

# $f_4(2050)$

$$I^G(J^{PC}) = 0^+(4^{++})$$

## $f_4(2050)$ MASS

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>2018±11</b>	<b>OUR AVERAGE</b>	Error includes scale factor of 2.1. See the ideogram below.		
1960±15		AMELIN	06 VES	36 $\pi^- p \rightarrow \omega \omega n$
2005±10		<sup>1</sup> BINON	05 GAMS	33 $\pi^- p \rightarrow \eta \eta n$
1998±15		ALDE	98 GAM4	100 $\pi^- p \rightarrow \pi^0 \pi^0 n$
2060±20		ALDE	90 GAM2	38 $\pi^- p \rightarrow \omega \omega n$
2038±30		AUGUSTIN	87 DM2	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
2086±15		BALTRUSAIT..	87 MRK3	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
2000±60		ALDE	86D GAM4	100 $\pi^- p \rightarrow n 2\eta$
2020±20	40k	<sup>2</sup> BINON	84B GAM2	38 $\pi^- p \rightarrow n 2\pi^0$
2015±28		<sup>3</sup> CASON	82 STRC	8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$
2031 <sup>+25</sup> <sub>-36</sub>		ETKIN	82B MPS	23 $\pi^- p \rightarrow n 2K_S^0$
2020±30	700	APEL	75 NICE	40 $\pi^- p \rightarrow n 2\pi^0$
2050±25		BLUM	75 ASPK	18.4 $\pi^- p \rightarrow n K^+ K^-$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
1966±25		<sup>4</sup> ANISOVICH	09 RVUE	0.0 $\bar{p} p, \pi N$
1885 <sup>+14+218</sup> <sub>-13-25</sub>		<sup>5</sup> UEHARA	09 BELL	10.6 $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0$
2018±6		ANISOVICH	00J SPEC	2.0 $\bar{p} p \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ $\eta \eta, \eta \eta', \pi \pi$
~ 2000		<sup>6</sup> MARTIN	98 RVUE	$N \bar{N} \rightarrow \pi \pi$
~ 2010		<sup>7</sup> MARTIN	97 RVUE	$\bar{N} N \rightarrow \pi \pi$
~ 2040		<sup>8</sup> OAKDEN	94 RVUE	0.36–1.55 $\bar{p} p \rightarrow \pi \pi$
~ 1990		<sup>9</sup> OAKDEN	94 RVUE	0.36–1.55 $\bar{p} p \rightarrow \pi \pi$
1978±5		<sup>10</sup> ALPER	80 CNTR	62 $\pi^- p \rightarrow K^+ K^- n$
2040±10		<sup>10</sup> ROZANSKA	80 SPRK	18 $\pi^- p \rightarrow p \bar{p} n$
1935±13		<sup>10</sup> CORDEN	79 OMEG	12–15 $\pi^- p \rightarrow n 2\pi$
1988±7		EVANGELIS...	79B OMEG	10 $\pi^- p \rightarrow K^+ K^- n$
1922±14		<sup>11</sup> ANTIPOV	77 CIBS	25 $\pi^- p \rightarrow p 3\pi$

<sup>1</sup> From the first PWA solution.

<sup>2</sup> From a partial-wave analysis of the data.

<sup>3</sup> From an amplitude analysis of the reaction  $\pi^+ \pi^- \rightarrow 2\pi^0$ .

<sup>4</sup> K matrix pole.

<sup>5</sup> Taking into account the  $f_2(1950)$ . Helicity-2 production favored.

<sup>6</sup> Energy-dependent analysis.

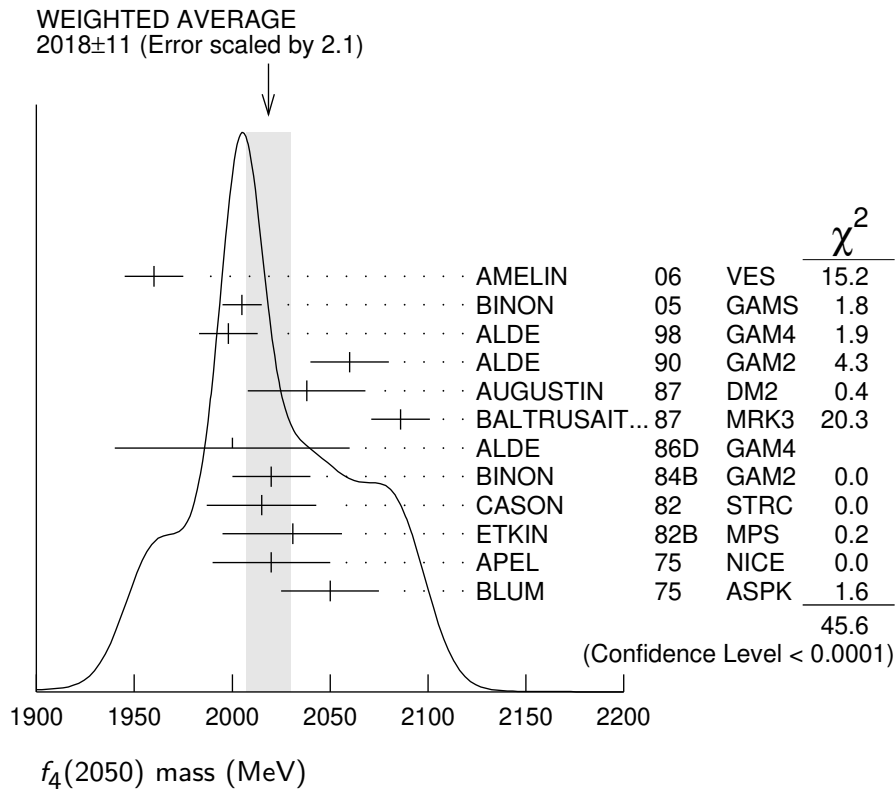
<sup>7</sup> Single energy analysis.

<sup>8</sup> From solution A of amplitude analysis of data on  $\bar{p} p \rightarrow \pi \pi$ . See however KLOET 96 who fit  $\pi^+ \pi^-$  only and find waves only up to  $J = 3$  to be important but not significantly resonant.

<sup>9</sup> From solution B of amplitude analysis of data on  $\bar{p} p \rightarrow \pi \pi$ . See however KLOET 96 who fit  $\pi^+ \pi^-$  only and find waves only up to  $J = 3$  to be important but not significantly resonant.

<sup>10</sup>  $I(J^P) = 0(4^+)$  from amplitude analysis assuming one-pion exchange.

<sup>11</sup> Width errors enlarged by us to  $4\Gamma/\sqrt{N}$ ; see the note with the  $K^*(892)$  mass.



### $f_4(2050)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
<b>237 ± 18 OUR AVERAGE</b>		Error includes scale factor of 1.9. See the ideogram below.		
290 ± 20		AMELIN 06	VES	36 $\pi^- p \rightarrow \omega \omega n$
340 ± 80		12 BINON 05	GAMS	33 $\pi^- p \rightarrow \eta \eta n$
395 ± 40		ALDE 98	GAM4	100 $\pi^- p \rightarrow \pi^0 \pi^0 n$
170 ± 60		ALDE 90	GAM2	38 $\pi^- p \rightarrow \omega \omega n$
304 ± 60		AUGUSTIN 87	DM2	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
210 ± 63		BALTRUSAIT..87	MRK3	$J/\psi \rightarrow \gamma \pi^+ \pi^-$
400 ± 100		ALDE 86D	GAM4	100 $\pi^- p \rightarrow n 2 \eta$
240 ± 40	40k	13 BINON 84B	GAM2	38 $\pi^- p \rightarrow n 2 \pi^0$
190 ± 14		DENNEY 83	LASS	10 $\pi^+ n / \pi^+ p$
186 <sup>+103</sup> <sub>-58</sub>		14 CASON 82	STRC	8 $\pi^+ p \rightarrow \Delta^{++} \pi^0 \pi^0$
305 <sup>+36</sup> <sub>-119</sub>		ETKIN 82B	MPS	23 $\pi^- p \rightarrow n 2 K_S^0$
180 ± 60	700	APEL 75	NICE	40 $\pi^- p \rightarrow n 2 \pi^0$
225 <sup>+120</sup> <sub>-70</sub>		BLUM 75	ASPK	18.4 $\pi^- p \rightarrow n K^+ K^-$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
260 ± 40		15 ANISOVICH 09	RVUE	0.0 $\bar{p} p, \pi N$
453 ± 20 <sup>+31</sup> <sub>-129</sub>		16 UEHARA 09	BELL	10.6 $e^+ e^- \rightarrow e^+ e^- \pi^0 \pi^0$
182 ± 7		ANISOVICH 00J	SPEC	2.0 $\bar{p} p \rightarrow \eta \pi^0 \pi^0, \pi^0 \pi^0,$ $\eta \eta, \eta \eta', \pi \pi$
~ 170		17 MARTIN 98	RVUE	$N \bar{N} \rightarrow \pi \pi$

~ 200	18 MARTIN	97 RVUE	$\bar{N}N \rightarrow \pi\pi$
~ 60	19 OAKDEN	94 RVUE	0.36–1.55 $\bar{p}p \rightarrow \pi\pi$
~ 80	20 OAKDEN	94 RVUE	0.36–1.55 $\bar{p}p \rightarrow \pi\pi$
243 ± 16	21 ALPER	80 CNTR	62 $\pi^- p \rightarrow K^+ K^- n$
140 ± 15	21 ROZANSKA	80 SPRK	18 $\pi^- p \rightarrow p\bar{p}n$
263 ± 57	21 CORDEN	79 OMEG	12–15 $\pi^- p \rightarrow n2\pi$
100 ± 28	EVANGELIS...	79B OMEG	10 $\pi^- p \rightarrow K^+ K^- n$
107 ± 56	22 ANTIPOV	77 CIBS	25 $\pi^- p \rightarrow p3\pi$

<sup>12</sup> From the first PWA solution.

<sup>13</sup> From a partial-wave analysis of the data.

<sup>14</sup> From an amplitude analysis of the reaction  $\pi^+\pi^- \rightarrow 2\pi^0$ .

<sup>15</sup> K matrix pole.

<sup>16</sup> Taking into account the  $f_2(1950)$ . Helicity-2 production favored.

<sup>17</sup> Energy-dependent analysis.

<sup>18</sup> Single energy analysis.

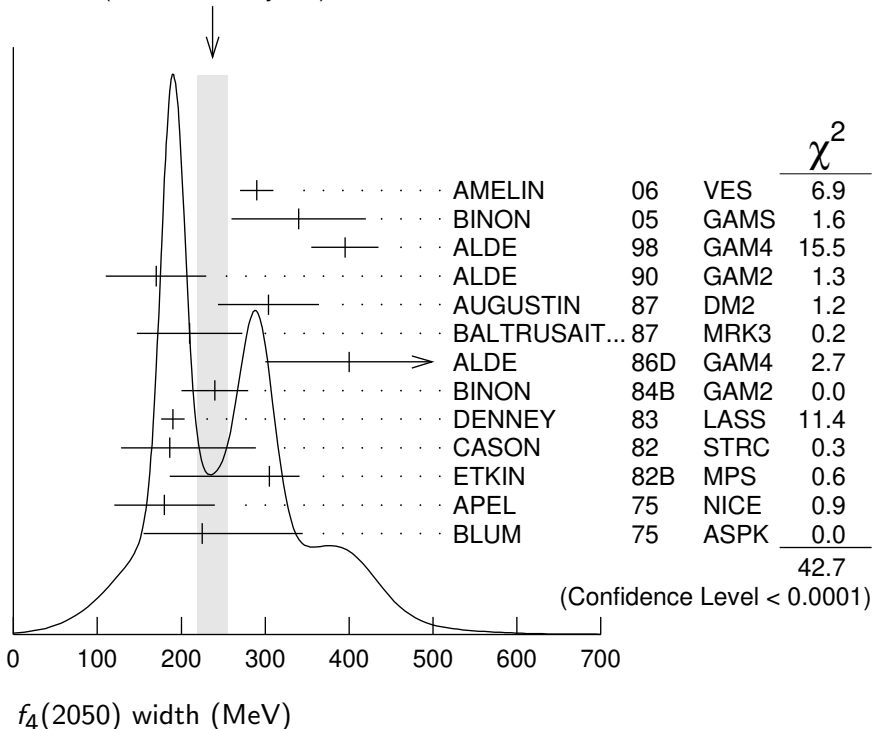
<sup>19</sup> From solution A of amplitude analysis of data on  $\bar{p}p \rightarrow \pi\pi$ . See however KLOET 96 who fit  $\pi^+\pi^-$  only and find waves only up to  $J = 3$  to be important but not significantly resonant.

<sup>20</sup> From solution B of amplitude analysis of data on  $\bar{p}p \rightarrow \pi\pi$ . See however KLOET 96 who fit  $\pi^+\pi^-$  only and find waves only up to  $J = 3$  to be important but not significantly resonant.

<sup>21</sup>  $I(J^P) = 0(4^+)$  from amplitude analysis assuming one-pion exchange.

<sup>22</sup> Width errors enlarged by us to  $4\Gamma/\sqrt{N}$ ; see the note with the  $K^*(892)$  mass.

WEIGHTED AVERAGE  
237 ± 18 (Error scaled by 1.9)



### $f_4(2050)$ DECAY MODES

Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $\omega\omega$	seen
$\Gamma_2$ $\pi\pi$	$(17.0 \pm 1.5) \%$
$\Gamma_3$ $K\bar{K}$	$(6.8^{+3.4}_{-1.8}) \times 10^{-3}$
$\Gamma_4$ $\eta\eta$	$(2.1 \pm 0.8) \times 10^{-3}$
$\Gamma_5$ $4\pi^0$	$< 1.2 \%$
$\Gamma_6$ $\gamma\gamma$	
$\Gamma_7$ $a_2(1320)\pi$	seen

### $f_4(2050) \Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\bar{K}) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_3\Gamma_6/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$< 0.29$	95	ALTHOFF	85B TASS	$\gamma\gamma \rightarrow K\bar{K}\pi$
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$\Gamma(\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$   $\Gamma_2\Gamma_6/\Gamma$

VALUE (eV)	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$23.1^{+3.6+70.5}_{-3.3-15.6}$			<sup>23</sup> UEHARA	09 BELL	$10.6 e^+e^- \rightarrow e^+e^-\pi^0\pi^0$
$< 1100$	95	$13 \pm 4$	OEST	90 JADE	$e^+e^- \rightarrow e^+e^-\pi^0\pi^0$

<sup>23</sup> Taking into account the  $f_2(1950)$ . Helicity-2 production favored.

### $f_4(2050)$ BRANCHING RATIOS

$\Gamma(\omega\omega)/\Gamma_{\text{total}}$   $\Gamma_1/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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seen AMELIN 06 VES  $36 \pi^- p \rightarrow \omega\omega n$

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

not seen BARBERIS 00F  $450 pp \rightarrow p_f\omega\omega p_s$

$\Gamma(\omega\omega)/\Gamma(\pi\pi)$   $\Gamma_1/\Gamma_2$

VALUE	DOCUMENT ID	TECN	COMMENT
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**$1.5 \pm 0.3$**  ALDE 90 GAM2  $38 \pi^- p \rightarrow \omega\omega n$

$\Gamma(\pi\pi)/\Gamma_{\text{total}}$   $\Gamma_2/\Gamma$

VALUE	DOCUMENT ID	TECN	COMMENT
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**$0.170 \pm 0.015$  OUR AVERAGE**

0.18  $\pm 0.03$  <sup>24</sup> BINON 83C GAM2  $38 \pi^- p \rightarrow n4\gamma$

0.16  $\pm 0.03$  <sup>24</sup> CASON 82 STRC  $8 \pi^+ p \rightarrow \Delta^{++}\pi^0\pi^0$

0.17  $\pm 0.02$  <sup>24</sup> CORDEN 79 OMEG  $12-15 \pi^- p \rightarrow n2\pi$

<sup>24</sup> Assuming one pion exchange.

$\Gamma(K\bar{K})/\Gamma(\pi\pi)$	$\Gamma_3/\Gamma_2$		
VALUE	DOCUMENT ID	TECN	COMMENT
$0.04^{+0.02}_{-0.01}$	ETKIN	82B MPS	$23 \pi^- p \rightarrow n 2K_S^0$
$\Gamma(\eta\eta)/\Gamma_{\text{total}}$	$\Gamma_4/\Gamma$		
VALUE (units $10^{-3}$ )	DOCUMENT ID	TECN	COMMENT
$2.1 \pm 0.8$	ALDE	86D GAM4	$100 \pi^- p \rightarrow n 4\gamma$
$\Gamma(4\pi^0)/\Gamma_{\text{total}}$	$\Gamma_5/\Gamma$		
VALUE	DOCUMENT ID	TECN	COMMENT
$<0.012$	ALDE	87 GAM4	$100 \pi^- p \rightarrow 4\pi^0 n$
$\Gamma(a_2(1320)\pi)/\Gamma_{\text{total}}$	$\Gamma_7/\Gamma$		
VALUE	DOCUMENT ID	TECN	COMMENT
<b>seen</b>	AMELIN	00 VES	$37 \pi^- p \rightarrow \eta \pi^+ \pi^- n$

 **$f_4(2050)$  REFERENCES**

ANISOVICH	09	IJMP A24 2481	V.V. Anisovich, A.V. Sarantsev	
UEHARA	09	PR D79 052009	S. Uehara <i>et al.</i>	(BELLE Collab.)
AMELIN	06	PAN 69 690	D.V. Amelin <i>et al.</i>	(VES Collab.)
		Translated from YAF 69 715.		
BINON	05	PAN 68 960	F. Binon <i>et al.</i>	
		Translated from YAF 68 998.		
AMELIN	00	NP A668 83	D. Amelin <i>et al.</i>	(VES Collab.)
ANISOVICH	00J	PL B491 47	A.V. Anisovich <i>et al.</i>	(RAL, LOQM, PNPI+)
BARBERIS	00F	PL B484 198	D. Barberis <i>et al.</i>	(WA 102 Collab.)
ALDE	98	EPJ A3 361	D. Alde <i>et al.</i>	(GAM4 Collab.)
Also		PAN 62 405	D. Alde <i>et al.</i>	(GAMS Collab.)
		Translated from YAF 62 446.		
MARTIN	98	PR C57 3492	B.R. Martin <i>et al.</i>	
MARTIN	97	PR C56 1114	B.R. Martin, G.C. Oades	(LOUC, AARH)
KLOET	96	PR D53 6120	W.M. Kloet, F. Myhrer	(RUTG, NORD)
OAKDEN	94	NP A574 731	M.N. Oakden, M.R. Pennington	(DURH)
ALDE	90	PL B241 600	D.M. Alde <i>et al.</i>	(SERP, BELG, LANL, LAPP+)
OEST	90	ZPHY C47 343	T. Oest <i>et al.</i>	(JADE Collab.)
ALDE	87	PL B198 286	D.M. Alde <i>et al.</i>	(LANL, BRUX, SERP, LAPP)
AUGUSTIN	87	ZPHY C36 369	J.E. Augustin <i>et al.</i>	(LALO, CLER, FRAS+)
BALTRUSAITIS...	87	PR D35 2077	R.M. Baltrusaitis <i>et al.</i>	(Mark III Collab.)
ALDE	86D	NP B269 485	D.M. Alde <i>et al.</i>	(BELG, LAPP, SERP, CERN+)
ALTHOFF	85B	ZPHY C29 189	M. Althoff <i>et al.</i>	(TASSO Collab.)
BINON	84B	LNC 39 41	F.G. Binon <i>et al.</i>	(SERP, BELG, LAPP)
BINON	83C	SJNP 38 723	F.G. Binon <i>et al.</i>	(SERP, BRUX+)
		Translated from YAF 38 1199.		
DENNEY	83	PR D28 2726	D.L. Denney <i>et al.</i>	(IOWA, MICH)
CASON	82	PRL 48 1316	N.M. Cason <i>et al.</i>	(NDAM, ANL)
ETKIN	82B	PR D25 1786	A. Etkin <i>et al.</i>	(BNL, CUNY, TUFTS, VAND)
ALPER	80	PL 94B 422	B. Alper <i>et al.</i>	(AMST, CERN, CRAC, MPIM+)
ROZANSKA	80	NP B162 505	M. Rozanska <i>et al.</i>	(MPIM, CERN)
CORDEN	79	NP B157 250	M.J. Corden <i>et al.</i>	(BIRM, RHEL, TELA+) JP
EVANGELIS...	79B	NP B154 381	C. Evangelista <i>et al.</i>	(BARI, BONN, CERN+)
ANTIPOV	77	NP B119 45	Y.M. Antipov <i>et al.</i>	(SERP, GEVA)
APEL	75	PL 57B 398	W.D. Apel <i>et al.</i>	(KARLK, KARLE, PISA, SERP+) JP
BLUM	75	PL 57B 403	W. Blum <i>et al.</i>	(CERN, MPIM) JP