$h_c(1P)$

$$j^G(j^{PC}) = 0^- (1^-)$$

Quantum numbers are quark model prediction, $C = -$ established by $\eta_c \gamma$ decay.

### $h_c(1P)$ Mass

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3525.38 \pm 0.11 OUR AVERAGE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3525.31 \pm 0.11 \pm 0.14</td>
<td>832</td>
<td>ABLIKIM 12n BES3</td>
<td></td>
<td>$\psi(2S) \rightarrow \pi^0 \gamma$ hadrons</td>
</tr>
<tr>
<td>3525.40 \pm 0.13 \pm 0.18</td>
<td>3679</td>
<td>ABLIKIM 10B BES3</td>
<td></td>
<td>$\psi(2S) \rightarrow \pi^0 \eta_c$</td>
</tr>
<tr>
<td>3525.20 \pm 0.18 \pm 0.12</td>
<td>1282</td>
<td>2 DOBBS 08A CLEO</td>
<td></td>
<td>$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$</td>
</tr>
<tr>
<td>3525.8 \pm 0.2 \pm 0.2</td>
<td>13</td>
<td>ANDREOTTI 05B E835</td>
<td></td>
<td>$\pi p \rightarrow \eta_c \gamma$</td>
</tr>
</tbody>
</table>

- **1** With floating width.
- **2** Combination of exclusive and inclusive analyses for the reaction $\psi(2S) \rightarrow \pi^0 h_c \rightarrow \pi^0 \eta_c \gamma$. This result is the average of DOBBS 08A and ROSNER 05.
- **3** Superseded by DOBBS 08A.
- **4** Mass central value and systematic error recalculated by us according to Eq. (16) in ARMSTRONG 93B, using the value for the $\psi(2S)$ mass from AULCHENKO 03.

### $h_c(1P)$ Width

<table>
<thead>
<tr>
<th>VALUE (MeV)</th>
<th>CL%</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>0.70 \pm 0.28 \pm 0.22</strong></td>
<td>832</td>
<td>ABLIKIM 12n BES3</td>
<td></td>
<td>$\psi(2S) \rightarrow \pi^0 \gamma$ hadrons</td>
<td></td>
</tr>
</tbody>
</table>

- **1** With floating mass.
- **2** The central value is $\Gamma = 0.73 \pm 0.45 \pm 0.28$ MeV.

### $h_c(1P)$ Decay Modes

<table>
<thead>
<tr>
<th>Mode</th>
<th>Fraction ($\Gamma_j/\Gamma$)</th>
<th>Confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Gamma_1$</td>
<td>$J/\psi(1S) \pi^0$</td>
<td>not seen</td>
</tr>
<tr>
<td>$\Gamma_2$</td>
<td>$J/\psi(1S) \pi \pi$</td>
<td>not seen</td>
</tr>
<tr>
<td>$\Gamma_3$</td>
<td>$J/\psi(1S) \pi^+ \pi^-$</td>
<td>$&lt; 2.3 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

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\[ \Gamma_4 \quad \rho \bar{\rho} \quad < 1.5 \times 10^{-4} \quad 90\% \]
\[ \Gamma_5 \quad \pi^+ \pi^- \pi^0 \quad < 2.2 \times 10^{-3} \]
\[ \Gamma_6 \quad 2\pi^+ 2\pi^- \pi^0 \quad (2.2 \pm 0.8) \% \]
\[ \Gamma_7 \quad 3\pi^+ 3\pi^- \pi^0 \quad < 2.9 \% \]

Radiative decays

\[ \Gamma_8 \quad \gamma \eta \quad (4.7 \pm 2.1) \times 10^{-4} \]
\[ \Gamma_9 \quad \gamma \eta' (958) \quad (1.5 \pm 0.4) \times 10^{-3} \]
\[ \Gamma_{10} \quad \gamma \eta_c (1S) \quad (51 \pm 6) \% \]

---

**h_c(1P) PARTIAL WIDTHS**

\[ \Gamma_c(1P) \frac{\Gamma(i)\Gamma(\bar{p}p)/\Gamma(\text{total})}{\Gamma(\gamma \eta_c (1S)) \times \Gamma(\rho \bar{\rho})/\Gamma(\text{total})} \]

<table>
<thead>
<tr>
<th>(\Gamma(\gamma \eta_c (1S)) \times \Gamma(\rho \bar{\rho})/\Gamma(\text{total}))</th>
<th>(\Gamma_4/\Gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALUE (eV)</td>
<td>EVTS</td>
</tr>
<tr>
<td>dot</td>
<td>dot</td>
</tr>
<tr>
<td>dot</td>
<td>dot</td>
</tr>
</tbody>
</table>

1 Assuming \(\Gamma = 1\) MeV.

---

**h_c(1P) BRANCHING RATIOS**

\[ \frac{\Gamma(J/\psi (1S) \pi \pi)}{\Gamma(J/\psi (1S) \pi^0)} \quad \frac{\Gamma_2}{\Gamma_1} \]

\[ \frac{\Gamma(J/\psi (1S) \pi^+ \pi^-)}{\Gamma(\text{total})} \quad \frac{\Gamma_3}{\Gamma} \]

\[ \Gamma(J/\psi (1S) \pi^+ \pi^-) \]

\[ \text{VALUE (units of } 10^{-3}) \]

1 ABLIKIM 18M reports \([\Gamma(h_c(1P) \rightarrow J/\psi (1S) \pi^+ \pi^-)/\Gamma(\text{total})\] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] < 2.0 \times 10^{-6} \) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4} \).

\[ \frac{\Gamma(\pi^+ \pi^- \pi^0)}{\Gamma(\text{total})} \quad \frac{\Gamma_5}{\Gamma} \]

\[ \text{VALUE (units of } 10^{-3}) \]

1 ADAMS 09 reports \([\Gamma(h_c(1P) \rightarrow \pi^+ \pi^- \pi^0)/\Gamma(\text{total})\] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] < 0.19 \times 10^{-5} \) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4} \).

\[ \frac{\Gamma(2\pi^+ 2\pi^-)}{\Gamma(\text{total})} \quad \frac{\Gamma_6}{\Gamma} \]

\[ \text{VALUE (units of } 10^{-2}) \]

1 ADAMS 09 reports \([\Gamma(h_c(1P) \rightarrow 2\pi^+ 2\pi^- \pi^0)/\Gamma(\text{total})\] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (1.88 \pm 0.48 \pm 0.47) \times 10^{-5} \) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 \pm 1.3) \times 10^{-4} \). Our first error is their experiment’s error and our second error is the systematic error from using our best value.
\[ \Gamma(3\pi^+3\pi^-\pi^0)/\Gamma_{\text{total}} \]

\[ \Gamma_7/\Gamma \]

<table>
<thead>
<tr>
<th>VALUE (units 10^{-2})</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;2.9</td>
<td>1</td>
<td>ADAMS 09 CLEO</td>
<td>( \psi(2S) \rightarrow \pi^0\gamma\eta_c )</td>
</tr>
</tbody>
</table>

1 ADAMS 09 reports \([\Gamma(h_c(1P) \rightarrow 3\pi^+3\pi^-\pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] < 2.5 \times 10^{-5}\) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4}\).

---

**RADIATIVE DECAYS**

\[ \Gamma(\gamma\eta)/\Gamma_{\text{total}} \]

\[ \Gamma_8/\Gamma \]

<table>
<thead>
<tr>
<th>VALUE (units 10^{-4})</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.7±1.5±1.4</td>
<td>18</td>
<td>ABLIKIM 16i BES3</td>
<td>( \psi(2S) \rightarrow \pi^0\gamma\eta )</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Gamma(\gamma\eta(958))/\Gamma_{\text{total}} \]

\[ \Gamma_9/\Gamma \]

<table>
<thead>
<tr>
<th>VALUE (units 10^{-3})</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.52±0.27±0.29</td>
<td>44</td>
<td>ABLIKIM 16i BES3</td>
<td>( \psi(2S) \rightarrow \pi^0\gamma\eta(958) )</td>
<td></td>
</tr>
</tbody>
</table>

\[ \Gamma(\gamma\eta_c(1S))/\Gamma_{\text{total}} \]

\[ \Gamma_{10}/\Gamma \]

<table>
<thead>
<tr>
<th>VALUE (units 10^{-2})</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>51 ± 6</td>
<td>OUR AVERAGE</td>
<td>3679</td>
<td>ABLIKIM 10B BES3</td>
<td>( \psi(2S) \rightarrow \pi^0\gamma\eta_c )</td>
</tr>
<tr>
<td>48 ± 6 ± 7</td>
<td>3679</td>
<td>ABLIKIM 10B BES3</td>
<td>( \psi(2S) \rightarrow \pi^0\eta_c \gamma )</td>
<td></td>
</tr>
</tbody>
</table>

1 Average of DOBBS 08A and ROSNER 05. DOBBS 08A reports \([\Gamma(h_c(1P) \rightarrow \gamma\eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.16 ± 0.30 ± 0.37) \times 10^{-4}\) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 ± 1.3) \times 10^{-4}\). Our first error is their experiment’s error and our second error is the systematic error from using our best value.

2 DOBBS 08A reports \([\Gamma(h_c(1P) \rightarrow \gamma\eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.19 ± 0.32 ± 0.45) \times 10^{-4}\) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 ± 1.3) \times 10^{-4}\). Our first error is their experiment’s error and our second error is the systematic error from using our best value.

3 ROSNER 05 reports \([\Gamma(h_c(1P) \rightarrow \gamma\eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.0 ± 0.8 ± 0.7) \times 10^{-4}\) which we divide by our best value \(B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 ± 1.3) \times 10^{-4}\). Our first error is their experiment’s error and our second error is the systematic error from using our best value.

---

**CROSS-PARTICLE BRANCHING RATIOS**

\[ \Gamma(h_c(1P) \rightarrow p\bar{p})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \pi^0 h_c(1P))/\Gamma_{\text{total}} \]

\[ \Gamma_4/\Gamma \times \Gamma_{15}^{\psi(2S)}/\Gamma_{\psi(2S)} \]

<table>
<thead>
<tr>
<th>VALUE (&lt;1.3 \times 10^{-7})</th>
<th>CL%</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.3 \times 10^{-7}</td>
<td>90</td>
<td>ABLIKIM 13v BES3</td>
<td>( \psi(2S) \rightarrow \gamma p\bar{p} )</td>
<td></td>
</tr>
</tbody>
</table>

Citation: M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018) and 2019 update

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\[
\frac{\Gamma(h_c(1P) \to \gamma \eta_c(1S))}{\Gamma_{\text{total}}} \times \frac{\Gamma(\psi(2S) \to \pi^0 h_c(1P))}{\Gamma_{\text{total}}} = \frac{\Gamma_{10}}{\Gamma} \times \frac{\Gamma_{\psi(2S)}}{\Gamma_{\psi(2S)}}
\]

<table>
<thead>
<tr>
<th>VALUE (units 10^{-4})</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECN</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.58 ± 0.40 ± 0.50</td>
<td>3679</td>
<td>ABLIKIM 10B</td>
<td>BES3</td>
<td>ψ(2S) → π^0 γ X</td>
</tr>
<tr>
<td>4.16 ± 0.30 ± 0.37</td>
<td>1430</td>
<td>DOBBS 08A</td>
<td>CLEO</td>
<td>ψ(2S) → π^0 γ η_c</td>
</tr>
</tbody>
</table>

1 Not independent of other branching fractions in ABLIKIM 10B.
2 Not independent of other branching fractions in DOBBS 08A.

\[h_c(1P)\] REFERENCES

| ABLIKIM 18M | PR D97 052008 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM 16I | PRL 116 251802 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM 13V | PR D88 112001 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM 12N | PR D86 092009 | M. Ablikim et al. | (BES III Collab.) |
| ABLIKIM 10B | PRL 104 132002 | M. Ablikim et al. | (BES III Collab.) |
| ADAMS 09   | PR D80 051106 | G.S. Adams et al. | (CLEO Collab.) |
| DOBBS 08A  | PRL 101 182003 | S. Dobbs et al.   | (CLEO Collab.) |
| ANDREOTTI 05B | PR D72 032001 | M. Andreotti et al. | (FNAL E835 Collab.) |
| ROSNER 05  | PRL 95 102003 | J.L. Rosner et al. | (CLEO Collab.) |
| AULCHENKO 03 | PL B573 63 | V.M. Aulchenko et al. | (KEDR Collab.) |
| ANTONIAZZI 94 | PR D50 4258 | L. Antoniazzi et al. | (E705 Collab.) |
| ARMSTRONG 93B | PR D47 772 | T.A. Armstrong et al. | (FNAL E760 Collab.) |
| ARMSTRONG 92D | PRL 69 2337 | T.A. Armstrong et al. | (FNAL, FERR, GENO+) |
| BAGLIN 86   | PL B171 135 | C. Baglin et al.   | (LAPP, CERN, TORI, STRB+) |