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On behalf of «OKA» collaboration (IHEP-INR-JINR)

Study of radiative kaon decay $K^+ \to \pi^0 e^+ \nu \gamma$ using OKA detector

The talk layout

- OKA detector
- Ke3 and Ke3γ decays selection
- Background suppression
- Results
- Conclusions

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

The matrix element for $K \to \pi^0 e \nu \gamma$ has general structure

$$T = \frac{G_F}{\sqrt{2}} e V_{us} \varepsilon^\mu(q) \Big\{ (V_{\mu\nu} - A_{\mu\nu}) \overline{u}(p_\nu) \gamma^\nu (1-\gamma_5) v(p_l) \qquad (1)$$

$$+ \frac{F_\nu}{2 p_l q} \overline{u}(p_\nu) \gamma^\nu (1-\gamma_5)(m_l - \not{p}_l - \not{q}) \gamma_\mu v(p_l) \Big\} \equiv \epsilon^\mu A_\mu .$$

First term of the matrix element describes Bremsstrahlung of kaon and direct emission(Fig.1a The lepton Bremsstrahlung is presented by second part of Eq(1) and (Fig.1b).

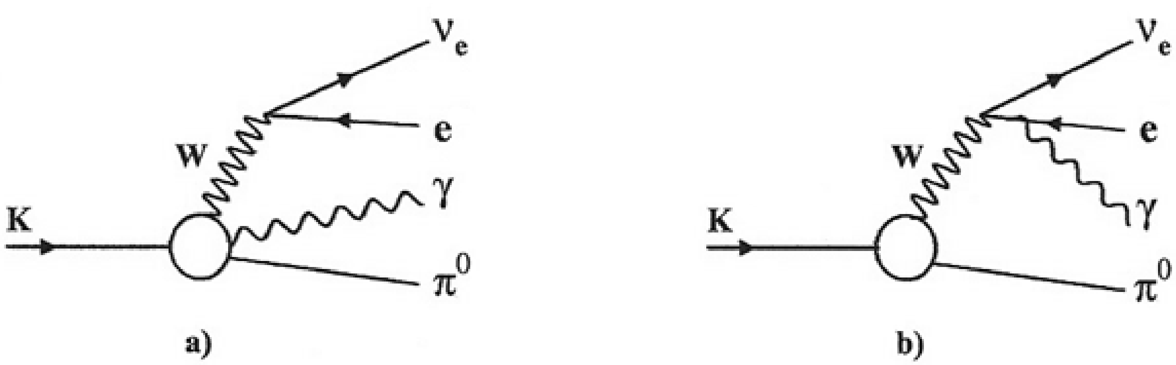


Figure 1: *Diagrammatic repressentation of the $K_{l3\gamma}$ amplitude.*

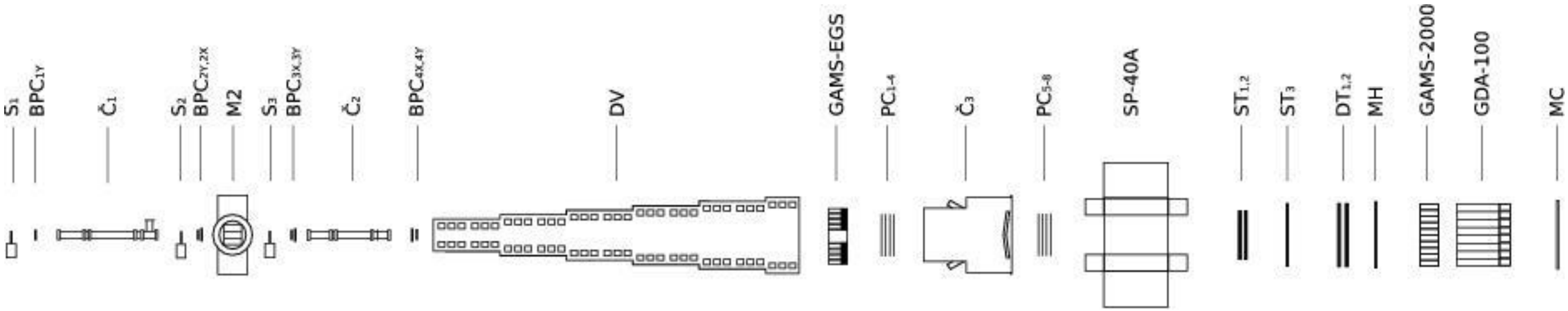
IHEP PS U-70

U-70 ring

IHEP Protvino

OKA collaboration operate at IHEP PS U-70 in Protvino, Moscow region.
Detector is located in positive RF-separated beam with up to 20% of K-meson.

OKA detector

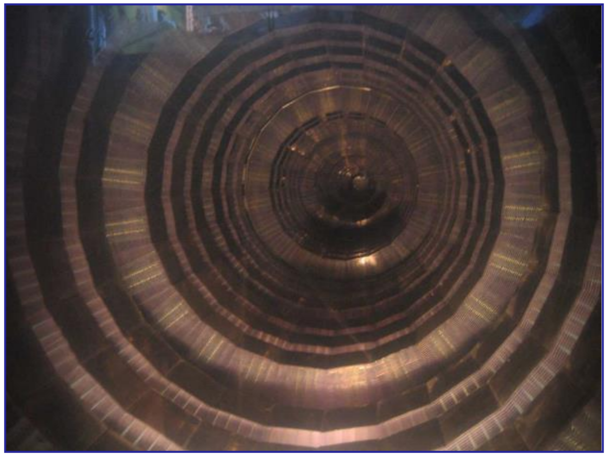


$$Trg = S_1 \cdot S_2 \cdot S_3 \cdot \check{C}_1 \cdot \bar{\check{C}}_2 \cdot \bar{S}_{bk} \cdot (\Sigma_{GAMS} > \text{Mip})$$

1. Beam spectrometer: 1mm pitch PC, ~1500 channels; Cherenkov counters
2. Decay volume with Veto system:
   11m; Veto: 670 Lead-Scintillator sandwiches 20* (5mm Sc+1.5 mmPb), WLS readout
3. PC's and DT's for magnetic spectrometer:
   ~5000 ch. PC (2 mm pitch) + 1300 DT (1 and 3 cm)
4. Pad(Matrix) Hodoscope ~300 ch. WLS+SiPM readout
5. Magnet: aperture 200*140 cm^2
6. Gamma detectors: GAMS2000, EHS-backward EM cal. ~ 4000 LG.
7. Muon identification: GDA-100 HCAL+ 4 muon trigger counters behind

Decay volume with Veto System

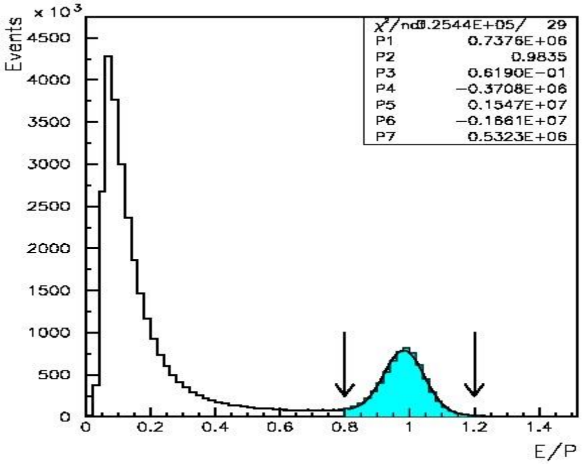
Decay volume with the Veto System



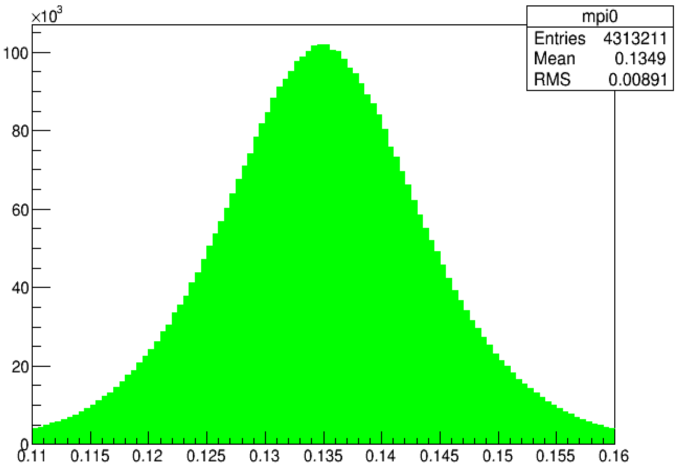
Decay volume inside view

Veto System

K_{e3} decay selection



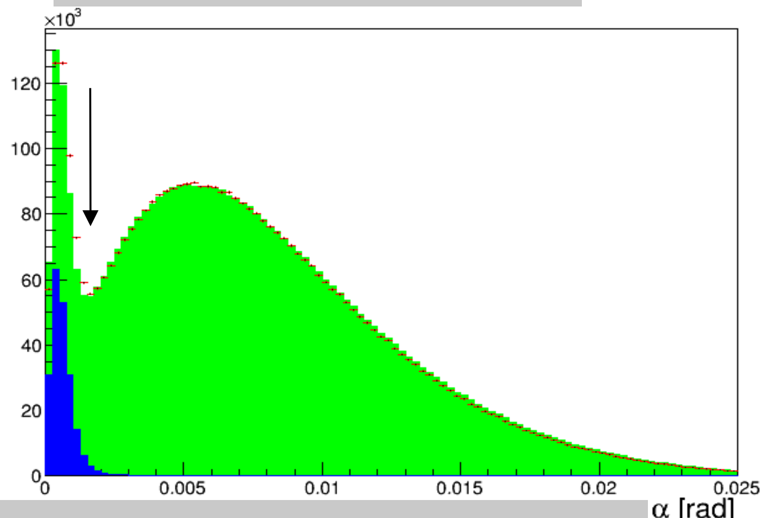
0.8 <E/P<1.2



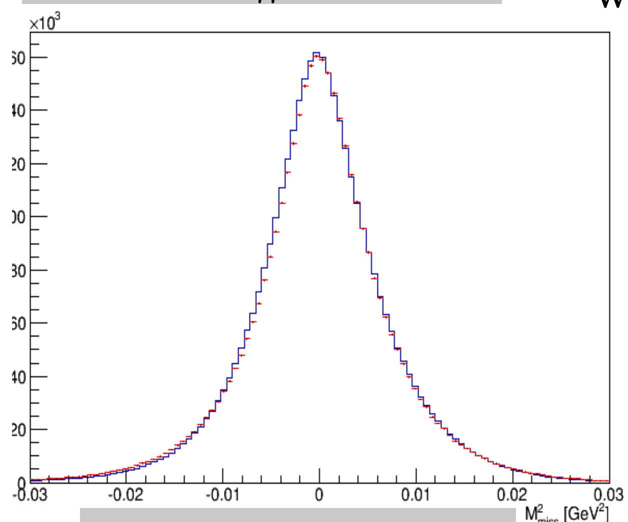
0.11 <Mγγ<0.16 GeV

1. 1 ch. track θ>2mrad point to em-shower in ECAL: (r<3cm) .8 <E/P<1.2
2. 2 extra showers (n_{cl} >3); 0.115 <Mγγ<0.165 GeV
3. α-angle between p_K and $p_{e\pi}$ α>2mrad
4. 2C -constrained fit χ^2<20

10M K_{e3} events with E_γ > 0.5GeV



α - angle between p_K and $p_{e\pi}$; α>2mrad



$M^2_{mis} = (p_K - p_{e\pi})^2$

$K^+ \to \pi^0 e^+ \nu\gamma$ events selection

1) One positive charged track detected in tracking system and 4 showers ($E_\gamma > 0.7$GeV (0.5 for π^0) detected in electromagnetic calorimeters.

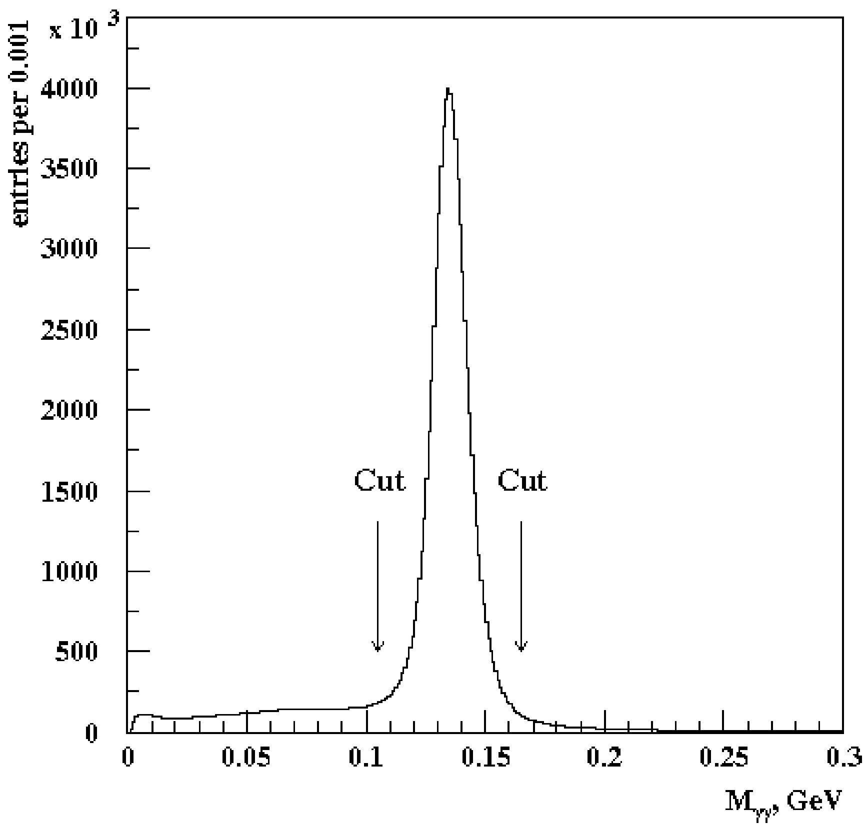
2) One shower must be associated with charged track.

3) Charged track is identified as positron.

4) Vertex of event situated within the decay volume.

5) The effective mass $M_{\gamma\gamma}$ for one $\gamma\gamma$ –pair is $0.115 < M_{\gamma\gamma} < 0.165$ GeV.

$K^+ \to \pi^0 e^+ \nu \gamma$ events selection



$0.115 < M_{\gamma\gamma} < 0.165$ GeV

Background suppression

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

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

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

3) $K^+\rightarrow\pi^+\pi^0$ with fake photon and π^+ decayed or misidentified as positron. Fake photon clusters can come from π^+ hadron interaction in the detector, accidentals. All these sources are included in our MC calculations.

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

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

Background suppression

1) $E_{miss} > 0.5$GeV, $E_{veto} < 50$ МэВ, $-2200 < Z_{vx} < -950$, $E_{\gamma} > 0.7(0.5)$GeV;

2) $|\Delta y| = |y_{\gamma} - y_{e+}| > 3$ cm, Δy - vertical distance in GAMS plane;

3) |x,y| of reconstructed "ν" < 100cm in GAMS-2000 plane;

4) 4 mrad $< \theta_{e\gamma} <$ 80 mrad,

5) $M_K > 0.45$GeV;

6) $|M^2_{miss}(\pi^0 e^+ \gamma)| < 0.006$ GeV^2,

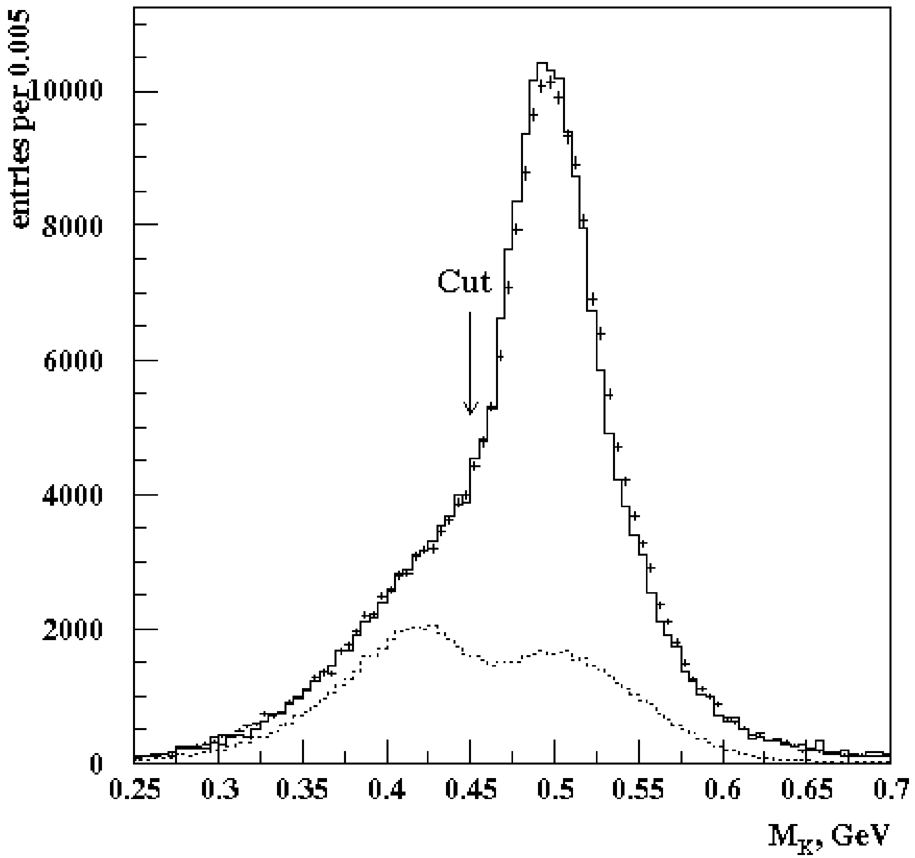
where $M^2_{miss}(\pi^0 e^+ \gamma) = (P_K - P_{\pi^0} - P_e - P_{\gamma})^2$,

M_K - K meson mass recovered, mass of the $(\pi^0 e^+ \nu \gamma)$- system, assuming $m_{\nu}=0$.

After applying cuts 1 to 6, we received 112000 candidates.

MC calculations gave us a total background 18500 decay, which is 16.5%.
We extracted investigated decay with a relatively small background.

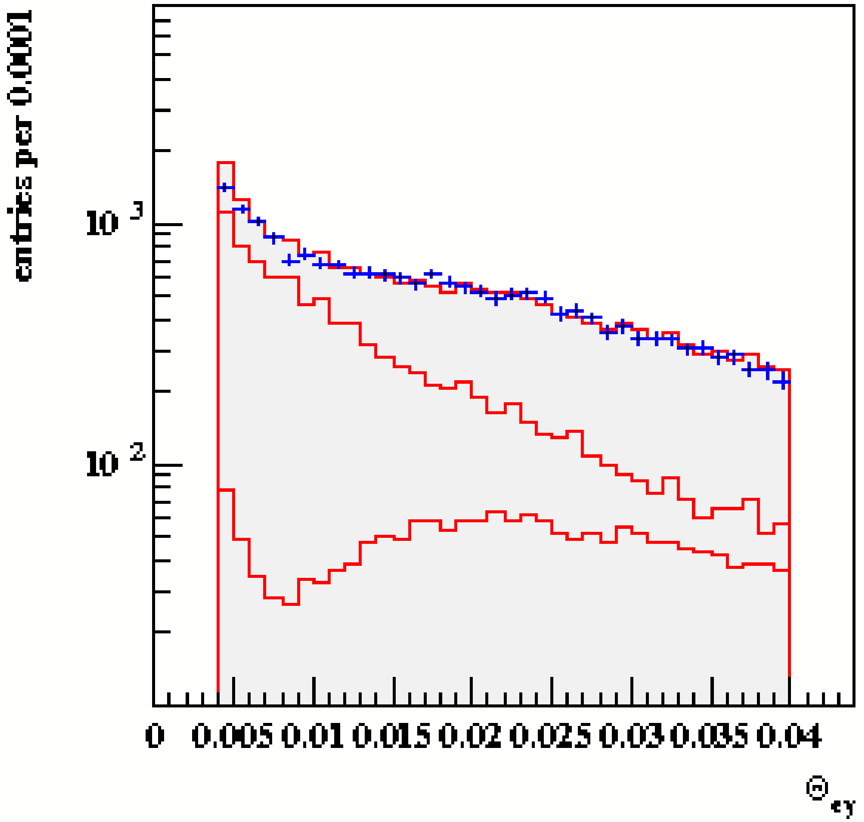
$K_{3\pi}$ background suppression



Cut 5. $M_K > 0.45$GeV

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

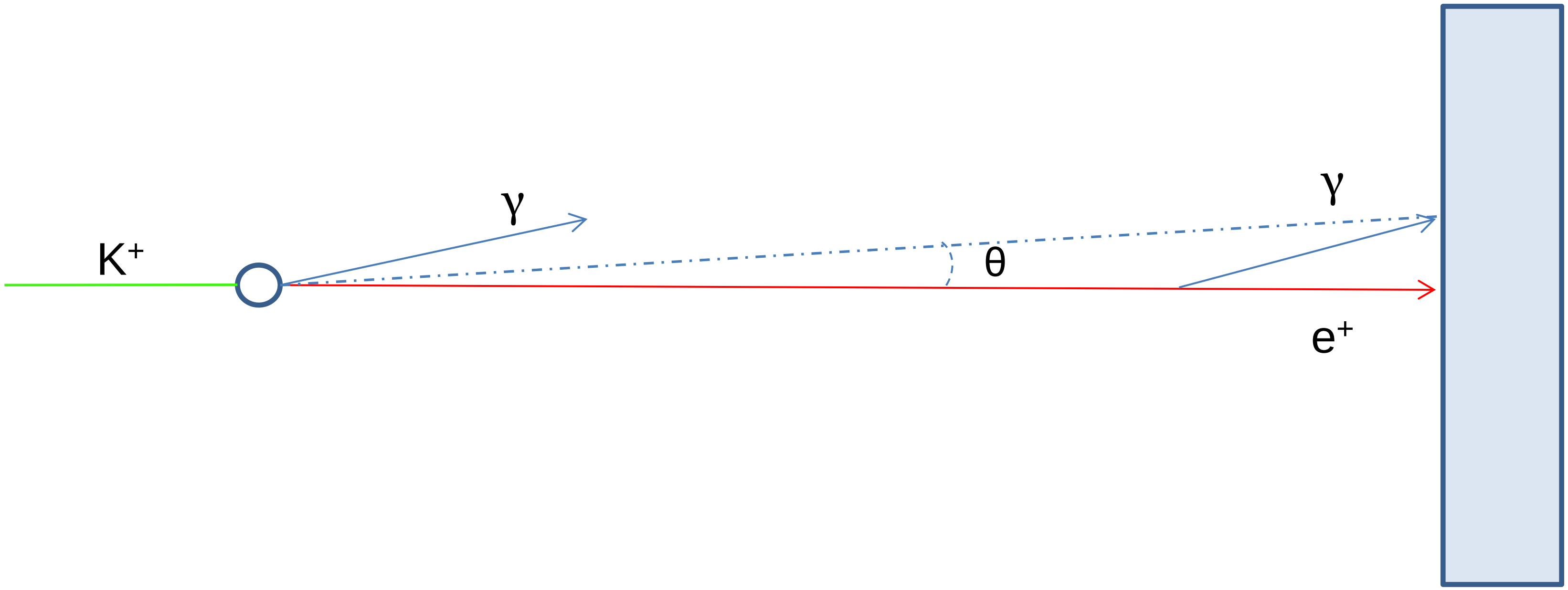
Results



Experiment
Bg + signal

Signal
Bg

K_{e3} background suppression



Results

For $E^*\gamma$ > 10MeV $\theta^*e\gamma$ >10° for the relative branching ratio we got

$$R_1=\Gamma(K^+\rightarrow\pi^0e^+\nu\gamma\ ) / \Gamma(K^+\rightarrow\pi^0e^+\nu) = (1.805 \pm 0.017 \pm0.020) \cdot10^{-2}$$

Theoretical prediction for R from CHPT is $R_1 = 1.804\pm0.021 \cdot10^{-2}$

[Eur. Phys. J. C 50 (2007) 557.]

For E^*_γ > 30MeV $\theta^*_{e\gamma}$ >20° for the relative branching ratio we got

$$R_2=\Gamma(K^+\rightarrow\pi^0e^+\nu\gamma\ ) / \Gamma(K^+\rightarrow\pi^0e^+\nu) = (0.621 \pm 0.010 \pm0.015) \cdot10^{-2}$$

Theoretical prediction for R from CHPT is $R_2 = 0.640\pm0.008 \cdot10^{-2}$

Results

For E^*_γ > 10MeV and 0.6 <cos*θ <0.9 we have 24840 selected events with 1870 background events. Comparing this after efficiency correction with our 10041000 K_{e3} events, for the relative branching ratio we got

$$R_3=\Gamma(K^+\to\pi^0 e^+\nu\gamma) / \Gamma(K^+\to\pi^0 e^+\nu) = (0.542 \pm 0.010 \pm 0.012)\cdot 10^{-2}$$

Theoretical prediction for R_3 from CHPT is $R_3 = (0.559\pm0.008)\cdot 10^{-2}$

N_{ev}	$R_{exp} \cdot 10^{-2}$	Reference
24840	0.54 ± 0.01 ± 0.01	This work
7248	0.53 ± 0.01 ± 0.01	OKA
1456	0.48 ± 0.02 ± 0.03	ISTRA+
82	0.46 ± 0.08	XEBC
192	0.56 ± 0.04	ISTRA
13	0.76 ± 0.28	HLBC

Table 1.

Systematic

Systematic errors are estimated by variation of cuts 1-6

R_i \ cut	1	2	3	4	5	6
R_1	0.003	0.004	0.006	0.008	0.012	0.011
R_2	0.004	0.002	0.004	0.005	0.010	0.004
R_3	0.001	0.001	0.005	0.001	0.010	0.004

Table 2

Summary

1) OKA collaboration, operating at IHEP Protvino U-70 PS in RF-separated beam, has accumulated large statistics of K^+ decays.

2) **$K^+ \to \pi^0 e^+ \nu\gamma$** decay signal is extracted with a low background.

3) For $E^*\gamma > 10$MeV $\theta^*e\gamma > 10°$ for the relative branching ratio we got

$R_1 = \Gamma(K^+ \to \pi^0 e^+ \nu\gamma) / \Gamma(K^+ \to \pi^0 e^+ \nu) = (1.804 \pm 0.017 \pm 0.020) \cdot 10^{-2}$

4) For $E^*\gamma > 30$MeV $\theta^*e\gamma > 20°$ for the relative branching ratio we got

$R_2 = \Gamma(K^+ \to \pi^0 e^+ \nu\gamma) / \Gamma(K^+ \to \pi^0 e^+ \nu) = (0.621 \pm 0.010 \pm 0.013) \cdot 10^{-2}$

5) for the region $E^*\gamma > 10$ MeV and $0.6 < \cos^*\theta_{e\gamma} < 0.9$ at statistic 24840 events.

$R_3 = \Gamma(K^+ \to \pi^0 e^+ \nu\gamma) / \Gamma(K^+ \to \pi^0 e^+ \nu) = (0.542 \pm 0.010 \pm 0.012) \cdot 10^{-2}$

Next step – to measure SD terms.