Will CLAS Yield a Cornucopia of 'Strange' Resonances?

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ABSTRACT

We consider the existing data for photoproduction of strange particles in the energy range from 1 to 5 GeV. There is some experimental evidence that the majority of strange particle production modes have not been identified. Exclusive two-body channels which have been measured account for less than 10% of the total strangeness cross section. This may be a hint that numerous non-strange nucleon resonances in quark models which couple dominantly to strange particles are accessible via strangeness photoproduction. New experiments at, for example, Jefferson Lab, could reveal a new spectrum of baryonic resonances which decay to strange particles. Finally, a case is discussed for photoproduction of two purported "hidden-strangeness" states at a mass near 2 GeV, for which evidence has recently been reported. Some hints of one of these states is found in old data.

TOTAL CROSS SECTIONS

Bubble chamber experiments published in the late sixties provide us with a glimpse of strange particle photoproduction. They typically did not achieve enough resolution or statistics to make detailed analyses of isobar formation. They did have very good acceptance for all charged final states, and thus were able to broadly measure and categorize whole classes of reactions. We consider first the total cross section for photoproduction of strange particles from the Cambridge Bubble Chamber Group [1] in Figure 1. Strangeness-producing events were determined via neutral V's, kinked tracks, and energy-loss particle identifications. The data were corrected for both the neutral decay modes and for V's that would have appeared outside the 12" bubble chamber; the error bars reflect the resulting uncertainties. The measurement is probably reliable, given that in a bubble chamber it is pretty easy to identify strangeness-containing events by looking at the event topologies. The other major experiment of that era, from the ABBHHM Collaboration [2], published lower limits for strangeness photoproduction which were roughly consistent with the CBCG results.

As a function of photon energy the cross section rises from the Lambda threshold at .911 GeV. At about 2 GeV the cross section rises rapidly to 10 to 15 μb. The size of this cross section is quite large, given that the exclusive two-body $\gamma + p \rightarrow K^+ + \Lambda, \Sigma$ cross section peaks at only about 1 to 2 μb. This implies that strangeness in 3 and more-body final states is dominant at these energies, larger in fact than the two-body channels. Below we support this claim. If true, then analysis of the structure of these final states could reveal much about the resonant structure of the nucleon (or lack thereof) in the mass range above 2 GeV.

The total strangeness photoproduction cross section [1] seems to be much larger than the sum of the measured two-body exclusive channels. Figure 2 shows the breakdown by two-body channels including the reactions

$$\begin{aligned} \gamma + p &\rightarrow K^+ + \Lambda \\ &\rightarrow K^+ + \Sigma^0 \\ &\rightarrow K^+ + \Sigma(1385) \\ &\rightarrow K^+ + \Lambda(1520) \\ &\rightarrow \phi + p \end{aligned}$$

Below 2 GeV the strangeness production total cross section is well explained by the sum of Λ and Σ^0 production [3]. Both of these cross sections fall rapidly above 2 GeV, in a region where the total of all strange final states makes a substantial jump upwards. The $\Sigma(1385)$ is the only excited hyperon state which was identified in the bubble chamber data [1] [2], but without extracting the photon energy dependence. Both $\Sigma^0(1385)K^+$ and $\Sigma^+(1385)K^0$ final states were seen by ABBHHM. The best results were those of ABBHHM [2]: roughly $.67 \pm .27 \mu b$ for 1.4 to 2.0 GeV, and $.14 \pm .09$ μb for 2.0 to 5.8 GeV. Boyarski et al [4] detected the $\Sigma(1385)$ and the $\Lambda(1405)$ in an 11 GeV bremsstrahlung experiment at SLAC; by scaling their results by $1/k^2$, where k is the photon energy, they were consistent with [1] and [2]. Data for the $\Lambda(1520)$ came from the LAMP2 group at NINA [5]. This state was extracted using a tagged photon beam and a large aperture magnetic spectrometer. The cross section dropped from .74 to .24 μb over the energies of 2.8 to 4.8 GeV. The same group measured phi photoproduction [6], which is relevant since the phi decays to K^+K^-. Using their fits to the s and t dependence of this reaction, the total phi photoproduction cross section between 2.8 and 4.8 GeV is 0.3 μb.

It is thus clear that two-body exclusive channels do not sum up to the total strangeness photoproduction cross section seen by the CBCG. This fact was further examined with modest statistical precision [7], and the cross section was found to reside largely in the channels

$$\begin{aligned} \gamma + p &\rightarrow K + \Lambda + \pi \\ &\rightarrow K + \Sigma + \pi \\ &\rightarrow K + \overline{K} + N \end{aligned}$$

as seen in Figure 3. Their sample of events was too small (283 events) to do more than a preliminary analysis of isobar formation.

For the first of these three-body reactions, the $\Lambda\pi$ invariant mass spectrum from that study showed a peak corresponding to $\Sigma(1385)$ production, comprising about 26% of the $\Lambda + \pi + K$ final states. Thus, one sees a large cross section which has a significant component going through a particular two-body decay, in this case involving an excited Sigma. One can thus ask whether there might be non-strange nucleon resonances which decay to $K\Sigma(1385)$

which play a role in the large observed cross section; the relevant invariant mass data from CBCG are too poor in statistics to make any statements about this. Only new measurements can tell whether photons in this energy range are producing baryonic resonances which decay strongly to strange particles.

The phi, which reveals itself in the $K\overline{K}$ final state, accounts for only about 20% of the $K\overline{K}N$ final states seen [1]. It thus seems that there is also the possibility for strange resonances which decay to KN to contribute to the large cross section.

THEORETICAL ARGUMENTS

Might there be non-strange systems that decay preferentially to strange particles? The N^* states are known primarily through their πN decay modes. Among the known N^* states only the $N(1650)S11, N(1710)P11$, and $N(1720)P13$ are known to have ΛK couplings leading to decay branches in the neighborhood of 10%, but the uncertainties are very large.

In quark models of the non-strange baryons, there are typically many states which have not been observed in nature. Mechanisms have been proposed by which some of the unseen states can "decouple" from the $\pi - N$ "elastic" channel, and therefore evade detection in typical pion beam and pion detector experiments. As an example, in one QCD-improved quark shell model by Forsyth and Cutkosky [8], a handful of the "missing" states have substantial couplings to strange particles in the final state, as well as significant photocouplings. In that model only excitations of three valence quarks are considered. Table 1 gives a set of some of the states in this model which fall into this category.

	Mass State	Gamma piN (MeV)	Gamma piDelta (MeV)	Gamma KLambda (MeV)	Gamma KSigma (MeV)	Gamma Total (MeV)	Quad. Sum of Helicity Amp.
P13	1768	33	28	13	1	113	78
F35	1896	37	84	0	13	169	47
P33	1924	1	91	0	29	154	43
F37	1945	93	76	0	15	218	78
F15	2088	0	173	1	36	273	45
P33	2036	2	27	0	11	78	56
D35	2262	27	104	0	40	223	33
P33	1232	134	-	-	-	120	254

Table 1 - A few states from a QCD-improved quark shell model calculation [8] which predicts states decoupled from the πN channel but with substantial strange and photo couplings.

The primary aim of that study was to calculate the pionic widths of the known resonances, and in this they were quite successful. Decays to the inelastic channels were computed only for stable states, not including broader intermediate decay states like the Sigma(1385). There are thus concrete predictions for "new" states which can be reached in strangeness photoproduction. Most of these have total widths typical of resonances in the mass range around 2 GeV, and most of them couple to the Sigma rather than the Lambda. The photon energy needed to create these states needs to be above 1.6 GeV, where existing data leave off.

Beyond the valence quark model there are concepts leading to structures with active degrees of freedom involving the gluons or color-non-singlet quark groupings.

As an example of an 'exotic' kind of structure which might be exposed in the GeV energy range of photoproduction, we consider two putative hidden-strangeness states reported at the 1996 PANIC meeting by L. Landsberg [9]. He presented two states seen in coherent diffractive production in p + 12C reactions. They were:

$X(2000) \rightarrow \Sigma^0 + K^+$ $\quad M = 1996 \pm 7$ MeV, $\quad \Gamma = 99 \pm 21$ MeV

and

$X(2050) \rightarrow \Sigma(1385) + K^+$ $\quad M = 2052 \pm 6$ MeV, $\quad \Gamma = 35^{+22}_{-35}$ MeV

The states decayed predominantly to strange particles, with no signal seen in non-strange (pionic) final states. Their narrowness is surprising given their mass, since most resonances in this mass range have width from 200 to 400 MeV. These signals were interpreted as die to 5-quark exotics containing $s-\overline{s}$ quark pairs [10]. The authors believe that the states may be examples of $(qqq)-(q\overline{q})$ color-octet bonded or $(qq)-(qq\overline{q})$ color-sextet bonded states [11]. In this interpretation the narrowness of the states is due to an angular momentum barrier between the colored quark clusters, inhibiting decay, and the decoupling from pionic decay channels stems from an OZI suppression of decays that involve annihilation of the strange quarks.

Another possible interpretation is that these states, if they exist, are weakly bound 'molecular' states of strange particles. In particular, note that the masses are suggestive of K^*Y bound states, as shown in Table 2. The $K^*(892)$ has a width of 50 MeV. The binding energy of the states observed in Refs [9] [10] are in the range of a few tens of MeV. The states may be analogous to the $a0/f0(980)$ states, which have been widely interpreted as K-K bound states [12]. The K^*-Y states could therefore only decay directly through the "tails" of the K^* mass width. Alternatively, the decays could involve more complicated quark rearrangements, would be correspondingly slower, and yield other particles, such as ground state kaons, Λ's and Σ's or $\Sigma(1385)$'s.

Photoproduction offers a good way to test these internal structure hypotheses. Considering that a photon in the GeV energy range can act as a vector-dominance phi, photoproduction is a natural possibility for injecting the right quark content into the nucleonic system in the s channel. These states would appear as s-channel bumps of the appropriate widths, and thus would be straightforward to detect using a tagged bremsstrahlung beam and a suitable spectrometer, provided the s channel is dominant.

Internal Structure	Constituent Mass Sum (MeV)	Observed State	'Binding Energy' (MeV)
K*+ + Lambda	2007	X(2000)	10
K*+ + Sigma0	2084	X(2050)	35
K+ K-	988	a0/f0(980)	8

Table 2 - Mass comparisons of 'narrow' states with 'molecular' combinations of known mesons and baryons.

In both the 'exotic' and the 'molecular' interpretations of these states, the line shapes for a given channel should be Breit-Wigner resonances modified by the opening of the K^*Y channel. The integrated branching fractions for KY versus K^*Y final states ought to be strong clues to the structure of these states. In principal, using photoproduction with good (5 MeV) energy resolution should make it possible to measure the line shapes directly.

What do the existing data have to say about this?

EXPERIMENTAL ARGUMENTS

In terms of resonance physics involving strange particles, if the CBCG data are indeed reliable, then they suggest that CLAS at Jefferson Lab may be able to obtain a wealth of strange particle production data above 2 GeV which may reveal new information about non-strange baryon resonances. The argument is essentially that the photoproduction cross section between 2 and 4 GeV is large compared to ground state hyperon production, but very little else has been determined in the old experiments. Clearly CLAS is the preferred instrument, since photon energy rate and resolution is important, and ideally multi-particle final states must be reconstructed. Of course, facilities at GRAAL or ELSA could do some of this work as well, if their tracking and particle identification schemes work well enough. This is nearly virgin experimental territory, with very little previous information.

The hidden strangeness states introduced above would be produced as s channel resonances in photoproduction at photon energies of

$X(2000) \rightarrow \Sigma^0 + K^+ \qquad E_\gamma = 1700 MeV$

and

$X(2050) \rightarrow \Sigma(1385) + K^+ \qquad E_\gamma = 1750 MeV$

The bubble chamber total cross section data were too poor to reveal anything at these energies. In magnetic spectrometer experiments it should be possible to pick out strong s-channel resonances directly, simply by looking for the K^+ at any kinematically allowed fixed angle. Feller et al [13] used the bremsstrahlung difference method to detect $\gamma+p \to \Sigma^0+K^+$ at approximately fixed t (spectrometer angle) at Bonn. Figure 4 shows their data for $\Sigma 0$ production. (Also shown is Λ production for comparison of data quality, though these data result from an endpoint measurement.) It is surprising and unfortunate that a data point at a mass of 2000 MeV, where the $X(2000)$ might lurk, is missing. There is not much in the way of a hint that a 100 MeV wide structure is in this region. Fortunately, a experiment by Going et al from DESY covered a similar range of W (c.m. energy) [14]. This was a bremsstrahlung experiment where the photon endpoint was scanned over the range of interest, and results extracted from the excitation curves at fixed spectrometer momenta. Figure 5 shows their results for Λ and Σ^0's. For the Σ^0 case the mass coverage ranges up to exactly 2 GeV where the state of Landsberg *etal* might be. There is no sign of an s-channel resonance centered at 2 GeV with a 100 MeV width in these data. Thus we can conclude that there is no hint in the old photoproduction data for the $X(2000)$. In the Lambda channel there are various bumps that may or may not be significant. In both cases it would be interesting to obtain higher statistics samples.

The $\Sigma(1385)$ has not been extracted from any spectrometer experiment. We are forced to reconsider the sparse bubble chamber data. As was discussed in connection with Figure 3, the $\Sigma(1385)$ accounts for about 26% of the $\Lambda + K + \pi$ final state. Examining the second panel in Figure 3 we find a possible bump at roughly the right energy ($E_\gamma = 1.75$ GeV) to form the $X(2050)$. This bump amounts to no more that one high channel with a one-sigma error bar, but note how the error bars in this plot look suspiciously too large to be only statistical. The number of counts in each bin of this histogram is not clear, but perhaps the significance of the peak is statistically greater than it appears. In any event, this bump is the only hint of narrow s-channel structure in any of the final states from this CBCG measurement.

ABBHHM produced the analogous spectra from their experiment, as shown in Figure 6. The upper panel shows the $\Lambda + \pi^+ + K^0$ final state, to be compared to the second panel in Figure 3. Once again, there is one high channel near the photon energy corresponding to formation of an $X(2050)$, albeit with an enormous statistical uncertainty. Thus there are two measurements which hint at a possible feature which could be related to a fairly narrow s-channel resonance near a mass of 2050 MeV. It would be exciting to explore this with newer techniques.

NEW MEASUREMENTS AT CLAS

It would be very interesting if CLAS could improve upon this situation. The bulk of the planned "G1" data taking is to take place with a beam energy of 2.4 GeV, situating the data in a very good position to explore the 'transition' region, from the photoproduction of the ground state Lambda and Sigma to where the total strangeness cross section rises rapidly. Some data will be collected at 3.2 GeV as well. The kaon momenta are well within the range of capabilities of a detector like CLAS. The next step is to study the acceptance of the spectrometer for the three body strange final states of interest.

Only the K^+ would need to be detected initially. Combined with the photon tagging information one would form the missing mass spectrum of the recoiling particles. Based on the old experiments, there should be a prominant peak corresponding to formation of the $\Sigma(1385)$, probably sitting on top of a non-resonant background of $K^+\Lambda\pi$. Selecting the 36 MeV wide $\Sigma(1385)$ region with a suitable cut, one would then examine the cross section as a function of photon energy, or W. This would isolate formation of the $X(2050)$, if this state exists. Similarly, isolation of Lambda and Sigma formation could yield high-statistics data on s-channel bumps going to those final states.

Data for this work will already be collected as part of the G1 running period at CLAS. A measurement of the radiative decays of the low-lying hyperons is already approved [15]. It is essentially that same data set which can be analyzed for the study proposed in this note, but instead of concentrating on detection of the decays, this study would concentrate on the formation cross sections of the hyperons in the s-channel.

More exclusive final states would help isolate the intermediate and final states. For example, reconstructing the $K^*(892)$ via the $K\pi$ final states would be useful to make visible the K^*Y decays of the states. The CLAS acceptance for detecting single charged kaons in the relevant momentum range is about 20%. Count rates are adequate for detailed studies of these states. Acceptance studies for exclusive final state selection are in progress.

CONCLUSIONS

The large amount of strangeness photoproduction in the energy range of 1.7 to 5 GeV has been generally overlooked. Bubble chamber data and low-statistics spectrometer data are all that exist. Given that there are solid quark model predictions for nucleon resonant states leading preferentially to strange final states, and given suggestions that there may be interesting exotic structures in the same energy range, it would be useful to concentrate new experimental efforts on exploring this range. Initial experiments would be straightforward 'single-arm' kaon measurements using a tagged photon beam.

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- NOTE: THE FIGURES FOR THIS DOCUMENT ARE NOT IN ELECTRONIC FORM
- Figure 1 - Total cross section for strange particle photoproduction. From Ref. [1], bottom half of fig 10.
- Figure 2 - Exclusive strangeness production total cross sections. Total cross section (circles), $\Lambda + K^+$ (squares), $\Sigma 0 + K^+$ (triangles).
- Figure 3 - Cross sections as a function of photon energy for several final states with strangeness. Note especially panel (b). From Ref. [7], fig 1.
- Figure 4 - From Ref. [13] the exclusive differential cross sections as a function of photon energy for fixed t. a) Σ^0 production via bremsstrahlung difference method; b) Λ production via bremsstrahlung endpoint method.
- Figure 5 - From Ref. [14] the exclusive differential cross sections as a function of photon energy for fixed t. a) Σ^0 production; b) Λ production.
- Figure 6 - Cross sections as a function of photon energy for several final states with strangeness. Note especially the upper panel in comparison to the second panel in Fig. 3. From Ref. [2], fig 29.

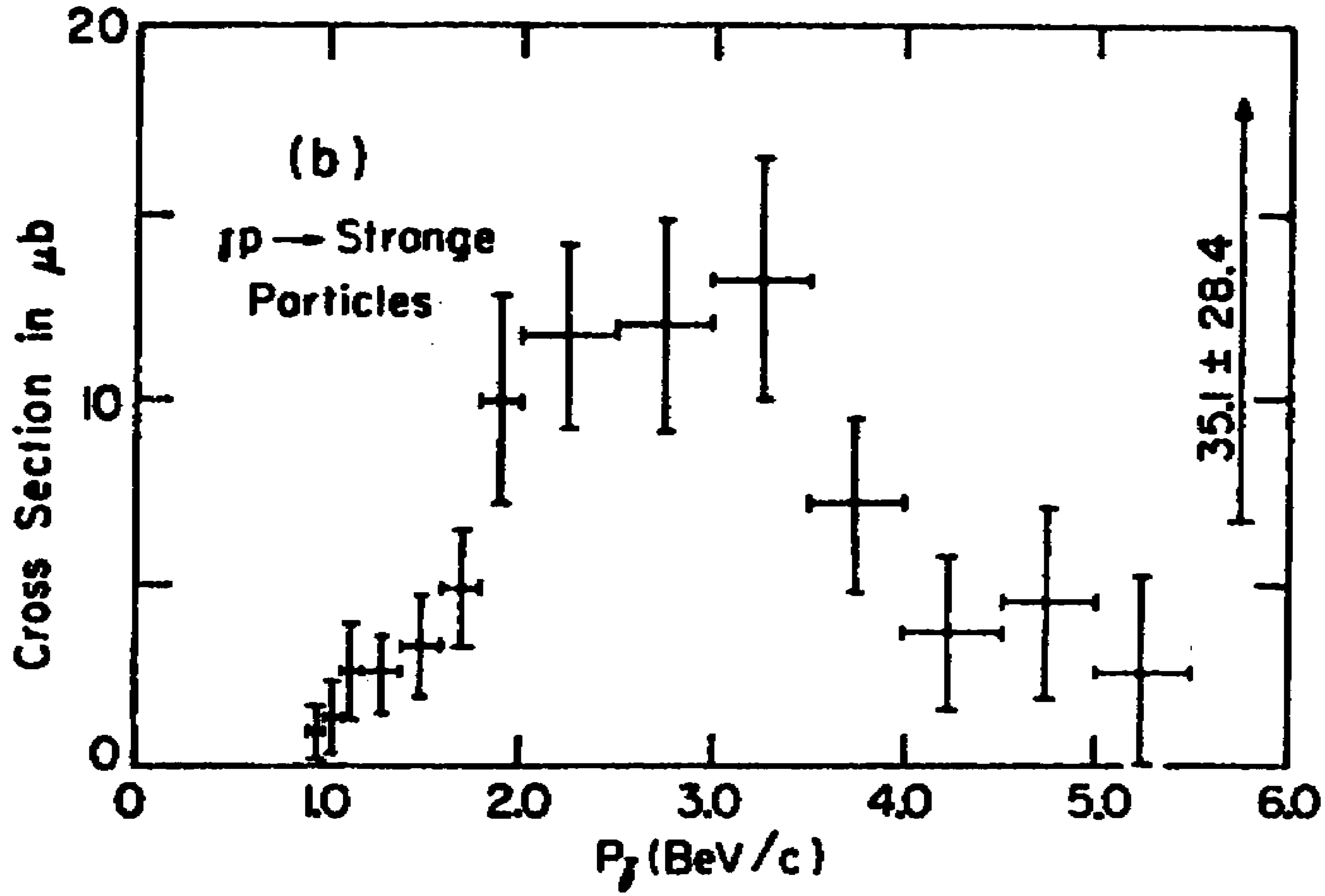

FIG. 10. Cross sections for (a) $\gamma p \rightarrow p + \pi^+ + \pi^- + \pi^-$ and (b) strange-particle events. The strange-particle cross section has been corrected for neutral decay modes and potential path.

FIGURE 1

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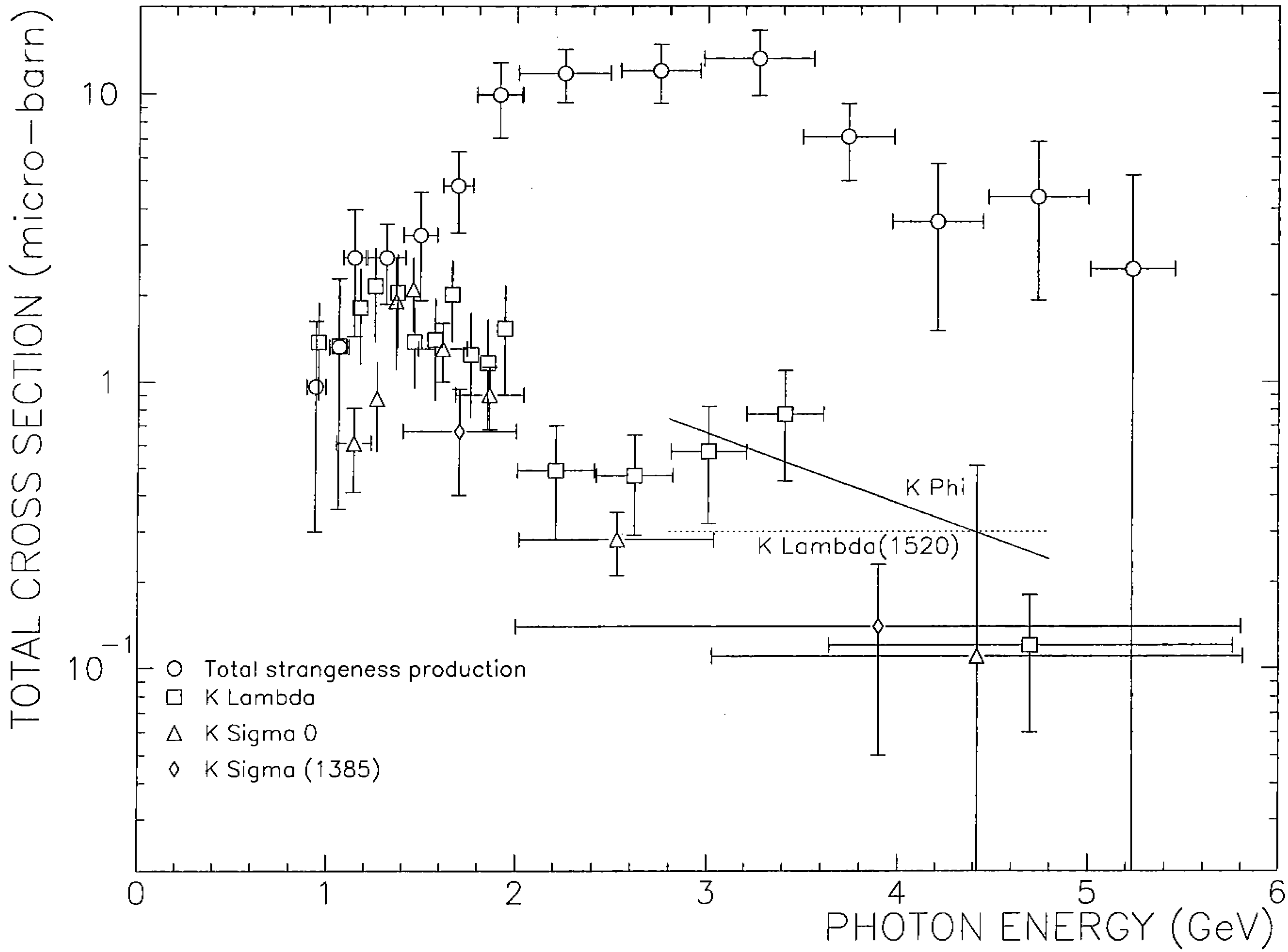

FIGURE 2

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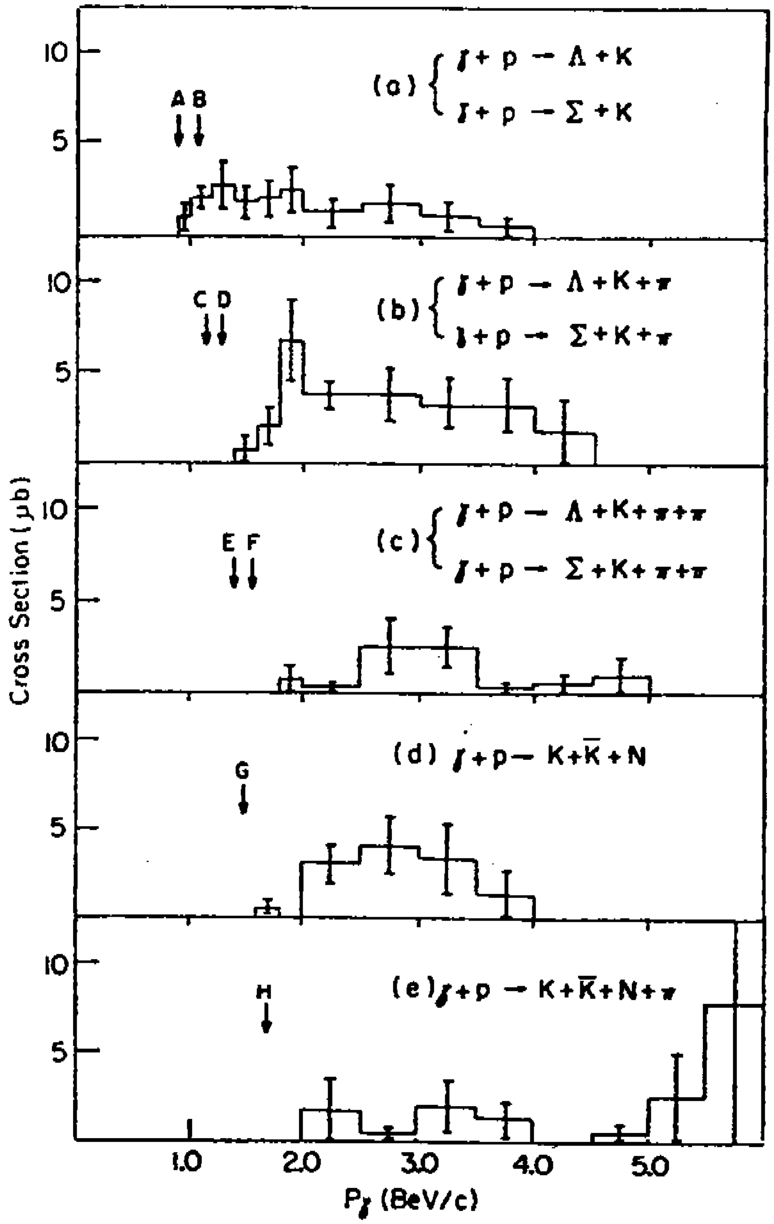

FIG. 1. Cross sections for production of various types of strange articles as a function of photon momentum. Threshold momenta or various event types: (A) $\Lambda^0 K^+$, (B) ΣK, (C) $\Lambda K\pi$, (D) $\Sigma K\pi$, (E) $\Lambda K\pi\pi$, (F) $\Sigma K\pi\pi$, (G) $K\bar{K}N$, (H) $K\bar{K}N\pi$.

FIGURE 3

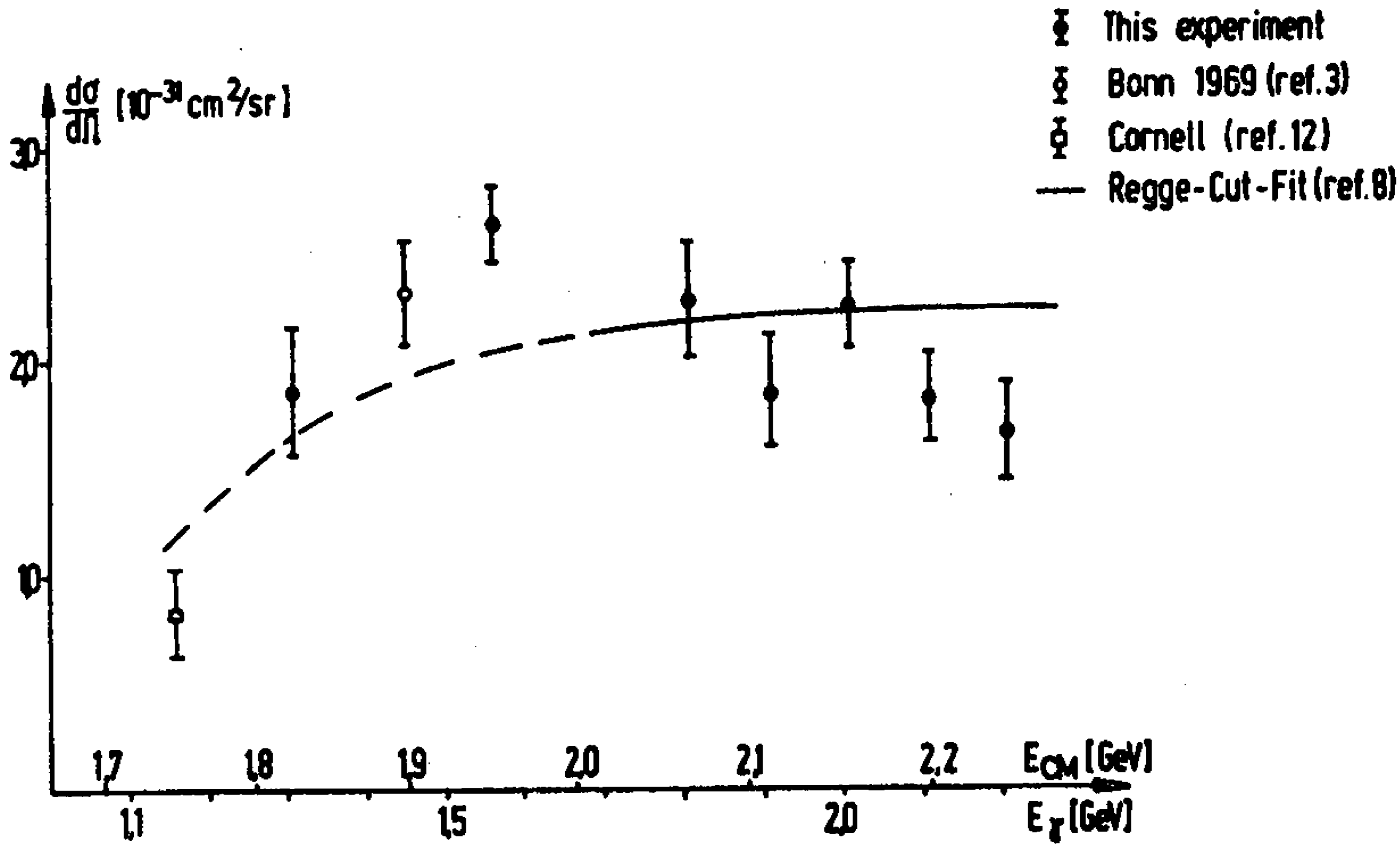

Fig. 4. $K^+\Sigma^0$ photoproduction at $t \approx -0.17$ [GeV²] ($25° < \theta_{C.M.} < 32°$).

FIGURE 4a

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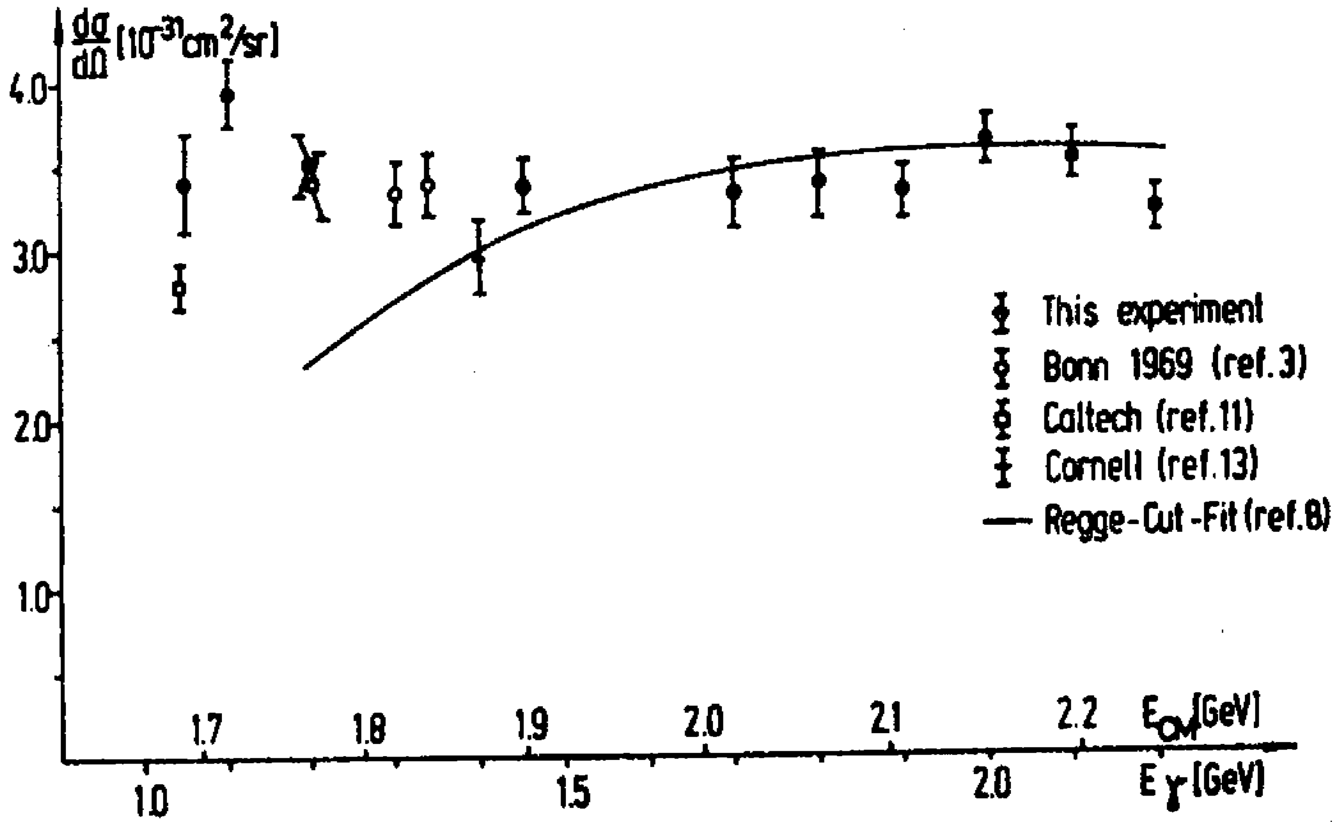

Fig. 3. $K^+\Lambda^0$ photoproduction at $t = -0.147$ [GeV^2]. ($23° < \theta_{C.M.} < 30°$).

FIGURE 4b

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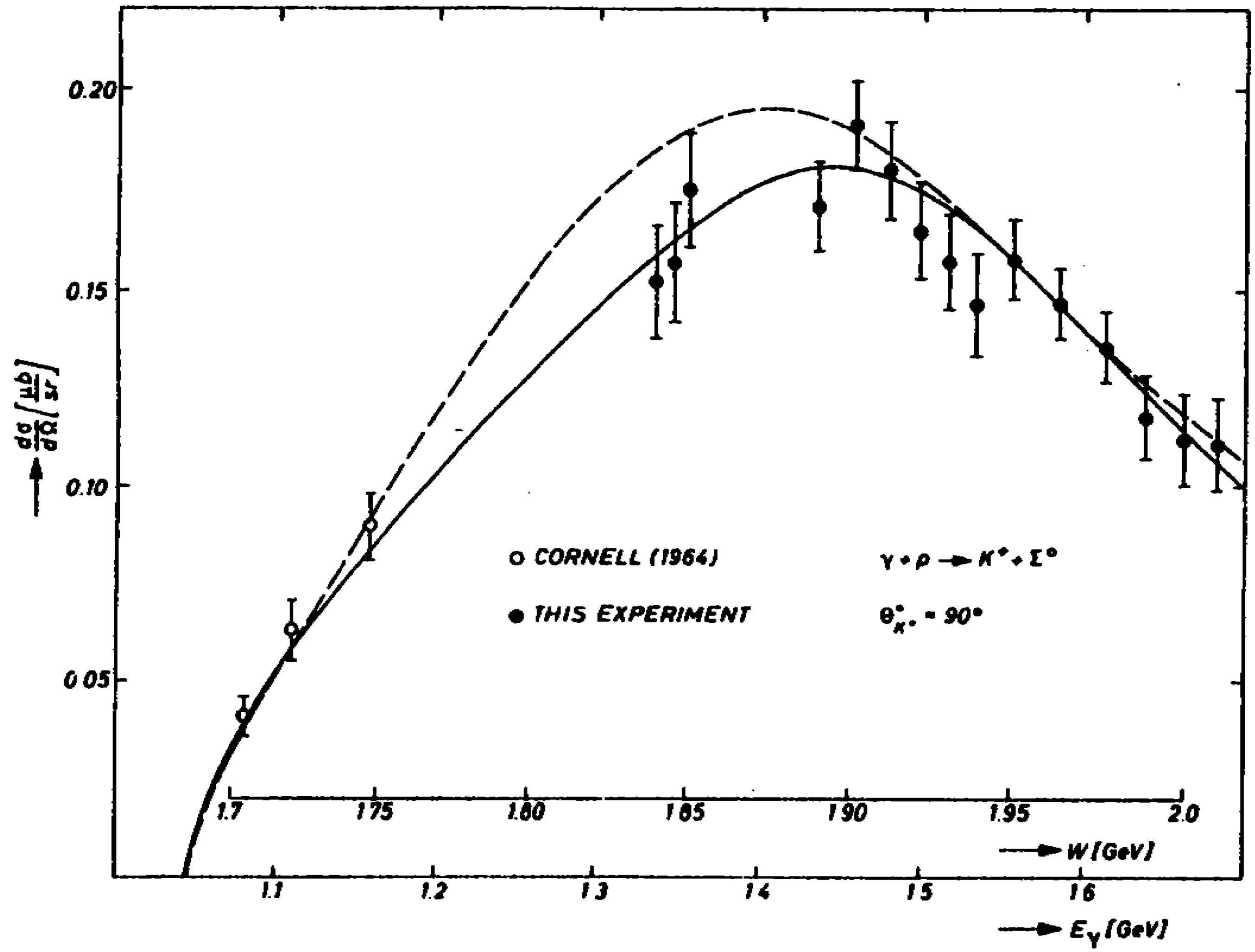

'ig. 7. Differential cross section for $\gamma p \to K^+\Sigma^0$ at a c.m. angle $\theta^*_K = 90^0$. Here E_γ s the photon energy in the lab. system and W the corresponding c.m. energy. The curves are results of phenomenological fits to the data [12].

FIGURE 5a

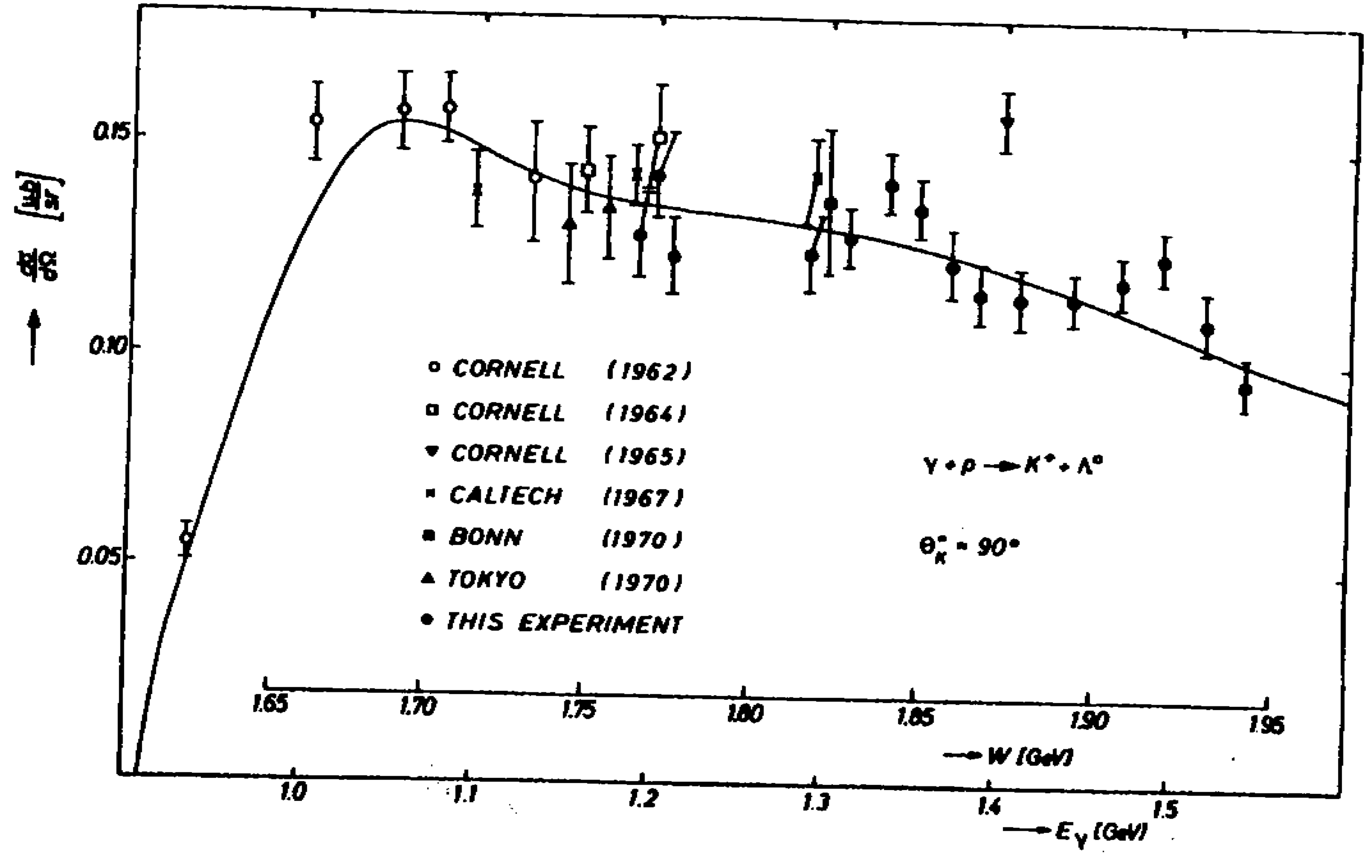

Fig. 6. Differential cross section for $\gamma p \rightarrow K^+\Lambda$ at a c.m. angle $\theta_K^* = 90^o$. Here E_γ is the photon energy in the lab. system and W the corresponding c.m. energy. The curve is a result of a phenomenological fit to the data [12].

FIGURE 5h

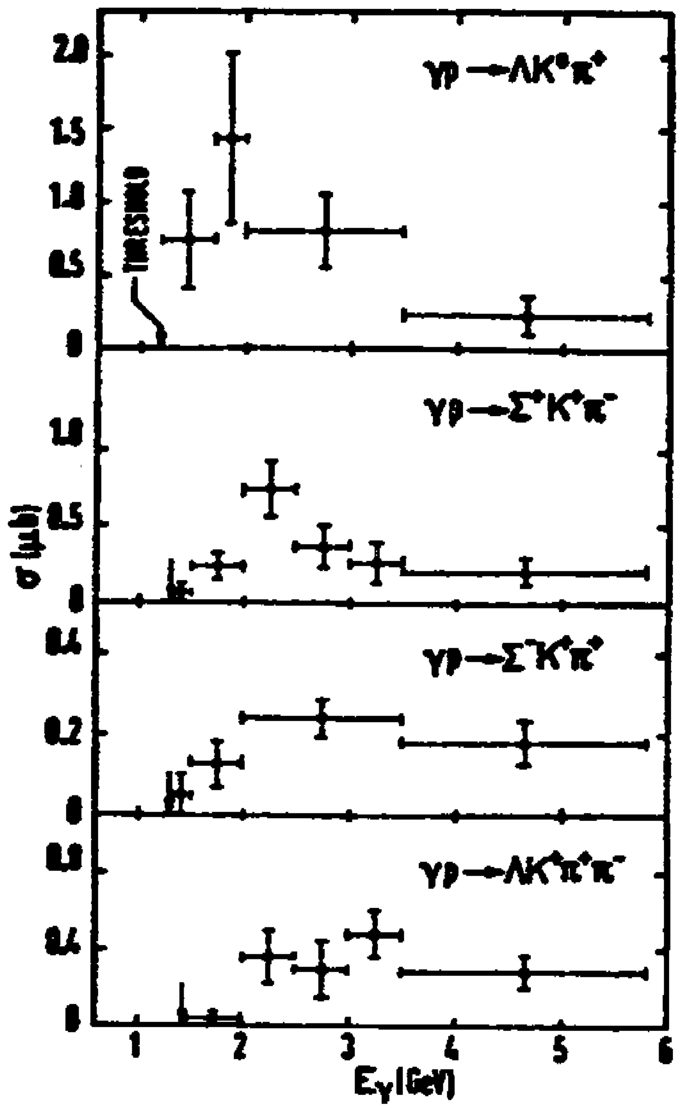

FIG. 29. Reactions $\gamma p \to \Lambda K^0 \pi^+$, $\Sigma^+ K^+ \pi^-$, $\Sigma^- K^+ \pi^+$, and $\Lambda K^+ \pi^+ \pi^-$. Cross sections as function of the photon energy.

FIGURE 6