s-wave resonances in meson-baryon scattering induced by Weinberg-Tomozawa interaction

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Motivation : Exotic hadrons

Exotic hadrons : states other than $q\bar{q}$, qqq.
--> QCD does not forbid exotic states,
effective models neither.

Experimentally, (almost?) completely absent
--> highly non-trivial fact

Existence of exotic hadrons?

○ Resonance saturation + duality

J.L. Rosner, Phys. Rev. Lett. 21, 950 (1968)

D.P. Roy and M. Suzuki, Phys. Lett. B28, 558 (1969)

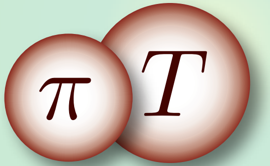
○ Large Nc + heavy quark

T.D. Cohen, *et al.*, Phys. Rev. D72, 074010 (2005)

--> Examine existence of exotic hadrons in flavor SU(3) limit.

Outline

Hadron-NG boson bound state



Chiral symmetry

s-wave low energy interaction

$$V_\alpha = -\frac{\omega}{2f^2} C_{\alpha,T} \qquad C_{\mathrm{exotic}} = 1$$

Scattering theory

Critical strength for a bound state

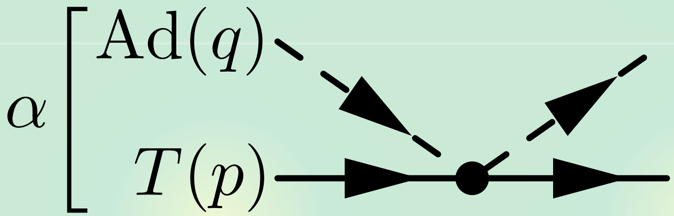
$$C_{\mathrm{crit}} = \frac{2f^2}{m\left(-G(M_T + m)\right)}$$

physical values : $C_{\mathrm{exotic}} < C_{\mathrm{crit}}$

No exotic state exists.

Low energy interaction : kinematic structure

Scattering of a target (T) with the pion (Ad)



$$= \frac{1}{f^2}\frac{p\cdot q}{2M_T}\left\langle \boldsymbol{F}_T\cdot\boldsymbol{F}_{\mathrm{Ad}}\right\rangle_\alpha + \mathcal{O}\left((m/M_T)^2\right)$$

In s-wave,

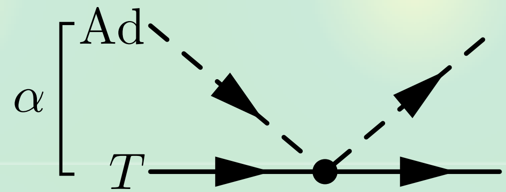
$$V_\alpha = -\frac{\omega}{2f^2}C_{\alpha,T} \qquad C_{\alpha,T}\equiv -\left\langle 2\boldsymbol{F}_T\cdot\boldsymbol{F}_{\mathrm{Ad}}\right\rangle_\alpha$$

- ○ proportional to pion energy
- ○ pion decay constant (No LEC)

Y. Tomozawa, Nuovo Cim. 46A, 707 (1966)
S. Weinberg, Phys. Rev. Lett. 17, 616 (1966)

Low energy interaction : group theoretical structure

Coupling strength



$$C_{\alpha,T} = -\langle 2\boldsymbol{F}_T \cdot \boldsymbol{F}_{\mathrm{Ad}} \rangle_\alpha$$
$$= \left\langle \boldsymbol{F}^2_{\mathrm{Ad}} + \boldsymbol{F}^2_T - \boldsymbol{F}^2_{[MT]_\alpha} \right\rangle_\alpha$$
$$= C_2(T) - C_2(\alpha) + 3 \quad (\text{for } N_f = 3)$$

$$(F_{[MT]_\alpha})^2 = (F_{\mathrm{Ad}})^2 \otimes (1_T) + (1_{\mathrm{Ad}}) \otimes (F_T)^2 + 2F^a_{\mathrm{Ad}} \otimes F^a_T$$

S. Weinberg, Phys. Rev. Lett. 17, 616 (1966)

$$c.f. \quad C = I_T(I_T+1) - I_\alpha(I_\alpha+1) + 2 \quad (\text{for } N_f = 2)$$

Coupling strengths : Examples

Examples of C_α : (positive is attractive)

$$C_{\alpha,T} = C_2(T) - C_2(\alpha) + 3$$

α	1	8	10	$\overline{10}$	27	35
T=8 (N,Λ,Σ,Ξ)	6	3	0	0	-2	
T=10(Δ,Σ*,Ξ*,Ω)		6	3		1	-3

α	$\bar{3}$	6	$\overline{15}$	24
T=$\bar{3}$ (Λ_c,Ξ_c)	3	1	-1	-2
T=6 (Σ_c,Ξ_c*,Ω_c)	5	3	1	

- **Exotic channels : mostly repulsive**
- **Attractive interaction : C =1**

Coupling strengths : General expression

$$T = [p,q] \qquad \alpha \in [p,q] \otimes [1,1]$$

α	$C_{\alpha,T}$	sign	ΔE
$[p+1,q+1]$	$-p-q$	repulsive	1 or 0
$[p+2,q-1]$	$1-p$		1 or 0
$[p-1,q+2]$	$1-q$		1 or 0
$[p,q]$	3	attractive	0
$[p,q]$	3	attractive	0
$[p+1,q-2]$	$3+q$	attractive	0 or -1
$[p-2,q+1]$	$3+p$	attractive	0 or -1
$[p-1,q-1]$	$4+p+q$	attractive	0 or -1

- ○ **C should be integer.**
- ○ **Sign is determined for most cases.**

Exoticness

Exoticness : minimal number of extra $\bar{q}q$.

For $[p,q]$ and baryon number B,

$$E = \epsilon\theta(\epsilon) + \nu\theta(\nu) \qquad \epsilon \equiv \frac{p+2q}{3} - B, \quad \nu \equiv \frac{p-q}{3} - B$$

$\Delta E = E_\alpha - E_T = +1$ is realized when

- $\Delta\epsilon = 1,\ \Delta\nu = 0,\ \epsilon_T \geq 0,$

  $\alpha = [p+1, q+1] : C_{\alpha,T} = -p-q$ **repulsive**

- $\Delta\epsilon = 0,\ \Delta\nu = 1,\ \nu_T \geq 0,$

  $\alpha = [p+2, q-1] : C_{\alpha,T} = 1-p$

  attraction : $p = 0$ then $\nu_T \geq 0 \to B \leq -q/3$ **not considered here**

- $\Delta\epsilon = 1,\ \Delta\nu = -1,\ \nu_T \leq 0,$

  $\alpha = [p-1, q+2] : C_{\alpha,T} = 1-q$

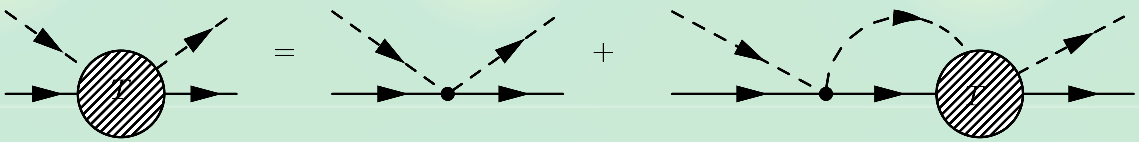
  attraction : $q = 0$ then $\nu_T \leq 0 \to B \geq p/3$ **OK!**

Universal attraction for more "exotic" channel

$$C_{\text{exotic}} = 1 \quad \text{for} \quad T = [p,0], \quad \alpha = [p-1, 2]$$

Renormalization and bound states

$$T = \frac{1}{1 - VG} V$$



Unitarity : OK

Renormalization parameter : condition

$$G(\mu) = 0, \quad \Leftrightarrow \quad T(\mu) = V(\mu) \quad \text{at} \quad \mu = M_T$$

K. Igi, and K. Hikasa, PRD59, 034005 (1999)
M.F.M. Lutz, and E. Kolomeitsev, NPA 700, 193-308 (2002)

Approximate crossing symmetry : OK

Bound state:

$$1 - V(M_b)G(M_b) = 0 \qquad M_T < M_b < M_T + m$$

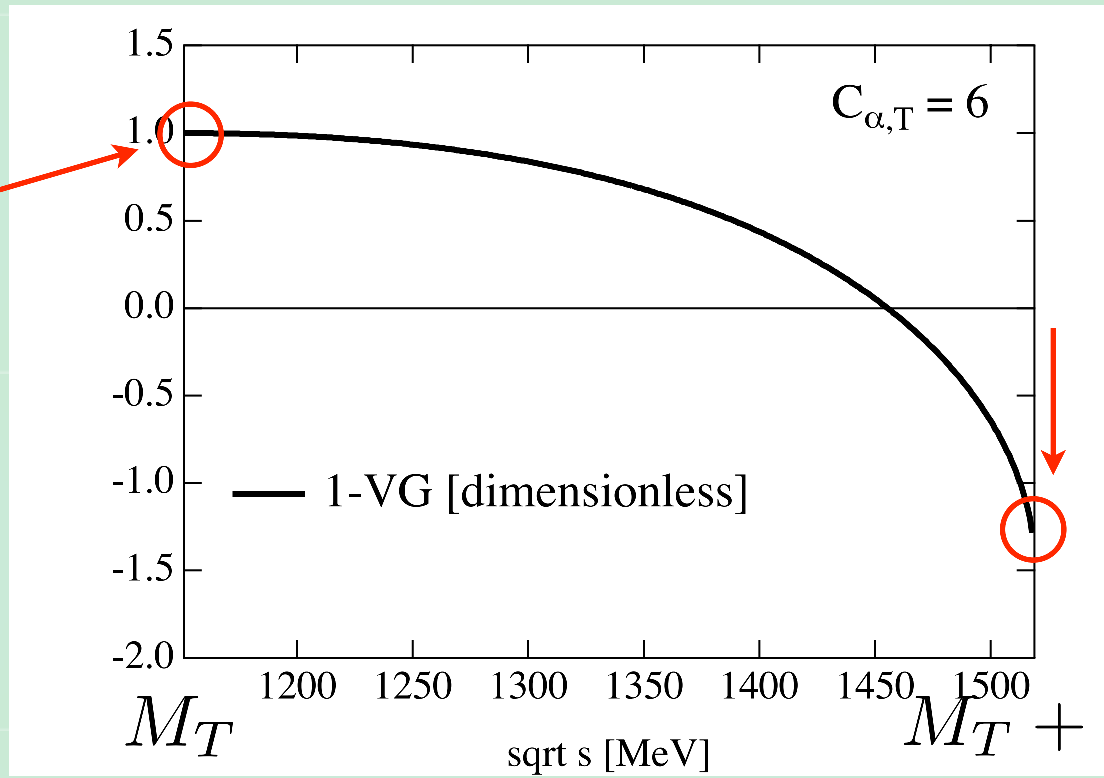
Critical attraction

$1 - V(\sqrt{s})G(\sqrt{s})$ **: monotonically decreasing.**

Fixed

$G(M_T) = 0$

$1 - VG = 1$



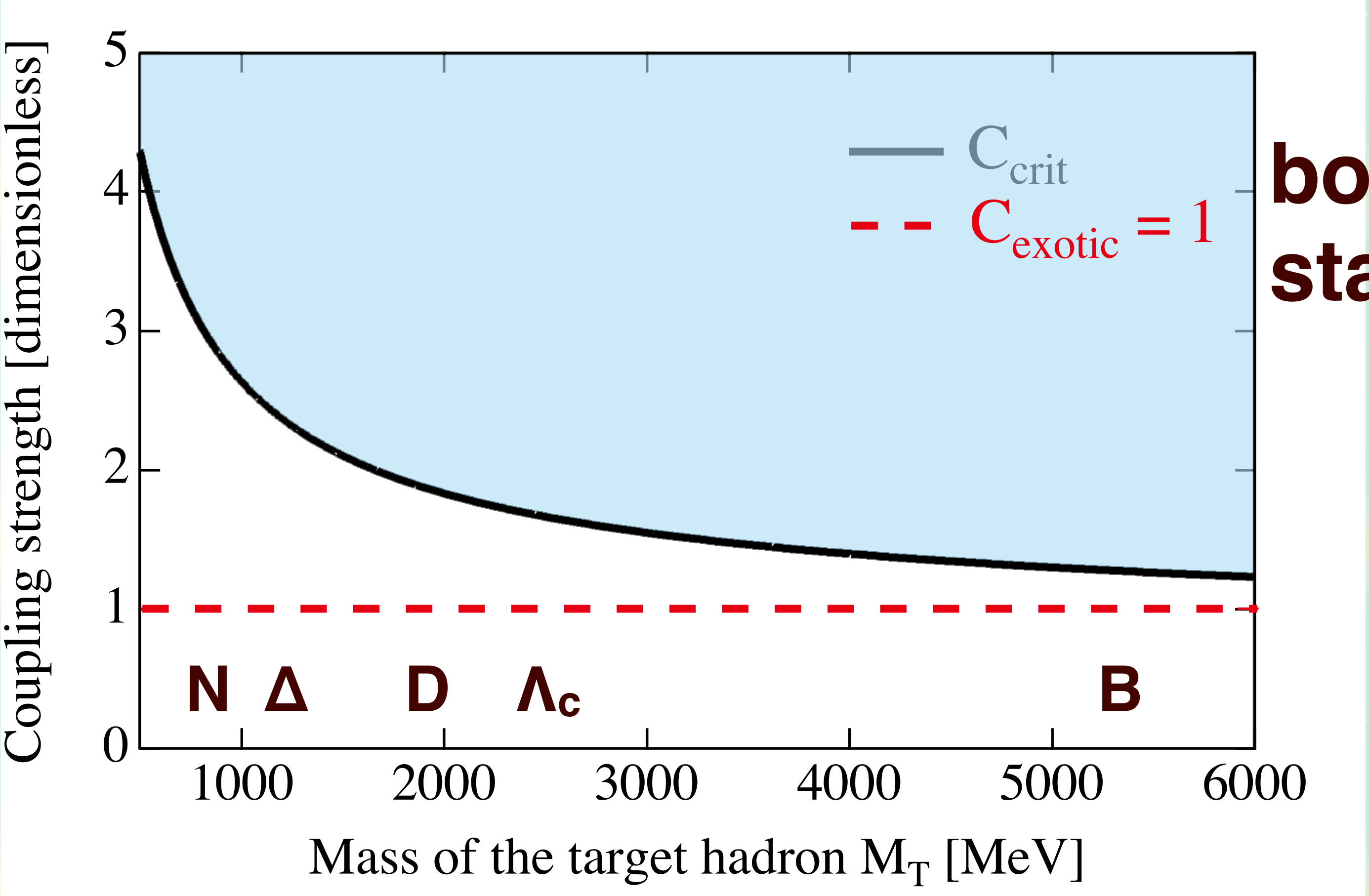
M_T $M_T + m$

Critical attraction : $1 - VG = 0$ at $\sqrt{s} = M_T + m$

$$C_{\text{crit}} = \frac{2f^2}{m\left(-G(M_T + m)\right)}$$

Critical attraction and exotic channel

$$m = 368\ \text{MeV and } f = 93\ \text{MeV}$$



bound state

Strength is not enough.

Summary

We study the exotic bound states in s-wave chiral dynamics in flavor SU(3) limit.

- **There are attractions in exotic channels, with universal and the smallest strength :** $C_{\text{exotic}} = 1$
- **This is not enough to generate a bound state :** $C_{\text{exotic}} < C_{\text{crit}}$
- **This does not exclude the exotic states with other origin.**

Tetsuo Hyodo, Daisuke Jido, Atsushi Hosaka, hep-ph/0609014.