

STRANGE MESONS

($S = \pm 1, C = B = 0$)

$$K^+ = u\bar{s}, K^0 = d\bar{s}, \bar{K}^0 = \bar{d}s, K^- = \bar{u}s, \quad \text{similarly for } K^{*'}\text{'s}$$

K^\pm

$$I(J^P) = \frac{1}{2}(0^-)$$

$$\text{Mass } m = 493.677 \pm 0.015 \text{ MeV} \text{ [a]} \quad (S = 2.8)$$

$$\text{Mean life } \tau = (1.2380 \pm 0.0020) \times 10^{-8} \text{ s} \quad (S = 1.8)$$

$$c\tau = 3.711 \text{ m}$$

CP violation parameters ($\Delta = \text{rate difference/sum}$)

$$\Delta(K^\pm \rightarrow \mu^\pm \nu_\mu) = (-0.27 \pm 0.21)\%$$

$$\Delta(K^\pm \rightarrow \pi^\pm \pi^0) = (0.4 \pm 0.6)\% \text{ [b]}$$

$$\Delta(K^\pm \rightarrow \pi^\pm e^+ e^-) = (-2.2 \pm 1.6) \times 10^{-2}$$

$$\Delta(K^\pm \rightarrow \pi^\pm \mu^+ \mu^-) = 0.010 \pm 0.023$$

$$\Delta(K^\pm \rightarrow \pi^\pm \pi^0 \gamma) = (0.0 \pm 1.2) \times 10^{-3}$$

$$\Delta(K^\pm \rightarrow \pi^\pm \pi^+ \pi^-) = (0.04 \pm 0.06)\%$$

$$\Delta(K^\pm \rightarrow \pi^\pm \pi^0 \pi^0) = (-0.02 \pm 0.28)\%$$

T violation parameters

$$K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \quad P_T = (-1.7 \pm 2.5) \times 10^{-3}$$

$$K^+ \rightarrow \mu^+ \nu_\mu \gamma \quad P_T = (-0.6 \pm 1.9) \times 10^{-2}$$

$$K^+ \rightarrow \pi^0 \mu^+ \nu_\mu \quad \text{Im}(\xi) = -0.006 \pm 0.008$$

Slope parameter g [c]

(See Particle Listings for quadratic coefficients and alternative parametrization related to $\pi\pi$ scattering)

$$K^\pm \rightarrow \pi^\pm \pi^+ \pi^- \quad g = -0.21134 \pm 0.00017$$

$$(g_+ - g_-) / (g_+ + g_-) = (-1.5 \pm 2.2) \times 10^{-4}$$

$$K^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \quad g = 0.626 \pm 0.007$$

$$(g_+ - g_-) / (g_+ + g_-) = (1.8 \pm 1.8) \times 10^{-4}$$

K^\pm decay form factors [d,e]

Assuming μ -e universality

$$\lambda_+(K_{\mu 3}^+) = \lambda_+(K_{e 3}^+) = (2.959 \pm 0.025) \times 10^{-2}$$

$$\lambda_0(K_{\mu 3}^+) = (1.76 \pm 0.25) \times 10^{-2} \quad (S = 2.7)$$

Not assuming μ - e universality

$$\lambda_+(K_{e3}^+) = (2.956 \pm 0.025) \times 10^{-2}$$

$$\lambda_+(K_{\mu 3}^+) = (3.09 \pm 0.25) \times 10^{-2} \quad (S = 1.5)$$

$$\lambda_0(K_{\mu 3}^+) = (1.73 \pm 0.27) \times 10^{-2} \quad (S = 2.6)$$

K_{e3} form factor quadratic fit

$$\lambda'_+(K_{e3}^\pm) \text{ linear coeff.} = (2.59 \pm 0.04) \times 10^{-2}$$

$$\lambda''_+(K_{e3}^\pm) \text{ quadratic coeff.} = (0.186 \pm 0.021) \times 10^{-2}$$

$$\lambda'_+(\text{LINEAR } K_{\mu 3}^\pm \text{ FORM FACTOR FROM QUADRATIC FIT}) = (24 \pm 4) \times 10^{-3}$$

$$\lambda''_+(\text{QUADRATIC } K_{\mu 3}^\pm \text{ FORM FACTOR}) = (1.8 \pm 1.5) \times 10^{-3}$$

$$M_V (\text{VECTOR POLE MASS FOR } K_{e3}^\pm \text{ DECAY}) = 890.3 \pm 2.8 \text{ MeV}$$

$$M_V (\text{VECTOR POLE MASS FOR } K_{\mu 3}^\pm \text{ DECAY}) = 878 \pm 12 \text{ MeV}$$

$$M_S (\text{SCALAR POLE MASS FOR } K_{\mu 3}^\pm \text{ DECAY}) = 1210 \pm 50 \text{ MeV}$$

$$\Lambda_+ (\text{DISPERSIVE VECTOR FORM FACTOR IN } K_{e3}^\pm \text{ DECAY}) = (2.460 \pm 0.017) \times 10^{-2}$$

$$\Lambda_+ (\text{DISPERSIVE VECTOR FORM FACTOR IN } K_{\mu 3}^\pm \text{ DECAY}) = (25.4 \pm 0.9) \times 10^{-3}$$

$$\ln(C) (\text{DISPERSIVE SCALAR FORM FACTOR in } K_{\mu 3}^\pm \text{ decays}) = (182 \pm 16) \times 10^{-3}$$

$$K_{e3}^+ \quad |f_S/f_+| = (-0.08^{+0.34}_{-0.40}) \times 10^{-2}$$

$$K_{e3}^+ \quad |f_T/f_+| = (-1.2^{+1.3}_{-1.1}) \times 10^{-2}$$

$$K_{\mu 3}^+ \quad |f_S/f_+| = (0.2 \pm 0.6) \times 10^{-2}$$

$$K_{\mu 3}^+ \quad |f_T/f_+| = (-0.1 \pm 0.7) \times 10^{-2}$$

$$K^+ \rightarrow e^+ \nu_e \gamma \quad |F_A + F_V| = 0.133 \pm 0.008 \quad (S = 1.3)$$

$$K^+ \rightarrow \mu^+ \nu_\mu \gamma \quad |F_A + F_V| = 0.165 \pm 0.013$$

$$K^+ \rightarrow e^+ \nu_e \gamma \quad |F_A - F_V| < 0.49, \text{ CL} = 90\%$$

$$K^+ \rightarrow \mu^+ \nu_\mu \gamma \quad |F_A - F_V| = -0.153 \pm 0.033 \quad (S = 1.1)$$

Charge radius

$$\langle r \rangle = 0.560 \pm 0.031 \text{ fm}$$

Forward-backward asymmetry

$$A_{FB}(K_{\pi\mu\mu}^\pm) = \frac{\Gamma(\cos(\theta_{K\mu}) > 0) - \Gamma(\cos(\theta_{K\mu}) < 0)}{\Gamma(\cos(\theta_{K\mu}) > 0) + \Gamma(\cos(\theta_{K\mu}) < 0)} < 0.9 \times 10^{-2}, \text{ CL} = 90\%$$

K^- modes are charge conjugates of the modes below.

K^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level (MeV/c)	p
Leptonic and semileptonic modes			
$e^+ \nu_e$	(1.582 ± 0.007) $\times 10^{-5}$		247
$\mu^+ \nu_\mu$	(63.56 ± 0.11) %	S=1.2	236
$\pi^0 e^+ \nu_e$	(5.07 ± 0.04) %	S=2.1	228
Called K_{e3}^+ .			
$\pi^0 \mu^+ \nu_\mu$	(3.352 ± 0.034) %	S=1.9	215
Called $K_{\mu 3}^+$.			
$\pi^0 \pi^0 e^+ \nu_e$	(2.55 ± 0.04) $\times 10^{-5}$	S=1.1	206
$\pi^0 \pi^0 \mu^+ \nu_\mu$	(3.45 ± 0.16) $\times 10^{-6}$		156
$\pi^+ \pi^- e^+ \nu_e$	(4.247 ± 0.024) $\times 10^{-5}$		203
$\pi^+ \pi^- \mu^+ \nu_\mu$	(1.4 ± 0.9) $\times 10^{-5}$		151
$\pi^0 \pi^0 \pi^0 e^+ \nu_e$	< 5.4×10^{-8}	CL=90%	135
Hadronic modes			
$\pi^+ \pi^0$	(20.67 ± 0.08) %	S=1.2	205
$\pi^+ \pi^0 \pi^0$	(1.760 ± 0.023) %	S=1.1	133
$\pi^+ \pi^+ \pi^-$	(5.583 ± 0.024) %		125
Leptonic and semileptonic modes with photons			
$\mu^+ \nu_\mu \gamma$	[f,g] (6.2 ± 0.8) $\times 10^{-3}$		236
$\mu^+ \nu_\mu \gamma$ (SD ⁺)	[d,h] (1.33 ± 0.22) $\times 10^{-5}$		—
$\mu^+ \nu_\mu \gamma$ (SD ⁺ INT)	[d,h] < 2.7×10^{-5}	CL=90%	—
$\mu^+ \nu_\mu \gamma$ (SD ⁻ + SD ⁻ INT)	[d,h] < 2.6×10^{-4}	CL=90%	—
$e^+ \nu_e \gamma$	(1.03 ± 0.14) $\times 10^{-5}$		247
$\pi^0 e^+ \nu_e \gamma$	[f,g] (2.698 ± 0.033) $\times 10^{-4}$		228
$\pi^0 e^+ \nu_e \gamma$ (SD)	[d,h] < 5.3×10^{-5}	CL=90%	228
$\pi^0 \mu^+ \nu_\mu \gamma$	[f,g] (1.25 ± 0.25) $\times 10^{-5}$		215
$\pi^0 \pi^0 e^+ \nu_e \gamma$	< 5×10^{-6}	CL=90%	206
Hadronic modes with photons or $l\bar{l}$ pairs			
$\pi^+ \pi^0 \gamma$ (INT)	(-4.2 ± 0.9) $\times 10^{-6}$		—
$\pi^+ \pi^0 \gamma$ (DE)	[f,i] (6.0 ± 0.4) $\times 10^{-6}$		205
$\pi^+ \pi^0 e^+ e^-$	(4.24 ± 0.14) $\times 10^{-6}$		205
$\pi^+ \pi^0 \pi^0 \gamma$	[f,g] (4.0 ± 1.1) $\times 10^{-6}$		133
$\pi^+ \pi^+ \pi^- \gamma$	[f,g] (7.1 ± 0.5) $\times 10^{-6}$		125
$\pi^+ \gamma \gamma$	[f] (9.65 ± 0.16) $\times 10^{-7}$		227
$\pi^+ 3\gamma$	[f] < 1.0×10^{-4}	CL=90%	227
$\pi^+ e^+ e^- \gamma$	(1.19 ± 0.13) $\times 10^{-8}$		227

Leptonic modes with $\ell\bar{\ell}$ pairs

$e^+ \nu_e \nu \bar{\nu}$	<	6	$\times 10^{-5}$	CL=90%	247
$\mu^+ \nu_\mu \nu \bar{\nu}$	<	1.0	$\times 10^{-6}$	CL=90%	236
$e^+ \nu_e e^+ e^-$	(	2.48 ± 0.20	$) \times 10^{-8}$		247
$\mu^+ \nu_\mu e^+ e^-$	(	7.06 ± 0.31	$) \times 10^{-8}$		236
$e^+ \nu_e \mu^+ \mu^-$	(	1.7 ± 0.5	$) \times 10^{-8}$		223
$\mu^+ \nu_\mu \mu^+ \mu^-$	<	4.1	$\times 10^{-7}$	CL=90%	185

Lepton family number (LF), Lepton number (L), $\Delta S = \Delta Q$ (SQ) violating modes, or $\Delta S = 1$ weak neutral current (S1) modes

$\pi^+ \pi^+ e^- \bar{\nu}_e$	SQ	<	1.3	$\times 10^{-8}$	CL=90%	203
$\pi^+ \pi^+ \mu^- \bar{\nu}_\mu$	SQ	<	3.0	$\times 10^{-6}$	CL=95%	151
$\pi^+ e^+ e^-$	S1	(	3.00 ± 0.09	$) \times 10^{-7}$		227
$\pi^+ \mu^+ \mu^-$	S1	(	9.17 ± 0.14	$) \times 10^{-8}$	S=1.8	172
$\pi^+ e^+ e^- e^+ e^-$	S1	<	1.4	$\times 10^{-8}$	CL=90%	227
$\pi^+ \nu \bar{\nu}$	S1	(	1.33 ± 0.30	$) \times 10^{-10}$		227
$\pi^+ \pi^0 \nu \bar{\nu}$	S1	<	4.3	$\times 10^{-5}$	CL=90%	205
$\mu^- \nu e^+ e^+$	LF	<	8.1	$\times 10^{-11}$	CL=90%	236
$\mu^+ \nu_e$	LF	[j] <	4	$\times 10^{-3}$	CL=90%	236
$\pi^+ \mu^+ e^-$	LF	<	1.3	$\times 10^{-11}$	CL=90%	214
$\pi^0 \pi^+ \mu^+ e^-$	LF	<	5.0	$\times 10^{-10}$	CL=90%	154
$\pi^+ \mu^- e^+$	LF	<	6.6	$\times 10^{-11}$	CL=90%	214
$\pi^0 \pi^+ \mu^- e^+$	LF	<	3.1	$\times 10^{-10}$	CL=90%	154
$\pi^- \mu^+ e^+$	L	<	4.2	$\times 10^{-11}$	CL=90%	214
$\pi^0 \pi^- \mu^+ e^+$	L	<	2.9	$\times 10^{-10}$	CL=90%	154
$\pi^- e^+ e^+$	L	<	5.3	$\times 10^{-11}$	CL=90%	227
$\pi^- \mu^+ \mu^+$	L	<	4.2	$\times 10^{-11}$	CL=90%	172
$\pi^- \pi^0 e^+ e^+$	L	<	8.5	$\times 10^{-10}$	CL=90%	205
$\mu^+ \bar{\nu}_e$	L	[j] <	3.3	$\times 10^{-3}$	CL=90%	236
$\pi^0 e^+ \bar{\nu}_e$	L	<	3	$\times 10^{-3}$	CL=90%	228
$\pi^+ \gamma$		[k] <	2.3	$\times 10^{-9}$	CL=90%	227

K^0

$$I(J^P) = \frac{1}{2}(0^-)$$

50% K_S , 50% K_L

$$\text{Mass } m = 497.611 \pm 0.013 \text{ MeV} \quad (S = 1.2)$$

$$m_{K^0} - m_{K^\pm} = 3.934 \pm 0.020 \text{ MeV} \quad (S = 1.6)$$

Mean square charge radius

$$\langle r^2 \rangle = -0.077 \pm 0.010 \text{ fm}^2$$

T-violation parameters in $K^0-\bar{K}^0$ mixing [e]

$$\text{Asymmetry } A_T \text{ in } K^0-\bar{K}^0 \text{ mixing} = (6.6 \pm 1.6) \times 10^{-3}$$

CP-violation parameters

$$\text{Re}(\epsilon) = (1.596 \pm 0.013) \times 10^{-3}$$

CPT-violation parameters [e]

$$\text{Re} \delta = (2.5 \pm 2.3) \times 10^{-4}$$

$$\text{Im} \delta = (-1.5 \pm 1.6) \times 10^{-5}$$

$$\text{Re}(y), K_{e3} \text{ parameter} = (0.4 \pm 2.5) \times 10^{-3}$$

$$\text{Re}(x_-), K_{e3} \text{ parameter} = (-2.9 \pm 2.0) \times 10^{-3}$$

$$|m_{K^0} - m_{\bar{K}^0}| / m_{\text{average}} < 6 \times 10^{-19}, \text{CL} = 90\% [f]$$

$$(\Gamma_{K^0} - \Gamma_{\bar{K}^0}) / m_{\text{average}} = (8 \pm 8) \times 10^{-18}$$

Tests of $\Delta S = \Delta Q$

$$\text{Re}(x_+), K_{e3} \text{ parameter} = (-0.9 \pm 3.0) \times 10^{-3}$$



$$I(J^P) = \frac{1}{2}(0^-)$$

Mean life $\tau = (0.8954 \pm 0.0004) \times 10^{-10}$ s (S = 1.1) Assuming CPT

Mean life $\tau = (0.89564 \pm 0.00033) \times 10^{-10}$ s Not assuming CPT

$$c\tau = 2.6844 \text{ cm} \quad \text{Assuming CPT}$$

CP-violation parameters [n]

$$\text{Im}(\eta_{+-0}) = -0.002 \pm 0.009$$

$$\text{Im}(\eta_{000}) = -0.001 \pm 0.016$$

$$|\eta_{000}| = |A(K_S^0 \rightarrow 3\pi^0) / A(K_L^0 \rightarrow 3\pi^0)| < 0.0088, \text{CL} = 90\%$$

$$\text{CP asymmetry } A \text{ in } \pi^+ \pi^- e^+ e^- = (-0.4 \pm 0.8)\%$$

K_S^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
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Hadronic modes

$\pi^0 \pi^0$	(30.69 ± 0.05) %		209
$\pi^+ \pi^-$	(69.20 ± 0.05) %		206
$\pi^+ \pi^- \pi^0$	(3.5 $\begin{smallmatrix} +1.1 \\ -0.9 \end{smallmatrix}$) × 10 ⁻⁷		133

Modes with photons or $\ell\bar{\ell}$ pairs

$\pi^+ \pi^- \gamma$	[g,o] (1.79 ± 0.05) × 10 ⁻³		206
$\pi^+ \pi^- e^+ e^-$	(4.79 ± 0.15) × 10 ⁻⁵		206
$\pi^0 \gamma \gamma$	[o] (4.9 ± 1.8) × 10 ⁻⁸		230
$\gamma \gamma$	(2.63 ± 0.17) × 10 ⁻⁶	S=3.1	249
$\mu^+ \mu^- \mu^+ \mu^-$	< 5.1 × 10 ⁻¹²	CL=90%	119

Semileptonic modes

$$\pi^\pm e^\mp \nu_e \quad [p] \quad (7.14 \pm 0.06) \times 10^{-4} \quad 229$$

CP violating (CP) and $\Delta S = 1$ weak neutral current (S1) modes

$3\pi^0$	CP	< 2.6	$\times 10^{-8}$	CL=90%	139
$\mu^+ \mu^-$	S1	< 2.1	$\times 10^{-10}$	CL=90%	225
$e^+ e^-$	S1	< 9	$\times 10^{-9}$	CL=90%	249
$\pi^0 e^+ e^-$	S1	[o] (3.0 $\begin{smallmatrix} +1.5 \\ -1.2 \end{smallmatrix}$)	$\times 10^{-9}$		230
$\pi^0 \mu^+ \mu^-$	S1	(2.9 $\begin{smallmatrix} +1.5 \\ -1.2 \end{smallmatrix}$)	$\times 10^{-9}$		177
invisible		< 8.4	$\times 10^{-4}$	CL=90%	–



$$I(J^P) = \frac{1}{2}(0^-)$$

$$m_{K_L} - m_{K_S}$$

$$= (0.5293 \pm 0.0009) \times 10^{10} \hbar s^{-1} \quad (S = 1.3) \quad \text{Assuming } CPT$$

$$= (3.484 \pm 0.006) \times 10^{-12} \text{ MeV} \quad \text{Assuming } CPT$$

$$= (0.5289 \pm 0.0010) \times 10^{10} \hbar s^{-1} \quad \text{Not assuming } CPT$$

$$\text{Mean life } \tau = (5.116 \pm 0.021) \times 10^{-8} \text{ s} \quad (S = 1.1)$$

$$c\tau = 15.34 \text{ m}$$

Slope parameters [c]

(See Particle Listings for other linear and quadratic coefficients)

$$K_L^0 \rightarrow \pi^+ \pi^- \pi^0: g = 0.678 \pm 0.008 \quad (S = 1.5)$$

$$K_L^0 \rightarrow \pi^+ \pi^- \pi^0: h = 0.076 \pm 0.006$$

$$K_L^0 \rightarrow \pi^+ \pi^- \pi^0: k = 0.0099 \pm 0.0015$$

$$K_L^0 \rightarrow \pi^0 \pi^0 \pi^0: h = (0.6 \pm 1.2) \times 10^{-3}$$

K_L decay form factors [e]

Linear parametrization assuming μ -e universality

$$\lambda_+(K_{\mu 3}^0) = \lambda_+(K_{e 3}^0) = (2.82 \pm 0.04) \times 10^{-2} \quad (S = 1.1)$$

$$\lambda_0(K_{\mu 3}^0) = (1.38 \pm 0.18) \times 10^{-2} \quad (S = 2.2)$$

Quadratic parametrization assuming μ -e universality

$$\lambda'_+(K_{\mu 3}^0) = \lambda'_+(K_{e 3}^0) = (2.40 \pm 0.12) \times 10^{-2} \quad (S = 1.2)$$

$$\lambda''_+(K_{\mu 3}^0) = \lambda''_+(K_{e 3}^0) = (0.20 \pm 0.05) \times 10^{-2} \quad (S = 1.2)$$

$$\lambda_0(K_{\mu 3}^0) = (1.16 \pm 0.09) \times 10^{-2} \quad (S = 1.2)$$

Pole parametrization assuming μ -e universality

$$M_V^\mu(K_{\mu 3}^0) = M_V^e(K_{e 3}^0) = 878 \pm 6 \text{ MeV} \quad (S = 1.1)$$

$$M_S^\mu(K_{\mu 3}^0) = 1252 \pm 90 \text{ MeV} \quad (S = 2.6)$$

Dispersive parametrization assuming μ - e universality

$$\begin{aligned} \Lambda_+ &= (2.51 \pm 0.06) \times 10^{-2} \quad (S = 1.5) \\ \ln(C) &= (1.75 \pm 0.18) \times 10^{-1} \quad (S = 2.0) \\ K_{e3}^0 \quad |f_S/f_+| &= (1.5^{+1.4}_{-1.6}) \times 10^{-2} \\ K_{e3}^0 \quad |f_T/f_+| &= (5^{+4}_{-5}) \times 10^{-2} \\ K_{\mu 3}^0 \quad |f_T/f_+| &= (12 \pm 12) \times 10^{-2} \\ K_L \rightarrow \ell^+ \ell^- \gamma, K_L \rightarrow \ell^+ \ell^- \ell'^+ \ell'^-: \alpha_{K^*} &= -0.205 \pm 0.022 \quad (S = 1.8) \\ K_L^0 \rightarrow \ell^+ \ell^- \gamma, K_L^0 \rightarrow \ell^+ \ell^- \ell'^+ \ell'^-: \alpha_{DIP} &= -1.69 \pm 0.08 \quad (S = 1.7) \\ K_L \rightarrow \pi^+ \pi^- e^+ e^-: a_1/a_2 &= -0.737 \pm 0.014 \text{ GeV}^2 \\ K_L \rightarrow \pi^0 2\gamma: a_V &= -0.43 \pm 0.06 \quad (S = 1.5) \end{aligned}$$

CP-violation parameters ^[n]

$$\begin{aligned} A_L &= (0.332 \pm 0.006)\% \\ |\eta_{00}| &= (2.222 \pm 0.012) \times 10^{-3} \quad (S = 1.7) \\ |\eta_{+-}| &= (2.233 \pm 0.012) \times 10^{-3} \quad (S = 1.7) \\ |\epsilon| &= (2.229 \pm 0.012) \times 10^{-3} \quad (S = 1.7) \\ |\eta_{00}/\eta_{+-}| &= 0.9950 \pm 0.0007 \text{ [q]} \quad (S = 1.6) \\ \text{Re}(\epsilon'/\epsilon) &= (1.67 \pm 0.23) \times 10^{-3} \text{ [q]} \quad (S = 1.6) \end{aligned}$$

Assuming *CPT*

$$\begin{aligned} \phi_{+-} &= (43.51 \pm 0.05)^\circ \quad (S = 1.2) \\ \phi_{00} &= (43.52 \pm 0.05)^\circ \quad (S = 1.2) \\ \phi_\epsilon = \phi_{\text{SW}} &= (43.52 \pm 0.04)^\circ \quad (S = 1.2) \\ \text{Im}(\epsilon'/\epsilon) &= -(\phi_{00} - \phi_{+-})/3 = (-0.002 \pm 0.005)^\circ \quad (S = 1.7) \end{aligned}$$

Not assuming *CPT*

$$\begin{aligned} \phi_{+-} &= (43.4 \pm 0.5)^\circ \quad (S = 1.2) \\ \phi_{00} &= (43.7 \pm 0.6)^\circ \quad (S = 1.2) \\ \phi_\epsilon &= (43.5 \pm 0.5)^\circ \quad (S = 1.3) \\ \text{CP asymmetry } A \text{ in } K_L^0 \rightarrow \pi^+ \pi^- e^+ e^- &= (13.7 \pm 1.5)\% \\ \beta_{CP} \text{ from } K_L^0 \rightarrow e^+ e^- e^+ e^- &= -0.19 \pm 0.07 \\ \gamma_{CP} \text{ from } K_L^0 \rightarrow e^+ e^- e^+ e^- &= 0.01 \pm 0.11 \quad (S = 1.6) \\ j \text{ for } K_L^0 \rightarrow \pi^+ \pi^- \pi^0 &= 0.0012 \pm 0.0008 \\ f \text{ for } K_L^0 \rightarrow \pi^+ \pi^- \pi^0 &= 0.004 \pm 0.006 \end{aligned}$$

$$|\eta_{+-\gamma}| = (2.35 \pm 0.07) \times 10^{-3}$$

$$\phi_{+-\gamma} = (44 \pm 4)^\circ$$

$$|\epsilon'_{+-\gamma}|/\epsilon < 0.3, \text{ CL} = 90\%$$

$$|g_{E1}| \text{ for } K_L^0 \rightarrow \pi^+ \pi^- \gamma < 0.21, \text{ CL} = 90\%$$

T-violation parameters

$$\text{Im}(\xi) \text{ in } K_{\mu 3}^0 = -0.007 \pm 0.026$$

CPT invariance tests

$$\phi_{00} - \phi_{+-} = (0.34 \pm 0.32)^\circ$$

$$\text{Re}\left(\frac{2}{3}\eta_{+-} + \frac{1}{3}\eta_{00}\right) - \frac{A_L}{2} = (-3 \pm 35) \times 10^{-6}$$

$\Delta S = -\Delta Q$ in $K_{\ell 3}^0$ decay

$$\text{Re } x = -0.002 \pm 0.006$$

$$\text{Im } x = 0.0012 \pm 0.0021$$

K_L^0 DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level(MeV/c)	p
Semileptonic modes			
$\pi^\pm e^\mp \nu_e$ Called K_{e3}^0 .	[p] (40.55 \pm 0.11) %	S=1.7	229
$\pi^\pm \mu^\mp \nu_\mu$ Called $K_{\mu 3}^0$.	[p] (27.04 \pm 0.07) %	S=1.1	216
$(\pi \mu \text{atom}) \nu$	(1.05 \pm 0.11) $\times 10^{-7}$		188
$\pi^0 \pi^\pm e^\mp \nu$	[p] (5.20 \pm 0.11) $\times 10^{-5}$		207
$\pi^\pm e^\mp \nu e^+ e^-$	[p] (1.26 \pm 0.04) $\times 10^{-5}$		229
Hadronic modes, including Charge conjugation \times Parity Violating (CPV) modes			
$3\pi^0$	(19.52 \pm 0.12) %	S=1.6	139
$\pi^+ \pi^- \pi^0$	(12.54 \pm 0.05) %		133
$\pi^+ \pi^-$	CPV [r] (1.967 \pm 0.010) $\times 10^{-3}$	S=1.5	206
$\pi^0 \pi^0$	CPV (8.64 \pm 0.06) $\times 10^{-4}$	S=1.8	209
Semileptonic modes with photons			
$\pi^\pm e^\mp \nu_e \gamma$	[g,p,s] (3.79 \pm 0.06) $\times 10^{-3}$		229
$\pi^\pm \mu^\mp \nu_\mu \gamma$	(5.65 \pm 0.23) $\times 10^{-4}$		216
Hadronic modes with photons or $\ell\bar{\ell}$ pairs			
$\pi^0 \pi^0 \gamma$	< 2.43 $\times 10^{-7}$	CL=90%	209
$\pi^+ \pi^- \gamma$	[g,s] (4.15 \pm 0.15) $\times 10^{-5}$	S=2.8	206
$\pi^+ \pi^- \gamma$ (DE)	(2.84 \pm 0.11) $\times 10^{-5}$	S=2.0	206
$\pi^0 2\gamma$	[s] (1.273 \pm 0.033) $\times 10^{-6}$		230
$\pi^0 \gamma e^+ e^-$	(1.62 \pm 0.17) $\times 10^{-8}$		230

Other modes with photons or $\ell\bar{\ell}$ pairs

2γ		$(5.47 \pm 0.04) \times 10^{-4}$	S=1.1	249
3γ		$< 7.4 \times 10^{-8}$	CL=90%	249
$e^+ e^- \gamma$		$(9.4 \pm 0.4) \times 10^{-6}$	S=2.0	249
$\mu^+ \mu^- \gamma$		$(3.59 \pm 0.11) \times 10^{-7}$	S=1.3	225
$\mu^+ \mu^- \mu^+ \mu^-$		$< 2.3 \times 10^{-9}$	CL=90%	119
$e^+ e^- \gamma\gamma$	[s]	$(5.95 \pm 0.33) \times 10^{-7}$		249
$\mu^+ \mu^- \gamma\gamma$	[s]	$(1.0 \begin{smallmatrix} +0.8 \\ -0.6 \end{smallmatrix}) \times 10^{-8}$		225

Charge conjugation \times Parity (CP) or Lepton Family number (LF) violating modes, or $\Delta S = 1$ weak neutral current (S1) modes

$\mu^+ \mu^-$	S1	$(6.84 \pm 0.11) \times 10^{-9}$		225
$e^+ e^-$	S1	$(9 \begin{smallmatrix} +6 \\ -4 \end{smallmatrix}) \times 10^{-12}$		249
$\pi^+ \pi^- e^+ e^-$	S1 [s]	$(3.11 \pm 0.19) \times 10^{-7}$		206
$\pi^0 \pi^0 e^+ e^-$	S1	$< 6.6 \times 10^{-9}$	CL=90%	209
$\pi^0 \pi^0 \mu^+ \mu^-$	S1	$< 9.2 \times 10^{-11}$	CL=90%	57
$\mu^+ \mu^- e^+ e^-$	S1	$(2.69 \pm 0.27) \times 10^{-9}$		225
$e^+ e^- e^+ e^-$	S1	$(3.56 \pm 0.21) \times 10^{-8}$		249
$\pi^0 \mu^+ \mu^-$	CP,S1 [t]	$< 3.8 \times 10^{-10}$	CL=90%	177
$\pi^0 e^+ e^-$	CP,S1 [t]	$< 2.8 \times 10^{-10}$	CL=90%	230
$\pi^0 \nu \bar{\nu}$	CP,S1 [u]	$< 2.2 \times 10^{-9}$	CL=90%	230
$\pi^0 \pi^0 \nu \bar{\nu}$	S1	$< 8.1 \times 10^{-7}$	CL=90%	209
$e^\pm \mu^\mp$	LF [p]	$< 4.7 \times 10^{-12}$	CL=90%	238
$e^\pm e^\pm \mu^\mp \mu^\mp$	LF [p]	$< 4.12 \times 10^{-11}$	CL=90%	225
$\pi^0 \mu^\pm e^\mp$	LF [p]	$< 7.6 \times 10^{-11}$	CL=90%	217
$\pi^0 \pi^0 \mu^\pm e^\mp$	LF	$< 1.7 \times 10^{-10}$	CL=90%	159

Lorentz invariance violating modes

$\pi^0 \gamma$		$< 1.7 \times 10^{-7}$	CL=90%	230
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$K_0^*(700)$

$$I(J^P) = \frac{1}{2}(0^+)$$

also known as κ ; was $K_0^*(800)$

See the review on "Scalar Mesons below 1 GeV."

Mass (T-Matrix Pole \sqrt{s}) = $(630-730) - i(260-340)$ MeV

Mass (Breit-Wigner) = 838 ± 11 MeV

Full width (Breit-Wigner) = 463 ± 27 MeV

$K_0^*(700)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K \pi$	100 %	250

$K^*(892)$

$$I(J^P) = \frac{1}{2}(1^-)$$

Mass (T-Matrix Pole \sqrt{s}) = $(890 \pm 14) - i(26 \pm 6)$ MeV

$K^*(892)^\pm$ hadroproduced mass $m = 891.88 \pm 0.23$ MeV

$K^*(892)^\pm$ in τ decays mass $m = 895.5 \pm 0.8$ MeV

$K^*(892)^0$ mass $m = 895.56 \pm 0.20$ MeV (S = 1.7)

$K^*(892)^\pm$ hadroproduced full width $\Gamma = 48.5 \pm 1.2$ MeV (S = 2.1)

$K^*(892)^\pm$ in τ decays full width $\Gamma = 46.2 \pm 1.3$ MeV

$K^*(892)^0$ full width $\Gamma = 47.1 \pm 0.5$ MeV (S = 2.0)

$K^*(892)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\pi$	~ 100	%	290
$K^0\gamma$	$(2.47 \pm 0.21) \times 10^{-3}$		307
$K^\pm\gamma$	$(1.04 \pm 0.10) \times 10^{-3}$		309
$K\pi\pi$	< 7	$\times 10^{-4}$ 95%	223

$K_1(1270)$

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m = 1256 \pm 6$ MeV (S = 2.2)

Full width $\Gamma = 90 \pm 20$ MeV [ν]

$K_1(1270)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor	p (MeV/c)
$K\rho$	(53 ± 8) %	2.1	†
$K_0^*(1430)\pi$	(14 ± 8) %	4.0	†
$K^*(892)\pi$	(18 ± 4) %	1.2	288
$K\omega$	(9.6 ± 2.1) %	1.3	†
$Kf_0(1370)$	(3.0 ± 2.0) %		†
γK^0	seen		529

$K_1(1400)$

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m = 1403 \pm 7$ MeV

Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

$K_1(1400)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	(94 ± 6) %	402
$K\rho$	(3.0 ± 3.0) %	293
$Kf_0(1370)$	(2.0 ± 2.0) %	†
$K\omega$	(1.0 ± 1.0) %	284

$K_0^*(1430)\pi$	not seen	†
γK^0	seen	613
$K\phi$	seen	†

 $K^*(1410)$

$$I(J^P) = \frac{1}{2}(1^-)$$

T-matrix pole $\sqrt{s} = (1368 \pm 38) - i(106_{-59}^{+48})$ MeV

Mass $m = 1414 \pm 15$ MeV (S = 1.3)

Full width $\Gamma = 232 \pm 21$ MeV (S = 1.1)

$K^*(1410)$ DECAY MODES	Fraction (Γ_i/Γ)		Confidence level	p (MeV/c)
$K^*(892)\pi$	> 40	%	95%	410
$K\pi$	(6.6 ± 1.3) %			612
$K\rho$	< 7	%	95%	306
γK^0	< 2.3	$\times 10^{-4}$	90%	619
$K\phi$	seen			†

 $K_0^*(1430)$

$$I(J^P) = \frac{1}{2}(0^+)$$

T-matrix pole $\sqrt{s} = (1431 \pm 6) - i(110 \pm 19)$ MeV

Mass $m = 1425 \pm 50$ MeV [v]

Full width $\Gamma = 270 \pm 80$ MeV [v]

$K_0^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(93 ± 10) %	619
$K\eta$	($8.6_{-3.4}^{+2.7}$) %	486
$K\eta'(958)$	seen	†

 $K_2^*(1430)$

$$I(J^P) = \frac{1}{2}(2^+)$$

T-matrix pole $\sqrt{s} = (1424 \pm 4) - i(66 \pm 2)$ MeV

$K_2^*(1430)^\pm$ mass $m = 1427.3 \pm 1.5$ MeV (S = 1.3)

$K_2^*(1430)^0$ mass $m = 1432.4 \pm 1.3$ MeV

$K_2^*(1430)^\pm$ full width $\Gamma = 100.0 \pm 2.2$ MeV (S = 1.1)

$K_2^*(1430)^0$ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)

$K_2^*(1430)$ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
$K\pi$	(49.9 ± 1.2) %		620

$K^*(892)\pi$	$(24.7 \pm 1.5) \%$		420
$K^*(892)\pi\pi$	$(13.4 \pm 2.2) \%$		373
$K\rho$	$(8.7 \pm 0.8) \%$	S=1.2	320
$K\omega$	$(2.9 \pm 0.8) \%$		313
$K^+\gamma$	$(2.4 \pm 0.5) \times 10^{-3}$	S=1.1	628
$K\eta$	$(1.5^{+3.4}_{-1.0}) \times 10^{-3}$	S=1.3	488
$K\omega\pi$	$< 7.2 \times 10^{-4}$	CL=95%	106
$K^0\gamma$	$< 9 \times 10^{-4}$	CL=90%	627

$K(1460)$

$$I(J^P) = \frac{1}{2}(0^-)$$

$K(1460)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	seen	—
$K\rho$	seen	—
$K_0^*(1430)\pi$	seen	—
$K\phi$	seen	—

$K_1(1650)$

$$I(J^P) = \frac{1}{2}(1^+)$$

Mass $m = 1650 \pm 50$ MeV
 Full width $\Gamma = 150 \pm 50$ MeV

$K^*(1680)$

$$I(J^P) = \frac{1}{2}(1^-)$$

Mass $m = 1718 \pm 18$ MeV
 Full width $\Gamma = 320 \pm 110$ MeV (S = 4.2)

$K^*(1680)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	$(38.7 \pm 2.5) \%$	782
$K\rho$	$(31.4^{+5.0}_{-2.1}) \%$	571
$K^*(892)\pi$	$(29.9^{+2.2}_{-5.0}) \%$	618
$K\phi$	seen	387
$K\eta$	$(1.4^{+1.0}_{-0.8}) \%$	683

$K_2(1770)$ [x]

$$I(J^P) = \frac{1}{2}(2^-)$$

Mass $m = 1773 \pm 8$ MeV
 Full width $\Gamma = 186 \pm 14$ MeV

$K_2(1770)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi\pi$		794
$K_2^*(1430)\pi$	seen	287
$K^*(892)\pi$	seen	654
$Kf_2(1270)$	seen	53
$Kf_0(980)$	possibly seen	466
$K\phi$	seen	441
$K\omega$	seen	607

 $K_3^*(1780)$

$$I(J^P) = \frac{1}{2}(3^-)$$

T-matrix pole $\sqrt{s} = (1754 \pm 13) - i(119 \pm 14)$ MeV

Mass $m = 1779 \pm 8$ MeV (S = 1.2)

Full width $\Gamma = 161 \pm 17$ MeV (S = 1.1)

$K_3^*(1780)$ DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$K\rho$	(31 \pm 9) %		616
$K^*(892)\pi$	(20 \pm 5) %		657
$K\pi$	(18.8 \pm 1.0) %		815
$K\eta$	(30 \pm 13) %		721
$K_2^*(1430)\pi$	< 16 %	95%	292

 $K_2(1820)$ [x]

$$I(J^P) = \frac{1}{2}(2^-)$$

Mass $m = 1819 \pm 12$ MeV

Full width $\Gamma = 264 \pm 34$ MeV

$K_2(1820)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi\pi$	seen	819
$K_2^*(1430)\pi$	seen	328
$K^*(892)\pi$	seen	683
$Kf_2(1270)$	seen	191
$K\omega$	seen	640
$K\phi$	seen	483

 $K_0^*(1950)$

$$I(J^P) = \frac{1}{2}(0^+)$$

Mass $m = 1957 \pm 14$ MeV

Full width $\Gamma = 170 \pm 50$ MeV (S = 2.2)

$K_0^*(1950)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^- \pi^+$	(52±14) %	911

 $K_2^*(1980)$

$$I(J^P) = \frac{1}{2}(2^+)$$

$$\text{Mass } m = 1990_{-50}^{+60} \text{ MeV} \quad (S = 2.8)$$

$$\text{Full width } \Gamma = 348_{-30}^{+50} \text{ MeV} \quad (S = 1.3)$$

$K_2^*(1980)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K^*(892)\pi$	possibly seen	791
$K\rho$	possibly seen	762
$K f_2(1270)$	possibly seen	424
$K\phi$	seen	627
$K\eta$	seen	850

 $K_4^*(2045)$

$$I(J^P) = \frac{1}{2}(4^+)$$

$$\text{Mass } m = 2048_{-9}^{+8} \text{ MeV} \quad (S = 1.1)$$

$$\text{Full width } \Gamma = 199_{-19}^{+27} \text{ MeV}$$

$K_4^*(2045)$ DECAY MODES	Fraction (Γ_i/Γ)	p (MeV/c)
$K\pi$	(9.9±1.2) %	960
$K^*(892)\pi\pi$	(9 ±5) %	804
$K^*(892)\pi\pi\pi$	(7 ±5) %	770
$\rho K\pi$	(5.7±3.2) %	744
$\omega K\pi$	(5.0±3.0) %	740
$\phi K\pi$	(2.8±1.4) %	597
$\phi K^*(892)$	(1.4±0.7) %	367

NOTES

- [a] See the note in the K^\pm Particle Listings.
- [b] Neglecting photon channels. See, *e.g.*, A. Pais and S.B. Treiman, *Phys. Rev.* **D12**, 2744 (1975).
- [c] The definition of the slope parameters of the $K \rightarrow 3\pi$ Dalitz plot is as follows (see also “Note on Dalitz Plot Parameters for $K \rightarrow 3\pi$ Decays” in the K^\pm Particle Listings):

$$|M|^2 = 1 + g(s_3 - s_0)/m_{\pi^+}^2 + \dots$$

- [d] See the review on “Form Factors for Radiative Pion and Kaon Decays” for definitions and details.
- [e] For more details and definitions of parameters see the Particle Listings.
- [f] See the K^\pm Particle Listings for the energy limits used in this measurement.
- [g] Most of this radiative mode, the low-momentum γ part, is also included in the parent mode listed without γ 's.
- [h] Structure-dependent part.
- [i] Direct-emission branching fraction.
- [j] Derived from an analysis of neutrino-oscillation experiments.
- [k] Violates angular-momentum conservation.
- [l] Derived from measured values of ϕ_{+-} , ϕ_{00} , $|\eta|$, $|m_{K_L^0} - m_{K_S^0}|$, and $\tau_{K_S^0}$, as described in the introduction to “Tests of Conservation Laws.”

- [n] The CP -violation parameters are defined as follows (see also “Note on CP Violation in $K_S \rightarrow 3\pi$ ” and “Note on CP Violation in K_L^0 Decay” in the Particle Listings):

$$\eta_{+-} = |\eta_{+-}|e^{i\phi_{+-}} = \frac{A(K_L^0 \rightarrow \pi^+\pi^-)}{A(K_S^0 \rightarrow \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}|e^{i\phi_{00}} = \frac{A(K_L^0 \rightarrow \pi^0\pi^0)}{A(K_S^0 \rightarrow \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K_L^0 \rightarrow \pi^-\ell^+\nu) - \Gamma(K_L^0 \rightarrow \pi^+\ell^-\nu)}{\Gamma(K_L^0 \rightarrow \pi^-\ell^+\nu) + \Gamma(K_L^0 \rightarrow \pi^+\ell^-\nu)},$$

$$\text{Im}(\eta_{+-0})^2 = \frac{\Gamma(K_S^0 \rightarrow \pi^+\pi^-\pi^0)^{CP \text{ viol.}}}{\Gamma(K_L^0 \rightarrow \pi^+\pi^-\pi^0)},$$

$$\text{Im}(\eta_{000})^2 = \frac{\Gamma(K_S^0 \rightarrow \pi^0\pi^0\pi^0)}{\Gamma(K_L^0 \rightarrow \pi^0\pi^0\pi^0)}.$$

where for the last two relations CPT is assumed valid, *i.e.*, $\text{Re}(\eta_{+-0}) \simeq 0$ and $\text{Re}(\eta_{000}) \simeq 0$.

- [o] See the K_S^0 Particle Listings for the energy limits used in this measurement.
- [p] The value is for the sum of the charge states or particle/antiparticle states indicated.
- [q] $\text{Re}(\epsilon'/\epsilon) = \epsilon'/\epsilon$ to a very good approximation provided the phases satisfy CPT invariance.
- [r] This mode includes gammas from inner bremsstrahlung but not the direct emission mode $K_L^0 \rightarrow \pi^+ \pi^- \gamma(\text{DE})$.
- [s] See the K_L^0 Particle Listings for the energy limits used in this measurement.
- [t] Allowed by higher-order electroweak interactions.
- [u] Violates CP in leading order. Test of direct CP violation since the indirect CP -violating and CP -conserving contributions are expected to be suppressed.
- [v] Our estimate. See the Particle Listings for details.
- [x] See our minireview under the $K_2(1770)$ in the 2004 edition of this *Review*.