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INCLUSIVE ϕ PRODUCTION IN K^-p AND π^+p INTERACTIONS AND
COMPARISON WITH J/ψ PRODUCTION

Aachen-Berlin-Bonn-CERN-Cracow-London-Vienna-Warsaw Collaboration

P. Sixel

III. Physikalisches Institut der Technischen Hochschule, Aachen

W. Lohmann and H.J. Schreiber*

Institut für Hochenergiephysik der Akademie der Wissenschaften der DDR,
Berlin-Zeuthen

K. Böckmann, K. von Holt and H. Saarikko

Physikalisches Institut der Universität Bonn, Bonn

V.T. Cocconi, D.R.O. Morrison and P. Schmid

CERN, European Organization for Nuclear Research, Geneva

B. Muryn

Institute of Nuclear Research and Academy of Mining and Metallurgy,
Department of Physics, Cracow

K.W.J. Barnham, J. Wells**, P.R.S. Wright*** and M. Zomorrodian
The Blackett Laboratory, Imperial College, London

J. MacNaughton and M. Markytan

Institut für Hochenergiephysik der Österreichischen Akademie der
Wissenschaften, Vienna

M. Bardadin-Otwinowska+

Institute of Experimental Physics, University of Warsaw, Warsaw

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(*) Now at JINR, Dubna.

(**) Supported by S.R.C. Fellowship. Now at Nuclear Physics Laboratory,
Oxford.

(***) Now Fellow at CERN, Geneva.

(+) Now visiting Scientist at CERN.

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ABSTRACT

The production of $\phi(1020)$ -mesons is studied in bubble chamber experiments of 10 and 16 GeV/c K^-p and 16 GeV/c π^+p interactions. At 16 GeV/c, the inclusive ϕ -production cross section is 0.39 ± 0.05 mb with incident kaons and 0.13 ± 0.03 mb with incident pions. The differential cross sections $d\sigma/dp_T^2$ and $d\sigma/dx$ are determined, as well as the ϕ -meson decay angular distribution. Comparison is made with $\psi(3100)$ -production. Evidence is presented for the dominant role of kaon fragmentation in ϕ -production in K^-p interactions and for remarkable similarities in ϕ and ψ production in π^+p interactions.

1. INTRODUCTION

In recent years inclusive resonance production in high-energy interactions has been widely studied. One reason for this is that resonances, being a more direct product of the collisions, are apt to reflect more closely the dynamical mechanisms involved than the final state particles, the majority of which originates indirectly from resonance decay. The determination of the characteristics of resonance production is thus valuable for testing theoretical models.

Studies of inclusive resonance production require experiments possessing event samples large enough to allow the observation of clear resonance signals. So far, only abundantly produced resonances like ρ^0 , Δ^{++} , etc. have been thoroughly studied, while less is known about resonances with small production cross sections. This is the case for the $\phi(1020)$ -meson, a resonance particularly interesting, being the lowest mass member in the series of $J^P = 1^-$ vector mesons consisting of heavy quark-antiquark pairs: $\phi(s\bar{s})$, $\psi(c\bar{c})$, $T(b\bar{b})$, ...

The results reported so far on inclusive ϕ -meson production [1-14] are based mostly on counter experiments, and hence are limited to a restricted phase-space region.

In this paper we present results covering the whole phase-space for the reactions

$$K^- p \rightarrow \phi + \text{anything} \quad (1)$$

$$\pi^+ p \rightarrow \phi + \text{anything} \quad (2)$$

obtained in the 1.5m British and 2m CERN H_2 bubble chambers at the CERN PS.

The data used in this work consist of 240 000 and 400 000 events of $K^- p$ interactions at 10 and 16 GeV/c (10 and 20 events/ μb), respectively, and of 571 000 events (20 events/ μb) of $\pi^+ p$ interactions at 16 GeV/c.

The comparison of reaction (1) with reaction (2) at the same beam momentum is of particular interest, as the ϕ -meson produced in reaction (1) may contain the valence s quark of the incident K^- , whereas in reaction (2) the incident π^+ and the produced ϕ have no common valence quark.

The results obtained here for the ϕ are compared, whenever possible, with those obtained in other experiments for the production of ψ -meson.

Various models have been proposed to describe the production of these "heavy quark" states [15]. They are based on the quark-parton model and envisage the production mechanisms essentially as fusion processes of valence or sea quarks, or of gluons. The models are meant to be applied to ψ , ψ' , T, etc. production, while their validity for the ϕ -meson, because of its low mass, is open to doubt.

2. INCLUSIVE MASS SPECTRA AND TOTAL CROSS SECTION

The ϕ -meson signal has been searched for in the decay mode $\phi \rightarrow K^+ K^-$. All cross sections for ϕ -meson production given in this paper are corrected for the corresponding branching ratio (48.6%) [16].

As only a small fraction of the charged kaons is identified in a bare bubble chamber experiment, each of the positively (negatively) charged secondaries, in turn, was taken as a K^+ (K^-), except when the kaon hypothesis was excluded by ionisation, or by production or decay fits.

The resulting spectra of the $(K^+ K^-)$ invariant mass are shown in figs 1 and 2 for reactions (1) and (2), respectively. Clear enhancements at the ϕ -meson mass are visible in both spectra, but much stronger in the $K^- p$ than in the $\pi^+ p$ data.

The ϕ -meson production cross sections were obtained from these spectra by fitting to the experimental distributions a Breit-Wigner function for the resonance and a background described by the function

$$BGD = \alpha_1 (m - m_{th})^{\alpha_2} \cdot \exp(-\alpha_3 m - \alpha_4 m^2) \quad (3)$$

where m_{th} is the threshold mass.

The results of these fits are the solid line curves in figs 1 and 2. There are about 2000 and 4600 ϕ -mesons above background in the $K^- p$

spectra at 10 and 16 GeV/c, respectively, and about 1500 ϕ -mesons in the π^+p spectrum at 16 GeV/c (see the shaded areas in figs 1 and 2).

The values obtained for the ϕ mass and width^(*) are listed in table 1. The mass values are in excellent agreement with the value in the PDG tables [16], which lends credibility to the belief that the signals obtained in the two experiments are indeed due to genuine ϕ production. The values of the ϕ -meson inclusive production cross sections obtained in these fits are listed in table 2.

As a cross-check, values of the cross sections have been calculated also by summing the partial cross sections determined in successive bins in the charged multiplicity distribution, as well as in the distributions of the Feynman x and of the transverse momentum squared (table 2). The results obtained are in close agreement among themselves and with those obtained by fitting the inclusive spectra. The best estimates of the ϕ production cross sections are given in the last row of table 2. One can see that at 16 GeV/c the production of ϕ -mesons is approximately three times more abundant in K^-p than in π^+p interactions. In K^-p interactions at 16 GeV/c, the average number of ϕ -mesons per event is ~ 0.02 .

In table 3 the ϕ production cross sections are presented as functions of the number of charged particles associated with the ϕ meson. In K^-p interactions the bulk of ϕ production occurs in low multiplicity events (0 or 2 charged particles besides the ϕ), whereas in π^+p interactions, ϕ production is more evenly distributed among the events of various multiplicities. This difference can be qualitatively understood considering that the reactions $K^-p \rightarrow \phi\Lambda(+\pi^0s)$ (0 associated prongs) and the diffractive channel $K^-p \rightarrow \phi K^-p$ (2 associated prongs), both known to have sizeable cross sections at these energies, have no counterpart in π^+p interactions.

Fig. 3 shows a compilation of ϕ production cross sections for various incident particles (π^+ , $K^\pm$ and p) at various energies. In the energy range

(*) The widths in table 1 include the broadening of the ϕ signal due to the experimental resolution.

of 10-30 GeV/c, the ϕ production cross section is approximately the same for π^+p and pp interactions, and is 2 to 5 times smaller than in K^+p interactions. Only for pp interactions do there exist results covering an energy range sufficiently large to study the energy dependence. It can be seen that $\sigma^{PP}(\phi)$ is about one order of magnitude larger at the highest ISR energies ($s \approx 3900 \text{ GeV}^2$) than at 24 GeV/c ($s \approx 50 \text{ GeV}^2$).

For π^+p interactions, the value of $280 \pm 84 \text{ } \mu\text{b}$ determined at 150 GeV/c [2] for the forward ($x > 0$) cross section, compared with the corresponding quantity obtained in this experiment, namely $71 \pm 11 \text{ } \mu\text{b}$, indicates a rise consistent with that observed in pp interactions. Also the few results available for K^+p interactions seem to follow this general trend.

3. DIFFERENTIAL CROSS SECTIONS FOR ϕ PRODUCTION

3.1 Transverse momentum distributions

The transverse momentum squared distributions, $d\sigma/dp_T^2$, of the ϕ -mesons are shown in fig. 4 for reactions (1) and (2). They are described by the exponential function

$$d\sigma/dp_T^2 \propto \exp(-B p_T^2) \quad (4)$$

with $B = 3.5 \pm 0.3(\text{GeV}/c)^{-2}$ for incident kaons at 10 and 16 GeV/c and $B = 3.6 \pm 0.9(\text{GeV}/c)^{-2}$ for incident pions at 16 GeV/c. These values are consistent with the value of $3.4 \pm 0.2(\text{GeV}/c)^{-2}$ reported for many other secondary particles with mass of $\approx 1 \text{ GeV}$ at 16 GeV/c [17].

The average values of the ϕ -meson transverse momentum squared are $\langle p_T^2 \rangle = 0.28 \pm 0.02(\text{GeV}/c)^2$ and $0.22 \pm 0.04(\text{GeV}/c)^2$ in K^-p and π^+p interactions, respectively. The corresponding values of $\langle p_T \rangle$ are 0.48 ± 0.02 and $0.43 \pm 0.04 \text{ GeV}/c$. For the ϕ -mesons produced by incident π^+ at 150 GeV/c, the value of $\langle p_T \rangle$ is reported to be $0.55 \pm 0.06 \text{ GeV}/c$ [2].

3.2 Longitudinal distributions

Fig. 5 shows the distributions of the ϕ -mesons in Feynman x ($x = p_{\parallel}^*/p_{\max}^*$, where $p_{\parallel}^*$ is the c.m. longitudinal momentum and $p_{\max}^*$ its maximum values for reactions (1) and (2). The K^-p distributions at 10 and 16 GeV/c, found to agree within errors, are here combined. The striking feature of these results is the huge excess of ϕ -meson production in the forward direction in K^-p interactions over that in π^+p interactions, while for $x < 0$ the two distributions are roughly equal. The presence of a strange valence quark in the incident K^- offers an obvious qualitative explanation of this forward excess, which is thus evidence for the importance of the fragmentation process of the incoming kaon.

The x distribution obtained for K^-N interactions at 43 GeV/c [6] is also shown in fig. 5, for comparison. No noteworthy energy dependence is observed between 10 and 43 GeV/c, for $x > 0.5$. However, for $x \approx 0.15$, ϕ production cross sections about twice as large as those at 10-16 GeV/c were obtained for 93 GeV/c K^-p and π^+p interactions [14].

In fig. 6 the Lorentz invariant ϕ -production cross section

$$f(x) = \frac{1}{p_{\max}^*} \int_0^{\infty} E^* \frac{d^2\sigma}{dx dp_T^2} dp_T^2, \quad (5)$$

where E^* is the c.m. energy of the ϕ -meson, is shown for reactions (1) and (2). The solid line in the figure represents the results obtained in this K^-p experiment for the reaction

at 10-16 GeV/c [18]. In K^-p interactions, the ϕ and $\bar{K}^{*0}(890)$ distributions are remarkably similar in shape over the whole x -range. This is in agreement with the expectation of the additive quark model of Anisovich and Shekhter [15(a)] which predicts that in high-energy K^-p interactions the production of ϕ -mesons is suppressed relative to $\bar{K}^{*0}(890)$ production by a factor λ which is the same in the central and in the fragmentation regions of the incident kaon. This factor measures, in the framework of the model, the relative probability of extracting strange to non-strange quarks from

the sea. Thus, no separation of central and fragmentation components of ϕ and $K^{*0}(890)$ production is needed for the determination of λ , which is directly obtained from the ratio of the inclusive ϕ and $K^{*0}(890)$ production cross sections. This ratio is found here to be the same at 10 and 16 GeV/c and to amount to

$$\lambda = \frac{\sigma(\phi)}{\sigma(K^{*0})} = \frac{0.38 \pm 0.05}{3.3 \pm 0.4} = 0.12 \pm 0.02.$$

In 32 GeV/c K^+p [7] and K^-p [8] interactions, this ratio was found to have the values 0.14 ± 0.03 and 0.21 ± 0.05 , respectively. Similar values have been deduced from comparison of ρ^0 and $K^{*0}(890)$ production in pp and π^+p interactions [19].

4. COMPARISON OF ϕ AND ψ PRODUCTION

4.1 Fits to the longitudinal distributions

In order to obtain a more quantitative description of the characteristics of ϕ -meson production in our experiments, and allow comparison with other experiments of ϕ and ψ production, the x distributions shown in figs 5 and 6 have been fitted with the functions

$$d\sigma/dx \propto (1 - x)^{n_1} \tag{6}$$

and

$$f(x) \propto (1 - x)^{n_2}, \tag{7}$$

respectively.

The fitted values of the exponents n_1 and n_2 in the x ranges indicated, are listed in table 4, together with the results of other experiments [2,3,6,20]. The n_1 and n_2 values obtained in our experiments agree fairly well with the corresponding results obtained in previous kaon and pion interaction experiments.

From inspection of the table one can deduce:

- (a) The ϕ -meson spectrum is much harder, i.e. n smaller, when the incident particle is a kaon than when it is a pion or a nucleon.

- (b) For both incident pions and nucleons, the spectra of the ϕ and ψ mesons in the forward direction are remarkably similar in shape (with a factor $\sim 10^3$ in cross section).
- (c) In proton induced reactions, the ϕ and ψ spectra have values of the exponent n about twice as large as in pion induced reactions.
- (d) The value of the exponent n does not depend strongly on the momentum of the incident particle (at least for pion induced processes, where data exist between 16 and 225 GeV/c).

These results justify the following comments:

- (a) The hardness of the ϕ spectrum in kaon interactions reveals the importance of ϕ production by fragmentation of the beam particle, and reflects the momentum distribution of the valence strange quark in the kaon.
- (b) For non-strange beams, the fact that ϕ and ψ spectra in the forward direction have approximately the same shape points to similar production mechanisms and to similar momentum distributions of the s and c quarks in the sea. The production process does not seem to change drastically from ~ 10 to ~ 200 GeV/c.
- (c) The softer spectrum of the ϕ and ψ mesons produced by nucleon interactions indicates that in baryons the quark sea is softer than in pions, as expected.

4.2 Comparison of ϕ and ψ production in pion-induced reactions

For pion induced reactions, the results available warrant further comparison of ϕ and ψ production, as shown in figs 7 and 8. As can be seen in fig. 7, the squared transverse momentum distribution is flatter for the ψ than for the ϕ meson, in agreement with the common observation that the average p_T increases with increasing mass of the produced particle.

Fig. 8 shows that for ϕ and ψ mesons produced by pion beams the x distributions in the forward hemisphere ($x > \sim 0.1$) have strikingly similar shape (though the absolute values differ by a factor of 10^3). Both distributions exhibit a strong forward/backward asymmetry, with excess in the forward direction, and both have a maximum at $x \approx 0.02$. For ψ -meson production, these features have been interpreted as revealing that the valence quarks of the incident pion play an important role in the production process [15(c), 21]. The same may be true for the ϕ -meson.

4.3 Decay angular distributions

A sensitive function, at least in principle, of the mechanism of resonance production is the shape of the decay angular distribution, in the resonance rest-frame, relative to a properly chosen axis. The distribution of the polar angle θ in the Gottfried-Jackson frame, is expected to have the general form

$$d\sigma/d\cos\theta_{GJ} \propto 1 + \alpha \cos^2\theta_{GJ}, \quad (8)$$

where the value of the parameter α depends on the production mechanism involved [22].

In ref. [2] it has been shown that the angular distribution of the $(\mu^+ \mu^-)$ system produced in the reactions $pp \rightarrow (\mu^+ \mu^-) + X$ and $\pi^+ p \rightarrow (\mu^+ \mu^-) + X$ is isotropic when the $(\mu^+ \mu^-)$ system has mass in the ψ -meson mass band and has the form $(1 + \cos^2\theta)$ outside the ψ region, as expected if the two muons are produced by the Drell-Yan mechanism. This is taken as proof of the hadronic origin of ψ -production, above the electromagnetic background.

Fig. 9 presents the angular distributions obtained by fitting the $(K^+ K^-)$ mass spectra binned in $\cos\theta_{GJ}$, for reactions (1) and (2). In 10-16 GeV/c $K^- p$ interactions, the distribution appears to be almost flat. For $\pi^+ p$ interactions some structure could be present, but the distribution is still consistent with isotropy. The values of α obtained by fitting the distributions with the function (8) are 0.18 ± 0.24 for $K^- p$ and 0.8 ± 1.1 for $\pi^+ p$ (table 5). In a quark fusion model [22], neglecting the quark's transverse momenta, α can be expressed by

$$\alpha = \frac{1 - 4 \frac{m_q^2}{m_\phi^2}}{1 + 4 \frac{m_q^2}{m_\phi^2}} \quad (9)$$

where m_q is the mass of each of the fusing quarks. The values of m_q obtained from the fitted values of α are given in table 5.

The m_q value of 425^{+115}_{-100} MeV obtained for K^-p interactions is consistent with the hypothesis that the dominant mechanism of ϕ production at our energies is the fusion of the strange valence quark of the incoming kaon with an $\bar{s}$ quark from the sea, in the kaon fragmentation process. In the π^+p experiment, the result for m_q (170^{+525}_{-170} MeV) has too large errors to distinguish between light-quark and strange-quark fusion.

5. DISCUSSION

The results presented in sect. 3 strongly indicate that in K^-p interactions at medium energies the dominant process of ϕ -meson production is the fragmentation of the incoming kaon, i.e. - in the QPM language - the fusion of the strange valence quark of the incoming kaon with an $\bar{s}$ quark from the sea.

For π^+p interactions, the situation is less clear and several production processes may be invoked. The relatively large ϕ production cross section indicates that the dominant mechanisms involved are hadronic and not, e.g., electromagnetic of the Drell-Yan type. This is also supported by the scaling behaviour discussed later in this section. Amalgamation of three gluons into a ϕ is possible, but the corresponding coupling is too small to account for the measured cross section. Fusion of two gluons or production through heavy gluons require cascade emission of one or more gluons to yield the ϕ meson. Thus, although gluon processes may account for part of the ϕ production, the dominant mechanism operating in πN and NN interactions at medium energies is likely to be quark fusion [15(c,e)]. Fusion of an $s\bar{s}$ pair from the sea could, in principle, yield asymmetric x distributions such as those shown in fig. 8 if the valence quarks of the incoming hadron carry an associated sea of $q\bar{q}$ pairs. However, most models agree in estimating that the sea-sea contribution is too small

to account for the largest part of the cross section. Detailed calculations by Donnachie and Landshoff [15(c)], supported by experimental results on ϕ production at low energies [23,24], have shown that at the energies considered here, the fusion of a valence u or d quark with the corresponding antiquark is especially important in πN interactions, where these "Zweig violating" couplings could dominate up to ISR energies. The x distributions observed in this experiment are qualitatively consistent with such a model.

Halzen et al. [15(d), 25] have suggested that the hadronic origin of narrow vector mesons production by non-strange (non-charmed, etc.) beam particles should be revealed by a scaling behaviour, common to all vector (V) mesons, of the function

$$F(s/M^2) = \frac{M^3}{\Gamma} \sigma(h + h \rightarrow V + X) \quad (10)$$

provided the ratio Γ/M is small, where M and Γ are the mass and the direct hadronic width, respectively, of the vector meson V, and h represents a hadron. The function $F(s/M^2)$ reflects the kinematics and dynamics of assembling a mass M out of the total c.m.s. energy $\sqrt{s}$, and the differences between the various resonances are assumed to be contained in Γ .

This scaling behaviour has been previously verified for ϕ , ψ , ψ' and T production in pp interactions over a wide range of energies. The plot of $(M^3/\Gamma) \cdot \sigma$ versus s/M^2 shown in fig. 10 contains also the results now available from this and other experiments on πN interactions. It demonstrates that the same scaling curve is valid for both pion- and proton-induced processes^(*). The scaling eq. (10) has been used to predict production cross sections of new quark flavours and weak bosons [25].

(*) The $\omega(783)$ meson, also of relatively small width, seems to fall on the same curve, while the scaled cross sections of broader resonances like $K^*(890)$ and $\rho^0(770)$ fall clearly (a factor of ~ 10) below the curve.

6. CONCLUSIONS

From a study of the (K^+K^-) mass spectra in K^-p interactions at 10 and 16 GeV/c and in π^+p interactions at 16 GeV/c the following main results have been obtained:

- (a) The inclusive cross section for production of ϕ mesons in K^-p interactions at 16 GeV/c is 0.39 ± 0.05 mb, which corresponds to the average production of 0.02 ϕ mesons per event.
- (b) In π^+p interactions at the same momentum the ϕ production cross section is ~ 3 times smaller, 0.13 ± 0.03 mb.
- (c) In K^-p interactions at 16 GeV/c, the ratio between the inclusive cross sections for ϕ and $K^{*0}(890)$ production is 0.12 ± 0.02 . In the QPM, this ratio represents the suppression factor of the strange $s\bar{s}$ pairs relative to the non-strange $d\bar{d}$ pairs in the sea, irrespectively of whether the resonances are produced centrally or by fragmentation of the incoming kaon.
- (d) Both in K^-p and in π^+p interactions the rise of the ϕ cross section with energy appears to be consistent with the same trend as observed for pp interactions.
- (e) With both K^- and π^+ beams, the p_T^2 distributions of the ϕ mesons are well described by a falling exponential with slope parameters close to the value of $\sim 3.4(\text{GeV}/c)^{-2}$ found to hold at these energies for other particles with mass of ~ 1 GeV.
- (f) The momentum spectrum of the ϕ -mesons produced in K^-p interactions is much harder than that of the ϕ -mesons produced in π^+p or pp interactions. This is interpreted as evidence for the dominant role, among the possible mechanisms of ϕ -production in K^-p interactions, of the fragmentation of the incoming kaon, i.e. of the fusion of the valence s-quark in the kaon with an $\bar{s}$ from the sea.
- (g) In π^+p interactions, the ϕ -meson x-distribution is remarkably similar in shape to that observed in other experiments for the ψ -meson, and it

depends weakly on the energy, from 16 to 225 GeV/c. The fact that both ϕ and ψ are produced more abundantly in the forward than in the backward direction is interpreted as revealing that fusion processes involving the ordinary (non-strange, non-charmed) valence quarks of the incoming pion play an important role both in ψ and ϕ production.

- (h) The ϕ meson decay angular distribution in the Gottfried-Jackson frame is found to be approximately isotropic in 10-16 GeV/c K^-p interactions.
- (i) The scaling behaviour previously observed for the narrow vector meson production cross sections in pp interactions is here verified to hold also in πN interactions.

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TABLE CAPTIONS

- Table 1 Values of the ϕ -meson mass and width obtained by fitting the K^+K^- mass spectra shown in figs 1 and 2.
- Table 2 Cross sections for ϕ -meson production in 10 and 16 GeV/c K^-p interactions, and in 16 GeV/c π^+p interactions obtained inclusively and by summing up the partial cross sections calculated in bins of the charged multiplicity, of the Feynman x and of the transverse momentum squared. The errors given on the best estimates take into account also the systematic uncertainties.
- Table 3 Cross sections for ϕ -production as functions of the number of charged particles produced in association with the ϕ -meson.
- Table 4 Values of the exponents n_1 and n_2 in the functions (6) and (7), obtained by fitting the experimental x distributions of the ϕ and ψ -mesons, over the x -range indicated.
- Table 5 Values of the parameter α and of the corresponding quark mass m_q (see eqs (8) and (9)) obtained by fitting the ϕ -meson decay angular distribution in the Gottfried-Jackson system.

TABLE 1

Experiment	Mass (MeV)	Width (MeV)	χ^2/NF
$K^- p$ 10 GeV/c	1019.2 ± 0.5	11.2 ± 2.0	10/11
$K^- p$ 16 GeV/c	1019.7 ± 0.3	10.8 ± 1.4	10/11
$\pi^+ p$ 16 GeV/c	1019.5 ± 1.2	11.0 (fixed)	24/12
PDG value	1019.6 ± 0.1		

TABLE 2

Bins in	$\sigma(\phi)$ (μb)		
	$K^- p$ (10 GeV/c)	$K^- p$ (16 GeV/c)	$\pi^+ p$ (16 GeV/c)
Charged multiplicity	360 ± 29	389 ± 22	121 ± 23
Feynman x	357 ± 33	388 ± 26	121 ± 21
p_T^2	401 ± 29	384 ± 25	137 ± 23
Inclusive	371 ± 52	381 ± 56	120 ± 26
Best estimate	370 ± 50	385 ± 50	125 ± 30

TABLE 3

Associated charged multiplicity	$\sigma(\phi)$ (μb)		
	$K^- p$ (10 GeV/c)	$K^- p$ (16 GeV/c)	$\pi^+ p$ (16 GeV/c)
0	107 ± 12	65 ± 6	-
2	231 ± 24	231 ± 15	50 ± 12
4	13 ± 8	69 ± 13	40 ± 13
6	9 ± 6	24 ± 7	31 ± 14

TABLE 4

Reaction	P_{lab} (GeV/c)	x-range	n_1	n_2	Ref.
$K^- p \rightarrow \phi X$	10-16	$x > 0.6$	0.61 ± 0.18	0.34 ± 0.17	This work
$K^- Be \rightarrow \phi X$	43	$x > 0.4$	0.98 ± 0.13		[6]
$\pi^+ p \rightarrow \phi X$	16	$x > 0$	1.8 ± 0.3	1.05 ± 0.41	This work
$\pi^- p \rightarrow \phi X$	16	$x > 0.2$	2.0 ± 0.2		[3]
$\pi^+ Be \rightarrow \phi X$	150	$x > 0.15$		1.73 ± 0.44	[2]
$\pi^+ C \rightarrow \phi X$	225	$x > 0.1$		1.67 ± 0.17	[20]
$\pi^- C \rightarrow \phi X$	225	$x > 0.1$		1.60 ± 0.16	[20]
$\pi^+ Sn \rightarrow \phi X$	225	$x > 0.1$		2.16 ± 0.24	[20]
$\pi^+ Be \rightarrow \psi X$	150	$x > 0.15$		1.72 ± 0.38	[2]
$\pi^+ C \rightarrow \psi X$	225	$x > 0.1$		1.33 ± 0.21	[20]
$\pi^- C \rightarrow \psi X$	225	$x > 0.1$		1.93 ± 0.20	[20]
$\pi^+ Sn \rightarrow \psi X$	225	$x > 0.1$		1.50 ± 0.28	[20]
$pBe \rightarrow \phi X$	150	$x > 0.15$		4.06 ± 0.40	[2]
$pC \rightarrow \phi X$	225	$x > 0.1$		3.82 ± 0.14	[20]
$pSn \rightarrow \phi X$	225	$x > 0.1$		4.76 ± 0.21	[20]
$pBe \rightarrow \psi X$	150	$x > 0.15$		2.94 ± 0.32	[2]
$pC \rightarrow \psi X$	225	$x > 0.1$		3.44 ± 0.14	[20]
$pSn \rightarrow \psi X$	225	$x > 0.1$		4.01 ± 0.37	[20]

TABLE 5

Reaction	P_{lab} (GeV/c)	α	m_q (MeV)
$K^- p \rightarrow \phi X$	10-16	$+ 0.18 \pm 0.24$	425^{+115}_{-100}
$\pi^+ p \rightarrow \phi X$	16	$+ 0.8 \pm 1.1$	170^{+525}_{-170}

FIGURE CAPTIONS

- Fig. 1 Spectra of the K^+K^- invariant mass in 10 and 16 GeV/c K^-p interactions. The solid lines are the results of fitting them with a Breit-Wigner function and the background shown by the dashed line. The shaded areas represent the ϕ -meson signals obtained, containing ~ 2000 ϕ -mesons at 10 GeV/c and ~ 4600 at 16 GeV/c.
- Fig. 2 Spectrum of the K^+K^- invariant mass in 16 GeV/c π^+p interaction. The solid line is the fit obtained with a Breit-Wigner function and the background represented by the dashed line. The resonance signal (see dashed area) corresponds to ~ 1500 ϕ -mesons.
- Fig. 3 Inclusive ϕ -meson production cross sections for various hadron-hadron interactions, as functions of the c.m. energy squared, s .
- Fig. 4 Distribution in transverse momentum squared of the ϕ -mesons produced in 10 and 16 GeV/c K^-p interactions and in 16 GeV/c π^+p interactions. The lines are exponential fits to the data.
- Fig. 5 Comparison of the x distributions of the ϕ -meson produced in K^-p and π^+p interactions. The results plotted for K^-p interactions at 43 GeV/c are derived from the K^-Be data in ref. [6].
- Fig. 6 Lorentz-invariant x -distributions of the ϕ -mesons produced in K^-p and π^+p interactions. The x -distribution of the $\bar{K}^{*0}(890)$ -mesons produced in the same K^-p interactions is shown for comparison (solid line).
- Fig. 7 Comparison of the p_T^2 distributions of the ϕ -mesons produced in 16 GeV/c π^+p interactions and of the ψ -mesons produced in 27 GeV/c π^-Cu interactions.

FIGURE CAPTIONS (Cont'd)

- Fig. 8 Comparison of the x distributions of the ϕ -mesons produced in 16 GeV/c π^+p interactions and of the ψ mesons produced in 150 GeV/c π^-N .
- Fig. 9 Decay angular distributions of the ϕ -mesons in the Gottfried-Jackson system, for the K^-p and the π^+p experiments. The solid lines are fits with the function $\propto(1 + \alpha \cos^2 \theta_{GJ})$.
- Fig. 10 Values of $\frac{M^3}{\Gamma} \cdot \sigma$ for $\phi(1020)$, $\psi(3100)$, $\psi'(3685)$ and $T(9500)$ in πN and pp interactions as functions of s/M^2 . Here σ is the inclusive production cross section of the resonance considered and M and Γ are its mass and its direct hadronic width. The values for $\omega(783)$ are shown for comparison, as well as some representative points for $K^*(890)$ and $\rho^0(770)$ obtained in pp interactions.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 3
 Fig. 3

Fig. 9

Fig. 10