Hadron dynamics with vector mesons: matching theory and experiment to identify new resonances

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Chu Wen Xiao, J.J. Wu, B.S. Zou, Wei Hong Liang, T. Uchino

Chiral dynamics and the local hidden gauge approach

Meson-meson interaction (vector-vector interaction)

Vector baryon interaction

Vector- Vector and Vector-Baryon molecules

Evidence for a new h_1 state around 1820 MeV

The $\gamma p \rightarrow K^0 \Sigma^+$ and $\gamma n \rightarrow K^0 \Sigma^0$ in the $K^*\Lambda$ threshold →

Evidence for a new baryon resonance $1/2^-$ around 2035 MeV

Recent developments in the charm and beauty sectors

Hidden gauge formalism for vector mesons, pseudoscalars and photons

Bando et al. PRL, 112 (85);   Phys. Rep. 164, 217 (88)
Meissner, U.G., Phys. Rep. 161,213 (88)

$$\mathcal{L} = \mathcal{L}^{(2)} + \mathcal{L}_{III} \tag{1}$$

with

$$\mathcal{L}^{(2)} = \frac{1}{4} f^2 \langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + \chi^\dagger U \rangle \tag{2}$$

$$\mathcal{L}_{III} = -\frac{1}{4}\langle V_{\mu\nu} V^{\mu\nu} \rangle + \frac{1}{2} M_V^2 \langle [V_\mu - \frac{i}{g}\Gamma_\mu]^2 \rangle, \tag{3}$$

where $\langle ... \rangle$ represents a trace over $SU(3)$ matrices. The covariant derivative is defined by

$$D_\mu U = \partial_\mu U - ieQA_\mu U + ieUQA_\mu, \tag{4}$$

with $Q = diag(2, -1, -1)/3$, $e = -|e|$ the electron charge, and A_μ the photon field. The chiral matrix U is given by

$$U = e^{i\sqrt{2}\phi/f} \tag{5}$$

$$\phi \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & \pi^+ & K^+ \\ \pi^- & -\frac{1}{\sqrt{2}}\pi^0 + \frac{1}{\sqrt{6}}\eta_8 & K^0 \\ K^- & \bar{K}^0 & -\frac{2}{\sqrt{6}}\eta_8 \end{pmatrix}, \quad V_\mu \equiv \begin{pmatrix} \frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & \rho^+ & K^{*+} \\ \rho^- & -\frac{1}{\sqrt{2}}\rho^0 + \frac{1}{\sqrt{2}}\omega & K^{*0} \\ K^{*-} & \bar{K}^{*0} & \phi \end{pmatrix}_\mu . \tag{6}$$

In $\mathcal{L}_{III}$, $V_{\mu\nu}$ is defined as

$$V_{\mu\nu} = \partial_\mu V_\nu - \partial_\nu V_\mu - ig[V_\mu, V_\nu] \tag{9}$$

and

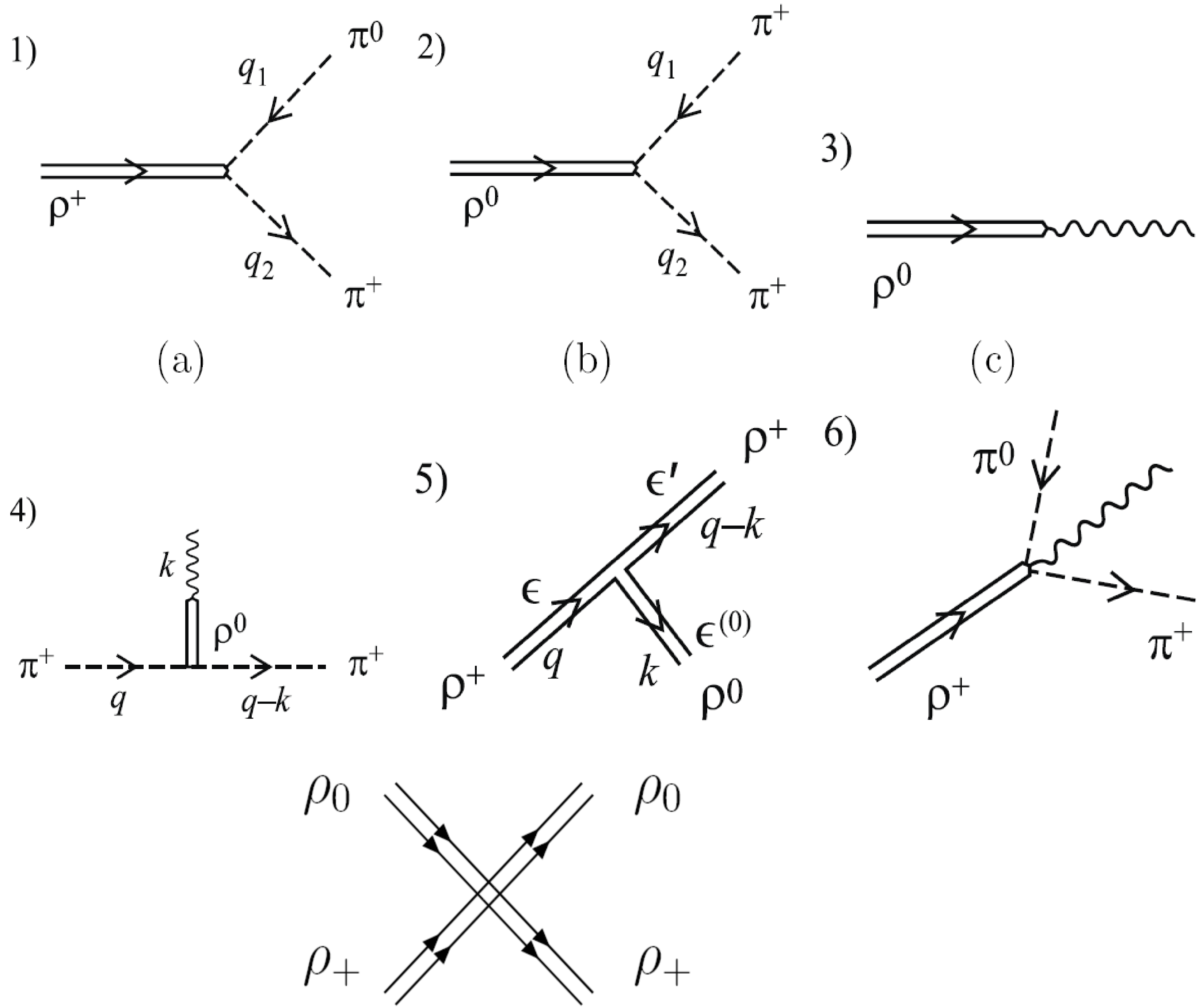
$$\Gamma_\mu = \frac{1}{2}[u^\dagger(\partial_\mu - ieQA_\mu)u + u(\partial_\mu - ieQA_\mu)u^\dagger] \tag{10}$$

with $u^2 = U$. The hidden gauge coupling constant g is related to f and the vector meson mass (M_V) through

$$g = \frac{M_V}{2f}, \tag{11}$$

$$\begin{aligned} \mathcal{L}_{V\gamma} &= -M_V^2 \frac{e}{g} A_\mu \langle V^\mu Q \rangle \\ \mathcal{L}_{V\gamma PP} &= e\frac{M_V^2}{4gf^2} A_\mu \langle V^\mu (Q\phi^2 + \phi^2 Q - 2\phi Q \phi) \rangle \\ \mathcal{L}_{VPP} &= -i\frac{M_V^2}{4gf^2} \langle V^\mu [\phi, \partial_\mu \phi] \rangle \end{aligned}$$

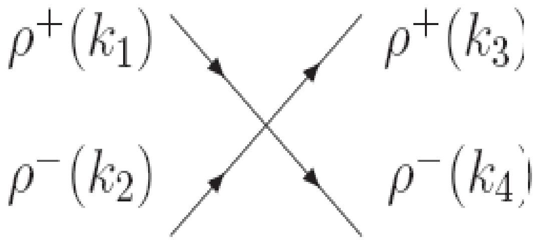
$$\mathcal{L}_{III}^{(c)} = \frac{g^2}{2} \langle V_\mu V_\nu V^\mu V^\nu - V_\nu V_\mu V^\mu V^\nu \rangle \ , \qquad \mathcal{L}_{III}^{(3V)} = ig \langle (\partial_\mu V_\nu - \partial_\nu V_\mu) V^\mu V^\nu \rangle \ ,$$


1)
π^0
q_1
ρ^+
q_2
π^+
(a)
2)
π^+
q_1
ρ^0
q_2
π^+
(b)
3)
ρ^0
(c)
4)
k
ρ^0
π^+
q
$q-k$
π^+
5)
ρ^+
ϵ'
$q-k$
ϵ
$\epsilon^{(0)}$
ρ^+
q
k
ρ^0
6)
π^0
π^+
ρ^+
ρ_0
ρ_0
ρ_+
ρ_+

Rho-rho interaction in the hidden gauge approach

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

V=-



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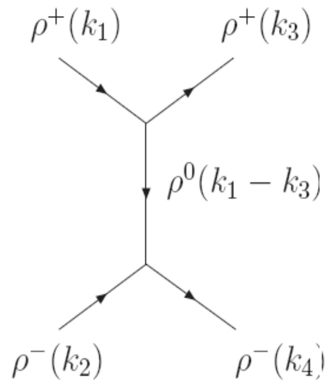

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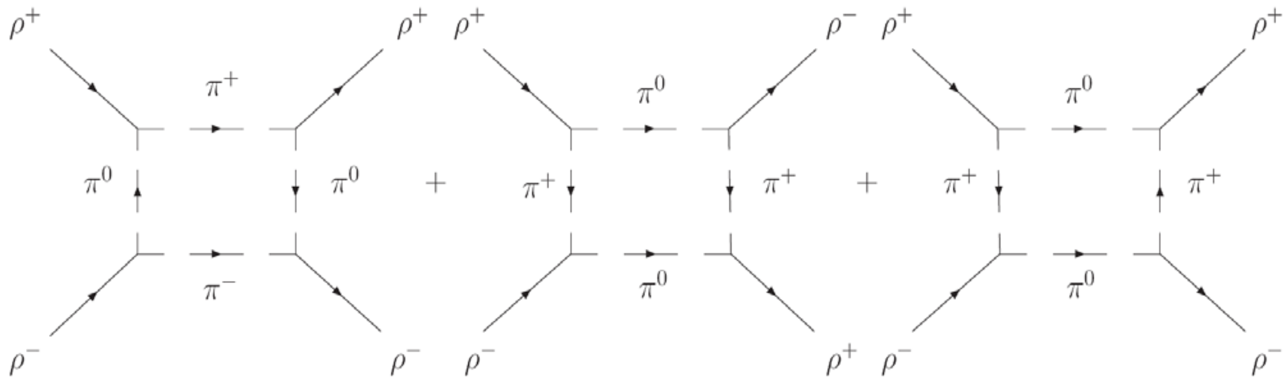


Spin projectors neglecting q/M_V, in L=0

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

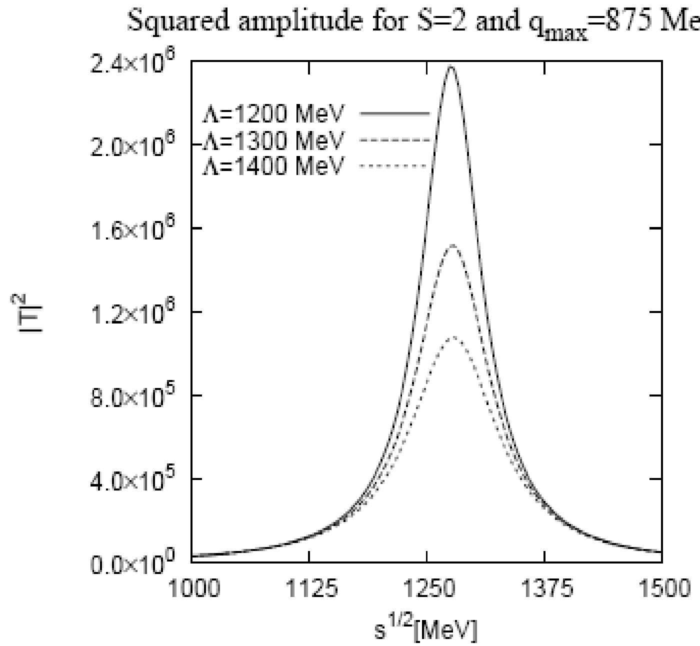
$$\mathcal{P}^{(1)} = \frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu - \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu)$$

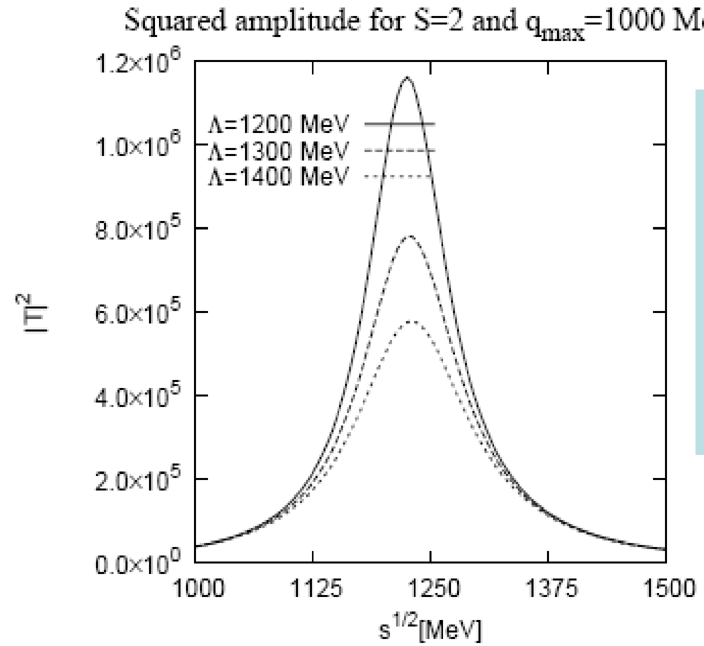
$$\mathcal{P}^{(2)} = \{\frac{1}{2}(\epsilon_\mu\epsilon_\nu\epsilon^\mu\epsilon^\nu + \epsilon_\mu\epsilon_\nu\epsilon^\nu\epsilon^\mu) - \frac{1}{3}\epsilon_\alpha\epsilon^\alpha\epsilon_\beta\epsilon^\beta\}$$

Bethe Salpeter eqn.

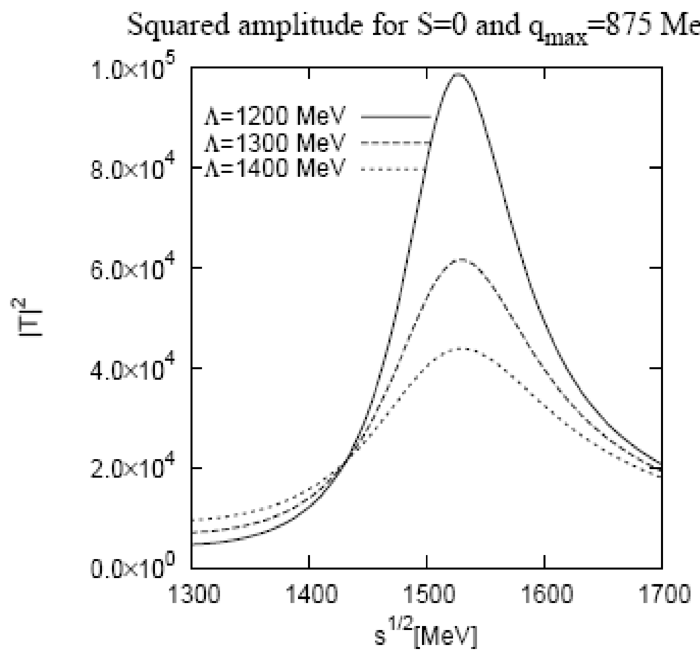
$$T = \frac{V}{1 - VG}$$

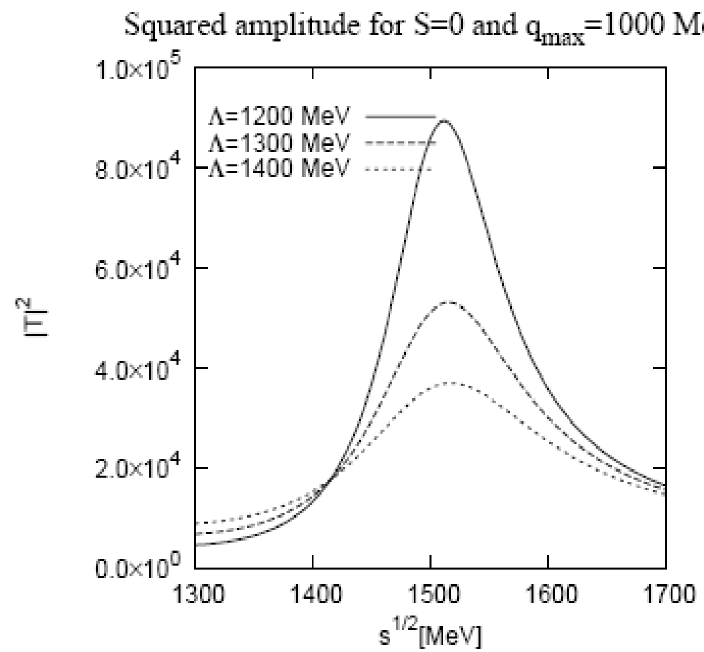
G is the ρρ propagator





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

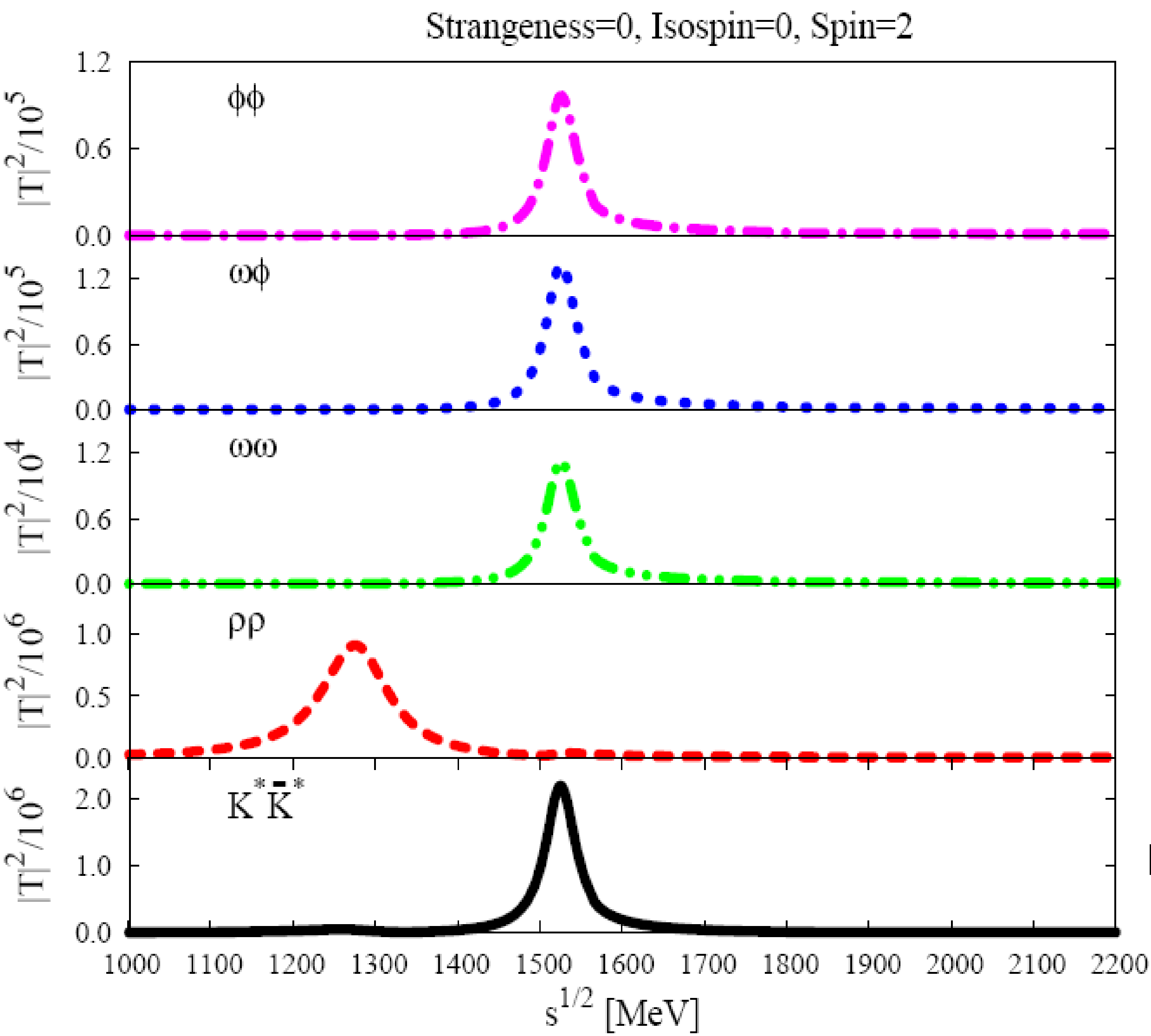




Belle finds the $f_0(1370)$ around 1470 MeV

Generalization to coupled channels: L. S. Geng , E.O, Phys Rev D 09

Attraction found in many channels



The $f_2(1270)$ is not changed by the addition of new channels, but a new resonance appears can be associated to $f'_2(1525)$

Exp : $\Gamma(f_2(1270))$ = 185 MeV

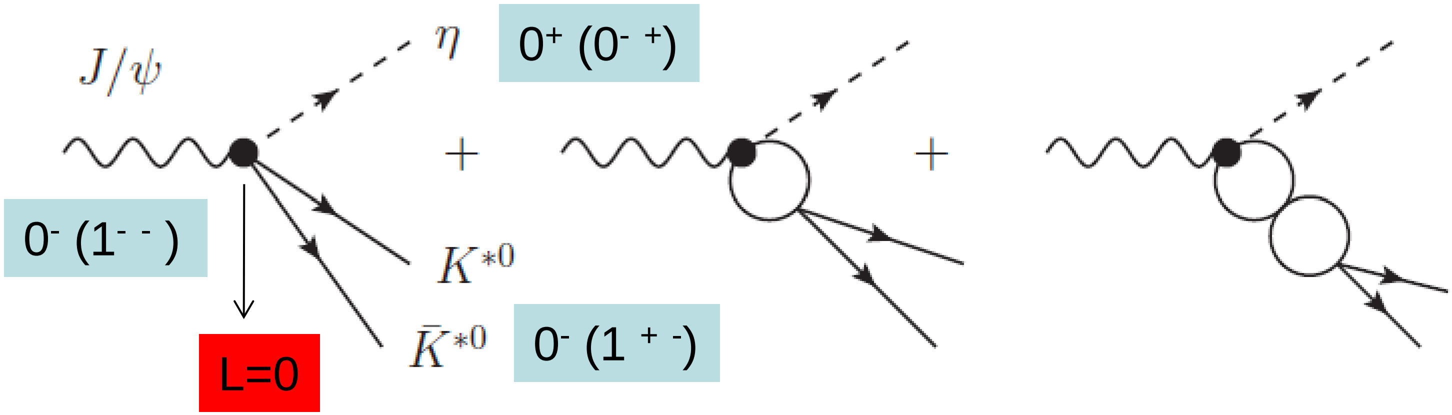
Exp: $\Gamma(f'_2(1525))$ = 76 MeV

Predicted meson states from V V interaction

$I^G(J^{PC})$	M , Γ [MeV] Theory			PDG data		
	Pole position	Real axis		Name	Mass	Width
		$\Lambda_b = 1.4$ GeV	$\Lambda_b = 1.5$ GeV			
$0^+(0^{++})$	(1512,51)	(1523,257)	(1517,396)	$f_0(1370)$	1200∼1500	200∼500
$0^+(0^{++})$	(1726,28)	(1721,133)	(1717,151)	$f_0(1710)$	1724 ± 7	137 ± 8
$0^-(1^{+-})$	(1802,78)	(1802,49)		h_1		
$0^+(2^{++})$	(1275,2)	(1276,97)	(1275,111)	$f_2(1270)$	1275.1 ± 1.2	$185.0^{+2.9}_{-2.4}$
$0^+(2^{++})$	(1525,6)	(1525,45)	(1525,51)	$f_2'(1525)$	1525 ± 5	73^{+6}_{-5}
$1^-(0^{++})$	(1780,133)	(1777,148)	(1777,172)	a_0		
$1^+(1^{+-})$	(1679,235)	(1703,188)		b_1		
$1^-(2^{++})$	(1569,32)	(1567,47)	(1566,51)	$a_2(1700)$?? $a_2(1320)$ Nagahiro PRD 11		
$1/2(0^+)$	(1643,47)	(1639,139)	(1637,162)	K_0^*		
$1/2(1^+)$	(1737,165)	(1743,126)		$K_1(1650)$?		
$1/2(2^+)$	(1431,1)	(1431,56)	(1431,63)	$K_2^*(1430)$	1429 ± 1.4	104 ± 4

Signature of an h_1 state in the $J/\psi \to \eta h_1 \to \eta K^{*0}\bar{K}^{*0}$ decay

Xie Ju Jun, M. Albaladejo and E. O, PLB 2014



$I^G(J^{PC})$			
$0^-(1^{+-})$	(1802,78)	(1802,49)	h_1

Pole positions and residues in the strangeness=0 and isospin=0 channel. All quantities are in units of MeV.

(1802, $-i39$) [spin=1]

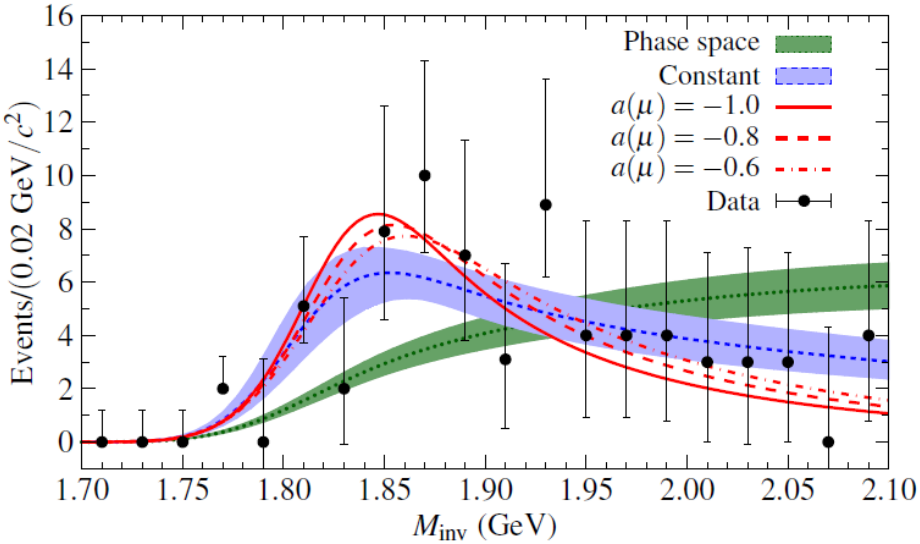
	$K^*\bar{K}^*$	$\rho\rho$	$\omega\omega$	$\omega\phi$	$\phi\phi$
g	(8034, $-i2542$)	0	0	0	0

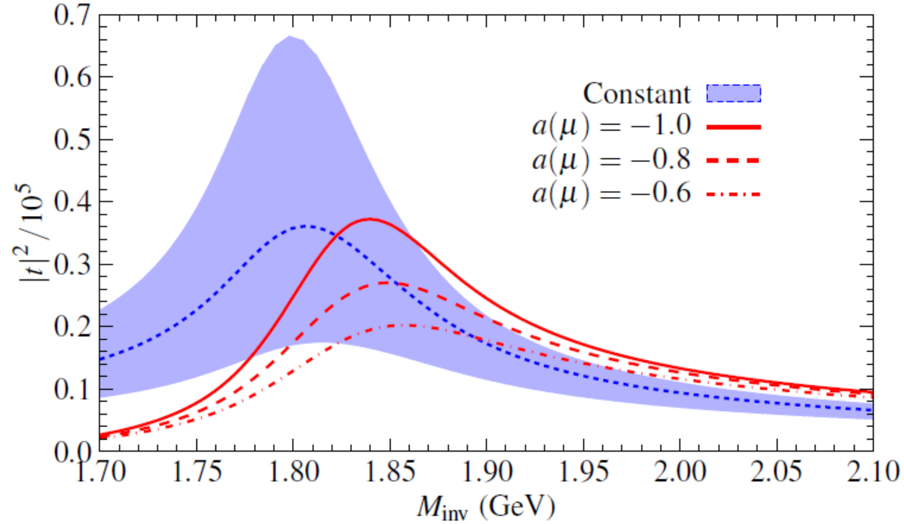
does not go to VV because of C-parity

It cannot go to PP , because J=1 requires L=1 in PP -> negative parity

Thus K* K*bar is the only open channel

M.Ablikim *et al.* [BES Collaboration], Phys. Lett. B **685**, 27 (2010).





$$t = v + v\widetilde{G}t = v(1+\widetilde{G}t) = (1 - v\widetilde{G})^{-1}v = (v^{-1} - \widetilde{G})^{-1} \qquad v = \left(9 + b\left(1 - \frac{3M_{\rm inv}^2}{4m_{K^*}^2}\right)\right) g^2$$

$$t_P = V_P\left(1 + \widetilde{G}(M_{\rm inv}^2)t(M_{\rm inv}^2)\right) = V_P\frac{t(M_{\rm inv}^2)}{v(M_{\rm inv}^2)} \qquad g = m_\rho/2f$$

$$G = \frac{1}{16\pi^2}\left(\alpha + Log\frac{m_1^2}{\mu^2} + \frac{m_2^2 - m_1^2 + s}{2s}Log\frac{m_2^2}{m_1^2} + \frac{p}{\sqrt{s}}\left(Log\frac{s - m_2^2 + m_1^2 + 2p\sqrt{s}}{-s + m_2^2 - m_1^2 + 2p\sqrt{s}} + Log\frac{s + m_2^2 - m_1^2 + 2p\sqrt{s}}{-s - m_2^2 + m_1^2 + 2p\sqrt{s}}\right)\right)$$

μ= 1000 MeV
a(μ) = α

$$\frac{d\Gamma}{dM_{\rm inv}} = \frac{C}{|v(M_{\rm inv}^2)|^2}\frac{p_1\widetilde{p}_2}{M_{J/\psi}}\left|t(M_{\rm inv}^2)\right|^2$$

A fit to data is made changing a(μ)

$M_{h_1} = 1830 \pm 20$ MeV and $\Gamma_{h_1} = 110 \pm 10$ MeV

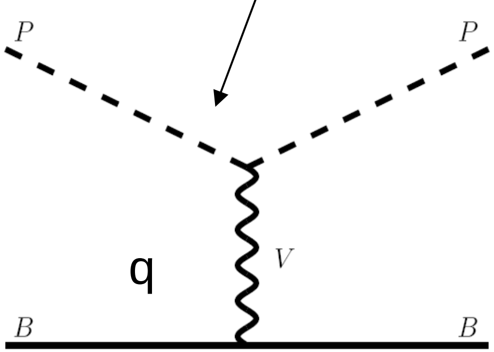
Extension to the baryon sector

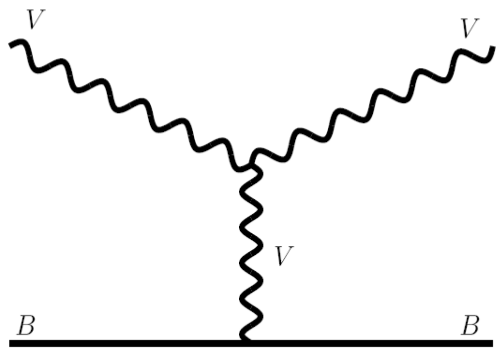
$$\mathcal{L}_{BBV} = -\frac{g}{2\sqrt{2}}\left(tr(\bar{B}\gamma_\mu[V^\mu, B] + tr(\bar{B}\gamma_\mu B)tr(V^\mu)\right)$$

Vector propagator $1/(q^2-M_V^2)$

In the approximation $q^2/M_V^2= 0$ one recovers the chiral Lagrangians Weinberg-Tomozawa term. For consistency, for vectors we take $\vec{q}/M_V=0$

> 200 works

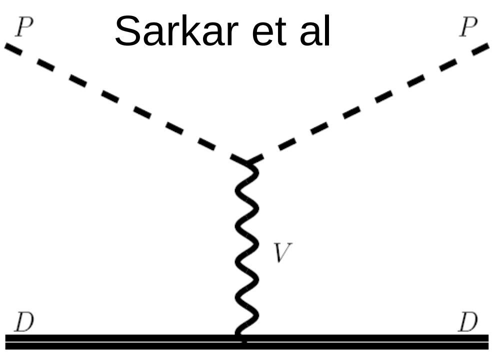


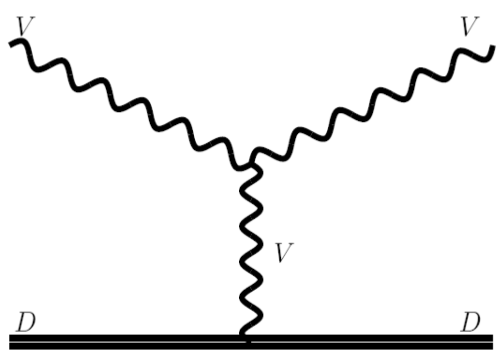


A. Ramos, E. O. EPJA 10

Khemchandani, Hosaka, Kaneko, Martinez, Nagahiro, PRD 11

Kolomeitsev et al
Sarkar et al





J. Vijande, P. Gonzalez. E.O PRC,2009
Sarkar, Vicente Vacas, B.X.Sun, E.O, EPJA 10

Vector octet – baryon octet interaction

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

$$\mathcal{L}_{VPP} = -ig\ tr\left([P, \partial_\mu P] V^\mu\right)$$

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & \Sigma^+ & p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\Sigma^0 + \frac{1}{\sqrt{6}}\Lambda & n \\ \Xi^- & \Xi^0 & -\frac{2}{\sqrt{6}}\Lambda \end{pmatrix}$$

V^ν cannot correspond to an external vector.
Indeed, external vectors have only spatial components in the approximation of neglecting three momenta, ε^0= k/M for longitudinal vectors, ε^0=0 for transverse vectors. Then ∂_ν becomes three momentum which is neglected. →
V^ν corresponds to the exchanged vector. → complete analogy to VPP
Extra $\varepsilon_\mu \varepsilon^\mu = -\varepsilon_i \varepsilon_i$ but the interaction is formally identical to the case of PB→PB
In the same approximation only γ^0 is kept for the baryons → the spin dependence is only $\varepsilon_i \varepsilon_i$ and the states are degenerate in spin 1/2 and 3/2

$$V_{ij} = -C_{ij} \frac{1}{4f^2} \left(k^0 + k'^0\right) \vec{\epsilon}\vec{\epsilon}'$$

K^0 energy of vector mesons

We solve the Bethe Salpeter equation in coupled channels Vector-Baryon octet.

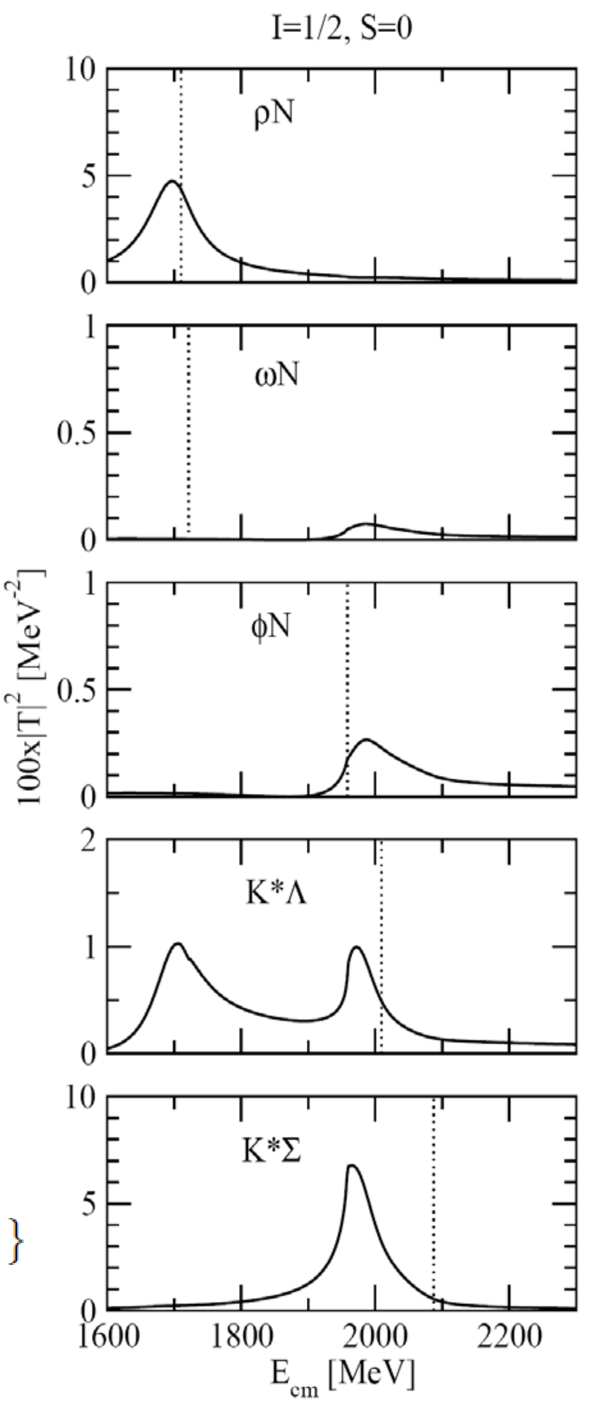
$T = (1-GV)^{-1} V$

with G the loop function of vector-baryon

Apart from the peaks, poles are searched In the second Riemann sheet and pole positions and residues are determined.

The G function takes into account the mass distribution of the vectors (width).

$$G_{(P,B)} = i2M_B \int \frac{d^4q}{(2\pi)^4} \frac{1}{(P-q)^2 - M_B^2 + i\varepsilon} \frac{1}{q^2 - M_P^2 + i\varepsilon},$$
$$= \frac{2M_B}{16\pi^2}\{a_\mu + \ln\frac{M_B^2}{\mu^2} + \frac{M_P^2 - M_B^2 + s}{2s}\ln\frac{M_P^2}{M_B^2}$$
$$+\frac{\bar{q}}{\sqrt{s}}[\ln(s-(M_B^2-M_P^2)+2\bar{q}\sqrt{s}) + \ln(s+(M_B^2-M_P^2)+2\bar{q}\sqrt{s})$$
$$-\ln(-s-(M_B^2-M_P^2)+2\bar{q}\sqrt{s}) - \ln(-s+(M_B^2-M_P^2)+2\bar{q}\sqrt{s})]\}$$

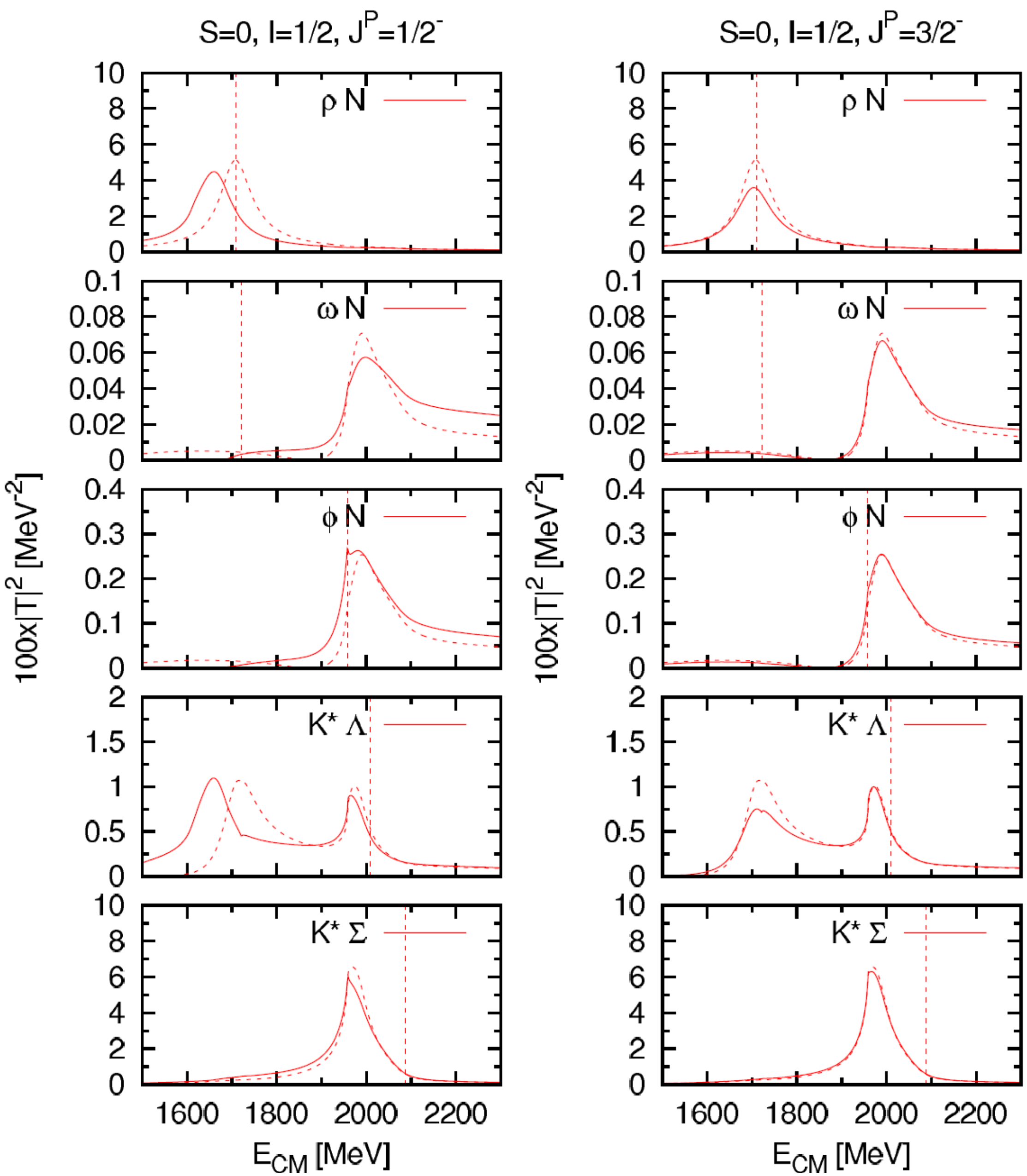


a_μ is a subtraction constant that regularizes the loop

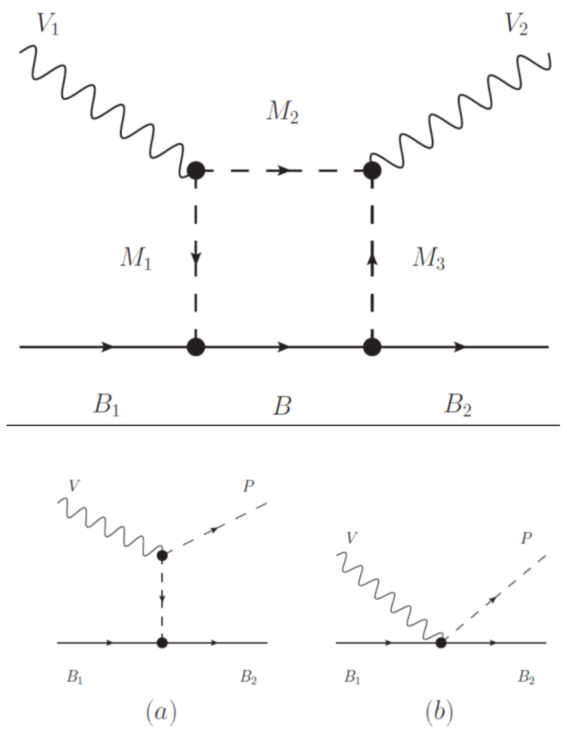
S, I	Theory		PDG data				
	(real axis)		name	J^P	status	mass	width
	mass	width					
$0, 1/2$	1699	84	$N(1650)$	$1/2^-$	$\star\star\star\star$	1645-1670	145-185
			$N(1700)$	$3/2^-$	$\star\star\star$	1650-1750	50-150
	1967	82	$N(2080)$	$3/2^-$	$\star\star$	≈ 2080	180-450
			$N(2090)$	$1/2^-$	$\star$	≈ 2090	100-400
$-1, 0$	1783	8	$\Lambda(1690)$	$3/2^-$	$\star\star\star\star$	1685-1695	50-70
			$\Lambda(1800)$	$3/2^-$	$\star\star\star$	1720-1850	200-400
	1900	54	$\Lambda(2000)$	$?^?$	$\star$	≈ 2000	73-240
	2158	20					
$-1, 1$	1830	44	$\Sigma(1750)$	$1/2^-$	$\star\star\star$	1730-1800	60-160
	1985	244	$\Sigma(1940)$	$3/2^-$	$\star\star\star$	1900-1950	150-300
			$\Sigma(2000)$	$1/2^-$	$\star$	≈ 2000	100-450
$-2, 1/2$	2030	52	$\Xi(2030)$	$?^?$	$\star\star\star$	2025 ± 5	21 ± 6
	2080	24	$\Xi(2120)$	$?^?$	$\star$	≈ 2120	25

Table 1: The properties of the 9 dynamically generated resonances and their possible PDG counterparts.

Improvements needed to account for the width: E. J. Garzon, E. O, EPJA 12



Mixing of VB and PB channels



Note the degeneracy between J=1/2, 3/2 is broken. The J=1/2 moves to 1650 MeV, while J=3/2 stays at 1700 MeV, as in experiment

Other works that consider the mixing between PB and VB

Romanets, Tolos, Garcia Recio, Nieves, Salcedo, Timmermanns, 2012
SU(6), SU(8) spin symmetry

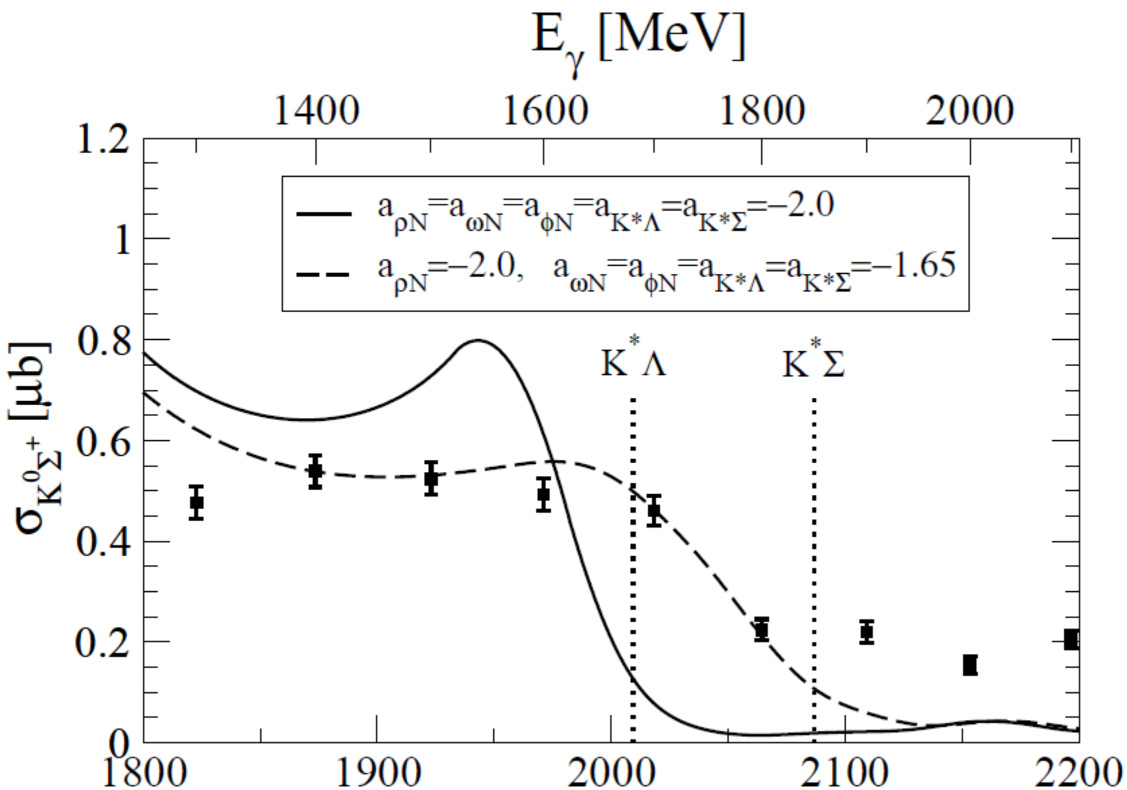
Khemchandani, Martinez, Nagahiro, Kaneko, Hosaka, 2011
Gauge terms from anomalous coupling of vector mesons to baryons

Kolomeitsev, Lutz some work in $3/2^-$ sector
……..

The role of vector-baryon channels and resonances in the $\gamma p \to K^0\Sigma^+$ and $\gamma n \to K^0\Sigma^0$ reactions near the $K^*\Lambda$ threshold.

A. Ramos and E. Oset, Phys. Lett B 2013

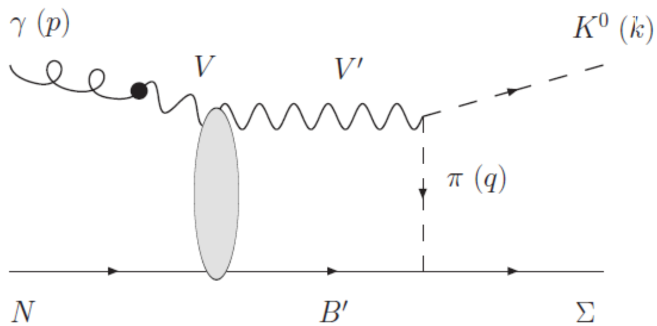
CBELSA/TAPS
R. Ewald…..
H. Schmieden…..
PLB 2012



Sudden drop of cross section around K* Λ threshold
Angular dependence also becomes flat around this energy
Hints at an important role of vector baryon interaction in L=0

Standard models MAID, SAID fail badly to reproduce these features

We use the tools of the local hidden gauge formalism to describe the reaction



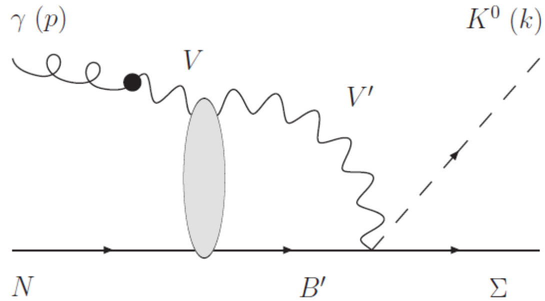
Tree level is null with final K^0

$$\mathcal{L}_{PBB} = \frac{1}{2}(D+F)\langle \bar{B}\gamma^\mu \gamma^5 u_\mu B\rangle + \frac{1}{2}(D-F)\langle \bar{B}\gamma^\mu \gamma^5 B u_\mu\rangle$$

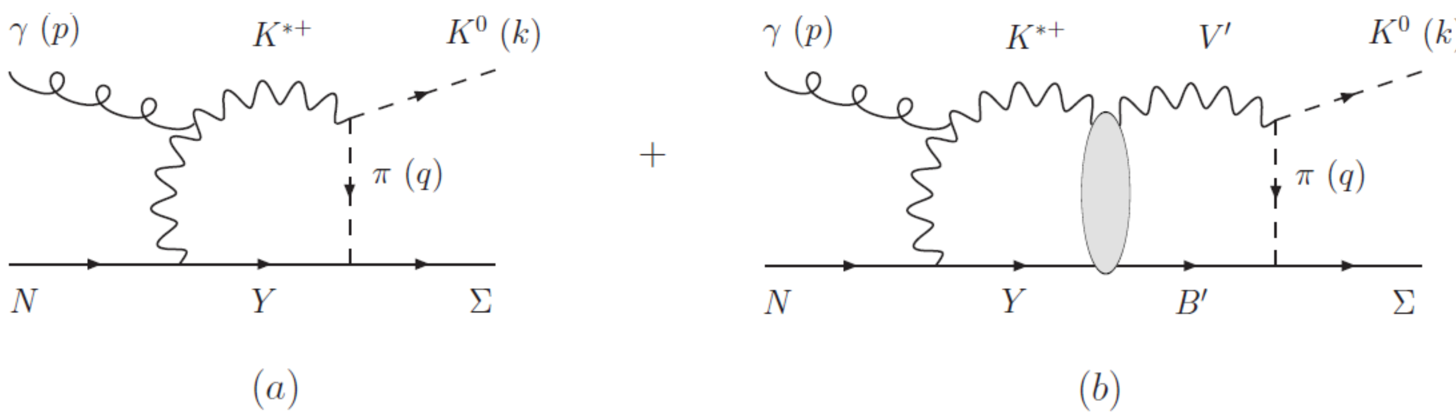
$$\gamma^\mu \gamma^5 u_\mu \rightarrow \frac{\sqrt{2}}{f}\sigma^i \partial_i \phi$$

$$-it^{\pi-\mathrm{pole}}_{\gamma N \to K^0\Sigma} = e \sum_{V=\rho^0,\omega,\phi} \mathcal{C}_{\gamma V} \sum_{V'B'} t_{VN\to V'B'}\; i\int \frac{d^4q}{(2\pi)^4} \frac{1}{(q+k)^2 - M^2_{V'} + i\varepsilon} \frac{1}{q^2 - m^2_\pi + i\varepsilon}$$
$$\frac{M_{B'}}{E_{B'}} \frac{1}{P^0 - q^0 - k^0 - E_{B'}(\vec{q}+\vec{k}\,) + i\varepsilon} (\vec{q}-\vec{k}\,)\vec{\epsilon}_\gamma\, \vec{\sigma}\vec{q}\; V_{Y,B'} F(q)\ ,$$

$$\mathcal{C}_{\gamma V} = \begin{cases} \frac{1}{\sqrt{2}} & \text{for } V = \rho \\ \frac{1}{3\sqrt{2}} & \text{for } V = \omega \\ -\frac{1}{3} & \text{for } V = \phi \end{cases}$$



$$
-\, i t^{KR}_{\gamma N \to K^0 \Sigma} = e \sum_{V=\rho^0,\omega,\phi} \mathcal{C}_{\gamma V} \sum_{V' B'} t_{VN \to V'B'}\, i \int \frac{d^4 q}{(2\pi)^4} \frac{1}{(q+k)^2 - M^2_{V'} + i\varepsilon}
\frac{M_{B'}}{E_{B'}} \frac{1}{P^0 - q^0 - k^0 - E_{B'}(\vec{q} + \vec{k}\,) + i\varepsilon}\, \vec{\sigma}\vec{\epsilon}_\gamma\, V_{Y,B'}\, F(q) \ .
$$



$$\frac{d\sigma_{\gamma N \to K^0\Sigma}}{d\Omega} = \frac{1}{16\pi^2} \frac{M_N M_\Sigma}{s} \frac{k}{p} \overline{\sum} \sum \mid t^{KR}_{\gamma N \to K^0\Sigma} \mid^2 ,$$

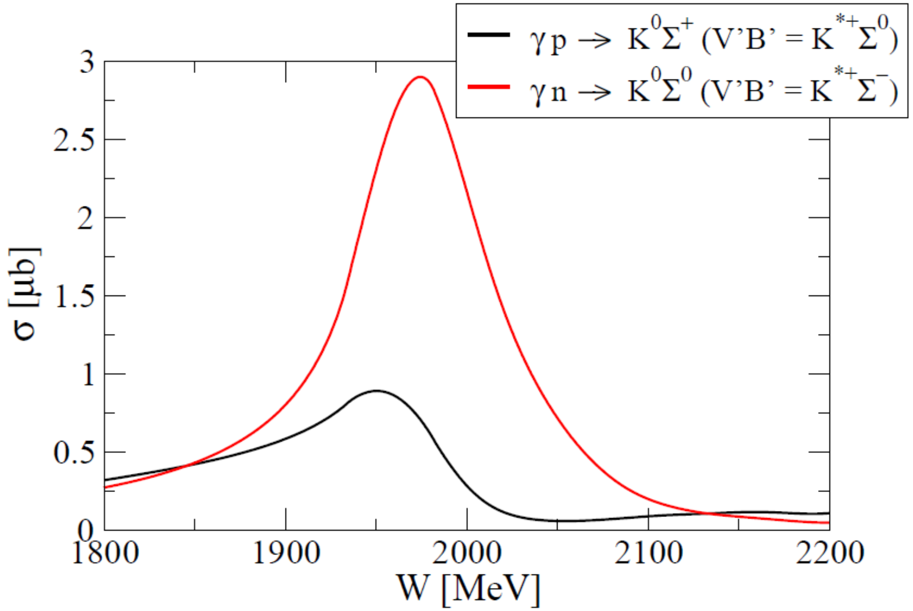
$$\overline{\sum} \sum \mid t^{KR}_{\gamma N \to K^0\Sigma} \mid^2 = \frac{1}{2} \left\{ \left[\mid A \mid^2 \vec{k}^{\,2} + 2\,\mathrm{Re}\,(AB^*) \right] \vec{k}^{\,2} \sin^2\theta + 2 \mid B \mid^2 \right\}$$

A term comes from π-exchange. B term from Kroll Ruderman plus part of π-exchange.

Angular dependence is symmetrical with respect to π/2.

Cancellations between A and B parts weaken angular dependence

Background will change a bit the main behaviour.

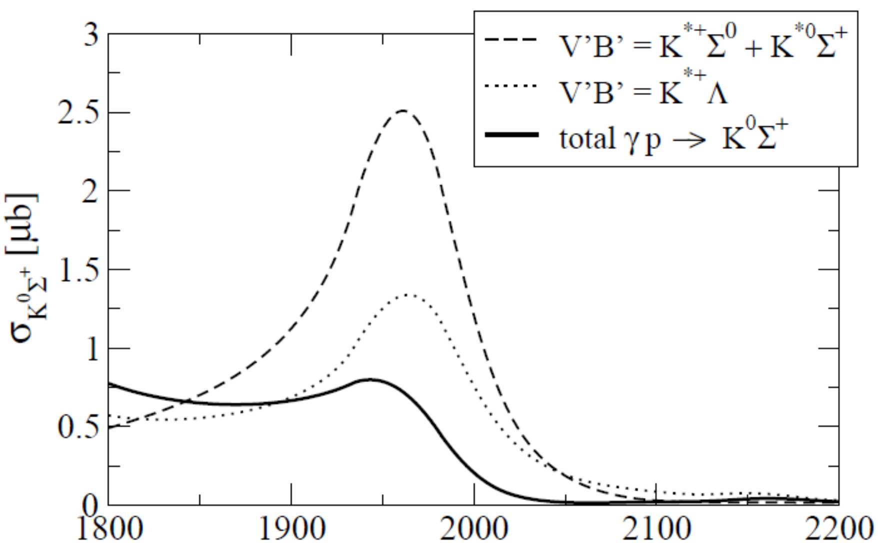


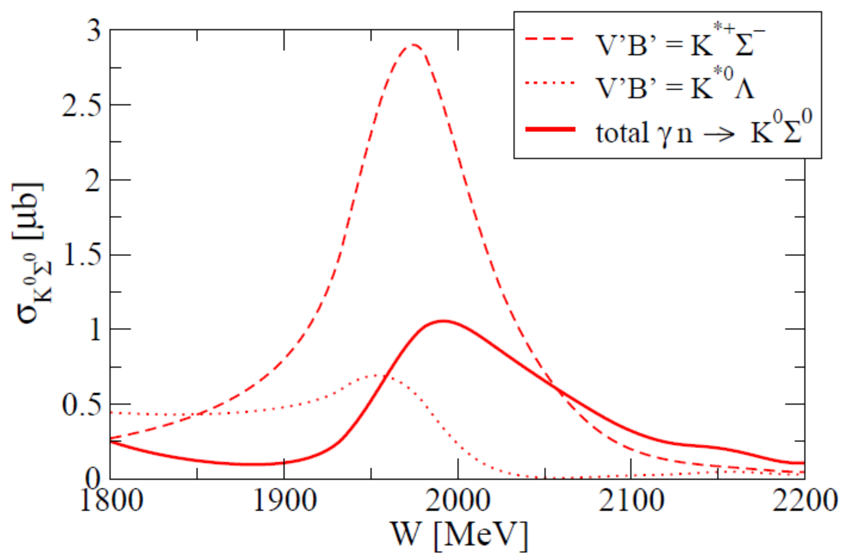
Spectacular difference:
In γp first loop contains $K^{*+}\ \Sigma^0$ and $K^{*+}\ \Lambda$ → interfere destructively.

In γn first loop only contains $K^{*+}\ \Sigma^-$ and there is no interference →
This is the effect found by
Doring and Nakayama, PLB 2010
In γp → ηp and γn → ηn to interprete second peak in γn → ηn

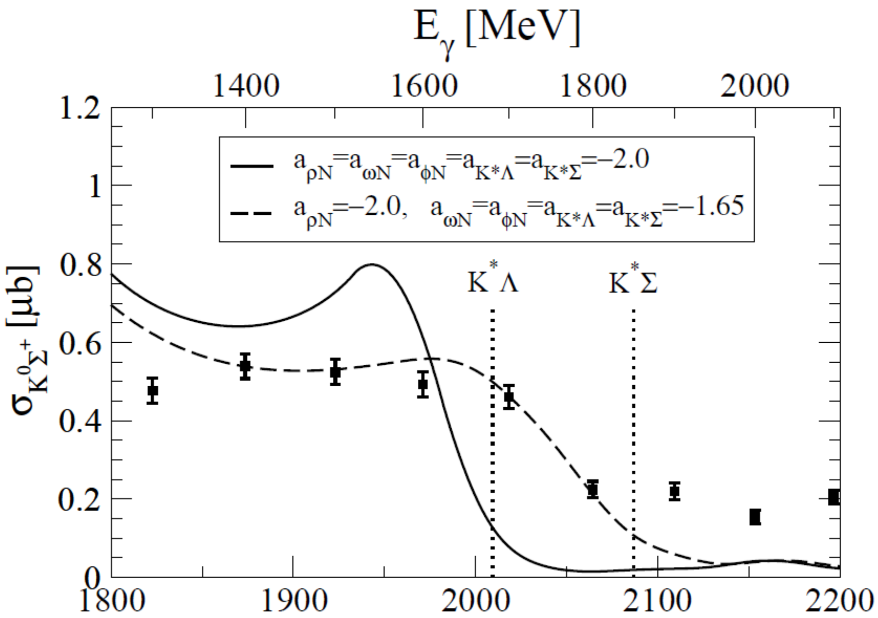
FIG. 4: Cross section for the $\gamma p \to K^0\Sigma^+$ (black line) and $\gamma n \to K^0\Sigma^0$ reactions, including only an intermediate $K^{*+}\Sigma$ channel before the transition to the final $K^0\Sigma$ state.

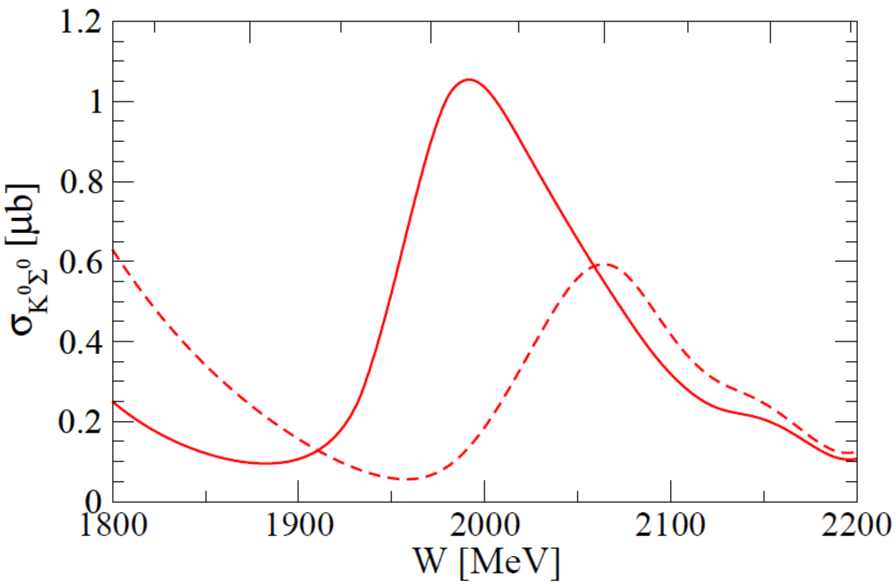
But we have a second loop for VB -→ PB transition → extra interference





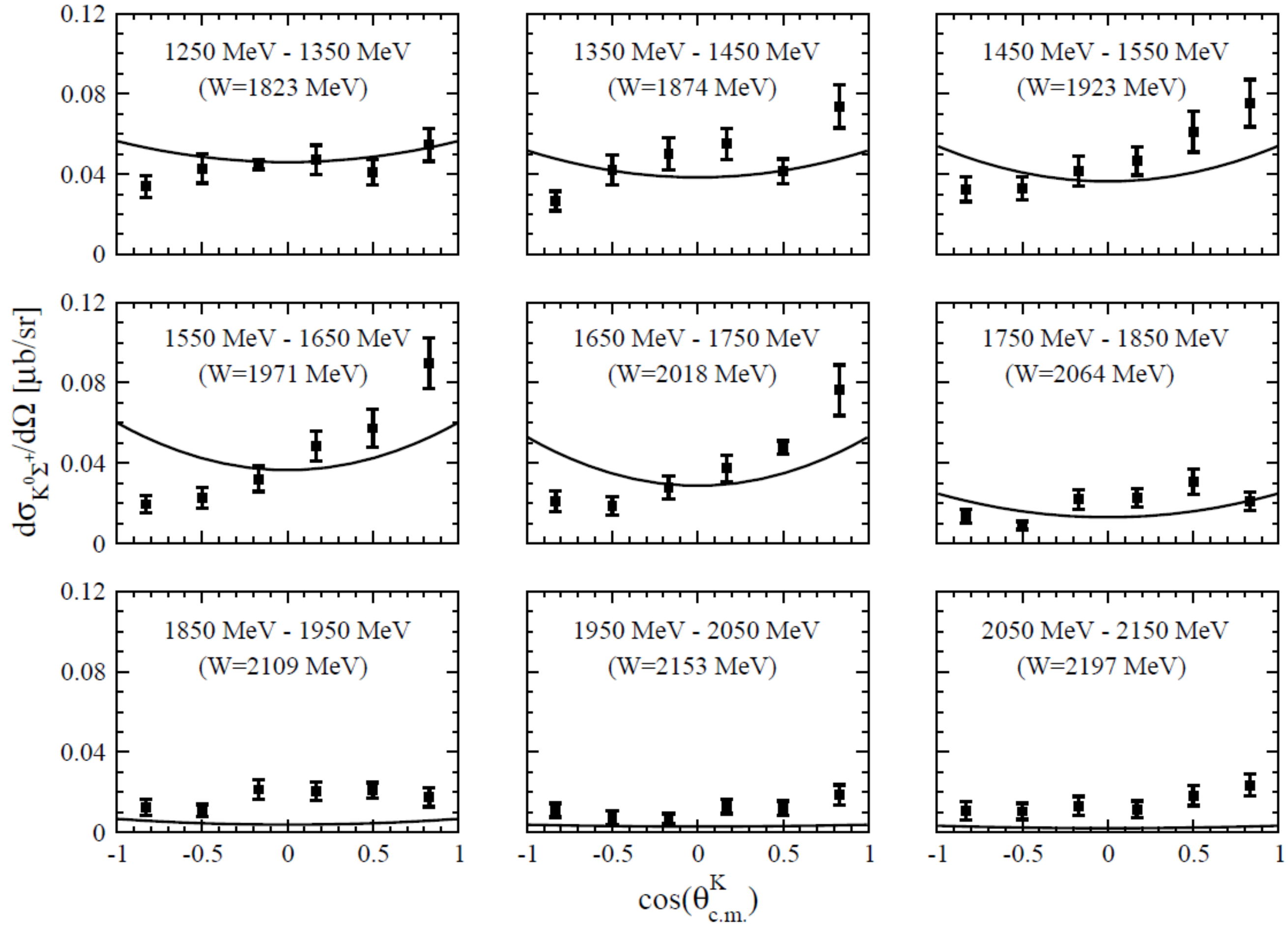
Fine tuning to experiment changing a bit the subtraction constants





With the new parameters we solve again the BS equation and the resonance moves from M_R=1972 MeV , Γ=64 MeV → M_R=2035 MeV , Γ=125 MeV

Prediction for a resonance $1/2^-$, or $3/2^-$ (degenerate in our model)
Important because resonances around this energy have been removed in the latest edition of the PDG.



Conclusion: Physical explanation of basic features of the reaction

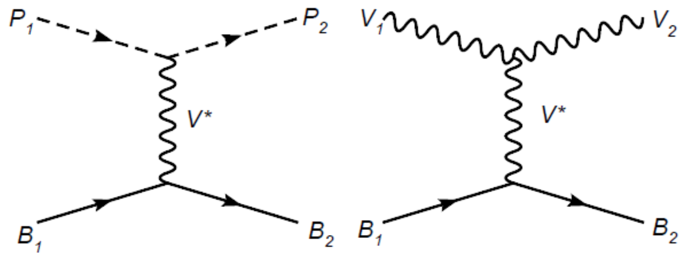
Prediction of a new resonance around 2035 MeV

Importance of VB interaction and coupled channels

Prediction of spectacular differences in the shape of σ for γn → K^0 Σ^0

Prediction of narrow N^* and Λ^* resonances with hidden charm above 4 GeV

J.J. Wu, R. Molina, E. O. and B. S. Zou, Phys Rev Lett 2010



$$V_{ab(P_1 B_1 \to P_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1} + E_{P_2}),$$

$$V_{ab(V_1 B_1 \to V_2 B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1} + E_{V_2})\vec{\epsilon}_1 \cdot \vec{\epsilon}_2$$

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

TABLE I: Coefficients C_{ab} in Eq. (2) for $(I, S) = (1/2, 0)$

	$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	$\eta_c N$	πN	ηN	$\eta' N$	$K\Sigma$	$K\Lambda$
$\bar{D}\Sigma_c$	-1	0	$-\sqrt{3/2}$	$-1/2$	$-1/\sqrt{2}$	$1/2$	1	0
$\bar{D}\Lambda_c^+$		1	$\sqrt{3/2}$	$-3/2$	$1/\sqrt{2}$	$-1/2$	0	1

TABLE II: Coefficients C_{ab} in Eq. (2) for $(I, S) = (0, -1)$

	$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi_c'$	$\eta_c\Lambda$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$\bar{K}N$	K Ξ
$\bar{D}_s\Lambda_c^+$	0	$-\sqrt{2}$	0	1	0	$\sqrt{\frac{1}{3}}$	$\sqrt{\frac{2}{3}}$	$-\sqrt{3}$	0
$\bar{D}\Xi_c$		-1	0	$\sqrt{\frac{1}{2}}$	$-\frac{3}{2}$	$\sqrt{\frac{1}{6}}$	$-\sqrt{\frac{1}{12}}$	0	$\sqrt{\frac{3}{2}}$
$\bar{D}\Xi_c'$			-1	$-\sqrt{\frac{3}{2}}$	$\sqrt{\frac{3}{4}}$	$-\sqrt{\frac{1}{2}}$	$\frac{1}{2}$	0	$\sqrt{\frac{1}{2}}$
$\eta_c\Lambda$				0	0	0	0	0	0

(I,S)	z_R (MeV)	g_a		
$(1/2,0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
	4269	2.85	0	
$(0,-1)$		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi_c'$
	4213	1.37	3.25	0
	4403	0	0	2.64

TABLE III: Pole positions z_R and coupling constants g_a for the states from $PB \to PB$.

(I,S)	z_R (MeV)	g_a		
$(1/2,0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
	4418	2.75	0	
$(0,-1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi_c'$
	4370	1.23	3.14	0
	4550	0	0	2.53

TABLE IV: Pole position and coupling constants for the bound states from $VB \to VB$.

(I,S)	M	Γ	Γ_i					
$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$
	4261	56.9	3.8	8.1	3.9	17.0		23.4
$(0,-1)$			KN	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
	4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
	4394	43.3	0	10.6	7.1	3.3	5.8	16.3

(I,S)	M	Γ	Γ_i					
$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$
	4412	47.3	3.2	10.4	13.7			19.2
$(0,-1)$			$\bar{K}^* N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
	4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
	4544	36.6	0	8.8	9.1	0	5.0	13.8

Prediction of super-heavy N^* and Λ^* resonances with hidden beauty

J. J. Wu, L. Zhao and B.S. Zou, Phys Lett B 2012

Pole positions z_R and coupling constants g_a for the states in (I, S) = (1/2, 0) sector

z_R (MeV)	g_α	
	$B\Sigma_b$	$B\Lambda_b$
11052	2.05	0
	$B^*\Sigma_b$	$B^*\Lambda_b$
11100	2.02	0

Pole positions z_R and coupling constants g_a for the states in (I, S) = (0, -1) sector

z_R (MeV)	g_α		
	$B_s\Lambda_b$	$B\Xi_b$	$B\Xi_b'$
$11021 - 0.59i$	$0.14 - 0.11i$	$2.27 + 0.004i$	0
11191	0	0	1.92
	$B_s^*\Lambda_b$	$B^*\Xi_b$	$B^*\Xi_b'$
$11069 - 0.59i$	$0.14 - 0.12i$	$2.24 + 0.005i$	0
11238	0	0	1.89

The search for molecules in the charm and beauty sectors has experienced a recent boom.

Nieves, Hidalgo, Pavon, Guo, Garcia, Salcedo, Romanets, Tolos, Ramos implementing heavy quark spin symmetry (HQSS)

S. L. Zhu, Xiang Liu … with dynamics of meson exchange

Fernandez –Carames et al, Gutsche et al, Ding et al, Bondar et al., Cleven et al., Li et al,
Guo, Hanhart, Meissner, Sun, Liu, Zhu, Wang, Zhao, Dong, Zhang ….

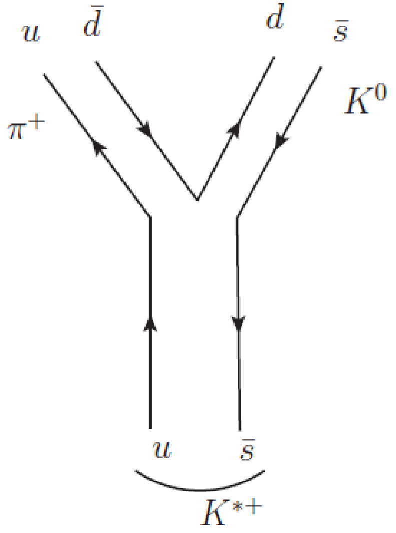
Xiao, Nieves, Ozpineci, E. O. local hidden gauge (exchange of vector mesons) with HQSS.

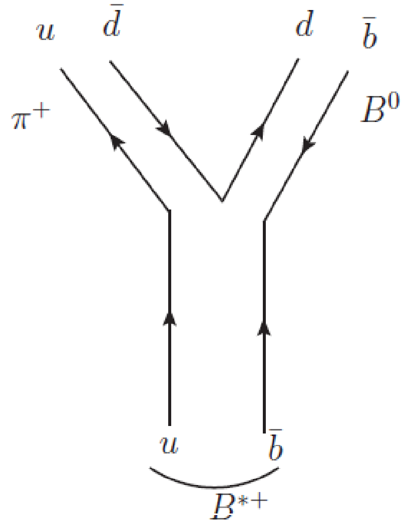
Wei Hong Liang, Xiao, E. O. , how to get the heavy quark spin symmetry results from the impulse approximation at the quark level with heavy quarks as spectators, and the $\Lambda_b(5912)$, $\Lambda_b(5920)$ states.

F. Aceti, M. Bayar, A. Martinez Torres, K. Khemchandani, F. Navarra, M. Nielsen, E. O, on "$Z_c(4025)$", $Z_c(3900)$ …..

Very recent work on open charm and open beauty baryons.
Wei Hong Liang, Chu Wen Xiao, T. Uchino, E. O. 2014

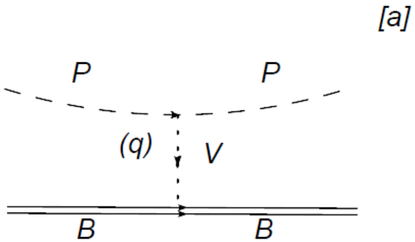
A new look at Heavy Quark Spin Symmetry from the perspective of the Impulse Approximation at the quark level: Below s, b quarks are both spectators

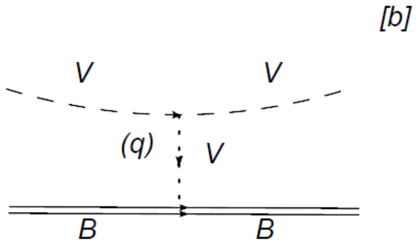




$$\frac{t_{B^*}}{t_{K^*}} \equiv \frac{\sqrt{m_{B^*} m_B}}{\sqrt{m_{K^*} m_K}} \simeq \frac{m_{B^*}}{m_{K^*}}$$

The difference is due to the normalization factors of the fields





In the heavy sector: dominant terms come from exchange of light vectors
Then the heavy quarks are spectators
→ Independence of spin-flavor of
→ heavy quarks.

Heavy quark spin symmetry (HQSS) and the local hidden gauge approach (LHGA):

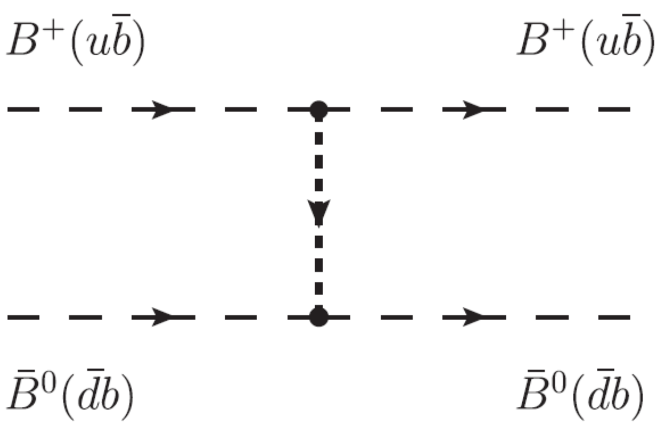
1) Dominant term of LHGA comes from exchange of light vector mesons

→ The heavy quarks are spectators → interaction is independent of spin and flavour of heavy quarks (HQSS)

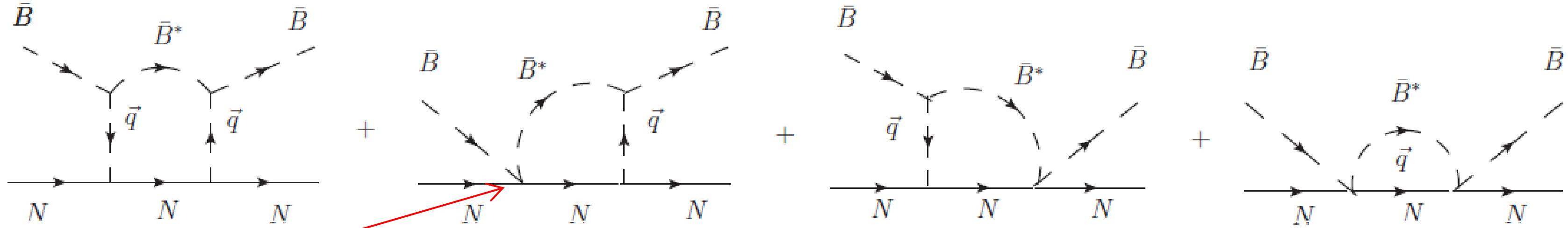
→ The LHGA automatically implements HQSS

2) Take I=1 in meson-meson as in figure: the light exchange involves u ubar from upper vertex and d dbar from lower vertex → OZI forbidden: ρ and ω exchange cancel.
But so does pseudoscalar exchange if masses of nonet are taken equal.

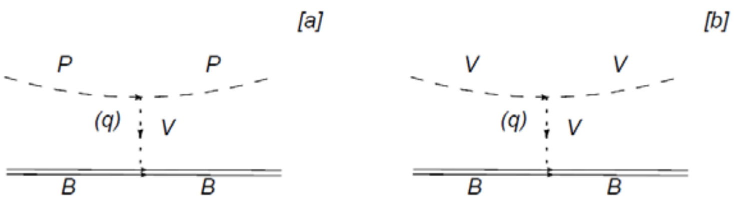
I=1 becomes subdominant



Mixing of the BN and B* N sectors



The Kroll Ruderman term only acts on J=1/2 and breaks the degeneracy of J=1/2, 3/2 for the B* N states



main channel	J	I	$(E,\,\Gamma)$ [MeV]	Exp.
$\bar{B}N$	1/2	0	5820.9, 0	-
$\pi\Sigma_b$	1/2	0	5969.5, 49.2	-
$\bar{B}^*N$	1/2	0	5910.7, 0	$\Lambda_b(5912)$
$\bar{B}^*N$	3/2	0	5920.7, 0	$\Lambda_b(5920)$
$\rho\Sigma_b$	1/2	0	6316.6, 2.8	-
$\rho\Sigma_b$	3/2	0	6315.7, 3.8	-
$\bar{B}N$, $\pi\Sigma_b$	1/2	1	6179.4, 122.8	-
$\pi\Sigma_b$	1/2	1	6002.8, 132.4	-
$\bar{B}\Delta$, $\pi\Sigma_b^*$	3/2	1	5932.9, 0	-
$\pi\Sigma_b^*$	3/2	1	6063.8, 167.0	-
$\bar{B}^*N$	1/2, 3/2	1	6202.2, 0	-
$\rho\Sigma_b$	1/2, 3/2	1	6477.2, 10.0	-
$\bar{B}^*\Delta$	1/2, 3/2, 5/2	1	6022.9, 0	-
$\rho\Sigma_b^*$	1/2, 3/2, 5/2	1	6491.7, 1.6	-

Predictions in the charm sector:

main channel	J	I	(E, Γ) [MeV]	Exp.
$DN, \quad \pi\Sigma_c$	$1/2$	0	2592, 9	$\Lambda_c(2595)$
$\pi\Sigma_c$	$1/2$	0	2623, 53	-
D^*N	$1/2$	0	2615, 0	-
D^*N	$3/2$	0	2628, 0	$\Lambda_c(2625)$
$\pi\Sigma_c^*$	$3/2$	0	2668, 70	-
$\rho\Sigma_c$	$1/2, 3/2$	0	2959, 2	$\Lambda_c(2940)$?
$\pi\Sigma_c$	$1/2$	1	2669, 224	-
$D\Delta$	$3/2$	1	2789, 9	-
$\pi\Sigma_c^*$	$3/2$	1	2736, 224	-
D^*N	$1/2, 3/2$	1	2917, 0	-
$\rho\Sigma_c$	$1/2, 3/2$	1	3126, 9	-
$D^*\Delta$	$1/2, 3/2, 5/2$	1	2749, 0	-
$\rho\Sigma_c^*$	$1/2, 3/2, 5/2$	1	3185, 2	-

Conclusions

Chiral dynamics or its extension with the LHGA is a good tool to deal with hadron interaction.

Its combination with nonperturbative unitary techniques allows to study the interaction of hadrons. Poles in amplitudes correspond to dynamically generated resonances. Many known resonances can be described in this way.

The interaction of vector mesons with other mesons or baryons plays an important role in many hadronic reactions.

We analyzed a recent BES reaction on $J/\psi \to \eta K^{*0} \bar{K}^{*0}$ and interpreted it as showing evidence for a new h_1 state around 1830 MeV predicted from the VV interaction.

The dynamics of vector baryon interaction allowed us to interprete the experimental results of the $\gamma p \to K^0 \Sigma^+$ reaction and make interesting and unexpected predictions for $\gamma n \to K^0 \Sigma^0$.

Plus the prediction of a N* $1/2^-$, $3/2^-$ resonance around 2035 MeV.

Extension to the heavy quark sector is proving fruitful. More data beyond spectra needed.