THE STANDARD MODEL PREDICTION FOR ε'/ε

OUTLINE

- FSI IN KAON DECAYS
  - CONCEPTS
  - THE OMNES PROBLEM
  - PION SCALAR FORM FACTOR
  - $K \to \pi\pi$ AMPLITUDES
- SM ESTIMATE OF ε'/ε

REFS. :

A. PICH, E.P. hep-ph/9911233 PRL 84 (2000)

E.P. hep-ph/0007017

A. PICH, E.P. hep-ph/0007208

A. PICH, I. SCIMEMI, E.P. to appear

The present experimental world average is

$$\mathrm{Re}(\varepsilon'/\varepsilon) = (19.3 \pm 2.4) \times 10^{-4}$$

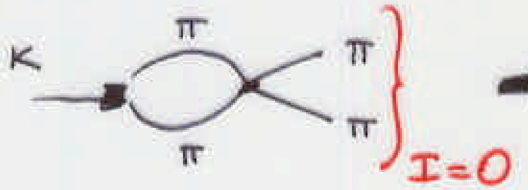
SM predictions are sistematically below

$$(\varepsilon'/\varepsilon)_{SM} \simeq 7 \times 10^{-4} \pm \; ?$$

[S. Bosch et al. hep-ph/9904408]

But FSI effects are not included

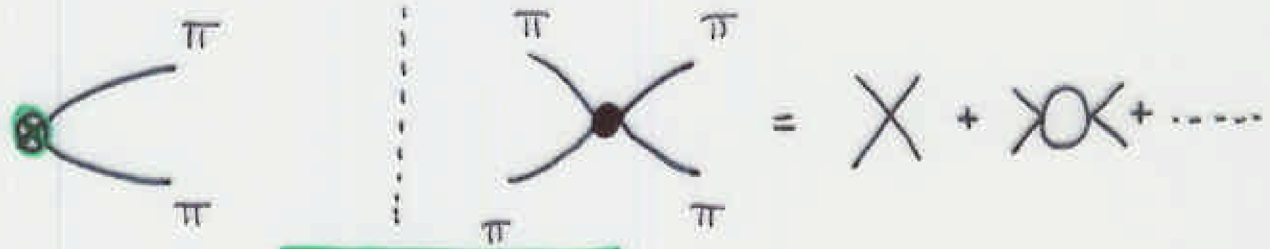
$K \to \pi\pi$ at one-loop in CHPT gives



$\Rightarrow$ $\sim 40\%$ enhanced

$$\boxed{\text{FSI are large for } I = 0}$$

FSI - CONCEPTS



$\boxed{J^P = 0^+ \quad I = 0}$

PRODUCTION | **RESCATTERING**

- universal
- no factorization scale dependence
- well known

$$A_I \equiv A[K \to (\pi\pi)_I] = A_I \, e^{i\delta_0^I} \qquad I = 0, 2$$

$$(\delta_0^0 - \delta_0^2)(m_K^2) = 45^\circ \pm 6^\circ$$ [GASSER, MEISSNER 91]

ABSORPTIVE PART	DISPERSIVE PART

ANALITICITY + UNITARITY

THE OMNÈS PROBLEM

$$A(s) = \langle (\pi\pi)^I_\ell \,|\, O \,|\, i \rangle \qquad s = P_f^2$$

$$L = [4m_\pi^2, \infty]$$

In the Elastic region + Watson's Therem

$$A(s) = |A(s)|\, e^{i\delta^I_\ell(s)}$$

$$\mathrm{Im}\, A(s) = \sigma T^I_\ell A^* = e^{i\delta^I_\ell} \sin\delta^I_\ell A^*$$

Dispersion relation

$$A(s) = \frac{1}{\pi}\int_L dz \,\frac{\mathrm{Im}\, A(z)}{z - s - i\varepsilon} + \text{SUBTRACTIONS}$$

Omnès Solution [s_0 = subtraction point]

$$A(s) = Q_M(s, s_0)\, \Omega_M(s, s_0)$$

OMNÈS FACTOR

$$\Omega_M(s,s_0) = \exp\left\{ \frac{(s-s_0)^M}{\pi} \int_L \frac{dz}{(z-s_0)^M} \frac{\delta_e^I(z)}{z-s-i\varepsilon} \right\}$$

$$\equiv e^{i\delta_e^I(s)} \cdot R_m(s,s_0)$$

N.B. $\Omega_M(s_0, s_0) = 1$

$$\ln Q_M(s,s_0) = \sum_{k=0}^{M-1} \frac{(s-s_0)^k}{k!} \left. \frac{\partial^{(k)} \ln A}{\partial s^{(k)}} \right|_{s=s_0}$$

$F_S^\pi(t)$: SCALAR FORM FACTOR

$\langle \pi^i | \bar{u}u + \bar{d}d | \pi^k \rangle = \delta^{ik} F_S^\pi(t)$

$\boxed{I=0}$

Known at one loop (up to two loops) in ChPT

$$F_S^\pi(t) = F_S^\pi(0) \left\{ 1 + g(t) + O(p^4) \right\}$$

The Omnès solution gives:

$$\boxed{F_S^\pi(t) = \Omega_0(t,t_0) \cdot F_S^\pi(t_0) \approx \Omega_0(t,t_0) \cdot F_S^\pi(0) \left[1 + g(t_0) \right]}$$

where $g(t_0) \to 0$ for $t_0 \to 0$

$$\Omega_0(t,t_0) \equiv e^{i\delta_0^0(t)} \cdot \mathcal{R}_0(t,t_0)$$

A twice-subtracted analysis gives

$$\boxed{R_0(M_K^2, 0) = 1.55 \pm 0.10}$$

It takes into account:

- Inelastic contributions ($t > 1\ \mathrm{GeV}^2$)
- Experimental phase-shifts uncertainties

$K \to \pi\pi$

- The Omnès solution

$$\boxed{I = 0,\ 2}$$

$$A_I(M_K^2) = (M_K^2 - M_\pi^2) \cdot \Omega_I(M_K^2, s_0) \cdot a_I(s_0)$$

where $a_I(s) = a_I(0) \left\{ 1 + g_I(s) + O(p^4) \right\}$

dominated by FSI (IR) effects

- The Omnès factors at $s_0 = 0$

$$\boxed{\Re_0(M_K^2, 0) = 1.55 \pm 0.10} \qquad \boxed{\Re_2(M_K^2, 0) = 0.92 \pm 0.03}$$

$\uparrow$ $\uparrow$ $\uparrow$

$I=0$ $\quad$ $I=2$ $\quad\quad$ $I=2$

("LARGE N_c") $\quad \times R_0 \quad \times R_2 \quad\quad \times R_2$

MATCHING
EXACT

The SM prediction is enhanced to

$$\boxed{\mathrm{Re}(\varepsilon'/\varepsilon)_{SM} = (17 \pm 6) \times 10^{-4}}$$

ε'/ε

$$\varepsilon'/\varepsilon \approx \overset{\text{EXP}}{\tau} \sum_i y_i(\mu) \overset{\text{THEORY}}{\langle Q_i(\mu)\rangle_0} (1-\Omega_{IB}) - \overset{\text{EXP.}}{\frac{\tau}{\omega}} \sum_i y_i(\mu) \overset{\text{THEORY}}{\langle Q_i(\mu)\rangle_2}$$

$\alpha_s \sim \frac{1}{N_c}$

$N_c \to \infty$

$\ln \frac{m_c}{\mu}$ SMALL

$$\langle Q(\mu)\rangle_I \sim \left(\text{LARGE } N_c\right) \times R^{I}_{FSI}$$

ENERGY SCALE	FIELDS	EFFECTIVE THEORY
M_W	W, Z, γ, g τ, μ, e, ν_i t, b, c, s, d, u	Standard Model
	$\downarrow$ OPE	
$\lesssim m_c$	γ, g ; μ, e, ν_i s, d, u	$\mathcal{L}_{QCD}^{(n_f=3)}$, $\mathcal{L}_{eff}^{\Delta S=1,2}$
MATCHING AT μ $\rightarrow$	$\downarrow$	
M_K	γ ; μ, e, ν_i π, K, η	ChPT , Lattice...