dices. Doing the θ integration, we then have

$$W_\nu(\eta, \eta^\dagger) = \int \mathfrak{D}A\mathfrak{D}\varphi \exp[\int d^4x \mathfrak{L}(A, \varphi)] \prod_{\Lambda = n_L, n_R} \int d^4y\, \eta^\dagger(y) f_{0\Lambda}(y, A)$$

$$\times \int d^4z\, f_{0\Lambda}^\dagger(z, A)\eta(z) \exp\{-\int d^4w[\psi_\perp^\dagger(w, A)\not{D}\psi_\perp(w, A) + \eta^\dagger\psi_\perp(w, A) + \psi_\perp^\dagger(w, A)\eta]\}, \quad (6)$$

where $\psi_\perp$ is also a functional of A. This formal result is useful because of the Atiyah-Singer[7] index theorem which states that

$$n_R - n_L = \nu N_f \quad (7)$$

with Eq. (6) implies that the two-point function $(\delta^2 W/\delta\eta\,\delta\eta^\dagger|_{\eta,\,\eta^\dagger=0})$ vanishes for $\nu N_f > 1$.[8] Thus there can be no contribution to the quark propagator and therefore no quark mass generation from paths with nonzero integer winding number in massless quantum chromodynamics.

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Observation of Double ϕ-Meson Production in $\pi^- p$ Interactions

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We report a measurement of the reaction $\pi^- p \to \varphi\varphi n$ at 22.6 GeV/c. The $\varphi\varphi$ effective-mass spectrum shows a concentration of events from threshold to about 2.4 GeV/c^2. From the data near 2.8 GeV/c^2 effective mass, we place an upper limit on σ times the branching ratio of 2 nb (90% confidence level) for the production of η_c and its decay into $\varphi\varphi$.

We report the first measurement of the cross section for the reaction

$$\pi^- p \to \varphi\varphi n.$$

The φ mesons were detected by observing the charged-kaon decay mode. The φ shows a clear signal in our K^+K^- effective-mass plot. By selecting a pair of φ's, an even greater enhancement of signal over background is observed.

The φ, which is composed predominantly of a strange quark and its antiquark ($s\bar{s}$), is a particularly interesting particle since its production without strange particles in π^-p interactions is suppressed by the Okubo-Zweig-Iizuka (OZI) rule.[1] The explanation of the OZI-rule suppression is unclear, but one recent approach is to attribute it to the need to exchange additional gluons.[2] Whereas OZI-rule-allowed processes can proceed via one-gluon exchange, π^-p single-φ production without strange particles requires a three-gluon exchange; π^-p double-φ production without strange particles requires two- or three-gluon exchange. Thus, the study of $\varphi\varphi$ production processes is useful for understanding gluon dynamics. Furthermore, the study of $\varphi\varphi$ spectroscopy is potentially fruitful since high-mass $s\bar{s}$ states can decay into $\varphi\varphi$ without violating the OZI rule, and the $\varphi\varphi$ spectrum should be relatively free from other background sources. Also, the decay $\eta_c \to \varphi\varphi$ might be visible above the low background from other sources of $\varphi\varphi$.[3]

We used the Brookhaven National Laboratory (BNL) multiparticle spectrometer (MPS) in a 22.6-GeV/c negative unseparated beam at the alternating gradient synchrotron. The beam transport included superconducting dipole magnets. The apparatus is shown in Fig. 1. The trigger was designed to select events with three or more charged kaons produced in a 60-cm-long liquid-hydrogen target. The K-meson signature was a track emerging from the target with a momentum between 4 and 12 GeV/c, as measured by the proportional wire chambers TPX2 and TPX3 and the counter hodoscope H5, with no signal from the corresponding cell in C6, a Freon 114 threshold-Čerenkov-counter hodoscope. The threshold of C6 for pions was 2.8 GeV/c, and the efficiency was measured to be 99.3% for momenta above 4 GeV/c. Thus, the contamination of pions in the sample is small, although, of course, the counter does not distinguish between kaons and protons. The above selection criteria were applied by use of a special trigger system, designed and built at BNL, that used a fast random-access memory (RAM) with two millon bits in a 128 $\times 128 \times 128$ three-dimensional array. Each dimension represented one of the three trigger elements (TPX2, TPX3, and H5 $\cdot\,\overline{\text{C6}}$) with the memory preloaded to contain "ones" at all three-dimensional points satisfying the chosen criteria. A full description of the RAM trigger system has been published.[4] The hardware is arranged so that the outputs in one dimension are added linearly to give a signal proportional to the number of combinations satisfying the trigger criteria. For this experiment we chose to use H5 $\cdot\,\overline{\text{C6}}$ as this dimension, since at that point the spatial separation between kaons of positive and negative charge is almost complete; by dividing the memory into two sections, we were able to determine the number of particles of each charge. We triggered the spark chambers on events with three or more "kaons" with at least one of each charge. The trigger requirements were satisfied for one in approximately 45 000 incident particles; we recorded 1.3 million triggers.

The data sample presented here was reconstructed by the analysis program as comprising four-prong final states with at least three iden-

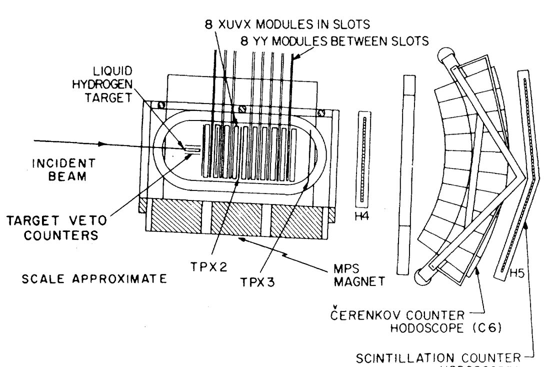

FIG. 1. The configuration of the MPS used for this measurement. C6 is a Freon 114 threshold Čerenkov hodoscope. $XUVX$ and YY indicate magnetostrictive-readout spark chamber modules.

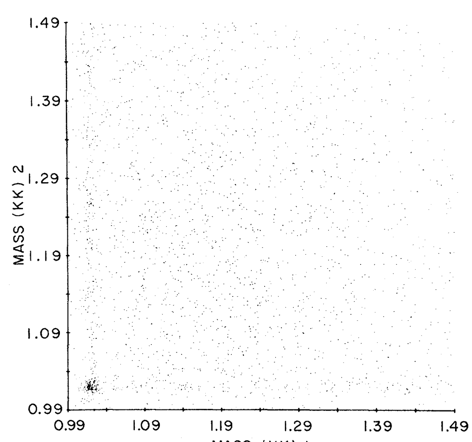

FIG. 2. Scatter plot of K^+K^- effective mass for effective masses less than 1.49 GeV/c^2. Two mass combinations are plotted for each event. The axis labeled 1 is arbitrarily assigned to the first K^+ encountered by the reconstruction program. Clear bands at φ(1019) are seen with a strong enhancement at the overlap.

tified kaons. We also demanded a missing mass (M) such that $M^2 < 2$ GeV^2. Our resolution is $\Delta(M^2) \approx 0.8$ GeV^2 [full width at half-maximum (FWHM)]. Figure 2 is a scatter plot of the effective mass of one K^+K^- pair plotted against the mass of the other K^+K^- pair. Since the "correct" association of K^+K^- pairs is not known, each event is plotted twice, and the K^+K^- state labeled 1 is arbitrarily assigned to the first K^+ found by the pattern-recognition program. Clear bands corresponding to single-φ production are seen in Fig. 2 with a very strong enhancement for $\varphi\varphi$ production. From the apparent width of the φ we determined our φ mass resolution to be 14 MeV (FWHM). Events with both K^+K^- pairs within 20 MeV of the accepted φ mass (1019.6 MeV) are included in the $\varphi\varphi$ sample. The $\varphi\varphi$ mass resolution is estimated to be ≈ 20 MeV (FWHM). The background of events under the $\varphi\varphi$ peak is estimated to be less than 20%.[5]

Figure 3(a) is a histogram of the $\varphi\varphi$ effective mass containing 147 events. Except for the early part of the experiment, signals from a cylindrical scintillation-counter hodoscope surrounding the target were recorded with the data. We have selected an enhanced sample of neutron recoils by using the counters as vetos. The resulting $\varphi\varphi$ spectrum (102 events) is shown as a shaded histogram in Fig. 3(a). Our estimate of the acceptance as a function of $\varphi\varphi$ effective mass, which is based on a Monte Carlo calculation, is shown as the solid curve in Fig. 3(a). The major losses in the acceptance are due to the 4-GeV/c cutoff on the kaon momentum and to kaon decay. The falloff at small effective mass is due to the loss of events with badly overlapping tracks, a more frequent problem for small-Q values. This includes losses caused by overlapping sparks from out-of-time beam tracks. These effects were calculated by processing Monte Carlo events with the same program used to analyze the data.

The results of dividing the data by the acceptance are shown in Fig. 3(b) for data with only the missing-mass cut and in Fig. 3(c) with the target counters in veto. Both spectra peak at about 2.35 GeV and fall sharply thereafter, but the uncertainty in the acceptance at low mass and the limited statistics prevent us from drawing a definitive conclusion. The shape of the differential cross section for the data shown [Fig. 3(c)] is consistent with $e^{(10\pm2)t}$ and the total cross section measured for peripheral $\varphi\varphi n$ production (corrected for the $\varphi \to K^+K^-$ branching fraction of 0.466) is 23 ± 2 nb with an estimated systematic scale error of 30%.

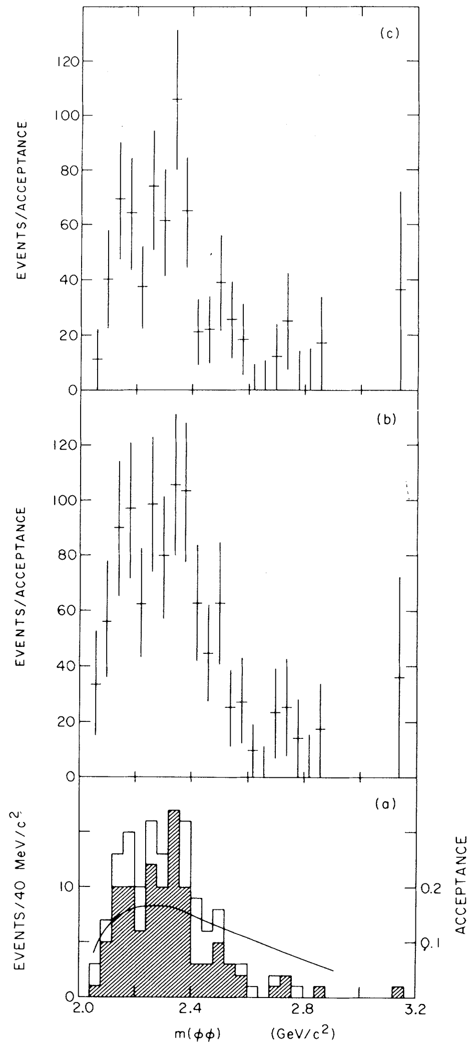

FIG. 3. Effective mass of the $\varphi\varphi$ system. (a) Uncorrected events. The shaded histogram is the sample with target veto hodoscope imposed. The curve is the calculated acceptance. (b) Events of (a) divided by acceptance. (c) Events of shaded histogram of (a) divided by acceptance.

One purpose of the measurement was to search for the η_c. We estimate that one event in the spectrum at 2.8 GeV would correspond to $\sigma \cdot B \approx 0.5$ nb, where B is the branching ratio, for $\pi^- p \to \eta_c n$, $\eta_c \to \varphi\varphi$. Taking the average population of the spectrum in this region, we find an upper limit (90% confidence level) for $\sigma \cdot B$ of approximately 2 nb.

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Measurement of the Energy Dependence of Elastic πp and pp Scattering at Large Angles

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We have measured $\pi^{\pm}p$ and pp elastic differential cross sections in the range $|\cos\theta_{\text{c.m.}}| < 0.35$ for incident momenta from 2 to 9.7 GeV/c for π^-p and pp and from 2 to 6.3 GeV/c for π^+p. We find that the fixed-c.m.-angle πp differential cross sections cannot be described as simple functions of s. The data are compared to the energy and angular dependence predicted by the constituent model of Gunion, Brodsky, and Blankenbecler.

It is generally believed that hadrons are composite particles. In this context, one attractive model for large-angle hadron-hadron scattering involves scattering of the constituents (e.g., quarks) of the projectile and target particles. An early encouragement for this approach was the apparent success of the dimensional counting rule,[1] which predicts the asymptotic energy dependence of differential cross sections at large fixed angles. The rule predicts that at constant c.m. angle, $d\sigma/dt \propto s^{-n}$, where $n = m - 2$ and m is the sum of the number of quarks in the initial and final states of the interaction, s is the square of the c.m. energy, and t is the square of the four-momentum transfer. It has been claimed that previous data agree with the predicted exponents (7 for photoproduction of pions, 8 for πp and Kp elastic scattering, and 10 for pp elastic scattering) for laboratory momenta above 5 GeV/c. However, in the πp case the comparison is based on very few data points with generally large statistical uncertainties. While the pp data have much better statistics, the case for s^{-10} is debated in the literature.[2]

We are reporting here some results from a new experiment which supplement and check the existing pp data and provide enough additional π^-p data for a stringent test of the dimensional counting rule.

This high-statistics experiment measured the differential cross section, $d\sigma/dt$, for $-0.35 < \cos\theta_{\text{c.m.}} < 0.35$ from 1.9 to 9.7 GeV/c for π^-p, from 1.9 to 6.3 GeV/c for π^+p, and from 1.9 to 9.0 GeV/c for pp interactions. The momentum

