$\chi_{b1}(1P)$

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

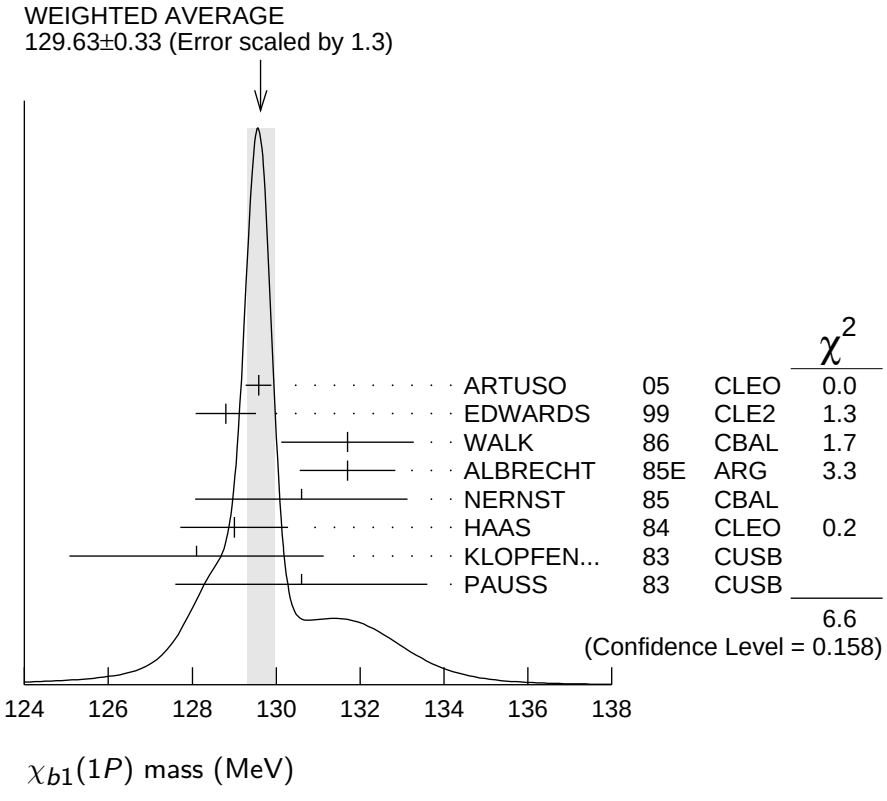
Observed in radiative decay of the $\Upsilon(2S)$, therefore $C = +$. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$. $J = 1$ from SKWARNICKI 87.

$\chi_{b1}(1P)$ MASS

VALUE (MeV)	*DOCUMENT ID*
9892.78±0.26±0.31 OUR EVALUATION	From average γ energy below, using $\Upsilon(2S)$ mass = 10023.26 ± 0.31 MeV

γ ENERGY IN $\Upsilon(2S)$ DECAY

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
129.63±0.33 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.			
129.58±0.09±0.29	ARTUSO	05	CLEO	$\Upsilon(2S) \rightarrow \gamma X$
128.8 ±0.4 ±0.6	EDWARDS	99	CLE2	$\Upsilon(2S) \rightarrow \gamma\chi(1P)$
131.7 ±0.9 ±1.3	WALK	86	CBAL	$\Upsilon(2S) \rightarrow \gamma\gamma\ell^+\ell^-$
131.7 ±0.3 ±1.1	ALBRECHT	85E	ARG	$\Upsilon(2S) \rightarrow$ conv.γX
130.6 ±0.8 ±2.4	NERNST	85	CBAL	$\Upsilon(2S) \rightarrow \gamma X$
129 ±0.8 ±1	HAAS	84	CLEO	$\Upsilon(2S) \rightarrow$ conv.γX
128.1 ±0.4 ±3.0	KLOPFEN...	83	CUSB	$\Upsilon(2S) \rightarrow \gamma X$
130.6 ±3.0	PAUSS	83	CUSB	$\Upsilon(2S) \rightarrow \gamma\gamma\ell^+\ell^-$



$\chi_{b1}(1P)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$\gamma\,\Upsilon(1S)$	(33.9±2.2) %	
Γ_2	$D^0 X$	(12.6±2.2) %	
Γ_3	$\pi^+\pi^- K^+ K^- \pi^0$	(2.0±0.6) × 10^{-4}	
Γ_4	$2\pi^+\pi^- K^- K^0_S$	(1.3±0.5) × 10^{-4}	
Γ_5	$2\pi^+\pi^- K^- K^0_S 2\pi^0$	< 6 × 10^{-4}	90%
Γ_6	$2\pi^+ 2\pi^- 2\pi^0$	(8.0±2.5) × 10^{-4}	
Γ_7	$2\pi^+ 2\pi^- K^+ K^-$	(1.5±0.5) × 10^{-4}	
Γ_8	$2\pi^+ 2\pi^- K^+ K^- \pi^0$	(3.5±1.2) × 10^{-4}	
Γ_9	$2\pi^+ 2\pi^- K^+ K^- 2\pi^0$	(8.6±3.2) × 10^{-4}	
Γ_{10}	$3\pi^+ 2\pi^- K^- K^0_S \pi^0$	(9.3±3.3) × 10^{-4}	
Γ_{11}	$3\pi^+ 3\pi^-$	(1.9±0.6) × 10^{-4}	
Γ_{12}	$3\pi^+ 3\pi^- 2\pi^0$	(1.7±0.5) × 10^{-3}	
Γ_{13}	$3\pi^+ 3\pi^- K^+ K^-$	(2.6±0.8) × 10^{-4}	
Γ_{14}	$3\pi^+ 3\pi^- K^+ K^- \pi^0$	(7.5±2.6) × 10^{-4}	
Γ_{15}	$4\pi^+ 4\pi^-$	(2.6±0.9) × 10^{-4}	
Γ_{16}	$4\pi^+ 4\pi^- 2\pi^0$	(1.4±0.6) × 10^{-3}	

$\chi_{b1}(1P)$ BRANCHING RATIOS

$\Gamma(\gamma\,\Upsilon(1S))/\Gamma_{\text{total}}$ Γ_1/Γ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.339±0.022 OUR AVERAGE					
0.331±0.018±0.017	3222	[1,2] KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$
0.350±0.023±0.018	13k	[3] LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$
0.32 ±0.06 ±0.07		WALK	86	CBAL	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$
0.47 ±0.18		KLOPFEN...	83	CUSB	$\Upsilon(2S) \to \gamma\gamma\ell^+\ell^-$

[1] Assuming B($\Upsilon(1S) \to \ell^+\ell^-$) = (2.48 ± 0.05)%.

[2] KORNICER 11 reports [$\Gamma(\chi_{b1}(1P) \to \gamma\,\Upsilon(1S))/\Gamma_{\text{total}}$] × [B($\Upsilon(2S) \to \gamma\chi_{b1}(1P)$)] = (22.8 ± 0.4 ± 1.2) × 10^{-3} which we divide by our best value B($\Upsilon(2S) \to \gamma\chi_{b1}(1P)$) = (6.9 ± 0.4) × 10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value.

[3] LEES 11J reports [$\Gamma(\chi_{b1}(1P) \to \gamma\,\Upsilon(1S))/\Gamma_{\text{total}}$] × [B($\Upsilon(2S) \to \gamma\chi_{b1}(1P)$)] = (24.1 ± 0.6 ± 1.5) × 10^{-3} which we divide by our best value B($\Upsilon(2S) \to \gamma\chi_{b1}(1P)$) = (6.9 ± 0.4) × 10^{-2}. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(D^0 X)/\Gamma_{\text{total}}$ Γ_2/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
12.6±1.9±1.1	2310	[4] BRIERE	08	CLEO	$\Upsilon(2S) \to \gamma D^0 X$

[4] For $p_{D^0} > 2.5$ GeV/c.

$\Gamma(\pi^+\pi^- K^+ K^- \pi^0)/\Gamma_{total}$ Γ_3/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.0±0.6±0.1	18	[5] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma\pi^+\pi^- K^+ K^- \pi^0$

[5] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to \pi^+\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (14 \pm 3 \pm 3) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+\pi^- K^- K^0_S)/\Gamma_{total}$ Γ_4/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.3±0.5±0.1	11	[6] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- K^0_S$

[6] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+\pi^- K^- K^0_S)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (9 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+\pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}$ Γ_5/Γ

VALUE (units 10^{-4})	CL%	DOCUMENT ID		TECN	COMMENT
<6	90	[7] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+\pi^- K^- 2\pi^0$

[7] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+\pi^- K^- K^0_S 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] < 42 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = 6.9 \times 10^{-2}$.

$\Gamma(2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}$ Γ_6/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
8.0±2.4±0.4	46	[8] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- 2\pi^0$

[8] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (55 \pm 9 \pm 14) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}$ Γ_7/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.5±0.5±0.1	18	[9] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^-$

[9] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (10 \pm 3 \pm 2) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}$ Γ_8/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
3.5±1.2±0.2	22	[10] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$

[10] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (24 \pm 6 \pm 6) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{total}$ Γ_9/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
8.6±3.2±0.4	26	[11] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 2\pi^+2\pi^-K^+K^-2\pi^0$

[11] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 2\pi^+2\pi^-K^+K^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (59 \pm 14 \pm 17) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+2\pi^-K^-K^0_S\pi^0)/\Gamma_{total}$ Γ_{10}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
9.3±3.3±0.5	21	[12] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+2\pi^-K^-K^0_S\pi^0$

[12] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+2\pi^-K^-K^0_S\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (64 \pm 16 \pm 16) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-)/\Gamma_{total}$ Γ_{11}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
1.9±0.6±0.1	25	[13] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-$

[13] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (13 \pm 3 \pm 3) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{total}$ Γ_{12}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
17±5±1	56	[14] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-2\pi^0$

[14] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (119 \pm 18 \pm 32) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-)/\Gamma_{total}$ Γ_{13}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
2.6±0.8±0.1	21	[15] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-$

[15] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-K^+K^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (18 \pm 4 \pm 4) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{total}$ Γ_{14}/Γ

VALUE (units 10^{-4})	EVTS	DOCUMENT ID		TECN	COMMENT
7.5±2.6±0.4	28	[16] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 3\pi^+3\pi^-K^+K^-\pi^0$

[16] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (52 \pm 11 \pm 14) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(4\pi^+4\pi^-)/\Gamma_{total}$ Γ_{15}/Γ

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
2.6±0.9±0.1	24	[17] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+4\pi^-$

[17] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 4\pi^+4\pi^-)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (18 \pm 4 \pm 5) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\Gamma(4\pi^+4\pi^-2\pi^0)/\Gamma_{total}$ Γ_{16}/Γ

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
14±5±1	26	[18] ASNER	08A	CLEO	$\Upsilon(2S) \to \gamma 4\pi^+4\pi^-2\pi^0$

[18] ASNER 08A reports $[\Gamma(\chi_{b1}(1P) \to 4\pi^+4\pi^-2\pi^0)/\Gamma_{total}] \times [B(\Upsilon(2S) \to \gamma\chi_{b1}(1P))] = (96 \pm 24 \pm 29) \times 10^{-6}$ which we divide by our best value $B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) = (6.9 \pm 0.4) \times 10^{-2}$. Our first error is their experiment's error and our second error is the systematic error from using our best value.

$\chi_{b1}(1P)$ Cross-Particle Branching Ratios

$\Gamma(\chi_{b1}(1P) \to \gamma\Upsilon(1S))/\Gamma_{total} \times \Gamma(\Upsilon(2S) \to \gamma\chi_{b1}(1P))/\Gamma_{total}$ $\Gamma_1/\Gamma \times \Gamma_{13}^{\Upsilon(2S)}/\Gamma^{\Upsilon(2S)}$

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
24.1±0.6±1.5	13k	LEES	11J	BABR	$\Upsilon(2S) \to X\gamma$

$B(\chi_{b1}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(2S) \to \gamma\chi_{b1}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
5.65±0.11±0.27	3222	KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$B(\chi_{b1}(1P) \to \gamma\Upsilon(1S)) \times B(\Upsilon(3S) \to \gamma\chi_{b1}(1P)) \times B(\Upsilon(1S) \to \ell^+\ell^-)$

VALUE (units 10^{-5})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1.33±0.30±0.23	50	KORNICER	11	CLEO	$e^+e^- \to \gamma\gamma\ell^+\ell^-$

$B(\chi_{b2}(1P) \to pX + \bar{p}X)/B(\chi_{b1}(1P) \to pX + \bar{p}X)$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.068±0.010±0.040	BRIERE	07	CLEO	$\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$

$B(\chi_{b0}(1P) \to pX + \bar{p}X)/B(\chi_{b1}(1P) \to pX + \bar{p}X)$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.11±0.15±0.20	BRIERE	07	CLEO	$\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$

$\chi_{b1}(1P)$ REFERENCES

KORNICER	11	PR D83 054003	M. Kornicer *et al.*	(CLEO Collab.)
LEES	11J	PR D84 072002	J.P. Lees *et al.*	(BABAR Collab.)
ASNER	08A	PR D78 091103	D.M. Asner *et al.*	(CLEO Collab.)
BRIERE	08	PR D78 092007	R.A. Briere *et al.*	(CLEO Collab.)
BRIERE	07	PR D76 012005	R.A. Briere *et al.*	(CLEO Collab.)
ARTUSO	05	PRL 94 032001	M. Artuso *et al.*	(CLEO Collab.)
EDWARDS	99	PR D59 032003	K.W. Edwards *et al.*	(CLEO Collab.)

SKWARNICKI	87	PRL 58 972	T. Skwarnicki *et al.*	(Crystal Ball Collab.) J
WALK	86	PR D34 2611	W.S. Walk *et al.*	(Crystal Ball Collab.)
ALBRECHT	85E	PL 160B 331	H. Albrecht *et al.*	(ARGUS Collab.)
NERNST	85	PRL 54 2195	R. Nernst *et al.*	(Crystal Ball Collab.)
HAAS	84	PRL 52 799	J. Haas *et al.*	(CLEO Collab.)
KLOPFEN...	83	PRL 51 160	C. Klopfenstein *et al.*	(CUSB Collab.)
PAUSS	83	PL 130B 439	F. Pauss *et al.*	(MPIM, COLU, CORN, LSU+)