Kaons (23 papers and 44 measurements)

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- K_S
- K^+, cusp effect in $K \to 3\pi$
- K_L
- K^0 and Minireview by Mario Antonelli and G.D. help by KLOE coll.

K_S

- KLOE $B(K_S \to \gamma\gamma)$
- KLOE bound $B(K_S \to e^+e^-) < 9 \times 10^{-9} \quad 90\%\ CL$

K^+

- KLOE CP-asymmetry from lifetime asymm $\frac{\tau_K^+ - \tau_K^-}{\tau_{\rm ave}}$
- KLOE $\frac{\Gamma(K^+ \to e\nu)}{\Gamma(K^+ \to \mu\nu)}$, $\frac{\Gamma(K^+ \to e\nu\gamma)}{\Gamma(K^+ \to \mu\nu)}$, $\frac{\Gamma(K^+ \to \pi^+\pi^0)}{\Gamma(K^+}$
- Previous B787 expt. (Adler 00B) $\Gamma(K^+ \to e\nu\gamma)_{SD}$ inserted
- B949 $B(K^+ \to \nu\bar{\nu}) = (0.173^{+0.115}_{-0.105}) \times 10^{-9}$ more complete Kin. region

$$K^+ \to \pi^+\pi^0\pi^0$$

- This decay, the coupled one, $K^+ \to \pi^+\pi^+\pi^-$ and also $K_L \to 3\pi$ have been attracted a lot of attention: the slopes have been discussed in different models and form factors

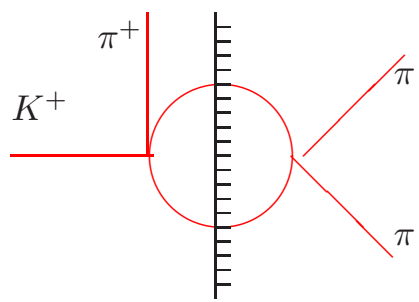
- This is particularly relevant since allow a different measurement of the $\pi\pi$ -scattering length to be compared with the one extracted in K_{e4}

- Why so many form ff 's? Are they useful?

a_0, a_2 from $K \to 3\pi$ rescattering; Cabibbo,Cabibbo-Isidori, Bern Group

- rescattering generates an absorptive contribution proportional to the scattering lenghts a_0, a_2

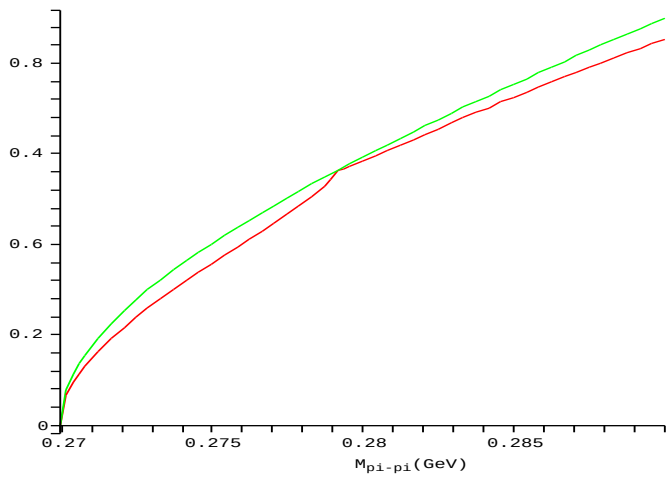
Final State Interaction



Zeldovich,Grinstein et al
Isidori,Maiani,Pugliese

The amplitude T(s) has a critical behaviour near $\pi\pi$ threshold: NA48 good energy resolution$\Longrightarrow a_0, a_2$

a_0, a_2 Cabibbo,Cabibbo-Isidori



- No cusp with cusp
- cusp: opening of the $\pi^+\pi^-$-threshold
- Rescattering $\pi^+\pi^- \to \pi^0\pi^0$ proportional to $a_0 - a_2 \Longrightarrow$

$$\left.\frac{d\Gamma(K^+ \to \pi^+\pi^0\pi^0)}{dM_{\pi^0\pi^0}}\right|_{\mathrm{NA48}} \Rightarrow \mathrm{cusp\,for} M_{\pi^0\pi^0} = M_{\pi^+\pi^-}$$

$$\stackrel{\mathrm{cusp}}{\Rightarrow} a_0 - a_2.$$

Form factors

- Try to have an optimal form factor to extract properly a_0, a_2: 3 ff's
- i) Cabibbo parameterization: only the linear slopes
- ii) Cabibbo Isidori: up to quadratic slopes but phenomenological
- iii) Bern approach: non-relativistic EFT
- we have encoded all, waiting for the final jury

K_L

- KTeV $B(K_L \to \pi^0\gamma\gamma)$ reanalysis a_V
- K391 $K_L \to \pi^0\nu\bar{\nu}$, $K_L \to \pi^0\pi^0\nu\bar{\nu}$
- KTeV rare searches - lepton violations $K_L \to \pi^0\pi^0\mu^\pm e^\mp$

K_L KTeV quadratic slope in $K_L \to \pi^0\pi^0\pi^0$

- Previously No cusp

  NA48 $(-6.1 \pm 0.9 \pm 0.5) \cdot 10^{-3}$ LAI 01B

  E731 $(-3.3 \pm 1.1 \pm 0.7) \cdot 10^{-3}$ Somalwar 92

- KTeV fit with the cusp, input $(a0 - a2)$

  KTeV $(0.59 \pm 0.2 \pm 1.16) \cdot 10^{-3}$

- KTeV has a syst external error from $(a0 - a2)$

- usual problem particularly critical here: remove old measurements?

CPT Invariance tests in Neutral Kaon Decay

Minireview by Mario Antonelli and G.D. help by KLOE coll.

- Hermiticity of the Hamiltonian (probabilty conservation), QFT
- Locality
- Lorentz invariance

$\Longrightarrow$ CPT conservation

CPT violated at the Plank scale

- Quantum gravity may lead to CPT violation
- The low energy limit not known
- Interesting probe

$$|M_K - M_{\bar{K}}| < 10^{-18} M_K$$

$\not{CPT}$ in the K's mass matrix

$$\text{Diagonalize} \quad \begin{pmatrix} M_{11} - i\Gamma_{11}/2 & M_{12} - i\Gamma_{12}/2 \\ M_{21} - i\Gamma_{21}/2 & M_{22} - i\Gamma_{22}/2 \end{pmatrix}$$

$$K_{S,L} = \frac{1}{\sqrt{2\left(1 + |\epsilon_{S,L}|^2\right)}} \left[\left(1 + \epsilon_{S,L}\right) K^0 \pm \left(1 - \epsilon_{S,L}\right) \bar{K}^0\right]$$

$$\begin{aligned} \epsilon_{S,L} &= \frac{-i\Im\left(M_{12}\right) - \frac{1}{2}\Im\left(\Gamma_{12}\right) \mp \frac{1}{2}\left[M_{11} - M_{22} - \frac{i}{2}\left(\Gamma_{11} - \Gamma_{22}\right)\right]}{m_L - m_S + i(\Gamma_S - \Gamma_L)/2} \\ &= \epsilon \mp \delta \end{aligned}$$

$$\epsilon \equiv |\epsilon| e^{i\varphi_{SW}} \qquad \tan\varphi_{SW} = \frac{2(m_L - m_S)}{\Gamma_S - \Gamma_L} \simeq 43.5^o$$

Challenge

$$\epsilon_{S,L} = \frac{-i\Im\left(M_{12}\right) - \frac{1}{2}\Im\left(\Gamma_{12}\right) \mp \frac{1}{2}\left[M_K - M_{\bar{K}} - \frac{i}{2}\left(\Gamma_K - \Gamma_{\bar{K}}\right)\right]}{m_L - m_S + i(\Gamma_S - \Gamma_L)/2}$$

$$= \epsilon \mp \delta$$

$$\frac{M_K - M_{\bar{K}}}{M_K} \sim 3 \times 10^{-14}\ \Im(\delta) \sim \frac{m_K}{m_{Pl}}$$

Unitarity must be valid even if $\not{CPT}$ in the K's mass matrix

$$i\frac{d}{dt}\begin{bmatrix} K^0 \\ \bar{K}^0 \end{bmatrix} = [M - i\Gamma/2]\begin{bmatrix} K^0 \\ \bar{K}^0 \end{bmatrix}$$

For any superposition of K_S, K_L mass and width eigenstates

$$|\Psi\rangle = a|K_S\rangle + b|K_L\rangle$$

$$\sum_{\Gamma} \mid \langle \Gamma \mid T \mid \Psi \rangle \mid^2 = -\frac{d}{d\tau} \mid \Psi \mid^2$$

Bell Steinberger relations

$$\overset{\text{input}}{\left[\frac{\Gamma_S+\Gamma_L}{\Gamma_S-\Gamma_L}+i\tan\phi_{\rm SW}\right]}\overset{\text{output}}{\left[\frac{\Re(\epsilon)}{1+|\epsilon|^2}-i\Im(\delta)\right]}=\frac{1}{\Gamma_S-\Gamma_L}\sum_f \overset{\text{input}}{A_L(f)}\overset{(\alpha_f)}{A_S^*(f)}$$

$f=\pi\pi,\quad \pi l\nu,\quad \pi\pi\pi,..$

CPLEAR, NA48, KLOE, PDGfit, KTEV

Actual SM expectations for Bell Steinberger relations

Channel	$B(K_S)$	$B(K_L)$	$10^5\ \alpha_f^{\rm SM}$
$\pi^+\pi^-(\gamma)$	0.69	2.1×10^{-3}	$110.8+105.1i$
$\pi^0\pi^0$	0.31	9.3×10^{-3}	$49.2+46.6i$
$\pi^\pm e^\mp\nu$	6.7×10^{-4}	0.39	$0.22+0.00i$
$\pi^\pm\mu^\mp\nu$	4.7×10^{-4}	0.27	$0.17+0.00i$
$\pi^0\pi^0\pi^0$	1.9×10^{-9}	0.21	$0.06+0.06i$
$\pi^+\pi^-\pi^0$	2.7×10^{-7}	0.12	$0.04+0.04i$
$\pi^+\pi^-\gamma_{\rm DE}$	10^{-5}	10^{-5}	<0.01

α_f determinations for Bell Steinberger relations

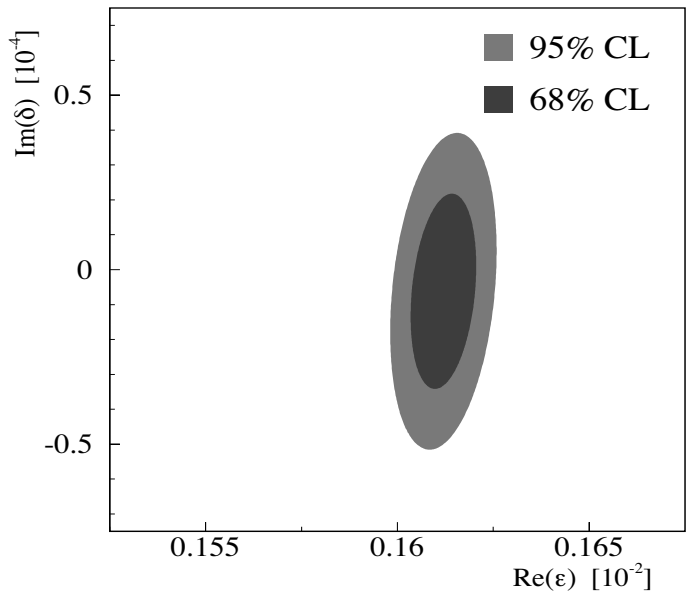
- CPLEAR, NA48, KLOE have improved a lot $f = \quad \pi l \nu, \quad \pi\pi\pi, ..$

- Now major source of error from $f = \pi\pi$ ϕ_{+-}, ϕ_{00}, in our review taken from PDGfit

$$\phi_{+-} = (43.4 \pm 0.7)^o, \ \phi_{00} = (43.7 \pm 0.8)^o$$

- KTeV preliminary $\phi_{+-} = (43.6 \pm 0.5)^o, \ \phi_{00} = (43.7 \pm 0.6)^o$ (we have updated our review)

Bell-Steinberger determination



- $\Re(\epsilon) = (161.2 \pm 0.6) \times 10^{-5}, \Im(\delta) = (-0.6 \pm 1.9) \times 10^{-5}$
- + KTeV $\Re(\epsilon) = (161.2 \pm 0.6) \times 10^{-5}, \quad \Im(\delta) = (-0.6 \pm 1.4) \times 10^{-5}$

Bell-Steinberger determination

Unitarity so allows

$$-5.1 \times 10^{-19}\ \mathrm{GeV} < m_{K^0} - m_{\overline{K}^0} < 5.1 \times 10^{-19}\ \mathrm{GeV} \quad 95\%\mathrm{CL}$$

and with KTeV

$$-4 \times 10^{-19}\ \mathrm{GeV} < m_{K^0} - m_{\overline{K}^0} < 4 \times 10^{-19}\ \mathrm{GeV} \quad 95\ \%\mathrm{CL}$$