FITS FOR K_L^0 CP-VIOLATION PARAMETERS

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In recent years, K_L^0 CP-violation experiments have improved the precision of our knowledge of the values of CP-violation parameters and the consistency of these best values with the expectations of CPT invaraiance and unitarity [Sec. 12, CP violation]. This note describes our two fits for K_L^0 CP-violation parameters, one for the phases ϕ_{+-} and ϕ_{00}, and another for the amplitudes $|\eta_{+-}|$ and $|\eta_{00}|$. The data and resulting best values from the fit are unchanged from our 1996 version. For definitions of K_L^0 CP-violation parameters and a brief discussion of the theory, see the article "CP Violation" by L. Wolfenstein in Section 12 of this *Review*.

Fit to ϕ_{+-}, ϕ_{00} ϕ_{00}–ϕ_{+-}, Δm, and τ_s data: We perform a joint fit to the data on ϕ_{+-}, ϕ_{00}, $\phi_{00} - \phi_{+-}$, Δm, and τ_s, including the effects of correlations. Measurements of ϕ_{+-} and ϕ_{00} are highly correlated with Δm and τ_s. The correlations are given in the footnotes of the ϕ_{+-} and ϕ_{00} data listings. In editions of the Review prior to 1996, we adjusted the experimental values of ϕ_{+-} and ϕ_{00} to account for correlations with Δm and τ_s but did not include the effects of these correlations when evaluating Δm and τ_s. When a joint fit is done, the ϕ_{+-} measurements and their correlations have a strong influence on the fitted value of Δm. This is because the CERN NA31 vacuum regeneration experiments (CAROSI 90 [1] and GEWENIGER 74B [2]), the Fermilab E773/E731 regenerator experiments (SCHWINGENHEUER 95 [3] and GIBBONS 93 [4]), and the CPLEAR $K^0 - \overline{K}^0$ asymmetry experiment (ADLER 95B [5]) have very different dependences of ϕ_{+-} on Δm, as can be seen in Fig. 1. The correlations move the fitted Δm lower so that the ϕ_{+-} measurements are in good agreement with each other and with ϕ(superweak).

The (ϕ_{+-}, τ_s) correlations influence the τ_s fit result in a similar manner, as can be seen in Fig. 2. The influence of the ϕ_{+-} experiments is not as great on τ_s as it is on Δm because the indirect measurements of τ_s derived from the diagonal

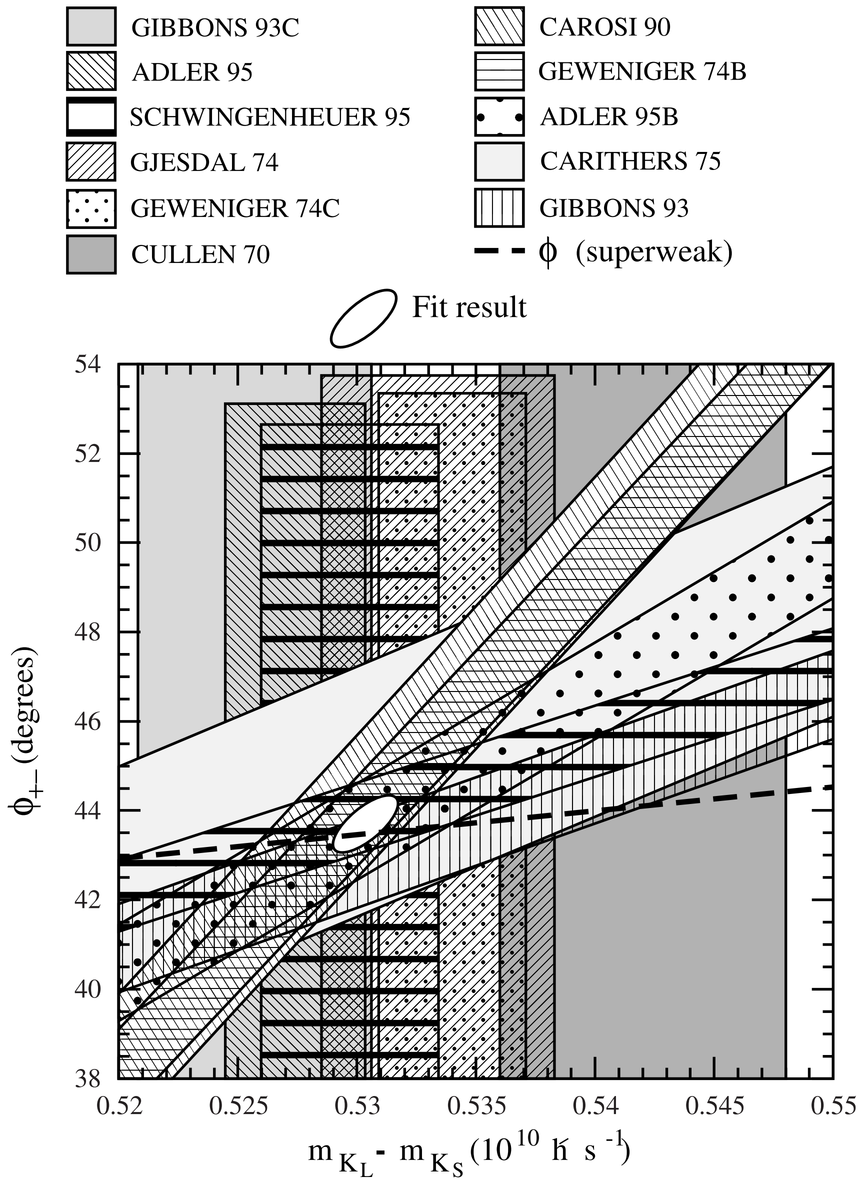

Figure 1: ϕ_{+-} vs Δm. Δm measurements appear as vertical bands spanning $\Delta m \pm 1\sigma$, some of which are cut near the top to aid the eye. The ϕ_{+-} measurements appear as diagonal bands spanning $\phi_{+-} \pm \sigma_\phi$. The dashed line shows ϕ(superweak). The ellipse shows the 1σ contour of the fit result. See Table 1 for data references.

crossing bands in Fig. 2 are not as precise as the direct measurements of τ_s from E773/E731 (SCHWINGENHEUER 95 [3] and GIBBONS 93 [4]).

Table 1: References for Fig. 1 and Fig. 2

Meas. / Fig. No.				
ϕ_{+-}	Δm	τ_s	PDG Document ID	Ref.
1,2			CAROSI 90	[1]
1		2	GEWENIGER 74B	[2]
1,2			ADLER 95B	[5]
1		2	CARITHERS 75	[6]
1,2	1	2	SCHWINGENHEUER 95	[3]
1,2		2	GIBBONS 93	[4]
	1		GIBBONS 93C	[7]
	1		ADLER 95	[8]
	1		GJESDAL 74	[9]
	1		GEWENIGER 74C	[10]
	1		CULLEN 70	[11]
		2	ARONSON 76	[12]
		2	GROSSMAN 87	[13]
		2	SKJEGGESTAD 72	[14]

In Fig. 1 [Fig. 2] the slope of the diagonal ϕ_{+-} bands shows the Δm [τ_s] dependence; the unseen τ_s [Δm] dependent term is evaluated using the fitted τ_s [Δm]. The vertical half-width σ_ϕ of each band is the ϕ_{+-} error for fixed Δm [τ_s] and includes the systematic error due to the error in the fitted τ_s [Δm].

Table 2 gives the resulting fit values for the parameters and Table 3 gives the correlation matrix.

Table 2: Results of the fit for ϕ_{+-}, ϕ_{00}, $\phi_{00} - \phi_{+-}$, Δm, and τ_s. The fit has $\chi^2 = 12.0$ for 18 degrees of freedom (22 measurements -5 parameters $+1$ constraint).

Quantity	Fit Result
ϕ_{+-}	$43.7 \pm 0.6°$
Δm	$(0.5304 \pm 0.0014) \times 10^{10} \hbar\ \mathrm{s}^{-1}$
τ_s	$(0.8927 \pm 0.0009) \times 10^{-10}\mathrm{s}$
ϕ_{00}	$43.5 \pm 1.0°$
$\Delta\phi$	$-0.2 \pm 0.8°$

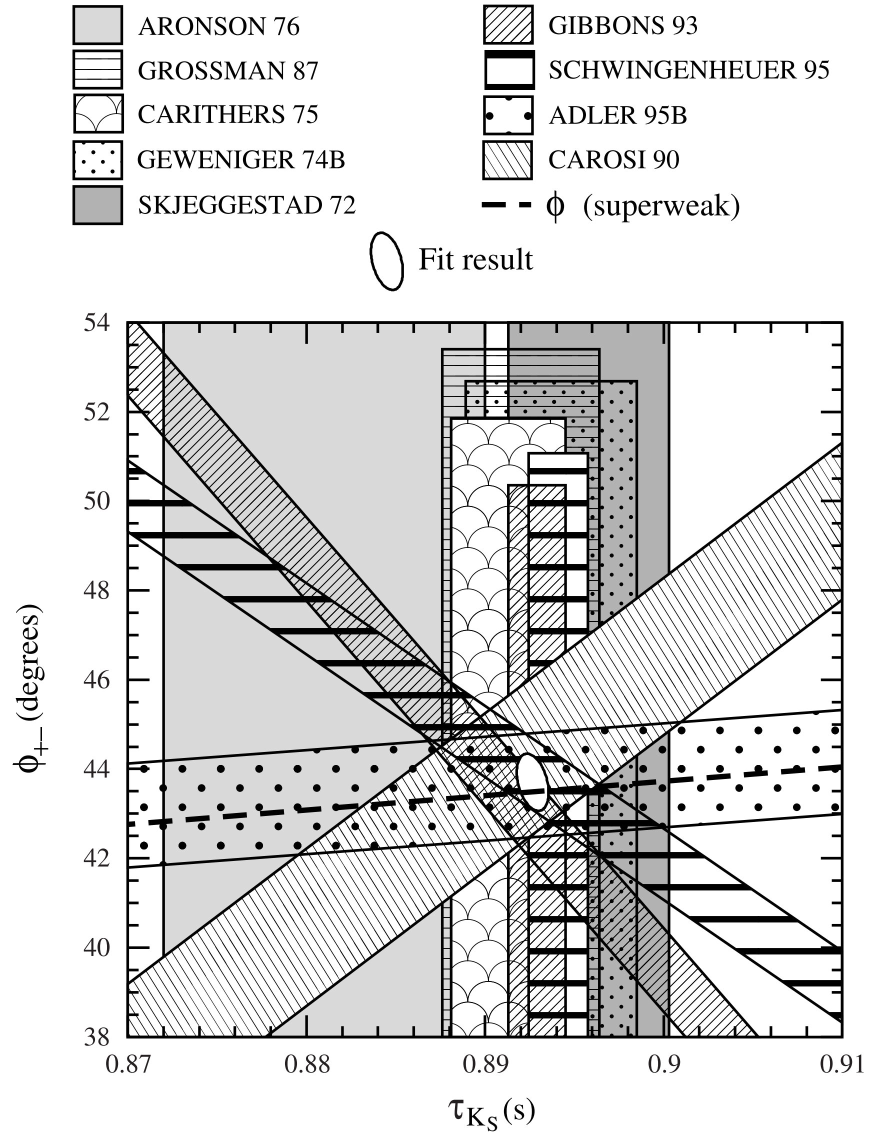

Figure 2: ϕ_{+-} vs τ_s. τ_s measurements appear as vertical bands spanning $\tau_s \pm 1\sigma$, some of which are cut near the top to aid the eye. The ϕ_{+-} measurements appear as diagonal bands spanning $\phi_{+-} \pm \sigma_\phi$. The dashed line shows ϕ(superweak). The ellipse shows the fit result's 1σ contour. See Table 1 for data references.

The χ^2 is 12 for 18 degrees of freedom, indicating good agreement of the input data. Nevertheless, there has been criticism that Fermilab E773 (SCHWINGENHEUER 95 [3]) and E731 (GIBBONS 93 [4]) measure $\phi_{+-} - \phi_f$ and calculate the regeneration phase ϕ_f from the power law momentum

Table 3: Correlation matrix for the fitted parameters.

	ϕ_{+-}	Δm	τ_s	ϕ_{00}	$\Delta\phi$
ϕ_{+-}	1.00	0.71	−0.36	0.60	−0.02
Δm	0.71	1.00	−0.21	0.48	0.04
τ_s	−0.36	−0.21	1.00	−0.19	0.04
ϕ_{00}	0.60	0.48	−0.19	1.00	0.79
$\Delta\phi$	−0.02	0.04	0.04	0.79	1.00

dependence of the regeneration amplitude using analyticity and dispersion relations. In the E731 result, a systematic error of ± 0.5 degrees for departures from a pure power-law is included. For the E773 result, they modeled a variety of effects that do distort the amplitude from a pure power law and ascribed a $\pm 0.35°$ systematic error from uncertainties in these effects. Even so, the E731 result remains valid within its quoted errors. KLEINKNECHT 94 [15] and KLEINKNECHT 95 [16] argue that these systematic errors should be around 3°, primarily because of the absence of data on the momentum dependence of the regeneration amplitude above 160 GeV/c. BRIERE 95 [17] and BRIERE 95C [18] reply that the current understanding of regeneration is sufficient to allow a precise and reliable correction for the region above 160 GeV/c. The question is one of judgement about the reliability of the assumptions used. In the absence of any contradictory evidence, we choose to accept the judgement of the E731/E773 experimenters in setting their systematic errors.

A similar analysis has been done by the CPLEAR Collaboration [19]. The small differences between their results and ours are due primarily to different treatments of τ_s. Their fit constrains τ_s to the PDG 1994 value, while our fit includes the more recent SCHWINGENHEUER 95 [3] τ measurement.

Fit for ϵ'/ϵ, $|\eta_{+-}|$, $|\eta_{00}|$, and $B(K_L \to \pi\pi)$

We list measurements of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$ and ϵ'/ϵ. Independent information on $|\eta_{+-}|$ and $|\eta_{00}|$ can be obtained from measurements of the K_L^0 and K_S^0 lifetimes (τ_s) and branching ratios (B) to $\pi\pi$, using the relations

$$|\eta_{+-}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^+\pi^-)}{\tau(K_L^0)} \; \frac{\tau(K_S^0)}{\mathrm{B}(K_S^0 \to \pi^+\pi^-)}\right]^{1/2} \quad , \tag{1a}$$

$$|\eta_{00}| = \left[\frac{\mathrm{B}(K_L^0 \to \pi^0\pi^0)}{\tau(K_L^0)} \; \frac{\tau(K_S^0)}{\mathrm{B}(K_S^0 \to \pi^0\pi^0)}\right]^{1/2} \quad . \tag{1b}$$

For historical reasons the branching ratio fits and the CP-violation fits are done separately, but we want to include the influence of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ measurements on $\mathrm{B}(K_L^0 \to \pi^+\pi^-)$ and $\mathrm{B}(K_L^0 \to \pi^0\pi^0)$ and vice versa. We approximate a global fit to all of these measurements by first performing two independent fits: 1) BRFIT, a fit to the K_L^0 branching ratios, rates, and mean life, and 2) ETAFIT, a fit to the $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{+-}/\eta_{00}|$, and ϵ'/ϵ measurements. The results from fit 1, along with the K_S^0 values from this edition are used to compute values of $|\eta_{+-}|$ and $|\eta_{00}|$ which are included as measurements in the $|\eta_{00}|$ and $|\eta_{+-}|$ sections with a document ID of BRFIT 96. Thus the fit values of $|\eta_{+-}|$ and $|\eta_{00}|$ given in this edition include both the direct measurements and the results from the branching ratio fit.

The process is reversed in order to include the direct $|\,\eta\,|$ measurements in the branching ratio fit. The results from fit 2 above (before including BRFIT 96 values) are used along with the K_L^0 and K_S^0 mean lives and the $K_S^0 \to \pi\pi$ branching fractions to compute the K_L^0 branching ratios $\Gamma(K_L^0 \to \pi^+\pi^-)/\Gamma(\text{total})$ and $\Gamma(K_L^0 \to \pi^0\pi^0)/\Gamma(K_L^0 \to \pi^+\pi^-)$. These branching ratio values are included as measurements in the branching ratio section with a document ID of ETAFIT 96. Thus the K_L^0 branching ratio fit values in this edition include the results of direct measurements of $|\eta_{+-}|$, $|\eta_{00}|$, $|\eta_{00}/\eta_{+-}|$, and ϵ'/ϵ. A more detailed discussion of these fits is given in the 1990 edition of this *Review* [20].

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