

$\Delta(1600) P_{33}$

$$I(J^P) = \frac{3}{2}(\frac{3}{2}^+) \text{ Status: } ***$$

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** 1 (1982).

The various analyses are not in good agreement.

$\Delta(1600)$ BREIT-WIGNER MASS

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1550 to 1700 (\approx 1600) OUR ESTIMATE			
1706 \pm 10	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
1600 \pm 50	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
1522 \pm 13	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
1667 \pm 1	PENNER	02C	DPWA Multichannel
1687 \pm 44	VRANA	00	DPWA Multichannel
1672 \pm 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

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
250 to 450 (\approx 350) OUR ESTIMATE			
430 \pm 73	MANLEY	92	IPWA $\pi N \rightarrow \pi N$ & $N\pi\pi$
300 \pm 100	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$
220 \pm 40	HOEHLER	79	IPWA $\pi N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
397 \pm 10	PENNER	02C	DPWA Multichannel
493 \pm 75	VRANA	00	DPWA Multichannel
315 \pm 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

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
1500 to 1700 (\approx 1600) OUR ESTIMATE			
1457	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
1550	³ HOEHLER	93	SPED $\pi N \rightarrow \pi N$
1550 \pm 40	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

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

1599	VRANA	00	DPWA	Multichannel
1675	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
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

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
200 to 400 (≈ 300) OUR ESTIMATE			

400	ARNDT	06	DPWA	$\pi N \rightarrow \pi N, \eta N$
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	DPWA	Multichannel
386	ARNDT	95	DPWA	$\pi N \rightarrow N\pi$
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	$\pi N \rightarrow N\pi\pi$

$\Delta(1600)$ ELASTIC POLE RESIDUE

MODULUS $|r|$

<u>VALUE (MeV)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
44	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
17±4	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

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

52	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
16	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

PHASE θ

<u>VALUE ($^\circ$)</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>
+147	ARNDT	06	DPWA $\pi N \rightarrow \pi N, \eta N$
–150±30	CUTKOSKY	80	IPWA $\pi N \rightarrow \pi N$

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

+ 14	ARNDT	95	DPWA $\pi N \rightarrow N\pi$
– 73	ARNDT	91	DPWA $\pi N \rightarrow \pi N$ Soln SM90

$\Delta(1600)$ 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 $\Delta(1232)\pi$, <i>P</i> -wave	
Γ_6 $\Delta(1232)\pi$, <i>F</i> -wave	
Γ_7 $N\rho$	<25 %

Γ_8	$N\rho, S=1/2, P\text{-wave}$	
Γ_9	$N\rho, S=3/2, P\text{-wave}$	
Γ_{10}	$N\rho, S=3/2, F\text{-wave}$	
Γ_{11}	$N(1440)\pi$	10–35 %
Γ_{12}	$N(1440)\pi, P\text{-wave}$	
Γ_{13}	$N\gamma$	0.001–0.02 %
Γ_{14}	$N\gamma, \text{helicity}=1/2$	0.0–0.02 %
Γ_{15}	$N\gamma, \text{helicity}=3/2$	0.001–0.005 %

$\Delta(1600)$ BRANCHING RATIOS

$\Gamma(N\pi)/\Gamma_{\text{total}}$					Γ_1/Γ
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
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. • • •					
0.13±0.01	PENNER	02C	DPWA	Multichannel	
0.28±0.05	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Sigma K$					$(\Gamma_1\Gamma_2)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
–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 $\Delta(1232)\pi$.

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi, P\text{-wave}$					$(\Gamma_1\Gamma_5)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
+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	$\pi N \rightarrow N\pi\pi$	

$\Gamma(\Delta(1232)\pi, P\text{-wave})/\Gamma_{\text{total}}$					Γ_5/Γ
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
0.59±0.10	VRANA	00	DPWA	Multichannel	

$(\Gamma_i\Gamma_f)^{1/2}/\Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow \Delta(1232)\pi, F\text{-wave}$					$(\Gamma_1\Gamma_6)^{1/2}/\Gamma$
<u>VALUE</u>	<u>DOCUMENT ID</u>	<u>TECN</u>	<u>COMMENT</u>		
–0.15 to –0.03 OUR ESTIMATE					
–0.07	^{1,6} LONGACRE	77	IPWA	$\pi N \rightarrow N\pi\pi$	

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=1/2, P\text{-wave}$	$(\Gamma_1 \Gamma_8)^{1/2} / \Gamma$		
VALUE	DOCUMENT ID	TECN	COMMENT
+0.10	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

$(\Gamma_i \Gamma_f)^{1/2} / \Gamma_{\text{total}}$ in $N\pi \rightarrow \Delta(1600) \rightarrow N\rho, S=3/2, P\text{-wave}$	$(\Gamma_1 \Gamma_9)^{1/2} / \Gamma$		
VALUE	DOCUMENT ID	TECN	COMMENT
+0.10	1,6 LONGACRE	77	IPWA $\pi N \rightarrow N\pi\pi$

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

$\Gamma(N(1440)\pi) / \Gamma_{\text{total}}$	Γ_{11} / Γ		
VALUE	DOCUMENT ID	TECN	COMMENT
0.13 ± 0.04	VRANA	00	DPWA Multichannel

$\Delta(1600)$ PHOTON DECAY AMPLITUDES

$\Delta(1600) \rightarrow N\gamma$, helicity-1/2 amplitude $A_{1/2}$

VALUE ($\text{GeV}^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
-0.023 ± 0.020 OUR ESTIMATE			
-0.018 ± 0.015	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
-0.039 ± 0.030	CRAWFORD	83	IPWA $\gamma N \rightarrow \pi N$
-0.046 ± 0.013	AWAJI	81	DPWA $\gamma N \rightarrow \pi N$
0.005 ± 0.020	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
0.0	PENNER	02D	DPWA Multichannel
-0.026 ± 0.002	LI	93	IPWA $\gamma N \rightarrow \pi N$
-0.200	⁷ WADA	84	DPWA Compton scattering
0.000 ± 0.030	BARBOUR	78	DPWA $\gamma N \rightarrow \pi N$
0.0 ± 0.020	FELLER	76	DPWA $\gamma N \rightarrow \pi N$

$\Delta(1600) \rightarrow N\gamma$, helicity-3/2 amplitude $A_{3/2}$

VALUE ($\text{GeV}^{-1/2}$)	DOCUMENT ID	TECN	COMMENT
-0.009 ± 0.021 OUR ESTIMATE			
-0.025 ± 0.015	ARNDT	96	IPWA $\gamma N \rightarrow \pi N$
-0.013 ± 0.014	CRAWFORD	83	IPWA $\gamma N \rightarrow \pi N$
0.025 ± 0.031	AWAJI	81	DPWA $\gamma N \rightarrow \pi N$
-0.009 ± 0.020	CRAWFORD	80	DPWA $\gamma N \rightarrow \pi N$
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
-0.024	PENNER	02D	DPWA Multichannel
-0.016 ± 0.002	LI	93	IPWA $\gamma N \rightarrow \pi N$
0.023	WADA	84	DPWA Compton scattering
0.000 ± 0.045	BARBOUR	78	DPWA $\gamma N \rightarrow \pi N$
0.0 ± 0.015	FELLER	76	DPWA $\gamma N \rightarrow \pi N$

$\Delta(1600)$ 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 $\pi N \rightarrow N\pi\pi$ 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.
- 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 $\pi N \rightarrow N\pi\pi$ data, elastic amplitudes from a Saclay (CERN) partial-wave analysis.
- ⁵ The range given is from the four best solutions. DEANS 75 disagrees with $\pi^+ p \rightarrow \Sigma^+ K^+$ 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** 1 (1982).

ARNDT	06	PR C74 045205	R.A. Arndt <i>et al.</i>	(GWU)
PENNER	02C	PR C66 055211	G. Penner, U. Mosel	(GIES)
PENNER	02D	PR C66 055212	G. Penner, U. Mosel	(GIES)
VRANA	00	PRPL 328 181	T.P. Vrana, S.A. Dytman,, T.-S.H. Lee	(PITT+)
ARNDT	96	PR C53 430	R.A. Arndt, I.I. Strakovsky, R.L. Workman	(VPI)
ARNDT	95	PR C52 2120	R.A. Arndt <i>et al.</i>	(VPI, BRCO)
HOEHLER	93	πN Newsletter 9 1	G. Hohler	(KARL)
LI	93	PR C47 2759	Z.J. Li <i>et al.</i>	(VPI)
MANLEY	92	PR D45 4002	D.M. Manley, E.M. Saleski	(KENT) IJP
Also		PR D30 904	D.M. Manley <i>et al.</i>	(VPI)
ARNDT	91	PR D43 2131	R.A. Arndt <i>et al.</i>	(VPI, TELE) IJP
WADA	84	NP B247 313	Y. Wada <i>et al.</i>	(INUS)
CRAWFORD	83	NP B211 1	R.L. Crawford, W.T. Morton	(GLAS)
PDG	82	PL 111B 1	M. Roos <i>et al.</i>	(HELSE, CIT, CERN)
AWAJI	81	Bonn Conf. 352	N. Awaji, R. Kajikawa	(NAGO)
Also		NP B197 365	K. Fujii <i>et al.</i>	(NAGO)
BARNHAM	80	NP B168 243	K.W.J. Barnham <i>et al.</i>	(LOIC)
CRAWFORD	80	Toronto Conf. 107	R.L. Crawford	(GLAS)
CUTKOSKY	80	Toronto Conf. 19	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
Also		PR D20 2839	R.E. Cutkosky <i>et al.</i>	(CMU, LBL) IJP
HOEHLER	79	PDAT 12-1	G. Hohler <i>et al.</i>	(KARLT) IJP
Also		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 <i>et al.</i>	(LBL, SLAC)
LONGACRE	77	NP B122 493	R.S. Longacre, J. Dolbeau	(SACL) IJP
Also		NP B108 365	J. Dolbeau <i>et al.</i>	(SACL) IJP
WINNIK	77	NP B128 66	M. Winnik <i>et al.</i>	(HAIF) I
FELLER	76	NP B104 219	P. Feller <i>et al.</i>	(NAGO, OSAK) IJP
DEANS	75	NP B96 90	S.R. Deans <i>et al.</i>	(SFLA, ALAH) IJP
LONGACRE	75	PL 55B 415	R.S. Longacre <i>et al.</i>	(LBL, SLAC) IJP