Search for CP-Violation in $K_S \rightarrow 3\pi^0$ decays

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On behalf of the NA48 Collaboration

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Motivation

- As you all know, CP-Violation in $K_L \rightarrow \pi\pi$ is firmly established $(\eta_{+-}, \eta_{00}, \varepsilon')$
- CP-Violation in $K_S \rightarrow 3\pi$ decays is equally allowed in the SM but has been investigated in much less detail owing to the difficulty of the measurement
- $CP(\pi^+\pi^-\pi^0)$ =-1 (L=0) +1 (L=1) $CP(3\pi^0)=-1$
- The equivalent of η_{00} for $3\pi^0$ decays is:
  $\eta_{000} = A(K_S \rightarrow 3\pi^0)/A(K_L \rightarrow 3\pi^0)$
- Limits on η_{000} are still very poor
- In SM: $\eta_{000} = \varepsilon + i \, \mathrm{Im}\, a_1 / \mathrm{Re}\, a_1 \sim \varepsilon$

CP violation in $\pi^+\pi^-\pi^0$ and $3\pi^0$ decays

	Exp	Year	Technique	Result
η_{+-0}	FNAL-E621	1994	K_0-K_0bar incoherent	Im η_{+-0}=-1.5 ± 1.7 ± 2.5 ×10^{-2}
	CERN-CPLEAR	1998	ppbar→K^+K_0barπ^- $K^-K_0\pi^+$	Re η_{+-0}=-2 ± 7 $^{+4}_{-1}$ × 10^{-3} Im η_{+-0}=-2 ± 9 $^{+2}_{-1}$ × 10^{-3}
η_{000}	Barmin et al.	1983	Bubble ch.	Re η_{000}=-8 ± 18 × 10^{-2} Im η_{000}=-5 ± 27 × 10^{-2}
	CPLEAR	1998	ppbar→K^+K_0barπ^- $K^-K_0\pi^+$	Re η_{000}=18 ± 14± 6 × 10^{-2} Im η_{000}=15 ± 20 ± 3 × 10^{-2}
	Novosibirsk SND	1999	Tagged K_s ee→ϕ→K_SK_L	BR(K_S→$3\pi^0$)<1.4 10^{-5} 90%CL

New Opportunity

- During Y2K NA48 did not have drift chambers because they were damaged by the beam pipe implosion...
- ...so we used excellent energy resolution of NA48 Lkr calorimeter and the NA48 beam line to improve $K_S \to 3\pi^0$
- Method:
  - The K^0-K^0bar incoherent mixture produced by 400 GeV protons on 40 cm long Be target
  - Look for K_S-K_L interference studying the intensity of $K \to 3\pi^0$ decays as a function of proper time
  - Measure the detector acceptance using $3\pi^0$ decays from a K_L beam (taken a month before)
  - Apply MC corrections to take into account the slight geometrical difference of the two beams

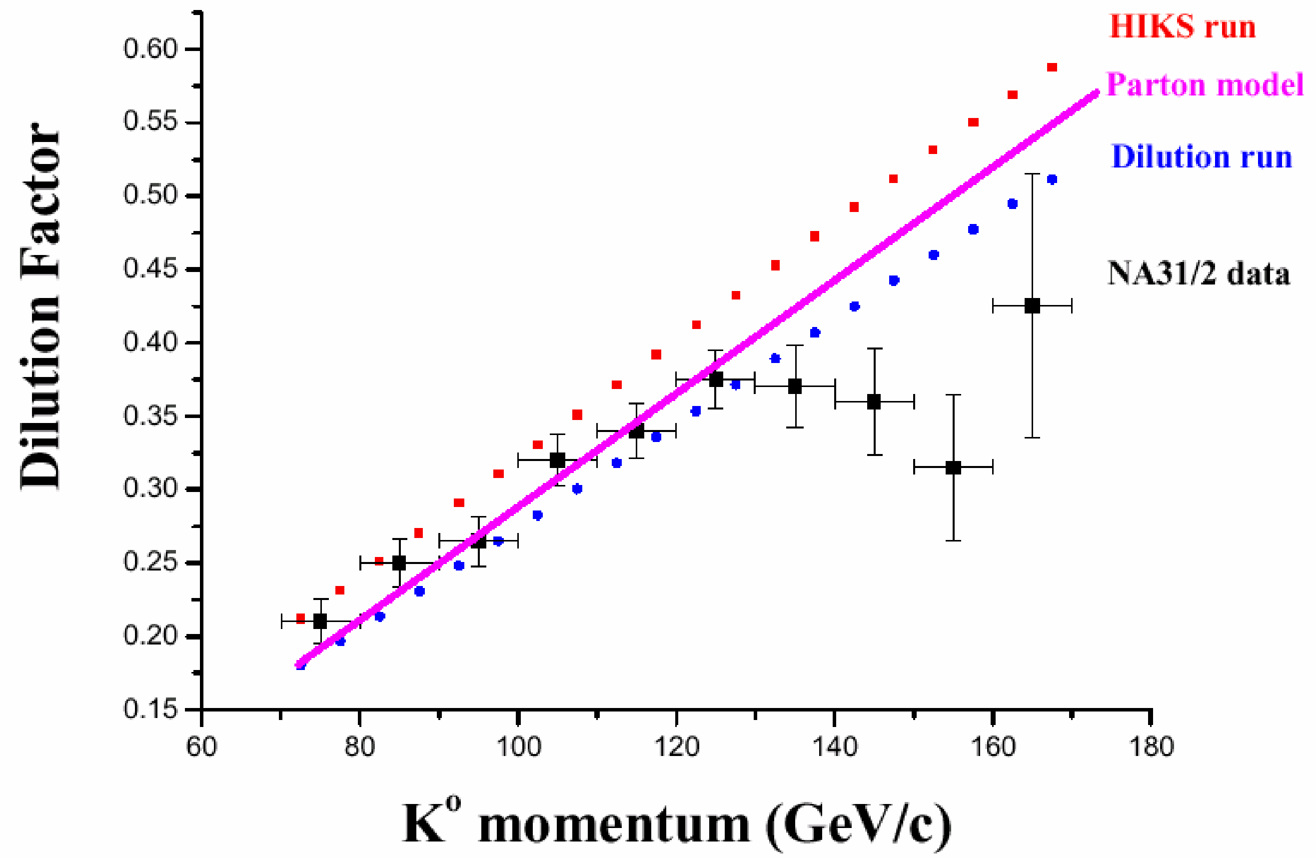
Fitted function

$$f(E,t) = \frac{NEAR}{FAR}$$

$$A(E)\left[1 + |\eta_{000}|^2 e^{(\Gamma_L - \Gamma_S)t} + 2D(E)e^{\frac{1}{2}(\Gamma_L - \Gamma_S)t}\left(\mathrm{Re}\,\eta_{000}\cos\Delta m t - \mathrm{Im}\,\eta_{000}\sin\Delta m t\right)\right]$$

$$D(E) = \frac{N_{K^0} - N_{\overline{K}^0}}{N_{K^0} + N_{\overline{K}^0}}$$

K^0-K^0bar Dilution



Data Taking

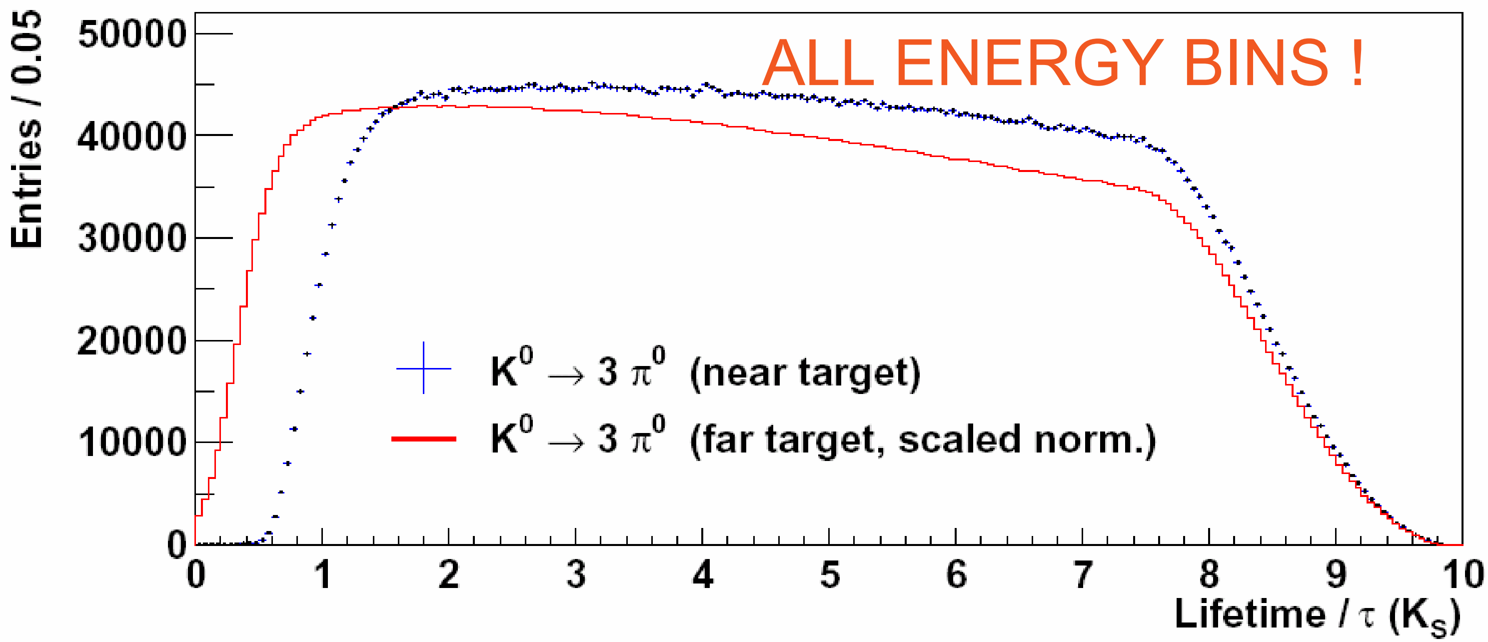
- We took data with the NEAR and far FAR beam configuration at different times
- Same trigger and detector
- We kept similar accidental activity adjusting the beam intensity
- P_t (Energy centre of gravity) distribution of the two beams is different (unavoidable).

Data Taking Conditions

	P Energy (GeV)	Prod angle (mrad)	Beam length (m)	Dipole	Dates (Y2K)
FAR	450	2.4	120	ON	~15/6 ~15/7
NEAR	400	3.0	6	OFF	~20/7 ~28/8

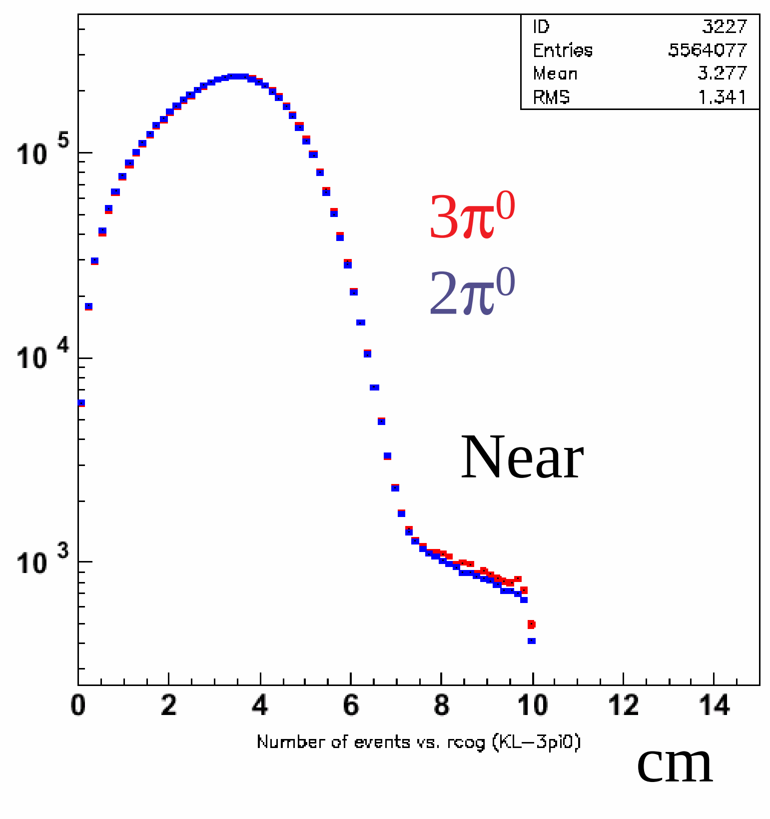
Data as a function of proper time

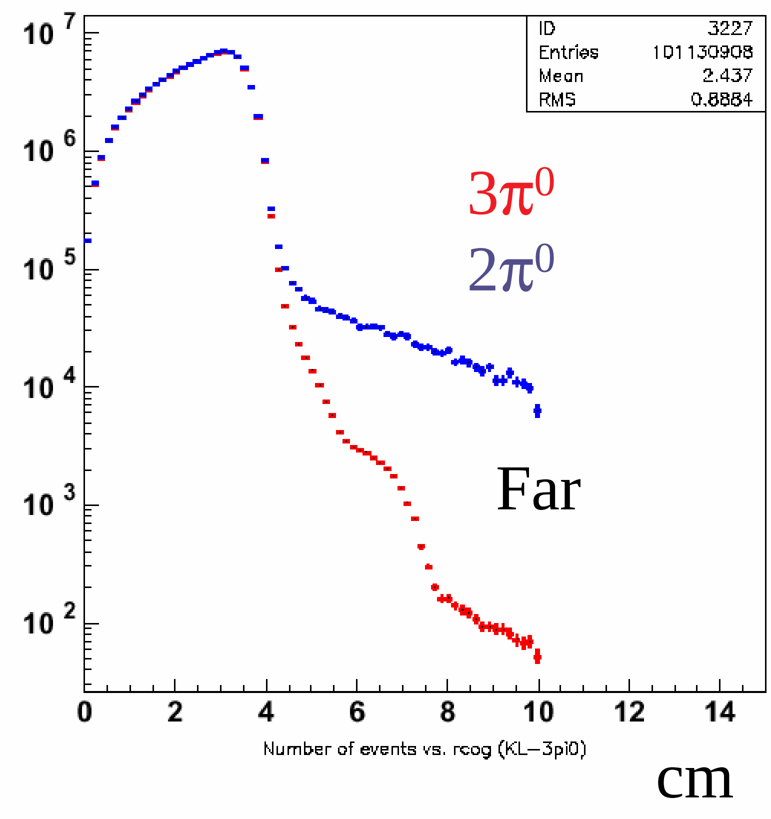
- Trigger efficiency: 99.7%
- Statistics from NEAR target:~5.6 10^6 $K \to 3\pi^0$
- Statistics from FAR target:~10^7 $K_L \to 3\pi^0$



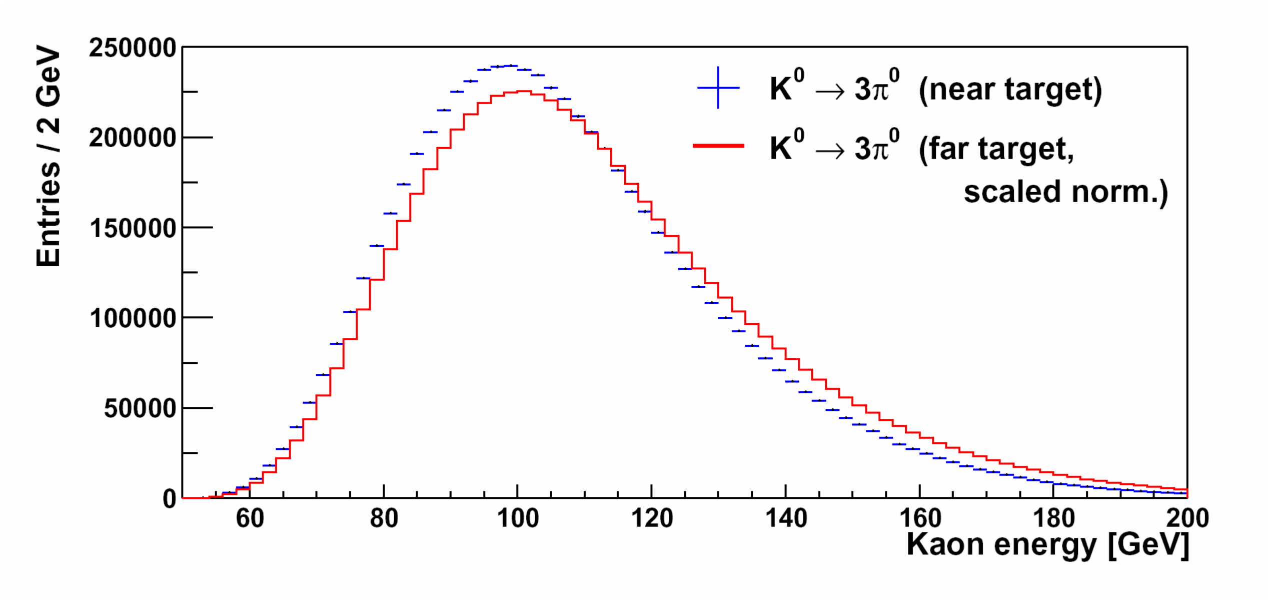
Energy Centre of Gravity

Normalised to $3\pi^0$ statistics





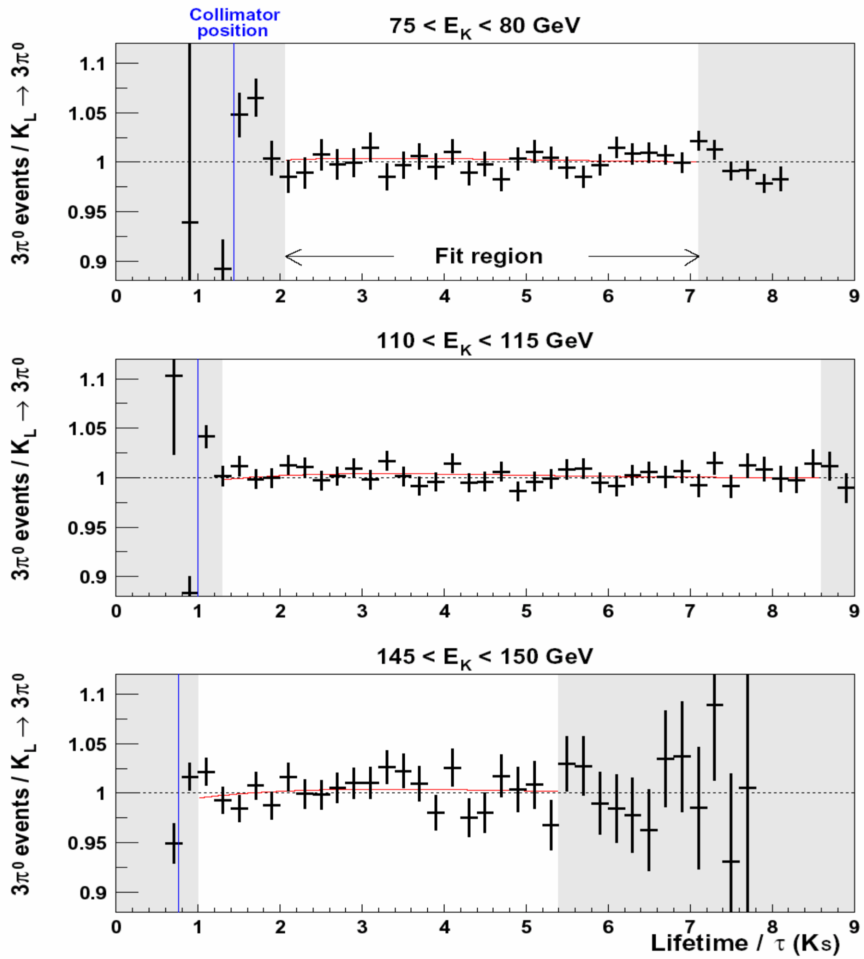
Kaon Energy distribution



- To take into account the slightly different kaon spectra, the analysis is done in bins of energy

NEAR/FAR data (MC corrected)

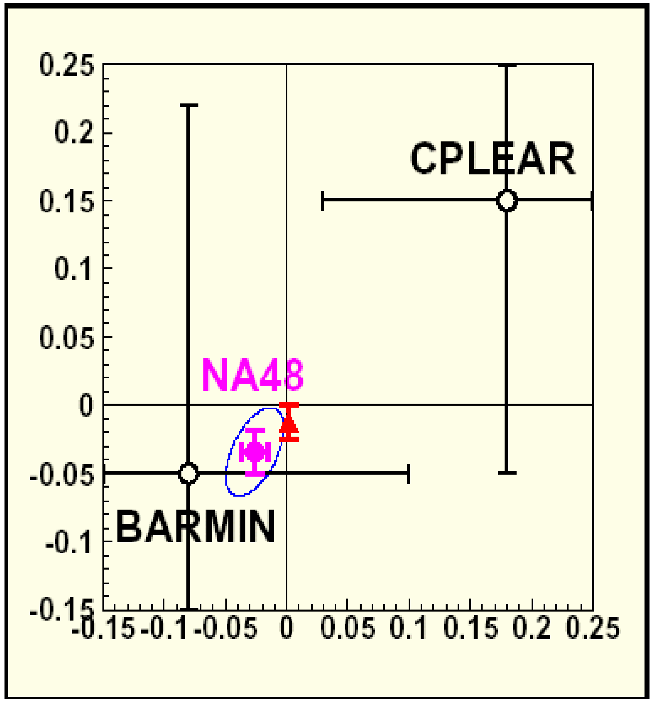
- The distribution as a function of proper time is shown for three different energy bins.
- For each energy bin, the NEAR/FAR event distribution is corrected for the FAR/NEAR Monte Carlo

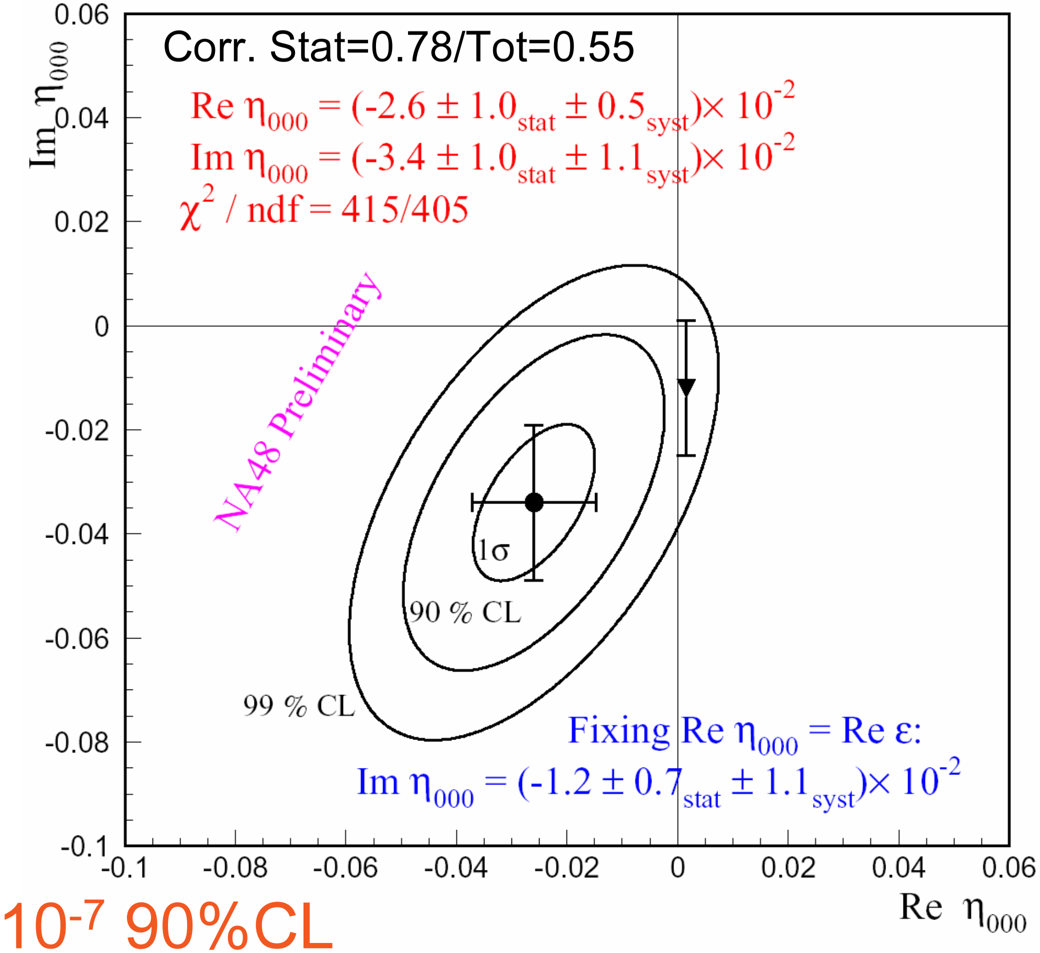


Systematics

	Re η_{000} (10^{-2})	Im η_{000} (10^{-2})
Accidentals	±0.1	±0.6
Energy Scale	±0.1	±0.1
K^0-K^0bar Dilution	±0.3	±0.4
Acceptance	±0.3	±0.8
Binning	±0.1	±0.2
Total	±0.5	±1.1

Result of the fit





$BR(K_S \to 3\pi^0) < 3.0\ 10^{-7}$ 90%CL

Discussion

- The result is not only interesting as a test of CP conservation
- It also provides input to the Bell-Steinberger unitarity relation, improving by about 40% the error on the CPT-Violation parameter Im δ

$$K_L \sim K_2 + (\varepsilon_k + \delta_k) K_1$$

$$K_S \sim K_1 + (\varepsilon_k - \delta_k) K_2$$

ε_k is CP-Violating and CPT-Conserving

δ_k is CP- and CPT-Violating

Bell-Steinberger relation

$$\left[-i(m_S - m_L) + \frac{1}{2}(\Gamma_S + \Gamma_L)\right] < L | S > = \sum_f A(K_S \to f)^* A(K_L \to f)$$

$$\mathrm{Re}\,\varepsilon_k - i\,\mathrm{Im}\,\delta_k = \frac{1}{2\left(i\Delta m + \frac{1}{2}(\Gamma_S + \Gamma_L)\right)} \sum_f A(K_S \to f)^* A(K_L \to f)$$

Error dominated by the poor knowledge of $A(K_s \to 3\pi^0)$

Conclusion

- Im $\delta = (-1.2 \pm 3.0)\ 10^{-5}$
- Previously: Im $\delta = (2.4 \pm 5.0)\ 10^{-5}$

- If CPT is conserved in the semi-leptonic K^0 decays the phase of δ is fixed and:

$$M_{K^0} - M_{\overline{K}^0} = (-1.7 \pm 4.2) \times 10^{-19}\, GeV$$