

NA48 Results on K_L and K_S Rare Decays

On behalf of NA48 Collaboration

G. Ruggiero

University of Firenze and INFN

Pheno 2003, Madison

5 May 2003

Outline

➔ Introduction.

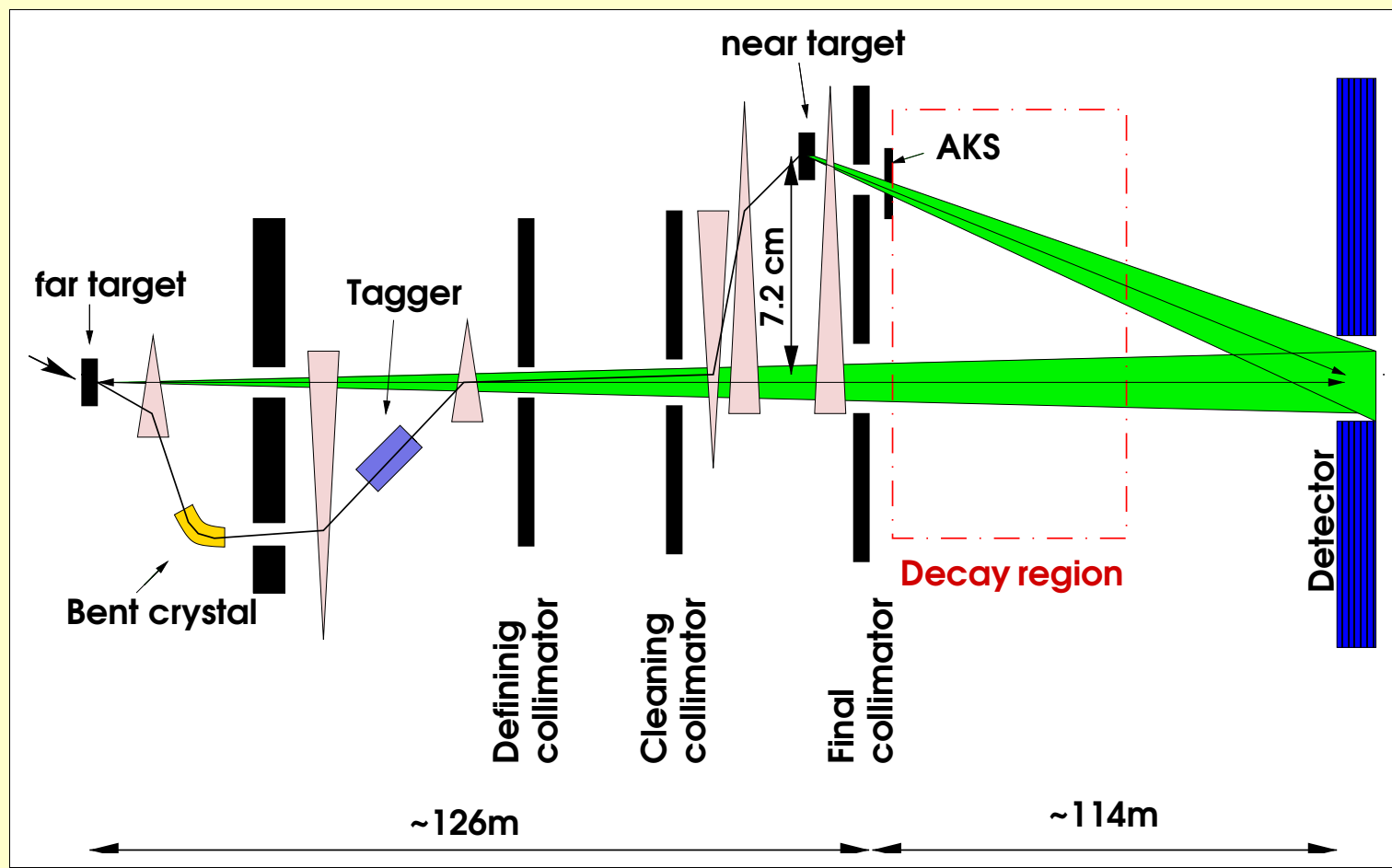
➔ Results on χ PT:

- $K_L \rightarrow \pi^0 \gamma \gamma$
- $K_S \rightarrow \pi^0 \gamma \gamma$
- $K_{L,S} \rightarrow \gamma \gamma$

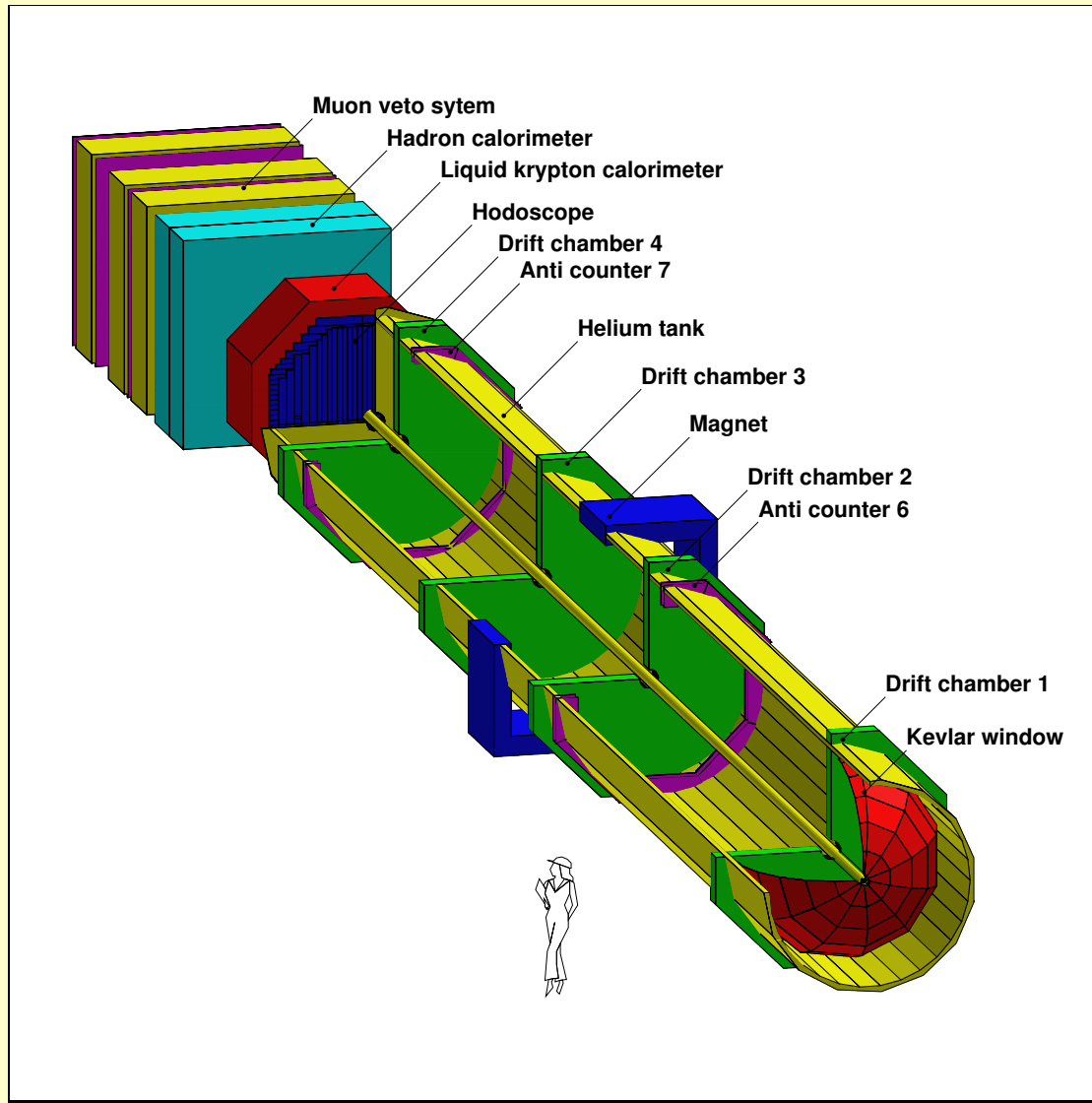
➔ Results on indirect CP-violation:

- $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$
- $K_L \rightarrow e^\pm \pi^\mp \nu_e$ not so rare...

Beam Line



Detector



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Overview of NA48 runs

1997
 $K_L + K_S$
 ϵ'/ϵ

1998
 $K_L + K_S$
 ϵ'/ϵ
 (K_L decays)

1999		
$K_L + K_S$	K_L	HI K_S
ϵ'/ϵ	K_{e3}	K_S decays
K_L decays	$K_{\mu3}$	

2000 (no spectrometer)		
K_L	η	HI K_S
ϵ'/ϵ checks	checks	K_S decays
K_L decays		

2001
 $K_L + K_S$
 ϵ'/ϵ
 ($K_{L,S}$ decays)

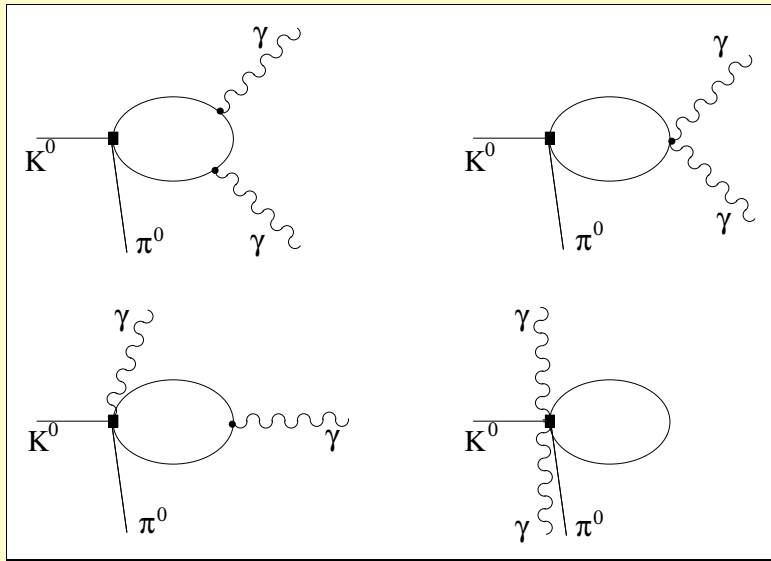
2002
 HI K_S
 K_S, Λ decays

$K_L \rightarrow \pi^0 \gamma \gamma$: Physics

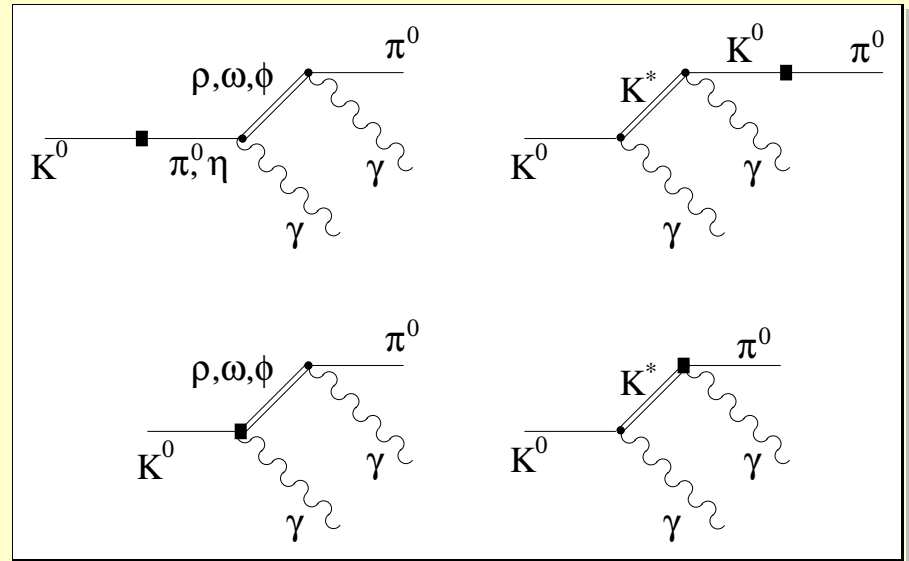
→ Decay amplitudes

- χ PT, $\mathcal{O}(p^4)$ prediction: $BR \sim 0.6 \cdot 10^{-6}$ ($\sim 1/3$ observed rate)
- $\mathcal{O}(p^6)$: rate and $m_{\gamma\gamma}$ spectrum well reproduced by VMD mechanism (a_v parameter).
- a_v allows *CPC* component of $K_L \rightarrow \pi^0 e^+ e^-$ to be predicted.

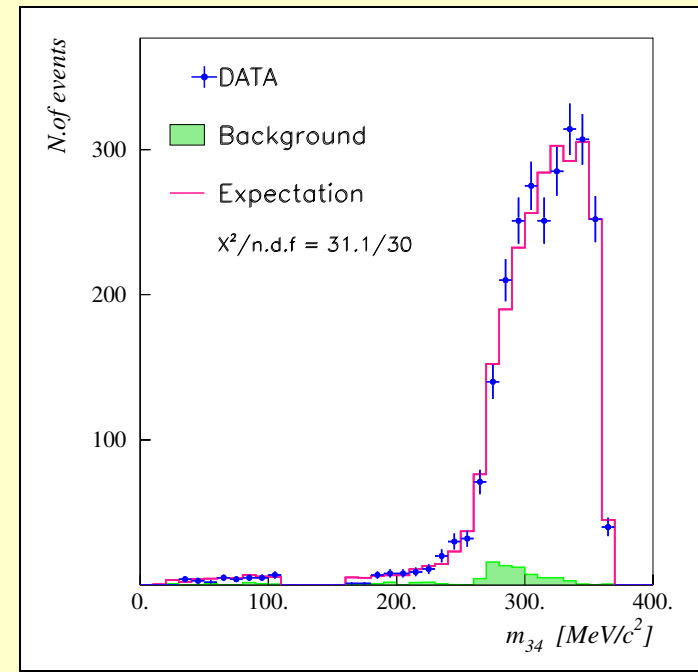
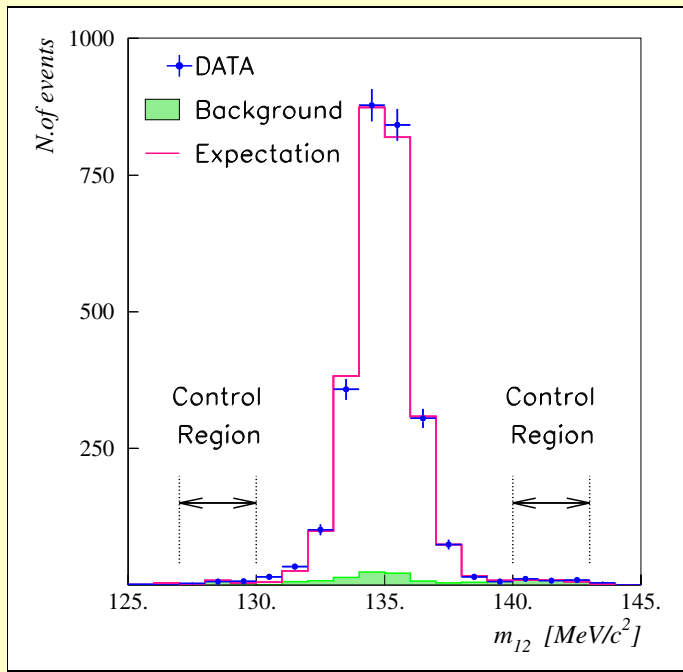
$\mathcal{O}(p^4)$



VMD



$K_L \rightarrow \pi^0 \gamma \gamma$: Analysis



➔ 1998-1999 Data.

➔ 2558 $K_L \rightarrow \pi^0 \gamma \gamma$ selected events ($132 < m_{1,2} < 138$ MeV/c²).

➔ Background:

- $K_L \rightarrow 2\pi^0$: $(0.16 \pm 0.08)\%$
- $K_L \rightarrow 3\pi^0$: $(2.74 \pm 0.42)\%$
- Pile-up: $(0.32 \pm 0.21)\%$

$K_L \rightarrow \pi^0 \gamma \gamma$: Results



$$a_v = -0.46 \pm 0.03_{stat} \pm 0.04_{syst}$$

- Main systematic sources:
 - Monte Carlo, Acceptance, Background.



$$BR(K_L \rightarrow \pi^0 \gamma \gamma) = (1.36 \pm 0.03_{stat} \pm 0.03_{syst} \pm 0.03_{norm}) \cdot 10^{-6}$$

- Normalization channel: $K_L \rightarrow \pi^0 \pi^0$
- Main systematic sources:
 - Acceptance, a_v .

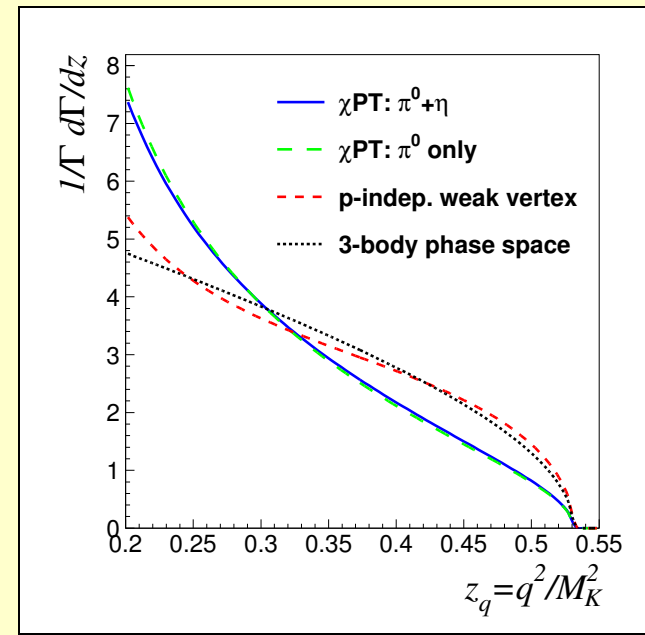


$$BR(K_L \rightarrow \pi^0 e^+ e^-)|_{CPC} = \left(4.7^{+2.2}_{-1.8}\right) \cdot 10^{-13}$$

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

→ χ PT prediction

- $BR(K_S \rightarrow \pi^0 \gamma \gamma)_{z_q > 0.2} = 3.8 \cdot 10^{-8}$
(Ecker, Pich, De Rafael 1987)
- Chiral structure of the weak vertex from $d\Gamma/dq^2$ distribution.



→ Measurement

- Data from 2000 near-target run.
- Background:
 - **Accidental**
 - $K_S \rightarrow \pi^0 \pi^0$
 - $\Xi^0 \rightarrow \Lambda \pi^0 \rightarrow n \pi^0 \pi^0$
 - $K_L \rightarrow \pi^0 \gamma \gamma$

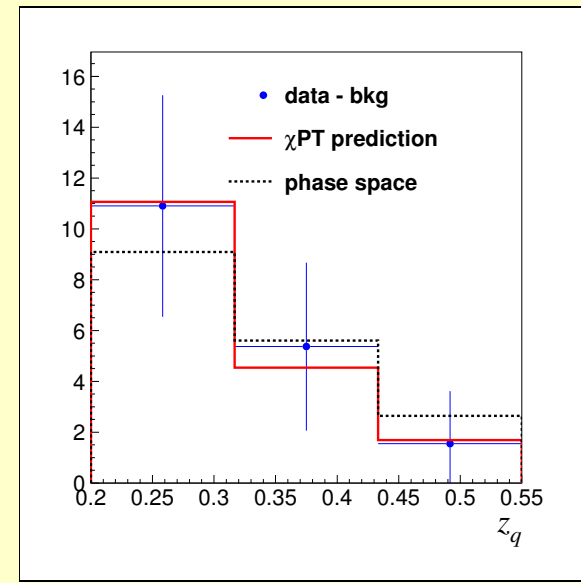
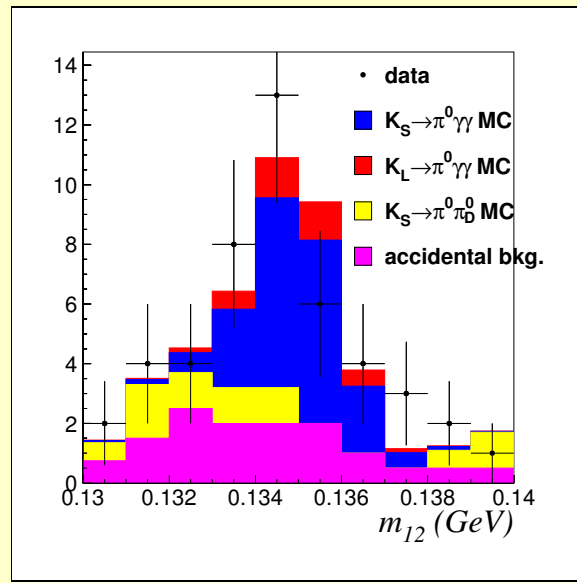
- Timing
- Kinematics
- Kinematics
- Irreducible

$K_S \rightarrow \pi^0 \gamma \gamma$: Result (Preliminary)

→ 31 signal candidates

→ Systematic Effects

Source	Events
Accidental	7.4 ± 2.4
$K_S \rightarrow \pi^0 \pi^0$	2.4 ± 1.2
$K_L \rightarrow \pi^0 \gamma \gamma$	3.8 ± 0.0
Acceptance	± 0.7



→ Result

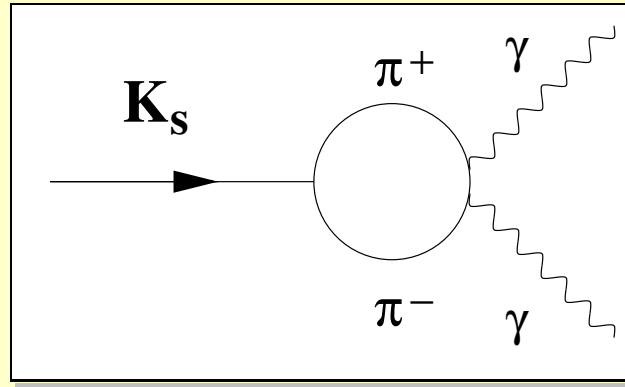
$$BR(K_S \rightarrow \pi^0 \gamma \gamma) = (4.9 \pm 1.6_{stat} \pm 0.8_{syst}) \cdot 10^{-8}$$

PRELIMINARY

$K_S \rightarrow \gamma\gamma$: Physics

→ Decay Amplitude

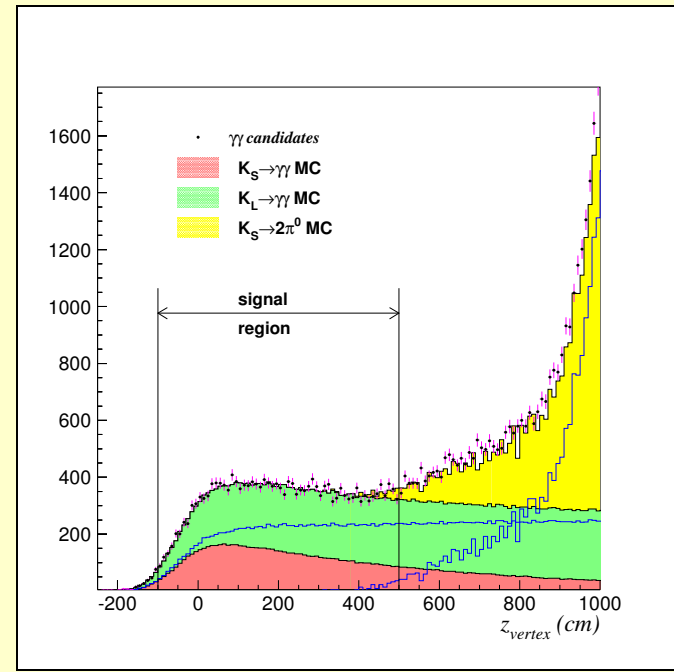
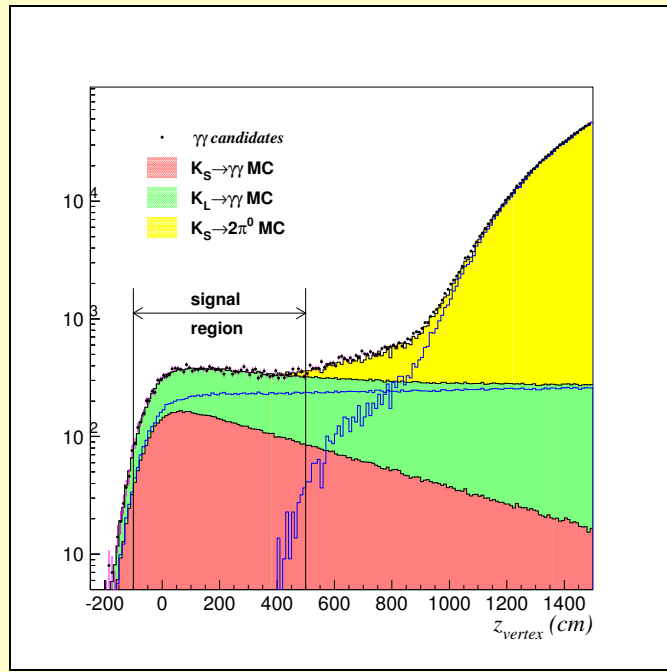
- χ PT $\mathcal{O}(p^4)$ prediction: $BR = 2.1 \cdot 10^{-6}$ (D'Ambrosio, Espriu, Goity)



→ Measurement

- Data from 2000 near-target run.
- Main background sources:
 - $K_S \rightarrow \pi^0 \pi^0$ → → → Cut on z vertex
 - $K_L \rightarrow \gamma\gamma$ → → → Irreducible
- Other backgrounds:
 - hadronic bckg., accidental $\gamma\gamma$ pairs ($2.1 \pm 0.7\%$)
 - residual $K_S \rightarrow \pi^0 \pi^0$ ($2.1 \pm 0.4\%$), Dalitz decays ($1.5 \pm 0.3\%$).

$K_S \rightarrow \gamma\gamma$: Analysis



➔ K_L flux from $K_L \rightarrow 3\pi^0$ (2000 far-target data):

$$\frac{\Gamma(K_L \rightarrow \gamma\gamma)}{\Gamma(K_L \rightarrow 3\pi^0)} = (2.81 \pm 0.01_{stat} \pm 0.02_{syst}) \cdot 10^{-3}$$

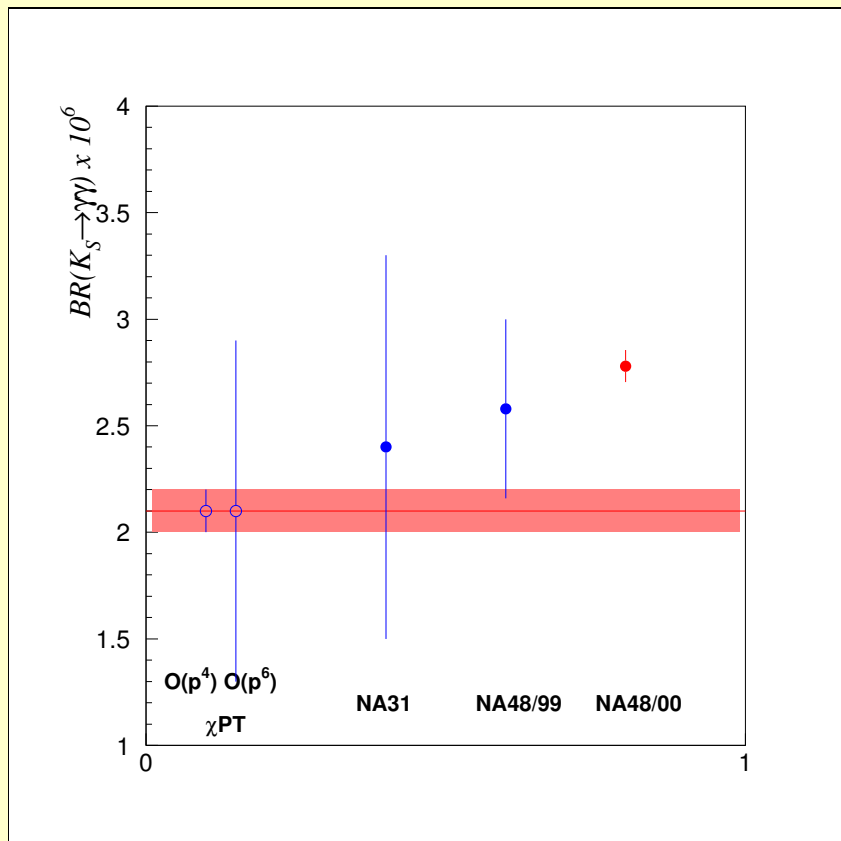
PDG: $(2.77 \pm 0.08) \cdot 10^{-3}$

➔ Normalization to $K_S \rightarrow \pi^0\pi^0$ decay rate

$K_S \rightarrow \gamma\gamma$: Result

➡ **7461 ± 172 signal candidates**

➡ $BR(K_S \rightarrow \gamma\gamma) = (2.78 \pm 0.06_{stat} \pm 0.03_{syst} \pm 0.02_{ext}) \cdot 10^{-6}$

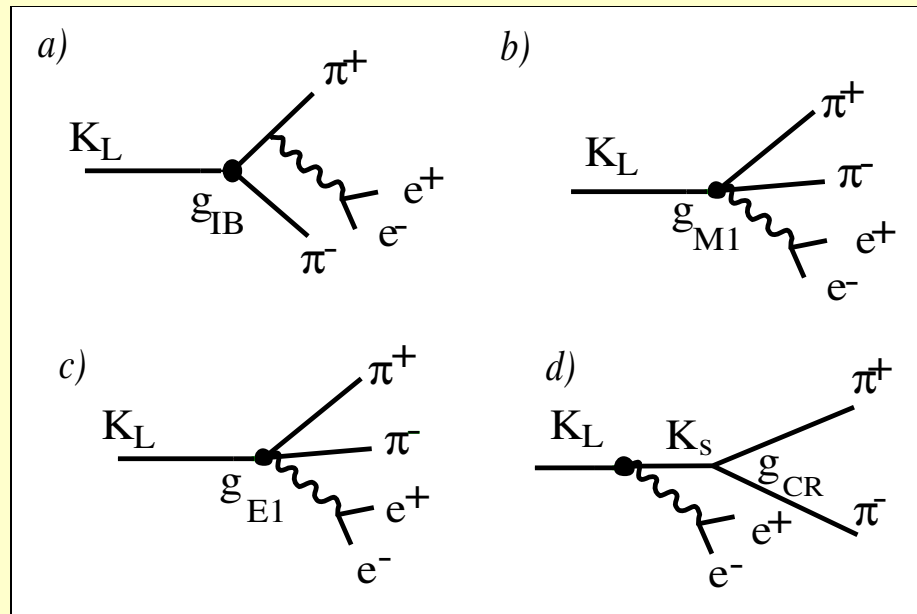


➡ 30% difference from $O(p^4)$ χPT prediction.

➡ Indication of a large $O(p^6)$ contribution.

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

→ K_L



- The M1-IB interference yields an asymmetric distribution of the azimuthal angle between the CM $\pi^+ \pi^-$ and $e^+ e^-$ decay planes
- **Prediction:** $A(\phi) \simeq 14\%$ (Indirect CP violation).

→ K_S

- Only IB contribution (No asymmetry).

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



1998-1999 Data.



Signature: **4 Tracks**



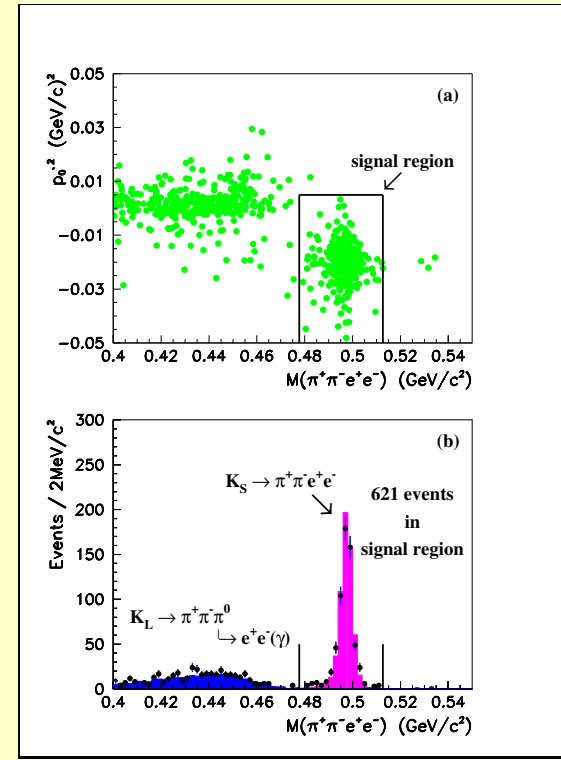
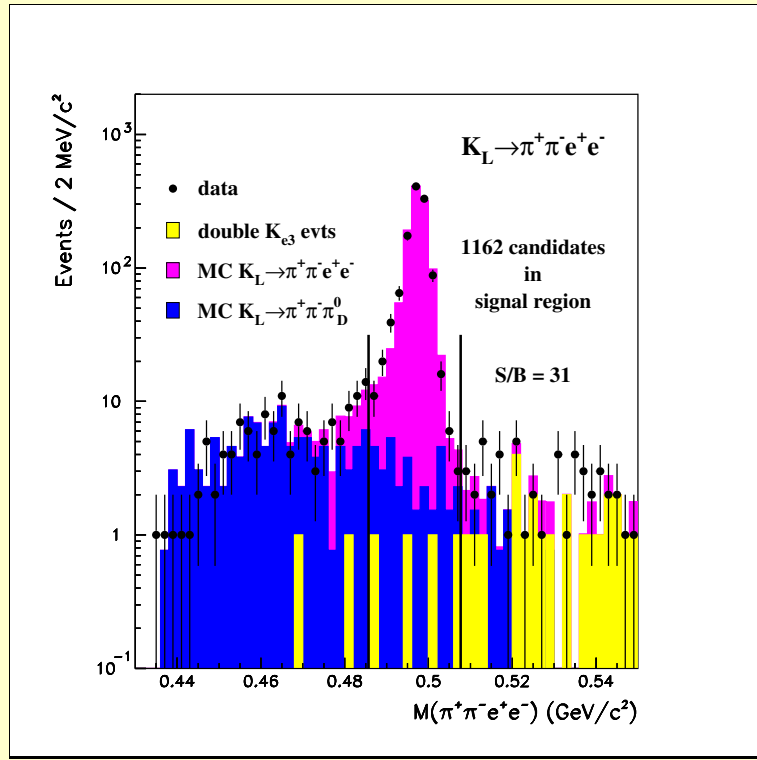
Selected Events: K_L : 1162

K_S : 621



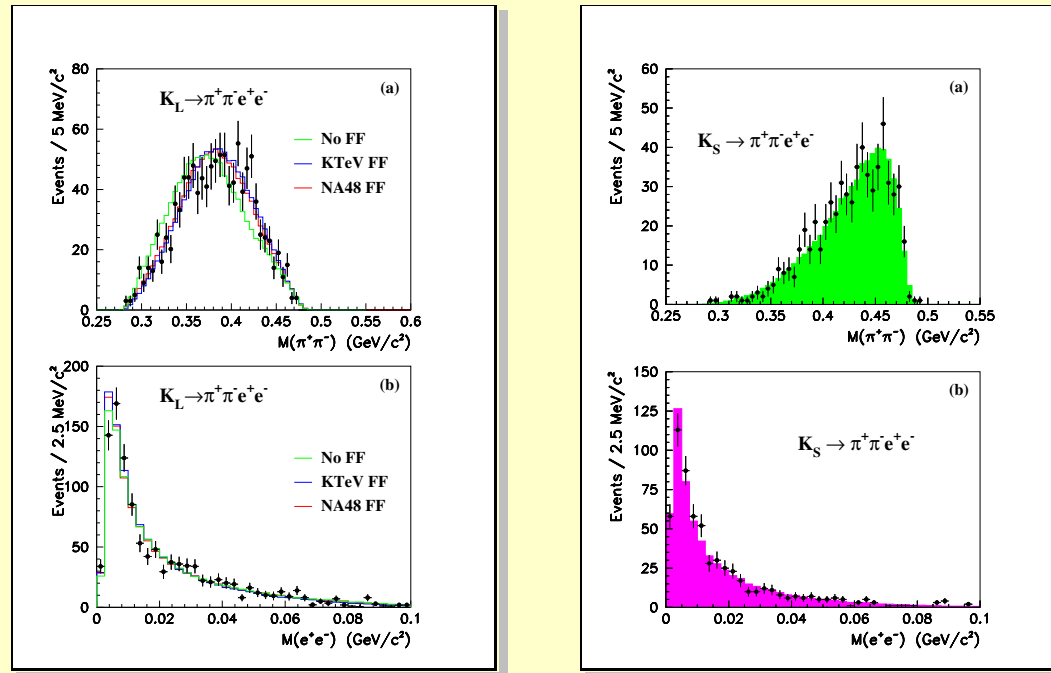
Background: K_L : $(3.2 \pm 0.5)\%$

K_S : $(0.1 \pm 0.2)\%$



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

- Normalization channel $K_L \rightarrow \pi^+ \pi^- \pi_D^0$.
- Acceptance by Monte Carlo. M1 coupling form factors of K_L decay measured from data.

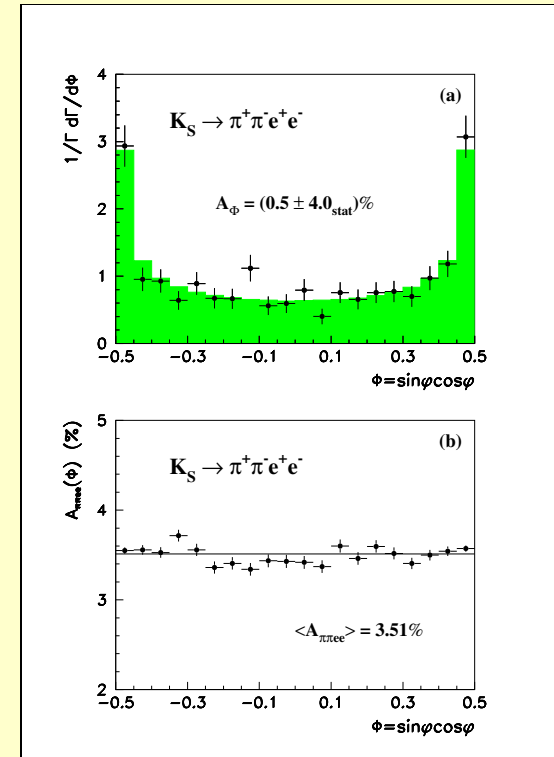
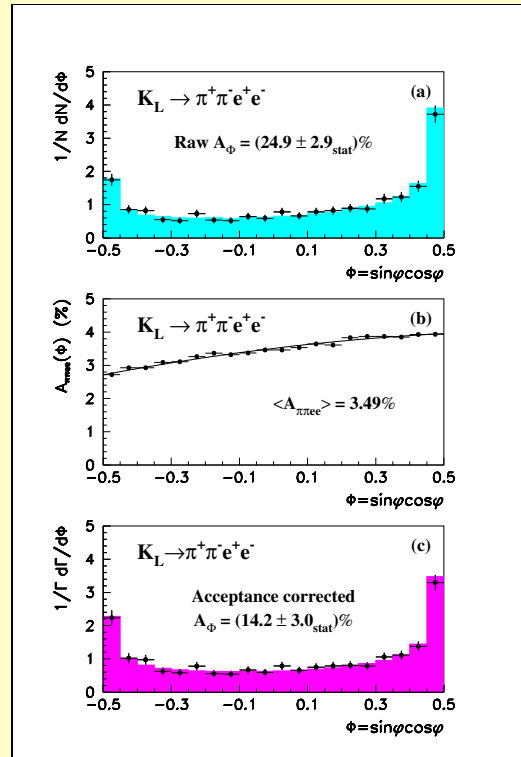


$$BR(K_L \rightarrow \pi^+ \pi^- e^+ e^-) = (3.08 \pm 0.09_{stat} \pm 0.15_{syst} \pm 0.10_{norm}) \cdot 10^{-7}$$



$$BR(K_S \rightarrow \pi^+ \pi^- e^+ e^-) = (4.71 \pm 0.23_{stat} \pm 0.16_{syst} \pm 0.15_{norm}) \cdot 10^{-5}$$

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



$$K_L : A_\phi = (14.2 \pm 3.0_{stat} \pm 1.9_{syst})\%$$

$$A_\phi^{raw} = (24.9 \pm 2.9_{stat})\%$$



$$K_S : A_\phi = (0.5 \pm 4.0_{stat} \pm 1.6_{syst})\%$$

$$K_L \rightarrow e^\pm \pi^\mp \nu_e$$



$$\delta_e \equiv \frac{BR(K_L \rightarrow e^+ \pi^- \bar{\nu}_e) - BR(K_L \rightarrow e^- \pi^+ \nu_e)}{BR(K_L \rightarrow e^+ \pi^- \bar{\nu}_e) + BR(K_L \rightarrow e^- \pi^+ \nu_e)} = \frac{2\Re(\epsilon)}{1 + |\epsilon|^2}$$

- CPT invariance.
- $\Delta S = \Delta Q$.



Measurement:

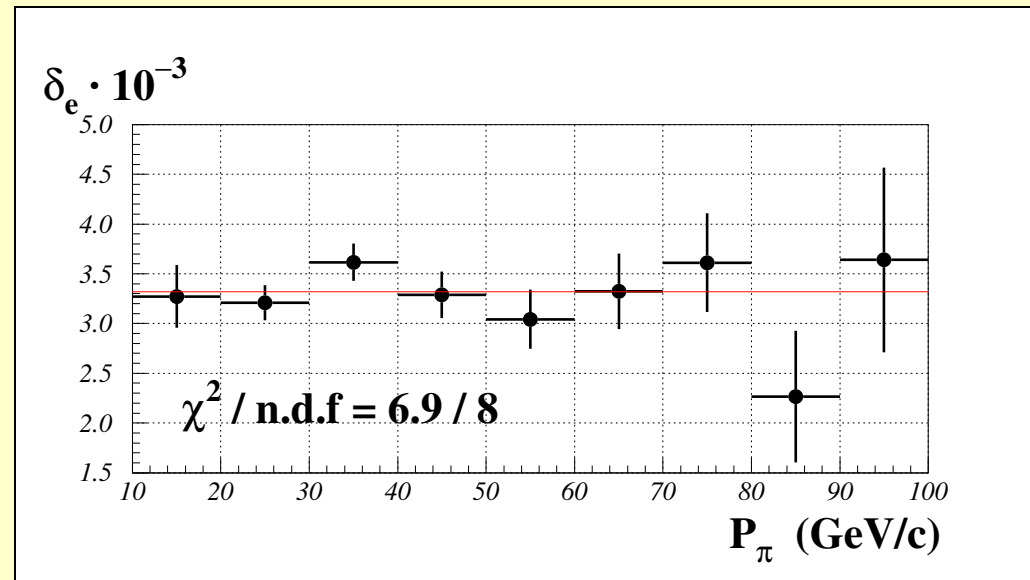
- 2001 Data.
- $\delta_e = \frac{N(K_{e3}^+) - N(K_{e3}^-)}{N(K_{e3}^+) + N(K_{e3}^-)}$.
- $e - \pi$ identification by $E(LKr)/p$.
- Selected Events $\sim 2.1 \cdot 10^8$ ($\sim 10^8$ per B orientation mode).
- Statistical Error $\sim 7 \cdot 10^{-5}$.

$K_L \rightarrow e^\pm \pi^\mp \nu_e$: Analysis (Preliminary)

→ Systematic Effects

- Fake asymmetry from particle interactions
- Data control samples:
 - $K_L \rightarrow \pi^+ \pi^- \pi^0$
 - $K_S \rightarrow \pi^+ \pi^-$
- Corrections track momentum dependent

Source	(10^{-5})
Trigger	$+25.7 \pm 5.8$
Pion ID	-16.7 ± 2.4
Punch-through	-1.9 ± 2.3
Acceptance	± 2.0
$K_L - K_S$ int	± 0.4
Accidentals	± 0.4
Background	± 0.3



$K_L \rightarrow e^\pm \pi^\mp \nu_e$: Result (Preliminary)

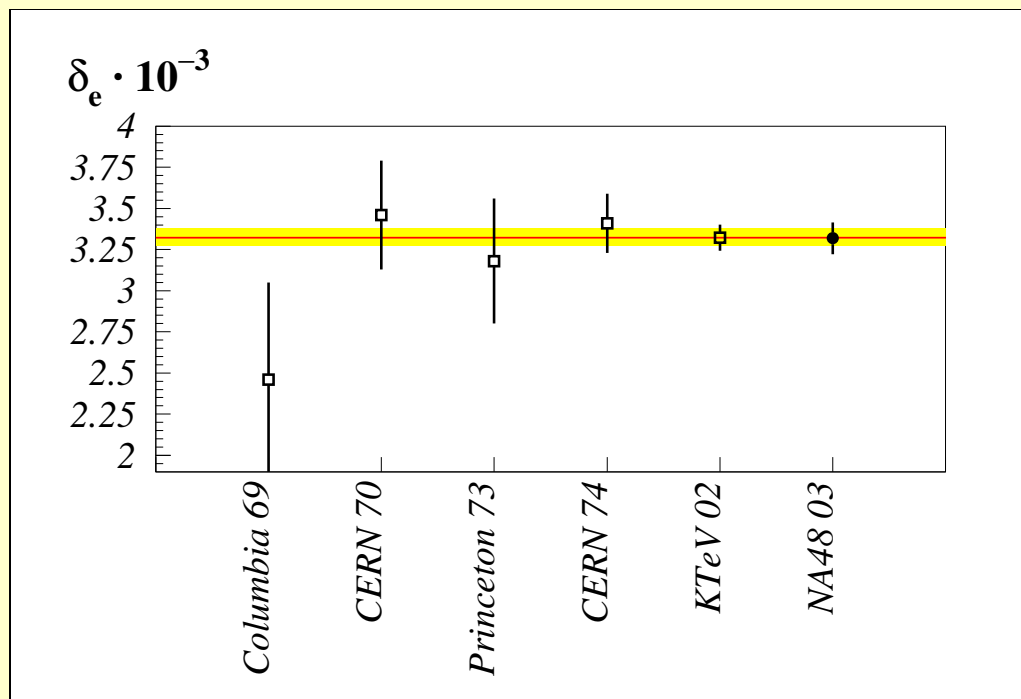


$$\delta_e = (3.319 \pm 0.070_{stat} \pm 0.068_{syst}) \cdot 10^{-3}$$

- Average over magnetic field orientations (l-r fake asymmetry suppressed).



World average:



$$\delta_e = (3.323 \pm 0.055) \cdot 10^{-3}$$

Conclusions

→ $K_L \rightarrow \pi^0 \gamma \gamma$ Phys.Lett. B 536 (2002) 229-240

- $a_\nu = -0.46$.
- Negligible CPC contribution to $K_L \rightarrow \pi^0 e^+ e^-$.

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

- First measurement of Branching Ratio.

→ $K_{L,S} \rightarrow \gamma \gamma$ Phys.Lett. B 551 (2003) 7

- Precise measurement of the $\Gamma(K_L \rightarrow \gamma \gamma) / \Gamma(K_L \rightarrow 3\pi^0)$.
- Large $\mathcal{O}(p^6)$ contribution to $BR(K_S \rightarrow \gamma \gamma)$.

→ $K_{L,S} \rightarrow \pi^+ \pi^- e^+ e^-$ submitted to CERN preprint

- CPV evidence in K_L decay.
- First measurement of the K_S Branching Ratio.

→ $K_L \rightarrow e^\pm \pi^\mp \nu$ Preliminary

- Competitive charge asymmetry measurement.