Experimental limitation on the probability for the decay $\pi^0 \to 4\gamma$

V. N. Bolotov, S. N. Gninenko, R. M. Dzhilkibaev, V. V. Isakov, Yu. M. Klubakov, V. D. Laptev, V. M. Lobashev, V. N. Marin, V. E. Postoev, A. A. Poblaguev, and A. N. Toropin
Institute of Nuclear Studies, Academy of Sciences of the USSR

(Submitted 20 March 1986)
Pis'ma Zh. Eksp. Teor. Fiz. **43**, No. 9, 405–407 (10 May 1986)

The use of the decay $K^- \to \pi^- \pi^0$ as a source of π^0 mesons has led to a limitation on the branching ratio for the decay $\pi^0 \to 4\gamma$: B.R.$(\pi^0 \to 4\gamma) < 1.6 \times 10^{-6}$.

The decay $\pi^0 \to 4\gamma$ is allowed by all known selection rules. The branching ratio expected for the decay, B.R.$(\pi^0 \to 4\gamma) = \Gamma(\pi^0 \to 4\gamma)/\Gamma(\pi^0 \to 2\gamma)$, is quite small, and the theoretical predictions are quite uncertain[1,2]: B.R.$(\pi^0 \to 4\gamma) \cong 10^{-9}$–$10^{-16}$. The decay $\pi^0 \to 4\gamma$ has also attracted interest, because it is one source of the background in the experiments being carried out to search for the violation of C invariance in the decay[1] $\pi^0 \to 3\gamma$. A better experimental limitation on the branching ratio for the decay, B.R.$(\pi^0 \to 4\gamma) < 4.4 \times 10^{-6}$, was found in Ref. 3. In the present letter we report a new value: B.R.$(\pi^0 \to 4\gamma) < 1.6 \times 10^{-6}$.

The measurements were carried out in parallel with a study for rare modes of in-flight decay of π^- and K^- mesons at the 70-GeV accelerator of the Institute of High-Energy Physics (the Istra apparatus). We used the decay $K^- \to \pi^- \pi^0$ as the source of π^0 mesons. The energy of the unseparated beam of K^- mesons was 25 GeV. The γ rays from the decay of the π^0 mesons were detected by a total-absorption Čerenkov spectrometer (Sp), which consists of a matrix of 24×22 lead glass counters.[4] The coordinates of the K^- and π^- mesons were detected by means of hodoscopic photomultipliers and proportional chambers with analog data readout, respectively.[5,6] The composition and characteristics of the Istra installation are described in more detail in Ref. 4. To single out events with $n \geqslant 3$ γ rays and to suppress the dominant decay mode $K^- \to \pi^- \pi^0 \to \pi^- 2\gamma$, we used a system for selecting γ-ray showers in the Čerenkov spectrometer as part of the triggering system.[7]

In selecting candidate events for the decay $K^- \to \pi^- \pi^0 \to \pi^- 4\gamma$ we used the following criteria:

1) The presence in the total-absorption Čerenkov spectrometer of four γ-ray showers with a threshold $E_\gamma > 1$ GeV;

2) A total energy evolution of more than 10 GeV in the same Čerenkov spectrometer;

3) The presence of only a single track in the hodoscopic photomultipliers and the proportional chambers;

4) A minimum distance $R_{\pi\gamma} > 10$ cm between the projection of the π^- track onto the total-absorption Čerenkov spectrometer and the nearest γ-ray shower.

For all the events that passed these tests, we tested the hypotheses $K^- \to \pi^- 4\gamma$ (a $4C$ fit). We eliminated from further consideration events with $\chi^2 > 15$. For the other events, we found the distribution in the effective mass of the four γ rays, $M_{4\gamma}$, shown in Fig. 1. The events that lie in the region 275 MeV $< M_{4\gamma} <$ 360 MeV are the decay $K^- \to \pi^- \pi^0 \pi^0$ (τ'); the number of these events after subtraction of the low background is $N(\tau') = 51\,454 \pm 230$. This number is used below for a normalization. The arrows in Fig. 1 mark the mass region of the four γ-ray showers which was determined by Monte-Carlo calculations and which corresponds to 95% of the events from the decay $\pi^0 \to 4\gamma$. In this simulation it was assumed that the momenta of the γ rays in the decay $\pi^0 \to 4\gamma$ are distributed in phase space. This region contains 38 candidates for the decay $\pi^0 \to 4\gamma$.

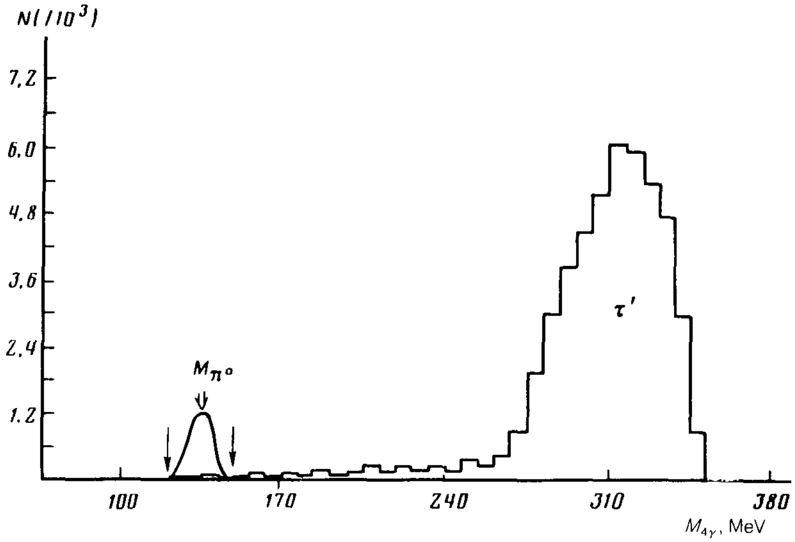

FIG. 1. Distribution in the effective mass of the four γ rays, $M_{4\gamma}$. The arrows mark the region of the simulated spectrum of the masses $M_{4\gamma}$, which contains 95% of the events from the decay $\pi^0 \to 4\gamma$.

In order to lower the background due to the overload of the total-absorption Čerenkov spectrometer in the central region and the superposition of events that occur at nearly the same time, we then introduced some additional selection rules: a) The lowest of the four energies of the γ rays in the laboratory frame must be $E_{\gamma\min} > 1.2$ GeV. b) The distance ($R_{\gamma\min}$) from this γ ray to the beam axis must be $R_{\gamma\min} > 2$ cm. c) We reduced the region of values of the effective mass of the four γ rays to 129 MeV $< M_{4\gamma} < 141$ MeV.

These conditions eliminated $\sim 16\%$ of the events from the decay $\pi^0 \to 4\gamma$. Of the 38 candidate events, none simultaneously satisfied conditions (a), (b), and (c). The upper limit on the number of $\pi^0 \to 4\gamma$ decays is thus < 2.3 at a 90% confidence level. The numbers of decays τ' and of the decays $\pi^0 \to 4\gamma$ for a particular number of decayed K^- mesons, N_k, are

$$N(\tau') = N_k \, \text{B.R.}(\tau') \, \epsilon_{\text{geom}} \, \epsilon_{\chi^2} \, \epsilon,$$

$$N(\pi^0 \to 4\gamma) = N_k \, \text{B.R.}(K^- \to \pi^-\pi^0) \, \text{B.R.}(\pi^0 \to 4\gamma) \, \epsilon'_{\text{geom}} \, \epsilon'_{\chi^2} \, \epsilon',$$

where ϵ_{geom} is the geometric efficiency at which the process is detected, ϵ_{χ^2} is the effective cutoff along the χ^2 scale, and ϵ is the resultant efficiency based on the selection criteria and the detection efficiency. After some simple manipulations, we find

$$\text{B.R.}(\pi^0 \to 4\gamma) = \frac{N(\pi^0 \to 4\gamma)}{N(\tau')} \, \frac{\text{B.R.}(\tau')}{\text{B.R.}(K^- \to \pi^-\pi^0)} \, \frac{\epsilon_{\text{geom}}}{\epsilon'_{\text{geom}}} \, \frac{\epsilon_{\chi^2}}{\epsilon'_{\chi^2}} \, \frac{\epsilon}{\epsilon'} \, .$$

For the values $\dfrac{N(\pi^0 \to 4\gamma)}{N(\tau')} < 4.5 \times 10^{-5}$, $\dfrac{\text{B.R.}(\tau')}{\text{B.R.}(K^- \to \pi^- \pi^0)} = 0.08$, and (the following were found through the simulation)

$$\frac{\epsilon_{\text{geom}}}{\epsilon'_{\text{geom}}} = 0.37; \quad \frac{\epsilon}{\epsilon'} = 1.2; \quad \frac{\epsilon_{\chi^2}}{\epsilon'_{\chi^2}} = 1,$$

we find $\text{B.R.}(\pi^0 \to 4\gamma) < 1.6 \times 10^{-6}$.

We wish to take this opportunity to thank the directors of the Institute of Nuclear Studies and the Institute of High-Energy Physics for support of this program of research on the Istra apparatus, of which the present study was part. We also thank A. V. Berlev and O. V. Karavichev for assistance in this study.

[1]A. V. Tarasov, Yad. Fiz **5**, 445 (1967) [*sic*].
[2]R. L. Schult and B. L. Young, Phys. Rev. D **6**, 1988 (1972).
[3]Averbach *et al.*, Phys. Rev. B **90**, 317 (1980).
[4]B. H. Bolotov *et al.*, Preprint P-0428, Institute of Nuclear Research, Academy of Sciences of the USSR, Moscow, 1985.
[5]V. G. Vasil'chenko *et al.*, Preprint 78-16, Institute of High-Energy Physics, Serpukhov, 1978.
[6]V. N. Bolotov *et al.*, Nucl. Instrum. Methods **A227**, 287 (1985).
[7]S. N. Gninenko *et al.*, Preprint P-0427, Institute of Nuclear Research, Academy of Sciences of the USSR, Moscow, 1985.

Translated by Dave Parsons