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INCLUSIVE ϕ PRODUCTION IN K^+p INTERACTIONS AT 70 GeV/c

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ABSTRACT

We present results on inclusive ϕ meson production in K^+p interactions at 70 GeV/c in the kaon fragmentation $x > 0.2$ region. Comparison with other data on ϕ meson production in $K^\pm$ and p induced reactions provides evidence that the strange valence-quark fragmentation or recombination processes play the dominant role in the $K^\pm \rightarrow \phi$ transitions. Arguments are presented that the kaon valence strange $\bar{s}$ -quark carries a much higher momentum fraction than the u-quark. Evidence for the previously observed narrow $\phi\pi^+$ state at mass ~ 2.1 GeV is discussed.

The present experimental data strongly indicate that the longitudinal momentum spectra of low p_T particles and especially resonances in soft hadron-hadron collisions probe the constituent structure of fragmenting particles and the dynamics of their interactions. In this respect the inclusive properties of the vector mesons $K^*(890)$, $\phi(1020)$ and $\rho^0(760)$ in kaon induced reactions are of special interest providing information on the distribution of the heavy s and light u valence quark in the kaon.

The production of ϕ mesons in the reaction

$$K^+ p \rightarrow \phi + X \quad (1)$$

is of special interest. As a light member of a family of vector meson resonances with pure "hidden" quantum numbers [$\phi(s\bar{s})$, $J/\psi(c\bar{c})$, $T(b\bar{b})$] it is more copiously produced in kaon beams than in non-strange (π , p) beams, due to the presence of a strange valence-quark in the kaon. At the present energies beam fragmentation or recombination processes dominate ϕ production in Kp reactions, over other proposed such as Okuba-Zweig-Iizuka (OZI) allowed strange sea-quark fusion, OZI-forbidden non-strange valence and sea-quark annihilation or gluon fusion [1]. As a consequence, reaction (1) provides cleaner information on the fate of the $\bar{s}$ valence-quark in a soft hadron collision than e.g. the reaction

$$K^+ p \rightarrow K^{*+,0}(890) + X$$

where contributions may be present from other processes such as recombination of $\bar{s}$ and u valence-quarks (for the K^{*+}), fusion of the kaon $\bar{s}$ valence-quark with the proton valence quarks, or fragmentation or recombination of the proton valence quarks into the K^* .

In this paper we report measurements of inclusive ϕ meson production in reaction (1) at an incident K^+ momentum of 70 GeV/c. This is the highest energy at which such data for kaon induced reactions are available, apart from the $K^\pm p$ data of the ACCMOR Collaboration at 93 GeV/c [2] in the restricted Feynman-x range, $0.04 \leq x \leq 0.24$. The only other study of reaction (1) was at 32 GeV/c [3] by the Mirabelle Collaboration.

The present experiment was performed in the hydrogen bubble chamber BEBC exposed to an RF separated K^+ beam at the CERN SPS. Details of the

experiment are given in ref. [4]. The properties of the inclusive production of other vector and tensor mesons are discussed in detail in ref. [5].

The results presented come from a final sample of ~ 45 K (excluding 2-prong topologies) completely measured and reconstructed events, corresponding to a sensitivity of about 3.1 events/microbarn. This sample does not include a small fraction ($\sim 16\%$) of our available data, obtained during the first BEBC exposure, and where the measurement quality was not sufficiently good to analyse ϕ production with the required experimental resolution.

The ϕ -meson was detected in the K^+K^- invariant mass distribution obtained by assigning the $K^+(K^-)$ mass to each positive (negative) charged secondary, except for rare cases when the kaon hypothesis was excluded by ionization. A clear ϕ -meson signal is seen in the K^+K^- mass spectrum starting from $x(K^+K^-) > 0.2$ (fig. 1(a), upper histogram). The ϕ signal-to-background ratio improves significantly as $x \rightarrow 1$ (figs 1(a)-(d)).

The ϕ meson production cross sections were obtained from these spectra by fits to the function

$$d\sigma/dM = BG(1 + \beta BW) \quad (2)$$

where BW is the relativistic p-wave Breit-Wigner and BG represents the background parametrized by the usual form [3,5] $BG = \alpha_1(M - M_{\text{threshold}})^{\alpha_2} \exp(-\alpha_3 M - \alpha_4 M^2)$. However better results were obtained after the removal of the contribution of the $K^{*0}(890)$ which reflects into the " K^+K^- " mass distribution and affects strongly the background on the high-mass-side of the ϕ signal. The $K^{*0}(890)$ reflection was taken into account as follows. For each K^+K^- pair falling into a given x (or p_T) interval we reassigned the mass of the negative particle to the π^- mass, plotted the corresponding $K^+\pi^-$ effective mass distribution and fitted the $K^{*0}(890)$ contribution using the expression (2). For each particle pair with mass M , the probability that it does not belong to the $K^{*0}(890)$ can therefore be calculated. The K^+K^- effective mass distributions of the same particle pairs but taken with weights $W(M_i) = 1/(1 + \beta_K * BW_K(M_i))$ are then corrected for the $K^{*0}(890)$ reflection. The ϕ cross sections were then obtained by fitting these

weighted distributions to the expression (2). The ϕ meson mass was fixed at experimental value of 1022 MeV slightly shifted in comparison with the value of 1019.6 MeV in the PDG tables [6]. The width was fixed at the PDG value, increased by the experimental resolution which is a function of x , varying from ~ 3 MeV at $0.2 < x < 0.3$ up to ~ 9 MeV at $0.8 < x < 1.0$. The K^+K^- mass spectra corrected for the $K^{*0}(890)$ reflection are presented in fig. 1 (lower histograms) for several x intervals. It is seen that the procedure used to subtract the $K^{*0}(890)$ reflection contribution hardly affects the K^+K^- spectra in the ϕ meson mass region, but reduces significantly the background at $M(K^+K^-) > 1.05$ GeV especially for high x values. The results of the fits are shown by smooth curves. For $x > 0.2$ ($x > 0.4$) the number of ϕ 's amounts to 560 (360) above background.

The non-invariant $d\sigma/dx$ and invariant

$$f(x) = \frac{1}{*} \int_{p_{inc}}^* E \frac{d^2\sigma}{dx dp_T^2} dp_T^2$$

ϕ meson production cross sections are tabulated in table 1 and shown in fig. 2. The cross sections are corrected for unseen decay modes. Errors here and elsewhere include our estimates of systematical uncertainties. Our results in fig. 2 are compared with data of 32 GeV/c K^+p [3] and 10 and 16 GeV/c K^-p [7] from bubble chamber experiments and data from K^-Be and pBe electronics experiments at 43 GeV/c [8] and 70 GeV/c [9]. The results presented for K^-p interactions at 43 GeV/c and pp interactions at 70 GeV/c are derived from the K^-Be and pBe data in refs [8,9] by normalizing the ϕ cross sections for $x > 0.4$ to the values of $\sigma(K^-p \rightarrow \phi X) = 0.22 \pm 0.03$ mb and $\sigma(pp \rightarrow \phi X) = 3.9 \pm 0.8$ μb obtained with the assumption of an $A^{2/3}$ -dependence of cross section. We show also in fig. 2(a) the ϕ meson $d\sigma/dx$ cross sections for K^+p interactions at 93 GeV/c and K^-p interactions at 63 GeV/c, measured [2] in the intervals $0.04 \leq x \leq 0.24$ and $0.12 \leq x \leq 0.36$ respectively.

Comparison of the $f(x)$ -spectra in reaction (1) at 70 and 32 GeV/c (fig. 2(b)) reveals at most only a weak energy dependence. The values of the ϕ inclusive cross sections for $x > 0.2$ are equal to 347 ± 27 μb at 32 GeV/c and 377 ± 50 μb at 70 GeV/c; for $x > 0.4$ they amount respectively to 194 ± 17 μb and 239 ± 30 μb . Comparison of our K^+p data with K^-p data

at 43, 63 and 93 GeV/c (fig. 2(a)) again exhibits no apparent energy dependence. Even the lower energy K^-p data (10 and 16 GeV/c) are in good agreement with our results in the region $x > 0.5$. There is a significant difference between the results of 10 and 16 GeV/c experiment and other data at higher energies only in the region $0 < x < 0.5$. These results suggest that the OZI forbidden fusion of the kaon non-strange valence quark with a valence quark of the proton is small, since otherwise the ϕ cross section would be significantly larger for K^-p than for K^+p interactions. The statistical and systematic errors are however too large to estimate the relative contribution of this process.

Comparing the ϕ production in K^+p and pp interactions at the same beam momentum of 70 GeV/c (fig. 2(b)) we observe a striking excess of the ϕ production cross section in the beam fragmentation region for the kaon induced reaction. The inclusive ϕ cross section at $x > 0.4$ is almost two orders of magnitude lower for pp interactions, where the ϕ x $d\sigma/dx$ spectrum is well described [9] by the form $(1-x)^{6.0 \pm 1.7}$ suggesting that in pp reactions the dominant process for ϕ production is the OZI allowed fusion of strange sea quarks.

The above features of the data support in a consistent way the idea that the ϕ meson in reaction (1) is dominantly produced in processes involving the kaon strange valence-quark fragmentation or recombination. This explains the large ϕ production in the forward c.m. hemisphere.

In the recombination and fragmentation pictures the flatness of the ϕ meson $f(x)$ spectra is explained by the valence $\bar{s}$ and u quark mass difference, resulting in a much harder x distribution for the particle produced on the heavier and consequently higher momentum strange $\bar{s}$ quark. Several quark parton models [10-12] have tried to accommodate a strong SU(3) symmetry breaking parametrizing the valence quark distribution in the kaon by the Kuti-Weisskopf form $x F(x) \sim x^\alpha (1-x)^\beta$ with different parameters α and β for the $\bar{s}$ and u quarks. The smooth line in fig. 2(b) shows that the distribution of the kaon strange valence quark in the form $x(1-x)$, suggested in ref. [10] and fitted to our data in the $x > 0.2$ interval, describes the ϕ meson $f(x)$ spectrum. The same parametrization also successfully describes the 32 GeV/c K^+p data. A similar result was

obtained for the 43 GeV/c K^-p data, where the $d\sigma/dx$ spectrum for $x > 0.4$ was well fitted to the form $(1 - x)^n$ with $n = 0.98 \pm 0.13$ [8]. Fitting the ϕ meson $d\sigma/dx$ spectrum at 70 GeV/c for $x > 0.4$ to this form, yields the same result, $n = 0.99 \pm 0.18$.

The transverse momentum distribution ($d\sigma/dp_T^2$) for reaction (1) in the region $x > 0.2$ is given in table 1. It is described by a simple exponential $a \exp(-bp_T^2)$, with $b = 2.4 \pm 0.2(\text{GeV}/c)^{-2}$, consistent with the value found at 32 GeV/c [3].

The results presented increase the rather scarce experimental information on the inclusive production of ϕ mesons in hadron interactions. In particular, the OZI-allowed processes of strange sea-quark fusion are found to be strongly suppressed in comparison with the fragmentation or recombination processes of the strange valence-quark in the incoming kaon. The kaon strange $\bar{s}$ quark appears to carry a higher momentum fraction than the u quark in accordance with the SU(3) symmetry breaking arguments of refs [10-12].

Finally we discuss the $\phi\pi^\pm$ mass distributions, where a narrow $\phi\pi^+$ state of mass 2145 ± 10 MeV was recently reported in the 32 GeV/c K^+p experiment [13]. The $K^+K^-\pi^+$ effective mass distribution for the events with the K^+K^- effective mass within the ϕ meson mass band $1019 \leq M(K^+K^-) \leq 1025$ MeV and satisfying the cuts $x(\phi) > 0.2$ and $p_T(K^+K^-\pi^+) > 0.8$ GeV/c, similar to those used in ref. [13], is presented in fig. 3(a). In the vicinity of the claimed $\phi\pi^+$ state we observe a narrow peak at 2100 ± 20 MeV with a statistical significance of about 3 standard deviations. As in ref. [13], no corresponding peak is seen in the $\phi\pi^-$ mode (not shown). Fig. 3(b) demonstrates that the ϕ signal is indeed present in the K^+K^- mass distribution for the events with mass $2.07 \leq M(K^+K^-\pi^+) \leq 2.13$ GeV, satisfying the cuts $x(K^+K^-) > 0.2$ and $p_T(K^+K^-\pi^+) > 0.8$ GeV/c, while the ϕ is not evident in the control regions on either side of this mass region. The cross section estimate of the $\phi\pi^+$ signal with $x(\phi) > 0.2$ and corrected for Breit-Wigner tails of the ϕ and for unseen ϕ decay modes, amounts to about 20 μb , being twice higher than at 32 GeV/c K^+p experiment. Although the statistical significance of the observed $\phi\pi^+$ peak is small, it gives some confirmation of the results in ref. [13]. We note, however, that such a state has not been found in the 32 GeV/c K^-p experiment [14] nor in the photoproduction experiment with the Omega spectrometer [15].

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TABLE 1

(a) Differential cross section $d\sigma/dx$ and Lorentz invariant $f(x)$ function for reaction $K^+p \rightarrow \phi X$ at 70 GeV/c

x interval	$d\sigma/dx$ (mb)	$f(x)$ (mb)
0.2 - 0.3	0.70 ± 0.24	0.22 ± 0.05
0.3 - 0.4	0.60 ± 0.16	0.25 ± 0.05
0.4 - 0.5	0.78 ± 0.15	0.39 ± 0.07
0.5 - 0.6	0.47 ± 0.08	0.29 ± 0.05
0.6 - 0.7	0.62 ± 0.08	0.43 ± 0.10
0.7 - 0.8	0.31 ± 0.08	0.29 ± 0.05
0.8 - 0.9	0.20 ± 0.06	0.20 ± 0.06
0.9 - 1.0	0.055 ± 0.03	0.05 ± 0.03

(b) $d\sigma/dp_T^2$ for $x > 0.2$

p_T^2 interval (GeV/c) ²	$d\sigma/dp_T^2$ (mb/(GeV/c) ²)
0.0 - 0.3	0.57 ± 0.08
0.3 - 0.6	0.38 ± 0.07
0.6 - 0.9	0.22 ± 0.03
0.9 - 1.5	0.032 ± 0.009
1.5 - 2.3	0.020 ± 0.008

FIGURE CAPTIONS

- Fig. 1 K^+K^- effective mass distributions for the x-intervals indicated. Upper histogram is experimental. The lower one is obtained after subtraction of the $K^{*0}(890)$ reflection. The curves are results of the fit, showing also the background contribution.
- Fig. 2 (a) Non-invariant $d\sigma/dx$ and (b) invariant $f(x)$ distributions of the ϕ in reaction (1) at 70 GeV/c in comparison with other data [2,3,7-9]. The results plotted for K^-p interactions at 43 GeV/c are derived from the K^-Be data of ref. [8] as explained in the text. The results plotted for pp interactions at 70 GeV/c represent $x d\sigma/dx$ spectrum with superimposed $(1-x)^6$ dependence (dashed curve). They are derived from the pBe data of ref. [9] (see text). The continuous curve describes the parametrization of the ϕ meson $f(x)$ -spectrum in reaction (1) at 70 GeV/c by a function $f(x) = Ax(1-x)$.
- Fig. 3 (a) $K^+K^-\pi^+$ effective mass distribution for the events with K^+K^- mass in the ϕ meson mass region $1.019 \leq M(K^+K^-) \leq 1.025$ GeV satisfying the cuts $x(K^+K^-) > 0.2$ and $p_T(K^+K^-\pi^+) > 0.8$ GeV/c. (b) K^+K^- effective mass distribution for the events with $K^+K^-\pi^+$ mass in the region $2.07 \leq M(K^+K^-\pi^+) \leq 2.13$ GeV satisfying the cuts $x(K^+K^-) > 0.2$ and $p_T(K^+K^-\pi^+) > 0.8$ GeV/c.

Fig. 1

Fig. 2

Fig. 3