# Lattice Study on the Excited States of Omega Baryon

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# Outline

I. Motivation
II. The spectrum of Omega baryons
III. The BS wave functions
IV. Conclusion

# I.Motivation

- There are only four Ω baryons in the PDG.

| | | |
|---|---|---|
| $\Omega^-$ | $I(J^P) = 0(\frac{3}{2}^+)$ | Status: $****$ |
| $\Omega(2250)^-$ | $I(J^P) = 0(?^?)$ | Status: $***$ |
| $\Omega(2380)^-$ | | Status: $**$ |
| $\Omega(2470)^-$ | | Status: $**$ |

- Apart from the Ω(1672) baryons, the $J^P$ quantum numbers of the other three states are not determined yet.

- In the

$$SU(6)\otimes O(3) \supset SU(3)_F \otimes SU(2)_{spin} \otimes O(3)$$

quark model, the level ordering should be

$$M(\frac{3}{2}^+) < M(\frac{3}{2}^-) \approx M(\frac{1}{2}^-) < M(\frac{3}{2}^{+*}) \approx M(\frac{1}{2}^+)$$

- Phenomenologicalstudies shows that the the mixing of the three-quark and five quarrk Fock space may drag the $M(\frac{3}{2}^-)$ lower than $M(\frac{1}{2}^-)$ ( An & Zou, PRC87(2013)065207, PRC89(2014)055209) ).

$$\underset{\text{antisymmetric}}{\Phi_{baryon}} = \underbrace{\phi_{space} \otimes \xi_{spin}}_{\text{symmetric}} \otimes \underset{\text{symmetric}}{\chi_{flavor}} \otimes \underset{\text{antisymmetric}}{\psi_{color}}$$

In a harmonious oscillator potential

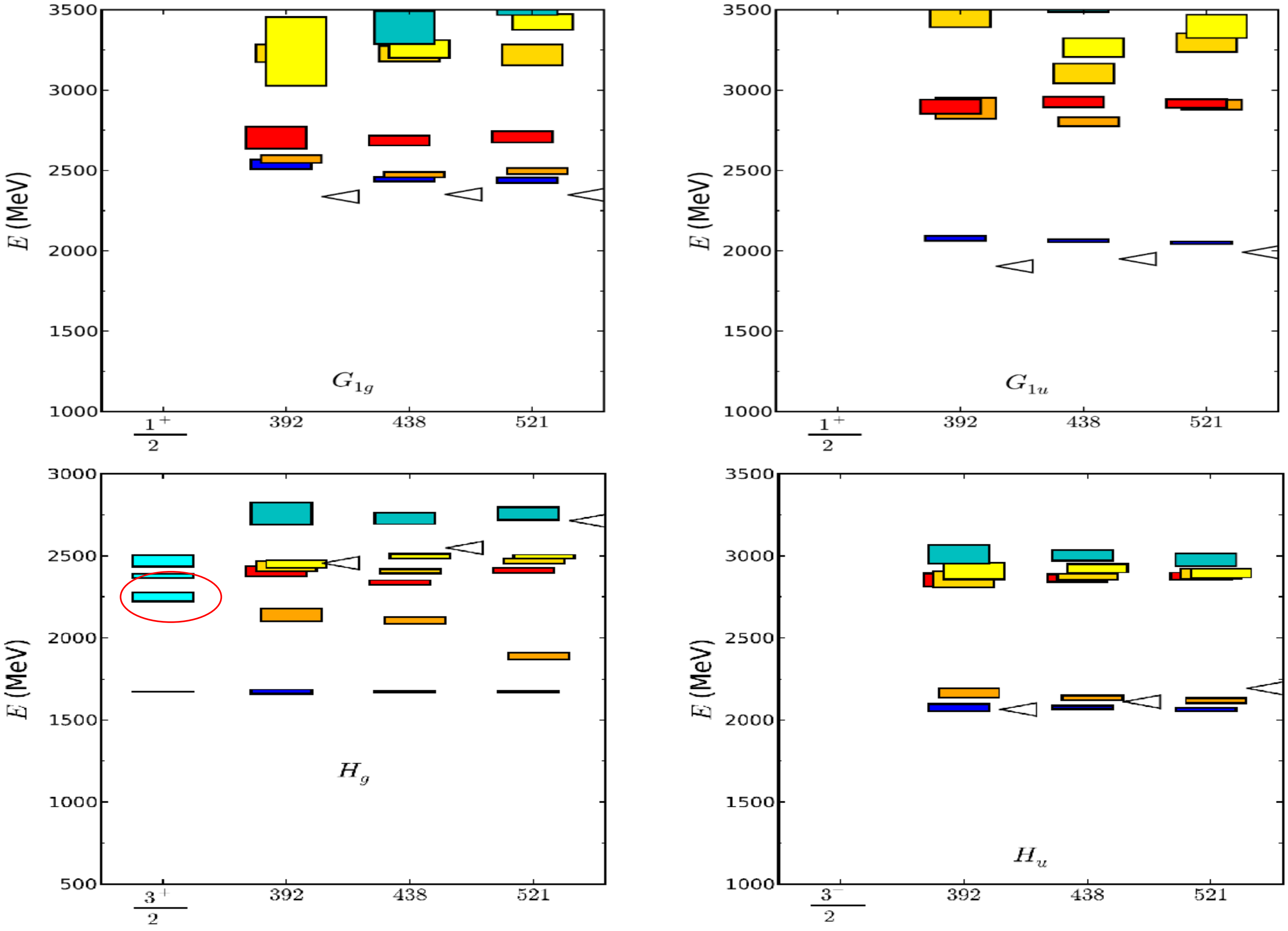
$$E = (2n_r + l + 3/2)\omega$$

| | | | |
|---|---|---|---|
| $J = \frac{3}{2}^{+}$ : | $1s1s1s$ | | $1s1s2s$ |
| $J = \frac{3}{2}^{-}$ : | | $1s1s1p$ | |
| $J = \frac{1}{2}^{+}$ : | | | $1s1s2s$ |
| $J = \frac{1}{2}^{-}$ : | | $1s1s1p$ | |

Energy increases.

# The latest lattice calculation of $\Omega$ baryon spectrum

Bulava et al. (Hadron Spectrum Collaboration),
Phys. Rev. D 82, 014507 (2010)

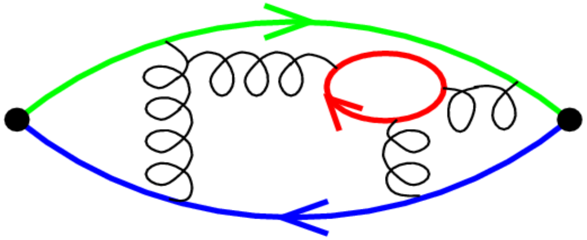


# The physical interpretation of their results:

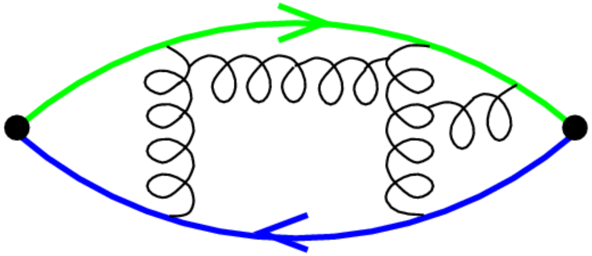
1. 2+1 flavor full-QCD calculation
2. Many interpolation fields involved in the calculation
3. There are many states extracted in each symmetry channel.
4. The nature of the these states cannot be identified reliably:

Which are the one-particle states?
Which are the two-particle states?
Which state corresponds to the physical resonance observed in the experiments?

# II. The spectrum of Ω baryons



(B) Full QCD



(A) Quenched QCD: quark loops neglected

Quenched theory:

Quark model

⬍

Lattice QCD in the quenched approximation

| $\beta$ | $\xi$ | $a_s/r_0$ | $a_s(\mathrm{fm})$ | $La_s(\mathrm{fm})$ | $L^3 \times T$ | $N_{\mathrm{conf}}$ |
|---|---|---|---|---|---|---|
| 2.4 | 5 | 0.461(4) | 0.222(2)(11) | $\sim 1.78$ | $8^3 \times 96$ | 3000 |
| 2.8 | 5 | 0.288(2) | 0.138(1)(7) | $\sim 1.66$ | $12^3 \times 144$ | 1000 |

- Interpolation field operator for Ω baryons

$$\mathcal{O}^{\mu}_{\Omega} = \epsilon^{abc}(s^{T}_{a}\mathcal{C}\gamma^{\mu}s_{b})s_{c}$$

- This operator has both the spin-1/2 and spin-3/2 components

- Introducing the projection operators from the quantum field theory

$$\mathcal{P}^{\mu\nu}_{3/2} = \delta^{\mu\nu} - \frac{1}{3}\gamma^{\mu}\gamma^{\nu} - \frac{1}{3p^2}(\not{p}\gamma^{\mu}p^{\nu} + p^{\mu}\gamma^{\nu}\not{p})$$

$$\mathcal{P}^{\mu\nu}_{1/2} = \delta^{\mu\nu} - \mathcal{P}^{\mu\nu}_{3/2}$$

- We obtain the following operators with definite spin quantum number

$$\mathcal{O}^{\mu}_{3/2} = \sum_{\nu}\mathcal{P}^{\mu\nu}_{3/2}\mathcal{O}^{\nu}_{\Omega}$$

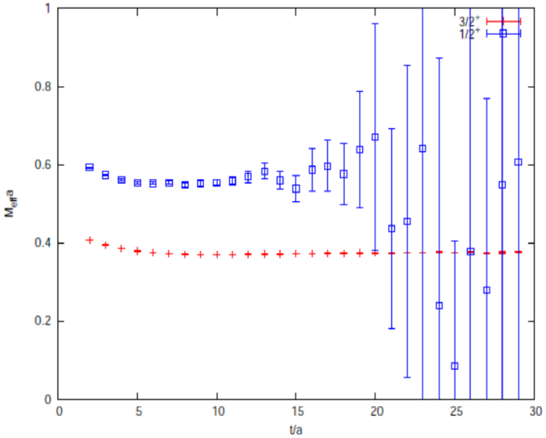
$$\mathcal{O}^{\mu}_{1/2} = \sum_{\nu}\mathcal{P}^{\mu\nu}_{1/2}\mathcal{O}^{\nu}_{\Omega}$$

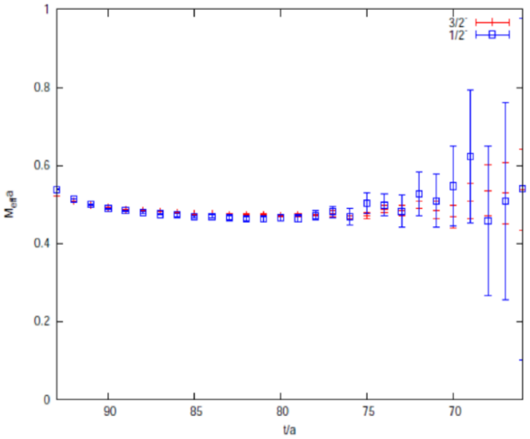
- Then we can calculate the two-point functions of these operators

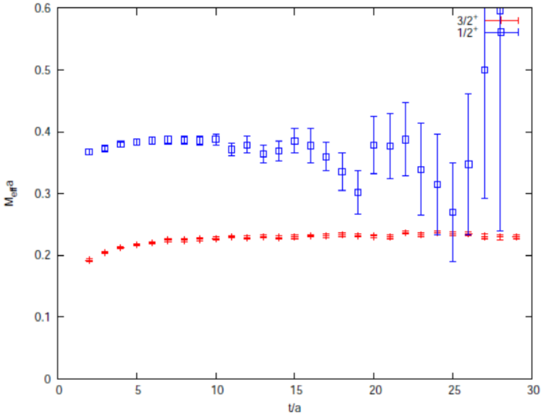
$$C_J(t) = \sum_{\vec{x}} Tr(1 \pm \gamma_4)\langle O_J(\vec{x},t)\bar{O}_J(0)\rangle = \sum_{n} Z_J e^{-m_J t}$$

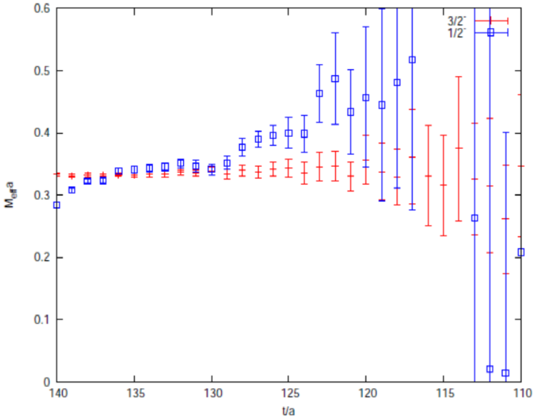
# Effecitve mass plateaus

$$m_{eff}(r,t) = \ln \frac{C(r,t)}{C(r,t+1)}$$









# The fitted masses for the lowest-lying Ω baryons

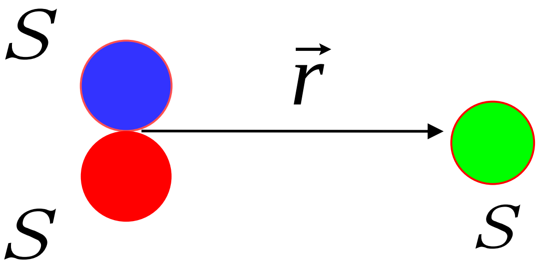
| | mass(lattice unit) | mass(MeV) | mass(PDG) |
|---|---|---|---|
| $\frac{3}{2}^+$ | 0.375(1) | 1650(75) | 1672 |
| $\frac{3}{2}^-$ | 0.473(4) | 2080(95) | 2250 |
| $\frac{1}{2}^-$ | 0.469(4) | 2060(94) | 2380 |
| $\frac{1}{2}^+$ | 0.55(1) | 2420(100) | 2470 |

| | mass(lattice unit) | mass(MeV) | mass(PDG) |
|---|---|---|---|
| $\frac{3}{2}^+$ | 0.231(4) | 1640(69) | 1672 |
| $\frac{3}{2}^-$ | 0.333(5) | 2360(100) | 2250 |
| $\frac{1}{2}^-$ | 0.33(4) | 2340(99) | 2380 |
| $\frac{1}{2}^+$ | 0.37(3) | 2620(111) | 2470 |

(very preliminary)

# III. The BS wave functions of Ω baryons in the Coulomb gauge

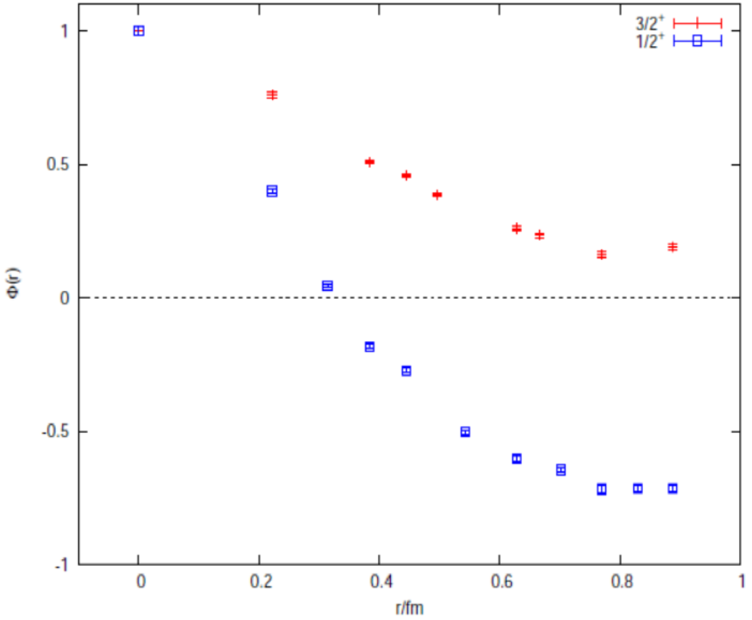
- We use the spatially extended operators by splitting the three quark fields into two parts with spatial separations in the Coulomb gauge



$$\mathcal{O}_1(r) = \sum_{|\vec{r}|} \epsilon^{abc}[s_a^T(x+\vec{r})\mathcal{C}\gamma^\mu s_b(x)]s_c(x)$$

$$\mathcal{O}_2(r) = \sum_{|\vec{r}|} \epsilon^{abc}[s_a^T(x)\mathcal{C}\gamma^\mu s_b(x+\vec{r})]s_c(x)$$

$$\mathcal{O}_3(r) = \sum_{|\vec{r}|} \epsilon^{abc}[s_a^T(x)\mathcal{C}\gamma^\mu s_b(x)]s_c(x+\vec{r})$$



$$C(r,t) = \left\langle O(\vec{r},t)\bar{O}^{(W)}(0)\right\rangle = \sum_i W_i(r)e^{-m_i t}$$

# IV. Conclusion

- We calculate the spectrum of the lowest-lying $\Omega$ baryons in the quenched approximation.
- The level ordering is in qualitative agreement with the expectation of the Quark Model.
- We also calculate the BS wave functions of the lowest 3/2+ and 1/2+ states. There does exist a radial node in the BS wave function of 1/2+ state, which implies that this state is a radial excited state as expected by the Quark model.
- The masses of these states are compatible with those of the experimental resonances. However, no solid conclusion can be obtained at present.

# Thanks!