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

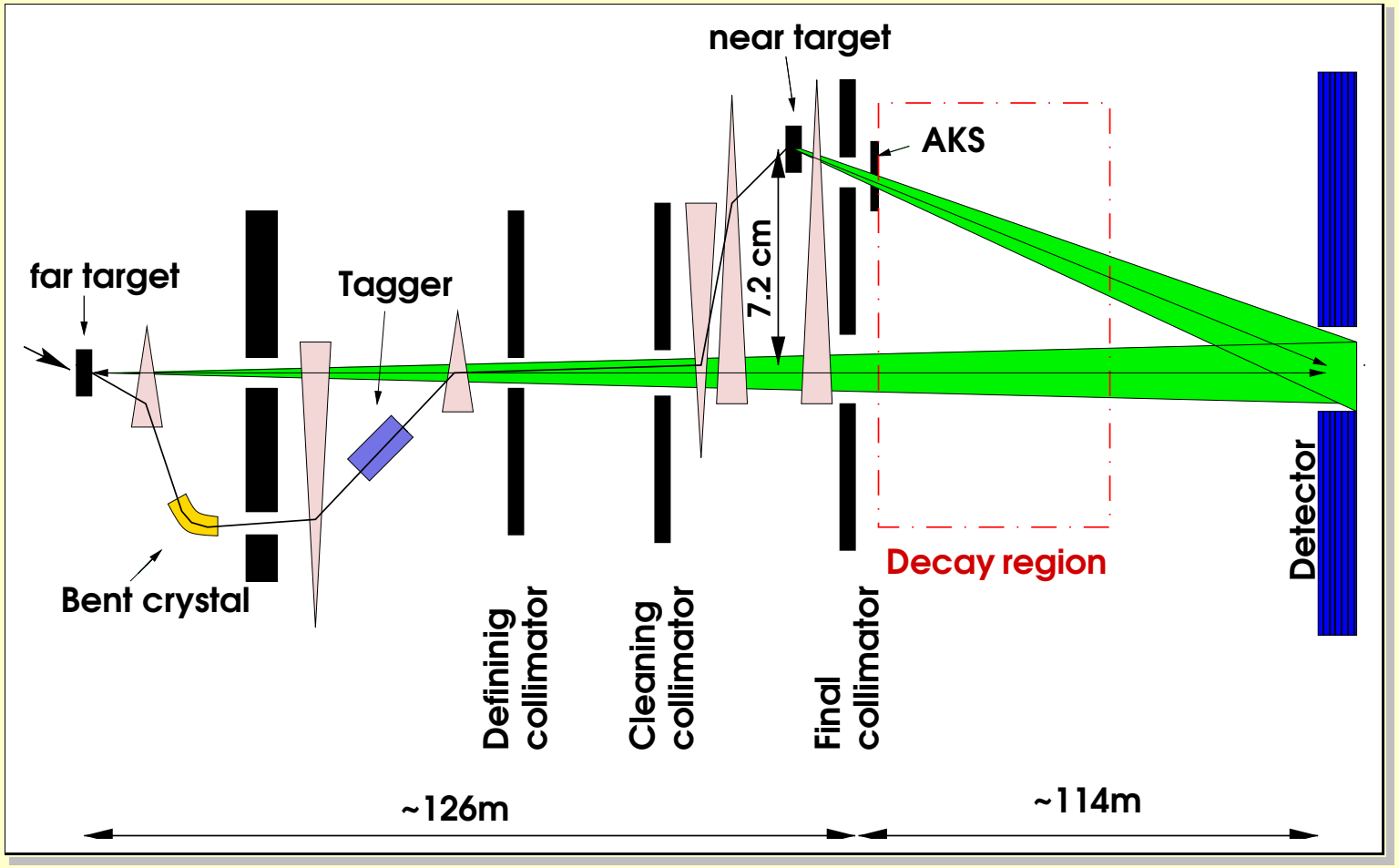
Outline

- Introduction.

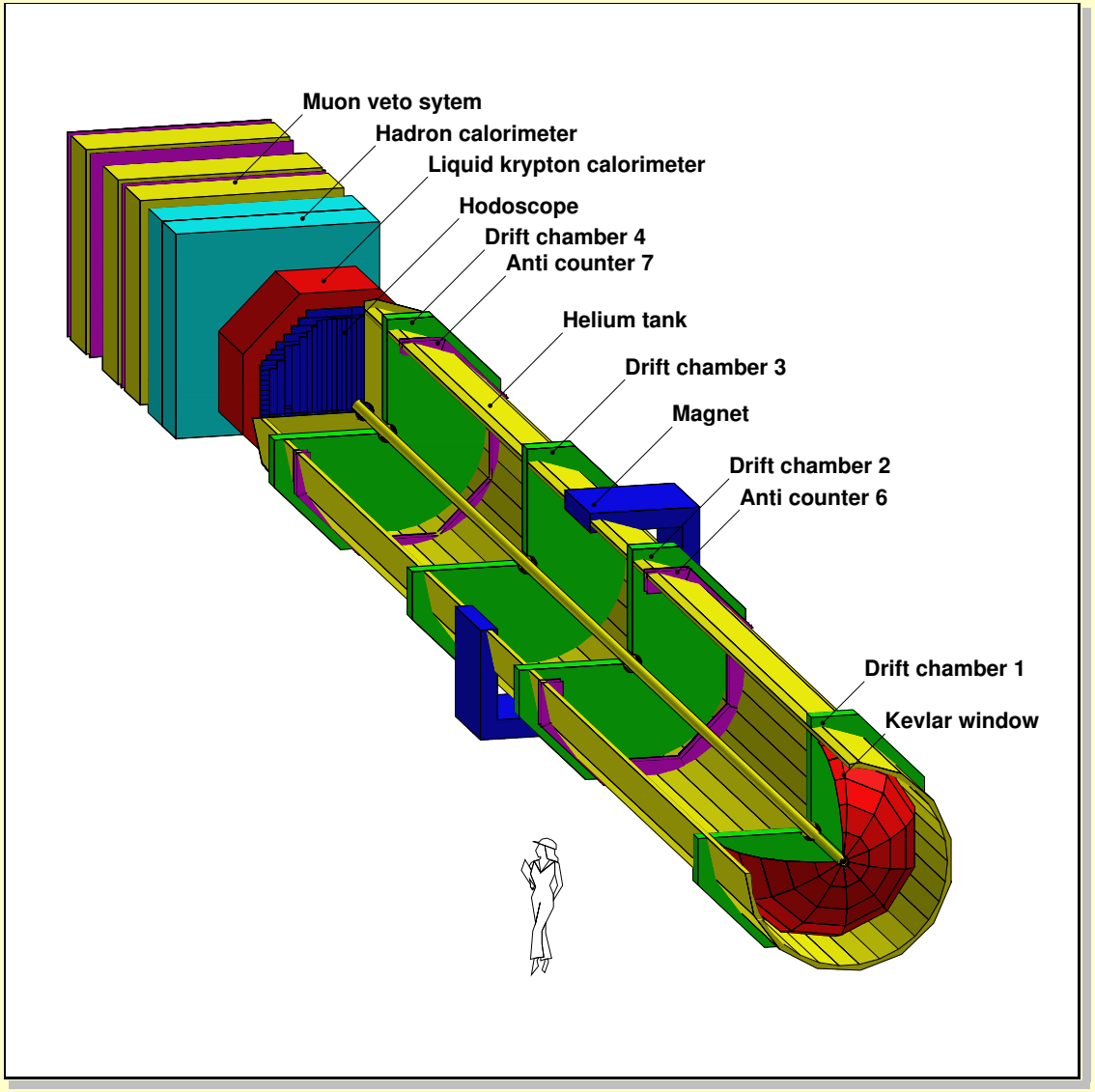
- Results on χPT:
  - $K_L \to \pi^0\gamma\gamma$
  - $K_S \to \pi^0\gamma\gamma$
  - $K_{L,S} \to \gamma\gamma$

- Results on indirect CP-violation:
  - $K_{L,S} \to \pi^+\pi^- e^+ e^-$
  - $K_L \to e^\pm\pi^\mp\nu_e$ not so rare...

Beam Line


near target
AKS
7.2 cm
far target
Tagger
Bent crystal
Definig collimator
Cleaning collimator
Final collimator
Decay region
Detector
~126m
~114m

Detector


Muon veto sytem
Hadron calorimeter
Liquid krypton calorimeter
Hodoscope
Drift chamber 4
Anti counter 7
Helium tank
Drift chamber 3
Magnet
Drift chamber 2
Anti counter 6
Drift chamber 1
Kevlar window

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	$K_{\mu 3}$	

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)

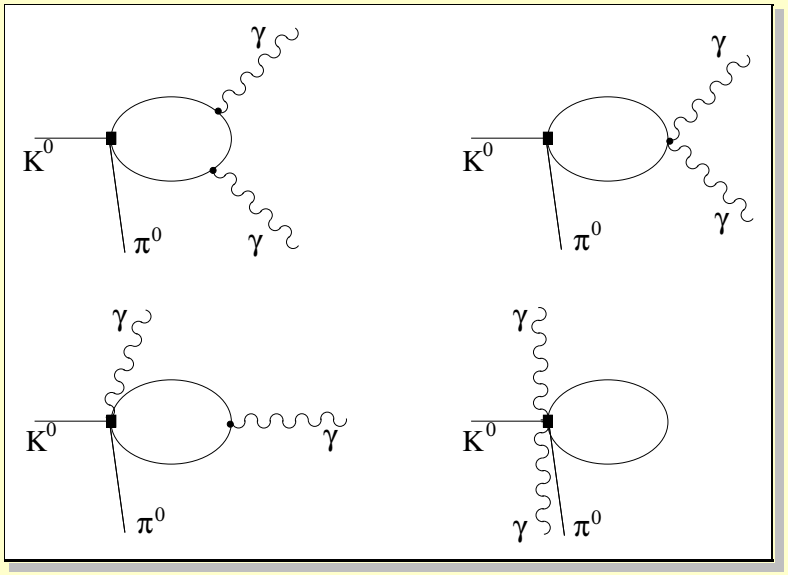
2002
HI K_S
K_S, Λ decays

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

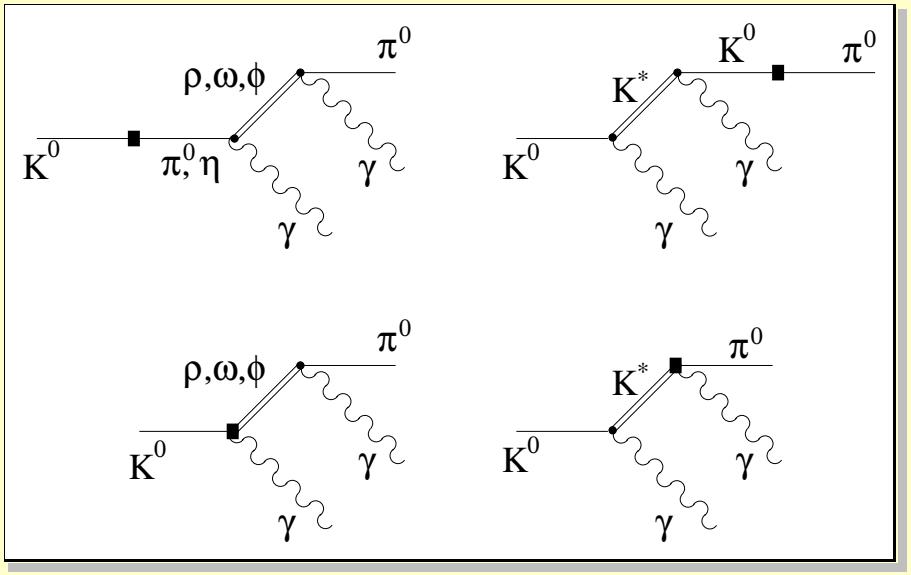
Decay amplitudes

- χPT, $\mathcal{O}(p^4)$ 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 $\boldsymbol{K_L \to \pi^0 e^+ e^-}$ to be predicted.

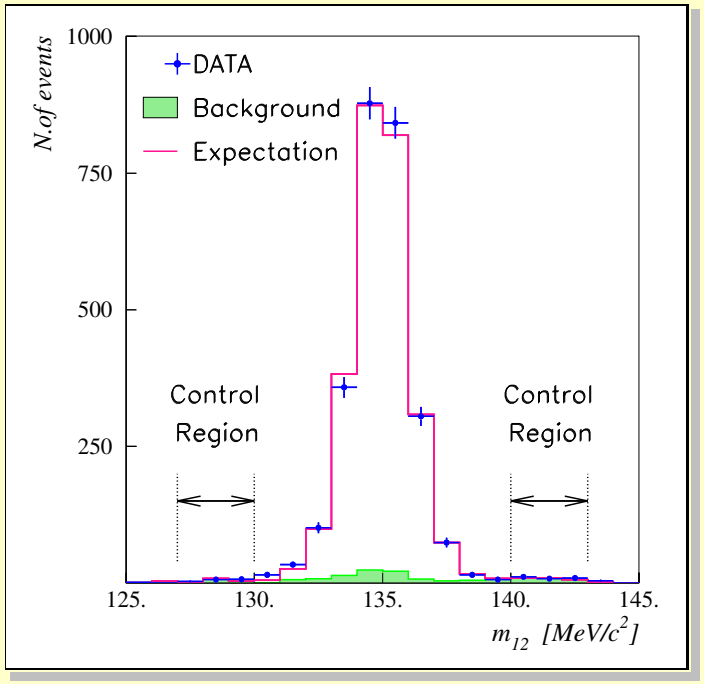
$\mathcal{O}(p^4)$

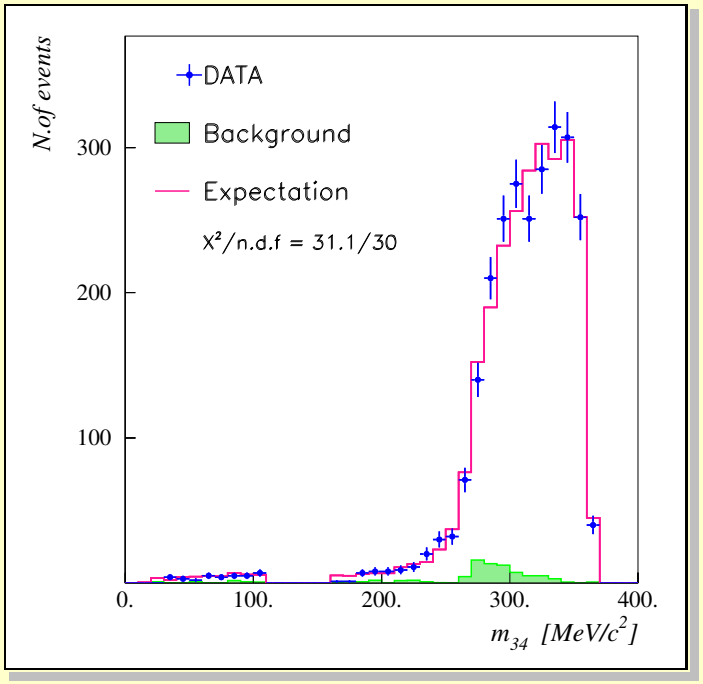


VMD



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





- 1998-1999 Data.
- **2558 $K_L \to \pi^0\gamma\gamma$** selected events $(132 < m_{1,2} < 138$ MeV/c$^2)$.
- Background:
  - $K_L \to 2\pi^0$: $(0.16 \pm 0.08)\%$
  - $K_L \to 3\pi^0$: $(2.74 \pm 0.42)\%$
  - **Pile-up**: $(0.32 \pm 0.21)\%$

G. Ruggiero
University of Firenze and INFN

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

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

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

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

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

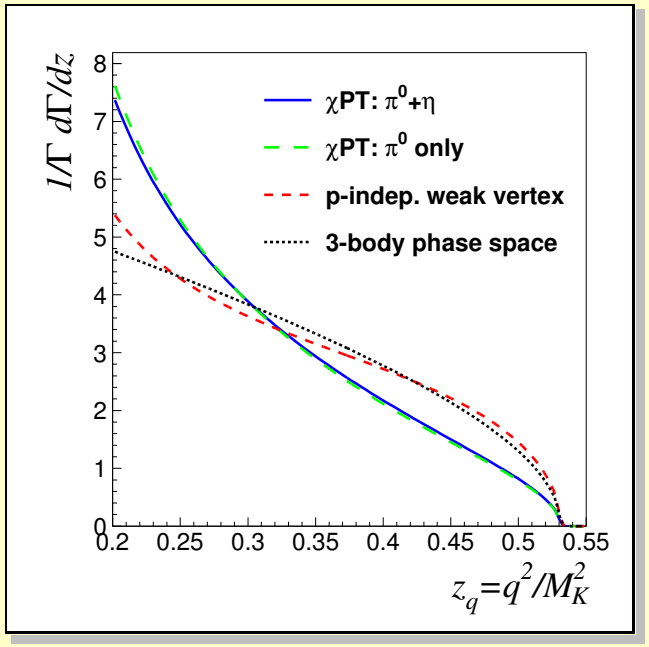
$$BR(K_L \to \pi^0 e^+ e^-)|_{CPC} = \left(4.7^{+2.2}_{-1.8}\right) \cdot 10^{-13}$$

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

χPT prediction

- $BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} = 3.8 \cdot 10^{-8}$
  (Ecker, Pich, De Rafael 1987)

- Chiral structure of the weak vertex from $d\Gamma/dq^2$ distribution.



Measurement

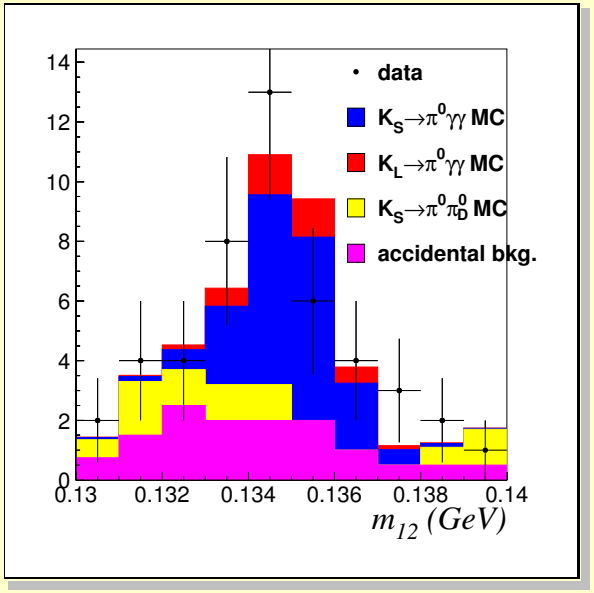
- Data from 2000 near-target run.
- Background:
  - **Accidental** → Timing
  - $K_S \to \pi^0\pi^0$ → Kinematics
  - $\Xi^0 \to \Lambda\pi^0 \to n\pi^0\pi^0$ → Kinematics
  - $K_L \to \pi^0\gamma\gamma$ → Irreducible

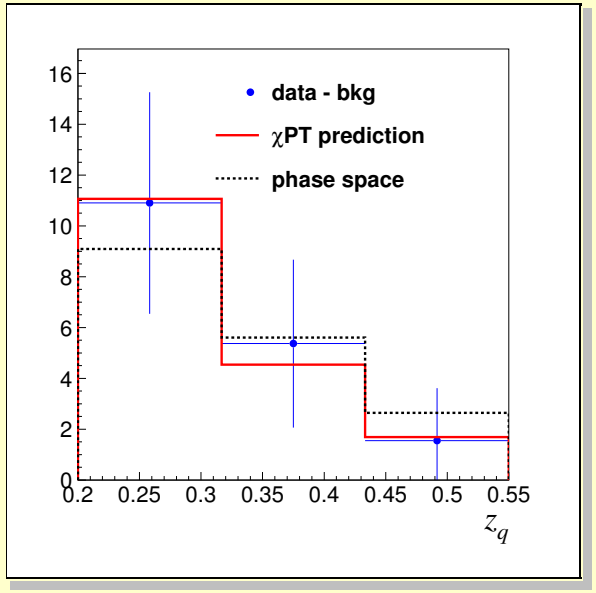
$K_S \to \pi^0\gamma\gamma$: Result (Preliminary)

31 signal candidates

Systematic Effects

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





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

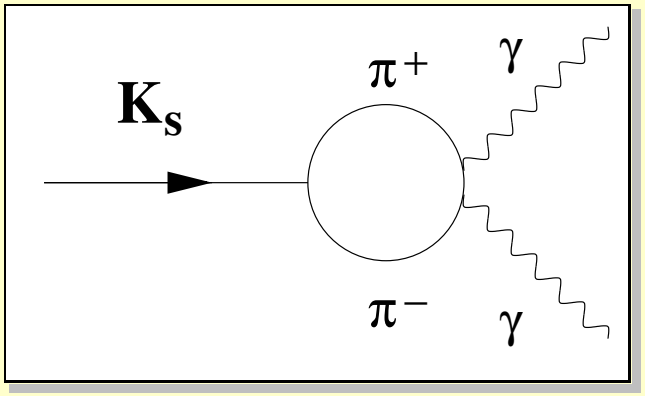
PRELIMINARY

G. Ruggiero
University of Firenze and INFN

$K_S \to \gamma\gamma$: Physics

Decay Amplitude

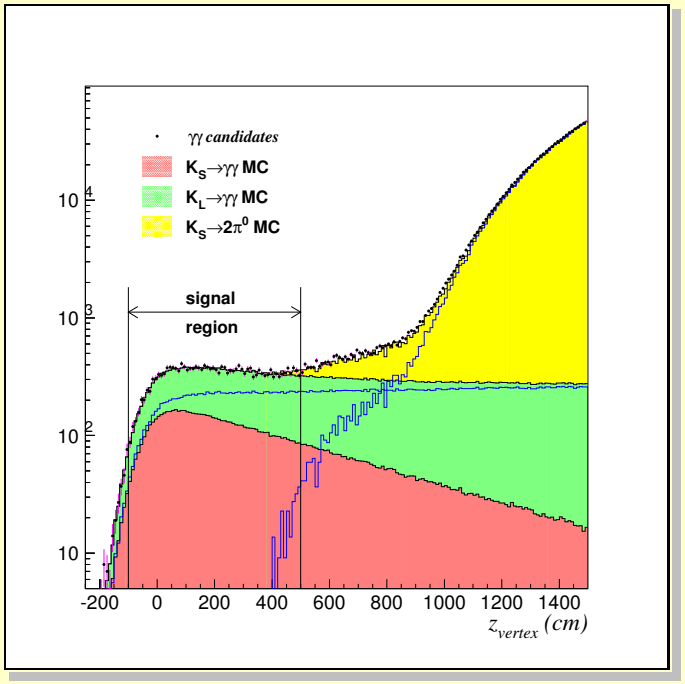
- χPT $\mathcal{O}(p^4)$ prediction: $BR = 2.1 \cdot 10^{-6}$ (D'Ambrosio, Espriu, Goity)

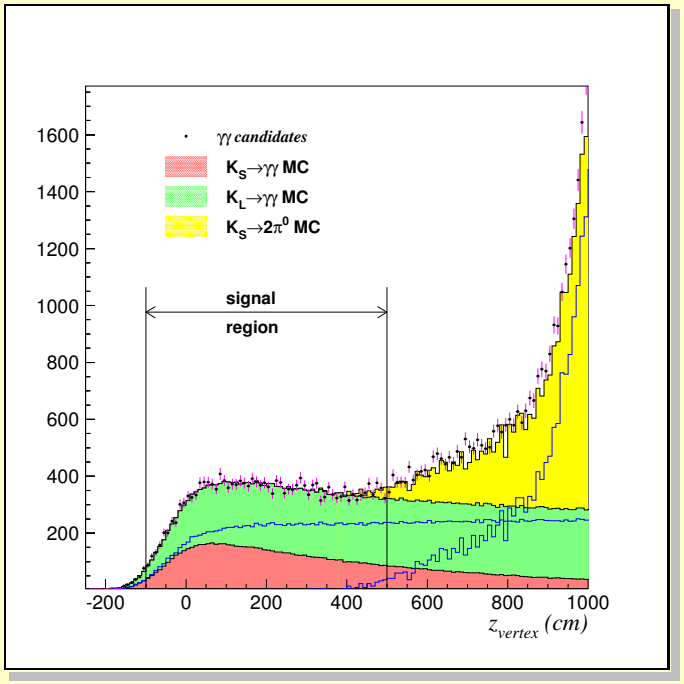


Measurement

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

$K_S \to \gamma\gamma$: Analysis





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

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

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

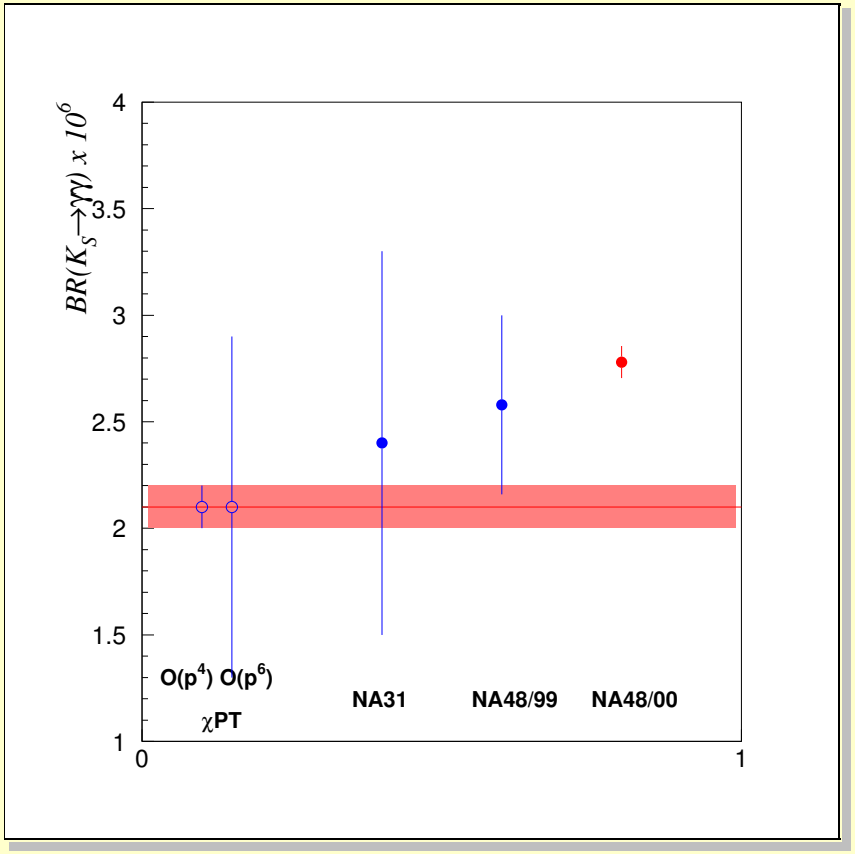
➡ Normalization to $K_S \to \pi^0\pi^0$ decay rate

G. Ruggiero
University of Firenze and INFN

$K_S \to \gamma\gamma$: Result

7461±172 signal candidates

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



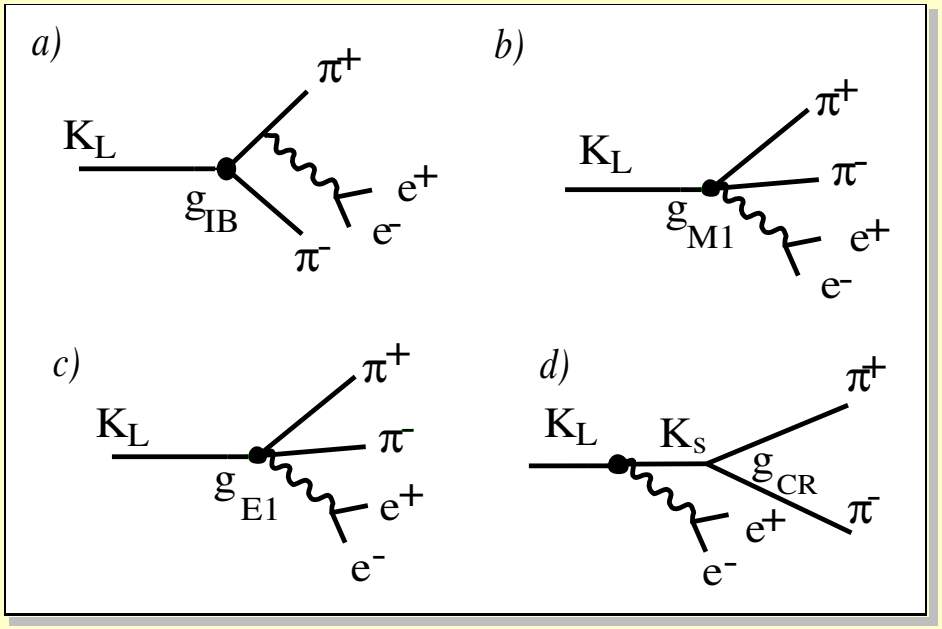
30% difference from $\mathcal{O}(p^4)$ χPT prediction.

Indication of a large $\mathcal{O}(p^6)$ contribution.

G. Ruggiero
University of Firenze and INFN

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

K_L



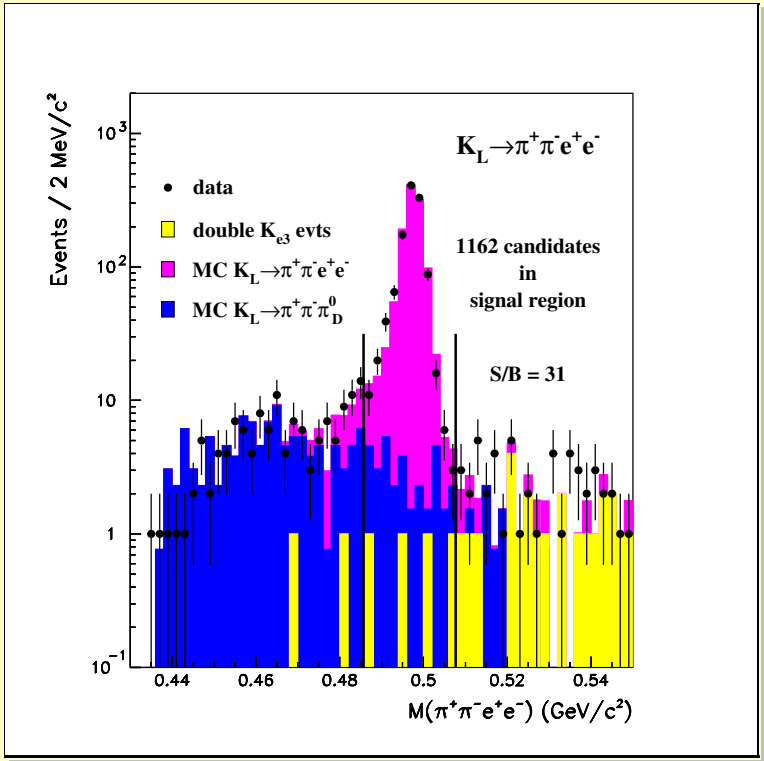
- The M1-IB interference yields an asymmetric distribution of the azimuthal angle between the CM $\pi^+\pi^-$ and e^+e^- decay planes
- **Prediction:** $A(\phi) \simeq 14\%$ (Indirect CP violation).

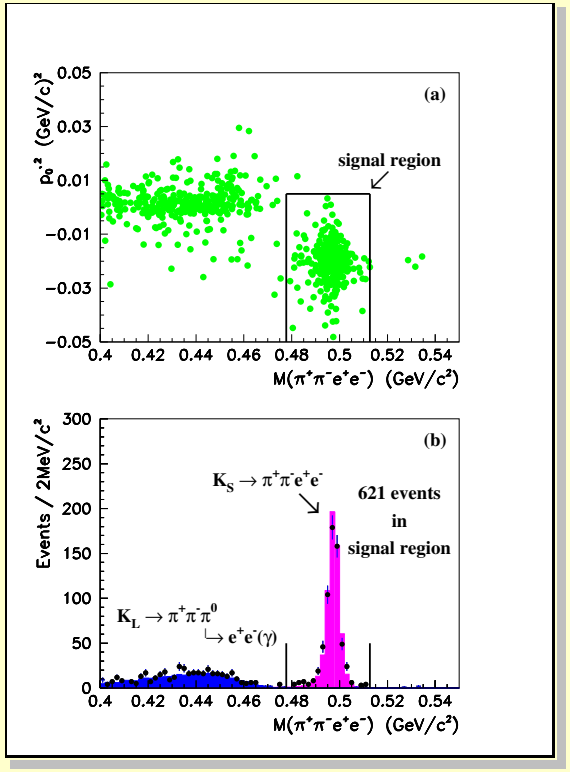
K_S

- Only IB contribution (No asymmetry).

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

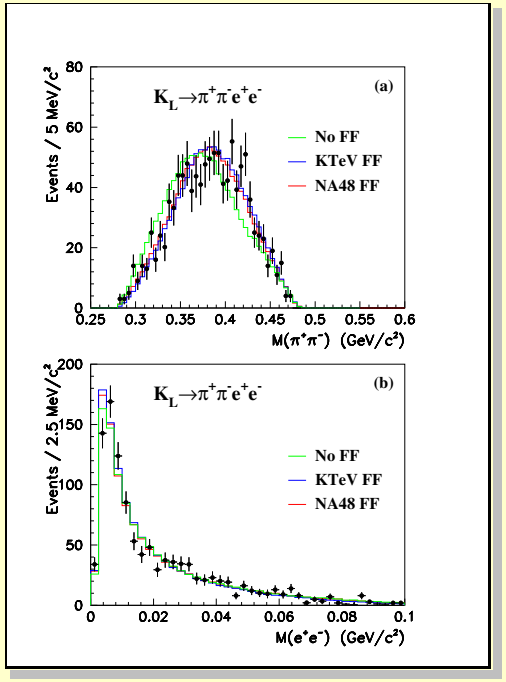
- 1998-1999 Data.
- Signature: **4 Tracks**
- Selected Events: $K_L : 1162$ $K_S : 621$
- Background: $K_L : (3.2 \pm 0.5)\%$ $K_S : (0.1 \pm 0.2)\%$

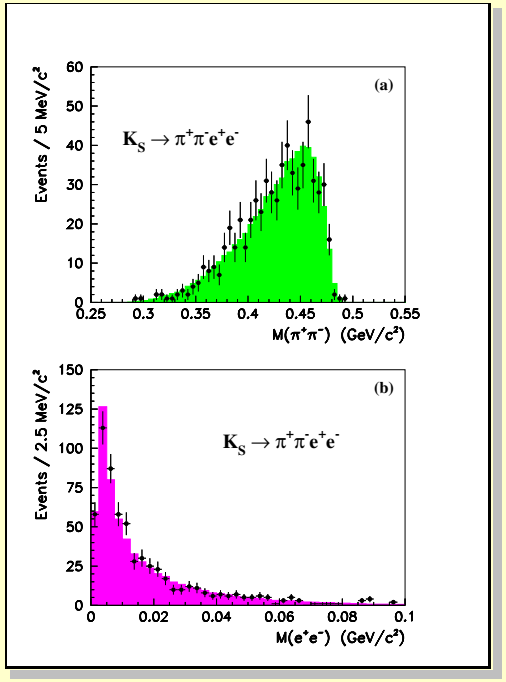




$K_{S,L} \to \pi^+\pi^-e^+e^-$: Branching Ratio

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



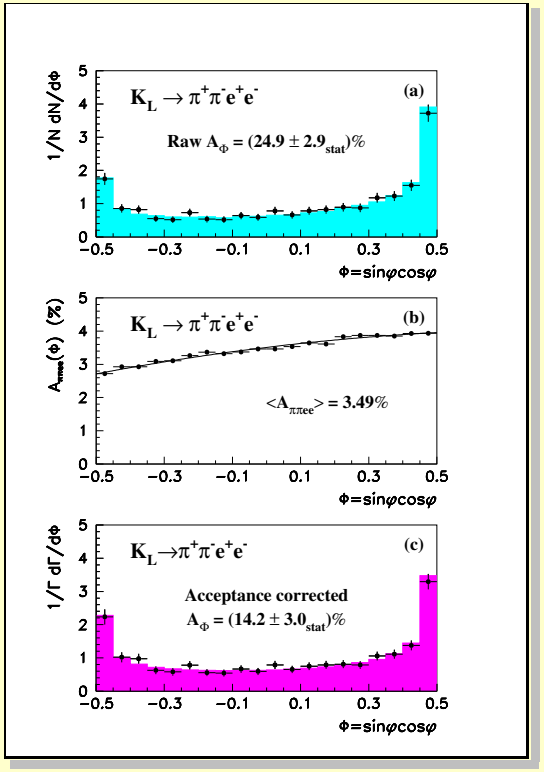


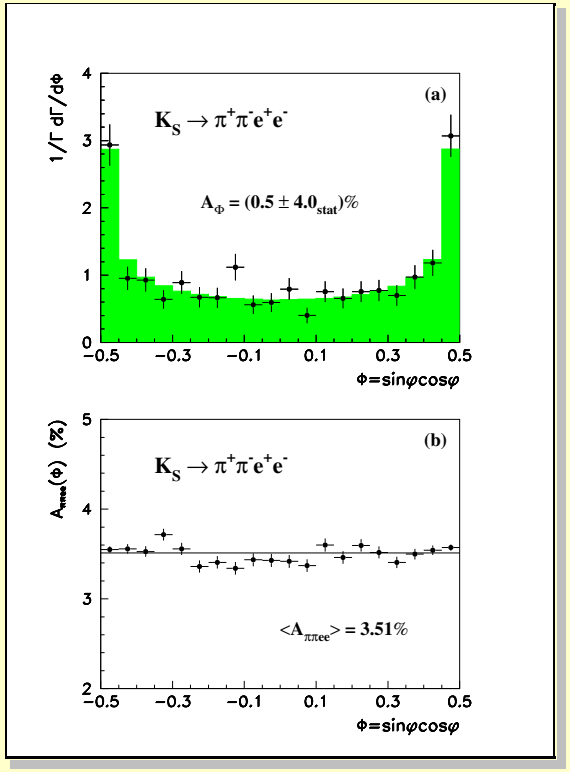
$$BR(K_L \to \pi^+\pi^-e^+e^-) = (3.08 \pm 0.09_{stat} \pm 0.15_{syst} \pm 0.10_{norm}) \cdot 10^{-7}$$

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

G. Ruggiero
University of Firenze and INFN

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





$$K_L: \quad A_\phi = (14.2 \pm 3.0_{stat} \pm 1.9_{syst})\% \qquad A_\phi^{raw} = (24.9 \pm 2.9_{stat})\%$$

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

G. Ruggiero
University of Firenze and INFN

$K_L \to e^{\pm}\pi^{\mp}\nu_e$

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

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

Measurement:

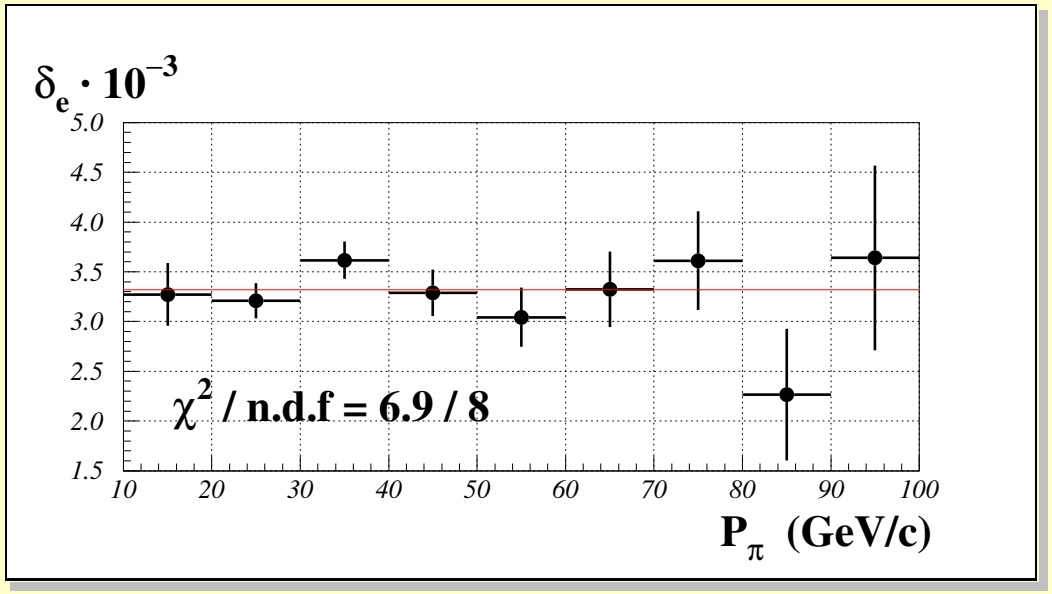
- 2001 Data.
- $\delta_e = \frac{N(K^+_{e3}) - N(K^-_{e3})}{N(K^+_{e3}) + N(K^-_{e3})}$.
- $e - \pi$ identification by $E(LKr)/p$.
- Selected Events $\sim \mathbf{2.1 \cdot 10^8}$ ($\sim 10^8$ per B orientation mode).
- Statistical Error $\sim \mathbf{7 \cdot 10^{-5}}$.

$K_L \to e^{\pm}\pi^{\mp}\nu_e$: Analysis (Preliminary)

Systematic Effects

- Fake asymmetry from particle interactions
- Data control samples:
  - $K_L \to \pi^+\pi^-\pi^0$
  - $K_S \to \pi^+\pi^-$
- 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



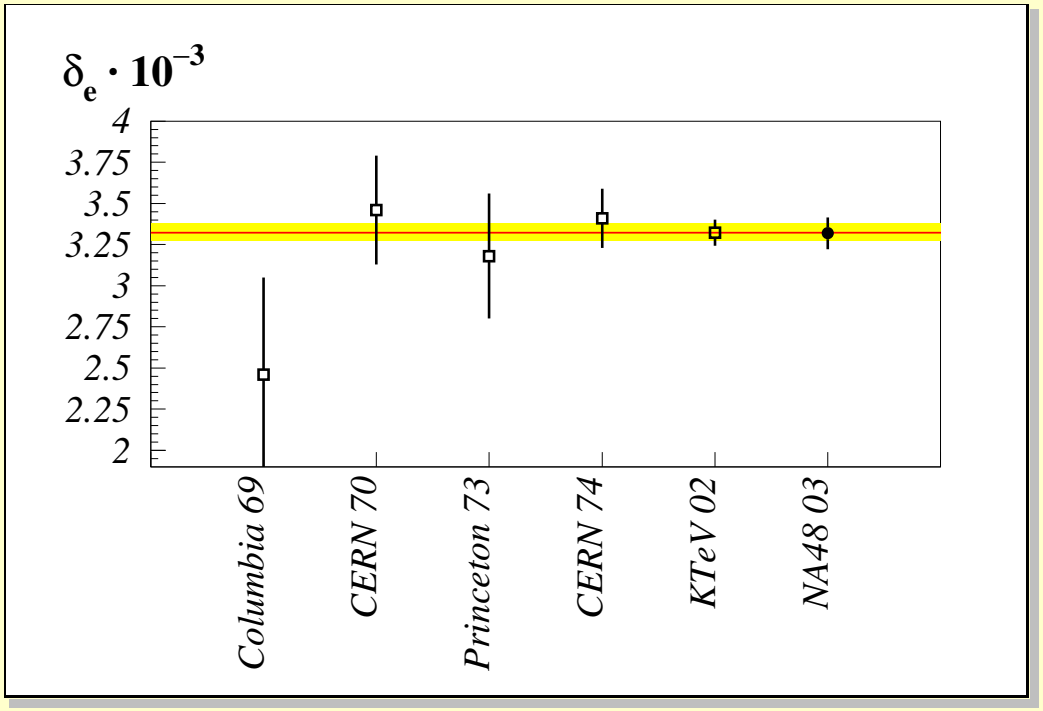
$K_L \to e^{\pm}\pi^{\mp}\nu_e$: Result (Preliminary)

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

PRELIMINARY

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

World average:



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

G. Ruggiero
University of Firenze and INFN

Conclusions

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

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

$K_S \to \pi^0\gamma\gamma$ Preliminary

- First measurement of Branching Ratio.

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

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

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

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

$K_L \to e^\pm \pi^\mp \nu$ Preliminary

- Competitive charge asymmetry measurement.