Rare K^0 Decays

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The NA48 Collaboration:

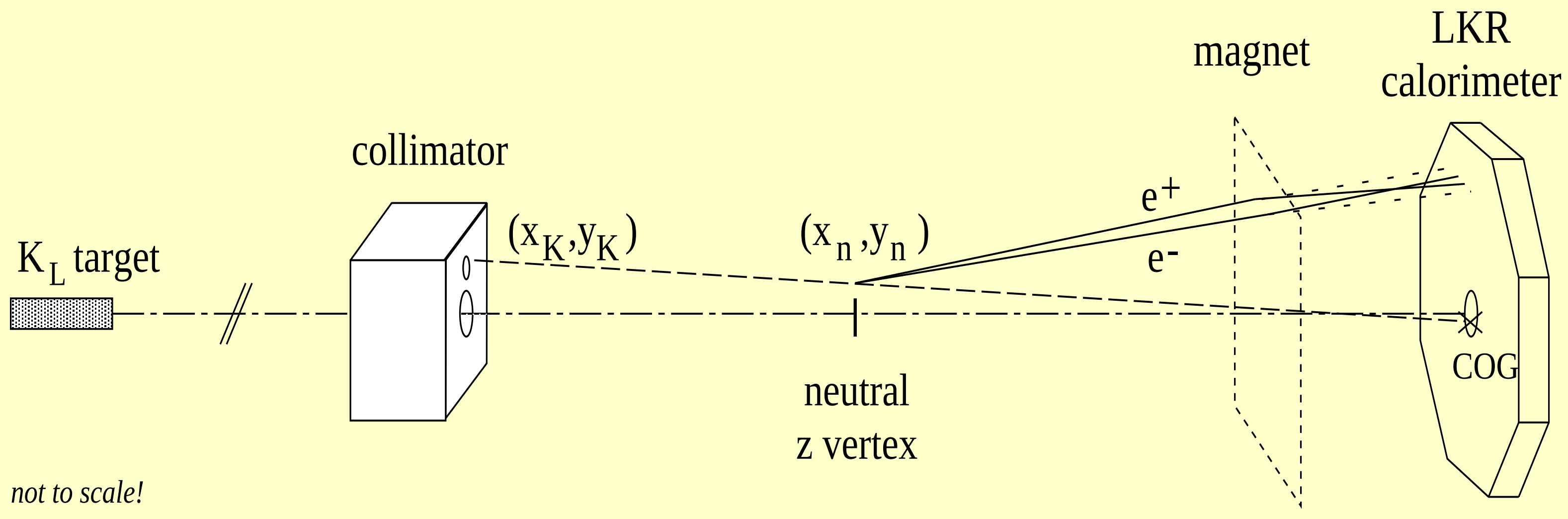
Cambridge, Cagliari, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Vienna, Warsaw

Content

NA48 experiment at CERN SPS to measure ϵ'/ϵ

- Experimental Technique
- Serarch for $K_S^0 \to \pi^0 e^+ e^-$
- Study of $K_S^0 \to \pi^+ \pi^- e^+ e^-$
- Measurement of $Br(K_S^0 \to \gamma\gamma)$
- Measurement of $Br(K_L^0 \to e^+ e^- e^+ e^-)$
- Observation of $K_L^0 \to \mu^+ \mu^- e^+ e^-$
- Measurement of $Br(K_L \to \pi^0 \gamma\gamma)$
- Measurement of $Br(K_L \to e^+ e^- \gamma\gamma)$
- Summary

$60 < P(K_S), P(K_L) < 170 GeV/c^2$



Magnetic Spectrometer: $\sigma_p/p \simeq 0.5\% \oplus 0.009\ (GeV/c)^{-1} \cdot p$

Charged vertex:

CDA of *tracks* / *track(s)* and $(target \leftrightarrow COG)$-line

LKr Calorimeter: $\sigma(E)/E \simeq 0.100/E \oplus 0.032/\sqrt{E} \oplus 0.005(E\ in\ GeV)$

Neutral vertex of M^0 decay:

$$Z_V = Z_{LKr} - \sqrt{\Sigma_{(i<j)} E_i \cdot E_j \cdot r_{ij}^2}\ /\ M^0$$

Search for $K^0_S \to \pi^0 e^+ e^-$

Interest: *estimation of indirect CP-violation contribution to the decay $K^0_L \to \pi^0 e^+ e^-$*

Models: *G.D. Ambrosio, G. Echer, G. Isidori and J. Portoles (hep-ph/9808289)*
G. Ecker, A. Pich and E.De Rafael (N.P.B303,665,1998)

Data: high intensity K_S run in 1999

	K_S channel	Acceptance %	Selected / estimated events
Search for	$\pi^0 e^+ e^-$	7.68	0 ($M_{ee} > 165 MeV/c^2$)
Normaliz.	$\pi^0 \pi^0_D \to \pi^0 e^+ e^- \gamma$	4.81	83960
Backgr.	$\pi^0 \pi^0_D \to \pi^0 e^+ e^- (\gamma)$		0.3

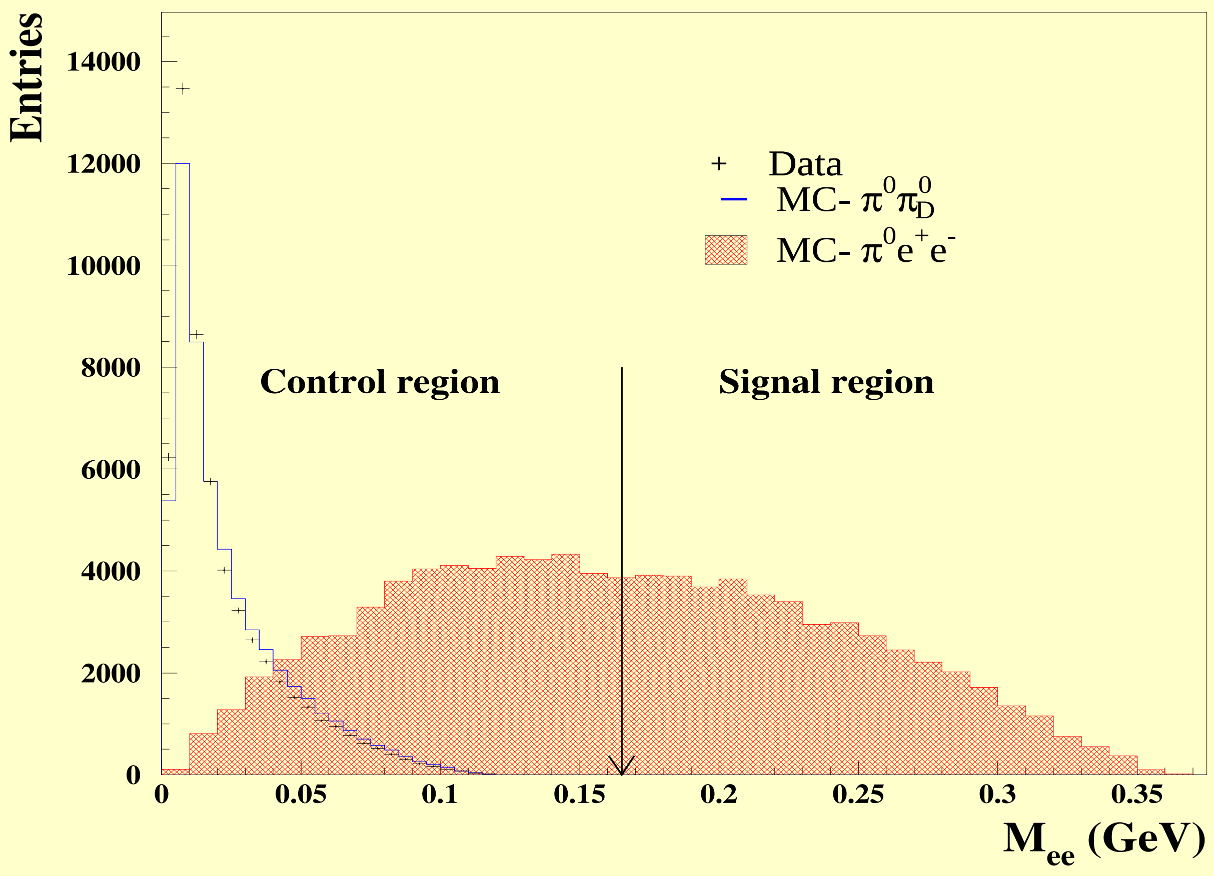
Systematics:

LKr cluster limitation	3%
Radiative corr.	4%
MC / data difference	3%

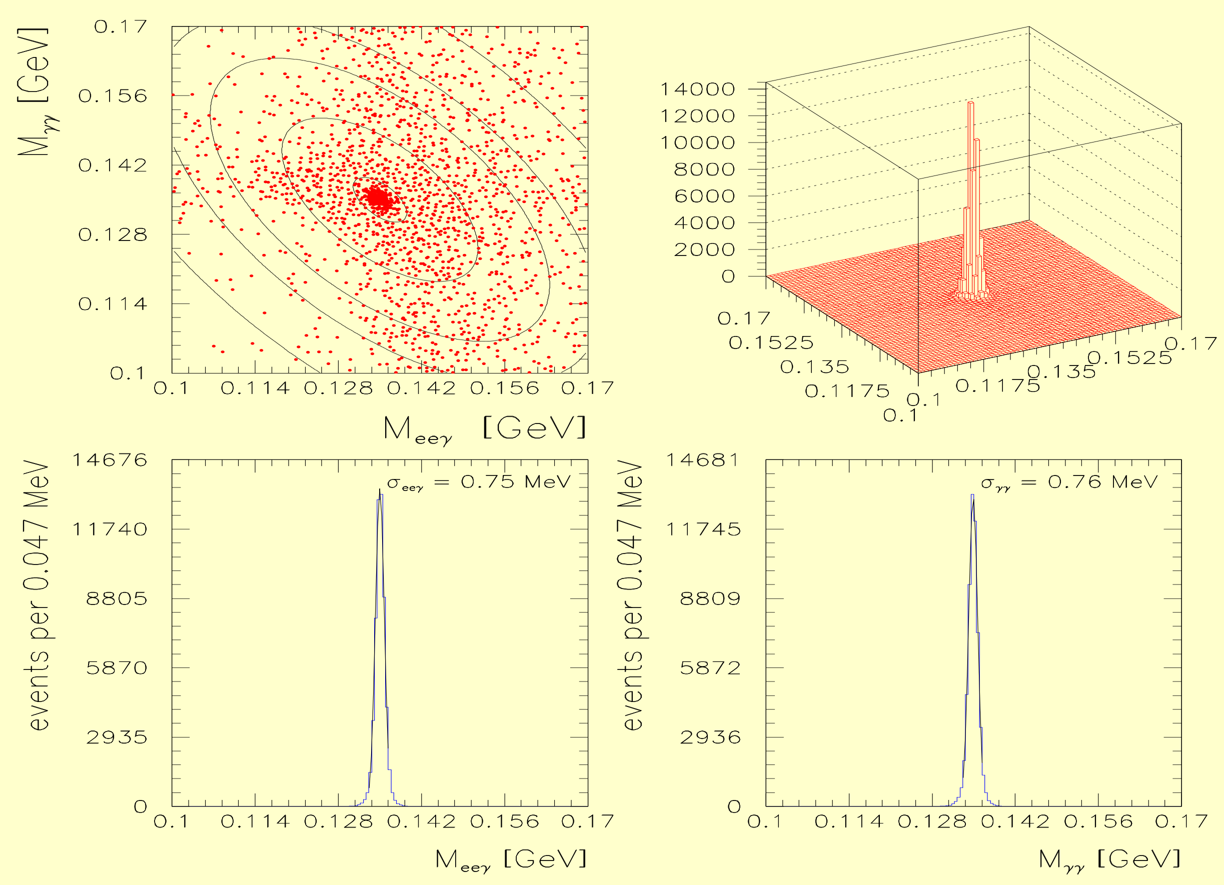
$Br(K_S \to \pi^0 e^+ e^-, M_{ee} > 165 MeV/c^2) < 8.3 \cdot 10^{-8}$, at 90% C.L.

$Br(K_S \to \pi^0 e^+ e^-)_{model} < 1.6 \cdot 10^{-7}$

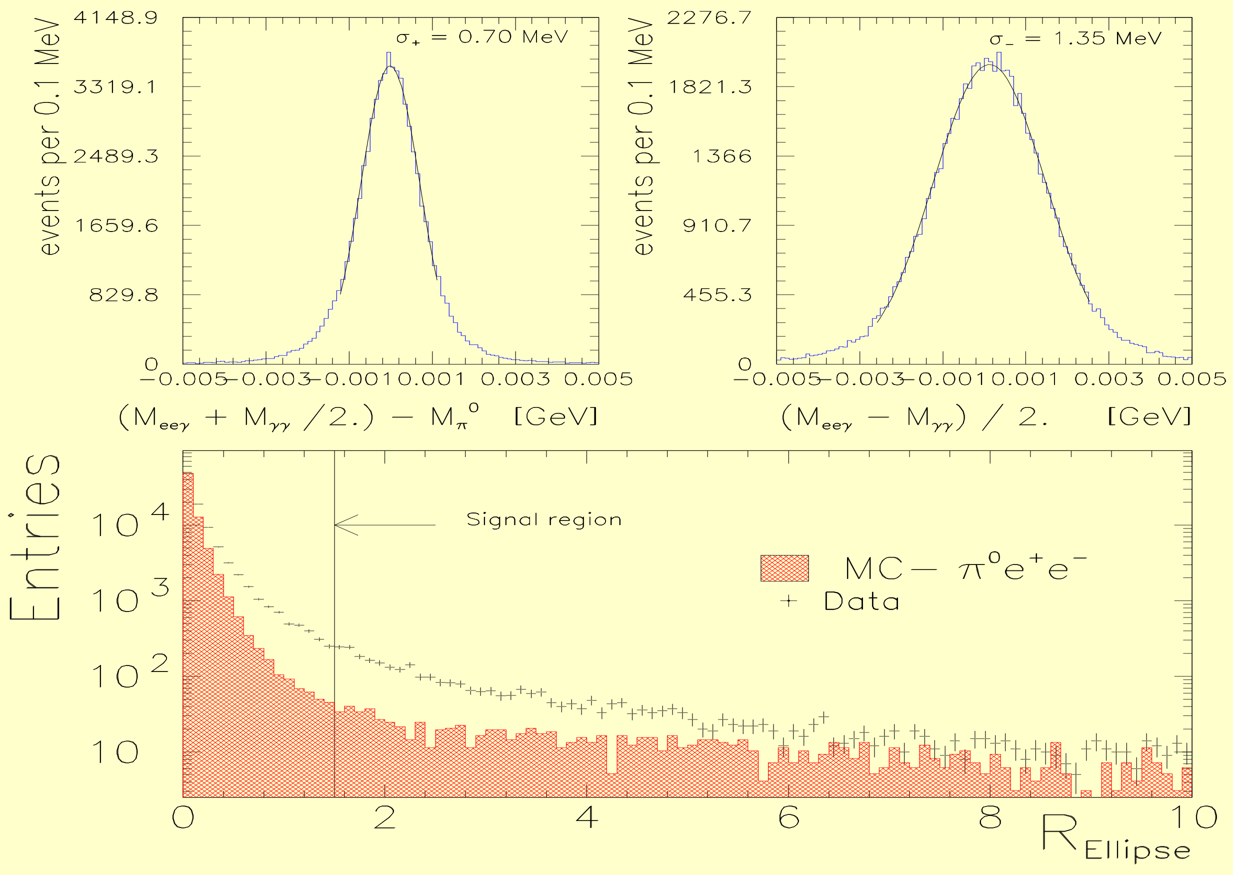
M_{ee} spectra for data and MC



Reconstruction of $K_S^0 \to \pi^0 \pi_D^0 \to \pi^0 e^+ e^- (\gamma)$ decays



Comparison of reconstructed $K_S^0 \to \pi^0 \pi_D^0 \to \pi^0 e^+ e^- (\gamma)$ decays with MC



Interest:

estimation of CP-conserving contribution to $K_L^0 \to \pi^+\pi^-e^+e^-$

test of asymmetry: $A = cos\phi \cdot sin\phi$ $(\phi = 2\pi \vee 2e)$

Model: Heiliger, Sehgal-93

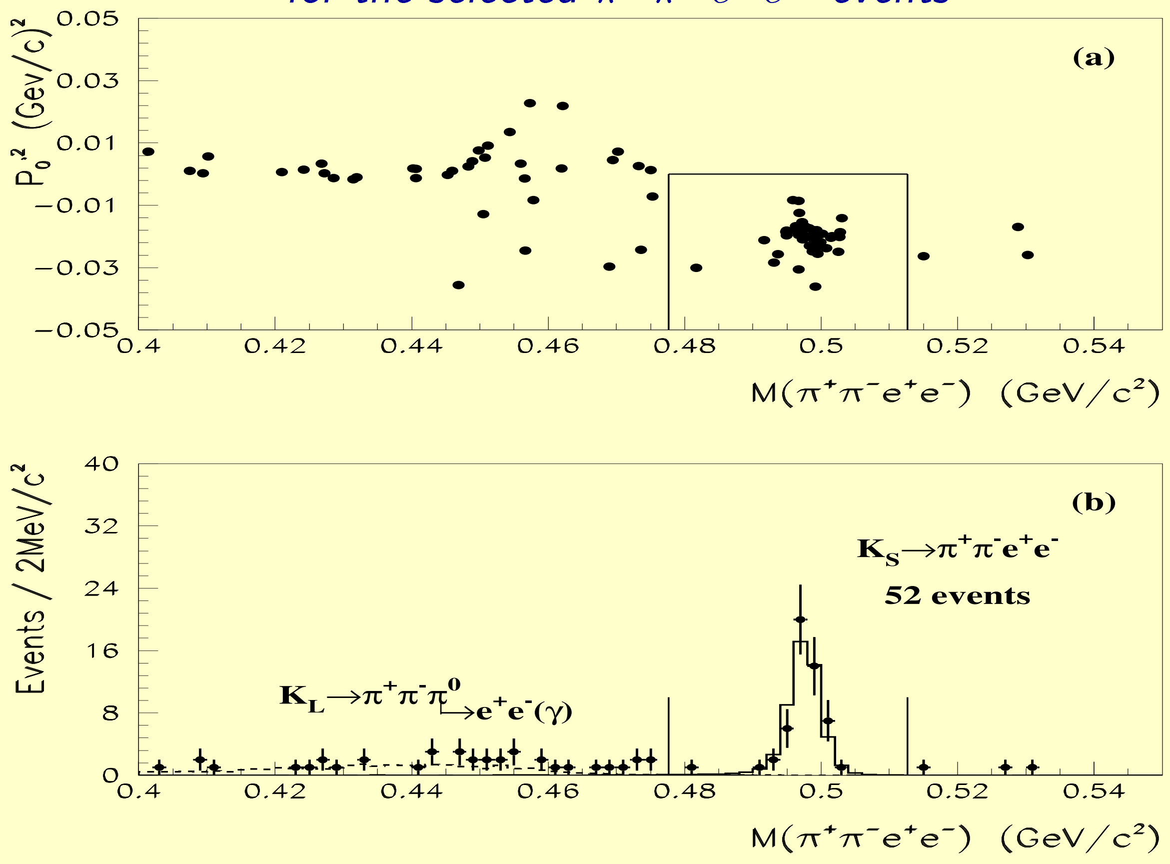
Data recorded in 1998

	Channel	Selected / estimated events
Study of	$K_S^0 \to \pi^+\pi^-e^+e^-$	52
Normalization	$K_L^0 \to \pi^+\pi^-\pi_D^0 \to \pi^+\pi^-e^+e^-\gamma$	89
Background	$K_L^0 \to \pi^+\pi^-\pi_D^0 \to \pi^+\pi^-e^+e^-(\gamma)$	< 1

Systematics:

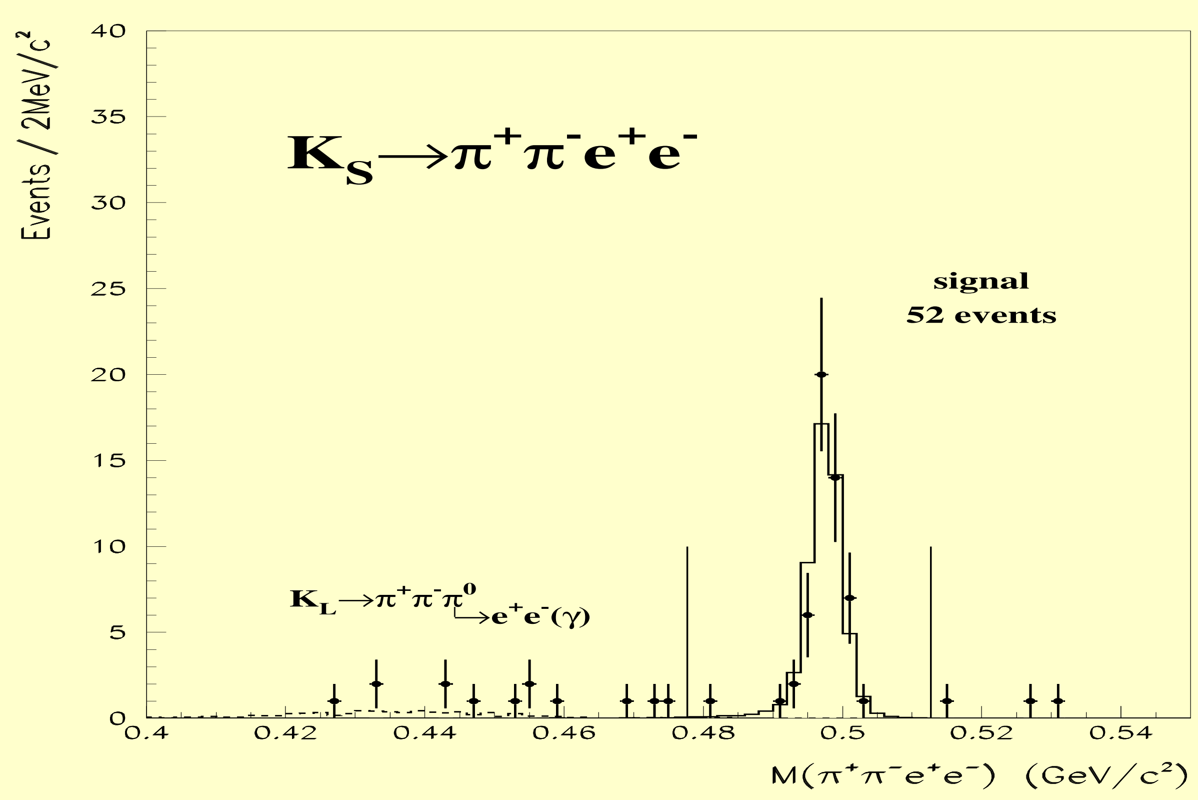
LKr cluster choice	3%
Radiative corrections	4%
MC / data difference	3%

Reconstructed $M(\pi^+\pi^-e^+e^-)$ spectrum versus $P_0'^2$
for the selected $\pi^+\pi^-e^+e^-$ events



$$\boxed{Br(K_S \to \pi^+\pi^- e^+ e^-) = (5.1 \pm 0.9_{stat} \pm 0.3_{syst}) \cdot 10^{-5}}$$

No Asymmetry



Measurement of $Br(K_S^0 \to \gamma\gamma)$

Interest:

test of χ_{PT} (no short distance contribution)

Data: *high intensity run in 1999 ($6 \cdot 10^9$ ppp on K_S target)*

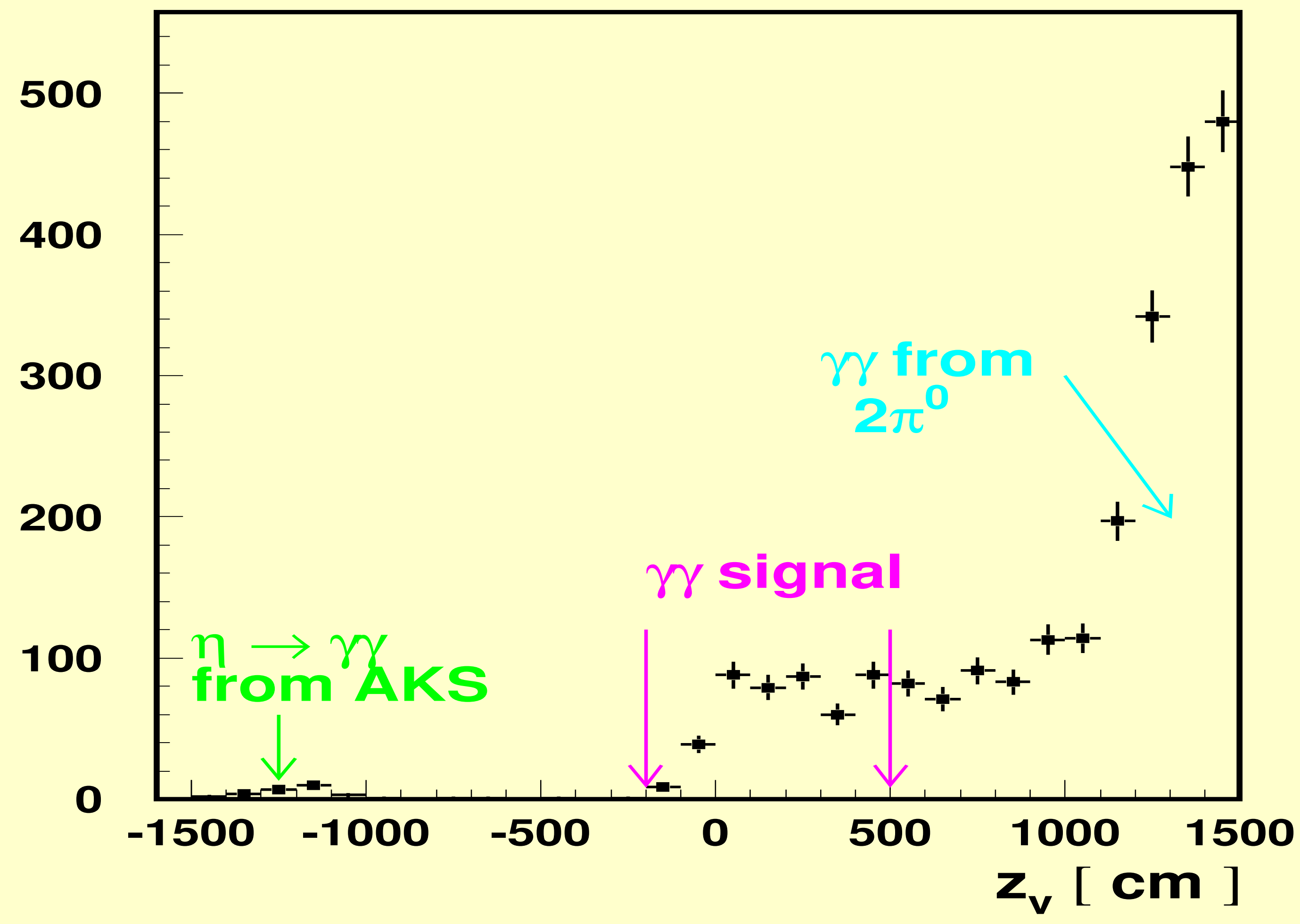
Event selection:

- $3 < E_{cl} < 100\ GeV$
- $r_{ij} > 10cm$
- time window: $\pm 5\ ns$
- no extra clsusters ($E_{cl} > 1.5\ GeV$)

Method: *binned MaxLkhd fit to Z_V spectrum of $K \to 2\gamma$ decays*

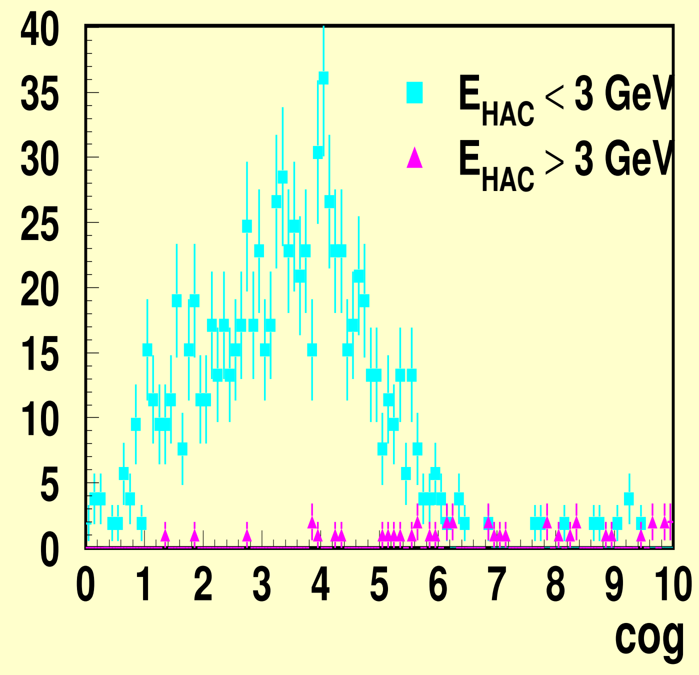
$-200 < Z_V < 500cm$ region *to supress the background from* $K_S \to 2\pi^0 \to 2\gamma(2\gamma)$

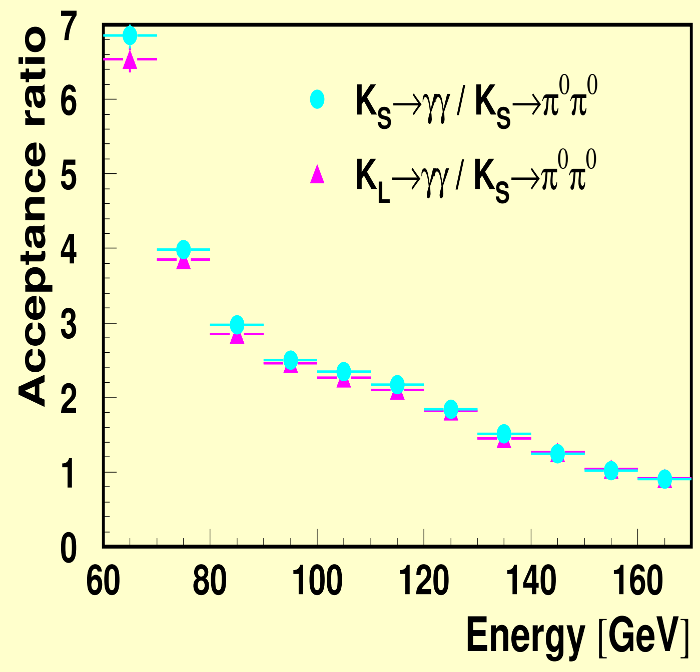
Distribution of the reconstructed z-vertices of 2γ's from various sources



Background contribution:
neutral hadronic ($\simeq 14$ $events$)
$K_S \to 2\pi^0 (\simeq 2$ $events)$.
Estimation of $K_L \to 2\gamma$ (294 events) using relative acceptances:

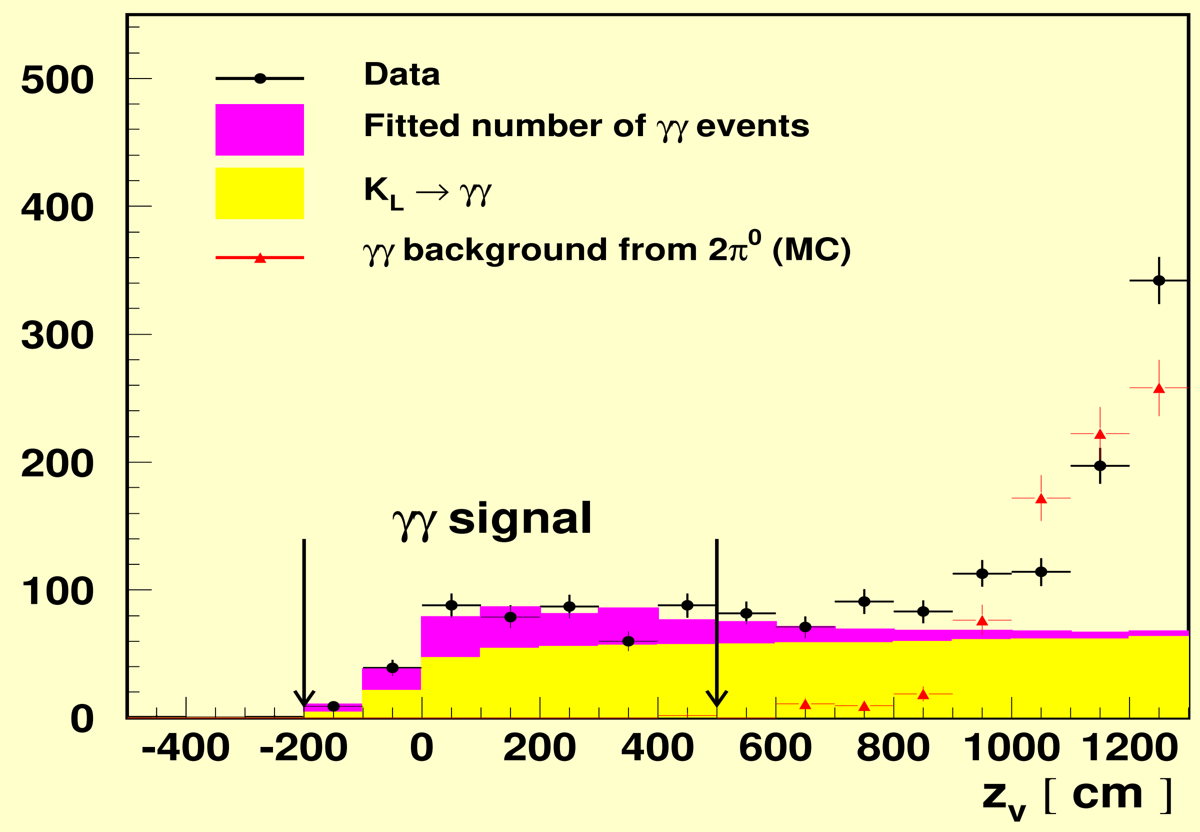
$$N_L = N_{2\pi^0} \cdot \frac{A(K_L \to 2\gamma)}{A(K_S \to 2\pi^0)} \cdot \frac{Br(K_L \to 2\gamma)}{Br(K_S \to 2\pi^0)} \cdot \frac{1}{\epsilon_{2\pi^0}}$$





$$\textbf{Br}(K_S \to 2\gamma) = (2.6 \pm 0.4_{stat} \pm 0.2_{sys}) \cdot 10^{-6}$$

148 $K_S \to 2\gamma$ decays



Systematics:

source	contribution to Br, %
background	3
$Br(K_L \to \gamma\gamma)$	5
MC simulation	2
Trigger efficiency $2\pi^0$	1-2
cuts	4

Measurement of $Br(K_L^0 \to e^+e^-e^+e^-)$

contributed paper # 229

Interest:

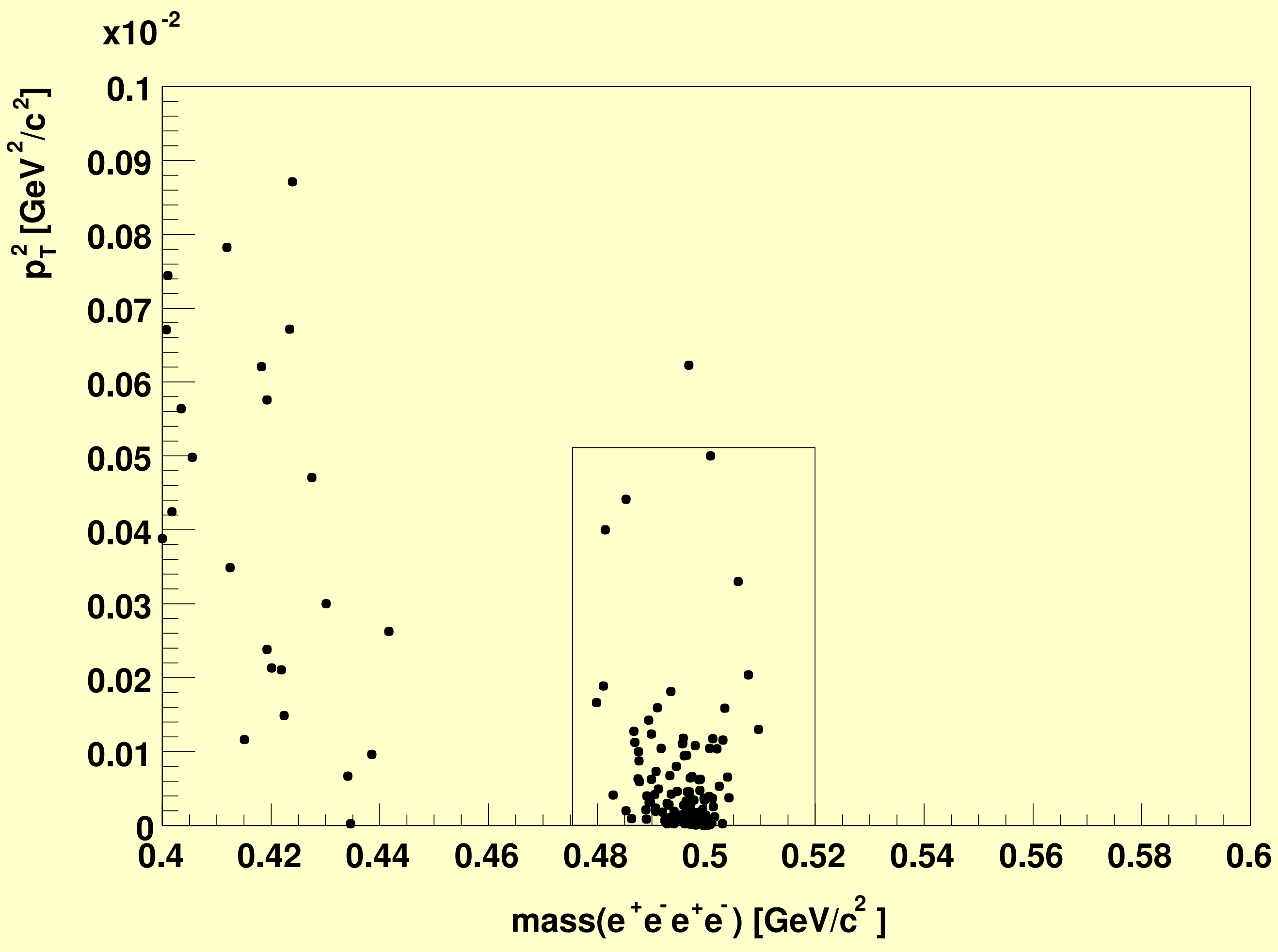
information of $K_L \to \gamma^*\gamma^*$ vertex structure
model tests: VMD, QCD, χ_{PT}

Data of the 1999 run

	channel	acceptance %	events
search for	$K_L^0 \to e^+e^-e^+e^-$	7.8	132
norm. 1	$K_L^0 \to \pi^+\pi^-\pi^0_D \to \pi^+\pi^-e^+e^-\gamma$	1.34	17123
norm. 2	$K_L^0 \to \pi^0\pi^0_D\pi^0_D \to e^+e^-e^+e^-4\gamma$		5162

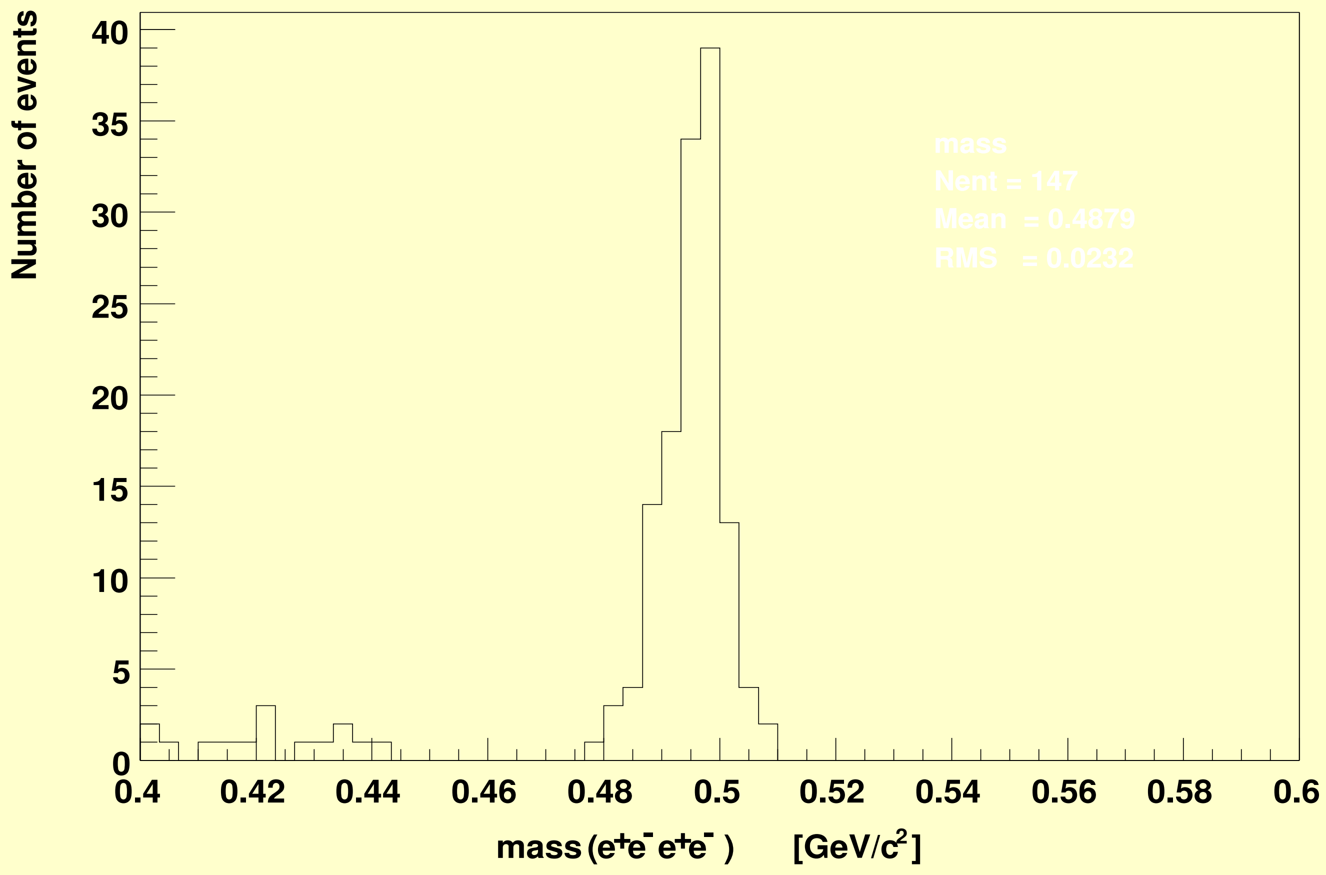
Systematic of 6.2% is defined mainly by:
MC efficiency calculation and selection criteria

P_T^2 versus $M(e^+e^-e^+e^-)$

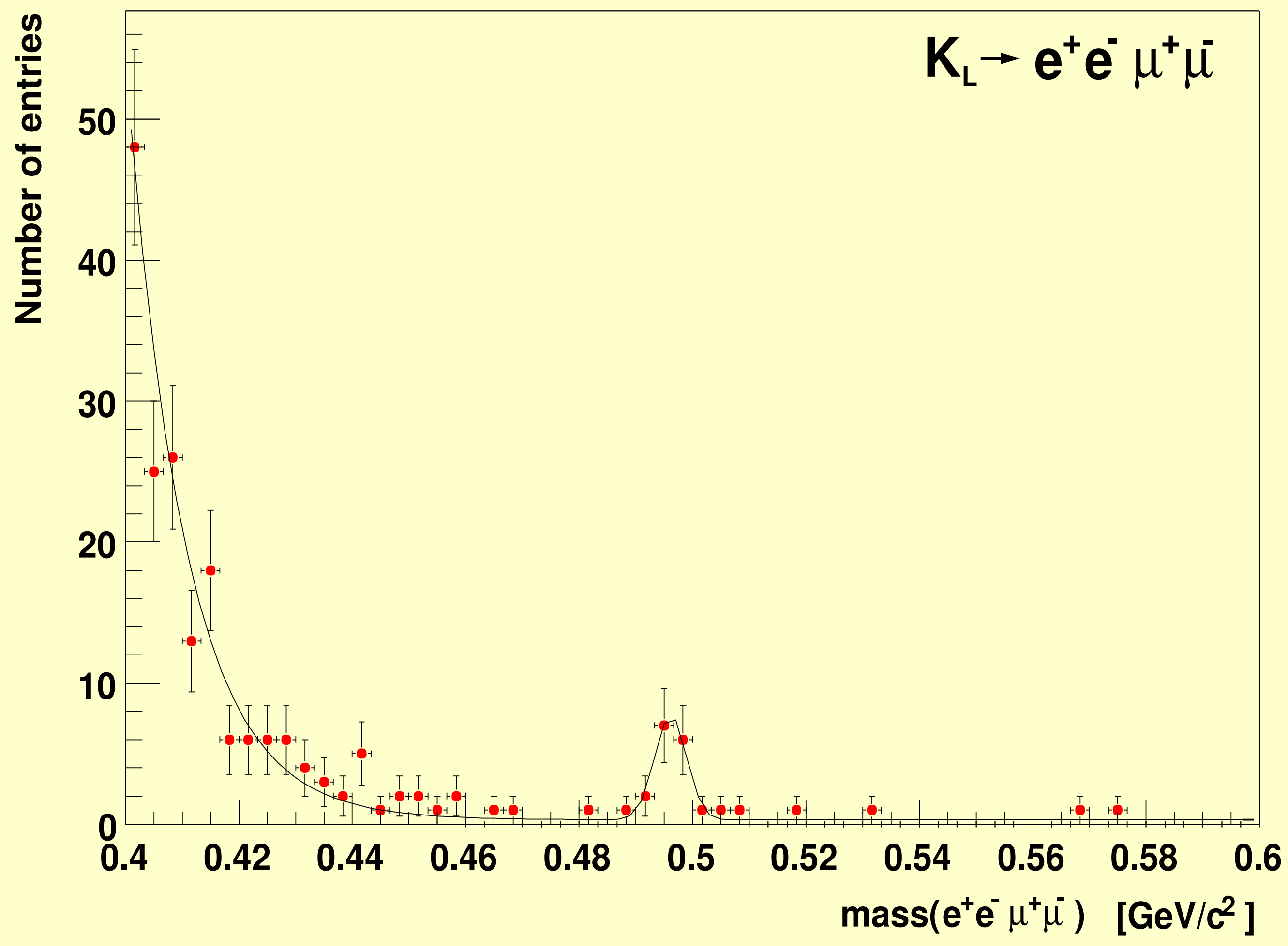


$$\boxed{\mathbf{Br}(K_L \to 4e) = (3.67 \pm 0.32_{stat} \pm 0.23_{sys} \pm 0.08_{norm}) \cdot 10^{-8}}$$

Reconstructed $e^+e^+e^-e^-$ invariant mass spectrum (signal of 132)



Reconstructed $M(\mu^+\mu^- e^+e^-)$ spectrum (signal = 19; bkgr. $\simeq 2$)



Measurement of $Br(K_L^0 \to \pi^0\gamma\gamma)$

Interest:

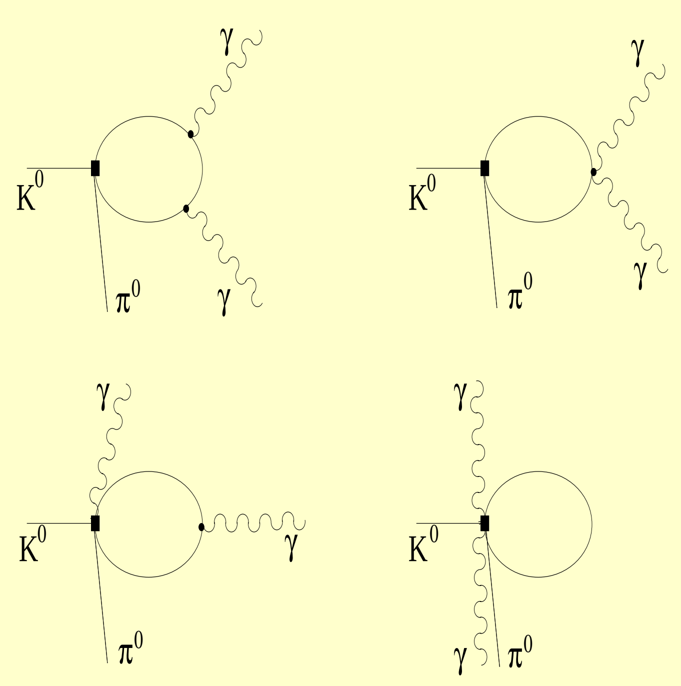
- *test of χ_{PT} calculations of the order p^6*
- *test of the vector meson exchange mechanism (p^6)*
- *estimation of CP-conserving intermediate state in $K_L \to \pi^0 e^+ e^-$*

Data used: 1998 (part) and 1999 runs

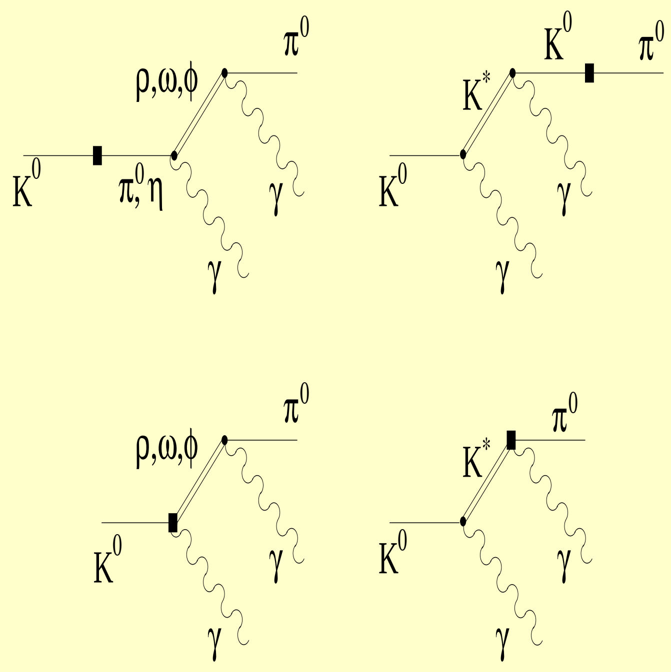
MC efficiency calculations using an effective vector coupling constant $a_v = -0.45$

selected events	1397
background estimation	30

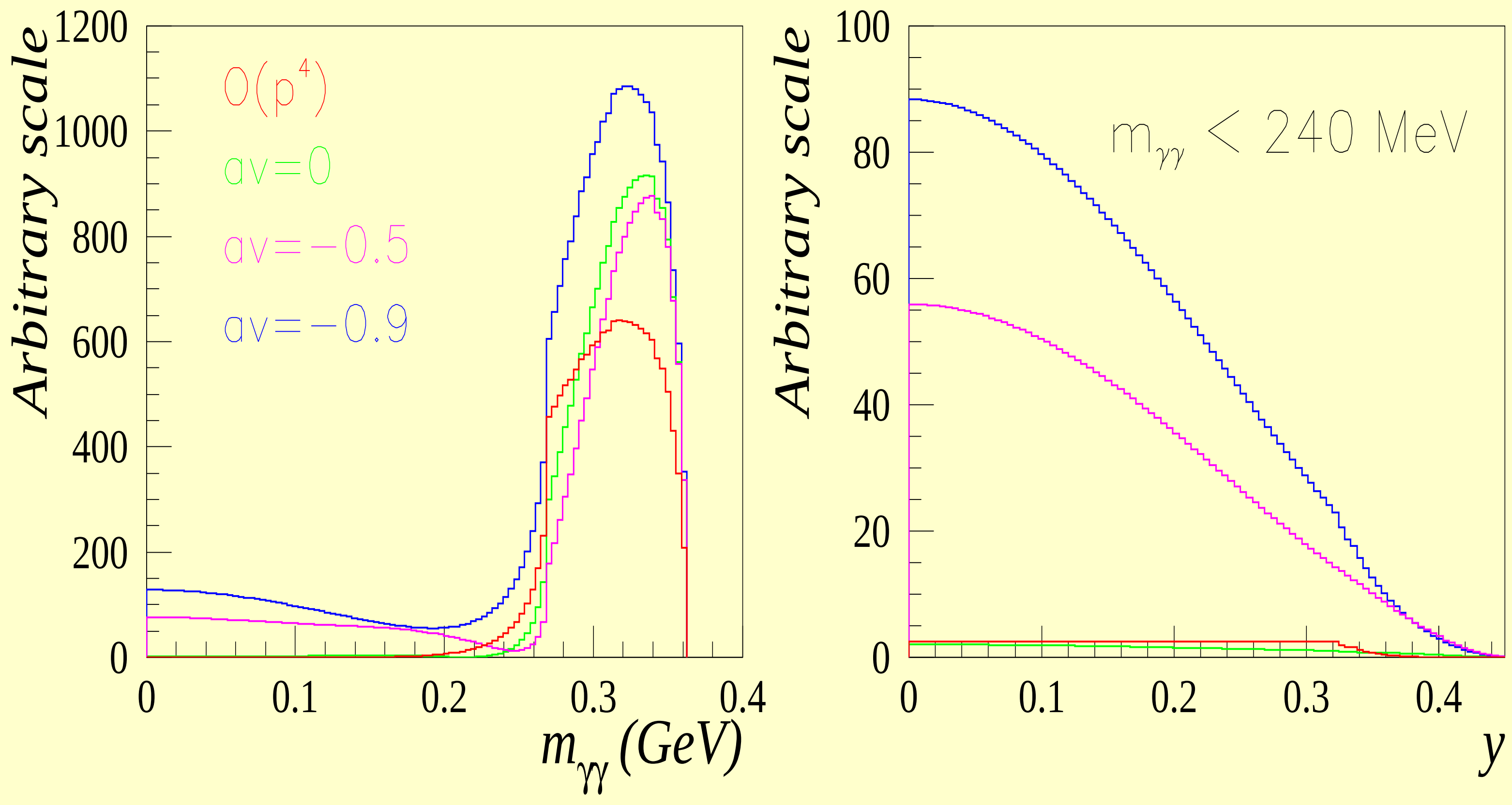
p^4 order χ_{PT} diagrams



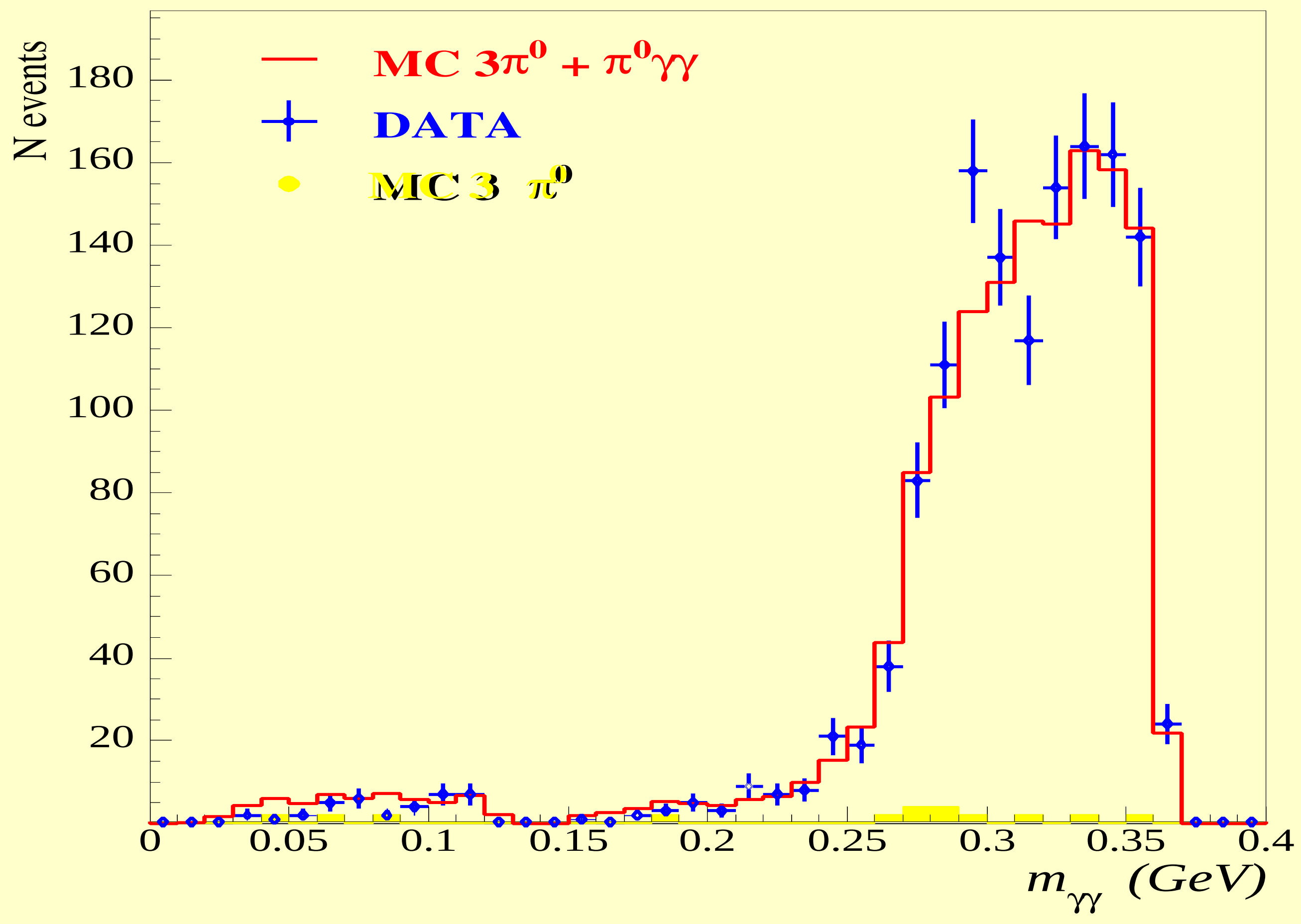
VMD diagrams



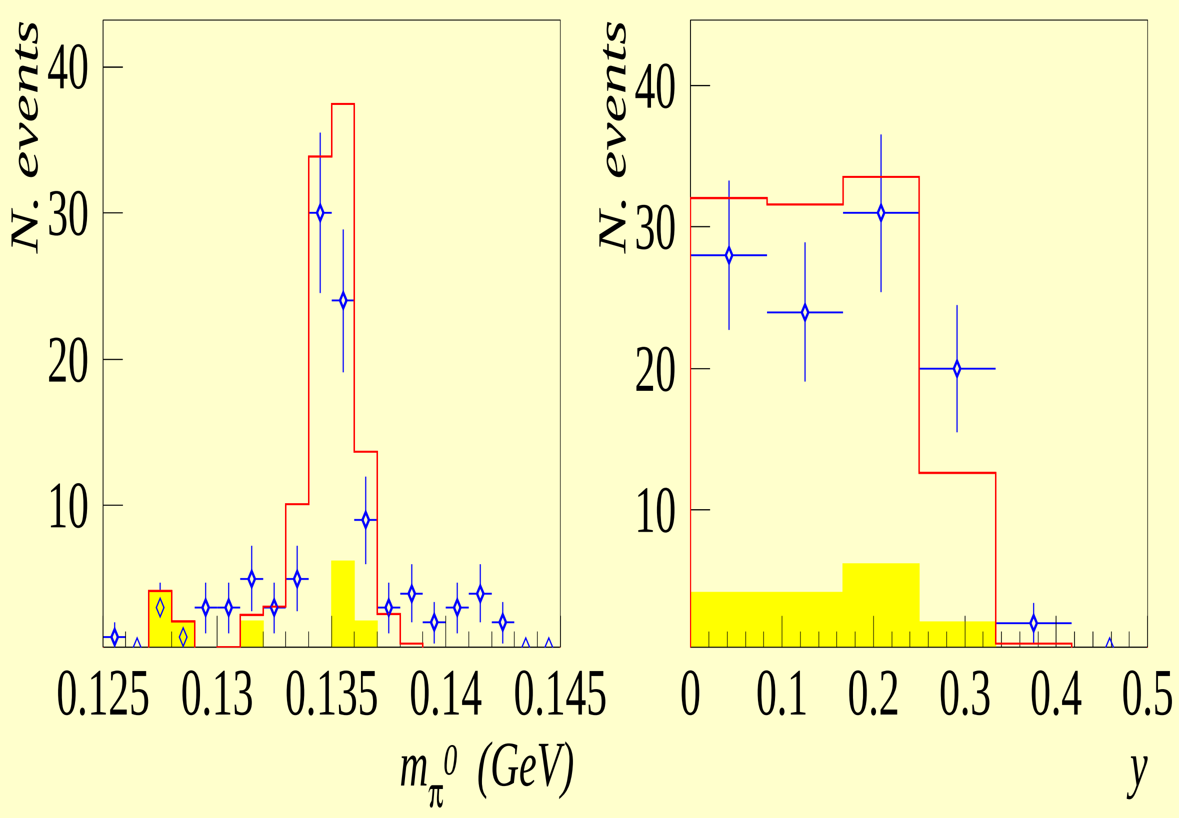
theoretical predictions for $M_{\gamma\gamma}$ and photon energy difference in the CM system ($y = \mid E_1^* - E_2^* \mid / M_K$)



$M_{\gamma\gamma}$ spectrum comparison with MC

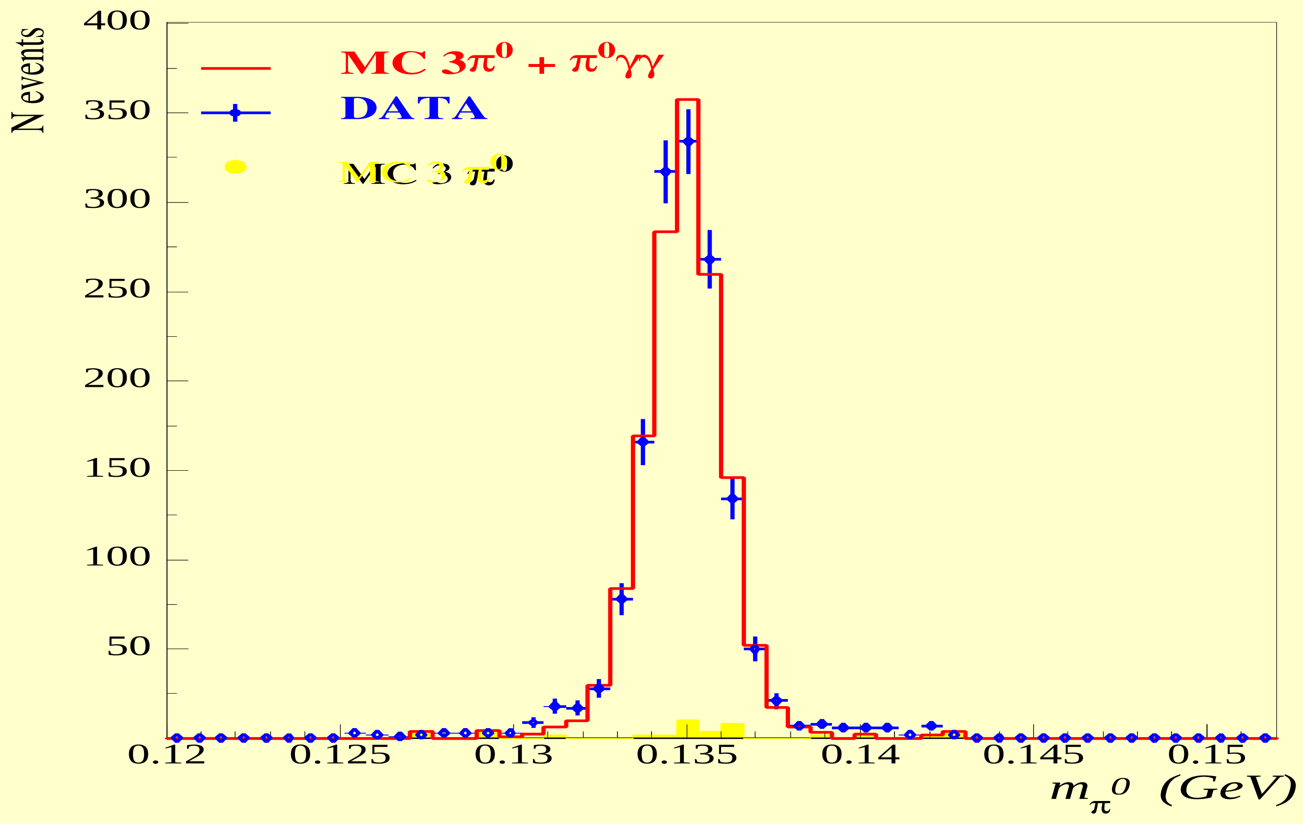


Comparison of reconstructed $M(\pi^0)$ and $y =\mid E_1^* - E_2^* \mid /M_K$ spectrum, both at $M_{\gamma\gamma} < 240MeV/c^2$, with MC



$$\boxed{Br(K_L \to \pi^0\gamma\gamma, a_v = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{syst}) \cdot 10^{-6}}$$

reconstructed $M(\pi^0)\ at\ M_{\gamma\gamma} < 240 MeV/c^2$



Interest:

as a background channel for the CP-violating decay $K_L \to \pi^0 e^+ e^-$

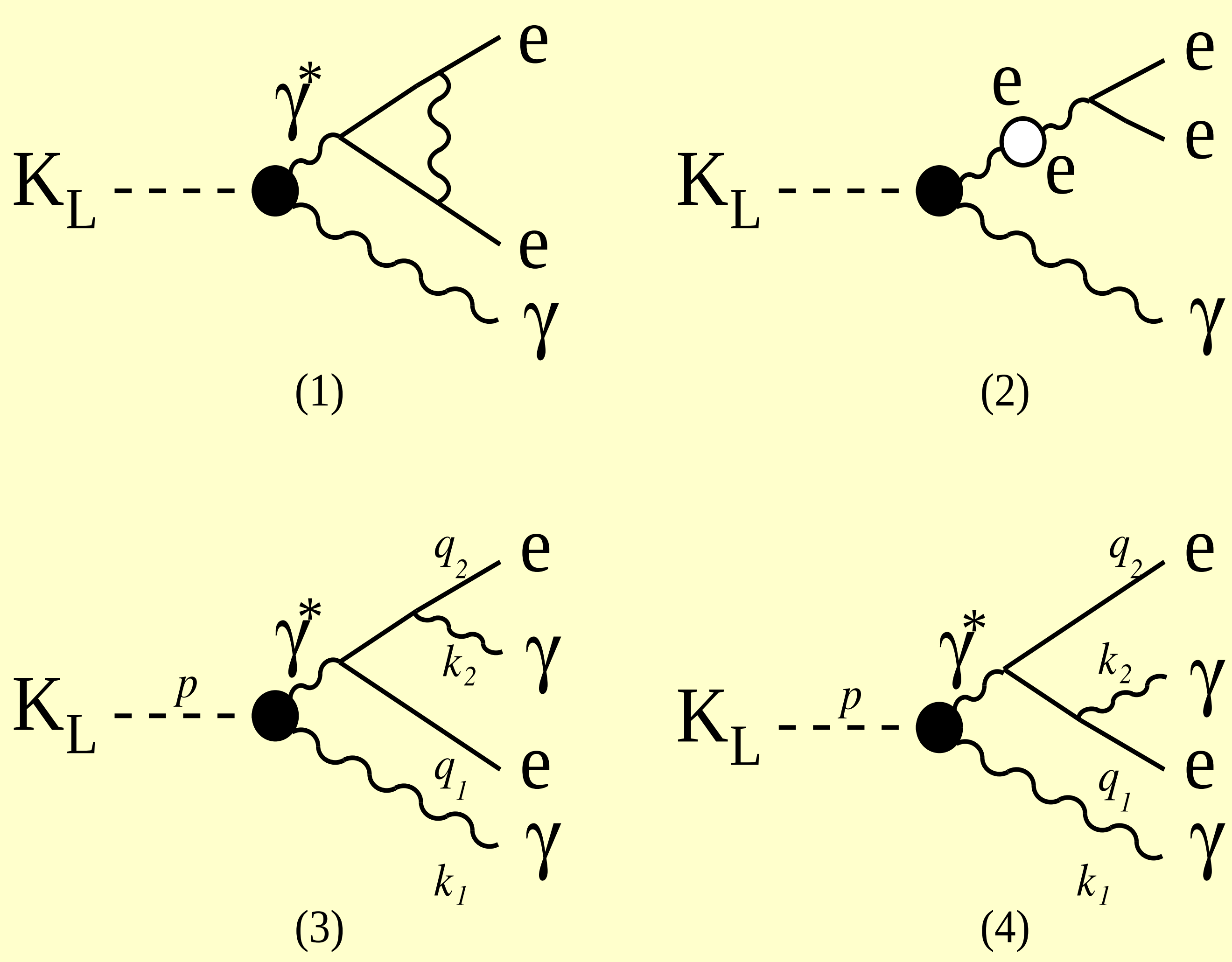
Data used: 1997 and 1998 runs

	channel	selected / estimated events
searched for	$K_L \to e^+e^-\gamma\gamma$	492
normalization	$K_L \to e^+e^-\gamma$	29879
background	$K_S \to \pi^0\pi^0_D \to \pi^0 e^+e^-(\gamma)$	3.8
	$K_L \to e^+e^-\gamma + (\gamma)_{bremss.}$	9.9
	$K_L \to all \quad others$	11.4

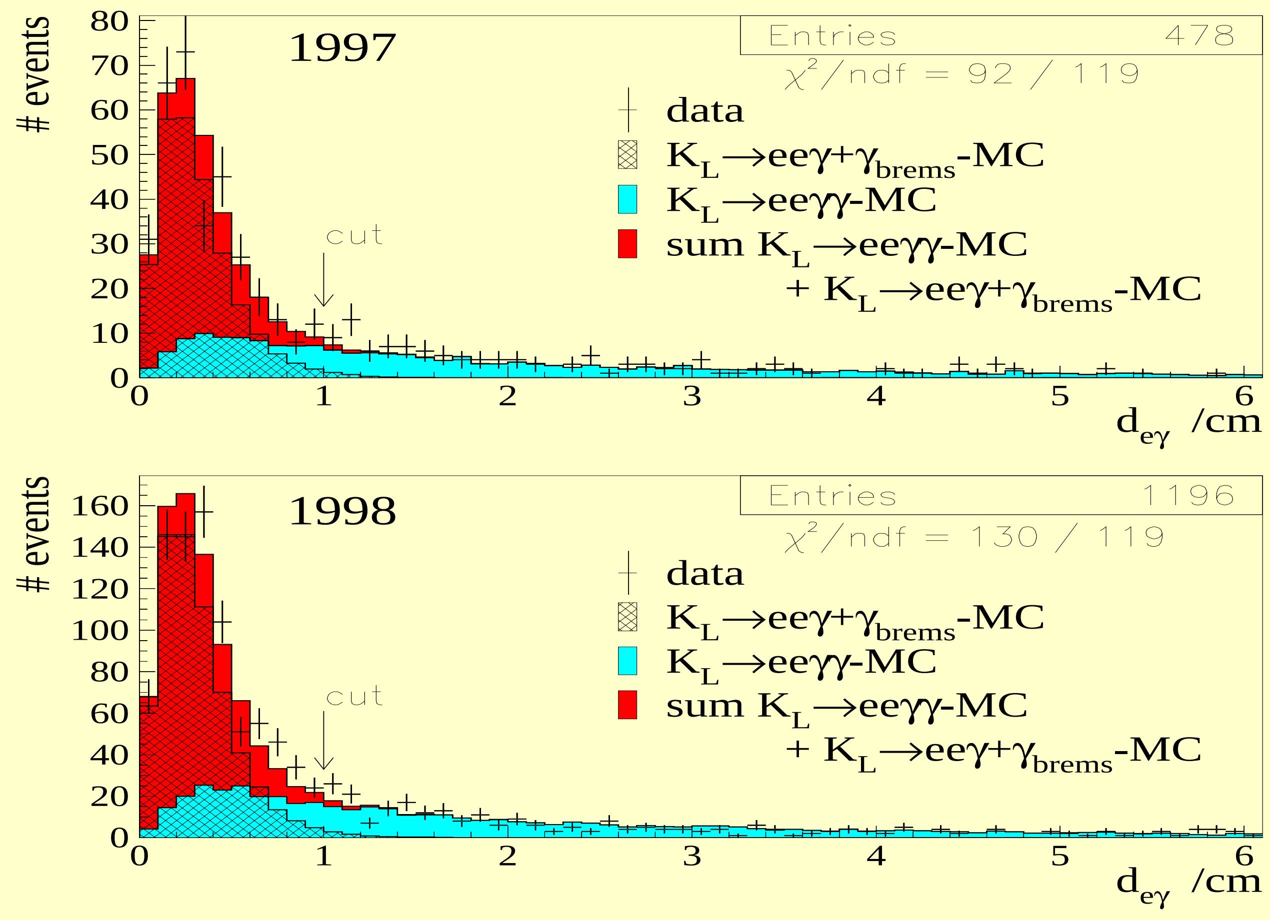
Systematic of $\simeq 3.2\%$ is caused by:

uncertainty of: α_{K^*}, ext. bremss.

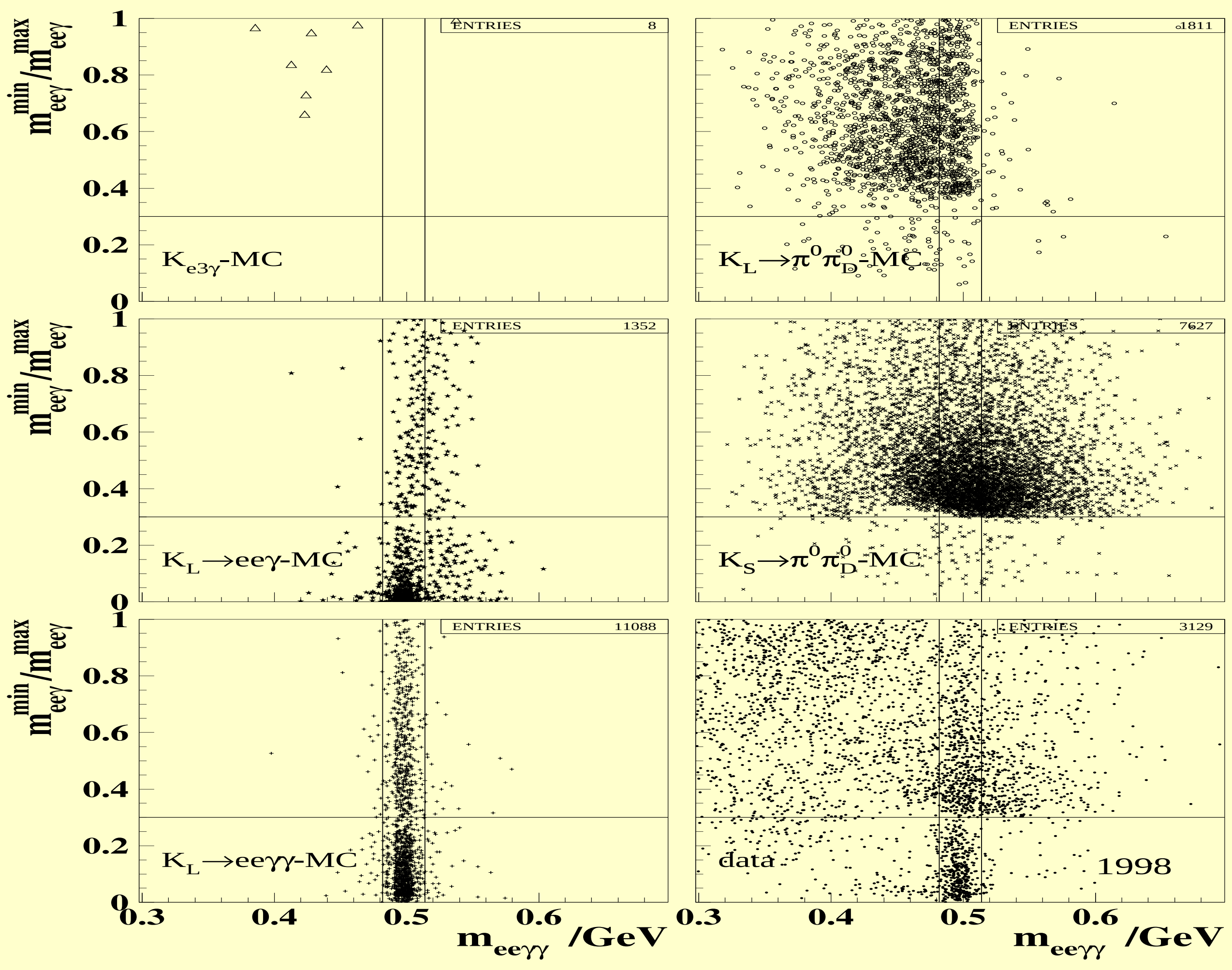
cuts on: E_{cl}, r_{COG}, τ_{K_S}, $min(r_{ij})$, $min(R_{LKr})$


K L
γ*
e
e
γ
(1)
K L
e
e
e
e
γ
(2)
K L
p
γ*
q 2
e
k 2
γ
e
q 1
γ
k 1
(3)
K L
p
γ*
q 2
e
k 2
γ
e
q 1
γ
k 1
(4)

rejection of the external bremsstrahlung contribution



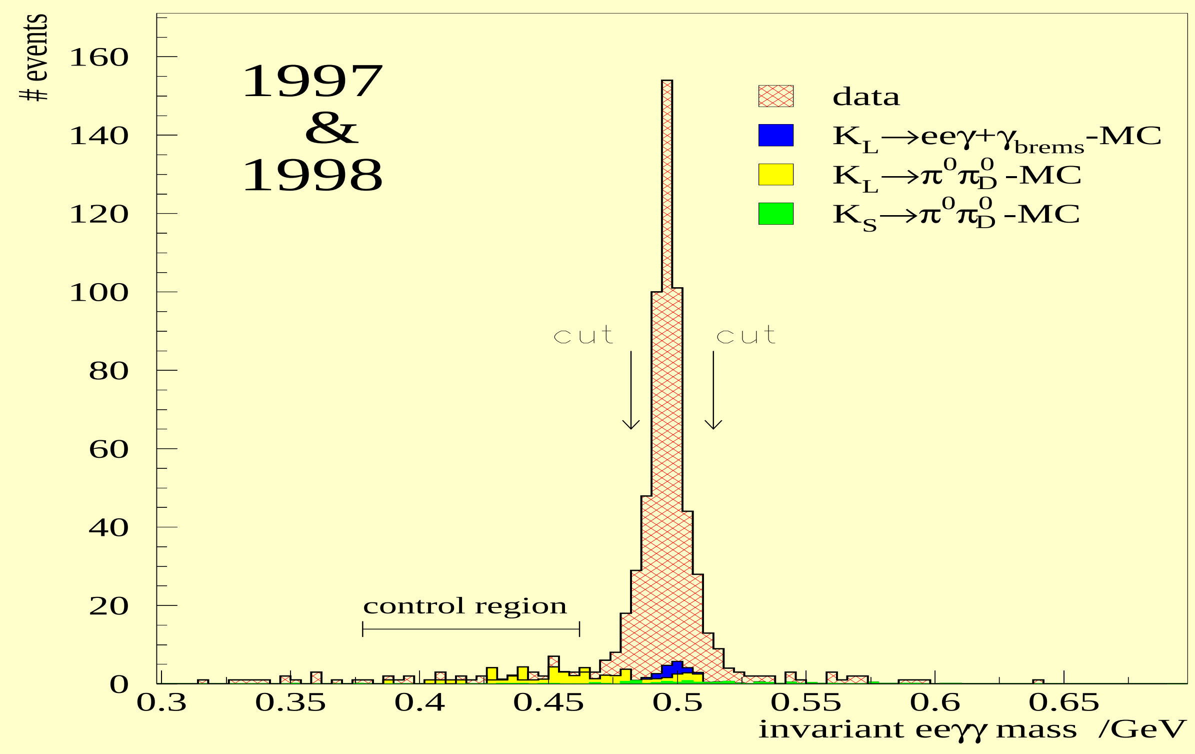
Min/Max of $M(e^+e^-\gamma)$ vs $M(e^+e^-\gamma\gamma)$



1 0.8 0.6 0.4 0.2 0
1 0.8 0.6 0.4 0.2 0
1 0.8 0.6 0.4 0.2 0
0.3 0.4 0.5 0.6 0.3 0.4 0.5 0.6
0.3 0.4 0.5 0.6 0.3 0.4 0.5 0.6

$Br(K_L \to e^+e^-\gamma\gamma) = (6.32 \pm 0.31_{stat} \pm 0.20_{syst} \pm 0.29_{norm}) \cdot 10^{-7}$
$(E^*_\gamma > 5MeV)$

Composition of $M(e^+e^-\gamma\gamma)$ spectrum



Summary (results are preliminary)

$\boxed{Br(K_S \to \pi^0 e^+ e^-, M_{ee} > 165 MeV/c^2) < 8.3 \cdot 10^{-8}\text{, at 90\% C.L.}}$

$Br(K_S \to \pi^0 e^+ e^-)_{MODEL} < 1.6 \cdot 10^{-7}$

PDG-98:
$< 1.1 \cdot 10^{-6}$

$\boxed{Br(K_S \to \pi^+ \pi^- e^+ e^-) = (5.1 \pm 0.9_{stat} \pm 0.3_{syst}) \cdot 10^{-5}}$ Asymmetry $\simeq 0$

$\boxed{\text{Br}(K_S \to 2\gamma) = (2.6 \pm 0.4_{stat} \pm 0.2_{sys}) \cdot 10^{-6}}$

$(2.4 \pm 0.9) \cdot 10^{-6}$

$\boxed{\text{Br}(K_L \to 4e) = (3.67 \pm 0.32_{stat} \pm 0.23_{sys} \pm 0.08_{norm}) \cdot 10^{-8}}$

$(4.1 \pm 0.8) \cdot 10^{-8}$

Summary (results are preliminary)

$$\boxed{Br(K_L \to \pi^0\gamma\gamma, a_v = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{syst}) \cdot 10^{-6}}$$

$$\chi_{PT}: \quad (1.70 \pm 0.30) \cdot 10^{-6}$$
$$PDG-98: \quad (1.70 \pm 0.28) \cdot 10^{-6}$$

$$\boxed{\begin{array}{l} Br(K_L \to e^+e^-\gamma\gamma) = (6.32 \pm 0.31_{stat} \pm 0.20_{syst} \pm 0.29_{norm}) \cdot 10^{-7} \\ (E^*_\gamma > 5MeV) \end{array}}$$

$$PDG-98: \quad (6.5 \pm 1.2) \cdot 10^{-7}$$