Charming Baryons

Carmen Garcia-Recio,

C. Hidalgo-Duque, J. Nieves, O. Romanets, L.L. Salcedo, L. Tolos

Universidad de Granada

June 16, 2015

Outline

- One heavy **h** and three light $u, \; d, \; s$ flavors are considered.
- Heavy Flavor Spin Symmetry (HQSS) is important.
- P and V mesons and Baryons with $J = 1/2^+$ and $3/2^+$ are considered as constituent hadrons.
- For hidden charm sector ($N_c = N_{\bar{c}} = 1$), meson -Baryon Lagrangian with Heavy Flavor Spin Symmetry is constructed.
- Minimal extension of the SU(3) **WT** Lagrangian to fulfill HQSS
- No free parameter...

Universidad de Granada

Outline

- This interaction is presented in different ways:
  - Field Lagrangian
  - Hadron creation-annihilation operators
  - SU(6)×HQSS projectors
  - Multichannel Matrices
- Multichannel Bethe-Salpeter equation is solved $T = V + VGT$
- Use of our **WT** extended model is done for
  - Hidden Charm N and Δ
  - Beauty Baryons (Λ_b)
- Study of Compositeness $X = 1 - Z$ of $\Lambda,\ \Lambda_c,\ \Lambda_b$ with $J^P = 1/2^-,\ 3/2^-$

N and Δ with hidden charm $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$

- *Quarks:* $q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.
- Heavy flavor ==> Heavy Quark Spin Symmetry ($O(1/m_{\mathbf{h}})$)
  HQSS = $\mathrm{SU}_{\mathbf{h}}(2) \times \mathrm{SU}_{\bar{\mathbf{h}}}(2) \times U_{\mathbf{h}}(1) \times \mathrm{U}_{\bar{\mathbf{h}}}(1)$
  - Hadrons : HQSS multiplets.
  - (D^0, D^{*0}) is a HQSS doublet. mesons : P and V.
  - (Ξ'_c, Ξ^*_c) is a HQSS doublet. Baryons : $B(1/2^+)$ and $B(3/2^+)$
  - Lagrangian with HQSS .
- The resonances are generated by solving the Bethe- Salpeter equation $T = V + VGT$ with the appropriate V interaction and meson -Baryon channels.
- Masses, widths and couplings of N and Δ resonances are calculated.

[*CGR, Nieves, Romanets, Salcedo, Tolos PRD87 (13) 074034*]

N and Δ with hidden charm $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$

- *Quarks:* $q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.
- Heavy flavor ==> Heavy Quark Spin Symmetry ($O(1/m_{\mathbf{h}})$)
  HQSS = $\mathrm{SU}_{\mathbf{h}}(2) \times \mathrm{SU}_{\bar{\mathbf{h}}}(2) \times U_{\mathbf{h}}(1) \times \mathrm{U}_{\bar{\mathbf{h}}}(1)$
  - Hadrons : HQSS multiplets.
  - (D^0, D^{*0}) is a HQSS doublet. mesons : P and V.
  - (Ξ'_c, Ξ^*_c) is a HQSS doublet. Baryons : $B(1/2^+)$ and $B(3/2^+)$
  - Lagrangian with HQSS .
- The resonances are generated by solving the Bethe- Salpeter equation $T = V + VGT$ with the appropriate V interaction and meson -Baryon channels.
- Masses, widths and couplings of N and Δ resonances are calculated.

[*CGR, Nieves, Romanets, Salcedo, Tolos PRD87 (13) 074034*]

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ {D_s}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$$\begin{array}{ccc} & {D_s}^+ & \\ D^0 & & D^+ \end{array} \qquad \begin{array}{ccc} & D_s^{*+} & \\ D^{*0} & & D^{*+} \end{array}$$

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet　　　V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$　　　D_s^{*+}

D^0　D^+　　　D^{*0}　D^{*+}

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Universidad de Granada

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3_1^*-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3_3^*-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3_1^*-plet V 3_3^*-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Universidad de Granada

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ {D_s}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==> $\mathrm{SU}_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

${D_s}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Universidad de Granada

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==>
  $SU_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Universidad de Granada

Constituent Heavy Mesons ($\mathbf{h}\bar{q}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$.

mesons : $N_{\mathbf{h}} = 1, N_{\bar{\mathbf{h}}} = 0$, $(\mathbf{h}_{1/2}\bar{q}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar $D^+, D^0,\ D_s{}^+$ (3^*_1-plet) are HQSS partners of
- Vector D^{*+}, D^{*0}, D_s^{*+} (3^*_3-plet) mesons.
- Global Spin invariance + HQ spin invariance ==> all quark spin invariance for heavy-light mesons==>
  $\mathrm{SU}_{SF}(6)$ of spin-flavor for light quarks is also fulfilled.
- (P) + (V) with $N_{\mathbf{h}} = 1$ are made of a light SU(6) 6^*-plet coupled to the spin $j_{\mathbf{h}} = 1/2$ of the $\mathbf{h}$−quark.

P 3^*_1-plet V 3^*_3-plet

HQSS − *doublet*

$D_s{}^+$ D_s^{*+}

D^0 D^+ D^{*0} D^{*+}

Universidad de Granada

Constituent Heavy Mesons ($\mathbf{h}\bar{\mathbf{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$

mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\,1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet

HQSS − *doublet*

η_c ψ

Constituent Heavy Mesons ($\mathbf{h\bar{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$

mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\,1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet

HQSS − *doublet*

η_c ψ

Constituent Heavy Mesons ($\mathbf{h}\bar{\mathbf{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$

mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet

HQSS − *doublet*

η_c ψ

Constituent Heavy Mesons ($\mathbf{h}\bar{\mathbf{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$

mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\ 1}$,

HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet

HQSS − *doublet*

η_c ψ

Constituent Heavy Mesons ($\mathbf{h}\bar{\mathbf{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$
mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\,1}$,
HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet
HQSS − *doublet*
η_c ψ

Constituent Heavy Mesons ($\mathbf{h}\bar{\mathbf{h}}$)

$q \in \{u, d, s\}$, $\mathbf{h} \in \{c, b\}$
mesons : $N_{\mathbf{h}} = N_{\bar{\mathbf{h}}} = 1$, $(\mathbf{h}_{1/2}\bar{\mathbf{h}}_{1/2})_{J=0,\ 1}$,
HQSS implies $J^P = 0^-,\ 1^-$ are degenerated.

- Pseudoscalar η_c (1_1-plet) is HQSS partner of
- Vector ψ (1_3-plet) meson.

P 1_1-plet V 1_3-plet
HQSS − *doublet*
η_c ψ

Constituent Heavy Baryons ($\mathbf{h}qq$)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1 q_2)_{j_l})$, considering that $q_1 q_2$ are in a symmetric state in spin-flavor, they belong to a $SU_{SF}(6)$ 21-plet which can be reduced in $SU_F(3) \times SU_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0} \times \mathbf{h}_{j_h=1/2} = 3^*_{J=1/2}$: $\Lambda_{\mathbf{h}}, \Xi_{\mathbf{h}}$
  - HQSS Doublet $6_{j_l=1} \times \mathbf{h}_{j_h=1/2} = 6_{J=1/2,3/2}$: $\Sigma_{\mathbf{h}}, \Xi'_{\mathbf{h}}, \Omega_{\mathbf{h}}$ with $J = 1/2$ are HQSS partners of $\Sigma^*_{\mathbf{h}}, \Xi^*_{\mathbf{h}}, \Omega^*_{\mathbf{h}}$ with $J = 3/2$.

3^*_2-plet	6_2-plet	6_4-plet
HQSS -singlet	HQSS -doublet	
	$\Sigma_c^{\,0}$ $\Sigma_c^{\,+}$ $\Sigma_c^{\,++}$	Σ_c^{*0} Σ_c^{*+} Σ_c^{*++}
$\Lambda_c^{\,+}$	$\Xi_c'^{\,0}$ $\Xi_c'^{\,+}$	Ξ_c^{*0} Ξ_c^{*+}
$\Xi_c^{\,0}$ $\Xi_c^{\,+}$	Ω_c^{*0}	Ω_c^{*0}

Universidad de Granada

Constituent Heavy Baryons (**h**qq)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1 q_2)_{j_l})$, considering that $q_1 q_2$ are in a symmetric state in spin-flavor, they belong to a $SU_{SF}(6)$ 21-plet which can be reduced in $SU_F(3) \times SU_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0} \times \mathbf{h}_{j_h=1/2} = 3^*_{J=1/2}$: $\Lambda_\mathbf{h}, \Xi_\mathbf{h}$
  - HQSS Doublet $6_{j_l=1} \times \mathbf{h}_{j_h=1/2} = 6_{J=1/2,3/2}$: $\Sigma_\mathbf{h}, \Xi'_\mathbf{h}, \Omega_\mathbf{h}$ with $J = 1/2$ are HQSS partners of $\Sigma^*_\mathbf{h}, \Xi^*_\mathbf{h}, \Omega^*_\mathbf{h}$ with $J = 3/2$.

3^*_2-plet	6_2-plet	6_4-plet
HQSS -singlet	HQSS -doublet	
	$\Sigma_c{}^0$ $\Sigma_c{}^+$ $\Sigma_c{}^{++}$	Σ_c^{*0} Σ_c^{*+} Σ_c^{*++}
$\Lambda_c{}^+$	$\Xi'^{\,0}_c$ $\Xi'^{\,+}_c$	Ξ_c^{*0} Ξ_c^{*+}
$\Xi_c{}^0$ $\Xi_c{}^+$	Ω_c^{*0}	Ω_c^{*0}

Constituent Heavy Baryons ($\mathbf{h}qq$)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1q_2)_{j_l})$, considering that q_1q_2 are in a symmetric state in spin-flavor, they belong to a $SU_{SF}(6)$ 21-plet which can be reduced in $SU_F(3)\times SU_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0}\times \mathbf{h}_{j_h=1/2} = 3^*_{J=1/2}$: $\Lambda_\mathbf{h}, \Xi_\mathbf{h}$
  - HQSS Doublet $6_{j_l=1}\times \mathbf{h}_{j_h=1/2} = 6_{J=1/2,3/2}$: $\Sigma_\mathbf{h}, \Xi'_\mathbf{h}, \Omega_\mathbf{h}$ with $J=1/2$ are HQSS partners of $\Sigma^*_\mathbf{h}, \Xi^*_\mathbf{h}, \Omega^*_\mathbf{h}$ with $J=3/2$.

3^*_2-plet HQSS -singlet

$\Lambda_c{}^+$

$\Xi_c{}^0$ $\Xi_c{}^+$

6_2-plet

$\Sigma_c{}^0$ $\Sigma_c{}^+$ $\Sigma_c{}^{++}$

$\Xi'_c{}^0$ $\Xi'_c{}^+$

Ω_c^{*0}

6_4-plet

HQSS -doublet

Σ_c^{*0} Σ_c^{*+} Σ_c^{*++}

Ξ_c^{*0} Ξ_c^{*+}

Ω_c^{*0}

Constituent Heavy Baryons ($\mathbf{h}qq$)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1 q_2)_{j_l})$, considering that $q_1 q_2$ are in a symmetric state in spin-flavor, they belong to a $SU_{SF}(6)$ 21-plet which can be reduced in $SU_F(3) \times SU_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0} \times \mathbf{h}_{j_\mathbf{h}=1/2} = 3^*_{J=1/2}$: $\Lambda_\mathbf{h}, \Xi_\mathbf{h}$
  - HQSS Doublet $6_{j_l=1} \times \mathbf{h}_{j_\mathbf{h}=1/2} = 6_{J=1/2,\,3/2}$:
    $\Sigma_\mathbf{h}, \Xi'_\mathbf{h}, \Omega_\mathbf{h}$ with $J = 1/2$ are HQSS partners of
    $\Sigma^*_\mathbf{h}, \Xi^*_\mathbf{h}, \Omega^*_\mathbf{h}$ with $J = 3/2$.

3^*_2-plet
HQSS -singlet

6_2-plet
HQSS -doublet

6_4-plet

$\Sigma_c{}^0$ $\Sigma_c{}^+$ $\Sigma_c{}^{++}$ Σ_c^{*0} Σ_c^{*+} Σ_c^{*++}

$\Lambda_c{}^+$

$\Xi'_c{}^0$ $\Xi'_c{}^+$ Ξ_c^{*0} Ξ_c^{*+}

$\Xi_c{}^0$ $\Xi_c{}^+$

Ω_c^{*0} Ω_c^{*0}

Constituent Heavy Baryons ($\mathbf{h}qq$)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1q_2)_{j_l})$, considering that q_1q_2 are in a symmetric state in spin-flavor, they belong to a $SU_{SF}(6)$ 21-plet which can be reduced in $SU_F(3)\times SU_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0}\times \mathbf{h}_{j_h=1/2} = 3^*_{J=1/2}$: $\Lambda_\mathbf{h}, \Xi_\mathbf{h}$
  - HQSS Doublet $6_{j_l=1}\times \mathbf{h}_{j_h=1/2} = 6_{J=1/2,3/2}$: $\Sigma_\mathbf{h}, \Xi'_\mathbf{h}, \Omega_\mathbf{h}$ with $J=1/2$ are HQSS partners of $\Sigma^*_\mathbf{h}, \Xi^*_\mathbf{h}, \Omega^*_\mathbf{h}$ with $J=3/2$.

Constituent Heavy Baryons ($\mathbf{h}qq$)

- **Baryons:** $(\mathbf{h}_{j_h=1/2}(q_1 q_2)_{j_l})$, considering that $q_1 q_2$ are in a symmetric state in spin-flavor, they belong to a $\mathrm{SU}_{SF}(6)$ 21-plet which can be reduced in $\mathrm{SU}_F(3) \times \mathrm{SU}_S(2)$ as $21 = 3^*_0 \oplus 6_1$
  - HQSS Singlet $3^*_{j_l=0} \times \mathbf{h}_{j_h=1/2} = 3^*_{J=1/2}$: $\Lambda_\mathbf{h}, \Xi_\mathbf{h}$
  - HQSS Doublet $6_{j_l=1} \times \mathbf{h}_{j_\mathbf{h}=1/2} = 6_{J=1/2,3/2}$: $\Sigma_\mathbf{h}, \Xi'_\mathbf{h}, \Omega_\mathbf{h}$ with $J = 1/2$ are HQSS partners of $\Sigma^*_\mathbf{h}, \Xi^*_\mathbf{h}, \Omega^*_\mathbf{h}$ with $J = 3/2$.

3^*_2-plet

HQSS -singlet

$\Lambda_c{}^+$

$\Xi_c{}^0$ $\Xi_c{}^+$

6_2-plet

$\Sigma_c{}^0$ $\Sigma_c{}^+$ $\Sigma_c{}^{++}$

$\Xi'_c{}^0$ $\Xi'_c{}^+$

Ω_c^{*0}

HQSS -doublet

6_4-plet

Σ_c^{*0} Σ_c^{*+} Σ_c^{*++}

Ξ_c^{*0} Ξ_c^{*+}

Ω_c^{*0}

Universidad de Granada

Constituent light hadrons, $(q\bar{q})$ and (qqq)

- For consistency: P and V mesons and $1/2^+$ and $3/2^+$ Baryons .
- The light mesons are those of the 35-SU(6)-plet$=8_1 \oplus (8_3 \oplus 1_3)$, which includes the pseudoscalar meson octet of the pions, $(\pi,\ \eta,\ K,\ \bar{K}) \in 8_1$ and the vector nonet of the rho-mesons, $(\rho, \omega, \phi, K^*, \bar{K}^*) \in 8_3 \oplus 1_3$.
- The Baryons are those of the 56-SU(6)-plet$=8_2 \oplus 10_4$, made of the $1/2^+$ octet of the N $(N,\ \Lambda,\ \Sigma,\ \Xi)$ and the $3/2^+$ decuplet of the Δ $(\Delta,\ \Sigma^*,\ \Xi^*,\ \Omega)$.

Universidad de Granada

Constituent light hadrons, $(q\bar{q})$ and (qqq)

- For consistency: P and V mesons and $1/2^+$ and $3/2^+$ Baryons .
- The light mesons are those of the 35-SU(6)-plet$=8_1 \oplus (8_3 \oplus 1_3)$, which includes the pseudoscalar meson octet of the pions, $(\pi,\ \eta,\ K,\ \bar{K}) \in 8_1$ and the vector nonet of the rho-mesons, $(\rho, \omega, \phi, K^*, \bar{K}^*) \in 8_3 \oplus 1_3$.
- The Baryons are those of the 56-SU(6)-plet$=8_2 \oplus 10_4$, made of the $1/2^+$ octet of the N $(N,\ \Lambda,\ \Sigma,\ \Xi)$ and the $3/2^+$ decuplet of the Δ $(\Delta,\ \Sigma^*,\ \Xi^*,\ \Omega)$.

ugr Universidad de Granada

Constituent light hadrons, $(q\bar{q})$ and (qqq)

- For consistency: P and V mesons and $1/2^+$ and $3/2^+$ Baryons .
- The light mesons are those of the 35-SU(6)-plet$=8_1 \oplus(8_3 \oplus 1_3)$, which includes the pseudoscalar meson octet of the pions, $(\pi,\ \eta,\ K,\ \bar{K}) \in 8_1$ and the vector nonet of the rho-mesons, $(\rho, \omega, \phi, K^*, \bar{K}^*) \in 8_3 \oplus 1_3$.
- The Baryons are those of the 56-SU(6)-plet$=8_2 \oplus 10_4$, made of the $1/2^+$ octet of the N ($N,\ \Lambda,\ \Sigma,\ \Xi$) and the $3/2^+$ decuplet of the Δ ($\Delta,\ \Sigma^*,\ \Xi^*,\ \Omega$).

Universidad de Granada

Constituent light hadrons, $(q\bar{q})$ and (qqq)

- For consistency: P and V mesons and $1/2^+$ and $3/2^+$ Baryons .
- The light mesons are those of the 35-SU(6)-plet$=8_1 \oplus (8_3 \oplus 1_3)$, which includes the pseudoscalar meson octet of the pions, $(\pi,\ \eta,\ K,\ \bar{K}) \in 8_1$ and the vector nonet of the rho-mesons, $(\rho, \omega, \phi, K^*, \bar{K}^*) \in 8_3 \oplus 1_3$.
- The Baryons are those of the 56-SU(6)-plet$=8_2 \oplus 10_4$, made of the $1/2^+$ octet of the N $(N,\ \Lambda,\ \Sigma,\ \Xi)$ and the $3/2^+$ decuplet of the Δ $(\Delta,\ \Sigma^*,\ \Xi^*,\ \Omega)$.

Hadronic Building Blocks

$$
\begin{aligned}
\bar{\mathbf{D}} &= (\{\bar{D}, \bar{D}^*\}, \{\bar{D}_s, \bar{D}_s^*\}), \\
\boldsymbol{\psi} &= \{\eta_c, \psi\}, \\
N &= (N, \Sigma, \Xi, \Lambda), \\
\Delta &= (\Delta, \Sigma^*, \Xi^*, \Omega), \\
\boldsymbol{\Xi_c} &= (\Xi_c, \Lambda_c), \\
\boldsymbol{\Sigma_c} &= (\{\Sigma_c, \Sigma_c^*\}, \{\Xi_c', \Xi_c^*\}, \{\Omega_c, \Omega_c^*\}).
\end{aligned}
$$

Universidad de Granada

- Focus on the sector with hidden charm and $C = 0$.
- Write down the most general (modulo kinematical factors) S-wave Lagrangian consistent with SU(3) $\times$ HQSS for the baryon-meson coupled-channels space.
- For this purpose it is convenient to organize the hadrons forming multiplets of HQSS into building blocks with well defined HQSS transformation properties. *[Falk,Grinstein,Jenkins,Manohar,Wise]*.

Specifically, consider a HQSS doublet composed of pseudoscalar meson and vector meson with one heavy quark (e.g. D and D^*).

HQSS field doublets:

$$\begin{aligned} \mathbf{D} &= Q_+({D^*_\mu}^{(+)}\gamma^\mu + D^{(+)}\gamma_5), \\ \boldsymbol{\psi} &= Q_+({\psi_\mu}^{(+)}\gamma^\mu + {\eta_c}^{(+)}\gamma_5). \end{aligned}$$

As usual $(+)$ represents the positive frequency part of the fields, corresponding to purely annihilation field.

$$Q_+ = \frac{1+ \not{v}}{2} \qquad \text{(-1)}$$

where v^μ is the heavy hadron velocity ($v^2 = 1$)

[A.V. Manohar and M.B. Wise, *Heavy Quark Physics*, Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology, vol. 10 (2000).]

ugr Universidad de Granada

HQSS $N_{\mathbf{h}} = 1$ Baryon doublets:

$$\boldsymbol{\Sigma}_{\mathbf{c}}{}^{\mu} = \Sigma_c^{*\,\mu(+)} + \frac{1}{\sqrt{3}}(\gamma^\mu + v^\mu)\gamma_5 \Sigma_c{}^{(+)}.$$

- Σ_c is the Dirac spinor of the $1/2^+$ baryon in the doublet
- $\Sigma_c^{*\,\mu}$ is the Rarita-Schwinger field for the $3/2^+$ baryon $v_\mu \Sigma_c^{*\,\mu} = \gamma_\mu \Sigma_c^{*\,\mu} = 0$.

Finally, for a HQSS singlet baryon with exactly one **h** quark (e.g., Λ_c)

HQSS $N_{\mathbf{h}} = 1$ Baryon singlets:

$$\boldsymbol{\Lambda}_{\mathbf{c}} = \Lambda_c{}^{(+)}, \qquad \overline{\boldsymbol{\Lambda}_{\mathbf{c}}} = \boldsymbol{\Lambda}_{\mathbf{c}}{}^{\dagger}\gamma_0 = \overline{\Lambda_c}{}^{(-)}$$

[A.V. Manohar and M.B. Wise, *Heavy Quark Physics*, Cambridge Monographs on Particle Physics, Nuclear Physics and Cosmology, vol. 10 (2000).]

Universidad de Granada

Lagrangian with SU(3)− and HQSS symmetries

[*CGR, Nieves, Romanets, Salcedo, Tolos PRD87 (13) 074034*]

Hidden Heavy Flavor: $N_{\mathbf{h}} = 1, \; N_{\bar{\mathbf{h}}} = 1$

- Next, we write down the 12 most general operators allowed by SU(3) × HQSS in the baryon-meson coupled-channels space, in S-wave and preserving parity.
- The operator $\overleftrightarrow{\partial}_v = v^\mu(\overrightarrow{\partial}_\mu - \overleftarrow{\partial}_\mu)$ acts on the mesons only
- and it is introduced in order to produce the correct kinematical dependence in the amplitudes.

$$
\begin{aligned}
\mathscr{L}_1(x) &= g_1 \, \overline{N}^a{}_b N^b{}_a \, \mathrm{tr}(\overline{\psi} \, i \overleftrightarrow{\partial}_v \psi), \\
\mathscr{L}_2(x) &= g_2 \, \frac{1}{3!} \overline{\Delta}^\mu_{abc} \Delta^{abc}_\mu \, \mathrm{tr}(\overline{\psi} \, i \overleftrightarrow{\partial}_v \psi),
\end{aligned}
$$

ugr Universidad de Granada

$$
\begin{aligned}
\mathcal{L}_1(x) &= g_1\, \overline{N}^a{}_b N^b{}_a \,\mathrm{tr}(\overline{\psi}\, i\overleftrightarrow{\partial}_\nu \psi), \\
\mathcal{L}_2(x) &= g_2\, \frac{1}{3!}\overline{\Delta}^{\mu}_{abc}\Delta^{abc}_{\mu}\,\mathrm{tr}(\overline{\psi}\, i\overleftrightarrow{\partial}_\nu \psi), \\
\mathcal{L}_3(x) &= g_3\, \overline{\boldsymbol{\Xi}_{\mathbf{c}}}^{a}\psi(-i\overleftrightarrow{\partial}_\nu)\bar{\bar{\mathbf{D}}}_b N^b{}_a + \text{h.c.}, \\
\mathcal{L}_4(x) &= g_4\, \epsilon^{bcd}\overline{\boldsymbol{\Sigma}_{\mathbf{c}}}^{\mu}{}_{ab}\psi(-i\overleftrightarrow{\partial}_\nu)\bar{\bar{\mathbf{D}}}_c\gamma_\mu\gamma_5 N^a{}_d + \text{h.c.}, \\
\mathcal{L}_5(x) &= g_5\, \frac{1}{2}\overline{\boldsymbol{\Sigma}_{\mathbf{c}}}^{\mu}{}_{ab}\psi(-i\overleftrightarrow{\partial}_\nu)\bar{\bar{\mathbf{D}}}_c\,\Delta^{abc}_{\mu} + \text{h.c.}, \\
\mathcal{L}_6(x) &= g_6\, \overline{\boldsymbol{\Xi}_{\mathbf{c}}}^{a}\boldsymbol{\Xi}_{\mathbf{c}a}\,\mathrm{tr}(\bar{\bar{\mathbf{D}}}_b\, i\overleftrightarrow{\partial}_\nu \bar{\mathbf{D}}^b), \\
\mathcal{L}_7(x) &= g_7\, \overline{\boldsymbol{\Xi}_{\mathbf{c}}}^{a}\boldsymbol{\Xi}_{\mathbf{c}b}\,\mathrm{tr}(\bar{\bar{\mathbf{D}}}_a\, i\overleftrightarrow{\partial}_\nu \bar{\mathbf{D}}^b), \\
\mathcal{L}_8(x) &= g_8\, \epsilon^{bcd}\overline{\boldsymbol{\Sigma}_{\mathbf{c}}}^{\mu}{}_{ab}\boldsymbol{\Xi}_{\mathbf{c}d}\,\mathrm{tr}(\bar{\bar{\mathbf{D}}}_c\gamma_\mu\gamma_5\, i\overleftrightarrow{\partial}_\nu \bar{\mathbf{D}}^a) + \text{h.c.}, \\
\mathcal{L}_9(x)+\mathcal{L}_{10}(x) &= \frac{1}{2}\overline{\boldsymbol{\Sigma}_{\mathbf{c}}}^{\mu}{}_{ab}\boldsymbol{\Sigma}_{\mathbf{c}}{}^{\nu ab}\,\mathrm{tr}(\bar{\bar{\mathbf{D}}}_c(g_9\, g_{\mu\nu} + g_{10}\, i\sigma_{\mu\nu})\, i\overleftrightarrow{\partial}_\nu \bar{\mathbf{D}}^c), \\
\mathcal{L}_{11}(x)+\mathcal{L}_{12}(x) &= \overline{\boldsymbol{\Sigma}_{\mathbf{c}}}^{\mu}{}_{ac}\boldsymbol{\Sigma}_{\mathbf{c}}{}^{\nu bc}\,\mathrm{tr}(\bar{\bar{\mathbf{D}}}_b(g_{11}\, g_{\mu\nu} + g_{12}\, i\sigma_{\mu\nu})\, i\overleftrightarrow{\partial}_\nu \bar{\mathbf{D}}^a).
\end{aligned}
$$

The traces refer to Dirac space.

- It has **12** independent terms.
- We want to use symmetries or appropriate assumptions to reduce them
- Enforcing also $SU(6)$ **light spin-flavor** and **Chiral** symmetries
- plus *minimal* extension of **WT** interaction, only **one** independent combination remains.

- It has **12** independent terms.
- We want to use symmetries or appropriate assumptions to reduce them
- Enforcing also $SU(6)$ **light spin-flavor** and **Chiral** symmetries
- plus *minimal* extension of **WT** interaction, only **one** independent combination remains.

Universidad de Granada

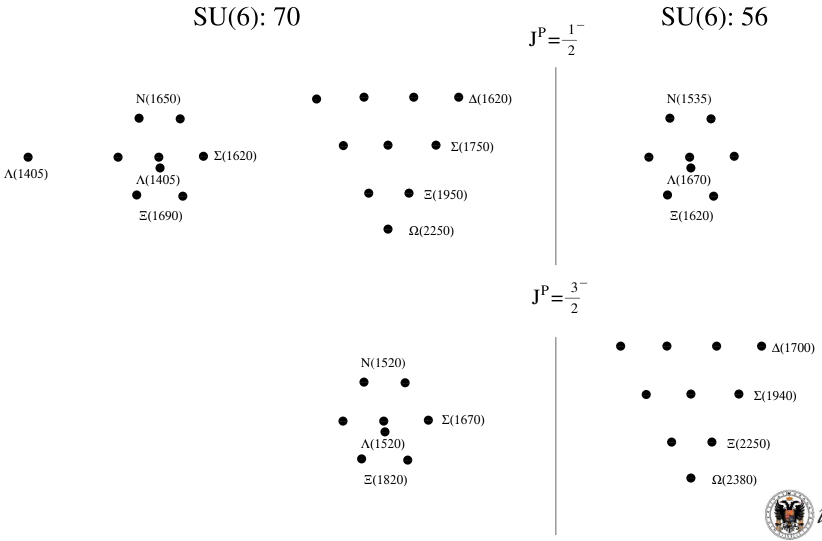
- It has **12** independent terms.
- We want to use symmetries or appropriate assumptions to reduce them
- Enforcing also $SU(6)$ **light spin-flavor** and **Chiral** symmetries
- plus *minimal* extension of **WT** interaction, only **one** independent combination remains.

- It has **12** independent terms.
- We want to use symmetries or appropriate assumptions to reduce them
- Enforcing also $SU(6)$ **light spin-flavor** and **Chiral** symmetries
- plus *minimal* extension of **WT** interaction, only **one** independent combination remains.

Justifying SU(6) light SF symmetry

- Theoretical reasons:
  - Experimental spectroscopy
  - Large N_C limit
  - LQCD results
- Previous Calculations:
  - $\Lambda_c \cdots$, "Charmed baryon resonances ",
    PRD 79, 054004 (2009), CGR, Magas, Mizutani, Nieves, Ramos, Salcedo, Tolos
  - N, Δ, "Odd-parity light baryon resonances"
    PRD 84, 056017 (2011),D Gamermann, CGR, J Nieves, L L Salcedo *

Odd-parity light excited baryon resonances



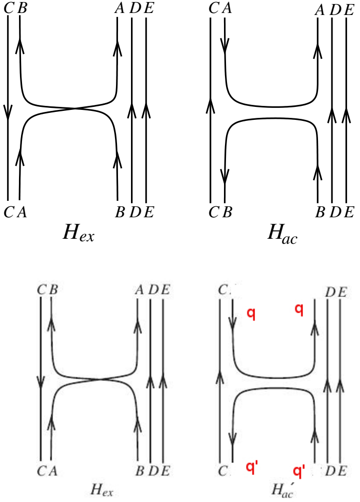
Universidad de Granada

Justifying SU(6) light SF symmetry

- Theoretical reasons:
  - Experimental spectroscopy
  - Large N_C limit
  - LQCD results
- Previous Calculations:
  - $\Lambda_c \cdots$, "Charmed baryon resonances ",
    PRD 79, 054004 (2009), CGR, Magas, Mizutani, Nieves, Ramos, Salcedo, Tolos
  - N, Δ, "Odd-parity light baryon resonances"
    PRD 84, 056017 (2011),D Gamermann, CGR, J Nieves, L L Salcedo *
- Practical reasons:
  - P and V mesons has to be included together (HQSS).
  - $1/2^+$ and $3/2^+$ Baryons also.
  - Importance of P and V mesons interferences.
  - Reduce number of parameters.

Extended WT model with SU(6) and HQSS

- Unique $SU(2N_F)$ extension of $SU(3)$ **WT** interaction:
  $H_{WT} = H_{ex} + H_{ac}$,
- Including heavy flavors:
  $\mathbf{h\bar{h}}$ annihilation in H_{ac} breaks HQSS
  H_{WT} is not HQSS
- Minimal modification to impose HQSS
  - Omit $\mathbf{h\bar{h}}$ annihilation in H
  - $A, B \notin \mathbf{h}$ for H_{ac}',
    $H_{WT}' = H_{ex} + H_{ac}'$ is HQSS
- H_{WT}' keeps light spin-flavor SU(6), HQSS and Chiral symmetries.



Our extended **WT** model with **SF** and HQSS gives the following values for the parameters:

$$\hat{g}_i = 4f^2 g_i,$$

$$
\begin{aligned}
N\psi &\to N\psi, & \hat{g}_1 &= 0, & &\text{OZI rule}\\
\Delta\psi &\to \Delta\psi, & \hat{g}_2 &= 0, & &\text{OZI rule}\\
N\psi &\leftrightarrow \Xi_c\bar{D}, & \hat{g}_3 &= \sqrt{3/2}, & &\\
N\psi &\leftrightarrow \Sigma_c\bar{D}, & \hat{g}_4 &= \sqrt{1/6}, & &\\
\Delta\psi &\leftrightarrow \Sigma_c\bar{D}, & \hat{g}_5 &= -1, & &\\
\Xi_c\bar{D} &\to \Xi_c\bar{D}, & \hat{g}_6 &= 1/2, & \hat{g}_7 &= -1/2,\\
\Xi_c\bar{D} &\leftrightarrow \Sigma_c\bar{D}, & \hat{g}_8 &= 1/2, & &\\
\Sigma_c\bar{D} &\to \Sigma_c\bar{D}, & \hat{g}_9 &= \hat{g}_{10} = 0, \hat{g}_{11} = \hat{g}_{12} = -1/2. & &
\end{aligned}
$$

Our model fulfills OZI rule (the vanishing of g_1 and g_2).

Universidad de Granada

- **Hidden gauge model** also fulfills HQSS and reduces to SU(3) **WT** potential for the hidden charm N, Δ, Λ sector.
- It gives a different set of g_i parameters.

  CW Xiao, J Nieves, E Oset - PRD 88 (2013) 056012 "Combining heavy quark spin and local hidden gauge symmetries in the dynamical generation of hidden charm baryons"
- The HQSS extension of **WT** model is not unique.
- The model has been recently used for studying hidden beauty baryon states.

  CW Xiao, E Oset - Eur.Phys.J. A49 (2013) 139, "Hidden beauty baryon states in the local hidden gauge approach with heavy quark spin symmetry "

ugr Universidad de Granada

- We should note that we actually compute the matrix elements of our interaction using directly the expressions
  - either in terms of hadron creation and annihilation operators in spin-flavor space, by taking Wick contractions.

$$
\begin{aligned}
H_{\rm WT}' &= H_{\rm ex} + H_{\rm ac}', \\
H_{\rm ex} &= :M^A{}_C M^{\dagger C}{}_B B^{BDE} B^\dagger_{ADE}:, \quad A,\dots,E = 1,\dots,2N_F, \\
H_{\rm ac}' &= -:M^{\dagger a}{}_C M^C{}_b B^{bDE} B^\dagger_{aDE}:, \quad a,b = 1,\dots,2(N_F-1).
\end{aligned}
$$

  - Or given in terms of projectors using Clebsch-Gordan coefficients

$$
\mathscr{H}_{C=0} = \mathbf{56}_{2,0} \oplus \mathbf{56}_{2,0} \oplus \mathbf{70}_{2,0}, \quad (\mathrm{SU}(6) \times \mathrm{HQSS}) \quad R_{2j_c+1,\,C}.
$$

The eigenvalues turn out to be $\lambda_{\mathbf{56}_{2,0}} = \lambda_{\mathbf{70}_{2,0}} = -2, \qquad \lambda'_{\mathbf{56}_{2,0}} = 6.$

- Nevertheless, writing the interaction in field-theoretical Lagrangian form is highly interesting in order to make contact with alternative approaches in the literature.

Multichannel form of interaction

The final expression for the potential to be used throughout this work is

$$V_{ij}^{CSIJ} = D_{ij}^{CSIJ} \frac{1}{4 f_i f_j} (k_i^0 + k_j'^0) ,$$

where k_i^0 and $k_j'^0$ are the CM energies of the incoming and outgoing mesons, respectively, and f_i and f_j are the decay constants of the meson in the i-channel and j-channel.

Table : $N(1/2^-)$, $C = 0$, $S = 0$, $I = 1/2$, $J = 1/2$.

D^{CSIJ}	$N\eta_c$	$N\psi$	$\Lambda_c\bar{D}$	$\Lambda_c\bar{D}^*$	$\Sigma_c\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$
$N\eta_c$	0	0	$\sqrt{\frac{3}{2}}$	$-\sqrt{\frac{9}{2}}$	$\sqrt{\frac{3}{2}}$	$\sqrt{\frac{1}{2}}$	2
$N\psi$	0	0	$-\sqrt{\frac{9}{2}}$	$-\sqrt{\frac{3}{2}}$	$\sqrt{\frac{1}{2}}$	$\sqrt{\frac{25}{6}}$	$-\sqrt{\frac{4}{3}}$
$\Lambda_c\bar{D}$	$\sqrt{\frac{3}{2}}$	$-\sqrt{\frac{9}{2}}$	1	0	0	$-\sqrt{3}$	$\sqrt{6}$
$\Lambda_c\bar{D}^*$	$-\sqrt{\frac{9}{2}}$	$-\sqrt{\frac{3}{2}}$	0	1	$-\sqrt{3}$	-2	$-\sqrt{2}$
$\Sigma_c\bar{D}$	$\sqrt{\frac{3}{2}}$	$\sqrt{\frac{1}{2}}$	0	$-\sqrt{3}$	-1	$\sqrt{\frac{4}{3}}$	$\sqrt{\frac{2}{3}}$
$\Sigma_c\bar{D}^*$	$\sqrt{\frac{1}{2}}$	$\sqrt{\frac{25}{6}}$	$-\sqrt{3}$	-2	$\sqrt{\frac{4}{3}}$	$\frac{1}{3}$	$-\sqrt{\frac{2}{9}}$
$\Sigma_c^*\bar{D}^*$	2	$-\sqrt{\frac{4}{3}}$	$\sqrt{6}$	$-\sqrt{2}$	$\sqrt{\frac{2}{3}}$	$-\sqrt{\frac{2}{9}}$	$\frac{2}{3}$

ugr Universidad de Granada

Table : $N(3/2^-)$, $C=0$, $S=0$, $I=1/2$, $J=3/2$.

D^{CSIJ}	$N\psi$	$\Lambda_c\bar{D}^*$	$\Sigma_c^*\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$
$N\psi$	0	$\sqrt{6}$	$-\sqrt{2}$	$\sqrt{\frac{2}{3}}$	$-\sqrt{\frac{10}{3}}$
$\Lambda_c\bar{D}^*$	$\sqrt{6}$	1	$-\sqrt{3}$	1	$-\sqrt{5}$
$\Sigma_c^*\bar{D}$	$-\sqrt{2}$	$-\sqrt{3}$	-1	$-\sqrt{\frac{1}{3}}$	$\sqrt{\frac{5}{3}}$
$\Sigma_c\bar{D}^*$	$\sqrt{\frac{2}{3}}$	1	$-\sqrt{\frac{1}{3}}$	$-\frac{5}{3}$	$-\sqrt{\frac{5}{9}}$
$\Sigma_c^*\bar{D}^*$	$-\sqrt{\frac{10}{3}}$	$-\sqrt{5}$	$\sqrt{\frac{5}{3}}$	$-\sqrt{\frac{5}{9}}$	$-\frac{1}{3}$

Previous hidden charm investigations

- Hidden gauge formalism
  - J.-J. Wu, R. Molina, E. Oset, and B. S. Zou, Phys. Rev. C 84, 015202 (2011),
  - J.-J. Wu, T.-S. H. Lee, and B. S. Zou, Phys. Rev. C 85, 044002 (2012).
- Zero range vector exchange model
  - J. Hofmann and M. F. M. Lutz, Nucl. Phys. A763, 90 (2005),
  - J. Hofmann and M. F. M. Lutz, Nucl. Phys. A776, 17 (2006).
- Constituent quark model
  - S. G. Yuan, K.W. Wei, J. He, H. S. Xu, and B. S. Zou, Eur. Phys. J. A 48, 61 (2012).

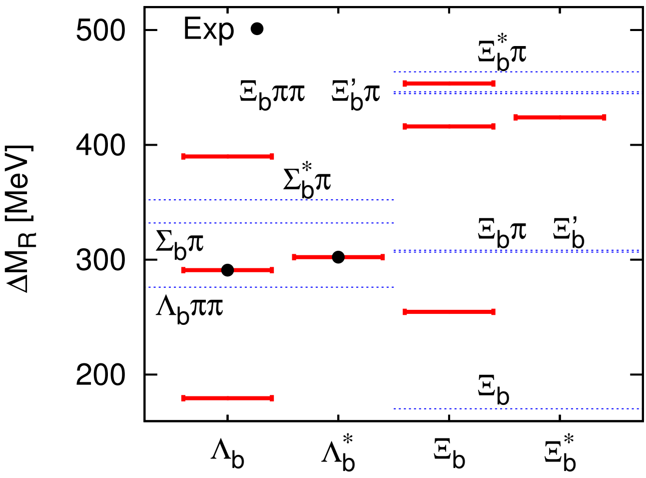
Hidden charm resonances

[*CGR, Nieves, Romanets, Salcedo, Tolos PRD87 (13) 074034*]

		$N(1/2^-)$						$N(3/2^-)$					$N(5/2^-)$	
			g to main channels						g to main channels					g
Ref.	Model	M_R [MeV]	$\Lambda_c\bar{D}$	$\Lambda_c\bar{D}^*$	$\Sigma_c\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$	M_R [MeV]	$\Lambda_c\bar{D}^*$	$\Sigma_c^*\bar{D}$	$\Sigma_c\bar{D}^*$	$\Sigma_c^*\bar{D}^*$	M_R [MeV]	$\Sigma_c^*\bar{D}^*$
This work:	$(\mathbf{8}_2)_{2,0} \subset \mathbf{70}_{2,0}$	3918	3.1	0.5	0.2	2.6	2.6							
		3926	0.4	3.0	4.2	0.2	0.7	3946	3.4	3.6	1.1	1.5		
	$(\mathbf{8}_4)_{2,0} \subset \mathbf{70}_{2,0}$	3974	0.4	2.2	2.1	3.4	3.1	3987	1.0	2.7	4.3	1.8		
								4006	1.0	1.6	3.2	4.2	4027	5.6
[65,66]	zero range vector exchange	3520			5.3			3430			5.6			
[75]	hidden gauge	4265	0.1		3.0									
		4415		0.1		2.8		4415	0.1		2.8			
[76]	hidden gauge	4315	×		×									
		4454		×		×		4454	×		×			
[119]	quark model	FS-CM						FS-CM					FS-CM	
	$uudc\bar{c}$	3933–4267												
		4013–4363						4013–4389						
		4119–4377						4119–4445						
		4136–4471						4136–4476						
		4156–4541						4236–4526					4236–4616	

Exp: $1/2^-$ $\Lambda_b(5912)$ and $3/2^-$ $\Lambda_b(5920)$. LHCb, PRL 109, 172003 (2012)

Extended **WT**model: CGR, Nieves, Romanets,Salcedo, Tolos, PRD 87,034032 (2013)



Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-, \ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-,\ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-,\ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-,\ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-,\ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Universidad de Granada

Low laying odd Λ, Λ_c, Λ_b with $J^P = 1/2^-,\ 3/2^-$

Aim: Flavor structure of odd lowest Λ resonances, $J^P = 1/2^-, 3/2^-$:
strange: Λ, charm Λ_c, beauty Λ_b with our hadronic model
also *Gubler's yesterday talk with LQCD*

- Meson-Baryon dynamically generated resonances
- Heavy Quark Spin Symmetry (HQSS)
- Weinberg-Tomozawa (WT) extended model for u, d, s and c/b flavors
- meson-Baryon Compositeness sum-rule *Ramos's yesterday talk*
- ???, forgetting ... something
- As advertised in **L. Tolos's yesterday talk :)**

Universidad de Granada

- Λ $(1/2^-)$ Two $\Lambda(1405)$: (1^{st}) narrow $\propto \bar{K}N$, (2^{nd}) wide $\propto \pi\Sigma$
- $\Lambda_c(1/2^-)$ Two $\Lambda_c(2595)$: (1^{st}) narrow $\propto DN$, (2^{nd}) wide $\propto \pi\Sigma_c$
- Λ_b $(1/2^-)$ Two $\Lambda_b(5912)$, (1^{st}) $\Gamma = 0 \propto \bar{B}N$, ($2^{nd}$) $\Gamma = 0 \propto \pi\Sigma_b$
- Λ $(3/2^-)$ One pole $\Lambda(1520)$
- Λ_c: $(3/2^-)$ One pole $\Lambda_c(2625)$
- Λ_b: $(3/2^-)$ One pole $\Lambda_b(5920)$

Our model with no free parameter provides this structure.
As many other models
Details for charm sector $I = 0$, $C = 1$: Λ_c's

Universidad de Granada

- Λ $(1/2^-)$ Two $\Lambda(1405)$: (1^{st}) narrow $\propto \bar{K}N$, (2^{nd}) wide $\propto \pi\Sigma$
- $\Lambda_c(1/2^-)$ Two $\Lambda_c(2595)$: (1^{st}) narrow $\propto DN$, (2^{nd}) wide $\propto \pi\Sigma_c$
- Λ_b $(1/2^-)$ Two $\Lambda_b(5912)$, (1^{st}) $\Gamma = 0 \propto \bar{B}N$, (2^{nd}) $\Gamma = 0 \propto \pi\Sigma_b$
- Λ $(3/2^-)$ One pole $\Lambda(1520)$
- Λ_c: $(3/2^-)$ One pole $\Lambda_c(2625)$
- Λ_b: $(3/2^-)$ One pole $\Lambda_b(5920)$

Our model with no free parameter provides this structure.
As many other models
Details for charm sector $I = 0$, $C = 1$: Λ_c's

- Λ $(1/2^-)$ Two $\Lambda(1405)$: (1^{st}) narrow $\propto \bar{K}N$, (2^{nd}) wide $\propto \pi\Sigma$
- $\Lambda_c(1/2^-)$ Two $\Lambda_c(2595)$: (1^{st}) narrow $\propto DN$, (2^{nd}) wide $\propto \pi\Sigma_c$
- Λ_b $(1/2^-)$ Two $\Lambda_b(5912)$, (1^{st}) $\Gamma = 0 \propto \bar{B}N$, (2^{nd}) $\Gamma = 0 \propto \pi\Sigma_b$
- Λ $(3/2^-)$ One pole $\Lambda(1520)$
- Λ_c: $(3/2^-)$ One pole $\Lambda_c(2625)$
- Λ_b: $(3/2^-)$ One pole $\Lambda_b(5920)$

Our model with no free parameter provides this structure.
As many other models
Details for charm sector $I = 0$, $C = 1$: Λ_c's

- Λ $(1/2^-)$ Two $\Lambda(1405)$: (1^{st}) narrow $\propto \bar{K}N$, (2^{nd}) wide $\propto \pi\Sigma$
- $\Lambda_c(1/2^-)$ Two $\Lambda_c(2595)$: (1^{st}) narrow $\propto DN$, (2^{nd}) wide $\propto \pi\Sigma_c$
- Λ_b $(1/2^-)$ Two $\Lambda_b(5912)$, (1^{st}) $\Gamma = 0 \propto \bar{B}N$, (2^{nd}) $\Gamma = 0 \propto \pi\Sigma_b$
- Λ $(3/2^-)$ One pole $\Lambda(1520)$
- Λ_c: $(3/2^-)$ One pole $\Lambda_c(2625)$
- Λ_b: $(3/2^-)$ One pole $\Lambda_b(5920)$

Our model with no free parameter provides this structure.
As many other models
Details for charm sector $I = 0$, $C = 1$: Λ_c's

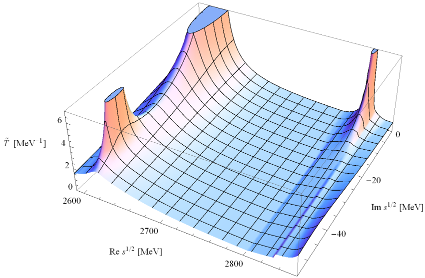
- Λ $(1/2^-)$ Two $\Lambda(1405)$: (1^{st}) narrow $\propto \bar{K}N$, (2^{nd}) wide $\propto \pi\Sigma$
- $\Lambda_c(1/2^-)$ Two $\Lambda_c(2595)$: (1^{st}) narrow $\propto DN$, (2^{nd}) wide $\propto \pi\Sigma_c$
- Λ_b $(1/2^-)$ Two $\Lambda_b(5912)$, (1^{st}) $\Gamma = 0 \propto \bar{B}N$, (2^{nd}) $\Gamma = 0 \propto \pi\Sigma_b$
- Λ $(3/2^-)$ One pole $\Lambda(1520)$
- Λ_c: $(3/2^-)$ One pole $\Lambda_c(2625)$
- Λ_b: $(3/2^-)$ One pole $\Lambda_b(5920)$

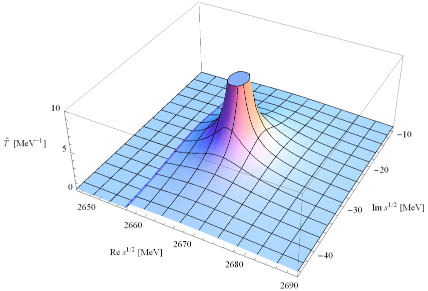
Our model with no free parameter provides this structure.
As many other models
Details for charm sector $I = 0, \ C = 1$: Λ_c's

Low laying Λ_c

Results for charm:

$\boxed{1/2^-}$ $\Lambda_c(2595)$ O. Romanets PRD 85 114032 $\boxed{3/2^-}$ $\Lambda_c(2625)$.





$$\tilde{T}^{IJC}(z) \equiv \max_j \sum_i |T^{IJC}_{ij}(z)|$$

Universidad de Granada

Results for charm

State	J^P	$\sqrt{\alpha}$	M_R	Γ_R
Λ_c(2595) 1st	$1/2^-$	1	2619.0	1.2
Λ_c(2595) 2nd	$1/2^-$	1	2617.0	90.0
Λ_c(2625) 3rd	$3/2^-$	1	2667.0	55.0

Couplings to $\pi\Sigma$ or $\pi\Sigma^*$

State	J^P	$\sqrt{\alpha}$	M_R	Γ_R	$\lvert g_i \rvert$
Λ_c(2595) 1st	$1/2^-$	1	2619.0	1.2	0.30 ($\pi\Sigma_c$)
Λ_c(2595) 2nd	$1/2^-$	1	2617.0	90.0	2.4 ($\pi\Sigma_c$)
Λ_c(2625) 3rd	$3/2^-$	1	2667.0	55.0	2.2 ($\pi\Sigma_c^*$)

Universidad de Granada

All flavors

State	J^P	$\sqrt{\alpha}$	M_R	Γ_R	$\lvert g_{\pi\Sigma^{(*)}}\rvert$
Λ(1405)	$1/2^-$	1	1430.0	5.5	0.50 ($\pi\Sigma$)
Λ(1405)	$1/2^-$	1	1373.0	170.0	2.6 ($\pi\Sigma$)
Λ(1520)	$3/2^-$	1	1540.0	74.0	2.3 ($\pi\Sigma^*$)
Λ_c(2595) 1st	$1/2^-$	1	2619.0	1.2	0.30 ($\pi\Sigma_c$)
Λ_c(2595) 2nd	$1/2^-$	1	2617.0	90.0	2.4 ($\pi\Sigma_c$)
Λ_c(2625) 3rd	$3/2^-$	1	2667.0	55.0	2.2 ($\pi\Sigma_c^*$)
Λ_b(5912)	$1/2^-$	1	5878.0	0.0	0.04 ($\pi\Sigma_b$)
Λ_b(5912)	$1/2^-$	1	5949.0	0.0	1.3 ($\pi\Sigma_b$)
Λ_b(5920)	$3/2^-$	1	5963.0	0.0	1.5 ($\pi\Sigma_b^*$)

1st Λ_c

State	J^P	$\sqrt{\alpha}$	M_R	Γ_R	$1-Z$
$\mathbf{\Lambda_c(2595)}$	$\frac{1}{2}^-$	1	2619.0	1.2	0.878

Channel	$\lvert g_i \rvert$	g_i	X_i	(X_i')
$\pi\Sigma_c$	0.31	$0.22+0.22i$	-0.012	(-0.023)
DN	3.49	$-3.49-0.14i$	**0.275**	(**0.292**)
$\eta\Lambda_c$	0.40	$0.40-0.00i$	0.007	(0.009)
$\mathbf{D^*N}$	5.64	$-5.64+0.14i$	**0.465**	(**0.451**)
$K\Xi_c$	0.22	$0.22-0.00i$	0.002	(0.001)
$\omega\Lambda_c$	0.18	$0.18+0.04i$	0.001	(0.001)
$K\Xi_c'$	0.04	$0.02+0.04i$	-0.000	(0.000)
$D_s\Lambda$	1.38	$-1.38+0.01i$	0.026	(0.026)
$\mathbf{D_s^*\Lambda}$	2.87	$-2.87+0.03i$	**0.086**	(**0.057**)
$\rho\Sigma_c$	0.41	$0.39+0.12i$	0.003	(0.005)
$\eta'\Lambda_c$	0.92	$0.92+0.01i$	0.018	(0.018)
$\rho\Sigma_c^*$	0.58	$0.58-0.07i$	0.007	(0.006)
$\phi\Lambda_c$	0.01	$0.01+0.00i$	0.000	(0.000)
$K^*\Xi_c'$	[illegible]	[illegible]	[illegible]	[illegible]

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**

  *Weinberg, PR***137***, B672 (1965)*
- Recently, the issue of compositeness was addressed in for s-waves and small binding energies. *C. Hanhart et al. PRD* **81***, 094028 (2010)*

  V. Baru et al.PLB **586***, 53 (2004)*

  M. Cleven et al. EPJA **47***, 120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* **83***, 014003 (2011)*

  F. Aceti and E. Oset, PRD **86***, 014012 (2012)*

  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A **49***, 22 (2013)*

  F. Aceti et al EPJ A **50***, 57 (2014)*
- Formal and theoretical aspects have been recently discussed in *T. Hyodo, D. Jido and A. Hosaka, PRC* **85***, 015201 (2012)*

  H. Nagahiro and A. Hosaka, Phys. Rev. C **90***, no. 6, 065201 (2014)*

ugr Universidad de Granada

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**
  *Weinberg, PR***137***, B672 (1965)*
- Recently, the issue of compositeness was addressed in for *s*-waves and small binding energies. *C. Hanhart et al. PRD* **81***, 094028 (2010)*
  V. Baru et al.PLB **586***, 53 (2004)*
  M. Cleven et al. EPJA **47***, 120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* **83***, 014003 (2011)*
  F. Aceti and E. Oset, PRD **86***, 014012 (2012)*
  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A **49***, 22 (2013)*
  F. Aceti et al EPJ A **50***, 57 (2014)*
- Formal and theoretical aspects have been recently discussed in
  T. Hyodo, D. Jido and A. Hosaka, PRC **85***, 015201 (2012)*
  H. Nagahiro and A. Hosaka, Phys. Rev. C **90***, no. 6, 065201 (2014)*

ugr Universidad de Granada

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**
  *Weinberg, PR***137***, B672 (1965)*
- Recently, the issue of compositeness was addressed in for *s*-waves and small binding energies. *C. Hanhart et al. PRD* **81***, 094028 (2010)*
  V. Baru et al.PLB **586***, 53 (2004)*
  M. Cleven et al. EPJA **47***, 120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* **83***, 014003 (2011)*
  F. Aceti and E. Oset, PRD **86***, 014012 (2012)*
  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A **49***, 22 (2013)*
  F. Aceti et al EPJ A **50***, 57 (2014)*
- Formal and theoretical aspects have been recently discussed in
  T. Hyodo, D. Jido and A. Hosaka, PRC **85***, 015201 (2012)*
  H. Nagahiro and A. Hosaka, Phys. Rev. C **90***, no. 6, 065201 (2014)*

Universidad de Granada

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**
  Weinberg, PR ***137****, B672 (1965)*
- Recently, the issue of compositeness was addressed in for *s*-waves and small binding energies. *C. Hanhart et al. PRD* ***81****, 094028 (2010)*
  V. Baru et al.PLB ***586****, 53 (2004)*
  M. Cleven et al. EPJA ***47****, 120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* ***83****, 014003 (2011)*
  F. Aceti and E. Oset, PRD ***86****, 014012 (2012)*
  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A ***49****, 22 (2013)*
  F. Aceti et al EPJ A ***50****, 57 (2014)*
- Formal and theoretical aspects have been recently discussed in *T. Hyodo, D. Jido and A. Hosaka, PRC* ***85****, 015201 (2012)*
  H. Nagahiro and A. Hosaka, Phys. Rev. C ***90****, no. 6, 065201 (2014)*

ugr Universidad de Granada

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**
  Weinberg, PR **137**, *B672 (1965)*
- Recently, the issue of compositeness was addressed in for *s*-waves and small binding energies. *C. Hanhart et al. PRD* **81**, *094028 (2010)*
  V. Baru et al.PLB **586**, *53 (2004)*
  M. Cleven et al. EPJA **47**, *120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* **83**, *014003 (2011)*
  F. Aceti and E. Oset, PRD **86**, *014012 (2012)*
  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A **49**, *22 (2013)*
  F. Aceti et al EPJ A **50**, *57 (2014)*
- Formal and theoretical aspects have been recently discussed in *T. Hyodo, D. Jido and A. Hosaka, PRC* **85**, *015201 (2012)*
  H. Nagahiro and A. Hosaka, Phys. Rev. C **90**, *no. 6, 065201 (2014)*

ugr Universidad de Granada

Compositeness of the Λ states: Weights of Weinberg

- 60's Weinberg: the deuteron is best described as composed of a proton and a neutron, rather than a genuine dibaryon. **Sum-rule = 1**
  *Weinberg, PR***137***, B672 (1965)*
- Recently, the issue of compositeness was addressed in for *s*-waves and small binding energies. *C. Hanhart et al. PRD* **81***, 094028 (2010)*
  V. Baru et al.PLB **586***, 53 (2004)*
  M. Cleven et al. EPJA **47***, 120 (2011)*
- An extension to larger binding energies in coupled-channel dynamics was undertaken in *Gamermann et al. PRD 81, 014029(2010)*
- Extension to resonances and analysis of some mesonic and baryonic resonances in *J. Yamagata-Sekihara et al.,PRD* **83***, 014003 (2011)*
  F. Aceti and E. Oset, PRD **86***, 014012 (2012)*
  C. W. Xiao et al. , F. Aceti and M. Bayar, EPJ A **49***, 22 (2013)*
  F. Aceti et al EPJ A **50***, 57 (2014)*
- Formal and theoretical aspects have been recently discussed in
  T. Hyodo, D. Jido and A. Hosaka, PRC **85***, 015201 (2012)*
  H. Nagahiro and A. Hosaka, Phys. Rev. C **90***, no. 6, 065201 (2014)*

ugr Universidad de Granada

- Compositeness introduced yesterday in *A. Ramos's talk*
- Follow *F. Aceti et al. EPJ A* **50**, *57 (2014)* for the interpretation of the Weinberg's sum rule and its generalization to resonances.
- In the unitarized setting the sum rule follows from the identity:

$$-1 = \sum_{i,j} g_i g_j \left(\delta_{ij} \frac{\partial G_i(\sqrt{s})}{\partial \sqrt{s}} + G_i(\sqrt{s}) \frac{\partial V_{ij}(\sqrt{s})}{\partial \sqrt{s}} G_j(\sqrt{s}) \right) \Bigg|_{\sqrt{s}=\sqrt{s_R}} .$$

G_j is the meson-baryon loop. It holds for bounds states and resonances, as well as energy dependent or energy independent interactions.

- Use of the definitions

$$X_i = -\mathrm{Re} \left(g_i^2 \left. \frac{dG_i}{d\sqrt{s}} \right|_{\sqrt{s_R}} \right), \qquad Z = -\mathrm{Re} \sum_{i,j} g_i g_j \left(G_i \frac{\partial V_{ij}}{\partial \sqrt{s}} G_j \right) \Bigg|_{\sqrt{s_R}} \quad (-2)$$

provides the sum rule

$$1 = Z + \sum_i X_i .$$

- Compositeness introduced yesterday in *A. Ramos's talk*
- Follow *F. Aceti et al. EPJ A* **50**, *57 (2014)* for the interpretation of the Weinberg's sum rule and its generalization to resonances.
- In the unitarized setting the sum rule follows from the identity:

$$-1 = \sum_{i,j} g_i g_j \left(\delta_{ij} \frac{\partial G_i(\sqrt{s})}{\partial \sqrt{s}} + G_i(\sqrt{s}) \frac{\partial V_{ij}(\sqrt{s})}{\partial \sqrt{s}} G_j(\sqrt{s}) \right) \Bigg|_{\sqrt{s}=\sqrt{s_R}} .$$

G_j is the meson-baryon loop. It holds for bounds states and resonances, as well as energy dependent or energy independent interactions.

- Use of the definitions

$$X_i = -\mathrm{Re} \left(g_i^2 \left. \frac{dG_i}{d\sqrt{s}} \right|_{\sqrt{s_R}} \right), \qquad Z = -\mathrm{Re} \sum_{i,j} g_i g_j \left(G_i \frac{\partial V_{ij}}{\partial \sqrt{s}} G_j \right) \Bigg|_{\sqrt{s_R}} \tag{-2}$$

provides the sum rule

$$1 = Z + \sum_i X_i .$$

- Compositeness introduced yesterday in *A. Ramos's talk*
- Follow *F. Aceti et al. EPJ A* **50**, *57 (2014)* for the interpretation of the Weinberg's sum rule and its generalization to resonances.
- In the unitarized setting the sum rule follows from the identity:

$$-1 = \sum_{i,j} g_i g_j \left(\delta_{ij} \frac{\partial G_i(\sqrt{s})}{\partial \sqrt{s}} + G_i(\sqrt{s}) \frac{\partial V_{ij}(\sqrt{s})}{\partial \sqrt{s}} G_j(\sqrt{s}) \right) \Bigg|_{\sqrt{s}=\sqrt{s_R}} .$$

  G_j is the meson-baryon loop. It holds for bounds states and resonances, as well as energy dependent or energy independent interactions.

- Use of the definitions

$$X_i = -\mathrm{Re} \left(g_i^2 \frac{dG_i}{d\sqrt{s}} \Bigg|_{\sqrt{s_R}} \right), \qquad Z = -\mathrm{Re} \sum_{i,j} g_i g_j \left(G_i \frac{\partial V_{ij}}{\partial \sqrt{s}} G_j \right) \Bigg|_{\sqrt{s_R}} \quad (-2)$$

  provides the sum rule

$$1 = Z + \sum_i X_i .$$

Universidad de Granada

- Compositeness introduced yesterday in *A. Ramos's talk*
- Follow *F. Aceti et al. EPJ A* **50**, *57 (2014)* for the interpretation of the Weinberg's sum rule and its generalization to resonances.
- In the unitarized setting the sum rule follows from the identity:

$$-1 = \sum_{i,j} g_i g_j \left(\delta_{ij} \frac{\partial G_i(\sqrt{s})}{\partial \sqrt{s}} + G_i(\sqrt{s}) \frac{\partial V_{ij}(\sqrt{s})}{\partial \sqrt{s}} G_j(\sqrt{s}) \right) \Bigg|_{\sqrt{s}=\sqrt{s_R}} .$$

  G_j is the meson-baryon loop. It holds for bounds states and resonances, as well as energy dependent or energy independent interactions.
- Use of the definitions

$$X_i = -\mathrm{Re} \left(g_i^2 \left. \frac{dG_i}{d\sqrt{s}} \right|_{\sqrt{s_R}} \right), \qquad Z = -\mathrm{Re} \sum_{i,j} g_i g_j \left(G_i \frac{\partial V_{ij}}{\partial \sqrt{s}} G_j \right) \Bigg|_{\sqrt{s_R}} \tag{-2}$$

  provides the sum rule

$$1 = Z + \sum_i X_i .$$

- The quantity X_i is related to the probability of finding the state in the channel i.
- For resonances, X_i is still related to the squared wave function of the channel i and so it can be used as a measure of the weight of that meson-baryon channel in the composition of the resonant state.
- The quantity $\sum_i X_i = 1 - Z$ represents the *compositeness* of the hadronic state in terms of all the considered channels

- The quantity X_i is related to the probability of finding the state in the channel i.
- For resonances, X_i is still related to the squared wave function of the channel i and so it can be used as a measure of the weight of that meson-baryon channel in the composition of the resonant state.
- The quantity $\sum_i X_i = 1 - Z$ represents the *compositeness* of the hadronic state in terms of all the considered channels

- The quantity X_i is related to the probability of finding the state in the channel i.
- For resonances, X_i is still related to the squared wave function of the channel i and so it can be used as a measure of the weight of that meson-baryon channel in the composition of the resonant state.
- The quantity $\sum_i X_i = 1 - Z$ represents the *compositeness* of the hadronic state in terms of all the considered channels

1st Λ_c

State	J^P	$\sqrt{\alpha}$	M_R	Γ_R	$1-Z$	
$\mathbf{\Lambda_c(2595)}$	$\frac{1}{2}^-$	1	2619.0	1.2	0.878	bf (0.844)

Channel	$\lvert g_i \rvert$	g_i	X_i	(X_i')
$\pi\Sigma_c$	0.31	$0.22 + 0.22i$	-0.012	(-0.023)
DN	3.49	$-3.49 - 0.14i$	**0.275**	(**0.292**)
$\eta\Lambda_c$	0.40	$0.40 - 0.00i$	0.007	(0.009)
$\mathbf{D^*N}$	5.64	$-5.64 + 0.14i$	**0.465**	(**0.451**)
$K\Xi_c$	0.22	$0.22 - 0.00i$	0.002	(0.001)
$\omega\Lambda_c$	0.18	$0.18 + 0.04i$	0.001	(0.001)
$K\Xi_c'$	0.04	$0.02 + 0.04i$	-0.000	(0.000)
$D_s\Lambda$	1.38	$-1.38 + 0.01i$	0.026	(0.026)
$\mathbf{D_s^*\Lambda}$	2.87	$-2.87 + 0.03i$	**0.086**	(**0.057**)
$\rho\Sigma_c$	0.41	$0.39 + 0.12i$	0.003	(0.005)
$\eta'\Lambda_c$	0.92	$0.92 + 0.01i$	0.018	(0.018)
$\rho\Sigma_c^*$	0.58	$0.58 - 0.07i$	0.007	(0.006)
$\phi\Lambda_c$	0.01	$0.01 + 0.00i$	0.000	(0.000)

Compositeness

The novelty comes from the systematic study of the 2composition of these resonances, as a function of the heavy quark mass, addressing the question of to what extent the structure of the resonances is fully saturated by the available s-wave meson-baryon channels.

	s	c	b
1st Λ	**0.90**	**0.85**	**0.95**
2nd Λ	0.35	0.40	**0.85**
3rd Λ	0.25	0.35	**0.80**

- Regarding the overall compositeness of the nine Λ resonances studied, we find that for a given flavor sector, the closer to threshold (on the complex plane) the better the resonance is described as an s-wave meson-baryon molecule.
- Also, the heavier the flavor the higher the compositeness $1 - Z$. More explicitly, we find that $1 - Z$ is large for the first $\Lambda(1/2^-)$ of each flavor and the compositeness decreases as we move to the second $\Lambda(1/2^-)$ states and then to the $\Lambda(3/2^-)$ ones.
- Also, the compositeness is large for all bottom Λ states. This would

Compositeness

The novelty comes from the systematic study of the 2composition of these resonances, as a function of the heavy quark mass, addressing the question of to what extent the structure of the resonances is fully saturated by the available s-wave meson-baryon channels.

	s	c	b
1st Λ	**0.90**	**0.85**	**0.95**
2nd Λ	0.35	0.40	**0.85**
3rd Λ	0.25	0.35	**0.80**

- Regarding the overall compositeness of the nine Λ resonances studied, we find that for a given flavor sector, the closer to threshold (on the complex plane) the better the resonance is described as an s-wave meson-baryon molecule.
- Also, the heavier the flavor the higher the compositeness $1-Z$. More explicitly, we find that $1-Z$ is large for the first $\Lambda(1/2^-)$ of each flavor and the compositeness decreases as we move to the second $\Lambda(1/2^-)$ states and then to the $\Lambda(3/2^-)$ ones.
- Also, the compositeness is large for all bottom Λ states. This would

Compositeness

The novelty comes from the systematic study of the 2composition of these resonances, as a function of the heavy quark mass, addressing the question of to what extent the structure of the resonances is fully saturated by the available s-wave meson-baryon channels.

	s	c	b
1st Λ	**0.90**	**0.85**	**0.95**
2nd Λ	0.35	0.40	**0.85**
3rd Λ	0.25	0.35	**0.80**

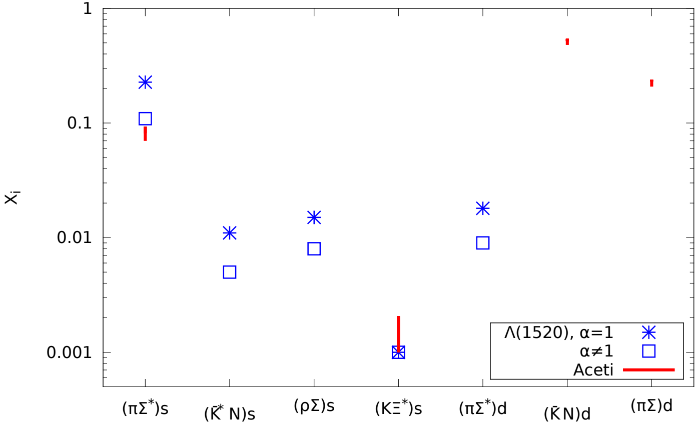
- Regarding the overall compositeness of the nine Λ resonances studied, we find that for a given flavor sector, the closer to threshold (on the complex plane) the better the resonance is described as an s-wave meson-baryon molecule.
- Also, the heavier the flavor the higher the compositeness $1 - Z$. More explicitly, we find that $1 - Z$ is large for the first $\Lambda(1/2^-)$ of each flavor and the compositeness decreases as we move to the second $\Lambda(1/2^-)$ states and then to the $\Lambda(3/2^-)$ ones.
- Also, the compositeness is large for all bottom Λ states. This would

Compositeness

The novelty comes from the systematic study of the 2composition of these resonances, as a function of the heavy quark mass, addressing the question of to what extent the structure of the resonances is fully saturated by the available s-wave meson-baryon channels.

	s	c	b
1st Λ	**0.90**	**0.85**	**0.95**
2nd Λ	0.35	0.40	**0.85**
3rd Λ	0.25	0.35	**0.80**

- Regarding the overall compositeness of the nine Λ resonances studied, we find that for a given flavor sector, the closer to threshold (on the complex plane) the better the resonance is described as an s-wave meson-baryon molecule.
- Also, the heavier the flavor the higher the compositeness $1 - Z$. More explicitly, we find that $1 - Z$ is large for the first $\Lambda(1/2^-)$ of each flavor and the compositeness decreases as we move to the second $\Lambda(1/2^-)$ states and then to the $\Lambda(3/2^-)$ ones.
- Also, the compositeness is large for all bottom Λ states. This would



Weights X_i of the main channels contributing to the composition of the Λ(1520). Our results (in blue) are represented by stars for $\alpha = 1$, and by squares when the subtraction point is modified to bring the mass of the resonance to its experimental value. The vertical lines in red indicate the weights obtained in *Aceti, Oset and Roca, PRC* **90** *025208 (2014)* for the two *s*-wave and two *d*-wave channels considered there using various sets of fitting parameters.

Summary

- For hidden charm sector ($N_c = N_{\bar{c}} = 1$), using hadronic degrees of freedom, the most general parity, SU(3) and HQSS symmetric meson-Baryon Lagrangian is constructed

  12 independent operators
- Minimal extension of SU(3) **WT** Lagrangian provides a $H_{WT}{}'$ Hamiltonian that preserves **chiral**, **light spin-flavor** and HQSS symmetries
- This interaction is presented in different ways:
  - Field Lagrangian
  - Hadron creation-annihilation operators
  - SU(6) projectors
  - Multichannel Matrices
- Results of our **WT** extended model are presented for
  - Hidden Charm N and Δ
  - Beauty Baryons (Λ_b)

Compositeness of the strange, charm and beauty odd Λ states

- Appears today in arXiv
- Authors: C. Hidalgo-Duque, J. Nieves, L.L. Salcedo, L. Tolos
- The compositeness of the Λ states in the strange, charm and beauty sectors is studied on a unitarized meson-baryon model.
- In the strange sector we use an SU(6) extension of the Weinberg-Tomozawa meson-baryon interaction
- We further implement the heavy-quark spin symmetry (HQSS) to construct the meson-baryon interaction when charmed or beauty hadrons are involved.
- We obtain two $J^P = 1/2^-$ Λ states and one $J^P = 3/2^-$ Λ for the strange, charm and beauty sectors.
- We find that the Λ states which are bound states (the three Λ_b) or narrow resonances (one $\Lambda(1405)$ and one $\Lambda_c(2965)$) are well described as molecular states composed of s-wave meson-baryon pairs.
- The $\frac{1}{2}^-$ wide $\Lambda(1405)$ and $\Lambda_c(2965)$ as well as the $\frac{3}{2}^-$ $\Lambda(1520)$ and