The direct CP Violation measurement of the CERN NA48 experiment

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Theoretical Introduction

The neutral kaon system :

- $K^0(\bar{s}d)$ et $\overline{K^0}(s\bar{d})$: Flavour Eigenstates
- $K_1(+1)$ et $K_2(-1)$ 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 : The CP Violation discovery

$$K_2\ (-1) \rightarrow \pi^+\pi^-\ (+1)\ ???$$

⇒ In reality the mass eigenstates are $\mathrm{K_L}$ et $\mathrm{K_S}$:

$\mathrm{K_S} \simeq$	$K_1 +$	εK_2	$\mathrm{K_L} \simeq$	$K_2 +$	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 %		$\pi^0\pi^0$

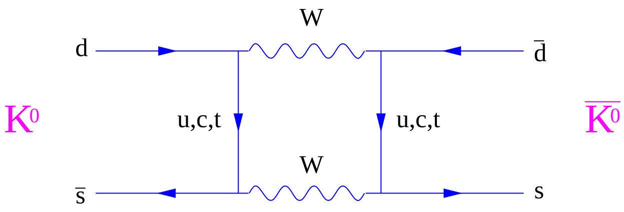
$c\tau_S = 2,67\ cm$ $\qquad$ $c\tau_L = 15,5\ m$

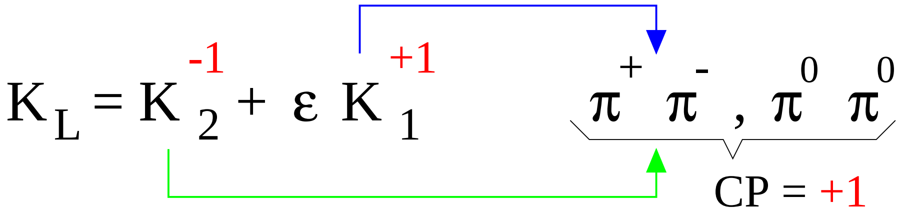
$$\boxed{\varepsilon = (2,28 \pm 0,02)\ 10^{-3}}$$

indirect CP Violation

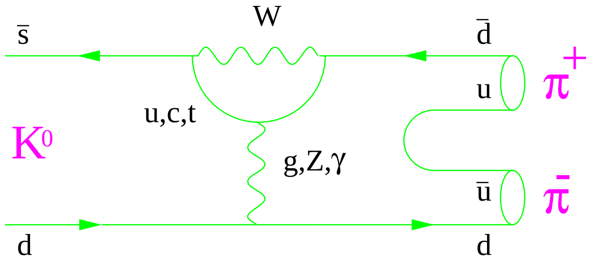
Direct CP Violation

Indirect Violation
due to $K^0/\overline{K^0}$ mix.
$\Rightarrow$ parameter ε





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



Direct Violation :
Decay violating
directly CP
$\Rightarrow$ parameter ε'

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

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

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

Introduction

NA48 aims at measuring the direct CP violation parameter $\mathrm{Re}(\varepsilon'/\varepsilon)$ in the neutral Kaon system with an accuracy of 2×10^{-4}.

This is accomplished measuring the double ratio:

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

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

Previous precision measurements results are:

NA31	$(23.0 \pm 6.5) \times 10^{-4}$
E731	$(7.4 \pm 5.9) \times 10^{-4}$

Measurement results published in '99 are:

KTeV	$(28.0 \pm 4.1) \times 10^{-4}$
NA48	$(18.5 \pm 7.3) \times 10^{-4}$

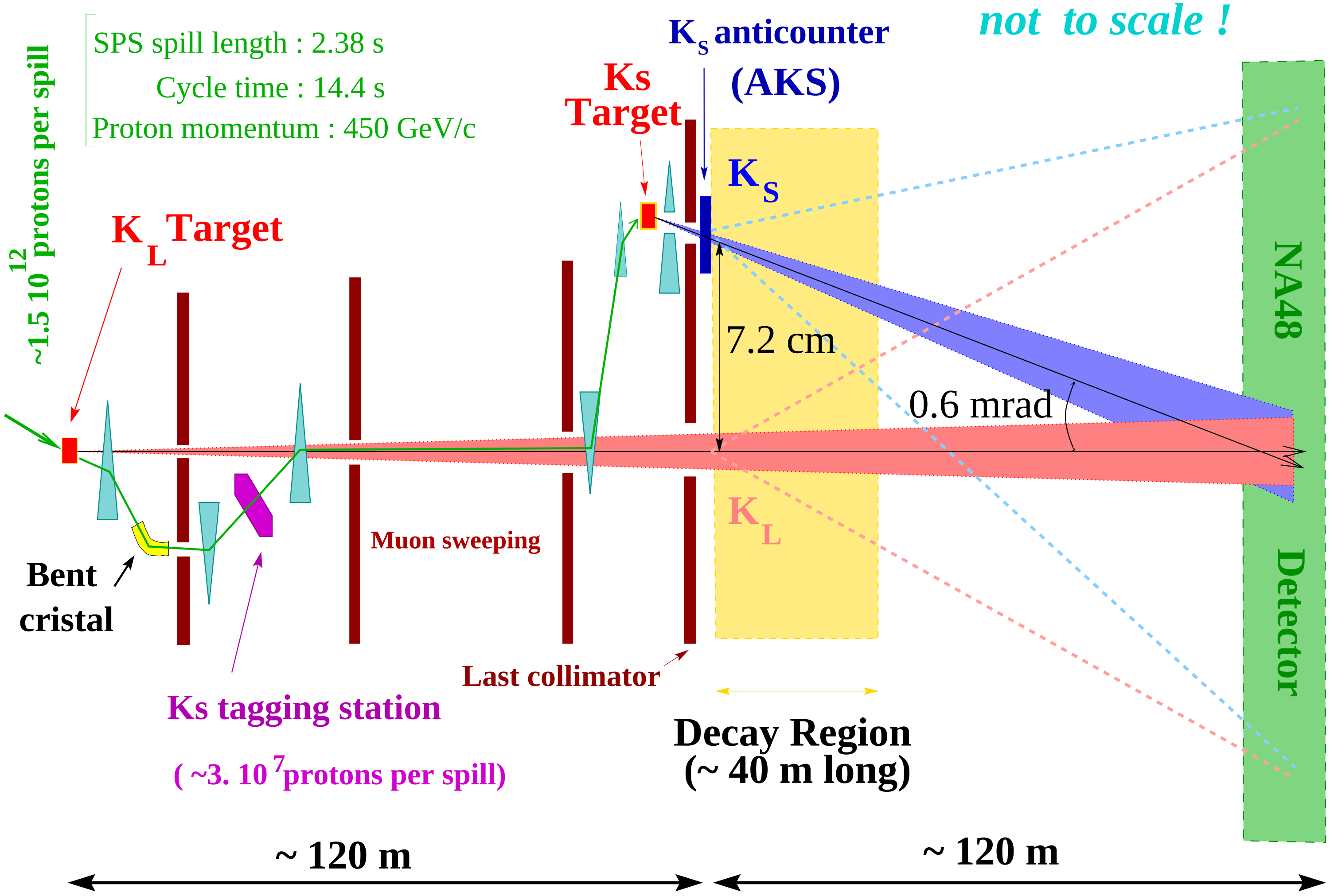
Overview of NA48 method

To achieve the required statistical precision *several* 10^6 $K_L \to \pi^0\pi^0$ decays (limiting mode) have to be collected.

To maximize systematic accuracy and to have minimal corrections, NA48 uses:

- ▷ simultaneous, almost collinear K_L and K_S beams, allowing for
- ▷ concurrent detection of the four decay modes in the same decay region to have cancellation of fluxes, acceptances, inefficiences, dead time, accidental losses;
- ▷ K_S identification by proton tagging upstream of K_S production target;
- ▷ a detector based on a magnetic spectrometer and a quasi-homogeneous liquid Krypton calorimeter, to achieve good resolutions and minimize the background contributions;
- ▷ lifetime weighting procedure to minimize acceptance corrections by making K_S and K_L decay distributions similar.

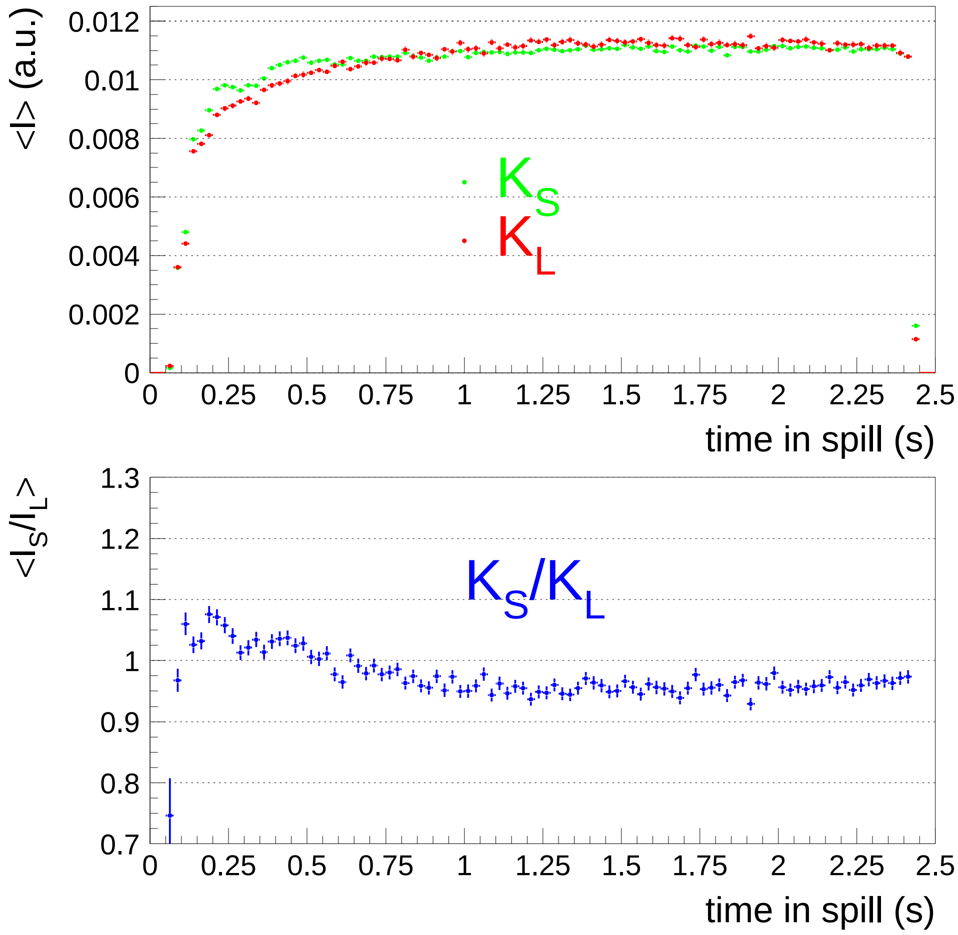
Simultaneous K_S and K_L Beams



K_S are distinguished from K_L by tagging the protons upstream of their production target.

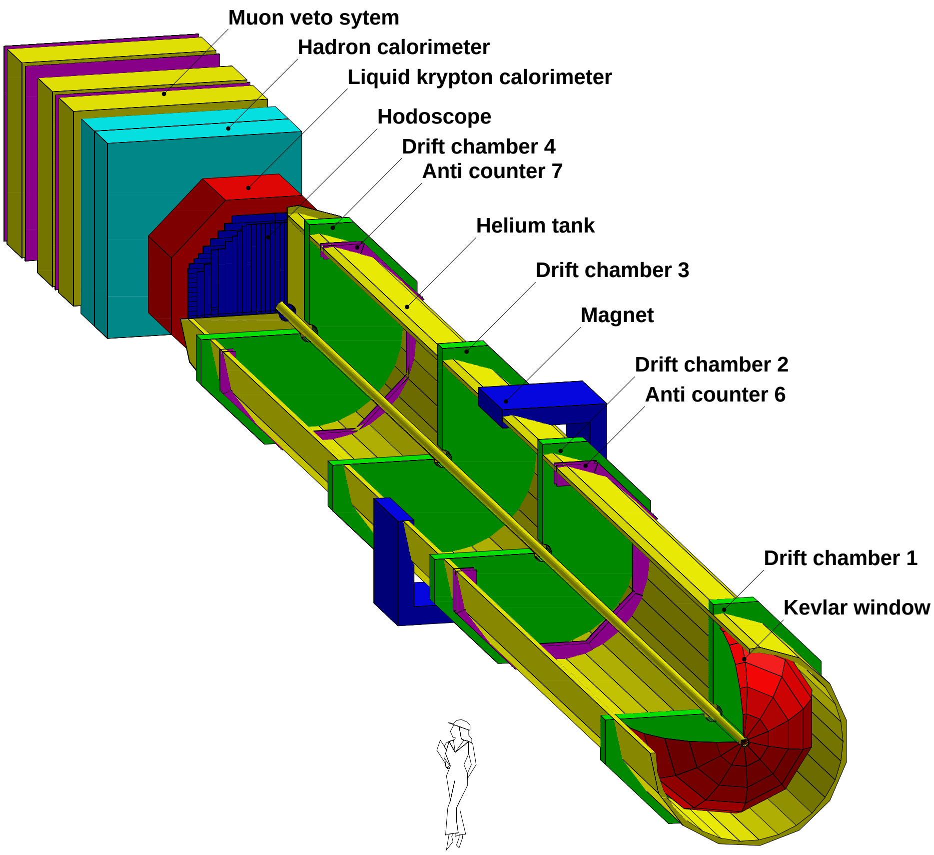
Beam performance

- K_S and K_L beam intensities are continuously monitored, their ratio is constant within ± 10%



- Average beam intensities seen by K_S and K_L events at the 200 ns ÷ 1 ms time scale, are equal at the level of few %: beam intensities are time correlated at this level.

The NA48 detector



- $K_{\mathrm{L,S}} \rightarrow \pi^+\pi^-$: magn. spectr. ($P_T^{KICK} \sim 265$ MeV/c); evt time measured with scintill. hodos

- $K_{\mathrm{L,S}} \rightarrow \pi^0\pi^0$: $\sim 27X_0$ quasi-homogeneous LKr e.m. calorimeter with high granularity (13212 cells 2×2 cm^2) and proj. geometry

- $K_{\mu 3}$ rejection: muon veto counters

- K_{e3} rejection: E(LKr)/P(spectrometer)

- $\mathrm{K_L} \rightarrow 3\pi^0$ rejection: hi res. e.m. calorimeter

1997: First data-taking period

- Installation and commissioning of the complete readout and trigger electronics for the LKr calorimeter

- Full DAQ and trigger integration, detector calibration

- First physics run (after fire in SPS power supply): Sep-Oct 1997 (42 days)

- $1 \cdot 10^{12}$ ppp on $\mathrm{K_L}$ target ($\simeq 2/3$ of nominal beam intensity)

- $\simeq$ 12K evts read-out in 2.4 s spill every 14.4 s; $\pi^+\pi^-$ triggers downscaled by 2

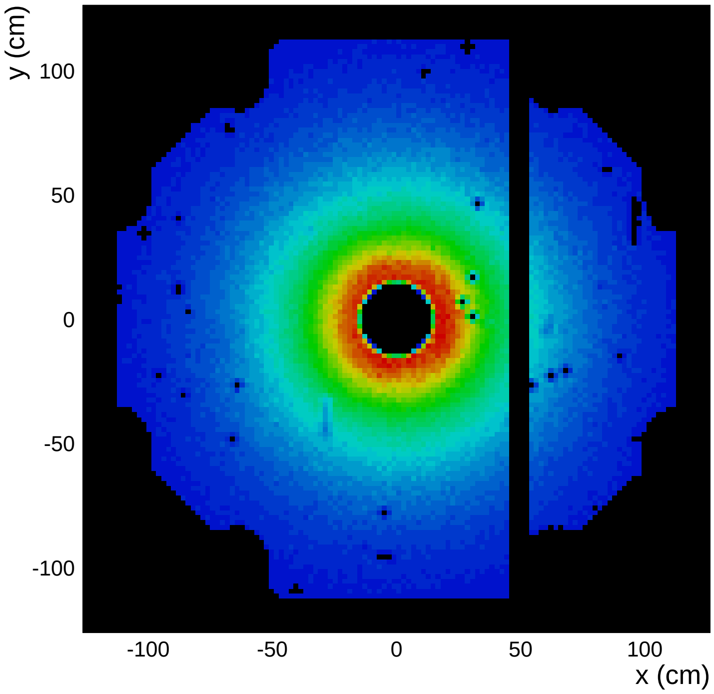
- 80 MB/s read-out rate, 12 MB/s to Central Data Recording facility

- 25 TB of data on tape

- $\approx 0.5 \cdot 10^6\ K_\mathrm{L} \to \pi^0\pi^0$ corresponding to $\simeq 10\%$ of the expected final statistics

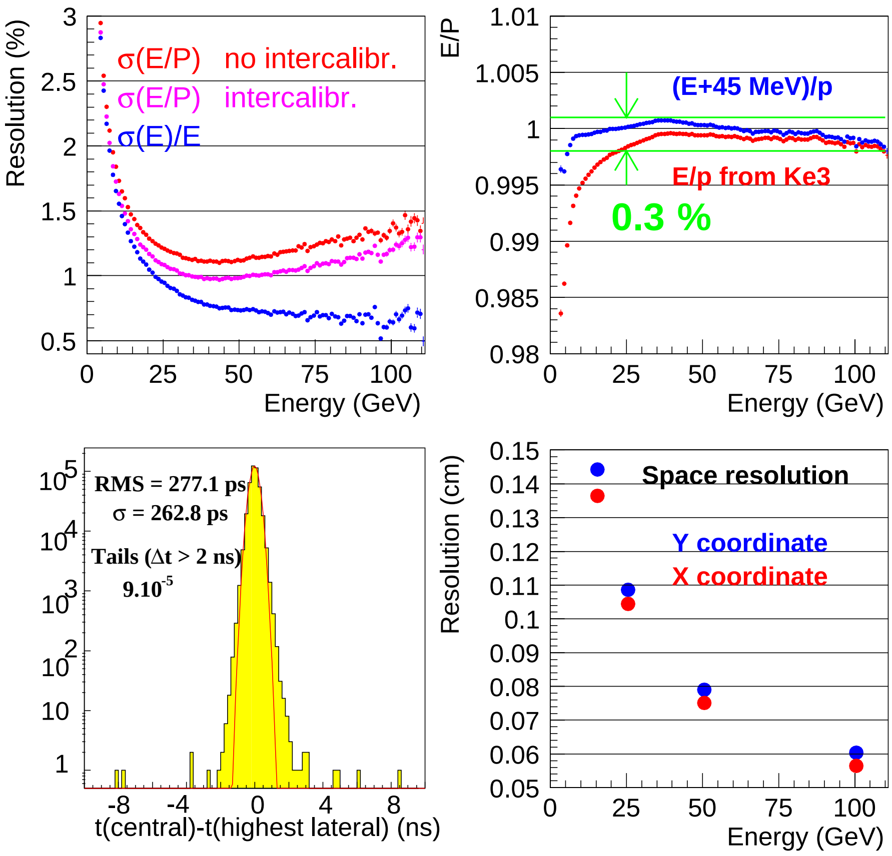
$K_{S,L} \rightarrow \pi^0\pi^0$ - Detector

- ✦ LKr calorimeter operated at reduced HV (1.5 KV) due to few leaking capacitors:
  - ▷ electronic noise $\approx 20\%$ higher
  - ▷ $< 0.5\%$ energy correction for space charge
- ✦ 4 cm wide column not connected to HV: 15% acceptance loss for $\pi^0\pi^0$
- ✦ $\approx$ 40 dead channels (0.3 %)



- ✦ redundant time information
- ✦ El. chann. calibr. at $\lesssim 1\%$ during data-taking
- ✦ single intercalibration factor per cell based on K_{e3} and π^0, η response to improve resolution

$K_{S,L} \to \pi^0\pi^0$ - Detector performance



- ✦ energy resolution:

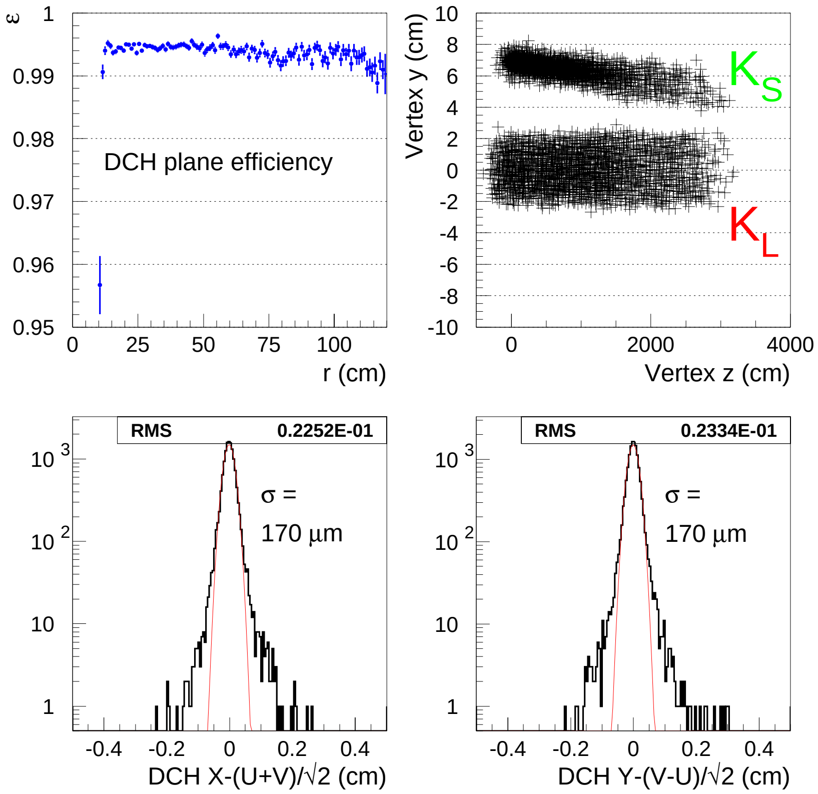
$$\frac{\sigma_E}{E} = \frac{3.2\%}{\sqrt{E(GeV)}} \oplus \frac{125MeV}{E} \oplus 0.5\%$$

$< 1\%$ above 20 GeV

- ✦ cell to cell disuniformity 0.67 % corrected with K_{e3} and π^0, η events
- ✦ En. linearity $\lesssim 0.3\%$ in the 5-100 GeV range
- ✦ $\sigma(x)$,$\sigma(y)$ < 1.3 mm above 20 GeV
- ✦ $\sigma(t)$ < 300 ps above 20 GeV
- ✦ time stability $\approx 0.1\%$
- ✦ π^0 mass resolution 1.1 MeV$/c^2$

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

- Hi-rate DCH's: 5 mm drift dist. $(t_d \sim 100 ns)$
- Absolute position of wires: better than $100.\mu$m

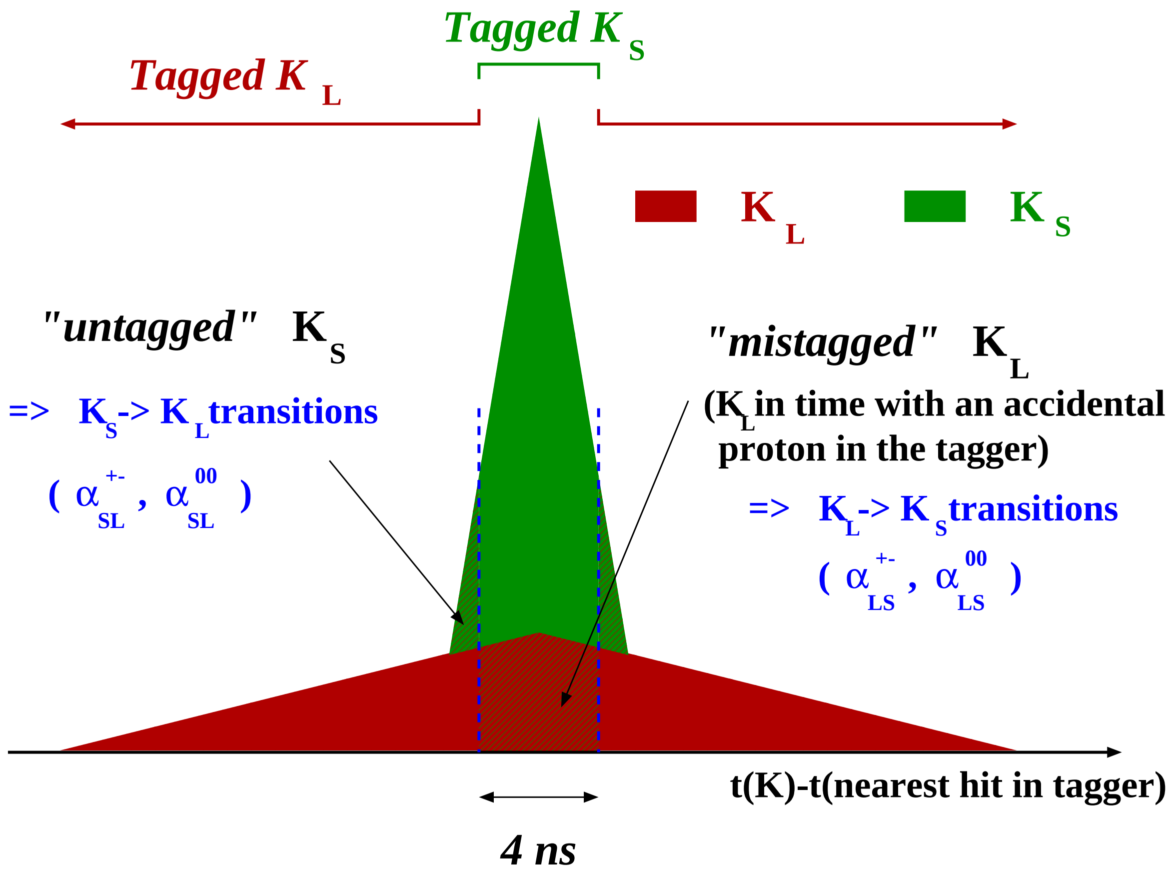


- DCH plane efficiency: 99.5%
- DCH space resolution: $\approx 90.\mu$m per projection
- $\sigma(vertex)$: $\approx$ 2 mm transv. and $\approx$ 50 cm long.
- DCH momentum resolution:

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

- time resolution: $\approx$ 200 ps per track
- $\pi\pi$ mass resolution: $\sim 2.5\ \mathrm{MeV}/c^2$

Tagging: $\mathrm{K_S}$ vs $\mathrm{K_L}$ Identification



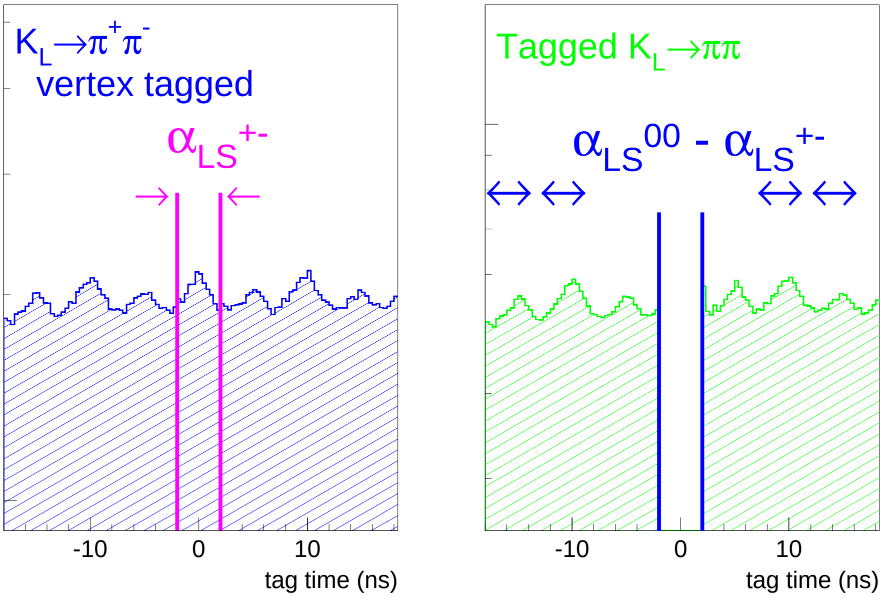
- $\mathrm{K_S}$ = event time within ± 2 ns of proton.
- $\mathrm{K_L}$ mistagging ($\mathrm{K_L} \rightarrow \mathrm{K_S}$, α_{LS}) due to accidental protons in tagger: charged-neutral symmetric to first order.
- $\mathrm{K_S}$ mistagging ($\mathrm{K_S} \rightarrow \mathrm{K_L}$, α_{SL}) due to inefficiencies & time reconstr. tails: can be different btw charged-neutral decays.
- Mistagging only "dilutes" R if charged-neutral symmetric.

$$\Delta R \approx 5.3(\alpha_{SL}^{00} - \alpha_{SL}^{+-}) - 1.7(\alpha_{LS}^{00} - \alpha_{LS}^{+-})$$

Tagging - $K_L \to K_S$ transitions

- ✦ α_{LS} measures the $K_L \to K_S$ mistagging probability due to accidental protons in the tagger.
- ✦ α_{LS} is charged/neutral symmetric, except for rate-dependent trigger inefficiencies.
- ✦ α_{LS}^{+-} is directly measured by vertex tagging:

$$\alpha_{LS}^{+-} = (11.19 \pm 0.03)\ \%$$



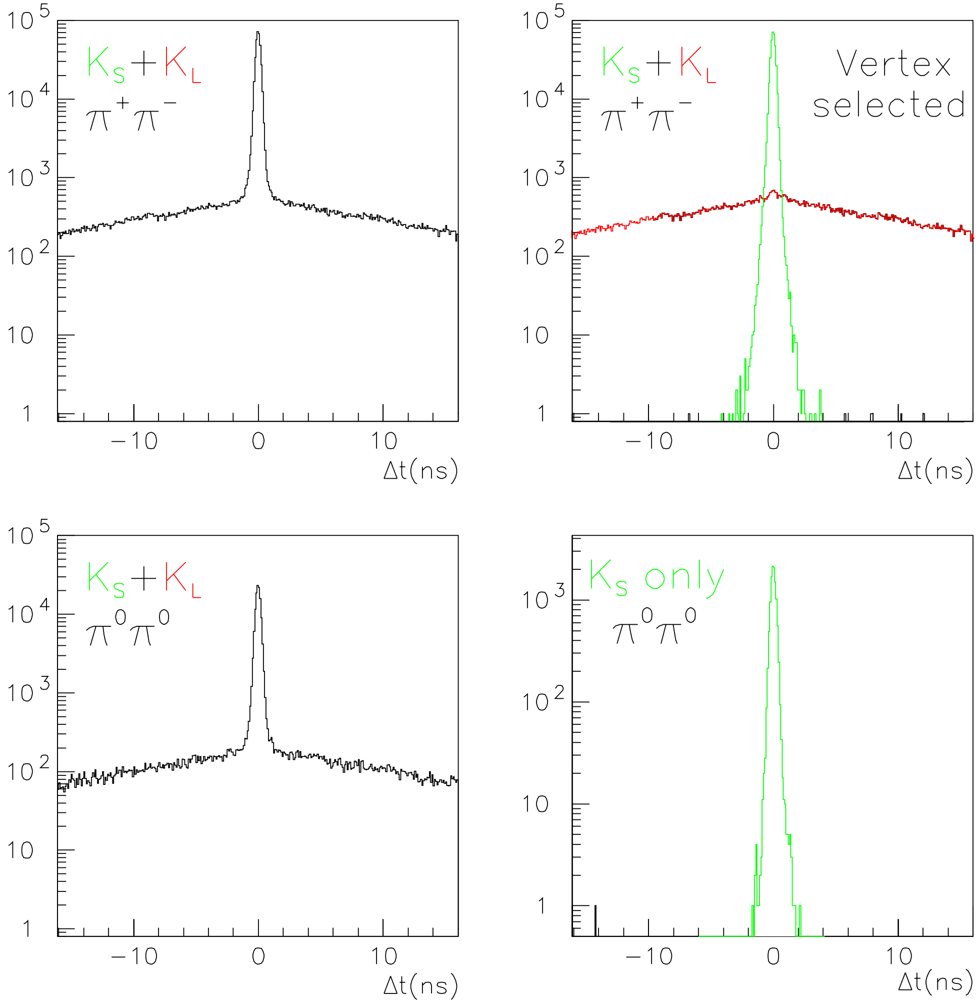
- ✦ $\alpha_{LS}^{00} - \alpha_{LS}^{+-}$ is measured by comparing suitable side bands (4 ns wide) outside the tagged region in charged and neutral modes:

$$\alpha_{LS}^{00} - \alpha_{LS}^{+-} = (0.10 \pm 0.05)\ \%$$

☞ The net effect on the double ratio is:

$$\boxed{\Delta R = (-18 \pm 9) \cdot 10^{-4}}$$

Tagging - Measurements



- Charged mode: K_L and K_S well distinguished by decay vertex vertical position.
  - $\alpha_{LS}^{+-} = (11.19 \pm 0.03)\,\%$
  - $\alpha_{SL}^{+-} = (1.5 \pm 0.1) \times 10^{-4}$
- Neutral mode:
  - $(\alpha_{LS}^{00} - \alpha_{LS}^{+-}) = (0.10 \pm 0.05)\,\%$ measured with side bands of tagging window.
  - $(\alpha_{SL}^{00} - \alpha_{SL}^{+-}) = (0 \pm 1) \cdot 10^{-4}$ measured with $K_S \to \pi^0 e^+ e^- \gamma$ and γ conversions.

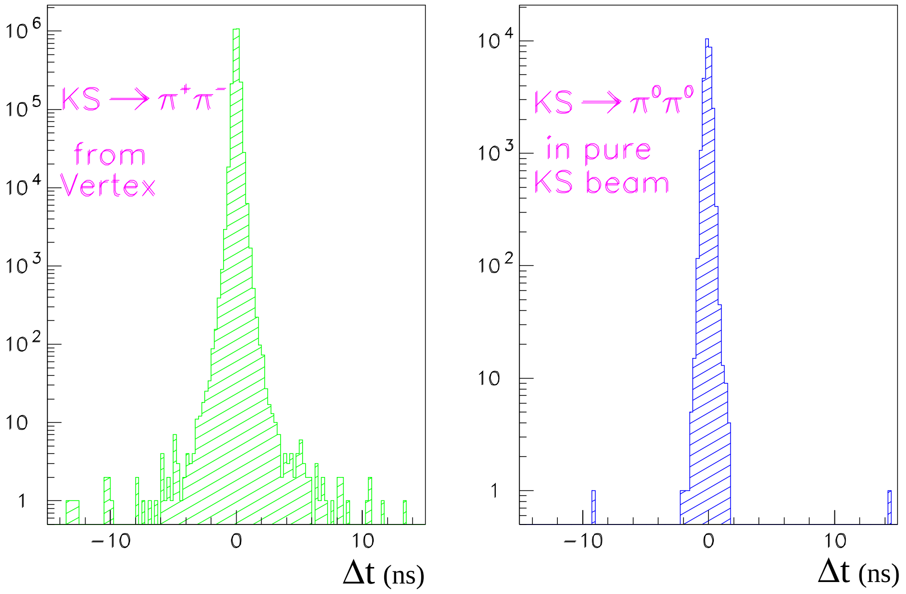
☞ Tagging uncertainty on R is statistically dominated and net effect is:

$$\boxed{\Delta R = (-18 \pm 11) \cdot 10^{-4}}$$

Tagging - $\mathrm{K_S} \to \mathrm{K_L}$ transitions

- α_{SL} measures the $\mathrm{K_S} \to \mathrm{K_L}$ mistagging probability due to tails in the proton or event time reconstruction (tagging inefficiences)
- Measurement shows that 2/3 of α_{SL} is due to the tagger, therefore charged/neutral symmetric
- α_{SL}^{+-} is directly measured by vertex tagging

$$\alpha_{SL}^{+-} = (1.5 \pm 0.1) \cdot 10^{-4}$$



- α_{SL}^{00} is measured in pure $\mathrm{K_S}$ runs and using $\mathrm{K_S} \to \pi^0 e^+ e^- \gamma$ decays
- $(\alpha_{SL}^{00} - \alpha_{SL}^{+-})$ is bounded by neutral/charged time comparison on γ conversions

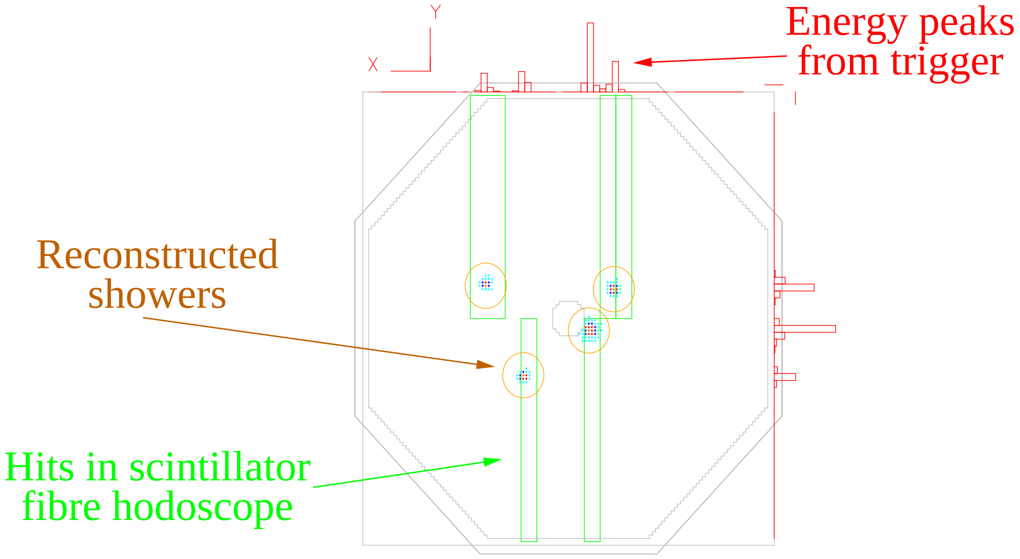
$$\alpha_{SL}^{00} - \alpha_{SL}^{+-} = (0 \pm 1) \cdot 10^{-4}$$

☞ The net effect on the double ratio is:

$$\boxed{\Delta R = (0 \pm 6) \cdot 10^{-4}}$$

Neutral trigger

- 40 MHz pipelined system based on 64 hor. and 64 vert. projections of e.m. calorimeter cells
- rejects dominant $\mathrm{K_L} \to 3\pi^0$ background by on-line reconstruction of:
    - number of in-time clusters in each projection
    - total energy in E.M. and HAD. calorimeters
    - longitudinal decay vertex position



- During 1997 run:
    - Input rate: ~ 500 kHz $\mathrm{K_L}$ decays in detector
    - Output rate: ~ 2 kHz
    - Efficiency: $\epsilon_{NT} = (99.88 \pm 0.04)\%$

☞ The net effect on R is due to the differential $\mathrm{K_L} - \mathrm{K_S}$ inefficiency:

$$\boxed{\Delta R = \epsilon_{NT}^{L(W)} - \epsilon_{NT}^{S} < 2 \cdot 10^{-4}}$$

Charged trigger - General

- Hardware and software trigger reduces dominant background from 3-body $\mathrm{K_L}$ decays

- Level 1: Two track topology in scintillation hodoscopes and $E_{TOT} \gtrsim 30$ GeV in calorimeters

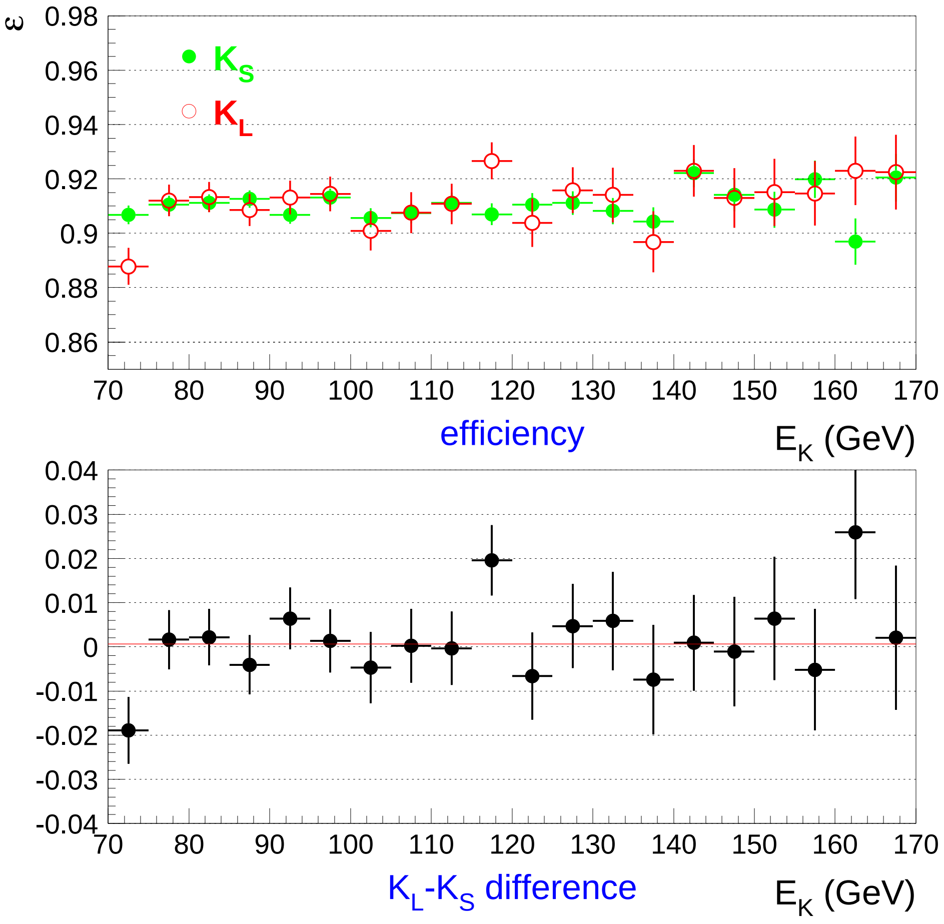
- Level 2: fast tracking in the spectrometer by a farm of processors reconstructing and cutting on:
  - ▷ longitudinal decay vertex position
  - ▷ proper lifetime
  - ▷ $\pi^+\pi^-$ invariant mass

- During 1997 run:
  - ▷ Input rate: $\sim$ 500 kHz $\mathrm{K_L}$ decays in detector
  - ▷ Level 1 output rate: $\sim$ 100 KHz
  - ▷ Level 2 output rate: $\sim$ 1.5 KHz
  - ▷ Dead time $\sim$ 0.3 % (monitored)

Charged trigger - Efficiency

- Combined $L1 \cdot L2$ efficiency:

$$\epsilon_{ChTr} = (91.68 \pm 0.09)\%$$



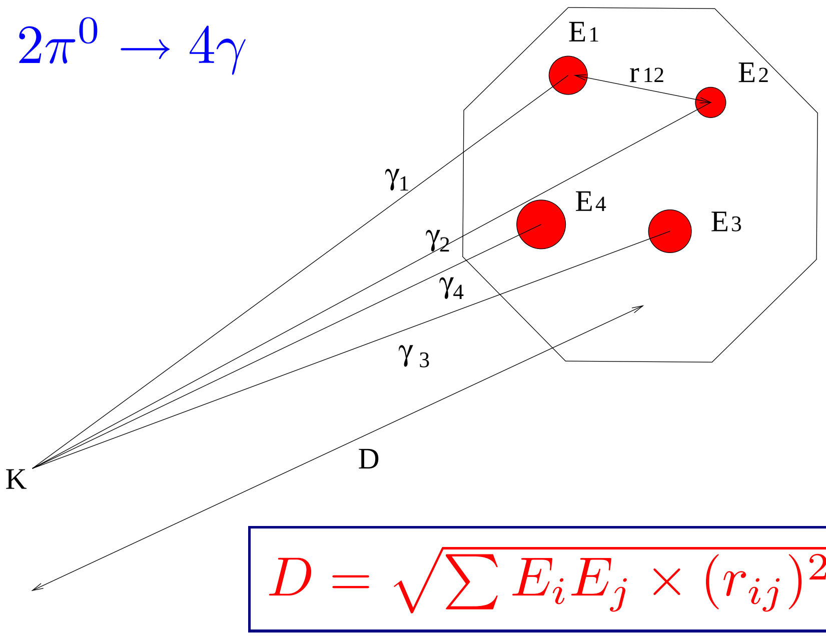
- Efficiency measurement limited by control sample statistics

☞ The net effect on R is due to the differential $\mathrm{K_S} - \mathrm{K_L}$ inefficiency:

$$\boxed{\Delta R = \epsilon^{S}_{CT} - \epsilon^{L(W)}_{CT} = (-9 \pm 23) \cdot 10^{-4}}$$

$K^0 \to \pi^0\pi^0$ Reconstruction

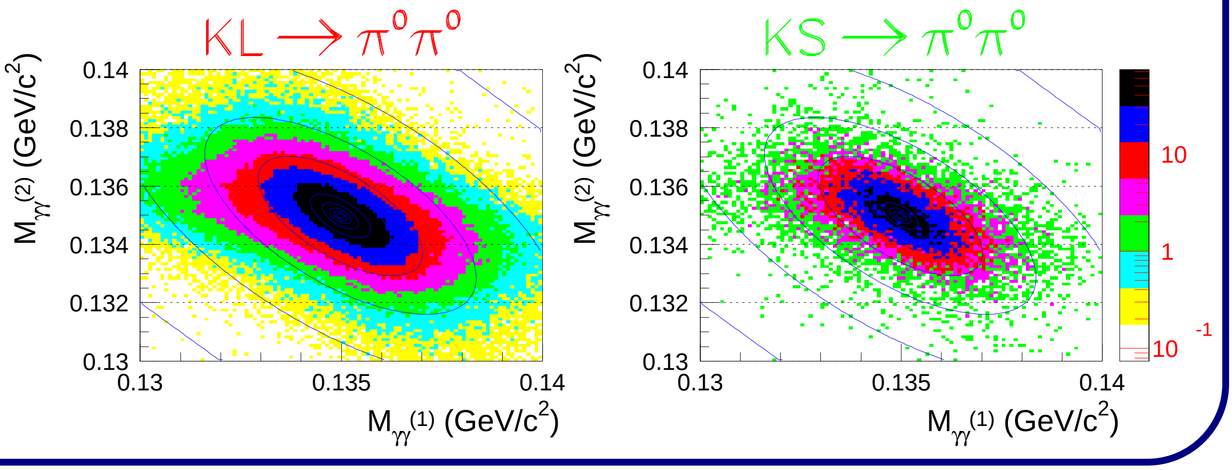
$K_{\mathrm{L,S}} \to 2\pi^0 \to 4\gamma$



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

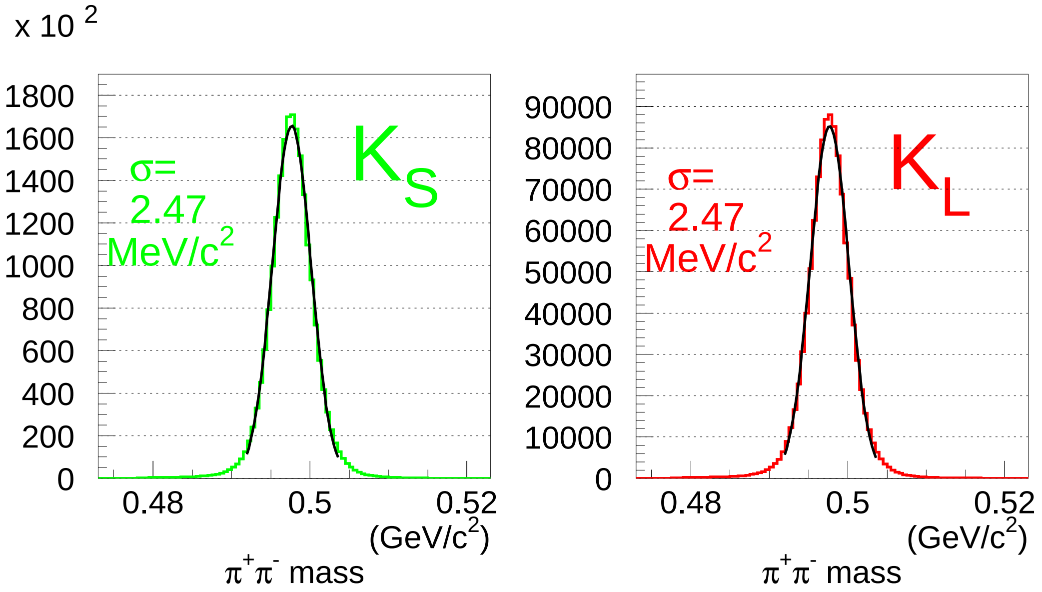
- Vertex position along the beam line found by imposing the K mass $\sigma(Z_{VTX}) \approx 70$ cm
- Pairing of photons to get the best π^0 mass : $m_{ij} = \sqrt{E_i E_j}\ .\ r_{ij}/D$
- Use pseudo-χ^2 variable

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



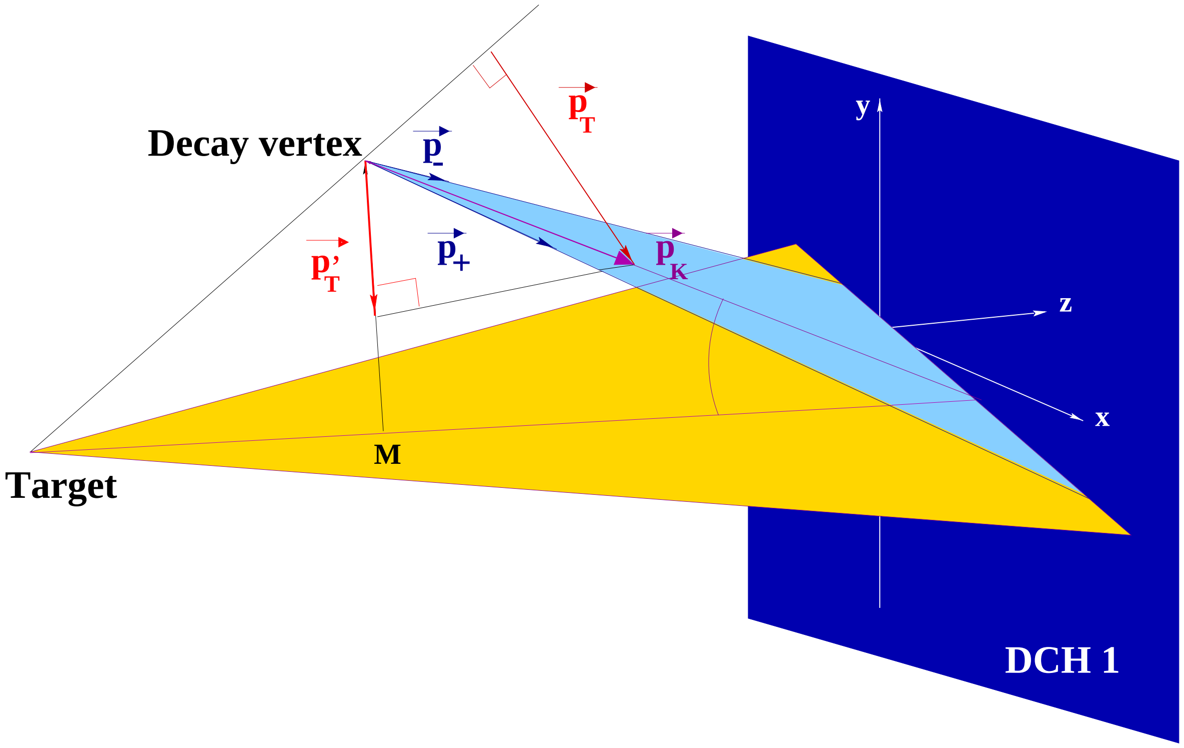
$K \rightarrow \pi^+\pi^-$ event reconstruction

- ✦ Tracks from spectrometer using detailed field map including stray fields
- ✦ Small correction for residual magnetic field in decay region ($O(1 \cdot 10^{-3}$ T·m)
- ✦ $\approx 20\%$ of events are lost due to an *overflow* condition in DCH electronics for high multiplicity events (recorded and applied also to neutral events)
- ✦ Kaon energy computed from ratio of track momenta and opening angle ⇒ less sensitive to magnetic field knowledge
- ✦ Effective energy-dependent cut on center of mass decay angle ⇒ reduced K_S/K_L acceptance difference



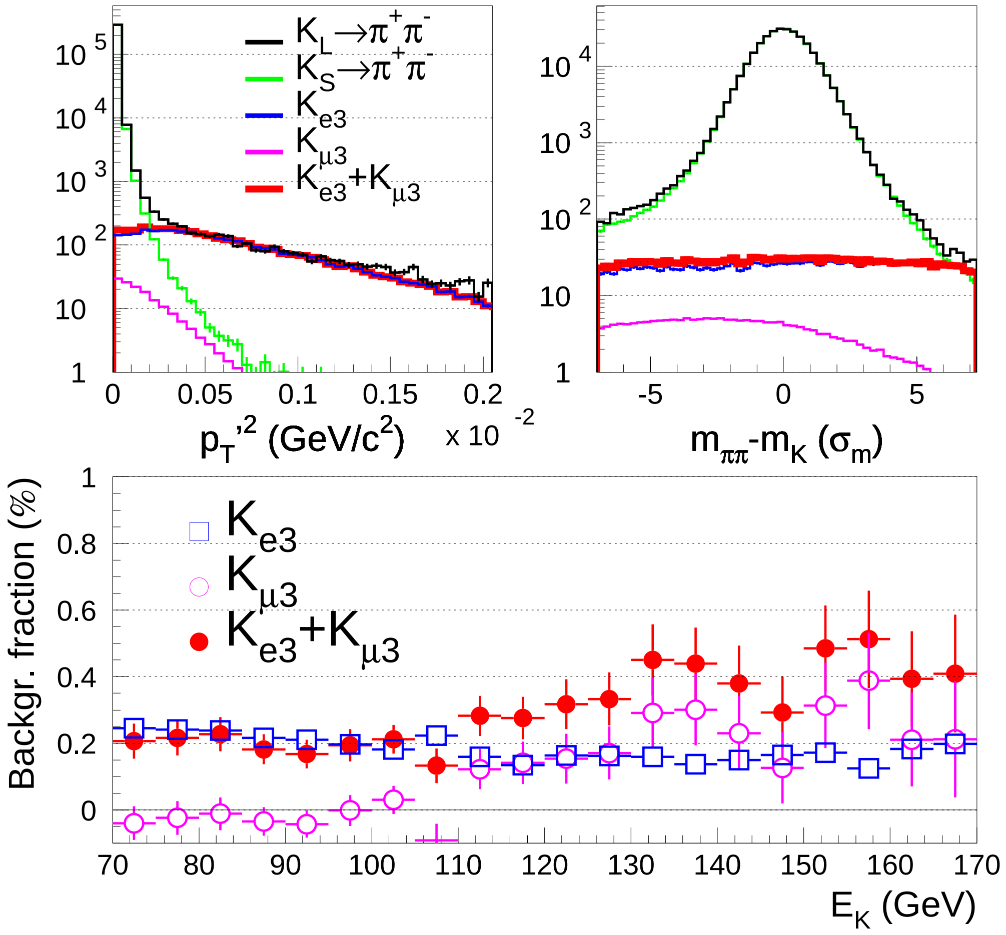
Charged background - Method

- $\mathrm{K_L}$ 3-body decays are O(100) × signal
- K_{e3} rejection O(500) by E/P requirement on tracks, with 5% $\mathrm{K_S/K_L}$ symmetric signal loss
- $K_{\mu 3}$ rejection O(500) by muon veto counter hits matching tracks in space and time, with 3% $\mathrm{K_S/K_L}$ symmetric signal loss
- kinematical cuts reject $\pi^+\pi^-\pi^0$ background and $\Lambda(\bar{\Lambda})$ decays
- cut on rescaled transverse momentum ${P'_T}^2$ (similar $\mathrm{K_S}$ and $\mathrm{K_L}$ distributions) with $8 \cdot 10^{-4}$ $\mathrm{K_S/K_L}$ symmetric signal loss



Charged background - Measurement

✦ Check systematics by varying signal and control region



☞ Averaged charged background fraction is:

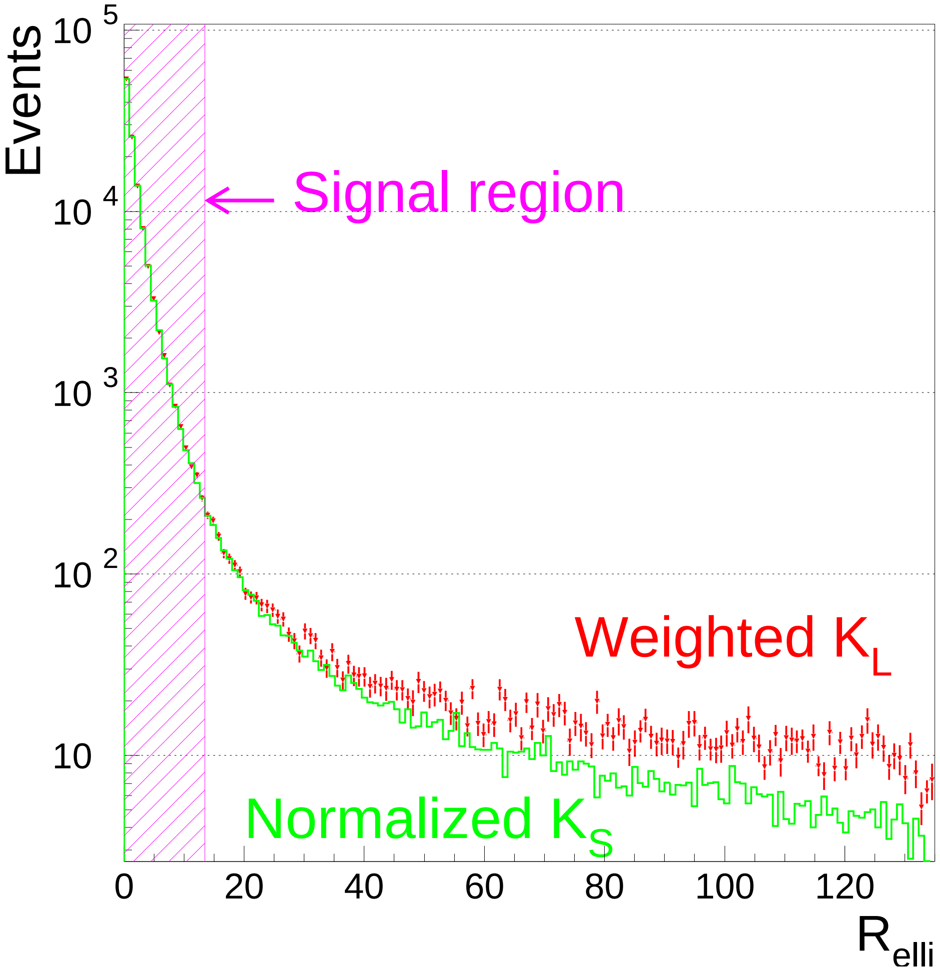
$$\boxed{B_C = (+23 \pm 2 \pm 4) \cdot 10^{-4} = -\Delta R}$$

☞ Small fraction ($\approx 0.5 \cdot 10^{-3}$) of $\pi\pi$ events due to K_S regenerated on final collimator gives

$$\boxed{\Delta R = (+12 \pm 3) \cdot 10^{-4}}$$

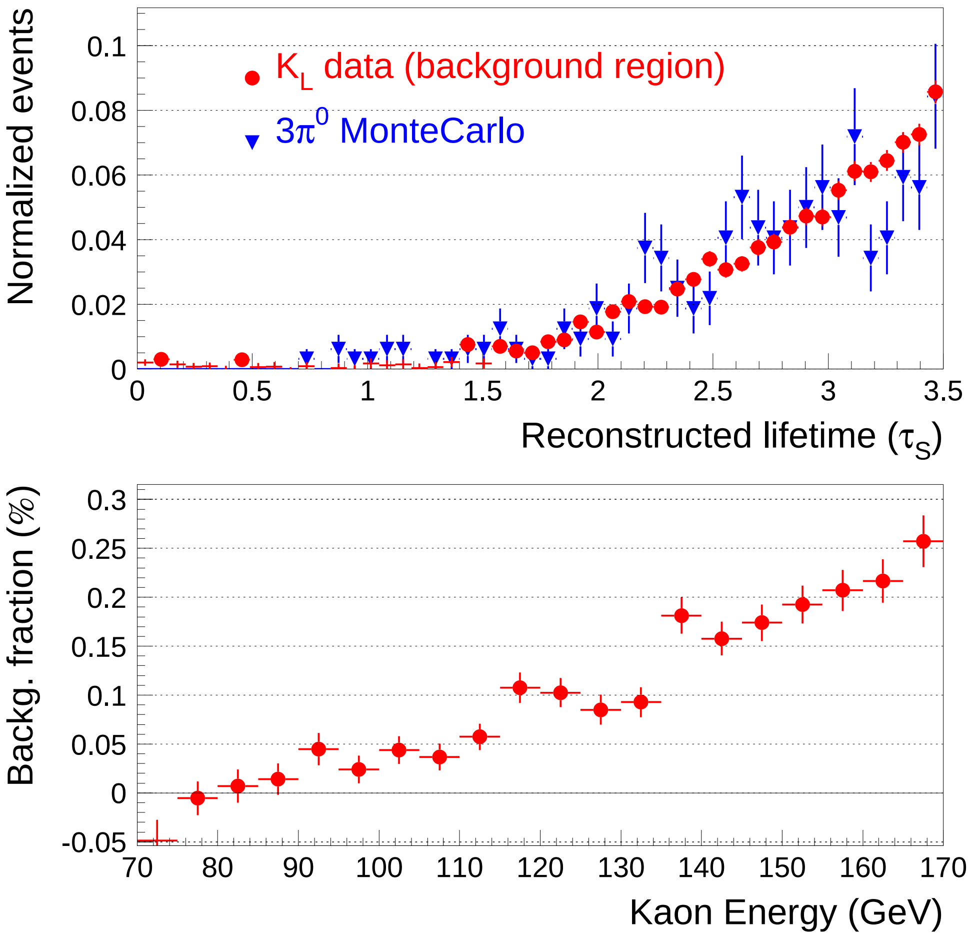
Neutral background - Method

- $K_L \rightarrow 3\pi^0$ is 210 × signal
- $K_L \rightarrow 3\pi^0$ with 2 missing photons have larger reconstructed lifetime and non-peaked $\gamma\gamma$ mass
- Signal region: $R_{elli} < 13.5$ with 7% K_S/K_L symmetric signal loss (mostly γ conversions)
- Control region: $36 < R_{elli} < 135$



Neutral background - Measurement

- Use $K_S \rightarrow \pi^0\pi^0$ decays to measure signal R_{elli} shape to account for non-gaussian tails
- Extrapolate from large R_{elli} control region $36. < R_{elli} < 135.$ using factor 1.2 ± 0.2 computed from MonteCarlo

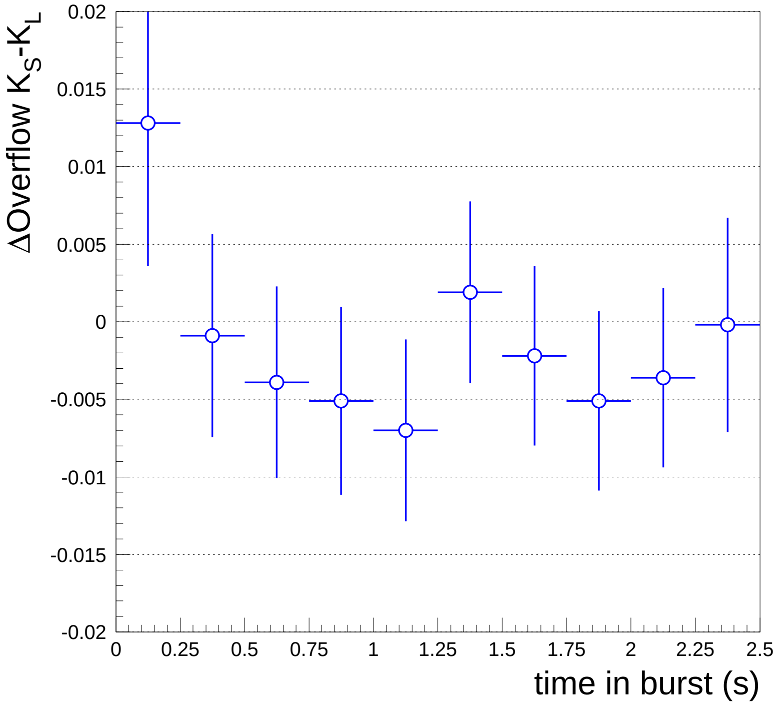


☞ Averaged background is:

$$\boxed{B_N = (+8 \pm 2) \cdot 10^{-4} = \Delta R}$$

DCH overflow condition

- Whenever the DCH plane hit multiplicity in a 100 ns window gets above 7, the front end buffers are flushed and the occurrence is recorded
- This has no effect on events outside a ± 300 ns time window around that time
- The loss of events due to such a cut is $\approx 20\%$
- The same cut is applied to neutral events, and the K_L/K_S differential loss is estimated by studying side time intervals for $\pi^+\pi^-$ decays: $(0.02 \pm 0.03)\%$, and is directly measured for $\pi^0\pi^0$ decays: $(-0.02 \pm 0.06)\%$, in both cases being negligible



☞ No significant effect on R

Accidental activity

- Simultaneous beams ⇒ K_S/K_L differential effects intrinsically small
- "Instantaneous" beam intensity is continuously monitored: K_S and K_L beam intensities are correlated to $\approx 1\%$
- Accidental activity for K_S and K_L measured to be the same at 1% level
- "Randomly" triggered events proportional to K_L and K_S beam intensities are overlaid onto $\pi\pi$ events to measure event gains and losses:
  - $\pi^+\pi^-$: losses - gains $\simeq 2\%$ (K_S/K_L symmetric)
  - $\pi^0\pi^0$: losses - gains $\simeq 2.5\%$ (K_S/K_L symmetric)

☞ Net effect on double ratio:

$$\boxed{\Delta R = (+2 \pm 14) \cdot 10^{-4}}$$

- In-time activity from close K_S target measured in K_S only runs to be $< 3 \cdot 10^{-4}$

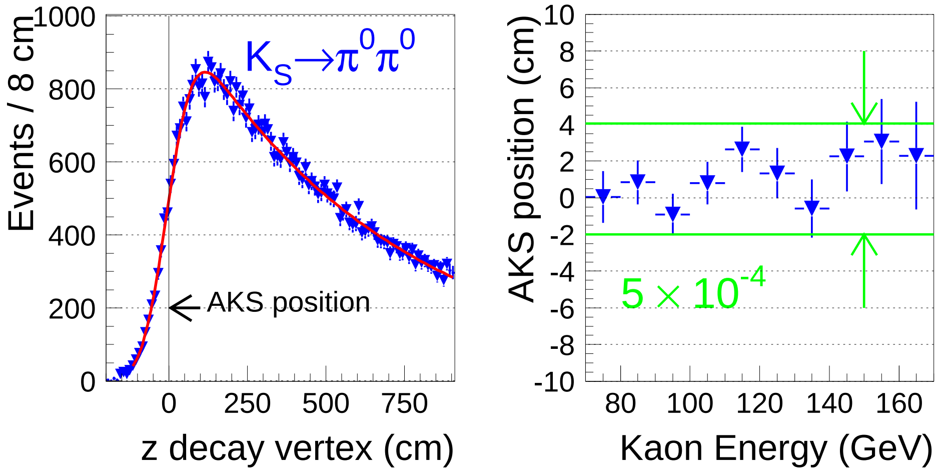
☞ Double ratio uncertainty:

$$\boxed{\delta(R) < 3 \cdot 10^{-4}}$$

which can be neglected.

Neutral energy and distance scales

- In neutral mode the longitudinal vertex distance and energy scales are related
- Absolute energy scale is set by adjusting the reconstructed position of the AKS veto counter in the $\mathrm{K_S} \rightarrow \pi^0\pi^0$ vertex distribution, accounting for non-gaussian tails, with a conservative uncertainty of $5 \cdot 10^{-4}$



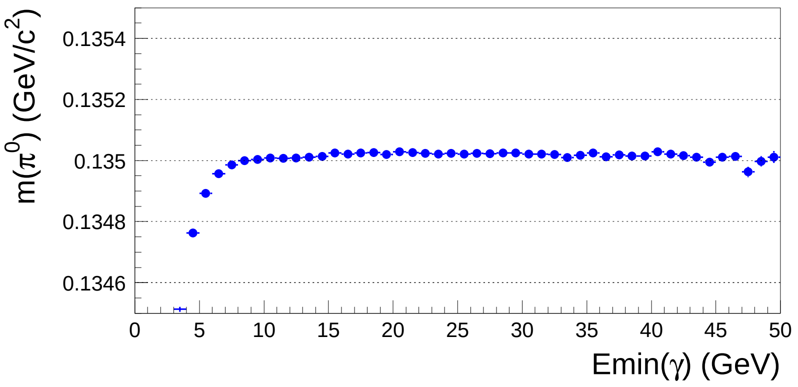
- Energy scale is stable in time within $5 \cdot 10^{-4}$
- Cross checks: reconstructed position of thin movable target in dedicated runs with π^- beam: consistent results with $\pi^0 \rightarrow 2\gamma$, $\eta \rightarrow 2\gamma/6\gamma$
- Transverse distance scale of e.m. calorimeter checked against spectrometer using K_{e3} decays to 0.3 mm/m

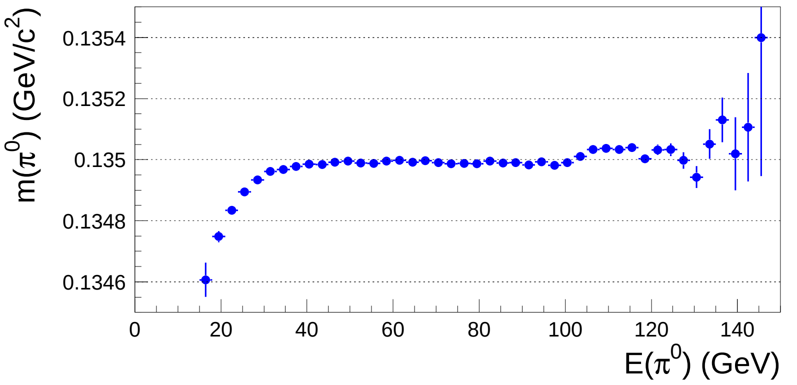
☞ R uncertainty from neutral scales:

$$\boxed{\delta(R) = \pm 6 \cdot 10^{-4}}$$

Calorimeter response

- Calorimeter response is equalized using K_{e3} decays during normal data taking and π^0 decays in special runs to $O(10^{-3})$
- Calorimeter non-linearity is studied using K_{e3} events, $\pi^0\pi^0$ decays and π^0 or η decays, and measured to be at the level of 0.3%
- Sensitivity to longitudinal development of e.m. showers is minimized by detector projectivity





☞ Non-linearity, non-uniformity and other systematics on e.m. calorimeter response give a double ratio uncertainty:

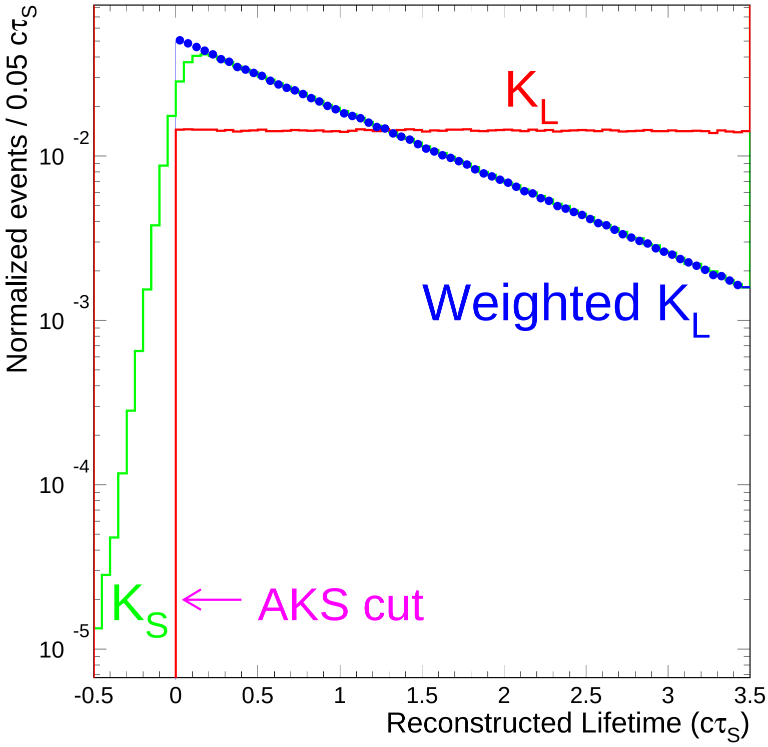
$$\boxed{\delta(R) = \pm 10 \cdot 10^{-4}}$$

Lifetime weighting

- $\mathrm{K_S}$ and $\mathrm{K_L}$ are collected in the same fiducial region
- Weighting $\mathrm{K_L}$ events as a function of decay proper time, according to expected ratio of $\pi\pi$ rates $\Rightarrow$ very similar lifetime distributions
- Accounts for small terms due to $\mathrm{K_S}$ and $\mathrm{K_L}$ interference and $K^0/\bar{K}^0$ production difference

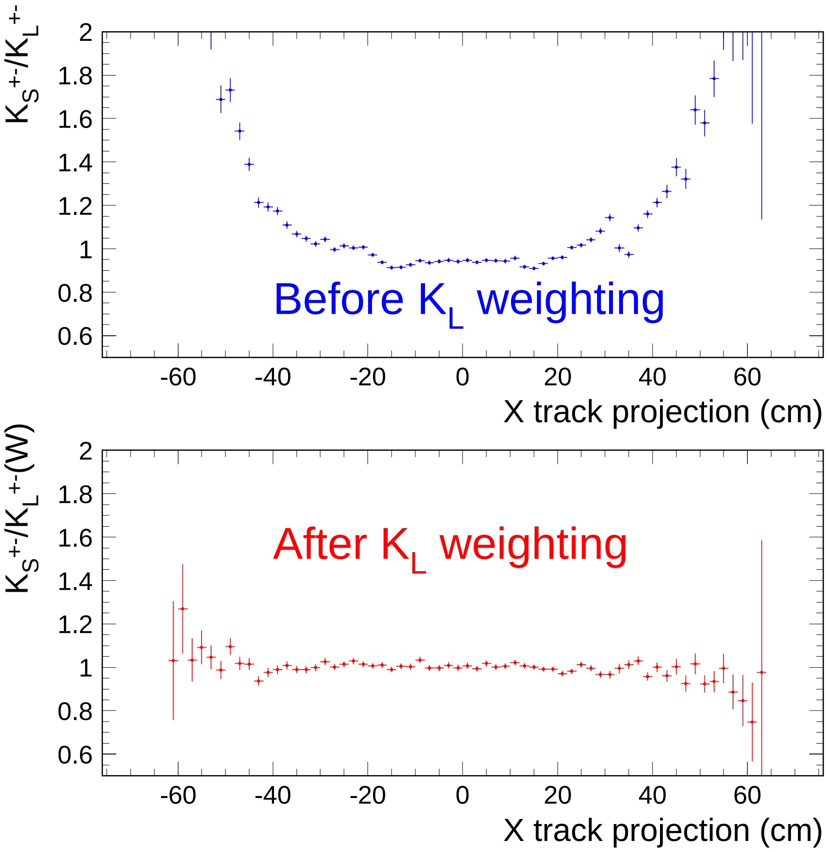
☞ Reduces potentially large acceptance corrections to $< 0.5\%$

- Increases statistical error



Acceptance correction

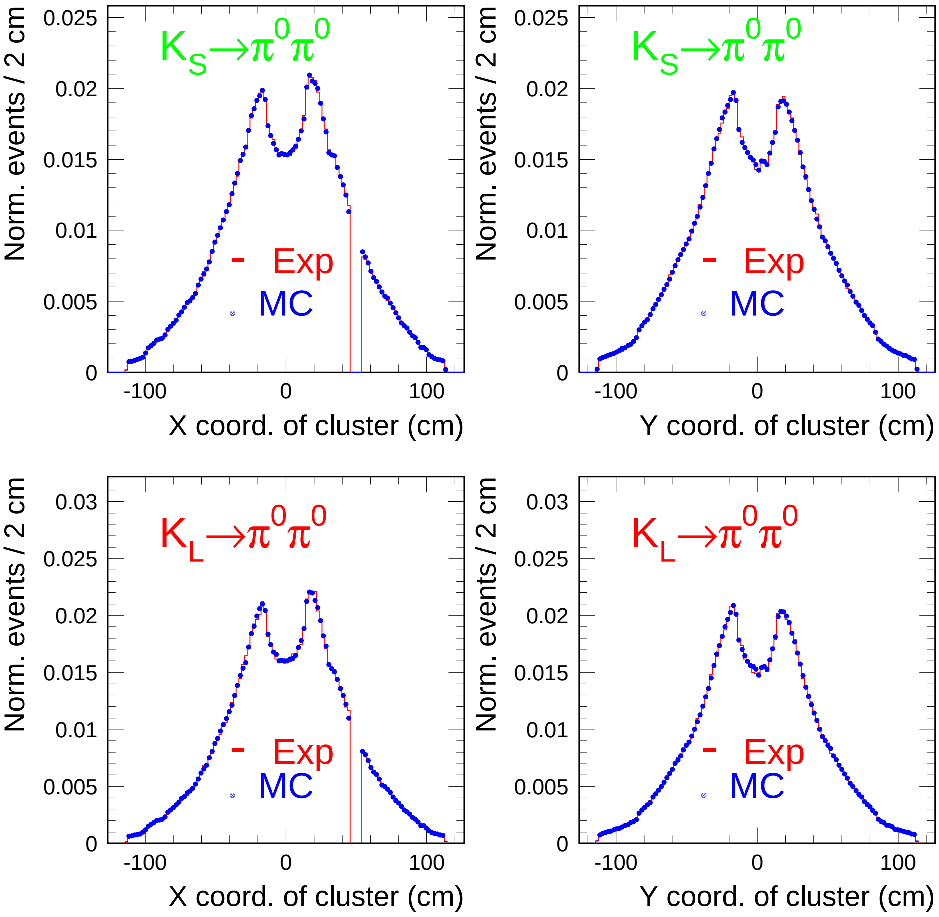
- Analysis in K^0 energy bins and lifetime weighting of $\mathrm{K_L}$ events minimizes corrections due to $\mathrm{K_S/K_L}$ energy spectra and acceptance differences, making the experiment almost indipendent from MonteCarlo simulation



- $\mathrm{K_S/K_L}$ beam halo differences minimized by wide centre of gravity cut
- Residual $\mathrm{K_S/K_L}$ acceptance difference (due to beam divergence) minimized for charged mode by energy-dependent cut on $\pi^+\pi^-$ momentum asymmetry

MonteCarlo acceptance correction

- Residual effect studied with a full simulation of the detector, including all known deficiences (faulty channels, etc.)



- MonteCarlo statistics 5 × data sample

☞ Averaged effect on double ratio:

$$\boxed{\Delta R = (-29 \pm 11 \pm 5) \cdot 10^{-4}}$$

where the first error is due to MC statistics and the second is systematic.

Statistics

1997 event statistics
(Unweighted, tagging and background corrected)

$K_L \rightarrow \pi^0\pi^0$:	$0.49 \cdot 10^6$
$K_S \rightarrow \pi^0\pi^0$:	$0.98 \cdot 10^6$
$K_L \rightarrow \pi^+\pi^-$:	$1.07 \cdot 10^6$
$K_S \rightarrow \pi^+\pi^-$:	$2.09 \cdot 10^6$

Corrections to R and uncertainties

1997 Statistics (millions)			
$K_S \to \pi^+\pi^-$ $K_S \to \pi^0\pi^0$	2,09 0,98	$K_L \to \pi^+\pi^-$ $K_L \to \pi^0\pi^0$	1,07 0,49

Unweighted, tagging and bkgr corrected

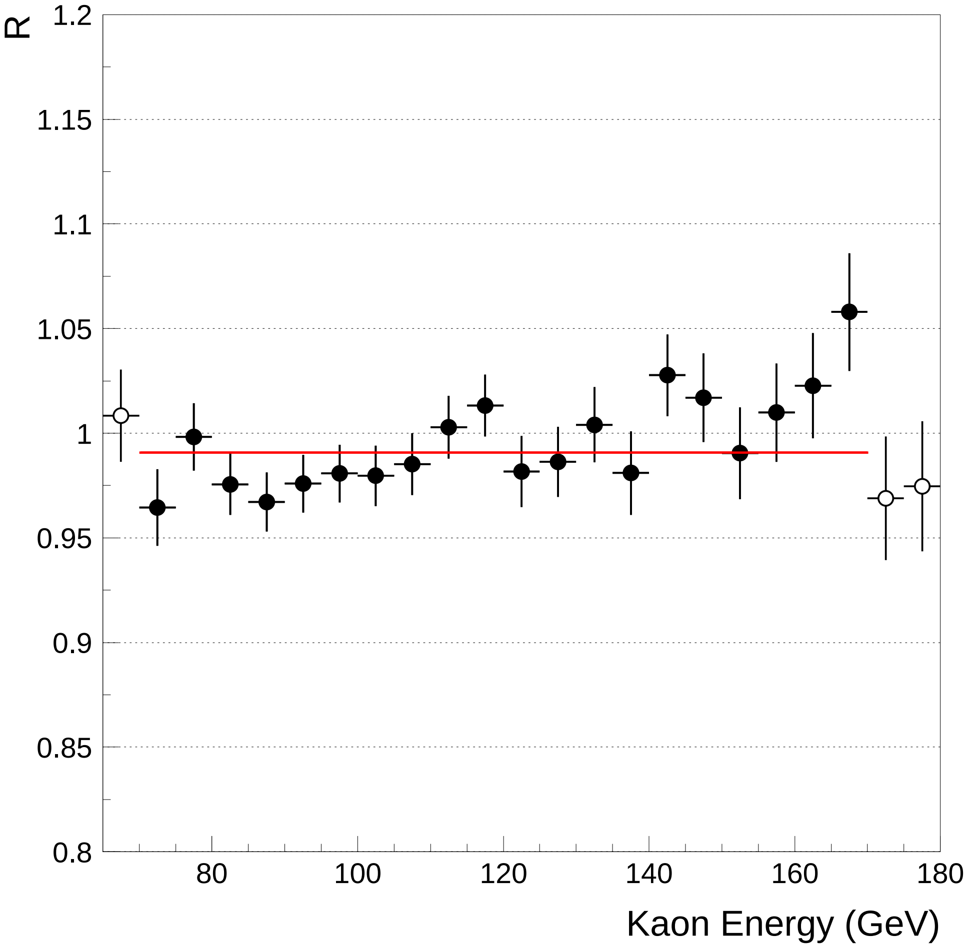
Corrections and systematic errors on R

Source	Corr. (10^{-4})	Uncert. (10^{-4})	Lim.
Ch. Tr. Eff.	+9	23	(stat.)
Reconstr. Eff.	-	3	
Tagging Dilut.	+18	9	(stat.)
Tagging Ineff.	0	6	(stat.)
En. scale/lin.	-	12	
Charged Vtx	-	5	
Acceptance	+29	12	(MC stat.)
Neutral Bkgr	-8	2	
Charged Bkgr	+23	4	
Beam Scatt.	-12	3	
Accid. Act.	-2	14	(stat.)
Total	+57	35	

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

Averaging R

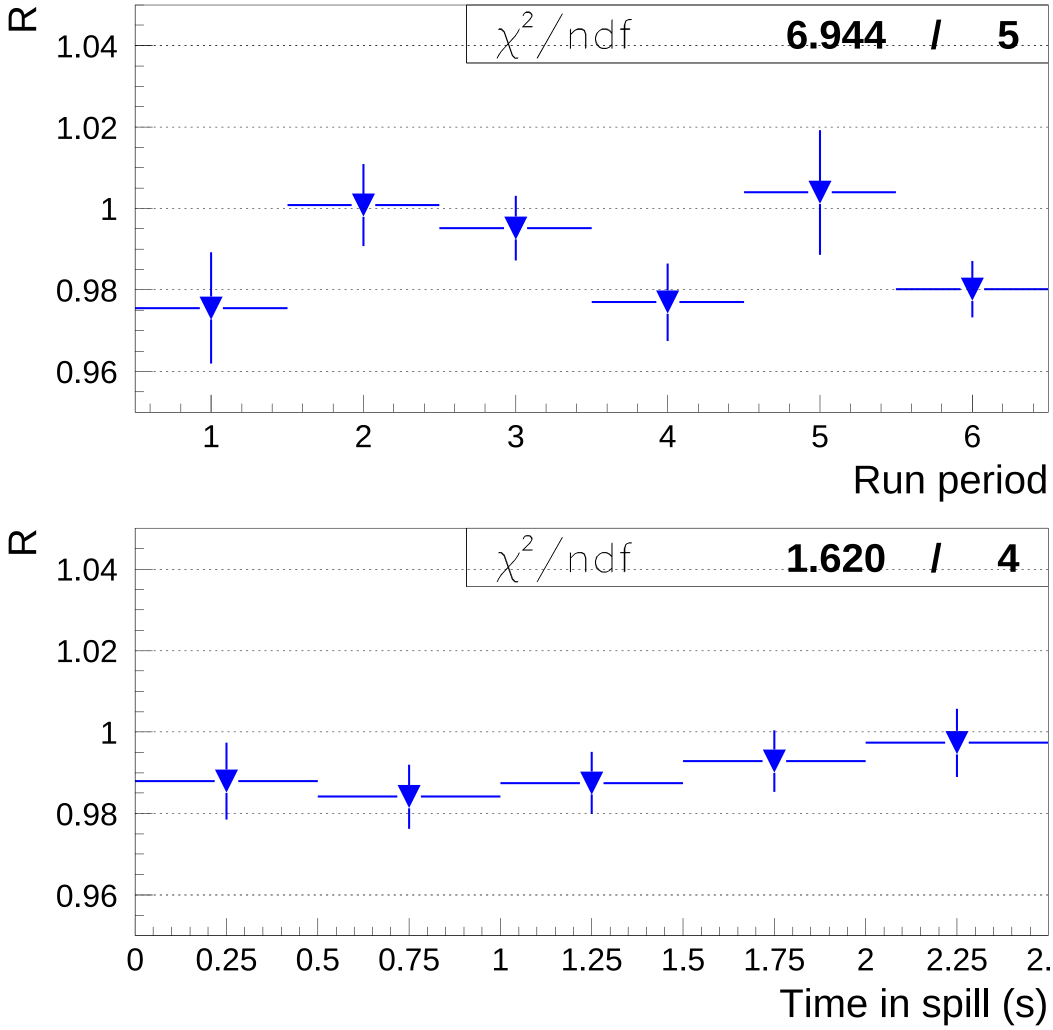
- The double ratio is avrgd over 20 K^0 En. bins btw 70 and 170 GeV/c using an unbiased estim.
- Data are plotted btw 65 and 180 GeV/c
- Bin by bin corrections include: stat. error and syst. errors on tagging, trigger, bkgr and acceptance
- $\chi^2/\mathrm{ndf} = 25.7/19$



$$R = 0.9889 \pm 0.0027(\mathrm{stat}) \pm 0.0035(\mathrm{syst})$$

Time dependence

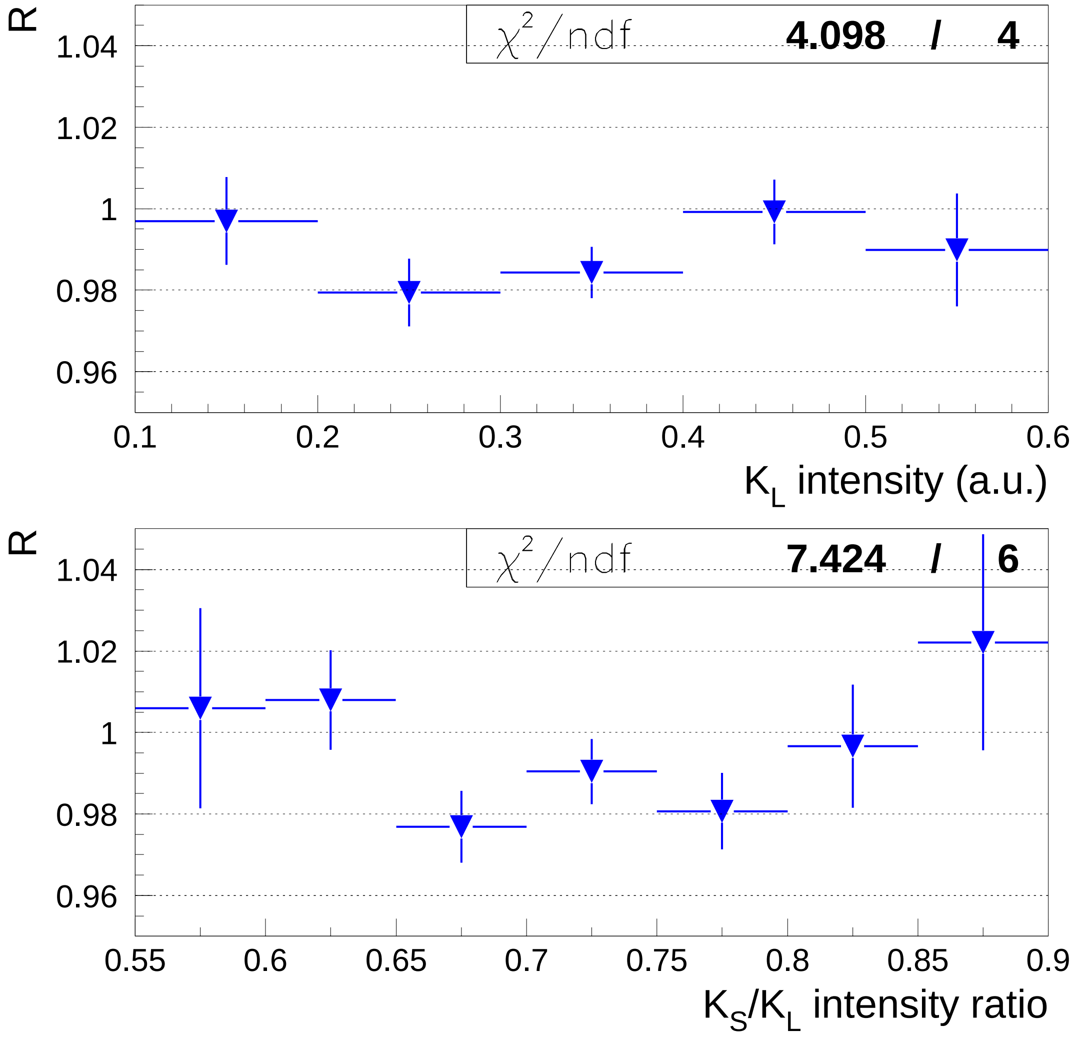
Run period dependence (changes in trigger and magnetic field configuration) and time in spill dependence:



☞ No systematic effect

Beam intensity dependence

K_L beam intensity and K_S/K_L intensity ratio dependence:



☞ No systematic effect

The result

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

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

Combining all errors in quadrature:

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

The systematic error is dominated by its statistical contribution due to the size of the control samples.

Next Data Samples

✦ 1998 run: 135 days. Data analysis quite advanced.

- ▷ All HV blocking capacitors of e.m. calor. replaced ⇒ stable operation at 3 kV
- ▷ New carbon fibre beam pipe ⇒ reduced overflows in DCH (30% current reduct.)
- ▷ Ch. trigger upgrade ⇒ higher eff. ≈ 97%
- ▷ New DAQ ⇒ + 30% trigger rate
- ▷ $\gtrsim$ 2 times more $\pi^0\pi^0$ statistics ($\approx$ 1.1 10^6)
  $\gtrsim$ 4 times more $\pi^+\pi^-$ statistics
- ▷ Statistical error on $\mathrm{Re}(\varepsilon'/\varepsilon)$ $\approx 3 \cdot 10^{-4}$
  Syst. error $\lesssim 4 \cdot 10^{-4}$

✦ 1999 run: 128 days. Checked quality of data.

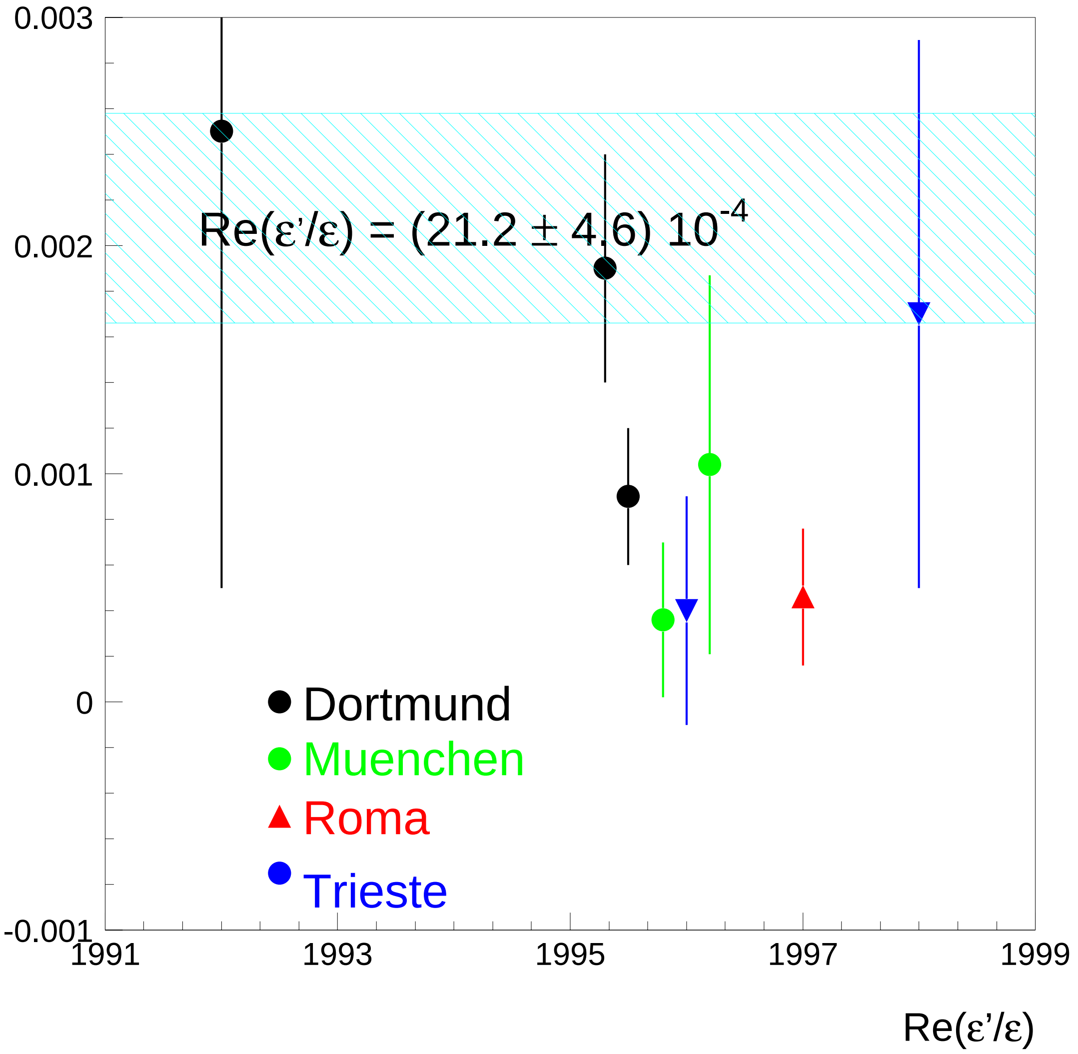
- ▷ Improved DCH readout and DAQ
  New muon veto counters
- ▷ $\approx 2 \cdot 10^6$ $\pi^0\pi^0$ candidates expected

✦ year 2000: systematic studies on neutral decays (SPSLC Meeting on Jan. 25) ?

✦ year 2001: complement statistics and systematic studies (one year shift) ?

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

- Theoretical predictions for $\mathrm{Re}(\varepsilon'/\varepsilon)$ generally below $1 \cdot 10^{-3}$



- New prediction (BNL/RIKEN group) from lattice computation using domain wall fermion gives a large negative value: $-(122 \pm 68) \times 10^{-4}$

Conclusions

The preliminary NA48 measurement of Re(ε'/ε)
(18.5 ± 4.5 (ev. stat.) ± 5.8 (syst.)) $\times 10^{-4}$
based on the first data sample taken in '97, with a **new** technique, agrees with the previous NA31 result and with the recent KTeV one, establishing a non zero value of Re(ε'/ε)

The systematic error of the preliminary result is dominated by its statistical component

The data sample for this result is a small fraction ($\sim$ 10%) of the total expected amount which has been and (hopefully) will be collected by NA48 to reach its design error of 2 $\times 10^{-4}$

Conclusions

The world average before this measurement was

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (21.7 \pm 6.1) \cdot 10^{-4}$$

(after rescaling of errors), with $\chi^2/\mathrm{ndf} = 4.2$.

The grand average of experimental results is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (21.2 \pm 4.6) \cdot 10^{-4}$$

(after rescaling of errors), with $\chi^2/\mathrm{ndf} = 2.8$, which firmly estabilishes direct CP violation in the K^0 system with $4.6\ \sigma$ significance ($\mathrm{Re}(\varepsilon'/\varepsilon) > 13.6 \cdot 10^{-4}$ at 95% C.L.) at a level higher than typically predicted within the standard model

In view of the unsatisfactory $\chi 2$ of the world average, it is important that NA48 and KTeV still improve their precision on $\mathrm{Re}(\varepsilon'/\varepsilon)$, and that KLOE provides a new measurement, to settle better the value of this fundamental parameter