

$N(1440) \frac{1}{2}^+$ $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ 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>
1420 to 1470 (≈ 1440) OUR ESTIMATE			
1430 ± 8	ANISOVICH	12A	DPWA Multichannel
1485.0 ± 1.2	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1462 ± 10	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
1440 ± 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1410 ± 12	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1440 ± 12	ANISOVICH	10	DPWA Multichannel
1439 ± 19	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
1436 ± 15	SARANTSEV	08	DPWA Multichannel
1468.0 ± 4.5	ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
1518 ± 5	PENNER	02C	DPWA Multichannel
1479 ± 80	VRANA	00	DPWA Multichannel
1463 ± 7	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
1467	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1465	LI	93	IPWA $\gamma N \rightarrow \pi N$
1471	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
1380	¹ LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
1390	² 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>
200 to 450 (≈ 300) OUR ESTIMATE			
365 ± 35	ANISOVICH	12A	DPWA Multichannel
284 ± 18	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
391 ± 34	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
340 ± 70	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
135 ± 10	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
335 ± 50	ANISOVICH	10	DPWA Multichannel
437 ± 141	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
335 ± 40	SARANTSEV	08	DPWA Multichannel
360 ± 26	ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
668 ± 41	PENNER	02C	DPWA Multichannel
490 ± 120	VRANA	00	DPWA Multichannel

360 ± 20	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
440	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
315	LI	93	IPWA	$\gamma N \rightarrow \pi N$
545 ± 170	CUTKOSKY	90	IPWA	$\pi N \rightarrow \pi N$
200	¹ LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
200	² 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>
1350 to 1380 (\approx 1365) OUR ESTIMATE			
1370 ± 4	ANISOVICH	12A	DPWA Multichannel
1359	³ ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1385	⁴ HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1375 ± 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1370 ± 4	ANISOVICH	10	DPWA Multichannel
1363 ± 11	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
1371 ± 7	SARANTSEV	08	DPWA Multichannel
1357	⁵ ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
1383	VRANA	00	DPWA Multichannel
1346	⁶ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1360	⁷ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
1370	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
1381 or 1379	⁸ LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
1360 or 1333	¹ LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

−2×IMAGINARY PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
160 to 220 (\approx 190) OUR ESTIMATE			
190 ± 7	ANISOVICH	12A	DPWA Multichannel
162	³ ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
164	⁴ HOEHLER	93	SPED $\pi N \rightarrow \pi N$
180 ± 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
193 ± 7	ANISOVICH	10	DPWA Multichannel
151 ± 13	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
192 ± 20	SARANTSEV	08	DPWA Multichannel
160	⁵ ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
316	VRANA	00	DPWA Multichannel
176	⁶ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
252	⁷ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
228	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
209 or 210	⁸ LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
167 or 234	¹ 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>
40 to 52 (≈ 46) OUR ESTIMATE			
48 ± 3	ANISOVICH	12A	DPWA Multichannel
38	³ ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
40	HOEHLER	93	SPED $\pi N \rightarrow \pi N$
52 ± 5	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
44	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
36	⁵ ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
42	⁶ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
109	⁷ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
74	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$

PHASE θ

<u>VALUE ($^\circ$)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
75 to 100 (≈ 85) OUR ESTIMATE			
-78 ± 4	ANISOVICH	12A	DPWA Multichannel
-98	³ ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
-100 ± 35	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-88	BATINIC	10	DPWA $\pi N \rightarrow N\pi, N\eta$
-102	⁵ ARNDT	04	DPWA $\pi N \rightarrow \pi N, \eta N$
-101	⁶ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
-93	⁷ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
-84	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$

 $N(1440)$ INELASTIC POLE RESIDUE

The "normalized residue" is the residue divided by Γ_{pole} .

Normalized residue in $N\pi \rightarrow N(1440) \rightarrow \Delta\pi$, P -wave

<u>MODULUS (%)</u>	<u>PHASE ($^\circ$)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
27 ± 2	40 ± 5	ANISOVICH	12A	DPWA Multichannel

Normalized residue in $N\pi \rightarrow N(1440) \rightarrow N(\pi\pi)_{S=0}^{I=0}$ S -wave

<u>MODULUS (%)</u>	<u>PHASE ($^\circ$)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
21 ± 5	-135 ± 7	ANISOVICH	12A	DPWA Multichannel

N(1440) DECAY MODES

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

Mode	Fraction (Γ_i/Γ)
Γ_1 $N\pi$	55–75 %
Γ_2 $N\eta$	(0.0±1.0) %
Γ_3 $N\pi\pi$	30–40 %
Γ_4 $\Delta\pi$	20–30 %
Γ_5 $\Delta(1232)\pi$, <i>P</i> -wave	15–30 %
Γ_6 $N\rho$	<8 %
Γ_7 $N\rho$, <i>S</i> =1/2, <i>P</i> -wave	(0.0±1.0) %
Γ_8 $N\rho$, <i>S</i> =3/2, <i>P</i> -wave	
Γ_9 $N(\pi\pi)_{S\text{-wave}}^{I=0}$	10–20 %
Γ_{10} $p\gamma$	0.035–0.048 %
Γ_{11} $p\gamma$, helicity=1/2	0.035–0.048 %
Γ_{12} $n\gamma$	0.02–0.04 %
Γ_{13} $n\gamma$, helicity=1/2	0.02–0.04 %

N(1440) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$					Γ_1/Γ	
VALUE (%)	DOCUMENT ID	TECN	COMMENT			
55 to 75 OUR ESTIMATE						
62 ±3	ANISOVICH	12A	DPWA	Multichannel		
78.7±1.6	ARNDT	06	DPWA	$\pi N \rightarrow \pi N, \eta N$		
69 ±3	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$		
68 ±4	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$		
51 ±5	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$		
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●						
60 ±6	ANISOVICH	10	DPWA	Multichannel		
62 ±4	BATINIC	10	DPWA	$\pi N \rightarrow N\pi, N\eta$		
75.0±2.4	ARNDT	04	DPWA	$\pi N \rightarrow \pi N, \eta N$		
57 ±1	PENNER	02C	DPWA	Multichannel		
72 ±5	VRANA	00	DPWA	Multichannel		
68	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$		
$\Gamma(N\eta)/\Gamma_{\text{total}}$						
VALUE (%)	DOCUMENT ID	TECN	COMMENT	Γ_2/Γ		
0±1	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 $N\pi \rightarrow N(1440) \rightarrow \Delta(1232)\pi$, P -wave $(\Gamma_1 \Gamma_5)^{1/2} / \Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
+0.37 to +0.41 OUR ESTIMATE			
+0.39±0.02	MANLEY 92	IPWA	$\pi N \rightarrow \pi N \ \& \ N\pi\pi$
+0.41	^{1,9} LONGACRE 77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.37	² LONGACRE 75	IPWA	$\pi N \rightarrow N\pi\pi$

$\Gamma(\Delta(1232)\pi, P\text{-wave}) / \Gamma_{\text{total}}$ Γ_5 / Γ

<u>VALUE (%)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
15 to 30 (≈ 20) OUR ESTIMATE			
21±8	ANISOVICH 12A	DPWA	Multichannel
16±1	VRANA 00	DPWA	Multichannel

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N\rho, S=1/2$, P -wave $(\Gamma_1 \Gamma_7)^{1/2} / \Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
±0.07 to ±0.25 OUR ESTIMATE			
-0.11	^{1,9} LONGACRE 77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.23	² LONGACRE 75	IPWA	$\pi N \rightarrow N\pi\pi$

$\Gamma(N\rho, S=1/2, P\text{-wave}) / \Gamma_{\text{total}}$ Γ_7 / Γ

<u>VALUE (%)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
0±1	VRANA 00	DPWA	Multichannel

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N\rho, S=3/2$, P -wave $(\Gamma_1 \Gamma_8)^{1/2} / \Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
+0.18	^{1,9} LONGACRE 77	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N(\pi\pi)_{S\text{-wave}}^{I=0}$ $(\Gamma_1 \Gamma_9)^{1/2} / \Gamma$

<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
±0.17 to ±0.25 OUR ESTIMATE			
+0.24±0.03	MANLEY 92	IPWA	$\pi N \rightarrow \pi N \ \& \ N\pi\pi$
-0.18	^{1,9} LONGACRE 77	IPWA	$\pi N \rightarrow N\pi\pi$
-0.23	² LONGACRE 75	IPWA	$\pi N \rightarrow N\pi\pi$

$\Gamma(N(\pi\pi)_{S\text{-wave}}^{I=0}) / \Gamma_{\text{total}}$ Γ_9 / Γ

<u>VALUE (%)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
10 to 20 (≈ 15) OUR ESTIMATE			
17±7	ANISOVICH 12A	DPWA	Multichannel
12±1	VRANA 00	DPWA	Multichannel

$N(1440)$ PHOTON DECAY AMPLITUDES

Papers on γN 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^{-1/2})</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
-0.060±0.004 OUR ESTIMATE			
-0.061±0.008	ANISOVICH	12A DPWA	Multichannel
-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. ● ● ●			
-0.052±0.010	ANISOVICH	10 DPWA	Multichannel
-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	¹⁰ WADA	84 DPWA	Compton scattering

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

<u>VALUE (GeV^{-1/2})</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
+0.040±0.010 OUR ESTIMATE			
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

- ¹ 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.
- ² From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ³ 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 degrees.
- ⁴ See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.
- ⁵ 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° .
- ⁶ 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° .
- ⁷ 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.
- ⁸ 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.

⁹ LONGACRE 77 considers this coupling to be well determined.

¹⁰ WADA 84 is inconsistent with other analyses; see the Note on N and Δ Resonances.

$N(1440)$ REFERENCES

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

ANISOVICH	12A	EPJ A48 15	A.V. Anisovich <i>et al.</i>	(BONN, PNPI)
ANISOVICH	10	EPJ A44 203	A.V. Anisovich <i>et al.</i>	(BONN, PNPI)
BATINIC	10	PR C82 038203	M. Batinic <i>et al.</i>	(ZAGR)
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)
HOEHLER	93	πN 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