SOME COMMENTS ON ASSOCIATED Y-K PRODUCTION NEAR THRESHOLD BY PIONS AND PHOTONS

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Summary: Evidence is presented that the reactions (π or γ) $+ p \rightarrow$ (Λ or Σ) $+ K$, in the region of pion kinetic energies 0.8—1.4 GeV, are dominated by the resonances previously observed in the total $\pi - p$ cross-sections. Some general consequences of the resonant nature of these interactions are discussed.

1. It has been observed (Cresti, N. Y. Meeting, Am. Phys. Soc., 1958) that the cross-section for the reaction

$$\pi^- + p \rightarrow \Lambda^0 + K^0$$

rises very rapidly above threshold (0.76 GeV) to a peak in the region of 0.9 GeV, and thereafter follows a curve roughly parallel to the total $\pi^- + p$ cross-section. The latter is known to exhibit a $T = 1/2$ resonance in this region.

2. For a resonance, the relative decay probability for any mode should be independent of the mechanism of excitation of the resonance. At the pion kinetic energy $t_\pi = 0.9$ GeV

$$\frac{\sigma(\pi^- + p \rightarrow \Lambda^0 + K^0)}{\sigma_{tot}(\pi^- + p)} \simeq \frac{0.5 \text{ mb}}{40 \text{ mb}} = 0.012.$$

At the equivalent photon energy, $E_\gamma = 1.05$ GeV,

$$\frac{\sigma(\gamma + p \rightarrow \Lambda^0 + K^+)}{\sigma_{tot}(\gamma + p)} \simeq \frac{3\ \mu b}{200\ \mu b} = 0.015.$$

(These cross-sections are estimated from the work of a number of Cornell groups; private communications.)

3. There are a number of means of investigating the resonant $Y-K$ production. Assuming the resonant state were known, the energy dependence of the cross-section near threshold is determined by the relative $Y-K$ parity. However, for a resonance in the $\pi-p$ interaction, the interaction range is expected to be $R_\pi \approx \hbar/m_\pi c$, instead of $R_K \approx \hbar/m_K c$, which renders the angular momentum barriers rather ineffective. In the following table we give $\eta = kR$ for the $\pi + p \rightarrow Y + K$.

t_π (GeV)	$\Lambda + K$		$\Sigma + K$	
	kR_K	kR_π	kR_K	kR_π
0.95	0.57	2.15	0.28	1.0
1.25	0.91	3.30	0.75	2.7

It is clear that even relatively close to threshold (0.76 GeV for $\Lambda^0 - K$; 0.9 GeV for Σ-K) it will be very difficult to distinguish, through barrier-penetration effects, the parity of the resonant state (say, between $p_{3/2}$ and $d_{3/2}$ K meson emission).

4. Angular distributions could tell us more, but the observations are not yet sufficiently accurate. Example: Assume a $j = 3/2$ resonance in $\Lambda^0 - K$ production. The final state is $p_{3/2}$ or $d_{3/2}$. Let its (resonance) amplitude be $re^{i\alpha}$; since the threshold is above the resonance, $\pi/2 < \alpha < \pi$. Let the amplitude for s-wave production be a. Then

$$\frac{\sigma}{4\pi} = a^2 + 2r^2$$

in both cases. The " front-to-back "ratio is

$$Q = 2\,ar\cos\alpha \,/\, (a^2 + 2r^2)$$

for a $p_{3/2}$-resonance, and

$$Q = [ab + \tfrac{1}{2}(3b' + b)\,r\cos\alpha] \,/\, (a^2 + 2r^2)$$

for a $d_{3/2}$-resonance (b and b' are, respectively, the non-spin-flip and spin-flip p-wave production amplitudes). The observations indicate $Q < 0, |Q| \gg 0$ and increasing with π meson energy. Both these observations are consistent with the expected behaviour of the resonant phase-factor, $\cos\alpha$.

5. Another tool available is the Λ^0-polarization ($\bar{P}$), as observed by the decay asymmetry. In the examples quoted above, we would have, for a $p_{3/2}$-resonance

$$\bar{P} = \left[\tfrac{\pi}{2}\,ar\sin\alpha\right] \,/\, (a^2 + 2r^2)$$

and, for a $d_{3/2}$-resonance

$$\bar{P} = -\left[\frac{\pi}{8}(3b + b')\, r \sin\alpha\right] / (a^2 + 2r^2)\,.$$

Here, the indications are of $|\bar{P}| \approx 1$ and decreasing with increasing pion energy; this is not inconsistent with the expected $\sin\alpha$-behaviour.

6. The interpretation of $\Sigma - K$ production is considerably more complicated. Here we are involved with two resonances, the $T = 1/2$ (0.8 GeV) and the $T = 3/2$ (1.3 GeV). The data indicate: $\Sigma^{\pm}$ go forward; Σ^0 go back; $|\bar{P}(\Sigma^-)| \ll 1$ in $\pi^- + p \rightarrow \Sigma^- + K^+$. These data are not sufficient to yield a unique interpretation, especially in the absence of any other information concerning the nature of the $T = 3/2\, \pi - p$ resonance.

LIST OF REFERENCES

1. Blumenfeld, H., Chinowsky, W. and Lederman, L. M., Nuov. Cim., *8*, p. 296, 1958.

DISCUSSION — Steinberger and Feld

Morpurgo: I would like to make two remarks concerning the investigation of parity non-conservation in strong interactions. The first point is that it is very possible, in my opinion, although not necessary, that the longitudinal polarization of the produced hyperon is a relativistic effect of the order of v/c. To detect such effects one should perhaps go to higher energies. The second point is that pion-nucleon interactions at high energies should also be investigated and, for instance, in a reaction of double production of pions in pion-nucleon or photon-nucleon collision, there are some obvious angular distributions which may be investigated.

Adair: Perhaps it is appropriate now to say something about some of the phenomenological aspects of the strange particle production by pions and photons. These phenomenological estimates were made, using the R-matrix methods that Wigner used to derive threshold theorems quite a while ago. Such an analysis leads to interesting consequences. Let us regard the experimental data, particularly around 950 MeV, the energy region which was discussed most thoroughly by Steinberger. We find that the s-wave scattering and production amplitudes in the $T = \frac{1}{2}$ state for both Λ^0 and Σ production by π mesons interacting with nucleons are very nearly $\frac{1}{3}$ to $\frac{1}{2}$ of the maximum allowed by the conservation laws. This immediately suggests that perhaps the K meson coupling constant is not small. We can use the values of these production amplitudes then to make an extrapolation in energy of the Λ^0 cross-section on the basis that the effects of the internal region may not change very much over the small energy region involved. This will then be an extrapolation of the s-wave cross-section from 950 MeV. The Λ^0 and Σ cross-sections as a function of the pion energy are given in Fig. 25.

Notice that the Λ^0 cross-section and the Σ cross-section have a characteristic $\sqrt{E}$ dependence near threshold, but this energy dependence breaks down very near the threshold for Λ^0 production as the s-wave Λ^0 cross-section will go up to a cusp at the energy of the Σ-threshold. Of course, on top of the s-wave cross-section are superimposed contributions from the p-waves. This cusp in the s-wave cross-section will only occur if the Σ and Λ^0 have the same parity. The very large values of these S-matrix elements for the production of Λ^0- and Σ-hyperons provides some information about the final state interaction for Λ^0- and Σ-production in photon-nucleon interactions. Photoproduction of K mesons is related to pion production of K mesons in very much the same way as the photoproduction of π mesons is related to π-nucleon scattering. Using then the same matrix elements which will derive from the experimental values presented here, one can make some comments upon the K meson photoproduction. One can say that the phase of photoproduction matrix elements, for example, the photoproduction of Λ^0's and K's, is not simply related to the Λ^0-K scattering phase-shifts as it is when

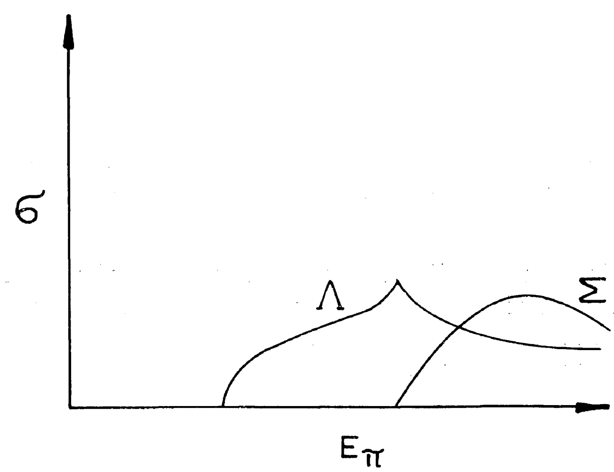

Fig. 25. *Λ^0 and Σ production cross-section.*

there is only one channel open. In fact, near threshold the phase-shift is not zero or even necessarily small. Another factor of interest is that one can make an estimate of the following reaction :

$$\gamma + p \rightarrow \Lambda^0 + K$$

via the final state interaction of the reaction

$$\gamma + p \rightarrow \pi + n \; .$$

If one takes the values of the cross-section of $\gamma + p \rightarrow \pi + n$ from the Cornell and Cal. Tech. data and the values of the matrix elements for $\pi + n \rightarrow \Lambda^0 + K$, one can get complete qualitative agreement with the experimental measurements of the $\Lambda^0 + K$ photoproduction from this contribution alone. In general, the final state interaction has the property that, as compared to the perturbation calculation into plane waves, it can either decrease or increase the interaction rate by factors of perhaps 3 or 4.

Treiman: Two questions : it was not clear to me how the amplitudes obtained by the Berkeley group were arrived at. What was assumed about the parameter α? Secondly, can such an analysis be done for Σ-production in order to set limits on the polarization? This is for purposes of later discussions of up-down asymmetries.

Good: The way the analysis was done was simply to repeat it several times for different values of α (*). The analysis cannot be performed for values of α less than about $\frac{3}{4}$ because then one cannot fit the angular distribution and the polarization with *s*- and *p*-waves. I should say that the analysis is based on *s*- and *p*-waves only. As for the Σ-production it is not possible to set a limit, one does not know whether the Σ's have no asymmetry because they are unpolarized or because they have no intrinsic asymmetry parameter.

Reynolds: One remark concerning the direct nucleon-nucleon strange particle production cross-section : a little information is supplied by an experiment done by the Princeton group with Bowen and others, in studying the Z dependence of Λ^0-production with both pion and proton beams. One finds that if one takes the value of possible absorption cross-sections of Λ^0's in getting out of the nuclei, the nucleon-nucleon production results can be explained without involving any significant direct nucleon-nucleon production cross-section. That is, nothing is required more than $^1/_{10}$ of the known pion-nucleon Λ^0-production cross-section.

Lederman: With respect to the question of non-conservation of parity in Λ^0-production, I would just like to remind you that there are a large number of experiments, all done with cloud chambers on production of Λ^0's in complex nuclei and showing a forward-backward asymmetry of the pion emission relative to the Λ^0 line-of-flight. This kind of data would indicate violation of parity in the production process unless one wants to revive parity doublets. A recent review of the literature is given by Blumenfeld, Chinowsky and Lederman [1]. Whether the agreement of so many different experiments represents a propagation of bias or not, I do not know but it is all in the literature.

Newth: Could I ask Steinberger whether he has any information on pair production of K mesons, even an excitation curve from machine data?

Steinberger: No.

R. R. Wilson: We have examined at Cornell our excitation curve looking for the effects just mentioned by Feld concerning the possible effects of the resonance in the pion production on the photoproduction of the K-Λ^0 and looking for the implied momentum cubed variation of the cross-section with the momentum of the K . The measurements do go down quite close to threshold, namely to within 23 MeV. The data indicate instead a linear variation with the momentum which means that the K meson is made in an *s*-wave. In trying to determine the question of the scalarity of the K, the photoproduction in an S-state implies that one has magnetic dipole absorption in the case that the K meson is a scalar, or electric dipole absorption in the case that the K meson is a pseudoscalar. We can expect now to be able to make a very clear differentiation between these two possibilities if we look for the photoproduction of the θ^0's on neutrons. Experiments in this direction are being started.

Adair: This is rather a minor point concerning Feld's discussion on the possible effects of *d*-waves. Even if one uses a radius so small as the K meson Compton wavelength (I made some calculations using a particular model which probably does not make too much sense) one can get enough *d*-wave, particularly in amplitude, to affect considerably the production amplitude calculations shown by Steinberger from the Columbia group and the Berkeley group.

Marshak: I just want to ask Wilson : does not a combination of the excitation function for a K^+ and your angular distribution indicate more strongly that it is a pseudoscalar than a scalar particle? That is, one can reconcile the excitation function with both possibilities as you indicated, but one needs a combination of accidents to get the rather isotropic angular distribution which goes so nicely with the pseudoscalar possibility.

R. R. Wilson: Yes, if we compare your weak coupling calculation and that of Moravcsik with our measurements, then we get slightly better agreement with your pseudoscalar calculations than with the scalar case. The scalar case does require a particular choice of the effective magnetic moment of the proton, of the Λ^0, and of the coupling constant.

(*) See appendix p. 323.

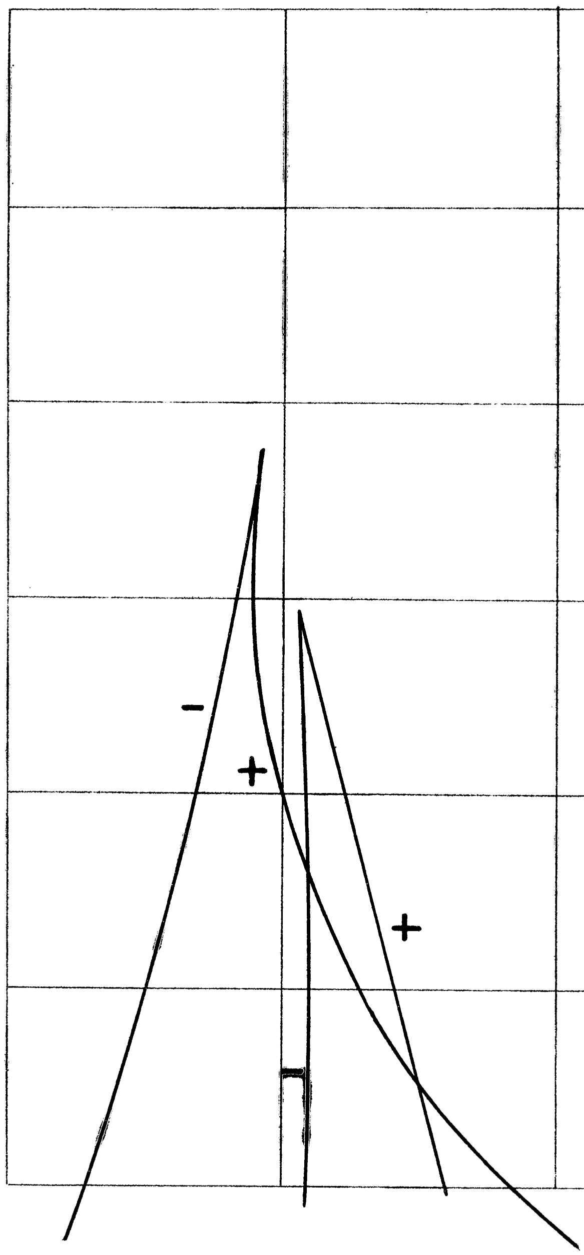

Fig. 26. *Probable case of the decay of a* Ξ^0 *in the Pic du Midi cloud chamber:*
$\Xi^0 \rightarrow \Lambda^0 + \pi^0$; $\Lambda^0 \rightarrow p + \pi^-$; $\pi^0 \rightarrow e^+ + e^- + \gamma$.

But the limits of disagreement are not at all beyond our experimental errors.

Marshak: Nor the theoretical.

W. Powell: For the sake of completeness we might add here the fact that we obtained two cascade particles in a beam of 5 GeV π^- mesons. The cross-section based on these two events is between one and two μbarns with no corrections made.

Kaplon: Also for the sake of completeness I would like to point out that I have received an event, which should have been turned over to Steinberger, from the Pic du Midi group of the Ecole Polytechnique, observed in their double cloud chamber experiment. This event is best interpreted as the decay of a Ξ^0 (Fig. 26). I think this is the first experimental evidence indicating the existence of this particle. I would like to make another comment with respect to Newth's question concerning K^+ and K^- production. If my memory is correct, a group at Brookhaven some time ago ran an excitation function on K^- at the Brookhaven energies and it seemed to be, with very coarse statistics, in agreement with phase-space considerations on some simple model calculations by Sternheimer.

Nikitin: I should like to stress that the weakest point of the paper of Alikhanian's group is surely the intensity of the mass 500 component relative to the μ meson flux. It may be uncertain, at least by a factor of three, because of the large difficulties involved in evaluating the geometrical correction for the efficiency of the apparatus used.

Reynolds: With reference to Keuffel's experimental set-up, I should like to point out the obvious possibility that his dE/dx-counter might be detecting a fluctuation on the high side of the Landau distribution. He minimizes this effect by having a Cherenkov-counter in anticoincidence, so that only slow particles are detected, not fast particles giving high dE/dx accidentally; so only slow particles are measured. One other remark concerns the work of Lindeberg using the upper cloud chamber of the Princeton set-up. Using only drop counting and momentum, he obtained three particles with a mass very close to 500; the internal errors are essentially the same as the external errors on the events. The total number of μ mesons is unknown since the data were not scanned statistically. So that this is what actually led us on to continue the double cloud chamber experiments which have proved negative so far.

Peyrou: I do not understand exactly the point of this uncertainty in the geometrical correction of the luminosity of the apparatus of Alikhanian, because the calculation is quite straightforward; secondly the apparatus could be very well standardized by the flux of protons and μ mesons which is known at 3200 m. So I cannot believe that there is an uncertainty of a factor of twenty or even five.

Nikitin: I suppose that the most difficult thing in evaluating these corrections is the stray field because the μ mesons have quite small momenta. One has to take into account the stray field, but it is very difficult to do it, and all the uncertainties come from this point, as far as I know.

Goldhaber: I want to ask Nikitin if somebody knows in how many cases Alikhanian and his group saw secondaries from stopping μ mesons, especially negative ones. The efficiency of detecting such secondaries would be useful to know in discussing conceivable decay modes of his particles.

Nikitin: I have no information on this point.

W. T. Sharp: I should just like to remark that to look for the mass 500 particle, Hincks at Chalk River is doing a cosmic ray sea level counter telescope experiment which in a few weeks' running should give rather better sensitivity than the results quoted. Unfortunately there are no results as yet.

Kaplon: I would also like to comment again here, for the sake of completeness, that there exists in the literature, in JETP, the report of three events observed in emulsion, of particles which decay into π mesons of the unique range of something like 390 μ. Two cases of π^+, I believe, and one case of π^-. This is a short note in the journal but it is very difficult really to understand what the people mean to interpret from this note. But if on this basis one assumes that this is a two-body decay to a π^+ and a π^0, one again gets a mass 500 particle out of this. I would like to hear some comment if possible from the Russian people about this observation.

Nikitin: I have no comment.

Butler: From all these contributions to the discussion on the existence of the mass 500 particle we must conclude that this is a very fascinating topic, but obviously no definite conclusions can be reached at the meeting this year. Many of us have heard that Alikhanian and his colleagues have a very fine new apparatus which they are taking to the mountains this summer. We have also heard of other experiments elsewhere now being planned and started, as well as those already running. Thus I feel we can only conclude that there are still suspicions of this particle's existence, but we must wait until the high energy conference next year for a definite answer.