Other aspects of K-decays

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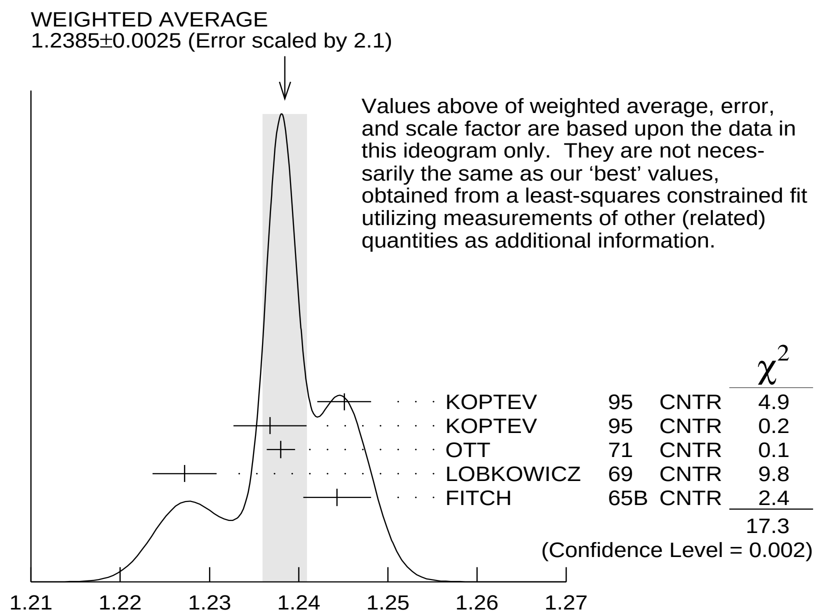
Topics

- Motivations
- CPT tests and improvements in Bell-Steinberger relation
- Charge asymmetries
- μ-Polarization in $K_L \to \mu\bar{\mu}$
- μ-Polarization in $K^+ \to \pi^0 \mu^+ \nu$
- Conclusions

Important K-physics still to be done



τ_{K^+} measured:

in flight (left) or at rest

KLOE $\Longrightarrow$ τ_{K^+} in flight

$|V_{us}|$: 2.2 σ 's discrepancy from unitarity reconciliated

$C\not{P}T$ tests in semileptonic decays

$$\delta_{S,L} = \frac{\Gamma^{l^+}_{S,L} - \Gamma^{l^-}_{S,L}}{\Gamma^{l^+}_{S,L} + \Gamma^{l^-}_{S,L}} = 2\Re(\epsilon_{S,L}) + 2\Re\left(\frac{b}{a}\right) \mp 2\Re\left(\frac{d^*}{a}\right)$$

- $\epsilon_{S,L} = \epsilon \mp \Delta$ $\qquad \Delta = \frac{\frac{1}{2}\left[M_{K^0} - M_{\bar{K}^0} - \frac{i}{2}\left(\Gamma_{K^0} - \Gamma_{\bar{K}^0}\right)\right]}{m_L - m_S + i(\Gamma_S - \Gamma_L)/2}$
- a (CPT conserving) $\qquad b$, d ($C\not{P}T$) semileptonic amplitudes
- Δ $\qquad C\not{P}T$ in the mass
- $\delta_S - \delta_L \propto \Re\Delta, \Re d^* \Longrightarrow$ accurate determination of δ_S required.

$C\not{P}T$ in $K \to \pi\pi$

$$A(K^0 \to \pi\pi(I)) \equiv (A_I + B_I)e^{i\delta_I}$$
$$A(\bar{K}^0 \to \pi\pi(I)) \equiv (A_I^* - B_I^*)e^{i\delta_I}$$

- B_I is $C\not{P}T$ as $\left(\eta_{+-}=|\eta_{+-}|e^{i\phi_{+-}} \quad \eta_{00}=|\eta_{00}|e^{i\phi_{00}}\right)$

$$\phi_{+-} - \phi_{00} = (0.22 \pm 0.45)^o$$ KTEV,NA48

TH $\mathcal{O}(\epsilon'/\epsilon)$

Bell-Steinberger relation and $C\not{P}T$

- Even if $C\not{P}T$ unitarity must be valid. Then $|K(t)\rangle = a_S|K_S\rangle + a_L|K_L\rangle$

$$-\frac{d}{dt}|\langle K(0)|K(0)\rangle|^2 = \sum_f |a_S A(K_S \to f) + a_L A(K_L \to f)|^2 \Longrightarrow$$

$$(1 + i\tan\varphi_{SW})\,[\Re(\epsilon_M) - i\Im(\Delta)] = \sum_f \alpha_f$$

- $\alpha_f = B^S_{+-}\eta_{+-},\ B^S_{00}\eta_{00},\ B^S_{+-\gamma}\eta_{+-\gamma},\ \frac{\tau_L}{\tau_S}B^L_{000}\eta_{000}, ..$
- $\varphi_{SW},\ \epsilon_M,\ \alpha_{\pi\pi},\ \alpha_{\pi\pi\gamma},\ \alpha_{000} \Longrightarrow \Im(\Delta)$ Maiani,Thomson-Zou,KTEV,NA48

New Limits from NA48

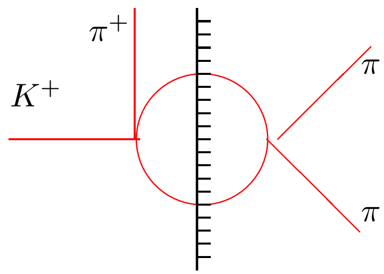
- SM $B_{000}^S = 1.9 \cdot 10^{-9}$
- CPLEAR ($B_{000}^S < 1.4 \cdot 10^{-5}$) $\Longrightarrow \Im(\Delta) = (4.5 \pm 5.0) \times 10^{-5}$
- NA48 ($B_{000}^S < 3 \cdot 10^{-7}$) $\Longrightarrow \Im(\Delta) = (-1.2 \pm 3.0) \times 10^{-5}$

  $\Longrightarrow M_{K^0} - M_{\bar{K}^0} = (-1.7 \pm 4.2) \cdot 10^{-19} GeV$
- KLOE ($B_{000}^S < 2.1 \cdot 10^{-7}$) (preliminary)
- To further improve we have to determine better $\phi_{+-} - \phi_{00}$

CP violation in in $K^{\pm} \to 3\pi$

- Dalitz distribution in X,Y $\quad |A(K^{\pm} \to 3\pi)|^2 \sim 1 + g_{\pm}\, Y + j_{\pm}\, X$
- we can define the slope asymmetry $\Delta g/2g = (g_+ - g_-)/(g_+ + g_-)$
- Isospin+rescattering: $\quad A(K^+ \to \pi^+\pi^+\pi^-) = a e^{i\alpha_0} + b e^{i\beta_0} Y$

Final State Interaction



Zeldovich,Grinstein et al
Isidori,Maiani,Pugliese

Compared to $K \to \pi\pi$

- two $\Delta I = 1/2$ transitions (a, b)
- final state small ($\alpha_0, \beta_0 \sim 0.1$)

- $\mathcal{O}(p^4)$ necessary for the slopes ($\frac{\Delta a}{a} \sim \frac{\Delta b}{b} \sim 30\%$) and for $\Delta g/2g \neq 0$

$$\Downarrow$$

- splitting $a = a^{(2)} + a^{(4)}$ and $b = b^{(2)} + b^{(4)}$ G.D.,Isidori,Paver

$$\frac{\Delta g}{2g} = \frac{\Im A^0}{\Re A^0} \ (\alpha_0 - \beta_0) \left(\frac{\Re b^{(4)}}{\Re b^{(2)}} - \frac{\Im b^{(4)}}{\Im b^{(2)}} + \frac{\Im a^{(4)}}{\Im a^{(2)}} - \frac{\Re a^{(4)}}{\Re a^{(2)}} \right)$$

$$\left|\frac{\Im A^0}{\Re A^0}\right| \sim 22\epsilon' \sim 10^{-4} \qquad (\alpha_0 - \beta_0) \sim 0.1$$

- to maximize Δg, we take $\mathcal{O}(p^4) \sim \mathcal{O}(p^2) \Longrightarrow \Delta g/2g \leq 10^{-5}$

- $(-2.4 \pm 1.2) \cdot 10^{-5}$ Prades et al

New Physics to have large $\Delta g/2g$

- an operator which affects $K \to 3\pi$ but not $K \to 2\pi$, limited by expt. size of ϵ'

- Actually Masiero- Murayama:new flavour structures to only the $\Delta S = 1$ and not $\Delta S = 2$

$$(\delta^D_{LR})_{ij} = (M^2_D)_{i_L j_R}/m^2_{\tilde{q}}$$

- Through the gluino box diagram

$$C^{\pm}_g(m_{\tilde{g}}) = \frac{\pi\alpha_s(m_{\tilde{g}})}{m_{\tilde{g}}}\left[\left(\delta^D_{LR}\right)_{21} \pm \left(\delta^D_{LR}\right)^*_{12}\right] G_0(x_{gq})$$

$$\mathcal{H}_{\rm mag} = C^+_g Q^+_g + C^-_g Q^-_g + {\rm h.c.}$$

$$Q_g^{\pm} = \frac{g}{16\pi^2}\left(\bar{s}_L\sigma^{\mu\nu}t^aG^a_{\mu\nu}d_R \pm \bar{s}_R\sigma^{\mu\nu}t^aG^a_{\mu\nu}d_L\right)$$

- Q_g^+ is affects only $K \to 3\pi$; Q_g^- only $K \to 2\pi$

G.D,Isidori,Martinelli

- As a result by tuning properly $C_g^{\pm}$ we can generate large $\Delta g/2g$ $(\leq 10^{-4})$

- NA48/2 will measure

$$\frac{\Delta g}{2g} \quad \overset{\rm NA48}{<} 10^{-4} \quad \overset{\rm SM}{<} 10^{-5} \quad \overset{\rm PDG}{<} 7\cdot 10^{-3} \quad \overset{\rm NP}{<} 10^{-4}$$

$$K(p_K) \to \pi(p_1)\pi(p_2)\gamma(q)$$

- Lorentz + gauge invariance $\Rightarrow$ Electric (E) and Magnetic(M) amplitude

$$A(K \to \pi\pi\gamma) = F^{\mu\nu}\left[E\partial_\mu K \partial_\nu \pi + M\varepsilon_{\mu\nu\rho\sigma}\partial^\rho K \partial^\sigma \pi\right]$$

- Unpolarizated photons

$$\frac{d^2\Gamma}{dz_1 dz_2} \sim |E|^2 + |M|^2$$

$$|E^2| = |E_{IB}|^2 + 2Re(E^*_{IB}E_D) + |E_D|^2$$

$$\downarrow$$

Low Theorem $\Rightarrow E_{IB} \sim \frac{1}{E^*_\gamma} + \text{c}$ E_D, M chiral tests

We need FIGHT DE/IB$\sim 10^{-3}$

	IB	DE_{exp}	
$K_S \to \pi^+\pi^-\gamma$	10^{-3}	$< 9 \cdot 10^{-5}$	$E1$
$K^+ \to \pi^+\pi^0\gamma$	10^{-4} $(\Delta I = \frac{3}{2})$	$(0.472 \pm 0.077)10^{-5}$ E787	$M1$,$E1$
$K_L \to \pi^+\pi^-\gamma$	10^{-5} (CPV)	$(2.92 \pm 0.07)10^{-5}$ KTeVnew	$M1$, VMD

CPV is only from IB K_L (also measured in $K_L \to \pi^+\pi^-e^+e^-$)

BUT IB suppressed in K^+ and K_L.

$K^+ \to \pi^+\pi^0\gamma$: attempts to measure interf. $E1$ with E_{IB}

- E1 and M1 distinguished by Dalitz plot analysis.

$$\frac{\partial^2\Gamma}{\partial T_c^* \partial W^2} = \frac{\partial^2\Gamma_{IB}}{\partial T_c^* \partial W^2}\left[1 + \frac{m_{\pi^+}^2}{m_K} 2Re\left(\frac{E1}{eA}\right) W^2 + \frac{m_{\pi^+}^4}{m_K^2}\left(\left|\frac{E1}{eA}\right|^2 + \left|\frac{M1}{eA}\right|^2\right) W^4\right]$$

$$W^2 = (q \cdot p_K)(q \cdot p_+)/(m_\pi^2 m_K^2) \qquad A = A(K^+ \to \pi^+\pi^0)$$

- E787 has measured Re$\left(\frac{E1}{E_{IB}}\right) \sim (-0.4 \pm 1.6)\%$ (TH. expected)

- These Dalitz variables allow to select interf. $E1$ with E_{IB}

CP asymmetry

- In the asymmetry in the slope, $\dfrac{\partial^2\Gamma^\pm}{\partial T_c^* \partial W^2}$ select a favourable kin. region (large W^2)

- This asymm., Ω, in extensions of SM $\sim \mathcal{O}(10^{-4})$ Colangelo et al.

- SM $\leq \mathcal{O}(10^{-5})$ Paver et al.

- Assuming the expts. are almost seeing the CP conserving $E1$ Statistics seems tough

- Similar analysis for CPV in K_L: but time interf. required

μ-Polarization in $K_L \to \mu\bar{\mu}$

- $P_L = \frac{N_R - N_L}{N_R + N_L} \overset{\mathrm{SM}}{<} 2 \cdot 10^{-3}$ Herczek,Ecker and Pich
- Left-Right Models and leptoquark exchange may generate $P_L \sim \mathcal{O}(10^{-2}, 10^{-1})$ Hewett,Rizzo,Thomas
- $B(K_L \to \mu\bar{\mu}) = (7.27 \pm 0.14) \cdot 10^{-9}$ PDG
- E871 looked for $K_L \to \mu e$ and found also 6,200 $K_L \to \mu\bar{\mu}$, if instead optimized for $K_L \to \mu\bar{\mu}$ maybe 20,000 evts.$K_L \to \mu\bar{\mu}$ Diwan

μ-Polarization in $K^+ \to \pi^0 \mu^+ \nu$

- $\langle P_\perp \rangle \sim \langle \vec{s_\mu} \cdot (\vec{p_\mu} \times \vec{p_\pi}) \rangle$ is T-odd, $\Longrightarrow$ CP violation

- FSI $\langle P_\perp \rangle \sim 10^{-6}$ Zhitniskii,Hiller-Isidori

$$M_{K_{\mu 3}} = G_F \sin\theta_c f_+(q^2)[p_\alpha \overline{u_\mu} \gamma^\alpha (1-\gamma_5) u_{\nu_\mu} + f_s(q^2) m_\mu \overline{u_\mu} (1-\gamma_5) u_{\nu_\mu}]$$

$$\langle P_\perp \rangle \sim 0.2 \quad Im(f_s)$$

- Bounds on models $\langle P_\perp \rangle \leq 10^{-2}$ Peccei

  but interesting models (multi-Higgs, leptoquarks) $\langle P_\perp \rangle \sim 10^{-4}$ Garisto-Kane

- KEK E246 $\langle P_\perp \rangle < 5 \cdot 10^{-3}$

Conclusions

- Left-over:
  - μ-Polarization in $K^+ \to \pi^+\mu^+\mu^-$ and $K^+ \to \mu^+\nu\gamma$
  - $K_L \to \pi^+\pi^-e^+e^-$
  - $K_L \to \mu e$
- Missing energy in the final states, $K^+ \to \pi^+ P$, Sgoldstino-like
- More on time interference
- Chiral tests