

**$T_{b\bar{b}1}(10650)^+$** 

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

$I, G, C$  need confirmation.

was  $Z_b(10650), X(10650)^\pm$

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

Observed by BONDAR 12 in  $\Upsilon(nS)$  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.

 **$T_{b\bar{b}1}(10650)^+$  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 $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$
$10651 \pm 2_{-3} \pm 3_{-2}$	<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 Superseded by the average measurement of BONDAR 12.

 **$T_{b\bar{b}1}(10650)^+$  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>1</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>2</sup> GARMASH	15	BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
$14.2 \pm 3.7^{+0.9}_{-0.4}$	<sup>2</sup> GARMASH	15	BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
$9.3 \pm 2.2^{+0.3}_{-0.5}$	<sup>2</sup> GARMASH	15	BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
$16.3 \pm 9.8^{+6.0}_{-2.0}$	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
$13.3 \pm 3.3^{+4.0}_{-3.0}$	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
$8.4 \pm 2.0 \pm 2.0$	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
$20.9^{+5.4+2.1}_{-4.7-5.7}$	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$
$19 \pm 7 \pm 11_{-7}$	<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.

## $T_{b\bar{b}1}(10650)^+$ DECAY MODES

$T_{b\bar{b}1}(10650)^-$  decay modes are charge conjugates of the modes below.

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

## $T_{b\bar{b}1}(10650)^+$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S)\pi^+)/\Gamma_{\text{total}}$	$\Gamma_1/\Gamma$
<u>VALUE (units <math>10^{-3}</math>)</u>	<u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

<b><math>1.7^{+0.7+0.3}_{-0.6-0.2}</math></b>	<sup>1</sup>	GARMASH	16	BELL	$e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$
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• • • We do not use the following data for averages, fits, limits, etc. • • •

seen	GARMASH	15	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
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seen	BONDAR	12	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
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<sup>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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.

$\Gamma(\Upsilon(2S)\pi^+)/\Gamma_{\text{total}}$	$\Gamma_2/\Gamma$
<u>VALUE (units <math>10^{-2}</math>)</u>	<u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>

<b><math>1.39^{+0.48+0.34}_{-0.38-0.23}</math></b>	<sup>1</sup>	GARMASH	16		$e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$
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• • • We do not use the following data for averages, fits, limits, etc. • • •

seen	GARMASH	15	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
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seen	BONDAR	12	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
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<sup>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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.

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

<u>VALUE (units <math>10^{-2}</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b><math>1.63^{+0.53+0.39}_{-0.42-0.28}</math></b>	<sup>1</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>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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>
<b><math>8.41^{+2.43+1.49}_{-2.12-1.06}</math></b>	<sup>1</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>2</sup> MIZUK	16	BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$
seen	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$

<sup>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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>2</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>3</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>
<b><math>14.7^{+3.2+2.8}_{-2.8-2.3}</math></b>	<sup>1</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>2</sup> MIZUK	16	BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$
seen	<sup>3</sup> BONDAR	12	BELL $e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$

<sup>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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>2</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>3</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>1</sup> GARMASH	16	BELL	$e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$

<sup>1</sup> Assuming the  $T_{b\bar{b}1}(10650)$  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  $T_{b\bar{b}1}(10650)$  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	
$2.80^{+0.69+0.54}_{-0.40-0.36}$	161	<sup>1</sup> GARMASH	16	BELL	$e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$

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

$2.80^{+0.69+0.54}_{-0.40-0.36}$	161	<sup>1</sup> GARMASH	16	BELL	$e^+e^- \rightarrow \pi^- B^{*+}\bar{B}^{*0}$
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<sup>1</sup> Combined with the results of BONDAR 12 and MIZUK 16. Not independent from  $T_{b\bar{b}1}(10650)$  branching fractions to  $\pi^+ \gamma(1S, 2S, 3S)$ ,  $\pi^+ h_b(1P, 2P)$ , and  $B^{*+}\bar{B}^{*0}$ .

### $T_{b\bar{b}1}(10650)^+$ 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.)