

# $b\bar{b}$ MESONS

**$\Upsilon(1S)$**

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

Mass  $m = 9460.30 \pm 0.26$  MeV (S = 3.3)

Full width  $\Gamma = 52.5 \pm 1.8$  keV

$\Gamma_{ee} = 1.32 \pm 0.05$  keV

<b><math>\Upsilon(1S)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$P$ (MeV/c)
$\tau^+ \tau^-$	$(2.67^{+0.14}_{-0.16}) \%$		4384
$e^+ e^-$	$(2.38 \pm 0.11) \%$		4730
$\mu^+ \mu^-$	$(2.48 \pm 0.06) \%$		4729

### Hadronic decays

$J/\psi(1S)$ anything	$(1.1 \pm 0.4) \times 10^{-3}$		4223
$\rho\pi$	$< 2 \times 10^{-4}$	90%	4698
$\pi^+ \pi^-$	$< 5 \times 10^{-4}$	90%	4728
$K^+ K^-$	$< 5 \times 10^{-4}$	90%	4704
$p\bar{p}$	$< 5 \times 10^{-4}$	90%	4636
$\pi^0 \pi^+ \pi^-$	$< 1.84 \times 10^{-5}$	90%	—

### Radiative decays

$\gamma \pi^+ \pi^-$	$(6.3 \pm 1.8) \times 10^{-5}$		—
$\gamma \pi^0 \pi^0$	$(1.7 \pm 0.7) \times 10^{-5}$		—
$\gamma 2h^+ 2h^-$	$(7.0 \pm 1.5) \times 10^{-4}$		4720
$\gamma 3h^+ 3h^-$	$(5.4 \pm 2.0) \times 10^{-4}$		4703
$\gamma 4h^+ 4h^-$	$(7.4 \pm 3.5) \times 10^{-4}$		4679
$\gamma \pi^+ \pi^- K^+ K^-$	$(2.9 \pm 0.9) \times 10^{-4}$		4686
$\gamma 2\pi^+ 2\pi^-$	$(2.5 \pm 0.9) \times 10^{-4}$		4720
$\gamma 3\pi^+ 3\pi^-$	$(2.5 \pm 1.2) \times 10^{-4}$		4703
$\gamma 2\pi^+ 2\pi^- K^+ K^-$	$(2.4 \pm 1.2) \times 10^{-4}$		4658
$\gamma \pi^+ \pi^- p\bar{p}$	$(1.5 \pm 0.6) \times 10^{-4}$		4604
$\gamma 2\pi^+ 2\pi^- p\bar{p}$	$(4 \pm 6) \times 10^{-5}$		4563
$\gamma 2K^+ 2K^-$	$(2.0 \pm 2.0) \times 10^{-5}$		4601
$\gamma \eta'(958)$	$< 1.6 \times 10^{-5}$	90%	4682
$\gamma \eta$	$< 3.5 \times 10^{-4}$	90%	4714
$\gamma f'_2(1525)$	$< 1.4 \times 10^{-4}$	90%	4607

$\gamma f_2(1270)$	$(8 \pm 4) \times 10^{-5}$		4644
$\gamma \eta(1440)$	$< 8.2 \times 10^{-5}$	90%	4624
$\gamma f_0(1710) \rightarrow \gamma K \bar{K}$	$< 2.6 \times 10^{-4}$	90%	4576
$\gamma f_0(2200) \rightarrow \gamma K^+ K^-$	$< 2 \times 10^{-4}$	90%	4475
$\gamma f_J(2220) \rightarrow \gamma K^+ K^-$	$< 1.5 \times 10^{-5}$	90%	4469
$\gamma \eta(2225) \rightarrow \gamma \phi \phi$	$< 3 \times 10^{-3}$	90%	4469
$\gamma X$	$< 3 \times 10^{-5}$	90%	—
$X = \text{pseudoscalar with } m < 7.2 \text{ GeV}$			
$\gamma X \bar{X}$	$< 1 \times 10^{-3}$	90%	—
$X \bar{X} = \text{vectors with } m < 3.1 \text{ GeV}$			

**$\chi_{b0}(1P)$  [///]**

$I^G(J^{PC}) = 0^+(0^{++})$   
*J* needs confirmation.

Mass  $m = 9859.9 \pm 1.0 \text{ MeV}$

<b><math>\chi_{b0}(1P)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$p$ (MeV/c)
$\gamma \Upsilon(1S)$	$< 6 \%$	90%	391

**$\chi_{b1}(1P)$  [///]**

$I^G(J^{PC}) = 0^+(1^{++})$   
*J* needs confirmation.

Mass  $m = 9892.7 \pm 0.6 \text{ MeV}$  ( $S = 1.1$ )

<b><math>\chi_{b1}(1P)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$\gamma \Upsilon(1S)$	$(35 \pm 8) \%$	422

**$\chi_{b2}(1P)$  [///]**

$I^G(J^{PC}) = 0^+(2^{++})$   
*J* needs confirmation.

Mass  $m = 9912.6 \pm 0.5 \text{ MeV}$  ( $S = 1.1$ )

<b><math>\chi_{b2}(1P)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$\gamma \Upsilon(1S)$	$(22 \pm 4) \%$	443

## $\Upsilon(2S)$

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

Mass  $m = 10.02326 \pm 0.00031$  GeV

Full width  $\Gamma = 44 \pm 7$  keV

$\Gamma_{ee} = 0.520 \pm 0.032$  keV

$\Upsilon(2S)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$p$ (MeV/c)
$\Upsilon(1S)\pi^+\pi^-$	(18.8 $\pm$ 0.6) %		475
$\Upsilon(1S)\pi^0\pi^0$	( 9.0 $\pm$ 0.8 ) %		480
$\tau^+\tau^-$	( 1.7 $\pm$ 1.6 ) %		4686
$\mu^+\mu^-$	( 1.31 $\pm$ 0.21) %		5011
$e^+e^-$	( 1.18 $\pm$ 0.20) %		5012
$\Upsilon(1S)\pi^0$	< 1.1	$\times 10^{-3}$	90% 531
$\Upsilon(1S)\eta$	< 2	$\times 10^{-3}$	90% 127
$J/\psi(1S)$ anything	< 6	$\times 10^{-3}$	90% 4533

### Radiative decays

$\gamma\chi_{b1}(1P)$	( 6.8 $\pm$ 0.7 ) %		131
$\gamma\chi_{b2}(1P)$	( 7.0 $\pm$ 0.6 ) %		110
$\gamma\chi_{b0}(1P)$	( 3.8 $\pm$ 0.6 ) %		162
$\gamma f_0(1710)$	< 5.9	$\times 10^{-4}$	90% 4866
$\gamma f'_2(1525)$	< 5.3	$\times 10^{-4}$	90% 4896
$\gamma f_2(1270)$	< 2.41	$\times 10^{-4}$	90% 4931

## $\chi_{b0}(2P)$ [!!!]

$$J^{PC} = 0^{+}(0^{++})$$

$J$  needs confirmation.

Mass  $m = 10.2321 \pm 0.0006$  GeV

$\chi_{b0}(2P)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$\gamma\Upsilon(2S)$	(4.6 $\pm$ 2.1) %	210
$\gamma\Upsilon(1S)$	(9 $\pm$ 6 ) $\times 10^{-3}$	746

## $\chi_{b1}(2P)$ [!!!]

$$J^{PC} = 0^{+}(1^{++})$$

$J$  needs confirmation.

Mass  $m = 10.2552 \pm 0.0005$  GeV

$m_{\chi_{b1}(2P)} - m_{\chi_{b0}(2P)} = 23.5 \pm 1.0$  MeV

$\chi_{b1}(2P)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Scale factor	$p$ (MeV/c)
$\gamma\Upsilon(2S)$	(21 $\pm$ 4 ) %	1.5	229
$\gamma\Upsilon(1S)$	( 8.5 $\pm$ 1.3) %	1.3	764

**$\chi_{b2}(2P)$  [III]**

$$I^G(J^{PC}) = 0^+(2^{++})$$

$J$  needs confirmation.

Mass  $m = 10.2685 \pm 0.0004$  GeV

$$m_{\chi_{b2}(2P)} - m_{\chi_{b1}(2P)} = 13.5 \pm 0.6$$
 MeV

$\chi_{b2}(2P)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$\gamma \Upsilon(2S)$	(16.2±2.4) %	242
$\gamma \Upsilon(1S)$	( 7.1±1.0) %	776

**$\Upsilon(3S)$**

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

Mass  $m = 10.3552 \pm 0.0005$  GeV

Full width  $\Gamma = 26.3 \pm 3.5$  keV

$\Upsilon(3S)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Scale factor/ Confidence level	$p$ (MeV/c)
$\Upsilon(2S)$ anything	(10.6 ±0.8 ) %		296
$\Upsilon(2S) \pi^+ \pi^-$	( 2.8 ±0.6 ) %	S=2.2	177
$\Upsilon(2S) \pi^0 \pi^0$	( 2.00±0.32) %		190
$\Upsilon(2S) \gamma \gamma$	( 5.0 ±0.7 ) %		327
$\Upsilon(1S) \pi^+ \pi^-$	( 4.48±0.21) %		814
$\Upsilon(1S) \pi^0 \pi^0$	( 2.06±0.28) %		816
$\Upsilon(1S) \eta$	< 2.2	$\times 10^{-3}$ CL=90%	—
$\mu^+ \mu^-$	( 1.81±0.17) %		5177
$e^+ e^-$	seen		5177

**Radiative decays**

$\gamma \chi_{b2}(2P)$	(11.4 ±0.8 ) %	S=1.3	87
$\gamma \chi_{b1}(2P)$	(11.3 ±0.6 ) %		100
$\gamma \chi_{b0}(2P)$	( 5.4 ±0.6 ) %	S=1.1	123

**$\Upsilon(4S)$   
or  $\Upsilon(10580)$**

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

Mass  $m = 10.5800 \pm 0.0035$  GeV

Full width  $\Gamma = 14 \pm 5$  MeV ( $S = 1.7$ )

$\Gamma_{ee} = 0.248 \pm 0.031$  keV ( $S = 1.3$ )

$\Upsilon(4S)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$p$ (MeV/c)
$B \bar{B}$	> 96 %	95%	—
non- $B \bar{B}$	< 4 %	95%	—
$e^+ e^-$	( 2.8±0.7) $\times 10^{-5}$		5290
$J/\psi(1S)$ anything	< 1.9 $\times 10^{-4}$	95%	—

$D^{*+}$ anything + c.c.	< 7.4	%	90%	5099
$\phi$ anything	< 2.3	$\times 10^{-3}$	90%	5240
$\Upsilon(1S)$ anything	< 4	$\times 10^{-3}$	90%	1053
$\Upsilon(1S)\pi^+\pi^-$	< 1.2	$\times 10^{-4}$	90%	—
$\Upsilon(2S)\pi^+\pi^-$	< 3.9	$\times 10^{-4}$	90%	—

### $\Upsilon(10860)$

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

Mass  $m = 10.865 \pm 0.008$  GeV (S = 1.1)

Full width  $\Gamma = 110 \pm 13$  MeV

$\Gamma_{ee} = 0.31 \pm 0.07$  keV (S = 1.3)

$\Upsilon(10860)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$e^+e^-$	$(2.8 \pm 0.7) \times 10^{-6}$	5432

### $\Upsilon(11020)$

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

Mass  $m = 11.019 \pm 0.008$  GeV

Full width  $\Gamma = 79 \pm 16$  MeV

$\Gamma_{ee} = 0.130 \pm 0.030$  keV

$\Upsilon(11020)$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$e^+e^-$	$(1.6 \pm 0.5) \times 10^{-6}$	5509