Charmonium tetraquarks and pentaquarks or an additional quark?

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Most of the exotic hadrons discovered over the last 20 years fit into the quark model as normal mesons and baryons if the existence of a seventh flavor of quark is hypothesized. For the quark to reproduce the mass, spin, parity, production and decay modes of exotic hadrons, it would have to have a mass of $\sim 2.8$ GeV, a charge of $-\frac{1}{3}$, and a W-boson-mediated interaction with the right-chiral component of the charm quark. The proposed spectrum of hadrons involving this quark is presented.

The existence of a fourth down-type quark (charge of $-1/3$) with a mass of $\sim 2.8$ GeV was recently hypothesized. The theory involving the additional quark was presented in [1], where the quark’s production and decay mechanisms were described in detail, and explanations were provided for how the theory had the possibility to reproduce data that would seemingly rule out another quark with mass in that range.

This paper presents a listing of many of the expected mesons and baryons involving the hypothesized quark. Each hadron is mapped to (a) an observed exotic hadron, (b) an exotic hadron seen with $< 5\sigma$ evidence, or (c) a predicted hadron. For the above 3 cases, the “σ” column in each table is (a) $5\sigma$, (b) the σ of the evidence, or (c) blank. The hypothesized additional quark is denoted by the symbol $f$. The Name column includes the approximate mass of the hadron, and the $\Gamma$ column includes its observed or predicted width; both are in MeV.

Production and decay modes for observed hadrons are described in the references of the “Ref.” column. The Production and Decay columns predict as-yet-unobserved processes. For each observed hadron, three tests of these predictions can be performed: (i) observed production + predicted decay, (ii) predicted production + observed decay, and (iii) predicted production + predicted decay. For the unobserved hadrons, only the third of these is available for testing. The proposed $f$-quark mesons and baryons are shown in the following tables.

Proposed $\bar{d}f$ and $f d$ mesons

| QM | Name | $\Gamma$ | $\sigma$ | Ref. | Predicted Production | Predicted Decay | Predicted Decay BR |
|----|------|----------|----------|------|----------------------|----------------|-------------------|
| $1^1S_0$ | $X(3250)$ | $< 45$ | $5\sigma$ | $[2, 3]$ | $X(6600) \rightarrow X^0 X^0$ | $X^0 \rightarrow (K\bar{K})^0$ | $> 10 \times [X^0 \rightarrow \Lambda \bar{p}K^+]$ |
| $1^3S_1$ | $X(3350)$ | $70$ | $5\sigma$ | $[4, 3]$ | $B^0 \rightarrow \omega X^0$ | $X^0 \rightarrow D^{*+}\pi^-$ | $\sim 5\%[B^0 \rightarrow \omega D^{*+}\pi^-]$ |
| $1^3P_0$ | $\chi_c(3860)$ | $201$ | $5\sigma$ | $[3]$ | $\psi^+(0)(4320) \rightarrow \pi^+\pi^0 X^0$ | $\chi_c \rightarrow \pi^0 X(3250)$ | $> 30\%[Z_c^0(3900) \rightarrow \pi^0 J/\psi]$ |
| $1^3P_1$ | $\chi_{c1}(3872)$ | $12$ | $5\sigma$ | $[3]$ | $Y(7250) \rightarrow J/\psi \chi_{c0}$ | $\chi_{c1} \rightarrow \pi^0 D^0 D^* + c.c.$ | $> 5 \times [\chi_{c0} \rightarrow D\bar{D}]$ |
| $1^1P_1$ | $Z_c^+(3900)$ | $28$ | $5\sigma$ | $[3]$ | $\psi(4660) \rightarrow \pi^0 Z_c^+(3900)$ | $Z_c^0 \rightarrow \pi^0 X^0(3250)$ | $> 10 \times [Z_c^0 \rightarrow \pi^0 J/\psi]$ |
| $1^3S_0$ | $Z_{c0}(3985)$ | $8$ | $4.6\%$ | $[5]$ | $\psi(4680) \rightarrow K^0\bar{K}^0 Z_c^0(3985)$ | $Z_{c0} \rightarrow \pi^0 X^0(3250)$ | $> 5 \times [\chi_{c0} \rightarrow D\bar{D}]$ |
| $1^3P_0$ | $\chi(4014)$ | $4.2$ | $2.8\%$ | $[6]$ | $\psi(4230) \rightarrow \gamma \chi_{c2}$ | $\chi_{c2} \rightarrow \pi^0 X^0(3250)$ | $> 5 \times [\chi_{c2} \rightarrow \gamma J/\psi]$ |
| $2^1S_0$ | $X(4020)$ | $15$ | $5\sigma$ | $[3]$ | $B^0 \rightarrow \pi^+ X^0$ | $X^0 \rightarrow \pi^+\pi^0 X(3250)$ | $> 5 \times [\chi_{c0} \rightarrow \phi J/\psi]$ |
| $2^3P_0$ | $X(4100)$ | $150$ | $5\sigma$ | $[3]$ | $B^0 \rightarrow \pi^+ X^0$ | $X^0 \rightarrow D^- D_s^+$ | $\sim 1\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |
| $1^3D_2$ | $X(4160)$ | $136$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ \psi$ | $\psi \rightarrow \pi^+\pi^- X(3250)$ | $> 5 \times [\psi \rightarrow \pi^+\pi^- J/\psi]$ |
| $1^3D_3$ | $X(4230)$ | $49$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ \chi_{c1}$ | $\chi_{c1} \rightarrow \pi^+\pi^- X(3250)$ | $> 5 \times [\chi_{c1} \rightarrow \phi J/\psi]$ |
| $2^1P_1$ | $\chi_{c1}(4274)$ | $51$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ X$ | $X \rightarrow D^- D_s^+$ | $\sim 2\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |
| $2^1P_2$ | $X(4380)$ | $10$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ X$ | $X \rightarrow D^- D_s^+$ | $\sim 3\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |
| $2^3P_1$ | $Z_0^+(4430)$ | $180$ | $5\sigma$ | $[3]$ | $\psi(4660) \rightarrow \pi^0 Z_0^+(4430)$ | $Z_0^0 \rightarrow \pi^0 X^0(4230)$ | $> 10 \times [Z_0^0 \rightarrow \pi^0 \psi(2S)]$ |
| $3^3P_1$ | $Y(4500)$ | $111$ | $5\sigma$ | $[7, 8]$ | $B^+ \rightarrow \pi^0 Y$ | $Y \rightarrow D^- D_s^+$ | $\sim 3\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |
| $2^3D_1$ | $X(4660)$ | $72$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ \chi_{c1}$ | $\chi_{c1} \rightarrow \phi X^0(3250)$ | $> 5 \times [\chi_{c1} \rightarrow \phi J/\psi]$ |
| $3^3P_1$ | $\chi_{c1}(4685)$ | $126$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ \chi_{c1}$ | $\chi_{c1} \rightarrow \phi X^0(3250)$ | $> 5 \times [\chi_{c1} \rightarrow \phi J/\psi]$ |
| $3^3P_0$ | $\chi(4700)$ | $87$ | $5\sigma$ | $[3]$ | $B^+ \rightarrow \pi^+ \chi_{c0}$ | $\chi_{c0} \rightarrow D^- D_s^+$ | $\sim 2\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |
| $4^3S_1$ | $Y(4710)$ | $126$ | $5\sigma$ | $[8]$ | $B^+ \rightarrow \pi^+ Y$ | $Y \rightarrow D^- D_s^+$ | $\sim 2\%[B^+ \rightarrow \pi^+ D^- D_s^+]$ |

The above mapping of $\chi_{c0}(3860)$ assumes the hypothesis of [9] that $\chi_{c0}(3915)$ and $\chi_{c2}(3930)$ are the $2^3P_0$ and $2^3P_2$ resonances of $\bar{c}c$. Fig 2. of [10] may contain evidence of the second predicted decay of $X^0(3350)$. 

\[ (1) \]
Proposed $u\bar{f}$ and $f\bar{u}$ Mesons

| QM | Name   | $\Gamma$ | $\sigma$ | Ref. | Predicted Production | Predicted Decay | Predicted Decay BR |
|----|--------|----------|----------|------|----------------------|----------------|-------------------|
| $1^3S_0$ | $X^0(3250)$ | < 45 | 5+ | [2], [3] | $X(6600) \to X^0 X^\mp$ | $X^\pm \to (K K^{\mp})^\pm$ | $> 10 \times [X^0 \to \Lambda p K^{+} \pi^-]$ |
| $1^3S_1$ | $X^\pm(3350)$ | 70 | | | $B^- \to \omega X^-$ | $X^- \to D_s^{*0} \pi^-$ | $\sim 5\% [B^- \to \omega D^{*0} \pi^-]$ |
|  | $\chi^{\pm}_0(3860)$ | 201 | | | $\psi(4230) \to \gamma X^{\pm}_0$ | $X^{\pm} \to \pi^\mp J/\psi$ | $10^{-3} \times [X \to \text{anything}]$ |
| $1^3P_0$ | $T_{cc}^\pm(3875)$ | 0.4 | 5+ | [3] | $B^0 \to \pi^- T_{cc}$ | $T_{cc}^+ \to D^- \pi^+ \pi^0$ | $> 5 \times [X_{cc} \to D \bar{D}]$ |
| $1^3P_1$ | $Z^\pm_c(3900)$ | 28 | 5+ | [3] | $\psi(4660) \to \pi^+ Z^\pm_c$ | $Z^\pm_c \to \pi^0 \pi^\pm X^{0.0}(3350)$ | $> 10 \times [Z^\pm_c \to \pi^+ J/\psi]$ |
| $2^1S_0$ | $Z^\pm_{cs}(3985)$ | 8 | 4.6 | [5] | $\psi(4680) \to K^\mp Z^\pm_{cs}$ | $Z^\pm_{cs} \to \pi^0 \pi^\pm X^{0.0}(3350)$ | $> [Z_{cs} \to D_s \bar{D}^*]$ |
|  | $\chi^{\pm}_2(4014)$ | 4 | | | $\psi(4230) \to \gamma X^{\pm}_2$ | $\chi^{\pm}_2 \to \pi^0 \pi^\pm X^{0.0}(3250)$ | $> [X_{c2} \to \gamma J/\psi]$ |
| $2^3S_1$ | $X^\pm(4020)$ | 13 | 5+ | [3] | $B^0 \to \pi^- X^+$ | $X^\pm \to \pi^\mp \pi^- X^\pm(3350)$ | $> [X \to \pi^\mp h_{1}(1P)]$ |
| $2^3P_0$ | $X^\pm(4100)$ | 150 | 3.4 | [3] | $B^0 \to \pi^- X^+$ | $X^\pm \to \bar{D}^0 D_s^+$ | $\sim 1\% [B^0 \to \pi^- D^0 D_s^+]$ |
| $1^3D_1$ | $\psi(4230)$ | 49 | | | $B^0 \to \pi^- \psi^+$ | $\psi^+ \to (\pi \pi X(3350))^{\pm}$ | $>5 \times [\psi^0 \to \pi^+ J/\psi]$ |
| $2^3P_1$ | $\chi^{\pm}_1(4274)$ | 51 | | | $B^0 \to \pi^- \chi^{\pm}_1$ | $\chi^{\pm}_1 \to \pi^\mp \pi^- X^\pm(3350)$ | $>5 \times [X^{\pm}_1 \to \phi J/\psi]$ |
| $2^3P_2$ | $X^\pm(4380)$ | 10 | | | $B^0 \to \pi^- X^+$ | $X^\pm \to \bar{D}^0 D_s^+$ | $\sim 2\% [B^0 \to \pi^- D^0 D_s^+]$ |
| $2^1P_1$ | $Z^\pm_{c}(4430)$ | 180 | 5+ | [3] | $\psi^{\pm,0}(4660) \to \pi^0 \pi^\pm Z^\pm_c$ | $Z^\pm_c \to \pi^0 \pi^\pm X^{0.0}(4230)$ | $> 10 \times [Z^\pm_c \to \pi^\pm \psi(2S)]$ |
| $3^3S_1$ | $Y^\pm(4500)$ | 111 | | | $B^0 \to \pi^- Y^+$ | $Y^+ \to \bar{D}^0 D_s^+$ | $\sim 3\% [B^0 \to \pi^- D^0 D_s^+]$ |
| $2^3D_1$ | $\psi(4660)$ | 72 | | | $B^0 \to \pi^- \psi^+$ | $\psi^+ \to \bar{D}^0 D_s^+$ | $\sim 3\% [B^0 \to \pi^- D^0 D_s^+]$ |
| $3^3P_1$ | $\chi^{\pm}_1(4685)$ | 126 | | | $B^0 \to \pi^- \chi^{\pm}_1$ | $\chi^{\pm}_1 \to \phi X^{(3350)}$ | $>5 \times [X^{\pm}_1 \to \phi J/\psi]$ |
| $3^3P_0$ | $\chi^{\pm}_0(4700)$ | 87 | | | $B^0 \to \pi^- \chi^{\pm}_0$ | $\chi^{\pm}_0 \to \bar{D}^0 D_s^+$ | $\sim 2\% [B^0 \to \pi^- D^0 D_s^+]$ |
| $4^3S_1$ | $Y^\pm(4710)$ | 126 | | | $B^0 \to \pi^- Y^+$ | $Y^+ \to \bar{D}^0 D_s^+$ | $\sim 2\% [B^0 \to \pi^- D^0 D_s^+]$ |

Fig. 5 of [11] may contain evidence of the above predicted decays to $\bar{D}^0 D_s^+$.  

Proposed $s\bar{f}$ and $f\bar{s}$ Mesons

| QM | Name   | $\Gamma$ | $\sigma$ | Ref. | Predicted Production | Predicted Decay | Predicted Decay BR |
|----|--------|----------|----------|------|----------------------|----------------|-------------------|
| $1^1S_0$ | $X(3550)$ | 30 | | | | $X \to \Lambda^{+} \bar{p}$ | $\sim 1\% [B^- \to \pi^- \Lambda^{+} \bar{p}]$ |
| $1^3S_1$ | $R(3760)$ | 22 | 5+ | [12] | $B^- \to \pi^- X^+$ | $X \to \pi^0 J/\psi$ | $> 10\% [Z_0^0(3900) \to \pi^0 J/\psi]$ |
|  | $\psi^{\pm,0}(4230) \to \pi^0 \pi^\pm R$ | | | | $B^0 \to \omega R$ | $R \to D^{*-+} \pi^-$ | $\sim 4\% [B^0 \to \omega D^{*-+} \pi^-]$ |
| $1^3P_0$ | $X(3960)$ | 43 | 5+ | [13] | $\psi^{\pm,0}(4230) \to \pi^0 \pi^\pm R$ | $R \to \pi^0 J/\psi$ | $> 10\% [Z_0^0(3900) \to \pi^0 J/\psi]$ |
|  | $\chi^{\pm}_1(4140)$ | 19 | 5+ | [3] | | | |
| $1^3P_2$ | $\chi^{\pm}_0(4400)$ | 10 | | | | | |
| $2^3S_1$ | $X(4200)$ | 115 | 5+ | [3] | | | |
| $2^3D_1$ | $\psi(4360)$ | 128 | 5+ | [14] | | | |
| $2^3P_0$ | $X(4500)$ | 77 | | | | | |
| $3^3S_1$ | $\psi(4680)$ | 100 | | | | | |

Fig. 2. of [10] may contain evidence of the second predicted decays of $X(3550)$ and $R(3760)$. The predicted $X(4200)$ decay overlaps with the observed $\psi(4160)$ decay [15] and could provide a reason why the experimental signal is approximately double the calculated amount expected for the latter decay.

Proposed $c\bar{f}$ and $f\bar{c}$ Mesons

| QM | Name   | $\Gamma$ | $\sigma$ | Ref. | Predicted Production | Predicted Decay | Predicted Decay BR |
|----|--------|----------|----------|------|----------------------|----------------|-------------------|
| $1^1S_0$ | $X^\pm(4680)$ | < 30 | | | | | |
| $2^3S_1$ | $X^\pm(5400)$ | < 100 | | | | | |
| $2^1P_0$ | $X^\pm(5568)$ | 19 | 6.7+ | [16] | $B^+ \to \rho^0 X^+$ | $X^\pm \to \pi^\pm J/\psi$ | $> 5\% [B^+ \to \rho^0 \pi^+ J/\psi]$ |
| $p\bar{p}$ (prompt) $\to X^+$ | | | | | | | |

Fig. 2. of [10] may contain evidence of the second predicted decays of $X(3550)$ and $R(3760)$. The predicted $X(4200)$ decay overlaps with the observed $\psi(4160)$ decay [15] and could provide a reason why the experimental signal is approximately double the calculated amount expected for the latter decay.
The question mark associated with $X^{\pm}(5568)$ denotes the fact that only one collaboration has found evidence for it. Other collaborations with experiments at different CM energies or with different kinematics did not find evidence for this resonance. Due to the predicted prompt production and strong decay of $X^{\pm}(5568)$, certain experiments may not have had the optimal geometry to reproduce the results of [16].

Proposed $f \bar{f}$ Mesons

| QM | Name   | $\Gamma$ | $\sigma$ | Ref. | Predicted Production            | Predicted Decay                             | Predicted Decay BR                        |
|----|--------|----------|----------|------|----------------------------------|--------------------------------------------|-------------------------------------------|
| 1$^3S_0$ | X(6500) | 5+       | 440      | [17], [18] | $p\bar{p}$ (prompt) $\rightarrow X$ | $X \rightarrow J/\psi J/\psi$ | $\sim 4\%[pp \rightarrow J/\psi J/\psi]$ |
| 1$^3S_1$ | X(6600) | 5+       | 440      | [17], [18] | $e^+e^- \rightarrow X$ | $X \rightarrow X^{\pm,0}(3250), X^{\mp,0}(3250)$ | $> 50\%[X \rightarrow$ anything] |
| 1$^3P_0$ | X(6900) | 5+       | 191      | [17], [19] | $Y(7250) \rightarrow \gamma X$ | $X \rightarrow X^{\pm,0}(3250), X^{\mp,0}(3250)$ | $> 20\%[X \rightarrow$ anything] |
| 2$^1S_0$ | X(7200) | 4.1      | 97       | [17]   | $e^+e^- \rightarrow Y$ | $Y \rightarrow X^{\pm,0}(3250), X^{\mp,0}(3250)$ | $> 10\%[X \rightarrow$ anything] |
| 2$^1S_1$ | Y(7250) | 3.5      | 3.5      | [20]   | $e^+e^- \rightarrow Y$ | $Y \rightarrow X^{\pm,0}(3250), X^{\mp,0}(3250)$ | $> 10\%[Y \rightarrow$ anything] |
| 2$^3P_1$ | X(7500) |          |          |        | $\sim 3\%[p\bar{p} \rightarrow \psi(2S)\psi]$ |                            |                                            |
| 3$^3S_1$ | Y(7700) |          |          |        | $> 5\%[Y \rightarrow$ anything] |                            |                                            |

The $\psi(2S)J/\psi$ data of [18] may contain evidence of the $X(7500)$.

Proposed $b\bar{f}$ and $f\bar{b}$ Mesons

| QM | Name   | $\Gamma$ | $\sigma$ | Ref. | Predicted Production            | Predicted Decay                             | Predicted Decay BR                        |
|----|--------|----------|----------|------|----------------------------------|--------------------------------------------|-------------------------------------------|
| 1$^3P_1$ | X(8322) |          |          | < 80 | [21], [22] | $Y(9480) \rightarrow \gamma X$ | $X \rightarrow J/\psi J/\psi$ | $1\%[p\bar{p} \rightarrow J/\psi J/\psi]$ |
| 2$^1D_1$ | Y(8900) | ~ 80     |          |      | $e^+e^- \rightarrow Y$ | $Y \rightarrow B^+ X^\pm(3250)$ | $> 5\%[e^+e^- \rightarrow B^+ X^\pm(3250)]$ |
| 5$^3S_1$ | Y(9480) |          | < 20     |      | $e^+e^- \rightarrow Y$ |                             |                                            |

The question mark is due to the fact that the resonance was only seen at one run at one experiment and not at others. It could nonetheless have been an actual observation if a resonance 16-26 MeV heavier than the $Y(1S)$ is produced in $e^+e^- \rightarrow \gamma X$ collisions [22]. The $Y(9480)$ listed above is proposed to be that resonance. Evidence of the predicted decay of $X(8322)$ may be contained in Fig. 1 of [18], Fig. 1 of [17] and Fig. 4b of [19].

Proposed isospin 1 $fuu$ baryons in relation to their $suu$ counterparts

| $suu$ Name | $J^P$ | $fuu$ Name  | $\Gamma$ | $\sigma$ | Ref. | Predicted Production            | Predicted Decay                             | Predicted Decay BR                        |
|------------|------|-------------|----------|----------|------|----------------------------------|--------------------------------------------|-------------------------------------------|
| $\Sigma$   | $\frac{1}{2}^+$ | $P_c^+(3870)$ | < 5    |          | [3] | $B^0 \rightarrow P_c^+ \bar{p}$ | $P_c^+ \rightarrow D^+ \pi^- p$ | $> 5\%[B_s^0 \rightarrow \bar{p} D^+ \pi^- p]$ |
| $\Sigma(1383)$ | $\frac{3}{2}^+$ | $P_c^+(4065)$ | < 5    |          | [3] | $\Lambda_c^0 \rightarrow P_c^+ K^-$ | $P_c^+ \rightarrow D^0 \pi^- \pi^-$ | $> 5\%[\Lambda_c^0 \rightarrow K^- D^0 \pi^+ \pi^-]$ |
| $\Sigma(1580)$ | $\frac{1}{2}^-$ | $P_c^+(4260)$ | 5      |          | [21] | $B^- \rightarrow P_c^+ \bar{p}$ | $P_{c0}^- \rightarrow J/\psi \Lambda$ | $\sim 2\%[B^- \rightarrow J/\psi \Lambda \bar{p}]$ |
| $\Sigma(1620)$ | $\frac{3}{2}^-$ | $P_c^+(4312)$ | 10     | 5+       | [3] | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |
| $\Sigma(1660)$ | $\frac{1}{2}^+$ | $P_c^+(4380)$ | 200    | 5+       | [3] | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |
| $\Sigma(1670)$ | $\frac{3}{2}^+$ | $P_c^+(4337)$ | 29     | 5+       | [22] | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |
| $\Sigma(1750)$ | $\frac{1}{2}^+$ | $P_c^+(4440)$ | 21     | 5+       | [3] | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |
| $\Sigma(1775)$ | $\frac{3}{2}^+$ | $P_c^+(4457)$ | 6      | 5+       | [3] | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |
| $\Sigma(1780)$ | $\frac{1}{2}^+$ | $P_c^+(4457)$ |          |          |      | $P_{c0}^+ \rightarrow D^{*+} P_{c0}^+$ | $P_{c+}^+ \rightarrow D^{*0} \pi^-$ | $> 10\%[P_{c+}^+ \rightarrow J/\psi \Lambda]$ |

For the above table, it is assumed that the $P_c^+(4457)$ is a very close double peak analog of the $\Sigma(1775)$ and $\Sigma(1780)$. It appears that the data could support splitting $P_c^+(4457)$ into two resonances. It is also assumed that $P_{c0}^0(4459)$ from [24] is the $fud$ isospin partner of the $P_c^+(4457)$ resonance(s). $P_{c0}^0(4260)$ is similarly a neutral $I = 1$ baryon.
Proposed isospin 0 \( fuu \) baryons in relation to their \( sud \) counterparts

| \( suu \) Name | \( f^0 \) | \( f^0 \) Name | \( \Gamma \) | \( \sigma \) | Ref. | Predicted Production | Predicted Decay | Predicted Decay BR |
|----------------|---------|----------------|------|-----|------|--------------------|----------------|-------------------|
| \( \Lambda \)   | \( \frac{1}{2}^+ \) | \( \Lambda_f(3795) \) | < 5 | 5+  | [25] | \( B^- \to \Lambda_f \bar{p} \) | \( \Lambda_f \to D^0 \pi^- p \) | \( > 5\% \) |
| \( \Lambda(1405) \) | \( \frac{1}{2}^+ \) | \( \Lambda_f(4085) \) | < 5 | 5+  |  | \( B^- \to \Lambda_f \bar{p} \) | \( \Lambda_f \to D^0 \pi^- p \) | \( > 5\% \) |
| \( \Lambda(1520) \) | \( \frac{1}{2}^+ \) | \( \Lambda_f(4200) \) | < 5 | 5+  |  | \( B^- \to \Lambda_f \bar{p} \) | \( \Lambda_f \to D^0 \pi^- p \) | \( > 5\% \) |
| \( \Lambda(1600) \) | \( \frac{1}{2}^+ \) | \( \Lambda_f(4280) \) | < 10 |  |  | \( B^- \to \Lambda_f \bar{p} \) | \( \Lambda_f \to J/\psi \Lambda \) | \( \sim 2\% \) |
| \( \Lambda(1670) \) | \( \frac{1}{2}^+ \) | \( P^0_{\psi}(4338) \) | 7    | 5+  | [25] |  | \( \Lambda_f \to \eta \Lambda \) | \( \sim 1\% \) |

Fig. 3 of [25] may contain evidence of the predicted decays of \( D^0_{c}(4260) \) and \( \Lambda_f(4280) \).

An advantage to the model generating the predictions of this paper is that it classifies almost all of the previously discovered charmonium tetraquarks and pentaquarks within a single framework. But the model has significant differences from the Standard Model, so it can only be accepted after surviving very thorough testing. An advantage of the predicted production and decay processes in this paper is that most of them can be tested using data already collected in previous or ongoing experiments. It would be interesting to see if such tests would support or contradict the hypothesis of an additional quark.

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