$a_1(1260)$

$I^G(J^{PC}) = 1^-(1^{++})$

THE $a_1(1260)$ AND $a_1(1640)$

Updated December 2003 by S. Eidelman (Novosibirsk).

The main experimental data on the $a_1(1260)$ may be grouped into two classes:

(1) Hadronic Production: This comprises diffractive production with incident π^- (DAUM 80, 81B) and charge-exchange production with low-energy π^- (DANKOWYCH 81, ANDO 92). The 1980's experiments explain the $I^GLJ^P = 1^+S0^+$ data using a phenomenological amplitude consisting of a rescattered Deck amplitude plus a direct resonance-production term. They agree on an $a_1(1260)$ mass of about 1270 MeV and a width of 300–380 MeV. ANDO 92 finds rather lower values for the mass (1121 MeV) and width (239 MeV) in a partial-wave analysis based on the isobar model of the $\pi^+\pi^-\pi^0$ system. However, in this analysis, only Breit-Wigner terms were considered. Recently BARBERIS 98B studied central production of the $\pi^+\pi^-\pi^0$ system, and observed the $a_1(1260)$ meson with a mass of 1240 MeV and a width of about 400 MeV.

CONDO 93 found no evidence for charge-exchange photoproduction of the $a_1(1260)$ (but found a clear signal of $a_2(1320)$ photoproduction). Similarly, MOLCHANOV 01 found no evidence for Coulomb production of $a_1(1260)$ studying coherent production of three pions (but observed a prominent signal of $a_2(1320)$). They show that it is consistent with either an extremely large $a_1(1260)$ hadronic width, or with a small radiative width to $\pi\gamma$, which could be accommodated if the a_1 mass is somewhat below 1260 MeV.

(2) τ Decay: Various experiments reported good data on $\tau \rightarrow a_1(1260)\nu_\tau \rightarrow \rho\pi\nu_\tau$ (RUCKSTUHL 86, SCHMIDKE 86,

ALBRECHT 86B, BAND 87, ACKERSTAFF 97R, ABREU 98G, and ASNER 00). They are somewhat inconsistent concerning the $a_1(1260)$ mass, which can, however, be attributed to model-dependent systematic uncertainties (BOWLER 86, ALBRECHT 93C, ACKERSTAFF 97R). They all find a width greater than 400 MeV.

The discrepancies between the hadronic- and τ-decay results have stimulated several reanalyses. BASDEVANT 77, 78 used the early diffractive dissociation and τ decay data, and showed that they could be well reproduced with an a_1 resonance mass of 1180 ± 50 MeV and width of 400 ± 50 MeV. Later, BOWLER 86, TORNQVIST 87, ISGUR 89, and IVANOV 91 have studied the process $\tau \to 3\pi\nu_\tau$. Despite quite different approaches, they all found a good overall description of the τ-decay data with an $a_1(1260)$ mass near 1230 MeV, consistent with the hadronic data. However, their widths remain significantly larger (400–600 MeV) than those extracted from diffractive-hadronic data. This is also the case with the later OPAL experiment (ACKERSTAFF 97R). In the high statistics analysis of ACKERSTAFF 97R, the models of ISGUR 89 and KUHN 90 are used to fit distributions of the 3π invariant mass, as well as the 2π invariant mass projections of the Dalitz plot, and neither model is found to provide a completely satisfactory description of the data. Another recent high statistics analysis of ABREU 98G obtains a good description of the $\tau \to 3\pi$ data using the model of FEINDT 90, which includes the $a_1(1640)$ meson, most probably a radial excitation of the $a_1(1260)$ meson (BARNES 97), with a mass of 1700 MeV and a width of 300 MeV. A similar signal has been observed in various hadroproduction processes: by AMELIN 95B and CHUNG 02 in the D-wave of the $\rho\pi$ state, by GOUZ 92 in the $f_1(1285)\pi$ state, and by BAKER 99 in the $f_0(600)\pi$ state, as well as by BAKER 03 in the $\omega\pi^+\pi^-$

state. The existence of such a resonance is also suggested by the very big data sample of ASNER 00, which shows an excess of events at high 3π mass. Their data are better described by the a_1' contribution, though at a level below that reported by ABREU 98G. Since the statistical significance of the a_1' contribution is 2–3 standard deviations only, they conclude that more data is needed to establish the a_1' existence.

ASNER 00 has also performed the analysis of the sub-structures in the Dalitz plot and found significant contributions of the a_1 decay to $f_0(600)\pi, f_0(1370)\pi$, and $f_2(1270)\pi$. The contribution of the $a_1 \to f_0(600)\pi$ at a similar level has independently been observed in $e^+e^- \to 4\pi$ annihilation (AKHMETSHIN 99E), where the $2\pi^+2\pi^-$ final state was shown to be dominated by the $a_1(1260)\pi$ mechanism. Note that existence of the isoscalar contributions to the two-pion state, in addition to the isovector one ($\rho\pi$), will influence the ratio $\mathrm{B}(a_1^- \to \pi^-\pi^+\pi^-)/\mathrm{B}(a_1^- \to \pi^-\pi^0\pi^0)$, which should be equal to 1 for the pure $\rho\pi$ state. The fit of ASNER 00 improves when the $K\overline{K}^*(892)$ threshold is included. Recently DRUTSKOY 02 found direct evidence for the decay mode $a_1(1260) \to K\overline{K}^*(892)+$ c.c. in B-meson decays.

BOWLER 88 showed that good fits to both the hadronic and the τ-decay data could be obtained with a width of about 400 MeV. However, applying the same type of analysis to the ANDO 92 data, the low mass and narrow width they obtained with the Breit-Wigner PWA do not change appreciably.

$a_1(1260)$ MASS

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*CHG*	*COMMENT*
1230±40 OUR ESTIMATE					

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

$1331\pm10\pm\ 3$	37k	[1]	ASNER	00	CLE2		$10.6\ e^+e^- \to \tau^+\tau^-,\ \tau^- \to \pi^-\pi^0\pi^0\nu_\tau$
$1255\pm\ 7\pm\ 6$	5904	[2]	ABREU	98G	DLPH		e^+e^-
$1207\pm\ 5\pm\ 8$	5904	[3]	ABREU	98G	DLPH		e^+e^-
$1196\pm\ 4\pm\ 5$	5904	[4,5]	ABREU	98G	DLPH		e^+e^-
1240 ± 10			BARBERIS	98B			$450\ pp \to p_f\pi^+\pi^-\pi^0 p_s$
$1262\pm\ 9\pm\ 7$		[2,6]	ACKERSTAFF	97R	OPAL		E^{ee}_{cm}= 88–94, $\tau \to 3\pi\nu$
$1210\pm\ 7\pm\ 2$		[3,6]	ACKERSTAFF	97R	OPAL		E^{ee}_{cm}= 88–94, $\tau \to 3\pi\nu$
$1211\pm\ 7^{+50}_{-\ 0}$		[3]	ALBRECHT	93C	ARG		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
$1121\pm\ 8$		[7]	ANDO	92	SPEC		$8\ \pi^-p \to \pi^+\pi^-\pi^0 n$
1242 ± 37		[8]	IVANOV	91	RVUE		$\tau \to \pi^+\pi^+\pi^-\nu$
1260 ± 14		[9]	IVANOV	91	RVUE		$\tau \to \pi^+\pi^+\pi^-\nu$
$1250\pm\ 9$		[10]	IVANOV	91	RVUE		$\tau \to \pi^+\pi^+\pi^-\nu$
1208 ± 15			ARMSTRONG	90	OMEG	0	$300.0 pp \to pp\pi^+\pi^-\pi^0$
1220 ± 15		[11]	ISGUR	89	RVUE		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1260 ± 25		[12]	BOWLER	88	RVUE		
$1166\pm18\pm11$			BAND	87	MAC		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
$1164\pm41\pm23$			BAND	87	MAC		$\tau^+ \to \pi^+\pi^0\pi^0\nu$
1250 ± 40		[11]	TORNQVIST	87	RVUE		
1046 ± 11			ALBRECHT	86B	ARG		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
$1056\pm20\pm15$			RUCKSTUHL	86	DLCO		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
$1194\pm14\pm10$			SCHMIDKE	86	MRK2		$\tau^+ \to \pi^+\pi^+\pi^-\nu$
1255 ± 23			BELLINI	85	SPEC		$40\ \pi^-A \to \pi^-\pi^+\pi^-A$
1240 ± 80		[13]	DANKOWY...	81	SPEC	0	$8.45\ \pi^-p \to n3\pi$
1280 ± 30		[13]	DAUM	81B	CNTR		$63{,}94\ \pi^-p \to p3\pi$
1041 ± 13		[14]	GAVILLET	77	HBC	+	$4.2\ K^-p \to \Sigma 3\pi$

[1] From a fit to the 3π mass spectrum including the $K\overline{K}^*(892)$ threshold.
[2] Uses the model of KUHN 90.
[3] Uses the model of ISGUR 89.
[4] Includes the effect of a possible a_1' state.
[5] Uses the model of FEINDT 90.
[6] Supersedes AKERS 95P.
[7] Average and spread of values using 2 variants of the model of BOWLER 75.
[8] Reanalysis of RUCKSTUHL 86.
[9] Reanalysis of SCHMIDKE 86.
[10] Reanalysis of ALBRECHT 86B.
[11] From a combined reanalysis of ALBRECHT 86B, SCHMIDKE 86, and RUCKSTUHL 86.
[12] From a combined reanalysis of ALBRECHT 86B and DAUM 81B.
[13] Uses the model of BOWLER 75.
[14] Produced in K^- backward scattering.

$a_1(1260)$ WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
250 to 600 OUR ESTIMATE					
• • • We do not use the following data for averages, fits, limits, etc. • • •					
460 ± 85	205	[15] DRUTSKOY 02	BELL		$B \to D^{(*)} K^- K^{*0}$
$814 \pm 36 \pm 13$	37k	[16] ASNER 00	CLE2		10.6 $e^+ e^- \to \tau^+ \tau^-$, $\tau^- \to \pi^- \pi^0 \pi^0 \nu_\tau$
450 ± 50	22k	[17] AKHMETSHIN 99E	CMD2		1.05–1.38 $e^+ e^- \to \pi^+ \pi^- \pi^0 \pi^0$
570 ± 10		[18] BONDAR 99	RVUE		$e^+ e^- \to 4\pi$, $\tau \to 3\pi \nu_\tau$
$587 \pm 27 \pm 21$	5904	[19] ABREU 98G	DLPH		$e^+ e^-$
$478 \pm 3 \pm 15$	5904	[20] ABREU 98G	DLPH		$e^+ e^-$
$425 \pm 14 \pm 8$	5904	[21,22] ABREU 98G	DLPH		$e^+ e^-$
400 ± 35		BARBERIS 98B			450 $p p \to p_f \pi^+ \pi^- \pi^0 p_s$
$621 \pm 32 \pm 58$		[19,23] ACKERSTAFF 97R	OPAL		$E^{ee}_{\rm cm}$= 88–94, $\tau \to 3\pi \nu$
$457 \pm 15 \pm 17$		[20,23] ACKERSTAFF 97R	OPAL		$E^{ee}_{\rm cm}$= 88–94, $\tau \to 3\pi \nu$
$446 \pm 21 {}^{+140}_{-0}$		[20] ALBRECHT 93C	ARG		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
239 ± 11		ANDO 92	SPEC		8 $\pi^- p \to \pi^+ \pi^- \pi^0 n$
$266 \pm 13 \pm 4$		[24] ANDO 92	SPEC		8 $\pi^- p \to \pi^+ \pi^- \pi^0 n$
$465 {}^{+228}_{-143}$		[25] IVANOV 91	RVUE		$\tau \to \pi^+ \pi^+ \pi^- \nu$
$298 {}^{+40}_{-34}$		[26] IVANOV 91	RVUE		$\tau \to \pi^+ \pi^+ \pi^- \nu$
488 ± 32		[27] IVANOV 91	RVUE		$\tau \to \pi^+ \pi^+ \pi^- \nu$
430 ± 50		ARMSTRONG 90	OMEG	0	300.0 $p p \to p p \pi^+ \pi^- \pi^0$
420 ± 40		[28] ISGUR 89	RVUE		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
396 ± 43		[29] BOWLER 88	RVUE		
$405 \pm 75 \pm 25$		BAND 87	MAC		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
$419 \pm 108 \pm 57$		BAND 87	MAC		$\tau^+ \to \pi^+ \pi^0 \pi^0 \nu$
521 ± 27		ALBRECHT 86B	ARG		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
$476 {}^{+132}_{-120} \pm 54$		RUCKSTUHL 86	DLCO		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
$462 \pm 56 \pm 30$		SCHMIDKE 86	MRK2		$\tau^+ \to \pi^+ \pi^+ \pi^- \nu$
292 ± 40		BELLINI 85	SPEC		40 $\pi^- A \to \pi^- \pi^+ \pi^- A$
380 ± 100		[30] DANKOWY... 81	SPEC	0	8.45 $\pi^- p \to n 3\pi$
300 ± 50		[30] DAUM 81B	CNTR		63,94 $\pi^- p \to p 3\pi$
230 ± 50		[31] GAVILLET 77	HBC	+	4.2 $K^- p \to \Sigma 3\pi$

[15] From a fit of the $K^- K^{*0}$ distribution assuming m_{a_1}= 1230 MeV and purely resonant production of the $K^- K^{*0}$ system.
[16] From a fit to the 3π mass spectrum including the $K \overline{K}^*(892)$ threshold.
[17] Using the $a_1(1260)$ mass of 1230 MeV.
[18] From AKHMETSHIN 99E and ASNER 00 data using the $a_1(1260)$ mass of 1230 MeV.

[19] Uses the model of KUHN 90.
[20] Uses the model of ISGUR 89.
[21] Includes the effect of a possible a_1' state.
[22] Uses the model of FEINDT 90.
[23] Supersedes AKERS 95P.
[24] Average and spread of values using 2 variants of the model of BOWLER 75.
[25] Reanalysis of RUCKSTUHL 86.
[26] Reanalysis of SCHMIDKE 86.
[27] Reanalysis of ALBRECHT 86B.
[28] From a combined reanalysis of ALBRECHT 86B, SCHMIDKE 86, and RUCKSTUHL 86.
[29] From a combined reanalysis of ALBRECHT 86B and DAUM 81B.
[30] Uses the model of BOWLER 75.
[31] Produced in K^- backward scattering.

$a_1(1260)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\pi^+\pi^-\pi^0$	
Γ_2	$\pi^0\pi^0\pi^0$	
Γ_3	$(\rho\pi)_{S-\text{wave}}$	seen
Γ_4	$(\rho\pi)_{D-\text{wave}}$	seen
Γ_5	$(\rho(1450)\pi)_{S-\text{wave}}$	seen
Γ_6	$(\rho(1450)\pi)_{D-\text{wave}}$	seen
Γ_7	$\sigma\pi$	seen
Γ_8	$f_0(980)\pi$	not seen
Γ_9	$f_0(1370)\pi$	seen
Γ_{10}	$f_2(1270)\pi$	seen
Γ_{11}	$K\overline{K}^*(892)+$ c.c.	seen
Γ_{12}	$\pi\gamma$	seen

$a_1(1260)$ PARTIAL WIDTHS

$\Gamma(\pi\gamma)$ — Γ_{12}

VALUE (keV)	DOCUMENT ID		TECN	COMMENT
640±246	ZIELINSKI	84C	SPEC	200 $\pi^+ Z \to Z 3\pi$

D-wave/S-wave AMPLITUDE RATIO IN DECAY OF $a_1(1260) \to \rho\pi$

VALUE	DOCUMENT ID		TECN	COMMENT
−0.108±0.016 OUR AVERAGE				
−0.14 ±0.04 ±0.07	[34] CHUNG	02	MPS	18.3 $\pi^- p \to \pi^+\pi^-\pi^- p$
−0.10 ±0.02 ±0.02	[32,33] ACKERSTAFF	97R	OPAL	E^{ee}_{cm}= 88–94, $\tau \to 3\pi\nu$
−0.11 ±0.02	[32] ALBRECHT	93C	ARG	$\tau^+ \to \pi^+\pi^+\pi^-\nu$

[32] Uses the model of ISGUR 89.
[33] Supersedes AKERS 95P.
[34] Deck-type background not subtracted.

$a_1(1260)$ BRANCHING RATIOS

$\Gamma\big((\rho\pi)_{S-\text{wave}}\big)/\Gamma_{\text{total}}$ — Γ_3/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
60.19	37k	[35] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big((\rho\pi)_{D-\text{wave}}\big)/\Gamma_{\text{total}}$ — Γ_4/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.30\pm0.60\pm0.22$	37k	[35] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big((\rho(1450)\pi)_{S-\text{wave}}\big)/\Gamma_{\text{total}}$ — Γ_5/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.56\pm0.84\pm0.32$	37k	[35,36] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big((\rho(1450)\pi)_{D-\text{wave}}\big)/\Gamma_{\text{total}}$ — Γ_6/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$2.04\pm1.20\pm0.28$	37k	[35,36] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big(\sigma\pi\big)/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
seen		CHUNG	02	MPS	18.3 $\pi^- p \rightarrow \pi^+\pi^-\pi^- p$
$18.76\pm4.29\pm1.48$	37k	[35,37] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big(f_0(980)\pi\big)/\Gamma_{\text{total}}$ — Γ_8/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
not seen	37k	ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma\big(f_0(1370)\pi\big)/\Gamma_{\text{total}}$ — Γ_9/Γ

VALUE (units 10^{-2})	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$7.40\pm2.71\pm1.26$	37k	[35,38] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma(f_2(1270)\pi)/\Gamma_{total}$ — Γ_{10}/Γ

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$1.19\pm0.49\pm0.17$	37k	[35,39] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma(K\overline{K}^*(892)+\text{c.c.})/\Gamma_{total}$ — Γ_{11}/Γ

VALUE (units 10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
8 to 15	205	[40] DRUTSKOY	02	BELL	$B \rightarrow D^{(*)}K^-K^{*0}$
$3.3\pm0.5\pm0.1$	37k	[41] ASNER	00	CLE2	10.6 $e^+e^- \rightarrow \tau^+\tau^-$, $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau$

$\Gamma(\sigma\pi)/\Gamma((\rho\pi)_{S-\text{wave}})$ — Γ_7/Γ_3

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
~ 0.3	28k	AKHMETSHIN	99E	CMD2	1.05–1.38 $e^+e^- \rightarrow \pi^+\pi^-\pi^+\pi^-$
0.003 ± 0.003		[42] LONGACRE	82	RVUE	

$\Gamma(\pi^0\pi^0\pi^0)/\Gamma(\pi^+\pi^-\pi^0)$ — Γ_2/Γ_1

VALUE	*CL%*	*DOCUMENT ID*		*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
<0.008	90	[43] BARBERIS	01	450 $pp \rightarrow p_f 3\pi^0 p_s$

[35] From a fit to the Dalitz plot.
[36] Assuming for $\rho(1450)$ mass and width of 1370 and 386 MeV respectively.
[37] Assuming for σ mass and width of 860 and 880 MeV respectively.
[38] Assuming for $f_0(1370)$ mass and width of 1186 and 350 MeV respectively.
[39] Assuming for $f_2(1270)$ mass and width of 1275 and 185 MeV respectively.
[40] From a comparison to ALAM 94 assuming purely resonant production of the K^-K^{*0} system.
[41] From a fit to the 3π mass spectrum including the $K\overline{K}^*(892)$ threshold.
[42] Uses multichannel Aitchison-Bowler model (BOWLER 75). Uses data from GAVILLET 77, DAUM 80, and DANKOWYCH 81.
[43] Inconsistent with observations of $\sigma\pi$, $f_0(1370)\pi$, and $f_2(1270)\pi$ decay modes.

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