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NUCLEON ELECTROMAGNETIC FORM FACTORS: EVIDENCE FOR q^{-6} DEPENDENCE

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NUCLEON ELECTROMAGNETIC FORM FACTORS: EVIDENCE FOR q^{-6} DEPENDENCE^{*)}

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Some time ago, we proposed a simple model of the nucleon electromagnetic form factors¹⁾. Its essential features were:

- i) The assumption of pole dominance using only the ρ , ω , and ϕ mesons.
- ii) The interpretation of the residues c_i of these poles as the products of coupling constants whose behaviour did not necessarily have to be point-like. This gave a very simple explanation of the q^{-4} dependence of the form factors observed in the momentum transfer region $[q^2 \lesssim 5 \text{ (GeV/c)}^2]$.
- iii) The introduction of SU_3 symmetry and of its breaking.

For further details, the reader is referred to the original paper¹⁾. The experimental data available at that time were fitted with this model, using only one free parameter. The resultant value of χ^2 was comparable to those values which had been obtained previously in fits with several free parameters.

Soon afterwards, the model received a theoretical basis, thanks to the work of Kroll, Lee and Zumino²⁾, who showed that our interpretation was completely consistent with vector-meson dominance and gauge invariance. The q^{-2} dependence of the vector-meson-nucleon vertex turns out to be the simplest form within the general theoretical framework of field current identity, which then gives the q^{-4} dependence of the nucleon electromagnetic form factors. These authors also emphasized the need, pointed out by

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^{*)} The main results of this paper were communicated at the 14th International Conference on High-Energy Physics, Vienna, 28 August-5 September, 1968.

Coleman and Schnitzer³⁾, for describing the mixing between vector particles such as ω and ϕ in terms of two coupling constants g_Y and g_N , and of two mixing angles θ_Y and θ_N ^{*)}.

In our paper¹⁾ the residues of the poles were given the form:

$$\text{constant} \cdot \frac{1}{1 + q^2/\Lambda_Y^2} \cdot \frac{1}{1 + q^2/\Lambda_S^2} \quad (1)$$

to describe the deviation from point coupling, but as only one parameter had to be left free, Λ_Y was assumed to be infinite. Later we presented an analysis⁴⁾ in which the form factors were used to derive a value of the ω - ϕ mixing angle, and in which Λ_Y was left as a free parameter. A result of this analysis was that the experimental data then available were not accurate enough to determine a meaningful value for Λ_Y in the range ~ 10 GeV to ∞ . The data still permitted a model with $g_Y = g_N$ and $\theta_Y = \theta_N$.

With the advent of new and more precise experimental data, the condition $g_Y \neq g_N$ became imperative, and in fact Ng⁵⁾ obtained a fit to all electron-nucleon scattering data with a remarkably low value^{**) of} $\chi^2 = 1.4/\text{point}$. However, the new, high q^2 , electron-proton scattering data obtained at Stanford⁶⁾ were not compatible with the parameters of the Ng fit.

The purpose of this note is to show that if our complete formulation¹⁾ is used in the Ng analysis, the Stanford data become compatible with the results at lower q^2 , and allow the derivation of a value for Λ_Y . This will be done in the simplest way, so as to illustrate a graphical derivation of Λ_Y .

In fact, on the basis of (1), the ratio

$$R = \frac{G_M^P \text{ calculated using the Ng fit}}{\text{Experimental result}} = 1 + q^2/\Lambda_Y^2$$

gives a measure of Λ_Y .

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*) For the notation see Ref. 2.

**) For form factor data.

Figure 1 shows the values of R obtained from the Stanford results^{*)} plotted as a function of q^2 . The results fall on a straight line with a slope corresponding to

$$\Lambda_\gamma = 7.7 \pm 1.1 \text{ GeV} . \quad (2)$$

The line should pass through the point $R = 1$ at $q^2 = 0$. The 2.5% discrepancy here is smaller than the systematic uncertainty quoted in electron scattering data, and therefore is not important.

The first conclusion of the above analysis is that the high-momentum transfer data obtained at Stanford constitute the first experimental evidence for a further q^{-2} dependence in the nucleon electromagnetic form factors, the total dependence being therefore q^{-6} .

Now the question arises: what is the physical origin of this extra q^{-2} dependence? A fascinating possibility is the 'heavy photon' recently discussed by Lee and Wick⁷⁾, in connection with the problem of removing divergence difficulties in physics. In contrast with the old QED 'cut-off' models, their theory preserves unitarity and relativistic invariance. According to this proposal⁷⁾, the usual photon propagator should be replaced, as in the old days of 'cut-off' theories, by $(1/q^2) - [1/(q^2 + \Lambda_\gamma^2)]$, where Λ_γ is the mass of the 'heavy photon'.

We recall here that the study of the nucleon electromagnetic form factors alone cannot allow a unique identification of the various deviations from point-like behaviour with either the hadron-hadron or the hadron-photon coupling¹⁾.

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*) The values of G_M^P were obtained assuming $G_E^P = G_M^P/\mu_p$. If this assumption is not valid, then the value of G_M^P will be different. We are at present reanalysing all experimental data on form factors and investigating the above possibility. It seems that a complete analysis of all form factors data will not change the value of Λ_γ by more than $\sim 20\%$.

However, if this further q^{-2} dependence is really due to the heavy photon, it is possible to predict⁷⁾, in terms of the heavy photon mass [Eq. (2)], some straightforward effects in purely electromagnetic processes. Thus, for example:

- i) the muon (g-2) experiment should give a deviation from the standard QED calculation:

$$\delta g = (g)_{\text{QED}} - (g)_{\text{heavy photon}} \simeq 15 \times 10^{-8}$$

- ii) The colliding beam cross-section for

$$e^+ e^- \rightarrow \mu^+ \mu^-$$

should deviate from QED by $\sim 25\%$ at 1.5 GeV colliding beam energy, which is the ADONE design energy.

We would like to thank Prof. T.D. Lee for illuminating discussions on his new theory of the heavy photon.

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Figure captions

Fig. 1 : Showing the value of $R = (G_M^P \text{ calculated using the Ng fit}) /$
(Experimental result) as a function of q^2 for the Stanford
high q^2 data. The slope gives a value of $\Lambda_Y = 7.7 \pm 1.1 \text{ GeV}$.

FIG.1