S-wave exotic resonances induced by chiral interaction

 

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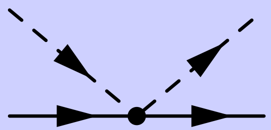
Chiral unitary model

Flavor SU(3) meson-hadron scatterings (s wave)

Chiral symmetry

Low energy behavior



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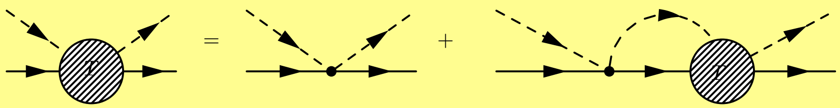
Unitarity of S-matrix

Non-perturbative resummation



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Scattering amplitude

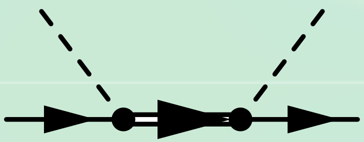
s-wave resonances

N. Kaiser, P. B. Siegel and W. Weise, NPA594, 325, PLB362, 23 (1995)
E. Oset and A. Ramos, NPA635, 99 (1998)
J. A. Oller and U. G. Meissner, PLB500, 263 (2001)

Resonance state

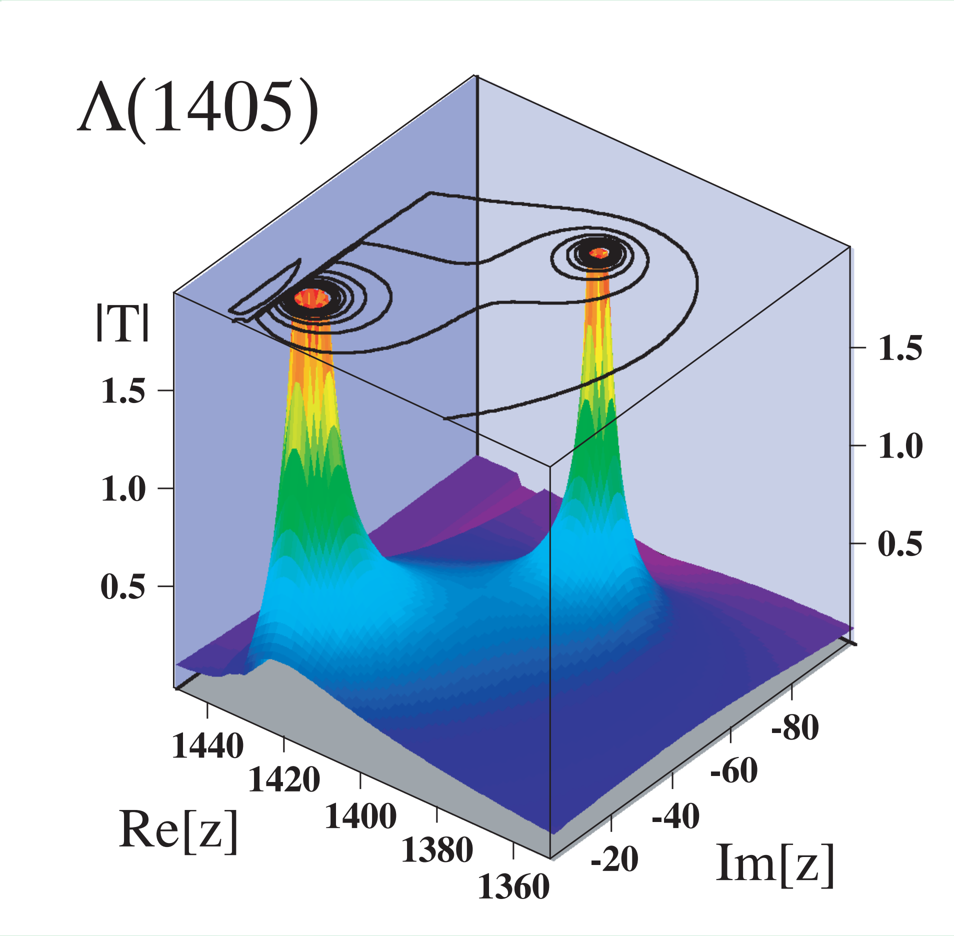
If there is a sufficient attraction, resonances can be dynamically generated.

$$T_{ij}(\sqrt{s}) \sim \frac{g_i g_j}{\sqrt{s} - M_R + i\Gamma_R/2}$$

$\sim$ 

Position of the pole, Residues

-> Mass, Width, Coupling strengths

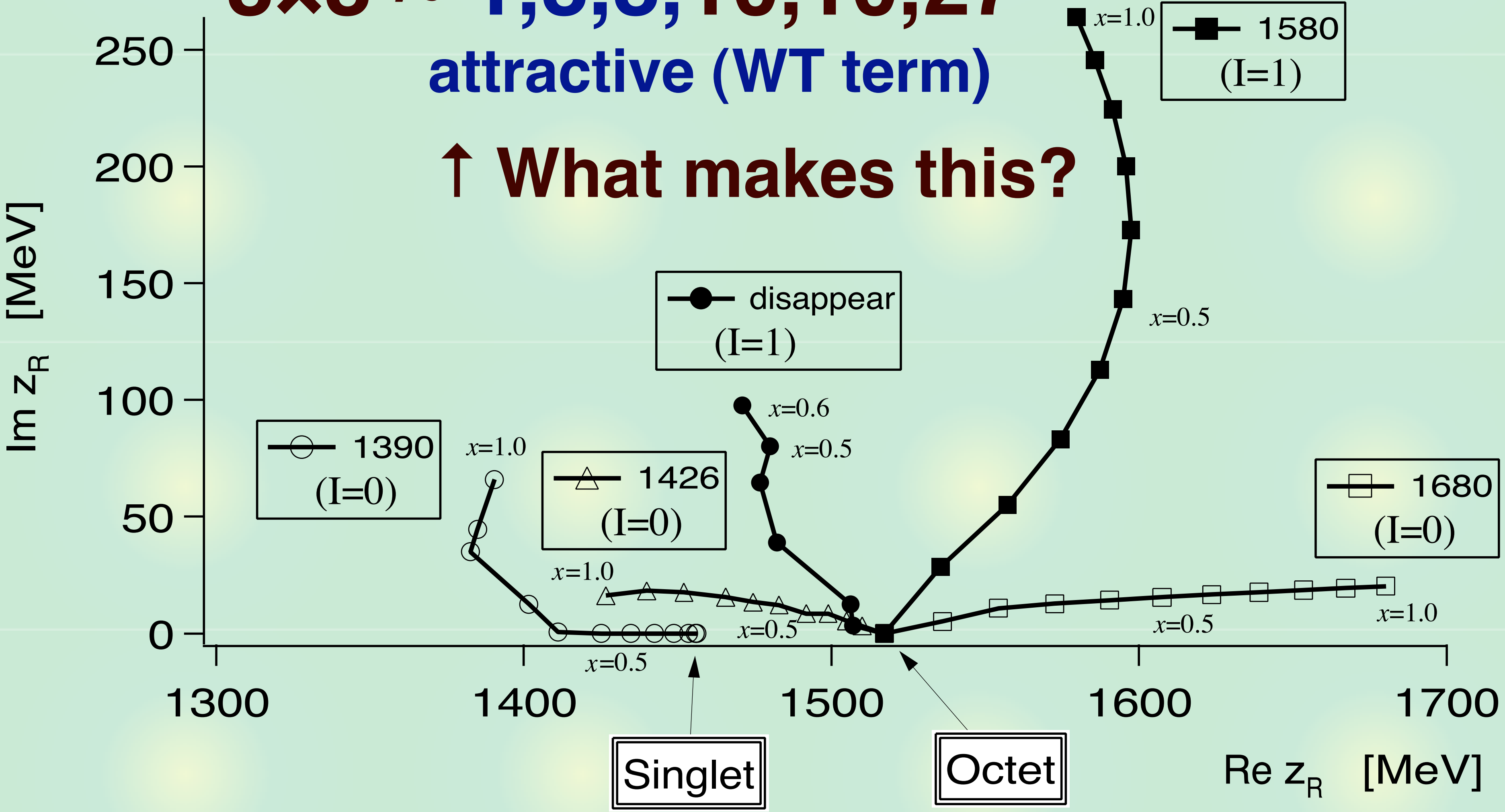


Poles in the SU(3) limit : Origin of the resonances

$8\times 8 \sim 1, 8, 8, 10, \overline{10}, 27$

attractive (WT term)

↑ What makes this?



D. Jido, *et al.*, Nucl. Phys. A 723, 205 (2003)

Motivation : Exotic hadrons

What about exotic states?

hadronic states other than $q\bar{q}$, qqq : tetra- penta-quarks...

QCD does not forbid exotic states.

Effective models, lattice simulations, ...

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

Can exotic states be generated by ChU?

S. Sarkar, *et al.*, Eur. Phys. J. A24, 287-292 (2005)

--> Study the chiral unitary model systematically in flavor SU(3) limit.

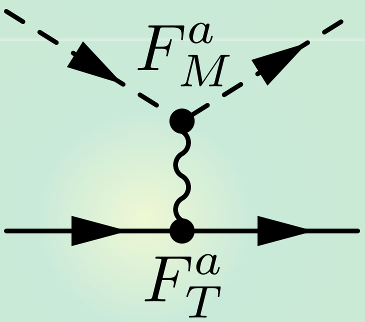
Weinberg-Tomozawa interaction

Low energy behavior of s-wave amplitude

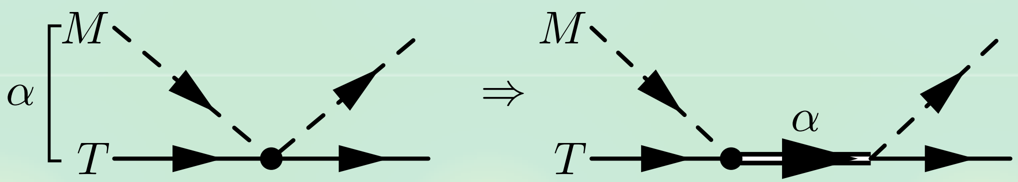
Coupling structure : chiral symmetry

$$V_{\alpha\beta}^{(WT)} \sim -\frac{1}{2f^2}C_\alpha(\sqrt{s}-M_\alpha)\frac{E_\alpha+M_\alpha}{2M_\alpha}\delta_{\alpha\beta} \sim -\frac{1}{2f^2}C_\alpha\omega_\alpha\delta_{\alpha\beta}$$

Coupling strength : SU(3) symmetry



current-current interaction
--> universal for any target particles



$$C_\alpha = -2\langle\,[MT]_\alpha\,|F^a_M F^a_T|\,[MT]_\alpha\,\rangle$$
$$= -\,[C(\alpha) - C(M) - C(T)]$$

quadratic
<-- Casimir

Coupling strengths

Examples of C_α : (positive is attractive)

$$C_\alpha = -\left[C(\alpha) - C(M) - C(T)\right]$$

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

Can the attraction generate a bound state?

Coupling strengths

$T = [p, q]$

$[p, q] \otimes [1, 1]$

$\Delta E = +1$

α	condition	Cα	sign
$[p+1, q+1]$		$-p-q$	repulsive
$[p+2, q-1]$	$q \geq 1$	$1-p$	
$[p-1, q+2]$	$p \geq 1$	$1-q$	
$[p, q]$		3	attractive
$[p, q]$	$q \geq 1$	3	attractive
$[p+1, q-2]$	$q \geq 2$	$3+q$	attractive
$[p-2, q+1]$	$p \geq 2$	$3+p$	attractive
$[p-1, q-1]$	$p \geq 1, \ q \geq 1$	$4+p+q$	attractive

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

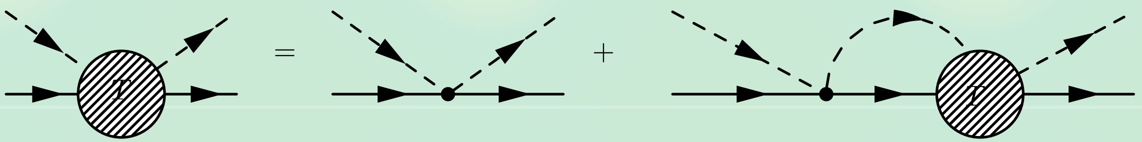
$$E = \frac{p+2q}{3} - B + N, \quad \text{if} \quad N = \frac{p-q}{3} - B > 0$$

Universal attraction for more "exotic" channel

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

Renormalization and bound states

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



Renomalization condition :

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

M.F.M. Lutz, and E. Kolomeitsev, NPA 700, 193-308 (2002)

K. Igi, and K. Hikasa, PRD59, 034005 (1999)

Approximate crossing symmetry
It almost agrees with the natural value of cutoff.

$$a(630\ \text{MeV}) \sim -1.98 \quad \text{with} \quad M = 1151\ \text{MeV}$$

Bound state:

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

Parameters for numerical analysis

Mass of the target

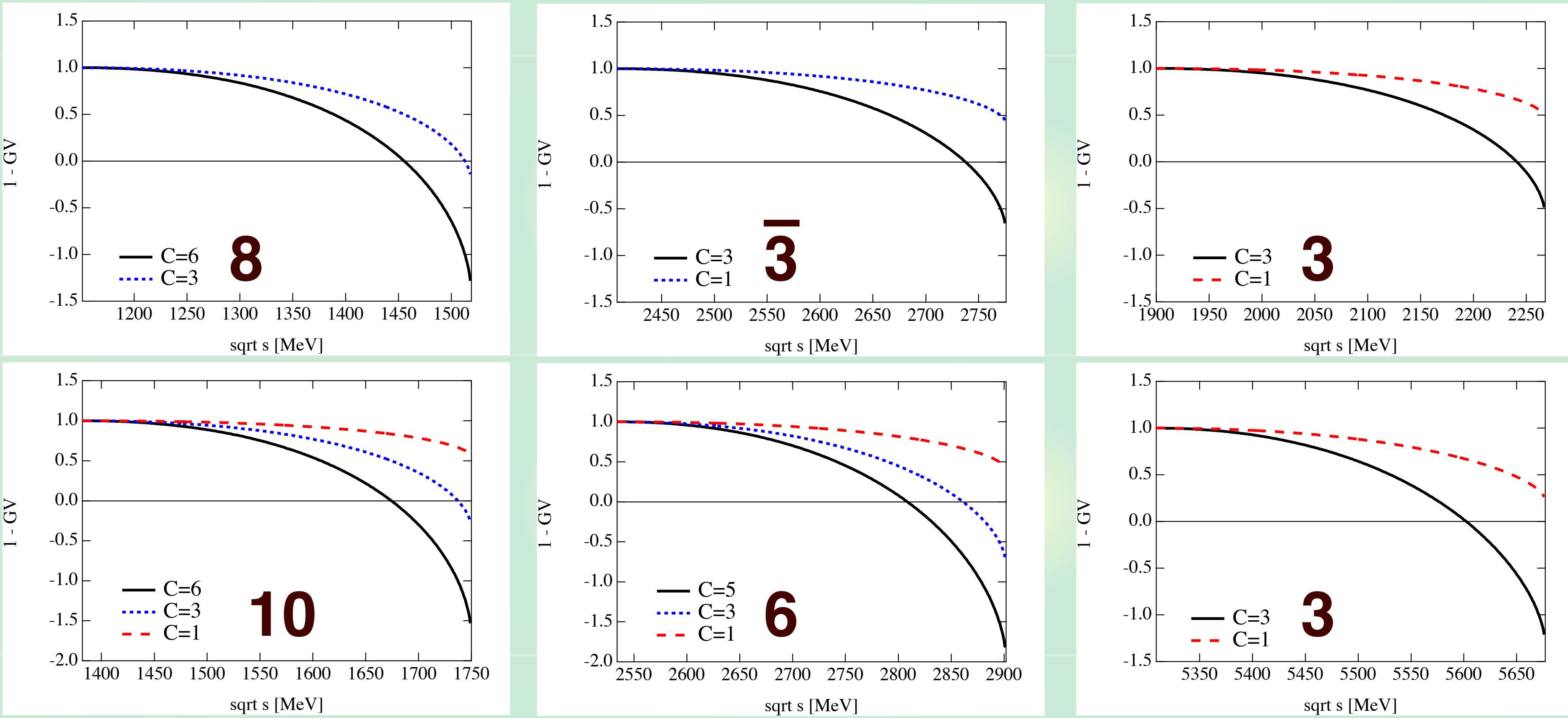
Target	Representations	M [MeV]
light baryon	8 (N,Λ,Σ,Ξ)	1151
	10 (Δ,Σ*,Ξ*,Ω)	1382
charm baryon	$\bar{3}$ (Λ_c,Ξ_c)	2408
	6 (Σ_c,Ξ_c^*,Ω_c)	2534
D meson	3 (D,D_s)	1900
B meson	3 (B,B_s)	5309

Mass of NG boson : m=368 MeV

Meson decay constant : f=93 MeV

Numerical result for 1-VG

$$1 - V(M_b)G(M_b) = 0$$



No bound state for exotic channel :

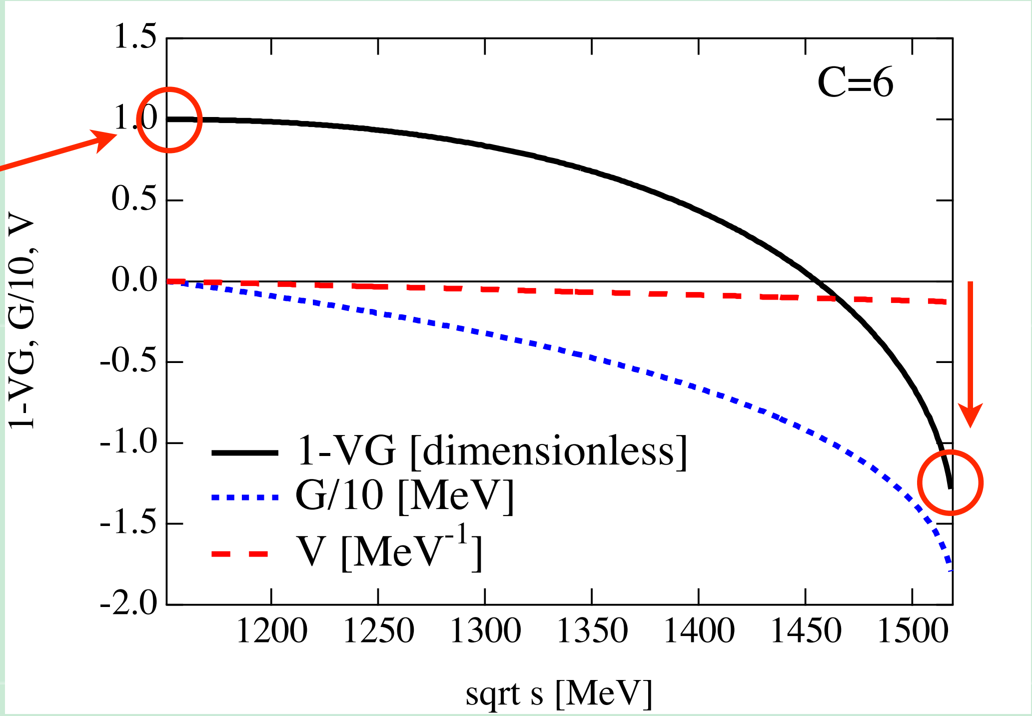
Strength of the attraction in exotic channel is not enough to generate a bound state.

Critical attraction

Since G(M)=0 by renormalization, 1-V(M)G(M) = 1

1-VG is monotonically decreasing.

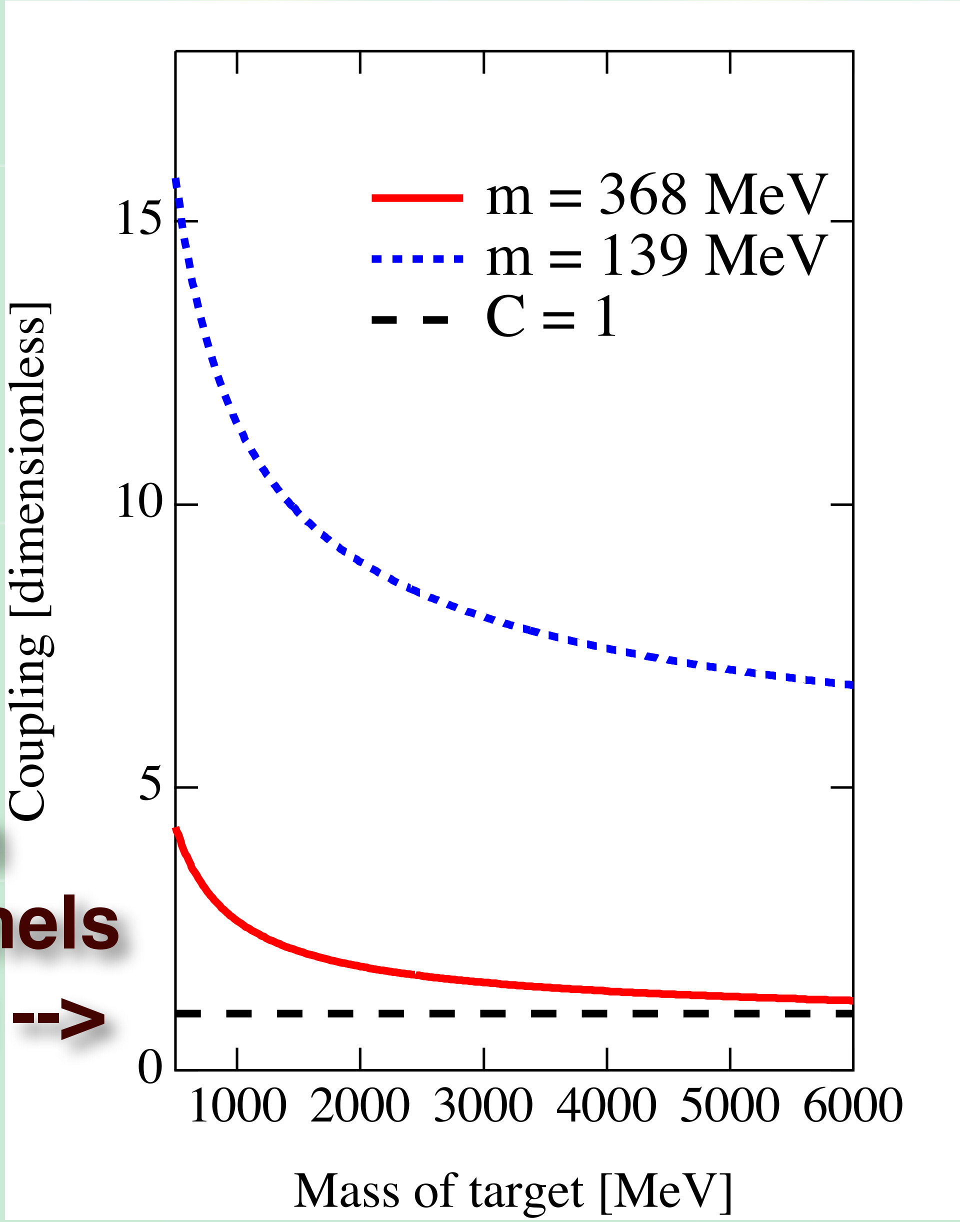
Fixed



--> Critical attraction : 1 - VG = 0 at M+m

$$C_{\rm crit} = -\frac{2f^2}{mG(M+m)}$$

Critical attraction and exotic channel



Attraction in exotic channels

C=1 -->

cross at M ~ 14 GeV

Coupling strengths in large Nc limit

Take large Nc limit

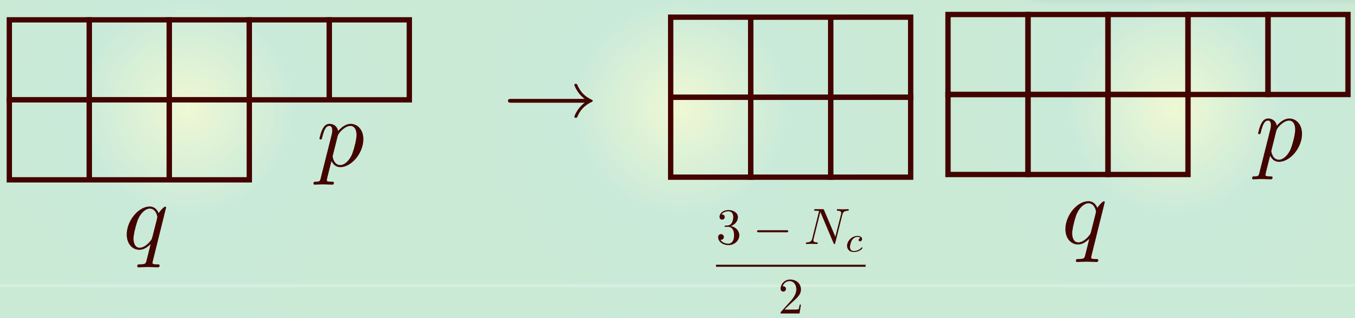
$$V^{(WT)}_{\alpha\beta} \sim -\frac{1}{2f^2} C_\alpha \omega_\alpha \delta_{\alpha\beta} \sim \frac{1}{N_c} \times C_\alpha$$

Flavor representation

$$C_\alpha = -2\langle\, [MT]_\alpha \,| F^a_M F^a_T |\, [MT]_\alpha \,\rangle$$
$$= -\, [C(\alpha) - C(M) - C(T)]$$

=3

$$[p,q] \rightarrow [p, q + \frac{3-N_c}{2}]$$



$$C([p, q + \frac{3-N_c}{2}]) = \frac{1}{3}\left(-\frac{9}{4} + p^2 + \frac{3q}{2} + pq + q^2\right) + \frac{1}{3}\left(p + \frac{q}{2}\right) N_c + \frac{N_c^2}{12}$$

Non-trivial Nc dependence

Coupling strengths in large Nc limit

Cα in large Nc : (positive is attractive)

α	1	8	10	$\overline{10}$	27	35
T=8	$\frac{9}{2}+\frac{N_c}{2}$	3	0	$\frac{3}{2}-\frac{N_c}{2}$	$-\frac{1}{2}-\frac{N_c}{2}$	
T=10		6	3		$\frac{5}{2}-\frac{N_c}{2}$	$-\frac{1}{2}-\frac{N_c}{2}$

α	$\overline{3}$	6	$\overline{15}$	24
T=$\overline{3}$	3	1	$-\frac{N_c}{3}$	
T=6	5	3	$\frac{5}{2}-\frac{N_c}{2}$	$\frac{1}{2}-\frac{5N_c}{6}$

Exotic attractions --> repulsions

Summary

We study the exotics bound states in chiral unitary approach in flavor SU(3) limit.

- We give the general formula of coupling strength of WT interaction.
- There are attractions in exotic channels, with universal and the smallest strength of C=1.

Summary

- We find **the critical attraction** which is the smallest strength to generate a bound state. The attraction in exotic channel is **beyond this value**.

- In large Nc limit, the attraction in exotic channel turns into **repulsive**.