Laboratori Nazionali di Frascati

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PHOTOPRODUCTION AND NEUTRAL DECAY MODES OF THE η PARTICLE

C. Bacci, G. Penso, G. Salvini, and A. Wattenberg*
Istituto di Fisica dell'Università di Roma, Roma, Italy
and Istituto Nazionale di Fisica Nucleare, Sezione di Roma, Roma, Italy

and

C. Mencuccini, R. Querzoli, and V. Silvestrini
Laboratori Nazionali del Comitato Nazionale per l'Energia Nucleare, Frascati, Roma, Italy
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Photoproduction of the η particle has been observed at 978 and 939 MeV using the 1100-MeV Frascati electron synchrotron. We have evaluated the branching ratio of the $\gamma+\gamma$ decay mode relative to other neutral modes, and the differential production cross section $d\sigma/d\Omega$ for the process

$$\gamma+p\rightarrow\eta+p. \quad (1)$$

The quantity directly measured was $(d\sigma/d\Omega)\times(\Gamma_{\gamma\gamma}/\Gamma_{\text{total}})$. The results are given in Table I.

The experimental arrangement[1] is shown in Fig. 1. The γ-ray beam from the electron syn-

Table I. Results of the present experiment (reaction $\gamma+p\rightarrow\eta+p$). E_0 is the energy of the electrons in the synchrotron; $k\pm\Delta k$ is the lab energy and energy interval of the photons hitting the proton; $T_p\pm\Delta T_p$ is the energy and energy interval for the proton; θ^* is the c.m. angle of the η; $[(d\sigma/d\Omega)(\Gamma_{\gamma\gamma}/\Gamma_{\text{total}})]_{\text{c.m.}}$ is the differential cross section for photoproduction of η's decaying in the $\gamma+\gamma$ mode; $d\sigma/d\Omega$ is the c.m. differential cross section for η photoproduction (3.2 times the preceding values; we obtain from the branching ratio measurements and other results that $\Gamma_{\gamma\gamma}/\Gamma_{\text{total}}=1/3.2$). $R=(\gamma+\gamma)/[(3\pi^0)+(\pi^0+\gamma+\gamma)]$ is the branching ratio. The numbers in parentheses are less certain; see text. The errors include an estimate for our uncertainties in solid angle, efficiency, and background.[a]

E_0 (MeV)	$k\pm\Delta k$ (MeV)	$T_p\pm\Delta T_p$ (MeV)	θ^*	$(d\sigma/d\Omega)(\Gamma_{\gamma\gamma}/\Gamma_{\text{total}})$ (10^{-32} cm²/sr)	$(d\sigma/d\Omega)$ (10^{-32} cm²/sr)	R	Method	Dosis (10^{14} equiv. quanta)
1000	978± 22	278± 18	106°± 5°	7.6± 1.6	~24	0.78± 0.34	γ method	2.05
1000	978± 22	278± 18	106°± 5°	6.2± 1.3	~20	0.83± 0.31	step	3.5
1000	939± 14	248± 11	103°± 5°	(11.5± 2.6)	~(36)	(0.53± 0.22)	γ method	1.53
950	937± 13	248± 11	103°± 5°	(10 ± 2.1)	~(32)	(0.88± 0.58)	γ method	1.95

[a]See reference 1.

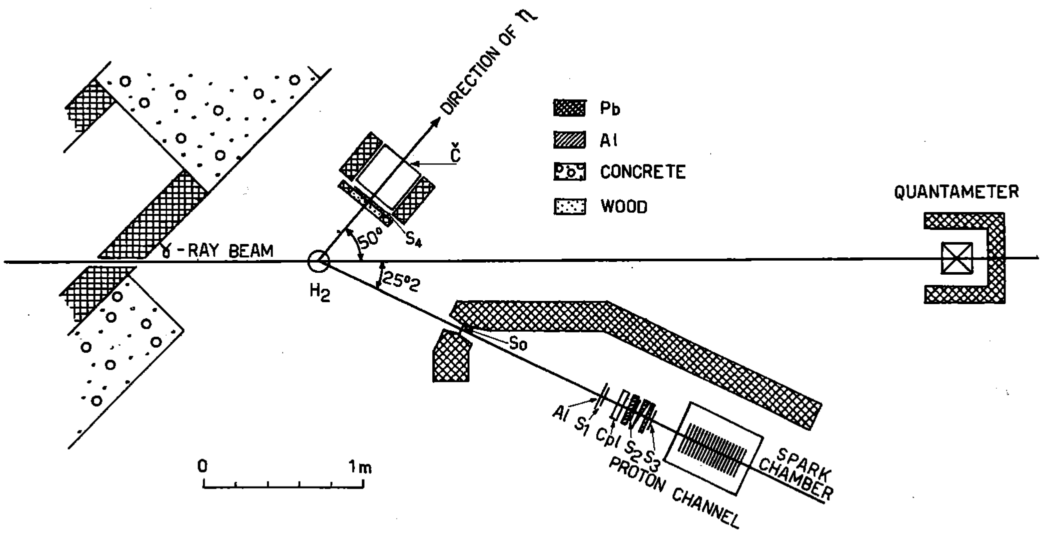

FIG. 1. Experimental arrangement.[1] The wedge-shaped shim in the proton channel corrects for the angular dependence of the proton energy.

chrotron hits the 7-cm liquid hydrogen target, H_2. The protons are measured in a telescope spark-chamber combination which discriminates against pions.

On the line of flight of the η, there is a total-absorption, lead glass, Cherenkov counter C, with an anticoincidence in front, to detect γ rays in coincidence with the recoil protons. The energy of the γ rays detected by C is measured by a pulse-height analyzer and recorded on the photograph of the spark chamber by means of neon lamps. γ rays with an energy <200 MeV do not trigger the spark chamber. In this way single pion photoproduction is avoided.

With the described setup the η can be detected essentially by two different methods.

(1) The step method.– The energy E_0 of the electron synchrotron and the absorbers in the proton telescope are chosen in such a way that protons due to process (1) can reach at most the center of the spark chamber (an appropriate wedge-shaped shim was inserted). When one plots the number of the protons as a function of their energy, a step appears due to process (1). The background processes (mostly multipion photoproduction) do not give rise to any step.

Along the line of flight of the η the process $\gamma+p\to\eta+p$ when $\eta\to\gamma+\gamma$ produces a γ-ray spectrum which is almost monochromatic, centered around ~560 MeV; instead the decay $\eta\to 3\pi^0$ (and $\eta\to\pi^0+\gamma+\gamma$) produce γ rays which have a smooth spectrum ending at about 500 MeV. If one chooses only those protons which are in coincidence with γ rays of energy greater than 400 MeV, one obtains a step in the proton distribution predominantly due to η's which decay only via the $\gamma+\gamma$ mode. For γ-ray energies less than 400 MeV, the step is due to those η's which decay via three-body modes.

The multipion photoproduction gives rise to a spectrum similar to the one due to the process $\eta\to 3\pi^0$ [see Fig. 4(a)].

The experimental results of the step method are shown in Figs. 2 and 3. Fig. 2(a) gives the proton distribution (corrected for nuclear absorption) for the γ-ray energy greater than 400 MeV, essentially the $\gamma+\gamma$ mode.

The multipion background was studied experimentally under kinematical conditions, in which the η could not be observed. All these background corrections [e.g., solid line of Fig. 2(a)] are extrapolated to the η region from a single function. Independent phase-space calculations of multipion production give very similar results.

The difference between the experimental results and the solid line of Fig. 2(a) gives in Fig. 2(b) the step distribution of the protons, as one expects from Reaction (1). One sees that the mass of the η appears to be 550 ± 6 MeV, in good agreement with the known mass, 548 ± 1 MeV.[2] This makes us confident that we are really observing the η. The expected shape for the step was determined experimentally from the single photoproduction of π^0 mesons with the same equipment.

Figures 2(c) and 2(d) show a multipion background measurement. Figures 3(a), 3(b), 3(c), and 3(d) are similar to Fig. 2, but the energy of the γ ray in the Cherenkov counter C was between 240 and 400 MeV, corresponding to three-body decays of the η. In this case the determination of the η contribution is more uncertain than before due to the increased percentage of multipion processes.

(2) The γ method.– This method has already been used in a preliminary experiment by us.[3] A relatively small energy band of protons is chosen, and we look at the spectrum of the γ rays which are in coincidence.

Some of the spectra we obtained with the γ method are shown in Fig. 4. Figure 4(a) shows a spectrum taken where the η can not contribute due to kinematical requirements. Figures 4(b), 4(c), and 4(d), corresponding to different production energies, show spectra where the η is present. In these cases it is not possible to obtain a good fit with a line like the full line of Fig. 4(a) (multipion production only); one must add a Gaussian centered at 560 MeV, having a width arising from the experimental resolution. In the upper part of each figure the multipion background has been subtracted. As we can see, the distributions appear to have the shape expected from the process $\eta\to\gamma+\gamma$ plus a contribution from the process $\eta\to 3\pi^0$.

It is important to note that a contribution to the three-body neutral decays of the mode $\pi^0+\gamma+\gamma$ is not excluded from our experiment and is not forbidden by selection rules. The decay $\pi^0+\gamma+\gamma$ is a process of the same order, α^2, as the $\gamma+\gamma$ mode, but it should be depressed by phase space and the strength of the $\gamma\rho\omega$ interaction. An estimate may be indirectly deduced from the paper of Gell-Mann, Sharp, and Wagner.[4] However, we have not found any theoretical consideration of this decay mode. The average efficiency of our apparatus for detecting the $\pi^0+\gamma+\gamma$ and the $\pi^0+\pi^0+\pi^0$ decay mode is approximately the same. To get a quantitative evaluation of the different decay modes of the η, we have obtained the "best-fit" values of a and b for the distributions of Figs. 4(b), 4(c), and 4(d) with curves of the type

$$a(\phi_1+b\phi_2),$$

where ϕ_1 and ϕ_2 are the distributions expected from the decay modes $\eta\to3\pi^0$ and $\eta\to\gamma+\gamma$, respectively. The curves obtained are shown in the upper part of Figs. 4(b), 4(c), and 4(d), and it can be seen that they fit rather well. We wish to point out that these three curves are independent measurements of the branching ratio.

If we assume from theory that the $\pi^0+\gamma+\gamma$ mode is negligible, then the above results lead us to believe we are observing the $\eta\to3\pi^0$ mode as well as the $\eta\to\gamma+\gamma$ mode. However, in Table I we report the branching ratio in the form

$$R=(\gamma+\gamma)/[(3\pi^0)+(\pi^0+\gamma+\gamma)] \qquad (2)$$

as obtained from our two methods. In the same table the results of the cross section also are reported.

One can see that the values of R are equal within the errors. In obtaining R, a correction was applied for the contribution of the decay $\pi^+ +\pi^- +\pi^0$ whose ratio to all the neutral modes is known[5] as being 1:3.

We also can estimate $d\sigma/d\Omega$ and R by using the γ method on the events with protons which did not enter the spark chamber but traversed all the counters ($T_p=248\pm11$ MeV). The results in this case are less certain, due to some possible larger systematic errors. These results are reported in parentheses in Table I, and one

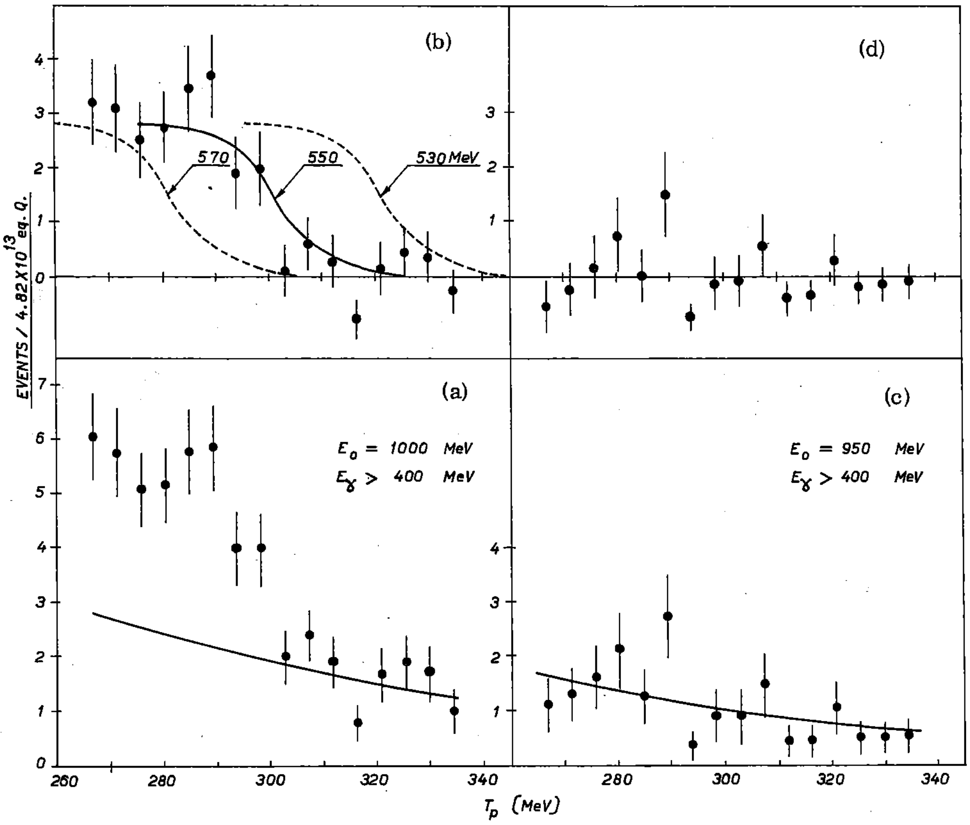

FIG. 2. Energy spectra of protons in coincidence with γ rays of energy >400 MeV. (a) The case when the process $\gamma+p\to\eta+p$ is permitted kinematically; the solid line is the expected contribution from multipion processes. (b) The "η events," namely, the difference between the experimental points and the multipion background. The solid line is the expected shape of the proton spectrum from the process $\gamma+p\to X^0+p$ if X^0 has a mass of 550 MeV, that of the η. The dashed lines are for X^0, having a mass 530 and 570 MeV. (c) and (d) Same as (a) and (b) except that the process $\gamma+p\to\eta+p$ is forbidden kinematically. This is a null check.

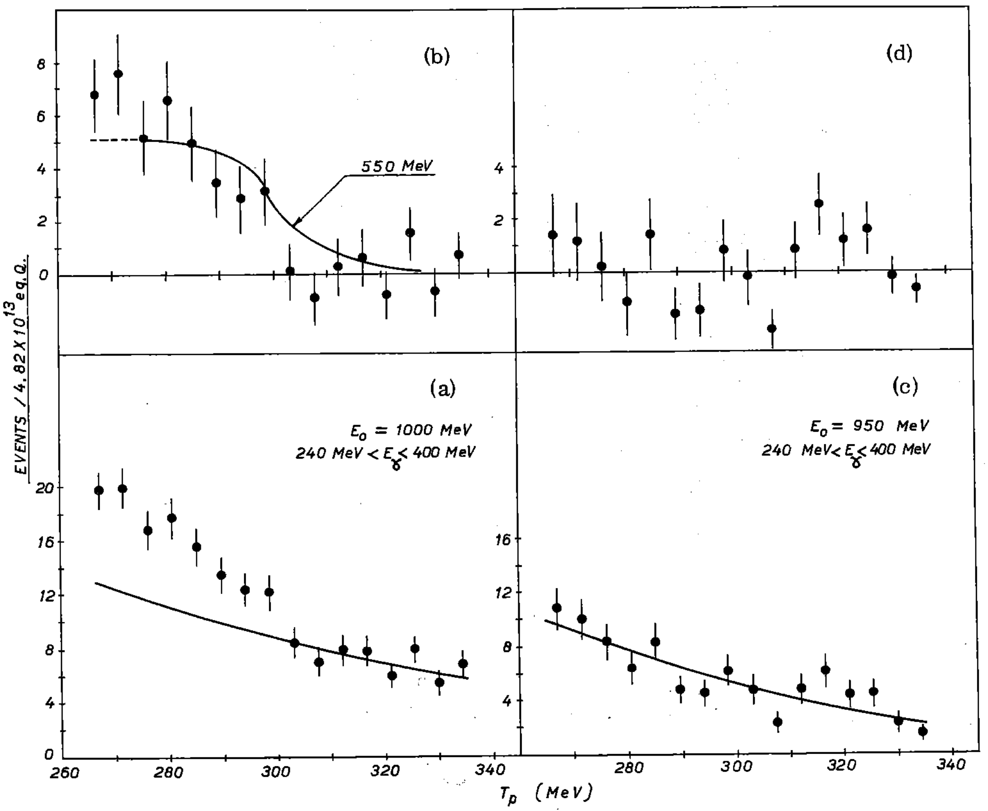

FIG. 3. Energy spectra of protons in coincidence with γ rays of energy between 240 and 400 MeV. The step of (b) must be due to a three-body decay mode of the η (e.g., $\eta \to 3\pi^0$ and/or $\eta \to \pi^0+\gamma+\gamma$). (c) and (d) are again a null check.

cannot yet be sure that they indicate a change of the cross section with the energy. Our result

$$R=0.8\pm0.25$$

does not disagree with the lower limit (0.9 ± 0.3) given by Chrétien et al.[6] for the ratio $(\gamma+\gamma)/(3\pi^0)$.

The branching ratio R found in our measurements when combined with the reported values[5] of (all neutrals)/$(\pi^+\pi^-\pi^0)=3.0\pm0.5$ and $(\pi^+\pi^-\gamma)/(\pi^+\pi^-\pi^0)=0.26\pm0.08$ enable one to list the following percentages for the various decay modes of the η:

$$\begin{aligned}(\pi^0\pi^0\pi^0)+(\pi^0\gamma\gamma), &\quad (40\pm14)\%;\\ (\gamma\gamma), &\quad (31\pm11)\%;\\ (\pi^+\pi^-\pi^0), &\quad (23\pm\ 4)\%;\\ (\pi^+\pi^-\gamma), &\quad (\ 6\pm\ 2)\%.\end{aligned}$$

The experimental values are compared with some theoretical predictions in Table II.

From our measurements we obtain that the ratio of π^0 photoproduction[7] to η photoproduction at the same center-of-mass energy and angle is

$$\frac{(d\sigma/d\Omega)_{105°,\,\pi^0}}{(d\sigma/d\Omega)_{105°,\,\eta}}\cong 8. \quad (4)$$

The ratio of pion scattering[8] to pion production[6] of the η is also of the same order. For example,

$$\frac{\sigma(\pi^-+p\to\pi^-+p)_{1015\text{ MeV}}}{\sigma(\pi^-+p\to n+\eta)_{1015\text{ MeV}}}=\frac{18\text{ mb}}{0.5\times3.2\text{ mb}}\cong 11. \quad (5)$$

As we see, the η is produced rather abundantly, and the equality of these ratios could indicate that the type of interaction which exists between the η and a nucleon is similar to that for a π and a nucleon. The above ratio, ~8, of photoproduction cross sections is not inconsistent with a calculation by Fujii and Holloway[9] based on unitary symmetry models.

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*National Science Foundation Fellow, on leave from the University of Illinois, Urbana, Illinois.

[1]A detailed description of the experimental arrangement and method will be published elsewhere.

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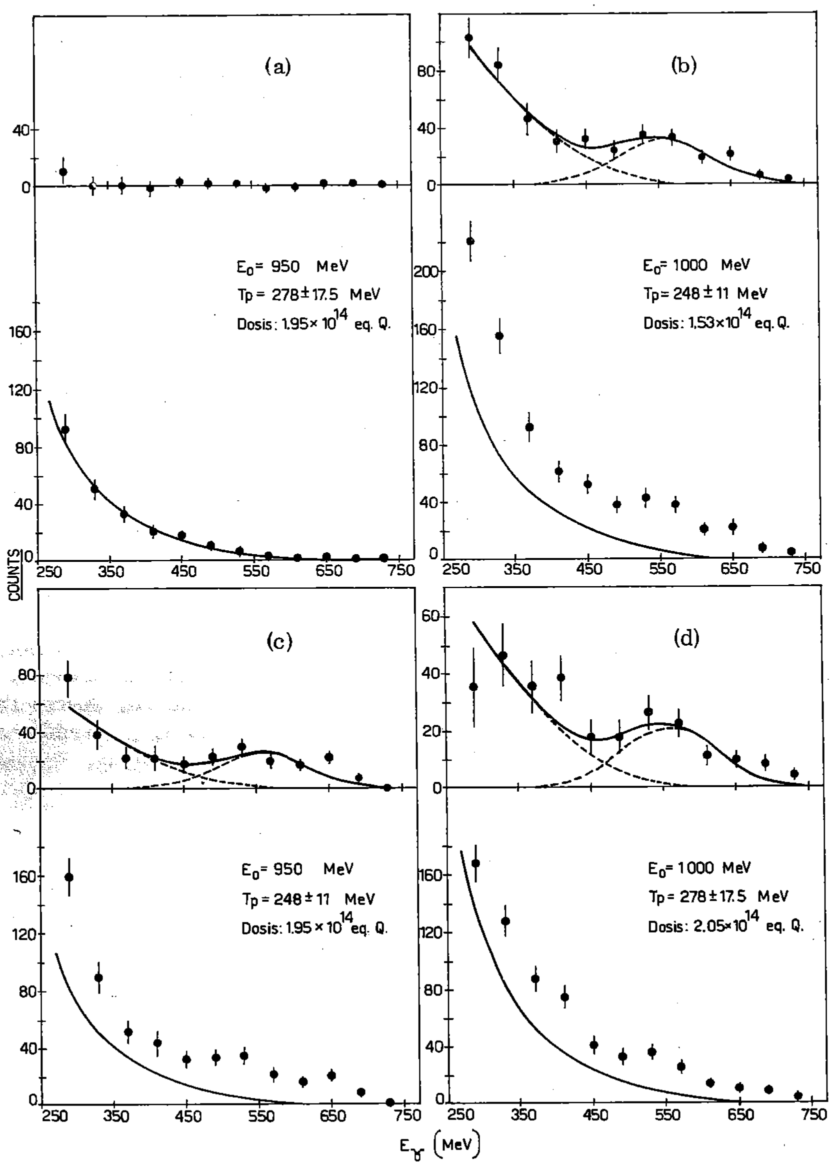

FIG. 4. Spectra obtained with the γ-ray method from the lead glass Cherenkov detector and the multichannel analyzer. (a) A typical "non-η spectrum." In abscissas the energy in MeV of the γ ray detected in Cherenkov $\check{C}$ is given. The solid line is the multipion contribution in this case obtained by a best fit to the experimental points. The upper part of the figure shows the difference between the experimental points and the multipion process. (b), (c), and (d) "η spectra" at different energies. The solid lines in the lower part of each figure are the expected contributions from multipion processes. The upper part shows the difference between the experimental points and the solid line. They are "best fitted" by a function of the form $a(\phi_1+b\phi_2)$. See text.

Table II. A comparison of experimental values from our results and theoretical predictions of decay ratios of the η.

Decay ratio	Experimental value	Theoretical value	Authors	Basis of theoretical calculations
$\gamma\gamma/\pi^+\pi^-\pi^0$	1.3 ± 0.4	0.6 to 1.9	Barrett and Barton[a]	Unitary symmetry model[b, c] (the uncertainty is due to the uncertainty in the experimental value of the lifetime of the π^0).
$3\pi^0/\pi^+\pi^-\pi^0$	$\leq 1.7\pm0.6$[d]	<1.73	Feinberg and Pais[e]	Similarity of the final states for K and η decays into 3π.
		1.5 to 1.73	Wali[f] and Bég[g]	
$\gamma\gamma/\pi^+\pi^-\gamma$	5.0 ± 1.6	≈4	Gell-Mann[b, h, i]	Unitary symmetry model.
		8	Brown and Singer[j]	Unitary symmetry model.

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κ MESON [K^* (725)] AND THE STRANGENESS-CHANGING CURRENTS OF UNITARY SYMMETRY*

Yoichiro Nambu and J. J. Sakurai†
The Enrico Fermi Institute for Nuclear Studies and the Department of Physics, The University of Chicago, Chicago, Illinois
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We wish to examine, within the framework of unitary symmetry, the hypothesis that the vector mesons M and $\overline{M}$ (to be identified with the observed K^* meson of mass 885 MeV) are coupled to strangeness-changing currents that are conserved "as exactly as possible." It is pointed out that this hypothesis suggests the existence of $Y=\pm1$, $T=1/2$, and $J=0^+$ mesons (with no unitary partners) whose couplings to other strongly interacting particles vanish in the limit of exact unitary symmetry. The possible connection between the conjectured scalar meson and the experimentally observed κ meson (the K^* meson of 725 MeV) is discussed.

Some time ago, it was argued that there should exist one $Y=0$, $T=1$ vector meson and two $Y=0$, $T=0$ vector mesons coupled, respectively, to the exactly conserved currents of the strong interac-