Update on ϵ'/ϵ from the NA48 experiment

Patrizia Cenci
INFN Perugia - Italy

July 18, 2000
III Workshop on Chiral Dynamics

Jefferson Lab - Newport News - Virginia

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

Outline:

- The NA48 method
- The Re(ϵ'/ϵ) analysis of 1998 data
- Prospects and conclusions

The NA48 method

The double ratio R definition:

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

$\Rightarrow$ if K_S/K_L or $\pi^+\pi^-/\pi^0\pi^0$ are collected at the same time then $\mathrm{Re}(\varepsilon'/\varepsilon)$ is connected to four observable numbers:

$$\boxed{R = \frac{N_L^{00}}{N_S^{00}} \Big/ \frac{N_L^{+-}}{N_S^{+-}} \simeq 1 - 6\,\mathrm{Re}(\varepsilon'/\varepsilon)}$$

R measurement $\Rightarrow$ count number of events

Previous measurements of $\mathrm{Re}(\varepsilon'/\varepsilon)$ **:**

NA31	$(23.0 \pm 6.5) \times 10^{-4}$	(3.5σ)
E731	$(7.4 \pm 5.9) \times 10^{-4}$	(1.2σ)
KTEV	$(28.0 \pm 4.1) \times 10^{-4}$	(6.8σ)
NA48 97	$(18.5 \pm 7.3) \times 10^{-4}$	(2.5σ)

The NA48 method

Method: double ratio technique

Aim: 2×10^{-4} ultimate accuracy on $\mathrm{Re}(\varepsilon'/\varepsilon)$

High statistics: collect (limiting mode):

$$4 - 5 \times 10^{6} \ \ \mathrm{K_L} \ \rightarrow \pi^0\pi^0$$

- High intensity beam
- Powerful Trigger and DAQ systems

Minimize systematics effects:

- use simultaneous $\mathrm{K_S}$ and $\mathrm{K_L}$ beams
- the 4 modes are collected simultaneously and from the same fiducial volume (lifetime $< 3.5\tau_S$)

$\Rightarrow$ cancellation of fluxes, inefficiencies, dead time, accidental activity losses

- lifetime weighting is applied to equalize $\mathrm{K_L}$ and $\mathrm{K_S}$ decay positions

$\Rightarrow$ minimize acceptance corrections

- use a high resolution magnetic spectrometer for $\pi^+\pi^-$ and a quasi-homogeneous Liquid Krypton calorimeter for $\pi^0\pi^0$

$\Rightarrow$ minimize background levels

- analysis in bins of energy to eliminate slight differences in kaon energy spectra

Measurement of R step by step:

⇒ Identify K_L and K_S events by proton tagging and check the misidentification probabilities;

⇒ Identify $\pi^+\pi^-$ and $\pi^0\pi^0$ decays and subtract the small residual background;

⇒ Define the same fiducial region to count $\pi^+\pi^-$ and $\pi^0\pi^0$ events (energy scale definition);

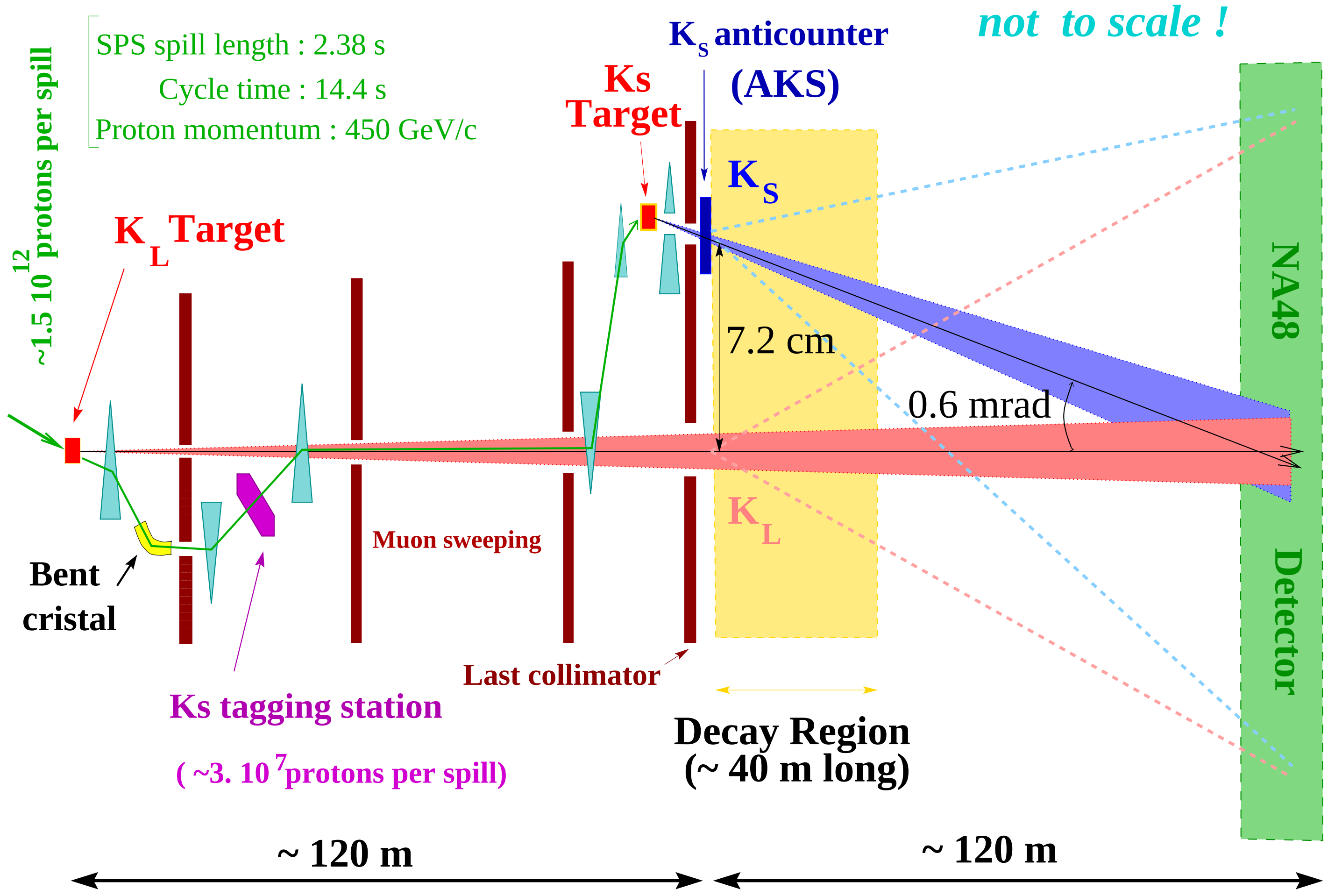
⇒ Weight K_L events and correct for small residual acceptance differences;

⇒ Check other systematics effects: trigger efficiency, accidental activity.

Systematics corrections applied to R:

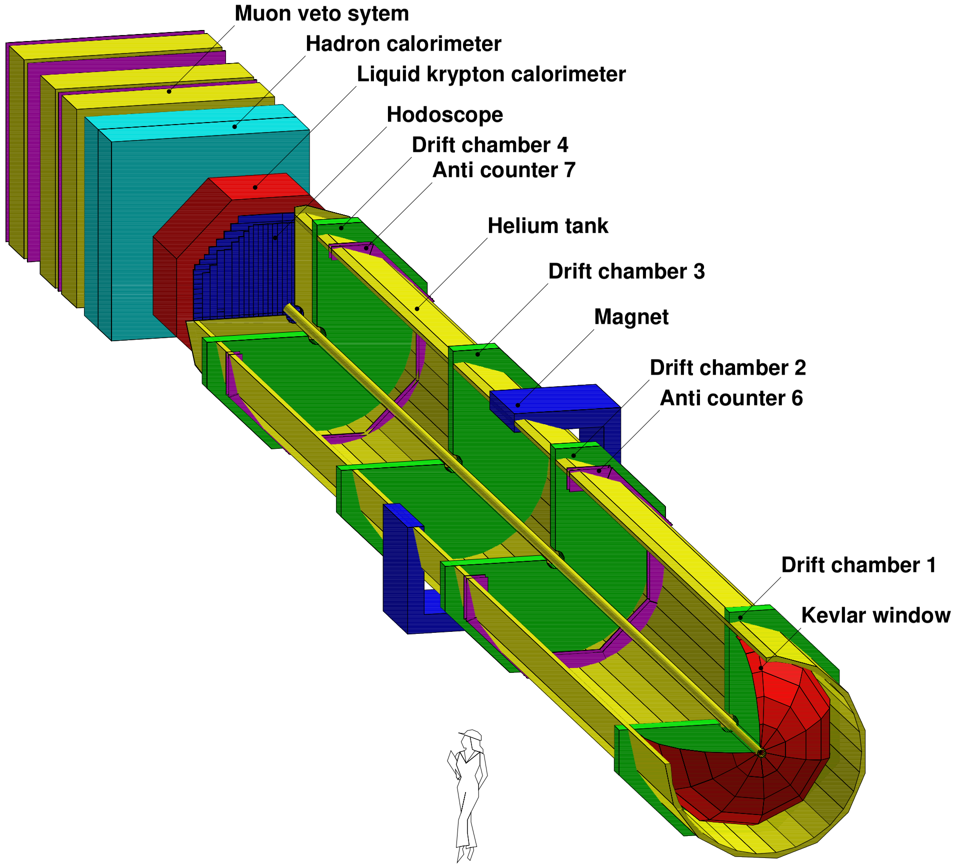
- K_S and K_L identification by proton tagging
- trigger inefficiency
- background subtraction
- energy scale definition
- acceptance difference
- accidental activity

NA48: simultaneous K_L and K_S beams



- K_S are distinguished from K_L by tagging the protons upstream of the K_S target
- All the 4 decay modes are collected from the same decay region

NA48: detectors



- $\mathrm{K_{L,S}} \to \pi^+\pi^-$
  - magnetic spectrometer ($\sigma_{x,y} \sim 90\ \mu m$)
  - scintillator hodoscope for timing ($\sigma_t \sim 200\ ps$)
  - muon veto (background rejection)
- $\mathrm{K_{L,S}} \to \pi^0\pi^0$
  - quasi-homogeneous Liquid Krypton electromagnetic calorimeter:
    - ∗ high granularity (13212 cells $2 \times 2\ cm^2$)
    - ∗ projective geometry

NA48: Data sample

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

  $\Rightarrow$ 0.49 million of $K_L \to \pi^0\pi^0$

  PUBLISHED Phys. Lett. B 465 (1999)

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

- 1998: 135 days, $\sim1.4\times10^{12}$ ppp on $\mathrm{K_L}$ target

  Main improvements:

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

  $\Rightarrow$ 1.14 million of $K_L \to \pi^0\pi^0$

  $\Rightarrow$ four-fold increase of $\pi^+\pi^-$

  PRELIMINARY RESULT now

- 1999: 128 days, $\sim1.4\times10^{12}$ ppp on $\mathrm{K_L}$ target

  Further improvements:

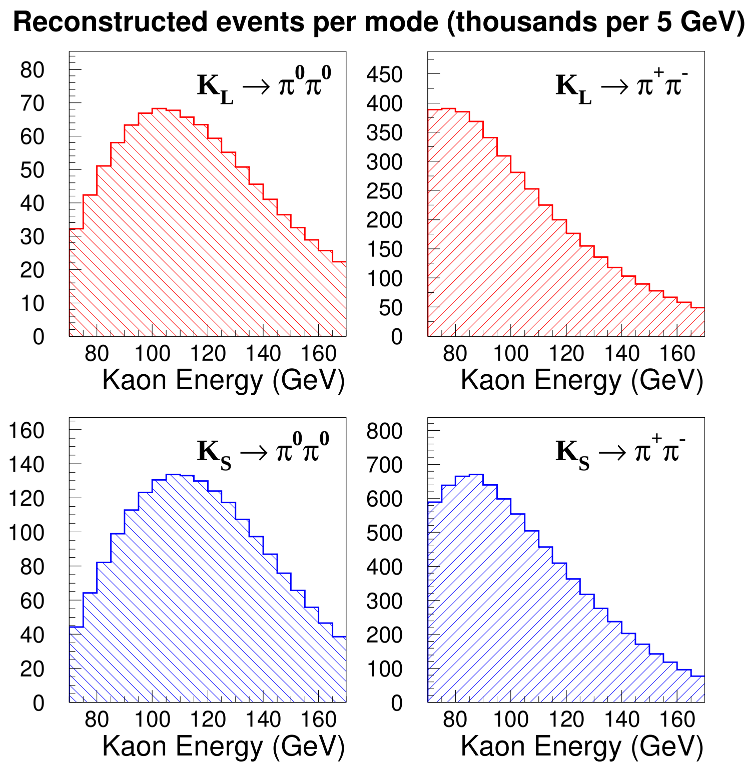
  - DCh read-out, dead time, DAQ efficiency, spill length

  $\Rightarrow \sim$ 2 million of identified $K_L \to \pi^0\pi^0$

  ANALYSIS in progress

NA48: Analysis strategy

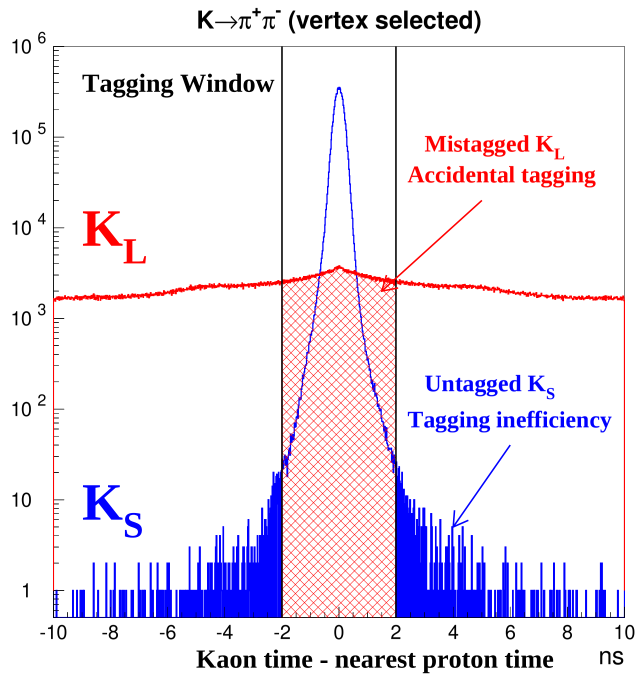
- $70 < E_{\mathrm{K}} < 170$ GeV
- Decay region: $0 < t < 3.5\,\tau_{\mathrm{S}}$
- Centre of Gravity: $R_{\mathrm{cog}} < 10\,\mathrm{cm}$



- Charged dead time (<5 % from charged trigger and ≈ 25 % from DCH read out) is applied to neutrals
  ⇒ symmetric collection of events
- All corrections are applied in bins of energy to account for the slight difference in the spectra of $\mathrm{K_S}$ and $\mathrm{K_L}$

NA48: Tagging

K_L / K_S identification: TOF between a reconstructed Kaon decay and the tagger



- Tagging inefficiency α_{SL}: $K_S \rightarrow K_L$

  the $\pi^+\pi^+/\pi^0\pi^0$ difference comes from tails in the detector (hodoscope/LKr) time distributions

- Accidental tagging α_{LS}: $K_L \rightarrow K_S$

  accidental protons in the ± 2 ns tagging window

- Vertex reconstruction is used for $K \rightarrow \pi^+\pi^-$:

  $\alpha_{LS}^{+-} = (11.05 \pm 0.01)\%$ $\alpha_{SL}^{+-} = (1.97 \pm 0.05) \times 10^{-4}$

- Indirect methods are used in $K \rightarrow \pi^0\pi^0$:

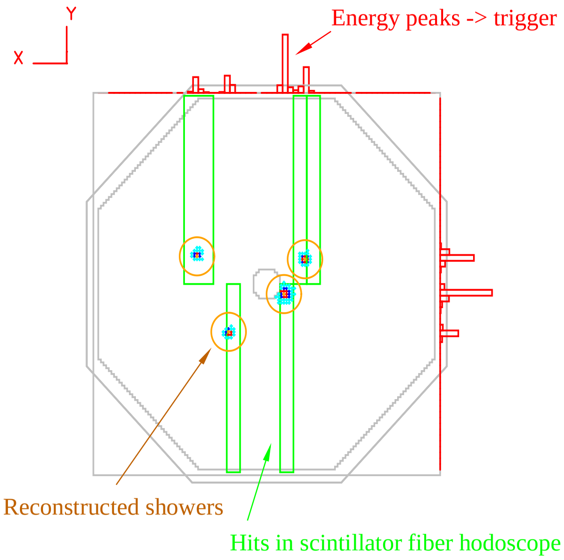
  $|\alpha_{SL}^{00} - \alpha_{SL}^{+-}| < 0.5 \times 10^{-4}$ $\boxed{\Delta R < 3 \times 10^{-4}}$

  $\alpha_{LS}^{00} - \alpha_{LS}^{+-} = (0.5 \pm 4)\ 10^{-4}$ $\boxed{\Delta R = (1 \pm 8) \times 10^{-4}}$

NA48: Triggers

$\pi^0\pi^0$ trigger

- Fully pipelined system use LKr cells information to compute energy, centre of gravity and proper time
- Output rate $\sim$ 2 kHz
- Negligible dead time
- Efficiency:
  99.93 ± 0.02 %

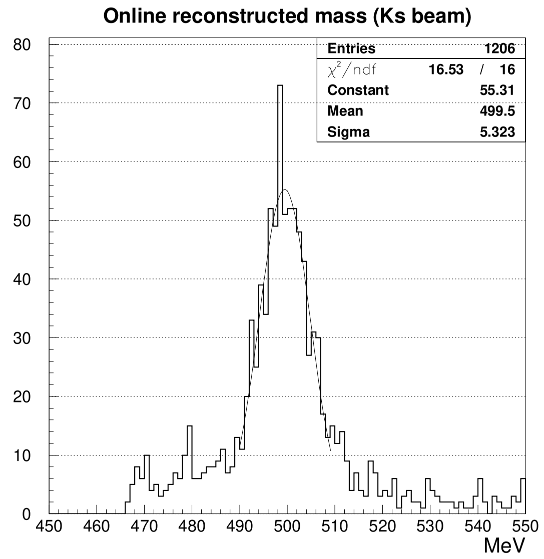


$\pi^+\pi^-$ trigger

- Level 1:

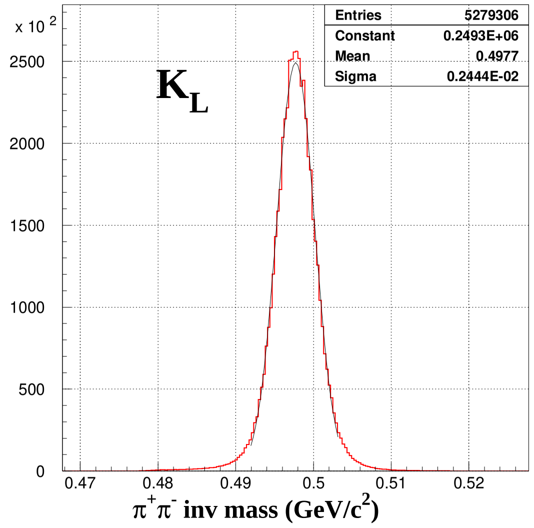
	Efficiency
+ Energy in calorimeters > 35 GeV	99.49 ± 0.03 %
+ Two track topology in hodoscope	99.95 ± 0.01 %
+ Two track multiplicity in chamber 1	> 99.99 %

- Level 2: online processing of vertices and $\pi^+\pi^-$ invariant mass
  - Latency : $< 102\ \mu s$
  - Rejection ~ 45
    $\rightarrow$ 2 kHz output
  - Dead Time $< 5\%$ monitored and applied to $\pi^0\pi^0$
  - Efficiency:
    $97.75 \pm 0.05\%$



$$\boxed{\Delta R = (-1 \pm 11) \times 10^{-4}}$$

NA48: $K^0 \rightarrow \pi^+ \pi^-$ reconstruction



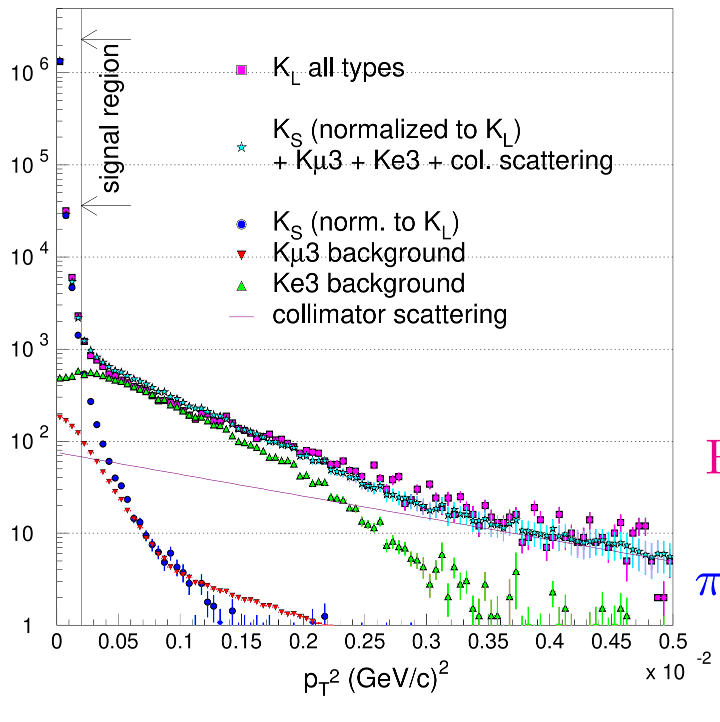
$\pi^+\pi^-$ energy: opening angle and tracks energy ratio (drift chambers geometry)

K mass $\sigma \sim 2.5$ MeV/c^2

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

(p in GeV/c)

Background to $K_L \rightarrow \pi^+\pi^-$: $\pi\mu\nu$ and $\pi e\nu$ decays



Rejection:

$\pi\mu\nu$: no hits in μ-veto

$\pi e\nu$: $E/p < 0.8$

$M_{\pi\pi}$ and p_T^2 cuts

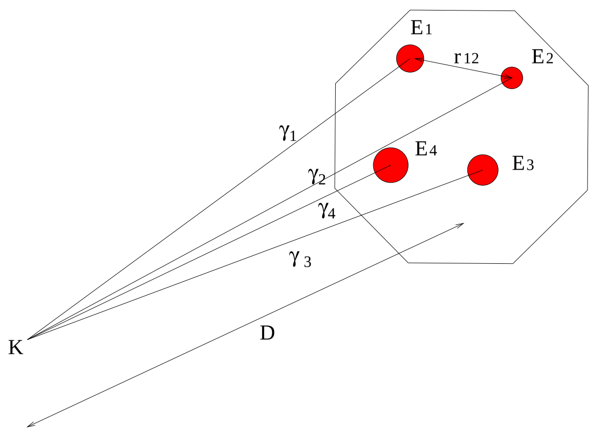
Subtraction:

Fit K_L distribution in control region: $\pi^+\pi^- + \pi\mu\nu + \pi e\nu$

Overall background: $\boxed{(19 \pm 3) \times 10^{-4}}$

NA48: $K^0 \rightarrow \pi^0 \pi^0$ reconstruction

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



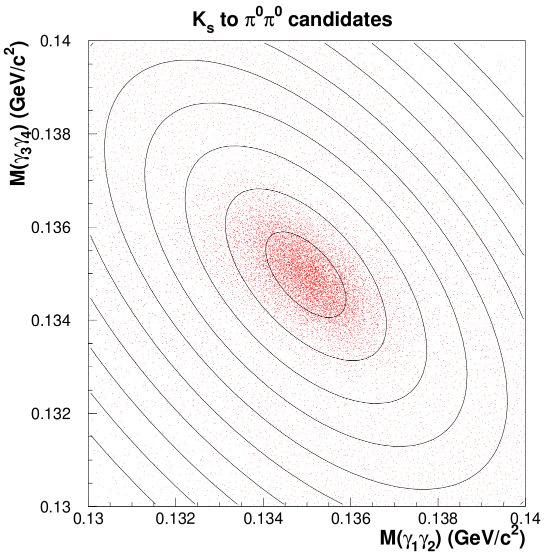
- Measure (E,x,y) of 4γ in the LKr calorimenter
- Reconstruct decay vertex position D assuming K mass for 4γ:

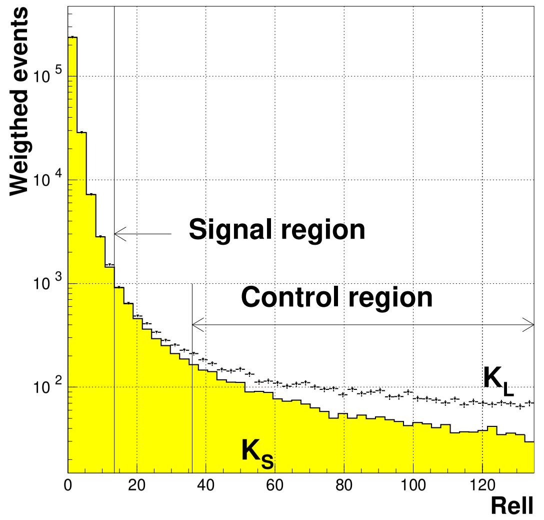
$$D = \sqrt{\Sigma E_i E_j d_{ij}^2}/M_K$$

- Photon pairing to get the best π^0 masses m_{ij}:

$$m_{ij} = \sqrt{E_i E_j} d_{ij}/D$$

Background to $K_L \rightarrow \pi^0\pi^0$: $3\pi^0$ with 2 missing γ



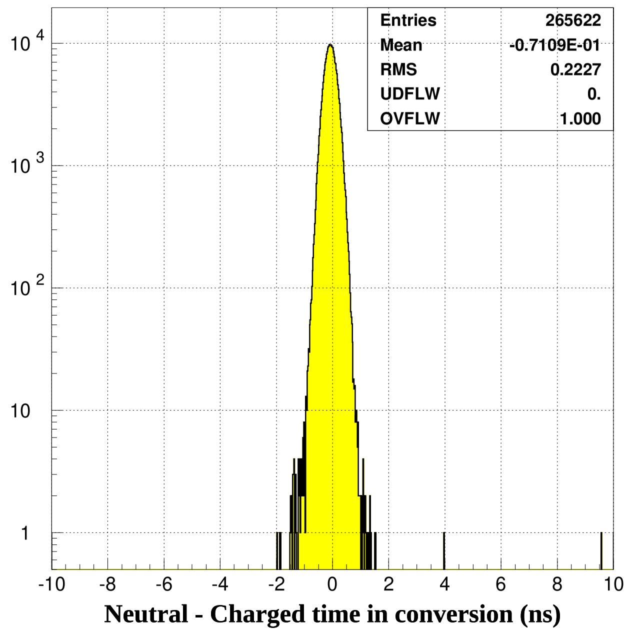


Background Subtraction: R_{ell} (pseudo χ^2) cut

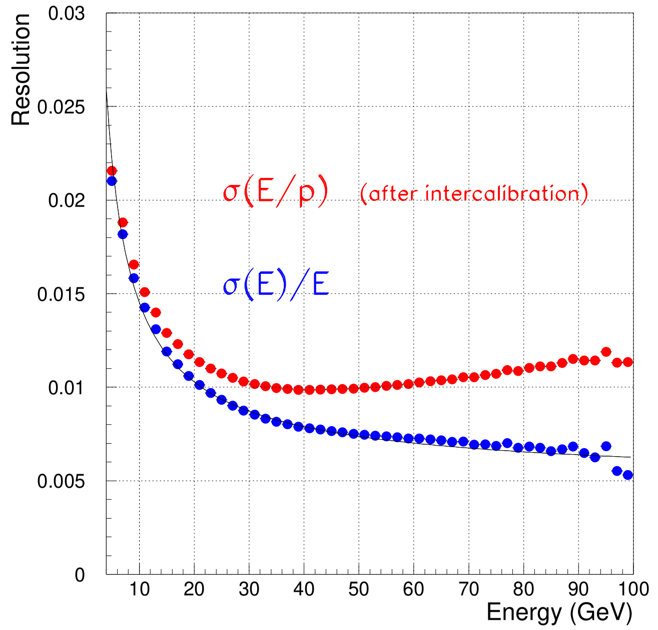
no in-time extra γ ($\pm$ 3 ns) $K_S - K_L$ extrapolation from R_{ell} control region into K_L signal region:

$$\boxed{(7 \pm 2) \times 10^{-4}}$$

NA48: $\pi^+\pi^- - \pi^0\pi^0$ time and energy resolution



Comparison of LKr and scintillators hodoscope times in K_L and K_S events ($3\pi^0$ and $2\pi^0$) containing a photon conversion

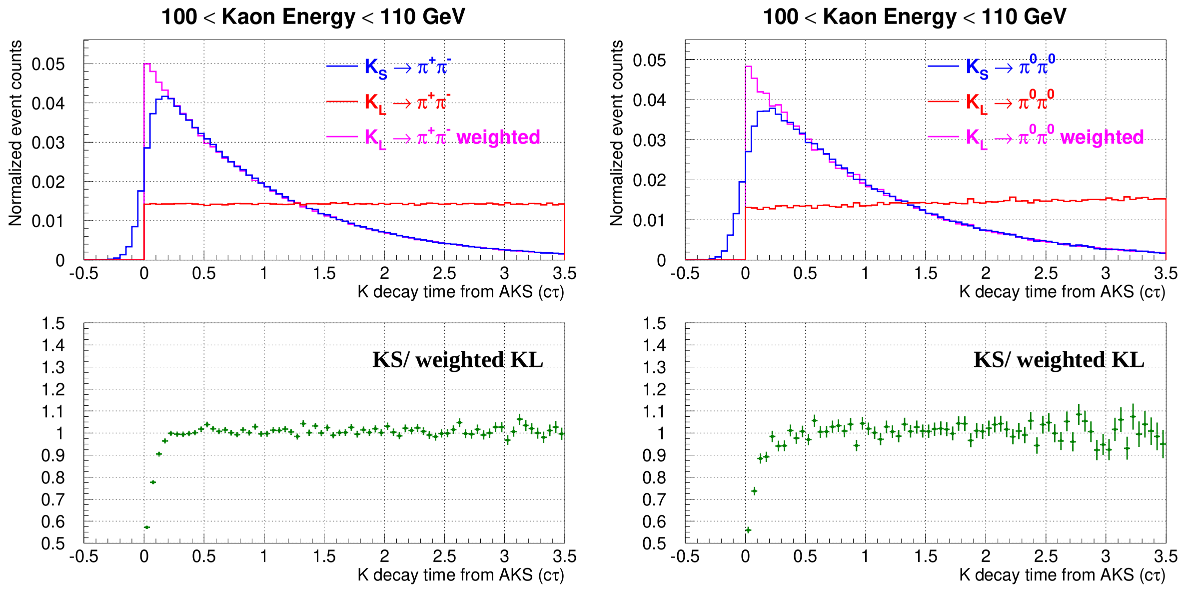


Comparison of LKr energy and magnetic spectrometer momentum for electrons in K_{e3} decays

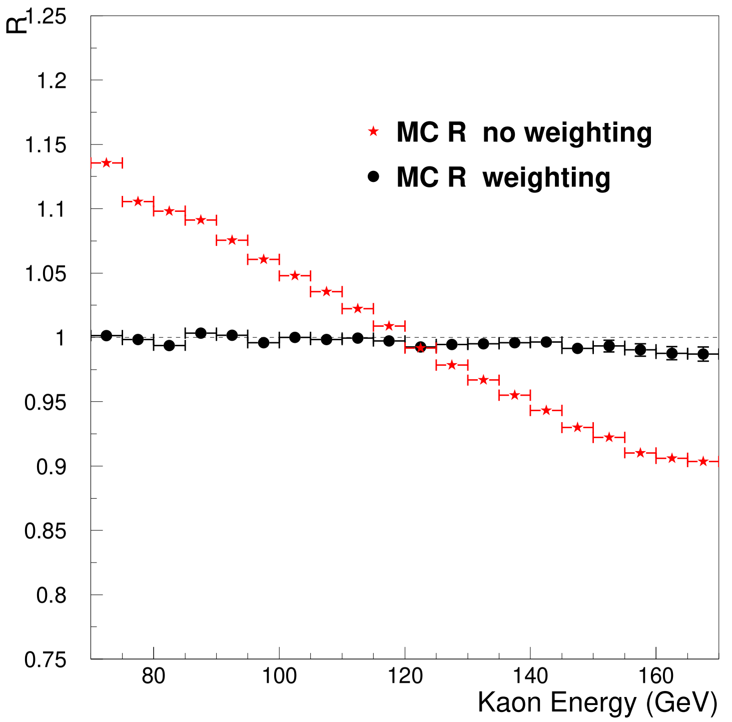
$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{100MeV}{E} \oplus 0.5\%$$

NA48: K_L proper time weighting

Fiducial volume: $70 < E_K < 170\ GeV \quad \tau < 3.5\tau_S$



K_L are weighted with the K_S proper time



The increase of statistical error due to weighting is 35%

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

NA48: energy scale

- Energy of $\pi^0\pi^0$: determined by the LKr

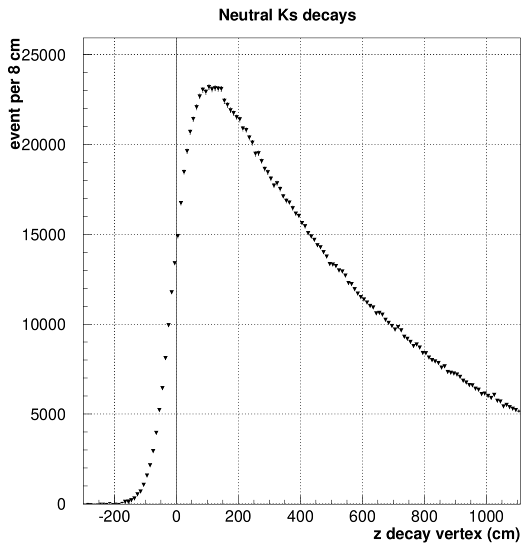
$\Rightarrow$ it relies on the calorimeter calibration

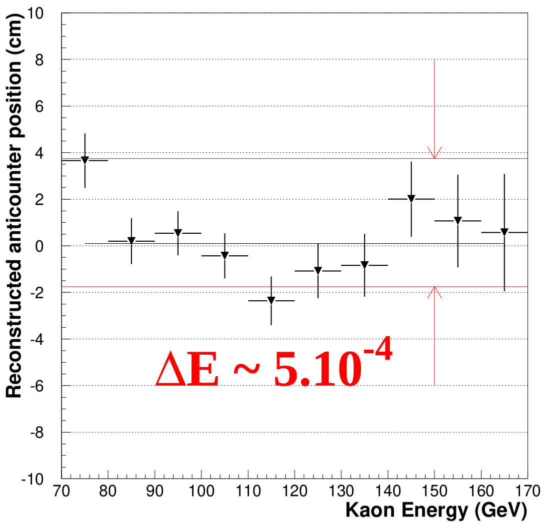
- Neutral mode: $D = \sqrt{\sum E_i E_j \times (r_{ij})^2} \; / M_K$

$\Rightarrow$ a good knowledge of energy scale is needed to define the fiducial region

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

$\Rightarrow$ to set the overall distance/energy scale, the known position of the AKS is used as a reference for the beginning of longitudinal vertex distribution





- Neutral reconstruction global uncertainty:

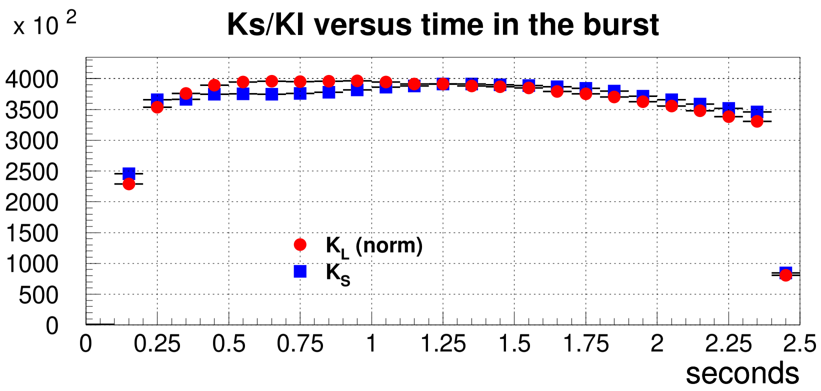
$$\boxed{\Delta R < 10 \times 10^{-4}}$$

- Energy of $\pi^+\pi^-$: from drift chambers geometry
- Charged reconstruction global uncertainty:

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

NA48: accidental activity

Accidental activity: asymmetric losses or gains in K_S and K_L $\rightarrow$ 4 modes collected simultaneously



- Geometric difference of the K_S and K_L beams: overlay events collected proportionally to the beam intensity (random triggers) to $\pi^+\pi^-$ and $\pi^0\pi^0$ and evaluate gain and loss of events induced by the analysis cuts:

$$\boxed{\Delta R = (2 \pm 6) \times 10^{-4}}$$

- Effects related to the variation of the K_S / K_L ratio (R.M.S. of 10%) and effects not related to the K_L accidental activity:
  - difference in accidental activity seen by K_S and K_L events: < 1 %
  - asymmetric losses on $\pi^+\pi^-$ and $\pi^0\pi^0$ induced by the noise in the DCH read out: $< 2.5\%$
  - the noise in the detector does not change by more than a factor of two as a function of time

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

NA48: 1998 Result

Statistics 1998 - Units: 10^6 events (corrected for accidental tagging)			
$K_S \rightarrow \pi^+\pi^-$	7.46	$K_L \rightarrow \pi^+\pi^-$	4.87
$K_S \rightarrow \pi^0\pi^0$	1.80	$K_L \rightarrow \pi^0\pi^0$	1.14
Uncertainty on R $= 17.3 \times 10^{-4}$ (taking weighting into account)			

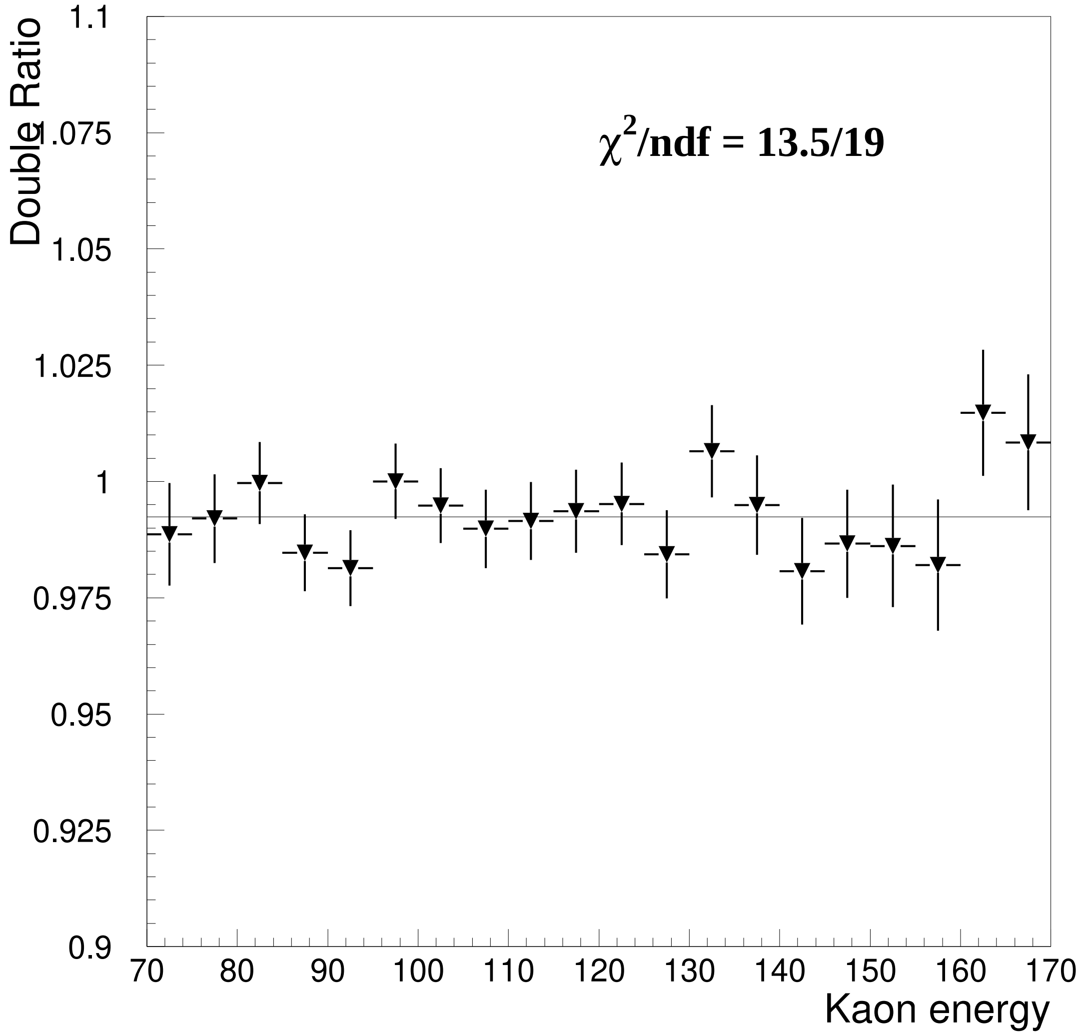
Corrections and systematic uncertainties on R
Units $= 10^{-4}$

Source	1998 sample	
Charged trigger	–1	± 11
Mistagging probability	+1	± 8
Tagging efficiency	–	± 3
Neutral scale	–	± 10
Charged vertex	+2	± 2
Acceptance	+31	± 9
Neutral BG	–7	± 2
Charged BG	+19	± 3
Beam scattering	–10	± 3
Accidental activity	+2	± 12
Total	+37	± 24

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

NA48: 1998 Result

PRELIMINARY RESULT ON 1998 DATA



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

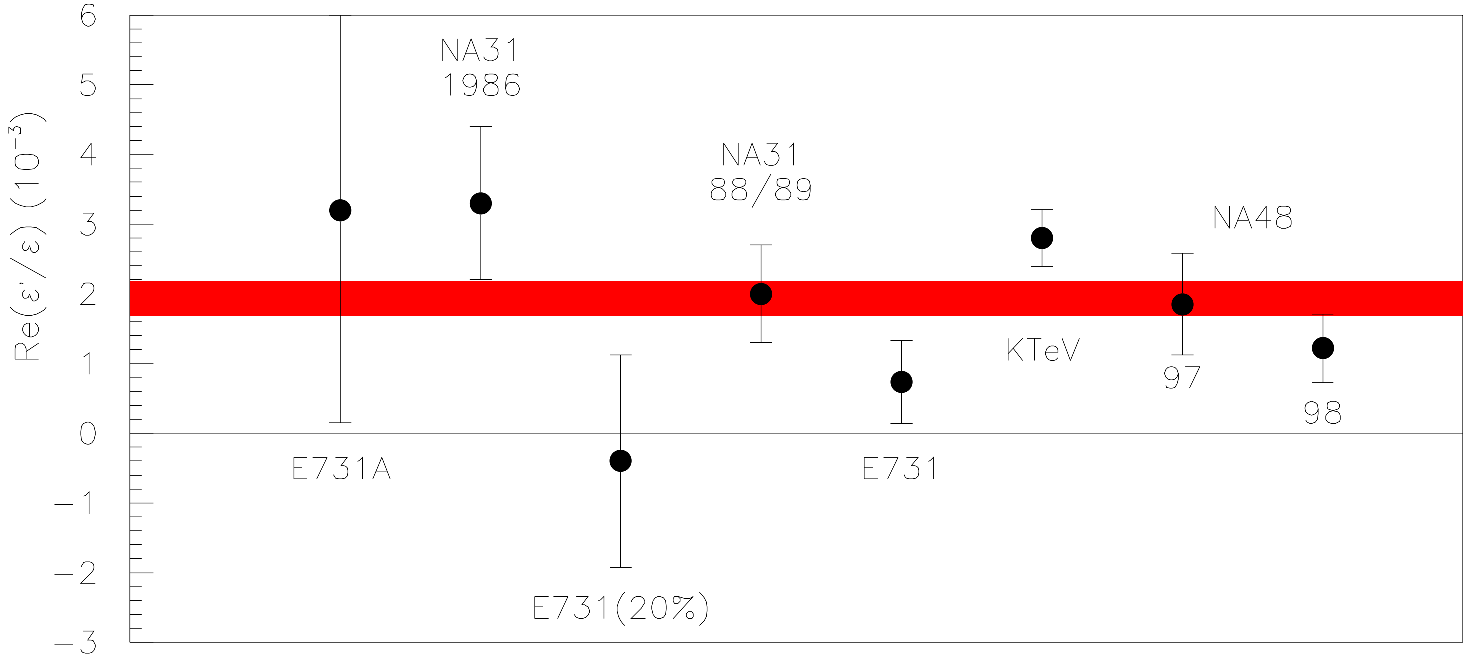
$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 4.9) \times 10^{-4}}$$

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

Combined 1997 and preliminary 1998

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

New world average



New world average:

$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) \;=\; (19.4 \pm 2.5) \times 10^{-4}}$$

$(\chi^2/ndf = 10.4/3)$

NA48: running in 2000 and 2001

- Year 2000: with no DCH available we will focus on the neutral decays.

$\Rightarrow$ measure the difference in mistagging probability for $\pi^0\pi^0$

$\Rightarrow$ improve the neutral energy scale knowledge: distance/momentum scale and non linearity of the LKr studied using dedicated runs with a π^- beam to produce large amount of $\eta \to \gamma\gamma$ and $\eta \to 3\pi^0$

- Year 2001: last physics run for $\mathrm{Re}(\varepsilon'/\varepsilon)$. We plan to collect data with the restored drift chambers. The aim is to address in particular the systematic errors related to the beam intensity variation

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:

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

- This new result from NA48 confirms a non-zero, positive value for $\mathrm{Re}(\varepsilon'/\varepsilon)$

- Improvement on systematics expected:
  - 1999 data analysis in progress
  - data taking in 2000 (neutral systematics) and 2001 (restored detector)

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

Recent results from NA48

- **1997 Published Result:**

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

  Phys. Lett. B 465, 335-348, 1999

- **Preliminary 1998 Result:**

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

- **Combined 1997+1998 Result:**

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

New World average result (χ^2=10.4/3):

$$\boxed{Re(\varepsilon'/\varepsilon) = (19.4 \pm 2.5) \times 10^{-4}}$$

Comparison of most recent results on $Re(\varepsilon'/\varepsilon)$