

# Recent results of NA48 on neutral kaon rare decays

## *NAPP 2003*

Marco Clemencic

INFN Torino

[Marco.Clemencic@cern.ch](mailto:Marco.Clemencic@cern.ch)

On Behalf of NA48 Collaboration <sup>a</sup>

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<sup>a</sup>Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien



# Outline

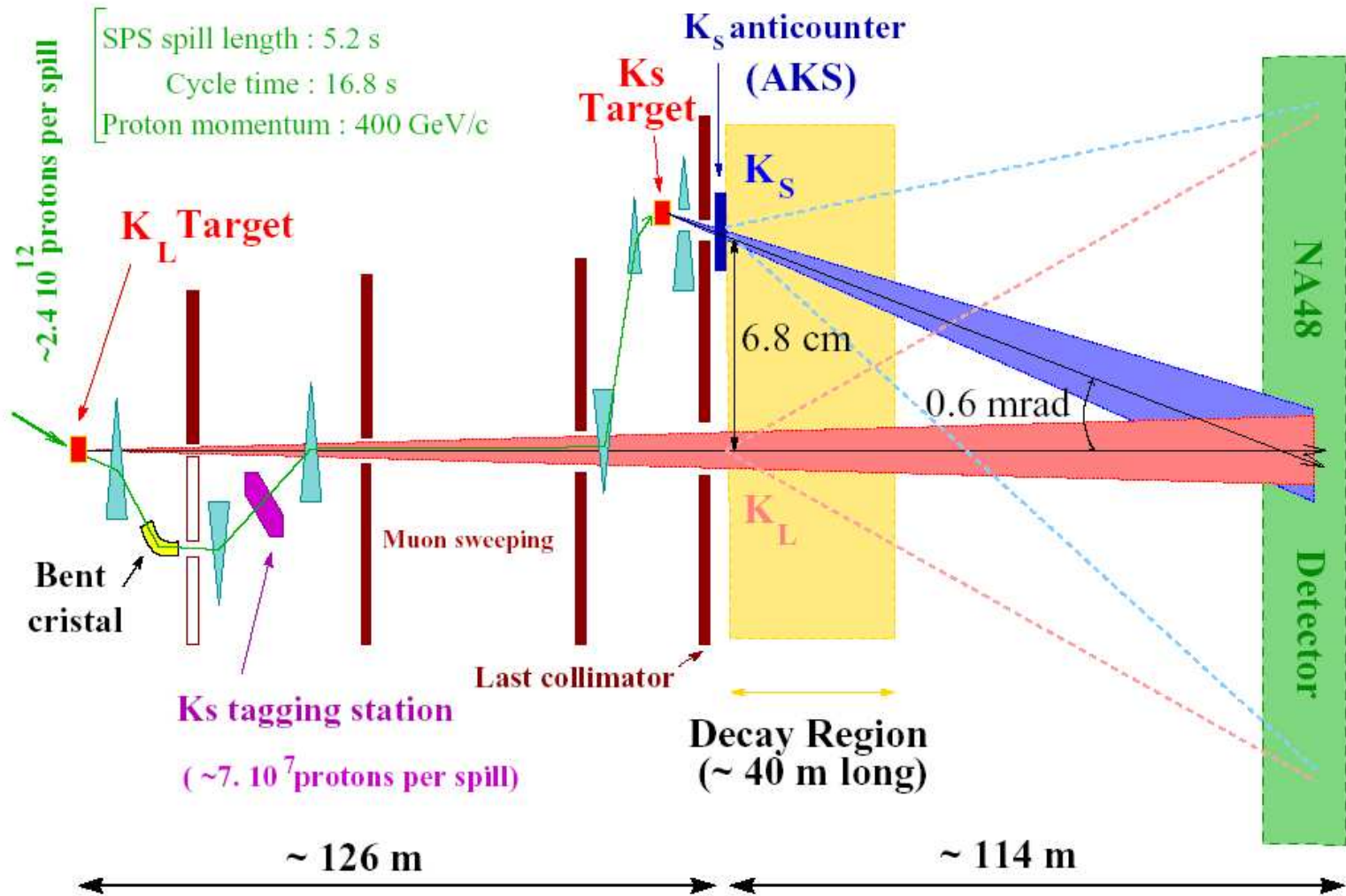
- NA48 Setup
- Data samples
- First observation of  $K_S \rightarrow \pi^0 \gamma \gamma$
- Detailed study of  $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$
- Present and future
  - 2002
  - 2003



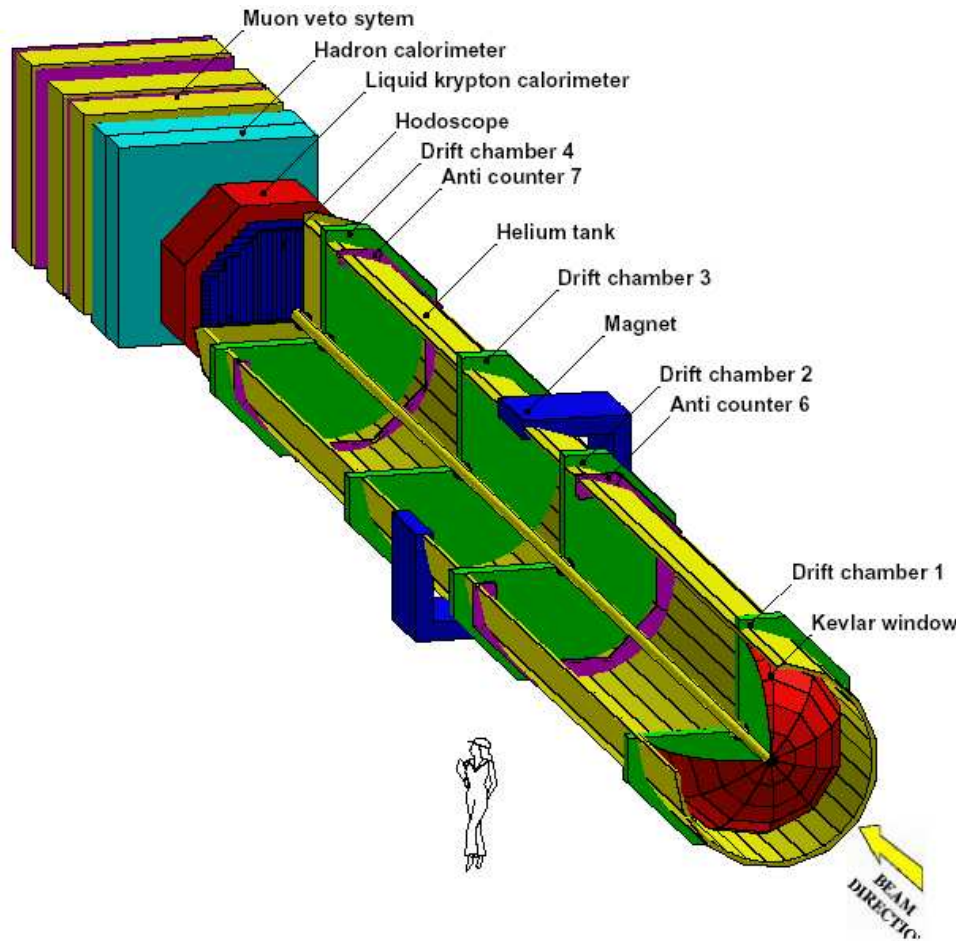
# NA48



# Experimental setup: *the beam lines*



# Experimental setup: *the detector*



Magnetic Spectrometer

$$\frac{\sigma_p}{p} (\%) = 0.48 \oplus 0.009 \times p(\text{GeV}/c)$$

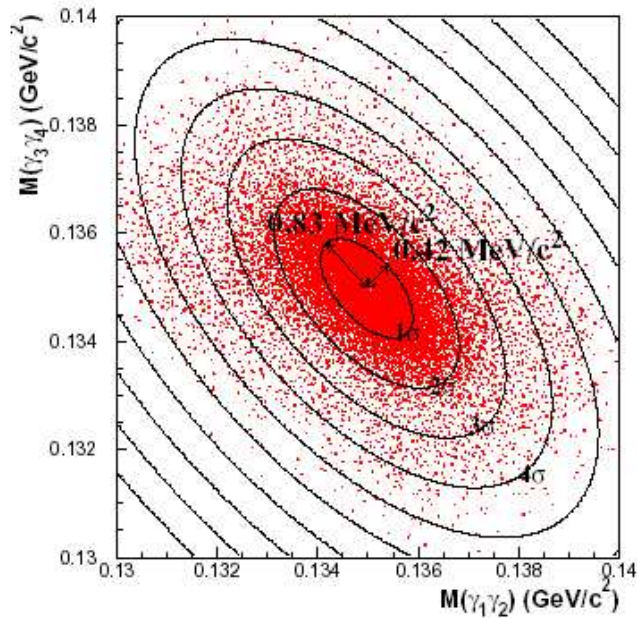
Liquid Kr e.m. spectrometer

$$\frac{\sigma_E}{E} (\%) = \frac{3.2}{\sqrt{E}} \oplus \frac{10.0}{E} \oplus 0.5(\text{GeV})$$



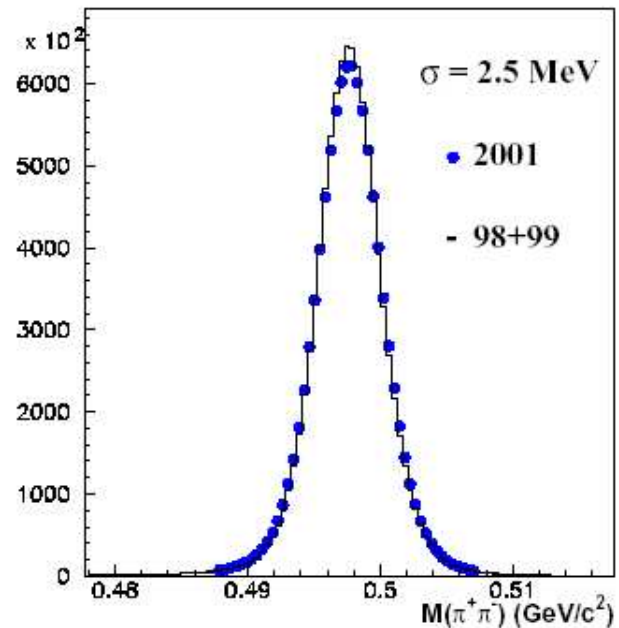
# Experimental setup: *resolution*

LKr e.m. calorimeter



$\gamma\gamma$  invariant mass in  
 $K_S \rightarrow \pi^0\pi^0$  candidates

Spectrometer



Kaon invariant mass in  
 $K_S \rightarrow \pi^+\pi^-$  candidates



# Data samples

1997 →  $\epsilon'/\epsilon$  run ( $K_L + K_S$ )

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1998 →  $\epsilon'/\epsilon$  run ( $K_L + K_S$ )

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1999 →  $\epsilon'/\epsilon$  run ( $K_L + K_S$ )  
 $K_S$  high intensity

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2000 →  $K_L$  only  
(no spectr.) →  $K_S$  high intensity

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2001 →  $\epsilon'/\epsilon$  run ( $K_L + K_S$ )  
 $K_S$  high intensity

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2002 →  $K_S$  high intensity

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2003 →  $K_+ + K_-$



$$K_S \rightarrow \pi^0 \gamma \gamma$$



# $K_S \rightarrow \pi^0 \gamma \gamma$ : motivation

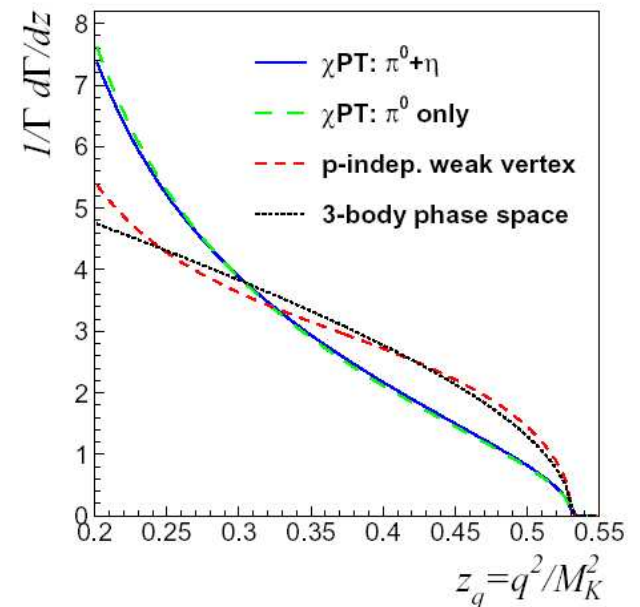
$\chi$ PT prediction:

(Ecker, Pich, De Rafael – 1987)

- $\text{BR}(K_S \rightarrow \pi^0 \gamma \gamma)|_{z>0.2} = 3.8 \times 10^{-8}$
- $d\Gamma/dz$  distribution  $\rightarrow$  structure of the **weak vertex**

Experimental limit:

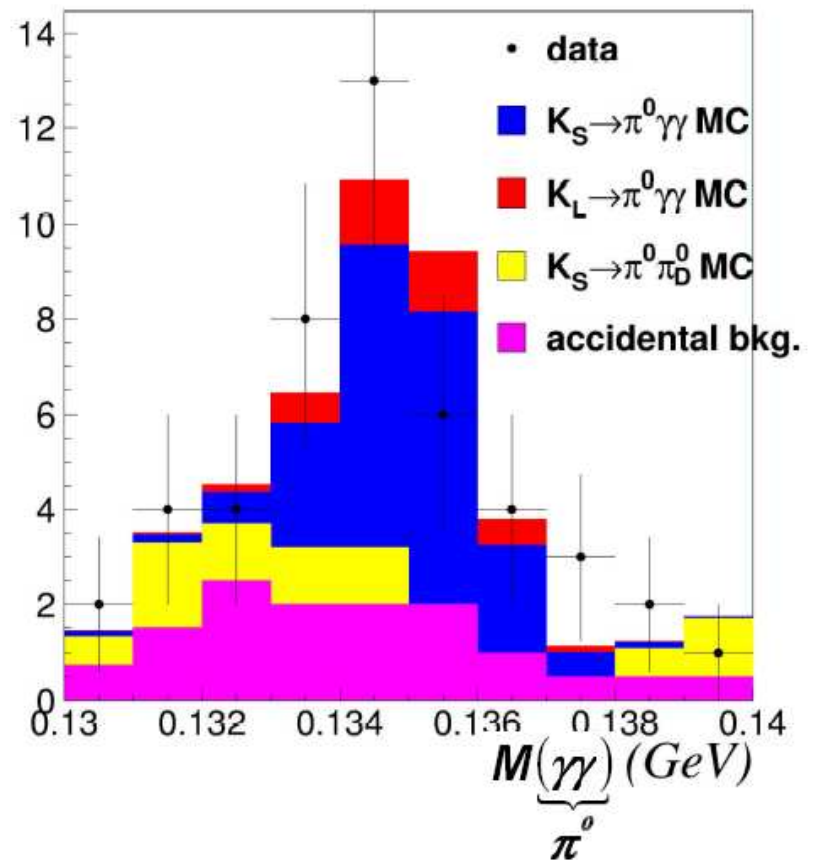
- NA48 recently (1999 test run data)  
 $\text{BR}(K_S \rightarrow \pi^0 \gamma \gamma)|_{z>0.2} < 3.3 \times 10^{-7}$



# $K_S \rightarrow \pi^0 \gamma \gamma$ : backgrounds

- beam activity
  - time cuts
  - anti-counters
- $K_S \rightarrow \pi^0 \pi^0, K_S \rightarrow \pi^0 \pi_D^0$ 
  - kinematical cuts
- $K_L \rightarrow \pi^0 \gamma \gamma$ 
  - irreducible
- $\Xi^0 \rightarrow \Lambda \pi^0 \rightarrow n \pi^0 \pi^0$ 
  - $E_\gamma$  asymmetries cut
  - Estimated using neutron shower profile distribution

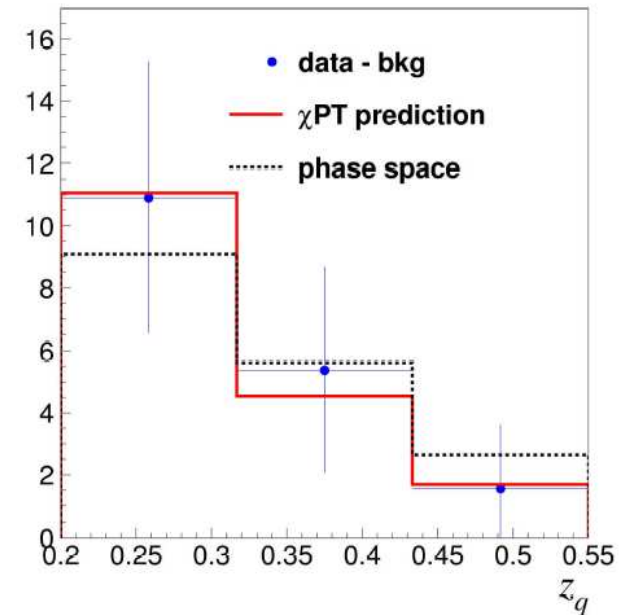
preliminary



# $K_S \rightarrow \pi^0 \gamma \gamma$ : preliminary result

- 31 candidates in the signal region
- backgrounds & systematics (estimated events)

beam activity	$7.4 \pm 2.4$
$K_S \rightarrow \pi^0 \pi_D^0$	$2.4 \pm 1.2$
$K_L \rightarrow \pi^0 \gamma \gamma$	$3.8 \pm 0.0$
acceptance	$\pm 0.7$
<b>total</b>	$13.6 \pm 2.8$



Preliminary result:

$$\text{BR}(K_S \rightarrow \pi^0 \gamma \gamma)|_{z>0.2} = (4.9 \pm 1.6_{\text{stat}} \pm 0.8_{\text{syst}}) \times 10^{-8}$$

Probability of background fluctuation:  $< 9 \times 10^{-4}$

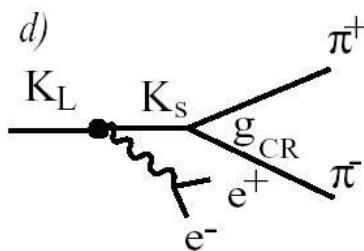
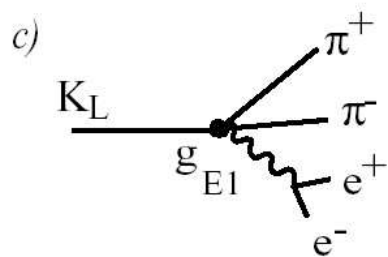
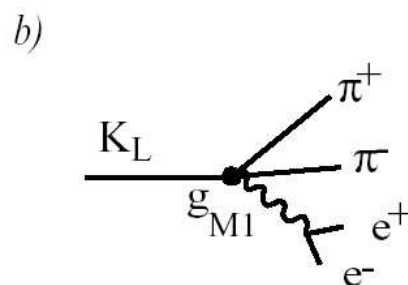
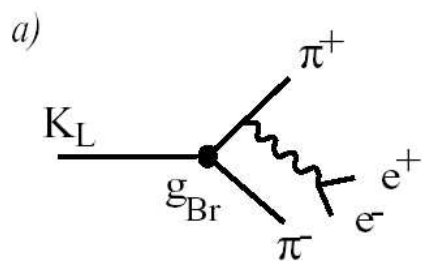


$$K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$$



# $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$ : motivation

Matrix element of  $K_L \rightarrow \pi^+ \pi^- e^+ e^-$  receives contributions (Helinger, Sehgal – 1993) from:



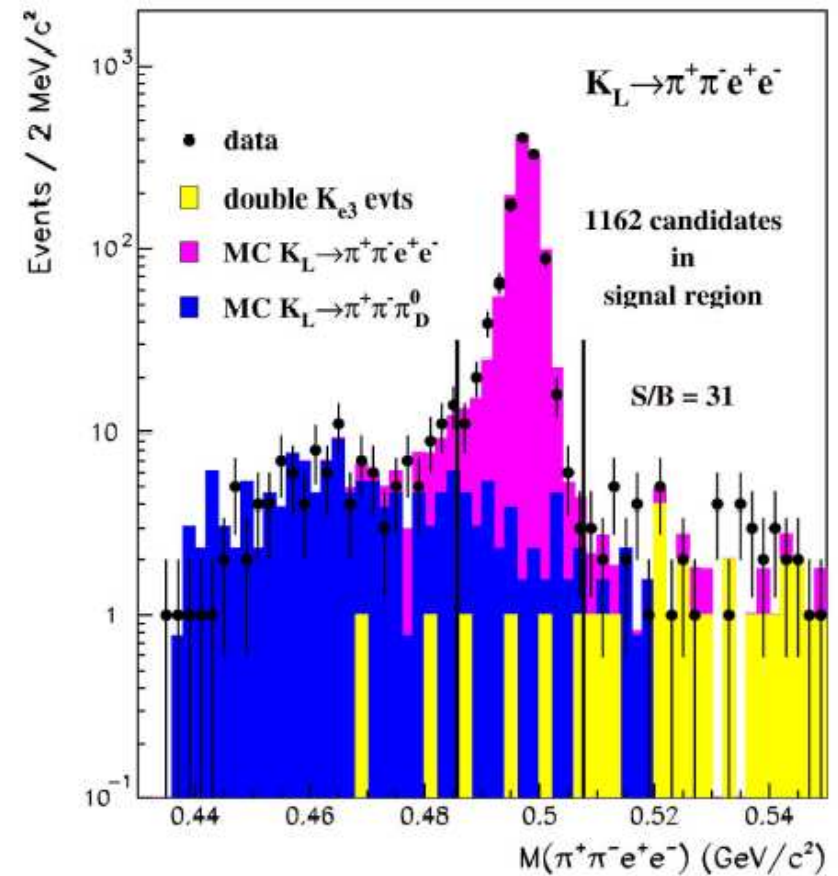
In the  $K_L$  case, interference between CP violating Inner Brem. and CP conserving Direct Emission processes, produces an asymmetry in the distribution of  $\phi$  between  $\pi^+ \pi^-$  and  $e^+ e^-$  decay planes ( $\sim 14\%$ ).

In the  $K_S$  case, the only contribution is IB.



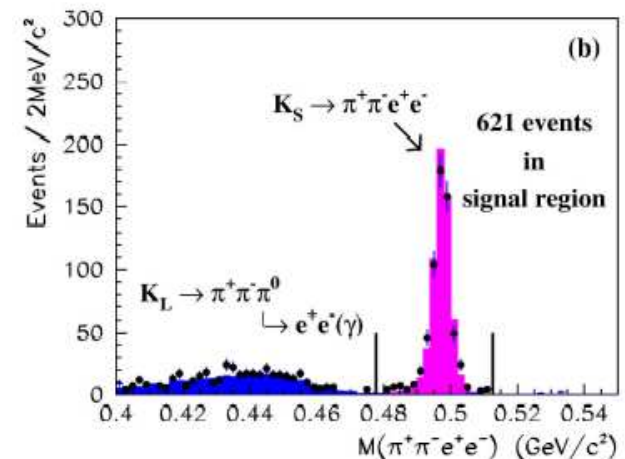
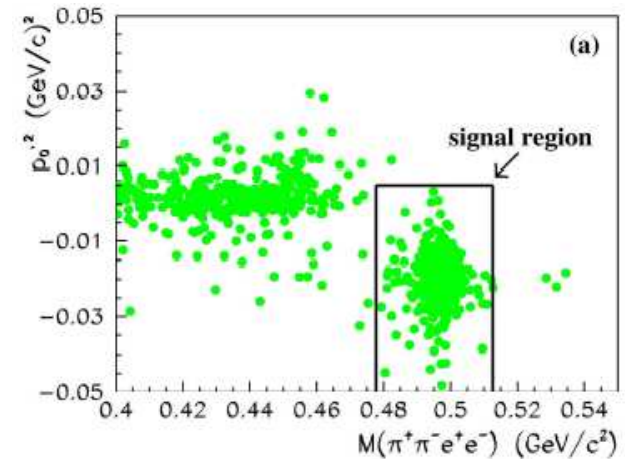
# $K_L \rightarrow \pi^+ \pi^- e^+ e^-$ : backgrounds

- $K_L \rightarrow \pi^+ \pi^- \pi_D^0$  ( $\gamma$  lost)
  - kinematical cuts
- **2 overlapping  $Ke3$** 
  - vertex quality cut
  - $\pi^+ e^-$  vs.  $\pi^- e^+$  time cut
  - estimated using  $\pi^\pm \pi^\pm e^\mp e^\mp$  accidental events
- $K_L \rightarrow \pi^+ \pi^- \gamma$  + conv.  
 $K_L \rightarrow \pi^+ \pi^-$  + acc.  $\gamma$  + conv.
  - negligible



# $K_S \rightarrow \pi^+ \pi^- e^+ e^-$ : backgrounds

- $K_L \rightarrow \pi^+ \pi^- \pi_D^0$   
(much smaller than in  $K_L$ )
  - looser kinematical cuts
- $K_L \rightarrow \pi^+ \pi^- e^+ e^-$  (irreducible)
  - constraint on  $Z$  of the decay vertex
- $\Xi^0 \rightarrow \Lambda \pi_D^0$ 
  - $\Lambda$  mass rejection cut
- Interactions and  $\gamma$  conv. in the collimator
  - AKS anti-counter



# $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$ : couplings

- Couplings are extracted by max likelihood fitting of data to MC

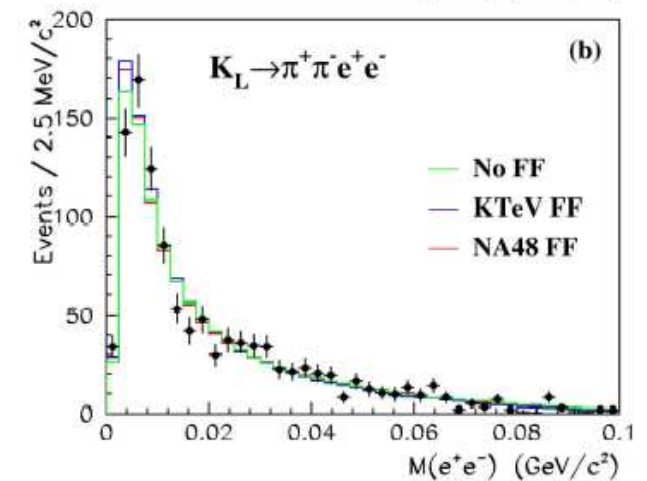
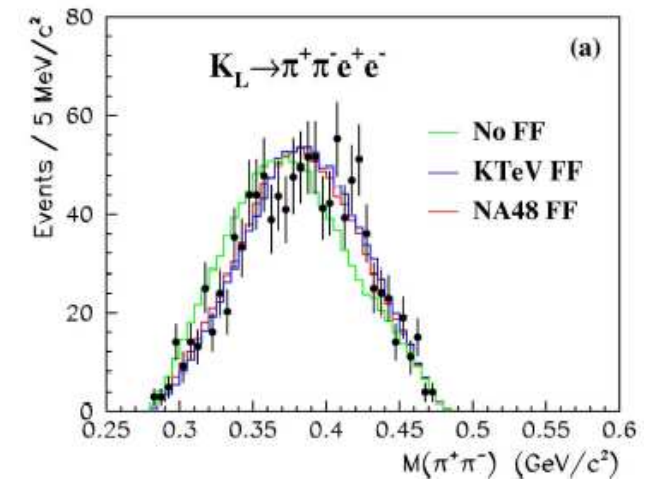
- $a_1/a_2 = (-0.81_{-0.13}^{+0.07}_{\text{stat}} \pm 0.02_{\text{syst}}) \text{ GeV}^2$

- $\tilde{g}_{M1} = 0.99_{-0.27}^{+0.28}_{\text{stat}} \pm 0.07_{\text{syst}}$

- $g_{CR} = 0.19 \pm 0.04_{\text{stat}} \pm 0.02_{\text{syst}}$

- In agreement with KTeV results

- $K_S$  data is consistent with pure IB



# $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$ : BR results

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

$$\text{BR} = (3.08 \pm 0.09_{\text{stat}} \pm 0.15_{\text{syst}} \pm 0.10_{\text{norm}}) \times 10^{-7}$$

- $K_S \rightarrow \pi^+ \pi^- e^+ e^-$

$$\text{BR} = (4.69 \pm 0.30) \times 10^{-5} \text{ (adding 98 data)}$$

- the main systematic errors come from the **model** applied ( $K_L$ ) and the variation of **selection cuts** (both  $K_L$  and  $K_S$ )
- the results agree with Helinger and Seghal predictions



# $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$ : results for $A_\phi$

- $K_L \rightarrow \pi^+ \pi^- e^+ e^-$   
after acceptance correction:

$$A_\phi^L = (14.2 \pm 3.0_{\text{stat}} \pm 1.9_{\text{syst}}) \%$$

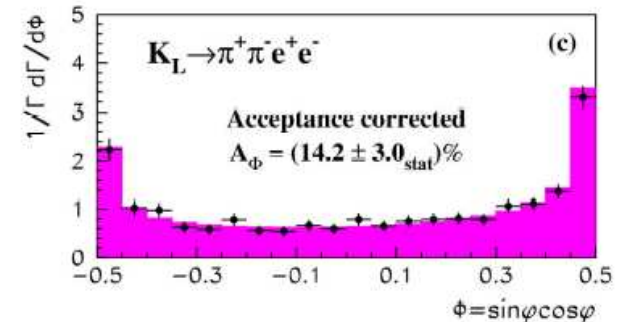
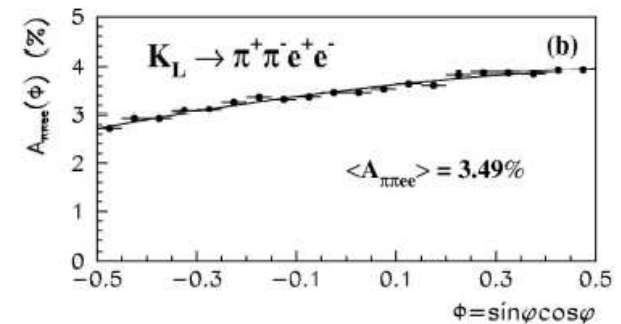
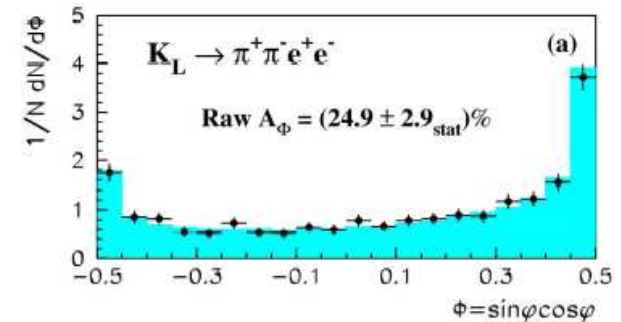
- clear signature of indirect CP-violation
- in agreement with KTeV results and theoretical predictions

- $K_S \rightarrow \pi^+ \pi^- e^+ e^-$

$$A_\phi^S = (-1.1 \pm 4.1) \% (\text{adding 98 data})$$

- consistent with 0

- main systematics sources as in BR



# Conclusions



# NA48: conclusions

- we observed for the first time the  $K_S \rightarrow \pi^0 \gamma \gamma$  decay

$$\text{BR}(K_S \rightarrow \pi^0 \gamma \gamma)|_{z>0.2} = (4.9 \pm 1.6_{\text{stat}} \pm 0.8_{\text{syst}}) \times 10^{-8}$$

- we performed a full study of  $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$  decay

Both the analysis are consistent with the predictions of the  $\chi PT$



# NA48: present (... and near future)

- 2002 data taking with a high intensity  $K_S$  beam
  - search for  $K_S \rightarrow \pi^0 e^+ e^-$  ... *almost ready*
  - study of  $\Xi^0$  semileptonic decays (BR and form factors)
- 2003 data taking with simultaneous  $K^+$  and  $K^-$  beams (*now*)
  - direct CP-violation in the asymmetry of Dalitz plots for 3 charged pions decays
  - scattering length  $a_0^0$  from  $K^\pm e_4$  decays
  - rare  $K^\pm$  decays

