

$h_c(1P)$

$$I^G(J^{PC}) = 0^-(1^{+-})$$

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

 $h_c(1P)$ MASS

<u>VALUE (MeV)</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
3525.38 ± 0.11 OUR AVERAGE				
3525.31 ± 0.11 ± 0.14	832	¹ 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	² 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 ⁺²³ ₋₂₂	ADAMS	09 CLEO	$\psi(2S) \rightarrow 2(\pi^+ \pi^- \pi^0)$
3524.4 ± 0.6 ± 0.4	168 ± 40	³ 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	⁴ ARMSTRONG	92D E760	$\bar{p} p \rightarrow J/\psi \pi^0$
3525.4 ± 0.8 ± 0.4	5	BAGLIN	86 SPEC	$\bar{p} p \rightarrow J/\psi X$

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 This result is the average of DOBBS 08A and ROSNER 05.³ Superseded by DOBBS 08A.⁴ Mass central value and systematic error recalculated by us according to Eq.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**

<u>VALUE (MeV)</u>	<u>CL%</u>	<u>EVTS</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0.70 ± 0.28 ± 0.22					
< 1.44	90	3679	¹ ABLIKIM	12N BES3	$\psi(2S) \rightarrow \pi^0 \gamma$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 1		13	ANDREOTTI	05B E835	$\bar{p} p \rightarrow \eta_c \gamma$
< 1.1	90	59	ARMSTRONG	92D E760	$\bar{p} p \rightarrow J/\psi \pi^0$

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

Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1 $J/\psi(1S) \pi^0$		
Γ_2 $J/\psi(1S) \pi \pi$	not seen	
Γ_3 $J/\psi(1S) \pi^+ \pi^-$	< 2.3 × 10 ⁻³	90%

Γ_4	$p\bar{p}$	< 1.5	$\times 10^{-4}$	90%
Γ_5	$\pi^+\pi^-\pi^0$	< 2.2	$\times 10^{-3}$	
Γ_6	$2\pi^+2\pi^-\pi^0$	$(2.2^{+0.8}_{-0.7})\%$		
Γ_7	$3\pi^+3\pi^-\pi^0$	< 2.9	%	

Radiative decays

Γ_8	$\gamma\eta$	$(4.7\pm 2.1)\times 10^{-4}$
Γ_9	$\gamma\eta'(958)$	$(1.5\pm 0.4)\times 10^{-3}$
Γ_{10}	$\gamma\eta_c(1S)$	$(51 \pm 6)\%$

$h_c(1P)$ PARTIAL WIDTHS

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

$\Gamma(\gamma\eta_c(1S)) \times \Gamma(p\bar{p})/\Gamma_{\text{total}}$ $\Gamma_{10}\Gamma_4/\Gamma$

VALUE (eV)	EVTS	DOCUMENT ID	TECN	COMMENT
12.0 ± 4.5	13	¹ ANDREOTTI 05B	E835	$\bar{p}p \rightarrow \eta_c\gamma$

¹ Assuming $\Gamma = 1$ MeV.

$h_c(1P)$ BRANCHING RATIOS

$\Gamma(J/\psi(1S)\pi\pi)/\Gamma(J/\psi(1S)\pi^0)$ Γ_2/Γ_1

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<0.18	90	ARMSTRONG 92D	E760	$\bar{p}p \rightarrow J/\psi\pi^0$

$\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<2.3 $\times 10^{-3}$	90	¹ ABLIKIM 18M	BES3	$\psi(2S) \rightarrow \pi^0\pi^+\pi^- J/\psi$

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 $B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4}$.

$\Gamma(\pi^+\pi^-\pi^0)/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT
<2.2	¹ ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0\gamma\eta_c$

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 $B(\psi(2S) \rightarrow \pi^0 h_c(1P)) = 8.6 \times 10^{-4}$.

$\Gamma(2\pi^+2\pi^-\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
$2.2^{+0.8}_{-0.6} \pm 0.3$	92	¹ ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0\gamma\eta_c$

¹ ADAMS 09 reports $[\Gamma(h_c(1P) \rightarrow 2\pi^+ 2\pi^- \pi^0)/\Gamma_{\text{total}}] \times [\text{B}(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (1.88_{-0.45}^{+0.48+0.47}) \times 10^{-5}$ which we divide by our best value $\text{B}(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 \pm 1.3) \times 10^{-4}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+ 3\pi^- \pi^0)/\Gamma_{\text{total}}$ Γ_7/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
<2.9	¹ ADAMS 09	CLEO	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$

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

———— RADIATIVE DECAYS ————

$\Gamma(\gamma\eta)/\Gamma_{\text{total}}$ Γ_8/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
$4.7 \pm 1.5 \pm 1.4$	18	ABLIKIM 16i	BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta$

$\Gamma(\gamma\eta'(958))/\Gamma_{\text{total}}$ Γ_9/Γ

VALUE (units 10^{-3})	EVTS	DOCUMENT ID	TECN	COMMENT
$1.52 \pm 0.27 \pm 0.29$	44	ABLIKIM 16i	BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta'(958)$

$\Gamma(\gamma\eta_c(1S))/\Gamma_{\text{total}}$ Γ_{10}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
51 ± 6 OUR AVERAGE				
$54.3 \pm 6.7 \pm 5.2$	3679	ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$
$48 \pm 6 \pm 7$		¹ DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$48 \pm 6 \pm 7$	1282	² DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$
$46 \pm 12 \pm 7$	168	³ ROSNER	05 CLEO	$\psi(2S) \rightarrow \pi^0 \eta_c \gamma$

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

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

³ ROSNER 05 reports $[\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S))/\Gamma_{\text{total}}] \times [\text{B}(\psi(2S) \rightarrow \pi^0 h_c(1P))] = (4.0 \pm 0.8 \pm 0.7) \times 10^{-4}$ which we divide by our best value $\text{B}(\psi(2S) \rightarrow \pi^0 h_c(1P)) = (8.6 \pm 1.3) \times 10^{-4}$. 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 ————

$\Gamma(h_c(1P) \rightarrow p\bar{p})/\Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \pi^0 h_c(1P))/\Gamma_{\text{total}}$ $\Gamma_4/\Gamma \times \Gamma_{15}^{\psi(2S)}/\Gamma_{\psi(2S)}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$<1.3 \times 10^{-7}$	90	ABLIKIM 13V	BES3	$\psi(2S) \rightarrow \gamma p\bar{p}$

$$\Gamma(h_c(1P) \rightarrow \gamma \eta_c(1S)) / \Gamma_{\text{total}} \times \Gamma(\psi(2S) \rightarrow \pi^0 h_c(1P)) / \Gamma_{\text{total}} \times \Gamma_{10} / \Gamma \times \Gamma_{15}^{\psi(2S)} / \Gamma_{\psi(2S)}$$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
4.3 ± 0.4 OUR AVERAGE				
4.58 ± 0.40 ± 0.50	3679	¹ ABLIKIM	10B BES3	$\psi(2S) \rightarrow \pi^0 \gamma X$
4.16 ± 0.30 ± 0.37	1430	² DOBBS	08A CLEO	$\psi(2S) \rightarrow \pi^0 \gamma \eta_c$

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 <i>et al.</i>	(BES III Collab.)
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+)