$\psi_2(3823)$

$I^G(J^{PC}) = 0^-(2^{--})$
I, J, P need confirmation.

was $\psi(3823)$, $X(3823)$

Seen by BHARDWAJ 13 in $B \to \chi_{c1}\gamma K$ and ABLIKIM 15S in $e^+e^- \to \pi^+\pi^-\gamma\chi_{c1}$ decays as a narrow peak in the invariant mass distribution of the $\chi_{c1}\gamma$ system. Properties consistent with the $\psi_2(1^3D_2)$ $c\overline{c}$ state.

$\psi_2(3823)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
3823.51±0.34 OUR AVERAGE					
3824.5 ±2.4 ±1.0	30	[1] ABLIKIM	23J	BES3	$e^+e^- \to \pi^0\pi^0\chi_{c1}\gamma$
3823.12±0.43±0.13	120	ABLIKIM	22R	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$
3824.08±0.53±0.14	137	[2] AAIJ	20S	LHCB	$B^+ \to J/\psi\pi^+\pi^-K^+$
3823.1 ±1.8 ±0.7	33±10	[3] BHARDWAJ	13	BELL	$B^\pm \to \chi_{c1}\gamma K^\pm$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
3821.7 ±1.3 ±0.7	19 ± 5	[4] ABLIKIM	15S	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$

[1] Using the measured $m_{\psi_2(3823)} - m_{\psi(2S)}$ and assuming $m_{\psi(2S)} = 3686.097$ MeV from PDG 22.

[2] Using the measured $m_{\psi_2(3823)} - m_{\psi(2S)} = 137.98 \pm 0.53 \pm 0.14$ MeV.

[3] From a simultaneous fit to $B^\pm \to (\chi_{c1}\gamma)K^\pm$ and $B^0 \to (\chi_{c1}\gamma)K^0_S$ with significance 4.0σ including systematics. Corrected for the measured $\psi(2S)$ mass using $B \to \psi(2S)K \to (\gamma\chi_{c1})K$ decays.

[4] From a simultaneous unbinned maximum likelihood fit of $e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$ data (the $\pi^+\pi^-$ recoil mass) taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to simulated events including both $\psi(2S) \to \chi_{c1}\gamma$ and $\psi_2(3823) \to \chi_{c1}\gamma$ together, with floating mass scale offset for $\psi(2S)$, floating $\psi_2(3823)$ mass, and zero $\psi_2(3823)$ width, resulting in a significance of 5.9σ when including systematic uncertainties. Superseded by ABLIKIM 22R.

$m_{\psi_2(3823)} - m_{\psi(2S)}$

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
137.98±0.53±0.14	137	[1] AAIJ	20S	LHCB	$B^+ \to J/\psi\pi^+\pi^-K^+$

[1] AAIJ 20S also reports $m_{\chi_{c1}(3872)} - m_{\psi_2(3823)} = 47.50 \pm 0.53 \pm 0.13$ MeV.

$\psi_2(3823)$ WIDTH

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
< 2.9	90	120	ABLIKIM	22R	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<18.8	90	30	[1] ABLIKIM	23J	BES3	$e^+e^- \to \pi^0\pi^0\chi_{c1}\gamma$
< 5.2	90		[2] AAIJ	20S	LHCB	$B^+ \to J/\psi\pi^+\pi^-K^+$
<16	90		[3] ABLIKIM	15S	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$
<24	90		[4] BHARDWAJ	13	BELL	$B^\pm \to \chi_{c1}\gamma K^\pm$

[1] From a fit of $e^+e^- \to \pi^0\pi^0\chi_{c1}\gamma$ data at $\sqrt{s}$ values from 4.23 to 4.70 GeV to a Breit-Wigner function with floating width, using the Bayesian approach.
[2] AAIJ 20S also provides a limit of < 6.6 MeV with 95% CL.
[3] From a fit of $e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$ data (the $\pi^+\pi^-$ recoil mass) taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to a Breit-Wigner function with the mass fixed from the likelihood fit above, Gaussian resolution smearing, and floating width.
[4] From a simultaneous fit to $B^\pm \to (\chi_{c1}\gamma)K^\pm$ and $B^0 \to (\chi_{c1}\gamma)K^0_S$ with significance 4.0σ including systematics.

$\psi_2(3823)$ DECAY MODES

Branching fractions are given relative to the one **DEFINED AS 1**.

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$J/\psi(1S)\pi^+\pi^-$	<0.06	90%
Γ_2	$J/\psi(1S)\pi^0\pi^0$	<0.11	90%
Γ_3	$J/\psi(1S)\pi^0$	<0.030	90%
Γ_4	$J/\psi(1S)\eta$	<0.14	90%
Γ_5	$\chi_{c0}\gamma$	<0.24	90%
Γ_6	$\chi_{c1}\gamma$	**DEFINED AS 1**	
Γ_7	$\chi_{c2}\gamma$	$0.28\ ^{+0.14}_{-0.11}$	

$\psi_2(3823)$ BRANCHING RATIOS

$\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
not seen		[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$
seen	137 ± 26	AAIJ	20S	LHCB	$B^+ \to J/\psi\pi^+\pi^- K^+$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(J/\psi(1S)\pi^+\pi^-)/\Gamma(\chi_{c1}\gamma)$ Γ_1/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.06	90	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(J/\psi(1S)\pi^0\pi^0)/\Gamma(\chi_{c1}\gamma)$ Γ_2/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.11	90	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(J/\psi(1S)\pi^0)/\Gamma(\chi_{c1}\gamma)$ Γ_3/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.03	90	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(J/\psi(1S)\eta)/\Gamma(\chi_{c1}\gamma)$ Γ_4/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.14	90	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(J/\psi(1S)\eta)/\Gamma(J/\psi(1S)\pi^+\pi^-)$ Γ_4/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
$\mathbf{4.4^{+2.5}_{-1.9}\pm0.9}$	[1] AAIJ	22D	LHCB	$B^+ \to J/\psi(1S)\eta K^+$

[1] Using the branching ratio for $B^+ \to \psi_2(3823)K^+$ with $\psi_2(3823) \to J/\psi(1S)\pi^+\pi^-$ from AAIJ 20S.

$\Gamma(\chi_{c0}\gamma)/\Gamma_{\text{total}}$ Γ_5/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
not seen	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(\chi_{c1}\gamma)/\Gamma_{\text{total}}$ Γ_6/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
seen	120	[1] ABLIKIM	22R	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c1}\gamma$
seen	63 ± 9	[2] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$
seen	16 ± 5	[3] ABLIKIM	21O	BES3	$e^+e^- \to \pi^0\pi^0 X$
seen	33 ± 10	[4] BHARDWAJ	13	BELL	$B^\pm \to \chi_{c1}\gamma K^\pm$

[1] From a fit to the $e^+e^- \to \pi^+\pi^-\psi(3823)$ cross section between 4.23 and 4.70 GeV with two coherent Breit-Wigner resonances. The data is also consistent with a single peak R with mass 4417.5 ± 26.2 ± 3.5 MeV and width 245 ± 48 ± 13 MeV, which leads to Γ(e+ e-) B($R \to \pi^+\pi^-\psi_2(3823)$) B($\psi_2(3823) \to \chi_{c1}\gamma$) = 0.57 ± 0.08 eV.

[2] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$. Signal has a 11.8 σ significance.

[3] From a fit of the invariant $\pi^0\pi^0$ recoil-mass distribution. Signal has a 4.3 σ significance.

[4] BHARDWAJ 13 reports B($B^\pm \to \psi_2(3823)K^\pm$) × B($\psi_2(3823) \to \gamma\chi_{c1}$) = (9.7 ± 2.8 ± 1.1) × 10^{-6} with statistical significance 3.8 σ.

$\Gamma(\chi_{c0}\gamma)/\Gamma(\chi_{c1}\gamma)$ Γ_5/Γ_6

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.24	90	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

$\Gamma(\chi_{c2}\gamma)/\Gamma_{\text{total}}$ Γ_7/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
seen	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^- X$
not seen	[2] ABLIKIM	15S	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c2}\gamma$
not seen	[3] BHARDWAJ	13	BELL	$B^\pm \to \chi_{c2}\gamma K^\pm$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$. Signal has a 3.2 σ significance.

[2] From a simultaneous unbinned maximum likelihood fit of $e^+e^- \to \pi^+\pi^-\chi_{c2}\gamma$ data (the $\pi^+\pi^-$ recoil mass) taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to simulated events including both $\psi(2S) \to \chi_{c2}\gamma$ and $\psi_2(3823) \to \chi_{c2}\gamma$ together, with floating mass scale offset for $\psi(2S)$, $\psi_2(3823)$ mass floating (fixed to that above), and zero $\psi_2(3823)$ width.

[3] BHARDWAJ 13 reports $B(B^\pm \to \psi_2(3823)K^\pm) \times B(\psi_2(3823) \to \gamma\chi_{c2}) < 3.6 \times 10^{-6}$ at 90% CL.

$\Gamma(\chi_{c2}\gamma)/\Gamma(\chi_{c1}\gamma)$ Γ_7/Γ_6

VALUE	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
$\mathbf{0.28^{+0.14}_{-0.11}\pm0.02}$		9 ± 4	[1] ABLIKIM	21O	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c2}\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •						
<0.42	90		[2] ABLIKIM	15S	BES3	$e^+e^- \to \pi^+\pi^-\chi_{c2}\gamma$
<0.41	90		BHARDWAJ	13	BELL	$B^\pm \to \chi_{c1/c2}\gamma K^\pm$

[1] From a simultaneous unbinned maximum likelihood fit of the $\pi^+\pi^-$ recoil mass distributions of seven decay channels in the process $e^+e^- \to \pi^+\pi^- X$.

[2] From a simultaneous unbinned maximum likelihood fit of $e^+e^- \to \pi^+\pi^-\chi_{c1(2)}\gamma$ data (the $\pi^+\pi^-$ recoil mass) taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to simulated events including both $\psi(2S) \to \chi_{c1(2)}\gamma$ and $\psi_2(3823) \to \chi_{c1(2)}\gamma$ together, with floating mass scale offset for $\psi(2S)$, $\psi_2(3823)$ mass floating (fixed to that above), and zero $\psi_2(3823)$ width.

$\psi_2(3823)$ REFERENCES

ABLIKIM	23J	JHEP 2302 171	M. Ablikim *et al.*	(BESIII Collab.)
AAIJ	22D	JHEP 2204 046	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	22R	PRL 129 102003	M. Ablikim *et al.*	(BESIII Collab.)
PDG	22	PTEP 2022 083C01	R.L. Workman *et al.*	(PDG Collab.)
ABLIKIM	21O	PR D103 L091102	M. Ablikim *et al.*	(BESIII Collab.)
AAIJ	20S	JHEP 2008 123	R. Aaij *et al.*	(LHCb Collab.)
ABLIKIM	15S	PRL 115 011803	M. Ablikim *et al.*	(BESIII Collab.)
BHARDWAJ	13	PRL 111 032001	V. Bhardwaj *et al.*	(BELLE Collab.)