Study of Charmed Baryons and Its Structure

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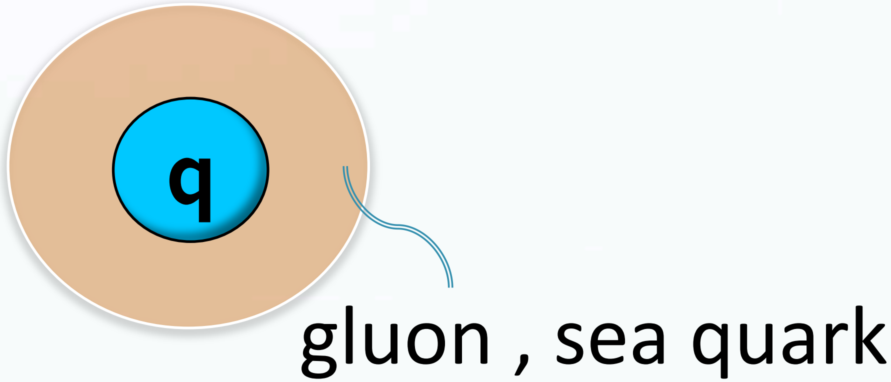
what is constituent quark？

Quark

m~5[MeV]

constituent quark

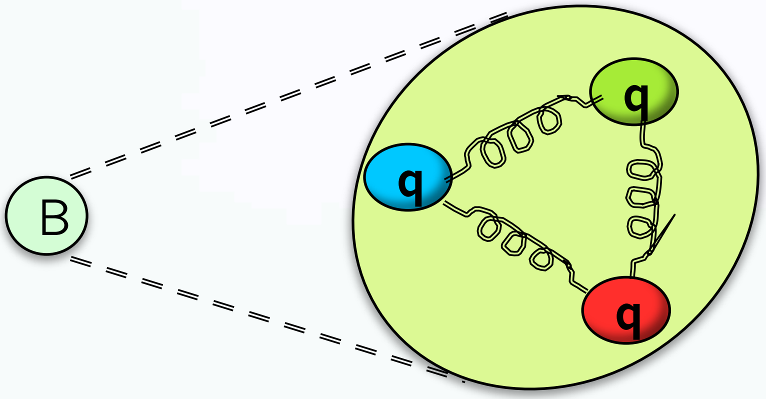


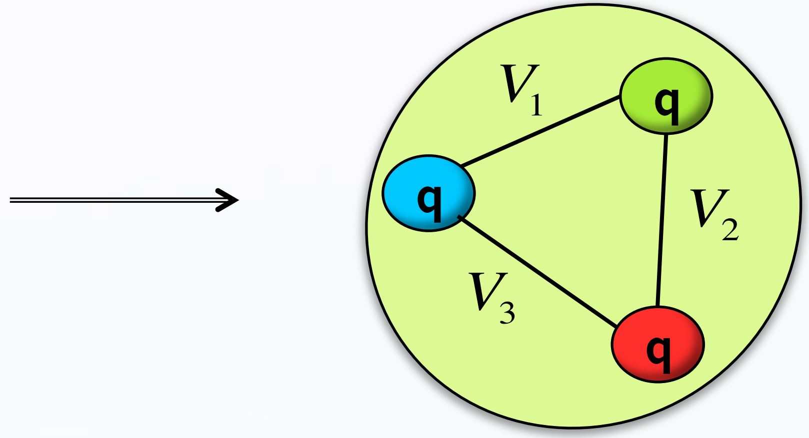
M_q~300[MeV]

- gluon and sea quark are put into effective quark mass of valence quarks
- mass of constituent quarks are not equal to mass of valence quarks
- constituent quark is not point particle like valence quark

Potential Model

V. Dmitrasinovic, Toru Sato, Milovan Suvakov . Phys.Rev. D80 (2009)





We can't use perturbation theory because of ' Asymptotic freedom'.

By cosidering phenomenological potential , we can deal with baryon as quark three body system

Schrodinger equation

$$\left[T + V(r_1) + V(r_2) + V(r_3) - E\right]\left|\Psi_{JM}\right\rangle = 0$$

phenomenological potential

We use the variational method to solve the equation

Hamiltonian

$$H = \sum_i K_i + \sum_{i<j} (V_{conf}^{ij} + H_{hyp}^{ij} + V_{LS}^{ij}) + C_{qqq}$$

$$= \sum_i (m_i + p_i^2/2m_i) + \frac{\pi}{3}\alpha_{con} \sum_{i<j} \left(\frac{1}{m_i^2} + \frac{1}{m_j^2} \right) \delta(\mathbf{r}) + \sum_{i<j} \left(\frac{br_{ij}}{2} - \frac{2\alpha_{Coul}}{3r_{ij}} \right)$$

$$+ \sum_{i<j} \left[\frac{2\alpha_{con}}{3m_i m_j} \frac{8\pi}{3} \mathbf{S}_i \cdot \mathbf{S}_j \delta^3(\mathbf{r}_{ij}) + \frac{2\alpha_{ten}}{3m_i m_j} \frac{1}{r_{ij}^3} \left(\frac{3\mathbf{S}_i \cdot \mathbf{r}_{ij} \mathbf{S}_j \cdot \mathbf{r}_{ij}}{r_{ij}^2} - \mathbf{S}_i \cdot \mathbf{S}_j \right) \right]$$

$$+ \sum_{i<j} \alpha_{SO} \frac{1}{3m_q^2 r_{ij}^3} \left(\xi_i^2 + \xi_j^2 + 4\xi_i \xi_j \right) \mathbf{l}_{ij} \cdot \mathbf{s}_{ij} + C_{qqq}$$

$$\xi_i = m_u/m_i.$$

Confinement

Coulomb

Spin-Spin

Tensor

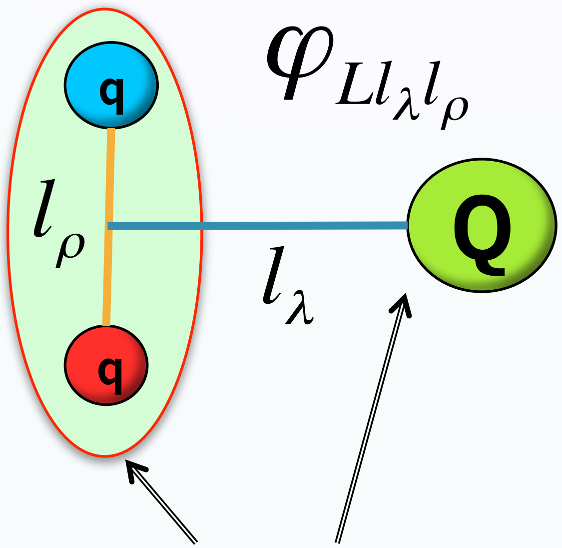
Spin orbit

the cause of mass splitting

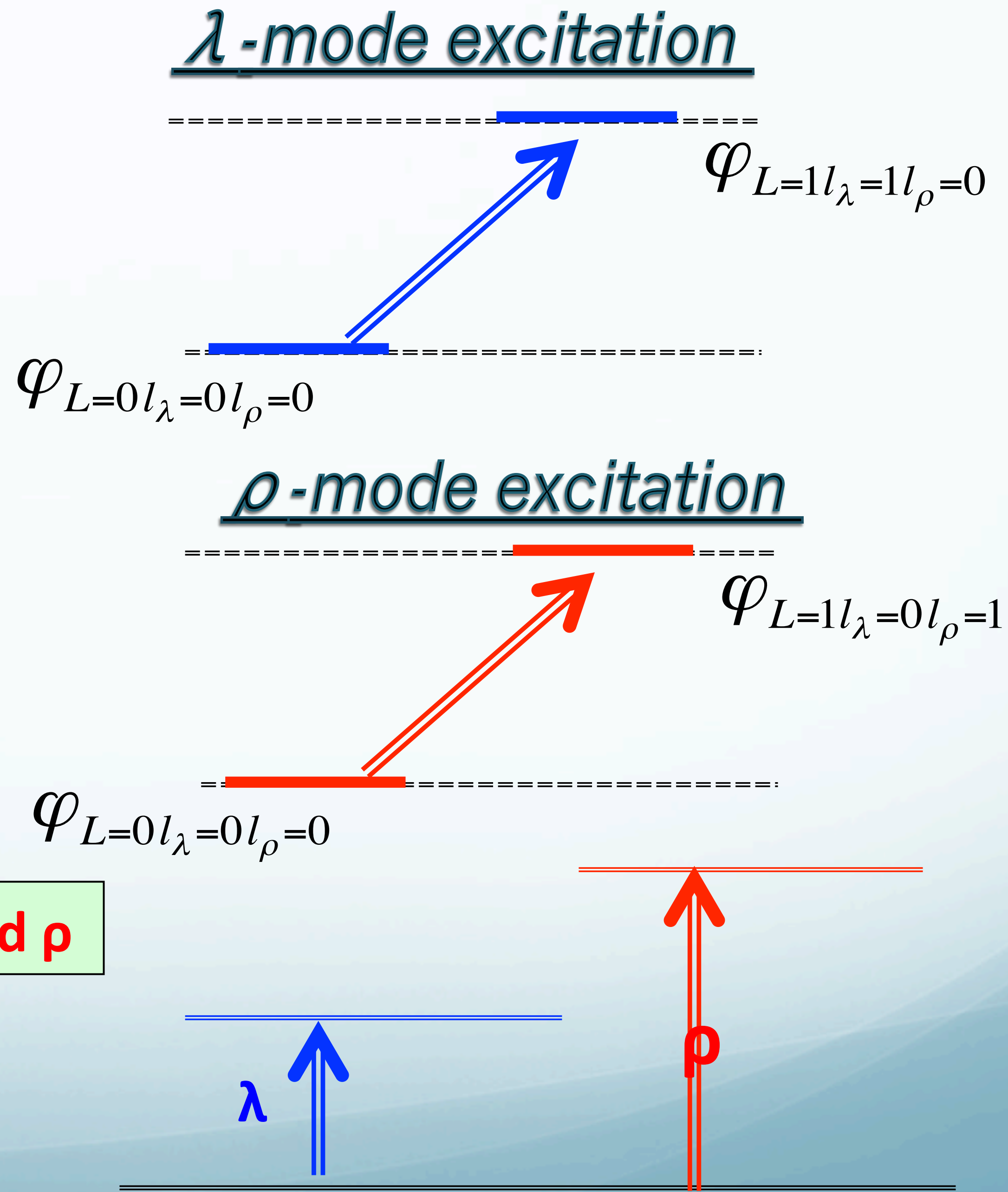
We determined the parameter that the result of the Strange baryon will suit an experimental result . Using the parameter , we performed spectral calculation of the charm and the bottom baryon.

Distinction of excited state

For P-Wave baryon, we can consider 2-excited state.



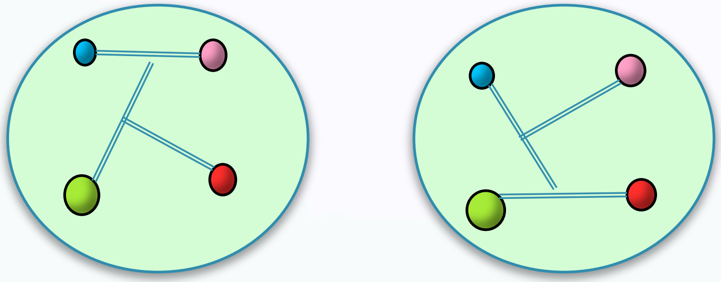
Which excitation is dominant?

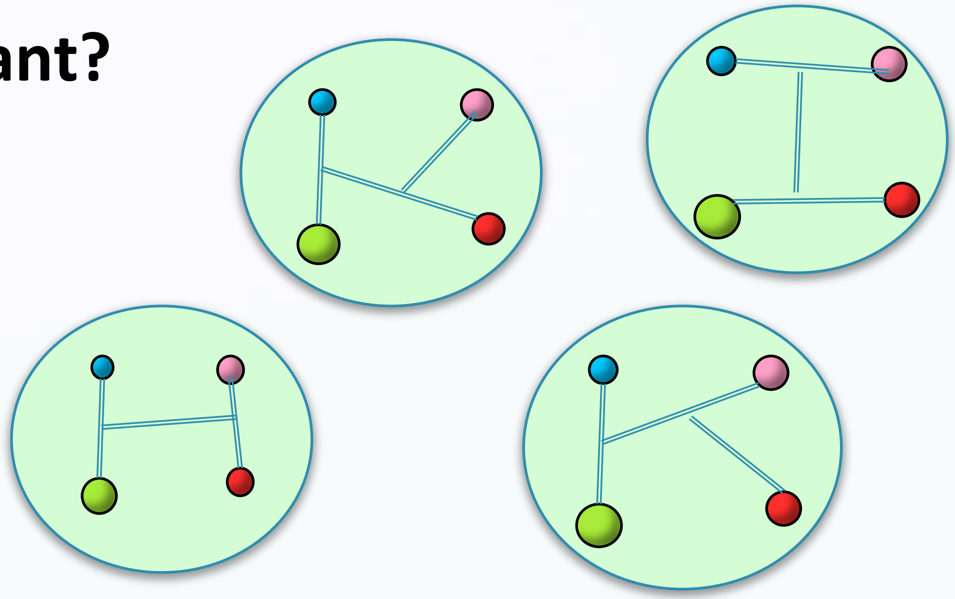


Excited energy is different between λ and ρ

Structure of tetra or penta quark

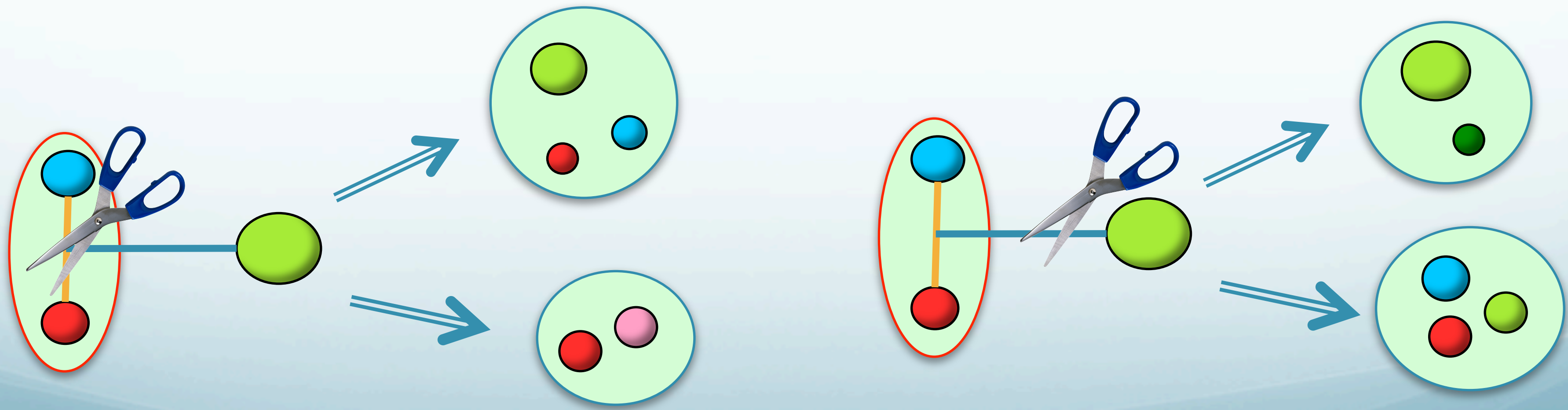
Which excitation state is dominant?





Decay mode

Which is decay pattern?



Flow chart

Baryon wave function

Use some bases

We used the Gaussian expansion basis.

$$\psi^{G}_{Space} = N_{nl} r^{l} \exp(-\nu_n r^2) Y_{lm}(\hat{\mathbf{r}})$$

Discussion of symmetry

$$\phi_f \times \psi_{space} \times \chi_{spin} \times (colar)$$

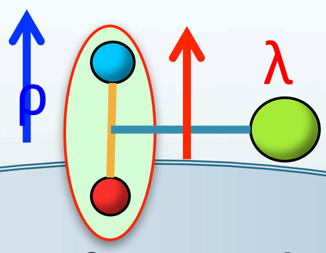
anti-symmetrization

Provide the Hamiltonian

$$H = \sum_i K_i + \sum_{i<j} (V^{ij}_{conf} + H^{ij}_{hyp}) + C_{qqq}$$

Diagonalization of the Hamiltonian

[Solve $H\Psi = E\Psi$]



analysis of excited mode

Predictions for heavy baryons

Λ_c Ξ_c Ξ_{bc} Ω_{cc} ....

Result

Table1:The singly charmed baryon spectrumobtained in our model (MeV)

flavor	J^P	Exp	This work	[1]	[2]	[3]	[4]
Λ_C	$1/2^+$	2284	2285	2268	2265	2297	2272
	$3/2^+$		2911	2887	2910	2874	2848
	$5/2^+$		2928	2887	2910		
	$1/2^-$	2595	2599	2625	2630	2598	2594
	$3/2^-$	2628	2617	2636	2640	2628	2586
	$5/2^-$		2854	2872	2900		
Σ_C	$1/2^+$	2455	2453	2455	2440	2439	2459
	$3/2^+$	2518	2513	2519	2495	2518	2539
	$5/2^+$		3104	3002	3065		
	$1/2^-$		2680	2748	2765	2795	2769
	$3/2^-$		2698	2763	2770	2761	2799
	$5/2^-$		2834	2790	2815		

[1] S. Capstick and N. Isgur, Phys. Rev. D 34 , 2809 (1986).
[2] D. Ebert, R. N. Faustov and V. O. Galkin, arXiv:0705.2957v2 .
[3] S. Migura, D. Merten, B. Metsch and H. R. Petry, Eur. Phys. J. A 28 , 41 (2006).
[4] H. Garcilazo, J. Vijande and A. Valcarce, J. Phys. G 34 , 961 (2007).

Table2:The singly bottom baryon spectrum obtained in our model (MeV)

flavor	J^P	Exp	This work	[1]	[2]	[3]	[4]
Λ_b	$1/2^+$	5624	5624	5612	5585	5622	5624
	$3/2^+$		6202	6181	6145	6189	6246
	$5/2^+$		6216	6183	6165		
	$1/2^-$	5912	5915	5939	5912	5930	5890
	$3/2^-$	5928	5920	5941	5920	5947	5890
	$5/2^-$		6166	6206	6205		
Σ_b	$1/2^+$	5812	5818	5833	5795	5805	5789
	$3/2^+$	5833	5839	5858	5805	5834	5844
	$5/2^+$		6402				
	$1/2^-$		6008	6099	6070	6108	6039
	$3/2^-$		6022	6101	6070	6076	6039
	$5/2^-$		6138				

[1] S. Capstick and N. Isgur, Phys. Rev. D 34 , 2809 (1986).
[2] D. Ebert, R. N. Faustov and V. O. Galkin, arXiv:0705.2957v2 .
[3] S. Migura, D. Merten, B. Metsch and H. R. Petry, Eur. Phys. J. A 28 , 41 (2006).
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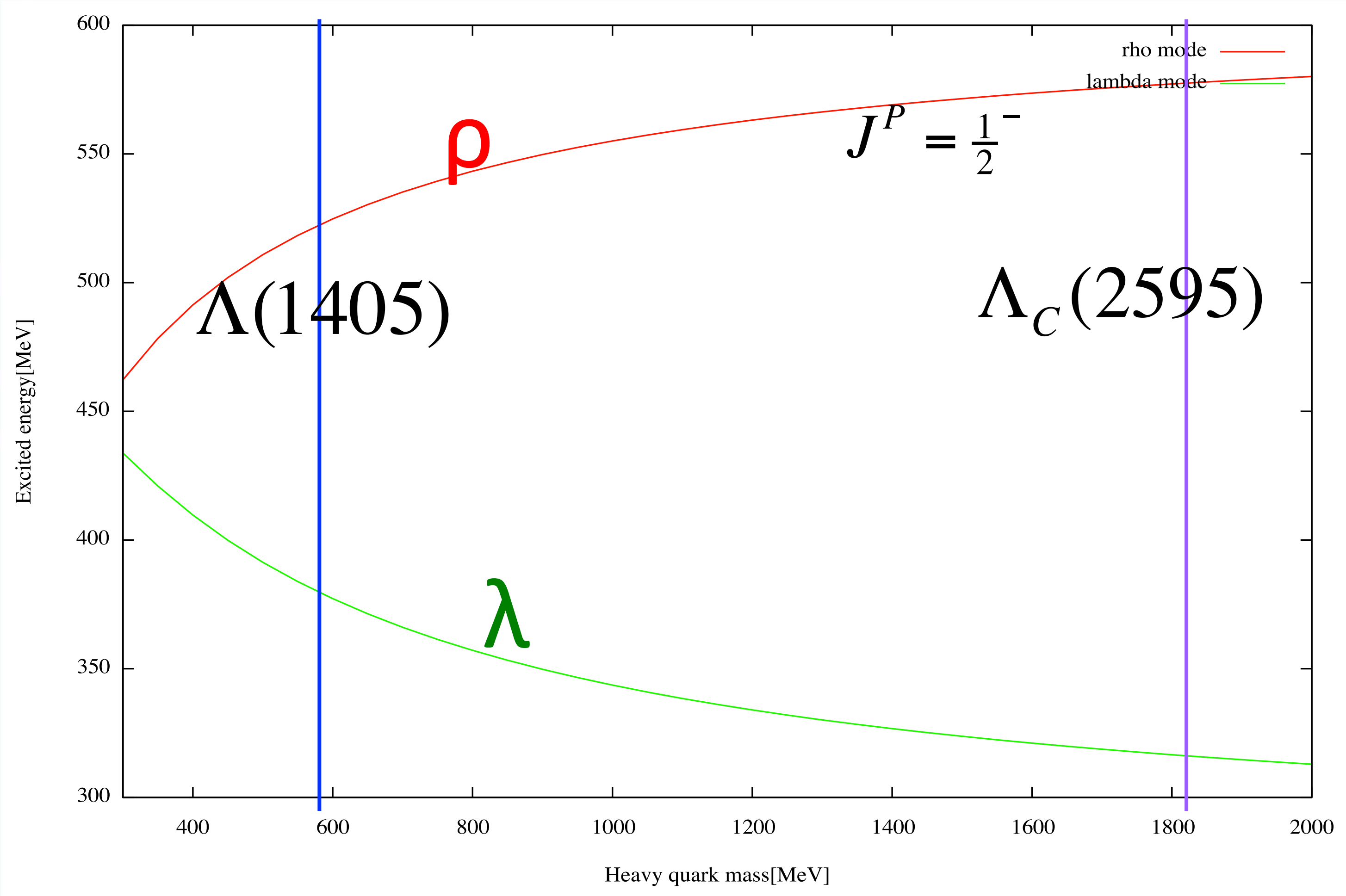
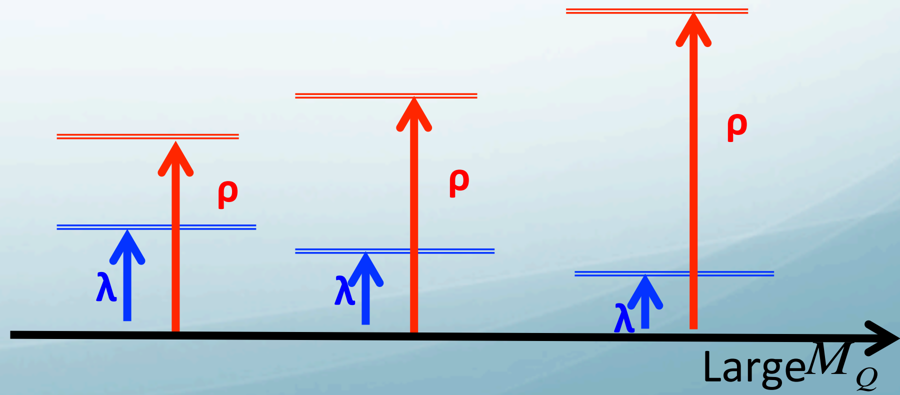


Figure1. Excited energy of 2 modes for Λ(1/2$^-$)

From Figure1 , We can see that excited energy of λ mode become small. So, we find that in heavy quark sector, λ mode excitation state is dominant and diquark is hard to



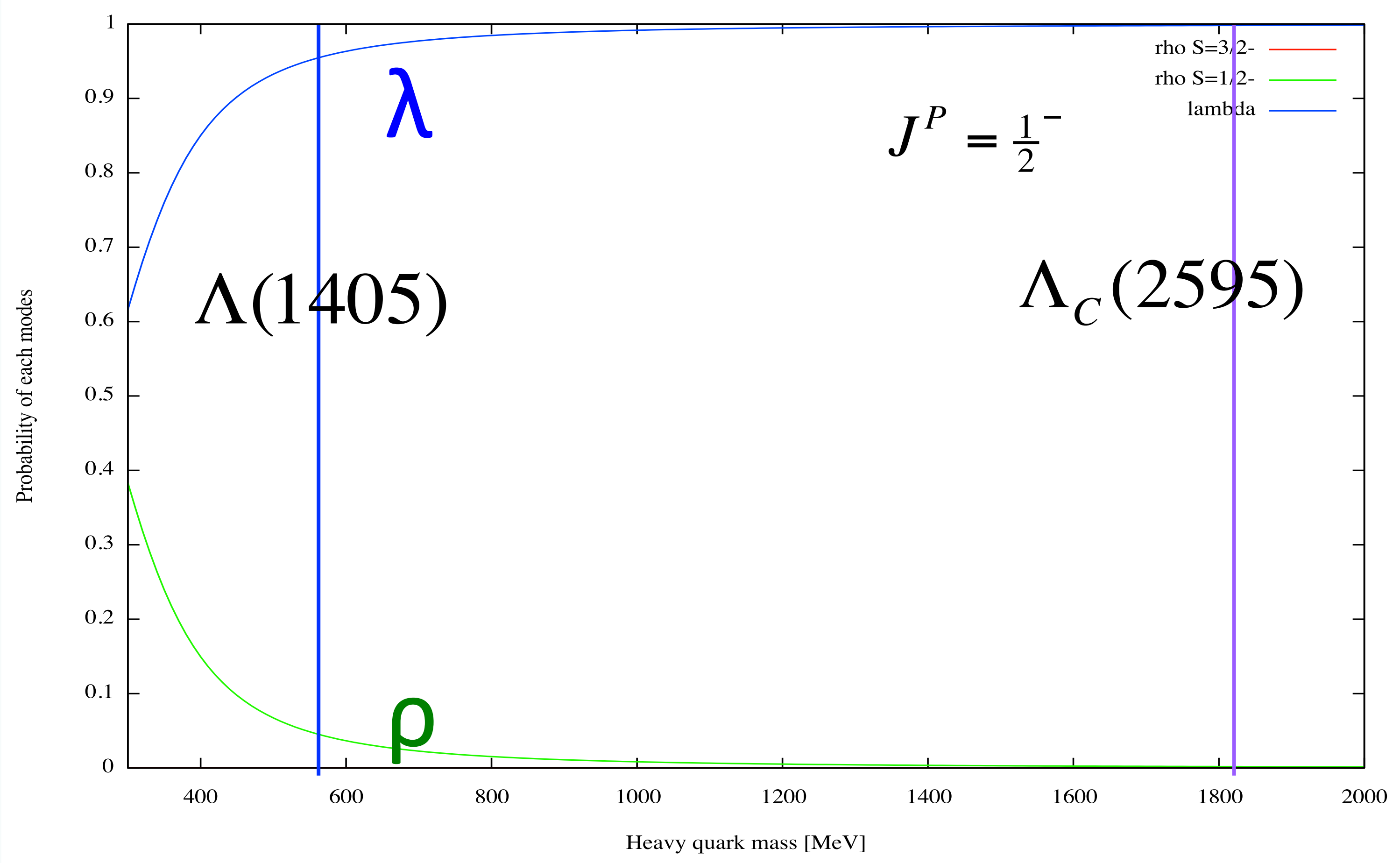


Figure2. Probability of 2 modes for $\Lambda(1/2^-)$

From Figure2 , We can see that the wave function change rapidly and in heavy quarksector, ρ mode excitation state is disappear.So,we say that $\Lambda(1/2^-)$ is in the state of λ mode.

Strange sector

$$\langle \varphi^\lambda | \varphi^\lambda \rangle : \langle \varphi^\rho | \varphi^\rho \rangle = 0{:}9618 : 0{:}0382$$

Charm sector

$$\langle \varphi^\lambda | \varphi^\lambda \rangle : \langle \varphi^\rho | \varphi^\rho \rangle = 0{:}9985 : 0{:}0015$$

Bottom sector

$$\langle \varphi^\lambda | \varphi^\lambda \rangle : \langle \varphi^\rho | \varphi^\rho \rangle = 0{:}99999902 : 0{:}98\times10^{-6}$$

Summary

In the sector of states containing a single charmed quark ,the results obtained are in good agreement with experimental observations and other works overall.
Comparing λ-mode excitation with ρ-mode excitation , It turned out that wave function changed rapidly when quark mass is increased.

Outlook

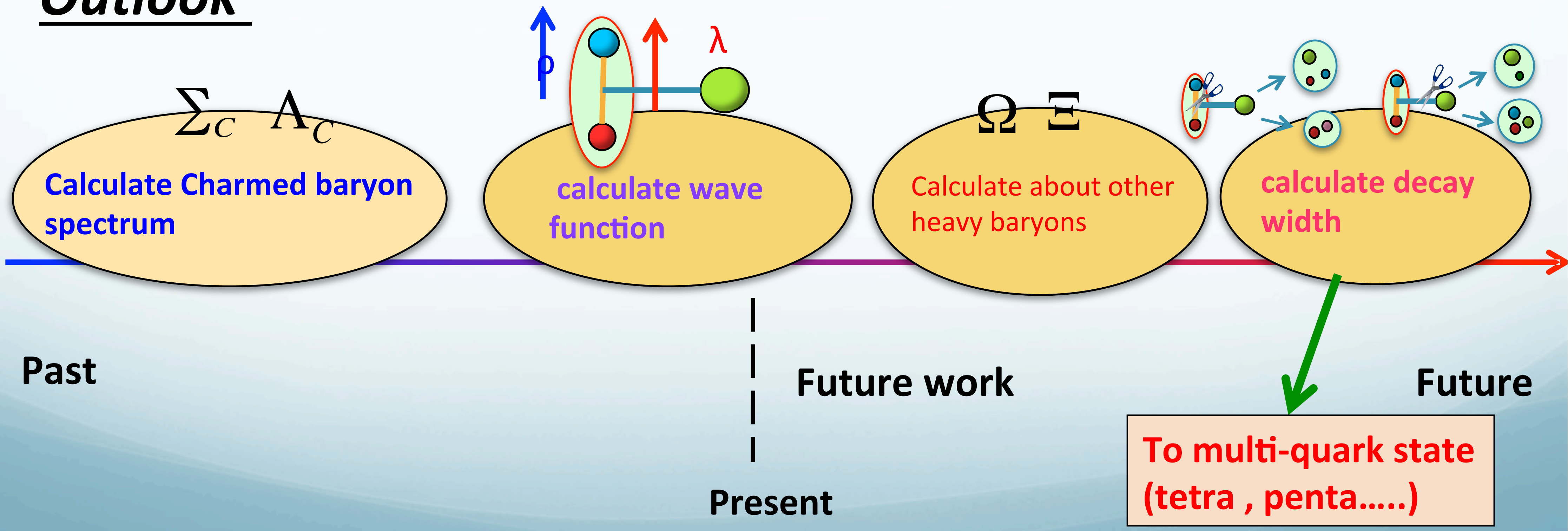


Table2:The singly bottom baryon spectrum obtained in our model (MeV)

Flavor	J^P	This work	Experimet
Λ	$1/2^+$	1115	1116
	$3/2^+$	1781	1850-1910
	$5/2^+$	1841	1815-1825
	$7/2^+$	2110	2020-2120
	$1/2^-$	1657	1660-1680
	$3/2^-$	1678	1685-1695
	$5/2^-$	1752	1810-1830
	$7/2^-$	2200	2090-2110
Σ	$1/2^+$	1176	1189
	$3/2^+$	1381	1385
	$5/2^+$	1926	1900-1935
	$1/2^-$	1658	1610-1635
	$3/2^-$	1675	1665-1685
	$5/2^-$	1748	1770-1780

Baryon wave function

The full wave function is described in terms of a totally antisymmetric one.

We used the Gaussian expantion basis.

$$\psi^{G}_{Space} = N_{nl} r^{l} \exp(-\nu_n r^2) Y_{lm}(\hat{\mathbf{r}})$$

$$\phi_f \times \psi_{space} \times \chi_{spin} \times (colar)$$

6

$$\Sigma_c^{++} = uuc, \quad \Sigma_c^{+} = \frac{1}{\sqrt{2}}(ud+du)c, \quad \Sigma_c^{0} = ddc$$

$$\Xi_c^{\prime +} = \frac{1}{\sqrt{2}}(us+su)c, \quad \Xi_c^{\prime 0} = \frac{1}{\sqrt{2}}(ds+sd)c,$$

$$\Omega_c^{0} = ssc,$$

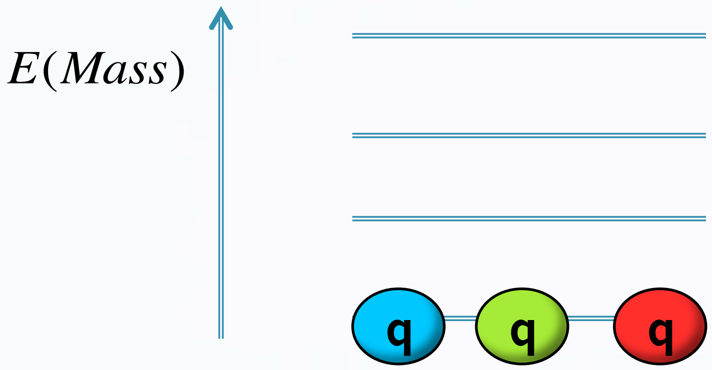
$\overline{\mathbf{3}}$

$$\Lambda_c^{+} = \frac{1}{\sqrt{2}}(ud-du)c, \quad \Xi_c^{+} = \frac{1}{\sqrt{2}}(us-su)c, \quad \Xi_c^{0} = \frac{1}{\sqrt{2}}(ds-sd)c,$$

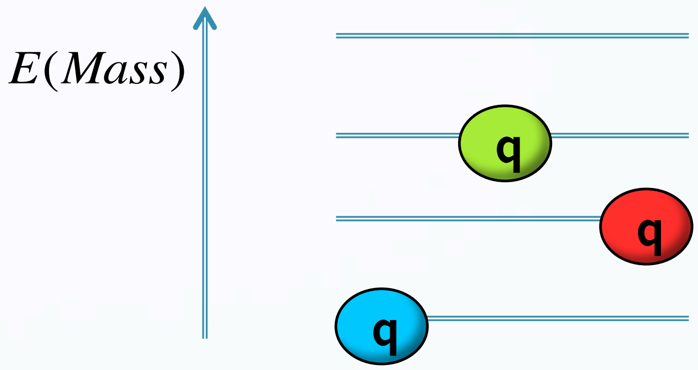
$$\chi^{S}_{3/2}(+3/2) = |\uparrow\uparrow\uparrow\rangle$$

$$\chi^{\rho}_{1/2}(+1/2) = \frac{1}{\sqrt{2}}\left(|\uparrow\downarrow\uparrow\rangle - |\downarrow\uparrow\uparrow\rangle\right)$$

$$\chi^{\lambda}_{1/2}(+1/2) = -\frac{1}{\sqrt{6}}\left(|\uparrow\downarrow\uparrow\rangle + |\downarrow\uparrow\uparrow\rangle - 2|\uparrow\uparrow\downarrow\rangle\right)$$

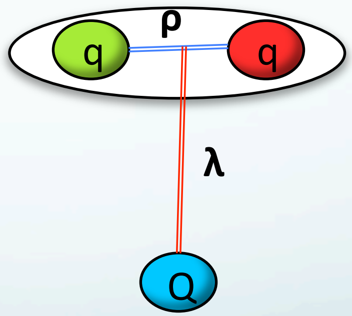


We know the ground state relatively



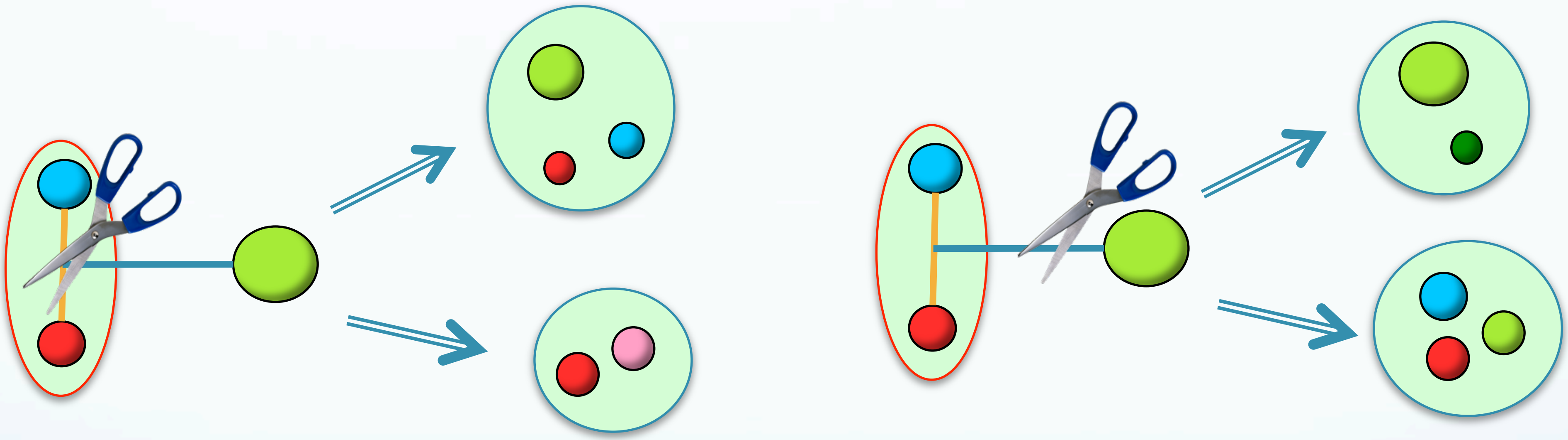
But , How it is the excited state?
(especially heavy baryon)

・Study heavy baryon excited states
especially λ , ρ excited states.



What do we find from the analysis in two excitation modes?

We can know the decay pattern of Λ_Q Σ_Q



Which is decay pattern?