A new result from NA48

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Rencontres de la vallée d'Aoste

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- → Direct CP violation
- → K_L and K_S beams
- → NA48 detector
- → 1998 $\mathrm{Re}(\varepsilon'/\varepsilon)$ result
- → Prospects

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on behalf of NA48 COLLABORATION

Cagliari, Cambridge, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Orsay, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien

I. CP violation

In the neutral kaon system :

- $K^0(\bar{s}d)$ and $\overline{K^0}(s\bar{d})$ are flavour eigenstates.
- $K_1(+1)$ et $K_2(-1)$ are CP eigenstates.

$$K_1 = (K^0 + \overline{K^0})/\sqrt{2} \rightarrow 2\pi \quad (CP = +1)$$
$$K_2 = (K^0 - \overline{K^0})/\sqrt{2} \rightarrow 3\pi \quad (CP = -1)$$

- 1964 : CP violation discovery

$\Rightarrow$ Mass eigenstates are not pure CP eigenstates :

$K_S \simeq$	$K_1 +$	$\varepsilon.K_2$	$K_L \simeq$	$K_2 +$	$\varepsilon.K_1$
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 %		$\pi^0\pi^0$

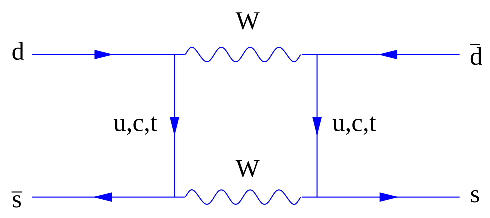
$c\tau_S = 2.67\ cm$ $\qquad$ $c\tau_L = 15.5\ m$

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

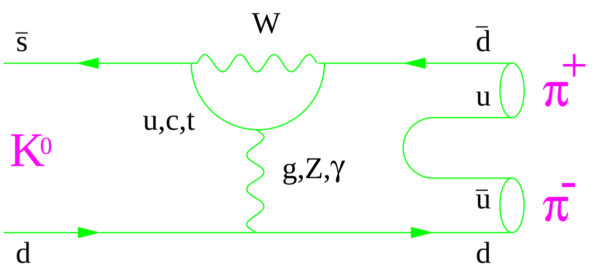
indirect CP violation

Direct CP violation

Indirect violation
through mixing
$K^0/\overline{K^0}$ oscillations
$\Rightarrow \varepsilon$ parameter



$$K_L = \underset{-1}{K_2} + \varepsilon \underset{+1}{K_1} \qquad \underbrace{\pi^+ \pi^- , \pi^0 \pi^0}_{CP = +1}$$



Direct violation
through decay
penguin diagrams
$\Rightarrow \varepsilon'$ parameter

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

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

$$\boxed{\begin{aligned} R &= \frac{\Gamma(K_L \to \pi^0\pi^0)}{\Gamma(K_S \to \pi^0\pi^0)} \Big/ \frac{\Gamma(K_L \to \pi^+\pi^-)}{\Gamma(K_S \to \pi^+\pi^-)} \\ &\simeq 1 - 6 \times \mathrm{Re}(\varepsilon'/\varepsilon) \end{aligned}}$$

Previous Measurements of $\mathrm{Re}(\varepsilon'/\varepsilon)$

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

II. NA48 method and analysis

- Goal : measure $\mathrm{Re}(\varepsilon'/\varepsilon)$ (final precision : 2×10^{-4})
- Mean : measure the double ratio of the four modes

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

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

Principle to keep systematic effects at low level :

- The 4 modes are taken simultaneously
- From the same fiducial volume (life time $< 3.5 \times \tau_S$)
- Analysis in bins of energy to get rid of slight differences of $\mathrm{K_S}$ and $\mathrm{K_L}$ energy spectra (20 bins 70–170 GeV)

Estimation of remaining effects :

$\rightarrow$ $\mathrm{K_S}$ /$\mathrm{K_L}$ identification by proton tagging

$\rightarrow$ Subtraction of CP-conserving background in $\mathrm{K_L}$ beam

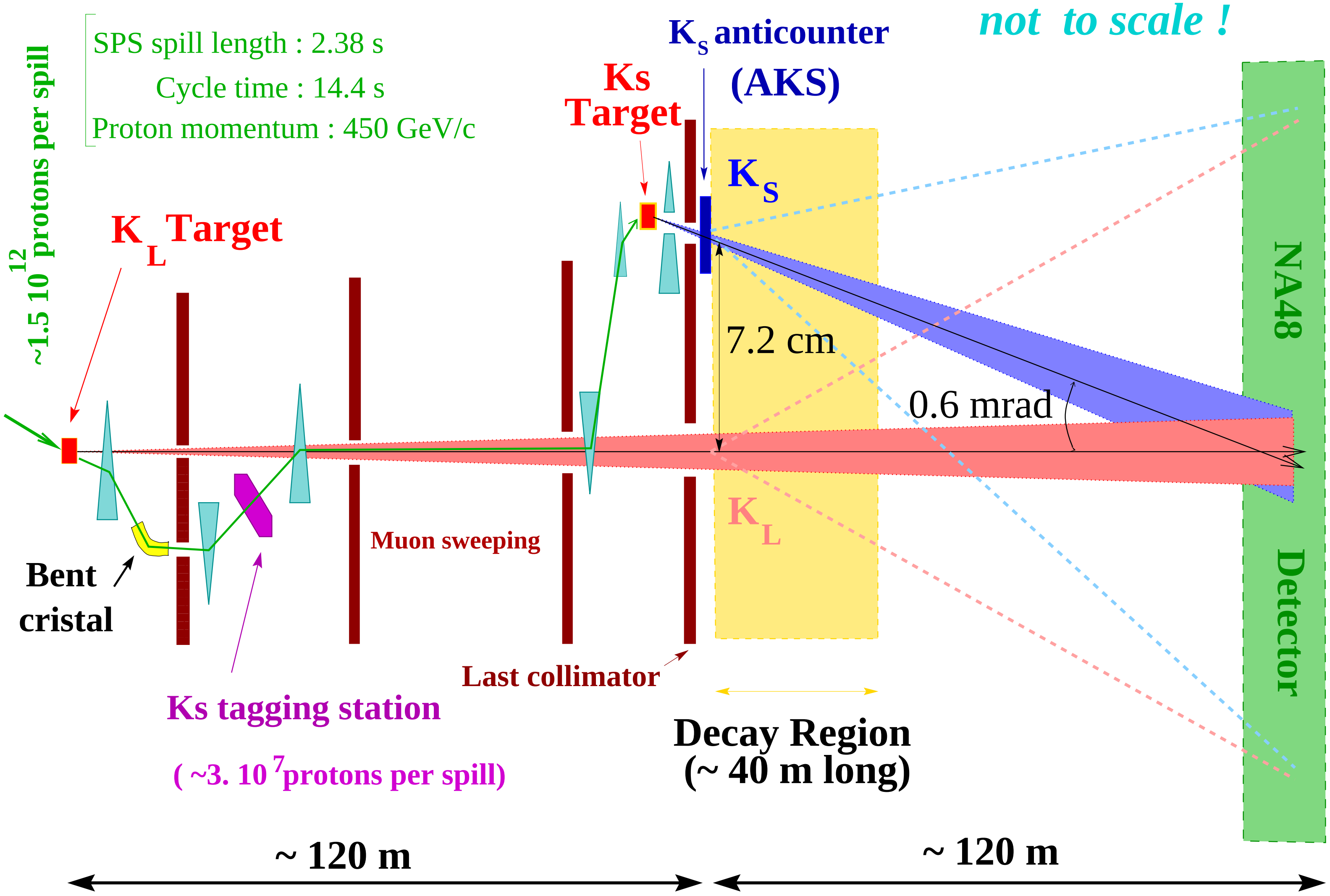
$\rightarrow$ Effect of neutral distance and energy scale

$\rightarrow$ Small acceptance correction by lifetime weighting

$\rightarrow$ Effect of accidental activity

$\rightarrow$ Effect of trigger inefficiencies

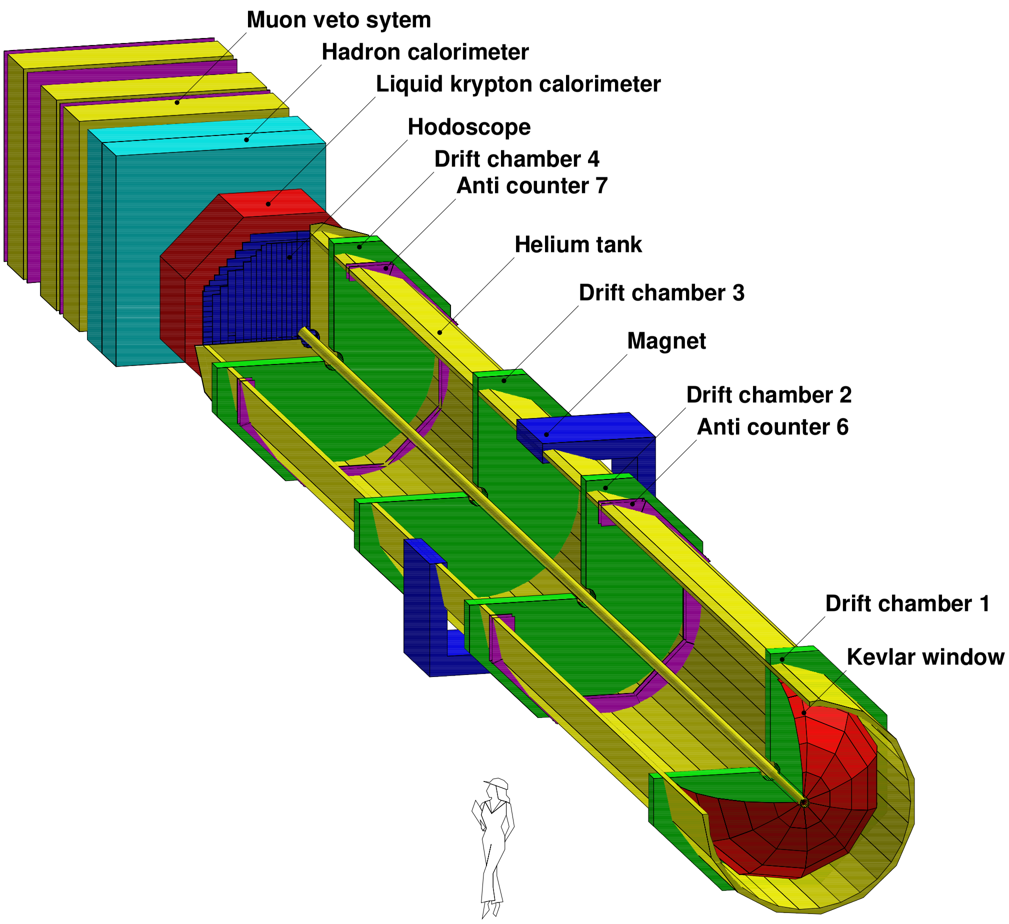
NA48 simultaneous and collinear K_S and K_L beams



K_S and K_L beams are distinguished by proton tagging upstream of the K_S target.

NA48 detector

- A beam pipe goes through all detectors.

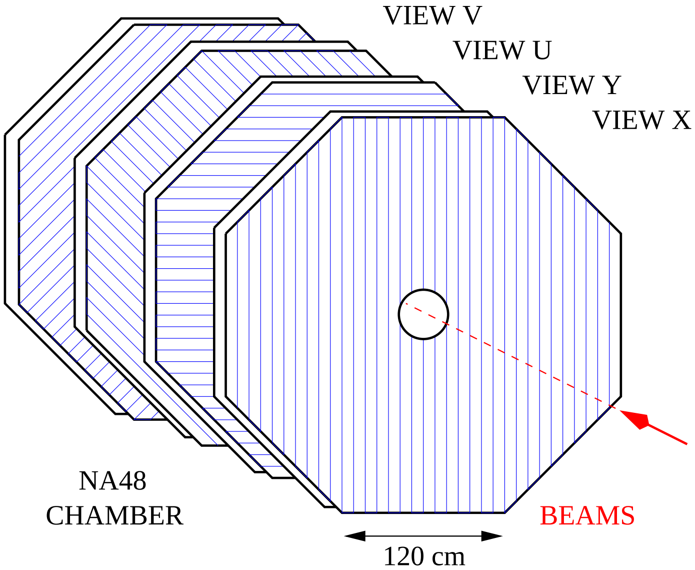


- $K_{\mathrm{L,S}} \to \pi^+\pi^-$
  - Magnetic spectrometer ($\sigma_{X,Y} \sim 90\ \mu$m)
  - Hodoscope for timing measurements ($\sigma_t \sim 200\ ps$)
  - Muon veto to reject $\pi\mu\nu$ background.

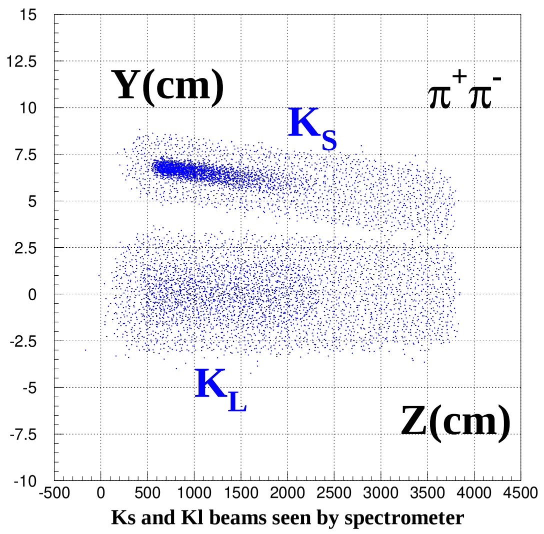
- $K_{\mathrm{L,S}} \to \pi^0\pi^0$
  - Liquid Krypton electromagnetic calorimeter ($\sigma_t \sim 270\ ps$)

The magnetic spectrometer

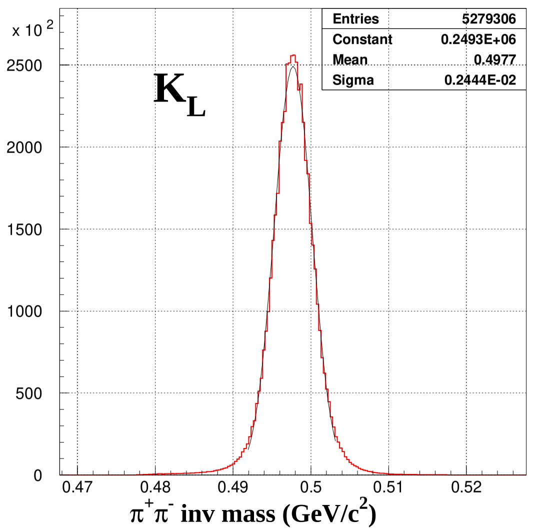
- 2×2 drift chambers + magnet $\rightarrow$ 265 MeV/c p_t kick.



- Each chamber has 4×2 planes $\times$ 256 wires
- Absolute wire position better than 100 $\mu m/m$
- $\frac{1}{2}$ argon / $\frac{1}{2}$ ethane
- Gain $\sim 8.10^4$



Vertex reconstruction allows beam separation



Kaon mass resolution $\sim$ 2.5 MeV/c^2

$$\boxed{\sigma(P)/P \simeq 0.5\,\% \oplus 0.009\, P[\mathrm{GeV}/c]\,\%}$$

($\sim$ 1 % for 100 GeV/c track momentum)

LKr electromagnetic calorimeter

- Quasi-homogeneous detector

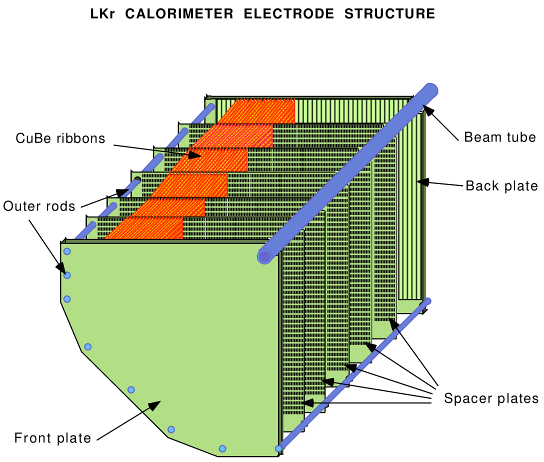
  10 m^3 liquid krypton (120 K)

  ($X_0 = 4.7\ cm$, $R_M = 6.1\ cm$)

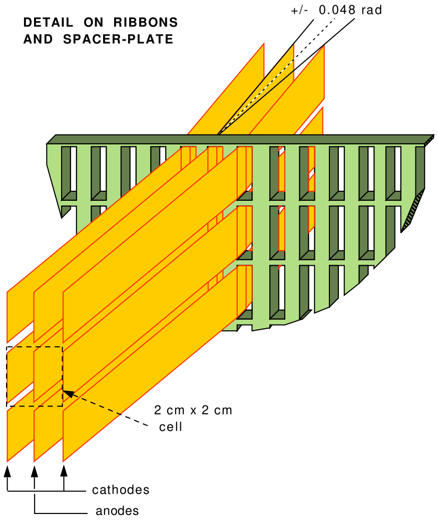
- 13212 cells
  - Granularity $2 \times 2\ cm^2$
  - Depth 1.25 m ($\sim 27\ X_0$)

- Projective geometry pointing to decay region ($\sim$ 114 m upstream)

- Accordion geometry ($\pm 48\ mrad$) to diminish anode effects.



A quarter of calorimeter

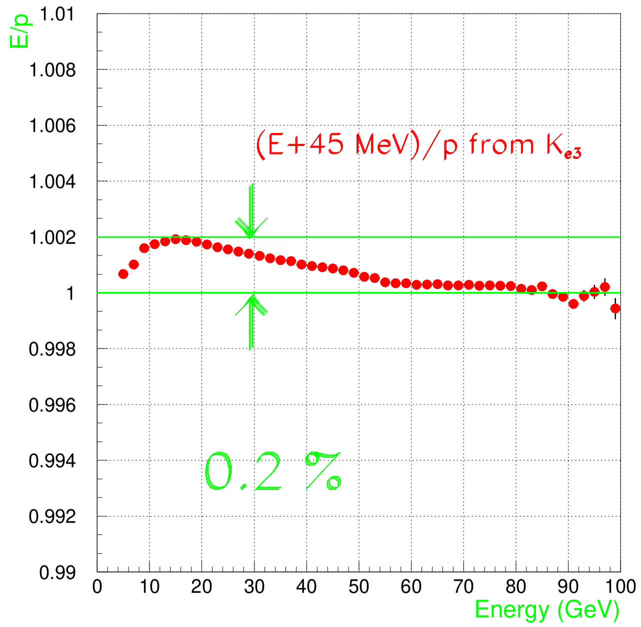


Ribbons and a spacer

- Initial current read-out technique.

Calorimeter performances

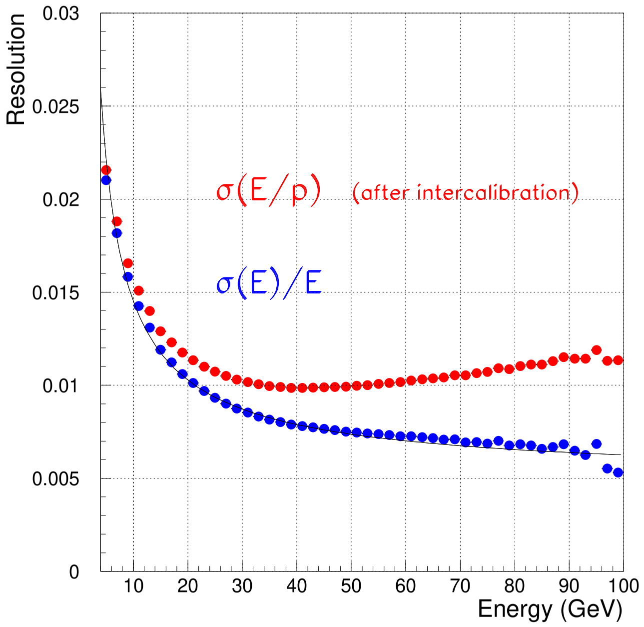
Using electrons from $\pi e \nu$ decay as a probe



- Linearity

$$\frac{Energy(LKR)}{Momentum(DCH)}$$

$\Rightarrow$ Linearity $< 0.2\%$
(from 5 to 100 GeV)



- Resolutions

E/P resolution

drift chamber
deconvoluted

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

$\pi^0 \to \gamma\gamma$ mass resolution : 1.1 MeV/c^2

III. Data Samples

- 1997 run : 42 days at 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) 335-348

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

- 1998 run : 105 days $\sim 1.4 \times 10^{12}$ ppp on $\mathrm{K_L}$ target

  Main improvements :
  - LKr High Voltage 1500 $\to$ 3000 V
  - 1997 LKr dead column cured
  - Charged trigger efficiency 91.3 $\to$ 97.7 %
  - Downscaling factor of 2 removed in charged trigger
  - Lighter beam pipe $\to$ less activity
  - New data acquisition system (PC farm) + 30 % rate

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

  PRELIMINARY RESULT in this presentation

- 1999 run : 124 days $\sim 1.4 \times 10^{12}$ ppp on $\mathrm{K_L}$ target

  Further improvements :
  - DCh read-out, dead time, DAQ efficiency, spill length

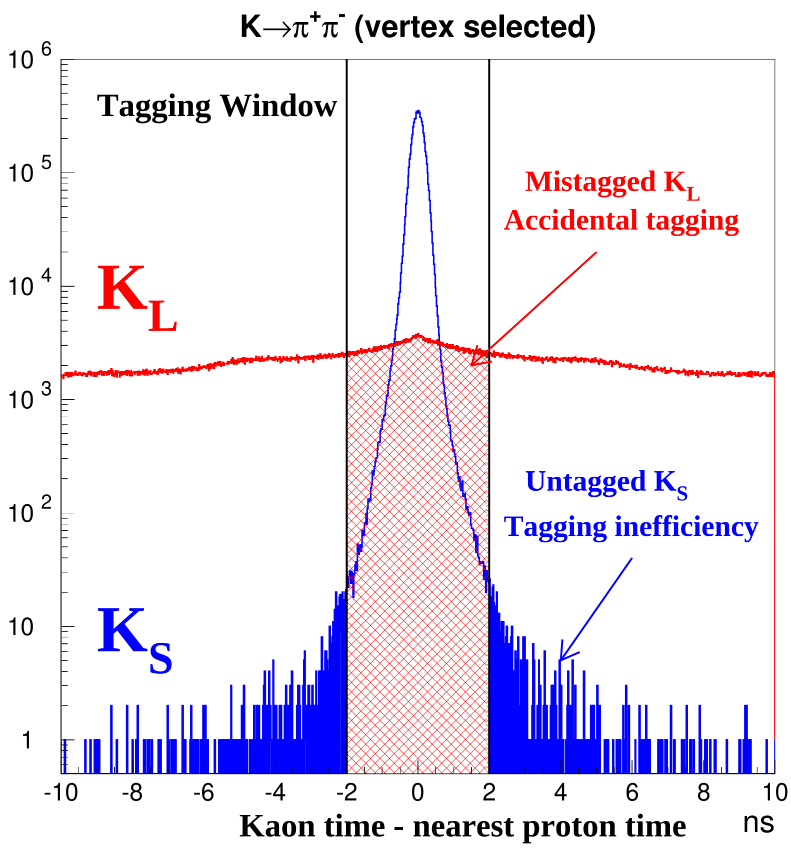
  $\Rightarrow$ Around 2 millions of $K_L \to \pi^0\pi^0$

  Analysis in progress...

Tagging : K_L / K_S identification

Precise time measurements provided by the hodoscope ($\pi^+\pi^-$), the calorimeter ($\pi^0\pi^0$) and the tagger (proton) with resolutions < 250 ps

Plot : event time – nearest proton time



In the charged modes only, identification can also be done by vertex reconstruction.

- Tagging inefficiency (K_S taken as K_L)

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

- Accidental tagging (K_L taken as K_S)

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

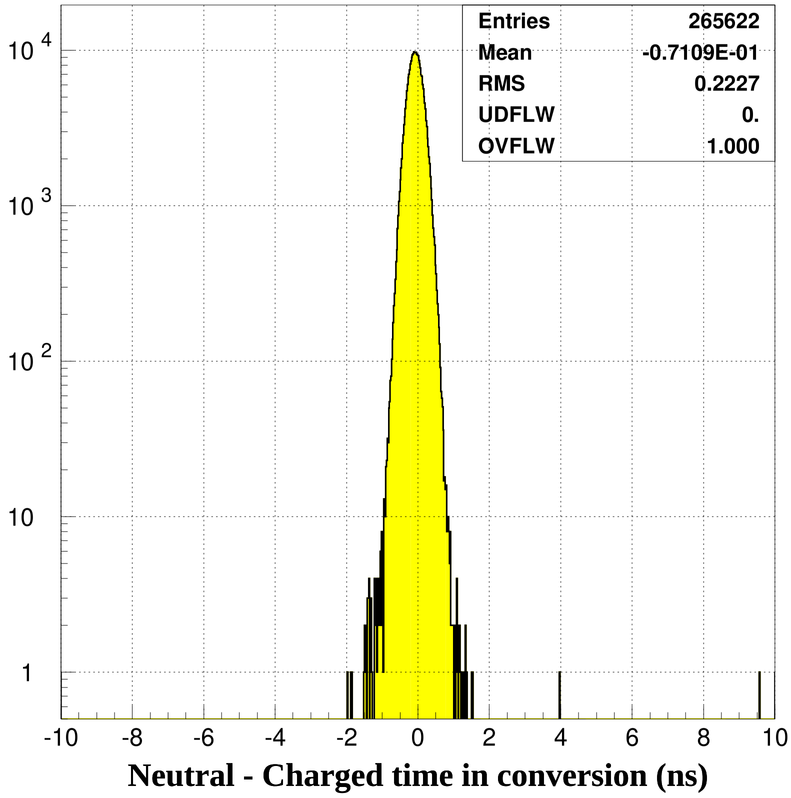
Tagging Inefficiency (K_S taken as K_L)

R sensitivity to tagging inefficiency :

$$\Delta R \simeq 6.0 \times (\alpha_{SL}^{+-} - \alpha_{SL}^{00})$$

$\rightarrow$ The tagger contribution to inefficiency is highly symmetric between $\pi^0\pi^0$ and $\pi^+\pi^-$.

$\rightarrow$ Comparison of charged and neutral times in $\mathrm{K_L}$ and $\mathrm{K_S}$ neutral events ($3\pi^0$ and $2\pi^0$) containing a conversion.



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

$\Rightarrow$ $\boxed{\text{Effect on } R < 3 \times 10^{-4}}$

As a cross-check, measure the inefficiencies in $\mathrm{K_S}$ only runs

$\alpha_{SL}^{00} = (1.3 \pm 0.5) \times 10^{-4}$ $\qquad$ $\alpha_{SL}^{+-} = (1.4 \pm 0.2) \times 10^{-4}$

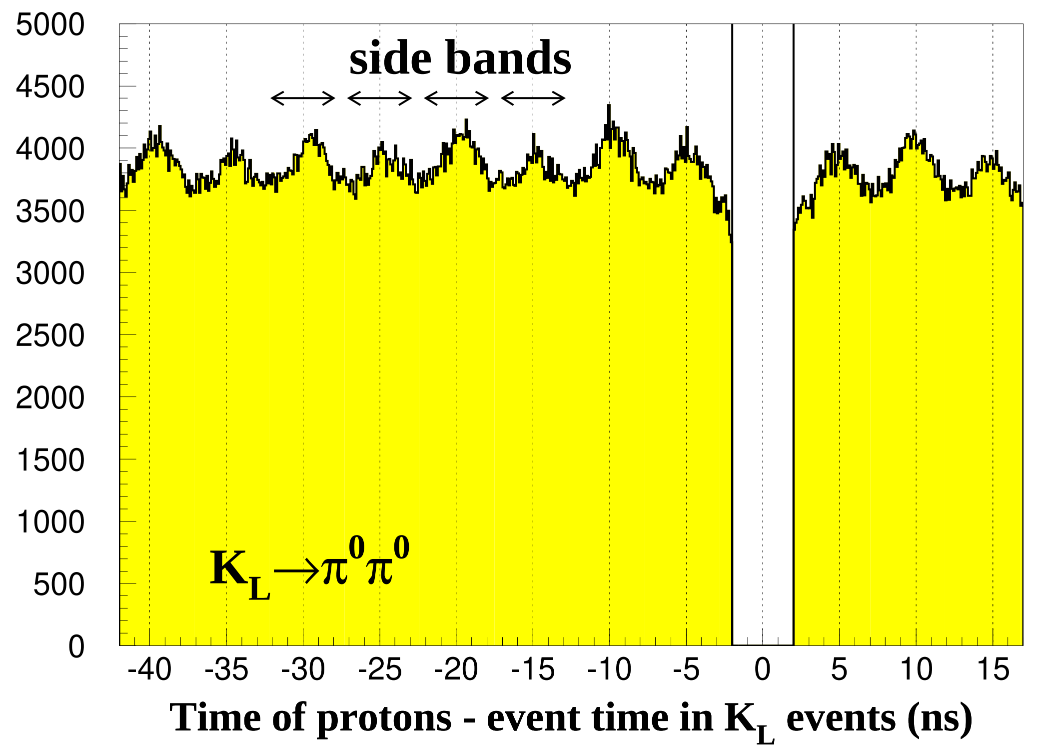
Accidental tagging (K_L taken as K_S)

R sensitivity to accidental tagging :

$$\Delta R \simeq 2.0 \times (\alpha^{00}_{LS} - \alpha^{+-}_{LS}) = 2.0 \times (\Delta\beta + \Delta W)$$

- With tagged $K_L \to 2\pi$ (no proton), we compute the difference between charged and neutral rates in 4 ns wide SIDE-BANDS :

$$\beta^{00}_{LS} - \beta^{+-}_{LS} = (5.3 \pm 1.6) \times 10^{-4}$$



- Differences of activity between central and side bands estimated with $K_L \to 3\pi^0$ and $K_L \to \pi^+\pi^-$ vertex-id.

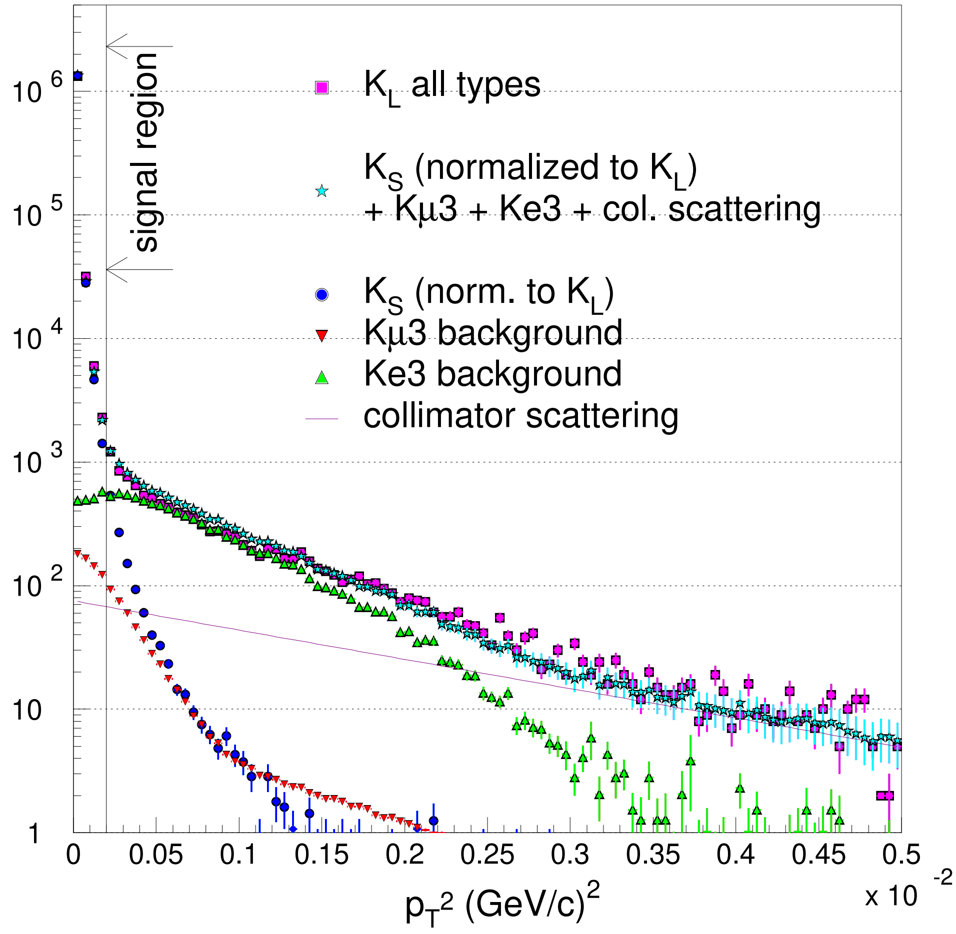
$$W^{00} - W^{+-} = (-5.0 \pm 3.9) \times 10^{-4}$$

(Improvement to come from more $3\pi^0$ processing)

$\Rightarrow$ $\boxed{\text{R correction } (+0.6 \pm 8.4) \times 10^{-4}}$

Charged background

CP-conserving $\pi\mu\nu$ and $\pi e\nu$ decays in K_L beam



Background rejection

$\pi\mu\nu$ no hit in μ veto

$\pi e\nu$ $\frac{E_{LKr}}{P_{DCh}} < 0.8$

$\pi\pi$ mass within 3σ

$p_t^2 < 200\ (MeV/c)^2$

Background subtraction

Fit K_L distribution as $\pi^+\pi^- + \pi\mu\nu + \pi e\nu$ (from K_S)

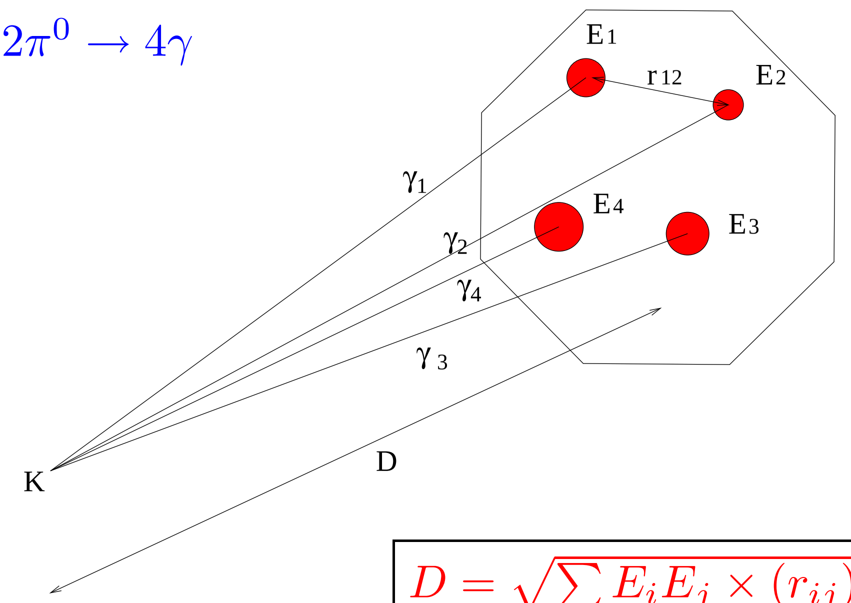
(in a wide $m_{\pi\pi} \times p_t$ control region)

Overall background = $\boxed{(19 \pm 3) \times 10^{-4}}$ $\Rightarrow$ R correction

+ Fit beam scattering from high p_t region.
No similar cut in neutral $\Rightarrow \Delta R = (-9.9 \pm 3.3) \times 10^{-4}$

$K^0 \to \pi^0\pi^0$ identification

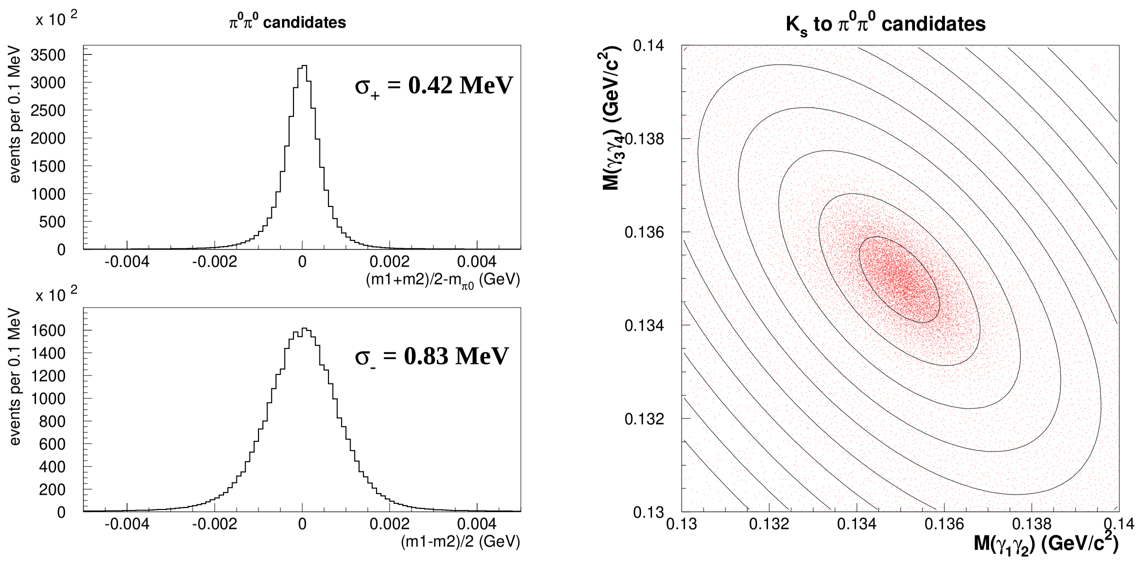
$K_{\mathrm{L,S}} \to 2\pi^0 \to 4\gamma$



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

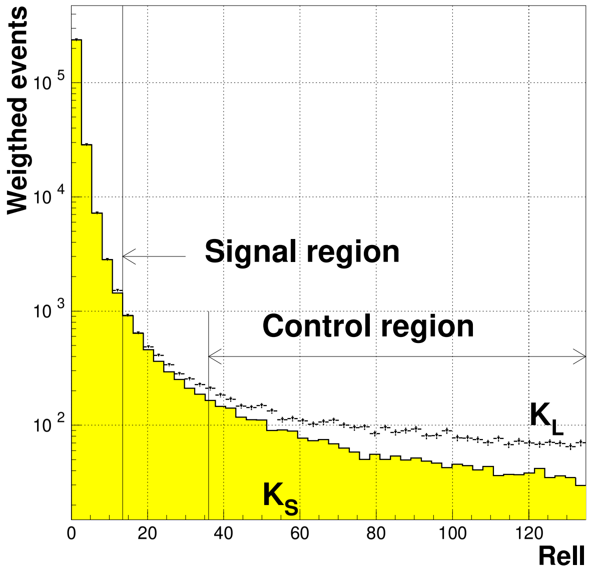
- Vertex position under kaon mass assumption
- Photon pairing to get best π^0 masses :

$$m_{ij} = \sqrt{E_i E_j} \;.\; r_{ij}/D$$



Neutral background subtraction

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

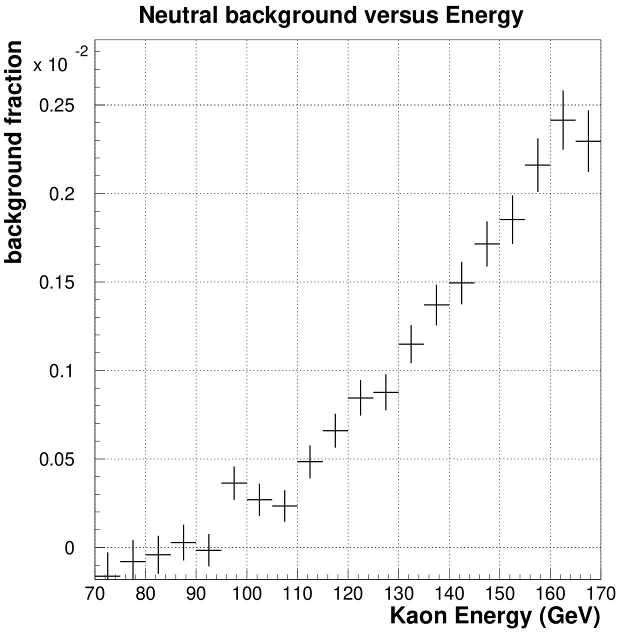


Background subtraction

Signal region : $R_{ell} < 13.5$

$K_L - K_S$ in control region $\rightarrow$ background

$= (6.6 \pm 2.0).10^{-4}$



Background rejection

Background is CP-conserving 3 π^0

Events with extra intime (± 3) cluster ($E > 1.5$ GeV) are rejected

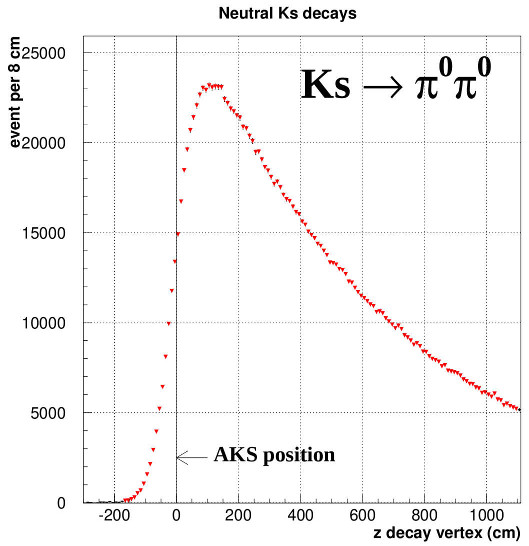
$\Rightarrow$ bin by bin correction to R

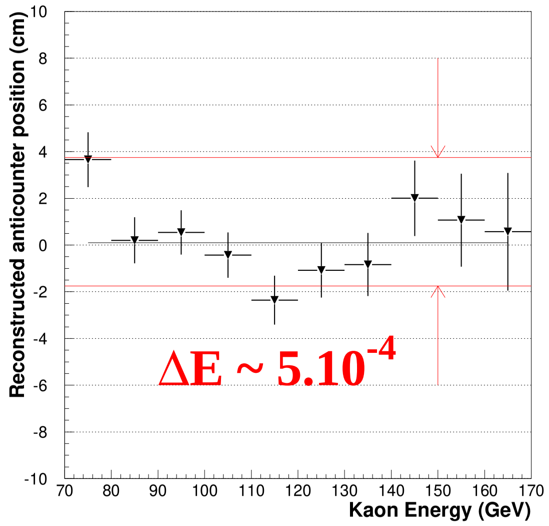
Calorimeter energy scale and non linearitiy

Energy scale

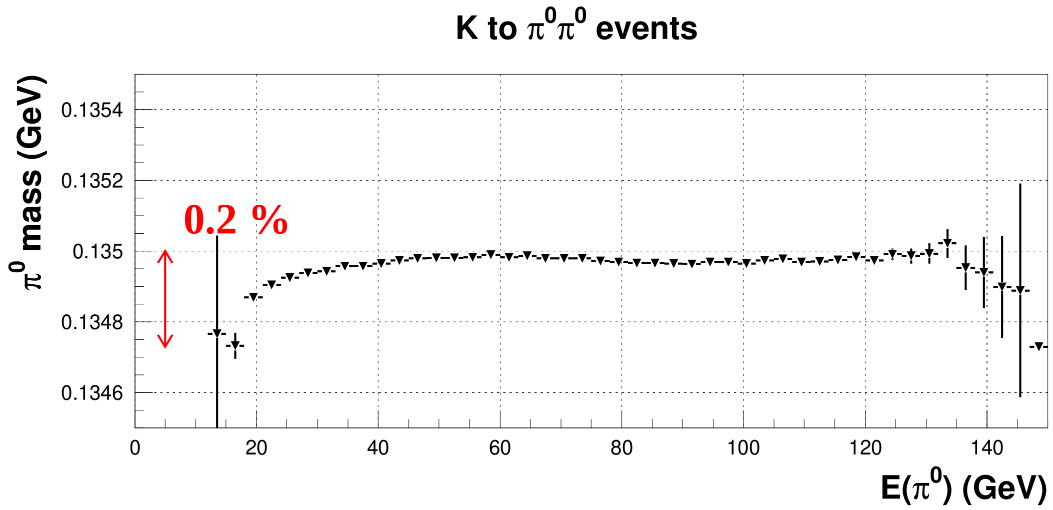
In the neutral mode : $D = \sqrt{\sum E_i E_j \times (r_{ij})^2} \; /M_K$

Fit of the Anti-K_S counter position $\rightarrow$ energy scale





Non-linearity



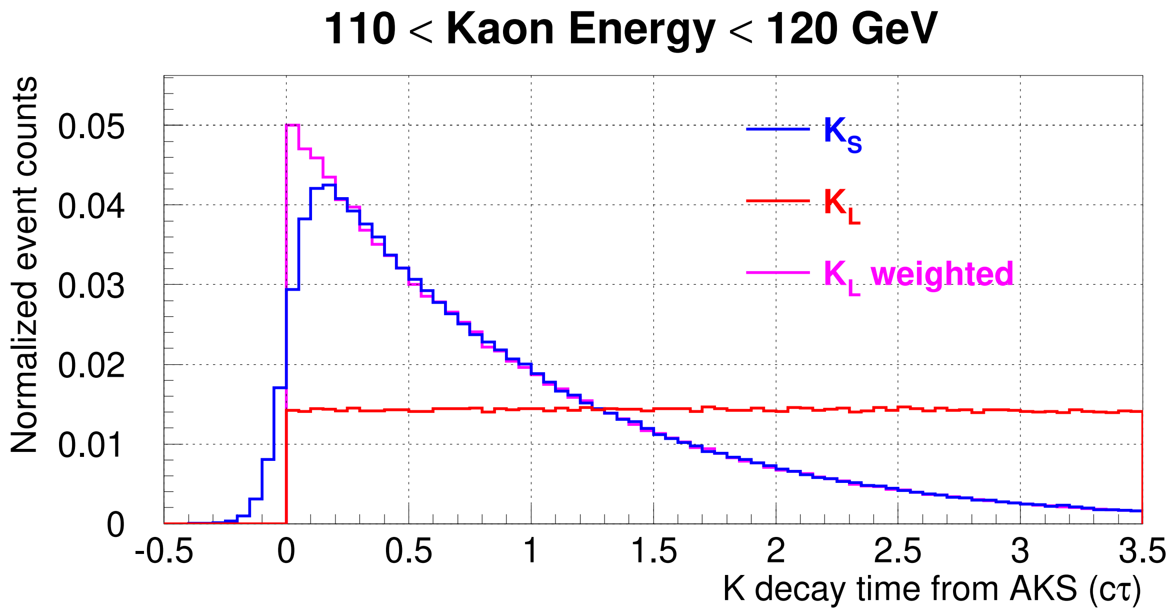
Non-linearity (5.10^{-4}) $\oplus$ energy scale (3.10^{-4}) $\oplus$ transverse scale (3.10^{-4}) $\oplus$ non-gaussian tails (5.10^{-4}) $\oplus$...

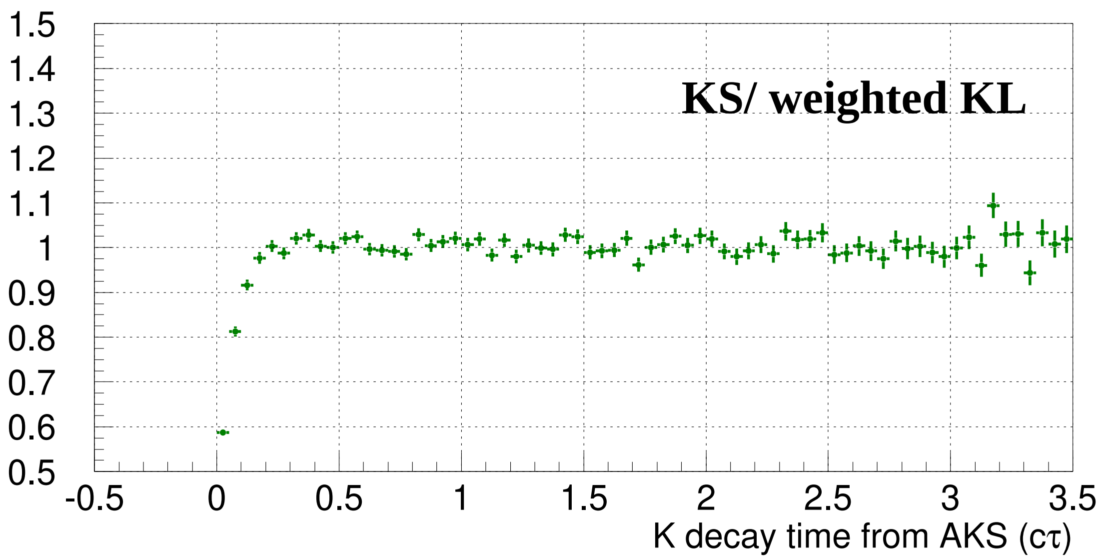
$\Rightarrow$ $\boxed{\text{Uncertainty on } R: \; 10.2 \times 10^{-4}}$

Acceptance : weighting procedure

We weight the K_L events by $exp(-c\tau/c\tau_S)$

$\Rightarrow$ z-distributions look similar



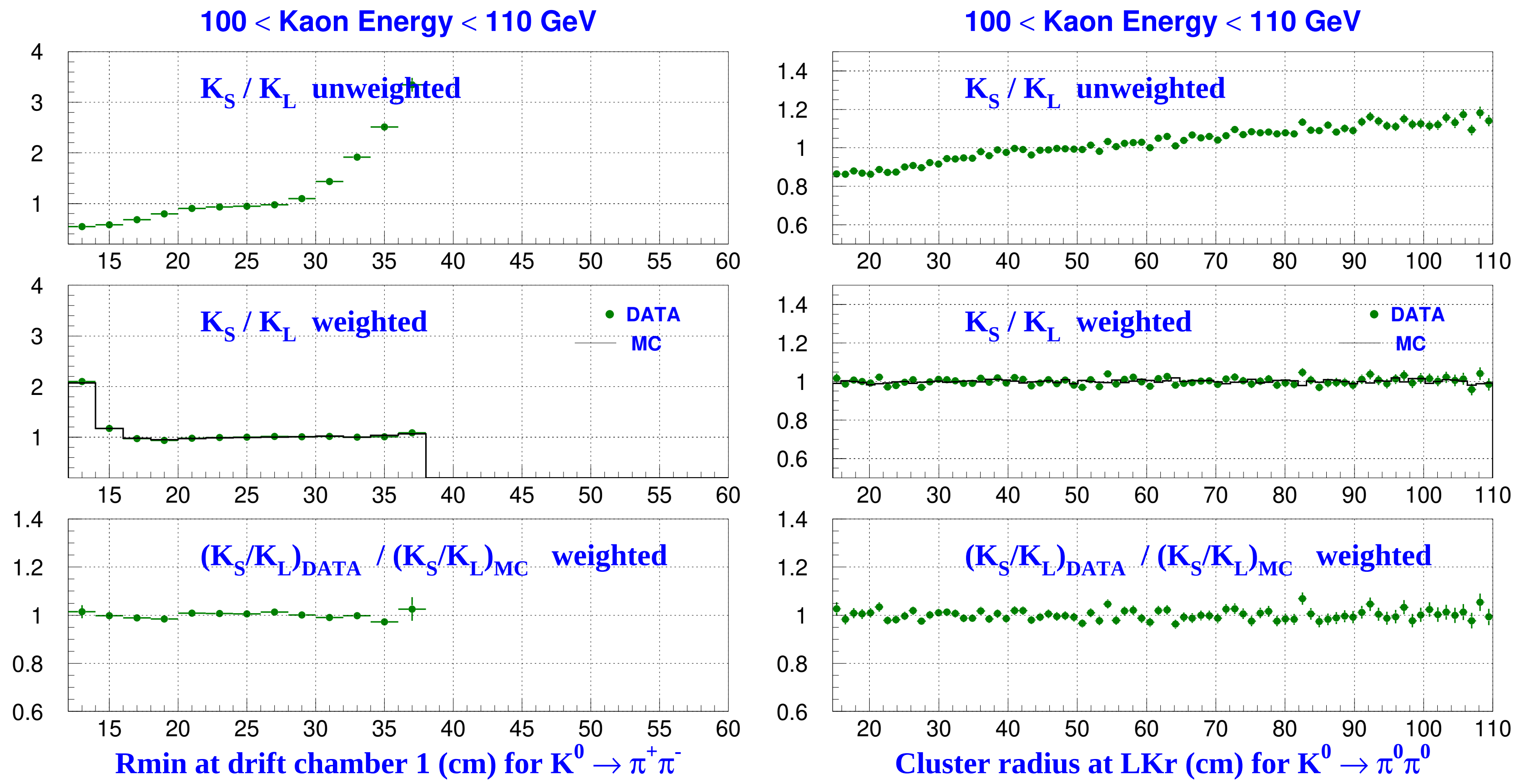


z=0 is defined by

- an Anti-Counter in the K_S beam
- a cut on reconstructed z for K_L

Acceptance : weighting effect

Weighting makes K_S and K_L acceptances similar



For $\pi^+\pi^-$: radial distribution of hits in chamber 1

(Δy beams $\sim 6\ mm$)

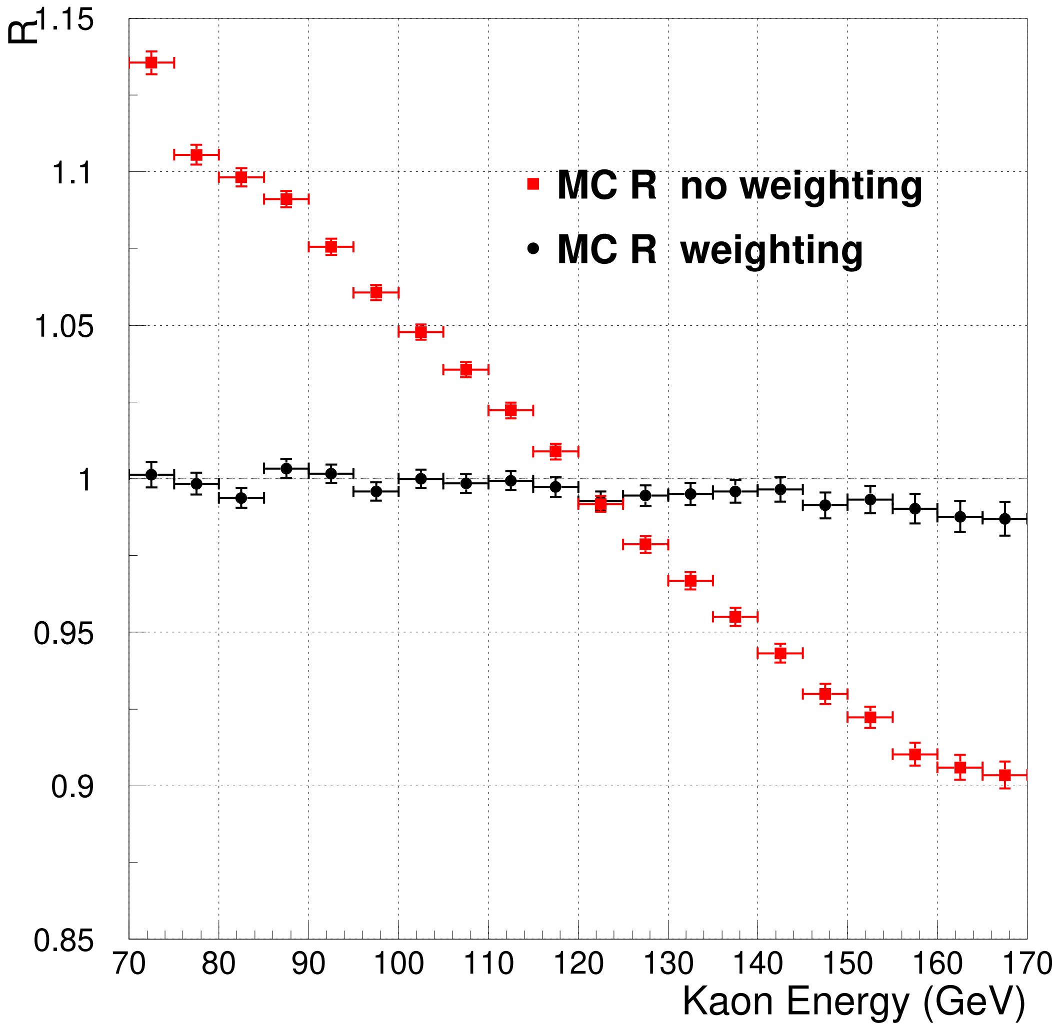
For $\pi^0\pi^0$: radial distribution of clusters in calorimeter

(beams convergence point)

Acceptance : R correction

A detailed montecarlo simulation is used to correct the remaining effect of acceptances.

MC sample $\sim 5 \times$ data sample



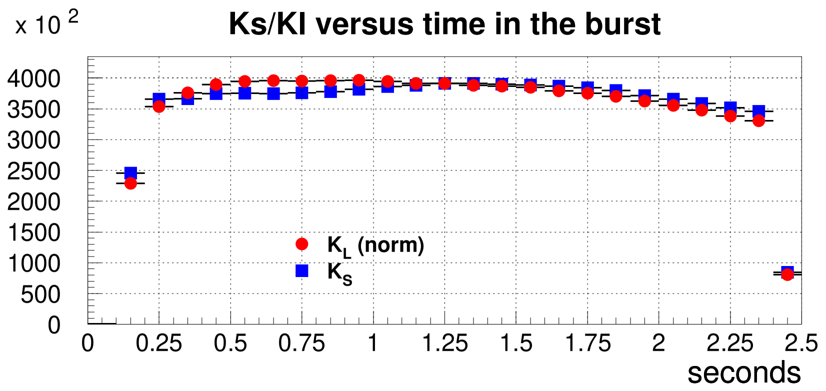
$\Rightarrow$ Bin by bin correction to R :

30.3 ± 7.4 (MC stat.) ± 6.0 (syst.) $\times 10^{-4}$

Price : statistical error increase by $\sim 35\%$

Accidental activity

- Beams simultaneity reduces differential accidental loss.



- Accidental activity (extra clusters and tracks) is found to be identical within 1 % between $\mathrm{K_S}$ et $\mathrm{K_L}$.

Correction for accidental activity

- Superimpose events triggered proportionally to the beam intensity on top of $\pi\pi$ candidates.
- Counting gains and losses leads to :

$$\boxed{\Rightarrow \text{Correction to } R : \ (+2.0 \pm 6.4) \times 10^{-4}}$$

Effect of noise in DCh

- High multiplicity in DCh causes losses of $\pi^+\pi^-$ events.
- We cut both $\pi^+\pi^-$ and $\pi^0\pi^0$ when such an *overflow* occurs, to symmetrize the loss.
- Remaining effect is conservatively estimated to be lower than 10×10^{-4} on R.
- This effect is under further study.

Trigger effects

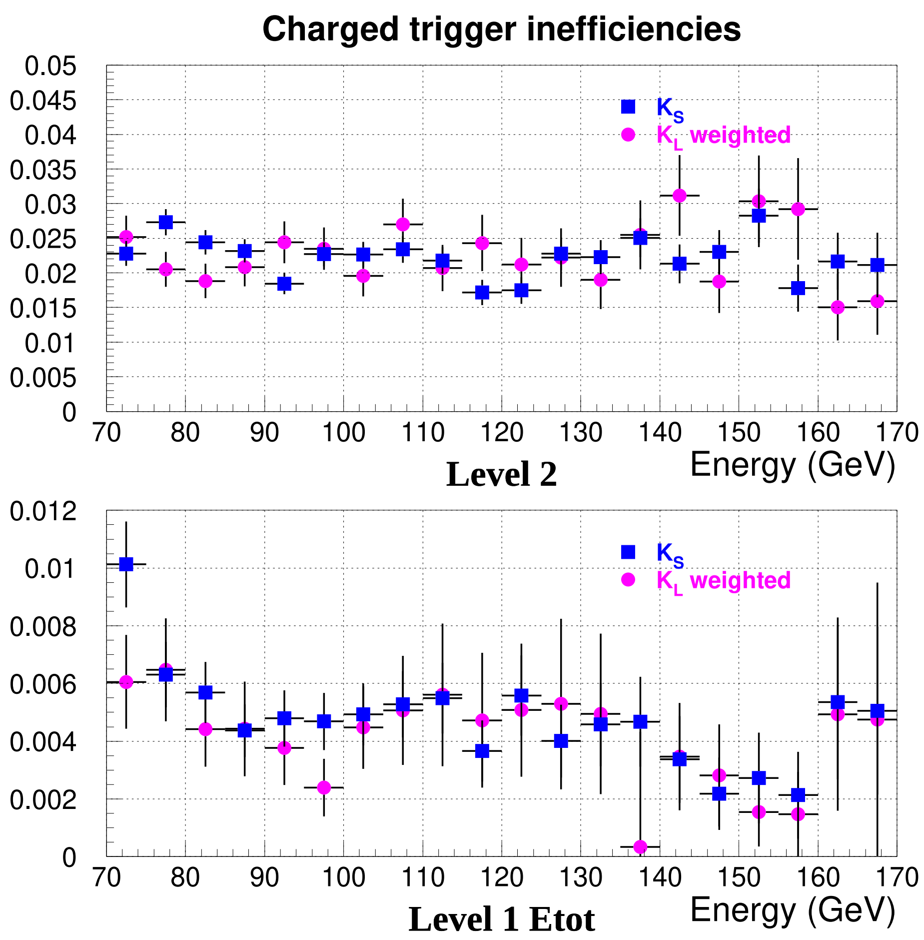
Trigger inefficiencies can generate a bias on R if not K_S /K_L symmetric

- $\pi^0\pi^0$ trigger is very efficient (99,93 %) $\rightarrow$ no bias
- $\pi^+\pi^-$ trigger has two possible sources of bias :

$\rightarrow$ Energy signal used in level 1 is 0.5 % inefficient

$\rightarrow$ Level 2 online processing is 2.3 % inefficient

Measure the inefficiencies for K_S and K_L and correct.



Bin by bin corrections on R leading to

✥ Level 2 : $(-7.3 \pm 10.1).10^{-4}$

✥ L1 Energy : $(+5.9 \pm 5.4).10^{-4}$

Counting events...

Statistics (millions)	1997	1998
$K_S \to \pi^+\pi^-$	2.09	7.46
$K_L \to \pi^+\pi^-$	1.07	4.87
$K_S \to \pi^0\pi^0$	0.98	1.80
$K_L \to \pi^0\pi^0$	0.49	1.14

(after correcting for accidental tagging)

Statistical uncertainty on R :

(taking weighting into account)

$$\boxed{17.3 \times 10^{-4}}$$

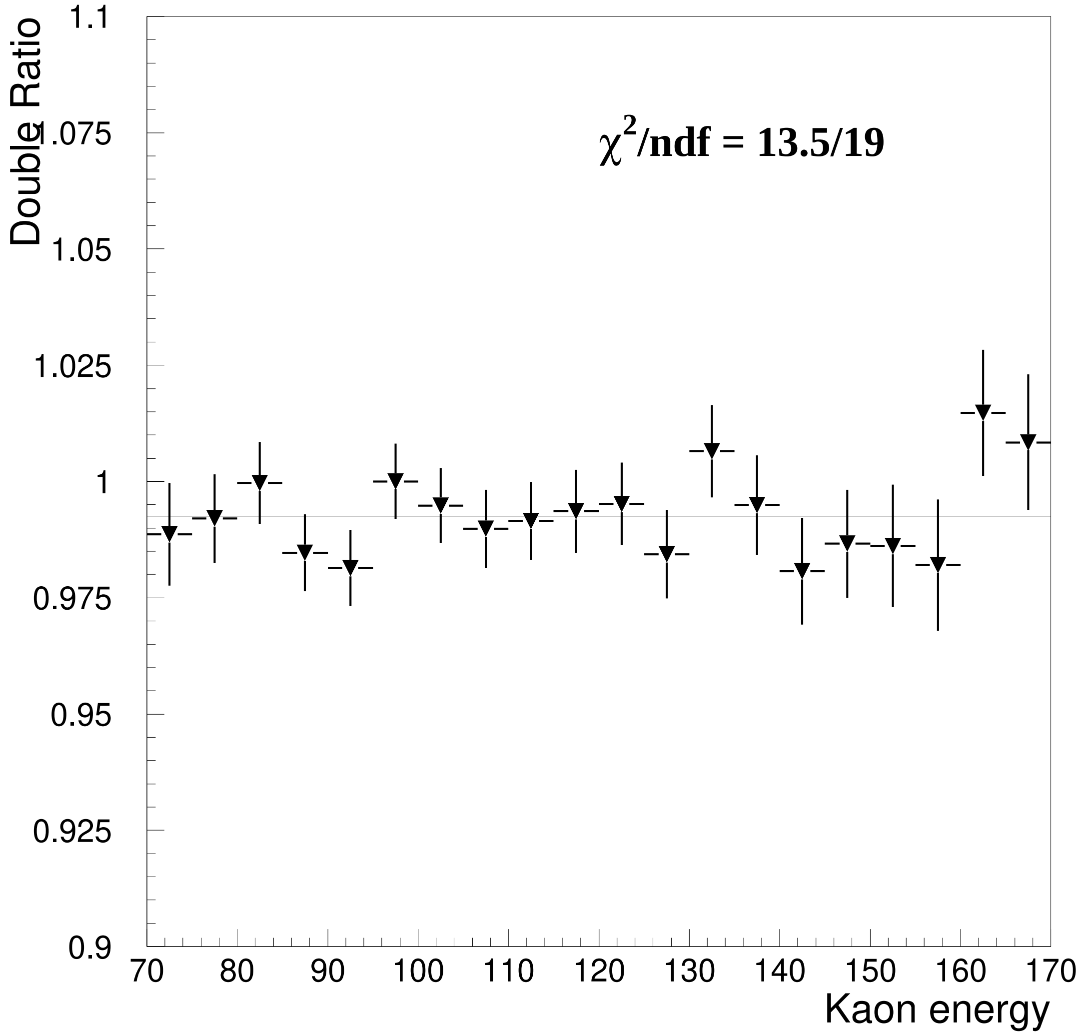
Systematic uncertainty summary

Corrections and uncertainties on R (Unit = 10^{-4})				
Source	1997 sample		1998 sample	
Charged trigger	+9	23	−1.4	11.5
Accidental tagging	+18	9	+0.6	8.5
Tagging efficiency	–	6	–	3.0
Neutral scale	–	12	–	10.2
Charged vertex	–	5	+2.0	2.0
Acceptance	+29	12	+31.1	8.7
Neutral BG	−8	2	−6.6	2.0
Charged BG	+23	4	+19.0	3.0
Beam scattering	−12	3	−9.9	3.0
Accid. activity	−2	14	+2.0	12.2
Total	+57	35	+36.8	23.8

$$\mathrm{Re}(\varepsilon'/\varepsilon) = \frac{1}{6} \times (1 - R)$$

IV. Results

PRELIMINARY RESULT ON 1998 DATA



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

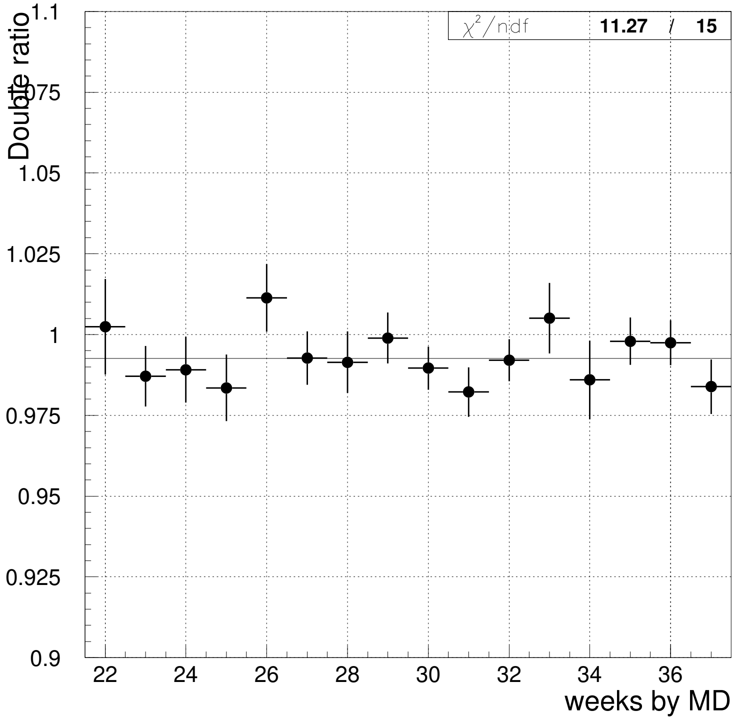
Systematic uncertainty is partly of statistical nature.

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

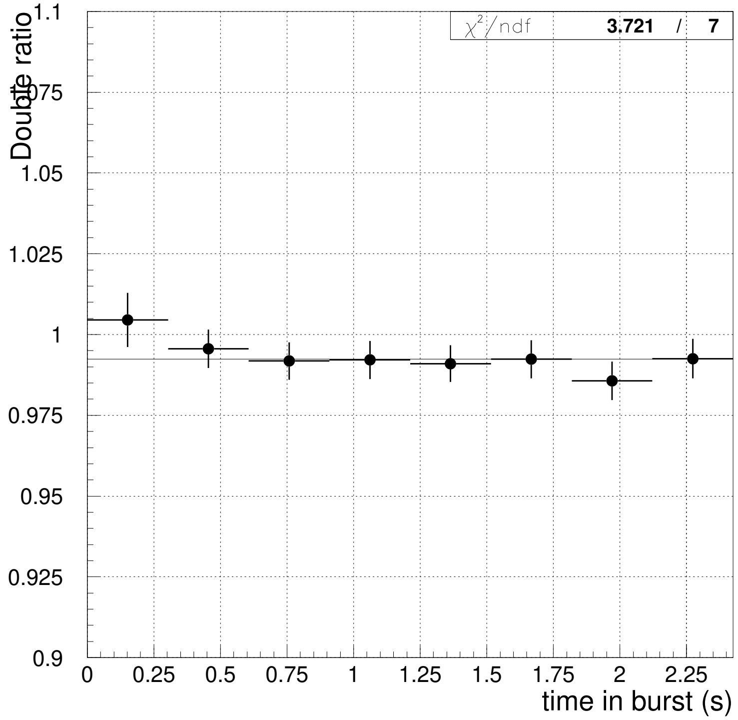
$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 4.9) \times 10^{-4}}$$

Checks of R stability I

R was computed and found stable as a function many variables, for instance :



Week of datataking



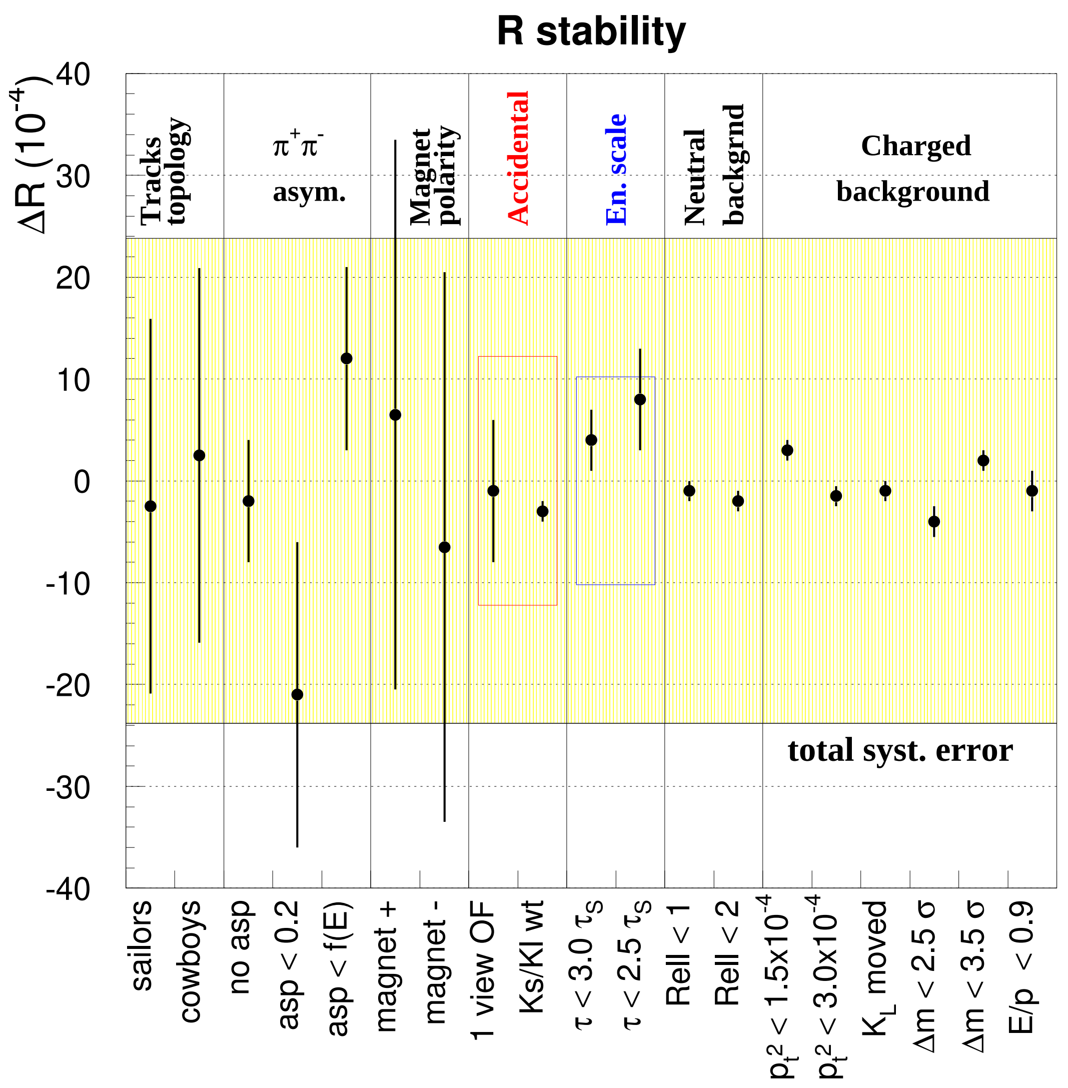
Time in the burst

Checks of R stability II

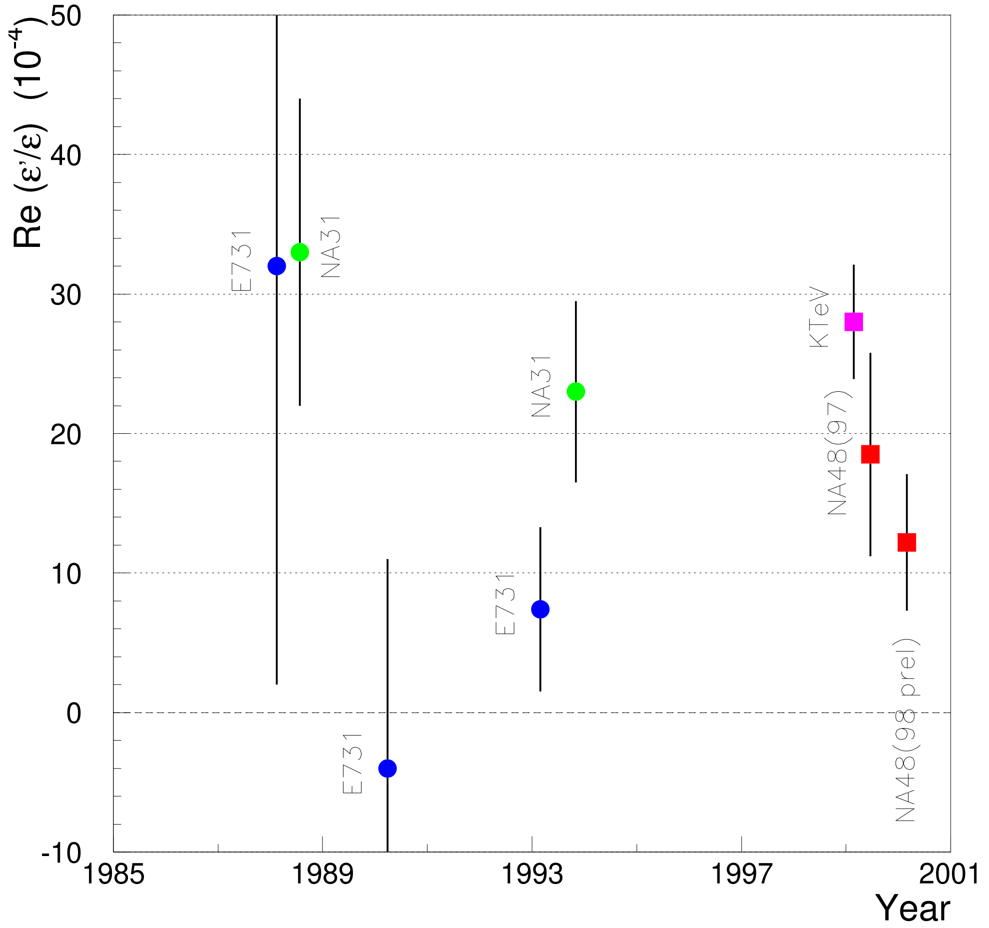
Varying analysis cuts, we check the stability of the result.

Quoted error is only the uncorrelated statistical error.

The variations are within the concerned systematic error.



V. Experimental discussion



Combined 1997 and 1998 NA48 result

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

(taking into account (small) correlated systematics)

World average result

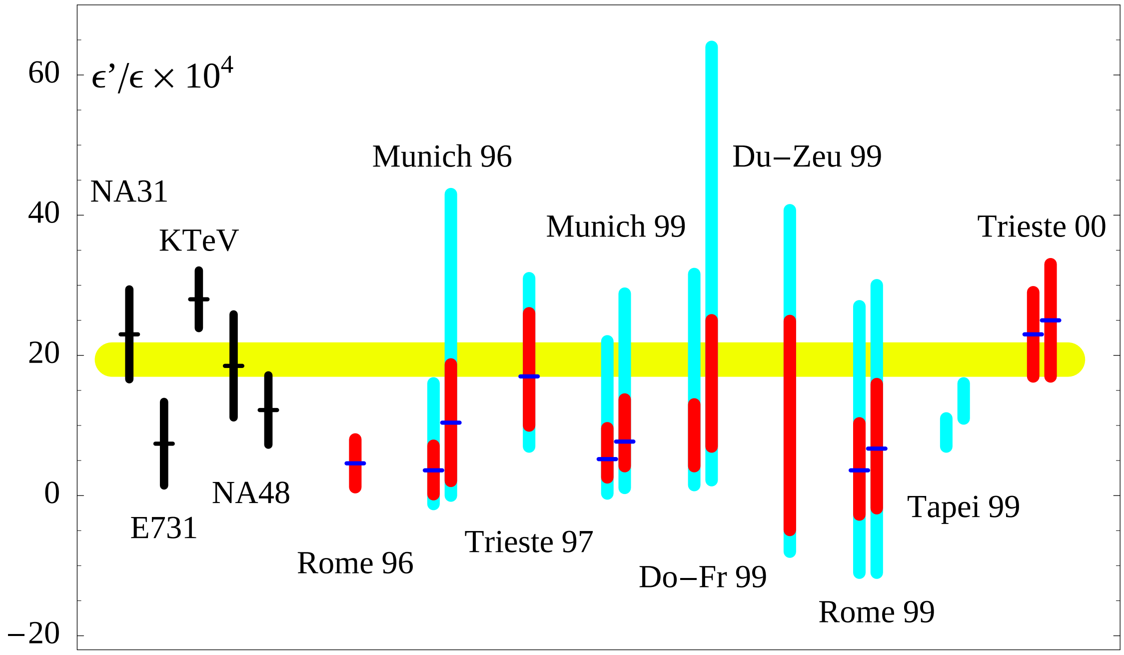
$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon) \;=\; (19.3 \pm 2.4) \times 10^{-4}}$$

$(\chi^2/\mathrm{dof} = 10.9/5)$

Theory vs experiment

Experimental average result is $(19.3 \pm 2.4) \times 10^{-4}$

Standard Model predictions point to lower values of $\mathrm{Re}(\varepsilon'/\varepsilon)$, but a *conspiracy* of input parameters can lead to high values.



Experiments versus Theory

Theoretical error bars are obtained by :

- Propagating gaussian uncertainty
- Scanning input parameters

See Marco Ciuchini's talk for a review of these computations.

Conclusions

- New NA48 (preliminary) result based on 1998 data :

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

- Combining with our previous result, we obtain :

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

- It confirms the existence of direct CP violation.

- The world average value for $\mathrm{Re}(\varepsilon'/\varepsilon)$, including this new measurement is :

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

but poor agreement ($\chi^2/\mathrm{dof} = 10.9/5$)

- Comparison with new results from KLOE (DAΦNE) and KTeV (FNAL) will be very enriching.

- NA48 is analysing its 1999 data, which is twice larger than 1998 sample.

- On 11/11/99, the implosion of the carbon-fiber beam pipe damaged the four chambers. NA48 has been approved to rebuild the spectrometer, in order to fulfill the $\mathrm{Re}(\varepsilon'/\varepsilon)$ measurement. In 2001, runs will be dedicated to the reduction of systematic uncertainties.