Z

$J = 1$

See the related review(s):

Z Boson

Z MASS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The *Z* boson" and ref. LEP-SLC 06). The fit is performed using the *Z* mass and width, the *Z* hadronic pole cross section, the ratios of hadronic to leptonic partial widths, and the *Z* pole forward-backward lepton asymmetries. This set is believed to be most free of correlations.

The *Z*-boson mass listed here corresponds to the mass parameter in a Breit-Wigner distribution with mass dependent width. The value is 34 MeV greater than the real part of the position of the pole (in the energy-squared plane) in the *Z*-boson propagator. Also the LEP experiments have generally assumed a fixed value of the $\gamma - Z$ interferences term based on the standard model. Keeping this term as free parameter leads to a somewhat larger error on the fitted *Z* mass. See ACCIARRI 00Q and ABBIENDI 04G for a detailed investigation of both these issues.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
91.1876±0.0021 OUR FIT				
91.1852±0.0030	4.57M	[1] ABBIENDI 01A	OPAL	E^{ee}_{cm}= 88–94 GeV
91.1863±0.0028	4.08M	[2] ABREU 00F	DLPH	E^{ee}_{cm}= 88–94 GeV
91.1898±0.0031	3.96M	[3] ACCIARRI 00C	L3	E^{ee}_{cm}= 88–94 GeV
91.1885±0.0031	4.57M	[4] BARATE 00C	ALEP	E^{ee}_{cm}= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
91.084 ±0.107		[5] ANDREEV 18A	H1	$e^{\pm} p$
91.1872±0.0033		[6] ABBIENDI 04G	OPAL	E^{ee}_{cm}= LEP1 + 130–209 GeV
91.272 ±0.032 ±0.033		[7] ACHARD 04C	L3	E^{ee}_{cm}= 183–209 GeV
91.1875±0.0039	3.97M	[8] ACCIARRI 00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV
91.151 ±0.008		[9] MIYABAYASHI 95	TOPZ	E^{ee}_{cm}= 57.8 GeV
91.74 ±0.28 ±0.93	156	[10] ALITTI 92B	UA2	$E^{p\overline{p}}_{cm}$= 630 GeV
90.9 ±0.3 ±0.2	188	[11] ABE 89C	CDF	$E^{p\overline{p}}_{cm}$= 1.8 TeV
91.14 ±0.12	480	[12] ABRAMS 89B	MRK2	E^{ee}_{cm}= 89–93 GeV
93.1 ±1.0 ±3.0	24	[13] ALBAJAR 89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV

[1] ABBIENDI 01A error includes approximately 2.3 MeV due to statistics and 1.8 MeV due to LEP energy uncertainty.

[2] The error includes 1.6 MeV due to LEP energy uncertainty.

[3] The error includes 1.8 MeV due to LEP energy uncertainty.

[4] BARATE 00C error includes approximately 2.4 MeV due to statistics, 0.2 MeV due to experimental systematics, and 1.7 MeV due to LEP energy uncertainty.

[5] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic $e^+ p$ and $e^- p$ neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[6] ABBIENDI 04G obtain this result using the S–matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 34 MeV shift with respect to the Breit–Wigner fits.

[7] ACHARD 04C select $e^+ e^- \rightarrow Z\gamma$ events with hard initial–state radiation. Z decays to $q\overline{q}$ and muon pairs are considered. The fit results obtained in the two samples are found consistent to each other and combined considering the uncertainty due to ISR modelling as fully correlated.

[8] ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the γ/Z interference term. The authors have corrected the measurement for the 34.1 MeV shift with respect to the Breit-Wigner fits. The error contains a contribution of ±2.3 MeV due to the uncertainty on the γZ interference.

[9] MIYABAYASHI 95 combine their low energy total hadronic cross-section measurement with the ACTON 93D data and perform a fit using an S-matrix formalism. As expected, this result is below the mass values obtained with the standard Breit-Wigner parametrization.

[10] Enters fit through W/Z mass ratio given in the W Particle Listings. The ALITTI 92B systematic error (±0.93) has two contributions: one (±0.92) cancels in m_W/m_Z and one (±0.12) is noncancelling. These were added in quadrature.

[11] First error of ABE 89 is combination of statistical and systematic contributions; second is mass scale uncertainty.

[12] ABRAMS 89B uncertainty includes 35 MeV due to the absolute energy measurement.

[13] ALBAJAR 89 result is from a total sample of 33 $Z \rightarrow e^+ e^-$ events.

Z WIDTH

OUR EVALUATION is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The *Z* boson" and ref. LEP-SLC 06). Corrections as discussed in VOUTSINAS 20 and JANOT 20 are also included.

VALUE (GeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
2.4955±0.0023 OUR EVALUATION				
2.4955±0.0023		[1] JANOT 20		
• • • We do not use the following data for averages, fits, limits, etc. • • •				
2.4955±0.0023		[2] VOUTSINAS 20		
2.4952±0.0023		LEP-SLC 06		E^{ee}_{cm} = 88–94 GeV
2.4943±0.0041		[3] ABBIENDI 04G	OPAL	E^{ee}_{cm}= LEP1 + 130–209 GeV
2.4948±0.0041	4.57M	[4] ABBIENDI 01A	OPAL	E^{ee}_{cm}= 88–94 GeV
2.4876±0.0041	4.08M	[5] ABREU 00F	DLPH	E^{ee}_{cm}= 88–94 GeV
2.5024±0.0042	3.96M	[6] ACCIARRI 00C	L3	E^{ee}_{cm}= 88–94 GeV
2.5025±0.0041	3.97M	[7] ACCIARRI 00Q	L3	E^{ee}_{cm}= LEP1 + 130–189 GeV

2.4951	±0.0043		4.57M	[8] BARATE	00C	ALEP $E^{ee}_{\rm cm}$= 88–94 GeV
2.50	±0.21	±0.06		[9] ABREU	96R	DLPH $E^{ee}_{\rm cm}$= 91.2 GeV
3.8	±0.8	±1.0	188	ABE	89C	CDF $E^{p\overline{p}}_{\rm cm}$= 1.8 TeV
2.42	$^{+0.45}_{-0.35}$		480	[10] ABRAMS	89B	MRK2 $E^{ee}_{\rm cm}$= 89–93 GeV
2.7	$^{+1.2}_{-1.0}$	±1.3	24	[11] ALBAJAR	89	UA1 $E^{p\overline{p}}_{\rm cm}$= 546,630 GeV
2.7	±2.0	±1.0	25	[12] ANSARI	87	UA2 $E^{p\overline{p}}_{\rm cm}$= 546,630 GeV

[1] JANOT 20 applies a correction to LEP-SLC 06 using an updated Bhabha cross section calculation. This result also includes a correction to account for correlated luminosity bias as presented in VOUTSINAS 20.

[2] VOUTSINAS 20 applies a correction to LEP-SLC 06 to account for correlated luminosity bias.

[3] ABBIENDI 04G obtain this result using the S–matrix formalism for a combined fit to their cross section and asymmetry data at the Z peak and their data at 130–209 GeV. The authors have corrected the measurement for the 1 MeV shift with respect to the Breit–Wigner fits.

[4] ABBIENDI 01A error includes approximately 3.6 MeV due to statistics, 1 MeV due to event selection systematics, and 1.3 MeV due to LEP energy uncertainty.

[5] The error includes 1.2 MeV due to LEP energy uncertainty.

[6] The error includes 1.3 MeV due to LEP energy uncertainty.

[7] ACCIARRI 00Q interpret the s-dependence of the cross sections and lepton forward-backward asymmetries in the framework of the S-matrix formalism. They fit to their cross section and asymmetry data at high energies, using the results of S-matrix fits to Z-peak data (ACCIARRI 00C) as constraints. The 130–189 GeV data constrains the γ/Z interference term. The authors have corrected the measurement for the 0.9 MeV shift with respect to the Breit-Wigner fits.

[8] BARATE 00C error includes approximately 3.8 MeV due to statistics, 0.9 MeV due to experimental systematics, and 1.3 MeV due to LEP energy uncertainty.

[9] ABREU 96R obtain this value from a study of the interference between initial and final state radiation in the process $e^+e^- \rightarrow Z \rightarrow \mu^+\mu^-$.

[10] ABRAMS 89B uncertainty includes 50 MeV due to the miniSAM background subtraction error.

[11] ALBAJAR 89 result is from a total sample of 33 $Z \rightarrow e^+e^-$ events.

[12] Quoted values of ANSARI 87 are from direct fit. Ratio of Z and W production gives either $\Gamma(Z) < (1.09 \pm 0.07) \times \Gamma(W)$, CL = 90% or $\Gamma(Z) = (0.82^{+0.19}_{-0.14} \pm 0.06) \times \Gamma(W)$. Assuming Standard-Model value $\Gamma(W)$ = 2.65 GeV then gives $\Gamma(Z) <$ 2.89 ± 0.19 or $= 2.17^{+0.50}_{-0.37} \pm 0.16$.

Z DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	e^+e^-	[a]	(3.3632±0.0042) %	
Γ_2	$\mu^+\mu^-$	[a]	(3.3662±0.0066) %	
Γ_3	$\tau^+\tau^-$	[a]	(3.3696±0.0083) %	
Γ_4	$\ell^+\ell^-$	[a,b]	(3.3658±0.0023) %	
Γ_5	$\mu^+\mu^-\mu^+\mu^-$			
Γ_6	$\ell^+\ell^-\ell^+\ell^-$	[c]	(4.55 ±0.17) $\times 10^{-6}$	
Γ_7	invisible	[a]	(20.000 ±0.055) %	
Γ_8	hadrons	[a]	(69.911 ±0.056) %	

Γ_{9}	$(u\overline{u}+c\overline{c})/2$		(11.6 ± 0.6) %	
Γ_{10}	$(d\overline{d}+s\overline{s}+b\overline{b})/3$		(15.6 ± 0.4) %	
Γ_{11}	$c\overline{c}$		(12.03 ± 0.21) %	
Γ_{12}	$b\overline{b}$		(15.12 ± 0.05) %	
Γ_{13}	$b\overline{b}b\overline{b}$		$(3.6 \pm 1.3) \times 10^{-4}$	
Γ_{14}	ggg		< 1.1 %	CL=95%
Γ_{15}	$\pi^0\gamma$		$< 2.01 \times 10^{-5}$	CL=95%
Γ_{16}	$\eta\gamma$		$< 5.1 \times 10^{-5}$	CL=95%
Γ_{17}	$\rho^0\gamma$		$< 2.5 \times 10^{-5}$	CL=95%
Γ_{18}	$\omega\gamma$		$< 6.5 \times 10^{-4}$	CL=95%
Γ_{19}	$\eta'(958)\gamma$		$< 4.2 \times 10^{-5}$	CL=95%
Γ_{20}	$\phi\gamma$		$< 9 \times 10^{-7}$	CL=95%
Γ_{21}	$\gamma\gamma$		$< 1.46 \times 10^{-5}$	CL=95%
Γ_{22}	$\pi^0\pi^0$		$< 1.52 \times 10^{-5}$	CL=95%
Γ_{23}	$\gamma\gamma\gamma$		$< 2.2 \times 10^{-6}$	CL=95%
Γ_{24}	$\pi^{\pm}W^{\mp}$	[*d*]	$< 7 \times 10^{-5}$	CL=95%
Γ_{25}	$\rho^{\pm}W^{\mp}$	[*d*]	$< 8.3 \times 10^{-5}$	CL=95%
Γ_{26}	$J/\psi(1S)$X		$(3.51 {}^{+0.23}_{-0.25}) \times 10^{-3}$	S=1.1
Γ_{27}	$J/\psi(1S)\gamma$		$< 1.4 \times 10^{-6}$	CL=95%
Γ_{28}	$\psi(2S)$X		$(1.60 \pm 0.29) \times 10^{-3}$	
Γ_{29}	$\psi(2S)\gamma$		$< 4.5 \times 10^{-6}$	CL=95%
Γ_{30}	$J/\psi(1S)\ell^+\ell^-$			
Γ_{31}	$J/\psi(1S)J/\psi(1S)$		$< 2.2 \times 10^{-6}$	CL=95%
Γ_{32}	$\chi_{c1}(1P)$X		$(2.9 \pm 0.7) \times 10^{-3}$	
Γ_{33}	$\chi_{c2}(1P)$X		$< 3.2 \times 10^{-3}$	CL=90%
Γ_{34}	$\Upsilon(1S)$ X $+\Upsilon(2S)$ X $+\Upsilon(3S)$ X		$(1.0 \pm 0.5) \times 10^{-4}$	
Γ_{35}	$\Upsilon(1S)$X		$< 4.4 \times 10^{-5}$	CL=95%
Γ_{36}	$\Upsilon(1S)\gamma$		$< 2.8 \times 10^{-6}$	CL=95%
Γ_{37}	$\Upsilon(2S)$X		$< 1.39 \times 10^{-4}$	CL=95%
Γ_{38}	$\Upsilon(2S)\gamma$		$< 1.7 \times 10^{-6}$	CL=95%
Γ_{39}	$\Upsilon(3S)$X		$< 9.4 \times 10^{-5}$	CL=95%
Γ_{40}	$\Upsilon(3S)\gamma$		$< 4.8 \times 10^{-6}$	CL=95%
Γ_{41}	$\Upsilon(1,2,3S)\,\Upsilon(1,2,3S)$		$< 1.5 \times 10^{-6}$	CL=95%
Γ_{42}	$(D^0/\overline{D}^0)$ X		(20.7 ± 2.0) %	
Γ_{43}	$D^{\pm}$X		(12.2 ± 1.7) %	
Γ_{44}	$D^*(2010)^{\pm}$X	[*d*]	(11.4 ± 1.3) %	
Γ_{45}	$D_{s1}(2536)^{\pm}$X		$(3.6 \pm 0.8) \times 10^{-3}$	
Γ_{46}	$D_{sJ}(2573)^{\pm}$X		$(5.8 \pm 2.2) \times 10^{-3}$	
Γ_{47}	$D^{*\prime}(2629)^{\pm}$X		searched for	
Γ_{48}	BX			
Γ_{49}	B^*X			
Γ_{50}	B^+X	[*e*]	(6.08 ± 0.13) %	

Γ_{51}	$B^0_s X$		[e]	(1.59 ± 0.13) %	
Γ_{52}	$B^+_c X$			searched for	
Γ_{53}	$\Lambda^+_c X$			(1.54 ± 0.33) %	
Γ_{54}	$\Xi^0_c X$			seen	
Γ_{55}	$\Xi_b X$			seen	
Γ_{56}	b-baryon X		[e]	(1.38 ± 0.22) %	
Γ_{57}	anomalous $\gamma+$ hadrons		[f]	$< 3.2 \times 10^{-3}$	CL=95%
Γ_{58}	$e^+ e^- \gamma$		[f]	$< 5.2 \times 10^{-4}$	CL=95%
Γ_{59}	$\mu^+ \mu^- \gamma$		[f]	$< 5.6 \times 10^{-4}$	CL=95%
Γ_{60}	$\tau^+ \tau^- \gamma$		[f]	$< 7.3 \times 10^{-4}$	CL=95%
Γ_{61}	$\ell^+ \ell^- \gamma\gamma$		[g]	$< 6.8 \times 10^{-6}$	CL=95%
Γ_{62}	$q\overline{q}\gamma\gamma$		[g]	$< 5.5 \times 10^{-6}$	CL=95%
Γ_{63}	$\nu\overline{\nu}\gamma\gamma$		[g]	$< 3.1 \times 10^{-6}$	CL=95%
Γ_{64}	$e^\pm \mu^\mp$	*LF*	[d]	$< 7.5 \times 10^{-7}$	CL=95%
Γ_{65}	$e^\pm \tau^\mp$	*LF*	[d]	$< 5.0 \times 10^{-6}$	CL=95%
Γ_{66}	$\mu^\pm \tau^\mp$	*LF*	[d]	$< 6.5 \times 10^{-6}$	CL=95%
Γ_{67}	$p e$	*L,B*		$< 1.8 \times 10^{-6}$	CL=95%
Γ_{68}	$p \mu$	*L,B*		$< 1.8 \times 10^{-6}$	CL=95%

[a] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The *Z* boson" and ref. LEP-SLC 06 (Physics Reports (Physics Letters C) **427** 257 (2006)).

[b] ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

[c] Here ℓ indicates e or μ.

[d] The value is for the sum of the charge states or particle/antiparticle states indicated.

[e] This value is updated using the product of (i) the $Z \to b\overline{b}$ fraction from this listing and (ii) the *b*-hadron fraction in an unbiased sample of weakly decaying *b*-hadrons produced in *Z*-decays provided by the Heavy Flavor Averaging Group (HFLAV, http://www.slac.stanford.edu/xorg/hflav/osc/PDG_2009/#FRACZ).

[f] See the Particle Listings below for the γ energy range used in this measurement.

[g] For $m_{\gamma\gamma} = (60 \pm 5)$ GeV.

Z PARTIAL WIDTHS

$\Gamma(e^+e^-)$ **Γ_1**

For the LEP experiments, this parameter is not directly used in the overall fit but is derived using the fit results; see the note "The *Z* boson" and ref. LEP-SLC 06.

VALUE (MeV)		*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.91±0.12 OUR FIT						
83.66±0.20		137.0k	ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
83.54±0.27		117.8k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
84.16±0.22		124.4k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
83.88±0.19			BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
82.89±1.20±0.89			[1] ABE	95J	SLD	$E^{ee}_{\rm cm}$= 91.31 GeV

[1] ABE 95J obtain this measurement from Bhabha events in a restricted fiducial region to improve systematics. They use the values 91.187 and 2.489 GeV for the Z mass and total decay width to extract this partial width.

$\Gamma(\mu^+\mu^-)$ Γ_2

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.99±0.18 OUR FIT					
84.03±0.30	182.8k	ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
84.48±0.40	157.6k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
83.95±0.44	113.4k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
84.02±0.28		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

$\Gamma(\tau^+\tau^-)$ Γ_3

This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
84.08±0.22 OUR FIT					
83.94±0.41	151.5k	ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
83.71±0.58	104.0k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
84.23±0.58	103.0k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
84.38±0.31		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

$\Gamma(\ell^+\ell^-)$ Γ_4

ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

In our fit $\Gamma(\ell^+\ell^-)$ is defined as the partial Z width for the decay into a pair of massless charged leptons. This parameter is not directly used in the 5-parameter fit assuming lepton universality but is derived using the fit results. See the note "The Z boson" and ref. LEP-SLC 06.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
83.984±0.086 OUR FIT					
83.82 ±0.15	471.3k	ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
83.85 ±0.17	379.4k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
84.14 ±0.17	340.8k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
84.02 ±0.15	500k	BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

Γ(invisible) Γ_7

We use only direct measurements of the invisible partial width using the single photon channel to obtain the average value quoted below. OUR FIT value is obtained as a difference between the total and the observed partial widths assuming lepton universality.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
499.0± 1.5 OUR FIT				
503 ±16 OUR AVERAGE		Error includes scale factor of 1.2.		
498 ±12 ±12	1791	ACCIARRI 98G	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
539 ±26 ±17	410	AKERS 95C	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
450 ±34 ±34	258	BUSKULIC 93L	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
540 ±80 ±40	52	ADEVA 92	L3	$E^{ee}_{\rm cm}$= 88–94 GeV

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

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
498.1± 2.6		[1] ABBIENDI 01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
498.1± 3.2		[1] ABREU 00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
499.1± 2.9		[1] ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
499.1± 2.5		[1] BARATE 00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] This is an indirect determination of Γ(invisible) from a fit to the visible Z decay modes.

Γ(hadrons) Γ_8

This parameter is not directly used in the 5-parameter fit assuming lepton universality, but is derived using the fit results. See the note "The Z boson" and ref. LEP-SLC 06.

VALUE (MeV)	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
1744.4±2.0 OUR FIT				
1745.4±3.5	4.10M	ABBIENDI 01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
1738.1±4.0	3.70M	ABREU 00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
1751.1±3.8	3.54M	ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
1744.0±3.4	4.07M	BARATE 00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

Z BRANCHING RATIOS

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06).

$\Gamma(\mu^+\mu^-)/\Gamma(e^+e^-)$ Γ_2/Γ_1

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
1.0001±0.0024 OUR AVERAGE			
0.9974±0.0050	[1] AABOUD 17Q	ATLS	$E^{pp}_{\rm cm}$ = 7 TeV
1.0009±0.0028	[2] LEP-SLC 06		$E^{ee}_{\rm cm}$ = 88–94 GeV

[1] AABOUD 17Q make a precise determination of $Z \rightarrow ee$ and $Z \rightarrow \mu\mu$ production in the lepton pseudo-rapidity range $|\eta| < 2.5$ and determine the ratio of the Z branching fractions $B(Z \rightarrow ee)/B(Z \rightarrow \mu\mu) = 1.0026 \pm 0.0013 \pm 0.0048 = 1.0026 \pm 0.0050$.

[2] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

$\Gamma(\tau^+\tau^-)/\Gamma(e^+e^-)$ Γ_3/Γ_1

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.0020±0.0032 OUR AVERAGE				
1.02 ±0.06	[1] AAIJ	18AR	LHCB	$E^{pp}_{\text{cm}} = 8$ TeV
1.0019±0.0032	[2] LEP-SLC	06		$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] AAIJ 18AR obtain the result from the ratio of the measured $pp \to Z + X$ cross sections in the corresponding Z decay channels.

[2] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

$\Gamma(\tau^+\tau^-)/\Gamma(\mu^+\mu^-)$ Γ_3/Γ_2

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.0010±0.0026 OUR AVERAGE				
1.01 ±0.05	[1] AAIJ	18AR	LHCB	$E^{pp}_{\text{cm}} = 8$ TeV
1.0010±0.0026	[2] LEP-SLC	06		$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] AAIJ 18AR obtain the result from the ratio of the measured $pp \to Z + X$ cross sections in the corresponding Z decay channels.

[2] This parameter is not directly used in the overall fit but is derived using the fit results; see the note "The Z boson" and ref. LEP-SLC 06.

$\Gamma(\ell^+\ell^-\ell^+\ell^-)/\Gamma_{\text{total}}$ Γ_6/Γ

Here ℓ indicates either e or μ. The branching fractions in this node are given within the phase-space defined by the requirements that (i) the 4-lepton invariant mass is between 80 GeV and 100 GeV, and (ii) any opposite-sign same-flavor lepton pair has a di-lepton invariant mass larger than 4 GeV.

VALUE (units 10^{-6})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
4.55±0.17 OUR AVERAGE					
$4.41\pm0.13\pm0.27$		[1] AAD	21AQ	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
$4.70\pm0.32\pm0.25$		[2] AABOUD	19N	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
$4.83^{+0.23}_{-0.22}{}^{+0.35}_{-0.32}$	509	[3] SIRUNYAN	18BT	CMS	$E^{pp}_{\text{cm}} = 13$ TeV
$4.9\ ^{+0.8}_{-0.7}\ ^{+0.4}_{-0.2}$	39	[4] KHACHATRY...	16CC	CMS	$E^{pp}_{\text{cm}} = 13$ TeV
$4.31\pm0.34\pm0.17$	172	AAD	14N	ATLS	$E^{pp}_{\text{cm}} = 7, 8$ TeV
$4.6\ ^{+1.0}_{-0.9}\ \pm0.2$	28	[5] CHATRCHYAN	12BN	CMS	$E^{pp}_{\text{cm}} = 7$ TeV

[1] AAD 21AQ analyze differential cross-sections in four-lepton events. Based on the measured cross section in the $Z \to 4\ell$ channel, a branching fraction of $\text{B}(Z \to 4\ell) = (4.41 \pm 0.13 \pm 0.23 \pm 0.09 \pm 0.12) \times 10^{-6}$ is obtained, where the uncertainties are statistical, systematic, theory and luminosity, respectively.

[2] AABOUD 19N reports $(4.70 \pm 0.32 \pm 0.21 \pm 0.14) \times 10^{-6}$, where the uncertainties are statistical, systematic, and luminosity. We have combined the latter two in quadrature.

[3] SIRUNYAN 18BT report the $Z \to 4\ell$ branching fraction $= (4.83^{+0.23}_{-0.22}{}^{+0.32}_{-0.29} \pm 0.08 \pm 0.12) \times 10^{-6}$, where the uncertainties are statistical, systematic, due to theory, and luminosity. The last three have been added in quadrature to obtain the total systematic error.

[4] KHACHATRYAN 16CC reports $(4.9^{+0.8}_{-0.7}{}^{+0.3}_{-0.2}{}^{+0.2}_{-0.1}{}^{+0.1}_{-0.1}) \times 10^{-6}$ value, where the uncertainties are statistical, systematic, theory, and due to luminosity. We have combined uncertainties in quadrature.

[5] CHATRCHYAN 12BN reports $(4.2^{+0.9}_{-0.8} \pm 0.2) \times 10^{-6}$ value. Their result (both central value and uncertainties) is scaled up by 10% to account for the different phase-space definition used here (see RAINBOLT 19).

$\Gamma(\text{hadrons})/\Gamma(e^+e^-)$ Γ_8/Γ_1

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.804± 0.050 OUR FIT					
20.902± 0.084	137.0k	[1] ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
20.88 ± 0.12	117.8k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
20.816± 0.089	124.4k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
20.677± 0.075		[2] BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$27.0\ {}^{+11.7}_{-\ 8.8}$	12	[3] ABRAMS	89D	MRK2	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01A error includes approximately 0.067 due to statistics, 0.040 due to event selection systematics, 0.027 due to the theoretical uncertainty in t-channel prediction, and 0.014 due to LEP energy uncertainty.

[2] BARATE 00C error includes approximately 0.062 due to statistics, 0.033 due to experimental systematics, and 0.026 due to the theoretical uncertainty in t-channel prediction.

[3] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

$\Gamma(\text{hadrons})/\Gamma(\mu^+\mu^-)$ Γ_8/Γ_2

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06).

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.785±0.033 OUR FIT					
20.811±0.058	182.8k	[1] ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
20.65 ±0.08	157.6k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
20.861±0.097	113.4k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
20.799±0.056		[2] BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$18.9\ {}^{+7.1}_{-5.3}$	13	[3] ABRAMS	89D	MRK2	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01A error includes approximately 0.050 due to statistics and 0.027 due to event selection systematics.

[2] BARATE 00C error includes approximately 0.053 due to statistics and 0.021 due to experimental systematics.

[3] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

$\Gamma(\text{hadrons})/\Gamma(\tau^+\tau^-)$ Γ_8/Γ_3

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06).

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.764±0.045 OUR FIT					
20.832±0.091	151.5k	[1] ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
20.84 ±0.13	104.0k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
20.792±0.133	103.0k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
20.707±0.062		[2] BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

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

$15.2\ ^{+4.8}_{-3.9}$	21	[3] ABRAMS	89D	MRK2	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01A error includes approximately 0.055 due to statistics and 0.071 due to event selection systematics.

[2] BARATE 00C error includes approximately 0.054 due to statistics and 0.033 due to experimental systematics.

[3] ABRAMS 89D have included both statistical and systematic uncertainties in their quoted errors.

$\Gamma(\text{hadrons})/\Gamma(\ell^+\ell^-)$ $\qquad\Gamma_8/\Gamma_4$

ℓ indicates each type of lepton (e, μ, and τ), not sum over them.

Our fit result is obtained requiring lepton universality.

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
20.767±0.025 OUR FIT					
20.823±0.044	471.3k	[1] ABBIENDI	01A	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
20.730±0.060	379.4k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
20.810±0.060	340.8k	ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
20.725±0.039	500k	[2] BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$18.9\ ^{+3.6}_{-3.2}$	46	ABRAMS	89B	MRK2	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01A error includes approximately 0.034 due to statistics and 0.027 due to event selection systematics.

[2] BARATE 00C error includes approximately 0.033 due to statistics, 0.020 due to experimental systematics, and 0.005 due to the theoretical uncertainty in t-channel prediction.

$\Gamma((u\overline{u}+c\overline{c})/2)/\Gamma(\text{hadrons})$ $\qquad\Gamma_9/\Gamma_8$

This quantity is the branching ratio of $Z \rightarrow$ "up-type" quarks to $Z \rightarrow$ hadrons. Except ACKERSTAFF 97T the values of $Z \rightarrow$ "up-type" and $Z \rightarrow$ "down-type" branchings are extracted from measurements of Γ(hadrons), and $\Gamma(Z \rightarrow \gamma+$ jets) where γ is a high-energy (>5 or 7 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_Z, Γ(hadrons) and α_s in their extraction procedures, our average has to be taken with caution.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.166±0.009 OUR AVERAGE				
$0.172^{+0.011}_{-0.010}$	[1] ABBIENDI	04E	OPAL	$E^{ee}_{\rm cm}$ = 91.2 GeV
0.160±0.019±0.019	[2] ACKERSTAFF	97T	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$0.137^{+0.038}_{-0.054}$	[3] ABREU	95X	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.137±0.033	[4] ADRIANI	93	L3	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ABBIENDI 04E select photons with energy > 7 GeV and use Γ(hadrons) = 1744.4 ± 2.0 MeV and α_s = 0.1172 ± 0.002 to obtain $\Gamma_u = 300^{+19}_{-18}$ MeV.

[2] ACKERSTAFF 97T measure $\Gamma_{u\overline{u}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}}) = 0.258\pm0.031\pm0.032$. To obtain this branching ratio authors use R_c+R_b = 0.380 ± 0.010. This measurement is fully negatively correlated with the measurement of $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})$ given in the next data block.

[3] ABREU 95X use M_Z = 91.187 ± 0.009 GeV, Γ(hadrons) = 1725 ± 12 MeV and α_s = 0.123 ± 0.005. To obtain this branching ratio we divide their value of $C_{2/3} = 0.91^{+0.25}_{-0.36}$ by their value of $(3C_{1/3} + 2C_{2/3})$ = 6.66 ± 0.05.

[4] ADRIANI 93 use M_Z = 91.181 ± 0.022 GeV, Γ(hadrons) = 1742 ± 19 MeV and α_s = 0.125 ± 0.009. To obtain this branching ratio we divide their value of $C_{2/3} = 0.92 \pm 0.22$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

$\Gamma\big((d\overline{d}+s\overline{s}+b\overline{b})/3\big)/\Gamma(\text{hadrons})$ Γ_{10}/Γ_8

This quantity is the branching ratio of $Z \to$ "down-type" quarks to $Z \to$ hadrons. Except ACKERSTAFF 97T the values of $Z \to$ "up-type" and $Z \to$ "down-type" branchings are extracted from measurements of Γ(hadrons), and Γ($Z \to \gamma +$ jets) where γ is a high-energy (>5 or 7 GeV) isolated photon. As the experiments use different procedures and slightly different values of M_Z, Γ(hadrons) and α_s in their extraction procedures, our average has to be taken with caution.

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
0.223±0.006 OUR AVERAGE			
0.218±0.007	[1] ABBIENDI 04E	OPAL	$E^{ee}_{\rm cm}$ = 91.2 GeV
0.230±0.010±0.010	[2] ACKERSTAFF 97T	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$0.243^{+0.036}_{-0.026}$	[3] ABREU 95X	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.243±0.022	[4] ADRIANI 93	L3	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ABBIENDI 04E select photons with energy > 7 GeV and use Γ(hadrons) = 1744.4 ± 2.0 MeV and α_s = 0.1172 ± 0.002 to obtain Γ_d = 381 ± 12 MeV.

[2] ACKERSTAFF 97T measure $\Gamma_{d\overline{d},s\overline{s}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}}) = 0.371 \pm 0.016 \pm 0.016$. To obtain this branching ratio authors use $R_c+R_b = 0.380 \pm 0.010$. This measurement is fully negatively correlated with the measurement of $\Gamma_{u\overline{u}}/(\Gamma_{d\overline{d}}+\Gamma_{u\overline{u}}+\Gamma_{s\overline{s}})$ presented in the previous data block.

[3] ABREU 95X use M_Z = 91.187 ± 0.009 GeV, Γ(hadrons) = 1725 ± 12 MeV and α_s = 0.123 ± 0.005. To obtain this branching ratio we divide their value of $C_{1/3} = 1.62^{+0.24}_{-0.17}$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.66 \pm 0.05$.

[4] ADRIANI 93 use M_Z = 91.181 ± 0.022 GeV, Γ(hadrons) = 1742 ± 19 MeV and α_s = 0.125 ± 0.009. To obtain this branching ratio we divide their value of $C_{1/3} = 1.63 \pm 0.15$ by their value of $(3C_{1/3} + 2C_{2/3}) = 6.720 \pm 0.076$.

$R_c = \Gamma(c\overline{c})/\Gamma(\text{hadrons})$ Γ_{11}/Γ_8

OUR FIT is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the note "The *Z* boson" and ref. LEP-SLC 06.

The Standard Model predicts $R_c = 0.1723$ for m_t = 174.3 GeV and M_H = 150 GeV.

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
0.1721±0.0030 OUR FIT			
0.1744±0.0031±0.0021	[1] ABE 05F	SLD	$E^{ee}_{\rm cm}$=91.28 GeV
0.1665±0.0051±0.0081	[2] ABREU 00	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.1698±0.0069	[3] BARATE 00B	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
0.180 ±0.011 ±0.013	[4] ACKERSTAFF 98E	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
0.167 ±0.011 ±0.012	[5] ALEXANDER 96R	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •			
0.1623±0.0085±0.0209	[6] ABREU 95D	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABE 05F use hadronic *Z* decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events using a double tag method. The single *c*–tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of

the hemisphere). A multitag approach is used, defining 4 regions of the output value of the neural network and R_c is extracted from a simultaneous fit to the count rates of the 4 different tags. The quoted systematic error includes an uncertainty of ±0.0006 due to the uncertainty on R_b.

[2] ABREU 00 obtain this result properly combining the measurement from the D^{*+} production rate (R_c= 0.1610 ± 0.0104 ± 0.0077 ± 0.0043 (BR)) with that from the overall charm counting (R_c= 0.1692 ± 0.0047 ± 0.0063 ± 0.0074 (BR)) in $c\overline{c}$ events. The systematic error includes an uncertainty of ±0.0054 due to the uncertainty on the charmed hadron branching fractions.

[3] BARATE 00B use exclusive decay modes to independently determine the quantities $R_c \times$f($c \rightarrow$ X), X=D^0, D^+, D^+_s, and Λ_c. Estimating $R_c \times$f($c \rightarrow$ Ξ_c / Ω_c)= 0.0034, they simply sum over all the charm decays to obtain R_c= 0.1738 ± 0.0047 ± 0.0088 ± 0.0075(BR). This is combined with all previous ALEPH measurements (BARATE 98T and BUSKULIC 94G, R_c= 0.1681 ± 0.0054 ± 0.0062) to obtain the quoted value.

[4] ACKERSTAFF 98E use an inclusive/exclusive double tag. In one jet $D^{*\pm}$ mesons are exclusively reconstructed in several decay channels and in the opposite jet a slow pion (opposite charge inclusive $D^{*\pm}$) tag is used. The b content of this sample is measured by the simultaneous detection of a lepton in one jet and an inclusively reconstructed $D^{*\pm}$ meson in the opposite jet. The systematic error includes an uncertainty of ±0.006 due to the external branching ratios.

[5] ALEXANDER 96R obtain this value via direct charm counting, summing the partial contributions from D^0, D^+, D^+_s, and Λ^+_c, and assuming that strange-charmed baryons account for the 15% of the Λ^+_c production. An uncertainty of ±0.005 due to the uncertainties in the charm hadron branching ratios is included in the overall systematics.

[6] ABREU 95D perform a maximum likelihood fit to the combined p and p_T distributions of single and dilepton samples. The second error includes an uncertainty of ±0.0124 due to models and branching ratios.

$R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$ Γ_{12}/Γ_8

OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

The Standard Model predicts R_b=0.21581 for m_t=174.3 GeV and M_H=150 GeV.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.21629±0.00066 OUR FIT				
0.21594±0.00094±0.00075	[1] ABE	05F	SLD	$E^{ee}_{\rm cm}$=91.28 GeV
0.2174 ±0.0015 ±0.0028	[2] ACCIARRI	00	L3	$E^{ee}_{\rm cm}$= 89–93 GeV
0.2178 ±0.0011 ±0.0013	[3] ABBIENDI	99B	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
0.21634±0.00067±0.00060	[4] ABREU	99B	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.2159 ±0.0009 ±0.0011	[5] BARATE	97F	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.2145 ±0.0089 ±0.0067	[6] ABREU	95D	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.219 ±0.006 ±0.005	[7] BUSKULIC	94G	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
0.251 ±0.049 ±0.030	[8] JACOBSEN	91	MRK2	$E^{ee}_{\rm cm}$= 91 GeV

[1] ABE 05F use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $b\overline{b}$ events using a double tag method. The single b–tag is obtained with a neural network trained to perform flavor discrimination using as input several signatures (corrected secondary vertex mass, vertex decay length, multiplicity and total momentum of the hemisphere; the key tag is obtained requiring the secondary vertex corrected mass to be above the D–meson mass). ABE 05F obtain R_b =0.21604 ± 0.00098 ± 0.00074 where the systematic error includes an uncertainty of ±0.00012 due to the uncertainty on

R_c. The value reported here is obtained properly combining with ABE 98D. The quoted systematic error includes an uncertainty of ±0.00012 due to the uncertainty on R_c.

[2] ACCIARRI 00 obtain this result using a double-tagging technique, with a high p_T lepton tag and an impact parameter tag in opposite hemispheres.

[3] ABBIENDI 99B tag $Z \to b\overline{b}$ decays using leptons and/or separated decay vertices. The b-tagging efficiency is measured directly from the data using a double-tagging technique.

[4] ABREU 99B obtain this result combining in a multivariate analysis several tagging methods (impact parameter and secondary vertex reconstruction, complemented by event shape variables). For R_c different from its Standard Model value of 0.172, R_b varies as $-0.024\times(R_c-0.172)$.

[5] BARATE 97F combine the lifetime-mass hemisphere tag (BARATE 97E) with event shape information and lepton tag to identify $Z \to b\overline{b}$ candidates. They further use c- and uds-selection tags to identify the background. For R_c different from its Standard Model value of 0.172, R_b varies as $-0.019\times(R_c - 0.172)$.

[6] ABREU 95D perform a maximum likelihood fit to the combined p and p_T distributions of single and dilepton samples. The second error includes an uncertainty of ±0.0023 due to models and branching ratios.

[7] BUSKULIC 94G perform a simultaneous fit to the p and p_T spectra of both single and dilepton events.

[8] JACOBSEN 91 tagged $b\overline{b}$ events by requiring coincidence of ≥ 3 tracks with significant impact parameters using vertex detector. Systematic error includes lifetime and decay uncertainties (±0.014).

$\Gamma(b\overline{b}b\overline{b})/\Gamma(\text{hadrons})$ Γ_{13}/Γ_8

VALUE (units 10^{-4})	*DOCUMENT ID*		*TECN*	*COMMENT*
5.2±1.9 OUR AVERAGE				
3.6±1.7±2.7	[1] ABBIENDI	01G	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
6.0±1.9±1.4	[2] ABREU	99U	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABBIENDI 01G use a sample of four-jet events from hadronic Z decays. To enhance the $b\overline{b}b\overline{b}$ signal, at least three of the four jets are required to have a significantly detached secondary vertex.

[2] ABREU 99U force hadronic Z decays into 3 jets to use all the available phase space and require a b tag for every jet. This decay mode includes primary and secondary 4b production, *e.g*, from gluon splitting to $b\overline{b}$.

$\Gamma(ggg)/\Gamma(\text{hadrons})$ Γ_{14}/Γ_8

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.6 \times 10^{-2}$	95	[1] ABREU	96S	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] This branching ratio is slightly dependent on the jet-finder algorithm. The value we quote is obtained using the JADE algorithm, while using the DURHAM algorithm ABREU 96S obtain an upper limit of 1.5×10^{-2}.

$\Gamma(\pi^0\gamma)/\Gamma_{\rm total}$ Γ_{15}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<2.01 \times 10^{-5}$	95	AALTONEN	14E	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
$<5.2 \times 10^{-5}$	95	[1] ACCIARRI	95G	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$<5.5 \times 10^{-5}$	95	ABREU	94B	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$<2.1 \times 10^{-4}$	95	DECAMP	92	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
$<1.4 \times 10^{-4}$	95	AKRAWY	91F	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ACCIARRI 95G.

$\Gamma(\eta\gamma)/\Gamma_{\text{total}}$ Γ_{16}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<7.6 \times 10^{-5}$	95	ACCIARRI	95G	L3	E^{ee}_{cm}= 88–94 GeV
$<8.0 \times 10^{-5}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$\mathbf{<5.1 \times 10^{-5}}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV
$<2.0 \times 10^{-4}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\rho^0\gamma)/\Gamma_{\text{total}}$ Γ_{17}/Γ

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<2.5 \times 10^{-5}}$	95	12.5k	[1] AABOUD	18AU	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV

[1] AABOUD 18AU search for the $Z \to \rho\gamma$ decay mode where the ρ is identified through its decay $\rho \to \pi^+\pi^-$. In the data corresponding to 32.3 fb^{-1}, 12,583 events are selected for 635 $<$ m($\pi^+\pi^-$) $<$ 915 MeV.

$\Gamma(\omega\gamma)/\Gamma_{\text{total}}$ Γ_{18}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<6.5 \times 10^{-4}}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\eta'(958)\gamma)/\Gamma_{\text{total}}$ Γ_{19}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<4.2 \times 10^{-5}}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\phi\gamma)/\Gamma_{\text{total}}$ Γ_{20}/Γ

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<9 \times 10^{-7}}$	95	3.3k	[1] AABOUD	18AU	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •						
$<8.3 \times 10^{-6}$	95	1.0k	[2] AABOUD	16K	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV

[1] AABOUD 18AU search for the $Z \to \phi\gamma$ decay mode where the ϕ is identified through its decay $\phi \to K^+K^-$. In the data corresponding to 32.3 fb^{-1}, 3,364 events are selected for 1012 $<$ m(K^+K^-) $<$ 1028 MeV.

[2] AABOUD 16K search for the $Z \to \phi\gamma$ decay mode where the ϕ is identified through its decay into K^+K^-. In the data corresponding to a total luminosity of 2.7 fb^{-1}, 1065 events are selected and their $K^+K^-\gamma$ invariant mass spectrum is analyzed.

$\Gamma(\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{21}/Γ

This decay would violate the Landau-Yang theorem.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<1.46 \times 10^{-5}}$	95	AALTONEN	14E	CDF	$E^{p\overline{p}}_{\text{cm}} = 1.96$ TeV
$<5.2 \times 10^{-5}$	95	[1] ACCIARRI	95G	L3	E^{ee}_{cm}= 88–94 GeV
$<5.5 \times 10^{-5}$	95	ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<1.4 \times 10^{-4}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] This limit is for both decay modes $Z \to \pi^0\gamma/\gamma\gamma$ which are indistinguishable in ACCIARRI 95G.

$\Gamma(\pi^0\pi^0)/\Gamma_{\text{total}}$ Γ_{22}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$\mathbf{<1.52 \times 10^{-5}}$	95	AALTONEN	14E	CDF	$E^{p\overline{p}}_{\text{cm}} = 1.96$ TeV

$\Gamma(\gamma\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{23}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<2.2 \times 10^{-6}$	95	AAD	16L	ATLS	$E^{pp}_{\text{cm}} = 8$ TeV

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

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.0 \times 10^{-5}$	95	[1] ACCIARRI	95C	L3	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-5}$	95	[1] ABREU	94B	DLPH	E^{ee}_{cm}= 88–94 GeV
$<6.6 \times 10^{-5}$	95	AKRAWY	91F	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] Limit derived in the context of composite Z model.

$\Gamma(\pi^{\pm} W^{\mp})/\Gamma_{\text{total}}$ Γ_{24}/Γ

The value is for the sum of the charge states indicated.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<7 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\rho^{\pm} W^{\mp})/\Gamma_{\text{total}}$ Γ_{25}/Γ

The value is for the sum of the charge states indicated.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<8.3 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(J/\psi(1S)\text{X})/\Gamma_{\text{total}}$ Γ_{26}/Γ

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$3.51^{+0.23}_{-0.25}$ OUR AVERAGE Error includes scale factor of 1.1.					
$3.21 \pm 0.21^{+0.19}_{-0.28}$	553	[1] ACCIARRI	99F	L3	E^{ee}_{cm}= 88–94 GeV
$3.9 \pm 0.2 \pm 0.3$	511	[2] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
$3.73 \pm 0.39 \pm 0.36$	153	[3] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV

[1] ACCIARRI 99F combine $\mu^+ \mu^-$ and $e^+ e^-$ $J/\psi(1S)$ decay channels. The branching ratio for prompt $J/\psi(1S)$ production is measured to be $(2.1 \pm 0.6 \pm 0.4^{+0.4}_{-0.2}(\text{theor.})) \times 10^{-4}$.

[2] ALEXANDER 96B identify $J/\psi(1S)$ from the decays into lepton pairs. (4.8 ± 2.4)% of this branching ratio is due to prompt $J/\psi(1S)$ production (ALEXANDER 96N).

[3] Combining $\mu^+ \mu^-$ and $e^+ e^-$ channels and taking into account the common systematic errors. $(7.7^{+6.3}_{-5.4})$% of this branching ratio is due to prompt $J/\psi(1S)$ production.

$\Gamma(J/\psi(1S)\gamma)/\Gamma_{\text{total}}$ Γ_{27}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.4 \times 10^{-6}$	95	[1] SIRUNYAN	19AJ	CMS	$E^{pp}_{\text{cm}} = 13$ TeV

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

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<2.3 \times 10^{-6}$	95	[2] AABOUD	18BL	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
$<2.6 \times 10^{-6}$	95	[3] AAD	15I	ATLS	$E^{pp}_{\text{cm}} = 8$ TeV

[1] SIRUNYAN 19AJ study $Z \rightarrow J/\psi\gamma$ with $J/\psi \rightarrow \mu^+ \mu^-$. Candidate events are selected by requiring a pair of oppositely charged muons and a well isolated photon. The leading (subleading) muon is require to have a transverse momentum larger than 20 GeV (4 GeV), while the photon must have a transverse energy larger than 33 GeV. Requiring the invariant mass of the $\mu\mu$ ($\mu\mu\gamma$) system in the range 3.0 to 3.2 (81 to 101) GeV, selects 183 data events which is consistent with the expected background. The 95% C.L. limit on the Z branching fraction is obtained assuming the J/ψ to be unpolarized.

[2] AABOUD 18BL study $Z \to J/\psi\gamma$ in 13 TeV pp interactions. Two triggers were used: isolated photon of $p_T > 35(25)$ GeV and a muon with $p_T > 18(24)$ GeV. The J/ψ is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the J/ψ in the plane transverse to the beam direction is $> \pi/2$. The number of observed/expected background events is $92/89 \pm 6$ in the dimuon mass range 2.9–3.3 GeV leading to the quoted 95% C.L. limit.

[3] AAD 15I use events with the highest p_T muon in the pair required to have $p_T > 20$ GeV, the dimuon mass required to be within 0.2 GeV of the $J/\psi(1S)$ mass and it's transverse momentum required to be $>$ 36 GeV. The photon is also required to have it's $p_T > 36$ GeV.

$\Gamma(\psi(2S)X)/\Gamma_{\text{total}}$ Γ_{28}/Γ

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
1.60±0.29 OUR AVERAGE					
1.6 ±0.5 ±0.3	39	[1] ACCIARRI	97J	L3	E^{ee}_{cm}= 88–94 GeV
1.6 ±0.3 ±0.2	46.9	[2] ALEXANDER	96B	OPAL	E^{ee}_{cm}= 88–94 GeV
1.60±0.73±0.33	5.4	[3] ABREU	94P	DLPH	E^{ee}_{cm}= 88–94 GeV

[1] ACCIARRI 97J measure this branching ratio via the decay channel $\psi(2S) \to \ell^+\ell^-$ ($\ell = \mu$, e).

[2] ALEXANDER 96B measure this branching ratio via the decay channel $\psi(2S) \to J/\psi\pi^+\pi^-$, with $J/\psi \to \ell^+\ell^-$.

[3] ABREU 94P measure this branching ratio via decay channel $\psi(2S) \to J/\psi\pi^+\pi^-$, with $J/\psi \to \mu^+\mu^-$.

$\Gamma(\psi(2S)\gamma)/\Gamma_{\text{total}}$ Γ_{29}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<4.5 \times 10^{-6}$	95	[1] AABOUD	18BL	ATLS	E^{pp}_{cm} = 13 TeV

[1] AABOUD 18BL study $Z \to \psi(2S)\gamma$ in 13 TeV pp interactions. Two triggers were used: isolated photon of $p_T > 35(25)$ GeV and a muon with $p_T > 18(24)$ GeV. The $\psi(2S)$ is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the $\psi(2S)$ in the plane transverse to the beam direction is $> \pi/2$. The number of observed/expected background events is $43/42 \pm 5$ in the dimuon mass range 3.5–3.9 GeV leading to the quoted 95% C.L. limit.

$\Gamma(J/\psi(1S)\ell^+\ell^-)/\Gamma(\mu^+\mu^-\mu^+\mu^-)$ Γ_{30}/Γ_5

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.67±0.18±0.05	[1] SIRUNYAN	18DZ	CMS	pp at 13 TeV

[1] SIRUNYAN 18DZ observe the decay $Z \to \Psi\ell^+\ell^-$ in pp collisions at $\sqrt{s} = 13$ TeV, where Ψ includes J/ψ as well as $\psi(2S) \to J/\psi X$, and $\ell^+\ell^-$ represents an electron or muon pair while the J/ψ is detected via its $\mu^+\mu^-$ decay channel. To reduce systematic errors they determine the ratio of the branching fraction of this decay to that of $Z \to \mu^+\mu^-\mu^+\mu^-$ within phase-space cuts imposed on lepton transverse momentum and pseudo rapidity, dilepton invariant mass, and J/ψ transverse momentum. The number of selected $\Psi\mu^+\mu^-$ (Ψe^+e^-) candidate events is 29 (18). Analyzing the $\mu^+\mu^-$ and $\mu^+\mu^-\ell^+\ell^-$ invariant mass distributions, a yield of 13.0 ± 3.9 (11.2 ± 3.4) events for the $\Psi\mu^+\mu^-$ (Ψe^+e^-) mode is obtained. The ratio of the branching fractions is determined as 0.67 ± 0.18 ± 0.05 within the selected phase-space cuts. Assuming extrapolation to full phase space cancels in the ratio, and using their measured value of B($Z \to \mu^+\mu^-\mu^+\mu^-$) = $(1.20 \pm 0.08) \times 10^{-6}$, they estimate B($Z \to J/\psi\ell^+\ell^-$) = 8×10^{-7}.

$\Gamma(J/\psi(1S)\,J/\psi(1S))/\Gamma_{\text{total}}$ $\qquad\Gamma_{31}/\Gamma$

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
$<2.2 \times 10^{-6}$	95	189	[1] SIRUNYAN 19BR	CMS	$E^{pp}_{\text{cm}} = 13$ TeV

[1] SIRUNYAN 19BR search for Z decays to a pair of J/ψ mesons in the channel $J/\psi \rightarrow \mu^+\mu^-$. The invariant masses of the higher/lower-p_T J/ψ candidates have to be within 0.1/0.15 GeV of the nominal J/ψ mass. A total of 189 events are selected in the 40–140 GeV 4-muon invariant mass range. An un-binned extended maximum likelihood fit leads to the 95% C.L. upper limit, obtained assuming the J/ψ mesons to be unpolarised.

$\Gamma(\chi_{c1}(1P)X)/\Gamma_{\text{total}}$ $\qquad\Gamma_{32}/\Gamma$

VALUE (units 10^{-3})	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
2.9±0.7 OUR AVERAGE				
$2.7 \pm 0.6 \pm 0.5$	33	[1] ACCIARRI 97J	L3	$E^{ee}_{\text{cm}} = 88$–94 GeV
$5.0 \pm 2.1^{+1.5}_{-0.9}$	6.4	[2] ABREU 94P	DLPH	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ACCIARRI 97J measure this branching ratio via the decay channel $\chi_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \ell^+\ell^-$ ($\ell = \mu$, e). The $M(\ell^+\ell^-\gamma)$–$M(\ell^+\ell^-)$ mass difference spectrum is fitted with two gaussian shapes for χ_{c1} and χ_{c2}.

[2] This branching ratio is measured via the decay channel $\chi_{c1} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \mu^+\mu^-$.

$\Gamma(\chi_{c2}(1P)X)/\Gamma_{\text{total}}$ $\qquad\Gamma_{33}/\Gamma$

VALUE	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$<3.2 \times 10^{-3}$	90	[1] ACCIARRI 97J	L3	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ACCIARRI 97J derive this limit via the decay channel $\chi_{c2} \rightarrow J/\psi + \gamma$, with $J/\psi \rightarrow \ell^+\ell^-$ ($\ell = \mu$, e). The $M(\ell^+\ell^-\gamma)$–$M(\ell^+\ell^-)$ mass difference spectrum is fitted with two gaussian shapes for χ_{c1} and χ_{c2}.

$\Gamma(\Upsilon(1S)X + \Upsilon(2S)X + \Upsilon(3S)X)/\Gamma_{\text{total}}$ $\qquad\Gamma_{34}/\Gamma = (\Gamma_{35}+\Gamma_{37}+\Gamma_{39})/\Gamma$

VALUE (units 10^{-4})	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
$1.0 \pm 0.4 \pm 0.22$	6.4	[1] ALEXANDER 96F	OPAL	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ALEXANDER 96F identify the Υ (which refers to any of the three lowest bound states) through its decay into e^+e^- and $\mu^+\mu^-$. The systematic error includes an uncertainty of ± 0.2 due to the production mechanism.

$\Gamma(\Upsilon(1S)X)/\Gamma_{\text{total}}$ $\qquad\Gamma_{35}/\Gamma$

VALUE	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$<4.4 \times 10^{-5}$	95	[1] ACCIARRI 99F	L3	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ACCIARRI 99F search for $\Upsilon(1S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(1S)\gamma)/\Gamma_{\text{total}}$ $\qquad\Gamma_{36}/\Gamma$

VALUE	*CL%*	*DOCUMENT ID*	*TECN*	*COMMENT*
$<2.8 \times 10^{-6}$	95	[1] AABOUD 18BL	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<3.4 \times 10^{-6}$	95	[2] AAD 15I	ATLS	$E^{pp}_{\text{cm}} = 8$ TeV

[1] AABOUD 18BL study $Z \rightarrow \Upsilon(1S)\gamma$ in 13 TeV pp interactions. Two triggers were used: isolated photon of $p_T > 35(25)$ GeV and a muon with $p_T > 18(24)$ GeV. The $\Upsilon(1S)$

is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the $\Upsilon(1S)$ in the plane transverse to the beam direction is $> \pi/2$. The number of observed/expected background events is 115/126 ± 8 in the dimuon mass range 9.0–10.0 GeV leading to the quoted 95% C.L. limit.

[2] AAD 15I use events with the highest p_T muon in the pair required to have $p_T > 20$ GeV, the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be $>$ 36 GeV. The photon is also required to have it's $p_T > 36$ GeV.

$\Gamma(\Upsilon(2S)X)/\Gamma_{\text{total}}$ Γ_{37}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
<13.9 × 10⁻⁵	95	[1] ACCIARRI	97R	L3	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ACCIARRI 97R search for $\Upsilon(2S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(2S)\gamma)/\Gamma_{\text{total}}$ Γ_{38}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.7 \times 10^{-6}$	95	[1] AABOUD	18BL	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<6.5 \times 10^{-6}$	95	[2] AAD	15I	ATLS	$E^{pp}_{\text{cm}} = 8$ TeV

[1] AABOUD 18BL study $Z \to \Upsilon(2S)\gamma$ in 13 TeV pp interactions. Two triggers were used: isolated photon of $p_T > 35(25)$ GeV and a muon with $p_T > 18(24)$ GeV. The $\Upsilon(2S)$ is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the $\Upsilon(2S)$ in the plane transverse to the beam direction is $> \pi/2$. The number of observed/expected background events is 106/121 ± 8 in the dimuon mass range 9.5–10.5 GeV leading to the quoted 95% C.L. limit.

[2] AAD 15I use events with the highest p_T muon in the pair required to have $p_T > 20$ GeV, the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be $>$ 36 GeV. The photon is also required to have it's $p_T > 36$ GeV.

$\Gamma(\Upsilon(3S)X)/\Gamma_{\text{total}}$ Γ_{39}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<9.4 \times 10^{-5}$	95	[1] ACCIARRI	97R	L3	$E^{ee}_{\text{cm}} = 88$–94 GeV

[1] ACCIARRI 97R search for $\Upsilon(3S)$ through its decay into $\ell^+\ell^-$ ($\ell = e$ or μ).

$\Gamma(\Upsilon(3S)\gamma)/\Gamma_{\text{total}}$ Γ_{40}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<4.8 \times 10^{-6}$	95	[1] AABOUD	18BL	ATLS	$E^{pp}_{\text{cm}} = 13$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<5.4 \times 10^{-6}$	95	[2] AAD	15I	ATLS	$E^{pp}_{\text{cm}} = 8$ TeV

[1] AABOUD 18BL study $Z \to \Upsilon(3S)\gamma$ in 13 TeV pp interactions. Two triggers were used: isolated photon of $p_T > 35(25)$ GeV and a muon with $p_T > 18(24)$ GeV. The $\Upsilon(3S)$ is detected via its dimuon decay and it is required that the azimuthal angle between the photon and the $\Upsilon(3S)$ in the plane transverse to the beam direction is $> \pi/2$. The number of observed/expected background events is 112/113 ± 8 in the dimuon mass range 10.0–11.0 GeV leading to the quoted 95% C.L. limit.

[2] AAD 15I use events with the highest p_T muon in the pair required to have $p_T > 20$ GeV, the dimuon mass required to be in the range 8–12 GeV and it's transverse momentum required to be $>$ 36 GeV. The photon is also required to have it's $p_T > 36$ GeV.

$\Gamma(\Upsilon(1,2,3S)\,\Upsilon(1,2,3S))/\Gamma_{\text{total}}$ Γ_{41}/Γ

VALUE	*CL%*	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.5 \times 10^{-6}$	95	106	[1] SIRUNYAN	19BR	CMS	$E^{pp}_{\text{cm}} = 13$ TeV

[1] SIRUNYAN 19BR search for Z decays to a pair of Υ mesons in the channel $\Upsilon \rightarrow \mu^+ \mu^-$. The invariant mass of the Υ candidates has to be in the range of 8.5 to 11 GeV. A total of 106 events are selected in the 20–140 GeV 4-muon invariant mass range. An un-binned extended maximum likelihood fit leads to the 95% C.L. upper limit, obtained assuming the Υ mesons to be unpolarised.

$\Gamma((D^0/\overline{D}^0)\,X)/\Gamma(\text{hadrons})$ Γ_{42}/Γ_8

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.296±0.019±0.021	369	[1] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[1] The $(D^0/\overline{D}^0)$ states in ABREU 93I are detected by the $K\pi$ decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^{\pm}X)/\Gamma(\text{hadrons})$ Γ_{43}/Γ_8

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.174±0.016±0.018	539	[1] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV

[1] The $D^{\pm}$ states in ABREU 93I are detected by the $K\pi\pi$ decay mode. This is a corrected result (see the erratum of ABREU 93I).

$\Gamma(D^*(2010)^{\pm}X)/\Gamma(\text{hadrons})$ Γ_{44}/Γ_8

The value is for the sum of the charge states indicated.

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.163±0.019 OUR AVERAGE	Error includes scale factor of 1.3.				
0.155±0.010±0.013	358	[1] ABREU	93I	DLPH	E^{ee}_{cm}= 88–94 GeV
0.21 ±0.04	362	[2] DECAMP	91J	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] $D^*(2010)^{\pm}$ in ABREU 93I are reconstructed from $D^0\pi^{\pm}$, with $D^0 \rightarrow K^-\pi^+$. The new CLEO II measurement of B($D^{*\pm} \rightarrow D^0\pi^{\pm}$) = (68.1 ± 1.6) % is used. This is a corrected result (see the erratum of ABREU 93I).

[2] DECAMP 91J report B($D^*(2010)^+ \rightarrow D^0\pi^+$) B($D^0 \rightarrow K^-\pi^+$) Γ($D^*(2010)^{\pm}$X) / Γ(hadrons) = (5.11 ± 0.34) × 10^{-3}. They obtained the above number assuming B($D^0 \rightarrow K^-\pi^+$) = (3.62±0.34±0.44)% and B($D^*(2010)^+ \rightarrow D^0\pi^+$) = (55±4)%. We have rescaled their original result of 0.26 ± 0.05 taking into account the new CLEO II branching ratio B($D^*(2010)^+ \rightarrow D^0\pi^+$) = (68.1 ± 1.6)%.

$\Gamma(D_{s1}(2536)^{\pm}X)/\Gamma(\text{hadrons})$ Γ_{45}/Γ_8

$D_{s1}(2536)^{\pm}$ is an expected orbitally-excited state of the D_s meson.

VALUE (%)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.52±0.09±0.06	92	[1] HEISTER	02B	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] HEISTER 02B reconstruct this meson in the decay modes $D_{s1}(2536)^{\pm} \rightarrow D^{*\pm}K^0$ and $D_{s1}(2536)^{\pm} \rightarrow D^{*0}K^{\pm}$. The quoted branching ratio assumes that the decay width of the $D_{s1}(2536)$ is saturated by the two measured decay modes.

$\Gamma(D_{sJ}(2573)^{\pm}X)/\Gamma(\text{hadrons})$ Γ_{46}/Γ_8

$D_{sJ}(2573)^{\pm}$ is an expected orbitally-excited state of the D_s meson.

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
$0.83\pm0.29^{+0.07}_{-0.13}$	64	[1] HEISTER	02B	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] HEISTER 02B reconstruct this meson in the decay mode $D^*_{s2}(2573)^{\pm} \rightarrow D^0 K^{\pm}$. The quoted branching ratio assumes that the detected decay mode represents 45% of the full decay width.

$\Gamma(D^{*\prime}(2629)^{\pm}X)/\Gamma(\text{hadrons})$ Γ_{47}/Γ_8

$D^{*\prime}(2629)^{\pm}$ is a predicted radial excitation of the $D^*(2010)^{\pm}$ meson.

VALUE	DOCUMENT ID		TECN	COMMENT
searched for	[1] ABBIENDI	01N	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] ABBIENDI 01N searched for the decay mode $D^{*\prime}(2629)^{\pm} \rightarrow D^{*\pm}\pi^+\pi^-$ with $D^{*+} \rightarrow D^0\pi^+$, and $D^0 \rightarrow K^-\pi^+$. They quote a 95% CL limit for $Z \rightarrow D^{*\prime}(2629)^{\pm} \times \text{B}(D^{*\prime}(2629)^+ \rightarrow D^{*+}\pi^+\pi^-) < 3.1\times10^{-3}$.

$\Gamma(B^*X)/[\Gamma(BX)+\Gamma(B^*X)]$ $\Gamma_{49}/(\Gamma_{48}+\Gamma_{49})$

As the experiments assume different values of the *b*-baryon contribution, our average should be taken with caution.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.75 ±0.04 OUR AVERAGE					
0.760±0.036±0.083		[1] ACKERSTAFF	97M	OPAL	E^{ee}_{cm}= 88–94 GeV
0.771±0.026±0.070		[2] BUSKULIC	96D	ALEP	E^{ee}_{cm}= 88–94 GeV
0.72 ±0.03 ±0.06		[3] ABREU	95R	DLPH	E^{ee}_{cm}= 88–94 GeV
0.76 ±0.08 ±0.06	1378	[4] ACCIARRI	95B	L3	E^{ee}_{cm}= 88–94 GeV

[1] ACKERSTAFF 97M use an inclusive *B* reconstruction method and assume a (13.2 ± 4.1)% *b*-baryon contribution. The value refers to a *b*-flavored meson mixture of B_u, B_d, and B_s.

[2] BUSKULIC 96D use an inclusive reconstruction of *B* hadrons and assume a (12.2 ± 4.3)% *b*-baryon contribution. The value refers to a *b*-flavored mixture of B_u, B_d, and B_s.

[3] ABREU 95R use an inclusive *B*-reconstruction method and assume a (10 ± 4)% *b*-baryon contribution. The value refers to a *b*-flavored meson mixture of B_u, B_d, and B_s.

[4] ACCIARRI 95B assume a 9.4% *b*-baryon contribution. The value refers to a *b*-flavored mixture of B_u, B_d, and B_s.

$\Gamma(B^+X)/\Gamma(\text{hadrons})$ Γ_{50}/Γ_8

"OUR EVALUATION" is obtained using our current values for f($\overline{b} \rightarrow B^+$) and R_b = $\Gamma(b\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(B^+ X)/\Gamma(\text{hadrons})$ = R_b × f($\overline{b} \rightarrow B^+$). The decay fraction f($\overline{b} \rightarrow B^+$) was provided by the Heavy Flavor Averaging Group (HFLAV, https://hflav.web.cern.ch/).

VALUE	DOCUMENT ID		TECN	COMMENT
0.0869±0.0019 OUR EVALUATION				
0.0887±0.0030	[1] ABDALLAH	03K	DLPH	E^{ee}_{cm} = 88–94 GeV

[1] ABDALLAH 03K measure the production fraction of B^+ mesons in hadronic *Z* decays f(B^+) = (40.99 ± 0.82 ± 1.11)%. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(\overline{b}b)/\Gamma(\text{hadrons})$.

$\Gamma(B_s^0 X)/\Gamma(\text{hadrons})$ Γ_{51}/Γ_8

"OUR EVALUATION" is obtained using our current values for $f(\overline{b} \to B_s^0)$ and $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(B_s^0)/\Gamma(\text{hadrons}) = R_b \times f(\overline{b} \to B_s^0)$. The decay fraction $f(\overline{b} \to B_s^0)$ was provided by the Heavy Flavor Averaging Group (HFLAV, https://hflav.web.cern.ch/).

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.0227±0.0019 OUR EVALUATION				
seen	[1] ABREU	92M	DLPH	E^{ee}_{cm}= 88–94 GeV
seen	[2] ACTON	92N	OPAL	E^{ee}_{cm}= 88–94 GeV
seen	[3] BUSKULIC	92E	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] ABREU 92M reported value is $\Gamma(B_s^0 X) * B(B_s^0 \to D_s \mu \nu_\mu X) * B(D_s \to \phi\pi)/\Gamma(\text{hadrons}) = (18 \pm 8) \times 10^{-5}$.

[2] ACTON 92N find evidence for B_s^0 production using D_s-ℓ correlations, with $D_s^+ \to \phi\pi^+$ and $K^*(892) K^+$. Assuming R_b from the Standard Model and averaging over the e and μ channels, authors measure the product branching fraction to be $f(\overline{b} \to B_s^0) \times B(B_s^0 \to D_s^- \ell^+ \nu_\ell X) \times B(D_s^- \to \phi\pi^-) = (3.9 \pm 1.1 \pm 0.8) \times 10^{-4}$.

[3] BUSKULIC 92E find evidence for B_s^0 production using D_s-ℓ correlations, with $D_s^+ \to \phi\pi^+$ and $K^*(892) K^+$. Using $B(D_s^+ \to \phi\pi^+) = (2.7 \pm 0.7)\%$ and summing up the e and μ channels, the weighted average product branching fraction is measured to be $B(\overline{b} \to B_s^0) \times B(B_s^0 \to D_s^- \ell^+ \nu_\ell X) = 0.040 \pm 0.011^{+0.010}_{-0.012}$.

$\Gamma(B_c^+ X)/\Gamma(\text{hadrons})$ Γ_{52}/Γ_8

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
searched for	[1] ACKERSTAFF	98O	OPAL	E^{ee}_{cm}= 88–94 GeV
searched for	[2] ABREU	97E	DLPH	E^{ee}_{cm}= 88–94 GeV
searched for	[3] BARATE	97H	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] ACKERSTAFF 98O searched for the decay modes $B_c \to J/\psi\pi^+$, $J/\psi a_1^+$, and $J/\psi \ell^+ \nu_\ell$, with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the three decay modes is 2 (0.63 ± 0.2), 0 (1.10 ± 0.22), and 1 (0.82 ± 0.19) respectively. Interpreting the 2 $B_c \to J/\psi\pi^+$ candidates as signal, they report $\Gamma(B_c^+ X) \times B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) = (3.8^{+5.0}_{-2.4} \pm 0.5) \times 10^{-5}$. Interpreted as background, the 90% CL bounds are $\Gamma(B_c^+ X) * B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) < 1.06 \times 10^{-4}$, $\Gamma(B_c^+ X) * B(B_c \to J/\psi a_1^+)/\Gamma(\text{hadrons}) < 5.29 \times 10^{-4}$, $\Gamma(B_c^+ X) * B(B_c \to J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 6.96 \times 10^{-5}$.

[2] ABREU 97E searched for the decay modes $B_c \to J/\psi\pi^+$, $J/\psi \ell^+ \nu_\ell$, and $J/\psi(3\pi)^+$, with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the three decay modes is 1 (1.7), 0 (0.3), and 1 (2.3) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ X) * B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) < (1.05–0.84) \times 10^{-4}$, $\Gamma(B_c^+ X) * B(B_c \to J/\psi \ell \nu_\ell)/\Gamma(\text{hadrons}) < (5.8–5.0) \times 10^{-5}$, $\Gamma(B_c^+ X) * B(B_c \to J/\psi(3\pi)^+)/\Gamma(\text{hadrons}) < 1.75 \times 10^{-4}$, where the ranges are due to the predicted B_c lifetime (0.4–1.4) ps.

[3] BARATE 97H searched for the decay modes $B_c \to J/\psi\pi^+$ and $J/\psi \ell^+ \nu_\ell$ with $J/\psi \to \ell^+\ell^-$, $\ell = e,\mu$. The number of candidates (background) for the two decay modes is 0 (0.44) and 2 (0.81) respectively. They report the following 90% CL limits: $\Gamma(B_c^+ X) * B(B_c \to J/\psi\pi^+)/\Gamma(\text{hadrons}) < 3.6 \times 10^{-5}$ and $\Gamma(B_c^+ X) * B(B_c \to J/\psi \ell^+ \nu_\ell)/\Gamma(\text{hadrons}) < 5.2 \times 10^{-5}$.

$\Gamma(\Lambda_c^+ X)/\Gamma(\text{hadrons})$ Γ_{53}/Γ_8

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.022±0.005 OUR AVERAGE				
0.024±0.005±0.006	[1] ALEXANDER	96R	OPAL	$E^{ee}_{\rm cm}$ = 88–94 GeV
0.021±0.003±0.005	[2] BUSKULIC	96Y	ALEP	$E^{ee}_{\rm cm}$ = 88–94 GeV

[1] ALEXANDER 96R measure $R_b \times f(b \to \Lambda_c^+ X) \times B(\Lambda_c^+ \to pK^-\pi^+) = (0.122 \pm 0.023 \pm 0.010)\%$ in hadronic Z decays; the value quoted here is obtained using our best value $B(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$. The first error is the total experiment's error and the second error is the systematic error due to the branching fraction uncertainty.

[2] BUSKULIC 96Y obtain the production fraction of Λ_c^+ baryons in hadronic Z decays $f(b \to \Lambda_c^+ X) = 0.110 \pm 0.014 \pm 0.006$ using $B(\Lambda_c^+ \to pK^-\pi^+) = (4.4 \pm 0.6)\%$; we have rescaled using our best value $B(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$ obtaining $f(b \to \Lambda_c^+ X) = 0.097 \pm 0.013 \pm 0.025$ where the first error is their total experiment's error and the second error is the systematic error due to the branching fraction uncertainty. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$.

$\Gamma(\Xi_c^0 X)/\Gamma(\text{hadrons})$ Γ_{54}/Γ_8

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
seen	[1] ABDALLAH	05C	DLPH	$E^{ee}_{\rm cm}$ = 88–94 GeV

[1] ABDALLAH 05C searched for the charmed strange baryon Ξ_c^0 in the decay channel $\Xi_c^0 \to \Xi^-\pi^+$ ($\Xi^- \to \Lambda\pi^-$). The production rate is measured to be $f_{\Xi_c^0} \times B(\Xi_c^0 \to \Xi^-\pi^+) = (4.7 \pm 1.4 \pm 1.1) \times 10^{-4}$ per hadronic Z decay.

$\Gamma(\Xi_b X)/\Gamma(\text{hadrons})$ Γ_{55}/Γ_8

Here Ξ_b is used as a notation for the strange b-baryon states Ξ_b^- and Ξ_b^0.

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
seen	[1] ABDALLAH	05C	DLPH	$E^{ee}_{\rm cm}$ = 88–94 GeV
seen	[2] BUSKULIC	96T	ALEP	$E^{ee}_{\rm cm}$ = 88–94 GeV
seen	[3] ABREU	95V	DLPH	$E^{ee}_{\rm cm}$ = 88–94 GeV

[1] ABDALLAH 05C searched for the beauty strange baryon Ξ_b in the inclusive semileptonic decay channel $\Xi_b \to \Xi^-\ell^-\overline{\nu}_\ell X$. Evidence for the Ξ_b production is seen from the observation of $\Xi^\mp$ production accompanied by a lepton of the same sign. From the excess of "right-sign" pairs $\Xi^\mp\ell^\mp$ compared to "wrong-sign" pairs $\Xi^\mp\ell^\pm$ the production rate is measured to be $B(b \to \Xi_b) \times B(\Xi_b \to \Xi^-\ell^- X) = (3.0 \pm 1.0 \pm 0.3) \times 10^{-4}$ per lepton species, averaged over electrons and muons.

[2] BUSKULIC 96T investigate Ξ-lepton correlations and find a significant excess of "right–sign" pairs $\Xi^\mp\ell^\mp$ compared to "wrong–sign" pairs $\Xi^\mp\ell^\pm$. This excess is interpreted as evidence for Ξ_b semileptonic decay. The measured product branching ratio is $B(b \to \Xi_b) \times B(\Xi_b \to X_c X \ell^-\overline{\nu}_\ell) \times B(X_c \to \Xi^- X') = (5.4 \pm 1.1 \pm 0.8) \times 10^{-4}$ per lepton species, averaged over electrons and muons, with X_c a charmed baryon.

[3] ABREU 95V observe an excess of "right-sign" pairs $\Xi^\mp\ell^\mp$ compared to "wrong-sign" pairs $\Xi^\mp\ell^\pm$ in jets: this excess is interpreted as evidence for the beauty strange baryon Ξ_b production, with $\Xi_b \to \Xi^-\ell^-\overline{\nu}_\ell X$. They find that the probability for this signal to

come from non b-baryon decays is less than 5×10^{-4} and that Λ_b decays can account for less than 10% of these events. The Ξ_b production rate is then measured to be $B(b \to \Xi_b) \times B(\Xi_b \to \Xi^- \ell^- X) = (5.9 \pm 2.1 \pm 1.0) \times 10^{-4}$ per lepton species, averaged over electrons and muons.

$\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons})$ Γ_{56}/Γ_8

"OUR EVALUATION" is obtained using our current values for f($b \to$ b-baryon) and $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$. We calculate $\Gamma(b\text{-baryon } X)/\Gamma(\text{hadrons}) = R_b \times f(b \to b\text{-baryon})$. The decay fraction f($b \to$ b-baryon) was provided by the Heavy Flavor Averaging Group (https://hflav.web.cern.ch/).

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.0197 ± 0.0032 OUR EVALUATION				
$0.0221 \pm 0.0015 \pm 0.0058$	[1] BARATE	98V	ALEP	E^{ee}_{cm}= 88–94 GeV

[1] BARATE 98V use the overall number of identified protons in b-hadron decays to measure f($b \to$ b-baryon) = $0.102 \pm 0.007 \pm 0.027$. They assume BR($b$-baryon$\to$ pX) = (58 ± 6)% and BR($B^0_s \to pX$) = (8.0 ± 4.0)%. The value quoted here is obtained multiplying this production fraction by our value of $R_b = \Gamma(b\overline{b})/\Gamma(\text{hadrons})$.

$\Gamma(\text{anomalous } \gamma + \text{hadrons})/\Gamma_{\text{total}}$ Γ_{57}/Γ

Limits on additional sources of prompt photons beyond expectations for final-state bremsstrahlung.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<3.2 \times 10^{-3}$	95	[1] AKRAWY	90J	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] AKRAWY 90J report $\Gamma(\gamma X) <$ 8.2 MeV at 95%CL. They assume a three-body $\gamma q \overline{q}$ distribution and use $E(\gamma) > 10$ GeV.

$\Gamma(e^+ e^- \gamma)/\Gamma_{\text{total}}$ Γ_{58}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<5.2 \times 10^{-4}$	95	[1] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[1] ACTON 91B looked for isolated photons with $E>2$% of beam energy ($>$ 0.9 GeV).

$\Gamma(\mu^+ \mu^- \gamma)/\Gamma_{\text{total}}$ Γ_{59}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<5.6 \times 10^{-4}$	95	[1] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[1] ACTON 91B looked for isolated photons with $E>2$% of beam energy ($>$ 0.9 GeV).

$\Gamma(\tau^+ \tau^- \gamma)/\Gamma_{\text{total}}$ Γ_{60}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<7.3 \times 10^{-4}$	95	[1] ACTON	91B	OPAL	E^{ee}_{cm}= 91.2 GeV

[1] ACTON 91B looked for isolated photons with $E>2$% of beam energy ($>$ 0.9 GeV).

$\Gamma(\ell^+ \ell^- \gamma\gamma)/\Gamma_{\text{total}}$ Γ_{61}/Γ

The value is the sum over $\ell = e, \mu, \tau$.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<6.8 \times 10^{-6}$	95	[1] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(q\overline{q}\gamma\gamma)/\Gamma_{\text{total}}$ Γ_{62}/Γ

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<5.5 \times 10^{-6}$	95	[1] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(\nu\overline{\nu}\gamma\gamma)/\Gamma_{total}$ Γ_{63}/Γ

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<3.1 \times 10^{-6}$	95	[1] ACTON	93E	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] For $m_{\gamma\gamma} = 60 \pm 5$ GeV.

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma_{total}$ Γ_{64}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<7.5 \times 10^{-7}$	95	AAD	14AU	ATLS	E^{pp}_{cm} = 8 TeV
$<2.5 \times 10^{-6}$	95	ABREU	97C	DLPH	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-6}$	95	AKERS	95W	OPAL	E^{ee}_{cm}= 88–94 GeV
$<0.6 \times 10^{-5}$	95	ADRIANI	93I	L3	E^{ee}_{cm}= 88–94 GeV
$<2.6 \times 10^{-5}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(e^{\pm}\mu^{\mp})/\Gamma(e^+e^-)$ Γ_{64}/Γ_1

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
<0.07	90	ALBAJAR	89	UA1	$E^{p\overline{p}}_{cm}$= 546,630 GeV

$\Gamma(e^{\pm}\tau^{\mp})/\Gamma_{total}$ Γ_{65}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<5.0 \times 10^{-6}$	95	AAD	21AV	ATLS	E^{pp}_{cm} = 13 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<8.1 \times 10^{-6}$	95	AAD	21AO	ATLS	E^{pp}_{cm} = 13 TeV
$<5.8 \times 10^{-5}$	95	AABOUD	18CN	ATLS	E^{pp}_{cm} = 13 TeV
$<2.2 \times 10^{-5}$	95	ABREU	97C	DLPH	E^{ee}_{cm}= 88–94 GeV
$<9.8 \times 10^{-6}$	95	AKERS	95W	OPAL	E^{ee}_{cm}= 88–94 GeV
$<1.3 \times 10^{-5}$	95	ADRIANI	93I	L3	E^{ee}_{cm}= 88–94 GeV
$<1.2 \times 10^{-4}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(\mu^{\pm}\tau^{\mp})/\Gamma_{total}$ Γ_{66}/Γ

Test of lepton family number conservation. The value is for the sum of the charge states indicated.

VALUE	CL%	DOCUMENT ID		TECN	COMMENT
$<6.5 \times 10^{-6}$	95	AAD	21AV	ATLS	E^{pp}_{cm} = 13 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$<9.5 \times 10^{-6}$	95	AAD	21AO	ATLS	E^{pp}_{cm} = 13 TeV
$<1.3 \times 10^{-5}$	95	AABOUD	18CN	ATLS	E^{pp}_{cm} = 8, 13 TeV
$<1.2 \times 10^{-5}$	95	ABREU	97C	DLPH	E^{ee}_{cm}= 88–94 GeV
$<1.7 \times 10^{-5}$	95	AKERS	95W	OPAL	E^{ee}_{cm}= 88–94 GeV
$<1.9 \times 10^{-5}$	95	ADRIANI	93I	L3	E^{ee}_{cm}= 88–94 GeV
$<1.0 \times 10^{-4}$	95	DECAMP	92	ALEP	E^{ee}_{cm}= 88–94 GeV

$\Gamma(pe)/\Gamma_{\text{total}}$ Γ_{67}/Γ

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.8 \times 10^{-6}$	95	[1] ABBIENDI	99I	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] ABBIENDI 99I give the 95%CL limit on the partial width $\Gamma(Z^0 \rightarrow pe) < 4.6$ KeV and we have transformed it into a branching ratio.

$\Gamma(p\mu)/\Gamma_{\text{total}}$ Γ_{68}/Γ

Test of baryon number and lepton number conservations. Charge conjugate states are implied.

VALUE	*CL%*	*DOCUMENT ID*		*TECN*	*COMMENT*
$<1.8 \times 10^{-6}$	95	[1] ABBIENDI	99I	OPAL	E^{ee}_{cm}= 88–94 GeV

[1] ABBIENDI 99I give the 95%CL limit on the partial width $\Gamma(Z^0 \rightarrow p\mu) < 4.4$ KeV and we have transformed it into a branching ratio.

AVERAGE PARTICLE MULTIPLICITIES IN HADRONIC *Z* DECAY

Summed over particle and antiparticle, when appropriate.

$\langle N_\gamma \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
20.97±0.02±1.15	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\pi^\pm} \rangle$

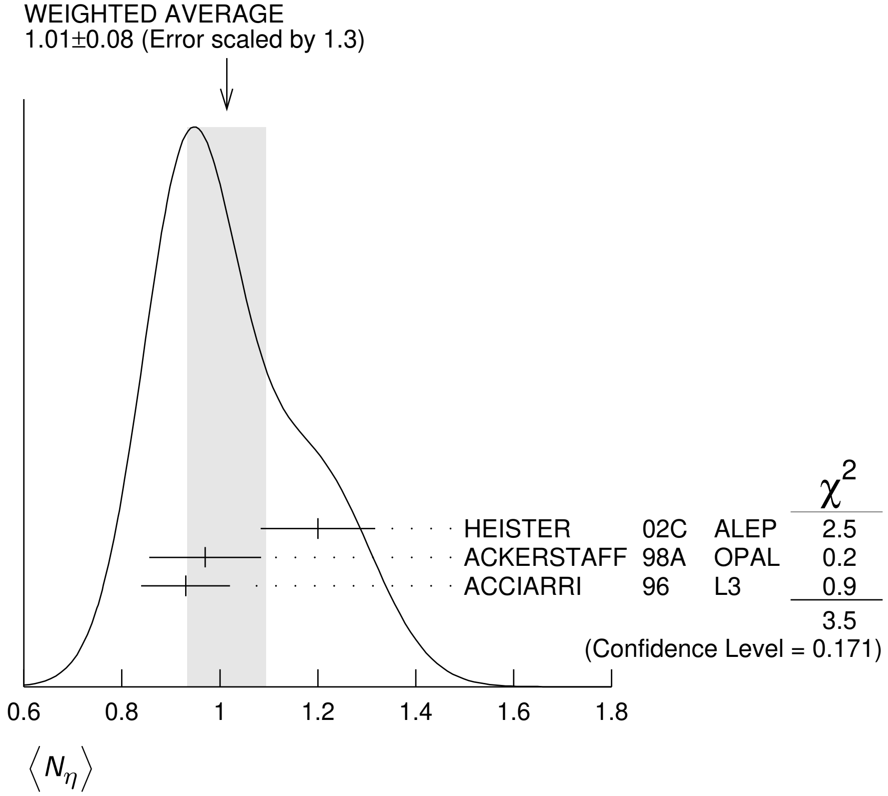
VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
17.03 ±0.16 OUR AVERAGE				
17.007±0.209	ABE	04C	SLD	E^{ee}_{cm}= 91.2 GeV
17.26 ±0.10 ±0.88	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
17.04 ±0.31	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
17.05 ±0.43	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{\pi^0} \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
9.76±0.26 OUR AVERAGE				
9.55±0.06±0.75	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
9.63±0.13±0.63	BARATE	97J	ALEP	E^{ee}_{cm}= 91.2 GeV
9.90±0.02±0.33	ACCIARRI	96	L3	E^{ee}_{cm}= 91.2 GeV
9.2 ±0.2 ±1.0	ADAM	96	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_\eta \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
1.01±0.08 OUR AVERAGE Error includes scale factor of 1.3. See the ideogram below.				
1.20±0.04±0.11	HEISTER	02C	ALEP	E^{ee}_{cm}= 91.2 GeV
0.97±0.03±0.11	ACKERSTAFF	98A	OPAL	E^{ee}_{cm}= 91.2 GeV
0.93±0.01±0.09	ACCIARRI	96	L3	E^{ee}_{cm}= 91.2 GeV



$\langle N_{\rho^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.57±0.15 OUR AVERAGE				
2.59±0.03±0.16	[1] BEDDALL	09		ALEPH archive, $E^{ee}_{\rm cm}$= 91.2 GeV
2.40±0.06±0.43	ACKERSTAFF	98A	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] BEDDALL 09 analyse 3.2 million hadronic Z decays as archived by ALEPH collaboration and report a value of 2.59 ± 0.03 ± 0.15 ± 0.04. The first error is statistical, the second systematic, and the third arises from extrapolation to full phase space. We combine the systematic errors in quadrature.

$\langle N_{\rho^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
1.24±0.10 OUR AVERAGE Error includes scale factor of 1.1.				
1.19±0.10	ABREU	99J	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
1.45±0.06±0.20	BUSKULIC	96H	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_\omega \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
1.02±0.06 OUR AVERAGE				
1.00±0.03±0.06	HEISTER	02C	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
1.04±0.04±0.14	ACKERSTAFF	98A	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
1.17±0.09±0.15	ACCIARRI	97D	L3	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\eta'} \rangle$

VALUE		*DOCUMENT ID*		*TECN*	*COMMENT*
0.17 ±0.05 OUR AVERAGE	Error includes scale factor of 2.4.				
0.14 ±0.01 ±0.02		ACKERSTAFF	98A	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.25 ±0.04		[1] ACCIARRI	97D	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.068±0.018±0.016		[2] BUSKULIC	92D	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ACCIARRI 97D obtain this value averaging over the two decay channels $\eta' \to \pi^+\pi^-\eta$ and $\eta' \to \rho^0\gamma$.

[2] BUSKULIC 92D obtain this value for x> 0.1.

$\langle N_{f_0(980)} \rangle$

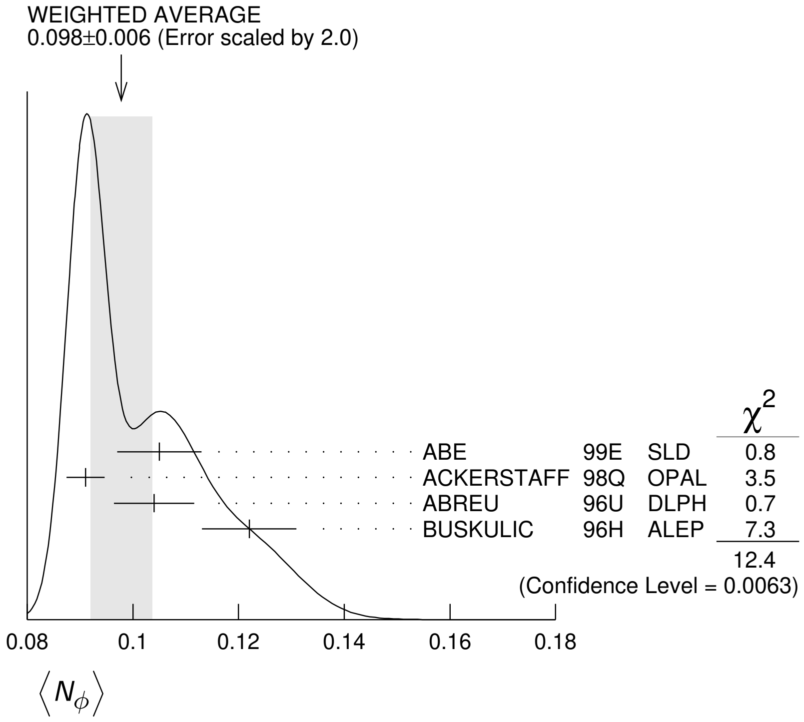
VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.147±0.011 OUR AVERAGE				
0.164±0.021	ABREU	99J	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.141±0.007±0.011	ACKERSTAFF	98Q	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{a_0(980)^\pm} \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.27±0.04±0.10	ACKERSTAFF	98A	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\phi} \rangle$

VALUE		*DOCUMENT ID*		*TECN*	*COMMENT*
0.098±0.006 OUR AVERAGE	Error includes scale factor of 2.0. See the ideogram below.				
0.105±0.008		ABE	99E	SLD	$E^{ee}_{\rm cm}$= 91.2 GeV
0.091±0.002±0.003		ACKERSTAFF	98Q	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.104±0.003±0.007		ABREU	96U	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.122±0.004±0.008		BUSKULIC	96H	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV



$\langle N_{f_2(1270)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.169±0.025 OUR AVERAGE	Error includes scale factor of 1.4.			
0.214±0.038	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV
0.155±0.011±0.018	ACKERSTAFF	98Q	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{f_1(1285)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.165±0.051	[1] ABDALLAH	03H	DLPH	E^{ee}_{cm}= 91.2 GeV

[1] ABDALLAH 03H assume a $K\overline{K}\pi$ branching ratio of (9.0 ± 0.4)%.

$\langle N_{f_1(1420)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.056±0.012	[1] ABDALLAH	03H	DLPH	E^{ee}_{cm}= 91.2 GeV

[1] ABDALLAH 03H assume a $K\overline{K}\pi$ branching ratio of 100%.

$\langle N_{f'_2(1525)} \rangle$

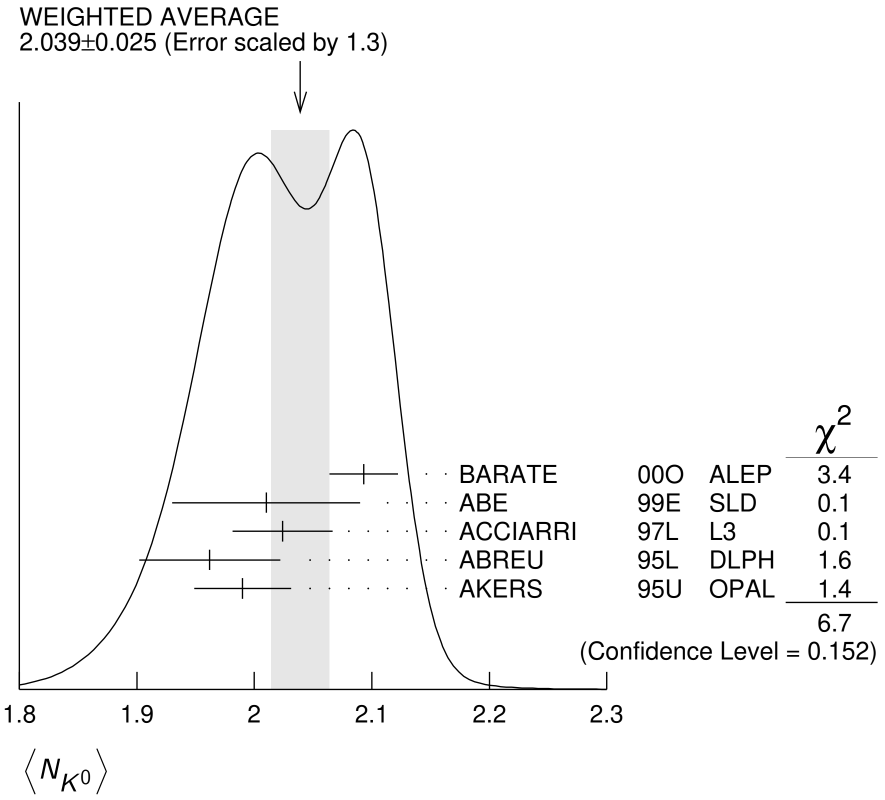
VALUE	DOCUMENT ID		TECN	COMMENT
0.012±0.006	ABREU	99J	DLPH	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.24 ±0.04 OUR AVERAGE				
2.203±0.071	ABE	04C	SLD	E^{ee}_{cm}= 91.2 GeV
2.21 ±0.05 ±0.05	ABREU	98L	DLPH	E^{ee}_{cm}= 91.2 GeV
2.26 ±0.12	BARATE	98V	ALEP	E^{ee}_{cm}= 91.2 GeV
2.42 ±0.13	AKERS	94P	OPAL	E^{ee}_{cm}= 91.2 GeV

$\langle N_{K^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
2.039±0.025 OUR AVERAGE	Error includes scale factor of 1.3. See the ideogram below.			
2.093±0.004±0.029	BARATE	00O	ALEP	E^{ee}_{cm}= 91.2 GeV
2.01 ±0.08	ABE	99E	SLD	E^{ee}_{cm}= 91.2 GeV
2.024±0.006±0.042	ACCIARRI	97L	L3	E^{ee}_{cm}= 91.2 GeV
1.962±0.022±0.056	ABREU	95L	DLPH	E^{ee}_{cm}= 91.2 GeV
1.99 ±0.01 ±0.04	AKERS	95U	OPAL	E^{ee}_{cm}= 91.2 GeV



$\langle N_{K^*(892)^\pm}\rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.72 ±0.05 OUR AVERAGE				
0.712±0.031±0.059	ABREU	95L	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.72 ±0.02 ±0.08	ACTON	93	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{K^*(892)^0}\rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.739±0.022 OUR AVERAGE				
0.707±0.041	ABE	99E	SLD	$E^{ee}_{\rm cm}$= 91.2 GeV
0.74 ±0.02 ±0.02	ACKERSTAFF	97S	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.77 ±0.02 ±0.07	ABREU	96U	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.83 ±0.01 ±0.09	BUSKULIC	96H	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.97 ±0.18 ±0.31	ABREU	93	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{K^*_2(1430)}\rangle$

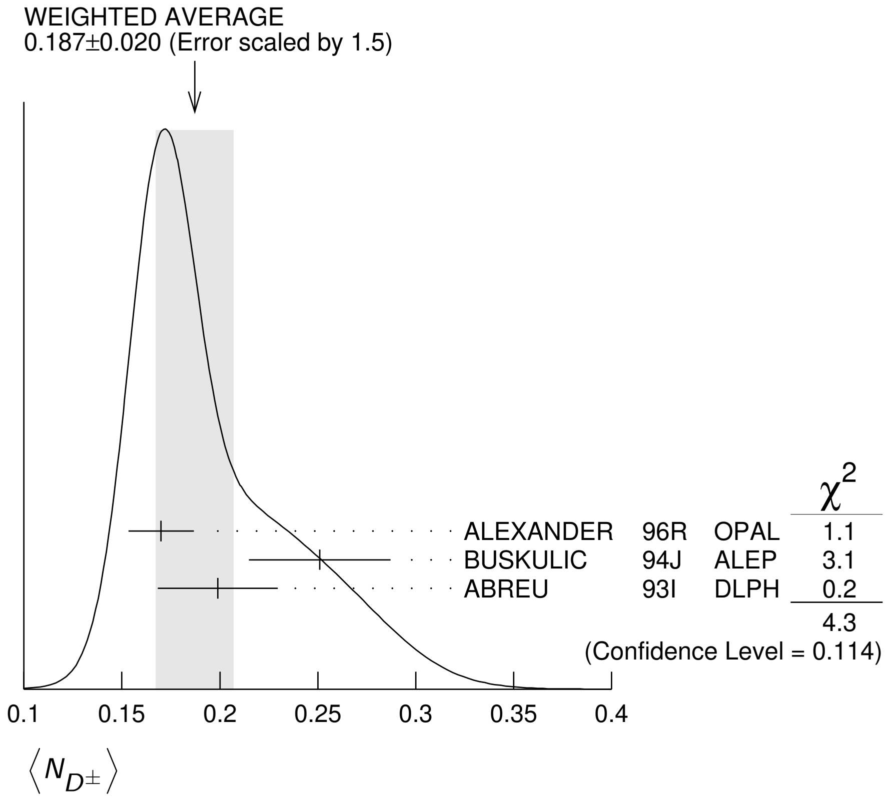
VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.073±0.023	ABREU	99J	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.19 ±0.04 ±0.06	[1] AKERS	95X	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] AKERS 95X obtain this value for $x< 0.3$.

$\langle N_{D^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.187±0.020 OUR AVERAGE	Error includes scale factor of 1.5. See the ideogram below.			
0.170±0.009±0.014	ALEXANDER	96R	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.251±0.026±0.025	BUSKULIC	94J	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.199±0.019±0.024	[1] ABREU	93I	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] See ABREU 95 (erratum).



$\langle N_{D^0} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.462±0.026 OUR AVERAGE				
0.465±0.017±0.027	ALEXANDER	96R	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.518±0.052±0.035	BUSKULIC	94J	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.403±0.038±0.044	[1] ABREU	93I	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] See ABREU 95 (erratum).

$\langle N_{D_s^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.131±0.010±0.018	ALEXANDER	96R	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{D^*(2010)^\pm} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.183 ±0.008 OUR AVERAGE				
0.1854±0.0041±0.0091	[1] ACKERSTAFF	98E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

0.187 ±0.015 ±0.013	BUSKULIC	94J	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.171 ±0.012 ±0.016	[2] ABREU	93I	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ACKERSTAFF 98E systematic error includes an uncertainty of ±0.0069 due to the branching ratios B($D^{*+} \rightarrow D^0 \pi^+$) = 0.683 ± 0.014 and B($D^0 \rightarrow K^- \pi^+$) = 0.0383 ± 0.0012.

[2] See ABREU 95 (erratum).

$\langle N_{D_{s1}(2536)^+} \rangle$

VALUE (units 10^{-3})	DOCUMENT ID		TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$2.9^{+0.7}_{-0.6} \pm 0.2$	[1] ACKERSTAFF	97W	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ACKERSTAFF 97W obtain this value for x> 0.6 and with the assumption that its decay width is saturated by the $D^* K$ final states.

$\langle N_{B^*} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.28±0.01±0.03	[1] ABREU	95R	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ABREU 95R quote this value for a flavor-averaged excited state.

$\langle N_{J/\psi(1S)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0056±0.0003±0.0004	[1] ALEXANDER	96B	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] ALEXANDER 96B identify $J/\psi(1S)$ from the decays into lepton pairs.

$\langle N_{\psi(2S)} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.0023±0.0004±0.0003	ALEXANDER	96B	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_p \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
1.046±0.026 OUR AVERAGE				
1.054±0.035	ABE	04C	SLD	$E^{ee}_{\rm cm}$= 91.2 GeV
1.08 ±0.04 ±0.03	ABREU	98L	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
1.00 ±0.07	BARATE	98V	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.92 ±0.11	AKERS	94P	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

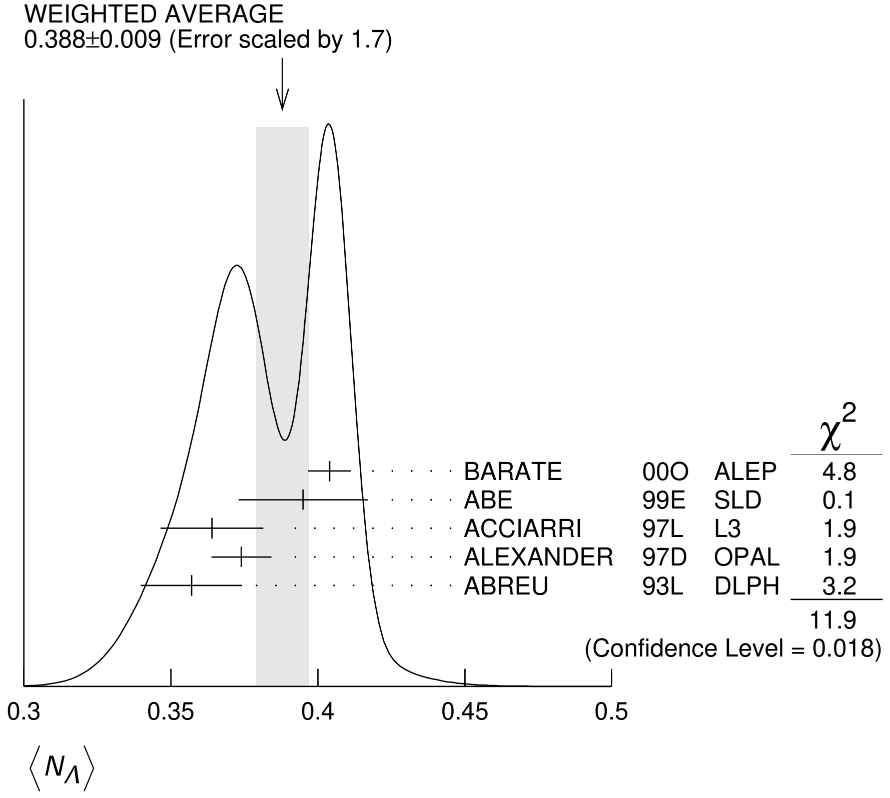
$\langle N_{\Delta(1232)^{++}} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.087±0.033 OUR AVERAGE	Error includes scale factor of 2.4.			
0.079±0.009±0.011	ABREU	95W	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.22 ±0.04 ±0.04	ALEXANDER	95D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Lambda} \rangle$

VALUE	DOCUMENT ID		TECN	COMMENT
0.388±0.009 OUR AVERAGE	Error includes scale factor of 1.7. See the ideogram below.			
0.404±0.002±0.007	BARATE	00O	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
0.395±0.022	ABE	99E	SLD	$E^{ee}_{\rm cm}$= 91.2 GeV

0.364 ± 0.004 ± 0.017	ACCIARRI 97L	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
0.374 ± 0.002 ± 0.010	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.357 ± 0.003 ± 0.017	ABREU 93L	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV



$\langle N_{\Lambda(1520)} \rangle$

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
0.0224 ± 0.0027 OUR AVERAGE			
0.029 ± 0.005 ± 0.005	ABREU 00P	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.0213 ± 0.0021 ± 0.0019	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma^+} \rangle$

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
0.107 ± 0.010 OUR AVERAGE			
0.114 ± 0.011 ± 0.009	ACCIARRI 00J	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
0.099 ± 0.008 ± 0.013	ALEXANDER 97E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma^-} \rangle$

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*
0.082 ± 0.007 OUR AVERAGE			
0.081 ± 0.002 ± 0.010	ABREU 00P	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.083 ± 0.006 ± 0.009	ALEXANDER 97E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma^+ + \Sigma^-} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.181±0.018 OUR AVERAGE			
0.182±0.010±0.016	[1] ALEXANDER 97E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.170±0.014±0.061	ABREU 95O	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

[1] We have combined the values of $\langle N_{\Sigma^+} \rangle$ and $\langle N_{\Sigma^-} \rangle$ from ALEXANDER 97E adding the statistical and systematic errors of the two final states separately in quadrature. If isospin symmetry is assumed this value becomes 0.174 ± 0.010 ± 0.015.

$\langle N_{\Sigma^0} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.076±0.010 OUR AVERAGE			
0.095±0.015±0.013	ACCIARRI 00J	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
0.071±0.012±0.013	ALEXANDER 97E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.070±0.010±0.010	ADAM 96B	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{(\Sigma^+ + \Sigma^- + \Sigma^0)/3} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.084±0.005±0.008	ALEXANDER 97E	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma(1385)^+} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.0239±0.0009±0.0012	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma(1385)^-} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.0240±0.0010±0.0014	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Sigma(1385)^+ + \Sigma(1385)^-} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.046 ±0.004 OUR AVERAGE	Error includes scale factor of 1.6.		
0.0479±0.0013±0.0026	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.0382±0.0028±0.0045	ABREU 95O	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Xi^-} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.0258±0.0009 OUR AVERAGE			
0.0247±0.0009±0.0025	ABDALLAH 06E	DLPH	$E^{ee}_{\rm cm}$ = 91.2 GeV
0.0259±0.0004±0.0009	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$ = 91.2 GeV

$\langle N_{\Xi(1530)^0} \rangle$

VALUE	DOCUMENT ID	TECN	COMMENT
0.0059±0.0011 OUR AVERAGE	Error includes scale factor of 2.3.		
0.0045±0.0005±0.0006	ABDALLAH 05C	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
0.0068±0.0005±0.0004	ALEXANDER 97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Omega^-} \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.00164±0.00028 OUR AVERAGE				
0.0018 ±0.0003 ±0.0002	ALEXANDER	97D	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
0.0014 ±0.0002 ±0.0004	ADAM	96B	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV

$\langle N_{\Lambda_c^+} \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.078±0.012±0.012	ALEXANDER	96R	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV

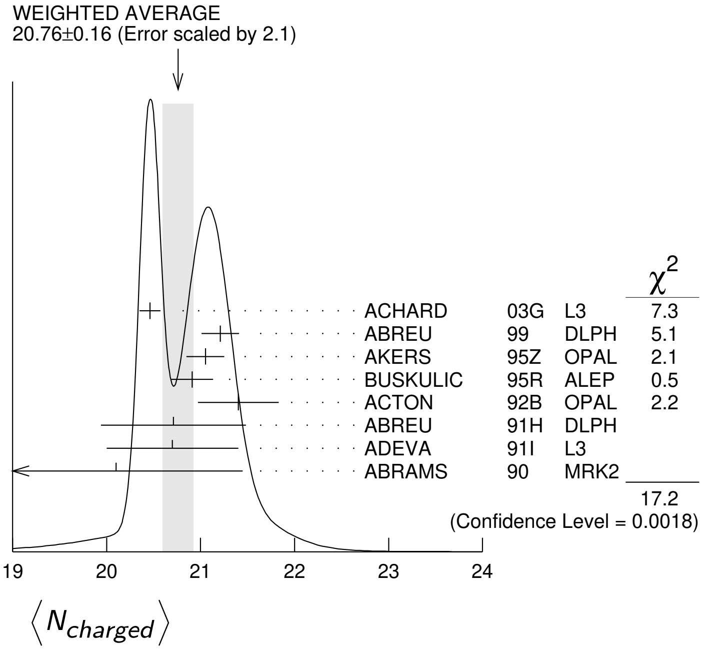
$\langle N_{\overline{D}} \rangle$

VALUE (units 10^{-6})	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
5.9±1.8±0.5	[1] SCHAEL	06A	ALEP	$E^{ee}_{\rm cm}$ = 91.2 GeV

[1] SCHAEL 06A obtain this anti-deuteron production rate per hadronic Z decay in the anti-deuteron momentum range from 0.62 to 1.03 GeV/c.

$\langle N_{charged} \rangle$

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
20.76±0.16 OUR AVERAGE	Error includes scale factor of 2.1. See the ideogram below.			
20.46±0.01±0.11	ACHARD	03G	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
21.21±0.01±0.20	ABREU	99	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
21.05±0.20	AKERS	95Z	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
20.91±0.03±0.22	BUSKULIC	95R	ALEP	$E^{ee}_{\rm cm}$= 91.2 GeV
21.40±0.43	ACTON	92B	OPAL	$E^{ee}_{\rm cm}$= 91.2 GeV
20.71±0.04±0.77	ABREU	91H	DLPH	$E^{ee}_{\rm cm}$= 91.2 GeV
20.7 ±0.7	ADEVA	91I	L3	$E^{ee}_{\rm cm}$= 91.2 GeV
20.1 ±1.0 ±0.9	ABRAMS	90	MRK2	$E^{ee}_{\rm cm}$= 91.1 GeV



Z HADRONIC POLE CROSS SECTION

OUR EVALUATION is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The *Z* boson" and ref. LEP-SLC 06). Corrections as discussed in VOUTSINAS 20 and JANOT 20 are also included. This quantity is defined as

$$\sigma_h^0 = \frac{12\pi}{M_Z^2} \frac{\Gamma(e^+ e^-)\,\Gamma(\text{hadrons})}{\Gamma_Z^2}$$

It is one of the parameters used in the *Z* lineshape fit.

VALUE (nb)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
41.4802±0.0325 OUR EVALUATION					
41.4802±0.0325		[1] JANOT	20		
• • • We do not use the following data for averages, fits, limits, etc. • • •					
41.500 ±0.037		[2] VOUTSINAS	20		
41.541 ±0.037		LEP-SLC	06		$E_{\rm cm}^{ee}$ = 88–94 GeV
41.501 ±0.055	4.10M	[3] ABBIENDI	01A	OPAL	$E_{\rm cm}^{ee}$= 88–94 GeV
41.578 ±0.069	3.70M	ABREU	00F	DLPH	$E_{\rm cm}^{ee}$= 88–94 GeV
41.535 ±0.055	3.54M	ACCIARRI	00C	L3	$E_{\rm cm}^{ee}$= 88–94 GeV
41.559 ±0.058	4.07M	[4] BARATE	00C	ALEP	$E_{\rm cm}^{ee}$= 88–94 GeV
42 ±4	450	ABRAMS	89B	MRK2	$E_{\rm cm}^{ee}$= 89.2–93.0 GeV

[1] JANOT 20 applies a correction to LEP-SLC 06 using an updated Bhabha cross section calculation. This result also includes a correction to account for correlated luminosity bias as presented in VOUTSINAS 20.

[2] VOUTSINAS 20 applies a correction to LEP-SLC 06 to account for correlated luminosity bias.

[3] ABBIENDI 01A error includes approximately 0.031 due to statistics, 0.033 due to event selection systematics, 0.029 due to uncertainty in luminosity measurement, and 0.011 due to LEP energy uncertainty.

[4] BARATE 00C error includes approximately 0.030 due to statistics, 0.026 due to experimental systematics, and 0.025 due to uncertainty in luminosity measurement.

Z VECTOR COUPLINGS

These quantities are the effective vector couplings of the *Z* to charged leptons and quarks. Their magnitude is derived from a measurement of the *Z* lineshape and the forward-backward lepton asymmetries as a function of energy around the *Z* mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the *Z* asymmetry parameters, A_e, A_μ, and A_τ. By convention the sign of g_A^e is fixed to be negative (and opposite to that of g^{ν_e} obtained using ν_e scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The LEP/SLD-based fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and A_e, A_μ, and A_τ measurements. See the note "The *Z* boson" and ref. LEP-SLC 06 for details. Where $p\overline{p}$ and $e\,p$ data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

g^e_V

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.03817±0.00047 OUR FIT				
−0.058 ±0.016 ±0.007	5026	[1] ACOSTA 05M	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.96 TeV
−0.0346 ±0.0023	137.0k	[2] ABBIENDI 01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0412 ±0.0027	124.4k	[3] ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0400 ±0.0037		BARATE 00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0414 ±0.0020		[4] ABE 95J	SLD	$E^{ee}_{\rm cm}$= 91.31 GeV

[1] ACOSTA 05M determine the forward–backward asymmetry of e^+e^- pairs produced via $q\overline{q} \rightarrow Z/\gamma^* \rightarrow e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial–vector couplings of the Z to e^+e^-, assuming the quark couplings are as predicted by the standard model. Higher order radiative corrections have not been taken into account.

[2] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[3] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[4] ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94C. The Bhabha results alone give −0.0507 ± 0.0096 ± 0.0020.

g^{μ}_V

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.0367±0.0023 OUR FIT				
$-0.0388^{+0.0060}_{-0.0064}$	182.8k	[1] ABBIENDI 01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0386±0.0073	113.4k	[2] ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0362±0.0061		BARATE 00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
−0.0413±0.0060	66143	[3] ABBIENDI 01K	OPAL	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[3] ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

g^{τ}_V

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
−0.0366±0.0010 OUR FIT				
−0.0365±0.0023	151.5k	[1] ABBIENDI 01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0384±0.0026	103.0k	[2] ACCIARRI 00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
−0.0361±0.0068		BARATE 00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g_V^ℓ

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
-0.03783 ± 0.00041 OUR FIT					
$-0.0358\ \pm0.0014$	471.3k	[1] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$-0.0397\ \pm0.0020$	379.4k	[2] ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$-0.0397\ \pm0.0017$	340.8k	[3] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$-0.0383\ \pm0.0018$	500k	BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] Using forward-backward lepton asymmetries.

[3] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g_V^u

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.266 ± 0.034 OUR AVERAGE					
0.270 ± 0.037		[1] ANDREEV	18A	H1	$e^\pm p$
0.201 ± 0.112	156k	[2] ABAZOV	11D	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.97 TeV
$0.24\ {+0.28 \atop -0.11}$		[3] LEP-SLC	06		$E^{ee}_{\rm cm}$ = 88–94 GeV
$0.399{+0.152 \atop -0.188}\pm0.066$	5026	[4] ACOSTA	05M	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.96 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.14\ {+0.09 \atop -0.09}$		[5] ABRAMOWICZ	16A	ZEUS	
$0.144{+0.066 \atop -0.058}$		[6] ABT	16		
$0.27\ \pm0.13$	1500	[7] AKTAS	06	H1	$e^\pm p \to \overline{\nu}_e(\nu_e)X$, $\sqrt{s}\approx$ 300 GeV

[1] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic $e^+ p$ and $e^- p$ neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[2] ABAZOV 11D study $p\overline{p} \to Z/\gamma^* e^+ e^-$ events using 5 fb^{-1} data at $\sqrt{s}$ = 1.96 TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T > 25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the *u*- and *d*- quarks and the value of $\sin^2\theta^\ell_{eff} = 0.2309 \pm 0.0008(\text{stat})\pm0.0006(\text{syst})$.

[3] LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

[4] ACOSTA 05M determine the forward-backward asymmetry of $e^+ e^-$ pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+ e^-$ in 15 M($e^+ e^-$) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the *Z* to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

[5] ABRAMOWICZ 16A determine the Z^0 couplings to *u*- and *d*-quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.

[6] ABT 16 determine the Z^0 couplings to *u*- and *d*-quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.

[7] AKTAS 06 fit the neutral current ($1.5 \leq Q^2 \leq 30{,}000$ GeV^2) and charged current ($1.5 \leq Q^2 \leq 15{,}000$ GeV^2) differential cross sections. In the determination of the *u*-quark couplings the electron and *d*-quark couplings are fixed to their standard model values.

g^d_V

VALUE	EVTS	DOCUMENT ID	TECN	COMMENT
$-0.38\ ^{+0.04}_{-0.05}$ OUR AVERAGE				
-0.488 ± 0.092		[1] ANDREEV 18A	H1	$e^{\pm} p$
-0.351 ± 0.251	156k	[2] ABAZOV 11D	D0	$E^{p\overline{p}}_{\rm cm} = 1.97$ TeV
$-0.33\ ^{+0.05}_{-0.07}$		[3] LEP-SLC 06		$E^{ee}_{\rm cm} = 88–94$ GeV
$-0.226^{+0.635}_{-0.290} \pm 0.090$	5026	[4] ACOSTA 05M	CDF	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$-0.41\ ^{+0.25}_{-0.20}$		[5] ABRAMOWICZ 16A	ZEUS	
$-0.503^{+0.171}_{-0.103}$		[6] ABT 16		
$-0.33\ \pm 0.33$	1500	[7] AKTAS 06	H1	$e^{\pm} p \rightarrow \overline{\nu}_e(\nu_e) X$, $\sqrt{s} \approx 300$ GeV

[1] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic $e^+ p$ and $e^- p$ neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[2] ABAZOV 11D study $p\overline{p} \rightarrow Z/\gamma^* e^+ e^-$ events using 5 fb^{-1} data at $\sqrt{s} = 1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T > 25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the *u*- and *d*- quarks and the value of $\sin^2\theta^{\ell}_{eff} = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{syst})$.

[3] LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

[4] ACOSTA 05M determine the forward-backward asymmetry of $e^+ e^-$ pairs produced via $q\overline{q} \rightarrow Z/\gamma^* \rightarrow e^+ e^-$ in 15 M($e^+ e^-$) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the *Z* to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

[5] ABRAMOWICZ 16A determine the Z^0 couplings to *u*- and *d*-quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.

[6] ABT 16 determine the Z^0 couplings to *u*- and *d*-quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.

[7] AKTAS 06 fit the neutral current ($1.5 \leq Q^2 \leq 30{,}000$ GeV^2) and charged current ($1.5 \leq Q^2 \leq 15{,}000$ GeV^2) differential cross sections. In the determination of the *d*-quark couplings the electron and *u*-quark couplings are fixed to their standard model values.

Z AXIAL-VECTOR COUPLINGS

These quantities are the effective axial-vector couplings of the Z to charged leptons and quarks. Their magnitude is derived from a measurement of the Z lineshape and the forward-backward lepton asymmetries as a function of energy around the Z mass. The relative sign among the vector to axial-vector couplings is obtained from a measurement of the Z asymmetry parameters, A_e, A_μ, and A_τ. By convention the sign of g^e_A is fixed to be negative (and opposite to that of g^{ν_e} obtained using ν_e scattering measurements). For the light quarks, the sign of the couplings is assigned consistently with this assumption. The LEP/SLD-based fit values quoted below correspond to global nine- or five-parameter fits to lineshape, lepton forward-backward asymmetry, and A_e, A_μ, and A_τ measurements. See the note "The Z boson" and ref. LEP-SLC 06 for details. Where $p\overline{p}$ and $e p$ data is quoted, OUR FIT value corresponds to a weighted average of this with the LEP/SLD fit result.

g^e_A

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$-$0.50111$\pm$0.00035 OUR FIT					
$-$0.528 $\pm$0.123 $\pm$0.059	5026	[1] ACOSTA	05M	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.96 TeV
$-$0.50062$\pm$0.00062	137.0k	[2] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.5015 $\pm$0.0007	124.4k	[3] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.50166$\pm$0.00057		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.4977 $\pm$0.0045		[4] ABE	95J	SLD	$E^{ee}_{\rm cm}$= 91.31 GeV

[1] ACOSTA 05M determine the forward–backward asymmetry of e^+e^- pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial–vector couplings of the Z to e^+e^-, assuming the quark couplings are as predicted by the standard model. Higher order radiative corrections have not been taken into account.

[2] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[3] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[4] ABE 95J obtain this result combining polarized Bhabha results with the A_{LR} measurement of ABE 94C. The Bhabha results alone give $-0.4968 \pm 0.0039 \pm 0.0027$.

g^μ_A

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
$-$0.50120$\pm$0.00054 OUR FIT					
$-$0.50117$\pm$0.00099	182.8k	[1] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.5009 $\pm$0.0014	113.4k	[2] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.50046$\pm$0.00093		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-$0.520 $\pm$0.015	66143	[3] ABBIENDI	01K	OPAL	$E^{ee}_{\rm cm}$= 89–93 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

[3] ABBIENDI 01K obtain this from an angular analysis of the muon pair asymmetry which takes into account effects of initial state radiation on an event by event basis and of initial-final state interference.

g^{τ}_{A}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-$0.50204$\pm$0.00064 OUR FIT					
$-$0.50165$\pm$0.00124	151.5k	[1] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.5023 $\pm$0.0017	103.0k	[2] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.50216$\pm$0.00100		BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g^{ℓ}_{A}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$-$0.50123$\pm$0.00026 OUR FIT					
$-$0.50089$\pm$0.00045	471.3k	[1] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.5007 $\pm$0.0005	379.4k	ABREU	00F	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.50153$\pm$0.00053	340.8k	[2] ACCIARRI	00C	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
$-$0.50150$\pm$0.00046	500k	BARATE	00C	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV

[1] ABBIENDI 01O use their measurement of the τ polarization in addition to the lineshape and forward-backward lepton asymmetries.

[2] ACCIARRI 00C use their measurement of the τ polarization in addition to forward-backward lepton asymmetries.

g^{u}_{A}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
$0.519^{+0.028}_{-0.033}$ OUR AVERAGE					
0.548$\pm$0.036		[1] ANDREEV	18A	H1	$e^{\pm}p$
0.501$\pm$0.110	156k	[2] ABAZOV	11D	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.97 TeV
$0.47\ ^{+0.05}_{-0.33}$		[3] LEP-SLC	06		$E^{ee}_{\rm cm}$ = 88–94 GeV
$0.441^{+0.207}_{-0.173}\pm0.067$	5026	[4] ACOSTA	05M	CDF	$E^{p\overline{p}}_{\rm cm}$= 1.96 TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$0.50\ ^{+0.12}_{-0.05}$		[5] ABRAMOWICZ	16A	ZEUS	
$0.532^{+0.107}_{-0.063}$		[6] ABT	16		
0.57 $\pm$0.08	1500	[7] AKTAS	06	H1	$e^{\pm}p \to \overline{\nu}_e(\nu_e)X$, $\sqrt{s} \approx 300$ GeV

[1] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic $e^{+}p$ and $e^{-}p$ neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[2] ABAZOV 11D study $p\overline{p} \to Z/\gamma^{*}e^{+}e^{-}$ events using 5 fb^{-1} data at $\sqrt{s} = 1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T > 25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the *u*- and *d*- quarks and the value of $\sin^2\theta^{\ell}_{eff} = 0.2309 \pm 0.0008({\rm stat})\pm0.0006({\rm syst})$.

[3] LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

[4] ACOSTA 05M determine the forward-backward asymmetry of e^+e^- pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

[5] ABRAMOWICZ 16A determine the Z^0 couplings to u- and d-quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.

[6] ABT 16 determine the Z^0 couplings to u- and d-quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.

[7] AKTAS 06 fit the neutral current ($1.5 \leq Q^2 \leq 30{,}000$ GeV^2) and charged current ($1.5 \leq Q^2 \leq 15{,}000$ GeV^2) differential cross sections. In the determination of the u-quark couplings the electron and d-quark couplings are fixed to their standard model values.

g^d_A

VALUE	*EVTS*	*DOCUMENT ID*	*TECN*	*COMMENT*
$-0.527^{+0.040}_{-0.028}$ OUR AVERAGE				
-0.619 ± 0.108		[1] ANDREEV 18A	H1	$e^{\pm}p$
-0.497 ± 0.165	156k	[2] ABAZOV 11D	D0	$E^{p\overline{p}}_{\rm cm} = 1.97$ TeV
$-0.52\ ^{+0.05}_{-0.03}$		[3] LEP-SLC 06		$E^{ee}_{\rm cm} = 88$–94 GeV
$-0.016^{+0.346}_{-0.536}\pm0.091$	5026	[4] ACOSTA 05M	CDF	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$-0.56\ ^{+0.41}_{-0.15}$		[5] ABRAMOWICZ 16A	ZEUS	
$-0.409^{+0.373}_{-0.213}$		[6] ABT 16		
$-0.80\ \pm0.24$	1500	[7] AKTAS 06	H1	$e^{\pm}p \to \overline{\nu}_e(\nu_e)X$, $\sqrt{s} \approx 300$ GeV

[1] ANDREEV 18A obtain this result in a combined electroweak and QCD analysis using all deep-inelastic e^+p and e^-p neutral current and charged current scattering cross sections published by the H1 Collaboration, including data with longitudinally polarized lepton beams.

[2] ABAZOV 11D study $p\overline{p} \to Z/\gamma^* e^+e^-$ events using 5 fb^{-1} data at $\sqrt{s} = 1.96$ TeV. The candidate events are selected by requiring two isolated electromagnetic showers with $E_T > 25$ GeV, at least one electron in the central region and the di-electron mass in the range 50–1000 GeV. From the forward-backward asymmetry, determined as a function of the di-electron mass, they derive the axial and vector couplings of the u- and d- quarks and the value of $\sin^2\theta^{\ell}_{eff} = 0.2309 \pm 0.0008(\text{stat}) \pm 0.0006(\text{syst})$.

[3] LEP-SLC 06 is a combination of the results from LEP and SLC experiments using light quark tagging. s- and d-quark couplings are assumed to be identical.

[4] ACOSTA 05M determine the forward-backward asymmetry of e^+e^- pairs produced via $q\overline{q} \to Z/\gamma^* \to e^+e^-$ in 15 M(e^+e^-) effective mass bins ranging from 40 GeV to 600 GeV. These results are used to obtain the vector and axial-vector couplings of the Z to the light quarks, assuming the electron couplings are as predicted by the Standard Model. Higher order radiative corrections have not been taken into account.

[5] ABRAMOWICZ 16A determine the Z^0 couplings to u- and d-quarks using the ZEUS polarised data from Run II together with the unpolarised data from both ZEUS and H1 Collaborations for Run I and unpolarised H1 data from Run II.

[6] ABT 16 determine the Z^0 couplings to u- and d-quarks using the same techniques and data as ABRAMOWICZ 16A but additionally use the published H1 polarised data.

[7] AKTAS 06 fit the neutral current ($1.5 \leq Q^2 \leq 30{,}000$ GeV^2) and charged current ($1.5 \leq Q^2 \leq 15{,}000$ GeV^2) differential cross sections. In the determination of the d-quark couplings the electron and u-quark couplings are fixed to their standard model values.

Z COUPLINGS TO NEUTRAL LEPTONS

Averaging over neutrino species, the invisible Z decay width determines the effective neutrino coupling g^{ν_ℓ}. For g^{ν_e} and g^{ν_μ}, $\nu_e e$ and $\nu_\mu e$ scattering results are combined with g^e_A and g^e_V measurements at the Z mass to obtain g^{ν_e} and g^{ν_μ} following NOVIKOV 93C.

g^{ν_ℓ}

VALUE	*DOCUMENT ID*		*COMMENT*
0.50076±0.00076	[1] LEP-SLC	06	$E^{ee}_{\rm cm}$ = 88–94 GeV

[1] From invisible Z-decay width.

g^{ν_e}

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.528±0.085	[1] VILAIN	94	CHM2	From $\nu_\mu e$ and $\nu_e e$ scattering

[1] VILAIN 94 derive this value from their value of g^{ν_μ} and their ratio $g^{\nu_e}/g^{\nu_\mu} = 1.05^{+0.15}_{-0.18}$.

g^{ν_μ}

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
0.502±0.017	[1] VILAIN	94	CHM2	From $\nu_\mu e$ scattering

[1] VILAIN 94 derive this value from their measurement of the couplings $g^{e\nu_\mu}_A = -0.503 \pm 0.017$ and $g^{e\nu_\mu}_V = -0.035 \pm 0.017$ obtained from $\nu_\mu e$ scattering. We have re-evaluated this value using the current PDG values for g^e_A and g^e_V.

Z ASYMMETRY PARAMETERS

For each fermion-antifermion pair coupling to the Z these quantities are defined as

$$A_f = \frac{2g^f_V g^f_A}{(g^f_V)^2 + (g^f_A)^2}$$

where g^f_V and g^f_A are the effective vector and axial-vector couplings. For their relation to the various lepton asymmetries see the note "The Z boson" and ref. LEP-SLC 06.

A_e

Using polarized beams, this quantity can also be measured as $(\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$, where σ_L and σ_R are the $e^+ e^-$ production cross sections for Z bosons produced with left-handed and right-handed electrons respectively.

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.1515±0.0019 OUR AVERAGE					
0.1454±0.0108±0.0036	144810	[1] ABBIENDI	01O	OPAL	$E^{ee}_{\rm cm}$= 88–94 GeV
0.1516±0.0021	559000	[2] ABE	01B	SLD	$E^{ee}_{\rm cm}$= 91.24 GeV
0.1504±0.0068±0.0008		[3] HEISTER	01	ALEP	$E^{ee}_{\rm cm}$= 88–94 GeV
0.1382±0.0116±0.0005	105000	[4] ABREU	00E	DLPH	$E^{ee}_{\rm cm}$= 88–94 GeV
0.1678±0.0127±0.0030	137092	[5] ACCIARRI	98H	L3	$E^{ee}_{\rm cm}$= 88–94 GeV
0.162 ±0.041 ±0.014	89838	[6] ABE	97	SLD	$E^{ee}_{\rm cm}$= 91.27 GeV
0.202 ±0.038 ±0.008		[7] ABE	95J	SLD	$E^{ee}_{\rm cm}$= 91.31 GeV

[1] ABBIENDI 01O fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

[2] ABE 01B use the left-right production and left-right forward-backward decay asymmetries in leptonic Z decays to obtain a value of 0.1544 ± 0.0060. This is combined with left-right production asymmetry measurement using hadronic Z decays (ABE 00B) to obtain the quoted value.

[3] HEISTER 01 obtain this result fitting the τ polarization as a function of the polar production angle of the τ.

[4] ABREU 00E obtain this result fitting the τ polarization as a function of the polar τ production angle. This measurement is a combination of different analyses (exclusive τ decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

[5] Derived from the measurement of forward-backward τ polarization asymmetry.

[6] ABE 97 obtain this result from a measurement of the observed left-right charge asymmetry, $A^{\rm obs}_Q$ = 0.225 ± 0.056 ± 0.019, in hadronic Z decays. If they combine this value of $A^{\rm obs}_Q$ with their earlier measurement of $A^{\rm obs}_{LR}$ they determine A_e to be 0.1574 ± 0.0197 ± 0.0067 independent of the beam polarization.

[7] ABE 95J obtain this result from polarized Bhabha scattering.

A_μ

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $\mu^+\mu^-$ production at SLC using a polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.142±0.015	16844	[1] ABE	01B	SLD	$E^{ee}_{\rm cm}$= 91.24 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.153±0.012	1.7M	[2] AAD	15BT	ATLS	$E^{pp}_{\rm cm}$ = 7 TeV

[1] ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in $\mu^+\mu^-$ decays of the Z boson obtained with a polarized electron beam.

[2] AAD 15BT study $pp \rightarrow Z \rightarrow \ell^+\ell^-$ events where ℓ is an electron or a muon in the dilepton mass region 70–1000 GeV. The background in the Z peak region is estimated to be $<$ 1% for the muon channel. The muon asymmetry parameter is derived from the measured forward-backward asymmetry assuming the value of the quark asymmetry parameter from the SM. For this reason it is not used in the average.

A_τ

The LEP Collaborations derive this quantity from the measurement of the τ polarization in $Z \to \tau^+\tau^-$. The SLD Collaboration directly extracts this quantity from its measured left-right forward-backward asymmetry in $Z \to \tau^+\tau^-$ produced using a polarized e^- beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.143 ±0.004 OUR AVERAGE					
0.1456±0.0076±0.0057	144810	[1] ABBIENDI	01O	OPAL	E^{ee}_{cm}= 88–94 GeV
0.136 ±0.015	16083	[2] ABE	01B	SLD	E^{ee}_{cm}= 91.24 GeV
0.1451±0.0052±0.0029		[3] HEISTER	01	ALEP	E^{ee}_{cm}= 88–94 GeV
0.1359±0.0079±0.0055	105000	[4] ABREU	00E	DLPH	E^{ee}_{cm}= 88–94 GeV
0.1476±0.0088±0.0062	137092	ACCIARRI	98H	L3	E^{ee}_{cm}= 88–94 GeV

[1] ABBIENDI 01O fit for A_e and A_τ from measurements of the τ polarization at varying τ production angles. The correlation between A_e and A_τ is less than 0.03.

[2] ABE 01B obtain this direct measurement using the left-right production and left-right forward-backward polar angle asymmetries in $\tau^+\tau^-$ decays of the Z boson obtained with a polarized electron beam.

[3] HEISTER 01 obtain this result fitting the τ polarization as a function of the polar production angle of the τ.

[4] ABREU 00E obtain this result fitting the τ polarization as a function of the polar τ production angle. This measurement is a combination of different analyses (exclusive τ decay modes, inclusive hadronic 1-prong reconstruction, and a neural network analysis).

A_s

The SLD Collaboration directly extracts this quantity by a simultaneous fit to four measured s-quark polar angle distributions corresponding to two states of e^- polarization (positive and negative) and to the K^+K^- and $K^\pm K^0_S$ strange particle tagging modes in the hadronic final states.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.895±0.066±0.062	2870	[1] ABE	00D	SLD	E^{ee}_{cm}= 91.2 GeV

[1] ABE 00D tag $Z \to s\overline{s}$ events by an absence of B or D hadrons and the presence in each hemisphere of a high momentum $K^\pm$ or K^0_S.

A_c

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $c\overline{c}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e. OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

VALUE	DOCUMENT ID		TECN	COMMENT
0.670 ±0.027 OUR FIT				
0.6712±0.0224±0.0157	[1] ABE	05	SLD	E^{ee}_{cm}= 91.24 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •				
0.583 ±0.055 ±0.055	[2] ABE	02G	SLD	E^{ee}_{cm}= 91.24 GeV
0.688 ±0.041	[3] ABE	01C	SLD	E^{ee}_{cm}= 91.25 GeV

[1] ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $c\overline{c}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying c–quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and

identified as kaons. This yields (9970 events) $A_c = 0.6747 \pm 0.0290 \pm 0.0233$. Taking into account all correlations with earlier results reported in ABE 02G and ABE 01C, they obtain the quoted overall SLD result.

[2] ABE 02G tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_c.

[3] ABE 01C tag $Z \to c\overline{c}$ events using two techniques: exclusive reconstruction of D^{*+}, D^+ and D^0 mesons and the soft pion tag for $D^{*+} \to D^0 \pi^+$. The large background from D mesons produced in $b\overline{b}$ events is separated efficiently from the signal using precision vertex information. When combining the A_c values from these two samples, care is taken to avoid double counting of events common to the two samples, and common systematic errors are properly taken into account.

A_b

This quantity is directly extracted from a measurement of the left-right forward-backward asymmetry in $b\overline{b}$ production at SLC using polarized electron beam. This double asymmetry eliminates the dependence on the Z-e-e coupling parameter A_e. OUR FIT is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06.

VALUE	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
0.923 ±0.020 OUR FIT					
0.9170±0.0147±0.0145		[1] ABE	05	SLD	E^{ee}_{cm}= 91.24 GeV
• • • We do not use the following data for averages, fits, limits, etc. • • •					
0.907 ±0.020 ±0.024	48028	[2] ABE	03F	SLD	E^{ee}_{cm}= 91.24 GeV
0.919 ±0.030 ±0.024		[3] ABE	02G	SLD	E^{ee}_{cm}= 91.24 GeV
0.855 ±0.088 ±0.102	7473	[4] ABE	99L	SLD	E^{ee}_{cm}= 91.27 GeV

[1] ABE 05 use hadronic Z decays collected during 1996–98 to obtain an enriched sample of $b\overline{b}$ events tagging on the invariant mass of reconstructed secondary decay vertices. The charge of the underlying b–quark is obtained with an algorithm that takes into account the net charge of the vertex as well as the charge of tracks emanating from the vertex and identified as kaons. This yields (25917 events) $A_b = 0.9173 \pm 0.0184 \pm 0.0173$. Taking into account all correlations with earlier results reported in ABE 03F, ABE 02G and ABE 99L, they obtain the quoted overall SLD result.

[2] ABE 03F obtain an enriched sample of $b\overline{b}$ events tagging on the invariant mass of a 3-dimensional topologically reconstructed secondary decay. The charge of the underlying b quark is obtained using a self-calibrating track-charge method. For the 1996–1998 data sample they measure $A_b = 0.906 \pm 0.022 \pm 0.023$. The value quoted here is obtained combining the above with the result of ABE 98I (1993–1995 data sample).

[3] ABE 02G tag b and c quarks through their semileptonic decays into electrons and muons. A maximum likelihood fit is performed to extract simultaneously A_b and A_c.

[4] ABE 99L obtain an enriched sample of $b\overline{b}$ events tagging with an inclusive vertex mass cut. For distinguishing b and $\overline{b}$ quarks they use the charge of identified $K^\pm$.

TRANSVERSE SPIN CORRELATIONS IN $Z \to \tau^+\tau^-$

The correlations between the transverse spin components of $\tau^+\tau^-$ produced in Z decays may be expressed in terms of the vector and axial-vector couplings:

$$C_{TT} = \frac{|g_A^\tau|^2 - |g_V^\tau|^2}{|g_A^\tau|^2 + |g_V^\tau|^2}$$

$$C_{TN} = -2\frac{|g_A^\tau||g_V^\tau|}{|g_A^\tau|^2 + |g_V^\tau|^2} \sin(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

C_{TT} refers to the transverse-transverse (within the collision plane) spin correlation and C_{TN} refers to the transverse-normal (to the collision plane) spin correlation.

The longitudinal τ polarization P_τ $(= -A_\tau)$ is given by:

$$P_\tau = -2\frac{|g_A^\tau||g_V^\tau|}{|g_A^\tau|^2+|g_V^\tau|^2}\cos(\Phi_{g_V^\tau} - \Phi_{g_A^\tau})$$

Here Φ is the phase and the phase difference $\Phi_{g_V^\tau} - \Phi_{g_A^\tau}$ can be obtained using both the measurements of C_{TN} and P_τ.

C_{TT}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
1.01±0.12 OUR AVERAGE					
$0.87\pm0.20^{+0.10}_{-0.12}$	9.1k	ABREU	97G	DLPH	E^{ee}_{cm}= 91.2 GeV
1.06±0.13±0.05	120k	BARATE	97D	ALEP	E^{ee}_{cm}= 91.2 GeV

C_{TN}

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.08±0.13±0.04	120k	[1] BARATE	97D	ALEP	E^{ee}_{cm}= 91.2 GeV

[1] BARATE 97D combine their value of C_{TN} with the world average $P_\tau = -0.140 \pm 0.007$ to obtain $\tan(\Phi_{g_V^\tau} - \Phi_{g_A^\tau}) = -0.57 \pm 0.97$.

FORWARD-BACKWARD $e^+e^- \to f\overline{f}$ CHARGE ASYMMETRIES

These asymmetries are experimentally determined by tagging the respective lepton or quark flavor in e^+e^- interactions. Details of heavy flavor (c- or b-quark) tagging at LEP are described in the note on "The Z boson" and ref. LEP-SLC 06. The Standard Model predictions for LEP data have been (re)computed using the ZFITTER package (version 6.36) with input parameters M_Z=91.187 GeV, M_{top}=174.3 GeV, M_{Higgs}=150 GeV, α_s=0.119, $\alpha^{(5)}$ (M_Z)= 1/128.877 and the Fermi constant G_F= 1.16637×10^{-5} GeV^{-2} (see the note on "The Z boson" for references). For non-LEP data the Standard Model predictions are as given by the authors of the respective publications.

$A_{FB}^{(0,e)}$ CHARGE ASYMMETRY IN $e^+e^- \to e^+e^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e^2$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	*STD. MODEL*	$\sqrt{s}$ *(GeV)*	*DOCUMENT ID*		*TECN*
1.45±0.25 OUR FIT					
0.89±0.44	1.57	91.2	[1] ABBIENDI	01A	OPAL
1.71±0.49	1.57	91.2	ABREU	00F	DLPH
1.06±0.58	1.57	91.2	ACCIARRI	00C	L3
1.88±0.34	1.57	91.2	[2] BARATE	00C	ALEP

[1] ABBIENDI 01A error includes approximately 0.38 due to statistics, 0.16 due to event selection systematics, and 0.18 due to the theoretical uncertainty in t-channel prediction.

[2] BARATE 00C error includes approximately 0.31 due to statistics, 0.06 due to experimental systematics, and 0.13 due to the theoretical uncertainty in t-channel prediction.

$A_{FB}^{(0,\mu)}$ CHARGE ASYMMETRY IN $e^+e^- \to \mu^+\mu^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e A_\mu$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	*STD. MODEL*	$\sqrt{s}$ *(GeV)*	*DOCUMENT ID*		*TECN*
1.69± 0.13 OUR FIT					
1.59± 0.23	1.57	91.2	[1] ABBIENDI	01A	OPAL
1.65± 0.25	1.57	91.2	ABREU	00F	DLPH
1.88± 0.33	1.57	91.2	ACCIARRI	00C	L3
1.71± 0.24	1.57	91.2	[2] BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
9 ±30	−1.3	20	[3] ABREU	95M	DLPH
7 ±26	−8.3	40	[3] ABREU	95M	DLPH
−11 ±33	−24.1	57	[3] ABREU	95M	DLPH
−62 ±17	−44.6	69	[3] ABREU	95M	DLPH
−56 ±10	−63.5	79	[3] ABREU	95M	DLPH
−13 ± 5	−34.4	87.5	[3] ABREU	95M	DLPH
$-29.0\,^{+\,5.0}_{-\,4.8}\,\pm 0.5$	−32.1	56.9	[4] ABE	90I	VNS
− 9.9 ± 1.5 ±0.5	−9.2	35	HEGNER	90	JADE
0.05± 0.22	0.026	91.14	[5] ABRAMS	89D	MRK2
−43.4 ±17.0	−24.9	52.0	[6] BACALA	89	AMY
−11.0 ±16.5	−29.4	55.0	[6] BACALA	89	AMY
−30.0 ±12.4	−31.2	56.0	[6] BACALA	89	AMY
−46.2 ±14.9	−33.0	57.0	[6] BACALA	89	AMY
−29 ±13	−25.9	53.3	ADACHI	88C	TOPZ
+ 5.3 ± 5.0 ±0.5	−1.2	14.0	ADEVA	88	MRKJ
−10.4 ± 1.3 ±0.5	−8.6	34.8	ADEVA	88	MRKJ
−12.3 ± 5.3 ±0.5	−10.7	38.3	ADEVA	88	MRKJ
−15.6 ± 3.0 ±0.5	−14.9	43.8	ADEVA	88	MRKJ
− 1.0 ± 6.0	−1.2	13.9	BRAUNSCH...	88D	TASS
− 9.1 ± 2.3 ±0.5	−8.6	34.5	BRAUNSCH...	88D	TASS
$-10.6\,^{+\,2.2}_{-\,2.3}\,\pm 0.5$	−8.9	35.0	BRAUNSCH...	88D	TASS

$-17.6\ ^{+4.4}_{-4.3}\ \pm 0.5$	-15.2	43.6	BRAUNSCH...	88D	TASS
$-\ 4.8 \pm 6.5 \pm 1.0$	-11.5	39	BEHREND	87C	CELL
$-18.8 \pm 4.5 \pm 1.0$	-15.5	44	BEHREND	87C	CELL
$+\ 2.7 \pm 4.9$	-1.2	13.9	BARTEL	86C	JADE
$-11.1 \pm 1.8 \pm 1.0$	-8.6	34.4	BARTEL	86C	JADE
$-17.3 \pm 4.8 \pm 1.0$	-13.7	41.5	BARTEL	86C	JADE
$-22.8 \pm 5.1 \pm 1.0$	-16.6	44.8	BARTEL	86C	JADE
$-\ 6.3 \pm 0.8 \pm 0.2$	-6.3	29	ASH	85	MAC
$-\ 4.9 \pm 1.5 \pm 0.5$	-5.9	29	DERRICK	85	HRS
$-\ 7.1 \pm 1.7$	-5.7	29	LEVI	83	MRK2
-16.1 ± 3.2	-9.2	34.2	BRANDELIK	82C	TASS

[1] ABBIENDI 01A error is almost entirely on account of statistics.

[2] BARATE 00C error is almost entirely on account of statistics.

[3] ABREU 95M perform this measurement using radiative muon-pair events associated with high-energy isolated photons.

[4] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.

[5] ABRAMS 89D asymmetry includes both 9 $\mu^+\mu^-$ and 15 $\tau^+\tau^-$ events.

[6] BACALA 89 systematic error is about 5%.

$A_{FB}^{(0,\tau)}$ CHARGE ASYMMETRY IN $e^+e^- \to \tau^+\tau^-$

OUR FIT is obtained using the fit procedure and correlations as determined by the LEP Electroweak Working Group (see the note "The Z boson" and ref. LEP-SLC 06). For the Z peak, we report the pole asymmetry defined by $(3/4)A_e A_\tau$ as determined by the nine-parameter fit to cross-section and lepton forward-backward asymmetry data.

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*		*TECN*
1.88± 0.17 OUR FIT					
1.45± 0.30	1.57	91.2	[1] ABBIENDI	01A	OPAL
2.41± 0.37	1.57	91.2	ABREU	00F	DLPH
2.60± 0.47	1.57	91.2	ACCIARRI	00C	L3
1.70± 0.28	1.57	91.2	[2] BARATE	00C	ALEP
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-32.8\ ^{+6.4}_{-6.2}\ \pm 1.5$	-32.1	56.9	[3] ABE	90I	VNS
$-\ 8.1 \pm 2.0 \pm 0.6$	-9.2	35	HEGNER	90	JADE
-18.4 ± 19.2	-24.9	52.0	[4] BACALA	89	AMY
-17.7 ± 26.1	-29.4	55.0	[4] BACALA	89	AMY
-45.9 ± 16.6	-31.2	56.0	[4] BACALA	89	AMY
-49.5 ± 18.0	-33.0	57.0	[4] BACALA	89	AMY
-20 ± 14	-25.9	53.3	ADACHI	88C	TOPZ
$-10.6 \pm 3.1 \pm 1.5$	-8.5	34.7	ADEVA	88	MRKJ
$-\ 8.5 \pm 6.6 \pm 1.5$	-15.4	43.8	ADEVA	88	MRKJ
$-\ 6.0 \pm 2.5 \pm 1.0$	8.8	34.6	BARTEL	85F	JADE
$-11.8 \pm 4.6 \pm 1.0$	14.8	43.0	BARTEL	85F	JADE
$-\ 5.5 \pm 1.2 \pm 0.5$	-0.063	29.0	FERNANDEZ	85A	MAC
$-\ 4.2 \pm 2.0$	0.057	29	LEVI	83	MRK2

−10.3 ± 5.2	−9.2	34.2	BEHREND 82	CELL
− 0.4 ± 6.6	−9.1	34.2	BRANDELIK 82C	TASS

[1] ABBIENDI 01A error includes approximately 0.26 due to statistics and 0.14 due to event selection systematics.

[2] BARATE 00C error includes approximately 0.26 due to statistics and 0.11 due to experimental systematics.

[3] ABE 90I measurements in the range 50 $\leq \sqrt{s} \leq$ 60.8 GeV.

[4] BACALA 89 systematic error is about 5%.

$A_{FB}^{(0,\ell)}$ CHARGE ASYMMETRY IN $e^+e^- \to \ell^+\ell^-$

For the Z peak, we report the pole asymmetry defined by $(3/4)A_\ell^2$ as determined by the five-parameter fit to cross-section and lepton forward-backward asymmetry data assuming lepton universality. For details see the note "The Z boson" and ref. LEP-SLC 06.

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*	*TECN*
1.71±0.10 OUR FIT				
1.45±0.17	1.57	91.2	[1] ABBIENDI 01A	OPAL
1.87±0.19	1.57	91.2	ABREU 00F	DLPH
1.92±0.24	1.57	91.2	ACCIARRI 00C	L3
1.73±0.16	1.57	91.2	[2] BARATE 00C	ALEP

[1] ABBIENDI 01A error includes approximately 0.15 due to statistics, 0.06 due to event selection systematics, and 0.03 due to the theoretical uncertainty in t-channel prediction.

[2] BARATE 00C error includes approximately 0.15 due to statistics, 0.04 due to experimental systematics, and 0.02 due to the theoretical uncertainty in t-channel prediction.

$A_{FB}^{(0,u)}$ CHARGE ASYMMETRY IN $e^+e^- \to u\overline{u}$

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*	*TECN*
4.0±6.7±2.8	**7.2**	**91.2**	[1] ACKERSTAFF 97T	OPAL

[1] ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types.

$A_{FB}^{(0,s)}$ CHARGE ASYMMETRY IN $e^+e^- \to s\overline{s}$

The s-quark asymmetry is derived from measurements of the forward-backward asymmetry of fast hadrons containing an s quark.

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*	*TECN*
9.8 ±1.1 OUR AVERAGE				
10.08±1.13±0.40	10.1	91.2	[1] ABREU 00B	DLPH
6.8 ±3.5 ±1.1	10.1	91.2	[2] ACKERSTAFF 97T	OPAL

[1] ABREU 00B tag the presence of an s quark requiring a high-momentum-identified charged kaon. The s-quark pole asymmetry is extracted from the charged-kaon asymmetry taking the expected d- and u-quark asymmetries from the Standard Model and using the measured values for the c- and b-quark asymmetries.

[2] ACKERSTAFF 97T measure the forward-backward asymmetry of various fast hadrons made of light quarks. Then using SU(2) isospin symmetry and flavor independence for down and strange quarks authors solve for the different quark types. The value reported here corresponds then to the forward-backward asymmetry for "down-type" quarks.

$A_{FB}^{(0,c)}$ CHARGE ASYMMETRY IN $e^+e^- \to c\overline{c}$

OUR FIT, which is obtained by a simultaneous fit to several *c*- and *b*-quark measurements as explained in the note "The *Z* boson" and ref. LEP-SLC 06, refers to the ***Z* pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*	*TECN*
7.07± 0.35 OUR FIT				
6.31± 0.93±0.65	6.35	91.26	[1] ABDALLAH 04F	DLPH
5.68± 0.54±0.39	6.3	91.25	[2] ABBIENDI 03P	OPAL
6.45± 0.57±0.37	6.10	91.21	[3] HEISTER 02H	ALEP
6.59± 0.94±0.35	6.2	91.235	[4] ABREU 99Y	DLPH
6.3 ± 0.9 ±0.3	6.1	91.22	[5] BARATE 98O	ALEP
6.3 ± 1.2 ±0.6	6.1	91.22	[6] ALEXANDER 97C	OPAL
8.3 ± 3.8 ±2.7	6.2	91.24	[7] ADRIANI 92D	L3
• • • We do not use the following data for averages, fits, limits, etc. • • •				
3.1 ± 3.5 ±0.5	−3.5	89.43	[1] ABDALLAH 04F	DLPH
11.0 ± 2.8 ±0.7	12.3	92.99	[1] ABDALLAH 04F	DLPH
− 6.8 ± 2.5 ±0.9	−3.0	89.51	[2] ABBIENDI 03P	OPAL
14.6 ± 2.0 ±0.8	12.2	92.95	[2] ABBIENDI 03P	OPAL
−12.4 ±15.9 ±2.0	−9.6	88.38	[3] HEISTER 02H	ALEP
− 2.3 ± 2.6 ±0.2	−3.8	89.38	[3] HEISTER 02H	ALEP
− 0.3 ± 8.3 ±0.6	0.9	90.21	[3] HEISTER 02H	ALEP
10.6 ± 7.7 ±0.7	9.6	92.05	[3] HEISTER 02H	ALEP
11.9 ± 2.1 ±0.6	12.2	92.94	[3] HEISTER 02H	ALEP
12.1 ±11.0 ±1.0	14.2	93.90	[3] HEISTER 02H	ALEP
− 4.96± 3.68±0.53	−3.5	89.434	[4] ABREU 99Y	DLPH
11.80± 3.18±0.62	12.3	92.990	[4] ABREU 99Y	DLPH
− 1.0 ± 4.3 ±1.0	−3.9	89.37	[5] BARATE 98O	ALEP
11.0 ± 3.3 ±0.8	12.3	92.96	[5] BARATE 98O	ALEP
3.9 ± 5.1 ±0.9	−3.4	89.45	[6] ALEXANDER 97C	OPAL
15.8 ± 4.1 ±1.1	12.4	93.00	[6] ALEXANDER 97C	OPAL
−12.9 ± 7.8 ±5.5	−13.6	35	BEHREND 90D	CELL
7.7 ±13.4 ±5.0	−22.1	43	BEHREND 90D	CELL
−12.8 ± 4.4 ±4.1	−13.6	35	ELSEN 90	JADE
−10.9 ±12.9 ±4.6	−23.2	44	ELSEN 90	JADE
−14.9 ± 6.7	−13.3	35	OULD-SAADA 89	JADE

[1] ABDALLAH 04F tag *b*– and *c*–quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of $c\overline{c}$ and $b\overline{b}$ events are obtained using lifetime information.

[2] ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the *b* and *c* quark forward-backward asymmetries as well as the average B^0-$\overline{B}^0$ mixing.

[3] HEISTER 02H measure simultaneously b and c quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.
[4] ABREU 99Y tag $Z \to b\overline{b}$ and $Z \to c\overline{c}$ events by an exclusive reconstruction of several D meson decay modes (D^{*+}, D^0, and D^+ with their charge-conjugate states).
[5] BARATE 98O tag $Z \to c\overline{c}$ events requiring the presence of high-momentum reconstructed D^{*+}, D^+, or D^0 mesons.
[6] ALEXANDER 97C identify the b and c events using a D/D^* tag.
[7] ADRIANI 92D use both electron and muon semileptonic decays.

$A_{FB}^{(0,b)}$ CHARGE ASYMMETRY IN $e^+e^- \to b\overline{b}$

OUR FIT, which is obtained by a simultaneous fit to several c- and b-quark measurements as explained in the note "The Z boson" and ref. LEP-SLC 06, refers to the ***Z* pole** asymmetry. The experimental values, on the other hand, correspond to the measurements carried out at the respective energies.

ASYMMETRY (%)	*STD. MODEL*	$\sqrt{s}$ *(GeV)*	*DOCUMENT ID*		*TECN*
9.92± 0.16 OUR FIT					
9.58± 0.32± 0.14	9.68	91.231	[1] ABDALLAH	05	DLPH
10.04± 0.56± 0.25	9.69	91.26	[2] ABDALLAH	04F	DLPH
9.72± 0.42± 0.15	9.67	91.25	[3] ABBIENDI	03P	OPAL
9.77± 0.36± 0.18	9.69	91.26	[4] ABBIENDI	02I	OPAL
9.52± 0.41± 0.17	9.59	91.21	[5] HEISTER	02H	ALEP
10.00± 0.27± 0.11	9.63	91.232	[6] HEISTER	01D	ALEP
7.62± 1.94± 0.85	9.64	91.235	[7] ABREU	99Y	DLPH
9.60± 0.66± 0.33	9.69	91.26	[8] ACCIARRI	99D	L3
9.31± 1.01± 0.55	9.65	91.24	[9] ACCIARRI	98U	L3
9.4 ± 2.7 ± 2.2	9.61	91.22	[10] ALEXANDER	97C	OPAL
• • • We do not use the following data for averages, fits, limits, etc. • • •					
6.37± 1.43± 0.17	5.8	89.449	[1] ABDALLAH	05	DLPH
10.41± 1.15± 0.24	12.1	92.990	[1] ABDALLAH	05	DLPH
6.7 ± 2.2 ± 0.2	5.7	89.43	[2] ABDALLAH	04F	DLPH
11.2 ± 1.8 ± 0.2	12.1	92.99	[2] ABDALLAH	04F	DLPH
4.7 ± 1.8 ± 0.1	5.9	89.51	[3] ABBIENDI	03P	OPAL
10.3 ± 1.5 ± 0.2	12.0	92.95	[3] ABBIENDI	03P	OPAL
5.82± 1.53± 0.12	5.9	89.50	[4] ABBIENDI	02I	OPAL
12.21± 1.23± 0.25	12.0	92.91	[4] ABBIENDI	02I	OPAL
−13.1 ±13.5 ± 1.0	3.2	88.38	[5] HEISTER	02H	ALEP
5.5 ± 1.9 ± 0.1	5.6	89.38	[5] HEISTER	02H	ALEP
− 0.4 ± 6.7 ± 0.8	7.5	90.21	[5] HEISTER	02H	ALEP
11.1 ± 6.4 ± 0.5	11.0	92.05	[5] HEISTER	02H	ALEP
10.4 ± 1.5 ± 0.3	12.0	92.94	[5] HEISTER	02H	ALEP
13.8 ± 9.3 ± 1.1	12.9	93.90	[5] HEISTER	02H	ALEP
4.36± 1.19± 0.11	5.8	89.472	[6] HEISTER	01D	ALEP
11.72± 0.97± 0.11	12.0	92.950	[6] HEISTER	01D	ALEP
5.67± 7.56± 1.17	5.7	89.434	[7] ABREU	99Y	DLPH
8.82± 6.33± 1.22	12.1	92.990	[7] ABREU	99Y	DLPH

6.11 ± 2.93 ± 0.43	5.9	89.50	[8] ACCIARRI	99D L3
13.71 ± 2.40 ± 0.44	12.2	93.10	[8] ACCIARRI	99D L3
4.95 ± 5.23 ± 0.40	5.8	89.45	[9] ACCIARRI	98U L3
11.37 ± 3.99 ± 0.65	12.1	92.99	[9] ACCIARRI	98U L3
− 8.6 ± 10.8 ± 2.9	5.8	89.45	[10] ALEXANDER	97C OPAL
− 2.1 ± 9.0 ± 2.6	12.1	93.00	[10] ALEXANDER	97C OPAL
$-71 \pm 34 {}^{+7}_{-8}$	−58	58.3	SHIMONAKA	91 TOPZ
−22.2 ± 7.7 ± 3.5	−26.0	35	BEHREND	90D CELL
−49.1 ± 16.0 ± 5.0	−39.7	43	BEHREND	90D CELL
−28 ± 11	−23	35	BRAUNSCH...	90 TASS
−16.6 ± 7.7 ± 4.8	−24.3	35	ELSEN	90 JADE
−33.6 ± 22.2 ± 5.2	−39.9	44	ELSEN	90 JADE
3.4 ± 7.0 ± 3.5	−16.0	29.0	BAND	89 MAC
−72 ± 28 ± 13	−56	55.2	SAGAWA	89 AMY

[1] ABDALLAH 05 obtain an enriched samples of $b\overline{b}$ events using lifetime information. The quark (or antiquark) charge is determined with a neural network using the secondary vertex charge, the jet charge and particle identification.

[2] ABDALLAH 04F tag b– and c–quarks using semileptonic decays combined with charge flow information from the hemisphere opposite to the lepton. Enriched samples of $c\overline{c}$ and $b\overline{b}$ events are obtained using lifetime information.

[3] ABBIENDI 03P tag heavy flavors using events with one or two identified leptons. This allows the simultaneous fitting of the b and c quark forward-backward asymmetries as well as the average B^0-$\overline{B}^0$ mixing.

[4] ABBIENDI 02I tag $Z^0 \rightarrow b\overline{b}$ decays using a combination of secondary vertex and lepton tags. The sign of the b-quark charge is determined using an inclusive tag based on jet, vertex, and kaon charges.

[5] HEISTER 02H measure simultaneously b and c quark forward-backward asymmetries using their semileptonic decays to tag the quark charge. The flavor separation is obtained with a discriminating multivariate analysis.

[6] HEISTER 01D tag $Z \rightarrow b\overline{b}$ events using the impact parameters of charged tracks complemented with information from displaced vertices, event shape variables, and lepton identification. The b-quark direction and charge is determined using the hemisphere charge method along with information from fast kaon tagging and charge estimators of primary and secondary vertices. The change in the quoted value due to variation of A^c_{FB} and R_b is given as $+0.103$ (A^c_{FB} – 0.0651) -0.440 (R_b – 0.21585).

[7] ABREU 99Y tag $Z \rightarrow b\overline{b}$ and $Z \rightarrow c\overline{c}$ events by an exclusive reconstruction of several D meson decay modes (D^{*+}, D^0, and D^+ with their charge-conjugate states).

[8] ACCIARRI 99D tag $Z \rightarrow b\overline{b}$ events using high p and p_T leptons. The analysis determines simultaneously a mixing parameter $\chi_b = 0.1192 \pm 0.0068 \pm 0.0051$ which is used to correct the observed asymmetry.

[9] ACCIARRI 98U tag $Z \rightarrow b\overline{b}$ events using lifetime and measure the jet charge using the hemisphere charge.

[10] ALEXANDER 97C identify the b and c events using a D/D^* tag.

CHARGE ASYMMETRY IN $e^+e^- \rightarrow q\overline{q}$

Summed over five lighter flavors.

Experimental and Standard Model values are somewhat event-selection dependent. Standard Model expectations contain some assumptions on B^0-$\overline{B}^0$ mixing and on other electroweak parameters.

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
$-$ 0.76±0.12±0.15		91.2	[1] ABREU	92I	DLPH
4.0 ±0.4 ±0.63	4.0	91.3	[2] ACTON	92L	OPAL
9.1 ±1.4 ±1.6	9.0	57.9	ADACHI	91	TOPZ
$-$ 0.84±0.15±0.04		91	DECAMP	91B	ALEP
8.3 ±2.9 ±1.9	8.7	56.6	STUART	90	AMY
11.4 ±2.2 ±2.1	8.7	57.6	ABE	89L	VNS
6.0 ±1.3	5.0	34.8	GREENSHAW	89	JADE
8.2 ±2.9	8.5	43.6	GREENSHAW	89	JADE

[1] ABREU 92I has 0.14 systematic error due to uncertainty of quark fragmentation.

[2] ACTON 92L use the weight function method on 259k selected $Z \rightarrow$ hadrons events. The systematic error includes a contribution of 0.2 due to B^0-$\overline{B}^0$ mixing effect, 0.4 due to Monte Carlo (MC) fragmentation uncertainties and 0.3 due to MC statistics. ACTON 92L derive a value of $\sin^2\theta_W^{\text{eff}}$ to be 0.2321 ± 0.0017 ± 0.0028.

CHARGE ASYMMETRY IN $p\overline{p} \rightarrow Z \rightarrow e^+e^-$

ASYMMETRY (%)	*STD. MODEL*	*$\sqrt{s}$ (GeV)*	*DOCUMENT ID*		*TECN*
• • • We do not use the following data for averages, fits, limits, etc. • • •					
5.2±5.9±0.4		91	ABE	91E	CDF

ANOMALOUS $ZZ\gamma$, $Z\gamma\gamma$, AND ZZV COUPLINGS

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In on-shell $Z\gamma$ production, deviations from the Standard Model for the $Z\gamma\gamma^*$ and $Z\gamma Z^*$ couplings may be described in terms of eight parameters, h_i^V $(i = 1, 4;\ V = \gamma, Z)$ [1]. The parameters h_i^γ describe the $Z\gamma\gamma^*$ couplings and the parameters h_i^Z the $Z\gamma Z^*$ couplings. In this formalism h_1^V and h_2^V lead to CP-violating and h_3^V and h_4^V to CP-conserving effects. All these anomalous contributions to the cross section increase rapidly with center-of-mass energy. In order to ensure unitarity, these parameters are usually described by a form-factor representation, $h_i^V(s) = h_{i\circ}^V/(1+s/\Lambda^2)^n$, where Λ is the energy scale for the manifestation of a new phenomenon and n is a sufficiently large power. By convention one uses $n = 3$ for $h_{1,3}^V$ and $n = 4$ for $h_{2,4}^V$. Usually limits on h_i^V's are put assuming some value of Λ, sometimes ∞.

In on-shell ZZ production, deviations from the Standard Model for the $ZZ\gamma^*$ and ZZZ^* couplings may be described by means of four anomalous couplings f_i^V $(i = 4, 5; V = \gamma, Z)$ [2]. As above, the parameters f_i^γ describe the $ZZ\gamma^*$ couplings and the parameters f_i^Z the ZZZ^* couplings. The anomalous couplings f_5^V lead to violation of C and P symmetries while f_4^V introduces CP violation. Also here, formfactors depending on a scale Λ are used.

All these couplings h_i^V and f_i^V are zero at tree level in the Standard Model; they are measured in e^+e^-, $p\bar{p}$ and pp collisions at LEP, Tevatron and LHC.

References

1. U. Baur and E.L. Berger, Phys. Rev. **D47**, 4889 (1993).
2. K. Hagiwara *et al.*, Nucl. Phys. **B282**, 253 (1987).

h_i^V

Combining the LEP-2 results taking into account the correlations, the following 95% CL limits are derived [SCHAEL 13A]:

$$-0.12 < h_1^Z < +0.11, \qquad -0.07 < h_2^Z < +0.07,$$
$$-0.19 < h_3^Z < +0.06, \qquad -0.04 < h_4^Z < +0.13,$$
$$-0.05 < h_1^\gamma < +0.05, \qquad -0.04 < h_2^\gamma < +0.02,$$
$$-0.05 < h_3^\gamma < +0.00, \qquad +0.01 < h_4^\gamma < +0.05.$$

Some of the recent results from the Tevatron and LHC experiments individually surpass the combined LEP-2 results in precision (see below).

VALUE	*DOCUMENT ID*	*TECN*	*COMMENT*

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

[1]	AAD	16Q	ATLS	$E^{pp}_{\rm cm}$ = 8 TeV
[2]	KHACHATRY...	16AE	CMS	$E^{pp}_{\rm cm}$ = 8 TeV
[3]	KHACHATRY...	15AC	CMS	$E^{pp}_{\rm cm}$ = 8 TeV
[4]	CHATRCHYAN	14AB	CMS	$E^{pp}_{\rm cm}$ = 7 TeV
[5]	AAD	13AN	ATLS	$E^{pp}_{\rm cm}$ = 7 TeV
[6]	CHATRCHYAN	13BI	CMS	$E^{pp}_{\rm cm}$ = 7 TeV
[7]	ABAZOV	12S	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
[8]	AALTONEN	11S	CDF	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
[9]	CHATRCHYAN	11M	CMS	$E^{pp}_{\rm cm}$ = 7 TeV
[10]	ABAZOV	09L	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
[11]	ABAZOV	07M	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.96 TeV
[12]	ABDALLAH	07C	DLPH	$E^{ee}_{\rm cm}$ = 183–208 GeV
[13]	ACHARD	04H	L3	$E^{ee}_{\rm cm}$ = 183–208 GeV
[14]	ABBIENDI,G	00C	OPAL	$E^{ee}_{\rm cm}$ = 189 GeV
[15]	ABBOTT	98M	D0	$E^{p\overline{p}}_{\rm cm}$ = 1.8 TeV
[16]	ABREU	98K	DLPH	$E^{ee}_{\rm cm}$ = 161, 172 GeV

[1] AAD 16Q study $Z\gamma$ production in pp collisions. In events with no additional jets, 10268 (12738) Z decays to electron (muon) pairs are selected, with an expected background of 1291 ± 340 (1537 ± 408) events, as well as 1039 Z decays to neutrino pairs with an expected background of 450 ± 96 events. Analyzing the photon transverse momentum distribution above 250 GeV (400 GeV) for lepton (neutrino) events, yields the 95% C.L. limits: $-7.8 \times 10^{-4} < h^{Z}_{3} < 8.6 \times 10^{-4}$, $-3.0 \times 10^{-6} < h^{Z}_{4} < 2.9 \times 10^{-6}$, $-9.5 \times 10^{-4} < h^{\gamma}_{3} < 9.9 \times 10^{-4}$, $-3.2 \times 10^{-6} < h^{\gamma}_{4} < 3.2 \times 10^{-6}$.

[2] KHACHATRYAN 16AE determine the $Z\gamma \to \nu\overline{\nu}\gamma$ cross section by selecting events with a photon of $E_T > 145$ GeV and $\not{E}_T > 140$ GeV. 630 candidate events are observed with an expected SM background of 269 ± 26. The E_T spectrum of the photon is used to set 95% C.L. limits as follows: $-1.5 \times 10^{-3} < h^{Z}_{3} < 1.6 \times 10^{-3}$, $-3.9 \times 10^{-6} < h^{Z}_{4} < 4.5 \times 10^{-6}$, $-1.1 \times 10^{-3} < h^{\gamma}_{3} < 0.9 \times 10^{-3}$, $-3.8 \times 10^{-6} < h^{\gamma}_{4} < 4.3 \times 10^{-6}$.

[3] KHACHATRYAN 15AC study $Z\gamma$ events in 8 TeV pp interactions, where the Z decays into 2 same-flavor, opposite sign leptons (e or μ) and a photon with $p_T > 15$ GeV. The p_T of a lepton is required to be > 20 GeV/c, their effective mass > 50 GeV, and the photon should have a separation ΔR > 0.7 with each lepton. The observed p_T distribution of the photons is used to extract the 95% C.L. limits: $-3.8 \times 10^{-3} < h^{Z}_{3} < 3.7 \times 10^{-3}$, $-3.1 \times 10^{-5} < h^{Z}_{4} < 3.0 \times 10^{-5}$, $-4.6 \times 10^{-3} < h^{\gamma}_{3} < 4.6 \times 10^{-3}$, $-3.6 \times 10^{-5} < h^{\gamma}_{4} < 3.5 \times 10^{-5}$.

[4] CHATRCHYAN 14AB measure $Z\gamma$ production cross section for $p^{\gamma}_{T} > 15$ GeV and R($\ell\gamma$) > 0.7, which is the separation between the γ and the final state charged lepton (e or μ) in the azimuthal angle-pseudorapidity ($\phi - \eta$) plane. The di-lepton mass is required to be > 50 GeV. After background subtraction the number of $ee\gamma$ and $\mu\mu\gamma$ events is determined to be 3160 ± 120 and 5030 ± 233 respectively, compatible with expectations from the SM. This leads to a 95% CL limits of $-1 \times 10^{-2} < h^{\gamma}_{3} < 1 \times 10^{-2}$, $-9 \times 10^{-5} < h^{\gamma}_{4} < 9 \times 10^{-5}$, $-9 \times 10^{-3} < h^{Z}_{3} < 9 \times 10^{-3}$, $-8 \times 10^{-5} < h^{Z}_{4} < 8 \times 10^{-5}$, assuming h^{V}_{1} and h^{V}_{2} have SM values, $V = \gamma$ or Z.

[5] AAD 13AN study $Z\gamma$ production in pp collisions. In events with no additional jet, 1417 (2031) Z decays to electron (muon) pairs are selected, with an expected background of

156 ± 54 (244 ± 64) events, as well as 662 Z decays to neutrino pairs with an expected background of 302 ± 42 events. Analysing the photon p_T spectrum above 100 GeV yields the 95% C.L. limts: $-0.013 < h_3^Z < 0.014$, $-8.7 \times 10^{-5} < h_4^Z < 8.7 \times 10^{-5}$, $-0.015 < h_3^\gamma < 0.016$, $-9.4 \times 10^{-5} < h_4^\gamma < 9.2 \times 10^{-5}$. Supersedes AAD 12BX.

[6] CHATRCHYAN 13BI determine the $Z\gamma \rightarrow \nu\overline{\nu}\gamma$ cross section by selecting events with a photon of $E_T > 145$ GeV and a $\not{E}_T > 130$ GeV. 73 candidate events are observed with an expected SM background of 30.2 ± 6.5. The E_T spectrum of the photon is used to set 95% C.L. limits as follows: $|h_3^Z| < 2.7\times10^{-3}$, $|h_4^Z| < 1.3\times10^{-5}$, $|h_3^\gamma| < 2.9\times10^{-3}$, $|h_4^\gamma| < 1.5\times10^{-5}$.

[7] ABAZOV 12S study $Z\gamma$ production in $p\overline{p}$ collisions at $\sqrt{s} = 1.96$ TeV using 6.2 fb^{-1} of data where the Z decays to electron (muon) pairs and the photon has at least 10 GeV of transverse momentum. In data, 304 (308) di-electron (di-muon) events are observed with an expected background of 255 ± 16 (285 ± 24) events. Based on the photon p_T spectrum, and including also earlier data and the $Z \rightarrow \nu\overline{\nu}$ decay mode (from ABAZOV 09L), the following 95% C.L. limits are reported: $|h_{03}^Z| < 0.026$, $|h_{04}^Z| < 0.0013$, $|h_{03}^\gamma| < 0.027$, $|h_{04}^\gamma| < 0.0014$ for a form factor scale of $\Lambda = 1.5$ TeV.

[8] AALTONEN 11S study $Z\gamma$ events in $p\overline{p}$ interactions at $\sqrt{s} = 1.96$ TeV with integrated luminosity 5.1 fb^{-1} for $Z \rightarrow e^+e^-/\mu^+\mu^-$ and 4.9 fb^{-1} for $Z \rightarrow \nu\overline{\nu}$. For the charged lepton case, the two leptons must be of the same flavor with the transverse momentum/energy of one > 20 GeV and the other > 10 GeV. The isolated photon must have $E_T > 50$ GeV. They observe 91 events with 87.2 ± 7.8 events expected from standard model processes. For the $\nu\overline{\nu}$ case they require solitary photons with $E_T > 25$ GeV and missing $E_T > 25$ GeV and observe 85 events with standard model expectation of 85.9 ± 5.6 events. Taking the form factor $\Lambda = 1.5$ TeV they derive 95% C.L. limits as $|h_3^{\gamma,Z}| < 0.022$ and $|h_4^{\gamma,Z}| < 0.0009$.

[9] CHATRCHYAN 11M study $Z\gamma$ production in pp collisions at $\sqrt{s} = 7$ TeV using 36 pb^{-1} pp data, where the Z decays to e^+e^- or $\mu^+\mu^-$. The total cross sections are measured for photon transverse energy $E_T^\gamma > 10$ GeV and spatial separation from charged leptons in the plane of pseudo rapidity and azimuthal angle $\Delta R(\ell,\gamma) > 0.7$ with the dilepton invariant mass requirement of $M_{\ell\ell} > 50$ GeV. The number of $e^+e^-\gamma$ and $\mu^+\mu^-\gamma$ candidates is 81 and 90 with estimated backgrounds of 20.5 ± 2.5 and 27.3 ± 3.2 events respectively. The 95% CL limits for $ZZ\gamma$ couplings are $-0.05 < h_3^Z < 0.06$ and $-0.0005 < h_4^Z < 0.0005$, and for $Z\gamma\gamma$ couplings are $-0.07 < h_3^\gamma < 0.07$ and $-0.0005 < h_4^\gamma < 0.0006$.

[10] ABAZOV 09L study $Z\gamma$, $Z \rightarrow \nu\overline{\nu}$ production in $p\overline{p}$ collisions at 1.96 TeV C.M. energy. They select 51 events with a photon of transverse energy E_T larger than 90 GeV, with an expected background of 17 events. Based on the photon E_T spectrum and including also Z decays to charged leptons (from ABAZOV 07M), the following 95% CL limits are reported: $|h_{30}^\gamma| < 0.033$, $|h_{40}^\gamma| < 0.0017$, $|h_{30}^Z| < 0.033$, $|h_{40}^Z| < 0.0017$.

[11] ABAZOV 07M use 968 $p\overline{p} \rightarrow e^+e^-/\mu^+\mu^-\gamma X$ candidates, at 1.96 TeV center of mass energy, to tag $p\overline{p} \rightarrow Z\gamma$ events by requiring $E_T(\gamma) > 7$ GeV, lepton-gamma separation $\Delta R_{\ell\gamma} > 0.7$, and di-lepton invariant mass > 30 GeV. The cross section is in agreement with the SM prediction. Using these $Z\gamma$ events they obtain 95% C.L. limits on each h_i^V, keeping all others fixed at their SM values. They report: $-0.083 < h_{30}^Z < 0.082$, $-0.0053 < h_{40}^Z < 0.0054$, $-0.085 < h_{30}^\gamma < 0.084$, $-0.0053 < h_{40}^\gamma < 0.0054$, for the form factor scale Λ= 1.2 TeV.

[12] Using data collected at $\sqrt{s} = 183$–208, ABDALLAH 07C select 1,877 $e^+e^- \rightarrow Z\gamma$ events with $Z \rightarrow q\overline{q}$ or $\nu\overline{\nu}$, 171 $e^+e^- \rightarrow ZZ$ events with $Z \rightarrow q\overline{q}$ or lepton pair

(except an explicit τ pair), and 74 $e^+e^- \to Z\gamma^*$ events with a $q\overline{q}\mu^+\mu^-$ or $q\overline{q}e^+e^-$ signature, to derive 95% CL limits on h_i^V. Each limit is derived with other parameters set to zero. They report: $-0.23 < h_1^Z < 0.23$, $-0.30 < h_3^Z < 0.16$, $-0.14 < h_1^\gamma < 0.14$, $-0.049 < h_3^\gamma < 0.044$.

[13] ACHARD 04H select 3515 $e^+e^- \to Z\gamma$ events with $Z \to q\overline{q}$ or $\nu\overline{\nu}$ at $\sqrt{s}$ = 189–209 GeV to derive 95% CL limits on h_i^V. For deriving each limit the other parameters are fixed at zero. They report: $-0.153 < h_1^Z < 0.141$, $-0.087 < h_2^Z < 0.079$, $-0.220 < h_3^Z < 0.112$, $-0.068 < h_4^Z < 0.148$, $-0.057 < h_1^\gamma < 0.057$, $-0.050 < h_2^\gamma < 0.023$, $-0.059 < h_3^\gamma < 0.004$, $-0.004 < h_4^\gamma < 0.042$.

[14] ABBIENDI,G 00C study $e^+e^- \to Z\gamma$ events (with $Z \to q\overline{q}$ and $Z \to \nu\overline{\nu}$) at 189 GeV to obtain the central values (and 95% CL limits) of these couplings: $h_1^Z = 0.000 \pm 0.100$ $(-0.190, 0.190)$, $h_2^Z = 0.000 \pm 0.068$ $(-0.128, 0.128)$, $h_3^Z = -0.074^{+0.102}_{-0.103}$ $(-0.269, 0.119)$, $h_4^Z = 0.046 \pm 0.068$ $(-0.084, 0.175)$, $h_1^\gamma = 0.000 \pm 0.061$ $(-0.115, 0.115)$, $h_2^\gamma = 0.000 \pm 0.041$ $(-0.077, 0.077)$, $h_3^\gamma = -0.080^{+0.039}_{-0.041}$ $(-0.164, -0.006)$, $h_4^\gamma = 0.064^{+0.033}_{-0.030}$ $(+0.007, +0.134)$. The results are derived assuming that only one coupling at a time is different from zero.

[15] ABBOTT 98M study $p\overline{p} \to Z\gamma + X$, with $Z \to e^+e^-$, $\mu^+\mu^-$, $\overline{\nu}\nu$ at 1.8 TeV, to obtain 95% CL limits at Λ= 750 GeV: $|h_{30}^Z| < 0.36$, $|h_{40}^Z| < 0.05$ (keeping h_i^γ=0), and $|h_{30}^\gamma| < 0.37$, $|h_{40}^\gamma| < 0.05$ (keeping h_i^Z=0). Limits on the *CP*-violating couplings are $|h_{10}^Z| < 0.36$, $|h_{20}^Z| < 0.05$ (keeping h_i^γ=0), and $|h_{10}^\gamma| < 0.37$, $|h_{20}^\gamma| < 0.05$ (keeping h_i^Z=0).

[16] ABREU 98K determine a 95% CL upper limit on $\sigma(e^+e^- \to \gamma +$ invisible particles$) <$ 2.5 pb using 161 and 172 GeV data. This is used to set 95% CL limits on $|h_{30}^\gamma| < 0.8$ and $|h_{30}^Z| < 1.3$, derived at a scale Λ=1 TeV and with n=3 in the form factor representation.

f_i^V

Combining the LEP-2 results taking into account the correlations, the following 95% CL limits are derived [SCHAEL 13A]:

$$-0.28 < f_4^Z < +0.32, \qquad -0.34 < f_5^Z < +0.35,$$
$$-0.17 < f_4^\gamma < +0.19, \qquad -0.35 < f_5^\gamma < +0.32.$$

Some of the recent results from the Tevatron and LHC experiments individually surpass the combined LEP-2 results in precision (see below).

VALUE	*DOCUMENT ID*		*TECN*	*COMMENT*
• • • We do not use the following data for averages, fits, limits, etc. • • •				
	[1] SIRUNYAN	21Q	CMS	$E_{\rm cm}^{pp}$ = 13 TeV
	[2] AABOUD	19AY	ATLS	$E_{\rm cm}^{pp}$ = 13 TeV
	[3] AABOUD	18Q	ATLS	$E_{\rm cm}^{pp}$ = 13 TeV
	[4] SIRUNYAN	18BT	CMS	$E_{\rm cm}^{pp}$ = 13 TeV
	[5] KHACHATRY...	15B	CMS	$E_{\rm cm}^{pp}$ = 8 TeV
	[6] KHACHATRY...	15BC	CMS	$E_{\rm cm}^{pp}$ = 7, 8 TeV

[7] AAD	13Z	ATLS	$E^{pp}_{\rm cm} = 7$ TeV
[8] CHATRCHYAN	13B	CMS	$E^{pp}_{\rm cm} = 7$ TeV
[9] SCHAEL	09	ALEP	$E^{ee}_{\rm cm} =$ 192–209 GeV
[10] ABAZOV	08K	D0	$E^{p\overline{p}}_{\rm cm} = 1.96$ TeV
[11] ABDALLAH	07C	DLPH	$E^{ee}_{\rm cm} =$ 183–208 GeV
[12] ABBIENDI	04C	OPAL	
[13] ACHARD	03D	L3	

[1] SIRUNYAN 21Q measure ZZ production where both Z bosons decay in the electron or muon channel. Analyzing the four-lepton invariant mass distribution, the following limits are derived at 95% C.L. in units of 10^{-4}: $-6.6 < f^Z_4 < 6.0$, $-5.5 < f^Z_5 < 7.5$, $-7.8 < f^\gamma_4 < 7.1$, $-6.8 < f^\gamma_5 < 7.5$. This set of parameters is linearly related to a set of EFT parameters, resulting in the following limits at 95% C.L. in units of TeV^{-4}: $-2.3 < c_{\widetilde{B}W}/\Lambda^4 < 2.5$, $-1.4 < c_{WW}/\Lambda^4 < 1.2$, $-1.4 < c_{BW}/\Lambda^4 < 1.3$, $-1.2 < c_{BB}/\Lambda^4 < 1.2$.

[2] AABOUD 19AY study ZZ production in the $\ell\ell\nu\nu$ decay channel. Events with a pair of isolated high-transverse momentum charged leptons (electron pairs or muon pairs), and with large missing energy, are selected. In the data, 371 (416) di-electron (di-muon) events are found, with a total expected background of 128 ± 8 (143 ± 8) events. Analysing the transverse momentum distribution of the charged dilepton system above 150 GeV, the following 95% C.L. limits are derived in units of 10^{-3}: $-1.2 < f^\gamma_4 < 1.2$, $-1.0 < f^Z_4 < 1.0$, $-1.2 < f^\gamma_5 < 1.2$, $-1.0 < f^Z_5 < 1.0$.

[3] AABOUD 18Q study $pp \rightarrow ZZ$ events at $\sqrt{s} = 13$ TeV with $Z \rightarrow e^+e^-$ or $Z \rightarrow \mu^+\mu^-$. The number of events observed in the $4e$, $2e\ 2\mu$, and 4μ channels is 249, 465, and 303 respectively. Analysing the p_T spectrum of the leading Z boson, the following the following 95% C.L. limits are derived in units of 10^{-4}: $-1.8 < f^\gamma_4 < 1.8$, $-1.5 < f^Z_4 < 1.5$, $-1.8 < f^\gamma_5 < 1.8$, $-1.5 < f^Z_5 < 1.5$.

[4] SIRUNYAN 18BT study $ppZZ$ events at $\sqrt{s} = 13$ TeV with $Z \rightarrow e^+e^-$ or $Z \rightarrow \mu^+\mu^-$. The number of events observed in the $4e$, $2e2\mu$, and 4μ channels is 220, 543 and 335 respectively. Analysing the 4-lepton invariant mass spectrum, the following 95% C.L. limits are derived in units of 10^{-3}: $-1.2 < f^\gamma_4 < 1.3$, $-1.2 < f^Z_4 < 1.0$, $-1.2 < f^\gamma_5 < 1.3$, $-1.0 < f^Z_5 < 1.3$.

[5] KHACHATRYAN 15B study ZZ production in 8 TeV pp collisions. In the decay modes $ZZ \rightarrow 4e$, 4μ, $2e2\mu$, 54, 75, 148 events are observed, with an expected background of 2.2 ± 0.9, 1.2 ± 0.6, and 2.4 ± 1.0 events, respectively. Analysing the 4-lepton invariant mass spectrum in the range from 110 GeV to 1200 GeV, the following 95% C.L. limits are obtained: $\left|f^Z_4\right| < 0.004$, $\left|f^Z_5\right| < 0.004$, $\left|f^\gamma_4\right| < 0.005$, $\left|f^\gamma_5\right| < 0.005$.

[6] KHACHATRYAN 15BC use the cross section measurement of the final state $pp \rightarrow ZZ \rightarrow 2\ell 2\nu$, ($\ell$ being an electron or a muon) at 7 and 8 TeV to put limits on these triple gauge couplings. Effective mass of the charged lepton pair is required to be in the range 83.5–98.5 GeV and the dilepton $p_T > 45$ GeV. The reduced missing E_T is required to be > 65 GeV, which takes into account the fake missing E_T due to detector effects. The numbers of e^+e^- and $\mu^+\mu^-$ events selected are 35 and 40 at 7 TeV and 176 and 271 at 8 TeV respectively. The production cross sections so obtained are in agreement with SM predictions. The following 95% C.L. limits are set: $-0.0028 < f^Z_4 < 0.0032$, $-0.0037 < f^\gamma_4 < 0.0033$, $-0.0029 < f^Z_5 < 0.0031$, $-0.0033 < f^\gamma_5 < 0.0037$. Combining with previous results (KHACHATRYAN 15B and CHATRCHYAN 13B) which include 7 TeV and 8 TeV data on the final states $pp \rightarrow ZZ \rightarrow 2\ell 2\ell'$ where ℓ and ℓ' are

an electron or a muon, the best limits are $-0.0022 < f_4^Z < 0.0026$, $-0.0029 < f_4^\gamma < 0.0026$, $-0.0023 < f_5^Z < 0.0023$, $-0.0026 < f_5^\gamma < 0.0027$.

[7] AAD 13Z study ZZ production in pp collisions at $\sqrt{s} = 7$ TeV. In the $ZZ \to \ell^+\ell^-\ell'^+\ell'^-$ final state they observe a total of 66 events with an expected background of 0.9 ± 1.3. In the $ZZ \to \ell^+\ell^-\nu\nu$ final state they observe a total of 87 events with an expected background of 46.9 ± 5.2. The limits on anomalous TGCs are determined using the observed and expected numbers of these ZZ events binned in p_T^Z. The 95% C.L. are as follows: for form factor scale $\Lambda = \infty$, $-0.015 < f_4^\gamma < 0.015$, $-0.013 < f_4^Z < 0.013$, $-0.016 < f_5^\gamma < 0.015$, $-0.013 < f_5^Z < 0.013$; for form factor scale $\Lambda = 3$ TeV, $-0.022 < f_4^\gamma < 0.023$, $-0.019 < f_4^Z < 0.019$, $-0.023 < f_5^\gamma < 0.023$, $-0.020 < f_5^Z < 0.019$.

[8] CHATRCHYAN 13B study ZZ production in pp collisions and select 54 ZZ candidates in the Z decay channel with electrons or muons with an expected background of 1.4 ± 0.5 events. The resulting 95% C.L. ranges are: $-0.013 < f_4^\gamma < 0.015$, $-0.011 < f_4^Z < 0.012$, $-0.014 < f_5^\gamma < 0.014$, $-0.012 < f_5^Z < 0.012$.

[9] Using data collected in the center of mass energy range 192–209 GeV, SCHAEL 09 select 318 $e^+e^- \to ZZ$ events with 319.4 expected from the standard model. Using this data they derive the following 95% CL limits: $-0.321 < f_4^\gamma < 0.318$, $-0.534 < f_4^Z < 0.534$, $-0.724 < f_5^\gamma < 0.733$, $-1.194 < f_5^Z < 1.190$.

[10] ABAZOV 08K search for ZZ and $Z\gamma^*$ events with 1 fb^{-1} $p\overline{p}$ data at $\sqrt{s} = 1.96$ TeV in $(ee)(ee)$, $(\mu\mu)(\mu\mu)$, $(ee)(\mu\mu)$ final states requiring the lepton pair masses to be > 30 GeV. They observe 1 event, which is consistent with an expected signal of 1.71 ± 0.15 events and a background of 0.13 ± 0.03 events. From this they derive the following limits, for a form factor (Λ) value of 1.2 TeV: $-0.28 < f_{40}^Z < 0.28$, $-0.31 < f_{50}^Z < 0.29$, $-0.26 < f_{40}^\gamma < 0.26$, $-0.30 < f_{50}^\gamma < 0.28$.

[11] Using data collected at $\sqrt{s} = 183$–208 GeV, ABDALLAH 07C select 171 $e^+e^- \to ZZ$ events with $Z \to q\overline{q}$ or lepton pair (except an explicit τ pair), and 74 $e^+e^- \to Z\gamma^*$ events with a $q\overline{q}\mu^+\mu^-$ or $q\overline{q}e^+e^-$ signature, to derive 95% CL limits on f_i^V. Each limit is derived with other parameters set to zero. They report: $-0.40 < f_4^Z < 0.42$, $-0.38 < f_5^Z < 0.62$, $-0.23 < f_4^\gamma < 0.25$, $-0.52 < f_5^\gamma < 0.48$.

[12] ABBIENDI 04C study ZZ production in e^+e^- collisions in the C.M. energy range 190–209 GeV. They select 340 events with an expected background of 180 events. Including the ABBIENDI 00N data at 183 and 189 GeV (118 events with an expected background of 65 events) they report the following 95% CL limits: $-0.45 < f_4^Z < 0.58$, $-0.94 < f_5^Z < 0.25$, $-0.32 < f_4^\gamma < 0.33$, and $-0.71 < f_5^\gamma < 0.59$.

[13] ACHARD 03D study Z-boson pair production in e^+e^- collisions in the C.M. energy range 200–209 GeV. They select 549 events with an expected background of 432 events. Including the ACCIARRI 99G and ACCIARRI 99O data (183 and 189 GeV respectively, 286 events with an expected background of 241 events) and the 192–202 GeV ACCIARRI 01I results (656 events, expected background of 512 events), they report the following 95% CL limits: $-0.48 \leq f_4^Z \leq 0.46$, $-0.36 \leq f_5^Z \leq 1.03$, $-0.28 \leq f_4^\gamma \leq 0.28$, and $-0.40 \leq f_5^\gamma \leq 0.47$.

ANOMALOUS *W*/*Z* QUARTIC COUPLINGS

Revised November 2015 by M.W. Grünewald (U. College Dublin) and A. Gurtu (Formerly Tata Inst.).

Quartic couplings, $WWZZ$, $WWZ\gamma$, $WW\gamma\gamma$, and $ZZ\gamma\gamma$, were studied at LEP and Tevatron at energies at which the Standard Model predicts negligible contributions to multiboson production. Thus, to parametrize limits on these couplings, an effective theory approach is adopted which supplements the Standard Model Lagrangian with higher dimensional operators which include quartic couplings. The LEP collaborations chose the lowest dimensional representation of operators (dimension 6) which presumes the SU(2)×U(1) gauge symmetry is broken by means other than the conventional Higgs scalar doublet [1–3]. In this representation possible quartic couplings, a_0, a_c, a_n, are expressed in terms of the following dimension-6 operators [1,2];

$$L_6^0 = -\frac{e^2}{16\Lambda^2}\, a_0\, F^{\mu\nu}\, F_{\mu\nu} \vec{W}^{\alpha} \cdot \vec{W}_{\alpha}$$

$$L_6^c = -\frac{e^2}{16\Lambda^2}\, a_c\, F^{\mu\alpha}\, F_{\mu\beta} \vec{W}^{\beta} \cdot \vec{W}_{\alpha}$$

$$L_6^n = -i\frac{e^2}{16\Lambda^2}\, a_n \epsilon_{ijk}\, W^{(i)}_{\mu\alpha}\, W^{(j)}_{\nu}\, W^{(k)\alpha} F^{\mu\nu}$$

$$\widetilde{L}_6^0 = -\frac{e^2}{16\Lambda^2}\, \widetilde{a}_0\, F^{\mu\nu}\, \widetilde{F}_{\mu\nu} \vec{W}^{\alpha} \cdot \vec{W}_{\alpha}$$

$$\widetilde{L}_6^n = -i\frac{e^2}{16\Lambda^2}\, \widetilde{a}_n \epsilon_{ijk}\, W^{(i)}_{\mu\alpha}\, W^{(j)}_{\nu}\, W^{(k)\alpha} \widetilde{F}^{\mu\nu}$$

where F, W are photon and W fields, L_6^0 and L_6^c conserve C, P separately ($\widetilde{L}_6^0$ conserves only C) and generate anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ couplings, L_6^n violates CP ($\widetilde{L}_6^n$ violates both C and P) and generates an anomalous $W^+W^-Z\gamma$ coupling, and Λ is an energy scale for new physics. For the $ZZ\gamma\gamma$ coupling the CP-violating term represented by L_6^n does not contribute. These couplings are assumed to be real and to vanish at tree level in the Standard Model.

Within the same framework as above, a more recent description of the quartic couplings [3] treats the anomalous parts of the $WW\gamma\gamma$ and $ZZ\gamma\gamma$ couplings separately, leading to two sets parametrized as a_0^V/Λ^2 and a_c^V/Λ^2, where $V = W$ or Z.

With the discovery of a Higgs at the LHC in 2012, it is then useful to go to the next higher dimensional representation (dimension 8 operators) in which the gauge symmetry is broken by the conventional Higgs scalar doublet [3,4]. There are 14 operators which can contribute to the anomalous quartic coupling signal. Some of the operators have analogues in the dimension 6 scheme. The CMS collaboration, [5], have used this parametrization, in which the connections between the two schemes are also summarized:

$$\begin{aligned}
\mathcal{L}_{AQGC} = &- \frac{e^2}{8}\frac{a_0^W}{\Lambda^2}F_{\mu\nu}F^{\mu\nu}W^{+a}W_a^- \\
&- \frac{e^2}{16}\frac{a_c^W}{\Lambda^2}F_{\mu\nu}F^{\mu a}(W^{+\nu}W_a^- + W^{-\nu}W_a^+) \\
&- e^2g^2\frac{\kappa_0^W}{\Lambda^2}F_{\mu\nu}Z^{\mu\nu}W^{+a}W_a^- \\
&- \frac{e^2g^2}{2}\frac{\kappa_c^W}{\Lambda^2}F_{\mu\nu}Z^{\mu a}(W^{+\nu}W_a^- + W^{-\nu}W_a^+) \\
&+ \frac{f_{T,0}}{\Lambda^4}Tr[\widehat{W}_{\mu\nu}\widehat{W}^{\mu\nu}] \times Tr[\widehat{W}_{\alpha\beta}\widehat{W}^{\alpha\beta}]
\end{aligned}$$

The energy scale of possible new physics is Λ, and $g = e/sin(\theta_W)$, e being the unit electric charge and θ_W the Weinberg angle. The field tensors are described in [3,4].

The two dimension 6 operators a_0^W/Λ^2 and a_c^W/Λ^2 are associated with the $WW\gamma\gamma$ vertex. Among dimension 8 operators, κ_0^W/Λ^2 and κ_c^W/Λ^2 are associated with the $WWZ\gamma$ vertex, whereas the parameter $f_{T,0}/\Lambda^4$ contributes to both vertices. There is a relationship between these two dimension 6 parameters and the dimension 8 parameters $f_{M,i}/\Lambda^4$ as follows [3]:

$$\frac{a_0^W}{\Lambda^2} = -\frac{4M_W^2}{g^2}\frac{f_{M,0}}{\Lambda^4} - \frac{8M_W^2}{g'^2}\frac{f_{M,2}}{\Lambda^4}$$

$$\frac{a_c^W}{\Lambda^2} = -\frac{4M_W^2}{g^2}\frac{f_{M,1}}{\Lambda^4} - \frac{8M_W^2}{g'^2}\frac{f_{M,3}}{\Lambda^4}$$

where $g' = e/cos(\theta_W)$ and M_W is the invariant mass of the W boson. This relation provides a translation between limits on dimension 6 operators $a_{0,c}^W$ and $f_{M,j}/\Lambda^4$. It is further required [4] that $f_{M,0} = 2f_{M,2}$ and $f_{M,1} = 2f_{M,3}$ which suppresses contributions to the $WWZ\gamma$ vertex. The complete set of Lagrangian contributions as presented in [4] corresponds to 19 anomalous couplings in total – $f_{S,i},\ i = 1, 2,\ f_{M,i},\ i = 0, \ldots, 8$ and $f_{T,i}, i = 0, \ldots, 9$ – each scaled by $1/\Lambda^4$.

The ATLAS collaboration [6], on the other hand, follows a K-matrix driven approach of Ref. 7 in which the anomalous couplings can be expressed in terms of two parameters α_4 and α_5, which account for all BSM effects.

It is the early stages in the determination of quartic couplings by the LHC experiments. It is hoped that the two collaborations, ATLAS and CMS, will agree to use at least one common set of parameters to express these limits to enable the reader to make a comparison and allow for a possible LHC combination.

References

1. G. Belanger and F. Boudjema, Phys. Lett. **B288**, 201 (1992).
2. J.W. Stirling and A. Werthenbach, Eur. Phys. J. **C14**, 103 (2000);
   J.W. Stirling and A. Werthenbach, Phys. Lett. **B466**, 369 (1999);
   A. Denner *et al.*, Eur. Phys. J. **C20**, 201 (2001);
   G. Montagna *et al.*, Phys. Lett. **B515**, 197 (2001).
3. G. Belanger *et al.*, Eur. Phys. J. **C13**, 283 (2000).

4. O.J.P. Éboli, M.C. Gonzalez-Garcia, and S.M. Lietti, Phys. Rev. **D69**, 095005 (2004);
   O.J.P. Éboli, M.C. Gonzalez-Garcia, and J.K. Mizukoshi, Phys. Rev. **D77**, 073005 (2006).
5. S. Chatrchyan *et al.*, Phys. Rev. **D90**, 032008 (2014);
   S. Chatrchyan *et al.*, Phys. Rev. Lett. **114**, 051801 (2015).
6. G. Aad *et al.*, Phys. Rev. Lett. **113**, 141803 (2014).
7. A. Albateanu, W. Killian, and J. Reuter, JHEP **0811**, 010 (2008).

a_0/Λ^2, a_c/Λ^2

Combining published and unpublished preliminary LEP results the following 95% CL intervals for the QGCs associated with the $ZZ\gamma\gamma$ vertex are derived (CERN-PH-EP/2005-051 or hep-ex/0511027):

$$-0.008 < a_0^Z/\Lambda^2 < +0.021$$
$$-0.029 < a_c^Z/\Lambda^2 < +0.039$$

Anomalous Z quartic couplings have also been measured by the Tevatron and LHC experiments. As discussed in the review on "Anomalous W/Z quartic couplings," the coupling parameters in the Anomalous QGC Lagrangian may relate to processes involving only the W or only to the Z or to both. Thus, results on all other AQGCs are reported together in the W listings.

VALUE	DOCUMENT ID		TECN
• • • We do not use the following data for averages, fits, limits, etc. • • •			
	[1] ABBIENDI	04L	OPAL
	[2] HEISTER	04A	ALEP
	[3] ACHARD	02G	L3

[1] ABBIENDI 04L select 20 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ acoplanar events in the energy range 180–209 GeV and 176 $e^+e^- \to q\overline{q}\gamma\gamma$ events in the energy range 130–209 GeV. These samples are used to constrain possible anomalous $W^+W^-\gamma\gamma$ and $ZZ\gamma\gamma$ quartic couplings. Further combining with the $W^+W^-\gamma$ sample of ABBIENDI 04B the following one–parameter 95% CL limits are obtained: $-0.007 < a_0^Z/\Lambda^2 < 0.023$ GeV^{-2}, $-0.029 < a_c^Z/\Lambda^2 < 0.029$ GeV^{-2}, $-0.020 < a_0^W/\Lambda^2 < 0.020$ GeV^{-2}, $-0.052 < a_c^W/\Lambda^2 < 0.037$ GeV^{-2}.

[2] In the CM energy range 183 to 209 GeV HEISTER 04A select 30 $e^+e^- \to \nu\overline{\nu}\gamma\gamma$ events with two acoplanar, high energy and high transverse momentum photons. The photon–photon acoplanarity is required to be $> 5°$, $E_\gamma/\sqrt{s} > 0.025$ (the more energetic photon having energy $> 0.2\sqrt{s}$), $p_{T_\gamma}/E_{\text{beam}} > 0.05$ and $|\cos\theta_\gamma| < 0.94$. A likelihood fit to the photon energy and recoil missing mass yields the following one–parameter 95% CL limits: $-0.012 < a_0^Z/\Lambda^2 < 0.019$ GeV^{-2}, $-0.041 < a_c^Z/\Lambda^2 < 0.044$ GeV^{-2}, $-0.060 < a_0^W/\Lambda^2 < 0.055$ GeV^{-2}, $-0.099 < a_c^W/\Lambda^2 < 0.093$ GeV^{-2}.

[3] ACHARD 02G study $e^+e^- \to Z\gamma\gamma \to q\overline{q}\gamma\gamma$ events using data at center-of-mass energies from 200 to 209 GeV. The photons are required to be isolated, each with energy $>$5 GeV and $|\cos\theta| < 0.97$, and the di-jet invariant mass to be compatible with that

of the *Z* boson (74–111 GeV). Cuts on *Z* velocity ($\beta < 0.73$) and on the energy of the most energetic photon reduce the backgrounds due to non-resonant production of the $q\overline{q}\gamma\gamma$ state and due to ISR respectively, yielding a total of 40 candidate events of which 8.6 are expected to be due to background. The energy spectra of the least energetic photon are fitted for all ten center-of-mass energy values from 130 GeV to 209 GeV (as obtained adding to the present analysis 130–202 GeV data of ACCIARRI 01E, for a total of 137 events with an expected background of 34.1 events) to obtain the fitted values $a_0/\Lambda^2 = 0.00^{+0.02}_{-0.01}$ GeV^{-2} and $a_c/\Lambda^2 = 0.03^{+0.01}_{-0.02}$ GeV^{-2}, where the other parameter is kept fixed to its Standard Model value (0). A simultaneous fit to both parameters yields the 95% CL limits -0.02 GeV^{-2} $< a_0/\Lambda^2 < 0.03$ GeV^{-2} and -0.07 GeV^{-2} $< a_c/\Lambda^2 < 0.05$ GeV^{-2}.

Z REFERENCES

AAD	21AO	NATP 17 819	G. Aad *et al.*	(ATLAS Collab.)
AAD	21AQ	JHEP 2107 005	G. Aad *et al.*	(ATLAS Collab.)
AAD	21AV	PRL 127 271801	G. Aad *et al.*	(ATLAS Collab.)
SIRUNYAN	21Q	EPJ C81 200	A.M. Sirunyan *et al.*	(CMS Collab.)
JANOT	20	PL B803 135319	P. Janot, S. Jadach	(CERN, CRAC)
VOUTSINAS	20	PL B800 135068	G. Voutsinas *et al.*	(CERN, BOHR)
AABOUD	19AY	JHEP 1910 127	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	19N	JHEP 1904 048	M. Aaboud *et al.*	(ATLAS Collab.)
RAINBOLT	19	PR D99 013004	J.L. Rainbolt, M. Schmitt	(NWES)
SIRUNYAN	19AJ	EPJ C79 94	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	19BR	PL B797 134811	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	18AU	JHEP 1807 127	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18BL	PL B786 134	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18CN	PR D98 092010	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	18Q	PR D97 032005	M. Aaboud *et al.*	(ATLAS Collab.)
AAIJ	18AR	JHEP 1809 159	R. Aaij *et al.*	(LHCb Collab.)
ANDREEV	18A	EPJ C78 777	V. Andreev *et al.*	(H1 Collab.)
SIRUNYAN	18BT	EPJ C78 165	A.M. Sirunyan *et al.*	(CMS Collab.)
SIRUNYAN	18DZ	PRL 121 141801	A.M. Sirunyan *et al.*	(CMS Collab.)
AABOUD	17Q	EPJ C77 367	M. Aaboud *et al.*	(ATLAS Collab.)
AABOUD	16K	PRL 117 111802	M. Aaboud *et al.*	(ATLAS Collab.)
AAD	16L	EPJ C76 210	G. Aad *et al.*	(ATLAS Collab.)
AAD	16Q	PR D93 112002	G. Aad *et al.*	(ATLAS Collab.)
ABRAMOWICZ	16A	PR D93 092002	H. Abramowicz *et al.*	(ZEUS Collab.)
ABT	16	PR D94 052007	I. Abt *et al.*	(MPIM, OXF, HAMB, DESY)
KHACHATRY...	16AE	PL B760 448	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	16CC	PL B763 280	V. Khachatryan *et al.*	(CMS Collab.)
AAD	15BT	JHEP 1509 049	G. Aad *et al.*	(ATLAS Collab.)
AAD	15I	PRL 114 121801	G. Aad *et al.*	(ATLAS Collab.)
KHACHATRY...	15AC	JHEP 1504 164	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15B	PL B740 250	V. Khachatryan *et al.*	(CMS Collab.)
KHACHATRY...	15BC	EPJ C75 511	V. Khachatryan *et al.*	(CMS Collab.)
AAD	14AU	PR D90 072010	G. Aad *et al.*	(ATLAS Collab.)
AAD	14N	PRL 112 231806	G. Aad *et al.*	(ATLAS Collab.)
AALTONEN	14E	PRL 112 111803	T. Aaltonen *et al.*	(CDF Collab.)
CHATRCHYAN	14AB	PR D89 092005	S. Chatrchyan *et al.*	(CMS Collab.)
AAD	13AN	PR D87 112003	G. Aad *et al.*	(ATLAS Collab.)
Also		PR D91 119901 (errat.)	G. Aad *et al.*	(ATLAS Collab.)
AAD	13Z	JHEP 1303 128	G. Aad *et al.*	(ATLAS Collab.)
CHATRCHYAN	13B	JHEP 1301 063	S. Chatrchyan *et al.*	(CMS Collab.)
CHATRCHYAN	13BI	JHEP 1310 164	S. Chatrchyan *et al.*	(CMS Collab.)
SCHAEL	13A	PRPL 532 119	S. Schael *et al.*	
AAD	12BX	PL B717 49	G. Aad *et al.*	(ATLAS Collab.)
ABAZOV	12S	PR D85 052001	V.M. Abazov *et al.*	(D0 Collab.)
CHATRCHYAN	12BN	JHEP 1212 034	S. Chatrchyan *et al.*	(CMS Collab.)
AALTONEN	11S	PRL 107 051802	T. Aaltonen *et al.*	(CDF Collab.)
ABAZOV	11D	PR D84 012007	V.M. Abazov *et al.*	(D0 Collab.)
CHATRCHYAN	11M	PL B701 535	S. Chatrchyan *et al.*	(CMS Collab.)
ABAZOV	09L	PRL 102 201802	V.M. Abazov *et al.*	(D0 Collab.)
BEDDALL	09	PL B670 300	A. Beddall, A. Beddall, A. Bingul	(UGAZ)
SCHAEL	09	JHEP 0904 124	S. Schael *et al.*	(ALEPH Collab.)
ABAZOV	08K	PRL 100 131801	V.M. Abazov *et al.*	(D0 Collab.)

ABAZOV	07M	PL B653 378	V.M. Abazov *et al.*	(D0 Collab.)
ABDALLAH	07C	EPJ C51 525	J. Abdallah *et al.*	(DELPHI Collab.)
ABDALLAH	06E	PL B639 179	J. Abdallah *et al.*	(DELPHI Collab.)
AKTAS	06	PL B632 35	A. Aktas *et al.*	(H1 Collab.)
LEP-SLC	06	PRPL 427 257	ALEPH, DELPHI, L3, OPAL, SLD and working groups	
SCHAEL	06A	PL B639 192	S. Schael *et al.*	(ALEPH Collab.)
ABDALLAH	05	EPJ C40 1	J. Abdallah *et al.*	(DELPHI Collab.)
ABDALLAH	05C	EPJ C44 299	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	05	PRL 94 091801	K. Abe *et al.*	(SLD Collab.)
ABE	05F	PR D71 112004	K. Abe *et al.*	(SLD Collab.)
ACOSTA	05M	PR D71 052002	D. Acosta *et al.*	(CDF Collab.)
ABBIENDI	04B	PL B580 17	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04C	EPJ C32 303	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04E	PL B586 167	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04G	EPJ C33 173	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	04L	PR D70 032005	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	04F	EPJ C34 109	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	04C	PR D69 072003	K. Abe *et al.*	(SLD Collab.)
ACHARD	04C	PL B585 42	P. Achard *et al.*	(L3 Collab.)
ACHARD	04H	PL B597 119	P. Achard *et al.*	(L3 Collab.)
HEISTER	04A	PL B602 31	A. Heister *et al.*	(ALEPH Collab.)
ABBIENDI	03P	PL B577 18	G. Abbiendi *et al.*	(OPAL Collab.)
ABDALLAH	03H	PL B569 129	J. Abdallah *et al.*	(DELPHI Collab.)
ABDALLAH	03K	PL B576 29	J. Abdallah *et al.*	(DELPHI Collab.)
ABE	03F	PRL 90 141804	K. Abe *et al.*	(SLD Collab.)
ACHARD	03D	PL B572 133	P. Achard *et al.*	(L3 Collab.)
ACHARD	03G	PL B577 109	P. Achard *et al.*	(L3 Collab.)
ABBIENDI	02I	PL B546 29	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	02G	PRL 88 151801	K. Abe *et al.*	(SLD Collab.)
ACHARD	02G	PL B540 43	P. Achard *et al.*	(L3 Collab.)
HEISTER	02B	PL B526 34	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	02C	PL B528 19	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	02H	EPJ C24 177	A. Heister *et al.*	(ALEPH Collab.)
ABBIENDI	01A	EPJ C19 587	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01G	EPJ C18 447	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01K	PL B516 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01N	EPJ C20 445	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	01O	EPJ C21 1	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	01B	PRL 86 1162	K. Abe *et al.*	(SLD Collab.)
ABE	01C	PR D63 032005	K. Abe *et al.*	(SLD Collab.)
ACCIARRI	01E	PL B505 47	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	01I	PL B497 23	M. Acciarri *et al.*	(L3 Collab.)
HEISTER	01	EPJ C20 401	A. Heister *et al.*	(ALEPH Collab.)
HEISTER	01D	EPJ C22 201	A. Heister *et al.*	(ALEPH Collab.)
ABBIENDI	00N	PL B476 256	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI,G	00C	EPJ C17 553	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	00B	PRL 84 5945	K. Abe *et al.*	(SLD Collab.)
ABE	00D	PRL 85 5059	K. Abe *et al.*	(SLD Collab.)
ABREU	00	EPJ C12 225	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00B	EPJ C14 613	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00E	EPJ C14 585	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00F	EPJ C16 371	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	00P	PL B475 429	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	00	EPJ C13 47	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00C	EPJ C16 1	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00J	PL B479 79	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	00Q	PL B489 93	M. Acciarri *et al.*	(L3 Collab.)
BARATE	00B	EPJ C16 597	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00C	EPJ C14 1	R. Barate *et al.*	(ALEPH Collab.)
BARATE	00O	EPJ C16 613	R. Barate *et al.*	(ALEPH Collab.)
ABBIENDI	99B	EPJ C8 217	G. Abbiendi *et al.*	(OPAL Collab.)
ABBIENDI	99I	PL B447 157	G. Abbiendi *et al.*	(OPAL Collab.)
ABE	99E	PR D59 052001	K. Abe *et al.*	(SLD Collab.)
ABE	99L	PRL 83 1902	K. Abe *et al.*	(SLD Collab.)
ABREU	99	EPJ C6 19	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99B	EPJ C10 415	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99J	PL B449 364	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99U	PL B462 425	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	99Y	EPJ C10 219	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	99D	PL B448 152	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99F	PL B453 94	M. Acciarri *et al.*	(L3 Collab.)

ACCIARRI	99G	PL B450 281	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	99O	PL B465 363	M. Acciarri *et al.*	(L3 Collab.)
ABBOTT	98M	PR D57 3817	B. Abbott *et al.*	(D0 Collab.)
ABE	98D	PRL 80 660	K. Abe *et al.*	(SLD Collab.)
ABE	98I	PRL 81 942	K. Abe *et al.*	(SLD Collab.)
ABREU	98K	PL B423 194	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	98L	EPJ C5 585	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	98G	PL B431 199	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98H	PL B429 387	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	98U	PL B439 225	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	98A	EPJ C5 411	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98E	EPJ C1 439	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98O	PL B420 157	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	98Q	EPJ C4 19	K. Ackerstaff *et al.*	(OPAL Collab.)
BARATE	98O	PL B434 415	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98T	EPJ C4 557	R. Barate *et al.*	(ALEPH Collab.)
BARATE	98V	EPJ C5 205	R. Barate *et al.*	(ALEPH Collab.)
ABE	97	PRL 78 17	K. Abe *et al.*	(SLD Collab.)
ABREU	97C	ZPHY C73 243	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	97E	PL B398 207	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	97G	PL B404 194	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	97D	PL B393 465	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97J	PL B407 351	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97L	PL B407 389	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	97R	PL B413 167	M. Acciarri *et al.*	(L3 Collab.)
ACKERSTAFF	97M	ZPHY C74 413	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97S	PL B412 210	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97T	ZPHY C76 387	K. Ackerstaff *et al.*	(OPAL Collab.)
ACKERSTAFF	97W	ZPHY C76 425	K. Ackerstaff *et al.*	(OPAL Collab.)
ALEXANDER	97C	ZPHY C73 379	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	97D	ZPHY C73 569	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	97E	ZPHY C73 587	G. Alexander *et al.*	(OPAL Collab.)
BARATE	97D	PL B405 191	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97E	PL B401 150	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97F	PL B401 163	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97H	PL B402 213	R. Barate *et al.*	(ALEPH Collab.)
BARATE	97J	ZPHY C74 451	R. Barate *et al.*	(ALEPH Collab.)
ABREU	96R	ZPHY C72 31	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	96S	PL B389 405	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	96U	ZPHY C73 61	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	96	PL B371 126	M. Acciarri *et al.*	(L3 Collab.)
ADAM	96	ZPHY C69 561	W. Adam *et al.*	(DELPHI Collab.)
ADAM	96B	ZPHY C70 371	W. Adam *et al.*	(DELPHI Collab.)
ALEXANDER	96B	ZPHY C70 197	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96F	PL B370 185	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96N	PL B384 343	G. Alexander *et al.*	(OPAL Collab.)
ALEXANDER	96R	ZPHY C72 1	G. Alexander *et al.*	(OPAL Collab.)
BUSKULIC	96D	ZPHY C69 393	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96H	ZPHY C69 379	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96T	PL B384 449	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	96Y	PL B388 648	D. Buskulic *et al.*	(ALEPH Collab.)
ABE	95J	PRL 74 2880	K. Abe *et al.*	(SLD Collab.)
ABREU	95	ZPHY C65 709 (erratum)	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95D	ZPHY C66 323	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95L	ZPHY C65 587	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95M	ZPHY C65 603	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95O	ZPHY C67 543	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95R	ZPHY C68 353	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95V	ZPHY C68 541	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95W	PL B361 207	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	95X	ZPHY C69 1	P. Abreu *et al.*	(DELPHI Collab.)
ACCIARRI	95B	PL B345 589	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	95C	PL B345 609	M. Acciarri *et al.*	(L3 Collab.)
ACCIARRI	95G	PL B353 136	M. Acciarri *et al.*	(L3 Collab.)
AKERS	95C	ZPHY C65 47	R. Akers *et al.*	(OPAL Collab.)
AKERS	95U	ZPHY C67 389	R. Akers *et al.*	(OPAL Collab.)
AKERS	95W	ZPHY C67 555	R. Akers *et al.*	(OPAL Collab.)
AKERS	95X	ZPHY C68 1	R. Akers *et al.*	(OPAL Collab.)
AKERS	95Z	ZPHY C68 203	R. Akers *et al.*	(OPAL Collab.)
ALEXANDER	95D	PL B358 162	G. Alexander *et al.*	(OPAL Collab.)
BUSKULIC	95R	ZPHY C69 15	D. Buskulic *et al.*	(ALEPH Collab.)

MIYABAYASHI	95	PL B347 171	K. Miyabayashi *et al.*	(TOPAZ Collab.)
ABE	94C	PRL 73 25	K. Abe *et al.*	(SLD Collab.)
ABREU	94B	PL B327 386	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	94P	PL B341 109	P. Abreu *et al.*	(DELPHI Collab.)
AKERS	94P	ZPHY C63 181	R. Akers *et al.*	(OPAL Collab.)
BUSKULIC	94G	ZPHY C62 179	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	94J	ZPHY C62 1	D. Buskulic *et al.*	(ALEPH Collab.)
VILAIN	94	PL B320 203	P. Vilain *et al.*	(CHARM II Collab.)
ABREU	93	PL B298 236	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	93I	ZPHY C59 533	P. Abreu *et al.*	(DELPHI Collab.)
Also		ZPHY C65 709 (erratum)	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	93L	PL B318 249	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	93	PL B305 407	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	93D	ZPHY C58 219	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	93E	PL B311 391	P.D. Acton *et al.*	(OPAL Collab.)
ADRIANI	93	PL B301 136	O. Adriani *et al.*	(L3 Collab.)
ADRIANI	93I	PL B316 427	O. Adriani *et al.*	(L3 Collab.)
BUSKULIC	93L	PL B313 520	D. Buskulic *et al.*	(ALEPH Collab.)
NOVIKOV	93C	PL B298 453	V.A. Novikov, L.B. Okun, M.I. Vysotsky	(ITEP)
ABREU	92I	PL B277 371	P. Abreu *et al.*	(DELPHI Collab.)
ABREU	92M	PL B289 199	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	92B	ZPHY C53 539	D.P. Acton *et al.*	(OPAL Collab.)
ACTON	92L	PL B294 436	P.D. Acton *et al.*	(OPAL Collab.)
ACTON	92N	PL B295 357	P.D. Acton *et al.*	(OPAL Collab.)
ADEVA	92	PL B275 209	B. Adeva *et al.*	(L3 Collab.)
ADRIANI	92D	PL B292 454	O. Adriani *et al.*	(L3 Collab.)
ALITTI	92B	PL B276 354	J. Alitti *et al.*	(UA2 Collab.)
BUSKULIC	92D	PL B292 210	D. Buskulic *et al.*	(ALEPH Collab.)
BUSKULIC	92E	PL B294 145	D. Buskulic *et al.*	(ALEPH Collab.)
DECAMP	92	PRPL 216 253	D. Decamp *et al.*	(ALEPH Collab.)
ABE	91E	PRL 67 1502	F. Abe *et al.*	(CDF Collab.)
ABREU	91H	ZPHY C50 185	P. Abreu *et al.*	(DELPHI Collab.)
ACTON	91B	PL B273 338	D.P. Acton *et al.*	(OPAL Collab.)
ADACHI	91	PL B255 613	I. Adachi *et al.*	(TOPAZ Collab.)
ADEVA	91I	PL B259 199	B. Adeva *et al.*	(L3 Collab.)
AKRAWY	91F	PL B257 531	M.Z. Akrawy *et al.*	(OPAL Collab.)
DECAMP	91B	PL B259 377	D. Decamp *et al.*	(ALEPH Collab.)
DECAMP	91J	PL B266 218	D. Decamp *et al.*	(ALEPH Collab.)
JACOBSEN	91	PRL 67 3347	R.G. Jacobsen *et al.*	(Mark II Collab.)
SHIMONAKA	91	PL B268 457	A. Shimonaka *et al.*	(TOPAZ Collab.)
ABE	90I	ZPHY C48 13	K. Abe *et al.*	(VENUS Collab.)
ABRAMS	90	PRL 64 1334	G.S. Abrams *et al.*	(Mark II Collab.)
AKRAWY	90J	PL B246 285	M.Z. Akrawy *et al.*	(OPAL Collab.)
BEHREND	90D	ZPHY C47 333	H.J. Behrend *et al.*	(CELLO Collab.)
BRAUNSCH...	90	ZPHY C48 433	W. Braunschweig *et al.*	(TASSO Collab.)
ELSEN	90	ZPHY C46 349	E. Elsen *et al.*	(JADE Collab.)
HEGNER	90	ZPHY C46 547	S. Hegner *et al.*	(JADE Collab.)
STUART	90	PRL 64 983	D. Stuart *et al.*	(AMY Collab.)
ABE	89	PRL 62 613	F. Abe *et al.*	(CDF Collab.)
ABE	89C	PRL 63 720	F. Abe *et al.*	(CDF Collab.)
ABE	89L	PL B232 425	K. Abe *et al.*	(VENUS Collab.)
ABRAMS	89B	PRL 63 2173	G.S. Abrams *et al.*	(Mark II Collab.)
ABRAMS	89D	PRL 63 2780	G.S. Abrams *et al.*	(Mark II Collab.)
ALBAJAR	89	ZPHY C44 15	C. Albajar *et al.*	(UA1 Collab.)
BACALA	89	PL B218 112	A. Bacala *et al.*	(AMY Collab.)
BAND	89	PL B218 369	H.R. Band *et al.*	(MAC Collab.)
GREENSHAW	89	ZPHY C42 1	T. Greenshaw *et al.*	(JADE Collab.)
OULD-SAADA	89	ZPHY C44 567	F. Ould-Saada *et al.*	(JADE Collab.)
SAGAWA	89	PRL 63 2341	H. Sagawa *et al.*	(AMY Collab.)
ADACHI	88C	PL B208 319	I. Adachi *et al.*	(TOPAZ Collab.)
ADEVA	88	PR D38 2665	B. Adeva *et al.*	(Mark-J Collab.)
BRAUNSCH...	88D	ZPHY C40 163	W. Braunschweig *et al.*	(TASSO Collab.)
ANSARI	87	PL B186 440	R. Ansari *et al.*	(UA2 Collab.)
BEHREND	87C	PL B191 209	H.J. Behrend *et al.*	(CELLO Collab.)
BARTEL	86C	ZPHY C30 371	W. Bartel *et al.*	(JADE Collab.)
Also		ZPHY C26 507	W. Bartel *et al.*	(JADE Collab.)
Also		PL 108B 140	W. Bartel *et al.*	(JADE Collab.)
ASH	85	PRL 55 1831	W.W. Ash *et al.*	(MAC Collab.)
BARTEL	85F	PL 161B 188	W. Bartel *et al.*	(JADE Collab.)
DERRICK	85	PR D31 2352	M. Derrick *et al.*	(HRS Collab.)
FERNANDEZ	85A	PRL 54 1620	E. Fernandez *et al.*	(MAC Collab.)

LEVI	83	PRL 51 1941	M.E. Levi *et al.*	(Mark II Collab.)
BEHREND	82	PL 114B 282	H.J. Behrend *et al.*	(CELLO Collab.)
BRANDELIK	82C	PL 110B 173	R. Brandelik *et al.*	(TASSO Collab.)