CP violation and rare decays in K sector at NA48

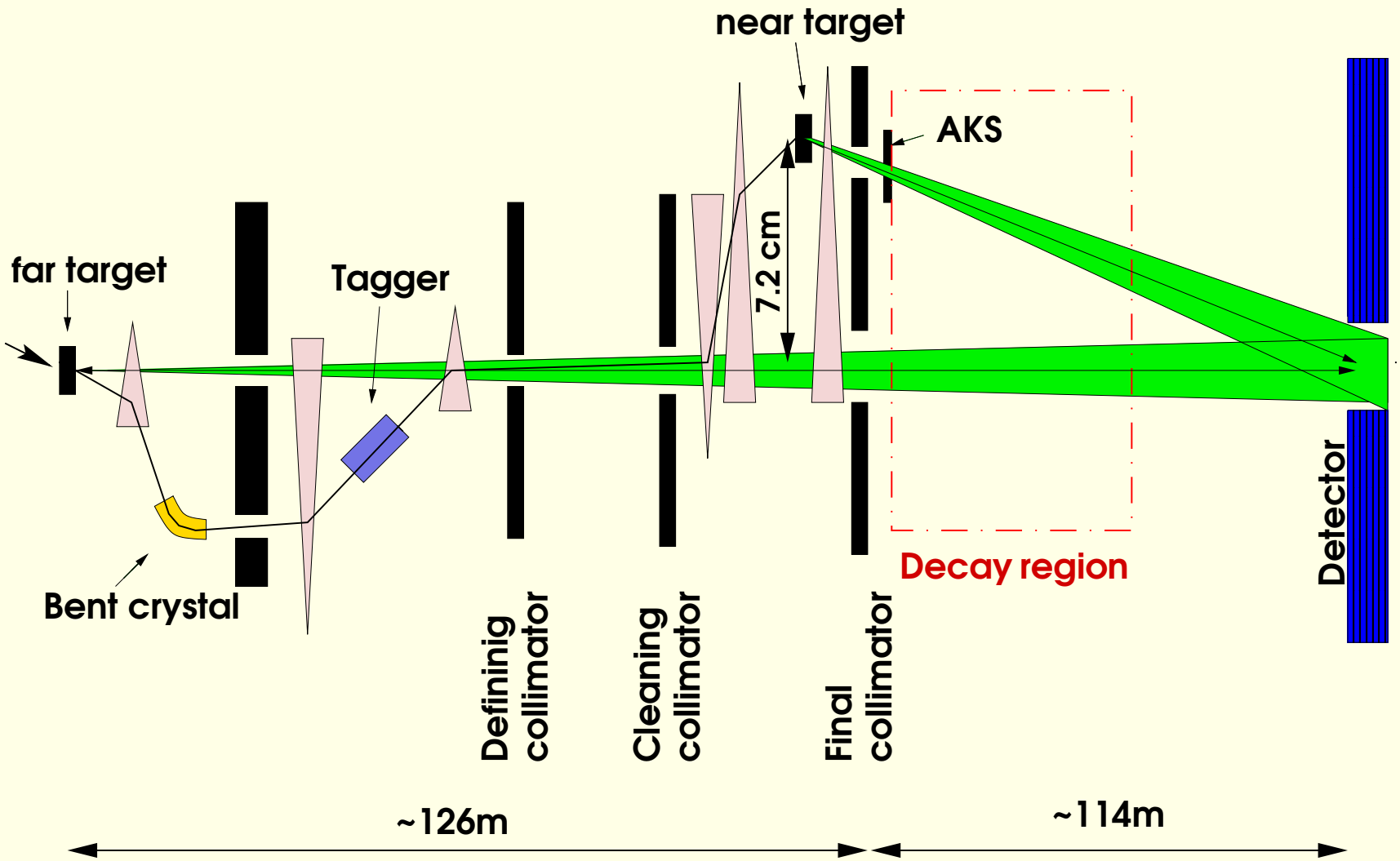
Ivan Mikulec
HEPHY, Vienna, Austria

La Thuile
March 13, 2003

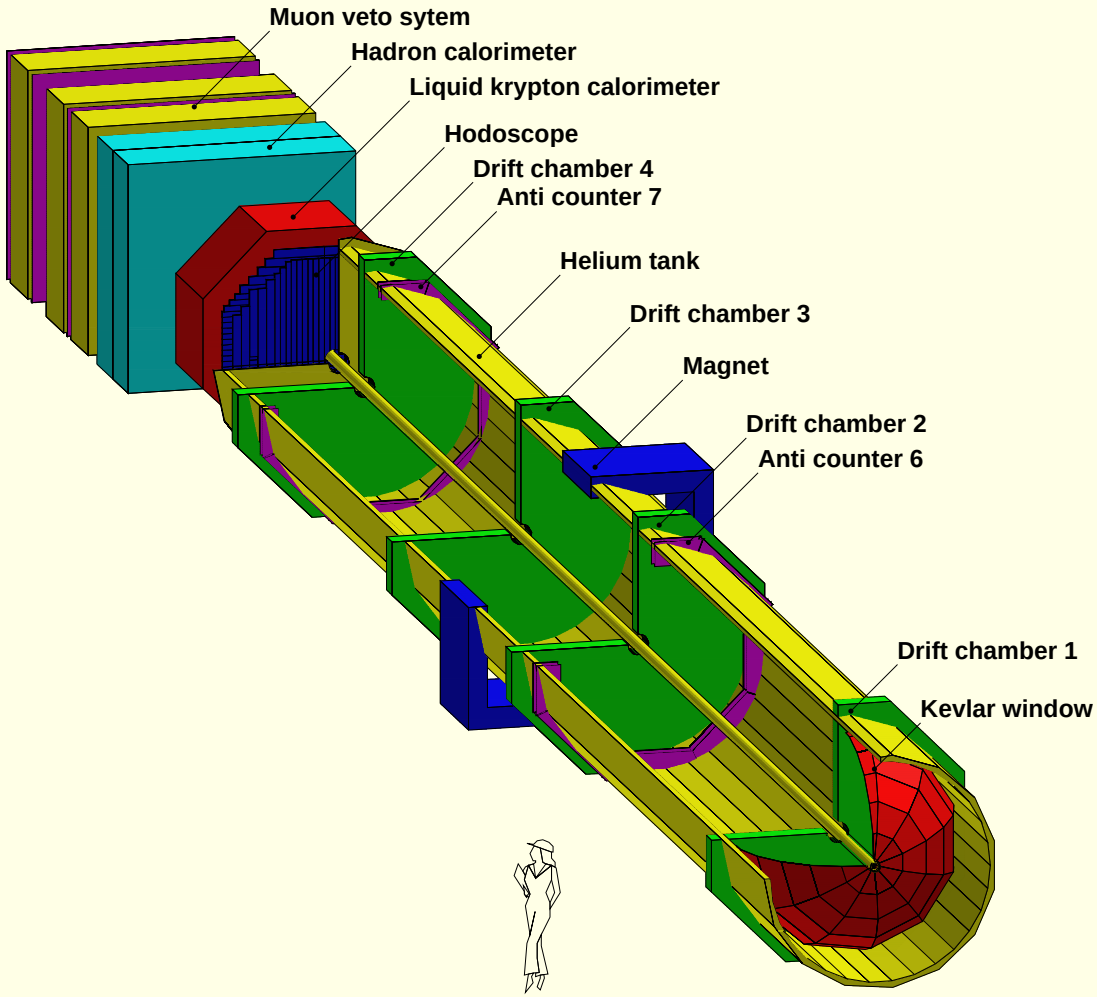
On behalf of the NA48 Collaboration:
Cagliari Cambridge CERN Chicago Dubna Edinburgh Ferrara Firenze Mainz
Northwestern Orsay Perugia Pisa Saclay Siegen Torino Vienna Warsaw

Outline

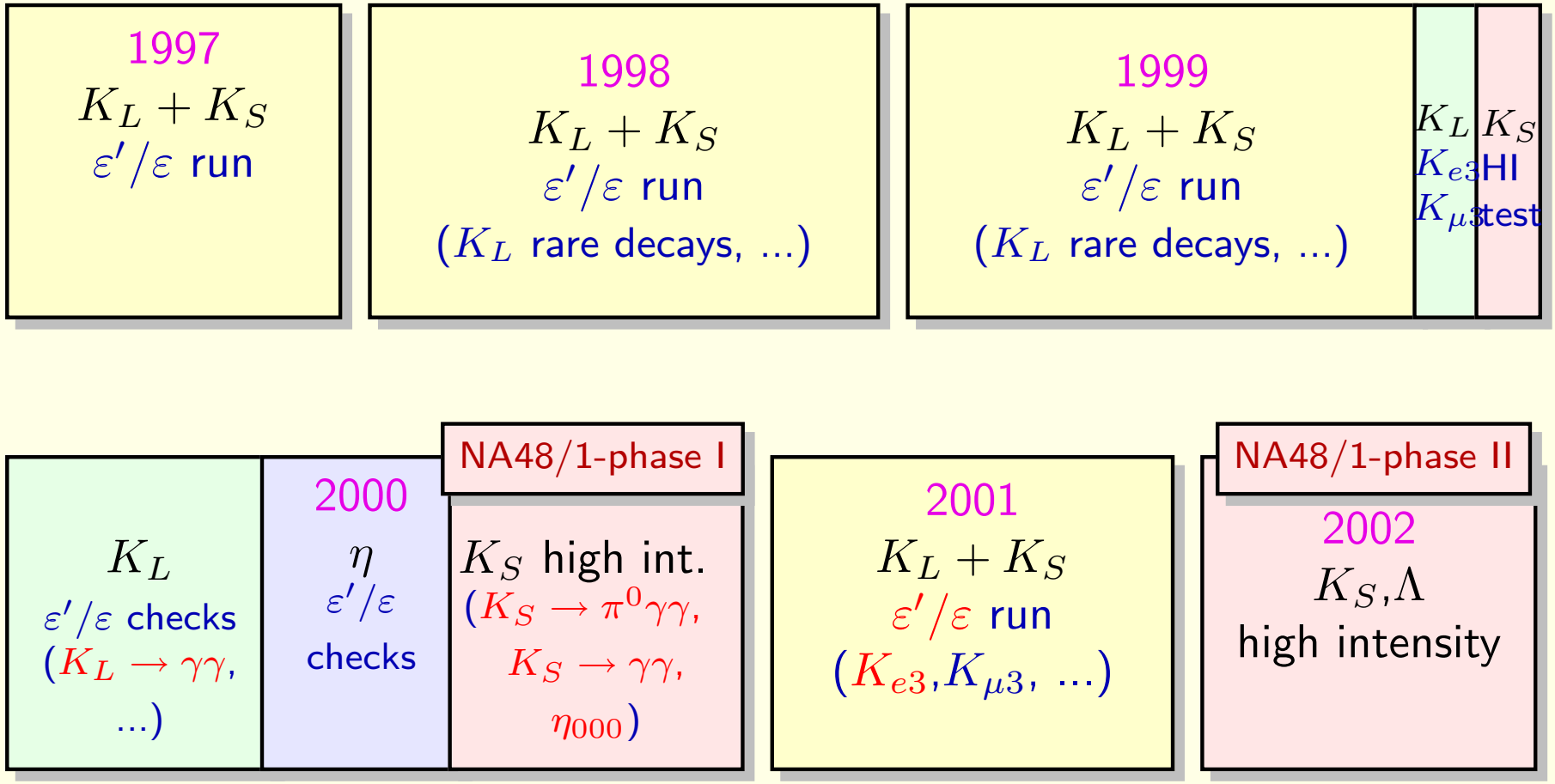
NA48 beam lines



NA48 detector



Overview of NA48 runs

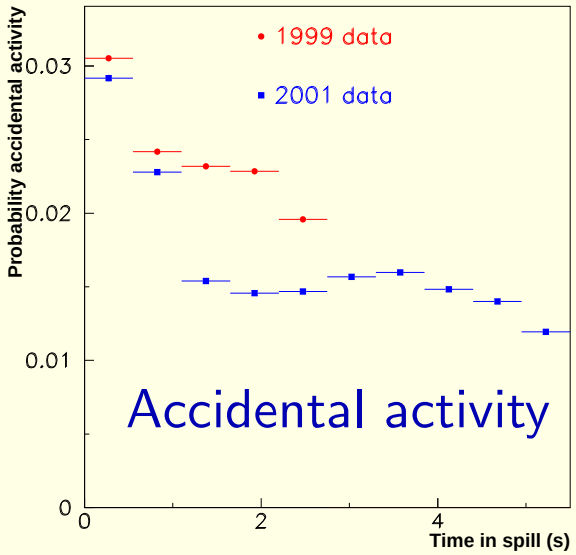


Results on CP violation

Final NA48 result on $\Re e\frac{\varepsilon'}{\varepsilon}$

Change in conditions for 2001 run:

	98-99	2001
proton energy	450 GeV/c	400 GeV/c
SPS cycle time	14.4 s	16.8 s
spill length (effective)	2.4 s (1.7 s)	5.2 s (3.6 s)
duty cycle	0.17	0.31
K_L beam intensity	$\sim 1.5 \times 10^{12}$ ppp	$\sim 2.4 \times 10^{12}$ ppp
K_S beam intensity	$\sim 3 \times 10^{7}$ ppp	$\sim 5 \times 10^{7}$ ppp
		+ rebuilt spectrometer



Result from 2001 data alone:

(29% of total statistics)

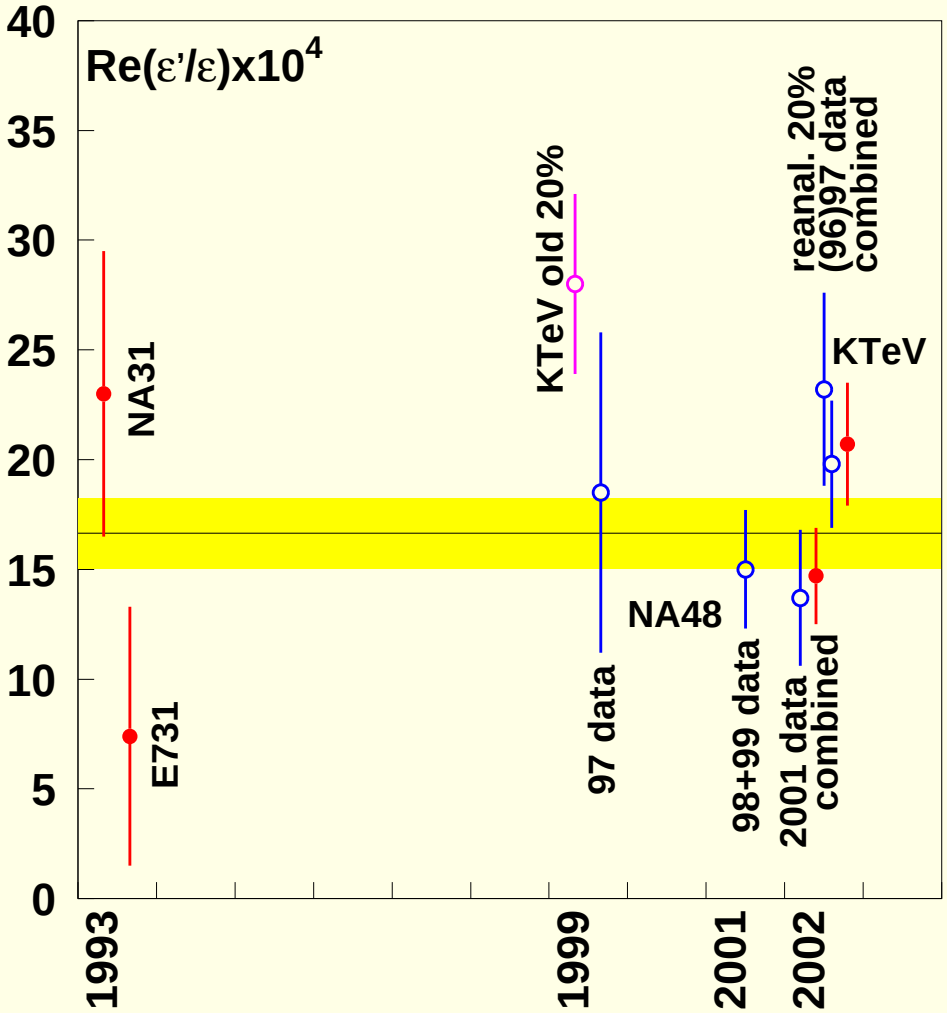
$$\Re e\frac{\varepsilon'}{\varepsilon} = (13.7 \pm 3.1) \times 10^{-4}$$

Combined NA48 result:

$$\Re e\frac{\varepsilon'}{\varepsilon} = (14.7 \pm 2.2) \times 10^{-4}$$

reached NA48 proposal accuracy

New $\Re e\frac{\varepsilon'}{\varepsilon}$ world average



→ New world average:

$$\Re e\frac{\varepsilon'}{\varepsilon} = (16.6 \pm 1.6) \times 10^{-4}$$

→ $\chi^2 = 6.3/3$

Probability: 10%

$\delta_L(e)$ measurement

$$\delta_L(e) \equiv \frac{BR(K_L \to \pi^- e^+ \nu_e) - BR(K_L \to \pi^+ e^- \overline{\nu_e})}{BR(K_L \to \pi^- e^+ \nu_e) + BR(K_L \to \pi^+ e^- \overline{\nu_e})} = 2\mathfrak{Re}\ \varepsilon$$

if CPT conserved

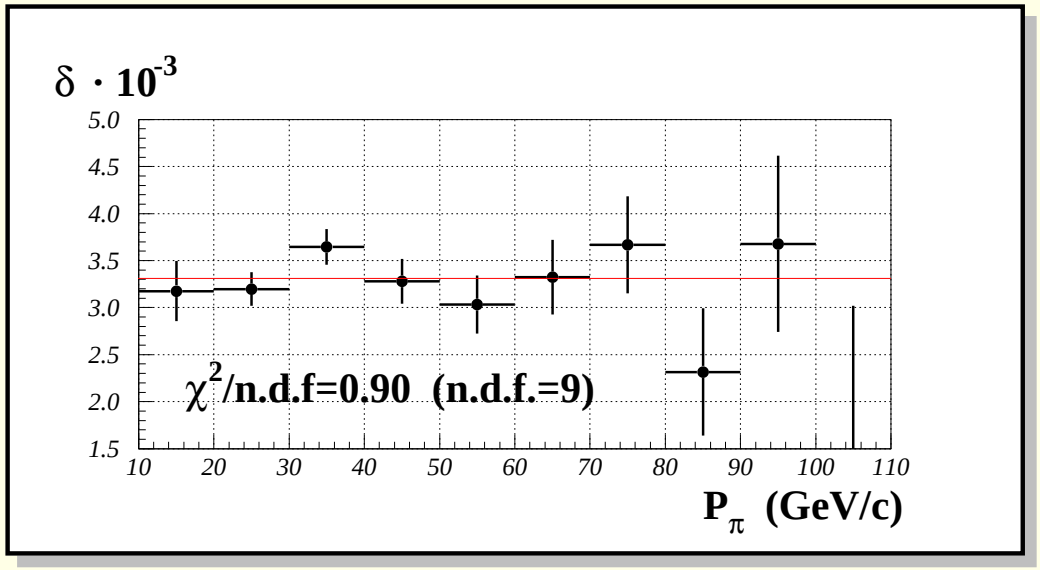
Measurement:

- from **2001** data
- $\delta_L(e) = \frac{N(\pi^- e^+) - N(\pi^+ e^-)}{N(\pi^- e^+) + N(\pi^+ e^-)}$
- $\sim 10^8$ events from each mode collected
- main source of systematics: asymmetry in particle interactions

$\delta_L(e)$ measurement - *Preliminary*

Systematic effects:

	in 10^{-5}		
Trigger	+26.2	±	6.0
Punch trough	-1.4	±	3.5
Pion ID	-17.1	±	2.4
Acceptance		±	0.5
Background		±	0.5

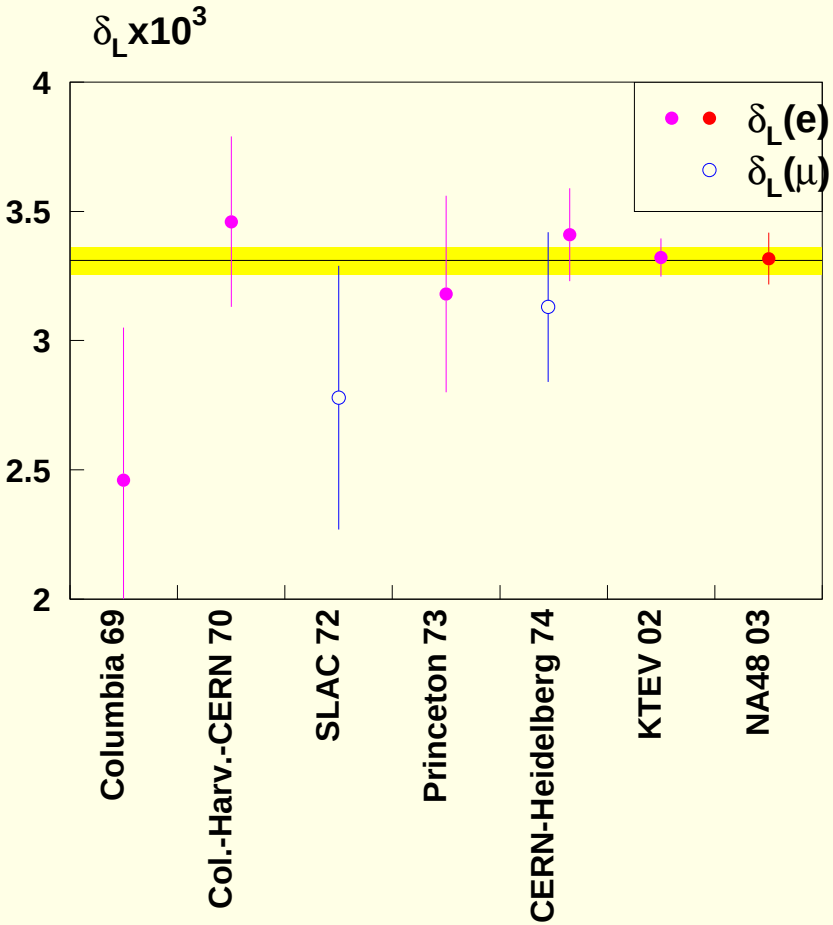


Fit in pion momentum bins:

$\delta_L(e)$ measurement - *Preliminary*

Preliminary result:

$$\delta_L(e) = (3.317 \pm 0.070_{stat} \pm 0.072_{syst}) \times 10^{-3}$$



World average:

$$\delta_L(e) = (3.322 \pm 0.055) \times 10^{-3}$$

$$\delta_L = (3.310 \pm 0.054) \times 10^{-3}$$

$$\chi^2 = 4.2/7$$

old average:

$$\delta_L = (3.307 \pm 0.063) \times 10^{-3}$$

CPT test using 2π data:

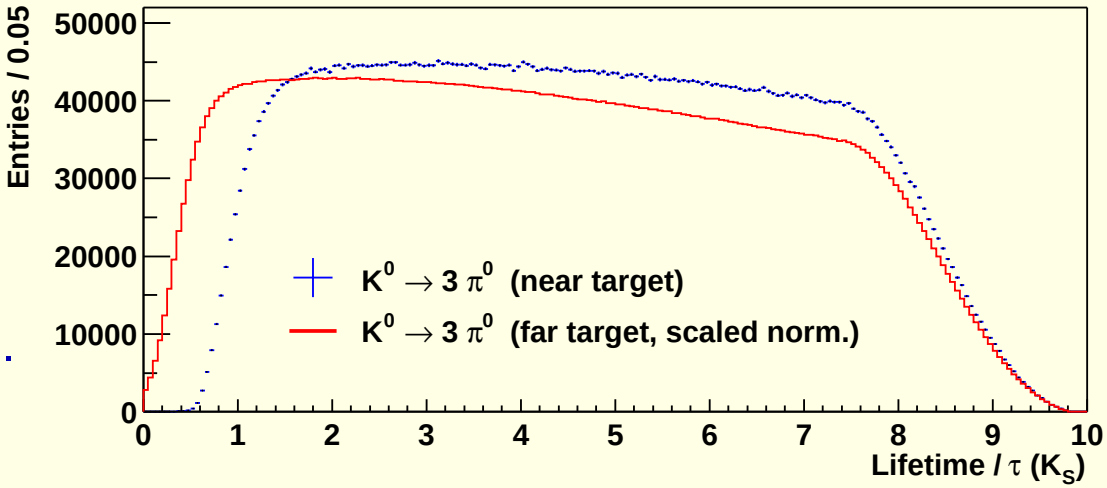
$$\Re\mathrm{e}(y + \tfrac{x-\overline{x}}{2} + a) = (-5 \pm 31) \times 10^{-6}$$

η_{000} measurement

$$\eta_{000} = \frac{A(K_S \to \pi^0\pi^0\pi^0)}{A(K_L \to \pi^0\pi^0\pi^0)}$$

If CPT conserved:
$\mathfrak{Re}\eta_{000}$ - CP violation in mixing
$\mathfrak{Im}\eta_{000}$ - Sensitive to direct CP violation

- **2000 near-target** data
  5.9×10^6 events
- first order acceptance corr.
  with **2000 far-target** data
- MC used only for
  second order acceptance corr.
- fit $f(E,t)$ in
  $70 < E < 170$ GeV



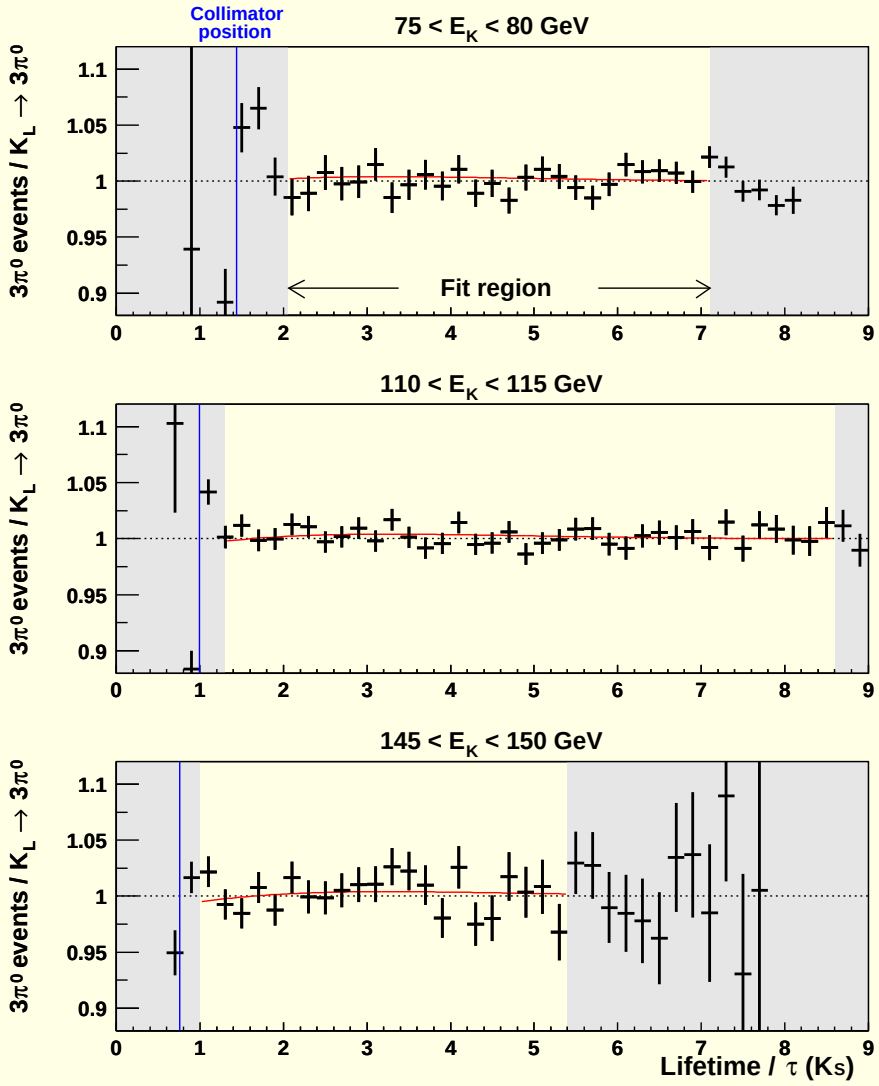
$$f(E,t) = \frac{I^{near}_{3\pi^0}}{I^{far}_{3\pi^0}} = A(E)\big[1 + |\eta_{000}|^2 e^{t/\tau_L - t/\tau_S} + 2D(E)e^{t/2\tau_L - t/2\tau_S}(\mathfrak{Re}\eta_{000}cos(\Delta mt) - \mathfrak{Im}\eta_{000}sin(\Delta mt))\big]$$

$D(E)$: $K^0 - \overline{K^0}$ dilution at target (from NA31)

fit parameters: $A(E), \mathfrak{Re}\eta_{000}, \mathfrak{Im}\eta_{000}$

η_{000} measurement - *Preliminary*

fit in E bins:



Systematic effects:

	in 10^{-2}	
	$\Re e\eta_{000}$	$\Im m\eta_{000}$
Accidentals	± 0.1	± 0.6
Energy scale	± 0.1	± 0.1
$K^0 - \overline{K^0}$ dilution	± 0.3	± 0.4
Acceptance	± 0.3	± 0.8
Binning	± 0.1	± 0.2
Total	± 0.5	± 1.1

η_{000} measurement - *Preliminary*

Preliminary result:

$$\Re e\eta_{000} = (-2.6 \pm 1.0_{stat} \pm 0.5_{syst}) \times 10^{-2}$$

$$\Im m\eta_{000} = (-3.4 \pm 1.0_{stat} \pm 1.1_{syst}) \times 10^{-2}$$

CPLEAR:

$\Re e\eta_{000} = (18 \pm 14_{stat} \pm 6_{syst}) \times 10^{-2}$

$\Im m\eta_{000} = (15 \pm 20_{stat} \pm 3_{syst}) \times 10^{-2}$

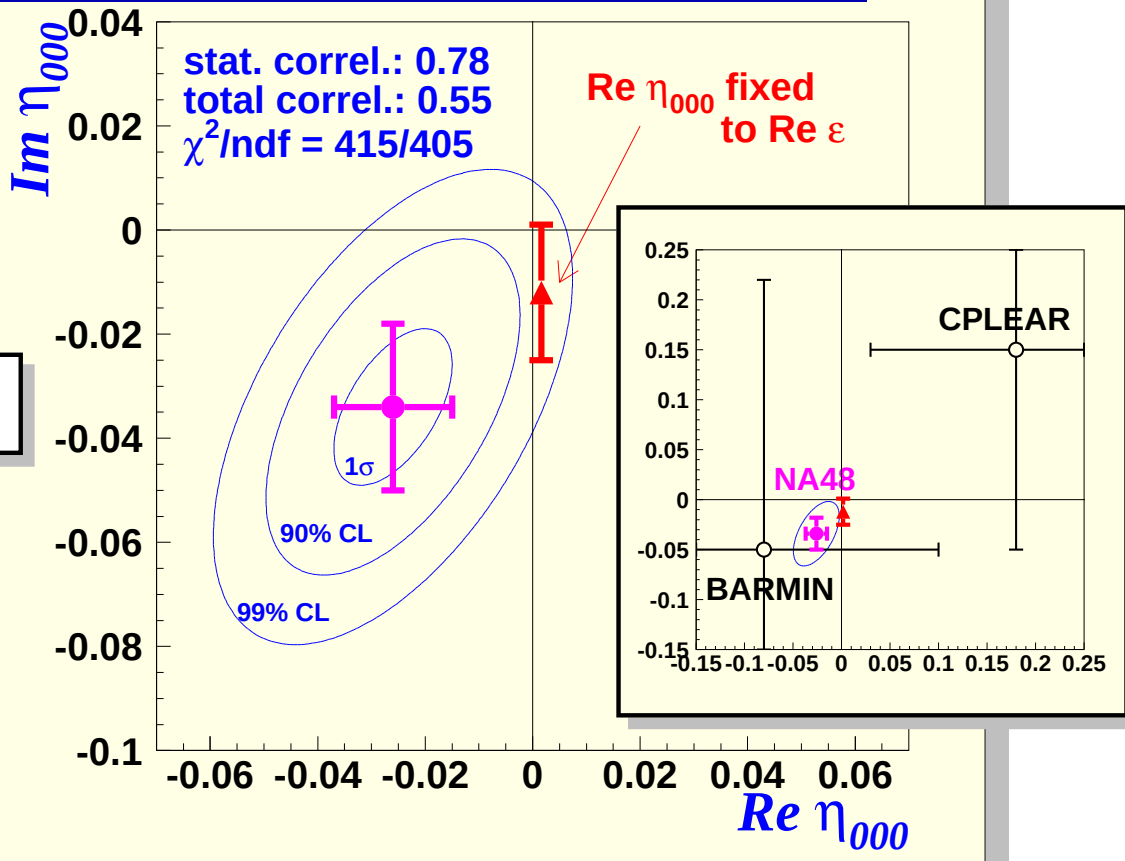
CPT test using BS unitarity relation :

$$\Im m\delta = (-1.2 \pm 3.0) \times 10^{-5}$$

CPLEAR: $\Im m\delta = (2.4 \pm 5.0) \times 10^{-5}$

If CPT conserved *in the decay*

$$m_{K^0} - m_{\overline{K^0}} = (-1.7 \pm 4.2) \times 10^{-19} GeV$$



With $\Re e\eta_{000}$ fixed:

$$\Im m\eta_{000} = (-1.2 \pm 1.3) \times 10^{-2}$$

$$BR(K_S \to \pi^0\pi^0\pi^0) < 3.0 \times 10^{-7}$$

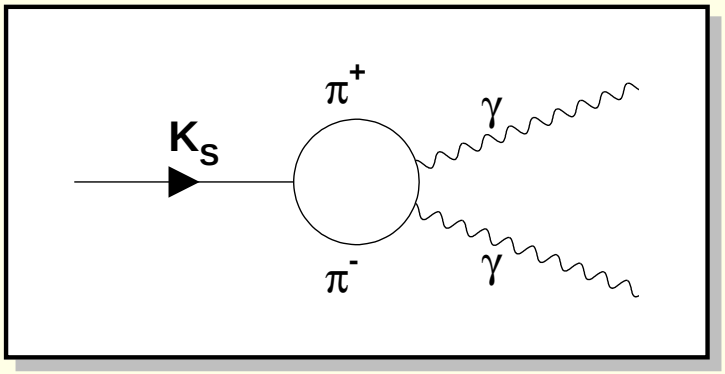
SND: $BR(K_S \to \pi^0\pi^0\pi^0) < 1.4 \times 10^{-5}$

Results on rare decays

$K_S \to \gamma\gamma$ measurement

Unambiguous and clean prediction of O(p^4) amplitude from χPT:

$BR = 2.1 \times 10^{-6}$ D'Ambrosio, Espriu Goity



⟹ Data from **2000 near-target** run, normalised to $K_S \to \pi^0\pi^0$ decay rate

⟹ Principal background sources:

$K_S \to \pi^0\pi^0$ with only 2 showers in the LKr calorimeter.

⟹ reconstructed vertex moves downstream due to missing energy

⟹ choose decays in $-1m < z_{vertex} < 5m$ wrt. collimator exit.

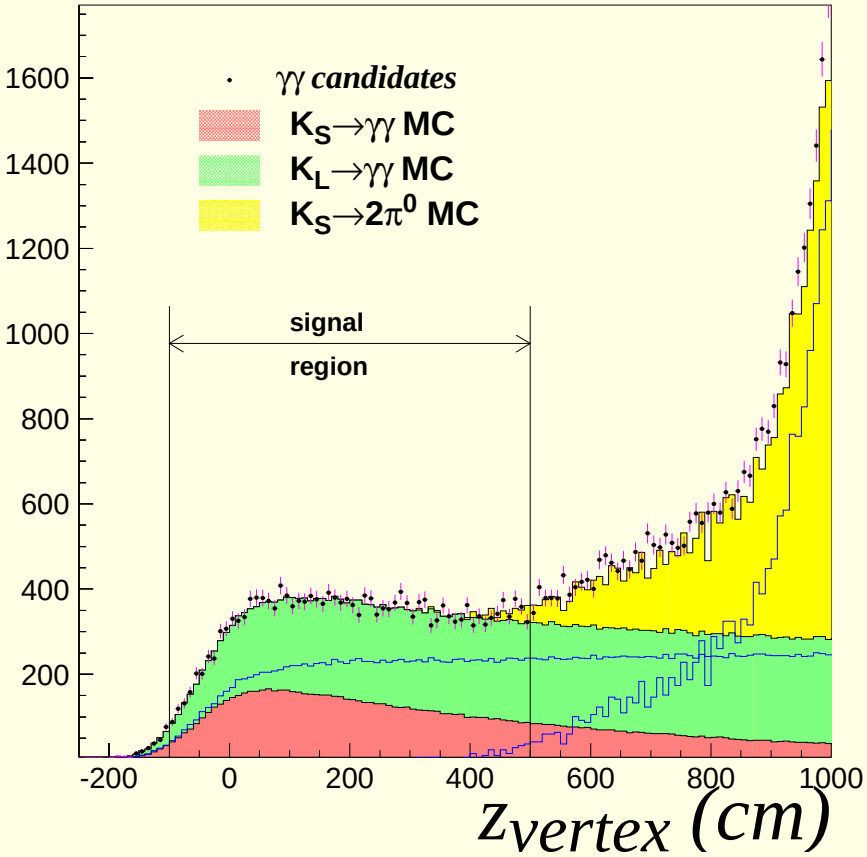
$K_L \to \gamma\gamma$ – irreducible: $\frac{N(K_L \to \gamma\gamma)}{N(K_S \to \gamma\gamma)} \sim 1.5$ in the decay volume

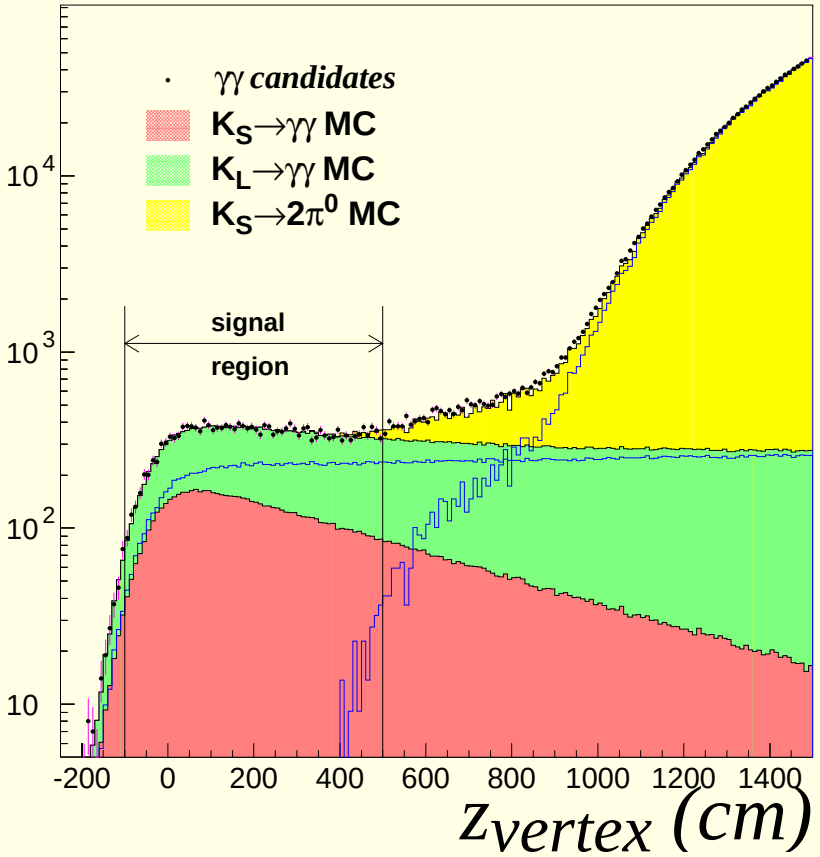
- use $K_L \to 3\pi^0$ to estimate K_L flux
- use **2000 far-target** run to measure $\frac{\Gamma(K_L \to \gamma\gamma)}{\Gamma(K_L \to 3\pi^0)}$ (present PDG accuracy insufficient)

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

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

$K_S \to \gamma\gamma$ measurement

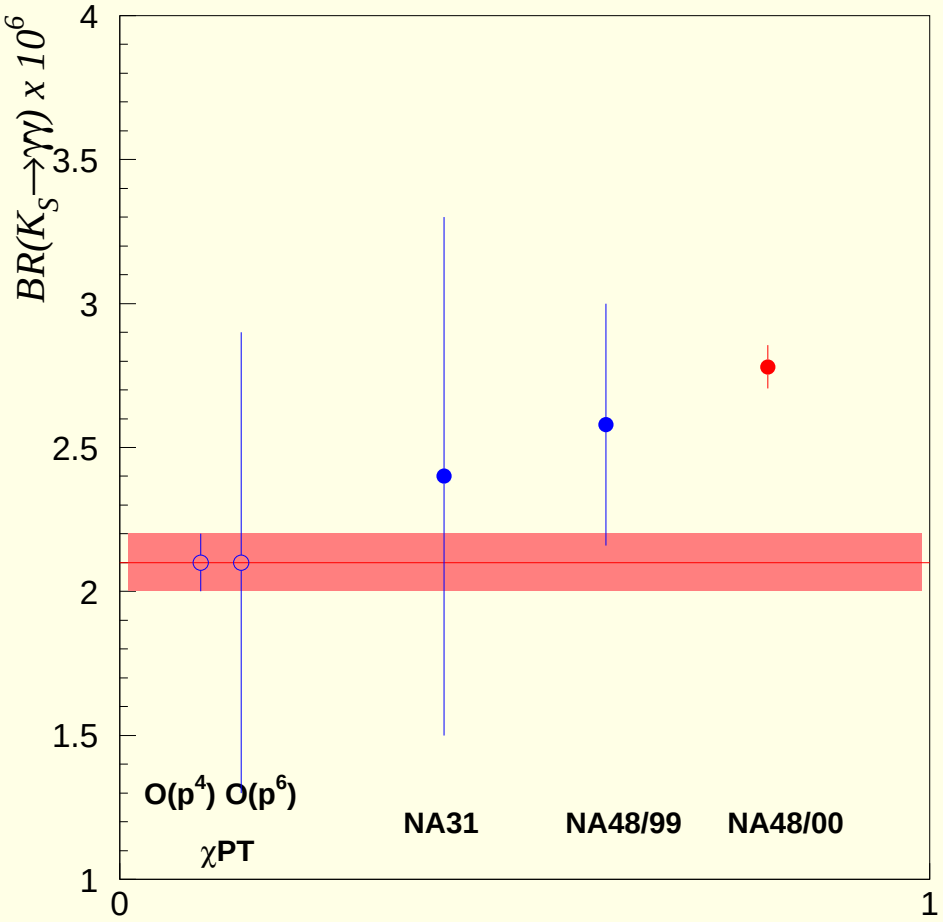




→ Result (Phys. Lett. B 551 (2003) 7)

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

$K_S \to \gamma\gamma$ measurement

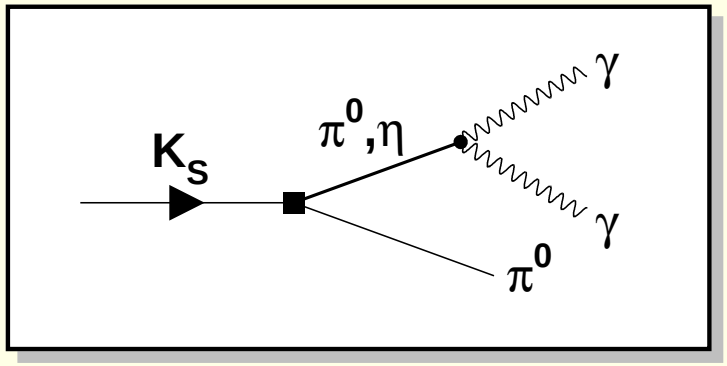


- The new result differs by 30% from O(p^4) prediction of χPT
- Indication of a large O(p^6) contribution
- Compatible with previous measurements

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

➡ Up to now unobserved: NA48 placed recently the best limit to
$BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} < 3.3 \times 10^{-7}$ at 90% CL from 1999 test-run data

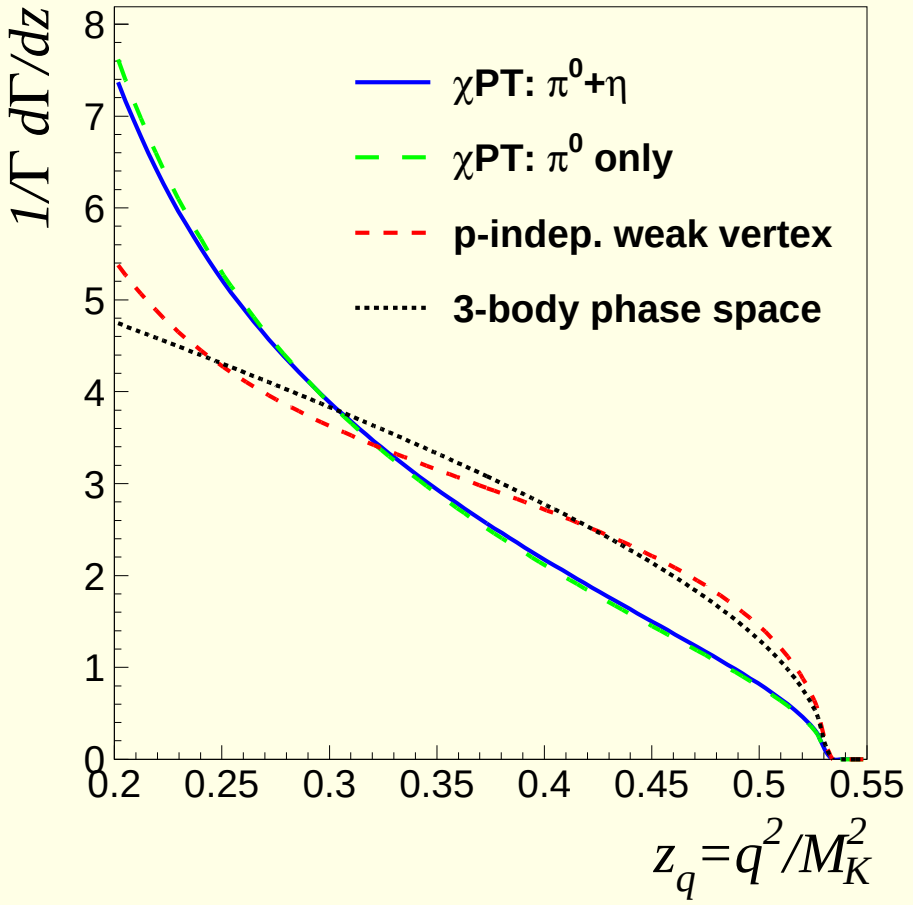
χPT predictions: Ecker, Pich and de Rafael: Phys. Lett B 189 (1987) 363.



χPT predicts:

- $BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} = 3.8 \times 10^{-8}$
- momentum dependence of the weak vertex

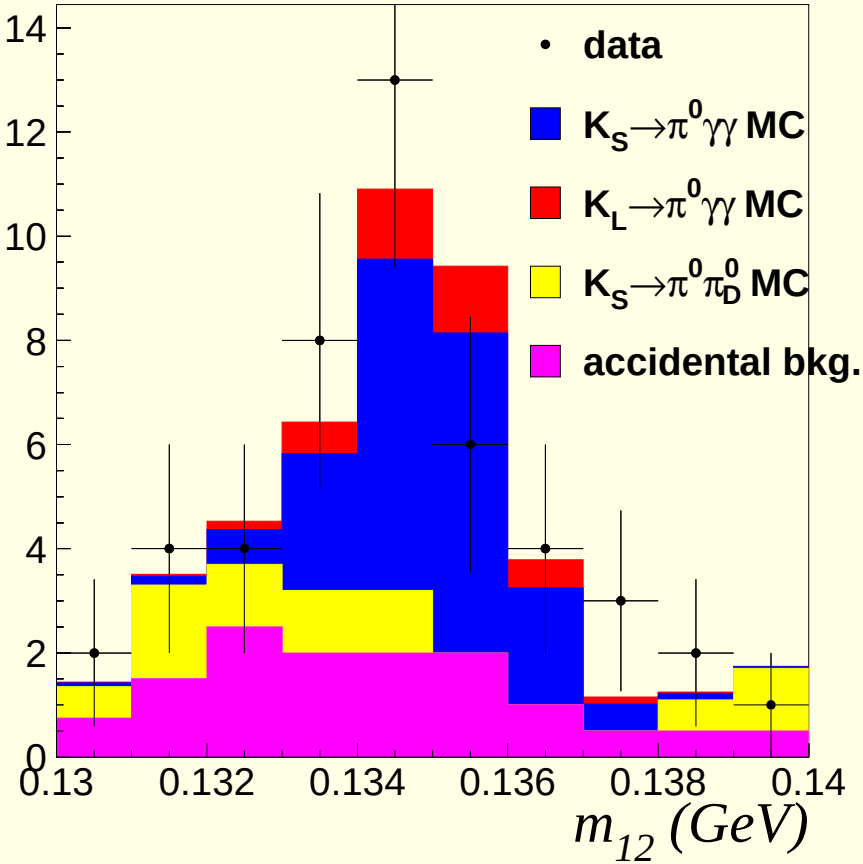
➡ chiral structure of the weak vertex is testable from the shape of the $z_q = (m_{34}/m_K)^2$ distribution



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

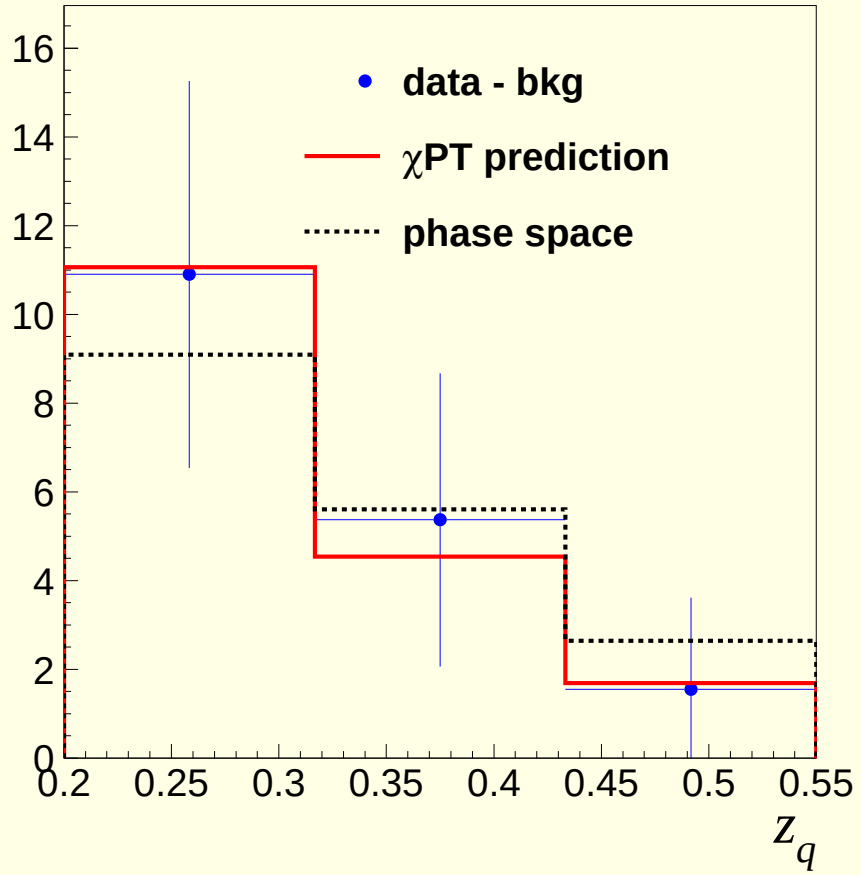
Preliminary

- **2000 near-target** data
- Normalised to $K_S \to \pi^0\pi^0$ decays
- Main backgrounds:
  - beam activity - time constraints anti-counters
  - $K_S \to \pi^0\pi^0$, $K_S \to \pi^0\pi^0_D$ - kinematic cuts
  - $K_L \to \pi^0\gamma\gamma$ - irreducible
  - $\Xi^0 \to \Lambda\pi^0 \to n\pi^0\pi^0$ - energy asymmetry



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

Preliminary



- Statistics insufficient to test the chiral structure of the weak vertex

$K_S \to \pi^0\gamma\gamma$ measurement - *Preliminary*

	events		
Number of events in sig. region	31.0	$\pm$	5.6
Beam activity	-7.4	$\pm$	2.4
$K_S \to \pi^0\pi^0_D$ background	-2.4	$\pm$	1.2
$K_L \to \pi^0\gamma\gamma$	-3.8	$\pm$	0.0
Acceptance		$\pm$	0.7
Remaining	17.4	$\pm$	6.2

Preliminary result:

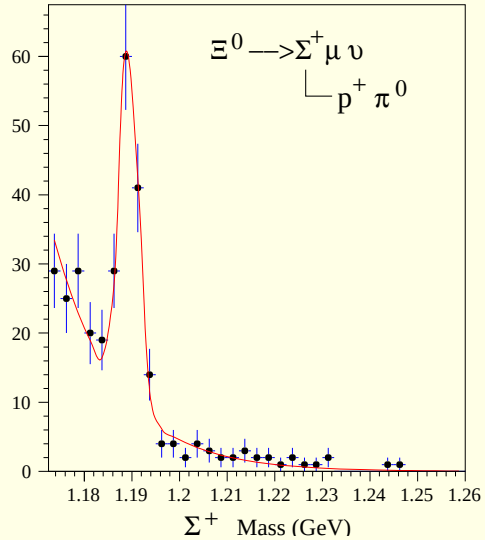
$$BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} = (4.9 \pm 1.6_{stat} \pm 0.8_{syst}) \times 10^{-8}$$

$$BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} = (4.9 \pm 1.7) \times 10^{-8}$$

(χPT Theory: $BR(K_S \to \pi^0\gamma\gamma)_{z_q>0.2} = 3.8 \times 10^{-8}$)

→ Probability that ≥ 31 events are consistent with background is $< 9 \times 10^{-4}$

Outlook



➡ 2002 run with **near-target neutral beam** was succesfull and analysis is advanced

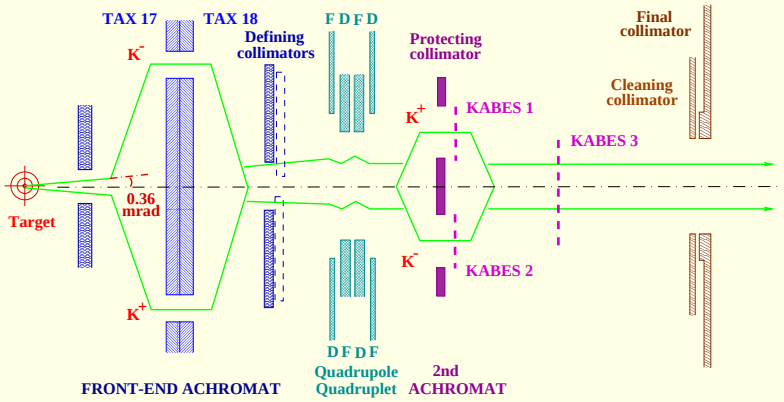
Main topics:

- Search for $K_S \to \pi^0 e^+ e^-$, $K_S \to \pi^0 \mu^+ \mu^-$ decays
- Ξ^0 beta decays
- Ξ^0 radiative decays
- Other K_S and hyperon rare decays

➡ Preparations for 2003 run with **charged kaon beam** are in full speed

Main topics:

- Search for direct CP violation by measuring slope asymmetry in $K^\pm \to 3\pi$ decays
- $K^\pm e4$ decay
- $K^\pm l3$ decays
- Rare $K^\pm$ decays



Summary

➡ CP violation

- The direct CP violation in $K^0 \to 2\pi$ measurement is finished with a highly significant result. The design precision was achieved.
- $\delta_L(e)$ has been measured with competitive precision
- An order of magnitude improvement in determination of η_{000} has been achieved – improvement of the CPT test using Bell-Steinberger relation

➡ Rare kaon decays

- Precise measurement of $K_S \to \gamma\gamma$ decay indicates a significant $O(p^6)$ contribution and provides an input for higher loop calculations of χPT
- Decay $K_S \to \pi^0\gamma\gamma$ was observed for the first time with BR in agreement with χPT

➡ There is more to come:

- NA48/1 studying K_S and hyperon decays collected successfuly data in 2002 and the analysis is in advanced stage
- NA48/2 run this year with simultaneous charged kaon beams is in full preparation