Neglecting baryon mass differences, one finds the ratio of the two (reduced) matrix elements to be the same as was obtained before.

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[16] We also adopt the value of the pion-nucleon coupling, $g^2/4\pi = 14.6$, used by Gronau (Ref. 14) in this fit.

[17] The fourth parameter in Gronau's fit (his δ/φ, Ref. 14) is the ratio D/F for the γ_μ coupling at the strong VBB vertex in the case of the vector meson pole and does not figure in our considerations. The interested reader should consult Gronau's paper for a more detailed discussion of the theoretical (and mechanical) aspects of this fit.

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Evidence for Stray Baryonic States from a Study of $K^+\Lambda$ Photoproduction

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Strong confirmatory evidence is found for the existence of a D_{13} resonant state around 1670 MeV c.m. energy; and evidence, though somewhat weaker, is obtained for the existence of a stray baryonic F_{15} state recently conjectured by Donnachie.

We have studied the available data[1,2] below 2.25 GeV c.m. energy for the process $\gamma p \rightarrow K^+\Lambda$ by use of an energy-dependent multipole analysis. The analysis was done in keeping with the spirit of duality and only direct-channel resonance terms with a phase rotation were included along with background terms in both S and P waves.[2,3]

There are several reasons why it is particularly important to study this process at this time. (1) New data[1] indicate considerable structure in the differential cross section. There seems to be a rather pronounced dip around 1750 MeV c.m. energy and a second rather broad maximum centered at about 1910 MeV. This dip is more pronounced in the backward direction (Fig. 1), but can still be detected in the forward direction. (2) Our recently gained knowledge with regard to $K\Lambda$ and γN partial widths[3-6] makes it possible to determine the approximate contribution of several of the isospin-$\frac{1}{2}$ nucleon resonances to $K^+\Lambda$ photoproduction. (3) A very interesting conjecture made by Donnachie,[7] concerning the possibility of stray baryonic states (in particular the stray F_{15} state) which do not couple significantly to the πN channel, can be tested. (4) New and confirming information can be obtained regarding

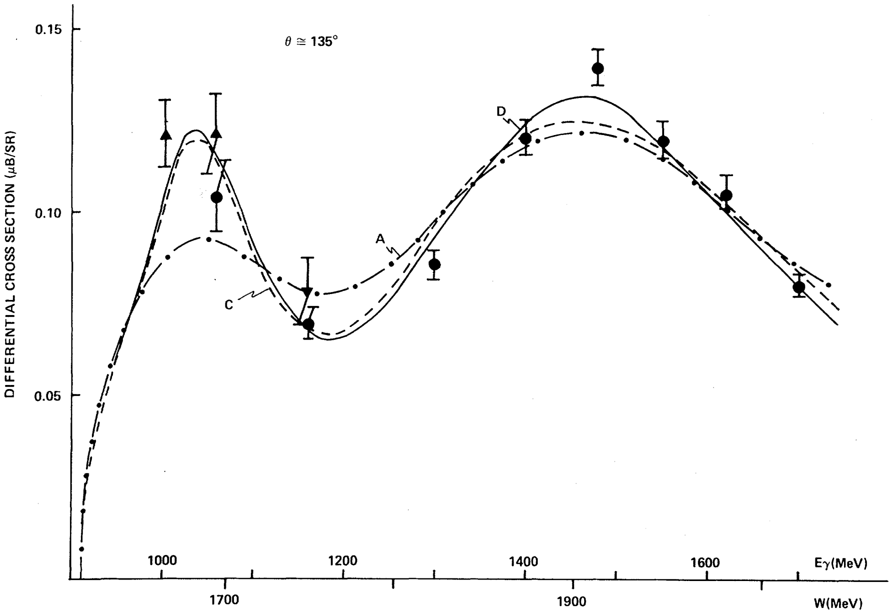

FIG. 1. Differential cross section as a function of c.m. energy W or lab photon energy E_γ at constant c.m. scattering angle θ. Circles, from Décamp *et al.*; triangles, from the Cornell data given in the compilation of Ref. 2.

the radiative decay widths of certain isospin-$\frac{1}{2}$ nucleon states. (5) More information about the elusive $D_{13}(1700)$ state can be obtained.

Here we shall be concerned mainly with the possible existence of stray baryonic states which do not couple significantly to the πN channel. A detailed quantitative discussion and a graphical description along with complete results on radiative widths will be given in a more lengthy future publication.[8]

There are several well-established isospin-$\frac{1}{2}$ nucleon resonance states over the energy region from threshold (1609 MeV) to 2250 MeV; however, from studies of pion photoproduction and $\pi^- p \to K^0\Lambda$ we have enough information[3-6] on the partial widths $\Gamma_{K\Lambda}$ and $\Gamma_{\gamma N}$ to be able to eliminate the $F_{15}(1688)$ and the $D_{15}(1670)$ as significant contributors to $K^+\Lambda$ photoproduction. There are also other reasons,[9] based on the quark model, for eliminating the D_{15}. On this same basis[9] one might be tempted to omit the $S_{11}(1700)$ state or a second D_{13} state, but in view of possible mixing[10,11] one cannot safely rule them out. In addition, we do not wish to be ruled by the quark model in making a comparison with data. Thus, we have as input the states listed as solution A in Table I. We make a comparison with the data using these states along with all known results

TABLE I. Comparison of solutions.

Solution	Description	States included	χ^2/N
A	γN and πN results; no stray states	$S_{11}(1700)$, $P_{11}(1750)$, $D_{13}(2040)$, $F_{17}(1990)$, $G_{17}(2190)$, $P_{13}(1860)$	3.44
B	γN and πN results; stray F_{15}	Same as A plus $F_{15}(1930)$	3.20
C	γN and πN results; stray D_{13}	Same as A plus $D_{13}(1670)$	1.86
D	γN and πN results; stray D_{13} and F_{15}	Same as A plus $D_{13}(1670)$ and $F_{15}(1930)$	1.70
E	Mass and width changes; no stray states	Same as A with small changes in masses and widths	3.04

about their masses, widths, and decay rates.[4-6,12] There are still several adjustable parameters including phase angles, background, and unknown radiative widths. The resulting χ^2 is not good; $\chi^2 = 544$ with 178 data points and 20 adjustable parameters.

Additional freedom is required to fit the data. We try two different approaches. First, we allow for stray states, making full use of known γN and πN results. Since the $D_{13}(1700)$ is not well established, we treat it as a stray state in this discussion. Second, we allow for small modifications in γN and πN results (reasonable changes in masses, widths, and decay rates) but do not allow for any stray states. These combinations along with the resulting values of χ^2/N are given in Table I. Here, N is the number of data points minus the number of adjustable parameters. In addition, some of the solutions from Table I are shown in Fig. 1.

It is quite clear that significant improvement is obtained by including a stray D_{13} state with a mass of about 1670 MeV. This is shown by comparing solutions A and C in Table I. We have searched for a solution with the only stray state being an F_{15} state in the mass region ($\simeq 1730$ MeV) suggested by Donnachie,[7] and while we certainly cannot rule this state out, we find no compelling evidence for it in that region. It appears that a much more optimum position for a stray F_{15} is at approximately 1930 MeV with a width of about 100 MeV. Solution D in Table I shows the relative importance of including this state, if the $D_{13}(1670)$ is also included. From solution B it is clear that the $F_{15}(1930)$ alone is not sufficient.

The second approach, allowing for small mass and width changes in the states listed in solution A of Table I, does not yield a good solution as can be seen by solution E. In addition, we have attempted to improve solutions B, C, and D by allowing small changes in the masses and widths. The values of χ^2 do indeed improve; however, since N decreases considerably, the ratio χ^2/N undergoes only small change and we do not show these results.

The importance of the $D_{13}(1670)$ is thus apparent. We have done well over 300 computer runs using a modified version of MINUIT[13] in an attempt to locate a satisfactory solution which does not include stray states and our best results are solutions A and E in Table I. All attempts to find solutions as good as D with the $D_{13}(1670)$ replaced by other states in this region (S_{11} and D_{15}) have thus far been unsuccessful. The most likely possibility as a replacement is an S_{11} state with a mass of about 1670 MeV and a rather narrow width of around 100 MeV. Detailed information about variable parameters throughout this region and the precautions which have been taken to check that the need for the $D_{13}(1670)$ is real will appear later in a more complete publication.[8]

TABLE II. Probable parameters for stray states.

State	Mass (MeV)	Width (MeV)	$\Gamma_{\gamma N}\Gamma_{K\Lambda}$ (MeV^2)
D_{13}	1670	100	0.48
F_{15}	1930	100	0.06

The resulting parameters for the D_{13} and F_{15} states are shown in Table II. The values of the parameters obtained for the D_{13} make it possible to identify it with the rather elusive $D_{13}(1700)$ reported earlier,[12,14] and the $F_{15}(1930)$ is new. This new state may be partly responsible for the second maximum which seems to be centered around 1910 MeV.

In conclusion, we find good evidence for a $D_{13}(1670)$ with a width of about 100 MeV, and there is evidence, though not as convincing, for a new $F_{15}(1930)$ with a width of about 100 MeV. It appears that these states can be accommodated in the l-excitation quark model as discussed by Donnachie.[7]

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