

**$Z_b(10610)$** 

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

was  $X(10610)$ 

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.

 **$Z_b(10610)^\pm$  MASS**

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 Superseded by the average measurement of BONDAR 12.

 **$Z_b(10610)^0$  MASS**

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

<sup>1</sup> 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  $\Gamma(Z_b(10610)^0) = 18.4$  MeV.

 **$Z_b(10610)^\pm$  WIDTH**

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>18.4 ± 2.4</b>	<sup>1</sup> BONDAR 12	BELL	$e^+e^- \rightarrow \text{hadrons}$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
18.5 ± 5.3 <sup>+6.1</sup> <sub>-2.3</sub>	<sup>2</sup> GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$
20.8 ± 2.5 <sup>+0.3</sup> <sub>-2.1</sub>	<sup>2</sup> GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$
18.7 ± 3.4 <sup>+2.5</sup> <sub>-1.3</sub>	<sup>2</sup> GARMASH 15	BELL	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$
22.3 ± 7.7 <sup>+3.0</sup> <sub>-4.0</sub>	<sup>3</sup> BONDAR 12	BELL	$e^+e^- \rightarrow \Upsilon(1S)\pi^+\pi^-$

$24.2 \pm 3.1^{+2.0}_{-3.0}$	<sup>3</sup> BONDAR	12	BELL	$e^+ e^- \rightarrow \Upsilon(2S) \pi^+ \pi^-$
$17.6 \pm 3.0 \pm 3.0$	<sup>3</sup> BONDAR	12	BELL	$e^+ e^- \rightarrow \Upsilon(3S) \pi^+ \pi^-$
$11.4^{+4.5+2.1}_{-3.9-1.2}$	<sup>3</sup> BONDAR	12	BELL	$e^+ e^- \rightarrow h_b(1P) \pi^+ \pi^-$
$13^{+10}_{-8} \quad ^{+9}_{-7}$	<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.

### $Z_b(10610)$ DECAY MODES

Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1 \quad \Upsilon(1S) \pi^+$	$(5.4^{+1.9}_{-1.5}) \times 10^{-3}$
$\Gamma_2 \quad \Upsilon(1S) \pi^0$	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
$\Gamma_{10} \quad B^+ \bar{B}^{*0} + B^{*+} \bar{B}^0$	$(85.6^{+2.1}_{-2.9}) \%$

### $Z_b(10610)$ BRANCHING RATIOS

$\Gamma(\Upsilon(1S) \pi^+)/\Gamma_{\text{total}}$				$\Gamma_1/\Gamma$
VALUE (units $10^{-3}$ )	DOCUMENT ID	TECN	COMMENT	
$5.4^{+1.6+1.1}_{-1.3-0.8}$	<sup>1</sup> 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	$e^+ e^- \rightarrow \Upsilon(1S) \pi^+ \pi^-$

<sup>1</sup> Assuming the  $Z_b(10610)$  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.

$\Gamma(\Upsilon(1S) \pi^0)/\Gamma_{\text{total}}$				$\Gamma_2/\Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
not seen	KROKOVNY	13	BELL	$e^+ e^- \rightarrow \Upsilon(1S) \pi^0 \pi^0$

$\Gamma(\Upsilon(2S)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_3/\Gamma$

<u>VALUE (units <math>10^{-2}</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$3.62^{+0.76+0.79}_{-0.59-0.53}$	<sup>1</sup> 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	$e^+e^- \rightarrow \Upsilon(2S)\pi^+\pi^-$

<sup>1</sup> Assuming the  $Z_b(10610)$  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.

$\Gamma(\Upsilon(2S)\pi^0)/\Gamma_{\text{total}}$   $\Gamma_4/\Gamma$

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

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

$\Gamma(\Upsilon(3S)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_5/\Gamma$

<u>VALUE (units <math>10^{-2}</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$2.15^{+0.55+0.60}_{-0.42-0.43}$	<sup>1</sup> 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	$e^+e^- \rightarrow \Upsilon(3S)\pi^+\pi^-$

<sup>1</sup> Assuming the  $Z_b(10610)$  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.

$\Gamma(\Upsilon(3S)\pi^0)/\Gamma_{\text{total}}$   $\Gamma_6/\Gamma$

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

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

$\Gamma(h_b(1P)\pi^+)/\Gamma_{\text{total}}$   $\Gamma_7/\Gamma$

<u>VALUE (units <math>10^{-2}</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
$3.45^{+0.87+0.86}_{-0.71-0.63}$	<sup>1</sup> 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	<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  $Z_b(10610)$  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.

<sup>2</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>3</sup> Using  $e^+e^-$  energies near the  $\Upsilon(10860)$ .

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

VALUE (units $10^{-2}$ )	DOCUMENT ID	TECN	COMMENT
$4.67^{+1.24+1.18}_{-1.00-0.89}$	<sup>1</sup> 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	<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  $Z_b(10610)$  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.

<sup>2</sup> Using  $e^+e^-$  energies near the  $\Upsilon(11020)$ .

<sup>3</sup> Using  $e^+e^-$  energies near the  $\Upsilon(10860)$ .

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

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

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

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

<sup>1</sup> Assuming the  $Z_b(10610)$  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  $Z_b(10610)$  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	<sup>1</sup> GARMASH	16	BELL $e^+e^- \rightarrow \pi^- B^+ \bar{B}^{*0}, \pi^- \bar{B}^0 B^{*+}$
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<sup>1</sup> Combined with the results of BONDAR 12 and MIZUK 16. Not independent from  $Z_b(10610)$  branching fractions to  $\pi^+ \Upsilon(1S, 2S, 3S)$ ,  $\pi^+ h_b(1P, 2P)$ , and  $B^+ \bar{B}^{*0} + \bar{B}^0 B^{*+}$ .

**$Z_b(10610)$  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.)