

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

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

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±3.4 ^{+3.7} _{-1.4}	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
10608.1±1.2 ^{+1.5} _{-0.2}	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
10607.4±1.5 ^{+0.8} _{-0.2}	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
10611 ±4 ±3	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
10609 ±2 ±3	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
10608 ±2 ±3	³ BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
10605 ±2 ⁺³ ₋₁	³ BONDAR 12	BELL	$e^+e^- \rightarrow h_b(1P)\pi^+\pi^-$
10599 ⁺⁶ ₋₃ ⁺⁵ ₋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Average of the BONDAR 12 measurements in separate channels.² Correlated with the corresponding result from BONDAR 12.³ Superseded by the average measurement of BONDAR 12.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±4±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± 5.3 ^{+6.1} _{-2.3}	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
20.8± 2.5 ^{+0.3} _{-2.1}	² GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
18.7± 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 $T_{b\bar{b}1}(10610)$ 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.

$\Gamma(\Upsilon(1S)\pi^0)/\Gamma_{\text{total}}$				Γ_2/Γ
VALUE	DOCUMENT ID	TECN	COMMENT	
not seen	KROKOVNY	13	BELL	$e^+ e^- \rightarrow \Upsilon(1S)\pi^0\pi^0$

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

<u>VALUE (units 10^{-2})</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$3.62^{+0.76+0.79}_{-0.59-0.53}$	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 $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
seen	BONDAR	12	BELL $e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$

¹ Assuming the $T_{b\bar{b}1}(10610)$ 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.

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

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

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

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

<u>VALUE (units 10^{-2})</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$2.15^{+0.55+0.60}_{-0.42-0.43}$	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 $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
seen	BONDAR	12	BELL $e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$

¹ Assuming the $T_{b\bar{b}1}(10610)$ 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.

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

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

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

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

<u>VALUE (units 10^{-2})</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$3.45^{+0.87+0.86}_{-0.71-0.63}$	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 $T_{b\bar{b}1}(10610)$ 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 $\Upsilon(10860)$.

$$\Gamma(h_b(2P)\pi^+)/\Gamma_{\text{total}} \qquad \Gamma_8/\Gamma$$

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 $T_{b\bar{b}1}(10610)$ 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 $\Upsilon(10860)$.

$$\Gamma(B^+ \bar{B}^0)/\Gamma_{\text{total}} \qquad \Gamma_9/\Gamma$$

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

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

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 $T_{b\bar{b}1}(10610)$ 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 $T_{b\bar{b}1}(10610)$ from BONDAR 12.

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

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 $T_{b\bar{b}1}(10610)$ branching fractions to $\pi^+ \Upsilon(1S, 2S, 3S)$, $\pi^+ h_b(1P, 2P)$, and $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$.

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