Mass spectra of excited baryons in a mean-field approach

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Motivation

- Puzzles in mass spectra of excited baryon : Missing resonances & Mass ordering.
- Missing resonances problem : A large number of resonances are predicted but those are much lager than the observed resonances.
- Mass ordering problem : Discordant mass orderings from the observed resonances, e.g. N(1535, 1/2-) & N(1520, 3/2-).

Chiral quark-soliton model(CQSM)

- Basic concept : Baryons can be considered as N_c quarks bound by the mesonic mean fields at large N_c (E. Witten, 1979)

$$\mathcal{S}_{\rm eff} = -N_c \mathrm{Tr}\ln\left[\partial_\tau + h(U) - i\gamma_4 \hat{m}\right]$$

$$h(U) = -\gamma_4\gamma_k\partial^k - i\gamma_4 M U^{\gamma_5}$$

$$\hat{m} = \mathrm{diag}\left[m_u,\, m_d,\, m_s\right]$$

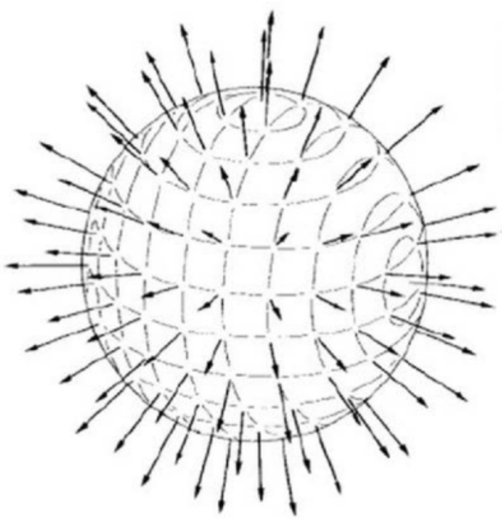
[E. Witten, Nucl. Phys. B160. 57, 1979]

[HCh. Kim et al. Prog. Part. Nucl. Phys. Vol.37, 91 (1996)]

Classical solitons

- Hedgehog Ansatz :

$$U_{SU(2)} = e^{i\boldsymbol{\tau}\cdot\boldsymbol{r}\pi(r)}$$



- Correlation function

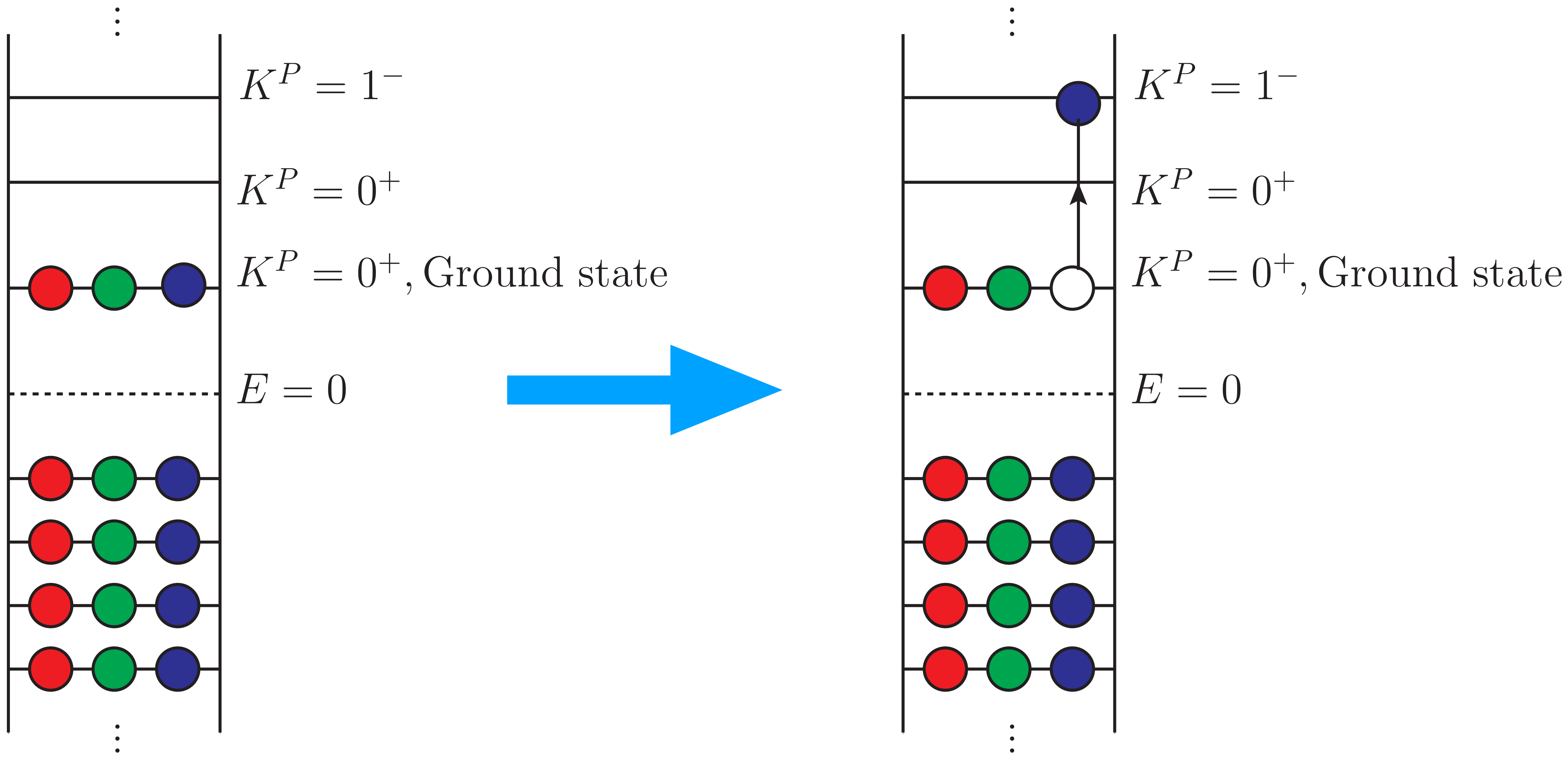
$$\langle J_N^\dagger(\vec{x}, T) J_N(\vec{x}', -T)\rangle \sim \Pi_N(T) \sim e^{-[N_c E_{val} + E_{sea}]T}$$

- Classical mass

$$\frac{\partial}{\partial U}\left[N_c E_{val} + E_{sea}\right] = 0 \quad \Rightarrow \quad M_{\rm cl} = N_c E_{val}(U_c) + E_{sea}(U_c)$$

[HCh. Kim et al. Prog. Part. Nucl. Phys. Vol.37, 91 (1996)]

Schematic pictures of the excited baryons



- Ground state of baryon
- Excited state of baryon

Hedgehog Ansatz and mean field

- Trivial embedding of the SU(2) field into the SU(3) field

$$U_{SU(3)} = \begin{bmatrix} e^{i\boldsymbol{\tau}\cdot\boldsymbol{r}\pi(r)} & 0 \\ 0 & 1 \end{bmatrix}$$

$$\mathrm{SU}(3)_{\mathrm{f}} \otimes \mathrm{O}(3)_{\mathrm{space}} \to \mathrm{SU}(2)_{\mathrm{iso+space}}$$

By hedgehog Ansatz

[E. Witten, Nucl. Phys. B223. 422, 1983]

- Breaking of this higher symmetry will reduce the number of baryon states
  $\longrightarrow$ Missing resonances could be solved

- Collective(Zero-mode) quantization

$$U(\boldsymbol{x},t) = R(t)U_c(\boldsymbol{x}-\boldsymbol{Z}(t))R^{\dagger}(t)$$

$$\int DU[\cdots] \to \int DRDZ[\cdots]$$

- We keep the collective quantization for the moment

Collective Hamiltonians

- Hamiltonian for rotational energy

$$\mathcal{H}_{rot} = \frac{1}{2I_2}\sum_{a=4}^{7}\tilde{T}_a^2 + \frac{(\tilde{\boldsymbol{T}} - a_K\hat{\boldsymbol{K}})^2}{2I_1}$$

Quantization rule :

$$\tilde{T} + \tilde{J} = \hat{K}, \quad \hat{Y} = \frac{N_c}{3}$$

- Hamiltonian for SU(3)$_f$ symmetry breaking

$$\mathcal{H}_{br} = \alpha\mathcal{D}_{88}^{(8)}(R) + \beta\hat{Y} - \frac{\gamma}{\sqrt{3}}\sum_{i=1}^{3}\mathcal{D}_{8i}^{(8)}(R)\tilde{T}_i - \frac{\delta_K}{\sqrt{3}}\sum_{i=1}^{3}\mathcal{D}_{8i}^{(8)}(R)\hat{K}_i$$

$$\alpha = -\frac{2}{3}\frac{m_s}{m_u+m_d}\Sigma_{\pi N} + m_s\frac{K_2}{I_2}, \qquad \beta = -m_s\frac{K_2}{I_2}$$

Additional terms in the K>0 state

$$\gamma = 2m_s\left(\frac{K_1}{I_1} - \frac{K_2}{I_2}\right), \qquad \delta_K = 2m_s\left(d_K - \frac{K_1}{I_1}a_K\right)$$

[D. Diakonov, V. Petrov, and A. Vladimirov, Phys. Rev. D88, 074030 (2013)]

Model-Independent analysis

K	J^P	N	Λ	Σ	Ξ
0,Ground	1/2+	939	1115	1192	1317
0	1/2+	1440	1600	1660	1690
	1/2-	1650	1800	1620	
1	1/2-	1535	1670	1560	
	3/2-	1520	1690	1670	1820
	1/2+	1710	1810	1880	1950
2	3/2+	1720	1890	1840	
	5/2+	1680	1820	1915	2030
	3/2-	1700		1940	
	5/2-	1675	1830	1775	

(MeV)

[V. Guzey, M. V. Polyakov, hep-ph/0512355 (2005)]

- The baryons are categorized according to quantization rule
- In octet, $\hat{Y} = 1,\ \tilde{T} = \frac{1}{2}$

$$J = \left|\tilde{T} - K\right|, \sim \left|\tilde{T} + K\right|$$

- K=0, J=1/2
- K=1, J=(1/2, 3/2)
- K=2, J=(3/2, 5/2)

Model-Independent analysis

K	J^P	Δ	Σ	Ξ	Ω
0, Ground	3/2+	1232	1385	1530	1672
0	3/2+	1600	1690		
1	1/2-	1620	1750		
	3/2-	1700			
	5/2-	1930			
	1/2+	1910			
	5/2+	2000			
2	3/2+	1920	2080		2470
	5/2+	1905	2070	2250	2380
	7/2+	1950	2030	2120	2250

(MeV)

[V. Guzey, M. V. Polyakov, hep-ph/0512355 (2005)]

- In decuplet, $\hat{Y} = 1,\ \tilde{T} = \frac{3}{2}$

$$J = \left|\tilde{T} - K\right|, \sim \left|\tilde{T} + K\right|$$

- K=0, J=3/2
- K=1, J=(1/2, 3/2, 5/2)
- K=2, J=(1/2, 3/2, 5/2, 7/2)

Model-Independent analysis

- Center mass

$$M_C = M_{cl} + \Delta\mathcal{E}(0^+ \to K^P) + \frac{C_2(SU(3)) - \tilde{T}(\tilde{T}+1) - \frac{3}{4}\hat{Y}^2}{2I_2}$$
$$+ \frac{1}{2I_1}\left[a_K J(J+1) + (1-a_K)\tilde{T}(\tilde{T}+1) - a_K(1-a_K)K(K+1)\right]$$

M_{cl}=787.4 MeV I_2^{-1}=407.0 MeV

K^P	I_1^{-1}	a_K	$\Delta\varepsilon$
Ground, 0+	154.1	0	0
0+	56.7	0	491.1
0-			596.1
1-	128.3	0.30	501.2
1+			732.4
2+	138	-0.04	719.9
2-			664.3

(MeV)

Model-Independent analysis

- Center masses

Octet

K	J^P	PDG	This work
0	1/2+	1605±27	1605
	1/2-	1710^{+35}_{-57}	1710
1	1/2-	1615±13	1615
	3/2-	1673±5	1673
	1/2+	1846^{+61}_{-49}	1846
2	3/2+	1865^{+10}_{-30}	1872
	5/2+	1873^{+55}_{-60}	1858
	3/2-		1816
	5/2-	1803^{+3}_{-13}	1802

(MeV)

Decuplet

K	JP	PDG	This work
0	3/2+	1690^{+25}_{-8}	1690
1	1/2-	1750^{+50}_{-20}	1750
	3/2-		1807
	5/2-		1903
	1/2+		1981
	5/2+		2135
2	3/2+	2087^{+48}_{-21}	2087
	5/2+	2071^{+20}_{-44}	2073
	7/2+	2038^{+18}_{-22}	2054

(MeV)

Model-Independent analysis

- Baryon mass

$$M_B = M_C + \langle B|\mathcal{H}_{\rm br}|B\rangle$$
$$= M_C$$
$$+ \langle B| \left[\alpha \mathcal{D}^{(8)}_{88}(R) + \beta \hat{Y} - \frac{\gamma}{\sqrt{3}} \sum_{i=1}^{3} \mathcal{D}^{(8)}_{8i}(R)\tilde{T}_i - \frac{\delta_K}{\sqrt{3}} \sum_{i=1}^{3} \mathcal{D}^{(8)}_{8i}(R)\hat{K}_i \right] |B\rangle$$

- Collective wave function

$$|B\rangle = \sqrt{\frac{\dim(r)(2J+1)}{2K+1}} \sum_{\tilde{T}',\tilde{T}'_3,\tilde{J}'_3} C^{KK'_3}_{\tilde{T}'-\tilde{T}'_3 J \tilde{J}'_3} (-1)^{-\tilde{T}'-\tilde{T}'_3} \mathcal{D}^{(r)}_{(-\tilde{Y}\tilde{T}'\tilde{T}'_3)(YTT_3)}(R^\dagger) \mathcal{D}^{J}_{\tilde{J}'_3 J_3}(S^\dagger) \chi_{K'_3}$$

[D. Diakonov, V. Petrov, and A. Vladimirov, Phys. Rev. D88, 074030 (2013)]

Model-Independent analysis

α	β	γ
-255.03	-140.04	-101.08

(MeV)

[Ghil-Seok Yang, Hyun-Chul Kim, Prog. Theor. Phys. 128, 397 (2012)]

- K=0 case

8	K(J^P)	N	Λ	Σ	Ξ
PDG	0(1/2+)	1440^{+10}_{-30}	1600^{+100}_{-40}	1660±30	1690±10
This Work		1394	1564	1645	1776
PDG	0(1/2-)	1650^{+25}_{-5}	1800^{+50}_{-80}	1620^{+20}_{-35}	
This Work		1498	1669	1751	1881

10	K(J^P)	Δ	Σ	Ξ	Ω
PDG	0(1/2+)	1600±100	1690^{+30}_{-10}		
This Work		1550	1690	1830	1971

(MeV)

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(MeV)

What are we considering?

- Valence states are changed in excited state of baryon.
- All parameters related with valence states can be changed also.
- Therefore, the value of α, β, γ can be changed at each K^P.

Summary & Outlook

- The excited baryons can be categorized according to the quantization rule in CQSM.
- We extract parameters from the experimental data and then we can obtain masses of excited baryons.
- We are investigating the α, β, γ values at each K^P.

Thank you for listening!!!!