$\Delta(1600)$ P_{33}

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

The various analyses are not in good agreement.

$\Delta(1600)$ BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1550 to 1700 (≈ 1600) OUR ESTIMATE				
1706±10	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
1600±50	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1522±13	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1687±44	VRANA	00		Multichannel
1672±15	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
1706	LI	93	IPWA	$\gamma N \rightarrow \pi N$
1690	BARNHAM	80	IPWA	$\pi N \rightarrow N\pi\pi$
1560	[1] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
1640	[2] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$\Delta(1600)$ BREIT-WIGNER WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
250 to 450 (≈ 350) OUR ESTIMATE				
430± 73	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
300±100	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
220± 40	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
493± 75	VRANA	00		Multichannel
315± 20	ARNDT	96	IPWA	$\gamma N \rightarrow \pi N$
215	LI	93	IPWA	$\gamma N \rightarrow \pi N$
250	BARNHAM	80	IPWA	$\pi N \rightarrow N\pi\pi$
180	[1] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
300	[2] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$\Delta(1600)$ POLE POSITION

REAL PART

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1500 to 1700 (≈ 1600) OUR ESTIMATE				
1675	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
1550	[3] HOEHLER	93	SPED	$\pi N \rightarrow \pi N$
1550±40	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1599	VRANA	00		Multichannel
1612	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90
1609 or 1610	[4] LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
1541 or 1542	[1] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

−2×IMAGINARY PART

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
200 to 400 (≈ 300) OUR ESTIMATE				
386	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
200±60	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
312	VRANA	00		Multichannel
230	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90
323 or 325	[4] LONGACRE	78	IPWA	$\pi N \rightarrow N\pi\pi$
178 or 178	[1] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

Δ(1600) ELASTIC POLE RESIDUE

MODULUS |r|

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
52	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
17±4	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
16	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90

PHASE θ

VALUE (°)	*DOCUMENT ID*		*TECN*	*COMMENT*
+ 14	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
−150±30	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
− 73	ARNDT	91	DPWA	$\pi N \rightarrow \pi N$ Soln SM90

Δ(1600) DECAY MODES

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

	Mode	Fraction (Γ_i/Γ)
Γ_1	$N\pi$	10–25 %
Γ_2	ΣK	
Γ_3	$N\pi\pi$	75–90 %
Γ_4	$\Delta\pi$	40–70 %
Γ_5	$\Delta(1232)\pi$, *P*-wave	
Γ_6	$\Delta(1232)\pi$, *F*-wave	
Γ_7	$N\rho$	<25 %
Γ_8	$N\rho$, S=1/2, *P*-wave	
Γ_9	$N\rho$, S=3/2, *P*-wave	
Γ_{10}	$N\rho$, S=3/2, *F*-wave	
Γ_{11}	$N(1440)\pi$	10–35 %
Γ_{12}	$N(1440)\pi$, *P*-wave	
Γ_{13}	$N\gamma$	0.001–0.02 %
Γ_{14}	$N\gamma$, helicity=1/2	0.0–0.02 %
Γ_{15}	$N\gamma$, helicity=3/2	0.001–0.005 %

Δ(1600) BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{total}$ Γ_1/Γ

VALUE	DOCUMENT ID		TECN	COMMENT
0.10 to 0.25 OUR ESTIMATE				
0.12±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
0.18±0.04	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
0.21±0.06	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.28±0.05	VRANA	00		Multichannel

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Sigma K$ $(\Gamma_1\Gamma_2)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.36 to −0.28 OUR ESTIMATE				
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.006 to 0.042	[5] DEANS	75	DPWA	$\pi N \rightarrow \Sigma K$

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 $\Delta(1232)\pi$.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi$, *P*-wave $(\Gamma_1\Gamma_5)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.27 to +0.33 OUR ESTIMATE				
+0.29±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
+0.24±0.05	BARNHAM	80	IPWA	$\pi N \rightarrow N\pi\pi$
+0.34	[1,6] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$
+0.30	[2] LONGACRE	75	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi$, *F*-wave $(\Gamma_1\Gamma_6)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.15 to −0.03 OUR ESTIMATE				
−0.07	[1,6] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho$, S=1/2, *P*-wave $(\Gamma_1\Gamma_8)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.10	[1,6] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho$, S=3/2, *P*-wave $(\Gamma_1\Gamma_9)^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.10	[1,6] LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{total}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N(1440)\pi$, *P*-wave $(\Gamma_1\Gamma_{12})^{1/2}/\Gamma$

VALUE	DOCUMENT ID		TECN	COMMENT
+0.15 to +0.23 OUR ESTIMATE				
+0.16±0.02	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N\pi\pi$
+0.23±0.04	BARNHAM	80	IPWA	$\pi N \rightarrow N\pi\pi$

Δ(1600) PHOTON DECAY AMPLITUDES

Δ(1600) → Nγ, helicity-1/2 amplitude $A_{1/2}$

VALUE ($GeV^{-1/2}$)	*DOCUMENT ID*		*TECN*	*COMMENT*
−0.023±0.020 OUR ESTIMATE				
−0.018±0.015	ARNDT	96	IPWA	$\gamma N \to \pi N$
−0.039±0.030	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
−0.046±0.013	AWAJI	81	DPWA	$\gamma N \to \pi N$
0.005±0.020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.026±0.002	LI	93	IPWA	$\gamma N \to \pi N$
−0.200	[7] WADA	84	DPWA	Compton scattering
0.000±0.030	BARBOUR	78	DPWA	$\gamma N \to \pi N$
0.0 ±0.020	FELLER	76	DPWA	$\gamma N \to \pi N$

Δ(1600) → Nγ, helicity-3/2 amplitude $A_{3/2}$

VALUE ($GeV^{-1/2}$)	*DOCUMENT ID*		*TECN*	*COMMENT*
−0.009±0.021 OUR ESTIMATE				
−0.025±0.015	ARNDT	96	IPWA	$\gamma N \to \pi N$
−0.013±0.014	CRAWFORD	83	IPWA	$\gamma N \to \pi N$
0.025±0.031	AWAJI	81	DPWA	$\gamma N \to \pi N$
−0.009±0.020	CRAWFORD	80	DPWA	$\gamma N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.016±0.002	LI	93	IPWA	$\gamma N \to \pi N$
0.023	WADA	84	DPWA	Compton scattering
0.000±0.045	BARBOUR	78	DPWA	$\gamma N \to \pi N$
0.0 ±0.015	FELLER	76	DPWA	$\gamma N \to \pi N$

Δ(1600) FOOTNOTES

[1] LONGACRE 77 pole positions are from a search for poles in the unitarized T-matrix; the first (second) value uses, in addition to $\pi N \to N\pi\pi$ 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.

[2] From method II of LONGACRE 75: eyeball fits with Breit-Wigner circles to the T-matrix amplitudes.

[3] See HOEHLER 93 for a detailed discussion of the evidence for and the pole parameters of N and Δ resonances as determined from Argand diagrams of πN elastic partial-wave amplitudes and from plots of the speeds with which the amplitudes traverse the diagrams.

[4] LONGACRE 78 values are from a search for poles in the unitarized T-matrix. The first (second) value uses, in addition to $\pi N \to N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.

[5] The range given is from the four best solutions. DEANS 75 disagrees with $\pi^+ p \to \Sigma^+ K^+$ data of WINNIK 77 around 1920 MeV.

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

[7] WADA 84 is inconsistent with other analyses — see the Note on N and Δ Resonances.

$\Delta(1600)$ REFERENCES

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

VRANA	00	PRPL 328 181	T.P. Vrana, S.A. Dytman,, T.-S.H. Lee	
ARNDT	96	PR C53 430	R.A. Arndt, I.I. Strakovsky, R.L. Workman	(VPI)
ARNDT	95	PR C52 2120	R.A. Arndt *et al.*	(VPI, BRCO)
HOEHLER	93	πN Newsletter 9 1	G. Hohler	(KARL)
LI	93	PR C47 2759	Z.J. Li *et al.*	(VPI)
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KENT) IJP
Also	84	PR D30 904	D.M. Manley *et al.*	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt *et al.*	(VPI, TELE) IJP
WADA	84	NP B247 313	Y. Wada *et al.*	(INUS)
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B	M. Roos *et al.*	(HELS, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also	82	NP B197 365	K. Fujii *et al.*	(NAGO)
BARNHAM	80	NP B168 243	K.W.J. Barnham *et al.*	(LOIC)
CRAWFORD	80	Toronto Conf. 107	R.L. Crawford	(GLAS)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
Also	79	PR D20 2839	R.E. Cutkosky *et al.*	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler *et al.*	(KARLT) IJP
Also	80	Toronto Conf. 3	R. Koch	(KARLT) IJP
BARBOUR	78	NP B141 253	I.M. Barbour, R.L. Crawford, N.H. Parsons	(GLAS)
LONGACRE	78	PR D17 1795	R.S. Longacre *et al.*	(LBL, SLAC)
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also	76	NP B108 365	J. Dolbeau *et al.*	(SACL) IJP
WINNIK	77	NP B128 66	M. Winnik *et al.*	(HAIF) I
FELLER	76	NP B104 219	P. Feller *et al.*	(NAGO, OSAK) IJP
DEANS	75	NP B96 90	S.R. Deans *et al.*	(SFLA, ALAH) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre *et al.*	(LBL, SLAC) IJP