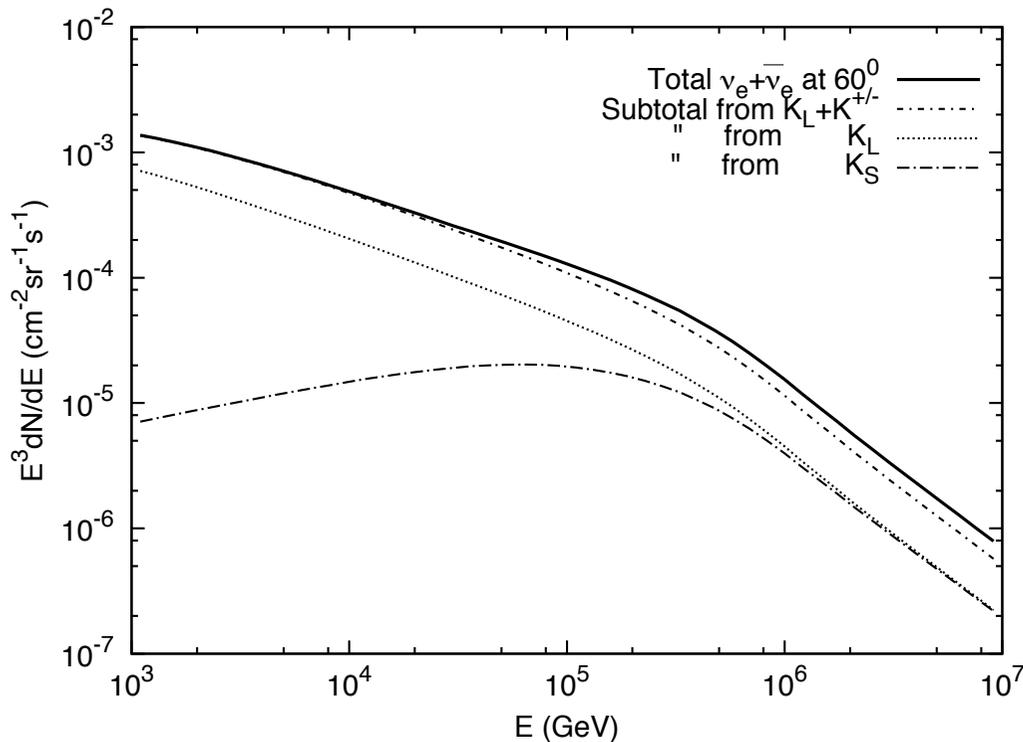TG & Spencer Klein, 1409.4924

K_S contribution to atmospheric ν_e

A previously neglected contribution
to atmospheric electron neutrinos
becomes significant for $E_\nu > 100$ TeV

Calculation (accounts for knee in primary spectrum)

$$\phi_\nu(E_\nu) = \phi_N(E_\nu) \times \left\{ \frac{Z_3\, b_{K+e3}(Z_{NK+} + Z_{NK-})}{1 + B_3 \cos\theta\, E_\nu/\epsilon_K} \right.$$

$$+ \frac{Z_3\, b_{K_L e3} Z_{NK_L}}{1 + B_3^* \cos\theta\, E_\nu/\epsilon_{K_L}}$$

$$\left. + \frac{Z_3\, b_{K_S e3} Z_{NK_S}}{1 + B_3 \cos\theta\, E_\nu/\epsilon_{K_S}} \right\}.$$

$$B_3 \approx \frac{0.134}{0.061}\left(\frac{\Lambda_K - \Lambda_N}{\Lambda_K \ln \frac{\Lambda_K}{\Lambda_N}}\right)$$

Branching fractions and lifetimes

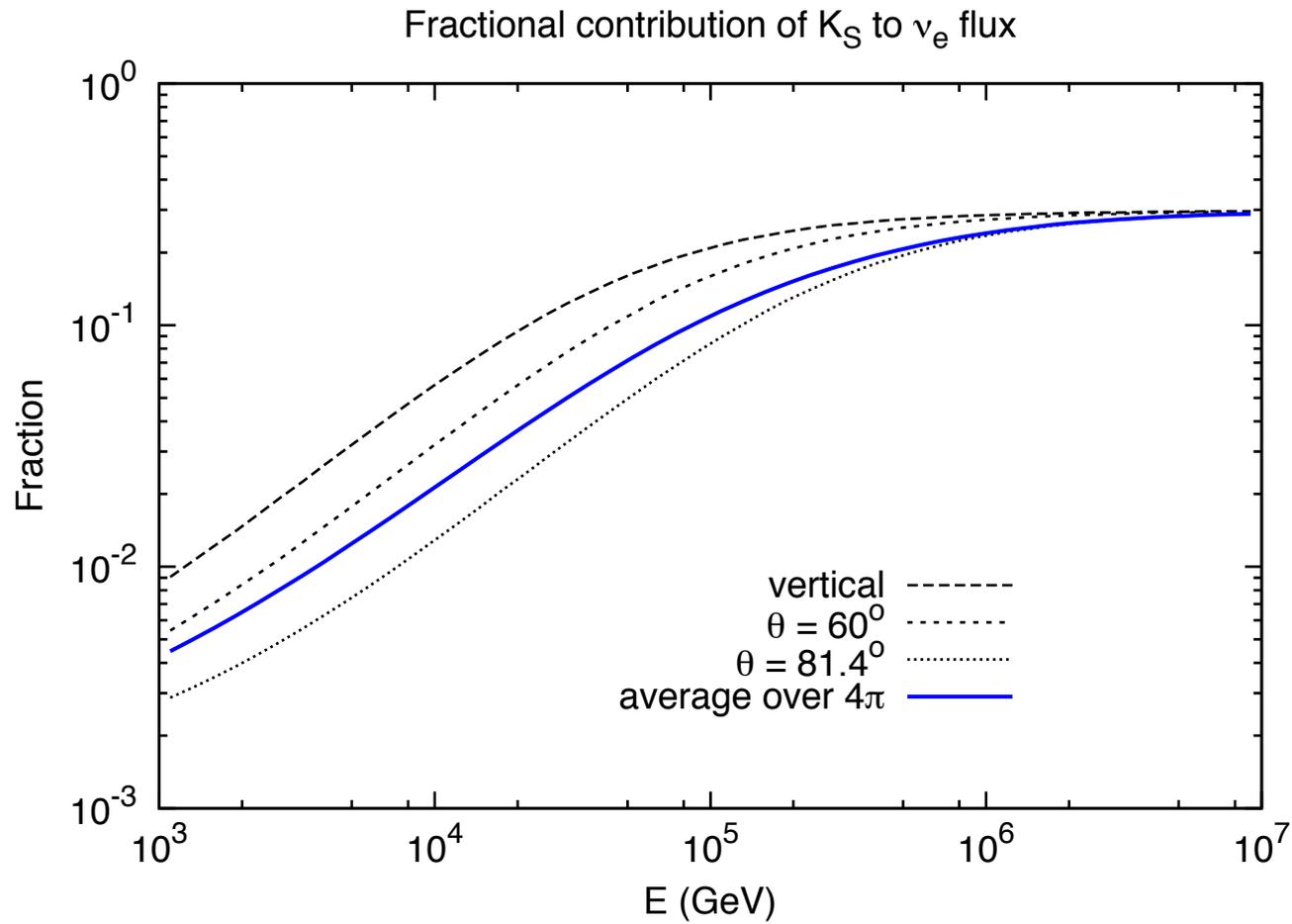| Type	Mass (MeV)	Br($K \to \pi e \nu$) (%)	Lifetime (s)	Characteristic energy (GeV)
K^+	493.6	5.04	1.24×10^{-8}	850
K_L^0	497.6	40.55	5.12×10^{-8}	210
K_S^0	497.6	0.07	0.90×10^{-10}	120,000
Charm	≈ 1800		$\approx 10^{-12}$	$\approx 4 \times 10^7$

$$\epsilon_{K_S} = \frac{m_K c^2 h_0}{c \tau_S} \approx 120 \text{ TeV}$$

$$
\begin{aligned}
\frac{\phi(\nu_e \text{from} K_S)}{\phi(\nu_e \text{from} K_L)} &= \frac{Br(K_S \to \pi e \nu)}{Br(K_L \to \pi e \nu)} \frac{\epsilon_{K_S}}{\epsilon_{K_L}} \\
&= \frac{\Gamma_{SL}(K_S)/\Gamma_{Tot}(K_S)}{\Gamma_{SL}(K_L)/\Gamma_{Tot}(K_L)} \frac{(1/\tau_{K_S})}{(1/\tau_{K_L})} = 1.
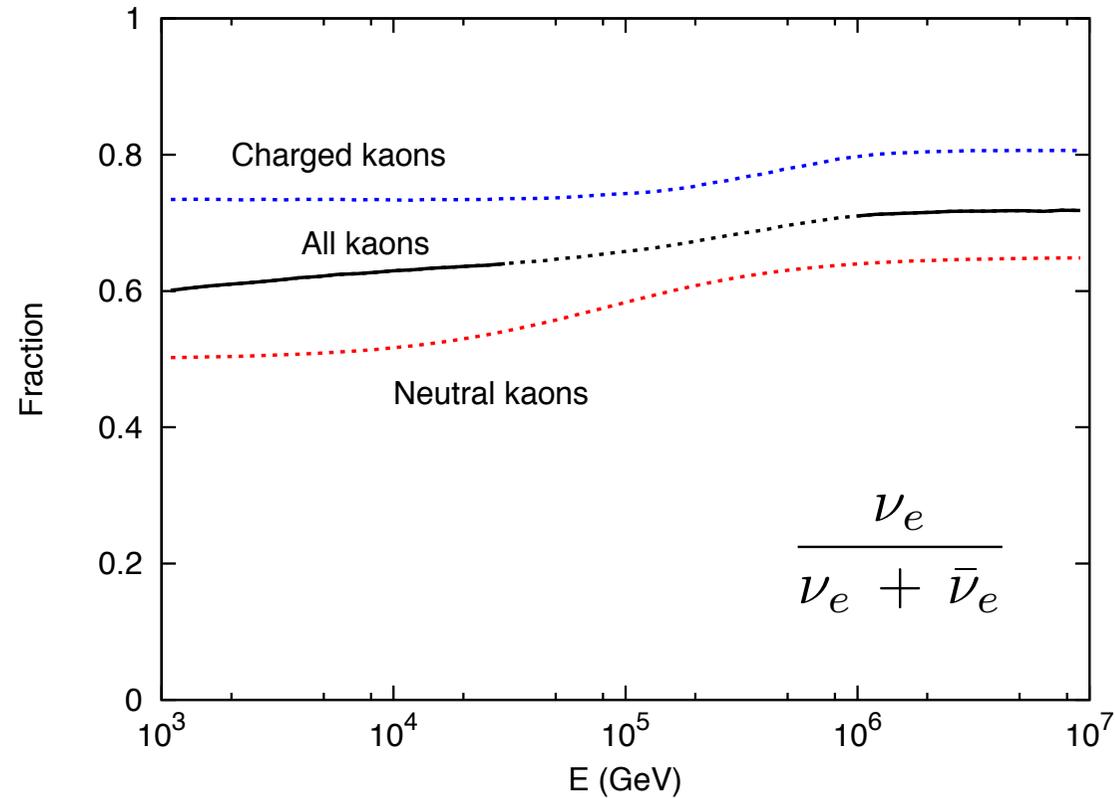\end{aligned}
$$

Implications (Pointed out recently by S.K.):
- Spectrum of ν_e from rare Ke3 decay of K_S has spectrum harder by one power of E than ν_e from K_L until > 100 TeV
- Contribution of K_S and K_L are equal for E_ν > 120 TeV / cos(θ)

Fraction from K_S

Fractional contribution of K_S to ν_e flux

- vertical
- $\theta = 60^o$
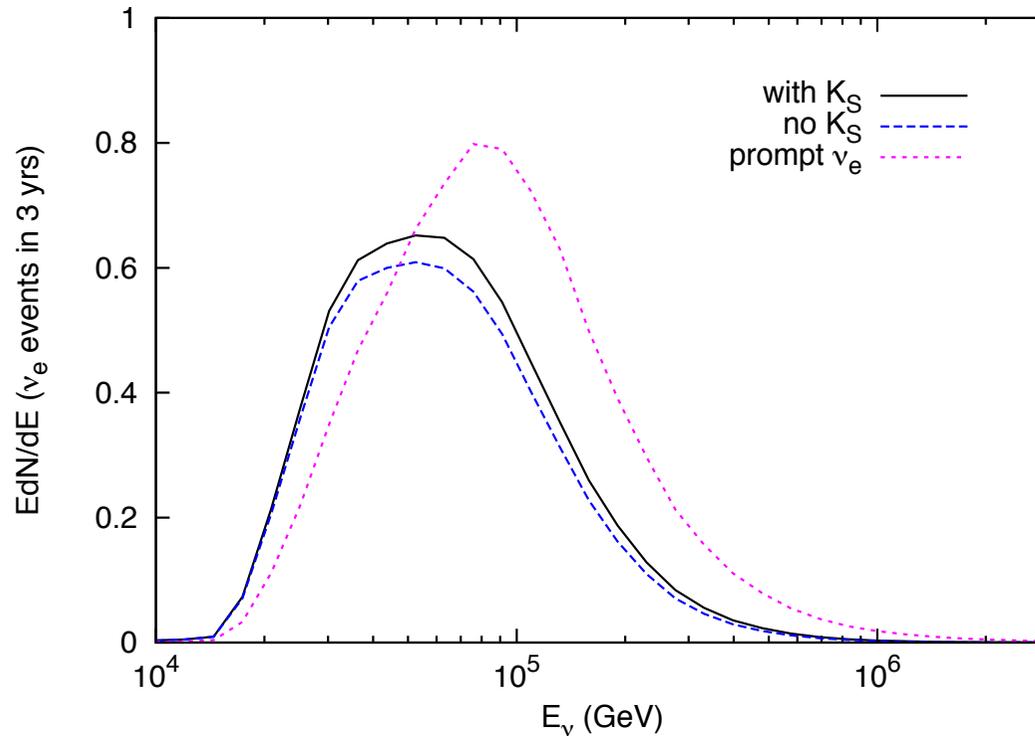- $\theta = 81.4^o$
- average over 4π

Neutrino/anti-neutrino ratio

- Increase for neutral kaon reflects incomplete oscillations at high energy (D. Seckel)
- Increase for charged kaons because knee has less effect on the harder K$^+$ spectrum

Electron neutrino background in IceCube

- Contribution to the conventional atmospheric ν_e background increased by <10%
- (0.96 → 1.05 events in three years of HESE analysis)
- This background is small in any case, perhaps comparable or smaller the prompt ν_e

Summary

- Atmospheric ν_e from Ke3 decay of K_S
  - Negligible for $E_\nu < 100$ TeV
  - Needs to be accounted for when $E_\nu > 100$ TeV
  - $\dfrac{\nu_e}{\nu_e + \bar{\nu}_e}$ ratio depends on energy