Looking for chiral anomaly in $K\gamma \to K\pi$ reactions

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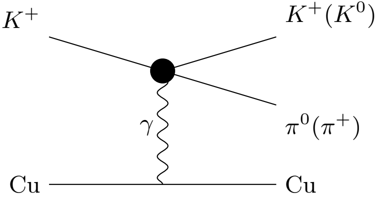
Institute for High-Energy Physics
Protvino, Russia
OKA Detector

Current experiment
$E_K = 17.7$ GeV.



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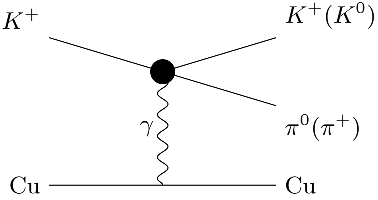
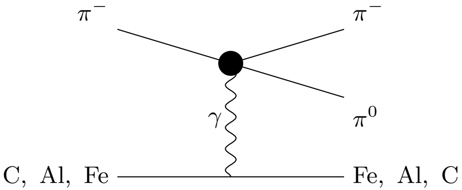
$E_K = 17.7$ GeV.

[Yu. M. Antipov *et. al.*, Phys. Rev. **D36**, 21 (1987)]
$E_\pi = 40$ GeV.





$$A(\pi^-\gamma \to \pi^-\pi^0) = h(s,t,u) \cdot \varepsilon^{\mu\alpha\beta\gamma} A_\mu \partial_\alpha \pi^- \partial_\beta \pi^+ \partial_\gamma \pi^0$$

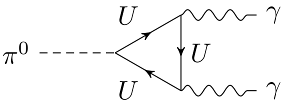
Sutherland-Veltman (chiral symmetry): $h(0,0,0) \equiv h(0) = 0$

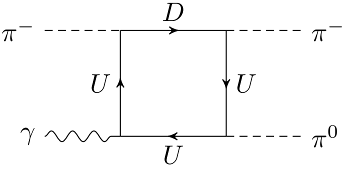
Relation to the $\pi^0 \to \gamma\gamma$ process[1]
Wess-Zumino anomaly[2]
Direct calculation of the box

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

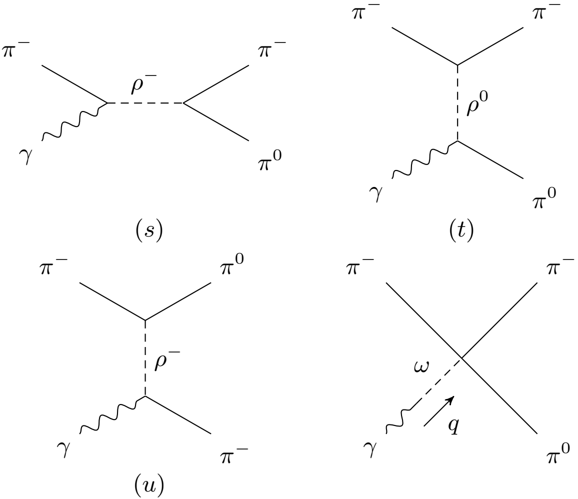
($F_\pi = 92.2$ MeV from $\pi \to \ell\nu$ decay)

$h(0) \neq 0 \Rightarrow$ chiral anomaly





[1][Terent'ev, JETP Letters **14**, 94 (1971)]
[2][Wess, Zumino, Phys. Lett. **37B**, 95 (1971)]



$$A(\pi^-\gamma \to \pi^-\pi^0) = h(s,t,u) \cdot \varepsilon^{\mu\alpha\beta\gamma} A_\mu \partial_\alpha \pi^- \partial_\beta \pi^+ \partial_\gamma \pi^0$$

$$h(s,t,u) = h(0) \left\{ 1 + \frac{2 f_{\rho\pi\pi} f_{\rho\pi\gamma}}{m_\rho^2 h(0)} \left[\frac{s}{m_\rho^2 - s} + \frac{t}{m_\rho^2 - t} + \frac{u}{m_\rho^2 - u} \right] + \frac{f_{\omega\gamma} f_{\omega 3\pi}}{m_\omega^2 h(0)} \frac{q^2}{m_\omega^2 - q^2} \right\}$$

[Terent'ev, Phys. Lett. **38B**, 419 (1972)]

$$A(\pi^-\gamma \to \pi^-\pi^0) = h(s,t,u)\cdot \varepsilon^{\mu\alpha\beta\gamma} A_\mu \partial_\alpha \pi^- \partial_\beta \pi^+ \partial_\gamma \pi^0$$

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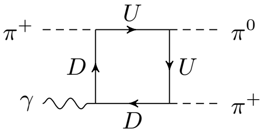
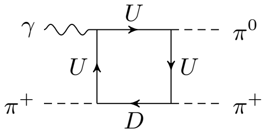
$h(0)$ values

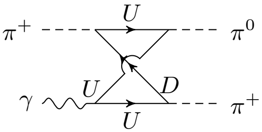
Theory	9.8 GeV^{-3}
Experiment at LO (1987)	$12.9 \pm 0.9 \pm 0.5 \pm 1.0$ GeV^{-3}
Experiment at NNLO + EMC (2001)	10.7 ± 1.2 GeV^{-3}

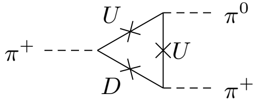
Update from the COMPASS Collaboration?

$\pi^+\gamma \to \pi^+\pi^0$



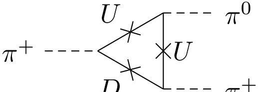




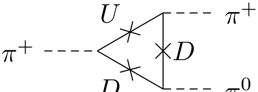


$$-\frac{1}{3} + \frac{2}{3} + \frac{2}{3} = 1$$

$\pi^+\gamma \to \pi^+\pi^0$

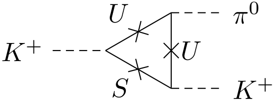


$-\frac{1}{3} + \frac{2}{3} + \frac{2}{3} = 1$



$-\frac{1}{3} + \frac{2}{3} - \frac{1}{3} = 0$

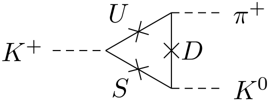
$K^+\gamma \to K^+\pi^0$



$-\frac{1}{3} + \frac{2}{3} + \frac{2}{3} = 1$

neutral pion production

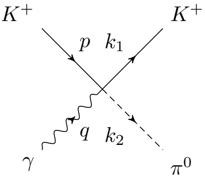
$K^+\gamma \to K^0\pi^+$



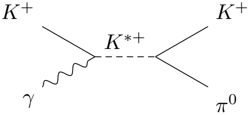
$-\frac{1}{3} + \frac{2}{3} - \frac{1}{3} = 0$

charged pion production

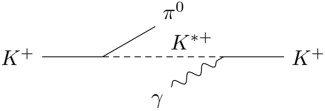
$K^+\gamma \to K^+\pi^0$



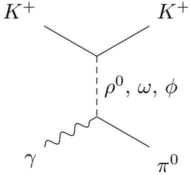
anomaly



s channel

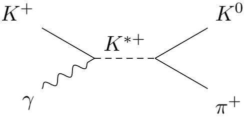


u channel

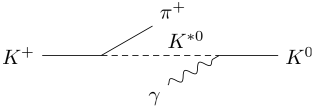


t channels

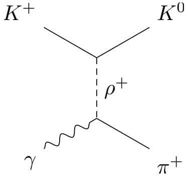
$K^+\gamma \to K^0\pi^+$



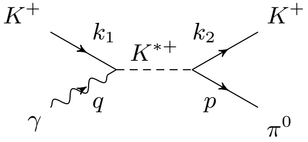
s channel



u channel



t channel



s-channel amplitude:

$$A_s^{(0)}(K^+\gamma \to K^+\pi^0) = -\frac{2f_{K^{*+}K^+\gamma}f_{K^{*+}K^+\pi^0}}{s - m_{K^{*+}}^2 + i\sqrt{s}\,\Gamma_{K^{*+}}(s)}\varepsilon^{\alpha\beta\gamma\delta}\epsilon_\alpha p_\beta k_{1\gamma}k_{2\delta}$$

$$A_s(K^+\gamma \to K^+\pi^0) = A_s^{(0)}(K^+\gamma \to K^+\pi^0) - A_s^{(0)}(K^+\gamma \to K^+\pi^0)|_{s=0}$$

Cross section:

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

$f_{K^{*+}K^+\pi^0}$	$=$	3.10
$f_{K^{*+}K^0\pi^+}$	$=$	4.38
$f_{K^{*0}K^+\pi^+}$	$=$	4.41
$f_{\rho^0 K^+K^+}$	$=$	3.16
$f_{\rho^+ K^+K^0}$	$=$	-4.47
$f_{\omega K^+K^+}$	$=$	3.16
$f_{\phi K^+K^+}$	$=$	-4.47
$f_{K^{*+}K^+\gamma}$	$=$	0.240 GeV^{-1}
$f_{K^{*0}K^0\gamma}$	$=$	-0.385 GeV^{-1}
$f_{\rho^0\pi^0\gamma}$	$=$	0.252 GeV^{-1}
$f_{\rho^+\pi^+\gamma}$	$=$	0.219 GeV^{-1}
$f_{\omega\pi^0\gamma}$	$=$	0.696 GeV^{-1}
$f_{\phi\pi^0\gamma}$	$=$	0.040 GeV^{-1}

Decay widths:

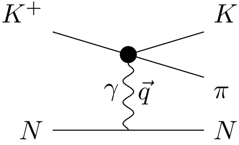
$$\Gamma(K^* \to K\pi) \implies |f_{K^*K\pi}|$$
$$\Gamma(K^* \to K\gamma) \implies |f_{K^*K\gamma}|$$
$$\Gamma(\phi \to K^+K^-) \implies |f_{\phi K^+K^+}|$$
$$\Gamma(\rho^+ \to \pi^+\gamma) \implies |f_{\rho^+\pi^+\gamma}|$$
$$\Gamma(\rho^0 \to \pi^0\gamma) \implies |f_{\rho^0\pi^0\gamma}|$$
$$\Gamma(\omega \to \pi^0\gamma) \implies |f_{\omega\pi^0\gamma}|$$
$$\Gamma(\phi \to \pi^0\gamma) \implies |f_{\phi\pi^0\gamma}|$$

$SU(3)$ symmetry:

$$\begin{aligned}\sqrt{2} f_{K^{*+}K^+\pi^0} &= f_{K^{*+}K^0\pi^+} = f_{K^{*0}K^+\pi^+} = -f_{\rho^+K^+K^0} \\ &= \sqrt{2} f_{\rho^0K^+K^+} = \sqrt{2} f_{\omega K^+K^+} = -f_{\phi K^+K^+}\end{aligned}$$

$$f_{K^{*+}K^+\gamma} = f_{\rho^+\pi^+\gamma} = f_{\rho^0\pi^0\gamma} = \frac{1}{3} f_{\omega\pi^0\gamma} = -\frac{1}{2} f_{K^{*0}K^0\gamma}$$

The sign of the anomaly term is unknown.



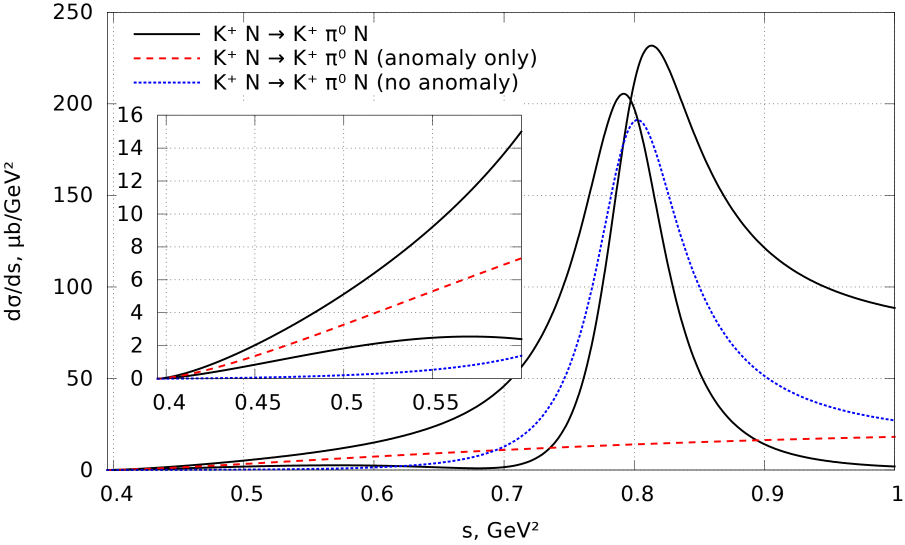
Weizsacker-Williams equivalent photons approximation:

$$\frac{d\sigma(K^+N \to K\pi N)}{dt\ ds\ dq_\perp^2} = \frac{Z^2\alpha}{\pi(s-m_{K^+}^2)} \frac{q_\perp^2}{\left(q_\perp^2 + \left(\frac{s-m_{K^+}^2}{2E_K}\right)^2\right)^2} \frac{d\sigma(K^+\gamma \to K\pi)}{dt} |F(\vec{q}^{\,2})|^2$$

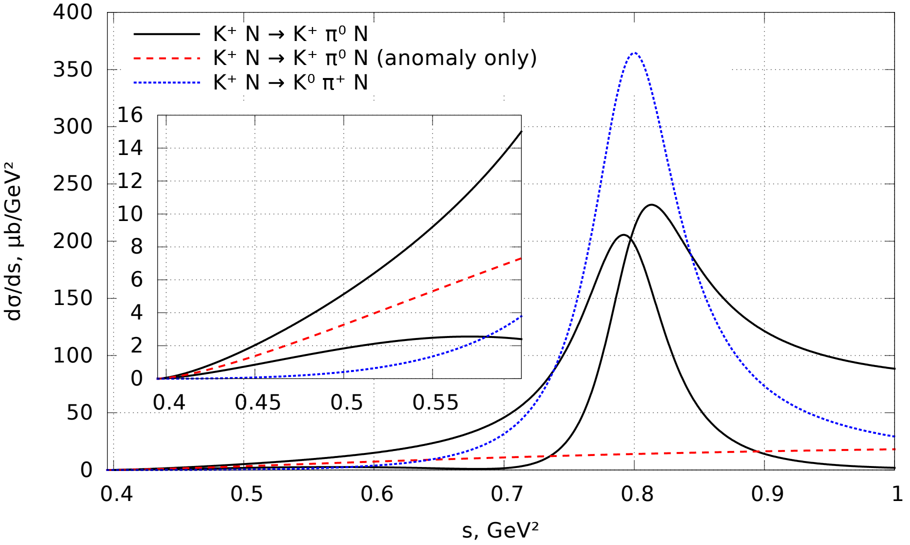
$$F(\vec{q}^{\,2}) = \exp\left(-\frac{\langle r^2 \rangle \vec{q}^{\,2}}{6}\right)$$

$$\frac{d\sigma(K^+N \to K\pi N)}{dt\ ds} = \frac{Z^2\alpha}{\pi} \frac{E_1(a)-1}{s-m_{K^+}^2} \frac{d\sigma(K^+\gamma \to K\pi)}{dt}$$

$$E_1(a) = \int_a^\infty \frac{\mathrm{e}^{-z}}{z} dz, \ \ a = \frac{1}{3} r_0^2 A^{2/3} \left(\frac{s-m_{K^+}^2}{2E_K}\right)^2$$



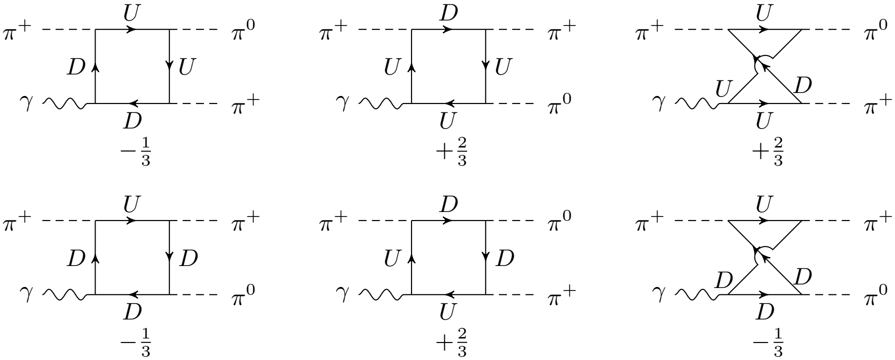
K⁺ N → K⁺ π⁰ N
K⁺ N → K⁺ π⁰ N (anomaly only)
K⁺ N → K⁺ π⁰ N (no anomaly)
dσ/ds, μb/GeV²
s, GeV²
0
50
100
150
200
250
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14
16
0.4
0.45
0.5
0.55


K⁺ N → K⁺ π⁰ N
K⁺ N → K⁺ π⁰ N (anomaly only)
K⁺ N → K⁰ π⁺ N
dσ/ds, μb/GeV²
s, GeV²
0
50
100
150
200
250
300
350
400
0.4
0.5
0.6
0.7
0.8
0.9
1
0
2
4
6
8
10
12
14
16
0.4
0.45
0.5
0.55

Conclusions

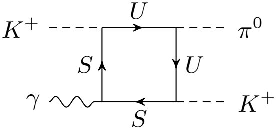
- A theoretical prediction has been made for the cross sections of $K^+\gamma \to K^+\pi^0$ and $K^+\gamma \to K^0\pi^+$ reactions at low energies. For the anomalous reaction, we predict two possible values depending on the a priori unknown sign of the interference term, which should be resolved by the experiment.
- It is possible to observe the chiral anomaly through comparison of cross section of $K^+\,\mathrm{Cu} \to K^+\pi^0\,\mathrm{Cu}$ reaction with that of $K^+\,\mathrm{Cu} \to K^0\pi^+\,\mathrm{Cu}$ reaction at $\sqrt{s} \lesssim 0.6$ GeV^2. The point is that only the first one has the anomaly which manifests itself as an increase in the cross section at low $\sqrt{s}$.
- Luminosity of 60μb^{-1} at $0.4 < s < 0.6$ GeV^2 is planned to be collected in the Protvino experiment. In this case expected observations are ≈ 10 events of $K^0\pi^+$ production and either ≈ 20 or ≈ 70 events of $K^+\pi^0$ production, depending on the sign of the interference term.

$$\pi^+\gamma \to \pi^+\pi^0$$

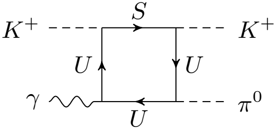


Total: 1

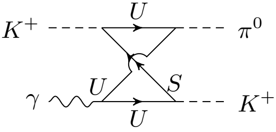
$$K^+\gamma \to K^+\pi^0$$



$-\frac{1}{3}$



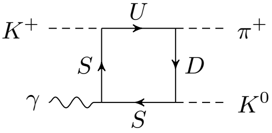
$+\frac{2}{3}$



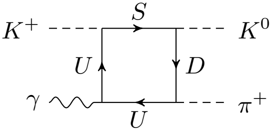
$+\frac{2}{3}$

Total: 1

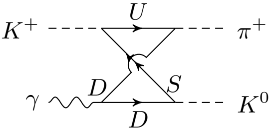
$$K^+\gamma \to K^0\pi^+$$



$-\frac{1}{3}$



$+\frac{2}{3}$



$-\frac{1}{3}$

Total: 0