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Gauge Theories and νp Elastic Scattering

CARL H. ALBRIGHT[*], C. QUIGG[†], R. E. SHROCK
and J. SMITH[§]
Fermi National Accelerator Laboratory[**]
P.O. Box 500, Batavia, Illinois 60510

ABSTRACT

The predictions of several popular gauge models are compared with new data on νp elastic scattering. Predictions for $\bar{\nu} p$ elastic scattering are presented. A brief discussion is given of the possible role of elastic $(\nu, \bar{\nu})n$ scattering as a source of experimental background.

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[*] Permanent address: Department of Physics, Northern Illinois University, DeKalb, Illinois 60115; work supported in part by National Science Foundation Grant No. MPS 75-05467.

[†] Alfred P. Sloan Foundation Fellow; also at Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637.

[§] Permanent address: Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11794; work supported in part by National Science Foundation Grant No. GP-32998X.

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The observation[1] of neutrino-proton elastic scattering in two experiments at Brookhaven National Laboratory opens new horizons for the study of the structure of the weak neutral current. Given the wealth of information accumulating on deep inelastic neutral current phenomena,[2] it is now possible to require that models of weak interactions account for many different observables at once. Accordingly, we have undertaken an analysis of the experimental results in the context of several popular theoretical models. Our considerations are limited to models based on $SU(2) \otimes U(1)$ gauge theories having only vector and axial vector currents.[3]

Our strategy is to fix parameters by fitting data on inclusive reactions with isoscalar targets. Using these constraints we predict the inclusive cross sections for proton targets and the differential cross sections for elastic scattering. A full account has been submitted for publication elsewhere;[4] in this Letter we summarize the main results that apply to elastic scattering.

On the basis of the data now available[1] we can draw the following tentative conclusions. The Weinberg-Salam (W-S) model[5] is in good agreement with the shape of the differential cross section, but predicts a magnitude about one and one-half standard deviations smaller than is observed. Six quark vector-like (V) models[6] appear to be inconsistent with the shape of the differential cross section. A five-quark model due to Achiman, Koller, and Walsh[7] (AKW), and two variants of the Gürsey-Sikivie (G-S) model[8] satisfactorily account for the observed data in shape and magnitude.

The elastic and quasielastic scattering of neutrinos from nucleons has been the subject of a great deal of theoretical work, so the basic expressions are well-known.[9, 4] The CVC hypothesis is used to relate the charged weak current form factors to the electromagnetic form factors which are parametrized as dipole forms. For the vector form factors, the dipole parameter is $M_V^2 = 0.71$ GeV^2. The axial mass, M_A, is less precisely fixed.[10] To illustrate the range of possibilities consistent with existing experimental information, we present results for two values: $M_A^2 = 0.71$ and 1.32 GeV^2.

The neutral current form factors (for elastic scattering) are taken to be proportional to the charged current form factors:

$$G_E^0(q^2) = \frac{1}{2}(\alpha + \gamma)G_E(q^2)$$

$$G_M^0(q^2) = \frac{1}{2}(\alpha + 0.88\ \gamma/4.7)G_M(q^2)$$

$$G_A^0(q^2) = \frac{1}{2}(\beta + \delta)G_A(q^2) \quad .$$

The isovector parameters α and β and the isoscalar parameters γ and δ are easily determined from the structure of the neutral current in each model. Specifically, writing $x_W = \sin^2\theta_W$, we have $[\alpha, \beta, \gamma, \delta] = [1 - 2x_W, 1, -2x_W, 0]$ in the W-S model; $[2 - 2x_W, 0, -2x_W, 0]$ in the vector model; and $\left[\frac{3}{2} - 2x_W, \frac{1}{2}, \frac{3}{2} - 2x_W, 0\right]$ in G-S model (B).[11]

We have computed the differential cross sections for elastic and quasielastic scattering in each of the models cited above.[12] To compare the predictions of the various models with data, we have imposed the appropriate experimental cuts.[1,13] The predicted values of $R_{el}^{\nu} \equiv \sigma(\nu p \to \nu p)/\sigma(\nu n \to \mu^- p)$ and $R_{el}^{\bar{\nu}} \equiv \sigma(\bar{\nu} p \to \bar{\nu} p)/\sigma(\bar{\nu} p \to \mu^+ n)$ for values of the Weinberg angle favored[4] by the deep inelastic data are given in Table I. They are to be compared with the measured values,[1] $R_{el}^{\nu} = 0.17 \pm 0.05$ (HPW); 0.23 ± 0.09 (CIR). The prediction of the Weinberg-Salam model[5] lies approximately 1.5 standard deviations below the data. That of the vector model lies at least two standard deviations below the data. The Gürsey-Sikivie model (B)[8] is in agreement with the experimental values.[14] The five-quark model of Achiman, Koller, and Walsh[7] interpolates between the Weinberg-Salam model and the Gürsey-Sikivie model (B). In all models considered, the ratio $R_{el}^{\bar{\nu}}$ is significantly larger than R_{el}^{ν}.

We now turn to the differential cross sections. We plot in Fig. 1 the predictions of three models for the reactions $\nu n \to \mu^- p$ and $\nu p \to \nu p$, folded with the BNL neutrino spectrum,[12] for our two choices of the axial form factor. The theoretical curves are given with absolute normalization. The HPW data[1] are plotted as events. We have assumed agreement between theory and experiment for the quasielastic cross section, and we test the predictions of the models for elastic scattering.

The Weinberg-Salam model gives a good description of the shape of the differential cross section, but (as we noted in connection with Table I) yields a smaller cross section than is observed. In contrast, the vector model prediction[15] is significantly flatter than the data. The Gürsey-Sikivie model (B) is in excellent agreement with experiment.

It is possible that the reaction $\nu n \to \nu n$ can mimic νp elastic scattering as a result of np charge exchange within the detector, so theoretical cross sections for neutron targets are of interest. In the Weinberg-Salam model, $d\sigma(\nu n)/dq^2 \approx 1.5\, d\sigma(\nu p)/dq^2$ and $d\sigma(\bar{\nu} n)/dq^2 \approx d\sigma(\bar{\nu} p)/dq^2$, over the range $0 \leq q^2 \leq 1\ \mathrm{GeV}^2$. In the vector model, the cross section for scattering off neutrons is about 1/3 that for scattering off protons. In model (B) of Gürsey and Sikivie, $d\sigma(\nu n)/dq^2 \approx 1/3\, d\sigma(\nu p)/dq^2$ and $d\sigma(\bar{\nu} n)/dq^2 \approx 1/4\, d\sigma(\bar{\nu} p)/dq^2$. Evidently if some of the reported νp elastic scattering events were to be attributed to contamination from νn scattering, agreement between the Weinberg-Salam model and experiment would be improved.

We show in Fig. 2 the predictions for antineutrino quasielastic and elastic scattering, folded with the BNL spectrum.[12] In every model, the differential cross sections for elastic neutrino and antineutrino scattering are quite similar. (They are of course identical in the vector-like models.) Consequently, detection of parity violation in the neutral current by observation of differences between νp and $\bar{\nu} p$ elastic scattering at large q^2 appears to be extremely demanding. This procedure will in addition be complicated by any differences between the spectra of incident neutrinos and antineutrinos.[4]

In conclusion, having constrained the Weinberg angle in all models by requiring optimal agreement with deep-inelastic data, we have confronted the models with elastic scattering data and arrived at the following judgments. The Weinberg-Salam model[5] satisfactorily describes the slope of the differential cross section but predicts a magnitude somewhat too small. In view of the possible presence in the data of contamination from the reaction $\nu n \rightarrow \nu n$, this model still must be regarded as an entirely adequate description of elastic scattering. However, it is not rich enough to describe satisfactorily all the phenomena observed in deep-inelastic scattering at high energies. The vector models[6] are in significant disagreement with the differential cross section for elastic scattering. These models are also in serious conflict with high-energy data on deep-inelastic scattering. Finally, the Gürsey-Sikivie models (B) and (C)[8] are in excellent agreement with the elastic scattering data in magnitude and shape. Both models (B) and (C) also appear to agree with the trends of the deep-inelastic scattering data at high energies.

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Note added: While preparing this manuscript for publication, we received a related preprint from Barger and Nanopoulos.[17] The corrected version of their article is in agreement with our results, where the two works overlap.

FOOTNOTES AND REFERENCES

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[2] J. G. Morfin, in Proc. 1975 Int. Symposium on Lepton and Photon Interactions at High Energies, ed. W. T. Kirk (Stanford: SLAC, 1976), p. 537; V. Brisson, talk given at the Rencontre de Moriond, Flaine (1976); D. C. Cundy, private communication; L. Stutte, talk given at the Conference on the Production of Particles with new Quantum Numbers, Madison (1976); A. Benvenuti, et al., HPWF preprint 76/4.

[3] No data yet suggest the insufficiency of (V, A) currents. SPT models are considered by E. Fischbach, et al., to be published.

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[9] See, e.g., A. Pais, Ann. Phys. (N.Y.) 63, 361 (1971) and F. Martin, Nucl. Phys. B104, 111 (1976), and references therein.

[10] P. A. Schreiner, in *Neutrino-1974*, ed. C. Baltay (New York: AIP, 1974), p. 101.

[11] Isoscalar contributions to the axial form factor are neglected.

[12] We have folded the theoretical distributions with a parametrization of the BNL neutrino spectrum, $dN^{\nu}(E)/dE = 0.12 \exp\left[0.8(E-1.6)^2\right]$, $0.5 < E < 2.4$; $\exp[-E] + 0.0133 \exp[-0.3\,E]$, $E > 2.4$, where E is measured in GeV. This is a provisional version based on the Sanford-Wang π, K spectrum [see BNL Report 11299, parts 1 and 2 (1967)]. Our results for neutrino scattering are quite insensitive to details of the spectrum. Those for antineutrino scattering are more dependent upon precise features of the spectrum.

[13] The analysis by Y.-P. Yao, Phys. Rev. 176, 1680 (1968) shows that nuclear corrections, which we ignore, are unimportant for $q^2 > 0.3\ \mathrm{GeV}^2$.

[14] Model (C) of Gürsey and Sikivie leads to predictions nearly identical to those of model (B) for elastic scattering. It is discussed in detail in Ref. 4.

[15] The value $x_W = 0.68$ was selected by DGG on the basis of now superseded HPWF data.

[16] D. P. Sidhu, Brookhaven report, in preparation, has computed R_{el} in the Weinberg model.

[17] V. Barger and D. Nanopoulos, Wisconsin preprint.

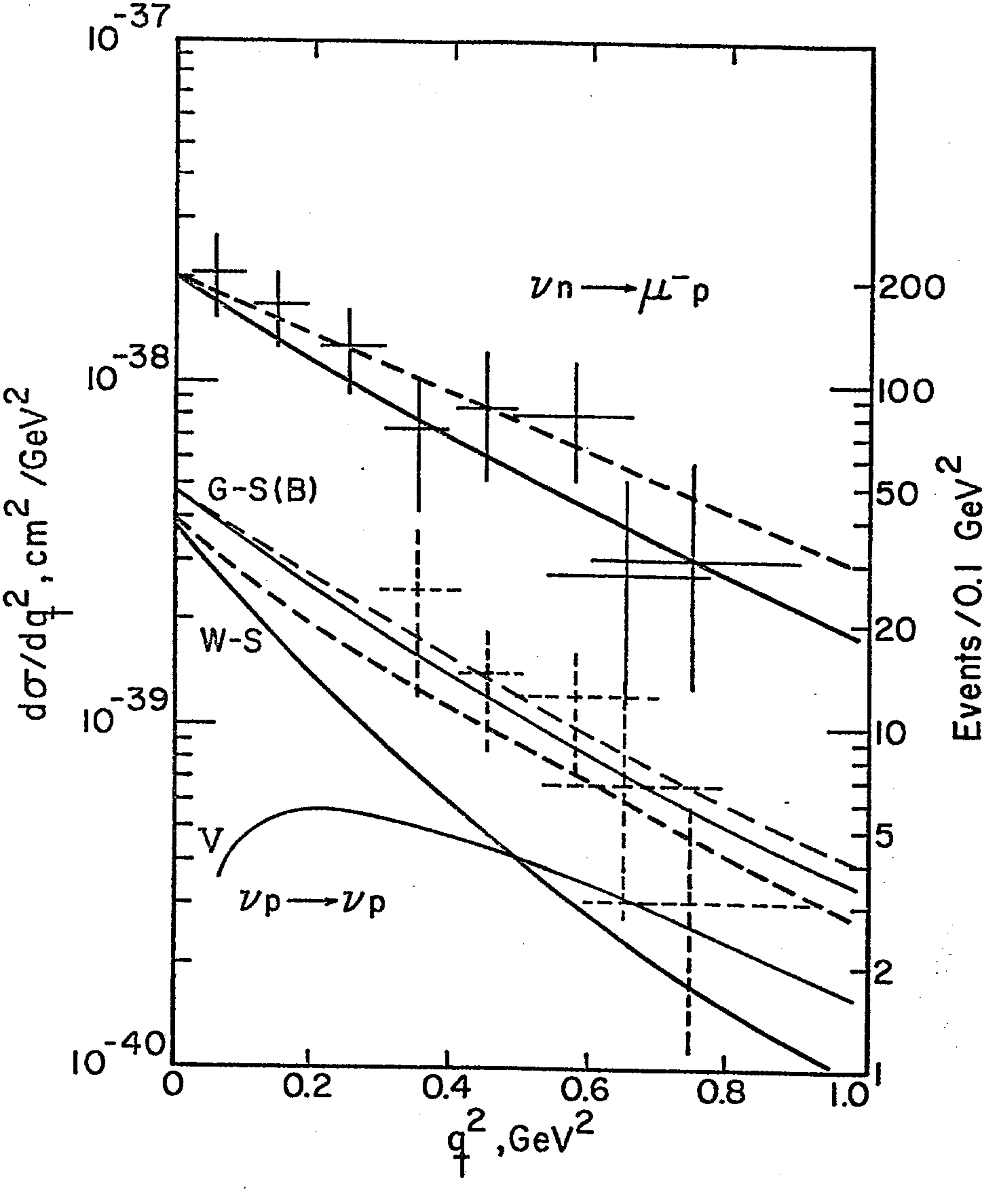
Table I. Ratios of elastic to quasielastic cross sections predicted for the BNL experiments

Model	Cuts	R_{el}^{ν} $M_A^2 = 0.71$	$M_A^2 = 1.32$	$R_{el}^{\bar{\nu}}$ $M_A^2 = 0.71$	$M_A^2 = 1.32$
W-S	HPW	0.075	0.109	0.140	0.226
$\left(x_W = 0.4\right)$	CIR	0.068	0.104	0.129	0.236
Vector	HPW	0.071	0.049	0.146	0.110
$\left(x_W = 0.5\right)$	CIR	0.075	0.050	0.159	0.122
G-S(B)	HPW	0.176	0.147	0.245	0.191
$\left(x_W = 0.4\right)$	CIR	0.173	0.142	0.243	0.188

FIGURE CAPTIONS

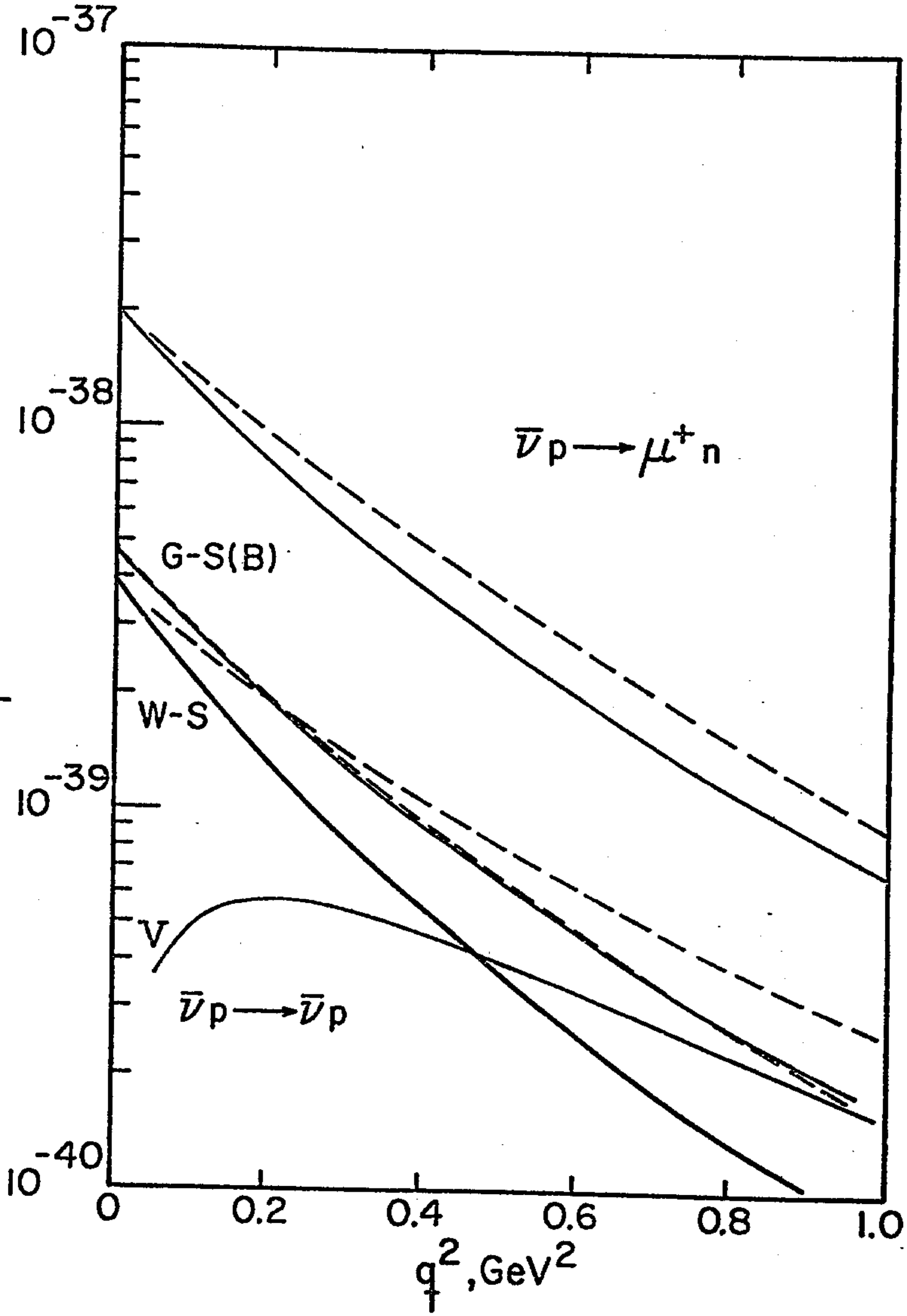
Fig. 1: Differential cross sections for quasielastic and elastic scattering of neutrinos. Solid lines correspond to the axial form factor with ${M_A}^2 = 0.71$ GeV^2; dashed lines are for ${M_A}^2 = 1.32$ GeV^2. The data are from HPW. For the elastic reaction we plot predictions of the Weinberg-Salam [W-S] model, the vector [V] model, and model (B) of Gürsey and Sikivie [G-S(B)].

Fig. 2: Same as Fig. 1, for quasielastic and elastic scattering of antineutrinos.



10^{-37}
10^{-38}
10^{-39}
10^{-40}
$d\sigma/dq_t^2$, cm^2 /GeV^2
$\nu n \longrightarrow \mu^- p$
G-S(B)
W-S
V
$\nu p \longrightarrow \nu p$
200
100
50
20
10
5
2
1
Events /0.1 GeV^2
0
0.2
0.4
0.6
0.8
1.0
q_t^2 ,GeV^2

Fig. 1



10^{-37}
10^{-38}
10^{-39}
10^{-40}
$d\sigma/dq_t^2$, cm^2/GeV^2
G-S(B)
W-S
V
$\bar{\nu}p \rightarrow \mu^+ n$
$\bar{\nu}p \rightarrow \bar{\nu}p$
0
0.2
0.4
0.6
0.8
1.0
q_t^2, GeV^2

Fig. 2