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EVIDENCE FOR HIGHER TWIST EFFECTS IN FAST π^- PRODUCTION

BY ANTINEUTRINOS IN NEON

BEBC WA59 Collaboration

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ABSTRACT

Evidence for a significant higher twist contribution to high z π^- production in antineutrino scattering is presented. In events with $W > 3$ GeV and $Q^2 > 1$ GeV² in our data, it accounts for $(51 \pm 8)\%$ of all π^- with z above 0.5. It is consistent with the z - Q^2 correlations of Berger's higher twist prediction. The data are inconclusive concerning the predicted y - z correlation and p_T dependence. The $z - Q^2$ correlation is not adequately described by the Lund Monte-Carlo.

1. INTRODUCTION

In Quantum Chromodynamics (QCD) deviations from the Quark Parton Model (QPM) can be due to $1/Q^2$ terms as well as terms involving logarithms of Q^2 . These $1/Q^2$ or "higher twist" terms usually arise from final state interactions between the partons. A specific higher twist term, arising from pion bound state effects, has been calculated by E. Berger [1]. From the gauge invariant set of diagrams shown in fig. 1, the following relations, applicable at large z and Q^2 , are predicted:

$$\frac{d^4\sigma(\bar{\nu}N \rightarrow \mu^+ \pi^- X)}{dx dy dz dp_T^2} \propto \frac{q(x)}{zp_T^4} [(1-y)^2(1-z)^2 + \frac{4}{9} \frac{(1-y)}{Q^2} p_T^2] \quad (1)$$

$$\frac{d^4\sigma(\nu N \rightarrow \mu^- \pi^+ X)}{dx dy dz dp_T^2} \propto \frac{q(x)}{zp_T^4} [(1-z)^2 + \frac{4}{9} \frac{(1-y)}{Q^2} p_T^2] \quad (2)$$

Here p_T is the transverse momentum of the produced pion relative to the fragmenting quark direction, $q(x)$ is the quark momentum distribution in the nucleon and x , y , Q^2 , and z are the usual kinematic variables^(*).

Previous analyses of neutrino and antineutrino data have looked for higher twist effects by comparing the z -distributions of high and low y events. The results obtained were inconclusive; the Gargamelle neutrino data [2] suggested a large signal whereas the BEBC neutrino and anti-neutrino data in deuterium [3], which were adequately reproduced by first order QCD, detected no higher twist contribution. The Gargamelle analysis used a soft W cut ($W > 2$ GeV) which introduces systematic biases due to misidentified protons contaminating the π^+ z -distributions [4] and due to phase space effects which, for $\bar{\nu}$ data, can give y - z correlations [5] ambiguous with the signal. The BEBC D_2 experiment [3], using $\bar{\nu}$ data with a harder W cut ($W > 3$ GeV²), avoids the above biases. But $\bar{\nu}$ data suffer from other effects which tend to obscure any higher twist signal in the y - z correlations. Firstly, the antiquark term (not taken into account by ref. [1]) has y - z correlations that are opposite to those of the quark term. Secondly the Q^2 dependence of the higher twist term also reduces the y - z correlations since high y values are correlated with high Q^2 values. However the relative importance of the higher twist term in $\bar{\nu}$ data is expected to be twice that in ν data.

(*) In this paper we define z as E_π/ν , the ratio of the pion energy to the total energy transferred from the leptonic to the hadronic system.

The present analysis is designed to be more sensitive to possible higher twist effects than these previous analyses because:

- (a) It uses $\bar{\nu}$ interactions in neon yielding larger statistics in the low Q^2 region and better z resolution due to larger detection efficiency for neutral secondaries;
- (b) It includes sea quark terms in eq. (1) and studies in detail the effects of loss of neutral energy and other experimental deficiencies;
- (c) It uses the maximum likelihood method to extract maximum information about the correlations between x , y , Q^2 , and z .

Preliminary results from this experiment showing effects partly consistent with higher twist predictions were presented previously [6,7]. An analysis of the FNAL-15 foot bubble chamber experiment applying the recipe of ref. [6] gave similar results [8]. In a muon proton scattering experiment [9] higher twist like effects were not observed in the variables studied.

Higher twist terms will also induce effects in the $\cos\phi$ distribution [11]; such effects are considered in a separate paper.

2. EXPERIMENTAL DETAILS

The data used in this analysis were taken with BEBC, filled with a 75 mole % neon-hydrogen mixture operated at 29.5 K (density 0.71 g cm^{-3} , radiation length 42 cm), exposed to the CERN SPS wide band antineutrino beam produced by protons of 400 GeV. Muons were identified using the 2-plane external muon identifier (EMI) [10]. The data sample used consisted of 15603 fully measured $\bar{\nu}$ charged current events lying inside the fiducial volume with an EMI identified muon of momentum above 5 GeV. All secondary charged hadron tracks apart from short proton stubs were measured and reconstructed together with associated gamma conversions and charged decays of neutral strange particles. Short interacting tracks had their momenta estimated from the interaction products. Neutral hadron interactions were rejected. All charged hadrons were interpreted as pions unless positively identified as protons. Transverse momentum balance

indicated that, on average, 84% of the hadron-shower energy was measured. Throughout this analysis we use three different methods [11] to correct for the missing energy, in order to obtain a measure of systematic errors.

For this analysis a relatively hard W cut ($W > 3$ GeV) was used in order to reduce phase space induced correlations [5] and any residual effects due to misidentified protons [4]. We also applied a Q^2 cut ($Q^2 > 1$ GeV²) since the prediction is not applicable at very low Q^2 . This cut excludes 90% of the coherent interactions found in this experiment [12]. After applying these cuts we had 8100 events with a mean Q^2 of 7.4 GeV², a mean W of 5.4 GeV, a mean x of 0.20 and a mean y of 0.55. Corrections for neutral current backgrounds and EMI inefficiencies were applied but found to be negligible.

3. METHOD OF ANALYSIS

To account for the different y -dependences expected for the sea and valence quarks we have generalised eq. (1) to

$$\begin{aligned} \frac{d^4\sigma(\bar{\nu}N \rightarrow \mu^+ \pi^- X)}{dx dy dz dp_T^2} \propto & \frac{1}{p_T^4} \frac{(1-z)^2}{z} [\bar{q}(x) + q(x)(1-y)^2] \\ & + \frac{4}{9} \frac{1}{p_T^2} \frac{1}{z} \frac{(1-y)}{Q^2} [\bar{q}(x) + q(x)] \end{aligned} \quad (3)$$

where the first term is the "leading twist" contribution to the cross section having the x, y, Q^2 dependence expected from the QPM and the second term is the higher twist contribution. Firstly we test the x, y, Q^2 dependence of the z -distribution. The z -distribution of the negative pions was studied as a function of a variable $R(x, y, Q^2)$:

$$R(x, y, Q^2) \equiv \frac{4}{9} \frac{(1-y)}{Q^2} \frac{\bar{q}(x) + q(x)}{\bar{q}(x) + q(x)(1-y)^2} \quad (4)$$

which contains the entire x, y and Q^2 dependence of the ratio of the higher twist to leading twist cross sections. In terms of this variable eq. (3), averaged over p_T^2 , becomes

$$\sigma(R, z) \equiv \frac{d^3 \sigma(\bar{\nu} N \rightarrow \mu^+ \pi^- X)}{dx dy dz} \propto \left[\frac{(1-z)^2}{z} + \langle K_T^2 \rangle \frac{R(x, y, Q^2)}{z} \right] (\bar{q}(x) + q(x)(1-y)^2) \quad (5)$$

In the formalism of ref. [1] the variable $\langle K_T^2 \rangle$ should be understood as a measure of the relative importance of the higher twist contribution which effectively includes mass terms as well as the mean p_T^2 of the pion relative to the fragmenting quark. More precisely, $\langle K_T^2 \rangle$ measures the ratio of the higher twist cross section, σ_{HT} , to the leading twist cross section, σ_{LT} , for z above z_0 :

$$\frac{\sigma_{HT}(z > z_0)}{\sigma_{LT}(z > z_0)} = \langle K_T^2 \rangle \frac{\int_{z_0}^1 1/z dz}{\int_{z_0}^1 (1-z)^2/z dz} R(x, y, Q^2) \quad (6)$$

The data were analyzed with a log-likelihood function constructed from two independent probability densities θ_z and θ_R , where

$$\theta_z(R, z) = \frac{\sigma(R, z)|_{z > z_0}}{\int_{z_0}^1 \sigma(R, z) dz} \quad (7)$$

describes the shape of the z -distribution of the fastest pion of appropriate charge for $z > z_0$ as a function of $R(x, y, Q^2)$, and

$$\theta_R(R) = \frac{\int_{z_0}^1 \sigma(R, z) dz}{\sigma_{tot}(R)} \quad (8)$$

is the fraction of events containing such pions with $z > z_0$ as a function of $R(x, y, Q^2)$. For the main analysis z_0 was taken as 0.5.

The log likelihood function used was

$$L = \sum \{ \ln \theta_z + \ln \theta_R \} + \sum \{ \ln(1 - \theta_R) \} \quad (9)$$

where the sums are over all events lying inside the cuts and the first sum applies to events with pions of appropriate charge and $z > z_0$ and the second sum to events with no such pions.

The function θ_z allows one to measure $\langle K_T^2 \rangle$. The function θ_R gives additional information on $\langle K_T^2 \rangle$ and allows one to measure two other related parameters, α and β , as defined below:

$$\frac{\sigma_{HT}(z > z_o)}{\sigma_{LT}(All\ z)} = \alpha \int_{z_o}^1 1/z\ dz\ R(x, y, Q^2) \quad (10)$$

$$\frac{\sigma_{HT}(All\ z)}{\sigma_{LT}(All\ z)} = \beta\ R(x, y, Q^2) \quad (11)$$

The parameters α and β contain information about the low z cross section for which no prediction is made in ref. [1].

The quark and antiquark momentum distributions, $q(x)$ and $\bar{q}(x)$, were calculated using the parameter set determined by Allasia et al. [13]. Use of other parameters that also described our x and y distributions adequately did not significantly change the results.

4. DETERMINATION OF $\langle K_T^2 \rangle$, α AND β

4.1 Monte-Carlo simulation and unsmearing

The fitted values of the parameters depend on how the data are corrected for the loss of neutral hadronic energy. Monte-Carlo events were used to understand these differences. We refer to effects due to experimental imprecision as "smearing" and the Monte-Carlo correction of them as "unsmearing".

The Monte-Carlo events were generated with x , y , Q^2 distributions according to eq. (5) with various values of $\langle K_T^2 \rangle$. This leading twist plus higher twist (LT + HT) Monte-Carlo generated the z -distribution of the leading pion according to eq. (5), assumed to be valid for $z > 0.4$, with a smooth continuation to low z chosen to reproduce the data (see solid curve on fig. 2). In generating the events account was taken of nuclear reinteraction, Fermi-motion and all known experimental effects including energy loss, measurement errors and particle misidentification. The Monte-Carlo events were then corrected for missing energy in exactly the same way as the data. The good agreement between the data and the Monte-Carlo in fig. 2 for all energy correction methods shows that the effect of smearing on the z -distributions is well reproduced.

Fig. 3 shows how the values of $\langle K_T^2 \rangle$ fitted to Monte-Carlo events varied with the input values of $\langle K_T^2 \rangle$ for uncorrected events and for events corrected by each of the three methods described in ref. [11]. These curves, and similar curves constructed for α and β , were used to obtain unsmeared values of $\langle K_T^2 \rangle$, α and β from the fitted values.

4.2 Results for magnitude of higher twist contribution

Table 1 gives the fitted and unsmeared values of $\langle K_T^2 \rangle$ obtained from each correction method. The errors given are purely statistical. Also given are the χ^2 values per degree of freedom to show how consistent the values in each column are. The good agreement obtained after unsmearing, as indicated by the low value of χ^2 per degree of freedom, demonstrates the reliability of the procedure. Similar results were obtained for α and β with χ^2/N improving from 28/3 to 2.0/3 and from 12/3 to 3.6/3 respectively. Although the unsmeared values agree well within their statistical errors they are statistically correlated so that the remaining discrepancies are partly due to systematics. The results are obtained by averaging the unsmeared values, systematic errors being estimated from the excess spread of these values:

$$\langle K_T^2 \rangle = 0.65_{-0.16}^{+0.24} \text{ (statistical)} \pm 0.09 \text{ (systematic)}$$

$$\alpha = 0.59_{-0.15}^{+0.18} \text{ (statistical)} \pm 0.07 \text{ (systematic)}$$

$$\beta = 3.3_{-1.4}^{+1.5} \text{ (statistical)} \pm 1.8 \text{ (systematic)}$$

The mean value of R is 0.14 for all events selected by the cuts and 0.16 for events with a π^- with z above 0.5. Hence this value of $\langle K_T^2 \rangle$ implies that $(51_{-8}^{+8})\%$ of the π^- with z above 0.5 are attributable to higher twist effects. The values obtained for α and β and their correlation imply that $(3.9_{-0.5}^{+0.6})\%$ of the events within our cuts have such a π^- . The value of β implies that $(32_{-19}^{+12})\%$ of the events show higher twist effects; however this result is not only statistically badly determined, β being the coefficient of a second order correction term, but also depends on the extrapolation of the predicted z -distributions to low z . The errors quoted on these percentages include the systematic errors.

The Monte-Carlo predictions corresponding to these fits are compared with the data in figs 4 and 5 (solid lines). In fig. 4 we have plotted $z\theta_z$ averaged over R against $(1 - z)^2$ which is predicted to be a straight line with non-zero intercept; for comparison we show also the prediction with no higher twist term ($\langle K_T^2 \rangle = 0$). Fig. 5 plots θ_R versus R which should also rise linearly (see solid lines, the dashed and dotted curves in fig. 5 will be described later). In both cases the LT + HT Monte-Carlo fits the data well.

The results did not change, apart from an increase in errors, when the analysis was repeated with $z_0 = 0.7$ instead of 0.5:

$$\langle K_T^2 \rangle = 1.0^{+0.7}_{-0.5} \quad \alpha = 0.69^{+0.31}_{-0.20} \quad \beta = 3.5^{+2.9}_{-2.1}$$

where only statistical errors are given. Similarly, raising the W and/or Q^2 cuts merely increased the errors without changing the result.

Fitting to the π^+ z-distributions instead of the π^- z-distributions gave values for $\langle K_T^2 \rangle$, α and β consistent with zero, as expected for a leading particle effect.

Previous fits to data in our W and Q^2 region which ignored the possible presence of higher twist effects have instead suggested that the leading twist z-distribution is harder than that given by eq. 5; namely for $z \cdot d\sigma/dz \sim (1 - z)^m$ they have suggested $m = 1.43 \pm 0.08$ [14] or 1.6 ± 0.1 [15] instead of $m = 2$. We therefore tested the effect on this analysis of assuming $m = 1.5$ instead of $m = 2$; the fraction of $z > 0.5$ π^- attributed to higher twist effects fell from $(51 \pm 8)\%$ to $(41 \pm 10)\%$. The value of this fraction is also insensitive to the assumption that the higher twist term has the specific y dependence predicted.

5. CHECK OF x, y AND Q^2 DEPENDENCE

From the previous section it would appear that we have a signal which is significant by more than 6 standard deviations (note that this is better estimated from the percentages which have a more symmetric error distribution than $\langle K_T^2 \rangle$, α and β). However, most of this significance

arises from the fact that the z -distributions obtained from the data have a hard z component which cannot be described with a $(1 - z)^2/z$ term. Thus a significantly non-zero value for $\langle K_T^2 \rangle$ could be obtained from the above fits even if the predicted x , y and Q^2 dependence of the hard z component was not present.

To test explicitly for the x , y and Q^2 dependence predicted, the expression for R (eq. (4)) was generalised to

$$R(x, y, Q^2) = \frac{4}{9} \frac{1}{Q^{2b}} \frac{q(x)(1 - y)^{2-a} + \bar{q}(x)(1 - y)^a}{q(x)(1 - y)^2 + \bar{q}(x)} \quad (12)$$

where $a = b = 1$ corresponds to the x , y and Q^2 dependence predicted in ref. [1]; $a = b = 0$ corresponds to the absence of any x , y or Q^2 dependence; and $a = 0$, $b \neq 0$ corresponds to a simple Q^2 dependence without any explicit x or y dependences. The same maximum likelihood method as above was used with a and b as additional parameters.

The fitted values of these parameters are also subject to smearing. However, rather than attempting to unsmear them we have compared fitted values from the data with those expected from the prediction of ref. [1] and from the QPM. To do this we use two sets of Monte-Carlo events:

- (a) LT + HT Monte-Carlo events, in which $\langle K_T^2 \rangle$ has been fitted to the data, representing the prediction of ref. [1].
- (b) LT Monte-Carlo events with a hard z component which gives the same z -distribution as the LT + HT Monte-Carlo but with no x , y or Q^2 dependence; this represents the QPM.

The values of the Q^2 power, b , obtained by fitting the data in this way are shown in table 2, column 1. Those obtained by fitting the Monte-Carlo events are shown in columns 2 and 3. The data values are in much better agreement with the values obtained from the LT + HT Monte-Carlo, clearly demonstrating a Q^2 dependence similar to that predicted [1]. The predictions of the two Monte-Carlos are compared with the data in fig. 5 (solid and dashed lines).

Both Monte-Carlos gave values for parameter a which were in good agreement with the value obtained from the data. Hence we are unable to resolve the y dependence. This is because a y - z correlation similar to that predicted [1] is introduced by experimental smearing. Indeed, the correlation observed previously [6,8] may arise entirely from this source.

6. COMPARISON WITH THE LUND MODEL

It has been shown [15,16] that the Lund model and kinematics can account for the Q^2 evolution of the fragmentation functions in the deuterium data with $W^2 > 5 \text{ GeV}^2$ without assuming higher twist effects. There is also the possibility of a Q^2 dependence arising from leading twist QCD effects (gluon bremsstrahlung). We have therefore compared our data with the predictions of the Lund Monte-Carlo with and without gluon bremsstrahlung.

Version 5.23 of the Lund [17] Monte-Carlo, used with $E_{\text{min}} = 0.2 \text{ GeV}$ and $s/u = 0.21$ [18], represents the general features of our data (fig. 2, dotted curve). The effects of our experimental conditions have been incorporated in the Lund Monte-Carlo in the same way as in the other Monte-Carlos used.

Firstly, we compare the Lund model with our data in exactly the same way as was done with the D_2 data [15,16]. As can be seen in fig. 6, in the $z > 0.5$ region which is relevant for this analysis there is indeed qualitative agreement between the Lund model and our data. However, our data are quantitatively better represented by the LT + HT Monte-Carlo, as was also the case in fig. 5.

Secondly we examine the Q^2 dependence obtained using the full maximum likelihood analysis. Without gluon emission the values of b are given in table 2, column 4. Column 5 shows the result of including maximal gluon

emission^(*). The strong Q^2 dependence observed in the data is not reproduced in either case.

7. p_T^2 DEPENDENCE

According to eq. (3) the presence of the higher twist term hardens the p_T^2 distribution. Therefore as p_T^2 increases the mean value of $R(x,y,Q^2)$ should rise and that of $(1-z)^2$ should fall, i.e. $\langle(1-z)^2/R\rangle$ should fall. In fig. 7 we plot the value of $\langle(1-z)^2/R\rangle$ as a function of p_{T0}^2 (the p_T^2 component out of the lepton plane, a well measured quantity - insensitive to energy corrections).

Fig. 7 shows no evidence for the predicted fall of $\langle(1-z)^2/R\rangle$ with respect to p_T^2 ; instead there is a rise. A rise is expected from the Lund Monte-Carlo (dotted curve) because of kinematical effects which limit p_T^2 at low $(1-z)^2$ and at low W^2 (low W^2 is statistically correlated with high R values in our data) and of QCD effects which widen the p_T^2 distribution at high W^2 . These effects are neglected in eq. (3). At low p_T the higher twist prediction may be changed by the mass terms which have to be added in eq. (3) to remove the p_T divergences. The magnitudes of these mass terms are not predicted, but at sufficiently large p_T^2 their effects should disappear.

(*) The b values obtained by fitting no-gluon events from Lund version 4.3 (in common use) and from Lund version 5.23 (used here) were in excellent agreement. However, in version 5.23 there is no longer any formal distinction between "soft" and "hard" gluons: the soft gluon mechanism of earlier versions is replaced by the possibility of changing the cut-off parameters so as to generate so-called "hard" gluons arbitrarily close to the infrared and collinear divergences of first order QCD if required. Here "maximal" gluon emission corresponds to cutoff parameter values $PARL(11) = 0.25$ and $PARL(12) = 0.10$ giving 0.06 "hard" gluons per event on average. Further reducing either parameter without simultaneously increasing the other one makes the sum of first order QCD quark-gluon and quark-antiquark cross sections exceed the total cross section in some kinematic regions at the upper end of our energy spectrum. Other choices of these cut-off parameters that also saturated unitarity in this way, and gave from 0.01 to 0.19 gluons per event on average, gave similar fitted values of b . This stability is to be understood as a consequence of gluons near the cutoffs having little effect on the z -distributions provided the cutoffs are low enough.

In summary, if the higher twist effect behaves as predicted it is masked in the p_T distribution of our data by the above kinematical, QCD and mass-term effects.

8. CONCLUSIONS AND DISCUSSION

The high z π^- 's in antineutrino-neon interactions show evidence of a significant higher twist effect. Their z -distribution is well described as a Q^2 dependent hard z component plus a Q^2 independent soft z component. The Q^2 dependence of the hard z component cannot be reproduced by kinematical effects contained in the Lund Monte-Carlo as suggested in ref. [15,16]. Neither can it be attributed to leading twist QCD effects as implemented in the most recent version of the Lund Monte-Carlo (version 5.23). For this reason we attribute it to a dynamical higher twist effect. It is consistent with the specific prediction of ref. [1].

Assuming that the higher twist effect is described by eq. (5), its relative importance at high z is measured by the variable $\langle K_T^2 \rangle = 0.65^{+0.24}_{-0.16} \pm 0.09 \text{ GeV}^2$. On average within our cuts it accounts for $(51^{+8}_{-8})\%$ of the π^- with z above 0.5 and $(3.9^{+0.5}_{-0.6})\%$ of our events have such a π^- attributable to higher twist effects.

Concerning the y - z correlation of the predicted [1] higher twist contribution, even the maximum likelihood method used in this analysis is inconclusive. This is consistent with previous results [3,9].

The predicted higher twist effect has also been searched for in p_T distributions. If it exists it is masked in our data, and perhaps also in other data [9], by kinematical, QCD and mass term effects.

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TABLE CAPTIONS

TABLE 1 Fitted and unsmeared values of $\langle K_T^2 \rangle$ in eq. (5).

TABLE 2 Fitted values of Q^2 power (parameter b in eq. (12)) for the data and various Monte-Carlo samples.

TABLE 1

Energy correction method [11]	$\langle K_T^2 \rangle \text{ GeV}^2$	
	Fitted	Unsmearcd
Heilmann	$0.23^{+0.06}_{-0.05}$	$0.82^{+0.34}_{-0.22}$
François	$0.66^{+0.16}_{-0.12}$	$0.69^{+0.22}_{-0.16}$
Myatt	$0.45^{+0.16}_{-0.09}$	$0.64^{+0.29}_{-0.15}$
No correction	$0.97^{+0.17}_{-0.13}$	$0.46^{+0.11}_{-0.09}$
χ^2/N	32/3	2.9/3

TABLE 2

Energy correction method [11]	(1) Data	(2) LT + HT Monte-Carlo	(3) LT (hard z) Monte-Carlo	(4) Lund (no gluons)	(5) Lund (maximal gluons)
Heilmann	$1.22^{+0.44}_{-0.37}$	$0.93^{+0.11}_{-0.10}$	$0.12^{+0.09}_{-0.09}$	$0.27^{+0.09}_{-0.09}$	$0.35^{+0.19}_{-0.19}$
François	$0.52^{+0.12}_{-0.11}$	$0.47^{+0.05}_{-0.05}$	$0.12^{+0.04}_{-0.04}$	$0.25^{+0.07}_{-0.07}$	$0.30^{+0.08}_{-0.08}$
Myatt	$0.58^{+0.19}_{-0.14}$	$0.54^{+0.05}_{-0.05}$	$0.08^{+0.03}_{-0.04}$	$0.25^{+0.07}_{-0.07}$	$0.36^{+0.09}_{-0.09}$
No correction	$1.02^{+0.23}_{-0.22}$	$0.91^{+0.04}_{-0.04}$	$0.38^{+0.09}_{-0.09}$	$0.22^{+0.04}_{-0.04}$	$0.22^{+0.05}_{-0.05}$

FIGURE CAPTIONS

- Fig. 1 Gauge invariant set of diagrams used in ref. [1] to calculate a higher twist contribution to $\bar{\nu}$ nucleon scattering.
- Fig. 2 z -distributions for the fastest π^- in the data compared with the LT + HT Monte-Carlo (solid) and the Lund Monte-Carlo (dotted) predictions for Heilmann corrected (H), François corrected (F), Myatt corrected (M) and uncorrected (U) events.
- Fig. 3 Unsmearing curves for $\langle K_T^2 \rangle$ obtained with different correction methods: Heilmann (H), François (F), Myatt (M) and uncorrected (U).
- Fig. 4 $z\langle\theta_z\rangle$ vs $(1 - z)^2$ for each correction method: Heilmann (H), François (F), Myatt (M) and uncorrected (U). The solid lines are LT + HT Monte-Carlo predictions with $\langle K_T^2 \rangle$ set to the fitted values. The dashed lines correspond to $\langle K_T^2 \rangle = 0$ (no higher twist term).
- Fig. 5 θ_R vs $R(x, y, Q^2)$ for each correction method: Heilmann (H), François (F), Myatt (M) and uncorrected (U). The solid lines are LT + HT Monte-Carlo predictions with $\langle K_T^2 \rangle$ set to the fitted values. The dashed lines are from the LT Monte-Carlo with a hardened z -distribution and the dotted curves are the Lund predictions with maximal gluon emission.
- Fig. 6 Q^2 dependence for each energy correction method (Heilmann (H), François (F), Myatt (M), and uncorrected (U)) of the fragmentation function

$$D_Q^- = \frac{1}{N(Q^2)} \frac{1}{z_2 - z_1} \int_{z_1}^{z_2} \frac{dN^{\pi^-}(Q^2)}{dz} dz$$

for (a) $z_1 = 0.5$, $z_2 = 0.7$ and (b) $z_1 = 0.7$, $z_2 = 1.0$ for each correction method. Solid curves show LT + HT Monte-Carlo predictions, dotted curves show Lund model predictions with maximal gluon emission.

FIGURE CAPTIONS (Cont'd)

Fig. 7 Mean $(1 - z)^2/R(x,y,Q^2)$ vs $p_{T_0}^2$ for events with a π^- with $z > 0.5$ for each correction method: Heilmann (H), François (F), Myatt (M) and uncorrected (U). The dotted curves show the Lund predictions with maximal gluon emission. The dashed lines are the expected means for pure LT (top) and pure HT (bottom).

Fig. 1

Fig. 2

Fig. 3

Fig. 4

$R(x,y,Q^2)$

Fig. 5

Fig. 6

Fig. 7