

$\chi_{b0}(2P)$

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

J needs confirmation.

Observed in radiative decay of the $\Upsilon(3S)$, therefore $C = +$. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$.

$\chi_{b0}(2P)$ MASS

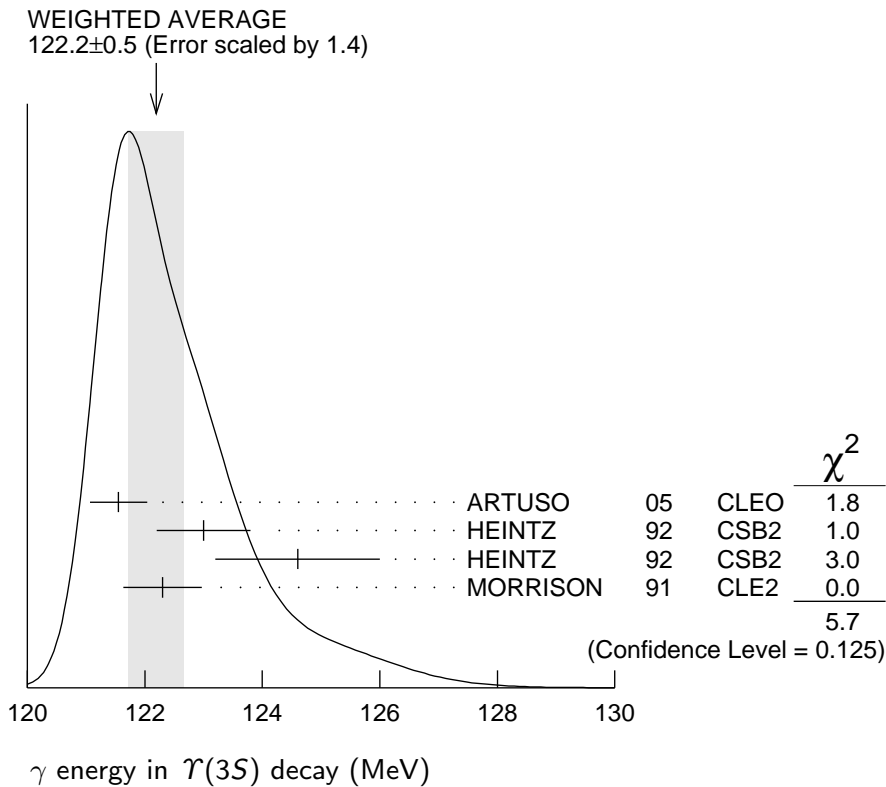
VALUE (GeV)	DOCUMENT ID
10.2325 ± 0.0004 ± 0.0005 OUR EVALUATION	From γ energy below, using $\Upsilon(3S)$ mass = 10355.2 ± 0.5 MeV

γ ENERGY IN $\Upsilon(3S)$ DECAY

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
121.9 ± 0.4 OUR EVALUATION				Treating systematic errors as correlated
122.2 ± 0.5 OUR AVERAGE				Error includes scale factor of 1.4. See the ideogram below.
121.55 ± 0.16 ± 0.46		ARTUSO	05	CLEO $\Upsilon(3S) \rightarrow \gamma X$
123.0 ± 0.8	4959	¹ HEINTZ	92	CSB2 $e^+ e^- \rightarrow \gamma X$
124.6 ± 1.4	17	² HEINTZ	92	CSB2 $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$
122.3 ± 0.3 ± 0.6	9903	MORRISON	91	CLE2 $e^+ e^- \rightarrow \gamma X$

¹ A systematic uncertainty on the energy scale of 0.9% not included. Supersedes NARAIN 91.

² A systematic uncertainty on the energy scale of 0.9% not included. Supersedes HEINTZ 91.



$\chi_{b0}(2P)$ DECAY MODES

Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1 $\gamma \Upsilon(2S)$	$(4.6 \pm 2.1) \%$	
Γ_2 $\gamma \Upsilon(1S)$	$(9 \pm 6) \times 10^{-3}$	
Γ_3 $D^0 X$	$< 8.2 \%$	90%
Γ_4 $\pi^+ \pi^- K^+ K^- \pi^0$	$< 3.4 \times 10^{-5}$	90%
Γ_5 $2\pi^+ \pi^- K^- K_S^0$	$< 5 \times 10^{-5}$	90%
Γ_6 $2\pi^+ \pi^- K^- K_S^0 2\pi^0$	$< 2.2 \times 10^{-4}$	90%
Γ_7 $2\pi^+ 2\pi^- 2\pi^0$	$< 2.4 \times 10^{-4}$	90%
Γ_8 $2\pi^+ 2\pi^- K^+ K^-$	$< 1.5 \times 10^{-4}$	90%
Γ_9 $2\pi^+ 2\pi^- K^+ K^- \pi^0$	$< 2.2 \times 10^{-4}$	90%
Γ_{10} $2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	$< 1.1 \times 10^{-3}$	90%
Γ_{11} $3\pi^+ 2\pi^- K^- K_S^0 \pi^0$	$< 7 \times 10^{-4}$	90%
Γ_{12} $3\pi^+ 3\pi^-$	$< 7 \times 10^{-5}$	90%
Γ_{13} $3\pi^+ 3\pi^- 2\pi^0$	$< 1.2 \times 10^{-3}$	90%
Γ_{14} $3\pi^+ 3\pi^- K^+ K^-$	$< 1.5 \times 10^{-4}$	90%
Γ_{15} $3\pi^+ 3\pi^- K^+ K^- \pi^0$	$< 7 \times 10^{-4}$	90%
Γ_{16} $4\pi^+ 4\pi^-$	$< 1.7 \times 10^{-4}$	90%
Γ_{17} $4\pi^+ 4\pi^- 2\pi^0$	$< 6 \times 10^{-4}$	90%

$\chi_{b0}(2P)$ BRANCHING RATIOS

$\Gamma(\gamma \Upsilon(2S))/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$0.046 \pm 0.020 \pm 0.007$		³ HEINTZ	92 CSB2	$e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 0.028	90	⁴ LEES	11J BABR	$\Upsilon(3S) \rightarrow X \gamma$
< 0.089	90	⁵ CRAWFORD	92B CLE2	$e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$

³ Using $B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) = (1.44 \pm 0.10)\%$, $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (6.0 \pm 0.4 \pm 0.6)\%$ and assuming $e\mu$ universality. Supersedes HEINTZ 91.

⁴ LEES 11J quotes a central value of $\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(2S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}} = (-0.3 \pm 0.2_{-0.4}^{+0.5})\%$.

⁵ Using $B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) = (1.37 \pm 0.26)\%$, $B(\Upsilon(3S) \rightarrow \gamma \Upsilon(2S)) \times 2 B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) < 1.19 \times 10^{-4}$, and $B(\Upsilon(3S) \rightarrow \chi_{b0}(2P) \gamma) = 0.049$.

$\Gamma(\gamma \Upsilon(1S))/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
$0.009 \pm 0.006 \pm 0.001$		⁶ HEINTZ	92 CSB2	$e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 0.012	90	⁷ LEES	11J BABR	$\Upsilon(3S) \rightarrow X \gamma$
< 0.025	90	⁸ CRAWFORD	92B CLE2	$e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$

⁶ Using $B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.57 \pm 0.07)\%$, $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (6.0 \pm 0.4 \pm 0.6)\%$ and assuming $e\mu$ universality. Supersedes HEINTZ 91.

⁷ LEES 11J quotes a central value of $\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}} = (3.9 \pm 2.2^{+1.2}_{-0.6}) \times 10^{-4}$.

⁸ Using $B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.57 \pm 0.07)\%$, $B(\Upsilon(3S) \rightarrow \gamma \Upsilon(1S)) \times 2 B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) < 0.63 \times 10^{-4}$, and $B(\Upsilon(3S) \rightarrow \chi_{b0}(2P)\gamma) = 0.049$.

$\Gamma(D^0 X)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<8.2 × 10⁻²	90	9,10 BRIERE	08	CLEO $\Upsilon(3S) \rightarrow \gamma D^0 X$

⁹ For $p_{D^0} > 2.5$ GeV/c.

¹⁰ The authors also present their result as $(4.1 \pm 3.0 \pm 0.4) \times 10^{-2}$.

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

VALUE (units 10 ⁻⁴)	CL%	DOCUMENT ID	TECN	COMMENT
<0.34	90	11 ASNER	08A	CLEO $\Upsilon(3S) \rightarrow \gamma \pi^+ \pi^- K^+ K^- \pi^0$

¹¹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow \pi^+ \pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 2 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

VALUE (units 10 ⁻⁴)	CL%	DOCUMENT ID	TECN	COMMENT
<0.5	90	12 ASNER	08A	CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ \pi^- K^- K_S^0$

¹² ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ \pi^- K^- K_S^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

VALUE (units 10 ⁻⁴)	CL%	DOCUMENT ID	TECN	COMMENT
<2.2	90	13 ASNER	08A	CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ \pi^- K^- 2\pi^0$

¹³ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ \pi^- K^- K_S^0 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 13 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{\text{total}}$ Γ_7/Γ

VALUE (units 10 ⁻⁴)	CL%	DOCUMENT ID	TECN	COMMENT
<2.4	90	14 ASNER	08A	CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- 2\pi^0$

¹⁴ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 14 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

VALUE (units 10 ⁻⁴)	CL%	DOCUMENT ID	TECN	COMMENT
<1.5	90	15 ASNER	08A	CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^-$

¹⁵ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 9 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<2.2	90	¹⁶ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 2\pi^+2\pi^-K^+K^-\pi^0$ ¹⁶ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 13×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<11	90	¹⁷ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 2\pi^+2\pi^-K^+K^-2\pi^0$ ¹⁷ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 63×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}$ **Γ_{11}/Γ**

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<7	90	¹⁸ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 3\pi^+2\pi^-K^-K_S^0\pi^0$ ¹⁸ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 39×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(3\pi^+3\pi^-)/\Gamma_{\text{total}}$ **Γ_{12}/Γ**

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<0.7	90	¹⁹ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 3\pi^+3\pi^-$ ¹⁹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+3\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 4×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$ **Γ_{13}/Γ**

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<12	90	²⁰ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 3\pi^+3\pi^-2\pi^0$ ²⁰ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 72×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<1.5	90	²¹ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 3\pi^+3\pi^-K^+K^-$ ²¹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+3\pi^-K^+K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 9×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ **Γ_{15}/Γ**

<u>VALUE (units 10^{-4})</u>	<u>CL%</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<7	90	²² ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 3\pi^+3\pi^-K^+K^-\pi^0$ ²² ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P))]$ < 43×10^{-6} which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma\chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<1.7	90	²³ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 4\pi^+ 4\pi^-$
²³ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 4\pi^+ 4\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))]$ $< 10 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.				

$\Gamma(4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{\text{total}}$ Γ_{17}/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<6	90	²⁴ ASNER	08A CLEO	$\Upsilon(3S) \rightarrow \gamma 4\pi^+ 4\pi^- 2\pi^0$
²⁴ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))]$ $< 38 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.				

$\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}}$
 $\Gamma_2/\Gamma \times \Gamma_{21}^{\Upsilon(3S)}/\Gamma \Upsilon(3S)$

VALUE (units 10^{-4})	CL%	DOCUMENT ID	TECN	COMMENT
<8.2	90	²⁵ LEES	11J BABR	$\Upsilon(3S) \rightarrow X\gamma$
²⁵ LEES 11J quotes a central value of $\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}} = (3.9 \pm 2.2^{+1.2}_{-0.6}) \times 10^{-4}$ and derives a 90% CL upper limit of $B(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(1S)) < 1.2\%$ using $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (5.9 \pm 0.6)\%$.				

$\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(2S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}}$
 $\Gamma_1/\Gamma \times \Gamma_{21}^{\Upsilon(3S)}/\Gamma \Upsilon(3S)$

VALUE (units 10^{-3})	CL%	DOCUMENT ID	TECN	COMMENT
<1.6	90	²⁶ LEES	11J BABR	$\Upsilon(3S) \rightarrow X\gamma$
²⁶ LEES 11J quotes a central value of $\Gamma(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(2S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))/\Gamma_{\text{total}} = (-0.3 \pm 0.2^{+0.5}_{-0.4})\%$ and derives a 90% CL upper limit of $B(\chi_{b0}(2P) \rightarrow \gamma \Upsilon(2S)) < 2.8\%$ using $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (5.9 \pm 0.6)\%$.				

$\chi_{b0}(2P)$ REFERENCES

LEES	11J	PR D84 072002	J.P. Lees <i>et al.</i>	(BABAR Collab.)
ASNER	08A	PR D78 091103	D.M. Asner <i>et al.</i>	(CLEO Collab.)
BRIERE	08	PR D78 092007	R.A. Briere <i>et al.</i>	(CLEO Collab.)
ARTUSO	05	PRL 94 032001	M. Artuso <i>et al.</i>	(CLEO Collab.)
CRAWFORD	92B	PL B294 139	G. Crawford, R. Fulton	(CLEO Collab.)
HEINTZ	92	PR D46 1928	U. Heintz <i>et al.</i>	(CUSB II Collab.)
HEINTZ	91	PRL 66 1563	U. Heintz <i>et al.</i>	(CUSB Collab.)
MORRISON	91	PRL 67 1696	R.J. Morrison <i>et al.</i>	(CLEO Collab.)
NARAIN	91	PRL 66 3113	M. Narain <i>et al.</i>	(CUSB Collab.)