

**$N(1440) P_{11}$** 

$$I(J^P) = \frac{1}{2}(\frac{1}{2}^+) \text{ Status: } ****$$

Most of the results published before 1975 were last included in our 1982 edition, Physics Letters **111B** 1 (1982). Some further obsolete results published before 1984 were last included in our 2006 edition, Journal of Physics, G **33** 1 (2006).

 **$N(1440)$  BREIT-WIGNER MASS**

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1420 to 1470 (<math>\approx 1440</math>) OUR ESTIMATE</b>			
1485.0 $\pm$ 1.2	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1462 $\pm$ 10	MANLEY	92	IPWA $\pi N \rightarrow \pi N \& N\pi\pi$
1440 $\pm$ 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1410 $\pm$ 12	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1436 $\pm$ 15	SARANTSEV	08	DPWA Multichannel
1468.0 $\pm$ 4.5	ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
1518 $\pm$ 5	PENNER	02C	DPWA Multichannel
1479 $\pm$ 80	VRANA	00	DPWA Multichannel
1463 $\pm$ 7	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
1467	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1421 $\pm$ 18	BATINIC	95	DPWA $\pi N \rightarrow N\pi, N\eta$
1465	LI	93	IPWA $\gamma N \rightarrow \pi N$
1471	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
1380	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
1390	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

 **$N(1440)$  BREIT-WIGNER WIDTH**

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>200 to 450 (<math>\approx 300</math>) OUR ESTIMATE</b>			
284 $\pm$ 18	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
391 $\pm$ 34	MANLEY	92	IPWA $\pi N \rightarrow \pi N \& N\pi\pi$
340 $\pm$ 70	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
135 $\pm$ 10	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
335 $\pm$ 40	SARANTSEV	08	DPWA Multichannel
360 $\pm$ 26	ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
668 $\pm$ 41	PENNER	02C	DPWA Multichannel
490 $\pm$ 120	VRANA	00	DPWA Multichannel
360 $\pm$ 20	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
440	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
250 $\pm$ 63	BATINIC	95	DPWA $\pi N \rightarrow N\pi, N\eta$
315	LI	93	IPWA $\gamma N \rightarrow \pi N$
545 $\pm$ 170	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
200	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
200	<sup>2</sup> LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

## N(1440) POLE POSITION

### REAL PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1350 to 1380 (<math>\approx</math> 1365) OUR ESTIMATE</b>			
1359	<sup>3</sup> ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1385	<sup>4</sup> HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1375 $\pm$ 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1371 $\pm$ 7	SARANTSEV	08	DPWA Multichannel
1357	<sup>5</sup> ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
1383	VRANA	00	DPWA Multichannel
1346	<sup>6</sup> ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1360	<sup>7</sup> ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
1370	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
1381 or 1379	<sup>8</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
1360 or 1333	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

### -2xIMAGINARY PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>160 to 220 (<math>\approx</math> 190) OUR ESTIMATE</b>			
162	<sup>3</sup> ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
164	<sup>4</sup> HOEHLER	93	SPED $\pi N \rightarrow \pi N$
180 $\pm$ 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
192 $\pm$ 20	SARANTSEV	08	DPWA Multichannel
160	<sup>5</sup> ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
316	VRANA	00	DPWA Multichannel
176	<sup>6</sup> ARNDT	95	DPWA $\pi N \rightarrow N\pi$
252	<sup>7</sup> ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
228	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
209 or 210	<sup>8</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
167 or 234	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

## N(1440) ELASTIC POLE RESIDUE

### MODULUS $|r|$

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
38	<sup>3</sup> ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
40	HOEHLER	93	SPED $\pi N \rightarrow \pi N$
52 $\pm$ 5	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
36	<sup>5</sup> ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
42	<sup>6</sup> ARNDT	95	DPWA $\pi N \rightarrow N\pi$
109	<sup>7</sup> ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
74	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$

## PHASE $\theta$

VALUE ( $^\circ$ )	DOCUMENT ID	TECN	COMMENT
- 98	<sup>3</sup> ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
-100 $\pm$ 35	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-102	<sup>5</sup> ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
-101	<sup>6</sup> ARNDT	95	DPWA $\pi N \rightarrow N\pi$
- 93	<sup>7</sup> ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
- 84	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$

## N(1440) DECAY MODES

The following branching fractions are our estimates, not fits or averages.

Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $N\pi$	0.55 to 0.75
$\Gamma_2$ $N\eta$	
$\Gamma_3$ $N\pi\pi$	30-40 %
$\Gamma_4$ $\Delta\pi$	20-30 %
$\Gamma_5$ $\Delta(1232)\pi, P$ -wave	
$\Gamma_6$ $N\rho$	<8 %
$\Gamma_7$ $N\rho, S=1/2, P$ -wave	
$\Gamma_8$ $N\rho, S=3/2, P$ -wave	
$\Gamma_9$ $N(\pi\pi)_{S\text{-wave}}^{I=0}$	5-10 %
$\Gamma_{10}$ $p\gamma$	0.035-0.048 %
$\Gamma_{11}$ $p\gamma, \text{helicity}=1/2$	0.035-0.048 %
$\Gamma_{12}$ $n\gamma$	0.009-0.032 %
$\Gamma_{13}$ $n\gamma, \text{helicity}=1/2$	0.009-0.032 %

## N(1440) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$	DOCUMENT ID	TECN	COMMENT	$\Gamma_1/\Gamma$
<b>0.55 to 0.75 OUR ESTIMATE</b>				
0.787 $\pm$ 0.016	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$	
0.69 $\pm$ 0.03	MANLEY	92	IPWA $\pi N \rightarrow \pi N \& N\pi\pi$	
0.68 $\pm$ 0.04	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$	
0.51 $\pm$ 0.05	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$	
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
0.750 $\pm$ 0.024	ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$	
0.57 $\pm$ 0.01	PENNER	02C	DPWA Multichannel	
0.72 $\pm$ 0.05	VRANA	00	DPWA Multichannel	
0.68	ARNDT	95	DPWA $\pi N \rightarrow N\pi$	
0.56 $\pm$ 0.08	BATINIC	95	DPWA $\pi N \rightarrow N\pi, N\eta$	

$\Gamma(N\eta)/\Gamma_{\text{total}}$					$\Gamma_2/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.00±0.01	VRANA	00	DPWA	Multichannel	

Note: Signs of couplings from  $\pi N \rightarrow N\pi\pi$  analyses were changed in the 1986 edition to agree with the baryon-first convention; the overall phase ambiguity is resolved by choosing a negative sign for the  $\Delta(1620) S_{31}$  coupling to  $\Delta(1232)\pi$ .

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow \Delta(1232)\pi$ , <i>P-wave</i>					$(\Gamma_1\Gamma_5)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>+0.37 to +0.41 OUR ESTIMATE</b>					
+0.39±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N \& N\pi\pi$	
+0.41	<sup>1,9</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	
+0.37	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$	

$\Gamma(\Delta(1232)\pi)$ , <i>P-wave</i> / $\Gamma_{\text{total}}$					$\Gamma_5/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.16±0.01	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N\rho$ , <i>S=1/2, P-wave</i>					$(\Gamma_1\Gamma_7)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>±0.07 to ±0.25 OUR ESTIMATE</b>					
-0.11	<sup>1,9</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	
+0.23	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$	

$\Gamma(N\rho, S=1/2)$ , <i>P-wave</i> / $\Gamma_{\text{total}}$					$\Gamma_7/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.00±0.01	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N\rho$ , <i>S=3/2, P-wave</i>					$(\Gamma_1\Gamma_8)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
+0.18	<sup>1,9</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N(\pi\pi)_{S=0}^{I=0}$ , <i>S-wave</i>					$(\Gamma_1\Gamma_9)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
<b>±0.17 to ±0.25 OUR ESTIMATE</b>					
+0.24±0.03	MANLEY	92	IPWA	$\pi N \rightarrow \pi N \& N\pi\pi$	
-0.18	<sup>1,9</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	
-0.23	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$	

$\Gamma(N(\pi\pi)_{S=0}^{I=0})/\Gamma_{\text{total}}$					$\Gamma_9/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.12±0.01	VRANA	00	DPWA	Multichannel	

## N(1440) PHOTON DECAY AMPLITUDES

Papers on  $\gamma N$  amplitudes predating 1981 may be found in our 2006 edition,  
Journal of Physics, G **33** 1 (2006).

### **$N(1440) \rightarrow p\gamma$ , helicity-1/2 amplitude $A_{1/2}$**

<u>VALUE (GeV<sup>-1/2</sup>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>-0.065±0.004 OUR ESTIMATE</b>			
-0.051±0.002	DUGGER	07	DPWA $\gamma N \rightarrow \pi N$
-0.063±0.005	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
-0.069±0.018	CRAWFORD	83	IPWA $\gamma N \rightarrow \pi N$
-0.063±0.008	AWAJI	81	DPWA $\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
-0.061	DRECHSEL	07	DPWA $\gamma N \rightarrow \pi N$
-0.087	PENNER	02D	DPWA Multichannel
-0.085±0.003	LI	93	IPWA $\gamma N \rightarrow \pi N$
-0.129	<sup>10</sup> WADA	84	DPWA Compton scattering

### **$N(1440) \rightarrow n\gamma$ , helicity-1/2 amplitude $A_{1/2}$**

<u>VALUE (GeV<sup>-1/2</sup>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>+0.040±0.010 OUR ESTIMATE</b>			
0.045±0.015	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
0.037±0.010	AWAJI	81	DPWA $\gamma N \rightarrow \pi N$
0.030±0.003	FUJII	81	DPWA $\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.054	DRECHSEL	07	DPWA $\gamma N \rightarrow \pi N$
0.121	PENNER	02D	DPWA Multichannel
0.085±0.006	LI	93	IPWA $\gamma N \rightarrow \pi N$

## N(1440) FOOTNOTES

- <sup>1</sup> LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis. The other LONGACRE 77 values are from eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- <sup>2</sup> From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- <sup>3</sup> ARNDT 06 also finds a second-sheet pole with real part = 1388 MeV,  $-2 \times$  imaginary part = 165 MeV, and residue with modulus 86 MeV and phase =  $-46^\circ$ .
- <sup>4</sup> See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of  $N$  and  $\Delta$  resonances as determined from Argand diagrams of  $\pi N$  elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- <sup>5</sup> ARNDT 04 also finds a second-sheet pole with real part = 1385 MeV,  $-2 \times$  imaginary part = 166 MeV, and residue with modulus 82 MeV and phase =  $-51^\circ$ .
- <sup>6</sup> ARNDT 95 also finds a second-sheet pole with real part = 1383 MeV,  $-2 \times$  imaginary part = 210 MeV, and residue with modulus 92 MeV and phase =  $-54^\circ$ .
- <sup>7</sup> ARNDT 91 (Soln SM90) also finds a second-sheet pole with real part = 1413 MeV,  $-2 \times$  imaginary part = 256 MeV, and residue =  $(78-153i)$  MeV.
- <sup>8</sup> LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to  $\pi N \rightarrow N\pi\pi$  data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- <sup>9</sup> LONGACRE 77 considers this coupling to be well determined.
- <sup>10</sup> WADA 84 is inconsistent with other analyses; see the Note on  $N$  and  $\Delta$  Resonances.

## N(1440) REFERENCES

For early references, see Physics Letters **111B** 1 (1982).

SARANTSEV	08	PL B659 94	A.V. Sarantsev <i>et al.</i>	(CB-ELSA/A2-TAPS Collab.)
DRECHSEL	07	EPJ A34 69	D. Drechsel, S.S. Kamalov, L. Tiator	(MAINZ, JINR)
DUGGER	07	PR C76 025211	M. Dugger <i>et al.</i>	(Jefferson Lab CLAS Collab.)
ARNDT	06	PR C74 045205	R.A. Arndt <i>et al.</i>	(GWU)
PDG	06	JPG 33 1	W.-M. Yao <i>et al.</i>	(PDG Collab.)
ARNDT	04	PR C69 035213	R.A. Arndt <i>et al.</i>	(GWU, TRIU)
PENNER	02C	PR C66 055211	G. Penner, U. Mosel	(GIES)
PENNER	02D	PR C66 055212	G. Penner, U. Mosel	(GIES)
VRANA	00	PRPL 328 181	T.P. Vrana, S.A. Dytman,, T.-S.H. Lee	(PITT+)
ARNDT	96	PR C53 430	R.A. Arndt, I.I. Strakovsky, R.L. Workman	(VPI)
ARNDT	95	PR C52 2120	R.A. Arndt <i>et al.</i>	(VPI, BRCO)
BATINIC	95	PR C51 2310	M. Batinic <i>et al.</i>	(BOSK, UCLA)
Also		PR C57 1004 (erratum)	M. Batinic <i>et al.</i>	
HOEHLER	93	$\pi$ N Newsletter 9 1	G. Hohler	(KARL)
LI	93	PR C47 2759	Z.J. Li <i>et al.</i>	(VPI)
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KENT) IJP
Also		PR D30 904	D.M. Manley <i>et al.</i>	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt <i>et al.</i>	(VPI, TELE) IJP
CUTKOSKY	90	PR D42 235	R.E. Cutkosky, S. Wang	(CMU)
WADA	84	NP B247 313	Y. Wada <i>et al.</i>	(INUS)
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B 1	M. Roos <i>et al.</i>	(HELSE, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also		NP B197 365	K. Fujii <i>et al.</i>	(NAGO)
FUJII	81	NP B187 53	K. Fujii <i>et al.</i>	(NAGO, OSAK)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
Also		PR D20 2839	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler <i>et al.</i>	(KARLT) IJP
Also		Toronto Conf. 3	R. Koch	(KARLT) IJP
LONGACRE	78	PR D17 1795	R.S. Longacre <i>et al.</i>	(LBL, SLAC)
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also		NP B108 365	J. Dolbeau <i>et al.</i>	(SACL) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre <i>et al.</i>	(LBL, SLAC) IJP