

Excited baryons coupled to vector and pseudoscalar mesons

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Escuela Andina:
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Introduction: Hadrons

UNTIL ABOUT 1960:

- ❧ MATTER CONSTITUTED OF ELECTRONS, PROTONS AND NEUTRONS

e-	p	n
Q=-1	Q=1	Q=0

- ❧ AND VARIOUS BOUND SYSTEMS OF THREE TYPES OF PARTICLES FORM THE ELEMENTS.

Introduction: Hadrons

Periodic Table of the Elements

1 IA		New Original										13-18 IIIA-VIIIA						18 VIIIA			
1 H Hydrogen 1.00794	2 He Helium 4.002602											3 B Boron 10.811	4 C Carbon 12.0107	5 N Nitrogen 14.00674	6 O Oxygen 15.9994	7 F Fluorine 18.9984032	8 Ne Neon 20.1797	9 K			
3 Li Lithium 6.941	4 Be Beryllium 9.012182											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948	10 L			
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050	3 Sc Scandium 44.955910	4 Ti Titanium 47.867	5 V Vanadium 50.9415	6 Cr Chromium 51.9961	7 Mn Manganese 54.938049	8 Fe Iron 55.8457	9 Co Cobalt 58.933200	10 Ni Nickel 58.6934	11 Cu Copper 63.546	12 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798	11 M			
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.409	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293	12 I			
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)	13 O			
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 to 71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium	14 P
87 Fr Francium (223)	88 Ra Radium (226)	89 to 103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium	15 S			

Atomic masses in parentheses are those of the most stable or common isotope.

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57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

Introduction: Hadrons

❧ AND VARIOUS ELEMENTS FORMED MOLECULAR STATES



DURING 1964-1969:

SUB-STRUCTURE OF PROTONS AND NEUTRONS WAS
DISCOVERED

Ref: PHYS. REV, 142, 1966 T. JANSSENS,
R. HOFSTADTER, E. B. HUGHES, AND M.
R. YKARIAN

NOW THE LIGHTEST “HADRONS”!!

Introduction: Hadrons

❧ **HADRONS (MESONS AND BARYONS) ARE BOUND SYSTEMS OF QUARKS.**

u Q = +2/3	d Q = -1/3	s Q = -1/3
c Q = -1/3	b Q = -1/3	t Q = -1/3

❧ **STANDARD MODEL: THE BASIC CONSTITUENTS OF MATTER: **QUARKS** & **LEPTONS****

e Q = +2/3	μ Q = -1/3	τ Q = -1/3
ν Q = -1/3	ν Q = -1/3	ν Q = -1/3

Introduction: Hadrons

❧ **MANY HADRONS HAVE BEEN DISCOVERED SINCE THEN.**

The particle data group

▶ **Mesons**

- ▶ Light unflavoured
- ▶ Strange
- ▶ Charmed
- ▶ Charmed, Strange
- ▶ Bottom
- ▶ Bottom, Strange
- ▶ Bottom, Charmed
- ▶ cc
- ▶ bb
- ▶ Non qq Candidates

▶ **Baryons**

- ▶ N Baryons
- ▶ Baryons
- ▶ Exotic Baryons
- ▶ Baryons
- ▶ Baryons
- ▶ Baryons
- ▶ Baryons
- ▶ Charmed Baryons
- ▶ Doubly-Charmed Baryons
- ▶ Bottom Baryons

Introduction: Hadrons

❧ **MANY HADRONS HAVE BEEN DISCOVERED SINCE THEN.**

Introduction: Hadrons

π^\pm	$1^-(0^-)$	$\omega(1420)$	$0^-(1^{--})$	$\eta(1760)$	$0^+(0^{++})$
π^0	$1^-(0^{+-})$	$f_2(1430)$	$0^+(2^{++})$	$\pi(1800)$	$1^-(0^{+-})$
η	$0^+(0^{+-})$	$a_0(1450)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
$f_0(600)$ or σ	$0^+(0^{++})$	$\rho(1450)$	$1^+(1^{--})$	$X(1835)$	$??(?^{+-})$
$\rho(770)$	$1^+(1^-)$	$\eta(1475)$	$0^+(0^{+-})$	$\phi_3(1850)$	$0^-(3^-)$
$\omega(782)$	$0^-(1^-)$	$f_0(1500)$	$0^+(0^{++})$	$\eta_2(1870)$	$0^+(2^{+-})$
$\eta'(958)$	$0^+(0^{+-})$	$f_1(1510)$	$0^+(1^{++})$	$\pi_2(1880)$	$1^-(2^{+-})$
$f_0(980)$	$0^+(0^{++})$	$f_2'(1525)$	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^-)$
$a_0(980)$	$1^-(0^{++})$	$f_2(1565)$	$0^+(2^{++})$	$f_2(1910)$	$0^+(2^{++})$
$\phi(1020)$	$0^-(1^-)$	$\rho(1570)$	$1^+(1^{--})$	$f_2(1950)$	$0^+(2^{++})$
$h_1(1170)$	$0^-(1^{+-})$	$h_1(1595)$	$0^-(1^{+-})$	$\rho_3(1990)$	$1^+(3^-)$
$b_1(1235)$	$1^+(1^{+-})$	$\pi_1(1600)$	$1^-(1^{+-})$	$f_2(2010)$	$0^+(2^{++})$
$a_1(1260)$	$1^-(1^{++})$	$a_1(1640)$	$1^-(1^{++})$	$f_0(2020)$	$0^+(0^{++})$
$f_2(1270)$	$0^+(2^{++})$	$f_2(1640)$	$0^+(2^{++})$	$a_4(2040)$	$1^-(4^{++})$
$f_1(1285)$	$0^+(1^{++})$	$\eta_2(1645)$	$0^+(2^{+-})$	$f_4(2050)$	$0^+(4^{++})$
$\eta(1295)$	$0^+(0^{+-})$	$\omega(1650)$	$0^-(1^{--})$	$\pi_2(2100)$	$1^-(2^{+-})$
$\pi(1300)$	$1^-(0^{+-})$	$\omega_3(1670)$	$0^-(3^{--})$	$f_0(2100)$	$0^+(0^{++})$
$a_2(1320)$	$1^-(2^{++})$	$\pi_2(1670)$	$1^-(2^{+-})$	$f_2(2150)$	$0^+(2^{++})$
$f_0(1370)$	$0^+(0^{++})$	$\phi(1680)$	$0^-(1^{--})$	$\rho(2150)$	$1^+(1^-)$
$h_1(1380)$	$?^-(1^{+-})$	$\rho_3(1690)$	$1^+(3^{--})$	$\phi(2170)$	$0^-(1^-)$
$\pi_1(1400)$	$1^-(1^{+-})$	$\rho(1700)$	$1^+(1^{--})$	$f_0(2200)$	$0^+(0^{++})$
$\eta(1405)$	$0^+(0^{+-})$	$a_2(1700)$	$1^-(2^{++})$	$f_J(2220)$	$0^+(2^{++} \text{ or } 4^{++})$
$f_1(1420)$	$0^+(1^{++})$	$f_0(1710)$	$0^+(0^{++})$	$\eta(2225)$	$0^+(0^{+-})$
				$\rho_3(2250)$	$1^+(3^-)$

They can be

$q\bar{q}$

$(q\bar{q})^*$

$q\bar{q}q\bar{q}$

molecules

Glueballs



Not all of them can be explained in quark model.

More motivation

- ❧ Important contributions made by the study of hadrons:
 - ✦ **FORMULATION OF THE QUARK MODEL.**
 - ✦ **STUDIES OF Δ^{++} BROUGHT THE FIRST INDICATIONS OF AN ADDITIONAL QUANTUM NUMBER.**
 - ✦ **STUDIES OF J/ψ GAVE THE INDICATIONS OF EXISTENCE OF THE CHARM QUARKS.**
- ❧ By studying hadrons: we are still in the process of understanding the working of the strong interactions at lower energies.

Ref: SIGNATURES OF EXOTIC HADRONS, FRANCESCO RENGA: arXiv:1110.4151v1 [hep-ph]

Important objective: to study resonances

FROM THE THEORY OF STRONG INTERACTIONS



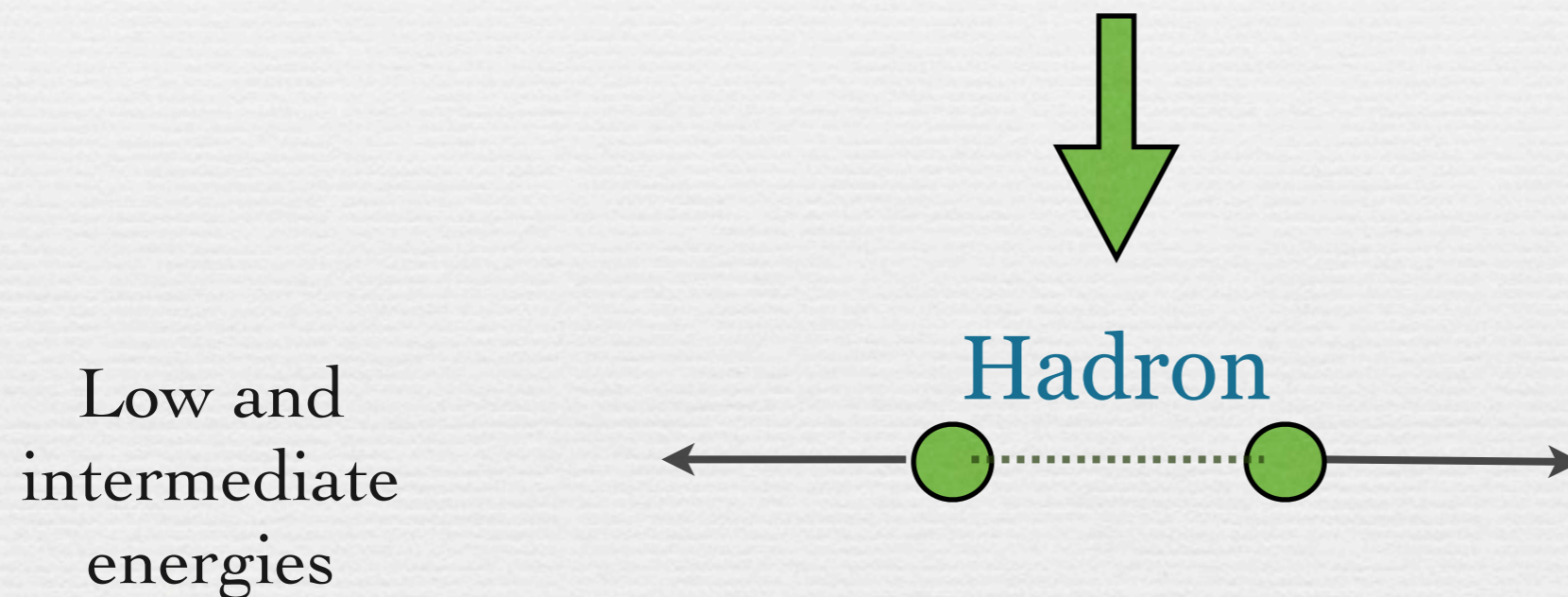
Low and
intermediate
energies



CONSEQUENCE: MANY UNSTABLE HADRONS/RESONANCES EXIST AT THESE ENERGIES.

Important objective: to study resonances

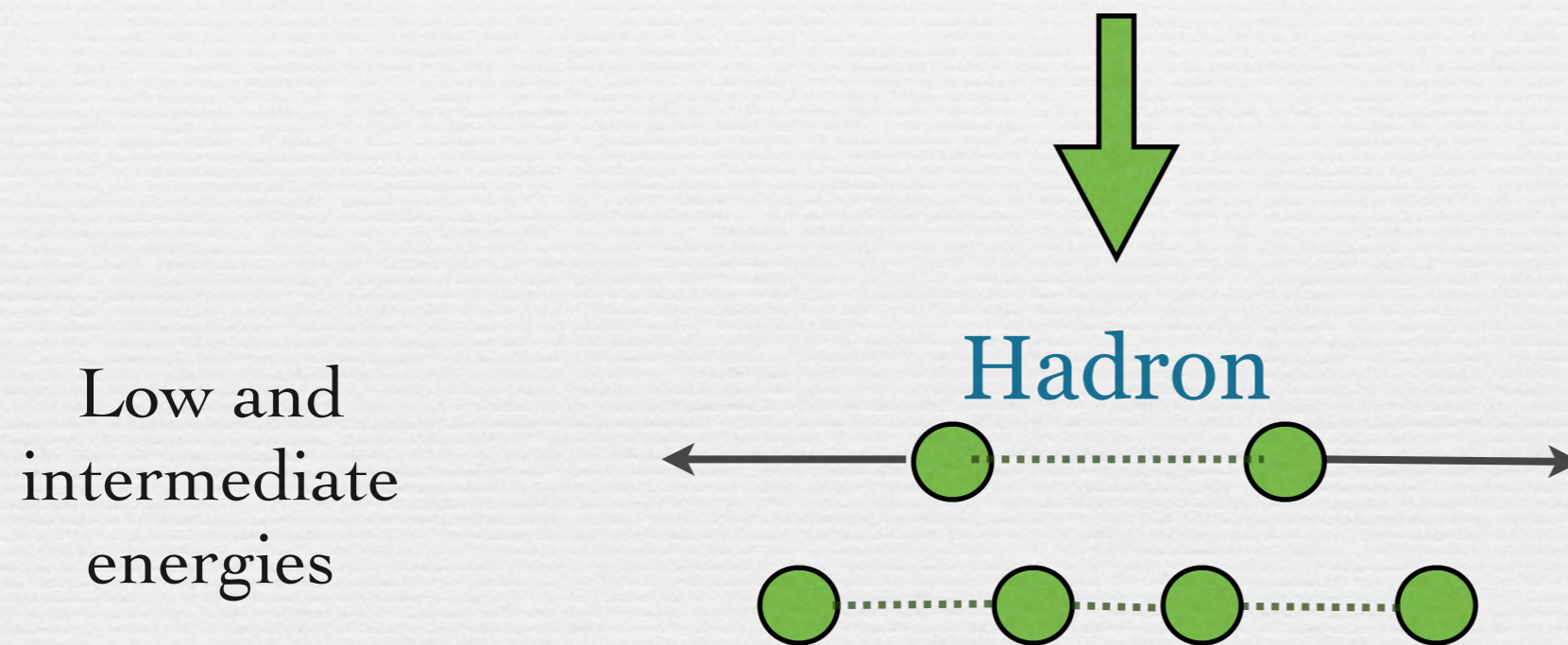
FROM THE THEORY OF STRONG INTERACTIONS



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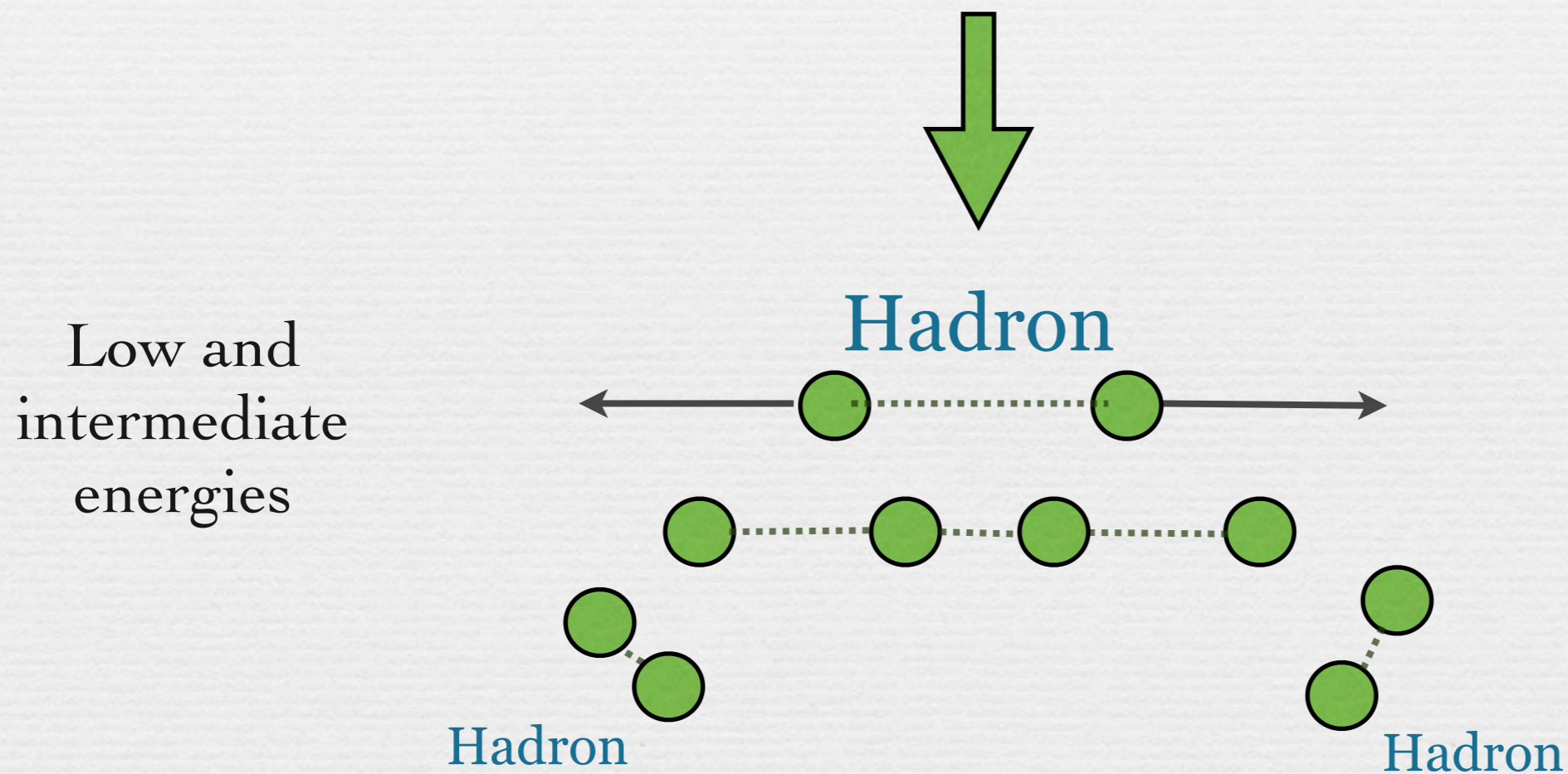
FROM THE THEORY OF STRONG INTERACTIONS



CONSEQUENCE: MANY UNSTABLE HADRONS/RESONANCES EXIST AT THESE ENERGIES.

Important objective: to study resonances

FROM THE THEORY OF STRONG INTERACTIONS



CONSEQUENCE: MANY UNSTABLE HADRONS/RESONANCES EXIST AT THESE ENERGIES.

How to make such studies?

- QCD becomes non-perturbative at such energies.
- Some excellent alternatives are available: (1) Lattice QCD (2) holographic QCD (3) QCD inspired Effective field theories
- In case (1) and (2) a lot of work is required to obtain information related to resonances.
- Option (3) can be more efficient to study resonances.

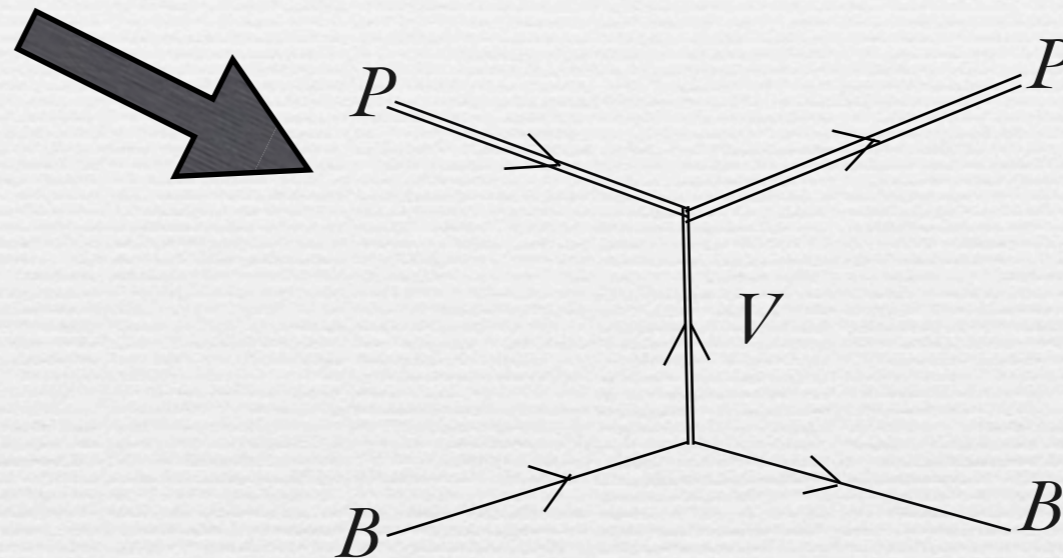
- In this talk we will focus on baryonic systems.
- Lightest meson-baryon system--> pseudoscalar mesons+ baryons
- Effective field theories^{##} for such system are **well studied**
- They are based on the idea that the low energy hadron dynamics is governed by **chiral symmetry^{\$\$}** and its **spontaneous breaking^{\$\$}**.

^{##} Explained in lectures by Prof. Bertulani

^{\$\$} For a brief introduction please see I.T.5 by Alberto Martinez Torres on Nov 30 at 10:30hrs.

Vector meson-baryon systems:

- Pseudoscalar-baryon systems: well explained in terms of Weinberg Tomozawa interaction + other low energy theorems.



- Interest in Vector-meson (VB) Baryon systems is relatively new.
- New issue/problem: Low energy theorems not applicable -->

No a priori reason to neglect s-, u-channel (etc.).

Hidden local symmetry:

Ref: Bando, Kugo, Yamawaki Phys. Rept. (1988)

(1) based on nonlinear realization of the chiral symmetry (one starts with the nonlinear sigma model)

$$\mathcal{L}_0 = \frac{f_\pi^2}{4} \text{Tr}(\partial_\mu U \partial^\mu U^\dagger) \quad U = (\sigma + i\vec{\tau} \cdot \vec{\pi})$$

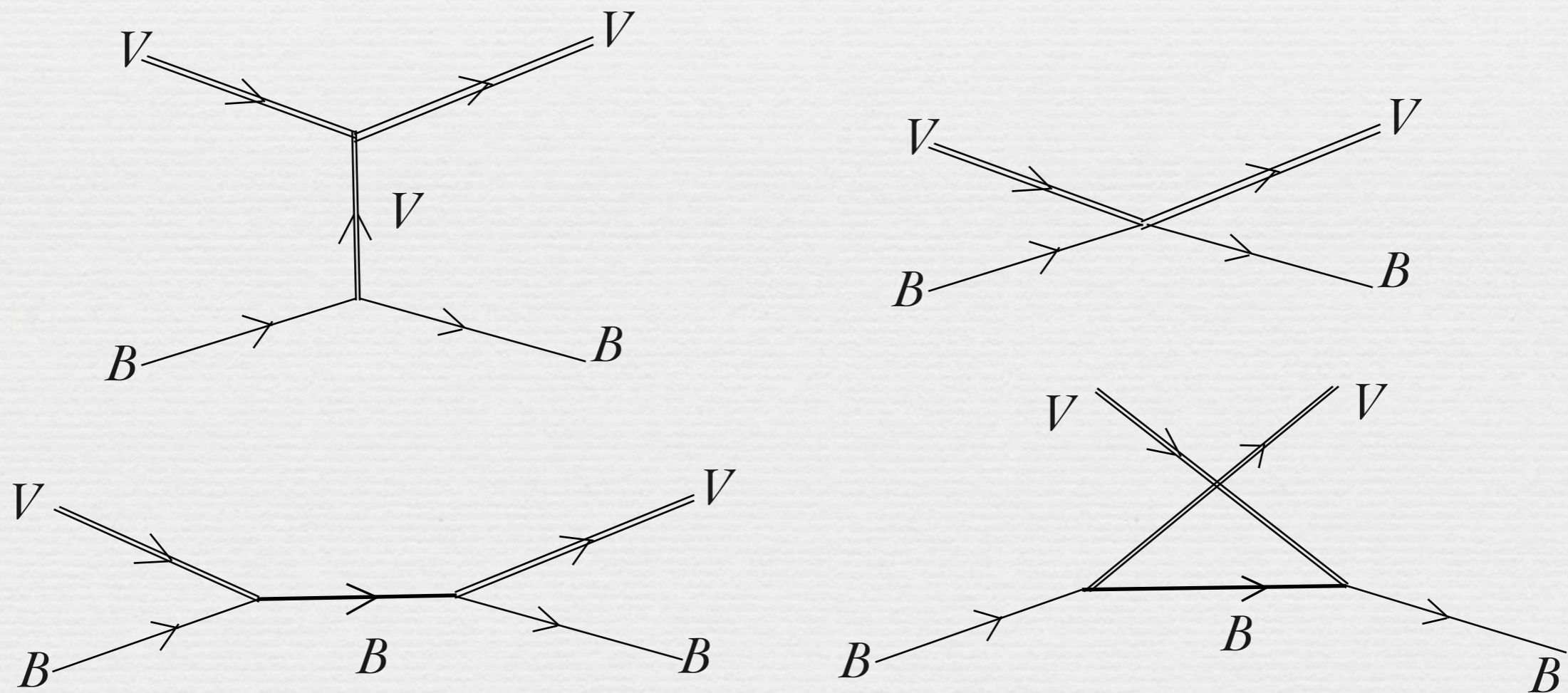
(2) take vector mesons as dynamical gauge bosons (in addition to the Goldstone bosons)

$$\mathcal{L} = \mathcal{L}_0 + a\mathcal{L}_V - \frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}(\partial_\nu B_\mu - \partial_\mu B_\nu)^2$$

(3) Motivation: vector meson dominance--> which naturally appears as a consequence in this theory, (+ universality of rho meson coupling $g_{\rho\pi\pi} = g_{\rho NN}$ (Sakurai) +KSFR relation [Kawarabayashi and Suzuki, 1966], [Riazuddin and Fayyazuddin, 1966 +)

Diagrams, we consider:

- t-channel (vector meson) exchange
- Contact interaction (Hidden local symmetry Lagrangian).
- s- and u-channel baryon exchange



Vector Meson-Baryon interaction

- Formalism: Lagrangian which is gauge invariant under the Hidden local symmetry transformations.

$$\mathcal{L}_{\rho NN} = -g\bar{N} \left\{ F_1 \gamma_\mu \rho^\mu + \frac{F_2}{4M} \sigma_{\mu\nu} \rho^{\mu\nu} \right\} N$$

Vector Meson-Baryon interaction

- Formalism: Lagrangian which is gauge invariant under the Hidden local symmetry transformations.

$$\text{SU(2):} \quad \mathcal{L}_{\rho NN} = -g\bar{N} \left\{ F_1 \gamma_\mu \rho^\mu + \frac{F_2}{4M} \sigma_{\mu\nu} \rho^{\mu\nu} \right\} N$$

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\swarrow
=1

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\swarrow
=1

Interesting feature: (in SU(2))

		WT	Contact interaction	(S+U)-channel
$l=1/2$	$s=1/2$	$-\frac{m_\rho}{f_\pi^2}$	$\frac{4m_\rho}{3f_\pi^2}$	$\left(\frac{1}{20} - \frac{1}{2}\right) \frac{m_\rho}{f_\pi^2}$
	$s=3/2$		$\frac{-2m_\rho}{3f_\pi^2}$	$\frac{m_\rho}{f_\pi^2}$
$l=3/2$	$s=1/2$	$\frac{m_\rho}{2f_\pi^2}$	$\frac{-4}{3} \frac{m_\rho}{2f_\pi^2}$	$2 \frac{m_\rho}{2f_\pi^2}$
	$s=3/2$		$\frac{2}{3} \frac{m_\rho}{2f_\pi^2}$	$-\frac{4m_\rho}{2f_\pi^2}$

$$V_{contact} = \frac{3m_\rho}{2f_\pi^2} \left\{ \frac{3}{4} \vec{s}_\rho \cdot \vec{s}_N + \frac{1}{2} \vec{s}_\rho \cdot \vec{s}_N \vec{\tau}_\rho \cdot \vec{\tau}_N \right\}$$

$$V_t = \frac{m_\rho}{f_\pi^2} \vec{\tau}_\rho \cdot \vec{\tau}_N$$

$$V_s = \left\{ \frac{1}{6} - \frac{1}{3} \vec{s}_\rho \cdot \vec{s}_N - \frac{1}{3} \vec{\tau}_\rho \cdot \vec{\tau}_N + \frac{2}{3} \vec{s}_\rho \cdot \vec{s}_N \vec{\tau}_\rho \cdot \vec{\tau}_N \right\} \frac{m_\rho}{f_\pi^2}$$

$$V_u = \left\{ \frac{1}{2} + \vec{s}_\rho \cdot \vec{s}_N + \vec{\tau}_\rho \cdot \vec{\tau}_N + 2 \vec{s}_\rho \cdot \vec{s}_N \vec{\tau}_\rho \cdot \vec{\tau}_N \right\} \frac{m_\rho}{f_\pi^2}$$

Vector Meson-Baryon interaction

$$\mathcal{L}_{\rho NN} = -g\bar{N} \left\{ F_1 \gamma_\mu \rho^\mu + \frac{F_2}{4M} \sigma_{\mu\nu} \rho^{\mu\nu} \right\} N$$

$$\text{SU(3): } \mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V^\mu, B] \rangle + \langle \bar{B} \gamma_\mu B \rangle \langle V^\mu \rangle + \frac{1}{4M} (F \langle \bar{B} \sigma_{\mu\nu} [V^{\mu\nu}, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{V^{\mu\nu}, B\} \rangle) \right\}$$

$$D = 2.4$$

$$F = 0.82$$

$$g = \frac{m_\nu}{\sqrt{2} f_\pi}$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$V = \begin{pmatrix} \frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{\rho^+}{\sqrt{2}} & \frac{K^{*+}}{\sqrt{2}} \\ \frac{\rho^-}{\sqrt{2}} & -\frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{K^{*0}}{\sqrt{2}} \\ \frac{K^{*-}}{\sqrt{2}} & \frac{\bar{K}^{*0}}{\sqrt{2}} & \frac{\phi}{\sqrt{2}} \end{pmatrix} \quad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & \frac{-2\Lambda}{\sqrt{6}} \end{pmatrix}$$

Vector Meson-Baryon interaction

$$\mathcal{L}_{\rho NN} = -g\bar{N} \left\{ F_1\gamma_\mu\rho^\mu + \frac{F_2}{4M}\sigma_{\mu\nu}\rho^{\mu\nu} \right\} N$$

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$$\begin{array}{ccc} D = 2.4 & & \\ F = 0.82 & \longrightarrow & D + F = 3.22 \approx \kappa_\rho \end{array} \quad g = \frac{m_\nu}{\sqrt{2}f_\pi}$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$V = \begin{pmatrix} \frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{\rho^+}{\sqrt{2}} & \frac{K^{*+}}{\sqrt{2}} \\ \frac{\rho^-}{\sqrt{2}} & -\frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{K^{*0}}{\sqrt{2}} \\ \frac{K^{*-}}{\sqrt{2}} & \frac{\bar{K}^{*0}}{\sqrt{2}} & \frac{\phi}{\sqrt{2}} \end{pmatrix} \quad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & \frac{-2\Lambda}{\sqrt{6}} \end{pmatrix}$$

Vector Meson-Baryon interaction

$$\text{SU(2): } \mathcal{L}_{\rho NN} = -g\bar{N} \left\{ F_1 \gamma_\mu \rho^\mu + \frac{F_2}{4M} \sigma_{\mu\nu} \rho^{\mu\nu} \right\} N$$

$$\text{SU(3): } \mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V^\mu, B] \rangle + \langle \bar{B} \gamma_\mu B \rangle \langle V^\mu \rangle + \frac{1}{4M} (F \langle \bar{B} \sigma_{\mu\nu} [V^{\mu\nu}, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{V^{\mu\nu}, B\} \rangle) \right\}$$

$$\begin{array}{ccc} D = 2.4 & & \\ F = 0.82 & \longrightarrow & D + F = 3.22 \approx \kappa_\rho \end{array} \quad g = \frac{m_\nu}{\sqrt{2} f_\pi}$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$V = \begin{pmatrix} \frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{\rho^+}{\sqrt{2}} & \frac{K^{*+}}{\sqrt{2}} \\ \frac{\rho^-}{\sqrt{2}} & -\frac{\rho^0}{2} + \frac{\varepsilon}{2} & \frac{K^{*0}}{\sqrt{2}} \\ \frac{K^{*-}}{\sqrt{2}} & \frac{\bar{K}^{*0}}{\sqrt{2}} & \frac{\phi}{\sqrt{2}} \end{pmatrix} \quad B = \begin{pmatrix} \frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & \Sigma^+ & p \\ \Sigma^- & -\frac{\Sigma^0}{\sqrt{2}} + \frac{\Lambda}{\sqrt{6}} & n \\ \Xi^- & \Xi^0 & \frac{-2\Lambda}{\sqrt{6}} \end{pmatrix}$$

Vector Meson-Baryon interaction: ω - ϕ mixing

Under the ideal mixing assumption:

$$\omega = \sqrt{\frac{1}{3}} \omega_8 + \sqrt{\frac{2}{3}} \omega_0$$

$$\phi = -\sqrt{\frac{2}{3}} \phi_8 + \sqrt{\frac{1}{3}} \phi_0;$$

Use the octet part of these wave-functions in

$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V^\mu, B] \rangle + \langle \bar{B} \gamma_\mu B \rangle \langle V^\mu \rangle + \frac{1}{4M} (F \langle \bar{B} \sigma_{\mu\nu} [V^{\mu\nu}, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{V^{\mu\nu}, B\} \rangle) \right\}$$

and add

$$\mathcal{L}_{V_0BB} = -g \left\{ \langle \bar{B} \gamma_\mu B \rangle \langle V_0^\mu \rangle + \frac{C_0}{4M} \langle \bar{B} \sigma_{\mu\nu} V_0^{\mu\nu} B \rangle \right\}$$

$\nearrow = 3F-D$

for the singlet meson-Baryon interaction.

Vector Meson-Baryon interaction: t-channel (vector exchange)

$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V_8^\mu, B] \rangle + \frac{1}{4M} \left(F \langle \bar{B} \sigma_{\mu\nu} [\partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ \partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B \} \rangle \right) \right. \\ \left. + \langle \bar{B} \gamma_\mu B \rangle \langle V_0^\mu \rangle + \frac{C_0}{4M} \langle \bar{B} \sigma_{\mu\nu} V_0^{\mu\nu} B \rangle \right\}$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$\mathcal{L}_{3V} = -\frac{1}{2} \langle V^{\mu\nu}, V_{\mu\nu} \rangle$$

$$V_t = -C_{ij}^t \frac{1}{4f_\pi^2} (k_1^0 + k_2^0) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2$$

Vector Meson-Baryon interaction: t-channel (vector exchange)

$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V_8^\mu, B] \rangle + \frac{1}{4M} \left(F \langle \bar{B} \sigma_{\mu\nu} [\partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ \partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B \} \rangle \right) \right. \\ \left. + \langle \bar{B} \gamma_\mu B \rangle \langle V_0^\mu \rangle + \frac{C_0}{4M} \langle \bar{B} \sigma_{\mu\nu} V_0^{\mu\nu} B \rangle \right\}$$

$$V^{\mu\nu} = \underbrace{(\partial^\mu V^\nu - \partial^\nu V^\mu)}_{\text{circled}} + ig[V^\mu, V^\nu]$$

$$\mathcal{L}_{3V} = -\frac{1}{2} \langle V^{\mu\nu}, V_{\mu\nu} \rangle$$

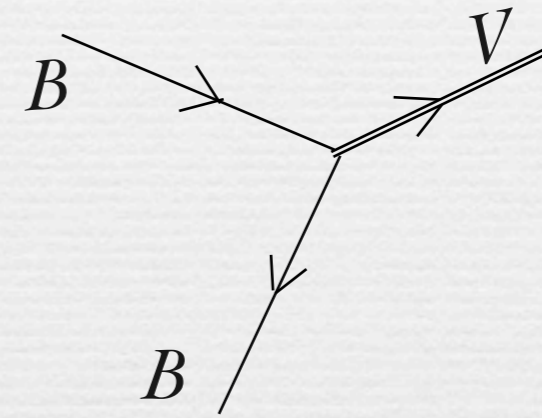
$$V_t = -C_{ij}^t \frac{1}{4f_\pi^2} (k_1^0 + k_2^0) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2$$

Vector Meson-Baryon interaction: t-channel (vector exchange)

$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V_8^\mu, B] \rangle + \frac{1}{4M} \left(F \langle \bar{B} \sigma_{\mu\nu} [\partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ \partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B \} \rangle \right) \right. \\ \left. + \langle \bar{B} \gamma_\mu B \rangle \langle V_0^\mu \rangle + \frac{C_0}{4M} \langle \bar{B} \sigma_{\mu\nu} V_0^{\mu\nu} B \rangle \right\}$$

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

$$\mathcal{L}_{3V} = -\frac{1}{2} \langle V^{\mu\nu}, V_{\mu\nu} \rangle$$



$$V_t = -C_{ij}^t \frac{1}{4f_\pi^2} (k_1^0 + k_2^0) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2$$

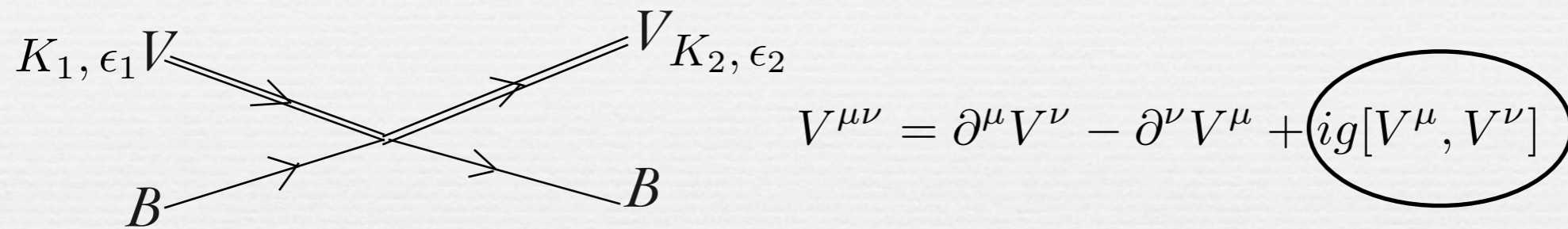
Vector Meson-Baryon contact interaction:

$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

Vector Meson-Baryon contact interaction:

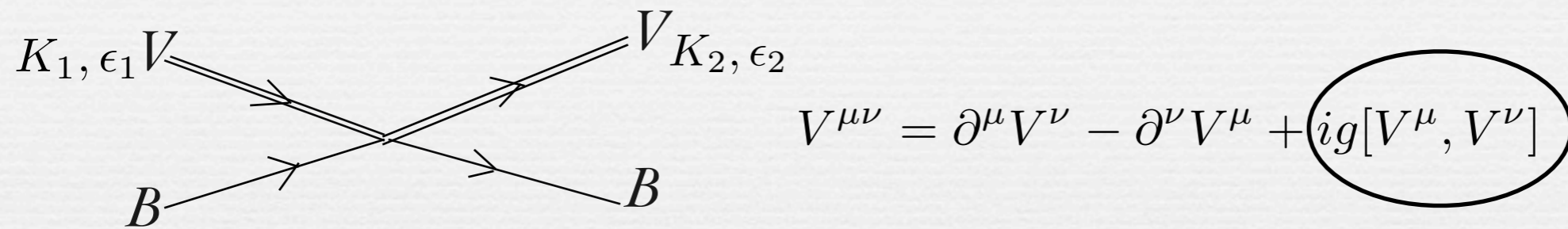
$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

Vector Meson-Baryon contact interaction:



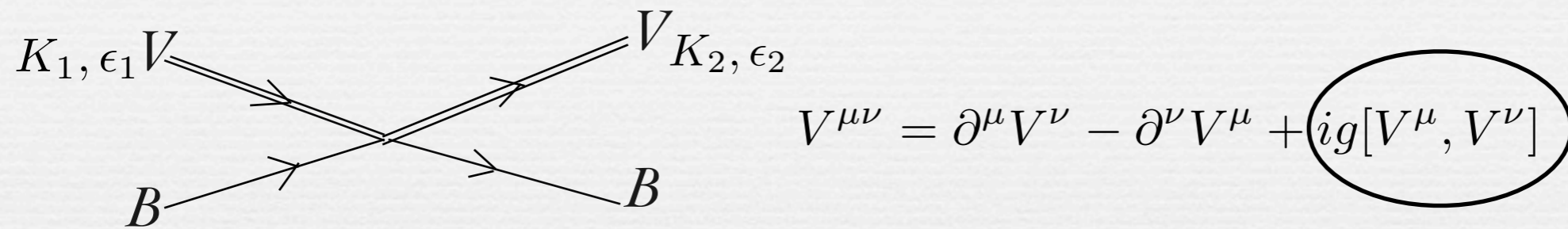
$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

Vector Meson-Baryon contact interaction:



$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} [2ig [V^\mu, V^\nu], B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ [2ig [V^\mu, V^\nu], B] \} \rangle \right\}$$

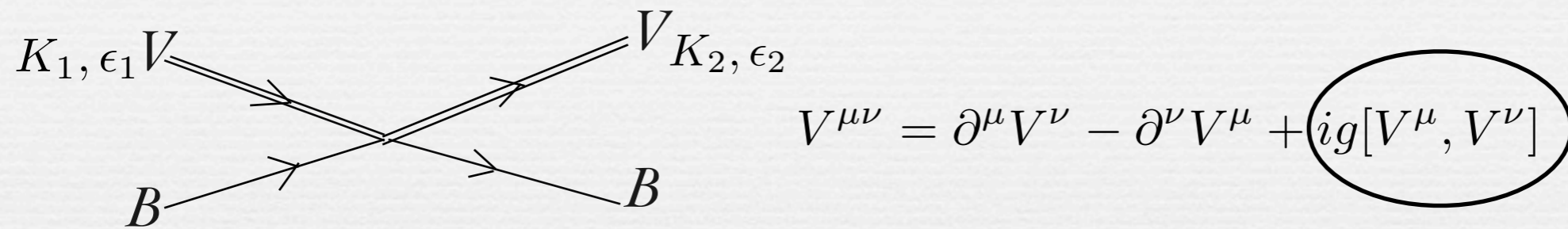
Vector Meson-Baryon contact interaction:



$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} [2ig [V^\mu, V^\nu], B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ [2ig [V^\mu, V^\nu], B] \} \rangle \right\}$$

$$V_{contact} = -iC_{ij}^{contact} \frac{g^2}{2M_B} \vec{\sigma} \cdot \vec{\epsilon}_2 \times \vec{\epsilon}_1$$

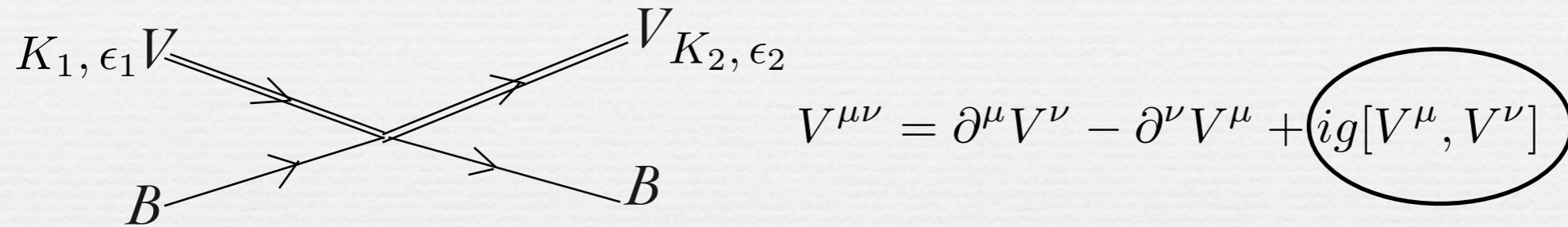
Vector Meson-Baryon contact interaction:



$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} [2ig [V^\mu, V^\nu], B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ [2ig [V^\mu, V^\nu], B] \} \rangle \right\}$$

$$V_{contact} = -iC_{ij}^{contact} \frac{g^2}{2M_B} \vec{\sigma} \cdot \underline{\vec{\epsilon}_2} \times \vec{\epsilon}_1$$

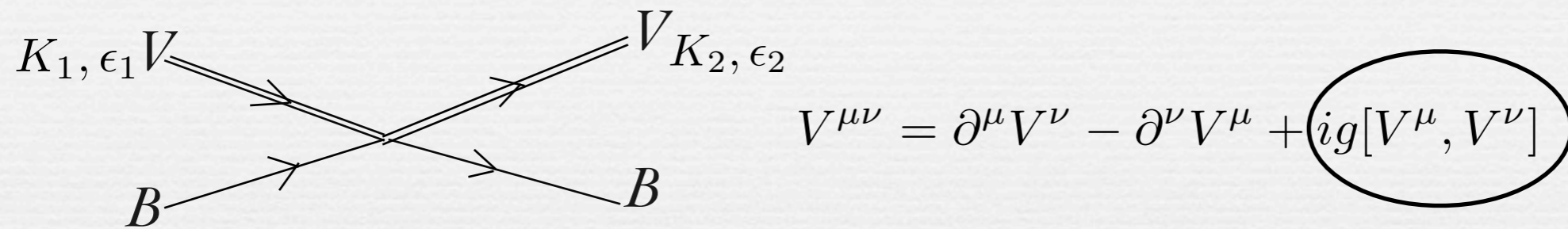
Vector Meson-Baryon contact interaction:



$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} [2ig [V^\mu, V^\nu], B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ [2ig [V^\mu, V^\nu], B] \} \rangle \right\}$$

$$V_{contact} = -iC_{ij}^{contact} \frac{g^2}{2M_B} \vec{\sigma} \cdot \frac{\vec{\epsilon}_2 \times \vec{\epsilon}_1}{i\vec{S}}$$

Vector Meson-Baryon contact interaction:

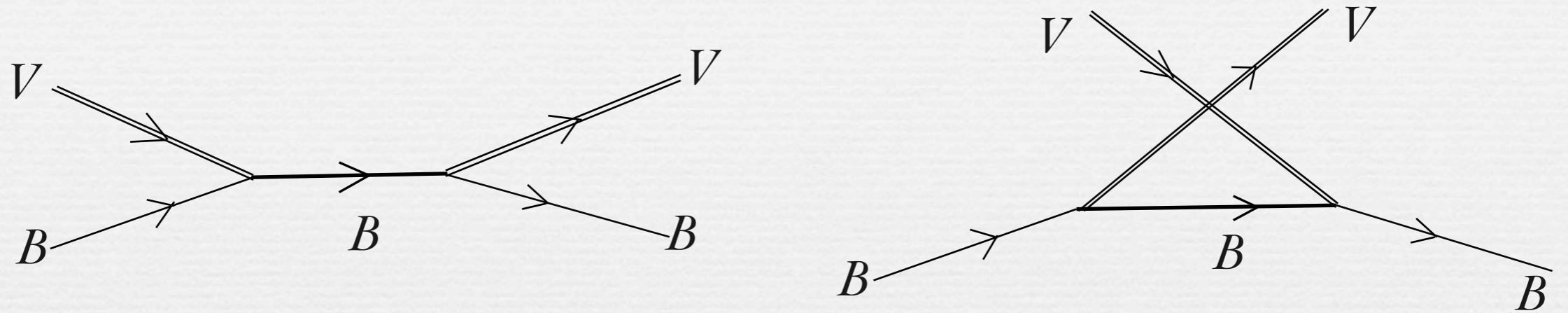


$$\mathcal{L}_{VVBB} = -\frac{g}{4M} \left\{ F \langle \bar{B} \sigma_{\mu\nu} [2ig [V^\mu, V^\nu], B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ [2ig [V^\mu, V^\nu], B] \} \rangle \right\}$$

$$V_{contact} = -iC_{ij}^{contact} \frac{g^2}{2M_B} \frac{\vec{\sigma} \cdot \vec{\epsilon}_2 \times \vec{\epsilon}_1}{\vec{s} \cdot i\vec{S}}$$

Spin dependent

S- and U-channel diagrams:



$$\mathcal{L}_{VBB} = -g \left\{ \langle \bar{B} \gamma_\mu [V_8^\mu, B] \rangle + \frac{1}{4M} \left(F \langle \bar{B} \sigma_{\mu\nu} [\partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B] \rangle + D \langle \bar{B} \sigma_{\mu\nu} \{ \partial^\mu V_8^\nu - \partial^\nu V_8^\mu, B \} \rangle \right) \right. \\ \left. + \langle \bar{B} \gamma_\mu B \rangle \langle V_0^\mu \rangle + \frac{C_0}{4M} \langle \bar{B} \sigma_{\mu\nu} V_0^{\mu\nu} B \rangle \right\}$$

$$V_S = C_{ij}^s g^2 \left(\frac{1}{m_v + 2M_B} \right) \vec{\epsilon}_2 \cdot \vec{\sigma} \vec{\epsilon}_1 \cdot \vec{\sigma}$$

$$V_U = -C_{ij}^u g^2 \left(\frac{1}{m_v - 2M_B} \right) \vec{\epsilon}_1 \cdot \vec{\sigma} \vec{\epsilon}_2 \cdot \vec{\sigma}$$

Solving Bethe-Salpeter equations in coupled channel formalism:

$$\mathbf{T} = \mathbf{V} + \mathbf{VGT}$$

$$V = V_t + V_{contact} + V_u + V_s$$

$$\begin{aligned} G &= i2M \int \frac{d^4q}{2\pi^4} \frac{1}{(P-q)^2 - M^2 + i\epsilon} \frac{1}{q^2 - m^2 + i\epsilon} \\ &= \frac{2M}{16\pi^2} \left\{ a(\mu) + \ln \frac{M^2}{\mu^2} + \frac{m^2 - M^2 + s}{2s} \ln \frac{m^2}{M^2} \right. \\ &\quad + \frac{\bar{q}}{\sqrt{s}} \left[\ln (s - (M^2 - m^2) + 2\bar{q}\sqrt{s}) - \ln (-s + (M^2 - m^2) + 2\bar{q}\sqrt{s}) \right. \\ &\quad \left. \left. - \ln (s - (M^2 - m^2) + 2\bar{q}\sqrt{s}) \right] \right\} \end{aligned}$$

But rho and K* mesons are quite wide!!

$$T = V + VGT$$

$$\tilde{G}(s) = \frac{1}{N} \int_{(m-2\Gamma_i)^2}^{(m+2\Gamma_i)^2} d\tilde{m}^2 \left(-\frac{1}{\pi} \right) \\ \times \text{Im} \frac{1}{\tilde{m}^2 - m^2 + im\Gamma(\tilde{m})} G(s, \tilde{m}^2, \tilde{M}_B^2),$$

with

$$N = \int_{(m-2\Gamma_i)^2}^{(m+2\Gamma_i)^2} d\tilde{m}^2 \left(-\frac{1}{\pi} \right) \text{Im} \frac{1}{\tilde{m}^2 - m^2 + im\Gamma(\tilde{m})}$$

where, for example, for rho meson --> 2 pions

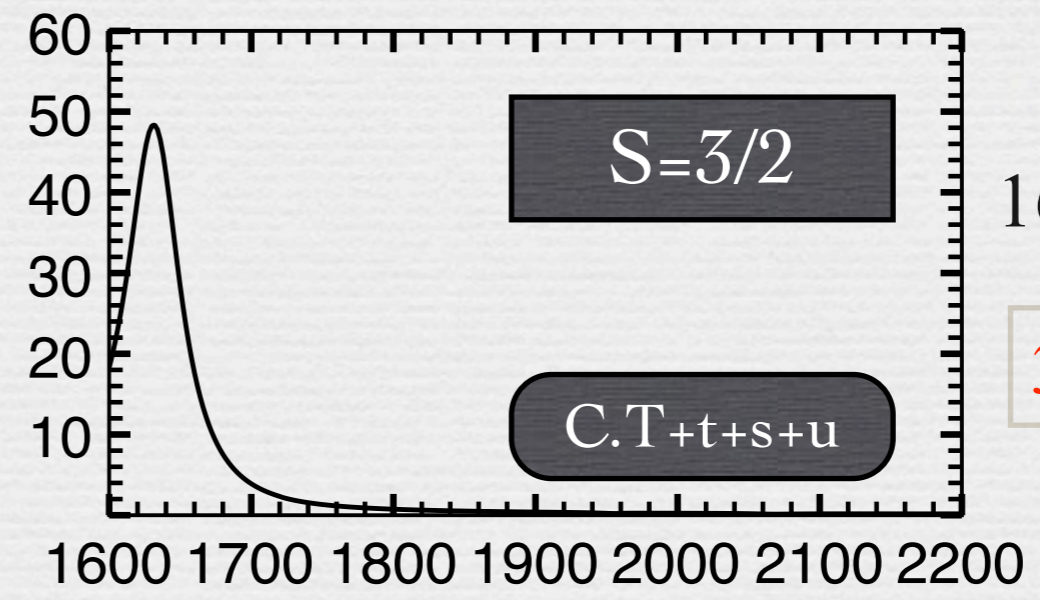
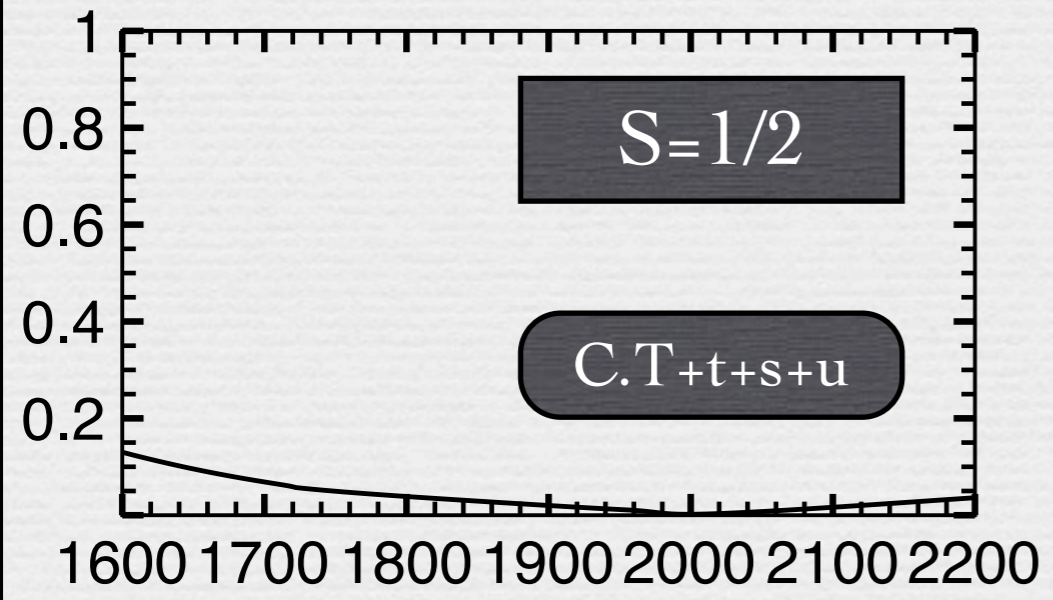
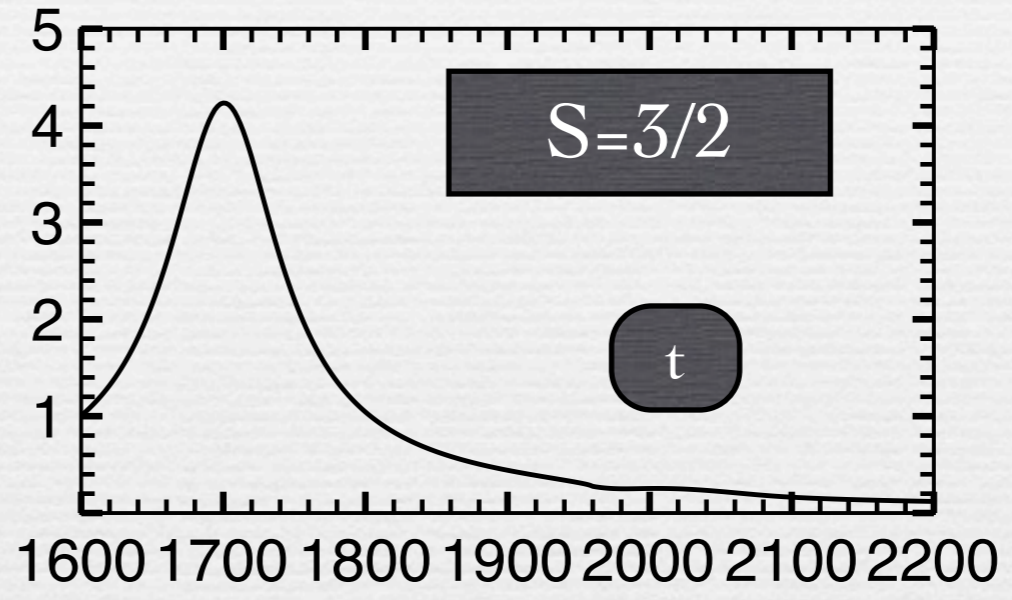
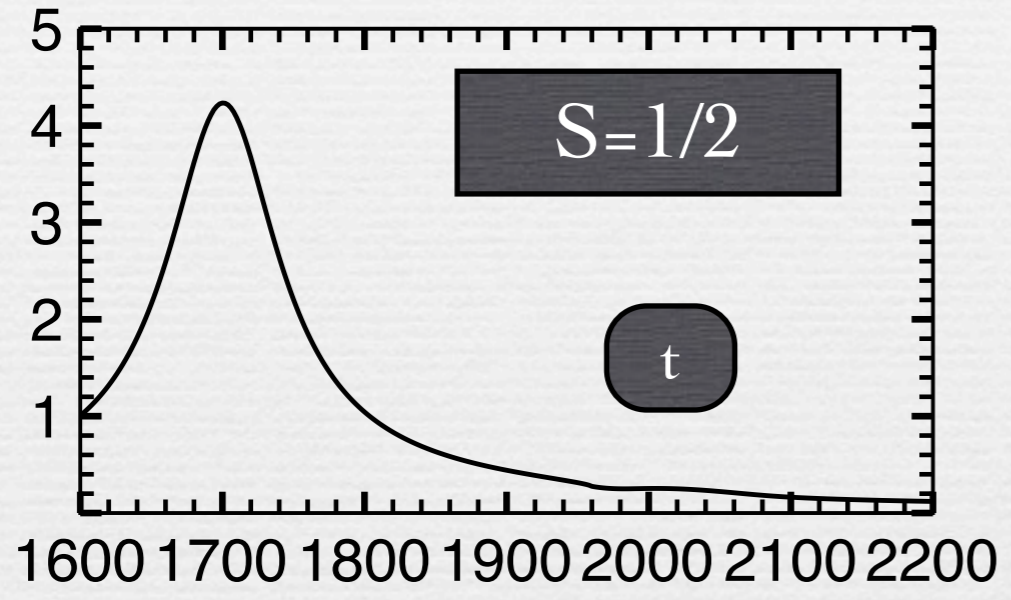
$$\Gamma(\tilde{m}) = \Gamma_\rho \frac{m_\rho^2}{\tilde{m}^2} \left(\frac{\tilde{m}^2 - 4m_\pi^2}{m_\rho^2 - 4m_\pi^2} \right)^{3/2} \theta(\tilde{m} - 2m_\pi).$$

Ref: E. Oset and A. Ramos
(EPJA 44, 445 (2010))

Vector Meson-Baryon interactions: Results

Strangeness 0, Isospin 1/2

ρN squared amplitude (100 MeV^{-2})



Pole:
1641 - i35 MeV

$3/2^- N^*(1700)$

Total energy (MeV)

The latest GWU analysis (ARNDT 2006) finds no evidence for this resonance.

Breit-Wigner mass = 1650 to 1750 (≈ 1700) MeV

Breit-Wigner full width = 50 to 150 (≈ 100) MeV

$P_{\text{beam}} = 1.05 \text{ GeV}/c$

$4\pi\lambda^2 = 14.5 \text{ mb}$

Re(pole position) = 1630 to 1730 (≈ 1680) MeV

$-2\text{Im}(\text{pole position}) = 50 \text{ to } 150 (\approx 100) \text{ MeV}$

$N(1700)$ DECAY MODES

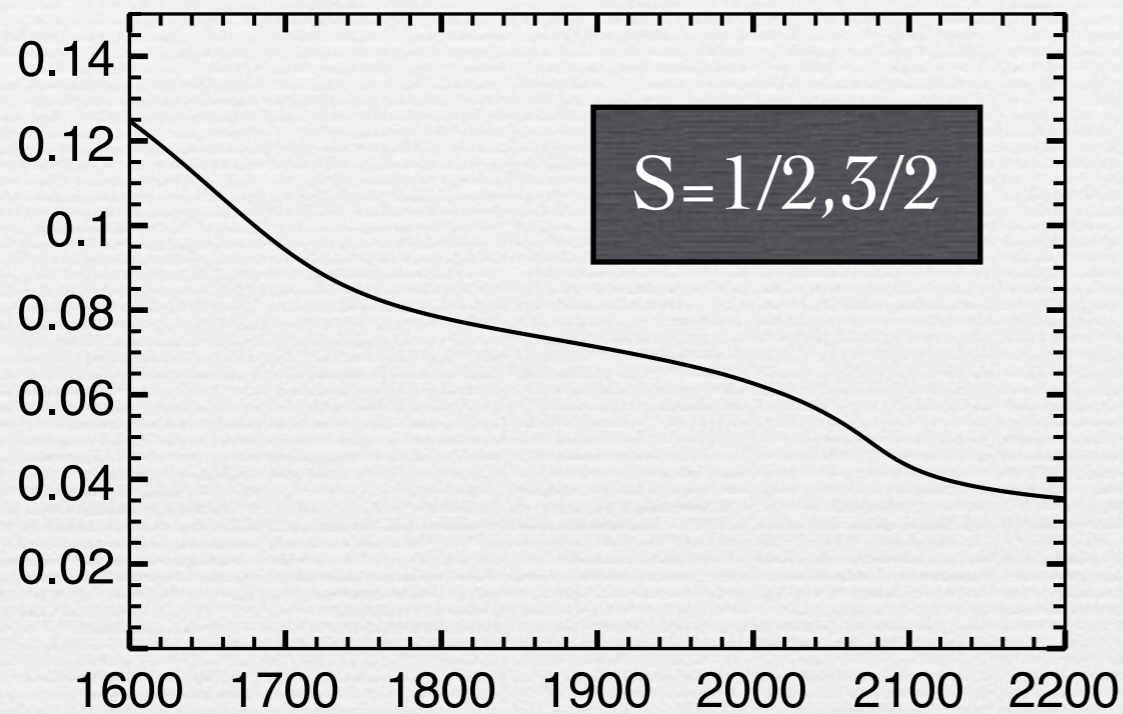
The following branching fractions are our estimates, not fits or averages.

Γ_i	Mode	Fraction (Γ_i / Γ)	$\frac{p}{(\text{MeV}/c)}$
Γ_1	$N \pi$	5–15%	581
Γ_2	$N \eta$	$(0.0 \pm 1.0) \times 10^{-2}$	402
Γ_3	ΛK	$< 3\%$	255
Γ_4	ΣK		109
Γ_5	$N \pi \pi$	85–95%	550
Γ_6	$\Delta \pi$		386
Γ_7	$\Delta(1232) \pi, S\text{-wave}$		386
Γ_8	$\Delta(1232) \pi, D\text{-wave}$		386
Γ_9	$N \rho$	$< 35\%$	-1
Γ_{10}	$N \rho, S=1/2, D\text{-wave}$		-1
Γ_{11}	$N \rho, S=3/2, S\text{-wave}$		-1
Γ_{12}	$N \rho, S=3/2, D\text{-wave}$		-1
Γ_{13}	$N((\pi\pi))_{S\text{-wave}}^{I=0}$		—
Γ_{14}	$p \gamma$	0.01 – 0.05%	591
Γ_{15}	$p \gamma, \text{ helicity}=1/2$	0.0 – 0.024%	591
Γ_{16}	$p \gamma, \text{ helicity}=3/2$	0.002 – 0.026%	591
Γ_{17}	$n \gamma$	0.01 – 0.13%	590
Γ_{18}	$n \gamma, \text{ helicity}=1/2$	0.0 – 0.09%	590
Γ_{19}	$n \gamma, \text{ helicity}=3/2$	0.01 – 0.05%	590

Vector Meson-Baryon interactions: Results

Strangeness 0, Isospin 3/2

- t-channel

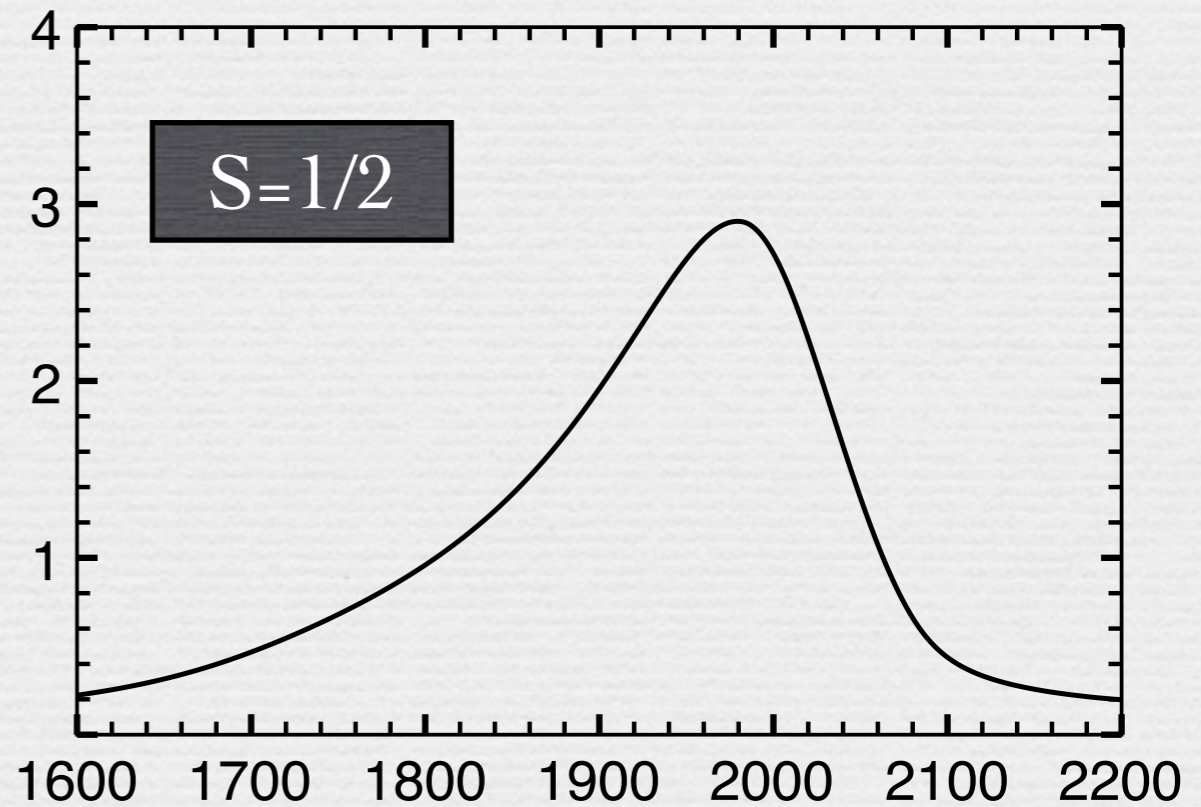


Total energy (MeV)

Pole (s=1/2): 2006 - i112 MeV

1/2- Δ (1900)

- t- + u-channel + contact interaction
spin=1/2



Total energy (MeV)

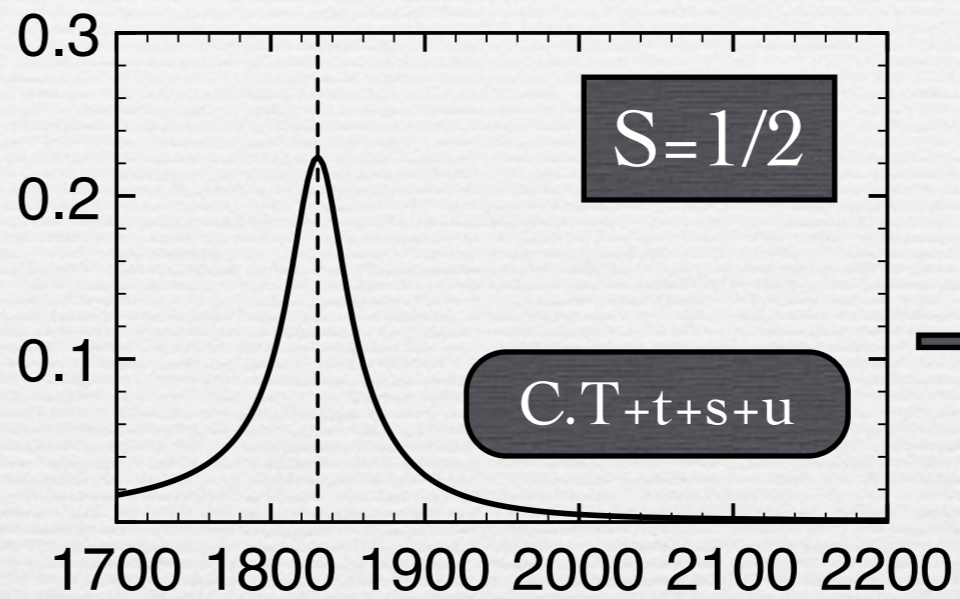
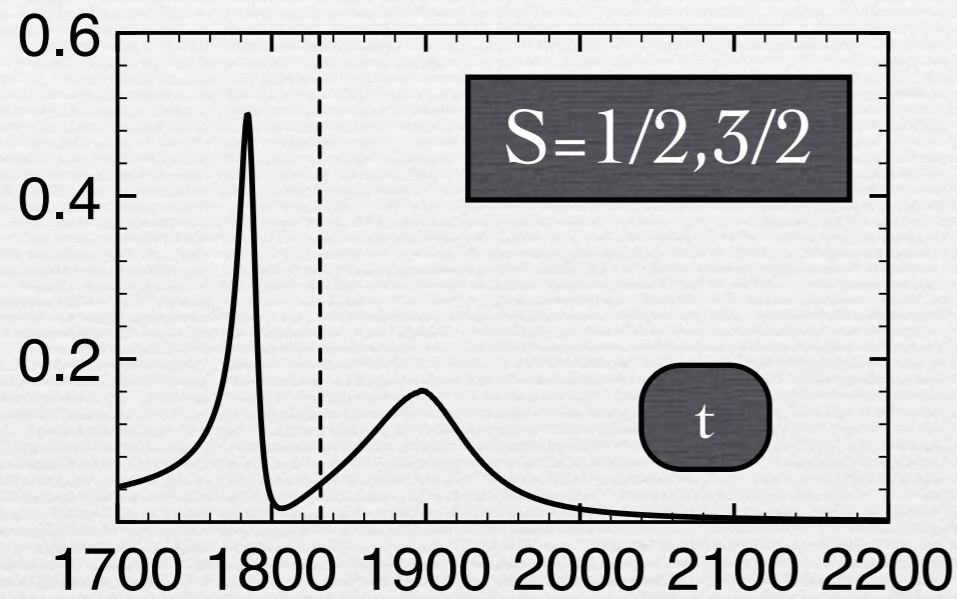
K*Σ squared amplitude (100 MeV⁻²)

Vector Meson-Baryon interactions: Results

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D 84, 094018 (2011); [arXiv:1107.0574 [nucl-th]].)

$S=-1$, Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})

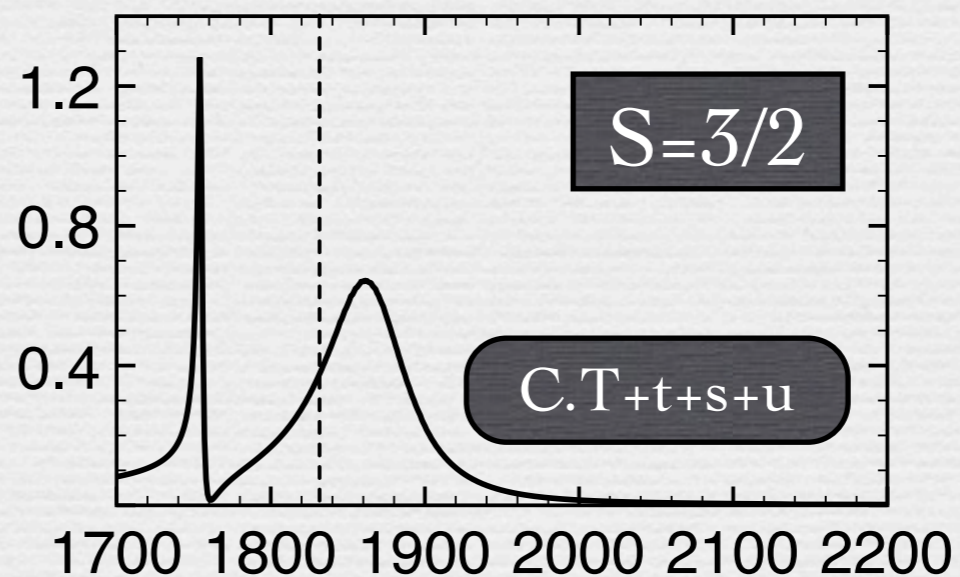


virtual state



Poles:

- (i) 1795 - i 7 MeV
- (ii) 1923 - i 20 MeV



Poles:

- (i) 1760 - i 4 MeV
- (ii) 1893 - i 35 MeV

Total energy (MeV)

Vector Meson-Baryon interactions: Results

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D85 (2012) 114020; arXiv:1203.6711.

Isospin 1

Spin	$\longleftarrow s = 1/2 \longrightarrow$	$\longleftarrow s = 3/2 \longrightarrow$		
	$V = V_t$	$V = V_{t+C.T+s+u}$	$V = V_t$	$V = V_{t+C.T+s+u}$

Vector Meson-Baryon interactions: Results

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D85 (2012) 114020; arXiv:1203.6711.

Isospin 1

Spin	$\longleftarrow s = 1/2 \longrightarrow$		$\longleftarrow s = 3/2 \longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$	$V = V_t$	$V = V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) \longrightarrow	—	1822 - i 15	—	1947 - i 17
Channels \downarrow	Couplings (g^i) of the poles to the different channels			
\bar{K}^*N (1831)	—	2.3 - i 0.0	—	-0.3 + i 0.2
$\rho\Lambda$ (1886)	—	-0.6 + i 0.0	—	-0.5 + i 0.2
$\rho\Sigma$ (1963)	—	-1.9 + i 0.0	—	2.7 + i 0.2
$\omega\Sigma$ (1975)	—	-1.0 + i 0.0	—	0.3 + i 0.1
$K^*\Xi$ (2210)	—	0.1 - i 0.0	—	1.9 + i 0.2
$\phi\Sigma$ (2213)	—	1.6 - i 0.0	—	0.2 - i 0.0

Vector Meson-Baryon interactions: Results

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D85 (2012) 114020; arXiv:1203.6711.

Isospin 1

Σ (1940) D_{13}

Spin	$\longleftarrow s = 1/2 \longrightarrow$		$\longleftarrow s = 3/2 \longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$	$V = V_t$	$V = V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) \longrightarrow	—	1822 - i 15	—	1947 - i 17
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Coupling Pseudoscalar and Vector Mesons to Baryon resonances

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, *PHYSICAL REVIEW D* **84**, 094018 (2011); [arXiv:1107.0574 [nucl-th]].)

- Some resonances are well known as dynamically generated ones in PB systems: eg., $\Lambda(1405)$, $\Lambda(1670)$.

Refs: (i) R. H. Dalitz and S. F. Tuan, Phys. Rev. Lett. 2, 425 (1959).

(ii) E. Oset and A. Ramos, Nucl. Phys. A635, 99–120 (1998).

(iii) D. Jido, T. Sekihara, Y. Ikeda, T. Hyodo, Y. Kanada-En'yo, E. Oset, Nucl. Phys. A835, 59-66 (2010).

(iv) D. Jido, J. A. Oller, E. Oset, A. Ramos and U. G. Meissner, Nucl. Phys. A 725, 181 (2003) [nucl-th/0303062]

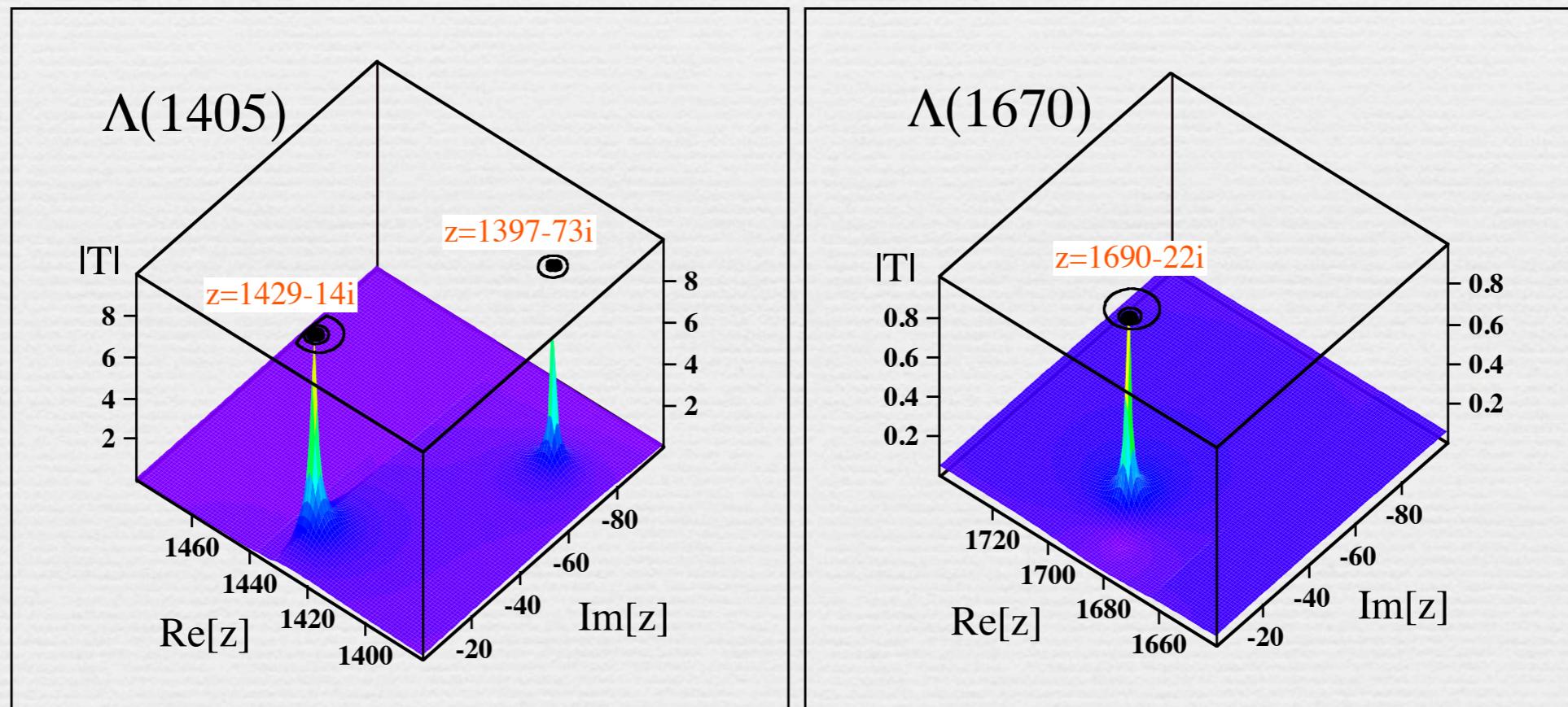
(v) Y. Ikeda, T. Hyodo and W. Weise, Phys. Lett. B 706, 63 (2011) [arXiv:1109.3005 [nucl-th]].

(vi) T. Hyodo and D. Jido, Prog. Part. Nucl. Phys. 67, 55 (2012) [arXiv:1104.4474 [nucl-th]].

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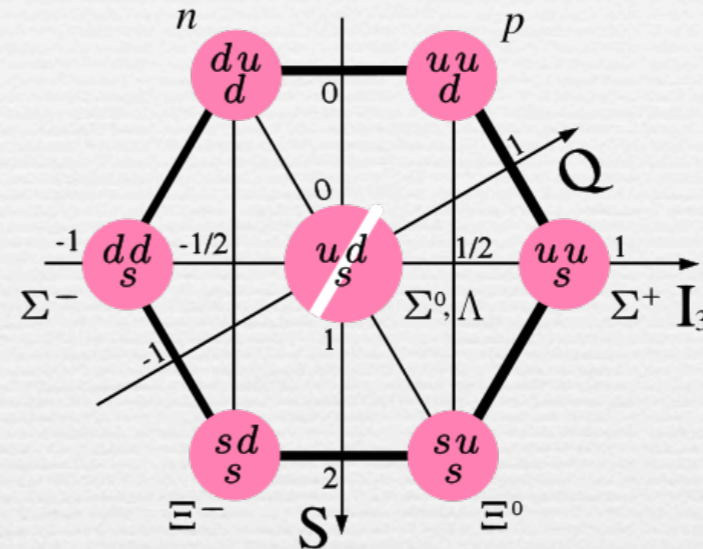
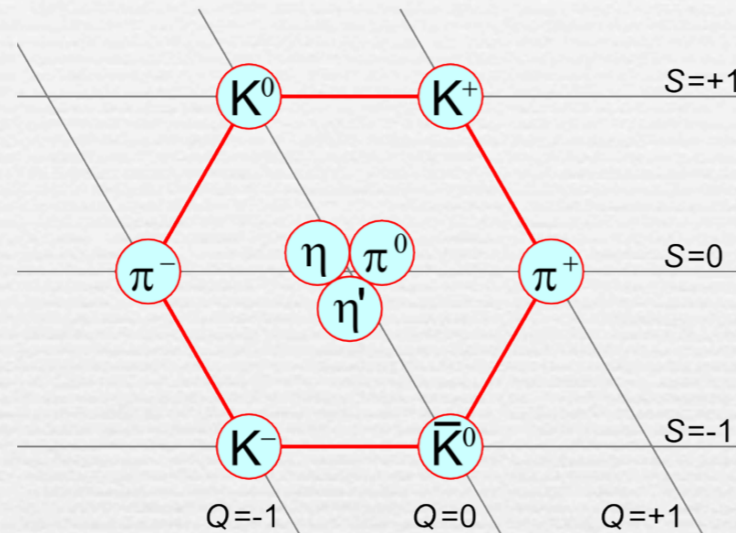
What is known about $\Lambda(1405)$, $\Lambda(1670)$?



Ref: Jido,Oller,Oset,Ramos, Meissner, NPA 725 (203) 181.

Coupling Pseudoscalar and Vector Mesons to Baryon resonances

Channels:



PB channels	Mass (MeV)	VB channels	Mass (MeV)
$\bar{K}N$	1435	\bar{K}^*N	1831
$\pi\Sigma$	1330	$\rho\Sigma$	1963
$\eta\Lambda$	1663	$\omega\Lambda$	1898
$K\Xi$	1814	$\Phi\Lambda$	2136
		$K^*\Xi$	2210

- Can these VB channel bring any new information regarding the properties of the $\Lambda(1405)$, $\Lambda(1670)$?

Coupling Pseudoscalar and Vector Mesons to Baryon resonances

From basics: QM two level problem



And the higher energy level
could get wider.

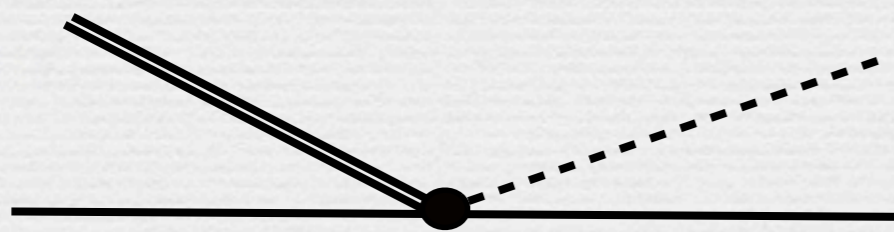
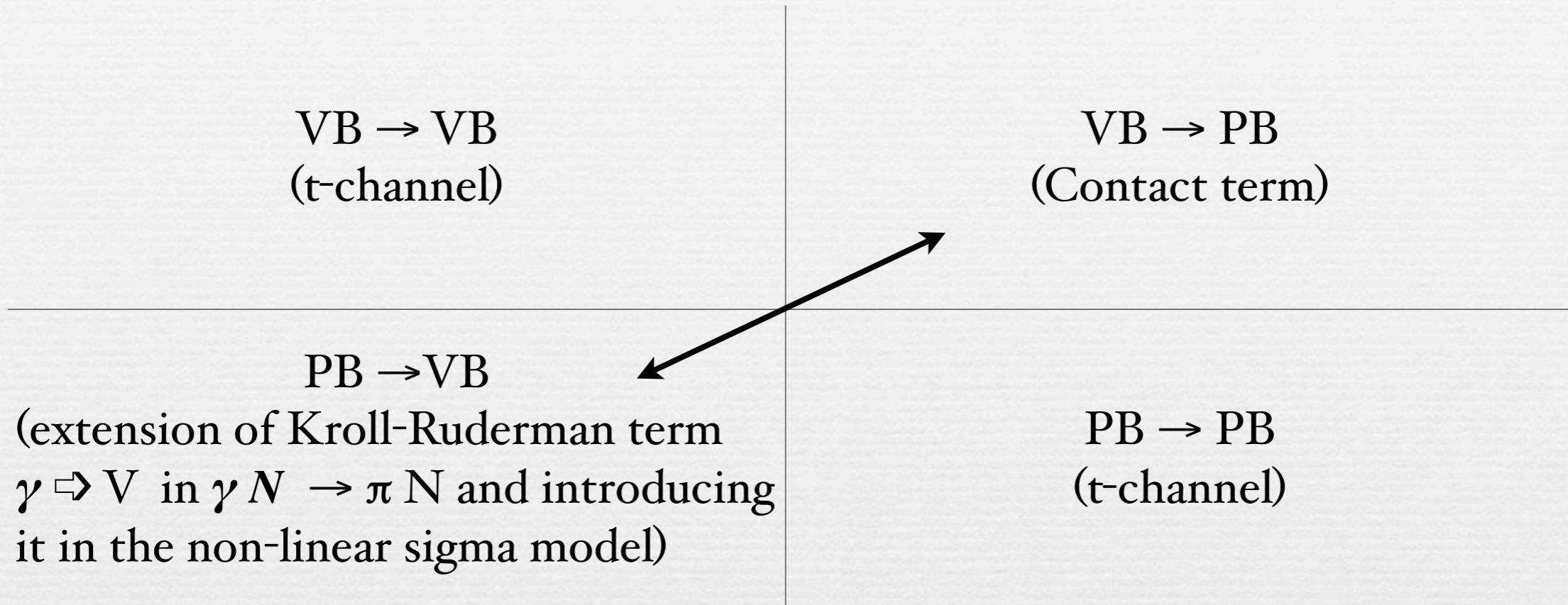
Coupling Pseudoscalar and Vector Mesons to Baryon resonances

From basics: QM two level problem



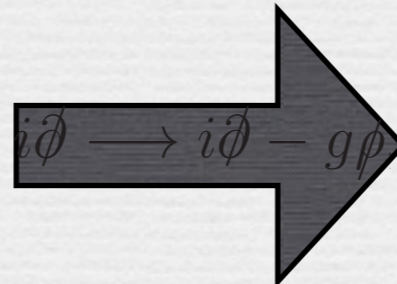
And the higher energy level
could get wider.

Coupling Pseudoscalar and Vector Mesons to Baryon resonances



INTRODUCE THE V-MESON
AS THE GAUGE BOSON OF
THE HLS

$$\mathcal{L}_{\pi N} = \bar{\psi} [i\gamma^\mu \partial_\mu - g_{\pi NN} (\sigma + i\vec{\tau} \cdot \vec{\pi} \gamma_5)] \psi$$



$$\mathcal{L}_{\pi N \rho N} = -i \frac{gg_A}{2f_\pi} \bar{N} [\pi, \rho^\mu] \gamma_\mu \gamma_5 N$$

SU(3)

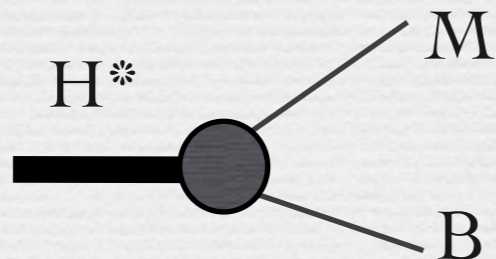
$$\mathcal{L}_{PBVB} = \frac{-ig}{2f_\pi} (F \langle \bar{B} \gamma_\mu \gamma_5 [[P, V_\mu], B] \rangle + D \langle \bar{B} \gamma_\mu \gamma_5 \{[P, V_\mu], B\} \rangle)$$

$= 6$

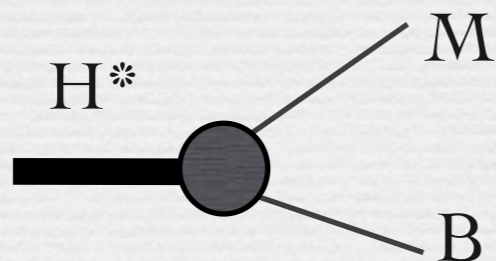
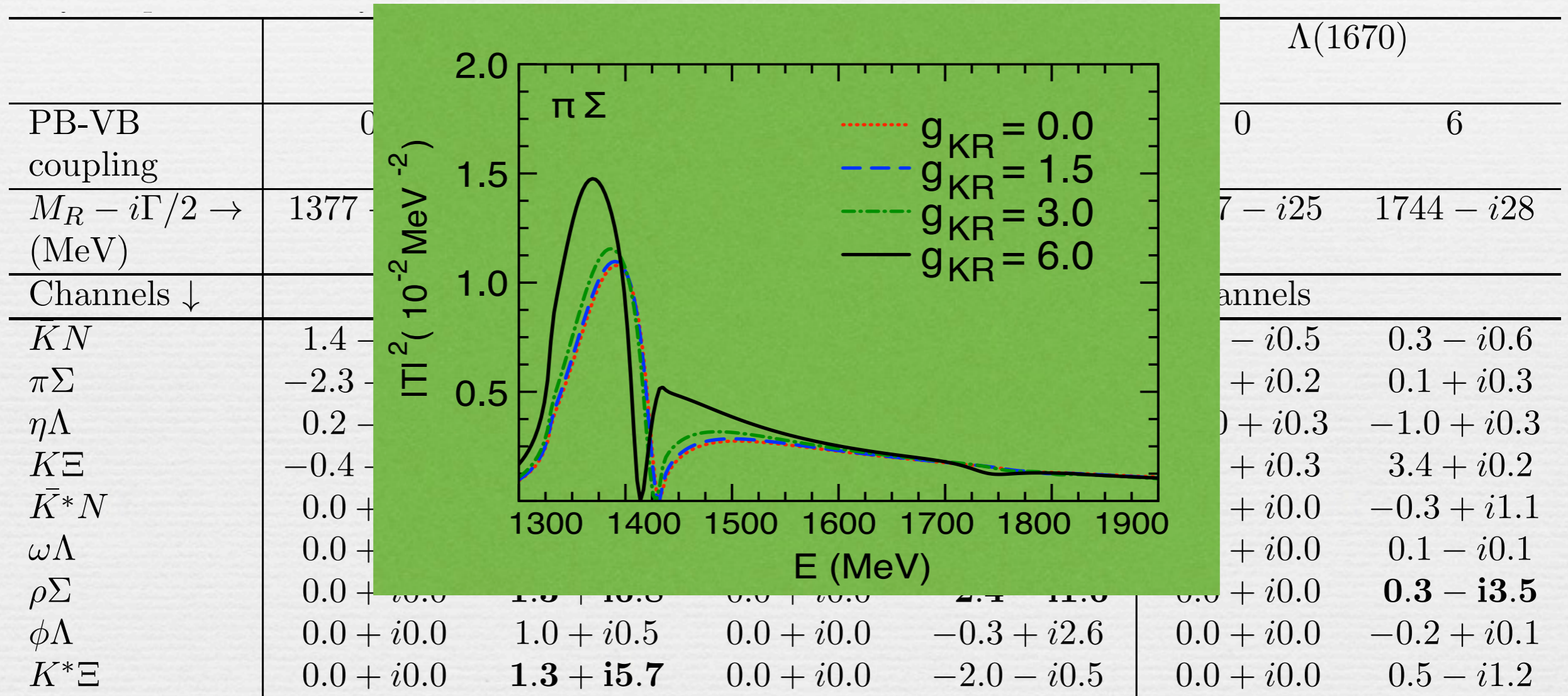
F = 0.46, D = 0.8

PB-VB coupled systems: Results on low-lying resonances

	$\Lambda(1405)$				$\Lambda(1670)$	
	Pole1		Pole2			
PB-VB coupling	0	6	0	6	0	6
$M_R - i\Gamma/2 \rightarrow$ (MeV)	1377 - i63	1357 - i53	1430 - i15	1412 - i11	1767 - i25	1744 - i28
Channels ↓	Couplings (g^i) of the poles to the different channels					
KN	1.4 - i1.6	1.1 - i1.4	2.4 + i1.1	2.8 + i0.5	0.2 - i0.5	0.3 - i0.6
$\pi\Sigma$	-2.3 + i1.4	-2.2 + i1.4	-0.2 - i1.4	-0.2 - i1.1	0.1 + i0.2	0.1 + i0.3
$\eta\Lambda$	0.2 - i0.7	0.1 - i0.6	1.3 + i0.3	1.5 + i0.1	-1.0 + i0.3	-1.0 + i0.3
$K\Xi$	-0.4 + i0.4	-0.6 + i0.4	0.0 - i0.3	0.0 - i0.3	3.2 + i0.3	3.4 + i0.2
\bar{K}^*N	0.0 + i0.0	-1.7 + i0.7	0.0 + i0.0	-0.1 - i5.3	0.0 + i0.0	-0.3 + i1.1
$\omega\Lambda$	0.0 + i0.0	-0.7 - i0.3	0.0 + i0.0	0.2 - i1.8	0.0 + i0.0	0.1 - i0.1
$\rho\Sigma$	0.0 + i0.0	1.3 + i6.8	0.0 + i0.0	-2.4 - i1.6	0.0 + i0.0	0.3 - i3.5
$\phi\Lambda$	0.0 + i0.0	1.0 + i0.5	0.0 + i0.0	-0.3 + i2.6	0.0 + i0.0	-0.2 + i0.1
$K^*\Xi$	0.0 + i0.0	1.3 + i5.7	0.0 + i0.0	-2.0 - i0.5	0.0 + i0.0	0.5 - i1.2



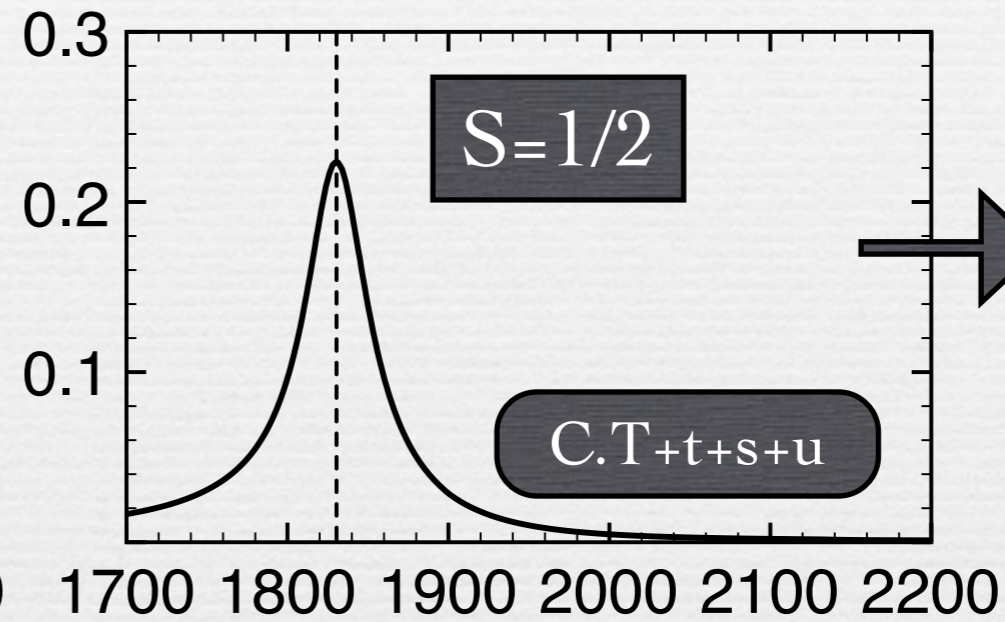
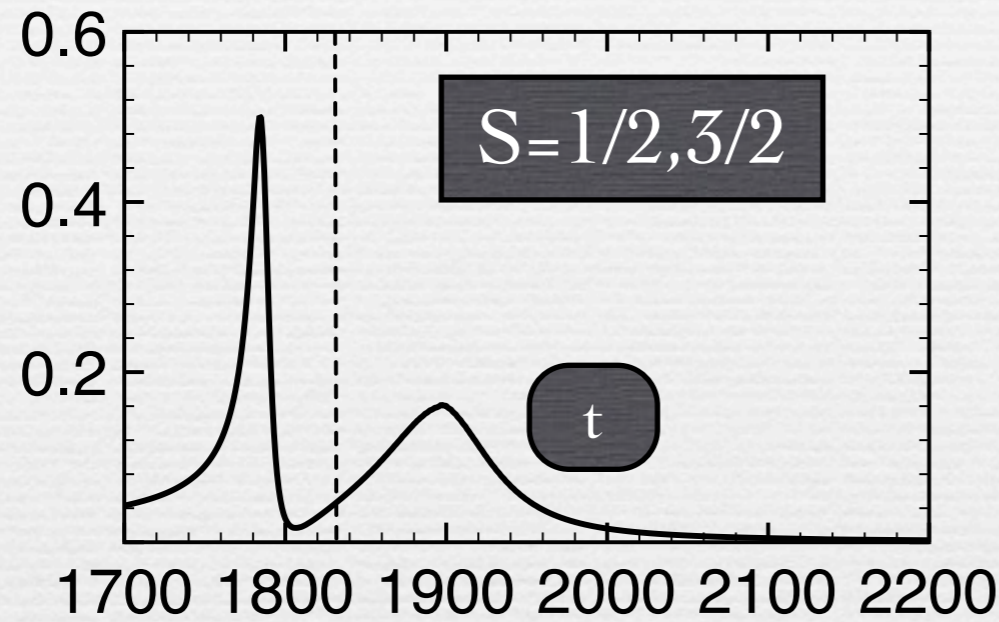
PB-VB coupled systems: Results on low-lying resonances



PB-VB coupled systems: Results

Isospin 0

$\rho\Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

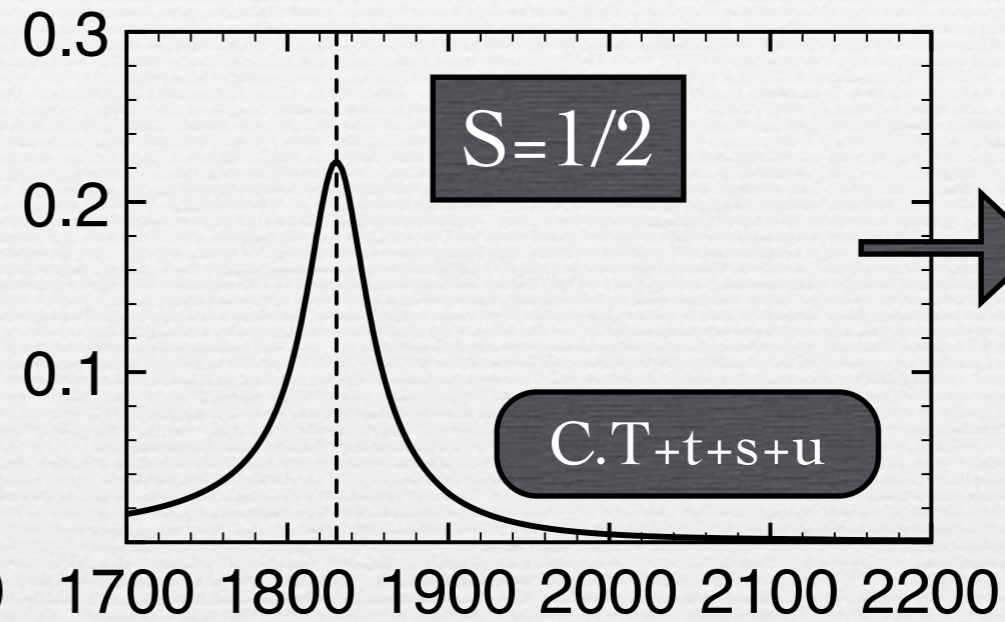
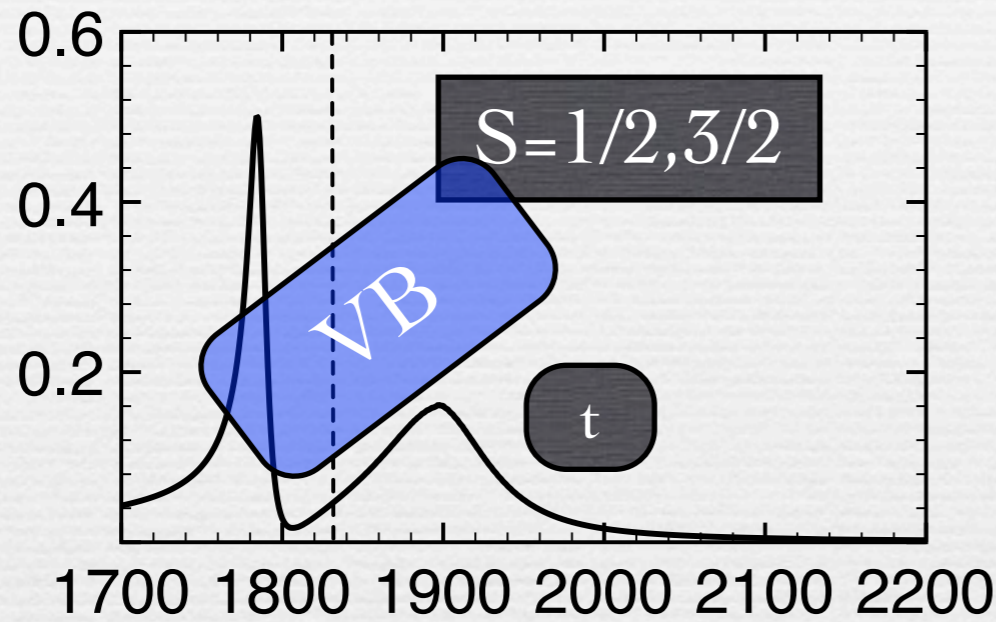
- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV

Total energy (MeV)

PB-VB coupled systems: Results

Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2} MeV^{-2})



Poles:

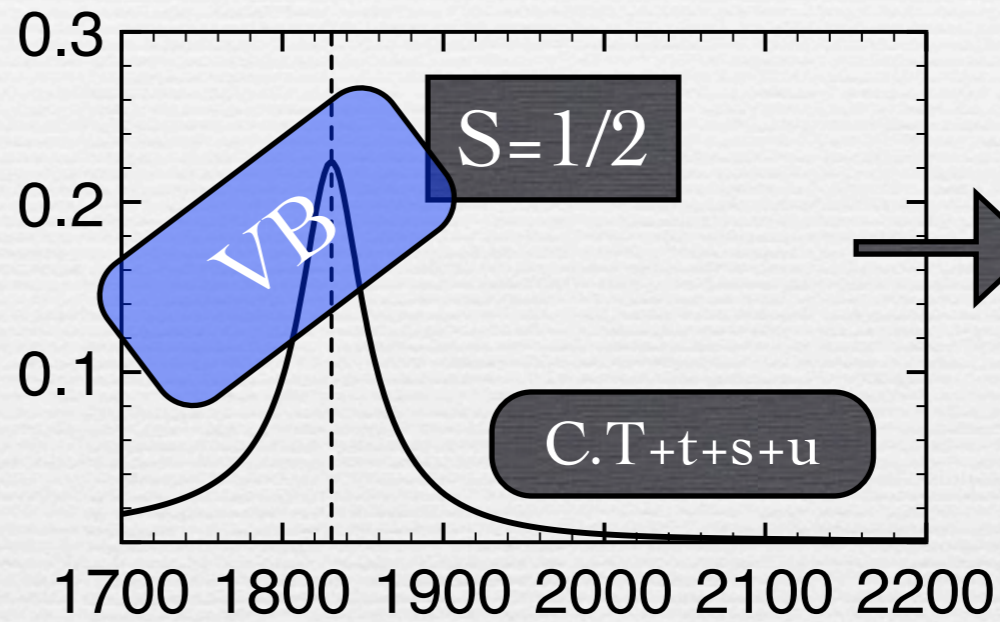
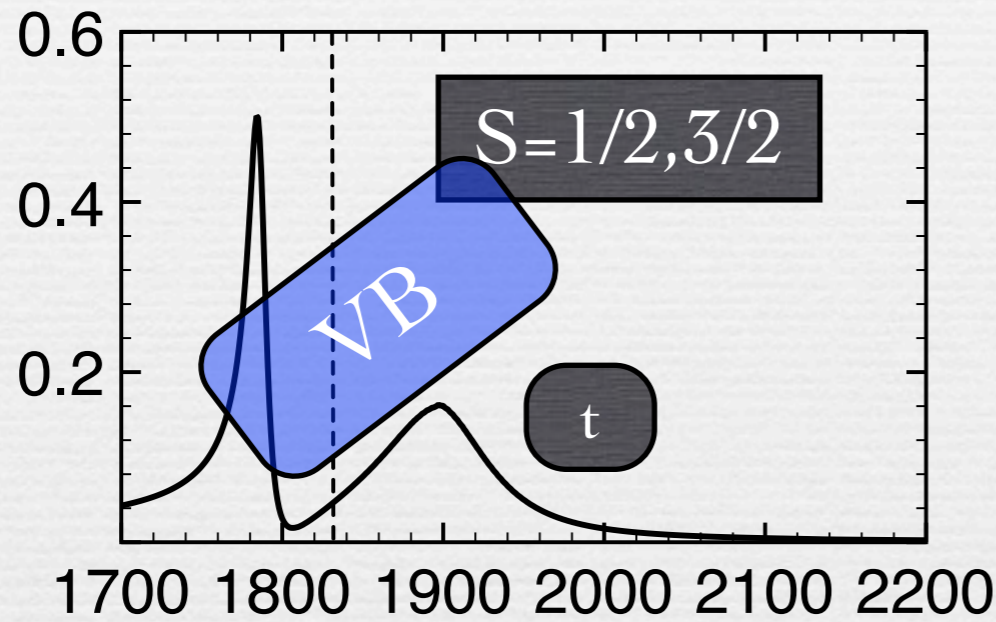
- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV

Total energy (MeV)

PB-VB coupled systems: Results

Isospin 0

$\rho\Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

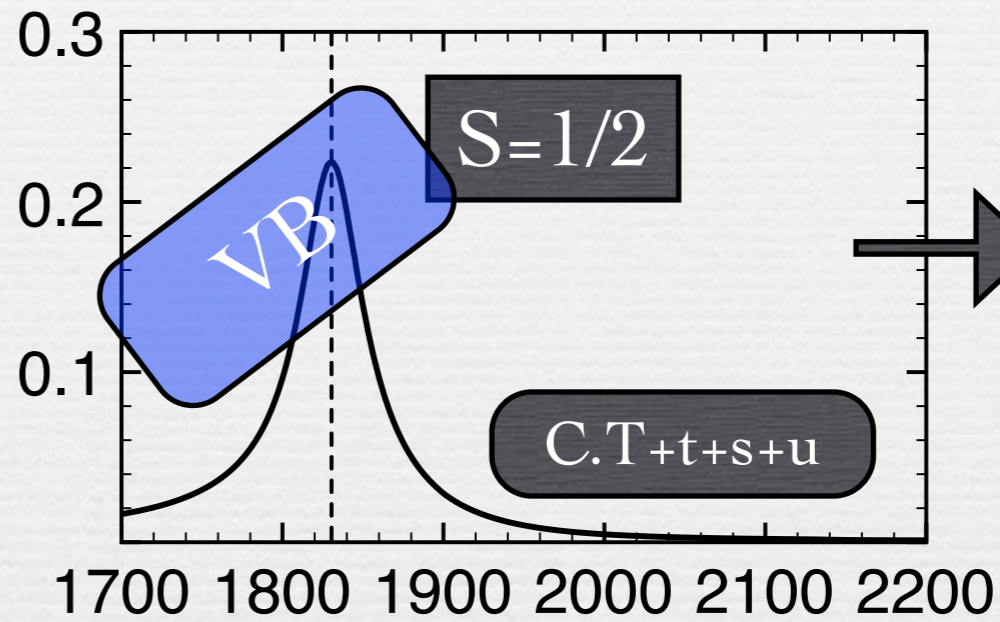
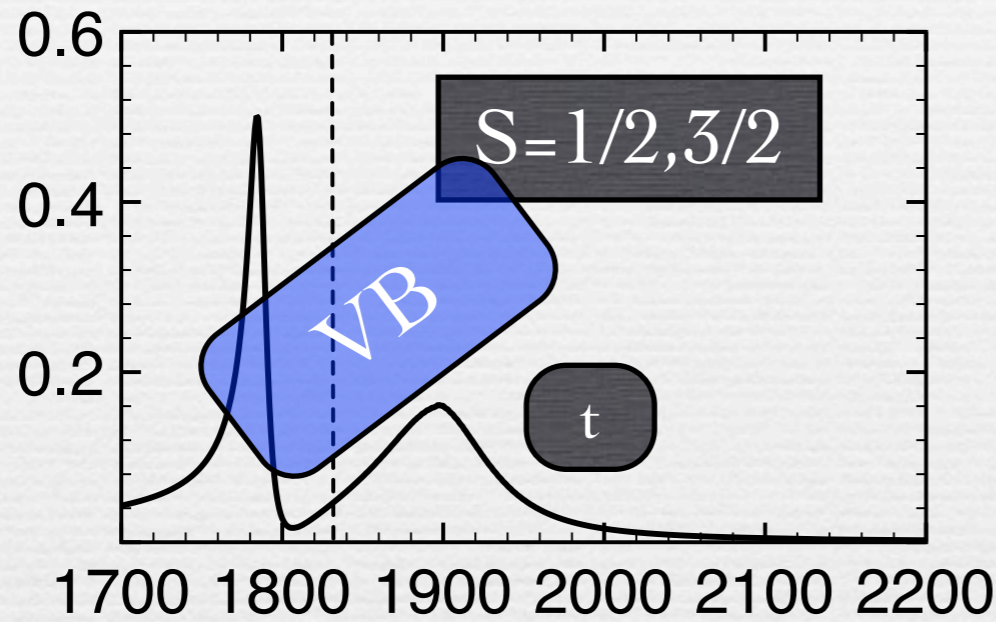
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Total energy (MeV)

PB-VB coupled systems: Results

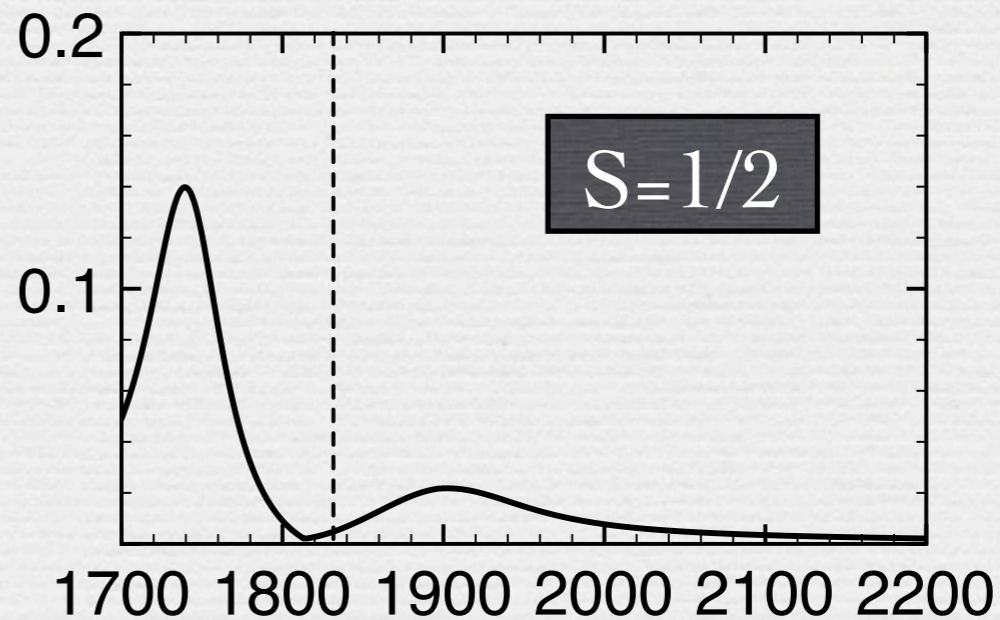
Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV

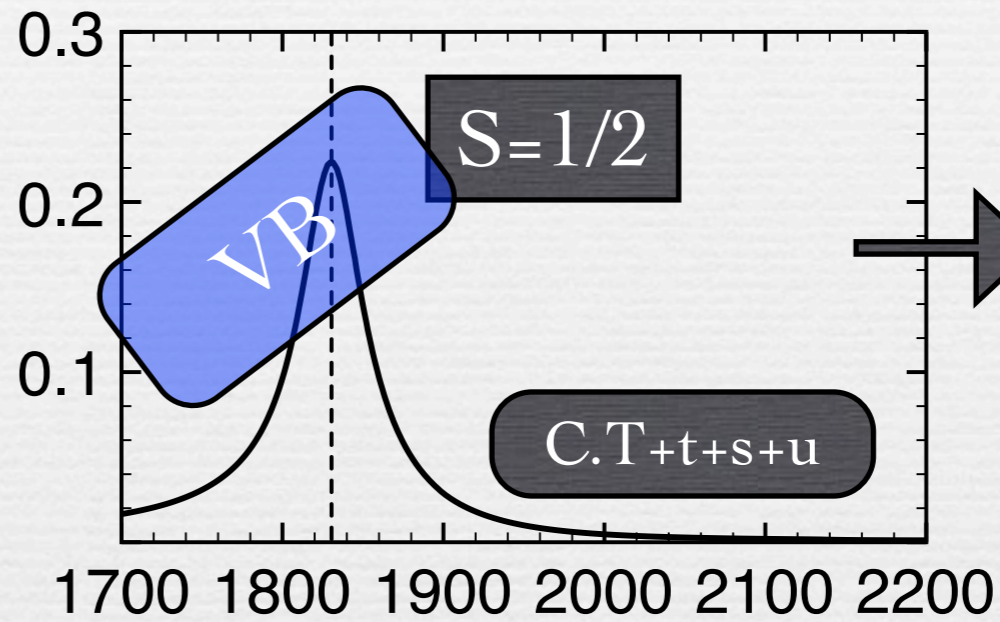
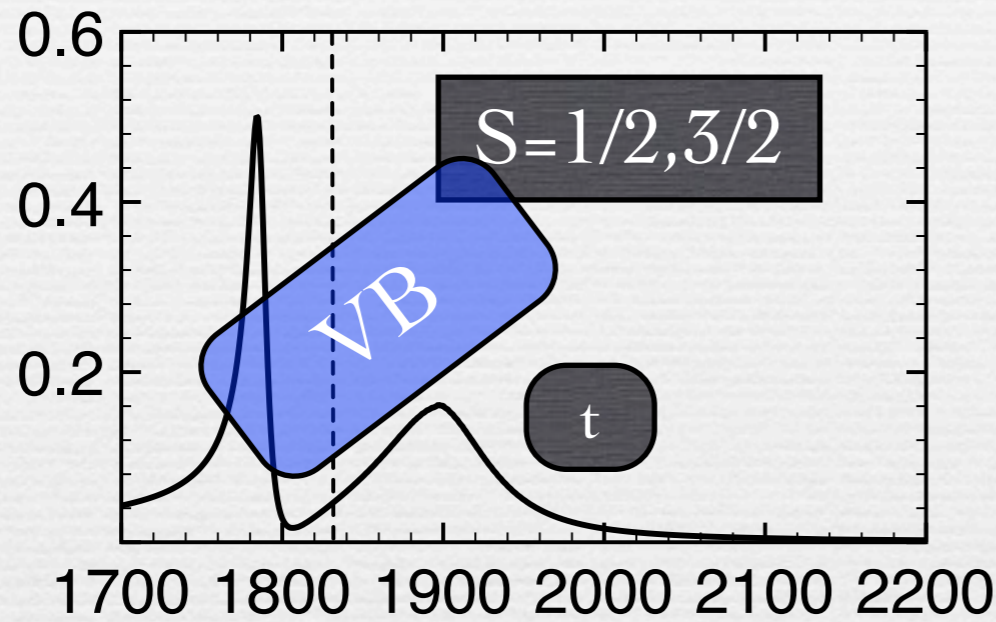


Total energy (MeV)

PB-VB coupled systems: Results

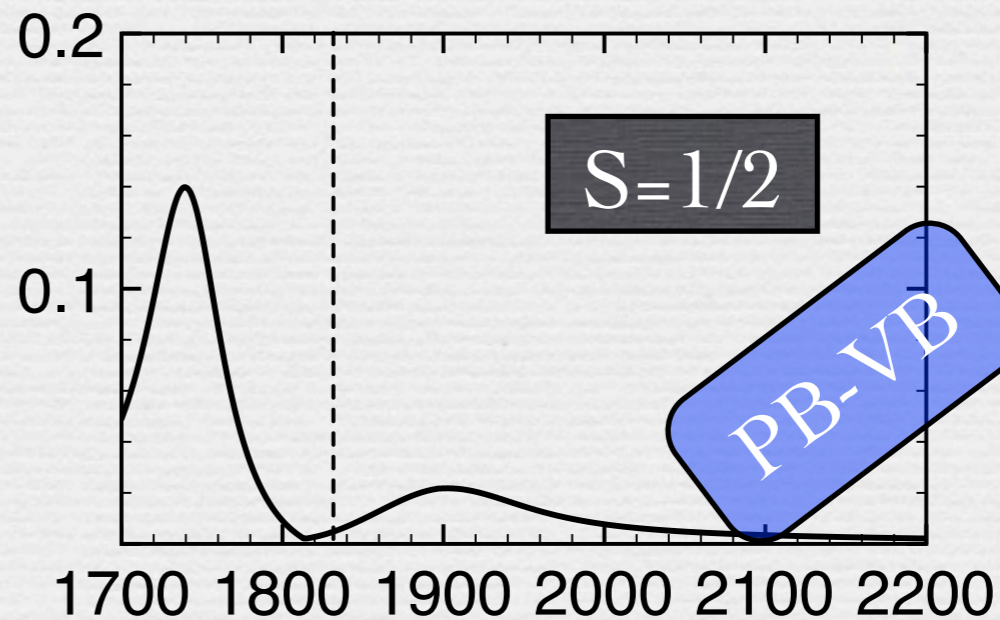
Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV

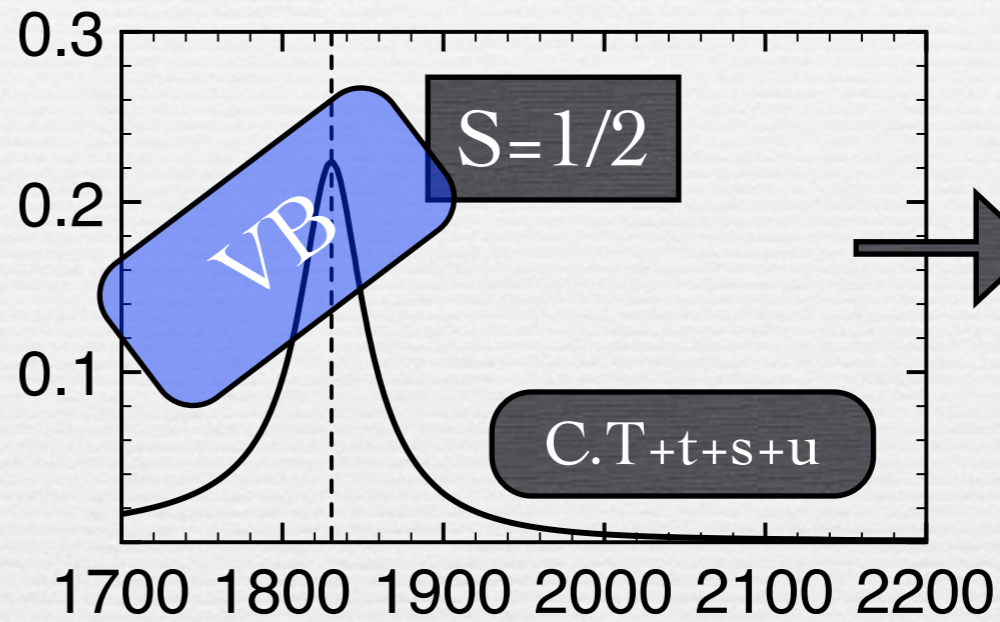
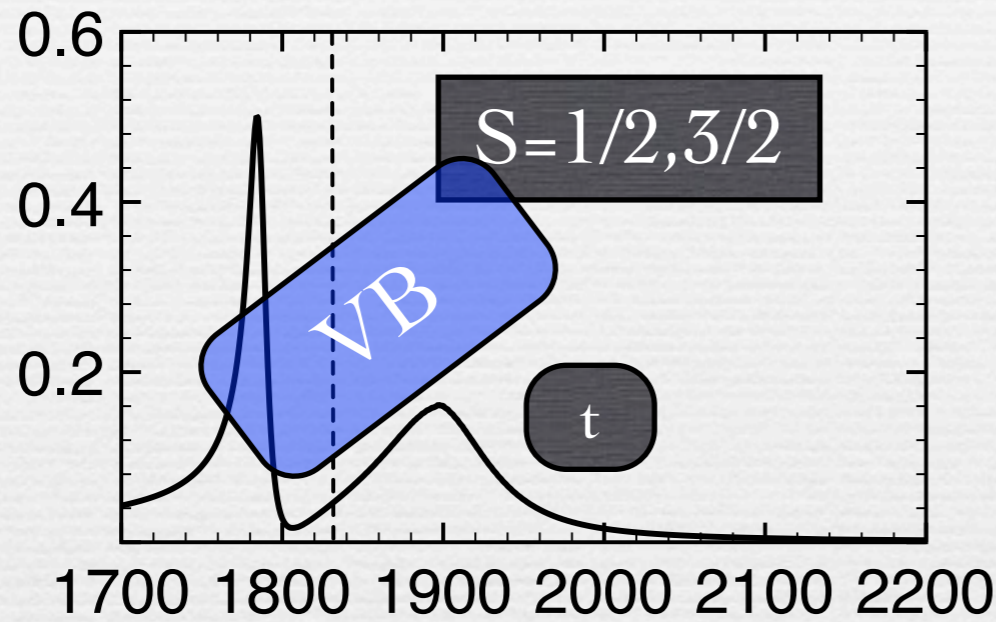


Total energy (MeV)

PB-VB coupled systems: Results

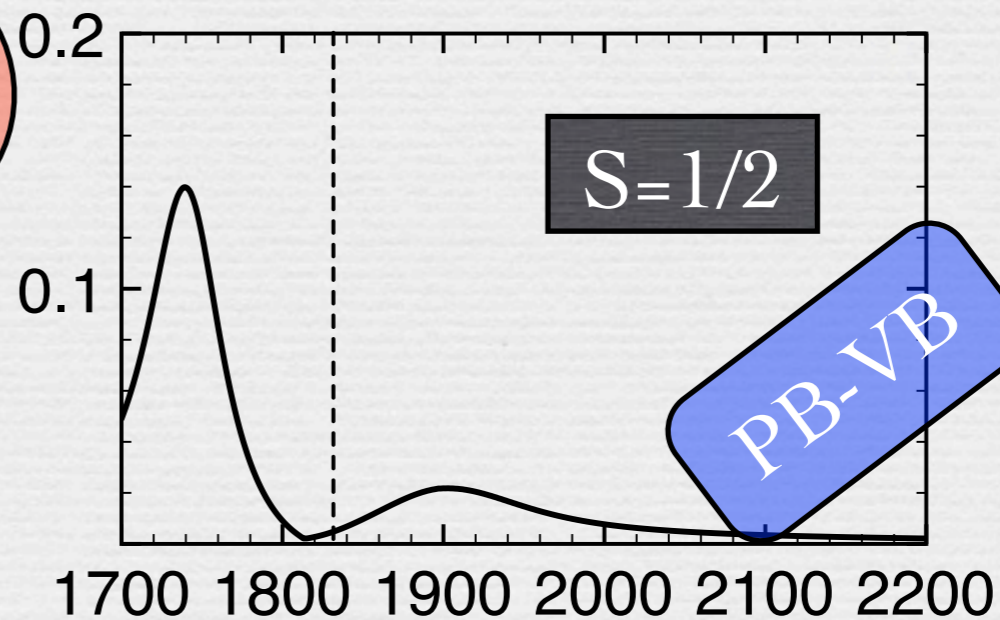
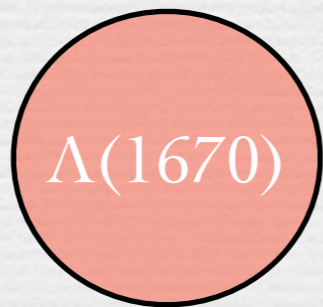
Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

- (i) $1795 - i 20 \text{ MeV}$
- (ii) $1923 - i 40 \text{ MeV}$

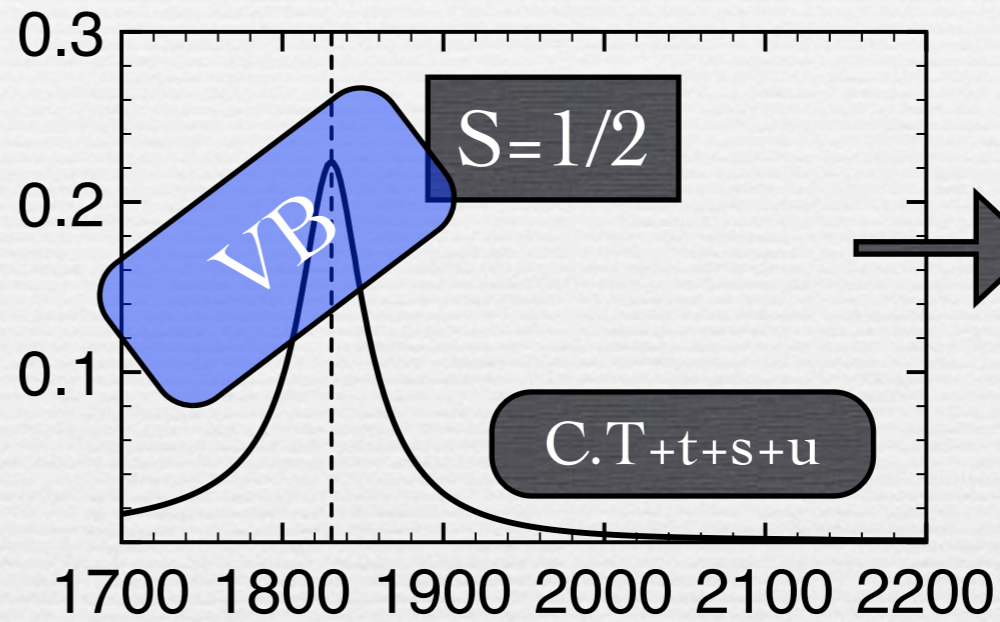
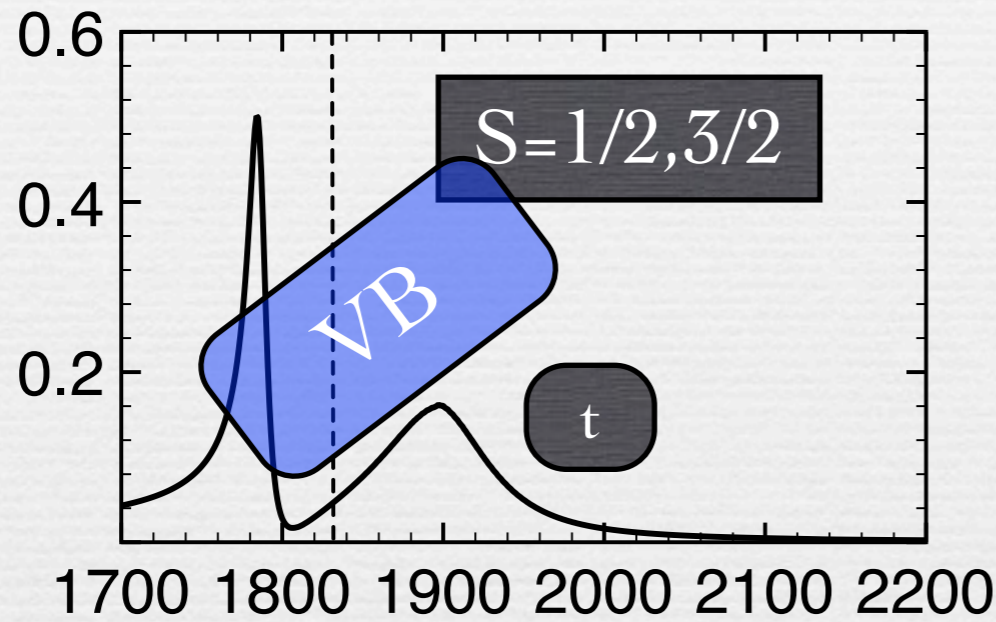


Total energy (MeV)

PB-VB coupled systems: Results

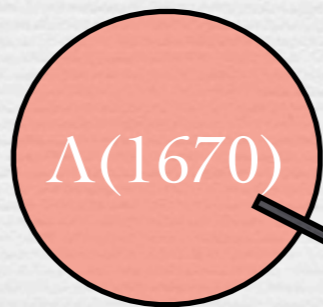
Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})

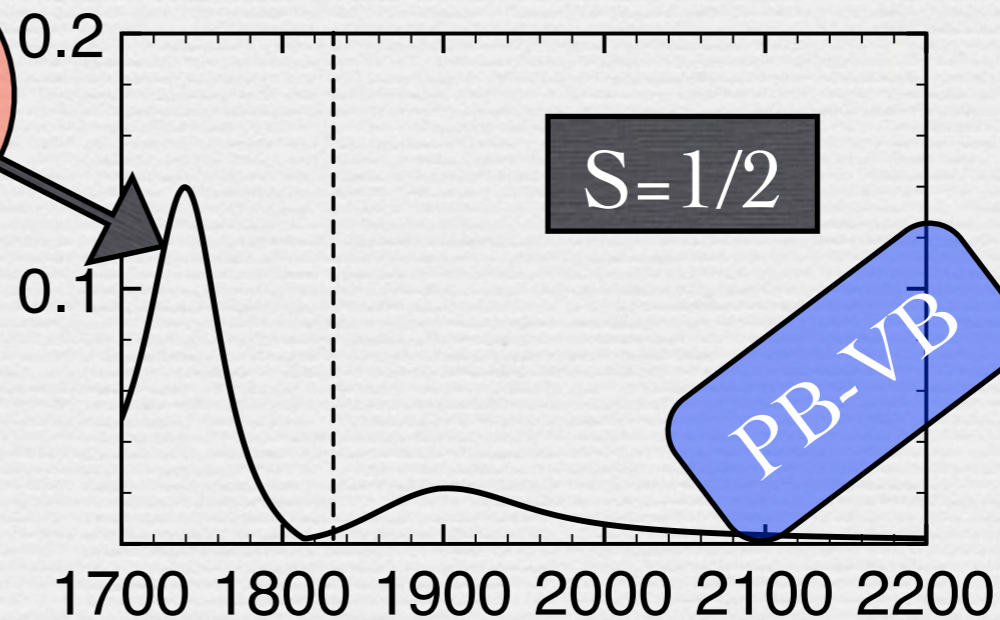


Poles:

- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV



$\Lambda(1670)$

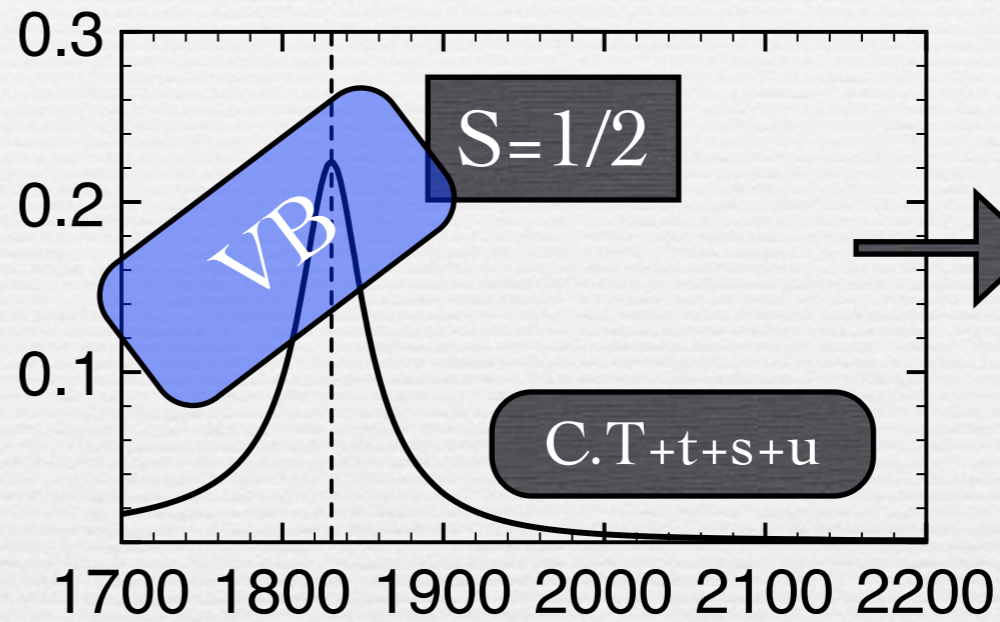
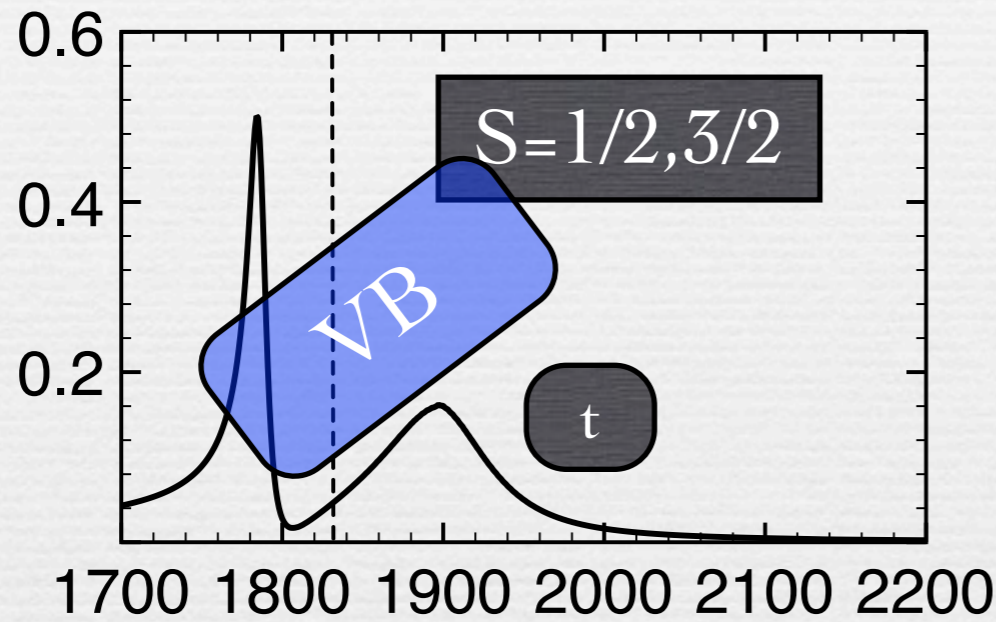


Total energy (MeV)

PB-VB coupled systems: Results

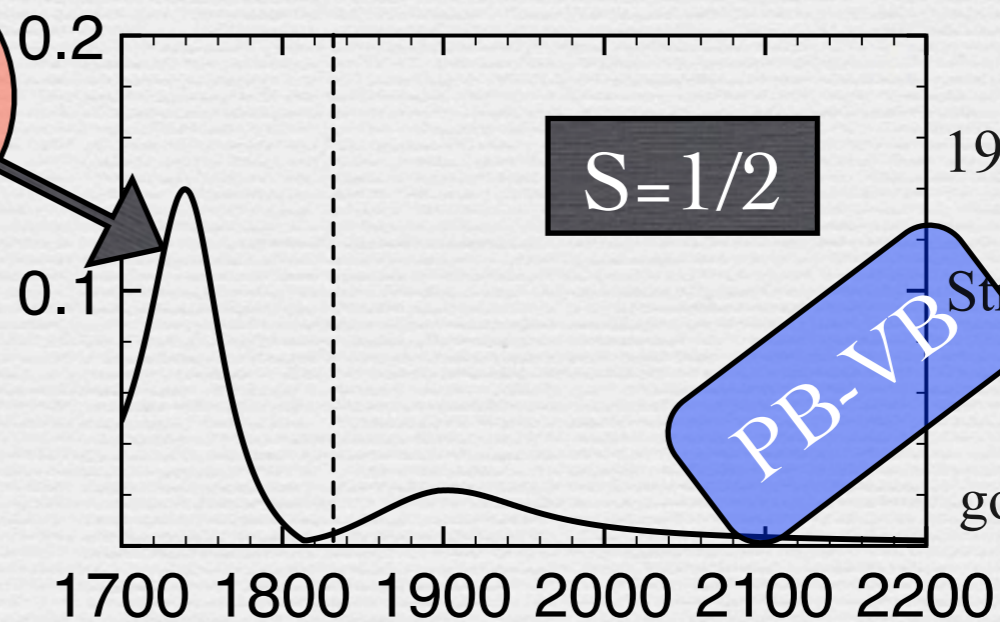
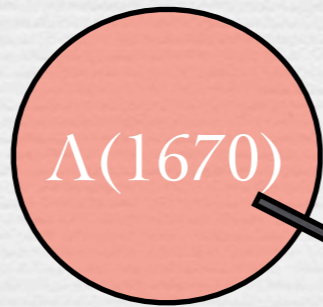
Isospin 0

$\rho \Sigma$ squared amplitude (10^{-2}MeV^{-2})



Poles:

- (i) 1795 - i 20 MeV
- (ii) 1923 - i 40 MeV



1929 - i 48 MeV
 $\Lambda(2000)$
 Strongly coupled to anti- K^*N
 ↓
 good agreement with PDG

Total energy (MeV)

Vector Meson-Baryon interactions: Results

Isospin 1

Spin	$\longleftrightarrow s = 1/2 \longrightarrow$		$\longleftrightarrow s = 3/2 \longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$	$V = V_t$	$V = V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) \longrightarrow	—	1822 - i 15	—	1947 - i 17
Channels \downarrow	Couplings (g^i) of the poles to the different channels			
\bar{K}^*N (1831)	—	2.3 - i 0.0	—	-0.3 + i 0.2
$\rho\Lambda$ (1886)	—	-0.6 + i 0.0	—	-0.5 + i 0.2
$\rho\Sigma$ (1963)	—	-1.9 + i 0.0	—	2.7 + i 0.2
$\omega\Sigma$ (1975)	—	-1.0 + i 0.0	—	0.3 + i 0.1
$K^*\Xi$ (2210)	—	0.1 - i 0.0	—	1.9 + i 0.2
$\phi\Sigma$ (2213)	—	1.6 - i 0.0	—	0.2 - i 0.0

(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D85 (2012) 114020; arXiv:1203.6711.

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(i) 1822 - i16

(ii) 1873 - i88

(iii) 1936 - i132

Vector Meson-Baryon interactions: Results

Isospin 1

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(i) 1822 - i 16
 Real axis: 1800, $\Gamma = 32$
 Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i 88

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Vector Meson-Baryon interactions: Results

Isospin 1

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(i) 1822 - i16 Σ (1750) $1/2^-$
 Real axis: 1800, $\Gamma = 32$
 Strongly coupled to: $\eta\Sigma$

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Vector Meson-Baryon interactions: Results

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 Real axis: 1800, $\Gamma = 32$
 Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i88

Σ (2000) $1/2^-$

(iii) 1936 - i132

Vector Meson-Baryon interactions: Results

Isospin 1

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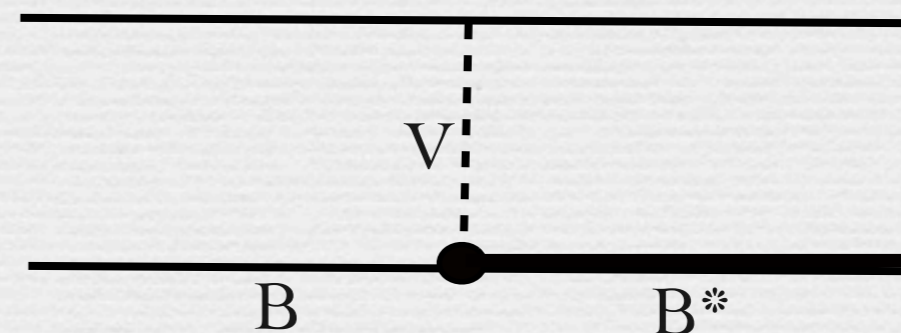
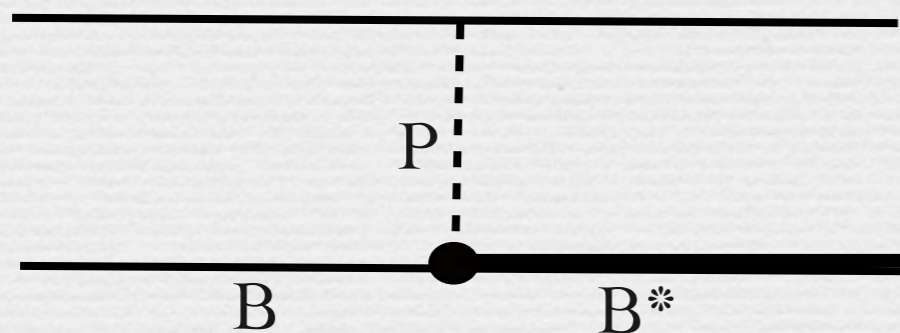
(i) 1822 - i 16 Σ (1750) $1/2^-$
 Real axis: 1800, $\Gamma = 32$
 Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i 88
 Real axis: 1 peak $\rightarrow \Sigma$ (2000) $1/2^-$

(iii) 1936 - i 132

Summary:

- The tree-level contributions from the contact term obtained from hidden gauge Lagrangian and from the s- and u- channel exchange diagrams are not negligible.
- The resulting vector meson-baryon interaction is very spin-isospin dependent. This is something which should be expected when two particles with spin interact.
- Many low-lying resonances like $\Lambda(1405)$ couple strongly to $VB \Rightarrow$ very useful information, for instance, to study photoproduction of $\Lambda(1405)^\dagger$.



[†]S. -i. Nam, J. -H. Park, A. Hosaka, H. -C. Kim, arXiv:0806.4029 [hep-ph].

Summary:

- ❧ Some resonance poles disappear (become unphysical).
- ❧ Also new poles can appear.
- ❧ It is important to use these amplitudes to study relevant reactions (which have been studied experimentally).