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

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

## $K^\pm$

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

Mass $m = 493.677 \pm 0.016$ MeV [a] (S = 2.8)
Mean life $\tau = (1.2380 \pm 0.0020) \times 10^{-8}$ s (S = 1.8)
$c\tau = 3.711$ m

### *CPT* violation parameters ($\Delta$ = rate difference/sum)

$\Delta(K^\pm \to \mu^\pm \nu_\mu) = (-0.27 \pm 0.21)\%$
$\Delta(K^\pm \to \pi^\pm \pi^0) = (0.4 \pm 0.6)\%$ [b]

### *CP* violation parameters ($\Delta$ = rate difference/sum)

$\Delta(K^\pm \to \pi^\pm e^+ e^-) = (-2.2 \pm 1.6) \times 10^{-2}$
$\Delta(K^\pm \to \pi^\pm \mu^+ \mu^-) = 0.010 \pm 0.023$
$\Delta(K^\pm \to \pi^\pm \pi^0 \gamma) = (0.0 \pm 1.2) \times 10^{-3}$
$\Delta(K^\pm \to \pi^\pm \pi^+ \pi^-) = (0.04 \pm 0.06)\%$
$\Delta(K^\pm \to \pi^\pm \pi^0 \pi^0) = (-0.02 \pm 0.28)\%$

### *T* violation parameters

$K^+ \to \pi^0 \mu^+ \nu_\mu \quad P_T = (-1.7 \pm 2.5) \times 10^{-3}$
$K^+ \to \mu^+ \nu_\mu \gamma \quad P_T = (-0.6 \pm 1.9) \times 10^{-2}$
$K^+ \to \pi^0 \mu^+ \nu_\mu \quad \mathrm{Im}(\xi) = -0.006 \pm 0.008$

### Slope parameter *g* [c]

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

$K^\pm \to \pi^\pm \pi^+ \pi^- \; g = -0.21134 \pm 0.00017$
$(g_+ - g_-) \,/\, (g_+ + g_-) = (-1.5 \pm 2.2) \times 10^{-4}$
$K^\pm \to \pi^\pm \pi^0 \pi^0 \; g = 0.626 \pm 0.007$
$(g_+ - g_-) \,/\, (g_+ + g_-) = (1.8 \pm 1.8) \times 10^{-4}$

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

Assuming $\mu$-$e$ universality

$\lambda_+(K^+_{\mu 3}) = \lambda_+(K^+_{e3}) = (2.97 \pm 0.05) \times 10^{-2}$
$\lambda_0(K^+_{\mu 3}) = (1.95 \pm 0.12) \times 10^{-2}$

Not assuming $\mu$-$e$ universality

$\lambda_+(K^+_{e3}) = (2.98 \pm 0.05) \times 10^{-2}$

$\lambda_+(K^+_{\mu 3}) = (2.96 \pm 0.17) \times 10^{-2}$

$\lambda_0(K^+_{\mu 3}) = (1.96 \pm 0.13) \times 10^{-2}$

$K_{e3}$ form factor quadratic fit

$\lambda'_+ \ (K^\pm_{e3})$ linear coeff. $= (2.49 \pm 0.17) \times 10^{-2}$

$\lambda''_+(K^\pm_{e3})$ quadratic coeff. $= (0.19 \pm 0.09) \times 10^{-2}$

$K^+_{e3} \quad |f_S/f_+| = (-0.3^{+0.8}_{-0.7}) \times 10^{-2}$

$K^+_{e3} \quad |f_T/f_+| = (-1.2 \pm 2.3) \times 10^{-2}$

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

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

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

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

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

$K^+ \to \mu^+ \nu_\mu \gamma \quad |F_A - F_V| = -0.21 \pm 0.06$

**Charge radius**

$\langle r \rangle = 0.560 \pm 0.031$ fm

**Forward-backward asymmetry**

$A_{FB}(K^\pm_{\pi\mu\mu}) = \frac{\Gamma(cos(\theta_{K\mu})>0) - \Gamma(cos(\theta_{K\mu})<0)}{\Gamma(cos(\theta_{K\mu})>0) + \Gamma(cos(\theta_{K\mu})<0)} < 2.3 \times 10^{-2}$, CL = 90%

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

| $K^+$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | Scale factor/ Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|
| **Leptonic and semileptonic modes** | | | |
| $e^+ \nu_e$ | ( 1.582±0.007) × $10^{-5}$ | | 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±0.033) % | S=1.9 | 215 |
| Called $K^+_{\mu 3}$. | | | |
| $\pi^0 \pi^0 e^+ \nu_e$ | ( 2.55 ±0.04 ) × $10^{-5}$ | S=1.1 | 206 |
| $\pi^+ \pi^- e^+ \nu_e$ | ( 4.247±0.024) × $10^{-5}$ | | 203 |
| $\pi^+ \pi^- \mu^+ \nu_\mu$ | ( 1.4 ±0.9 ) × $10^{-5}$ | | 151 |
| $\pi^0 \pi^0 \pi^0 e^+ \nu_e$ | < 3.5 × $10^{-6}$ | 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 |
| $\mu^+\nu_\mu\gamma(\mathrm{SD}^+)$ | [d,h] | ( | 1.33 ±0.22 ) | $\times 10^{-5}$ | | – |
| $\mu^+\nu_\mu\gamma(\mathrm{SD}^+\mathrm{INT})$ | [d,h] | < | 2.7 | $\times 10^{-5}$ | CL=90% | – |
| $\mu^+\nu_\mu\gamma(\mathrm{SD}^- + \mathrm{SD}^-\mathrm{INT})$ | [d,h] | < | 2.6 | $\times 10^{-4}$ | CL=90% | – |
| $e^+\nu_e\gamma$ | | ( | 9.4 ±0.4 ) | $\times 10^{-6}$ | | 247 |
| $\pi^0 e^+\nu_e\gamma$ | [f,g] | ( | 2.56 ±0.16 ) | $\times 10^{-4}$ | | 228 |
| $\pi^0 e^+\nu_e\gamma(\mathrm{SD})$ | [d,h] | < | 5.3 | $\times 10^{-5}$ | 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 | $\times 10^{-6}$ | CL=90% | 206 |

## Hadronic modes with photons or $\ell\overline{\ell}$ pairs

| | | | | | | |
|---|---|---|---|---|---|---|
| $\pi^+\pi^0\gamma(\mathrm{INT})$ | | (− | 4.2 ±0.9 ) | $\times 10^{-6}$ | | – |
| $\pi^+\pi^0\gamma(\mathrm{DE})$ | [f,i] | ( | 6.0 ±0.4 ) | $\times 10^{-6}$ | | 205 |
| $\pi^+\pi^0\pi^0\gamma$ | [f,g] | ( | 7.6 $^{+6.0}_{-3.0}$ ) | $\times 10^{-6}$ | | 133 |
| $\pi^+\pi^+\pi^-\gamma$ | [f,g] | ( | 1.04 ±0.31 ) | $\times 10^{-4}$ | | 125 |
| $\pi^+\gamma\gamma$ | [f] | ( | 1.01 ±0.06 ) | $\times 10^{-6}$ | | 227 |
| $\pi^+ 3\gamma$ | [f] | < | 1.0 | $\times 10^{-4}$ | CL=90% | 227 |
| $\pi^+ e^+ e^-\gamma$ | | ( | 1.19 ±0.13 ) | $\times 10^{-8}$ | | 227 |

## Leptonic modes with $\ell\overline{\ell}$ pairs

| | | | | | | |
|---|---|---|---|---|---|---|
| $e^+\nu_e\nu\overline{\nu}$ | | < | 6 | $\times 10^{-5}$ | CL=90% | 247 |
| $\mu^+\nu_\mu\nu\overline{\nu}$ | | < | 2.4 | $\times 10^{-6}$ | 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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $\pi^+\pi^+ e^-\overline{\nu}_e$ | $SQ$ | | < | 1.3 | $\times 10^{-8}$ | CL=90% | 203 |
| $\pi^+\pi^+\mu^-\overline{\nu}_\mu$ | $SQ$ | | < | 3.0 | $\times 10^{-6}$ | CL=95% | 151 |
| $\pi^+ e^+ e^-$ | $S1$ | | ( | 3.00 ±0.09 ) | $\times 10^{-7}$ | | 227 |
| $\pi^+\mu^+\mu^-$ | $S1$ | | ( | 9.4 ±0.6 ) | $\times 10^{-8}$ | S=2.6 | 172 |
| $\pi^+\nu\overline{\nu}$ | $S1$ | | ( | 1.7 ±1.1 ) | $\times 10^{-10}$ | | 227 |
| $\pi^+\pi^0\nu\overline{\nu}$ | $S1$ | | < | 4.3 | $\times 10^{-5}$ | CL=90% | 205 |
| $\mu^-\nu e^+ e^+$ | $LF$ | | < | 2.1 | $\times 10^{-8}$ | 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 |
| $\pi^+ \mu^- e^+$ | LF | < | 5.2 | $\times 10^{-10}$ | CL=90% | 214 |
| $\pi^- \mu^+ e^+$ | L | < | 5.0 | $\times 10^{-10}$ | CL=90% | 214 |
| $\pi^- e^+ e^+$ | L | < | 6.4 | $\times 10^{-10}$ | CL=90% | 227 |
| $\pi^- \mu^+ \mu^+$ | L | [j] < | 1.1 | $\times 10^{-9}$ | CL=90% | 172 |
| $\mu^+ \overline{\nu}_e$ | L | [j] < | 3.3 | $\times 10^{-3}$ | CL=90% | 236 |
| $\pi^0 e^+ \overline{\nu}_e$ | 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% $K_L$

Mass $m = 497.611 \pm 0.013$ MeV (S = 1.2)

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

### Mean square charge radius

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

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

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

### $CP$-violation parameters

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

### $CPT$-violation parameters [e]

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

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

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

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

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

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

### Tests of $\Delta S = \Delta Q$

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

## $K^0_S$

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

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 $CPT$

$c\tau = 2.6844$ cm Assuming $CPT$

### *CP*-violation parameters [n]

$\mathrm{Im}(\eta_{+-0}) = -0.002 \pm 0.009$
$\mathrm{Im}(\eta_{000}) = -0.001 \pm 0.016$
$|\eta_{000}| = |A(K_S^0 \to 3\pi^0)/A(K_L^0 \to 3\pi^0)| < 0.0088$, CL = 90%
*CP* asymmetry $A$ in $\pi^+\pi^- e^+ e^- = (-0.4 \pm 0.8)\%$

| $K_S^0$ DECAY MODES | | Fraction ($\Gamma_i/\Gamma$) | Scale factor/ Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|---|
| **Hadronic modes** | | | | |
| $\pi^0\pi^0$ | | (30.69±0.05) % | | 209 |
| $\pi^+\pi^-$ | | (69.20±0.05) % | | 206 |
| $\pi^+\pi^-\pi^0$ | | $( 3.5\ ^{+1.1}_{-0.9} ) \times 10^{-7}$ | | 133 |
| **Modes with photons or $\ell\bar{\ell}$ pairs** | | | | |
| $\pi^+\pi^-\gamma$ | [g,o] | $( 1.79\pm0.05) \times 10^{-3}$ | | 206 |
| $\pi^+\pi^- e^+ e^-$ | | $( 4.79\pm0.15) \times 10^{-5}$ | | 206 |
| $\pi^0\gamma\gamma$ | [o] | $( 4.9 \pm1.8 ) \times 10^{-8}$ | | 230 |
| $\gamma\gamma$ | | $( 2.63\pm0.17) \times 10^{-6}$ | S=3.0 | 249 |
| **Semileptonic modes** | | | | |
| $\pi^\pm e^\mp \nu_e$ | [p] | $( 7.04\pm0.08) \times 10^{-4}$ | | 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* | $< 9 \times 10^{-9}$ | CL=90% | 225 |
| $e^+ e^-$ | *S1* | $< 9 \times 10^{-9}$ | CL=90% | 249 |
| $\pi^0 e^+ e^-$ | *S1* | [o] $( 3.0\ ^{+1.5}_{-1.2} ) \times 10^{-9}$ | | 230 |
| $\pi^0\mu^+\mu^-$ | *S1* | $( 2.9\ ^{+1.5}_{-1.2} ) \times 10^{-9}$ | | 177 |

## $K_L^0$

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

$m_{K_L} - m_{K_S}$
$= (0.5293 \pm 0.0009) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$ (S = 1.3) Assuming *CPT*
$= (3.484 \pm 0.006) \times 10^{-12}$ MeV Assuming *CPT*
$= (0.5289 \pm 0.0010) \times 10^{10}\ \hbar\ \mathrm{s}^{-1}$ Not assuming *CPT*
Mean life $\tau = (5.116 \pm 0.021) \times 10^{-8}$ s (S = 1.1)
$c\tau = 15.34$ m

### Slope parameters [c]

(See Particle Listings for other linear and quadratic coefficients)

$K_L^0 \to \pi^+\pi^-\pi^0$: $g = 0.678 \pm 0.008$ (S = 1.5)
$K_L^0 \to \pi^+\pi^-\pi^0$: $h = 0.076 \pm 0.006$
$K_L^0 \to \pi^+\pi^-\pi^0$: $k = 0.0099 \pm 0.0015$
$K_L^0 \to \pi^0\pi^0\pi^0$: $h = (0.6 \pm 1.2) \times 10^{-3}$

### $K_L$ decay form factors [e]

Linear parametrization assuming $\mu$-$e$ universality

$\lambda_+(K_{\mu3}^0) = \lambda_+(K_{e3}^0) = (2.82 \pm 0.04) \times 10^{-2}$ (S = 1.1)
$\lambda_0(K_{\mu3}^0) = (1.38 \pm 0.18) \times 10^{-2}$ (S = 2.2)

Quadratic parametrization assuming $\mu$-$e$ universality

$\lambda'_+(K_{\mu3}^0) = \lambda'_+(K_{e3}^0) = (2.40 \pm 0.12) \times 10^{-2}$ (S = 1.2)
$\lambda''_+(K_{\mu3}^0) = \lambda''_+(K_{e3}^0) = (0.20 \pm 0.05) \times 10^{-2}$ (S = 1.2)
$\lambda_0(K_{\mu3}^0) = (1.16 \pm 0.09) \times 10^{-2}$ (S = 1.2)

Pole parametrization assuming $\mu$-$e$ universality

$M_V^\mu\ (K_{\mu3}^0) = M_V^e\ (K_{e3}^0) = 878 \pm 6$ MeV (S = 1.1)
$M_S^\mu\ (K_{\mu3}^0) = 1252 \pm 90$ MeV (S = 2.6)

Dispersive parametrization assuming $\mu$-$e$ universality

$\Lambda_+ = (0.251 \pm 0.006) \times 10^{-1}$ (S = 1.5)
$\ln(C) = (1.75 \pm 0.18) \times 10^{-1}$ (S = 2.0)

$K_{e3}^0$ $|f_S/f_+| = (1.5^{+1.4}_{-1.6}) \times 10^{-2}$
$K_{e3}^0$ $|f_T/f_+| = (5^{+4}_{-5}) \times 10^{-2}$
$K_{\mu3}^0$ $|f_T/f_+| = (12 \pm 12) \times 10^{-2}$

$K_L \to \ell^+\ell^-\gamma$, $K_L \to \ell^+\ell^-\ell'^+\ell'^-$: $\alpha_{K^*} = -0.205 \pm 0.022$ (S = 1.8)
$K_L^0 \to \ell^+\ell^-\gamma$, $K_L^0 \to \ell^+\ell^-\ell'^+\ell'^-$: $\alpha_{DIP} = -1.69 \pm 0.08$ (S = 1.7)
$K_L \to \pi^+\pi^- e^+ e^-$: $a_1/a_2 = -0.737 \pm 0.014$ GeV$^2$
$K_L \to \pi^0 2\gamma$: $a_V = -0.43 \pm 0.06$ (S = 1.5)

### *CP*-violation parameters [n]

$A_L = (0.332 \pm 0.006)\%$

$|\eta_{00}| = (2.220 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\eta_{+-}| = (2.232 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\epsilon| = (2.228 \pm 0.011) \times 10^{-3}$ (S = 1.8)

$|\eta_{00}/\eta_{+-}| = 0.9950 \pm 0.0007$ [q] (S = 1.6)

$\mathrm{Re}(\epsilon'/\epsilon) = (1.66 \pm 0.23) \times 10^{-3}$ [q] (S = 1.6)

Assuming *CPT*

$\phi_{+-} = (43.51 \pm 0.05)^\circ$ (S = 1.2)

$\phi_{00} = (43.52 \pm 0.05)^\circ$ (S = 1.3)

$\phi_\epsilon = \phi_{SW} = (43.52 \pm 0.05)^\circ$ (S = 1.2)

$\mathrm{Im}(\epsilon'/\epsilon) = -(\phi_{00} - \phi_{+-})/3 = (-0.002 \pm 0.005)^\circ$ (S = 1.7)

Not assuming *CPT*

$\phi_{+-} = (43.4 \pm 0.5)^\circ$ (S = 1.2)

$\phi_{00} = (43.7 \pm 0.6)^\circ$ (S = 1.2)

$\phi_\epsilon = (43.5 \pm 0.5)^\circ$ (S = 1.3)

*CP* asymmetry *A* in $K_L^0 \to \pi^+\pi^- e^+ e^- = (13.7 \pm 1.5)\%$

$\beta_{CP}$ from $K_L^0 \to e^+ e^- e^+ e^- = -0.19 \pm 0.07$

$\gamma_{CP}$ from $K_L^0 \to e^+ e^- e^+ e^- = 0.01 \pm 0.11$ (S = 1.6)

*j* for $K_L^0 \to \pi^+\pi^-\pi^0 = 0.0012 \pm 0.0008$

*f* for $K_L^0 \to \pi^+\pi^-\pi^0 = 0.004 \pm 0.006$

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

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

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

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

### *T*-violation parameters

$\mathrm{Im}(\xi)$ in $K^0_{\mu 3} = -0.007 \pm 0.026$

### *CPT* invariance tests

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

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

### $\Delta S = -\Delta Q$ in $K^0_{\ell 3}$ decay

Re $x = -0.002 \pm 0.006$

Im $x = 0.0012 \pm 0.0021$

| $K^0_L$ DECAY MODES | | | Fraction ($\Gamma_i/\Gamma$) | Scale factor/ Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|---|---|
| **Semileptonic modes** | | | | | |
| $\pi^\pm e^\mp \nu_e$ Called $K^0_{e3}$. | | [p] | (40.55 ±0.11 ) % | S=1.7 | 229 |
| $\pi^\pm \mu^\mp \nu_\mu$ Called $K^0_{\mu 3}$. | | [p] | (27.04 ±0.07 ) % | S=1.1 | 216 |
| $(\pi\mu\text{atom})\nu$ | | | ( 1.05 ±0.11 ) × $10^{-7}$ | | 188 |
| $\pi^0\pi^\pm e^\mp \nu$ | | [p] | ( 5.20 ±0.11 ) × $10^{-5}$ | | 207 |
| $\pi^\pm e^\mp \nu e^+ e^-$ | | [p] | ( 1.26 ±0.04 ) × $10^{-5}$ | | 229 |
| **Hadronic modes, including Charge conjugation×Parity Violating (*CPV*) modes** | | | | | |
| $3\pi^0$ | | | (19.52 ±0.12 ) % | S=1.6 | 139 |
| $\pi^+\pi^-\pi^0$ | | | (12.54 ±0.05 ) % | | 133 |
| $\pi^+\pi^-$ | *CPV* | [r] | ( 1.967±0.010) × $10^{-3}$ | S=1.5 | 206 |
| $\pi^0\pi^0$ | *CPV* | | ( 8.64 ±0.06 ) × $10^{-4}$ | S=1.8 | 209 |
| **Semileptonic modes with photons** | | | | | |
| $\pi^\pm e^\mp \nu_e \gamma$ | | [g,p,s] | ( 3.79 ±0.06 ) × $10^{-3}$ | | 229 |
| $\pi^\pm \mu^\mp \nu_\mu \gamma$ | | | ( 5.65 ±0.23 ) × $10^{-4}$ | | 216 |
| **Hadronic modes with photons or $\ell\bar{\ell}$ pairs** | | | | | |
| $\pi^0\pi^0\gamma$ | | | < 2.43 × $10^{-7}$ | CL=90% | 209 |
| $\pi^+\pi^-\gamma$ | | [g,s] | ( 4.15 ±0.15 ) × $10^{-5}$ | S=2.8 | 206 |
| $\pi^+\pi^-\gamma$(DE) | | | ( 2.84 ±0.11 ) × $10^{-5}$ | S=2.0 | 206 |
| $\pi^0 2\gamma$ | | [s] | ( 1.273±0.033) × $10^{-6}$ | | 230 |
| $\pi^0\gamma e^+ e^-$ | | | ( 1.62 ±0.17 ) × $10^{-8}$ | | 230 |
| **Other modes with photons or $\ell\bar{\ell}$ pairs** | | | | | |
| $2\gamma$ | | | ( 5.47 ±0.04 ) × $10^{-4}$ | S=1.1 | 249 |
| $3\gamma$ | | | < 7.4 × $10^{-8}$ | CL=90% | 249 |
| $e^+ e^-\gamma$ | | | ( 9.4 ±0.4 ) × $10^{-6}$ | S=2.0 | 249 |
| $\mu^+\mu^-\gamma$ | | | ( 3.59 ±0.11 ) × $10^{-7}$ | S=1.3 | 225 |
| $e^+ e^-\gamma\gamma$ | | [s] | ( 5.95 ±0.33 ) × $10^{-7}$ | | 249 |
| $\mu^+\mu^-\gamma\gamma$ | | [s] | ( 1.0 $^{+0.8}_{-0.6}$ ) × $10^{-8}$ | | 225 |
| **Charge conjugation × Parity (*CP*) or Lepton Family number (*LF*) violating modes, or $\Delta S = 1$ weak neutral current (*S1*) modes** | | | | | |
| $\mu^+\mu^-$ | *S1* | | ( 6.84 ±0.11 ) × $10^{-9}$ | | 225 |
| $e^+ e^-$ | *S1* | | ( 9 $^{+6}_{-4}$ ) × $10^{-12}$ | | 249 |
| $\pi^+\pi^- e^+ e^-$ | *S1* | [s] | ( 3.11 ±0.19 ) × $10^{-7}$ | | 206 |
| $\pi^0\pi^0 e^+ e^-$ | *S1* | | < 6.6 × $10^{-9}$ | CL=90% | 209 |
| $\pi^0\pi^0\mu^+\mu^-$ | *S1* | | < 9.2 × $10^{-11}$ | CL=90% | 57 |
| $\mu^+\mu^- e^+ e^-$ | *S1* | | ( 2.69 ±0.27 ) × $10^{-9}$ | | 225 |

| | | | | | | |
|---|---|---|---|---|---|---|
| $e^+ e^- e^+ e^-$ | *S1* | ( 3.56 ±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 |
| $\pi^0 \nu \overline{\nu}$ | *CP,S1* | [u] < 2.6 | $\times 10^{-8}$ | CL=90% | | 230 |
| $\pi^0 \pi^0 \nu \overline{\nu}$ | *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 |

## $K^*(892)$

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

$K^*(892)^\pm$ hadroproduced mass $m = 891.76 \pm 0.25$ MeV
$K^*(892)^\pm$ in $\tau$ decays mass $m = 895.5 \pm 0.8$ MeV
$K^*(892)^0$ mass $m = 895.55 \pm 0.20$ MeV (S = 1.7)
$K^*(892)^\pm$ hadroproduced full width $\Gamma = 50.3 \pm 0.8$ MeV
$K^*(892)^\pm$ in $\tau$ decays full width $\Gamma = 46.2 \pm 1.3$ MeV
$K^*(892)^0$ full width $\Gamma = 47.3 \pm 0.5$ MeV (S = 1.9)

| $K^*(892)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|
| $K\pi$ | ~ 100 % | | 290 |
| $K^0\gamma$ | ( 2.46±0.21) $\times 10^{-3}$ | | 307 |
| $K^\pm\gamma$ | ( 1.00±0.09) $\times 10^{-3}$ | | 309 |
| $K\pi\pi$ | < 7 $\times 10^{-4}$ | 95% | 223 |

## $K_1(1270)$

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

Mass $m = 1272 \pm 7$ MeV [v]
Full width $\Gamma = 90 \pm 20$ MeV [v]

| $K_1(1270)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K\rho$ | (42 ±6 ) % | 46 |
| $K_0^*(1430)\pi$ | (28 ±4 ) % | † |
| $K^*(892)\pi$ | (16 ±5 ) % | 302 |
| $K\omega$ | (11.0±2.0) % | † |
| $K f_0(1370)$ | ( 3.0±2.0) % | † |
| $\gamma K^0$ | seen | 539 |

## $K_1(1400)$

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

Mass $m = 1403 \pm 7$ MeV
Full width $\Gamma = 174 \pm 13$ MeV (S = 1.6)

| $K_1(1400)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K^*(892)\pi$ | (94 ±6 ) % | 402 |
| $K\rho$ | ( 3.0±3.0) % | 293 |
| $K f_0(1370)$ | ( 2.0±2.0) % | † |
| $K\omega$ | ( 1.0±1.0) % | 284 |
| $K_0^*(1430)\pi$ | not seen | † |
| $\gamma K^0$ | seen | 613 |

## $K^*(1410)$

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

Mass $m = 1421 \pm 9$ MeV
Full width $\Gamma = 236 \pm 18$ MeV

| $K^*(1410)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|
| $K^*(892)\pi$ | $> 40$ % | 95% | 416 |
| $K\pi$ | ( 6.6±1.3) % | | 617 |
| $K\rho$ | $< 7$ % | 95% | 313 |
| $\gamma K^0$ | $< 2.2 \times 10^{-4}$ | 90% | 623 |

## $K_0^*(1430)$ [x]

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

Mass $m = 1425 \pm 50$ MeV
Full width $\Gamma = 270 \pm 80$ MeV

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

## $K_2^*(1430)$

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

$K_2^*(1430)^\pm$ mass $m = 1425.6 \pm 1.5$ MeV (S = 1.1)
$K_2^*(1430)^0$ mass $m = 1432.4 \pm 1.3$ MeV
$K_2^*(1430)^\pm$ full width $\Gamma = 98.5 \pm 2.7$ MeV (S = 1.1)
$K_2^*(1430)^0$ full width $\Gamma = 109 \pm 5$ MeV (S = 1.9)

| $K_2^*(1430)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | Scale factor/ Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|
| $K\pi$ | (49.9±1.2) % | | 619 |
| $K^*(892)\pi$ | (24.7±1.5) % | | 419 |
| $K^*(892)\pi\pi$ | (13.4±2.2) % | | 372 |
| $K\rho$ | ( 8.7±0.8) % | S=1.2 | 318 |
| $K\omega$ | ( 2.9±0.8) % | | 311 |
| $K^+\gamma$ | ( 2.4±0.5) $\times 10^{-3}$ | S=1.1 | 627 |
| $K\eta$ | ( $1.5^{+3.4}_{-1.0}$) $\times 10^{-3}$ | S=1.3 | 486 |
| $K\omega\pi$ | $<$ 7.2 $\times 10^{-4}$ | CL=95% | 100 |
| $K^0\gamma$ | $<$ 9 $\times 10^{-4}$ | CL=90% | 626 |

## $K^*(1680)$

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

Mass $m = 1718 \pm 18$ MeV
Full width $\Gamma = 322 \pm 110$ MeV (S = 4.2)

| $K^*(1680)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K\pi$ | (38.7±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 |

## $K_2(1770)$ [y]

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

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

| $K_2(1770)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K\pi\pi$ | | 794 |
| $K_2^*(1430)\pi$ | dominant | 288 |
| $K^*(892)\pi$ | seen | 654 |
| $Kf_2(1270)$ | seen | 53 |
| $K\phi$ | seen | 441 |
| $K\omega$ | seen | 607 |

## $K_3^*(1780)$ $I(J^P) = \frac{1}{2}(3^-)$

Mass $m = 1776 \pm 7$ MeV (S = 1.1)
Full width $\Gamma = 159 \pm 21$ MeV (S = 1.3)

| $K_3^*(1780)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | Confidence level | $p$ (MeV/$c$) |
|---|---|---|---|
| $K\rho$ | (31 ± 9 ) % | | 613 |
| $K^*(892)\pi$ | (20 ± 5 ) % | | 656 |
| $K\pi$ | (18.8± 1.0) % | | 813 |
| $K\eta$ | (30 ±13 ) % | | 719 |
| $K_2^*(1430)\pi$ | < 16 % | 95% | 291 |

## $K_2(1820)$ [z] $I(J^P) = \frac{1}{2}(2^-)$

Mass $m = 1819 \pm 12$ MeV
Full width $\Gamma = 264 \pm 34$ MeV

| $K_2(1820)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K_2^*(1430)\pi$ | seen | 329 |
| $K^*(892)\pi$ | seen | 683 |
| $Kf_2(1270)$ | seen | 191 |
| $K\omega$ | seen | 640 |
| $K\phi$ | seen | 483 |

## $K_4^*(2045)$ $I(J^P) = \frac{1}{2}(4^+)$

Mass $m = 2045 \pm 9$ MeV (S = 1.1)
Full width $\Gamma = 198 \pm 30$ MeV

| $K_4^*(2045)$ DECAY MODES | Fraction ($\Gamma_i/\Gamma$) | $p$ (MeV/$c$) |
|---|---|---|
| $K\pi$ | (9.9±1.2) % | 958 |
| $K^*(892)\pi\pi$ | (9 ±5 ) % | 802 |
| $K^*(892)\pi\pi\pi$ | (7 ±5 ) % | 768 |
| $\rho K\pi$ | (5.7±3.2) % | 741 |
| $\omega K\pi$ | (5.0±3.0) % | 738 |
| $\phi K\pi$ | (2.8±1.4) % | 594 |
| $\phi K^*(892)$ | (1.4±0.7) % | 363 |

## 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 $K \to 3\pi$ Dalitz plot is as follows (see also "Note on Dalitz Plot Parameters for $K \to 3\pi$ Decays" in the $K^{\pm}$ Particle Listings):

$$|M|^2 = 1 + g(s_3 - s_0)/m^2_{\pi^+} + \cdots .$$

[*d*] See the "Note on $\pi^{\pm} \to \ell^{\pm}\nu\gamma$ and $K^{\pm} \to \ell^{\pm}\nu\gamma$ Form Factors" in the $\pi^{\pm}$ Particle Listings 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 $\gamma$ part, is also included in the parent mode listed without $\gamma$'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 $\phi_{+-}$, $\phi_{00}$, $|\eta|$, $|m_{K^0_L} - m_{K^0_S}|$, and $\tau_{K^0_S}$, 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 $K_S \to 3\pi$" and "Note on *CP* Violation in $K^0_L$ Decay" in the Particle Listings):

$$\eta_{+-} = |\eta_{+-}|e^{i\phi_{+-}} = \frac{A(K^0_L \to \pi^+\pi^-)}{A(K^0_S \to \pi^+\pi^-)} = \epsilon + \epsilon'$$

$$\eta_{00} = |\eta_{00}|e^{i\phi_{00}} = \frac{A(K^0_L \to \pi^0\pi^0)}{A(K^0_S \to \pi^0\pi^0)} = \epsilon - 2\epsilon'$$

$$\delta = \frac{\Gamma(K^0_L \to \pi^-\ell^+\nu) - \Gamma(K^0_L \to \pi^+\ell^-\nu)}{\Gamma(K^0_L \to \pi^-\ell^+\nu) + \Gamma(K^0_L \to \pi^+\ell^-\nu)} ,$$

$$\mathrm{Im}(\eta_{+-0})^2 = \frac{\Gamma(K^0_S \to \pi^+\pi^-\pi^0)^{CP \text{ viol.}}}{\Gamma(K^0_L \to \pi^+\pi^-\pi^0)} ,$$

$$\mathrm{Im}(\eta_{000})^2 = \frac{\Gamma(K^0_S \to \pi^0\pi^0\pi^0)}{\Gamma(K^0_L \to \pi^0\pi^0\pi^0)} .$$

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

[*o*] See the $K^0_S$ 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*] $\mathrm{Re}(\epsilon'/\epsilon) = \epsilon'/\epsilon$ 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 $K^0_L \to \pi^+\pi^-\gamma$(DE).

[*s*] See the $K^0_L$ 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*] This is only an educated guess; the error given is larger than the error on the average of the published values. See the Particle Listings for details.

[*x*] See the "Note on $f_0(1370)$" in the $f_0(1370)$ Particle Listings and in the 1994 edition.

[*y*] See the note in the $L(1770)$ Particle Listings in Reviews of Modern Physics **56** S1 (1984), p. S200. See also the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings .

[*z*] See the "Note on $K_2(1770)$ and the $K_2(1820)$" in the $K_2(1770)$ Particle Listings .