

**$h_c(1P)$** 

$$I^G(J^{PC}) = ??(1^{+-})$$

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

 **$h_c(1P)$  MASS**

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>3525.38 ± 0.11 OUR AVERAGE</b>				
3525.31 ± 0.11 ± 0.14	832	<sup>1</sup> ABLIKIM	12N BES3	$\psi(2S) \rightarrow \pi^0 \gamma$ hadrons
3525.40 ± 0.13 ± 0.18	3679	ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$
3525.20 ± 0.18 ± 0.12	1282	<sup>2</sup> DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$
3525.8 ± 0.2 ± 0.2	13	ANDREOTTI	05B E835	$\bar{p} p \rightarrow \eta_c \gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3525.6 ± 0.5	92 <sup>+23</sup> <sub>-22</sub>	ADAMS	09 CLEO	$\psi(2S) \rightarrow 2(\pi^+ \pi^- \pi^0)$
3524.4 ± 0.6 ± 0.4	168 ± 40	<sup>3</sup> ROSNER	05 CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$
3527 ± 8	42	ANTONIAZZI	94 E705	300 $\pi^\pm, p\text{Li} \rightarrow J/\psi \pi^0 X$
3526.28 ± 0.18 ± 0.19	59	<sup>4</sup> ARMSTRONG	92D E760	$\bar{p} p \rightarrow J/\psi \pi^0$
3525.4 ± 0.8 ± 0.4	5	BAGLIN	86 SPEC	$\bar{p} p \rightarrow J/\psi X$

<sup>1</sup> With floating width.<sup>2</sup> 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.<sup>3</sup> Superseded by DOBBS 08A.<sup>4</sup> 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**

VALUE (MeV)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
<b>0.70 ± 0.28 ± 0.22</b>					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 1.44	90	3679	<sup>2</sup> ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$
< 1		13	ANDREOTTI	05B E835	$\bar{p} p \rightarrow \eta_c \gamma$
< 1.1	90	59	ARMSTRONG	92D E760	$\bar{p} p \rightarrow J/\psi \pi^0$

<sup>1</sup> With floating mass.<sup>2</sup> The central value is  $\Gamma = 0.73 \pm 0.45 \pm 0.28$  MeV. **$h_c(1P)$  DECAY MODES**

Mode	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level
$\Gamma_1$ $J/\psi(1S) \pi^0$		
$\Gamma_2$ $J/\psi(1S) \pi \pi$	not seen	
$\Gamma_3$ $p\bar{p}$	< 1.5	$\times 10^{-4}$ 90%
$\Gamma_4$ $\pi^+ \pi^- \pi^0$	< 2.2	$\times 10^{-3}$
$\Gamma_5$ $2\pi^+ 2\pi^- \pi^0$	(2.2 <sup>+0.8</sup> <sub>-0.7</sub> ) %	
$\Gamma_6$ $3\pi^+ 3\pi^- \pi^0$	< 2.9	%

**Radiative decays**

$\Gamma_7$	$\gamma\eta$	$(4.7 \pm 2.1) \times 10^{-4}$
$\Gamma_8$	$\gamma\eta'(958)$	$(1.5 \pm 0.4) \times 10^{-3}$
$\Gamma_9$	$\gamma\eta_c(1S)$	$(51 \pm 6) \%$

 **$h_c(1P)$  PARTIAL WIDTHS** **$h_c(1P) \Gamma(i)\Gamma(\bar{p}p)/\Gamma(\text{total})$** 

**$\Gamma(\gamma\eta_c(1S)) \times \Gamma(\bar{p}p)/\Gamma_{\text{total}}$**   **$\Gamma_9\Gamma_3/\Gamma$**

VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$12.0 \pm 4.5$	13	<sup>1</sup> ANDREOTTI 05B	E835	$\bar{p}p \rightarrow \eta_c\gamma$
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<sup>1</sup> Assuming  $\Gamma = 1$  MeV.

 **$h_c(1P)$  BRANCHING RATIOS**

**$\Gamma(J/\psi(1S)\pi\pi)/\Gamma(J/\psi(1S)\pi^0)$**   **$\Gamma_2/\Gamma_1$**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
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<b><math>&lt;0.18</math></b>	90	ARMSTRONG 92D	E760	$\bar{p}p \rightarrow J/\psi\pi^0$
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**$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$**   **$\Gamma_4/\Gamma$**

VALUE (units $10^{-3}$ )	DOCUMENT ID	TECN	COMMENT
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<b><math>&lt;2.2</math></b>	<sup>1</sup> ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0\gamma\eta_c$
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<sup>1</sup> 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  $B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4}$ .

**$\Gamma(2\pi^+2\pi^-\pi^0)/\Gamma_{\text{total}}$**   **$\Gamma_5/\Gamma$**

VALUE (units $10^{-2}$ )	EVTS	DOCUMENT ID	TECN	COMMENT
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<b><math>2.2^{+0.8}_{-0.6} \pm 0.3</math></b>	92	<sup>1</sup> ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0\gamma\eta_c$
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<sup>1</sup> ADAMS 09 reports  $[\Gamma(h_c(1P) \rightarrow 2\pi^+2\pi^-\pi^0)/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))]$   
 $(1.88^{+0.48+0.47}_{-0.45-0.30}) \times 10^{-5}$  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.

**$\Gamma(3\pi^+3\pi^-\pi^0)/\Gamma_{\text{total}}$**   **$\Gamma_6/\Gamma$**

VALUE (units $10^{-2}$ )	DOCUMENT ID	TECN	COMMENT
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<b><math>&lt;2.9</math></b>	<sup>1</sup> ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0\gamma\eta_c$
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<sup>1</sup> 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**

**$\Gamma(\gamma\eta)/\Gamma_{\text{total}}$**   **$\Gamma_7/\Gamma$**

VALUE (units $10^{-4}$ )	EVTS	DOCUMENT ID	TECN	COMMENT
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<b><math>4.7 \pm 1.5 \pm 1.4</math></b>	18	ABLIKIM 16i	BES3	$\psi(2S) \rightarrow \pi^0\gamma\eta$
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$\Gamma(\gamma\eta'(958))/\Gamma_{\text{total}}$					$\Gamma_8/\Gamma$
VALUE (units $10^{-3}$ )	EVTS	DOCUMENT ID	TECN	COMMENT	
<b><math>1.52 \pm 0.27 \pm 0.29</math></b>	44	ABLIKIM 16i	BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta'(958)$	

$\Gamma(\gamma\eta_c(1S))/\Gamma_{\text{total}}$					$\Gamma_9/\Gamma$
VALUE (units $10^{-2}$ )	EVTS	DOCUMENT ID	TECN	COMMENT	
<b><math>51 \pm 6</math> OUR AVERAGE</b>					
$54.3 \pm 6.7 \pm 5.2$	3679	ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$	
$48 \pm 6 \pm 7$		<sup>1</sup> DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$	
$48 \pm 6 \pm 7$	1282	<sup>2</sup> DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$	
$46 \pm 12 \pm 7$	168	<sup>3</sup> ROSNER	05 CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$	

• • • We do not use the following data for averages, fits, limits, etc. • • •

<sup>1</sup> Average of DOBBS 08A and ROSNER 05. DOBBS 08A reports  $[\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.16 \pm 0.30 \pm 0.37) \times 10^{-4}$  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.

<sup>2</sup> DOBBS 08A reports  $[\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.19 \pm 0.32 \pm 0.45) \times 10^{-4}$  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.

<sup>3</sup> ROSNER 05 reports  $[\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S))/\Gamma_{\text{total}}] \times [B(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.0 \pm 0.8 \pm 0.7) \times 10^{-4}$  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.

### ————— CROSS-PARTICLE BRANCHING RATIOS —————

$\Gamma(h_c(1P) \rightarrow p\bar{p})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \pi^0 h_c(1P))/\Gamma_{\text{total}}$					$\Gamma_3/\Gamma \times \Gamma_{15}^{\psi(2S)}/\Gamma\psi(2S)$
VALUE	CL%	DOCUMENT ID	TECN	COMMENT	
<b><math>&lt;1.3 \times 10^{-7}</math></b>	90	ABLIKIM 13V	BES3	$\psi(2S) \rightarrow \gamma p\bar{p}$	

$\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S))/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \pi^0 h_c(1P))/\Gamma_{\text{total}}$					$\Gamma_9/\Gamma \times \Gamma_{15}^{\psi(2S)}/\Gamma\psi(2S)$
VALUE (units $10^{-4}$ )	EVTS	DOCUMENT ID	TECN	COMMENT	
<b><math>4.3 \pm 0.4</math> OUR AVERAGE</b>					
$4.58 \pm 0.40 \pm 0.50$	3679	<sup>1</sup> ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma X$	
$4.16 \pm 0.30 \pm 0.37$	1430	<sup>2</sup> DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$	

<sup>1</sup> Not independent of other branching fractions in ABLIKIM 10B.

<sup>2</sup> Not independent of other branching fractions in DOBBS 08A.

## $h_c(1P)$ REFERENCES

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

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