$N(1650)\ S_{11}$

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

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
145 to 190 (≈ 150) OUR ESTIMATE				
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
1673	ARNDT	95	DPWA	$\pi N \to N\pi$
1689	[1] ARNDT	95	DPWA	$\pi N \to N\pi$
1670	[6] 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	[7] 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
82	ARNDT	95	DPWA	$\pi N \to N\pi$
192	[1] ARNDT	95	DPWA	$\pi N \to N\pi$
163	[6] 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	[7] 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	$\pi N \to N\pi$
−85	[1] ARNDT	95	DPWA	$\pi N \to N\pi$
−37	HOEHLER	93	ARGD	$\pi N \to \pi N$
−75±25	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−38	ARNDT	91	DPWA	$\pi N \to \pi N$ 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
0.65 to 0.90 OUR ESTIMATE				
0.89±0.07	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
0.65±0.10	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
0.61±0.04	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.99	ARNDT	95	DPWA	$\pi N \to N\pi$
0.27	[1] ARNDT	95	DPWA	$\pi N \to N\pi$
0.94±0.07	BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$
0.49±0.21	[2] BATINIC	95	DPWA	$\pi N \to N\pi$, $N\eta$

$\Gamma(N\eta)/\Gamma_{total}$ — 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	[8] 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	[9] 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	[10] 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				
$+0.12\pm0.04$	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
$+0.29$	[4,11] 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	$\pi N \to \pi N$ & $N\pi\pi$
$+0.17$	[4,11] 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 $N\pi \to N(1650) \to N\rho$, S=3/2, D-wave — $(\Gamma_1\Gamma_{10})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
$+0.17$ to $+0.29$ OUR ESTIMATE				
$+0.16\pm0.06$	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
$+0.29$	[4,11] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
$+0.04$ to $+0.18$ OUR ESTIMATE				
$+0.12\pm0.08$	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
0.00	[4,11] LONGACRE	77	IPWA	$\pi N \to N\pi\pi$
$+0.25$	[5] LONGACRE	75	IPWA	$\pi N \to N\pi\pi$

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

VALUE	DOCUMENT ID		TECN	COMMENT
$+0.11\pm0.06$	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$

N(1650) PHOTON DECAY AMPLITUDES

N(1650) → $p\gamma$, 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) → $n\gamma$, 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
7.8 ±0.3	WORKMAN	90	DPWA
• • • We do not use the following data for averages, fits, limits, etc. • • •			
8.13	TANABE	89	DPWA

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

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

[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] BAKER 79 fixed this coupling during fitting, but the negative sign relative to the $N(1535)$ is well determined.

[9] The overall phase of BAKER 78 couplings has been changed to agree with previous conventions. Superseded by SAXON 80.

[10] The range given for DEANS 75 is from the four best solutions.

[11] LONGACRE 77 considers this coupling to be well determined.

N(1650) 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)	
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
WORKMAN	90	PR C42 781		(VPI)	
TANABE	89	PR C39 741	+Kohno, Bennhold	(MANZ)	
Also	89	NC 102A 193	Kohno, Tanabe, Bennhold	(MANZ)	
WADA	84	NP B247 313	+Egawa, Imanishi, Ishii, Kato, Ukai+	(INUS)	
BELL	83	NP B222 389	+Blissett, Broome, Daley, Hart, Lintern+	(RL)	IJP
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)	
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
LIVANOS	80	Toronto Conf. 35	+Baton, Coutures, Kochowski, Neveu	(SACL)	IJP
MUSETTE	80	NC 57A 37		(BRUX)	IJP
SAXON	80	NP B162 522	+Baker, Bell, Blissett, Bloodworth+	(RHEL, BRIS)	IJP
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
BAKER	78	NP B141 29	+Blissett, Bloodworth, Broome+	(RL, CAVE)	IJP
BARBOUR	78	NP B141 253	+Crawford, Parsons	(GLAS)	
LONGACRE	78	PR D17 1795	+Lasinski, Rosenfeld, Smadja+	(LBL, SLAC)	
BAKER	77	NP B126 365	+Blissett, Bloodworth, Broome, Hart+	(RHEL)	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
DEANS	75	NP B96 90	+Mitchell, Montgomery+	(SFLA, ALAH)	IJP
KNASEL	75	PR D11 1	+Lindquist, Nelson+	(CHIC, WUSL, OSU, ANL)	IJP
LONGACRE	75	PL 55B 415	+Rosenfeld, Lasinski, Smadja+	(LBL, SLAC)	IJP