Evidence for dominance of conjoint mechanisms in ϕ^0-meson production in π^+p interactions at 16 GeV/c

J. Hylen* and Z. Ming Ma†
Department of Physics, Michigan State University, East Lansing, Michigan 48824

A. Jawahery,‡ W. A. Mann, T. Maruyama,§ and R. H. Milburn
Department of Physics, Tufts University, Medford, Massachusetts 02155
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Evidence is presented that the production of ϕ^0 mesons in π^+p interactions at 16 GeV/c is dominated by conjoint mechanisms, i.e., ϕ^0 mesons are accompanied by additional strange particles. For $x>0.5$, the cross sections for conjoint production of ϕ^0 mesons are 0.37 ± 0.16 μb with a Λ^0 hyperon and 0.33 ± 0.15 μb with a K_S^0 meson. Assuming equal probability for each conjoint final state, the total conjoint production cross section is inferred to be 1.05 ± 0.33 μb. This is to be compared with the inclusive ϕ^0-meson production cross section of 1.3 ± 2.0 μb in the same kinematic region. The data suggest that conjoint mechanisms are responsible for 81% of the ϕ^0 production with a lower limit of 24% at the 94% confidence level.

Owing to its relatively copious production cross sections, the ϕ^0 meson provides a practical laboratory for studying the decay and production mechanisms of ideally mixed quark-antiquark states. One of the most remarkable insights gained due to such studies is the empirical rule advanced by Okubo, Zweig, and Iizuka,[1] commonly known as the OZI rule. The OZI rule was originally proposed to explain the suppression of ϕ^0-meson decay into the ρ-π states; however, it has been used extensively to interpret ϕ^0, J/ψ, and Υ production data. Although the applicability of the OZI rule to production dynamics has not been unambiguously demonstrated, available experimental studies comparing the production of ϕ^0 mesons in OZI-rule-suppressed reactions and the production of other members of the same vector-meson nonet lend qualitative support to such a notion. In the reaction $\pi^-p\to\phi^0n$, Ayres[2] reported a suppression factor of 3.5×10^{-3} relative to ρ-meson production from threshold to 6 GeV/c. At 19 GeV/c, the Omega Spectrometer group observed[3] that the reaction $\pi^-p\to\phi^0\pi^+\pi^-\pi^-p$ is suppressed by a factor of $5^{+5}_{-2}\times10^{-3}$ relative to the production of the ω meson. These results are consistent with the OZI rule. Except for the ϕ^0 meson, none of the other participants in these reactions carry a significant amount of s quark in its wave function. Therefore, the s- and $\bar{s}$-quark lines from the ϕ^0 meson must terminate on themselves, and this is specifically forbidden by the OZI rule.

However, experimental studies comparing ϕ^0-meson production cross sections in reactions forbidden by the OZI rule with those allowed do not lead to unambiguous interpretations. In $\bar{p}p$ interaction at 3.6 GeV/c, the cross-section ratio for a ϕ^0 meson produced with a pair of charged pions to that with a pair of charged kaons was reported[4] to be 0.7 ± 0.4. Data from the Omega Spectrometer group indicate[3] that in π^-p interactions at 19 GeV/c, the cross-section ratio for the exclusive production of $\pi^-p\phi^0$ in association with a $\pi^+\pi^-$ pair relative to that with a K^+K^- pair is $1.7^{+0.9}_{-0.5}$ for $x>0.3$. The absence of suppression of OZI-rule-forbidden reactions was attributed by Lipkin[5] to the lack of phase space for producing a pair of kaons at low energies. The negative result[6] in the search for OZI-rule-favored conjoint production[7] of the J/ψ particle with a pair of charmed particles at 300 GeV/c was explained[8] in terms of a final-state-interaction mechanism similar to that invoked in the quark-confinement question.

The results reported in this paper are obtained from π^+p interactions at 16 GeV/c. The experiment was performed at the Stanford Linear Accelerator Center (SLAC) using the 2-m streamer chamber. The experimental layout is shown in Fig. 1. Positively charged secondary particles, produced at 0°, were transported by beam line 23 to impinge upon a 61-cm-long liquid-hydrogen target in the 2-m streamer chamber. The downstream end of the target was located midway along the length of the chamber. A 1.3-T magnetic field was present over the entire volume of the chamber. The beam particles were identified using a high-pressure differential Čerenkov counter filled with Freon-13 placed at the

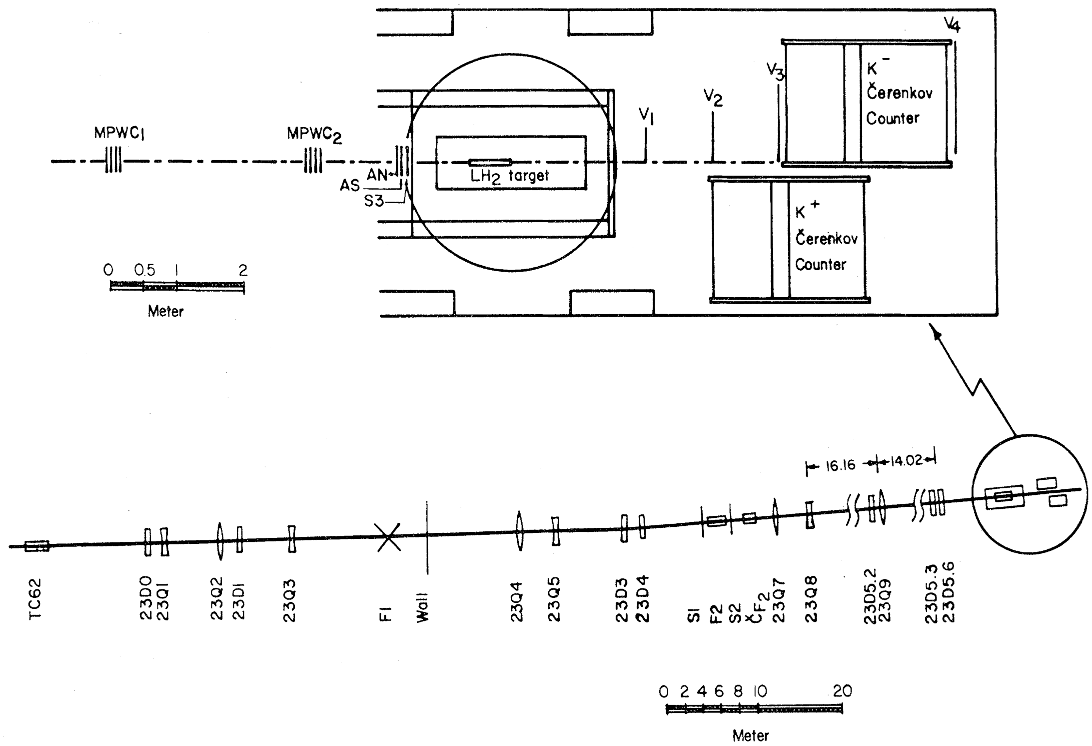

FIG. 1. Experimental setup at the Stanford Linear Accelerator Center streamer-chamber facility.

second focus F_2 of the beam optics. An average of nine positively charged particles was measured at F_2 per each 1.6-μsec long burst. The π^+ beam was electronically defined by a set of three scintillation counters to a circular spot of $\frac{5}{8}$-in. diameter at the entrance to the liquid-hydrogen target. The π^+ intensity at the same position averaged 7.2/pulse. The K^+ contamination in the beam was reduced from 8.1% to 1.5% using the differential Čerenkov counter.

Secondary particles produced by the incident π^+ were screened using the downstream trigger hodoscope for the presence of a high-momentum K^- particle. The hodoscope was composed of four picket-fence planes of scintillation counters, V_1, V_2, V_3, and V_4 and a ten-cell atmospheric-pressure isobutane Čerenkov counter. Each of the picket-fence arrays, V_1, V_2, and V_4, was composed of 20 counters. The third plane V_3 had 40 elements, half above and the other half below the beam plane, thus dividing the acceptance phase space into 40 separate channels. The widths of individual elements were designed such that requiring a coincidence from corresponding elements in each of the four planes ensured the detection of a negative charge particle with a minimum momentum of 2.5 GeV/c. Velocity discrimination was accomplished using a ten-cell atmospheric-pressure isobutane Čerenkov counter placed between the V_3 and V_4 planes. The cells were arranged in the form of a 2×5 matrix with each cell monitoring particles emerging from 4 of the 40 coincidence channels. With the Čerenkov counter operating in the anticoincidence mode, the system rejected events having either a π^- with a momentum greater than 2.73 GeV/c or a K^- with a momentum greater than 9.63 GeV/c. An identical ten-cell Čerenkov counter was placed on the opposite side of the beam line. Signals from the counter were used with the measured momentum from the streamer-chamber photographs to tag the mass of positively charged secondary particles. The pion rejection efficiencies of the Čerenkov counters were independently measured using a 9-GeV/c π^- beam to be 99.87±0.15% and 99.75±0.25%. The performance of the trigger system has been discussed elsewhere.[9,10]

A total of 302 000 trigger candidates were photographed on film. The associated trigger and pulse-height information from scintillation hodoscopes and Čerenkov-counter cells was also recorded online using a PDP-9 computer. The data reported in this paper come from a complete scan of all events with a visible strange-particle decay signature. The "vee scan" resulted in 6203 candidates, corresponding to a sensitivity of 526 events/μb. A general scan of approximately 7% of all legitimate trigger events with or without an associated neutral decay contributed 5824 candidates at 40.4 events/μb. These events were digitized on image plane digitizers. The data were processed through the program TVGP (Ref. 11) for spatial reconstruction. The determination of the hidden primary interaction vertices was performed using the program APACHE (Ref. 12) adapted to this experiment. Following two measurement passes, 91.1% of the events found in the two scanning passes were accepted for further analysis.

Figure 2(a) shows a typical $K^-\pi^+$ invariant-mass distribution where no mass identifications were attempted for either of the charged particles. In fact, the Čerenkov counters were turned off for these data. The negative particle was, otherwise, a trigger particle, i.e., its trajectory traversed 1 of the 40 coincidence channels. No significant enhancement was observed. When the negative particle was required to be the trigger K^- particle, i.e., no signal was detected from the corresponding Čerenkov cell, a prominent enhancement is observed at the $\bar{K}^*(890)$ mass as is shown in Fig. 2(b). Correcting for the combinatorial ambiguities, the data suggest that the $\bar{K}^*(890)$ particle is present in 30.0% of the trigger events. Figure 2(c) shows the $K^-\pi^+$ mass when both particle mass identifications were confirmed by the Čerenkov counters.

Figure 3(a) shows the mass distribution of K^+K^- from the general scan mentioned earlier. No significant enhancement is observed at the ϕ^0 mass. Since this mode of scan was carried out for about 7% of the sample, the cross-section sensitivity is somewhat low. The K^+K^- distribution from the vee scan is shown in Figs. 3(b) and 3(c). Here the K^+K^- is accompanied by at least one visible neutral-strange-particle decay. An enhancement at the $\phi^0(1019)$ mass is observed. A fit to the combined K_S^0 and Λ^0 associated samples in this region yields a mass of 1024 ± 6 MeV/c^2 with a Gaussian width of 14 ± 6 MeV/c^2. The mass is consistent with the accepted ϕ^0 mass of 1019.6 MeV/c^2, and the width is consistent with the calculated resolution of 17 MeV/c^2 in the ϕ^0 mass region. The background shape was generated by combining candidate tracks from dif-

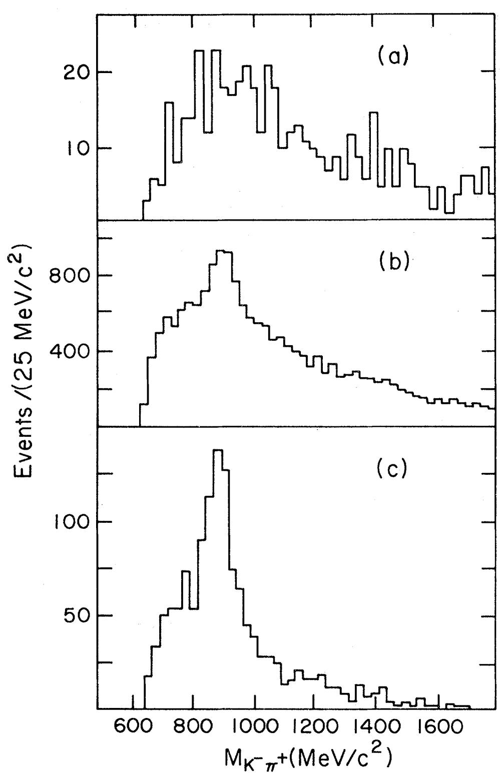

FIG. 2. Mass distributions for the $K^-\pi^+$ combination with the negative charged particle being the trigger candidate. (a) Both Čerenkov counters were turned off. (b) The K^- Čerenkov counter operated in the anticoincidence mode. (c) Both charged-particle masses were affirmed by Čerenkov counters.

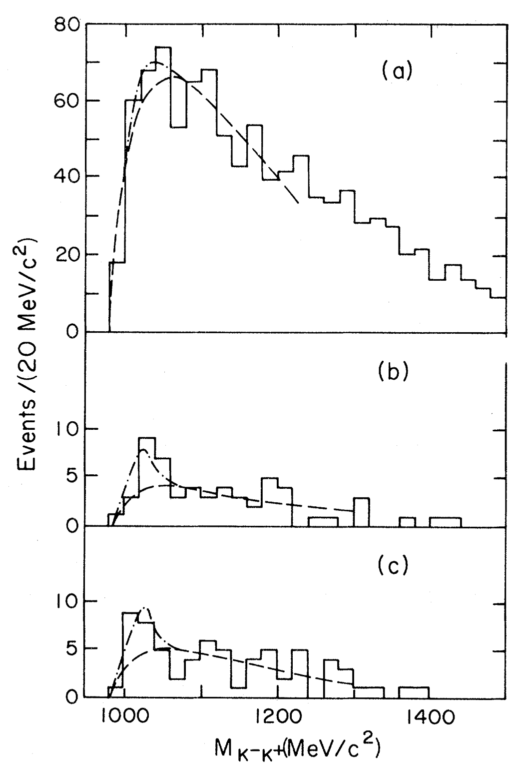

FIG. 3. The K^-K^+ mass distributions for (a) the inclusive sample from the general scan, (b) the semi-inclusive sample with a visible K_S^0 decay, and (c) the semi-inclusive sample with a visible Λ^0 decay. The curves represent fits to the data as discussed in the text.

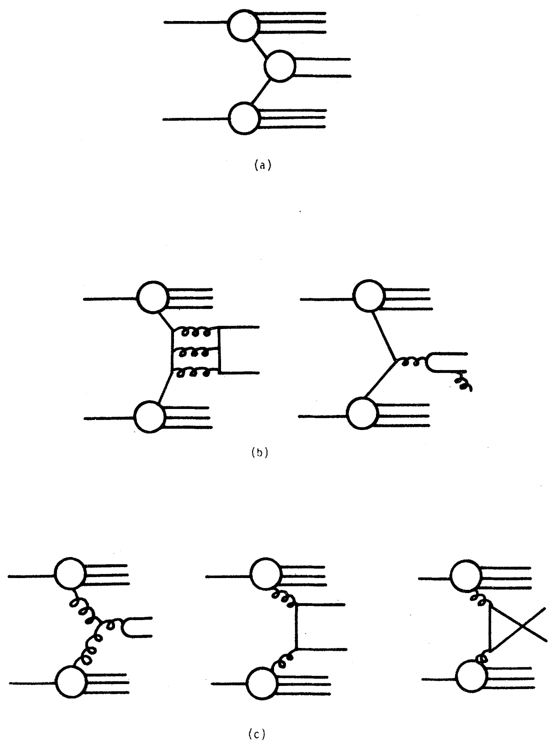

FIG. 4. QCD processes expected in ϕ^0 production. (a) $s\bar{s}$ quark fusion. (b) Light-quark—antiquark fusion. (c) Gluon fusion. With the exception of process (a), no accompanying strange particles are expected.

ferent events. The integrated area in the peak corresponds to 16.8 ± 5.3 events above the combinatorial background. Corrected for the acceptance and the neutral decay modes of Λ^0 and K_S^0, the ϕ^0 production cross section for $x>0.5$ amounts to 0.37 ± 0.16 μb with a Λ^0, and 0.33 ± 0.15 μb with a K_S^0. Fitting to the inclusive K^+K^- mass spectrum, shown in Fig. 3(a) using the ϕ^0 mass and width parameters obtained above and a combinatorial background, the inclusive ϕ^0 cross section is estimated to be 1.3 ± 2.0 μb in the same x region.

The conservation of strangeness dictates that ϕ^0 events with an associated strange particle in fact include at least one pair of strange particles; consequently, our results suggest that conjoint mechanisms are present. To estimate the magnitude of contribution due to these mechanisms, an equal probability for all eligible strange-particle pairs is assumed. For example, $K^0\phi^0\Lambda^0$ and $K^0\phi^0K^-$ states were assumed to be equally likely. Owing to the limited available c.m. energy, only states with one pair of accompanying strange particles was considered. Using these assumptions, the total conjoint cross section is estimated to be 1.05 ± 0.33 μb for $x>0.5$. This suggests that conjoint mechanisms may be responsible for some 81% of the ϕ^0 production in π^+p interaction at 16 GeV/c with a lower limit of 24% at 94% confidence level. This observation is in good accord with the OZI rule and is consistent with data[13] from π^-p interaction at 93 GeV/c.

In a survey of the available ϕ^0-production mechanisms within the framework of quantum chromodynamics (QCD), Kinnunen[14] investigated four possible processes using a quark fusion model.[8] Figure 4(a) shows the fusion of s and $\bar{s}$ quarks from the seas of the incident hadrons to produce a ϕ^0 meson. Figure 4(b) depicts the annihilation of a light-quark—antiquark pair to produce the ϕ^0 via the three-gluon intermediate state. Light-quark annihilation can also produce ϕ^0 via a single virtual gluon which decays into an $s\bar{s}$ pair with a subsequent emission of soft gluons. This is shown in Fig. 4(c). Another small contribution may be due to gluon fusion. The three graphs of this process are shown in Fig. 4(d). With the exception of Fig. 4(a), all of the other processes violate the OZI rule. The results from this experiment point to the $s\bar{s}$ quark fusion as being the dominant mechanism.

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*Present address: Johns Hopkins University, Baltimore, MD 21218.
†Present address: Bell Laboratories, Murray Hill, NJ 07974.
‡Present address: Syracuse University, Syracuse, NY 13210.
§Present address: University of Wisconsin, Madison, WI 53706.

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