$c\bar{c}$ MESONS

MINIREVIEW GOES HERE

$\eta_c(1S)$ or $\eta_c(2980)$

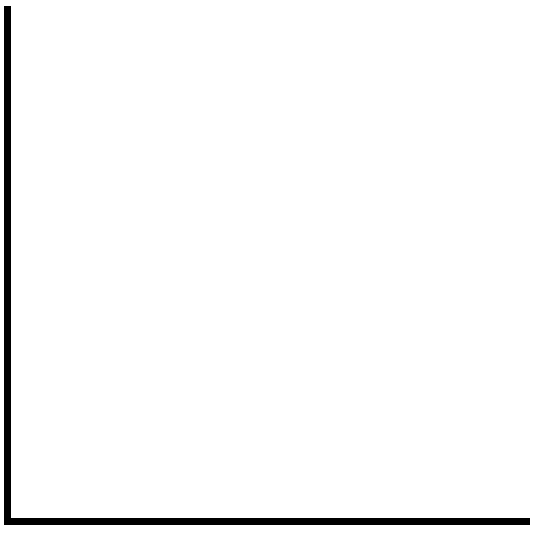
$I^G(J^{PC}) = 0^+(0^{-+})$

Observed in the inclusive γ spectrum generated from $\psi(2S)$ decay, therefore $C = +$. From the 4π decay $G = +$, therefore $I = 0$. From angular distribution in $J/\psi(1S) \to \eta_c\gamma$, $\eta_c \to \phi\phi$, $J^P = 0^-$ (BALTRUSAITIS 84).

$\eta_c(1S)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
2978.8± 1.9 OUR AVERAGE		Error includes scale factor of 1.8. See the ideogram below.			
2974.4± 1.9		[1] BISELLO	91	DM2	$J/\psi \to \eta_c\gamma$
2969 ± 4 ± 4	80	BAI	90B	MRK3	$J/\psi \to \gamma K^+K^-K^+K^-$
$2982.6^{+2.7}_{-2.3}$	12	BAGLIN	87B	SPEC	$\bar{p}p \to \gamma\gamma$
2980.2± 1.6		[1] BALTRUSAIT...	86	MRK3	$J/\psi \to \eta_c\gamma$
2984 ± 2.3± 4.0		GAISER	86	CBAL	$J/\psi \to \gamma X$, $\psi(2S) \to \gamma X$
2982 ± 8	18	[2] HIMEL	80B	MRK2	e^+e^-
• • • We do not use the following data for averages, fits, limits, etc. • • •					
2956 ±12 ±12		BAI	90B	MRK3	$J/\psi \to \gamma K^+K^-K^0_SK^0_L$
2976 ± 8		[3] BALTRUSAIT...	84	MRK3	$J/\psi \to 2\phi\gamma$
2980 ± 9		[2] PARTRIDGE	80B	CBAL	e^+e^-

[1] Average of several decay modes.
[2] Mass adjusted by us to correspond to $J/\psi(1S)$ mass = 3097 MeV.
[3] $\eta_c \to \phi\phi$.



$\eta_c(1S)$ mass (MeV)

$\eta_c(1S)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$10.3^{+3.8}_{-3.4}$ OUR AVERAGE						
$7.0^{+7.5}_{-7.0}$		12	BAGLIN	87B	SPEC	$\overline{p}p \to \gamma\gamma$
$10.1^{+33.0}_{-8.2} \pm 11$		23	[4] BALTRUSAIT...	86	MRK3	$J/\psi \to \gamma p\overline{p}$
11.5 ± 4.5			GAISER	86	CBAL	$J/\psi \to \gamma X$, $\psi(2S) \to \gamma X$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<40	90	18	HIMEL	80B	MRK2	e^+e^-
<20	90		PARTRIDGE	80B	CBAL	e^+e^-

[4] Positive and negative errors correspond to 90% confidence level.

$\eta_c(1S)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
	Decays involving hadronic resonances		
Γ_1	$\eta'(958)\pi\pi$	(4.1 ± 1.7) %	
Γ_2	$\rho\rho$	(2.6 ± 0.9) %	
Γ_3	$K^*(892)^0 K^-\pi^+ +$ c.c.	(2.0 ± 0.7) %	
Γ_4	$K^*(892)\overline{K}^*(892)$	$(8.5 \pm 3.1) \times 10^{-3}$	
Γ_5	$\phi\phi$	$(7.1 \pm 2.8) \times 10^{-3}$	
Γ_6	$a_0(980)\pi$	< 2 %	90%
Γ_7	$a_2(1320)\pi$	< 2 %	90%
Γ_8	$K^*(892)\overline{K} +$ c.c.	< 1.28 %	90%
Γ_9	$f_2(1270)\eta$	< 1.1 %	90%
Γ_{10}	$\omega\omega$	$< 3.1 \times 10^{-3}$	90%
	Decays into stable hadrons		
Γ_{11}	$K\overline{K}\pi$	(6.6 ± 1.8) %	
Γ_{12}	$\eta\pi\pi$	(4.9 ± 1.8) %	
Γ_{13}	$\pi^+\pi^- K^+K^-$	$(2.0\ ^{+0.7}_{-0.6})$ %	
Γ_{14}	$2(K^+K^-)$	(2.1 ± 1.2) %	
Γ_{15}	$2(\pi^+\pi^-)$	(1.2 ± 0.4) %	
Γ_{16}	$p\overline{p}$	$(1.2 \pm 0.4) \times 10^{-3}$	
Γ_{17}	$K\overline{K}\eta$	< 3.1 %	90%
Γ_{18}	$\pi^+\pi^- p\overline{p}$	< 1.2 %	90%
Γ_{19}	$\Lambda\overline{\Lambda}$	$< 2 \times 10^{-3}$	90%
	Radiative decays		
Γ_{20}	$\gamma\gamma$	$(6\ ^{+6}_{-5}) \times 10^{-4}$	

$\eta_c(1S)$ PARTIAL WIDTHS

$\Gamma(\gamma\gamma)$ Γ_{20}

VALUE (keV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
7.8 ± 1.7 OUR AVERAGE						
11.3 ± 4.2			ALBRECHT	94H	ARG	$\gamma\gamma$
$8.0 \pm 2.3 \pm 2.4$		17 ± 5	ADRIANI	93N	L3	$e^+e^- \to e^+e^-\eta_c$
$5.9^{+2.1}_{-1.8} \pm 1.9$			CHEN	90B	CLEO	$e^+e^- \to e^+e^-\eta_c$
$6.4^{+5.0}_{-3.4}$			AIHARA	88D	TPC	$e^+e^- \to e^+e^- X$
28 ± 15			[5] BERGER	86	PLUT	$\gamma\gamma \to K\overline{K}\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<11	90		BLINOV	86	MD1	$e^+e^- \to e^+e^- X$

[5] Re-evaluated by AIHARA 88D.

$\eta_c(1S)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(total)$

$\Gamma(K\overline{K}\pi) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ $\Gamma_{11}\Gamma_{20}/\Gamma$

VALUE (keV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.94±0.18 OUR AVERAGE						
0.84±0.21			[6] ALBRECHT	94H	ARG	$\gamma\gamma \to K^{\pm}K^0_S\pi^{\mp}$
1.06±0.41±0.27		11 ± 4	BRAUNSCH...	89	TASS	$\gamma\gamma \to K\overline{K}\pi$
$1.5\ ^{+0.60}_{-0.45}\pm0.3$		7	[6] BERGER	86	PLUT	$\gamma\gamma \to K\overline{K}\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.63	95		[6] BEHREND	89	CELL	$\gamma\gamma \to K^0_S K^{\pm}\pi^{\mp}$
<4.4	95		ALTHOFF	85B	TASS	$\gamma\gamma \to K\overline{K}\pi$

[6] $K^{\pm}K^0_S\pi^{\mp}$ corrected to $K\overline{K}\pi$ by factor 3.

$\eta_c(1S)$ BRANCHING RATIOS

HADRONIC DECAYS

$\Gamma(\eta'(958)\pi\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.041±0.017	14 ± 4	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\rho\rho)/\Gamma_{total}$ Γ_2/Γ

VALUE (units 10^{-3})	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
26 ± 9 OUR EVALUATION (Treating systematicerrors as correlated.)						
25 ± 8 OUR AVERAGE						
26.0± 2.4±8.8		113± 11	[7] BISELLO	91	DM2	$J/\psi \to \gamma\rho^0\rho^0$
23.6±10.6±8.2		32 ± 14	[7] BISELLO	91	DM2	$J/\psi \to \gamma\rho^+\rho^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<140	90		[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(K^*(892)^0K^-\pi^+ + c.c.)/\Gamma_{total}$ Γ_3/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.02 ±0.007	63 ± 10	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(K^*(892)\overline{K}^*(892))/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
85±31 OUR AVERAGE					
82±28±27	14 ± 5	[7] BISELLO	91	DM2	$e^+e^- \to \gamma K^+K^-\pi^+\pi^-$
90±50	9 ± 4	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(K^*(892)\overline{K} + c.c.)/\Gamma_{total}$ Γ_8/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0128	90	BISELLO	91	DM2	$J/\psi \to \gamma K^0_S K^{\pm}\pi^{\mp}$
<0.0132	90	[7] BISELLO	91	DM2	$J/\psi \to \gamma K^+K^-\pi^0$

$\Gamma(\phi\phi)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
71±28 OUR EVALUATION (Treating systematic errors as correlated.)					
71±22 OUR AVERAGE					
74±18±24	80	[7] BAI	90B	MRK3	$J/\psi \to \gamma K^+K^-K^+K^-$
67±21±24		[7] BAI	90B	MRK3	$J/\psi \to \gamma K^+K^-K^0_S K^0_L$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
31± 7±10	19 ± 5	[7] BISELLO	91	DM2	$J/\psi \to \gamma K^+K^-K^+K^-$
$30^{+18}_{-12}\pm10$	5 ± 3	[7] BISELLO	91	DM2	$J/\psi \to \gamma K^+K^-K^0_S K^0_L$

$\Gamma(a_0(980)\pi)/\Gamma_{total}$ Γ_6/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[7,8] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(a_2(1320)\pi)/\Gamma_{total}$ Γ_7/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.02	90	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(f_2(1270)\eta)/\Gamma_{total}$ Γ_9/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.011	90	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\omega\omega)/\Gamma_{total}$ Γ_{10}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.0031	90	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.0063		[7] BISELLO	91	DM2	$J/\psi \to \gamma\omega\omega$

$\Gamma(K\overline{K}\pi)/\Gamma_{total}$ Γ_{11}/Γ

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
0.066 ±0.018 OUR EVALUATION (Treating systematic errors as correlated.)						
0.063 ±0.013 OUR AVERAGE						
0.0690±0.0144±0.0234		33 ± 7	[7] BISELLO	91	DM2	$J/\psi \to \gamma K^+K^-\pi^0$
0.0543±0.0096±0.0180		68 ± 10	[7] BISELLO	91	DM2	$J/\psi \to \gamma K^\pm\pi^\mp K^0_S$
0.061 ±0.022		95 ± 18	[7,9] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$
$0.161\ ^{+0.092}_{-0.073}$			[10] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.107	90		[7] PARTRIDGE	80B	CBAL	$J/\psi \to \eta_c\gamma$

$\Gamma(\eta\pi\pi)/\Gamma_{total}$ Γ_{12}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.049±0.018 OUR EVALUATION					
0.047±0.015 OUR AVERAGE					
0.054±0.020	75 ± 11	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$
0.037±0.013±0.020	18	[7] PARTRIDGE	80B	CBAL	$J/\psi \to \eta\pi^+\pi^-\gamma$

$\Gamma(\pi^+\pi^-K^+K^-)/\Gamma_{total}$ Γ_{13}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.020\ ^{+0.007}_{-0.006}}$ **OUR AVERAGE**					
0.021±0.007	110± 17	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$
$0.014\ ^{+0.022}_{-0.009}$		[10] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(2(\pi^+\pi^-))/\Gamma_{total}$ Γ_{15}/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.012 ±0.004 OUR EVALUATION					
0.0120±0.0031 OUR AVERAGE					
0.0105±0.0017±0.0034	137± 23	[7] BISELLO	91	DM2	$J/\psi \to \gamma 2\pi^+ 2\pi^-$
0.013 ±0.006	25 ± 9	[7] BALTRUSAIT...86		MRK3	$J/\psi \to \eta_c\gamma$
$0.020\ ^{+0.015}_{-0.010}$		[10] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(2(K^+K^-))/\Gamma_{total}$ Γ_{14}/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.021±0.010±0.006	ALBRECHT	94H	ARG	$\gamma\gamma \to K^+K^-K^+K^-$

$\Gamma(p\overline{p})/\Gamma_{total}$ Γ_{16}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
12± 4 OUR AVERAGE					
10± 3±4	18 ± 6	[7] BISELLO	91	DM2	$J/\psi \to \gamma p\overline{p}$
11± 6	23 ± 11	[7] BALTRUSAIT...	86	MRK3	$J/\psi \to \eta_c\gamma$
29^{+29}_{-15}		[10] HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(K\overline{K}\eta)/\Gamma_{total}$ Γ_{17}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.031	90	[7] BALTRUSAIT...	86	MRK3	$J/\psi \to \eta_c\gamma$

$\Gamma(\pi^+\pi^- p\overline{p})/\Gamma_{total}$ Γ_{18}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.012	90	HIMEL	80B	MRK2	$\psi(2S) \to \eta_c\gamma$

$\Gamma(\Lambda\overline{\Lambda})/\Gamma_{total}$ Γ_{19}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.002	90	[7] BISELLO	91	DM2	$e^+e^- \to \gamma\Lambda\overline{\Lambda}$

$\Gamma_i\Gamma_f/\Gamma^2_{total}$ in $p\overline{p} \to \eta_c(1S) \to \phi\phi$ $\Gamma_{16}\Gamma_5/\Gamma^2$

VALUE (units 10^{-5})	DOCUMENT ID		TECN	COMMENT
$\mathbf{4.0^{+3.5}_{-3.2}}$	BAGLIN	89	SPEC	$\overline{p}p \to K^+K^-K^+K^-$

[7] The quoted branching ratios use $B(J/\psi(1S) \to \gamma\eta_c(1S)) = 0.0127 \pm 0.0036$. Where relevant, the error in this branching ratio is treated as a common systematic in computing averages.
[8] We are assuming $B(a_0(980) \to \eta\pi) > 0.5$.
[9] Average from $K^+K^-\pi^0$ and $K^\pm K^0_S\pi^\mp$ decay channels.
[10] Estimated using $B(\psi(2S) \to \gamma\eta_c(1S)) = 0.0028 \pm 0.0006$.

RADIATIVE DECAYS

$\Gamma(\gamma\gamma)/\Gamma_{total}$ Γ_{20}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
$\mathbf{6^{+4}_{-3}\pm4}$		BAGLIN	87B	SPEC	$\overline{p}p \to \gamma\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
< 9	90	[7] BISELLO	91	DM2	$J/\psi \to \gamma\gamma\gamma$
<18	90	[11] BLOOM	83	CBAL	$J/\psi \to \eta_c\gamma$

[11] Using $B(J/\psi(1S) \to \gamma\eta_c(1S)) = 0.0127 \pm 0.0036$.

$\Gamma_i\Gamma_f/\Gamma^2_{total}$ in $p\overline{p} \to \eta_c(1S) \to \gamma\gamma$ $\Gamma_{16}\Gamma_{20}/\Gamma^2$

VALUE (units 10^{-6})	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.68^{+0.42}_{-0.31}}$	12	BAGLIN	87B	SPEC	$\overline{p}p \to \gamma\gamma$

$\eta_c(1S)$ REFERENCES

ALBRECHT 94H PL B338 390 +Hamacher, Hofmann+ (ARGUS Collab.)
ADRIANI 93N PL B318 575 +Aguilar-Benitez, Ahlen+ (L3 Collab.)
BISELLO 91 NP B350 1 +Busetto+ (DM2 Collab.)
BAI 90B PRL 65 1309 +Blaylock+ (Mark III Collab.)
CHEN 90B PL B243 169 +McIlwain+ (CLEO Collab.)
BAGLIN 89 PL B231 557 +Baird, Bassompierre (R704 Collab.)
BEHREND 89 ZPHY C42 367 +Criegee+ (CELLO Collab.)
BRAUNSCH... 89 ZPHY C41 533 Braunschweig, Bock+ (TASSO Collab.)
AIHARA 88D PRL 60 2355 +Alston-Garnjost+ (TPC Collab.)
BAGLIN 87B PL B187 191 +Baird, Bassompierre, Borreani+ (R704 Collab.)
BALTRUSAIT... 86 PR D33 629 Baltrusaitis, Coffman, Hauser+ (Mark III Collab.)
BERGER 86 PL 167B 120 +Genzel, Lackas, Pielorz+ (PLUTO Collab.)
BLINOV 86 +Blinov, Bondar, Bukin+ (NOVO)
Proc. XXIII Int. HEP Conf., Berkeley, CA (1986); World Scientific, Singapore, 1987, ed. S.C. Loken
GAISER 86 PR D34 711 +Bloom, Bulos, Godfrey+ (Crystal Ball Collab.)
ALTHOFF 85B ZPHY C29 189 +Braunschweig, Kirschfink+ (TASSO Collab.)
BALTRUSAIT... 84 PRL 52 2126 Baltrusaitis+ (CIT, UCSC, ILL, SLAC, WASH) JP
BLOOM 83 ARNS 33 143 +Peck (SLAC, CIT)
HIMEL 80B PRL 45 1146 +Trilling, Abrams, Alam+ (SLAC, LBL, UCB)
PARTRIDGE 80B PRL 45 1150 +Peck+ (CIT, HARV, PRIN, STAN, SLAC)

OTHER RELATED PAPERS

ARMSTRONG 89 PL B221 216 +Benayoun+(CERN, CDEF, BIRM, BARI, ATHU, CURIN+)
BLOOM 79 Fermilab Symp. 92 (CIT, HARV, PRIN, SLAC, STAN)