QUARK MODEL WITH HIDDEN LOCAL SYMMETRY AND ITS APPLICATION TO THE HADRON SPECTRUM

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Outline

- ***Introduction***

- Chiral quark model with HLS

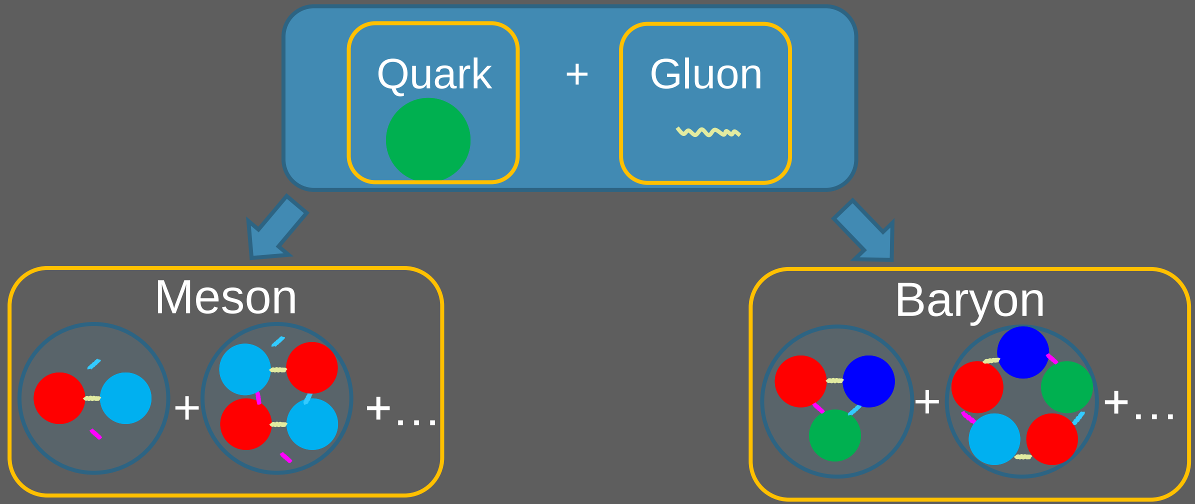
- $SU2$ ground states + excited states

- $SU3$ ground states

- Future works

Introduction

Hadron are made by quarks and gluons



The dynamics of quarks and gluons are described by Quantum chromodynamics (QCD)

- QCD have two important features:
  - Color confinement
  - Asymptotic freedom

- In low energy region the perturbative calculation for QCD is impossible, alternatively:
  - Lattice QCD (non-perturbative calculation)
  - Effective models (chiral perturbation theory, quark model, etc…)

Meson Summary Table

See also the table of suggested $q\overline{q}$ quark-model assignments in the Quark Model section.

• Indicates particles that appear in the preceding Meson Summary Table. We do not regard the other entries as being established.

LIGHT UNFLAVORED ($S = C = B = 0$)

	$I^G(J^{PC})$		$I^G(J^{PC})$
• $\pi^{\pm}$	$1^-(0^-)$	• $\pi_2(1670)$	$1^-(2^{-+})$
• π^0	$1^-(0^{-+})$	• $\phi(1680)$	$0^-(1^{--})$
• η	$0^+(0^{-+})$	• $\rho_3(1690)$	$1^+(3^{--})$
• $f_0(500)$	$0^+(0^{++})$	• $\rho(1700)$	$1^+(1^{--})$
• $\rho(770)$	$1^+(1^{--})$	• $a_2(1700)$	$1^-(2^{++})$
• $\omega(782)$	$0^-(1^{--})$	• $f_0(1710)$	$0^+(0^{++})$
• $\eta'(958)$	$0^+(0^{-+})$	$X(1750)$	$?^-(1^{--})$
• $f_0(980)$	$0^+(0^{++})$	$\eta(1760)$	$0^+(0^{-+})$
• $a_0(980)$	$1^-(0^{++})$	• $\pi(1800)$	$1^-(0^{-+})$
• $\phi(1020)$	$0^-(1^{--})$	$f_2(1810)$	$0^+(2^{++})$
• $h_1(1170)$	$0^-(1^{+-})$	$X(1835)$	$?^?(0^{-+})$
• $b_1(1235)$	$1^+(1^{+-})$	• $\phi_3(1850)$	$0^-(3^{--})$
• $a_1(1260)$	$1^-(1^{++})$	• $\eta_2(1870)$	$0^+(2^{-+})$
• $f_2(1270)$	$0^+(2^{++})$	• $\pi_2(1880)$	$1^-(2^{-+})$
• $f_1(1285)$	$0^+(1^{++})$	$\rho(1900)$	$1^+(1^{--})$
• $\eta(1295)$	$0^+(0^{-+})$	$f_2(1910)$	$0^+(2^{++})$
• $\pi(1300)$	$1^-(0^{-+})$	$a_0(1950)$	$1^-(0^{++})$
• $a_2(1320)$	$1^-(2^{++})$	• $f_2(1950)$	$0^+(2^{++})$
• $f_0(1370)$	$0^+(0^{++})$	• $a_4(1970)$	$1^-(4^{++})$
• $\pi_1(1400)$	$1^-(1^{-+})$	$\rho_3(1990)$	$1^+(3^{--})$
• $\eta(1405)$	$0^+(0^{-+})$	$\pi_2(2005)$	$1^-(2^{-+})$
• $h_1(1415)$	$0^-(1^{+-})$	• $f_2(2010)$	$0^+(2^{++})$
• $f_1(1420)$	$0^+(1^{++})$	$f_0(2020)$	$0^+(0^{++})$
• $\omega(1420)$	$0^-(1^{--})$	• $f_4(2050)$	$0^+(4^{++})$
$f_2(1430)$	$0^+(2^{++})$	$\pi_2(2100)$	$1^-(2^{-+})$
• $a_0(1450)$	$1^-(0^{++})$	$f_0(2100)$	$0^+(0^{++})$
• $\rho(1450)$	$1^+(1^{--})$	$f_2(2150)$	$0^+(2^{++})$
• $\eta(1475)$	$0^+(0^{-+})$	$\rho(2150)$	$1^+(1^{--})$
• $f_0(1500)$	$0^+(0^{++})$	• $\phi(2170)$	$0^-(1^{--})$
$f_1(1510)$	$0^+(1^{++})$	$f_0(2200)$	$0^+(0^{++})$
• $f'_2(1525)$	$0^+(2^{++})$	$f_J(2220)$	$0^+(2^{++}$ or $4^{++})$
$f_2(1565)$	$0^+(2^{++})$	$\eta(2225)$	$0^+(0^{-+})$
$\rho(1570)$	$1^+(1^{--})$	$\rho_3(2250)$	$1^+(3^{--})$
$h_1(1595)$	$0^-(1^{+-})$	• $f_2(2300)$	$0^+(2^{++})$
• $\pi_1(1600)$	$1^-(1^{-+})$	$f_4(2300)$	$0^+(4^{++})$
• $a_1(1640)$	$1^-(1^{++})$	$f_0(2330)$	$0^+(0^{++})$
$f_2(1640)$	$0^+(2^{++})$	• $f_2(2340)$	$0^+(2^{++})$
• $\eta_2(1645)$	$0^+(2^{-+})$	$\rho_5(2350)$	$1^+(5^{--})$
• $\omega(1650)$	$0^-(1^{--})$	$X(2370)$	$?^?(?^{??})$
• $\omega_3(1670)$	$0^-(3^{--})$	$f_6(2510)$	$0^+(6^{++})$

STRANGE ($S = \pm1$, $C = B = 0$)

	$I(J^P)$
• $K^{\pm}$	$1/2(0^-)$
• K^0	$1/2(0^-)$
• K^0_S	$1/2(0^-)$
• K^0_L	$1/2(0^-)$
• $K^*_0(700)$	$1/2(0^+)$
• $K^*(892)$	$1/2(1^-)$
• $K_1(1270)$	$1/2(1^+)$
• $K_1(1400)$	$1/2(1^+)$
• $K^*(1410)$	$1/2(1^-)$
• $K^*_0(1430)$	$1/2(0^+)$
• $K^*_2(1430)$	$1/2(2^+)$
• $K(1460)$	$1/2(0^-)$
$K_2(1580)$	$1/2(2^-)$
$K(1630)$	$1/2(?^?)$
• $K_1(1650)$	$1/2(1^+)$
• $K^*(1680)$	$1/2(1^-)$
• $K_2(1770)$	$1/2(2^-)$
• $K^*_3(1780)$	$1/2(3^-)$
• $K_2(1820)$	$1/2(2^-)$
$K(1830)$	$1/2(0^-)$
$K^*_0(1950)$	$1/2(0^+)$
• $K^*_2(1980)$	$1/2(2^+)$
• $K^*_4(2045)$	$1/2(4^+)$
$K_2(2250)$	$1/2(2^-)$
$K_3(2320)$	$1/2(3^+)$
$K^*_5(2380)$	$1/2(5^-)$
$K_4(2500)$	$1/2(4^-)$
$K(3100)$	$?^?(?^{??})$

CHARMED ($C = \pm1$)

	$I(J^P)$
• $D^{\pm}$	$1/2(0^-)$
• D^0	$1/2(0^-)$
• $D^*(2007)^0$	$1/2(1^-)$
• $D^*(2010)^{\pm}$	$1/2(1^-)$
• $D^*_0(2300)$	$1/2(0^+)$
• $D_1(2420)$	$1/2(1^+)$
• $D_1(2430)^0$	$1/2(1^+)$
• $D^*_2(2460)$	$1/2(2^+)$
$D_0(2550)^0$	$1/2(0^-)$
$D^*_1(2600)^0$	$1/2(1^-)$
$D^*(2640)^{\pm}$	$1/2(?^?)$
$D_2(2740)^0$	$1/2(2^-)$
• $D^*_3(2750)$	$1/2(3^-)$
$D^*_1(2760)^0$	$1/2(1^-)$
$D(3000)^0$	$1/2(?^?)$

CHARMED, STRANGE ($C = \pm1$, $S = \pm1$) (+ possibly non-$q\overline{q}$ states)

	$I(J^P)$
• $D^{\pm}_s$	$0(0^-)$
• $D^{*\pm}_s$	$0(?^?)$
• $D^*_{s0}(2317)^{\pm}$	$0(0^+)$
• $D_{s1}(2460)^{\pm}$	$0(1^+)$
• $D_{s1}(2536)^{\pm}$	$0(1^+)$
• $D^*_{s2}(2573)$	$0(2^+)$
$D_{s0}(2590)^+$	$0(0^-)$
• $D^*_{s1}(2700)^{\pm}$	$0(1^-)$
$D^*_{s1}(2860)^{\pm}$	$0(1^-)$
• $D^*_{s3}(2860)^{\pm}$	$0(3^-)$
$X_0(2900)$	$?(0^+)$
$X_1(2900)$	$?(1^-)$
$D_{sJ}(3040)^{\pm}$	$0(?^?)$

BOTTOM ($B = \pm1$)

• $B^{\pm}$	$1/2(0^-)$
• B^0	$1/2(0^-)$
• $B^{\pm}/B^0$ ADMIXTURE	
• $B^{\pm}/B^0/B^0_s/b$-baryon ADMIXTURE	
V_{cb} and V_{ub} CKM Matrix Elements	
• B^*	$1/2(1^-)$
• $B_1(5721)$	$1/2(1^+)$
$B^*_J(5732)$	$?(?^?)$
• $B^*_2(5747)$	$1/2(2^+)$
$B_J(5840)$	$1/2(?^?)$
• $B_J(5970)$	$1/2(?^?)$

BOTTOM, STRANGE ($B = \pm1$, $S = \mp1$)

• B^0_s	$0(0^-)$
• B^*_s	$0(1^-)$
$X(5568)^{\pm}$	$?(?^?)$
• $B_{s1}(5830)^0$	$0(1^+)$
• $B^*_{s2}(5840)^0$	$0(2^+)$
$B^*_{sJ}(5850)$	$?(?^?)$
$B_{sJ}(6063)^0$	$0(?^?)$
$B_{sJ}(6114)^0$	$0(?^?)$

BOTTOM, CHARMED ($B = C = \pm1$)

• B^+_c	$0(0^-)$
• $B_c(2S)^{\pm}$	$0(0^-)$

$c\overline{c}$ (+ possibly non-$q\overline{q}$ states)

	$I^G(J^{PC})$
• $\eta_c(1S)$	$0^+(0^{-+})$
• $J/\psi(1S)$	$0^-(1^{--})$
• $\chi_{c0}(1P)$	$0^+(0^{++})$
• $\chi_{c1}(1P)$	$0^+(1^{++})$
• $h_c(1P)$	$0^-(1^{+-})$
• $\chi_{c2}(1P)$	$0^+(2^{++})$
• $\eta_c(2S)$	$0^+(0^{-+})$
• $\psi(2S)$	$0^-(1^{--})$
• $\psi(3770)$	$0^-(1^{--})$

$c\overline{c}$ continued

	$I^G(J^{PC})$
• $\psi_2(3823)$	$0^-(2^{--})$
• $\psi_3(3842)$	$0^-(3^{--})$
$\chi_{c0}(3860)$	$0^+(0^{++})$
• $\chi_{c1}(3872)$	$0^+(1^{++})$
• $Z_c(3900)$	$1^+(1^{+-})$
• $\chi_{c0}(3915)$	$0^+(0^{++})$
• $\chi_{c2}(3930)$	$0^+(2^{++})$
$X(3940)$	$?^?(?^{??})$
• $X(4020)^{\pm}$	$1^+(?^{?-})$
• $\psi(4040)$	$0^-(1^{--})$
$X(4050)^{\pm}$	$1^-(?^{?+})$
$X(4055)^{\pm}$	$1^+(?^{?-})$
$X(4100)^{\pm}$	$1^-(?^{??})$
• $\chi_{c1}(4140)$	$0^+(1^{++})$
• $\psi(4160)$	$0^-(1^{--})$
$X(4160)$	$?^?(?^{??})$
$Z_c(4200)$	$1^+(1^{+-})$
• $\psi(4230)$	$0^-(1^{--})$
$R_{c0}(4240)$	$1^+(0^{--})$
$X(4250)^{\pm}$	$1^-(?^{?+})$
• $\chi_{c1}(4274)$	$0^+(1^{++})$
$X(4350)$	$0^+(?^{?+})$
• $\psi(4360)$	$0^-(1^{--})$
• $\psi(4415)$	$0^-(1^{--})$
• $Z_c(4430)$	$1^+(1^{+-})$
$\chi_{c0}(4500)$	$0^+(0^{++})$
$X(4630)$	$0^+(?^{?+})$
• $\psi(4660)$	$0^-(1^{--})$
$\chi_{c1}(4685)$	$0^+(1^{++})$
$\chi_{c0}(4700)$	$0^+(0^{++})$

$b\overline{b}$ (+ possibly non-$q\overline{q}$ states)

• $\eta_b(1S)$	$0^+(0^{-+})$
• $\Upsilon(1S)$	$0^-(1^{--})$
• $\chi_{b0}(1P)$	$0^+(0^{++})$
• $\chi_{b1}(1P)$	$0^+(1^{++})$
• $h_b(1P)$	$0^-(1^{+-})$
• $\chi_{b2}(1P)$	$0^+(2^{++})$
$\eta_b(2S)$	$0^+(0^{-+})$
• $\Upsilon(2S)$	$0^-(1^{--})$
• $\Upsilon_2(1D)$	$0^-(2^{--})$
• $\chi_{b0}(2P)$	$0^+(0^{++})$
• $\chi_{b1}(2P)$	$0^+(1^{++})$
• $h_b(2P)$	$0^-(1^{+-})$
• $\chi_{b2}(2P)$	$0^+(2^{++})$
• $\Upsilon(3S)$	$0^-(1^{--})$
• $\chi_{b1}(3P)$	$0^+(1^{++})$
• $\chi_{b2}(3P)$	$0^+(2^{++})$
• $\Upsilon(4S)$	$0^-(1^{--})$
• $Z_b(10610)$	$1^+(1^{+-})$
• $Z_b(10650)$	$1^+(1^{+-})$
$\Upsilon(10753)$	$?^?(1^{--})$
• $\Upsilon(10860)$	$0^-(1^{--})$
• $\Upsilon(11020)$	$0^-(1^{--})$

OTHER

Further States

Baryon Summary Table

This short table gives the name, the quantum numbers (where known), and the status of baryons in the Review. Only the baryons with 3- or 4-star status are included in the Baryon Summary Table. Due to insufficient data or uncertain interpretation, the other entries in the table are not established baryons. The names with masses are of baryons that decay strongly. The spin-parity J^P (when known) is given with each particle. For the strongly decaying particles, the J^P values are considered to be part of the names.

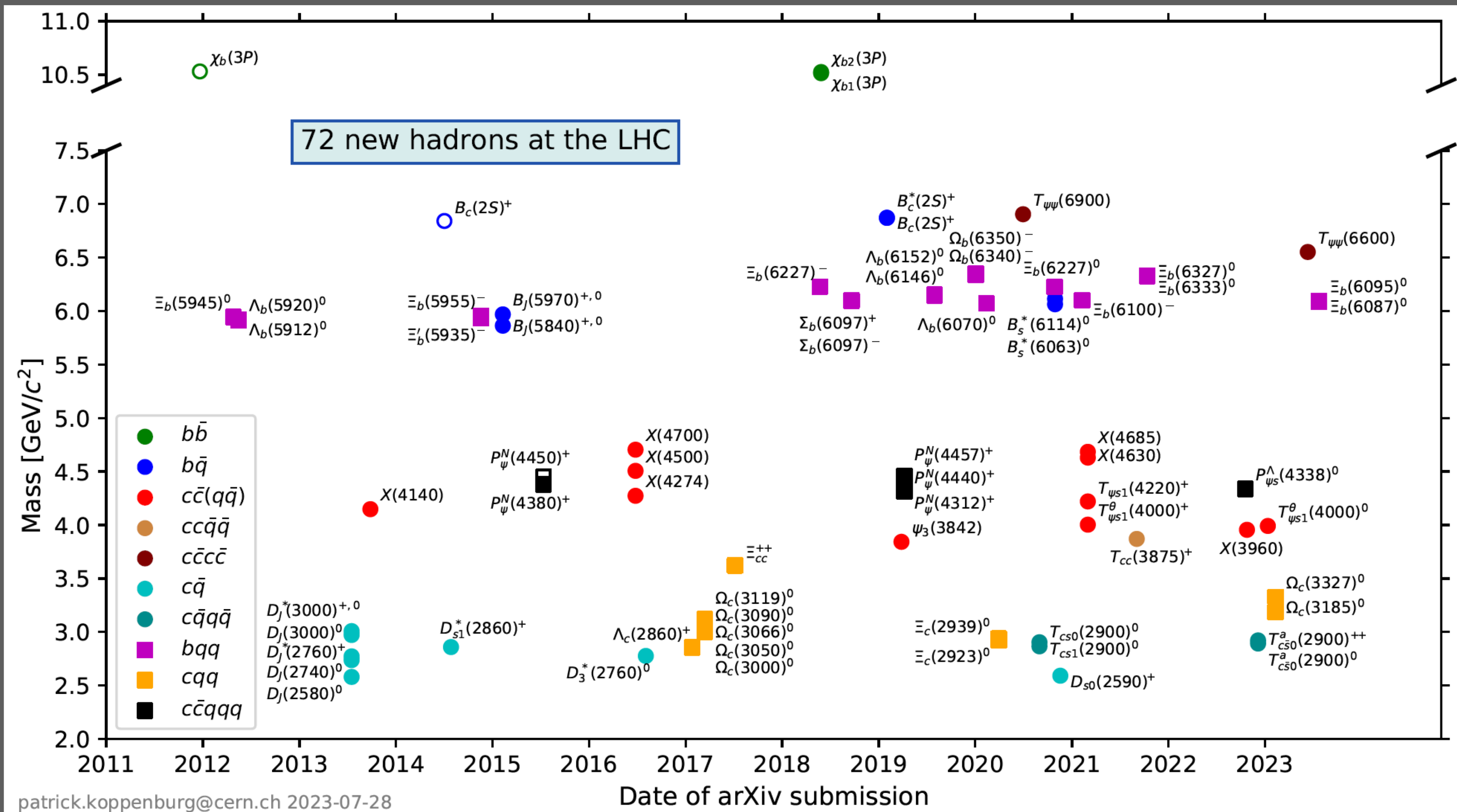
p	$1/2^+$	****
n	$1/2^+$	****
$N(1440)$	$1/2^+$	****
$N(1520)$	$3/2^-$	****
$N(1535)$	$1/2^-$	****
$N(1650)$	$1/2^-$	****
$N(1675)$	$5/2^-$	****
$N(1680)$	$5/2^+$	****
$N(1700)$	$3/2^-$	***
$N(1710)$	$1/2^+$	****
$N(1720)$	$3/2^+$	****
$N(1860)$	$5/2^+$	**
$N(1875)$	$3/2^-$	***
$N(1880)$	$1/2^+$	***
$N(1895)$	$1/2^-$	****
$N(1900)$	$3/2^+$	****
$N(1990)$	$7/2^+$	**
$N(2000)$	$5/2^+$	**
$N(2040)$	$3/2^+$	*
$N(2060)$	$5/2^-$	***
$N(2100)$	$1/2^+$	***
$N(2120)$	$3/2^-$	***
$N(2190)$	$7/2^-$	****
$N(2220)$	$9/2^+$	****
$N(2250)$	$9/2^-$	****
$N(2300)$	$1/2^+$	**
$N(2570)$	$5/2^-$	**
$N(2600)$	$11/2^-$	***
$N(2700)$	$13/2^+$	**

$\Delta(1232)$	$3/2^+$	****
$\Delta(1600)$	$3/2^+$	****
$\Delta(1620)$	$1/2^-$	****
$\Delta(1700)$	$3/2^-$	****
$\Delta(1750)$	$1/2^+$	*
$\Delta(1900)$	$1/2^-$	***
$\Delta(1905)$	$5/2^+$	****
$\Delta(1910)$	$1/2^+$	****
$\Delta(1920)$	$3/2^+$	***
$\Delta(1930)$	$5/2^-$	***
$\Delta(1940)$	$3/2^-$	**
$\Delta(1950)$	$7/2^+$	****
$\Delta(2000)$	$5/2^+$	**
$\Delta(2150)$	$1/2^-$	*
$\Delta(2200)$	$7/2^-$	***
$\Delta(2300)$	$9/2^+$	**
$\Delta(2350)$	$5/2^-$	*
$\Delta(2390)$	$7/2^+$	*
$\Delta(2400)$	$9/2^-$	**
$\Delta(2420)$	$11/2^+$	****
$\Delta(2750)$	$13/2^-$	**
$\Delta(2950)$	$15/2^+$	**
Λ	$1/2^+$	****
$\Lambda(1380)$	$1/2^-$	**
$\Lambda(1405)$	$1/2^-$	****
$\Lambda(1520)$	$3/2^-$	****
$\Lambda(1600)$	$1/2^+$	****
$\Lambda(1670)$	$1/2^-$	****
$\Lambda(1690)$	$3/2^-$	****
$\Lambda(1710)$	$1/2^+$	*
$\Lambda(1800)$	$1/2^-$	***
$\Lambda(1810)$	$1/2^+$	***
$\Lambda(1820)$	$5/2^+$	****
$\Lambda(1830)$	$5/2^-$	****
$\Lambda(1890)$	$3/2^+$	****
$\Lambda(2000)$	$1/2^-$	*
$\Lambda(2050)$	$3/2^-$	*
$\Lambda(2070)$	$3/2^+$	*
$\Lambda(2080)$	$5/2^-$	*
$\Lambda(2085)$	$7/2^+$	**
$\Lambda(2100)$	$7/2^-$	****
$\Lambda(2110)$	$5/2^+$	***
$\Lambda(2325)$	$3/2^-$	*
$\Lambda(2350)$	$9/2^+$	***
$\Lambda(2585)$		*

Σ^+	$1/2^+$	****
Σ^0	$1/2^+$	****
Σ^-	$1/2^+$	****
$\Sigma(1385)$	$3/2^+$	****
$\Sigma(1580)$	$3/2^-$	*
$\Sigma(1620)$	$1/2^-$	*
$\Sigma(1660)$	$1/2^+$	***
$\Sigma(1670)$	$3/2^-$	****
$\Sigma(1750)$	$1/2^-$	***
$\Sigma(1775)$	$5/2^-$	****
$\Sigma(1780)$	$3/2^+$	*
$\Sigma(1880)$	$1/2^+$	**
$\Sigma(1900)$	$1/2^-$	**
$\Sigma(1910)$	$3/2^-$	***
$\Sigma(1915)$	$5/2^+$	****
$\Sigma(1940)$	$3/2^+$	*
$\Sigma(2010)$	$3/2^-$	*
$\Sigma(2030)$	$7/2^+$	****
$\Sigma(2070)$	$5/2^+$	*
$\Sigma(2080)$	$3/2^+$	*
$\Sigma(2100)$	$7/2^-$	*
$\Sigma(2110)$	$1/2^-$	*
$\Sigma(2230)$	$3/2^+$	*
$\Sigma(2250)$		**
$\Sigma(2455)$		*
$\Sigma(2620)$		*
$\Sigma(3000)$		*
$\Sigma(3170)$		*
Ξ^0	$1/2^+$	****
Ξ^-	$1/2^+$	****
$\Xi(1530)$	$3/2^+$	****
$\Xi(1620)$		*
$\Xi(1690)$		***
$\Xi(1820)$	$3/2^-$	***
$\Xi(1950)$		***
$\Xi(2030)$	$\geq \frac{5}{2}^?$	***
$\Xi(2120)$		*
$\Xi(2250)$		**
$\Xi(2370)$		**
$\Xi(2500)$		*
Ω^-	$3/2^+$	****
$\Omega(2012)^-$	$?^-$	***
$\Omega(2250)^-$		***
$\Omega(2380)^-$		**
$\Omega(2470)^-$		**

Λ^+_c	$1/2^+$	****
$\Lambda_c(2595)^+$	$1/2^-$	***
$\Lambda_c(2625)^+$	$3/2^-$	***
$\Lambda_c(2765)^+$		*
$\Lambda_c(2860)^+$	$3/2^+$	***
$\Lambda_c(2880)^+$	$5/2^+$	***
$\Lambda_c(2940)^+$	$3/2^-$	***
$\Sigma_c(2455)$	$1/2^+$	****
$\Sigma_c(2520)$	$3/2^+$	***
$\Sigma_c(2800)$		***
Ξ^+_c	$1/2^+$	***
Ξ^0_c	$1/2^+$	****
Ξ'^+_c	$1/2^+$	***
Ξ'^0_c	$1/2^+$	***
$\Xi_c(2645)$	$3/2^+$	***
$\Xi_c(2790)$	$1/2^-$	***
$\Xi_c(2815)$	$3/2^-$	***
$\Xi_c(2923)$		**
$\Xi_c(2930)$		**
$\Xi_c(2970)$	$1/2^+$	***
$\Xi_c(3055)$		***
$\Xi_c(3080)$		***
$\Xi_c(3123)$		*
Ω^0_c	$1/2^+$	***
$\Omega_c(2770)^0$	$3/2^+$	***
$\Omega_c(3000)^0$		***
$\Omega_c(3050)^0$		***
$\Omega_c(3065)^0$		***
$\Omega_c(3090)^0$		***
$\Omega_c(3120)^0$		***
Ξ^+_{cc}		*
Ξ^{++}_{cc}		***

Λ^0_b	$1/2^+$	***
$\Lambda_b(5912)^0$	$1/2^-$	***
$\Lambda_b(5920)^0$	$3/2^-$	***
$\Lambda_b(6070)^0$	$1/2^+$	***
$\Lambda_b(6146)^0$	$3/2^+$	***
$\Lambda_b(6152)^0$	$5/2^+$	***
Σ_b	$1/2^+$	***
Σ^*_b	$3/2^+$	***
$\Sigma_b(6097)^+$		***
$\Sigma_b(6097)^-$		***
Ξ^-_b	$1/2^+$	***
Ξ^0_b	$1/2^+$	***
$\Xi'_b(5935)^-$	$1/2^+$	***
$\Xi_b(5945)^0$	$3/2^+$	***
$\Xi_b(5955)^-$	$3/2^+$	***
$\Xi_b(6100)^-$	$3/2^-$	***
$\Xi_b(6227)^-$		***
$\Xi_b(6227)^0$		***
Ω^-_b	$1/2^+$	***
$\Omega_b(6316)^-$		*
$\Omega_b(6330)^-$		*
$\Omega_b(6340)^-$		*
$\Omega_b(6350)^-$		*
$P_c(4312)^+$		*
$P_c(4380)^+$		*
$P_c(4440)^+$		*
$P_c(4457)^+$		*

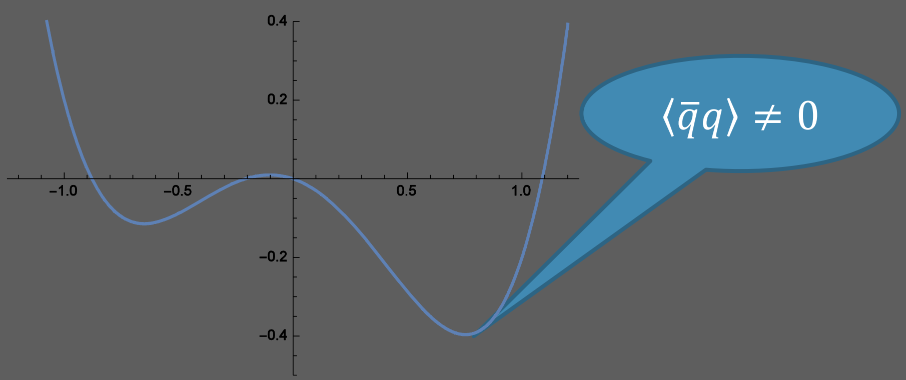

72 new hadrons at the LHC
Mass [GeV/c²]
Date of arXiv submission
2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023
2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 10.5 11.0
bb̄
bq̄
cc̄(qq̄)
ccq̄q̄
cc̄cc̄
cq̄
cq̄qq̄
bqq
cqq
cc̄qqq
χb(3P)
χb2(3P)
χb1(3P)
Bc(2S)+
B*c(2S)+
Bc(2S)+
Tψψ(6900)
Tψψ(6600)
Ξb(5945)0
Λb(5920)0
Λb(5912)0
Ξb(5955)−
Ξ′b(5935)−
BJ(5970)+,0
BJ(5840)+,0
Ξb(6227)−
Σb(6097)+
Σb(6097)−
Λb(6152)0
Λb(6146)0
Λb(6070)0
Ωb(6350)−
Ωb(6340)−
Ξb(6227)0
B*s(6114)0
B*s(6063)0
Ξb(6100)−
Ξb(6327)0
Ξb(6333)0
Ξb(6095)0
Ξb(6087)0
X(4140)
PNψ(4450)+
PNψ(4380)+
X(4700)
X(4500)
X(4274)
PNψ(4457)+
PNψ(4440)+
PNψ(4312)+
ψ3(3842)
X(4685)
X(4630)
Tψs1(4220)+
Tθψs1(4000)+
Tcc(3875)+
PΛψs(4338)0
Tθψs1(4000)0
X(3960)
Ξ++cc
D*J(3000)+,0
DJ(3000)0
D*J(2760)+
DJ(2740)0
DJ(2580)0
D*s1(2860)+
Λc(2860)+
D*3(2760)0
Ωc(3119)0
Ωc(3090)0
Ωc(3066)0
Ωc(3050)0
Ωc(3000)0
Ξc(2939)0
Ξc(2923)0
Tcs0(2900)0
Tcs1(2900)0
Ds0(2590)+
Ωc(3327)0
Ωc(3185)0
Tacs̄0(2900)++
Tacs̄0(2900)0
patrick.koppenburg@cern.ch 2023-07-28

The chiral symmetry

The chiral symmetry:

Spontaneously breaking of chiral symmetry:

$$\langle \bar{q}q \rangle = \langle \overline{q_L} q_R + \overline{q_R} q_L \rangle \neq 0$$



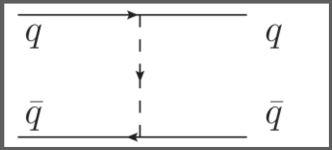
The effective theory based on chiral symmetry:

- Nonlinear sigma model
- Chiral perturbation theory

Chiral quark model

Naïve quark model:

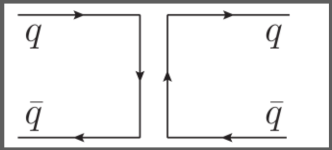
- Quark mass term
- Kinetic term
- Color confinement potential (CON)
- One gluon exchange (OGE)

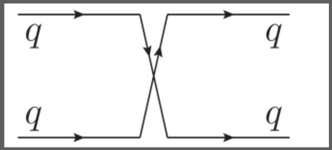


- Gell-Mann, M., 1964, Phys. Lett. 8, 214.
- Zweig, G., 1964, CERN Reports No. 8182/TH. 401 and No. 8419/TH. 412).
- N. Isgur, G. Karl, Phys.Lett.B 72 (1977) 109.

The Nambu–Goldstone boson exchange:

- Chiral symmetry is spontaneously broken
- Pseudoscalars (π, K, η) are the Nambu–Goldstone (NG) bosons of chiral symmetry breaking
- Scalar meson σ as the chiral partner of NG bosons





- K. Shimizu, Phys. Lett. B 148, 418-422 (1984)
- L.Ya Glozman, Z. Papp, W. Plessas, Physics Letters B 381 (1996) 311-316
- Z.Y. Zhang, Y.W. Yu, P.N. Shen, L.R. Dai, A. Faessler, U. Straub, Nucl. Phys. A 625 (1997) 59.
- J . Vijande, F . Fernandez, A . Valcarce, J. Phys. G 31, 481(2005)

The Hamiltonian

$$H = \sum_{i=1}^{n} \left(m_i + \frac{\boldsymbol{p}_i^2}{2m_i} \right) - T_{cm} + \sum_{j>i=1}^{n} \left(V_{ij}^{CON} + V_{ij}^{OGE} + V_{ij}^{\pi} + V_{ij}^{K} + V_{ij}^{\eta} + V_{ij}^{\sigma} \right)$$

J . Vijande, F . Fernandez, A . Valcarce, J. Phys. G 31, 481(2005)

$$V_{ij}^{CON} = (\boldsymbol{\lambda}_i^c \cdot \boldsymbol{\lambda}_j^c) \left[-a_c \left(1 - e^{-\mu_c r_{ij}} \right) + \Delta \right],$$

$$V_{ij}^{OGE} = \frac{1}{4} \alpha_s \left(\boldsymbol{\lambda}_i^c \cdot \boldsymbol{\lambda}_j^c \right) \left[\frac{1}{r_{ij}} - \frac{1}{6m_i m_j} \frac{e^{-\frac{r_{ij}}{r_0(\mu_{ij})}}}{r_{ij} r_0^2(\mu_{ij})} \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \right],$$

$$V_{ij}^{\sigma} = -\frac{g_{ch}^2}{4\pi} \frac{\Lambda_\sigma^2}{\Lambda_\sigma^2 - m_\sigma^2} m_\sigma \left[Y(m_\sigma r_{ij}) - \frac{\Lambda_\sigma}{m_\sigma} Y(\Lambda_\sigma r_{ij}) \right],$$

$$V_{ij}^{\pi} = \frac{g_{ch}^2}{4\pi} \frac{m_\pi^2}{12 m_i m_j} \frac{\Lambda_\pi^2}{\Lambda_\pi^2 - m_\pi^2} m_\pi \left[Y(m_\pi r_{ij}) - \frac{\Lambda_\pi^3}{m_\pi^3} Y(\Lambda_\pi r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \sum_{a=1}^{3} \lambda_i^a \lambda_j^a,$$

$$V_{ij}^{K} = \frac{g_{ch}^2}{4\pi} \frac{m_K^2}{12 m_i m_j} \frac{\Lambda_K^2}{\Lambda_K^2 - m_K^2} m_K \left[Y(m_K r_{ij}) - \frac{\Lambda_K^3}{m_K^3} Y(\Lambda_K r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \sum_{a=4}^{7} \lambda_i^a \lambda_j^a,$$

$$V_{ij}^{\eta} = \frac{g_{ch}^2}{4\pi} \frac{m_\eta^2}{12 m_i m_j} \frac{\Lambda_\eta^2}{\Lambda_\eta^2 - m_\eta^2} m_\eta \left[Y(m_\eta r_{ij}) - \frac{\Lambda_\eta^3}{m_\eta^3} Y(\Lambda_\eta r_{ij}) \right] \boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j \left(\lambda_i^8 \lambda_j^8 \cos\theta_p - \lambda_i^0 \lambda_j^0 \sin\theta_p \right).$$

The Gaussian expansion method

$$\psi_{lm}(\boldsymbol{r}) = \sum_{n=1}^{n_{max}} c_n \psi_{nlm}^{G}(\boldsymbol{r}),$$

$$\psi_{nlm}^{G}(\boldsymbol{r}) = N_{nl} r^l e^{-\nu_n r^2} Y_{lm}(\hat{\boldsymbol{r}}),$$

$$N_{nl} = \left(\frac{2^{l+2}(2\nu_n)^{l+\frac{3}{2}}}{\sqrt{\pi}(2l+1)!!} \right)^{\frac{1}{2}},$$

$$\nu_n = \frac{1}{r_n^2}, r_n = r_{min} a^{n-1}, a = \left(\frac{r_{max}}{r_{min}} \right)^{\frac{1}{n_{max}-1}}.$$

E. Hiyama, Y. Kino, and M. Kamimura, Prog. Part. Nucl. Phys. 51 223 (2003).

Outline

- Introduction
- ***Chiral quark model with HLS***
- $SU2$ ground states + excited states
- $SU3$ ground states
- Future works

Incorporate the vector meson contribution

The hidden local symmetry:

M. Bando, T. Kugo, K. Yamawaki.
Phys.Rept. 164 (1988) 217-314
M. Harada, K. Yamawaki.
Phys.Rept. 381 (2003) 1-233

$$U = \xi_L^\dagger \xi_R = e^{2i\frac{\pi(x)}{f_\pi}}$$

$$\xi_{L,R} \rightarrow h(x)\xi_{L,R} \cdot g_{L,R}^\dagger$$

$$h(x)^\dagger h(x) = 1$$

$$\xi_{L,R} = e^{i\frac{V(x)}{f_V}} e^{\mp i\frac{\pi(x)}{f_\pi}}$$

$$h(x) \in H_{\mathrm{local}}\ , \quad g_{\mathrm{L,R}} \in G_{\mathrm{global}}$$

- The transformation for U do not changes, which seems that the freedom of vector meson is "hidden"

$$[SU(N_f)_L \times SU(N_f)_R]_{global} \times [SU(N_f)_V]_{local} \rightarrow [SU(N_f)_V]_{global}$$

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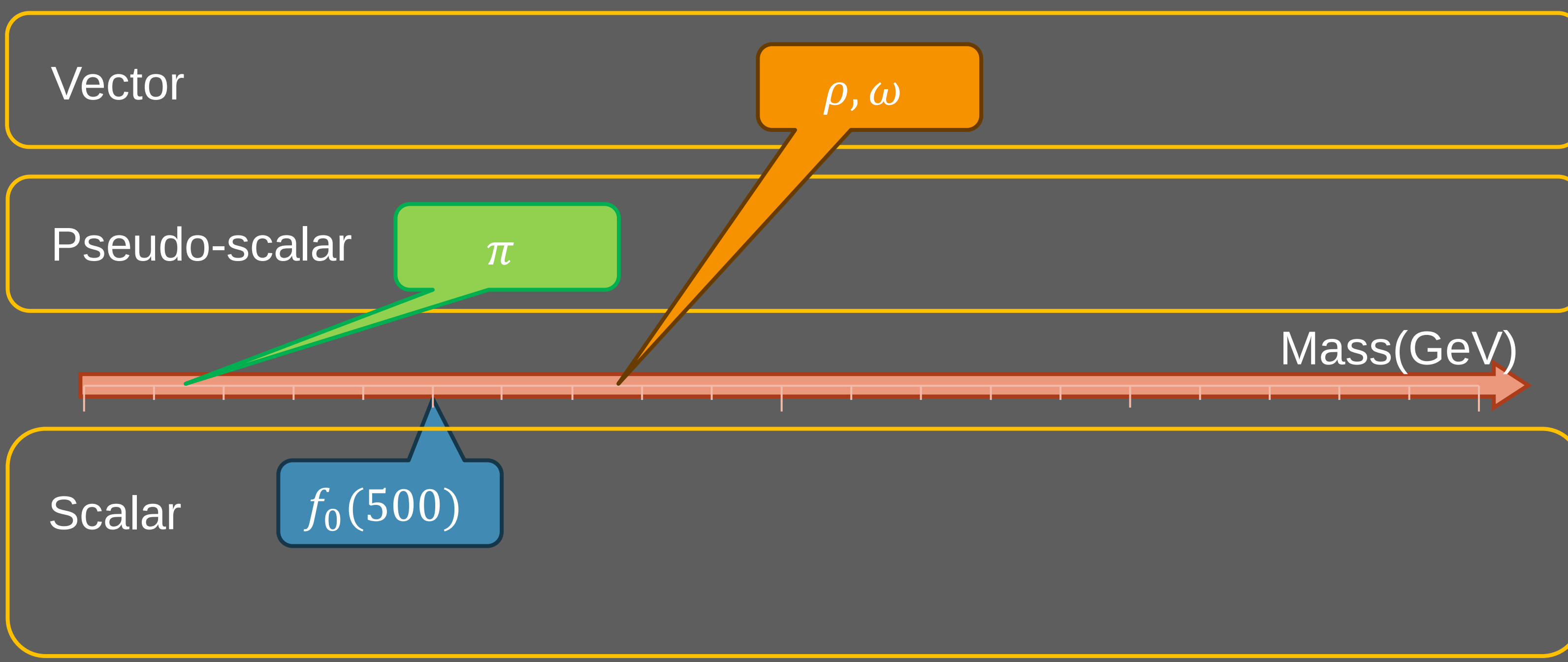
The Hamiltonian

$$H = \sum_{i=1} \left(m_i + \frac{p_i^2}{2m_i} \right) - T_{CM} + \sum_{j>i=1} \left(V_{ij}^{\mathrm{CON}} + V_{ij}^{\mathrm{OGE}} + V_{ij}^{\sigma} + V_{ij}^{\pi} + V_{ij}^{\omega} + V_{ij}^{\rho} \right)$$

Bing-Ran He, Masayasu Harada, Bing-Song Zou, 2306.03526

$$\begin{aligned}
V_{ij}^{v} = \frac{\Lambda_v^2}{\Lambda_v^2 - m_v^2} \Bigg\{ & \frac{g_v^2}{4\pi} m_v \left[Y(m_v r) - \left(\frac{\Lambda_v}{m_v} \right) Y(\Lambda_v r) \right] \\
& + \frac{m_v^3}{m_i m_j} \left(\frac{g_v(2f_v + g_v)}{16\pi} + \frac{\boldsymbol{\sigma}_i \cdot \boldsymbol{\sigma}_j}{6} \frac{(f_v + g_v)^2}{4\pi} \right) \\
& \times \left[Y(m_v r) - \left(\frac{\Lambda_v}{m_v} \right)^3 Y(\Lambda_v r) \right] \\
& - \boldsymbol{S}_+ \cdot \boldsymbol{L} \frac{g_v(4f_v + 3g_v)}{8\pi} \frac{m_v^3}{m_i m_j} \\
& \times \left[G(m_v r) - \left(\frac{\Lambda_v}{m_v} \right)^3 G(\Lambda_v r) \right] \\
& - \boldsymbol{S}_{ij} \frac{(f_v + g_v)^2}{4\pi} \frac{m_v^3}{12 m_i m_j} \\
& \times \left[H(m_v r) - \left(\frac{\Lambda_v}{m_v} \right)^3 H(\Lambda_v r) \right] \Bigg\}
\end{aligned}$$

The exchanged mesons in $SU2$ model



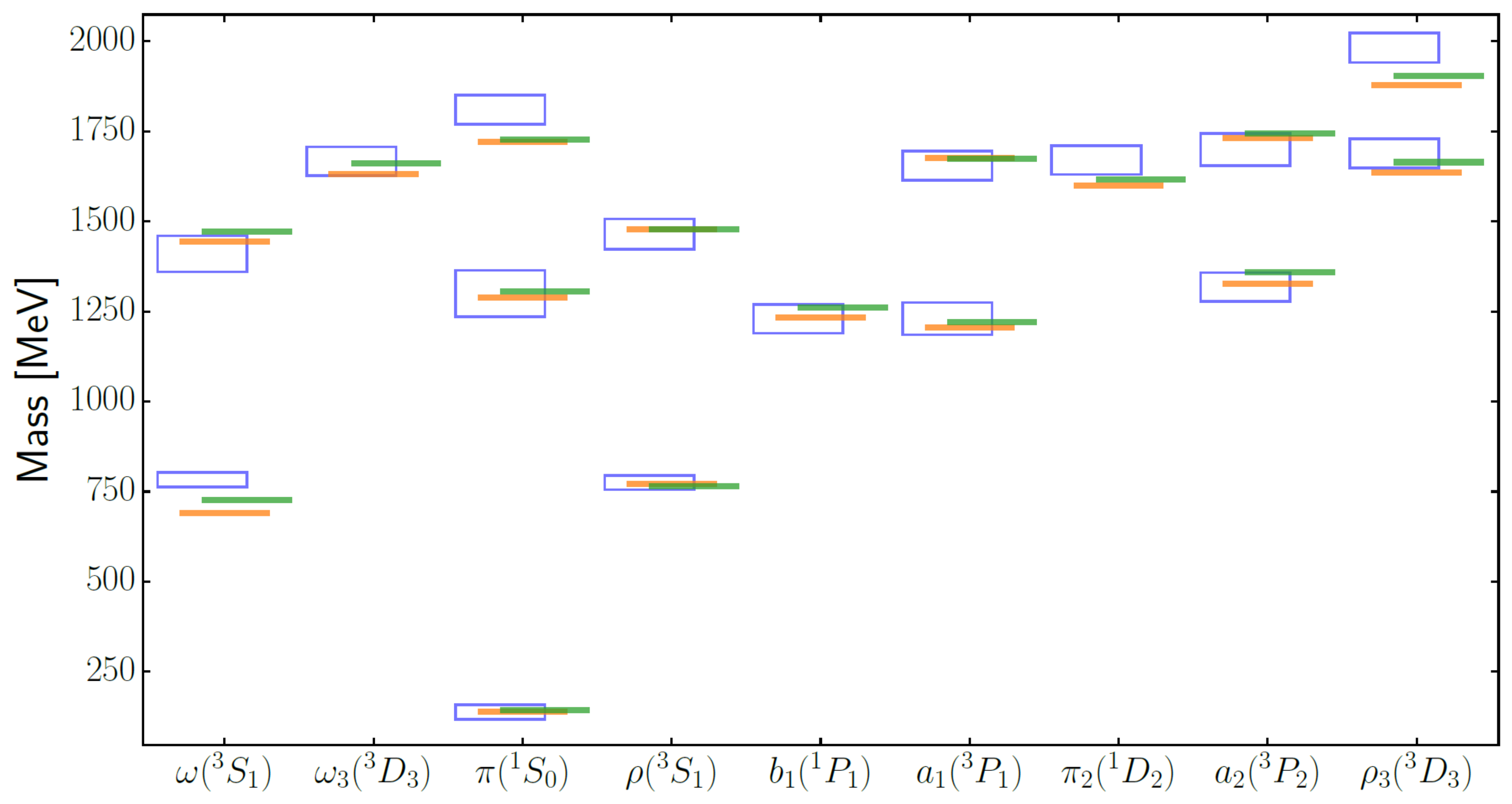
Symmetry of the model

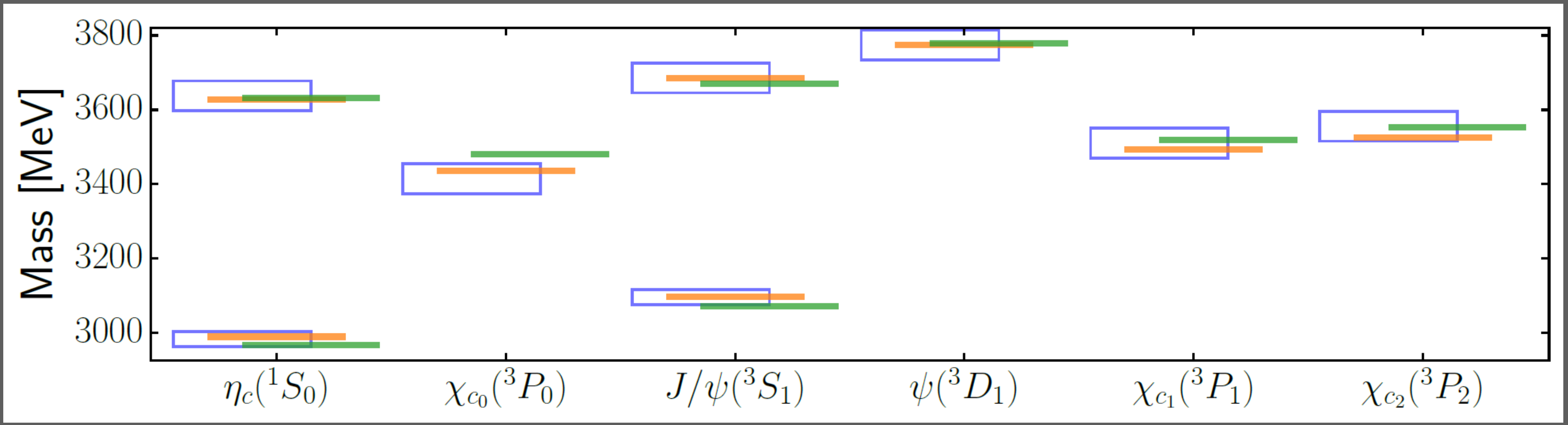
$$SU(2)_L \times SU(2)_R \times U(1)_V \Rightarrow SU(2)_V \times U(1)_V$$

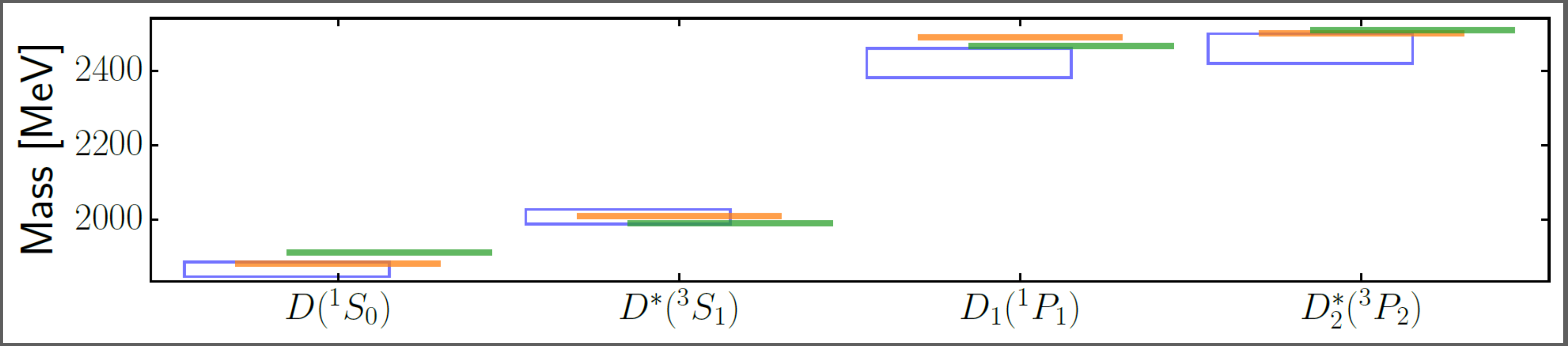
Wave functions

- Orbital (SO(3)): (ψ_L)
- Spin (SU(2)): (χ_S^σ)
- Flavor (SU(2)): (χ_I^f)
- Color (SU(3)): (χ^c)

$$\Psi^{ijk}_{JM_JIM_I} = \mathcal{A}\left[\left[\psi_L \chi_S^{\sigma i}\right]_{JM_J} \chi_I^{fj} \chi_k^c\right]$$


Mass [MeV]
2000
1750
1500
1250
1000
750
500
250
$\omega(^3S_1)$
$\omega_3(^3D_3)$
$\pi(^1S_0)$
$\rho(^3S_1)$
$b_1(^1P_1)$
$a_1(^3P_1)$
$\pi_2(^1D_2)$
$a_2(^3P_2)$
$\rho_3(^3D_3)$


Mass [MeV]
3800
3600
3400
3200
3000
$\eta_c(^1S_0)$
$\chi_{c_0}(^3P_0)$
$J/\psi(^3S_1)$
$\psi(^3D_1)$
$\chi_{c_1}(^3P_1)$
$\chi_{c_2}(^3P_2)$


Mass [MeV]
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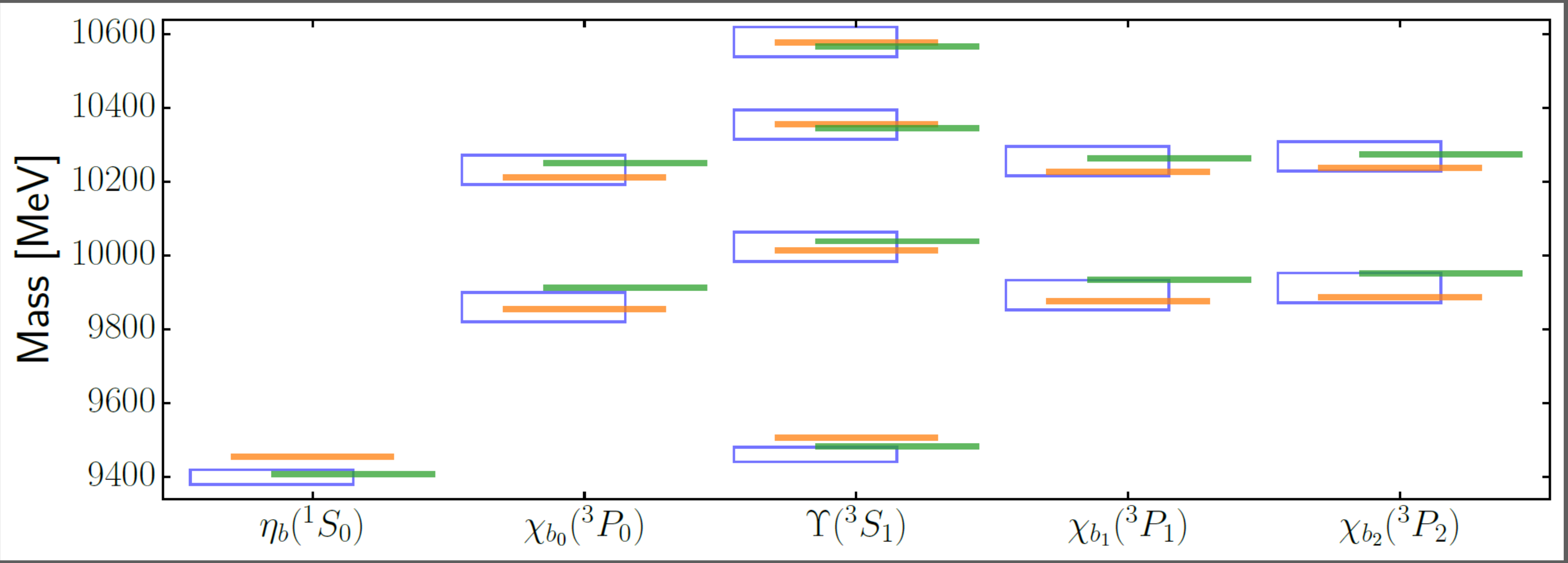
2200
2000
$D(^1S_0)$
$D^*(^3S_1)$
$D_1(^1P_1)$
$D_2^*(^3P_2)$


Mass [MeV]
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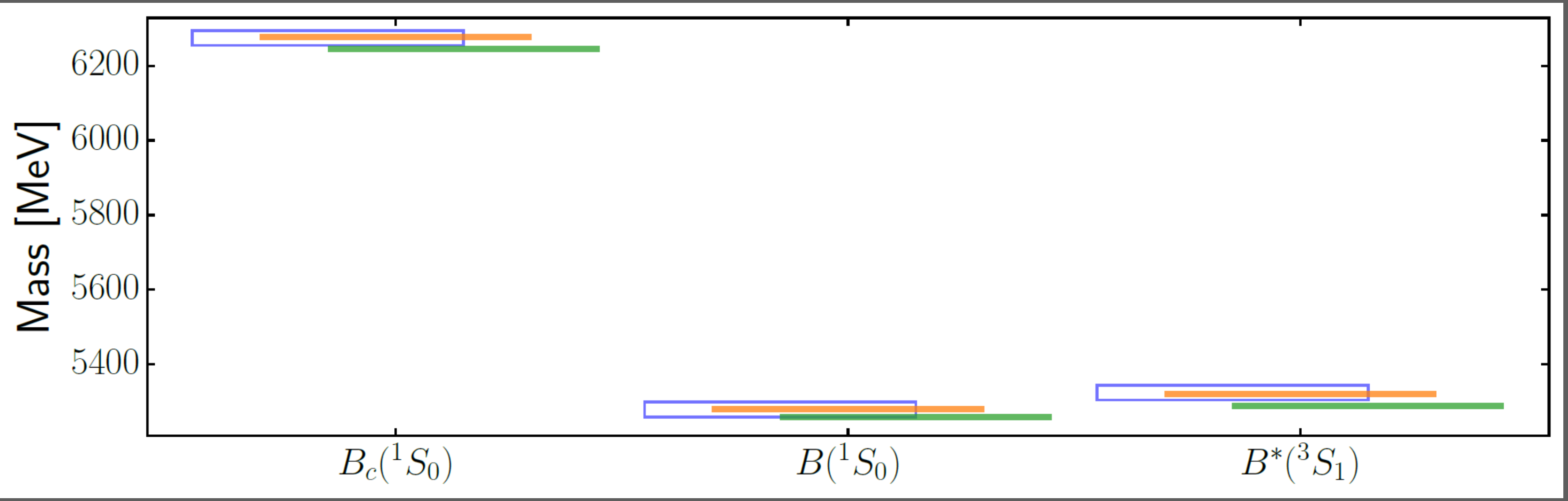
10400
10200
10000
9800
9600
9400
$\eta_b(^1S_0)$
$\chi_{b_0}(^3P_0)$
$\Upsilon(^3S_1)$
$\chi_{b_1}(^3P_1)$
$\chi_{b_2}(^3P_2)$


Mass [MeV]
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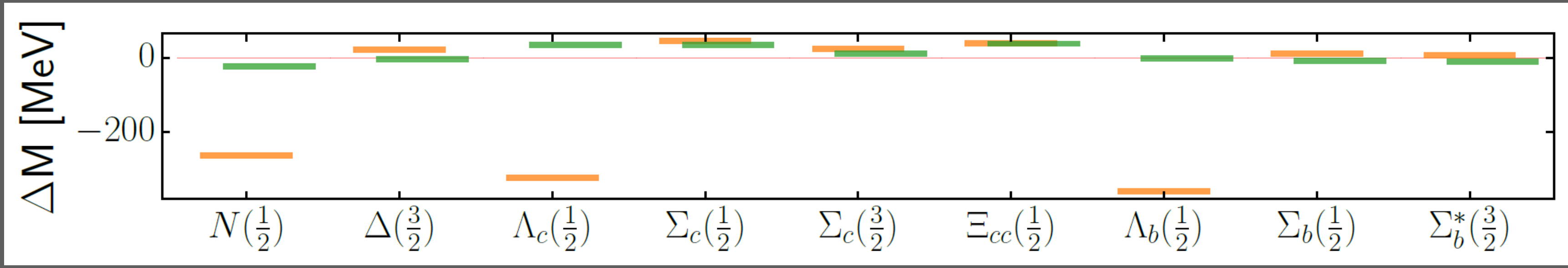
6000
5800
5600
5400
$B_c(^1S_0)$
$B(^1S_0)$
$B^*(^3S_1)$



	1	$\tau_i\tau_j$	$\sigma_i\sigma_j$	$\sigma_i\sigma_j \cdot \tau_i\tau_j$
σ	$-/-$			
π				$+/-$
a_0		$-/+$		
OGE	$-/-$		$+/+$	
CON	$+/+$			
ω (This work)	$+/-$		$+/-$	
ρ (This work)		$+/+$		$+/+$

$$qq/q\bar{q}$$

Channel	E_B		Channel	E_B	
$[DD^*]_{1\otimes 1}$	6.2	39%	$[BB^*]_{1\otimes 1}$	0.5	12%
$[D^*D]_{1\otimes 1}$	6.2	39%	$[B^*B]_{1\otimes 1}$	0.5	12%
$[D^*D^*]_{1\otimes 1}$	83.1	5%	$[B^*B^*]_{1\otimes 1}$	31	32%
$[DD^*]_{8\otimes 8}$	383.1	0%	$[BB^*]_{8\otimes 8}$	253.6	0%
$[D^*D]_{8\otimes 8}$	383.1	0%	$[B^*B]_{8\otimes 8}$	253.6	0%
$[D^*D^*]_{8\otimes 8}$	337.3	0%	$[B^*B^*]_{8\otimes 8}$	233.3	0%
$[(cc)(\bar{q}\bar{q})^*]_{6\otimes\bar{6}}$	337.5	0%	$[(bb)(\bar{q}\bar{q})^*]_{6\otimes\bar{6}}$	233.7	0%
$[(cc)^*(\bar{q}\bar{q})]_{\bar{3}\otimes 3}$	120.3	17%	$[(bb)^*(\bar{q}\bar{q})]_{\bar{3}\otimes 3}$	−37.8	44%
Mixed	−4.9		Mixed	−88.2	

	r_{cc}	$r_{\bar{q}c}$	$r_{\bar{q}\bar{q}}$	$r_{\bar{q}b}$	r_{bb}
T_{cc}	1.56	1.24	1.70		
T_{bb}			0.75	0.65	0.37

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The Hamiltonian

$$H=\sum_{i=1}\left(m_i+\frac{p_i^2}{2m_i}\right)-T_{CM}+\sum_{j>i=1}\left(V_{ij}^{\mathrm{CON}}+V_{ij}^{\mathrm{OGE}}\right.$$
$$\left.+V_{ij}^{\bar{\sigma}}+V_{ij}^{\eta}+V_{ij}^{\eta'}+V_{ij}^{\pi}+V_{ij}^{K}+V_{ij}^{\omega}+V_{ij}^{\phi}+V_{ij}^{\rho}+V_{ij}^{K^*}\right)$$

Bing-Ran He, Masayasu Harada, Bing-Song Zou, 2307.16280

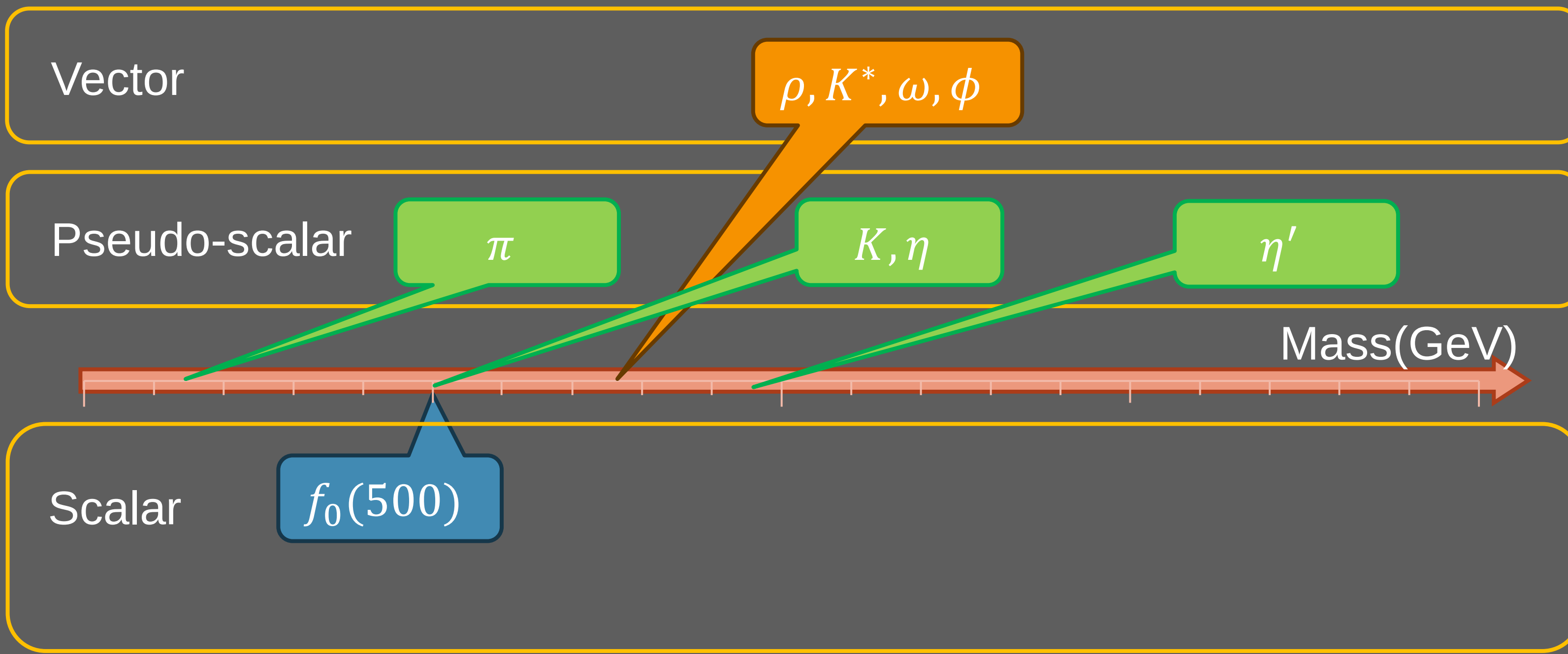
$$V_{ij}^{\bar{\sigma}}=V_{ij}^{s=\bar{\sigma},g_s=g_{\bar{\sigma}q}}\lambda_i^q\lambda_j^q+V_{ij}^{s=\bar{\sigma},g_s=g_{\bar{\sigma}s}}\lambda_i^s\lambda_j^s\,,$$
$$V_{ij}^{\eta}=V_{ij}^{p=\eta,g_p=g_{\eta q}}\lambda_i^q\lambda_j^q+V_{ij}^{p=\eta,g_p=g_{\eta s}}\lambda_i^s\lambda_j^s\,,$$
$$V_{ij}^{\eta'}=V_{ij}^{p=\eta',g_p=g_{\eta' q}}\lambda_i^q\lambda_j^q+V_{ij}^{p=\eta',g_p=g_{\eta' s}}\lambda_i^s\lambda_j^s\,,$$
$$V_{ij}^{\pi}=V_{ij}^{p=\pi,g_p=g_\pi}\sum_{a=1}^{3}\lambda_i^a\lambda_j^a\,,$$
$$V_{ij}^{K}=V_{ij}^{p=K,g_p=g_K}\sum_{a=4}^{7}\lambda_i^a\lambda_j^a\,,$$
$$V_{ij}^{\omega}=V_{ij}^{v=\omega,g_v=g_{\omega q}}\lambda_i^q\lambda_j^q+V_{ij}^{v=\omega,g_v=g_{\omega s}}\lambda_i^s\lambda_j^s\,,$$
$$V_{ij}^{\phi}=V_{ij}^{v=\phi,g_v=g_{\phi q}}\lambda_i^q\lambda_j^q+V_{ij}^{v=\phi,g_v=g_{\phi s}}\lambda_i^s\lambda_j^s\,,$$
$$V_{ij}^{\rho}=V_{ij}^{v=\rho,g_v=g_\rho}\sum_{a=1}^{3}\lambda_i^a\lambda_j^a\,,$$
$$V_{ij}^{K^*}=V_{ij}^{v=K^*,g_v=g_{K^*}}\sum_{a=4}^{7}\lambda_i^a\lambda_j^a$$

$$\lambda^q=\begin{pmatrix}1&0&0\\0&1&0\\0&0&0\end{pmatrix},\ \lambda^s=\begin{pmatrix}0&0&0\\0&0&0\\0&0&1\end{pmatrix}$$

The coupling have relations based on $SU3$ flavor symmetry:

$$g_{\eta s}=g_{\eta q}-\sqrt{3}\cos\theta_p g_\pi$$
$$g_{\eta' q}=-\cot\theta_p g_{\eta q}+\frac{1}{\sqrt{3}\sin\theta_p}g_\pi$$
$$g_{\eta' s}=-\cot\theta_p g_{\eta q}+\frac{\cos\theta_p\cot\theta_p-2\sin\theta_p}{\sqrt{3}}g_\pi$$
$$g_\pi=g_K$$
$$g_{\omega s}=g_{\omega q}-g_\rho$$
$$g_{\phi q}=-\sqrt{\tfrac{1}{2}}(g_{\omega q}-g_\rho)$$
$$g_{\phi s}=-\sqrt{\tfrac{1}{2}}(g_{\omega q}+g_\rho)$$
$$g_\rho=g_{K^*}\ \text{and}\ f_{\omega s}=f_{\omega q}-f_\rho$$
$$f_{\phi q}=-\sqrt{\tfrac{1}{2}}(f_{\omega q}-f_\rho)$$
$$f_{\phi s}=-\sqrt{\tfrac{1}{2}}(f_{\omega q}+f_\rho)$$
$$f_\rho=f_{K^*}$$

The exchanged mesons in $SU3$ model



Symmetry of the model

$$SU(3)_L \times SU(3)_R \times U(1)_V \rightarrow SU(3)_V \times U(1)_V$$

Wave functions

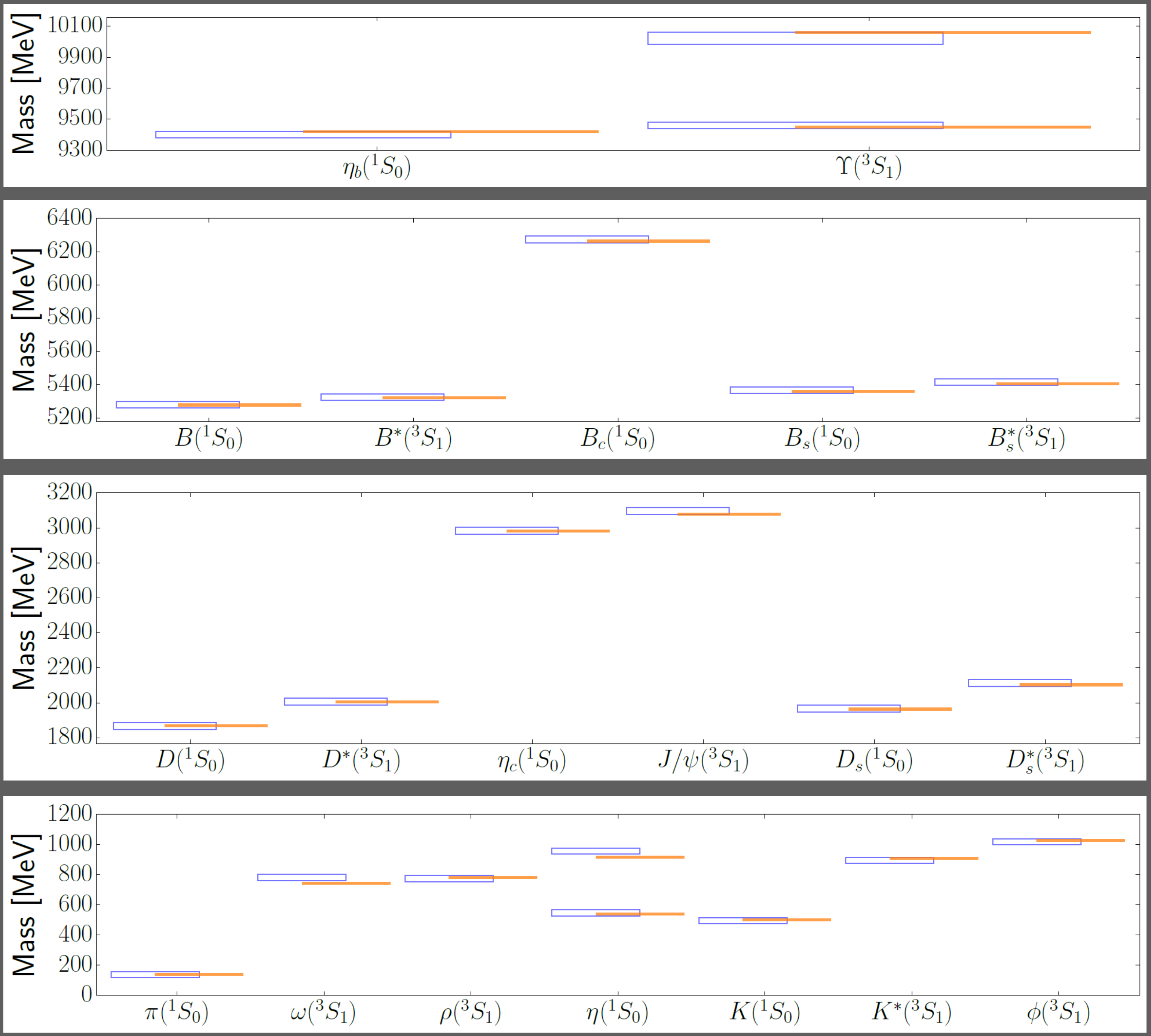
- Orbital (SO(3)): (ψ_L)
- Spin (SU(2)): (χ_S^σ)
- Flavor (SU(3)): (χ_I^f)
- Color (SU(3)): (χ^c)

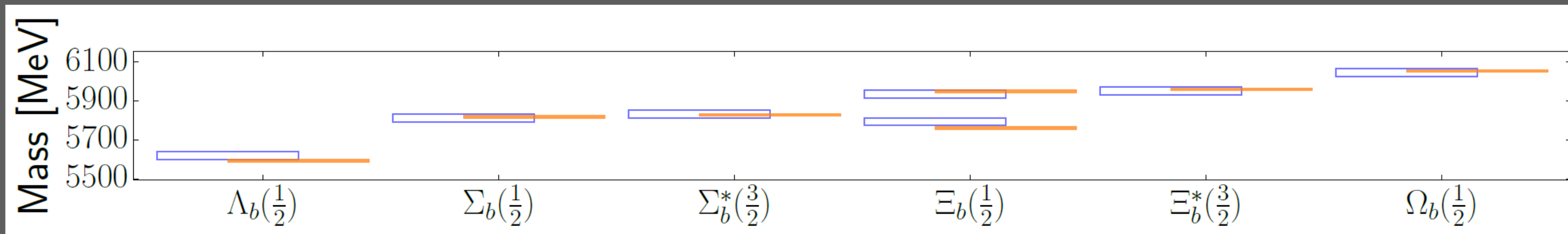
$$\Psi^{ijk}_{JM_J IM_I} = \mathcal{A}\left[\left[\psi_L \chi_S^{\sigma i}\right]_{JM_J} \chi_I^{fj} \chi_k^c\right]$$

	1	$\lambda_i\lambda_j$	$\sigma_i\sigma_j$	$\sigma_i\sigma_j \cdot \lambda_i\lambda_j$
$\bar{\sigma}$	$-/-$			
η/η'			$+/+$	
π/K				$+/-$
ω/ϕ	$+/-$		$+/-$	
ρ/K^*		$+/+$		$+/+$
OGE	$-/-$		$+/+$	
CON	$+/+$			

$qq/q\bar{q}$

	No vector J . Vijande, F . Fernandez, A . Valcarce, J. Phys. G 31, 481(2005)	$su2$ vector 2306.03526	$su3$ vector 2307.16280
$\alpha_s(qq)$	0.536	0.880	0.456
$\alpha_s(qs)$	0.479		0.426
$\alpha_s(qc)$	0.426	0.774	0.363
$\alpha_s(qb)$	0.409	0.749	0.339
$\alpha_s(ss)$	0.419		0.388
$\alpha_s(sc)$	0.360		0.308
$\alpha_s(sb)$	0.340		0.279
$\alpha_s(cc)$	0.288	0.510	0.205
$\alpha_s(cb)$	0.260	0.447	0.168
$\alpha_s(bb)$	0.223	0.366	0.128


Mass [MeV]
10100
9900
9700
9500
9300
$\eta_b(^1S_0)$
$\Upsilon(^3S_1)$
Mass [MeV]
6400
6200
6000
5800
5600
5400
5200
$B(^1S_0)$
$B^*(^3S_1)$
$B_c(^1S_0)$
$B_s(^1S_0)$
$B_s^*(^3S_1)$
Mass [MeV]
3200
3000
2800
2600
2400
2200
2000
1800
$D(^1S_0)$
$D^*(^3S_1)$
$\eta_c(^1S_0)$
$J/\psi(^3S_1)$
$D_s(^1S_0)$
$D_s^*(^3S_1)$
Mass [MeV]
1200
1000
800
600
400
200
0
$\pi(^1S_0)$
$\omega(^3S_1)$
$\rho(^3S_1)$
$\eta(^1S_0)$
$K(^1S_0)$
$K^*(^3S_1)$
$\phi(^3S_1)$


Mass [MeV]
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5900
5700
5500
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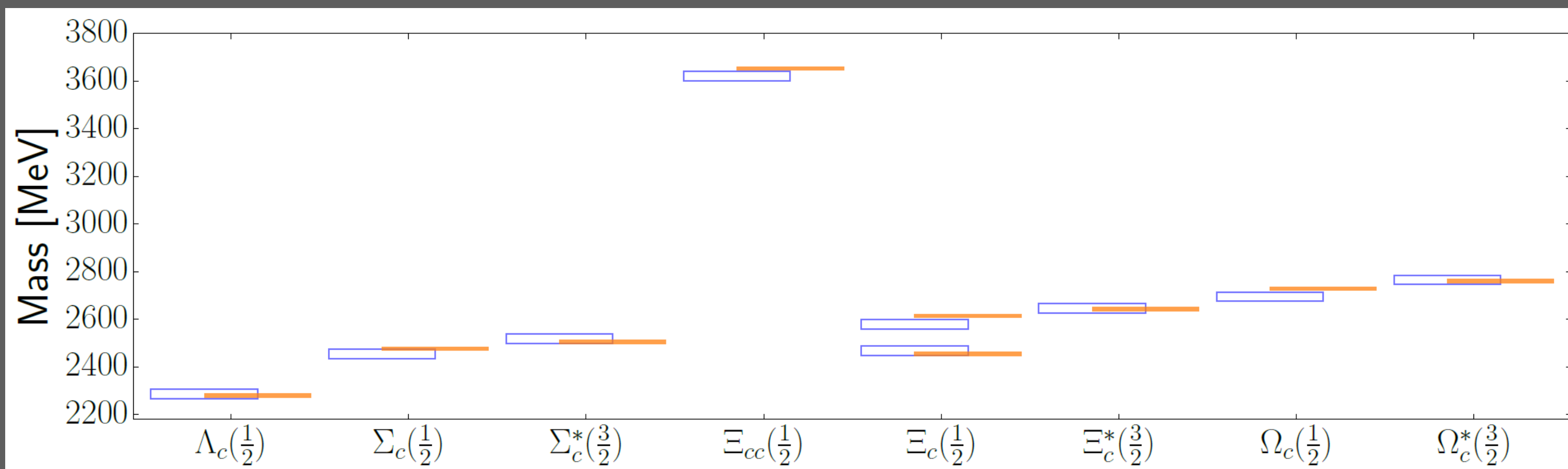
$\Sigma_b(\frac{1}{2})$
$\Sigma_b^*(\frac{3}{2})$
$\Xi_b(\frac{1}{2})$
$\Xi_b^*(\frac{3}{2})$
$\Omega_b(\frac{1}{2})$


Mass [MeV]
3800
3600
3400
3200
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2800
2600
2400
2200
$\Lambda_c(\frac{1}{2})$
$\Sigma_c(\frac{1}{2})$
$\Sigma_c^*(\frac{3}{2})$
$\Xi_{cc}(\frac{1}{2})$
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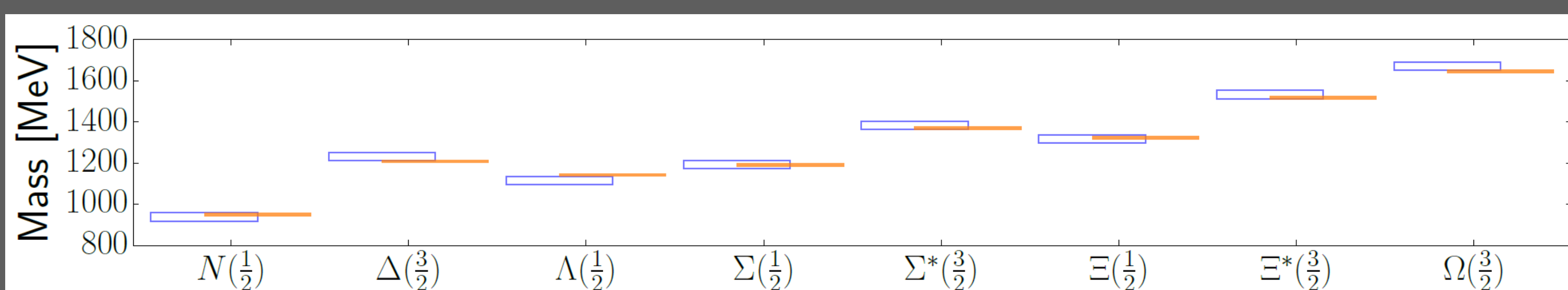
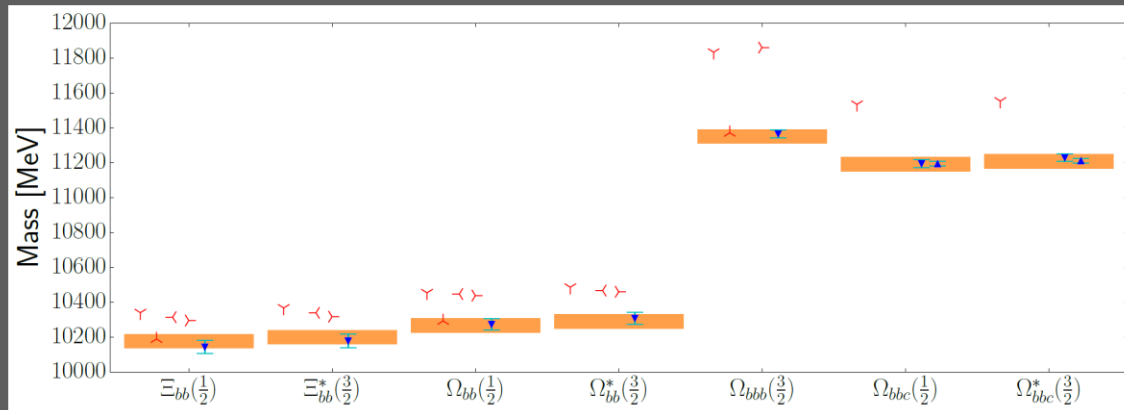
$\Xi_c^*(\frac{3}{2})$
$\Omega_c(\frac{1}{2})$
$\Omega_c^*(\frac{3}{2})$


Mass [MeV]
1800
1600
1400
1200
1000
800
$N(\frac{1}{2})$
$\Delta(\frac{3}{2})$
$\Lambda(\frac{1}{2})$
$\Sigma(\frac{1}{2})$
$\Sigma^*(\frac{3}{2})$
$\Xi(\frac{1}{2})$
$\Xi^*(\frac{3}{2})$
$\Omega(\frac{3}{2})$


Mass [MeV]
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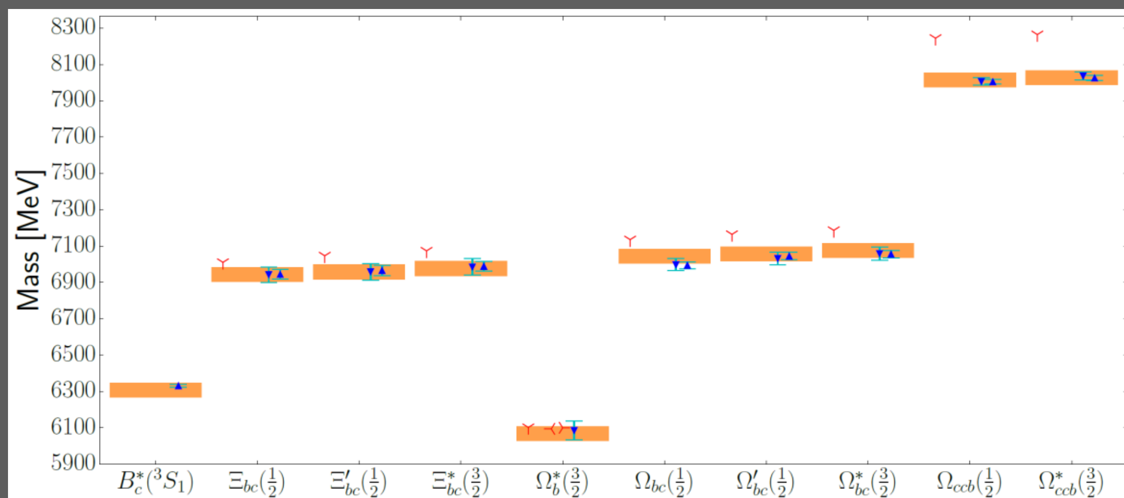
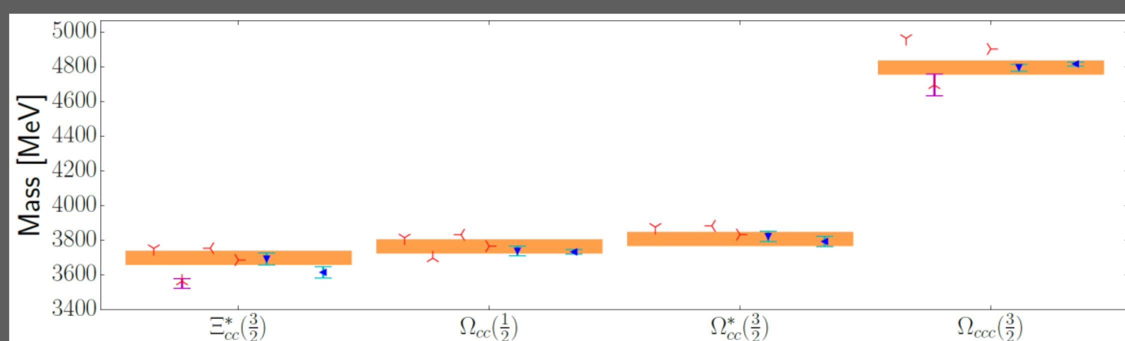
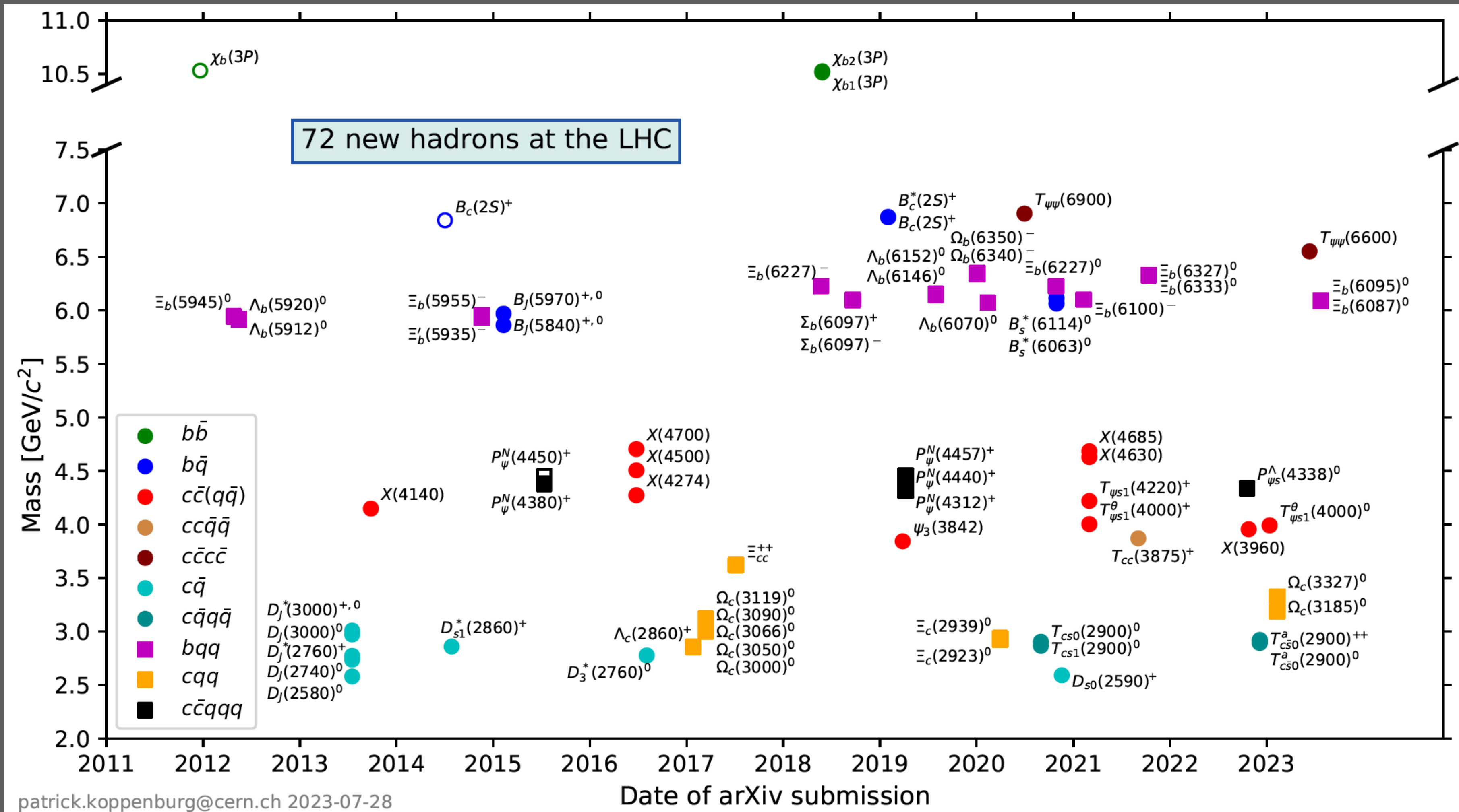
11800
11600
11400
11200
11000
10800
10600
10400
10200
10000
$\Xi_{bb}(\frac{1}{2})$
$\Xi^*_{bb}(\frac{3}{2})$
$\Omega_{bb}(\frac{1}{2})$
$\Omega^*_{bb}(\frac{3}{2})$
$\Omega_{bbb}(\frac{3}{2})$
$\Omega_{bbc}(\frac{1}{2})$
$\Omega^*_{bbc}(\frac{3}{2})$


Mass [MeV]
8300
8100
7900
7700
7500
7300
7100
6900
6700
6500
6300
6100
5900
$B^*_c(^3S_1)$
$\Xi_{bc}(\frac{1}{2})$
$\Xi'_{bc}(\frac{1}{2})$
$\Xi^*_{bc}(\frac{3}{2})$
$\Omega^*_b(\frac{3}{2})$
$\Omega_{bc}(\frac{1}{2})$
$\Omega'_{bc}(\frac{1}{2})$
$\Omega^*_{bc}(\frac{3}{2})$
$\Omega_{ccb}(\frac{1}{2})$
$\Omega^*_{ccb}(\frac{3}{2})$


Mass [MeV]
5000
4800
4600
4400
4200
4000
3800
3600
3400
$\Xi^*_{cc}(\frac{3}{2})$
$\Omega_{cc}(\frac{1}{2})$
$\Omega^*_{cc}(\frac{3}{2})$
$\Omega_{ccc}(\frac{3}{2})$

Outline

- Introduction
- Chiral quark model with HLS
- $SU2$ ground states + excited states
- $SU3$ ground states
- ***Future works***


72 new hadrons at the LHC
Mass [GeV/c^2]
Date of arXiv submission
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
10.5
11.0
$b\bar{b}$
$b\bar{q}$
$c\bar{c}(q\bar{q})$
$cc\bar{q}\bar{q}$
$c\bar{c}c\bar{c}$
$c\bar{q}$
$c\bar{q}q\bar{q}$
bqq
cqq
$c\bar{c}qqq$
$\chi_b(3P)$
$\chi_{b2}(3P)$
$\chi_{b1}(3P)$
$B_c(2S)^+$
$B_c^*(2S)^+$
$B_c(2S)^+$
$T_{\psi\psi}(6900)$
$T_{\psi\psi}(6600)$
$\Omega_b(6350)^-$
$\Omega_b(6340)^-$
$\Lambda_b(6152)^0$
$\Lambda_b(6146)^0$
$\Xi_b(6227)^-$
$\Xi_b(6227)^0$
$\Xi_b(6327)^0$
$\Xi_b(6333)^0$
$\Xi_b(6095)^0$
$\Xi_b(6087)^0$
$\Xi_b(5945)^0$
$\Lambda_b(5920)^0$
$\Lambda_b(5912)^0$
$\Xi_b(5955)^-$
$\Xi'_b(5935)^-$
$B_J(5970)^{+,0}$
$B_J(5840)^{+,0}$
$\Sigma_b(6097)^+$
$\Sigma_b(6097)^-$
$\Lambda_b(6070)^0$
$B_s^*(6114)^0$
$B_s^*(6063)^0$
$\Xi_b(6100)^-$
$X(4700)$
$X(4500)$
$X(4274)$
$X(4140)$
$P_\psi^N(4450)^+$
$P_\psi^N(4380)^+$
$P_\psi^N(4457)^+$
$P_\psi^N(4440)^+$
$P_\psi^N(4312)^+$
$\psi_3(3842)$
$X(4685)$
$X(4630)$
$T_{\psi s1}(4220)^+$
$T_{\psi s1}^\theta(4000)^+$
$T_{cc}(3875)^+$
$P_{\psi s}^\Lambda(4338)^0$
$T_{\psi s1}^\theta(4000)^0$
$X(3960)$
Ξ_{cc}^{++}
$\Omega_c(3119)^0$
$\Omega_c(3090)^0$
$\Omega_c(3066)^0$
$\Omega_c(3050)^0$
$\Omega_c(3000)^0$
$\Lambda_c(2860)^+$
$D_3^*(2760)^0$
$D_J^*(3000)^{+,0}$
$D_J(3000)^0$
$D_J^*(2760)^+$
$D_J(2740)^0$
$D_J(2580)^0$
$D_{s1}^*(2860)^+$
$\Xi_c(2939)^0$
$\Xi_c(2923)^0$
$T_{cs0}(2900)^0$
$T_{cs1}(2900)^0$
$D_{s0}(2590)^+$
$\Omega_c(3327)^0$
$\Omega_c(3185)^0$
$T_{c\bar{s}0}^a(2900)^{++}$
$T_{c\bar{s}0}^a(2900)^0$
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Thank you for your attention!