

⁸Kingsley *et al.*, Ref. 6.

⁹E. Golowich and B. B. Holstein, Phys. Rev. Lett. **35**, 831 (1975); Paschos, Ref. 4.

¹⁰A. Chodos, R. L. Jaffe, K. Johnson, and C. B. Thorn, Phys. Rev. D **10**, 2599 (1974).

¹¹B. W. Lee, J. R. Primack, and S. B. Treiman, Phys. Rev. D **7**, 510 (1973); Gaillard, Lee, and Rosner, Ref. 6.

¹²A. Benvenuti *et al.*, Phys. Rev. Lett. **37**, 189 (1976); M. Holder *et al.*, Phys. Rev. Lett. **39**, 433 (1977).

Measurement of ϕ Production in Proton-Nucleus Collisions at 400 GeV/c

C. W. Akerlof, P. Alley,^(a) D. Bintinger, W. R. Ditzler, D. A. Finley, O. E. Johnson, D. Koltick, F. J. Loeffler, R. L. Loveless, D. I. Meyer, E. I. Shibata, K. C. Stanfield, R. Thun, and D. D. Yovanovitch

Fermi National Accelerator Laboratory, Batavia, Illinois 60510, and University of Michigan, Ann Arbor, Michigan 48109, and Purdue University, West Lafayette, Indiana 47907

(Received 21 July 1977)

We have measured the invariant cross section for inclusive ϕ production in proton-nucleus collisions at 400 GeV/c near Feynman $x = 0$. For transverse momenta in the range between 0.8 and 3.5 GeV/c the ratio of ϕ to π^- rises from 1 to 7%. We also report on correlations with particles opposite the ϕ in the center-of-mass system as they relate to the Okubo-Zweig-Iizuka rule.

We have observed the ϕ in its K^+K^- decay mode in 400-GeV/c proton-nucleus collisions at the Fermi National Accelerator Laboratory. An accurate measurement of the production of a vector meson in high-energy hadronic interactions is possible with the ϕ because its narrow width allows a clear separation from the background. This measurement is of interest for two reasons. First, measurement of the ϕ , a meson containing "hidden" strangeness, allows a test of the Okubo-Zweig-Iizuka (OZI) rule which in this case states that the production of the ϕ should be suppressed unless accompanied by strange particles. Second, the level of prompt muons contributed by the decay $\phi \rightarrow \mu^+\mu^-$ can be established. Measurements by others of ϕ production have been described previously.^{1,2}

In our experiment the ϕ was detected when both decay kaons traversed the same arm of a two-arm spectrometer. This spectrometer has been described previously.³ Briefly, it consisted of two identical arms each positioned at 100 mrad with respect to a diffracted proton beam. Each arm included a momentum-analyzing magnet, sixteen drift-chamber planes, trigger scintillation counters, three threshold Cherenkov counters, and, at the downstream end, muon identifiers. In most of the data collected subsequent to that reported in Ref. 3, the Cherenkov counter in each arm closest to the target was replaced by steel shielding with apertures for the beam and spectrometers. The function of the displaced

counters was taken over by new Cherenkov counters positioned behind each analyzing magnet. Most of the data for this Letter were collected in the latter configuration. Data were collected for measurement of inclusive ϕ production and for correlations with particles in the spectrometer arm opposite that in which the ϕ was observed.

For the inclusive measurement, the effective-mass spectrum of neutral pairs within a single arm is displayed in Fig. 1 for those events whose

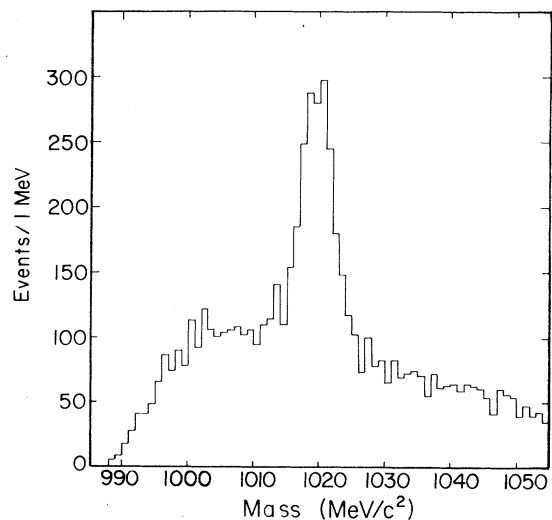


FIG. 1. Uncorrected effective-mass spectrum of K^+K^- candidates in a single spectrometer arm obtained in the inclusive measurement.

Cherenkov signals were compatible with a K^+K^- pair. A clear ϕ signal is observed at a mass of 1019.7 ± 0.2 MeV/ c^2 . The intrinsic width of the ϕ is determined to be 4.5 ± 0.4 MeV/ c^2 . The mass and width were calculated by fitting the acceptance-corrected mass spectrum from 1.002 to 1.042 MeV/ c^2 with a relativistic Breit-Wigner shape,⁴ smeared by a Gaussian-shaped mass resolution with $\sigma = 0.83$ MeV/ c , plus a linear background. The mass resolution was determined from our measured K^0 width. A sample of 1300 ϕ 's was collected in our inclusive measurement.

The ϕ inclusive invariant cross section was obtained from the K^+K^- spectrum as follows. First, the events in the ϕ peak ($1013 < m_{K^+K^-} < 1026$ MeV/ c^2) were binned in transverse momentum (p_\perp) and the background in each bin was subtracted. Corrections were made for geometric acceptance, kaon decay in flight, losses of kaons due to Cherenkov misidentification, tracking inefficiencies, finite target thickness, and a $\phi \rightarrow K^+K^-$ branching ratio of 0.466. The geometric acceptance is shown in Fig. 2 as a function of transverse momentum. The correction for kaon decay in flight varied from a factor of ~ 2.2 at $p_\perp = 1.0$ GeV/ c to ~ 1.3 at $p_\perp = 3.0$ GeV/ c . Spurious particles in Cherenkov counters caused a 10–20% loss of kaons. Tracking efficiency for the ϕ was $(51 \pm 4)\%$ independent of p_\perp . This was determined by tracking Monte Carlo simulated data and is low because of losses when both tracks overlapped in a single drift chamber cell. A correction for finite target thickness of 7% was applied for absorption of the beam and interaction of the outgoing kaons in the target.

The invariant cross section per nucleus for $p + \text{Be} \rightarrow \phi + X$ as a function of transverse momentum is displayed in Fig. 3. The mean Feynman x (x_F) and center-of-mass rapidity for these data were

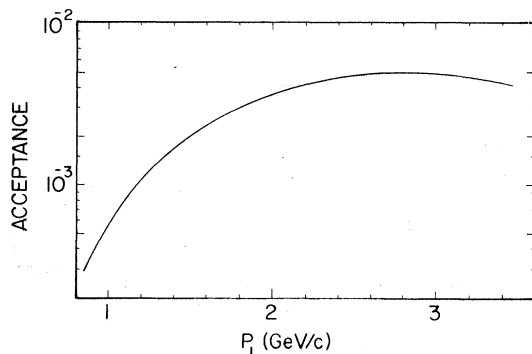


FIG. 2. Geometric acceptance of $\phi \rightarrow K^+K^-$ vs transverse momentum per unit interval of rapidity.

-0.08 and -0.55 , respectively. The range of x_F was $-0.10 < x_F < -0.07$. Errors from all sources, except overall beam normalization, are included in the indicated errors. Beam normalization, determined by a calibrated monitor telescope, was estimated to be uncertain to $\pm 10\%$. Fitting the invariant cross section with the functional shape $\exp(-ap_\perp)$ yields $a = 3.18 \pm 0.11$ (GeV/ c)⁻¹. This may be compared to $a = 3.93 \pm 0.28$ (GeV/ c)⁻¹ obtained in a different experiment² at 150 GeV/ c , $0.0 \lesssim p_\perp \lesssim 2.0$ GeV/ c , and $x_F > 0.15$.

The ϕ to π^- ratio has been determined as a function of transverse momentum utilizing inclusive hadron spectra obtained with the same apparatus and target (Fig. 4). As seen in Fig. 4 this ratio varies from approximately 1 to 7% as transverse momentum increases. As this experiment did not distinguish pions from kaons for $p_\perp \gtrsim 2.0$ GeV/ c , the kaon to pion ratios for Be computed from Antreasyan *et al.*⁶ and Kluberg *et al.*⁶ were used to correct for the K^- component of our inclusive negative spectra above $p_\perp \gtrsim 2.0$ GeV/ c . The contribution to the prompt μ^- to π^- ratio near $x_F \sim 0$ from the decay $\phi \rightarrow \mu^+\mu^-$ is also presented in Fig. 4. This contribution was calculated by Monte Carlo technique assuming a branching ratio for $\phi \rightarrow \mu^+\mu^-$ of 2.5×10^{-4} and no ϕ polarization. The level of prompt muons from

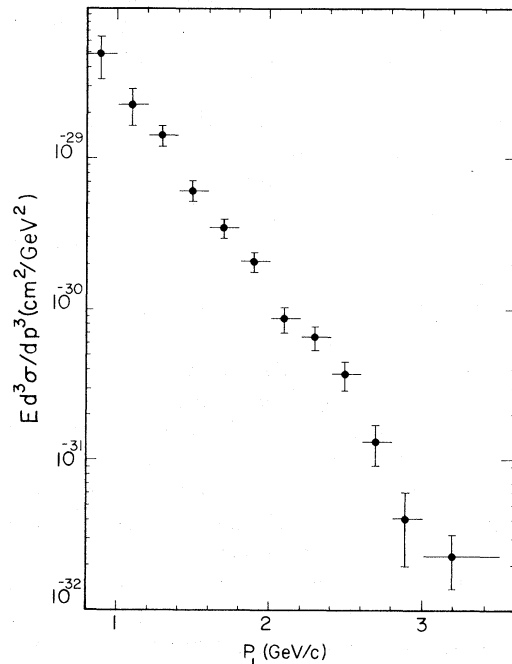


FIG. 3. Invariant cross section per nucleus vs transverse momentum for the reaction $p + \text{Be} \rightarrow \phi + X$ at $x_F \approx -0.08$.

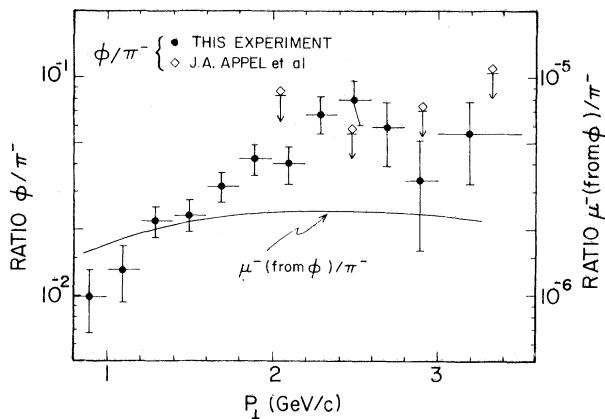


FIG. 4. Ratio of ϕ to π^- measured by this experiment at 400 GeV/c and $x_F \approx -0.08$ and upper limits on ϕ/π^- (Ref. 5) at 300 GeV/c and $x_F \approx 0.1$ (left scale). The μ^-/π^- ratio near $x_F = 0$ from the decay $\phi \rightarrow \mu^+\mu^-$ calculated from this experiment's measured ϕ/π^- ratio (right scale).

the ϕ is two orders of magnitude below the prompt μ to π ratio⁷ of $\sim 10^{-4}$.

We have recorded events in which a ϕ , pion, or kaon was detected in one arm in coincidence with another identified hadron with $0.7 \leq p_{\perp} \leq 2.0$ GeV/c in the other arm. With a sample of 490 ϕ -hadron coincidence events, we have searched for an enhancement of kaons that might result from ϕ mesons that are produced via an OZI-allowed mechanism.

Two steps are required to test for a kaon enhancement in ϕ events. First, the probability of observing a charged kaon in coincidence with the ϕ is compared to the probability of observing a kaon in coincidence with a pion. The motivation for this comparison is that the ratio of kaon occurrence in ϕ events to kaon occurrence in pion events should be unity if the ϕ behaves like an ordinary nonstrange particle such as the pion. If on the other hand, the ϕ is associated with additional strange-particle production, as would be expected in an OZI-allowed process, this ratio should be larger than one. As a measure of kaon occurrence in ϕ or pion events, we take the ratio of events in which a kaon is observed to events in which a pion is observed opposite the ϕ or pion. We express this quantity as $(K/\pi)_{\phi}$ or $(K/\pi)_{\pi}$. From our data, then, we measure $(K/\pi)_{\phi}/(K/\pi)_{\pi} = 1.21 \pm 0.24$. This ratio indicates no significant enhancement of kaons in events containing a ϕ .

The second step is to determine the expected size of the kaon enhancement in ϕ events under the assumption that the ϕ is always accompanied

by two additional strange particles. We do this by measuring K^+K^- correlations. The motivation for this is similar to that given above in that the detection of a strange particle (e.g., K^+) in one arm should enhance the occurrence of a particle with opposite strangeness (e.g., K^-) in the other arm. We measure the ratio K^-/π^- opposite K^+ or π^+ , and conversely K^+/π^+ opposite K^- or π^- . The two ratios $(K^-/\pi^-)_{K^+}/(K^-/\pi^-)_{\pi^+}$ and $(K^+/\pi^+)_{K^-}/(K^+/\pi^+)_{\pi^-}$ are equal within their statistical errors. Their weighted average is 1.38 ± 0.06 . Hence, the probability of detecting a kaon of opposite charge in the second arm is 38% larger when the particle in the first arm is a kaon instead of a pion. This sets the scale for interpreting the ϕ data. If the ϕ were always accompanied by two additional strange particles, then one would predict $(K/\pi)_{\phi}/(K/\pi)_{\pi} = 1.76 \pm 0.12$ for our data as compared to the measured value of 1.21 ± 0.24 .

Our measured ϕ/π^- ratio of ~ 0.01 at $p_{\perp} \sim 1$ GeV/c indicates a fairly strong suppression of inclusive ϕ production.⁸ Our results also suggest that ϕ mesons are produced primarily via a mechanism that does not generate additional strange particles. These observations are consistent with ϕ production by *other* than OZI-allowed processes involving the strange-quark constituents of the ϕ . Theoretical discussions of ϕ production with regard to the OZI rule have been published.⁹

This research was supported by the U. S. Energy Research and Development Administration and the National Science Foundation. We thank the Fermilab staff for their support. We are particularly grateful to Dr. R. A. Lundy for his help during early data taking and for many helpful discussions. We also express our gratitude to R. Fabrizio and P. Kraushaar for their assistance in data collection and to Dr. H. J. Lipkin for sharing his knowledge of the OZI rule with us.

^(a)Present address: LeCroy Research Systems/Far West, One First St., Los Altos, Calif. 94022.

¹V. Blobel *et al.*, Phys. Lett. **59B**, 88 (1975); R. A. Donald *et al.*, Phys. Lett. **61B**, 210 (1976); P. Woodworth *et al.*, Phys. Lett. **65B**, 89 (1976); D. Cohen *et al.*, Phys. Rev. Lett. **38**, 269 (1977); B. Ghidini *et al.*, CERN Report No. CERN/EP/Phys. 77-6 (to be published).

²K. J. Anderson *et al.*, Phys. Rev. Lett. **37**, 799 (1976).

³D. Bintinger *et al.*, Phys. Rev. Lett. **37**, 732 (1976);

R. Thun *et al.*, Nucl. Instrum. Methods **138**, 437 (1976).

⁴J. D. Jackson, Nuovo Cimento **34**, 1644 (1964).

- ⁵J. A. Appel *et al.*, Phys. Rev. Lett. **35**, 9 (1975).
⁶D. Antreasyan *et al.*, Phys. Rev. Lett. **38**, 115 (1977);
 L. Kluberg *et al.*, Phys. Rev. Lett. **38**, 670 (1977).
⁷J. P. Boymond *et al.*, Phys. Rev. Lett. **33**, 112 (1974);
 J. A. Appel *et al.*, Phys. Rev. Lett. **33**, 722 (1974);
 D. Bintinger *et al.*, Phys. Rev. Lett. **35**, 72 (1975); V. V.
 Abramov *et al.*, in *Proceedings of the Seventeenth Inter-*
national Conference on High Energy Physics, London,

England, 1974, edited by J. R. Smith (Rutherford High
 Energy Laboratory, Didcot, Berkshire, England,
 1974), p. V-53.

⁸The measurements of Ref. 2 yield a ρ/ρ^0 ratio of
 0.077 while R. Singer *et al.* [Phys. Lett. **60B**, 385 (1976)]
 find $\rho^0/\pi^- = 0.13 \pm 0.02$.

⁹H. J. Lipkin, Phys. Lett. **60B**, 371 (1976); S. C.
 Frautschi *et al.*, Nucl. Phys. **B121**, 141 (1977).

Experimental Study of the Reaction ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}$ in the (3, 3) Resonance Region

A. Altman, J. Alster, D. Ashery, and I. Navon

Physics Department, Tel Aviv University, Ramat Aviv, Israel

and

H. J. Pfeiffer and H. K. Walter

*Laboratorium für Hochenergiephysik der Eidgenössische Technische Hochschule, Zürich,
 CH-5234 Villigen, Switzerland*

and

E. A. Hermes and F. W. Schlepütz

Physikinstitut der Universität, Zürich, CH-8001 Zürich, Switzerland

(Received 2 August 1977)

Angularly integrated cross sections for the reaction ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}^*$ (429 keV) were measured over the energy range of 90 to 210 MeV by a selective "prompt- γ " detection method. These results, combined with the summed cross sections to the ground state and excited state, yield the cross section for the ground state alone. The excitation function for the excited state is flat with cross sections of about 0.3 mb. For the ground-state transition the cross sections are between 1.2 and 1.9 mb. The data are compared with theoretical calculations.

Results of recent pion single-charge-exchange experiments¹ have been the subject of much theoretical activity.²⁻⁴ The only experiment performed to date in which the cross section for the population of a single final state was measured is for the isobaric analog transition ${}^{13}\text{C}(\pi^+, \pi^0){}^{13}\text{N}$.¹ For the reaction ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}$, the summed angularly integrated cross section to two final states was measured¹: the isobaric-analog ground state ($\frac{3}{2}^-$) and the first excited state (429 keV, $\frac{1}{2}^-$). The various calculations carried out for the reaction ${}^{13}\text{C}(\pi^+, \pi^0){}^{13}\text{N}$,²⁻⁴ where mainly the monopole transition contributes, give too small cross sections and do not reproduce the shape of the excitation function.⁵ For the reaction ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}$ both monopole and quadrupole transitions are allowed when spin flip is included. In this case, reasonable agreement could be obtained for the sum of the two states by attributing a fair fraction of the cross section to the population of the excited state and to excitation modes other than the simple monopole transition.² Therefore, it

became interesting to measure the ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}$ cross section to each state separately. So far no experimental information is available for a transition to a single nonanalog state.

In this Letter we report the results of the ${}^7\text{Li}(\pi^+, \pi^0){}^7\text{Be}^*$ cross-section measurement to the 429-keV, $\frac{1}{2}^-$ excited state. In addition we present cross sections for the ground-state transition, which were obtained by subtracting the measured excited-state values from the summed cross sections.

The experiment was carried out at the $\pi M3$ channel of the Schweizerisches Institut für Nuklearforschung accelerator at bombarding energies of 90, 130, 170, and 210 MeV. The cross section for the excited state of ${}^7\text{Be}$ was measured by observing the 429-keV γ decay to the ground state. The γ spectrum was measured with a 50-cm³ Ge(Li) detector, positioned at 90° relative to the beam. The angular distribution of these γ rays is isotropic (due to the spin $\frac{1}{2}$ of the excited state) and the integration over the sphere is thus