

$T_{b\bar{b}1}(10610)$

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

was $Z_b(10610)$, $X(10610)$

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.

$T_{b\bar{b}1}(10610)^\pm$ MASS

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
10607.2 ± 2.0	¹ BONDAR 12	BELL	$e^+e^- \rightarrow \text{hadrons}$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$10608.5 \pm 3.4^{+3.7}_{-1.4}$	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
$10608.1 \pm 1.2^{+1.5}_{-0.2}$	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
$10607.4 \pm 1.5^{+0.8}_{-0.2}$	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
$10611 \pm 4 \pm 3$	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
$10609 \pm 2 \pm 3$	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
$10608 \pm 2 \pm 3$	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
$10605 \pm 2 \pm 3_{-1}$	³ BONDAR 12	BELL	$e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$
$10599 \pm 6 \pm 5_{-3 -4}$	³ BONDAR 12	BELL	$e^+e^- \rightarrow h_b(2P)\pi^+\pi^-$

¹ Average of the BONDAR 12 measurements in separate channels.

² Correlated with the corresponding result from BONDAR 12.

³ Superseded by the average measurement of BONDAR 12.

$T_{b\bar{b}1}(10610)^0$ MASS

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$10609 \pm 4 \pm 4$	¹ KROKOVNY 13	BELL	$e^+e^- \rightarrow \Upsilon(2S)/\Upsilon(3S)\pi^0\pi^0$

¹ From a simultaneous fit to the KROKOVNY 13 Dalitz analysis of $e^+e^- \rightarrow \Upsilon(2S)/\Upsilon(3S)\pi^0\pi^0$ decays with fixed width $\Gamma(T_{b\bar{b}1}(10610)^0) = 18.4$ MeV.

$T_{b\bar{b}1}(10610)^\pm$ WIDTH

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
18.4 ± 2.4	¹ BONDAR 12	BELL	$e^+e^- \rightarrow \text{hadrons}$

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

$18.5 \pm 5.3^{+6.1}_{-2.3}$	² GARMASH	15	BELL	$e^+ e^- \rightarrow \Upsilon(1S) \pi^+ \pi^-$
$20.8 \pm 2.5^{+0.3}_{-2.1}$	² GARMASH	15	BELL	$e^+ e^- \rightarrow \Upsilon(2S) \pi^+ \pi^-$
$18.7 \pm 3.4^{+2.5}_{-1.3}$	² GARMASH	15	BELL	$e^+ e^- \rightarrow \Upsilon(3S) \pi^+ \pi^-$
$22.3 \pm 7.7^{+3.0}_{-4.0}$	³ BONDAR	12	BELL	$e^+ e^- \rightarrow \Upsilon(1S) \pi^+ \pi^-$
$24.2 \pm 3.1^{+2.0}_{-3.0}$	³ BONDAR	12	BELL	$e^+ e^- \rightarrow \Upsilon(2S) \pi^+ \pi^-$
$17.6 \pm 3.0 \pm 3.0$	³ BONDAR	12	BELL	$e^+ e^- \rightarrow \Upsilon(3S) \pi^+ \pi^-$
$11.4^{+4.5+2.1}_{-3.9-1.2}$	³ BONDAR	12	BELL	$e^+ e^- \rightarrow h_b(1P) \pi^+ \pi^-$
$13^{+10}_{-8} \quad ^{+9}_{-7}$	³ BONDAR	12	BELL	$e^+ e^- \rightarrow h_b(2P) \pi^+ \pi^-$

¹ Average of the BONDAR 12 measurements in separate channels.

² Correlated with the corresponding result from BONDAR 12.

³ Superseded by the average measurement of BONDAR 12.

$T_{b\bar{b}1}(10610)$ DECAY MODES

Mode	Fraction (Γ_i/Γ)
$\Gamma_1 \quad \Upsilon(1S) \pi^+$	$(5.4^{+1.9}_{-1.5}) \times 10^{-3}$
$\Gamma_2 \quad \Upsilon(1S) \pi^0$	not seen
$\Gamma_3 \quad \Upsilon(2S) \pi^+$	$(3.6^{+1.1}_{-0.8}) \%$
$\Gamma_4 \quad \Upsilon(2S) \pi^0$	seen
$\Gamma_5 \quad \Upsilon(3S) \pi^+$	$(2.1^{+0.8}_{-0.6}) \%$
$\Gamma_6 \quad \Upsilon(3S) \pi^0$	seen
$\Gamma_7 \quad h_b(1P) \pi^+$	$(3.5^{+1.2}_{-0.9}) \%$
$\Gamma_8 \quad h_b(2P) \pi^+$	$(4.7^{+1.7}_{-1.3}) \%$
$\Gamma_9 \quad B^+ \bar{B}^0$	not seen
$\Gamma_{10} \quad B^+ \bar{B}^{*0} + B^{*+} \bar{B}^0$	$(85.6^{+2.1}_{-2.9}) \%$

$T_{b\bar{b}1}(10610)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S) \pi^+)/\Gamma_{\text{total}}$				Γ_1/Γ
VALUE (units 10^{-3})	DOCUMENT ID	TECN	COMMENT	
$5.4^{+1.6+1.1}_{-1.3-0.8}$	¹ GARMASH	16	BELL $e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$	

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

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

¹ Assuming the $T_{bb1}(10610)$ decay width is saturated by the channels $\pi^+ \gamma(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$, and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(\gamma(1S)\pi^0)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
not seen	KROKOVNY 13	BELL	$e^+ e^- \rightarrow \gamma(1S)\pi^0 \pi^0$

$\Gamma(\gamma(2S)\pi^+)/\Gamma_{\text{total}}$ Γ_3/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$3.62^{+0.76+0.79}_{-0.59-0.53}$	¹ GARMASH 16	BELL	$e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$

• • • 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	$e^+ e^- \rightarrow \gamma(2S)\pi^+ \pi^-$

¹ Assuming the $T_{bb1}(10610)$ decay width is saturated by the channels $\pi^+ \gamma(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$, and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(\gamma(2S)\pi^0)/\Gamma_{\text{total}}$ Γ_4/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
seen	¹ KROKOVNY 13	BELL	$e^+ e^- \rightarrow \gamma(2S)\pi^0 \pi^0$

¹ Combined significance in $e^+ e^- \rightarrow \gamma(2S)/\gamma(3S)\pi^0 \pi^0$, including systematics, of 6.5σ .

$\Gamma(\gamma(3S)\pi^+)/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$2.15^{+0.55+0.60}_{-0.42-0.43}$	¹ GARMASH 16	BELL	$e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$

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

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

¹ Assuming the $T_{bb1}(10610)$ decay width is saturated by the channels $\pi^+ \gamma(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$, and using the results from BONDAR 12 and MIZUK 16.

$\Gamma(\gamma(3S)\pi^0)/\Gamma_{\text{total}}$ Γ_6/Γ

VALUE	DOCUMENT ID	TECN	COMMENT
seen	¹ KROKOVNY 13	BELL	$e^+ e^- \rightarrow \gamma(3S)\pi^0 \pi^0$

¹ Combined significance in $e^+ e^- \rightarrow \gamma(2S)/\gamma(3S)\pi^0 \pi^0$, including systematics, of 6.5σ .

$\Gamma(h_b(1P)\pi^+)/\Gamma_{\text{total}}$ Γ_7/Γ

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$3.45^{+0.87+0.86}_{-0.71-0.63}$	¹ GARMASH 16	BELL	$e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$

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

possibly seen	² MIZUK 16	BELL	$e^+ e^- \rightarrow h_b(1P)\pi^+ \pi^-$
seen	³ BONDAR 12	BELL	$e^+ e^- \rightarrow h_b(1P)\pi^+ \pi^-$

- ¹ Assuming the $T_{bb\bar{1}}$ (10610) decay width is saturated by the channels $\pi^+ \Upsilon(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$, and using the results from BONDAR 12 and MIZUK 16.
² Using $e^+ e^-$ energies near the $\Upsilon(11020)$.
³ Using $e^+ e^-$ energies near the $\Upsilon(10860)$.

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

VALUE (units 10^{-2})	DOCUMENT ID	TECN	COMMENT
$4.67^{+1.24+1.18}_{-1.00-0.89}$	¹ GARMASH	16	BELL $e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$

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

possibly seen	² MIZUK	16	BELL $e^+ e^- \rightarrow h_b(2P)\pi^+\pi^-$
seen	³ BONDAR	12	BELL $e^+ e^- \rightarrow h_b(2P)\pi^+\pi^-$

- ¹ Assuming the $T_{bb\bar{1}}$ (10610) decay width is saturated by the channels $\pi^+ \Upsilon(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$, and using the results from BONDAR 12 and MIZUK 16.
² Using $e^+ e^-$ energies near the $\Upsilon(11020)$.
³ Using $e^+ e^-$ energies near the $\Upsilon(10860)$.

$\Gamma(B^+ \bar{B}^0)/\Gamma_{\text{total}}$ Γ_9/Γ

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

$[\Gamma(B^+ \bar{B}^{*0}) + \Gamma(B^{*+} \bar{B}^0)]/\Gamma_{\text{total}}$ Γ_{10}/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
$85.6^{+1.5+1.5}_{-2.0-2.1}$	357	¹ GARMASH	16	BELL $e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- B^{*+} \bar{B}^0$

- ¹ Assuming the $T_{bb\bar{1}}$ (10610) decay width is saturated by the channels $\pi^+ \Upsilon(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + B^{*+} \bar{B}^0$, and using the results from BONDAR 12 and MIZUK 16. Using the mass and width of the $T_{bb\bar{1}}$ (10610) from BONDAR 12.

$[\Gamma(B^+ \bar{B}^{*0}) + \Gamma(B^{*+} \bar{B}^0)] / [\Gamma(\Upsilon(1S)\pi^+) + \Gamma(\Upsilon(2S)\pi^+) + \Gamma(\Upsilon(3S)\pi^+) + \Gamma(h_b(1P)\pi^+) + \Gamma(h_b(2P)\pi^+)]$ $\Gamma_{10}/(\Gamma_1+\Gamma_3+\Gamma_5+\Gamma_7+\Gamma_8)$

VALUE (units 10^{-2})	EVTS	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$5.93^{+0.99+1.01}_{-0.69-0.73}$	357	¹ GARMASH	16	BELL $e^+ e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$
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- ¹ Combined with the results of BONDAR 12 and MIZUK 16. Not independent from $T_{bb\bar{1}}$ (10610) branching fractions to $\pi^+ \Upsilon(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$.

$T_{bb\bar{1}}$ (10610) 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.)
KROKOVNY	13	PR D88 052016	P. Krokovny <i>et al.</i>	(BELLE Collab.)
BONDAR	12	PRL 108 122001	A. Bondar <i>et al.</i>	(BELLE Collab.)