Measurement of Direct CP Violation by NA48 Experiment at CERN

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CERN, Geneva

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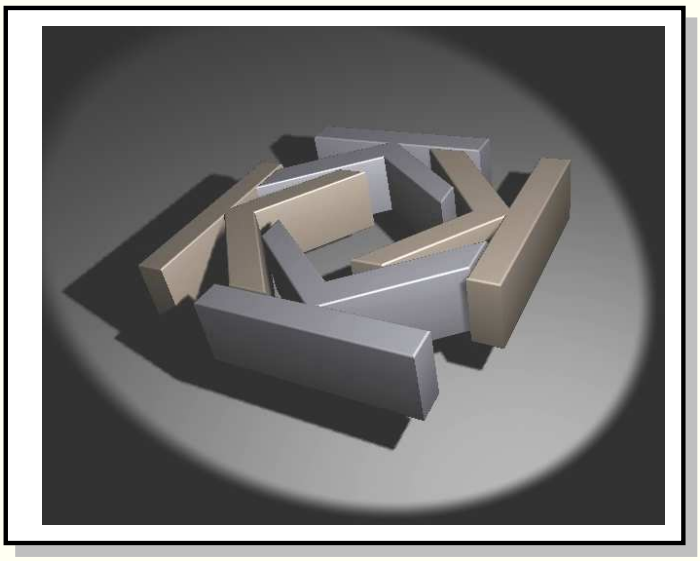

On behalf of the NA48 Collaboration:
Cagliari Cambridge CERN Dubna Edinburgh
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Siegen Torino Vienna Warsaw

Outline

➡ Our last result is a preliminary measurement of the $\mathrm{Re}(\varepsilon'/\varepsilon)$ parameter based on data collected by NA48 during the 1998 SPS run.

➡ The statistics have increased by 2.5 times with respect to the result already published by NA48

- Physics motivation
- NA48 method
  - Beams
  - Detectors
  - Trigger
- Analysis of the 1998 data
  - Data sample
  - Proper lifetime weighting
  - K_S tagging
  - Background subtraction
  - Relative energy scale
  - Accidental activity
- Result and checks
- Perspectives

CP violation in the K^0–$\overline{K^0}$ system

Strangeness eigenstates:

$$K^0(\bar{s}d)$$
$$\overline{K^0}(s\bar{d})$$

CP eigenstates:

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

Mass eigenstates:

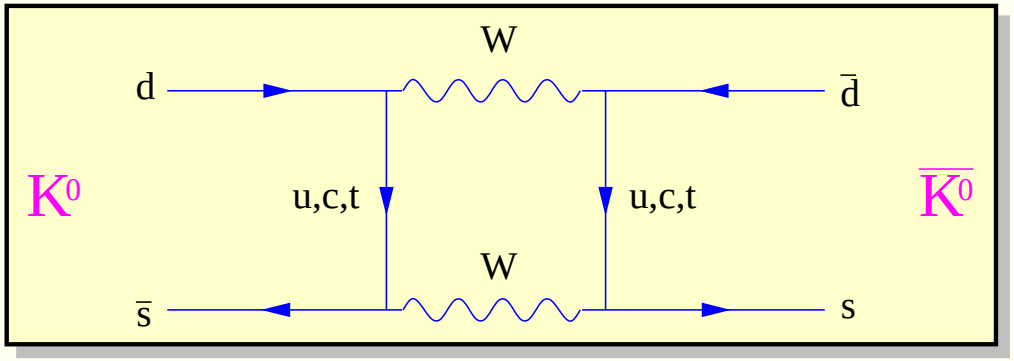
$K_S \simeq$	$K_1 +$	εK_2	$K_L \simeq$	$K_2 +$	εK_1
69 %	$\pi^+\pi^-$		21 %	$3\pi^0$	
31 %	$\pi^0\pi^0$		13 %	$\pi^+\pi^-\pi^0$	
			27 %	$\pi\mu\nu$	
			39 %	$\pi e\nu$	
			0.2 %		$\pi^+\pi^-$
			0.1 %		$\pi^0\pi^0$

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

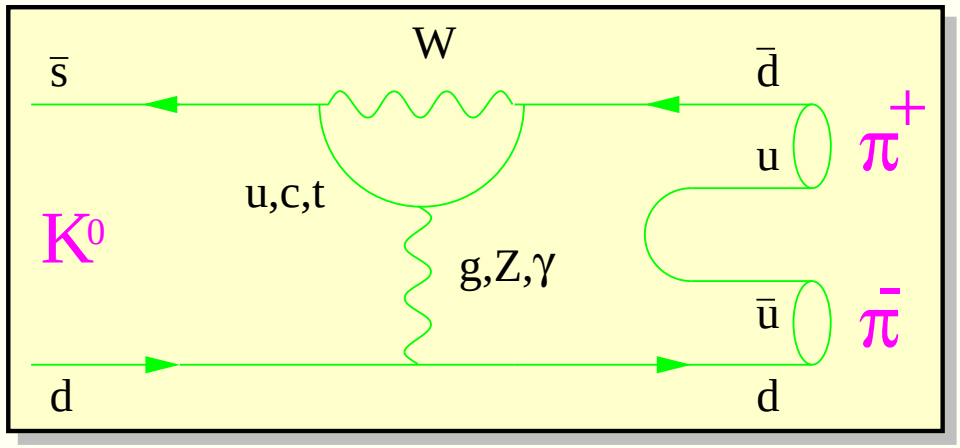
$$\varepsilon = (2.28 \pm 0.02) \times 10^{-3}$$

Direct CP violation

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



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



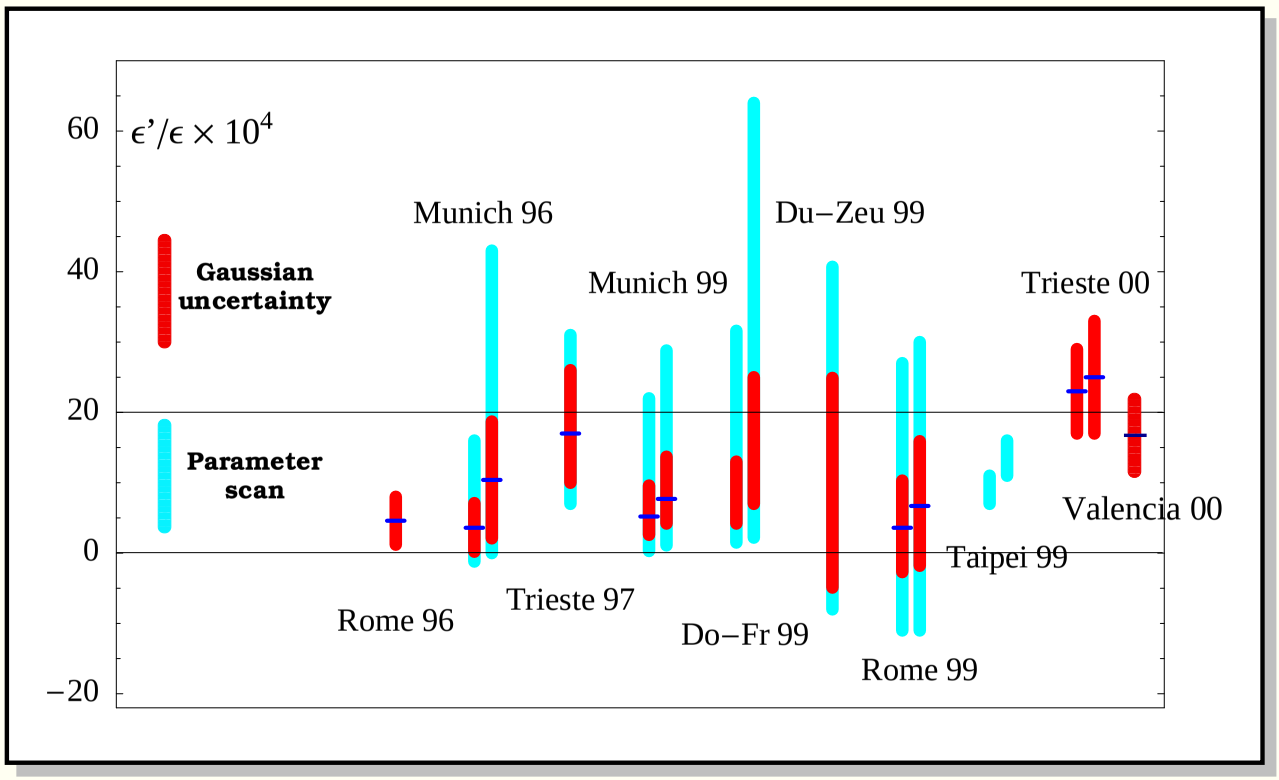
Direct CP violation:

$$\varepsilon' = \frac{i}{\sqrt{2}} \Im\mathrm{m} \frac{A_2}{A_0} \exp(i(\delta_2 - \delta_0))$$

$$\mathrm{A}(\mathrm{K}^0 \rightarrow \pi\,\pi\,, \mathrm{I}) = \mathrm{A}_\mathrm{I} \exp(\mathrm{i}\delta_\mathrm{I})$$
$$\mathrm{A}(\overline{\mathrm{K}^0} \rightarrow \pi\,\pi\,, \mathrm{I}) = \mathrm{A}_\mathrm{I}^* \exp(\mathrm{i}\delta_\mathrm{I})$$

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

Standard Model Predictions:



Measurements:

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

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

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

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

NA48 method

- Method: double ratio technique
- Aim: measure $\mathrm{Re}(\varepsilon'/\varepsilon)$ with an accuracy of 2×10^{-4}
- High statistics needed:
  - High intensity beam
  - Powerful Trigger and DAQ systems
- Minimize corrections
  $\rightarrow$ the 4 modes are measured:
  - Simultaneously

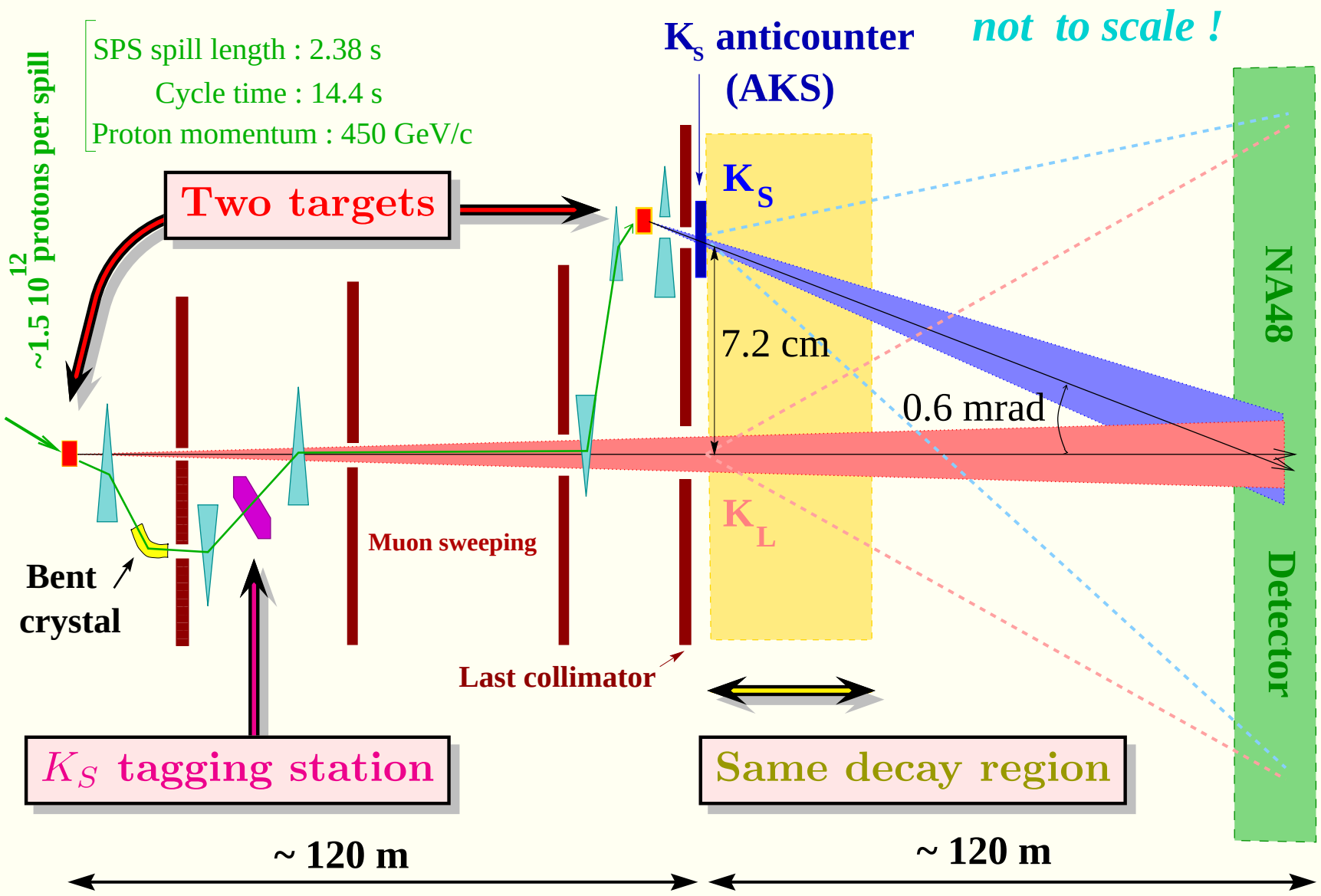
    $\Rightarrow$ charged/neutral cancellations of beam fluxes and $\mathrm{K_S}$ -tagging inefficiencies

    $\Rightarrow$ $\mathrm{K_S}$ /$\mathrm{K_L}$ cancellations of detector, trigger and selection inefficiencies and accidental losses
  - From the same fiducial volume and applying lifetime weighting of $\mathrm{K_L}$ to make longitudinal decay distributions similar for $\mathrm{K_L}$ and $\mathrm{K_S}$

    $\Rightarrow$ small acceptance correction
  - With a high resolution magnetic spectrometer for the $\pi^+\pi^-$ mode and with a homogeneous Liquid Krypton calorimeter for the $\pi^0\pi^0$ mode

    $\Rightarrow$ small background levels
  - In bins of energy to eliminate slight differences in energy spectra

Simultaneous K_L and K_S beams



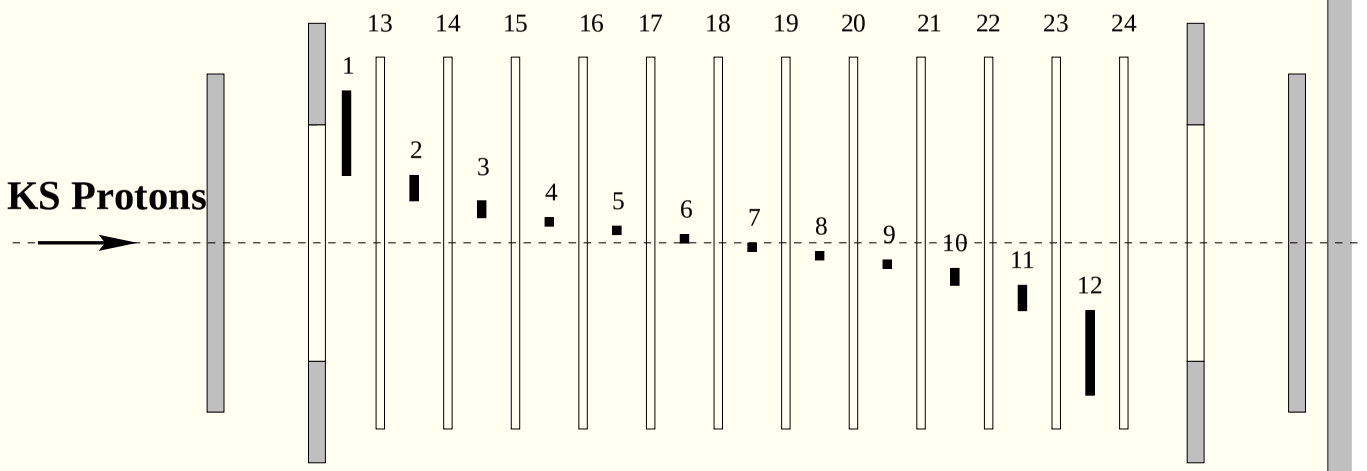
K_S Tagger

T.O.F. between the proton in the Tagger and the detected Kaon decay products:

$|t_K - t_{tagger}| < 2ns \Rightarrow K_S$

$|t_K - t_{tagger}| > 2ns \Rightarrow K_L$

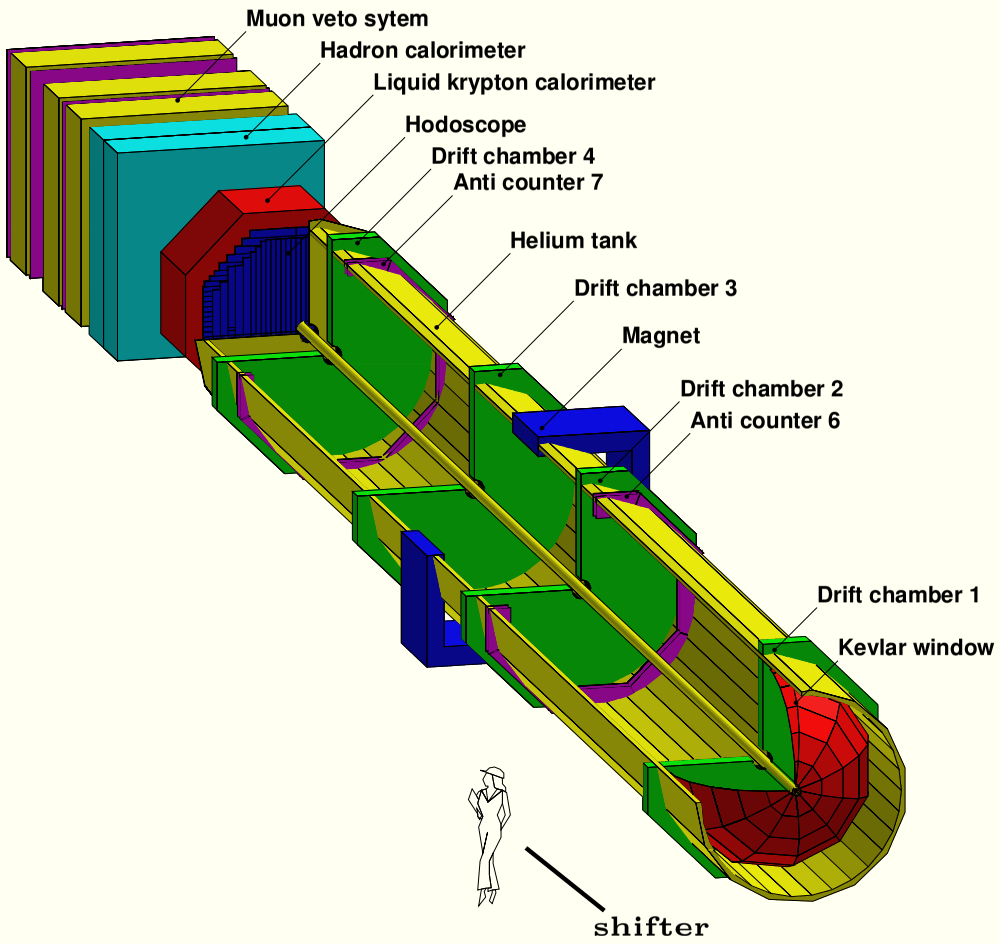
Tagger from side view



▮ : Vertical ladder ▯ : Horizontal ladder

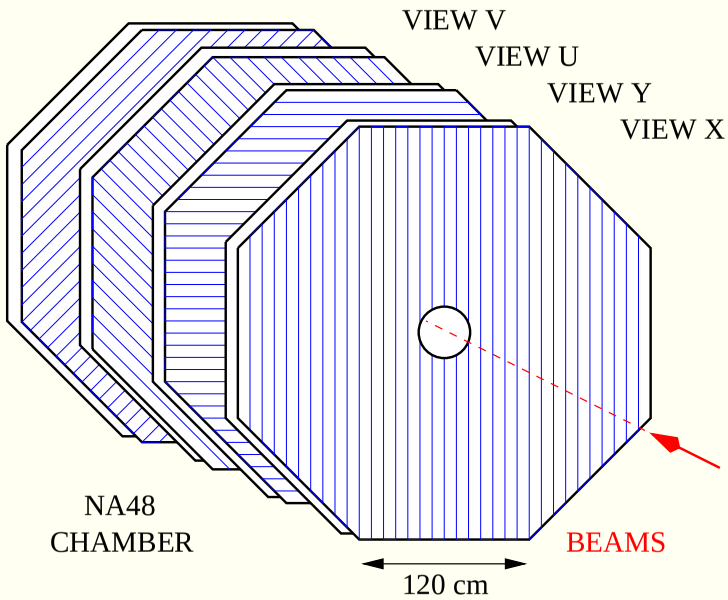
- 8-bit 960MHz FADC read-out
- 200ps time resolution per counter
- 4ns double pulse separation

NA48 detectors



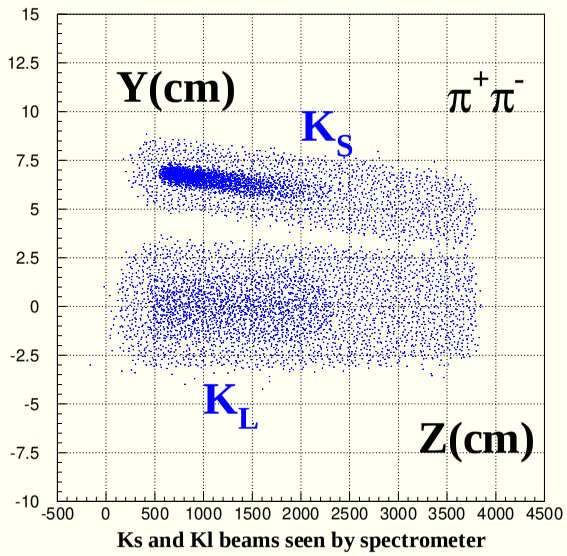
- $K_{L,S} \to \pi^+\pi^-$
  - magnetic spectrometer ($P_T{}^{kick} \sim 265 MeV/c$)
- $K_{L,S} \to \pi^0\pi^0$
  - quasi-homogeneous Liquid Krypton e.m. calorimeter :
    - high granularity (13212 2×2 cm^2 cells)
    - projective geometry

Magnetic spectrometer

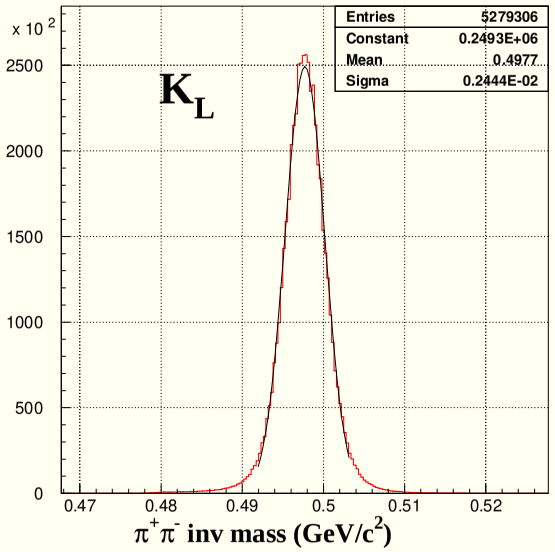


Per Chamber:

- 8 planes of 256 wires
- Positioning of wires to $\leq 100\mu$m/m
- Argon/Ethane
- Gain $\sim 8.10^4$



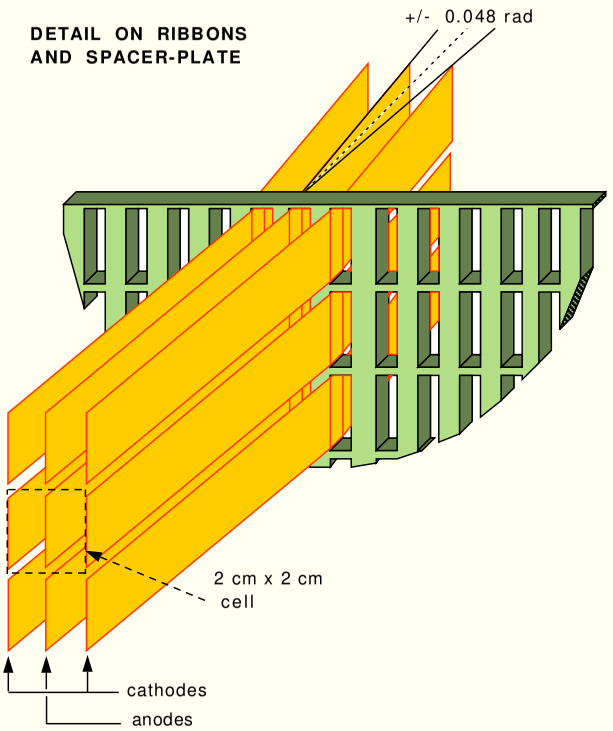
Vertex reconstruction allows beam separation



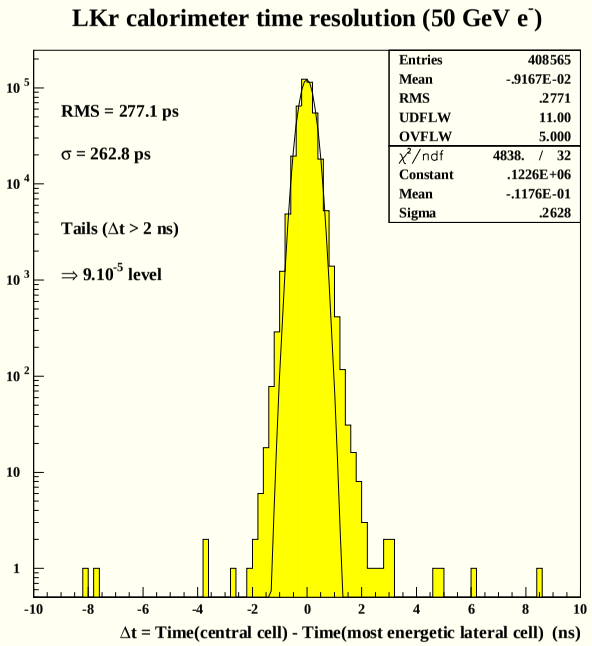
Kaon mass resolution ~ 2.5 MeV/c^2

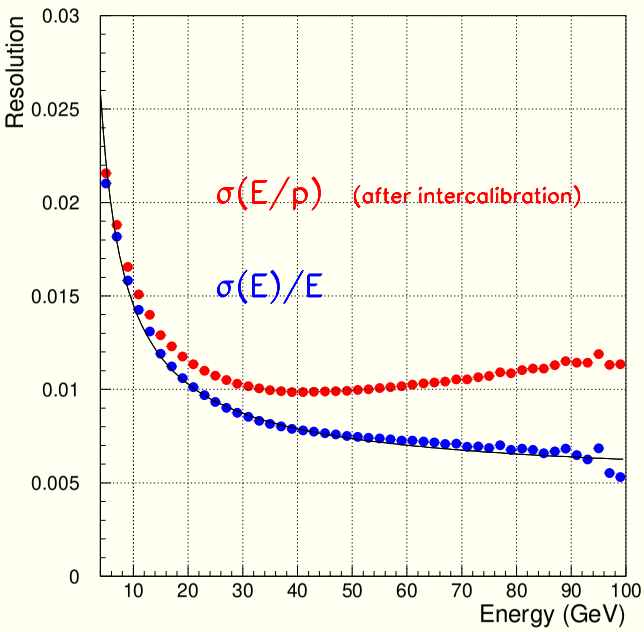
$$\sigma(p)/p \simeq 0.5\,\% \oplus 0.009\,p[\mathrm{GeV/c}]\,\%$$

Liquid Krypton calorimeter



- Contains $\approx 9m^3$ LKr
- Cu-Be electrodes
- Bias HV: +3 KV/cm
- Cell: 2cm×2cm×127cm
- Electrodes: ± 48mrad zig-zag in each spacer
- Geometry controlled to ≈0.2mm/1m
- stability ≈ 0.1%



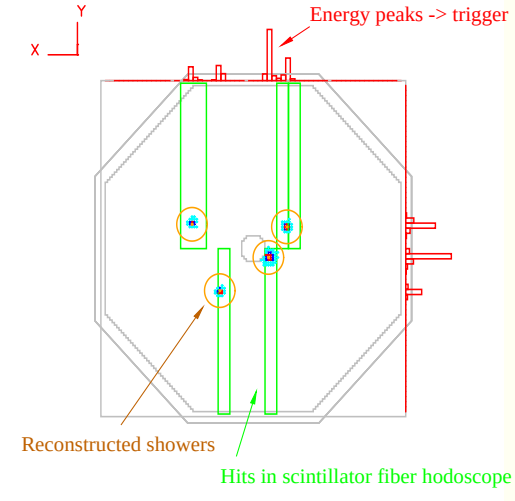


$$\frac{\sigma(E)}{E} = \frac{3.2\%}{\sqrt{E}} \oplus \frac{100MeV}{E} \oplus 0.5\%$$

Trigger

$\pi^0\pi^0$:

- Fully pipelined system using LKr cell information summed to horizontal and vertical projections to compute energy, centre of gravity, proper lifetime and number of showers
- Output rate $\sim$ 2 kHz
- Latency 5μs
- Negligible dead time
- Efficiency : 99.93 $\pm$ 0.02 %



$\pi^+\pi^-$:

- Level 1 :
  - Energy in calorimeters $>$ 35 GeV
    Efficiency 99.49 $\pm$ 0.03 %
  - Two track topology in hodoscope
    Efficiency 99.95 $\pm$ 0.01 %
  - Two track multiplicity
    in drift chamber 1
    Efficiency $>$ 99.99 %

- Level 2 : on-line processing of vertices and $\pi\pi$ invariant mass from spectrometer hits
  - Output rate $\sim$ 2 kHz
  - Latency : $<$ 102 μs
  - Dead Time : $<$ 5% monitored and applied to $\pi^0\pi^0$
  - Efficiency $\simeq$ 97.75 $\pm$ 0.05

Data sample

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

  ⟹ 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, $\sim 1.4 \times 10^{12}$ ppp on K_L target

  Main improvements :

  - LKr High Voltage 1500 → 3000 V
  - Charged trigger efficiency 91.3 → 97.7 % and downscaling of 2 removed
  - Carbon fibre pipe → less activity
  - New data acquisition PC farm + 30 % rate

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

  PRELIMINARY RESULT from February 2000

- 1999 : 128 days, $\sim 1.4 \times 10^{12}$ ppp on K_L target

  Further improvements :

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

  ⟹ Around 2 million of $K_L \to \pi^0\pi^0$

- 2000 : 40 days - systematic checks on $2\pi^0$: K_S tagging, energy scale (no spectrometer available)

  ANALYSIS in progress...

Analysis strategy

- Optimized general selection criteria:
  $70 < E_K < 170$ GeV and $0 < \tau < 3.5\tau_S$
  For K_S beginning of the decay volume
  ($\tau > 0$) is defined by requiring no hits in the
  anti-counter placed in the K_S beam
  ⟹ minimize sensitivity to the energy scale uncertainty

- Reject $\pi^0\pi^0$ events detected during
  dead time for $\pi^+\pi^-$:
  - <5 % from charged trigger
  - $\approx$ 25 % from multiplicity overflow
    in the spectrometer

  ⟹ equalize intensity conditions between charged and neutral samples

- K_S are identified by tagger in both charged and neutral modes
  ⟹ cancel out tagger inefficiencies and accidental tagging probabilities

Analysis strategy continued

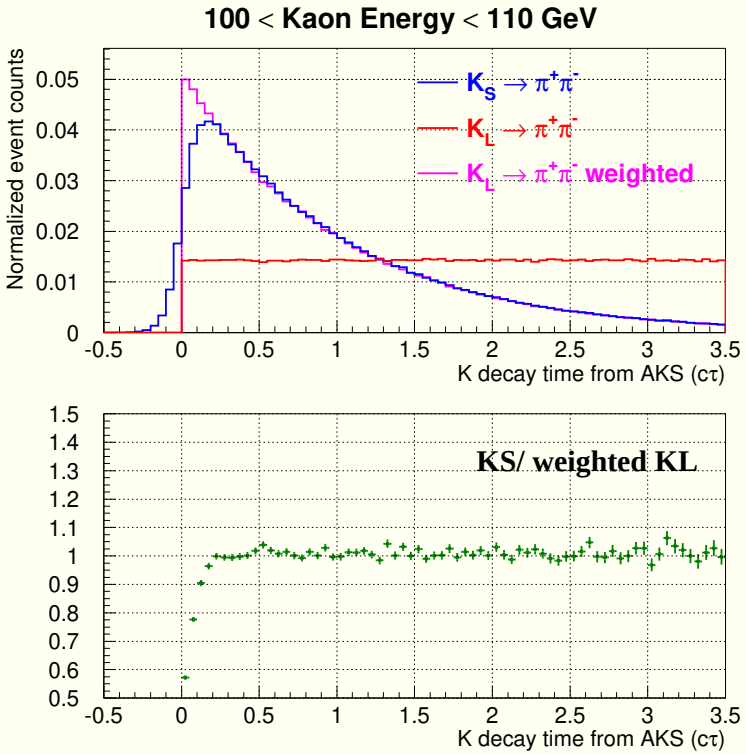
- K_L candidates are counted with a weight depending on the proper lifetime
  ⟹ minimize K_S /K_L acceptance difference

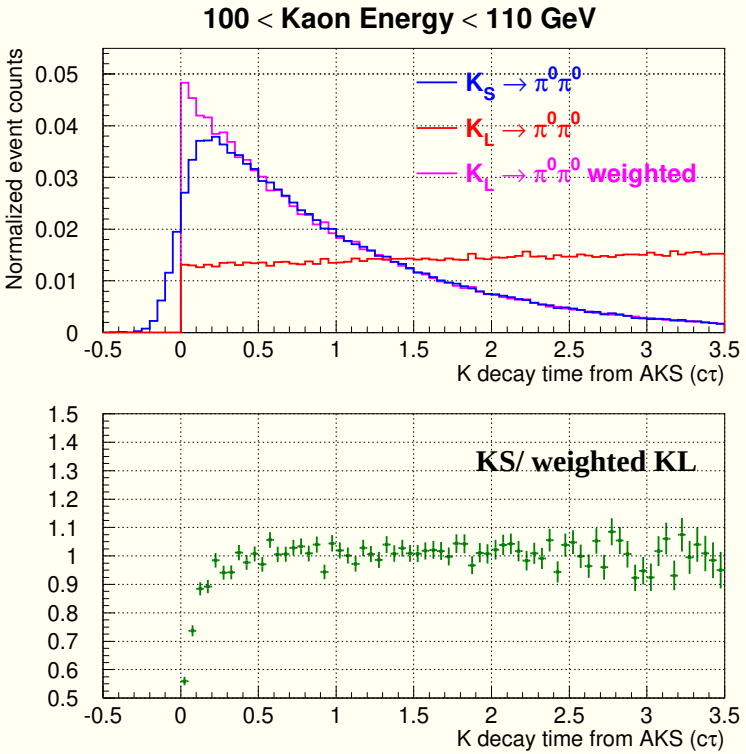
- Corrections on:
  - 3-body background in K_L samples
  - K_S /K_L trigger inefficiency difference
  - charged/neutral mistagging difference
  - residual K_S /K_L acceptance difference from MC

  are applied in bins of energy and the result is averaged using an unbiased estimator
  ⟹ account for the slight difference in the spectra of K_S and K_L

- Data selection and evaluation of corrections is performed independently by several groups/persons
  ⟹ eliminate bugs and misunderstandings

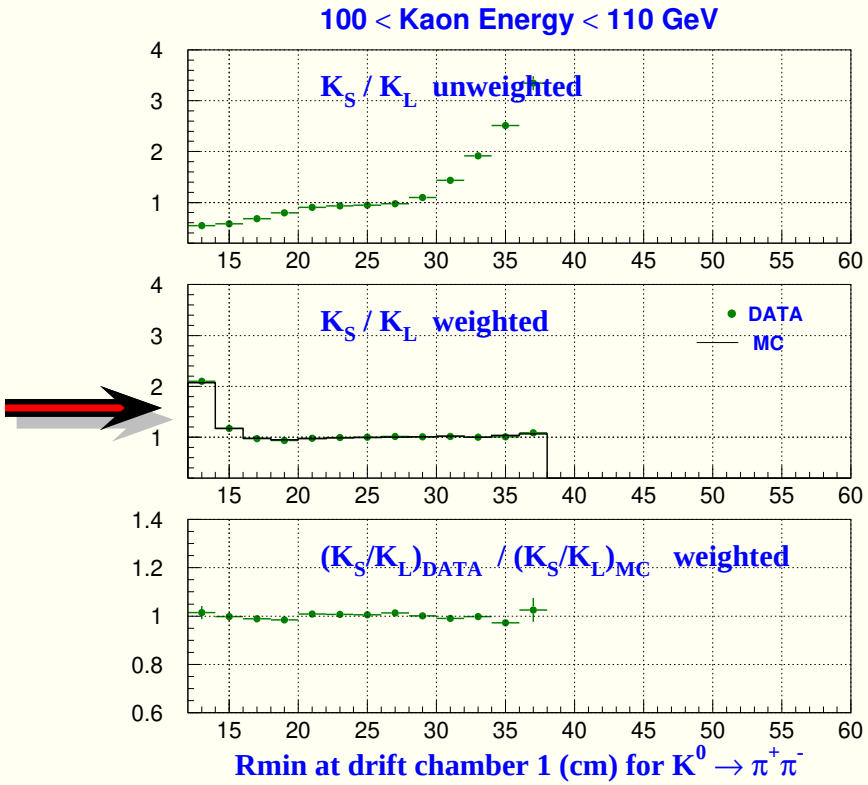
Proper time weighting

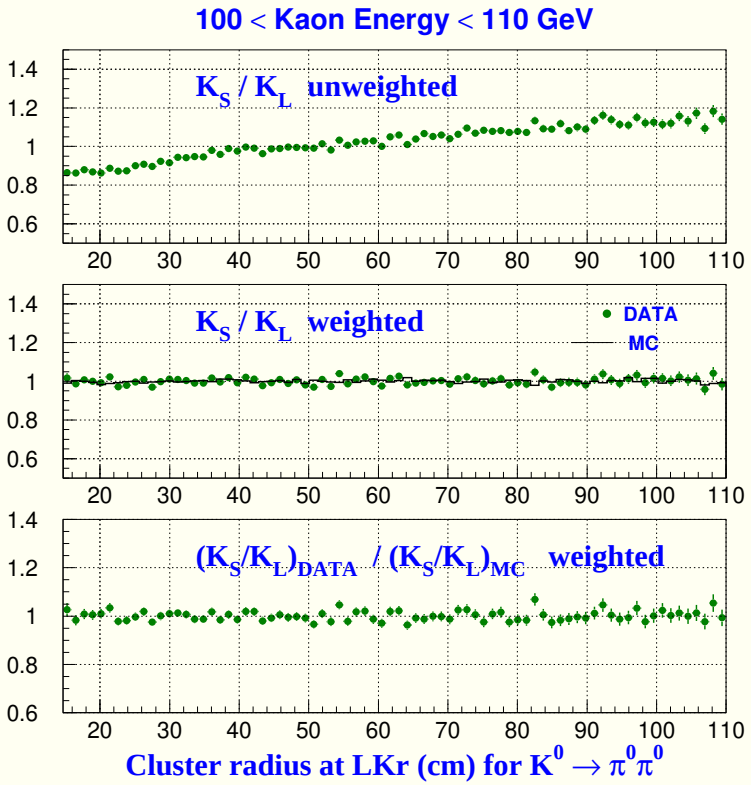




- The K_L events are weighted according to the ratio of the proper lifetime distribution of K_S
- This reduces the acceptance correction to few per mill

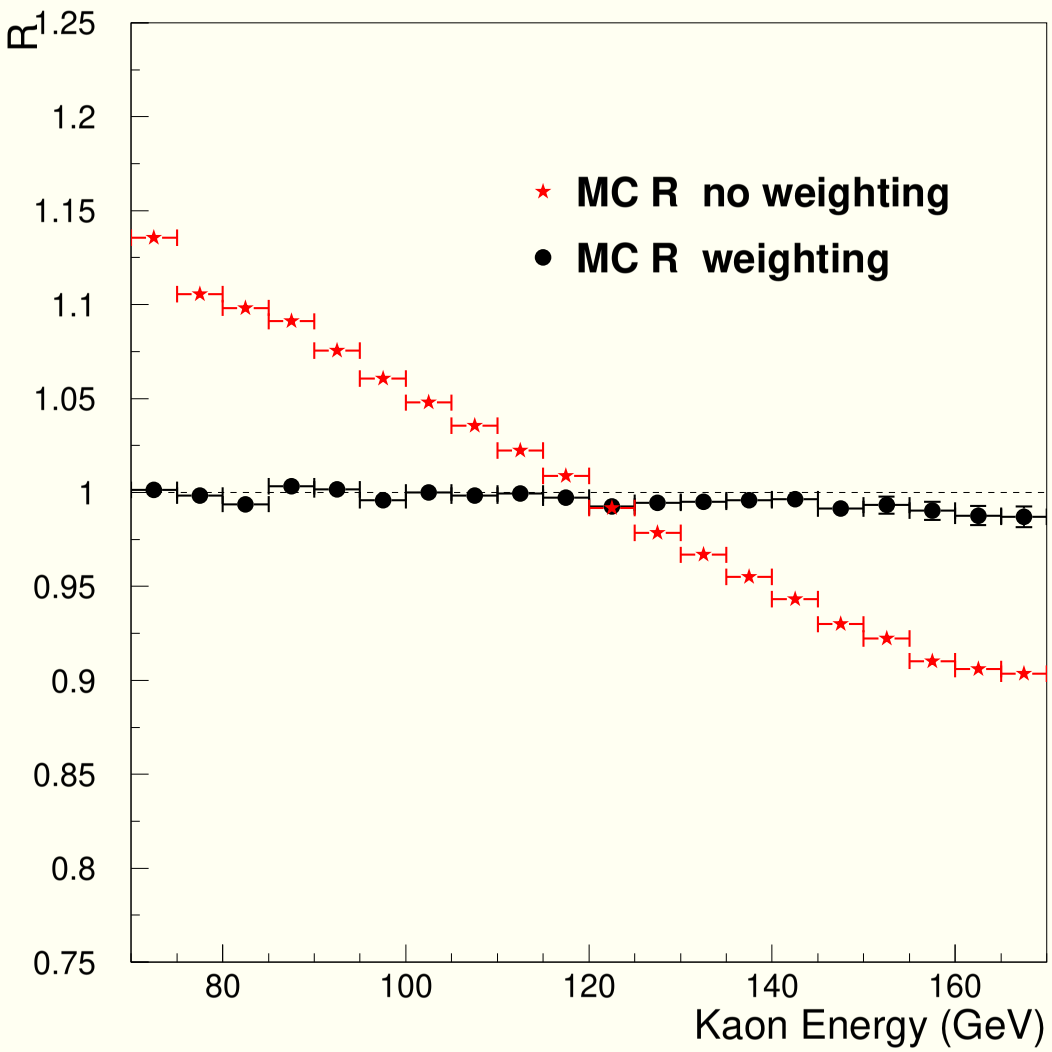
DATA/MC


100 < Kaon Energy < 110 GeV
K_S / K_L unweighted
K_S / K_L weighted
DATA
MC
$(K_S/K_L)_{DATA}$ / $(K_S/K_L)_{MC}$ weighted
Rmin at drift chamber 1 (cm) for $K^0 \to \pi^+\pi^-$


100 < Kaon Energy < 110 GeV
K_S / K_L unweighted
K_S / K_L weighted
DATA
MC
$(K_S/K_L)_{DATA}$ / $(K_S/K_L)_{MC}$ weighted
Cluster radius at LKr (cm) for $K^0 \to \pi^0\pi^0$

Acceptance

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

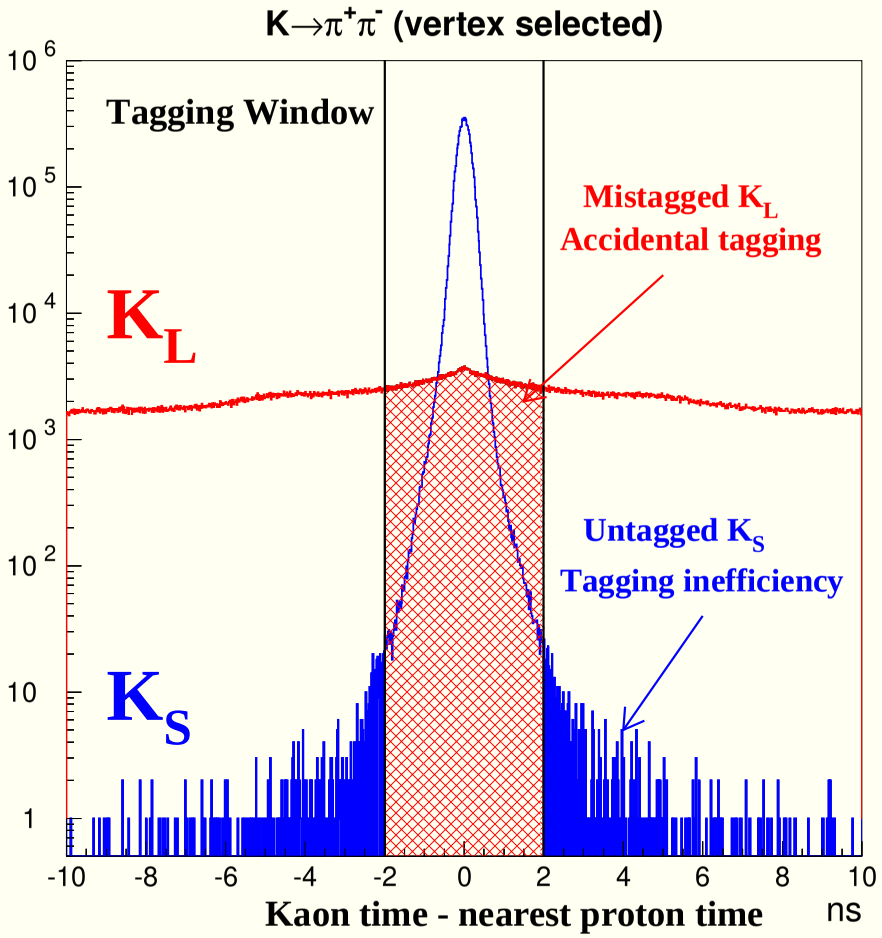


$$\Delta R = (+31 \pm 6_{statMC} \pm 6_{syst}) \times 10^{-4}$$

to be improved

Tagging principle

- Distinguish K_S from K_L in $2\pi^0$ decays
- To symmetrize it is used also for $\pi^+\pi^-$



- Tagging inefficiency: $\alpha_{\rm SL}$

  Due to tagging inefficiency K_S is identified as K_L . The $\pi^+\pi^+/\pi^0\pi^0$ difference comes from tails in the detector (hodoscope/LKr) time distributions:

$$\Delta R \simeq 6 \times \left(\alpha_{SL}^{00} - \alpha_{SL}^{+-}\right) = 6 \times \Delta\alpha_{\rm SL}$$

- Accidental tagging: $\alpha_{\rm LS}$

  A true K_L is counted as K_S if an accidental proton is found in the ± 2 ns tagging window:

$$\Delta R \simeq 2 \times \left(\alpha_{LS}^{00} - \alpha_{LS}^{+-}\right) = 2 \times \Delta\alpha_{\rm LS}$$

K_S tagging inefficiency

- Charged Mode : Use true K_S (from vertex) and count events outside the tagging window:

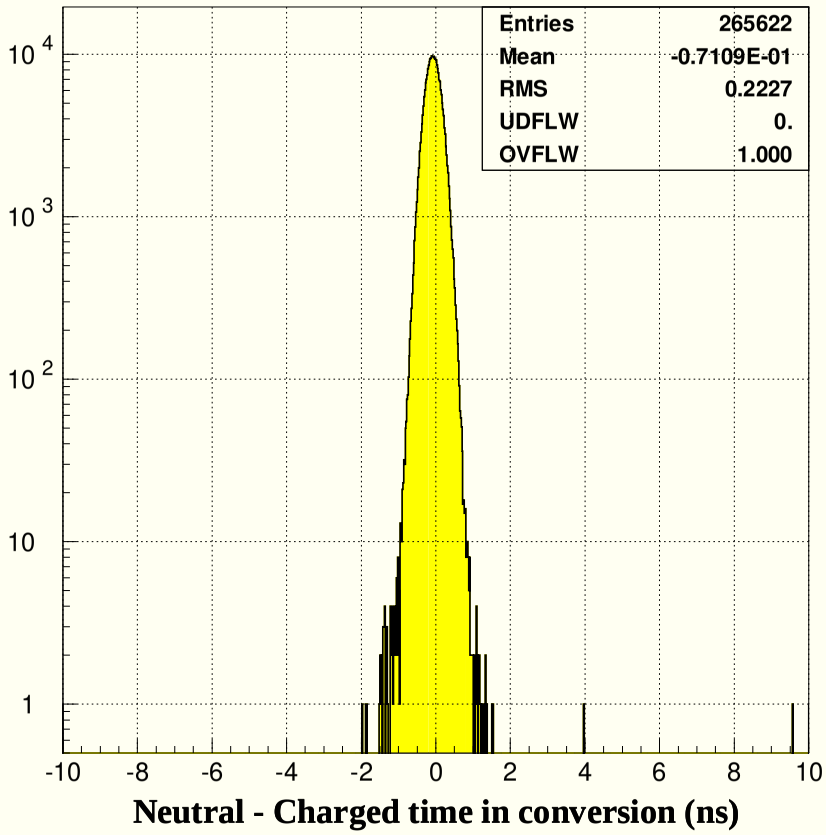
$$\alpha_{SL}{}^{+-} = (1.97 \pm 0.05) \times 10^{-4}$$

Dominant part due to Tagger $\Rightarrow$ charged neutral symmetric

- Neutral Mode : Verified with 3 methods:

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

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



2. K_S only runs (the K_L beam is stopped)

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

3. $K_S \rightarrow \pi^0 e^+ e^- \gamma$ events

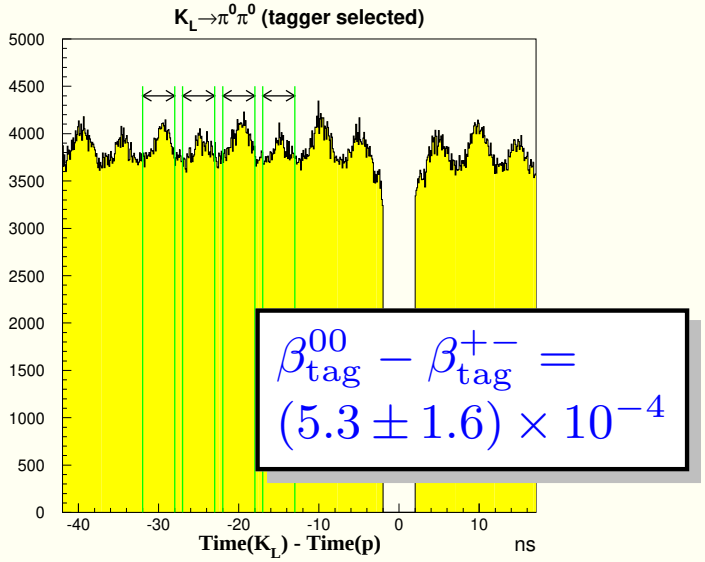
Accidental K_S tagging

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

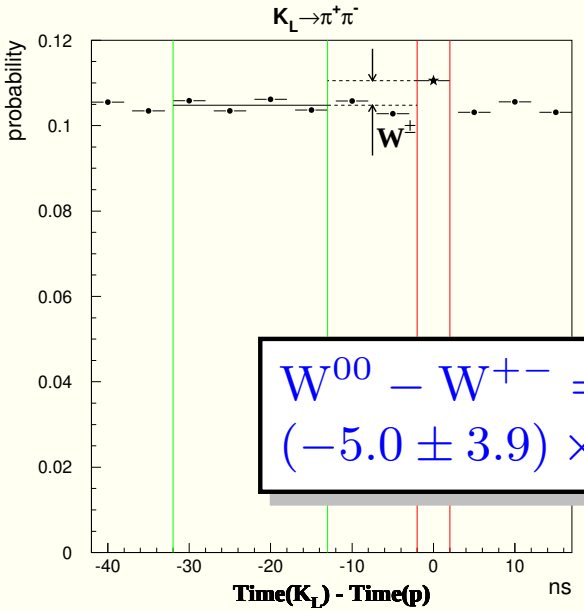
$$\alpha_{\rm LS}^{00} - \alpha_{\rm LS}^{+-} = (\beta_{\rm tag}^{00} - \beta_{\rm tag}^{+-}) + ({\rm W}^{00} - {\rm W}^{+-})$$

$\beta_{\rm tag}$ is the rate of protons for untagged (= no in-time proton) K_L events measured in 4 carefully chosen time intervals close to the coincidence time window

W is the difference in the rate of in-time protons for all K_L events and untagged K_L in the side time windows: $W = \alpha_{LS} - \beta_{tag}$ ($3\pi^0$ are used instead of $2\pi^0$: $W^{00} \simeq W^{000}$)



$$\beta_{\rm tag}^{00} - \beta_{\rm tag}^{+-} = (5.3 \pm 1.6) \times 10^{-4}$$



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

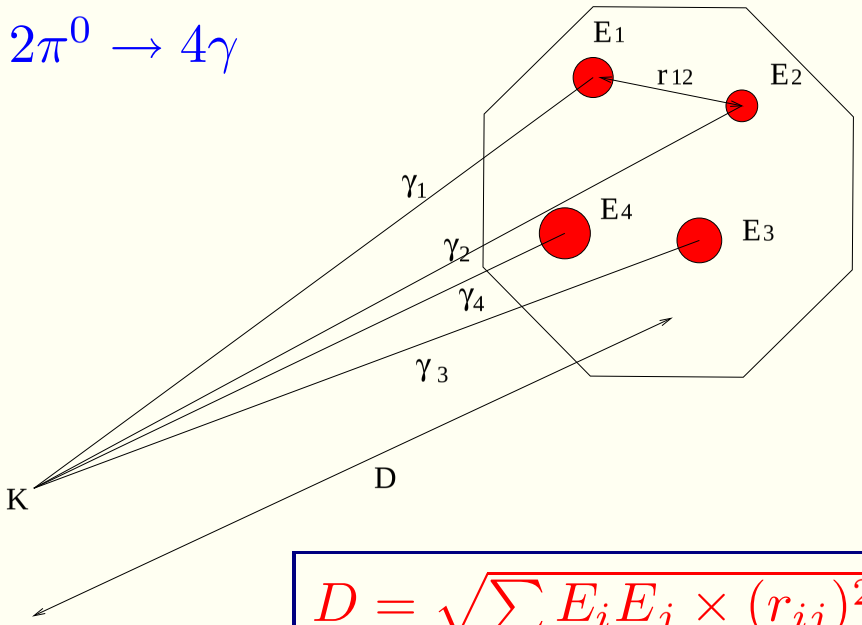
to be improved

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

to be improved

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

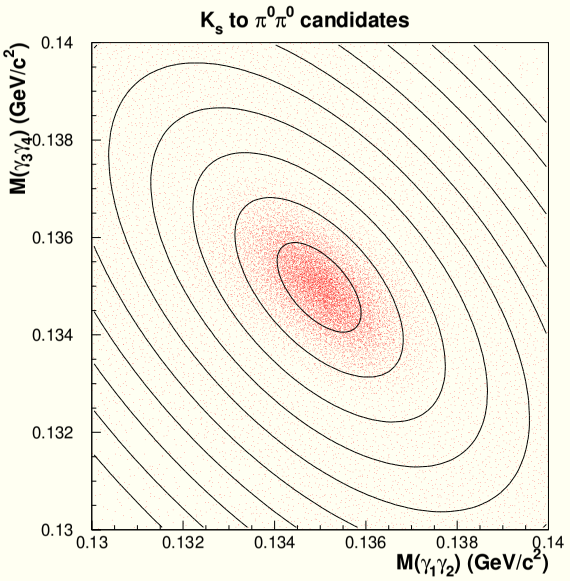
$K_{L,S} \to 2\pi^0 \to 4\gamma$

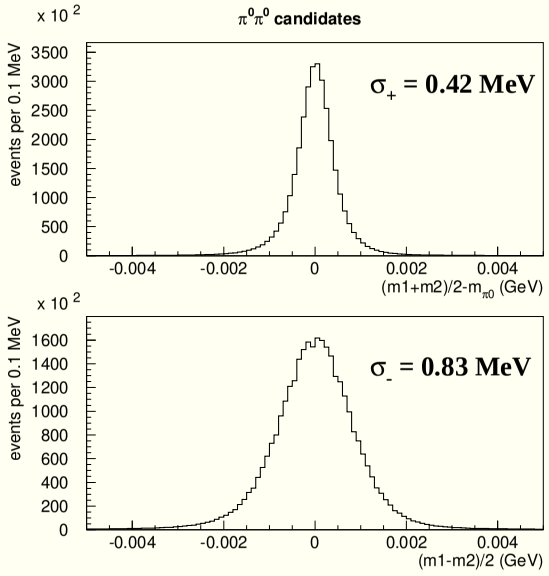


$$D = \sqrt{\sum E_i E_j \times (r_{ij})^2} \; / M_K$$

- Vertex position computed assuming the mass of K^0
- Photon pairing to get best π^0 masses :

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



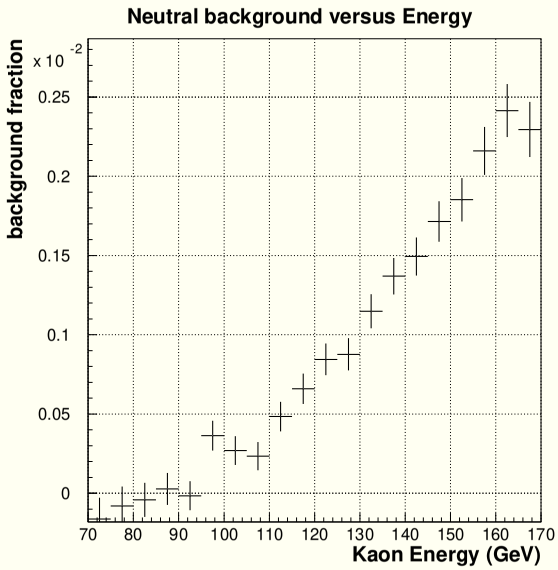


Background to $\pi^0\pi^0$

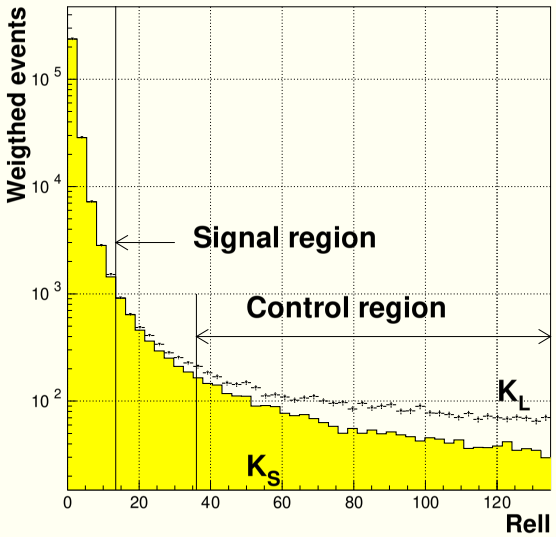
Background rejection

Main background:
$K_L \rightarrow 3\pi^0$

Events with extra in-time ($\pm$3ns) shower rejected



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



Background subtraction

Signal region :
$R_{ell} < 13.5$

$K_L - K_S$ in control region
$\rightarrow 3\pi^0$ background

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

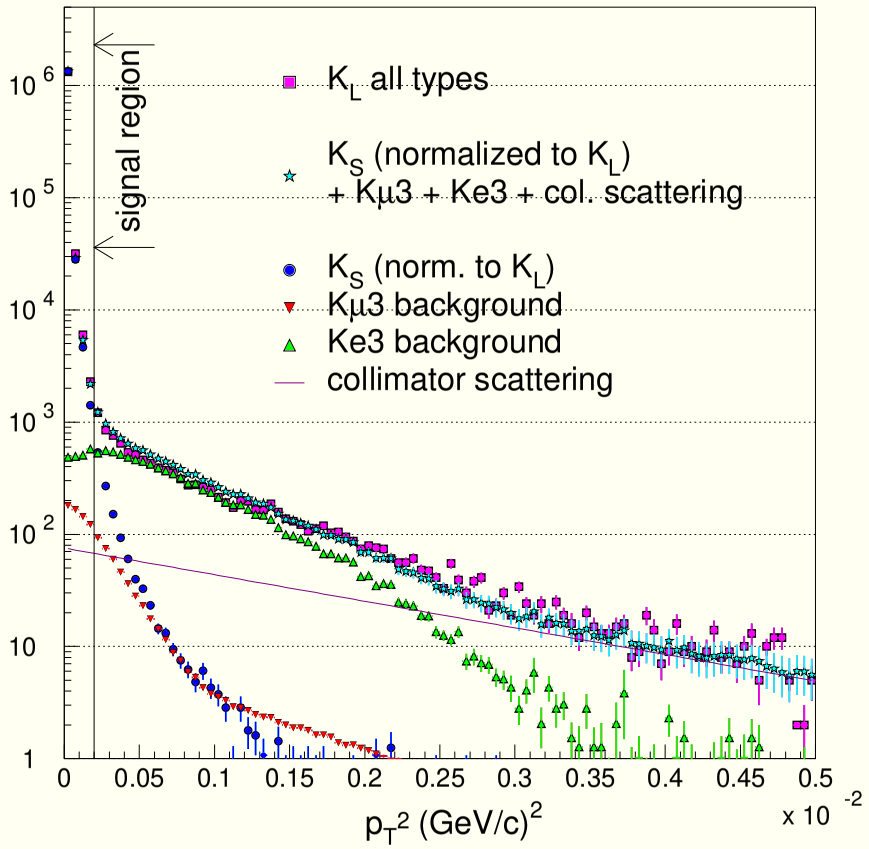
$$\Delta R = (-7 \pm 2) \times 10^{-4}$$

Background to $\pi^+\pi^-$

Dominated by $K_L \to \pi e \nu$ and $K_L \to \pi \mu \nu$

Rejected using:

- muon veto counters
- $E_{LKr}/P_{Spectrometer} < 0.8$
- invariant mass $|m_{\pi\pi} - M_{K^0}| < 3\sigma$
- total transverse momentum $p_T'^2 < 200$ (MeV/c)^2

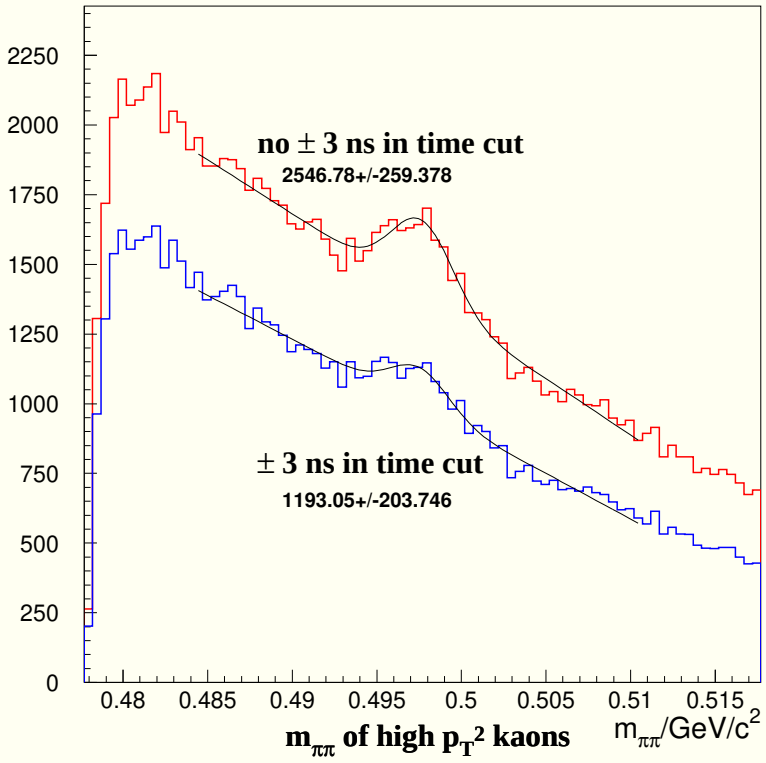


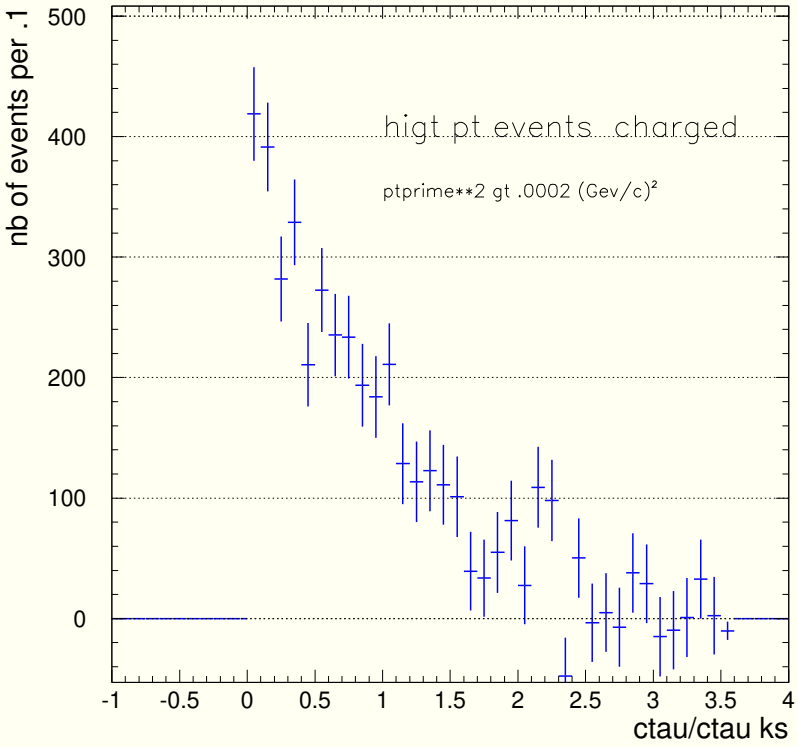
Estimated by fitting the distributions of $K_S \to \pi^+\pi^-$ + K_{e3} + $K_{\mu 3}$ in a control region in the plane of $(m_{\pi\pi}, p_T'^2)$ to the K_L shape

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

Scattered Events in the K_L beam

- There are $K \to \pi^+\pi^-$ with a large $p_T'^2$ mainly originating from the K_L final collimator and with a typical K_S decay distribution





- They are rejected by the $p_T'^2$ cut applied to $\pi^+\pi^-$ but not to $\pi^0\pi^0$

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

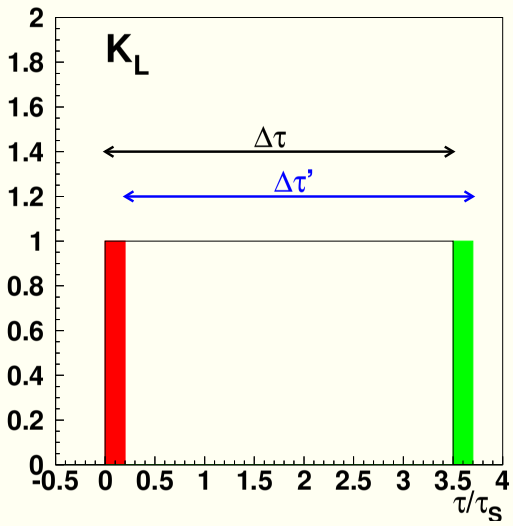
- Cross-checked with the $\pi^0\pi^0$ sample at a large centre of gravity (R_{cog})

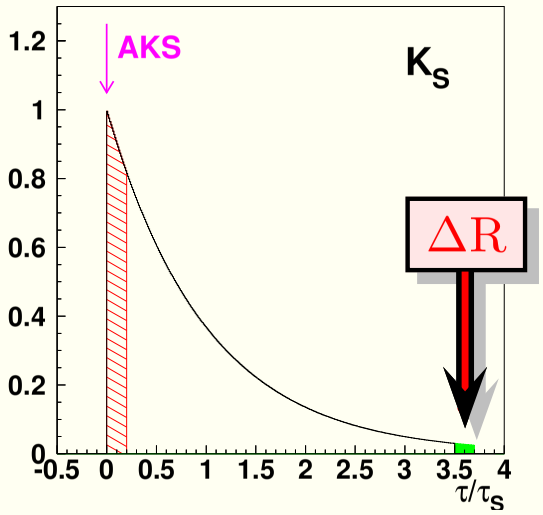
$\pi^0\pi^0/\pi^+\pi^-$ energy scale

Fiducial region given in τ_S units: $0 < \tau < 3.5\ \tau_S$
$\tau \propto (z_{vertex}$ - $z_{AKS})$ / E

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

Energy scale $\Leftrightarrow$ Distance scale:
$E \rightarrow (1+\alpha)\ E \Rightarrow \Delta z \rightarrow (1+\alpha)\ \Delta z$
BUT $\Delta\tau \rightarrow \Delta\tau$





The uncertainty introduced on R is small (0.6α) if the beginning of the K_S decay region is defined by an anti-counter (AKS)

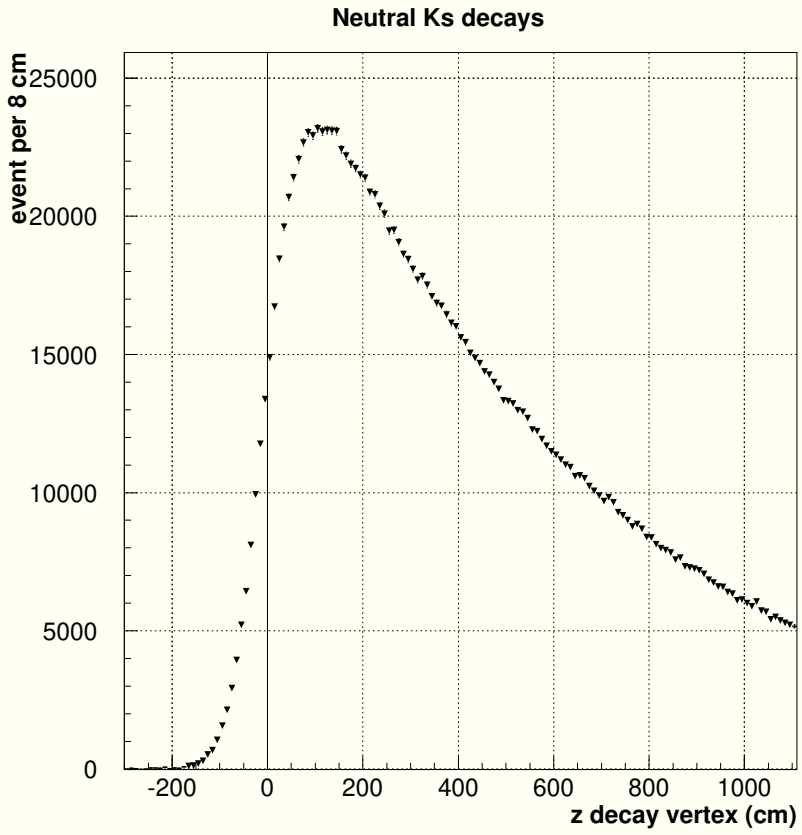
The energy for a $\pi^+\pi^-$ is determined from the opening angle and the ratio of the energy of the two tracks:

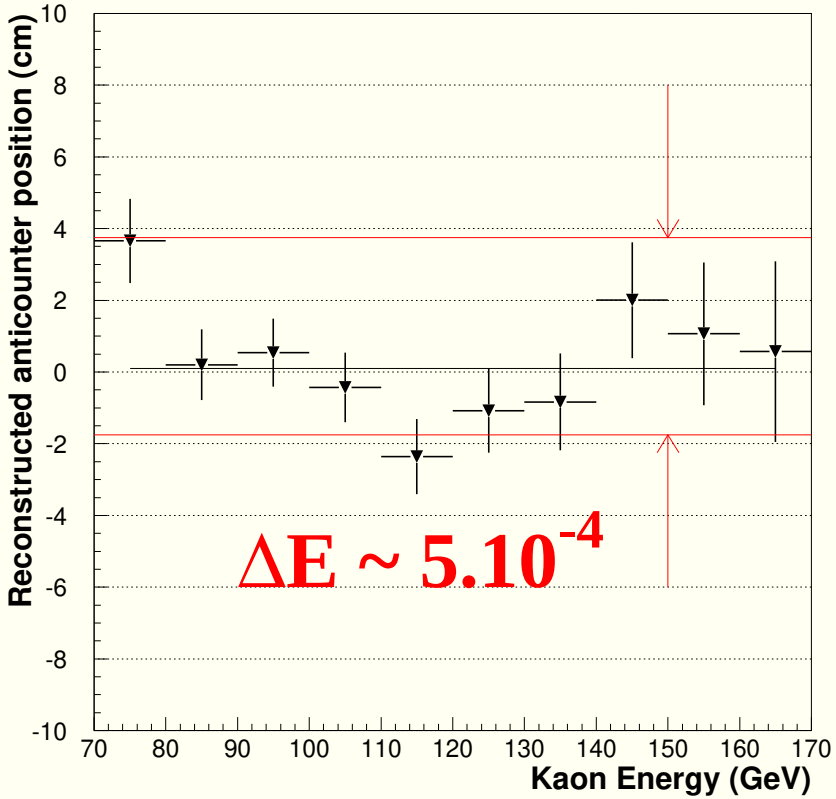
$$E_K^2 = (C/\theta^2)\left\{m_K^2 - C\ m_\pi^2\right\}$$
$$C = 2 + E_{\pi 1}/E_{\pi 2} + E_{\pi 2}/E_{\pi 1}$$

$\Rightarrow$ defined by the geometry of the drift chambers

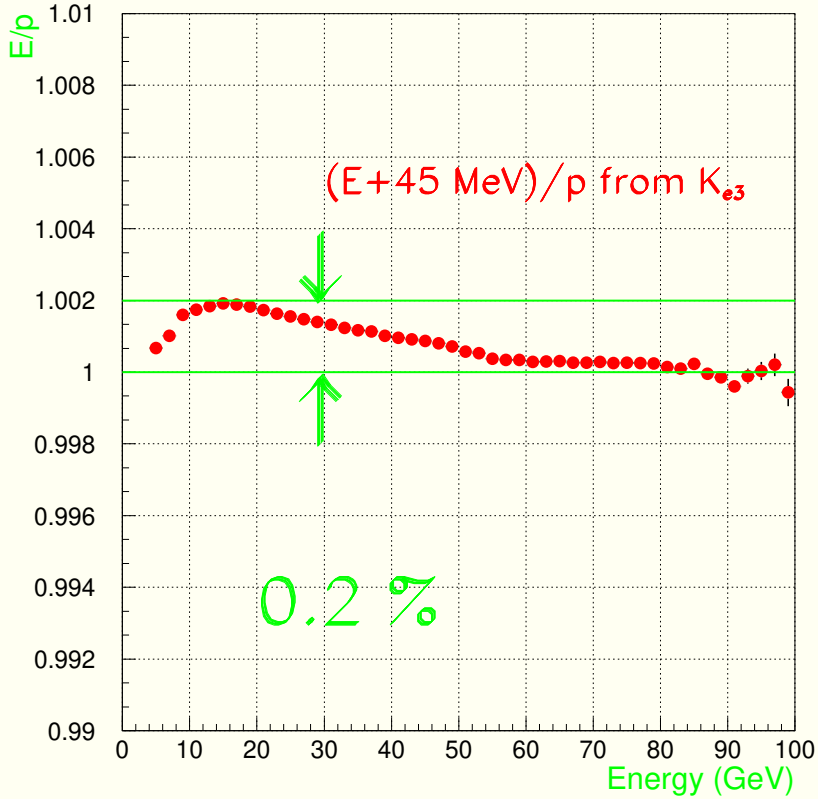
$\pi^0\pi^0$ distance/energy scale

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



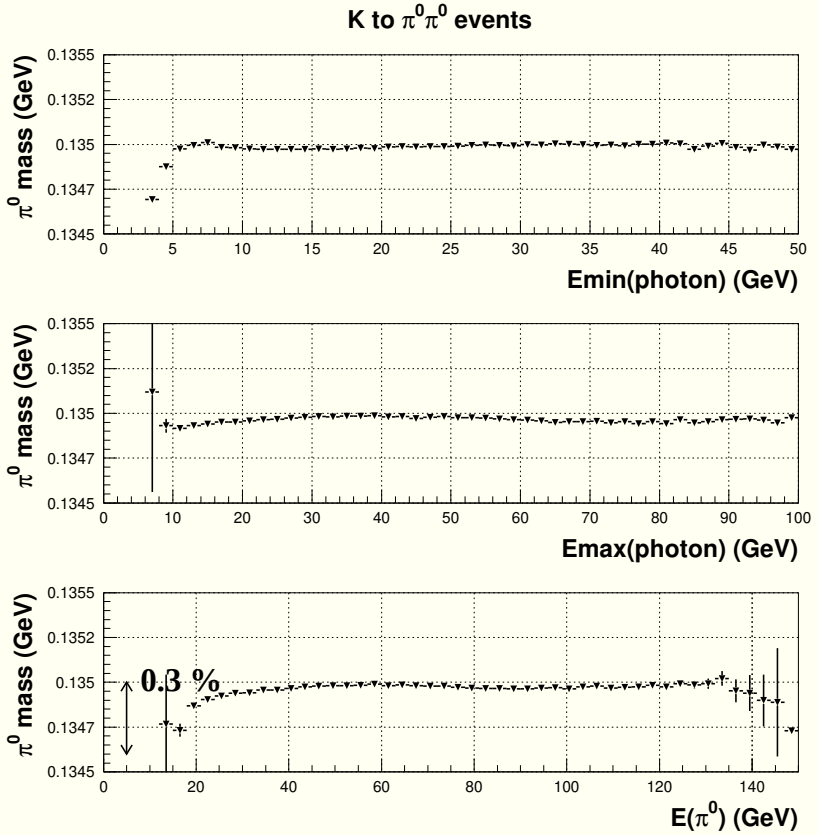


Linearity



$$\frac{E}{P} = \frac{\text{Energy from LKr}}{\text{Momentum from spectrometer}}$$

for Ke3 electrons as a function of the energy



Stability of m_{π^0} in $K \to 2\pi^0$ decays

Neutral systematics

Neutral reconstruction systematics	
Source	ΔR (units 10^{-4})
Non linearity	$\pm$ 5
Non Gaussian tails in σ_E	$\pm$ 5
Transverse scale	$\pm$ 3
Intercalibration	$\pm$ 3
Distance/Energy scale	$\pm$ 3
Other sources	$\pm$ 4

- We employ a π^- beam and two 3.5cm thick polyethylene targets, to produce $\eta, \pi^0 \rightarrow \gamma\gamma$ decays to cross check the distance scale using the published π^0 and η masses.
- A discrepancy at the level of 2 σ is found reconstructing the vertex for $\eta \rightarrow \gamma\gamma$

A dedicated η run took place this year to verify the effect

For the time being, we have increased the scale and/or the non linearity error to also cover the $\eta \rightarrow \gamma\gamma$ result.

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

Accidental activity

To account for the geometric difference of the K_S and K_L beams, we overlay events collected proportionally to the beam intensity (*randoms*) to $\pi^+\pi^-$ and $\pi^0\pi^0$ events and evaluate the gain and losses induced by the analysis cuts

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

To put bounds on the effects related to the variation of the K_S / K_L ratio (R.M.S. 10 %) and the effects which are not related to the K_L accidental activity, we use the following inputs:

- the difference in accidental activity seen by K_S and K_L events is < 1 %
- The asymmetric losses on $\pi^+\pi^-$ and $\pi^0\pi^0$ induced by the noise in the DCH are $< 2.5\%$
- the noise in the detector does not change by more than a factor of two as a function of time

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

For the final result we will overlay the randoms to the MC data to reduce the effect of doubling the noise.

1997/1998 Statistics

Statistics (millions)		
	1997	1998
$K_S \rightarrow \pi^+\pi^-$	2.09	7.46
$K_L \rightarrow \pi^+\pi^-$	1.07	4.87
$K_S \rightarrow \pi^0\pi^0$	0.98	1.80
$K_L \rightarrow \pi^0\pi^0$	0.49	1.14
Statistical error	27.0×10^{-4}	17.3×10^{-4}

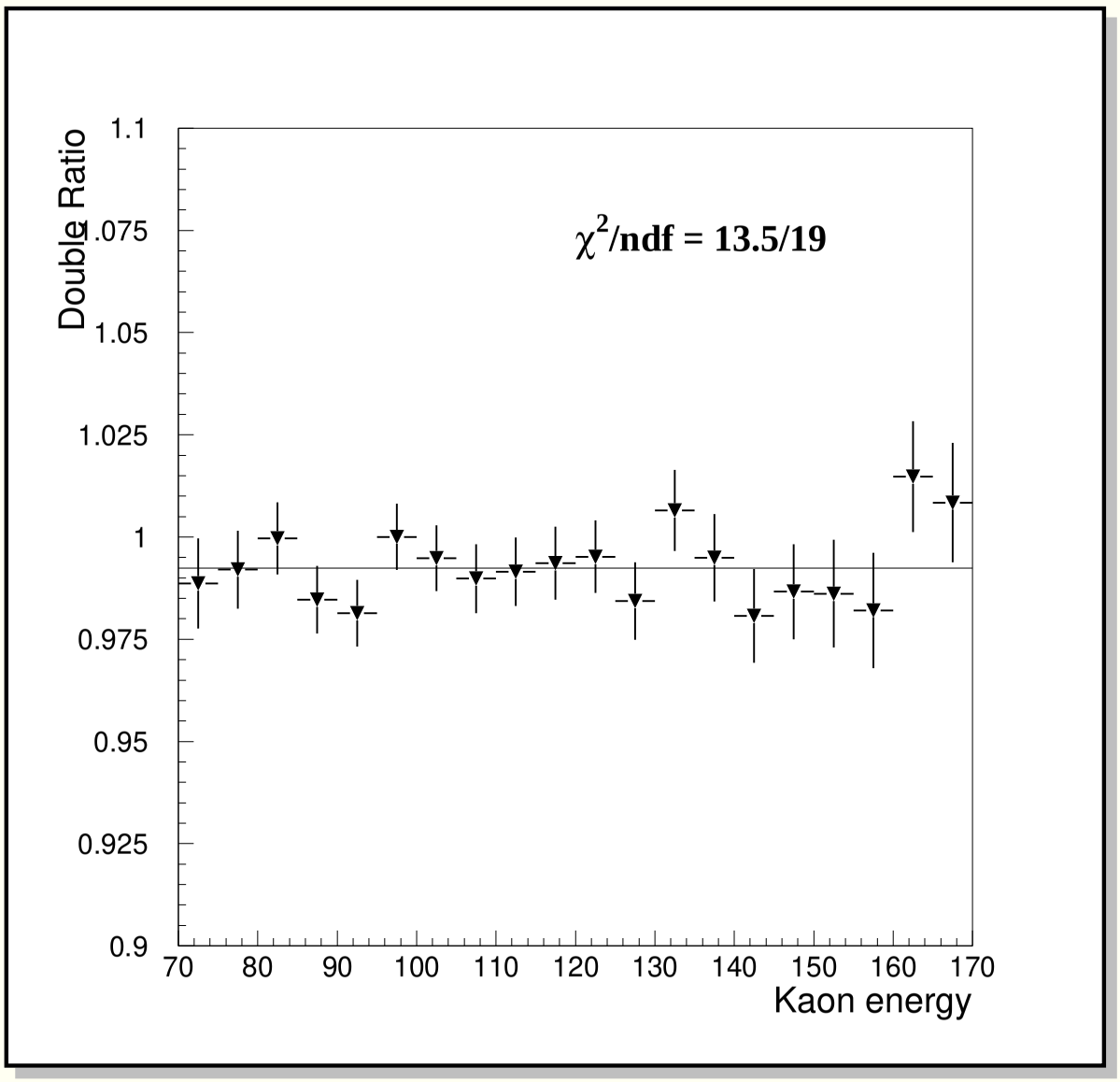
1997/1998 Systematics

Corrections and syst. uncertainties on R (Units = 10^{-4})					
Source	1997 sample		1998 sample		
Charged trigger	+9	± 23	–1	± 11	stat.
Accidental tagging	+18	±9	+1	±8	to be improved
Tagging efficiency	–	±6	–	± 3	
Neutral rec. systematics	–	±12	–	±10	to be improved
Charged vertex	–	±5	+2	±2	
Acceptance	+29	±12	+31	±9	to be improved
Neutral BKG	–8	±2	–7	±2	
Charged BKG	+23	±4	+19	±3	
Beam scattering	–12	±3	–10	±3	
Accid. activity	–2	±14	+2	±12	to be improved
Total	+57	±35	+37	±24	

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

Result 1998

PRELIMINARY RESULT ON 1998 DATA



$$R = 0.99267 \pm 0.00173_{stat} \pm 0.00238_{syst}$$

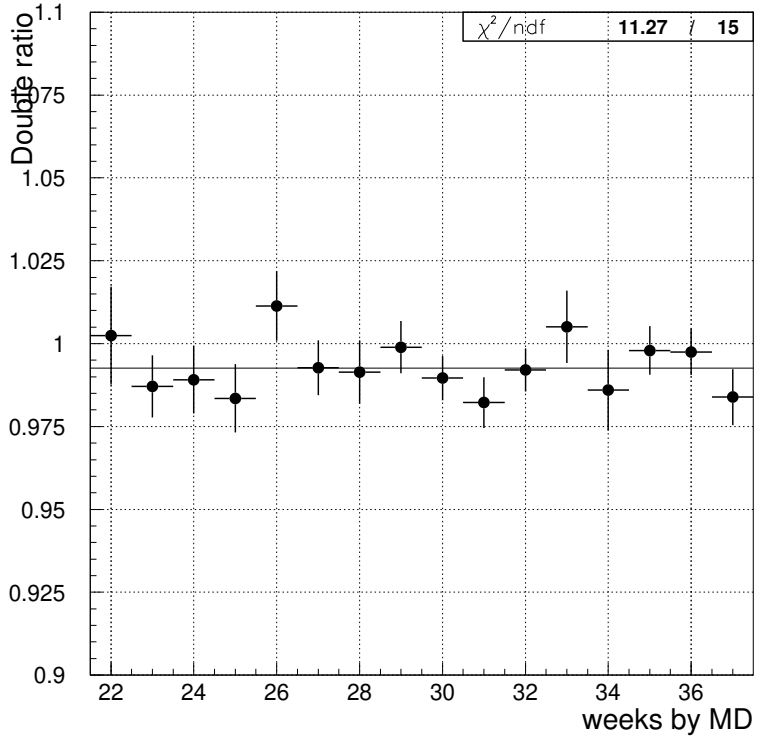
$$\mathrm{Re}(\varepsilon'/\varepsilon) = (12.2 \pm 2.9_{stat} \pm 4.0_{syst}) \times 10^{-4}$$

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

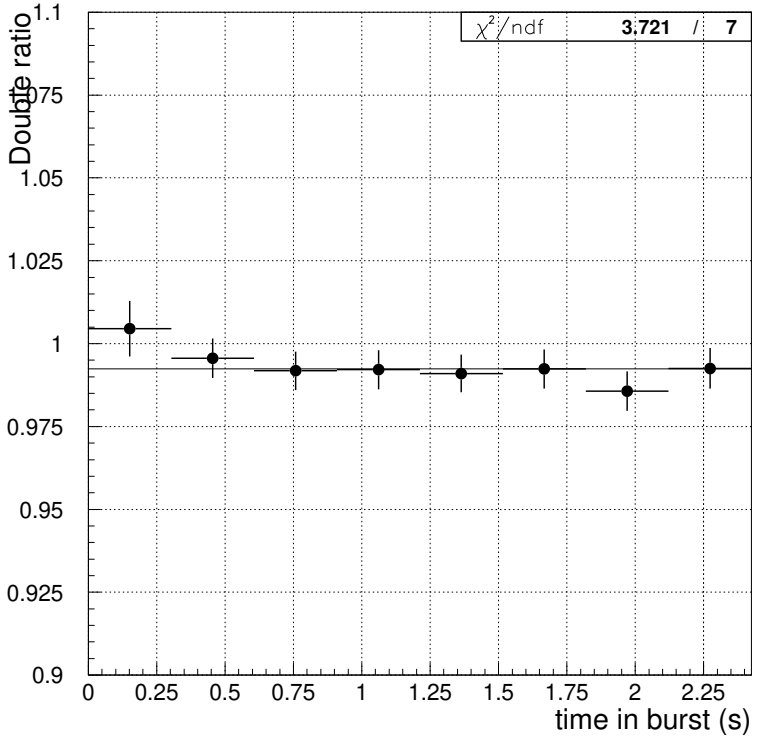
This result is preliminary. The systematic uncertainty is partly of statistical nature

Checks: R vs time

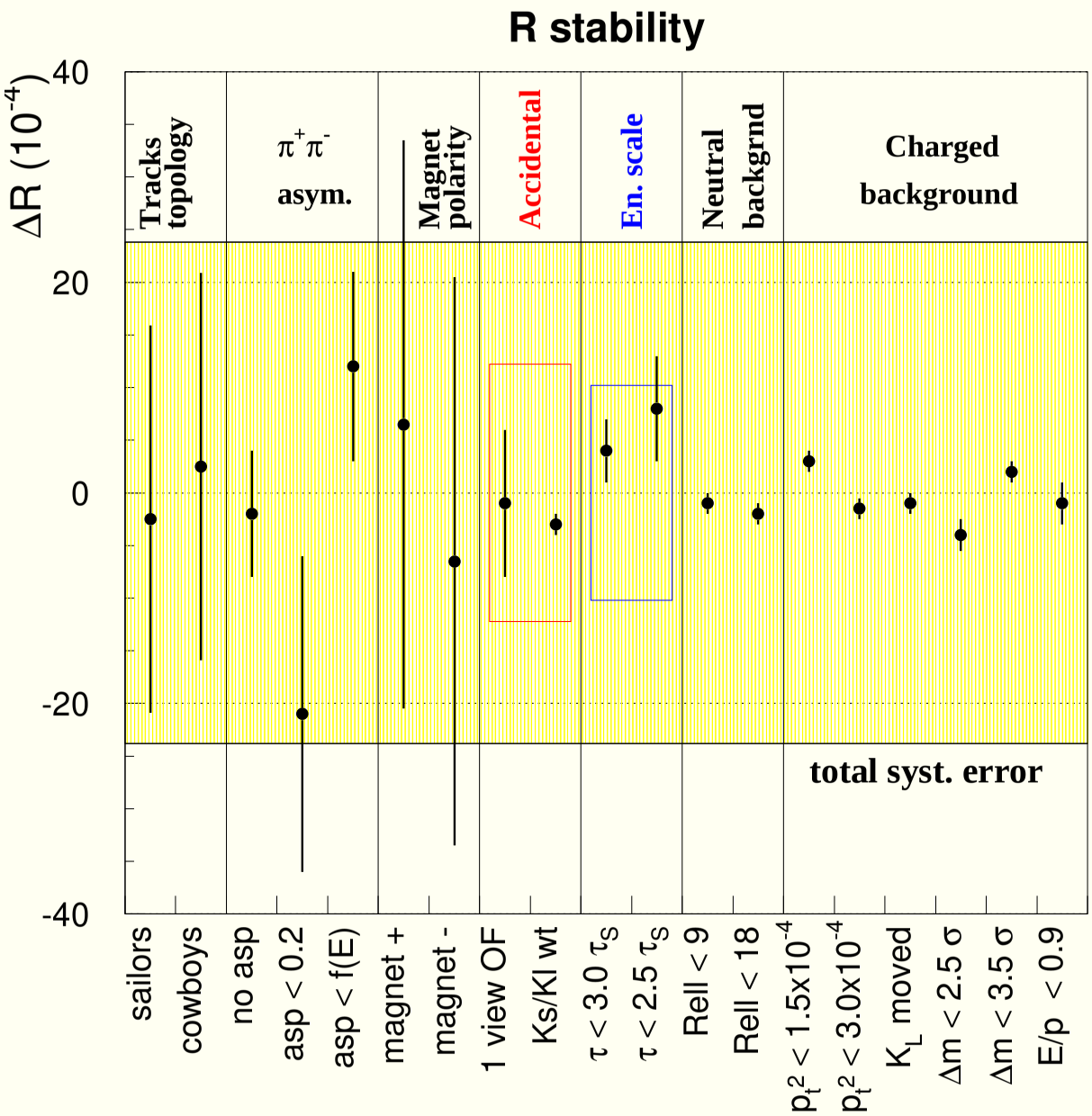
Stability vs. run period



Stability vs. time in burst



Checks


R stability
ΔR (10^-4)
40
20
0
-20
-40
Tracks topology
π+π- asym.
Magnet polarity
Accidental
En. scale
Neutral backgrnd
Charged background
total syst. error
sailors
cowboys
no asp
asp < 0.2
asp < f(E)
magnet +
magnet -
1 view OF
Ks/Kl wt
τ < 3.0 τS
τ < 2.5 τS
Rell < 9
Rell < 18
pt2 < 1.5x10-4
pt2 < 3.0x10-4
KL moved
Δm < 2.5 σ
Δm < 3.5 σ
E/p < 0.9

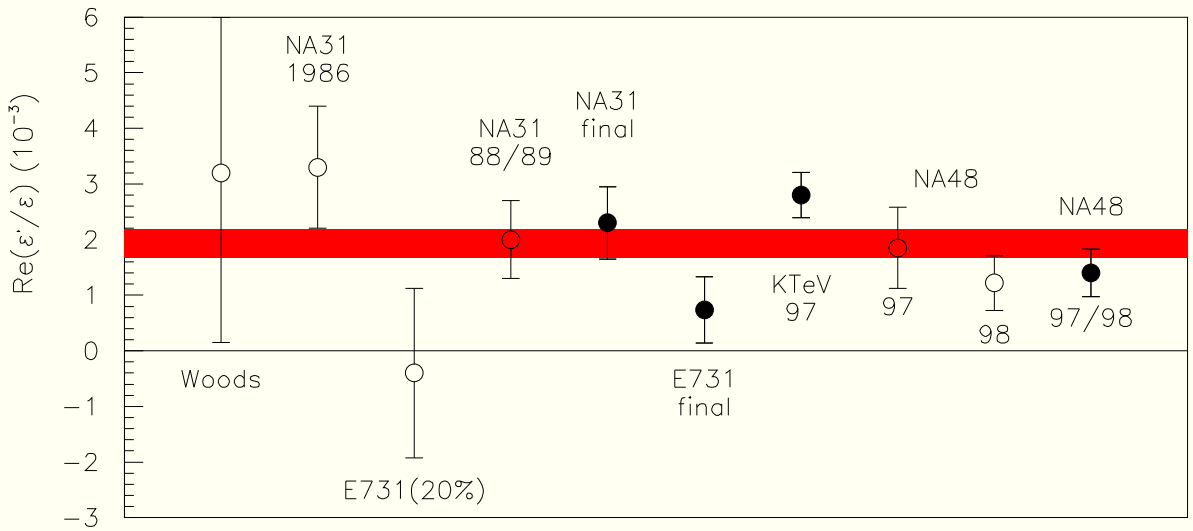
World average

Combined 1997 and preliminary 1998 NA48 result

$$\mathrm{Re}(\varepsilon'/\varepsilon)^{\,1997} = (18.5 \pm 4.5(stat.) \pm 5.8(syst.)) \times 10^{-4}$$
$$\mathrm{Re}(\varepsilon'/\varepsilon)^{\,1998} = (12.2 \pm 2.9(stat.) \pm 4.0(syst.)) \times 10^{-4}$$

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

(taking into account small correlated systematics)



World average:

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

$$(\chi^2/ndf = 10.5/3)$$

Perspectives

- More checks, new control samples and more Monte Carlo studies will allow to reduce the systematic uncertainty on the 1998 result

- The analysis of 1999 data is in progress
  taking advantage from new 2000 data for systematic checks (only neutral decays)
  $\rightarrow$ expected total uncertainty $\lesssim 3 \times 10^{-4}$

- Magnetic spectrometer is being repaired after the implosion of the carbon fibre beam tube in November 1999 which has damaged all four drift chambers

- final $\mathrm{Re}(\varepsilon'/\varepsilon)$ run is planned for summer 2001 after the repair of drift chambers

Conclusions

- Preliminary measurement of $\mathrm{Re}(\varepsilon'/\varepsilon)$ based on the 1998 data sample:

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

- Combined result with the NA48 published data and taking into account the (small) correlated systematics:

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

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

- We look forward to compare our result with those expected from KTEV (FNAL) and KLOE (DAΦNE)