# $\chi_{b1}(1P)$

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

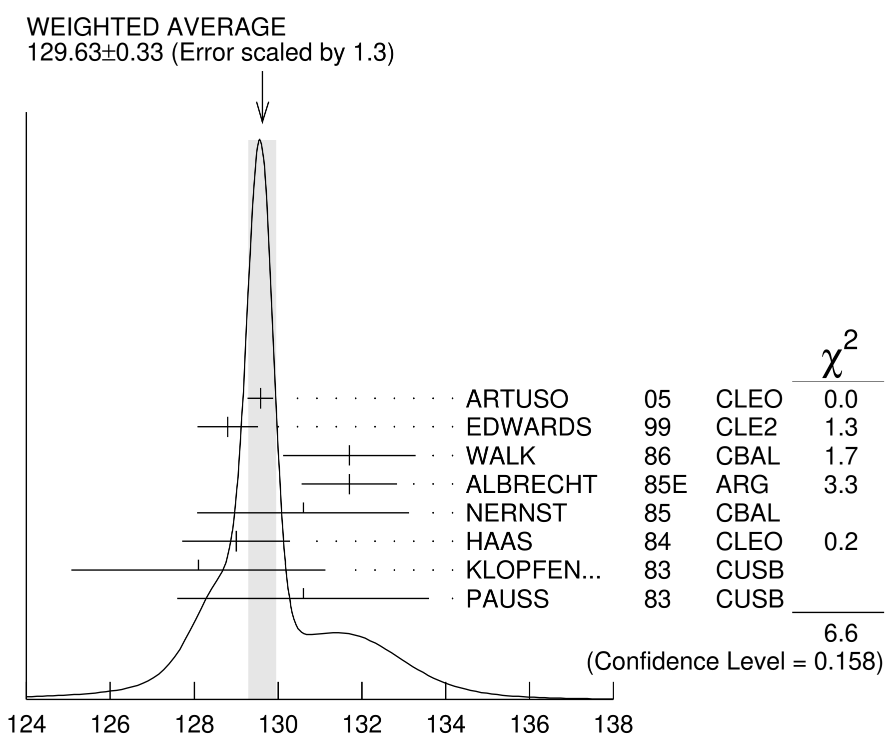
Observed in radiative decay of the $\Upsilon(2S)$, therefore $C = +$. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$. $J = 1$ from SKWARNICKI 87.

## $\chi_{b1}(1P)$ MASS

| *VALUE* (MeV) | *DOCUMENT ID* |
|---|---|
| **9892.78±0.26±0.31 OUR EVALUATION** | From average $\gamma$ energy below, using $\Upsilon(2S)$ mass = 10023.26 ± 0.31 MeV |

## $\gamma$ ENERGY IN $\Upsilon(2S)$ DECAY

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **129.63±0.33 OUR AVERAGE** | Error includes scale factor of 1.3. See the ideogram below. | | | |
| 129.58±0.09±0.29 | ARTUSO | 05 | CLEO | $\Upsilon(2S) \to \gamma X$ |
| 128.8 ±0.4 ±0.6 | EDWARDS | 99 | CLE2 | $\Upsilon(2S) \to \gamma \chi(1P)$ |
| 131.7 ±0.9 ±1.3 | WALK | 86 | CBAL | $\Upsilon(2S) \to \gamma \gamma \ell^+ \ell^-$ |
| 131.7 ±0.3 ±1.1 | ALBRECHT | 85E | ARG | $\Upsilon(2S) \to$ conv. $\gamma$ X |
| 130.6 ±0.8 ±2.4 | NERNST | 85 | CBAL | $\Upsilon(2S) \to \gamma$ X |
| 129 ±0.8 ±1 | HAAS | 84 | CLEO | $\Upsilon(2S) \to$ conv. $\gamma$ X |
| 128.1 ±0.4 ±3.0 | KLOPFEN... | 83 | CUSB | $\Upsilon(2S) \to \gamma$ X |
| 130.6 ±3.0 | PAUSS | 83 | CUSB | $\Upsilon(2S) \to \gamma \gamma \ell^+ \ell^-$ |




$\chi_{b1}(1P)$ mass (MeV)

## $\chi_{b1}(1P)$ DECAY MODES

| | Mode | Fraction ($\Gamma_i/\Gamma$) | Confidence level |
|---|---|---|---|
| $\Gamma_1$ | $\gamma \Upsilon(1S)$ | $(35.2 \pm 2.0)$ % | |
| $\Gamma_2$ | $D^0 X$ | $(12.6 \pm 2.2)$ % | |
| $\Gamma_3$ | $\pi^+ \pi^- K^+ K^- \pi^0$ | $(2.0 \pm 0.6) \times 10^{-4}$ | |
| $\Gamma_4$ | $2\pi^+ \pi^- K^- K^0_S$ | $(1.3 \pm 0.5) \times 10^{-4}$ | |
| $\Gamma_5$ | $2\pi^+ \pi^- K^- K^0_S 2\pi^0$ | $< 6 \times 10^{-4}$ | 90% |
| $\Gamma_6$ | $2\pi^+ 2\pi^- 2\pi^0$ | $(8.0 \pm 2.5) \times 10^{-4}$ | |
| $\Gamma_7$ | $2\pi^+ 2\pi^- K^+ K^-$ | $(1.5 \pm 0.5) \times 10^{-4}$ | |
| $\Gamma_8$ | $2\pi^+ 2\pi^- K^+ K^- \pi^0$ | $(3.5 \pm 1.2) \times 10^{-4}$ | |
| $\Gamma_9$ | $2\pi^+ 2\pi^- K^+ K^- 2\pi^0$ | $(8.6 \pm 3.2) \times 10^{-4}$ | |
| $\Gamma_{10}$ | $3\pi^+ 2\pi^- K^- K^0_S \pi^0$ | $(9.3 \pm 3.3) \times 10^{-4}$ | |
| $\Gamma_{11}$ | $3\pi^+ 3\pi^-$ | $(1.9 \pm 0.6) \times 10^{-4}$ | |
| $\Gamma_{12}$ | $3\pi^+ 3\pi^- 2\pi^0$ | $(1.7 \pm 0.5) \times 10^{-3}$ | |
| $\Gamma_{13}$ | $3\pi^+ 3\pi^- K^+ K^-$ | $(2.6 \pm 0.8) \times 10^{-4}$ | |
| $\Gamma_{14}$ | $3\pi^+ 3\pi^- K^+ K^- \pi^0$ | $(7.5 \pm 2.6) \times 10^{-4}$ | |
| $\Gamma_{15}$ | $4\pi^+ 4\pi^-$ | $(2.6 \pm 0.9) \times 10^{-4}$ | |
| $\Gamma_{16}$ | $4\pi^+ 4\pi^- 2\pi^0$ | $(1.4 \pm 0.6) \times 10^{-3}$ | |
| $\Gamma_{17}$ | $\omega$ anything | $(4.9 \pm 1.4)$ % | |
| $\Gamma_{18}$ | $\omega X_{tetra}$ | $< 4.44 \times 10^{-4}$ | 90% |
| $\Gamma_{19}$ | $J/\psi J/\psi$ | $< 2.7 \times 10^{-5}$ | 90% |
| $\Gamma_{20}$ | $J/\psi \psi(2S)$ | $< 1.7 \times 10^{-5}$ | 90% |
| $\Gamma_{21}$ | $\psi(2S) \psi(2S)$ | $< 6 \times 10^{-5}$ | 90% |
| $\Gamma_{22}$ | $J/\psi(1S)$ anything | $< 1.1 \times 10^{-3}$ | 90% |
| $\Gamma_{23}$ | $J/\psi(1S) X_{tetra}$ | $< 2.27 \times 10^{-4}$ | 90% |

## $\chi_{b1}(1P)$ BRANCHING RATIOS

### $\Gamma(\gamma \Upsilon(1S))/\Gamma_{total}$ $\qquad\qquad$ $\Gamma_1/\Gamma$

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **0.352±0.020 OUR AVERAGE** | | | | | |
| $0.356^{+0.016}_{-0.022} \pm 0.019$ | 964k | [1] FULSOM | 18 | BELL | $\Upsilon(2S) \to \gamma X$ |
| $0.364 \pm 0.017 \pm 0.019$ | | [2,3,4] LEES | 14M | BABR | $\Upsilon(2S) \to \gamma\gamma\mu^+\mu^-$ |
| $0.331 \pm 0.018 \pm 0.017$ | 3222 | [4,5] KORNICER | 11 | CLEO | $e^+e^- \to \gamma\gamma\ell^+\ell^-$ |
| $0.350 \pm 0.023 \pm 0.018$ | 13k | [6] LEES | 11J | BABR | $\Upsilon(2S) \to X\gamma$ |
| $0.34 \pm 0.07 \pm 0.02$ | 53 | [4,7,8] WALK | 86 | CBAL | $\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$ |
| $0.47 \pm 0.18$ | | KLOPFEN... | 83 | CUSB | $\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$ |

[1] FULSOM 18 reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (2.45 \pm 0.02^{+0.11}_{-0.15}) \times 10^{-2}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

[2] LEES 14M quotes $\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma \chi_{b1}(1P))/\Gamma_{total} = (2.51 \pm 0.12)$ % combining the results from samples of $\Upsilon(2S) \to \gamma\gamma\mu^+\mu^-$ with and without converted photons.

[3] LEES 14M reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (2.51 \pm 0.12) \times 10^{-2}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
[4] Assuming $B(\Upsilon(1S) \to \mu^+ \mu^-) = (2.48 \pm 0.05)\%$.
[5] KORNICER 11 reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (22.8 \pm 0.4 \pm 1.2) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
[6] LEES 11J reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (24.1 \pm 0.6 \pm 1.5) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.
[7] WALK 86 quotes $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) \times B(\chi_{b1}(1P) \to \gamma \Upsilon(1S)) \times B(\Upsilon(1S) \to \ell^+ \ell^-) = (5.8 \pm 0.9 \pm 0.7)\ \%$.
[8] WALK 86 reports $[\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (23.4 \pm 3.63 \pm 2.82) \times 10^{-3}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

## $\Gamma(D^0 X)/\Gamma_{total}$ — $\Gamma_2/\Gamma$

| VALUE (units $10^{-2}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **12.6±1.9±1.1** | 2310 | [1] BRIERE | 08 | CLEO | $\Upsilon(2S) \to \gamma D^0 X$ |

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

## $\Gamma(\pi^+ \pi^- K^+ K^- \pi^0)/\Gamma_{total}$ — $\Gamma_3/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **2.0±0.6±0.1** | 18 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma \pi^+ \pi^- K^+ K^- \pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to \pi^+ \pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (14 \pm 3 \pm 3) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

## $\Gamma(2\pi^+ \pi^- K^- K^0_S)/\Gamma_{total}$ — $\Gamma_4/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **1.3±0.5±0.1** | 11 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ \pi^- K^- K^0_S$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ \pi^- K^- K^0_S)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (9 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

## $\Gamma(2\pi^+ \pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}$ — $\Gamma_5/\Gamma$

| VALUE (units $10^{-4}$) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<6** | 90 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ \pi^- K^- 2\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ \pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] < 42 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = 6.9 \times 10^{-2}$.

### $\Gamma(2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}$ $\Gamma_6/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **8.0±2.4±0.4** | 46 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- 2\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (55 \pm 9 \pm 14) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

### $\Gamma(2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}$ $\Gamma_7/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **1.5±0.5±0.1** | 18 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^-$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (10 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

### $\Gamma(2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}$ $\Gamma_8/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **3.5±1.2±0.2** | 22 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (24 \pm 6 \pm 6) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

### $\Gamma(2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{total}$ $\Gamma_9/\Gamma$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **8.6±3.2±0.4** | 26 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (59 \pm 14 \pm 17) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **9.3±3.3±0.5** | 21 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 3\pi^+ 2\pi^- K^- K^0_S \pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+ 2\pi^- K^- K^0_S \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (64 \pm 16 \pm 16) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **1.9±0.6±0.1** | 25 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 3\pi^+ 3\pi^-$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+ 3\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))] = (13 \pm 3 \pm 3) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **17±5±1** | 56 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 3\pi^+3\pi^-2\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (119 \pm 18 \pm 32) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **2.6±0.8±0.1** | 21 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (18 \pm 4 \pm 4) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **7.5±2.6±0.4** | 28 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (52 \pm 11 \pm 14) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **2.6±0.9±0.1** | 24 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 4\pi^+4\pi^-$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 4\pi^+4\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (18 \pm 4 \pm 5) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

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

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **14±5±1** | 26 | [1] ASNER | 08A | CLEO | $\Upsilon(2S) \to \gamma 4\pi^+4\pi^-2\pi^0$ |

[1] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 4\pi^+4\pi^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (96 \pm 24 \pm 29) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

### $\Gamma(\omega\,\text{anything})/\Gamma_{total}$ — $\Gamma_{17}/\Gamma$

| VALUE (units $10^{-2}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **4.9±1.3±0.6** | 51k | JIA | 17A | BELL | $e^+e^- \to$ hadrons |

### $\Gamma(\omega X_{tetra})/\Gamma_{total}$ $\Gamma_{18}/\Gamma$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<44.4 × 10$^{-5}$** | 90 | [1] JIA | 17A | BELL | $e^+ e^- \to$ hadrons |

[1] For a tetraquark state $X_{tetra}$, with mass in the range 1.16–2.46 GeV and width in the range 0–0.3 GeV. Measured 90% CL limits as a function of $X_{tetra}$ mass and width range from $3.3 \times 10^{-5}$ to $44.4 \times 10^{-5}$.

### $\Gamma(J/\psi J/\psi)/\Gamma_{total}$ $\Gamma_{19}/\Gamma$

| VALUE (units $10^{-5}$) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<2.7** | 90 | [1] SHEN | 12 | BELL | $\Upsilon(2S) \to \gamma \psi X$ |

[1] SHEN 12 reports $< 2.7 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b1}(1P) \to J/\psi J/\psi)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$.

### $\Gamma(J/\psi \psi(2S))/\Gamma_{total}$ $\Gamma_{20}/\Gamma$

| VALUE (units $10^{-5}$) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<1.7** | 90 | [1] SHEN | 12 | BELL | $\Upsilon(2S) \to \gamma \psi X$ |

[1] SHEN 12 reports $< 1.7 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b1}(1P) \to J/\psi \psi(2S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$.

### $\Gamma(\psi(2S) \psi(2S))/\Gamma_{total}$ $\Gamma_{21}/\Gamma$

| VALUE (units $10^{-5}$) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<6** | 90 | [1] SHEN | 12 | BELL | $\Upsilon(2S) \to \gamma \psi X$ |

[1] SHEN 12 reports $< 6.2 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b1}(1P) \to \psi(2S) \psi(2S))/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma \chi_{b1}(1P))]$ assuming $B(\Upsilon(2S) \to \gamma \chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$.

### $\Gamma(J/\psi(1S)\text{anything})/\Gamma_{total}$ $\Gamma_{22}/\Gamma$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<1.1 × 10$^{-3}$** | 90 | JIA | 17A | BELL | $e^+ e^- \to$ hadrons |

### $\Gamma(J/\psi(1S) X_{tetra})/\Gamma_{total}$ $\Gamma_{23}/\Gamma$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<22.7 × 10$^{-5}$** | 90 | [1] JIA | 17A | BELL | $e^+ e^- \to$ hadrons |

[1] For a tetraquark state $X_{tetra}$, with mass in the range 1.16–2.46 GeV and width in the range 0–0.3 GeV. Measured 90% CL limits as a function of $X_{tetra}$ mass and width range from $1.8 \times 10^{-5}$ to $22.7 \times 10^{-5}$.

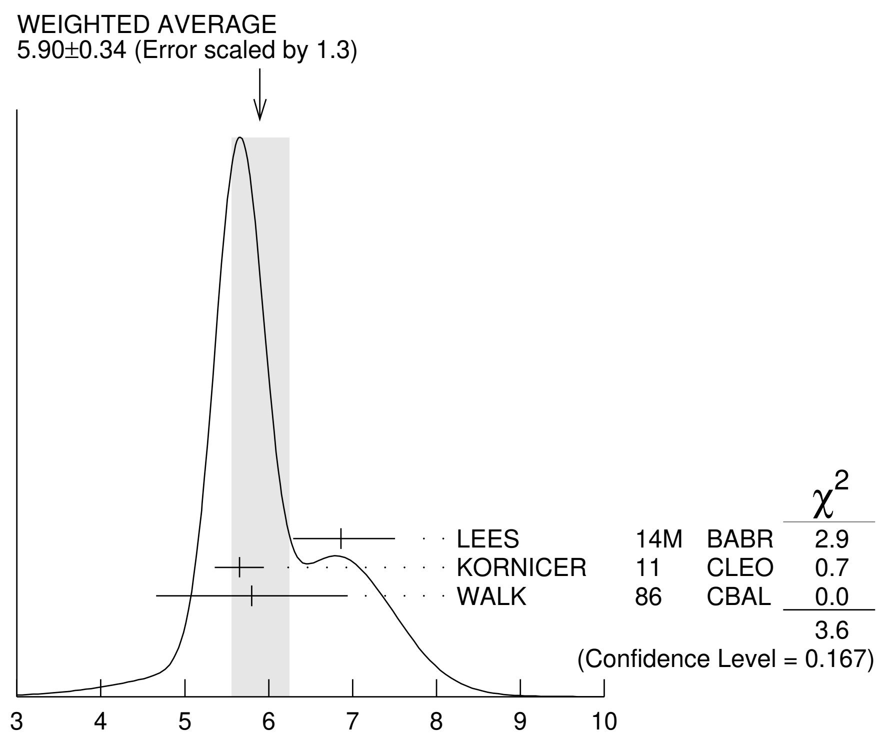
## $\chi_{b1}(1P)$ Cross-Particle Branching Ratios

### $\Gamma(\chi_{b1}(1P) \to \gamma \Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma \chi_{b1}(1P))/\Gamma_{total}$ $\Gamma_1/\Gamma \times \Gamma_{59}^{\Upsilon(2S)}/\Gamma^{\Upsilon(2S)}$

| VALUE (units $10^{-3}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **24.1±0.6±1.5** | 13k | LEES | 11J | BABR | $\Upsilon(2S) \to X \gamma$ |

## $B(\chi_{b1}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

| VALUE (units $10^{-4}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **5.90±0.34 OUR AVERAGE** | | Error includes scale factor of 1.3. See the ideogram below. | | | |
| $6.86^{+0.47}_{-0.45}{}^{+0.44}_{-0.35}$ | | [1] LEES | 14M | BABR | $\Upsilon(2S) \to \gamma\gamma\mu^+\mu^-$ |
| $5.65\pm0.11\pm0.27$ | 3222 | KORNICER | 11 | CLEO | $e^+e^- \to \gamma\gamma\ell^+\ell^-$ |
| $5.8\ \pm0.9\ \pm0.7$ | 53 | WALK | 86 | CBAL | $\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$ |




[1] From a sample of $\Upsilon(2S) \to \gamma\gamma\mu^+\mu^-$ with one converted photon.

$B(\chi_{b1}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$ (units $10^{-4}$)

## $B(\chi_{b1}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(3S) \to \gamma\chi_{b1}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

| VALUE (units $10^{-5}$) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **1.30±0.34 OUR AVERAGE** | | | | | |
| $1.16^{+0.78}_{-0.67}{}^{+0.14}_{-0.16}$ | | [1] LEES | 14M | BABR | $\Upsilon(3S) \to \gamma\gamma\mu^+\mu^-$ |
| $1.33\pm0.30\pm0.23$ | 50 | KORNICER | 11 | CLEO | $e^+e^- \to \gamma\gamma\ell^+\ell^-$ |

[1] From a sample of $\Upsilon(3S) \to \gamma\gamma\mu^+\mu^-$ with converted photons.

## $B(\chi_{b2}(1P) \to pX + \bar{p}X)/B(\chi_{b1}(1P) \to pX + \bar{p}X)$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **1.068±0.010±0.040** | BRIERE | 07 | CLEO | $\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$ |

## $B(\chi_{b0}(1P) \to pX + \bar{p}X)/B(\chi_{b1}(1P) \to pX + \bar{p}X)$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **1.11±0.15±0.20** | BRIERE | 07 | CLEO | $\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$ |

# $\chi_{b1}(1P)$ REFERENCES


| | | | | |
|---|---|---|---|---|
| FULSOM | 18 | PRL 121 232001 | B.G. Fulsom *et al.* | (BELLE Collab.) |
| JIA | 17A | PR D96 112002 | S. Jia *et al.* | (BELLE Collab.) |
| LEES | 14M | PR D90 112010 | J.P. Lees *et al.* | (BABAR Collab.) |
| 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.) |
| BRIERE | 07 | PR D76 012005 | 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+) |