

Rare K^0 Decays

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JINR

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The NA48 Collaboration:

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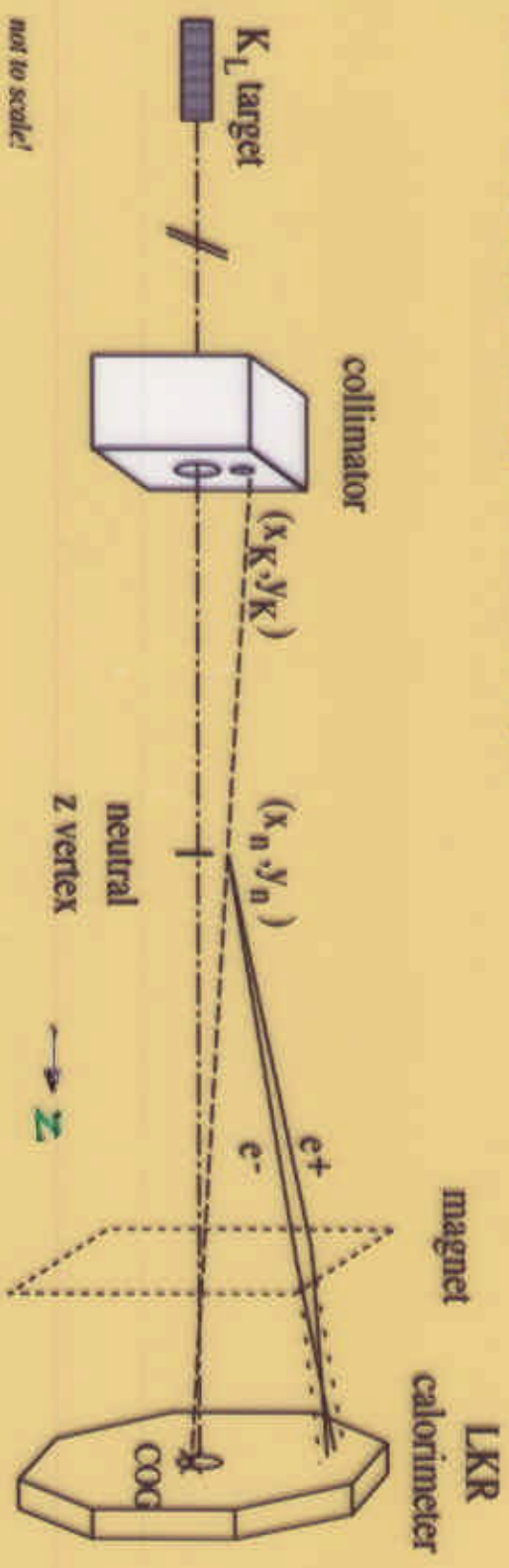
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NA48 experiment at CERN SPS to measure c/τ

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

$60 < P(K_S), P(K_L) < 170 \text{ GeV}/c^2$



not to scale!

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

Charged vertex:

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

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

Neutral vertex of M^0 decay:

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

Search for $K_S^0 \rightarrow \pi^0 e^+ e^-$

Interest: estimation of indirect CP-violation contribution to the decay $K_L^0 \rightarrow \pi^0 e^+ e^-$

Models: G.D. Ambrosio, G. Ecker, 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 ($M_{ee} > 165 \text{ MeV}/c^2$)
Normaliz.	$\pi^0 \pi_D^0 \rightarrow \pi^0 e^+ e^- \gamma$	4.81	83960
Backgr.	$\pi^0 \pi_D^0 \rightarrow \pi^0 e^+ e^- (\gamma)$		0.3
Systematics:			
LKr cluster limitation			3%
Radiative corr.			4%
MC / data difference			3%

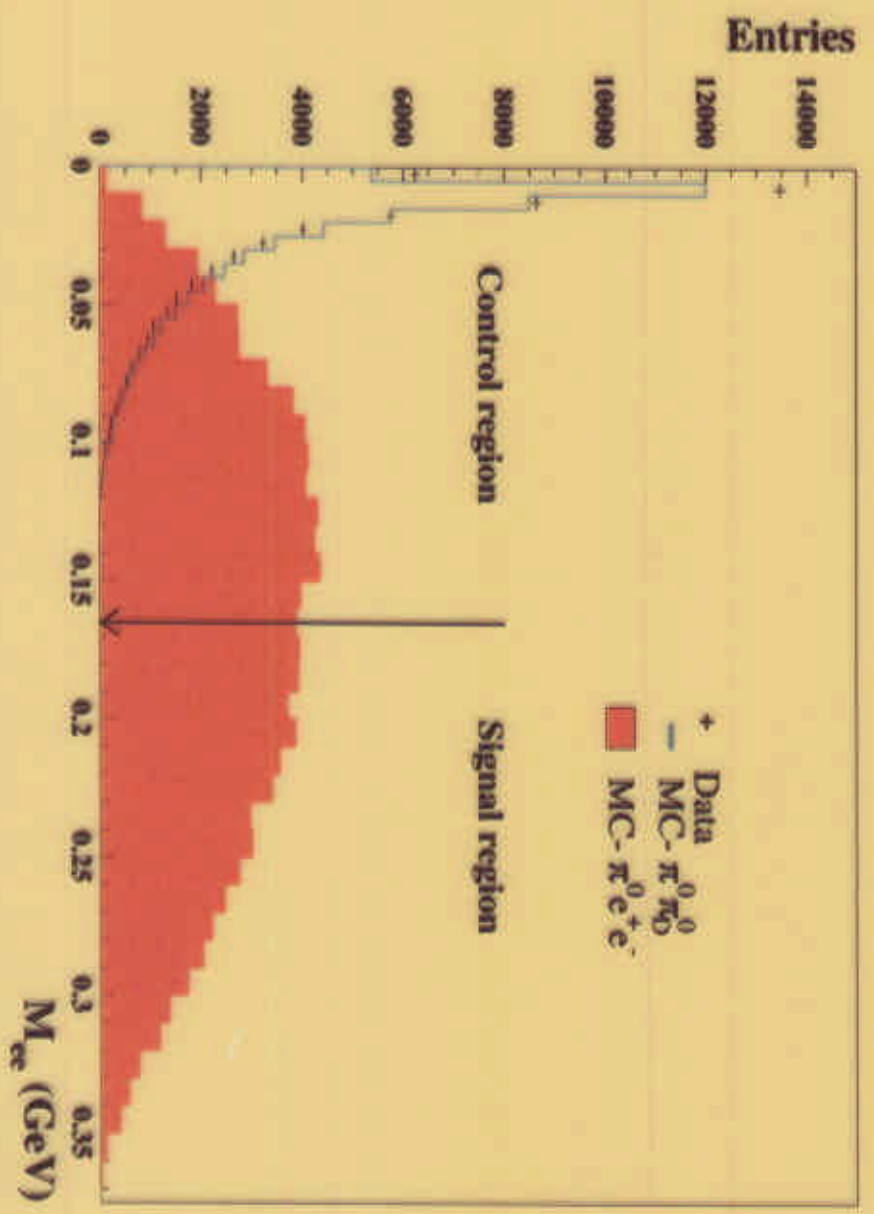
Search for $K_S^0 \rightarrow \pi^0 e^+ e^-$

preliminary

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

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

M_{ee} spectra for data and MC



Study of $K_S^0 \rightarrow \pi^+\pi^-e^+e^-$



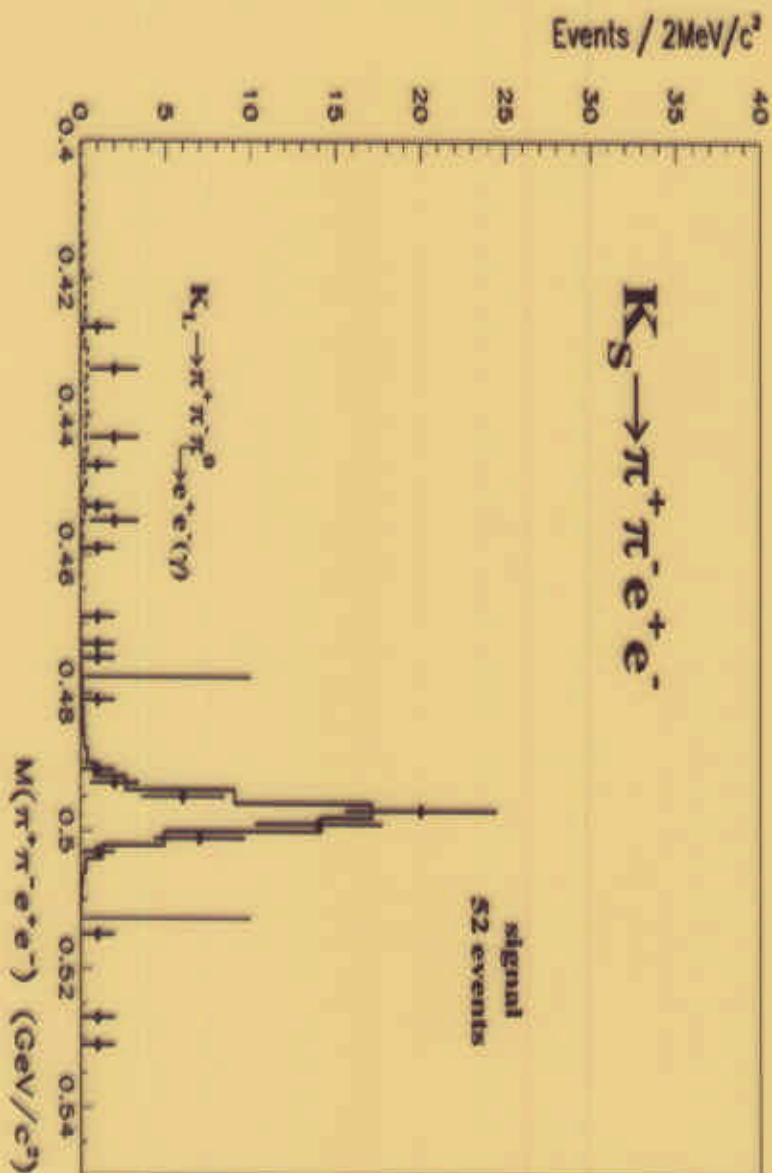
Interest:	<i>estimation of CP-conserving contribution to $K_L^0 \rightarrow \pi^+\pi^-e^+e^-$</i>	
	<i>test of asymmetry: $A = \cos\phi \cdot \sin\phi$ ($\phi = 2\pi \vee 2e$)</i>	
Model:	Heiliger, Sehgal-93	
Data recorded in 1998		
	Channel	Selected / estimated events
Study of	$K_S^0 \rightarrow \pi^+\pi^-e^+e^-$	52
Normalization	$K_L^0 \rightarrow \pi^+\pi^-\pi_D^0 \rightarrow \pi^+\pi^-e^+e^-\gamma$	89
Background	$K_L^0 \rightarrow \pi^+\pi^-\pi_D^0 \rightarrow \pi^+\pi^-e^+e^-(\gamma)$	< 1
Systematics:		
LKr cluster choice		3%
Radiative corrections		4%
MC / data difference		3%

Study of $K_S^0 \rightarrow \pi^+ \pi^- e^+ e^-$

Preliminary

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

No Asymmetry



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

Interest:

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

Data:

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

Event selection:

- ◆ $3 < E_d < 100$ GeV
- ◆ $r_{ij} > 10$ cm
- ◆ time window: ± 5 ns
- ◆ no extra clusters ($E_d > 1.5$ GeV)

Method:

binned Maxlkhd fit to Z_V spectrum of $K \rightarrow 2\gamma$ decays

$-200 < Z_V < 500$ cm region

to suppress the background from

$$K_S \rightarrow 2\pi^0 \rightarrow 2\gamma(2\gamma)$$

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

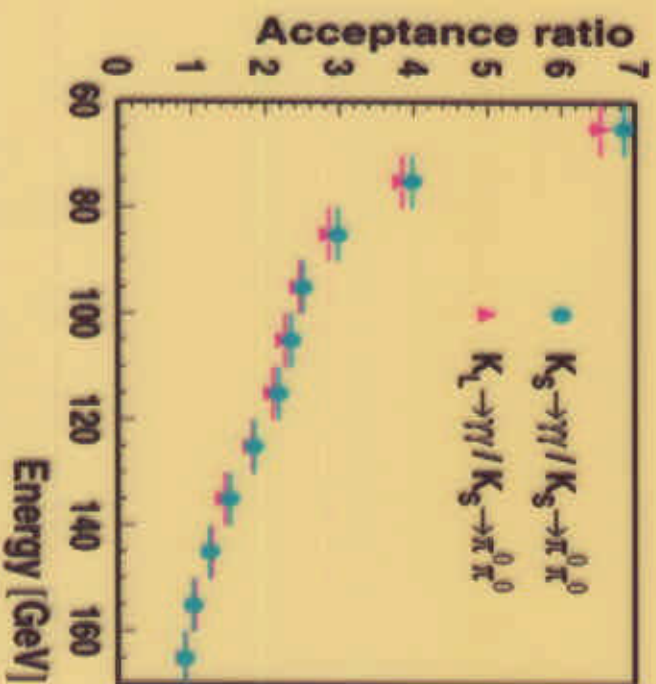
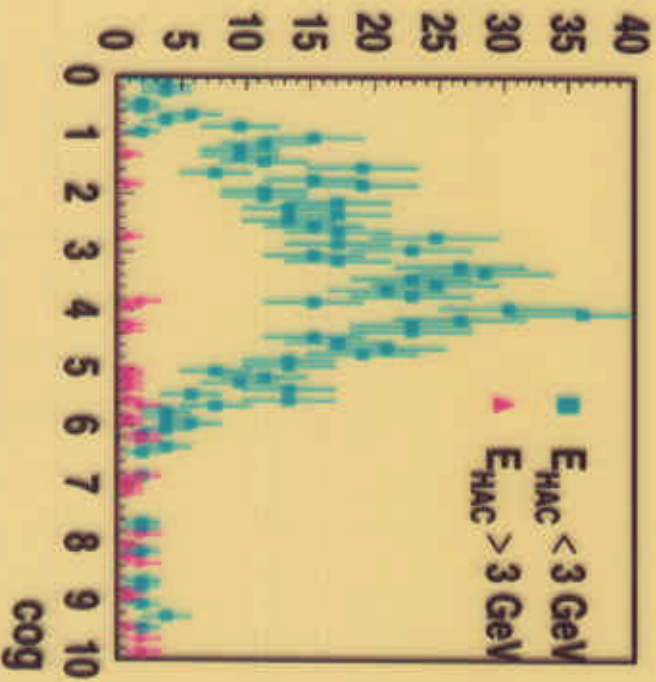
Background contribution:

neutral hadronic (≈ 14 events)

$K_S \rightarrow 2\pi^0$ (≈ 2 events).

Estimation of $K_L \rightarrow 2\gamma$ (294 events) using relative acceptances:

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



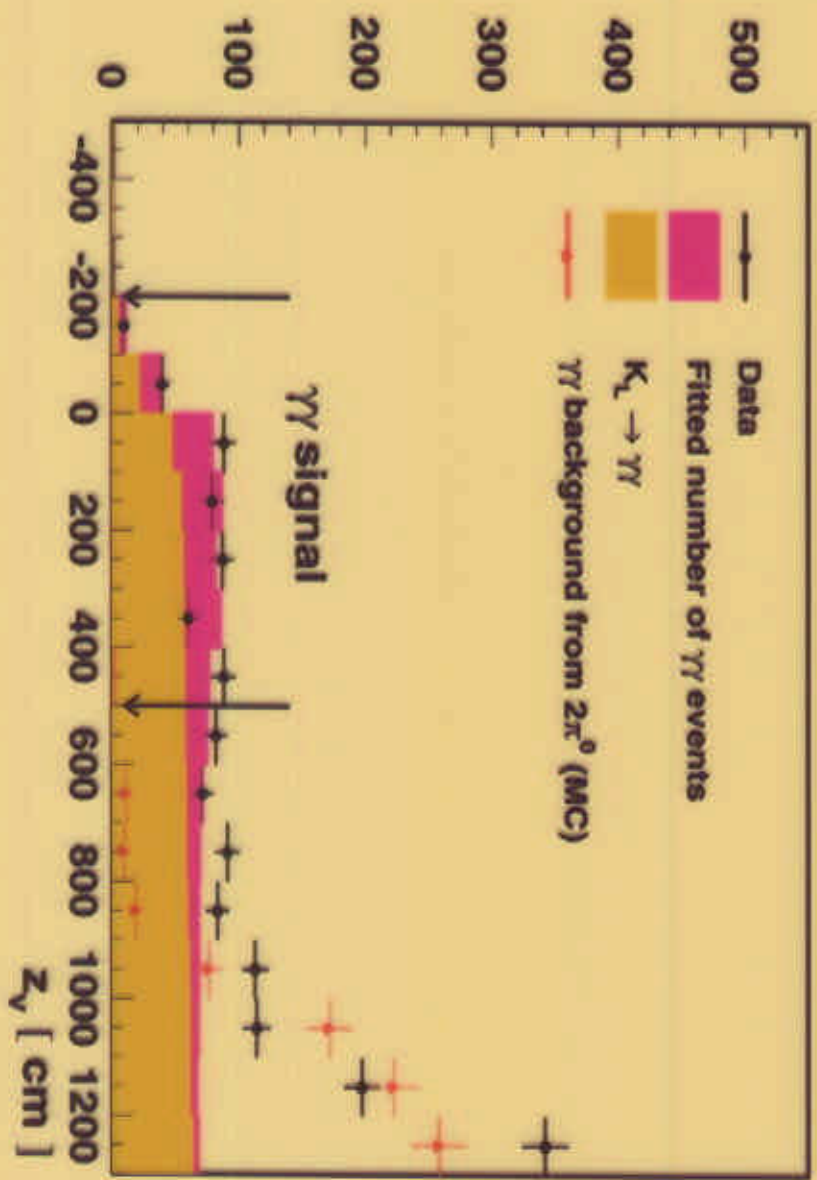
Measurement of $Br(K_S^0 \rightarrow \gamma\gamma)$

Systematics:

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

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

148 $K_S \rightarrow 2\gamma$ decays



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

contributed paper # 229

Interest:

information of $K_L \rightarrow \gamma^* \gamma^*$ vertex structure
model tests: VMD, QCD, XPT

Data of the 1999 run

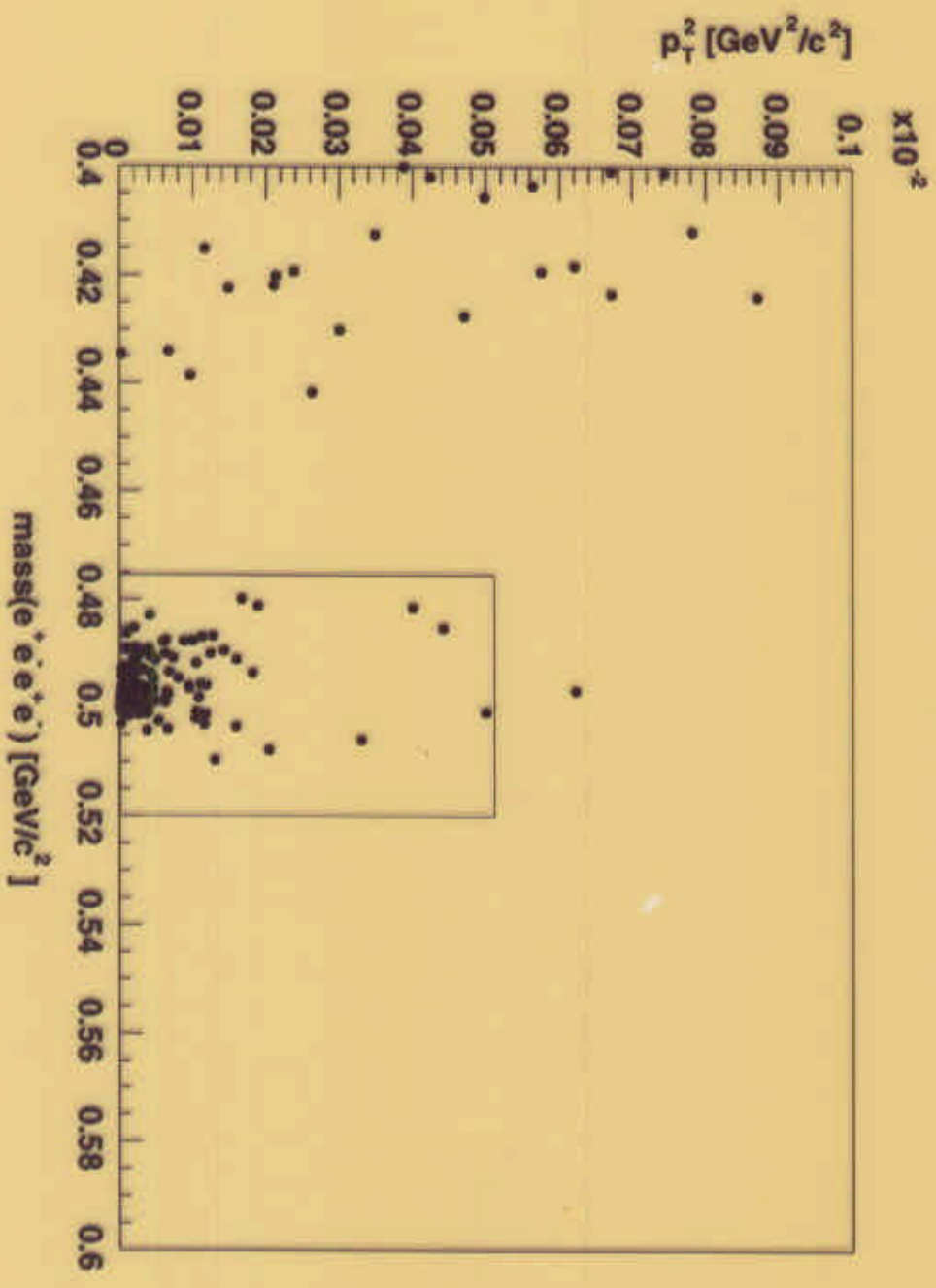
channel	acceptance %	events
search for $K_L^0 \rightarrow e^+e^-e^+e^-$	7.8	132
norm. 1 $K_L^0 \rightarrow \pi^+\pi^-\pi_D^0 \rightarrow \pi^+\pi^-e^+e^-\gamma$	1.34	17123
norm. 2 $K_L^0 \rightarrow \pi^0\pi_D^0\pi_D^0 \rightarrow e^+e^-e^+e^-4\gamma$		5162

Systematic of 6.2% is defined mainly by:

MC efficiency calculation and selection criteria

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

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

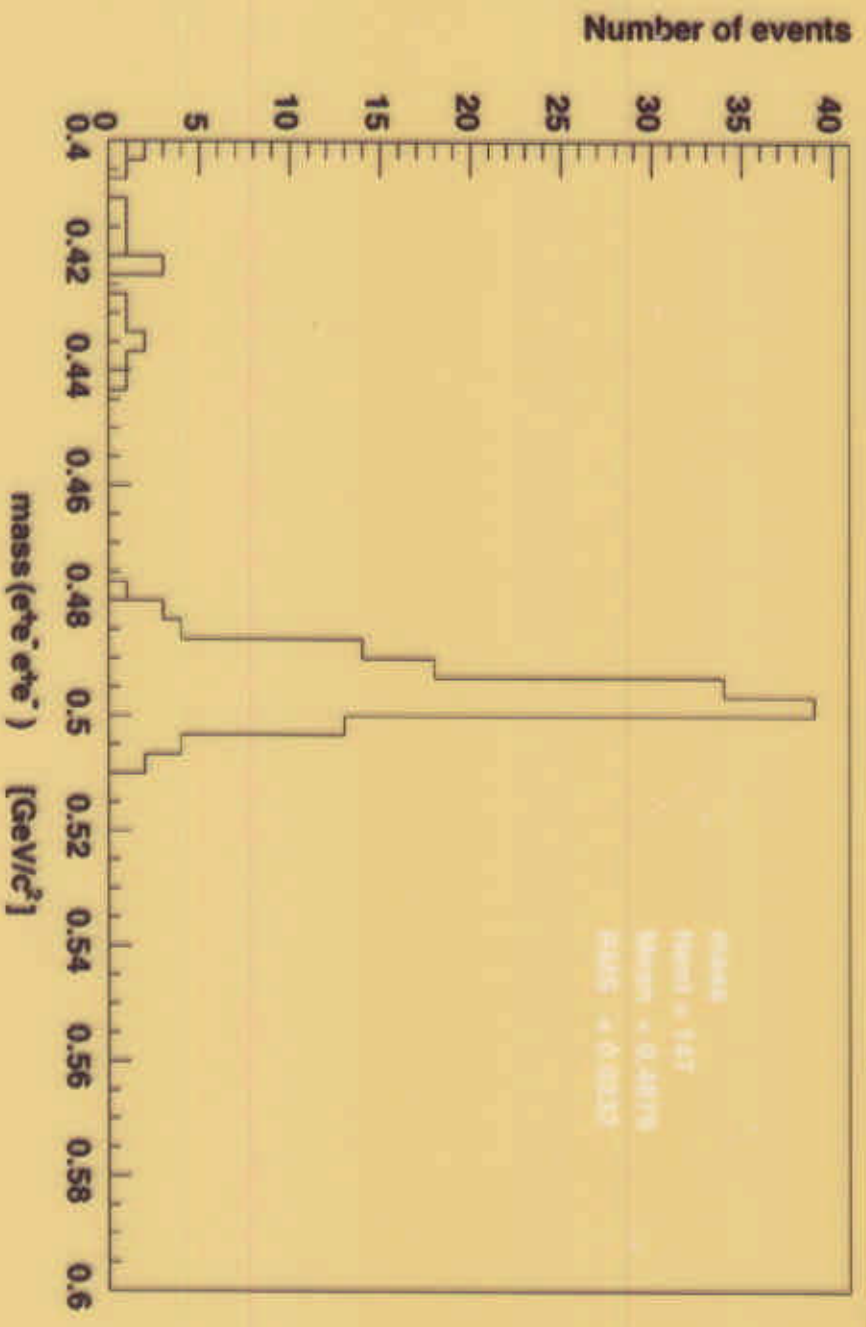


Measurement of $Br(K_L^0 \rightarrow e^+e^-e^+e^-)$

preliminary

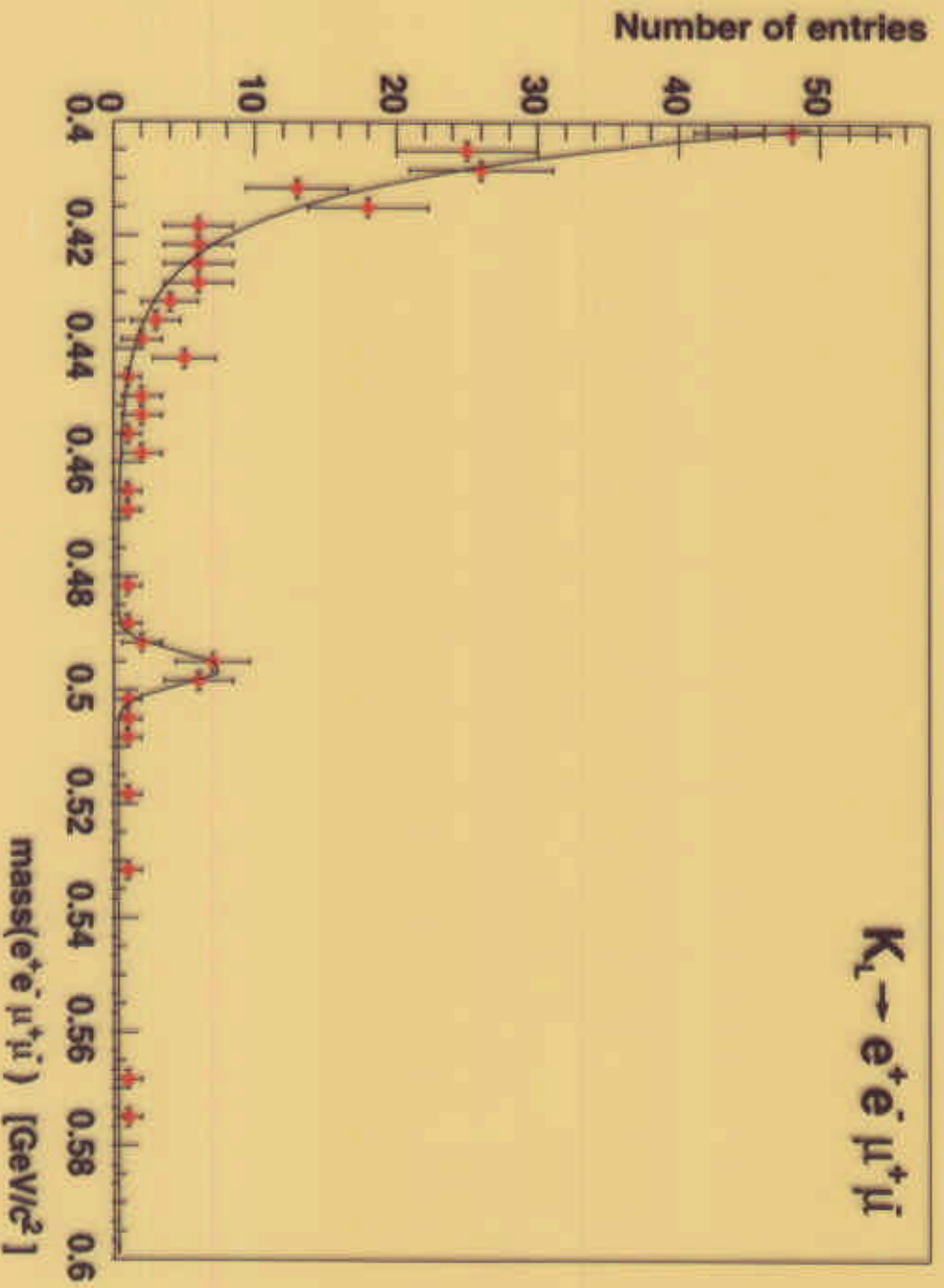
$$Br(K_L \rightarrow 4e) = (3.67 \pm 0.32_{stat} \pm 0.23_{sys} \pm 0.08_{norm}) \cdot 10^{-8}$$

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



Observation of $K_L^0 \rightarrow \mu^+ \mu^- e^+ e^-$

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



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

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 $K_L \rightarrow \pi^0 e^+ e^-$

Data used: 1998 (part) and 1999 runs

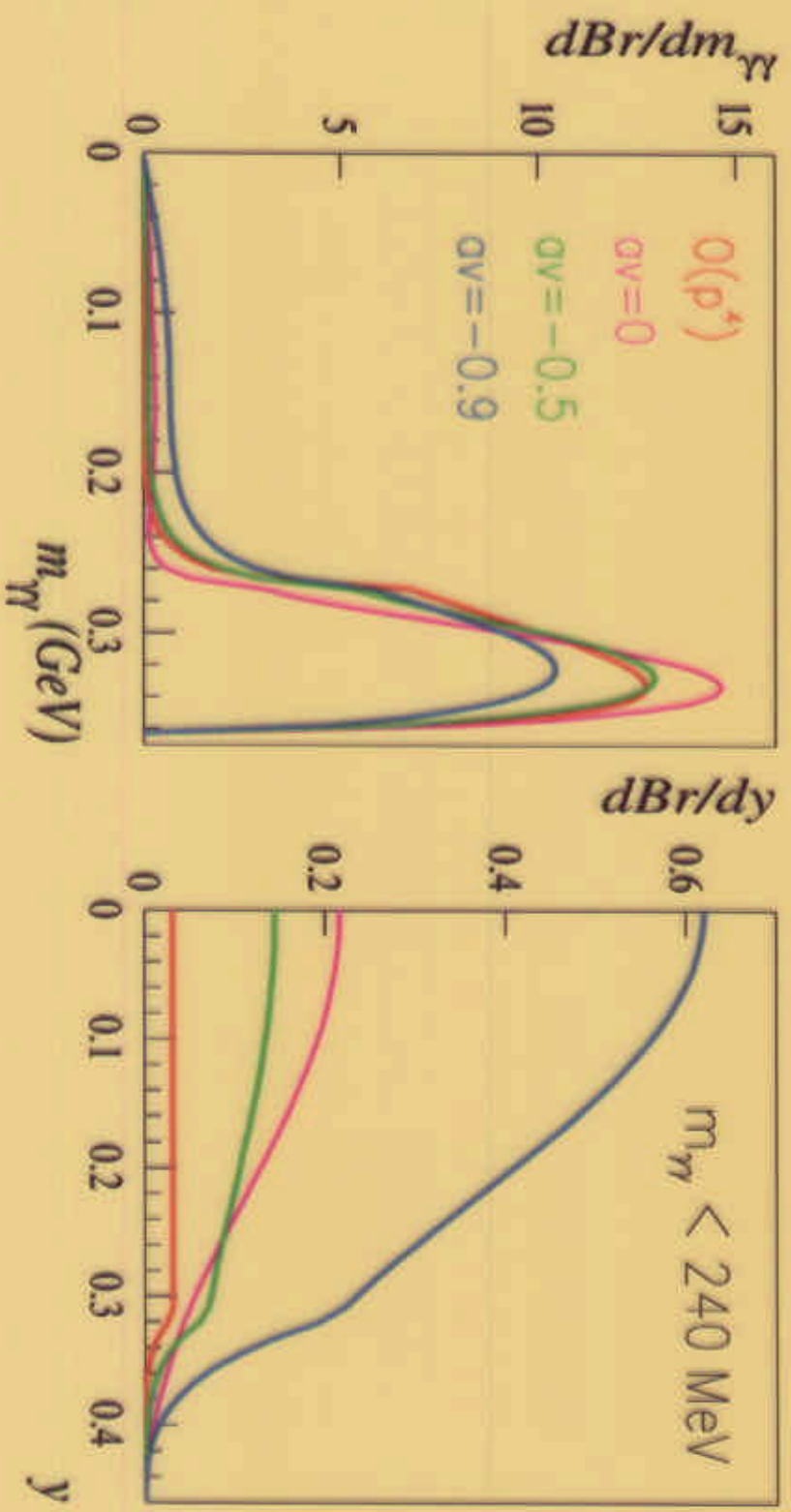
MC efficiency calculations using an effective vector coupling constant

$$a_v = -0.45$$

selected events	1397
background estimation	30

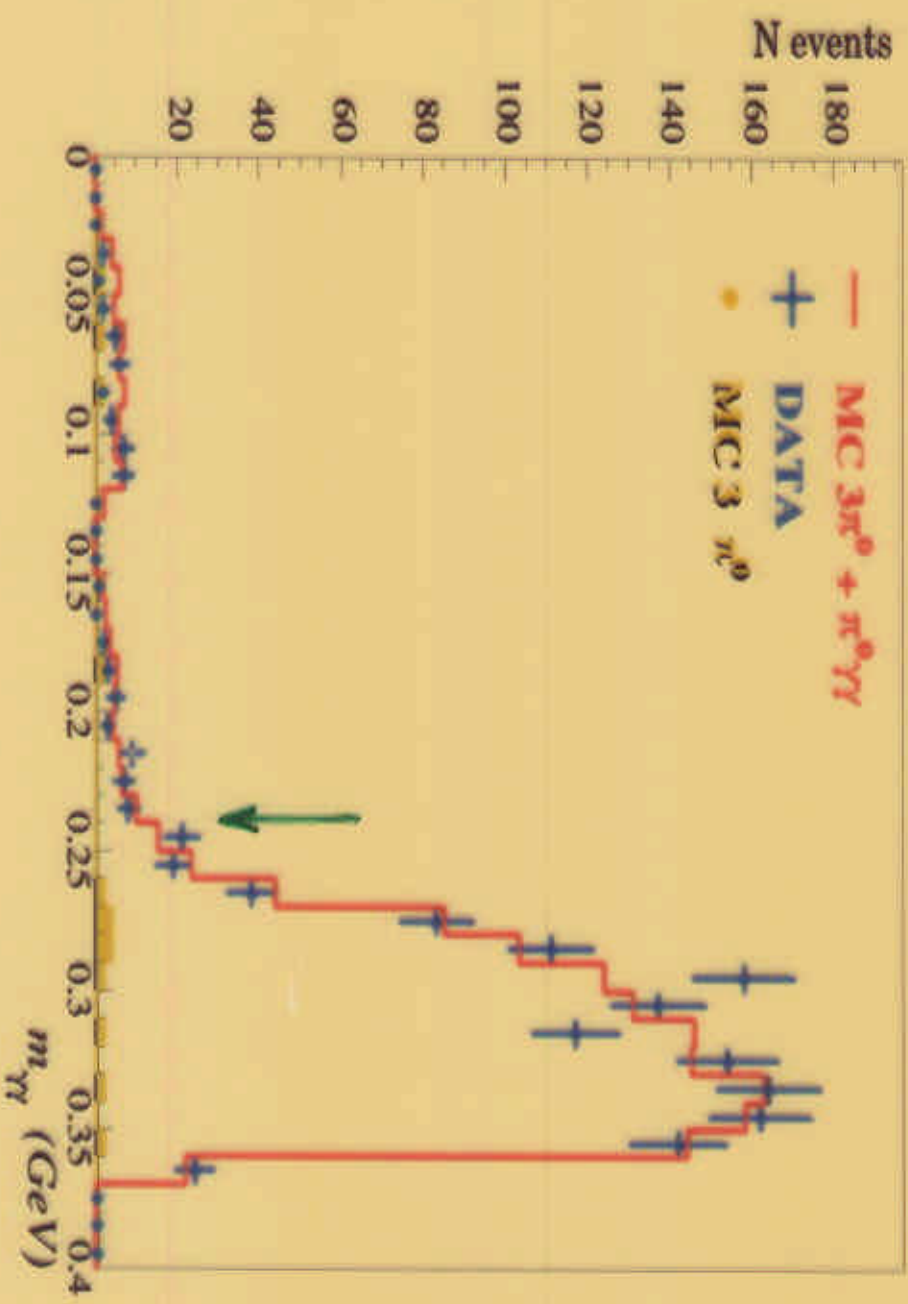
Measurement of $Br(K_L \rightarrow \pi^0 \gamma \gamma)$

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



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

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

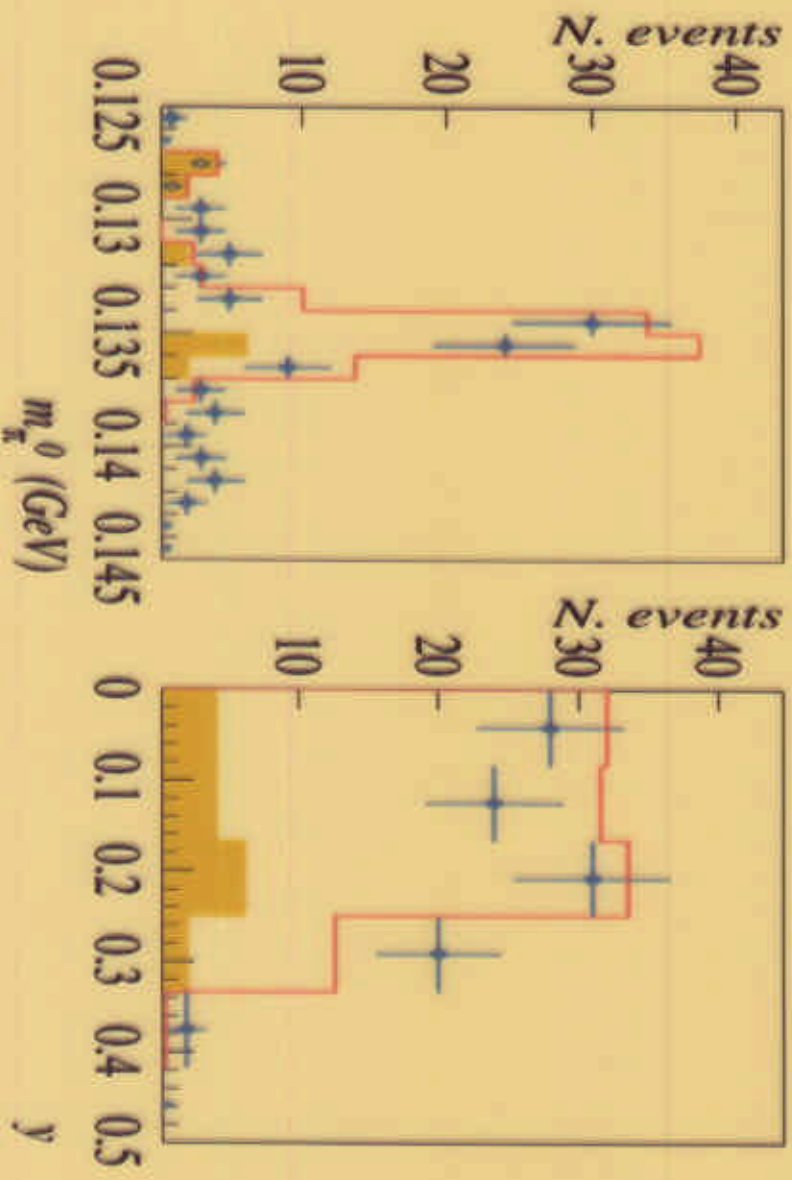


$a_V = -0.45$

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

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

$$a_v = -0.45$$



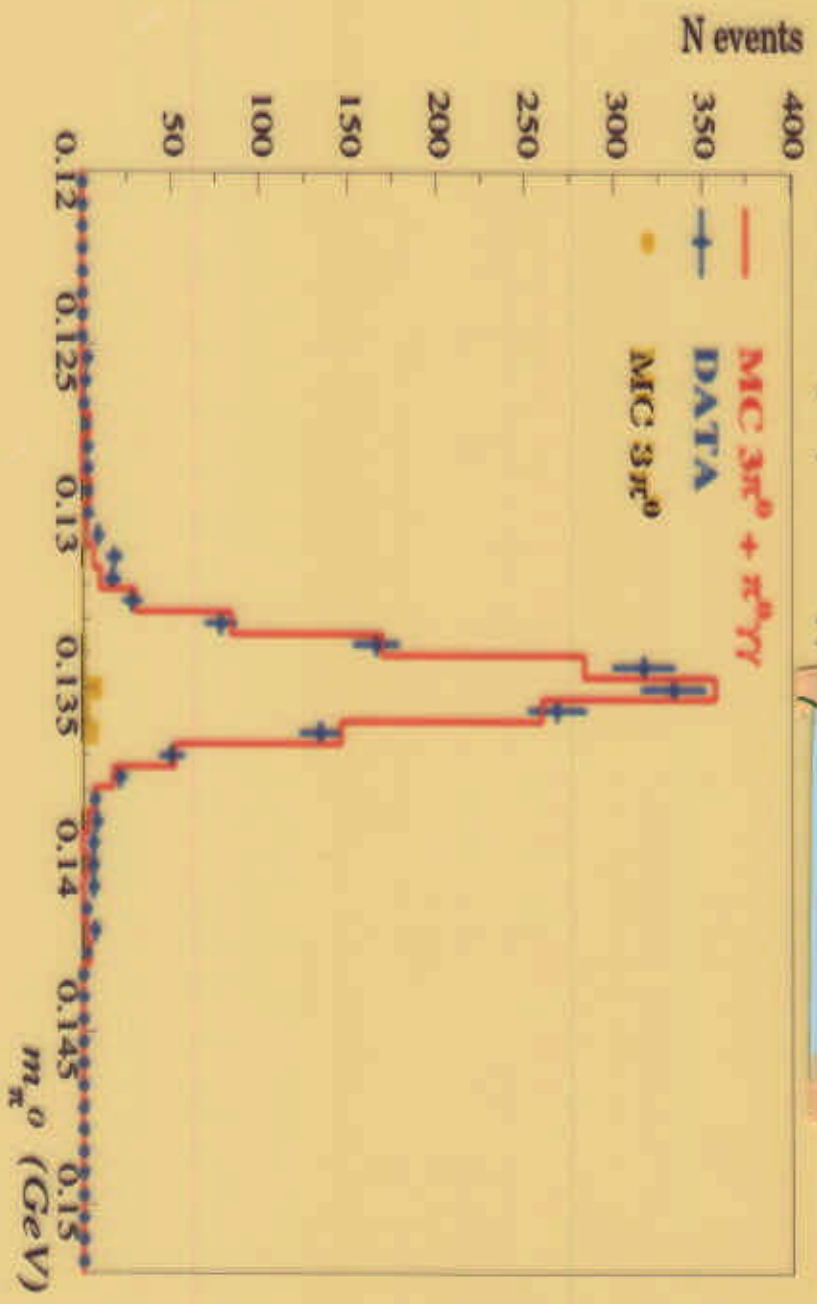
Measurement of $Br(K_L \rightarrow \pi^0 \gamma \gamma)$

Preliminary

$$Br(K_L \rightarrow \pi^0 \gamma \gamma, a_0 = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{syst}) \cdot 10^{-6}$$

reconstructed $M(\pi^0) \text{ at } M_{\gamma\gamma}$

$$a_0 = -0.45$$



Measurement of $Br(K_L \rightarrow e^+e^-\gamma\gamma)$

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

Data used: 1997 and 1998 runs

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

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

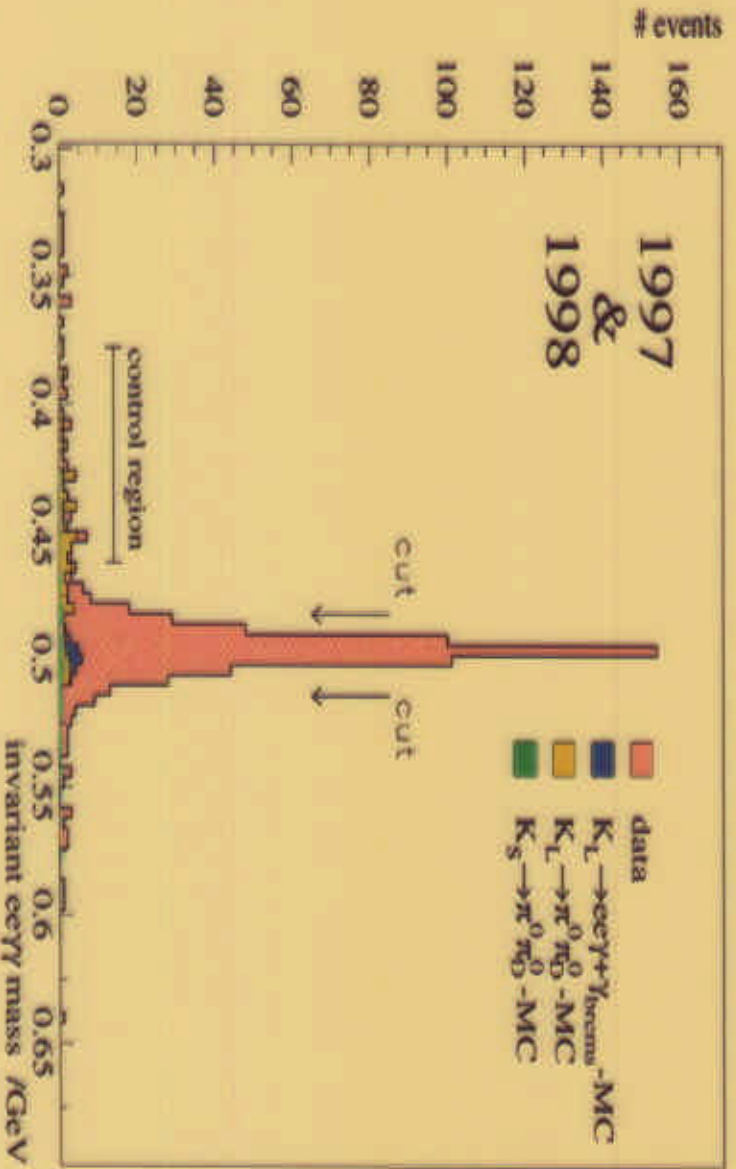
uncertainty of α_{K^*} , ext. bremss.
cuts on: $E_d, \tau_{COG}, \tau_{K_S}, \min(\tau_{ij}), \min(R_{LK^*})$

Measurement of $Br(K_L \rightarrow e^+e^-\gamma\gamma)$

Preliminary

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

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



Summary (results are preliminary)

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

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

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

$$\text{Br}(K_S \rightarrow \pi^+ \pi^- e^+ e^-) = (5.1 \pm 0.9_{\text{stat}} \pm 0.3_{\text{sys}}) \cdot 10^{-5}$$

Asymmetry

$$\simeq 0$$

$$\simeq 0$$

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

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

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

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

Summary (results are preliminary)

$$Br(K_L \rightarrow \pi^0 \gamma \gamma, a_0 = -0.45) = (1.51 \pm 0.05_{stat} \pm 0.20_{syst}) \cdot 10^{-6}$$

PDG - 98 :  (1.70 ± 0.28) · 10⁻⁶

$$Br(K_L \rightarrow e^+ e^- \gamma \gamma) = (6.32 \pm 0.31_{stat} \pm 0.20_{syst} \pm 0.29_{norm}) \cdot 10^{-7}$$

($E_\gamma^* > 5 \text{ MeV}$)

PDG - 98 : (6.5 ± 1.2) · 10⁻⁷

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