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Test of the Zweig Selection Rule in Φ Production by pp Collisions[$]

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Abstract

Φ production is studied in pp collisions at 24 GeV/c and compared with ρ^o, ω and K^* production. The relative suppression of the Φ is in qualitative accord with its coupling to nonstrange states. No tendency is observed for the final states to contain strange particles in conjunction with the Φ.

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According to the quark model with ideal mixing the Φ meson is a state $s\bar{s}$ of strange quarks. It is therefore interesting to investigate its mechanism of production by collisions of non-strange hadrons, in particular as there may be a close analogy with production of J's or Ψ's from non-charmed hadrons[1,2]. Of central importance here is Zweig's selection rule[3] which states that the two quarks in a meson do not annihilate; instead production and decay take place by connected quark diagrams. It is therefore suggested that Φ production in proton proton collisions should be accompanied by additional strange particles (possibly coming from decays of another Φ or a f') in the final state:

$$pp \rightarrow \Phi + \text{strange particles} + \ldots \qquad (1)$$

We have searched for this manifestation of Zweig's rule in pp interactions at 24 GeV/c ($\sqrt{s}$ = 6.84 GeV).

The experiment was done with the 2m hydrogen bubble chamber at CERN. A total of 3×10^5 events was measured, including the decay vertices of all detected strange particle decays. Experimental details are given elsewhere[4]. Results on the production of ρ^o, ω and $K^{*\pm}$ in this experiment have been published previously[5].

Inclusive Φ production

For the determination of the cross section σ_Φ of the inclusive reaction

$$pp \rightarrow \Phi + \text{anything} \qquad (2)$$

we used the decay mode $\Phi \rightarrow K^+K^-$. The possibility to identify both K's by their decays in the chamber is, however, too small for a useful cross section determination, and identification by ionization is too unreliable. We therefore took all events with (at least) one charged K identified by its decay*, and formed neutral particle pairs combining this K with all possible candidates for an oppositely charged kaon in the event. Of course, the second particle is in most cases not identified and will very often be a pion. The Φ however, due to its small width and with our mass resolution of ±10 MeV, is seen clearly in Fig. 1a above the background in the distribution of effective masses $M_{K^+K^-}$, where the kaon mass was assigned to the unidentified particle. If we plot the same events with the

* Tracks with $K\Sigma$ ambiguities and/or decay lengths <1 cm were omitted. It was checked that this caused only a negligible loss of true kaons.

unidentified particle assigned a pion mass instead of the kaon mass, the peak disappears (Fig. 1c); this demonstrates that the peak is due to K^+K^- pairs.* On the other hand, in this $K^\pm\pi^\mp$ distribution some hint of K^{*o} and $\bar{K}^{*o}$ production is seen. Background from $S^*(990) \to K^+K^-$ decays is negligible; this was ascertained from the inclusive $K_S^oK_S^o$ mass distribution (with both K_S^o detected) in which the $S^*(990)$ would have been seen if produced at a significant level.

To estimate the size of the Φ signal, a sum of Φ and K^* production and a smooth background in the $K^\pm\pi^\mp$ distribution was fitted simultaneoulsy to the K^+K^- and the $K^\pm\pi^\mp$ distributions (see curves in Fig. 1a and c). Corrections were applied for the detection efficiency of the kaon decay and for the branching fraction of $\Phi \to K^+K^-$. We obtain a cross section for reaction (2) of

$$\sigma_\Phi = (158 \pm 35)\mu b.$$

This is about 20 times smaller than the cross section for inclusive ρ^o production measured in the same experiment[5] (see table I).

There is no indication in our data that Φ's might be predominantly produced at large transverse momenta; in fact all our Φ signal is in $p_\perp < 1$ GeV/c.

Strange particles in conjunction with Φ's

We next consider the average number $<n_s>$ of further visible strange particle decays (i.e. in "anything") per event, as a function of $M_{K^+K^-}$ of the pair (Fig. 1b). As one member of the pair is always identified as a kaon, the events must due to strangeness conservation contain at least one more strange particle; for the non-Φ background it will often be among the particles in "anything". Consequently, outside the Φ mass region $<n_s>$ is not small, between 0.1 and 0.2 per event. If the Φ was always produced associated with an additional pair of strange particles, $<n_s>$ for the Φ events would have to be roughly twice as large as for the background. However, no enhancement of $<n_s>$ in the Φ mass region is seen (Fig. 1b); on the contrary $<n_s>$ seems to decrease in this region, suggesting that there is no enhancement in strange particle production in events with a Φ.

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* It was checked that after background subtraction the peak contains equal numbers of K^+ and K^- (while for the total event sample more K^+ than K^- were detected).

For a quantitative evaluation we have to consider the background under the Φ. We assume that the value of $<n_s>$ for these background events is the same as for the events in the neighboring mass region (1040 MeV$<M_{K\bar{K}}<$1180 MeV); we call it $<n_{s\pm}>$, taking into account also the different detection efficiences for the additional strange particles produced in association with the (detected) positive or negative kaon. Let $N_\pm$ be the total number of events, and $\alpha_\pm$ the fractions of true Φ events (as determined by the fit), in the Φ mass region (1000 MeV $< M_{K\bar{K}} <$ 1040 MeV); the index $\pm$ always refers to events with a $K^\pm$ identified. One then predicts for the Φ mass region (including background)

$$<n_s> = \begin{cases} \left(\frac{N_+}{N_+ + N_-}\right)[<n_{s+}> + \alpha_+ <n_{s-}>] + \left(\frac{N_-}{N_+ + N_-}\right)[<n_{s-}> + \alpha_- <n_{s+}>] & \left(\begin{matrix}\text{with strange}\\ \text{particles}\\ \text{conjoint}\\ \text{to } \Phi\text{'s}\end{matrix}\right) \\ \left(\frac{N_+}{N_+ + N_-}\right) <n_{s+}> [1 - \alpha_+] + \left(\frac{N_-}{N_+ + N_-}\right) <n_{s-}> [1 - \alpha_-] & \left(\begin{matrix}\text{no conjoint}\\ \text{strange par-}\\ \text{ticles in}\\ \text{the } \Phi \text{ events}\end{matrix}\right) \end{cases}$$

$$= \begin{cases} 0.24 \pm 0.02 & \text{(conjoint)} \\ 0.12 \pm 0.02 & \text{(non-conjoint)} \end{cases}$$

The experimental number

$$<n_s> = 0.11 \pm 0.02$$

is in agreement with no strange particles conjoint with Φ production, and disagrees with conjoint production (reaction (1)) by 4 standard deviations. It also disagrees with $\Phi\Phi$ pair production.

Exclusive channels

We now discuss Φ production in specific (exclusive) kinematically fitted channels. Here we rely on the decay mode $\Phi \rightarrow K^0_S K^0_L$ where the K^0_S decay is seen with finite probability while the K^0_L usually escapes undetected. We thus look for Φ's in the $K^0_S K^0$ mass distribution of the kinematically 1-constraint channels

$$pp \rightarrow pp\ m(\pi^+\pi^-)\ K^0_S K^0, \qquad m = 0, 1, \ldots$$

Background from $S^*(990) \rightarrow K^0_S K^0_S$ is again found to be negligible, as ascertained from the same reaction with both K^0's decaying in the chamber (i.e., the second K^0 then also being a K^0_S). After corrections for detection efficiency and the Φ branching ratio, we obtain the Φ cross sections (background in the Φ mass region is negligible) listed in Table I and compared there with the corresponding ones for ρ^0 and ω production in the same experiment[5]. The Φ production reactions

$$pp \rightarrow pp\ m(\pi^+\pi^-)\,\Phi\ , \qquad m = 0,\ 1,\ \ldots \tag{3}$$

are seen to be suppressed relatively to the analogous reactions with ρ^0 or ω by roughly a factor of 50. A suppression of Φ relative to ω by similar factors has also been observed[6] in the reaction

$$\pi^- p \rightarrow \Phi n. \tag{4}$$

Table I. Cross sections in μb for $pp \rightarrow pp\ m(\pi^+\pi^-)V^0$ at 24 GeV/c ($\sqrt{s}$ = 6.48 GeV) ($V^0 = \rho^0,\ \omega,\ \Phi$)

final state \ V^0	ρ^0	ω	Φ
ppV^0	125 ± 19	83 ± 10	2.2 ± 1.3
$pp\pi^+\pi^-V^0$	170 ± 30	200 ± 40	2.3 ± 1.3
$pp\pi^+\pi^+\pi^-\pi^-V^0$, $pp3\pi^+3\pi^-V^0$	60 ± 20	72 ± 25	2.1 ± 1.5
total $pp\ m(\pi^+\pi^-)V^0$	355 ± 40	355 ± 50	6.6 ± 2.4
total inclusive σ_{V^0}	3490 ± 420		158 ± 35

Discussion

Assuming the validity of Zweig's rule, reactions (3) and (4) can proceed through the admixture of nonstrange $q\bar{q}$ in the Φ. A mixing angle $\Theta_{\omega\Phi} = 39^0$ (as obtained from the quadratic mass formula) gives ≃10 % nonstrange $q\bar{q}$ in the Φ state, in accord with the ratio $g_{\Phi\rho\pi}/g_{\omega\rho\pi} \simeq \frac{1}{15}$ obtained from Φ decay. Thus, Φ production rates of the order of a few $\frac{1}{100}$ of the ω or ρ^0 rates are indeed expected in these exclusive "forbidden" reactions.

The result that also the inclusive Φ rate (reaction (2)), to which the large $s\bar{s}$ component of the Φ can contribute, is suppressed by a similar factor may not be so trivial. From this fact we could already have anticipated that production of associated strange particles (reaction (1)) cannot prevail in Φ production. We do not know why the associated process (1), allowed by Zweig's rule and strongly favored by mixing, is so small at $\sqrt{s}$ = 6.84 GeV. Let us note, however, that its smallness is consistent with the inclusive production rates for other vector mesons. From SU(3) with ideal mixing, assuming factorization of the couplings we predict

$$(\sigma_{\rho^0} + \sigma_{\omega})\sigma_{\Phi} = \sigma_{K^{*+}}\sigma_{K^{*-}} + \sigma_{K^{*0}}\sigma_{\bar{K}^{*0}} \quad . \qquad (5)$$

The same relation is suggested assuming f (f') dominated pomeron couplings[7] and connected reggeon couplings in the dual Mueller-Regge 6-point amplitudes, assuming Zweig's rule and ideal mixing. Corrections due to mass differences are expected to be small.* Taking[5] $\sigma_{\omega} = \sigma_{\rho^0}$ and our published values for $\sigma_{K^{*\pm}}$, and estimating $\sigma_{K^{*0}}\sigma_{\bar{K}^{*0}}$ from the fit to the $M^2_{K^\pm\pi}$ distribution described above (Fig. 1c), we predict for pp at $\sqrt{s}$ = 6.84 GeV

$$\sigma_{\Phi} = (18 \pm 4)\mu b, \qquad \text{(Zweig rule + ideal mixing)}$$

a negligible fraction of our total measured σ_{Φ}.

Conclusion

We find no indication for Zweig's selection rule to be operative in Φ production by pp collisions at $\sqrt{s}$ = 6.84 GeV. At this energy** production through the nonstrange component of the Φ is found to dominate strongly over production via the strange component. Our results, scaled to larger meson masses and larger s, may bear on J or ψ production in hadronic reactions if these particles are $c\bar{c}$ states[8].

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* Eq.(5) should really be used at fixed values of the transverse mass. It then follows that it also holds approximately for the integrated total inclusive cross sections, since the corrections to both sides of the equation are similar.

** Note that also at FNAL energies the inclusive Φ rates are still strongly suppressed relative to the ρ^0 or π.[2,9] Searches for Φ production at the CERN-ISR were, so far, unsuccessful.[10]

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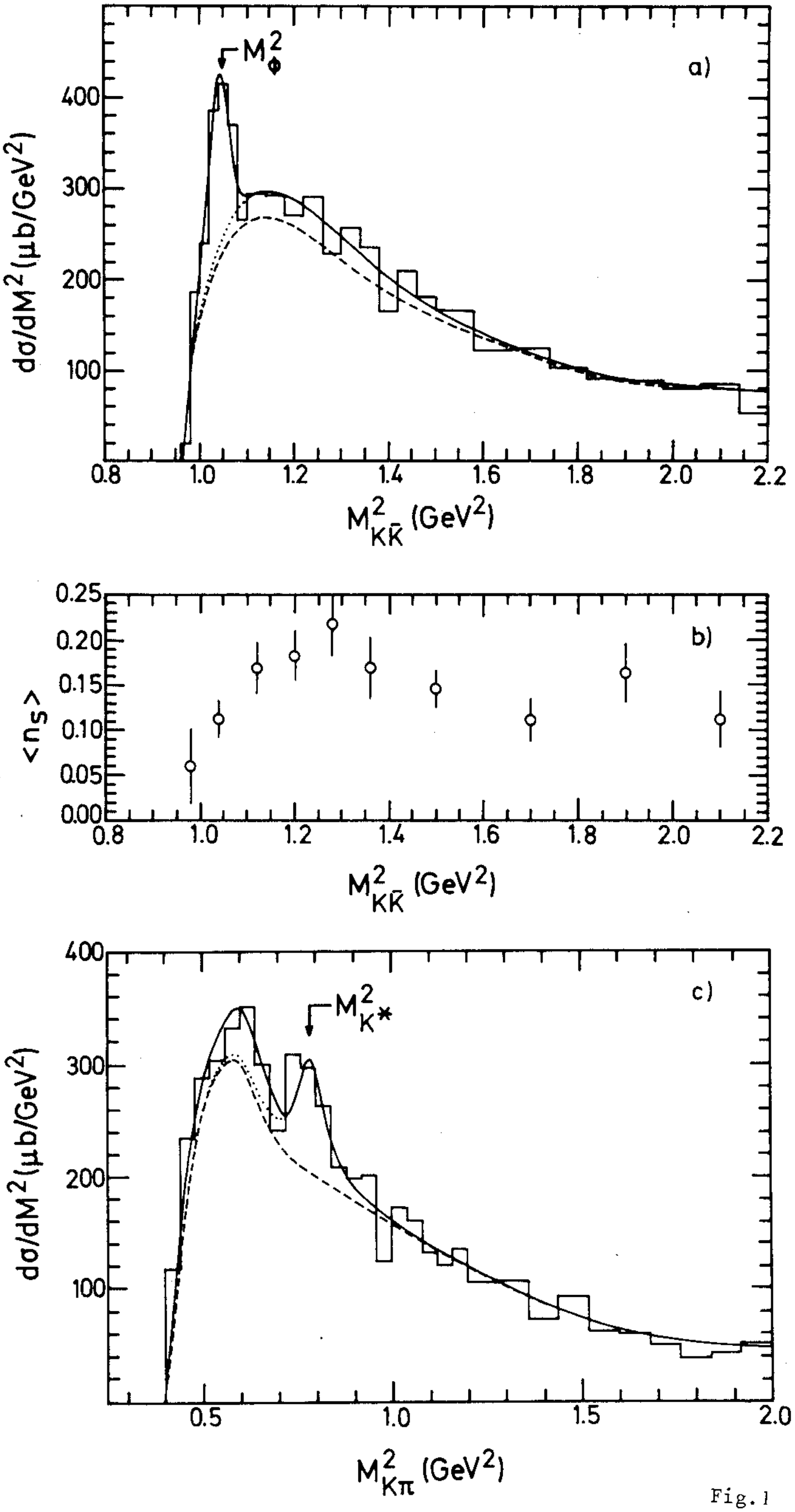
Figure Caption

1(a) Distribution of the square of the effective mass $M_{K\bar{K}}$ of $K^{\pm}h^{\mp}$ systems where the $K^{\pm}$ is identified by its decay, and $h^{\mp}$ is an unidentified hadron whose momentum is measured and whose mass was assumed to be a kaon mass. The histogram contains a total of 1898 entries; the ordinate gives the directly measured cross section, not yet corrected for decays outside the chamber. -

(b) Average number of strange particle decays detected per event (not including the $K^{\pm}h^{\mp}$ pair). -

(c) Same events as (a) but $h^{\mp}$ assumed to have a pion mass. -

The curves are from a fit described in the text: full curve = total (i.e. Φ plus K^{*} plus background), dotted = K^{*} plus background, dashed = background.



a)
M_ϕ^2
400
300
200
100
$d\sigma/dM^2$ (μb/GeV^2)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
$M^2_{K\bar{K}}$ (GeV^2)
b)
0.25
0.20
0.15
0.10
0.05
0.00
$\langle n_S \rangle$
$M^2_{K\bar{K}}$ (GeV^2)
c)
$M^2_{K^*}$
0.5
1.0
1.5
2.0
$M^2_{K\pi}$ (GeV^2)

Fig. 1