

$\chi_{b0}(1P)$

$I^G(J^{PC}) = 0^+(0^{++})$   
 $J$  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                                                                         |
|-----------------------------------------|-------------------------------------------------------------------------------------|
| <b>9859.44±0.42±0.31 OUR EVALUATION</b> | From average $\gamma$ energy below, using $\Upsilon(2S)$ mass = 10023.26 ± 0.31 MeV |

| $m_{\chi_{b1}(1P)} - m_{\chi_{b0}(1P)}$ | DOCUMENT ID | TECN     | COMMENT                                           |
|-----------------------------------------|-------------|----------|---------------------------------------------------|
| <b>32.49±0.93</b>                       | LEES        | 14M BABR | $\Upsilon(2S) \rightarrow \gamma\gamma\mu^+\mu^-$ |

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

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

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

| Mode                                              | Fraction ( $\Gamma_i/\Gamma$ )  | Confidence level |
|---------------------------------------------------|---------------------------------|------------------|
| $\Gamma_1 \quad \gamma \Upsilon(1S)$              | ( 1.94±0.27 ) %                 |                  |
| $\Gamma_2 \quad D^0 X$                            | < 10.4 %                        | 90%              |
| $\Gamma_3 \quad \pi^+ \pi^- K^+ K^- \pi^0$        | < 1.6 × 10 <sup>-4</sup>        | 90%              |
| $\Gamma_4 \quad 2\pi^+ \pi^- K^- K_S^0$           | < 5 × 10 <sup>-5</sup>          | 90%              |
| $\Gamma_5 \quad 2\pi^+ \pi^- K^- K_S^0 2\pi^0$    | < 5 × 10 <sup>-4</sup>          | 90%              |
| $\Gamma_6 \quad 2\pi^+ 2\pi^- 2\pi^0$             | < 2.1 × 10 <sup>-4</sup>        | 90%              |
| $\Gamma_7 \quad 2\pi^+ 2\pi^- K^+ K^-$            | ( 1.1 ±0.6 ) × 10 <sup>-4</sup> |                  |
| $\Gamma_8 \quad 2\pi^+ 2\pi^- K^+ K^- \pi^0$      | < 2.7 × 10 <sup>-4</sup>        | 90%              |
| $\Gamma_9 \quad 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$     | < 5 × 10 <sup>-4</sup>          | 90%              |
| $\Gamma_{10} \quad 3\pi^+ 2\pi^- K^- K_S^0 \pi^0$ | < 1.6 × 10 <sup>-4</sup>        | 90%              |
| $\Gamma_{11} \quad 3\pi^+ 3\pi^-$                 | < 8 × 10 <sup>-5</sup>          | 90%              |
| $\Gamma_{12} \quad 3\pi^+ 3\pi^- 2\pi^0$          | < 6 × 10 <sup>-4</sup>          | 90%              |
| $\Gamma_{13} \quad 3\pi^+ 3\pi^- K^+ K^-$         | ( 2.4 ±1.2 ) × 10 <sup>-4</sup> |                  |
| $\Gamma_{14} \quad 3\pi^+ 3\pi^- K^+ K^- \pi^0$   | < 1.0 × 10 <sup>-3</sup>        | 90%              |
| $\Gamma_{15} \quad 4\pi^+ 4\pi^-$                 | < 8 × 10 <sup>-5</sup>          | 90%              |

|               |                        |         |                  |     |
|---------------|------------------------|---------|------------------|-----|
| $\Gamma_{16}$ | $4\pi^+ 4\pi^- 2\pi^0$ | $< 2.1$ | $\times 10^{-3}$ | 90% |
| $\Gamma_{17}$ | $J/\psi J/\psi$        | $< 7$   | $\times 10^{-5}$ | 90% |
| $\Gamma_{18}$ | $J/\psi \psi(2S)$      | $< 1.2$ | $\times 10^{-4}$ | 90% |
| $\Gamma_{19}$ | $\psi(2S) \psi(2S)$    | $< 3.1$ | $\times 10^{-5}$ | 90% |
| $\Gamma_{20}$ | $J/\psi(1S)$ anything  | $< 2.3$ | $\times 10^{-3}$ | 90% |

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

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

| VALUE (%)                                                                     | CL% | EVTs | DOCUMENT ID  | TECN | COMMENT                                                     |
|-------------------------------------------------------------------------------|-----|------|--------------|------|-------------------------------------------------------------|
| <b><math>1.94 \pm 0.27</math> OUR AVERAGE</b>                                 |     |      |              |      |                                                             |
| $2.07 \pm 0.24 \pm 0.21$                                                      |     | 1,2  | LEES         | 14M  | BABR $\Upsilon(2S) \rightarrow \gamma \gamma \mu^+ \mu^-$   |
| $1.76 \pm 0.30 \pm 0.18$                                                      |     | 87   | 3,4 KORNICER | 11   | CLEO $e^+ e^- \rightarrow \gamma \gamma \ell^+ \ell^-$      |
| • • • We do not use the following data for averages, fits, limits, etc. • • • |     |      |              |      |                                                             |
| $< 4.6$                                                                       | 90  | 5    | LEES         | 11J  | BABR $\Upsilon(2S) \rightarrow X \gamma$                    |
| $< 6$                                                                         | 90  |      | WALK         | 86   | CBAL $\Upsilon(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |
| $< 11$                                                                        | 90  |      | PAUSS        | 83   | CUSB $\Upsilon(2S) \rightarrow \gamma \gamma \ell^+ \ell^-$ |

<sup>1</sup> LEES 14M quotes  $\Gamma(\chi_{b0}(1P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))/\Gamma_{\text{total}} = (7.75 \pm 0.91) \times 10^{-4}$  combining the results from samples of  $\Upsilon(2S) \rightarrow \gamma \gamma \mu^+ \mu^-$  with and without converted photons. Assumes  $B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.48 \pm 0.05)\%$ .

<sup>2</sup> LEES 14M reports  $[\Gamma(\chi_{b0}(1P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$  =  $(7.75 \pm 0.91) \times 10^{-4}$  which we divide by our best value  $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . Our first error is their experiment's error and our second error is the systematic error from using our best value.

<sup>3</sup> Assuming  $B(\Upsilon(1S) \rightarrow \ell^+ \ell^-) = (2.48 \pm 0.05)\%$ .

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

<sup>5</sup> LEES 11J quotes a central value of  $\Gamma(\chi_{b0}(1P) \rightarrow \gamma \Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))/\Gamma_{\text{total}} = (8.3 \pm 5.6^{+3.7}_{-2.6}) \times 10^{-4}$ .

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

| VALUE                                        | CL% | DOCUMENT ID | TECN | COMMENT                                      |
|----------------------------------------------|-----|-------------|------|----------------------------------------------|
| <b><math>&lt; 10.4 \times 10^{-2}</math></b> | 90  | 6,7 BRIERE  | 08   | CLEO $\Upsilon(2S) \rightarrow \gamma D^0 X$ |

<sup>6</sup> For  $p_{D^0} > 2.5 \text{ GeV}/c$ .

<sup>7</sup> The authors also present their result as  $(5.6 \pm 3.6 \pm 0.5) \times 10^{-2}$ .

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

| VALUE (units $10^{-4}$ )     | CL% | DOCUMENT ID | TECN | COMMENT                                                          |
|------------------------------|-----|-------------|------|------------------------------------------------------------------|
| <b><math>&lt; 1.6</math></b> | 90  | 8 ASNER     | 08A  | CLEO $\Upsilon(2S) \rightarrow \gamma \pi^+ \pi^- K^+ K^- \pi^0$ |

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

$\Gamma(2\pi^+ \pi^- K^- K_S^0)/\Gamma_{\text{total}}$   $\Gamma_4/\Gamma$

| VALUE (units $10^{-4}$ )     | CL% | DOCUMENT ID | TECN | COMMENT                                                       |
|------------------------------|-----|-------------|------|---------------------------------------------------------------|
| <b><math>&lt; 0.5</math></b> | 90  | 9 ASNER     | 08A  | CLEO $\Upsilon(2S) \rightarrow \gamma 2\pi^+ \pi^- K^- K_S^0$ |

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

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                         | CL% | DOCUMENT ID             | TECN | COMMENT                                                |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|------|--------------------------------------------------------|
| <b>&lt;5</b>                                                                                                                                                                                                                                                                                                     | 90  | <sup>10</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 2\pi^+\pi^-K^-2\pi^0$ |
| <sup>10</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+\pi^-K^-K_S^0 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $< 18 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                         |      |                                                        |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                | CL% | DOCUMENT ID             | TECN | COMMENT                                              |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|------|------------------------------------------------------|
| <b>&lt;2.1</b>                                                                                                                                                                                                                                                                                          | 90  | <sup>11</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 2\pi^+2\pi^-2\pi^0$ |
| <sup>11</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+2\pi^-2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $< 8 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                         |      |                                                      |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                                                                                                                                                            | EVTS | DOCUMENT ID             | TECN | COMMENT                                              |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|-------------------------|------|------------------------------------------------------|
| <b><math>1.1 \pm 0.6 \pm 0.1</math></b>                                                                                                                                                                                                                                                                                                                                                                                                             | 7    | <sup>12</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 2\pi^+2\pi^-K^+K^-$ |
| <sup>12</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+2\pi^-K^+K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $= (4 \pm 2 \pm 1) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . Our first error is their experiment's error and our second error is the systematic error from using our best value. |      |                         |      |                                                      |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                      | CL% | DOCUMENT ID             | TECN | COMMENT                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|------|-----------------------------------------------------------|
| <b>&lt;2.7</b>                                                                                                                                                                                                                                                                                                | 90  | <sup>13</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 2\pi^+2\pi^-K^+K^-\pi^0$ |
| <sup>13</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+2\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $< 10 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                         |      |                                                           |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                       | CL% | DOCUMENT ID             | TECN | COMMENT                                                    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|------|------------------------------------------------------------|
| <b>&lt;5</b>                                                                                                                                                                                                                                                                                                   | 90  | <sup>14</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 2\pi^+2\pi^-K^+K^-2\pi^0$ |
| <sup>14</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $< 20 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                         |      |                                                            |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                       | CL% | DOCUMENT ID             | TECN | COMMENT                                                     |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|-------------------------|------|-------------------------------------------------------------|
| <b>&lt;1.6</b>                                                                                                                                                                                                                                                                                                 | 90  | <sup>15</sup> ASNER 08A | CLEO | $\Upsilon(2S) \rightarrow \gamma 3\pi^+2\pi^-K^-K_S^0\pi^0$ |
| <sup>15</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ $< 6 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                         |      |                                                             |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                | CL% | DOCUMENT ID         | TECN     | COMMENT                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------|----------|-------------------------------------------------|
| <b>&lt;0.8</b>                                                                                                                                                                                                                                                                                          | 90  | <sup>16</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 3\pi^+ 3\pi^-$ |
| <sup>16</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+ 3\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$< 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                     |          |                                                 |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                        | CL% | DOCUMENT ID         | TECN     | COMMENT                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------|----------|--------------------------------------------------------|
| <b>&lt;6</b>                                                                                                                                                                                                                                                                                                    | 90  | <sup>17</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 3\pi^+ 3\pi^- 2\pi^0$ |
| <sup>17</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+ 3\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$< 22 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                     |          |                                                        |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                                                                                                                                                                    | EVTS | DOCUMENT ID         | TECN     | COMMENT                                                 |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|---------------------|----------|---------------------------------------------------------|
| <b><math>2.4 \pm 1.2 \pm 0.2</math></b>                                                                                                                                                                                                                                                                                                                                                                                                                     | 9    | <sup>18</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 3\pi^+ 3\pi^- K^+ K^-$ |
| <sup>18</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+ 3\pi^- K^+ K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$= (9 \pm 4 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . Our first error is their experiment's error and our second error is the systematic error from using our best value. |      |                     |          |                                                         |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                              | CL% | DOCUMENT ID         | TECN     | COMMENT                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------|----------|--------------------------------------------------------------|
| <b>&lt;10</b>                                                                                                                                                                                                                                                                                                         | 90  | <sup>19</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 3\pi^+ 3\pi^- K^+ K^-\pi^0$ |
| <sup>19</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 3\pi^+ 3\pi^- K^+ K^-\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$< 37 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                     |          |                                                              |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                | CL% | DOCUMENT ID         | TECN     | COMMENT                                         |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------|----------|-------------------------------------------------|
| <b>&lt;0.8</b>                                                                                                                                                                                                                                                                                          | 90  | <sup>20</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 4\pi^+ 4\pi^-$ |
| <sup>20</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 4\pi^+ 4\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$< 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                     |          |                                                 |

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

| VALUE (units $10^{-4}$ )                                                                                                                                                                                                                                                                                        | CL% | DOCUMENT ID         | TECN     | COMMENT                                                |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|---------------------|----------|--------------------------------------------------------|
| <b>&lt;21</b>                                                                                                                                                                                                                                                                                                   | 90  | <sup>21</sup> ASNER | 08A CLEO | $\Upsilon(2S) \rightarrow \gamma 4\pi^+ 4\pi^- 2\pi^0$ |
| <sup>21</sup> ASNER 08A reports $[\Gamma(\chi_{b0}(1P) \rightarrow 4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>$< 77 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = 3.8 \times 10^{-2}$ . |     |                     |          |                                                        |

### $\Gamma(J/\psi J/\psi)/\Gamma_{\text{total}}$ $\Gamma_{17}/\Gamma$

| VALUE (units $10^{-5}$ )                                                                                                                                                                                                                                                                                       | CL% | DOCUMENT ID        | TECN    | COMMENT                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|---------|------------------------------------------|
| <b>&lt;7</b>                                                                                                                                                                                                                                                                                                   | 90  | <sup>22</sup> SHEN | 12 BELL | $\Upsilon(2S) \rightarrow \gamma \psi X$ |
| <sup>22</sup> SHEN 12 reports $< 7.1 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \rightarrow J/\psi J/\psi)/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P))]$<br>assuming $B(\Upsilon(2S) \rightarrow \gamma \chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . |     |                    |         |                                          |

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

| VALUE (units $10^{-5}$ )                                                                                                                                                                                                                                                                                  | CL% | DOCUMENT ID        | TECN    | COMMENT                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|---------|-----------------------------------------|
| <b>&lt;12</b>                                                                                                                                                                                                                                                                                             | 90  | <sup>23</sup> SHEN | 12 BELL | $\Upsilon(2S) \rightarrow \gamma\psi X$ |
| <sup>23</sup> SHEN 12 reports $< 12 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \rightarrow J/\psi\psi(2S))/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ assuming $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . |     |                    |         |                                         |

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

| VALUE (units $10^{-5}$ )                                                                                                                                                                                                                                                                                     | CL% | DOCUMENT ID        | TECN    | COMMENT                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|---------|-----------------------------------------|
| <b>&lt;3.1</b>                                                                                                                                                                                                                                                                                               | 90  | <sup>24</sup> SHEN | 12 BELL | $\Upsilon(2S) \rightarrow \gamma\psi X$ |
| <sup>24</sup> SHEN 12 reports $< 3.1 \times 10^{-5}$ from a measurement of $[\Gamma(\chi_{b0}(1P) \rightarrow \psi(2S)\psi(2S))/\Gamma_{\text{total}}] \times [B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))]$ assuming $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4) \times 10^{-2}$ . |     |                    |         |                                         |

 $\Gamma(J/\psi(1S)\text{anything})/\Gamma_{\text{total}}$   $\Gamma_{20}/\Gamma$ 

| VALUE                                      | CL% | DOCUMENT ID | TECN     | COMMENT                             |
|--------------------------------------------|-----|-------------|----------|-------------------------------------|
| <b>&lt;2.3 <math>\times 10^{-3}</math></b> | 90  | JIA         | 17A BELL | $e^+e^- \rightarrow \text{hadrons}$ |

 **$\chi_{b0}(1P)$  CROSS-PARTICLE BRANCHING RATIOS**
 $\Gamma(\chi_{b0}(1P) \rightarrow \gamma\Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))/\Gamma_{\text{total}}$   $\Gamma_1/\Gamma \times \Gamma_{73}^{\Upsilon(2S)}/\Gamma\Upsilon(2S)$ 

| VALUE                                                                                                                                                                                                                                                                                                                                                                                                                                   | CL% | DOCUMENT ID        | TECN     | COMMENT                            |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|--------------------|----------|------------------------------------|
| <b>&lt;1.7 <math>\times 10^{-3}</math></b>                                                                                                                                                                                                                                                                                                                                                                                              | 90  | <sup>25</sup> LEES | 11J BABR | $\Upsilon(2S) \rightarrow X\gamma$ |
| <sup>25</sup> LEES 11J quotes a central value of $\Gamma(\chi_{b0}(1P) \rightarrow \gamma\Upsilon(1S))/\Gamma_{\text{total}} \times \Gamma(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))/\Gamma_{\text{total}} = (8.3 \pm 5.6^{+3.7}_{-2.6}) \times 10^{-4}$ and derives a 90% CL upper limit of $\Gamma(\gamma\Upsilon(1S))/\Gamma_{\text{total}} < 4.6\%$ using $B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P)) = (3.8 \pm 0.4)\%$ . |     |                    |          |                                    |

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

| VALUE (units $10^{-5}$ )                    | EVTS | DOCUMENT ID        | TECN     | COMMENT                                           |
|---------------------------------------------|------|--------------------|----------|---------------------------------------------------|
| <b>1.67<math>\pm</math>0.28 OUR AVERAGE</b> |      |                    |          |                                                   |
| 2.9 $^{+1.7}_{-1.4}$ $^{+0.1}_{-0.8}$       |      | <sup>26</sup> LEES | 14M BABR | $\Upsilon(2S) \rightarrow \gamma\gamma\mu^+\mu^-$ |
| 1.63 $\pm$ 0.24 $\pm$ 0.15                  | 87   | KORNICER           | 11 CLEO  | $e^+e^- \rightarrow \gamma\gamma\ell^+\ell^-$     |

<sup>26</sup> From a sample of  $\Upsilon(2S) \rightarrow \gamma\gamma\mu^+\mu^-$  with one converted photon. **$[B(\chi_{b0}(1P) \rightarrow \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \rightarrow \gamma\chi_{b0}(1P))] / [B(\chi_{b1}(1P) \rightarrow \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \rightarrow \gamma\chi_{b1}(1P))]$** 

| VALUE (%)                                                                                                   | DOCUMENT ID        | TECN     | COMMENT                                           |
|-------------------------------------------------------------------------------------------------------------|--------------------|----------|---------------------------------------------------|
| <b>3.28<math>\pm</math>0.37</b>                                                                             | <sup>27</sup> LEES | 14M BABR | $\Upsilon(2S) \rightarrow \gamma\gamma\mu^+\mu^-$ |
| <sup>27</sup> From a sample of $\Upsilon(2S) \rightarrow \gamma\gamma\mu^+\mu^-$ without converted photons. |                    |          |                                                   |

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

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