

$N(1440) P_{11}$

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

Most of the results published before 1975 are now obsolete and have been omitted. They may be found in our 1982 edition, Physics Letters **111B** (1982).

$N(1440)$ BREIT-WIGNER MASS

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1430 to 1470 (≈ 1440) OUR ESTIMATE			
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. ● ● ●			
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 $\pi N \rightarrow \pi N$
1411	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
1472	¹ BAKER	79	DPWA $\pi^- p \rightarrow n\eta$
1417	BARBOUR	78	DPWA $\gamma N \rightarrow \pi N$
1460	BERENDS	77	IPWA $\gamma N \rightarrow \pi N$
1380	² LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
1390	³ 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>
250 to 450 (≈ 350) OUR ESTIMATE			
391 \pm 34	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
545 \pm 170	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
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. ● ● ●			
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 $\gamma N \rightarrow \pi N$
334	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
113	¹ BAKER	79	DPWA $\pi^- p \rightarrow n\eta$
331	BARBOUR	78	DPWA $\gamma N \rightarrow \pi N$
279	BERENDS	77	IPWA $\gamma N \rightarrow \pi N$
200	² LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
200	³ LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

N(1440) POLE POSITION

REAL PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
1345 to 1385 (\approx 1365) OUR ESTIMATE			
1346	⁴ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1385	⁵ HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1370	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
1375 \pm 30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1360	⁶ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
1381 or 1379	⁷ LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
1360 or 1333	² LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

– 2×IMAGINARY PART

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
160 to 260 (\approx 210) OUR ESTIMATE			
176	⁴ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
164	⁵ HOEHLER	93	SPED $\pi N \rightarrow \pi N$
228	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
180 \pm 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
252	⁶ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
209 or 210	⁷ LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
167 or 234	² LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

N(1440) ELASTIC POLE RESIDUE

MODULUS $|r|$

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
42	⁴ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
40	HOEHLER	93	SPED $\pi N \rightarrow \pi N$
74	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
52 \pm 5	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
109	⁶ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

PHASE θ

VALUE ($^\circ$)	DOCUMENT ID	TECN	COMMENT
– 101	⁴ ARNDT	95	DPWA $\pi N \rightarrow N\pi$
– 84	CUTKOSKY	90	IPWA $\pi N \rightarrow \pi N$
– 100 \pm 35	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
– 93	⁶ ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

N(1440) DECAY MODES

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

Mode	Fraction (Γ_i/Γ)
Γ_1 $N\pi$	60–70 %
Γ_2 $N\eta$	
Γ_3 $N\pi\pi$	30–40 %
Γ_4 $\Delta\pi$	20–30 %
Γ_5 $\Delta(1232)\pi$, P -wave	
Γ_6 $N\rho$	<8 %
Γ_7 $N\rho$, $S=1/2$, P -wave	
Γ_8 $N\rho$, $S=3/2$, P -wave	
Γ_9 $N(\pi\pi)_{S\text{-wave}}^{I=0}$	5–10 %
Γ_{10} $p\gamma$	0.035–0.048 %
Γ_{11} $p\gamma$, helicity=1/2	0.035–0.048 %
Γ_{12} $n\gamma$	0.009–0.032 %
Γ_{13} $n\gamma$, helicity=1/2	0.009–0.032 %

N(1440) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$	Γ_1/Γ
VALUE	DOCUMENT ID TECN COMMENT
0.6 to 0.7 OUR ESTIMATE	
0.69±0.03	MANLEY 92 IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
0.68±0.04	CUTKOSKY 80 IPWA $\pi N \rightarrow \pi N$
0.51±0.05	HOEHLER 79 IPWA $\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •	
0.68	ARNDT 95 DPWA $\pi N \rightarrow N\pi$
0.56±0.08	BATINIC 95 DPWA $\pi N \rightarrow N\pi, N\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow N(1440) \rightarrow N\eta$	$(\Gamma_1\Gamma_2)^{1/2}/\Gamma$
VALUE	DOCUMENT ID TECN COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •	
seen	¹ BAKER 79 DPWA $\pi^- p \rightarrow n\eta$
+0.328	⁸ FELTESSE 75 DPWA 1488–1745 MeV

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	$(\Gamma_1\Gamma_5)^{1/2}/\Gamma$
VALUE	DOCUMENT ID TECN COMMENT
+0.37 to +0.41 OUR ESTIMATE	
+0.39±0.02	MANLEY 92 IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
+0.41	^{2,9} LONGACRE 77 IPWA $\pi N \rightarrow N\pi\pi$
+0.37	³ LONGACRE 75 IPWA $\pi N \rightarrow N\pi\pi$

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

VALUE	DOCUMENT ID	TECN	COMMENT
± 0.07 to ± 0.25 OUR ESTIMATE			
-0.11	^{2,9} LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
+0.23	³ LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

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

VALUE	DOCUMENT ID	TECN	COMMENT
+0.18	^{2,9} LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

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

VALUE	DOCUMENT ID	TECN	COMMENT
± 0.17 to ± 0.25 OUR ESTIMATE			
+0.24 ± 0.03	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
-0.18	^{2,9} LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$
-0.23	³ LONGACRE	75	IPWA $\pi N \rightarrow N\pi\pi$

N(1440) PHOTON DECAY AMPLITUDES

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

VALUE (GeV ^{-1/2})	DOCUMENT ID	TECN	COMMENT
-0.065 ± 0.004 OUR ESTIMATE			
-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 $\gamma N \rightarrow \pi N$
-0.069 ± 0.004	ARAI	80	DPWA $\gamma N \rightarrow \pi N$ (fit 1)
-0.066 ± 0.004	ARAI	80	DPWA $\gamma N \rightarrow \pi N$ (fit 2)
-0.079 ± 0.009	BRATASHEV...	80	DPWA $\gamma N \rightarrow \pi N$
-0.068 ± 0.015	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
-0.0584 ± 0.0148	ISHII	80	DPWA Compton scattering
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-0.085 ± 0.003	LI	93	IPWA $\gamma N \rightarrow \pi N$
-0.129	¹⁰ WADA	84	DPWA Compton scattering
-0.075 ± 0.015	BARBOUR	78	DPWA $\gamma N \rightarrow \pi N$
-0.125	¹¹ NOELLE	78	$\gamma N \rightarrow \pi N$
-0.076	BERENDS	77	IPWA $\gamma N \rightarrow \pi N$
-0.087 ± 0.006	FELLER	76	DPWA $\gamma N \rightarrow \pi N$

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

VALUE (GeV ^{-1/2})	DOCUMENT ID	TECN	COMMENT
+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 $\gamma N \rightarrow \pi N$
0.023 ± 0.009	ARAI	80	DPWA $\gamma N \rightarrow \pi N$ (fit 1)
0.019 ± 0.012	ARAI	80	DPWA $\gamma N \rightarrow \pi N$ (fit 2)
0.056 ± 0.015	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
-0.029 ± 0.035	TAKEDA	80	DPWA $\gamma N \rightarrow \pi N$

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

0.085 ± 0.006	LI	93	IPWA	$\gamma N \rightarrow \pi N$
+0.059 ± 0.016	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
0.062	11 NOELLE	78		$\gamma N \rightarrow \pi N$

N(1440) FOOTNOTES

- ¹ BAKER 79 finds a coupling of the $N(1440)$ to the $N\eta$ channel near (but slightly below) threshold.
- ² 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.
- ³ From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
- ⁴ 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° .
- ⁵ 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.
- ⁶ 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.
- ⁷ 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.
- ⁸ An alternative which cannot be distinguished from this is to have a P_{13} resonance with $M = 1530$ MeV, $\Gamma = 79$ MeV, and elasticity = $+0.271$.
- 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.
- ¹¹ Converted to our conventions using $M = 1486$ MeV, $\Gamma = 613$ MeV from NOELLE 78.

N(1440) REFERENCES

For early references, see Physics Letters **111B** 70 (1982).

ARNDT	96	PR C53 430	+Strakovsky, Workman	(VPI)
ARNDT	95	PR C52 2120	+Strakovsky, Workman, Pavan	(VPI, BRCO)
BATINIC	95	PR C51 2310	+Slaus, Svarc, Nefkens	(BOSK, UCLA)
Also	98	PR C57 1004 (erratum)	M. Batinic+	
HOEHLER	93	πN Newsletter 9 1		(KARL)
LI	93	PR C47 2759	+Arndt, Roper, Workman	(VPI)
MANLEY	92	PR D45 4002	+Saleski	(KENT) IJP
Also	84	PR D30 904	Manley, Arndt, Goradia, Teplitz	(VPI)
ARNDT	91	PR D43 2131	+Li, Roper, Workman, Ford	(VPI, TELE) IJP
CUTKOSKY	90	PR D42 235	+Wang	(CMU)
WADA	84	NP B247 313	+Egawa, Imanishi, Ishii, Kato, Ukai+	(INUS)
CRAWFORD	83	NP B211 1	+Morton	(GLAS)
PDG	82	PL 111B	Roos, Porter, Aguilar-Benitez+	(HELS, CIT, CERN)
AWAJI	81	Bonn Conf. 352	+Kajikawa	(NAGO)
Also	82	NP B197 365	Fujii, Hayashii, Iwata, Kajikawa+	(NAGO)
FUJII	81	NP B187 53	+Hayashii, Iwata, Kajikawa+	(NAGO, OSAK)
ARAI	80	Toronto Conf. 93		(INUS)
Also	82	NP B194 251	Arai, Fujii	(INUS)
BRATASHEV...	80	NP B166 525	Bratashevskij, Gorbenko, Derebchinskij+	(KFTI)

CRAWFORD	80	Toronto Conf. 107		(GLAS)
CUTKOSKY	80	Toronto Conf. 19	+Forsyth, Babcock, Kelly, Hendrick	(CMU, LBL) IJP
Also	79	PR D20 2839	Cutkosky, Forsyth, Hendrick, Kelly	(CMU, LBL) IJP
ISHII	80	NP B165 189	+Egawa, Kato, Miyachi+	(KYOT, INUS)
TAKEDA	80	NP B168 17	+Arai, Fujii, Ikeda, Iwasaki+	(TOKY, INUS)
BAKER	79	NP B156 93	+Brown, Clark, Davies, Depagter, Evans+	(RHEL) IJP
HOEHLER	79	PDAT 12-1	+Kaiser, Koch, Pietarinen	(KARLT) IJP
Also	80	Toronto Conf. 3	Koch	(KARLT) IJP
BARBOUR	78	NP B141 253	+Crawford, Parsons	(GLAS)
LONGACRE	78	PR D17 1795	+Lasinski, Rosenfeld, Smadja+	(LBL, SLAC)
NOELLE	78	PTP 60 778		(NAGO)
BERENDS	77	NP B136 317	+Donnachie	(LEID, MCHS) IJP
LONGACRE	77	NP B122 493	+Dolbeau	(SACL) IJP
Also	76	NP B108 365	Dolbeau, Triantis, Neveu, Cadiet	(SACL) IJP
FELLER	76	NP B104 219	+Fukushima, Horikawa, Kajikawa+	(NAGO, OSAK) IJP
FELTESSE	75	NP B93 242	+Ayed, Bareyre, Borgeaud, David+	(SACL) IJP
LONGACRE	75	PL 55B 415	+Rosenfeld, Lasinski, Smadja+	(LBL, SLAC) IJP