# Chiral Dynamics Predictions for η'→ηππ

R. Escribano, P. Masjuan, J.J. Sanz-Cillero

Grup de Física Teòrica & IFAE, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Catalunya, Spain.

We study the decay η'→ηππ in two different chiral invariant approaches: Large-$N_c$ Chiral Perturbation Theory and Large-$N_c$ Resonance Chiral Theory. We analyze the Dalitz plot and the invariant mass spectra. We also compare the relevance of the isoscalar and isovector channels in these approaches.

## Motivation:

| | $\eta' \to \eta\pi^+\pi^-$ | $\eta' \to \eta\pi^0\pi^0$ |
|---|---|---|
| Exp (PDG09) | $44.6 \pm 1.4\%$ | $20.7 \pm 1.2\%$ |
| ChPT@LO (Bijnens '06) | $0.9\%$ | $0.5\%$ |
| Unitarized $U(3)$ (Borasoy and Nißler, '05) | $39.7 \pm 2.0\%$ | $22.5 \pm 1.5\%$ |

We have used: $\Gamma^{exp}_{\eta'} = 0.204 \pm 0.015$ MeV

Theoretical problem?

In the limit $m_u, m_d \to 0$

The relative difference gets worse!

- η'-η system → Test spontaneous and explicit chiral symmetry breaking
- η'→ηππ in ChPT@LO → Very much off prediction vs experiment [Bijnens, '06]
- U(3) chiral effective field theory in combination with a coupled-channels approach, including final state interactions. [Borasoy and Nißler, '05]

## Large-$N_c$ ChPT:

Chiral Perturbation Theory (ChPT) + Large $N_c$

needs η' $\begin{cases} M_{\eta'} = 957.78 \pm 0.06 \text{ MeV} \\ \Gamma_{\eta'} = 0.204 \pm 0.015 \text{ MeV} \end{cases}$

[Gasser and Leutwyler, '84]
[Kaiser and Leutwyler, '00]

simultaneous expansion in: p, $m_q$, $1/N_c$.

- The proces $\eta' \to \eta\pi^+\pi^-$

$$\mathcal{M}_{\eta'\to\eta\pi^+\pi^-} = c_{qq} \times \frac{1}{F^2}\left[\frac{m_\pi^2}{2} - \frac{2L_5 m_\pi^2}{F^2}\left(m_{\eta'}^2 + m_\eta^2 + 2m_\pi^2\right) + \frac{2(3L_2+L_3)}{F^2}\left(s^2+t^2+u^2-(m_{\eta'}^4+m_\eta^4+2m_\pi^4)\right) + \frac{24L_8 m_\pi^4}{F^2} + \frac{2\Lambda_2 m_\pi^2}{3}\right] + c_{sq} \times \frac{\sqrt{2}\Lambda_2 m_\pi^2}{3F^2}$$

- With the universal η'-η mixing parameters

$$c_{qq} = \frac{F^2}{3F_1^2F_8^2\cos^2(\theta_8-\theta_1)}\left[F_1^2\sin(2\theta_1) - F_8^2\sin(2\theta_8) + 2\sqrt{2}F_1F_8\cos(\theta_1+\theta_8)\right]$$

$$c_{sq} = \frac{F^2}{3F_1^2F_8^2\cos^2(\theta_8-\theta_1)}\left[\sqrt{2}F_1^2\sin(2\theta_1) + \sqrt{2}F_8^2\sin(2\theta_8) + F_1F_8\cos(\theta_1+\theta_8)\right]$$

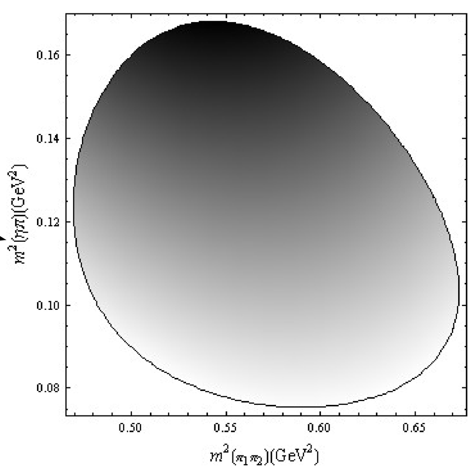
$$\begin{cases} \theta_8 = -20^\circ \\ \theta_1 = -5^\circ \\ F_8 = 1.3F_\pi \\ F_1 = 1.1F_\pi \\ F_\pi = 92.2 \text{ MeV} \end{cases}$$

[Pich, '08]

$$L_5 = 2.1 \times 10^{-3}, \quad 3L_2 + L_3 = 1.1 \times 10^{-3}, \quad L_8 = 0.8 \times 10^{-3}$$

+ using $\Lambda_2 = 0.3$

$$BR_{\eta'\to\eta\pi^+\pi^-} = 13.02\%$$




$3L_2+L_3$ dominance
+
interference of ($3L_2+L_3$)-$L_5$ in the cross section (=amplitude²)

Only $3L_2+L_3$: $BR_{\eta'\to\eta\pi^+\pi^-} = 24.11\%$

without $3L_2+L_3$: $BR^{w/o\,3L2+L3}_{\eta'\to\eta\pi^+\pi^-} = 4.33\%$

## Large-$N_c$ RχT:

Resonance Chiral Theory (RχT) + Large $N_c$

[Ecker et al, '89]

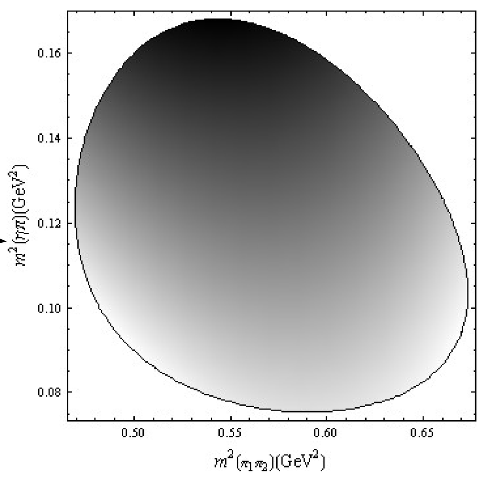
- The proces $\eta' \to \eta\pi^+\pi^-$

$$\mathcal{M}_{\eta'\to\eta\pi^+\pi^-} = c_{qq} \times \frac{1}{F_\pi^2}\left[\frac{m_\pi^2}{2} + \frac{4c_dc_m}{F^2}\frac{m_\pi^4}{M_S^2} + \frac{1}{F^2}\frac{[c_d(t-m_\eta^2-m_\pi^2)+2c_m^2m_\pi^2]\,[c_d(t-m_{\eta'}^2-m_\pi^2)+2c_mm_\pi^2]}{M_{a0}^2-t} + \frac{1}{F^2}\frac{[c_d(u-m_\eta^2-m_\pi^2)+2c_m^2m_\pi^2]\,[c_d(u-m_{\eta'}^2-m_\pi^2)+2c_mm_\pi^2]}{M_{a0}^2-u} + \frac{1}{F^2}[c_d(s-m_\eta^2-m_{\eta'}^2)+2c_m^2m_\pi^2]\,[c_d(s-2m_\pi^2)+2c_mm_\pi^2] \times \left\{\frac{\cos^2\phi_S}{M_\sigma^2-s} + \frac{\sin^2\phi_S}{M_{f0}^2-s}\right\}\right]$$

$$c_d = 30MeV, \quad c_m = 70MeV, \quad M_S = 0.980GeV \text{ (Scalar Multiplet)}, \quad \phi_S = -8^\circ$$

[Guo, Sanz-Cillero, '09]

$$BR_{\eta'\to\eta\pi^+\pi^-} = 22.34\%$$




$a_0$ dominance
+
interference between $a_0$-σ

Using only $M_\sigma = 0.980GeV$ ⇒ $BR^{only\,\sigma}_{\eta'\to\eta\pi^+\pi^-} = 0.82\%$

however

- Physical world: $M_\sigma < M_S$ → $BR^{only\,\sigma}_{\eta'\to\eta\pi^+\pi^-}$ will dominate

effect beyond Large-$N_c$ → σ-width has to be considered

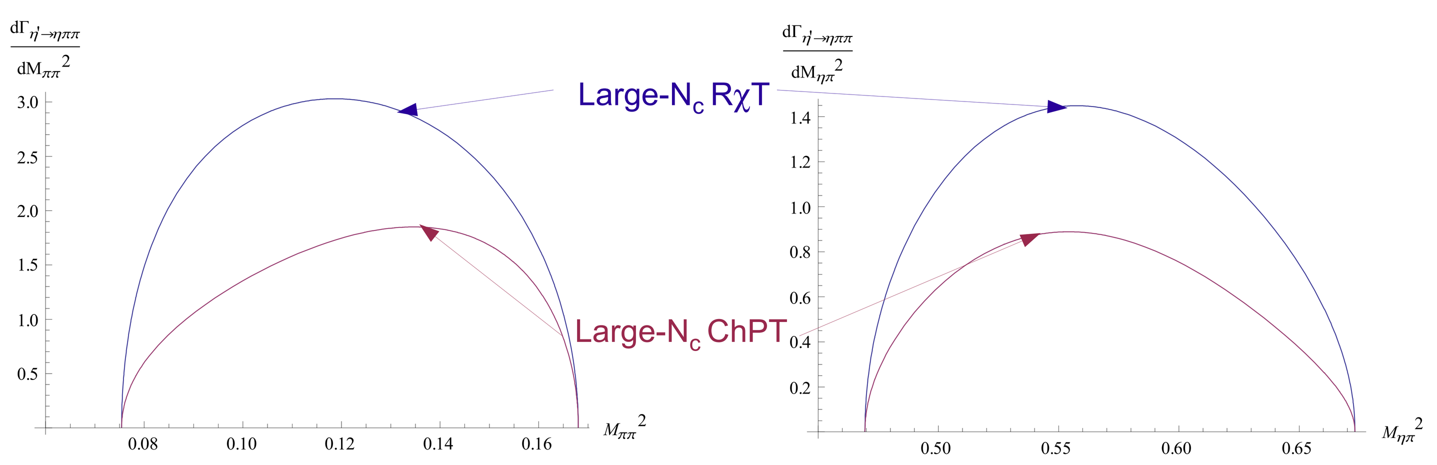
Using LEC's + $c_d$, $c_m$ ↔ LEC's relations

$$c_d = c_m = F/2 \sim 45MeV \quad \text{[Pich '08]}$$
+
$$M_S = 0.980GeV \text{ (Scalar Multiplet)}$$

$$BR_{\eta'\to\eta\pi^+\pi^-} = 131.72\%$$

## Comparison:

- Differential decay width




- Large-$N_c$ RχT → Large-$N_c$ ChPT

$p \to 0$, $m_\pi, m_\eta, m_{\eta'} \to 0$ — We recover

$$\begin{cases} L_5 = c_dc_m/M_S^2 \\ L_8 = c_m^2/2M_S^2 \\ 3L_2+L_3 = c_d^2/2M_S^2 \\ \Lambda_2 = 0 \end{cases}$$

- Dominant term in the amplitude:

$BR^{LN_c\,ChPT}_{\eta'\to\eta\pi^+\pi^-}$ — dominant term → $3L_2+L_3$

$BR^{LN_c\,R\chi T}_{\eta'\to\eta\pi^+\pi^-}$ — dominant term → $c_d^2/2M_S^2$

We recover $3L_2+L_3 = c_d^2/2M_S^2$

## Concluding Remarks:

- The decay η'→ηππ in ChPT@LO is supressed in the limit: $\begin{cases} m_{u,d} \to 0 \\ m_\pi \to 0 \end{cases}$

⇒ First non-chiral suppressed contribution arising at O($p^4$) → $\begin{cases} 3L_2+L_3 \\ c_d^2/2M_S^2 \end{cases}$ dominance

Similar to $\gamma\gamma \to \pi^0\pi^0$ or $\pi \to \gamma l \nu$

- We find agreement in the relation between the Low Energy Constants and $c_d$, $c_m$ from RχT.
- The present calculations are useful to understand the order of magnitude of the process.
- The process, in Large-$N_c$ RχT, is dominated by $c_d$. Precise value for $c_d$ is needed.

**Outlook**:

- However, to reach a more precise value, we need to incorporate the final state interactions, going beyond the Large-$N_c$ limit, and a more precise value for $c_d$.