$N(1650)\ S_{11}$

$I(J^P) = \frac{1}{2}(\frac{1}{2}^-)$ 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(1650) BREIT-WIGNER MASS

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
1640 to 1680 (≈ 1650) OUR ESTIMATE					
1659± 9		MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
1650±30		CUTKOSKY	80	IPWA	$\pi N \to \pi N$
1670± 8		HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1677± 8		ARNDT	96	IPWA	$\gamma N \to \pi N$
1667		ARNDT	95	DPWA	$\pi N \to N\pi$
1712	[1]	ARNDT	95	DPWA	$\pi N \to N\pi$
1669±17		BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
1713±27	[2]	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
1674		LI	93	IPWA	$\gamma N \to \pi N$
1688		CRAWFORD	80	DPWA	$\gamma N \to \pi N$
1672		MUSETTE	80	IPWA	$\pi^- p \to \Lambda K^0$
1680		SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
1680		BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
1694		BARBOUR	78	DPWA	$\gamma N \to \pi N$
1700± 5	[3]	BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
1680	[3]	BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
1700	[4]	LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
1675		KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$
1660	[5]	LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

N(1650) BREIT-WIGNER WIDTH

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
145 to 190 (≈ 150) OUR ESTIMATE					
167.9± 9.4		GREEN	97	DPWA	$\pi N \to \pi N$, ηN
173 ±12		MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
150 ±40		CUTKOSKY	80	IPWA	$\pi N \to \pi N$
180 ±20		HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
160 ±12		ARNDT	96	IPWA	$\gamma N \to \pi N$
90		ARNDT	95	DPWA	$\pi N \to N\pi$
184	[1]	ARNDT	95	DPWA	$\pi N \to N\pi$
215 ±32		BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
279 ±54	[2]	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
225		LI	93	IPWA	$\gamma N \to \pi N$
183		CRAWFORD	80	DPWA	$\gamma N \to \pi N$
179		MUSETTE	80	IPWA	$\pi^- p \to \Lambda K^0$

120		SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
90		BAKER	78	DPWA	$\pi^- p \to \Lambda K^0$
193		BARBOUR	78	DPWA	$\gamma N \to \pi N$
130 ±10	[3]	BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
90	[3]	BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
170	[4]	LONGACRE	77	IPWA	$\pi N \to N \pi \pi$
170		KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$
130	[5]	LONGACRE	75	IPWA	$\pi N \to N \pi \pi$

$N(1650)$ POLE POSITION

REAL PART

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
1640 to 1680 (≈ 1660) OUR ESTIMATE					
1660±10	[6]	ARNDT	98	DPWA	$\pi N \to \pi N, \eta N$
1673		ARNDT	95	DPWA	$\pi N \to N \pi$
1689	[1]	ARNDT	95	DPWA	$\pi N \to N \pi$
1670	[7]	HOEHLER	93	ARGD	$\pi N \to \pi N$
1640±20		CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1657		ARNDT	91	DPWA	$\pi N \to \pi N$ Soln SM90
1648 or 1651	[8]	LONGACRE	78	IPWA	$\pi N \to N \pi \pi$
1699 or 1698	[4]	LONGACRE	77	IPWA	$\pi N \to N \pi \pi$

−2×IMAGINARY PART

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
150 to 170 (≈ 160) OUR ESTIMATE					
140±20	[6]	ARNDT	98	DPWA	$\pi N \to \pi N, \eta N$
82		ARNDT	95	DPWA	$\pi N \to N \pi$
192	[1]	ARNDT	95	DPWA	$\pi N \to N \pi$
163	[7]	HOEHLER	93	ARGD	$\pi N \to \pi N$
150±30		CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
160		ARNDT	91	DPWA	$\pi N \to \pi N$ Soln SM90
117 or 119	[8]	LONGACRE	78	IPWA	$\pi N \to N \pi \pi$
174 or 173	[4]	LONGACRE	77	IPWA	$\pi N \to N \pi \pi$

$N(1650)$ ELASTIC POLE RESIDUE

MODULUS $|r|$

VALUE (MeV)		DOCUMENT ID		TECN	COMMENT
22		ARNDT	95	DPWA	$\pi N \to N \pi$
72	[1]	ARNDT	95	DPWA	$\pi N \to N \pi$
39		HOEHLER	93	ARGD	$\pi N \to \pi N$
60±10		CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
54		ARNDT	91	DPWA	$\pi N \to \pi N$ Soln SM90

PHASE θ

VALUE (°)	DOCUMENT ID		TECN	COMMENT
29	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
−85	[1] ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
−37	HOEHLER	93	ARGD	$\pi N \rightarrow \pi N$
−75±25	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−38	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90

$N(1650)$ DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	55–90 %
Γ_2	$N\eta$	3–10 %
Γ_3	ΛK	3–11 %
Γ_4	ΣK	
Γ_5	$N\pi\pi$	10–20 %
Γ_6	$\Delta\pi$	1–7 %
Γ_7	$\Delta(1232)\pi$, D-wave	
Γ_8	$N\rho$	4–12 %
Γ_9	$N\rho$, S=1/2, S-wave	
Γ_{10}	$N\rho$, S=3/2, D-wave	
Γ_{11}	$N(\pi\pi)^{I=0}_{S\text{-wave}}$	<4 %
Γ_{12}	$N(1440)\pi$	<5 %
Γ_{13}	$p\gamma$	0.04–0.18 %
Γ_{14}	$p\gamma$, helicity=1/2	0.04–0.18 %
Γ_{15}	$n\gamma$	0.003–0.17 %
Γ_{16}	$n\gamma$, helicity=1/2	0.003–0.17 %

$N(1650)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.55 to 0.90 OUR ESTIMATE				
0.735±0.011	GREEN	97	DPWA	$\pi N \rightarrow \pi N$, ηN
0.89 ±0.07	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
0.65 ±0.10	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
0.61 ±0.04	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.99	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
0.27	[1] ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
0.94 ±0.07	BATINIC	95	DPWA	$\pi N \rightarrow N\pi$, $N\eta$
0.49 ±0.21	[2] BATINIC	95	DPWA	$\pi N \rightarrow N\pi$, $N\eta$

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

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.06±0.05	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
0.02±0.03	[2] BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N\eta$ — $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.09	[9] BAKER	79	DPWA	$\pi^- p \to n\eta$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to \Lambda K$ — $(\Gamma_1\Gamma_3)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.27 to −0.17 OUR ESTIMATE				
−0.22	BELL	83	DPWA	$\pi^- p \to \Lambda K^0$
−0.22	SAXON	80	DPWA	$\pi^- p \to \Lambda K^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.25	[10] BAKER	78	DPWA	See SAXON 80
−0.23±0.01	[3] BAKER	77	IPWA	$\pi^- p \to \Lambda K^0$
−0.25	[3] BAKER	77	DPWA	$\pi^- p \to \Lambda K^0$
0.12	KNASEL	75	DPWA	$\pi^- p \to \Lambda K^0$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to \Sigma K$ — $(\Gamma_1\Gamma_4)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.254	LIVANOS	80	DPWA	$\pi p \to \Sigma K$
0.066 to 0.137	[11] DEANS	75	DPWA	$\pi N \to \Sigma K$
0.20	KNASEL	75	DPWA	

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 $N\pi \to N(1650) \to \Delta(1232)\pi$, D-wave — $(\Gamma_1\Gamma_7)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.15 to 0.23 OUR ESTIMATE				
+0.12±0.04	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
+0.29	[4,12] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
+0.15	[5] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \to N(1650) \to N\rho$, S=1/2, S-wave — $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
±0.03 to ±0.19 OUR ESTIMATE				
−0.01±0.09	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
+0.17	[4,12] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
−0.16	[5] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1650) \rightarrow N\rho$, S=3/2, D-wave $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE		DOCUMENT ID		TECN	COMMENT
+0.17 to +0.29 OUR ESTIMATE					
+0.16±0.06		MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
+0.29	[4,12]	LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1650) \rightarrow N(\pi\pi)^{I=0}_{S\text{-wave}}$ $(\Gamma_1\Gamma_{11})^{1/2}/\Gamma$

VALUE		DOCUMENT ID		TECN	COMMENT
+0.04 to +0.18 OUR ESTIMATE					
+0.12±0.08		MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
0.00	[4,12]	LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.25	[5]	LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow N(1650) \rightarrow N(1440)\pi$ $(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.11±0.06	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$

N(1650) PHOTON DECAY AMPLITUDES

$N(1650) \rightarrow p\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
+0.053±0.016 OUR ESTIMATE				
0.069±0.005	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
0.033±0.015	CRAWFORD	83	IPWA	$\gamma N \rightarrow \pi N$
0.050±0.010	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.065±0.005	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
0.061±0.005	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
0.031±0.017	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.068±0.003	LI	93	IPWA	$\gamma N \rightarrow \pi N$
0.091	WADA	84	DPWA	Compton scattering
+0.048±0.017	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
+0.068±0.009	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$

$N(1650) \rightarrow n\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV$^{-1/2}$)	DOCUMENT ID		TECN	COMMENT
−0.015±0.021 OUR ESTIMATE				
−0.015±0.005	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
−0.008±0.004	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.004±0.004	FUJII	81	DPWA	$\gamma N \rightarrow \pi N$
0.010±0.020	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
0.008±0.019	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
−0.068±0.040	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
−0.011±0.011	TAKEDA	80	DPWA	$\gamma N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.002±0.002	LI	93	IPWA	$\gamma N \rightarrow \pi N$
−0.045±0.024	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$

$N(1650)$ $\gamma p \rightarrow \Lambda K^+$ AMPLITUDES

$(\Gamma_i \Gamma_f)^{1/2}/\Gamma_{total}$ in $p\gamma \rightarrow N(1650) \rightarrow \Lambda K^+$ (E_{0+} amplitude)

VALUE (units 10^{-3})	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
7.8 ±0.3	WORKMAN	90	DPWA
8.13	TANABE	89	DPWA

$p\gamma \rightarrow N(1650) \rightarrow \Lambda K^+$ phase angle θ (E_{0+} amplitude)

VALUE (degrees)	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •			
−107 ±3	WORKMAN	90	DPWA
−107.8	TANABE	89	DPWA

$N(1650)$ FOOTNOTES

[1] ARNDT 95 finds two distinct states.
[2] BATINIC 95 finds two distinct states. This second resonance was associated with the $N(2090)$ S_{11}.
[3] The two BAKER 77 entries are from an IPWA using the Barrelet-zero method and from a conventional energy-dependent analysis.
[4] 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.
[5] From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.
[6] ARNDT 98 also lists pole residues, which display more model dependence than do the associated pole positions.
[7] 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.
[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] BAKER 79 fixed this coupling during fitting, but the negative sign relative to the $N(1535)$ is well determined.
[10] The overall phase of BAKER 78 couplings has been changed to agree with previous conventions. Superseded by SAXON 80.
[11] The range given for DEANS 75 is from the four best solutions.
[12] LONGACRE 77 considers this coupling to be well determined.

N(1650) REFERENCES

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

ARNDT	98	PR C58 3636	R.A. Arndt *et al.*	
GREEN	97	PR C55 R2167	A.M. Green, S. Wycech	(HELS, WINR)
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)
BATINIC	95	PR C51 2310	M. Batinic *et al.*	(BOSK, UCLA)
Also	98	PR C57 1004 (erratum)	M. Batinic *et al.*	
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	84	PR D30 904	D.M. Manley *et al.*	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt *et al.*	(VPI, TELE) IJP
WORKMAN	90	PR C42 781	R.L. Workman	(VPI)
TANABE	89	PR C39 741	H. Tanabe, M. Kohno, C. Bennhold	(MANZ)
Also	89	NC 102A 193	M. Kohno, H. Tanabe, C. Bennhold	(MANZ)
WADA	84	NP B247 313	Y. Wada *et al.*	(INUS)
BELL	83	NP B222 389	K.W. Bell *et al.*	(RL) IJP
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B	M. Roos *et al.*	(HELS, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also	82	NP B197 365	K. Fujii *et al.*	(NAGO)
FUJII	81	NP B187 53	K. Fujii *et al.*	(NAGO, OSAK)
ARAI	80	Toronto Conf. 93	I. Arai	(INUS)
Also	82	NP B194 251	I. Arai, H. Fujii	(INUS)
CRAWFORD	80	Toronto Conf. 107	R.L. Crawford	(GLAS)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
Also	79	PR D20 2839	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
LIVANOS	80	Toronto Conf. 35	P. Livanos *et al.*	(SACL) IJP
MUSETTE	80	NC 57A 37	M. Musette	(BRUX) IJP
SAXON	80	NP B162 522	D.H. Saxon *et al.*	(RHEL, BRIS) IJP
TAKEDA	80	NP B168 17	H. Takeda *et al.*	(TOKY, INUS)
BAKER	79	NP B156 93	R.D. Baker *et al.*	(RHEL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler *et al.*	(KARLT) IJP
Also	80	Toronto Conf. 3	R. Koch	(KARLT) IJP
BAKER	78	NP B141 29	R.D. Baker *et al.*	(RL, CAVE) IJP
BARBOUR	78	NP B141 253	I.M. Barbour, R.L. Crawford, N.H. Parsons	(GLAS)
LONGACRE	78	PR D17 1795	R.S. Longacre *et al.*	(LBL, SLAC)
BAKER	77	NP B126 365	R.D. Baker *et al.*	(RHEL) IJP
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also	76	NP B108 365	J. Dolbeau *et al.*	(SACL) IJP
FELLER	76	NP B104 219	P. Feller *et al.*	(NAGO, OSAK) IJP
DEANS	75	NP B96 90	S.R. Deans *et al.*	(SFLA, ALAH) IJP
KNASEL	75	PR D11 1	T.M. Knasel *et al.*	(CHIC, WUSL, OSU+) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre *et al.*	(LBL, SLAC) IJP