EVIDENCE FOR THE ASSOCIATED PRODUCTION
OF STRANGE PARTICLES AND ϕ MESONS

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ABSTRACT

Results are presented of an experiment studying inclusive ϕ -meson production off protons by hadrons of 93 and 63 GeV incident momentum. Evidence is found for an enhanced probability of observing additional strange particles when the final state contains a ϕ meson. This supports the assumption that central production of ϕ mesons proceeds, for a significant part, by the OZI allowed fusion of strange quarks.

1. INTRODUCTION

The validity of the Okubo-Zweig-Iizuka (OZI) rule [1-3] has been confirmed in πN and NN interactions by observing an enhanced probability for producing a ϕ meson in exclusive reaction channels with an extra K^+K^- pair [4,5]. This is in contrast to inclusive reactions, where similar evidence for the associated production of ϕ mesons and strange particles was lacking [6,7]. Enhanced strange particle production would be expected here as well, if the ϕ meson were produced by the OZI-allowed fusion of strange (sea) quarks, as illustrated in fig. 1a. From the absence of such a correlation it has been concluded that ϕ production proceeds through processes other than the OZI-allowed processes, such as those shown in figs. 1b and 1c.

The question whether the diagram of fig. 1a contributes significantly to the central production of ϕ mesons bears on the question of how the J/ψ is produced in hadronic interactions. Experiments which have searched for charmed particle production in conjunction with the J/ψ do not observe any correlation [8]. It has therefore been speculated that J/ψ production does not proceed by charmed quark fusion but is mainly due to gluon amalgamation resulting in a $C = +1$ χ state which subsequently decays into $\psi\gamma$ [9-11]. Indeed some evidence has been reported for an excess of single photons in reactions where a J/ψ is produced [12-14]. A different explanation has been given by Donnachie and Landshoff [15]. These authors argue that charmed quark fusion is the dominant mechanism in J/ψ production, but that the associated charmed particle production near threshold is suppressed due to final-state interactions.

The experiment described in this letter studies inclusive production of ϕ mesons off protons by hadron beams of 93 GeV and 63 GeV incident momentum. It shows conclusive evidence for the enhanced production of strange particles in interactions of pions where a ϕ meson is present in the final state. This suggests that in contrast to previous assumptions, the OZI-allowed fusion of strange quarks plays a non-negligible role.

Our observation is in agreement with the model of Donnachie and Landshoff, which predicts that because of the low mass of the s-quark, threshold effects in inclusive ϕ production, even in the 50-100 GeV incident momentum region, are considerably less important than in inclusive J/ψ production.

2. EXPERIMENT AND DATA

The results presented in this paper come from experiment WA3 in the West Area of the CERN Super Proton Synchrotron (SPS). Data on inclusive ϕ production off protons were obtained at 93 GeV incident momentum for hadron beams of both polarities and at 63 GeV for a negative polarity beam only.

Both the apparatus and the event trigger have been described in a previous letter [16]. The ϕ meson was identified by its K^+K^- decay mode. In the trigger, two particles were required to pass through separate elements of a Čerenkov hodoscope C_1 , without giving light. The particles were labelled K mesons if their momentum was in the interval $3.7 \text{ GeV} < p < 13 \text{ GeV}$, the limits corresponding to the π^- and respectively the K-threshold of the Čerenkov counter.

For the ϕ meson this momentum selection corresponds at 93 GeV to a range in Feynman x ($x_F = 2p_L^*/\sqrt{s}$) of $0.05 < x_F < 0.25$, and at 63 GeV of $0.12 < x_F < 0.35$. The geometric acceptance of the apparatus and the trigger conditions, moreover, restrict the transverse momentum of the ϕ meson to values of less than 1 GeV. The total number of triggers recorded, the observed number of ϕ events, and the nanobarn equivalent of one observed event are listed in table 1.

In this letter we will concentrate on the question of associated strange particle production. Our conclusions are mainly based on the 93 GeV negative beam data for which the largest statistics are available, and in particular on the 80% of events where the incident particle is identified as a pion. If not stated explicitly, results refer to this subsample.

The K^+K^- invariant mass spectrum is shown in fig. 2.

The ϕ peak is centred at $(1019.6 \pm 0.1) \text{ MeV}$. Assuming the natural width to be 4.1 MeV [7] the mass resolution is calculated to be 1.4 MeV. By using samples of K_S^0 and Λ decays in the same experiment, we estimate the systematic error in

the ϕ mass to be smaller than 0.1 MeV. The identification of the K mesons is not unique. The sample is contaminated by protons with momentum below the proton threshold of the Čerenkov counter (24 GeV) and to a lesser extent by pions due to a 1% inefficiency of this counter.

The background under the ϕ peak therefore not only consists of K^+K^- pairs but also includes all possible combinations of $K^\pm$, p, and $\bar{p}$, and some $\pi^\pm$. Data on inclusive K_S^0 , p, $\bar{p}$, and $\pi^\pm$ production at 100 GeV [18-20] have been used to estimate, by Monte Carlo generation, the contribution of K^+K^- , $p\bar{p}$, Kp ... pairs to the mass spectrum of fig. 2. The invariant mass spectrum below the ϕ peak, as well as the observed momentum spectrum of the triggering particles, is well reproduced by the Monte Carlo data.

The contribution of K^+K^- pairs to the background is about 40%, $p\bar{p}$ pairs account for another 25%, the remainder consists of K^-p , K^+p and to a small degree, $K^\pm\pi^\mp$ and $p^\pm\pi^\pm$ combinations. These contributions are indicated in fig. 2.

Additional neutral strange particles are identified by their decay ($K_S^0 \rightarrow \pi^+\pi^-$; $\Lambda \rightarrow p\pi^-$; $\bar{\Lambda} \rightarrow \bar{p}\pi^+$), additional charged K mesons by the absence of signals in one of the two Čerenkov hodoscopes $\check{C}_1$ and $\check{C}_2$ used for particle identification. In fig. 3 the $\pi^+\pi^-$, $p\pi^-$, and $\bar{p}\pi^+$ invariant mass distributions are shown for pairs of particles originating from a secondary vertex and with a resulting momentum vector pointing to the primary vertex. The particles are assigned to a K_S^0 decay if the $\pi^+\pi^-$ invariant mass is in the range $0.48 < M_{\pi^+\pi^-} < 0.52$ GeV, to a Λ or $\bar{\Lambda}$ decay if the $p\pi^\mp$ invariant mass is in the range $1.113 < M_{p\pi} < 1.118$ GeV.

The K thresholds of the two Čerenkovs are 13 and 43 GeV, respectively. Particles are labelled "SLOW K" if they give no signal in $\check{C}_1$ and have a momentum in the range $3.7 < p < 13$ GeV. They are labelled "FAST K" if the momentum is in the range $13 < p < 42$ GeV while no signal is observed in $\check{C}_2$.

These charged K samples have background contributions from p, $\bar{p}$, and some misidentified $\pi^\pm$ (inefficiencies and secondary interactions).

3. RESULTS

In figs. 4 we show as a function of K^+K^- invariant mass the fraction of events with an additional K_S^0 , "SLOW K", "FAST K", Λ , and $\bar{\Lambda}$. In all plots except that for the $\bar{\Lambda}$, where statistics are poor, there is a definite increase of the strange particle rate when passing the ϕ -meson mass. The observed K_S^0 rate for the non- ϕ events averages $(3.7 \pm 0.2)\%$. This is in agreement with the value $(3.6 \pm 0.5)\%$ calculated from the inclusive K_S^0 data of ref. [19] under the assumption of uncorrelated production, folding in the geometric acceptance of our apparatus. Also the expected x_F distribution for K_S^0 is in good agreement with that observed (fig. 5). This indicates that outside the ϕ there is an unbiased sample of inclusive K_S^0 , and that the observed increase is indeed associated with the production of the ϕ meson. This conclusion is assumed also to apply to the observed increase in the "SLOW K", "FAST K", and Λ rates.

The observed excess of the K_S^0 , "SLOW K", and "FAST K" rate in the ϕ -mass band amounts to $(1.6 \pm 0.35)\%$; $(2.8 \pm 0.6)\%$; and $(2.2 \pm 0.7)\%$, respectively. The actual excess rates are much larger, since one has to account for:

- i) background under the ϕ -meson peak (a factor of 2);
- ii) unobserved decay modes (a factor of 3 for K_S^0); and
- iii) acceptance (30% for K_S^0 ; 12% for "SLOW K"; 12% for "FAST K").

For the acceptance calculations, the measured x_F distributions for inclusive K_S^0 production was used [19]. It was further assumed that the x_F distribution for $K^\pm$ is similar to that of K_S^0 . With the above correction factors taken into account, we find that an extra K^0 is present in $(32 \pm 9)\%$ of the inclusive ϕ events. For the charged K mesons this fraction, again integrated over their full x_F range, can be independently determined from the "SLOW K" and "FAST K" samples. We obtain values of $(47 \pm 16)\%$ and $(37 \pm 16)\%$, respectively, and assume that the average $(42 \pm 12)\%$ is the fraction of inclusive ϕ events with an extra charged K.

Accordingly the total excess of strange particles which in our experiment can be associated with the inclusive production of a ϕ meson, amounts to $(74 \pm 15)\%$ of the observed number of ϕ events, neglecting contributions of Λ and Σ for which no reliable estimates can be made.

The above results are confirmed by the π^- data at 63 GeV although with less statistical significance. The observed increase amounts to $(1.6 \pm 0.5)\%$; $(2.4 \pm 0.9)\%$, and $(3.1 \pm 0.9)\%$ for the K_S^0 , "SLOW K", and "FAST K" samples, respectively, in excellent agreement with the 93 GeV data. For the 93 GeV proton data the effect is less clear, possibly apart from the result on associated Λ production (shown in fig. 3). The statistical significance of these data, however, is rather poor. For the incident K^- data, none of the distributions shows any increase of strange particle production at the ϕ mass.

4. CONCLUSIONS

Our results fit well in the framework of the quark fusion model. The diagram of fig. 1a would predict that in the absence of final-state interactions [15], two extra strange particles are produced for each inclusive ϕ event. Our measured excess rate of $(74 \pm 15)\%$ suggests that at least of the order of 40% of the inclusive ϕ production proceeds by such an OZI-allowed process.

The absence of such an excess for the incident K^- data can be explained by the presence of a valence s-quark in the incident K^- . Actually a decrease in the ϕ production rate would be expected for events where a strange particle with large x_F is present. Unfortunately our statistics are insufficient to confirm this. The charge ratio of the extra K mesons produced in inclusive ϕ interactions could reveal how the s-quark recombines when materializing into a meson. If at the upper vertex of fig. 1a it recombines with the valence quarks of the incident π^- , the excess of fast charged K mesons is expected to be mainly K^- . The observed excess rates for K^- and K^+ are $(1.3 \pm 0.5)\%$ and $(0.9 \pm 0.5)\%$, respectively, and do not indicate such a mechanism.

The ratio of K^0 's over charged K's should be one, irrespective of whether the s-quark recombines with a valence quark or a sea quark. The measured rates for K^0 and $K^\pm$ are indeed in rough agreement.

We conclude that our data strongly support the assumption that central production of ϕ mesons proceeds for a significant part by the OZI-allowed fusion of strange quarks. In π^-p interactions we observe a significant increase in the

strange-particle production rate for inclusive ϕ events. This observation is made both at 93 GeV and 63 GeV incident momentum and is of comparable magnitude. This result is in sharp contrast to measurements on inclusive J/ψ production, where no indication is found for enhanced charm production. This difference could be explained by a model in which final-state interactions are responsible for the suppression of associated charmed particles. Since the threshold for the associated production of ϕ mesons and strange particles is so much lower, this suppression would here be considerably less significant.

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Table 1

Beam	Total number of triggers	Incident particle	Number of ϕ mesons	nb equivalent
-93 GeV	800,000	π	5558	3.6 ± 0.3
		K	1403	23.8 ± 1.9
		$\bar{p}$	169	114.9 ± 9.2
-63 GeV	250,000	π	1925	11.5 ± 0.6
		K	692	82.0 ± 4.7
		$\bar{p}$	80	217 ± 14
+93 GeV	300,000	π	438	41.5 ± 3.2
		K	285	114.9 ± 9.2
		p	1272	18.2 ± 1.5

Figure captions

- Fig. 1 : Parton diagrams for ϕ -meson production:
- a) OZI-allowed strange quark fusion;
 - b) OZI-inhibited light quark fusion;
 - c) gluon fusion.
- Fig. 2 : Observed K^+K^- mass spectrum in 93 GeV π^-p interactions. Indicated is the calculated background due to random K^+K^- pairs and to misidentified p, $\bar{p}$, and $\pi^\pm$. The contributions of K^+K^- ($--$), $p\bar{p}$ ($---$), $K^+\bar{p}$ ($\cdots$), and K^-p ($---$) are respectively 40, 25, 15, and 15%. The inset shows the spectrum around 1.02 GeV with, superimposed, the results of a fit with a Breit-Wigner and a polynomial background.
- Fig. 3 : $\pi^+\pi^-$, $p\pi^-$, and $\bar{p}\pi^+$ invariant mass distributions for pairs of particles originating from a secondary vertex.
- Fig. 4 : Fraction of events with a) an extra K_S^0 ; b) a charged K with $3.7 < p_K < 13$ GeV; c) a charged K with $13 < p_K < 24.5$ GeV; d) a Λ ; and e) a $\bar{\Lambda}$ in π^-p interactions at 93 GeV; similarly for Λ 's in pp interactions at 93 GeV (f).
- Fig. 5 : Observed x_F distribution for K_S^0 . Superimposed is the distribution obtained from the x_F distribution measured by Biswas et al. [19] for K_S^0 by folding in the acceptance of our apparatus.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5