

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

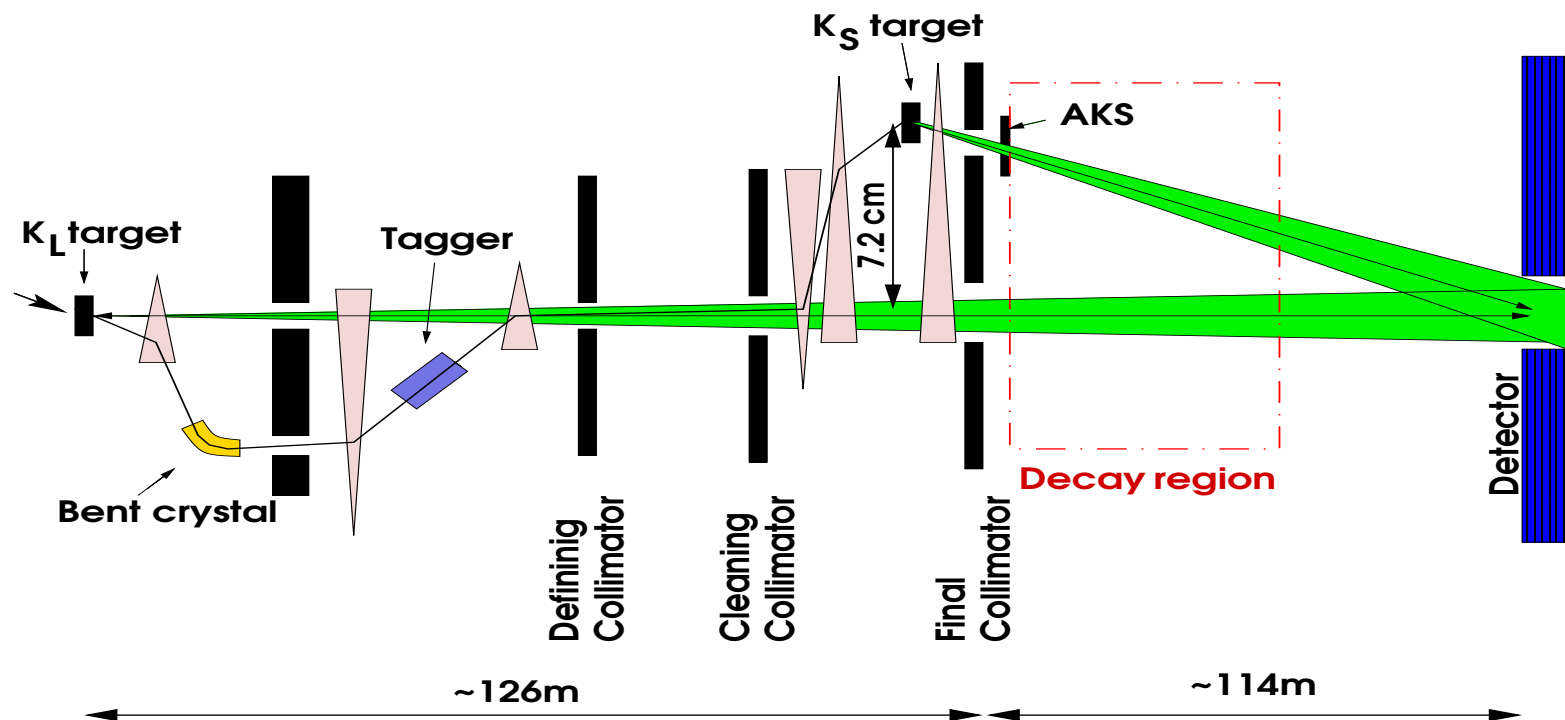
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On behalf of the NA48/1 Collaboration:

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:

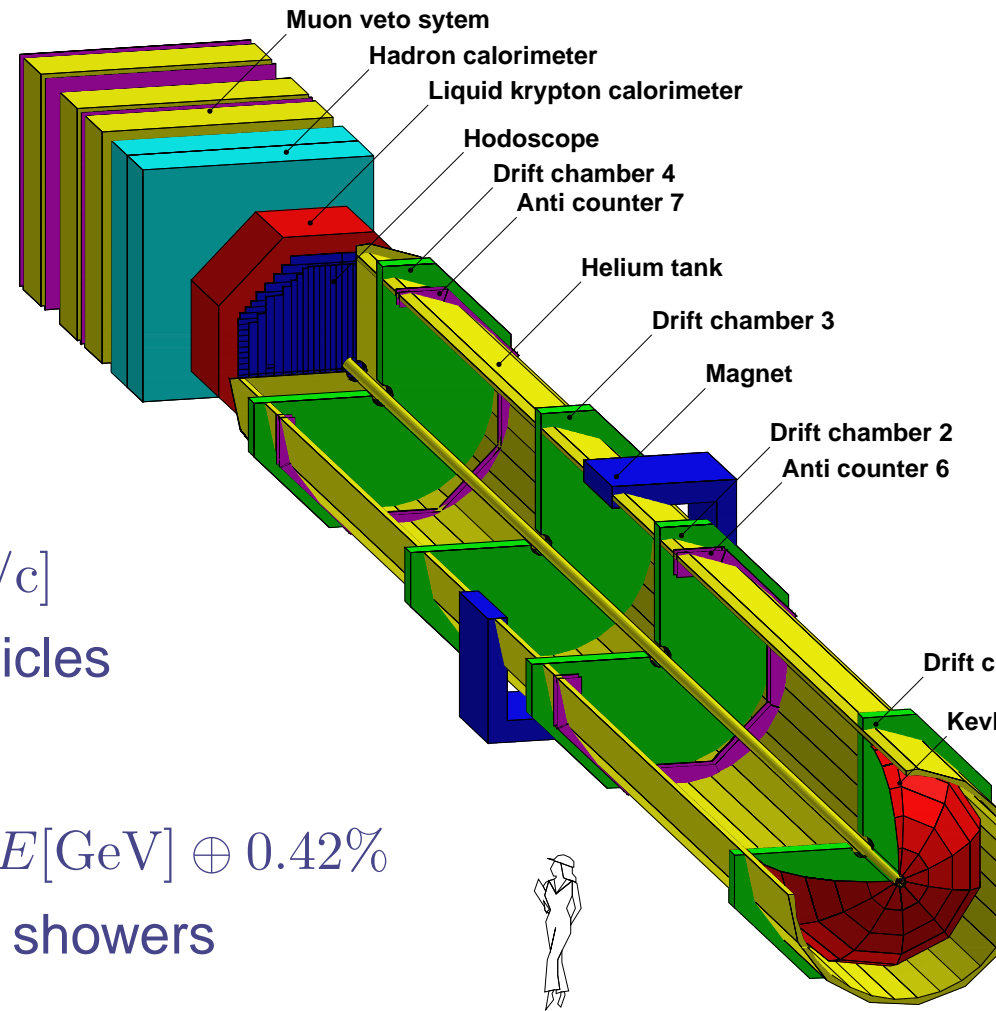
$$\Delta p/p = 0.5\% \oplus 0.009\% \times p[\text{GeV}/c]$$

Resolution $\sim 1\%$ for 20 GeV particles

- E.M. Calorimeter:

$$\Delta E/E = 3.2\%/\sqrt{E[\text{GeV}]} \oplus 9\%/E[\text{GeV}] \oplus 0.42\%$$

Resolution $\sim 1\%$ for 20 GeV em. showers



Method of the measurement:

$$\underline{K_S \rightarrow \pi^0 \pi^0 \pi^0} :$$

$$CP|\pi^0 \pi^0 \pi^0\rangle = -|\pi^0 \pi^0 \pi^0\rangle$$

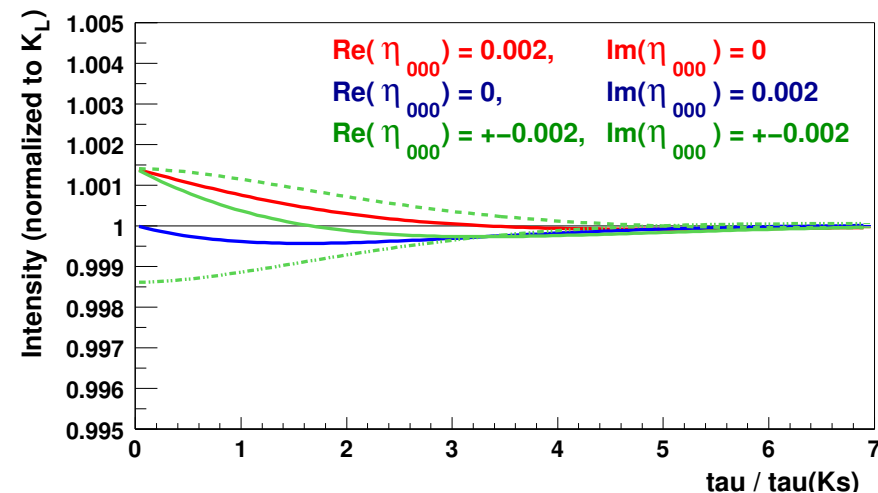
→ decay is **CP-violating** ($CP|K_S\rangle \approx CP|K_1\rangle = +|K_1\rangle$)

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

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

$$f_{3\pi^0}(t) = \frac{N_{3\pi^0}^{\text{near}}(t)}{N_{K_L \rightarrow 3\pi^0}^{\text{far}}(t)} \frac{\epsilon_{K_L \rightarrow 3\pi^0}^{\text{far}}(t)}{\epsilon_{K_L \rightarrow 3\pi^0}^{\text{near}}(t)}$$

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

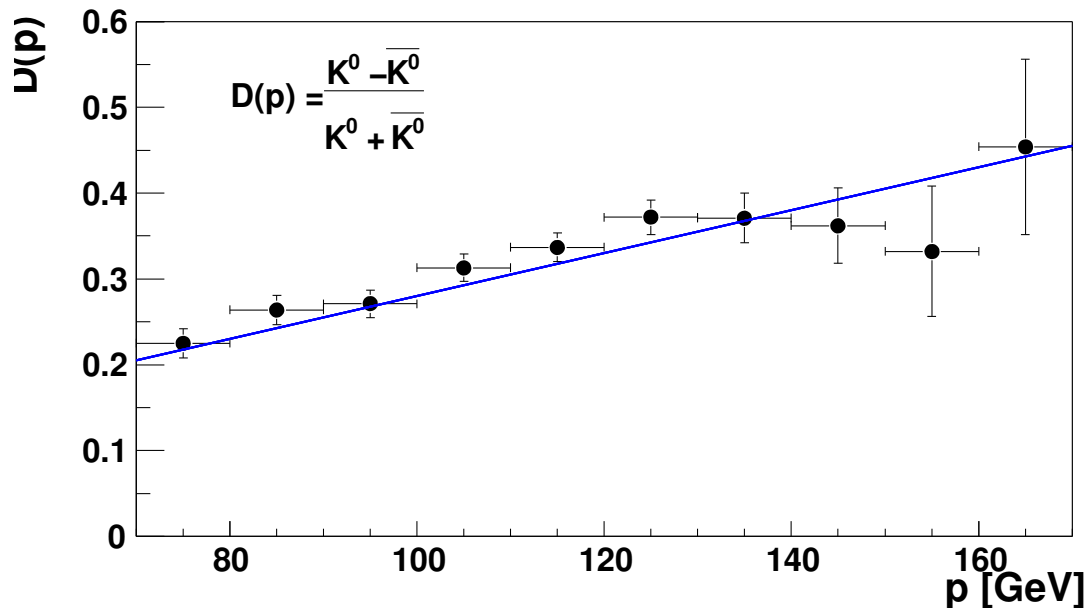
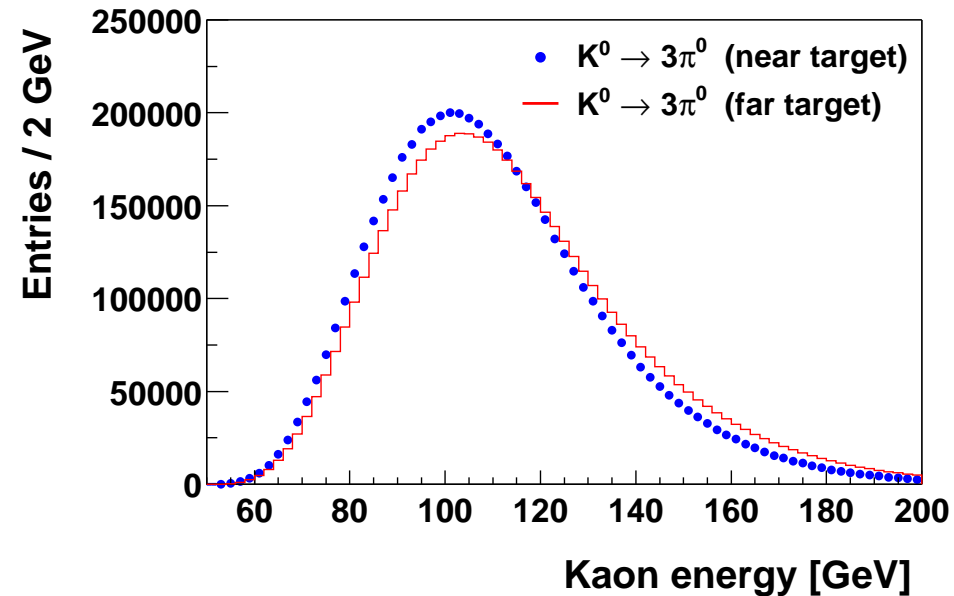


Data for $K_S \rightarrow 3\pi^0$

Selected Events:

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

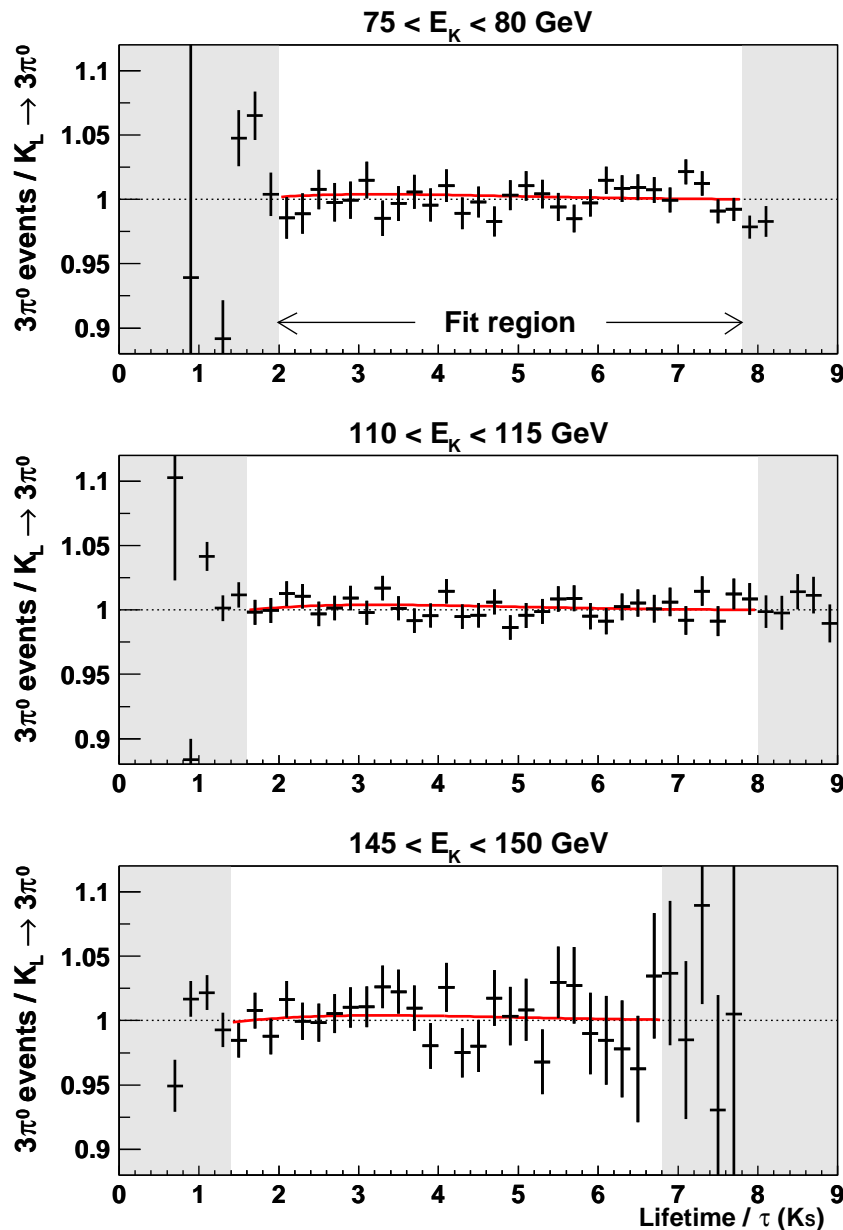
far Target : $109 \times 10^6 K_L \rightarrow 3\pi^0$



Dilution:

Use linear fit to NA31 Data

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



Fit simultaneously 20 energy bins

free parameters:

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

Fit Result:

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

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

correlation $\rho = 0.77$

sys. uncertainties:

	$\text{Re } \eta_{000}$	$\text{Im } \eta_{000}$
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 $K_S \rightarrow 3\pi^0$

Result:

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

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

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

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

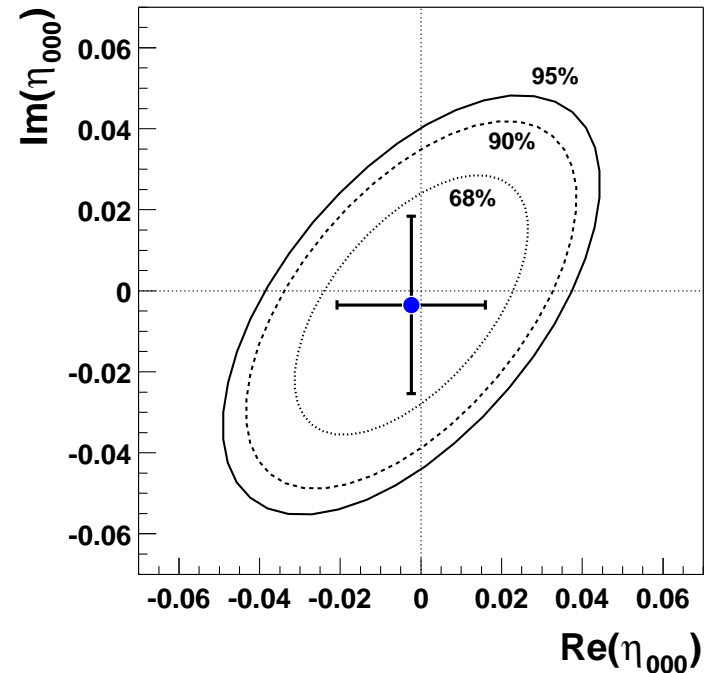
Branching Ratio:

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

CPT-test: Bell-Steinberger relation

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

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



Method of the measurement:

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

(angular momentum $l \neq 0$ possible)

→ **CP-violating** ($l = 0$) and **conserving** ($l = 1$) contributions!

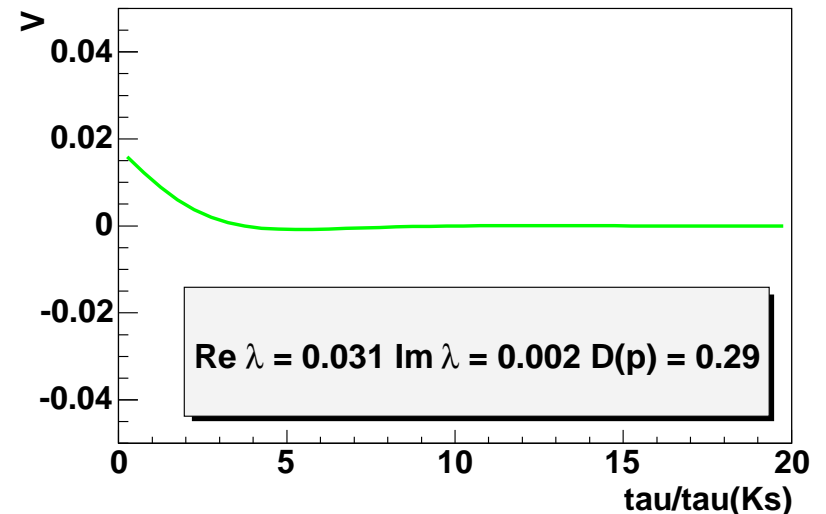
$$I_{\pi^+ \pi^- \pi^0}^{X \gtrless 0} \propto \overbrace{e^{-\Gamma_L t}}^{K_L} \quad \text{with } X = \frac{S_{\pi^-} - S_{\pi^+}}{m_{\pi^\pm}^2}$$

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

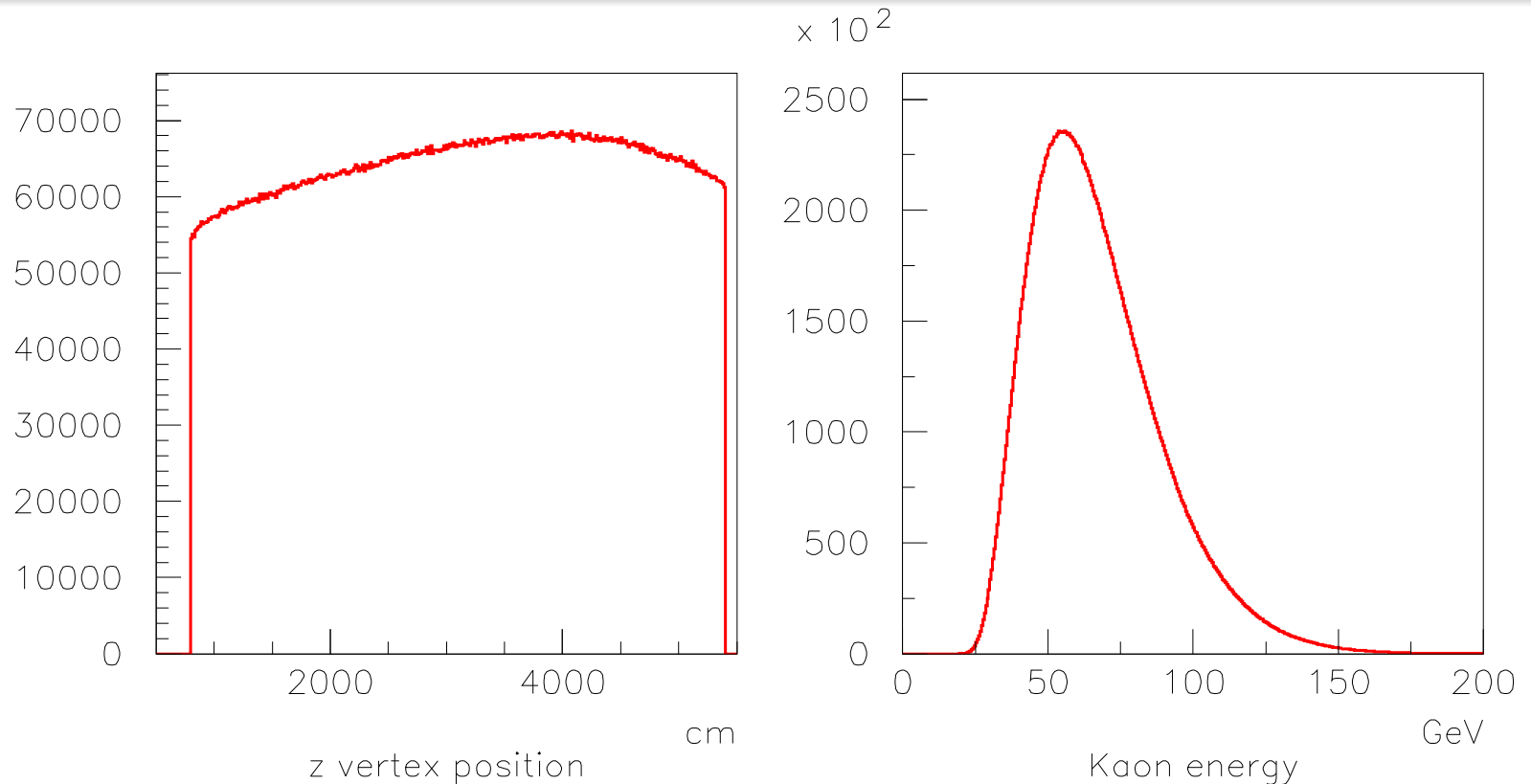
Split data into $X \gtrless 0$ to measure $l = 1$ contributions described by λ from the interference term:

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

We're **not** sensitive to **CPV**!



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

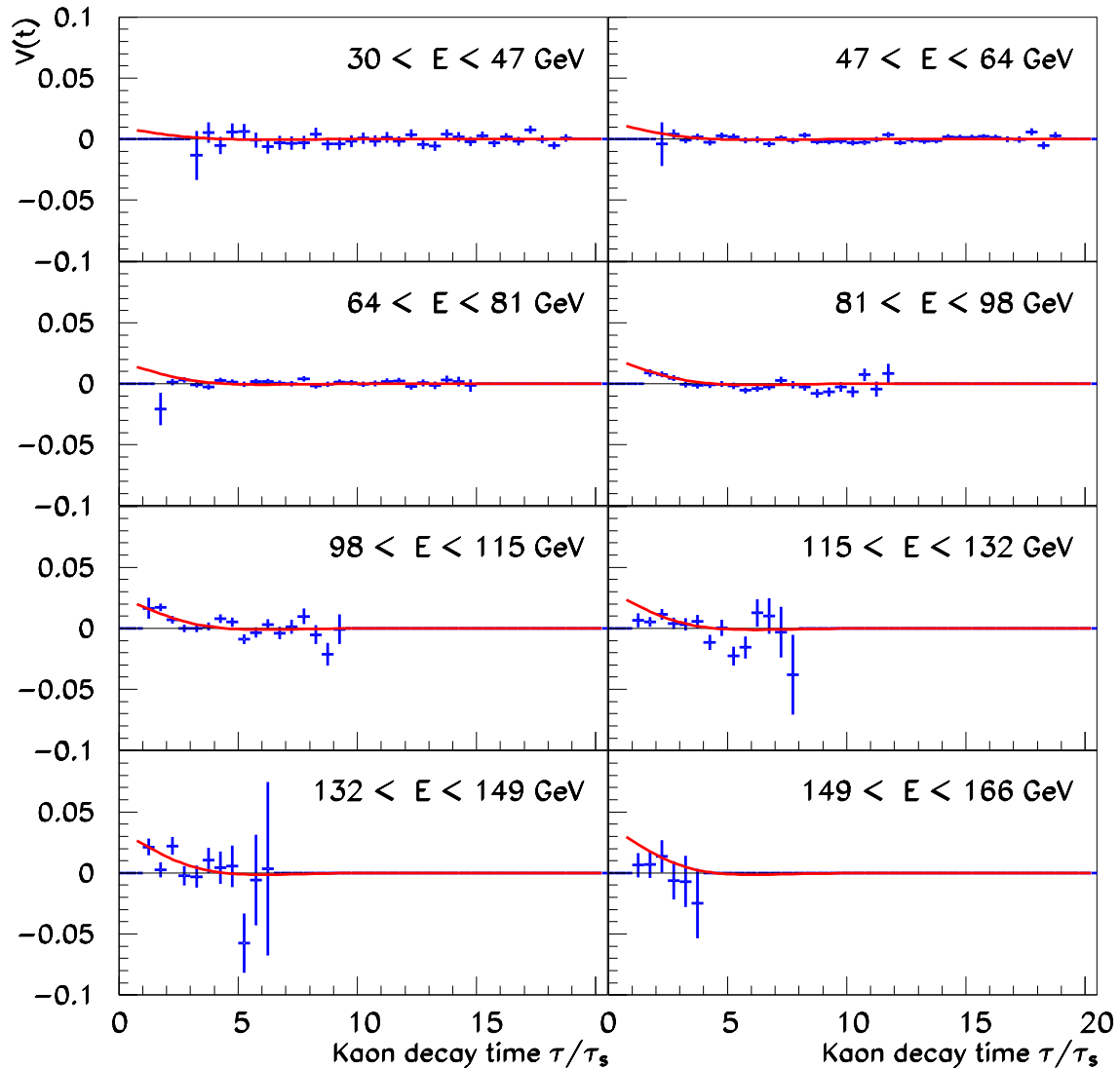


Selected Events: $19 \times 10^6 K_{L,S} \rightarrow \pi^+ \pi^- \pi^0$

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

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

Fit simultaneously all energy bins:



free parameters:

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

Result:

$\text{Re } \lambda = +0.038 \pm 0.008$

$\text{Im } \lambda = -0.013 \pm 0.005$

correlation $\rho = 0.66$

sys. uncertainties:

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

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

Result:

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

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

comparison with prev. Experiments:

● CPLEAR:

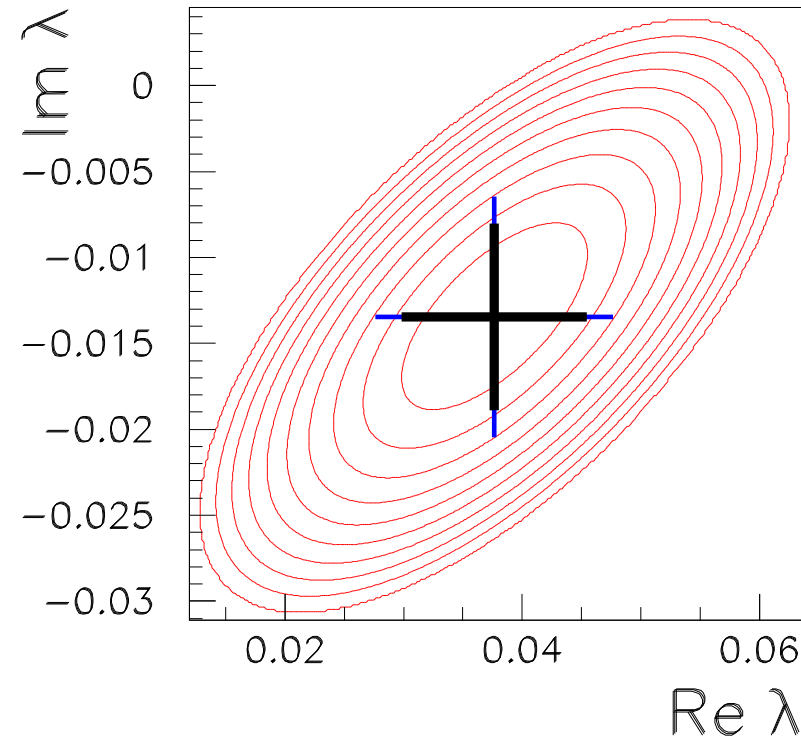
$$\text{Re } \lambda = +0.028 \pm 0.007_{stat} \pm 0.003_{sys}$$

$$\text{Im } \lambda = -0.010 \pm 0.008_{stat} \pm 0.002_{sys}$$

● E621:

$$\text{Re } \lambda = +0.038 \pm 0.009_{stat}$$

$$\text{Im } \lambda = -0.006 \pm 0.011_{stat}$$



CP-conserving Branching Ratio:

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

Conclusions:

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

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

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

- resulting in a limit on the branching ratio:

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

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

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

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

- yielding a branching ratio:

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