Narrow Peaks near $\eta'(958)$ †

S. F. Tuan
Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822
(Received 19 April 1971)

It is pointed out that recent evidence for sharp mesonic peaks near the $\eta'(958)$ may lend support to a theory proposed some years back that the broken nonchiral $SU(2)\otimes SU(2)$ symmetry is relevant to classification of hadronic states.

Some years back Tai Tsun Wu and I[1] proposed that the degeneracy observed between $\eta'(958)$ and a *narrow* $\delta^-(962)$ peak[2] was not accidental, but reflected the presence of a different underlying symmetry [distinct from SU(3)] at work. We suggested that the optimal clashing symmetry besides SU(3) [with multiplets of $q\bar{q}$ and qqq type] was a group[3] $\mathcal{G}\equiv SU(2)_{I_1}\otimes SU(2)_{I_2}$ [not contained in SU(3)], describing multiplets with isospin $I=I_1+I_2$, in analogy with the use of two different overlapping schemes in nuclear physics – e.g., the shell- and collective-model descriptions. For physically meaningful assignments to $SU(2)_{I_1}\otimes SU(2)_{I_2}$ multiplets, we must require that the *G parity of members of such a multiplet be the same.*[1,4] The pair $\eta'(958)$ and the sharp charged $\delta(962)$ ($\Gamma<5$ MeV) state[2] thus lend themselves naturally to assignment to the $(\frac{1}{2},\frac{1}{2})$ representation of this clashing $SU(2)\otimes SU(2)$ symmetry. Hence, the $\delta(962)$ is predicted to have quantum numbers $I^G=1^+$, $J^{PC}=0^{--}$ if we accept that the $\eta'(958)$ has quantum numbers $I^G=0^+$, $J^{PC}=0^{-+}$. These mesonic degeneracies now no longer appear to be isolated cases, since other examples of $SU(2)\otimes SU(2)$ classification have been suggested in connection with the $\omega(784)$ anomaly[5] and perhaps the A_2-splitting problem.[6] The baryonic system is replete with examples of the doublet-symmetry type.[3,7] However, since the G-parity constraint (exact in strong interactions) is not relevant for the baryons, nor for the $\Delta S\neq 0$ mesons, a typical $SU(2)\otimes SU(2)$ multiplet here might incorporate even a mass difference like the Σ-Λ one; hence, they are less spectacular than the remarkable degeneracies found in $\Delta S=0$ mesonic systems discussed above.

Let us return to the situation near $\eta'(958)$. There are two additional (and independent) experimental pieces of information which bear on this question. The CBS group[8] in the test run of the CERN-IHEP boson spectrometer identifies a "δ" ~955 MeV (at the $4\frac{1}{2}\sigma$ level) *narrow* enhancement (consistent with experimental resolution ±15 MeV) from the cascade process (at 10–11 and 25 GeV/c)

$$\pi^- + p \to p + X^-,\quad X^- \to \pi^- + X^0,\quad X^0 \to \pi^\pm + (\mathrm{MM})^\mp,\quad (\mathrm{MM})^\mp \to \text{“}\delta\text{” at 955 MeV,} \tag{1}$$

where $1240 < M(X^0) < 1300$ MeV, and (MM) denotes the missing mass. Little is known about the state associated with X^0 though the identification $X^0\equiv D(1271)$ has been suggested.[8] It is tempting to identify this *narrow* $\delta^\pm(955)$ with the previously found $\delta^-(962)$ sharp peak ($\Gamma<5$ MeV) of Kienzle *et al.*[2] because of common mass (within experimental error) and width characteristics. Both features *are* consistent with the assignment $I^G=1^+$, $J^{PC}=0^{--}$ for this charged meson state as required by the $SU(2)\otimes SU(2)$ theory.[1] Since the dominant strong decay mode of such a $J^{PC}=0^{--}$ $\delta(960)$ state is expected to be $\omega^0\pi^\pm$ with a predicted width $\Gamma_\delta\sim 1$ MeV, accurate measurement of the branching ratio for the decay of the charged δ into three charged particles plus possible neutrals (3c) versus one charged particle plus neutrals (1c) in missing-mass experiments remains highly desirable. As emphasized earlier,[1] the 3c mode dominates for $J^{PC}=0^{--}$, $I^G=1^+$. Additional information concerning the G parity of the $\delta(955)$ is possible if a clear-cut identification of X^0 in the strong decay $X^0\to\pi^\pm+\delta^\mp(955)$ of Baud *et al.*[8] can be made. If $X^0\equiv D^0(1271)$ and $D^0(1271)$ was *clearly identified* as a $G=+1$ state, then $G=-1$ would be the appropriate assignment for $\delta(955)$. The situation relative to $D(1271)$ is, however, confused; Astier[8] suggested that the hypothesis of *two D* enhancements in this mass range is entirely compatible with data. In fact, little reliable empirical information is available concerning the quantum numbers of[9] $D(1271)$ other than that it is probably an $I=0$ state.

Another experiment which may be relevant to the present discussion is the recent evidence[10] for the existence of a new narrow meson resonance $M(953)$, with mass 953 ± 2 MeV and width <10 MeV, produced in the final state $K^-p \to pK^-M^0$ at incident momenta 3.9 and 4.6 GeV/c. These results are based primarily on a signal of 68 ± 12 events in the decay mode $M \to \pi^+\pi^-\gamma$ where the $\pi\pi$ does not show a ρ^0 signal, in sharp distinction to the $\rho^0\gamma$ decay mode of $\eta'(958)$. The decay mode $M \to \pi^+\pi^-\eta_N^0$ (where η_N^0 signifies decay to all neutrals) is seen, and using the argument that $G=-1$ would necessitate a large $3\pi/\eta\pi\pi$ branching ratio (unobserved), Aguilar-Benitez *et al.*[10] conclude that the $\eta_N^0\pi^+\pi^-$ mode of the M is mediated by the strong interaction, which implies $G=+1$. Assuming C invariance in electromagnetism, they also suggested that the absence of a $\rho^0\gamma$ mode would imply that $C=-1$ for the M[11]; hence from $G=C(-1)^I$ the isospin is odd ($I=1, 3, \ldots$, etc.). All the above features are consistent with the attractive possibility *that* $M(953)$ *is the neutral member of the predicted*[12] $I^G=1^+$, $J^{PC}=0^{--}$ *narrow* $\delta^\pm$ *in the mass range* 955 *to* 962 MeV,[2,8] required on the basis of the clashing-symmetry scheme.[1] The two pions in $0^{--} \to \pi\pi\gamma$ will have relative $l=2$ and be produced by an $M2$ transition if C is conserved or have $l=1$ and be produced by an $M1$ transition if C is violated in electromagnetic interactions. Since $M2=O(k^2)$ [and $M1=O(k)$] in amplitude, where k is the photon energy in the $M(953)$ rest frame, we expect that $M \to \pi^+\pi^-\gamma$ will favor lower $\pi^+\pi^-$ masses. For the strong decay $0^{--} \to \pi\pi\eta$, the two pions can have $l=1$, while η^0 has $L=1$ relative to the c.m. of the $\pi\pi$ system. We shall not hazard at this stage a detailed guess of the $0^{--} \to \pi\pi\gamma/\pi\pi\eta$ branching ratio[13] (~1 experimentally[10]) nor the degree of structure expected in the $\eta\pi\pi$ Dalitz plot for this assignment. As emphasized earlier,[1] the production and coupling of a C-exotic $J^{PC}=0^{--}$, $I^G=1^+$ δ (or M) in strong processes can be attenuated substantially relative to that of the nearby C-normal (i.e., having Yukawa coupling to $N\bar{N}$) meson $\eta'(958)$. *It remains of the highest interest to search for a* δ *in the* 950–960-MeV *region with* $\Gamma_\delta \lesssim 1$ MeV, *and dominant strong decay* $(\pi\omega)$ from say $K^- + N \to \Lambda^0 + \delta$.

Remarks

(a) It is extremely important to emphasize that the *narrow* (δ and/or M) $I=1$ peaks[2,8,10] near η'(958) are to be *differentiated* from the so-called "δ" meson produced in the reaction

$$K^-p \to (\mathrm{MM})^0\pi^-\pi^+\Lambda^0 \qquad (2)$$

at 3.3 GeV/c[14] with mass (995 ± 15) MeV, fairly broad width $\Gamma \lesssim 40$ MeV, and suggested decay "δ" $\to \eta\pi$. This "δ" corroborates earlier bubble-chamber evidence for an $\eta\pi$ state at 980 MeV with comparable width[15] and may be related to the so-called $\pi_N(1016)$. Such a broad $\eta\pi$ state is, of course, expected as the $I^G=1^-$, $J^{PC}=0^{++}$ $^3P_0$ state of the quark-antiquark system. Note that this quark-antiquark state has been seen in $p+p \to d+$"$\delta(980)$ or $\pi_N(980)$" as a broad enhancement, whereas there is *no evidence* for a *narrow* δ near $\eta'(958)$ from this same reaction.[16] The latter result is, of course, *entirely compatible* with a $\delta(960)$ assigned to $I^G=1^+$, $J^{PC}=0^{--}$, since such a meson is not coupled to a nucleon-nucleon vertex,[1] and this (together with isospin conservation) implies that it will not be produced in $p+p \to d+\delta$ through either nucleon or $\Delta(1238)$ exchange.

(b) The existence of an approximate clashing-symmetry scheme to broken SU(3) in our understanding of hadron levels raises novel experimental and theoretical questions. For instance, strictly in terms of the $(q\bar{q})$ SU(3) picture, the presence of both $\eta'(958)$ and $E(1420)$ with possible identical quantum numbers[17] $I=0$, $J^{PC}=0^{-+}$ has been advanced as evidence for radial excitation in the $(q\bar{q})$ picture. However, though we do not rule out the possibility that SU(3) and SU(2)⊗SU(2) can share a common hadron level,[5,6] it is also possible that $\eta'(958)$ may owe its existence primarily to classification under the clashing nonchiral SU(2)⊗SU(2) symmetry[18] in the $(\frac{1}{2}, \frac{1}{2})$ representation together with $\delta(962)$.[1] Identification of $E(1420)$ as the $I=0$ ninth member of the $^1S_0$ nonet of $(q\bar{q})$ (without radial excitation) gives then a much more satisfactory fit to the Schwinger mass formula[19]

$$(\eta^2-\pi^2)(E^2-\pi^2)-\tfrac{4}{3}(K^2-\pi^2)(\eta^2+E^2-2K^2)=0, \qquad (3)$$

where each symbol (η^2, π^2, etc.) denotes (mass)^2. From a theoretical viewpoint, it is evidently desirable to develop some meaningful criteria as to when such SU(2)⊗SU(2)-type degeneracy is expected and when it is not. Perhaps a study of the encompassing group structure which includes both SU(3) and SU(2)⊗SU(2) may shed useful insight on this question. It is well known that a simple choice which contains the physically realized representations of SU(2)⊗SU(2) is nonchiral SU(3)⊗SU(3).[20]

---

†Work supported by the U. S. Atomic Energy Commission under Contract No. AT(04-3)-511.

[1]S. F. Tuan and Tai Tsun Wu, Phys. Rev. Letters 18, 349 (1967).

[2]W. Kienzle *et al.*, Phys. Letters 19, 438 (1965); M. N. Focacci, W. Kienzle, B. Levrat, B. C. Maglic, and M. Martin, Phys. Rev. Letters 17, 890 (1966).

[3]This is essentially the doublet-symmetry group of

A. Pais [Phys. Rev. 110, 574 (1958); 110, 1480 (1958); 112, 624 (1958); 122, 317 (1961)].

[4]T. D. Lee and C. N. Yang, Phys. Rev. 122, 1954 (1961).

[5]W. A. Simmons and S. F. Tuan, Phys. Rev. D 4, 663 (1971); G. S. Abrams, K. W. J. Barnham, W. R. Butler, D. G. Coyne, G. Goldhaber, B. H. Hall, J. MacNaughton, *ibid.* 4, 653 (1971).

[6]S. F. Tuan, Phys. Rev. Letters 23, 1198 (1969).

[7]S. F. Tuan, Phys. Rev. D 2, 617 (1970).

[8]R. Baud *et al.*, cited by A. Astier, Rapporteur talk, in *Proceedings of the Fifteenth International Conference on High-Energy Physics, Kiev, U.S.S.R., 1970* (Atomizdat, Moscow, to be published). Also W. Kienzle (private communication).

[9]C. Baltay (private communication).

[10]M. Aguilar-Benitez, D. Bassano, R. L. Eisner, J. B. Kinson, D. Pandoulas, and N. P. Samios, Phys. Rev. Letters 25, 1635 (1970).

[11]See, however, J. L. Rosner and E. W. Colglazier [Phys. Rev. Letters 26, 933 (1971)] where the assignment $C=+1$ is analyzed for $M(953)$.

[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.

[14]Oxford-UCLA group, Ref. 119 in A. Astier's rapporteur talk, Ref. 8. Note that this work does *not* claim that the $\pi\eta$ resonance is related to the *narrow* $\delta(960)$. We appreciate discussions with J. Mulvey.

[15]R. Ammar *et al.*, Phys. Rev. Letters 21, 1832 (1968); V. Barnes *et al.*, *ibid.* 23, 610 (1969).

[16]M. A. Abolins, in *Proceedings of the Conference on Experimental Meson Spectroscopy, Philadelphia, 1970*, edited by C. Baltay and A. Rosenfeld (Columbia Univ. Press, New York, 1970), p. 171.

[17]Particle Data Group, Phys. Letters 33B, 1 (1970).

[18]Since SU(2)⊗SU(2) and SU(3) are both *broken* symmetries, both SU(2)⊗SU(2) and SU(3) must share *all* hadron levels. The statement here relative to (η',δ) is to be understood in the approximate sense that SU(2)⊗SU(2) is *better obeyed* as a classification scheme than SU(3).

[19]J. Schwinger, Phys. Rev. 135, B816 (1964); P. N. Dobson and S. F. Tuan, Nuovo Cimento 67A, 474 (1970).

[20]Y. Y. Lee (private communication). See also S. F. Tuan, Tsing Hua University Lecture Notes, 1971, University of Hawaii Report No. UH-511-95-71 (unpublished).

PHYSICAL REVIEW D VOLUME 4, NUMBER 5 1 SEPTEMBER 1971

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

Francis E. Close* and J. F. Gunion
Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305

(Received 24 May 1971)

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