

$\chi_{b0}(2P)$

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

J needs confirmation.

Observed in radiative decay of the $\Upsilon(3S)$, therefore $C = +$. Branching ratio requires E1 transition, M1 is strongly disfavored, therefore $P = +$.

$\chi_{b0}(2P)$ MASS

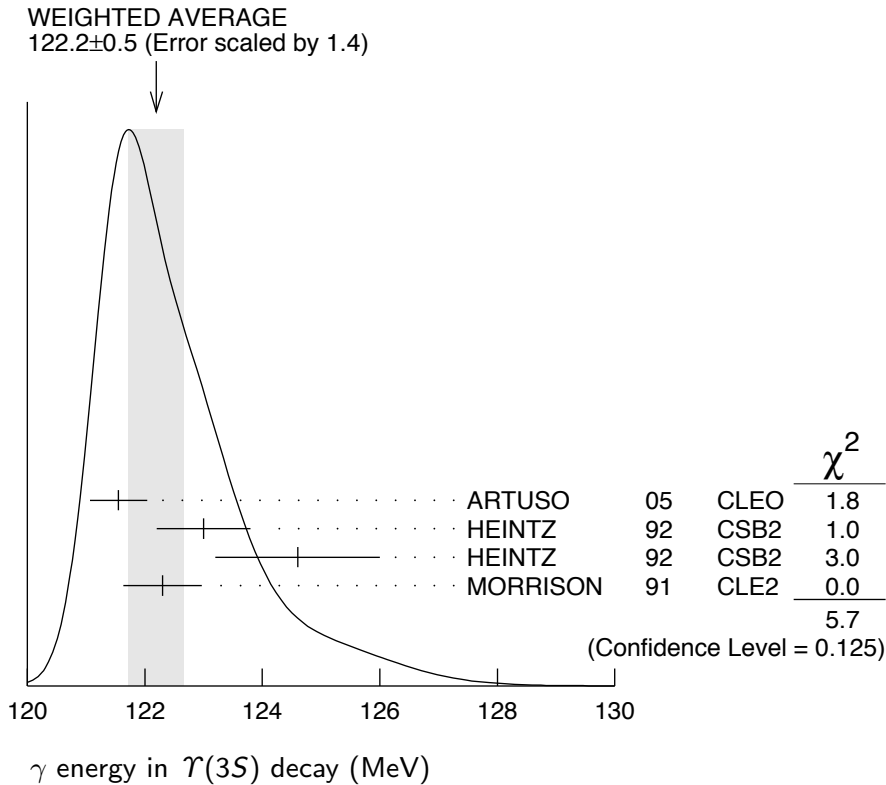
| VALUE (GeV) | DOCUMENT ID |
|---|---|
| 10.2325 ± 0.0004 ± 0.0005 OUR EVALUATION | From γ energy below, using $\Upsilon(3S)$ mass = 10355.2 ± 0.5 MeV |

γ ENERGY IN $\Upsilon(3S)$ DECAY

| VALUE (MeV) | EVTS | DOCUMENT ID | TECN | COMMENT |
|-----------------------------------|------|---------------------|------|---|
| 121.9 ± 0.4 OUR EVALUATION | | | | Treating systematic errors as correlated |
| 122.2 ± 0.5 OUR AVERAGE | | | | Error includes scale factor of 1.4. See the ideogram below. |
| 121.55 ± 0.16 ± 0.46 | | ARTUSO | 05 | CLEO $\Upsilon(3S) \rightarrow \gamma X$ |
| 123.0 ± 0.8 | 4959 | ¹ HEINTZ | 92 | CSB2 $e^+ e^- \rightarrow \gamma X$ |
| 124.6 ± 1.4 | 17 | ² HEINTZ | 92 | CSB2 $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |
| 122.3 ± 0.3 ± 0.6 | 9903 | MORRISON | 91 | CLE2 $e^+ e^- \rightarrow \gamma X$ |

¹ A systematic uncertainty on the energy scale of 0.9% not included. Supersedes NARAIN 91.

² A systematic uncertainty on the energy scale of 0.9% not included. Supersedes HEINTZ 91.



$\chi_{b0}(2P)$ DECAY MODES

| Mode | Fraction (Γ_i/Γ) | Confidence level |
|---|--------------------------------|------------------|
| Γ_1 $\gamma \Upsilon(2S)$ | $(4.6 \pm 2.1) \%$ | |
| Γ_2 $\gamma \Upsilon(1S)$ | $(9 \pm 6) \times 10^{-3}$ | |
| Γ_3 $D^0 X$ | $< 8.2 \%$ | 90% |
| Γ_4 $\pi^+ \pi^- K^+ K^- \pi^0$ | $< 3.4 \times 10^{-5}$ | 90% |
| Γ_5 $2\pi^+ \pi^- K^- K_S^0$ | $< 5 \times 10^{-5}$ | 90% |
| Γ_6 $2\pi^+ \pi^- K^- K_S^0 2\pi^0$ | $< 2.2 \times 10^{-4}$ | 90% |
| Γ_7 $2\pi^+ 2\pi^- 2\pi^0$ | $< 2.4 \times 10^{-4}$ | 90% |
| Γ_8 $2\pi^+ 2\pi^- K^+ K^-$ | $< 1.5 \times 10^{-4}$ | 90% |
| Γ_9 $2\pi^+ 2\pi^- K^+ K^- \pi^0$ | $< 2.2 \times 10^{-4}$ | 90% |
| Γ_{10} $2\pi^+ 2\pi^- K^+ K^- 2\pi^0$ | $< 1.1 \times 10^{-3}$ | 90% |
| Γ_{11} $3\pi^+ 2\pi^- K^- K_S^0 \pi^0$ | $< 7 \times 10^{-4}$ | 90% |
| Γ_{12} $3\pi^+ 3\pi^-$ | $< 7 \times 10^{-5}$ | 90% |
| Γ_{13} $3\pi^+ 3\pi^- 2\pi^0$ | $< 1.2 \times 10^{-3}$ | 90% |
| Γ_{14} $3\pi^+ 3\pi^- K^+ K^-$ | $< 1.5 \times 10^{-4}$ | 90% |
| Γ_{15} $3\pi^+ 3\pi^- K^+ K^- \pi^0$ | $< 7 \times 10^{-4}$ | 90% |
| Γ_{16} $4\pi^+ 4\pi^-$ | $< 1.7 \times 10^{-4}$ | 90% |
| Γ_{17} $4\pi^+ 4\pi^- 2\pi^0$ | $< 6 \times 10^{-4}$ | 90% |

$\chi_{b0}(2P)$ BRANCHING RATIOS

$\Gamma(\gamma \Upsilon(2S))/\Gamma_{\text{total}}$ Γ_1/Γ

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---|-----|---------------------|---------|---|
| $0.046 \pm 0.020 \pm 0.007$ | | ³ HEINTZ | 92 CSB2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

< 0.089 90 ⁴ CRAWFORD 92B CLE2 $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$

³ Using $B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) = (1.44 \pm 0.10)\%$, $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (6.0 \pm 0.4 \pm 0.6)\%$ and assuming $e\mu$ universality. Supersedes HEINTZ 91.

⁴ Using $B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) = (1.37 \pm 0.26)\%$, $B(\Upsilon(3S) \rightarrow \gamma \gamma \Upsilon(2S)) \times 2 B(\Upsilon(2S) \rightarrow \mu^+ \mu^-) < 1.19 \times 10^{-4}$, and $B(\Upsilon(3S) \rightarrow \chi_{b0}(2P) \gamma) = 0.049$.

$\Gamma(\gamma \Upsilon(1S))/\Gamma_{\text{total}}$ Γ_2/Γ

| VALUE | CL% | DOCUMENT ID | TECN | COMMENT |
|---|-----|---------------------|---------|---|
| $0.009 \pm 0.006 \pm 0.001$ | | ⁵ HEINTZ | 92 CSB2 | $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$ |

• • • We do not use the following data for averages, fits, limits, etc. • • •

< 0.025 90 ⁶ CRAWFORD 92B CLE2 $e^+ e^- \rightarrow \ell^+ \ell^- \gamma \gamma$

⁵ Using $B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.57 \pm 0.07)\%$, $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = (6.0 \pm 0.4 \pm 0.6)\%$ and assuming $e\mu$ universality. Supersedes HEINTZ 91.

⁶ Using $B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) = (2.57 \pm 0.07)\%$, $B(\Upsilon(3S) \rightarrow \gamma \gamma \Upsilon(1S)) \times 2 B(\Upsilon(1S) \rightarrow \mu^+ \mu^-) < 0.63 \times 10^{-4}$, and $B(\Upsilon(3S) \rightarrow \chi_{b0}(2P) \gamma) = 0.049$.

$\Gamma(D^0 X)/\Gamma_{\text{total}}$ Γ_3/Γ

| <u>VALUE</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|--|------------|--------------------|-------------|--|
| $<8.2 \times 10^{-2}$ | 90 | 7,8 BRIERE | 08 | CLEO $\Upsilon(3S) \rightarrow \gamma D^0 X$ |

⁷ For $p_{D^0} > 2.5$ GeV/c.

⁸ The authors also present their result as $(4.1 \pm 3.0 \pm 0.4) \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|--------------------|-------------|--|
| <0.34 | 90 | ⁹ ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma \pi^+ \pi^- K^+ K^- \pi^0$ |

⁹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow \pi^+ \pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 2 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|---|
| <0.5 | 90 | ¹⁰ ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ \pi^- K^- K_S^0$ |

¹⁰ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ \pi^- K^- K_S^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 3 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <2.2 | 90 | ¹¹ ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ \pi^- K^- 2\pi^0$ |

¹¹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ \pi^- K^- K_S^0 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 13 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

$\Gamma(2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{\text{total}}$ Γ_7/Γ

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|---|
| <2.4 | 90 | ¹² ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- 2\pi^0$ |

¹² ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 14 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <1.5 | 90 | ¹³ ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^-$ |

¹³ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- K^+ K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 9 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <2.2 | 90 | ¹⁴ ASNER | 08A | CLEO $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^- \pi^0$ |

¹⁴ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 13 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$.

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <11 | 90 | ¹⁵ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 2\pi^+ 2\pi^- K^+ K^- 2\pi^0$ ¹⁵ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 2\pi^+ 2\pi^- K^+ K^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 63 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

$\Gamma(3\pi^+2\pi^-K^-K_S^0\pi^0)/\Gamma_{\text{total}}$ **Γ_{11}/Γ**

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <7 | 90 | ¹⁶ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^+ 2\pi^- K^- K_S^0 \pi^0$ ¹⁶ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 2\pi^- K^- K_S^0 \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 39 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|---|
| <0.7 | 90 | ¹⁷ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^+ 3\pi^-$ ¹⁷ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 3\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 4 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

$\Gamma(3\pi^+3\pi^-2\pi^0)/\Gamma_{\text{total}}$ **Γ_{13}/Γ**

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <12 | 90 | ¹⁸ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^+ 3\pi^- 2\pi^0$ ¹⁸ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 3\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 72 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|---|
| <1.5 | 90 | ¹⁹ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^+ 3\pi^- K^+ K^-$ ¹⁹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 3\pi^- K^+ K^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 9 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

$\Gamma(3\pi^+3\pi^-K^+K^-\pi^0)/\Gamma_{\text{total}}$ **Γ_{15}/Γ**

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <7 | 90 | ²⁰ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 3\pi^+ 3\pi^- K^+ K^- \pi^0$ ²⁰ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 3\pi^+ 3\pi^- K^+ K^- \pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 43 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

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

| <u>VALUE (units 10^{-4})</u> | <u>CL%</u> | <u>DOCUMENT ID</u> | <u>TECN</u> | <u>COMMENT</u> |
|---|------------|---------------------|-------------|--|
| <1.7 | 90 | ²¹ ASNER | 08A CLEO | $\Upsilon(3S) \rightarrow \gamma 4\pi^+ 4\pi^-$ ²¹ ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 4\pi^+ 4\pi^-)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))] < 10 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. |

| $\Gamma(4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{\text{total}}$ | | | Γ_{17}/Γ | | |
|---|-----|---------------------|----------------------|---------|--|
| VALUE (units 10^{-4}) | CL% | DOCUMENT ID | TECN | COMMENT | |
| <6 | 90 | ²² ASNER | 08A | CLEO | $\Upsilon(3S) \rightarrow \gamma 4\pi^+ 4\pi^- 2\pi^0$ |
| ²² ASNER 08A reports $[\Gamma(\chi_{b0}(2P) \rightarrow 4\pi^+ 4\pi^- 2\pi^0)/\Gamma_{\text{total}}] \times [B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P))]$ $< 38 \times 10^{-6}$ which we divide by our best value $B(\Upsilon(3S) \rightarrow \gamma \chi_{b0}(2P)) = 5.9 \times 10^{-2}$. | | | | | |

$\chi_{b0}(2P)$ REFERENCES

| | | | | |
|----------|-----|---------------|-----------------------------|-------------------|
| ASNER | 08A | PR D78 091103 | D.M. Asner <i>et al.</i> | (CLEO Collab.) |
| BRIERE | 08 | PR D78 092007 | R.A. Briere <i>et al.</i> | (CLEO Collab.) |
| ARTUSO | 05 | PRL 94 032001 | M. Artuso <i>et al.</i> | (CLEO Collab.) |
| CRAWFORD | 92B | PL B294 139 | G. Crawford, R. Fulton | (CLEO Collab.) |
| HEINTZ | 92 | PR D46 1928 | U. Heintz <i>et al.</i> | (CUSB II Collab.) |
| HEINTZ | 91 | PRL 66 1563 | U. Heintz <i>et al.</i> | (CUSB Collab.) |
| MORRISON | 91 | PRL 67 1696 | R.J. Morrison <i>et al.</i> | (CLEO Collab.) |
| NARAIN | 91 | PRL 66 3113 | M. Narain <i>et al.</i> | (CUSB Collab.) |