$\chi_{c1}(1P)$

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

See the Review on "$\psi(2S)$ and χ_c branching ratios" before the $\chi_{c0}(1P)$ Listings.

$\chi_{c1}(1P)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3510.59± 0.10 OUR AVERAGE		Error includes scale factor of 1.1.			
3509.4 ± 0.9		BAI	99B	BES	$\psi(2S) \to \gamma X$
3510.61± 0.04±0.09	513	[1] ARMSTRONG	92	E760	$\overline{p}p \to e^+e^-\gamma$
3511.3 ± 0.4 ±0.4	30	BAGLIN	86B	SPEC	$\overline{p}p \to e^+e^- X$
3512.3 ± 0.3 ±4.0		[2] GAISER	86	CBAL	$\psi(2S) \to \gamma X$
3507.4 ± 1.7	91	[3] LEMOIGNE	82	GOLI	190 π^- Be $\to \gamma 2\mu$
3510.4 ± 0.6		OREGLIA	82	CBAL	$e^+e^- \to J/\psi 2\gamma$
3510.1 ± 1.1	254	[4] HIMEL	80	MRK2	$e^+e^- \to J/\psi 2\gamma$
3509 ±11	21	BRANDELIK	79B	DASP	$e^+e^- \to J/\psi 2\gamma$
3507 ± 3		[4] BARTEL	78B	CNTR	$e^+e^- \to J/\psi 2\gamma$
3505.0 ± 4 ±4		[4,5] TANENBAUM	78	MRK1	e^+e^-
3513 ± 7	367	[4] BIDDICK	77	CNTR	$\psi(2S) \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3500 ±10	40	TANENBAUM	75	MRK1	Hadrons γ

[1] 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.
[2] Using mass of $\psi(2S) = 3686.0$ MeV.
[3] $J/\psi(1S)$ mass constrained to 3097 MeV.
[4] Mass value shifted by us by amount appropriate for $\psi(2S)$ mass = 3686 MeV and $J/\psi(1S)$ mass = 3097 MeV.
[5] From a simultaneous fit to radiative and hadronic decay channels.

$\chi_{c1}(1P)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.91±0.13 OUR FIT						
0.88±0.11±0.08		513	ARMSTRONG	92	E760	$\overline{p}p \to e^+e^-\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<1.3	95		BAGLIN	86B	SPEC	$\overline{p}p \to e^+e^- X$
<3.8	90		GAISER	86	CBAL	$\psi(2S) \to \gamma X$

$\chi_{c1}(1P)$ DECAY MODES

Mode	Fraction (Γ_i/Γ)

Hadronic decays

Γ_1	$3(\pi^+\pi^-)$	$(6.2\pm1.6)\times10^{-3}$
Γ_2	$2(\pi^+\pi^-)$	$(8.2\pm2.9)\times10^{-3}$
Γ_3	$\pi^+\pi^-K^+K^-$	$(4.9\pm1.1)\times10^{-3}$
Γ_4	$\rho^0\pi^+\pi^-$	$(3.9\pm3.5)\times10^{-3}$
Γ_5	$K^+\overline{K}^*(892)^0\pi^-$ + c.c.	$(3.2\pm2.1)\times10^{-3}$
Γ_6	$K^0_S K^+\pi^-$ + c.c.	$(2.5\pm0.7)\times10^{-3}$
Γ_7	$\pi^+\pi^-p\overline{p}$	$(5.3\pm2.1)\times10^{-4}$
Γ_8	$K^+K^-K^+K^-$	$(4.2\pm1.9)\times10^{-4}$
Γ_9	$p\overline{p}$	$(7.2\pm1.3)\times10^{-5}$
Γ_{10}	$\Lambda\overline{\Lambda}$	$(2.6\pm1.2)\times10^{-4}$
Γ_{11}	$\pi^+\pi^- + K^+K^-$	$< 2.1\times10^{-3}$

Radiative decays

Γ_{12}	$\gamma J/\psi(1S)$	(31.6 ± 3.3) %
Γ_{13}	$\gamma\gamma$	

$\chi_{c1}(1P)$ PARTIAL WIDTHS

$\chi_{c1}(1P)$ $\Gamma(i)\Gamma(\gamma J/\psi(1S))/\Gamma(\text{total})$

$\Gamma(p\overline{p}) \times \Gamma(\gamma J/\psi(1S))/\Gamma_{\text{total}}$ — $\Gamma_9\Gamma_{12}/\Gamma$

VALUE (eV)	*DOCUMENT ID*		*TECN*	*COMMENT*
20.9±2.2 OUR FIT				
21.3±2.2 OUR AVERAGE				
21.8±1.5±2.2	[6] ARMSTRONG	92	E760	$\overline{p}p \to e^+e^-\gamma$
$19.9^{+4.4}_{-4.0}$	[6] BAGLIN	86B	SPEC	$\overline{p}p \to e^+e^-X$

[6] Calculated by us using $B(J/\psi(1S) \to e^+e^-) = 0.0593 \pm 0.0010$.

$\chi_{c1}(1P)$ BRANCHING RATIOS

HADRONIC DECAYS

$\Gamma(3(\pi^+\pi^-))/\Gamma_{\text{total}}$ — Γ_1/Γ

VALUE (units 10^{-3})	*DOCUMENT ID*		*TECN*	*COMMENT*
6.2±1.6 OUR EVALUATION Treating systematic error as correlated.				
6.2±1.3 OUR AVERAGE				
5.8±0.7±1.1	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$
17.2±6.4±1.7	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(2(\pi^+\pi^-))/\Gamma_{\text{total}}$ — Γ_2/Γ

VALUE (units 10^{-3})	*DOCUMENT ID*		*TECN*	*COMMENT*
8.2±2.9 OUR EVALUATION Treating systematic error as correlated.				
8 ±4 OUR AVERAGE Error includes scale factor of 1.5.				
4.9±2.2±2.8	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$
13.5±4.5±1.3	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{\text{total}}$ — Γ_3/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
4.9±1.1 OUR EVALUATION	Treating systematic error as correlated.			
4.9±1.1 OUR AVERAGE				
4.5±0.4±1.1	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$
7.9±3.2±0.8	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\rho^0\pi^+\pi^-)/\Gamma_{\text{total}}$ — Γ_4/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
39±35	[8] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(K^+\overline{K}^*(892)^0\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ — Γ_5/Γ

VALUE (units 10^{-4})	DOCUMENT ID		TECN	COMMENT
32±21	[8] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(K^0_S K^+\pi^- + \text{c.c.})/\Gamma_{\text{total}}$ — Γ_6/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
2.5±0.4±0.6	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(\pi^+\pi^-p\overline{p})/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
0.53±0.21 OUR EVALUATION	Treating systematic error as correlated.			
0.53±0.21 OUR AVERAGE				
0.49±0.13±0.17	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$
1.16±0.82±0.11	[7] TANENBAUM	78	MRK1	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(K^+K^-K^+K^-)/\Gamma_{\text{total}}$ — Γ_8/Γ

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
0.42±0.15±0.12	[7] BAI	99B	BES	$\psi(2S) \to \gamma\chi_{c1}$

$\Gamma(p\overline{p})/\Gamma_{\text{total}}$ — Γ_9/Γ

VALUE (units 10^{-4})	DOCUMENT ID
0.72±0.13 OUR FIT	

$\Gamma(\Lambda\overline{\Lambda})/\Gamma_{\text{total}}$ — Γ_{10}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.6±1.0±0.6	$9.0^{+3.5}_{-3.1}$	[7] BAI	03E	BES	$\psi(2S) \to \gamma\chi_{c1} \to \gamma\Lambda\overline{\Lambda}$

$[\Gamma(\pi^+\pi^-) + \Gamma(K^+K^-)]/\Gamma_{\text{total}}$ — Γ_{11}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<21		[8] FELDMAN	77	MRK1	$\psi(2S) \to \gamma\chi_{c1}$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<38	90	[8] BRANDELIK	79B	DASP	$\psi(2S) \to \gamma\chi_{c1}$

[7] Rescaled by us using $B(\psi(2S) \to \gamma\chi_{c1}) = (8.4 \pm 0.8)\%$ and $B(\psi(2S) \to J/\psi(1S)\pi^+\pi^-) = 0.317 \pm 0.011$.

[8] Estimated using $B(\psi(2S) \to \gamma\chi_{c1}(1P)) = 0.087$. The errors do not contain the uncertainty in the $\psi(2S)$ decay.

RADIATIVE DECAYS

$\Gamma(\gamma J/\psi(1S))/\Gamma_{total}$ — Γ_{12}/Γ

VALUE	DOCUMENT ID
0.316±0.033 OUR FIT	

$\Gamma(\gamma\gamma)/\Gamma_{total}$ — Γ_{13}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.0015	90	[9] YAMADA	77	DASP	$e^+e^- \rightarrow 3\gamma$

[9] Estimated using B($\psi(2S) \rightarrow \gamma\chi_{c1}(1P)$) = 0.087. The errors do not contain the uncertainty in the $\psi(2S)$ decay.

$\chi_{c1}(1P)$ CROSS-PARTICLE BRANCHING RATIOS

$B(\chi_{c1}(1P) \rightarrow p\overline{p}) \times \frac{\Gamma(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))}{\Gamma(\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-)}$

VALUE (units 10^{-5})	DOCUMENT ID		TECN	COMMENT
1.9±0.5 OUR FIT				
1.1±1.0	[10] BAI	98I	BES	$\psi(2S) \rightarrow \gamma\chi_{c1} \rightarrow \gamma\overline{p}p$

$B(\chi_{c1}(1P) \rightarrow \gamma J/\psi(1S)) \times B(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))$

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
2.67±0.15 OUR FIT				
2.66±0.16 OUR AVERAGE				
2.56±0.12±0.20	GAISER	86	CBAL	$\psi(2S) \rightarrow \gamma X$
2.78±0.30	[11] OREGLIA	82	CBAL	$\psi(2S) \rightarrow \gamma\chi_{c1}$
2.2 ±0.5	[12] BRANDELIK	79B	DASP	$\psi(2S) \rightarrow \gamma\chi_{c1}$
2.9 ±0.5	[12] BARTEL	78B	CNTR	$\psi(2S) \rightarrow \gamma\chi_{c1}$
5.0 ±1.5	[13] BIDDICK	77	CNTR	$e^+e^- \rightarrow \gamma X$
2.8 ±0.9	[11] WHITAKER	76	MRK1	e^+e^-

$B(\chi_{c1}(1P) \rightarrow \gamma J/\psi(1S)) \times \frac{\Gamma(\psi(2S) \rightarrow \gamma\chi_{c1}(1P))}{\Gamma(\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-)}$

VALUE (units 10^{-2})	DOCUMENT ID		TECN	COMMENT
8.4±0.6 OUR FIT				
8.5±2.1	[14] HIMEL	80	MRK2	$\psi(2S) \rightarrow \gamma\chi_{c1}$

[10] Calculated by us. The value for B($\chi_{c1} \rightarrow p\overline{p}$) reported in BAI 98I is derived using B($\psi(2S) \rightarrow \gamma\chi_{c1}$) = (8.7 ± 0.8)% and B($\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-$) = (32.4 ± 2.6)% [BAI 98D].

[11] Recalculated by us using B($J/\psi(1S) \rightarrow \ell^+\ell^-$) = 0.1181 ± 0.0020.

[12] Recalculated by us using B($J/\psi(1S) \rightarrow \mu^+\mu^-$) = 0.0588 ± 0.0010.

[13] Assumes isotropic gamma distribution.

[14] The value for B($\psi(2S) \rightarrow \gamma\chi_{c1}$)×B($\chi_{c1} \rightarrow \gamma J/\psi(1S)$) quoted in HIMEL 80 is derived using B($\psi(2S) \rightarrow J/\psi(1S)\pi^+\pi^-$) = (33 ± 3)% and B($J/\psi(1S) \rightarrow \ell^+\ell^-$) = 0.138 ± 0.018. Calculated by us using B($J/\psi(1S) \rightarrow \ell^+\ell^-$) = 0.1181 ± 0.0020.

MULTIPOLE AMPLITUDES IN $\chi_{c1}(1P) \rightarrow \gamma J/\psi(1S)$

$a_2 = M2/\sqrt{E1^2 + M2^2}$ Magnetic quadrupole fractional transition amplitude

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{-0.002^{+0.008}_{-0.017}}$ **OUR AVERAGE**					
$0.002 \pm 0.032 \pm 0.004$	2090	AMBROGIANI	02	E835	$p\overline{p} \rightarrow \chi_{c1} \rightarrow J/\psi\gamma$
$-0.002^{+0.008}_{-0.020}$	921	OREGLIA	82	CBAL	$\psi(2S) \rightarrow \chi_{c1}\gamma \rightarrow J/\psi\gamma\gamma$

$\chi_{c1}(1P)$ REFERENCES

AULCHENKO	03	PL B573 63	V.M. Aulchenko *et al.*	(KEDR Collab.)
BAI	03E	PR D67 112001	J.Z. Bai *et al.*	(BES Collab.)
AMBROGIANI	02	PR D65 052002	M. Ambrogiani *et al.*	(FNAL E835 Collab.)
BAI	99B	PR D60 072001	J.Z. Bai *et al.*	(BES Collab.)
BAI	98D	PR D58 092006	J.Z. Bai *et al.*	(BES Collab.)
BAI	98I	PRL 81 3091	J.Z. Bai *et al.*	(BES Collab.)
ARMSTRONG	93B	PR D47 772	T.A. Armstrong *et al.*	(FNAL E760 Collab.)
ARMSTRONG	92	NP B373 35	T.A. Armstrong *et al.*	(FNAL, FERR, GENO+)
Also	92B	PRL 68 1468	T.A. Armstrong *et al.*	(FNAL, FERR, GENO+)
BAGLIN	86B	PL B172 455	C. Baglin	(LAPP, CERN, GENO, LYON, OSLO+)
GAISER	86	PR D34 711	J. Gaiser *et al.*	(Crystal Ball Collab.)
LEMOIGNE	82	PL 113B 509	Y. Lemoigne *et al.*	(SACL, LOIC, SHMP+)
OREGLIA	82	PR D25 2259	M.J. Oreglia *et al.*	(SLAC, CIT, HARV+)
Also	82B	Private Comm.	M.J. Oreglia	(EFI)
HIMEL	80	PRL 44 920	T. Himel *et al.*	(LBL, SLAC)
Also	82	Private Comm.	G. Trilling	(LBL, UCB)
BRANDELIK	79B	NP B160 426	R. Brandelik *et al.*	(DASP Collab.)
BARTEL	78B	PL 79B 492	W. Bartel *et al.*	(DESY, HEIDP)
TANENBAUM	78	PR D17 1731	W.M. Tanenbaum *et al.*	(SLAC, LBL)
Also	82	Private Comm.	G. Trilling	(LBL, UCB)
BIDDICK	77	PRL 38 1324	C.J. Biddick *et al.*	(UCSD, UMD, PAVI+)
FELDMAN	77	PRPL 33C 285	G.J. Feldman, M.L. Perl	(LBL, SLAC)
YAMADA	77	Hamburg Conf. 69	S. Yamada	(DASP Collab.)
WHITAKER	76	PRL 37 1596	J.S. Whitaker *et al.*	(SLAC, LBL)
TANENBAUM	75	PRL 35 1323	W.M. Tanenbaum *et al.*	(LBL, SLAC)

OTHER RELATED PAPERS

BARBERIS	00G	PL B485 357	D. Barberis *et al.*	(Omega Expt.)
BARATE	83	PL 121B 449	R. Barate *et al.*	(SACL, LOIC, SHMP, IND)
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SIMPSON	75	PRL 35 699	J.W. Simpson *et al.*	(STAN, PENN)