national Symposium on Electron and Photon Interactions at High Energies, Bonn, W. Germany, 1973, edited by H. Rollnik and W. Pfeil (North-Holland, Amsterdam, 1974).

[16]For a review see M. K. Gaillard, B. W. Lee, and J. L. Rosner, Fermilab Report No. PUB-74/86-THY, 1974 (unpublished).

[17]Y. Nambu, unpublished lectures; P. Goddard, J. Goldstone, C. Rebbi, and C. B. Thorn, Nucl. Phys. B56, 109 (1973), and references therein.

[18]If the force between c and $\bar{c}$ may be approximated by a harmonic oscillator potential then the first radial excitation with $L=0$ is degenerate in energy with the lowest state with $L=2$.

[19]We note that the decay $\psi \to J+\eta$, which might otherwise be expected to be a strong competitor with $\psi \to J+2\pi$, should be suppressed because the available phase space is limited and the decay takes place only in the P wave. Moreover the process violates SU(3) symmetry.

COMMENTS

Intermediate Boson in the Fermion-Current Model of Neutral Currents*

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The intermediate-boson version of the earlier proposed fermion-current model of neutral currents is discussed. In particular I speculate on the possibility that the recently discovered 3.105-GeV particle may be identified with the intermediate boson of the fermion-current model.

Shortly after the discovery of neutrino-induced neutral-current reactions it was proposed that the hadronic piece of the neutral current be identified with the unitary singlet baryon current.[1] In the same paper I also speculated that all neutral-current phenomena are due to an extremely simple universal Fermi interaction of the form

$$\mathcal{L}_{\rm eff}=(G\lambda/\sqrt{2})j_\lambda^{(\rm F)}j_\lambda^{(\rm F)}, \tag{1}$$

with

$$j_\lambda^{(\rm F)}=i[\bar{e}\gamma_\lambda e+\bar{\mu}\gamma_\lambda\mu+\bar{\nu}_e\gamma_\lambda\nu_e+\bar{\nu}_\mu\gamma_\lambda\nu_\mu+\bar{u}\gamma_\lambda u+\bar{d}\gamma_\lambda d+\bar{s}\gamma_\lambda s], \tag{2}$$

where the notation of the uncolored quark model is used for hadrons. In view of the recently reported evidence for a narrow-width boson in e^+e^- production[2] and in e^+e^- annihilation,[3] it is of some interest to make a few comments on the intermediate-boson version of the "fermion-current model."

I propose that the effective interaction (1) applicable to low-q^2 phenomena arises from a more fundamental intermediate-boson coupling as follows:

$$\mathcal{L}=gZ_\mu j_\mu^{(\rm F)}, \tag{3}$$

where Z_μ is a neutral spin-1 field of mass m_Z. Clearly we have

$$g^2/4\pi=2(\lambda/4\pi)(G/\sqrt{2})m_Z^2, \tag{4}$$

where the factor 2 is necessary because the interaction (1) represents the product of two identical currents so that a typical term like $(\bar{e}e)(\bar{u}u)$ appears twice.[4] The partial decay width for the Z boson decaying into a lepton pair can easily be calculated to be

$$\Gamma(Z\to e^+e^-)=\Gamma(Z\to\mu^+\mu^-)=\tfrac{1}{3}(g^2/4\pi)m_Z \simeq(10^{-5}/\sqrt{2})(\lambda/6\pi)(m_Z^3/m_p^2). \tag{5}$$

As for the hadronic decay modes of the Z boson, let us first observe that the quantum numbers of the final states are characterized by

$$J^{PC}=1^{--},\quad I^G=0^-. \tag{6}$$

This quantum number assignment leads to numerous predictions some of which will be discussed later.

We now proceed to estimate the hadrons-to-lepton-pair ratio

$$R_Z \equiv \Gamma(Z \to \text{hadrons})/\Gamma(Z \to \mu^+\mu^-) \tag{7}$$

using the quark-parton model. Just by counting the number of quark pairs we find that this ratio is 3 in the uncolored quark model and 9 in the triply colored quark model. As is well known, the quark-parton model, with or without coloring, makes a disastrous prediction for the hadrons-to-lepton-pair ratio in e^+e^- annihilation. We may, however, take the point of view that the symmetry relations inferred from the quark-parton model are far more general than the model itself. We can then derive that

$$R_Z = \tfrac{9}{2}R \tag{8}$$

with or without coloring, where R stands for the ratio of hadrons to lepton pairs in e^+e^- annihilation right outside the Z-peak region.[5]

Very recently a boson with $m = 3.105$ GeV of a very narrow width has been reported in

$$p + \text{Be} \to e^+ + e^- + \text{anything}, \tag{9}$$

$$e^+ + e^- \to e^+ + e^-,\ \mu^+ + \mu^-,\ \text{hadrons}, \tag{10}$$

by two different groups.[2,3] It is amusing to speculate on whether we can identify the observed 3.105-GeV particle with the Z boson.

To compute the partial decay width for the lepton-pair mode we must first know the neutral-current coupling constant λ. This constant has previously been estimated from the deep inelastic neutrino data to be $\lambda^2 \simeq 0.2$ within perhaps $\pm 30\%$.[6,7] I therefore predict that

$$\Gamma(Z \to e^+e^-) = \Gamma(Z \to \mu^+\mu^-) = 4.8\text{–}6.5\ \text{keV}. \tag{11}$$

As for the hadrons-to-lepton-pair ratio for the Z boson, the corresponding ratio in e^+e^- annihilation in the vicinity of $s = 3.0$–3.2 GeV is known to be 2.5–3.0[8]; hence my prediction for this ratio is given by

$$R_Z = \Gamma(Z \to \text{hadrons})/\Gamma(Z \to \mu^+\mu^-) \simeq 11\text{–}14. \tag{12}$$

The partial decay widths, $\Gamma(Z \to \text{hadrons})$ and $\Gamma(Z \to \mu^+\mu^-)$, can be extracted from the colliding-beam data by using (after appropriate radiative corrections)

$$\int_{\text{peak}} \sigma(e^+e^- \to \text{hadrons})\, ds = \frac{12\pi^2 \Gamma(Z \to e^+e^-)\Gamma(Z \to \text{hadrons})}{m_Z \Gamma_{\text{tot}}} \tag{13}$$

and the analogous formula with "hadrons" replaced by $\mu^+\mu^-$. In (13) Γ_{tot} must include the contributions from $\Gamma(Z \to \nu_{e,\mu} + \bar{\nu}_{e,\mu})$ predicted in our model to be equal to $\Gamma(Z \to e^+e^-)$. The data of Ref. 3 appear to be roughly consistent with both (11) and (12); however, for more quantitative comparisons we must await more complete data.[9,10]

There are other more or less obvious suggestions we can make for the experimentalists:

(i) Attempts should be made to examine whether reactions

$$e^+ + e^- \to Z \to 2\pi^+ + 2\pi^-,\ 3\pi^+ + 3\pi^- \tag{14}$$

are indeed forbidden, as required in the present model. This is a good test of the G-parity assignment because appreciable signals for $4\pi^\pm$ and $6\pi^\pm$ have been observed outside the peak region.[8]

(ii) If there is a measurable cross section for $\rho + \pi$ in the Z-peak region, we can check the isospin assignment as follows:

$$\begin{aligned} &\Gamma(\rho^0 + \pi^0) = \Gamma(\rho^+ + \pi^-) = \Gamma(\rho^- + \pi^+) \text{ for } I = 0, \\ &\Gamma(\rho^0 + \pi^0) = 0 \text{ for } I = 1. \end{aligned} \tag{15}$$

(iii) We can think of other reactions that might be helpful in determining the isospin and C parity. For example, the final states of

$$e^+ + e^- \to Z \to f + \omega, \tag{16a}$$

$$e^+ + e^- \to Z \to \rho^0 + \omega, \tag{16b}$$

are both characterized by odd G parity but the present model allows (16a) and forbids (16b).

(iv) A careful study of the shape of $\sigma(e^+e^- \to \mu^+\mu^-)$ is worthwhile; I predict that the interference between the background and the Z boson is destructive below the peak and constructive above the peak. However, the same feature is expected in a large class of spin-1 models with μe universality.

The main virtue of my interpretation for the 3.105-GeV particle is that it makes many specific predictions some of which are quite quantitative.[11] I conclude this short note by listing two obvious defects of the interpretation. (i) We have no simple way of accommodating possible higher-mass peaks now being rumored.[12] (ii) With a Z-boson mass as low as 3.1 GeV it is somewhat strange that there is not much variation observed in the neutral-current-to-charged-current ratio as we go from CERN energies to Fermi National Accelerator Laboratory energies.[13]

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[1]J. J. Sakurai, Phys. Rev. D 9, 250 (1974).

[2]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).

[3]J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974).

[4]Note also that in computing the cross sections for neutrino-induced reactions we have to be careful with another factor of 2 arising from the replacement $\bar{\nu}\gamma_\lambda\nu \rightarrow \frac{1}{2}\bar{\nu}\gamma_\lambda(1+\gamma_5)\nu$ which we can freely make for reactions induced by left-handed accelerator neutrinos.

[5]Those who are skeptical of arguments based on the quark-parton model may be interested to know that the result (8) can be obtained in an equally convincing manner by using nonet symmetry for the low-lying vector mesons together with Q^2 duality [of the kind discussed by M. Greco, Nucl. Phys. B63, 393 (1973); and J. J. Sakurai, University of California at Los Angeles Report No. UCLA/73/TEP/90 (to be published)].

[6]G. Rajasekaran and K. V. L. Sarma, Pramana 2, 62 (1974); J. J. Sakurai, in *Neutrinos—1974*, edited by C. Baltay, AIP Conference Proceedings No. 22 (American Institute of Physics. New York, 1974), p. 57.

[7]This value of λ^2 is consistent with other ν scattering data. See J. J. Sakurai and F. Urrutia, Phys. Rev. D (to be published).

[8]B. Richter, SLAC Report No. SLAC-PUB-1478 (to be published).

[9]In attempting to deduce R_Z from Ref. 3 it is important to keep in mind that detection-efficiency corrections have been applied to Fig. 1(a) but not to Figs. 1(b) and 1(c). For a detector that covers the angular region $|\cos\theta|<0.7$ the purely geometric efficiency is 0.61 for $\mu^+\mu^-$ final states expected to exhibit a $1+\cos^2\theta$ distribution.

[10]To be able to deduce the absolute magnitude of $\Gamma(Z \rightarrow e^+e^-)$, etc., from the data our knowledge of the neutrino spectrum must be complete. Our crude estimate was made under the assumption that there are no "neutrinos" other than ν_e and ν_μ, e.g., no neutrinos associated with heavy leptons.

[11]Needless to say, similar speculations can be made by using other models of neutral currents. If the 3.105-GeV particle indeed turns out to be the mediator of neutral-current interactions, it will be relatively easy to devise stringent tests for the various neutral-current models proposed so far. For example, the "electromagnetic-current model" of the kind discussed by M. A. B. Bég and A. Zee [Phys. Rev. Lett. 30, 675 (1973)] predicts $R_Z=R$; the "$I=1$ $V-A$ model" of S. L. Adler and S. F. Tuan [Phys. Rev. D (to be published)] predicts a $(1+\cos\theta)^2$ distribution with a huge front-back asymmetry in $e^++e^-\rightarrow\mu^++\mu^-$ in the Z-peak region. Both models give sizable signals for $Z\rightarrow 4\pi^\pm, 6\pi^\pm$. More tests along these lines will be left as an exercise for the interested reader with his own pet model of neutral currents.

[12]Perhaps a single Z field can correspond to many (an infinite sequence of ?) weak boson states.

[13]F. J. Hasert *et al.*, Phys. Lett. 46B, 138 (1973); B. Aubert *et al.*, Phys. Rev. Lett. 32, 1457 (1974); B. C. Barish and F. J. Sciulli, private communication.