DEUTSCHES ELEKTRONEN-SYNCHROTRON DESY

DESY 76/03
January 1976

Are Neutral Heavy Leptons Being Produced?

by

T. C. Yang

2 HAMBURG 52 · NOTKESTIEG 1

Are Neutral Heavy Leptons Being Produced?

by

T. C. Yang
Deutsches Elektronen-Synchrotron DESY, Hamburg

Abstract:

Preliminary data is not conclusive but seggests that neutral heavy leptons may already be produced by neutrinos, perhaps along with new hadrons. Neutral heavy lepton production contributes substantially to the "y anomaly". We show how to distinguish new hadrons and neutral heavy lepton production.

Neutrino and anti-neutrino induced dimuon events have recently been reported,[1,2] suggesting the production and subsequent decay of one or more intermediate particles. It was pointed out that the data does not agree with the hypothesis of semi-weak vector bosons and neutral heavy leptons.[3] From that it was concluded that the data suggests the production of new hadrons.[4]

We will first review the arguments against the neutral heavy lepton hypothesis as an explanation of the data. The main argument comes from the Pais-Treiman bound[5] which requires that the ratio of the average momenta of the dimuon events satisfy $1/2 \leq \langle p_- \rangle / \langle p_+ \rangle \leq 2$ for $V \pm A$ currents, if due to heavy leptons. Experimentally, the ratio is $\langle p_- \rangle / \langle p_+ \rangle = 3.7 \pm 0.7$. We intend to show that a small "background" (for the purpose of this note, background means anything not coming from heavy leptons, including possible new hadron contribution) can easily upset the Pais-Treiman bound for heavy leptons. We find that with 10 ~ 30% background, the dimuon data can be explained by heavy lepton hypothesis and thus the heavy lepton production and decay can not yet be ruled out.

Next we will pursue experimental tests for neutral heavy leptons, if produced along with the new hadrons. Since whether such a heavy lepton exists or not will place an important constraint on future gauge models of weak and electromagnetic interactions, we are obliged to investigate whether there is evidence of heavy lepton production (independent of whether other particles are also produced or not) in dimuon as well as single muon events. Present data has large uncertainties; taking the average values, the data however indicates that a heavy lepton M^o might already be produced.

If dimuon events come from neutral heavy lepton production and decay, the dimuon mass distribution should be independent of the neutrino energy and cut off above at the mass of the heavy lepton. Experimentally data at different neutrino energies has 70% or more of the events with dimuon mass less or around 5 GeV and is compatible with an M^o of mass ~ 5 GeV.[3] (Data[4] beyond ~ 5 GeV seems unrelated and is assumed to be background). If we cut off the data with dimuon mass larger than, say, 5.2 GeV (which amounts to 6 events out of 51 events from a dominantly-neutrino run[6] we find the ratio of average momentum to be $\langle p_- \rangle / \langle p_+ \rangle = 2.75 \pm 0.7$; the lower limit is close to 2. We note further that if an M^o is produced and decays, one can no longer expect that every event with $p_{\mu+} > p_{\mu-}$ is always induced by antineutrino. Although neutrino induced events tend to have $p_{\mu-} > p_{\mu+}$ for most events, some events can have $p_{\mu+} > p_{\mu-}$.

Indeed, some events with $p_{\mu-} > p_{\mu+}$ can also be induced by anti-neutrino. Lacking a method for separating these events, we can only calculate the ratio of the average momentum for all the data. We conclude from these remarks that the ratio of the average momentum is rather sensitive to background[7] which tends to have large $p_{\mu-}/p_{\mu+}$ ratio. A small background inside the data[7] with $M \lesssim 5.2$ GeV could again modify the above value 2.75 ± 0.7 to within the Pais-Treiman bound. Thus the possibility that an M^o is responsible for $\sim 70\%$ of the data can not at this time be ruled out. An M^o with V - A interaction gives $\langle p_-\rangle/\langle p_+\rangle \sim 1.2 - 1.8$.[3]

The observed W_{min} $(\sim(s\bar{y}_{vis}(1-\bar{x}_{vis}))^{1/2})$ distribution[8] of the system recoiling against the negative muon is presented in Fig.1,[4] together with the theoretical distribution due to an M^o with neutrino energy $E_\nu = 50$, 100 GeV. For the theoretical distributions, we have assumed $M^o = 5$ GeV. We also assume that M^o couples to leptons and hadrons with V - A weak currents with hadronic structure functions described by electroproduction[9] and the coupling constants as free parameters. The relative normalization for each curve as well as for ν_μ versus $\bar{\nu}_\mu$ are however fixed in each figure. We note that the present data has only a small number of events. By experimental reason only a fraction of these contain information on W_{min} . For the observed W_{min} distribution, we note[6] that most of the events in Fig.1 (especially those under the $E_\nu = 50$ GeV curve) have $E_{vis} < 50$ GeV. If one assumes that these events are induced by high energy neutrinos ($\sim$ 100 - 150 GeV), the average value $\alpha \equiv \langle E_{vis}\rangle/E$ would be too small ($\lesssim 0.3 - 0.5$) as compared with the theory - we calculate α with an M^o production and we find for a V - A interaction, $\alpha = 0.77, 0.8, 0.82$ for $E_\nu = 50, 100, 150$ GeV. For this reason we believe that the events in Fig.1 for which the W_{min} information exists are mostly induced by low energy neutrinos. With this in mind, we find that an M^o production with $E_\nu \sim 50$ GeV is in good qualitative agreement with data. The fact α cannot be too small (or ν_μ^{out} cannot consume most of the energy) is actually more general than the particular interaction assumed and will hold in most theories. Thus it is probably questionable to compare the present data with theoretical predictions, folding in high energy neutrino contributions as in the spectrum. In order to make a further illustration on this point, we compare the observed E_{vis} distribution[4] with the neutrino energy spectrum $\rho(E_\nu)$. If we assume that $d\sigma/dE_{vis}$ for fixed E_ν cluster around $\langle E_{vis}\rangle$ and α varying slowing with energy, then the observed E_{vis} distribution on scales larger than cluster width should be proportional to $\rho(E_\nu)\sigma(E_\nu)D(E_\nu)$ up to a factor α where σ and D are the dimuon cross section and detection efficiency. The reported $\sigma(E_\nu)$ at $E_\nu = 50$ and 150 GeV is consistent with an M^O production and decay. Assuming $\sigma(M^O)$, the observed E_{vis} distribution[4] again are dominately due to low energy neutrinos.

Theoretical distributions for $\bar{y}^+_{vis}$, y_{vis} , $\bar{V}^+$ and $\bar{x}^+_{vis}$ [8] are given in Fig.2 and 3 to compare with the data.[2,4] We find an M^O production with $E_\nu \sim 50$ GeV is not contradicted by the data. The deviation from the theoretical distribution could be due to background which does not reflect itself so dramatically as in $\langle p_- \rangle / \langle p_+ \rangle$ ratio. In any case, the small number of events makes comparison only qualitatively meaningful. The small number of dimuon events of the same sign again could imply non-zero background which we do not know how to estimate theoretically if we assume associated production of (new) hadron pairs and decays.

We conclude from the above remarks that neutral heavy lepton production and decay can not yet be ruled out by the present dimuon data. It may well be more natural that more than one intermediate particles are being produced. We pursue this idea by giving experimental tests of the hypothesis that heavy lepton production is responsible for a significant fraction of the dimuon events. The following distributions show contrasting predictions of heavy lepton versus new hadron production which can be used to check each theory:

(1) Single muon y distribution of the new particles. Subtracting the low energy y distribution from the high energy ($E_\nu > 30$ GeV) single muon y distribution data[10] (Fig.4) and integrating over x , we obtain the y distribution $\frac{d\sigma'}{dy}$ due to production of new particles (Fig.5a) - where for definiteness, we have used the Barger et al.[11] fit for the ordinary hadron contribution. Since we need only be qualitative, the uncertainty in the theoretical fit is probably not crucial. The "y anomaly" is largely responsible for the anti-neutrino $\frac{d\sigma'}{dy}$. We note the neutrino $\frac{d\sigma'}{dy}$ data has also similar magnitude and shape as the anit-neutrino data. The heavy lepton hypothesis predicts $\frac{d\sigma'}{dy}$ peaks at large y[3] whereas the new hadron production predicts flat or decreasing y distribution at large y barring S,P interactions. Present data has large uncertainty,[12] but the average values, especially in the $\bar{\nu}_\mu$ case, seem to peak at large y , suggesting possible neutral heavy lepton production- if so, one should first subtract heavy lepton contribution before testing current algebra sum rules. An M^O production also predicts approximate equality of $\frac{d\sigma'}{dy}$ for ν_μ and $\bar{\nu}_\mu$ favored by present data. $\frac{d\sigma'}{dy}$ in charm models should differ significantly

for ν_μ versus $\bar{\nu}_\mu$ if valence quark contribution should dominate as indicated by present data.[13]

(2) Dimuon y distribution.- Dimuon events induced by new hadrons (denoted Y) should have exactly similar y distribution as $\frac{d\sigma'}{dy}$ of the single muon. This is because the y distribution is independent of how Y decays; nonleptonic decays contribute to single muon events and leptonic plus semi-leptonic decays to dimuon events. More specifically, in the parton model the y distribution is a property of the current only, the dimuon y distribution is the product of $\frac{d\sigma'}{dy}$ times the decay branching ratio, and and threshold effects, beam spectrum, detection efficiency all affect both processes simultaneously. The y distribution due to M^0 decay depends however on energy and on the decay matrix elements. Experimentally, only the $y^{\mp}_{vis}$ distribution is presently measured. With reasonable estimates of the final neutrino energy, one finds the shift from $y^{\mp}$ to $y^{\mp}_{vis}$ is smooth and relatively small, thus comparison with $\frac{d\sigma'}{dy}$ of single muon data may also test the new hadron hypothesis. The new hadron hypothesis does not seem to reflect the tendency of the data (Fig.5a, 5c). An M^0 production seems consistent with the data (Fig.5a,5b).

(3) One should look for threshold effect in neutral current induced processes due to M^0 production and subsequent decay to neutrino plus hadrons.[14] Neutral currents usually do no excite charm.

(4) M^0 could contribute to different rates for dilepton $\mu^+\mu^-$, e^+e^- and $\mu^{\pm}e^{\mp}$ events, since both charged current and neutral current contribute to $\mu^+\mu^-$ events, only the charged current contributes to $\mu^{\mp}e^{\pm}$, and only the neutral current contributes to e^+e^-. <u>e^+e^- induced by ν_μ will be direct evidence for an M^0 production</u>.

Lepton spectrum.- If in fact an M^0 induced by ν_μ should exist experimentally, by μ-e universality, we expect a heavy E^0 lepton should also exist and be produced by ν_e. The natural conclusion will be that the leptons, e.g. μ^-, ν_μ, M^0 form triplets. Generalized to include the charged new lepton favored for SLAC $\mu^{\pm}e^{\mp}$ events,[15] there will probably be nine leptons.[16] Another option will be to put leptons in doublets rather than triplets. Then M^0 must mix with ν_μ in order to be produced. In such a model, μ-e universality may be difficult to maintain and CVC (conserved vector current) compared with muon decay may be spoiled by the new leptonic mixing angle.

ACKNOWLEDGEMENT

I thank my colleagues at DESY for comments, H. Joos and T. Walsh for carefully reading the manuscript and T. Y. Ling for experimental information.

REFERENCES

1. A. Benvenuti et al., Phys. Rev. Lett. 34, 419 (1975); ibid 35, 1199 (1975); B. C. Barish et al., CALT-68-495.

2. A. Benvenuti et al., Phys. Rev. Lett. 35, 1249 (1975).

3. L. N. Chang, E. Derman and J. N. Ng; Phys. Rev. Lett. 35, 6 (1975); C. H. Albright (to be published).

4. A. Benvenuti et al., Phys. Rev. Lett. 35, 1203 (1975).

5. A. Pais and S. B. Treimann; Phys. Rev. Lett. 35, 1206 (1975).

6. I thank T. Y. Ling for information on data reported in Ref.4.

7. Similar point has been raised by B. C. Barish regarding π, K background, CALT-68-521 (presented at the Lepton Photon Symposium, Stanford, 1975). The HWPF data is consistent with 30% contamination due to π , K-decay.

8. For definition see, for example Ref.4 .

9. See C. H. Albright, Ref.3. Our computer calculation agrees qualitatively with Ref.3.

10. B. Aubert et al., Phys. Rev. Lett. 33, 984 (1974).

11. V. Barger, T. Weiler and R.J.N. Phillips; Phys. Rev. Lett. 35, 692 (1975), Fig.2 .

12. M^o production predicts $\frac{d\sigma'}{dy}(\nu_\mu) = \frac{d\sigma'}{dy}(\bar{\nu}_\mu)$ at y = 0. Recent HWPF and Calt-Fermilab data disagree near y = 0.

13. B. C. Barish, Ref.7.

14. I am indebted to L. Clavelli for the remarks.

15. M. L. Perl et al., Phys. Rev. Lett. 35, 1489 (1975).

16. T. C. Yang, Maryland report 75-025. The Cabibbo angle is determined in this model (T. C. Yang, to be published). The prediction of new heavy leptons can be used as a test. A different lepton model has been proposed by B. Stech, Heidelberg preprint.

FIGURE CAPTIONS

Fig.1 Observed W_{min} distribution compared with the heavy lepton (of mass 5 GeV) prediction. The dashed curve is 8 times smaller than its actual size. The cross hatched area denotes data with $p_+ > p_-$ in the ν_μ run. Relative normalization of the curves is fixed.

Fig.2 Comparison of data in $y^{\mp}_{vis}$ and y_{vis} distributions with heavy lepton predictions. See Fig.1 caption.

Fig.3 Comparison of data in $V^{\pm}$ and $x^{\mp}_{vis}$ distribution with heavy lepton predications. See Fig.1 caption.

Fig.4 Single muon y distribution. The dashed lines are the "uncharmed" background by quark-parton-model.

Fig.5 (a) $\frac{d\sigma'}{dy}$ of the new particle contribution.

(b) Dominant contribution to $\frac{d\sigma'}{dy}$ due to semi-leptonic decay of M^{O}.

(c) Dimuon $y^{\mp}_{vis}$ distribution for comparison with (a).

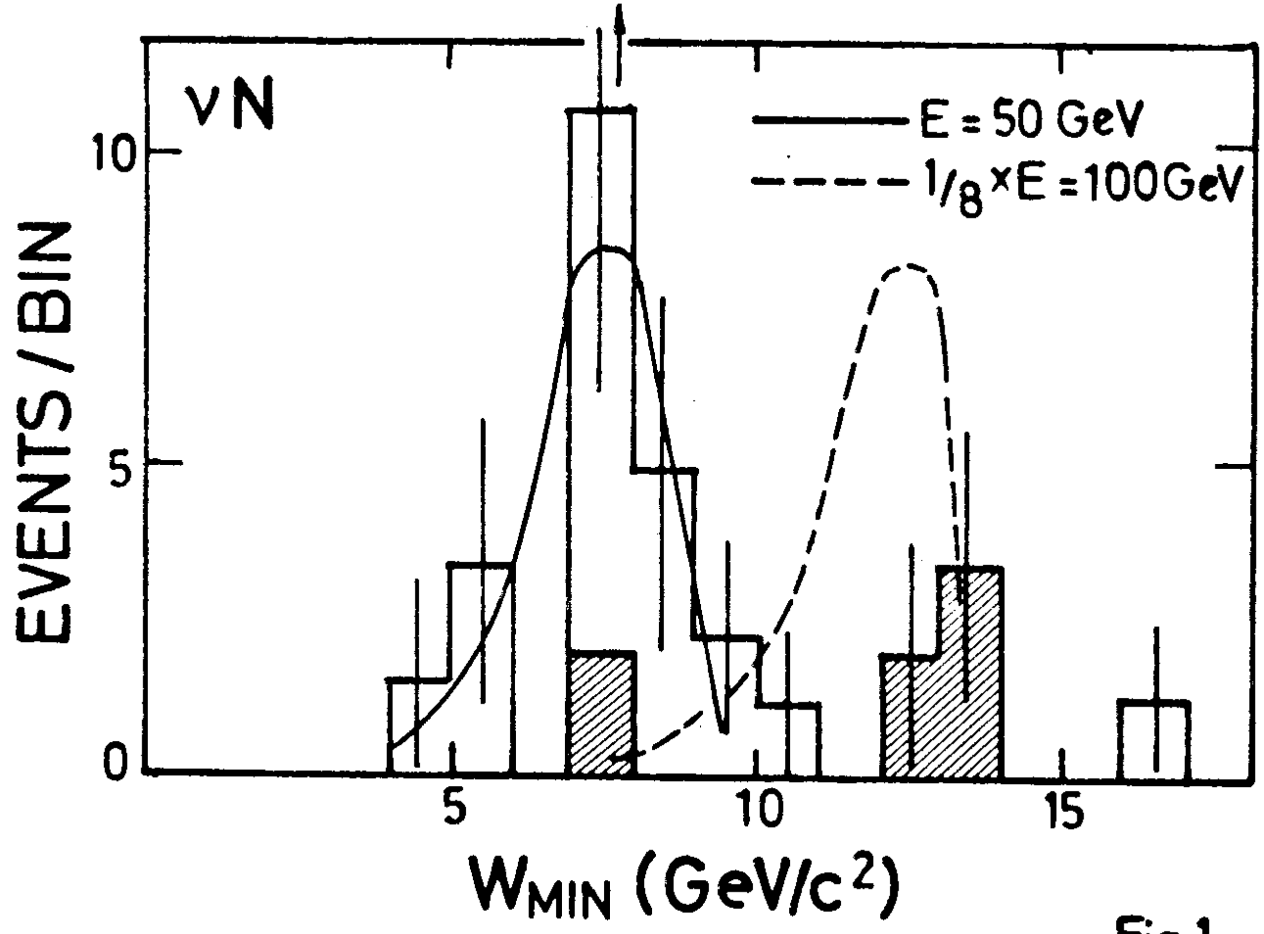
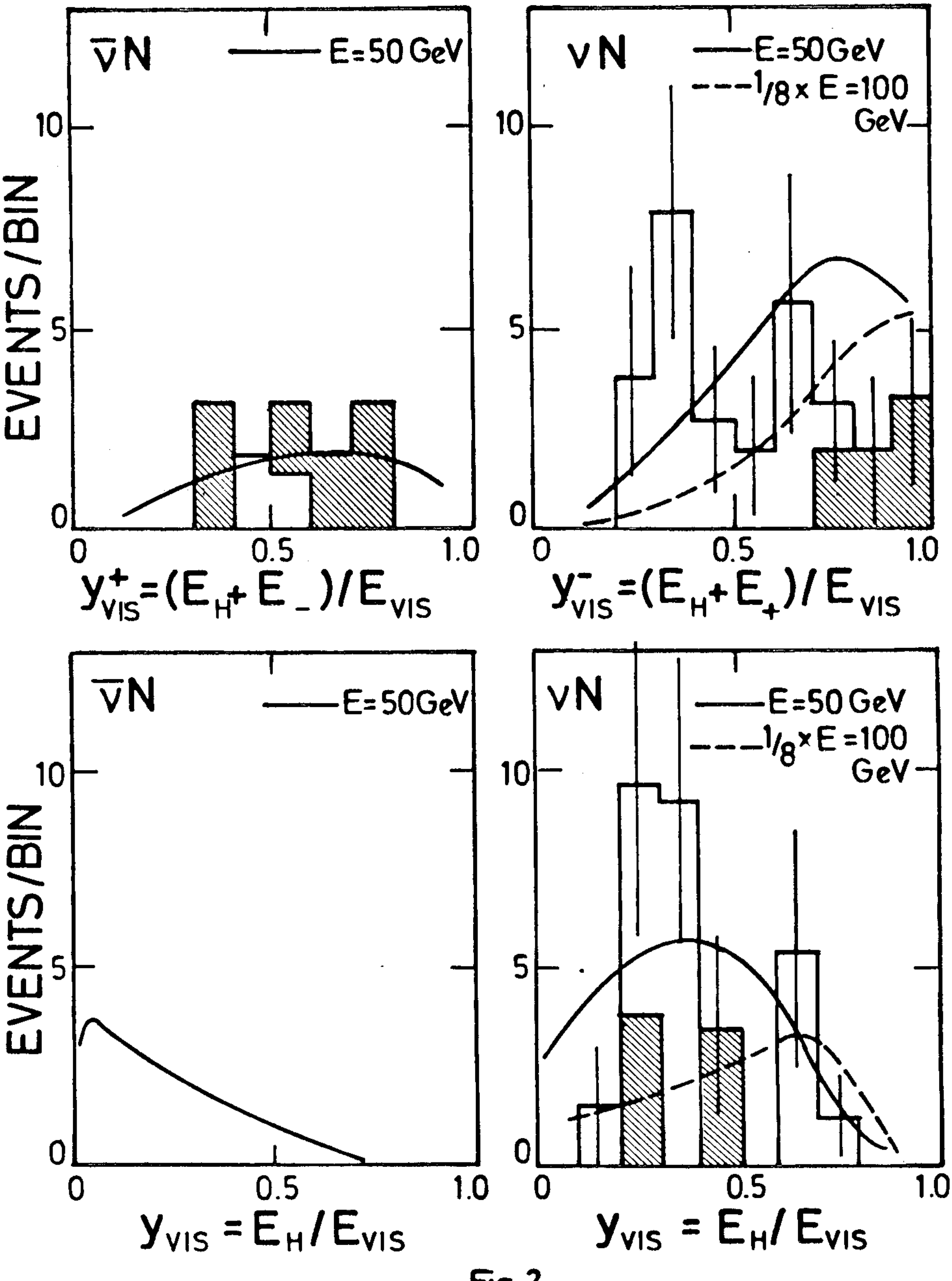


Fig.1



$\bar{\nu}$N
E=50 GeV
EVENTS/BIN
10
5
0
0
0.5
1.0
$y^+_{VIS}=(E_H+E_-)/E_{VIS}$
νN
E=50GeV
1/8 x E=100 GeV
10
5
0
0
0.5
1.0
$y^-_{VIS}=(E_H+E_+)/E_{VIS}$
$\bar{\nu}$N
E=50GeV
EVENTS/BIN
10
5
0
0
0.5
1.0
$y_{VIS}=E_H/E_{VIS}$
νN
E=50 GeV
1/8 x E=100 GeV
10
5
0
0
0.5
1.0
$y_{VIS}=E_H/E_{VIS}$

Fig.2

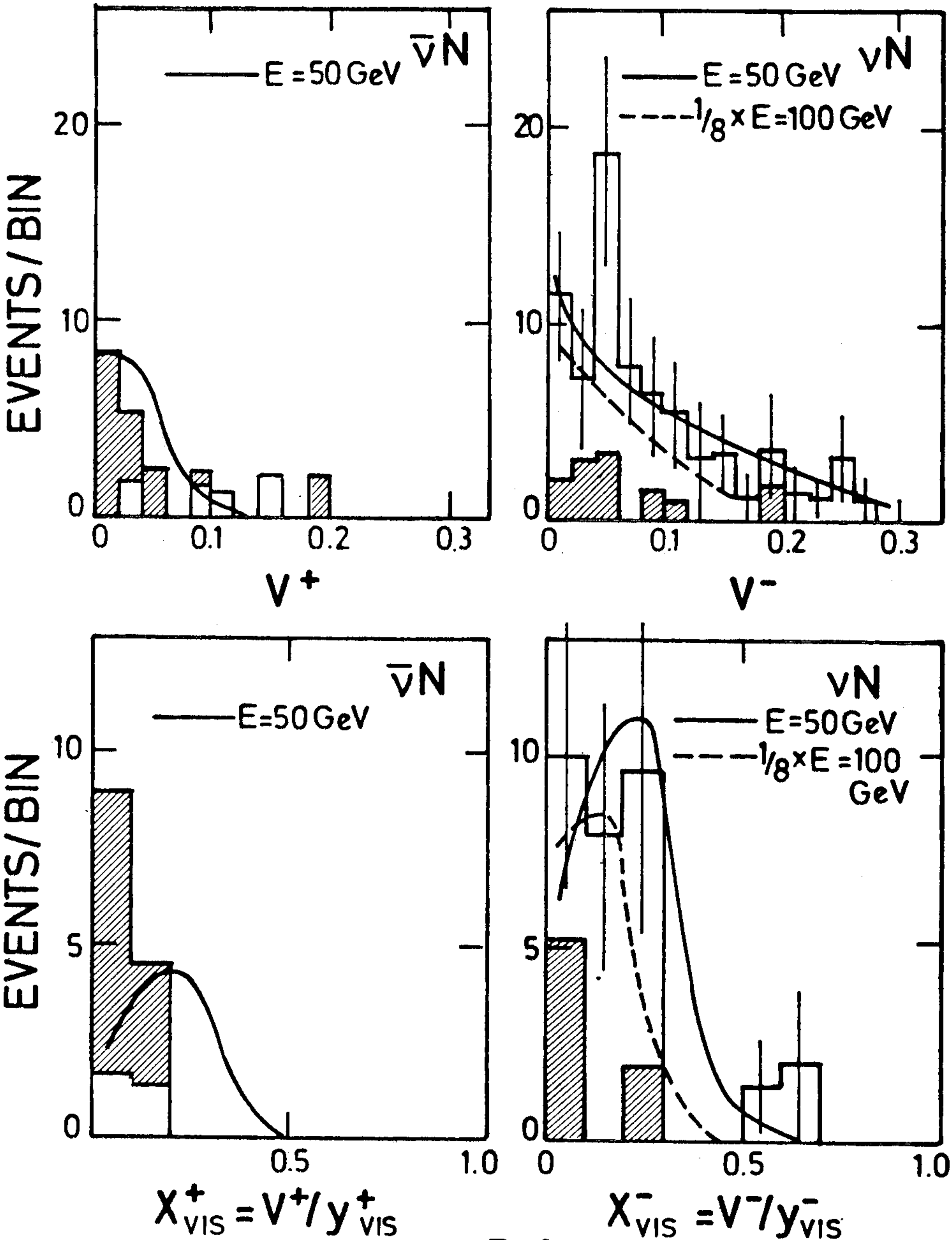

EVENTS/BIN
E = 50 GeV
$\bar{\nu}N$
20
10
0
0
0.1
0.2
0.3
V^+
E = 50 GeV
1/8 x E = 100 GeV
νN
20
10
0
0
0.1
0.2
0.3
V^-
EVENTS/BIN
E=50 GeV
$\bar{\nu}N$
10
5
0
0.5
1.0
$X^+_{VIS} = V^+/y^+_{VIS}$
νN
E=50GeV
1/8 x E =100 GeV
10
5
0
0
0.5
1.0
$X^-_{VIS} = V^-/y^-_{VIS}$

Fig.3

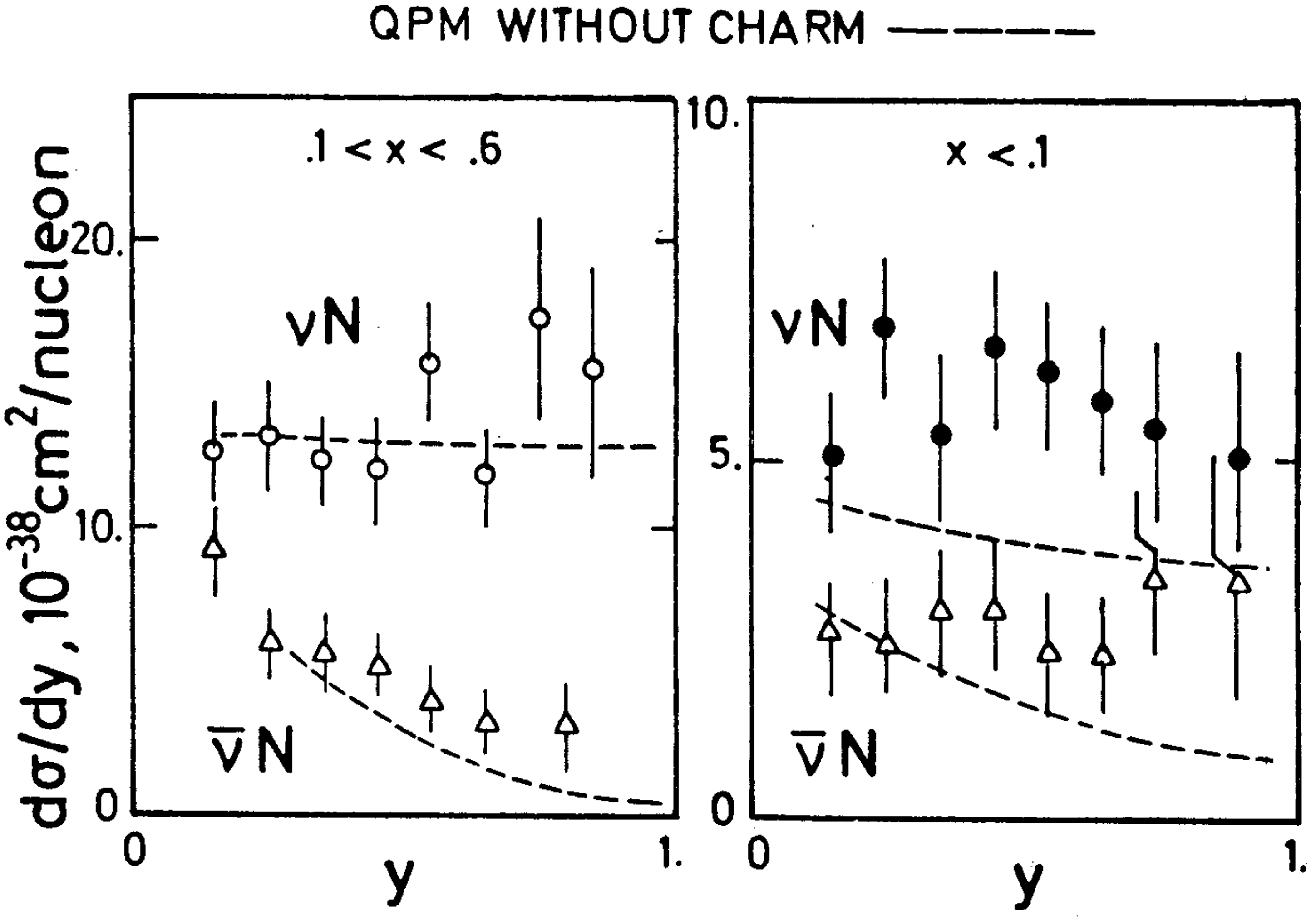
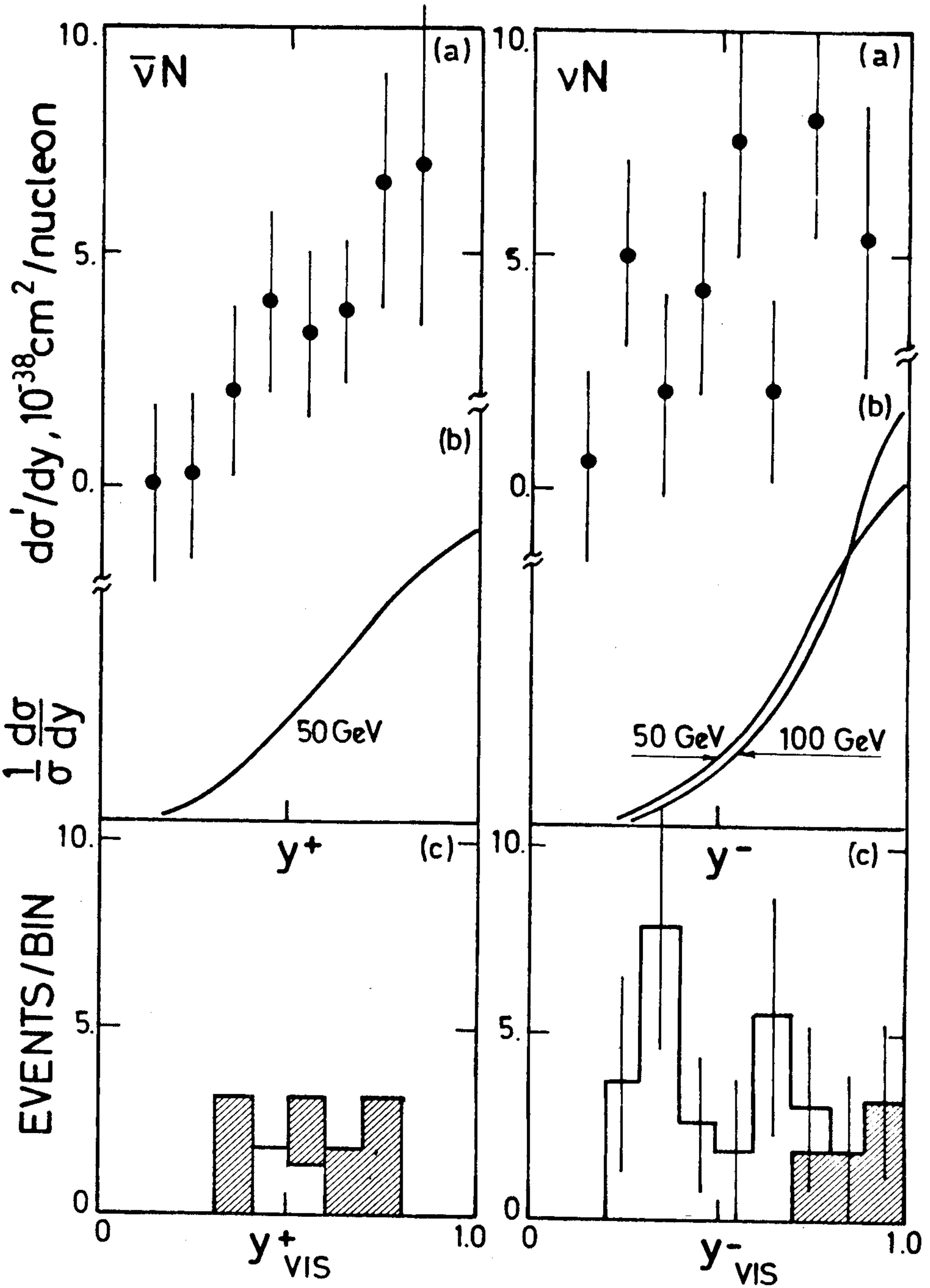

QPM WITHOUT CHARM ------
.1 < x < .6
x < .1
νN
ν̄N
dσ/dy, 10⁻³⁸cm²/nucleon
20.
10.
5.
0
1.
y

Fig.4



$\bar{\nu}N$
νN
(a)
(b)
(c)
$d\sigma'/dy$, $10^{-38}cm^2$/nucleon
$\frac{1}{\sigma}\frac{d\sigma}{dy}$
50 GeV
100 GeV
y^+
y^-
EVENTS/BIN
y^+_{VIS}
y^-_{VIS}
0
5.
10.
1.0

Fig.5