

**$Z_b(10650)$** 

$$I^G(J^{PC}) = 1^+(1^{+-})$$

$I, G, C$  need confirmation.

OMITTED FROM SUMMARY TABLE

was  $X(10650)^\pm$ 

Properties incompatible with a  $q\bar{q}$  structure (exotic state). See the review on non- $q\bar{q}$  states.

Observed by BONDAR 12 in  $\Upsilon(5S)$  decays to  $\Upsilon(nS)\pi^+\pi^-$  ( $n = 1, 2, 3$ ) and  $h_b(mP)\pi^+\pi^-$  ( $m = 1, 2$ ).  $J^P = 1^+$  is favored from angular analyses.

 **$Z_b(10650)$  MASS**

| <u>VALUE (MeV)</u>  | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                                   |
|---|----------------------|-------------|--|
| <b><math>10652.2 \pm 1.5</math></b>   | <sup>1</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow$ hadrons                |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |                      |             |  |
| $10656.7 \pm 5.0^{+1.1}_{-3.1}$   | <sup>2</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$ |
| $10650.7 \pm 1.5^{+0.5}_{-0.2}$   | <sup>2</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$ |
| $10651.2 \pm 1.0^{+0.4}_{-0.3}$   | <sup>2</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |
| $10657 \pm 6 \pm 3$   | <sup>3</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$ |
| $10651 \pm 2 \pm 3$   | <sup>3</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$ |
| $10652 \pm 1 \pm 2$   | <sup>3</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |
| $10654 \pm 3 \pm 1_{-2}$  | <sup>3</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$      |
| $10651 \pm 2 \pm 3_{-3 \ -2}$   | <sup>3</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$      |

<sup>1</sup> Average of the BONDAR 12 measurements in separate channels.

<sup>2</sup> Correlated with the corresponding result from BONDAR 12.

<sup>3</sup> Superseded by the average measurement of BONDAR 12.

 **$Z_b(10650)$  WIDTH**

| <u>VALUE (MeV)</u>  | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                                   |
|---|----------------------|-------------|--|
| <b><math>11.5 \pm 2.2</math></b>  | <sup>4</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow$ hadrons                |
| ● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ● |                      |             |  |
| $12.1^{+11.3+2.7}_{-4.8-0.6}$   | <sup>5</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$ |
| $14.2 \pm 3.7^{+0.9}_{-0.4}$  | <sup>5</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$ |
| $9.3 \pm 2.2^{+0.3}_{-0.5}$   | <sup>5</sup> GARMASH | 15          | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |
| $16.3 \pm 9.8^{+6.0}_{-2.0}$  | <sup>6</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$ |
| $13.3 \pm 3.3^{+4.0}_{-3.0}$  | <sup>6</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$ |
| $8.4 \pm 2.0 \pm 2.0$   | <sup>6</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |
| $20.9^{+5.4+2.1}_{-4.7-5.7}$  | <sup>6</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$      |
| $19 \pm 7 \pm 11_{-7}$  | <sup>6</sup> BONDAR  | 12          | BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$      |

<sup>4</sup> Average of the BONDAR 12 measurements in separate channels.

<sup>5</sup> Correlated with the corresponding result from BONDAR 12.

<sup>6</sup> Superseded by the average measurement of BONDAR 12.

## $Z_b(10650)^+$ DECAY MODES

$Z_b(10650)^-$  decay modes are charge conjugates of the modes below.

| Mode   | Fraction ( $\Gamma_i/\Gamma$ )       |
|--|--------------------------------------|
| $\Gamma_1$ $\gamma(1S)\pi^+$                   | $(1.7^{+0.8}_{-0.6}) \times 10^{-3}$ |
| $\Gamma_2$ $\gamma(2S)\pi^+$                   | $(1.4^{+0.6}_{-0.4}) \%$             |
| $\Gamma_3$ $\gamma(3S)\pi^+$                   | $(1.6^{+0.7}_{-0.5}) \%$             |
| $\Gamma_4$ $h_b(1P)\pi^+$                      | $(8.4^{+2.9}_{-2.4}) \%$             |
| $\Gamma_5$ $h_b(2P)\pi^+$                      | $(15 \pm 4) \%$                      |
| $\Gamma_6$ $B^+\bar{B}^0$                      | not seen                             |
| $\Gamma_7$ $B^+\bar{B}^{*0} + B^{*+}\bar{B}^0$ | not seen                             |
| $\Gamma_8$ $B^{*+}\bar{B}^{*0}$                | $(74^{+4}_{-6}) \%$                  |

## $Z_b(10650)$ BRANCHING RATIOS

$\Gamma(\gamma(1S)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_1/\Gamma$

| VALUE (units $10^{-3}$ )    | DOCUMENT ID          | TECN | COMMENT  |
|-----------------------------|----------------------|------|--|
| $1.7^{+0.7+0.3}_{-0.6-0.2}$ | <sup>7</sup> GARMASH | 16   | BELL $e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|      |         |    |  |
|------|---------|----|--|
| seen | GARMASH | 15 | BELL $e^+e^- \rightarrow \gamma(1S)\pi^+\pi^-$ |
| seen | BONDAR  | 12 | BELL $e^+e^- \rightarrow \gamma(1S)\pi^+\pi^-$ |

<sup>7</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+\gamma(1S, 2S, 3S)$ ,  $\pi^+h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(\gamma(2S)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_2/\Gamma$

| VALUE (units $10^{-2}$ )         | DOCUMENT ID          | TECN | COMMENT                                       |
|----------------------------------|----------------------|------|---|
| $1.39^{+0.48+0.34}_{-0.38-0.23}$ | <sup>8</sup> GARMASH | 16   | $e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|      |         |    |  |
|------|---------|----|--|
| seen | GARMASH | 15 | BELL $e^+e^- \rightarrow \gamma(2S)\pi^+\pi^-$ |
| seen | BONDAR  | 12 | BELL $e^+e^- \rightarrow \gamma(2S)\pi^+\pi^-$ |

<sup>8</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+\gamma(1S, 2S, 3S)$ ,  $\pi^+h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(\Upsilon(3S)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_3/\Gamma$

| <u>VALUE (units <math>10^{-2}</math>)</u> | <u>DOCUMENT ID</u>   | <u>TECN</u> | <u>COMMENT</u>                                      |
|---|----------------------|-------------|---|
| $1.63^{+0.53+0.39}_{-0.42-0.28}$          | <sup>9</sup> GARMASH | 16          | BELL $e^+e^- \rightarrow \pi^- B^{*+} \bar{B}^{*0}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|      |         |    |  |
|------|---------|----|--|
| seen | GARMASH | 15 | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |
| seen | BONDAR  | 12 | BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$ |

<sup>9</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+\Upsilon(1S, 2S, 3S)$ ,  $\pi^+h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(h_b(1P)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_4/\Gamma$

| <u>VALUE (units <math>10^{-2}</math>)</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                                      |
|---|-----------------------|-------------|---|
| $8.41^{+2.43+1.49}_{-2.12-1.06}$          | <sup>10</sup> GARMASH | 16          | BELL $e^+e^- \rightarrow \pi^- B^{*+} \bar{B}^{*0}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|      |                      |    |   |
|------|----------------------|----|---|
| seen | <sup>11</sup> MIZUK  | 16 | BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$ |
| seen | <sup>12</sup> BONDAR | 12 | BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$ |

<sup>10</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+\Upsilon(1S, 2S, 3S)$ ,  $\pi^+h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16.

<sup>11</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>12</sup> Using  $e^+e^-$  energies near the  $\Upsilon(10860)$ .

$\Gamma(h_b(2P)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_5/\Gamma$

| <u>VALUE (units <math>10^{-2}</math>)</u> | <u>DOCUMENT ID</u>    | <u>TECN</u> | <u>COMMENT</u>                                      |
|---|-----------------------|-------------|---|
| $14.7^{+3.2+2.8}_{-2.8-2.3}$              | <sup>13</sup> GARMASH | 16          | BELL $e^+e^- \rightarrow \pi^- B^{*+} \bar{B}^{*0}$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|               |                      |    |   |
|---------------|----------------------|----|---|
| possibly seen | <sup>14</sup> MIZUK  | 16 | BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$ |
| seen          | <sup>15</sup> BONDAR | 12 | BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$ |

<sup>13</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+\Upsilon(1S, 2S, 3S)$ ,  $\pi^+h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16.

<sup>14</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>15</sup> Using  $e^+e^-$  energies near the  $\Upsilon(10860)$ .

$\Gamma(B^+\bar{B}^0)/\Gamma_{\text{total}}$   $\Gamma_6/\Gamma$

| <u>VALUE</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>                                |
|--------------|--------------------|-------------|---|
| not seen     | GARMASH            | 16          | BELL $e^+e^- \rightarrow \pi^- B^+ \bar{B}^0$ |

$[\Gamma(B^+\bar{B}^{*0}) + \Gamma(B^{*+}\bar{B}^0)]/\Gamma_{\text{total}}$   $\Gamma_7/\Gamma$

| <u>VALUE</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u>   |
|--------------|--------------------|-------------|--|
| not seen     | GARMASH            | 16          | BELL $e^+e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$ |

| $\Gamma(B^{*+}\bar{B}^{*0})/\Gamma_{\text{total}}$ |      |                       |      |         | $\Gamma_8/\Gamma$                             |
|--|------|-----------------------|------|---------|---|
| VALUE (units $10^{-2}$ )                           | EVTS | DOCUMENT ID           | TECN | COMMENT |   |
| $73.7^{+3.4+2.7}_{-4.4-3.5}$                       | 161  | <sup>16</sup> GARMASH | 16   | BELL    | $e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$ |

<sup>16</sup> Assuming the  $Z_b(10650)$  decay width is saturated by the channels  $\pi^+ \gamma(1S, 2S, 3S)$ ,  $\pi^+ h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ , and using the results from BONDAR 12 and MIZUK 16. Using the mass and width of the  $Z_b(10650)$  from BONDAR 12.

| $\Gamma(B^{*+}\bar{B}^{*0})/[\Gamma(\gamma(1S)\pi^+) + \Gamma(\gamma(2S)\pi^+) + \Gamma(\gamma(3S)\pi^+) + \Gamma(h_b(1P)\pi^+) + \Gamma(h_b(2P)\pi^+)]$ |      |             |      |         | $\Gamma_8/(\Gamma_1+\Gamma_2+\Gamma_3+\Gamma_4+\Gamma_5)$ |
|--|------|-------------|------|---------|---|
| VALUE (units $10^{-2}$ )   | EVTS | DOCUMENT ID | TECN | COMMENT |   |

• • • We do not use the following data for averages, fits, limits, etc. • • •

|                                  |     |                       |    |      |   |
|----------------------------------|-----|-----------------------|----|------|---|
| $2.80^{+0.69+0.54}_{-0.40-0.36}$ | 161 | <sup>17</sup> GARMASH | 16 | BELL | $e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$ |
|----------------------------------|-----|-----------------------|----|------|---|

<sup>17</sup> Combined with the results of BONDAR 12 and MIZUK 16. Not independent from  $Z_b(10650)$  branching fractions to  $\pi^+ \gamma(1S, 2S, 3S)$ ,  $\pi^+ h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ .

### $Z_b(10650)$ REFERENCES

|         |    |                |                          |                 |
|---------|----|----------------|--------------------------|-----------------|
| GARMASH | 16 | PRL 116 212001 | A. Garmash <i>et al.</i> | (BELLE Collab.) |
| MIZUK   | 16 | PRL 117 142001 | R. Mizuk <i>et al.</i>   | (BELLE Collab.) |
| GARMASH | 15 | PR D91 072003  | A. Garmash <i>et al.</i> | (BELLE Collab.) |
| BONDAR  | 12 | PRL 108 122001 | A. Bondar <i>et al.</i>  | (BELLE Collab.) |