Measurement of Br($K_S \to \pi^+\pi^-\pi^0$) and limit on the CP violating Br($K_S \to 3\pi^0$)

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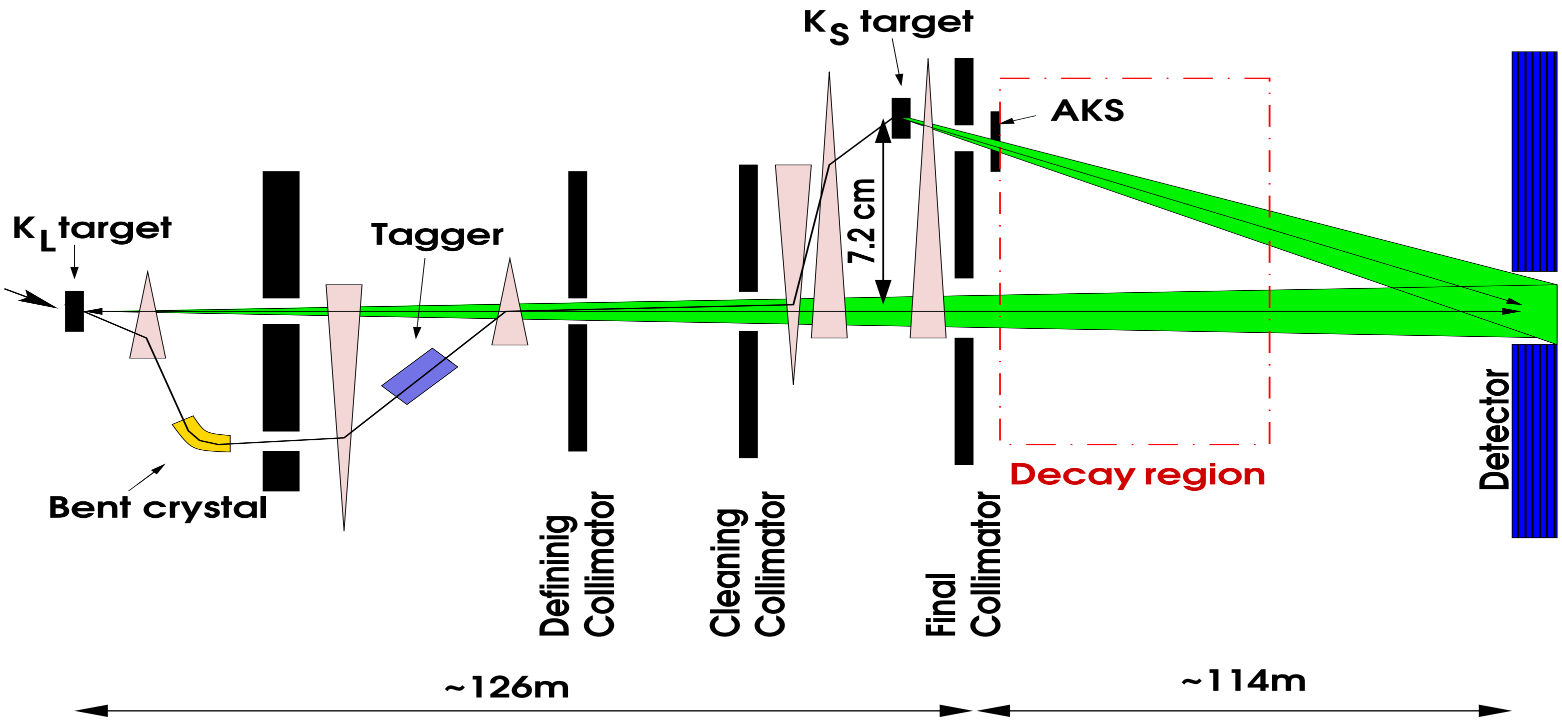
On behalf of the NA48/1 Collaboration:

Cambridge, Chicago, CERN, Dubna, Edinburgh, Ferrara, Firenze, Mainz, Northwestern, Perugia, Pisa, Saclay, Siegen, Torino, Warsaw, Wien

Data Taking:



2000: NA48

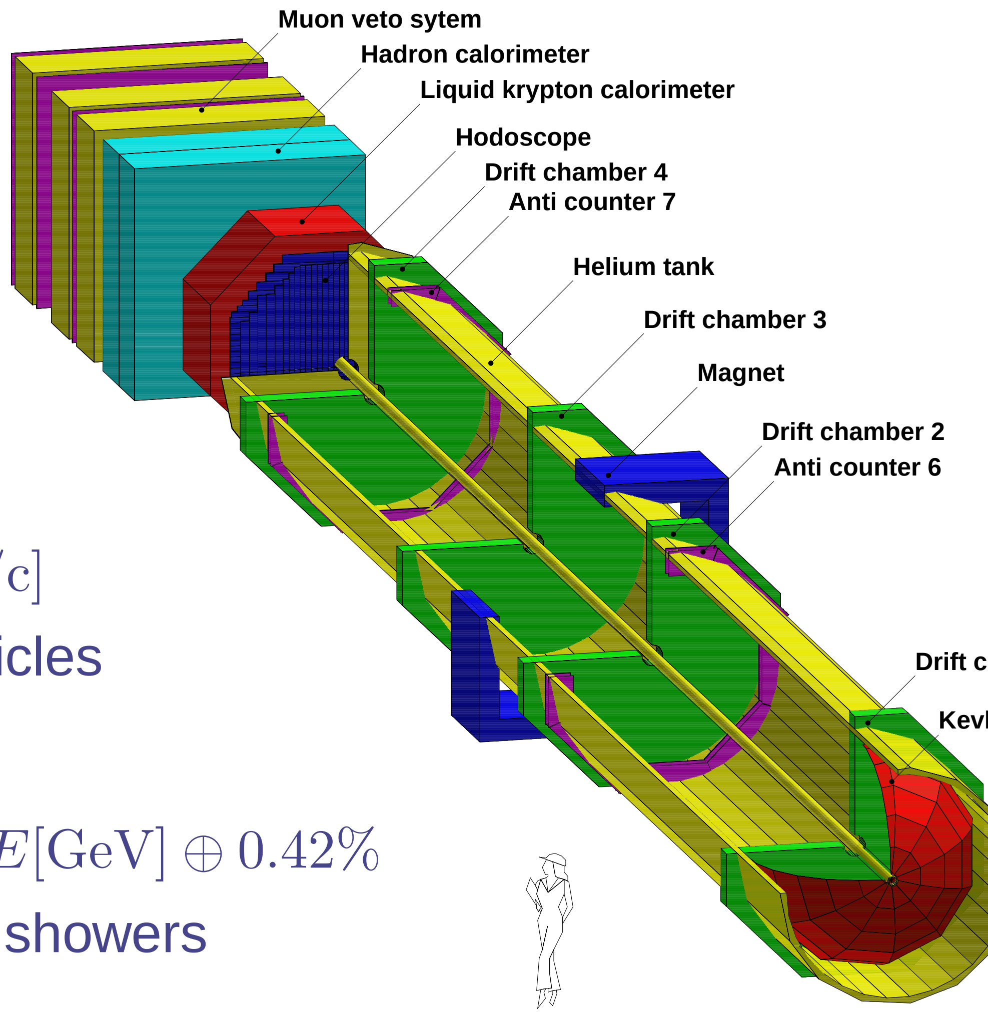
- first half: pure K_L-Beam
- second half: K_S-Beam
- no driftchambers

2002: NA48/1

- high intensity K_S-Beam
- total flux $4 \times 10^{10} K_S$
- no K_L-Beam

The NA48 Detector:

- No driftchambers in 2000!
- Magnet Spectrometer:
  $\Delta p/p = 0.5\% \oplus 0.009\% \times p[\mathrm{GeV/c}]$
  Resolution $\sim 1\%$ for 20 GeV particles
- E.M. Calorimeter:
  $\Delta E/E = 3.2\%/\sqrt{E[\mathrm{GeV}]} \oplus 9\%/E[\mathrm{GeV}] \oplus 0.42\%$
  Resolution $\sim 1\%$ for 20 GeV em. showers



Method of the measurement:

$\mathbf{K_S \to \pi^0\pi^0\pi^0}$: $\qquad CP|\pi^0\pi^0\pi^0\rangle = -|\pi^0\pi^0\pi^0\rangle$

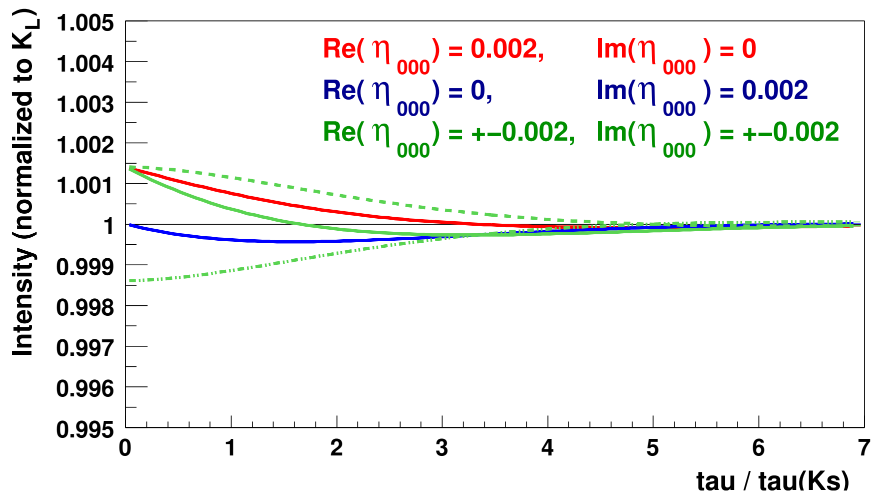
$\longrightarrow$ decay is CP-violating $(CP|K_S\rangle \approx CP|K_1\rangle = +|K_1\rangle)$

$$I_{3\pi^0} \propto \underbrace{e^{-\Gamma_L t}}_{K_L} + \underbrace{2D(p)\left(\mathrm{Re}(\eta_{000})\cos\Delta m t - \mathrm{Im}(\eta_{000})\sin\Delta m t\right) e^{-\frac{1}{2}(\Gamma_L+\Gamma_S)t}}_{K_L-K_S\ interference} + \underbrace{O(\eta_{000}{}^2)}_{K_S}$$

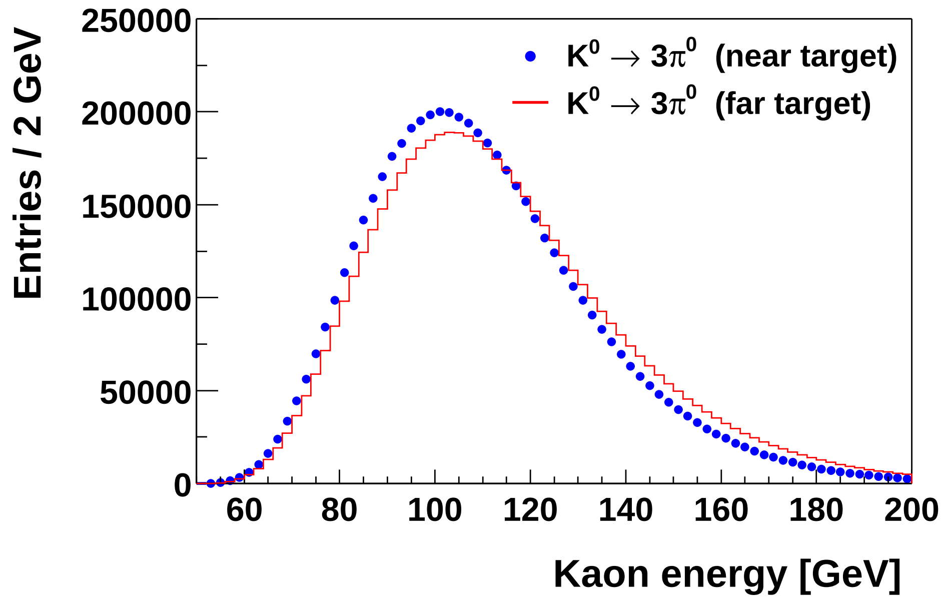
Use $K_L \to \pi^0\pi^0\pi^0$ from K_L-run and far/near target MC acceptance correction to measure the interference:

$$f_{3\pi^0}(t) = \frac{N^{\mathrm{near}}_{3\pi^0}(t)}{N^{\mathrm{far}}_{K_L\to3\pi^0}(t)}\,\frac{\epsilon^{\mathrm{far}}_{K_L\to3\pi^0}(t)}{\epsilon^{\mathrm{near}}_{K_L\to3\pi^0}(t)}$$

With dilution $D(p) = \frac{N(K^0)-N(\bar{K}^0)}{N(K^0)+N(\bar{K}^0)}$



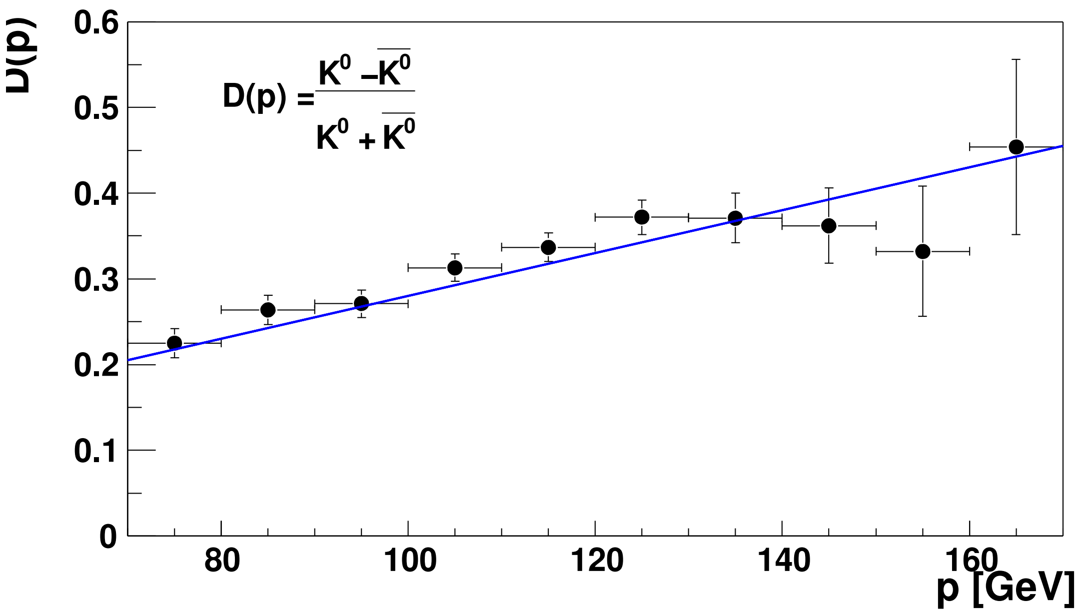
Data for $K_S \to 3\pi^0$



Selected Events:

near Target : $4.9 \times 10^6\ K_{L,S} \to 3\pi^0$

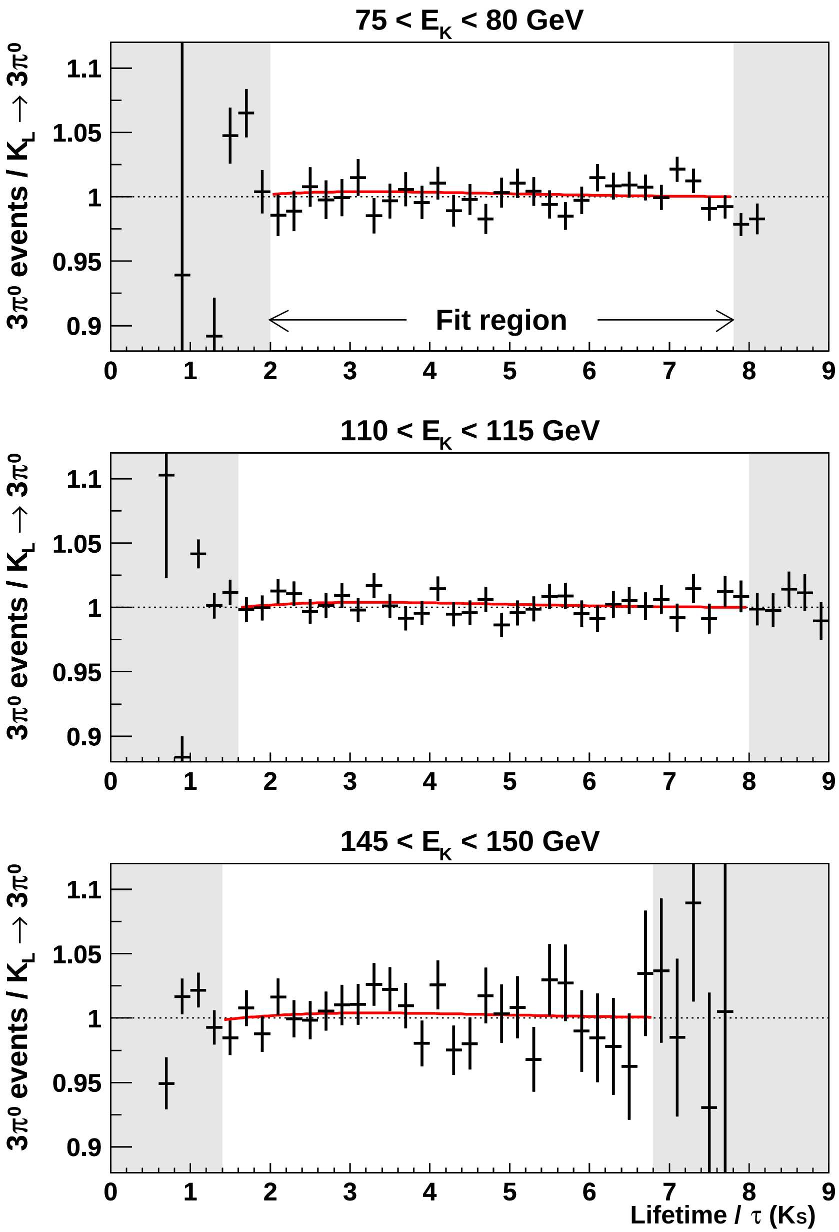
far Target : $109 \times 10^6\ K_L \to 3\pi^0$



Dilution:

Use linear fit to NA31 Data

Fit of $K_S \to 3\pi^0$



Fit simultanously 20 energy bins

free parameters:

$\mathrm{Re}\,\eta_{000}$, $\mathrm{Im}\,\eta_{000}$, normalisation

Fit Result:

$\mathrm{Re}\;\eta_{000} = -0.002 \pm 0.011$

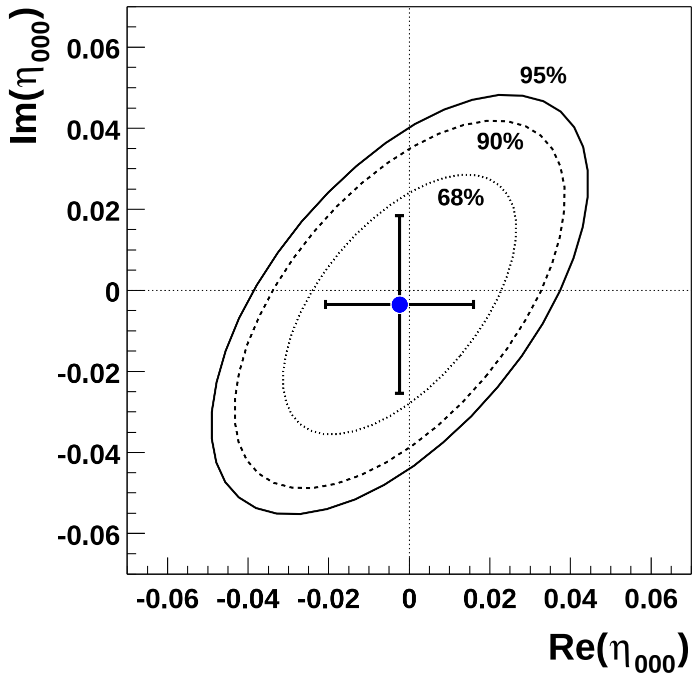
$\mathrm{Im}\;\eta_{000} = -0.003 \pm 0.013$

correlation $\rho = 0.77$

sys. uncertainties:

	$\mathrm{Re}\;\eta_{000}$	$\mathrm{Im}\;\eta_{000}$
rec. effic.	± 0.009	± 0.013
z resolution	± 0.010	± 0.000
beam geom.	± 0.005	± 0.007
background	± 0.002	± 0.009

Results for $K_S \to 3\pi^0$



Result:

$$\mathrm{Re}\ \eta_{000} = -0.002 \pm 0.011_{stat} \pm 0.015_{sys}$$

$$\mathrm{Im}\ \eta_{000} = -0.003 \pm 0.013_{stat} \pm 0.017_{sys}$$

Assuming $\mathrm{Re}\ \eta_{000} = \mathrm{Re}\ \eta_{00}$ (CPT):

$$\mathrm{Im}\eta_{000}|_{CPT} = -0.000 \pm 0.009_{stat} \pm 0.013_{sys}$$

Branching Ratio:

$$\mathrm{Br}(K_S \to 3\pi^0) = |\eta_{000}|^2 \frac{\tau_S}{\tau_L} \mathrm{Br}(K_L \to 3\pi^0) < 7.4 \times 10^{-7}$$ 90% CL

CPT-test: Bell-Steinberger relation

$$\mathrm{Im}\ \delta = (-0.2 \pm 2.0) \times 10^{-5}$$

$$\mathrm{Re}\ \epsilon = (166.4 \pm 1.0) \times 10^{-5}$$

Method of the measurement:

$\mathbf{K_S \to \pi^+\pi^-\pi^0}$**:** $\quad CP|\pi^+\pi^-\pi^0\rangle = (-1)^{l+1}|\pi^+\pi^-\pi^0\rangle$

(angular momentum $l \neq 0$ possible)

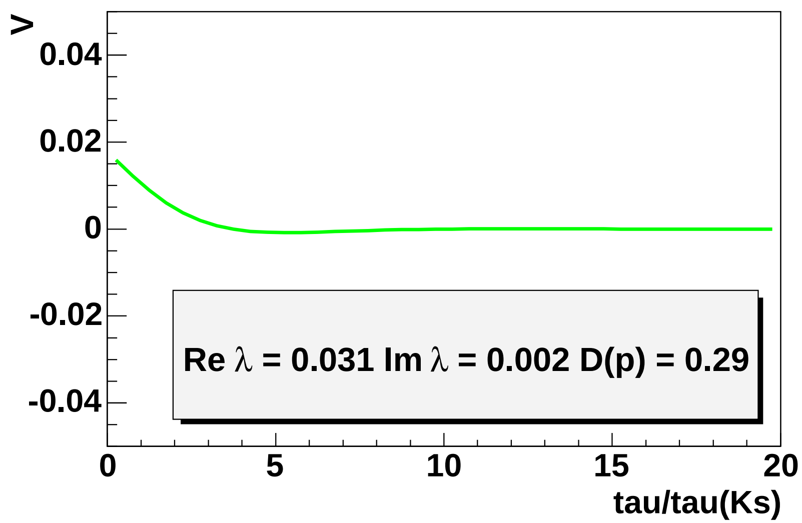
$\to$ CP-violating$(l = 0)$ and conserving$(l = 1)$ contributions!

$$I^{X \gtrless 0}_{\pi^+\pi^-\pi^0} \propto \overbrace{e^{-\Gamma_L t}}^{K_L} \qquad \text{with } X = \frac{S_{\pi^-} - S_{\pi^+}}{m^2_{\pi^\pm}}$$

$$+ \underbrace{D(p)\left(\mathrm{Re}(\eta_{+-0} \pm \lambda)\cos\Delta m t - \mathrm{Im}(\eta_{+-0} \pm \lambda)\sin\Delta m t\right) e^{-\frac{1}{2}(\Gamma_L+\Gamma_S)t}}_{K_L - K_S\ interference} + \underbrace{O(\eta_{+-0}{}^2, \lambda^2}_{K_S}$$

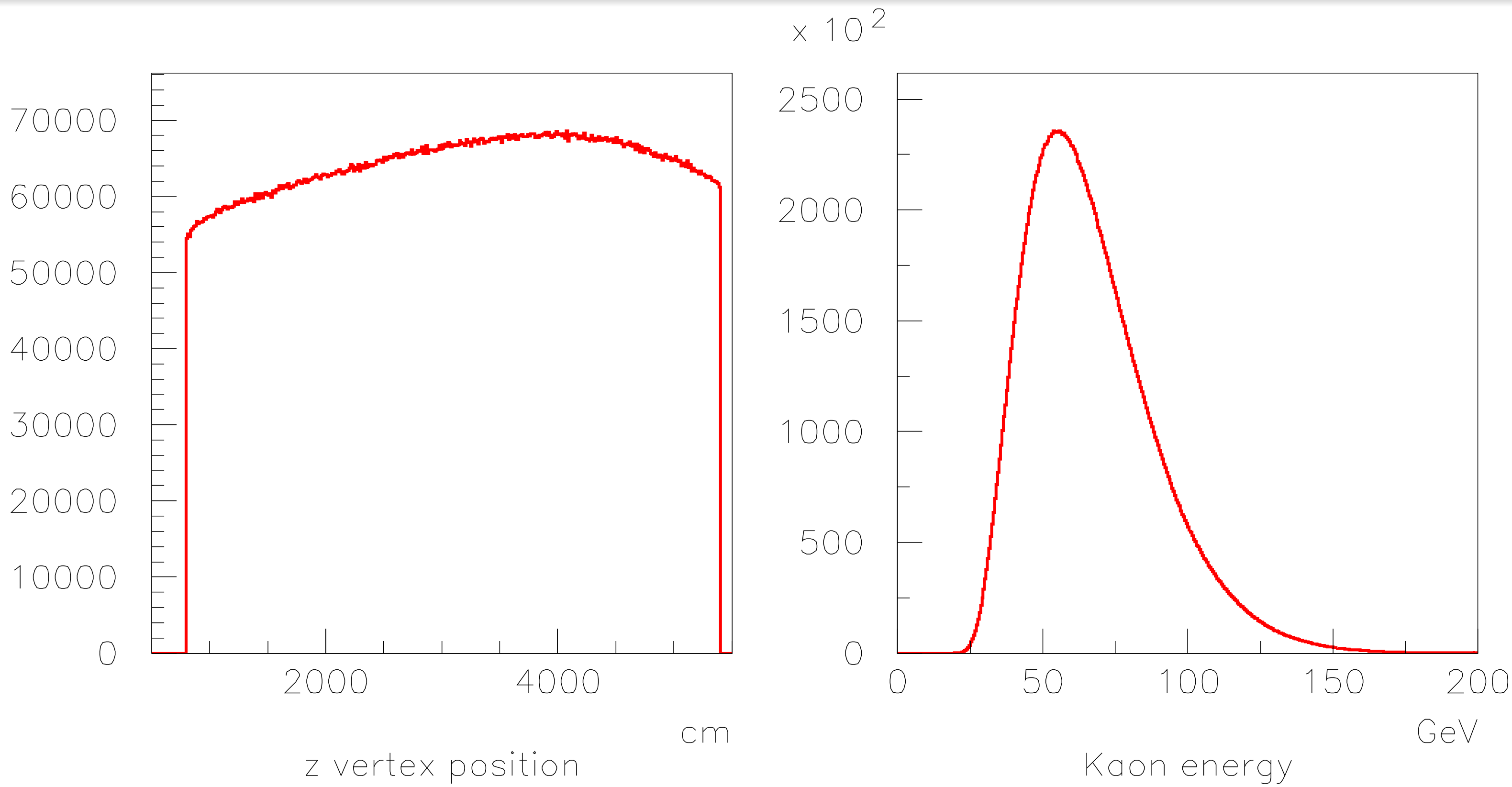
Split data into $X \gtrless 0$ to measure $l = 1$ contributions described by λ from the interference term:

$$V(t) = \frac{I^{X>0}_{\pi^+\pi^-\pi^0}(t) - I^{X<0}_{\pi^+\pi^-\pi^0}(t)}{I^{X>0}_{\pi^+\pi^-\pi^0}(t) + I^{X<0}_{\pi^+\pi^-\pi^0}(t)}$$



We're not sensitive to CPV!

$K_S \rightarrow \pi^+\pi^-\pi^0$ Data

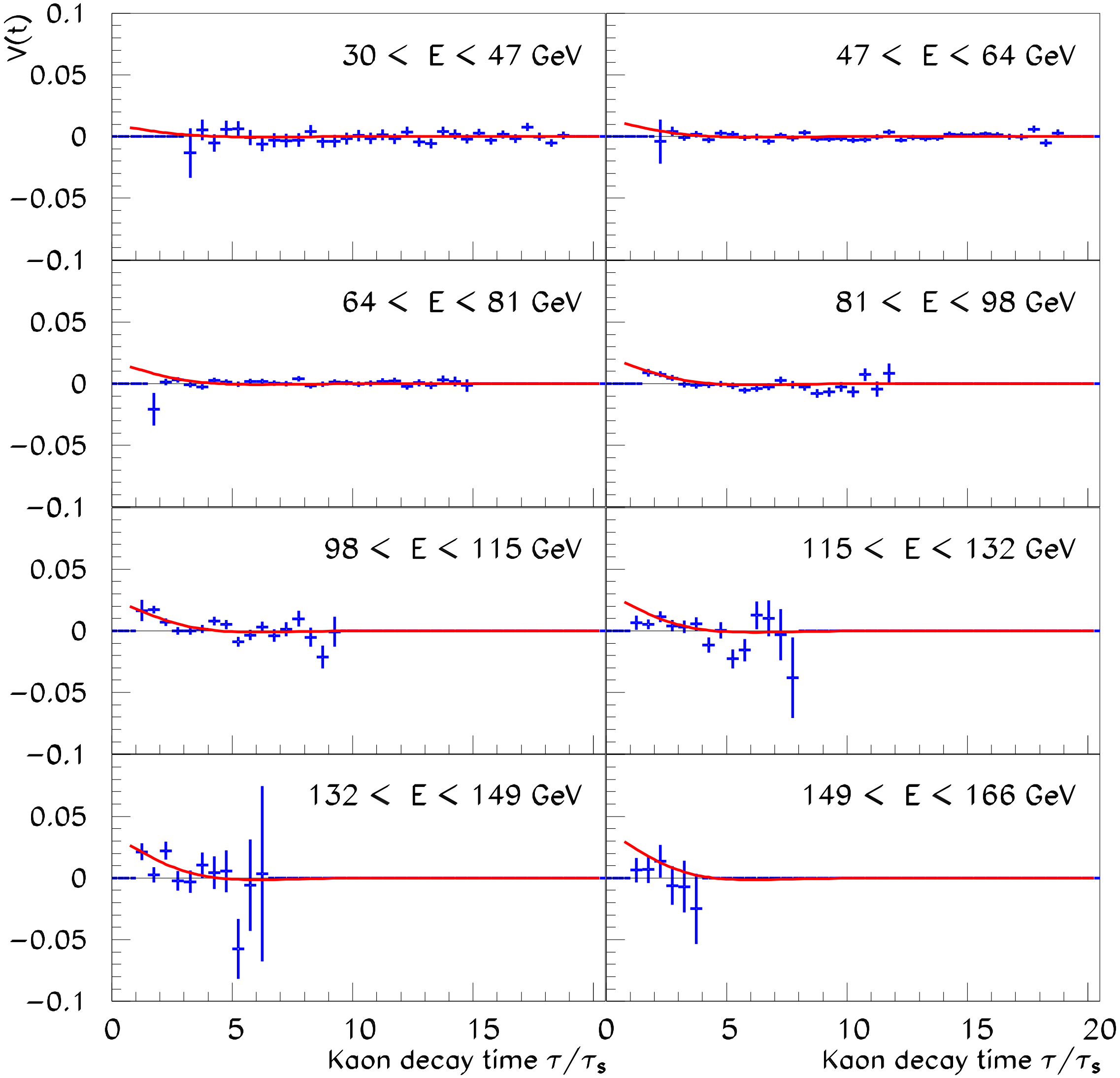


Selected Events: $19 \times 10^6\ K_{L,S} \rightarrow \pi^+\pi^-\pi^0$

- swapped magn. polarity every week
- used MC to correct for ineff. driftchambers

Fit of $K_S \to \pi^+\pi^-\pi^0$

Fit simultanously all energy bins:



free parameters:

$\mathrm{Re}\,\lambda$, $\mathrm{Im}\,\lambda$

Result:

$\mathrm{Re}\,\lambda = +0.038 \pm 0.008$

$\mathrm{Im}\,\lambda = -0.013 \pm 0.005$

correlation $\rho = 0.66$

sys. uncertainties:

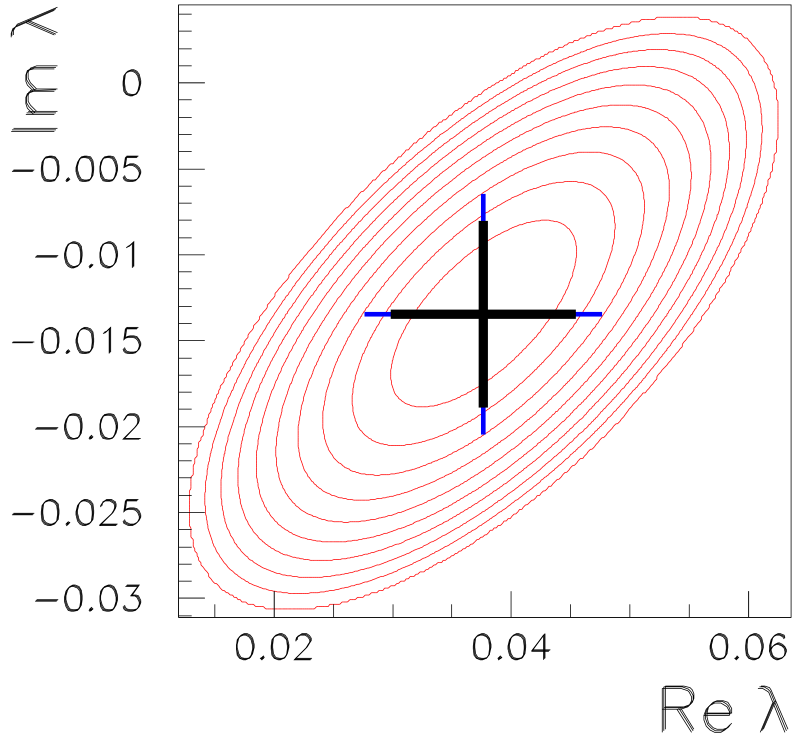
	$\mathrm{Re}\,\lambda$	$\mathrm{Im}\,\lambda$
magn. field	± 0.004	± 0.003
dilution	± 0.005	± 0.003

Results for $K_S \rightarrow \pi^+\pi^-\pi^0$

Result:

$\mathrm{Re}\,\lambda = +0.038 \pm 0.008_{stat} \pm 0.006_{sys}$

$\mathrm{Im}\,\lambda = -0.013 \pm 0.005_{stat} \pm 0.004_{sys}$



comparison with prev. Experiments:

- CPLEAR:
  $\mathrm{Re}\,\lambda = +0.028 \pm 0.007_{stat} \pm 0.003_{sys}$
  $\mathrm{Im}\,\lambda = -0.010 \pm 0.008_{stat} \pm 0.002_{sys}$
- E621:
  $\mathrm{Re}\,\lambda = +0.038 \pm 0.009_{stat}$
  $\mathrm{Im}\,\lambda = -0.006 \pm 0.011_{stat}$

CP-conserving Branching Ratio:

$$\mathrm{Br}(K_S \rightarrow \pi^+\pi^-\pi^0) = (4.7^{+2.2}_{-1.7}{}_{stat}{}^{+1.7}_{-1.5}{}_{sys}) \times 10^{-7}$$

Conclusions:

- The CP-violating parameter η_{000} has been measured:

$$\mathrm{Re}\,\eta_{000} = -0.002 \pm 0.011_{stat} \pm 0.015_{sys}$$
$$\mathrm{Im}\,\eta_{000} = -0.003 \pm 0.013_{stat} \pm 0.017_{sys}$$

- resulting in a limit on the branching ratio:

$$\mathrm{Br}(K_S \to 3\pi^0) < 7.4 \times 10^{-7} \text{ 90\% CL}$$

- For $K_S \to \pi^+\pi^-\pi^0$ the parameter λ describing the CP-conserving $(l = 1)$ has been measured:

$$\mathrm{Re}\,\lambda = +0.038 \pm 0.008_{stat \pm 0.006 sys}$$
$$\mathrm{Im}\,\lambda = -0.013 \pm 0.005_{stat \pm 0.004 sys}$$

- yielding a branching ratio:

$$\mathrm{Br}(K_S \to \pi^+\pi^-\pi^0) = (4.7^{+2.2}_{-1.7} stat^{+1.7}_{-1.5} sys) \times 10^{-7}$$