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WEINBERG-SALAM GAUGE MODEL AND NEUTRINO PROTON ELASTIC SCATTERING*

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* Work supported by Energy Research and Development Administration.

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Weinberg-Salam Gauge Model and Neutrino Proton Elastic Scattering*

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Elastic scattering of neutrino on proton is studied in the Weinberg-Salam gauge model of neutral currents. Particular attention is paid to the experimental cuts relevant to two recent BNL experiments and spectra averaging so that model predictions can be directly compared to the experimental data. The uncertainty in the calculation due to changes in the parameters which are not well determined such as the mass of the axial vector meson is emphasized. We conclude that the simple Weinberg-Salam gauge model with $\sin^2 \theta_W \approx 0.4$ is consistent with the recent measurement of $R_{el}^{\nu} = \langle \sigma(\nu p \rightarrow \nu p) \rangle / \langle \sigma(\nu n \rightarrow \mu^+ p) \rangle$ provided $M_A \approx 1.15$ GeV which is within the range of uncertainty of this parameter. Similar calculation for the case of antineutrino proton elastic scattering, i.e., $R_{el}^{\bar{\nu}} = \langle \sigma(\bar{\nu} p \rightarrow \bar{\nu} p) \rangle / \langle \sigma(\bar{\nu} p \rightarrow \mu^+ n) \rangle$ is presented.

Gauge theories based on spontaneously broken gauge symmetries are very attractive because they provide a framework for the construction of renormalizable models of weak and electromagnetic interactions. Other appealing features of the nonAbelian gauge theories are that they are asymptotically free and, perhaps, have a very severe infrared behaviour. These twin properties enable one to understand the Bjorken

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6
scaling phenomena in deep inelastic processes as well as the confinement of fractionally charged quarks. As of now, the first of these two properties appear to be well accepted; however, there is still a great deal of controversy about the exact nature of the infrared behaviour of the nonAbelian gauge theories.

9
Numerous gauge models have been written down which are based on the idea of spontaneously broken gauge symmetry. Most of them predict the existence of neutral currents as one of their natural consequences. Weinberg-Salam model is one such gauge model which is based on $SU(2) \otimes U(1)$ gauge group. The existence of many neutral current processes has been well-established during the last few years and this may be regarded as one of the triumphs of unified gauge theories of weak and electromagnetic interactions. Detailed study of the weak neutral current processes is underway in many experiments, but as of now, the spin and isospin structure of neutral currents is very much in the controversial stage.

10
The most general structure of neutral current is of the form

$$J_\mu^Z = g_V V_\mu^3 + g_A A_\mu^3 + g_V' V_\mu^0 + g_A' A_\mu^0 \quad (1)$$

where V_μ^3 and A_μ^3 being the neutral isospin members of the charged vector and axial vector currents, V_μ^0 and A_μ^0 the isoscalar vector and axial vector current. In this expansion, g_V , g_A , g_V' and g_A' are the strength constants of the relevant pieces of the neutral current; various models differ in the precise form of these parameters. In the simple Weinberg-Salam gauge model, one has

$$g_V = 1 - 2\sin^2\theta_W \quad (2)$$

$$g_V' = -\frac{2}{3} \sin^2 \theta_W \quad (3)$$

$$g_A = -1 \quad (4)$$

$$g_A' = 0 \quad (5)$$

where θ_W is the Weinberg angle. Note that the model has, in general, isoscalar axial vector contribution from c and s quarks which we ignore. Knowing the form of the neutral current as in Eqs. (1) to (5), one can write down the differential cross section, $d\sigma/dq^2$, in terms of vector and axial vector form factors. Details can be seen in Ref. 11. The form factors of the vector current appearing in the cross section for neutral current reactions can be related to the well known isoscalar and isovector form factors of the proton and neutron. Since the dipole form gives adequate representation of nucleon form factors, a similar form is generally attempted for the axial vector form factor. However, the axial vector mass parameter is not very well determined, present estimates range from 0.84 (GeV) to 1.25 (GeV). In the calculations presented in this paper, we take $M_V = 0.84$ (GeV) and fixed, but we vary M_A within the range of its uncertainty. Furthermore, in these calculations, we fold in the BNL neutrino and antineutrino spectra and also take into account the experimental cuts relevant to two recent BNL experiments. Prediction based on Weinberg-Salam model of neutral current for $R_{el}^V = \langle \sigma(\nu_\mu p \rightarrow \nu_\mu p) \rangle / \langle \sigma(\nu_\mu n \rightarrow \mu^- p) \rangle$ is given in Fig. 1 as a function of $\sin^2 \theta_W$ and for three values of M_A . Data points are also shown for comparison. It is clear that WS model with $\sin^2 \theta_W \approx 0.4$ is consistent with the experimental data, however, the agreement is better for larger values of the axial mass parameter, i.e., $M_A \gtrsim 1.15$ (GeV). Our prediction for $R_{el}^{\bar{\nu}} = \langle \sigma(\bar{\nu}_\mu p \rightarrow \bar{\nu}_\mu p) \rangle / \langle \sigma(\bar{\nu}_\mu p \rightarrow \mu^+ n) \rangle$ is given in Fig. 2, again for the same set of values of M_A . In Fig. 3 is shown the

calculation of differential cross section for $M_A = 0.84$ GeV, and 1.15 GeV for the charged current quasielastic reaction and also the experimental data from HPW experiment² at BNL. The normalization is fixed by area under the curve which correspond to $M_A = 0.85$ GeV and the data points.

Both values of M_A seem to be consistent with these data. Figure 4 contains our result for the differential cross section of the neutral current reaction for $M_A = 1.15$ GeV and $\sin^2 \theta_W = 0.2, 0.4$ and 0.6 . Any of these curves give a reasonable representation of these data. We conclude that the simple Weinberg-Salam model is consistent with the recent measurements of elastic $\nu_\mu p$ scattering; the agreement is better for $M_A \sim 1.15$ GeV for $\sin^2 \theta_W \approx 0.4$. Further details¹⁴ of the calculation will be given elsewhere.

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Note added: After this work was finished, we received a preprint by¹⁷ Barger and Nanopoulos (University of Wisconsin Preprint) containing some calculation similar to ours.

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FIGURE CAPTIONS

- Fig. 1 Prediction of $R_{el}^{\nu} = \langle \sigma(\nu p \rightarrow \nu p) \rangle / \langle \sigma(\nu n \rightarrow \mu^+ p) \rangle$ based on Weinberg-Salam model of neutral current as a function of $\sin^2 \theta_W$ for $M_V = 0.84$ GeV and $M_A = 0.84, 1.15$ and 1.25 GeV. $\langle \dots \rangle$ mean that BNL ν spectrum has been folded in. This calculation has the q^2 cut, i.e., $0.3 \leq q^2 \leq 0.9$ (GeV/c) 2 put in. Experimental points are from Ref. 2.
- Fig. 2 Prediction of $R_{el}^{\bar{\nu}} = \langle \sigma(\bar{\nu} p \rightarrow \bar{\nu} p) \rangle / \langle \sigma(\bar{\nu} p \rightarrow \mu^+ n) \rangle$ in the WS model as a function of $\sin^2 \theta_W$ for $M_V = 0.84$ GeV and $M_A = 0.84, 1.15$ and 1.25 GeV. The experimental cut on q^2 is assumed to be the same as in the case of neutrino beam.
- Fig. 3 Differential cross section of charged current quasielastic reaction $\nu_{\mu} + n \rightarrow \mu^+ + p$ for $M_V = 0.84$ GeV and $M_A = 0.84$ and 1.15 GeV. Normalization is discussed in the text.
- Fig. 4 Differential cross section of neutral current elastic reaction $\nu_{\mu} + p \rightarrow \nu_{\mu} + p$ for $M_V = 0.84$ GeV, $M_A = 1.15$ GeV and for $\sin^2 \theta_W = 0.2, 0.4$ and 0.6 .

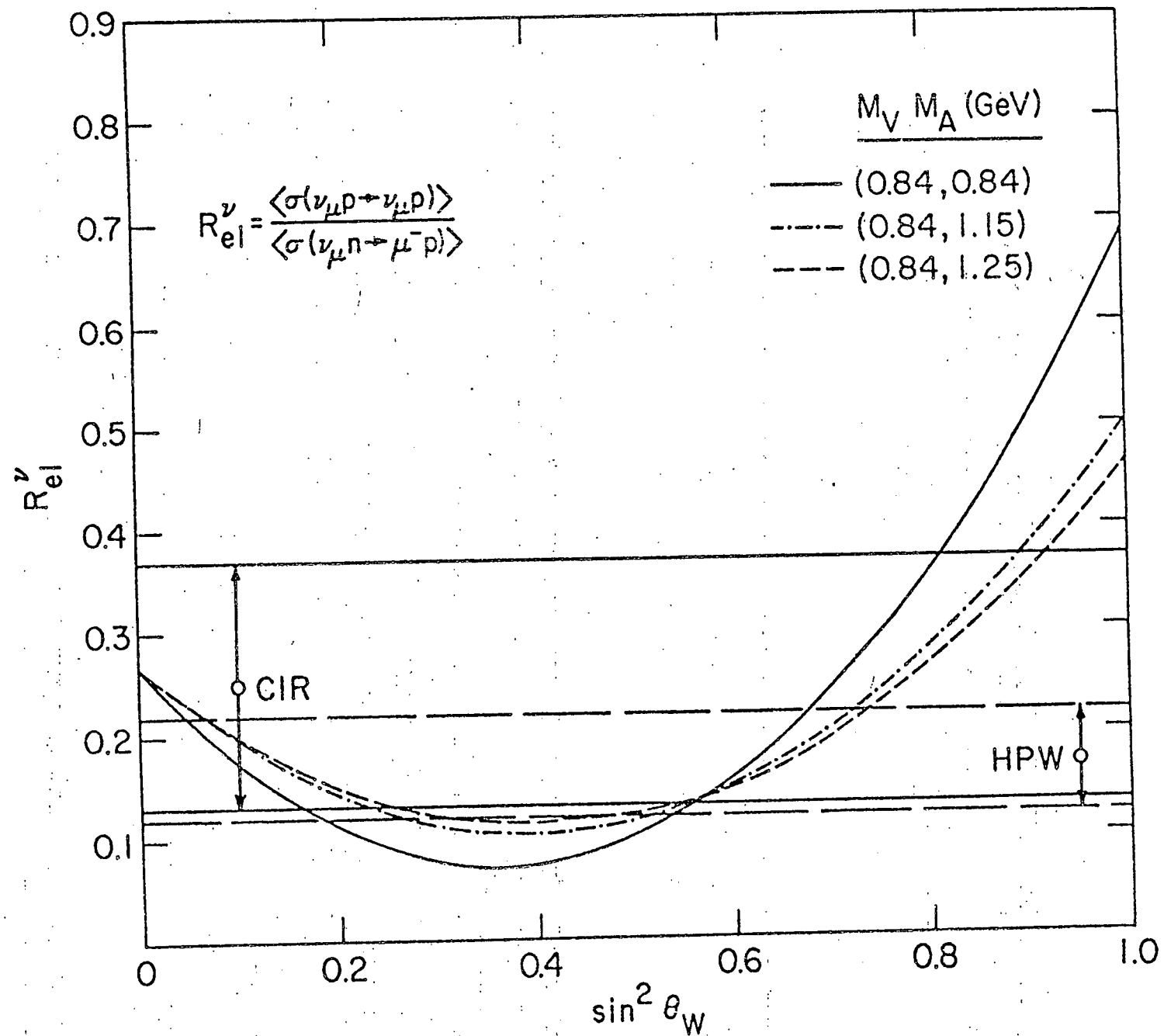


FIG. 1

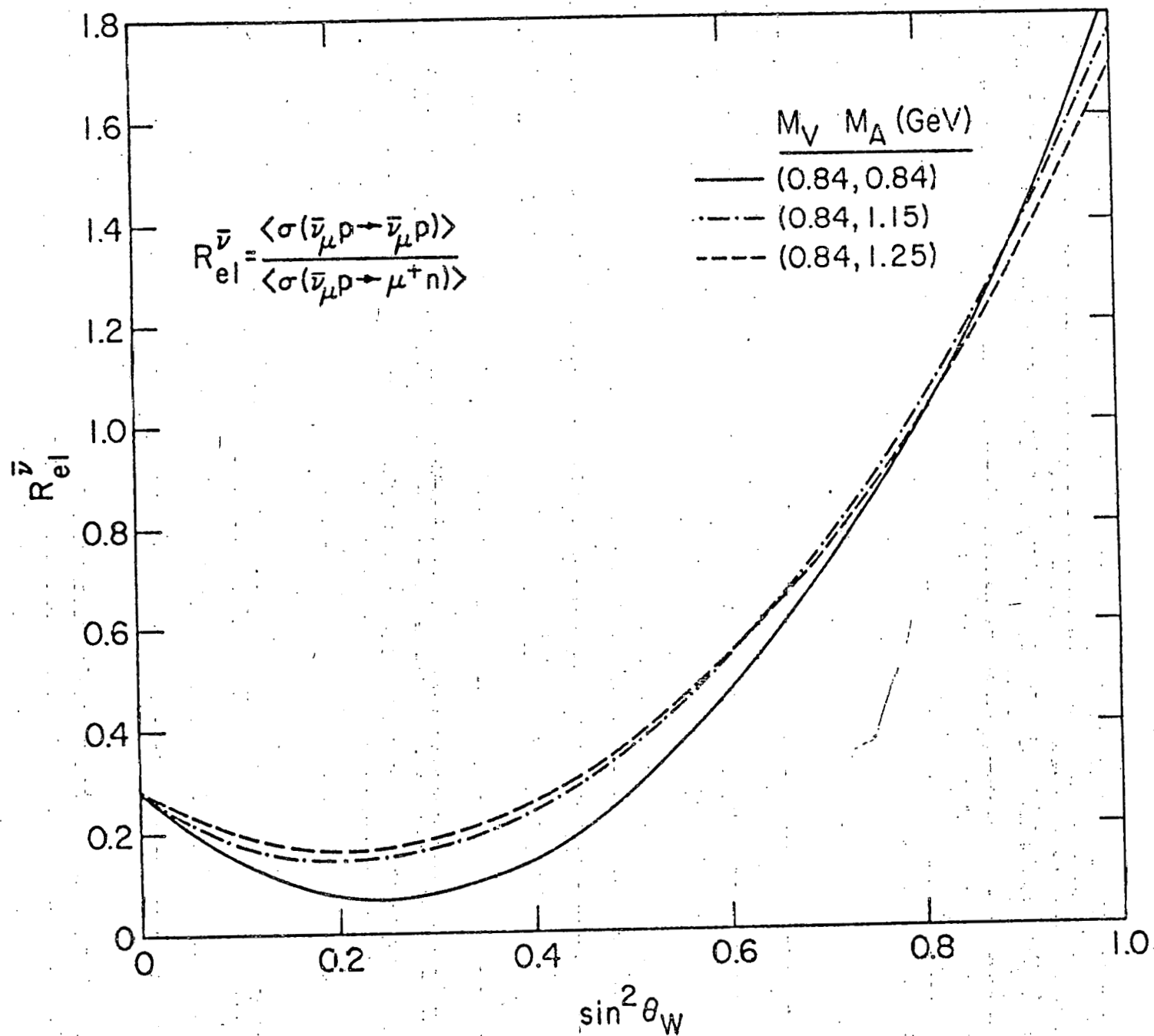


FIG. 2

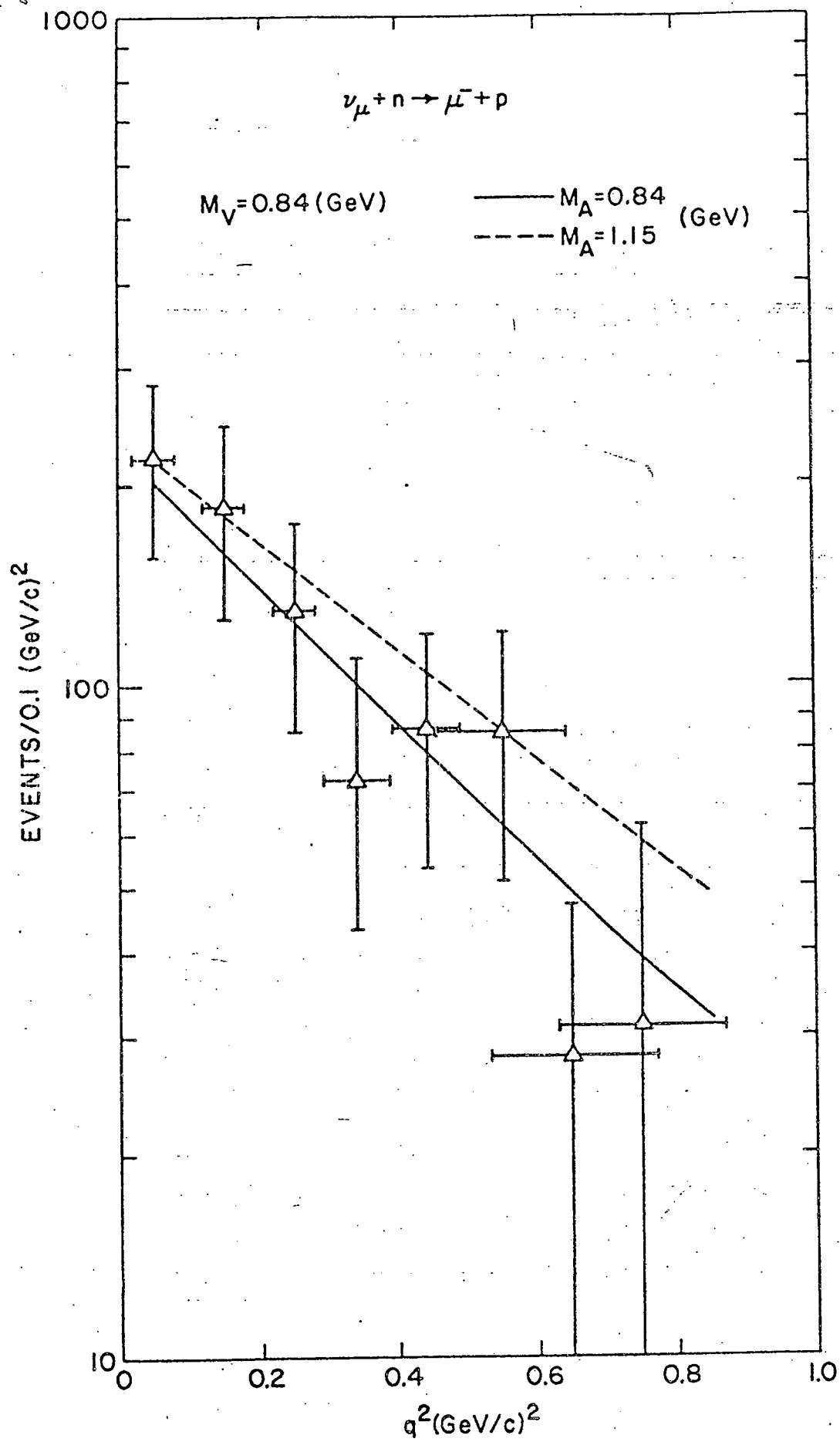


FIG. 3

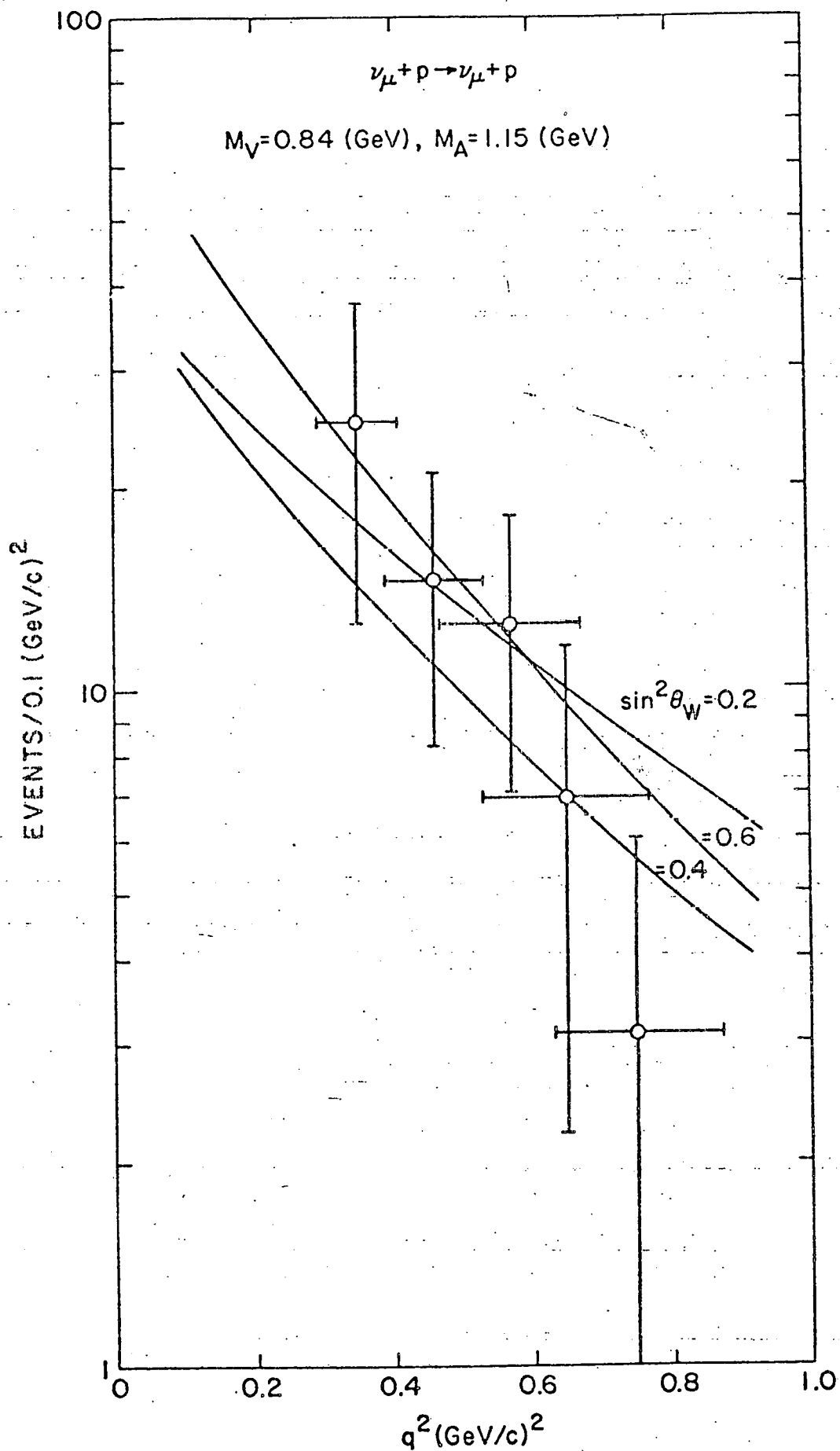


FIG. 4