$N(1440)\ P_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$ 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

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
1420 to 1470 (≈ 1440) OUR ESTIMATE				
1440 ±12	ANISOVICH	10	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. • • •				
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

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
200 to 450 (≈ 300) OUR ESTIMATE				
335± 50	ANISOVICH	10	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. • • •				
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

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1350 to 1380 (≈ 1365) OUR ESTIMATE				
1370± 4	ANISOVICH	10	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. • • •				
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

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
160 to 220 (≈ 190) OUR ESTIMATE				
193± 7	ANISOVICH	10	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. • • •				
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 $|r|$

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
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	$\pi N \to N\pi, N\eta$
36	[5] ARNDT	04	DPWA	$\pi N \to \pi N, \eta N$
42	[6] ARNDT	95	DPWA	$\pi N \to N\pi$
109	[7] ARNDT	91	DPWA	$\pi N \to \pi N$ Soln SM90
74	CUTKOSKY	90	IPWA	$\pi N \to \pi N$

PHASE θ

VALUE (°)	DOCUMENT ID		TECN	COMMENT
− 98	[3] ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
−100±35	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
− 88	BATINIC	10	DPWA	$\pi N \to N\pi, N\eta$
−102	[5] ARNDT	04	DPWA	$\pi N \to \pi N, \eta N$
−101	[6] ARNDT	95	DPWA	$\pi N \to N\pi$
− 93	[7] ARNDT	91	DPWA	$\pi N \to \pi N$ Soln SM90
− 84	CUTKOSKY	90	IPWA	$\pi N \to \pi N$

N(1440) DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	0.55 to 0.75
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	$N(\pi\pi)^{I=0}_{S\text{-wave}}$	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

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.55 to 0.75 OUR ESTIMATE				
0.60 ±0.06	ANISOVICH	10	DPWA	Multichannel
0.787±0.016	ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
0.69 ±0.03	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
0.68 ±0.04	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.51 ±0.05	HOEHLER	79	IPWA	$\pi N \to \pi N$

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

0.62 ±0.04	BATINIC	10	DPWA	$\pi N \to N\pi$, $N\eta$
0.750±0.024	ARNDT	04	DPWA	$\pi N \to \pi N$, ηN
0.57 ±0.01	PENNER	02C	DPWA	Multichannel
0.72 ±0.05	VRANA	00	DPWA	Multichannel
0.68	ARNDT	95	DPWA	$\pi N \to N\pi$

$\Gamma(N\eta)/\Gamma_{total}$ — Γ_2/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.00±0.01	VRANA	00	DPWA	Multichannel

Note: Signs of couplings from $\pi N \to N\pi\pi$ 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 $\Delta(1232)\pi$.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1440) \to \Delta(1232)\pi$, 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	$\pi N \to \pi N$ & $N\pi\pi$
+0.41	[1,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.37	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
0.16±0.01	VRANA	00	DPWA	Multichannel

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

VALUE	DOCUMENT ID		TECN	COMMENT
±0.07 to ±0.25 OUR ESTIMATE				
−0.11	[1,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.23	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
0.00±0.01	VRANA	00	DPWA	Multichannel

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

VALUE	DOCUMENT ID		TECN	COMMENT
+0.18	[1,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
±0.17 to ±0.25 OUR ESTIMATE				
+0.24±0.03	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
−0.18	[1,9] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.23	[2] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
0.12±0.01	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) → $p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.065±0.004 OUR ESTIMATE				
−0.052±0.010	ANISOVICH	10	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. • • •				
−0.061	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) → $n\gamma$, 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	$\gamma N \rightarrow \pi N$
• • • 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 × 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 × 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×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 = (78−153*i*) 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	10	EPJ A44 203	A.V. Anisovich *et al.*	(BONN, PNPI)
BATINIC	10	PR C82 038203	M. Batinic *et al.*	(ZAGR)
SARANTSEV	08	PL B659 94	A.V. Sarantsev *et al.*	(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 *et al.*	(Jefferson Lab CLAS Collab.)
ARNDT	06	PR C74 045205	R.A. Arndt *et al.*	(GWU)
PDG	06	JPG 33 1	W.-M. Yao *et al.*	(PDG Collab.)
ARNDT	04	PR C69 035213	R.A. Arndt *et al.*	(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 *et al.*	(VPI, BRCO)
HOEHLER	93	πN Newsletter 9 1	G. Hohler	(KARL)
LI	93	PR C47 2759	Z.J. Li *et al.*	(VPI)
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KENT) IJP
Also		PR D30 904	D.M. Manley *et al.*	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt *et al.*	(VPI, TELE) IJP
CUTKOSKY	90	PR D42 235	R.E. Cutkosky, S. Wang	(CMU)
WADA	84	NP B247 313	Y. Wada *et al.*	(INUS)
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B 1	M. Roos *et al.*	(HELS, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also		NP B197 365	K. Fujii *et al.*	(NAGO)
FUJII	81	NP B187 53	K. Fujii *et al.*	(NAGO, OSAK)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
Also		PR D20 2839	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler *et al.*	(KARLT) IJP
Also		Toronto Conf. 3	R. Koch	(KARLT) IJP
LONGACRE	78	PR D17 1795	R.S. Longacre *et al.*	(LBL, SLAC)
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also		NP B108 365	J. Dolbeau *et al.*	(SACL) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre *et al.*	(LBL, SLAC) IJP