Charmed and strange baryon resonances with heavy quark symmetry

Olena Romanets,

L. Tolos,

R. G. E. Timmermans,

In collaboration with:

J. Nieves,

C. Garcia-Recio,

L. L. Salcedo

Hirschegg 2012

Outline:

- Motivation
- Model:
  - symmetry structure [SU(8)]
  - interaction potential
  - Bethe-Salpeter equation
  - symmetry breaking
- Results
- Conclusions

Motivation

$\Lambda(1405)\ S_{01}$ *

$I(J^P) = 0(\frac{1}{2}^-)$

Mass $m = 1405.1^{+1.3}_{-1.0}$ MeV
Full width $\Gamma = 50 \pm 2$ MeV
Below $\overline{K}N$ threshold

$\Lambda_c(2625)^+$

$I(J^P) = 0(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

Mass $m = 2628.1 \pm 0.6$ MeV (S = 1.5)
$m - m_{\Lambda_c^+} = 341.7 \pm 0.6$ MeV (S = 1.6)
Full width $\Gamma < 1.9$ MeV, CL = 90%

$\Lambda_c(2595)^+$

$I(J^P) = 0(\frac{1}{2}^-)$

The spin-parity follows from the fact that $\Sigma_c(2455)\pi$ decays, with little available phase space, are dominant. This assumes that $J^P = 1/2^+$ for the $\Sigma_c(2455)$.

Mass $m = 2595.4 \pm 0.6$ MeV (S = 1.1)

$\Lambda_c(2880)^+$

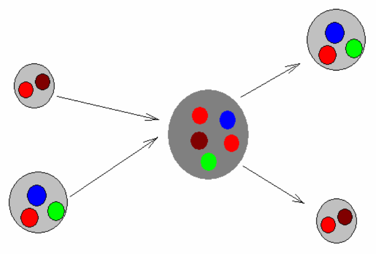
$I(J^P) = 0(\frac{5}{2}^+)$

There is some good evidence that indeed $J^P = 5/2^+$

Mass $m = 2881.53 \pm 0.35$ MeV
$m - m_{\Lambda_c^+} = 595.1 \pm 0.4$ MeV
Full width $\Gamma = 5.8 \pm 1.1$ MeV

Baryon resonances existence, which can not be described properly by the quark models

- We study baryon resonances generated via meson-baryon scattering,
- with charm and strange degrees of freedom (C=1, 2, 3)



* Jones, Dalitz and Horgan, Nucl. Phys. B129 (1977) 45

Motivation

- Charm physics is the hot topic in hadronic experimental and theoretical physics.
- In some sectors (C S I J) there is some experimental information available.

BaBar, Belle, CLEO

$\Xi_c(2790)$ $I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$

J^P has not been measured; $\frac{1}{2}^-$ is the quark-model prediction.

$\Xi_c(2815)$ $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

J^P has not been measured; $\frac{3}{2}^-$ is the quark-model prediction.

- In some sectors there is not (yet)

planned experiments:
PANDA

KVI
university of groningen

Model: symmetry structure

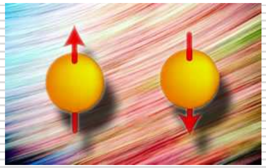
- We follow the SU(8) symmetric model:

$$\boxed{\mathrm{SU}(8) \supset \mathrm{SU}(4) \otimes \mathrm{SU}(2)}$$

SU(4) – flavor group

u	*c*
d	*s*

SU(2) – group of spin rotations



- SU(8) symmetric model respects the heavy-quark symmetry of QCD in the limit of infinite quark mass.
- In this scheme the vector mesons are treated on an equal footing as the pseudo-scalar mesons; spin-1/2 and spin-3/2 baryons are included.

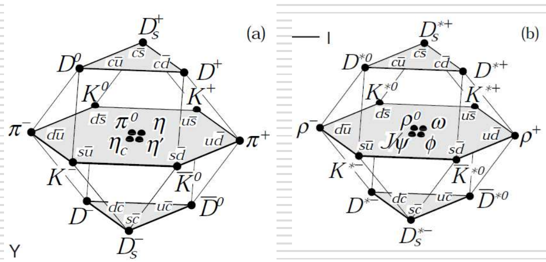
C. Garcia-Recio et al., Phys. Rev. D**79**, 054004

D. Gamermann et al., Phys. Rev. D **81** (2010) 094016, 1002.2763

Model: symmetry structure

- Mesons:

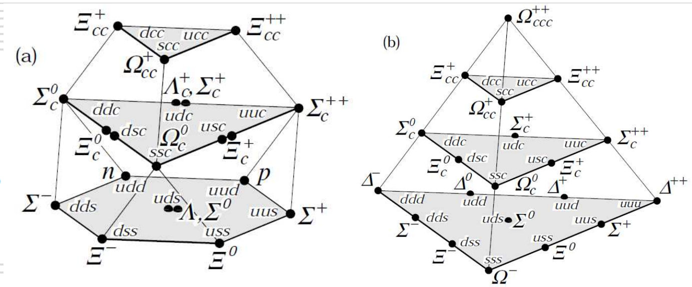
$$8 \otimes 8^* = 63 \oplus 1 = \underbrace{(15_1 \oplus 15_3 \oplus 1_3)}_{63} \oplus 1_1.$$



- Baryons:

$$8 \otimes 8 \otimes 8 = 120 \oplus 56 \oplus 168 \oplus 168$$

$$= \underbrace{(20_2 \oplus 20'_4)}_{120} \oplus \underbrace{(4_4 \oplus 20_2)}_{56} \oplus 2 \times \underbrace{(20'_2 \oplus 20_4 \oplus 20_2 \oplus 4_2)}_{168},$$



- Baryon resonances:

$$63 \otimes 120 = 120 \oplus 168 \oplus 2520 \oplus 4752,$$

$$\lambda_{168} = -22\ , \quad \lambda_{2520} = 6,$$
$$\lambda_{120} = -16\ , \quad \lambda_{4752} = -2.$$

Model: interaction potential

- We use the SU(8) extension of the Weinberg-Tomozawa potential:

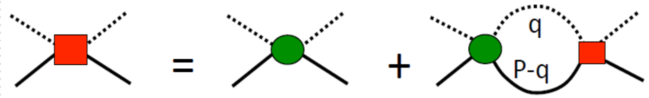
$$\boxed{V_{ij}(s) = D_{ij}\,\frac{2\sqrt{s} - M_i - M_j}{4\,f_i f_j}\sqrt{\frac{E_i + M_i}{2M_i}}\sqrt{\frac{E_j + M_j}{2M_j}}}$$

- M – the baryons masses in the SU(8) symmetric scheme; E – center-of-mass energies; f – meson weak decay constants.

C. Garcia-Recio et al., Phys. Rev. D**79**, 054004

Model: on-shell Bethe-Salpeter equation in coupled channels:

$$\boxed{T_{ij}^{IJSC}(\sqrt{s}) = \frac{1}{1 - V_{il}^{IJSC}(\sqrt{s})G_{ll}^{IJSC}(\sqrt{s})} V_{lj}^{IJSC}(\sqrt{s})}$$



$$T_{ij} = V_{ij} + V_{il}\, G_l\, T_{lj}$$

- The transitions to other meson-baryon channels are allowed, because the strong interaction connects states with the same quantum numbers

for example,

I=1, C=0, S=-1:

$$\begin{pmatrix} T_{\bar{K}N\to\bar{K}N} & T_{\pi\Sigma\to\bar{K}N} & T_{\pi\Lambda\to\bar{K}N} \\ T_{\bar{K}N\to\pi\Sigma} & T_{\pi\Sigma\to\pi\Sigma} & T_{\pi\Lambda\to\pi\Sigma} \\ T_{\bar{K}N\to\pi\Lambda} & T_{\pi\Sigma\to\pi\Lambda} & T_{\pi\Lambda\to\pi\Lambda} \end{pmatrix}$$

- The loop function regularization:

$$\boxed{G_{ii}^{IJSC}(\sqrt{s} = \mu_i^{IJSC}) = 0}$$

$$(\mu^{ISC})^2 = \alpha(m_{\rm th}^2 + M_{\rm th}^2)$$

Model: symmetry breaking

- The symmetry was broken gradually

SU(8) -> SU(6) -> SU(3) -> SU(2)

with changing the values of the meson masses and weak decay constants. In this way each found resonance was tagged with the original multiplet.

$$
\begin{aligned}
m(x) &= (1-x) m_{\mathrm{SU}(8)} + x\, m_{\mathrm{SU}(6)}, \\
f(x) &= (1-x) f_{\mathrm{SU}(8)} + x\, f_{\mathrm{SU}(6)}.
\end{aligned}
$$

$$
\begin{aligned}
m(x') &= (1-x') m_{\mathrm{SU}(6)} + x'\, m_{\mathrm{SU}(3)}, \\
f(x') &= (1-x') f_{\mathrm{SU}(6)} + x'\, f_{\mathrm{SU}(3)},
\end{aligned}
$$

Model

- Baryon resonances appear as poles of the scattering amplitude in the first and second Riemann sheets.
- Around a pole the scattering amplitude behaves like:

$$T_{ij}^{IJSC}(z) = \frac{g_i e^{i\phi_i} g_j e^{i\phi_j}}{(z - z_R)}$$

mass: $M_R = \mathrm{Re}(z_R^{1/2})$

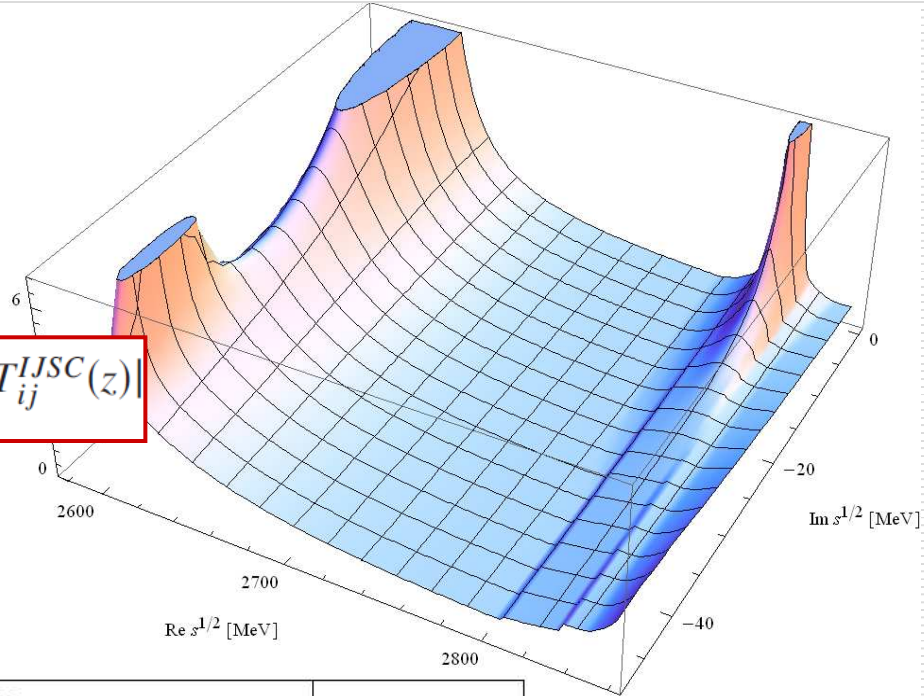
width: $\Gamma_R = -2\mathrm{Im}(z_R^{1/2})$

Results

$$\mathbf{C = 1,\ S = 0,\ I = 0}\ (\Lambda_c)$$

$\boxed{\Lambda_c(2595)^+}$ $I(J^P) = 0(\frac{1}{2}^-)$

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



Mass $m = 2595.4 \pm 0.6$ MeV

$m - m_{\Lambda_c^+} = 308.9 \pm 0.6$ MeV

Full width $\Gamma = 3.6^{+2.0}_{-1.3}$ MeV

SU(8) irrep	SU(6) irrep	SU(3) irrep	M_R	Γ_R	Couplings to main channels	possible ID
168	$\mathbf{15_{2,1}}$	$\mathbf{3_2}$	2617.3	89.8	$\mathbf{g_{\Sigma_c\pi} = 2.3}$, $g_{ND} = 1.6$, $g_{ND^*} = 1.4$, $g_{\Sigma_c\rho} = 1.3$	
168	$\mathbf{21_{2,1}}$	$\mathbf{3_2}$	2618.8	1.2	$\mathbf{g_{\Sigma_c\pi} = 0.3}$, $g_{ND} = 3.5$, $g_{ND^*} = 5.6$, $g_{\Lambda D_s} = 1.4$, $g_{\Lambda D_s^*} = 2.9$, $g_{\Lambda_c\eta'} = 0.9$	$\Lambda_c(2595)$ ***
120	$\mathbf{21_{2,1}}$	$\mathbf{3_2}$	2828.4	0.8	$\mathbf{g_{ND} = 0.3}$, $g_{\Lambda_c\eta} = 1.1$, $g_{\Xi_c K} = 1.6$, $g_{\Lambda D_s^*} = 1.1$, $g_{\Sigma_c\rho} = 1.1$, $g_{\Sigma_c^*\rho} = 1.0$, $g_{\Xi_c^* K^*} = 0.8$	

*

J = 1/2

* C. Garcia-Recio et al. Phys. Rev. D **79**, 054004

KVI university of groningen

Results

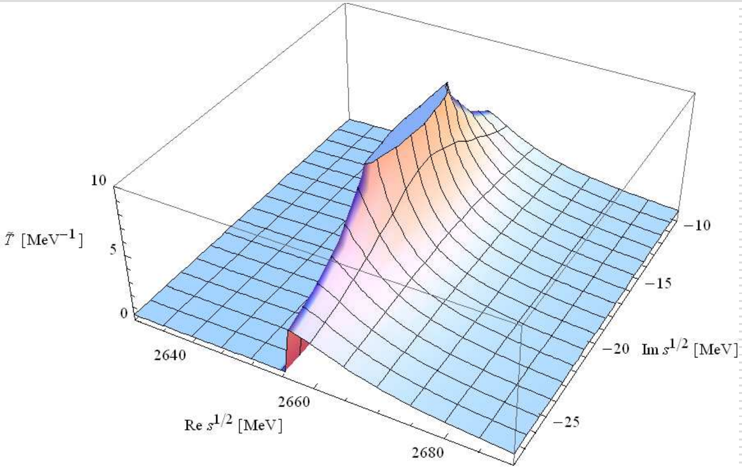
$\mathbf{C = 1,\ S = 0,\ I = 0\ (\Lambda_c)}$

$\boxed{\Lambda_c(2625)^+}$ $I(J^P) = 0(\frac{3}{2}^-)$

Mass $m = 2628.1 \pm 0.6$ MeV (S = 1.5)

$m - m_{\Lambda_c^+} = 341.7 \pm 0.6$ MeV (S = 1.6)

Full width $\Gamma < 1.9$ MeV, CL = 90%



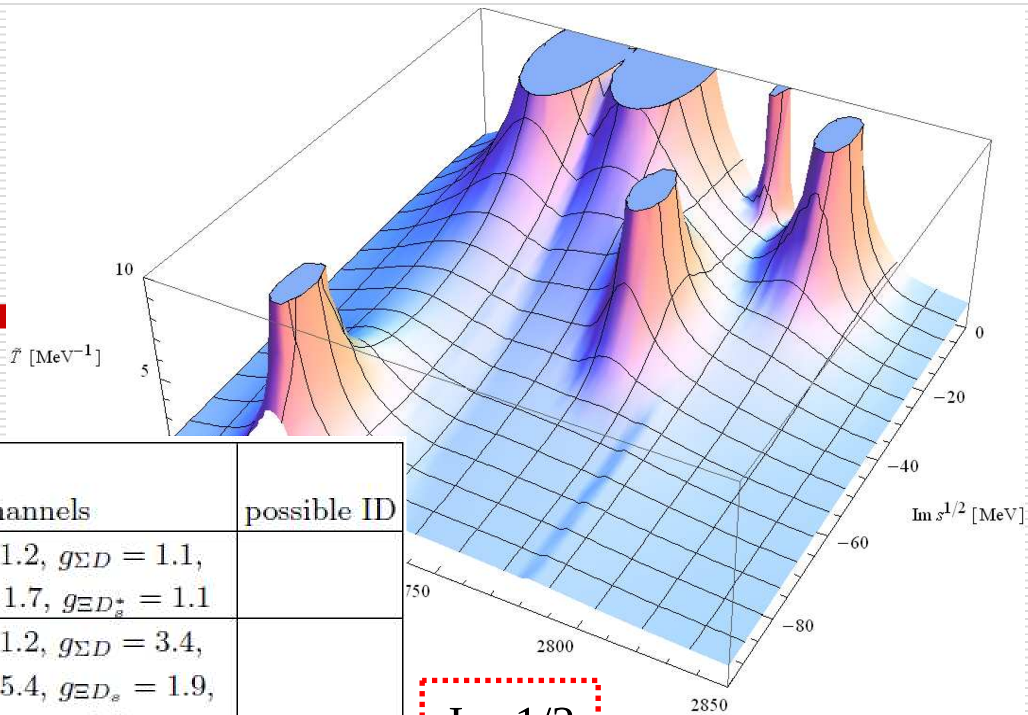
SU(8) irrep	SU(6) irrep	SU(3) irrep	M_R	Γ_R	Couplings to main channels	possible ID
168	$\mathbf{15_{2,1}}$	$\mathbf{3_4}$	2666.6	53.7	$\mathbf{g_{\Sigma_c^*\pi} = 2.2}$, $g_{ND^*} = 2.0$, $g_{\Sigma_c\rho} = 0.8$, $g_{\Sigma_c^*\rho} = 1.3$	$\Lambda_c(2625)^+$ ***

J = 3/2

KVI university of groningen

Results

$\mathbf{C = 1,\ S = -1,\ I = \frac{1}{2}\ (\Xi_c)}$



J = 1/2

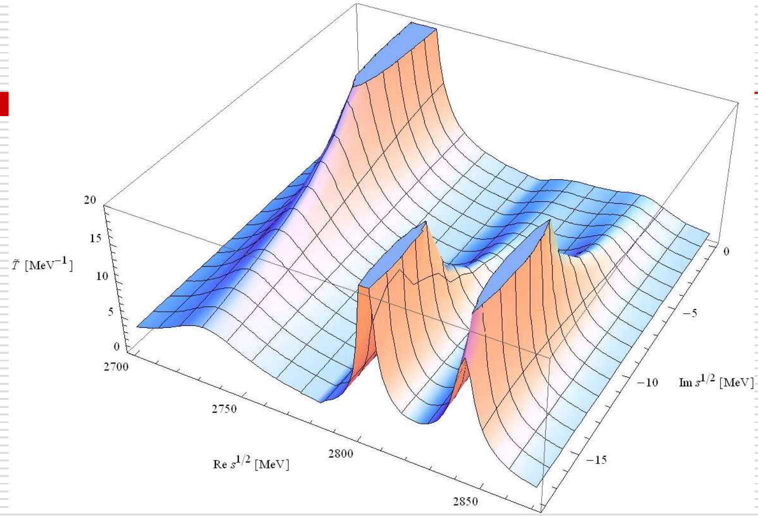
SU(8) irrep	SU(6) irrep	SU(3) irrep	M_R	Γ_R	the main channels	possible ID
168	$\mathbf{15_{2,1}}$	$\mathbf{6_2}$	2702.8	177.8	$\mathbf{g_{\Xi_c\pi} = 2.4}$, $g_{\Lambda D} = 1.2$, $g_{\Sigma D} = 1.1$, $g_{\Lambda D^*} = 2.1$, $g_{\Sigma D^*} = 1.7$, $g_{\Xi D_s^*} = 1.1$	
168	$\mathbf{21_{2,1}}$	$\mathbf{3^*_2}$	2699.4	12.6	$\mathbf{g_{\Xi_c\pi} = 0.8}$, $g_{\Lambda D} = 1.2$, $g_{\Sigma D} = 3.4$, $g_{\Lambda D^*} = 2.2$, $g_{\Sigma D^*} = 5.4$, $g_{\Xi D_s} = 1.9$, $g_{\Xi_c\eta'} = 1.0$, $g_{\Xi D_s^*} = 3.3$	
168	$\mathbf{21_{2,1}}$	$\mathbf{6_2}$	2733.0	2.2	$\mathbf{g_{\Xi'_c\pi} = 0.5}$, $g_{\Lambda D} = 1.9$, $g_{\Sigma D} = 1.8$, $g_{\Lambda D^*} = 0.9$, $g_{\Sigma D^*} = 1.2$, $g_{\Xi D_s} = 1.2$, $g_{\Sigma^* D^*} = 5.8$, $g_{\Xi'_c\eta'} = 0.9$, $g_{\Xi^* D_s^*} = 3.3$	
120	$\mathbf{21_{2,1}}$	$\mathbf{3^*_2}$	2772.9	83.7	$\mathbf{g_{\Xi_c\pi} = 0.1}$, $\mathbf{g_{\Xi'_c\pi} = 2.3}$, $g_{\Sigma_c\bar{K}} = 1.2$, $g_{\Lambda D} = 2.1$, $g_{\Lambda D^*} = 1.5$, $g_{\Omega_c K} = 0.9$, $g_{\Sigma D^*} = 0.9$, $g_{\Xi_c\rho} = 1.0$, $g_{\Sigma_c\bar{K}^*} = 0.9$, $g_{\Xi'_c\rho} = 1.0$, $g_{\Sigma^* D^*} = 1.4$, $g_{\Xi^* D_s^*} = 1.1$	
168	$\mathbf{15_{2,1}}$	$\mathbf{3^*_2}$	2775.4	0.6	$\mathbf{g_{\Xi_c\pi} = 0.1}$, $\mathbf{g_{\Xi'_c\pi} = 0.1}$, $g_{\Lambda_c\bar{K}} = 1.4$, $g_{\Xi_c\eta} = 0.9$, $g_{\Lambda D^*} = 1.0$, $g_{\Sigma D^*} = 1.4$, $g_{\Sigma_c K^*} = 1.0$, $g_{\Sigma_c^* K^*} = 1.3$	
120	$\mathbf{21_{2,1}}$	$\mathbf{6_2}$	2804.8	20.7	$\mathbf{g_{\Xi'_c\pi} = 1.1}$, $g_{\Sigma_c K} = 2.4$, $g_{\Lambda D} = 1.5$, $g_{\Sigma D} = 1.2$, $g_{\Xi'_c\eta} = 1.3$, $g_{\Lambda_c\bar{K}^*} = 1.2$, $g_{\Sigma D^*} = 0.9$, $g_{\Sigma_c\bar{K}^*} = 1.8$, $g_{\Sigma^* D^*} = 1.1$, $g_{\Sigma_c^* K^*} = 1.0$, $g_{\Xi^* D_s^*} = 1.2$	$\Xi_c(2790)$ ***

KVI university of groningen

Results

$$\mathbf{C = 1,\ S = -1,\ I = \tfrac{1}{2}}\ (\Xi_c)$$

$\boxed{\Xi_c(2815)}$ $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$



$\Xi_c(2815)^+$ mass $m = 2816.6 \pm 0.9$ MeV
$\Xi_c(2815)^0$ mass $m = 2819.6 \pm 1.2$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c^+} = 348.8 \pm 0.9$ MeV
$m_{\Xi_c(2815)^0} - m_{\Xi_c^0} = 348.7 \pm 1.2$ MeV
$m_{\Xi_c(2815)^+} - m_{\Xi_c(2815)^0} = -3.1 \pm 1.3$ MeV
$\Xi_c(2815)^+$ full width $\Gamma < 3.5$ MeV, CL = 90%
$\Xi_c(2815)^0$ full width $\Gamma < 6.5$ MeV, CL = 90%

J = 3/2

SU(8) irrep	SU(6) irrep	SU(3) irrep	M_R	Γ_R	Couplings to main channels	possible ID
168	$\mathbf{21_{2,1}}$	$\mathbf{6_4}$	2734.3	0.0	$g_{\Lambda D^*} = 2.2,\ g_{\Sigma D^*} = 2.1,\ g_{\Sigma^* D} = 3.6,$ $g_{\Sigma^* D^*} = 4.6,\ g_{\Xi D_s^*} = 1.3,\ g_{\Xi^* D_s} = 2.1,$ $g_{\Xi^* D_s^*} = 2.6$	
168	$\mathbf{15_{2,1}}$	$\mathbf{3^*_4}$	2819.7	32.4	$\mathbf{g_{\Xi_c^*\pi} = 1.9},\ g_{\Sigma_c^* \bar{K}} = 2.3,\ g_{\Lambda D^*} = 2.0,$ $g_{\Lambda_c \bar{K}^*} = 1.0,\ g_{\Xi_c^* \eta} = 1.1,\ g_{\Sigma D^*} = 1.2,$ $g_{\Xi_c \rho} = 1.1,\ g_{\Sigma_c \bar{K}^*} = 1.0,\ g_{\Sigma_c^* \bar{K}^*} = 2.0$	$\Xi_c(2815)$ ***
120	$\mathbf{21_{2,1}}$	$\mathbf{6_4}$	2845.2	44.0	$\mathbf{g_{\Xi_c^*\pi} = 1.9},\ g_{\Sigma_c^* \bar{K}} = 2.1,\ g_{\Lambda D^*} = 2.6,$ $g_{\Lambda_c \bar{K}^*} = 1.4,\ g_{\Xi_c^* \eta} = 1.2,\ g_{\Sigma D^*} = 1.2,$ $g_{\Xi_c \rho} = 0.9,\ g_{\Sigma_c \bar{K}^*} = 0.9,\ g_{\Sigma_c^* \bar{K}^*} = 1.7,$ $g_{\Xi^* D_s} = 0.9,\ g_{\Xi^* D_s^*} = 1.1$	

Conclusions:

- We have studied dynamically-generated strange and charmed resonances by solving the Bethe-Salpeter equation in coupled channels using, as bare interaction, the WT interaction and implementing heavy-quark symmetry.

- Some of those molecular states can be identified with resonances obtained experimentally (e.g. $\Lambda_c(2595)$, $\Xi_c(2790)$) and some others are predictions to be tested in on-going and future experiments.

Outlook:

- Continue the analysis of our predicted resonances and comparison with the available experimental data.
- Study of the resonances coming from the **4752** representation.
- Improvement of the bare meson-baryon interaction beyond WT.
- Inclusion of medium effects to study the properties of charmed and strange mesons in dense matter.