Structure of exotic compounds

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A bit of chiral dynamics

B^0 and B^0_s weak decays into J/psi and $f_0(500)$, $f_0(980)$

Predictions for Λ_b -> J/ψ k^- p and J/ψ Λ(1405)

Predictions for hidden charm baryon states

Comparison with the J/ψ p and K^- p spectra of recent LHCb pentaquark experiment

Exotic states: multirho states, K* multirho, D* multirho, pseudotensor mesons, rho K Kbar,
rho D* D*bar, D NN ….

Meson interaction

Pseudoscalar-pseudoscalar interaction: channels

1) $\pi^+ \pi^-$
2) $\pi^0 \pi^0$
3) $K^+ K^-$
4) K^0 Kbar^0
5) $\eta\eta$

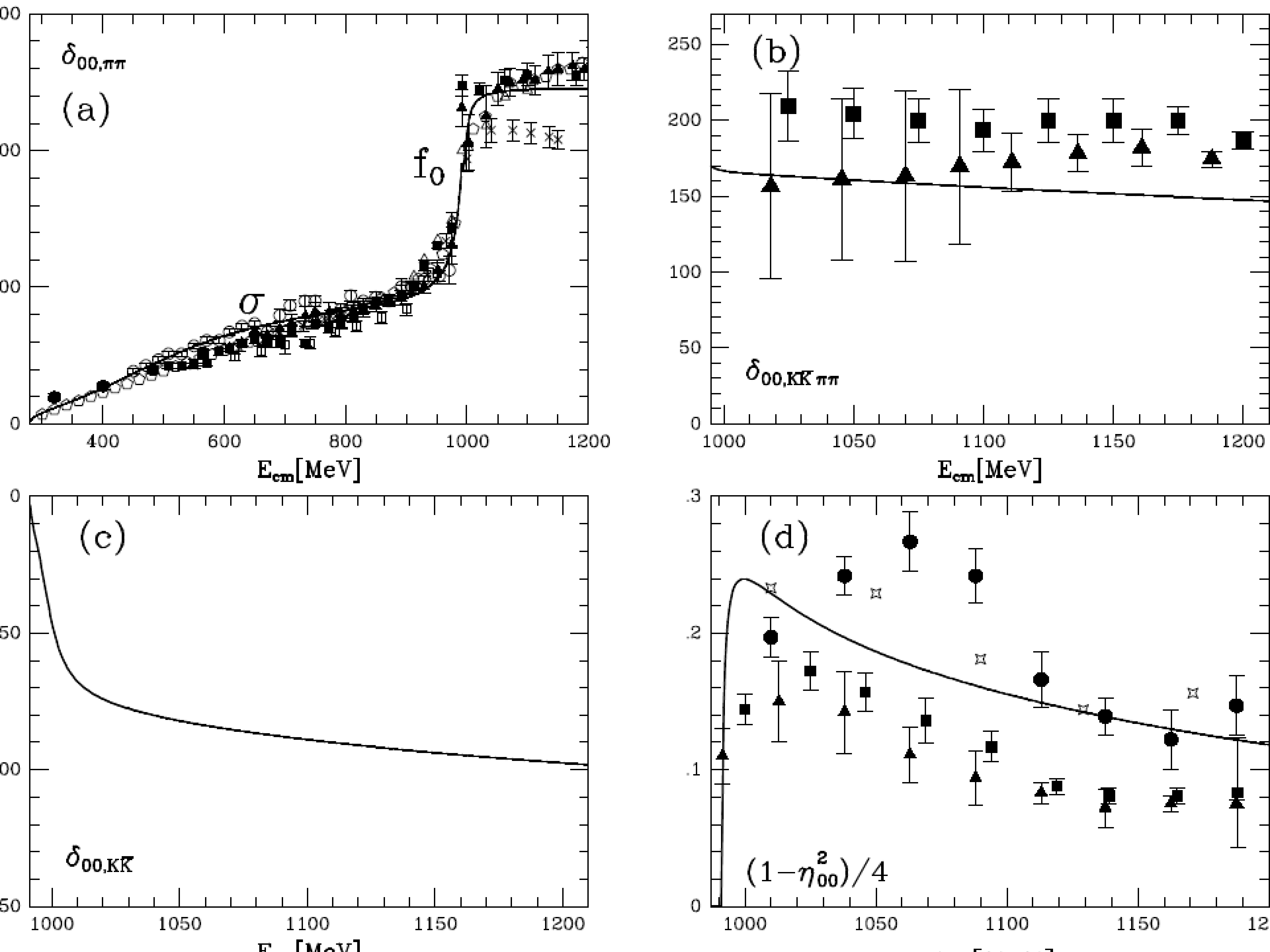
We use the chiral unitary approach: Bethe Salpeter equations in coupled channels

$$T=(1-VG)^{-1} V$$

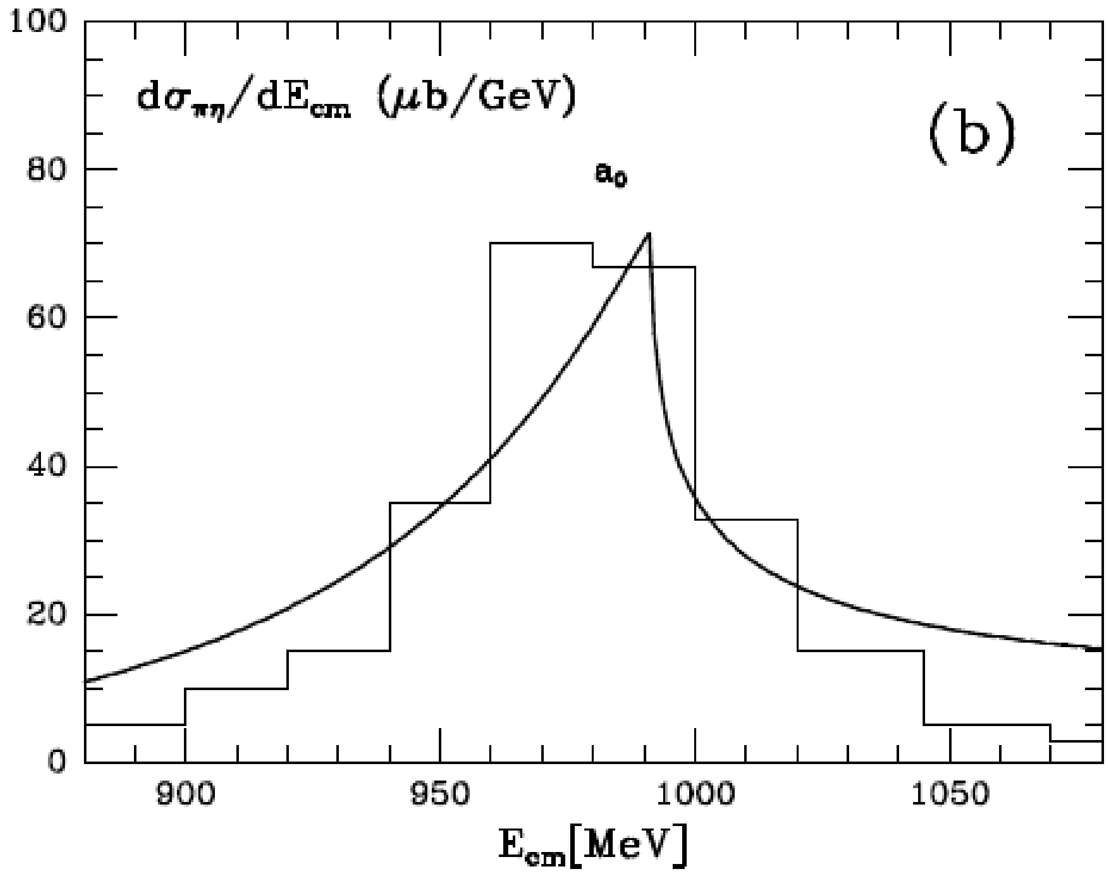
With V obtained from the chiral Lagrangians and G the loop function of two meson propagators .

$$G_{jj}(s) = \int_0^{q_{max}} \frac{q^2 dq}{(2\pi)^2} \frac{\omega_1+\omega_2}{\omega_1\omega_2[P^{02}-(\omega_1+\omega_2)^2+i\epsilon]}$$

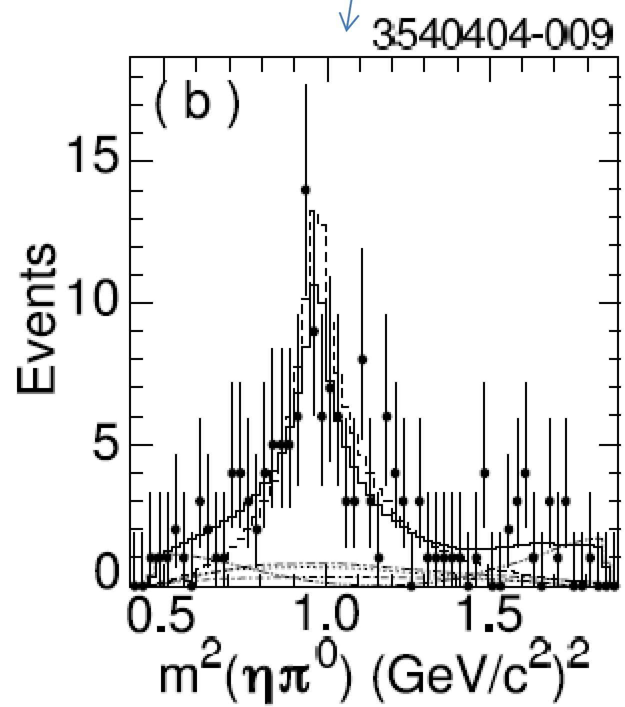
$$\begin{aligned}
V_{11} &= -\frac{1}{2f^2}s, & V_{12} &= -\frac{1}{\sqrt{2}f^2}(s-m_\pi^2), & V_{13} &= -\frac{1}{4f^2}s, \\
V_{14} &= -\frac{1}{4f^2}s, & V_{15} &= -\frac{1}{3\sqrt{2}f^2}m_\pi^2, & V_{22} &= -\frac{1}{2f^2}m_\pi^2, \\
V_{23} &= -\frac{1}{4\sqrt{2}f^2}s, & V_{24} &= -\frac{1}{4\sqrt{2}f^2}s, & V_{25} &= -\frac{1}{6f^2}m_\pi^2, \\
V_{33} &= -\frac{1}{2f^2}s, & V_{34} &= -\frac{1}{4f^2}s, & V_{35} &= -\frac{1}{12\sqrt{2}f^2}(9s-6m_\eta^2-2m_\pi^2), \\
V_{44} &= -\frac{1}{2f^2}s, & V_{45} &= -\frac{1}{12\sqrt{2}f^2}(9s-6m_\eta^2-2m_\pi^2), & V_{55} &= -\frac{1}{18f^2}(16m_K^2-7m_\pi^2),
\end{aligned} \tag{8}$$



δ00,ππ
(a)
f0
σ
Ecm[MeV]
(b)
δ00,KKππ
Ecm[MeV]
(c)
δ00,KK̄
(d)
(1−η²00)/4



$D^0 \to K_S^0\eta\pi^0$ **Decay**



Oset, Ramos NPA98

Coupled channels:

$$K^-p,\ \bar{K}^0 n,\ \pi^0\Lambda,\ \pi^0\Sigma^0,\ \pi^+\Sigma^-,\ \pi^-\Sigma^+,\ \eta\Lambda,\ \eta\Sigma^0,\ K^0\Xi^0 \text{ and } K^+\Xi^-$$

$$T = [1 - VG]^{-1} V$$

$$G_i = i \int \frac{d^4q}{(2\pi)^4} \frac{M_i}{E_i(\vec{q}\,)} \times \frac{1}{k^0 + p^0 - q^0 - E_i(\vec{q}\,) + i\epsilon} \frac{1}{q^2 - m_i^2 + i\epsilon}$$

$$V_{ij}(\sqrt{s}) = -C_{ij} \frac{1}{4f^2}(2\sqrt{s} - M_i - M_j) \times \left(\frac{M_i + E_i}{2M_i}\right)^{1/2} \left(\frac{M_j + E_j}{2M_j}\right)^{1/2},$$

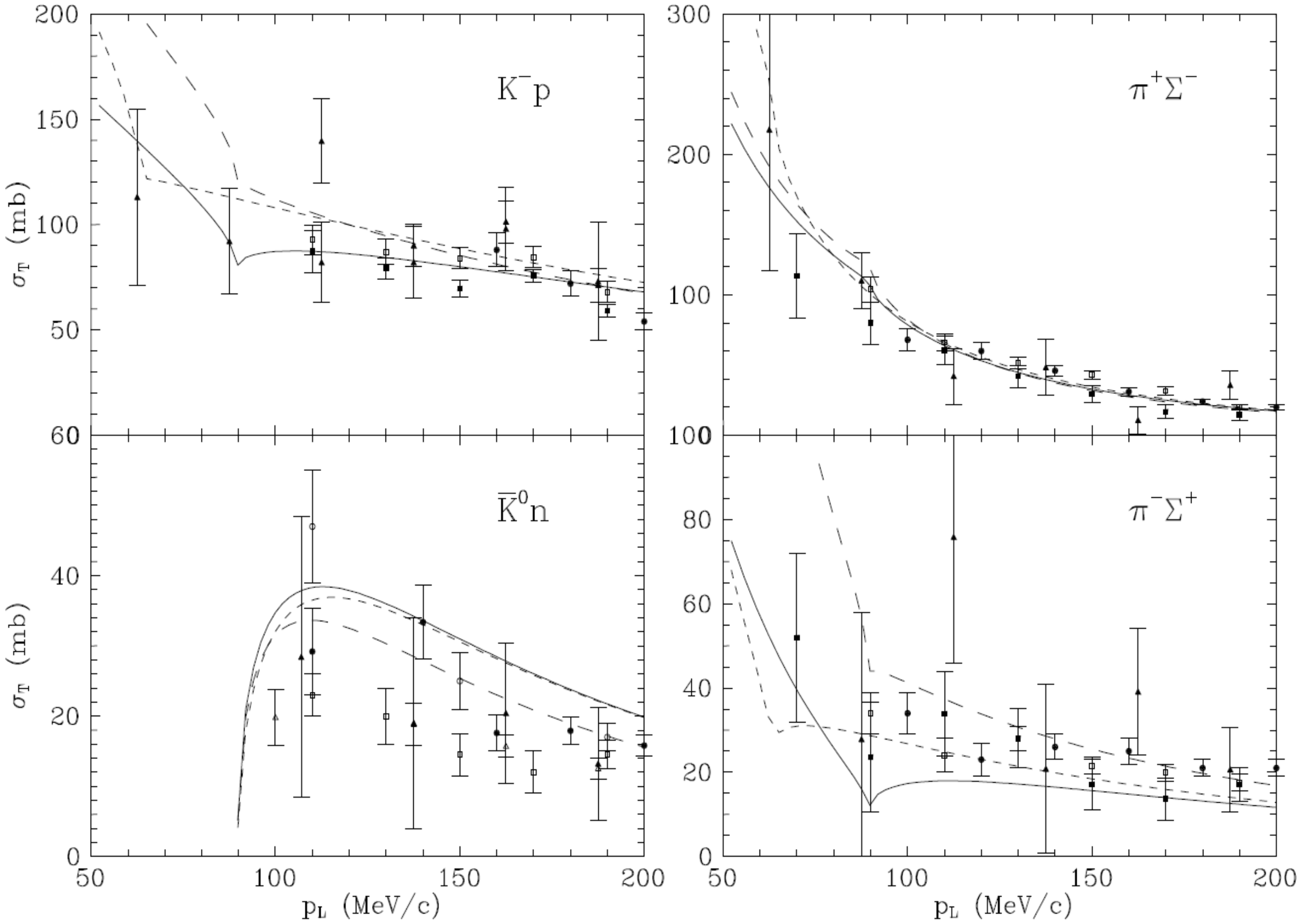
$$C_{ij} = \begin{pmatrix} 3 & -\sqrt{\frac{3}{2}} \\ -\sqrt{\frac{3}{2}} & 4 \end{pmatrix}$$ for I=0

Channels Kbar N , πΣ,

Oset, Ramos NPA98

Coupled channels:

$$K^-p,\ \bar{K}^0 n,\ \pi^0\Lambda,\ \pi^0\Sigma^0,\ \pi^+\Sigma^-,\ \pi^-\Sigma^+,\ \eta\Lambda,\ \eta\Sigma^0,\ K^0\Xi^0 \text{ and } K^+\Xi^-$$



B^0 and B_s^0 decays into $J/\psi\ f_0(980)$ and $J/\psi\ f_0(500)$ and the nature of the scalar resonances

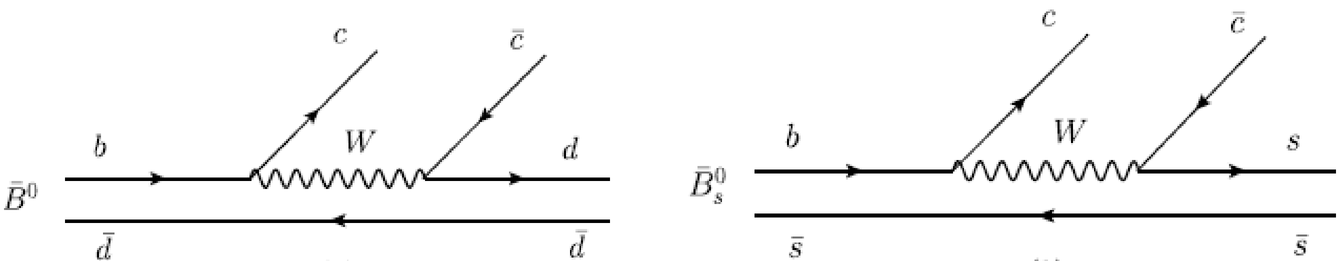
Much debate on recent LHCb experiments
(see S. Stone, L. Zhang, PRL 2013)

In $B^0_s \to J/\psi\ \pi^+\pi^-$, a big peak is seen for $f_0(980)$,
and no signal for $f_0(500)$. LHCb PLB 2011, PRD 2012
Corroborated by Belle, CDF, D0 collaborations.

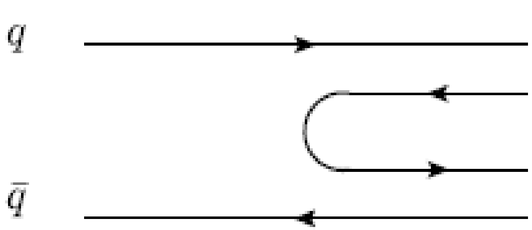
Conversely, in $B^0 \to J/\psi\ \pi^+\pi^-$ the $f_0(500)$ is seen and only a tiny signal for the $f_0(980)$ is observed , LHCb PRD 2013.

B^0 and B_s^0 decays into $J/\psi\ f_0(980)$ and $J/\psi\ f_0(500)$ and the nature of the scalar resonances

W.H. Liang, EO
PLB 2014



(a) (b)



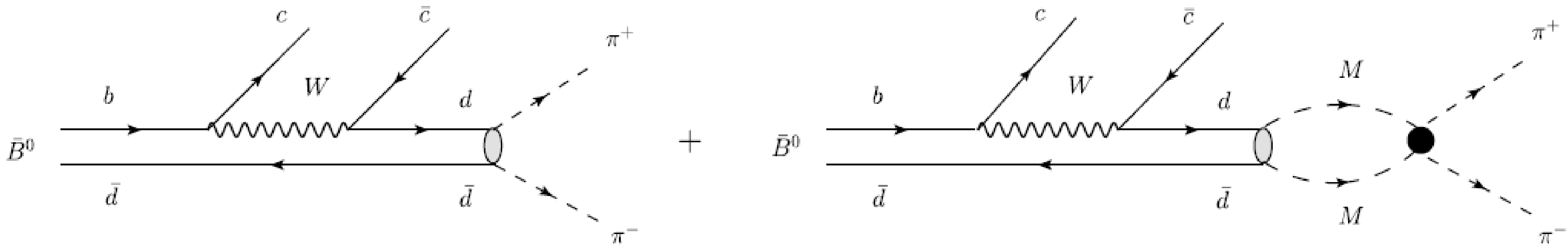
$$q\bar{q}(u\bar{u}+d\bar{d}+s\bar{s})$$

$$M = \begin{pmatrix} u\bar{u} & u\bar{d} & u\bar{s} \\ d\bar{u} & d\bar{d} & d\bar{s} \\ s\bar{u} & s\bar{d} & s\bar{s} \end{pmatrix}$$

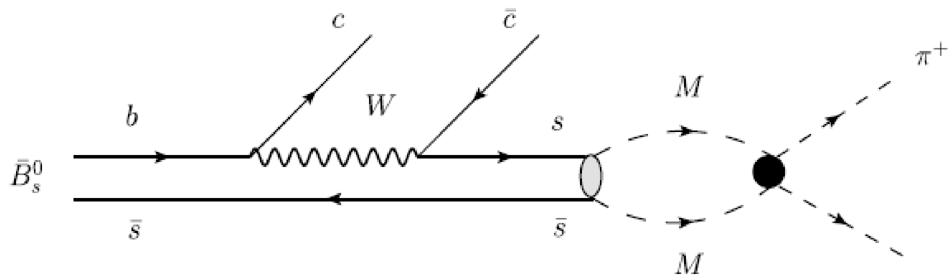
$$M \cdot M = M \times (u\bar{u} + d\bar{d} + s\bar{s})$$

$$\phi = \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta \end{pmatrix}$$

$$\begin{aligned} d\bar{d}(u\bar{u} + d\bar{d} + s\bar{s}) &\equiv (\phi \cdot \phi)_{22} \\ &= \pi^-\pi^+ + \frac{1}{2}\pi^0\pi^0 - \frac{1}{\sqrt{3}}\pi^0\eta + K^0\bar{K}^0 + \frac{1}{6}\eta\eta, \\ s\bar{s}(u\bar{u} + d\bar{d} + s\bar{s}) &\equiv (\phi \cdot \phi)_{33} = K^-K^+ + K^0\bar{K}^0 + \frac{4}{6}\eta\eta. \end{aligned} \tag{4}$$



(a)

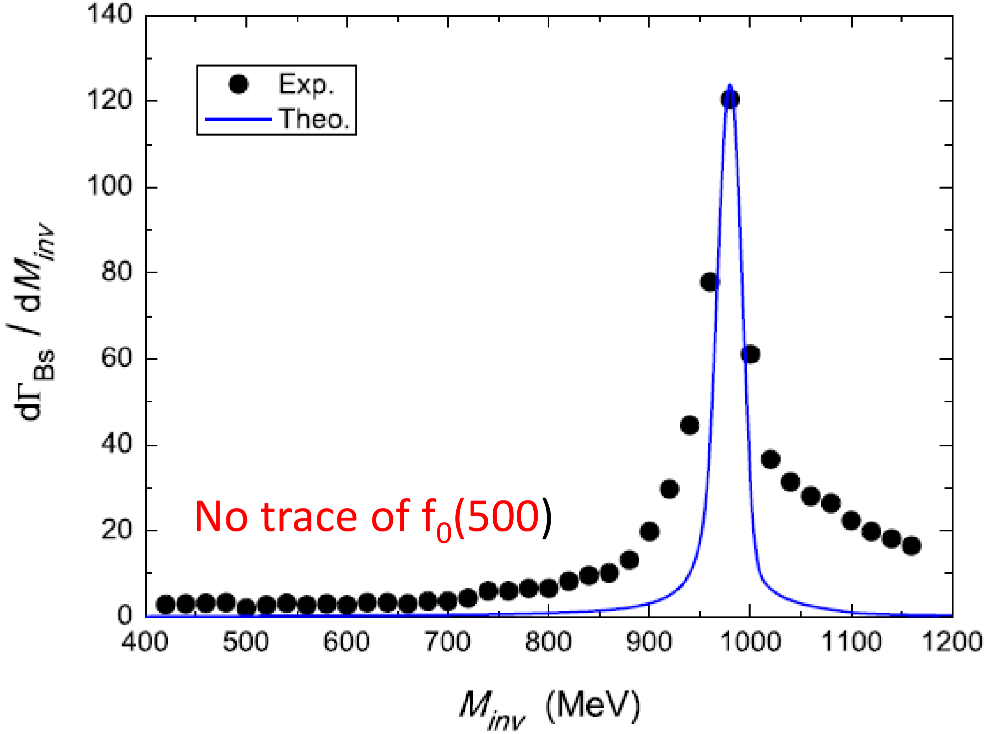


(b)

$$
\begin{aligned}
& t(\bar{B}^0 \to J/\psi \pi^+\pi^-) \\
& \quad = V_P V_{cd}\bigg(1 + G_{\pi^+\pi^-} t_{\pi^+\pi^- \to \pi^+\pi^-} + \frac{1}{2}\frac{1}{2} G_{\pi^0\pi^0} t_{\pi^0\pi^0 \to \pi^+\pi^-} \\
& \qquad + G_{K^0\bar{K}^0} t_{K^0\bar{K}^0 \to \pi^+\pi^-} + \frac{1}{6}\frac{1}{2} G_{\eta\eta} t_{\eta\eta \to \pi^+\pi^-}\bigg), \\
& t(\bar{B}_s^0 \to J/\psi \pi^+\pi^-) \\
& \quad = V_P V_{cs}\bigg(G_{K^+K^-} t_{K^+K^- \to \pi^+\pi^-} \\
& \qquad + G_{K^0\bar{K}^0} t_{K^0\bar{K}^0 \to \pi^+\pi^-} + \frac{4}{6}\frac{1}{2} G_{\eta\eta} t_{\eta\eta \to \pi^+\pi^-}\bigg), \qquad (5)
\end{aligned}
$$

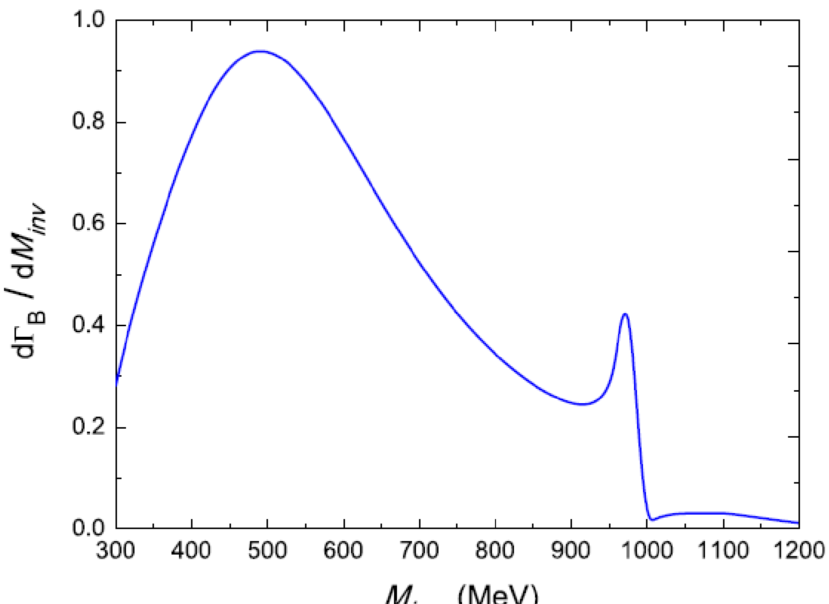
$$
V_{cd} = -\sin\theta_c = -0.22534
$$

$$
V_{cs} = \cos\theta_c = 0.97427.
$$



$\bar{B}_s^0 \to J/\psi \pi^+ \pi^-$ decay

One normalization is arbitrary but the two decays share the same normalization



$\bar{B}^0 \to J/\psi \pi^+ \pi^-$ decay

$$\frac{\mathcal{B}[\bar{B}^0 \to J/\psi f_0(980),\, f_0(980) \to \pi^+\pi^-]}{\mathcal{B}[\bar{B}^0 \to J/\psi f_0(500),\, f_0(500) \to \pi^+\pi^-]} = 0.033 \pm 0.007$$

Our result

Exp: $(0.6^{+0.7+3.3}_{-0.4-2.6}) \times 10^{-2}$ 0–0.046

$$\frac{\Gamma(B^0 \to J/\psi f_0(500))}{\Gamma(B_s^0 \to J/\psi f_0(980))} \simeq (4.5 \pm 1.0) \times 10^{-2}.$$

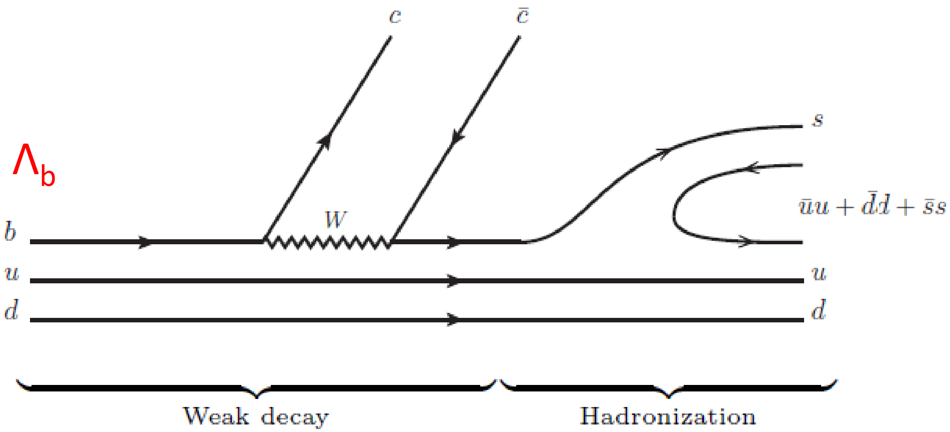
Our result

Exp: $(2.08–4.13) \times 10^{-2}$

Note: all the ratios and the mass distributions are obtained with no free parameters, the only one has been fitted to scattering data.

Predictions for the $\Lambda_b \to J/\psi\ \Lambda(1405)$ decay

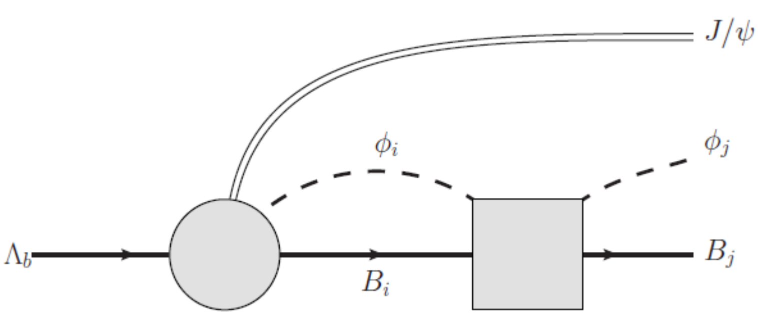
L. Roca, M. Mai, E.Oset and U.G. Meissner, EPJC 2015



$$|H\rangle = |K^- p\rangle + |\bar{K}^0 n\rangle - \frac{\sqrt{2}}{3}|\eta\Lambda\rangle + \frac{2}{3}|\eta'\Lambda\rangle$$

u d quarks in I=0

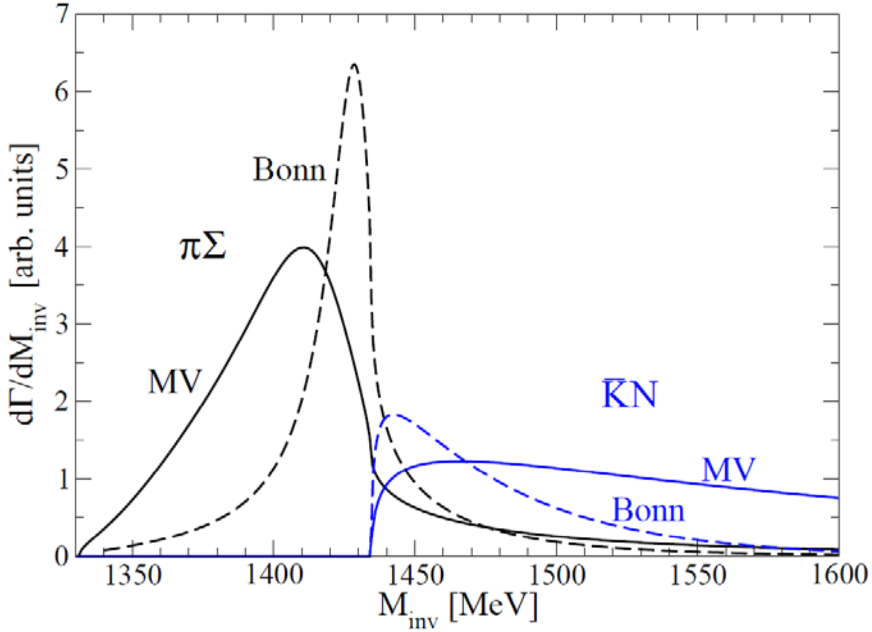
u d quarks in I=0 (spectators) an s quark -> total I=0



$$\mathcal{M}_j(M_{\rm inv}) = V_p \left(h_j + \sum_i h_i G_i(M_{\rm inv})\, t_{ij}(M_{\rm inv}) \right)$$

$$h_{\pi^0\Sigma^0} = h_{\pi^+\Sigma^-} = h_{\pi^-\Sigma^+} = 0\,,\ \ h_{\eta\Lambda} = -\frac{\sqrt{2}}{3}$$

$$h_{K^-p} = h_{\bar{K}^0 n} = 1\,,\ \ h_{K^+\Xi^-} = h_{K^0\Xi^0} = 0\,,$$

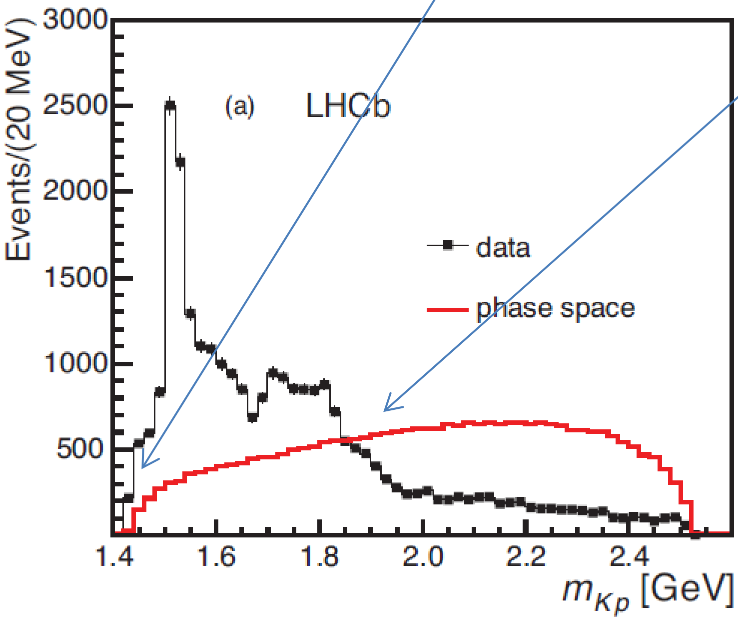


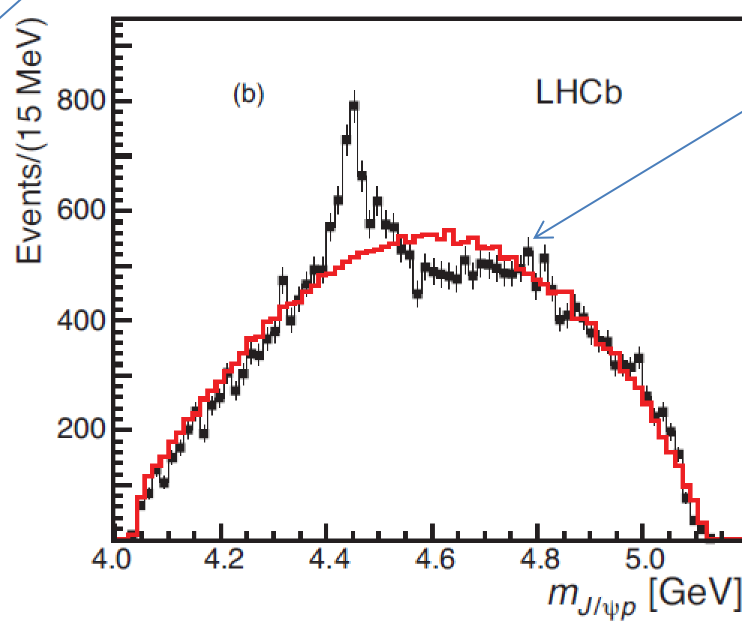
We have there J/ψ K^- p , the final state in the LHCb pentaquark experiment

Note the large deviation from Phase space for K^- p

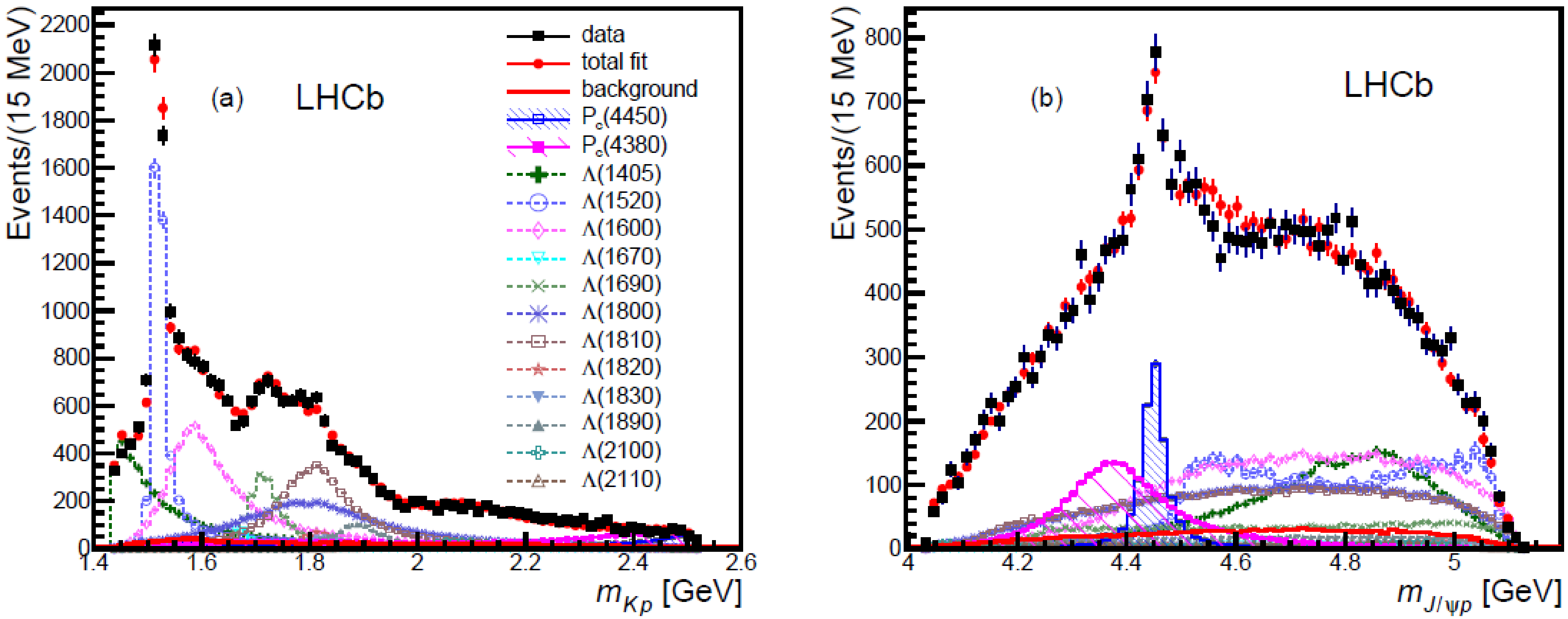
While for J/ψ p one has essentially Phase space except for the peak

Large concentration of strength around threshold

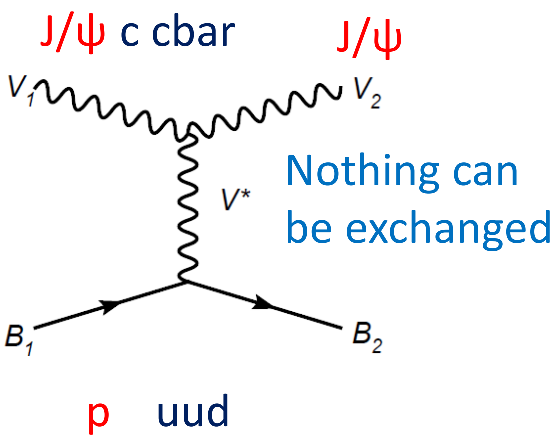


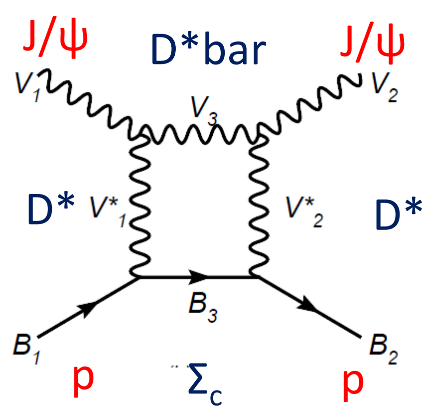


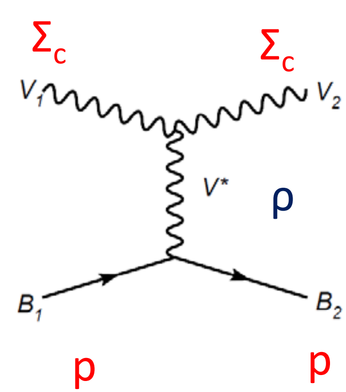
1507.03414



How can the peak in J/ψ appear? The J/ψ N interaction is very weak !!





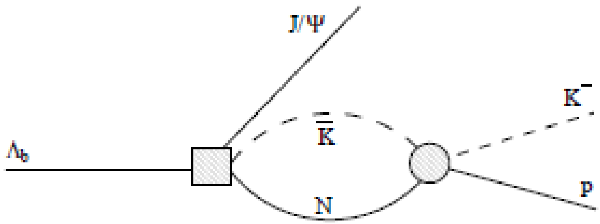


Predictions for hidden charm Baryon states J J Wu, R Molina, E. O, B S Zou, PRL (2010)

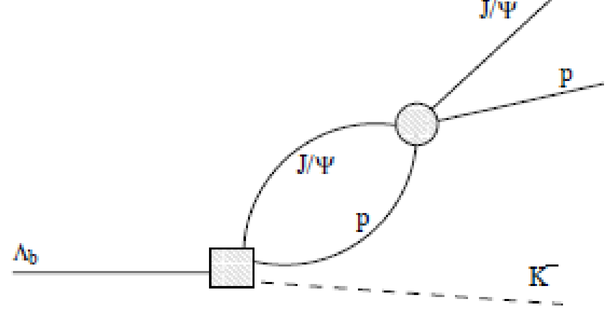
(I,S)	z_R	g_a		
$(1/2,0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	$J/\psi N$
	$4415-9.5i$	$2.83-0.19i$	$-0.07+0.05i$	$-0.85+0.02i$
		2.83	0.08	0.85

C W Xiao, J Nieves , E. O, PRD 2013 : D*bar Σ_c* channel included

$4417.04+i4.11$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$0.53-i0.07$	$0.08-i0.07$	$2.81-i0.07$	$0.12-i0.10$	$0.11-i0.51$
$\lvert g_i \rvert$	0.53	0.11	2.81	0.16	0.52
$4481.04+i17.38$	$J/\psi N$	$\bar{D}^*\Lambda_c$	$\bar{D}^*\Sigma_c$	$\bar{D}\Sigma_c^*$	$\bar{D}^*\Sigma_c^*$
g_i	$1.05+i0.10$	$0.18-i0.09$	$0.12-i0.10$	$0.22-i0.05$	$2.84-i0.34$
$\lvert g_i \rvert$	1.05	0.20	0.16	0.22	2.86



(b)



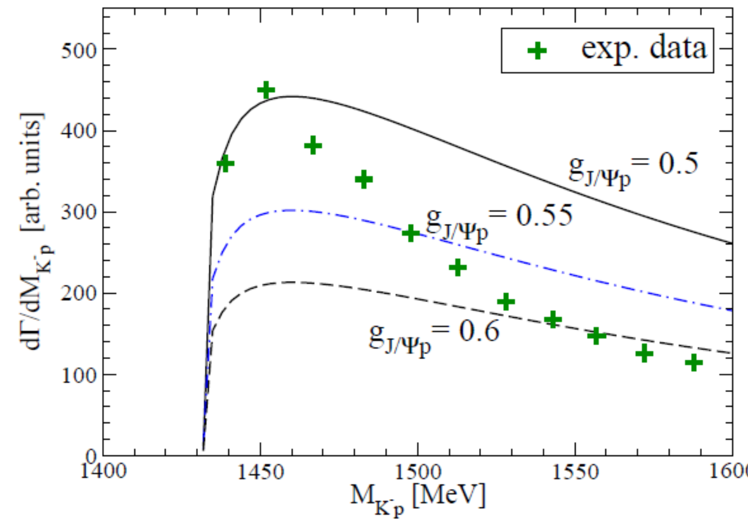
(c)

L. Roca, J. Nieves, E. O

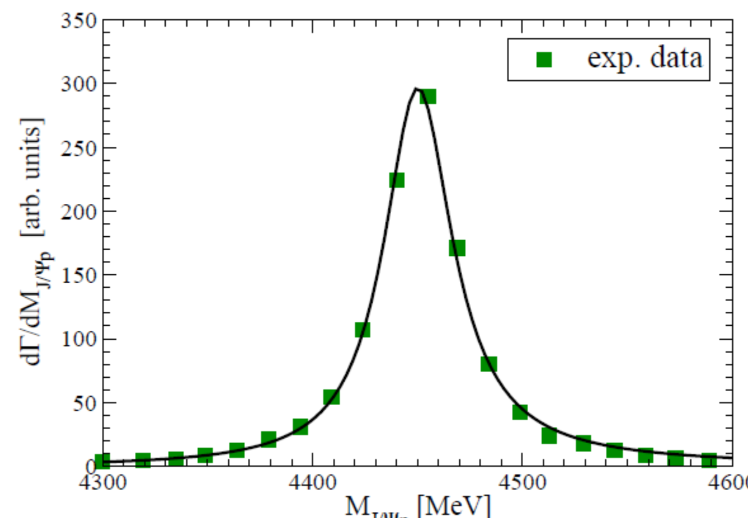
arXiv:1507.04249

$$T^{(J/\psi\, p)}(M_{J/\psi\, p}) = V_p\, h_{K^- p} G_{J/\psi\, p}(M_{J/\psi\, p}) \times t_{J/\psi\, p \to J/\psi\, p}(M_{J/\psi\, p})\,,$$

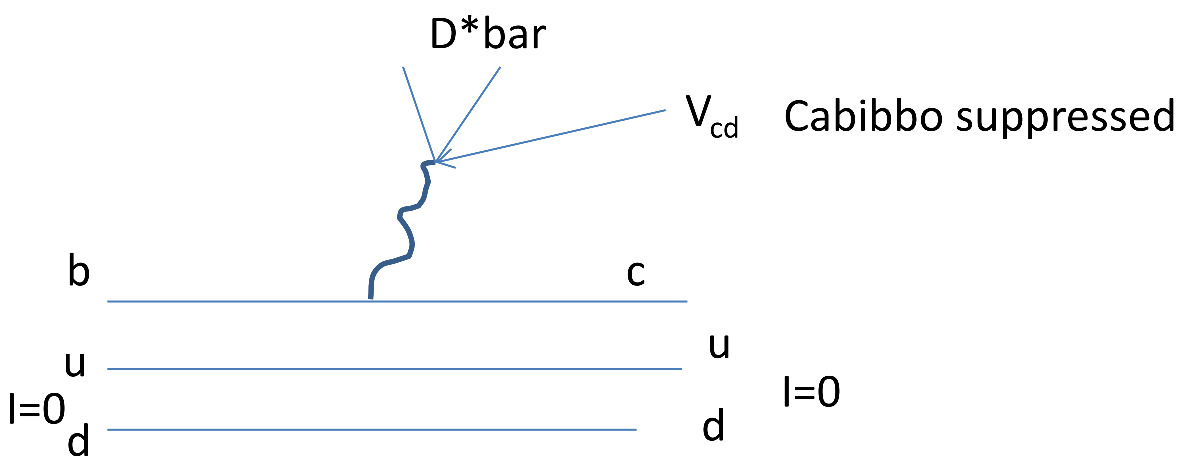
$$t_{J/\psi\, p \to J/\psi\, p} = \frac{g^2_{J/\psi\, p}}{M^2_{J/\psi\, p} - M^2_R + i M_R \Gamma_R} \quad 2M_R$$



(a)



It is not trivial that the K^- p and J/ψ p distributions can be related like that



Since D*bar Σ_c is the main channel one should start from this production and then make transition to J/ψ p, but this configuration is now allowed
D*bar Λ_c is allowed
but it is has small strength in the wave function and then is Cabibbo suppressed

This leaves only J/ψ p to initiate the interaction to produce the resonance

The D*bar Σ_c or D*bar Σ^*_c picture endures all tests of experiment: mass and width, spin parity $3/2^-$ acceptable, coupling of resonance to J/ψ acceptable, nontrivial relation of J/ψ p and K^- p distributions established.

Multirho states:

The vector vector interaction can be studied using the local hidden gauge formalism, Bando et al.

$$\mathcal{L}^{(4V)} = \frac{g^2}{2}\langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle \, ,$$

$g=M_V/2f_\pi$

$$\mathcal{L}^{(3V)} = ig\langle (V^\mu \partial_\nu V_\mu - \partial_\nu V_\mu V^\mu) V^\nu \rangle \, ,$$

$$V^{(I=0,S=2)}(s) = -4g^2 - 8g^2 \left(\frac{3s}{4m_\rho^2} - 1 \right) \sim -20g^2$$

$$V^{(I=2,S=2)}(s) = 2g^2 + 4g^2 \left(\frac{3s}{4m_\rho^2} - 1 \right) \sim 10g^2$$

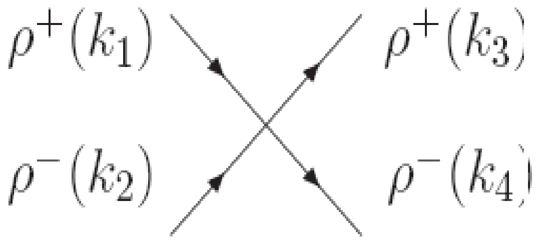
$$T = \frac{V}{1 - VG},$$

$$G(s) = i \int \frac{d^4p}{(2\pi)^4} \frac{1}{p^2 - m_\rho^2 + i\epsilon} \frac{1}{(Q-p)^2 - m_\rho^2 + i\epsilon} \, ,$$

Rho-rho interaction in the hidden gauge approach

R.Molina, D. Nicmorus, E. O. PRD (08)

V=-



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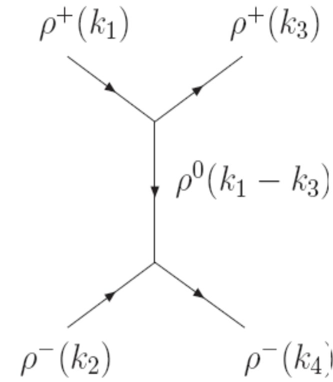

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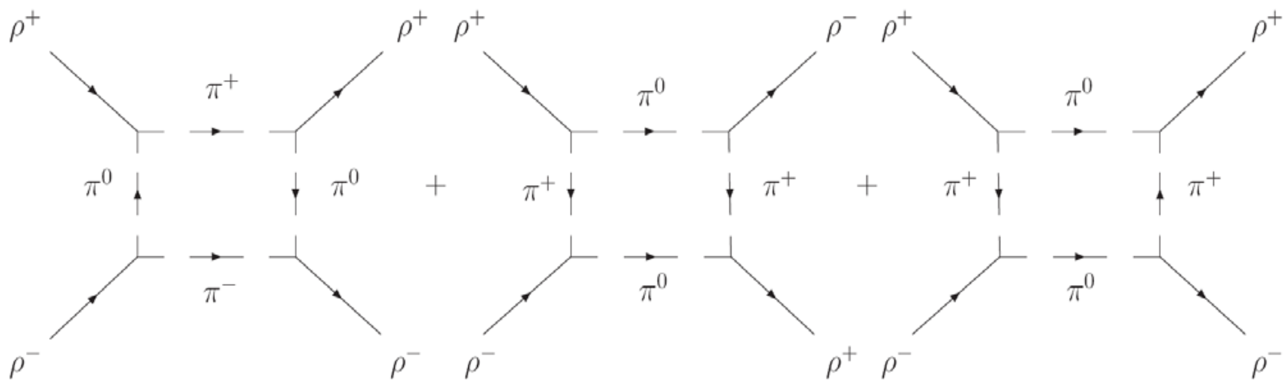


Spin projectors neglecting q/M_V, in L=0

$$\mathcal{P}^{(0)} = \frac{1}{3}\epsilon_\mu\epsilon^\mu\epsilon_\nu\epsilon^\nu$$

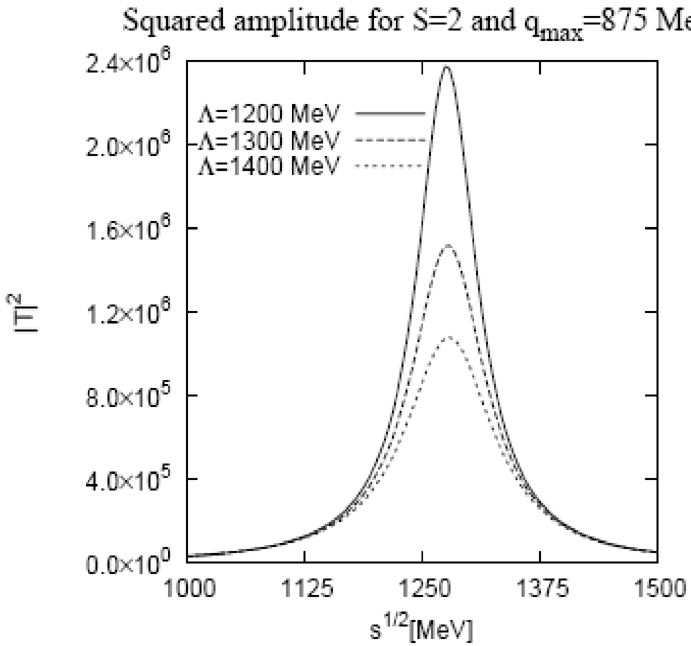
$$\mathcal{P}^{(1)} = \frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu - \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu)$$

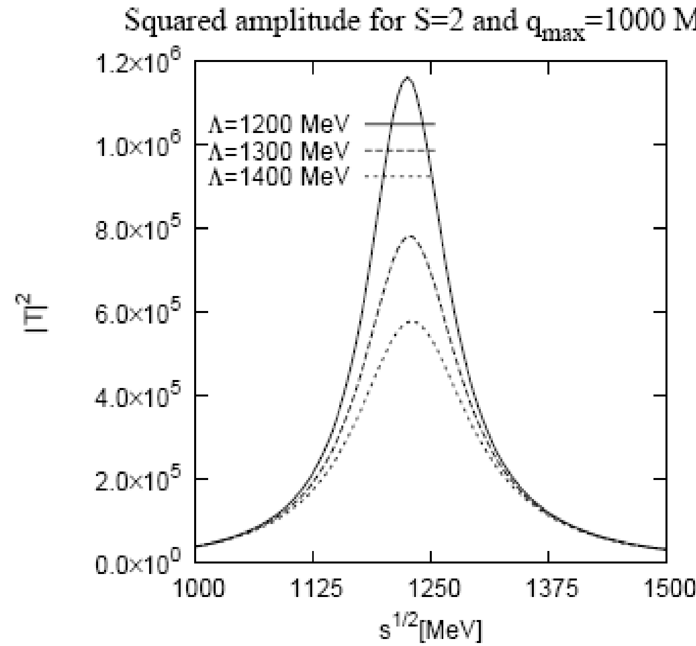
$$\mathcal{P}^{(2)} = \{\frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu + \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu) - \frac{1}{3}\epsilon_\alpha\epsilon^\alpha\epsilon_\beta\epsilon^\beta\}$$

Bethe Salpeter eqn.

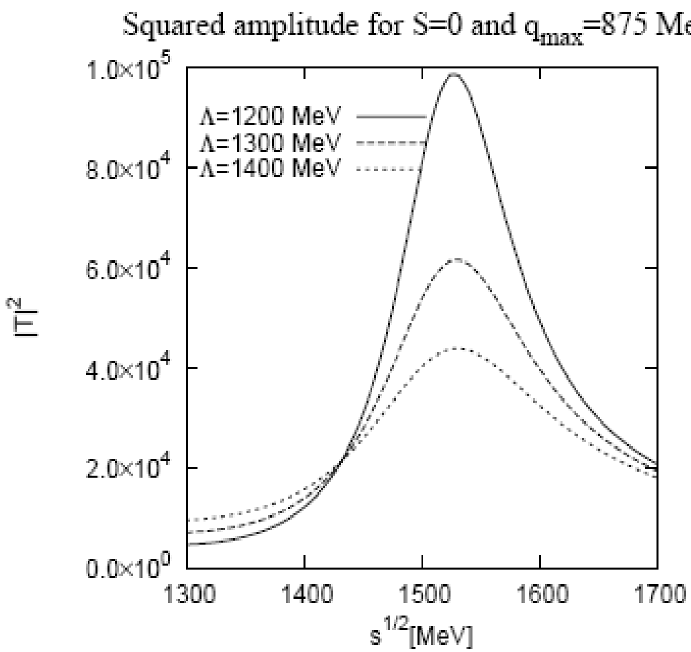
$$T = \frac{V}{1-VG}$$

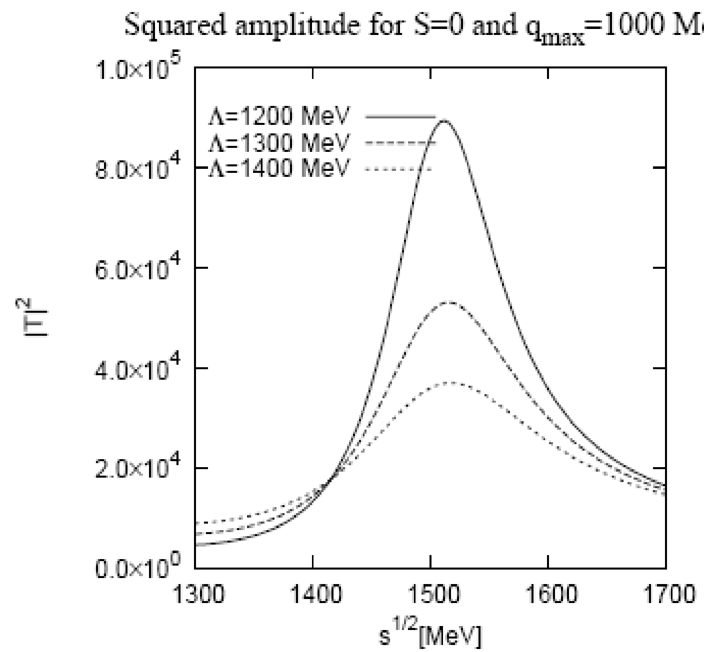
G is the ρρ propagator





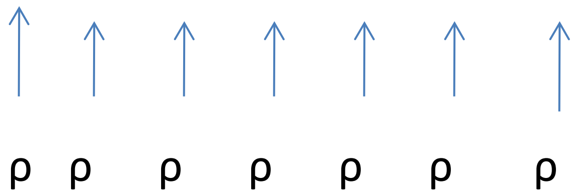
Two I=0 states generated f_0, f_2 that we associate to $f_0(1370)$ and $f_2(1270)$





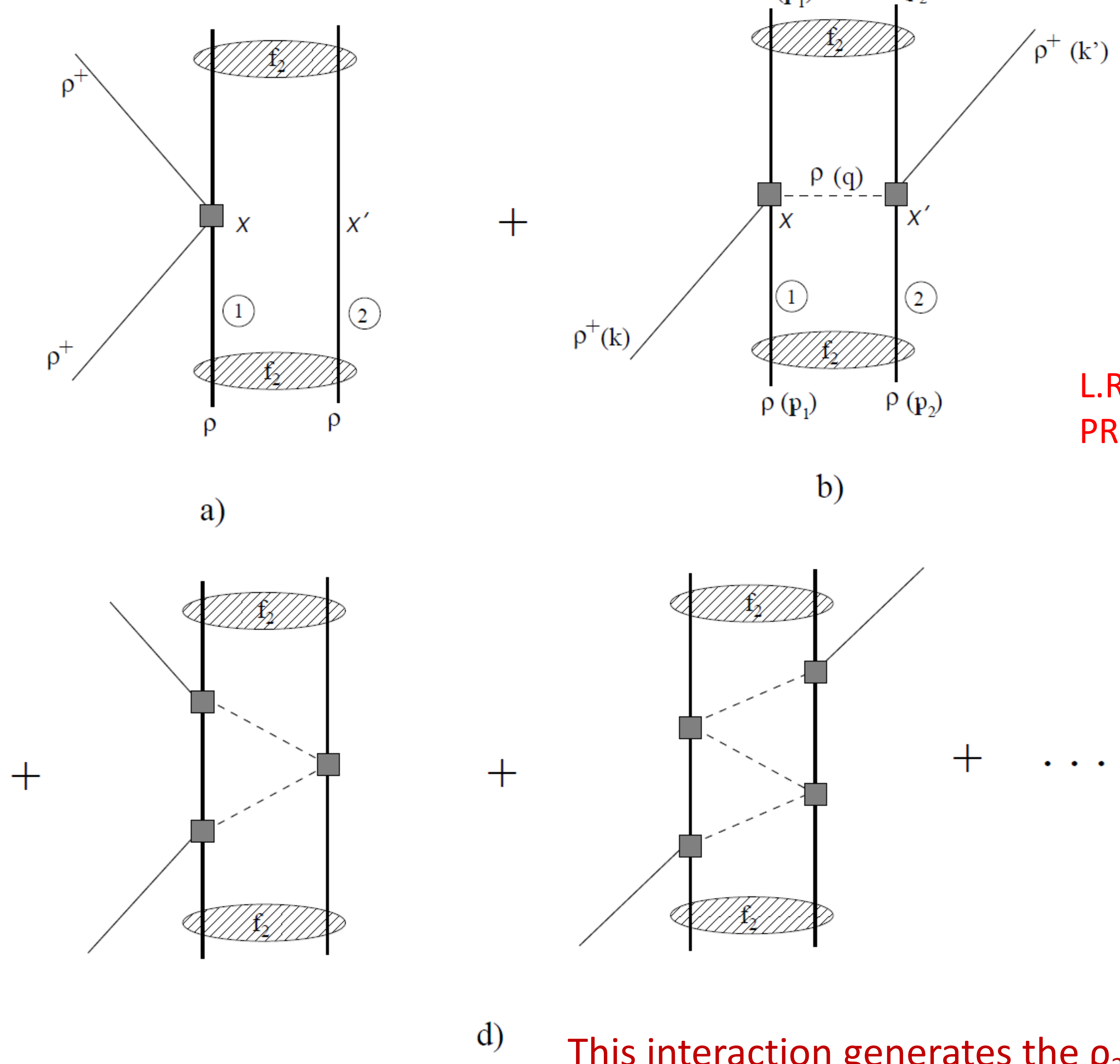
Belle finds the $f_0(1370)$ around 1470 MeV

We would like to construct states of many ρ with parallel spins, so as to have maximum binding for any pair



This is like a ferromagnet of ρ mesons

Fixed center approximation to ρ f_2 scattering



L.Roca, E.O. PRD82(2010)

This interaction generates the ρ_3

$$T_1 = t_1 + t_1 G_0 T_2$$
$$T_2 = t_2 + t_2 G_0 T_1$$
$$T = T_1 + T_2$$

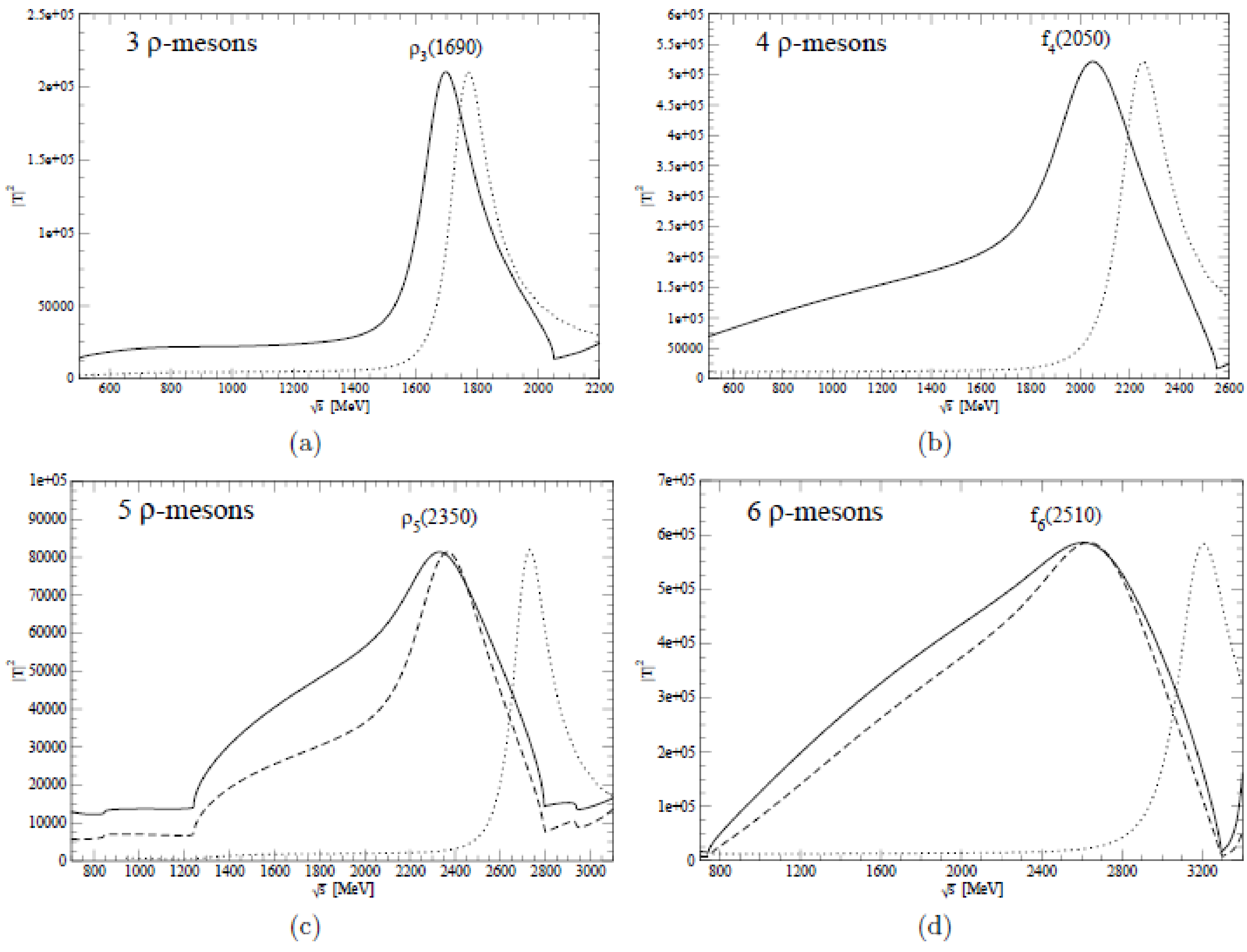
$$G_0 \equiv \frac{1}{M_{f_2}} \int \frac{d^3 q}{(2\pi)^3} F_{f_2}(q) \frac{1}{q^{0\,2} - \vec{q}^{\,2} - m_\rho^2 + i\epsilon}$$

$$F_{f_2}(q) = \frac{1}{\mathcal{N}} \int_{\substack{p<\Lambda \\ |\vec{p}-\vec{q}|<\Lambda}} d^3 p \, \frac{1}{M_{f_2} - 2\omega_\rho(\vec{p})} \, \frac{1}{M_{f_2} - 2\omega_\rho(\vec{p}-\vec{q})}$$

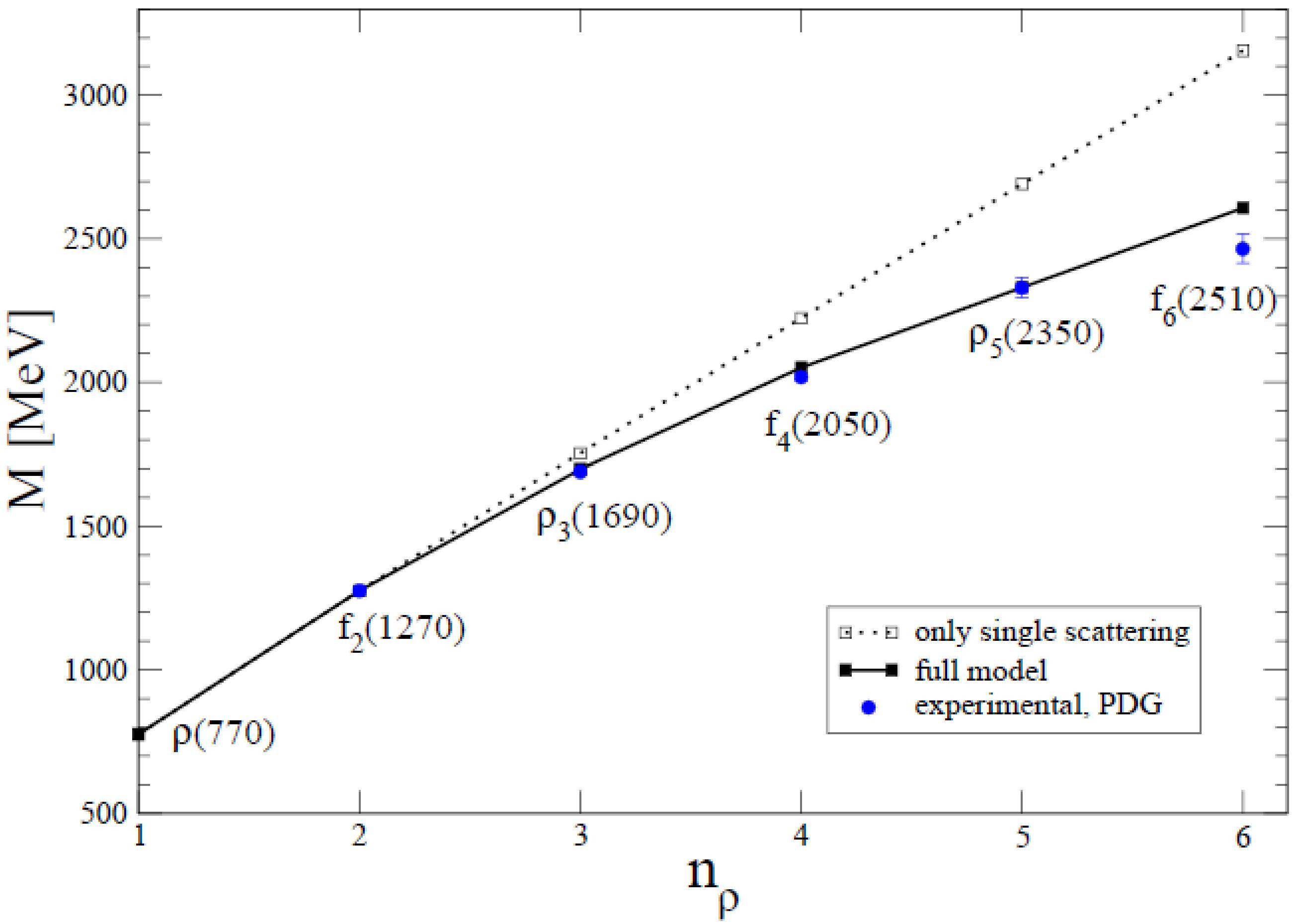
where the normalization factor $\mathcal{N}$ is

$$\mathcal{N} = \int_{p<\Lambda} d^3 p \frac{1}{\left(M_{f_2} - 2\omega_\rho(\vec{p})\right)^2}$$

One then continues and makes scattering of f_2 with f_2 to get the f_4 Then ρ interaction with f_4 to give ρ_5 and finally f_2 with f_4 to give f_6



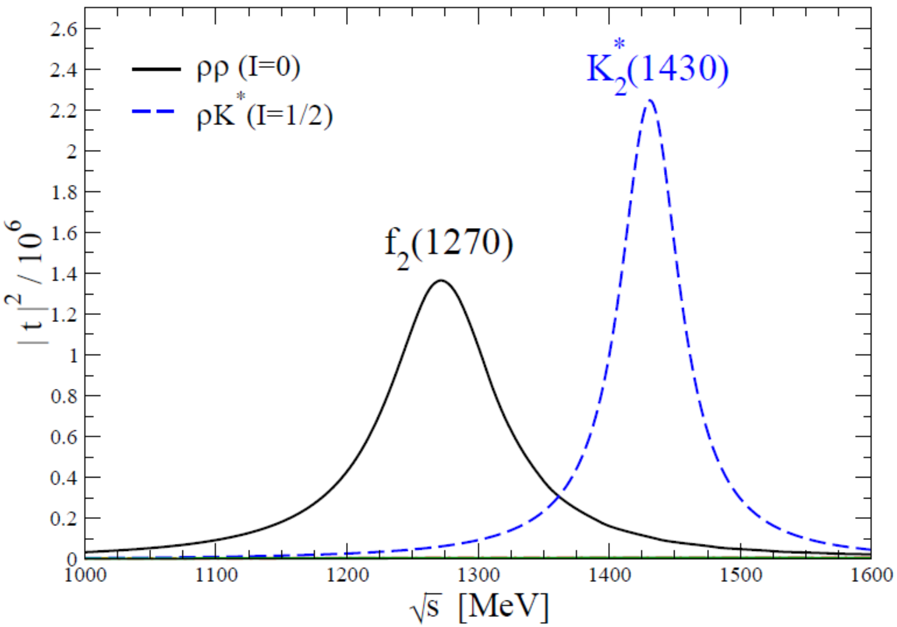
Luis Roca
E.O. 2010



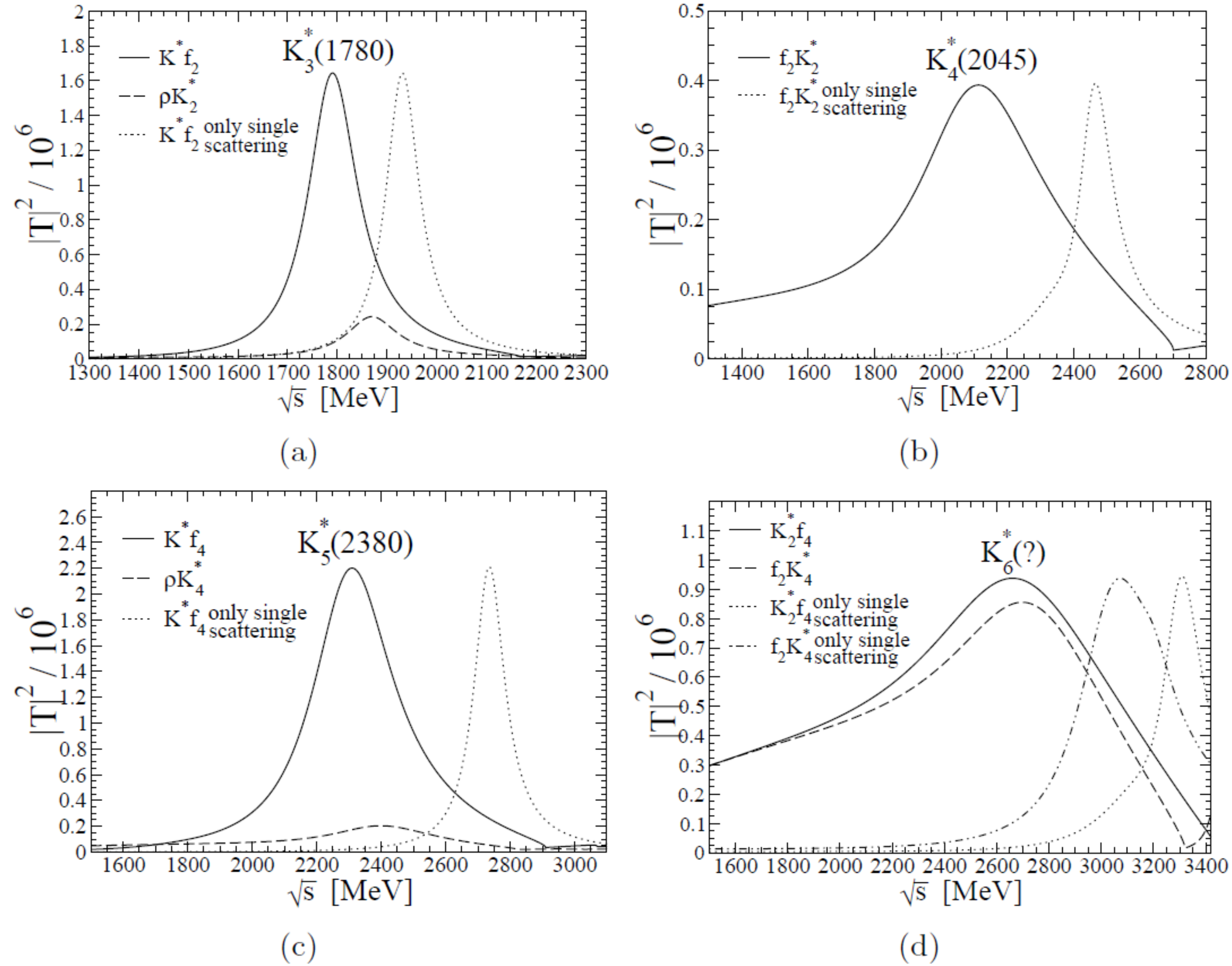
M [MeV]
n_ρ
500
1000
1500
2000
2500
3000
1
2
3
4
5
6
ρ(770)
f_2(1270)
ρ_3(1690)
f_4(2050)
ρ_5(2350)
f_6(2510)
only single scattering
full model
experimental, PDG

On the nature of the $K_2^*(1430)$, $K_3^*(1780)$, $K_4^*(2045)$, $K_5^*(2380)$ and K_6^* as K^*–multi-ρ states

J. Yamagata-Sekihara[1] L. Roca[2] and E. Oset[1] **Phys.Rev. D82 (2010) 094017**



	A	B $(b_1 b_2)$
two-body	ρ	K^*
three-body	K^* ρ	f_2 $(\rho\rho)$ K_2^* (ρK^*)
four-body	f_2	K_2^* (ρK^*)
five-body	K^* ρ	f_4 $(f_2 f_2)$ K_4^* $(f_2 K_2^*)$
six-body	K_2^* f_2	f_4 $(f_2 f_2)$ K_4^* $(f_2 K_2^*)$

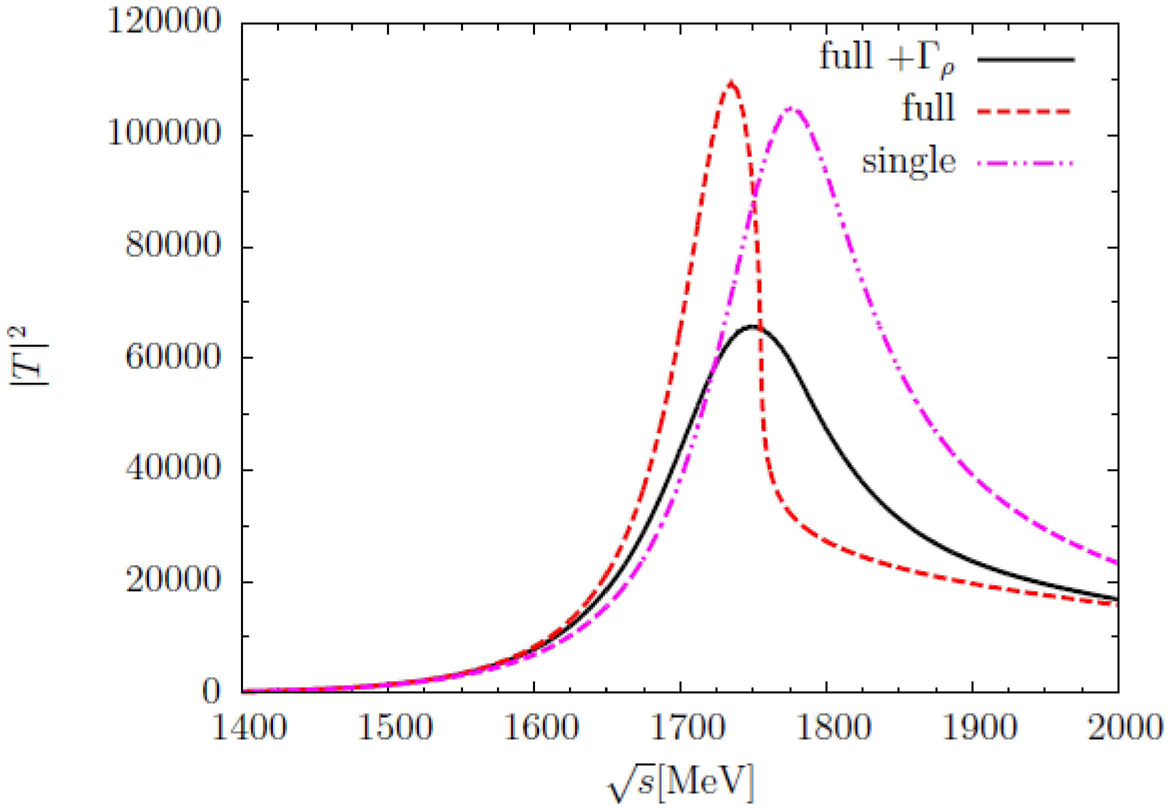


K*f2
ρK*2
K*f2 only single scattering
K*3(1780)
|T|2 / 10^6
√s [MeV]
(a)
f2K*2
f2K*2 only single scattering
K*4(2045)
|T|2 / 10^6
√s [MeV]
(b)
K*f4
ρK*4
K*f4 only single scattering
K*5(2380)
|T|2 / 10^6
√s [MeV]
(c)
K*2f4
f2K*4
K*2f4 only single scattering
f2K*4 only single scattering
K*6(?)
|T|2 / 10^6
√s [MeV]
(d)

generated resonance	amplitude	mass, PDG [21]	mass only single scatt.	mass full model
$K_2^*(1430)$	ρK^*	1429 ± 1.4	–	1430
$K_3^*(1780)$	$K^* f_2$	1776 ± 7	1930	1790
$K_4^*(2045)$	$f_2 K_2^*$	2045 ± 9	2466	2114
$K_5^*(2380)$	$K^* f_4$	$2382 \pm 14 \pm 19$	2736	2310
K_6^*	$K_2^* f_4$-$f_2 K_4^*$	–	3073-3310	2661-2698

Description of $\rho(1700)$ as a $\rho K\bar{K}$ system with the fixed center approximation

Bayar, Liang, Uchino and Xiao , EPJA 2014



The cluster is assumed to be the interacting K Kbar pair that forms the $f_0(980)$

	single	full	full + Γ_ρ	PDG [38]
Mass (MeV)	1777.9	1734.8	1748.0	1720 ± 20
Width (MeV)	144.4	63.7	160.8	250 ± 100

Pseudotensor mesons as three body resonances

Luis Roca, **Phys.Rev. D84(2011) 094006**

Systems with $J^{PC} = 2^{-+}$ can be regarded as molecules made of a pseudoscalar (P) 0^{-+} and a tensor 2^{++} meson

with the 2^{++} state made out of two vector mesons

assigned resonance	dominant channel	mass PDG [47]	mass, only single scatt.	mass full model
$\pi_2(1670$	$\eta a_2(1320)$	1672 ± 3	1800	1660
$\eta_2(1645)$	$\eta f_2(1270)$	1617 ± 5	1795	1695
$K_2^*(1770)$	$K a_2(1320)$	1773 ± 8	1775	1775

The era of charm

States of $\rho D^* \bar{D}^*$ with $J = 3$ within the Fixed Center Approximation to the Faddeev equations

M. Bayar, X. L. Ren, E. O, Eur. Phys. J. A 2015

In the D* D*bar interaction one state with $J^P=2^+$ is generated around 3920 MeV, which could be the X(3915) or the Z(3940) (with I=0)

We let the ρ interact with the D* D*bar cluster and obtain a new state

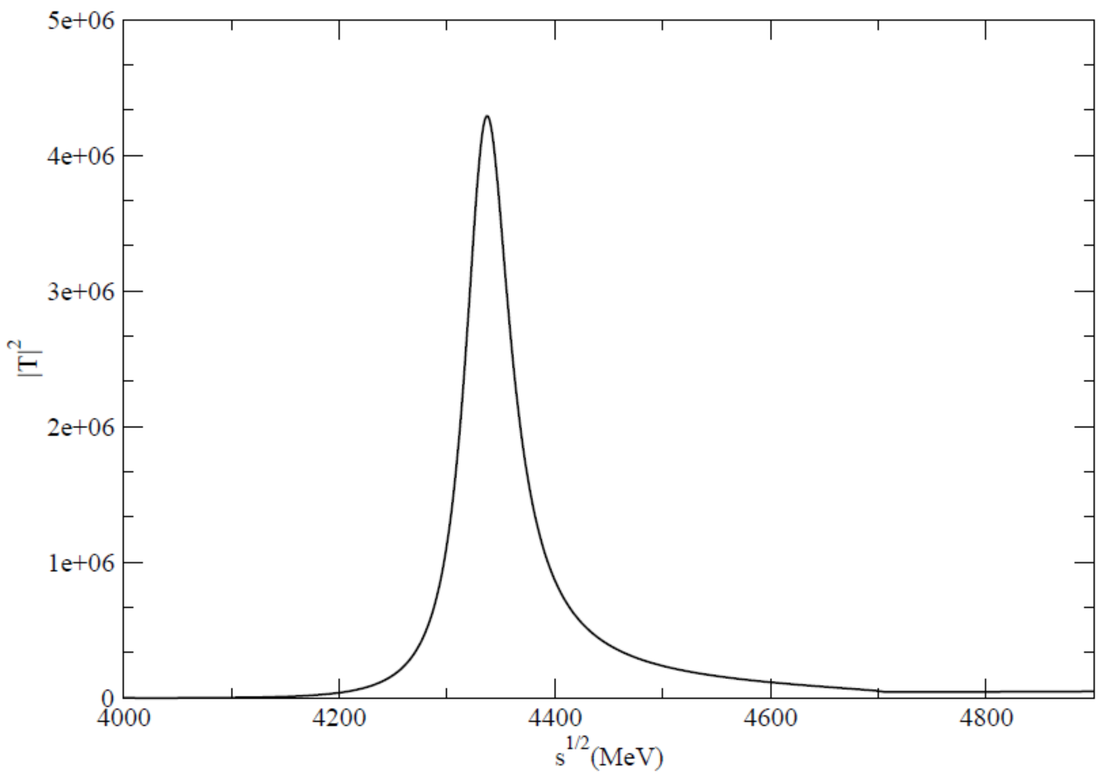


FIG. 3: Modulus squared of the $\rho(D^* \bar{D}^*)$ scattering amplitude with total isospin $I = 1$.

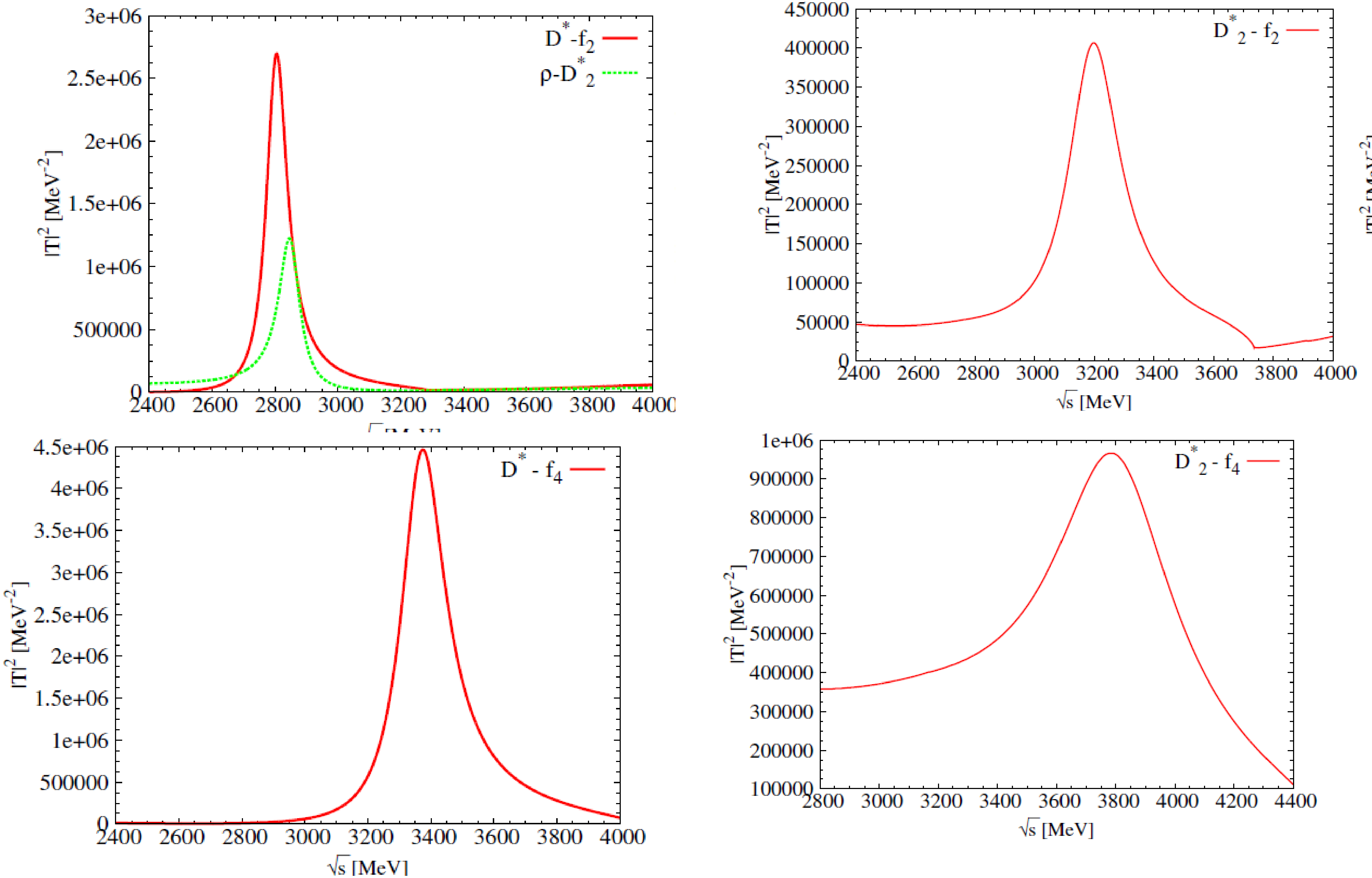
A state with the I=1, $J=3^-$ and hidden charm is predicted around 4330 MeV.

A prediction of D^*-multi-ρ states

Xiao, Bayar, E. O, PRD 2012

TABLE I: 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^* $(f_2 D_2^*)$	$T_{f_2-D_4^*}$



Mass $2800 - 2850$ MeV, $3075 - 3200$ MeV, $3360 - 3375$ MeV and 3775 MeV

Width $60 - 100$ MeV, $200 - 400$ MeV, $200 - 400$ MeV and 400 MeV

A narrow DNN quasi-bound state

Bayar, Xiao, Hyodo, Dote, Oka, E.O. , PRC 2012

Calculations done with variational method and with FCA

Bound state and narrow around 3500 -3530 MeV, Γ=30-40 MeV

Could be considered as a Λ_c(2595) N bound state.

Interesting : Narrower than the Kbar NN system

Conclusions:

The chiral unitary approach for the $f_0(500)$ and $f_0(980)$ provides a simple and natural explanation of the recent results of LHCb on B^0_s and B^0 decays.

Predictions for Λ_b -> J/ψ $\Lambda(1405)$ made prior to LHCb experiment
Preditions for D*bar Σ_c and D*bar Σ^*_c bound states also made before
The combination of both matches recent findings of experiment

The recent finding should stimulate the search for many other multiquark
multihadron states predicted by theoretical groups.

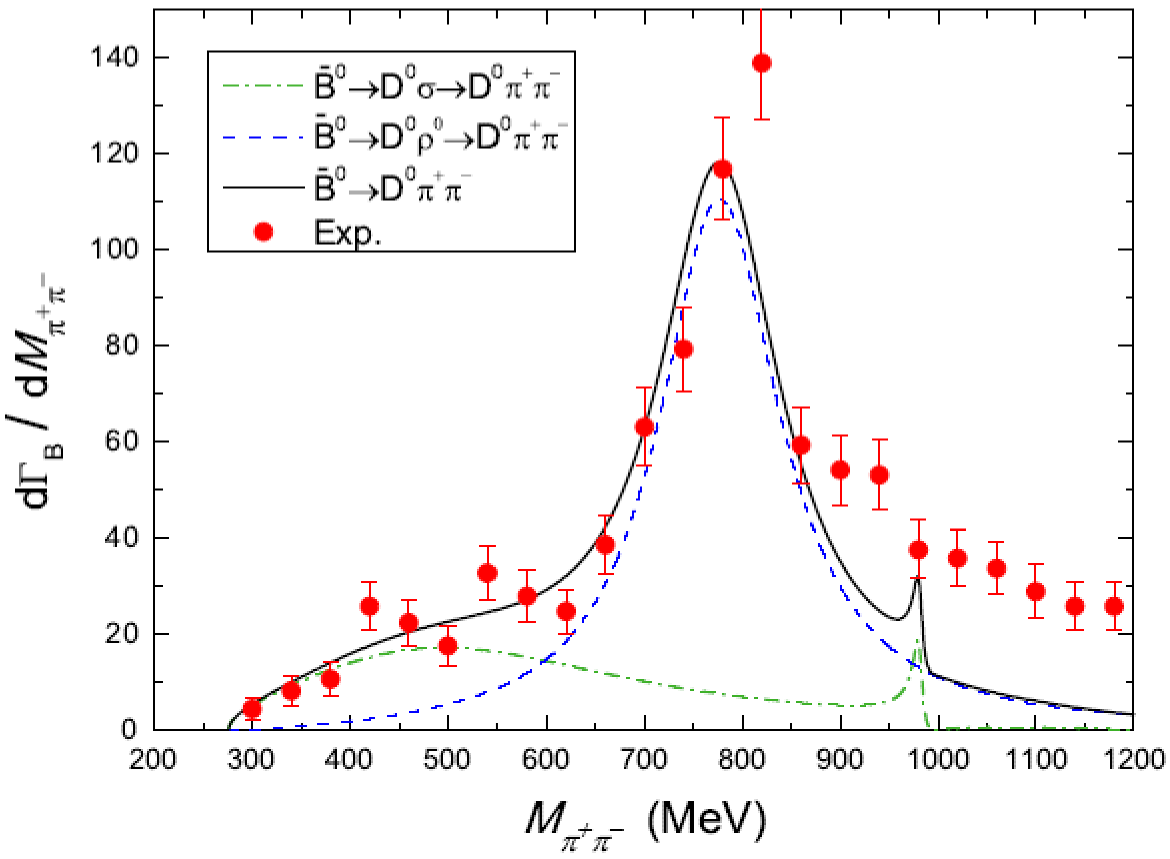
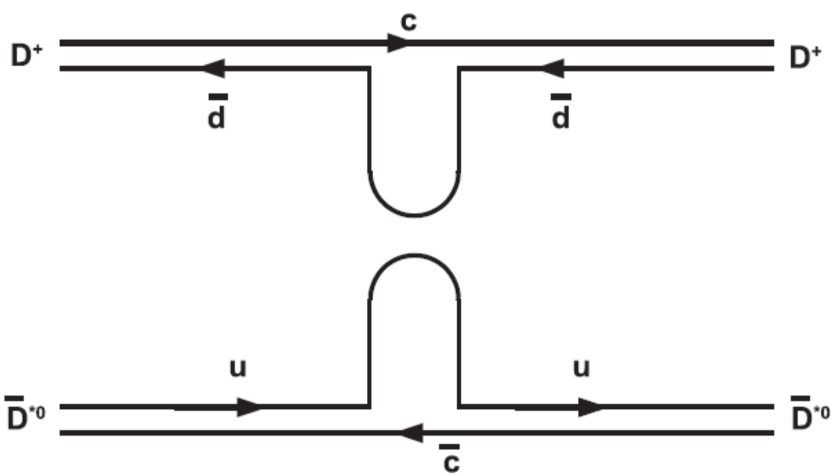


FIG. 5: (Color online) Invariant mass distribution for $\pi^+\pi^-$ in $\bar{B}^0 \to D^0\pi^+\pi^-$ decay. The experimental data are taken from Ref. [29].

I=1 hidden charm resonances, $Z_c(3900)$ and $Z_c(4020)$



We study them as D D*bar and D* D*bar molecules

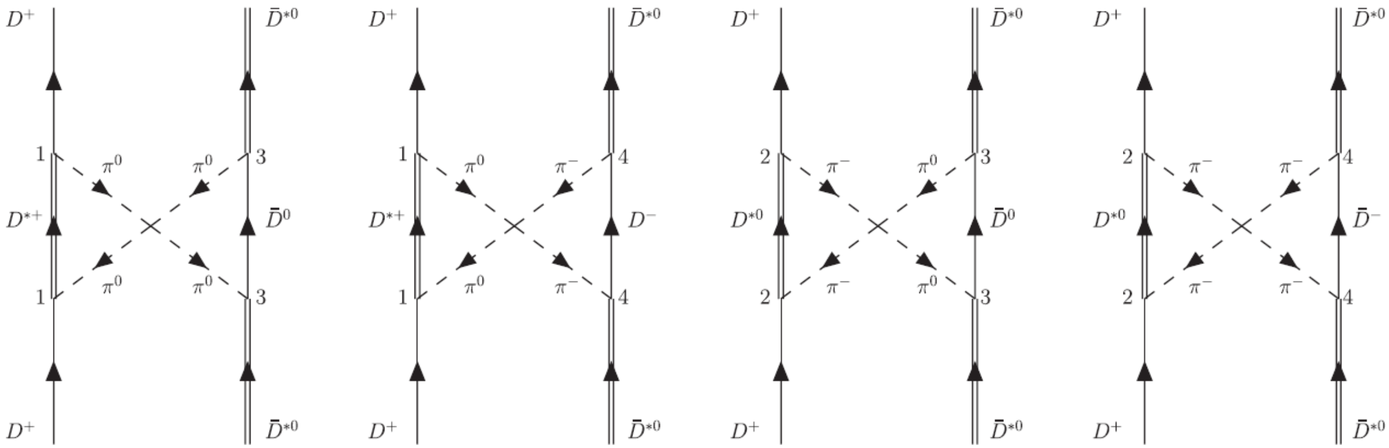
$$\mathcal{L}_{VPP} = -ig\langle V^\mu [P, \partial_\mu P]\rangle$$

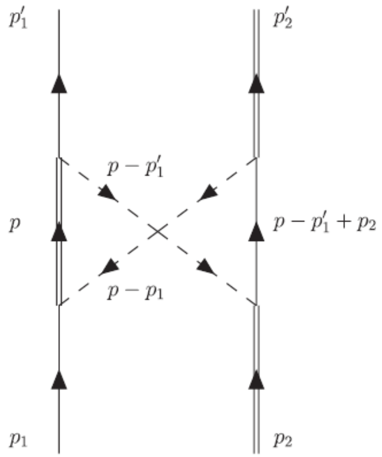
$$P = \begin{pmatrix} \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} + \frac{\pi^0}{\sqrt{2}} & \pi^+ & K^+ & \bar{D}^0 \\ \pi^- & \frac{\eta}{\sqrt{3}} + \frac{\eta'}{\sqrt{6}} - \frac{\pi^0}{\sqrt{2}} & K^0 & D^- \\ K^- & \bar{K}^0 & -\frac{\eta}{\sqrt{3}} + \sqrt{\frac{2}{3}}\eta' & D_s^- \\ D^0 & D^+ & D_s^+ & \eta_c \end{pmatrix}$$

$$V_\mu = \begin{pmatrix} \frac{\omega}{\sqrt{2}} + \frac{\rho^0}{\sqrt{2}} & \rho^+ & K^{*+} & \bar{D}^{*0} \\ \rho^- & \frac{\omega}{\sqrt{2}} - \frac{\rho^0}{\sqrt{2}} & K^{*0} & D^{*-} \\ K^{*-} & \bar{K}^{*0} & \phi & D_s^{*-} \\ D^{*0} & D^{*+} & D_s^{*+} & J/\psi \end{pmatrix}_\mu .$$

The exchange of a light meson is OZI forbidden . This means ρ,ω cancel and π,η,η’ cancel if equal masses (or for large q)

Then we exchange two pions with or without interactions





Plus heavy vector (J/psi, D*)

We find the heavy vector exchange still dominates but the interaction has a weak strenght.

F, Aceti, M.Bayar, J.M. Dias, A. Martinez, K. Khemchandani, M. Nielsen, F. Navarra, EO PRD2014

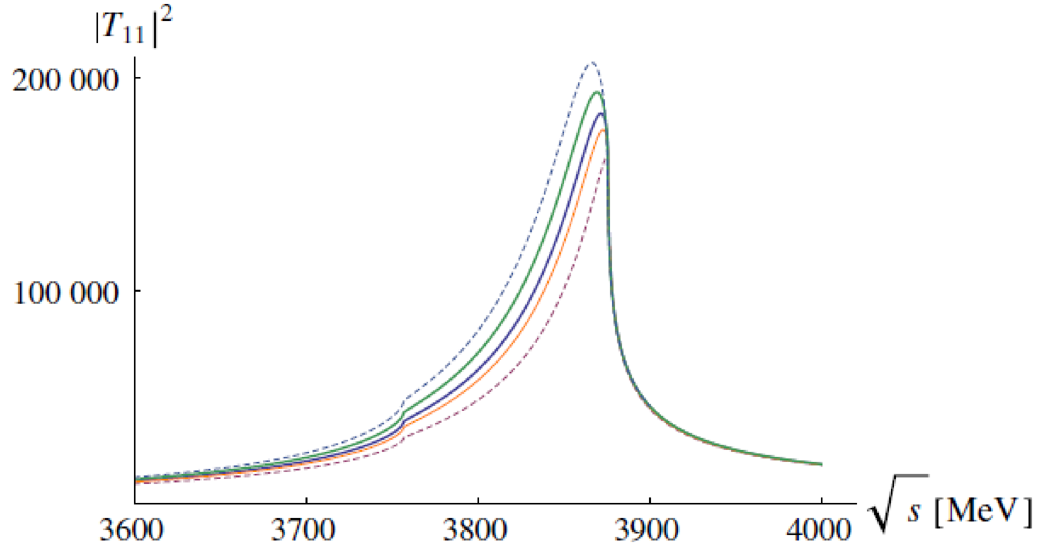


FIG. 12 (color online). $|T|^2$ as a function of $\sqrt{s}$ for values of the cutoff q_{max} equal to 850, 800, 770, 750, and 700 MeV. The peak moves to the left as the cutoff increases.

Prediction of a $Z_c(4000)$ $D^*\bar{D}^*$ state and relationship with the claimed $Z_c(4025)$

F. Aceti[1,a], M. Bayar[1,2], J.M. Dias[1,3], and E. Oset[1]

PRD2014

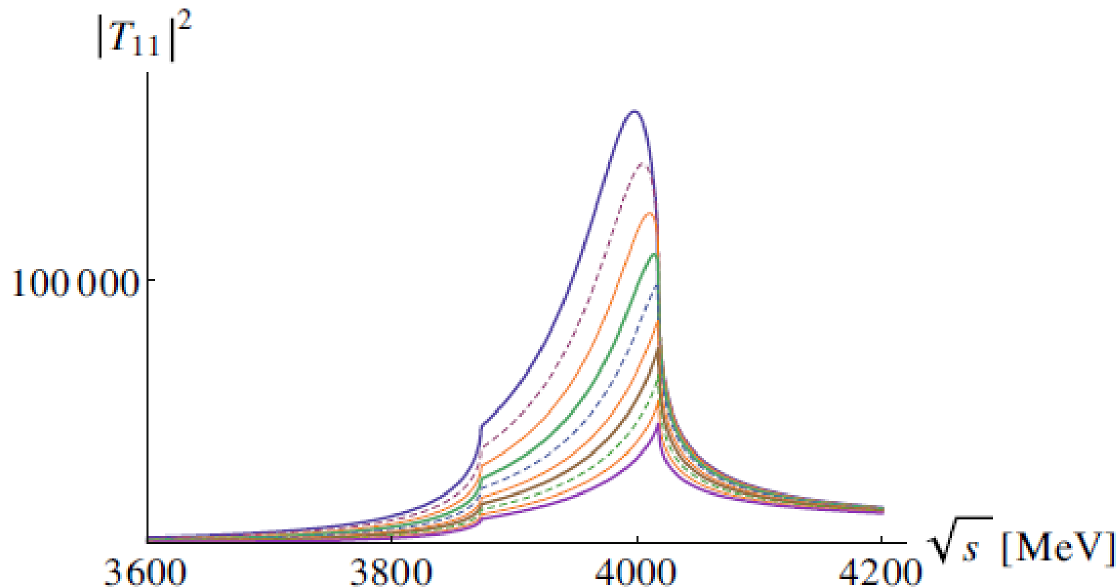


Fig. 16. $|T_{11}|^2$ as a function of $\sqrt{s}$, for different values of the cutoff $q_{\rm max}$. From up down, $q_{\rm max}$ = 960, 900, 850, 800, 750, 700, 650, 600, 550, 500 MeV.