Okubo-Zweig-Iizuka rule and lack of evidence for glueballs in $\pi^- p \to \phi\phi n$

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The Okubo-Zweig-Iizuka rule is a consequence of QCD. It is shown that in general disconnected diagrams are suppressed only if the gluons couple to the quark-antiquark pair of a single vector or tensor meson. Other disconnected diagrams are not strongly suppressed. It is shown that the threshold enhancement observed in $\pi^- p \to \phi\phi n$ is consistent with phenomenological expectations in the absence of resonances and thus does not contain any evidence for glueballs.

QCD is now accepted as the theory of the strong interactions, even though to date no physical observable has been calculated rigorously. In QCD constituents interact through their color charge. Both quarks and gluons carry color, which has led to the conjecture that bound states of gluons—called glueballs—exist. The experimental discovery of such states is seen by many physicists as a key test for QCD and has, therefore, attracted a great amount of interest.

In an interesting experiment a threshold enhancement has been observed in $\pi^- p \to \phi\phi n$ at $E_{\rm kin} = 22$ GeV.[1] Since the initial and final state are not connected by quark lines, it is tempting to regard this enhancement as a breakdown of the Okubo-Zweig-Iizuka (OZI) rule[2] and to consider this to be evidence for glueballs. The interpretation of the OZI rule has, however, led to controversies in the literature.[3] Here we will first discuss the OZI rule and then the experiment.

The OZI rule states that disconnected diagrams are suppressed and has been very successful in explaining the relative rates in the production and decay of vector and tensor mesons. It is not a fundamental rule but a consequence of QCD. We will now discuss the reasons for the suppression and when the OZI rule is expected to hold.

The decays of vector mesons proceed to lowest order through three gluons due to a theorem by Yang.[4] The OZI rule is in this case a reflection of the fact that the matrix element

$$\langle M(1^{--}) | H_{\rm QCD} | ggg \rangle$$

is small. Typical suppression factors are

$$\frac{\sigma(\pi^- p \to \phi n)}{\sigma(K^- p \to \phi\Lambda)} \approx \frac{1}{60} \; .$$

This interaction splits m_ρ and m_ω [Fig. 1(a)].

In tensor mesons ($J^{PC} = 2^{++}$) the hadron wave function is antisymmetric in space. Thus, the quark and antiquark are not likely to annihilate into gluons.

For other processes requiring only two gluons no such suppression has been observed. Rates such as

$$\frac{\sigma(\psi \to \phi\pi\pi)}{\sigma(\psi \to \omega\pi\pi)} = 0.21 \pm 0.10 \text{ (Ref. 5)}$$

can be accounted for by combinatorics, phase space, and the lower probability for the creation of strange rather than light quarks. The small rates for hadronic decays of heavy quarkonia, e.g., $\psi' \to \psi\pi\pi$, are mostly due to the low momenta of the gluons.[6] Thus, there is no suppression for similar reactions in scattering experiments, since the momenta are much larger. Quark-antiquark fusion also breaks the π-η degeneracy [Fig. 1(b)]. $(m_\omega - m_\rho)/(m_\eta - m_\pi)$ gives an estimate of the relative importance of quark-antiquark annihilation into three versus two gluons. This picture has been confirmed by an explicit calculation in the bag model.[7] Thus, there is, in general, no suppression of disconnected diagrams, if only two gluons need to be exchanged.

In the interpretation of $\pi^- p \to \phi\phi n$ (to be denoted by A) the OZI rule has been used to argue for glueballs. The cross section for A is ≈ 20 nb; for the similar experiment $K^- p \to \phi\phi\Lambda$ at 18.5 GeV (B) $\sigma \approx 100$ nb.[8] [Cross sections for $K^- p \to \pi^-\pi^+\Lambda$, $K\bar{K}\Lambda$, $K^-\phi p$, $K^-\omega p$ (Ref. 9), and $\pi^- p \to K\bar{K}n$ (Ref. 10) are typically two orders of magnitude larger.] If the OZI rule holds for A, as was asserted,[1] $\sigma(A)/\sigma(B)$ is too large and, therefore, proves the existence of glueballs. Neither theoretically, as shown above, nor experimentally is there any basis for that assertion. The ratio $\sigma(A)/\sigma(B) \approx 0.2$ is comparable to that of similar reactions, e.g.,

$$\sigma(\psi \to \phi\pi\pi)/\sigma(\psi \to \omega\pi\pi) = 0.21 \pm 0.10$$

or

$$\sigma(\gamma \to \phi\pi^+\pi^-)/\sigma(\gamma \to \rho K^+K^-) = 0.68 \pm 0.14 \text{ (Ref. 11)} \; .$$

Also, the different invariant-mass distributions for $m_{\phi\phi}$

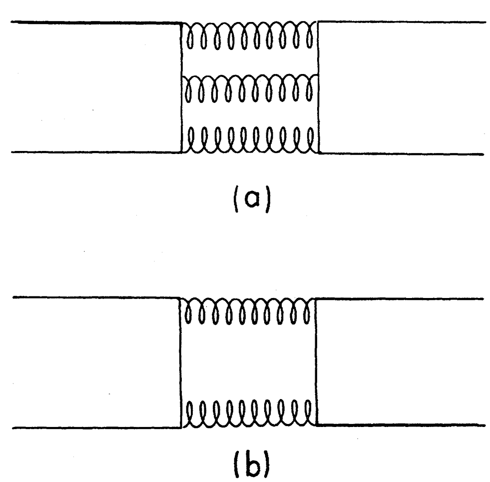

FIG. 1. The annihilation diagrams which split (a) m_ρ and m_ω, and (b) m_π and m_η.

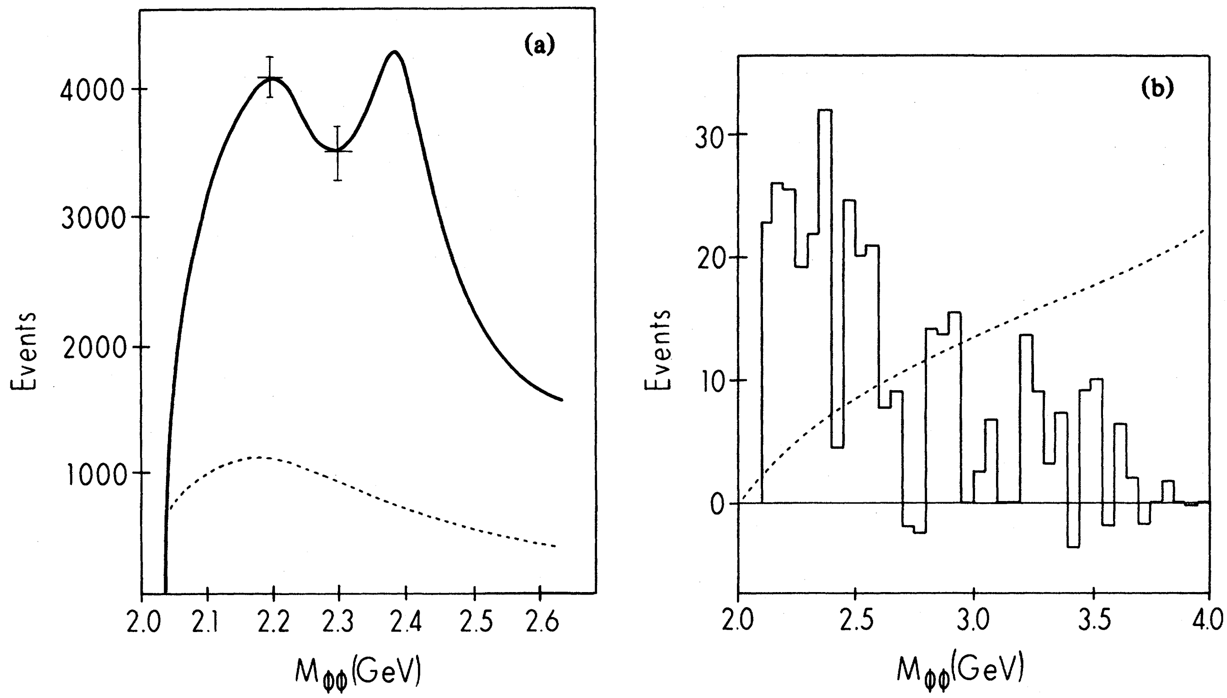

FIG. 2. Effective mass $m_{\phi\phi}$ corrected for acceptance for (a) $\pi^- p \rightarrow \phi\phi n$ and (b) $K^- p \rightarrow \phi\phi\Lambda$. The dashed curve shows the acceptances.

[Figs. 2(a) and (b)] are a consequence of the dynamics and not a result of resonances.

Even though a definitive interpretation of the experimental results cannot be given since the hadronic wave functions are not known, all its qualitative features can be derived from established phenomenology. In $\pi^- p \rightarrow \phi\phi n$ by symmetry states with even angular momentum are dominant for the $\phi\phi$ system. To lowest order (Fig. 3) two hard gluons, one spacelike, one timelike, are exchanged, which for kinematical reasons tend to be emitted in the same direction. The quark-antiquark pairs couple to $\phi\phi$ predominantly when the two gluons are collinear. To leading order the two gluons are independent of each other and should, therefore, have the same properties as the single gluons observed in Drell-Yan and hard-scattering processes. These processes show that hard gluons decay into lepton pairs with $\langle p_\perp \rangle \approx 0.6$ GeV and that higher transverse momenta are strongly suppressed.[12] Thus, for the S wave we expect

$$m_{\phi\phi} \simeq [(2m_\phi)^2 + 2\times(0.6\text{ GeV})^2]^{1/2} \simeq 2.2\text{ GeV} .$$

For D waves the angular momentum barrier requires an additional energy of

$$\frac{2l+1}{r} \approx 1\text{ GeV}$$

for $r = 1$ fm and, thus,

$$m_{\phi\phi} \simeq [(2m_\phi)^2 + 2\times(0.6\text{ GeV})^2 + (1\text{ GeV})^2]^{1/2} \approx 2.4\text{ GeV} .$$

The $p_\perp$ suppression is partially compensated for by the larger number $(2l+1)$ of accessible states, in agreement with the observed invariant-mass spectrum [Fig. 2(a)].

In $K^- p \rightarrow \phi\phi\Lambda$ two quarks hadronize with the fragments

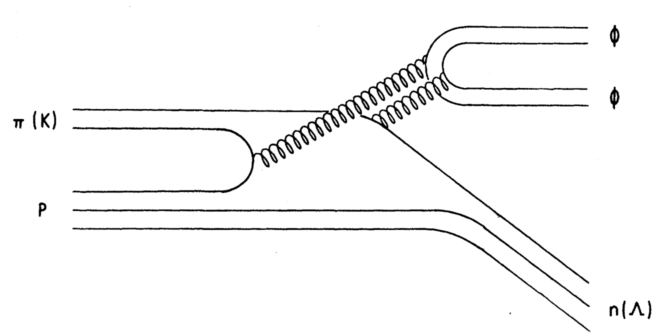

FIG. 3. Diagram for $\pi^- p \rightarrow \phi\phi n$ (and contributing to $K^- p \rightarrow \phi\phi\Lambda$).

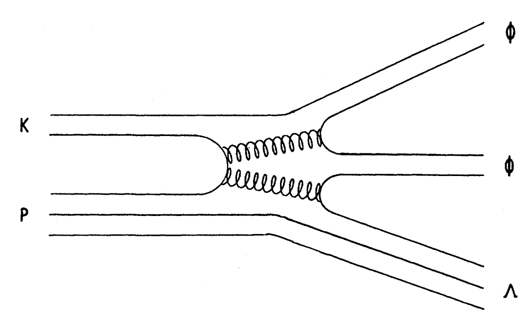

FIG. 4. Diagram contributing to $K^- p \rightarrow \phi\phi\Lambda$.

of the original particles (Fig. 4), which tend to move into opposite directions. The only constraint on the remaining ϕ is momentum conservation. The invariant-mass distribution will mainly be a function of the phase space. In the large-N limit the contribution to the cross section of Fig. 4 will dominate over Fig. 3.

In conclusion, we have seen that the OZI rule is a consequence of the underlying theory of the strong interactions. All experiments involving disconnected diagrams are in agreement with QCD. The OZI rule holds for production and decay of single vector and tensor mesons. Other disconnected diagrams are in general not suppressed. The threshold enhancement in $\pi^- p \to \phi\phi n$ is completely in agreement with phenomenological expectations and does not contain any evidence for glueballs. This result is consistent with the nonobservation of tensor glueballs in that mass region in other experiments.[13]

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