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[12]The assignment $I^G=1^+$, $J^{PC}=1^{+-}$ for $M(953)$ is possible phenomenologically; however, the dominant $\pi\omega$ decay width can be estimated to be as large as 30 MeV [with a reasonable choice of radius of interaction $\sim(500\text{ MeV})^{-1}$, and with the dimensionless strong coupling g normalized to give the proper ρ width]. It would be surprising if such a state had escaped detection till now.

[13]Simple estimates would suggest suppression of the $\pi\pi\gamma$ mode relative to $\eta^0\pi\pi$. However, at least for the case of virtual electromagnetic contributions (e.g., $\pi^\pm-\pi^0$ mass difference, perhaps $K^+\to\pi^+\pi^0$), enhanced effects over simple estimates have been known to occur.

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Nonleading Energy Behavior and the Breaking of Scale Invariance in νW_2†

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A recently proposed Regge model for describing the general features of on- and off-shell Compton scattering, using a simple form of scale-invariance breaking in q^2, is discussed and confronted with recent data. It is suggested that the mass size characteristic of the scale-invariance breaking is indicative, as well, of the relative contributions of the Pomeranchukon, $f-A_2$, and additional nonleading power behavior. The observed rapid approach to "scaling" in q^2 (at given ν) is seen to require a small characteristic mass which in turn requires a substantial nonleading contribution to the scaling function νW_2. Continuation of the resulting form to on-shell scattering predicts a nonleading power contribution to $\sigma_{\text{tot}}(\gamma p)$; a recent continuous-moment sum-rule analysis is consistent with this prediction.

In this paper we wish to point out the gradual accumulation of evidence in support of a fairly simple Reggeization scheme for describing the main features of both on- and off-shell Compton scattering. The model incorporates a particularly simple form of scale-invariance breaking in the small-q^2 region. The evidence also appears to support a substantial nonleading Regge contribution to $F_2(\omega)$ which would be consistent with the presence of a polynomial residue for the right-signatured fixed pole[1] at $J=0$.

In a recent paper[2] we analyzed the available data on the electroproduction structure function $\nu W_2(\nu, q^2)$, for both proton and neutron targets, in a Regge model [which incorporates the Pomeranchukon, an $(f-A_2)$-type behavior with pure F coupling and nonleading power behavior $\nu^{-3/2}$] by demanding that the Regge form be consistent with:

(i) the existence of a fixed pole at $J=0$ in $\nu T_2^{p,n}$ with residue linear in q^2 and magnitude suggested by the bare Born term (this would be the case if the fixed pole is entirely independent of the strong interactions)[2,3];

(ii) the magnitude of the $\nu W_2^{p,n}$ data at the largest values of ω for which data are available in the scaling region, and

(iii) the quark-model sum rule[4]

$$\int_0^\infty \frac{d\omega}{\omega}\left[F_2^p(\omega) - F_2^n(\omega)\right] = \tfrac{1}{3}.$$

Actual data were used in the sum rules resulting from (i) and (iii) out to the largest available ω data ($\omega \sim 12$) and for $\omega \gtrsim 12$ the Regge form was used. We found that satisfaction of the above three requirements would be possible if, and only if, a substantial nondiffractive component is present in νW_2 for large ν and q^2. This is contrary to some models[5] but, as pointed out by Gilman,[6] the difference between the low-energy data on proton and neutron targets and the success of the Bloom-Gilman sum rule[7] suggest the presence of some, perhaps substantial, nondiffractive component and $F_2(\omega)$ falling to less than 0.2 as $\omega \to \infty$. We found that no *unique* solution for the large-ω behavior of $F_2^p(\omega)$ could be obtained by our analysis, but we were able to severely limit the possibilities. In particular, we obtained the following "typical" solution (the error in the parameters is of the order of 20%):

$$F_2^p(\omega) = 0.12 + 0.462\,\omega^{-1/2} + 4.02\,\omega^{-3/2}. \tag{1}$$

Note that we predict that $F_2^p(\omega)$ will fall significantly from its present maximum (~ 0.35 at $\omega = 5$). When National Accelerator Laboratory energies become available it will be possible to test the above prediction for the high-energy, large-q^2 behavior.

Having once obtained the above form for νW_2 in the scaling region, it is desirable to relate it to on-shell Compton scattering. That is, we wish to make an interpolating ansatz for the scale-invariance-breaking mechanism in the Regge region. The demand that $\nu W_2(\nu, q^2) \to 0$ as $q^2 \to 0$ together with the requirement that as $\nu, q^2 \to \infty$, $\nu W_2(\nu, q^2) \to F_2(\omega)$ suggest the form

$$\nu W_2^p = \frac{q^2}{q^2 + m^2}\left(A + \frac{3B}{\sqrt{\tilde\omega}} + \frac{C_p}{\tilde\omega^{3/2}}\right), \tag{2}$$

with $\tilde\omega = 2M\nu/(q^2 + \mathfrak{M}^2)$. (Forms for scale-invariance breaking via an $\tilde\omega$ such as this have been suggested by a number of authors,[8] though by restricting their attention to presently available data, the Pomeranchukon and $f - A_2$ dependence are found to be quite large and the nonleading behavior is neglected altogether.)

Assuming such a simplified scale-invariance-breaking ansatz, the important question is the size of the masses m and $\mathfrak{M}$. These determine the relative contributions of the Pomeranchukon and $f - A_2$ in on-shell $\sigma_{\text{tot}}(\gamma p)$ as compared to their relative contributions in the "scaling data" and the rapidity with which the $q^2 = \infty$ value is approached at given ν. The Pomeranchukon to $f - A_2$ ratio is roughly 5 : 3 in $\sigma_{\text{tot}}(\gamma p)$, while in the deep-inelastic region, we arrive at a ratio of roughly 1 : 4 and as a result both m and $\mathfrak{M}$ will be quite small in our work (as compared to other similar parametrizations of this form). We find $m = 0.37$ GeV and $\mathfrak{M} = 0.22$ GeV (we emphasize that these are rough estimates).[9] Thus, we would predict that scaling is approached very rapidly as q^2 departs from zero, e.g., for a given ν we find that $\nu W_2(\nu, q^2)$ reaches 90% of its maximum value (at fixed ν) by $q^2 = 1$ (GeV/c)^2.

Support for such small masses has recently become available in the report of the SLAC μ-p scattering group.[10] Their results and the magnitudes predicted by our formula (2) are shown in Table I. If the masses m and $\mathfrak{M}$ were not so small the agreement would be lost very quickly. The $q^2 = 0.5$ (GeV/c)^2 points are particularly sensitive to $\mathfrak{M}$. We note again that the rapid approach of νW_2 to a maximum is due, in our model, to the small mass which is in turn connected with the small ratio of diffractive to nondiffractive contributions in the scaling region so long as one believes that the two characteristic masses should be of the same order of magnitude. A larger Pomeranchukon contribution would yield a larger characteristic mass and a slower approach to the maximum in νW_2.

Also in Table I we give older data points from the SLAC electron group and the predictions of Eq. (2). Agreement is not as satisfactory (note that we have in no way tried to "fit" the data). There appear to be systematic discrepancies between the μ-p and electron group's data at similar values of q^2 and ω which must be resolved before a precise fit would be meaningful.

So far we have avoided the question as to why the nonleading $\nu^{-3/2}$ term, which is necessary if the fixed pole is to have a polynomial residue, has not been seen in $\sigma_{\text{tot}}(\gamma p)$. The answer lies in the size of $\mathfrak{M}$ which predicts for $\sigma_{\text{tot}}(\gamma p)$ the following Regge form[2]:

$$\sigma_{\text{tot}}(\gamma p) = 100 + \frac{62}{\sqrt{\nu}} + \frac{14}{\nu^{3/2}} \tag{3}$$

(σ in μb, ν in GeV). The size of the nonleading term's residue makes it obvious that a very sensitive test of the large-ν $\sigma_{\text{tot}}(\gamma p)$ data is required in order to detect it. Such a test is provided by the continuous-moment sum-rule analysis recently performed by Shibasaki *et al.*[11] in which they found evidence for a $\nu^{-3/2}$ contribution with residue for $\sigma_{\text{tot}}(\gamma p)$ in the range 2 to 13 μb (GeV)$^{3/2}$ (Ref. 12)

TABLE I. Data from Ref. 10 for $\omega \gtrsim 11$ and † from the SLAC electron group for $q^2 < 1.0$ $(\mathrm{GeV}/c)^2$. Where data are binned, the νW_2 is calculated at the bin center using Eq. (2) of text. Note that Eq. (2) is *not* a fit to the data, but was derived from quite different considerations. The differences between the calculated νW_2 and some of the electron data points really represent inconsistencies between the data of the two groups, and with the electron data themselves, e.g., consider the ω values in the range 28–33; the particular example denoted by the asterisks shows that the electron group's $\omega = 29$ data point is too high.

q^2 $(\mathrm{GeV}/c)^2$	$\omega = 2M\nu/q^2$	$\nu W_2^{(\mathrm{data})}$	$\nu W_2^{(\mathrm{model})}$
0.1 – 0.2	80	0.098 ± 0.009	0.097
0.1 – 0.2	100	0.101 ± 0.011	0.095
0.3 – 0.4	11	0.233 ± 0.016	0.26
0.35†	13	0.247 ± 0.006	0.25
0.3 – 0.4	17	0.186 ± 0.019	0.21
0.29†	21	0.183 ± 0.01	0.19
0.25 – 0.4	25	0.266 ± 0.016	0.20
0.25†	28*	0.167 ± 0.015	0.17
0.2 – 0.4	40	0.152 ± 0.007	0.152
0.2 – 0.4	50	0.134 ± 0.011	0.14
0.4 – 0.6	11	0.268 ± 0.014	0.28
0.4 – 0.6	17	0.225 ± 0.013	0.24
0.4 – 0.6	24	0.213 ± 0.013	0.205
0.41†	29*	0.22 ± 0.02	0.18
0.4 – 0.6	33*	0.186 ± 0.023	0.187
0.5†	38	0.22 ± 0.04	0.17
0.6 – 0.8	12	0.276 ± 0.024	0.29
0.6†	14.5	0.285 ± 0.014	0.27
0.6 – 0.8	17	0.275 ± 0.026	0.25
0.6 – 0.8	23	0.272 ± 0.041	0.23
0.68†	33	0.25 ± 0.04	0.19
0.8 – 1.2	12	0.301 ± 0.032	0.31
0.8 – 1.0	16	0.236 ± 0.08	0.26
1.0†	19.5	0.28 ± 0.02	0.24

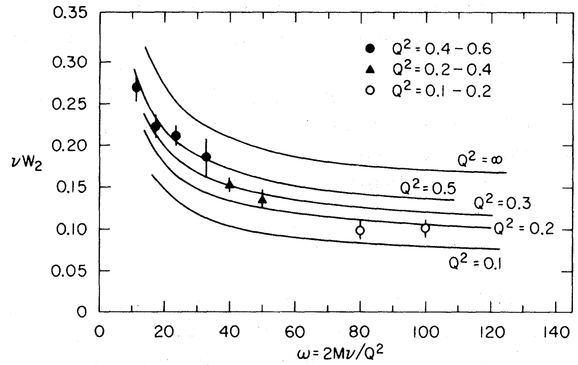

FIG. 1. $\nu W_2(\nu, q^2)$ from Eq. (2) plotted against $\omega = 2M\nu/q^2$ for various values of q^2. The scaling-limit curve $(q^2 \to \infty)$ is also included together with some data points from Table I to indicate the agreement of the form Eq. (2) with presently available data.

which they identify with the P''. Such a term will contribute between 2 and 5 μb to $\sigma_{\mathrm{tot}}(\gamma p)$ at $\nu = 1.68$ GeV.

We emphasize that the precise numbers given in this note are not to be taken too literally, but we do feel that the general picture has considerable support as an over-all description of νW_2 in the Regge region particularly with regard to the presence of an important nonleading contribution in νW_2 and the approximate interpolation between on- and off-shell scattering which predicts that $F_2(\omega)$ at $\omega = 100$ should have roughly the same relative Regge contributions as does $\sigma_{\mathrm{tot}}(\gamma p)$ at $\nu \sim 3$ GeV.

An additional test of this picture will be provided by the 4^0 electron-scattering data now being accumulated at SLAC. Data will be obtained in the region $0.1 \lesssim q^2 \lesssim 1$ $(\mathrm{GeV}/c)^2$ and $\nu_{\mathrm{threshold}} \lesssim \nu \lesssim 18$ GeV. The small-q^2 data should, in our picture, be consistent with a very rapid rise toward the eventual scaling value at a given ν. In Fig. 1 we exhibit the predicted magnitude of νW_2 in this region.

In conclusion, we wish to stress once again that there appears to be evidence for nonleading contributions of importance in $F_2(\omega)$ and that a relatively simple scale-breaking Regge form is capable of making this quite consistent with on-shell data and the apparent rapid approach in q^2 of νW_2 to its scaling value at a given value of ν.

It is not impossible, *a priori*, that the large nonleading term and the rapid approach to scaling are not connected at all; that is m and $\mathfrak{M}$ might be quite different (m being small and $\mathfrak{M}^2 \approx m_p^2$ for instance). The point of this note is to give credence to the theoretically more palatable idea that they may *both* be small on the basis of existing experimental data and theoretical biases.

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[8]For instance, J. Moffat and V. G. Snell, Phys. Rev. D 3, 2848 (1971); C. Gardiner and D. Majumdar, Syracuse University Report No. NYO-3399-236 (unpublished); V. Rittenberg and H. Rubinstein, Phys. Letters 35B, 50 (1971).
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Speculative Relation Between the Fine-Structure and Fermi Coupling Constants*

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It is pointed out that there exists a peculiar coincidence among several different predictions for the intermediate-boson mass: Both of the masses given by Lee and by the author are very close to $\alpha^{-1}M_p$ (where α is the fine-structure constant and M_p is the proton mass). By taking it seriously, we obtain the following two relations: $\alpha = (GM_p^{\ 2}/6\sqrt{2}\pi)^{1/3} \simeq 1/137.5$ for the Fermi coupling constant G and $\sin\theta = 1/3$ for the Cabibbo angle θ.

The possible existence of the hypothetical charged and neutral intermediate bosons, $W^{\pm}$ and W^0, was examined in great detail by Lee and Yang[1] more than ten years ago. Since that time no evidence for such particles has been discovered.[2] One finds, in the present intermediate-boson theory, no convincing prediction of the mass and the decay branching ratio.[3] Reasonable estimates of these quantities must be available before one can decide whether or not the existence of the intermediate boson can be excluded by experiment. The purpose of this short note is to point out a peculiar coincidence which exists among the predicted masses of the intermediate boson and to obtain speculative relations between the electromagnetic and weak coupling constants.

Let us begin with a review of the theoretical work on the intermediate-boson mass (see Table I). These attempts may be classified into the following two types. In the first class of attempts, an underlying SU(2) [or SU(3)] symmetry of the electromagnetic and weak interactions has been introduced. Such a symmetry (or a broken symmetry) was first examined by Glashow[4] and then assumed to be exact by Weinberg,[5] who could obtain the lower bounds of the intermediate-boson masses, i.e.,

$$M_{W^{\pm}} \geq (\sqrt{2}\,e^2/8G)^{1/2} \simeq 39.74 M_p$$

and

$$M_{W^0} \geq (\sqrt{2}\,e^2/4G)^{1/2} \simeq 56.20 M_p\,,$$

where $e^2/4\pi = \alpha \simeq 1/137.036$, G is the Fermi coupling constant, and M_p is the proton mass ($GM_p^{\ 2} \simeq 1.026\times10^{-5}$). More recently, Schechter and Ueda,[6] in their unified theory of the weak and electromagnetic interactions of leptons and hadrons, have predicted the intermediate-boson mass to be $M_{W^{\pm}} = (\sqrt{2}\,e^2/8G)^{1/2}$. The same value has been proposed independently by Lee[7] by a simpler formulation of the underlying theoretical hypothesis. Lee has derived, in another paper,[8] a lower bound of the mass

$$M_{W^{\pm}} \geq [(4\sqrt{2}\,e^2 \sec^2\theta)/3G]^{1/2} \simeq 133.7 M_p$$

(where θ is the Cabibbo angle,[9] $\theta \simeq 0.24$) by assuming SU(3) symmetry between the charged intermediate-boson field $W_\mu^{\pm}$ and the derivative of the electromagnetic field $\partial F_{\mu\nu}/\partial x_\nu$. In that paper, he has noticed that his lower bound is very close to $\alpha^{-1}M_p$.

In the second class of attempts to obtain a definite prediction of the weak-boson mass, the following model of the weak interactions for leptons has been proposed: The scalar part of the intermediate-boson field has a negative metric,[10] and the logarithmic weak and electromagnetic self-mass divergences cancel each other.[11] By making these as-