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Elastic Wide-Angle Hadronic Scattering*

H. M. Fried and B. Kirby
Physics Department, Brown University, Providence, Rhode Island 02912

T. K. Gaisser
Bartol Research Foundation of The Franklin Institute, Swarthmore, Pennsylvania 19081
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The most recent CERN Intersecting Storage Rings (ISR) elastic pp data are compared with predictions of the vector-meson–gluon model. The model is also used to examine and predict qualitative features of high-energy pp, np, $p\bar{p}$, $\pi^{\pm}p$, $K^{\pm}p$ elastic reactions, $\gamma p \to \pi^+ n$, $\pi^- p \to \pi^0 n$, and $K^- p \to \bar{K}^0 n$ at very large momentum transfers. The various processes are related to each other within the model by identifying the soft vector mesons as ω's and determining relative ω couplings by assuming that the ω couples to the hypercharge current.

I. INTRODUCTION

Recent experiments on elastic, hadronic scattering at wide angles[1] require a theoretical analysis qualitatively different from Regge descriptions valid for forward and backward peaks. One such gluon model has previously been employed to produce qualitative agreement with proton electromagnetic form-factor,[2] proton-proton scattering,[3] and proton-neutron scattering[4] data, at pre-ISR (CERN Intersecting Storage Rings) machine energies. In view of the latest ISR pp experiments, it becomes appropriate to evaluate the formulas of Ref. 3 at ISR energies, and to make qualitative predictions for other current[5-8] and anticipated two-body hadronic experiments at large momentum transfers and at energies up to and including those that will become available at the National Accelerator Laboratory (NAL).

The multiple exchanges which appear to be necessary at larger angles are here given by soft, virtual, neutral, vector mesons (SVNVM) exchanged between the external legs of specific hadronic scattering amplitudes. For forward (or backward) directions, this field-theoretic picture must be amended to include eikonal models of increasing complexity, as the exchanged NVM (neutral vector mesons) are themselves allowed to possess structure.[9] For the present wide-angle situation, this extra structure is not included in the specific sets of graphs corresponding to SVNVM exchange. However, not all the exchanged mesons may here be considered as soft, and a development may be made[10] of the entire amplitude in terms of an increasing number of nonsoft, or "hard" NVM. A single hard-meson exchange, plus all possible soft exchanges, have been combined into an approximate, wide-angle formula of form[3]

$$\frac{d\sigma}{dt}(s,t) = \left(\frac{d\sigma}{dt}\right)_H S(s,t), \qquad (1)$$

in which $(d\sigma/dt)_H$ denotes the differential cross section calculated from the Born approximation for single (hard) meson exchange, while $S(s,t)$ represents the strong damping effect of all exchanged SVNVM. For pp scattering and for $s \gg |t| \gg m^2$, $S(s,t)$ is approximately independent of s and proportional to the fourth power of the proton form factor. It has the explicit form

$$S(s,t) = \exp\{4\gamma[F(t) + F(u) - F(4m^2 - s)]\}, \qquad (2)$$

where

$$F(x) = 1 - (2x+1)[x(x+1)]^{-1/2} \ln[\sqrt{x} + (x+1)^{1/2}],$$

$$x \equiv -\frac{t}{4m^2}$$

and γ is a parameter combining nucleon-NVM coupling constant g, exchanged NVM mass μ, and a soft-momentum cutoff μ_c (see Ref. 11):

$$\gamma \simeq \frac{g^2}{8\pi^2} \ln\left(1+\frac{\mu_c^2}{\mu^2}\right) . \tag{3}$$

In this paper we make the specific assumption that the exchanged SVNVM are ω's so that $g^2 \to g_{\omega pp}^{\;2}$. In fitting previous data, [2-4] γ was chosen to be $\simeq 2.3$. We shall here continue to use the same μ_c/μ ratio for virtual mesons emitted by both nucleons and mesons, and to employ conventional $g_{\omega NN}$ and $g_{\omega K^\pm K^\pm}$ couplings in order to relate various scattering processes to one another.

We remind the reader of the elementary nature of the derivation of (2): a factor of $\exp[\pm\gamma F(\rho)]$ appears in the amplitude whenever two external hadrons of momentum p_a, p_b exchange multiple SVNVM, thereby providing damping in the $\rho = -(p_a \mp p_b)^2$ variables, leading to the factor $\exp\{2\gamma[F(t)+F(u)-F(s)]\}$, where the negative sign of $F(s)$ reflects the kinematical difference in the definitions of $s=-(p_1+p_2)^2$, $t=-(p_1-p_1')^2$, $u=-(p_2-p_2')^2$, for $p_1+p_2 \to p_1'+p_2'$. Since $\mathrm{Re}\,F(s) = F(4m^2-s)$, one obtains the factor $S(s,t)$ of (2) as the SVNVM contribution to $d\sigma/dt$.

In Ref. 3, curves have been drawn for a variety of s values (s, t, u in GeV^2), $41.7 \geq s \geq 11.3$, and over corresponding regions of all wide-angle $|t|$ values, using two (almost equivalent) models for $(d\sigma/dt)_H$, of the form ($s >> 4m^2$)

$$\left(\frac{d\sigma}{dt}\right)_H = \frac{C}{s^2}\,\phi(s,t,u), \tag{4}$$

where (for $|t| \sim \frac{1}{2}s$) $\phi \sim O(1)$ for a single hard vector exchange, $\phi \equiv 1$ for hard π^0 exchange, and C is an appropriate normalization constant. With just two parameters, C and γ, one obtains a rather good reproduction of the experimental data, which appear to be bounded from below by $G^4(t)$. According to the new ISR $s = 2800$ data, after the first dip at $|t| \gtrsim 1$, one finds $d\sigma/dt \sim 10^{-2} \times G^4(t)$, up to the maximum measured $|t| = 4.3$. At present, the forward (shrinking) diffraction peak can only be described phenomenologically; and it may be adjusted, by hand, to fit smoothly onto the wide-angle amplitude which, by itself, yields (1). According to (4), however, one expects a decrease of the wide-angle $d\sigma/dt$ in going (for example) from $s = 38$ to $s = 2800$ at fixed t of amount $(38/2800)^2 \simeq 2\times10^{-4}$. This is two orders of magnitude more than suggested by the data run at $|t| = 4.3$. Since the region of applicability of (1) should just begin at $|t| \gtrsim 4$, when the forward diffraction amplitude falls well below the (single hard, plus all soft exchanges of the) wide-angle amplitude, we expect a further decrease of $d\sigma/dt$ at larger $|t|$ by another two orders of magnitude. Unfortunately, this will

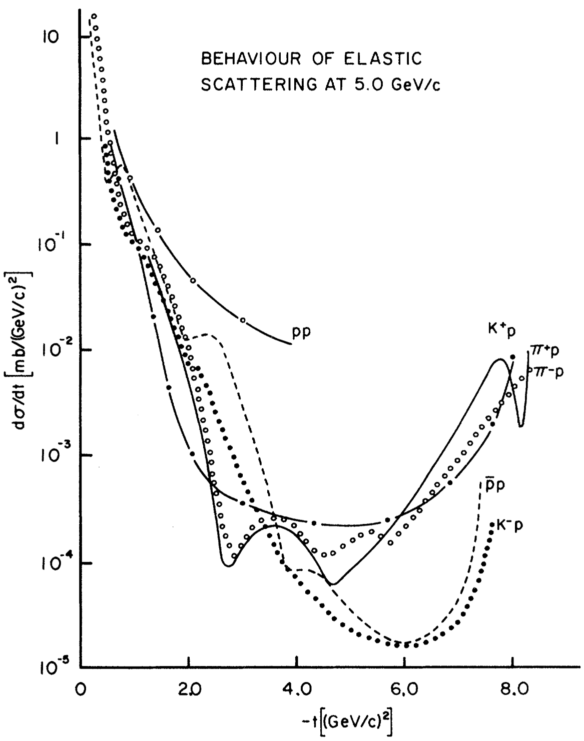

FIG. 1. Summary of 5-GeV/c wide-angle elastic scattering experiments (after V. Chabaud *et al.*, Ref. 7).

probably be somewhat difficult to measure.

This estimate is based upon the use of the Born approximation for $(d\sigma/dt)_H$, together with the observation that $S(s,t) \sim \exp[4\gamma F(t)] \sim G^4(t)$ for $s >> |t| >> m^2$. If experiments which can be performed in this region show less of a falloff with increasing s, but continue to display the gentle, wide-angle curvature of $S(s,t)$ out to values of $|t|$ approaching $\frac{1}{2}s$, it may be taken as an indication that a better $(d\sigma/dt)_H$ is needed. Even at $|t| \sim 4$ it is difficult to match the experimental ratio of $d\sigma/dt$ for $s = 2800$ to that of $s = 38$ with just a single hard vector exchange. (Of course, one may not yet be out of the forward peak.) It is also possible to employ other, slightly more complicated forms for $S(s,t)$.[11] But the clear deviation of $d\sigma/dt$ from $G^4(t)$ at $s = 2800$ and $|t| \sim 4$ is by no means unexpected in the SVNVM model.

II. ASYMPTOTIC SHAPE PREDICTIONS

Motivated by the resemblance of the model to the data in the wide-angle pp case, we have made the simple assumption that the exchanged SVNVM's are ω's in order to see if the model can account for the qualitative features of other hadronic processes at large s and $|t|$. Experimental results for various hadronic processes over the entire angular range are summarized in Fig. 1.[7] Unfortunately such wide-angle data presently exist only at relatively low energies, so that resemblance of this asymptotic model to present data can only be considered suggestive. To illustrate the nature of these wide-angle predictions, we have plotted in Fig. 2 a curve (labeled I) for $(d\sigma/dt)_{pp}$ given by (1), (2), and (4), with $\phi\equiv 1$, thereby assuming that all of the t dependence and most of the s dependence is due to $S(s,t)$, with the hard exchange providing a factor of s^{-2} only. With these assumptions we can write $d\sigma/dt$ in the form,

$$\frac{d\sigma}{dt}=10^{-b(\epsilon,s)}, \tag{5}$$

with $\epsilon\equiv|t|/s-\frac{1}{2}$. (Asymptotically, $2\epsilon\approx-\cos\theta_{\text{c.m.}}$; therefore $\epsilon=0$ corresponds to $\theta_{\text{c.m.}}=90°$.) For asymptotic s,t,u we have retained only the leading, logarithmic terms of each $F(t)$, $F(u)$, $F(-s)$ inside (2). Then $F(\rho)\to f(\rho)\equiv-\ln|\rho|$, and we find for pp scattering that

$$b_{\text{I}}(\epsilon,s)=4.87\ln s+4.0\ln(\tfrac{1}{2}+\epsilon)+4.0\ln(\tfrac{1}{2}-\epsilon)+\text{const}, \tag{6}$$

with the last, "constant" term of (6) reflecting both the magnitude of the Born exchange constant of (4) and the masses that set the scale of the logarithms. The numerical factors multiplying each log of (6) are determined by the previous choice $\gamma=2.3$. From (5) and (6) one sees that

$$\left(\frac{d\sigma}{dt}\right)_{90°}=10^{-b_{\text{I}}(0,s)}\sim s^{-11.2}, \tag{7}$$

a value quite compatible with existing machine experiments.[3]

The symmetry of pp scattering about $\epsilon=0$ will, in general, not be maintained for other hadronic reactions, although the cross sections for all two-two processes can be written in the form (5) within the model. It is convenient to introduce a parameter which measures this asymmetry, about $\theta_{\text{c.m.}}=90°$. For this purpose we define the skewness,

$$a\equiv\frac{d}{d\epsilon}b(\epsilon,s)\bigg|_{\epsilon=0}, \tag{8}$$

which is simply the slope of $-\log_{10}(d\sigma/dt)$ at 90°. For pp (and K^+p, as discussed below) this vanishes; for other asymptotic reactions it is positive and measures an essential feature of these wide-angle models, the relative strengths and phases of the couplings of different hadrons to SVNVM.

It must be emphasized that none of these predictions are supposed to be valid in the forward- and backward-peak regions, since the peak structure is expected to be due to other mechanisms.

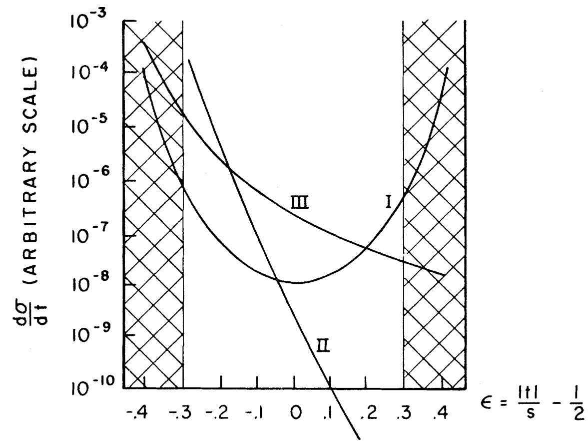

FIG. 2. Plot of shapes for $d\sigma/dt$ predicted by the model for wide-angle scattering for the three categories of two-body scattering processes discussed in the text. The cross sections are plotted versus $\epsilon=|t|/s-\frac{1}{2}$ $\approx-\frac{1}{2}\cos\theta_{\text{c.m.}}$, with s held fixed. Normalizations are arbitrary (including relative normalizations among the three curves), and the cross hatching denotes the near forward and backward regions where the model is not expected to apply.

(For this reason we have shaded these regions in Fig. 2.) In fact, unless the peaks shrink appreciably as s increases, it may be difficult to distinguish the "true" wide-angle region from the overlap of forward- and backward-peaks; an example of this sort of difficulty is present in the $\pi^{\pm}p$ curves at $p_\pi\sim 5$ GeV/c of Fig. 1, in contrast to the other $K^{\pm}p$, pp, $p\bar{p}$ curves which begin to exhibit, at this relatively low energy, the expected wide-angle behavior. Our prediction for the shape of the π^-p curve cannot be tested at recent $p_\pi\sim 10$ GeV/c experiments[5] for there is too much dip/bump structure over the entire wide-angle region. Hence, the asymptotic properties derived below for $\pi^{\pm}p$ elastic may be quite difficult to see until the energies become much higher and/or the peaks shrink away.

One of the more striking aspects of the curves of Fig. 1 is the approximate similarity in shape, over the wide-angle region, of pp and K^+p and of $p\bar{p}$ and K^-p scattering. These curves suggest that there is something almost electrical about the underlying theoretical mechanism, which we here interpret as exchange of multiple, soft ω's between the appropriate hadrons. The similarity of these curves provides a measure of justification for the intuitive NVM couplings originally used to fit the proton data.[2,3] We emphasize that this portion of the discussion is concerned only with the shape of wide-angle scattering; magnitudes depend upon the nonsoft structure and on particle masses, and must be treated separately (as in Sec. III, below). Hence the predicted curve I of Fig. 2 for pp and K^+p refers to the same shape, but not necessarily magnitude, expected for both processes; and similarly for K^-p and $\bar{p}p$ (curve II of Fig. 2), which seem to exhibit essentially the same shape and magnitudes everywhere, at 5 GeV/c.

In describing the very simple method of construction of these curves, we first note that almost any smooth, wide-angle curve may be reproduced by arbitrarily adjusting the coupling parameters of SVNVM to appropriate hadron. This we shall *not* do. Rather, we restrict ourselves to a single parameter, the constant γ of Eq. (3), itself proportional to $g_{\omega pp}{}^2$ and fixed by the fit to the proton form factor.[2] The relative strengths of ω couplings to p, n, $\bar{p}$, K^+, K^-, K^0, and $\bar{K}^0$ are determined by the assumption that the ω couples to the hypercharge current.[12] Thus we have

$$g_{\omega K^+K^+} = g_{\omega K^0 K^0} = -g_{\omega K^- K^-} = -g_{\omega \bar{K}^0 \bar{K}^0} = g_{\omega pp} = g_{\omega nn} = -g_{\omega \bar{p}\bar{p}} \,. \tag{9}$$

The simplest process to consider, after the symmetric pp case, is elastic $p\bar{p}$ scattering, for which the $S(s,t)$ dependence is given by $\exp\{4\gamma[F(t)-F(u)+F(s)]\}$, with the relative change of sign of the pp combination $F(u)-F(s)$ occurring because of the replacement of one p by $\bar{p}$ in the construction of each of these terms. The effect, as predicted long ago by the SVNVM model,[2] is to damp $p\bar{p}$ scattering severely relative to pp at large angles: $(d\sigma/dt)_{p\bar{p}} = 10^{-b_{II}(\epsilon,s)}$, and

$$b_{II}(\epsilon,s) = 4.87\ln s + 4.0\ln(\tfrac{1}{2}+\epsilon) - 4.0\ln(\tfrac{1}{2}-\epsilon) + \text{const} ,$$

$a_{II} = 16.0$, with the largest predicted skewness of this group of reactions (curve II of Fig. 2). Although a_{II} is larger than that of the nonasymptotic 5-GeV/c data of Fig. 1, the general trend seems to be present.

The relations given in Eq. (9) among the ω coupling constants make it obvious that, within the model, np elastic scattering will be identical to pp. K^+p elastic reactions will be identical in shape (but not in magnitude) to pp, and K^-p elastic and K^-p charge exchange reactions will be identical in shape to $p\bar{p}$ elastic scattering.

Since the ω does not couple to the pion, π-N elastic scattering has soft-ω exchanges only in the t channel. The same situation holds for photoproduction of pions and π^-p charge-exchange scattering. For all of these processes the model prediction is

$$S(s,t) = \exp[2\gamma F(t)] \,.$$

This corresponds to

$$b_{III}(\epsilon,s) = 2.87\ln s + 2.0\ln(\tfrac{1}{2}+\epsilon) + \text{const},$$

$$a_{III} = 4.0 \,.$$

At $\theta_{c.m.} = 90°$ we have for all these processes the predicted s dependence

$$\left(\frac{d\sigma}{dt}\right)_{90°} \sim s^{-6.6} \,.$$

This is to be compared, for example, with recent SLAC experiments[8] on $\gamma p \to \pi^+ n$ which fall off like $s^{-(7.3 \pm 0.4)}$ at $\theta_{c.m.} \approx 90°$. For π^-p elastic scattering a decrease of the 90° cross section like s^{-p} with p between 7 and 9 is consistent with the data of Owen *et al.*[13] between 5 and 10 GeV/c incident momentum.

III. MAGNITUDES AT 90°

We have mentioned above the damping of $p\bar{p}$ relative to pp elastic scattering which occurs because of the difference in sign of the $F(u)$ and $F(s)$ factors in the two cases. Relative magnitudes of various processes also depend, in the model, both on the strength and nature of the relevant hard exchanges and on the particle masses which set the scale for the asymptotic behavior of the F functions. For example, since $m_K < m_p$, K^+p is damped relative to pp because of mass dependence in the F functions; in fact, the ratio of the soft factors alone at $P_{lab} = 5$ GeV/c and $t = -3.89$ (GeV/c)^2 is $S_{K^+p}/S_{pp} = 10^{-1.8}$, in good agreement with the experimental results of Fig. 1.

The damping of $\bar{p}p$ relative to pp is given by the factor $\exp\{8\gamma[F(u)-F(4m^2-s)]\}$, which for $\gamma = 2.3$ is $\sim 2\times 10^{-4}$. Similarly, the damping of K^-p relative to pp is $\sim 10^{-6}$. Experimentally, both these ratios are $\sim 10^{-2}$. However, the nonsoft contributions to $\bar{p}p$ and to K^-p should contain strong s-channel dependence, absent in either pp or K^+p, which may easily be imagined to bring the ratios back to their experimental values.[14] As the experimental energies increase, it will become appropriate to construct detailed fits to the data, of the same quality as those of Ref. 3, by including simple Born approximation models for hard-meson exchange.

IV. SUMMARY

We have shown that within the soft-vector-gluon model the identification of the SVNVM with the ω leads to the classification of the various pseudoscalar-meson–nucleon and nucleon-nucleon two-body processes into three groups: (i) pp, pn, and K^+p, (ii) $p\bar{p}$ and K^-p (elastic and charge exchange reactions), and (iii) πN (elastic and charge exchange reactions) along with photoproduction of pions. The characteristic shapes for these three categories are shown in Fig. 2 where the cross hatching indicates the forward and backward regions where the model is not expected to apply.

With the exception of $\pi^{\pm}p$ elastic scattering, for which the forward and backward peaks tend to mask the wide-angle region at low energies, the general trend of existing data seems to support these predictions. It should also be mentioned that the model suggests a natural mechanism for breaking the degeneracy of shapes within each of the three categories and for making a prediction of the high-t behavior of the pion form factor. This is to include ρ exchange. This has not been done here since ρ_0 exchange requires (by isosopin invariance) charged ρ exchange, which we are unable to compute in the model. We note, however, that there are experimental indications that $g_\omega{}^2$ is significantly larger than $g_\rho{}^2$.[15]

Finally, we point out the similarity of the forms for $d\sigma/dt$ obtained by Gunion, Brodsky, and Blankenbecler[16] to those described here and in Refs. 2 and 3, namely,

$$\frac{d\sigma_i}{dt} \propto F_i(\epsilon)\, s^{-p_i} , \qquad (10)$$

where i denotes the particular process. This similarity of form is particularly striking in view of the fact that wide-angle scattering takes place in the model of Gunion *et al.* by parton exchange rather than by hard meson exchange as in this model. We emphasize, in particular, that our results show that a gluon exchange model can account both for the failure of $(d\sigma/dt)_{pp}$ to approach $G^4(t)$ at large s and for the difference in shape between pp and $p\bar{p}$ angular distributions. A significant difference between the predictions of this ω-exchange model and the model of Ref. 16 is that KN has the same fixed angle s dependence as NN scattering in this model, whereas in the SU(3)-symmetric parton-exchange model KN and πN have the same fixed-angle s dependence.

The form (10) for pp scattering has also been obtained recently from field theoretical arguments (which are more closely related to those of this approach than to the parton-exchange model) by Horn and Moshe[17] and by Theis.[18] The application of this hadronic bremsstrahlung model to production processes at large nucleon transverse momentum has been discussed elsewhere.[19]

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[8]R. L. Anderson *et al.*, Phys. Rev. Lett. 30, 627 (1973). We thank R. Anderson for permission to quote these results before publication. The graph of Fig. 2 of this paper, corresponding to $E_\gamma = 7.5$ GeV, seems to be developing the skewness suggested by our curves.

[9]For example, the tower-graph summation of H. Cheng and T. T. Wu [Phys. Rev. Lett. 24, 1456 (1970)], and S.-J. Chang and T.-M. Yan [*ibid.* 25, 1586 (1970)], and the generalizations to include all checkerboard graphs of S. Auerbach, R. Aviv, R. Sugar, and R. Blankenbecler [Phys. Rev. D 6, 2216 (1972)], and R. Blankenbecler and H. M. Fried [*ibid.* 8, 678 (1973)].

[10]H. M. Fried, *Functional Methods and Models in Quantum Field Theory* (MIT Press, Cambridge, Mass., 1972), Chap. 9.

[11]In Refs. 2–4, the cutoff μ_c has been introduced in an arbitrary, but simple, covariant way which avoids the somewhat more complicated forms resulting from the retention of quadratic meson-momentum dependence in virtual nucleon propagators. The latter produce an $F(t) \sim -\ln^2|t|$ rather than $\sim -\ln|t|$, which could conceivably be important for very large $|t|$.

[12]M. Gell-Mann, Caltech Report No. CTSL-20, 1961 (unpublished). By assuming multiple-soft-ω exchange, we are constructing amplitudes with built-in violations of SU(3). The question arises whether such "spontaneous" violations of lesser symmetry, in particular isospin, can exist at high energies and wide angles; perhaps, for the strong interactions, "everything not forbidden is compulsory." Such spontaneous violations of isospin could be accomplished by the multiple exchange of soft ρ_0's, coupled to the third component of the hadronic isospin current, yielding different pp and np amplitudes, and splitting apart π^+p, π^-p, and $\pi^-p \to \pi^0 n$. [Charge exchange and photopion production still have the same wide-angle forms.] Preliminary data contain no suggestion of any significant difference be-

tween wide-angle $\pi^{\pm}p$ elastic, and so we do not consider this possibility further.

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[14]Suppose there exists a strong s-channel π^0 contribution to $(d\sigma/dt)_H$ parametrized with coupling constant $g_{\pi pp}{}^2/4\pi \simeq 15$. In the amplitude for such a γ_5 (pseudoscalar) interaction, there appears a factor $\sim\sqrt{s}$ at each vertex, multiplied by a pion propagator $\sim s^{-1}$; one is not allowed to argue that the π_{NN} form factor will cut down the effective coupling, for in this model it is given by SVNVM exchanges, which must not be counted twice. The ratio $(g_{\pi pp}/g_{\rho pp})^2$ could then contribute the needed factor $\sim 10^2$.

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Scaling Behavior of the Ratio of Longitudinal to Transverse Total Virtual-Photoabsorption Cross Sections*

J. F. Gunion and R. L. Jaffe

Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139

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The Bjorken scaling of $R = \sigma_L/\sigma_T$ is studied. We show that the ratio $\nu^2 R/M^2Q^2$ [which scales in canonical spin-(1/2) theories] behaves as $1/x^2$ $(x = +Q^2/2\nu)$ for small x and as $(1-x)^{-\alpha}$ $(0 < \alpha < 2)$ for x near unity. We compare the scaling of νW_2 as extracted from the differential cross-section data using this form of R with that of νW_2 extracted using a form of R appropriate when some charged spin-0 constituents are present.

Inelastic electron scattering experiments performed at SLAC[1] have shown that the ratio, R, of longitudinal to transverse total virtual-photoabsorption cross sections is small. This is taken as evidence that the carriers of electric charge in the proton are primarily spin-$\frac{1}{2}$.[2] More precise determinations of R are expected in the near future.[3] In this paper we present the behavior expected of R in canonical field theories. Although we use the language (momentum space) of the parton model, our results, except where noted, may also be derived from light-cone considerations. R is related to structure functions with well-determined scaling, Regge and threshold behaviors which severely constrain its form. We analyze the presently available differential cross-section data with a form of R appropriate to an admixture of spin-0 and spin-$\frac{1}{2}$ constituents as well as with a form corresponding to purely spin $\frac{1}{2}$. The scaling of $\nu W_2(q^2, \nu)$ is examined for both choices.

R is defined by

$$R \equiv \frac{\sigma_L}{\sigma_T} = \frac{(1+\nu^2/M^2Q^2)W_2(q^2,\nu) - W_1(q^2,\nu)}{W_1(q^2,\nu)} \equiv \frac{W_L(q^2,\nu)}{W_1(q^2,\nu)}, \tag{1}$$

where $Q^2 = -q^2 > 0$ is the four-momentum transfer from the electron and $\nu = P\cdot q$. W_1 and W_2 are the usual structure functions.

The current data on R are presented in Fig. 1. It was noted in Ref. 1 that the data are consistent with (a) $R =$ constant and with (b) $R = M^2Q^2/\nu^2$. Recently, however, Sakurai[4] has shown that a bound derived from vector-meson photoproduction is inconsistent with (b).

We shall show that canonical scaling theories predict neither (a) nor (b). Though (a) may be a reasonable approximation in models with some spin-zero constituents, (b) is not a good approximation for any combination of spin-0 and spin-$\frac{1}{2}$ constituents.

In the Bjorken limit ($\lim_{\rm Bj}$) structure functions