$\chi_{b2}(1P)$

$I^G(J^{PC}) = 0^+(2^{++})$
J needs confirmation.

Observed in radiative decay of the $\Upsilon(2S)$, therefore $C = +$. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$. $J = 2$ from SKWARNICKI 87.

$\chi_{b2}(1P)$ MASS

VALUE (MeV)	DOCUMENT ID		
9912.21±0.26±0.31 OUR EVALUATION	From average γ energy below, using $\Upsilon(2S)$ mass = 10023.26 ± 0.31 MeV		

γ ENERGY IN $\Upsilon(2S)$ DECAY

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
110.44±0.29 OUR AVERAGE	Error includes scale factor of 1.1.			
110.58±0.08±0.30	ARTUSO	05	CLEO	$\Upsilon(2S) \to \gamma X$
110.8 ±0.3 ±0.6	EDWARDS	99	CLE2	$\Upsilon(2S) \to \gamma\chi(1P)$
107.0 ±1.1 ±1.3	WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
110.6 ±0.3 ±0.9	ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv.γX
110.4 ±0.8 ±2.2	NERNST	85	CBAL	$\Upsilon(2S) \to \gamma X$
109.5 ±0.7 ±1.0	HAAS	84	CLEO	$\Upsilon(2S) \to$ conv.γX
108.2 ±0.3 ±2.0	KLOPFEN...	83	CUSB	$\Upsilon(2S) \to \gamma X$
108.8 ±4.0	PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

$\chi_{b2}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\gamma\,\Upsilon(1S)$	(19.1 ± 1.2) %	
Γ_2	$D^0 X$	< 7.9 %	90%
Γ_3	$\pi^+\pi^- K^+ K^- \pi^0$	$(8 \pm 5) \times 10^{-5}$	
Γ_4	$2\pi^+\pi^- K^- K^0_S$	$< 1.0 \times 10^{-4}$	90%
Γ_5	$2\pi^+\pi^- K^- K^0_S 2\pi^0$	$(5.3\pm2.4) \times 10^{-4}$	
Γ_6	$2\pi^+ 2\pi^- 2\pi^0$	$(3.5\pm1.4) \times 10^{-4}$	
Γ_7	$2\pi^+ 2\pi^- K^+ K^-$	$(1.1\pm0.4) \times 10^{-4}$	
Γ_8	$2\pi^+ 2\pi^- K^+ K^- \pi^0$	$(2.1\pm0.9) \times 10^{-4}$	
Γ_9	$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$(3.9\pm1.8) \times 10^{-4}$	
Γ_{10}	$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	$< 5 \times 10^{-4}$	90%
Γ_{11}	$3\pi^+ 3\pi^-$	$(7.0\pm3.1) \times 10^{-5}$	
Γ_{12}	$3\pi^+ 3\pi^- 2\pi^0$	$(1.0\pm0.4) \times 10^{-3}$	
Γ_{13}	$3\pi^+ 3\pi^- K^+ K^-$	$< 8 \times 10^{-5}$	90%
Γ_{14}	$3\pi^+ 3\pi^- K^+ K^- \pi^0$	$(3.6\pm1.5) \times 10^{-4}$	
Γ_{15}	$4\pi^+ 4\pi^-$	$(8 \pm 4) \times 10^{-5}$	
Γ_{16}	$4\pi^+ 4\pi^- 2\pi^0$	$(1.8\pm0.7) \times 10^{-3}$	

$\chi_{b2}(1P)$ BRANCHING RATIOS

$\Gamma(\gamma\, \Upsilon(1S))/\Gamma_{total}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.191±0.012 OUR AVERAGE					
0.186±0.011±0.009	1770	[1,2] KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$
$0.194^{+0.014}_{-0.017}\pm0.009$	8k	[3] LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$
0.27 ±0.06 ±0.06		WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
0.20 ±0.05		KLOPFEN...	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

[1] Assuming B$(\Upsilon(1S) \to \ell^+\ell^-) = (2.48 \pm 0.05)\%$.

[2] KORNICER 11 reports $[\Gamma(\chi_{b2}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (1.33 \pm 0.04 \pm 0.07) \times 10^{-2}$ which we divide by our best value B$(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

[3] LEES 11J reports $[\Gamma(\chi_{b2}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (13.9 \pm 0.5^{+0.9}_{-1.1}) \times 10^{-3}$ which we divide by our best value B$(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D^0 X)/\Gamma_{total}$ Γ_2/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<7.9×10^{-2}	90	[4,5] BRIERE	08	CLEO	$\Upsilon(2S) \to \gamma D^0 X$

[4] For $p_{D^0} > 2.5$ GeV/c.

[5] The authors also present their result as $(5.4 \pm 1.9 \pm 0.5) \times 10^{-2}$.

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.84±0.50±0.04	8	[6] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma\pi^+\pi^- K^+ K^- \pi^0$

[6] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to \pi^+\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (6 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value B$(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+\pi^- K^- K^0_S)/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<1.0	90	[7] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- K^0_S$

[7] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+\pi^- K^- K^0_S)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] < 7 \times 10^{-6}$ which we divide by our best value B$(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = 7.15 \times 10^{-2}$.

$\Gamma(2\pi^+\pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
5.3±2.4±0.3	11	[8] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- 2\pi^0$

[8] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+\pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (38 \pm 14 \pm 10) \times 10^{-6}$ which we divide by our best value B$(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
3.5±1.4±0.2	19	[9] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- 2\pi^0$

[9] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))]$ $= (25 \pm 8 \pm 6) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{\text{total}}$ $\qquad\qquad\qquad\qquad\qquad\qquad$ Γ_7/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
1.1±0.4±0.1	14	[10] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^-$

[10] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (8 \pm 2 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}$ $\qquad\qquad\qquad\qquad\qquad\qquad$ Γ_8/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
2.1±0.9±0.1	13	[11] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$

[11] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (15 \pm 5 \pm 4) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{\text{total}}$ $\qquad\qquad\qquad\qquad\qquad\qquad$ Γ_9/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
3.9±1.8±0.2	11	[12] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$

[12] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (28 \pm 11 \pm 7) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+ 2\pi^- K^- K^0_S \pi^0)/\Gamma_{\text{total}}$ $\qquad\qquad\qquad\qquad\qquad\qquad$ Γ_{10}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<5	90	[13] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 2\pi^- K^- K^0_S \pi^0$

[13] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 3\pi^+ 2\pi^- K^- K^0_S \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] < 36 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = 7.15 \times 10^{-2}$.

$\Gamma(3\pi^+ 3\pi^-)/\Gamma_{\text{total}}$ $\qquad\qquad\qquad\qquad\qquad\qquad$ Γ_{11}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID	TECN	COMMENT
0.70±0.31±0.03	9	[14] ASNER	08A CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^-$

[14] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 3\pi^+ 3\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (5 \pm 2 \pm 1) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma\left(3\pi^+ 3\pi^- 2\pi^0\right)/\Gamma_{total}$ $\qquad$ Γ_{12}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
10.2±3.6±0.5	34	[15] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^- 2\pi^0$

[15] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 3\pi^+ 3\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))]$ $= (73 \pm 16 \pm 20) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))$ $= (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma\left(3\pi^+ 3\pi^- K^+ K^-\right)/\Gamma_{total}$ $\qquad$ Γ_{13}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.8	90	[16] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^- K^+ K^-$

[16] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 3\pi^+ 3\pi^- K^+ K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] < 6 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = 7.15 \times 10^{-2}$.

$\Gamma\left(3\pi^+ 3\pi^- K^+ K^- \pi^0\right)/\Gamma_{total}$ $\qquad$ Γ_{14}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
3.6±1.5±0.2	14	[17] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^- K^+ K^- \pi^0$

[17] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 3\pi^+ 3\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (26 \pm 8 \pm 7) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma\left(4\pi^+ 4\pi^-\right)/\Gamma_{total}$ $\qquad$ Γ_{15}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
0.84±0.40±0.04	7	[18] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+ 4\pi^-$

[18] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 4\pi^+ 4\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (6 \pm 2 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma\left(4\pi^+ 4\pi^- 2\pi^0\right)/\Gamma_{total}$ $\qquad$ Γ_{16}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
18±7±1	29	[19] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+ 4\pi^- 2\pi^0$

[19] ASNER 08A reports $[\Gamma(\chi_{b2}(1P) \to 4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b2}(1P))] = (132 \pm 31 \pm 40) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) = (7.15 \pm 0.35) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\chi_{b2}(1P)$ Cross-Particle Branching Ratios

$\Gamma\left(\chi_{b2}(1P) \to \gamma\,\Upsilon(1S)\right)/\Gamma_{total} \times \Gamma\left(\Upsilon(2S) \to \gamma\chi_{b2}(1P)\right)/\Gamma_{total}$

$$\Gamma_1/\Gamma \times \Gamma_{15}^{\Upsilon(2S)}/\Gamma^{\Upsilon(2S)}$$

VALUE (units 10^{-3})	EVTS	DOCUMENT ID		TECN	COMMENT
$13.9 \pm 0.5^{+0.9}_{-1.1}$	8k	LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$

$B(\chi_{b2}(1P) \to \gamma \Upsilon(1S)) \times B(\Upsilon(2S) \to \gamma\chi_{b2}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
3.29±0.09±0.16	1770	KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$B(\chi_{b2}(1P) \to \gamma \Upsilon(1S)) \times B(\Upsilon(3S) \to \gamma\chi_{b2}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
3.56±0.40±0.41	126	KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$\chi_{b2}(1P)$ REFERENCES

KORNICER	11	PR D83 054003	M. Kornicer *et al.*	(CLEO Collab.)
LEES	11J	PR D84 072002	J.P. Lees *et al.*	(BABAR Collab.)
ASNER	08A	PR D78 091103	D.M. Asner *et al.*	(CLEO Collab.)
BRIERE	08	PR D78 092007	R.A. Briere *et al.*	(CLEO Collab.)
ARTUSO	05	PRL 94 032001	M. Artuso *et al.*	(CLEO Collab.)
EDWARDS	99	PR D59 032003	K.W. Edwards *et al.*	(CLEO Collab.)
SKWARNICKI	87	PRL 58 972	T. Skwarnicki *et al.*	(Crystal Ball Collab.) J
WALK	86	PR D34 2611	W.S. Walk *et al.*	(Crystal Ball Collab.)
ALBRECHT	85E	PL 160B 331	H. Albrecht *et al.*	(ARGUS Collab.)
NERNST	85	PRL 54 2195	R. Nernst *et al.*	(Crystal Ball Collab.)
HAAS	84	PRL 52 799	J. Haas *et al.*	(CLEO Collab.)
KLOPFEN...	83	PRL 51 160	C. Klopfenstein *et al.*	(CUSB Collab.)
PAUSS	83	PL 130B 439	F. Pauss *et al.*	(MPIM, COLU, CORN, LSU+)