# $N(1440)$ $P_{11}$

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

## $N(1440)$ BREIT-WIGNER MASS

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **1430 to 1470 (≈ 1440) OUR ESTIMATE** | | | | |
| 1462±10 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| 1440±30 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |
| 1410±12 | HOEHLER | 79 | IPWA | $\pi N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 1463± 7 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| 1467 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| 1421±18 | BATINIC | 95 | DPWA | $\pi N \to N\pi$, $N\eta$ |
| 1465 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| 1471 | CUTKOSKY | 90 | IPWA | $\pi N \to \pi N$ |
| 1411 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| 1472 | [1] BAKER | 79 | DPWA | $\pi^- p \to n\eta$ |
| 1417 | BARBOUR | 78 | DPWA | $\gamma N \to \pi N$ |
| 1460 | BERENDS | 77 | IPWA | $\gamma N \to \pi N$ |
| 1380 | [2] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| 1390 | [3] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

## $N(1440)$ BREIT-WIGNER WIDTH

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **250 to 450 (≈ 350) OUR ESTIMATE** | | | | |
| 391± 34 | MANLEY | 92 | IPWA | $\pi N \to \pi N$ & $N\pi\pi$ |
| 545±170 | CUTKOSKY | 90 | IPWA | $\pi N \to \pi N$ |
| 340± 70 | CUTKOSKY | 80 | IPWA | $\pi N \to \pi N$ |
| 135± 10 | HOEHLER | 79 | IPWA | $\pi N \to \pi N$ |
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| 360± 20 | ARNDT | 96 | IPWA | $\gamma N \to \pi N$ |
| 440 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| 250± 63 | BATINIC | 95 | DPWA | $\pi N \to N\pi$, $N\eta$ |
| 315 | LI | 93 | IPWA | $\gamma N \to \pi N$ |
| 334 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| 113 | [1] BAKER | 79 | DPWA | $\pi^- p \to n\eta$ |
| 331 | BARBOUR | 78 | DPWA | $\gamma N \to \pi N$ |
| 279 | BERENDS | 77 | IPWA | $\gamma N \to \pi N$ |
| 200 | [2] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| 200 | [3] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

## *N*(1440) POLE POSITION

### REAL PART

| *VALUE* (MeV) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| **1345 to 1385 (≈ 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 ± 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 (≈ 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 ± 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 ± 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 $\theta$

| *VALUE* (°) | *DOCUMENT ID* | | *TECN* | *COMMENT* |
|---|---|---|---|---|
| −101 | [4] ARNDT | 95 | DPWA | $\pi N \rightarrow N\pi$ |
| − 84 | CUTKOSKY | 90 | IPWA | $\pi N \rightarrow \pi N$ |
| −100 ± 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 ($\Gamma_i/\Gamma$) |
|---|---|---|
| $\Gamma_1$ | $N\pi$ | 60–70 % |
| $\Gamma_2$ | $N\eta$ | |
| $\Gamma_3$ | $N\pi\pi$ | 30–40 % |
| $\Gamma_4$ | $\Delta\pi$ | 20–30 % |
| $\Gamma_5$ | $\Delta(1232)\pi$, $P$-wave | |
| $\Gamma_6$ | $N\rho$ | <8 % |
| $\Gamma_7$ | $N\rho$, $S$=1/2, $P$-wave | |
| $\Gamma_8$ | $N\rho$, $S$=3/2, $P$-wave | |
| $\Gamma_9$ | $N(\pi\pi)^{I=0}_{S\text{-wave}}$ | 5–10 % |
| $\Gamma_{10}$ | $p\gamma$ | 0.035–0.048 % |
| $\Gamma_{11}$ | $p\gamma$, helicity=1/2 | 0.035–0.048 % |
| $\Gamma_{12}$ | $n\gamma$ | 0.009–0.032 % |
| $\Gamma_{13}$ | $n\gamma$, helicity=1/2 | 0.009–0.032 % |

## *N*(1440) BRANCHING RATIOS

### $\Gamma(N\pi)/\Gamma_{\text{total}}$ $\Gamma_1/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| **0.6 to 0.7 OUR ESTIMATE** | | | | |
| 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. • • • | | | | |
| 0.68 | ARNDT | 95 | DPWA | $\pi N \to N\pi$ |
| 0.56±0.08 | BATINIC | 95 | DPWA | $\pi N \to N\pi$, $N\eta$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \to N(1440) \to N\eta$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

| VALUE | DOCUMENT ID | | TECN | COMMENT |
|---|---|---|---|---|
| • • • We do not use the following data for averages, fits, limits, etc. • • • | | | | |
| seen | [1] BAKER | 79 | DPWA | $\pi^- p \to n\eta$ |
| +0.328 | [8] FELTESSE | 75 | DPWA | 1488–1745 MeV |

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 $\Delta(1232)\pi$.

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ 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 | [2,9] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| +0.37 | [3] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ 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 | [2,9] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| +0.23 | [3] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

### $(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ 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 | [2,9] 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 | [2,9] LONGACRE | 77 | IPWA | $\pi N \to N\pi\pi$ |
| −0.23 | [3] LONGACRE | 75 | IPWA | $\pi N \to N\pi\pi$ |

## $N(1440)$ PHOTON DECAY AMPLITUDES

### $N(1440) \to p\gamma$, 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 | $\gamma N \to \pi N$ |
| −0.069 ±0.018 | CRAWFORD | 83 | IPWA | $\gamma N \to \pi N$ |
| −0.063 ±0.008 | AWAJI | 81 | DPWA | $\gamma N \to \pi N$ |
| −0.069 ±0.004 | ARAI | 80 | DPWA | $\gamma N \to \pi N$ (fit 1) |
| −0.066 ±0.004 | ARAI | 80 | DPWA | $\gamma N \to \pi N$ (fit 2) |
| −0.079 ±0.009 | BRATASHEV... | 80 | DPWA | $\gamma N \to \pi N$ |
| −0.068 ±0.015 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| −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 | $\gamma N \to \pi N$ |
| −0.129 | [10] WADA | 84 | DPWA | Compton scattering |
| −0.075 ±0.015 | BARBOUR | 78 | DPWA | $\gamma N \to \pi N$ |
| −0.125 | [11] NOELLE | 78 | | $\gamma N \to \pi N$ |
| −0.076 | BERENDS | 77 | IPWA | $\gamma N \to \pi N$ |
| −0.087 ±0.006 | FELLER | 76 | DPWA | $\gamma N \to \pi N$ |

### $N(1440) \to n\gamma$, 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 | $\gamma N \to \pi N$ |
| 0.037±0.010 | AWAJI | 81 | DPWA | $\gamma N \to \pi N$ |
| 0.030±0.003 | FUJII | 81 | DPWA | $\gamma N \to \pi N$ |
| 0.023±0.009 | ARAI | 80 | DPWA | $\gamma N \to \pi N$ (fit 1) |
| 0.019±0.012 | ARAI | 80 | DPWA | $\gamma N \to \pi N$ (fit 2) |
| 0.056±0.015 | CRAWFORD | 80 | DPWA | $\gamma N \to \pi N$ |
| −0.029±0.035 | TAKEDA | 80 | DPWA | $\gamma N \to \pi N$ |

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

| | | | | | |
|---|---|---|---|---|---|
| $0.085 \pm 0.006$ | LI | 93 | IPWA | $\gamma N \rightarrow \pi N$ | |
| $+0.059 \pm 0.016$ | 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 $= -54^{o}$.

[5] 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.

[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 $\Delta$ 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) |
| 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 |
| 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) |

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|---|---|---|---|---|---|
| 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 |