$\eta(1405)$

$I^G(J^{PC}) = 0^+(0^{-+})$

THE $\eta(1405)$, $\eta(1475)$ $f_1(1420)$, AND $f_1(1510)$

Revised in March 2006 by C. Amsler (Zürich) and A. Masoni (INFN Cagliari).

The first observation of the $\eta(1440)$ was made in $p\overline{p}$ annihilation at rest into $\eta(1440)\pi^+\pi^-$, $\eta(1440) \to K\overline{K}\pi$ (BAILLON 67). This state was reported to decay through $a_0(980)\pi$ and $K^*(892)\overline{K}$ with roughly equal contributions. The $\eta(1440)$ was also observed in radiative $J/\psi(1S)$ decay to $K\overline{K}\pi$ (SCHARRE 80, EDWARDS 82E, AUGUSTIN 90). There is now evidence for the existence of two pseudoscalars in this mass region, the $\eta(1405)$ and $\eta(1475)$. The former decays mainly through $a_0(980)\pi$ (or direct $K\overline{K}\pi$) and the latter mainly to $K^*(892)\overline{K}$.

The simultaneous observation of two pseudoscalars is reported in three production mechanisms: $\pi^- p$ (RATH 89, ADAMS 01); radiative $J/\psi(1S)$ decay (BAI 90C, AUGUSTIN 92); $\overline{p}p$ annihilation at rest (BERTIN 95, BERTIN 97, CICALO 99, NICHITIU 02). All of them give values for the masses, widths and decay modes in reasonable agreement. However, AUGUSTIN 92 favors a state decaying into $K^*(892)\overline{K}$ at a lower mass than the state decaying into $a_0(980)\pi$, although agreement with MARK-III is not excluded. In $J/\psi(1S)$ radiative decay, the $\eta(1405)$ decays into $K\overline{K}\pi$ through $a_0(980)\pi$ and hence a signal is also expected in the $\eta\pi\pi$ mass spectrum. This was indeed observed by MARK III in $\eta\pi^+\pi^-$ (BOLTON 92B) which report a mass of 1400 MeV, in line with the existence of the $\eta(1405)$ decaying to $a_0(980)\pi$. This state is also observed in $\overline{p}p$ annihilation at rest into $\eta\pi^+\pi^-\pi^0\pi^0$, where it decays into $\eta\pi\pi$ (AMSLER 95F). The intermediate $a_0(980)\pi$ accounts for roughly half of the $\eta\pi\pi$ signal, in agreement with MARK III (BOLTON 92B) and DM2 (AUGUSTIN 90).

The existence of the $\eta(1295)$ is questioned by KLEMPT 05. However, this state has been observed by four $\pi^- p$ experiments (ADAMS 01, FUKUI 91C, ALDE 97B, MANAK 00A) and evidence is also reported in $\overline{p}p$ annihilation (ABELE 98, ANISOVICH 01, AMSLER 04B). In J/ψ radiative decay an $\eta(1295)$ signal is seen in the 0^{-+} $\eta\pi\pi$ wave of DM2 data (AUGUSTIN 92).

Assuming that the $\eta(1295)$ is established, the $\eta(1475)$ could be the first radial excitation of the η', with the $\eta(1295)$ being the first radial excitation of the η. Ideal mixing, suggested by the $\eta(1295)$ and $\pi(1300)$ mass degeneracy, would then imply that the second isoscalar in the nonet is mainly $s\overline{s}$ and hence couples to $K^*\overline{K}$, in agreement with the $\eta(1475)$. Also its width matches the expected width for the radially excited $s\overline{s}$ state (CLOSE 97, BARNES 97).

The $K\overline{K}\pi$ and $\eta\pi\pi$ channels were studied in $\gamma\gamma$ collisions (ACCIARRI 01G). The analysis leads to an $\eta(1475)$ signal in $K\overline{K}\pi$, but the $\eta(1405)$ is not observed in $K\overline{K}\pi$ nor in $\eta\pi\pi$. This result is somewhat in disagreement with CLEO-II which did not observe any pseudoscalar signal in $\gamma\gamma \to \eta(1475) \to K^0_S K^\pm \pi^\mp$ (AHOHE 05), but more data are required. Since gluonium production is presumably suppressed in $\gamma\gamma$ collisions, the ACCIARRI 01G results suggest that the $\eta(1405)$ has a large gluonic content (see also CLOSE 97B, LI 03C). The observation of the $\eta(1475)$ combined with the absence of an $\eta(1405)$ signal strengthens the two-resonances hypothesis.

The gluonium interpretation is not favored by lattice gauge theories which predict the 0^{-+} state above 2 GeV (BALI 93). However, the $\eta(1405)$ is an excellent candidate for the 0^{-+} glueball in the flux tube model (FADDEEV 04). In this model the 0^{++} $f_0(1500)$ glueball is also naturally related to a 0^{-+} glueball with mass degeneracy broken in QCD.

Let us now deal with 1^{++} isoscalars. The $f_1(1420)$, decaying to $K^*\overline{K}$, was first reported in $\pi^- p$ reactions at 4 GeV/c (DIONISI 80). However, later analyses found that the 1400 –1500 MeV region was far more complex (CHUNG 85, REEVES 86, BIRMAN 88). A reanalysis of the MARK III data in radiative $J/\psi(1S)$ decay to $K\overline{K}\pi$ (BAI 90C) shows the $f_1(1420)$ decaying into $K^*\overline{K}$. Also, a C=+1 state is observed in tagged $\gamma\gamma$ collisions (*e.g.*, BEHREND 89).

In $\pi^- p \rightarrow \eta\pi\pi n$ charge-exchange reactions at 8–9 GeV/c the $\eta\pi\pi$ mass spectrum is dominated by the $\eta(1295)$ and $\eta(1440)$ (ANDO 86, FUKUI 91C) and at 100 GeV/c ALDE 97B report the $\eta(1295)$ and $\eta(1440)$ decaying to $\eta\pi^0\pi^0$, with a weak $f_1(1285)$ signal and no evidence for the $f_1(1420)$.

Axial (1^{++}) mesons are not observed in $\overline{p}p$ annihilation at rest in liquid hydrogen, which proceeds dominantly through S-wave annihilation. However, in gaseous hydrogen P-wave annihilation is enhanced and, indeed, BERTIN 97 report $f_1(1420)$ decaying to $K^*\overline{K}$.

The $f_1(1420)$, decaying into $K\overline{K}\pi$, is also seen in pp central production together with the $f_1(1285)$. The latter decays via $a_0(980)\pi$ and the former only via $K^*\overline{K}$, while the $\eta(1440)$ is absent (ARMSTRONG 89, BARBERIS 97C). The $K_S K_S \pi^0$ decay mode of the $f_1(1420)$ establishes unambiguously C=+1. On the other hand, there is no evidence for any state decaying to $\eta\pi\pi$ around 1400 MeV and hence the $\eta\pi\pi$ mode of $f_1(1420)$ must be suppressed (ARMSTRONG 91B).

We now turn to the experimental evidence for the $f_1(1510)$. Two states, the $f_1(1420)$ and the $f_1(1510)$, decaying to $K^*\overline{K}$, compete for the $s\overline{s}$ assignment in the 1^{++} nonet. The $f_1(1510)$ was seen in $K^- p \rightarrow \Lambda K\overline{K}\pi$ at 4 GeV/c (GAVILLET 82) and at 11 GeV/c (ASTON 88C). Evidence is also reported in $\pi^- p$ at 8 GeV/c, based on the phase motion of the 1^{++} $K^* \overline{K}$ wave (BIRMAN 88).

The absence of $f_1(1420)$ in $K^- p$ (ASTON 88C) argues against this state being the $s\overline{s}$ member of the 1^{++} nonet. However, the $f_1(1420)$ was reported in $K^- p$ but not in $\pi^- p$ (BITYUKOV 84) while two experiments do not observe the $f_1(1510)$ in $K^- p$ (BITYUKOV 84, KING 91). It is also not seen in radiative $J/\psi(1S)$ decay (BAI 90C, AUGUSTIN 92), central collisions (BARBERIS 97C), nor in $\gamma\gamma$ collisions (AIHARA 88C), although, surprisingly for an $s\overline{s}$ state, a signal is reported in 4π decays (BAUER 93B). These facts lead to the conclusion that the $f_1(1510)$ needs experimental confirmation (CLOSE 97D).

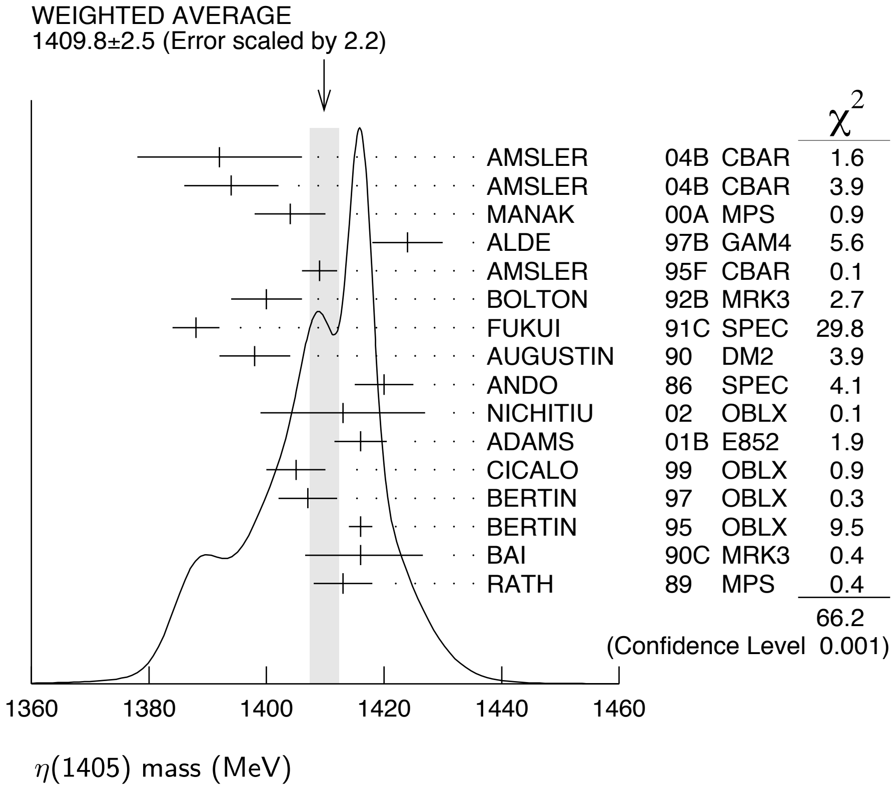
Assigning the $f_1(1420)$ to the 1^{++} nonet one finds a nonet mixing angle of $\sim 50°$ (CLOSE 97D). However, arguments favoring the $f_1(1420)$ being a hybrid $q\overline{q}g$ meson or a four-quark state were put forward by ISHIDA 89 and by CALDWELL 90, respectively, while LONGACRE 90 argued for a molecular state formed by the π orbiting in a P-wave around an S-wave $K\overline{K}$ state.

Summarizing, there is convincing evidence for the $f_1(1420)$ decaying to $K^* \overline{K}$, and for two pseudoscalars in the $\eta(1440)$ region, the $\eta(1405)$ and $\eta(1475)$, decaying to $a_0(980)\pi$ and $K^* \overline{K}$, respectively. The $f_1(1510)$ is not well established.

η(1405) MASS

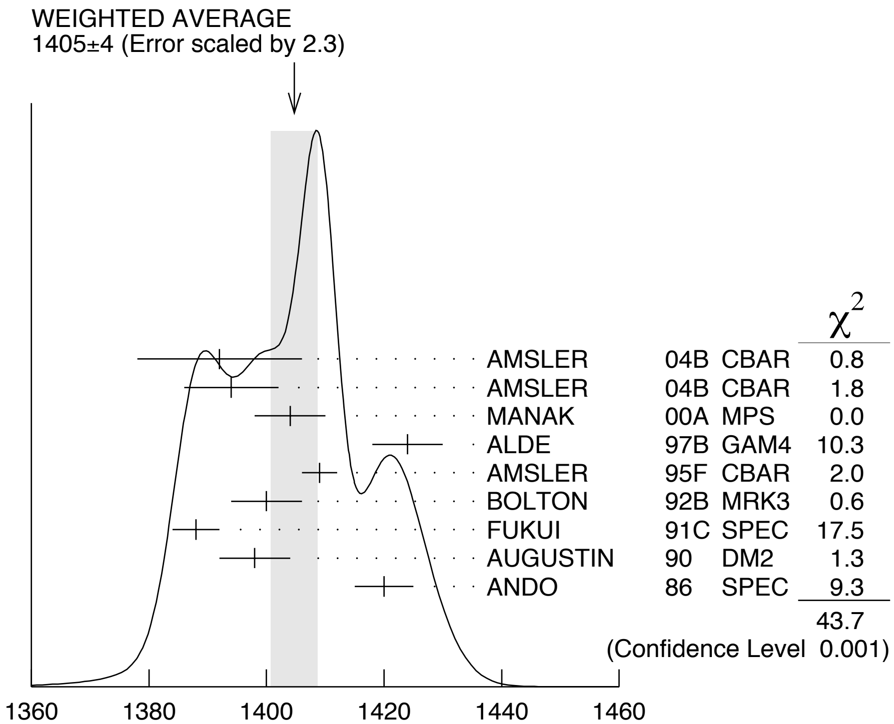
VALUE (MeV)	*DOCUMENT ID*

1409.8±2.5 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 2.2. See the ideogram below.



$\eta\pi\pi$ MODE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
The data in this block is included in the average printed for a previous datablock.				
1405± 4 OUR AVERAGE Error includes scale factor of 2.3. See the ideogram below.				
1392±14	900 ± 375	AMSLER	04B	CBAR 0 $\overline{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\eta$
1394± 8	6.6 ± 2.0k	AMSLER	04B	CBAR 0 $\overline{p}p \rightarrow \pi^+\pi^-\pi^0\pi^0\eta$
1404± 6	9082	MANAK	00A	MPS 18 $\pi^- p \rightarrow \eta\pi^+\pi^- n$
1424± 6	2200	ALDE	97B	GAM4 100 $\pi^- p \rightarrow \eta\pi^0\pi^0 n$
1409± 3		AMSLER	95F	CBAR 0 $\overline{p}p \rightarrow \pi^+\pi^-\pi^0\pi^0\eta$
1400± 6		[1] BOLTON	92B	MRK3 $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$
1388± 4		FUKUI	91C	SPEC 8.95 $\pi^- p \rightarrow \eta\pi^+\pi^- n$
1398± 6	261	[2] AUGUSTIN	90	DM2 $J/\psi \rightarrow \gamma\eta\pi^+\pi^-$
1420± 5		ANDO	86	SPEC 8 $\pi^- p \rightarrow \eta\pi^+\pi^- n$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1385± 7		BAI	99	BES $J/\psi \rightarrow \gamma\pi^+\pi^-$



$\eta(1405)$ mass, $\eta\pi\pi$ mode (MeV)

$K\overline{K}\pi$ MODE ($a_0(980)\pi$ or direct $K\overline{K}\pi$)

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
The data in this block is included in the average printed for a previous datablock.					
1413.9± 1.7 OUR AVERAGE	Error includes scale factor of 1.1.				
1413 ±14	3651	[3] NICHITIU	02	OBLX	
1416 ± 4 ±2	20k	ADAMS	01B	E852	18 GeV $\pi^- p \to K^+ K^- \pi^0 n$
1405 ± 5		[4] CICALO	99	OBLX	$0\ \overline{p}p \to K^\pm K^0_S \pi^\mp \pi^+ \pi^-$
1407 ± 5		[4] BERTIN	97	OBLX	$0\ \overline{p}p \to K^\pm (K^0) \pi^\mp \pi^+ \pi^-$
1416 ± 2		[4] BERTIN	95	OBLX	$0\ \overline{p}p \to K\overline{K}\pi\pi\pi$
1416 ± 8 $^{+7}_{-5}$	700	[5] BAI	90C	MRK3	$J/\psi \to \gamma K^0_S K^\pm \pi^\mp$
1413 ± 5		[5] RATH	89	MPS	$21.4\ \pi^- p \to n K^0_S K^0_S \pi^0$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1459 ± 5		[6] AUGUSTIN	92	DM2	$J/\psi \to \gamma K\overline{K}\pi$

$\pi\pi\gamma$ MODE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1390±12	235 ± 91	AMSLER	04B	CBAR	$0\ \overline{p}p \to \pi^+\pi^-\pi^+\pi^-\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1424±10±11	547	BAI	04J	BES2	$J/\psi \to \gamma\gamma\pi^+\pi^-$
1401±18		[7,8] AUGUSTIN	90	DM2	$J/\psi \to \pi^+\pi^-\gamma\gamma$
1432± 8		[8] COFFMAN	90	MRK3	$J/\psi \to \pi^+\pi^- 2\gamma$

4π MODE

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1420 ± 20		BUGG	95	MRK3	$J/\psi \rightarrow \gamma \pi^+ \pi^- \pi^+ \pi^-$
1489 ± 12	3270	[9] BISELLO	89B	DM2	$J/\psi \rightarrow 4\pi \gamma$

$K\overline{K}\pi$ MODE (unresolved)

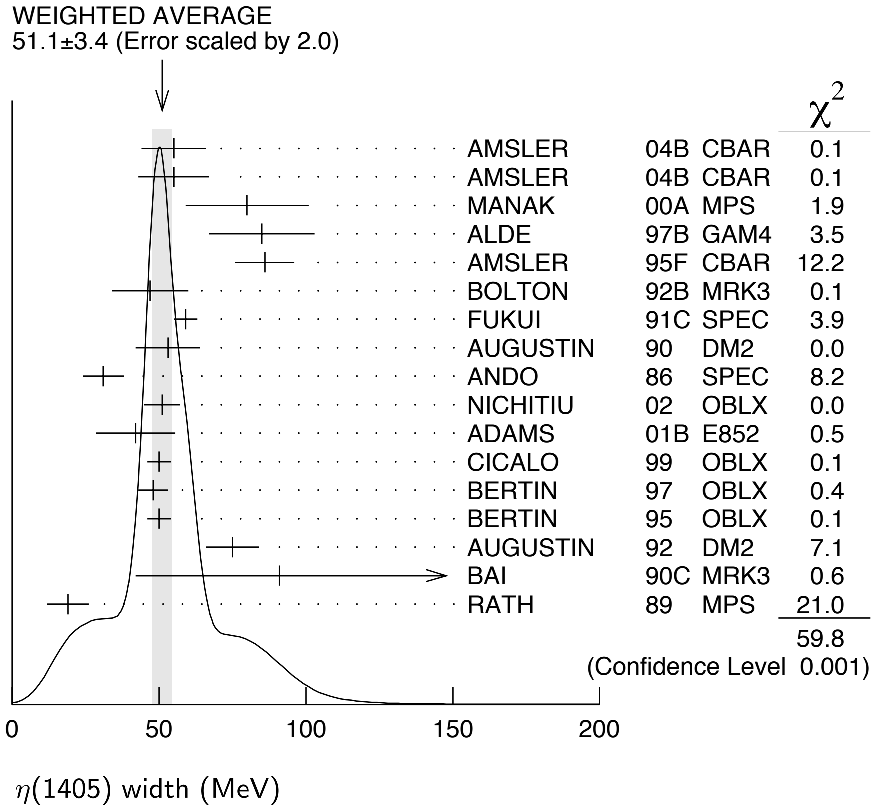
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1442 ± 10	410	[10] BAI	98C	BES	$J/\psi \rightarrow \gamma K^+ K^- \pi^0$
1445 ± 8	693	[10] AUGUSTIN	90	DM2	$J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp$
1433 ± 8	296	[10] AUGUSTIN	90	DM2	$J/\psi \rightarrow \gamma K^+ K^- \pi^0$
1413 ± 8	500	[10] DUCH	89	ASTE	$\overline{p} p \rightarrow \pi^+ \pi^- K^\pm \pi^\mp K^0$
1453 ± 7	170	[10] RATH	89	MPS	$21.4\ \pi^- p \rightarrow K^0_S K^0_S \pi^0 n$
1419 ± 1	8800	[10] BIRMAN	88	MPS	$8\ \pi^- p \rightarrow K^+ \overline{K}^0 \pi^- n$
1424 ± 3	620	[10] REEVES	86	SPEC	$6.6\ p\overline{p} \rightarrow K\overline{K}\pi X$
1421 ± 2		[10] CHUNG	85	SPEC	$8\ \pi^- p \rightarrow K\overline{K}\pi n$
1440^{+20}_{-15}	174	[10] EDWARDS	82E	CBAL	$J/\psi \rightarrow \gamma K^+ K^- \pi^0$
1440^{+10}_{-15}		[10] SCHARRE	80	MRK2	$J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp$
1425 ± 7	800	[10,11] BAILLON	67	HBC	$0\ \overline{p} p \rightarrow K\overline{K}\pi\pi\pi$

[1] From fit to the $a_0(980)\pi$ 0^{-+} partial wave.
[2] Best fit with a single Breit Wigner.
[3] Decaying dominantly directly to $K^+ K^- \pi^0$.
[4] Decaying into $(K\overline{K})_S \pi$, $(K\pi)_S \overline{K}$, and $a_0(980)\pi$.
[5] From fit to the $a_0(980)\pi$ 0^{-+} partial wave. Cannot rule out a $a_0(980)\pi$ 1^{++} partial wave.
[6] Excluded from averaging because averaging would be meaningless.
[7] Best fit with a single Breit Wigner.
[8] This peak in the $\gamma\rho$ channel may not be related to the $\eta(1405)$.
[9] Estimated by us from various fits.
[10] These experiments identify only one pseudoscalar in the 1400–1500 range. Data could also refer to $\eta(1475)$.
[11] From best fit of 0^{-+} partial wave , 50% $K^*(892)K$, 50% $a_0(980)\pi$.

$\eta(1405)$ WIDTH

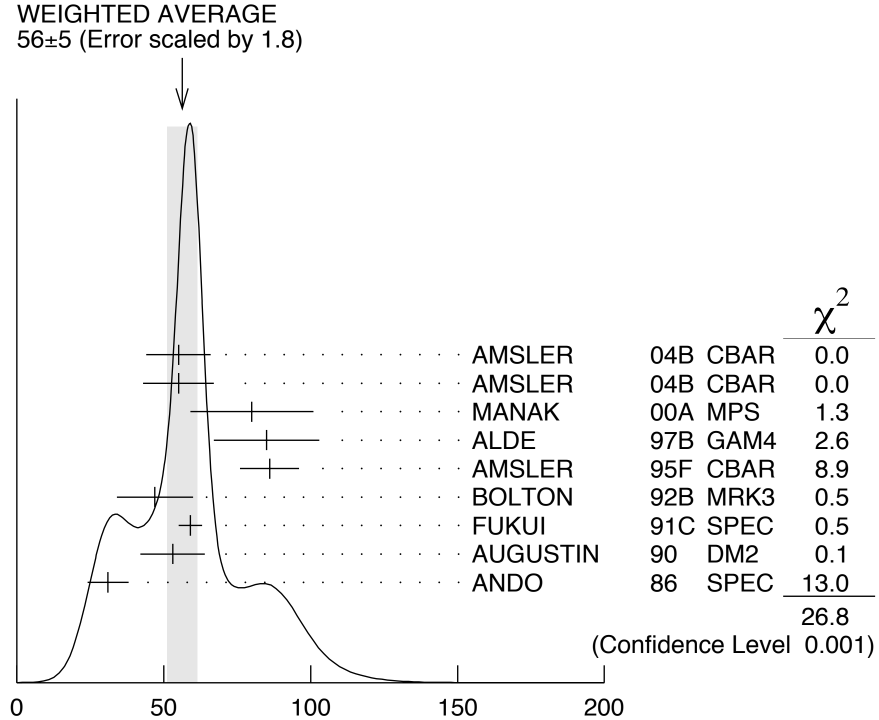
VALUE (MeV)	DOCUMENT ID

51.1±3.4 OUR AVERAGE Includes data from the 2 datablocks that follow this one. Error includes scale factor of 2.0. See the ideogram below.



$\eta\pi\pi$ MODE

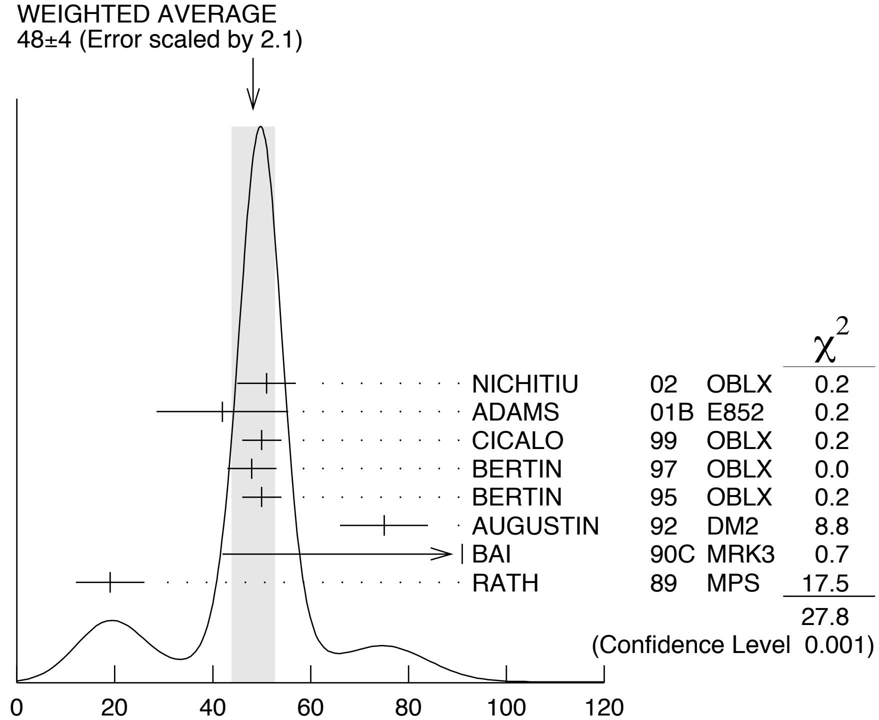
VALUE (MeV)	EVTS	DOCUMENT ID	TECN	COMMENT
The data in this block is included in the average printed for a previous datablock.				
56± 5 OUR AVERAGE	Error includes scale factor of 1.8. See the ideogram below.			
55±11	900 ± 375	AMSLER	04B CBAR	0 $\overline{p}p \to \pi^+\pi^-\pi^+\pi^-\eta$
55±12	6.6 ± 2.0k	AMSLER	04B CBAR	0 $\overline{p}p \to \pi^+\pi^-\pi^0\pi^0\gamma$
80±21	9082	MANAK	00A MPS	18 $\pi^- p \to \eta\pi^+\pi^- n$
85±18	2200	ALDE	97B GAM4	100 $\pi^- p \to \eta\pi^0\pi^0 n$
86±10		AMSLER	95F CBAR	0 $\overline{p}p \to \pi^+\pi^-\pi^0\pi^0\eta$
47±13		[12] BOLTON	92B MRK3	$J/\psi \to \gamma\eta\pi^+\pi^-$
59± 4		FUKUI	91C SPEC	8.95 $\pi^- p \to \eta\pi^+\pi^- n$
53±11		[13] AUGUSTIN	90 DM2	$J/\psi \to \gamma\eta\pi^+\pi^-$
31± 7		ANDO	86 SPEC	8 $\pi^- p \to \eta\pi^+\pi^- n$



$\eta(1405)$ width $\eta\pi\pi$ mode (MeV)

$K\overline{K}\pi$ MODE ($a_0(980)\pi$ or direct $K\overline{K}\pi$)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
The data in this block is included in the average printed for a previous datablock.					
48± 4 OUR AVERAGE	Error includes scale factor of 2.1. See the ideogram below.				
51± 6	3651	[14] NICHITIU	02	OBLX	
42±10± 9	20k	ADAMS	01B	E852	18 GeV $\pi^- p \rightarrow K^+ K^- \pi^0 n$
50± 4		CICALO	99	OBLX	0 $\overline{p}p \rightarrow K^\pm K^0_S \pi^\mp \pi^+ \pi^-$
48± 5		[15] BERTIN	97	OBLX	0.0 $\overline{p}p \rightarrow K^\pm (K^0) \pi^\mp \pi^+ \pi^-$
50± 4		[15] BERTIN	95	OBLX	0 $\overline{p}p \rightarrow K\overline{K}\pi\pi\pi$
75± 9		AUGUSTIN	92	DM2	$J/\psi \rightarrow \gamma K\overline{K}\pi$
$91^{+67}_{-31}{}^{+15}_{-38}$		[16] BAI	90C	MRK3	$J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp$
19± 7		[16] RATH	89	MPS	21.4 $\pi^- p \rightarrow n K^0_S K^0_S \pi^0$



$\eta(1405)$ width $K\overline{K}\pi$ mode ($a_0(980)$ π dominant)

$\pi\pi\gamma$ MODE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
64 ±18	235 ± 91	AMSLER	04B	CBAR	0 $\overline{p}p \to \pi^+\pi^-\pi^+\pi^-\gamma$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
101.0± 8.8±8.8	547	BAI	04J	BES2	$J/\psi \to \gamma\gamma\pi^+\pi^-$
174 ±44		AUGUSTIN	90	DM2	$J/\psi \to \pi^+\pi^-\gamma\gamma$
90 ±26		[17] COFFMAN	90	MRK3	$J/\psi \to \pi^+\pi^- 2\gamma$

4π MODE

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
160±30		BUGG	95	MRK3	$J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$
144±13	3270	[18] BISELLO	89B	DM2	$J/\psi \to 4\pi\gamma$

$K\overline{K}\pi$ MODE (unresolved)

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
93±14	296	[19] AUGUSTIN	90	DM2	$J/\psi \to \gamma K^+ K^- \pi^0$
105±10	693	[19] AUGUSTIN	90	DM2	$J/\psi \to \gamma K^0_S K^\pm \pi^\mp$
62±16	500	[19] DUCH	89	ASTE	$\overline{p}p \to K\overline{K}\pi\pi\pi$
100±11	170	[19] RATH	89	MPS	21.4 $\pi^- p \to K^0_S K^0_S \pi^0 n$
66± 2	8800	[19] BIRMAN	88	MPS	8 $\pi^- p \to K^+ \overline{K}^0 \pi^- n$

60 ± 10	620	[19] REEVES	86	SPEC	$6.6\ p\overline{p} \rightarrow K K \pi X$
60 ± 10		[19] CHUNG	85	SPEC	$8\ \pi^- p \rightarrow K \overline{K} \pi n$
55^{+20}_{-30}	174	[19] EDWARDS	82E	CBAL	$J/\psi \rightarrow \gamma K^+ K^- \pi^0$
50^{+30}_{-20}		[19] SCHARRE	80	MRK2	$J/\psi \rightarrow \gamma K^0_S K^\pm \pi^\mp$
80 ± 10	800	[19,20] BAILLON	67	HBC	$0.0\ \overline{p} p \rightarrow K \overline{K} \pi \pi \pi$

[12] From fit to the $a_0(980)\pi$ 0^{-+} partial wave.
[13] From $\eta\pi^+\pi^-$ mass distribution - mainly $a_0(980)\pi$ - no spin–parity determination available.
[14] Decaying dominantly directly to $K^+ K^- \pi^0$.
[15] Decaying into $(K\overline{K})_S\pi$, $(K\pi)_S\overline{K}$, and $a_0(980)\pi$.
[16] From fit to the $a_0(980)\pi$ 0^{-+} partial wave , but $a_0(980)\pi$ 1^{++} cannot be excluded.
[17] This peak in the $\gamma\rho$ channel may not be related to the $\eta(1405)$.
[18] Estimated by us from various fits.
[19] These experiments identify only one pseudoscalar in the 1400–1500 range. Data could also refer to $\eta(1475)$.
[20] From best fit to 0^{-+} partial wave , 50% $K^*(892) K$, 50% $a_0(980)\pi$.

$\eta(1405)$ DECAY MODES

	Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1	$K\overline{K}\pi$	seen	
Γ_2	$\eta\pi\pi$	seen	
Γ_3	$a_0(980)\pi$	seen	
Γ_4	$\eta(\pi\pi)_{S\text{-wave}}$	seen	
Γ_5	$f_0(980)\eta$	seen	
Γ_6	4π	seen	
Γ_7	$\rho\rho$	<58 %	99.85%
Γ_8	$\gamma\gamma$		
Γ_9	$\rho^0\gamma$		
Γ_{10}	$\phi\gamma$		
Γ_{11}	$K^*(892) K$	seen	

$\eta(1405)$ $\Gamma(i)\Gamma(\gamma\gamma)/\Gamma(\text{total})$

$\Gamma(K\overline{K}\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ — $\Gamma_1\Gamma_8/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.035	90	[21,22] AHOHE	05	CLE2	$10.6\ e^+e^- \rightarrow e^+e^- K^0_S K^\pm \pi^\mp$

$\Gamma(\eta\pi\pi) \times \Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ — $\Gamma_2\Gamma_8/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
<0.095	95	ACCIARRI	01G	L3	$183–202\ e^+e^- \rightarrow e^+e^- \eta\pi^+\pi^-$

$\Gamma(\rho^0\gamma) \times \Gamma(\gamma\gamma)/\Gamma_{total}$ — $\Gamma_9\Gamma_8/\Gamma$

VALUE (keV)	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<1.5	95	ALTHOFF	84E	TASS	$e^+e^- \rightarrow e^+e^-\pi^+\pi^-\gamma$

[21] Using $\eta(1405)$ mass and width 1410 MeV and 51 MeV, respectively.
[22] Assuming three-body phase-space decay to $K^0_S K^\pm \pi^\mp$.

$\eta(1405)$ BRANCHING RATIOS

$\Gamma(\eta\pi\pi)/\Gamma(K\overline{K}\pi)$ — Γ_2/Γ_1

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
1.09±0.48		[23] AMSLER	04B	CBAR	$0\ \overline{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\eta$
<0.5	90	EDWARDS	83B	CBAL	$J/\psi \rightarrow \eta\pi\pi\gamma$
<1.1	90	SCHARRE	80	MRK2	$J/\psi \rightarrow \eta\pi\pi\gamma$
<1.5	95	FOSTER	68B	HBC	$0.0\ \overline{p}p$

$\Gamma(\rho^0\gamma)/\Gamma(\eta\pi\pi)$ — Γ_9/Γ_2

VALUE	DOCUMENT ID		TECN	COMMENT
0.111±0.064	AMSLER	04B	CBAR	$0\ \overline{p}p$

$\Gamma(a_0(980)\pi)/\Gamma(K\overline{K}\pi)$ — Γ_3/Γ_1

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$\sim$ 0.15		[24] BERTIN	95	OBLX	$0\ \overline{p}p \rightarrow K\overline{K}\pi\pi\pi$
$\sim$ 0.8	500	[24] DUCH	89	ASTE	$\overline{p}p \rightarrow \pi^+\pi^-K^\pm\pi^\mp K^0$
$\sim$ 0.75		[24] REEVES	86	SPEC	$6.6\ p\overline{p} \rightarrow KK\pi X$

$\Gamma(a_0(980)\pi)/\Gamma(\eta\pi\pi)$ — Γ_3/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.29±0.10		ABELE	98E	CBAR	$0\ p\overline{p} \rightarrow \eta\pi^0\pi^0\pi^0$
0.19±0.04	2200	[25] ALDE	97B	GAM4	$100\ \pi^-p \rightarrow \eta\pi^0\pi^0 n$
0.56±0.04±0.03		[25] AMSLER	95F	CBAR	$0\ \overline{p}p \rightarrow \pi^+\pi^-\pi^0\pi^0\eta$

$\Gamma(a_0(980)\pi)/\Gamma(\eta(\pi\pi)_{S\text{-wave}})$ — Γ_3/Γ_4

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.91±0.12		ANISOVICH	01	SPEC	$0.0\ \overline{p}p \rightarrow \eta\pi^+\pi^-\pi^+\pi^-$
0.15±0.04	9082	MANAK	00A	MPS	$18\ \pi^-p \rightarrow \eta\pi^+\pi^- n$
0.70±0.12±0.20		[26] BAI	99	BES	$J/\psi \rightarrow \gamma\eta\pi^+\pi^-$

$\Gamma(\rho^0\gamma)/\Gamma(K\overline{K}\pi)$ — Γ_9/Γ_1

VALUE	DOCUMENT ID		TECN	COMMENT
0.0152±0.0038	[27] COFFMAN	90	MRK3	$J/\psi \rightarrow \gamma\gamma\pi^+\pi^-$

$\Gamma(\eta(\pi\pi)_{S\text{-wave}})/\Gamma(\eta\pi\pi)$ — Γ_4/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.81 ± 0.04	2200	ALDE	97B	GAM4	$100\ \pi^- p \to \eta\pi^0\pi^0 n$

$\Gamma(a_0(980)\pi)/\Gamma(\eta(\pi\pi)_{S\text{-wave}})$ — Γ_3/Γ_4

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.32 ± 0.07	[28] ANISOVICH	99I	SPEC	0.9–1.2 $\overline{p}p \to \eta 3\pi^0$

$\Gamma(\rho\rho)/\Gamma_{total}$ — Γ_7/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.58	99.85	[23,29] AMSLER	04B	CBAR	$0\ \overline{p}p$

$\Gamma(K^*(892)K)/\Gamma(a_0(980)\pi)$ — Γ_{11}/Γ_3

VALUE	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.084 ± 0.024	[30] ADAMS	01B	E852	18 GeV $\pi^- p \to K^+ K^- \pi^0 n$

$\Gamma(\phi\gamma)/\Gamma(\rho^0\gamma)$ — Γ_{10}/Γ_9

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •					
<0.77	95	[31] BAI	04J	BES2	$J/\psi \to \gamma\gamma K^+ K^-$

[23] Using the data of BAILLON 67 on $\overline{p}p \to K\overline{K}\pi$.
[24] Assuming that the $a_0(980)$ decays only into $K\overline{K}$.
[25] Assuming that the $a_0(980)$ decays only into $\eta\pi$.
[26] Assuming that the $a_0(980)$ decays only into $\eta\pi$.
[27] Using B($J/\psi \to \gamma\eta(1405) \to \gamma K\overline{K}\pi$)=$4.2\times10^{-3}$ and B($J/\psi \to \gamma\eta(1405) \to \gamma\gamma\rho^0$)=$6.4\times10^{-5}$ and assuming that the $\gamma\rho^0$ signal does not come from the $f_1(1420)$.
[28] Using preliminary Crystal Barrel data.
[29] Assuming that the $\eta(1405)$ decays are saturated by the $\pi\pi\eta$, $K\overline{K}\pi$ and $\rho\rho$ modes.
[30] Statistical error only.
[31] Calculated by us from B($J/\psi \to \eta(1405)\gamma \to \phi\gamma\gamma$) $< 0.82\times10^{-4}$ and B($J/\psi \to \eta(1405)\gamma \to \rho^0\gamma\gamma$) $= (1.07\pm0.17\pm0.11)\times10^{-4}$.

$\eta(1405)$ REFERENCES

AHOHE	05	PR D71 072001	R. Ahohe et al.	(CLEO Collab.)
AMSLER	04B	EPJ C33 23	C. Amsler et al.	(Crystal Barrel Collab.)
BAI	04J	PL B594 47	J.Z. Bai et al.	(BES Collab.)
NICHITIU	02	PL B545 261	F. Nichitiu et al.	(OBELIX Collab.)
ACCIARRI	01G	PL B501 1	M. Acciarri et al.	(L3 Collab.)
ADAMS	01B	PL B516 264	G.S. Adams et al.	(BNL E852 Collab.)
ANISOVICH	01	NP A690 567	A.V. Anisovich et al.	
MANAK	00A	PR D62 012003	J.J. Manak et al.	(BNL E852 Collab.)
ANISOVICH	99I	PL B468 304	A.V. Anisovich et al.	
BAI	99	PL B446 356	J.Z. Bai et al.	(BES Collab.)
CICALO	99	PL B462 453	C. Cicalo et al.	(OBELIX Collab.)
ABELE	98E	NP B514 45	A. Abele et al.	(Crystal Barrel Collab.)
BAI	98C	PL B440 217	J.Z. Bai et al.	(BES Collab.)
ALDE	97B	PAN 60 386 Translated from YAF 60 458.	D. Alde et al.	(GAMS Collab.)

BERTIN	97	PL B400 226	A. Bertin *et al.*	(OBELIX Collab.)
AMSLER	95F	PL B358 389	C. Amsler *et al.*	(Crystal Barrel Collab.)
BERTIN	95	PL B361 187	A. Bertin *et al.*	(OBELIX Collab.)
BUGG	95	PL B353 378	D.V. Bugg *et al.*	(LOQM, PNPI, WASH)
AUGUSTIN	92	PR D46 1951	J.E. Augustin, G. Cosme	(DM2 Collab.)
BOLTON	92B	PRL 69 1328	T. Bolton *et al.*	(Mark III Collab.)
FUKUI	91C	PL B267 293	S. Fukui *et al.*	(SUGI, NAGO, KEK, KYOT+)
AUGUSTIN	90	PR D42 10	J.E. Augustin *et al.*	(DM2 Collab.)
BAI	90C	PRL 65 2507	Z. Bai *et al.*	(Mark III Collab.)
COFFMAN	90	PR D41 1410	D.M. Coffman *et al.*	(Mark III Collab.)
BISELLO	89B	PR D39 701	G. Busetto *et al.*	(DM2 Collab.)
DUCH	89	ZPHY C45 223	K.D. Duch *et al.*	(ASTERIX Collab.) JP
RATH	89	PR D40 693	M.G. Rath *et al.*	(NDAM, BRAN, BNL, CUNY+)
BIRMAN	88	PRL 61 1557	A. Birman *et al.*	(BNL, FSU, IND, MASD) JP
ANDO	86	PRL 57 1296	A. Ando *et al.*	(KEK, KYOT, NIRS, SAGA+) IJP
REEVES	86	PR D34 1960	D.F. Reeves *et al.*	(FLOR, BNL, IND+) JP
CHUNG	85	PRL 55 779	S.U. Chung *et al.*	(BNL, FLOR, IND+) JP
ALTHOFF	84E	PL 147B 487	M. Althoff *et al.*	(TASSO Collab.)
EDWARDS	83B	PRL 51 859	C. Edwards *et al.*	(CIT, HARV, PRIN+)
EDWARDS	82E	PRL 49 259	C. Edwards *et al.*	(CIT, HARV, PRIN+)
Also		PRL 50 219	C. Edwards *et al.*	(CIT, HARV, PRIN+)
SCHARRE	80	PL 97B 329	D.L. Scharre *et al.*	(SLAC, LBL)
FOSTER	68B	NP B8 174	M. Foster *et al.*	(CERN, CDEF)
BAILLON	67	NC 50A 393	P.H. Baillon *et al.*	(CERN, CDEF, IRAD)

OTHER RELATED PAPERS

FADDEEV	04	PR D70 114033	L. Faddeev *et al.*	
LI	03C	EPJ C28 335	D.M. Li *et al.*	
LI	03D	IJMP A18 3335	D.M. Li *et al.*	
ADAMS	01	PRL 87 041801	T. Adams *et al.*	(NuTeV Collab.)
ANISOVICH	00F	EPJ A6 247	A.V. Anisovich *et al.*	
CARVALHO	99	EPJ C7 95	W.S. Carvalho *et al.*	
ABELE	98	PR D57 3860	A. Abele *et al.*	(Crystal Barrel Collab.)
NEKRASOV	98	EPJ C5 507	M.L. Nekrasov	
BARBERIS	97C	PL B413 225	D. Barberis *et al.*	(WA 102 Collab.)
BARNES	97	PR D55 4157	T. Barnes *et al.*	(ORNL, RAL, MCHS)
CLOSE	97	PL B397 333	F. Close *et al.*	(RAL, BIRM)
CLOSE	97B	PR D55 5749	F. Close *et al.*	(RAL, RUTG, BEIJT)
CLOSE	97D	ZPHY C76 469	F.E. Close *et al.*	
BERTIN	96	PL B385 493	A. Bertin *et al.*	(Obelix Collab.)
FARRAR	96	PRL 76 4111	G.R. Farrar	(RUTG)
AMELIN	95	ZPHY C66 71	D.V. Amelin *et al.*	(VES Collab.)
GENOVESE	94	ZPHY C61 425	M. Genovese, D.B. Lichtenberg, E. Predazzi	(TORI+)
BALI	93	PL B309 378	G.S. Bali *et al.*	(LIVP)
BAUER	93B	PR D48 3976	D.A. Bauer *et al.*	(SLAC)
ARMSTRONG	91B	ZPHY C52 389	T.A. Armstrong *et al.*	(ATHU, BARI, BIRM+)
KING	91	NPBPS B21 11	E. King *et al.*	(FSU, BNL+)
CALDWELL	90	Hadron 89 Conf. p 127	D.O. Caldwell	(UCSB)
LONGACRE	90	PR D42 874	R.S. Longacre	(BNL)
AHMAD	89	NP B (PROC.)8 50	S. Ahmad *et al.*	(ASTERIX Collab.)
ARMSTRONG	89	PL B221 216	T.A. Armstrong *et al.*	(CERN, CDEF, BIRM+)
BEHREND	89	ZPHY C42 367	H.J. Behrend *et al.*	(CELLO Collab.)
ISHIDA	89	PTP 82 119	S. Ishida *et al.*	(NIHO)
ASTON	88C	PL B201 573	D. Aston *et al.*	(SLAC, NAGO, CINC, INUS)
ARMSTRONG	87	ZPHY C34 23	T.A. Armstrong *et al.*	(CERN, BIRM, BARI+)
ARMSTRONG	84	PL 146B 273	T.A. Armstrong *et al.*	(ATHU, BARI, BIRM+)
BITYUKOV	84	SJNP 39 735	S. Bityukov *et al.*	(SERP)
		Translated from YAF 39 1165.		
GAVILLET	82	ZPHY C16 119	P. Gavillet *et al.*	(CERN, CDEF, PADO+)
DIONISI	80	NP B169 1	C. Dionisi *et al.*	(CERN, MADR, CDEF+)
DEFOIX	72	NP B44 125	C. Defoix *et al.*	(CDEF, CERN)
DUBOC	72	NP B46 429	J. Duboc *et al.*	(PARIS, LIVP)
LORSTAD	69	NP B14 63	B. Lorstad *et al.*	(CDEF, CERN)