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«OKA» collaboration (IHEP – INR – JINR)

Measurement of the T-odd correlation in the $K^{+} \rightarrow e^{+} \nu \pi^{0} \gamma$ radiative decay at OKA setup

The talk layout

OKA setup
Decays selection
Background suppression
Results

$K^+ \to e^+ \nu \pi^0 \gamma$ radiative decay

The matrix element for this decay has general structure:

$$T = \frac{G_F}{\sqrt{2}} e V_{us} \epsilon^{\mu}(q) \Big\{ (V_{\mu\nu} - A_{\mu\nu}) \overline{u}(p_\nu) \gamma^{\nu} (1 - \gamma_5) v(p_e)$$
$$+ \frac{F_\nu}{2 p_e q} \overline{u}(p_\nu) \gamma^{\nu} (1 - \gamma_5)(m_e - \hat{p}_e - \hat{q}) \gamma_\mu v(p_e) \Big\} \equiv \epsilon^{\mu} A_{\mu}.$$

First term of the T describes the bremsstrahlung of kaon and the direct emission Fig.1a. The lepton bremsstrahlung presented by the second part of T and Fig.1b.

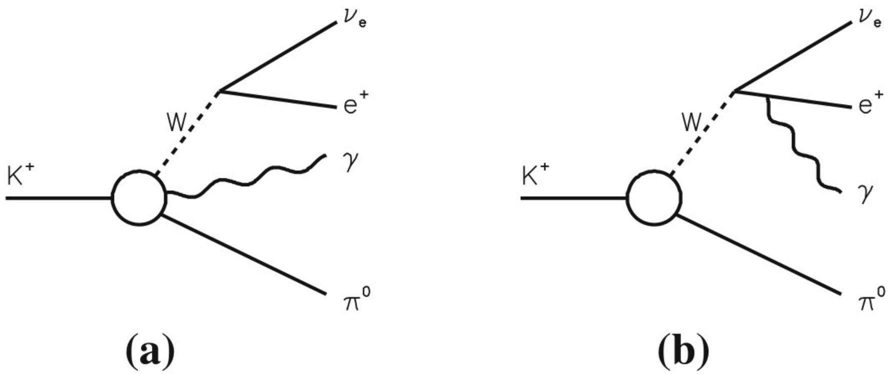

Fig. 1 Diagrams describing $K^+ \to \pi^0 e^+ \nu \gamma$ decay

$K^+ \to e^+ \nu \pi^0 \gamma$ radiative decay

$K^+ \to e^+ \nu \pi^0 \gamma$ decay allow as to perform quantitative tests ChPT, thanks to theoretical developments over the past couple of decades as well as recent and ongoing high-statistics experimental studies.

The first complete analysis within ChPT to $O(p^4)$ order was performed by Bijinens et al. [Nucl. Phys. B396 (1993) 81]. Recently, the ChPT analysis was revisited and extended to $O(p^6)$ by Kubis et al. [Eur. Phys. J. C50 (2007) 557].

$K^+ \to e^+ \nu \pi^0 \gamma$ decay is one of kaon decays where new physics beyond Standard model can be probed. This decay is especially interesting as it is sensitive to T-odd contributions. According to CPT theorem, observation of T-violation is equivalent to observation of CP-violating effects.

OKA: search for T-violation in K^+ decay

Important experimental observable used in CP-violation searches is the T-odd correlation for $K^+ \rightarrow e^+ \nu \pi^0 \gamma$ decay defined as

$$\xi_{\pi e \gamma} = \frac{1}{M_K^3} p_\gamma \cdot [p_\pi \times p_e]$$

To establish the presence of nonzero triple-product correlations, one construct a T-odd asymmetry of the form

$$A_\xi = \frac{N_+ - N_-}{N_+ + N_-}$$

$N_{+(-)}$ – number of events with $\xi >(<) 0$;

IHEP PS U-70

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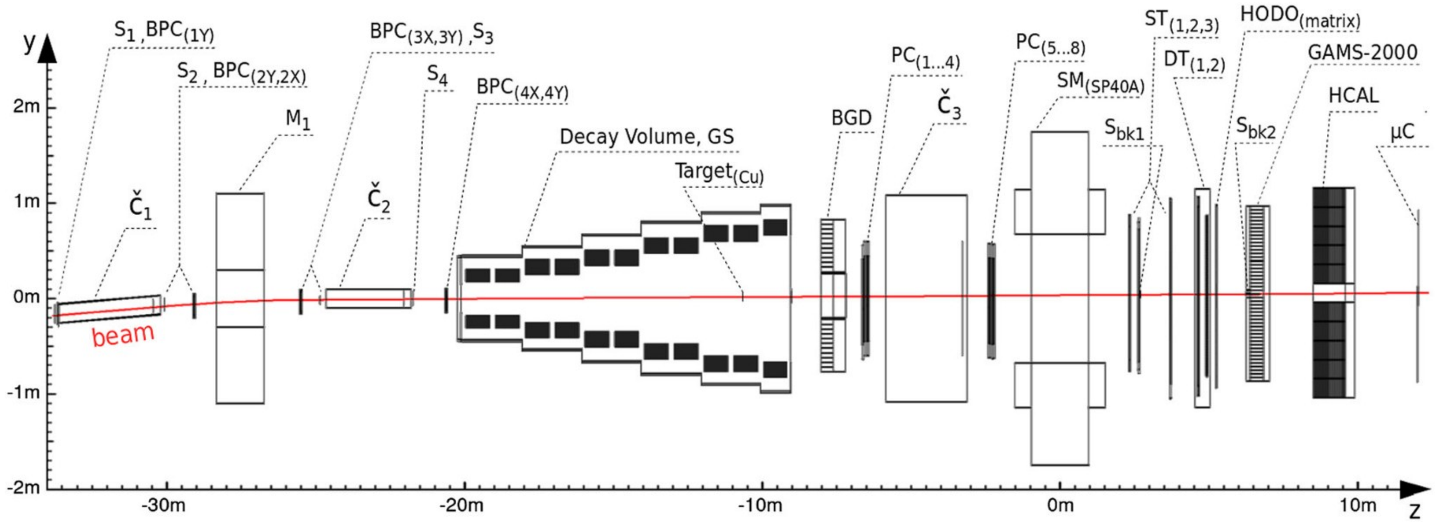
U-70 ring

The OKA collaboration operates at the IHEP Protvino U-70 Proton Synchrotron.

Detector is located in positive RF-separated beam with 20% of *K*-meson.

17.7 GeV/c $3 \cdot 10^5$ kaons per 2 sec U-70 spill. Separation is provided by two SC deflectors cooled by superfluid He.

OKA detector



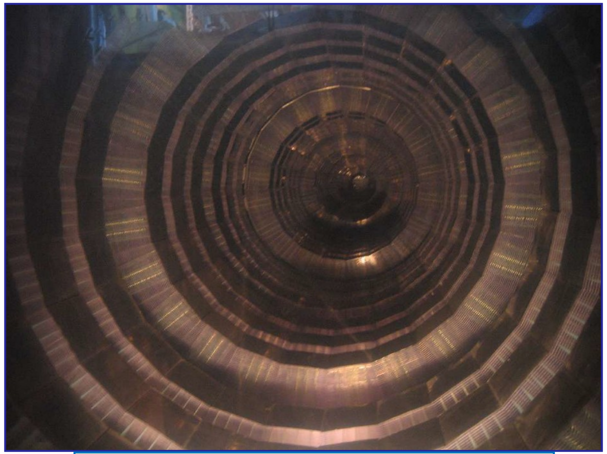
$$Trg = S_1 \cdot S_2 \cdot S_3 \cdot S_4 \cdot \bar{\check{C}}_1 \cdot \check{C}_2 \cdot \bar{S}_{bk} \cdot (E_{GAMS} > 2.5GeV)$$

$S_1 - S_4$ are scintillating counters; $\check{C}_1$, $\check{C}_2$ – Cherenkov counters ($\check{C}_1$ sees pions, $\check{C}_2$ pions and kaons); S_{bk} – two scintillation counters on the beam axis after the magnet to suppress undecayed particles.

1. Beam spectrometer: PC, 1500 channels; 2. Decay volume with Veto system;
3. PC's and DT's for magnetic spectrometer: 5000 + 1300 channels;
4. Magnet; 5. Matrix hodoscope: SiPM 300 channels;
6. Gamma detectors: GAMS-2000; 7. Muon identification: HCAL + 4 muon trigger;

Decay Volume with Veto system

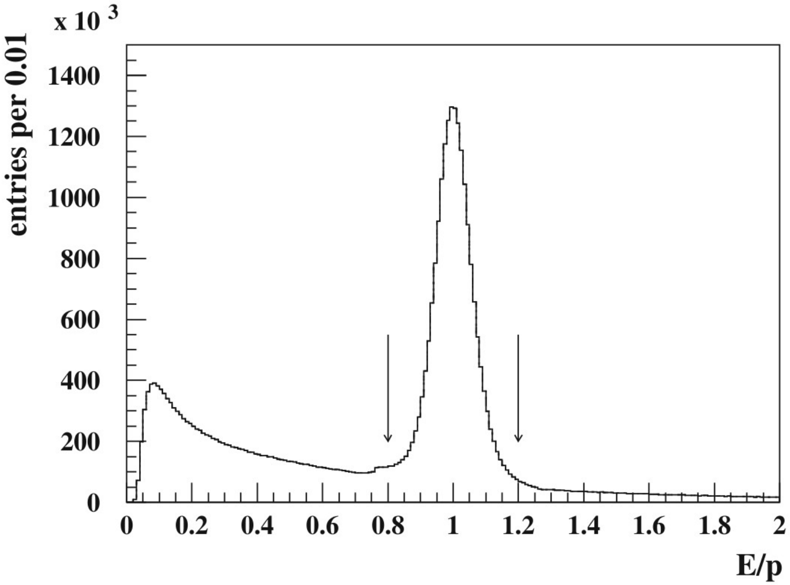
DV: 11m;
Veto: 670 Lead-Scintillator sandwiches 20×(5mm Sc + 1.5mm Pb), WLS readout;
The total number of kaons entering the DV corresponds to ~ 3.6×10^{10}.

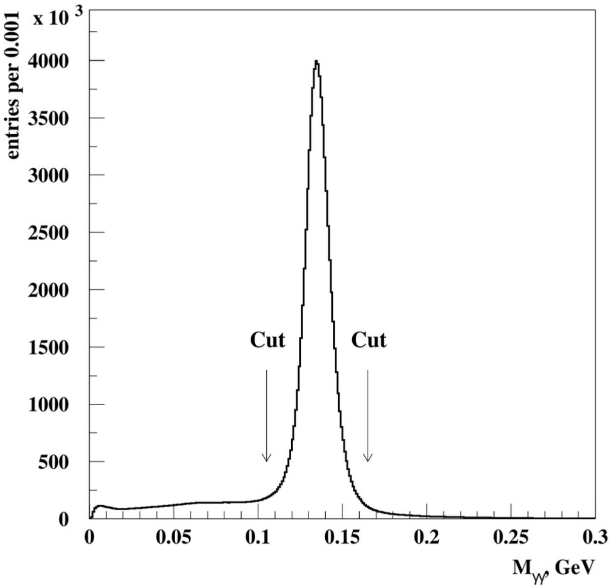


Inside

Veto System

$K^+ \rightarrow e^+ \nu \pi^0 \gamma$ decay selection





1. One charged track (K^+) in the tracking system, four showers ($E_\gamma > 0.7$GeV) in the e/m calorimeters;

2. One shower must be assotiated with the charged track;

3. One charged track is identified as e^+ with $0.8 < E/p < 1.2$;

4. The decay vertex situated within the decay volume;

5. The effective mass for γ-pair $0.12 < M_{\gamma\gamma} < 0.15$ GeV;

Background suppression

The main background decay channels for the decay $K^+ \to e^+ \nu \pi^0 \gamma$ are:

1) $K^+ \to e^+ \nu \pi^0$ with extra photon. The main source of extra photons are an interactions of positrons in the detector material;

2) $K^+ \to \pi^+ \pi^0 \pi^0$ where one π^0 photons not detected and π^+ decays to $e^+ \nu$ or misidentified as positron;

3) $K^+ \to \pi^+ \pi^0$ with fake photon and π^+ decayed or misidentified as positron. Fake photon clusters can come from π^+ hadron interaction in the detector, external bremsstrahlung, accidentals;

4) $K^+ \to \pi^+ \pi^0 \gamma$ when π^+ decays or is miss-identified as an positron;

5) $K^+ \to \pi^0 \pi^0 e^+ \nu$ when one γ is lost.

All these sources are included in our MC calculations.

Background suppression

To suppress the background channels we use a set of cuts:

1) $E_{miss} = E_{beam} - E_{detected} > 0.5$ GeV. The requirement on the missing energy mainly reduces the background (4);

2) $\Delta y = |y_\gamma - y_e| > 3$ cm, where y is the vertical coordinate of a particle in the electromagnetic calorimeter (the magnetic field turns charged particles in the xz-plane);

3) $|x_\nu , y_\nu| < 100$ cm. The reconstructed missing momentum direction must cross the active area of the electromagnetic calorimeter;

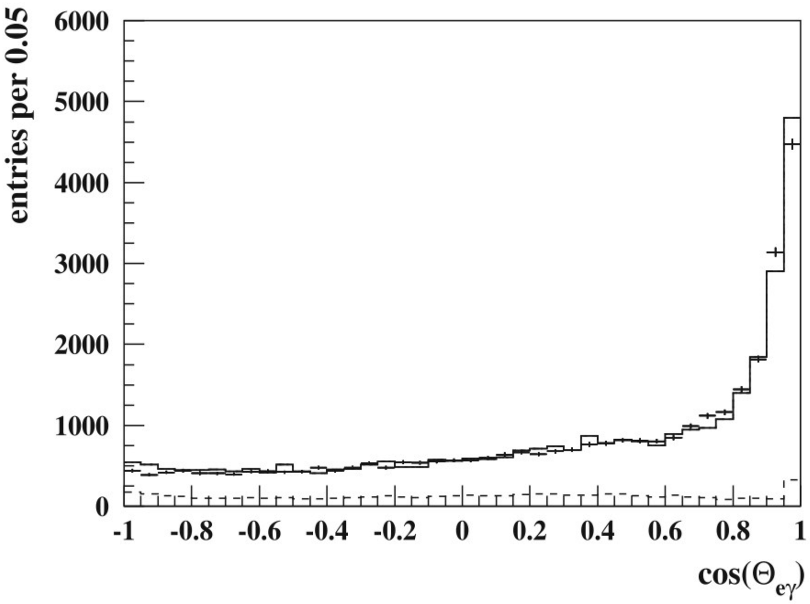
4) The reconstructed mass of the system $M (K^+ \rightarrow e^+ \nu \pi^0 \gamma) > 0.45$GeV;

5) $|M^2_{miss} (\pi^0 e^+ \gamma)| = (P_K - P_{\pi^o} - P_e - P_\gamma)^2 < 0.006$ GeV^2;

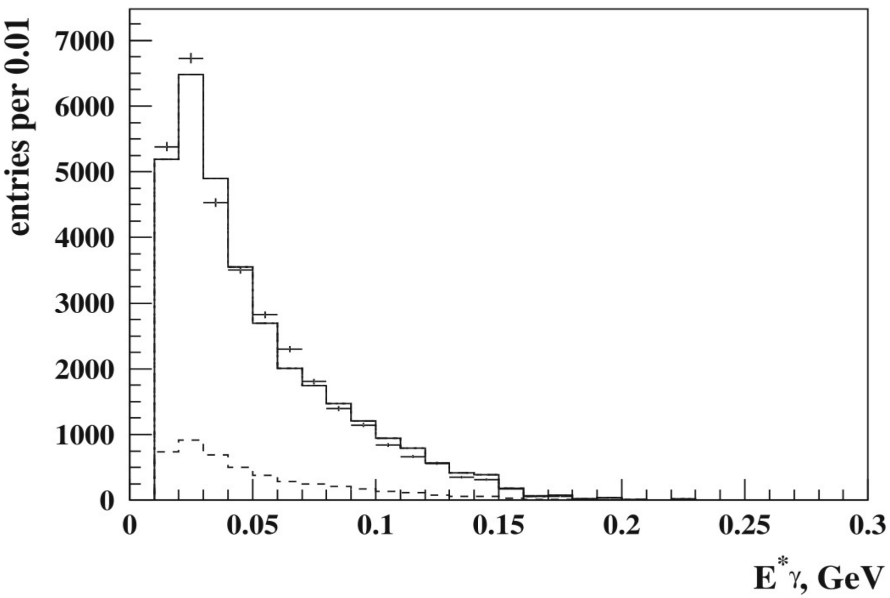
6) 4 mrad $< \theta_{e\gamma} <$ 80 mrad; The left part of this cut is introduced exactly for the suppression of background (1). The right cut is against $K_{\pi 2}$ background.

101200 candidates are selected, with a background of 17700 events.

Results

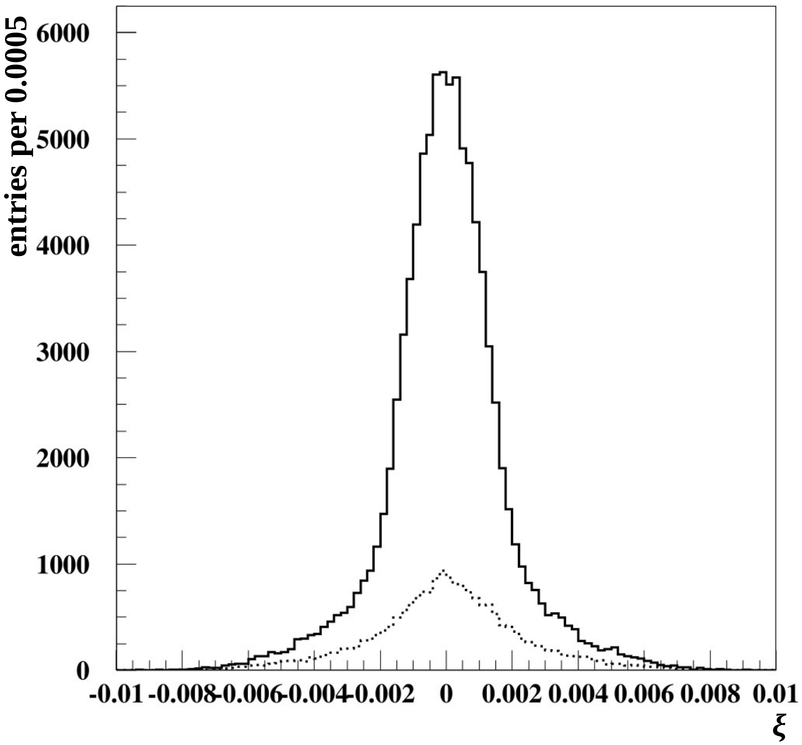


The distribution of the events over $\cos\theta^{*}_{e\gamma}$. Points with errors are the real data, histogram – MC signal plus background, MC background - dotted line histogram.



The distribution of the events over E_{γ}^{*}. Points with errors – the real data, histogram – MC signal plus background, MC background – dotted line histogram

Results



The distribution of the events over ξ. Background – dotted line histogram.

$A_\xi = (-0.01 \pm 0.390(\text{stat.}) \pm 0.14(\text{syst.}))\times 10^{-2}$

$|A_\xi| < 0.0076$, CL = 90%;

Theoretical prediction for A_ξ from ChPT:

$|A_\xi(K^+ \to \pi^0 e^+ \nu_e \gamma)| < 0.8 \times 10^{-4}$;

$$\xi_{\pi e \gamma} = \frac{1}{M_K^3} p_\gamma \cdot [p_\pi \times p_e]; \qquad A_\xi = \frac{N_+ - N_-}{N_+ + N_-};$$

Summary

1. OKA collaboration, operating at IHEP Protvino U-70 PS in RF-separated beam, has accumulated large statistics of $K^+ \to e^+ \nu \pi^0 \gamma$ decays;

2. Decay signal is extracted with a low background;

3. For our set of cuts we have 101200 selected events with 17700 background events. For the T-odd assymetry we got

$$A_\xi = (-0.01 \pm 0.39(\text{stat.}) \pm 0.14(\text{syst.}))\times 10^{-2}$$

Thank you for your attention!