New result on direct CP violation from NA48

Benedetto Gorini
CERN

ICHEP2000, Osaka

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

Plan of the presentation

- Physics motivation
- NA48 experimental technique
- Analysis of the 1998 data
- Conclusions

The neutral kaon system

- Strangeness eigenstates:

$$K^0(\bar{s}d) \quad (S = +1)$$
$$\overline{K^0}(s\bar{d}) \quad (S = -1)$$

- CP eigenstates:

$$K_1 = (K^0 + \overline{K^0})/\sqrt{2} \quad (CP = +1)$$
$$K_2 = (K^0 - \overline{K^0})/\sqrt{2} \quad (CP = -1)$$

- Mass and Lifetime eigenstates:

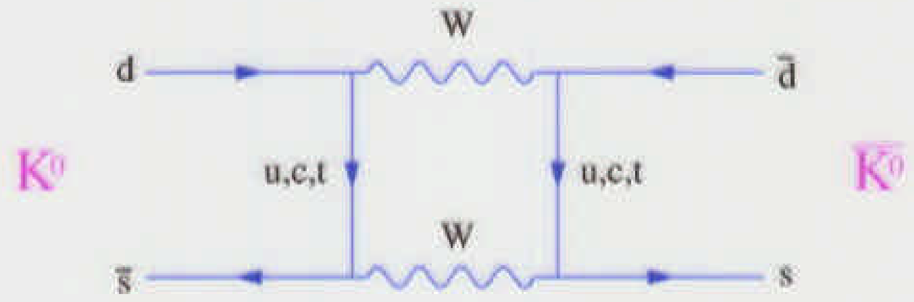
$$K_S \simeq K_1 + \varepsilon K_2 \quad (c\tau_S = 2.67\ \mathrm{cm})$$
$$K_L \simeq K_2 + \varepsilon K_1 \quad (c\tau_L = 15.5\ \mathrm{m})$$

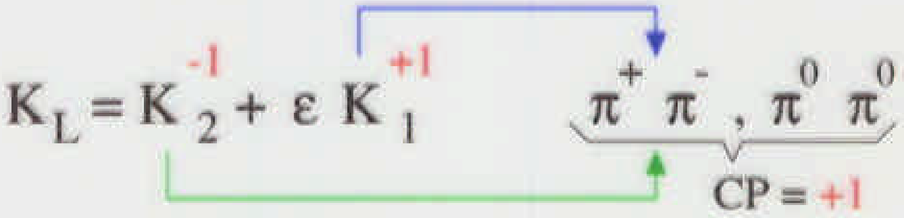
K_S		K_L	
69 %	$\pi^+\pi^-$	21 %	$3\pi^0$
31 %	$\pi^0\pi^0$	13 %	$\pi^+\pi^-\pi^0$
		27 %	$\pi\mu\nu$
		39 %	$\pi e\nu$
		0.2 %	$\pi^+\pi^-$
		0.1 %	$\pi^0\pi^0$

$$\varepsilon = (2.28 \pm 0.02) \times 10^{-3}$$

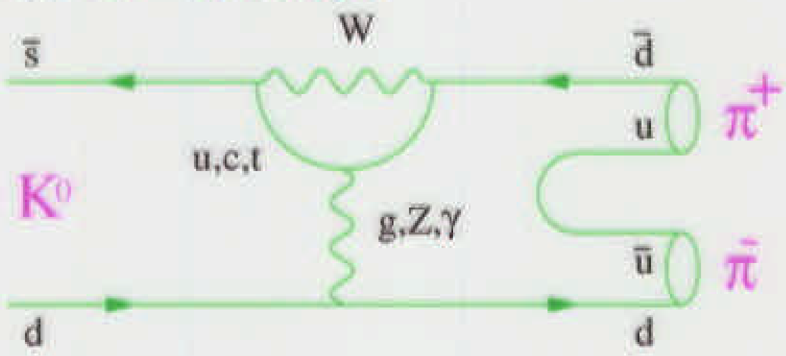
CP Violation in the neutral kaons

$\varepsilon \Rightarrow$ Indirect CP violation via $K^0/\overline{K^0}$ mixing





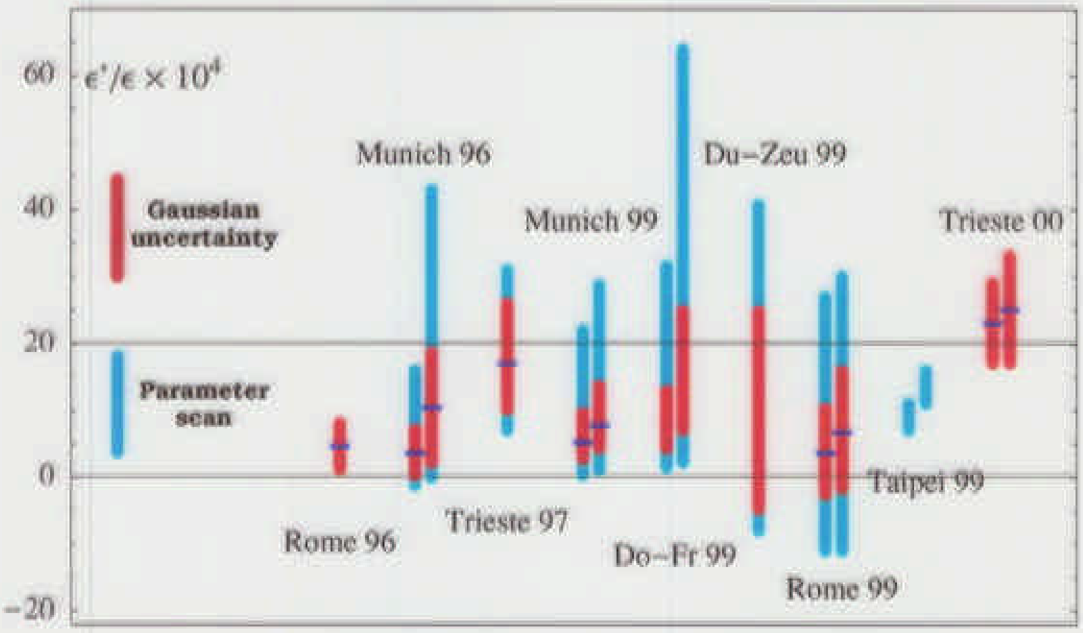
$\varepsilon' \Rightarrow$ Direct CP violation:



- $\varepsilon' = \frac{i}{\sqrt{2}} \Im m \frac{A_2}{A_0} \exp(i(\delta_2 - \delta_0))$
- $A(K^0 \rightarrow \pi\,\pi\,, I) = A_I \exp(i\delta_I)$
- $A(\overline{K^0} \rightarrow \pi\,\pi\,, I) = A_I^* \exp(i\delta_I)$

Predictions and measurements on $\mathrm{Re}(\varepsilon'/\varepsilon)$

- Standard Model Predictions:



- Latest published measurements:

$$\mathrm{Re}(\varepsilon'/\varepsilon) = \begin{array}{lll} (7.4 \pm 5.9) \times 10^{-4} & \text{E731} & 1993 \\ (23.0 \pm 6.5) \times 10^{-4} & \text{NA31} & 1993 \\ (28.0 \pm 4.1) \times 10^{-4} & \text{KTeV} & 1999 \\ (18.5 \pm 7.3) \times 10^{-4} & \text{NA48} & 1999 \end{array}$$

NA48 experimental strategy

- Measure the Double Ratio R :

$$\eta_{+-} \equiv \frac{A(K_L \to \pi^+\pi^-)}{A(K_S \to \pi^+\pi^-)} \simeq \varepsilon + \varepsilon'$$

$$\eta_{00} \equiv \frac{A(K_L \to \pi^0\pi^0)}{A(K_S \to \pi^0\pi^0)} \simeq \varepsilon - 2\,\varepsilon'$$

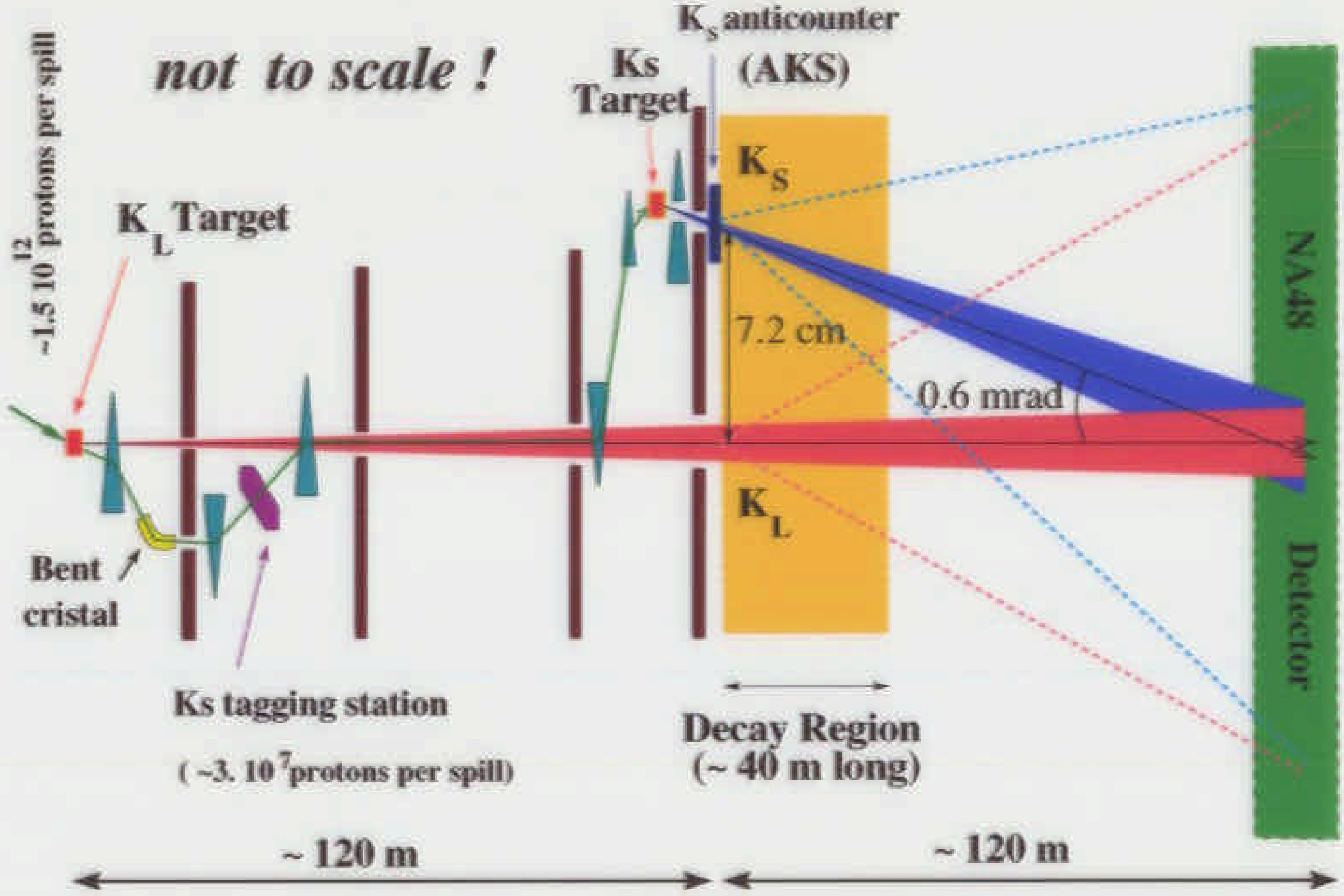
$$\Downarrow$$

$$\mathrm{Re}(\varepsilon'/\varepsilon) \simeq \frac{1}{6}\left\{1 - \frac{\frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)}}{\frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}}\right\} = \frac{1}{6}(1 - \mathrm{R})$$

- Collect $> 10^6$ $K_L \to \pi^0\pi^0$ (rarest mode)
- Minimal corrections ⇒ 4 modes measured
  - concurrently
    ⇒ minimise effect of accidental activity and inefficiencies
  - in the same fiducial volume
    ⇒ minimise acceptance corrections
  - with an apparatus based on
    * magnetic spectrometer ($\pi^+\pi^-$ mode)
    * liquid Krypton homogeneous calorimeter ($\pi^0\pi^0$ mode)

    ⇒ good resolutions ⇒ small background levels

Simultaneous K_S and K_L beams



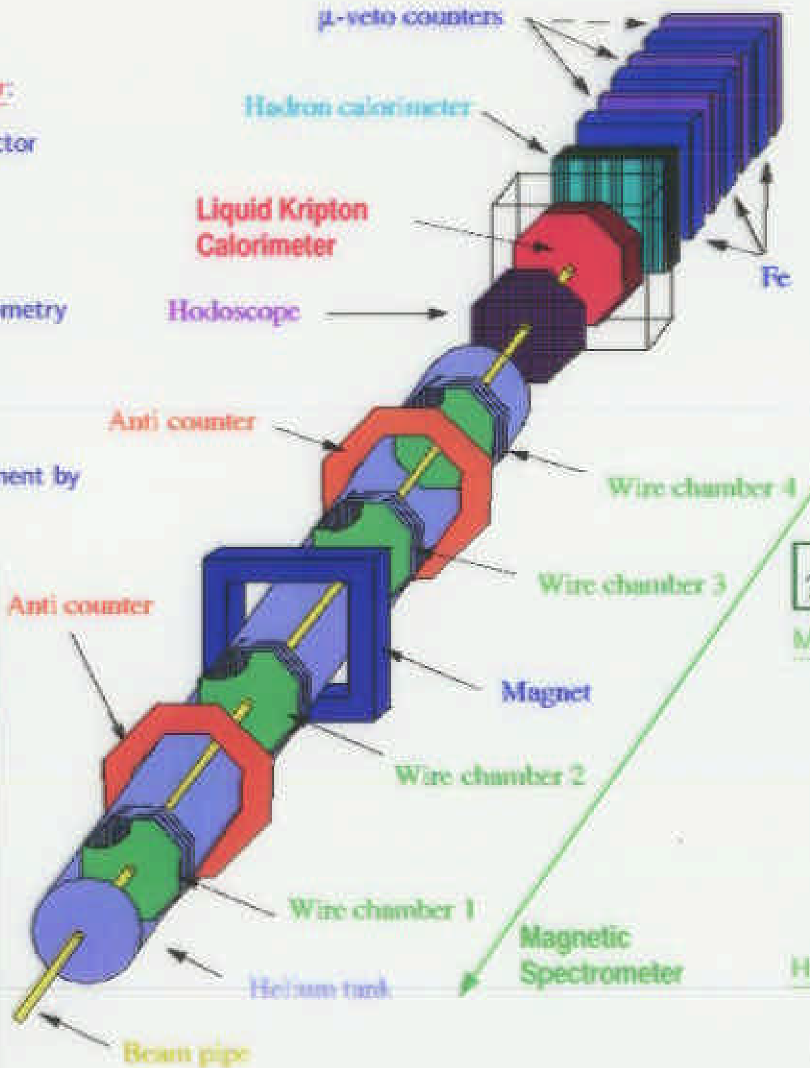
☞ K_S are distinguished from K_L by measuring the T.O.F. between the protons in the tagger and the kaon decay products in the detector

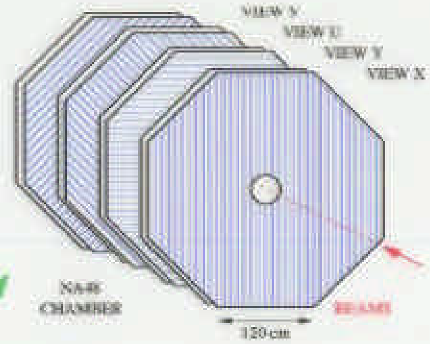
NA48 detector

$\pi^0\pi^0$

LKr electromagnetic calorimeter:

- quasi-homogeneous detector based on 9 m^3 LKr
- Cu–Be electrodes
- 13212 2 × 2 × 127 cm^3
- ± 48 mrad accordion geometry
- projective geometry
- geometry machined with 0.2 mm/m accuracy
- redundant time measurement by scintillating fiber neutral hodoscope





$\pi^+\pi^-$

Magnetic Spectrometer:

- 4 chambers with 4 views each, 2 staggered planes per view
- 90 μm spacepoint resolution
- wire position known better than 100 $\mu m/m$
- magnet providing 265 MeV/c p_T kick

Hodoscope:

- 2 planes of scintillators for precise measurement of event time

NA48 data samples

- 1997: 89 days, 1×10^{12} ppp on $\mathrm{K_L}$ target

  ⇒ 0.49 million of $K_L \rightarrow \pi^0\pi^0$

  PUBLISHED Phys. Lett. B 465 (1999)

  $$\mathrm{Re}(\varepsilon'/\varepsilon) = (18.5 \pm 4.5 \pm 5.8) \times 10^{-4}$$

- 1998: 135 days, $\sim 1.4\times10^{12}$ ppp on $\mathrm{K_L}$ target

  Main improvements :

  - LKr High Voltage 1500 → 3000 V
  - Charged trigger efficiency 91.3 → 97.7 %
  - Carbon fibre pipe → less showers in the detectors
  - New data acquisition system (PC farm) + 30 % rate

  ⇒ 1.14 million of $K_L \rightarrow \pi^0\pi^0$
  ⇒ four-fold increase of $\pi^+\pi^-$

- 1999: 128 days, $\sim 1.4\times10^{12}$ ppp on $\mathrm{K_L}$ target

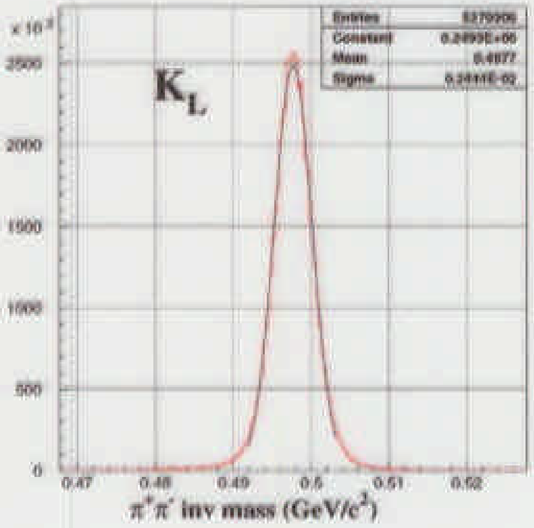
  Further improvements :

  - DCh read-out, dead time, DAQ efficiency, spill length

  ⇒ Around 2 million of $K_L \rightarrow \pi^0\pi^0$

  ANALYSIS in progress...

$K^0 \rightarrow \pi^+ \pi^-$ reconstruction



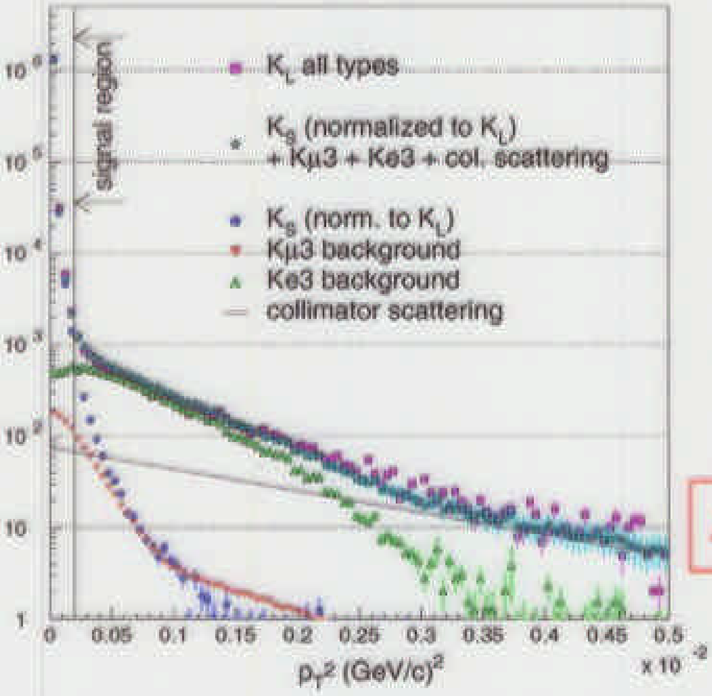
$$\frac{\sigma(p)}{p} \simeq 0.5\% \oplus 0.009\, p\%$$

(p in GeV/c)

$\Downarrow$

Kaon mass resolution

$\sim$ 2.5 MeV/c^2



Background rejection:

- No hits in the μ counters
- $E/p < 0.8$

$\Delta R = (+19 \pm 3) 10^{-4}$

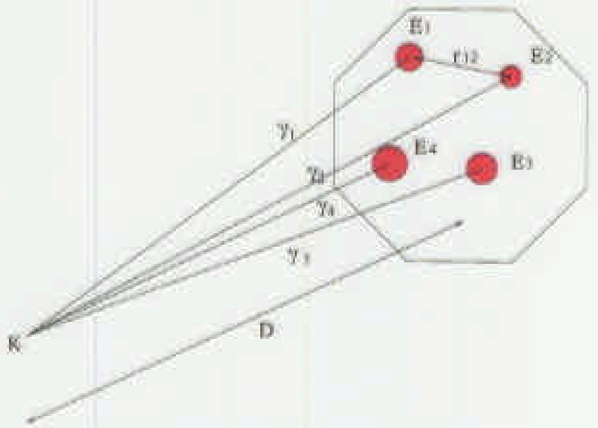
☞ $\pi^+\pi^-$ energy computed from opening angle and tracks energy ratio :

$$E_K^2 = (C/\theta^2)\left\{m_K^2 - C\, m_\pi^2\right\}$$
$$C = 2 + E_{\pi 1}/E_{\pi 2} + E_{\pi 1}/E_{\pi 2}$$

$\Rightarrow$ depends only on the geometry of the drift chambers

$K^0 \rightarrow \pi^0 \pi^0$ reconstruction

$K^0 \rightarrow 2\pi^0 \rightarrow 4\gamma$



$$D = \frac{\sqrt{\sum E_i E_j \times (r_{ij})^2}}{M_K}$$

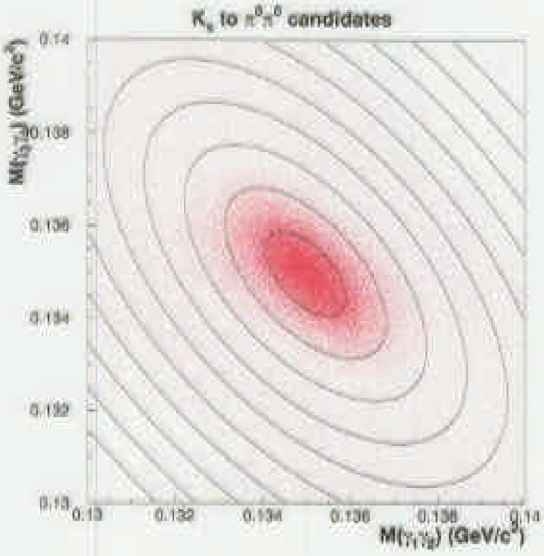
$$m_{ij} = \frac{\sqrt{E_i E_j} \cdot r_{ij}}{D}$$

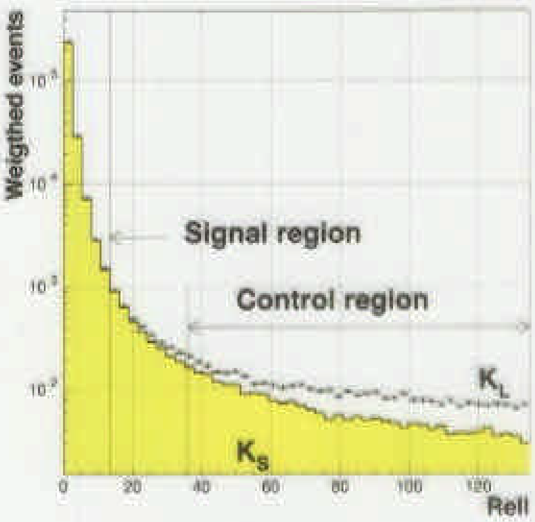
- Select best masses:

$$R_{ell} = \left[\frac{(m_1+m_2)/2-m_{\pi^0}}{\sigma_+}\right]^2 + \left[\frac{(m_1-m_2)/2}{\sigma_-}\right]^2$$

- $3\,\pi^0$ background rejection:

  Cut on in-time extra photons (± 3ns)





$$\Delta R = (-7 \pm 2) \times 10^{-4}$$

$\pi^0\pi^0$ energy scale

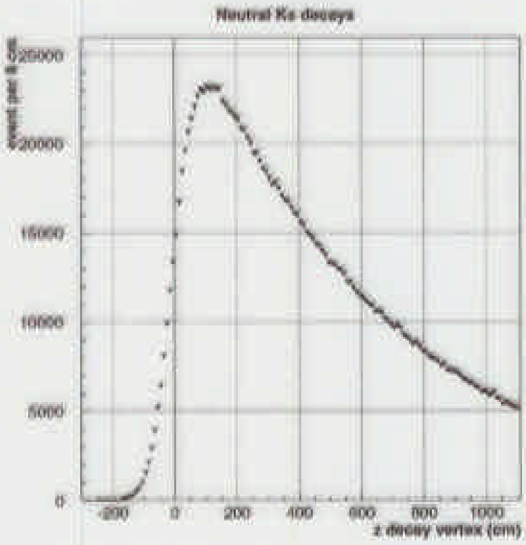
$$E_M = (1+\alpha)\times E_T$$

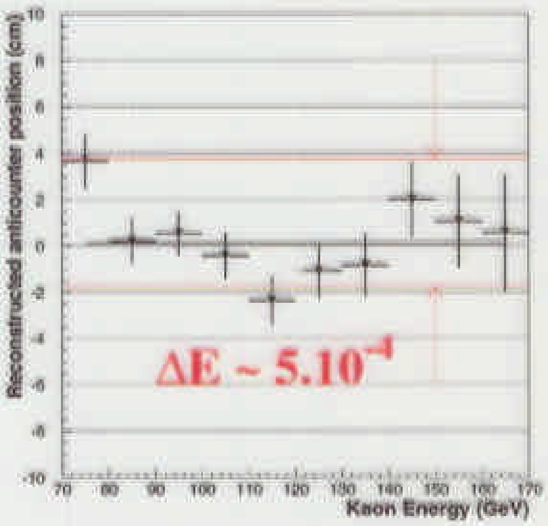
α = uncertainty on the $\pi^+\pi^-/\pi^0\pi^0$ energy scale

The beginning of the K_S decay region is defined by an anti-counter (AKS)

The energy of the $\pi^0\pi^0$ is determined by the Lkr
$\Rightarrow$ it relies on the calibration of the calorimeter

To set the overall distance/energy scale, the position of the K_S anti-counter is used as a reference in $K_S \rightarrow \pi^0\pi^0$ events

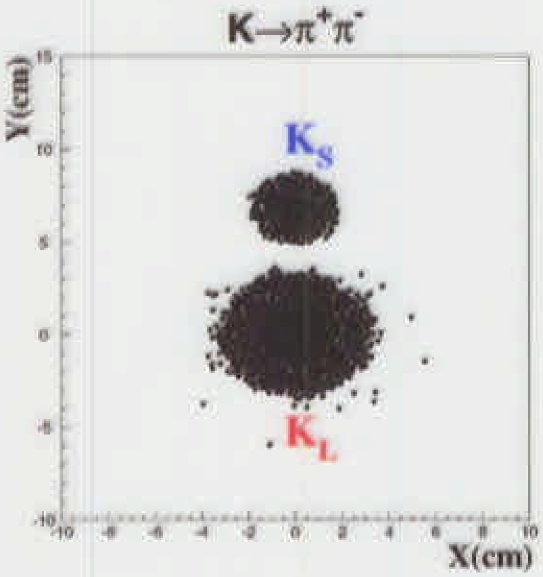


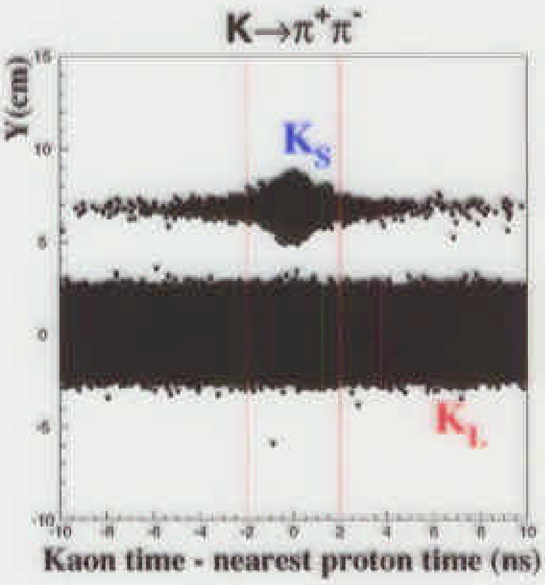


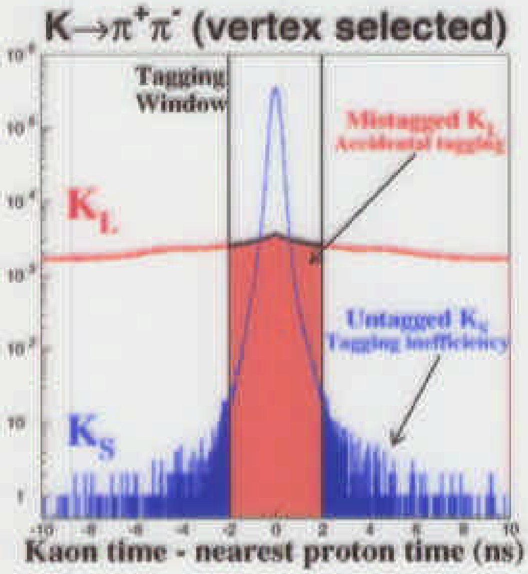
$$\Delta R < 10\times 10^{-4}$$

Tagging

- Direct cross check for $K \to \pi^+\pi^-$







Tagging inefficiency

$P(K_S \to K_L)$:

$\alpha_{SL}^{+-} = (1.97 \pm 0.05) 10^{-4}$

Accidental tagging

$P(K_L \to K_S)$:

$\alpha_{LS}^{+-} = (11.05 \pm 0.01)\%$

- Indirect methods to check for $K \to \pi^0\pi^0$

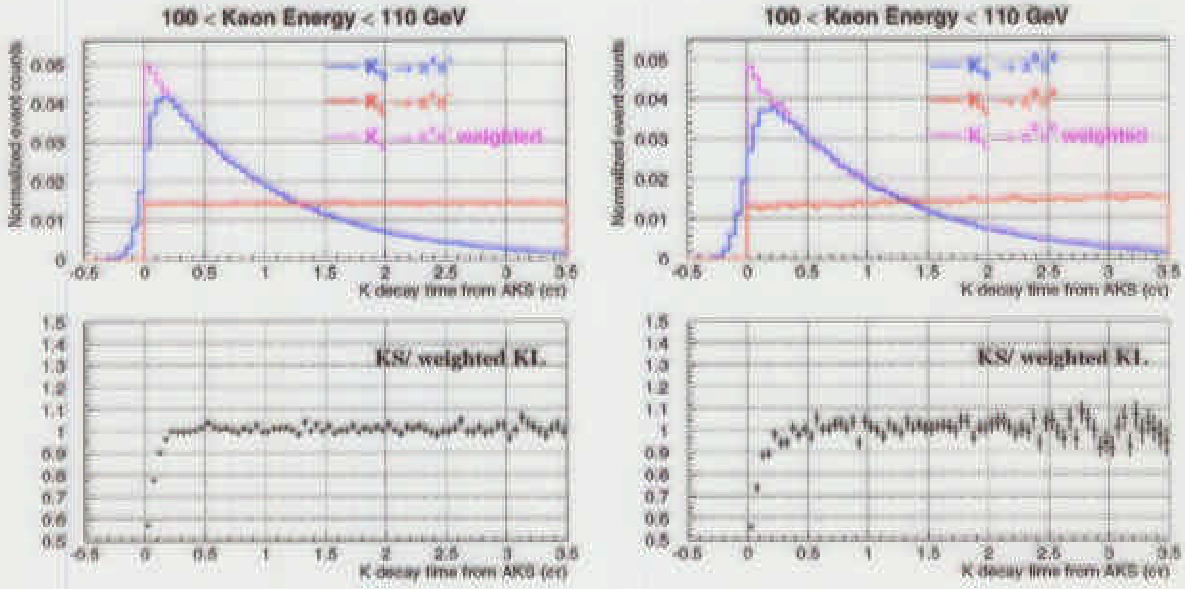
$$|\alpha_{SL}^{00} - \alpha_{SL}^{+-}| < 0.5 \times 10^{-4}$$

$$\Delta R < 3 \times 10^{-4}$$

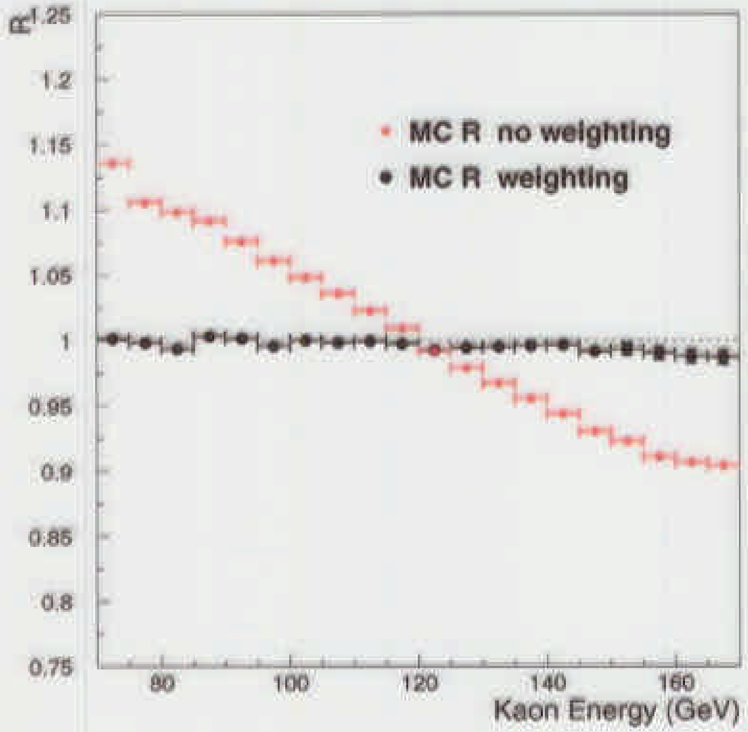
$$\alpha_{LS}^{00} - \alpha_{LS}^{+-} = (0.5 \pm 4) \times 10^{-4}$$

$$\Delta R = (1 \pm 8) \times 10^{-4}$$

K_L weighting



☞ K_L are weighted with the K_S proper time



The increase of the statistical error due to weighting is 35%

$$\Delta R = (+31 \pm 6(stat) \pm 6(syst)) \times 10^{-4}$$

1998 result: corrections on R

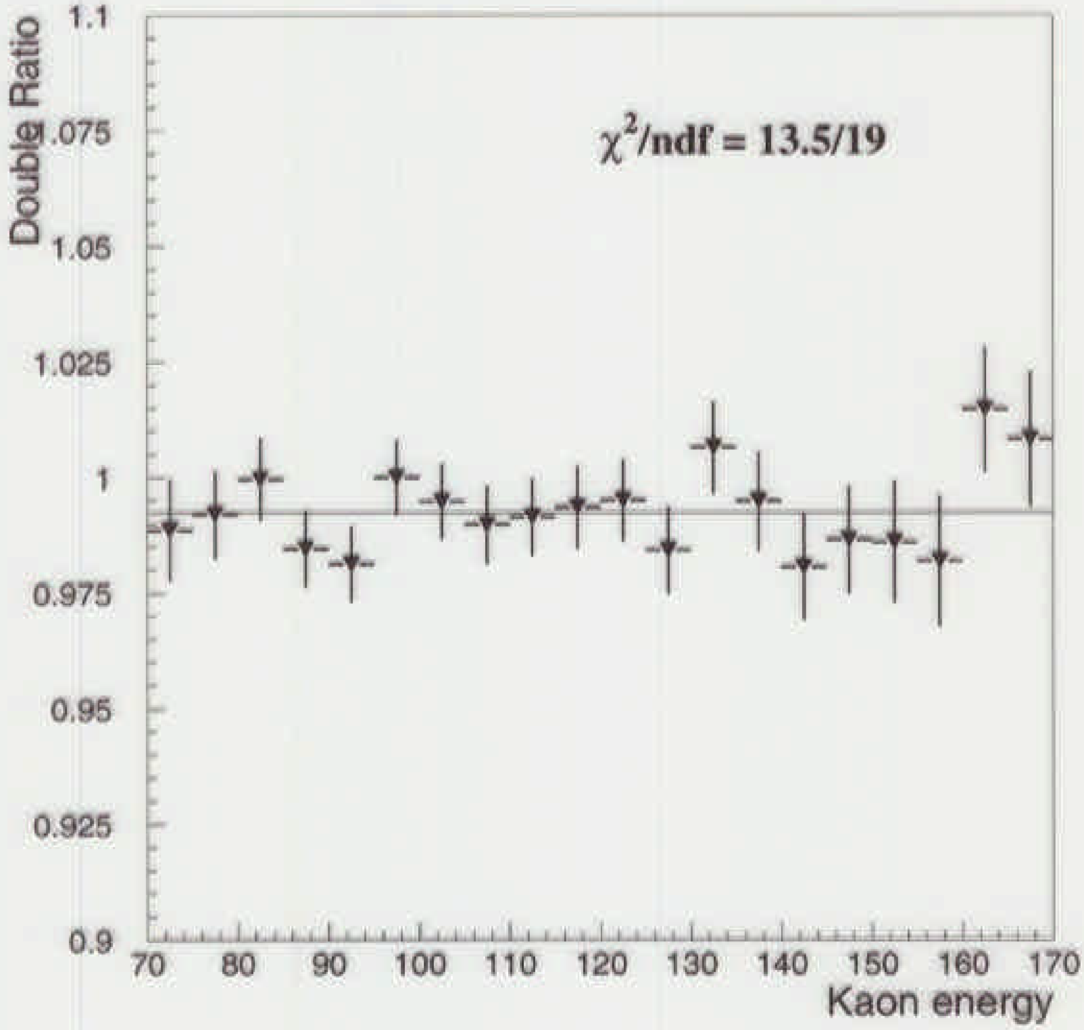
Statistics (millions) 1998			
$K_S \to \pi^+\pi^-$	7.46	$K_L \to \pi^+\pi^-$	4.87
$K_S \to \pi^0\pi^0$	1.80	$K_L \to \pi^0\pi^0$	1.14

Corrections and systematic uncertainties on R (Units = 10^{-4})		
Source	1998 sample	
Charged trigger	−1	± 11
Mistagging probability	+1	± 8
Tagging efficiency	–	± 3
Neutral scale	–	± 10
Charged vertex	+2	± 2
Acceptance and AKS eff.	+31	± 9
Neutral BG	−7	± 2
Charged BG	+19	± 3
Beam scattering	−10	± 3
Accid. activity and in-time BG	+2	± 12
Total	+37	± 24

$$R = 0.99267 \pm 0.00173(stat.) \pm 0.00238(syst.)$$

1998 result

PRELIMINARY RESULT ON 1998 DATA



$$\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 2.9\,(\mathrm{stat.}) \pm 4.0\,(\mathrm{syst.})) \times 10^{-4}$$

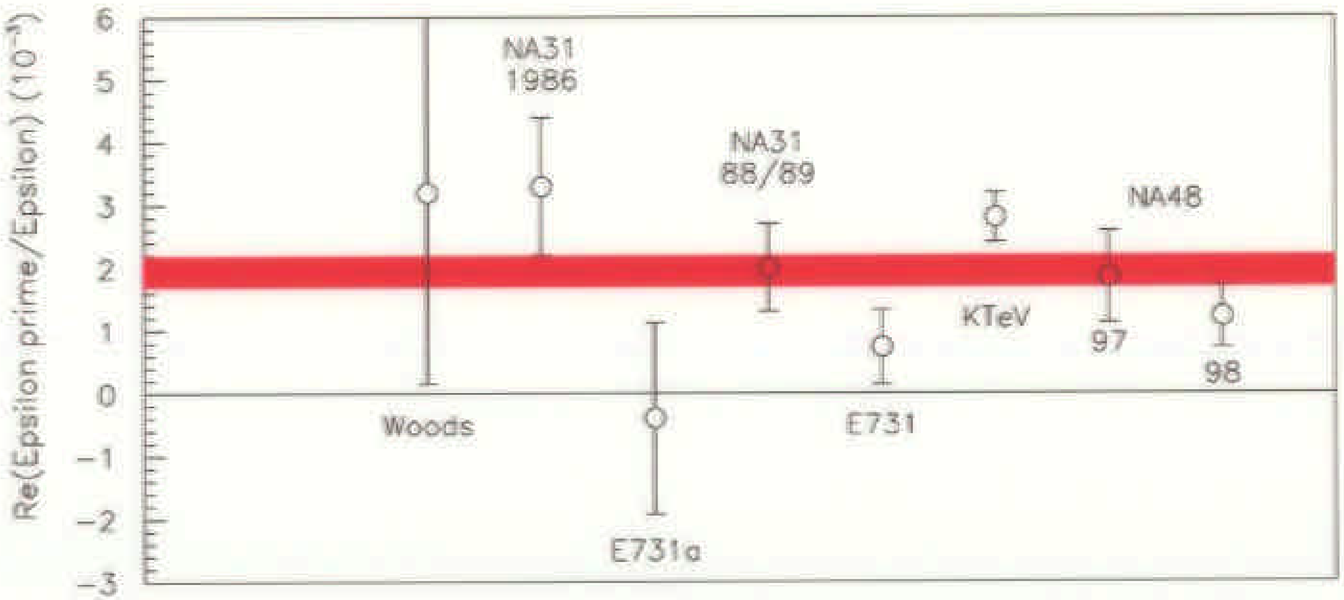
$$\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 4.9) \times 10^{-4}$$

This result is preliminary. The systematic uncertainty is partly of statistical nature

Combined 1997 and preliminary 1998

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4}$$

New world average



New world average:

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (19.3 \pm 2.4) \times 10^{-4}$$

$(\chi^2/ndf = 11.1/5)$

Conclusions

- NA48 has presented a new preliminary measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$ based on the 1998 data sample:

$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 4.9) \times 10^{-4}}$$

- Combining this result with the NA48 published data and taking into account the (small) correlated systematics, we obtain:

$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) = (14.0 \pm 4.3) \times 10^{-4}}$$

- The result confirms a non-zero, positive value for $\mathrm{Re}(\varepsilon'/\varepsilon)$

- Improvement on systematics expected.
  1999 data analysis in progress

- New results are expected from KTEV (FNAL) and KLOE (DAΦNE)