

# 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  $m = 1.00727646688 \pm 0.00000000013$  u

Mass  $m = 938.27203 \pm 0.00008$  MeV [a]

$$|m_p - m_{\bar{p}}|/m_p < 1.0 \times 10^{-8}, \text{ CL} = 90\% [b]$$

$$|\frac{q_{\bar{p}}}{m_{\bar{p}}}|/(\frac{q_p}{m_p}) = 0.99999999991 \pm 0.00000000009$$

$$|q_p + q_{\bar{p}}|/e < 1.0 \times 10^{-8}, \text{ CL} = 90\% [b]$$

$$|q_p + q_e|/e < 1.0 \times 10^{-21} [c]$$

Magnetic moment  $\mu = 2.792847351 \pm 0.0000000028 \mu_N$

$$(\mu_p + \mu_{\bar{p}}) / \mu_p = (-2.6 \pm 2.9) \times 10^{-3}$$

Electric dipole moment  $d < 0.54 \times 10^{-23}$  e cm

Electric polarizability  $\alpha = (12.0 \pm 0.6) \times 10^{-4}$  fm<sup>3</sup>

Magnetic polarizability  $\beta = (1.9 \pm 0.5) \times 10^{-4}$  fm<sup>3</sup>

Charge radius =  $0.875 \pm 0.007$  fm

Mean life  $\tau > 1.9 \times 10^{29}$  years, CL = 90% ( $p \rightarrow$  invisible mode)

Mean life  $\tau > 10^{31}$  to  $10^{33}$  years [d] (mode dependent)

See the "Note on Nucleon Decay" in our 1994 edition (Phys. Rev. **D50**, 1673) 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 ( $10^{30}$ years)	Confidence level	$p$ (MeV/c)
<b>Antilepton + meson</b>			
$N \rightarrow e^+ \pi$	$> 158$ ( $n$ ), $> 1600$ ( $p$ )	90%	459
$N \rightarrow \mu^+ \pi$	$> 100$ ( $n$ ), $> 473$ ( $p$ )	90%	453
$N \rightarrow \nu \pi$	$> 112$ ( $n$ ), $> 25$ ( $p$ )	90%	459
$p \rightarrow e^+ \eta$	$> 313$	90%	309
$p \rightarrow \mu^+ \eta$	$> 126$	90%	297
$n \rightarrow \nu \eta$	$> 158$	90%	310
$N \rightarrow e^+ \rho$	$> 217$ ( $n$ ), $> 75$ ( $p$ )	90%	149
$N \rightarrow \mu^+ \rho$	$> 228$ ( $n$ ), $> 110$ ( $p$ )	90%	113
$N \rightarrow \nu \rho$	$> 19$ ( $n$ ), $> 162$ ( $p$ )	90%	149
$p \rightarrow e^+ \omega$	$> 107$	90%	143

$p \rightarrow \mu^+ \omega$	> 117	90%	105
$n \rightarrow \nu \omega$	> 108	90%	144
$N \rightarrow e^+ K$	> 17 ( $n$ ), > 150 ( $p$ )	90%	339
$p \rightarrow e^+ K_S^0$	> 120	90%	337
$p \rightarrow e^+ K_L^0$	> 51	90%	337
$N \rightarrow \mu^+ K$	> 26 ( $n$ ), > 120 ( $p$ )	90%	329
$p \rightarrow \mu^+ K_S^0$	> 150	90%	326
$p \rightarrow \mu^+ K_L^0$	> 83	90%	326
$N \rightarrow \nu K$	> 86 ( $n$ ), > 670 ( $p$ )	90%	339
$n \rightarrow \nu K_S^0$	> 51	90%	338
$p \rightarrow e^+ K^*(892)^0$	> 84	90%	45
$N \rightarrow \nu K^*(892)$	> 78 ( $n$ ), > 51 ( $p$ )	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%	114
$n \rightarrow e^- K^+$	> 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
$n \rightarrow \nu \gamma$	> 28	90%	470
$p \rightarrow e^+ \gamma \gamma$	> 100	90%	469
$n \rightarrow \nu \gamma \gamma$	> 219	90%	470

**Three (or more) leptons**

$p \rightarrow e^+ e^+ e^-$	$> 793$	90%	469
$p \rightarrow e^+ \mu^+ \mu^-$	$> 359$	90%	457
$p \rightarrow e^+ \nu \nu$	$> 17$	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
$p \rightarrow \mu^+ \nu \nu$	$> 21$	90%	463
$p \rightarrow e^- \mu^+ \mu^+$	$> 6$	90%	457
$n \rightarrow 3\nu$	$> 0.0005$	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.

$pp \rightarrow \pi^+ \pi^+$	$> 0.7$	90%	—
$pn \rightarrow \pi^+ \pi^0$	$> 2$	90%	—
$nn \rightarrow \pi^+ \pi^-$	$> 0.7$	90%	—
$nn \rightarrow \pi^0 \pi^0$	$> 3.4$	90%	—
$pp \rightarrow e^+ e^+$	$> 5.8$	90%	—
$pp \rightarrow e^+ \mu^+$	$> 3.6$	90%	—
$pp \rightarrow \mu^+ \mu^+$	$> 1.7$	90%	—
$pn \rightarrow e^+ \bar{\nu}$	$> 2.8$	90%	—
$pn \rightarrow \mu^+ \bar{\nu}$	$> 1.6$	90%	—
$nn \rightarrow \nu_e \bar{\nu}_e$	$> 0.000049$	90%	—
$pn \rightarrow$ invisible	$> 2.1 \times 10^{-5}$	90%	—
$pp \rightarrow$ invisible	$> 0.00005$	90%	—

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

$\bar{p}$ DECAY MODES	Partial mean life (years)	Confidence level	$p$ (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  $m = 1.0086649156 \pm 0.0000000006$  u

Mass  $m = 939.56536 \pm 0.00008$  MeV [a]

$m_n - m_p = 1.2933317 \pm 0.0000005$  MeV  
 $= 0.0013884487 \pm 0.0000000006$  u

Mean life  $\tau = 885.7 \pm 0.8$  s

$c\tau = 2.655 \times 10^8$  km

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

Electric dipole moment  $d < 0.63 \times 10^{-25}$  e cm, CL = 90%

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

Electric polarizability  $\alpha = (11.6 \pm 1.5) \times 10^{-4} \text{ fm}^3$

Magnetic polarizability  $\beta = (3.7 \pm 2.0) \times 10^{-4} \text{ fm}^3$

Charge  $q = (-0.4 \pm 1.1) \times 10^{-21} e$

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

Mean  $n\bar{n}$ -oscillation time  $> 1.3 \times 10^8$  s, CL = 90% [e] (bound  $n$ )

#### Decay parameters [f]

$p e^- \bar{\nu}_e$	$\lambda \equiv g_A / g_V = -1.2695 \pm 0.0029$ (S = 2.0)
"	$A = -0.1173 \pm 0.0013$ (S = 2.3)
"	$B = 0.981 \pm 0.004$ (S = 1.1)
"	$a = -0.103 \pm 0.004$
"	$\phi_{AV} = (180.06 \pm 0.07)^\circ$ [g]
"	$D = (-4 \pm 6) \times 10^{-4}$

<b><i>n</i> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	Confidence level	$\frac{p}{\text{MeV/c}}$
$p e^- \bar{\nu}_e$	100 %		1
$p e^- \bar{\nu}_e \gamma$	[h] $< 6.9 \times 10^{-3}$	90%	1

#### Charge conservation (Q) violating mode

$p \nu_e \bar{\nu}_e$	Q	$< 8 \times 10^{-27}$	68%	1
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**$N(1440) P_{11}$** 

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

Breit-Wigner mass = 1420 to 1470 ( $\approx 1440$ ) MeV

Breit-Wigner full width = 200 to 450 ( $\approx 300$ ) MeV

$p_{\text{beam}} = 0.61 \text{ GeV}/c$        $4\pi\lambda^2 = 31.0 \text{ mb}$

Re(pole position) = 1350 to 1380 ( $\approx 1365$ ) MeV

$-2\text{Im}(\text{pole position}) = 160 \text{ to } 220$  ( $\approx 190$ ) MeV

<b><math>N(1440)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	0.55 to 0.75	398
$N\pi\pi$	30–40 %	347
$\Delta\pi$	20–30 %	147
$N\rho$	<8 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	5–10 %	—
$p\gamma$	0.035–0.048 %	414
$p\gamma$ , helicity=1/2	0.035–0.048 %	414
$n\gamma$	0.009–0.032 %	413
$n\gamma$ , helicity=1/2	0.009–0.032 %	413

 **$N(1520) D_{13}$** 

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

Breit-Wigner mass = 1515 to 1525 ( $\approx 1520$ ) MeV

Breit-Wigner full width = 100 to 125 ( $\approx 115$ ) MeV

$p_{\text{beam}} = 0.74 \text{ GeV}/c$        $4\pi\lambda^2 = 23.5 \text{ mb}$

Re(pole position) = 1505 to 1515 ( $\approx 1510$ ) MeV

$-2\text{Im}(\text{pole position}) = 105 \text{ to } 120$  ( $\approx 110$ ) MeV

<b><math>N(1520)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	0.55 to 0.65	457
$N\eta$	$(2.3 \pm 0.4) \times 10^{-3}$	155
$N\pi\pi$	40–50 %	414
$\Delta\pi$	15–25 %	230
$N\rho$	15–25 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	<8 %	—
$p\gamma$	0.46–0.56 %	470
$p\gamma$ , helicity=1/2	0.001–0.034 %	470
$p\gamma$ , helicity=3/2	0.44–0.53 %	470
$n\gamma$	0.30–0.53 %	470
$n\gamma$ , helicity=1/2	0.04–0.10 %	470
$n\gamma$ , helicity=3/2	0.25–0.45 %	470

**$N(1535) S_{11}$** 

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

Breit-Wigner mass = 1525 to 1545 ( $\approx 1535$ ) MeVBreit-Wigner full width = 125 to 175 ( $\approx 150$ ) MeV $p_{\text{beam}} = 0.76 \text{ GeV}/c$        $4\pi\lambda^2 = 22.5 \text{ mb}$ Re(pole position) = 1490 to 1530 ( $\approx 1510$ ) MeV $-2\text{Im}(\text{pole position}) = 90 \text{ to } 250$  ( $\approx 170$ ) MeV

<b><math>N(1535)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	35–55 %	468
$N\eta$	45–60 %	186
$N\pi\pi$	1–10 %	426
$\Delta\pi$	<1 %	244
$N\rho$	<4 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	<3 %	–
$N(1440)\pi$	<7 %	†
$p\gamma$	0.15–0.35 %	481
$p\gamma$ , helicity=1/2	0.15–0.35 %	481
$n\gamma$	0.004–0.29 %	480
$n\gamma$ , helicity=1/2	0.004–0.29 %	480

 **$N(1650) S_{11}$** 

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

Breit-Wigner mass = 1645 to 1670 ( $\approx 1655$ ) MeVBreit-Wigner full width = 145 to 185 ( $\approx 165$ ) MeV $p_{\text{beam}} = 0.97 \text{ GeV}/c$        $4\pi\lambda^2 = 16.2 \text{ mb}$ Re(pole position) = 1640 to 1670 ( $\approx 1655$ ) MeV $-2\text{Im}(\text{pole position}) = 150 \text{ to } 180$  ( $\approx 165$ ) MeV

<b><math>N(1650)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	0.60 to 0.95	551
$N\eta$	3–10 %	354
$\Lambda K$	3–11 %	179
$N\pi\pi$	10–20 %	517
$\Delta\pi$	1–7 %	349
$N\rho$	4–12 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	<4 %	–
$N(1440)\pi$	<5 %	156
$p\gamma$	0.04–0.18 %	562
$p\gamma$ , helicity=1/2	0.04–0.18 %	562
$n\gamma$	0.003–0.17 %	561
$n\gamma$ , helicity=1/2	0.003–0.17 %	561

**$N(1675) D_{15}$** 

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

Breit-Wigner mass = 1670 to 1680 ( $\approx 1675$ ) MeVBreit-Wigner full width = 130 to 165 ( $\approx 150$ ) MeV $p_{\text{beam}} = 1.01 \text{ GeV}/c$        $4\pi\chi^2 = 15.4 \text{ mb}$ Re(pole position) = 1655 to 1665 ( $\approx 1660$ ) MeV $-2\text{Im}(\text{pole position}) = 125 \text{ to } 150$  ( $\approx 135$ ) MeV

<b><math>N(1675)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	0.35 to 0.45	564
$N\eta$	(0.0 $\pm$ 1.0) %	376
$\Lambda K$	<1 %	216
$N\pi\pi$	50–60 %	532
$\Delta\pi$	50–60 %	366
$N\rho$	< 1–3 %	†
$p\gamma$	0.004–0.023 %	575
$p\gamma$ , helicity=1/2	0.0–0.015 %	575
$p\gamma$ , helicity=3/2	0.0–0.011 %	575
$n\gamma$	0.02–0.12 %	574
$n\gamma$ , helicity=1/2	0.006–0.046 %	574
$n\gamma$ , helicity=3/2	0.01–0.08 %	574

 **$N(1680) F_{15}$** 

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

Breit-Wigner mass = 1680 to 1690 ( $\approx 1685$ ) MeVBreit-Wigner full width = 120 to 140 ( $\approx 130$ ) MeV $p_{\text{beam}} = 1.02 \text{ GeV}/c$        $4\pi\chi^2 = 15.0 \text{ mb}$ Re(pole position) = 1665 to 1680 ( $\approx 1675$ ) MeV $-2\text{Im}(\text{pole position}) = 110 \text{ to } 135$  ( $\approx 120$ ) MeV

<b><math>N(1680)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	0.65 to 0.70	571
$N\eta$	(0.0 $\pm$ 1.0) %	387
$N\pi\pi$	30–40 %	539
$\Delta\pi$	5–15 %	374
$N\rho$	3–15 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	5–20 %	–
$p\gamma$	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

 **$N(1700) D_{13}$** 

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

Breit-Wigner mass = 1650 to 1750 ( $\approx 1700$ ) MeV

Breit-Wigner full width = 50 to 150 ( $\approx 100$ ) MeV

$$p_{\text{beam}} = 1.05 \text{ GeV}/c \quad 4\pi\lambda^2 = 14.5 \text{ mb}$$

Re(pole position) = 1630 to 1730 ( $\approx 1680$ ) MeV

–2Im(pole position) = 50 to 150 ( $\approx 100$ ) MeV

<b><math>N(1700)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	5–15 %	581
$N\eta$	( $0.0 \pm 1.0$ ) %	402
$\Lambda K$	<3 %	255
$N\pi\pi$	85–95 %	550
$N\rho$	<35 %	†
$p\gamma$	0.01–0.05 %	591
$p\gamma$ , helicity=1/2	0.0–0.024 %	591
$p\gamma$ , helicity=3/2	0.002–0.026 %	591
$n\gamma$	0.01–0.13 %	590
$n\gamma$ , helicity=1/2	0.0–0.09 %	590
$n\gamma$ , helicity=3/2	0.01–0.05 %	590

 **$N(1710) P_{11}$** 

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

Breit-Wigner mass = 1680 to 1740 ( $\approx 1710$ ) MeV

Breit-Wigner full width = 50 to 250 ( $\approx 100$ ) MeV

$$p_{\text{beam}} = 1.07 \text{ GeV}/c \quad 4\pi\lambda^2 = 14.2 \text{ mb}$$

Re(pole position) = 1670 to 1770 ( $\approx 1720$ ) MeV

–2Im(pole position) = 80 to 380 ( $\approx 230$ ) MeV



<b><math>N(1710)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	10–20 %	588
$N\eta$	( $6.2 \pm 1.0$ ) %	412
$N\omega$	( $13.0 \pm 2.0$ ) %	†
$\Lambda K$	5–25 %	269
$N\pi\pi$	40–90 %	557
$\Delta\pi$	15–40 %	394
$N\rho$	5–25 %	†
$N(\pi\pi)_{S\text{-wave}}^{I=0}$	10–40 %	–
$p\gamma$	0.002–0.05%	598
$p\gamma$ , helicity=1/2	0.002–0.05%	598
$n\gamma$	0.0–0.02%	597
$n\gamma$ , helicity=1/2	0.0–0.02%	597

 **$N(1720) P_{13}$** 

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

Breit-Wigner mass = 1700 to 1750 ( $\approx 1720$ ) MeV

Breit-Wigner full width = 150 to 300 ( $\approx 200$ ) MeV

$$p_{\text{beam}} = 1.09 \text{ GeV}/c \quad 4\pi\chi^2 = 13.9 \text{ mb}$$

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

–2Im(pole position) = 115 to 275 MeV

<b><math>N(1720)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	10–20 %	594
$N\eta$	( $4.0 \pm 1.0$ ) %	422
$\Lambda K$	1–15 %	283
$N\pi\pi$	>70 %	564
$N\rho$	70–85 %	73
$p\gamma$	0.003–0.10 %	604
$p\gamma$ , helicity=1/2	0.003–0.08 %	604
$p\gamma$ , helicity=3/2	0.001–0.03 %	604
$n\gamma$	0.002–0.39 %	603
$n\gamma$ , helicity=1/2	0.0–0.002 %	603
$n\gamma$ , helicity=3/2	0.001–0.39 %	603

 **$N(2190) G_{17}$** 

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

Breit-Wigner mass = 2100 to 2200 ( $\approx 2190$ ) MeV

Breit-Wigner full width = 300 to 700 ( $\approx 500$ ) MeV

$$p_{\text{beam}} = 2.07 \text{ GeV}/c \quad 4\pi\chi^2 = 6.21 \text{ mb}$$

Re(pole position) = 2050 to 2100 ( $\approx 2075$ ) MeV

–2Im(pole position) = 400 to 520 ( $\approx 450$ ) MeV

<b><math>N(2190)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	10–20 %	888
$N\eta$	$(0.0 \pm 1.0)$ %	792

 **$N(2220) H_{19}$** 

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

Breit-Wigner mass = 2200 to 2300 ( $\approx 2250$ ) MeV

Breit-Wigner full width = 350 to 500 ( $\approx 400$ ) MeV

$$p_{\text{beam}} = 2.21 \text{ GeV}/c \quad 4\pi\lambda^2 = 5.74 \text{ mb}$$

Re(pole position) = 2130 to 2200 ( $\approx 2170$ ) MeV

–2Im(pole position) = 400 to 560 ( $\approx 480$ ) MeV

<b><math>N(2220)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	10–20 %	924

 **$N(2250) G_{19}$** 

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

Breit-Wigner mass = 2200 to 2350 ( $\approx 2275$ ) MeV

Breit-Wigner full width = 230 to 800 ( $\approx 500$ ) MeV

$$p_{\text{beam}} = 2.27 \text{ GeV}/c \quad 4\pi\lambda^2 = 5.56 \text{ mb}$$

Re(pole position) = 2150 to 2250 ( $\approx 2200$ ) MeV

–2Im(pole position) = 350 to 550 ( $\approx 450$ ) MeV

<b><math>N(2250)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	5–15 %	938

 **$N(2600) I_{1,11}$** 

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

Breit-Wigner mass = 2550 to 2750 ( $\approx 2600$ ) MeV

Breit-Wigner full width = 500 to 800 ( $\approx 650$ ) MeV

$$p_{\text{beam}} = 3.12 \text{ GeV}/c \quad 4\pi\lambda^2 = 3.86 \text{ mb}$$

<b><math>N(2600)</math> DECAY MODES</b>	Fraction ( $\Gamma_i/\Gamma$ )	$p$ (MeV/c)
$N\pi$	5–10 %	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,  $1 u = 931.494043 \pm 0.000080$  MeV, is less well known than are the masses in  $u$ .
- [b] These two results 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 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.
- [e] 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.
- [f] The parameters  $g_A$ ,  $g_V$ , and  $g_{WM}$  for semileptonic modes are defined by  $\bar{B}_f[\gamma_\lambda(g_V + g_A\gamma_5) + i(g_{WM}/m_{B_i}) \sigma_{\lambda\nu} q^\nu]B_i$ , 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.
- [g] Time-reversal invariance requires this to be  $0^\circ$  or  $180^\circ$ .
- [h] This limit is for  $\gamma$  energies between 35 and 100 keV.