# $\psi(4360)$

$$I^G(J^{PC}) = 0^-(1^{--})$$

## also known as $Y(4360)$; was $X(4360)$

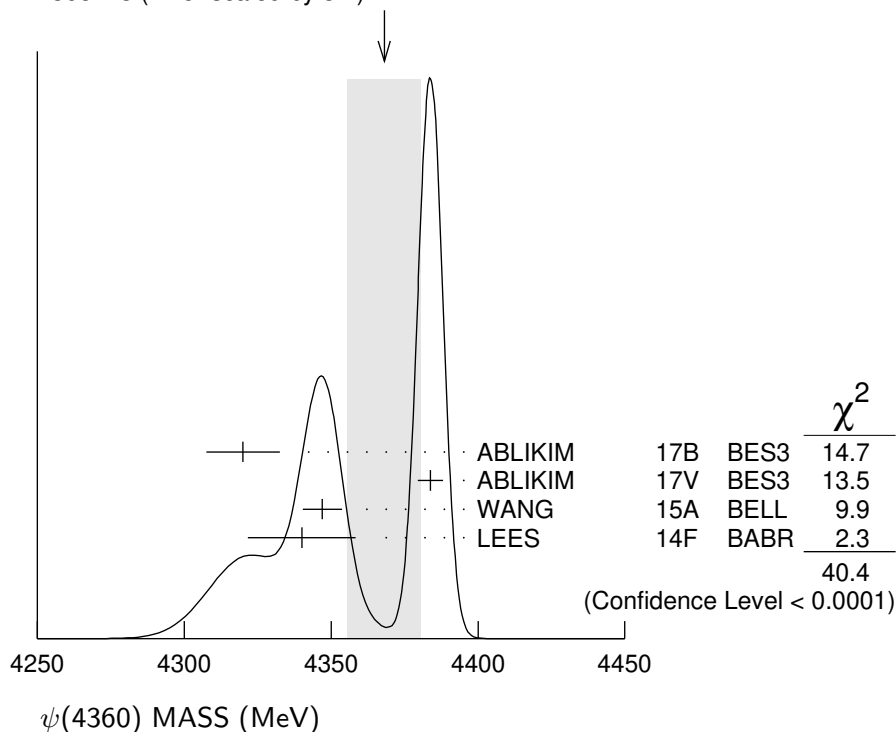This state shows properties different from a conventional $q\overline{q}$ state. A candidate for an exotic structure. See the review on non-$q\overline{q}$ states.

Seen in radiative return from $e^+e^-$ collisions at $\sqrt{s} = 9.54$–$10.58$ GeV by AUBERT 07S, WANG 07D, and LEES 14F. See also the review on "Spectroscopy of mesons containing two heavy quarks."

## $\psi(4360)$ MASS

| VALUE (MeV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **4368 ±13** | **OUR AVERAGE** | Error includes scale factor of 3.7. See the ideogram below. | | | |
| $4320.0\pm10.4\pm7.0$ | | [1] ABLIKIM | 17B | BES3 | $e^+e^- \to \pi^+\pi^- J/\psi$ |
| $4383.8\pm 4.2\pm0.8$ | | [2] ABLIKIM | 17V | BES3 | $e^+e^- \to \pi^+\pi^- \psi(2S)$ |
| $4347 \pm 6 \pm3$ | 279 | [3] WANG | 15A | BELL | 10.58 $e^+e^- \to \gamma\pi^+\pi^- \psi(2S)$ |
| $4340 \pm16 \pm9$ | 37 | [4] LEES | 14F | BABR | 10.58 $e^+e^- \to \gamma\pi^+\pi^- \psi(2S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $4383.7\pm 2.9\pm6.2$ | | [5] ZHANG | 17B | RVUE | $e^+e^- \to \pi^+\pi^- \psi(2S)$ |
| $4386.4\pm 2.1\pm6.4$ | | [6] ZHANG | 17C | RVUE | $e^+e^- \to \pi^+\pi^- J/\psi$ or $\psi(2S)$ |
| $4355 {}^{+9}_{-10} \pm9$ | 74 | [7] LIU | 08H | RVUE | 10.58 $e^+e^- \to \gamma\pi^+\pi^- \psi(2S)$ |
| $4324 \pm24$ | | [8] AUBERT | 07S | BABR | 10.58 $e^+e^- \to \gamma\pi^+\pi^- \psi(2S)$ |
| $4361 \pm 9 \pm9$ | 47 | [4] WANG | 07D | BELL | 10.58 $e^+e^- \to \gamma\pi^+\pi^- \psi(2S)$ |

WEIGHTED AVERAGE
4368±13 (Error scaled by 3.7)



| | | | $\chi^2$ |
|---|---|---|---|
| ABLIKIM | 17B | BES3 | 14.7 |
| ABLIKIM | 17V | BES3 | 13.5 |
| WANG | 15A | BELL | 9.9 |
| LEES | 14F | BABR | 2.3 |
| | | | 40.4 |

(Confidence Level < 0.0001)

$\psi(4360)$ MASS (MeV)

[1] From a three-resonance fit.
[2] From a fit to the cross section for $e^+ e^- \to \pi^+ \pi^- \psi(2S) \to 2(\pi^+ \pi^-)\ell^+ \ell^-$ obtained from 16 center-of-mass energies between 4.008 and 4.600 GeV and comprising 5.1 fb$^{-1}$.
[3] From a two-resonance fit. Supersedes WANG 07D.
[4] From a two-resonance fit.
[5] From a three-resonance fit.
[6] From a combined fit of BELLE, BABAR and BES3 $e^+ e^- \to \pi^+ \pi^- J/\psi$ and $e^+ e^- \to \pi^+ \pi^- \psi(2S)$ data.
[7] From a combined fit of AUBERT 07S and WANG 07D data with two resonances.
[8] From a single-resonance fit. Systematic errors not estimated.

## $\psi(4360)$ WIDTH

| VALUE (MeV) | EVTS | | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|---|
| **96 $\pm$ 7 OUR AVERAGE** | | | | | | |
| $101.4^{+25.3}_{-19.7} \pm 10.2$ | | [1] | ABLIKIM | 17B | BES3 | $e^+ e^- \to \pi^+ \pi^- J/\psi$ |
| $84.2 \pm 12.5 \pm 2.1$ | | [2] | ABLIKIM | 17V | BES3 | $e^+ e^- \to \pi^+ \pi^- \psi(2S)$ |
| $103 \pm 9 \pm 5$ | 279 | [3] | WANG | 15A | BELL | $10.58\ e^+ e^- \to \gamma \pi^+ \pi^- \psi(2S)$ |
| $94 \pm 32 \pm 13$ | 37 | [4] | LEES | 14F | BABR | $10.58\ e^+ e^- \to \gamma \pi^+ \pi^- \psi(2S)$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | | |
| $94.2 \pm 7.3 \pm 2.0$ | | [5] | ZHANG | 17B | RVUE | $e^+ e^- \to \pi^+ \pi^- \psi(2S)$ |
| $96.0 \pm 6.7 \pm 2.7$ | | [6] | ZHANG | 17C | RVUE | $e^+ e^- \to \pi^+ \pi^- J/\psi$ or $\psi(2S)$ |
| $103^{+17}_{-15} \pm 11$ | 74 | [7] | LIU | 08H | RVUE | $10.58\ e^+ e^- \to \gamma \pi^+ \pi^- \psi(2S)$ |
| $172 \pm 33$ | | [8] | AUBERT | 07S | BABR | $10.58\ e^+ e^- \to \gamma \pi^+ \pi^- \psi(2S)$ |
| $74 \pm 15 \pm 10$ | 47 | [4] | WANG | 07D | BELL | $10.58\ e^+ e^- \to \gamma \pi^+ \pi^- \psi(2S)$ |

[1] From a three-resonance fit.
[2] From a fit to the cross section for $e^+ e^- \to \pi^+ \pi^- \psi(2S) \to 2(\pi^+ \pi^-)\ell^+ \ell^-$ obtained from 16 center-of-mass energies between 4.008 and 4.600 GeV and comprising 5.1 fb$^{-1}$.
[3] From a two-resonance fit. Supersedes WANG 07D.
[4] From a two-resonance fit.
[5] From a three-resonance fit.
[6] From a combined fit of BELLE, BABAR and BES3 $e^+ e^- \to \pi^+ \pi^- J/\psi$ and $e^+ e^- \to \pi^+ \pi^- \psi(2S)$ data.
[7] From a combined fit of AUBERT 07S and WANG 07D data with two resonances.
[8] From a single-resonance fit. Systematic errors not estimated.

## $\psi(4360)$ DECAY MODES

| | Mode | Fraction ($\Gamma_i/\Gamma$) |
|---|---|---|
| $\Gamma_1$ | $e^+ e^-$ | |
| $\Gamma_2$ | $J/\psi \pi^+ \pi^-$ | |
| $\Gamma_3$ | $\psi(2S) \pi^+ \pi^-$ | seen |
| $\Gamma_4$ | $\psi_2(3823) \pi^+ \pi^-$ | possibly seen |
| $\Gamma_5$ | $J/\psi \eta$ | |
| $\Gamma_6$ | $D^0 D^{*-} \pi^+$ | |
| $\Gamma_7$ | $D_1(2420)\overline{D} +$ c.c. | possibly seen |
| $\Gamma_8$ | $\chi_{c1} \gamma$ | |
| $\Gamma_9$ | $\chi_{c2} \gamma$ | |

# $\psi(4360)$ $\Gamma(i) \times \Gamma(e^+e^-)/\Gamma(\text{total})$

## $\Gamma(\psi(2S)\pi^+\pi^-) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$  $\Gamma_3\Gamma_1/\Gamma$

| VALUE (eV) | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $7.3 \pm 2.8$ | | [1] ABLIKIM | 19K | BES3 | $e^+e^- \to \pi^+\pi^-\psi(2S)$ |
| $11.0 \pm 3.8$ | | [2] ABLIKIM | 19K | BES3 | $e^+e^- \to \pi^+\pi^-\psi(2S)$ |
| $9.2 \pm 0.6 \pm 0.6$ | 279 | [3] WANG | 15A | BELL | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $10.9 \pm 0.6 \pm 0.7$ | 279 | [4] WANG | 15A | BELL | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $6.0 \pm 1.0 \pm 0.5$ | 37 | [1] LEES | 14F | BABR | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $7.2 \pm 1.0 \pm 0.6$ | 37 | [2] LEES | 14F | BABR | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $11.1^{+1.3}_{-1.2}$ | 74 | [5] LIU | 08H | RVUE | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $12.3 \pm 1.2$ | 74 | [6] LIU | 08H | RVUE | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $10.4 \pm 1.7 \pm 1.5$ | 47 | [1] WANG | 07D | BELL | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |
| $11.8 \pm 1.8 \pm 1.4$ | 47 | [2] WANG | 07D | BELL | $10.58\ e^+e^- \to \gamma\pi^+\pi^-\psi(2S)$ |

[1] Solution I of two equivalent solutions in a fit using two interfering resonances.
[2] Solution II of two equivalent solutions in a fit using two interfering resonances.
[3] Solution I of two equivalent solutions from a fit using two interfering resonances. Supersedes WANG 07D.
[4] Solution II of two equivalent solutions from a fit using two interfering resonances. Supersedes WANG 07D.
[5] Solution I in a combined fit of AUBERT 07S and WANG 07D data with two resonances.
[6] Solution II in a combined fit of AUBERT 07S and WANG 07D data with two resonances.

## $\Gamma(J/\psi\eta) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$  $\Gamma_5\Gamma_1/\Gamma$

| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | | |
| $<6.8$ | 90 | WANG | 13B | BELL | $e^+e^- \to J/\psi\eta\gamma$ |

## $\Gamma(\chi_{c1}\gamma) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$  $\Gamma_8\Gamma_1/\Gamma$

| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<0.57** | 90 | [1] HAN | 15 | BELL | $10.58\ e^+e^- \to \chi_{c1}\gamma$ |

[1] Using B$(\eta \to \gamma\gamma) = (39.41 \pm 0.21)\%$.

## $\Gamma(\chi_{c2}\gamma) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$  $\Gamma_9\Gamma_1/\Gamma$

| VALUE (eV) | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<1.9** | 90 | [1] HAN | 15 | BELL | $10.58\ e^+e^- \to \chi_{c2}\gamma$ |

[1] Using B$(\eta \to \gamma\gamma) = (39.41 \pm 0.21)\%$.

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# $\psi(4360)$ BRANCHING RATIOS

## $\Gamma(D^0 D^{*-}\pi^+)/\Gamma(\psi(2S)\pi^+\pi^-)$  $\Gamma_6/\Gamma_3$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<8** | 90 | PAKHLOVA | 09 | BELL | $e^+e^- \to \psi(4360) \to D^0 D^{*-}\pi^+$ |

## $\Gamma\left(\psi(2S)\pi^+\pi^-\right)/\Gamma_{\text{total}}$ $\qquad$ $\Gamma_3/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **seen** | [1] ABLIKIM | 17V | BES3 | $e^+e^- \to \pi^+\pi^-\psi(2S)$ |

[1] From a fit to the cross section for $e^+e^- \to \pi^+\pi^-\psi(2S) \to 2(\pi^+\pi^-)\ell^+\ell^-$ obtained from 16 center-of-mass energies between 4.008 and 4.600 GeV and comprising 5.1 fb$^{-1}$.

## $\Gamma\left(\psi(2S)\pi^+\pi^-\right)/\Gamma\left(J/\psi\,\pi^+\pi^-\right)$ $\qquad$ $\Gamma_3/\Gamma_2$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| (0.81 ± 0.12 ± 0.13) to (42 ± 15 ± 15) | [1] ZHANG | 17C | RVUE | $e^+e^- \to \pi^+\pi^- J/\psi$ or $\psi(2S)$ |

[1] From a combined fit of BELLE, BABAR and BES3 $e^+e^- \to \pi^+\pi^- J/\psi$ and $e^+e^- \to \pi^+\pi^-\psi(2S)$ data.

## $\Gamma\left(\psi_2(3823)\pi^+\pi^-\right)/\Gamma_{\text{total}}$ $\qquad$ $\Gamma_4/\Gamma$

| VALUE | EVTS | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **possibly seen** | 19 | [1] ABLIKIM | 15S | BES3 | $e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$ |

[1] From a fit of $e^+e^- \to \pi^+\pi^-\psi_2(3823)$, $\psi_2(3823) \to \chi_{c1}\gamma$ cross sections taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to the $\psi(4360)$ line shape.

## $\Gamma\left(D^0 D^{*-}\pi^+\right)/\Gamma_{\text{total}} \times \Gamma\left(e^+e^-\right)/\Gamma_{\text{total}}$ $\qquad$ $\Gamma_6/\Gamma \times \Gamma_1/\Gamma$

| VALUE | CL% | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|---|
| **<0.72 × 10$^{-6}$** | 90 | [1] PAKHLOVA | 09 | BELL | $e^+e^- \to \psi(4360) \to$ $D^0 D^{*-}\pi^+$ |

[1] Using $4355^{+9}_{-10} \pm 9$ MeV for the mass of $\psi(4360)$.

## $\Gamma\left(D_1(2420)\overline{D} + \text{c.c.}\right)/\Gamma_{\text{total}}$ $\qquad$ $\Gamma_7/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **possibly seen** | [1] ABLIKIM | 19AR | BES3 | $e^+e^- \to \pi^+\pi^- D\overline{D}$ |

[1] Evidence for $e^+e^- \to D_1(2420)\overline{D} + $ c.c. between $\sqrt{s} = 4.3$ and 4.6 GeV, not necessarily resonant.

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# $\psi(4360)$ REFERENCES

| | | | | |
|---|---|---|---|---|
| ABLIKIM | 19AR | PR D100 032005 | M. Ablikim *et al.* | (BESIII Collab.) |
| ABLIKIM | 19K | PR D99 019903 (errat.) | M. Ablikim *et al.* | (BESIII Collab.) |
| ABLIKIM | 17B | PRL 118 092001 | M. Ablikim *et al.* | (BESIII Collab.) |
| ABLIKIM | 17V | PR D96 032004 | M. Ablikim *et al.* | (BESIII Collab.) |
| Also | | PR D99 019903 (errat.) | M. Ablikim *et al.* | (BESIII Collab.) |
| ZHANG | 17B | PR D96 054008 | J. Zhang, J. Zhang | |
| ZHANG | 17C | EPJ C77 727 | J. Zhang, L. Yuan | |
| ABLIKIM | 15S | PRL 115 011803 | M. Ablikim *et al.* | (BESIII Collab.) |
| HAN | 15 | PR D92 012011 | Y.L. Han *et al.* | (BELLE Collab.) |
| WANG | 15A | PR D91 112007 | X.L. Wang *et al.* | (BELLE Collab.) |
| LEES | 14F | PR D89 111103 | J.P. Lees *et al.* | (BABAR Collab.) |
| WANG | 13B | PR D87 051101 | X.L. Wang *et al.* | (BELLE Collab.) |
| PAKHLOVA | 09 | PR D80 091101 | G. Pakhlova *et al.* | (BELLE Collab.) |
| LIU | 08H | PR D78 014032 | Z.Q. Liu, X.S. Qin, C.Z. Yuan | |
| AUBERT | 07S | PRL 98 212001 | B. Aubert *et al.* | (BABAR Collab.) |
| WANG | 07D | PRL 99 142002 | X.L. Wang *et al.* | (BELLE Collab.) |