

# N(1535) S<sub>11</sub>

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

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(1535) BREIT-WIGNER MASS

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>1520 to 1555 (≈ 1535) OUR ESTIMATE</b>			
1534 ± 7	MANLEY	92	IPWA π N → π N & N π π
1550 ± 40	CUTKOSKY	80	IPWA π N → π N
1526 ± 7	HOEHLER	79	IPWA π N → π N
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1549 ± 2	ABAEV	96	DPWA π <sup>-</sup> p → η n
1525 ± 10	ARNDT	96	IPWA γ N → π N
1535	ARNDT	95	DPWA π N → N π
1542 ± 6	BATINIC	95	DPWA π N → N π, N η
1537	BATINIC	95B	DPWA π N → N π, N η
1544 ± 13	KRUSCHE	95	DPWA γ p → p η
1518	LI	93	IPWA γ N → π N
1513	CRAWFORD	80	DPWA γ N → π N
1511	BARBOUR	78	DPWA γ N → π N
1500	BERENDS	77	IPWA γ N → π N
1547 ± 6	BHANDARI	77	DPWA Uses N η cusp
1520	<sup>1</sup> LONGACRE	77	IPWA π N → N π π
1510	<sup>2</sup> LONGACRE	75	IPWA π N → N π π

## N(1535) BREIT-WIGNER WIDTH

VALUE (MeV)	DOCUMENT ID	TECN	COMMENT
<b>100 to 250 (≈ 150) OUR ESTIMATE</b>			
148.2 ± 8.1	GREEN	97	DPWA π N → π N, η N
151 ± 27	MANLEY	92	IPWA π N → π N & N π π
240 ± 80	CUTKOSKY	80	IPWA π N → π N
120 ± 20	HOEHLER	79	IPWA π N → π N
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
212 ± 20	<sup>3</sup> KRUSCHE	97	DPWA γ N → η N
169 ± 12	ABAEV	96	DPWA π <sup>-</sup> p → η n
103 ± 5	ARNDT	96	IPWA γ N → π N
66	ARNDT	95	DPWA π N → N π
150 ± 15	BATINIC	95	DPWA π N → N π, N η
145	BATINIC	95B	DPWA π N → N π, N η
200 ± 40	KRUSCHE	95	DPWA γ p → p η
84	LI	93	IPWA γ N → π N

136		CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
180		BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
132		BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
57		BERENDS	77	IPWA	$\gamma N \rightarrow \pi N$
139 $\pm 33$		BHANDARI	77	DPWA	Uses $N\eta$ cusp
135		<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
100		<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

## N(1535) POLE POSITION

### REAL PART

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
<b>1495 to 1515 (<math>\approx 1505</math>) OUR ESTIMATE</b>			
1510 $\pm 10$	<sup>4</sup> ARNDT	98	DPWA $\pi N \rightarrow \pi N, \eta N$
1501	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
1487	<sup>5</sup> HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1510 $\pm 50$	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1499	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
1496 or 1499	<sup>6</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
1519 $\pm 4$	BHANDARI	77	DPWA Uses $N\eta$ cusp
1525 or 1527	<sup>1</sup> 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>
<b>90 to 250 (<math>\approx 170</math>) OUR ESTIMATE</b>			
170 $\pm 30$	<sup>4</sup> ARNDT	98	DPWA $\pi N \rightarrow \pi N, \eta N$
124	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
260 $\pm 80$	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
110	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90
103 or 105	<sup>6</sup> LONGACRE	78	IPWA $\pi N \rightarrow N\pi\pi$
140 $\pm 32$	BHANDARI	77	DPWA Uses $N\eta$ cusp
135 or 123	<sup>1</sup> LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

## N(1535) ELASTIC POLE RESIDUE

### MODULUS $|r|$

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
31	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
120 $\pm 40$	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
23	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

### PHASE $\theta$

<u>VALUE (<math>^\circ</math>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
– 12	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
+ 15 $\pm 45$	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
– 13	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

## N(1535) DECAY MODES

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

Mode	Fraction ( $\Gamma_i/\Gamma$ )
$\Gamma_1$ $N\pi$	35–55 %
$\Gamma_2$ $N\eta$	30–55 %
$\Gamma_3$ $N\pi\pi$	1–10 %
$\Gamma_4$ $\Delta\pi$	<1 %
$\Gamma_5$ $\Delta(1232)\pi$ , <i>D-wave</i>	
$\Gamma_6$ $N\rho$	<4 %
$\Gamma_7$ $N\rho$ , <i>S=1/2, S-wave</i>	
$\Gamma_8$ $N\rho$ , <i>S=3/2, D-wave</i>	
$\Gamma_9$ $N(\pi\pi)_{S-wave}^{I=0}$	<3 %
$\Gamma_{10}$ $N(1440)\pi$	<7 %
$\Gamma_{11}$ $p\gamma$	0.15–0.35 %
$\Gamma_{12}$ $p\gamma$ , helicity=1/2	0.15–0.35 %
$\Gamma_{13}$ $n\gamma$	0.004–0.29 %
$\Gamma_{14}$ $n\gamma$ , helicity=1/2	0.004–0.29 %

## N(1535) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$	$\Gamma_1/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>
<b>0.35 to 0.55 OUR ESTIMATE</b>	
0.394 ± 0.009	GREEN    97    DPWA $\pi N \rightarrow \pi N, \eta N$
0.51 ± 0.05	MANLEY    92    IPWA $\pi N \rightarrow \pi N \ \& \ N\pi\pi$
0.50 ± 0.10	CUTKOSKY    80    IPWA $\pi N \rightarrow \pi N$
0.38 ± 0.04	HOEHLER    79    IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●	
0.31	ARNDT    95    DPWA $\pi N \rightarrow N\pi$
0.34 ± 0.09	BATINIC    95    DPWA $\pi N \rightarrow N\pi, N\eta$
0.297 ± 0.026	BHANDARI    77    DPWA    Uses $N\eta$ cusp

$\Gamma(N\eta)/\Gamma_{\text{total}}$	$\Gamma_2/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u> <u>TECN</u> <u>COMMENT</u>
<b>+0.30 to 0.55 OUR ESTIMATE</b>	
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●	
0.568 ± 0.011	GREEN    97    DPWA $\pi N \rightarrow \pi N, \eta N$
0.59 ± 0.02	ABAEV    96    DPWA $\pi^- p \rightarrow \eta n$
0.63 ± 0.07	BATINIC    95    DPWA $\pi N \rightarrow N\pi, N\eta$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1535) \rightarrow N\eta$				$(\Gamma_1 \Gamma_2)^{1/2} / \Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
<b>+0.44 to +0.50 OUR ESTIMATE</b>				
+0.47 ± 0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
+0.33	BAKER	79	DPWA	$\pi^- p \rightarrow n\eta$
+0.48	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 $N\pi \rightarrow N(1535) \rightarrow \Delta(1232)\pi$ , <i>D-wave</i>				$(\Gamma_1 \Gamma_5)^{1/2} / \Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
<b>−0.04 to +0.06 OUR ESTIMATE</b>				
+0.00 ± 0.04	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
0.00	<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.06	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1535) \rightarrow N\rho$ , <i>S=1/2, S-wave</i>				$(\Gamma_1 \Gamma_7)^{1/2} / \Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
<b>−0.14 to −0.06 OUR ESTIMATE</b>				
−0.10 ± 0.03	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
−0.10	<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
−0.09	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1535) \rightarrow N(\pi\pi)_{S=0}^{I=0}$ , <i>S-wave</i>				$(\Gamma_1 \Gamma_9)^{1/2} / \Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
<b>+0.03 to +0.13 OUR ESTIMATE</b>				
+0.07 ± 0.04	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
+0.08	<sup>1</sup> LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.09	<sup>2</sup> LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow N(1535) \rightarrow N(1440)\pi$				$(\Gamma_1 \Gamma_{10})^{1/2} / \Gamma$
VALUE	DOCUMENT ID	TECN	COMMENT	
+0.10 ± 0.05	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$

## N(1535) PHOTON DECAY AMPLITUDES

### $N(1535) \rightarrow p\gamma$ , helicity-1/2 amplitude $A_{1/2}$

VALUE (GeV <sup>−1/2</sup> )	DOCUMENT ID	TECN	COMMENT
<b>+0.090 ± 0.030 OUR ESTIMATE</b>			
0.120 ± 0.011 ± 0.015	<sup>3</sup> KRUSCHE	97	DPWA $\gamma N \rightarrow \eta N$
0.060 ± 0.015	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
0.097 ± 0.006	BENMERROU..95	DPWA	$\gamma N \rightarrow N\eta$
0.095 ± 0.011	<sup>7</sup> BENMERROU..91		$\gamma p \rightarrow p\eta$
0.053 ± 0.015	CRAWFORD	83	IPWA $\gamma N \rightarrow \pi N$

0.077 ±0.021	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
0.083 ±0.007	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
0.080 ±0.007	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
0.029 ±0.007	BRATASHEV...	80	DPWA	$\gamma N \rightarrow \pi N$
0.065 ±0.016	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
0.0704 ±0.0091	ISHII	80	DPWA	Compton scattering

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

0.110 to 0.140	KRUSCHE	95	DPWA	$\gamma p \rightarrow p\eta$
0.125 ±0.025	KRUSCHE	95C	IPWA	$\gamma d \rightarrow \eta N(N)$
0.061 ±0.003	LI	93	IPWA	$\gamma N \rightarrow \pi N$
0.055	WADA	84	DPWA	Compton scattering
+0.082 ±0.019	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
0.046	<sup>8</sup> NOELLE	78		$\gamma N \rightarrow \pi N$
+0.034	BERENDS	77	IPWA	$\gamma N \rightarrow \pi N$
+0.070 ±0.004	FELLER	76	DPWA	$\gamma N \rightarrow \pi N$

### $N(1535) \rightarrow n\gamma$ , helicity-1/2 amplitude $A_{1/2}$

<u>VALUE (GeV<sup>-1/2</sup>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
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**-0.046 ±0.027 OUR ESTIMATE**

-0.020 ±0.035	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
0.035 ±0.014	AWAJI	81	DPWA	$\gamma N \rightarrow \pi N$
-0.062 ±0.003	FUJII	81	DPWA	$\gamma N \rightarrow \pi N$
-0.075 ±0.019	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 1)
-0.075 ±0.018	ARAI	80	DPWA	$\gamma N \rightarrow \pi N$ (fit 2)
-0.098 ±0.026	CRAWFORD	80	DPWA	$\gamma N \rightarrow \pi N$
-0.011 ±0.017	TAKEDA	80	DPWA	$\gamma N \rightarrow \pi N$

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

-0.100 ±0.030	KRUSCHE	95C	IPWA	$\gamma d \rightarrow \eta N(N)$
-0.046 ±0.005	LI	93	IPWA	$\gamma N \rightarrow \pi N$
-0.112 ±0.034	BARBOUR	78	DPWA	$\gamma N \rightarrow \pi N$
-0.048	<sup>8</sup> NOELLE	78		$\gamma N \rightarrow \pi N$

### $N(1535) \rightarrow N\gamma$ , ratio $A_{1/2}^n/A_{1/2}^p$

<u>VALUE (GeV<sup>-1/2</sup>)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>
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• • • We do not use the following data for averages, fits, limits, etc. • • •

-0.84 ±0.15	MUKHOPAD...	95B	IPWA
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## **$N(1535)$ FOOTNOTES**

<sup>1</sup> 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.

<sup>2</sup> From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

<sup>3</sup> KRUSCHE 97 fits with the mass fixed at 1544 MeV.

<sup>4</sup> ARNDT 98 also lists pole residues, which display more model dependence than do the associated pole positions.

<sup>5</sup> See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of  $N$  and  $\Delta$  resonances as determined from Argand diagrams of  $\pi N$  elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

<sup>6</sup> 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.

<sup>7</sup> BENMERROUCHE 91 uses an effective Lagrangian approach to analyze  $\eta$  photoproduction data.

<sup>8</sup> Converted to our conventions using  $M = 1548$  MeV,  $\Gamma = 73$  MeV from NOELLE 78.

## N(1535) REFERENCES

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

ARNDT	98	PR C58 3636	R.A. Arndt+	
GREEN	97	PR C55 R2167	+Wycech	(HELs, WINR)
KRUSCHE	97	PL B397 171	+Mukhopadhyay, Zhang+	(GIES, RPI, SASK)
ABAEV	96	PR C53 385	+Nefkens	(UCLA)
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+	
BATINIC	95B	PR C52 2188	+Slaus, Svarc	(BOSK)
BENMERROU...	95	PR D51 3237	Benmerrouche, Mukhopadhyay, Zhang	(RPI, SASK)
KRUSCHE	95	PRL 74 3736	+Ahrens, Anton+	(GIES, MANZ, GLAS, BONN, DARM)
KRUSCHE	95C	PL B358 40	+Ahrens+	(GIES, MANZ, GLAS, BONN, DARM)
MUKHOPAD...	95B	PL B364 1	Mukhopadhyay, Zhang, Benmerrouche	(RPI, SASK)
HOEHLER	93	$\pi N$ 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
BENMERROU...	91	PRL 67 1070	Benmerrouche, Mukhopadhyay	(RPI)
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
BHANDARI	77	PR D15 192	+Chao	(CMU) 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