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IS THE K FACTOR IN THE DRELL-YAN PROCESS NECESSARY?*†

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Please note the following change:

Interchange Figs. 1(a) and 1(b)

without changing the captions.

Submitted to Physics Letters B

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* Work supported by the Department of Energy, contracts DE-AC03-76SF00515 and DE-AC02-76ER03533.

† This work is a modified and extended version of an earlier Syracuse preprint (82-0410(SU)) with similar title.

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ABSTRACT

A simple scale violating quark parton model incorporating only power suppressed correction to scaling is shown to describe simultaneously the deep inelastic lepton scattering, and the Drell-Yan lepton pair production data without the need for the K-factor. In contrast, additional large higher order correction to scaling through the K-factor is considered essential in quantum chromodynamics to explain the Drell-Yan data.

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The universality hypothesis of quark parton dynamics at short distance implies that the Drell-Yan (DY) [1] lepton pair production at high energy be calculable using the quark parton distributions measured in deep inelastic (lepton-hadron) scattering (DIS). Consider, e.g., the differential mass and rapidity distributions of the lepton pairs given by [1],[2]

$$m^3 \left.\frac{d\sigma}{dm}\right|_{x_F \geq 0} = \frac{8\pi\alpha^2}{9} \int_{\sqrt{\tau}}^{1} \frac{dx_1}{x_1} \tau \sum_i e_i^2 \Big[q_i^A(x_1,m^2)\, \bar{q}_i^B(x_2,m^2) + \bar{q}_i^A(x_1,m^2)\, q_i^B(x_2,m^2) \Big] \quad , \tag{1}$$

$$m^3 \left.\frac{d\sigma}{dm\,dy}\right|_{y=0} = \frac{8\pi\alpha^2}{9} \tau \sum_i e_i^2 \Big[q_i^A(x_1,m^2)\, \bar{q}_i^B(x_2,m^2) + \bar{q}_i^A(x_1,m^2)\, q_i^B(x_2,m^2) \Big] \tag{2}$$

where A, B refer to the beam and target hadrons, $\tau = m^2/s$, $s = (p_A + p_B)^2$, m^2 = invariant $(\text{mass})^2$ of the lepton pairs, y = c.m. rapidity, $x_1 = \sqrt{\tau}\, e^y$, $x_2 = \sqrt{\tau}\, e^{-y}$, $x_F = x_1 - x_2$ and other terms have their usual meaning. The lower limit of integration in eq. (1) corresponds to the experimental constraint $x_F \geq 0$. According to the hypothesis, these cross sections are calculable with the parton distributions determined in DIS as inputs along with the identification $Q^2 = m^2$. Several general expectations of the DY mechanism such as scaling, angular distributions and beam dependence of cross sections are in remarkable agreement with experiments [3].

However, quantum chromodynamics (QCD) predicts [4] large higher order corrections (HOC) in DY process unlike in DIS with the implication that the nature and magnitude of scaling violations may be substantially different in the two processes. QCD based parton models [2] incorporating leading order (LO) scaling violation are not successful in explaining the DY-data through eqs. (1)-(2). The inclusion of HOC through the K-factor given by [4]

$$K - 1 = \left(\frac{\alpha_s}{2\pi}\right)\left(\frac{4}{3}\right)\left(1 + \frac{4\pi^2}{3}\right) + \ldots \tag{3}$$

is deemed essential [3] for comparison with the experimental data. In the present range of measurements the HOC [eq. (3)] result in an overall approximately constant normalization of LO expressions, e.g., $(d\sigma/dmdy)_{LO} \to K(d\sigma/dmdy)_{LO}$. For reasonable values of $\alpha_s \sim 0.2$-0.3 inferred from DIS, the corrections in (3) are quite large (60-80%) leading to $K \approx 2$. However, these large corrections raise grave doubts regarding the validity of a perturbative treatment pending calculation in the next order.

In this note we wish to present a consistent simultaneous description of DIS- and DY-data as demanded by the simple parton mechanism underlying these processes without the requirement of any additional inputs such as the K-factor. Consider the following parametrization of the parton distributions given in standard notation by,

$$xu_v(x,Q^2) = \frac{2\sqrt{x}\ (1-x)^{\tilde{\beta}_u(Q^2)}}{B\left(\frac{1}{2}, 1+\tilde{\beta}_u(Q^2)\right)} \quad , \tag{4}$$

$$xd_v(x,Q^2) = \frac{\sqrt{x}\ (1-x)^{\tilde{\beta}_d(Q^2)}}{B\left(\frac{1}{2}, 1+\tilde{\beta}_d(Q^2)\right)} \quad , \tag{5}$$

$$xS(x,Q^2) = \tilde{A}(Q^2)(1-x)^{\beta_S} \quad , \quad \beta_S = 7 \quad , \tag{6}$$

$$xG(x,Q^2) = \tilde{B}(Q^2)(1-x)^{\beta_G} \quad , \quad \beta_G = 5 \quad , \tag{7}$$

where we assume

$$\tilde{\beta}_u(Q^2) = \beta_u Q^2/(Q^2+Q_1^2) \quad , \tag{8}$$

$$\tilde{\beta}_d(Q^2) = \beta_d Q^2/(Q^2+Q_2^2) \quad , \tag{9}$$

$$\tilde{A}(Q^2) = AQ^2/(Q^2+m_\rho^2) \quad , \quad m_\rho^2 = \rho(\text{mass})^2 \ . \tag{10}$$

The above ansatz constitutes a very simple framework [5] capable of simultaneous incorporation of the general requirements of positivity, asymptotic scaling, Regge behavior, quark counting rules, gauge invariance (i.e., correct behavior in the real photon limit, $Q^2 \to 0$), vector meson dominance in the low x (low Q^2) limit and the valency sum rules.

The correction to scaling implied by eqs. (8)-(10) is purely power suppressed,

$$q_i(x,Q^2) \underset{Q^2 \text{ large}}{\sim} q_i(x) + \left(\frac{m_i^2}{Q^2}\right)\tilde{q}_i(x) + \ldots \tag{11}$$

where xq_i is any of the parton distributions in eqs. (4)-(7). The main motivations for considering a purely power-correction to scaling arise from several recent observations: (a) the moments of the structure functions are [5],[6] straight lines in $1/Q^2$. (b) Recent high energy DIS data [7]-[10] are consistent with the absence of any appreciable scale-breaking for $Q^2 \geq$ 20-30 GeV^2 and with finite and nontrivial asymptotic limits for <u>all</u> measured values of x. (c) There is indication in these data of substantial nonperturbative QCD contribution [11] to scaling violations.

Note that the parton distributions (and hence, the structure functions) have <u>nontrivial</u> scaling limits according to (4)-(7). This is unlike the situation in QCD where the parton-distributions vanish in the scaling limit, $x\bar{q}_i(x) \sim a_i\delta(x)$, except for $x = 0$. Therefore, the pattern of scaling violation [eq. (11)] is characteristically different from that suggested by QCD <u>both</u> in the leading -- and higher twist [12] approximations.

Such a parametrization, in its simplest form, was shown in ref. [5] to provide a very economical and simultaneous description of the SLAC-MIT-CHIO data [13],[14] on $F_2^{ep,\mu p}$, $F_2^{ed,\mu d}$; the corresponding moments [14]; the CDHS neutrino data [15]; and the MSU-FNAL data [16] on $F_2^{\mu N}$. The Callan-Gross [17] and energy momentum sum rules [18] given respectively by

$$\int_0^1 F_2^{p,n}(x)\,dx = C_{p,n} \quad \text{and} \quad \int_0^1 \left[F_2^{\nu N}(x,Q^2) + xG(x,Q^2)\right]dx = 1$$

were used [5] to fix the sea- and the gluon-normalizations respectively.

The constants[1] $C_{p,n}$ were chosen to be those given by the Kuti-Weisskopf model [19],[20]: $C_p = 13/81$, $C_n = 10/81$ which agree excellently [5],[20] with the data on the second moments of F_2^p and F_2^d. These imply a value for $A = 8/45$ assuming a SU(4) symmetric sea. The threshold exponents for the valence distributions were chosen equal in the scaling limit, $\beta_u = \beta_d = 3$ implying $u_v(x) = 2d_v(x)$. The only parameters left free were the two scales Q_1^2, Q_2^2 which were determined [5] from the fits to the SLAC-MIT-CHIO data and given by $Q_1^2 = 2.1 \pm 0.23\ \mathrm{GeV}^2$, $Q_2^2 = 0.75 \pm 0.26\ \mathrm{GeV}^2$.

Here, we extend the analysis to include the recent high energy measurements of the structure functions by the EMC [7],[8], BCDMS [9] and CDHS [10] collaborations. We then confront the prediction of the model with the DY-data through eqs. (1)-(2). To accommodate the correct threshold behavior of the data [21] on the ratios F_2^n/F_2^p and $F_2^{\nu p}/F_2^{e,\mu(p)}$ it is necessary to relax the assumption [5]: $u_v(x) = 2d_v(x)$. Here, we assume [22], $\beta_d = \beta_u + 1$ implying the d/u threshold suppression: $d_v(x)/u_v(x) \underset{x \to 1}{\sim} (1-x)$ which is required by the data [21].

The EMC data [7] on $F_2^{\mu p}$ is shown in fig. 1(a). The fits correspond to $\beta_u = 3.25 \pm 0.05$ with other parameters determined as in ref. [5] . Also shown in this figure are the SLAC-MIT data for comparison. The normalization discrepancy (~10%) between the two sets of the data [fig. 1(a)] may account for the slightly higher value of β_u required by the EMC data compared to the SLAC-MIT data [13] which are consistent with the canonical value $\beta_u = 3$. In fig. 1(b) the low-x region of the

[1] In QCD with four effective flavors these numbers are $C_p = C_n = 5/42$ which do not seem to agree with the data on the second moments, see refs. [5] and [6] for discussion on this point.

data is emphasized. Again, the discrepancy between the EMC [7] and the CHIO data [14] is prominent.[2] Besides, the EMC data show considerably less variation [fig. 1(b)] in both x and Q^2 compared to the CHIO data. The present model, with its sea-distribution normalized to the SLAC-MIT-CHIO data cannot simultaneously describe the EMC-data at low-x for the above reasons. The agreement can, however, be easily achieved by decreasing the sea-normalization from the value dictated by the CHIO data.

The above parametrization also describes excellently the EMC [8]-BCDMS [9] data on $F_2^{\mu N}$, the new CDHS data [10] on $F_2^{\nu N}$ and $xF_3^{\nu N}$ and the data [21] on the ratios $F_2^{\mu n,en}/F_2^{\mu p,ep}$, $F_2^{\nu p}/F_2^{e,\mu p}$. As remarked earlier, the assumption $d_v/u_v \xrightarrow[x\to 1]{} 0$ is crucial for a correct description of these ratios. These latter fits are not shown for lack of space.

In fig. 2(a), the <u>prediction</u> of the model for the cross section $m^3 d\sigma/dmdy\big|_{y=0}$ for proton induced dimuons computed using eq. (2) is confronted with the data [23] at $\sqrt{s}$ = 63 GeV. There is no appreciable change (except for $\sqrt{\tau} \leq 0.1$) in the predicted cross section at lower values of $\sqrt{s}$ because of precocious scaling. The agreement with the data is remarkably good [fig. 2(a)]. We note that these data do not favor the use of a sea-distribution normalized to the EMC data at low-x, which tends to worsen the agreement for $\sqrt{\tau} \leq 0.15$.

For comparison, we also display in fig. 2(a) the predictions of two popular QCD-parton models [24],[25] with parton distributions determined by LO fits to DIS data. The Owens-Reya (OR) model [24] predicts the cross

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[2] A part of the discrepancy may be accounted for the different assumptions about $R = \sigma_L/\sigma_T$ employed by the different group in the extraction of structure functions [R(CHIO) = 0.52, R(SLAC-MIT) = 0.2, R(EMC) = 0].

section which is consistently below the data by a factor $\approx$2-2.5 whereas the Buras-Gaemers (BG) model [25] shows a much steeper decrease at large $\sqrt{\tau} \geq 0.15$. Of course, these QCD-predictions are based upon fits to the low energy data corresponding to the value of the QCD scale-parameter $\Lambda_{LO} \simeq 0.3$-0.5 GeV which is probably not consistent with the recent high energy measurements [7]-[10].

In fig. 2(b), the data [26] on $m^3 d\sigma/dm|_{x_F \geq 0}$ for pp and pN induced dimuons are compared with the prediction of the present model computed through eq. (1). The agreement is reasonably good considering that no attempt has been made to fit the data and that systematic errors are not shown. The fit corresponds to $p_L = 400$ GeV. Again there is no appreciable difference between the predictions at lower p_L values except for $\tau \lesssim 0.04$. The corresponding prediction of the OR-model falls much below the data [fig. 2(b)].

Before concluding, a few observations are in order:

(a) The above simultaneous description of the data on DIS- and DY-processes provides perhaps a very clear demonstration of the consistency of the hard scattering mechanism in these processes. No additional inputs, such as the K-factor, have been found necessary to describe the DY-data. This is the main result of the note.

(b) On the other hand, the inability of the LO-QCD predictions to account for the DY-data perhaps reflects, in our opinion, the consequence of an entirely different pattern of scaling violation. Note that the DY-process provides an excellent testing ground for asymptotic scaling laws because of the easy access to much larger values of m^2 than those of Q^2 attainable in DIS. Thus, for example, $m^2 \gtrsim 225$ GeV^2 for $\sqrt{\tau} \geq 0.25$ at

$\sqrt{s}$ = 60 GeV. Both the DIS- and the DY-data are probably indicating the necessity for nontrivial scaling limits for parton distributions in contrast to the situation in QCD. This could explain the lack of any appreciable scaling violations observed in DIS- [7],[10] and DY-processes [27] at such large values of Q^2 or m^2.

(c) We note that a substantial portion of the HOC in QCD for the DY-process is associated with the so-called "π^2-terms" [eq. (3)] which arise [28] because of analytic continuation in Q^2 from space-like (DIS)- to time-like (DY) regions and is closely related to the logarithmic nature of scaling violation. Such large corrections are naturally absent in the present model which employs functional forms for scale-breaking consistent with analyticity [29] in Q^2. Consequently, the scaling behavior (and its violations) are the same for both time-like and space-like Q^2 as long as the value of Q^2 in the former case lies in the continuum far above the mass thresholds.

(d) The so claimed "experimental support" [30] for the K-factor might possibly be correlated with the use of QCD-based parton distributions which, as shown above, indeed require a further normalization correction. Besides, it has been shown [31] that the inferred value of K depends somewhat sensitively on the input value of Λ_{QCD} decreasing with the latter. It is not surprising, therefore, to find $K \approx 1$ in the present model which corresponds to $\Lambda_{QCD} = 0$.

In conclusion, we have explicitly demonstrated the validity of the simple Drell-Yan conjecture in lepton-pair production. The nature and magnitude of scaling violations in the deep inelastic lepton scattering, and lepton-pair production may substantially be the same -- no additional inputs, such as the K-factor, may be necessary to explain the lepton-pair production data. It is remarkable to find a simultaneous explanation of the vast amount of experimental information in the two processes in the framework of a simple quark-parton description using canonical inputs and purely power-law correction to scaling.

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REFERENCES

[1] S. D. Drell and T. M. Yan, Phys. Rev. Lett. 25 (1970) 316; and Ann. Phys. 66 (1971) 578.

[2] E. Reya, Phys. Rep. 69C (1981) 195.

[3] R. Stroynowski, Phys. Rep. 71C (1981) 1.

[4] G. Altarelli, R. K. Ellis and G. Martinelli, Nucl. Phys. B157 (1979) 461.

[5] B. P. Mahapatra, Phys. Rev. D (to be published).

[6] B. P. Mahapatra, Phys. Lett. 97B (1980) 299.

[7] J. J. Aubert et al., Phys. Lett. 105B (1981) 315.

[8] J. J. Aubert et al., Phys. Lett. 105B (1981) 322.

[9] D. Bollini et al., Phys. Lett. 104B (1981) 403.

[10] H. Taureg, talk at the International Conference on High Energy Physics, Lisbon (Portugal) 1981; H. Wahlen, talk at the SLAC Summer Institute, 1981, edited by A. Mosher, p. 663.

[11] R. M. Barnett, Phys. Rev. Lett. 48 (1982) 1657 and references contained therein.

[12] F. Eisele, M. Glück, E. Hoffmann and E. Reya, Phys. Rev. D26 (1982) 41.

[13] A. Bodek et al., Phys. Rev. D20 (1979) 1471.

[14] B. A. Gordon et al., Phys. Rev. D20 (1979) 2645.

[15] J. G. H. de Groot et al., Z. Phys. C1 (1979) 143.

[16] R. C. Ball et al., presented at the XX International Conference on High Energy Physics, Madison, Wisconsin, 1980 (unpublished).

[17] C. G. Callan and D. J. Gross, Phys. Rev. Lett. 21 (1968) 311.

[18] E. Reya, ref. [2].

[19] J. Kuti and V. F. Weisskopf, Phys. Rev. D4 (1971) 3418.

[20] B. P. Mahapatra, Phys. Rev. D17 (1978) 163.

[21] G. Smadja, in Proceedings of the 1981 International Symposium on Lepton Photon Interactions at High Energies, Bonn, edited by W. Pfeil, p. 444; J. Wotschak, ibid., p. 461; H. Wahlen, ref. [10].

[22] R. McElhaney and S. F. Tuan, Phys. Rev. D8 (1973) 2267.

[23] C. Korkoumelis et al., Phys. Lett. 91B (1980) 475; R. Stroyonowski, ref. [3].

[24] J. F. Owens and E. Reya, Phys. Rev. D17 (1978) 3003.

[25] A. J. Buras and K. J. F. Gaemers, Nucl. Phys. B132 (1978) 249.

[26] G. E. Hogan et al., Phys. Rev. Lett. 42 (1979) 948.

[27] D. Antreasyan et al., Phys. Rev. Lett. 48 (1982) 302.

[28] G. Parisi, Phys. Lett. 90B (1980) 295.

[29] A. Suri, Phys. Rev. D4 (1971) 570; M. Nauenberg, Phys. Rev. Lett. 24 (1970) 625.

[30] See, for example, G. Matthiae, La Rivista del Nuovo Cimento 4 (1981) No. 3.

[31] M. Le Bellac, University of Nice print N-TH-82/5, submitted to Acta Physica Polonica B, and Lectures given at the 22nd Cracow School of Theoretical Physics, Zakopane, 1982.

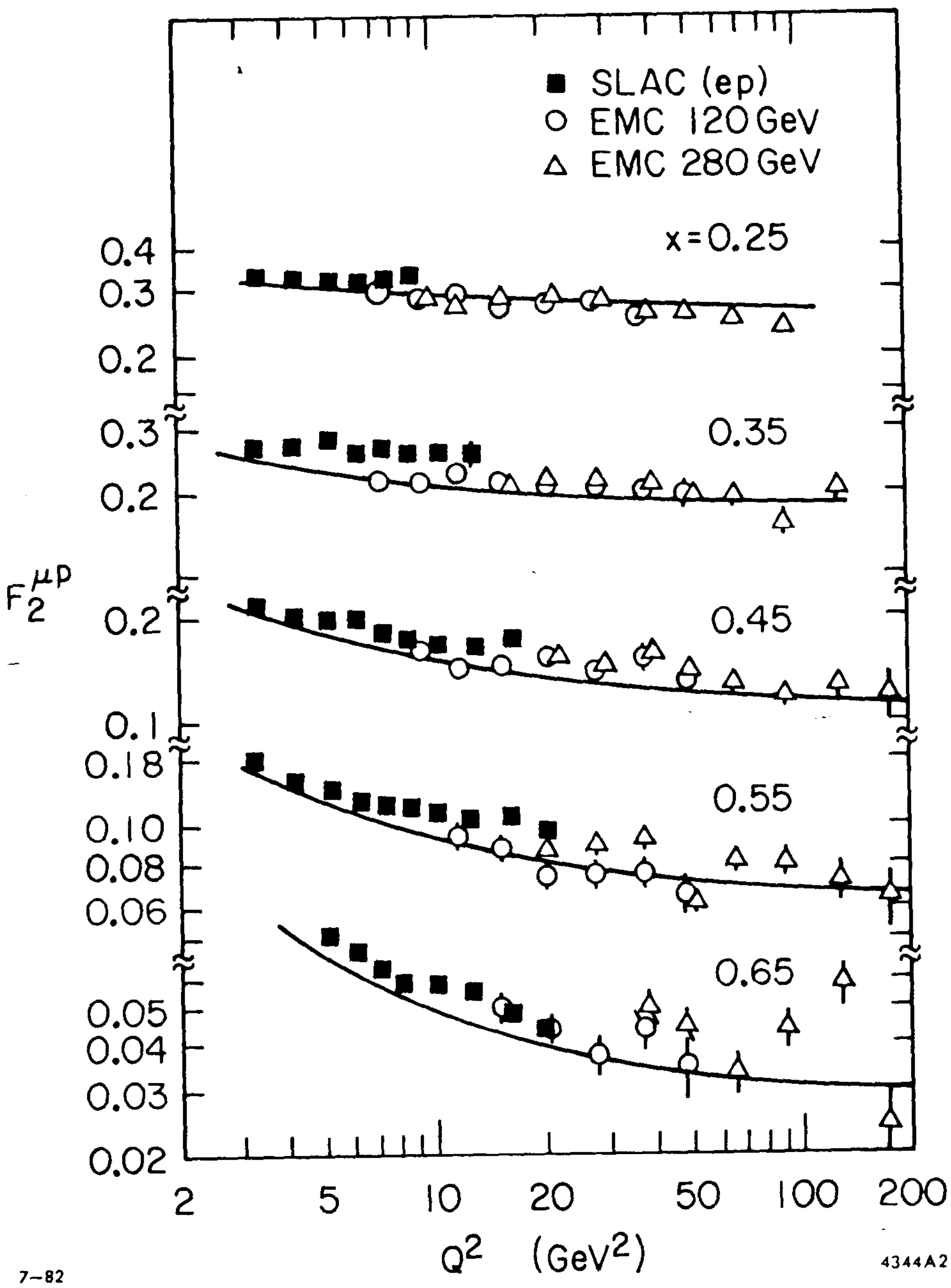
FIGURE CAPTIONS

Fig. 1(a) The proton structure function $F_2^{\mu p}$ measured by the EMC group (ref. [7]) shown for $x \geq 0.25$ along with the SLAC-MIT data for comparison. The figure is taken from H. Whalen (ref. [10]). The fits are described in the text.

(b) The SLAC-MIT-CHIO data (ref. [14]) on $F_2^{ep,\mu p}$ shown as a function of x for different Q^2-bins along with the EMC data (ref. [7]) (dark squares) for comparison. The fits (solid curves) are described in the text. The dashed curves are the predictions of the BG model (ref. [25]).

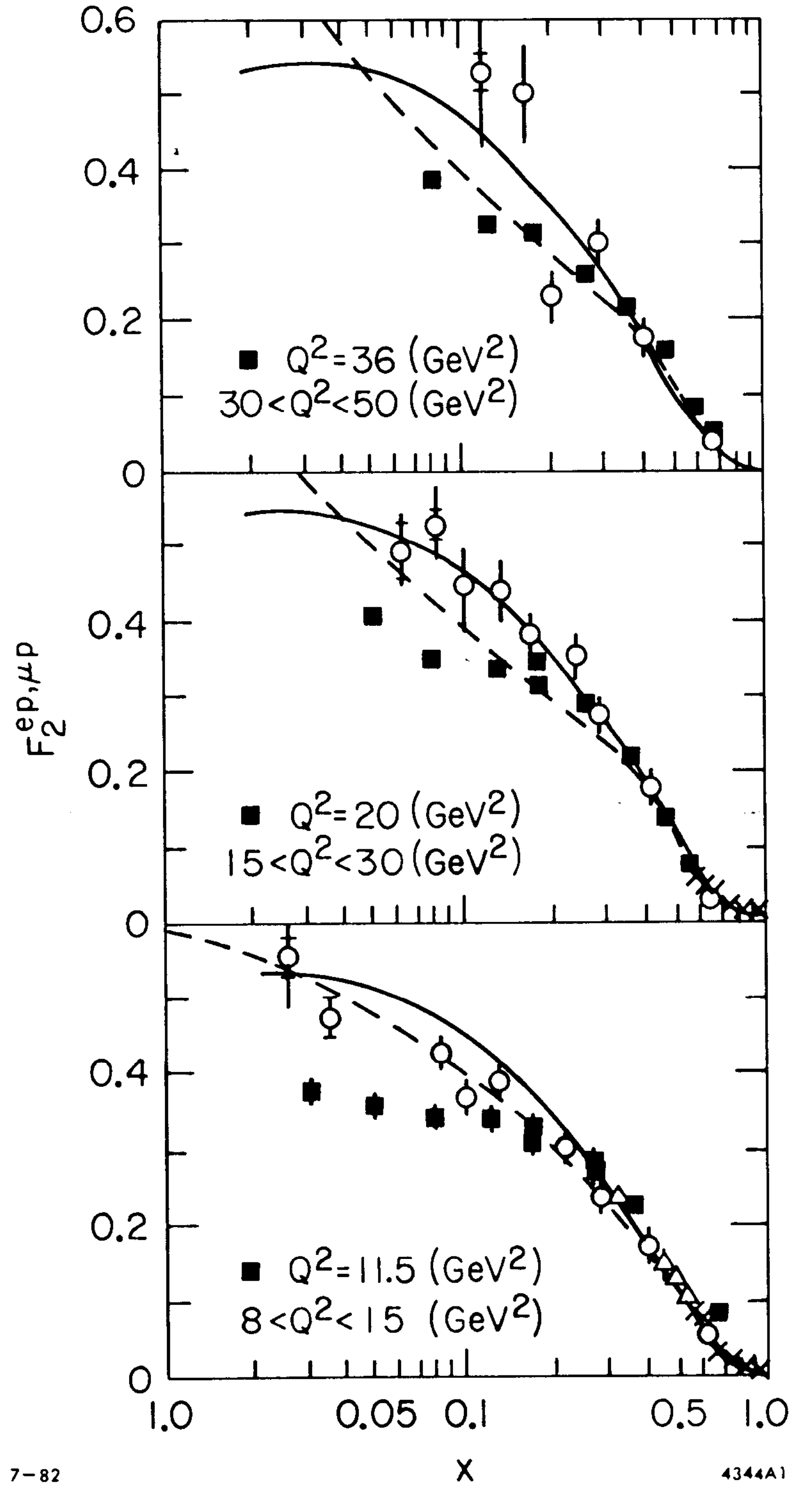
Fig. 2(a) The data (ref. [23]) on $m^3 d\sigma/dmdy\big|_{y=0}$ for proton induced dimuons compared with the predictions of the present model and those of the OR (ref. [24]) and BG (ref. [25]) models.

(b) The data (ref. [26]) on $m^3 d\sigma/dm\big|_{x_F \geq 0}$ for the pp, pN-dimuons compared with the prediction of the present model (solid curve) and that of the OR model (ref. [24]) (dashed curve).



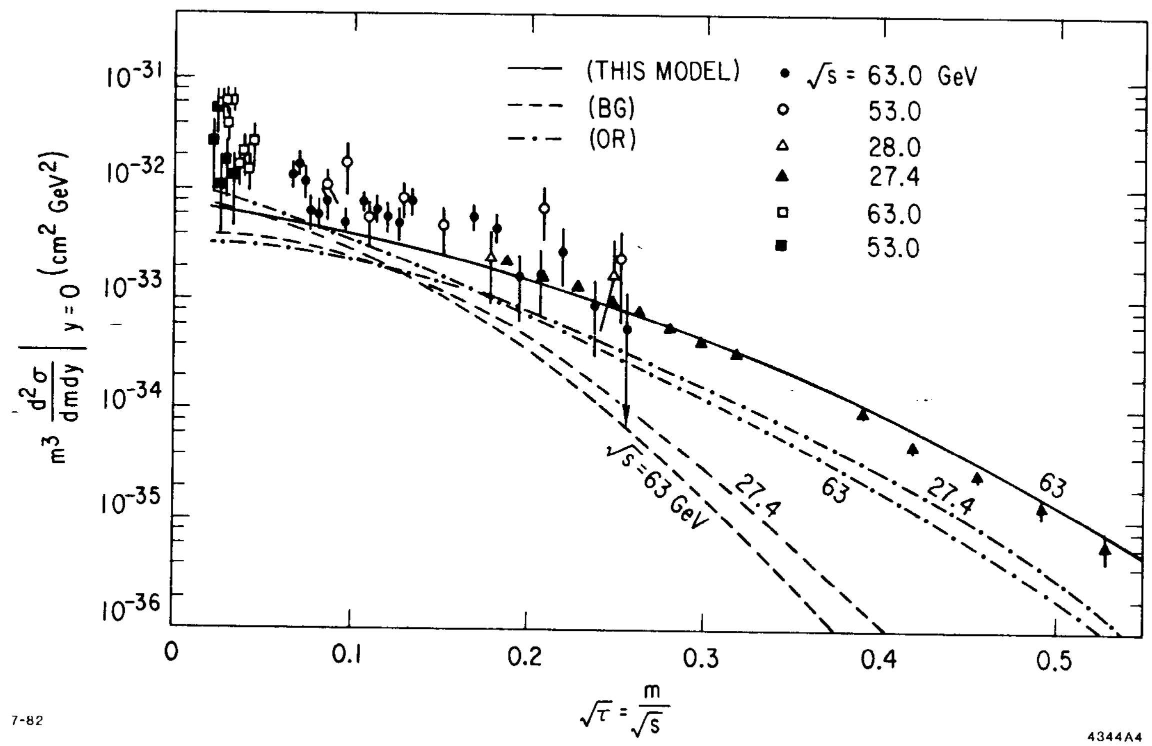
SLAC (ep)
EMC 120 GeV
EMC 280 GeV
x=0.25
0.35
0.45
0.55
0.65
0.4
0.3
0.2
0.3
0.2
0.2
0.1
0.18
0.10
0.08
0.06
0.05
0.04
0.03
0.02
$F_2^{\mu p}$
2
5
10
20
50
100
200
Q^2 (GeV^2)
7-82
4344A2

Fig. 1(a)



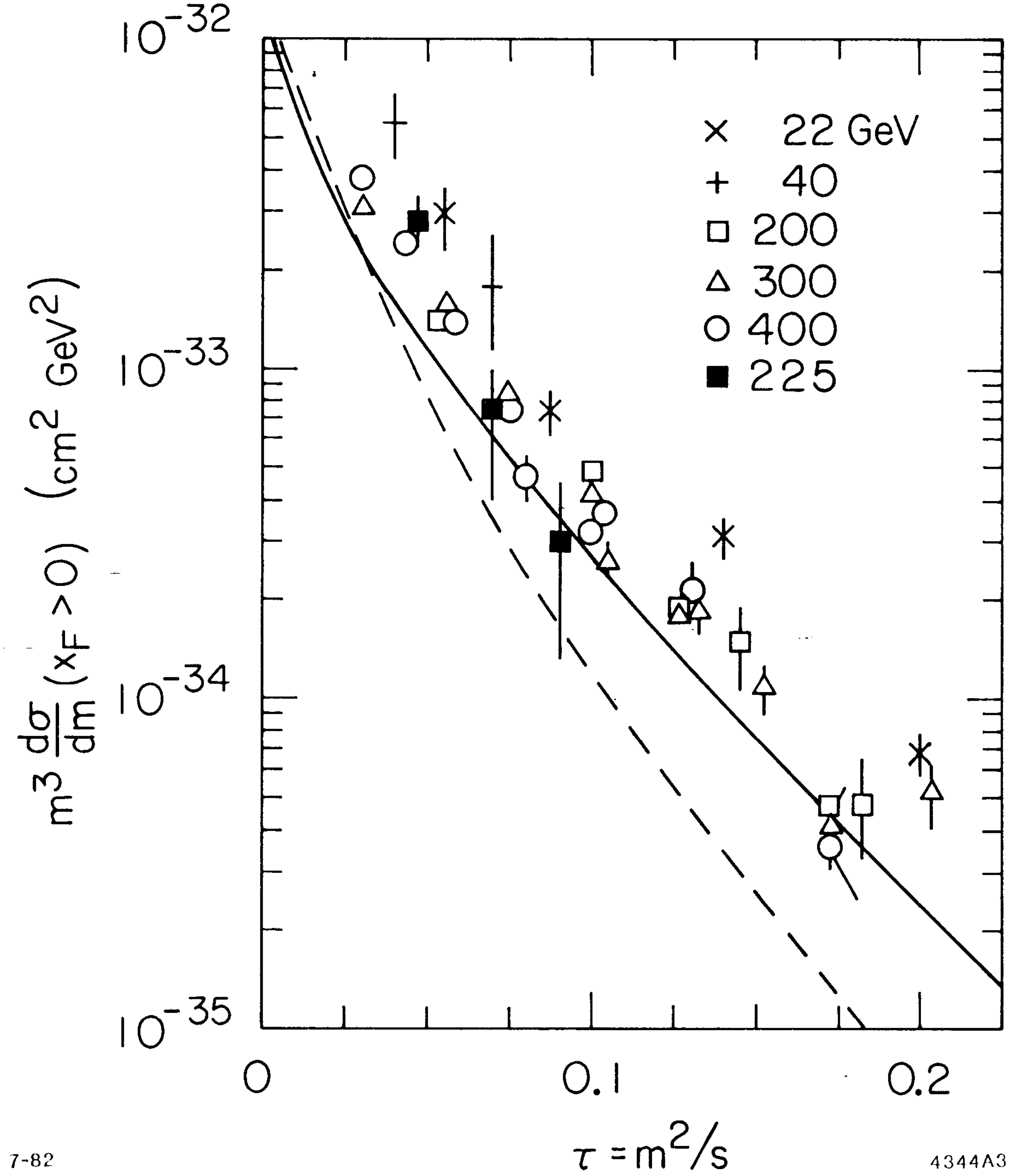
0.6
0.4
0.2
0
Q^2=36 (GeV^2)
30<Q^2<50 (GeV^2)
0.4
0.2
0
Q^2=20 (GeV^2)
15<Q^2<30 (GeV^2)
0.4
0.2
0
Q^2=11.5 (GeV^2)
8<Q^2<15 (GeV^2)
$F_2^{ep,\mu p}$
1.0
0.05
0.1
0.5
1.0
X
7-82
4344A1

Fig. 1(b)



(THIS MODEL)
(BG)
(OR)
$\sqrt{s}$ = 63.0 GeV
53.0
28.0
27.4
63.0
53.0
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
$m^3 \left.\frac{d^2\sigma}{dm\,dy}\right|_{y=0}$ (cm^2 GeV^2)
0
0.1
0.2
0.3
0.4
0.5
$\sqrt{\tau} = \frac{m}{\sqrt{s}}$
$\sqrt{s}$ = 63 GeV
27.4
63
27.4
63
7-82
4344A4

Fig. 2(a)



10^{-32}
10^{-33}
10^{-34}
10^{-35}
$m^3 \frac{d\sigma}{dm} (x_F > 0) \quad (cm^2 \; GeV^2)$
× 22 GeV
+ 40
□ 200
△ 300
○ 400
■ 225
0
0.1
0.2
$\tau = m^2/s$
7-82
4344A3

Fig. 2(b)