Upper limit on the $K_S \to 3\pi^0$ decay

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Theoretical prediction

Considering model:

$$|K_S >= N_S(|K_1 > +\epsilon_S|K_2 >), \qquad N_S^{-2} = 1 + |\epsilon_S|^2$$
$$|K_L >= N_L(|K_2 > +\epsilon_L|K_1 >), \qquad N_L^{-2} = 1 + |\epsilon_L|^2$$

prediction for $Br(K_S \to 3\pi^0)$:

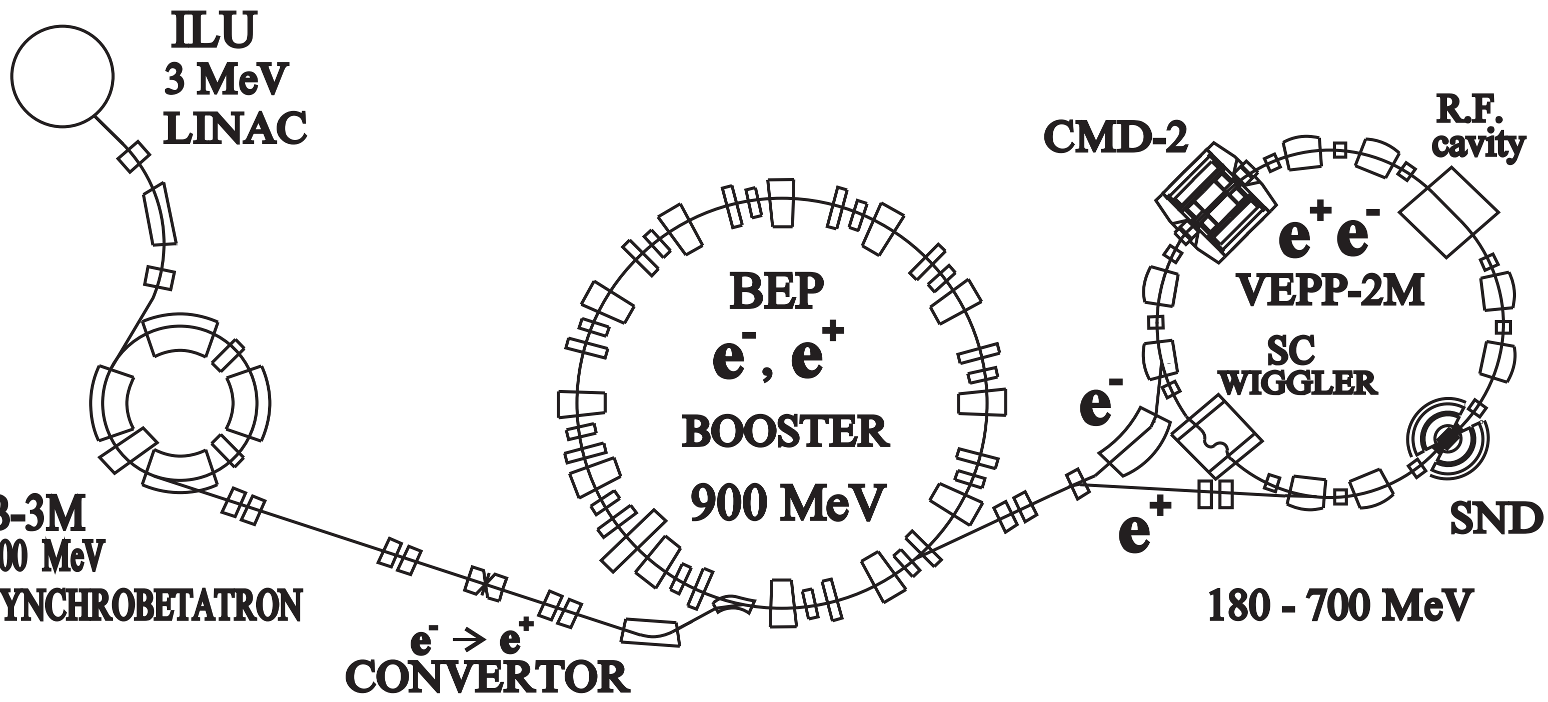
$$Br(K_S \to 3\pi^0) = |\epsilon_S|^2 \frac{\tau_S}{\tau_L} Br(K_L \to 3\pi^0) \sim 10^{-9}$$

Experimental limits

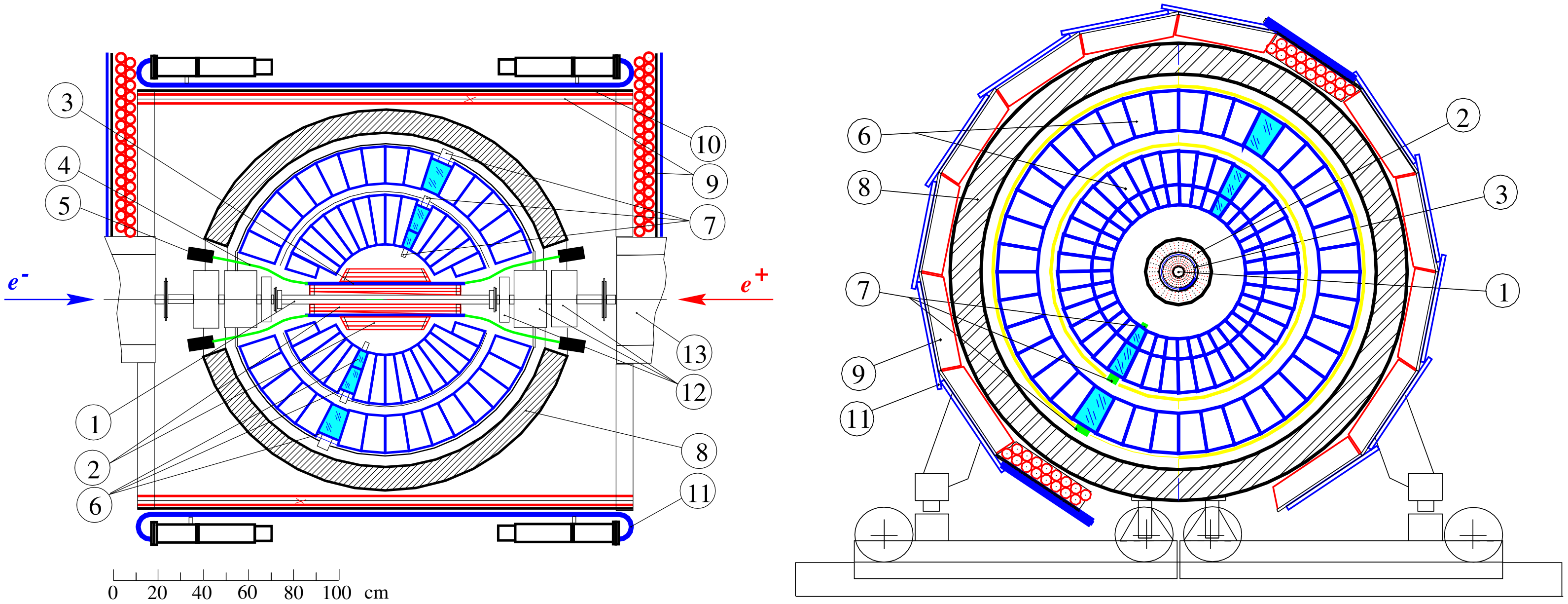
Barmin et al.(1983): $Br(K_S \to 3\pi^0) < 3.7 \cdot 10^{-5}, CL90\%$

CPLEAR (1998): $Br(K_S \to 3\pi^0) < 1.9 \cdot 10^{-5}, CL90\%$

VEPP-2M complex



Layout of SND



1 - beam pipe, 2 - drift chambers, 3 - scintillation counter, 4 - NaI(Tl) crystals, 5 - vacuum phototriodes, 6 - iron absorber, 7 - streamer tubes, 8 - scintillation system, 9 - streamer tubes, 10 - 1 cm iron plates, 11 - scintillation counters, 12 and 13 - collider magnets

SND Experiments at VEPP-2M

- Energy range $2E_0 = 980 - 1060$ MeV
- Luminosity integral $\int L = 12.2\ \mathrm{pb}^{-1}$
- $N_\phi = 2 \cdot 10^7$ corresponding to $6.8 \cdot 10^6$ $\phi \to K_S K_L$ decays

Process to search: $e^+e^- \to \phi \to K_S K_L, K_S \to 3\pi^0$

- K_L can produce additional clusters in the calorimeter. Selected are events with either 0 or 1 cluster from K_L
- Main background comes from:

$$e^+e^- \to \phi \to K_S K_L, \quad K_S \to 2\pi^0 + \text{ additional clusters from } K_L$$

$$e^+e^- \to \phi \to \eta\gamma, \quad \eta \to 3\pi^0$$

cosmic and beam background

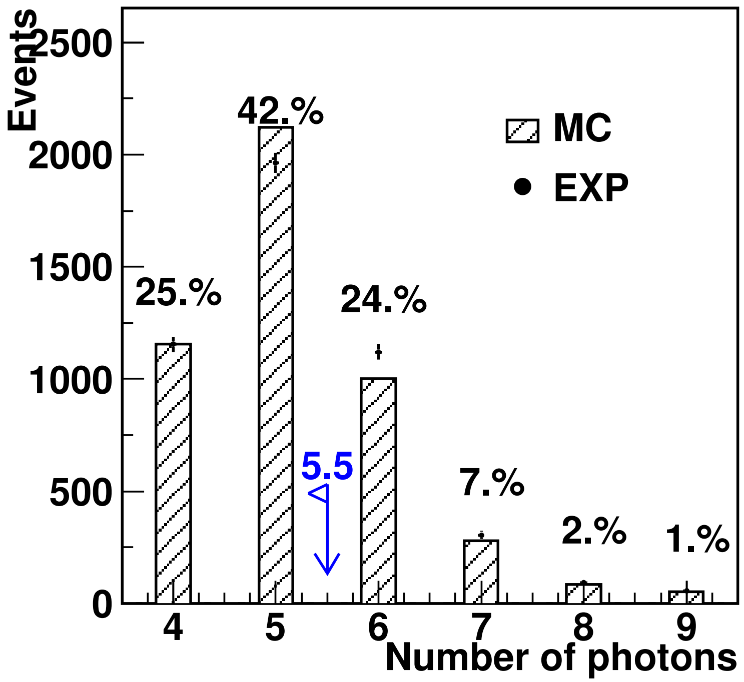
- Process $e^+e^- \to \phi \to K_S K_L, \quad K_S \to 2\pi^0$ is used as a reference (RP)

Event Pre-Selection

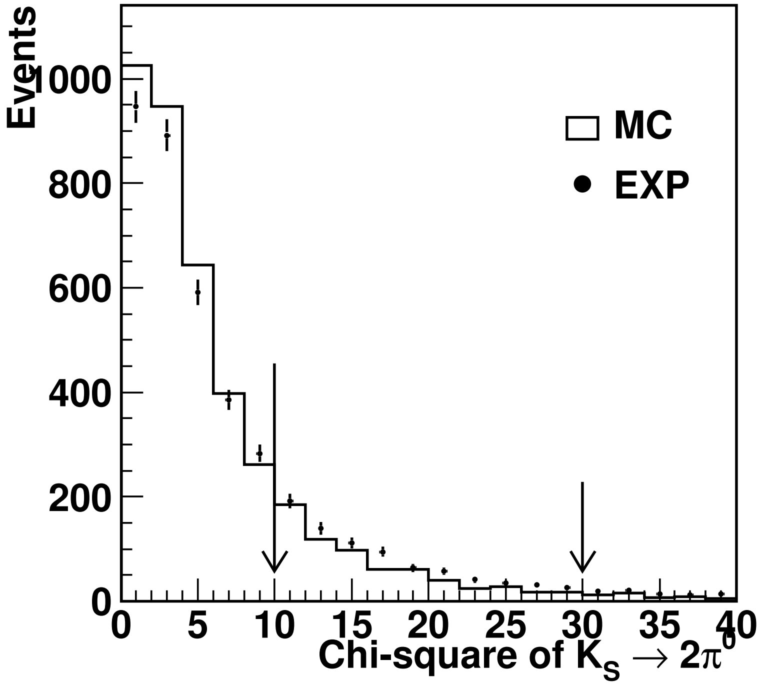
- Cuts are similar for main and reference processes, except explicitly stated
- 6 or 7 neutral particles (4 or 5 for RP)
- All particles are in the detectable region: $\theta > 30^\circ$
- Special rejections against beam and cosmic background
- Kinematic fit with $K_S \to 3\pi^0$ hypothesis ($K_S \to 2\pi^0$ for RP):
  - Logarithmic likelihood: $\chi^2_{K_S \to 3\pi^0} < 20$ ($\chi^2_{K_S \to 2\pi^0} < 10$ for RP)
  - K_S momentum: $80 < P_{K_S}(MeV) < 145$
  - K_S polar angle: $30^\circ < \theta_{K_S} < 150^\circ$.
  - Invariant masses of pions before kinematic fit (will be restricted later)
- $K_S \to 2\pi^0$ background reduction: $30 < \chi^2_{K_S \to 2\pi^0}$

Plots for $K_S \to 2\pi^0$ selection

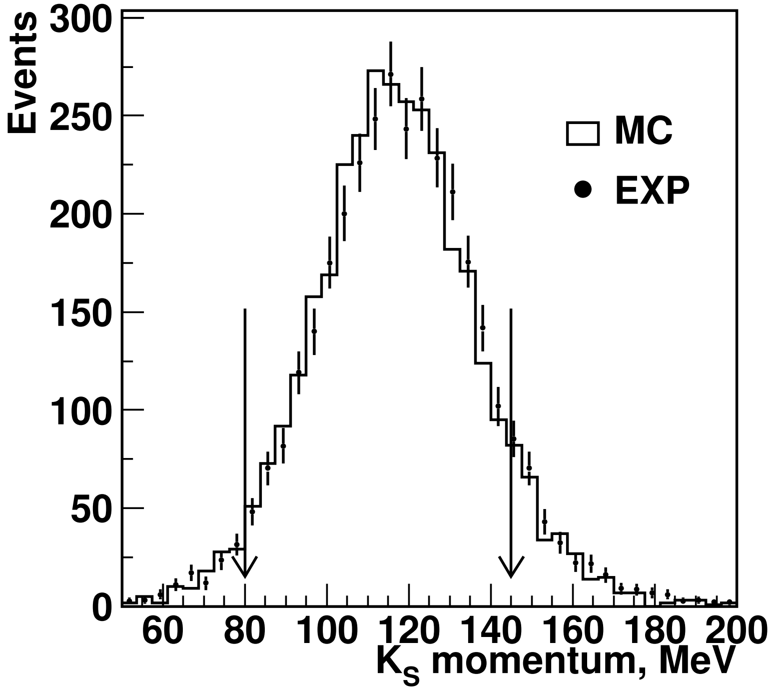
Number of photons



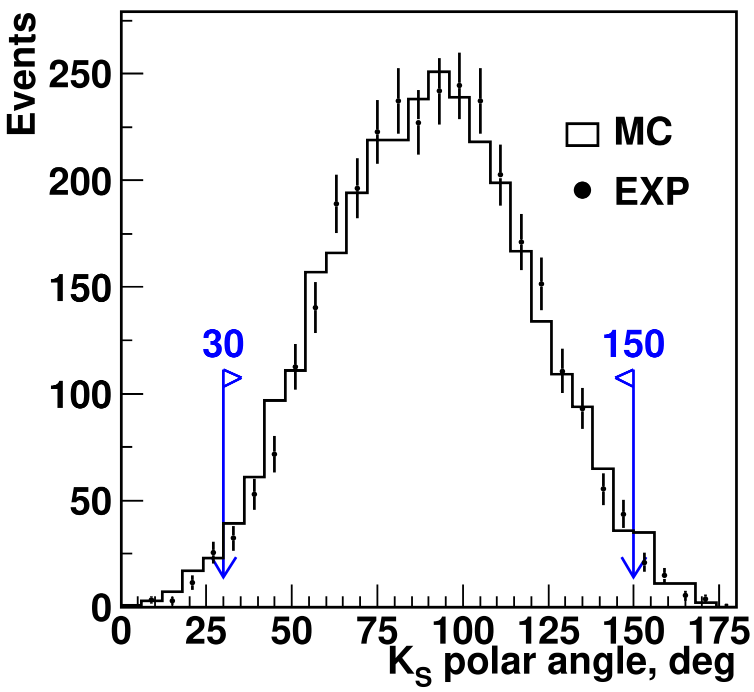
$K_S \to 2\pi^0$ likelihood

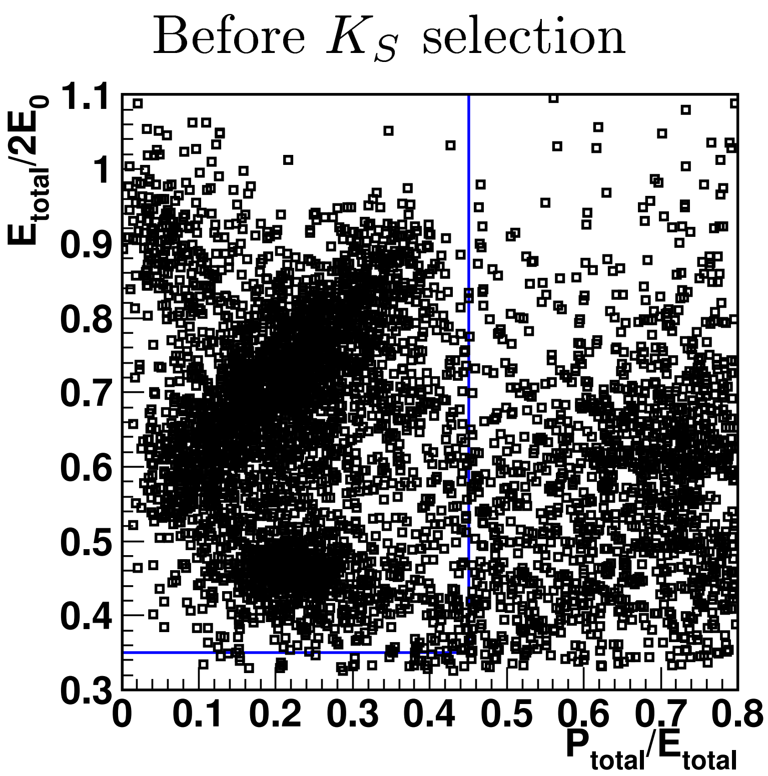


K_S momentum

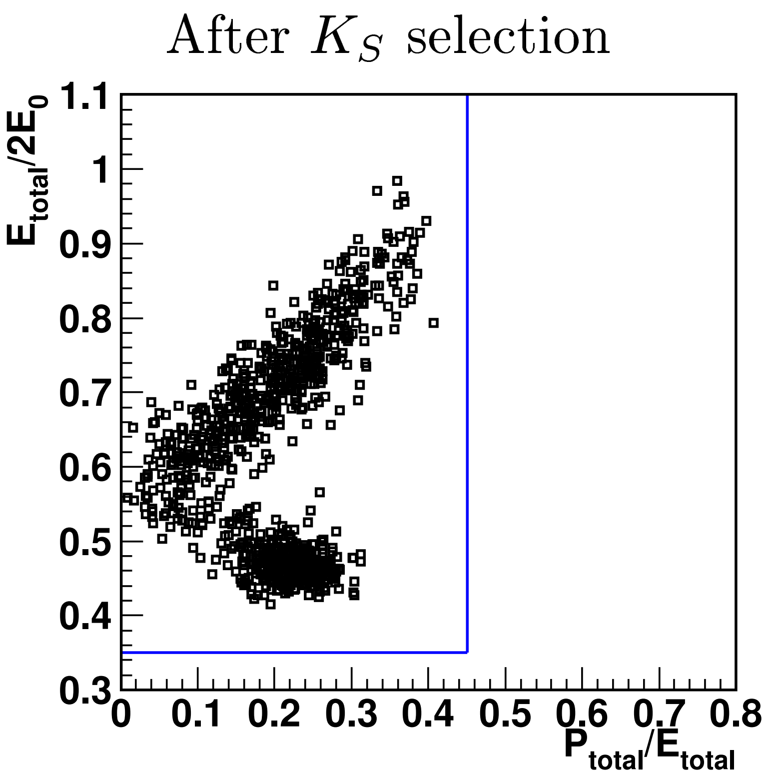


K_S polar angle





Before K_S selection
$E_{total}/2E_0$
P_{total}/E_{total}
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8



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1.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

Analysis branches into 2 ways

K_L is detected as one cluster

15 events after preselection. Further selection is:

- 7 neutral particles (5 for RP)
- The spatial angle between K_L and K_S, $\alpha > 120°$.
- K_L cluster is not from a photon, i.e. either transverse photon likelihood $\xi > 10$, or longitudinal photon likelihood $\zeta > 8$. Both functions show the quality of a photon.
- K_L total energy deposition $E_{K_L} > 100$ MeV

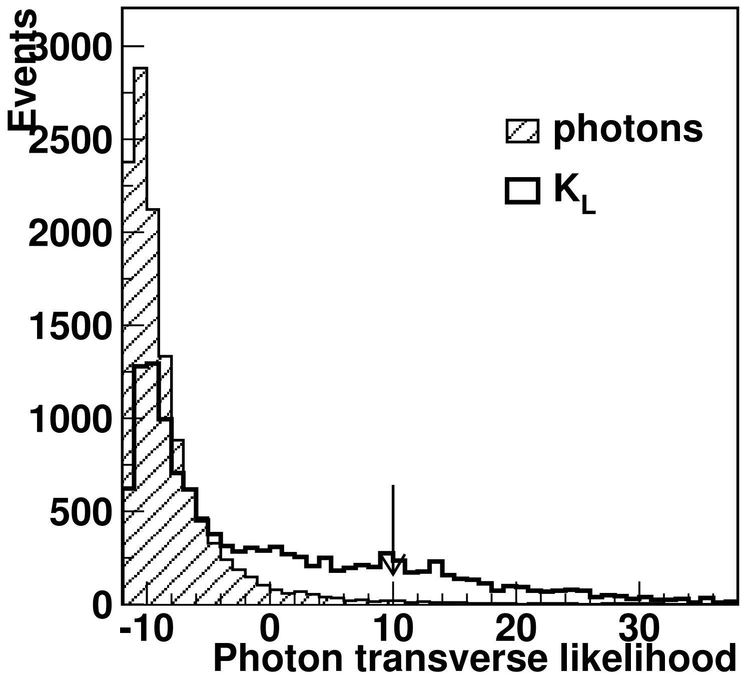
K_L not registered

19 events after preselection. Selection includes:

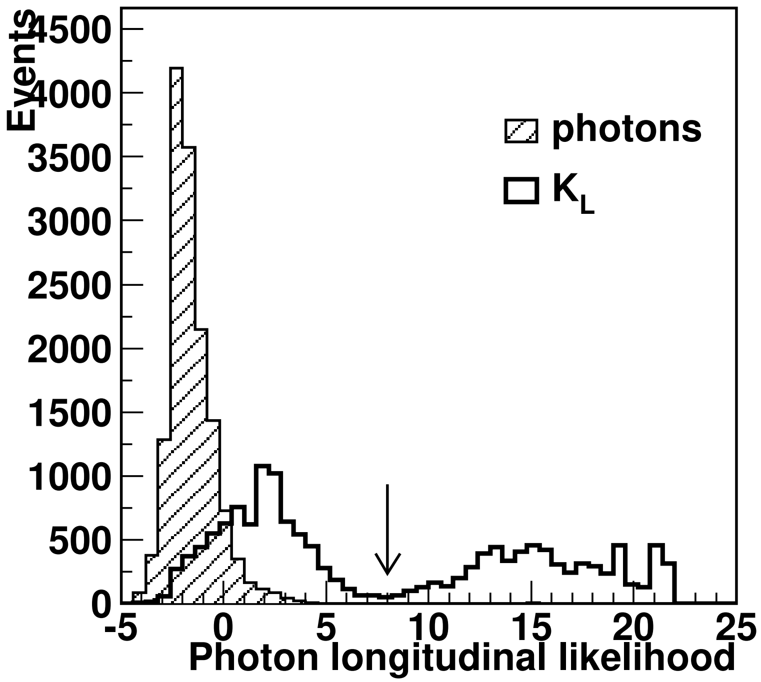
- 6 neutral particles (4 for RP)
- $\xi < 0$, $\zeta < 0$ for all photons
- Pion masses restricted to $120 < m_\pi < 155$

Plots for $K_S \to 2\pi^0$

Photon transverse likelihood



Photon longitudinal likelihood



Upper limit on $Br(K_S \to 3\pi^0)$

No events of process $K_S \to 3\pi^0$ have been observed. All efficiencies were calculated from simulation. Using formulae:

$$Br(K_S \to 3\pi^0) = Br(K_S \to 2\pi^0) N_{K_S \to 3\pi^0} \frac{\varepsilon_{K_S \to 2\pi^0}}{N_{K_S \to 2\pi^0} \varepsilon_{K_S \to 3\pi^0}}$$

	with K_L	w/o K_L
$K_S \to 3\pi^0$ efficiency, %	1.7	1.9
$K_S \to 2\pi^0$ efficiency, %	5.3	4.9
$K_S \to 3\pi^0$ events	0	0
$K_S \to 2\pi^0$ events	92676	57742
Upper limit (CL90%)	$2.4 \cdot 10^{-5}$	$2.8 \cdot 10^{-5}$

Combined result

$$Br(K_S \to 3\pi^0) < 1.3 \cdot 10^{-5}$$

Systematic errors

- K_L imprecise simulation. Reference process of $K_S \to 2\pi^0$ has 25% loss of experimental events.
- Photon showers differences for MC and EXP. Process $\eta \to 3\pi^0$ was studied under similar cuts with 8% loss of experimental events.
- Systematic errors in ratio of main and reference processes partially cancel
- Overall systematic errors is estimated as 10%, increasing the limit value:

$$Br(K_S \to 3\pi^0) < 1.4 \cdot 10^{-5}, CL90\%$$

Summary

- The search for $e^+e^- \to \phi \to K_S K_L, K_S \to 3\pi^0$ was performed with SND detector at VEPP-2M
- No events of the process were observed. As a result an upper limit with 90% confidence level was set:

$$Br(K_S \to 3\pi^0) < 1.4 \cdot 10^{-5}$$