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$\mu^+\mu^-$ DISTRIBUTIONS FROM THE PRODUCTION OF A NEW HADRON IN NEUTRINO SCATTERING‡

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ABSTRACT

We have analysed dimuon distributions due to the diffractive production of a new hadronic vector boson in neutrino scattering. Characteristic features that distinguish this mechanism from heavy lepton mediated dimuon distributions are presented.

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In this note we examine dimuon distributions in high energy neutrino-nucleon scattering[1] which are due to the diffractive production of a new hadron. Similar distributions for heavy lepton (L^o) mediated events were considered in Ref. 2. We focus here on features that distinguish between the two possibilities. For comparison with data, the reader is referred to Ref. 1.

For purposes of concrete illustration, we shall consider the diffractive production of a <u>hadronic</u> heavy vector boson, F^{*+}, which then decays semi-leptonically (see Fig. 1):

$$\nu(k) + N(p) \to \mu^-(k^-) + F^{*+}(f) + X(p_X) \tag{1a}$$

$$\hookrightarrow \mu^+(k_+) + X' + \nu(k') \tag{1b}$$

The resulting distributions, as we shall explain, are largely independent of the details of the model for (1a), since they are basically controlled by the kinematics of hadron production. Thus we shall not discriminate among the currently popular hadron spectroscopy schemes, including those with charm or color, all of which require the existence of such bosons. For definiteness we assume a mass $M_F = 3\ \mathrm{GeV}/c^2$ for the vector boson F^{*+}.

Although the precise way in which the semi-weak diffractive scattering occurs is as yet unclear, the following features may be deduced from photo- and electroproduction of ρ mesons.[3] Firstly, there is a pronounced peak in the momentum transfer squared, $t = (p-p_X)^2$, from the nucleon to the hadrons, with a width $1/b$. This means that the recoil hadrons get very little energy in the laboratory frame. Secondly, s-channel helicity conservation apparently holds; and finally, diffractive dissociation of the target gives a distribution in recoil hadronic mass of the form $f(M_X^2) \sim 1/M_X^2$ for fixed t. We shall assume that all these features persist in reaction (1). The inclusive cross section for (1.a) will be controlled by the structure function

$$W_{\mu\alpha;\nu\beta} \sim \sum_{X} < N \mid J_{\nu}^{+} \mid X;F_{\beta}^{*+} > < X;F_{\alpha}^{*+} \mid J_{\mu} \mid N > \delta^{4}(q+P-f-X) \quad (2)$$

where J_{μ} is the hadronic weak current and α, β denote the polarization indices of the F^{*+} boson. We assume that $W_{\mu\alpha;\nu\beta}$ may be adequately represented by

$$W_{\mu\alpha;\nu\beta} = (q{\cdot}f\, g_{\mu\alpha} - q_{\alpha} f_{\mu})(q{\cdot}f\, g_{\nu\beta} - q_{\beta} f_{\nu})\, W(q^{2}, q{\cdot}P, q{\cdot}f, M_{X}^{2}) \quad (3)$$

This tensorialform assumes the conservation of both the weak current and the source current responsible for F^{*+} production, and that the weak current is pure vector. Note that $W^{*}_{\mu\alpha;\nu\beta} = W_{\nu\beta;\mu\alpha}$ and W is real.

For $q^2 = f^2$, and for forward scattering with $q = f$ and $t = 0$, (2) conserves helicity. Since the dominant contributions to the cross section in diffractive scattering will come from $t \simeq 0$, and for q^2 small (see below), this matrix element therefore approximates s-channel helicity conservation. The precise dependence of $W(q^2, q{\cdot}P, q{\cdot}f, M_X^2)$ on its arguments is obtained by assuming the same tensorial structure of (2) for calculating ρ^{o} photoproduction. Requiring that the t and M_X^2 dependence be as described above yields

$$W \sim \frac{e^{bt} f(M_X^2)(s)^2}{\left(1 - \frac{q^2}{m_F^2}\right)^2 (t - M_F^2)^2} \quad (4)$$

where $s = (q + p)^2$, and the factor $(1 - q^2/M_F^2)^2$ is the empirical dependence on q^2 deduced from electroproduction data for small q^2, consistent with vector meson dominance. For simplicity we shall suppose that (4) holds for all q^2. We set

$b = 3\ \mathrm{GeV}^{-2}$ from ψ - photoproduction[4]. The final distributions are then obtained by a Monte Carlo integration with 200,000 events. We estimate an accuracy of about 20%.

Since the coupling strength of the new hadron whose production we are considering is unknown, the overall normalization of the cross section is left unspecified although most models could easily accommodate the reported rate. The energy dependence of the total cross section for F^{*+} production in our model is empirically found to be $\sim s\ell n^2(s/M_F^2)$ between 50 and 400 GeV. This logarithmic violation of scaling in neutrino diffractive production of the F^{+*}, if correct, should manifest itself in the total neutrino cross section above threshold. Our main aim below, however, is to discuss the behaviour of dimuon <u>distributions</u> typical of such a production mechanism. Although our results were specifically obtained from (4), they are sensitive only to the topological structure displayed in Fig. 1.

The crucial factor determining hadron-mediated dimuon events is that the primary μ^- is scattered promptly, so that dimuon pairs are produced non-locally (see Fig. 1). The dimuon mass ($M_{\mu\mu}$) distribution will therefore tail out towards larger values, with a shape and upper limit which depend upon the incoming neutrino energy E_ν (see Fig. 2). This is in marked contrast to heavy lepton mediated pairs. which are produced locally[2] and therefore have an $M_{\mu\mu}$ shape and upper bound independent of E_ν. At the same time, since the F^{*+} could pass only a small fraction of its energy onto the μ^+, the energy asymmetry $\alpha = (<E_-> - <E_+>)/(<E_-> + <E_+>)$ between the two muons could then approach values of $0.5 \sim 0.6$. This is in contrast to heavy lepton mediated pairs, where optimal values are ~ 0.3.

Figures 3a and 3b show the μ^-, μ^+ and hadronic energy (E_h) spectrum for $E_\nu = 50$ GeV. The E_- distribution extends to large values, characteristic of hard, prompt scattering, whereas the E_+ and E_h spectra resemble each other by sharply peaking for small values. This similarity is due to the fact that since diffraction imparts little energy to the nuclear target both the μ^+ and hadrons obtain their energy through the semileptonic decay of the F^{*+}. By contrast, in heavy lepton mediated events[2], the μ^- and μ^+, being decay products, have similar energy spectra, peaked for small energies, whereas the hadronic distribution extends to large energies.

Another distinguishing feature between heavy lepton and diffractive hadron mediated dimuon events is the behaviour of Q_-^2, or $v_- = Q_-^2/2ME_\nu$, where $Q_\pm^2 = -(\mathbf{k}-\mathbf{k}_\pm)^2$, and M denotes the nucleon mass. For diffractive production the v_- distribution (Fig. 4) has a zero at $v_- = 0$. This occurs because of the current-conserving form of $W_{\mu\alpha;\nu\beta}$ based on ρ^0-electroproduction, which leads to a kinematic zero in Q_-^2, and hence in v_-. Such a zero does not occur in heavy lepton production, where the kinematic zero is cancelled in the deep inelastic limit by the behaviour of the structure functions at $x_- = 0$. A similar compensation could occur in a diffractive framework too, although it would not lie within the spirit of weak Q_-^2 dependence we are using here.

Yet another signal for non-local or local dimuon production is the energy dependence of the ratio $\gamma = \langle Q_+^2 \rangle / \langle Q_-^2 \rangle \equiv \langle v_+ \rangle / \langle v_- \rangle$. The Q_-^2 distribution from (4) approaches scaling to within logarithms rapidly as E_ν increases, reflecting primary μ^- emission at an average angle $\theta_- \sim \sqrt{M/E_-}$ relative to the incident neutrino. The secondary μ^+ is, however, a decay product of the

F^{*+}. At lower E_ν, the F^{*+} emerges slowly from the diffractive scattering. The average angle θ_+ between the incident neutrino and the μ^+ is then determined by the mass of the parent, M_F, to be $\theta_+ \sim M_F/2E_+$, with average $Q_+^2 = < 4E_\nu E_+ \sin^2 \frac{\theta_+}{2} > \sim \frac{E_\nu}{< E_+ >} M_F^2$, which varies slowly with E_ν compared to the scaling Q_-^2. As E_ν increases so that M_F is negligible, the μ^+ emerges parallel to the F^{*+}, with $\theta_+ = \theta_- \approx \sqrt{M/E_-}$, since the diffractively excited hadrons carry little momentum. At this stage both Q_+^2 and Q_-^2 scale. The ratio γ decreases rapidly with E_ν between 50 and 200 GeV, shown in Table I, and then remains constant. In contrast, for L^o mediated events, γ is constant over the whole range since both muons reflect the behaviour of their parent L^o.

In passing, we point out that a possible asymmetry, τ, of the μ^+ about the μ^- production plane, is actually absent in our model. A non zero τ could arise either from time-reversal violation or from strong final state interactions which change the relative phases of interfering amplitudes, or both[2]. Thus unless time reversal is violated, a finite τ would rule out heavy lepton mediated pairs. The form of (2) chosen here for $W_{\mu\alpha;\nu\beta}$ ensures the absence of τ-inducing correlations of the type $\vec{k}_+ \cdot (\vec{k} \times \vec{k}_-)$ in the cross section; this is expected for diffractive scattering since diffractive amplitudes are generally pure imaginary.

The most recent data on dimuon pairs[1] can be used to assess its compatibility with F^{*+} production considered above. The energy asymmetry α and the dimuon mass distribution $M_{\mu\mu}$ are in qualitative agreement. However, the v_- distribution of Ref. 1 for dimuons is consistent with the single muon v_- distribution, and within the limits of experimental resolution shows no zero at $v = 0$. This possible inconsistency with diffraction, if confirmed, would suggest that single and dimuon reactions both occur via scattering off valence partons, and could exclude diffractive production as a dimuon mechanism.

Finally, we stress the model-independent nature of our qualitative results for $M_{\mu\mu}$, the $E_{\pm}$ asymmetry, and the energy dependence of Q_{+}^{2}/Q_{-}^{2}. The behaviour of these distributions in hadron or L^{0}-mediated production depends mainly on the non-local or local origin of the dimuons, and should obtain in any model for hadron production.

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Footnotes and References

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2. L. N. Chang, E. Derman, J. N. Ng, Phys. Rev. Letters **35**, 6 (1975).
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TABLE I

Average $< Q_{\pm}^2 >$ for various incoming neutrino energies E_ν, for $M_F = 3$ GeV/c^2. $\gamma \equiv Q_+^2/Q_-^2$ measures the asymmetry.

E_ν (GeV)	Q_+^2 (GeV/c^2)	Q_-^2 (GeV/c^2)	γ
50	7.6	13.3	0.57
100	9.4	28.3	0.33
200	15.1	55.4	0.27

Figure Captions

Fig. 1: Schematic diagram of diffractive neutrino production of hadronic vector meson F^{*+} which decays semileptonically. Symbols for particle momenta are shown in brackets.

Fig. 2: Dimuon mass distribution for $E_\nu = 50$ GeV and $M_F = 3$ GeV/c^2 (normalized to 10 events).

Fig. 3a: Energy, $E_\pm$, distributions for $\mu^\pm$ in the process of Fig. 1. Solid curve denotes E_+ and dashed curve denotes E_- (normalized to 10 events). These curves reflect the decay of the F^{*+} into light hadrons. Note that the ratio $< E_- >/< E_+ >$ would increase if F^{*+} decayed into heavier hadrons, conceivably accompanied by a radiative photon.

Fig. 3b: Distribution in hadronic energy, E_h, normalized to 10 events.

Fig. 4: Distribution in scaled momentum transfer $v_\pm = Q_\pm^2/2ME_\nu$ (see text). Solid line denotes v_+ and dashed line v_-. Normalization is to 10 events.

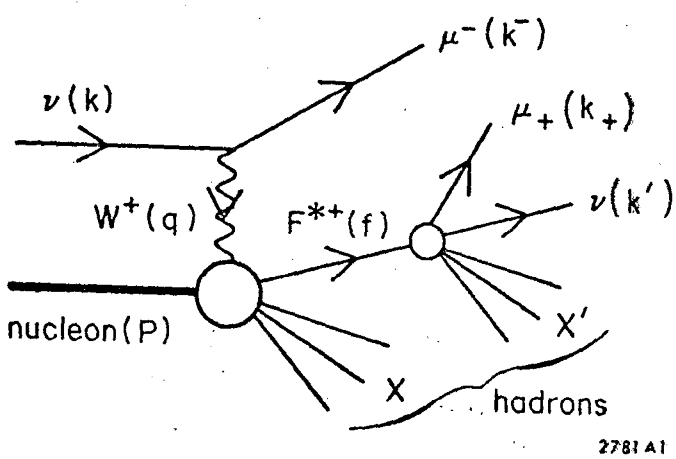


Fig. 1

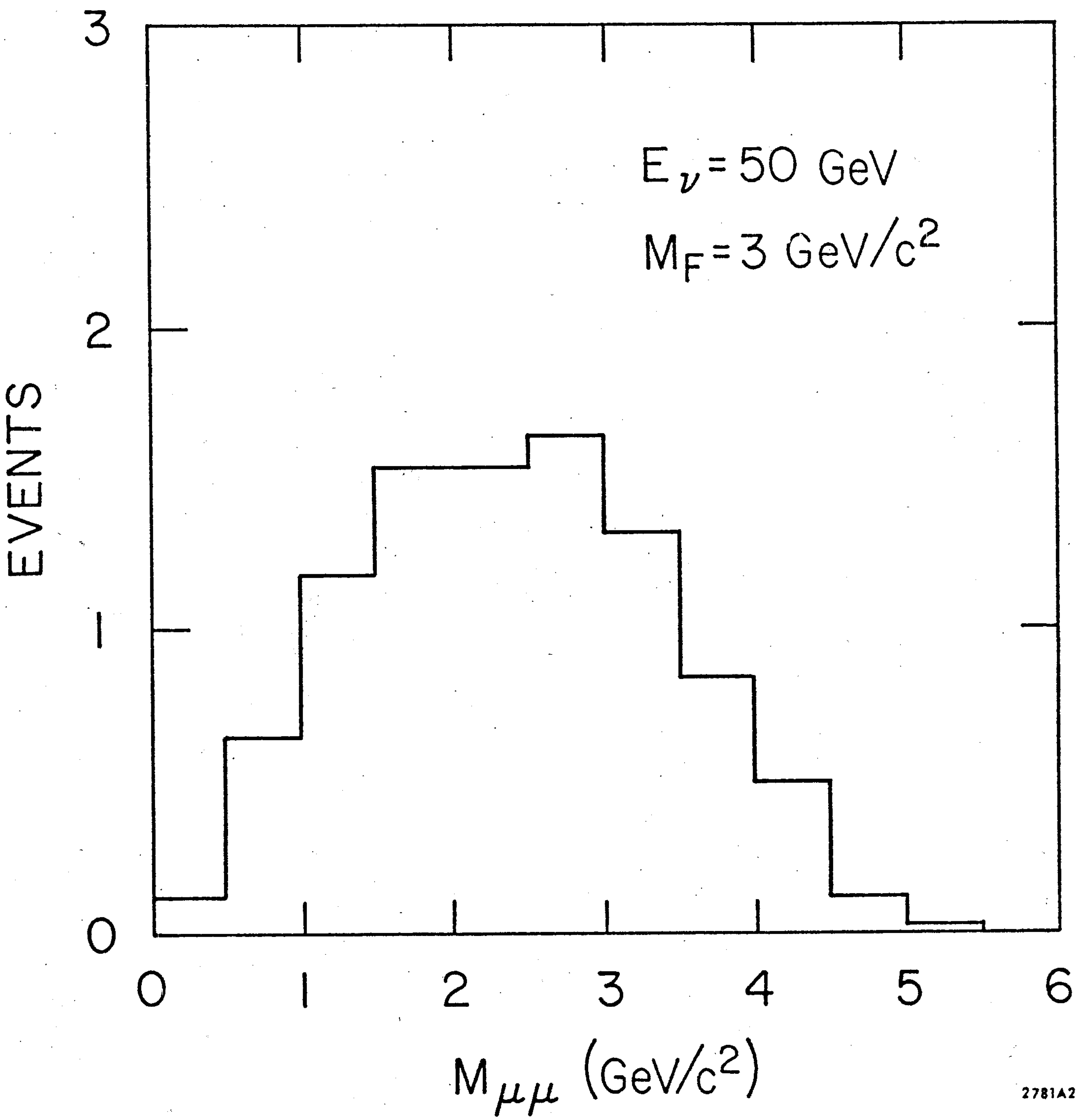
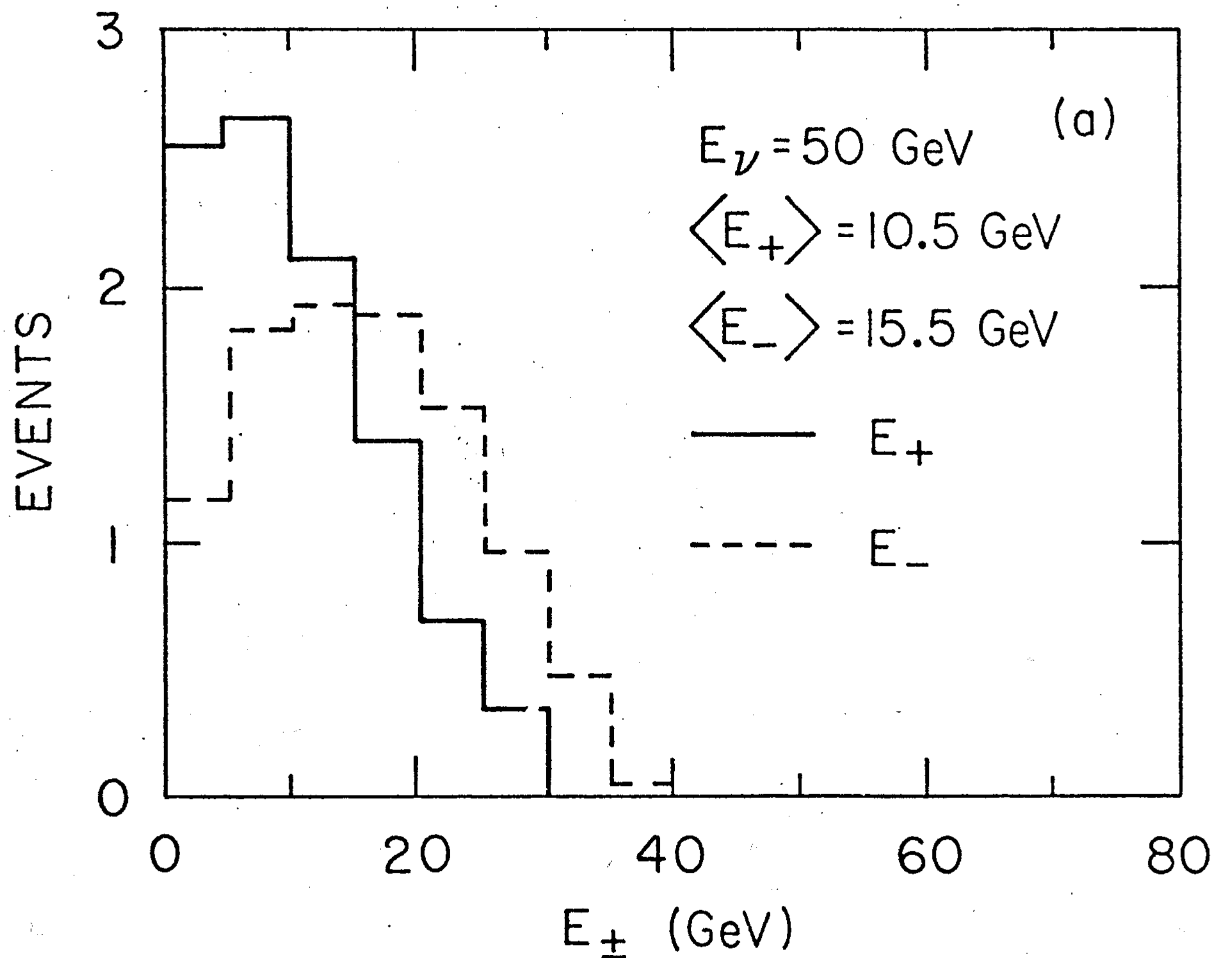
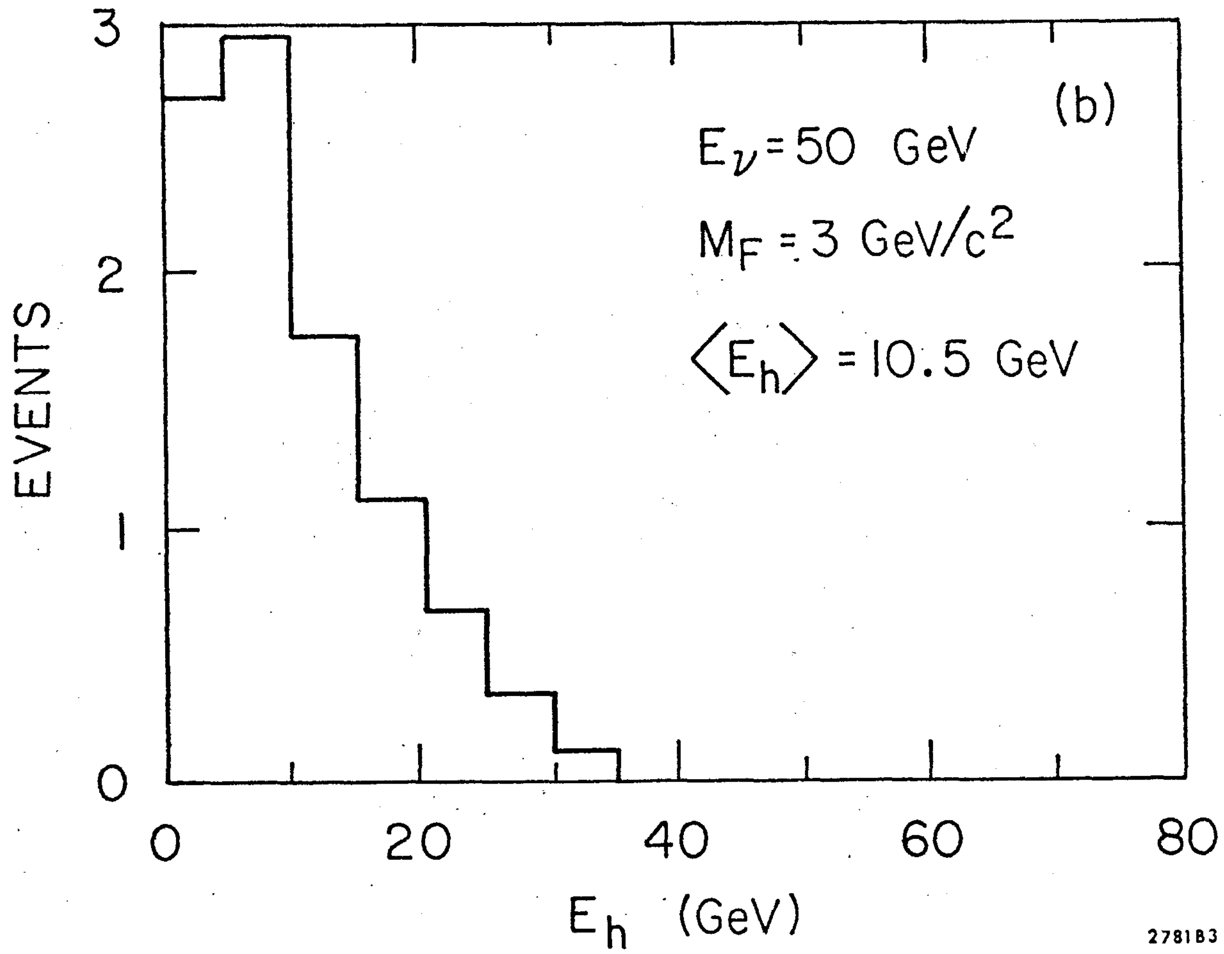


Fig. 2



(a)
$E_\nu = 50$ GeV
$\langle E_+ \rangle = 10.5$ GeV
$\langle E_- \rangle = 15.5$ GeV
E_+
E_-
EVENTS
$E_\pm$ (GeV)
0
1
2
3
0
20
40
60
80

Fig. 3 A



3
2
1
0
EVENTS
(b)
$E_\nu = 50$ GeV
$M_F = 3$ GeV/c^2
$\langle E_h \rangle = 10.5$ GeV
0
20
40
60
80
E_h (GeV)
2781B3

Fig. 3 B

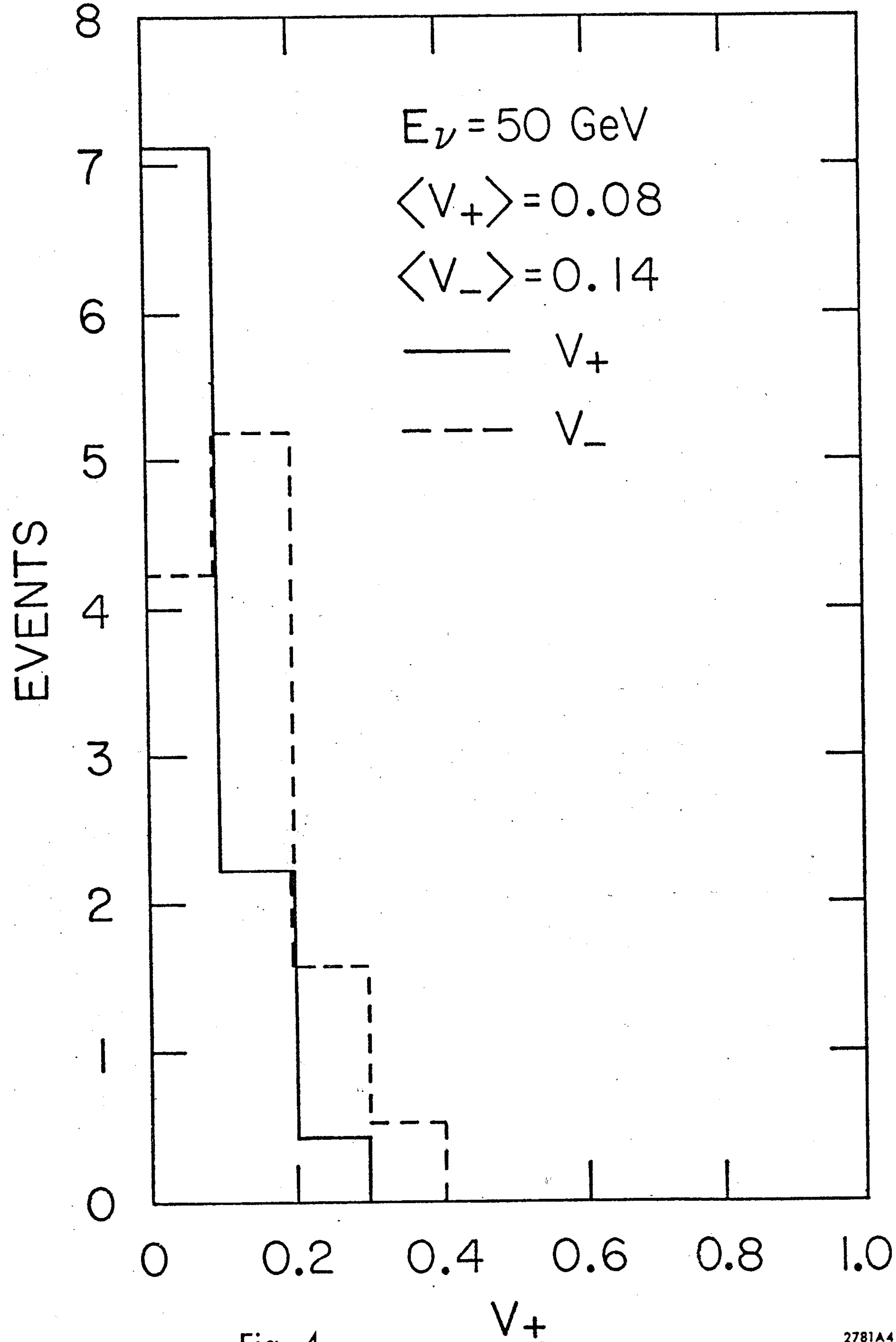

EVENTS
0
1
2
3
4
5
6
7
8
$E_\nu = 50$ GeV
$\langle V_+ \rangle = 0.08$
$\langle V_- \rangle = 0.14$
V_+
V_-
0
0.2
0.4
0.6
0.8
1.0
$V_\pm$
2781A4

Fig. 4