

# N BARYONS

## ( $S = 0, I = 1/2$ )

$p, N^+ = uud; \quad n, N^0 = udd$

**p**

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

- Mass  $m = 1.00727646688 \pm 0.00000000009$  u
- Mass  $m = 938.272081 \pm 0.000006$  MeV [a]
- $|m_p - m_{\bar{p}}|/m_p < 7 \times 10^{-10}$ , CL = 90% [b]
- $|\frac{q_{\bar{p}}}{m_{\bar{p}}}|/(\frac{q_p}{m_p}) = 1.00000000000 \pm 0.00000000007$
- $|q_p + q_{\bar{p}}|/e < 7 \times 10^{-10}$ , CL = 90% [b]
- $|q_p + q_e|/e < 1 \times 10^{-21}$  [c]
- Magnetic moment  $\mu = 2.7928473446 \pm 0.00000000008 \mu_N$
- $(\mu_p + \mu_{\bar{p}}) / \mu_p = (0.3 \pm 0.8) \times 10^{-6}$
- Electric dipole moment  $d < 0.021 \times 10^{-23}$  e cm
- Electric polarizability  $\alpha = (11.2 \pm 0.4) \times 10^{-4}$  fm<sup>3</sup>
- Magnetic polarizability  $\beta = (2.5 \pm 0.4) \times 10^{-4}$  fm<sup>3</sup> ( $S = 1.2$ )
- Charge radius,  $\mu p$  Lamb shift =  $0.84087 \pm 0.00039$  fm [d]
- Charge radius,  $e p$  CODATA value =  $0.8751 \pm 0.0061$  fm [d]
- Magnetic radius =  $0.78 \pm 0.04$  fm [e]
- Mean life  $\tau > 2.1 \times 10^{29}$  years, CL = 90% [f] ( $p \rightarrow$  invisible mode)
- Mean life  $\tau > 10^{31}$  to  $10^{33}$  years [f] (mode dependent)

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1173) for a short review.

The "partial mean life" limits tabulated here are the limits on  $\tau/B_i$ , where  $\tau$  is the total mean life and  $B_i$  is the branching fraction for the mode in question. For  $N$  decays,  $p$  and  $n$  indicate proton and neutron partial lifetimes.

| <b>p DECAY MODES</b>       | Partial mean life<br>(10 <sup>30</sup> years) | Confidence level | p<br>(MeV/c) |
|----------------------------|-----------------------------------------------|------------------|--------------|
| <b>Antilepton + meson</b>  |                                               |                  |              |
| $N \rightarrow e^+ \pi$    | > 2000 ( $n$ ), > 8200 ( $p$ )                | 90%              | 459          |
| $N \rightarrow \mu^+ \pi$  | > 1000 ( $n$ ), > 6600 ( $p$ )                | 90%              | 453          |
| $N \rightarrow \nu \pi$    | > 1100 ( $n$ ), > 390 ( $p$ )                 | 90%              | 459          |
| $p \rightarrow e^+ \eta$   | > 4200                                        | 90%              | 309          |
| $p \rightarrow \mu^+ \eta$ | > 1300                                        | 90%              | 297          |
| $n \rightarrow \nu \eta$   | > 158                                         | 90%              | 310          |
| $N \rightarrow e^+ \rho$   | > 217 ( $n$ ), > 710 ( $p$ )                  | 90%              | 149          |
| $N \rightarrow \mu^+ \rho$ | > 228 ( $n$ ), > 160 ( $p$ )                  | 90%              | 113          |

|                                |                                        |     |     |
|--------------------------------|----------------------------------------|-----|-----|
| $N \rightarrow \nu \rho$       | > 19 ( <i>n</i> ), > 162 ( <i>p</i> )  | 90% | 149 |
| $p \rightarrow e^+ \omega$     | > 320                                  | 90% | 143 |
| $p \rightarrow \mu^+ \omega$   | > 780                                  | 90% | 105 |
| $n \rightarrow \nu \omega$     | > 108                                  | 90% | 144 |
| $N \rightarrow e^+ K$          | > 17 ( <i>n</i> ), > 1000 ( <i>p</i> ) | 90% | 339 |
| $N \rightarrow \mu^+ K$        | > 26 ( <i>n</i> ), > 1600 ( <i>p</i> ) | 90% | 329 |
| $N \rightarrow \nu K$          | > 86 ( <i>n</i> ), > 5900 ( <i>p</i> ) | 90% | 339 |
| $n \rightarrow \nu K_S^0$      | > 260                                  | 90% | 338 |
| $p \rightarrow e^+ K^*(892)^0$ | > 84                                   | 90% | 45  |
| $N \rightarrow \nu K^*(892)$   | > 78 ( <i>n</i> ), > 51 ( <i>p</i> )   | 90% | 45  |

### Antilepton + mesons

|                                   |       |     |     |
|-----------------------------------|-------|-----|-----|
| $p \rightarrow e^+ \pi^+ \pi^-$   | > 82  | 90% | 448 |
| $p \rightarrow e^+ \pi^0 \pi^0$   | > 147 | 90% | 449 |
| $n \rightarrow e^+ \pi^- \pi^0$   | > 52  | 90% | 449 |
| $p \rightarrow \mu^+ \pi^+ \pi^-$ | > 133 | 90% | 425 |
| $p \rightarrow \mu^+ \pi^0 \pi^0$ | > 101 | 90% | 427 |
| $n \rightarrow \mu^+ \pi^- \pi^0$ | > 74  | 90% | 427 |
| $n \rightarrow e^+ K^0 \pi^-$     | > 18  | 90% | 319 |

### Lepton + meson

|                              |      |     |     |
|------------------------------|------|-----|-----|
| $n \rightarrow e^- \pi^+$    | > 65 | 90% | 459 |
| $n \rightarrow \mu^- \pi^+$  | > 49 | 90% | 453 |
| $n \rightarrow e^- \rho^+$   | > 62 | 90% | 150 |
| $n \rightarrow \mu^- \rho^+$ | > 7  | 90% | 115 |
| $n \rightarrow e^- K^+$      | > 32 | 90% | 340 |
| $n \rightarrow \mu^- K^+$    | > 57 | 90% | 330 |

### Lepton + mesons

|                                   |       |     |     |
|-----------------------------------|-------|-----|-----|
| $p \rightarrow e^- \pi^+ \pi^+$   | > 30  | 90% | 448 |
| $n \rightarrow e^- \pi^+ \pi^0$   | > 29  | 90% | 449 |
| $p \rightarrow \mu^- \pi^+ \pi^+$ | > 17  | 90% | 425 |
| $n \rightarrow \mu^- \pi^+ \pi^0$ | > 34  | 90% | 427 |
| $p \rightarrow e^- \pi^+ K^+$     | > 75  | 90% | 320 |
| $p \rightarrow \mu^- \pi^+ K^+$   | > 245 | 90% | 279 |

### Antilepton + photon(s)

|                                   |       |     |     |
|-----------------------------------|-------|-----|-----|
| $p \rightarrow e^+ \gamma$        | > 670 | 90% | 469 |
| $p \rightarrow \mu^+ \gamma$      | > 478 | 90% | 463 |
| $n \rightarrow \nu \gamma$        | > 550 | 90% | 470 |
| $p \rightarrow e^+ \gamma \gamma$ | > 100 | 90% | 469 |
| $n \rightarrow \nu \gamma \gamma$ | > 219 | 90% | 470 |

### Antilepton + single massless

|                         |       |     |   |
|-------------------------|-------|-----|---|
| $p \rightarrow e^+ X$   | > 790 | 90% | — |
| $p \rightarrow \mu^+ X$ | > 410 | 90% | — |

### Three (or more) leptons

|                                   |                      |     |     |
|-----------------------------------|----------------------|-----|-----|
| $p \rightarrow e^+ e^+ e^-$       | > 793                | 90% | 469 |
| $p \rightarrow e^+ \mu^+ \mu^-$   | > 359                | 90% | 457 |
| $p \rightarrow e^+ \nu \nu$       | > 170                | 90% | 469 |
| $n \rightarrow e^+ e^- \nu$       | > 257                | 90% | 470 |
| $n \rightarrow \mu^+ e^- \nu$     | > 83                 | 90% | 464 |
| $n \rightarrow \mu^+ \mu^- \nu$   | > 79                 | 90% | 458 |
| $p \rightarrow \mu^+ e^+ e^-$     | > 529                | 90% | 463 |
| $p \rightarrow \mu^+ \mu^+ \mu^-$ | > 675                | 90% | 439 |
| $p \rightarrow \mu^+ \nu \nu$     | > 220                | 90% | 463 |
| $p \rightarrow e^- \mu^+ \mu^+$   | > 6                  | 90% | 457 |
| $n \rightarrow 3\nu$              | > $5 \times 10^{-4}$ | 90% | 470 |

### Inclusive modes

|                                    |                  |     |   |
|------------------------------------|------------------|-----|---|
| $N \rightarrow e^+$ anything       | > 0.6 ( $n, p$ ) | 90% | — |
| $N \rightarrow \mu^+$ anything     | > 12 ( $n, p$ )  | 90% | — |
| $N \rightarrow e^+ \pi^0$ anything | > 0.6 ( $n, p$ ) | 90% | — |

### $\Delta B = 2$ dinucleon modes

The following are lifetime limits per iron nucleus.

|                                        |                        |     |   |
|----------------------------------------|------------------------|-----|---|
| $pp \rightarrow \pi^+ \pi^+$           | > 72.2                 | 90% | — |
| $pn \rightarrow \pi^+ \pi^0$           | > 170                  | 90% | — |
| $nn \rightarrow \pi^+ \pi^-$           | > 0.7                  | 90% | — |
| $nn \rightarrow \pi^0 \pi^0$           | > 404                  | 90% | — |
| $pp \rightarrow K^+ K^+$               | > 170                  | 90% | — |
| $pp \rightarrow e^+ e^+$               | > 5.8                  | 90% | — |
| $pp \rightarrow e^+ \mu^+$             | > 3.6                  | 90% | — |
| $pp \rightarrow \mu^+ \mu^+$           | > 1.7                  | 90% | — |
| $pn \rightarrow e^+ \bar{\nu}$         | > 260                  | 90% | — |
| $pn \rightarrow \mu^+ \bar{\nu}$       | > 200                  | 90% | — |
| $pn \rightarrow \tau^+ \bar{\nu}_\tau$ | > 29                   | 90% | — |
| $nn \rightarrow \nu_e \bar{\nu}_e$     | > 1.4                  | 90% | — |
| $nn \rightarrow \nu_\mu \bar{\nu}_\mu$ | > 1.4                  | 90% | — |
| $pn \rightarrow$ invisible             | > $2.1 \times 10^{-5}$ | 90% | — |
| $pp \rightarrow$ invisible             | > $5 \times 10^{-5}$   | 90% | — |

### $\bar{p}$ DECAY MODES

| $\bar{p}$ DECAY MODES              | Partial mean life<br>(years) | Confidence level | $p$<br>(MeV/c) |
|------------------------------------|------------------------------|------------------|----------------|
| $\bar{p} \rightarrow e^- \gamma$   | > $7 \times 10^5$            | 90%              | 469            |
| $\bar{p} \rightarrow \mu^- \gamma$ | > $5 \times 10^4$            | 90%              | 463            |
| $\bar{p} \rightarrow e^- \pi^0$    | > $4 \times 10^5$            | 90%              | 459            |
| $\bar{p} \rightarrow \mu^- \pi^0$  | > $5 \times 10^4$            | 90%              | 453            |
| $\bar{p} \rightarrow e^- \eta$     | > $2 \times 10^4$            | 90%              | 309            |

|                                           |                   |     |     |
|-------------------------------------------|-------------------|-----|-----|
| $\bar{p} \rightarrow \mu^- \eta$          | $> 8 \times 10^3$ | 90% | 297 |
| $\bar{p} \rightarrow e^- K_S^0$           | $> 900$           | 90% | 337 |
| $\bar{p} \rightarrow \mu^- K_S^0$         | $> 4 \times 10^3$ | 90% | 326 |
| $\bar{p} \rightarrow e^- K_L^0$           | $> 9 \times 10^3$ | 90% | 337 |
| $\bar{p} \rightarrow \mu^- K_L^0$         | $> 7 \times 10^3$ | 90% | 326 |
| $\bar{p} \rightarrow e^- \gamma \gamma$   | $> 2 \times 10^4$ | 90% | 469 |
| $\bar{p} \rightarrow \mu^- \gamma \gamma$ | $> 2 \times 10^4$ | 90% | 463 |
| $\bar{p} \rightarrow e^- \omega$          | $> 200$           | 90% | 143 |

## n

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

Mass  $m = 1.0086649159 \pm 0.0000000005$  u

Mass  $m = 939.565413 \pm 0.000006$  MeV [a]

$(m_n - m_{\bar{n}}) / m_n = (9 \pm 6) \times 10^{-5}$

$m_n - m_p = 1.2933321 \pm 0.0000005$  MeV  
 $= 0.00138844919(45)$  u

Mean life  $\tau = 880.2 \pm 1.0$  s (S = 1.9)

$c\tau = 2.6387 \times 10^8$  km

Magnetic moment  $\mu = -1.9130427 \pm 0.0000005 \mu_N$

Electric dipole moment  $d < 0.30 \times 10^{-25}$  e cm, CL = 90%

Mean-square charge radius  $\langle r_n^2 \rangle = -0.1161 \pm 0.0022$   
 $\text{fm}^2$  (S = 1.3)

Magnetic radius  $\sqrt{\langle r_M^2 \rangle} = 0.864_{-0.008}^{+0.009}$  fm

Electric polarizability  $\alpha = (11.8 \pm 1.1) \times 10^{-4}$  fm<sup>3</sup>

Magnetic polarizability  $\beta = (3.7 \pm 1.2) \times 10^{-4}$  fm<sup>3</sup>

Charge  $q = (-0.2 \pm 0.8) \times 10^{-21}$  e

Mean  $n\bar{n}$ -oscillation time  $> 8.6 \times 10^7$  s, CL = 90% (free  $n$ )

Mean  $n\bar{n}$ -oscillation time  $> 2.7 \times 10^8$  s, CL = 90% [g] (bound  $n$ )

Mean  $nn'$ -oscillation time  $> 414$  s, CL = 90% [h]

### $pe^- \nu_e$ decay parameters [i]

$\lambda \equiv g_A / g_V = -1.2724 \pm 0.0023$  (S = 2.2)

$A = -0.1184 \pm 0.0010$  (S = 2.4)

$B = 0.9807 \pm 0.0030$

$C = -0.2377 \pm 0.0026$

$a = -0.1059 \pm 0.0028$

$\phi_{AV} = (180.017 \pm 0.026)^\circ$  [j]

$D = (-1.2 \pm 2.0) \times 10^{-4}$  [k]

$R = 0.004 \pm 0.013$  [k]

| <b><i>n</i> DECAY MODES</b>                          | Fraction ( $\Gamma_i/\Gamma$ )     | Confidence level | $p$<br>(MeV/c) |
|------------------------------------------------------|------------------------------------|------------------|----------------|
| $p e^- \bar{\nu}_e$                                  | 100 %                              |                  | 1              |
| $p e^- \bar{\nu}_e \gamma$                           | [1] $(9.2 \pm 0.7) \times 10^{-3}$ |                  | 1              |
| <b>Charge conservation (<i>Q</i>) violating mode</b> |                                    |                  |                |
| $p \nu_e \bar{\nu}_e$                                | $Q < 8 \times 10^{-27}$            | 68%              | 1              |

**$N(1440) 1/2^+$**

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

Re(pole position) = 1360 to 1380 ( $\approx 1370$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 160$  to 190 ( $\approx 175$ ) MeV  
 Breit-Wigner mass = 1410 to 1470 ( $\approx 1440$ ) MeV  
 Breit-Wigner full width = 250 to 450 ( $\approx 350$ ) MeV

| <b><math>N(1440)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 55–75 %                        | 398         |
| $N\eta$                                 | <1 %                           | †           |
| $N\pi\pi$                               | 17–50 %                        | 347         |
| $\Delta(1232)\pi$ , <i>P</i> -wave      | 6–27 %                         | 147         |
| $N\sigma$                               | 11–23 %                        | –           |
| $p\gamma$ , helicity=1/2                | 0.035–0.048 %                  | 414         |
| $n\gamma$ , helicity=1/2                | 0.02–0.04 %                    | 413         |

**$N(1520) 3/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Re(pole position) = 1505 to 1515 ( $\approx 1510$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 105$  to 120 ( $\approx 110$ ) MeV  
 Breit-Wigner mass = 1510 to 1520 ( $\approx 1515$ ) MeV  
 Breit-Wigner full width = 100 to 120 ( $\approx 110$ ) MeV

| <b><math>N(1520)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 55–65 %                        | 453         |
| $N\eta$                                 | 0.07–0.09 %                    | 142         |
| $N\pi\pi$                               | 25–35 %                        | 410         |
| $\Delta(1232)\pi$                       | 22–34 %                        | 225         |
| $\Delta(1232)\pi$ , <i>S</i> -wave      | 15–23 %                        | 225         |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 7–11 %                         | 225         |

|                          |             |     |
|--------------------------|-------------|-----|
| $N\sigma$                | < 2 %       | —   |
| $p\gamma$                | 0.31–0.52 % | 467 |
| $p\gamma$ , helicity=1/2 | 0.01–0.02 % | 467 |
| $p\gamma$ , helicity=3/2 | 0.30–0.50 % | 467 |
| $n\gamma$                | 0.30–0.53 % | 466 |
| $n\gamma$ , helicity=1/2 | 0.04–0.10 % | 466 |
| $n\gamma$ , helicity=3/2 | 0.25–0.45 % | 466 |

**$N(1535) 1/2^-$**

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

Re(pole position) = 1500 to 1520 ( $\approx 1510$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 110$  to 150 ( $\approx 130$ ) MeV  
 Breit-Wigner mass = 1515 to 1545 ( $\approx 1530$ ) MeV  
 Breit-Wigner full width = 125 to 175 ( $\approx 150$ ) MeV

| <b><math>N(1535)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 32–52 %                        | 464         |
| $N\eta$                                 | 30–55 %                        | 176         |
| $N\pi\pi$                               | 3–14 %                         | 422         |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 1–4 %                          | 240         |
| $N\sigma$                               | 2–10 %                         | —           |
| $N(1440)\pi$                            | 5–12 %                         | †           |
| $p\gamma$ , helicity=1/2                | 0.15–0.30 %                    | 477         |
| $n\gamma$ , helicity=1/2                | 0.01–0.25 %                    | 477         |

**$N(1650) 1/2^-$**

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

Re(pole position) = 1640 to 1670 ( $\approx 1655$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 100$  to 170 ( $\approx 135$ ) MeV  
 Breit-Wigner mass = 1635 to 1665 ( $\approx 1650$ ) MeV  
 Breit-Wigner full width = 100 to 150 ( $\approx 125$ ) MeV

| <b><math>N(1650)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 50–70 %                        | 547         |
| $N\eta$                                 | 15–35 %                        | 348         |
| $\Lambda K$                             | 5–15 %                         | 169         |
| $N\pi\pi$                               | 8–36 %                         | 514         |

|                                    |              |     |
|------------------------------------|--------------|-----|
| $\Delta(1232)\pi$ , <i>D</i> -wave | 6–18 %       | 345 |
| $N\sigma$                          | 2–18 %       | –   |
| $N(1440)\pi$                       | 6–26 %       | 150 |
| $p\gamma$ , helicity=1/2           | 0.04–0.20 %  | 558 |
| $n\gamma$ , helicity=1/2           | 0.003–0.17 % | 557 |

### **$N(1675) 5/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$$

Re(pole position) = 1655 to 1665 ( $\approx$  1660) MeV  
 –2Im(pole position) = 125 to 150 ( $\approx$  135) MeV  
 Breit-Wigner mass = 1665 to 1680 ( $\approx$  1675) MeV  
 Breit-Wigner full width = 130 to 160 ( $\approx$  145) MeV

| <b><math>N(1675)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $\rho$ (MeV/c) |
|-----------------------------------------|--------------------------------|----------------|
| $N\pi$                                  | 38–42 %                        | 564            |
| $N\eta$                                 | < 1 %                          | 376            |
| $N\pi\pi$                               | 25–45 %                        | 532            |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 23–37 %                        | 366            |
| $N\sigma$                               | 3–7 %                          | –              |
| $p\gamma$                               | 0–0.02 %                       | 575            |
| $p\gamma$ , helicity=1/2                | 0–0.01 %                       | 575            |
| $p\gamma$ , helicity=3/2                | 0–0.01 %                       | 575            |
| $n\gamma$                               | 0–0.15 %                       | 574            |
| $n\gamma$ , helicity=1/2                | 0–0.05 %                       | 574            |
| $n\gamma$ , helicity=3/2                | 0–0.10 %                       | 574            |

### **$N(1680) 5/2^+$**

$$I(J^P) = \frac{1}{2}(\frac{5}{2}^+)$$

Re(pole position) = 1665 to 1680 ( $\approx$  1675) MeV  
 –2Im(pole position) = 110 to 135 ( $\approx$  120) MeV  
 Breit-Wigner mass = 1680 to 1690 ( $\approx$  1685) MeV  
 Breit-Wigner full width = 115 to 130 ( $\approx$  120) MeV

| <b><math>N(1680)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $\rho$ (MeV/c) |
|-----------------------------------------|--------------------------------|----------------|
| $N\pi$                                  | 60–70 %                        | 571            |
| $N\eta$                                 | <1 %                           | 386            |
| $N\pi\pi$                               | 20–40 %                        | 539            |
| $\Delta(1232)\pi$                       | 11–23 %                        | 374            |
| $\Delta(1232)\pi$ , <i>P</i> -wave      | 4–10 %                         | 374            |
| $\Delta(1232)\pi$ , <i>F</i> -wave      | 1–13 %                         | 374            |

|                          |               |     |
|--------------------------|---------------|-----|
| $N\sigma$                | 9–19 %        | –   |
| $p\gamma$                | 0.21–0.32 %   | 581 |
| $p\gamma$ , helicity=1/2 | 0.001–0.011 % | 581 |
| $p\gamma$ , helicity=3/2 | 0.20–0.32 %   | 581 |
| $n\gamma$                | 0.021–0.046 % | 581 |
| $n\gamma$ , helicity=1/2 | 0.004–0.029 % | 581 |
| $n\gamma$ , helicity=3/2 | 0.01–0.024 %  | 581 |

**$N(1700) 3/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Re(pole position) = 1650 to 1750 ( $\approx 1700$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 100$  to 300 ( $\approx 200$ ) MeV  
 Breit-Wigner mass = 1650 to 1800 ( $\approx 1720$ ) MeV  
 Breit-Wigner full width = 100 to 300 ( $\approx 200$ ) MeV

| <b><math>N(1700)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 7–17 %                         | 594         |
| $N\eta$                                 | seen                           | 422         |
| $N\omega$                               | 10–34 %                        | †           |
| $N\pi\pi$                               | 60–90 %                        | 564         |
| $\Delta(1232)\pi$                       | 55–85 %                        | 402         |
| $\Delta(1232)\pi$ , <i>S</i> -wave      | 50–80 %                        | 402         |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 4–14 %                         | 402         |
| $N(1440)\pi$                            | 3–11 %                         | 225         |
| $N(1520)\pi$                            | <4 %                           | 145         |
| $N\rho$ , <i>S</i> =3/2, <i>S</i> -wave | 32–44 %                        | 74          |
| $N\sigma$                               | 2–14 %                         | –           |
| $p\gamma$                               | 0.01–0.05 %                    | 604         |
| $p\gamma$ , helicity=1/2                | 0.0–0.024 %                    | 604         |
| $p\gamma$ , helicity=3/2                | 0.002–0.026 %                  | 604         |
| $n\gamma$                               | 0.01–0.13 %                    | 603         |
| $n\gamma$ , helicity=1/2                | 0.0–0.09 %                     | 603         |
| $n\gamma$ , helicity=3/2                | 0.01–0.05 %                    | 603         |

**$N(1710) 1/2^+$**

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

Re(pole position) = 1680 to 1720 ( $\approx 1700$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 80$  to 160 ( $\approx 120$ ) MeV  
 Breit-Wigner mass = 1680 to 1740 ( $\approx 1710$ ) MeV  
 Breit-Wigner full width = 80 to 200 ( $\approx 140$ ) MeV



| <b>N(1710) DECAY MODES</b>    | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-------------------------------|--------------------------------|-------------|
| $N\pi$                        | 5–20 %                         | 588         |
| $N\eta$                       | 10–50 %                        | 412         |
| $N\omega$                     | 1–5 %                          | †           |
| $\Lambda K$                   | 5–25 %                         | 269         |
| $\Sigma K$                    | seen                           | 138         |
| $N\pi\pi$                     | seen                           | 557         |
| $\Delta(1232)\pi$ , $P$ -wave | 3–9 %                          | 394         |
| $N(1535)\pi$                  | 9–21 %                         | 113         |
| $N\rho$ , $S=1/2$ , $P$ -wave | 11–23 %                        | †           |
| $p\gamma$ , helicity=1/2      | 0.002–0.08 %                   | 598         |
| $n\gamma$ , helicity=1/2      | 0.0–0.02%                      | 597         |

|                                |
|--------------------------------|
| <b>N(1720) 3/2<sup>+</sup></b> |
|--------------------------------|

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

Re(pole position) = 1660 to 1690 ( $\approx 1675$ ) MeV

–2Im(pole position) = 150 to 400 ( $\approx 250$ ) MeV

Breit-Wigner mass = 1680 to 1750 ( $\approx 1720$ ) MeV

Breit-Wigner full width = 150 to 400 ( $\approx 250$ ) MeV

| <b>N(1720) DECAY MODES</b>    | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-------------------------------|--------------------------------|-------------|
| $N\pi$                        | 8–14 %                         | 594         |
| $N\eta$                       | 1–5 %                          | 422         |
| $N\omega$                     | 12–40 %                        | †           |
| $\Lambda K$                   | 4–5 %                          | 283         |
| $N\pi\pi$                     | 50–90 %                        | 564         |
| $\Delta(1232)\pi$             | 47–89 %                        | 402         |
| $\Delta(1232)\pi$ , $P$ -wave | 47–77 %                        | 402         |
| $\Delta(1232)\pi$ , $F$ -wave | <12 %                          | 402         |
| $N\rho$ , $S=1/2$ , $P$ -wave | 1–2 %                          | 74          |
| $N\sigma$                     | 2–14 %                         | –           |
| $N(1440)\pi$                  | <2 %                           | 225         |
| $N(1520)\pi$ , $S$ -wave      | 1–5 %                          | 145         |
| $p\gamma$                     | 0.05–0.25 %                    | 604         |
| $p\gamma$ , helicity=1/2      | 0.05–0.15 %                    | 604         |
| $p\gamma$ , helicity=3/2      | 0.002–0.16 %                   | 604         |
| $n\gamma$                     | 0.0–0.016 %                    | 603         |
| $n\gamma$ , helicity=1/2      | 0.0–0.01 %                     | 603         |
| $n\gamma$ , helicity=3/2      | 0.0–0.015 %                    | 603         |

**$N(1875) 3/2^-$** 

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Re(pole position) = 1850 to 1950 ( $\approx 1900$ ) MeV $-2\text{Im}(\text{pole position}) = 100$  to 220 ( $\approx 160$ ) MeVBreit-Wigner mass = 1850 to 1920 ( $\approx 1875$ ) MeVBreit-Wigner full width = 120 to 250 ( $\approx 200$ ) MeV

| <b><math>N(1875)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 3–11 %                         | 695         |
| $N\eta$                                 | <1 %                           | 559         |
| $N\omega$                               | 15–25 %                        | 371         |
| $\Lambda K$                             | seen                           | 454         |
| $\Sigma K$                              | seen                           | 384         |
| $N\pi\pi$                               | 40–95 %                        | 670         |
| $\Delta(1232)\pi$                       | 10–35 %                        | 520         |
| $\Delta(1232)\pi$ , $S$ -wave           | 7–21 %                         | 520         |
| $\Delta(1232)\pi$ , $D$ -wave           | 2–12 %                         | 520         |
| $N\rho$ , $S=3/2$ , $S$ -wave           | seen                           | 379         |
| $N\sigma$                               | 30–60 %                        | –           |
| $N(1440)\pi$                            | 2–8 %                          | 365         |
| $N(1520)\pi$                            | <2 %                           | 301         |
| $p\gamma$                               | 0.001–0.025 %                  | 703         |
| $p\gamma$ , helicity=1/2                | 0.001–0.021 %                  | 703         |
| $p\gamma$ , helicity=3/2                | <0.003 %                       | 703         |
| $n\gamma$                               | <0.040 %                       | 702         |
| $n\gamma$ , helicity=1/2                | <0.007 %                       | 702         |
| $n\gamma$ , helicity=3/2                | <0.033 %                       | 702         |

 **$N(1880) 1/2^+$** 

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

Re(pole position) = 1820 to 1900 ( $\approx 1860$ ) MeV $-2\text{Im}(\text{pole position}) = 180$  to 280 ( $\approx 230$ ) MeVBreit-Wigner mass = 1830 to 1930 ( $\approx 1880$ ) MeVBreit-Wigner full width = 200 to 400 ( $\approx 300$ ) MeV

| <b><math>N(1880)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 3–9 %                          | 698         |
| $N\eta$                                 | 5–55 %                         | 563         |
| $N\omega$                               | 12–28 %                        | 377         |
| $\Lambda K$                             | 12–28 %                        | 459         |
| $\Sigma K$                              | 10–24 %                        | 389         |
| $N\pi\pi$                               | 30–80 %                        | 673         |

|                          |              |     |
|--------------------------|--------------|-----|
| $\Delta(1232)\pi$        | 18–42 %      | 524 |
| $N\sigma$                | 10–40 %      | 539 |
| $N(1535)\pi$             | 4–12 %       | 293 |
| $N_{a_0}(980)$           | 1–5 %        | †   |
| $\Lambda K^*(892)$       | 0.5–1 %      | †   |
| $p\gamma$ , helicity=1/2 | seen         | 706 |
| $n\gamma$ , helicity=1/2 | 0.002–0.63 % | 705 |

 **$N(1895) 1/2^-$** 

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

Re(pole position) = 1890 to 1930 ( $\approx 1910$ ) MeV

–2Im(pole position) = 80 to 140 ( $\approx 110$ ) MeV

Breit-Wigner mass = 1870 to 1920 ( $\approx 1895$ ) MeV

Breit-Wigner full width = 80 to 200 ( $\approx 120$ ) MeV

| <b><math>N(1895)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 2–18 %                         | 707         |
| $N\eta$                                 | 15–40 %                        | 575         |
| $N\eta'$                                | 10–40 %                        | †           |
| $N\omega$                               | 16–40 %                        | 395         |
| $\Lambda K$                             | 13–23 %                        | 473         |
| $\Sigma K$                              | 6–20 %                         | 405         |
| $\Delta(1232)\pi$ , $D$ -wave           | 3–11 %                         | 535         |
| $N\rho$ , $S=1/2$ , $S$ -wave           | seen                           | 403         |
| $N\rho$ , $S=3/2$ , $D$ -wave           | 3–12 %                         | 403         |
| $\Lambda K^*(892)$                      | 4–9 %                          | †           |
| $N\sigma$                               | seen                           | –           |
| $N(1440)\pi$                            | 1–4 %                          | 382         |
| $p\gamma$ , helicity=1/2                | 0.01–0.06 %                    | 715         |
| $n\gamma$ , helicity=1/2                | 0.003–0.05 %                   | 715         |

 **$N(1900) 3/2^+$** 

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$$

Re(pole position) = 1900 to 1940 ( $\approx 1920$ ) MeV

–2Im(pole position) = 100 to 200 ( $\approx 150$ ) MeV

Breit-Wigner mass = 1890 to 1950 ( $\approx 1920$ ) MeV

Breit-Wigner full width = 100 to 320 ( $\approx 200$ ) MeV

| <b><math>N(1900)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 1–20 %                         | 723         |
| $N\eta$                                 | 2–14 %                         | 595         |

|                                    |               |     |
|------------------------------------|---------------|-----|
| $N\eta'$                           | 4–8 %         | 151 |
| $N\omega$                          | 7–13 %        | 424 |
| $\Lambda K$                        | 2–20 %        | 495 |
| $\Sigma K$                         | 3–7 %         | 431 |
| $N\pi\pi$                          | 40–80 %       | 699 |
| $\Delta(1232)\pi$                  | 30–70 %       | 553 |
| $\Delta(1232)\pi$ , <i>P</i> -wave | 9–25 %        | 553 |
| $\Delta(1232)\pi$ , <i>F</i> -wave | 21–45 %       | 553 |
| $\Lambda K^*(892)$                 | < 0.2 %       | †   |
| $N\sigma$                          | 1–7 %         | –   |
| $N(1520)\pi$                       | 7–23 %        | 341 |
| $N(1535)\pi$                       | 4–10 %        | 328 |
| $p\gamma$                          | 0.001–0.025 % | 731 |
| $p\gamma$ , helicity=1/2           | 0.001–0.021 % | 731 |
| $p\gamma$ , helicity=3/2           | <0.003 %      | 731 |
| $n\gamma$                          | <0.040 %      | 730 |
| $n\gamma$ , helicity=1/2           | <0.007 %      | 730 |
| $n\gamma$ , helicity=3/2           | <0.033 %      | 730 |

**$N(2060) 5/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{5}{2}^-)$$

Re(pole position) = 2020 to 2130 ( $\approx 2070$ ) MeV  
 –2Im(pole position) = 350 to 430 ( $\approx 400$ ) MeV  
 Breit-Wigner mass = 2030 to 2200 ( $\approx 2100$ ) MeV  
 Breit-Wigner full width = 300 to 450 ( $\approx 400$ ) MeV

| <b><math>N(2060)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | <i>p</i> (MeV/c) |
|-----------------------------------------|--------------------------------|------------------|
| $N\pi$                                  | 7–12 %                         | 834              |
| $N\eta$                                 | 2–6 %                          | 729              |
| $N\omega$                               | 1–7 %                          | 600              |
| $\Lambda K$                             | seen                           | 644              |
| $\Sigma K$                              | 1–5 %                          | 593              |
| $N\pi\pi$                               | 7–19 %                         | 814              |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 4–10 %                         | 680              |
| $N\rho$ , <i>S</i> =1/2, <i>P</i> -wave | seen                           | 605              |
| $\Lambda K^*(892)$                      | 0.3–1.3 %                      | 307              |
| $N\sigma$                               | 3–9 %                          | –                |
| $N(1440)\pi$                            | 4–14 %                         | 544              |
| $N(1520)\pi$ , <i>P</i> -wave           | 9–21 %                         | 490              |
| $N(1680)\pi$ , <i>S</i> -wave           | 8–22 %                         | 353              |
| $p\gamma$                               | 0.03–0.19 %                    | 840              |

|                          |              |     |
|--------------------------|--------------|-----|
| $p\gamma$ , helicity=1/2 | 0.02–0.08 %  | 840 |
| $p\gamma$ , helicity=3/2 | 0.01–0.10 %  | 840 |
| $n\gamma$                | 0.003–0.07 % | 840 |
| $n\gamma$ , helicity=1/2 | 0.001–0.02 % | 840 |
| $n\gamma$ , helicity=3/2 | 0.002–0.05 % | 840 |

**$N(2100) 1/2^+$**

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

Re(pole position) = 2050 to 2150 ( $\approx 2100$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 240$  to  $340$  ( $\approx 300$ ) MeV  
 Breit-Wigner mass = 2050 to 2150 ( $\approx 2100$ ) MeV  
 Breit-Wigner full width = 200 to 320 ( $\approx 260$ ) MeV

| <b><math>N(2100)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 8–18 %                         | 834         |
| $N\eta$                                 | seen                           | 729         |
| $N\eta'$                                | 5–11 %                         | 451         |
| $N\omega$                               | 10–25 %                        | 600         |
| $\Lambda K$                             | seen                           | 644         |
| $N\pi\pi$                               | 20–40 %                        | 814         |
| $\Delta(1232)\pi$ , $P$ -wave           | 6–14 %                         | 680         |
| $N\rho$ , $S=1/2$ , $P$ -wave           | seen                           | 605         |
| $\Lambda K^*(892)$                      | 3–11 %                         | 307         |
| $N\sigma$                               | 14–26 %                        | –           |
| $N(1535)\pi$                            | 26–34 %                        | 478         |
| $N\gamma$ , helicity=1/2                | 0.001–0.012 %                  | 840         |

**$N(2120) 3/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$$

Re(pole position) = 2050 to 2150 ( $\approx 2100$ ) MeV  
 $-2\text{Im}(\text{pole position}) = 200$  to  $360$  ( $\approx 280$ ) MeV  
 Breit-Wigner mass = 2060 to 2160 ( $\approx 2120$ ) MeV  
 Breit-Wigner full width = 260 to 360 ( $\approx 300$ ) MeV

| <b><math>N(2120)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 5–15 %                         | 846         |
| $N\eta'$                                | 2–6 %                          | 474         |
| $N\omega$                               | 4–20 %                         | 617         |
| $N\pi\pi$                               | 50–95 %                        | 827         |
| $\Delta(1232)\pi$                       | 40–90 %                        | 693         |
| $\Delta(1232)\pi$ , $S$ -wave           | 30–70 %                        | 693         |

|                                    |              |     |
|------------------------------------|--------------|-----|
| $\Delta(1232)\pi$ , <i>D</i> -wave | 8–32 %       | 693 |
| $\Lambda K^*(892)$                 | < 0.2 %      | 339 |
| $N\sigma$                          | 7–15 %       | –   |
| $N(1535)\pi$                       | 7–23 %       | 494 |
| $p\gamma$                          | 0.16–2.1 %   | 852 |
| $p\gamma$ , helicity=1/2           | 0.07–0.80 %  | 852 |
| $p\gamma$ , helicity=3/2           | 0.09–1.3 %   | 852 |
| $n\gamma$                          | 0.04–0.72 %  | 852 |
| $n\gamma$ , helicity=1/2           | 0.04–0.60 %  | 852 |
| $n\gamma$ , helicity=3/2           | 0.001–0.12 % | 852 |

**$N(2190) 7/2^-$**

$$I(J^P) = \frac{1}{2}(\frac{7}{2}^-)$$

Re(pole position) = 2050 to 2150 ( $\approx$  2100) MeV  
 –2Im(pole position) = 300 to 500 ( $\approx$  400) MeV  
 Breit-Wigner mass = 2140 to 2220 ( $\approx$  2180) MeV  
 Breit-Wigner full width = 300 to 500 ( $\approx$  400) MeV

| <b><math>N(2190)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 10–20 %                        | 882         |
| $N\eta$                                 | 1–3 %                          | 785         |
| $N\omega$                               | 8–20 %                         | 667         |
| $\Delta(1232)\pi$ , <i>D</i> -wave      | 19–31 %                        | 734         |
| $N\rho$ , <i>S</i> =3/2, <i>D</i> -wave | seen                           | 672         |
| $\Lambda K^*(892)$                      | 0.2–0.8 %                      | 423         |
| $N\sigma$                               | 3–9 %                          | –           |
| $p\gamma$                               | 0.014–0.077 %                  | 888         |
| $n\gamma$                               | <0.04 %                        | 888         |
| $n\gamma$ , helicity=3/2                | <0.03 %                        | 888         |

**$N(2220) 9/2^+$**

$$I(J^P) = \frac{1}{2}(\frac{9}{2}^+)$$

Re(pole position) = 2130 to 2200 ( $\approx$  2170) MeV  
 –2Im(pole position) = 360 to 480 ( $\approx$  400) MeV  
 Breit-Wigner mass = 2200 to 2300 ( $\approx$  2250) MeV  
 Breit-Wigner full width = 350 to 500 ( $\approx$  400) MeV

| <b><math>N(2220)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 15–30 %                        | 924         |

**$N(2250) 9/2^-$** 

$$I(J^P) = \frac{1}{2}(\frac{9}{2}^-)$$

Re(pole position) = 2150 to 2250 ( $\approx 2200$ ) MeV $-2\text{Im}(\text{pole position}) = 350$  to 500 ( $\approx 420$ ) MeVBreit-Wigner mass = 2250 to 2320 ( $\approx 2280$ ) MeVBreit-Wigner full width = 300 to 600 ( $\approx 500$ ) MeV

| <b><math>N(2250)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ )  | $p$ (MeV/c) |
|-----------------------------------------|---------------------------------|-------------|
| $N\pi$                                  | 0.05 to 0.15 ( $\approx 0.10$ ) | 941         |

 **$N(2600) 11/2^-$** 

$$I(J^P) = \frac{1}{2}(\frac{11}{2}^-)$$

Breit-Wigner mass = 2550 to 2750 ( $\approx 2600$ ) MeVBreit-Wigner full width = 500 to 800 ( $\approx 650$ ) MeV

| <b><math>N(2600)</math> DECAY MODES</b> | Fraction ( $\Gamma_i/\Gamma$ ) | $p$ (MeV/c) |
|-----------------------------------------|--------------------------------|-------------|
| $N\pi$                                  | 3–8 %                          | 1126        |

## NOTES

- [a] The masses of the  $p$  and  $n$  are most precisely known in  $u$  (unified atomic mass units). The conversion factor to MeV,  $1 u = 931.494061(21)$  MeV, is less well known than are the masses in  $u$ .
- [b] The  $|m_p - m_{\bar{p}}|/m_p$  and  $|q_p + q_{\bar{p}}|/e$  are not independent, and both use the more precise measurement of  $|q_{\bar{p}}/m_{\bar{p}}|/(q_p/m_p)$ .
- [c] The limit is from neutrality-of-matter experiments; it assumes  $q_n = q_p + q_e$ . See also the charge of the neutron.
- [d] The  $\mu p$  and  $e p$  values for the charge radius are much too different to average them. The disagreement is not yet understood.
- [e] There is a lot of disagreement about the value of the proton magnetic charge radius. See the Listings.
- [f] The first limit is for  $p \rightarrow$  anything or "disappearance" modes of a bound proton. The second entry, a rough range of limits, assumes the dominant decay modes are among those investigated. For antiprotons the best limit, inferred from the observation of cosmic ray  $\bar{p}$ 's is  $\tau_{\bar{p}} > 10^7$  yr, the cosmic-ray storage time, but this limit depends on a number of assumptions. The best direct observation of stored antiprotons gives  $\tau_{\bar{p}}/B(\bar{p} \rightarrow e^- \gamma) > 7 \times 10^5$  yr.

- [g] There is some controversy about whether nuclear physics and model dependence complicate the analysis for bound neutrons (from which the best limit comes). The first limit here is from reactor experiments with free neutrons.
- [h] Lee and Yang in 1956 proposed the existence of a mirror world in an attempt to restore global parity symmetry—thus a search for oscillations between the two worlds. Oscillations between the worlds would be maximal when the magnetic fields  $B$  and  $B'$  were equal. The limit for any  $B'$  in the range 0 to  $12.5 \mu\text{T}$  is  $>12 \text{ s}$  (95% CL).
- [i] The parameters  $g_A$ ,  $g_V$ , and  $g_{WM}$  for semileptonic modes are defined by  $\overline{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i}) \sigma_{\lambda\nu} q^\nu]B_i$ , and  $\phi_{AV}$  is defined by  $g_A/g_V = |g_A/g_V|e^{i\phi_{AV}}$ . See the “Note on Baryon Decay Parameters” in the neutron Particle Listings.
- [j] Time-reversal invariance requires this to be  $0^\circ$  or  $180^\circ$ .
- [k] This coefficient is zero if time invariance is not violated.
- [l] This limit is for  $\gamma$  energies between 0.4 and 782 keV.