A prediction of D^*-multi-ρ states

M. Bayar

Physics Department
Kocaeli University

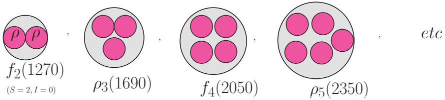
08 September, 2014
Collaborators: C. W. Xiao, E. Oset

Outline

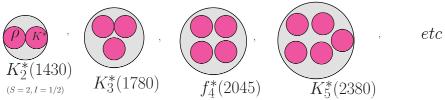
1. Introduction
2. Multibody Interaction Formalism
   - Three body scattering
   - Multi-body scattering
3. Results
4. Summary

- One of the important aims in the study of the strong interaction is to understand the nature and structure of hadronic resonances.
- The search for new resonances is goal both in theories and experiments
  $\Rightarrow$ quark-antiquark picture (the quark model) or tetraquarks, glueballs, meson molecules
- Using the unitary extensions of chiral perturbation theory(the chiral unitary approach) many resonances can be interpreted as meson-meson or meson-baryon molecules
  $\Rightarrow$ dynamically generated resonances

- The $f_2(1270)$, $\rho_3(1690)$, $f_4(2050)$, $\rho_5(2350)$, $f_6(2510)$ were described of increasing number of $\rho(770)$ particles. (L. Roca and E. Oset PRD 82 054013 (2010).)



- The $K_2^*(1430)$, $K_3^*(1780)$, $K_4^*(2045)$, $K_5^*(2380)$ are interpreted as molecules made of increasing number of $\rho(770)$ and $K^*(892)$ mesons. (J. Yamagata, L.Roca and E. Oset PRD 82 094017 (2010).)



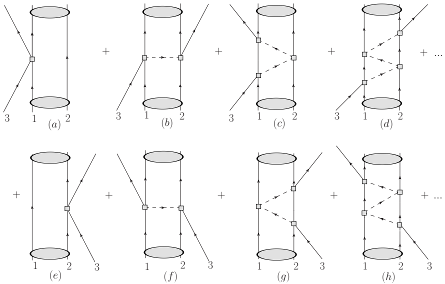
- What about new charmed resonances, D_3^*,D_4^*, D_5^*, D_6^*, basically made of one D^* meson and an increasing number of $\rho(770)$.

Table: The cases considered in the D^*-multi-ρ interactions.

particles:	3	R (1,2)	amplitudes
Two-body	ρ	D^*	$t_{\rho D^*}$
	ρ	ρ	$t_{\rho\rho}$
Three-body	D^*	f_2 $(\rho\rho)$	$T_{D^*-f_2}$
	ρ	D_2^* (ρD^*)	$T_{\rho-D_2^*}$
Four-body	D_2^*	f_2 $(\rho\rho)$	$T_{D_2^*-f_2}$
	f_2	D_2^* (ρD^*)	$T_{f_2-D_2^*}$
Five-body	D^*	f_4 $(f_2 f_2)$	$T_{D^*-f_4}$
	ρ	D_4^* $(f_2 D_2^*)$	$T_{\rho-D_4^*}$
Six-body	D_2^*	f_4 $(f_2 f_2)$	$T_{D_2^*-f_4}$
	f_2	D_4^* $(f_2 D_2^*)$	$T_{f_2-D_4^*}$

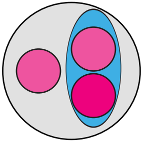
- The Faddeev equations under the Fixed Center Approximation (FCA) is an effective tool to deal with multi-hadron interaction.

$$T_1 = t_1 + t_1 G_0 T_2,\; T_2 = t_2 + t_2 G_0 T_1,\; T = T_1 + T_2 \tag{1}$$



Outline

- $\rho\rho$ interaction in $I = 0$ and $S = 2$ is very strong
  $\Rightarrow f_2(1270)$ is a molecule of two $\rho(770)$
- ρD^* interaction in $I = 1/2$ and $S = 2$ is also very strong
  $\Rightarrow D_2^*(2460)$ is a molecule of $\rho(770)$ and D^*
  $\Rightarrow$ Hence, $\rho\rho$ and ρD^* are the clusters
- Third particle interacts with the cluster

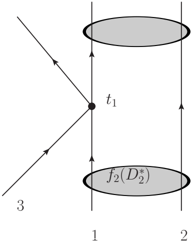


$D^* - f_2(\rho\rho)$
$\rho - D_2^*(\rho D^*)$

- Single Scattering:

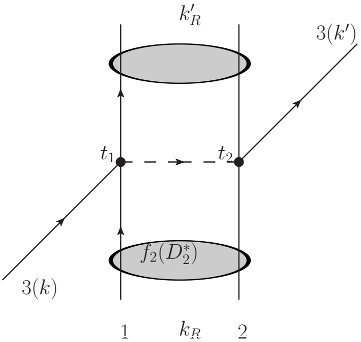
$$S_1^{(1)} = -\, i t_1 \frac{1}{\mathcal{V}^2} \frac{1}{\sqrt{2\omega_3}} \frac{1}{\sqrt{2\omega_3'}} \frac{1}{\sqrt{2\omega_1}} \frac{1}{\sqrt{2\omega_1'}} \times (2\pi)^4\, \delta(k + k_R - k' - k_R'), \quad (2)$$

$$S_2^{(1)} = -\, i t_2 \frac{1}{\mathcal{V}^2} \frac{1}{\sqrt{2\omega_3}} \frac{1}{\sqrt{2\omega_3'}} \frac{1}{\sqrt{2\omega_2}} \frac{1}{\sqrt{2\omega_2'}} \times (2\pi)^4\, \delta(k + k_R - k' - k_R'), \quad (3)$$



- Double Scattering:

$$S^{(2)} = -i(2\pi)^4 \delta(k + k_R - k' - k'_R) \frac{1}{\mathcal{V}^2} \frac{1}{\sqrt{2\omega_3}} \frac{1}{\sqrt{2\omega'_3}} \frac{1}{\sqrt{2\omega_1}} \frac{1}{\sqrt{2\omega'_1}} \frac{1}{\sqrt{2\omega_2}} \frac{1}{\sqrt{2\omega'_2}}$$
$$\times \int \frac{d^3q}{(2\pi)^3} F_R(q) \frac{1}{{q^0}^2 - \vec{q}^{\,2} - m_3^2 + i\,\epsilon} t_1 t_2, \tag{4}$$



$F_R(q)$ is the cluster form factor

$$F_R(q) = \frac{1}{\mathcal{N}} \int_{|\vec{p}|<\Lambda', |\vec{p}-\vec{q}|<\Lambda'} d^3\vec{p} \frac{1}{2E_1(\vec{p})} \frac{1}{2E_2(\vec{p})} \frac{1}{M_R - E_1(\vec{p}) - E_2(\vec{p})} \frac{1}{2E_1(\vec{p}-\vec{q})} \frac{1}{2E_2(\vec{p}-\vec{q})} \frac{1}{M_R - E_1(\vec{p}-\vec{q}) - E_2(\vec{p}-\vec{q})}, \tag{5}$$

$$\mathcal{N} = \int_{|\vec{p}|<\Lambda'} d^3\vec{p} \left(\frac{1}{2E_1(\vec{p})} \frac{1}{2E_2(\vec{p})} \frac{1}{M_R - E_1(\vec{p}) - E_2(\vec{p})} \right)^2, \tag{6}$$

J.Yamagata-Sekihara, J. Nieves, E. Oset Phys. Rev. D 83,014003 (2011)

- Full Scattering Amplitude:

$$S = -i\,T\,(2\pi)^4\delta(k + k_R - k' - k'_R)\frac{1}{\mathcal{V}^2} \times \frac{1}{\sqrt{2\omega_3}}\frac{1}{\sqrt{2\omega'_3}}\frac{1}{\sqrt{2\omega_R}}\frac{1}{\sqrt{2\omega'_R}}. \tag{7}$$

Comparing Eqs. (2)-(7)

$$\tilde{t_1} = \frac{2m_R}{2m_1}\,t_1, \quad \tilde{t_2} = \frac{2m_R}{2m_2}\,t_2, \tag{8}$$

Then

$$T = T_1 + T_2 = \frac{\tilde{t_1} + \tilde{t_2} + 2\, \tilde{t_1}\, \tilde{t_2}\, G_0}{1 - \tilde{t_1}\, \tilde{t_2}\, G_0^2}. \quad (9)$$

The function G_0 :

$$G_0(s) = \int \frac{d^3\vec{q}}{(2\pi)^3} F_R(q) \frac{1}{q^{02} - \vec{q}^{\ 2} - m_3^2 + i\,\epsilon}. \quad (10)$$

q^0, the energy carried by particle 3 in the rest frame of the three particle system

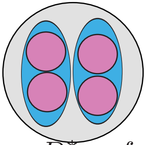
$$q^0(s) = \frac{s + m_3^2 - M_R^2}{2\sqrt{s}}. \quad (11)$$

The arguments of the amplitudes $T_i(s)$ and $t_i(s_i)$ are different

$$s_i = m_3^2 + m_i^2 + \frac{(M_R^2 + m_i^2 - m_j^2)(s - m_3^2 - M_R^2)}{2M_R^2}, (i,j = 1,2,\ i \neq j) \tag{12}$$

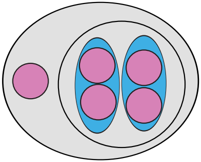
Outline

Four-Body



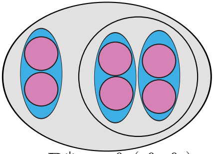
$$D_2^* - f_2(\rho\rho)$$
$$f_2 - D_2^*(\rho D^*)$$

Five-Body



$$D^* - f_4(f_2 f_2)$$
$$\rho - D_4^*(f_2 D_2^*)$$

Six-Body



$$D_2^* - f_4(f_2 f_2)$$
$$f_2 - D_4^*(f_2 D_2^*)$$

Three-body interaction:

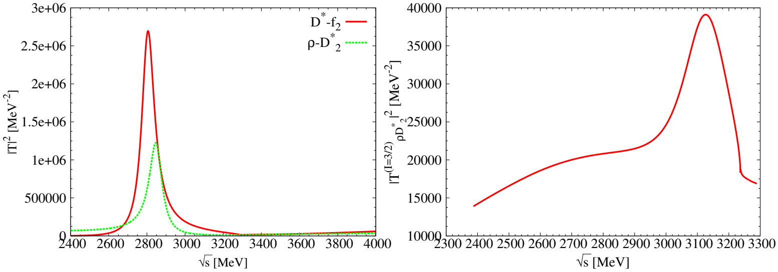


Figure: Modulus squared of the $T_{D^*-f_2}$ and $T_{\rho-D_2^*}$ scattering amplitudes. Left: $I_{total} = \frac{1}{2}$; Right: $I_{total} = \frac{3}{2}$.

2800-2850 MeV —— 3120 MeV

$\sim$ 400 MeV below $D^* - f_2$ thr. —- $|T^{I=3/2}_{\rho-D_2^*}|^2$ «(30 times)$|T^{I=1/2}_{\rho-D_2^*}|^2$

New D_3^* state ; mixture of $D^* - f_2$ and $\rho - D_2^*$ m $\sim$ 2800-2850 MeV Γ ~ 60-100 MeV

Four-body interaction:

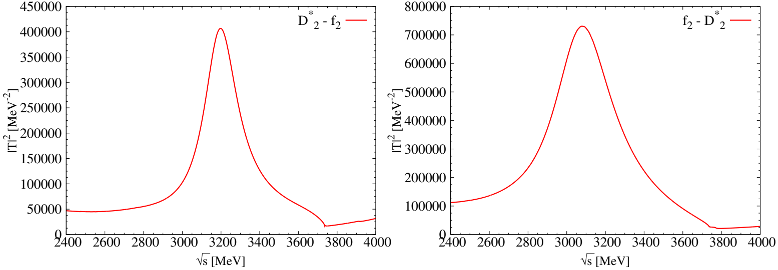


Figure: Modulus squared of the $T_{D_2^*-f_2}$ (left) and $T_{f_2-D_2^*}$ (right) scattering amplitudes.

3200 MeV, $\Gamma \sim$ 200 MeV —— 3075 MeV, $\Gamma \sim$ 400 MeV

New D_4^* resonance ; m $\sim$ 3075-3200 MeV, $\Gamma \sim$ 200-400 MeV

Five-body interaction:

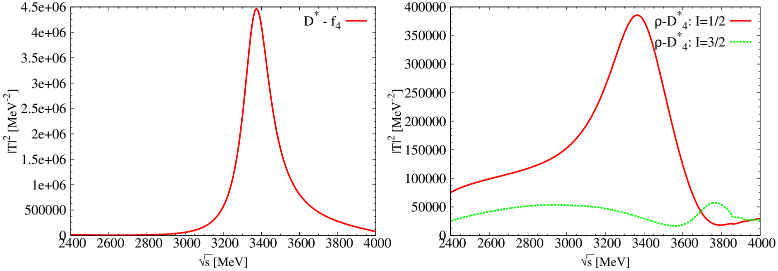


Figure: Modulus squared of the $T_{D^*-f_4}$ (left) and $T_{\rho-D_4^*}$ (right) scattering amplitudes.

3375 MeV, $\Gamma \sim$ 200 MeV —— 3360 MeV, $\Gamma \sim$ 400 MeV

New D_5^* resonance ; m $\sim$ 3360-3375 MeV, $\Gamma \sim$ 200-400 MeV

Six-body interaction:

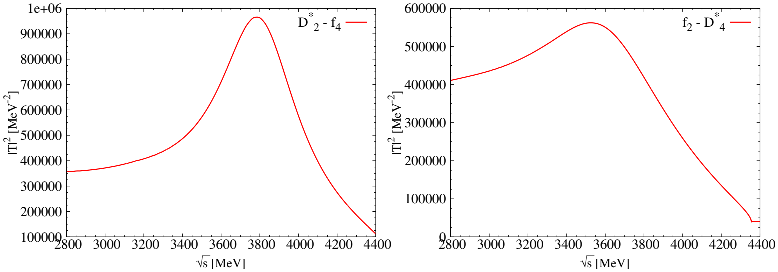


Figure: Modulus squared of the $T_{D_2^*-f_4}$ (left) and $T_{f_2-D_4^*}$ (right) scattering amplitudes.

3775 MeV, $\Gamma \sim 400$ MeV —— NOT a clear peak

New D_6^* resonance ; m $\sim$ 3775 MeV, $\Gamma \sim 400$ MeV

- $\rho\rho$ and ρD^* interactions in $I = 0$, $I = 1/2$ and $S = 2$ are very strong
  $\Rightarrow f_2(1270)$ and $D_2^*(2460)$ dynamically generated (UChPT)
- $\rho_3(1690)(3^{--})$, $f_4(2050)(4^{++})$, $\rho_5(2350)(5^{--})$, and $f_6(2510)(6^{++})$ were described as basically molecules of multi-$\rho(770)$ states
- $K_2^*(1430)$, $K_3^*(1780)$, $K_4^*(2045)$, $K_5^*(2380)$ and K_6^* could be interpreted as molecules made of one $K^*(892)$ meson and an increasing number of $\rho(770)$ mesons

- New charmed resonances, D_3^*, D_4^*, D_5^* and D_6^* , which are basically made of one D^* meson and an increasing number of $\rho(770)$ mesons are predicted
- Their masses are predicted around $2800 - 2850$, $3075 - 3200$, $3360 - 3375$ and 3775 MeV respectively
- Their widths are about $60 - 100$, $200 - 400$, $200 - 400$ and 400 MeV respectively
- Such states can be found in the future in coming facilities like FAIR and others

THANK YOU