Study of the $e^+e^- \to K_S K_L \pi^0$ process with the CMD-3 detector at the VEPP-2000 collider

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Purpose

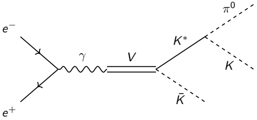
The purpose is to study $e^+ e^- \to K_S K_L \pi^0$ in the range $E_{c.m.}$ from the production threshold 1130 MeV to 2 GeV. The current study is based on integrated luminosity of 188.6 pb^{-1}.

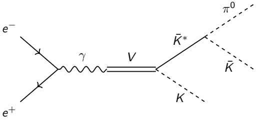
Motivation:

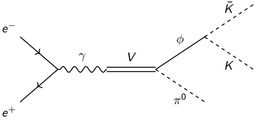
- Studying the interaction of light quarks
- Contribution into the vacuum polarization used in the calculation of the muon anomalous magnetic moment $(g-2)_\mu$
- Comparison of the cross-section energy dependants with the spectrals from τ-lepton decays.
- Studying the production dynamic of the process (VMD).
- Proving the isotopic ratio in conjunction with the processes $K^+ K^- \pi^0$, $K^* K$ $(K_S K^\pm \pi^\mp)$

About $e^+ e^- \to K_S K_L \pi^0$

$$M \propto \frac{J_\mu \cdot [\vec{P_1} \times \vec{P_2}]^\mu}{D_\gamma(s)} \cdot \left(\sum_{V=\phi,\omega,\rho,\ldots,I=0,1} \frac{A_V e^{i\alpha_V}}{D_V(s) \cdot D_{K^*}(Q_{K\pi^0})} + \sum_{V=\rho,\ldots,I=1} \frac{B_V e^{i\beta_V}}{D_V(s) \cdot D_\phi(Q_{K\bar{K}})} \right)$$







$$|1,0\rangle = |\uparrow\rangle_{K^*} |\downarrow\rangle_K + |\downarrow\rangle_{K^*} |\uparrow\rangle_K$$
$$|0,0\rangle = |\uparrow\rangle_{K^*} |\downarrow\rangle_K - |\downarrow\rangle_{K^*} |\uparrow\rangle_K$$

$$|1,0\rangle = |0,0\rangle_\phi |1,0\rangle_\pi$$

Suppressed by OZI rule

$$V = \phi(1020), \phi(1680), \rho(770), \rho(1450), \ldots$$

Isotopic ratio:

$$M_{K_S K_L \pi^0} = T_{1b} - \frac{1}{\sqrt{3}} T_0; \; M_{K^+ K^- \pi^0} = T_{1b} + \frac{1}{\sqrt{3}} T_0;$$

$$M_{K^\pm K^0 \pi^\mp} = \pm T_{1a} + \sqrt{\frac{2}{3}} T_0;$$

$$\sigma_{K_S K_L \pi^0} = \sigma_{K_S K^\pm \pi^\mp} - \sigma_{K^+ K^- \pi^0} + Br(\phi \to K\bar{K}) \cdot \sigma_{\phi\pi^0}$$

Analysis $e^+ e^- \to K_S K_L \pi^0$ with CMD-3

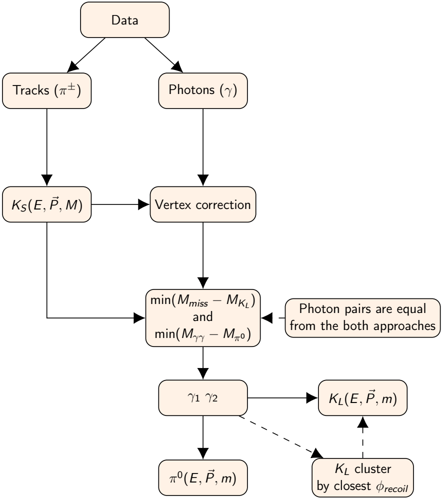
We study the process in channels:
$K_S \to \pi^+\pi^-$ and $\pi^0 \to \gamma\gamma$

$$\sigma_B = \frac{N_{selected} - N_{background}}{\varepsilon_{rec} \cdot \varepsilon_{trigger} \cdot L \cdot (1 + \delta_{rad})}$$

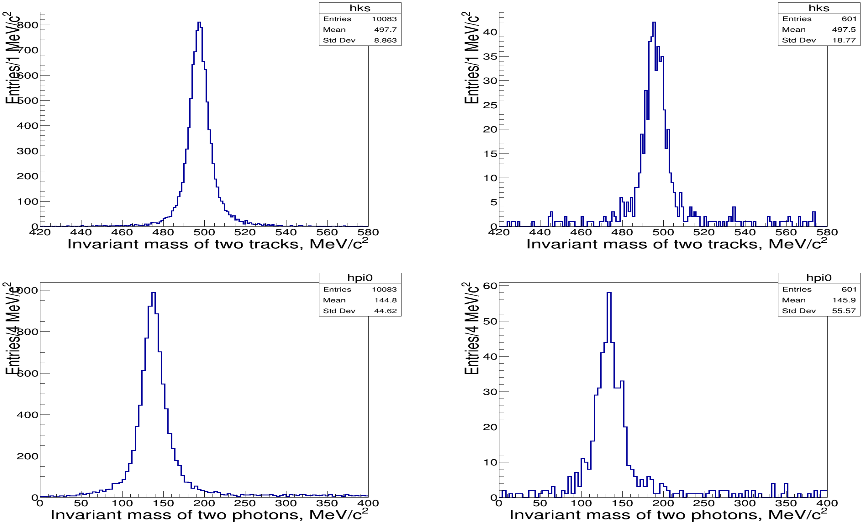
- Get the number of events
- Suppress/subtract background
- Get the efficiency
- Get the radiation corrections
- Estimate the systematic uncertainties

Selection criteria:

1.	$N_{tr} = 2$ ($\rho_{tr} < 6$ cm)
2.	$N_{K_S} = 1$
3.	$\xi_{\pm} < 1.6$ (dE/dx)
4.	$N_{trhit} > 10$ $(\theta_{tr} \in (0.8; \pi - 0.8))$
5.	$\cos XY_{K_S} > 0.8$
6.	$\rho_{\perp K_S} > 0.1$ cm
7.	$N_{ph} > 1$
8.	$E_{phlxe,bgo} > 15$ MeV
10.	$E_{\gamma} < 2 \cdot E_{beam} - 2 \cdot M_K$



Reconstructed masses at $E_{c.m.} = 1675\ MeV$

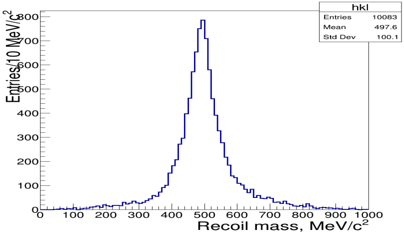


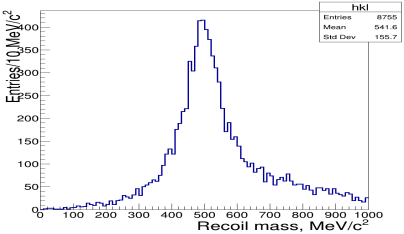
Simulation

Experimental data

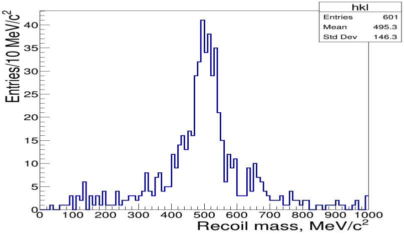
Recoil mass (1675 *MeV* and 1950 *MeV*)

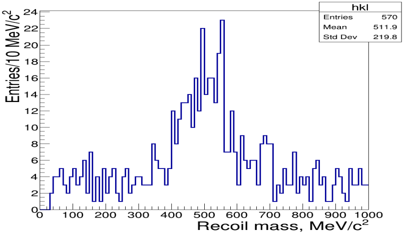
$$2E_{beam} = E_{K_S} + E_{K_L} + E_{\gamma_1} + E_{\gamma_2};\ 0 = \vec{P}_{K_S} + \vec{P}_{K_L} + \vec{P}_{\gamma_1} + \vec{P}_{\gamma_2}$$





Simulation

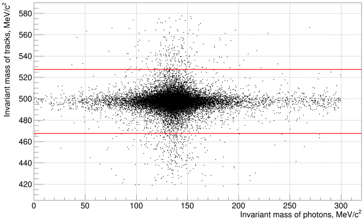




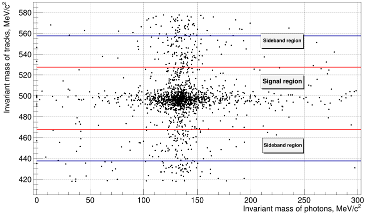
Experimental data

Determining the number of events

We determine the number of events with π^0 by an unbinned fit of the invariant mass of two photons of the joint distribution of the signal and sideband ranges with different weights ($+1$ and -1) in the RooFit package.



Simulation



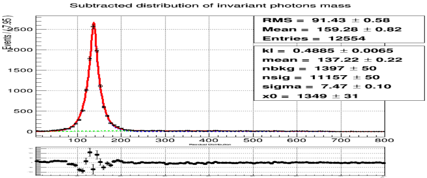
Experimental data

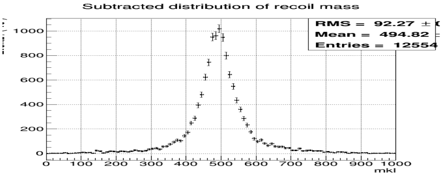
- By subtraction we suppress the events without K_S-meson (assuming uniform distribution for background)
- By fitting we determine the number of events with π^0-meson

*The width of the signal region is $\pm 30\ MeV$

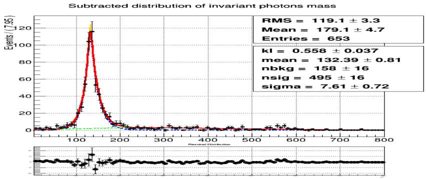
Number of events $E_{c.m.} = 1650\ MeV$

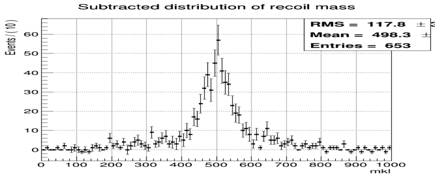
Simulation





Experimental data

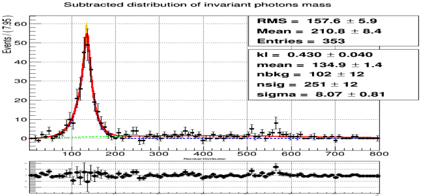


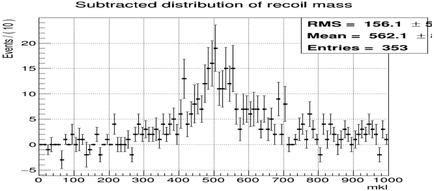


$$S(x; x_0, \sigma, k) = \begin{cases} exp(-\frac{v^2}{2} + k \cdot (v + \frac{x - x_0}{\sigma})), & \frac{x-x_0}{\sigma} \leq -v \\ exp(-\frac{(x-x_0)^2}{2\sigma^2}) & |\frac{x-x_0}{\sigma}| < v \\ exp(-\frac{v^2}{2} + (1-k) \cdot (v - \frac{x-x_0}{\sigma})), & \frac{x-x_0}{\sigma} \geq v \end{cases}, v = \frac{1}{2}$$

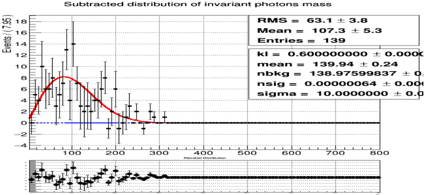
Number of events

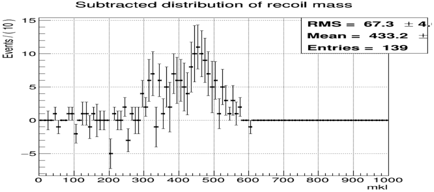
Experimental data, 1950 MeV





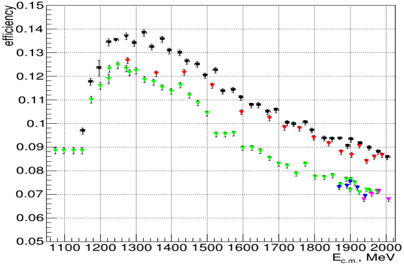
Experimental data, 1150 MeV

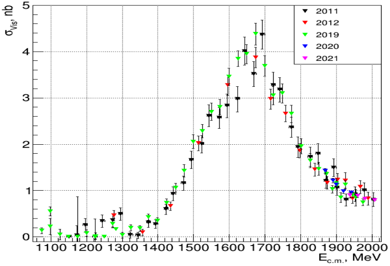




$$B(m; m_0, c, p) = m \cdot [1 - (\frac{m}{m_0})^2]^p \cdot exp[c \cdot (1 - (\frac{m}{m_0})^2)]$$

Cross section $e^+ e^- \to K_S K_L \pi^0$



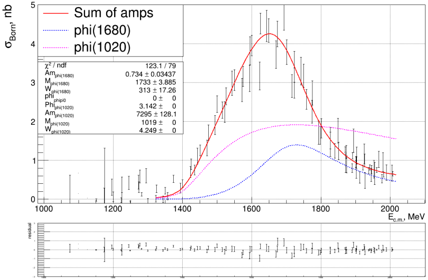


Specifics:

- Excluded 2017 season
- Simulation based on the detector state
- $\varepsilon(K_S K_L \pi^0 \pi^0) \approx 3\%$

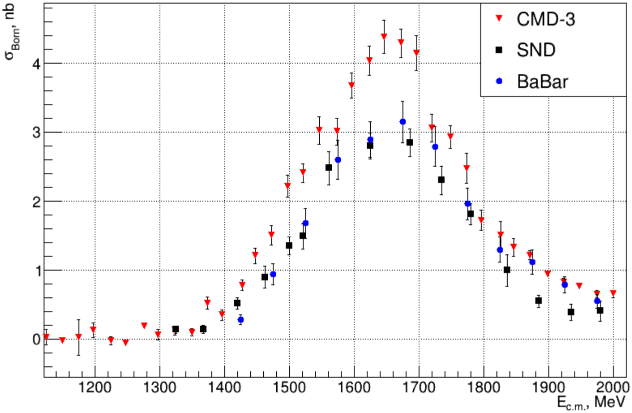
Cross section fit

- Main contribution: $\phi(1020)$, $\phi(1680)$
- Require the simultaneous fit with the processes $K^+K^-\pi^0$ and $K_S K^\pm \pi^\mp$



Cross section $e^+ e^- \to K_S K_L \pi^0$

The total number of the detected events is 17982.7. The preliminary result:



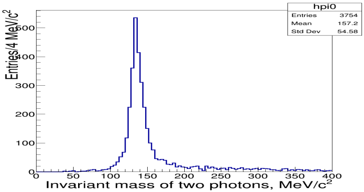
The resulted points are averaged with 25 *MeV* step for the better comparing. Systematic uncertainties is 8.3%.

Background processes

Based on simulation by MHG2000 generator.

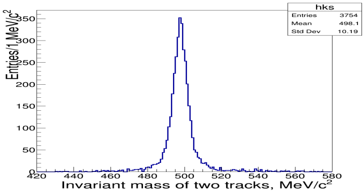
- $e^+e^- \to K_S K_L(\gamma)$
- $e^+e^- \to \pi^+\pi^-\pi^0\pi^0$
- $e^+e^- \to K_S K_L \pi^0\pi^0$

Invariant mass of photons

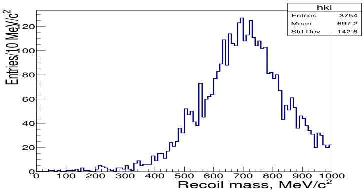


The distributions for $e^+e^- \to K_S K_L \pi^0\pi^0$ process (main systematic uncertainty).

Invariant mass of tracks



Recoil mass



Conclusion

Results:

- Obtain the preliminary cross section of the $e^+e^- \to K_S K_L \pi^0$ process
- The systematic uncertainty is 8%

Plans:

- Subtract the background process $e^+e^- \to K_S K_L \pi^0 \pi^0$
- Simultaneous fit with the processes $K^+ K^- \pi^0$, $K^* K$ ($K_S K^\pm \pi^\mp$)
- Obtain $K_S K_L \eta$, $K_S K_L \pi^0 \pi^0$ processes

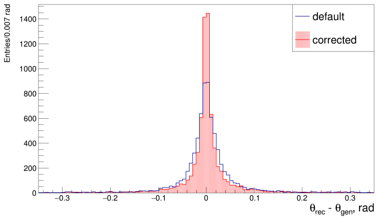
Systematic uncertainties

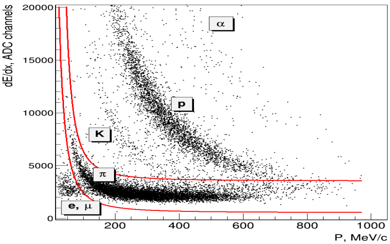
Criteria	$\delta\sigma, \%$
$\xi(dE/dx)$	3.5
N_{trhit}	0.3
$\rho_{\perp K_S}$	1.1
$cos(\vec{r}_{K_S}, \vec{P}_{K_S})_{XY}$	0.5
E_γ	0.1
$\sum$	3.7

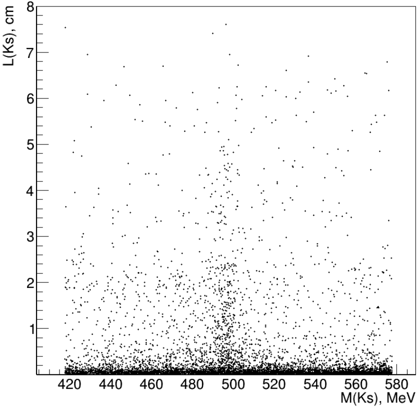
Selection criteria	3.7%
Determination of event numbers	4%
Contribution of $K_S K_L \pi^0 \pi^0$	6%
Registration of charged pions	1%
Registration of photons	1%
Radiation corrections	1%
Luminosity	1%
$\sum$	8.3%

Selection results

Correction of photon angles

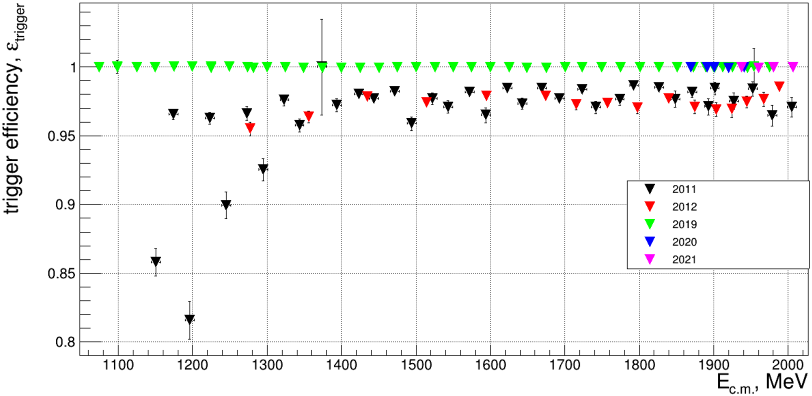






Experimental data at $E_{c.m.} = 1680\ MeV$

Trigger efficiency

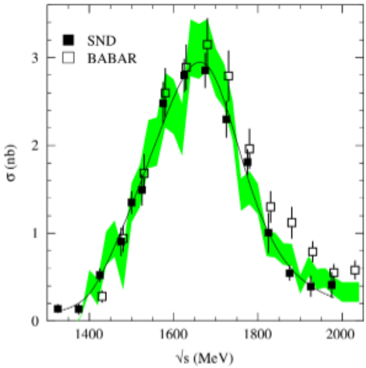


$$\varepsilon_{trig} = 1 - (1 - \varepsilon_{CT})(1 - \varepsilon_{NT})$$

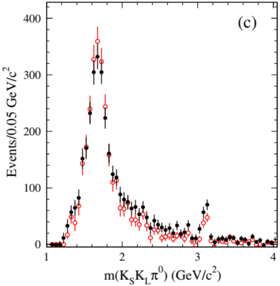
$$\varepsilon_{CT} = \frac{N_{both}}{N_{both} + N_{neutral}};\ \varepsilon_{NT} = \frac{N_{both}}{N_{both} + N_{charge}}$$

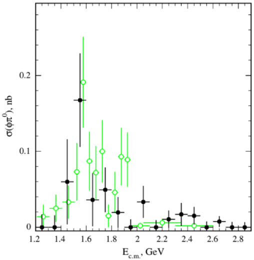
SND and BaBar results

SND



BaBar

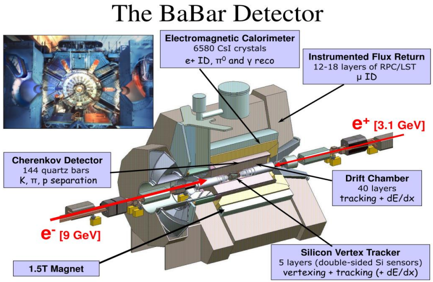


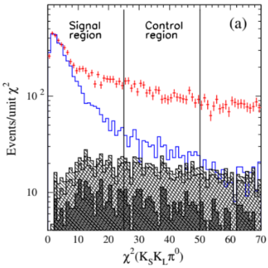


Isotopic ratio:

$$\sigma_{K_S K_L \pi^0} = \sigma_{K_S K^\pm \pi^\mp} - \sigma_{K^+ K^- \pi^0} + Br(\phi \to K\bar{K}) \cdot \sigma_{\phi\pi^0}$$

Study of $e^+ e^- \to K_S K_L \pi^0$ with BaBar





Selection criteria:

- At least two tracks
- At least four photons
- Cluster with ISR photon (> 3 GeV)
- Good K_S candidate
- Photons from π^0 decay with energy more than 0.1 GeV
- Cluster or K_L candidate with energy more than 0.2 GeV

Approach:

- Kinematic fit $4C$ χ^2
- Background subtraction (shape from simulation)

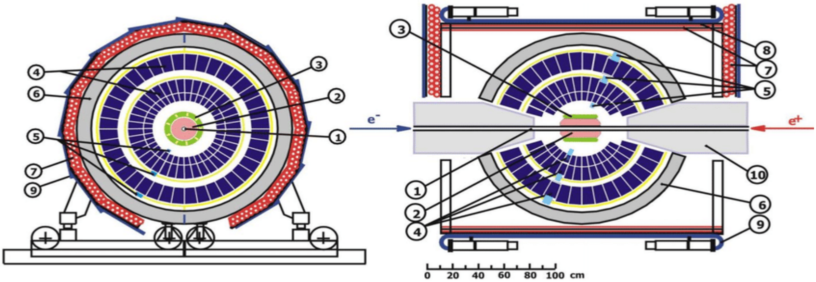
Results:

- Cross section
- Contributions $K^* K$ и $\phi \pi^0$ are obtained

Disadvantages:

- Systematic from ISR
- Systematic from registration of K_L
- Systematic from background subtraction $\approx 10\%$
- Big systematic of efficiency below 1.5 GeV
- Efficiency $\approx 3\%$

Study of $e^+ e^- \to K_S K_L \pi^0$ with SND



Approach:

- Kinematic fit $3\pi^0 + 1K_S$ χ^2
- Fit of $M_{recoil} = M_{K_L}$
- Background shape from simulation

Results:

- Cross section

Disadvantages:

- Efficiency from 6% to 2%
- Systematic from shape of M_{recoil}
- Systematic from registration of K_L
- Summary systematic $\approx$ 12%

Selection criteria:

- No track
- No parallel clusters
- At least 6 photons with energy more than 20 MeV
- Three good π^0 candidates
- Two π^0 with invariant mass of K_S