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Test of the OZI rule in hadroproduction of $\phi\phi$ and ϕK^+K^-

C. Landberg,[3] G. S. Adams,[3] C. Chan,[2] E. Efstathiadis,[2] R. W. Hackenburg,[1] M. A. Kramer,[2] S. J. Lindenbaum,[1,2] R. S. Longacre,[1] K. Vazeri,[3,*] B. Wojtsekhowski,[3,†] A. Wright,[3] K. Zhao,[2] and Y. Zhu[2]
[1]*Physics Department, Building 510A, Brookhaven National Laboratory, Upton, New York 11973*
[2]*Physics Department, City College of New York, New York, New York 10031*
[3]*Physics Department, Rensselaer Polytechnic Institute, Troy, New York 12180*
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The cross sections for $\phi\phi$ and ϕK^+K^- production were measured with 8 GeV/c pion and kaon beams to examine the OZI suppression of the reaction $\pi^- p \to \phi\phi n$. The measured cross section ratios indicate that this reaction is not suppressed for $\phi\phi$ invariant masses up to 2.5 GeV/c^2.

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I. INTRODUCTION

The $f_2(2010)$, $f_2(2300)$, and $f_2(2340)$ mesons (formerly g_t, g_t', and g_t'') were discovered in 1978 by Etkin *et al.* [1] as $\phi\phi$ resonances in the reaction

$$\pi^- p \to \phi\phi n. \tag{1}$$

It was argued that these states should be identified as the long sought $J^{PC}=2^{++}$ glueball [2]. Recent lattice gauge predictions place this state at about 2.3 GeV/c^2 [3]. Violation of the Okubo-Zweig-Iizuka (OZI) rule [4] in reaction (1) has been the basis for the glueball identification. At 22.5 GeV/c beam momentum reaction (1) is suppressed [5] by about a factor of 10 relative to the OZI allowed reaction

$$\pi^- p \to \phi K^+ K^- n. \tag{2}$$

However, typical OZI allowed to OZI suppressed ratios for single ϕ production are on the order of 50 [6]. Thus further study of $\phi\phi$ production is not only useful as a test of the OZI rule, but is also crucial for understanding meson spectroscopy.

It has been suggested that the OZI rule may be evaded in reaction (1) if it proceeds via two steps [7], or if the proton contains strange $q\bar{q}$ pairs in the nonvalence quark sea [8]. However, these arguments have been questioned on several fronts [9]. At present there is no compelling reason to expect any violation of the OZI rule for reaction (1) when conventional mesons are involved.

The OZI rule has been studied via several $\phi\phi$ production experiments in the 2–2.5 GeV/c^2 mass region [10–12]. The cross section for the OZI allowed reaction

$$K^- p \to \phi\phi\Lambda \tag{3}$$

at 8.25 GeV/c beam momentum is at least a factor of 4 less than that for the reaction

$$K^- p \to \phi K^+ K^- \Lambda, \tag{4}$$

which is also OZI allowed. However, the published data do not include comparisons between reactions (1) and (3) at the same beam momentum. Moreover, all of the cross section ratios are given as upper limits. Therefore it is not possible to extract quantitative information about the level of OZI suppression in reaction (1).

In this ϕ production experiment the reactions (1) and (2) were measured at 8 GeV/c beam momentum, along with the analogous exclusive reactions with K^- beam. From the present data we can construct the ratios

$$R_1 = \frac{\sigma(\pi^- p \to \phi K^+ K^- n)}{\sigma(\pi^- p \to \phi\phi n)} \tag{5}$$

and

$$R_2 = \frac{\sigma(K^- p \to \phi K^+ K^- \Lambda/\Sigma^0)}{\sigma(K^- p \to \phi\phi\Lambda/\Sigma^0)}. \tag{6}$$

According to the OZI rule, one expects $R_1 \gg R_2$.

II. EXPERIMENT

This experiment was performed at the B2 beam line of the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory. An electrostatically separated beam of pions (95%), kaons (3.5%), and antiprotons (1.5%) was de-

*Present address: Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510.

†Present address: CEBAF, 12000 Jefferson Ave., Newport News, VA 23606.

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livered to the experimental area. The identification of each beam track was accomplished with three threshold Cherenkov detectors in the beam line, two of which registered pions only, and one that registered pions and kaons.

The ϕ meson was detected via its decay to K^+K^- pairs. The Multiple Particle Spectrometer (MPS) [13] was used to analyze all events which yielded four charged kaons in the final state. A 50 cm long liquid hydrogen target was located inside the magnet gap. Surrounding the target was a scintillator hodoscope used to veto charged recoil particles, for the pion-beam events only. At the end of the target, inside the magnet, were five drift chambers containing a total of 35 sense-wire planes [14]. These chambers were used for charged-track reconstruction and momentum determination. Outside the magnet, at the downstream end, was an unsegmented freon Cherenkov detector [15] which operated at a pressure of 45 PSIG. This detector was used to veto pion events.

Data were acquired for approximately two months. The event trigger included an online veto by the Cherenkov detector. It also required at least three signals in each of three single-plane proportional wire chambers (PWC's) in front of the Cherenkov detector. In addition, a memory look-up unit rejected events that fell outside the relevant phase space [16].

III. DATA ANALYSIS

The analysis of the four-kaon events included a cut on the vertex location that required the intersection of the four production tracks and the beam to be inside the target. To assure efficient pion rejection, a cut was also applied which required at least two positive or two negative tracks with momenta greater than 1.7 GeV/c to pass through the veto Cherenkov detector. The Cherenkov detector efficiency was determined by tests using the charged-pion decay of K^0. The single-pion efficiency was found to be greater than 85% over the desired momentum range.

Missing-mass and ϕ-mass cuts were applied to the data. The values of the missing-mass cuts were determined by Monte Carlo simulations. The pion-data cut was placed at 0.664–1.089 GeV/c^2. The kaon-data cut was placed at 0.947–1.405 GeV/c^2, which encompassed both the Λ and the Σ^0. An event was accepted as a $\phi\phi$ event if one of two possible hypotheses of kaon-pair combinations had effective masses of 1.019 ± 0.0125 GeV/c^2. If either of the pairs or both passed this cut then the event was considered a ϕK^+K^- candidate. The mass spectra of the second K^+K^- pair, when the first lies within the ϕ mass band, are shown in Fig. 1. A second ϕ peak is evident at approximately 1.02 GeV/c^2 in the pion beam data, but the low-statistics kaon data do not show a similar peak. The events in Fig. 1 that lie outside the $\phi\phi$ peak constitute the ϕK^+K^- yield and four-kaon background.

Figure 2 shows the missing-mass spectra for the $\phi\phi$ final states, with the missing-mass cut removed. Enhancements corresponding to exclusive production are evident at the neutron and Λ/Σ^0 masses for π^- and K^- beams, respectively. The pion-beam data yielded 130 events which passed all cuts, but the kaon-beam data provided only eight.

Monte Carlo simulations were performed to determine the data cuts and the experimental acceptance. The Monte Carlo

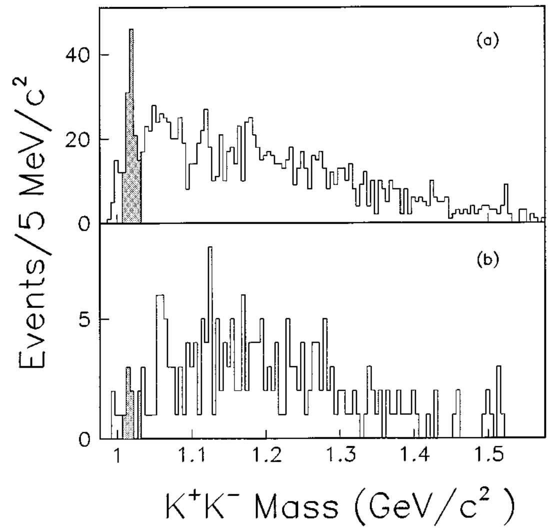

FIG. 1. The effective K^+K^- mass when the other K^+K^- pair passes the ϕ mass cut and the missing-mass cuts for (a) pion beam data, and (b) kaon beam data. The $\phi\phi$ events are plotted once per event, randomly selected.

simulations included the geometry of the apparatus, multiple scattering, kaon decay, detector inefficiencies, pattern recognition inefficiencies, and the cuts used in the actual data analysis. An exponential t dependence for the simulations was used. The acceptance for each 50 MeV/c^2 mass bin in the $\phi\phi$ or ϕK^+K^- effective mass was calculated separately, for each beam type. Figure 3 shows the uncorrected $\phi\phi$ effective-mass spectrum for the pion beam data along with the calculated acceptance. The shape of the acceptance curve is dictated mostly by the cuts on the momentum and location of the particles at the Cherenkov detector. A similar procedure was followed for the ϕK^+K^- data. It gave nearly identical acceptance curves [17].

The $\phi\phi$ production with π^- beam can be compared with the published results at higher energies. Figure 4(a) shows the present data, corrected for experimental acceptance. Figure 4(b) is for 16 GeV/c beam (reproduced from Fig. 5 in

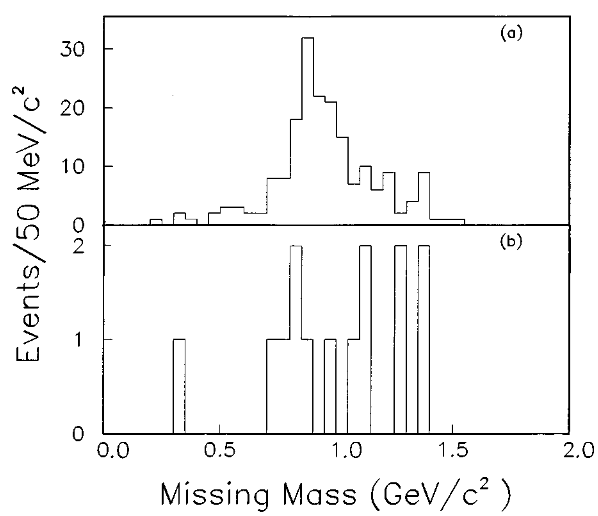

FIG. 2. The missing-mass spectra after $\phi\phi$ identification for (a) pion beam data, and (b) kaon beam data.

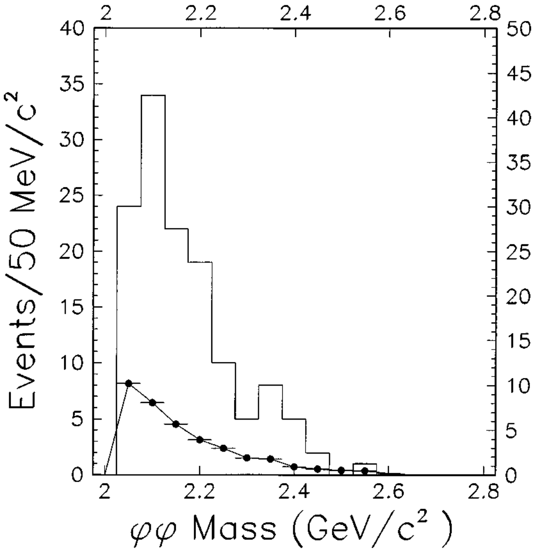

FIG. 3. The uncorrected $\phi\phi$ effective mass (solid line) and the calculated acceptance (solid points).

Ref. [10]), and Fig. 4(c) is for 22.5 GeV/c beam (reproduced from Fig. 1(a) in Ref. [1]). Each measurement shows an enhancement around 2.1–2.4 GeV/c^2. A partial-wave analysis of the 22.5 GeV/c data yielded the $f_2(2050)$, $f_2(2300)$, and $f_2(2340)$ glueball candidates. However the paucity of events in the present data sample precludes such an analysis at 8 GeV/c. Therefore, one cannot be certain that the same states are excited at all energies.

The nonresonant background in the $\phi\phi$ yield was removed by fitting a third-order polynomial to the ϕK^+K^- background outside the ϕ peak in Fig. 1. The ϕK^+K^- contribution to the $\phi\phi$ peak was then subtracted. The four-kaon contamination was removed from the ϕK^+K^- data in a similar fashion. The data on either side of the ϕ peak in a plot of the K^+K^- effective mass, where all four combinations of the K^+K^- were plotted, were fit by a third-order polynomial. The $\phi\phi$ contribution was removed by subtracting twice the number of $\phi\phi$ events found after the background subtraction. This method was used to compensate for the nonuniform background shape. The uncertainty in determining the background shape dominates the uncertainty in the extracted yields. For K^- production of $\phi\phi$ only an upper limit was determined.

IV. RESULTS AND CONCLUSION

The results of the present experiment are summarized in Table I. The cross section for the integrated yield (mass$\leqslant$2.5 GeV/c^2) and standard deviation are shown, where a correction has been applied for the unseen decay modes of the ϕ as well as the Λ and Σ^0 for reactions (3) and (4). The cross section for reaction (3) is consistent with that measured for the $\phi\phi\Lambda$ final state, 700$\pm$200 nb [11], provided the strength to the Σ^0 state in the present experiment is small. The cross section for reaction (1) is larger than the value obtained at 16 GeV/c, 40$\pm$10 nb [10], and the value obtained at 22.5 GeV/c, 23$\pm$2 nb [18].

The t dependance of reaction (1) indicates that it is dominated by peripheral production of the $\phi\phi$, and one-pion exchange. The pion-beam $\phi\phi$ production data were fit to the form $d\sigma/dt \propto e^{-bt'}$, where $t' = |t - t_{\min}|$, resulting in the value $b = 8.53 \pm 1.26$ (GeV/c)$^{-2}$. This result is similar to the results from the previous $\phi\phi$ experiments. Etkin *et al.* [1] found $b = 9.5 \pm 0.10$ (GeV/c)$^{-2}$, and Armstrong *et al.* [10] found $b = 12 \pm 2$ (GeV/c)$^{-2}$.

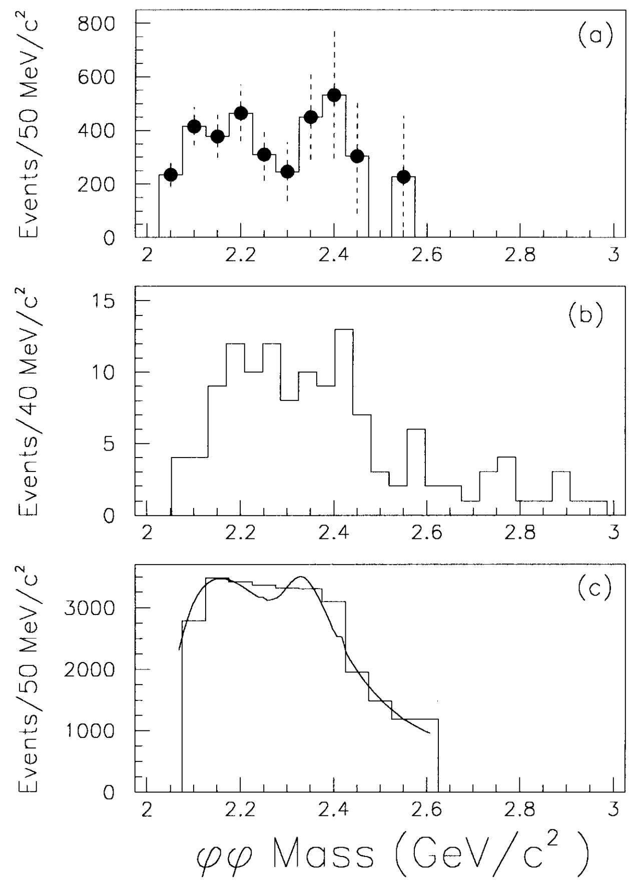

FIG. 4. Acceptance corrected $\phi\phi$ mass spectra for (a) this experiment, (b) Armstrong *et al.*, and (c) Etkin *et al.* The curve in (c) depicts the results of the published partial-wave analysis.

The data in Table I have been used to extract the ratios R_1 and R_2. The ratio $R_1 = 10.3 \pm 3.3$ is consistent with the 22.5 GeV/c value [5], $R_1 \approx 10$. What has been lacking until now is a similar comparison at the same beam energy for R_2. The data in Table I yield the value $R_2 > 7.2$. An upper limit for R_2 can be obtained by combining the present result for the kaon cross section for ϕK^+K^- production with the $\phi\phi$ results of Baubillier *et al.* [11]. Using a 8.25 GeV/c beam they measured a cross section of 700$\pm$200 nb, integrated over a simi-

TABLE I. Integrated cross sections.

Reaction	Cross section (nb)
$\pi^- p \to \phi\phi n$	108$\pm$26
$\pi^- p \to \phi K^+K^- n$	1112$\pm$227
$K^- p \to \phi\phi\Lambda/\Sigma^0$	$\leqslant$691
$K^- p \to \phi K^+K^- \Lambda/\Sigma^0$	7500 $\pm$ 2520

lar mass range for the $\phi\phi$ pair. This yields a ratio of 10.7 $\pm$4.7. However, since only the $\phi\phi\Lambda$ final state was measured in that experiment (no Σ production), this is an upper limit on R_2. The combined upper and lower limits for R_2 allow one to conclude that $R_1 \approx R_2$.

From the above results we observe that $\phi\phi$ production with pion beams does not obey the expected OZI suppression in the mass range up to about 2.5 GeV/c^2. This observation is consistent with the glueball identification for $f_2(2050)$, $f_2(2300)$, and $f_2(2340)$.

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