# NA48 Results on Rare $K_{S,L}$ Decays

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On behalf of the NA48 Collaboration

XIV Rencontres de Blois

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- $K_{S,L} \to \gamma\gamma$
- $K_{S,L} \to \pi^0\gamma\gamma$
- $K_S \to \pi^0 e^+ e^-$

# Physics Motivation

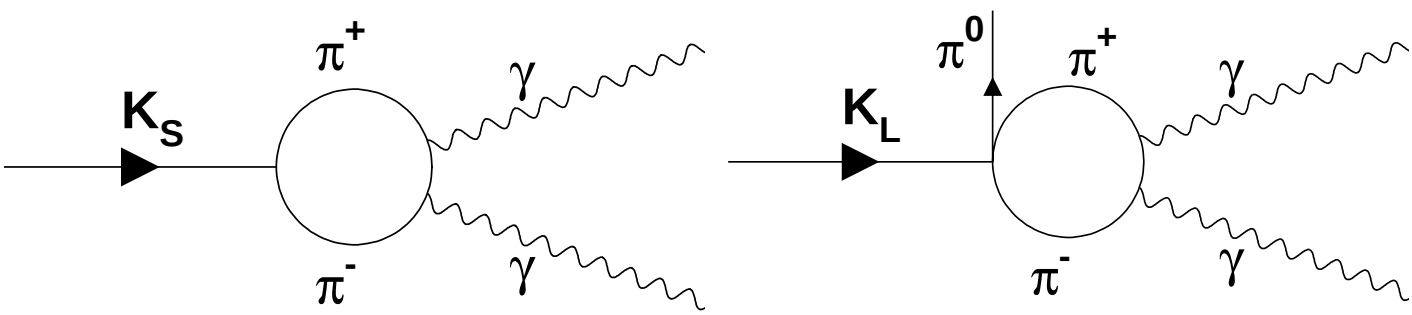
## 1) Tests of Chiral Perturbation Theory

($\chi$PT)

$K_S \to \gamma\gamma$ | $K_L \to \pi^0\gamma\gamma$

$O(p^2)$ : no contribution

$O(p^4)$ : finite .. unambiguous predictions ( $\pm$ 5% )



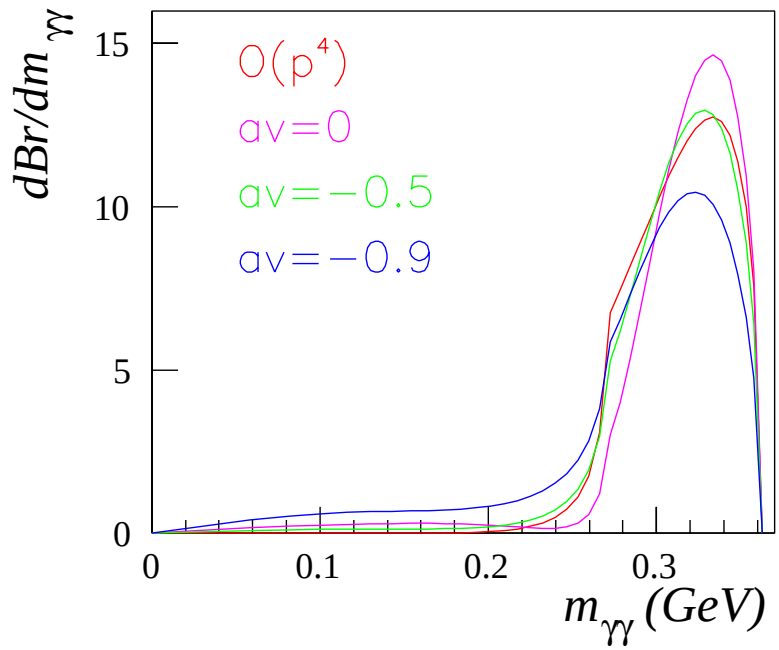

| | $K_S \to \gamma\gamma$ | $K_L \to \pi^0\gamma\gamma$ |
|---|---|---|
| $\chi$PT: | $(2.1 \pm 0.1) \times 10^{-6}$ | $0.6 \times 10^{-6}$ |
| expt: | $(2.6 \pm 0.4) \times 10^{-6}$ | $\sim 1.5 \times 10^{-6}$ |
| $O(p^6)$ : | needed ?? | definitely needed |

# 2) Input to CP Violation studies

$K_L \to \pi^0 \gamma\gamma$

$O(p^6)$ :

low mass tail in $m(\gamma\gamma)$

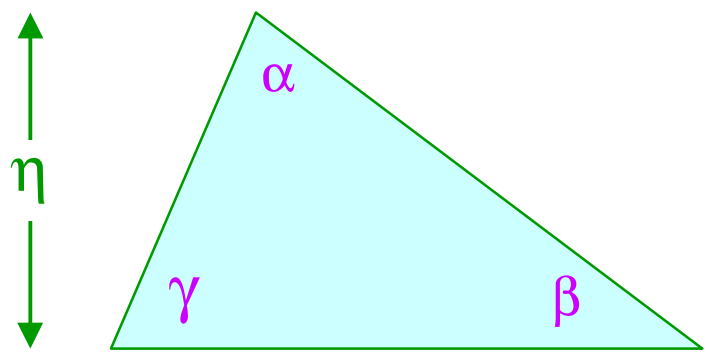



CP-conserving component of $K_L \to \pi^0 e^+ e^-$

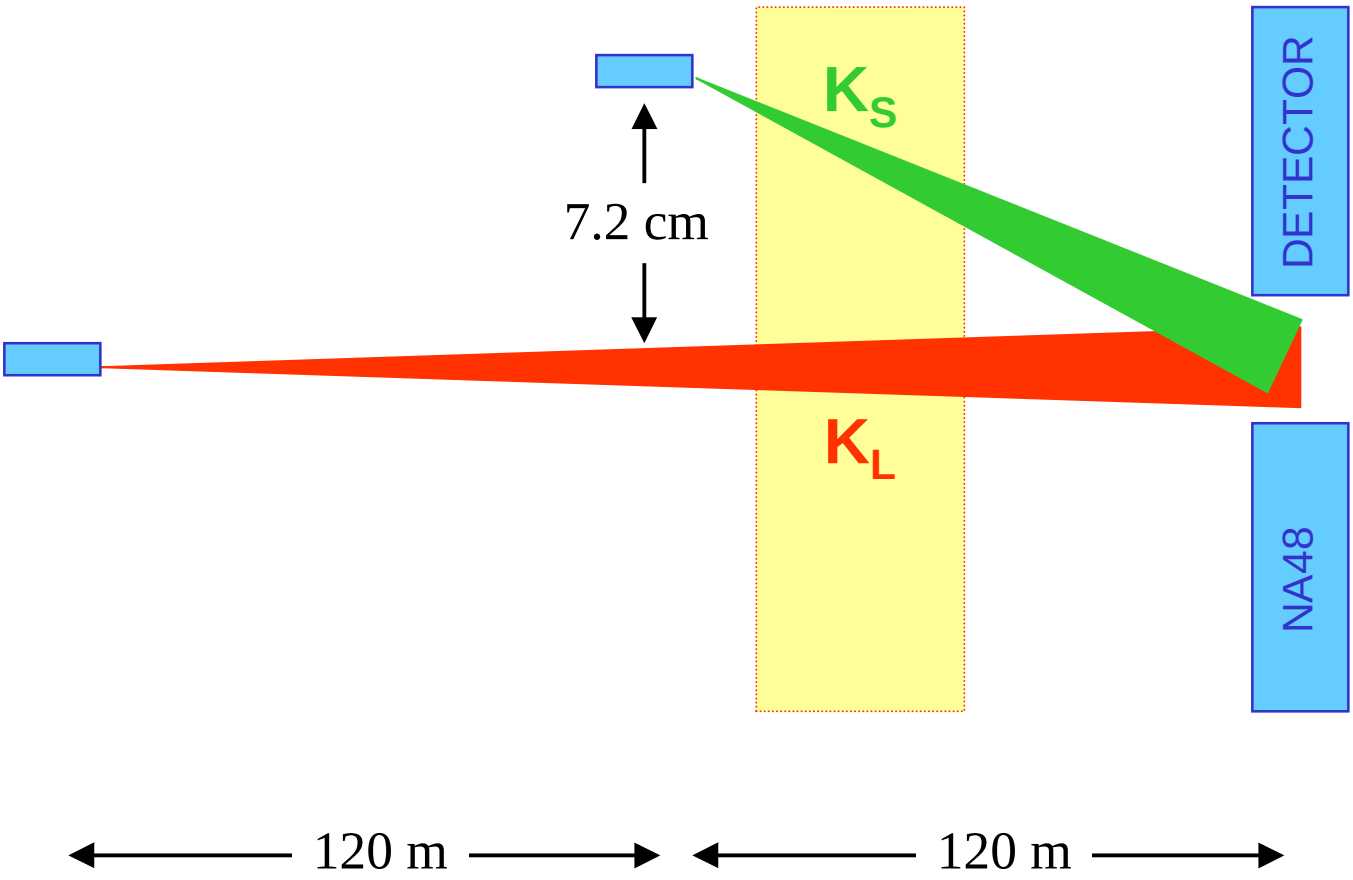
To fix indirect CP-violating component :

must measure $K_S \to \pi^0 e^+ e^-$

extract direct CP-violating component



# The NA48 Experiment




NA48 : $K_L + K_S$

NA48/1 : $K_S$ only (high intensity)

# The NA48 Detector

2000 Run :

NO SPECTROMETER

LKr EM calo.

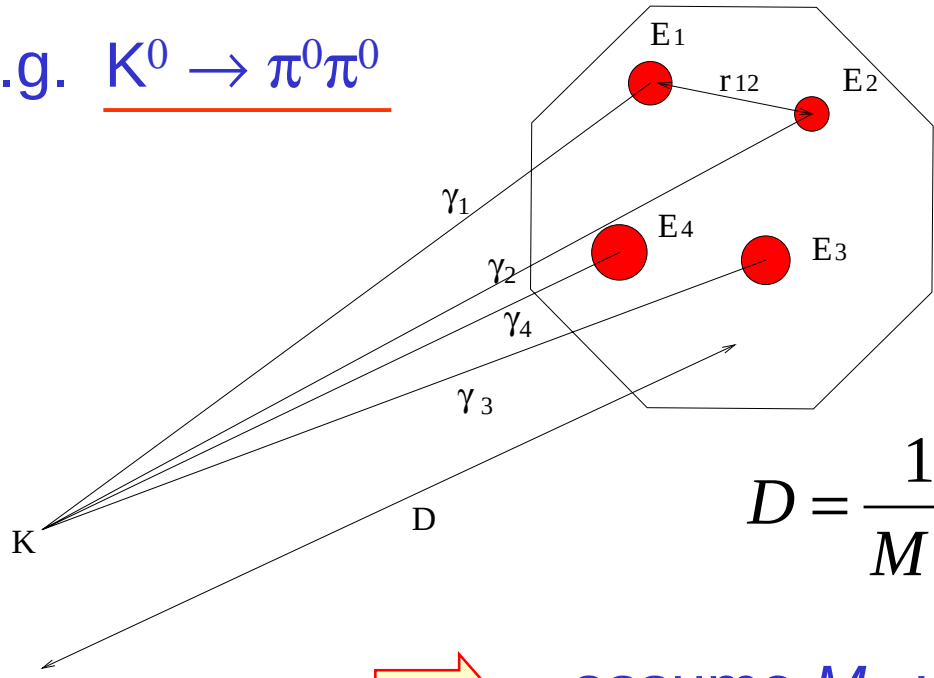
$\sigma_E/E \sim 0.8\%$

$\sigma_x \sim 1$ mm

$\sigma_t \sim 230$ ps

# Neutral Reconstruction

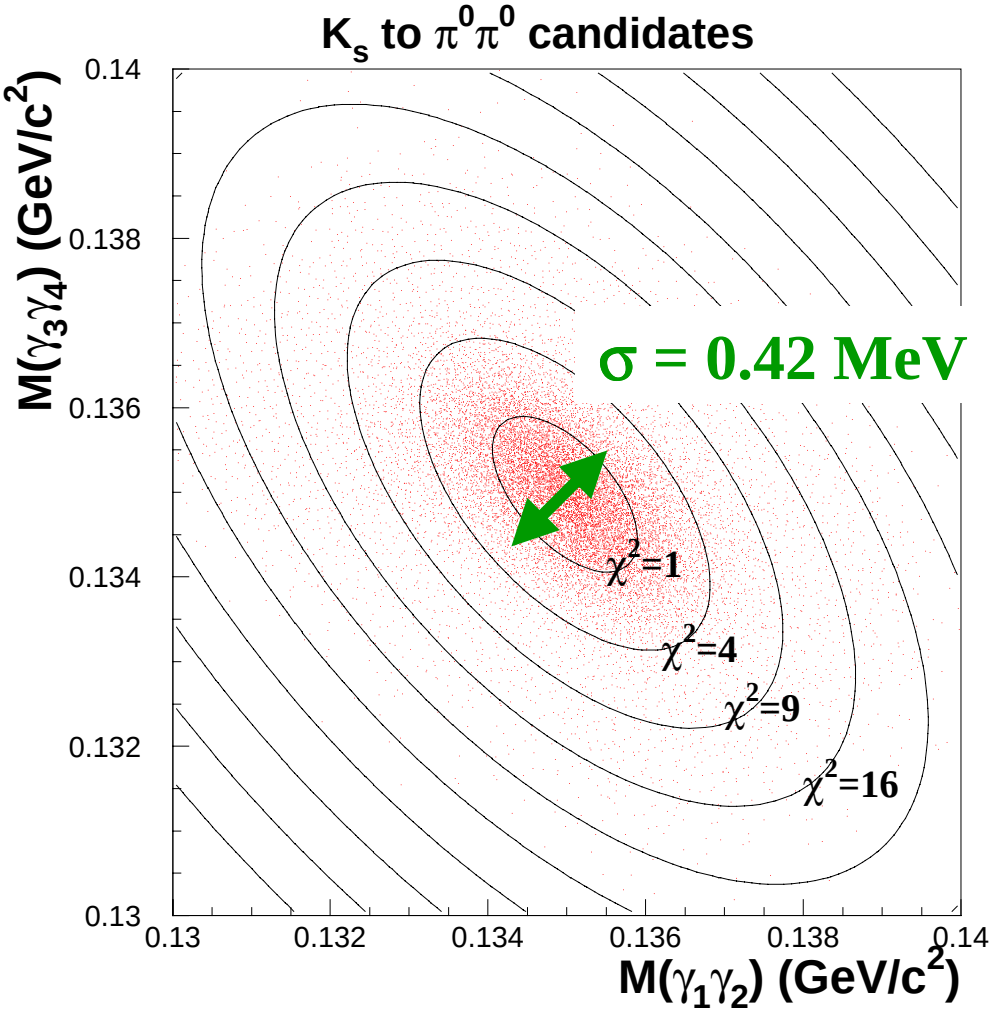
e.g. $K^0 \rightarrow \pi^0\pi^0$




$$D = \frac{1}{M_K}\sqrt{\sum E_i E_j \times r_{ij}^2}$$

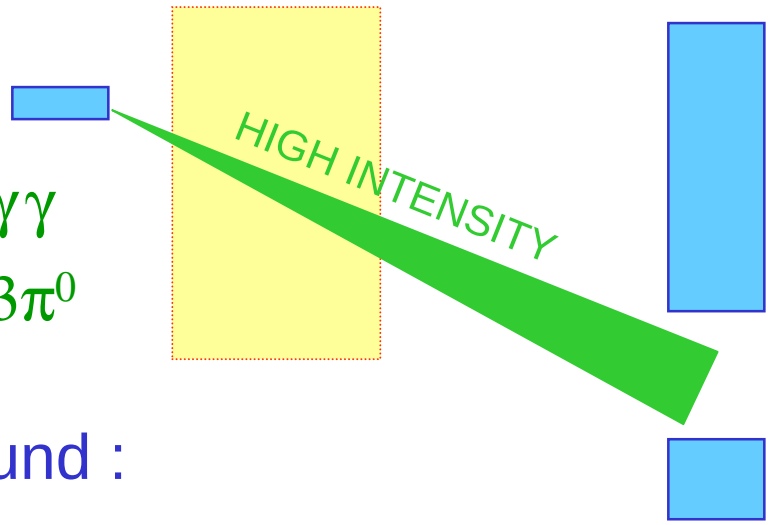
⇨ assume $M_K$ ; reconstruct $z$

$\pi^0$ masses in $K_S \rightarrow \pi^0\pi^0$



# Measurement of $K_S \to \gamma\gamma$

1) Use near target data from 2000(2) run :




$K_S \to \gamma\gamma$ $K_L \to \gamma\gamma$

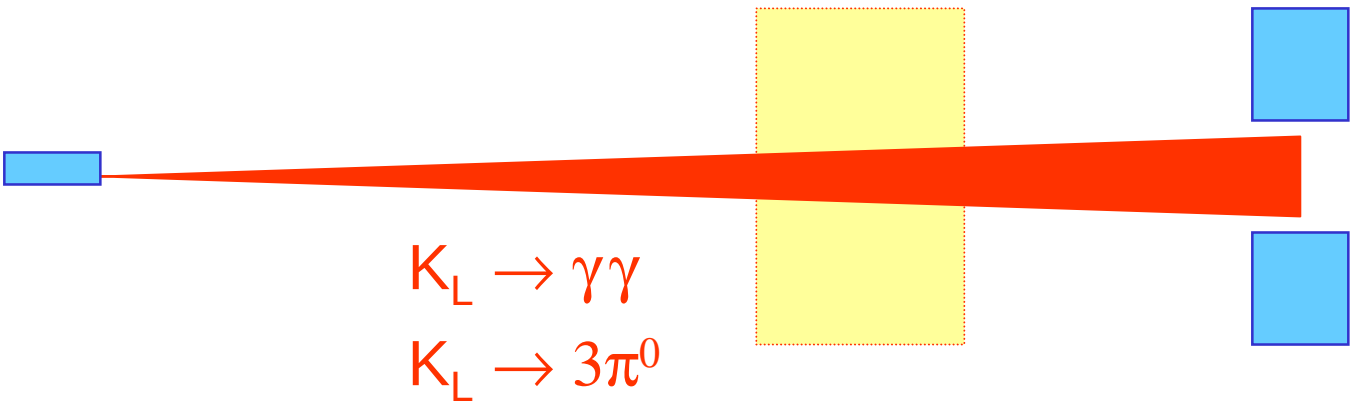
$K_S \to 2\pi^0$ $K_L \to 3\pi^0$

Irreducible background :

$$N(K_L \to \gamma\gamma) \sim 1.5 \times N(K_S \to \gamma\gamma)$$

BR($K_L \to \gamma\gamma$) would give $\pm 4\,\%$ uncertainty

2) So: use far target data from 2000(1) run :



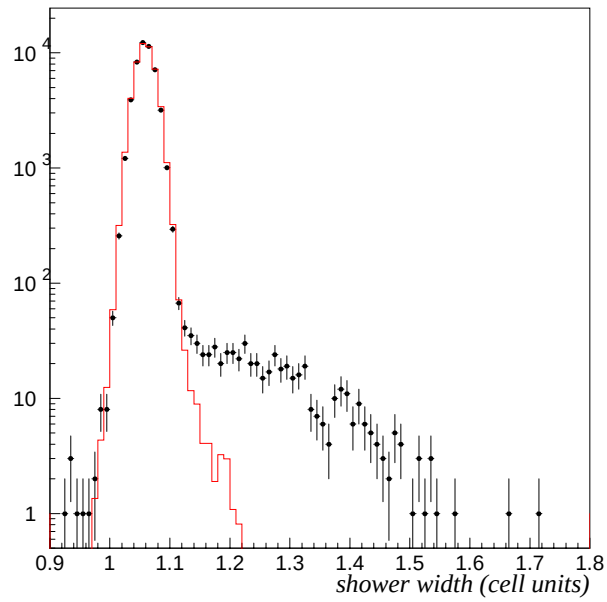
$K_L \to \gamma\gamma$

$K_L \to 3\pi^0$

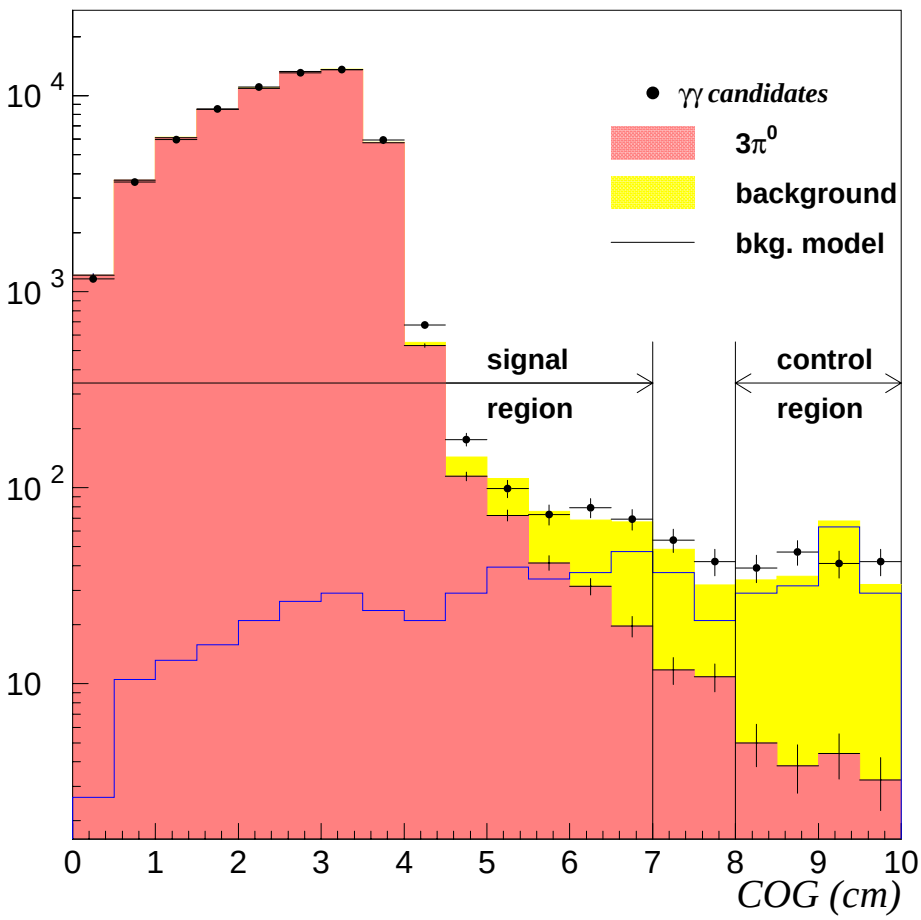
Normalise $K_L \to \gamma\gamma$ to $K_L \to 3\pi^0$

# Far target : $K_L \to \gamma\gamma$ , $K_L \to 3\pi^0$

- Hadronic background in $K_L \to \gamma\gamma$:



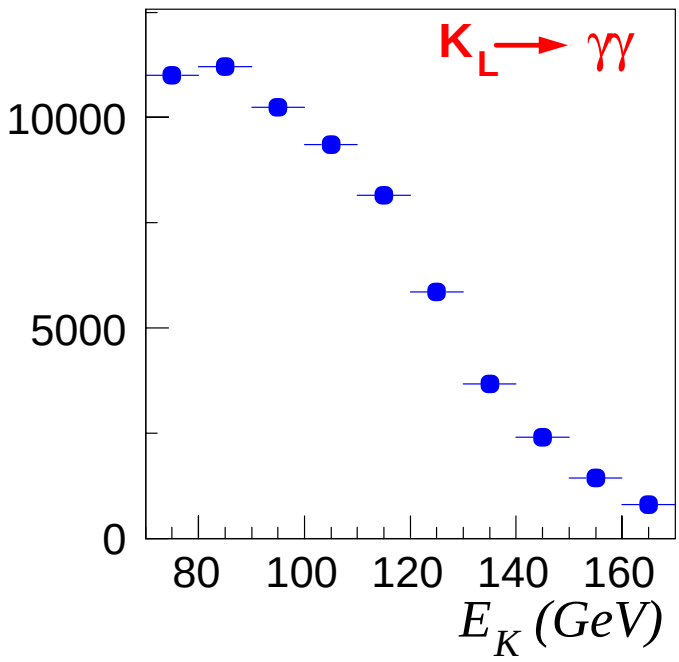

- Subtract using radius of centre of energy :

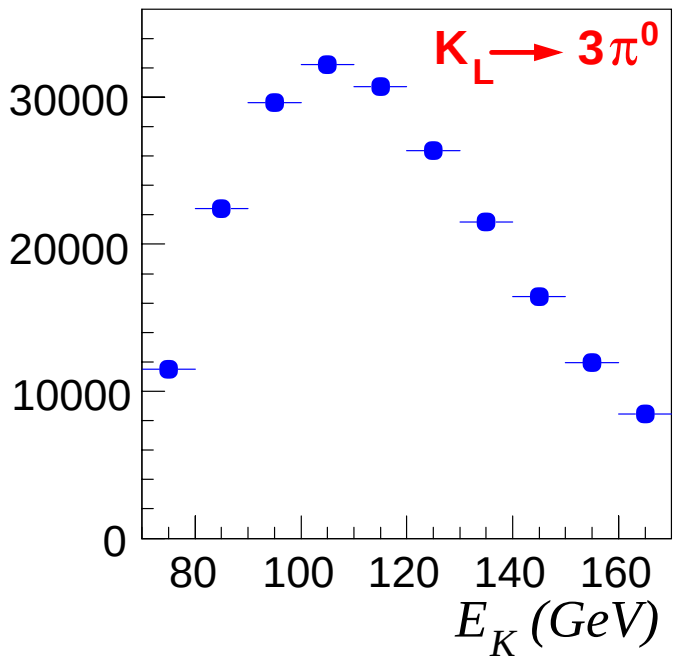



Background : **( 0.6 ± 0.3 ) %**

# Measurement of $\frac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to 3\pi^0)}$

## Energy spectra :




## Systematic uncertainties small :

Backgrounds : $\pm$ 0.3 %

Acceptance : $\pm$ 0.6 %

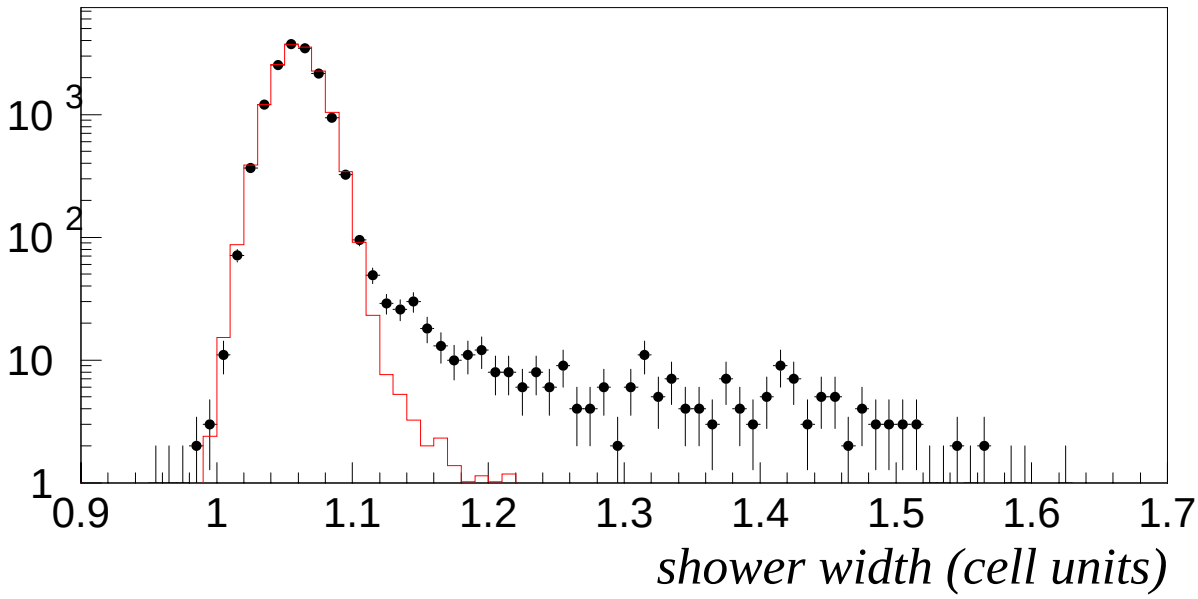
(preliminary)

$$\frac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to 3\pi^0)} = (2.81 \pm 0.01 \pm 0.02) \times 10^{-3}$$

PDG : $(2.77 \pm 0.08) \times 10^{-3}$

# $K_S \to \gamma\gamma$ : backgrounds

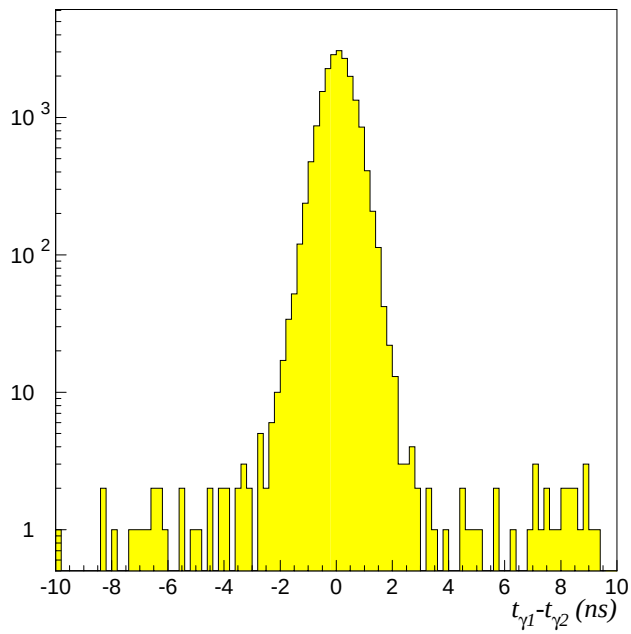
## Hadronic background :




## Accidental background :

→ tails in shower time difference

$\Delta t = t_1 - t_2$

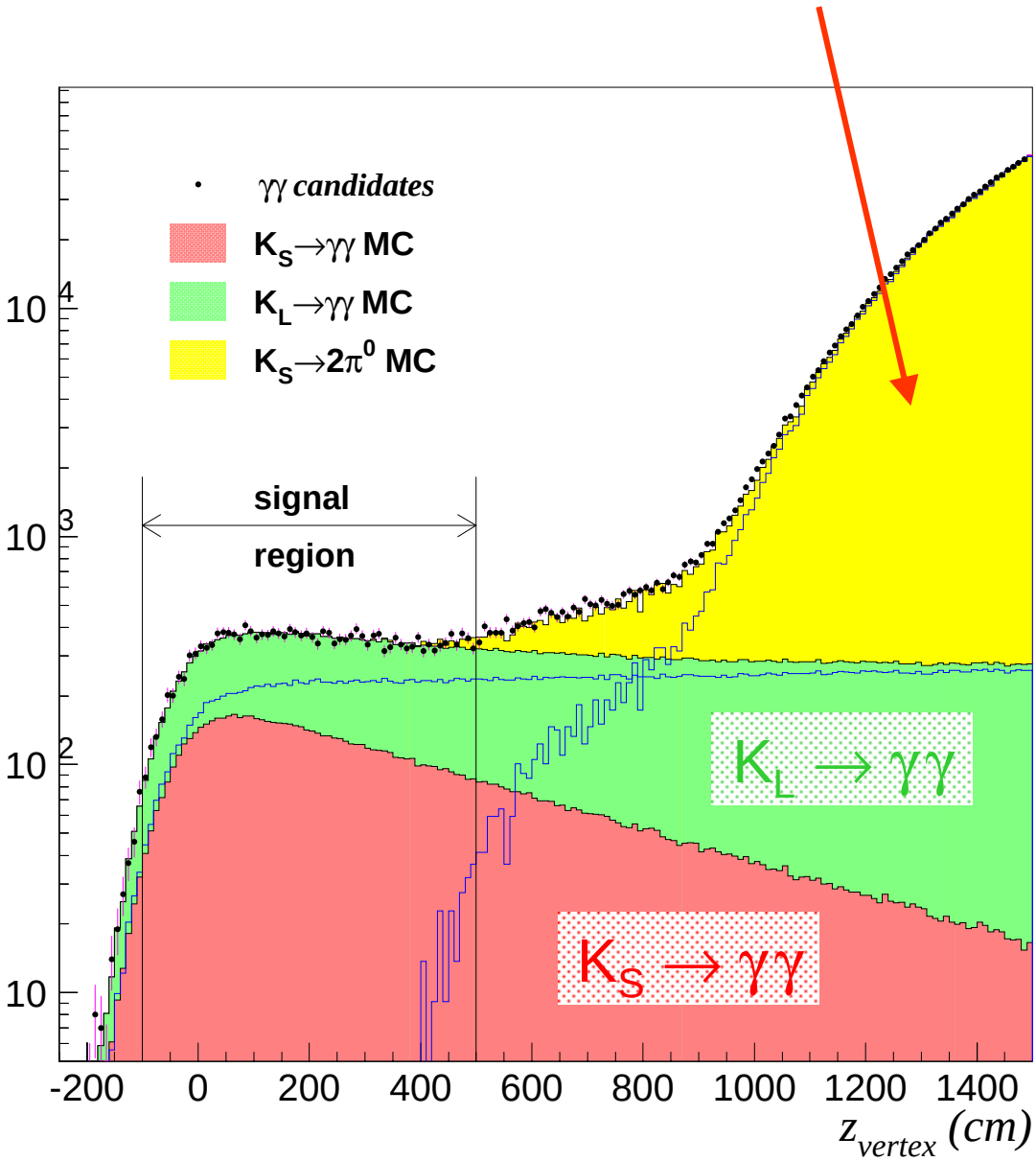



Had. + Acc. background : **( 0.8 ± 0.3 ) %**

# $K_S \to \gamma\gamma$ : bgd from $K_S \to 2\pi^0$

$K_S \to \pi^0\pi^0$ with two lost or overlapping photons

⇒ decay vertex shifts downstream :



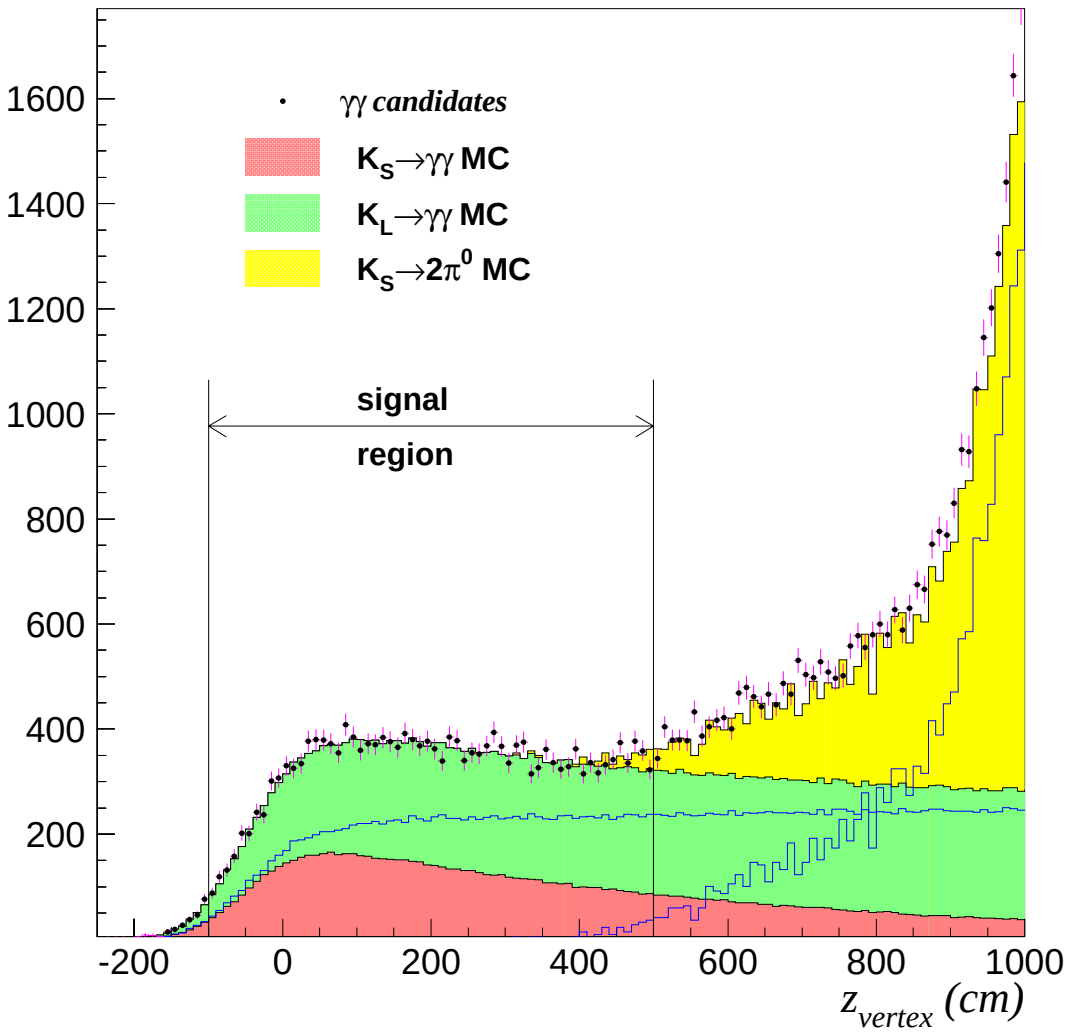

Normalise to fully reconstructed $K_S \to \pi^0\pi^0$ :

Bgd from $K_S \to \pi^0\pi^0$ : **( 0.8 ± 0.2 ) %**

# Measurement of $K_S \to \gamma\gamma$

~ 20000 $K_{S,L} \to \gamma\gamma$ candidates in signal region

( total non-$\gamma\gamma$ background ~ 2.0 % )



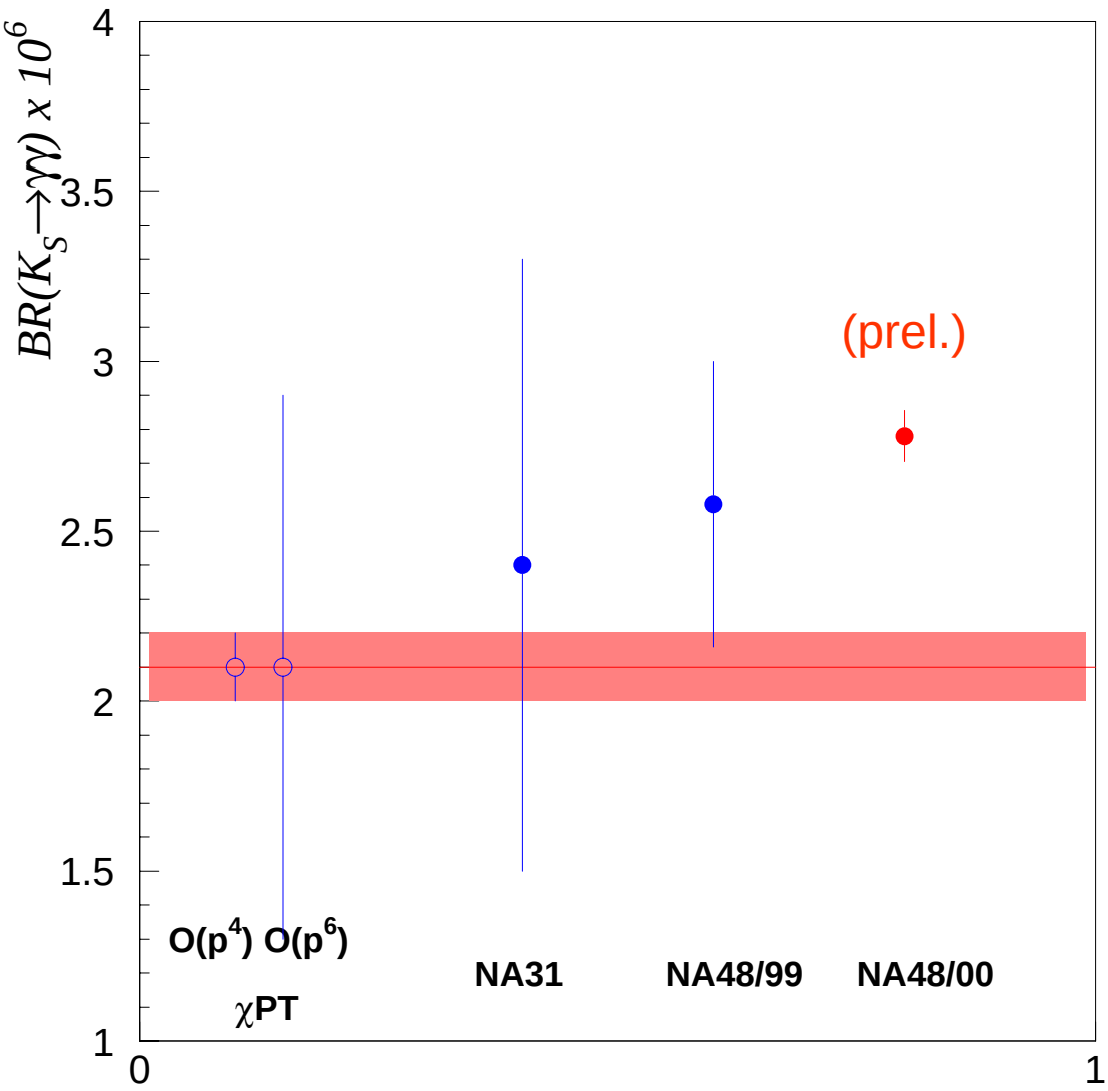

$$BR(K_S \to \gamma\gamma) = (2.78 \pm 0.06 \pm 0.04) \times 10^{-6}$$

(preliminary)

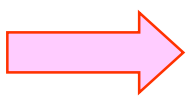
Main systematics :

| | |
|---|---|
| BR($K_S \to \pi^0\pi^0$) | ± 0.9 % |
| Had, acc bgd | ± 0.7 % |
| MC statistics | ± 0.6 % |

# $K_S \to \gamma\gamma$ measurements




~ 30 % larger than $O(p^4)$ $\chi$PT prediction

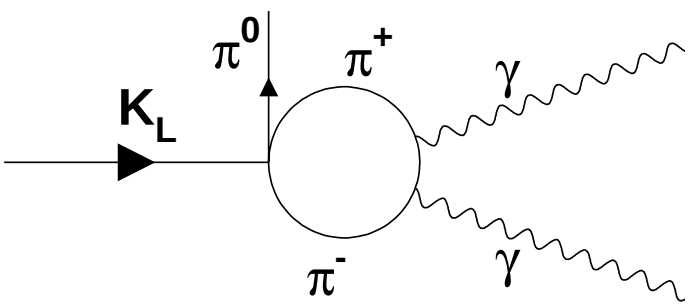


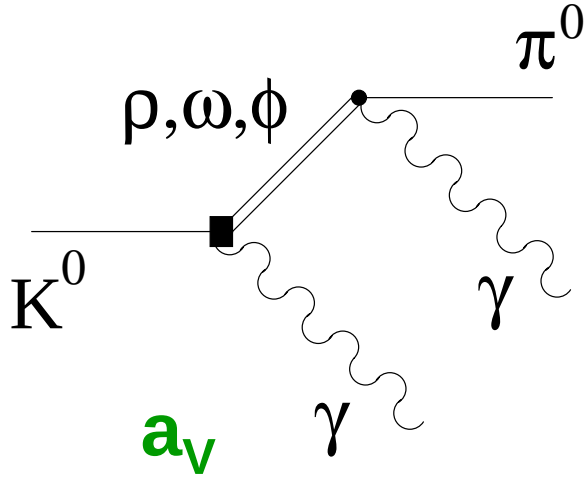
indication of a large $O(p^6)$ contribution

# $K_L \to \pi^0 \gamma\gamma$

CERN-EP / 2002-030
hep-ex / 0205010

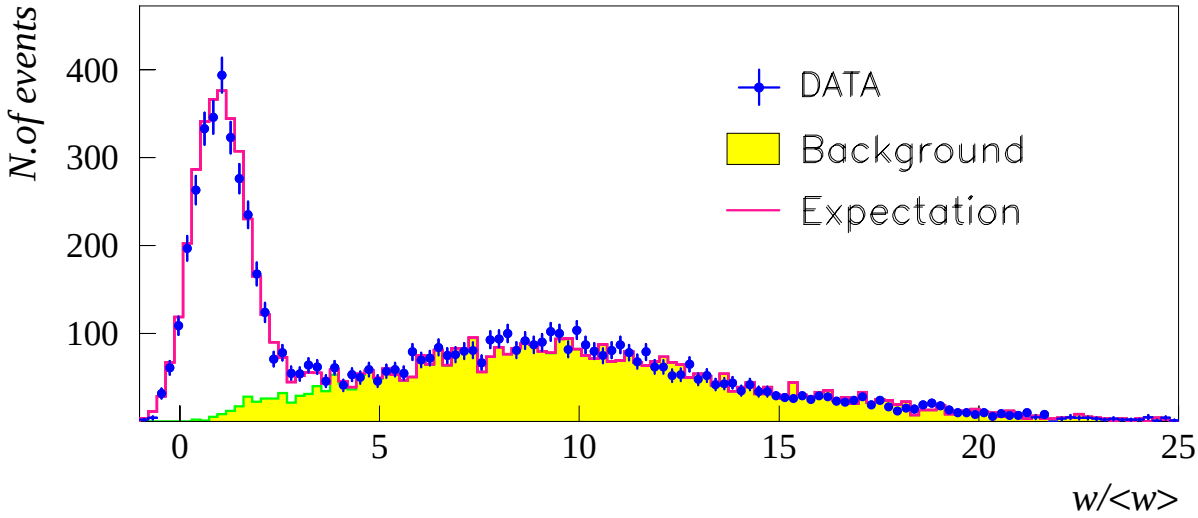
- Event selection :
  - use $\varepsilon'/\varepsilon$ data from 1998-99
  - normalise to $K_L \to 2\pi^0$
  - require 4 in-time photon showers
  - veto AKL or spectrometer activity
- Challenging backgrounds :
  - $K_L \to 3\pi^0$ (missing or overlapping showers)
  - badly reconstructed $K_L \to 2\pi^0$
  - accidental overlapping events
- $O(p^4)$ $O(p^6)$: VMD



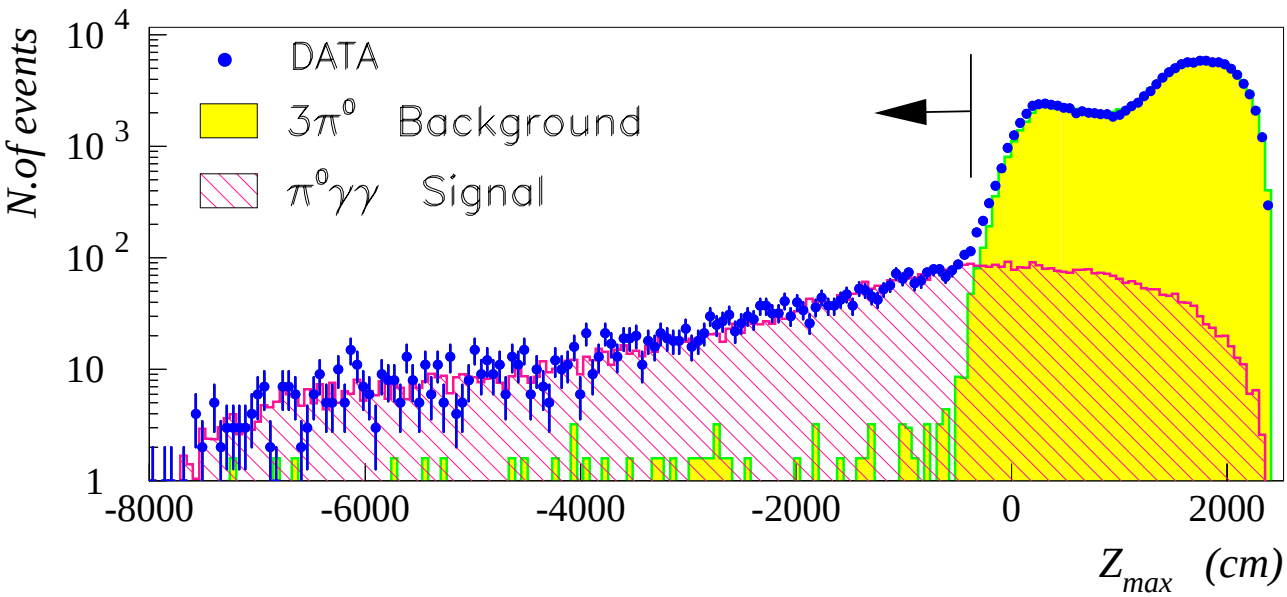



# Background from $K_L \to 3\pi^0$

- Reduce overlaps using shower width :




- Estimate $K_L \to 3\pi^0$ decay vertex position :



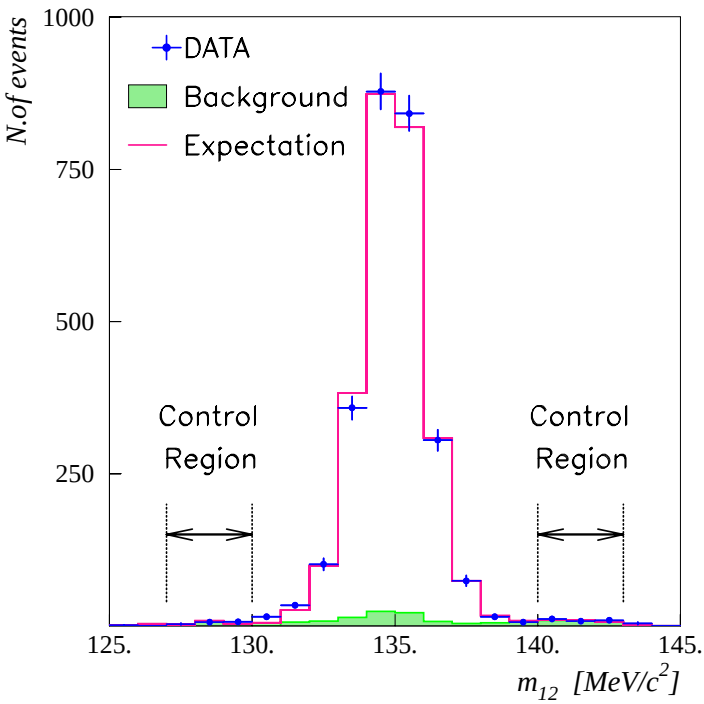

( $K_L \to \pi^0\gamma\gamma$ signal $\to$ unphysical $z_{max}$ region )

Background from $K_L \to 3\pi^0$ : **( 2.7 ± 0.4 ) %**

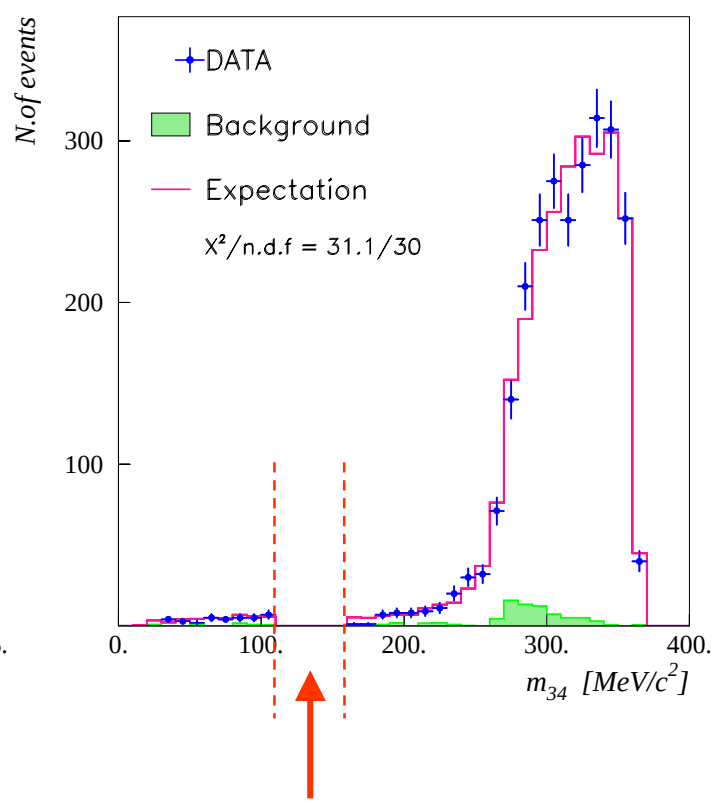
# $K_L \to \pi^0 \gamma\gamma$ sample

## Invariant mass distributions :

$\pi^0$




$\gamma\gamma$




remove $K_L \to \pi^0 \pi^0$

2558 signal candidates

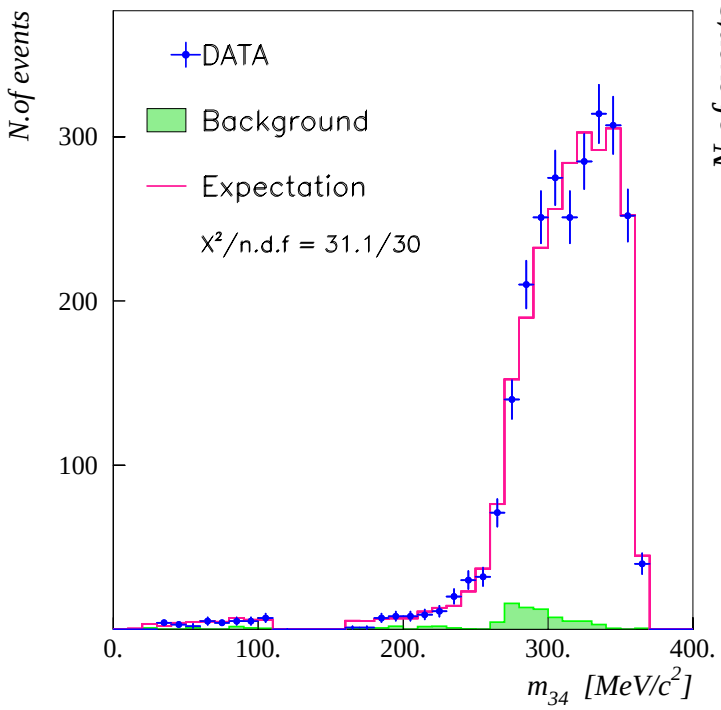
( total background : 82 ± 12 events )

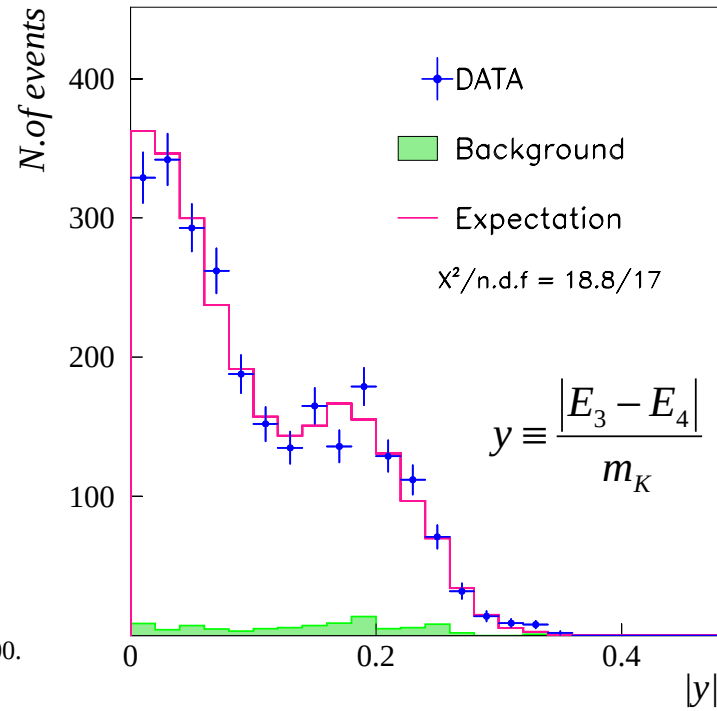
## Ambiguous mass assignment : 345 events

- especially affects low mass tail
- not used for determination of $a_V$

# $K_L \to \pi^0 \gamma\gamma$ measurement

## Simultaneous fit to $m_{\gamma\gamma}$ and $y$ distributions :




## determine $O(p^6)$ VMD contribution :

$$a_V = -0.46 \pm 0.03 \pm 0.04$$

KTeV : $-0.72 \pm 0.05 \pm 0.06$

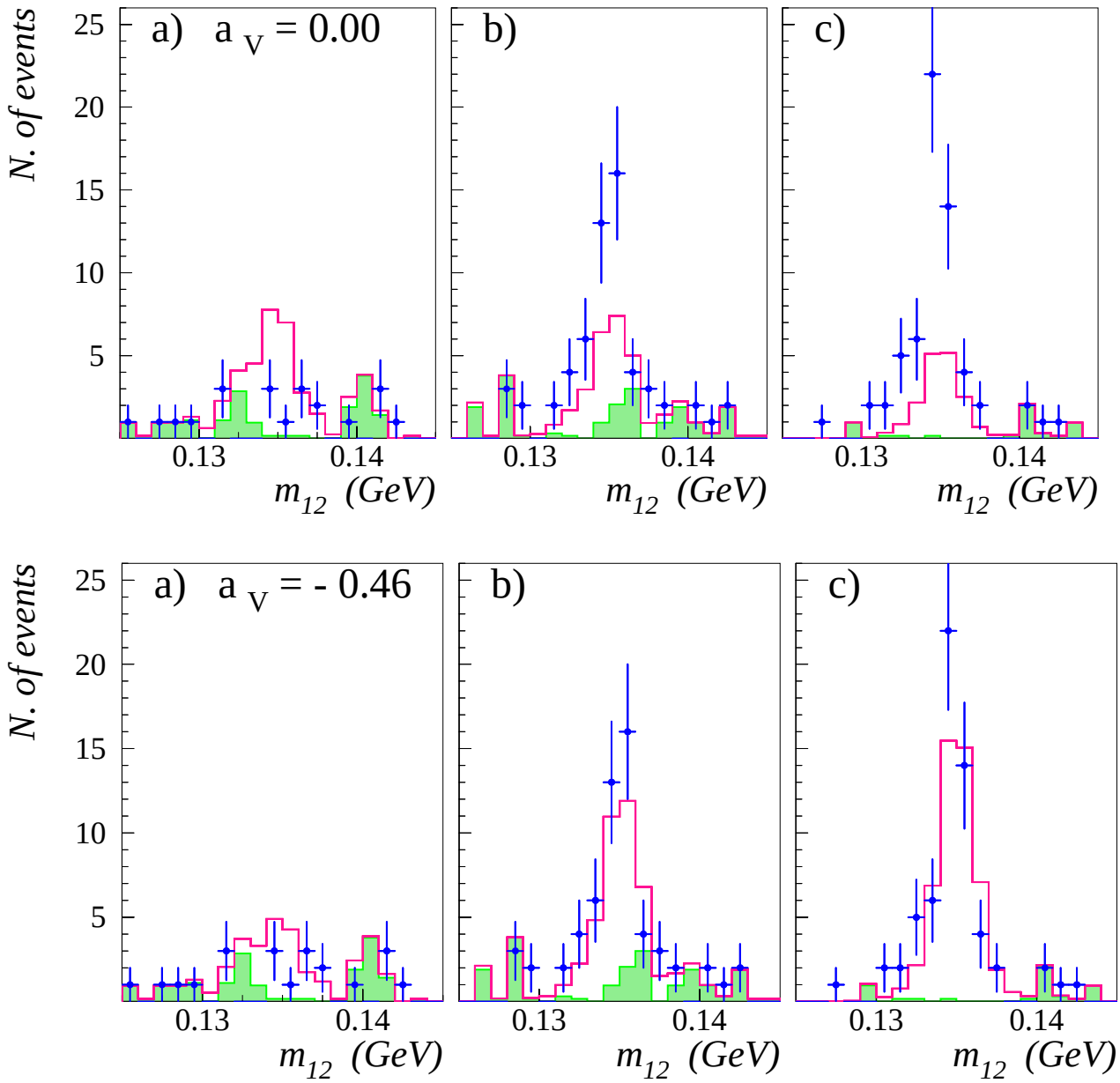
## Using this value of $a_V$ :

$$\mathrm{BR}(K_L \to \pi^0\gamma\gamma) = (1.36 \pm 0.03 \pm 0.04) \times 10^{-6}$$

KTeV : $(1.68 \pm 0.07 \pm 0.08) \times 10^{-6}$

# $K_L \to \pi^0 \gamma\gamma$ : low $m_{\gamma\gamma}$ region

$m_{\gamma\gamma}$ : 30 – 110 160 – 240 240 – 260 MeV



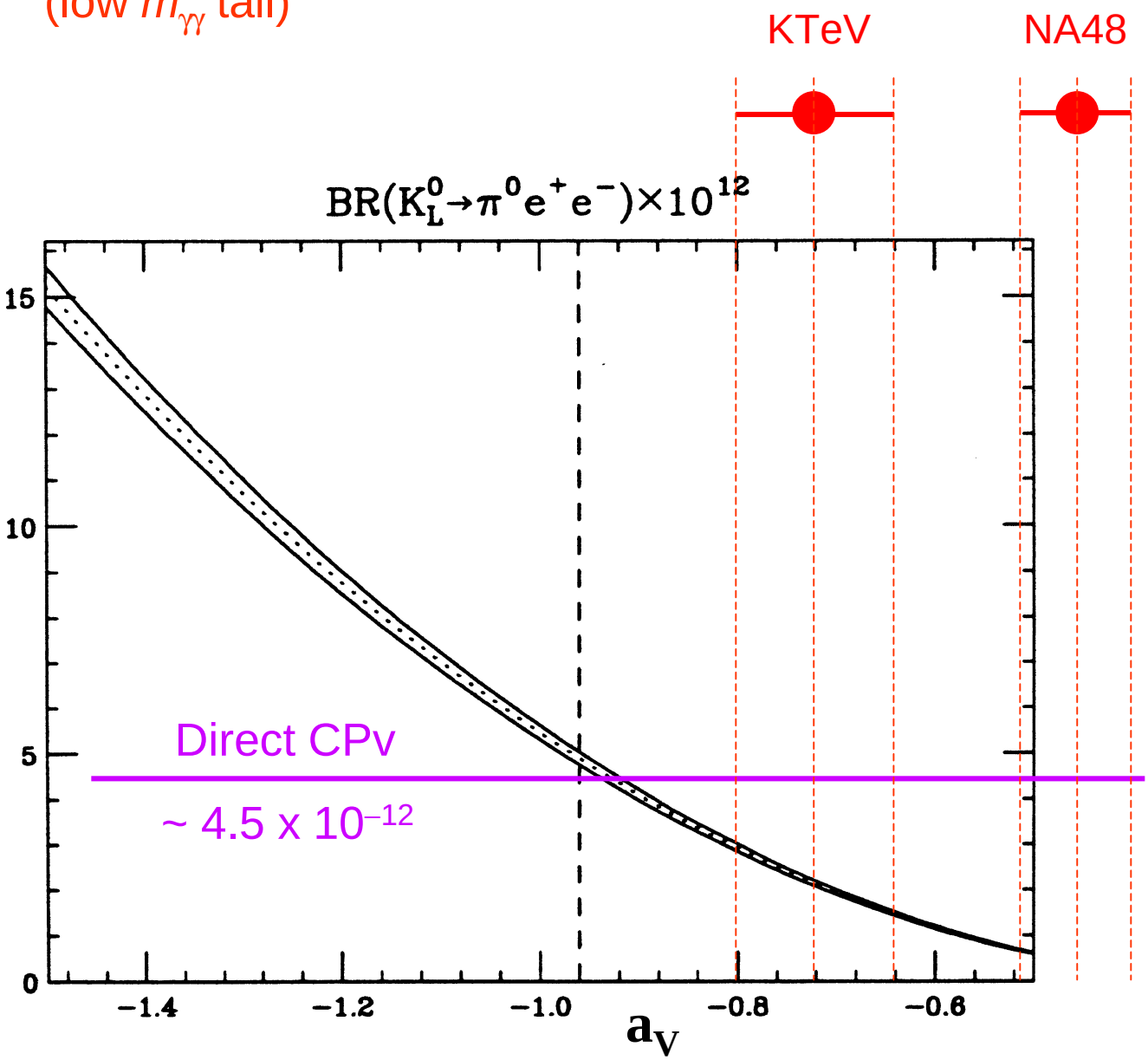

Clear $\pi^0$ signal

$\Rightarrow$ clear evidence for $O(p^6)$ contribution

# Consequences for $K_L \to \pi^0 e^+ e^-$

- $a_V$ determines CP conserving component

(low $m_{\gamma\gamma}$ tail)



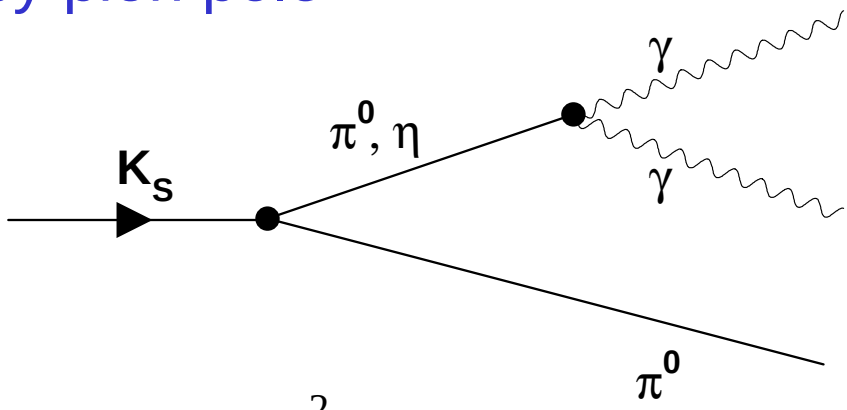

Donoghue + Gabbiani, hep-ph/9408390

$$\mathrm{BR}(K_L \to \pi^0 e^+ e^-)_{\mathrm{CP\ cons}} = \left(4.7^{+2.2}_{-1.8}\right) \times 10^{-13}$$

$\mathrm{BR}(K_S \to \gamma\gamma)$ ⟶ reassessment ?

# Search for $K_S \to \pi^0 \gamma\gamma$

- Dominated by pion pole




→ restrict to $z \equiv \frac{m_{\gamma\gamma}^2}{m_K^2} > 0.2$

χPT : $BR\left(K_S \to \pi^0\gamma\gamma\right)_{z>0.2} = 3.8\times10^{-8}$

Ecker, Pich, de Rafael

No experimental search so far

- NA48 analysis :

  - use High Intensity $K_S$ data from 1999

    (40 hour run, ~ 3 x $10^8$ $K_S$ decays)

  - veto events with any non-γ activity

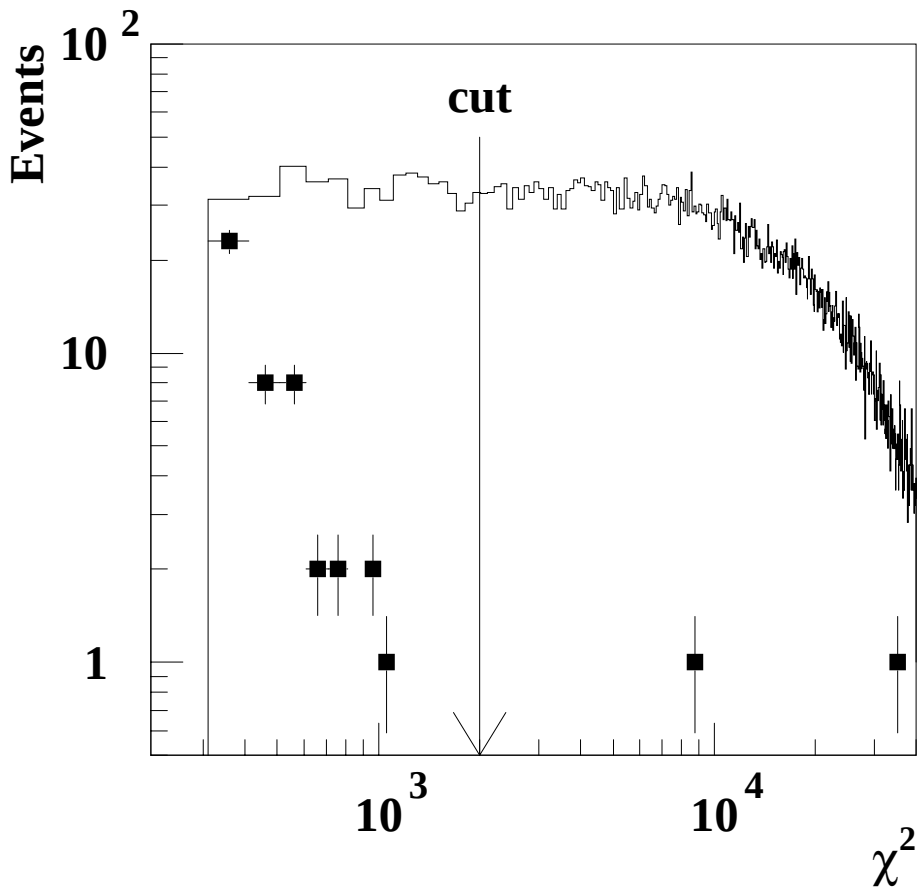
  - normalise to $K_S \to \pi^0 \pi^0$

# Search for $K_S \to \pi^0 \gamma\gamma$

Data : 2 candidate events

Expected bgd : $2.3 \pm 0.2$ events

mainly $K_S \to \pi^0\pi^0$ with one lost plus one accidental photon : $2.1 \pm 0.1$ events




$$\mathrm{BR}(K_S \to \pi^0\gamma\gamma) < 4.4\times10^{-7} \text{ at } 90\% \text{ C.L.}$$

(preliminary)

# Search for $K_S \to \pi^0 e^+ e^-$

PL **B514** (2001) 253

- Determines indirect CP-violating component of $K_L \to \pi^0 e^+ e^-$ :

$$BR(K_L \to \pi^0 e^+ e^-)_{\text{ind}} = |\varepsilon|^2 \frac{\tau_L}{\tau_S} BR(K_S \to \pi^0 e^+ e^-)$$

Expect : $$BR(K_S \to \pi^0 e^+ e^-) = 5.2 |a_s|^2 \times 10^{-9}$$

$$|a_s| \sim 1$$

- NA48 analysis :

  - use High Intensity $K_S$ data from 1999

    (40 hour run, ~ 3 x $10^8$ $K_S$ decays)

  - main background from Dalitz decays :

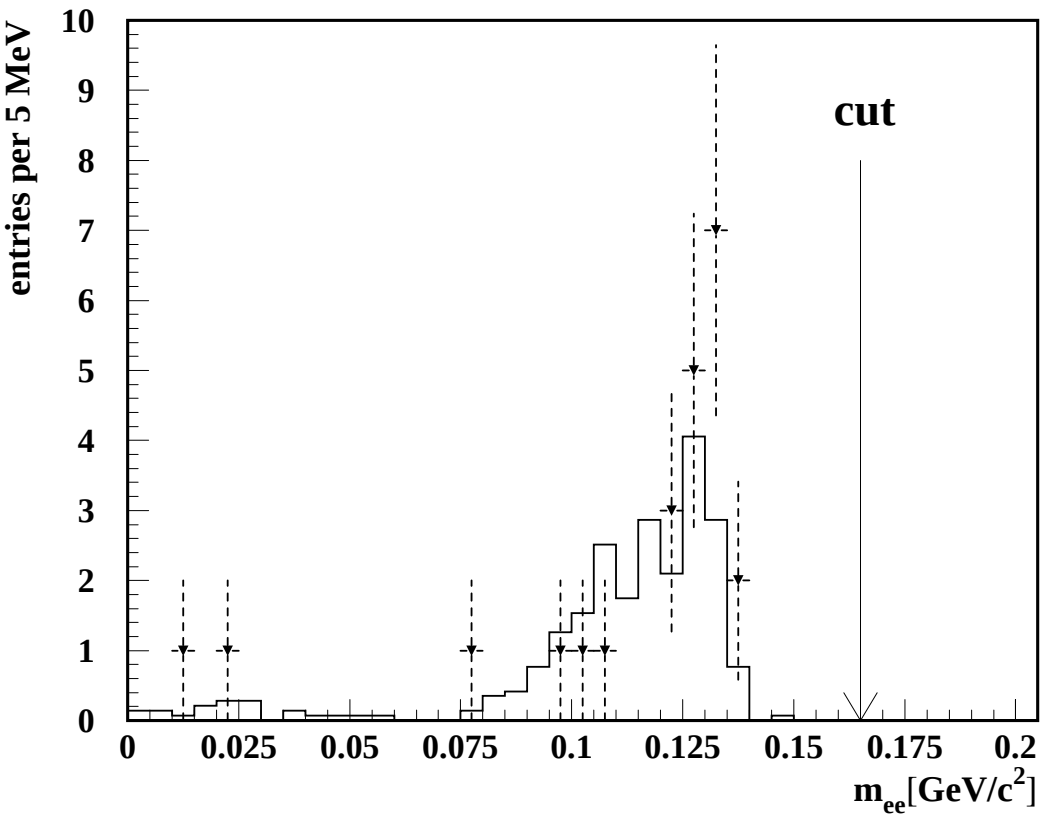
$K_S \to \pi^0 \pi^0$, $\pi^0 \to e^+ e^- \gamma$ (lost $\gamma$)

(normalisation channel)

⇒ require $m(e^+e^-) > 165$ MeV

# Search for $K_S \to \pi^0 e^+ e^-$

- No events survive :




( residual bgd 0.15 evts )

$$\mathrm{BR}(K_S \to \pi^0 e^+ e^-) < 1.4 \times 10^{-7} \text{ at } 90\% \text{ C.L.}$$

Geometrical acceptance = 31 %

Overall acceptance = 7.5 %

} MC

Matrix element from $\chi$PT

d'Ambrosio et al., Ecker et al.

# Summary

$K_S \to \gamma\gamma$

- BR measured to ±3 %
- ~ 30% above $O(p^4)$ prediction

byproduct : $\dfrac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to 3\pi^0)}$ factor 4 better than PDG

$K_L \to \pi^0\gamma\gamma$

$a_V$ → negligible CP-conserving contribution to $K_L \to \pi^0 e^+e^-$ ?

To extract direct CP violating component :

⇨ must measure $K_S \to \pi^0 e^+e^-$

⇨ main goal of NA48/1 2002 run

STARTS TODAY !!