

$\psi(4415)$ 

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

### $\psi(4415)$ MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>4421 ± 4 OUR ESTIMATE</b>			
<b>4415.1 ± 7.9</b>	<sup>1</sup> ABLIKIM	08D BES2	$e^+e^- \rightarrow$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
4412 ± 15	<sup>2</sup> MO	10 RVUE	$e^+e^- \rightarrow$ hadrons
4411 ± 7	<sup>3</sup> PAKHLOVA	08A BELL	10.6 $e^+e^- \rightarrow D^0 D^- \pi^+ \gamma$
4425 ± 6	<sup>4</sup> SETH	05A RVUE	$e^+e^- \rightarrow$ hadrons
4429 ± 9	<sup>5</sup> SETH	05A RVUE	$e^+e^- \rightarrow$ hadrons
4417 ± 10	BRANDELIK	78C DASP	$e^+e^-$
4414 ± 7	SIEGRIST	76 MRK1	$e^+e^-$

<sup>1</sup> Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$ , and  $\psi(4415)$  resonances. Phase angle fixed in the fit to  $\delta = (234 \pm 88)^\circ$ .

<sup>2</sup> Reanalysis of data presented in BAI 00 and BAI 02C. From a global fit over the center-of-mass energy 3.8–4.8 GeV covering the  $\psi(4040)$ ,  $\psi(4160)$  and  $\psi(4415)$  resonances and including interference effects.

<sup>3</sup> Systematic uncertainties not estimated.

<sup>4</sup> From a fit to Crystal Ball (OSTERHELD 86) data.

<sup>5</sup> From a fit to BES (BAI 02C) data.

### $\psi(4415)$ WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>62 ± 20 OUR ESTIMATE</b>			
<b>71.5 ± 19.0</b>	<sup>6</sup> ABLIKIM	08D BES2	$e^+e^- \rightarrow$ hadrons
• • • We do not use the following data for averages, fits, limits, etc. • • •			
118 ± 32	<sup>7</sup> MO	10 RVUE	$e^+e^- \rightarrow$ hadrons
77 ± 20	<sup>8</sup> PAKHLOVA	08A BELL	10.6 $e^+e^- \rightarrow D^0 D^- \pi^+ \gamma$
119 ± 16	<sup>9</sup> SETH	05A RVUE	$e^+e^- \rightarrow$ hadrons
118 ± 35	<sup>10</sup> SETH	05A RVUE	$e^+e^- \rightarrow$ hadrons
66 ± 15	BRANDELIK	78C DASP	$e^+e^-$
33 ± 10	SIEGRIST	76 MRK1	$e^+e^-$

<sup>6</sup> Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$ , and  $\psi(4415)$  resonances. Phase angle fixed in the fit to  $\delta = (234 \pm 88)^\circ$ .

<sup>7</sup> Reanalysis of data presented in BAI 00 and BAI 02C. From a global fit over the center-of-mass energy 3.8–4.8 GeV covering the  $\psi(4040)$ ,  $\psi(4160)$  and  $\psi(4415)$  resonances and including interference effects.

<sup>8</sup> Systematic uncertainties not estimated.

<sup>9</sup> From a fit to Crystal Ball (OSTERHELD 86) data.

<sup>10</sup> From a fit to BES (BAI 02C) data.

**$\psi(4415)$  DECAY MODES**

Due to the complexity of the  $c\bar{c}$  threshold region, in this listing, “seen” (“not seen”) means that a cross section for the mode in question has been measured at effective  $\sqrt{s}$  near this particle’s central mass value, more (less) than  $2\sigma$  above zero, without regard to any peaking behavior in  $\sqrt{s}$  or absence thereof. See mode listing(s) for details and references.

Mode	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level
$\Gamma_1$ $D\bar{D}$	seen	
$\Gamma_2$ $D^0\bar{D}^0$	seen	
$\Gamma_3$ $D^+D^-$	seen	
$\Gamma_4$ $D^*\bar{D} + \text{c.c.}$	seen	
$\Gamma_5$ $D^*(2007)^0\bar{D}^0 + \text{c.c.}$	seen	
$\Gamma_6$ $D^*(2010)^+D^- + \text{c.c.}$	seen	
$\Gamma_7$ $D^*\bar{D}^*$	seen	
$\Gamma_8$ $D^*(2007)^0\bar{D}^*(2007)^0 + \text{c.c.}$	seen	
$\Gamma_9$ $D^*(2010)^+D^*(2010)^- + \text{c.c.}$	seen	
$\Gamma_{10}$ $D^0D^-\pi^+$ (excl. $D^*(2007)^0\bar{D}^0$ +c.c., $D^*(2010)^+D^-$ +c.c.)	< 2.3 %	90%
$\Gamma_{11}$ $D\bar{D}_2^*(2460) \rightarrow D^0D^-\pi^+ + \text{c.c.}$	(10 $\pm$ 4) %	
$\Gamma_{12}$ $D^0D^{*-}\pi^+ + \text{c.c.}$	< 11 %	90%
$\Gamma_{13}$ $D_1(2420)\bar{D} + \text{c.c.}$	possibly seen	
$\Gamma_{14}$ $D_s^+D_s^-$	not seen	
$\Gamma_{15}$ $\omega\chi_{c2}$	possibly seen	
$\Gamma_{16}$ $D_s^{*+}D_s^- + \text{c.c.}$	seen	
$\Gamma_{17}$ $D_s^{*+}D_s^{*-}$	not seen	
$\Gamma_{18}$ $\psi_2(3823)\pi^+\pi^-$	possibly seen	
$\Gamma_{19}$ $\psi(3770)\pi^+\pi^-$	possibly seen	
$\Gamma_{20}$ $J/\psi\eta$	< 6 $\times 10^{-3}$	90%
$\Gamma_{21}$ $\chi_{c1}\gamma$	< 8 $\times 10^{-4}$	90%
$\Gamma_{22}$ $\chi_{c2}\gamma$	< 4 $\times 10^{-3}$	90%
$\Gamma_{23}$ $\Lambda\bar{\Lambda}$	< 3.1 $\times 10^{-6}$	90%
$\Gamma_{24}$ $e^+e^-$	(9.4 $\pm$ 3.2) $\times 10^{-6}$	
$\Gamma_{25}$ $\mu^+\mu^-$	(2.0 $\pm$ 1.0) $\times 10^{-5}$	

 **$\psi(4415)$  PARTIAL WIDTHS**

$\Gamma(e^+e^-)$	VALUE (keV)	DOCUMENT ID	TECN	COMMENT	$\Gamma_{24}$
<b>0.58<math>\pm</math>0.07 OUR ESTIMATE</b>					
<b>0.35<math>\pm</math>0.12</b>		<sup>11</sup> ABLIKIM	08D BES2	$e^+e^- \rightarrow$ hadrons	
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.4 to 0.8		<sup>12</sup> MO	10 RVUE	$e^+e^- \rightarrow$ hadrons	
0.72 $\pm$ 0.11		<sup>13</sup> SETH	05A RVUE	$e^+e^- \rightarrow$ hadrons	

$0.64 \pm 0.23$	<sup>14</sup> SETH	05A	RVUE	$e^+e^- \rightarrow$ hadrons
$0.49 \pm 0.13$	BRANDELIK	78C	DASP	$e^+e^-$
$0.44 \pm 0.14$	SIEGRIST	76	MRK1	$e^+e^-$

<sup>11</sup> Reanalysis of data presented in BAI 02C. From a global fit over the center-of-mass energy region 3.7–5.0 GeV covering the  $\psi(3770)$ ,  $\psi(4040)$ ,  $\psi(4160)$ , and  $\psi(4415)$  resonances. Phase angle fixed in the fit to  $\delta = (234 \pm 88)^\circ$ .

<sup>12</sup> Reanalysis of data presented in BAI 00 and BAI 02C. From a global fit over the center-of-mass energy 3.8–4.8 GeV covering the  $\psi(4040)$ ,  $\psi(4160)$  and  $\psi(4415)$  resonances and including interference effects. Four sets of solutions are obtained with the same fit quality, mass and total width, but with different  $e^+e^-$  partial widths. We quote only the range of values.

<sup>13</sup> From a fit to Crystal Ball (OSTERHELD 86) data.

<sup>14</sup> From a fit to BES (BAI 02C) data.

$\Gamma(\mu^+\mu^-)$					$\Gamma_{25}$
VALUE (keV)	DOCUMENT ID	TECN	COMMENT		
<b><math>1.25 \pm 0.28 \pm 0.35</math></b>	<sup>15,16</sup> ABLIKIM	20AG	BES3	$e^+e^- \rightarrow \mu^+\mu^-$	

<sup>15</sup> From a fit to the  $e^+e^- \rightarrow \mu^+\mu^-$  cross section between 3.8 and 4.6 GeV to the coherent sum of four resonant amplitudes assuming  $\Gamma(\mu^+\mu^-) = \Gamma(e^+e^-)$ .

<sup>16</sup> From solution 1 of 8 with equal fit quality. Other solutions range from  $1.24 \pm 0.28 \pm 0.35$  to  $1.27 \pm 0.41 \pm 0.36$  keV.

### $\psi(4415) \Gamma(i) \times \Gamma(e^+e^-)/\Gamma(\text{total})$

$\Gamma(J/\psi\eta) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_{20}\Gamma_{24}/\Gamma$
VALUE (eV)	CL%	DOCUMENT ID	TECN	COMMENT	
<b><math>&lt;3.6</math></b>	90	WANG	13B	BELL	$e^+e^- \rightarrow J/\psi\eta\gamma$

$\Gamma(\chi_{c1}\gamma) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_{21}\Gamma_{24}/\Gamma$
VALUE (eV)	CL%	DOCUMENT ID	TECN	COMMENT	
<b><math>&lt;0.47</math></b>	90	<sup>17</sup> HAN	15	BELL	$10.58 e^+e^- \rightarrow \chi_{c1}\gamma$

<sup>17</sup> Using  $B(\eta \rightarrow \gamma\gamma) = (39.41 \pm 0.21)\%$ .

$\Gamma(\chi_{c2}\gamma) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_{22}\Gamma_{24}/\Gamma$
VALUE (eV)	CL%	DOCUMENT ID	TECN	COMMENT	
<b><math>&lt;2.3</math></b>	90	<sup>18</sup> HAN	15	BELL	$10.58 e^+e^- \rightarrow \chi_{c2}\gamma$

<sup>18</sup> Using  $B(\eta \rightarrow \gamma\gamma) = (39.41 \pm 0.21)\%$ .

$\Gamma(\Lambda\bar{\Lambda}) \times \Gamma(e^+e^-)/\Gamma_{\text{total}}$					$\Gamma_{23}\Gamma_{24}/\Gamma$
VALUE (eV)	CL%	DOCUMENT ID	TECN	COMMENT	
<b><math>&lt;1.8 \times 10^{-3}</math></b>	90	<sup>19</sup> ABLIKIM	21AS	BES3	$e^+e^- \rightarrow \psi(4415)$

<sup>19</sup> From a measurement of the  $e^+e^- \rightarrow \Lambda\bar{\Lambda}$  cross section between 3.5 and 4.6 GeV.

### $\psi(4415)$ BRANCHING RATIOS

$\Gamma(D^0\bar{D}^0)/\Gamma_{\text{total}}$					$\Gamma_2/\Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT		
<b>seen</b>	PAKHLOVA	08	BELL	$e^+e^- \rightarrow D^0\bar{D}^0\gamma$	

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

not seen AUBERT 09M BABR  $e^+e^- \rightarrow D^0\bar{D}^0\gamma$

$\Gamma(D^+D^-)/\Gamma_{\text{total}}$   $\Gamma_3/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen PAKHLOVA 08 BELL  $e^+e^- \rightarrow D^+D^-\gamma$

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

not seen AUBERT 09M BABR  $e^+e^- \rightarrow D^+D^-\gamma$

$\Gamma(D\bar{D})/\Gamma(D^*\bar{D}^*)$   $\Gamma_1/\Gamma_7$

VALUE	DOCUMENT ID	TECN	COMMENT
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**0.14 ± 0.12 ± 0.03** AUBERT 09M BABR  $e^+e^- \rightarrow \gamma D^{(*)}\bar{D}^{(*)}$

$\Gamma(D^*(2007)^0\bar{D}^0 + \text{c.c.})/\Gamma_{\text{total}}$   $\Gamma_5/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen AUBERT 09M BABR  $e^+e^- \rightarrow D^{*0}\bar{D}^0\gamma$

$\Gamma(D^*(2010)^+D^- + \text{c.c.})/\Gamma_{\text{total}}$   $\Gamma_6/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen <sup>20</sup>ZHUKOVA 18 BELL  $e^+e^- \rightarrow D^{*+}D^-\gamma$

seen AUBERT 09M BABR  $e^+e^- \rightarrow D^{*+}D^-\gamma$

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

seen PAKHLOVA 07 BELL  $e^+e^- \rightarrow D^{*+}D^-\gamma$

<sup>20</sup>Supersedes PAKHLOVA 07.

$\Gamma(D^*\bar{D} + \text{c.c.})/\Gamma(D^*\bar{D}^*)$   $\Gamma_4/\Gamma_7$

VALUE	DOCUMENT ID	TECN	COMMENT
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**0.17 ± 0.25 ± 0.03** AUBERT 09M BABR  $e^+e^- \rightarrow \gamma D^{(*)}\bar{D}^{(*)}$

$\Gamma(D^*(2007)^0\bar{D}^*(2007)^0 + \text{c.c.})/\Gamma_{\text{total}}$   $\Gamma_8/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen AUBERT 09M BABR  $e^+e^- \rightarrow D^{*0}\bar{D}^{*0}\gamma$

$\Gamma(D^*(2010)^+D^*(2010)^- + \text{c.c.})/\Gamma_{\text{total}}$   $\Gamma_9/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen <sup>21</sup>ZHUKOVA 18 BELL  $e^+e^- \rightarrow D^{*+}D^{*-}\gamma$

seen AUBERT 09M BABR  $e^+e^- \rightarrow D^{*+}D^{*-}\gamma$

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

seen PAKHLOVA 07 BELL  $e^+e^- \rightarrow D^{*+}D^{*-}\gamma$

<sup>21</sup>Supersedes PAKHLOVA 07.

$\Gamma(D\bar{D}_2^*(2460) \rightarrow D^0D^-\pi^+ + \text{c.c.})/\Gamma_{\text{total}}$   $\Gamma_{11}/\Gamma$

VALUE (units $10^{-2}$ )	DOCUMENT ID	TECN	COMMENT
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**10.5 ± 2.4 ± 3.8** <sup>22</sup>PAKHLOVA 08A BELL 10.6  $e^+e^- \rightarrow D^0D^-\pi^+\gamma$

<sup>22</sup>Using  $4421 \pm 4$  MeV for the mass and  $62 \pm 20$  MeV for the width of  $\psi(4415)$ .

$\Gamma(D^0 D^- \pi^+ (\text{excl. } D^*(2007)^0 \bar{D}^0 + \text{c.c.}, D^*(2010)^+ D^- + \text{c.c.}) / \Gamma(D \bar{D}_2^*(2460) \rightarrow D^0 D^- \pi^+ + \text{c.c.})$   $\Gamma_{10}/\Gamma_{11}$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<b>&lt;0.22</b>	90	<sup>23</sup> PAKHLOVA 08A	BELL	$10.6 e^+ e^- \rightarrow D^0 D^- \pi^+ \gamma$ <sup>23</sup> Using $4421 \pm 4$ MeV for the mass and $62 \pm 20$ MeV for the width of $\psi(4415)$ .

$\Gamma(D^0 D^{*-} \pi^+ + \text{c.c.}) / \Gamma_{\text{total}} \times \Gamma(e^+ e^-) / \Gamma_{\text{total}}$   $\Gamma_{12}/\Gamma \times \Gamma_{24}/\Gamma$

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
<b>&lt;0.99 <math>\times 10^{-6}</math></b>	90	<sup>24</sup> PAKHLOVA 09	BELL	$e^+ e^- \rightarrow D^0 D^{*-} \pi^+$ <sup>24</sup> Using $4421 \pm 4$ MeV for the mass of $\psi(4415)$ .

$\Gamma(D_1(2420) \bar{D} + \text{c.c.}) / \Gamma_{\text{total}}$   $\Gamma_{13}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>possibly seen</b>	<sup>25</sup> ABLIKIM 19AR	BES3	$e^+ e^- \rightarrow \pi^+ \pi^- D \bar{D}$ <sup>25</sup> Evidence for $e^+ e^- \rightarrow D_1(2420) \bar{D} + \text{c.c.}$ between $\sqrt{s} = 4.3$ and 4.6 GeV, not necessarily resonant.

$\Gamma(D_s^+ D_s^-) / \Gamma_{\text{total}}$   $\Gamma_{14}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>not seen</b>	PAKHLOVA 11	BELL	$e^+ e^- \rightarrow D_s^+ D_s^- \gamma$
<b>not seen</b>	DEL-AMO-SA..10N	BABR	$e^+ e^- \rightarrow D_s^+ D_s^- \gamma$

$\Gamma(\omega \chi_{c2}) / \Gamma_{\text{total}}$   $\Gamma_{15}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>possibly seen</b>	ABLIKIM 16A	BES3	$e^+ e^- \rightarrow \gamma \pi^+ \pi^- \pi^0 \ell^+ \ell^-$

$\Gamma(D_s^{*+} D_s^- + \text{c.c.}) / \Gamma_{\text{total}}$   $\Gamma_{16}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>seen</b>	PAKHLOVA 11	BELL	$e^+ e^- \rightarrow D_s^{*+} D_s^- \gamma$
<b>seen</b>	DEL-AMO-SA..10N	BABR	$e^+ e^- \rightarrow D_s^{*+} D_s^- \gamma$

$\Gamma(D_s^{*+} D_s^{*-}) / \Gamma_{\text{total}}$   $\Gamma_{17}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>not seen</b>	PAKHLOVA 11	BELL	$e^+ e^- \rightarrow D_s^{*+} D_s^{*-} \gamma$
<b>not seen</b>	DEL-AMO-SA..10N	BABR	$e^+ e^- \rightarrow D_s^{*+} D_s^{*-} \gamma$

$\Gamma(\psi(3770) \pi^+ \pi^-) / \Gamma_{\text{total}}$   $\Gamma_{19}/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
<b>possibly seen</b>	<sup>26</sup> ABLIKIM 19AR	BES3	$e^+ e^- \rightarrow \pi^+ \pi^- D \bar{D}$ <sup>26</sup> Observe $e^+ e^- \rightarrow \pi^+ \pi^- \psi(3770)$ at $\sqrt{s} = 4.26, 4.36,$ and 4.42 GeV but cannot establish if continuum or resonant.

$\Gamma(\psi_2(3823) \pi^+ \pi^-) / \Gamma_{\text{total}}$   $\Gamma_{18}/\Gamma$

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
<b>possibly seen</b>	19	<sup>27</sup> ABLIKIM 15S	BES3	$e^+ e^- \rightarrow \pi^+ \pi^- \chi_{c1} \gamma$ <sup>27</sup> From a fit of $e^+ e^- \rightarrow \pi^+ \pi^- \psi_2(3823), \psi_2(3823) \rightarrow \chi_{c1} \gamma$ cross sections taken at $\sqrt{s}$ values of 4.23, 4.26, 4.36, 4.42, and 4.60 GeV to the $\psi(4415)$ line shape.

$\psi(4415)$  REFERENCES

ABLIKIM	21AS	PR D104 L091104	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	20AG	PR D102 112009	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	19AR	PR D100 032005	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ZHUKOVA	18	PR D97 012002	V. Zhukova <i>et al.</i>	(BELLE Collab.)
ABLIKIM	16A	PR D93 011102	M. Ablikim <i>et al.</i>	(BESIII Collab.)
ABLIKIM	15S	PRL 115 011803	M. Ablikim <i>et al.</i>	(BESIII Collab.)
HAN	15	PR D92 012011	Y.L. Han <i>et al.</i>	(BELLE Collab.)
WANG	13B	PR D87 051101	X.L. Wang <i>et al.</i>	(BELLE Collab.)
PAKHLOVA	11	PR D83 011101	G. Pakhlova <i>et al.</i>	(BELLE Collab.)
DEL-AMO-SA...	10N	PR D82 052004	P. del Amo Sanchez <i>et al.</i>	(BABAR Collab.)
MO	10	PR D82 077501	X.H. Mo, C.Z. Yuan, P. Wang	(BHEP)
AUBERT	09M	PR D79 092001	B. Aubert <i>et al.</i>	(BABAR Collab.)
PAKHLOVA	09	PR D80 091101	G. Pakhlova <i>et al.</i>	(BELLE Collab.)
ABLIKIM	08D	PL B660 315	M. Ablikim <i>et al.</i>	(BES Collab.)
PAKHLOVA	08	PR D77 011103	G. Pakhlova <i>et al.</i>	(BELLE Collab.)
PAKHLOVA	08A	PRL 100 062001	G. Pakhlova <i>et al.</i>	(BELLE Collab.)
PAKHLOVA	07	PRL 98 092001	G. Pakhlova <i>et al.</i>	(BELLE Collab.)
SETH	05A	PR D72 017501	K.K. Seth	
BAI	02C	PRL 88 101802	J.Z. Bai <i>et al.</i>	(BES Collab.)
BAI	00	PRL 84 594	J.Z. Bai <i>et al.</i>	(BES Collab.)
OSTERHELD	86	SLAC-PUB-4160	A. Osterheld <i>et al.</i>	(SLAC Crystal Ball Collab.)
BRANDELIK	78C	PL 76B 361	R. Brandelik <i>et al.</i>	(DASP Collab.)
SIEGRIST	76	PRL 36 700	J.L. Siegrist <i>et al.</i>	(LBL, SLAC)