark structure function distortions from deep inelastic lepton scattering measurements. In this paper we report the comparison of the production of J/ψ in 125 GeV/c $\bar{p}$ and π^- interactions with beryllium, copper and tungsten targets and the interpretation of the observed heavy target effects.

We have previously reported[4] the measurement of the production of high mass muon pairs ($M > 4.0 GeV/c^2$) by 125 GeV/c $\pi^- W$ and $\bar{p}\, W$ interactions in a dimuon spectrometer[5] in the High Intensity Laboratory of the Fermi National Accelerator Laboratory in Experiment E537. During this experiment, we also measured J/ψ production using the two beams and beryllium, copper and tungsten targets. Table I gives the cross sections ($x_F > 0$) measured for the various combinations of beam and targets.

All data reported in this paper have been corrected for background, acceptances, detector and trigger inefficiencies, multiple interactions in the target and Fermi motion of the target nucleons[6]. In addition, ψ' production was determined to be 2.0±0.3% and 2.6±0.2% of the J/ψ production for the $\bar{p}\, W$ and $\pi^- W$ interactions respectively and was excluded from the J/ψ signal. Fitting the A dependence of the cross section to:

$$\sigma_A \ = \ \sigma_N A^\alpha \tag{1}$$

for these three targets yields $\alpha(\pi^-)$=0.87±0.02 and $\alpha(\bar{p})$=0.90±0.03. Fig. 1 shows the data from this experiment and the appropriately scaled[7] (with $\exp[-10\sqrt{\tau}], \tau = M^2/s$) H_2 and Pt target data from NA3[8] together with the results of the fit to (1). The A dependence form given by (1) is clearly not adequate to describe the variation of the cross section for J/ψ production by π^- as a function of atomic number. We have fitted the A dependence of the π^- production cross section with the simple polynomial form:

$$\sigma/A \ = \ (a \ + \ b\ A) \tag{2}$$

and obtain a = 63.17 ± 2.0 and b = -0.110 ± 0.01 for $\chi^2/DF = 0.53$. This fit is also shown in Figure 1 for the π^- data and, scaled down by 0.834, for the $\bar{p}$ data.

To further investigate the source of the heavy target effects, we have studied the A dependence of the J/ψ cross sections as a function of x_F and p_t. We have formed the ratios

$$R_1(x_F : beam, A_1/A_2) \ = \ \frac{\frac{1}{A_1}\frac{d\sigma}{dx_F}\Big|_{A_1}}{\frac{1}{A_2}\frac{d\sigma}{dx_F}\Big|_{A_2}}; \ R_2(p_t : beam, A_1/A_2) \ = \ \frac{\frac{1}{A_1}\frac{d\sigma}{dp_t}\Big|_{A_1}}{\frac{1}{A_2}\frac{d\sigma}{dp_t}\Big|_{A_2}} \tag{3}$$

for our W/Be and W/Cu data for both π^- and $\bar{p}$ interactions (or equivalently in terms of $x_2 = \frac{1}{2}[-x_F(1-\tau) + \sqrt{x_F^2(1-\tau)^2 + 4\tau}]$). In these ratios systematic effects such as uncertainties in acceptances approximately cancel. $R_1(x_F : \pi^-, W/Be)$ and $R_1(x_F : \bar{p}, W/Be)$ are shown in Fig. 2a while $R_2(p_t : \pi^-, W/Be)$ and $R_2(p_t : \bar{p}, W/Be)$ are shown in Fig. 2b. We observe that the heavy target effects in J/ψ production vary with x_F and p_t. In both cases the heavier target is seen to be overall less efficient per nucleon in the production of J/ψ's.

The ratio R_1 for the pion data shows a decrease in the production of J/ψ's at high x_F for the tungsten target relative to the beryllium target and the same trend is seen in the lower statistics $\bar{p}$ data. Similar trends have been seen in the measurements of J/ψ production in π^- and p interactions with nuclear targets by other experiments[8,9]. The R_2 ratio shows a suppression of J/ψ production at low p_t in both $\pi^- W$ and $\bar{p}\,W$ interactions relative to $\pi^- Be$ and $\bar{p}Be$ interactions. The suppression at low p_t is almost identical for $\bar{p}$'s and π^-'s in our data.

We have examined our data for possible correlations of the heavy target effects in the x_F and p_t spectra. When $R_1(\pi^-, W/Be)$ is determined for low (p_t <1.2 GeV/c) and high (1.2< p_t <3.0 GeV/c) p_t regions, the value of the ratio is the smallest in the low p_t region, see Fig. 3a. When $R_2(\pi^-, W/Be)$ is calculated for two different x_F regions (0.0< x_F <0.3 and 0.3< x_F <1.0) both the absolute value of this ratio and the shape of the distribution are observed not to depend on the x_F region (Fig. 3b). Therefore, the decreased effectiveness per nucleon of the heavy target in producing J/ψ seems to be preferentially present in the low p_t region of J/ψ production.

Finally, our Cu data allows us to investigate in a modest way the dependence of R_1 on the nucleus by comparing the production of J/ψ in $\pi^- W$ to the production in both $\pi^- Cu$ and $\pi^- Be$ interactions. The two ratios, $R_1(\pi^-, W/Cu)$ and $R_1(\pi^-, W/Be)$ are shown in Fig. 4. While the statistical significance of the differences is limited, the ratio $R_1(\pi^-, W/Be)$ is systematically lower than $R_1(\pi^-, W/Cu)$ (in agreement with the total J/ψ production cross section) but the shape of the variation of R_1 with x_F seems quite similar for the W/Be and the W/Cu ratios.

Several mechanisms have been proposed to explain the observation of the difference in the deep inelastic nucleon quark structure function, $F_2(x_2, Q^2)$, measured using Fe and D_2 targets. Among the proposed mechanisms are: rescaling of nuclear confinement sizes[10], an increased soft pion cloud[11], and six quark clustering[12] in heavy nuclei. These mechanisms cause the momentum distribution of the quarks to have a significantly softer component than the free nucleon structure functions. In comparing these "EMC effect" models to our $\pi^- N \to J/\psi$ data, we have assumed that J/ψ production proceeds via gg and qq fusion in the Semi-Local Duality Model[13]. We have used the free nucleon structure functions of Duke and Owens (set 1)[14] and nuclear gluon structure functions derived from our own

$\bar{p}\,W \rightarrow J/\psi$ data[15]. The gluon structure function for the π^- was also derived from our $\pi^- W$ data[15]. For the purpose of these comparisons with "EMC" models, we have assumed no nuclear dependence in the gluon structure functions.

These models are compared in Fig. 5 with the ratio $R_1(\pi^-, W/Be)$ derived from our data. Each of these quarks mechanisms would cause J/ψ production to be more copious from heavy targets at large x_F by softening the quark momentum distribution in the target (the x_2 distribution) thereby allowing larger $x_F \sim x_1 - x_2$ to become more probable. As the data show, if these "EMC" type effects are indeed present, they are masked by a much stronger effect since the yield of J/ψ from heavy targets is actually seen to decrease at high x_F. Thus, it does not seem that EMC type distortions of the quark structure functions can cause the observed behavior of our data.

Because J/ψ production is thought to contain large contributions due to gluon fusion, it is natural to turn to the gluon distribution as a possible source of the heavy target effects observed in our data. Two mechanisms have been proposed which can modify in heavy targets the gluon distributions which moderate J/ψ production. The mechanism of Ref. 16 suggests that a significant portion of the J/ψ production proceeds via three gluon fusion. In heavy targets the three gluon mechanism would be significantly enhanced because of the increased probability of finding, in the target, such an extra gluon. This mechanism would serve to produce an effective gluon momentum distribution due to the combination of the two target gluons that is much harder than the single gluon momentum distribution. This harder component is reflected in a decrease at large x_F of J/ψ production. The second mechanism is the nuclear shadowing model[17] where the soft gluon component of a nucleon in a heavy nucleus is considerably depleted by their absorption by the other nucleons.

Another mechanism, the rescattering model[18], which may cause heavy target effects is the scattering by a neighboring nucleon of the beam pion or nucleon before the production of the J/ψ takes place, or scattering of the J/ψ itself after production. This process would significantly decrease the number of J/ψ at high x_F. Scattering of the J/ψ appears to be the most likely since initial state scattering is not observed in Drell-Yan production[19].

Calculations of the effects of these three mechanisms (with the Semi-Local Duality Model of Ref. 13 used for the basic J/ψ production mechanism for the rescattering and shadowing calculations, and the modified structure functions from the shadowing model[17]) are also shown in Fig. 5. As can be seen, they all predict an overall decrease in the production of J/ψ per nucleon in W relative to Be and, in particular, a decrease in R_1 at high x_F. In addition, the three gluon fusion and the rescattering models suggest that the magnitude of this effect will be more pronounced in the low p_t part of the J/ψ cross section. This is a result of the colinearity requirement for gluon fusion and of the broadening of the p_t distribution in the case of rescattering. These predictions are in qualitative agreement with our observations of the variation of $R_1(\pi^-, W/Be)$ on x_F, the dependence of the magnitude of $R_1(\pi^-, W/Be)$ on the p_t region and the comparison of $R_1(\pi^-, W/Be)$ to $R_1(\pi^-, W/Cu)$.

In conclusion, we have observed heavy target effects in the production of J/ψ resonance which are much larger and in a different direction from any EMC type effects that we might expect. There is an overall suppression of J/ψ production per nucleon in both $\pi^- W$ and $\bar{p}\ W$ interactions relative to $\pi^- Be$ and $\bar{p}\ Be$ interactions. The A dependence of the total cross section does not appear to follow the simple form $\sigma_A = \sigma_N A^\alpha$. When we examine the x_F dependence of J/ψ production we find an overall suppresion for heavy targets that becomes more pronounced for $x_F > 0.5$. In addition, we find that the production of J/ψ's at low p_t is suppressed in W relative to Be, with the effect diminishing towards higher p_t. Similar trends are observed in these heavy target effects for $\bar{p}$ as for π^- production of J/ψ's. These observations are difficult to explain in the context of the standard explanations of the EMC effect which rely on distortions of the quark structure functions in heavy nuclei. We can find qualitative explanations of these effects using models of J/ψ production which modify the distributions of the interacting gluons in such a way as to either harden the gluon distributions of the target nucleon or soften the gluon distributions of the beam particles. Alternately, rescattering of the J/ψ may also provide an explanation for the observed effects.

This work was performed at Fermi National Accelerator Laboratory and supported by the U.S. Department of Energy, the North Atlantic Treaty Organization Scientific Affairs Division, the International Programs and High Energy Physics Divisions of the National Science Foundation, the Natural Sciences and Engineering Research Council of Canada, the Quebec Department of Education, and the Hellenic Science and Technology Agency.

Authors Footnotes

[1]Present address: Northwestern University, Evanston, Illinois
[2]Present address: University of Colorado, Boulder, Colorado
[3]Present address: Prairie View A&M University, Prairie View, Texas
[4]Permanent address: Tata Institute, Bombay, India
[5]Present address: Fermilab, Batavia, Illinois
[6]Present address: Cornell University, Ithaca, New York
[7]Present address: University of Chicago, Chicago, Illinois
[8]Present address: Shell Oil, Houston, Texas

References

1. J.J. Aubert *et al.*, Phys. Lett. 123B, 275 (1983).

2. A. Bodek *et al.*, Phys. Rev. Lett. 50, 1431 (1983) and 51, 534 (1983); R.G. Arnold *et al.*, Phys. Rev. Lett. 52, 727 (1984).

3. C.H. Chang, Nucl. Phys. B172, 425 (1980); R. Baier and R. Ruckl, Z. Phys. C19, 251 (1983); B. Cox, Proceedings of the XXI International Conference on High Energy Physics, Paris, edited by P. Petiau and M. Pornuef, J. Physique 43, Suppl. C-3, (1982).

4. E. Anassontzis *et al.*, Phys. Rev. Lett. 54, 2572 (1985).

5. E. Anassontzis *et al.*, Nuclear Instr. and Methods A242, 215 (1986).

6. E. Anassontzis *et al.*, (to be published).

7. L. Lyons, Prog. Part. Nucl. Phys. 7, 169 (1981).

8. J. Badier *et al.*, Z. Phys. C20, 101 (1983).

9. Antipov *et al.*, Phys. Lett. 72B, 278 (1977), Phys. Lett. 76B, 235 (1978); M.J. Corden *et al.*, Phys. Lett. 110B, 415 (1982); K.J. Anderson *et al.*, Phys. Rev. Lett. 42, 944 (1979).

10. F.E. Close, R.G. Roberts and G.G. Ross, Phys. Lett. 129B, 346 (1983); R.L. Jaffe, F.E. Close, R.G. Roberts and G.G. Ross, Phys. Lett. 134B, 449 (1984).

11. C.H. Llewellyn-Smith, Phys. Lett. 128B, 107 (1983); M. Ericson and A.W. Thomas, ibid. 128B, 112 (1983); E.L. Berger, F. Coester and R.B. Wiringa, Phys. Rev. D29, 398 (1984).

12. R.J. Jaffe, Phys. Rev. Lett. 50, 228 (1983); C.E. Carlson and T.J. Havens, Phys. Rev. Lett. 51, 261 (1983).

13. V. Barger, W.Y. Keung and R.J.N. Phillips, Z. Phys. C6, 169 (1980).

14. D.W. Duke and J.F. Owens, Phys. Rev. D30, 49 (1984).

15. S. Tzamarias *et al.,* (to be published).

16. L. Clavelli, P.H. Cox, B. Harms and S. Jones, Phys. Rev. D32, 612 (1985).

17. J. Qiu, Nuc. Phys. B291, 746 (1987).

18. B.Z. Kopeliovich and F. Niedermayer, JINR-E2-84-834, Dubna (1984).

19. I. R. Kenyon, Rep. Prog. Phys. 45, 1261 (1982).

Table I.
Total Cross Sections ($x_F > 0$) for J/ψ Production from
Be, Cu and W at 125 GeV/c (nbarns per nucleus)*

Target Beam	Be	Cu	W
π^-	560±18 (2881)	3610±112 (1958)	7900±63 (33820)
$\bar{p}$	462±18 (588)	2820±110 (529)	6900±89 (12530)

*Errors are statistical and include background subtraction.
The number of J/ψ's in each data sample is given in () following the cross sections. Systematic errors are ±6% on all cross sections.

Figure Captions

Figure 1:

Total J/ψ production cross section ($x_F > 0$) divided by the atomic weight (A) vs. A for 125 GeV/c π^- and $\bar{p}$ interactions on Be, Cu and W targets. Also shown is the average of the NA3 150, 200 and 280 GeV/c $\pi^- H_2$ and $\pi^- Pt$ J/ψ production cross sections[8] extrapolated to 125 GeV/c (see text). The solid lines are fits to the E537 data of the form $\sigma = \sigma_N A^\alpha$ with $\alpha = 0.87$ for π^- and $\alpha = 0.90$ for $\bar{p}$ data. The dotted lines are a polynomial fit to the π^- data (see text), also shown scaled by 0.834 for the $\bar{p}$ data.

Figure 2a:

The ratio $d\sigma/dx_F$ for J/ψ production in $\pi^- W$ and $\bar{p}\,W$ to $\pi^- Be$ and $\bar{p}\,Be$ interactions at 125 GeV/c, as a function of x_F.

Figure 2b:

The ratio $d\sigma/dp_t$ for J/ψ production in $\pi^- W$ and $\bar{p}\,W$ to $\pi^- Be$ and $\bar{p}\,Be$ interactions at 125 GeV/c, as a function of p_t.

Figure 3a:

The ratio $d\sigma/dx_F(W/Be)$ for the $p_t < 1.2$ GeV/c and $1.2 < p_t < 3.0$ GeV/c regions, as a function of x_F, for the π^- data.

Figure 3b:

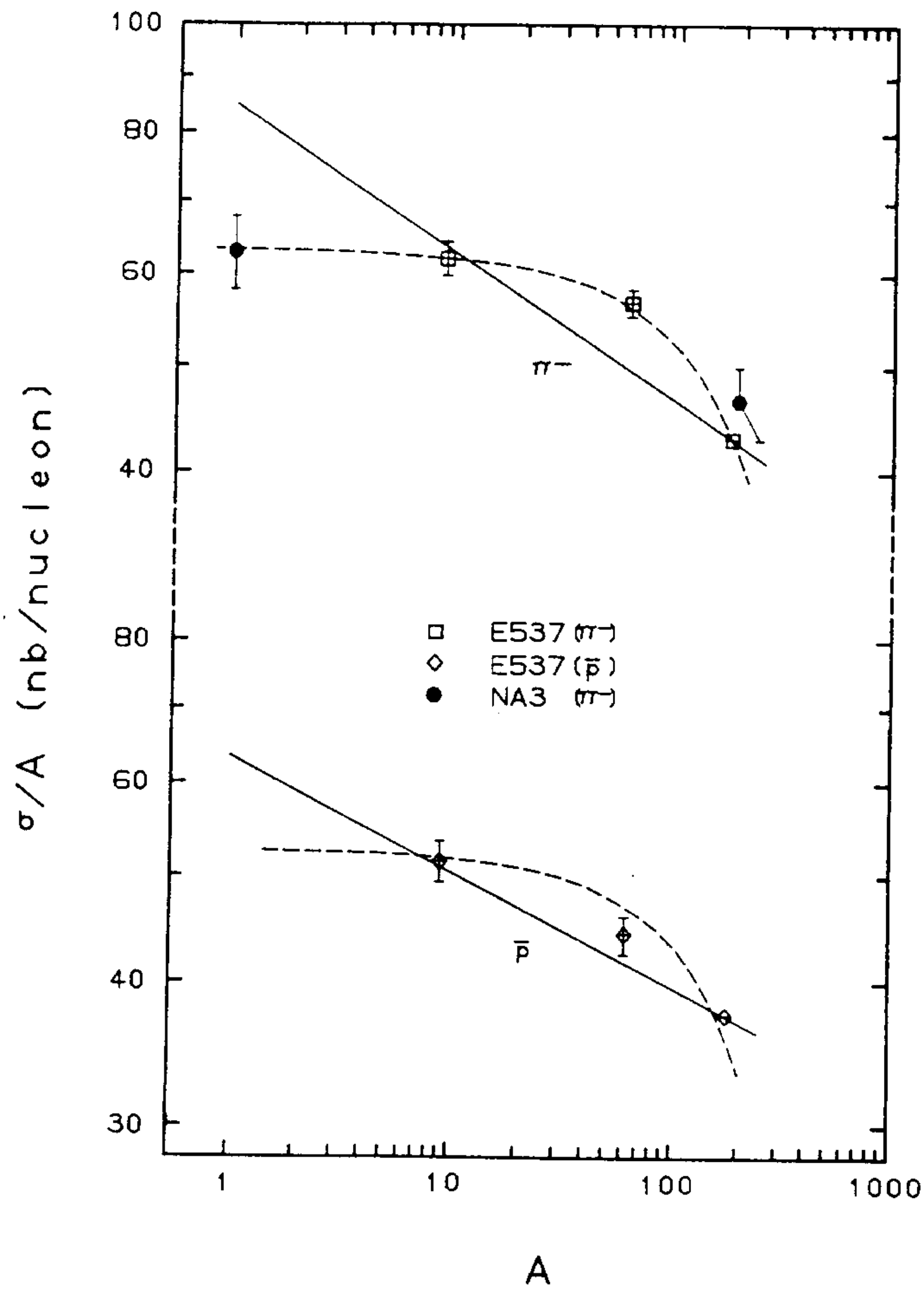
The ratio $d\sigma/dp_t(W/Be)$ for the $0. < x_F < 0.3$ and $0.3 < x_F < 1.0$ regions, as a function of p_t, for the π^- data.

Figure 4:

The ratios $d\sigma/dx_F(W/Be)$ and $d\sigma/dx_F(W/Cu)$, for π^- as a function of x_F.

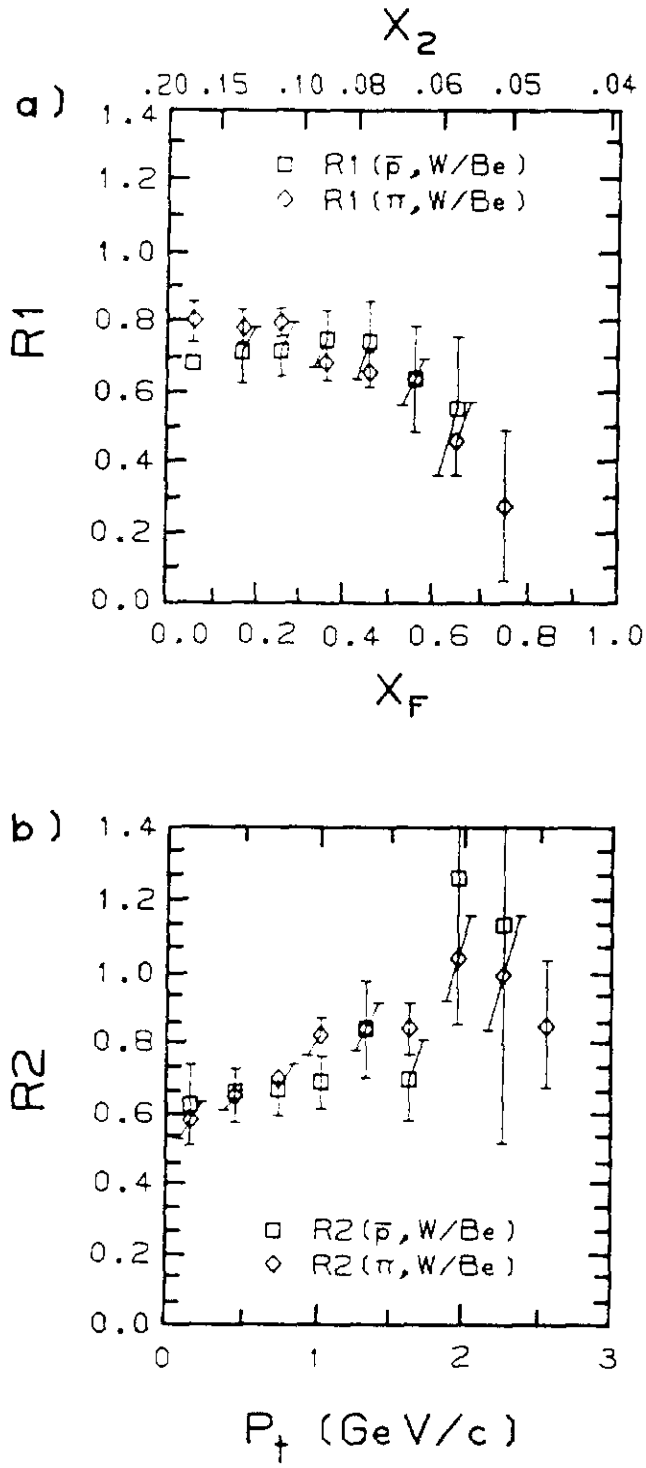
Figure 5:

Comparison of the ratio $d\sigma/dx_F(W/Be)$ for π^- to various models: EMC type: (a) soft π model, (b) rescaling model, (c) six quark model; Gluon type: (d) shadowing model, (e) rescattering model and (f) three gluon fusion model without $q\bar{q}$ contributions.



100
80
60
40
80
60
40
30
1
10
100
1000
σ/A (nb/nucleon)
A
π⁻
p̄
E537 (π⁻)
E537 (p̄)
NA3 (π⁻)

Figure 1



X2
.20 .15 .10 .08 .06 .05 .04
a)
R1 (p̄, W/Be)
R1 (π, W/Be)
R1
XF
b)
R2 (p̄, W/Be)
R2 (π, W/Be)
R2
Pt (GeV/c)

Figure 2

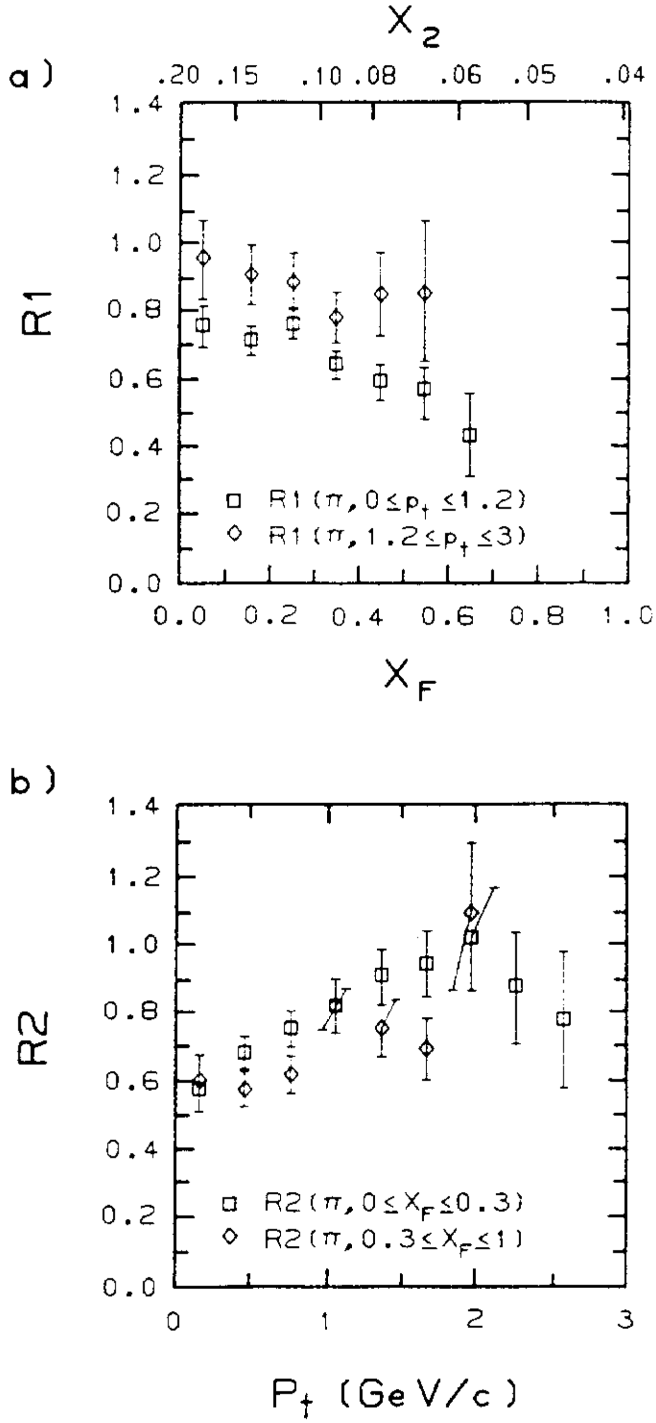
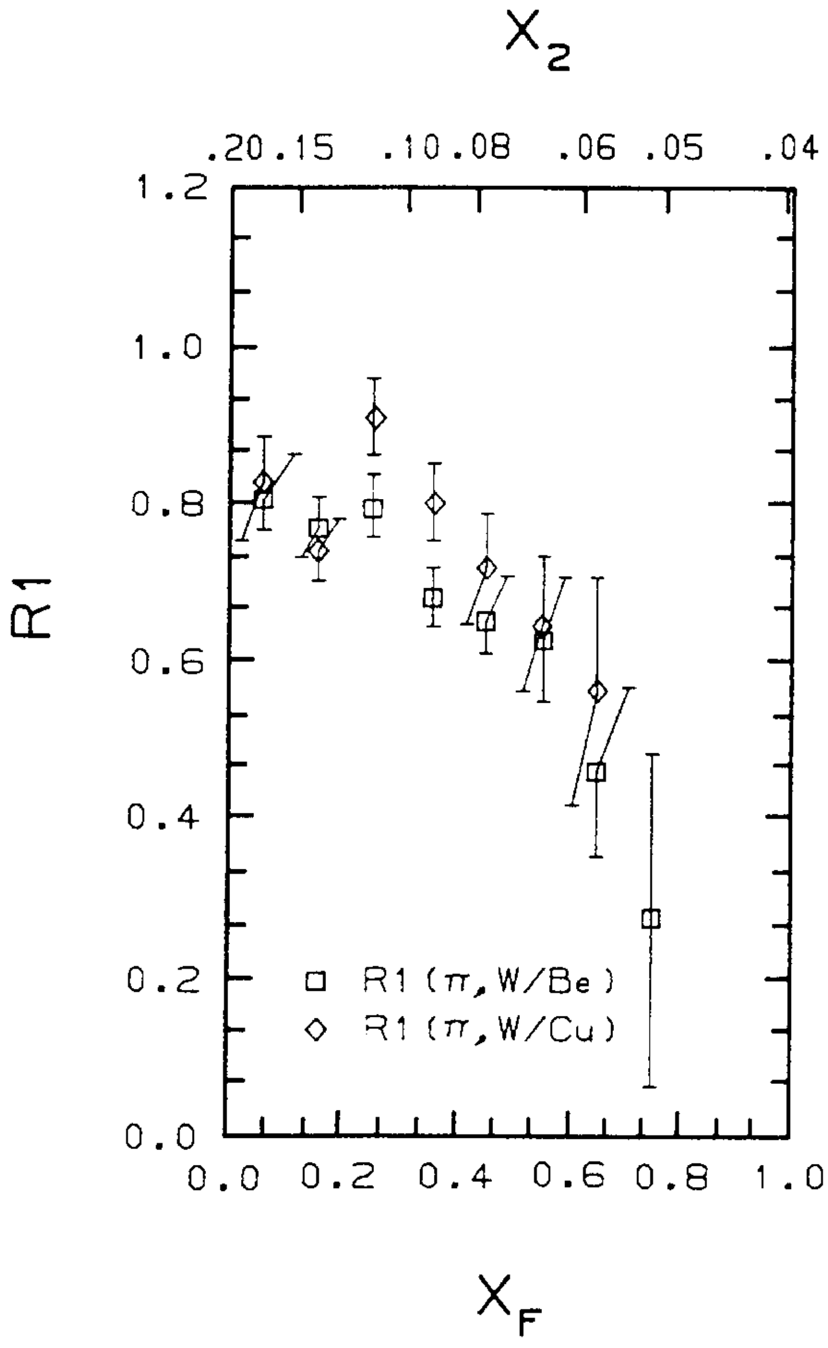
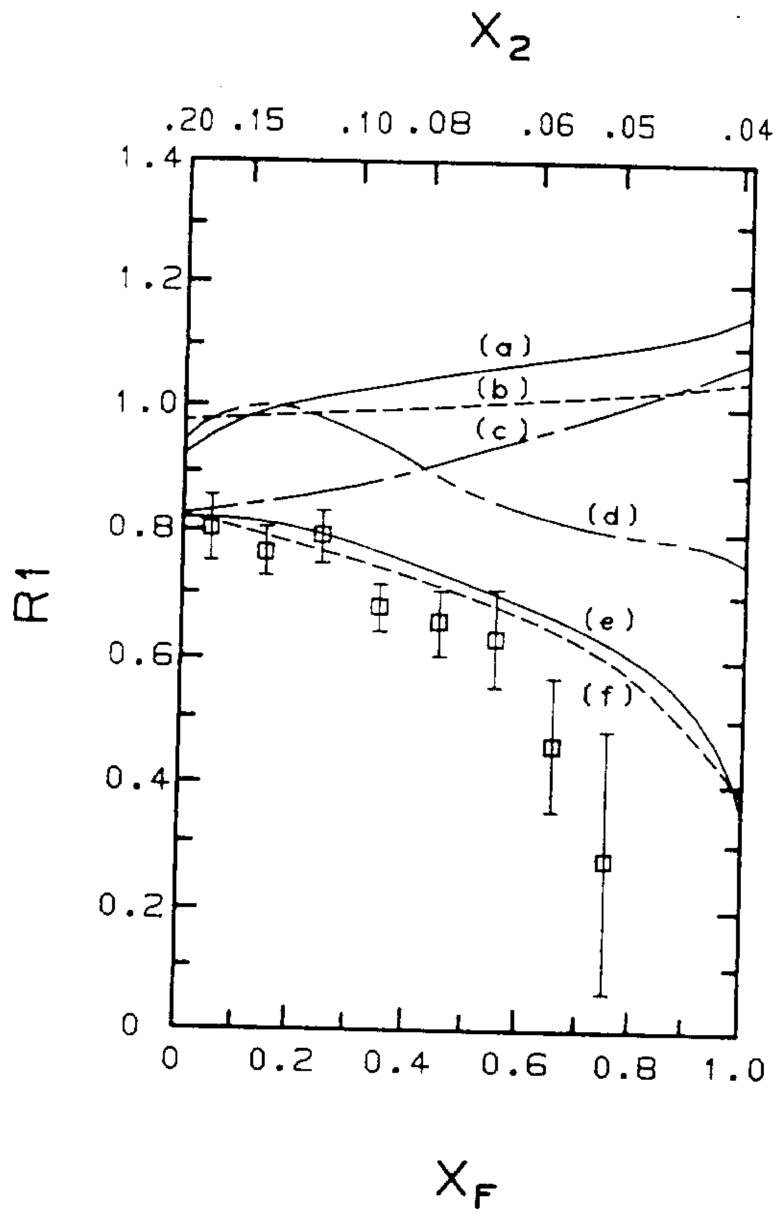

a)
X2
.20 .15 .10 .08 .06 .05 .04
R1
R1 (π, 0≤pt≤1.2)
R1 (π, 1.2≤pt≤3)
XF
b)
R2
R2 (π, 0≤XF≤0.3)
R2 (π, 0.3≤XF≤1)
Pt (GeV/c)

Figure 3



X_2
.20
.15
.10
.08
.06
.05
.04
1.2
1.0
0.8
0.6
0.4
0.2
0.0
R1
R1 (π, W/Be)
R1 (π, W/Cu)
0.0
0.2
0.4
0.6
0.8
1.0
X_F

Figure 4



X2
.20
.15
.10
.08
.06
.05
.04
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
R1
(a)
(b)
(c)
(d)
(e)
(f)
0
0.2
0.4
0.6
0.8
1.0
XF

Figure 5