CERN – EUROPEAN ORGANIZATION FOR NUCLEAR PHYSICS

TEST OF THE ZWEIG RULE IN π⁻p INTERACTIONS

AT 19 GeV/c

The Omega Groups

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ABSTRACT

We have observed ϕ production in $\pi^- p$ interactions at 19 GeV/c with (44 ± 10) events in the final state $\phi \pi^+ \pi^- \pi^- p$ and (45 ± 9) events in $\phi K^+ K^- \pi^- p$. The production ratios $\dfrac{\phi \pi^+ \pi^- \pi^- p}{\omega \pi^+ \pi^- \pi^- p} \simeq 0.005$ and $\dfrac{\phi K^- K^- \pi^- p}{\rho^0 K^+ K^- \pi^- p} \simeq 0.45$ agree with Zweig-rule expectations.

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Recently there has been renewed interest in testing the Zweig rule[1]. In particular, several authors[2] have suggested using the ψ as a signature in charmed particle searches.

The Zweig rule can be investigated more readily in the analogous situation of ϕ production by pions or nucleons. In the absence of strange particles, production of an ideal ϕ (strange quarks only) is Zweig-forbidden. If the ϕ is produced only through ω-ϕ mixing, it is suppressed relative to the ω by a factor $\tan^2 \theta_m \simeq 1/100$ ($\theta_m \simeq 5^o$ measures the departure from ideal ω-ϕ mixing[3]). When extra strange particles are present, connected quark diagrams are possible and ϕ production is Zweig-allowed. Then ϕ production should be comparable to ω or ρ^o production[4].

Experimentally, ϕ production in the Zweig-suppressed reactions is well-established at about the level expected from ω-ϕ mixing, but there is little data concerning Zweig-allowed processes where the ϕ is produced with associated strange particles. In $\bar{p}p$ annihilations at 3.6 GeV/c[5] enhanced ϕ production was found in channels with extra K's, but no such evidence was found in pp interactions at 24 GeV/c[6].

In the present experiment we have observed ϕ production in the six-prong reactions

$$\pi^- p \rightarrow K^+ K^- \pi^+ \pi^- \pi^- p \qquad (1)$$

and

$$\pi^- p \rightarrow K^+ K^- K^+ K^- \pi^- p \qquad (2)$$

at 19 GeV/c, with $\phi \rightarrow K^+ K^-$. We found about 45 ϕ's in each of these reactions, representing a small fraction ($\sim$ 2%) of reaction (1) and a large fraction ($\sim$ 60%) of a much smaller yield for reaction (2).

The experiment was performed at the CERN Omega spectrometer. The large gap 1.8 T magnet was filled with optical spark chambers arranged about a 60 cm liquid hydrogen target. Spark images were digitized by a television camera read-out. The trigger required a forward K^+ (or proton) with momentum between 3 and 10 GeV/c identified in a large Cerenkov counter. A multiwire

proportional chamber 80 cm downstream of the target required at least four forward tracks. The unseparated beam contains less than 1% K^-, and we have verified that this contamination does not affect the results presented here. The experimental conditions have been described in more detail in a previous publication[7].

Six-prong events with small missing momentum (missing P_T < 150 MeV/c and missing P_L < 500 MeV/c) were candidates for reactions (1) and (2). Events with any track shorter than 25 cm or a momentum below 300 MeV/c were removed. The program efficiency for reconstructing these events was about 40%. This sample contained 6993 events.

For each event test functions (Δ) were calculated for all possible mass assignments. The test function is equal to the difference between the effective mass of the five-meson system (M_5) and the recoil mass (M_R) from the track taken to be the proton, $\Delta = M_5 - M_R$. This function should be zero for the correct mass assignment when there are no missing neutrals.

For reaction (1), we find a strong signal at test function Δ = 0 of 2700 ± 300 events. The fitted K^+K^- mass spectrum for this channel contains a ϕ signal of 44 ± 10 events above background (fig. 1). The ϕ thus represents (1.6 ± 0.4)% of the channel. Only forward-produced ϕ's (Feynman variable x_ϕ > 0.3) are observed in this reaction, because the trigger K^+ must come from the ϕ.

For reaction (2), we find no significant signal at Δ = 0 when all combinations are plotted. However, the background is greatly reduced when the proton is taken to be the slowest positive track and events consistent with the reaction $\pi^- p \to p \bar{p} \pi^+ \pi^- \pi^- p$ are removed. These cuts reveal a signal at Δ = 0 containing 75 ± 25 events (fig. 2a). A cleaner signal is obtained when hypotheses with a K^+K^- mass combination in the ϕ region are chosen (fig. 2b). The cuts eliminate about 15% of the good events, independent of the K^+K^- mass.

Fig. 3 shows the fitted K^+K^- mass spectrum from reaction (2) for events passing the above cuts. A clear signal at the ϕ mass contains 45 ± 9 events above background (we have verified that these events are not ambiguous with the ϕ events of reaction (1)). Thus ϕ production accounts for $(60^{+40}_{-20})\%$ of the events of reaction (2).

The ϕ's from reaction (2) have a broad distribution in x because the trigger K^+ need not come from the ϕ. In fact, only 22 ± 6 of the triggers come from the ϕ; these ϕ's are forward ($x_\phi > 0.3$). The triggers of the remaining 23 ± 7 events come from the K^+ which is not in the ϕ; here the ϕ's are slower ($-.5 < x_\phi < .5$).

To test whether ϕ production without extra K's can be explained by ω-ϕ mixing alone, we have compared the production of ϕ in reaction (1) with ω production in the reaction $\pi^- p \rightarrow \omega \pi^+ \pi^- \pi^- p$. The acceptance for the ϕ reaction has been estimated, using a variety of production models, to be $(7 \pm 3)\%$. This leads to a cross section, corrected for the $\phi \rightarrow K^+K^-$ branching ratio, of $0.7^{+0.7}_{-0.3}$ µb. The ω cross section has been measured to be 130 ± 18 µb at 16 GeV/c[8]. Therefore,

$$\frac{\phi \pi^+ \pi^- \pi^- p}{\omega \pi^+ \pi^- \pi^- p} \approx \frac{0.7 \text{ µb}}{130 \text{ µb}} = 0.005^{+0.005}_{-0.002} \text{ .}$$

We conclude that ϕ production is suppressed in this channel to the extent expected from the known ω-ϕ mixing.

We can now compare ϕ production in reaction (2) with ρ^0 production in reaction (1). Both reactions are Zweig-allowed, and both require the production of an extra pair of K mesons. For the ρ^0 in reaction (1) we find a signal of 120 ± 40 events, with the ρ's produced in the central region ($-0.5 < x_{\rho^0} < 0.5$). Forward produced ρ^0's would not satisfy our trigger conditions. The trigger K^+ cannot come from the ρ^0 so we compare these events with the ϕ events where the trigger does not come from the ϕ. We find

$$\frac{\phi K^+ K^- \pi^- p}{\rho^0 K^+ K^- \pi^- p} = \frac{2.3 \times (23 \pm 7)}{120 \pm 40} = 0.45^{+0.25}_{-0.15} \text{ ,}$$

(the factor 2.3 on the numerator contains corrections for the $\phi \rightarrow K^+K^-$ branching ratio and for the effect of the cuts imposed on this channel). We conclude that ϕ production with extra K's behaves like a Zweig-allowed process, with a cross section comparable to ρ^0 production in a similar allowed process.

Our results from reactions (1) and (2) are in agreement with Zweig-rule predictions. However, this does not mean that ϕ's are produced mainly with other strange particles at our energy. In fact, when we compare ϕ production in reactions (1) and (2) for forward produced ϕ's which satisfy the trigger conditions ($x_\phi > 0.3$), we find

$$\frac{\phi \pi^+ \pi^- \pi^- p}{\phi K^+ K^- \pi^- p} = \frac{44 \pm 10}{1.15 \times (22 \pm 6)} = 1.7 {}^{+\ 0.9}_{-\ 0.5} \ .$$

Thus, the production of the Zweig-suppressed final state is comparable to that of the Zweig-allowed one. This fact can be understood as a consequence of the difficulty of producing extra K's at our moderate energy, and not as a violation of the Zweig-rule[2,4].

We conclude that Zweig rule expectations are satisfied because:

- $\phi \pi^+ \pi^- \pi^- p$ is suppressed relative to $\omega \pi^+ \pi^- \pi^- p$ by a factor ~ 0.005 as expected from ω-ϕ mixing.

- $\phi K^+ K^- \pi^- p$ is comparable to $\rho^0 K^+ K^- \pi^- p$ as expected for similar Zweig-allowed processes.

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FIGURE CAPTIONS

Fig. 1 K^+K^- effective mass from $\pi^-p \to K^+K^-\pi^+\pi^-\pi^-p$.

Fig. 2   Test functions (Δ) for the reaction $\pi^-p \to K^+K^-K^+K^-\pi^-p$; (a) with the proton taken to be the slowest positive track, and events consistent with the reaction $\pi^-p \to p\bar{p}\pi^+\pi^-\pi^-p$ removed; (b) when, in addition, the combination contains a K^+K^- effective mass in the range $1.01 < M_{K^+K^-} < 1.03$ GeV.

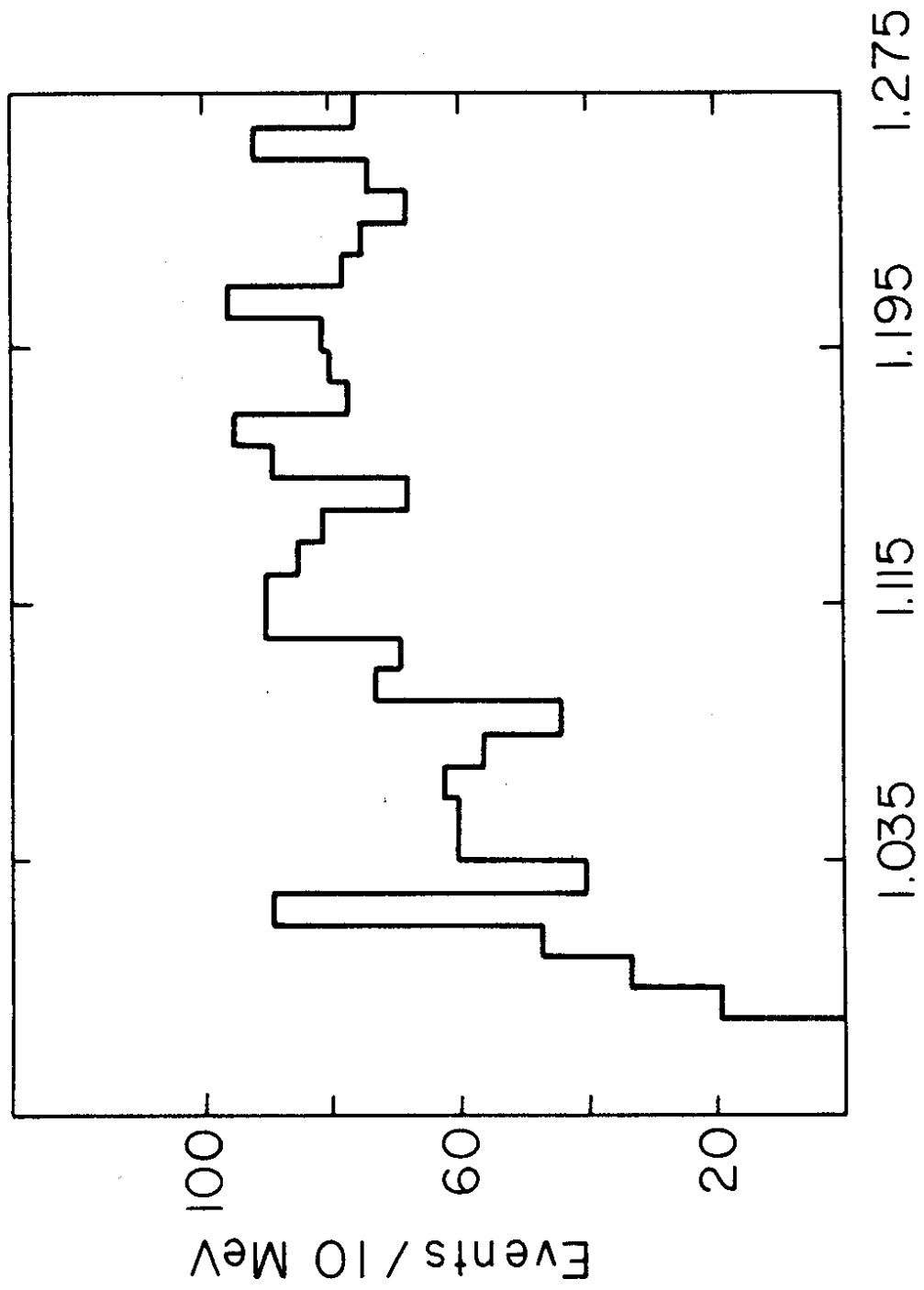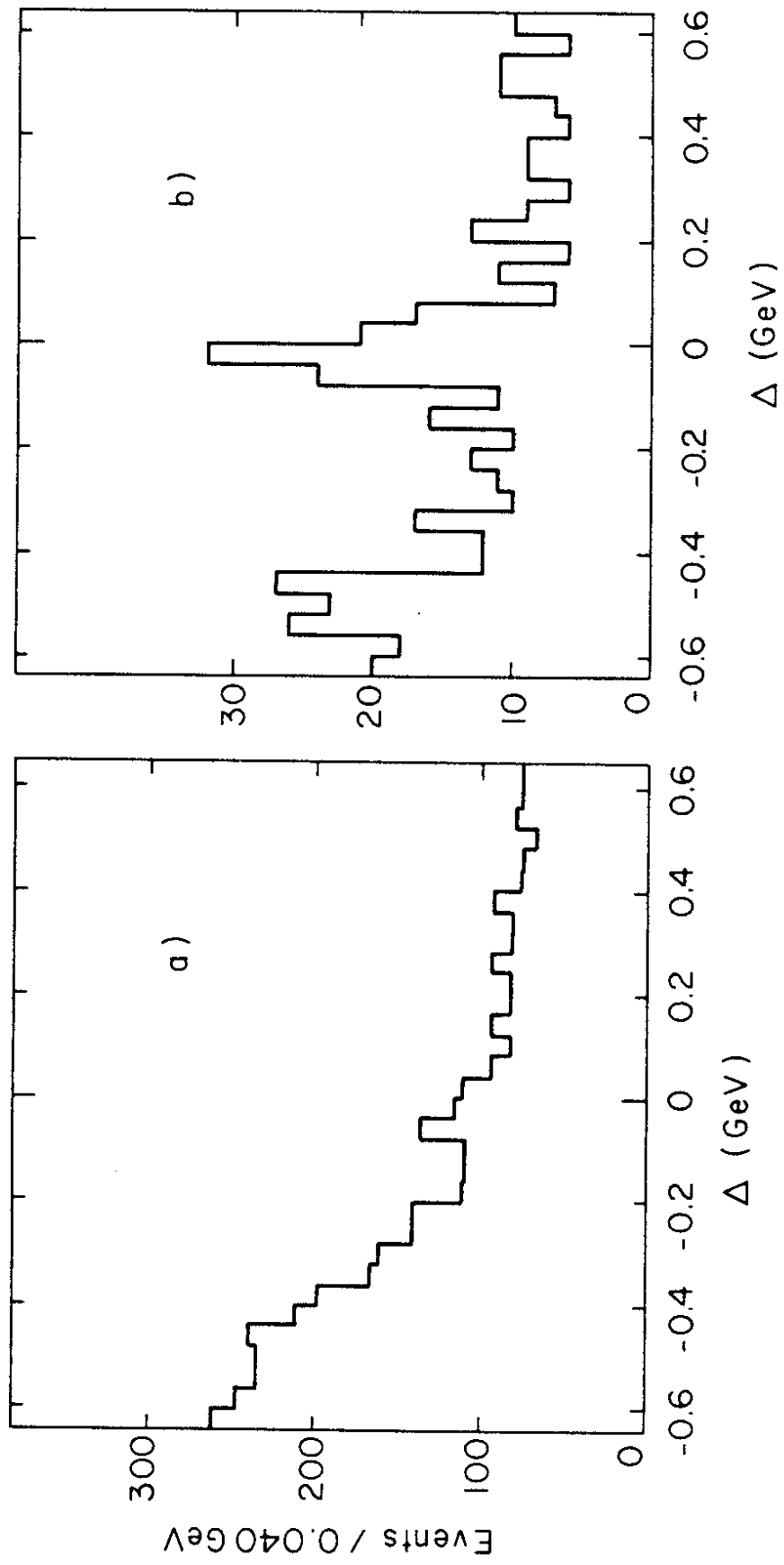Fig. 3 K^+K^- effective mass from $\pi^-p \to K^+K^-K^+K^-\pi^-p$ (4 combinations/event).

Fig. 1

Fig. 2

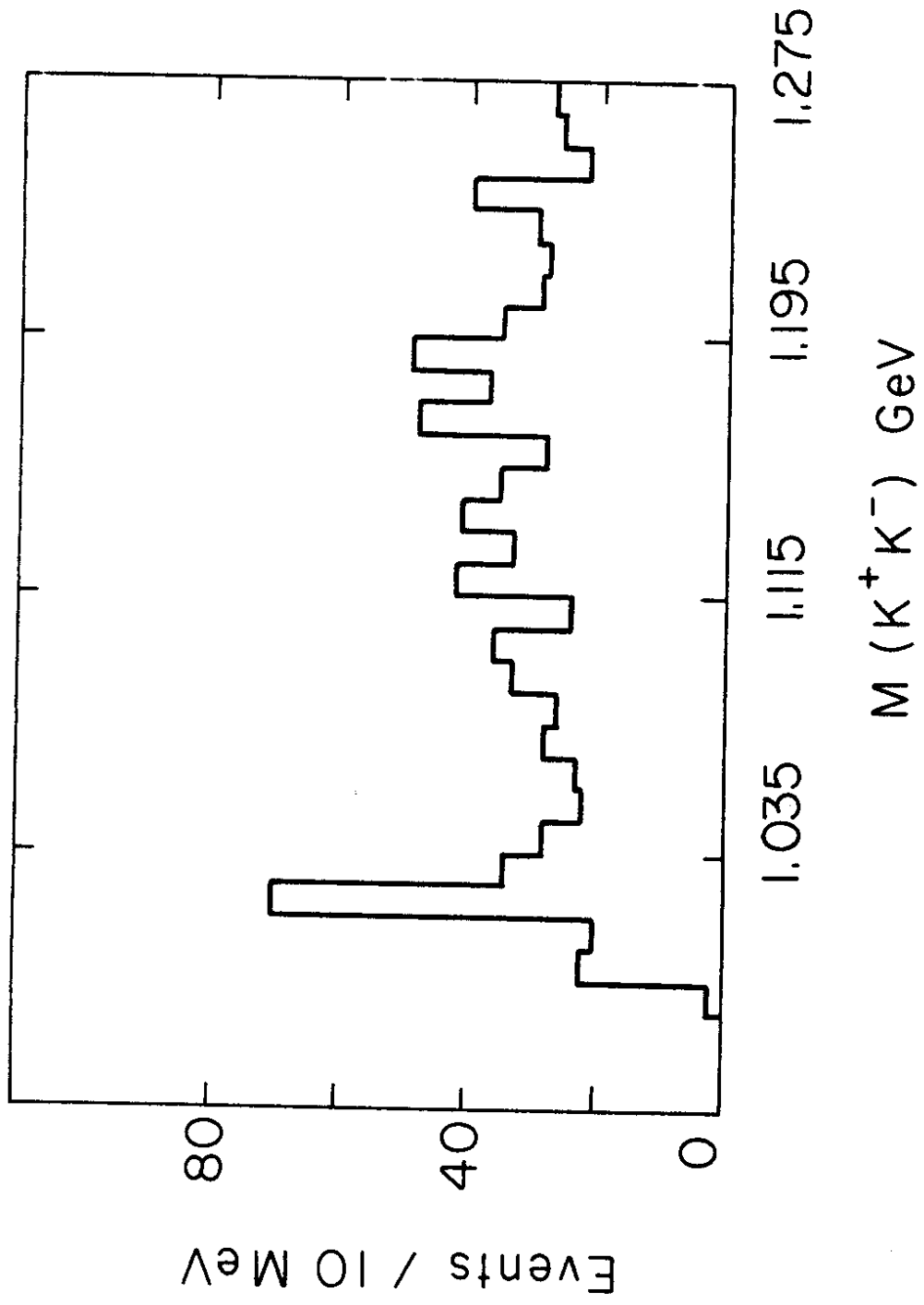Events / 10 MeV

M(K^+K^-) GeV

Fig. 3