Excited baryons coupled to vector and pseudoscalar mesons

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Escuela Andina:
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Introduction: Hadrons

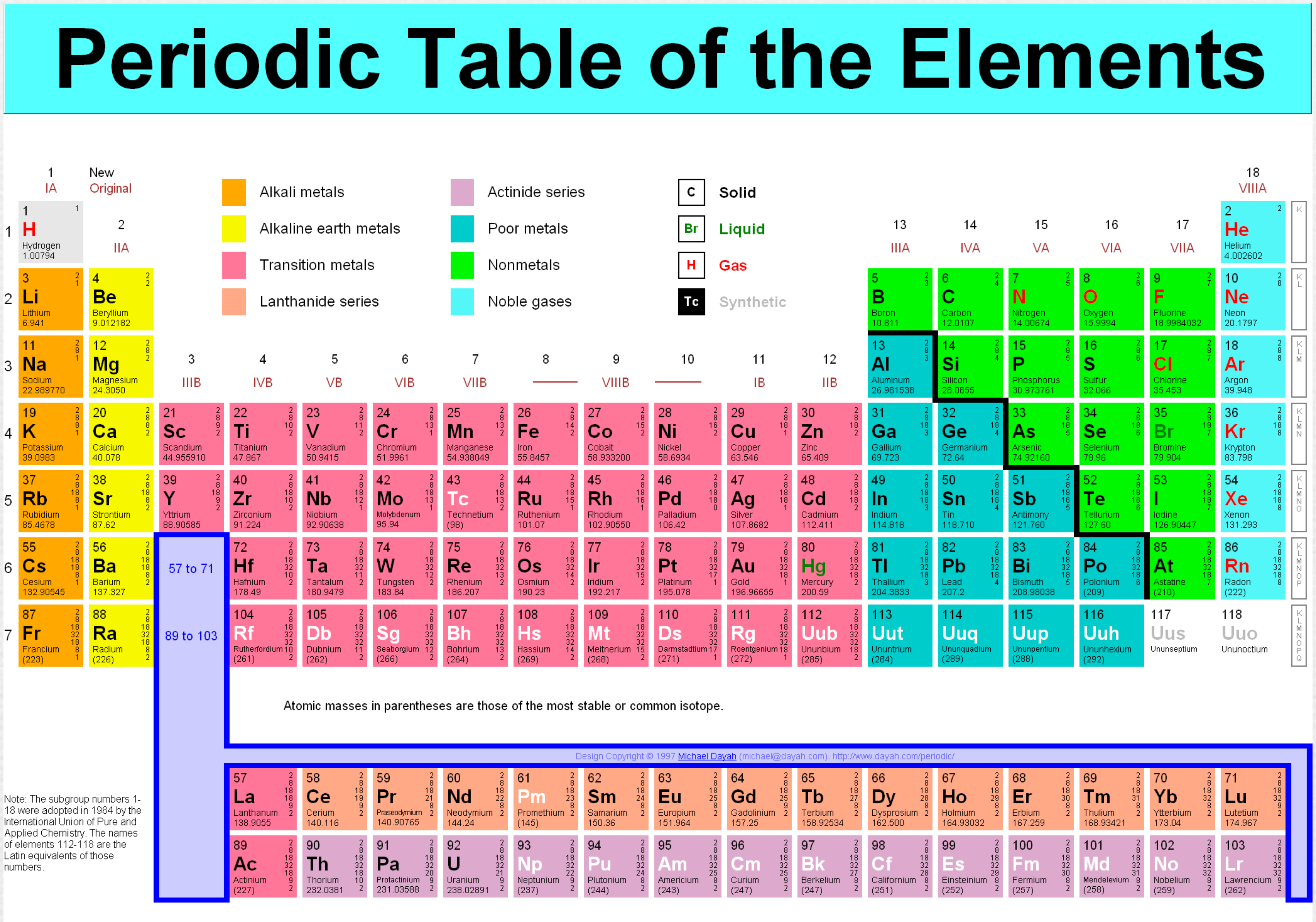
Until about 1960:

- 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



Introduction: Hadrons

- And various elements formed moleculer states

Eg: $2H + O \rightarrow H_2O$

$C + 2O \rightarrow CO_2$

<u>During 1964-1969:</u>

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

$\pi^\pm$	$1^-(0^-)$	$\omega(1420)$	$0^-(1^{--})$	$\eta(1760)$	$0^+(0^{-+})$
π^0	$1^-(0^{-+})$	$f2(1430)$	$0^+(2^{++})$	$\pi(1800)$	$1^-(0^{-+})$
η	$0^+(0^{-+})$	$a0(1450)$	$1^-(0^{++})$	$f_2(1810)$	$0^+(2^{++})$
$f_0(600)$ or σ	$0^+(0^{++})$	$\rho(1450)$	$1^+(1^{--})$	$X(1835)$	$?^?(?^{-+})$
$\rho(770)$	$1^+(1^{--})$	$\eta(1475)$	$0^+(0^{-+})$	$\varphi_3(1850)$	$0^-(3^{--})$
$\omega(782)$	$0^-(1^{--})$	$f_0(1500)$	$0^+(0^{++})$	$\eta_2(1870)$	$0^+(2^{-+})$
$\eta'(958)$	$0^+(0^{-+})$	$f_1(1510)$	$0^+(1^{++})$	$\pi_2(1880)$	$1^-(2^{-+})$
$f_0(980)$	$0^+(0^{++})$	$f_2'(1525)$	$0^+(2^{++})$	$\rho(1900)$	$1^+(1^{--})$
$a_0(980)$	$1^-(0^{++})$	$f_2(1565)$	$0^+(2^{++})$	$f_2(1910)$	$0^+(2^{++})$
$\varphi(1020)$	$0^-(1^{--})$	$\rho(1570)$	$1^+(1^{--})$	$f_2(1950)$	$0^+(2^{++})$
$h_1(1170)$	$0^-(1^{+-})$	$h_1(1595)$	$0^-(1^{+-})$	$\rho_3(1990)$	$1^+(3^{--})$
$b_1(1235)$	$1^+(1^{+-})$	$\pi_1(1600)$	$1^-(1^{-+})$	$f_2(2010)$	$0^+(2^{++})$
$a_1(1260)$	$1^-(1^{++})$	$a_1(1640)$	$1^-(1^{++})$	$f_0(2020)$	$0^+(0^{++})$
$f_2(1270)$	$0^+(2^{++})$	$f_2(1640)$	$0^+(2^{++})$	$a_4(2040)$	$1^-(4^{++})$
$f_1(1285)$	$0^+(1^{++})$	$\eta_2(1645)$	$0^+(2^{-+})$	$f_4(2050)$	$0^+(4^{++})$
$\eta(1295)$	$0^+(0^{-+})$	$\omega(1650)$	$0^-(1^{--})$	$\pi_2(2100)$	$1^-(2^{-+})$
$\pi(1300)$	$1^-(0^{-+})$	$\omega_3(1670)$	$0^-(3^{--})$	$f_0(2100)$	$0^+(0^{++})$
$a_2(1320)$	$1^-(2^{++})$	$\pi_2(1670)$	$1^-(2^{-+})$	$f_2(2150)$	$0^+(2^{++})$
$f_0(1370)$	$0^+(0^{++})$	$\varphi(1680)$	$0^-(1^{--})$	$\rho(2150)$	$1^+(1^{--})$
$h_1(1380)$	$?^-(1^{+-})$	$\rho_3(1690)$	$1^+(3^{--})$	$\varphi(2170)$	$0^-(1^{--})$
$\pi_1(1400)$	$1^-(1^{-+})$	$\rho(1700)$	$1^+(1^{--})$	$f_0(2200)$	$0^+(0^{++})$
$\eta(1405)$	$0^+(0^{-+})$	$a_2(1700)$	$1^-(2^{++})$	$f_J(2220)$	$0^+(2^{++}$ 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.

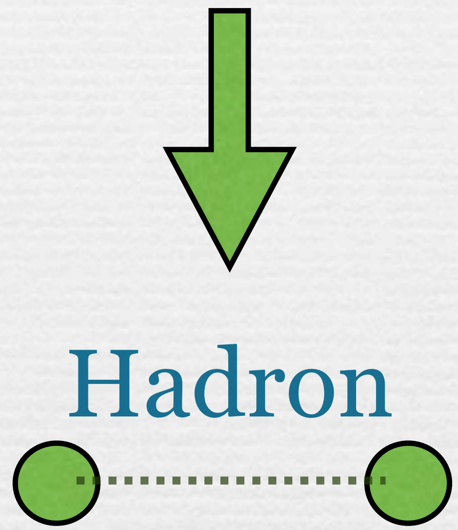
More motivation

- 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

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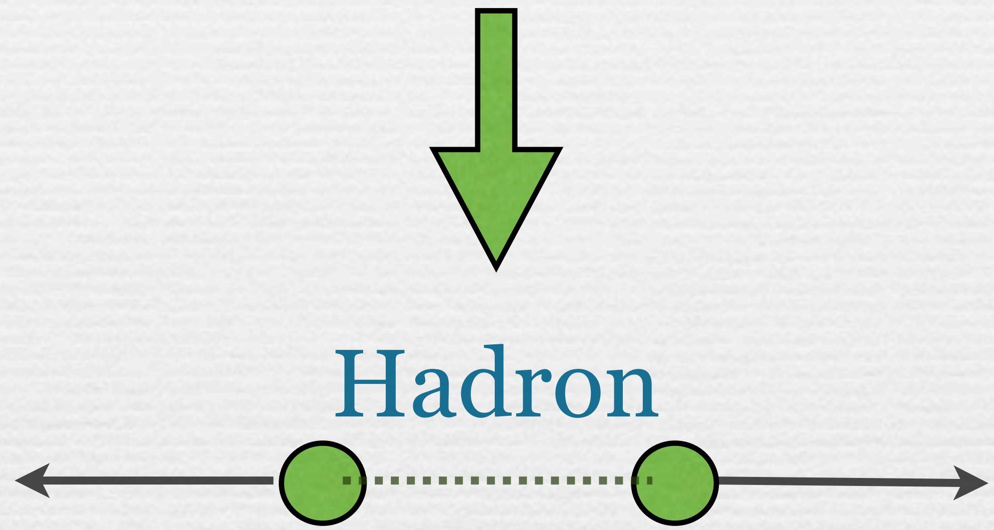

Low and intermediate energies

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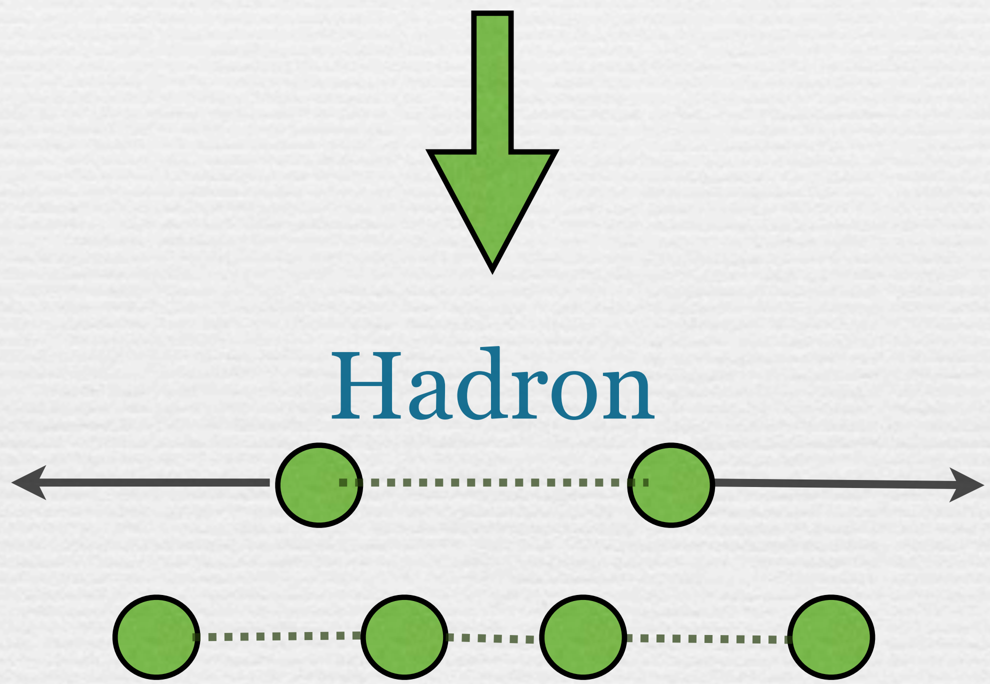

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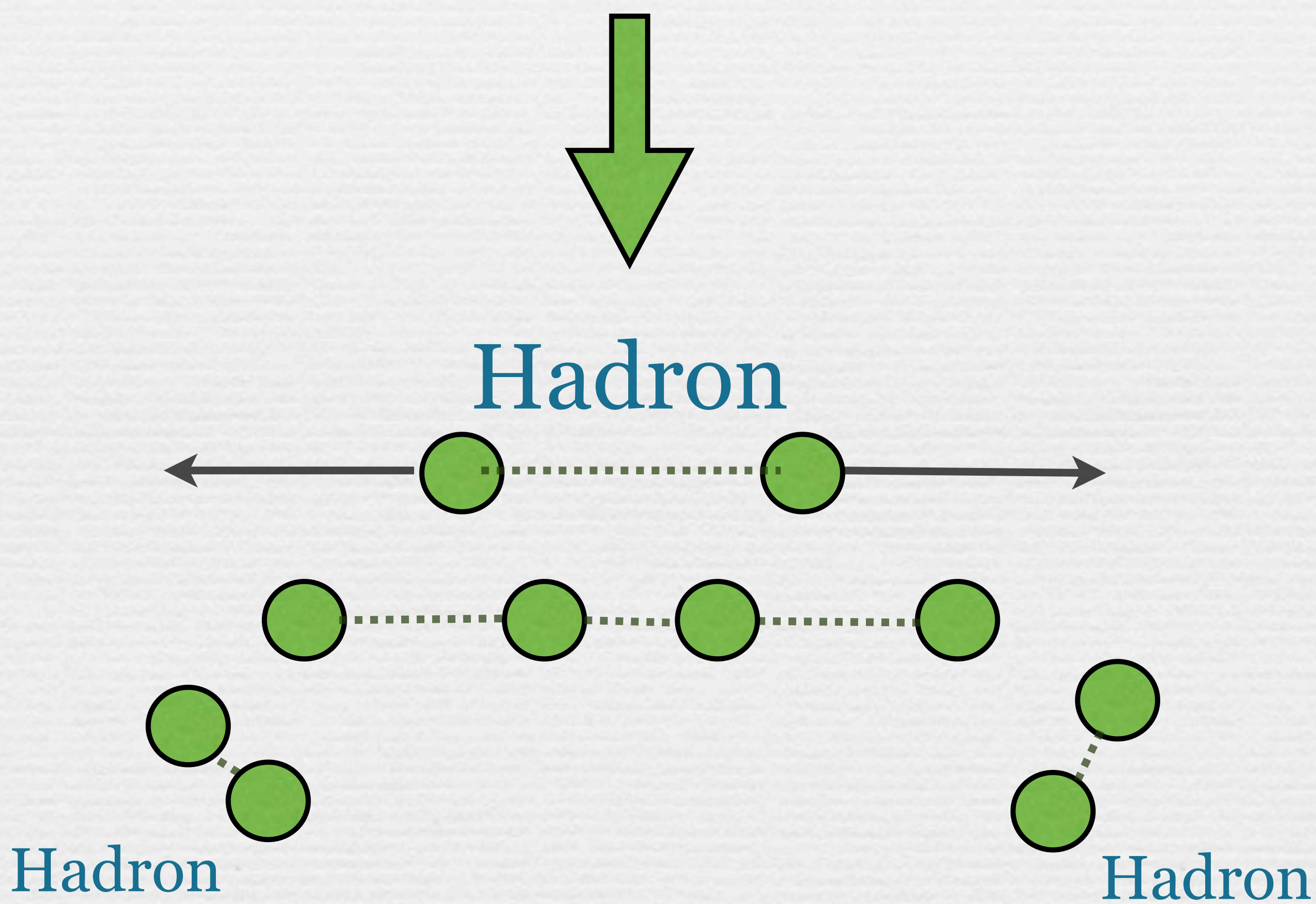
Low and intermediate energies



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.

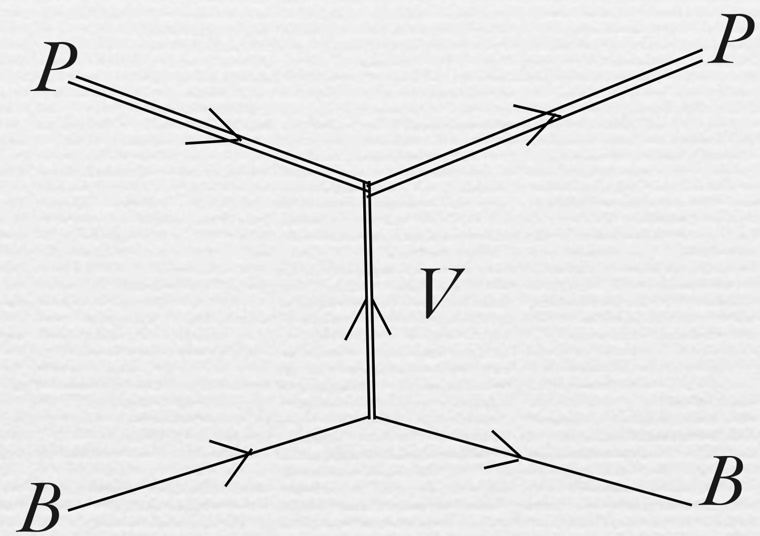
- In this talk we will focus on baryonic systems.
- Lightest meson-baryon system--> pseudoscalar mesons+ baryons
- Effective field theories## for such system are **well studied**
- They are based on the idea that the low energy hadron dynamics is governed by **chiral symmetry**$$and its **spontaneous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

##Explained in lectures by Prof. Bertulani

$$For a brief introduction please see I.T.5 by Alberto Martinez Torres on Nov 30 at10:30hrs.

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 apriori 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)

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

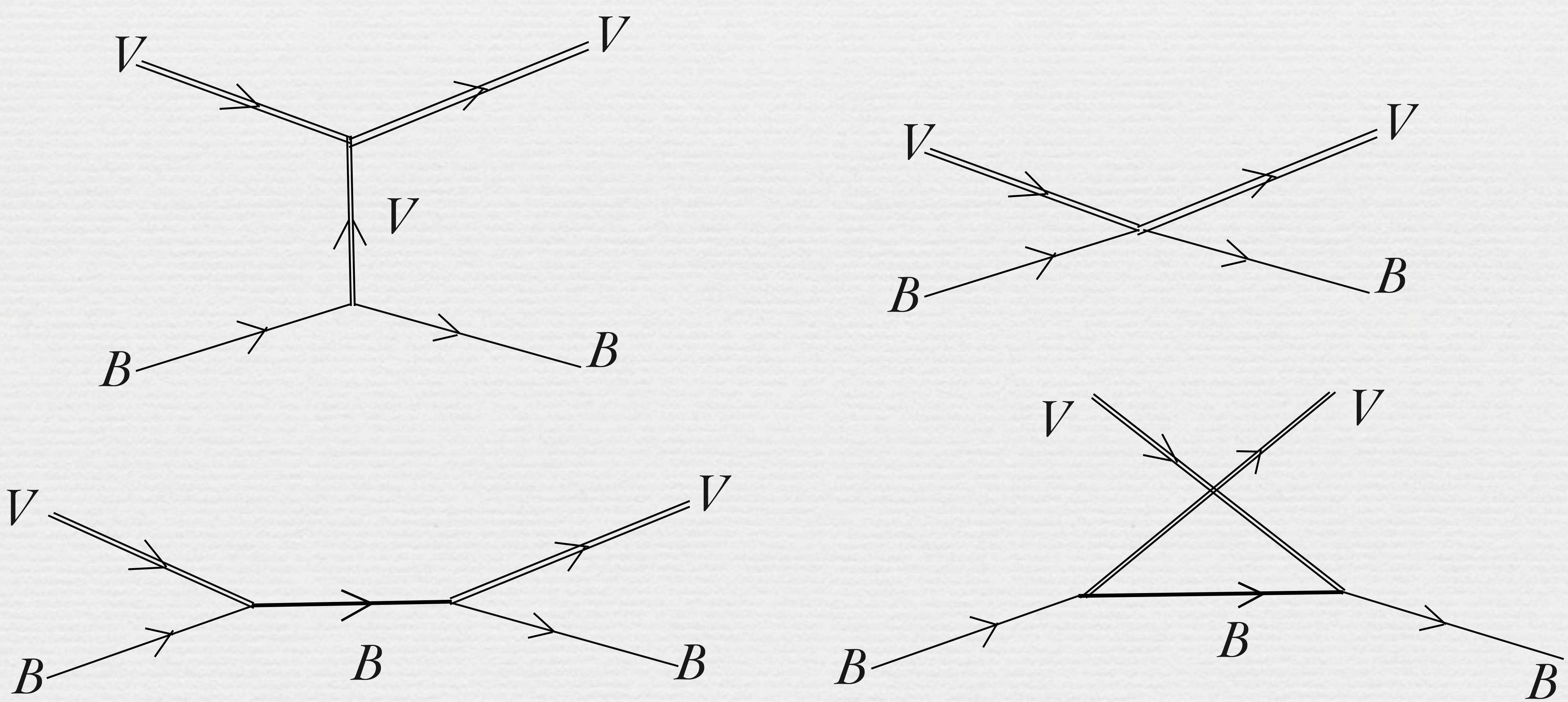
(2) take vector mesons as dynamical gauge bosons (in addition to the Goldstone bosons)

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

(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) +KSRF 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.

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

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=1

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=1

Vector Meson-Baryon interaction

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

$= \kappa_\rho \sim 3.22$

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

=1

Interesting feature: (in SU(2))

		WT	Contact interaction	(S+U)-channel
I=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		$\frac{-2m_\rho}{3f_\pi^2}$	$\frac{m_\rho}{f_\pi^2}$
I=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

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

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

D = 2.4

F = 0.82

$$g = \frac{m_v}{\sqrt{2}f_\pi}$$

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

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

Vector Meson-Baryon interaction

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D = 2.4

F = 0.82 $\longrightarrow$ D + F = 3.22 $\approx \kappa_\rho$ $\quad g = \dfrac{m_v}{\sqrt{2}f_\pi}$

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

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

Vector Meson-Baryon interaction

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

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

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

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

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

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

and add

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

=3F-D

for the singlet meson-Baryon interaction.

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

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

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

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

$$\boxed{V_t = -C_{ij}^t\,\frac{1}{4f_\pi^2}(k_1^0 + k_2^0)\vec{\epsilon_1}.\vec{\epsilon_2}}$$

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

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$$+ \langle \bar{B}\gamma_\mu B\rangle\langle V_0^\mu\rangle + \frac{C_0}{4M}\langle \bar{B}\sigma_{\mu\nu}V_0^{\mu\nu}B\rangle\Big\}$$

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

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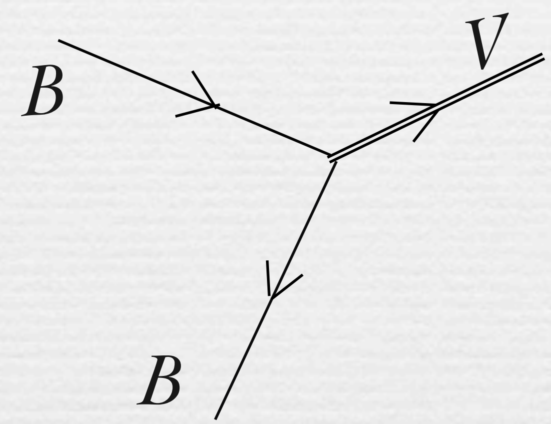
$$+ \langle\bar{B}\gamma_\mu B\rangle\langle V_0^\mu\rangle + \frac{C_0}{4M}\langle\bar{B}\sigma_{\mu\nu}V_0^{\mu\nu}B\rangle\Big\}$$

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



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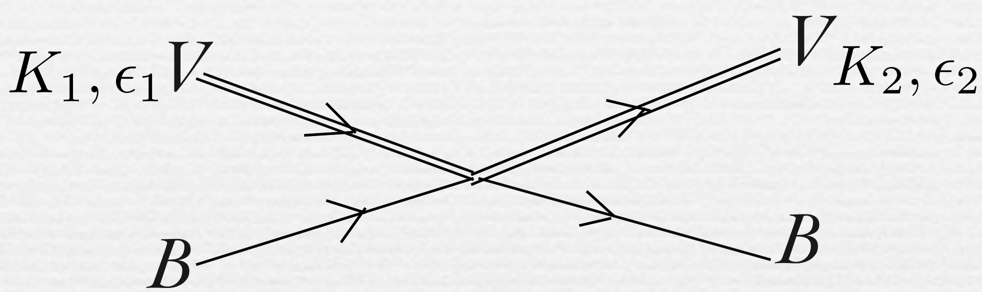
Vector Meson-Baryon contact interaction:

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

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:



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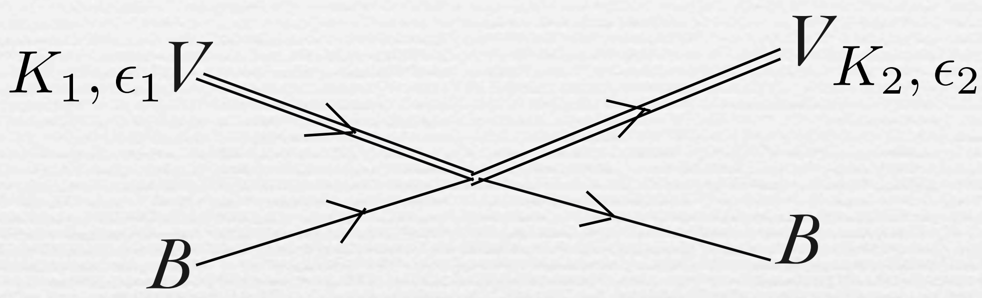
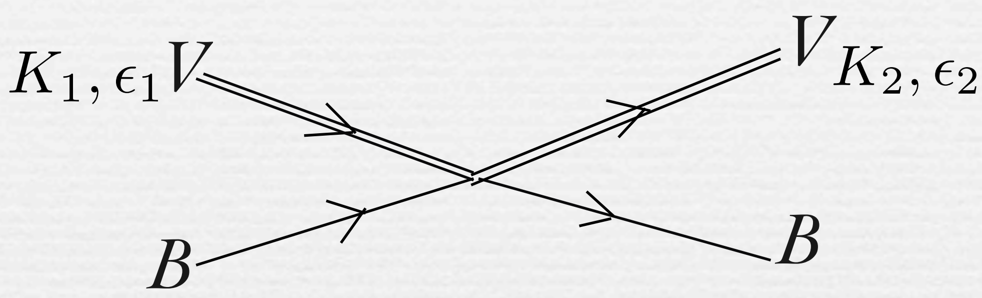


$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

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

Vector Meson-Baryon contact interaction:

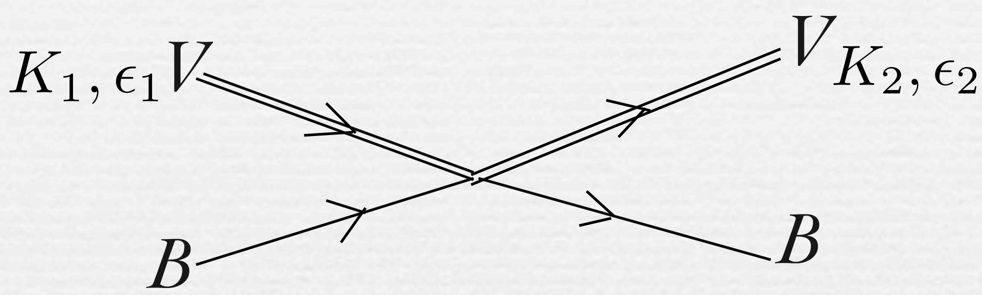


$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

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

$$\boxed{V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\vec{\sigma}\cdot\vec{\epsilon_2}\times\vec{\epsilon_1}}$$

Vector Meson-Baryon contact interaction:

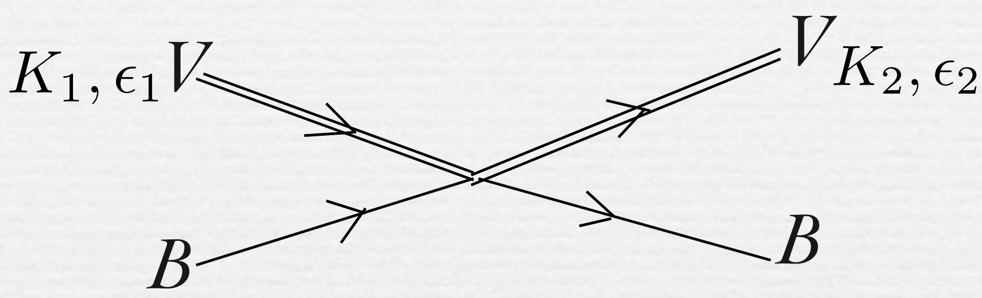


$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

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

$$\boxed{V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\vec{\sigma}\cdot \underline{\vec{\epsilon_2} \times \vec{\epsilon_1}}}$$

Vector Meson-Baryon contact interaction:

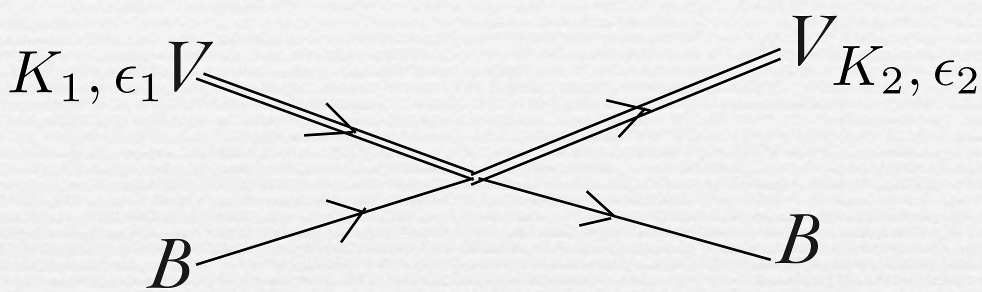


$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

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

$$\boxed{V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\vec{\sigma}\cdot\underbrace{\vec{\epsilon_2}\times\vec{\epsilon_1}}_{i\vec{S}}}$$

Vector Meson-Baryon contact interaction:



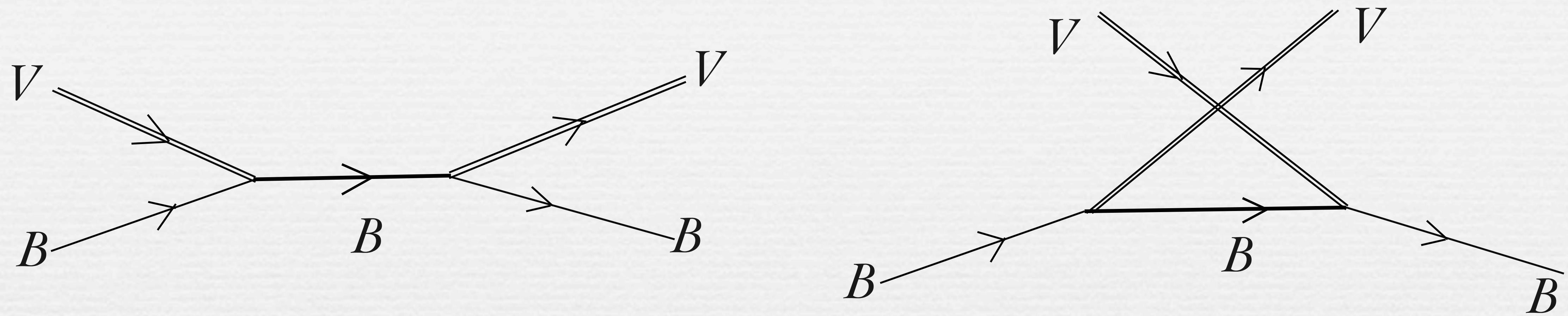
$$V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu + ig[V^\mu, V^\nu]$$

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

$$\boxed{V_{contact} = -iC_{ij}^{contact}\frac{g^2}{2M_B}\underbrace{\vec{\sigma}}_{\vec{s}}\cdot\underbrace{\vec{\epsilon_2}\times\vec{\epsilon_1}}_{i\vec{S}}}$$

Spin dependent

S- and U-channel diagrams:



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

$$V_S = C_{ij}^s\, g^2 \left(\frac{1}{m_v + 2M_B}\right)\vec{\epsilon_2}\cdot\vec{\sigma}\vec{\epsilon_1}\cdot\vec{\sigma}$$

$$V_U = -C_{ij}^u\, g^2 \left(\frac{1}{m_v - 2M_B}\right)\vec{\epsilon_1}\cdot\vec{\sigma}\vec{\epsilon_2}\cdot\vec{\sigma}$$

Solving Bethe-Salpeter equations in coupled channel formalism:

$$T = V + VGT$$

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

$$G = i2M \int \frac{d^4q}{2\pi^4} \frac{1}{(P-q)^2 - M^2 + i\epsilon} \frac{1}{q^2 - m^2 + i\epsilon}$$

$$= \frac{2M}{16\pi^2} \Bigg\{ a(\mu) + ln\frac{M^2}{\mu^2} + \frac{m^2 - M^2 + s}{2s} ln\frac{m^2}{M^2}$$

$$+ \frac{\bar{q}}{\sqrt{s}} \Big[ln\left(s - \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right) - ln\left(-s + \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right)$$

$$- ln\left(s - \left(M^2 - m^2\right) + 2\bar{q}\sqrt{s}\right) \Big] \Bigg\}$$

But rho and K* mesons are quite wide!!

T = V + VGT

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

with

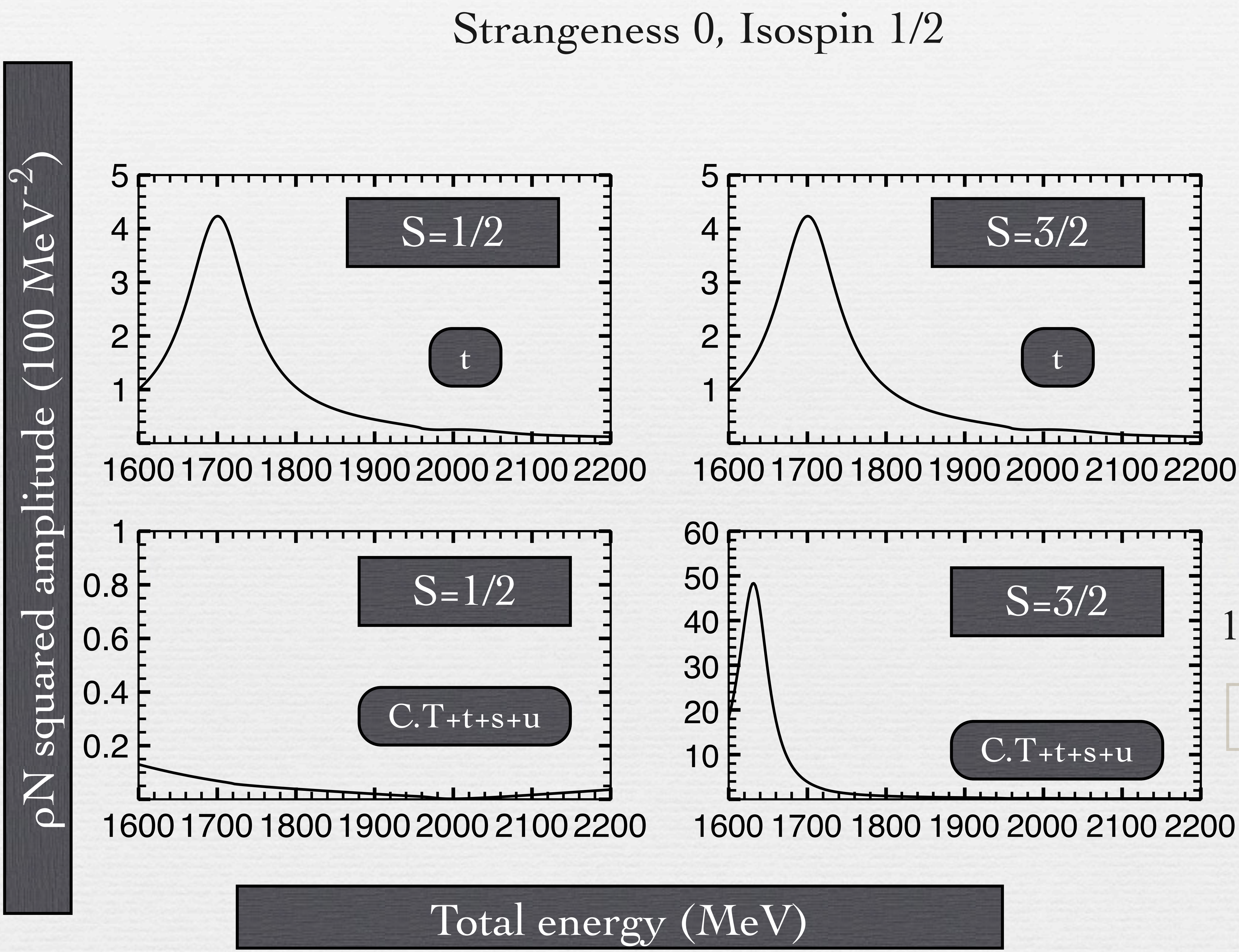
$$N = \int_{(m-2\Gamma_i)^2}^{(m+2\Gamma_i)^2} \mathrm{d}\tilde{m}^2 \left(-\frac{1}{\pi}\right) \mathrm{Im}\, \frac{1}{\tilde{m}^2 - m^2 + \mathrm{i} m \Gamma(\tilde{m})}$$

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



Pole:
1641 - i35 MeV

3/2- N*(1700)

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_{beam} = 1.05 GeV/c
$4\pi\lambda^2$ = 14.5 mb
Re(pole position) = 1630 to 1730 (≈1680) MeV
−2Im(pole position) = 50 to 150 (≈100) MeV

N(1700) DECAY MODES

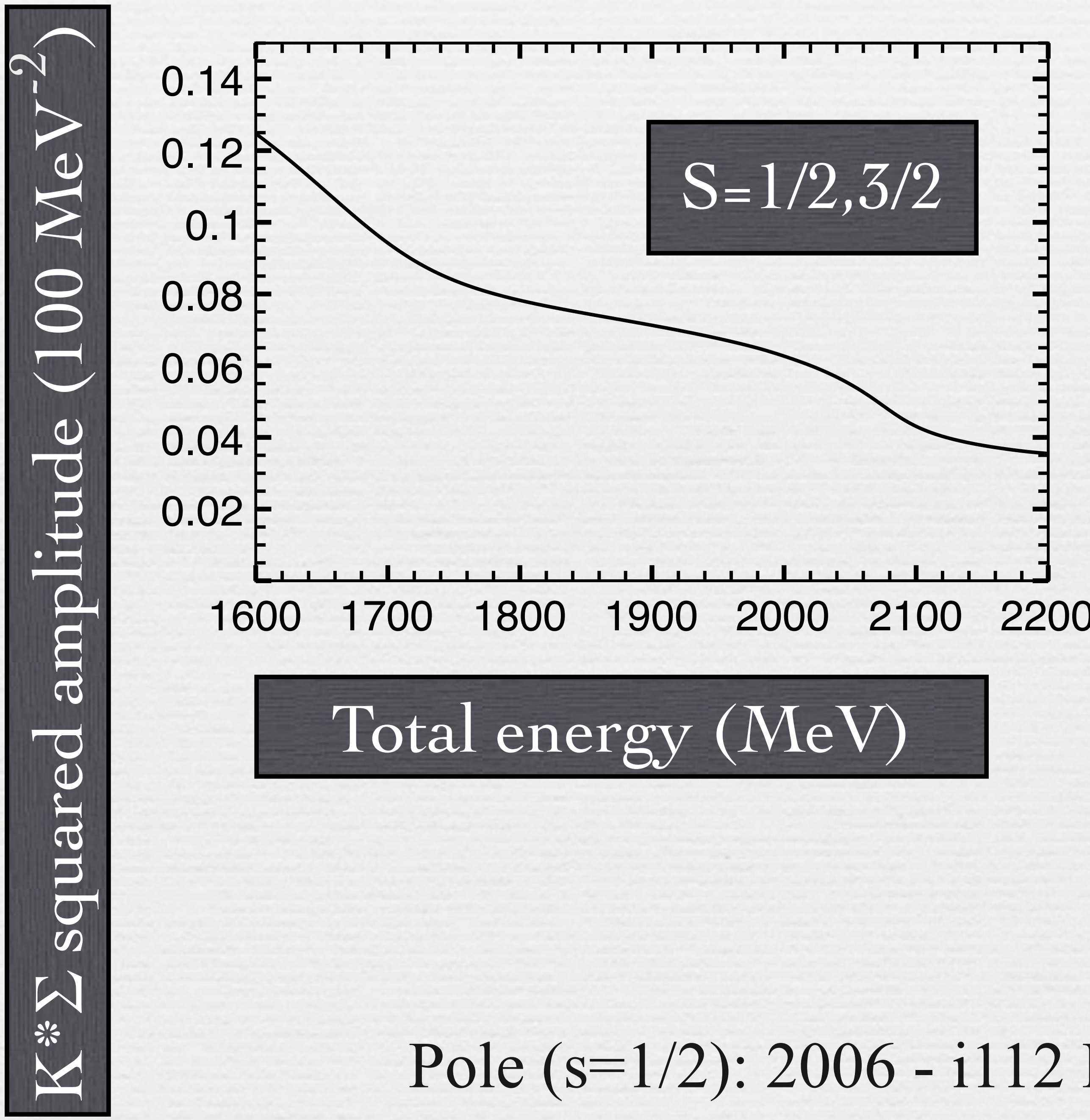
The following branching fractions are our estimates, not fits or averages.

Γ_i	Mode	Fraction (Γ_i/Γ)	p (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-wave		386
Γ_8	$\Delta(1232)\pi$, D-wave		386
Γ_9	$N\rho$	<35%	-1
Γ_{10}	$N\rho$, S=1/2, D-wave		-1
Γ_{11}	$N\rho$, S=3/2, S-wave		-1
Γ_{12}	$N\rho$, S=3/2, D-wave		-1
Γ_{13}	$N((\pi\pi))_{S\text{-wave}}^{I=0}$		—
Γ_{14}	$p\gamma$	0.01 – 0.05%	591
Γ_{15}	$p\gamma$, helicity=1/2	0.0 – 0.024%	591
Γ_{16}	$p\gamma$, helicity=3/2	0.002 – 0.026%	591
Γ_{17}	$n\gamma$	0.01 – 0.13%	590
Γ_{18}	$n\gamma$, helicity=1/2	0.0 – 0.09%	590
Γ_{19}	$n\gamma$, helicity=3/2	0.01 – 0.05%	590

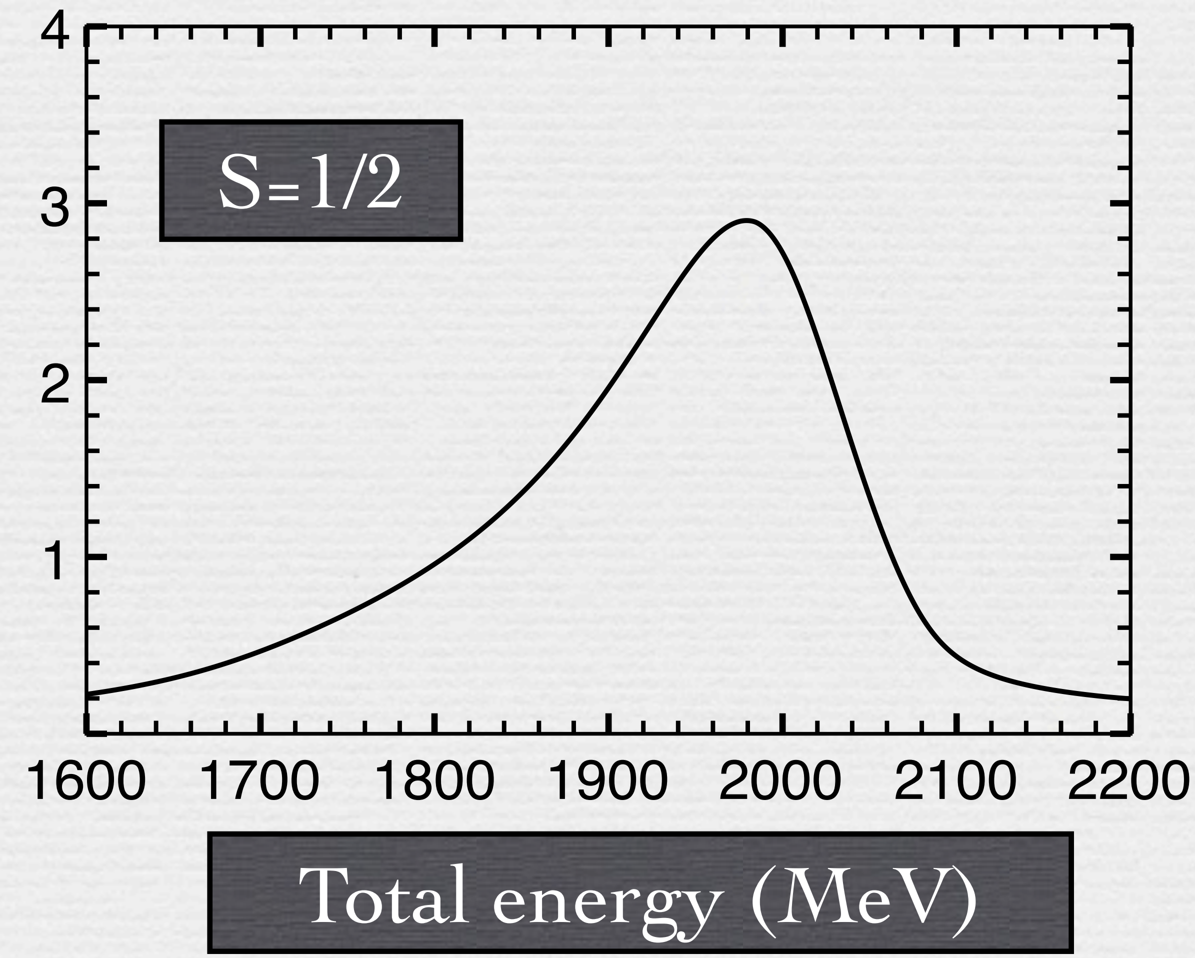
Vector Meson-Baryon interactions: Results

Strangeness 0, Isospin 3/2

- t-channel



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



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

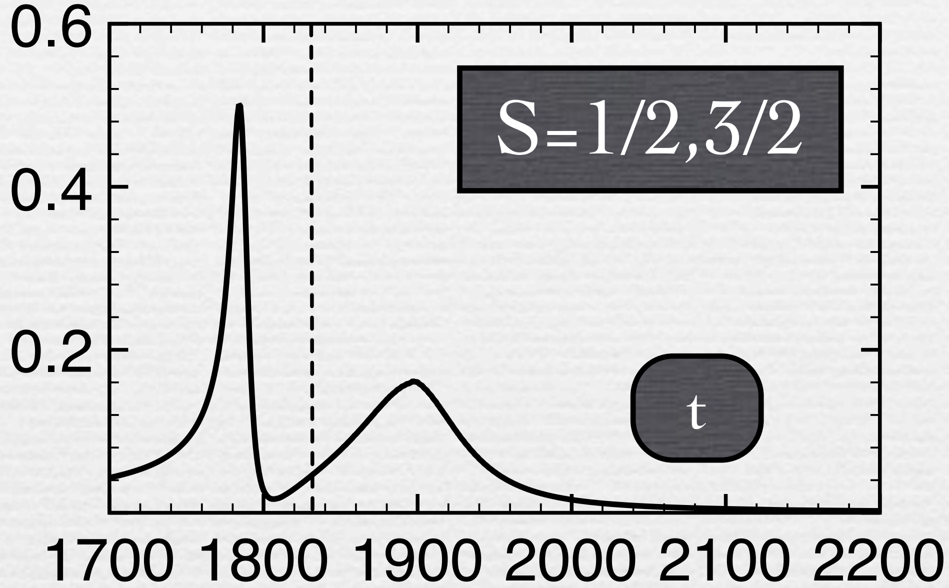
$1/2^-$ Δ (1900)

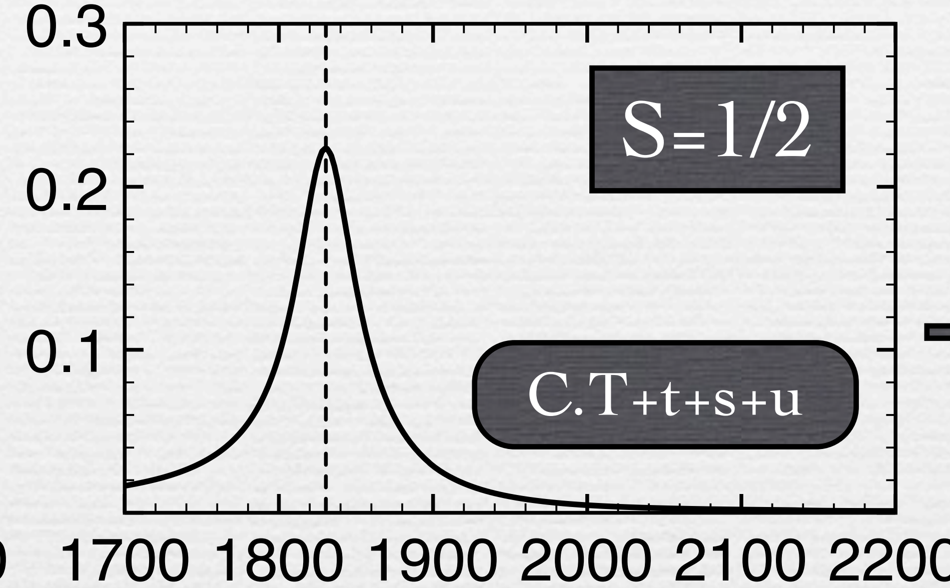
Vector Meson-Baryon interactions: Results

(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

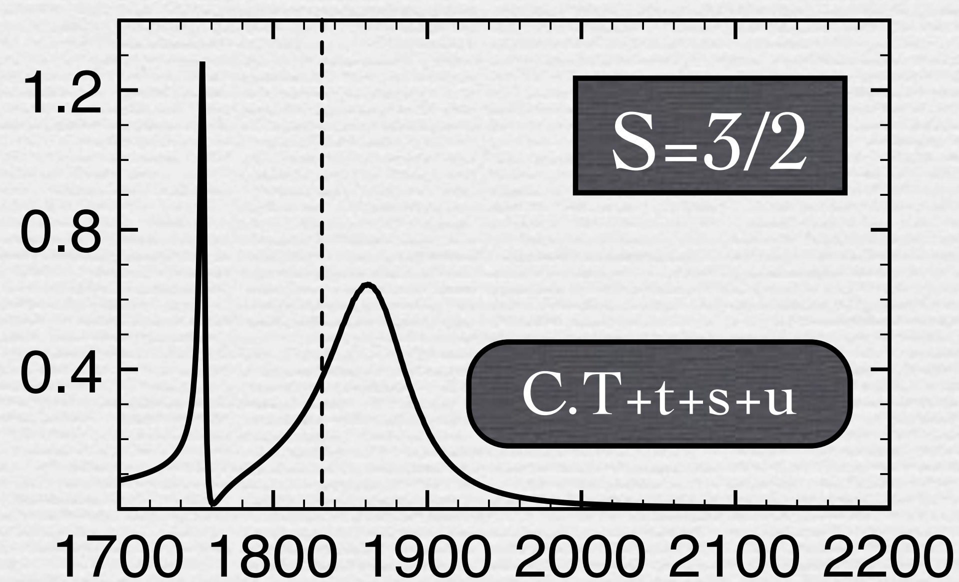
$\rho\Sigma$ squared amplitude (10^{-2} MeV^{-2})





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) $\longrightarrow$	–	$1822 - i15$	–	$1947 - i17$
Channels $\downarrow$	Couplings (g^i) of the poles to the different channels			
$\bar{K}^*N$ (1831)	–	$2.3 - i0.0$	–	$-0.3 + i0.2$
$\rho\Lambda$ (1886)	–	$-0.6 + i0.0$	–	$-0.5 + i0.2$
$\rho\Sigma$ (1963)	–	$-1.9 + i0.0$	–	$2.7 + i0.2$
$\omega\Sigma$ (1975)	–	$-1.0 + i0.0$	–	$0.3 + i0.1$
$K^*\Xi$ (2210)	–	$0.1 - i0.0$	–	$1.9 + i0.2$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$	–	$0.2 - i0.0$

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

$\Sigma\ (1940)\ D_{13}$

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) $\longrightarrow$	–	$1822 - i15$	–	$1947 - i17$
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$\phi\Sigma$ (2213)	–	$1.6 - i0.0$	–	$0.2 - i0.0$

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]].*

Coupling Pseudoscalar and Vector Mesons to Baryon resonances

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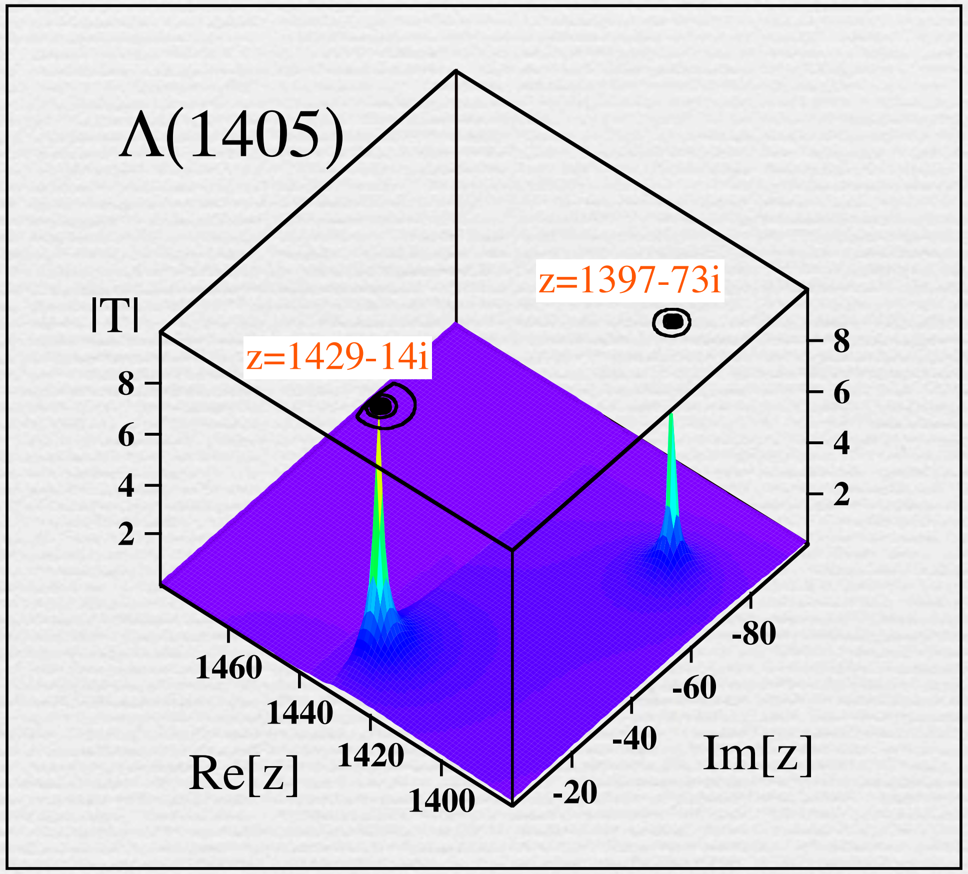
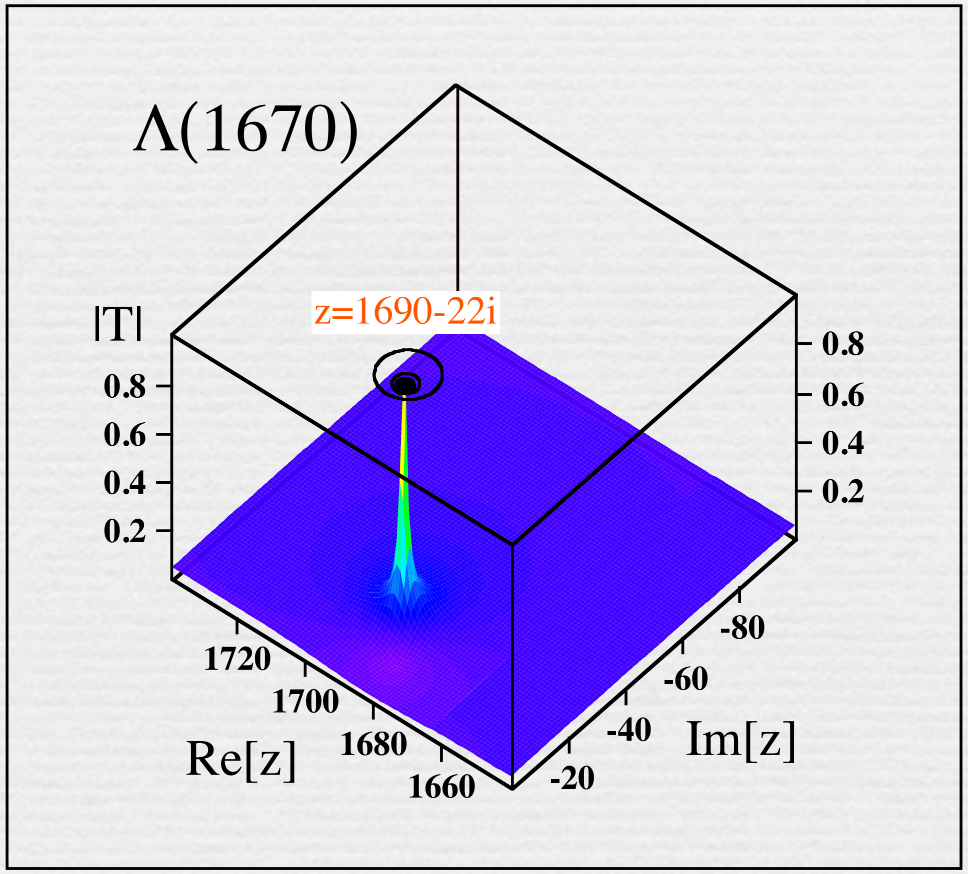
What is known about Λ(1405), Λ(1670)?

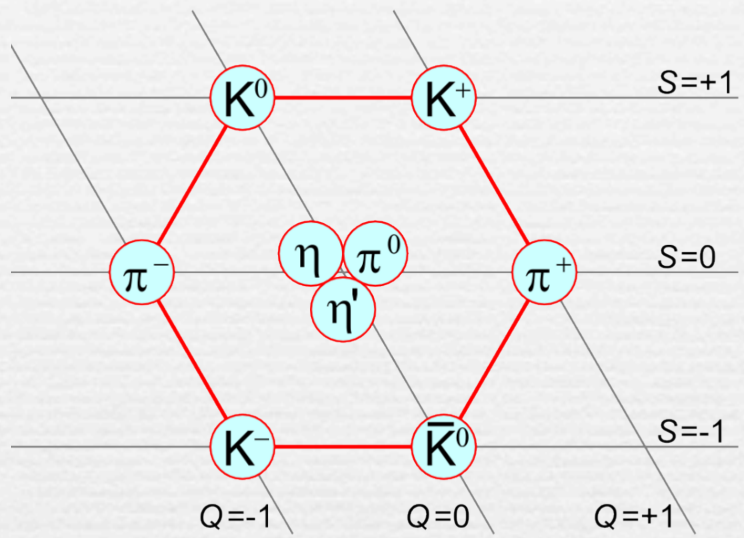


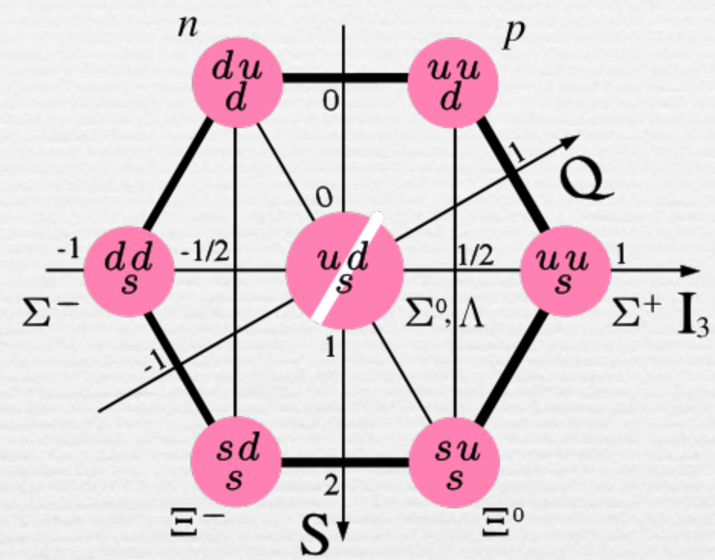


Ref: Jido,Oller,Oset,Ramos, Meissner, NPA 725 (203) 181.

Coupling Pseudoscalar and Vector Mesons to Baryon resonances

Channels:



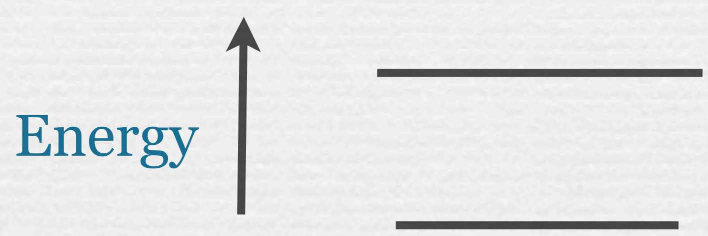


PB channels	Mass (MeV)	VB channels	Mass (MeV)
$\bar{K}N$	1435	$\bar{K}^*N$	1831
$\pi\Sigma$	1330	$\rho\Sigma$	1963
$\eta\Lambda$	1663	$\omega\Lambda$	1898
$K\Xi$	1814	$\Phi\Lambda$	2136
		$K^*\Xi$	2210

- 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

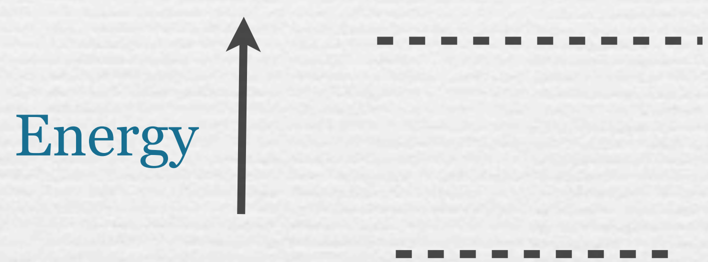
From basics: QM two level problem



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.

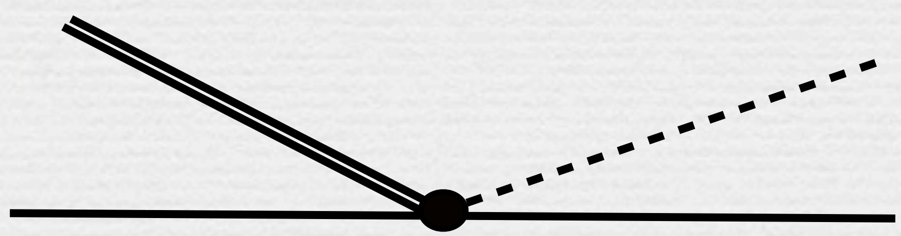
Coupling Pseudoscalar and Vector Mesons to Baryon resonances

VB → VB
(t-channel)

VB → PB
(Contact term)

PB → VB
(extension of Kroll-Ruderman term
γ ⇨ V in $\gamma N \to \pi$ N and introducing
it in the non-linear sigma model)

PB → PB
(t-channel)



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

$$\mathcal{L}_{\pi N} = \bar{\psi}\left[i\gamma^\mu \partial_\mu - g_{\pi NN}\left(\sigma + i\vec{\tau}.\vec{\pi}\gamma_5\right)\right]\psi \quad i\partial\!\!\!/ \longrightarrow i\partial\!\!\!/ - g\phi\!\!\!/ \quad \mathcal{L}_{\pi N\rho N} = -i\frac{g g_A}{2f_\pi}\bar{N}\left[\pi, \rho^\mu\right]\gamma_\mu\gamma_5 N$$

SU(3)

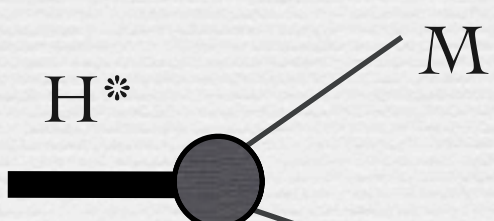
$$\mathcal{L}_{PBVB} = \frac{-ig}{2f_\pi}\left(F\langle\bar{B}\gamma_\mu\gamma_5\left[\left[P, V_\mu\right], B\right]\rangle + D\langle\bar{B}\gamma_\mu\gamma_5\left\{\left[P, V_\mu\right], B\right\}\rangle\right)$$

= 6

F = 0.46, D = 0.8

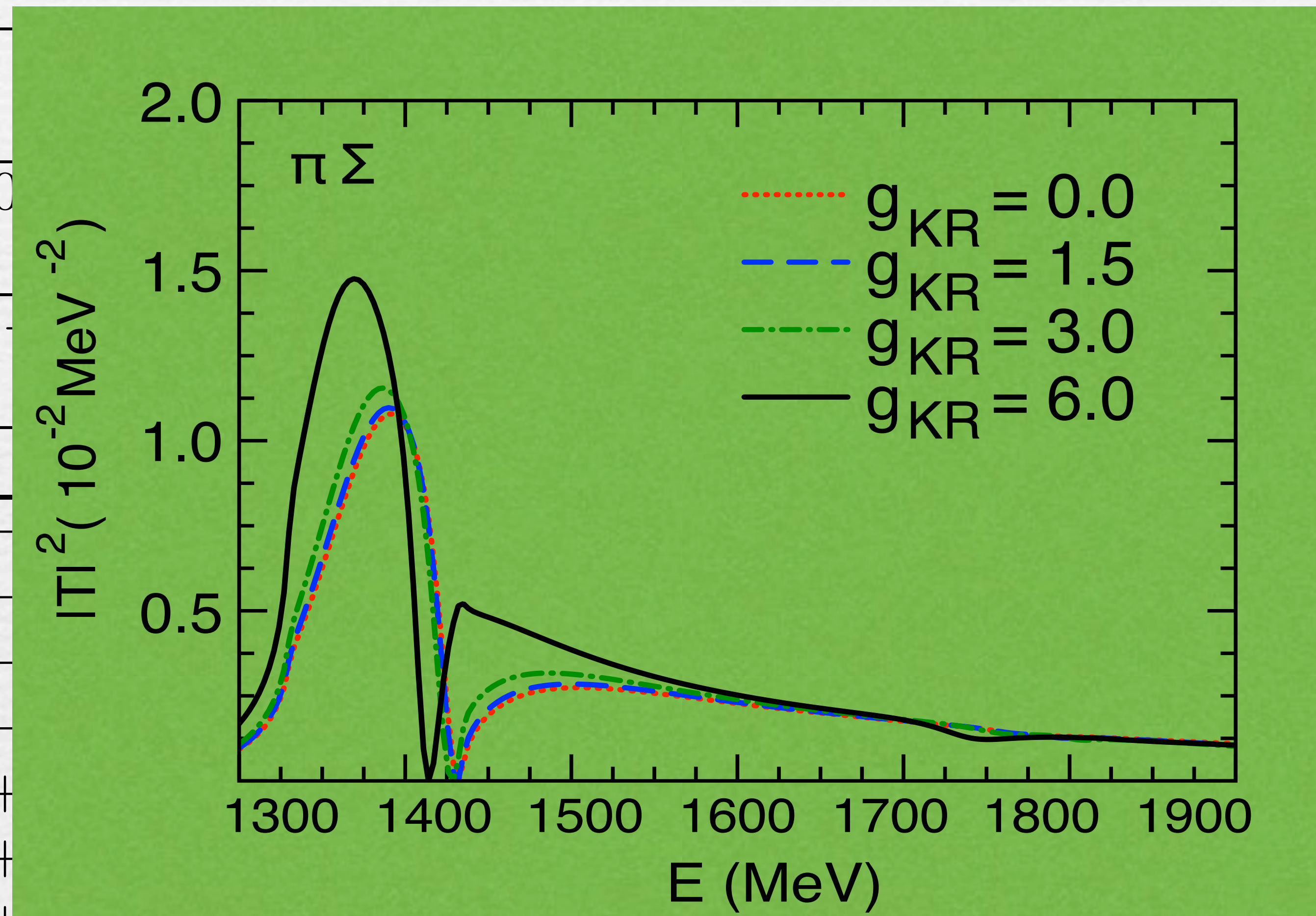
PB-VB coupled systems: Results on low-lying resonances

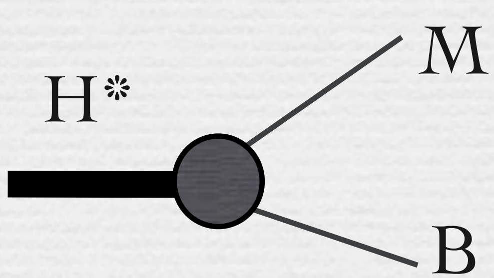
	$\Lambda(1405)$				$\Lambda(1670)$	
	Pole1		Pole2			
PB-VB coupling	0	6	0	6	0	6
$M_R - i\Gamma/2 \rightarrow$ (MeV)	$1377 - i63$	$1357 - i53$	$1430 - i15$	$1412 - i11$	$1767 - i25$	$1744 - i28$
Channels $\downarrow$	Couplings (g^i) of the poles to the different channels					
$\bar{K}N$	$1.4 - i1.6$	$1.1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



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

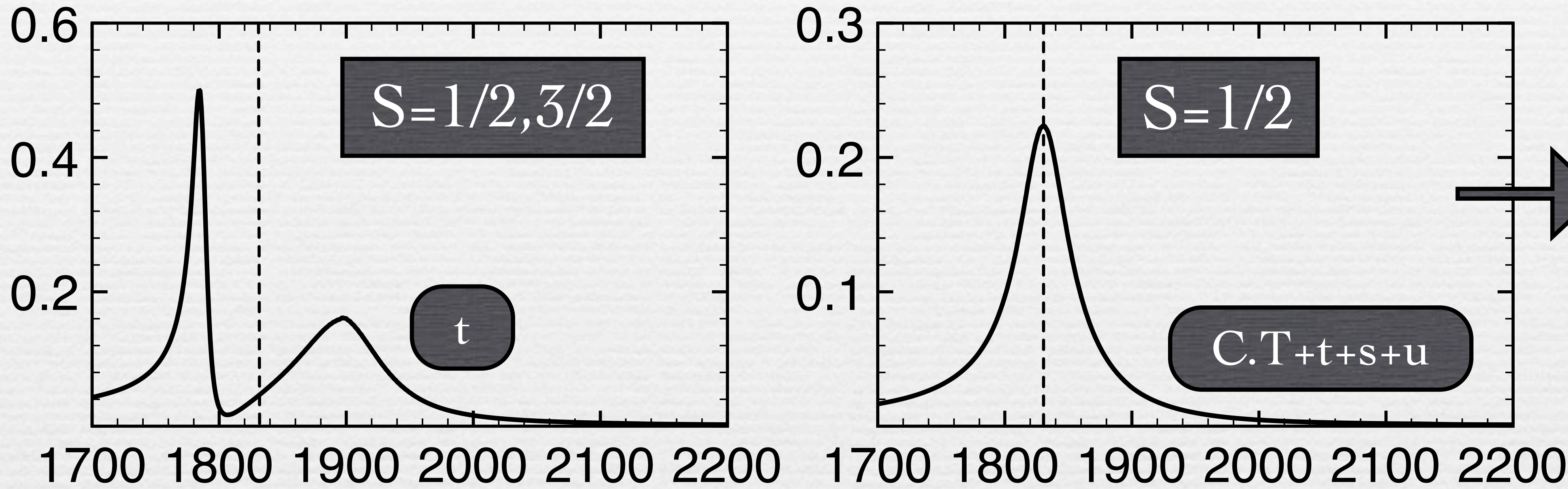
						Λ(1670)
PB-VB coupling	0				0	6
$M_R - i\Gamma/2 \rightarrow$ (MeV)	1377 –				7 $- i25$	$1744 - i28$
Channels ↓					annels	
$\bar{K}N$	1.4 –				$- i0.5$	$0.3 - i0.6$
$\pi\Sigma$	−2.3 –				$+ i0.2$	$0.1 + i0.3$
$\eta\Lambda$	0.2 –				0 $+ i0.3$	$-1.0 + i0.3$
$K\Xi$	−0.4 –				$+ i0.3$	$3.4 + i0.2$
$\bar{K}^*N$	0.0 +				$+ i0.0$	$-0.3 + i1.1$
$\omega\Lambda$	0.0 +				$+ i0.0$	$0.1 - i0.1$
$\rho\Sigma$	0.0 + [illegible]	[illegible]	[illegible]	[illegible]	[illegible] $+ i0.0$	$\mathbf{0.3 - i3.5}$
$\phi\Lambda$	$0.0 + i0.0$	$1.0 + i0.5$	$0.0 + i0.0$	$-0.3 + i2.6$	$0.0 + i0.0$	$-0.2 + i0.1$
$K^*\Xi$	$0.0 + i0.0$	$\mathbf{1.3 + i5.7}$	$0.0 + i0.0$	$-2.0 - i0.5$	$0.0 + i0.0$	$0.5 - i1.2$





PB-VB coupled systems: Results

Isospin 0



virtual state

Poles:

(i) 1795 - i 20 MeV

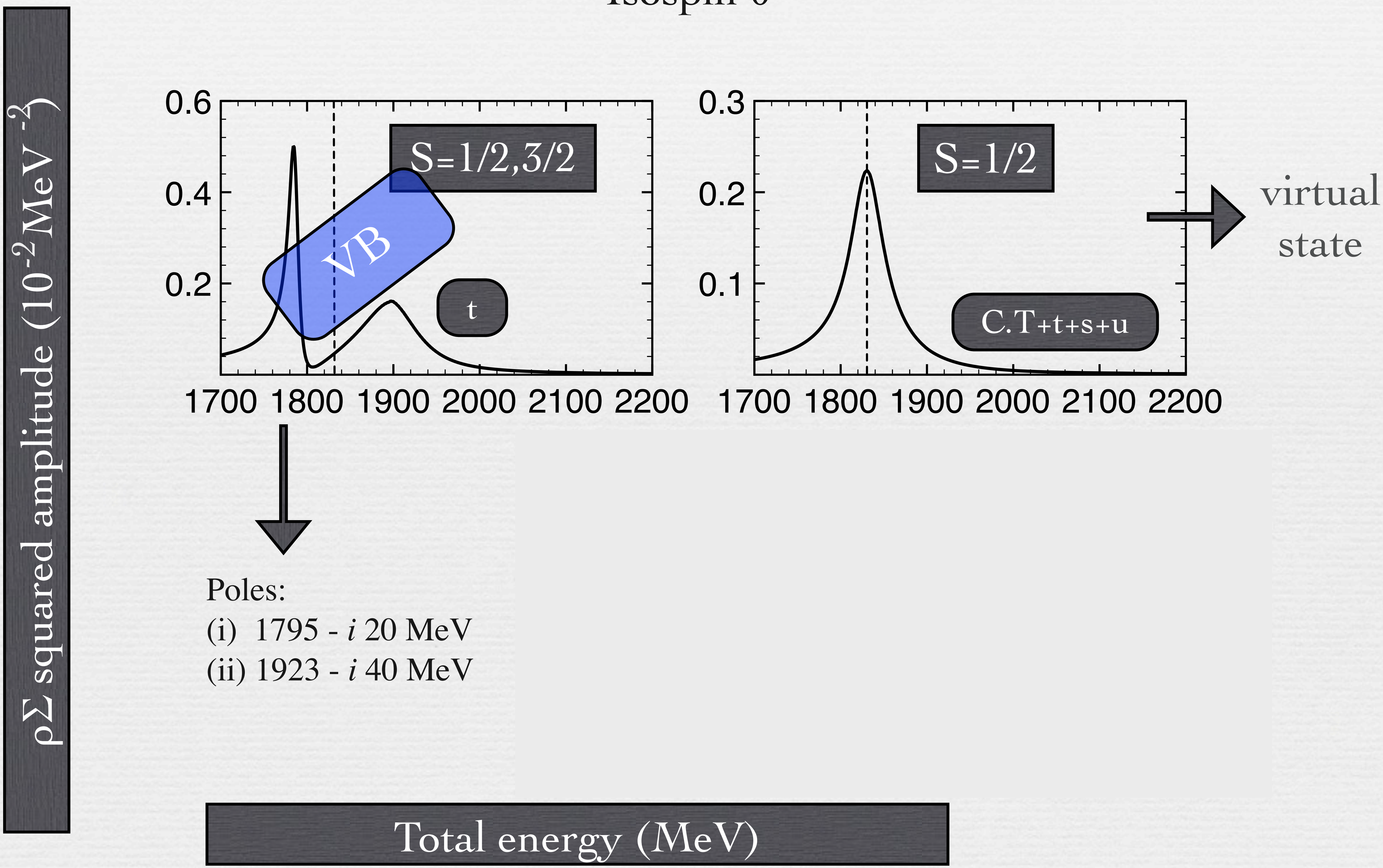
(ii) 1923 - i 40 MeV

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

Total energy (MeV)

PB-VB coupled systems: Results

Isospin 0



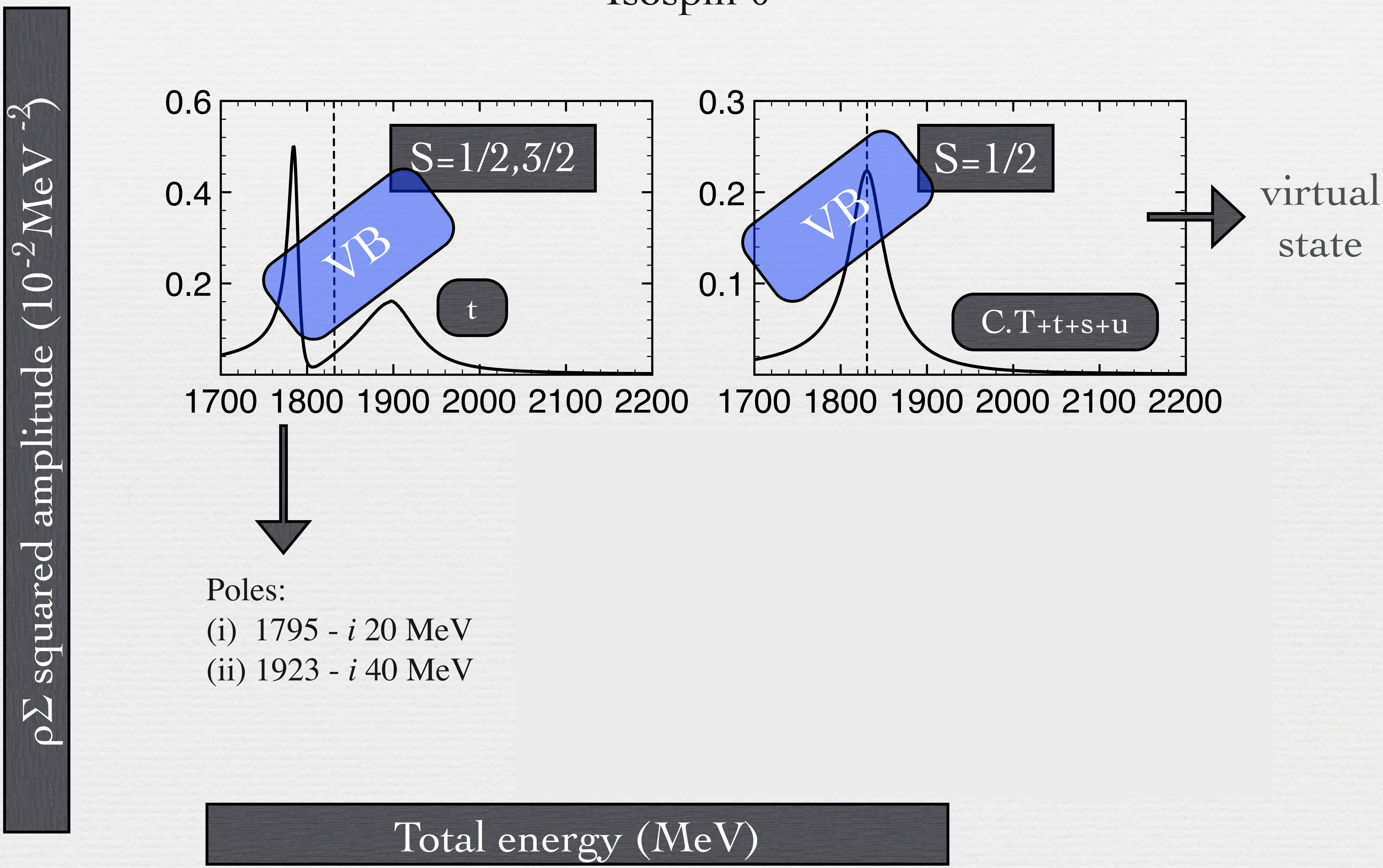
Poles:

(i) 1795 - *i* 20 MeV

(ii) 1923 - *i* 40 MeV

PB-VB coupled systems: Results

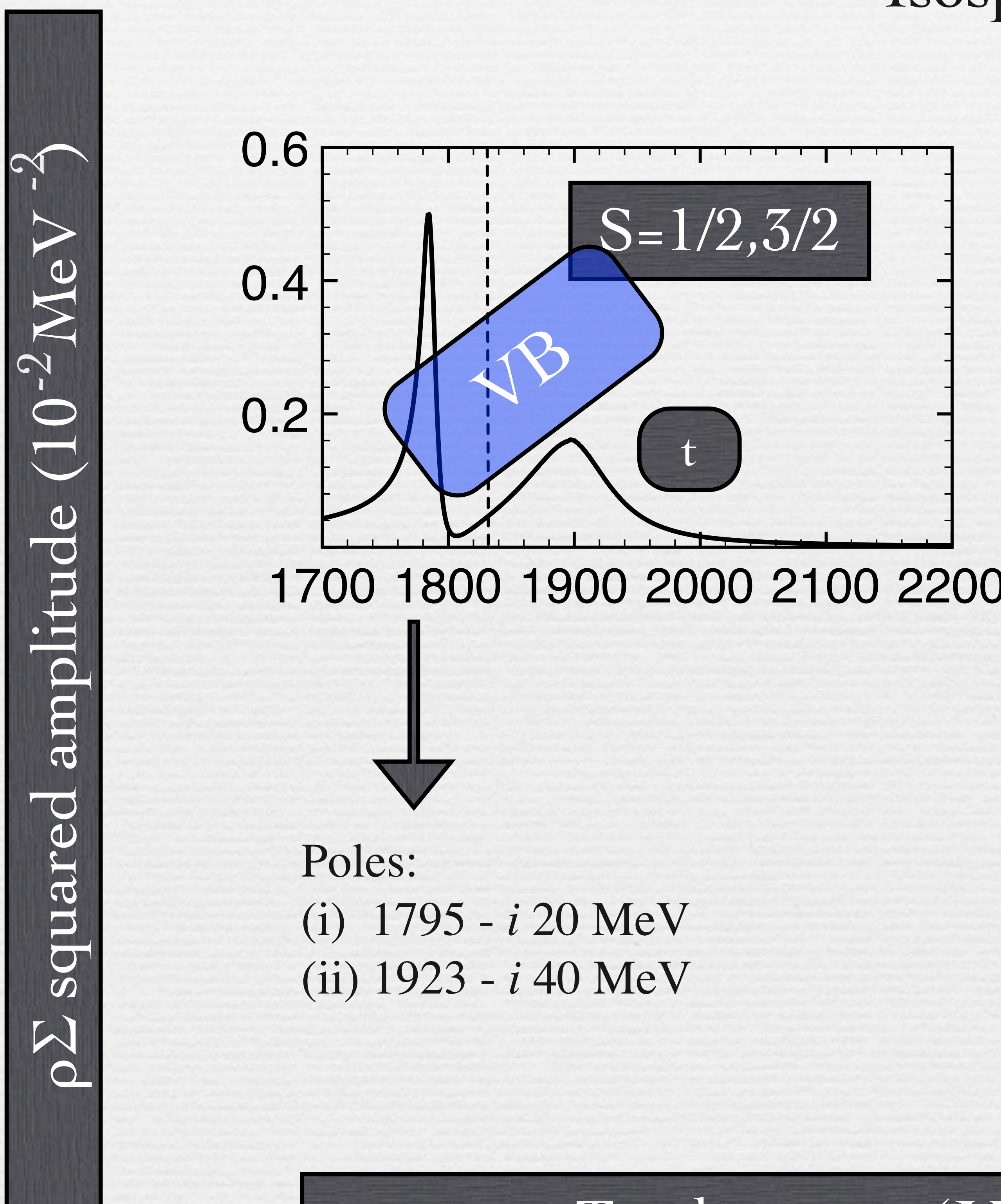
Isospin 0

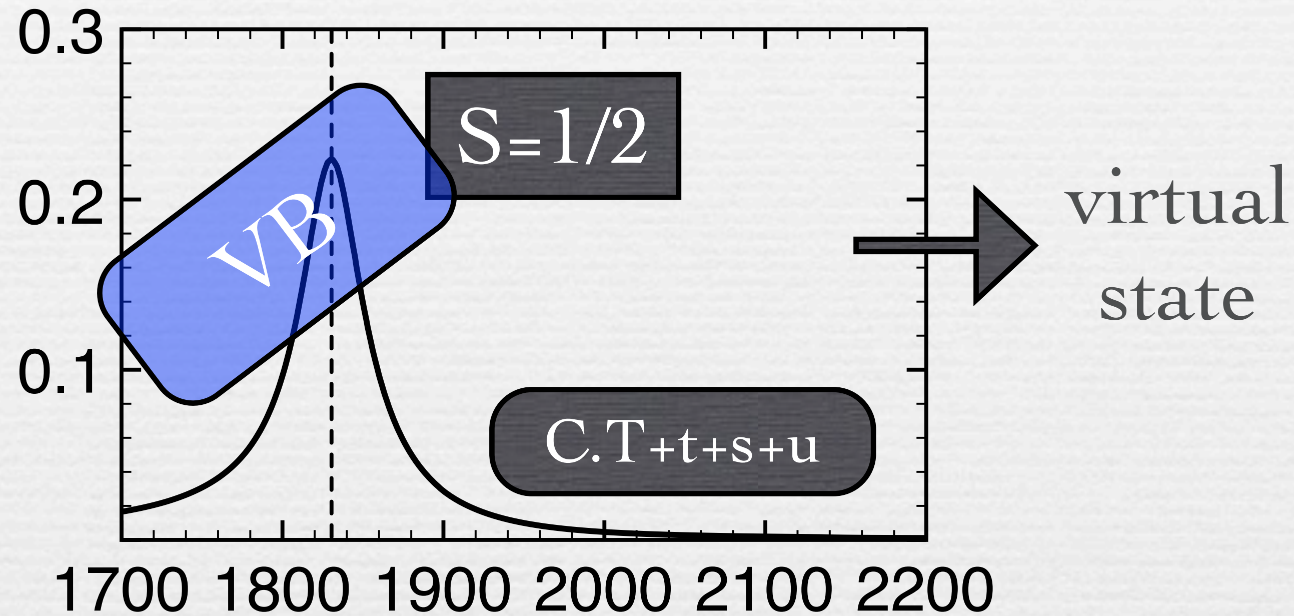


Poles:
(i) 1795 - *i* 20 MeV
(ii) 1923 - *i* 40 MeV

PB-VB coupled systems: Results

Isospin 0





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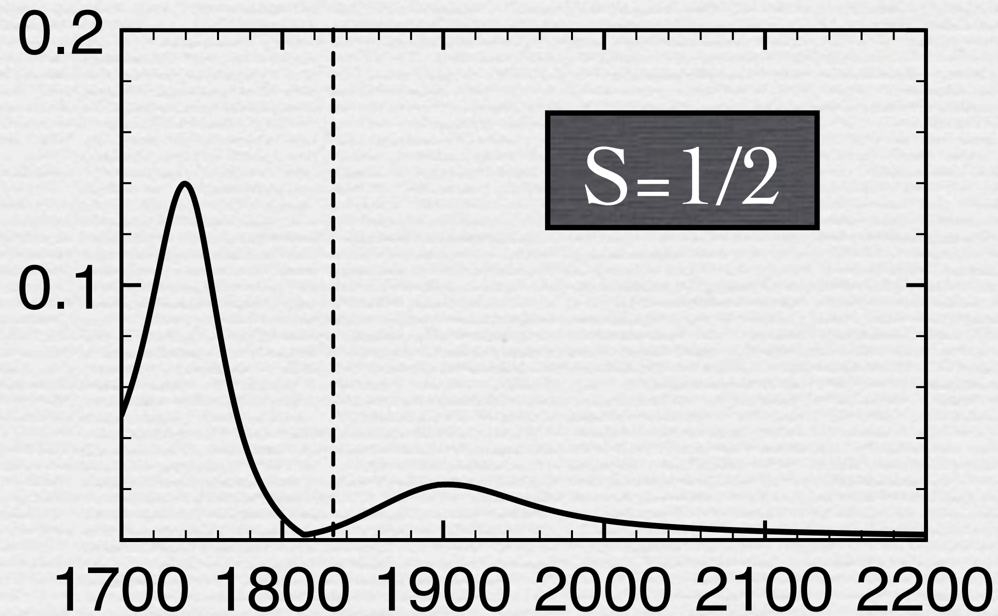
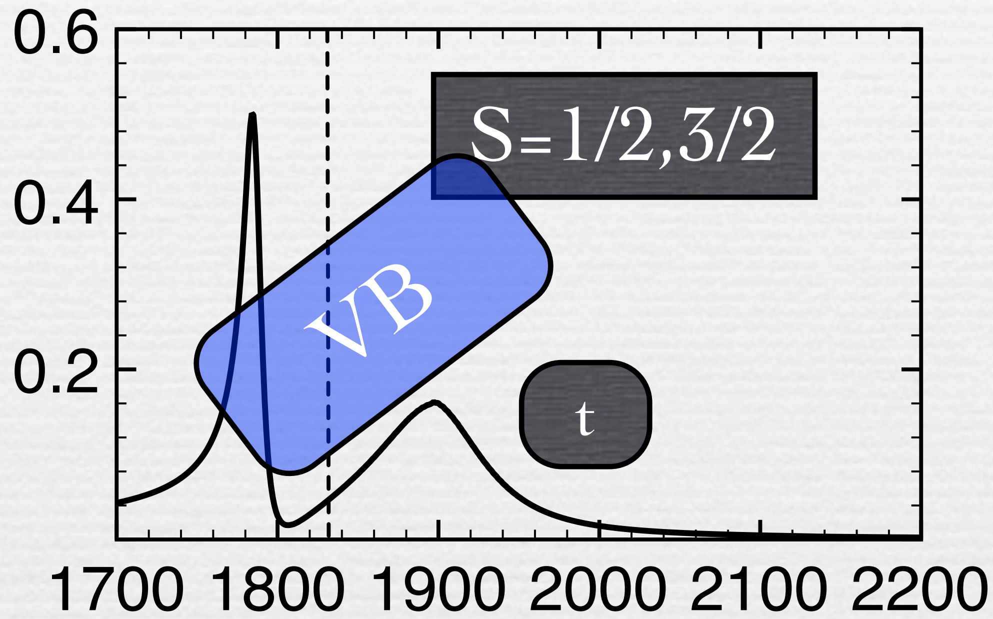
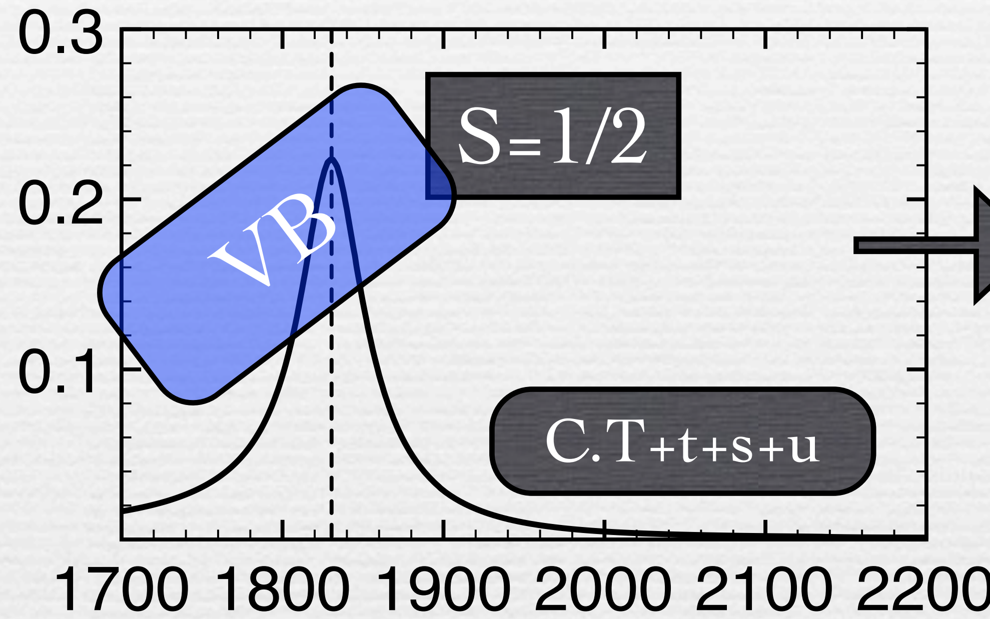


Total energy (MeV)

PB-VB coupled systems: Results

Isospin 0



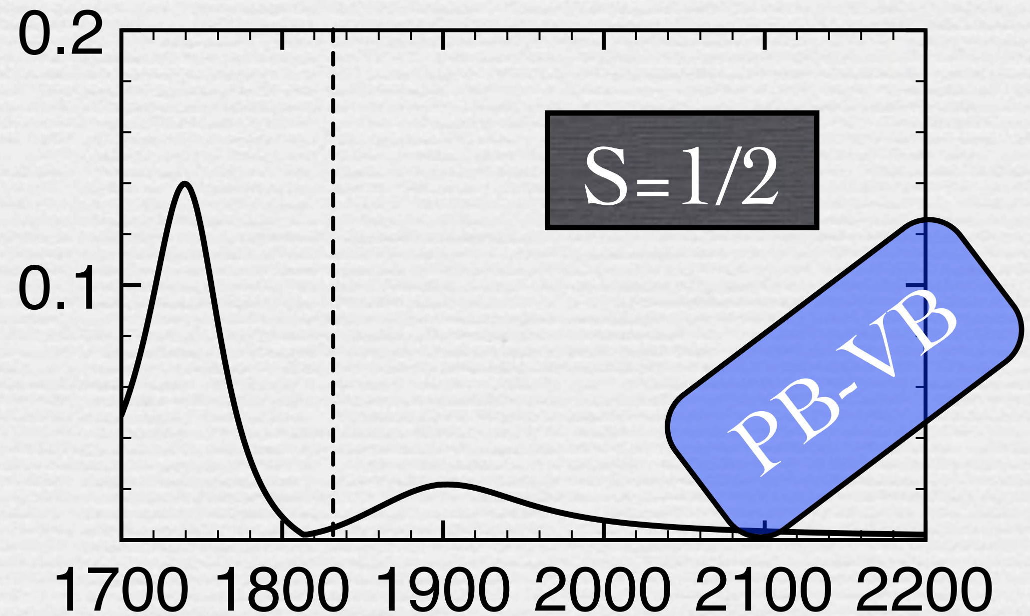


virtual state

Poles:

(i) 1795 - i 20 MeV

(ii) 1923 - i 40 MeV

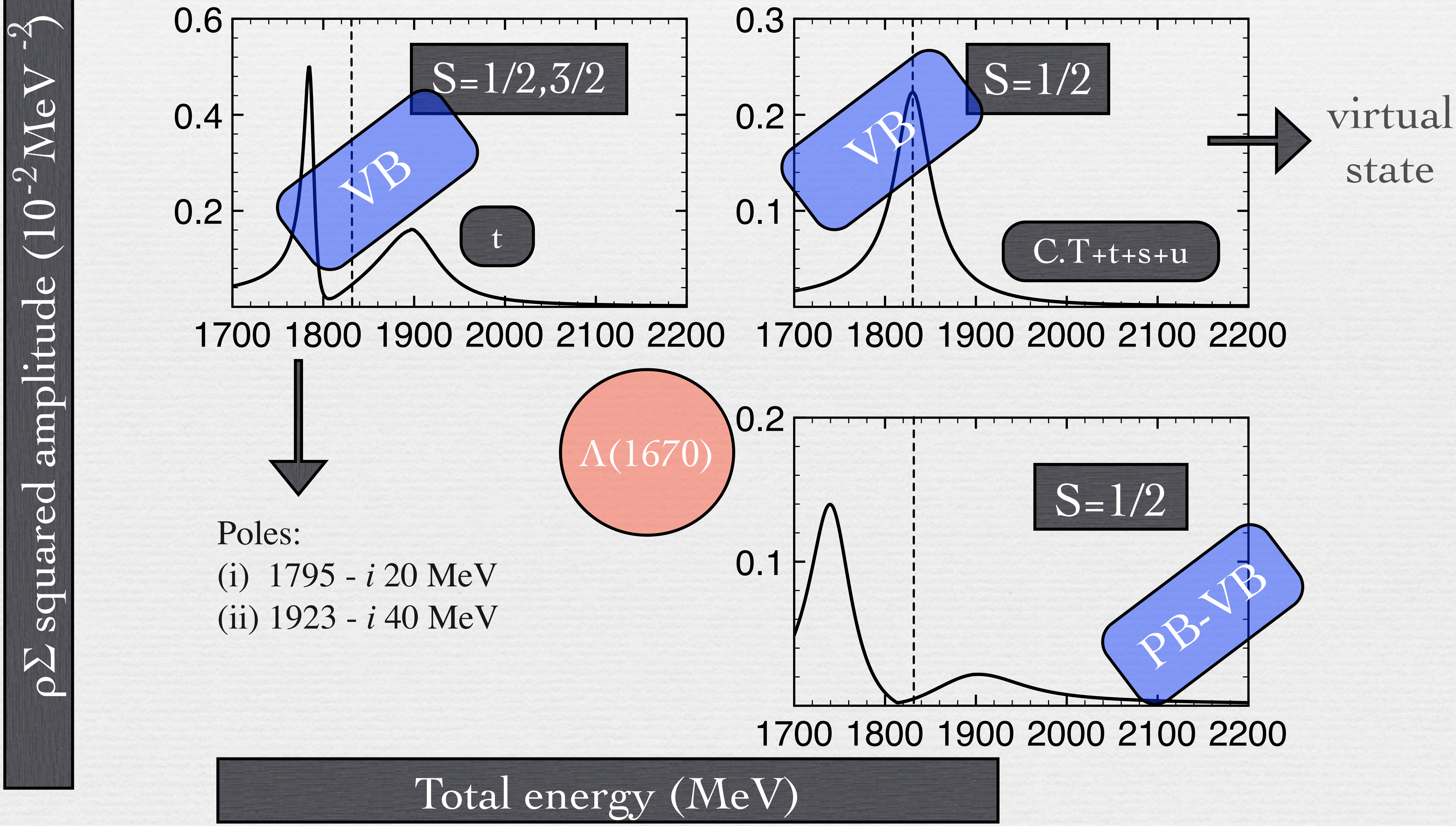


$\rho\Sigma$ squared amplitude (10^{-2}MeV^{-2})

Total energy (MeV)

PB-VB coupled systems: Results

Isospin 0



Poles:

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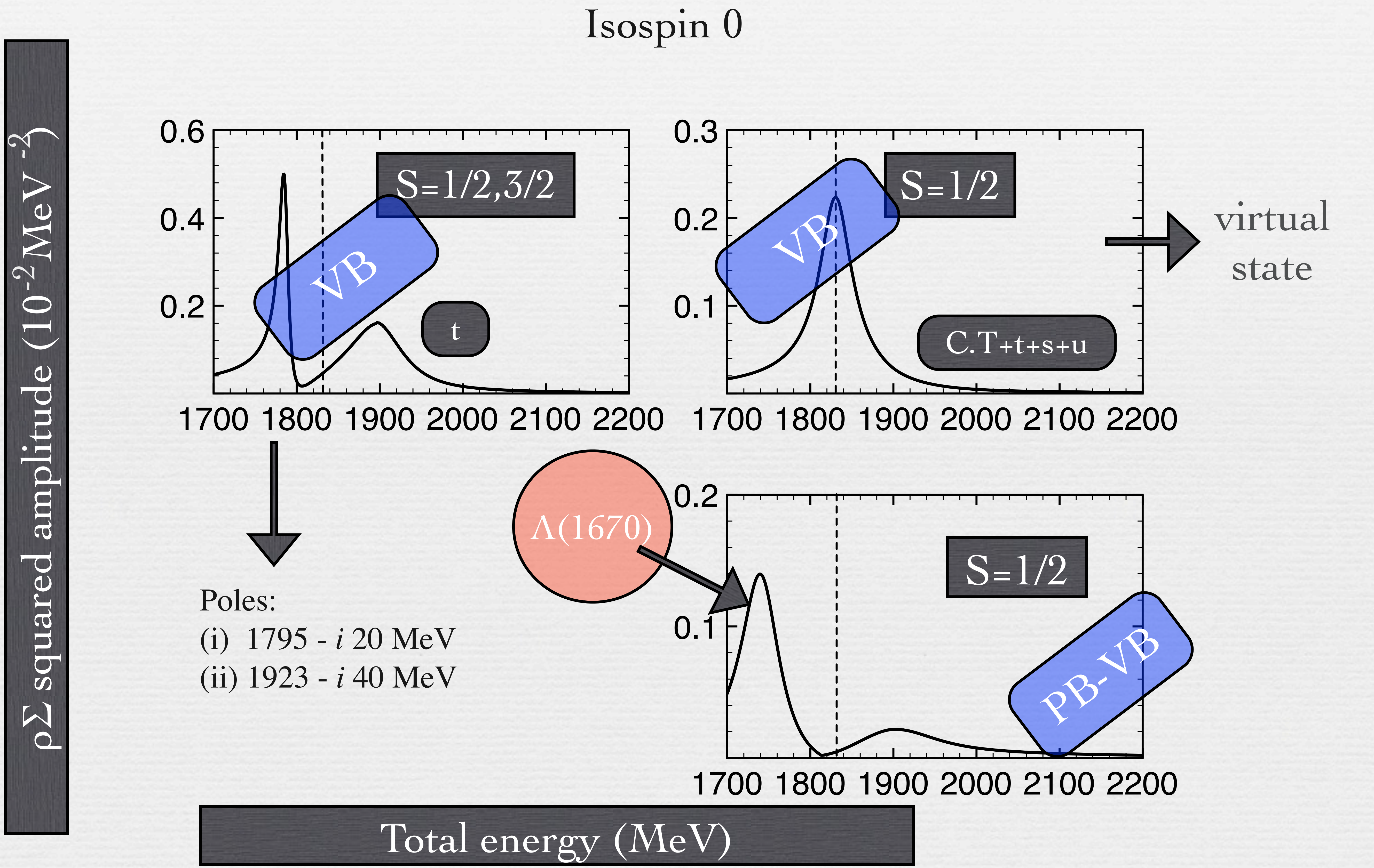
PB-VB coupled systems: Results



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(i) 1795 - *i* 20 MeV
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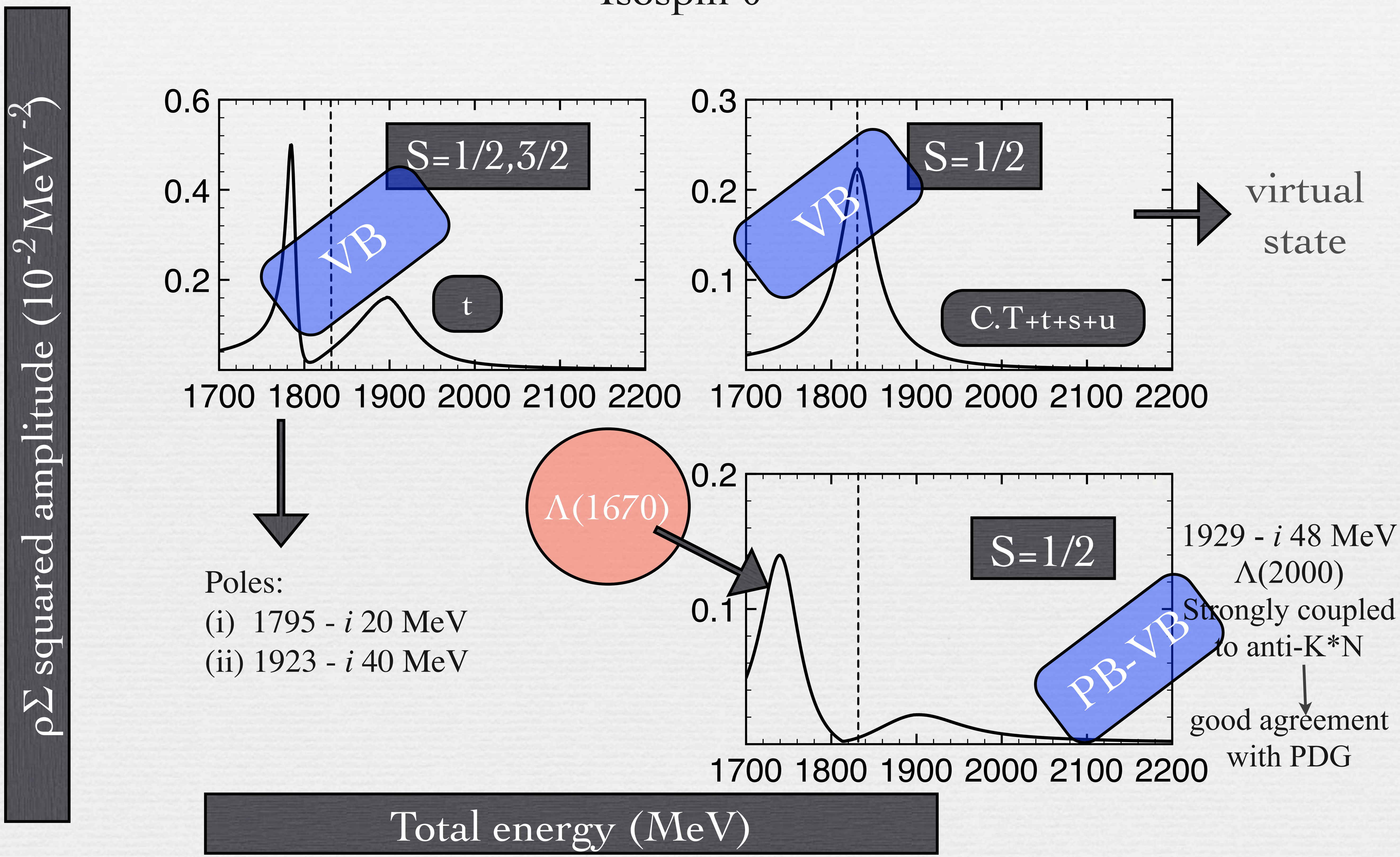
PB-VB coupled systems: Results

Isospin 0



Vector Meson-Baryon interactions: Results

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) $\longrightarrow$	–	$1822 - i15$	–	$1947 - i17$
Channels $\downarrow$	Couplings (g^i) of the poles to the different channels			
$\bar{K}^*N$ (1831)	–	$2.3 - i0.0$	–	$-0.3 + i0.2$
$\rho\Lambda$ (1886)	–	$-0.6 + i0.0$	–	$-0.5 + i0.2$
$\rho\Sigma$ (1963)	–	$-1.9 + i0.0$	–	$2.7 + i0.2$
$\omega\Sigma$ (1975)	–	$-1.0 + i0.0$	–	$0.3 + i0.1$
$K^*\Xi$ (2210)	–	$0.1 - i0.0$	–	$1.9 + i0.2$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$	–	$0.2 - i0.0$

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

Vector Meson-Baryon interactions: Results

Isospin 1

Spin	$\longleftarrow$ $s = 1/2$ $\longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$
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Channels $\downarrow$		Couplings (g^i) of the poles
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(i) 1822 - i16

(ii) 1873 - i88

(iii) 1936 - i132

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

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$K^*\Xi$ (2210)	–	$0.1 - i0.0$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$

(i) 1822 - i16
Real axis: 1800, Γ =32
Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i88

(iii) 1936 - i132

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

Vector Meson-Baryon interactions: Results

Isospin 1

Spin	$\longleftarrow$ $s=1/2$	$\longrightarrow$
	$V=V_t$	$V=V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) $\longrightarrow$	–	$1822 - i15$
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$K^*\Xi$ (2210)	–	$0.1 - i0.0$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$

(i) 1822 - i16 **Σ (1750) $1/2^-$**

Real axis: 1800, Γ =32

Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i88

(iii) 1936 - i132

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

Vector Meson-Baryon interactions: Results

Isospin 1

Spin	$\longleftarrow s = 1/2 \longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) $\longrightarrow$	–	$1822 - i15$
Channels $\downarrow$	Couplings (g^i) of the poles	
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$K^*\Xi$ (2210)	–	$0.1 - i0.0$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$

(i) 1822 - i16 Σ (1750) $1/2^-$

Real axis: 1800, Γ =32

Strongly coupled to: $\eta\Sigma$

(ii) 1873 - i88

Σ (2000) $1/2^-$

(iii) 1936 - i132

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

Vector Meson-Baryon interactions: Results

Isospin 1

Spin	$\longleftarrow s = 1/2 \longrightarrow$	
	$V = V_t$	$V = V_{t+C.T+s+u}$
$M_R - i\Gamma/2$ (MeV) $\longrightarrow$	–	$1822 - i15$
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$\rho\Sigma$ (1963)	–	$-1.9 + i0.0$
$\omega\Sigma$ (1975)	–	$-1.0 + i0.0$
$K^*\Xi$ (2210)	–	$0.1 - i0.0$
$\phi\Sigma$ (2213)	–	$1.6 - i0.0$

(i) 1822 - i16 $\quad$ Σ (1750) $1/2^-$

Real axis: 1800, Γ =32

Strongly coupled to: ηΣ

(ii) 1873 - i88

Real axis: 1 peak $\quad$ Σ (2000) $1/2^-$

(iii) 1936 - i132

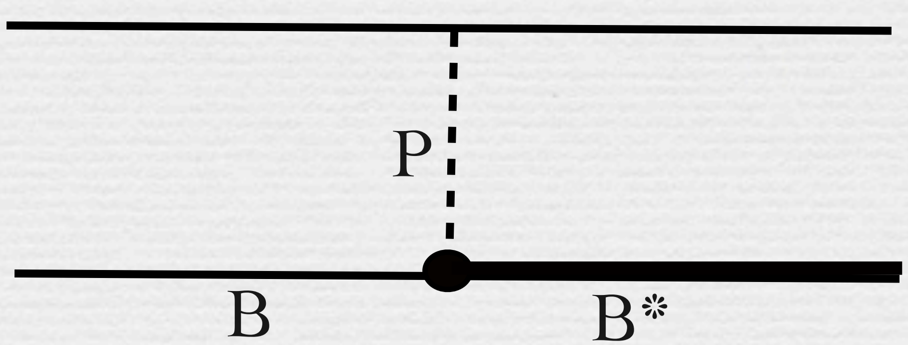
(K. P. Khemchandani, A. M. Torres, H. Kaneko, H. Nagahiro, A. Hosaka, PHYSICAL REVIEW D85 (2012) 114020; arXiv:1203.6711.

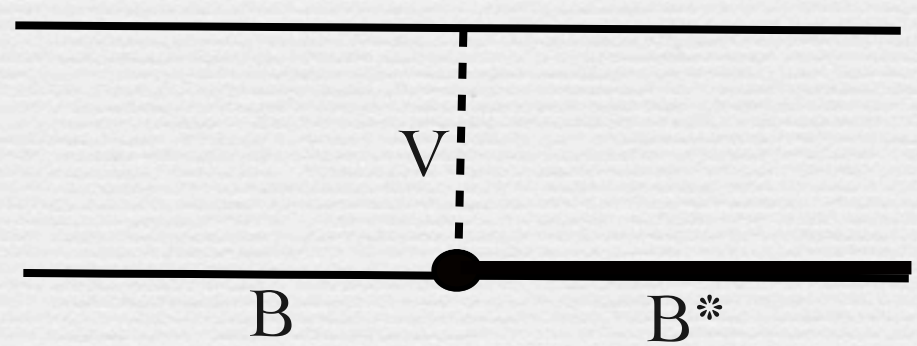
Summary:

- 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 ⇨ very useful information, for instance, to study photoproduction of $\Lambda(1405)$[†].





† **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.