Where is the stable Pentaquark

Woosung Park, Sungtae Cho, and Su Hyoung Lee

1 Department of Physics and Institute of Physics and Applied Physics, Yonsei University, Seoul 03722, Korea
2 Division of Science Education, Kangwon National University, Chuncheon 24341, Korea

(Dated: November 30, 2018)

We systematically analyze the flavor color spin structure of the pentaquark $q^4\bar{Q}$ system in a constituent quark model based on the chromomagnetic interaction in both the SU(3) flavor symmetric and SU(3) flavor broken case with and without charm quarks. We show that the originally proposed pentaquark state $\bar{Q}qqq$ by Gignoux et al and by Lipkin indeed belongs to the most stable pentaquark configuration, but that when charm quark mass correction based on recent experiments are taken into account, a doubly charmed antistrange pentaquark configuration ($uudd\bar{s}$) is perhaps the only flavor exotic configuration that could be stable and realistically searched for at present through the $\Lambda_cK^+K^-\pi^+$ final states. The proposed final state is just reconstructing $K^+$ instead of $\pi^+$ in the measurement of $\Xi_{cc}^{++} \to \Lambda_cK^+K^-\pi^+$ reported by LHCb collaboration and hence measurable immediately.

The possible existence of mutiquark hadrons beyond the ordinary hadrons were first discussed for the tetraquark states in Refs. [1,2], and for the H-dibaryon in Ref. [3]. Later, possible stable pentaquark configurations $\bar{Q}qqqq$ were proposed in Ref. [4] and in Ref. [5]. The long experimental search for the H-dibaryon was not successful so far but is still planned at JPARC [6]. The search by Fermilab E791 [7] for the proposed pentaquark state was for many years considered to be stable color sources that would allow for a stable multiquark configuration that does not fall into usual hadrons. In particular, with the recent experimental confirmation of the doubly charmed baryon $\Xi_{cc}$, there is a new excitement in the physics of exotics in general and in hitherto unobserved flavor exotic states with more than one heavy quarks [3,13].

In this work, we systematically analyze the color flavor spin structure of the pentaquark configuration within a constituent quark model based on chromomagnetic interaction. We show that the originally proposed pentaquark state $\bar{Q}qqqq$ indeed belong to the most stable pentaquark configuration, but that when charm quark mass correction based on recent experiments are taken into account, a doubly charmed antistrange pentaquark configuration ($uudd\bar{s}$) is perhaps the only stable flavor exotic configuration that could be stable and realistically searched for at present.

**Systematic analysis of $q^4\bar{Q}$:** We first discuss the classification of the flavor, color and spin wave function for the ground state of the pentaquark composed of $q^4$ light quarks and one heavy antiquark $Q$ ($c$ or $b$) assuming that the spatial parts of the wave function for all quarks are in the s-wave. We categorize them into the flavor states in SU(3)$_F$, and then examine the color $\otimes$ spin states.

The flavor states for $q^4$ can be decomposed into the direct sum of the irreducible representation of SU(3)$_F$ as follows:

$$[3]_F \otimes [3]_F \otimes [3]_F \otimes [3]_F = [4]_1 \otimes [15] \oplus [31]_3 \otimes [15'] \oplus [21^2]_3 \otimes [3] \oplus [2^2]_2 \otimes [6].$$

Here, $[4]_1$, $[15]$, $[31]_3$, $[15']$, $[21^2]_3$, $[3]$, $[2^2]_2$, and $[6]$ indicate the Young tableau of the SU(3)$_F$ multiplet, with the subscripts representing the corresponding dimensions, while $[15]$, $[15']$, $[31]_3$, $[21^2]_3$, $[3]$, $[2^2]_2$, and $[6]$ show the respective multiplicities.

The 7776 dimensional color $\otimes$ spin states of $q^4\bar{Q}$ can be classified as the direct sum of the irreducible representations of SU(6)$_{CS}$ as follows:

$$([6]_{CS} \otimes [6]_{CS} \otimes [6]_{CS} \otimes [6]_{CS} \otimes [6]_{CS})_{7776} = [4]_1 \otimes ([51^1] \otimes [3]) \oplus [2^2]_2 \otimes ([3^21^1] \otimes [21]) \oplus [31]_3 \otimes ([421^2] \otimes [3] \otimes [21]) \oplus [1^4]_1 \otimes ([2^41^1] \otimes [1^3]) \oplus [21^2]_3 \otimes ([32^21^2] \otimes [21] \otimes [1^3]).$$

The Young Tableau and its subscript outside of the bracket respectively indicates the SU(6)$_{CS}$ representation and its dimension of the light quark sector $q^4$ while the Young Tableau inside the bracket is the SU(6)$_{CS}$ representation of the pentaquark consisting of $q^4\bar{Q}$.

By further decomposing the SU(6)$_{CS}$ into the sum of SU(3)$_C \otimes$ SU(2)$_S$ multiplets, we can select out the physically allowed color singlet states. Table I shows the allowed color singlet states with the possible spin states, denoted by [1$_C$, S], allowed within each SU(6)$_{CS}$ representation.

Therefore, since the SU(6)$_{CS}$ representation of $q^4\bar{Q}$ as well as those of $q^4$ are given in Eq. (2), we can construct the flavor $\otimes$ color $\otimes$ spin states with color singlet, by using the fully antisymmetric property together with the conjugate relation between the flavor in Eq. (3) and the SU(6)$_{CS}$ representation in Eq. (4) among the four light quarks. Such combination will finally determine the allowed flavor and spin content of the pentaquarks in the flavor SU(3) symmetric limit.
Color spin interaction for pentaquark system: In the constituent quark model based on the color spin interaction, the stability of a pentaquark depends critically on the expectation value of the interaction. Therefore, we derive the following elegant formula of the chromomagnetic interaction relevant for the pentaquark configuration, which is similar to that of a tetraquark in Ref. 2, by introducing the first kind of Casimir operator of SU(6)$_{CS}$, which is denoted by $C^6$:

$$\sum_{i<j}^5 \lambda_i^c \lambda_j^c \vec{\sigma}_i \cdot \vec{\sigma}_j = 4C^6 - 8C^4 - 2C^3 + 4C^2 - \frac{4}{3} (\vec{S} \cdot \vec{S})_5 + \frac{8}{3} (\vec{S} \cdot \vec{S})_4 + 24 I. \quad (3)$$

Here the lower index indicates the number of the participant quarks, $C^3$ the first kind of Casimir operator of $SU(3)_{C}$, $S$ the spin operator, and $I$ the identity operator.

Spin=3/2: Let us discuss in detail the flavor [15$^1$] case with $S = 3/2$. Here, there are two flavor $\otimes$ color $\otimes$ spin states which are orthonormal to each other. There are two methods to obtain these states.

In one approach based on the coupling scheme, the first (second) state comes from the coupling scheme of the color $\otimes$ spin state in which the spin among the four quarks is one (two), as given in Eq. (26) (Eq.(32)) in 18. The fully antisymmetric flavor $\otimes$ color $\otimes$ spin states for $S = 3/2$ among the four quarks can be obtained by multiplying the color $\otimes$ spin state by their conjugate flavor [15$^1$] state. In the other approach, the state can be directly obtained from Eq. (4). As we can see in Eq. (2) and Table I both the [32$^2$1$^2$] and the [1$^3$] SU(6)$_{CS}$ representations have the state of the color singlet and $S = 3/2$. Also, these states involve the [21$^2$] multiplets in the SU(6)$_{CS}$ representation among the four quarks, which are conjugate to the flavor [15$^1$] states, so that the two fully antisymmetric flavor $\otimes$ color $\otimes$ spin states can be constructed from the SU(6)$_{CS}$ representation [32$^2$1$^2$] and [1$^3$].

From the SU(6)$_{CS}$ representation point of view, we can infer that the linear sum of two fully antisymmetric flavor $\otimes$ color $\otimes$ spin states coming from the coupling scheme must belong to either [32$^2$1$^2$] state or [1$^3$] state. We find that the coefficients of the linear sum can be calculated from the condition that these are the eigenstates of the Casimir operator of SU(6)$_{CS}$, given by,

$$C^6 = -\frac{1}{4} \sum_{i=1}^4 \lambda_i^c \lambda_i^c \vec{\sigma}_i \cdot \vec{\sigma}_5 + C^4 + \frac{1}{2} C^3 - \frac{1}{2} C^4 + \frac{1}{3} (\vec{S} \cdot \vec{S})_5 - \frac{1}{3} (\vec{S} \cdot \vec{S})_4 + 2I. \quad (4)$$

Following the same procedure, one can construct the flavor $\otimes$ color $\otimes$ spin states for the remaining flavor cases for $S = 3/2$, which satisfy the antisymmetry property among four quarks. From the result, it is found that there are all together 12 color $\otimes$ spin states that are both color singlet and $S = 3/2$. These are expressed by the Yamanouchi bases of the SU(6)$_{CS}$ representation among the four quarks, together with the SU(6)$_{CS}$ Young tableau for the full $q^3Q$ pentaquark state:

$$\begin{align*}
\begin{array}{cccc}
1 & 2 & 3 & [421^3] \\
4 & 5 & [421^3] & 2 \\
2 & 3 & [421^3] & 1 \\
4 & 5 & [32^21^2] & 1 \\
2 & 3 & [32^21^2] & 1 \\
1 & 4 & [32^21^2] & 1 \\
1 & 5 & [32^21^2] & 1 \\
1 & 3 & [32^21^2] & 1 \\
0 & 3 & [32^21^2] & 1 \\
0 & 2 & [32^21^2] & 1 \\
0 & 1 & [32^21^2] & 1 \\
0 & 0 & [32^21^2] & 1 \\
\end{array}
\end{align*} \quad (5)$$

Other spin states: In analogy to the $S = 3/2$ case, we can apply the same procedure to the $S = 1/2$ case. In this case, there are all together 15 color $\otimes$ spin states that are both color singlet and $S = 1/2$, and that are expressed by the Yamanouchi bases of the SU(6)$_{CS}$ representation among the four quarks, like Eq. 6. Finally, in the $S = 5/2$ case, there exist only one color $\otimes$ spin state coming from the [32$^2$1$^2$] representation in Table II.

By using the flavor $\otimes$ color $\otimes$ spin states for $S = 1/2$, $S = 3/2$, and $S = 5/2$, the expectation values of Eq. (3) can be calculated, as given in Table II. In Table II below each matrix element, we also show the relevant SU(6)$_{CS}$ representations for the pentaquark state as well as the eigenvalue of Eq. (3). As can be seen in the table, the most attractive channel is given by the $2 \times 2$ matrix valued $(F,S) = ([3],1/2)$ state. Upon diagonalizing the matrix in the $m_5 \rightarrow \infty$ one finds the eigenvalues (-16.40/3, where the lowest one corresponds to the most attractive pentaquark state discussed in Ref. 14, 15. It should be noted that the factor -16 in this case can also be naively obtained by assuming two diquarks (ud, us) in the udus$c$ pentaquark. However, as noted from the case of H dibaryon, SU(3) breaking effects together with the additional attraction from the strong charm quarks are important to the realistic estimate of the stability. The color spin interaction from the $m_{uds} - m_{ud}$ are much stronger than from naively scaling the color spin splitting in the light quark sector by the charm quark mass 14.

Pentaquark binding in the SU(3)$_F$ broken case: To analyze the stability of the pentaquarks against the lowest
This is because other potential terms are linear in the states arise only from the hyperfine energy difference [19].

We then assume that the difference between the pen-
taqark energy and the lowest threshold baryon meson
threshold, we introduce a simplified form for the matrix
element of the hyperfine potential term, where we approx-
imate the spatial overlap factors by constants that
depend only on the constituent quark masses of the two
quarks involved:

\[ H_{\text{hyp}} = - \sum_{i<j} C_{m_i m_j} \lambda_i^* \lambda_j^* \sigma_i \cdot \sigma_j. \]  

We then assume that the difference between the pen-
taqark energy and the lowest threshold baryon meson
states arise only from the hyperfine energy difference [19].

This is because other potential terms are linear in the
number of quark involved so that assuming that all
hadrons occupy the same size, the differences of their

correction to the pentaqark and baryon meson cancel.

To evaluate the binding energy of the pentaqark in
terms of Eq. (6), we extract the \( C_{m_i m_j} \) values from the
relevant mass differences between baryons and between
mesons when involving one antiquark. The relations are
given by,

\[ \Delta - P = 16 C_{uu}, \quad \Sigma^* - \Sigma + \Xi^* - \Xi = 32 C_{us}, \]
\[ \Omega^* - \Omega = 16 C_{sc}, \quad \Sigma^* - \Sigma + \Xi = 16 C_{uc}, \]
\[ 2 \Omega + \Delta - (2 \Xi^* + \Xi) = 8 C_{us} + 8 C_{uu}. \]  

For \( C_{cc} \) we take it to be 1/2 \( C_{cc} \). Then, we calculate
the binding energy, denoted by \( \Delta E \), by comparing
the hyperfine potential energy between the pentaqark
and its lowest decay channel.

**Isospin basis:** We now investigate the stability of the
pentaqark with respect to isospin \( I \) and spin \( S \), and
allow the antiquark of the pentaqark to be either \( \bar{s}, \bar{c} \) or \( \bar{b} \). The advantage of the Yamamuchi basis in the \( SU(6)_{CS} \)
representation to the pentaqark that characterizes the
symmetry property among the four quarks makes it pos-
sible to find the flavor \( \otimes \) color \( \otimes \) spin states suitable for
a certain symmetry, which is allowed by the Pauli prin-
inciple. Since it is possible that there are several flavor \( \otimes \)
color \( \otimes \) spin states, denoted by multiplicity, according to
the symmetry property, the binding energy is obtained from
diagonalizing the matrix element of the hyperfine
potential energy.

We need to characterize isospin states of \( q^4 \) in order
to classify the pentaqark with respect to \( I \). As can be seen in [20], the isospin states to \( q^4 \) can be decomposed in
the following way: \( I = 0 \) with Young tableau [2] consisting of \( uudd \) component, \( I = 1 \) with Young tableau
[31] consisting of \( uudd \) component, and \( I = 2 \) with Young
tableau [4] consisting of \( uudd \). The result for the binding
energy defined as the difference between the hyperfine
interaction of the pentaqark against its lowest threshold
values are given in Table [IV].

As can be seen in Table [IV] it is found that the most
attractive pentaquark states are those with \( (I, S) = (0, 1/2) \),
apart from \( udc \), and as well, the \( udc \) with \( (I, S) = (1/2, 1/2) \). To understand the reason why these
particles could be bound states, we need to analyze the
expectation matrix value of Eq. (6) in terms of a domin-
ant color \( \otimes \) spin state among the possible states. For
these states, the dominant color \( \otimes \) spin state comes from the
\( SU(6)_{CS} \) representation [21] having the Young
tableau [31] for the \( q^4 \) for which the expectation value
of Eq. (3) is -36, as can be seen in \( (F = 3), S = 1/2 \)
sector of Table [IV] when \( m_1 = m_3 \). In fact, the \( SU(6)_{CS} \)
representation [21] state with \( S = 1/2 \) gives the most
attractive contribution to the expectation value of Eq. (3).

---

1. This state corresponds to the most stable \( P_{cs} \) state discussed in
Ref. [4].
than any other state, and both the $I = 0$ and $I = 1/2$ comes from the breaking of the flavor [3] state of this representation.

In Table III we show the expectation value of Eq. (6) in terms of only a color $\otimes$ spin state coming from the $SU(6)_{CS}$ representation [21] as well as the corresponding binding energy against its threshold represented in the third row for each state. It should be noted that $H_{hyp}$ for each state reduces to $-36c_{m_{i}m_{j}}$ when the $c_{m_{i}m_{j}}$’s are taken to be a quark mass independent constant. It should be noted that all these possible stable states are related to the attractive pentaquark states discussed in Ref. [4, 5] in the flavor SU(3) symmetric limit. However, it should also be pointed out that when the charm quark is also included, together with its hyperfine contribution, it is the $udcc\bar{s}$ pentaquark configuration that is most attractive. This state has also been discussed recently in Ref. [21]. The attraction obtained in Table III should be large enough to overcome the additional kinetic energy, typically of order 100 MeV, to make the state compact of a hadron size.

Hence, the proposed pentaquark state is possibly the only stable pentaquark or a resonance state slightly above the lowest threshold, which is $\Xi_{cc} + K$ for this state. Noting that $\Xi_{cc}$ has been recently discovered, one can just add an additional Kaon to look for this possible resonance state. If the state is strongly bound, one could look at the $udcc\bar{s} \rightarrow \Lambda_{c}K^{+}K^{-}\pi^{+}$ decay or any hadronic decay mode similar to those of $\Lambda_{c}D_{s}^{+}$. The proposed final state is just reconstructing $K^{+}$ instead of $\pi^{+}$ in the measurement of $\Xi_{cc}^{++} \rightarrow \Lambda_{c}K^{-}\pi^{+}\pi^{+}$ reported in Ref. [10] and hence measurable immediately. Such a measurement would be the first confirmation of a flavour exotic pentaquark state.

Acknowledgement This work was supported by the Korea National Research Foundation under the grant number 2016R1D1A1B03930089, 2017R1D1A1B03028419(NRF) and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIP) (No. 2016R1C1B1016270).

| $I = 0$, $S = 1/2$ | $udcc\bar{s}$ ($\Delta E = -131$) |
|------------------|-----------------|
| $H_{hyp}$ | $-11/3C_{uu}+11/2C_{us}-25/2C_{cc}-33/2C_{uu}-17/4C_{uu}$ |
| $\Xi_{cc}K$ | $-8/3C_{uu}-16C_{cc}$ |

| $I = 0$, $S = 1/2$ | $udcc\bar{s}$ ($\Delta E = -122$) |
|------------------|-----------------|
| $H_{hyp}$ | $-22/3C_{uu}+44/3C_{cc}-28/3C_{uu}-14/3C_{uu}$ |
| $\Lambda_{D_{s}}$ | $-8C_{uu}+16C_{cc}$ |

| $I = 1/2$, $S = 1/2$ | $udcc\bar{s}$ ($\Delta E = -92$) |
|------------------|-----------------|
| $H_{hyp}$ | $-33/4C_{uu}-55/4C_{cc}-21/2C_{uu}$ |
| $PD_{s}$ | $-8C_{uu}+16C_{cc}$ |

TABLE III. The expectation value of Eq. (6) coming from the dominant color $\otimes$ spin state for stable pentaquark candidate states. (unit MeV)

[1] R. L. Jaffe, Phys. Rev. D 15, 267 (1977).
[2] R. L. Jaffe, Phys. Rev. D 15, 281 (1977).
[3] R. L. Jaffe, Phys. Rev. Lett. 38, 195 (1977) Erratum: [Phys. Rev. Lett. 38, 617 (1977)].
[4] C. Gignoux, B. Silvestre-Brac and J. M. Richard, Phys. Lett. B 193, 323 (1987).
[5] H. J. Lipkin, Phys. Lett. B 195, 484 (1987).
[6] J. K. Ahn [J-PARC E42 Collaboration], JPS Conf. Proc. 17, 031004 (2017).
[7] E. M. Aitala et al. [E791 Collaboration], Phys. Lett. B 448, 303 (1999).
[8] S. K. Choi et al. [Belle Collaboration], Phys. Rev. Lett. 91, 262001 (2003).
[9] R. Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 115, 072001 (2015).
[10] R. Aaij et al. [LHCb Collaboration], Phys. Rev. Lett. 119, no. 11, 112001 (2017).
[11] R. Aaij et al. [LHCb Collaboration], arXiv:1806.02744 [hep-ex].
[12] R. Aaij et al. [LHCb Collaboration], arXiv:1807.01919 [hep-ex].
[13] H. X. Chen, Q. Mao, W. Chen, X. Liu and S. L. Zhu, Phys. Rev. D 96, no. 3, 031501 (2017) Erratum: [Phys. Rev. D 96, no. 11, 119902 (2017)].
[14] M. Karliner and J. L. Rosner, Phys. Rev. Lett. 119, no. 20, 202001 (2017).
[15] Estia J. Eichten, and Chris Quigg, Phys. Rev. Lett. 119 (2017) no.20, 202002.
[16] A. Francis, R. J. Hudspith, R. Lewis and K. Maltman, Phys. Rev. Lett. 118, no. 14, 142001 (2017).
[17] J. Hong, S. Cho, T. Song and S. H. Lee, Phys. Rev. C 98, no. 1, 014913 (2018).
[18] W. Park, A. Park, S. Cho and S. H. Lee, Phys. Rev. D 95, no. 5, 054027 (2017).
[19] A. Park, W. Park and S. H. Lee, Phys. Rev. D 98, no. 3, 034001 (2018).
[20] W. Park, A. Park and S. H. Lee, Phys. Rev. D 93, no. 7, 074007 (2016).
[21] Q. S. Zhou, K. Chen, X. Liu, Y. R. Liu and S. L. Zhu, Phys. Rev. C 98, no. 4, 045204 (2018).
### TABLE IV. The binding energy of the pentaquark. (unit : MeV)

| Pentaquark | I = 0, Threshold, multiplicity | I = 1, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| uudcδ     | $\Delta E=124$, $\Lambda_8^c$, 7 | $\Delta E=-48$, $\Lambda J/\psi$, 5 |
| udscδ     | $\Delta E=-117$, $\Lambda D_5$, 4 | $\Delta E=-54$, $\Sigma D_5^*$, 4 |
| udcscδ    | $\Delta E=-135$, $\Xi_0^c K^*$, 3 | $\Delta E=-133$, $\Xi_0^c K^*$, 3 |
| udscδ     | $\Delta E=-38$, $\Lambda_8^c$, 4 | $\Delta E=14$, $\Sigma_1^c \eta_1$, 4 |
| uddsδ     | $\Delta E=-92$, $\Lambda B_5$, 4 | $\Delta E=-24$, $\Sigma B_5$, 4 |

| Pentaquark | I = 0, Threshold, multiplicity | I = 1, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| uuddδ     | $\Delta E=98$, $PK$, 1 $\Delta E=74$, $PK^*$, 1 | $\Delta E=337$, $PK$, 2 $\Delta E=79$, $PD^*$, 2 |
| uuddδ     | $\Delta E=54$, $PB$, 1 $\Delta E=52$, $PB^*$, 1 | $\Delta E=175$, $PB$, 2 $\Delta E=172$, $PB^*$, 2 |

| Pentaquark | I = 1/2, Threshold, multiplicity | I = 1/2, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| uudsb     | $\Delta E=-77$, $PB$, 5 $\Delta E=-45$, $PB^*$, 4 | $\Delta E=-99$, $PD$, 5 $\Delta E=-39$, $PD^*$, 4 |
| uudcδ     | $\Delta E=17$, $\Lambda K$, 5 $\Delta E=-88$, $\Sigma K^*$, 4 | $\Delta E=-34$, $P$, 5 $\Delta E=-15$, $P^*$, 4 |
| ssucδ     | $\Delta E=133$, $\Xi D_5$, 3 $\Delta E=-17$, $\Xi D_5^*$, 3 | $\Delta E=87$, $\Xi B_5$, 3 $\Delta E=73$, $\Xi B_5^*$, 3 |

| Pentaquak  | I = 3/2, Threshold, multiplicity | I = 3/2, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| uuucδ     | $\Delta E=-214$, $\Sigma_0^c$, 3 $\Delta E=-42$, $\Delta D_5$, 3 | $\Delta E=0$, $\Delta D_5^*$, 1 |
| uuusδ     | $\Delta E=170$, $\Sigma B$, 3 $\Delta E=-142$, $\Sigma B^*$, 3 | $\Delta E=0$, $\Delta B_5^*$, 1 |
| uuucδ     | $\Delta E=-274$, $\Sigma K$, 3 $\Delta E=186$, $\Sigma K^*$, 3 | $\Delta E=0$, $\Delta D_5^*$, 1 |
| uuucδ     | $\Delta E=-191$, $\Sigma D$, 3 $\Delta E=-20$, $\Delta \eta_1$, 3 | $\Delta E=0$, $\Delta J/\psi$, 1 |

| Pentaquak  | $I = 1$, S = 5/2, Threshold, multiplicity | $I = 1$, S = 5/2, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| udscδ     | $\Delta E=-44$, $\Sigma^* J/\psi$, 2 $\Delta E=17$, $\Sigma^* D_5^*$, 1 | $\Delta E=-17$, $\Sigma^* D_5^*$, 1 $\Delta E=0$, $\Sigma^* B^*$, 1 |

| Pentaquak  | $I = 0$, S = 5/2, Threshold, multiplicity | $I = 1/2$, S = 5/2, Threshold, multiplicity |
|------------|--------------------------------|--------------------------------|
| uudcδ     | $\Delta E=-12$, $\Delta E=-7$, $\Delta E=-17$, $\Delta E=-7$ | $\Delta E=-4$, $\Delta E=-9$, $\Delta E=-4$, $\Delta E=-34$, $\Delta E=-34$ |
| uudcδ     | $\Delta E=13$, $\Sigma^* J/\psi$, 1 $\Sigma^* D_5^*$, 1 $\Sigma^* D_5^*$, 1 $\Sigma^* B^*$, 1 $\Sigma^* B^*$, 1 | $\Sigma^* D_5^*$, 1 $\Sigma^* B^*$, 1 |