$\chi_{b0}(1P)$

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

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

$\chi_{b0}(1P)$ MASS

VALUE (MeV)	*DOCUMENT ID*
9859.44±0.42±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*
162.5 ±0.4 OUR AVERAGE				
162.56±0.19±0.42	ARTUSO	05	CLEO	$\Upsilon(2S) \to \gamma X$
162.0 ±0.8 ±1.2	EDWARDS	99	CLE2	$\Upsilon(2S) \to \gamma\chi(1P)$
162.1 ±0.5 ±1.4	ALBRECHT	85E	ARG	$\Upsilon(2S) \to$ conv. γX
163.8 ±1.6 ±2.7	NERNST	85	CBAL	$\Upsilon(2S) \to \gamma X$
158.0 ±7 ±1	HAAS	84	CLEO	$\Upsilon(2S) \to$ conv. γX
• • • We do not use the following data for averages, fits, limits, etc. • • •				
149.4 ±0.7 ±5.0	KLOPFEN...	83	CUSB	$\Upsilon(2S) \to \gamma X$

$\chi_{b0}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\gamma\,\Upsilon(1S)$	(1.76±0.35) %	
Γ_2	$D^0 X$	< 10.4 %	90%
Γ_3	$\pi^+\pi^- K^+ K^- \pi^0$	< 1.6 $\times 10^{-4}$	90%
Γ_4	$2\pi^+\pi^- K^- K^0_S$	< 5 $\times 10^{-5}$	90%
Γ_5	$2\pi^+\pi^- K^- K^0_S 2\pi^0$	< 5 $\times 10^{-4}$	90%
Γ_6	$2\pi^+ 2\pi^- 2\pi^0$	< 2.1 $\times 10^{-4}$	90%
Γ_7	$2\pi^+ 2\pi^- K^+ K^-$	(1.1 ±0.6) $\times 10^{-4}$	
Γ_8	$2\pi^+ 2\pi^- K^+ K^- \pi^0$	< 2.7 $\times 10^{-4}$	90%
Γ_9	$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	< 5 $\times 10^{-4}$	90%
Γ_{10}	$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	< 1.6 $\times 10^{-4}$	90%
Γ_{11}	$3\pi^+ 3\pi^-$	< 8 $\times 10^{-5}$	90%
Γ_{12}	$3\pi^+ 3\pi^- 2\pi^0$	< 6 $\times 10^{-4}$	90%
Γ_{13}	$3\pi^+ 3\pi^- K^+ K^-$	(2.4 ±1.2) $\times 10^{-4}$	
Γ_{14}	$3\pi^+ 3\pi^- K^+ K^- \pi^0$	< 1.0 $\times 10^{-3}$	90%
Γ_{15}	$4\pi^+ 4\pi^-$	< 8 $\times 10^{-5}$	90%
Γ_{16}	$4\pi^+ 4\pi^- 2\pi^0$	< 2.1 $\times 10^{-3}$	90%
Γ_{17}	$J/\psi J/\psi$	< 7 $\times 10^{-5}$	90%
Γ_{18}	$J/\psi\,\psi(2S)$	< 1.2 $\times 10^{-4}$	90%
Γ_{19}	$\psi(2S)\,\psi(2S)$	< 3.1 $\times 10^{-5}$	90%

$\chi_{b0}(1P)$ BRANCHING RATIOS

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

VALUE (%)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
1.76±0.30±0.18		87	[1,2] KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<$ 4.6	90		[3] LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$
$<$ 6	90		WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
$<$11	90		PAUSS	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

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

[2] KORNICER 11 reports $[\Gamma(\chi_{b0}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] = (6.59 \pm 0.96 \pm 0.60) \times 10^{-4}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

[3] LEES 11J quotes a central value of $\Gamma(\chi_{b0}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma\chi_{b0}(1P))/\Gamma_{total} = (8.3 \pm 5.6^{+3.7}_{-2.6}) \times 10^{-4}$.

$\Gamma(D^0 X)/\Gamma_{total}$ — Γ_2/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<10.4 \times 10^{-2}$	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 $(5.6 \pm 3.6 \pm 0.5) \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<1.6	90	[6] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma\pi^+\pi^- K^+ K^- \pi^0$

[6] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to \pi^+\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 6 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.5	90	[7] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- K^0_S$

[7] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+\pi^- K^- K^0_S)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 2 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<5	90	[8] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- 2\pi^0$

[8] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+\pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 18 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<2.1	90	[9] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- 2\pi^0$

[9] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 8 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.1±0.6±0.1	7	[10] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^-$

[10] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] = (4 \pm 2 \pm 1) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<2.7	90	[11] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$

[11] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 10 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<5	90	[12] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$

[12] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 20 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<1.6	90	[13] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 2\pi^- K^- K^0_S \pi^0$

[13] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 3\pi^+ 2\pi^- K^- K^0_S \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 6 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.8	90	[14] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^-$

[14] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 3\pi^+ 3\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<6	90	[15] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^- 2\pi^0$

[15] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 3\pi^+ 3\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 22 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.4±1.2±0.2	9	[16] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-$

[16] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] = (9 \pm 4 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<10	90	[17] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-\pi^0$

[17] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 37 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<0.8	90	[18] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+4\pi^-$

[18] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 4\pi^+4\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<21	90	[19] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+4\pi^-2\pi^0$

[19] ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \to 4\pi^+4\pi^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))] < 77 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$.

$\Gamma(J/\psi J/\psi)/\Gamma_{total}$ Γ_{17}/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<7	90	[20] SHEN	12	BELL	$\Upsilon(2S) \to \gamma\psi X$

[20] SHEN 12 reports $< 7.1 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \to J/\psi J/\psi)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$.

$\Gamma(J/\psi\psi(2S))/\Gamma_{total}$ Γ_{18}/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<12	90	[21] SHEN	12	BELL	$\Upsilon(2S) \to \gamma\psi X$

[21] SHEN 12 reports $< 12 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \to J/\psi\psi(2S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$.

$\Gamma(\psi(2S)\psi(2S))/\Gamma_{total}$ Γ_{19}/Γ

VALUE (units 10^{-5})	CL%	DOCUMENT ID		TECN	COMMENT
<3.1	90	[22] SHEN	12	BELL	$\Upsilon(2S) \to \gamma\psi X$

[22] SHEN 12 reports $< 3.1 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \to \psi(2S)\psi(2S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b0}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$.

$\chi_{b0}(1P)$ CROSS-PARTICLE BRANCHING RATIOS

$\Gamma(\chi_{b0}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma\chi_{b0}(1P))/\Gamma_{total}$ — $\Gamma_1/\Gamma \times \Gamma_{47}^{\Upsilon(2S)}/\Gamma^{\Upsilon(2S)}$

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<1.7 \times 10^{-3}$	90	[23] LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$

[23] LEES 11J quotes a central value of $\Gamma(\chi_{b0}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma\chi_{b0}(1P))/\Gamma_{total} = (8.3 \pm 5.6^{+3.7}_{-2.6}) \times 10^{-4}$ and derives a 90% CL upper limit of $\Gamma(\gamma\Upsilon(1S))/\Gamma_{total} < 4.6\%$ using $B(\Upsilon(4S) \to \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4)\%$.

$B(\chi_{b0}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \to \gamma\chi_{b0}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

VALUE (units 10^{-5})	EVTS	DOCUMENT ID		TECN	COMMENT
1.63±0.24±0.15	87	KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$\chi_{b0}(1P)$ REFERENCES

SHEN	12	PR D85 071102	C.P. Shen et al.	(BELLE Collab.)
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.)
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+)