

# Other Recent Kaon Decays Results

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# Plan of the talk

“Other” 

No  $V_{us}$ , no rares

“Recent” 

Nothing prior 2003

- $K_S$  decays:

$$K_S \rightarrow 3\pi^0$$

$$K_S \rightarrow \pi e \nu$$

} *CP, CPT tests*

- $K^\pm$  decays:

$$K^\pm \rightarrow 3\pi$$

$$K^\pm \rightarrow 2\pi e \nu$$

} *CP, ChPT tests*

- *A glance at the future*

Excluding  $K \rightarrow \pi l l$

$K_S$  DECAYS

## $K_S \rightarrow 3\pi^0$ ; test of CP and CPT

**Observation of  $K_S \rightarrow 3\pi^0$  signals  $CP$  violation in mixing and/or decay:**

If  $CPT$  conserved:  $\Gamma_{S000} = \Gamma_{L000} |\varepsilon + \varepsilon'_{000}|^2$   **$\text{BR}(K_S \rightarrow 3\pi^0) \sim 2 \times 10^{-9}$**

**Best results:**  $\text{BR} < 1.4 \times 10^{-5}$  90% CL SND '99

**Uncertainty on  $K_S \rightarrow 3\pi^0$  amplitude currently limits precision on  $\text{Im } \delta$**

**From unitarity (Bell-Steinberger relation):**

$\varepsilon$  describes CPV

$\delta$  describes CPTV

$$(1 + i \tan \phi_{\text{SW}}) [\text{Re } \varepsilon - i \text{Im } \delta] = \frac{1}{\Gamma_S} \sum_f A^*(K_S \rightarrow f) A(K_L \rightarrow f)$$

**Best results:**  $\text{Im } \delta = (2.4 \pm 5.0) \times 10^{-5}$  CPLEAR '99

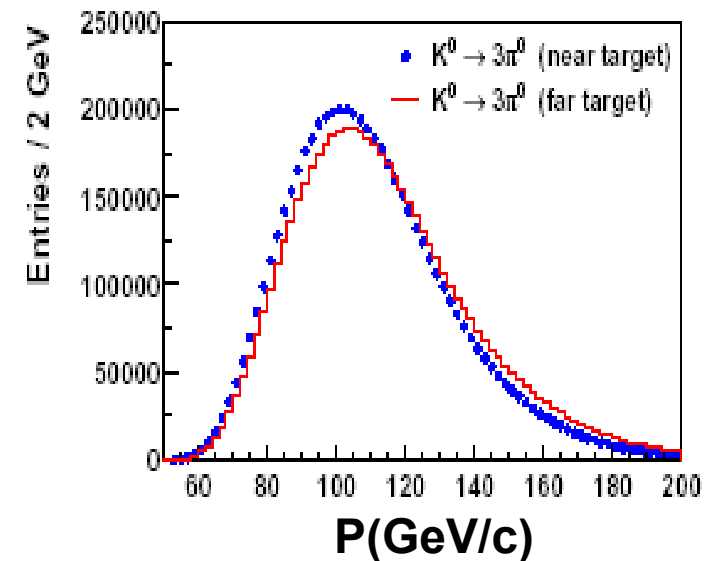
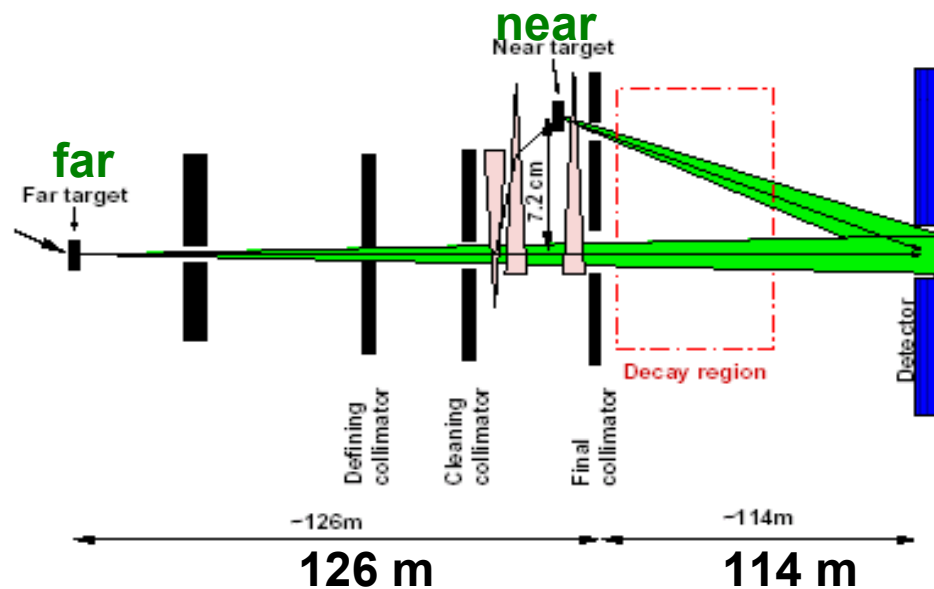
$ \text{Im } \delta  < \sim 2 \times 10^{-5} \Rightarrow \frac{m_{K^0} - m_{\bar{K}^0}}{\langle m_K \rangle} < \sim 8 \times 10^{-19}$	<i>Compare to</i> $m_K/m_{\text{Planck}} = 4 \times 10^{-20}$
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# The NA48/1 $K_S$ beam

Two simultaneous neutral beams from CERN SPS:

“near”:  $K_S$  enriched beam  $\longrightarrow$   $\sim 5 \times 10^{10}$  triggered  $K_S$  decays

“far”: almost pure  $K_L$  beam, used for normalization



## $K_S \rightarrow 3\pi^0$ : NA48/1

About 5 Millions  $K^0 / \bar{K}^0 \rightarrow 3\pi^0$  reconstructed from the near beam

Sensitivity to  $\eta_{000}$  comes from  $K_S / K_L$  interference at small decay times near the target

$$I(t) = e^{-\Gamma_L t} + |\eta_{000}|^2 e^{-\Gamma_S t} + D(p) \left\{ \text{Re}(\eta_{000}) \cos(\Delta m t) - \text{Im}(\eta_{000}) \sin(\Delta m t) \right\} e^{\frac{-(\Gamma_S + \Gamma_L)t}{2}}$$

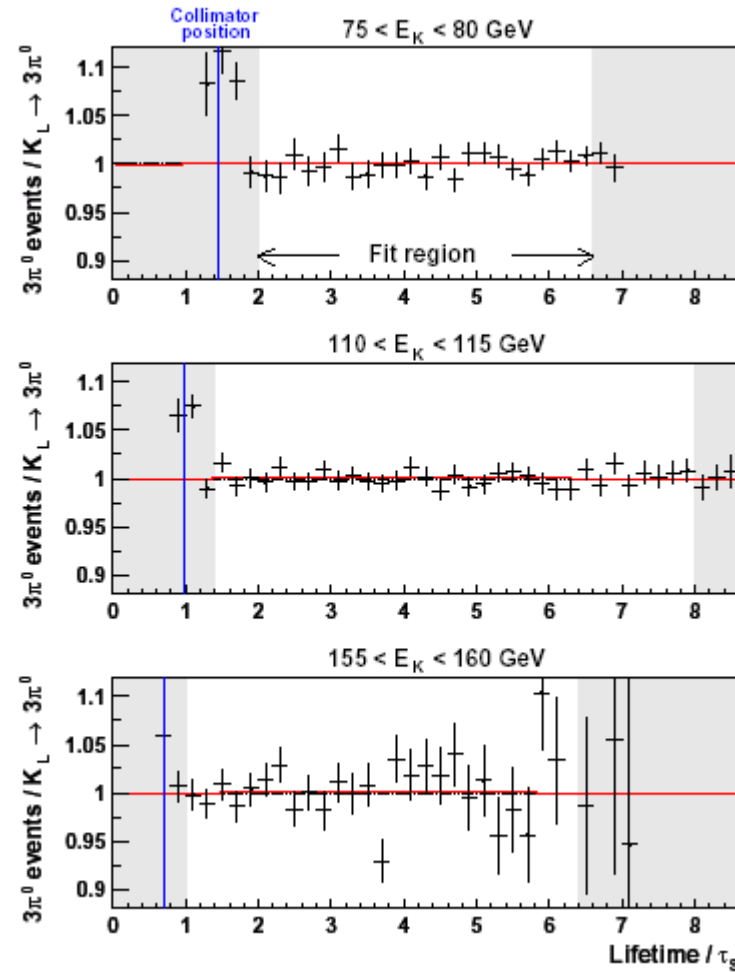
*dilution factor*: describes the momentum dependent production asymmetry between  $K^0$  and  $\bar{K}^0$ . Taken from previous measurements of NA31

# $K_S \rightarrow 3\pi^0$ : NA48/1

Fit performed in 5 GeV  
energy intervals

Free parameters:  $\text{Re}(\eta_{000})$ ,  
 $\text{Im}(\eta_{000})$ , normalizations of  
each interval

$$\chi^2/\text{ndf} = 689/660$$



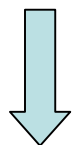
# $K_S \rightarrow 3\pi^0$ : NA48/1

A. Lai et al. **hep-ex 0408053**

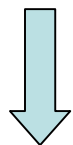
$$\text{Re}(\eta_{000}) = -0.002 \pm 0.011 \pm 0.015$$

$$\text{Im}(\eta_{000}) = -0.003 \pm 0.013 \pm 0.017$$

$$\rho = 0.57$$



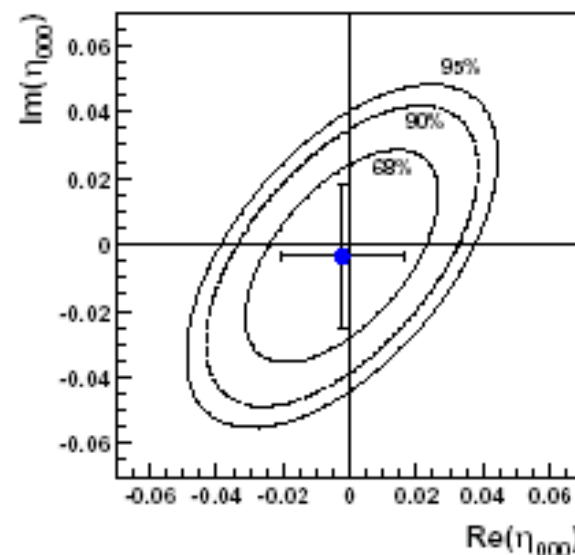
$$\text{BR}(K_S \rightarrow 3\pi^0) < 7.4 \times 10^{-7} \text{ @ 90\% CL}$$



*From unitarity*

$$\text{Im}(\delta) = (-0.2 \pm 2.0) \times 10^{-5}$$

$$\text{Re}(\varepsilon) = (166.4 \pm 1.0) \times 10^{-5}$$



Assuming CPT:

$$\text{BR}(K_S \rightarrow 3\pi^0) < 2.3 \times 10^{-7} \text{ @ 90\% CL}$$

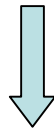


# The $K_S$ “beam” at DAΦNE

Measured particles  
fluxes at the  $\Phi$  peak

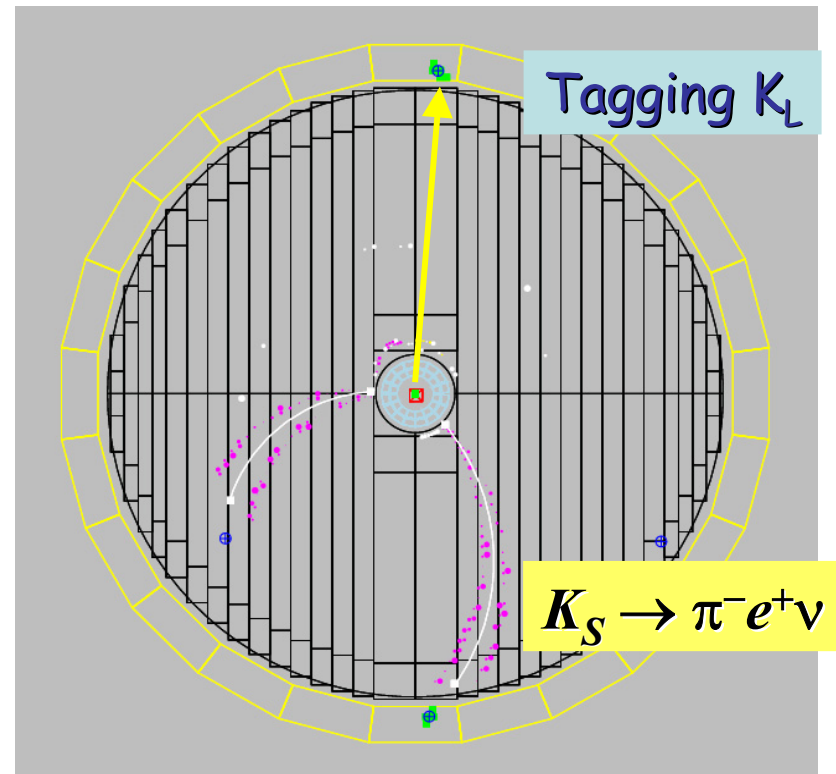
$$\left\{ \begin{array}{ll} K^+K^- & 1.5 \times 10^6 / \text{pb}^{-1} \\ K_L K_S & 1.0 \times 10^6 / \text{pb}^{-1} \\ \eta & 4.0 \times 10^4 / \text{pb}^{-1} \end{array} \right.$$

KLOE has collected  $\sim 450 \text{ pb}^{-1}$   
in 2001-2002



$\sim 2 \times 10^8$  tagged  $K_S$  decays

Tagging technique based on  
on  $K_L$  TOF  $\epsilon_{\text{tag}} \sim 35\%$



# $K_S \rightarrow 3\pi^0: KLOE$

## Preselection

- $K_S$  tagged by  $K_L$  interaction in EMC
- 6 photons, no tracks from IP
- Kinematic fit in  $2\pi^0$  &  $3\pi^0$  hypothesis

## Rejection of background

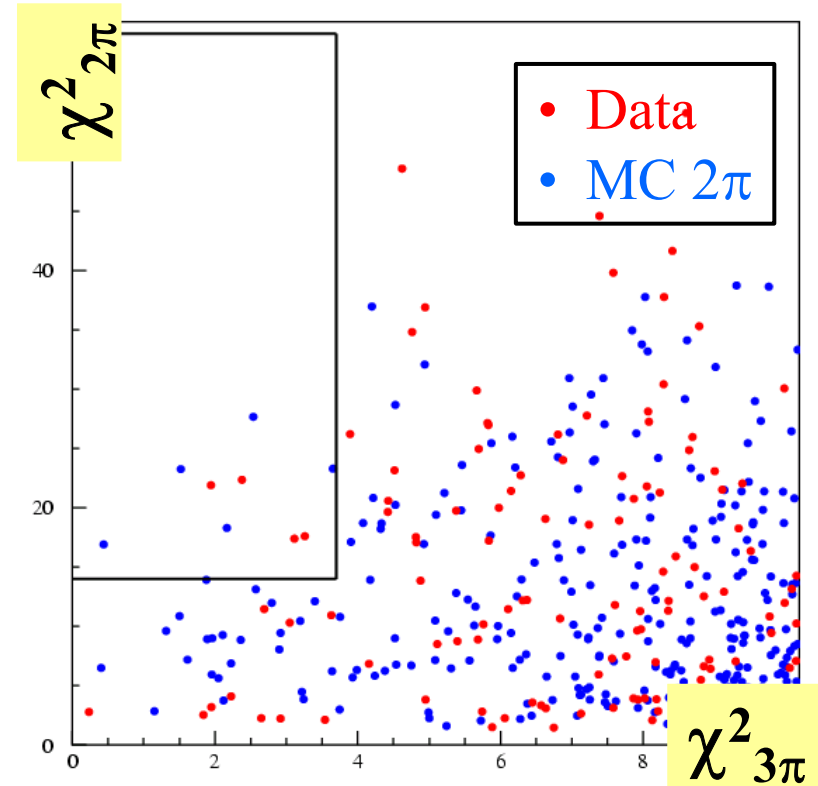
$K_S \rightarrow 2\pi^0 + 2$  split/accidental clusters

- Define signal box in  $\chi^2_{3\pi}$  vs.  $\chi^2_{2\pi}$  plane:

$\chi^2_{3\pi}$  “best” 3 photon pairs

$\chi^2_{2\pi}$  “best” 2 pairs

Cut on  $E(K_S) - \sum E_\pi$



$\varepsilon_{3\pi} =$	22.6%	$N_{\text{bkg}}(\text{MC}) = 3.2 \pm 1.4 \pm 0.5$	$N_{\text{obs}} = 4$
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# $K_S \rightarrow 3\pi^0$ : KLOE

$$BR(K_S \rightarrow 3\pi^0) < 2.1 \times 10^{-7} @ 90\% \text{ CL}$$

*KLOE*  
*Preliminary (\*)*

$$|\eta^{000}| = \left| \frac{A(K_S \rightarrow 3\pi^0)}{A(K_L \rightarrow 3\pi^0)} \right| = \sqrt{\frac{\tau_L B(K_S \rightarrow 3\pi^0)}{\tau_S B(K_L \rightarrow 3\pi^0)}}$$

$$|\eta_{000}| < 2.4 \times 10^{-2} @ 90\% \text{ CL}$$

Using **PDG** values

*From unitarity*

$$\text{Im}(\delta) = (-0.5 \pm 2.0) \times 10^{-5}$$

(\*) Presented at ICHEP 04

## $K_S \rightarrow 3\pi^0$ : unitarity

$$(1 + i \tan \phi_{SW}) [\text{Re } \varepsilon - i \text{Im } \delta] = \frac{1}{\Gamma_S} \sum_f A^*(K_S \rightarrow f) A(K_L \rightarrow f) \\ = \sum_f \alpha_f$$

**taken from: hep-ex 0408053**

**mostly PDG04 values**

$\alpha_f$	$10^3 \times \text{Re}(\alpha_f)$	$10^3 \times \text{Im}(\alpha_f)$
$\alpha_{+-} = \eta_{+-} \text{Br}(K_S \rightarrow \pi^+ \pi^-)$	$1.146 \pm 0.015$	$1.084 \pm 0.016$
$\alpha_{00} = \eta_{00} \text{Br}(K_S \rightarrow \pi^0 \pi^0)$	$0.511 \pm 0.008$	$0.488 \pm 0.008$
$\alpha_{+-\gamma} = \eta_{+-\gamma} \text{Br}(K_S \rightarrow \pi^+ \pi^- \gamma)$	$0.003 \pm 0.000$	$0.003 \pm 0.000$
$\alpha_{l3} = 2 \frac{\tau_S}{\tau_L} \text{Br}(K_L \rightarrow \pi l \nu) \times$ $[\text{Re}(\epsilon) - \text{Re}(y) - i(\text{Im}(x_+) + \text{Im}(\delta))]$	$-0.001 \pm 0.007$	$0.005 \pm 0.006$
$\alpha_{+-0} = \frac{\tau_S}{\tau_L} \eta_{+-0}^* \text{Br}(K_L \rightarrow \pi^+ \pi^- \pi^0)$	$0.000 \pm 0.002$	$0.000 \pm 0.002$
$\alpha_{000} = \frac{\tau_S}{\tau_L} \eta_{000}^* \text{Br}(K_L \rightarrow 3\pi^0)$	$-0.001 \pm 0.007$	$0.001 \pm 0.008$
$\sum \alpha_f$	$1.658 \pm 0.024$	$1.581 \pm 0.025$

**Error now dominated by  $\eta_{+-}$**

**recent KTeV measurement not included !!**

# $K_S \rightarrow \pi e \nu$ : KLOE

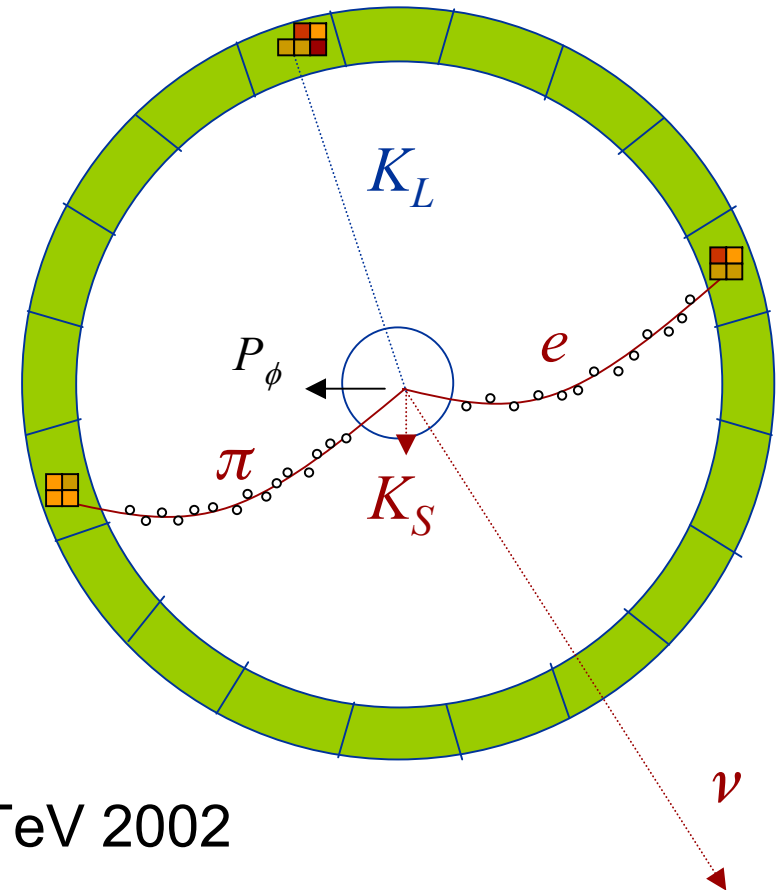
CPT test is also performed measuring  $K_L$ ,  $K_S$  semileptonic asymmetries:

$$A_{S,L} = \frac{\Gamma(K_{S,L} \rightarrow \pi^- e^+ \nu) - \Gamma(K_{S,L} \rightarrow \pi^+ e^- \nu)}{\Gamma(K_{S,L} \rightarrow \pi^- e^+ \nu) + \Gamma(K_{S,L} \rightarrow \pi^+ e^- \nu)}$$

$A_S - A_L = 0$  if CPT holds

$$A_L = (3.322 \pm 0.058 \pm 0.047) \times 10^{-3} \text{ KTeV 2002}$$

KLOE looks for **semileptonic**  $K_S$  decays in events with a tagging  $K_L$  and two tracks from the i.p.



# $K_S \rightarrow \pi e \nu$ : CPT

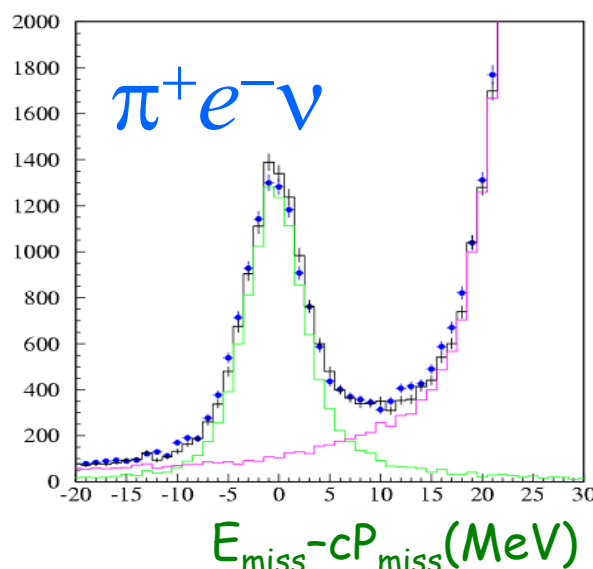
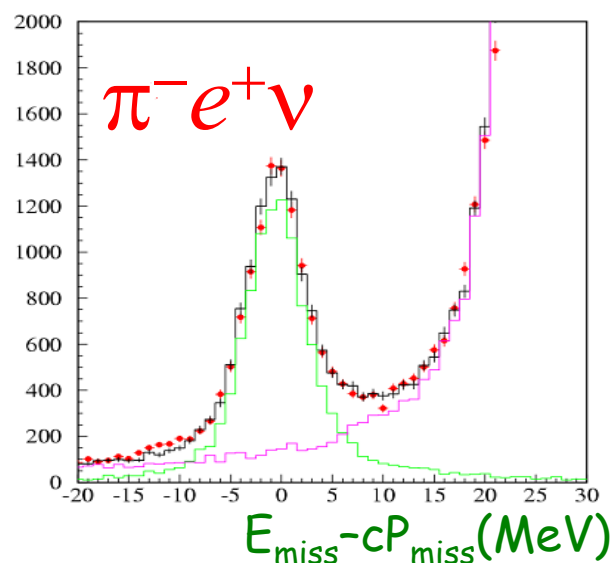
Reject events with  $M_{\pi\pi}$  close to kaon mass

$\pi / e$  separation with time of flight ( $\Delta t \sim 2$  ns )

Efficiency evaluated using  
 $K_L \rightarrow \pi e \nu$  close to the IP:

$$\varepsilon(\pi^+ e^-) = (23.6 \pm 0.1 \pm 0.6)\%$$

$$\varepsilon(\pi^- e^+) = (24.1 \pm 0.1 \pm 0.6)\%$$



Fit to MC spectra of  
signal and backgr.

Radiative decays  
included in MC!

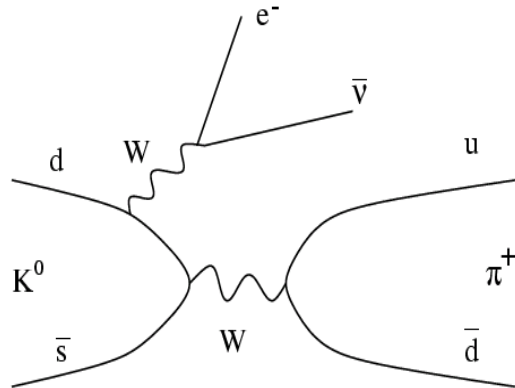
$$A_S = (2 \pm 9_{\text{stat}} \pm 6_{\text{syst}}) \times 10^{-3} \text{ KLOE2004 (preliminary)}$$

*Presented at ICHEP 04*

$$K_S \rightarrow \pi e \nu: \Delta S = \Delta Q$$

No  $\Delta S \neq \Delta Q$  transition at first order in SM

$$|x| \sim 10^{-7}$$



$$x = (c^* - d^*)/(a + b)$$

$\Delta S \neq \Delta Q$  in  $\bar{K}^0$  decay to  $e^+$

$$\bar{x} = (c + d)/(a^* - b^*)$$

$\Delta S \neq \Delta Q$  in  $K^0$  decay to  $e^-$

$$x_+ = (x + \bar{x})/2 \approx \text{Re}(c^*/a) + i \text{Im}(d^*/a)$$

**$\text{Re } x_+ \approx \text{Re}(c^*/a)$  describes**

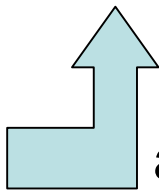
**$\Delta S \neq \Delta Q$  when CPT conserved**

$$2 \text{Re } x_+ = \frac{BR(K_S \rightarrow \pi e \nu) / \tau_S - BR(K_L \rightarrow \pi e \nu) / \tau_L}{BR(K_S \rightarrow \pi e \nu) / \tau_S + BR(K_L \rightarrow \pi e \nu) / \tau_L}$$

$$K_S \rightarrow \pi e \nu: \Delta S = \Delta Q$$

*KLOE Preliminary (ICHEP 04)*

$$\text{BR}(K_S \rightarrow \pi e \nu) = (7.09 \pm 0.07_{\text{stat}} \pm 0.08_{\text{syst}}) \times 10^{-4}$$

Using  and :

- A) PDG  $K_L \rightarrow \pi e \nu$  and  $\tau_L$
- B) KTeV  $K_L \rightarrow \pi e \nu$  and PDG  $\tau_L$
- C) KLOE  $K_L \rightarrow \pi e \nu$  and  $\tau_L$
- D) CPLEAR 98

**Re  $x_+$**

- A:  $(12.6 \pm 3.1_{\text{STAT}} \pm 2.9_{\text{SYST}}) \times 10^{-3}$
- B:  $(0.9 \pm 2.9_{\text{STAT}} \pm 2.9_{\text{SYST}}) \times 10^{-3}$
- C:  $(5.3 \pm 3.1_{\text{STAT}} \pm 2.9_{\text{SYST}}) \times 10^{-3}$
- D:  $(-1.8 \pm 4.1_{\text{STAT}} \pm 4.5_{\text{SYST}}) \times 10^{-3}$



# CHARGED KAONS DECAYS

# NA48/2 : goals of the experiment

Direct CP violation in  $K^\pm \rightarrow \pi^+\pi^-\pi^\pm$  and  $K^\pm \rightarrow \pi^\pm\pi^0\pi^0$

$$A_g = \frac{g_+ - g_-}{g_+ + g_-}$$

$$M(u) \propto 1 + g \cdot u$$

$$u = (2 m_K / m_\pi^2) (m_K/3 - E_{\pi\text{odd}}^*)$$

$V_{us}$  measurement in  $K_{e3}$  and  $K_{\mu3}$  decays

Rare or semirare  $K^\pm$  decays

$$K^\pm \rightarrow \pi^+\pi^-\text{e}^\pm\nu$$

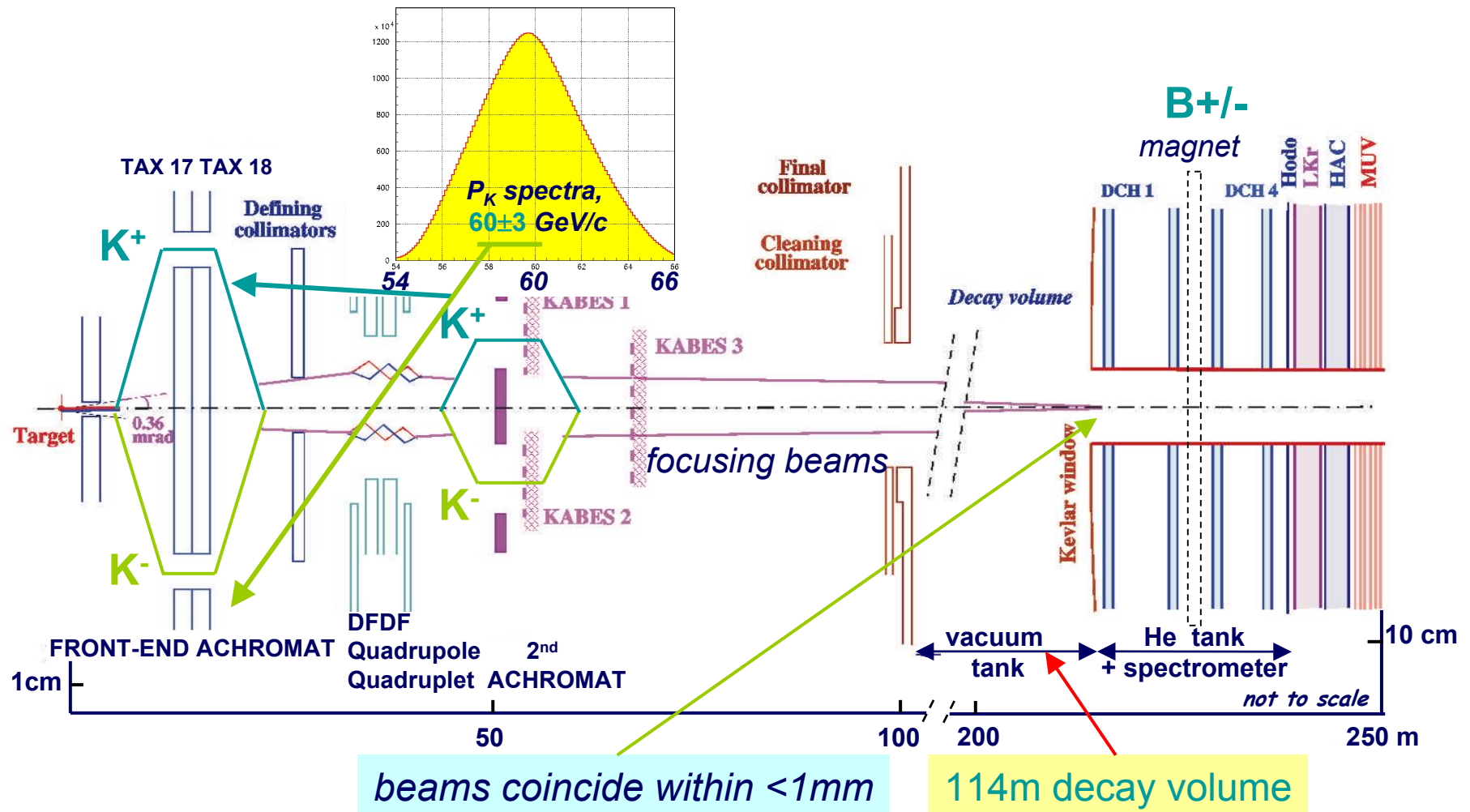
$$K^\pm \rightarrow \mu^+\mu^-\pi^\pm$$

$$K^\pm \rightarrow \text{e}^+\text{e}^-\pi^\pm$$

$$K^\pm \rightarrow \pi^\pm\gamma\gamma$$

# NA48/2 experiment configuration

The simultaneous  $K^+$  and  $K^-$  beams



# $K^\pm \rightarrow 3\pi$ : NA48/2 statistics so far

run	$\pi^+\pi^-\pi^\pm$ ( $\times 10^6$ )	$\pi^\pm\pi^0\pi^0$ ( $\times 10^6$ )
2003 (I)	600	20
2003 (II)	1300	50
2004	2150	70

*non stable  
conditions*

*analysis close  
to completion*

*run ended  
Aug. 11*

*my guess*

$\pi^+\pi^-\pi^\pm$

$$A_g^c = (\blacksquare \pm 2.7) \times 10^{-4}$$

$\pi^\pm\pi^0\pi^0$

$$A_g^0 = (\blacksquare \pm 5.0) \times 10^{-4}$$

One order of magnitude improvement wrt previous results!

# $K$ decays and the $\pi\text{--}\pi$ scattering length

Current algebra and PCAC + ChPT lead to precise prediction of the threshold behaviour of the  $\pi\text{--}\pi$  scattering

$$a_0 m_\pi = 0.220 \pm 0.005$$

*G. Colangelo, J. Gasser, H. Leutwyler,*

$$a_2 m_\pi = -0.0444 \pm 0.0010$$

*Nucl. Phys. B603, 125*

$$(a_0 - a_2) m_\pi = 0.265 \pm 0.004$$

Precise measurements of the above parameters can be made studying the following transitions:

$$K^\pm \rightarrow \pi^+ \pi^- e^\pm \nu \quad (K_{e4}^\pm)$$

$$K_L^0 \rightarrow \pi^0 \pi^- e^+ \nu \quad (K_{e4}^0)$$

$$K^\pm \rightarrow \pi^0 \pi^0 e^\pm \nu \quad (K_{e4}^{00})$$

# $K_{e4}^{\pm}$ : BNL-E865

> 400,000 observed  $K^{\pm} \rightarrow \pi^+ \pi^- e^{\pm} \nu$  events

( *S. Pislak et al.* **PRD 67** 072004 (2003) )

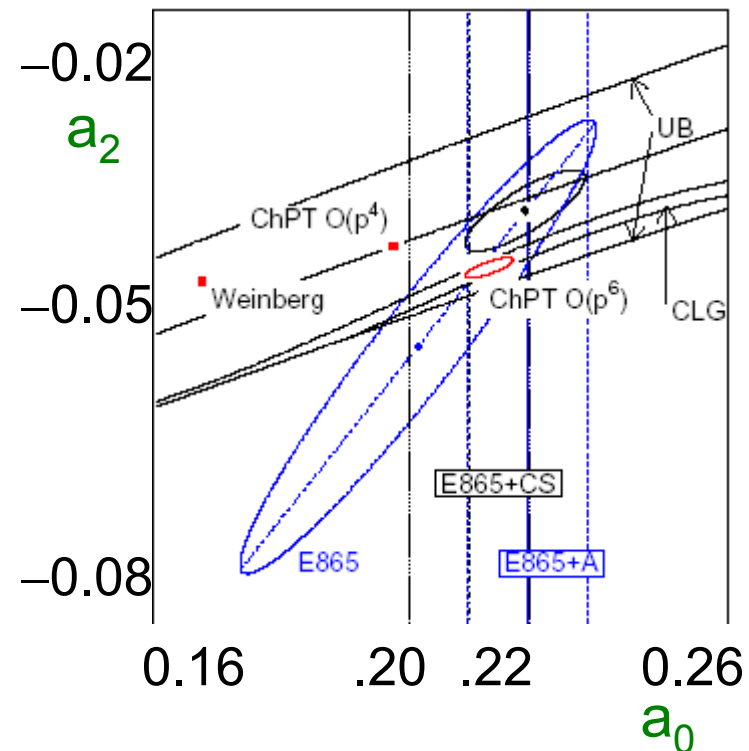
$$BR(K_{e4}^{\pm}) = (4.11 \pm 0.01 \pm 0.11) \times 10^{-5}$$

From a fit to the  $\pi\pi$  spectrum

$a_0 =$

$$0.216 \pm 0.013 \pm 0.002 \pm 0.02$$

*theory*



# $K_{e4}^{00}$ : KEK-E470

216 observed  $K^\pm \rightarrow \pi^0 \pi^0 e^\pm \nu$  events

( *S. Shimizu et al.* **PRD 70** 037101 (2004) )

factor ~6 larger wrt  
previous expt.'s

$$\Gamma(K_{e4}^{00}) =$$

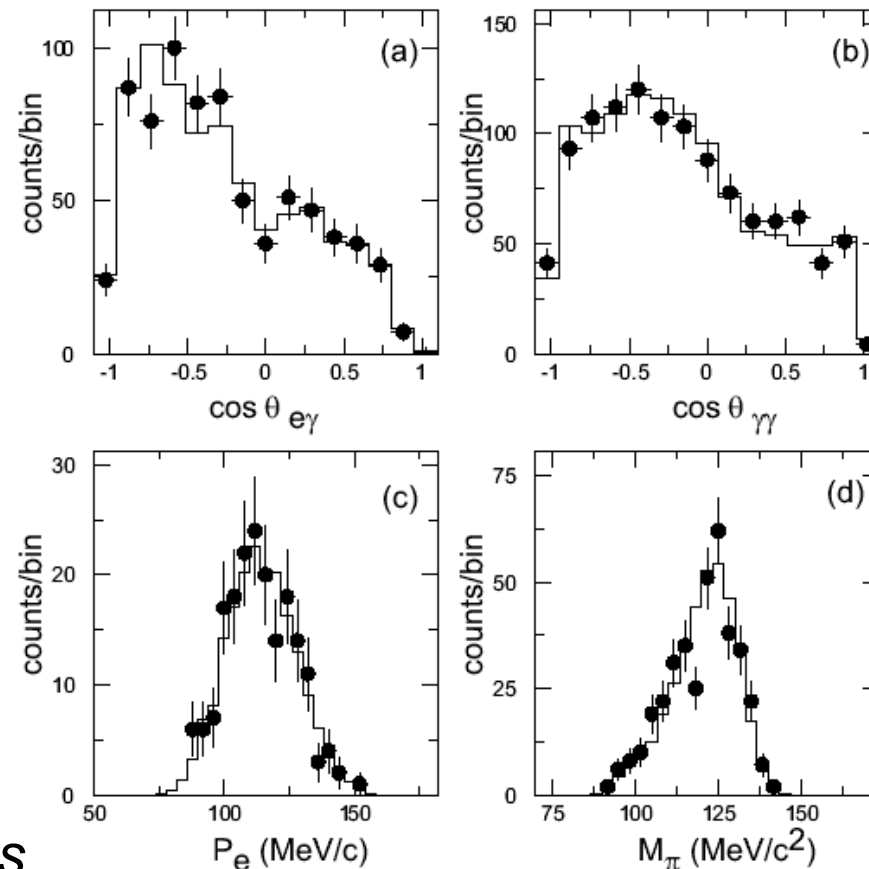
$$(3.56 \pm 0.26^{+7.51}_{-2.92}) \times 10^3 \text{ s}^{-1}$$

limited acceptance

$$(1.85 \pm 0.13 \pm 0.24) \times 10^3 \text{ s}^{-1}$$

if  $K_{e4}^\pm$  f.f. used

*Proof of principle for future expt's*



$$K^{\pm} \rightarrow \pi^{\pm} \pi^0 \pi^0$$

The value of  $(a_0 - a_2)$  can be extracted from the  $\pi^0 \pi^0$  spectrum of  $K^{\pm} \rightarrow \pi^{\pm} \pi^0 \pi^0$

( *N. Cabibbo*, PRL 93, 121801 (2004))

KLOE has recently measured

$$BR(K^{\pm} \rightarrow \pi^{\pm} \pi^0 \pi^0) = (1.763 \pm 0.013 \pm 0.022) \times 10^{-2}$$

( *A. Aloisio et al.* PLB 597, 139 (2004))

No attempt made to study kinematic distributions

Further experimental information might come from NA48/2



**A GLANCE AT THE FUTURE**

# A personal dictionary

In the following,

I will use

meaning

very near future

something which can be studied  
with data already on tape

near future

something which can be studied  
with data being taken now

not so far future

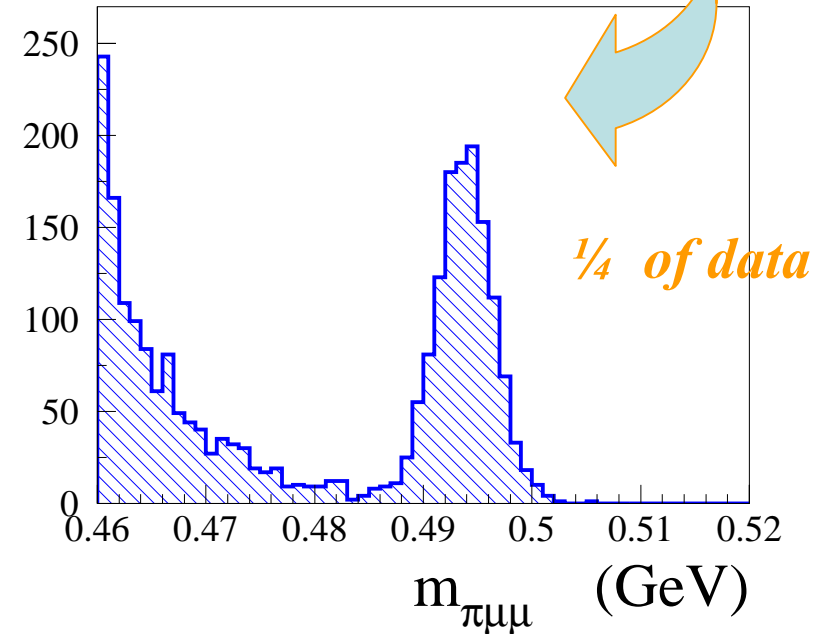
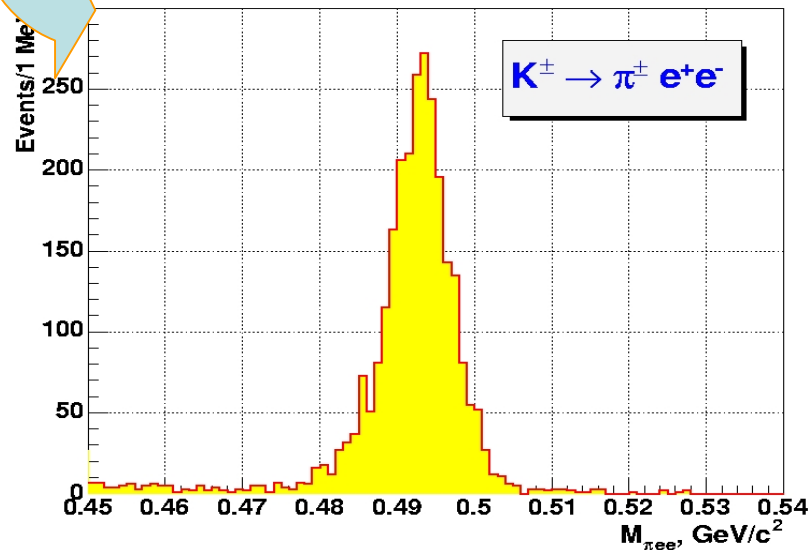
something which can be studied  
at facilities being planned to  
operate within the next ~ 6 years

# A glance at the very near future: NA48

Results expected soon on:

*Previous expt.  
statistics*

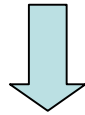
$K^\pm \rightarrow \pi^+ \pi^- e^\pm \nu$	500,000 (2003)	400,000
$K^\pm \rightarrow e^+ e^- \pi^\pm$	10,000	10,500
$K^\pm \rightarrow \mu^+ \mu^- \pi^\pm$	3,000 ( <i>my guess</i> )	800
$K^\pm \rightarrow \pi^\pm \gamma \gamma$	?	31



# A glance at the very near future: *KLOE*

In 2001-2002 KLOE has collected  $\sim 450 \text{ pb}^{-1}$ , which translates into:

- $\sim 2 \times 10^8$  tagged  $K_s$  decays
- $\sim 5 \times 10^7$  tagged  $K_l$  decays inside acceptance
- $\sim 2 \times 10^8$  tagged  $K^\pm$  decays



precision measurements of absolute branching ratios to  $< 1\%$

remember that almost all of present experimental information on kaons comes from ratios of branching ratios

if  $\text{BR}(K^\pm \rightarrow \mu^\pm \nu)$  lower then  $V_{us}$  from E865 will come down

In the era of precision measurement there is the need to be sure that:

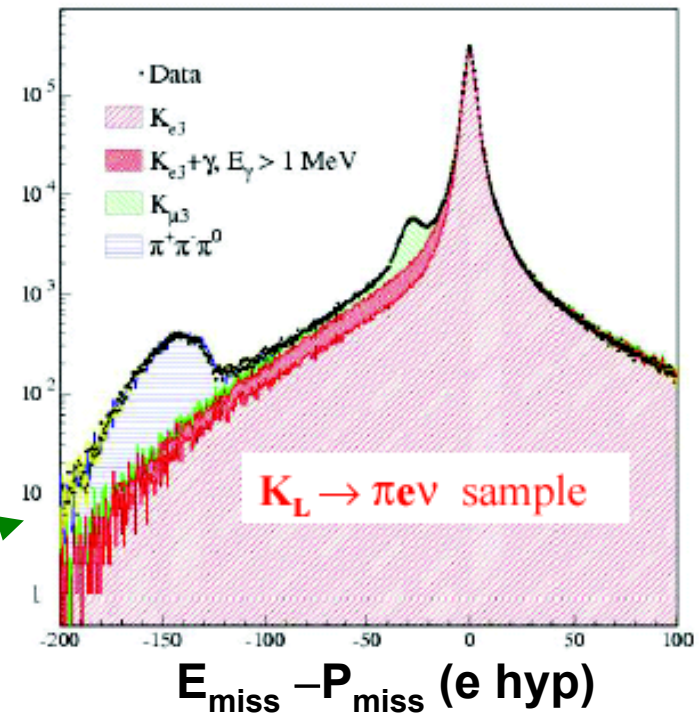
- ALL of the major branching ratios add up to unity

( Tagged beam of KLOE is a big bonus )

- Radiative corrections are properly treated

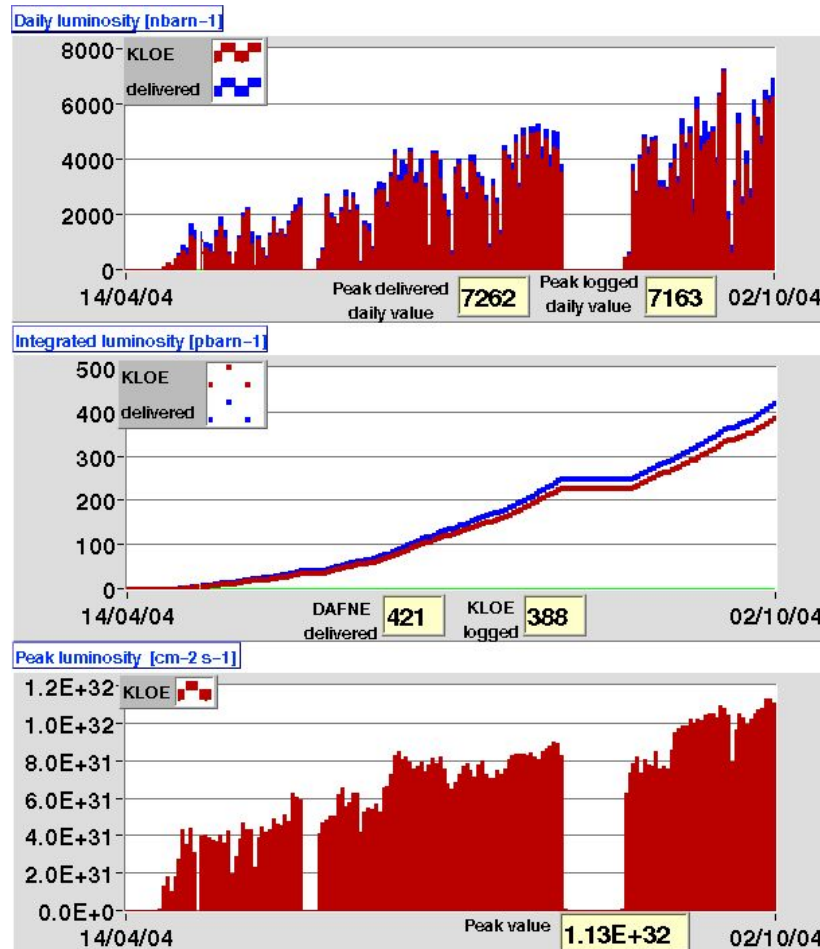
( We are talking about O(%) effects compared to O(0.1%) precisions!)

KLOE Data/MC comparison



# A glance at the near future: *KLOE*

*KLOE* started in May a long run (planned 15 months) with the goal of collecting  $\sim 2 \text{ fb}^{-1}$  i.e. a factor  $\sim 5$  the present statistics



*Daily luminosity:*

Best day 2004:  $7.1 \text{ pb}^{-1}$

Best day 2002:  $4.7 \text{ pb}^{-1}$

*Total luminosity:*

2004 (up to 10/2):  $390 \text{ pb}^{-1}$

2001+2002:  $460 \text{ pb}^{-1}$

*Peak luminosity:*

Best 2004:  $1.13 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

Best 2002:  $0.78 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$

# A glance at the near future: *KLOE*

2 fb<sup>-1</sup> “shopping list” :

- $K_S$  semileptonic asymmetry consistent with  $2 \operatorname{Re}(\varepsilon)$
- First observation of  $K_S \rightarrow \pi \mu \nu$
- Limit on  $B(K_S \rightarrow 3\pi^0) \sim 5 \times 10^{-8}$
- $K_{l4}$  studies
- A deeper look into quantum interferometry
- A first look to  $K_S \rightarrow \gamma \gamma$

# A glance at the not so far future: *KLOE*

INFN is considering plans for upgrading-renewing *DAΦNE* in a not so far future

Among others, a possibility is a  $\phi$ -factory at  $L \geq 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

With  $\geq 10 \text{ fb}^{-1}$  one can:

Complete the original KLOE program:  $\varepsilon'/\varepsilon$ , *interferometry*...

Improve on  $K_S$  rares,  $K_S \rightarrow 3\pi$ ,  $K_S \rightarrow \pi l \nu$

Be competitive for  $K_S \rightarrow \pi l l$



# CONCLUSIONS

Several new interesting results have appeared in the last ~ 2 years in K physics and are yet to come in the nearby future, addressing many different fundamental issues:

- *Tests of fundamental symmetries* (CP, T, CPT)
- *Studies of low energy Quantum Chromodynamics*
- *Tests of the Standard EW Model*

Not only  $K_L$  are interesting, but also  $K_S$  and  $K^\pm$

At the new facilities under study and/or construction we can improve a lot on all of the above and more...