VNIVERSITAT DE VALÈNCIA

CSIC

Resonance Chiral Theory approach

Jorge Portolés

Instituto de Física Corpuscular

CSIC-UVEG, Valencia (Spain)

Caltech-Marseille-Valencia-Vienna Collaboration

V. Cirigliano, G. Ecker, M. Eidemüller, R. Kaiser, A. Pich

EURIDICE

Euridice Network

Resonance Chiral Theory

Large N_C

↓

Lagrangian Theory

Spectrum: Goldstones and Resonances

Interactions:

- Chiral symmetry of massless QCD
- Resonances as matter fields

1/ **[Ecker et al, 1989]**

$$L_{R\chi T} = \mathcal{L}^{(2)} + L_{\text{kin}}^{R} + L_{\text{int}}^{1}(s=0,1)$$

$$L_{\text{int}} \sim \left\langle R \;\chi(p^2)\right\rangle$$

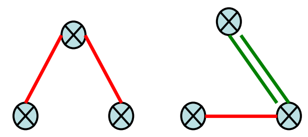
$$L_{\text{int}}^{1}(s=1) = \frac{F_V}{2\sqrt{2}}\left\langle V_{\mu\nu} f_{+}^{\mu\nu}\right\rangle + i\frac{G_V}{\sqrt{2}}\left\langle V_{\mu\nu} u^{\mu} u^{\nu}\right\rangle + \frac{F_A}{2\sqrt{2}}\left\langle A_{\mu\nu} f_{-}^{\mu\nu}\right\rangle$$

$$L_{\text{int}}^{1}(s=0) = c_d\left\langle S u_{\mu} u^{\mu}\right\rangle + c_m\left\langle S\chi_{+}\right\rangle + i d_m\left\langle P\chi_{-}\right\rangle$$

2/ Information on the couplings of $L_{R\chi T}$

a) OPE of Green Functions of QCD Currents

χPT $\xrightarrow{p^2, q^2 \ll M_R^2}$ $\Pi(p,q)$ $\xrightarrow{p^2, q^2 \gg M_R^2}$ **OPE** / **Perturbative QCD**



b) Asymptotic behaviour of form factors (Brodsky-Lepage)

Comparative features of the Resonance Chiral Theory approach

- More complex: Construction of full sets of operators (unknown couplings).

- More useful: Wide application in many settings…

• Hadronic decays of the tau lepton, decays of resonances,

• Hadronic cross-section, etc.

LEC's in Chiral Perturbation Theory

$$L_{\chi PT} = \mathcal{L}^{(2)} + \mathcal{L}^{(4)} + \mathcal{L}^{(6)} + \ldots$$

$$\mathcal{L}^{(2)} = \frac{F^2}{4} \left\langle u_\mu u^\mu + \chi_+ \right\rangle$$

($N_F = 3$)

Even-intrinsic-parity sector only

$$\mathcal{L}^{(4)} = L_1 \left\langle u_\mu u^\mu \right\rangle^2 + \ldots = \sum_{i=1}^{10} L_i \; O_i^4$$

[Gasser & Leutwyler, 1985]

$$\mathcal{L}^{(6)} = C_1 \left\langle u_\alpha u^\alpha h_{\mu\nu} h^{\mu\nu} \right\rangle + \ldots = \sum_{i=1}^{90} C_i \; O_i^6$$

[Fearing & Scherer, 1996]

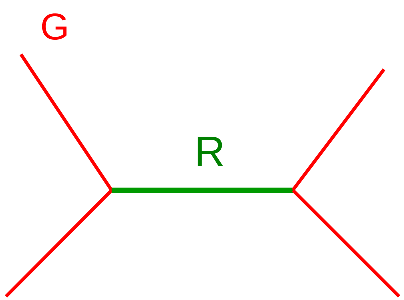
[Bijnens, Colangelo & Ecker, 1999,2000]

High-precision predictions within χPT : $F^\pi_{V,S}$, $K_{\ell 3}$, …

→ L_i , C_i ?

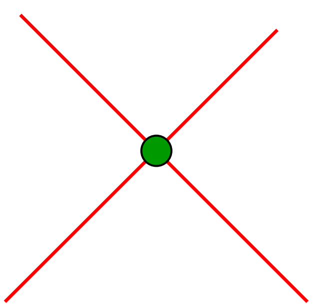
How do we get them?

[Gasser & Leutwyler, 1984] [Donoghue et al., 1989] [Ecker et al., 1989]



$$\int [dR] \ \exp\left[i \int L_{R\chi T}\left(R, U; \lambda_j\right)\right] = \exp\left[i \int L_{\text{No Local}}\left(U; \lambda_j\right)\right]$$

$q^2 \ll M_R^2$



$$L_{Local}(U; \lambda_j) = L_{Local}(U, L_i, C_i)$$

The role of Resonance Chiral Theory

$O(p^4)$ [Ecker et al, 1989]

$$L_{\text{int}} \sim \langle R\ \chi(p^2) \rangle$$

$$L_{R\chi T} = \mathcal{L}^{(2)} + L_{\text{kin}}^{R} + L_{\text{int}}^{1}(s=0,1)$$

$$L_{\text{int}}^{1}(s=1) = \frac{F_V}{2\sqrt{2}} \langle V_{\mu\nu} f_+^{\mu\nu} \rangle + i \frac{G_V}{\sqrt{2}} \langle V_{\mu\nu} u^\mu u^\nu \rangle + \frac{F_A}{2\sqrt{2}} \langle A_{\mu\nu} f_-^{\mu\nu} \rangle$$

$$L_{\text{int}}^{1}(s=0) = c_d \langle S u_\mu u^\mu \rangle + c_m \langle S \chi_+ \rangle + i d_m \langle P \chi_- \rangle$$

L_1	L_2	L_3	L_4	L_5	....
$\frac{G_V^2}{8M_V^2} - \frac{c_d^2}{6M_S^2}$	$\frac{G_V^2}{4M_V^2}$	$-\frac{3G_V^2}{4M_V^2} + \frac{c_d^2}{2M_S^2}$	$-\frac{c_d c_m}{3M_S^2}$	$\frac{c_d c_m}{M_S^2}$	

$O(p^6)$ [Cirigliano et al, 2005]

$$L_{\text{int}} = L^1_{\text{int}} + L^2_{\text{int}}$$

$R = V,A,S,P$

$$L^2_{\text{int}} \begin{cases} \langle R \ \chi(p^4) \rangle \longrightarrow \boxed{\text{70 operators}} \longrightarrow \lambda_i^R \\ \langle R_1 R_2 \ \chi(p^2) \rangle \longrightarrow \boxed{\text{38 operators}} \longrightarrow \lambda_i^{R_1 R_2} \\ \langle R_1 R_2 R_3 \ \chi(p^0) \rangle \longrightarrow \boxed{\text{7 operators}} \longrightarrow \lambda_i^{R_1 R_2 R_3} \end{cases}$$

e.g.

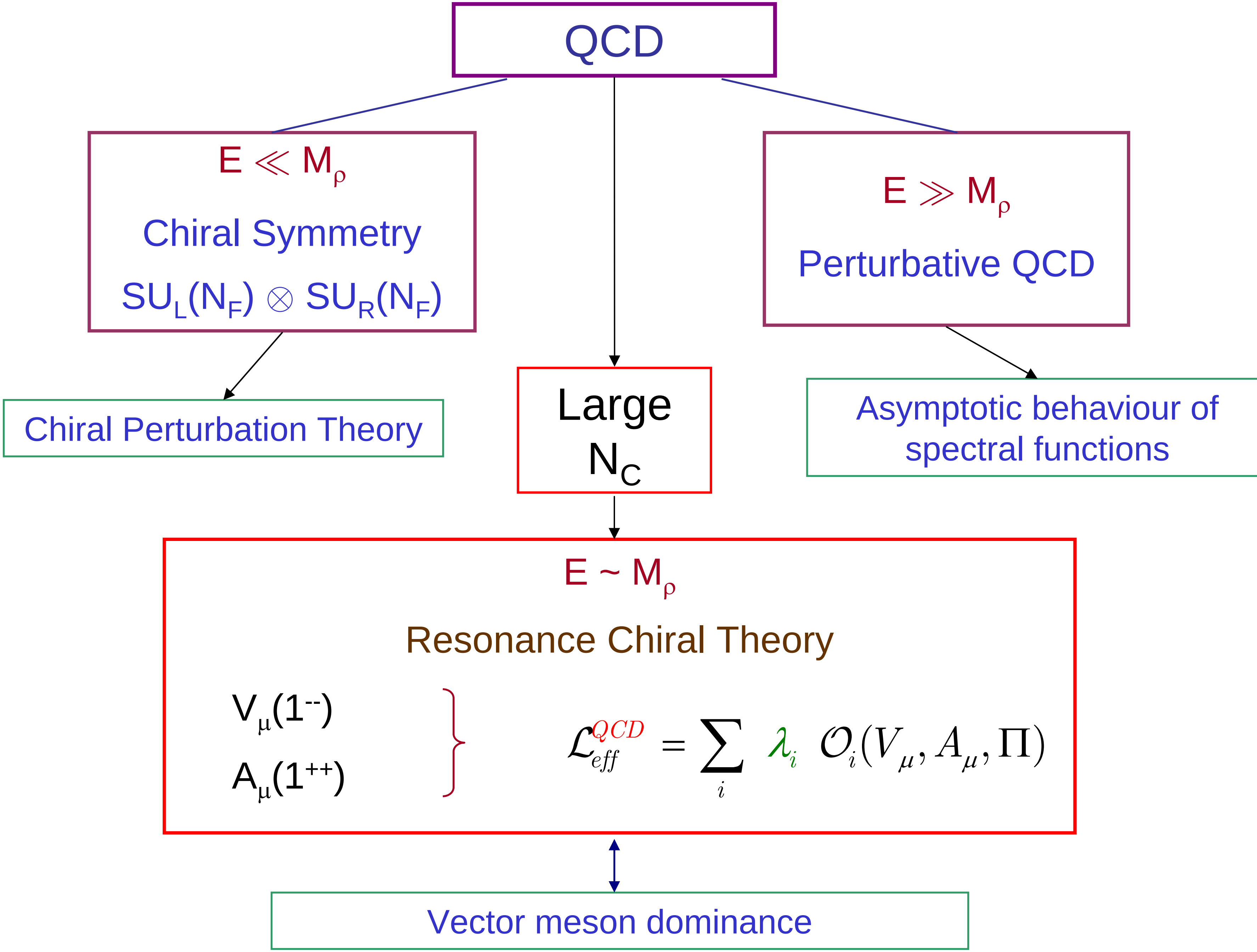
$$C_{12}^{R} = -\frac{c_d c_m}{2M_S^4}$$

$$C_{34}^{R} = \frac{1}{2}\left[\frac{c_m(c_m - c_d)}{M_S^4} + \frac{d_m^2}{M_P^4} + 2\frac{d_m}{M_P^2}\lambda_6^{P} - 2\frac{c_m}{M_S^2}\lambda_8^{S} + 2\frac{c_d c_m}{M_S^2 M_P^2}\lambda_1^{SP}\right]$$

$$C_{88}^{R} = -\frac{F_V G_V}{4M_V^4} + C_{90}^{R}$$

$$C_{90}^{R} = -\frac{d_m}{M_V^2 M_P^2}\left[\frac{F_V}{\sqrt{2}}\lambda_1^{PV} + M_V^2\lambda_9^{P}\right]$$

$L_{R\chi T}$ is NOT QCD for arbitrary values of the couplings


QCD
$E \ll M_\rho$
Chiral Symmetry
$SU_L(N_F) \otimes SU_R(N_F)$
Chiral Perturbation Theory
Large
N_C
$E \gg M_\rho$
Perturbative QCD
Asymptotic behaviour of spectral functions
$E \sim M_\rho$
Resonance Chiral Theory
$V_\mu(1^{--})$
$A_\mu(1^{++})$
$\mathcal{L}_{eff}^{QCD} = \sum_i \lambda_i \; \mathcal{O}_i(V_\mu, A_\mu, \Pi)$
Vector meson dominance

Results

<VAP> [Cirigliano et al, 2004]

$$C_{78}^{R} = \frac{F^2}{8M_V^4 M_A^2}\left(3M_A^2 + 4M_V^2\right) - \frac{F^2}{16M_V^2 M_P^2}$$

$$C_{82}^{R} = -\frac{F^2}{32M_V^4 M_A^2}\left(4M_A^2 + 5M_V^2\right) - \frac{F^2}{32M_A^2 M_P^2}$$

$\Bigg\}\ \pi \to \ell \nu_\ell \gamma$

$$C_{88}^{R} = -\frac{F^2}{4M_V^4} + \frac{F^2}{8M_V^2 M_P^2}$$

$$C_{90}^{R} = \frac{F^2}{8M_V^2 M_P^2}$$

$\Bigg\}\ F_V^{\pi}(q^2)$, $K_{\ell 3}$

also C_{87}^{R} , C_{89}^{R}

<SPP> [Cirigliano et al, 2005]

$$C_{12}^{R} = -\frac{F^2}{8M_S^4}$$

$$C_{34}^{R} = \frac{3F^2}{16M_S^4} + \frac{F^2}{16}\left(\frac{1}{M_S^2} - \frac{1}{M_P^2}\right)^2$$

$$C_{38}^{R} = \frac{F^2}{16M_S^4} + \frac{F^2}{16}\left(\frac{1}{M_S^4} - \frac{1}{M_P^4}\right)$$

$\Big\}$ $K_{\ell 3}$: $f_+^{K^0\pi^-}(0)\Big|_{O(p^6)}$