

Looking for Chiral Anomaly in Pion Photoproduction on Kaons¹

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Abstract—In an experiment currently being performed at the Institute for High Energy Physics, Serpukhov, Russia, a beam of charged kaons is directed on a copper target. In the electromagnetic field of the target nuclei, two reactions occur: $K^+\gamma \rightarrow K^+\pi^0$ and $K^+\gamma \rightarrow K^0\pi^+$. A peculiar distinction between these two reactions is that there is a chiral anomaly contribution in the former reaction, but not in the latter. This contribution can be directly seen through comparison of the cross sections of these reactions near the threshold. In Ref. [1] expressions for these cross sections are derived taking into account the anomaly and the contribution of the lightest vector mesons. In this talk an overview of the derivation is provided and cross sections numerical values near the threshold are presented.

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1. INTRODUCTION

An experiment is currently being performed at the Institute for High-Energy Physics at Serpukhov, Russia, in which a beam of charged kaons with the energy of 17.7 GeV is scattered by a copper target [2]. Two reactions occur in the electromagnetic field of copper nuclei: $K^+\gamma \rightarrow K^+\pi^0$ and $K^+\gamma \rightarrow K^0\pi^+$. A theoretical prediction of the results of the experiment is the subject of [1].

This experiment is in a way a continuation of a similar experiment performed earlier at the same facility [3]. Then a beam of charged pions with the energy of 40 GeV was directed at various targets, and cross section of the $\pi^-\gamma \rightarrow \pi^-\pi^0$ reaction near the threshold was measured. From the theoretical point of view both experiments are interesting because they allow for observation of the chiral anomaly.

2. PIONS

Let us consider first what research has been done in the case of pions. Let

$$A(\pi^-\gamma \rightarrow \pi^-\pi^0) = h(s, t, u) \epsilon^{\mu\alpha\beta\gamma} A_\mu \partial_\alpha \pi^- \partial_\beta \pi^+ \partial_\gamma \pi^0 \quad (1)$$

be the amplitude of the $\pi^-\gamma \rightarrow \pi^-\pi^0$ reaction, where $h(s, t, u)$ is some function of Mandelstam variables. At

$s = t = u = 0$, in the absence of the chiral anomaly, $h(0) \equiv h(0, 0, 0) = 0$. However, through the connection of (1) to the $\pi^0 \rightarrow \gamma\gamma$ amplitude it was obtained in [4, 5] that

$$h(0) \equiv h(0, 0, 0) = \frac{e}{4\pi^2 F_\pi^3} = 9.8 \text{ GeV}^{-3}, \quad (2)$$

where $F_\pi = 92.2 \text{ MeV}$ is the $\pi \rightarrow \ell\nu$ decay constant. This expression is also contained in the Wess–Zumino anomalous lagrangian term [6], and it can be calculated from diagrams like the one in Fig. 1. The fact that $h(0) \neq 0$ is the manifestation of the chiral anomaly.

The value $h(0)$ cannot be directly measured in an experiment, because no experiment can measure an amplitude at $s = t = u = 0$. However, $h(s, t, u)$ can be measured near the threshold and then extrapolated to the point $s = t = u = 0$ with the help of some phenomenological model. Using formulas from [8], experimentalists provided the following value for $h(0)$ [3]:

$$h(0)_{\text{exp}} = 12.9 \pm 0.9 \pm 0.5 \pm 1.0 \text{ GeV}^{-3}, \quad (3)$$

where the first error is statistical, the second error is systematic, and the last error comes from the unknown phase of the interference term between the anomaly and vector meson exchange contributions. Later this value was updated by taking into account higher-order and electromagnetic corrections [9–11] to

$$h(0)_{\text{exp, upd}} = 10.7 \pm 1.2 \text{ GeV}^{-3}, \quad (4)$$

which is in even better agreement with the theoretical value (2).

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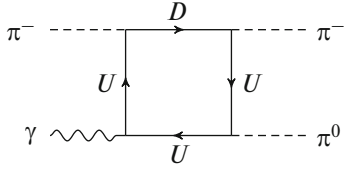


Fig. 1. One of the anomalous diagrams for the $\pi^- \gamma \rightarrow \pi^- \pi^0$ process. Here U and D are Pauli–Villars regulator fields. For more details see the textbook [7].

3. KAONS

As long as the full $SU(3)_L \times SU(3)_R$ chiral symmetry is taken into account, the $K^+ \gamma \rightarrow K^+ \pi^0$ reaction has the same anomalous contribution as the $\pi^- \gamma \rightarrow \pi^- \pi^0$ reaction [6]. It is instructive to remind the calculation of the anomalous contribution to these reactions. In Fig. 2 each triangle is a schematic representation of three Feynman diagrams. Attaching an incoming photon to a side of a triangle, one obtains a diagram similar to the anomalous diagram presented in Fig. 1. Summing up these diagrams one gets $\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = 1$ times the anomaly for diagrams in Figs. 2a, 2c, and $\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0$ times the anomaly for diagrams in Fig. 2b,d. Unlike the case of pions, the final states in diagrams in Figs. 2c, 2d are different, so cross sections of two different reactions can be measured at the experiment: $K^+ \gamma \rightarrow K^+ \pi^0$ which has an anomaly contribution, and $K^+ \gamma \rightarrow K^0 \pi^+$ which does not. Comparing these cross sections at low energies, one can directly observe the effect of the anomaly.

Following the approach developed for the case of pions in [8], cross sections for the reactions $K^+ \gamma \rightarrow K \pi$ were calculated in [1]. The calculation is straightforward except for the two tricky points which prior works [12, 13] failed to take into account:

(1) In the limit $s, t, u \rightarrow 0$, $SU(3)_L \times SU(3)_R$ chiral symmetry dictates that only the anomalous contribution should survive, however, direct application of Feynman rules to vector meson exchange diagrams result in expressions that do not satisfy this constraint. To force the correct amplitude behaviour, values of vector meson contri-

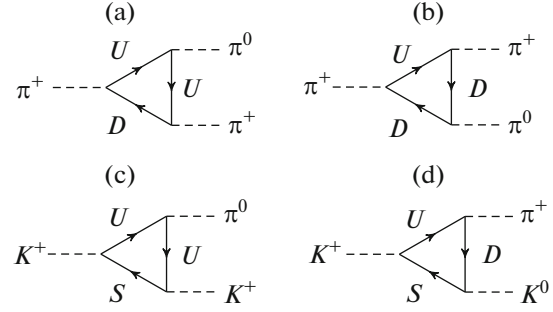


Fig. 2. Twelve Feynman diagrams for the $\pi^+ \gamma \rightarrow \pi^+ \pi^0$ and $K^+ \gamma \rightarrow K \pi$ reactions, presented in a schematic way. To restore the complete diagrams, a photon should be attached to each propagator of Pauli–Villars regulator fields. The anomaly contribution is proportional to the sum of electric charges of the regulator fields which enter the corresponding triangle graph.

butions at $s = t = u = 0$ were subtracted from the amplitude obtained from the Feynman diagrams.

(2) To properly consider interference between vector meson exchange diagrams, one needs to know relative signs of coupling constants. They were carefully extracted from the $SU(3)$ vector symmetry in [1]. The sign of the interference term between the sum of the vector meson exchange contributions and the anomalous contribution remained undetermined.

The result of the calculation is

$$\begin{aligned} \frac{d\sigma(K^+ \gamma \rightarrow K^+ \pi^0)}{dt} &= \frac{1}{2^7 \pi} \left(t + \frac{(st - m_{K^+}^2 m_{\pi^0}^2)(t - m_{\pi^0}^2)}{(s - m_{K^+}^2)^2} \right) \\ &\times \left| \frac{e}{4\pi^2 F_\pi^3} + \frac{2f_{K^{*+} K^+ \gamma} f_{K^{*+} K^+ \pi^0}}{m_{K^{*+}}^2 - s - i\sqrt{s} \Gamma_{K^{*+}}(s) m_{K^{*+}}^2} \frac{s}{m_{K^{*+}}^2} \right. \\ &+ \frac{2f_{K^{*+} K^+ \gamma} f_{K^{*+} K^+ \pi^0}}{m_{K^{*+}}^2 - u} \frac{u}{m_{K^{*+}}^2} + \frac{2f_{\rho^0 \pi^0 \gamma} f_{\rho^0 K^+ K^+}}{m_{\rho^0}^2 - t} \frac{t}{m_{\rho^0}^2} \\ &\left. + \frac{2f_{\omega \pi^0 \gamma} f_{\omega K^+ K^+}}{m_\omega^2 - t} \frac{t}{m_\omega^2} + \frac{2f_{\phi \pi^0 \gamma} f_{\phi K^+ K^+}}{m_\phi^2 - t} \frac{t}{m_\phi^2} \right|^2, \end{aligned} \quad (5)$$

$$\begin{aligned} \frac{d\sigma(K^+ \gamma \rightarrow K^0 \pi^+)}{dt} &= - \frac{stu - sm_{K^0}^2 m_{\pi^+}^2 - tm_{K^+}^2 m_{K^0}^2 - um_{K^+}^2 m_{\pi^+}^2 + 2m_{K^+}^2 m_{K^0}^2 m_{\pi^+}^2}{2^7 \pi (s - m_{K^+}^2)^2} \\ &\times \left| \frac{2f_{K^{*+} K^+ \gamma} f_{K^{*+} K^0 \pi^+}}{m_{K^{*+}}^2 - s - i\sqrt{s} \Gamma_{K^{*+}}(s) m_{K^{*+}}^2} \frac{s}{m_{K^{*+}}^2} + \frac{2f_{K^{*0} K^0 \gamma} f_{K^{*0} K^+ \pi^+}}{m_{K^{*0}}^2 - u} \frac{u}{m_{K^{*0}}^2} - \frac{2f_{\rho^+ \pi^+ \gamma} f_{\rho^+ K^+ K^0}}{m_{\rho^+}^2 - t} \frac{t}{m_{\rho^+}^2} \right|^2. \end{aligned} \quad (6)$$

where f_i are coupling constants, and $\Gamma_{K^{*+}}(s)$ is the full width of a virtual K^{*+} -meson.