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Photoproduction of Strange Particles at Energies up to 5.8 GeV

Aachen-Berlin-Bonn-Hamburg-Heidelberg-München Collaboration

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1. Introduction and Experimental Details

Photoproduction of strange particles has been studied in an 84-cm hydrogen bubble chamber exposed to a bremsstrahlung beam with a maximum photon energy of 5.8 GeV at the German Electron Synchrotron (DESY). Details of the experiment and results on various other reactions have already been published(1). So far we have evaluated 1 200 000 pictures resulting in a total of 709 events with visible strange particle decays.

All pictures were scanned twice. Cross section values given in this paper have been corrected a) for geometrical losses due to the finite chamber size and due to very short decay lengths and b) for the unobserved decay modes. The correction factor due to geometrical losses was on average 1.08 for Λ^0 and 1.11 for K_s^0 decays. Since the photon energy is not known a kinematic fit cannot be carried out for hypotheses with a neutral particle not decaying visibly in the chamber. For those hypotheses the photon energy was determined under the assumption that only one neutral particle was produced.

About one third of the events were ambiguous between several hypotheses. To a large extent these ambiguities were due to the fact that the photon energy was unknown. An investigation of simulated events from FAKE(2) showed that after a proper modification of the kinematics program GRIND events fitting a hypothesis for which the momenta of all outgoing particles can be measured, are not contaminated by other hypotheses. In particular the reactions $\gamma p \rightarrow \Lambda K^+$ and $\gamma p \rightarrow \Sigma^0 K^+$ (with visible Λ decay) could be separated from each other: only a negligible fraction of simulated $\Sigma^0 K^+$ events gave a ΛK^+ fit. In addition according to the FAKE results no true $\Sigma^0 K^+$ events were lost in the identification procedure. On the other hand contamination of the $\Sigma^0 K^+$ events by other reactions (mainly $\Lambda K^+ \pi^0$ ...) was less than 20 %.

Table I gives the number of unambiguous events for various reactions and the total number of events after apportionment of the ambiguous events. The apportionment could be done for most of the cases by starting for each reaction with those topologies in the chamber in which the reaction could be identified uniquely. From there the number of events for this reaction in the other topologies was then estimated. For example, for reaction $\gamma p \rightarrow \Lambda K^0 \pi^+$ 13 events were observed for which both the Λ and the K^0 decays were seen. This led to an estimate of 42 events for this reaction contained in the one-prong V^0 topology resulting in a total number of 55 events with at least one visible strange particle decay.

The events of the reaction $\gamma p \rightarrow pK^+K^-$ come mainly from three prong events with no visible decay for which kinematics and ionization were compatible with that hypothesis. This selection ensures that no pK^+K^- events are lost. On the other hand these events may be contaminated by events of non-strange reactions. The reactions $\gamma p \rightarrow pK^+K^-$ and $\gamma p \rightarrow pK^0\overline{K}^0$ have been investigated in Refs. 1c and 1d in connection with φ production via $\gamma p \rightarrow p\varphi$ and the results are presented there.

In the rest of this letter we discuss the following reactions:

(1) $\gamma p \rightarrow \Lambda K^+$

(2) $\gamma p \rightarrow \Sigma^0 K^+$

(3) $\gamma p \rightarrow \Sigma^+ K^0$

(4) $\gamma p \rightarrow \Lambda K^+ \pi^0 (\pi^0 ..)$

(5) $\gamma p \rightarrow \Lambda K^0 \pi^+$

(6) $\gamma p \rightarrow \Sigma^+ K^+ \pi^-$

(7) $\gamma p \rightarrow \Sigma^- K^+ \pi^+$

(8) $\gamma p \rightarrow \Lambda K^+ \pi^+ \pi^-$

These are the more abundant reactions for which, except for Reaction (4), also a clean kinematical identification was possible. For Reaction (3) only events with a visible K^0 decay were used.

2. YK Production

Fig. 1 shows the total cross section for Reactions (1), (2), and (3) as functions of the photon energy E_γ and Figs. 2 and 3 the differential cross section for Reactions (1) and (2), respectively, for various intervals of E_γ.

The differential cross sections for Reactions (1) and (2) show a marked change with photon energy from near-isotropy to strong forward peaking. This peaking at higher energies suggests a peripheral production mechanism; the processes most likely to contribute are K and K^* exchange. The contribution of K^* exchange however is probably very small because of the small $K^*K\gamma$ (3) and NYK^*(4) coupling constants. K exchange, on the other hand, cannot contribute to Reaction (3) since there is no direct $K^0\bar{K}^0\gamma$ coupling. This may be a reason why the cross section for Reaction (3) is comparatively small at higher energies. Reaction (1) was compared with the predictions of the K-exchange model with a gauge-invariant extension and with absorptive corrections, as calculated by K. Schilling(5). It turned out, however, that these corrections depend strongly on the various assumptions which must be made. Apart from the arbitrariness in the choice of a gauge-invariant extension, the biggest uncertainty comes from the unknown value of the absorption parameter C. Agreement with the experimental cross section above E_γ = 1.8 GeV and for momentum transfer squared $\Delta^2 < 0.4$ GeV^2 can be obtained by choosing the following parameters:

$$C = 0 \quad \text{(no absorption)}, \quad g^2_{KN\Lambda} / 4\pi = 4.9 \pm 1.1$$

$$C = 0.8, \; A = 8.5 \text{ GeV}^{-2}, \quad g^2_{KN\Lambda} / 4\pi = 15.8 \pm 3.5$$

$$C = 1.0, \; A = 8.5 \text{ GeV}^{-2}, \quad g^2_{KN\Lambda} / 4\pi = 42 \pm 9.4$$

Here $g_{KN\Lambda}$ is the $KN\Lambda$ coupling constant.

This shows that a determination of $g^2_{KN\Lambda}$ by this method requires a much better knowledge of the various corrections.

Measurements for Reactions (1) and (2) have also been carried out by various authors at photon energies below 1.2 GeV; the results, together with a summary of possible theoretical interpretations, have been compiled by Grilli et al.[6] and Thom[7]. Measurements have also been performed by Elings et al.[8] at around 4 GeV and by the Cambridge Bubble Chamber Group[9]. Our cross section values are in agreement with these previous results, within statistics.

3. Reactions (4) to (8)

Fig. 4 shows the total cross sections for Reactions (5) to (8) as functions of E_γ. For Reaction (5) only events with both Λ and K^o decaying visibly in the chamber were used.

In Fig. 5 we show as a function of E_γ the sum of the cross sections for Reactions (1), (2), (3), (5), (6), (7), and (8) plus a number of other reactions for which the momenta of all outgoing particles could be measured and for which therefore the photon energy could be determined uniquely. Thus these values are lower limits for the total cross section for strange particle production.

Fig. 6 shows the effective mass distributions of ΛK, $\Lambda\pi$ and $K\pi$ for the Reactions (4) and (5) and Fig. 7 the effective mass distributions of ΣK, $\Sigma\pi$ and $K\pi$ for Reactions (6) and (7). The events are plotted without geometrical correction factors. For Reactions (4) and (5) possible candidates among the ambiguous events have also been included.

In the $\Lambda\pi$ mass distribution for each reaction there is evidence for the $Y_1^*(1385)$, whereas no $K^*(891)$ is seen in the $K\pi$ mass distributions

In Table II we give estimates for the cross sections of Y^* production in the reactions

$$(4a) \quad \gamma p \rightarrow Y_1^{*o} K^+$$

$$(5a) \quad \gamma p \rightarrow Y_1^{*+} K^o$$

for three energy intervals. The cross sections have been corrected by a factor of 1.10 to account for the $\Sigma\pi$ decay mode of the $Y_1^*(1385)$.

The Y_1^* peak for Reaction (4) comes of course from events with only one π^0 and is therefore due to Reaction (4a).

To determine the cross section of Reaction (5a) only events with a visible K^0 decay were used. Therefore the Y_1^* peak for these selected events is uniquely due to Reaction (5a). For events where only the Λ decay is visible in the chamber, we cannot exclude the presence of one or more additional π^0 mesons. In fact from the events in the Y_1^* peak with a visible K^0 decay we estimated the total number of events from Reaction (5a) contributing to the Y_1^* peak in Fig. 6. This number cannot account for the whole Y_1^* peak in this $\Lambda\pi^+$ mass distribution. We therefore conclude that a considerable fraction of the Y_1^* peak in the $\Lambda\pi^+$ mass distribution is actually due to reactions with one or more π^0 mesons.

Strong production of the $Y_1^*(1385)$ has also been observed by the Cambridge Bubble Chamber Group[9].

Besides the $Y_1^*(1385)$ we see a peak in the $\Lambda\pi^+$ mass distribution of Reaction (5) at about 1770 MeV (Fig. 6).

Apart from the $Y_1^*(1385)$ and possibly the $Y_1^*(1770)$ we see no statistically significant production of other strange resonances in the Reactions (4) to (8).

Acknowledgment:

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TABLE I

Number of events with at least one visible strange particle decay

Reaction	Number of unique events	Total number of events	Reaction	Number of unique events	Total number of events
ΛK^+	122	127	$nK^0\bar{K}^0\pi^+(\pi^0\ldots)$	-	3
Σ^+K^0	5	16	$\binom{\Sigma^0}{\Lambda}K^0\pi^+\pi^0(\pi^0\ldots)$	18	79
Σ^0K^+	30	51	$\Sigma^+K^+\pi^-\pi^0(\pi^0\ldots)$	12	23
pK^+K^-	58	61	$\Sigma^-K^+\pi^+\pi^0(\pi^0\ldots)$	3	11
$pK^0\bar{K}^0$	13	21	$\Xi^-K^+\pi^+K^0(\pi^0\ldots)$	1	1
$\Lambda K^0\pi^+$	13	55	$\Lambda K^0\pi^+\pi^+\pi^-$	3	11
$\Sigma^+K^+\pi^-$	28	28	$\Sigma^-K^+\pi^+\pi^+\pi^-$	1	1
$\Sigma^0K^0\pi^+$	4	17	$pK^+\bar{K}^0\pi^-\pi^0(\pi^0..)$	1	2
$\Sigma^-K^+\pi^+$	19	19	$pK^0\bar{K}^0\pi^+\pi^-(\pi^0\ldots)$	6	8
$nK^+\bar{K}^0(\pi^0..)$	6	10	$pK^0K^-\pi^+\pi^0(\pi^0\ldots)$	2	3
$\binom{\Sigma^0}{\Lambda}K^+\pi^0(\pi^0\ldots)$	30	95	$nK^+\bar{K}^0\pi^+\pi^-(\pi^0\ldots)$	2	5
$\Sigma^+K^0\pi^0(\pi^0..)$	3	10	$nK^0K^-\pi^+\pi^+(\pi^0\ldots)$	1	2
$pK^+\bar{K}^0\pi^-$	2	2	$\binom{\Sigma^0}{\Lambda}K^+\pi^+\pi^-\pi^0(\pi^0\ldots)$	4	13
$pK^0K^-\pi^+$	8	10	$\Sigma^+K^0\pi^+\pi^-\pi^0(\pi^0\ldots)$	3	12
$\Lambda K^+\pi^+\pi^-$	19	22	$\binom{\Sigma^0}{\Lambda}K^0\pi^+\pi^+\pi^-(\pi^0\ldots)$	-	11
$\Sigma^+K^0\pi^+\pi^-$	1	3	$\Sigma^-K^0\pi^+\pi^+\pi^0(\pi^0..)$	3	14
$\Sigma^0K^+\pi^+\pi^-$	6	7	$\Sigma^+K^0\pi^+\pi^+\pi^-\pi^-(\pi^0\ldots)$	-	2
$\Sigma^-K^0\pi^+\pi^+$	-	-			

TABLE II

Cross sections for $Y_1^*(1385)$ Production

E_γ(GeV)	$Y_1^{*0}K^+$(μb)	$Y_1^{*+}K^0$(μb)
1.42 - 2.0	0.23 ± 0.23	0.3 ± 0.3
2.0 - 3.0	0.45 ± 0.20	0.4 ± 0.2
3.0 - 5.8	0.22 ± 0.10	0.1 ± 0.1

References:

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3.) See for instance: S.L. Glashow and R.H. Socolow, Phys.Rev.Lett. 15, 329 (1965); F.C. Chan: Nuovo Cim. 45A, 259 (1966)

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8.) V.B. Elings, K.J. Cohen, D.A. Garelick, S. Homma, R.A. Lewis, P.D. Luckey, and L.S. Osborne: Phys.Rev.Lett. 16, 474 (1966)

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Figure Captions:

Fig. 1 Total cross sections for (a) $\gamma p \rightarrow \Lambda K^+$, (b) $\gamma p \rightarrow \Sigma^0 K^+$ and (c) $\gamma p \rightarrow \Sigma^+ K^0$ as functions of the photon energy E_γ.

Fig. 2 Differential cross section $\frac{d\sigma}{d\Omega^*}$ in the cm system for $\gamma p \rightarrow \Lambda K^+$ for three intervals of the photon energy E_γ.

Fig. 3 Differential cross section $\frac{d\sigma}{d\Omega^*}$ in the cm system for $\gamma p \rightarrow \Sigma^0 K^+$ for two intervals of the photon energy E_γ.

Fig. 4 Total cross sections for (a) $\gamma p \rightarrow \Lambda K^0 \pi^+$, (b) $\gamma p \rightarrow \Sigma^+ K^+ \pi^-$, (c) $\gamma p \rightarrow \Sigma^- K^+ \pi^+$ and (d) $\gamma p \rightarrow \Lambda K^+ \pi^+ \pi^-$ as functions of E_γ.

Fig. 5 Lower limit forthe total cross section of strange particle production (see text)

Fig. 6 Effective mass distributions for the Reactions $\gamma p \rightarrow \Lambda K^+ \pi^0$ (unshaded) and $\gamma p \rightarrow \Lambda K^0 \pi^+$ (shaded): (a) ΛK, (b) $\Lambda \pi$ and (c) $K\pi$.

Fig. 7 Effective mass distributions for the Reactions $\gamma p \rightarrow \Sigma^+ K^+ \pi^-$ (shaded) and $\gamma p \rightarrow \Sigma^- K^+ \pi^+$ (unshaded): (a) ΣK, (b) $\Sigma \pi$ and (c) $K\pi$.

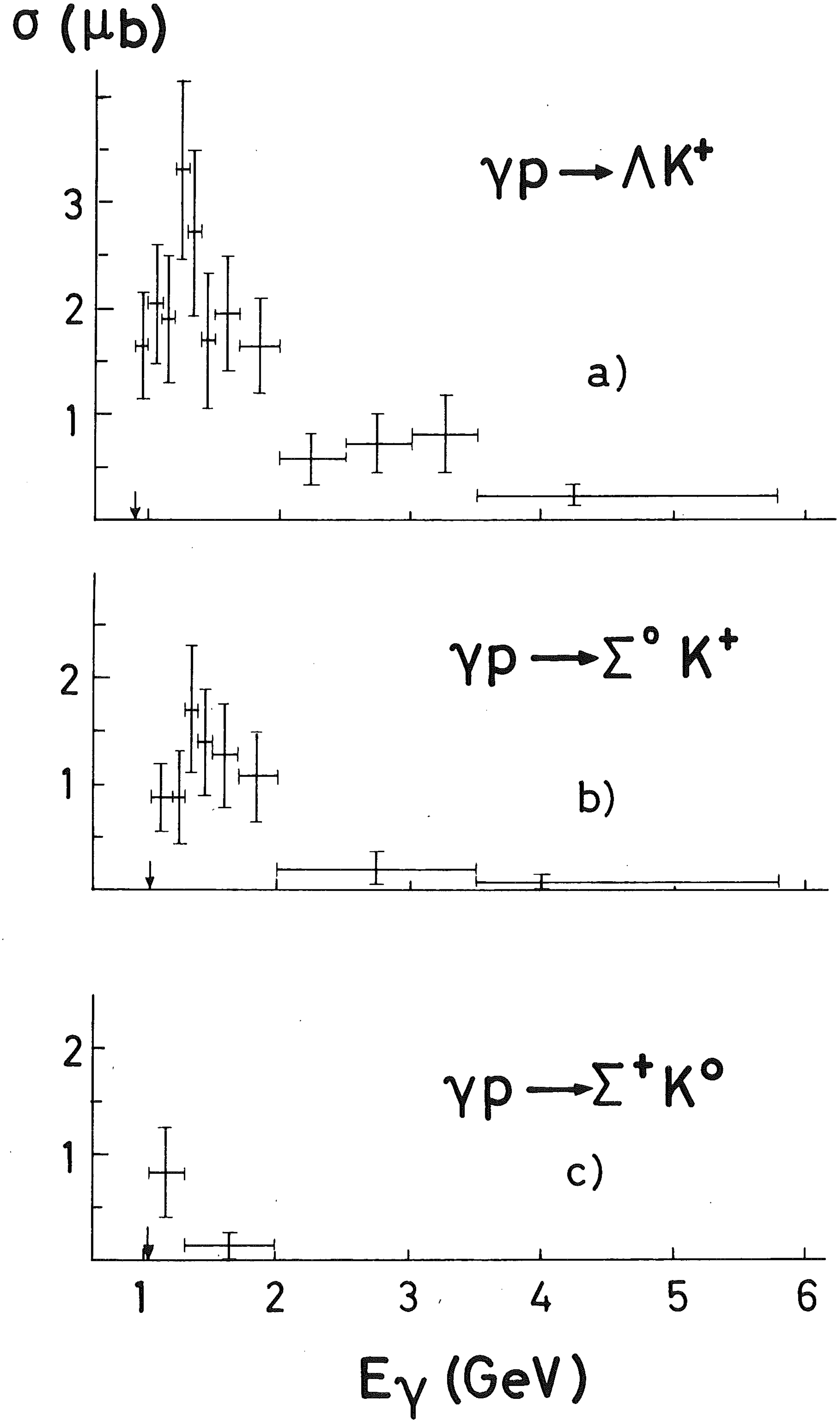
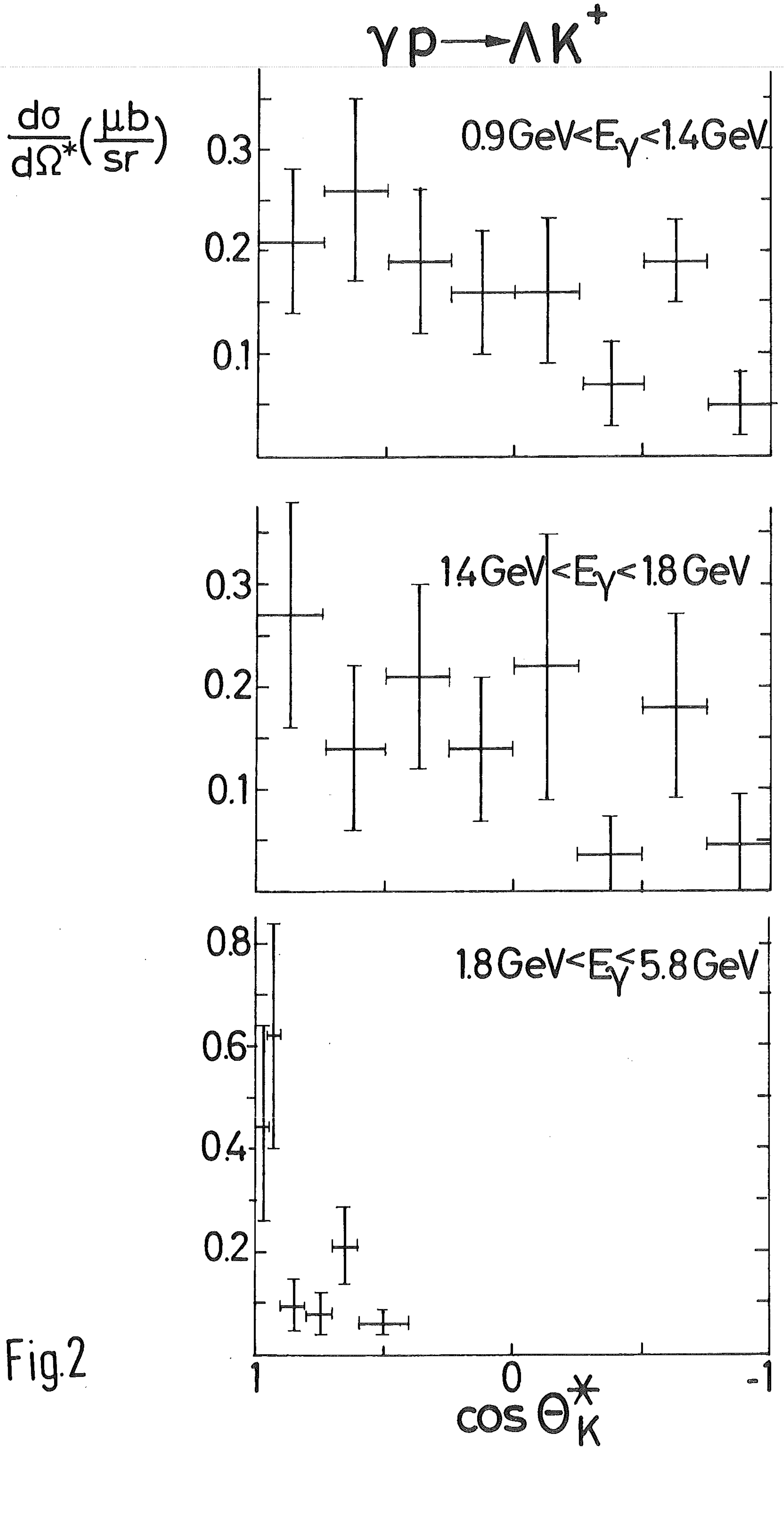


Fig.1



γp → ΛK⁺
dσ/dΩ* (μb/sr)
0.9 GeV<Eγ<1.4 GeV
1.4 GeV<Eγ<1.8 GeV
1.8 GeV<Eγ<5.8 GeV
0.1
0.2
0.3
0.4
0.6
0.8
1
0
-1
cos Θ*K

Fig.2

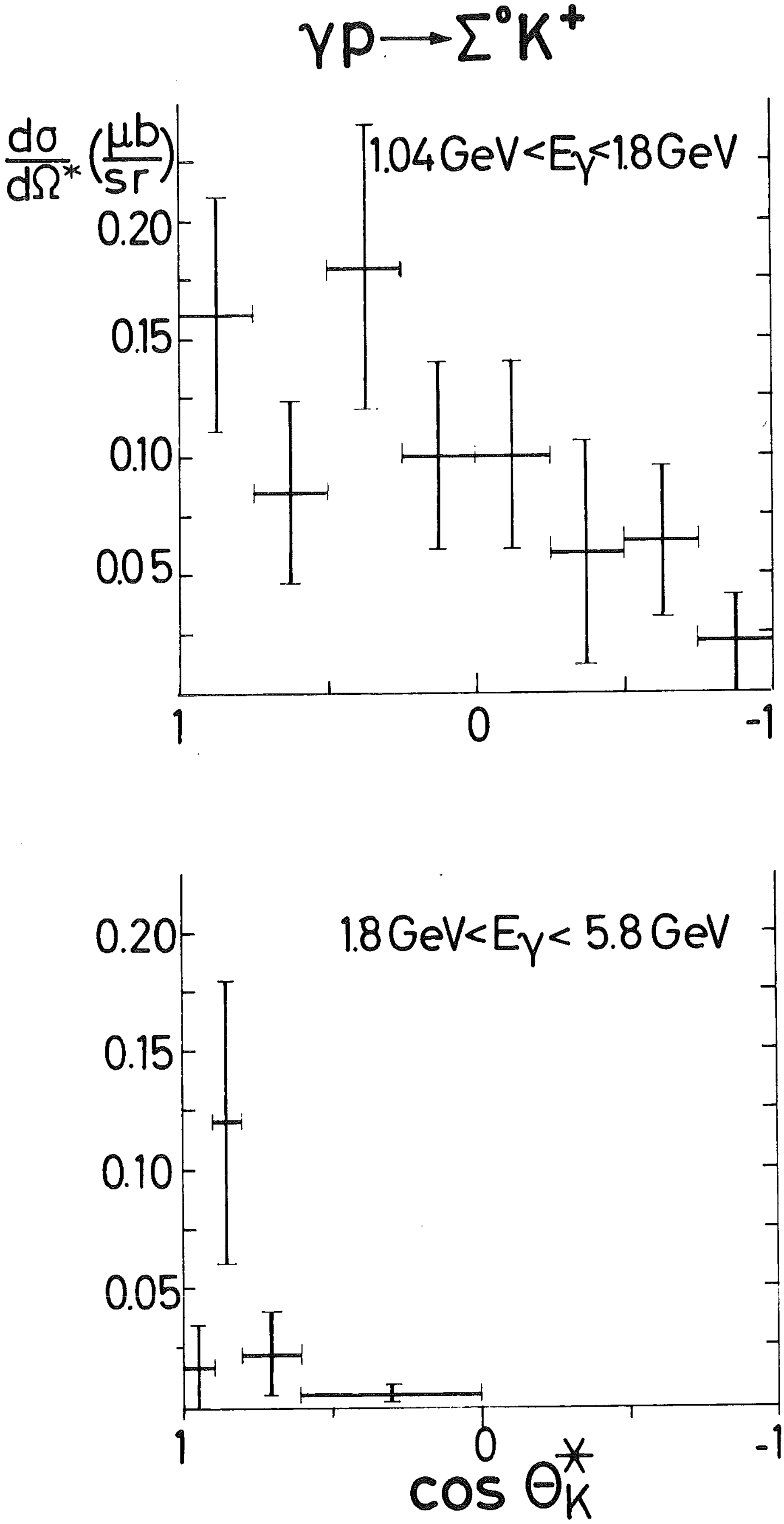
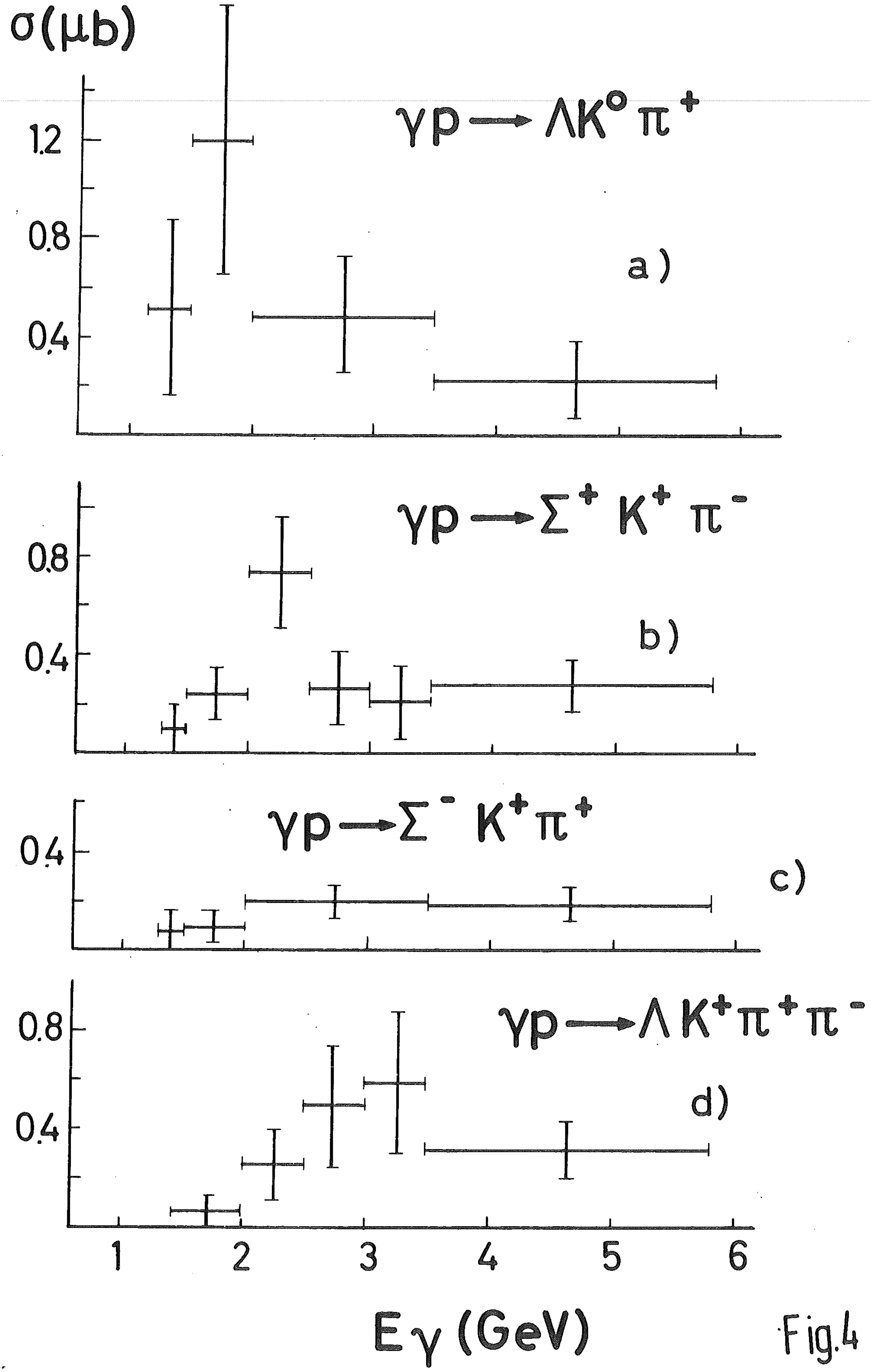

γp → Σ°K⁺
dσ/dΩ* (μb/sr)
1.04 GeV<Eγ<1.8 GeV
0.20
0.15
0.10
0.05
1
0
-1
1.8 GeV<Eγ< 5.8 GeV
0.20
0.15
0.10
0.05
1
0
-1
cos Θ*K

Fig.3



σ(μb)
1.2
0.8
0.4
γp → ΛK° π⁺
a)
0.8
0.4
γp → Σ⁺ K⁺ π⁻
b)
0.4
γp → Σ⁻ K⁺π⁺
c)
0.8
0.4
γp → Λ K⁺π⁺π⁻
d)
1
2
3
4
5
6
Eγ (GeV)

Fig.4

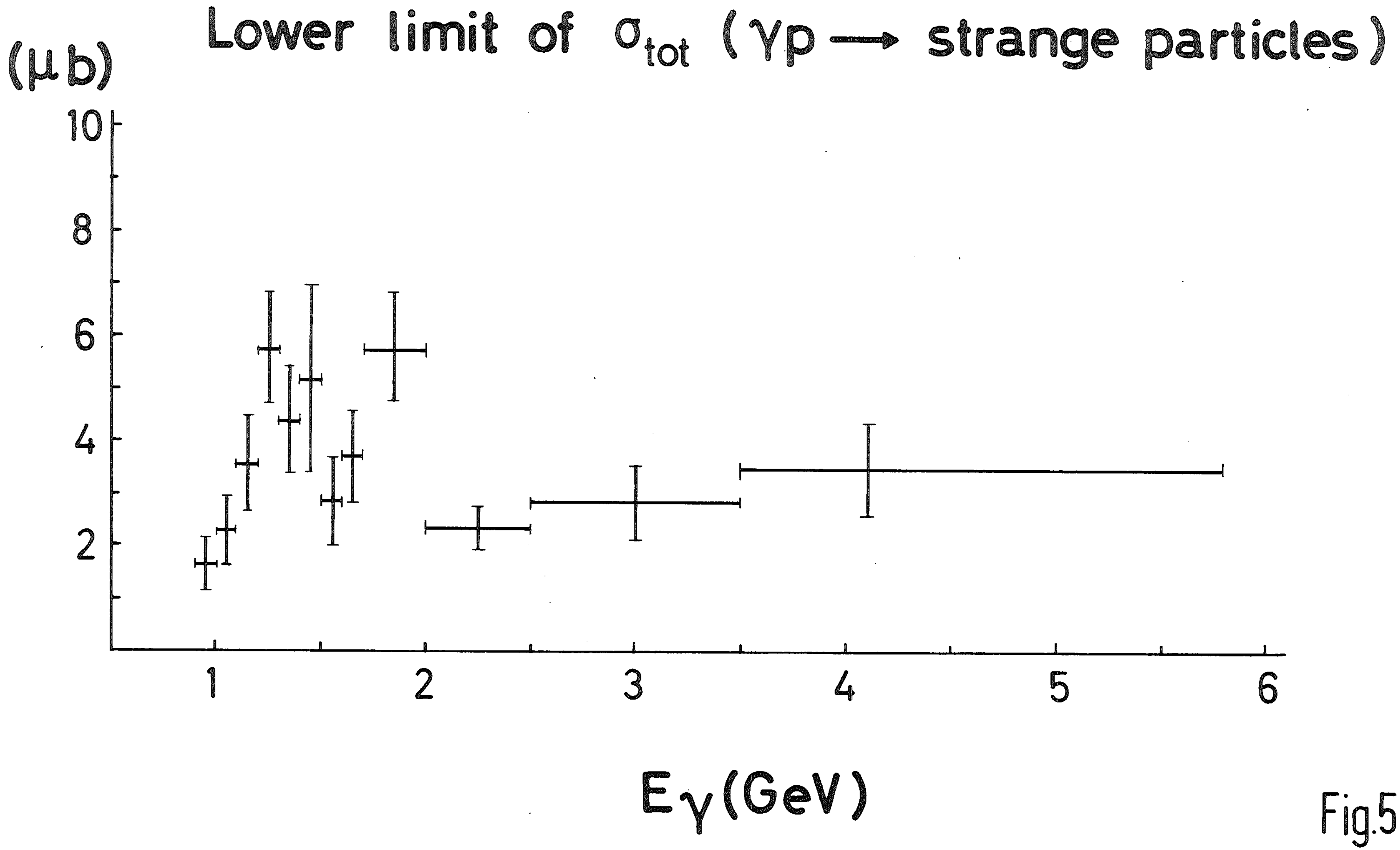
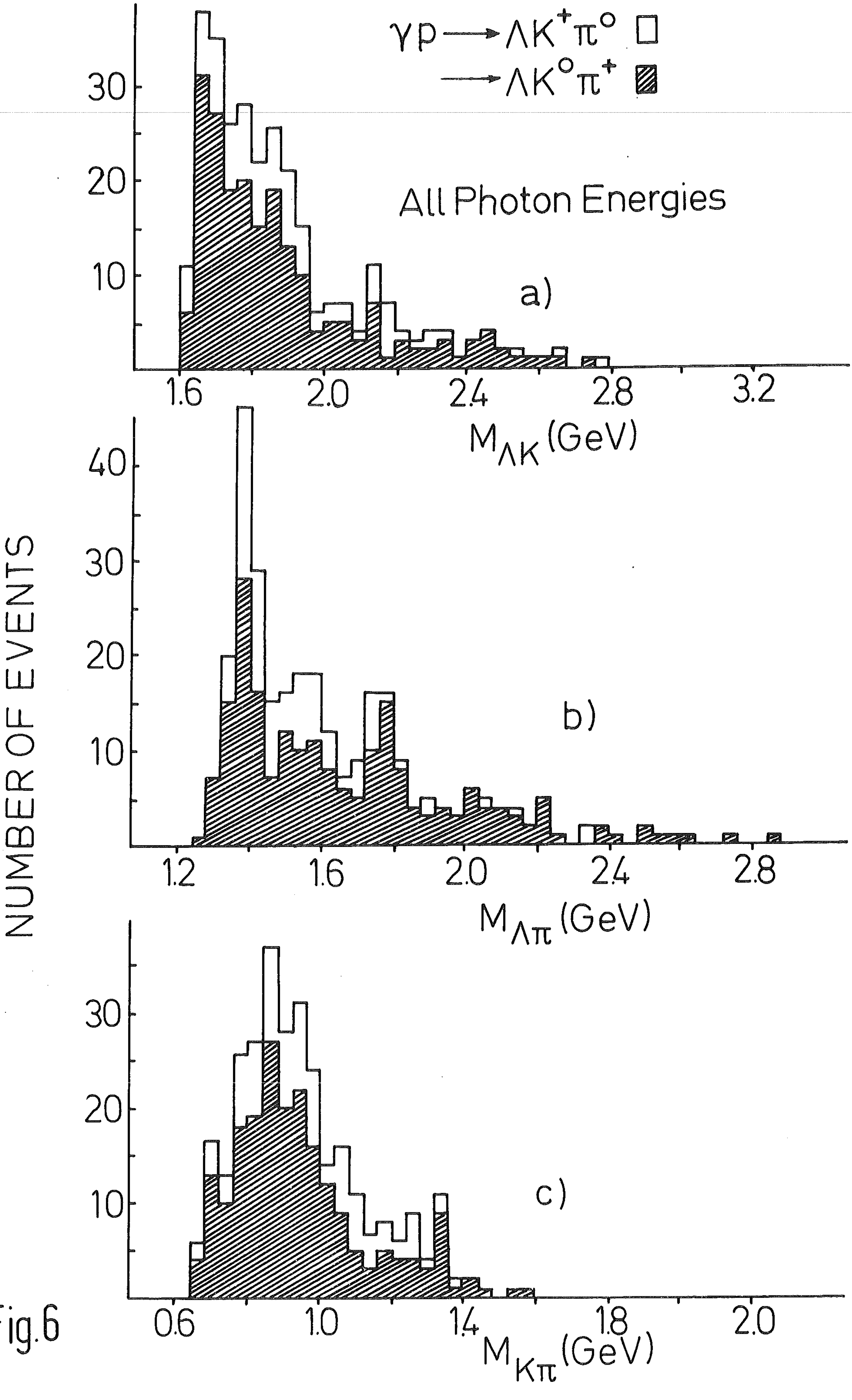
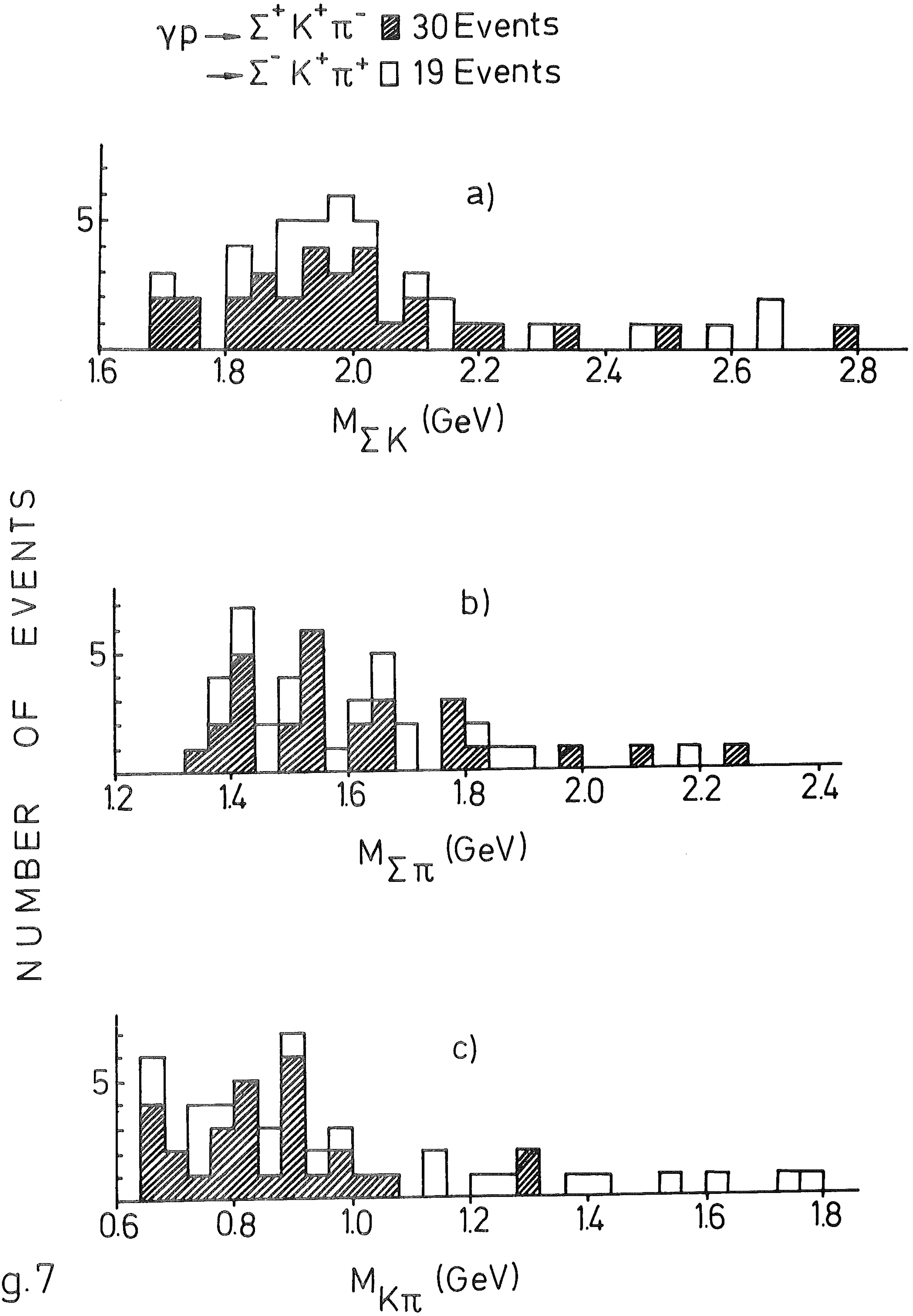

Lower limit of σ_{tot} ($\gamma p \longrightarrow$ strange particles)
(μb)
10
8
6
4
2
1
2
3
4
5
6
E_γ (GeV)

Fig.5



γp ⟶ ΛK⁺π⁰
⟶ ΛK⁰π⁺
All Photon Energies
a)
30
20
10
1.6
2.0
2.4
2.8
3.2
M_ΛK (GeV)
NUMBER OF EVENTS
b)
40
30
20
10
1.2
1.6
2.0
2.4
2.8
M_Λπ (GeV)
c)
30
20
10
0.6
1.0
1.4
1.8
2.0
M_Kπ (GeV)

Fig.6



γp → Σ⁺K⁺π⁻ 30 Events
→ Σ⁻K⁺π⁺ 19 Events
a)
5
1.6
1.8
2.0
2.2
2.4
2.6
2.8
M ΣK (GeV)
NUMBER OF EVENTS
b)
5
1.2
1.4
1.6
1.8
2.0
2.2
2.4
M Σπ (GeV)
c)
5
0.6
0.8
1.0
1.2
1.4
1.6
1.8
M Kπ (GeV)

Fig.7