$\mathrm{R}e(\varepsilon'/\varepsilon)$ **result from the NA48 experiment**

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Introduction

INDIRECT
CP VIOLATION
$\varepsilon = 2.27 \times 10^{-3}$
(1964)

$\Rightarrow$

Both K_S and K_L
have slightly more
K° than $\overline{K}^\circ$

If this were all:

$$K_2 \longrightarrow K_1 \longrightarrow \pi\pi$$

the $\pi\pi$ would be just like in K_S decays.
[Specifically, the ratio $\pi^\circ\pi^\circ/\pi^+\pi^-$].

Can the K_2 decay
DIRECTLY to $\pi\pi$?

[Expected if the CKM
matrix has $\eta \neq 0$]

$$\mathrm{R} = \frac{\Gamma(\mathrm{K_L}\rightarrow\pi^0\pi^0)}{\Gamma(\mathrm{K_S}\rightarrow\pi^0\pi^0)} \Big/ \frac{\Gamma(\mathrm{K_L}\rightarrow\pi^+\pi^-)}{\Gamma(\mathrm{K_S}\rightarrow\pi^+\pi^-)}$$

$$\simeq 1 \text{ - } 6\ \mathrm{Re}(\varepsilon'/\varepsilon)$$

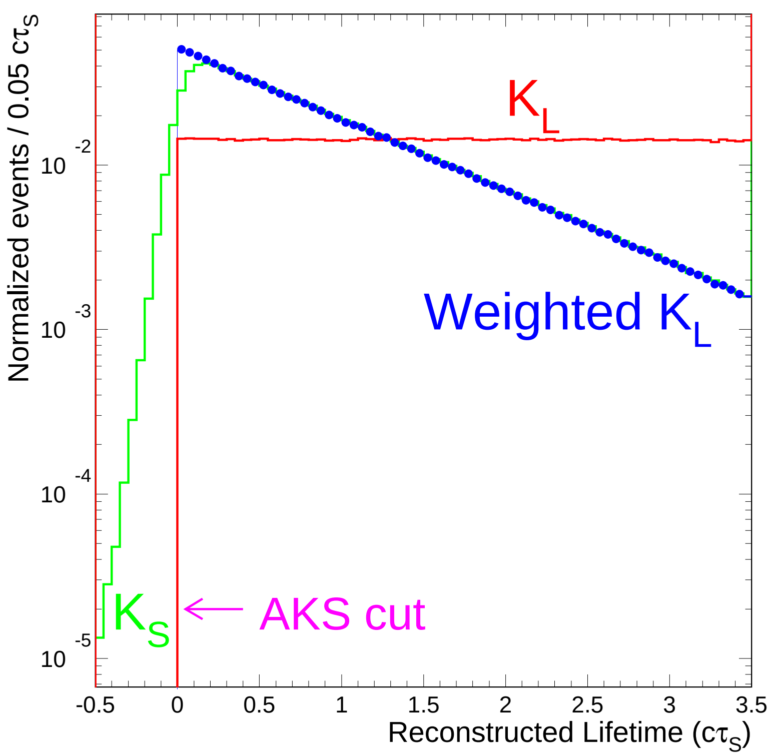
Measurement Principle

$$R = \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)}$$

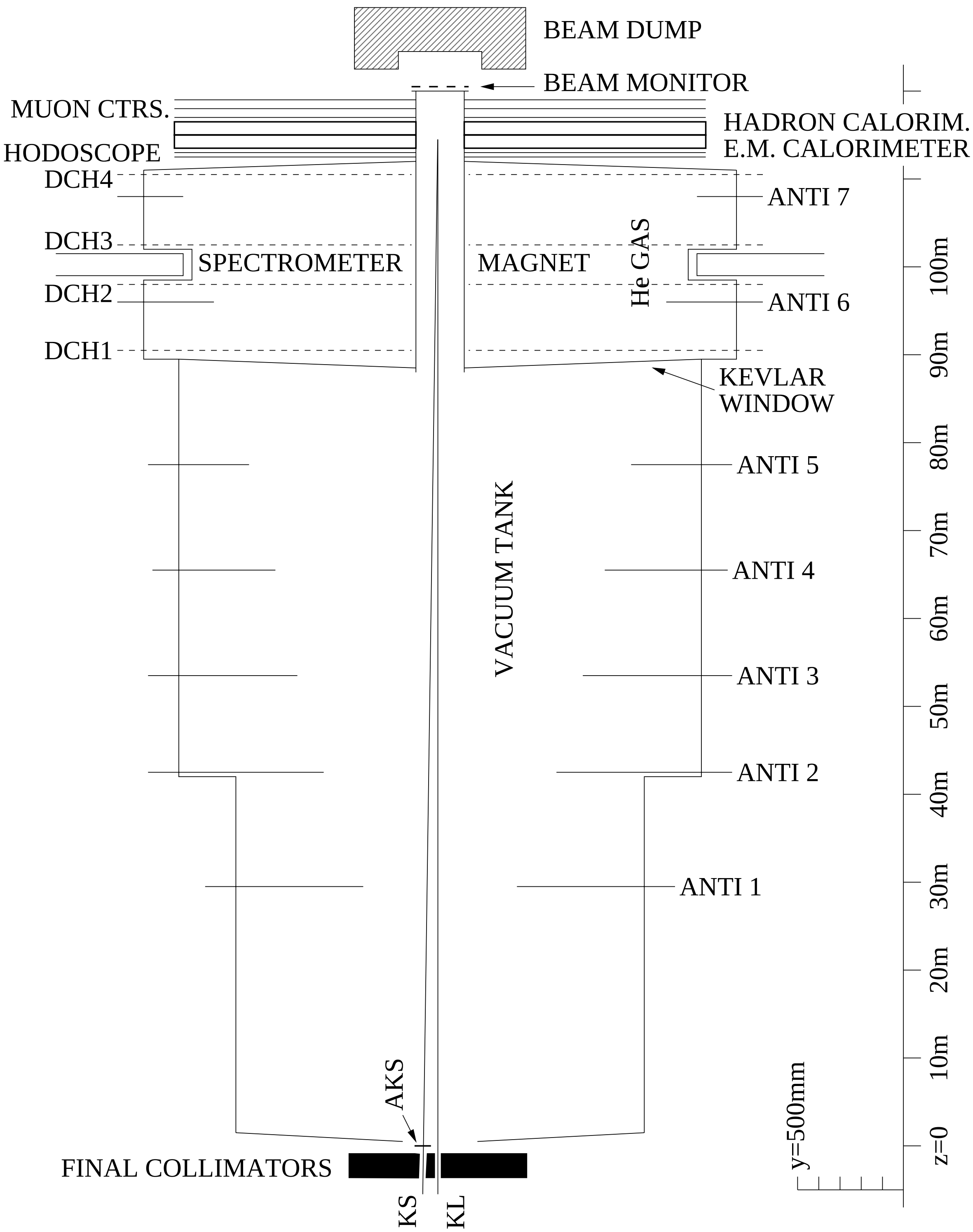
Exploit cancellations in R

Make systematics affect 2 modes symmetrically.

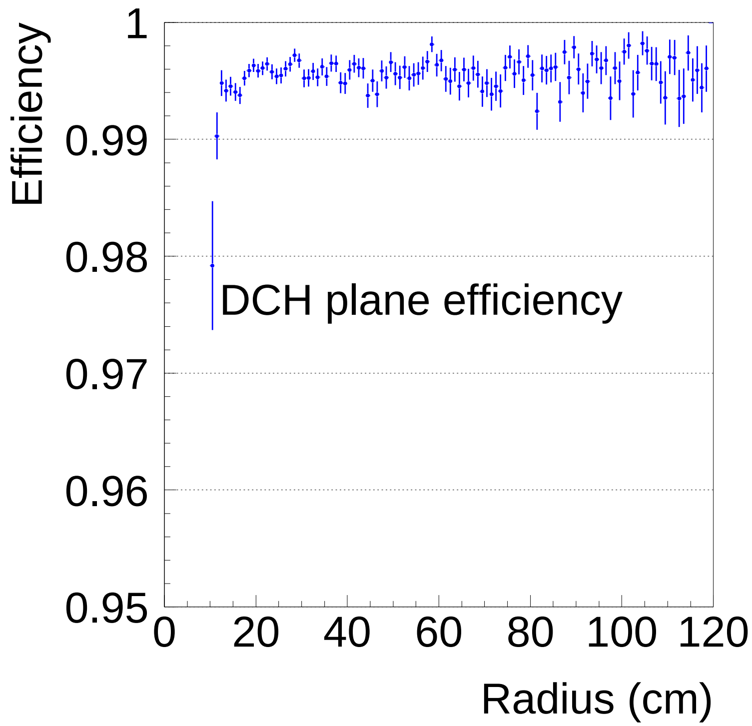
- ∗ Collected all 4 modes together – two beams.
  - – Minimize accidental activity difference.
  - – detection efficiency, trigger, ...
- ∗ Acceptance corrections:
  - – Different K_S and K_L lifetimes
  - – Use K_L only in region with K_S
  - – Weight the K_L with e^{t/τ_S} $\Rightarrow$ like K_S
  - – $\Rightarrow$ Residual MC correction is small

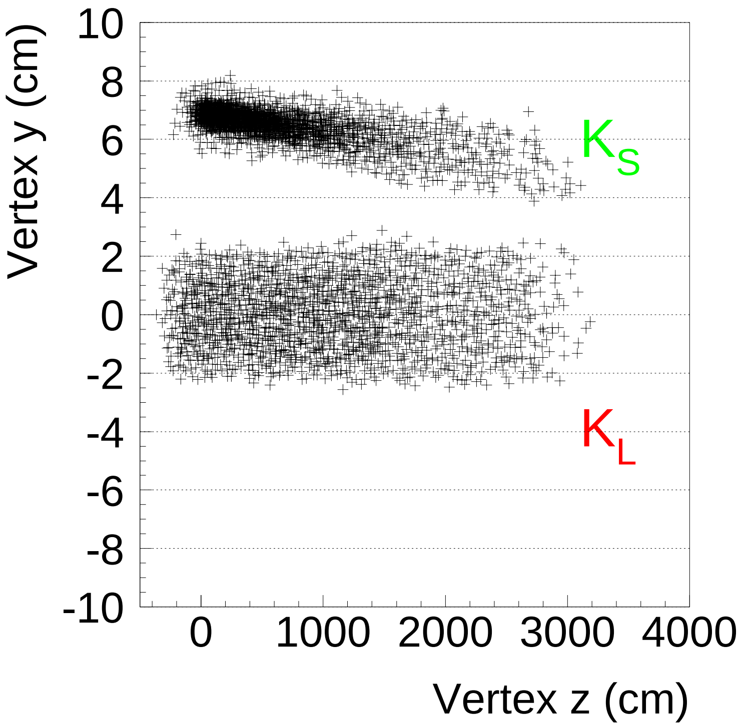


The NA48 detector



$K_{S,L} \to \pi^+\pi^-$ - Spectrometer





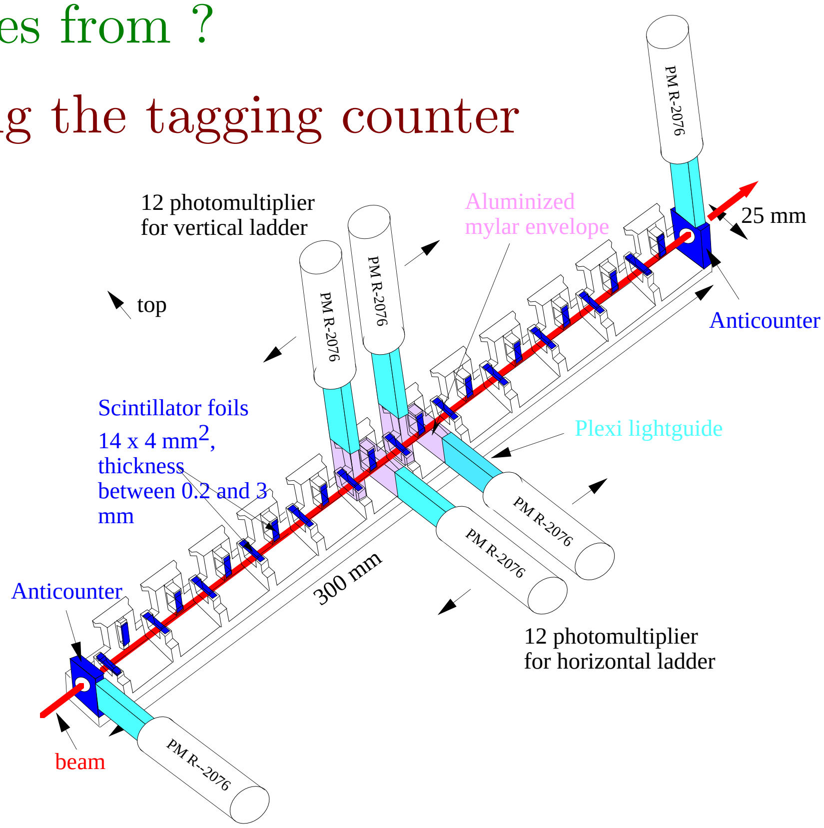
$$\frac{\sigma_P}{P} = 0.5\% \oplus 0.009P(\mathrm{GeV}/c)\%$$

- DCH plane efficiency: 99.5%
- DCH space resolution: $\approx 90\mu$m per projection
- Vertex resolution : 2 mm x, y and 50 cm z
- $\pi\pi$ mass resolution: ~ 2.5 MeV$/c^2$

Tagging - (1)

Q: How do we determine which beam each decay comes from ?

A: Using the tagging counter



The $\pi^+\pi^-$ events are easy to tag using the vertex position, but for symmetry we use the same technique as for $\pi^0\pi^0$ decays.

- $*$ We measure the time of the event
- $*$ Proton seen $\Rightarrow$ its a K_S

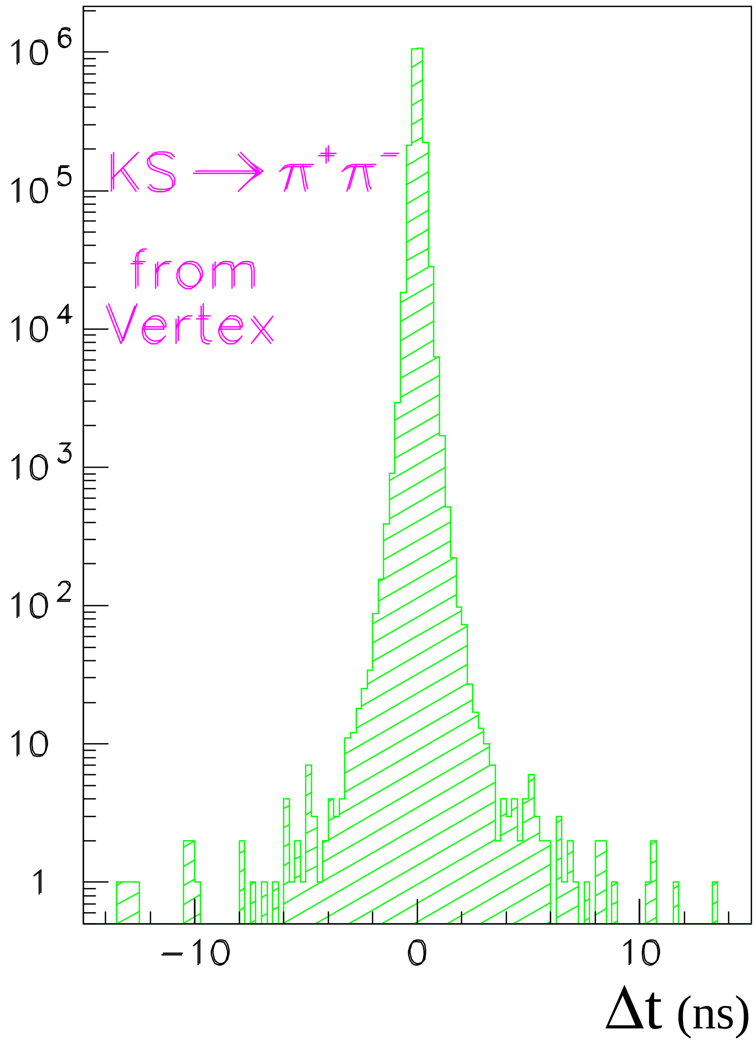
Study accidental arrival of a proton in time:

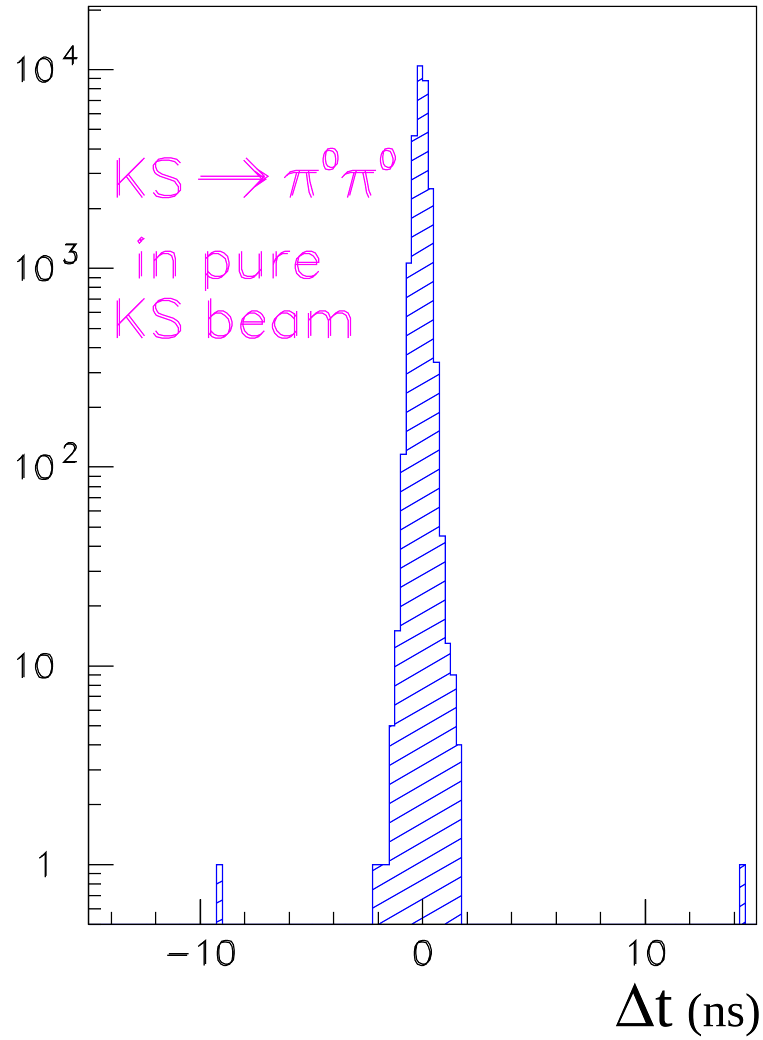
$$(+18 \pm 9) \times 10^{-4}$$

Study tails in event time reconstruction:

$$(0 \pm 6) \times 10^{-4}$$

Tagging



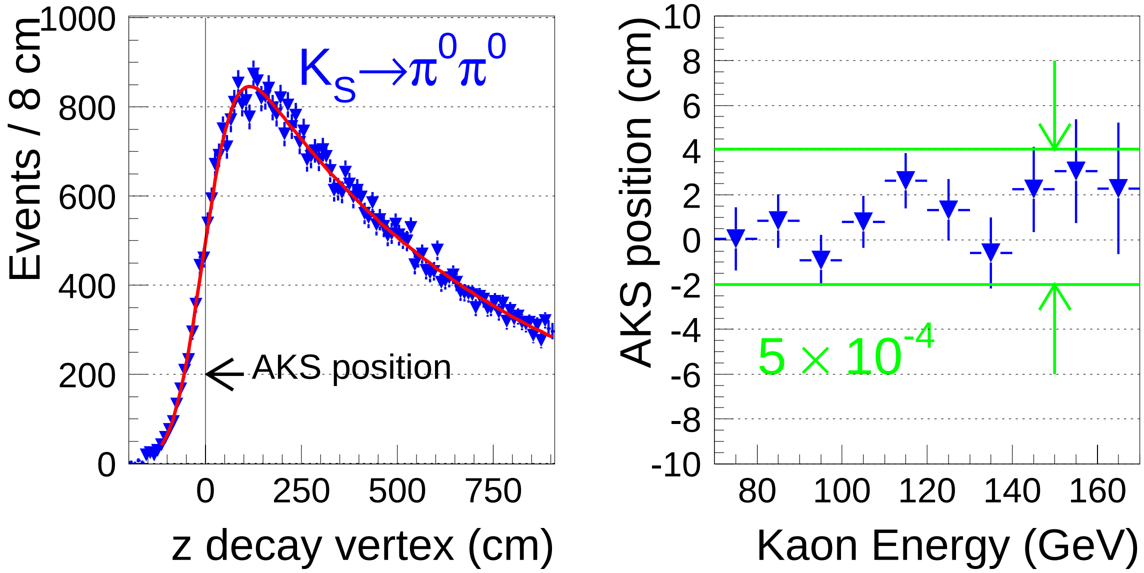


$\alpha_{SL}^{00} - \alpha_{SL}^{+-} = (0 \pm 1) \cdot 10^{-4}$

Tagging window $\pm 2ns$

Neutral energy and distance scales

$$D^2 = \frac{1}{m_K^2} \sum_{\gamma \text{pairs}} E_i E_j d_{ij}^2$$



- Stable in time within $5 \cdot 10^{-4}$
- Checks: $\pi^0 \to 2\gamma$, $\eta \to 2\gamma/6\gamma$ from π^- beam.
- Transverse distance scale checked with K_{e3} decays to 0.3 mm/m

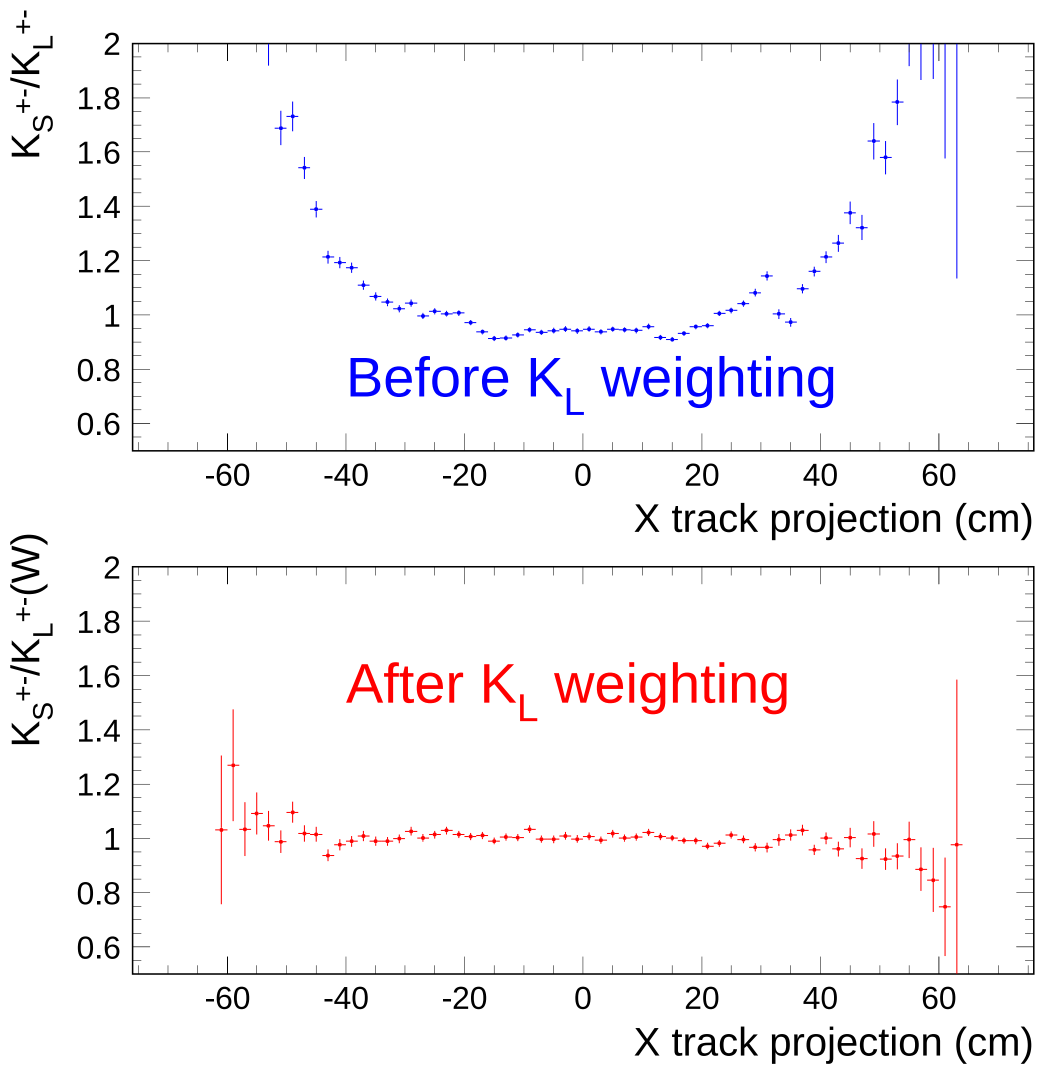
R uncertainty from neutral scales: $\pm 6 \times 10^{-4}$

Non-linearity, non-uniformity give an uncertainty on R: $\pm 10 \times 10^{-4}$

Acceptance correction

◆ Lifetime weighting of K_L minimizes acceptance differences.

◆ Analysis in K^0 energy bins minimizes K_S/K_L energy spectra corrections.



Total acceptance correction to R:

$$(+29 \pm 11(\text{MCstat}) \pm 5(\text{syst})) \times 10^{-4}$$

Accidental activity

- Simultaneous beams $\Rightarrow$ $\mathrm{K_S}/\mathrm{K_L}$ differential effects intrinsically small
- Most activity comes from K_L beam.
- Accidental activity for $\mathrm{K_S}$ and $\mathrm{K_L}$ measured to be the same at 1% level
- "Randomly" triggered events proportional to $\mathrm{K_L}$ and $\mathrm{K_S}$ beam intensities are overlaid onto $\pi\pi$ events to measure event gains and losses:
  - ▷ losses − gains $\simeq 2\%$

Double ratio correction: $(-2 \pm 14) \times 10^{-4}$

- In-time activity from close $\mathrm{K_S}$ target $< 3 \cdot 10^{-4}$

Corrections

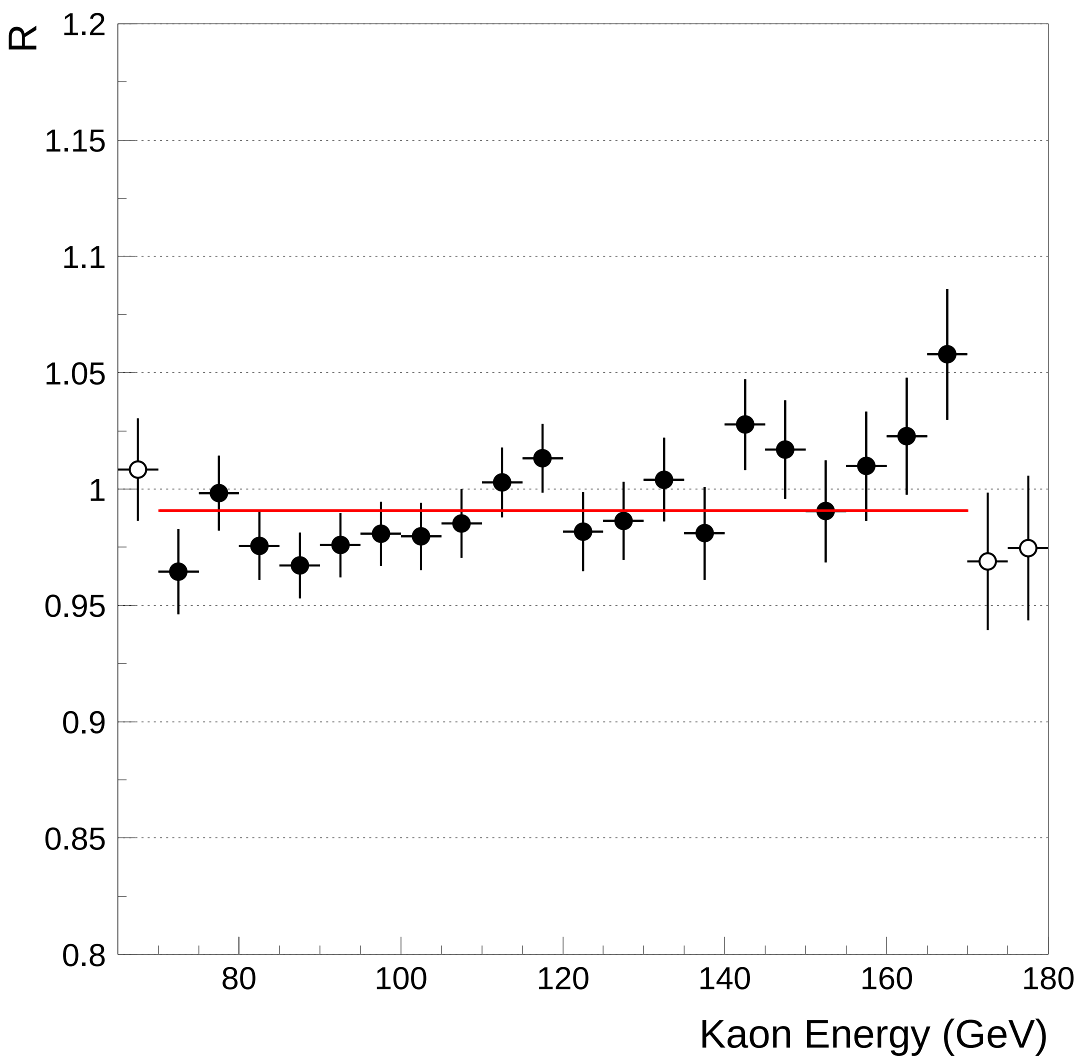
	ΔR $(\times 10^{-4})$
Trigger efficiency	$+9 \pm 23$
Tagging	$+18 \pm 11$
Background	$+3 \pm 6$
Accidental activity	$+2 \pm 14$
Acceptance	$+29 \pm 12$
Energy scale/linearity	± 13
Total correction/uncertainty	$+57 \pm 35$

Event statistics

$K_L \to \pi^0\pi^0$	490k	$K_S \to \pi^0\pi^0$	980k
$K_L \to \pi^+\pi^-$	1070k	$K_S \to \pi^+\pi^-$	2090k

Energy bins

- R is computed in 20 K^0 energy bins between 70 and 170 GeV.
- Many corrections are applied bin by bin.
- Result averaged with unbiased estimator, $\chi^2/\mathrm{dof} = 25.7/19$.



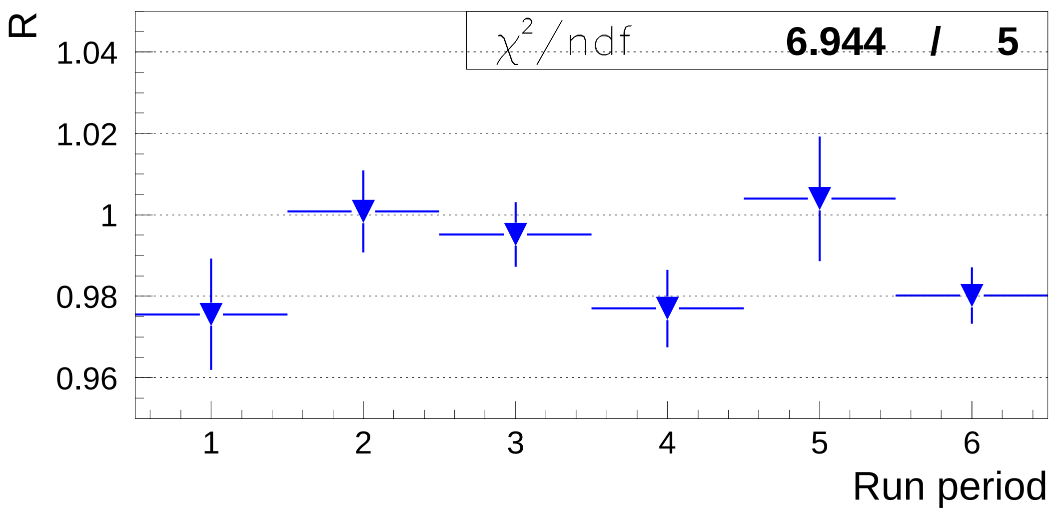
Extended K^0 energy range 65 to 180 GeV shown

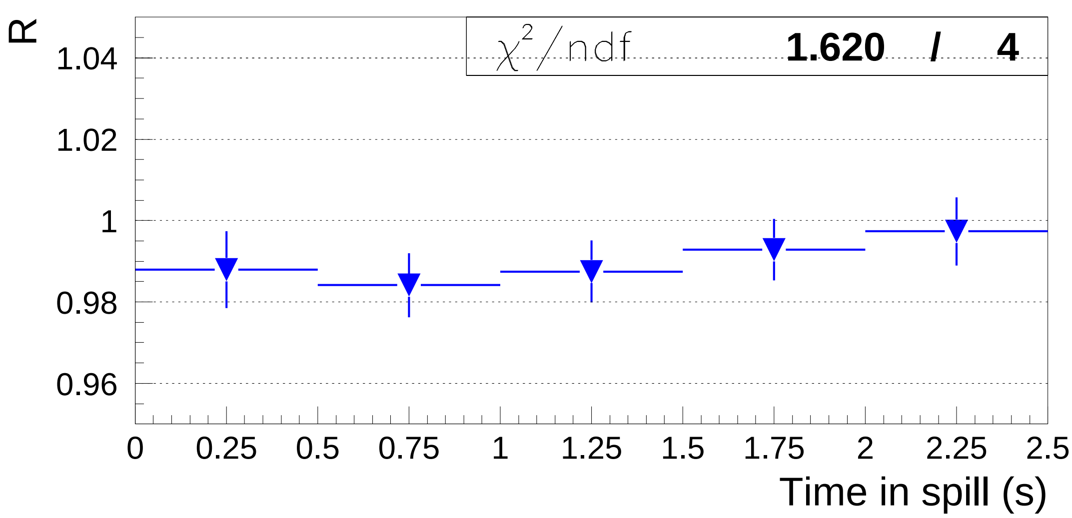
Event statistics

$K_L \to \pi^0\pi^0$	490k	$K_S \to \pi^0\pi^0$	980k
$K_L \to \pi^+\pi^-$	1070k	$K_S \to \pi^+\pi^-$	2090k

Time dependence

Run period dependence (changes in trigger and magnetic field configuration) and time in spill dependence:

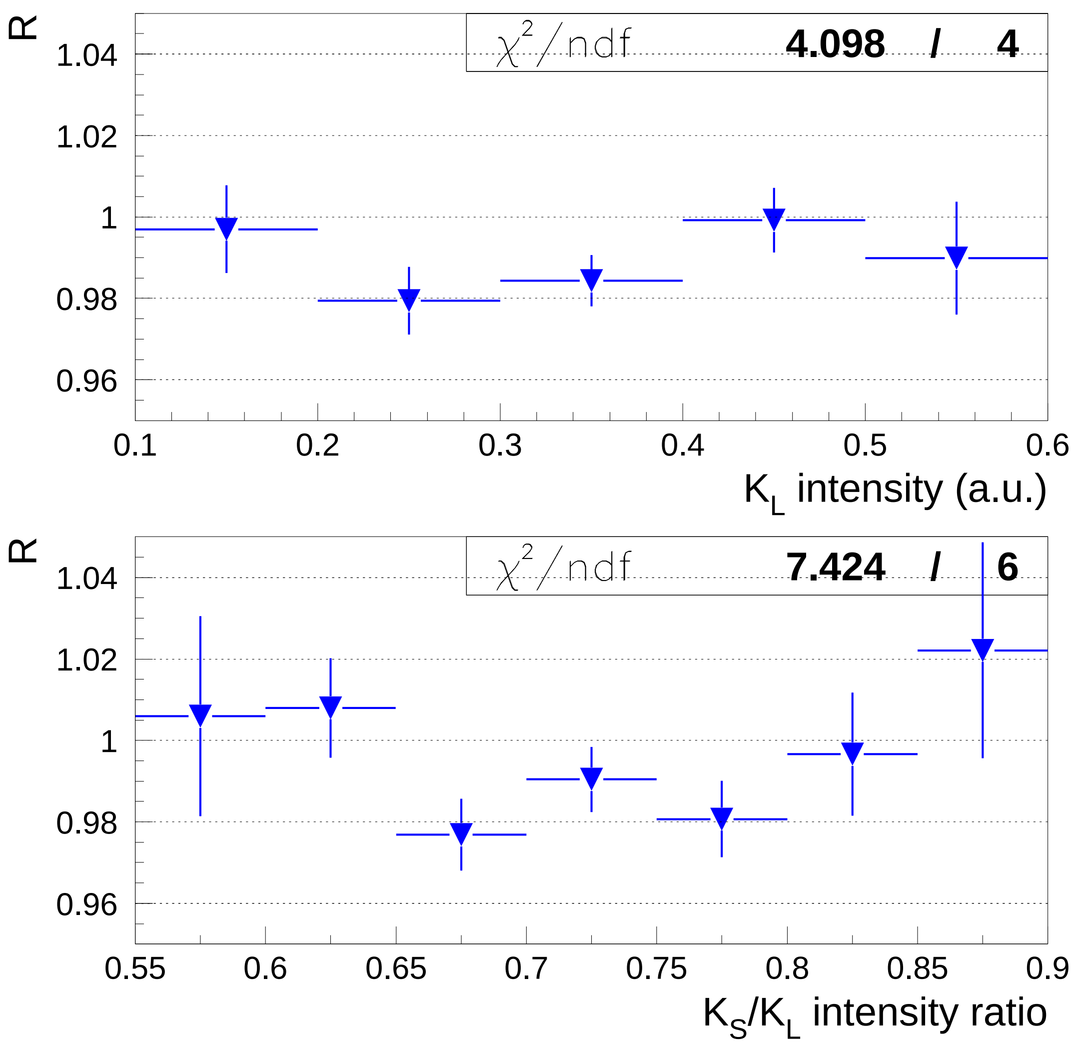




☞ No systematic effect

Beam intensity dependence

K_L beam intensity and K_S/K_L intensity ratio dependence:



☞ No systematic effect

The result

$$\mathrm{Re}(\varepsilon'/\varepsilon) \; = $$

$$(18.5 \pm 4.5 \text{ (event stat.)} \pm 5.8 \text{ (syst.)}) \times 10^{-4}$$

Combining errors in quadrature:

$$\mathrm{Re}(\varepsilon'/\varepsilon) \; = (18.5 \pm 7.3) \times 10^{-4}$$

The systematic error is dominated by the statistical contribution of the control samples.

(PRELIMINARY)

The Future

- **1998 run**: mid May to September 1998
  - All HV blocking capacitors of e.m. calorimeter replaced ⇒ stable operation at 3 kV
  - New carbon fibre beam pipe ⇒ reduced overflows in DCH
  - Charged trigger upgrade ⇒ higher efficiency ≈ 0.97
  - New DAQ ⇒ +30% trigger rate
  - 3 times more $\pi^0\pi^0$ statistics, 6 times more $\pi^+\pi^-$ statistics
  - Statistical error on $\mathrm{Re}(\varepsilon'/\varepsilon)$ $\approx 3 \cdot 10^{-4}$

- **1999 run**: in progress
  - Improved DCH readout and DAQ
  - Aim for more data than 1998 run

- **2000**: Complement Statistics and Systematic studies

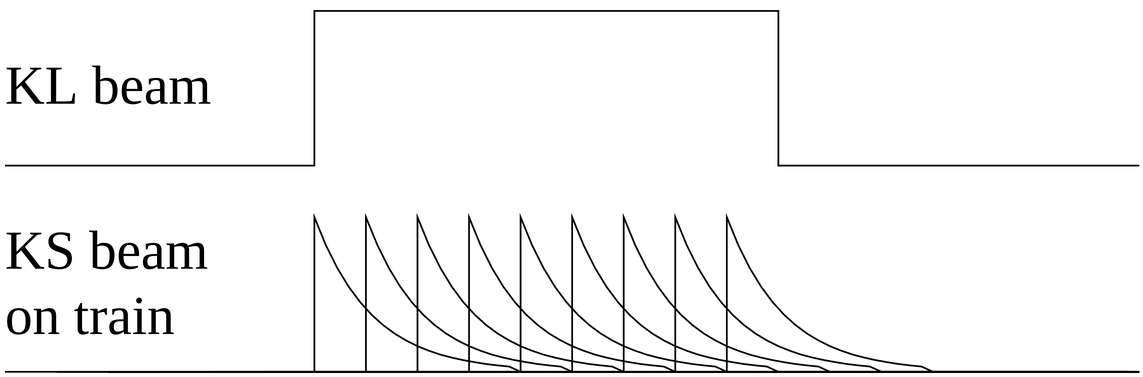
Comparison of techniques

NA31 somewhat different to NA48, E731, KTeV

K_S target on train moved along fiducial volume.

This produced a K_S decay distribution which was similar to the K_L distribution.

$\Rightarrow$ Like NA48, very small acceptance correction.



K_S and K_L were taken separately

- Careful control of trigger, $\pi^+\pi^-/\pi^0\pi^0$ cancellation of all deadtime, daq hangs etc. was meticulously correct.
- Careful accidental studies, low activity
- Energy scale did not shift from K_S and K_L.

NA48 $\leftrightarrow$ E731,KTeV differences more modest.

- Weighting technique.
- Two targets.

$\mathrm{Re}(\varepsilon'/\varepsilon)$ **Computations**

$$\frac{\varepsilon'}{\varepsilon} = \frac{\omega}{\sqrt{2}|\varepsilon|\mathrm{Re}A_0}\left(\mathrm{Im}A_0 - \frac{1}{\omega}\mathrm{Im}A_2\right)$$

Operator product expansion of $\mathrm{Im}A_0$ and $\mathrm{Im}A_2$:

$$\mathrm{Im}A_{0,2} = -\mathrm{Im}\lambda_t \frac{G_F}{\sqrt{2}} \sum_{i=3}^{10} y_i(\mu)\langle Q_i\rangle_{0,2}$$

- $\mathrm{Im}\lambda_t = \mathrm{Im}(V_{ts}^* V_{td}) = V_{us}|V_{cb}|\eta$ CKM elements
- y_i (short distance part) well known NLO QCD
- $\langle Q_i\rangle_{0,2}$ long distance, difficult, several approaches
  lattice, Chiral P.T. $1/N_c$, Chiral quark model

Big contributions from $\langle Q_6\rangle_0$ and $\langle Q_8\rangle_2$ which potentially cancel.

Illustrative formula . . .

$$\frac{\varepsilon'}{\varepsilon}\cdot 10^4 \approx -2 + (16B_6 - 8B_8)\left[\frac{110\,\mathrm{MeV}}{m_s(2\mathrm{GeV})}\right]^2$$

B_6	B_8	m_s(MeV)
-	0.69–1.06	110 ± 20
1	1	124 ± 22
0.72–1.10	0.42–0.64	≥ 100
1.07–1.58	0.75–0.79	

Consequently it is not too easy to get ε'/ε as big as the measured values.

$\mathrm{Re}(\varepsilon'/\varepsilon)$ **Computations**

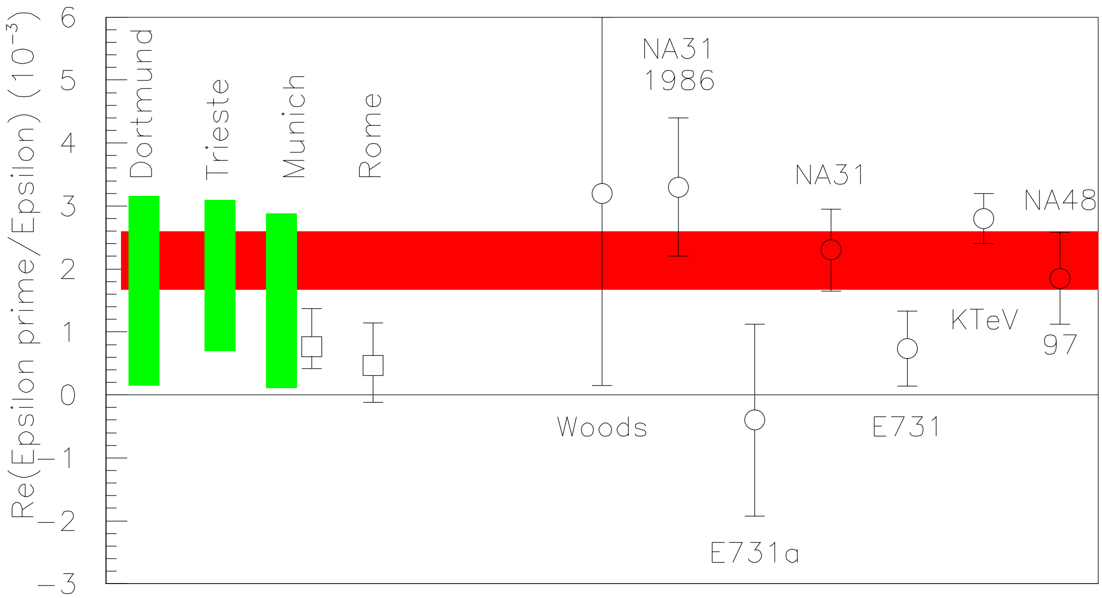
Predictions ($\times 10^4$):

Rome	Munich	Trieste	Dortmund
(1999)	(1999)	(1998)	(1999)
$4.7^{+6.7}_{-5.9}$	$7.7^{+6.0}_{-3.5}$		
	$1.1 \rightarrow 28.8$	$7 \rightarrow 31$	$1.5 \rightarrow 31.6$

Conclusions

The NA48 value for $\mathrm{Re}(\varepsilon'/\varepsilon)$ based on 10% of the data is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (18.5 \pm 7.3) \times 10^{-4}$$



A consistent experimental picture is emerging, $\mathrm{Re}(\varepsilon'/\varepsilon)$ is larger than zero.

Average $(21.3 \pm 4.6) \times 10^{-4}$ with P.D.G.-style scaling.

Future data from NA48, KTeV and Kloe (see next talk) will reduce errors to the 1×10^{-4} level – a 5% measurement.

Challenges for theoretical predictions - which prefer a lower $\mathrm{Re}(\varepsilon'/\varepsilon)$ than measured.

New physics ? — premature