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Preliminary L3 Results on Electroweak Parameters from 1990–96 Data

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Abstract

In this note we present preliminary L3 results on electroweak parameters for the 1997 winter conferences. The data used include the measurements of the total hadronic and leptonic cross sections and the leptonic forward–backward asymmetries performed in 1990–96. We add our results on tau polarisation asymmetries, the b–quark forward–backward asymmetry and the partial decay width of the Z boson into b–quarks to derive the couplings of charged leptons to the Z and to perform Standard Model fits. Published data are combined with recent preliminary results.

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1 Introduction

This note summarises the electroweak parameters determined from our published Z pole data collected up to 1992 [1], the improved measurements of total cross sections and forward–backward asymmetries of the 1993 and 1994 data [2–5] as well as preliminary measurements of the Z resonance scan performed in 1995. For the results in the S–Matrix framework we also use the published measurements of the 1995 run at centre–of–mass (cms) energies between 130 and 140 GeV [6] and the preliminary measurements at centre–of–mass energies between 161 and 172 GeV taken in 1996. The improved results on 1993/94 cross sections and asymmetries and the inclusion of the 1995 scan result in significant improvements in the precision of Z parameters.

We also update our fits in the Standard Model (SM) framework where we include L3 results from tau polarisation asymmetries, the b–quark forward–backward asymmetry, the partial decay width of the Z into b–quarks and the new results of the quark charge asymmetry and the W boson mass.

2 Data samples for total cross sections and forward–backward asymmetries

The data samples and results obtained in 1990–92 remain unchanged [1]. In 1993/94 we collected a total integrated luminosity of 74.9 pb^{-1} out of which 17.1 pb^{-1} were taken at cms energies approximately 1.8 GeV below and above the mass of the Z (referred to as peak-2 and peak$+2$ in the following). A total luminosity of 19.4 pb^{-1} has been recorded during the 1995 scan of the Z with 15.2 pb^{-1} taken at the peak-2 and peak$+2$ energies. We do not use 1995 data taken at the peak before the start of the scan (August 4th) corresponding to approximately 9.5 pb^{-1} because their average cms energy has not yet been determined with sufficient precision. The data samples at energies in the vicinity of the Z resonance are summarised in Table 1. For fits in the S–Matrix framework total cross sections and forward–backward asymmetries measured between 130 and 140 GeV [3, 6] and between 161 and 172 GeV corresponding to 5 pb^{-1} and 20 pb^{-1}, respectively, are included.

The systematic uncertainties on the determination of the total luminosity, the systematic errors on the cross section measurements and the systematic errors on the leptonic forward–backward asymmetries are summarised in Table 2. The numbers for 1995 are preliminary and represent conservative estimates of the current understanding of the data. The integrated luminosity is determined from the number of observed small angle Bhabha events. The total error of the luminosity measurement quoted in Table 2 includes a theoretical part describing the precision of the calculation of the observed cross section of small angle Bhabha scattering. This contribution amounts to 0.25% for the 1990–92 data and to 0.11% for the later years.

3 LEP energy calibration

The precise measurement of the cms energy and its uncertainty are important for the determination of the mass and total width of the Z boson. For our fits we use the cms energies and their errors at the L3 interaction point as provided by the working group on LEP energy. The precise energies of the 1993 scan as described in [7] and used in our previous compilations of electroweak parameters had to be revised after the discovery of an energy rise during fills (‘train effect') not taken into account before [8, 9]. Here we use the results of a preliminary combined analysis of the 1993 to 1995 LEP running periods [10]. The revised analysis leads to average cms energies in 1993 and 1994 which are $3-4$ MeV lower than previously determined.

The errors on the cms energies for the two scans performed in 1993 and 1995 are given in the form of a 6×6 covariance matrix (Table 3) which includes the uncertainty on the modelling of the train effect [10]. The error for the 1993 pre–scan period (18 MeV) remains unchanged while the uncertainty on the 1994 cms energy is now estimated to be 4.5 MeV comprising the preliminary error assignment of 4 MeV [11] and an additional component of 2 MeV from the train effect. The errors of these two run periods are uncorrelated to any other run period. The energies and errors of the runs in 1990–92 as described in [12, 13] remain unchanged.

A new analysis has been performed to improve the precision on the spread of the LEP cms energy [10] in 1993–95. While the central value remains essentially unchanged (≈ 55 MeV) its error is reduced to ± 1.1 MeV (1993/94) and ± 1.3 MeV (1995). Here we use 55 ± 1 MeV for the determination of the beam spread factors which causes a neglible contribution to the error on the total width Γ_Z.

4 Determination of Z parameters

The programs ZFITTER 4.9 [14], SMATASY 4.9 [15] and ALIBABA [16] are used for the calculations of theoretical predictions for total cross sections and forward–backward asymmetries. The results are compared to the SM predicitions using the following parameters [17–19]:

$$\begin{aligned} m_Z &= 91\,188 \text{ MeV} \\ m_t &= 175 \text{ GeV} \\ m_H &= 300 \text{ GeV} \\ 1/\alpha(m_Z) &= 128.896 \\ \alpha_s &= 0.123\,. \end{aligned} \tag{1}$$

Electroweak parameters are determined in a χ^2 fit using the MINUIT [20] program. The χ^2 is constructed from our measurements, their errors including the correlations and the theoretical expectations. Apart from experimental statistical and systematic errors we take into account uncertainties of the LEP cms energy. Theoretical errors on calculations of cross sections and asymmetries are small compared to our experimental accuracy and do not introduce sizeable uncertainties for the parameters determined below [21]. The only exception is the t–channel and st–interference contribution to the e^+e^- final state where we include a 0.2% error to the total cross section (0.002 for A_{fb}) from the ALIBABA calculations.

4.1 Mass, total and partial width of the Z

We determine the mass, the total width and partial decay widths of the Z into hadrons, electrons, muons and taus in a fit to the measured total cross sections. These parameters describe the contribution of the Z exchange to the total cross section. Photon exchange and the γZ interference contributions are added with their SM expectations. Two fits are performed with and without assuming lepton universality where in the first one a common leptonic width is obtained defined as the decay widths of the Z boson into a pair of massless charged leptons. The results of both fits are summarized in Table 4. The measured cross sections are compared in Figures 1, 2, 3 and 4 to the result of the fit assuming lepton universality. From this fit we also derive the partial widths of the Z decaying into invisible particles, Γ_{inv}, and the number of light neutrino generations, N_ν (Table 4).

To estimate the contributions of the uncertainty of the LEP energy to the mass and the total width we repeat the lepton universality fit to the 1993–95 cross sections with and without including the errors on the LEP energy. From quadratic subtraction of the errors of the fitted parameters we find

$$\Delta m_{\mathrm{Z}}(\mathrm{LEP}) = 1.5 \quad \mathrm{MeV} \qquad \Delta\Gamma_{\mathrm{Z}}(\mathrm{LEP}) = 1.4 \quad \mathrm{MeV}\,. \tag{2}$$

Other ways of estimating these errors give slightly larger numbers [17].

4.2 Fits to total cross sections and forward–backward asymmetries

We include our measurements of the leptonic forwardbackward asymmetries and perform fits for m_{Z}, Γ_{Z}, σ^0_{had}, R_ℓ and $\mathrm{A}^{0,\ell}_{\mathrm{fb}}$ with

$$\begin{aligned}
\sigma^0_{\mathrm{had}} &= \frac{12\pi}{m_{\mathrm{Z}}^2}\frac{\Gamma_{\mathrm{e}}\Gamma_{\mathrm{had}}}{\Gamma_{\mathrm{Z}}^2} \\
R_\ell &= \frac{\Gamma_{\mathrm{had}}}{\Gamma_\ell} \\
\mathrm{A}^{0,\ell}_{\mathrm{fb}} &= \frac{3}{4}A_{\mathrm{e}}\,A_\ell \quad \text{with } A_\ell = \frac{2\,\bar{\mathrm{g}}^\ell_{\mathrm{V}}\bar{\mathrm{g}}^\ell_{\mathrm{A}}}{(\bar{\mathrm{g}}^\ell_{\mathrm{V}})^2 + (\bar{\mathrm{g}}^\ell_{\mathrm{A}})^2}
\end{aligned} \tag{3}$$

The measured asymmetries are parametrised using effective vector and axial–vector couplings, $\bar{\mathrm{g}}_{\mathrm{V}}$ and $\bar{\mathrm{g}}_{\mathrm{A}}$. The leptonic widths and the leptonic γZ interference terms are expressed in these couplings allowing the interference term to be free in the fit. Since the hadronic final state events are a mixture of different quark final states with different couplings this parametrisation cannot be applied. The results for the two fits with and without assuming lepton universality are shown in Table 5. The correlation matrices of the fit parameters can be found in Tables 6 and 7. The measured leptonic forward–backward asymmetries are compared to the fit result in Figures 5, 6 and 7.

From the leptonic pole forward–backward asymmetry $\mathrm{A}^{0,\ell}_{\mathrm{fb}}$ we obtain the effective weak mixing angle defined as

$$\sin^2\overline{\theta}_{\mathrm{W}} = \frac{1}{4}\left(1 - \frac{\bar{\mathrm{g}}_{\mathrm{V}}}{\bar{\mathrm{g}}_{\mathrm{A}}}\right) \tag{4}$$

The result is compared in Table 8 to the efective weak mixing angles derived from the L3 results on tau polarisation and b–quark forward–backward asymmetry.

To determine the effective vector and axial–vector coupling constants of charged leptons we include the L3 result on tau polarisation [22, 23]:

$$A_{\mathrm{e}} = 0.156 \pm 0.017 \qquad A_\tau = 0.152 \pm 0.013 \tag{5}$$

The results are summarised in Table 9.

The test of lepton universality can be quantified by forming ratios of coupling constants. The ratios of muon and tau axial–vector and vector coupling constants with respect to the electron are displayed in Table 10.

4.3 Fits in the S–Matrix framework

We update our fits in the S–Matrix framework [24] which makes a minimum of theoretical assumptions. Details on this fitting approach can be found in [1, 3].

A particularity of the S–Matrix approach is the fact that the hadronic γZ interference term, $j^{\rm tot}_{\rm had}$, is not taken from the SM but is left free in the fit. Due to a strong correlation with the Z boson mass the error on $m_{\rm Z}$ in this fit is significantly enlarged as compared to the results quoted above. The γZ interference terms can be constrained using cross section and asymmetry measurement far away from the Z peak. Hence we include our cross section and forward–backward asymmetry measurements at high effective cms energies obtained during the 1995 LEP run at high energies (130 GeV $\leq \sqrt{s} \leq$ 140 GeV) [6] and during 1996 LEP running (161 GeV $\leq \sqrt{s} \leq$ 172 GeV).

The fitted S–Matrix parameters for hadrons electrons, muons and taus are listed in Table 11. Their correlations are given in Tables 12 and 13 for the two fits with and without assuming lepton universality. The mass and total width of the Z can be directly compared to the results given in Tables 4 and 5 as the different definition of the these two quantities in the S–Matrix ansatz has been corrected for.

The solid line in Figure 9 shows the correlation contour between $m_{\rm Z}$ and $j^{\rm tot}_{\rm had}$ obtained from the fit assuming lepton universality. Comparing the results for $m_{\rm Z}$ obtained with fixed hadronic interfence term and the result of the S–Matrix approach one finds that the experimental uncertainty on $j^{\rm tot}_{\rm had}$ adds an uncertainty of approximately $\pm$4.8 MeV to $m_{\rm Z}$.

5 Standard Model fits

We interpret our measurements in the framework of the SM to determine its parameters and to check its consistency by comparing our results to other measurements. Fits are performed to the set of SM parameters given in Equation 1. The program ZFITTER 4.9 [14] is used for SM calculations. In all fits the QED coupling constant at the Z–boson mass, $\alpha(m_{\rm Z})$, is constrained to the value obtained in Reference [18]:

$$1/\alpha(m_{\rm Z}) = 128.896 \pm 0.090 \tag{6}$$

The uncertainty on this parameter causes an error of $\pm$0.00023 on the SM prediction of the effective electroweak mixing angle $\sin^2\overline{\theta}_{\rm W}$ and a contribution of $\pm$4 GeV to the error of the fitted top mass.

The input data for the SM fits are the results of the fit to the total cross sections and forward–backward asymmetries assuming lepton universality (Tables 5 and 7). In addition, we include our measured tau polarisation asymmetries (Equation 5), the b–quark forward–backward asymmetry [25] $\mathrm{A}^{0,\rm b}_{\rm fb} = 0.0975 \pm 0.0076$, the partial width into b–quarks [26] $R_{\rm b} = 0.2185 \pm 0.0043$, the new result on the quark charge asymmetry which is converted into $\sin^2\overline{\theta}_{\rm W} = 0.2336 \pm 0.0019$ [27] and the new measurement of the W boson mass $m_{\rm W} = 80.75 \pm 0.28$ [28].

The first fit is performed for a fixed Higgs mass $m_{\rm H}$=300 GeV:

$$\begin{aligned} m_{\rm t} &= 187^{+13}_{-14} \pm 16(m_{\rm H}) \ \ \text{GeV} \\ \alpha_{\rm s} &= 0.126 \pm 0.006 \pm 0.002(m_{\rm H}) \end{aligned} \tag{7}$$

The second errors indicates the shift of the central values when fixing the Higgs mass to 60 and 1000 GeV.

The value for α_s is in good agreement with our determination of the strong coupling constant from hadronic event topologies and tau decays, α_s=0.123±0.006 [29]. Constraining α_s to this independent measurement improves the fit result for the top mass:

$$m_t = 189^{+12}_{-13} \pm 17 \ \ \text{GeV} \tag{8}$$

From this result we can derive the value of the electroweak radiative corrections Δr, the mass of the W boson, the on–shell ($\sin^2\theta_W$) and the effective ($\sin^2\overline{\theta}_W$) weak mixing angle:

$$\begin{aligned} \Delta r &= 0.0338^{+0.0050}_{-0.0050}{}^{+0.0005}_{-0.0008} \\ m_W &= 80.406^{+0.083}_{-0.085}{}^{+0.012}_{-0.008} \\ \sin^2\theta_W &= 0.2225 \pm 0.0016 \pm 0.0002 \\ \sin^2\overline{\theta}_W &= 0.23152 \pm 0.00044 \, {}^{+0.00008}_{-0.00024} \end{aligned} \tag{9}$$

Constraining the top mass to the combined value from the direct measurement of DØ and CDF, m_t=175.6±5.5 GeV, we can use our measurements to derive an estimate and an upper limit of the mass of the SM Higgs boson:

$$\begin{aligned} m_H &= 91^{+230}_{-\ 81} \ \ \text{GeV} \\ &< 645 \ \ \text{GeV} \qquad 95\% \ \text{CL} \end{aligned} \tag{10}$$

Figure 10 shows the 68% CL contour in the m_t–m_H plane. The fit for the Higgs mass is in agreement with the result of the direct search for the SM Higgs boson m_H>68.2 GeV [30]. Theory errors are not taken into account which would increase the upper bound on m_H in Equation 10.

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	1990/91	1992	1993	1994	1995
N_{ECMS}	7+7	1	3	1	3
$\mathcal{L}$ [pb$^{-\infty}$]	18.4	22.4	31.7	43.2	19.4
hadrons	416	678	646	1 307	311
bhabhas	16	22	23	43	12
muons	14	21	21	42	9
taus	10	15	20	42	7

Table 1: Number of events (in thousand) selected for cross section measurements of the four final states considered in different years at $\sqrt{s} \approx m_{\mathrm{Z}}$. N_{ECMS} indicates the number of different cms energies.

	1990	1991	1992	1993	1994	1995
$\delta\mathcal{L}$ [%]	0.6	0.6	0.6	0.15	0.14	0.17
$\delta\sigma$ (had) [%]	0.3	0.15	0.15	0.052	0.051	0.1
$\delta\sigma$ (e) [%]	0.4	0.3	0.3	0.27-0.32	0.23	1.0
$\delta\sigma$ (μ) [%]	0.8	0.5	0.5	0.31-0.32	0.31	1.0
$\delta\sigma$ (τ) [%]	0.9	0.7	0.7	0.64-0.71	0.65	0.6
$\delta\mathrm{A}_{\mathrm{fb}}$ (e)	0.004	0.004	0.002	0.003	0.003	0.01
$\delta\mathrm{A}_{\mathrm{fb}}$ (μ)	0.005	0.002	0.002	0.0008	0.0008	0.005
$\delta\mathrm{A}_{\mathrm{fb}}$ (τ)	0.005	0.005	0.003	0.003	0.003	0.003

Table 2: Summary of systematic uncertainties on the integrated luminosity, total cross sections and forward–backward asymmetries for the data taken at the Z resonance.

		1993			1995		
		peak–2	peak	peak+2	peak–2	peak	peak+2
1993	peak−2	8.38	4.39	4.27	0.43	0.03	−0.01
	peak		39.95	6.87	0.15	1.74	0.67
	peak+2			9.38	0.15	1.45	1.32
1995	peak−2				2.56	1.43	1.23
	peak					22.18	2.11
	peak+2						5.40

Table 3: The combined covariance matrix of the LEP cms energy uncertainty for the two scans of the Z resonance performed in 1993 and 1995 [10]. All values are given in units of MeV^2.

Parameter	Treatment of Charged Leptons		Standard
	non–universality	universality	Model
m_Z [MeV]	$91\,188.1\pm2.9$	$91\,188.1\pm2.9$	—
Γ_Z [MeV]	$2\,499.8\pm4.3$	$2\,499.8\pm4.3$	$2\,495.9$
Γ_{had} [MeV]	$1\,745.2\pm5.5$	$1\,745.6\pm4.2$	$1\,742.9$
Γ_e [MeV]	83.99 ± 0.26	—	
Γ_μ [MeV]	83.78 ± 0.47	—	
Γ_τ [MeV]	84.10 ± 0.62	—	
Γ_ℓ [MeV]	—	83.98 ± 0.19	83.92
Γ_{inv} [MeV]		502.5 ± 3.4	501.4
N_ν		3.001 ± 0.017	3

Table 4: Results of the fits to the 1990–95 total cross section data with and without assuming lepton universality. The Z resonance is parametrised using a Breit–Wigner with constant γZ interference term. From these results the invisible width Γ_{inv} and the number of light neutrino generations N_ν are derived.

Parameter	Treatment of Charged Leptons		Standard
	non–universality	universality	Model
m_Z [MeV]	$91\,188.3\pm2.9$	$91\,188.3\pm2.9$	—
Γ_Z [MeV]	$2\,499.6\pm4.3$	$2\,499.6\pm4.3$	$2\,495.9$
σ^0_{had} [nb^{-1}]	41.411 ± 0.074	41.411 ± 0.074	41.452
R_e	20.78 ± 0.11	—	
R_μ	20.84 ± 0.10	—	
R_τ	20.75 ± 0.14	—	
R_ℓ	—	20.788 ± 0.066	20.768
$A^{0,\mu}_{fb}$	0.0148 ± 0.0063	—	
$A^{0,\mu}_{fb}$	0.0176 ± 0.0035	—	
$A^{0,\tau}_{fb}$	0.0233 ± 0.0049	—	
$A^{0,\ell}_{fb}$	—	0.0187 ± 0.0026	0.0154

Table 5: Results of the fits to the 1990–95 total cross section and forward–backward asymmetry measurements with and without assuming lepton universality. The Z resonance is parametrised using a Breit–Wigner with constant hadronic γZ interference term and a vector and axial–vector coupling ansatz for the leptonic cross sections and asymmetries.

	m_Z	Γ_Z	σ^0_{had}	R_e	R_μ	R_τ	$A_{fb}^{0,\mu}$	$A_{fb}^{0,\mu}$	$A_{fb}^{0,\tau}$
m_Z	1.000	0.115	−0.059	−0.008	0.000	−0.001	0.042	0.053	0.039
Γ_Z		1.000	−0.257	−0.017	−0.009	0.000	0.005	−0.001	−0.001
σ^0_{had}			1.000	0.062	0.092	0.065	0.021	0.000	0.001
R_e				1.000	0.036	0.030	−0.111	0.014	0.009
R_μ					1.000	0.026	0.000	0.016	0.000
R_τ						1.000	−0.003	0.003	0.018
$A_{fb}^{0,\mu}$							1.000	−0.005	−0.003
$A_{fb}^{0,\mu}$								1.000	0.007
$A_{fb}^{0,\tau}$									1.000

Table 6: Correlation matrix of the parameters listed in table 5 not assuming lepton uinversality.

	m_Z	Γ_Z	σ^0_{had}	R_ℓ	$A_{fb}^{0,\ell}$
m_Z	1.000	0.115	−0.059	−0.005	0.077
Γ_Z		1.000	−0.258	−0.015	0.001
σ^0_{had}			1.000	0.125	0.009
R_ℓ				1.000	−0.007
$A_{fb}^{0,\ell}$					1.000

Table 7: Correlation matrix of the parameters listed in table 5 assuming lepton uinversality.

Input data	$\sin^2\overline{\theta}_W$
$A_{fb}^{0,\ell}$	0.2301±0.0014
tau pol.	0.2307±0.0013
$A_{fb}^{0,b}$	0.2304±0.0020
Average	0.2304±0.0009

Table 8: Determination of the effective weak mixing angle $\sin^2\overline{\theta}_W$ from different reactions. The SM prediction is $\sin^2\overline{\theta}_W$=0.2320.

Parameter	Treatment of Charged Leptons		Standard Model
	non–universality	universality	
$\bar{g}_A^e$	−0.5011±0.0008	—	
$\bar{g}_A^\mu$	−0.5006±0.0015	—	
$\bar{g}_A^\tau$	−0.5015±0.0019	—	
$\bar{g}_A^\ell$	—	−0.5010±0.0006	−0.5012
$\bar{g}_V^e$	−0.0396±0.0034	—	
$\bar{g}_V^\mu$	$-0.0374^{+0.0085}_{-0.0079}$	—	
$\bar{g}_V^\tau$	−0.0394±0.0032	—	
$\bar{g}_V^\ell$	—	$-0.0398^{+0.0027}_{-0.0029}$	−0.0361

Table 9: Results for the axial–vector and vector coupling constants of charged leptons as obtained from fits to the total cross sections and forward–backward asymmetries and including our results from tau polarisation asymmetries.

$\bar{g}_A^{\mu}/\bar{g}_A^{e}$	0.9990±0.0037
$\bar{g}_A^{\tau}/\bar{g}_A^{e}$	1.0008±0.0042
$\bar{g}_V^{\mu}/\bar{g}_V^{e}$	0.95±0.25
$\bar{g}_V^{\tau}/\bar{g}_V^{e}$	0.99±0.12

Table 10: Ratios of axial–vector and vector couplings constant obtain from a fit to the total cross sections and forward–backward asymmetries including our results from tau polarisation.

Parameter	Treatment of Charged Leptons		Standard Model
	non–universality	universality	
m_Z [MeV]	91 185.5±5.6	91 185.4±5.6	—
Γ_Z [MeV]	2 500.3±4.3	2 499.9±4.3	2 495.9
r_{had}^{tot}	2.972±0.010	2.971±0.010	2.965
r_e^{tot}	0.14266±0.00088	—	
r_μ^{tot}	0.14251±0.00083	—	
r_τ^{tot}	0.1433±0.0011	—	
r_ℓ^{tot}	—	0.14264±0.00066	0.14251
j_{had}^{tot}	0.34±0.28	0.34±0.28	0.22
j_e^{tot}	–0.009±0.046	—	
j_μ^{tot}	0.037±0.036	—	
j_τ^{tot}	0.047±0.039	—	
j_ℓ^{tot}	—	0.031±0.025	0.004
r_e^{fb}	0.0024±0.0013	—	
r_μ^{fb}	0.00321±0.00067	—	
r_τ^{fb}	0.00417±0.00096	—	
r_ℓ^{fb}	—	0.00327±0.00050	0.00265
j_e^{fb}	0.649±0.080	—	
j_μ^{fb}	0.837±0.047	—	
j_τ^{fb}	0.787±0.057	—	
j_ℓ^{fb}	—	0.788±0.033	0.799

Table 11: Results of the fits to the 1990–95 data within the S–Matrix framework with and without assuming lepton universality.

	m_Z	Γ_Z	r_{had}^{tot}	r_ℓ^{tot}	j_{had}^{tot}	j_ℓ^{tot}	r_ℓ^{fb}	j_ℓ^{fb}
m_Z	1.000	–0.103	–0.084	–0.066	–0.849	–0.487	0.142	–0.045
Γ_Z		1.000	0.870	0.666	0.166	0.077	0.006	0.053
r_{had}^{tot}			1.000	0.720	0.164	0.063	0.017	0.055
r_ℓ^{tot}				1.000	0.116	0.100	0.035	0.077
j_{had}^{tot}					1.000	0.452	–0.119	0.046
j_ℓ^{tot}						1.000	–0.036	0.093
r_ℓ^{fb}							1.000	0.145
j_ℓ^{fb}								1.000

Table 12: Correlation of the S–Matrix parameters listed in table 11 assuming lepton universality.

	m_{Z}	Γ_{Z}	$r^{\mathrm{tot}}_{\mathrm{had}}$	$r^{\mathrm{tot}}_{\mathrm{e}}$	r^{tot}_{μ}	r^{tot}_{τ}	$j^{\mathrm{tot}}_{\mathrm{had}}$	$j^{\mathrm{tot}}_{\mathrm{e}}$	j^{tot}_{μ}	j^{tot}_{τ}	$r^{\mathrm{fb}}_{\mathrm{e}}$	r^{fb}_{μ}	r^{fb}_{τ}	$j^{\mathrm{fb}}_{\mathrm{e}}$	j^{fb}_{μ}	j^{fb}_{τ}
m_{Z}	1.000	–0.101	–0.082	–0.043	–0.053	–0.040	–0.849	–0.309	–0.317	–0.301	0.058	0.106	0.075	–0.014	–0.039	–0.024
Γ_{Z}		1.000	0.870	0.503	0.528	0.405	0.165	0.017	0.059	0.060	0.001	0.006	0.008	–0.006	0.047	0.036
$r^{\mathrm{tot}}_{\mathrm{had}}$			1.000	0.550	0.568	0.435	0.162	–0.004	0.055	0.054	0.013	0.011	0.012	–0.014	0.050	0.039
$r^{\mathrm{tot}}_{\mathrm{e}}$				1.000	0.337	0.258	0.085	0.003	0.032	0.031	0.101	–0.006	–0.001	–0.042	0.029	0.022
r^{tot}_{μ}					1.000	0.266	0.091	–0.002	0.126	0.034	0.008	0.028	0.007	–0.009	0.093	0.024
r^{tot}_{τ}						1.000	0.070	–0.001	0.027	0.126	0.006	0.005	0.034	–0.007	0.024	0.093
$j^{\mathrm{tot}}_{\mathrm{had}}$							1.000	0.283	0.295	0.281	–0.047	–0.091	–0.063	0.011	0.040	0.026
$j^{\mathrm{tot}}_{\mathrm{e}}$								1.000	0.106	0.101	–0.025	–0.033	–0.023	0.186	0.011	0.007
j^{tot}_{μ}									1.000	0.105	–0.018	0.013	–0.023	0.004	0.069	0.010
j^{tot}_{τ}										1.000	–0.017	–0.031	0.013	0.004	0.014	0.060
$r^{\mathrm{fb}}_{\mathrm{e}}$											1.000	–0.003	–0.001	0.014	–0.002	–0.001
r^{fb}_{μ}												1.000	0.014	0.000	0.173	–0.001
r^{fb}_{τ}													1.000	0.000	–0.002	0.172
$j^{\mathrm{fb}}_{\mathrm{e}}$														1.000	0.000	0.000
j^{fb}_{μ}															1.000	0.003
j^{fb}_{τ}																1.000

Table 13: Correlation of the S–Matrix parameters listed in table 11 not assuming lepton universality.

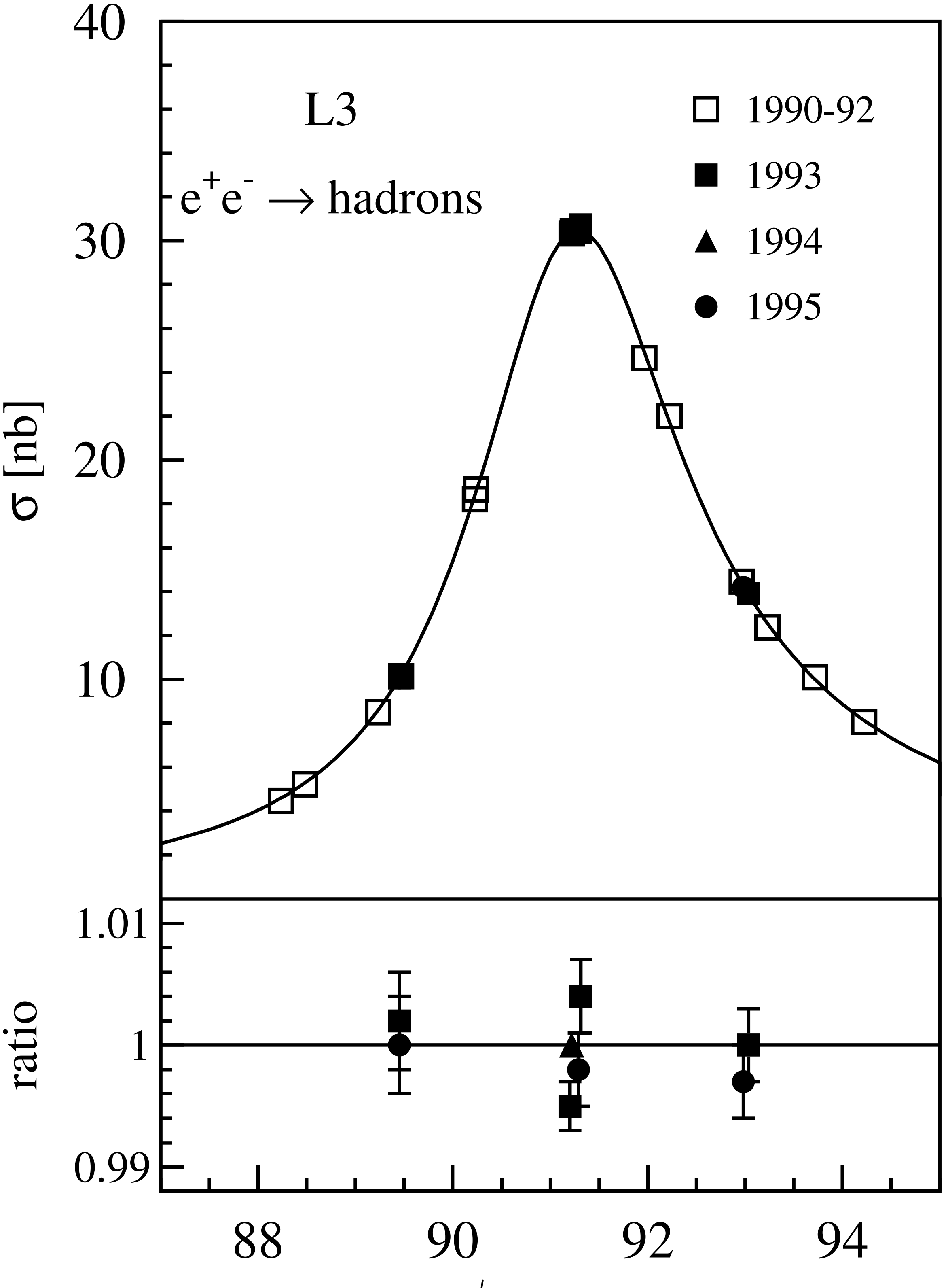

Figure 1: The measured cross sections $e^+e^- \to \text{hadrons}(\gamma)$ as function of the cms energy. The solid line shows the result of the fit. At the bottom the ratio of the measured cross section and the fit result for the data collected in 1993–95 is shown.

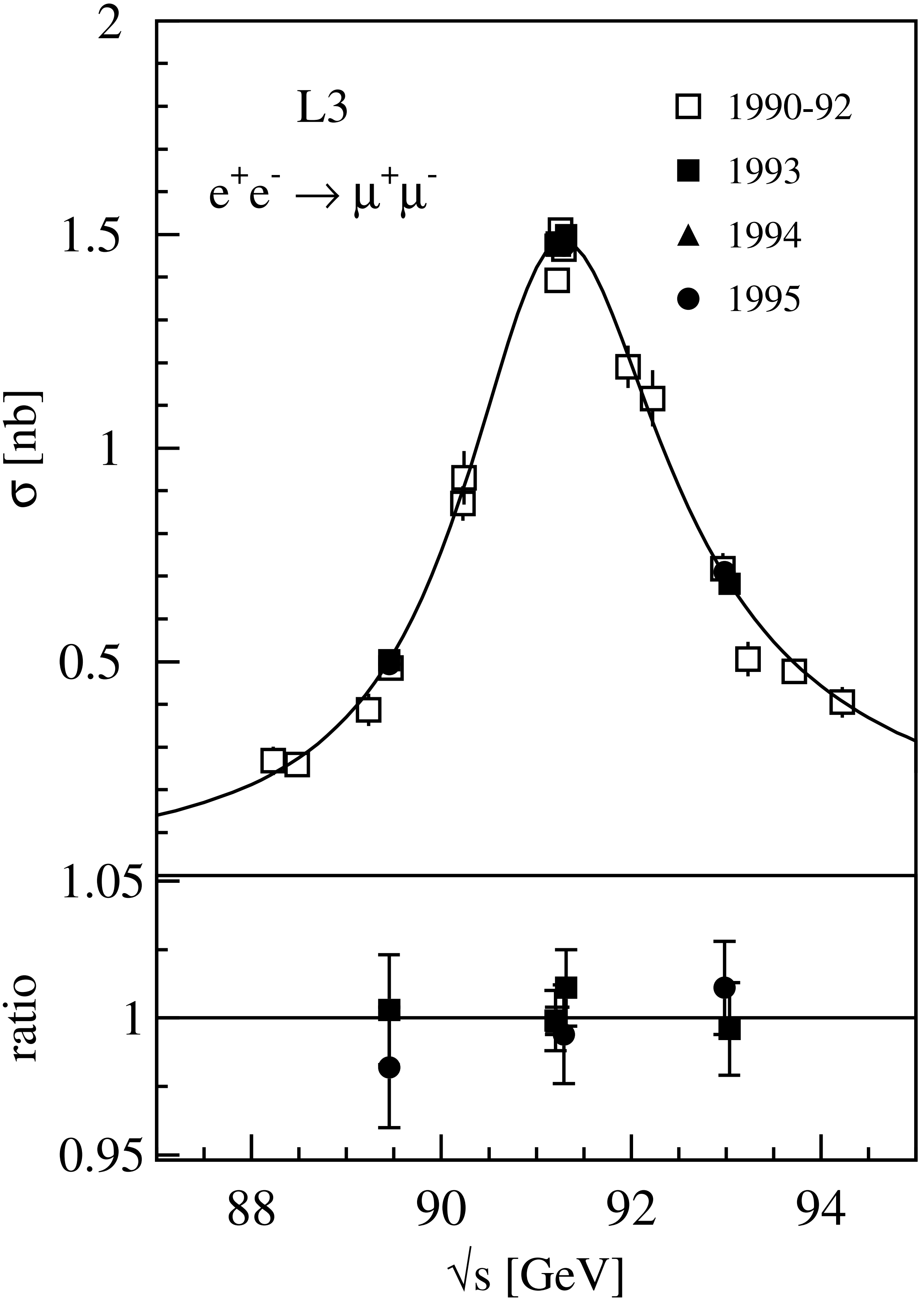

Figure 2: Same as figure 1 for $e^+e^- \to \mu^+\mu^-(\gamma)$.

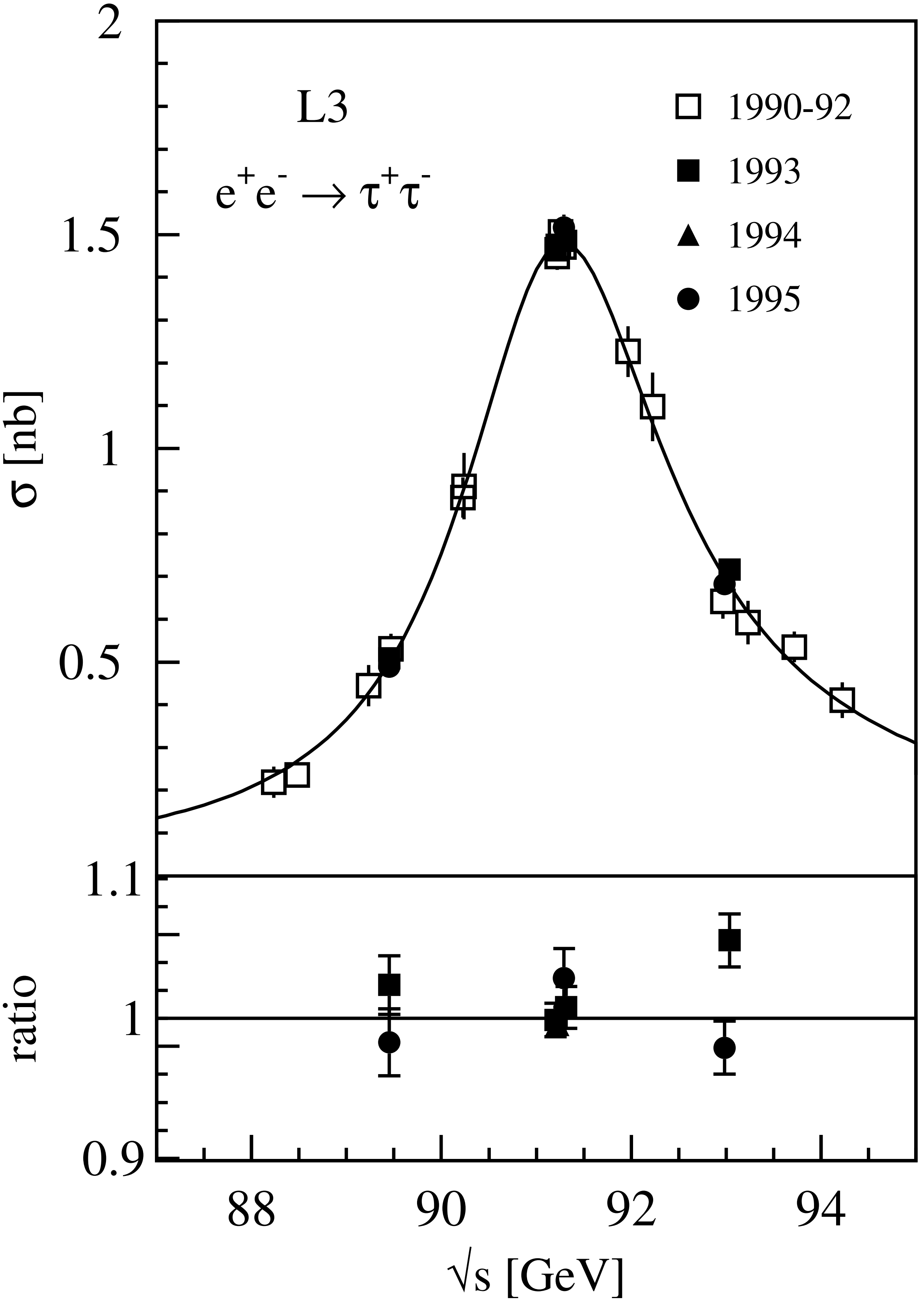

Figure 3: Same as figure 1 for $e^+e^- \to \tau^+\tau^-(\gamma)$.

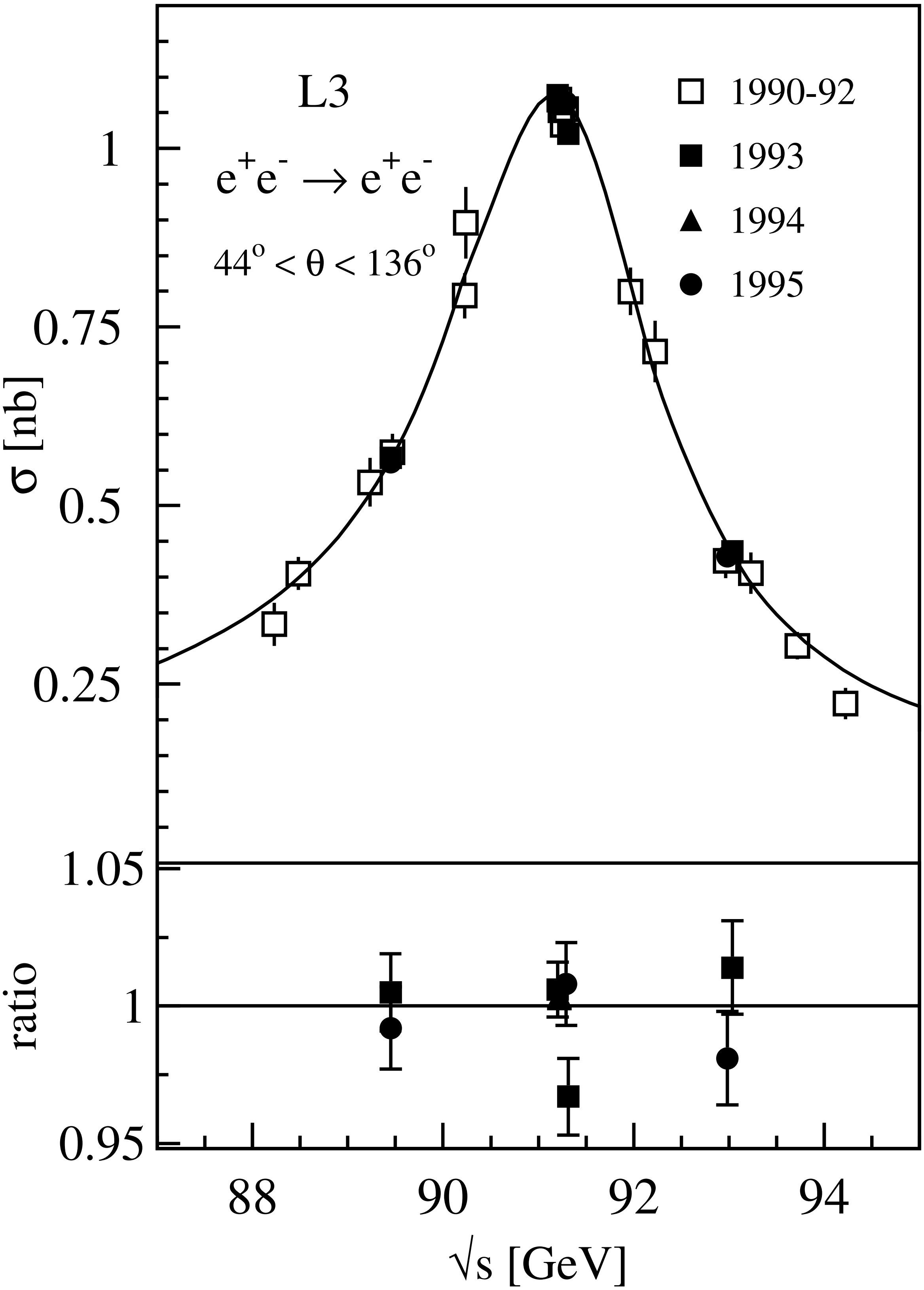

Figure 4: Same as figure 1 for $e^+e^- \rightarrow e^+e^-(\gamma)$ for scattering angles $44^\circ < \Theta_e < 136^\circ$ and acollinearity $\xi < 25^\circ$.

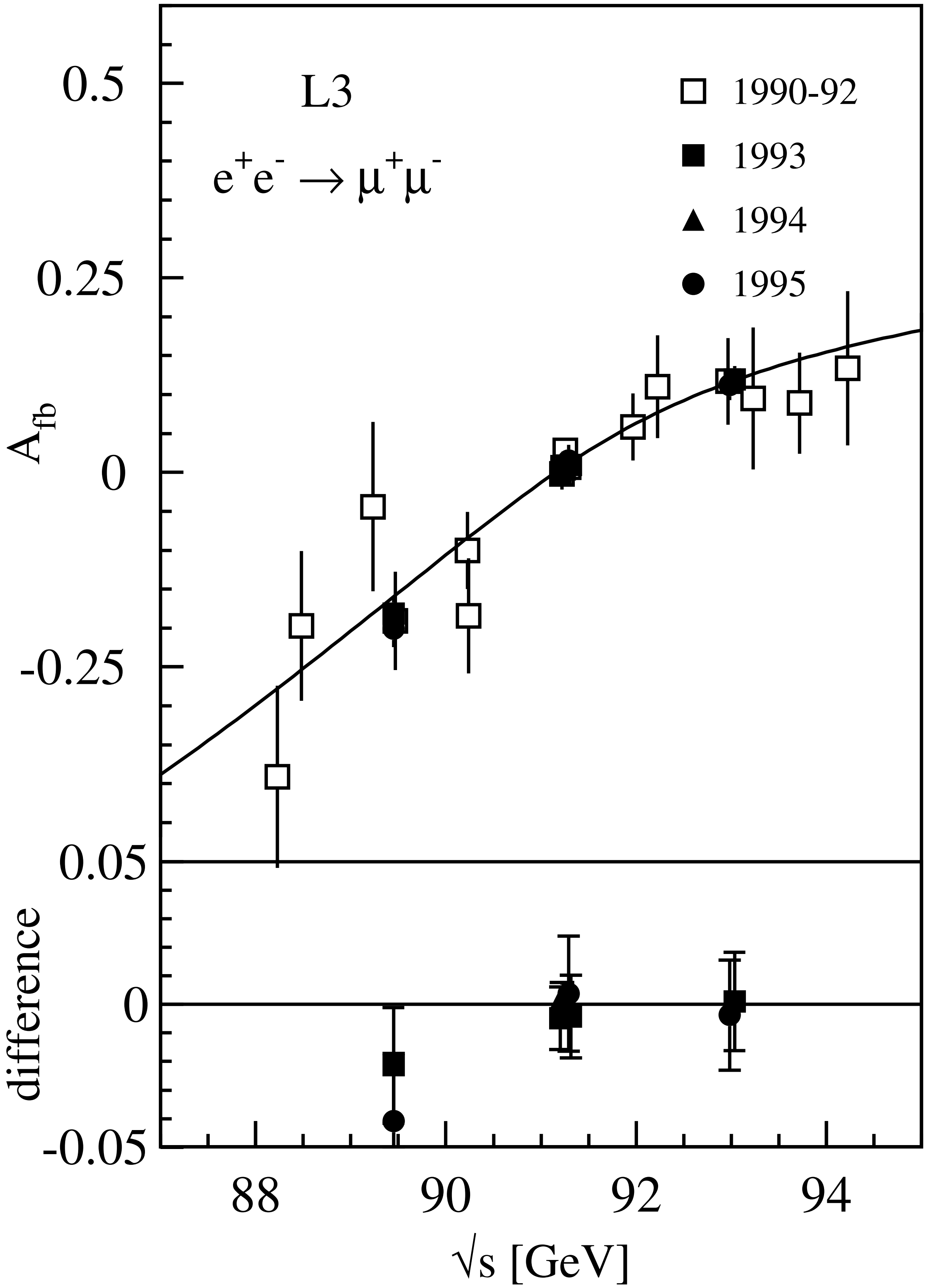

Figure 5: The measured forward–backward asymmetry in $e^+e^- \to \mu^+\mu^-(\gamma)$ as function of the cms energy. The solid line shows the result of the fit. At the bottom the difference of the measured asymmetry and the fit result for the data collected in 1993–95 is shown.

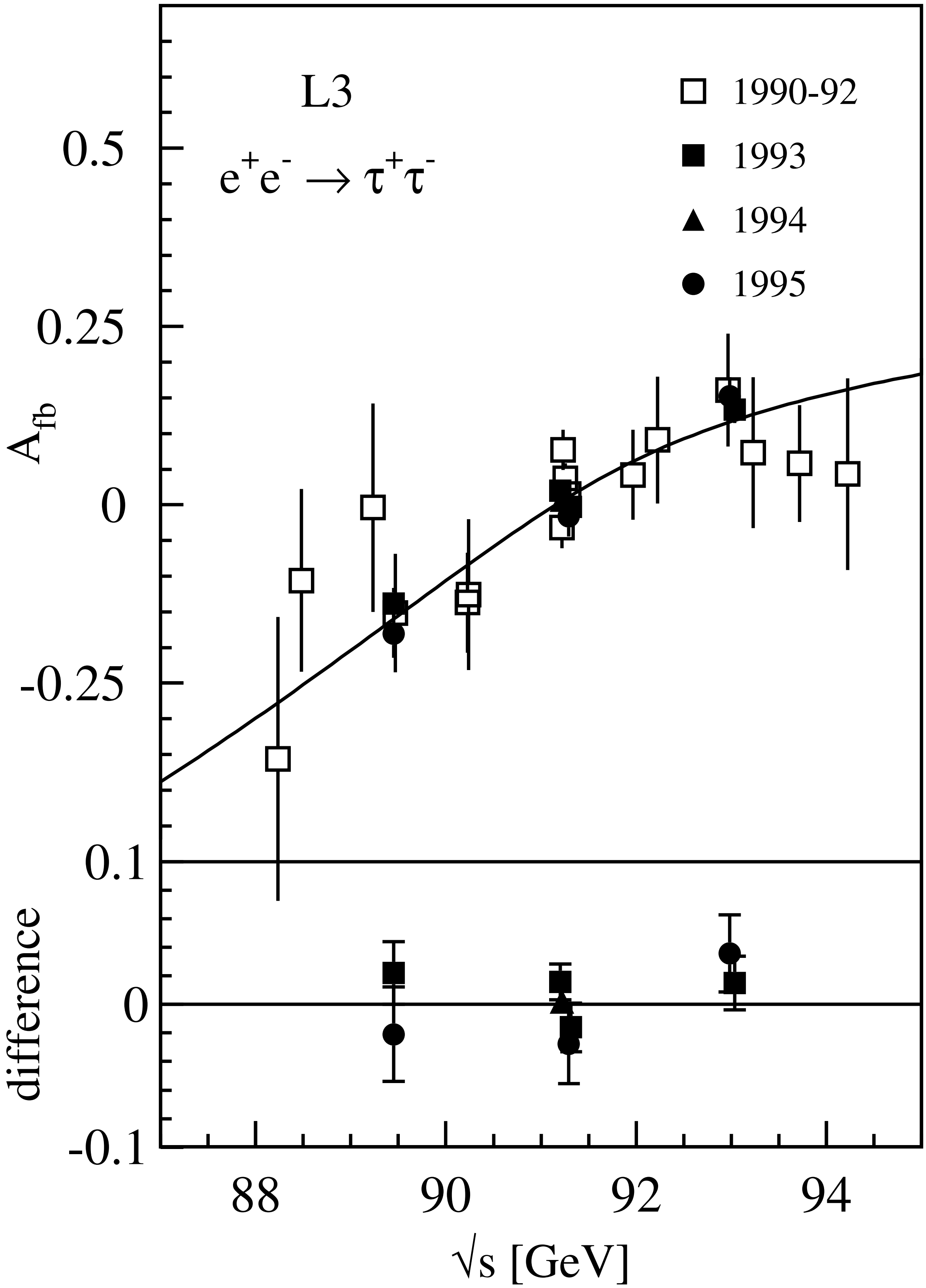

Figure 6: Same as figure 5 for $e^+e^- \to \tau^+\tau^-(\gamma)$.

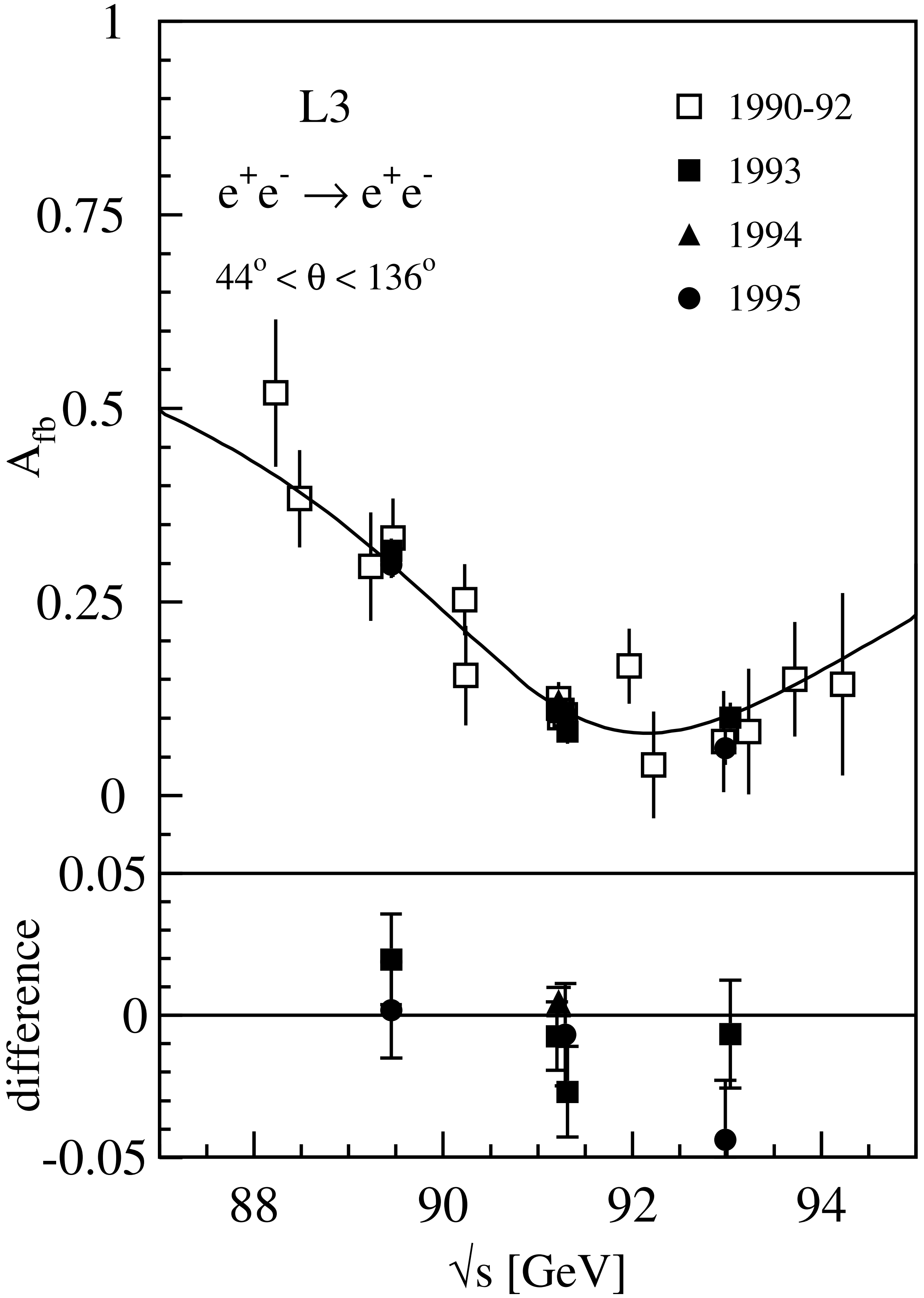

Figure 7: Same as figure 5 for $e^+e^- \to e^+e^-(\gamma)$ for scattering angles $44^\circ < \Theta_e < 136^\circ$ and acollinearity $\xi < 25^\circ$.

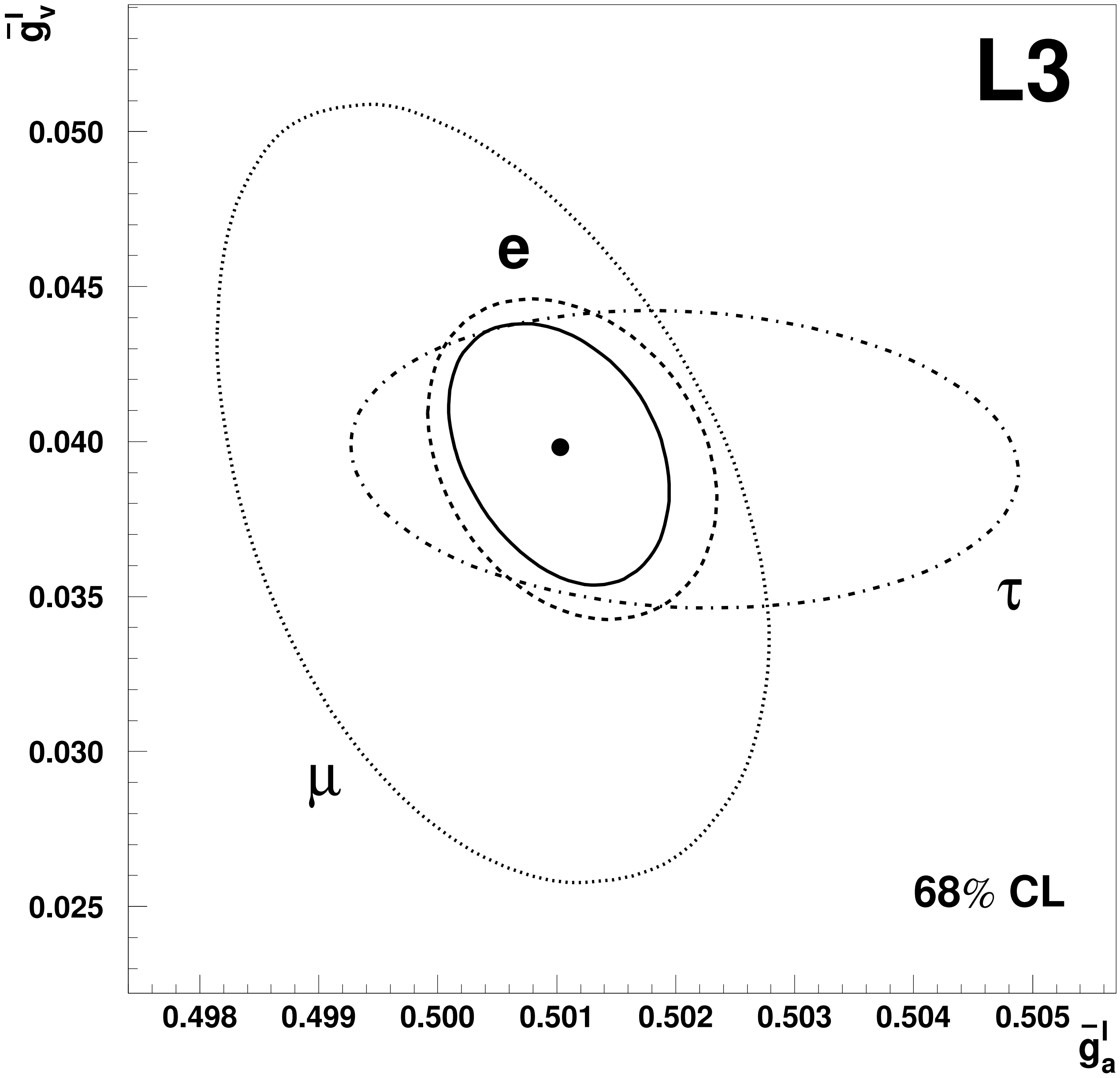

Figure 8: Contours in the $\bar{g}_V$–$\bar{g}_A$ plane (68% CL) for electrons, muons and taus obtained from a fit to total cross sections, forward–backward and tau polarisation asymmetries. The solid line shows the contour assuming lepton universality and the circle indicates the central value.

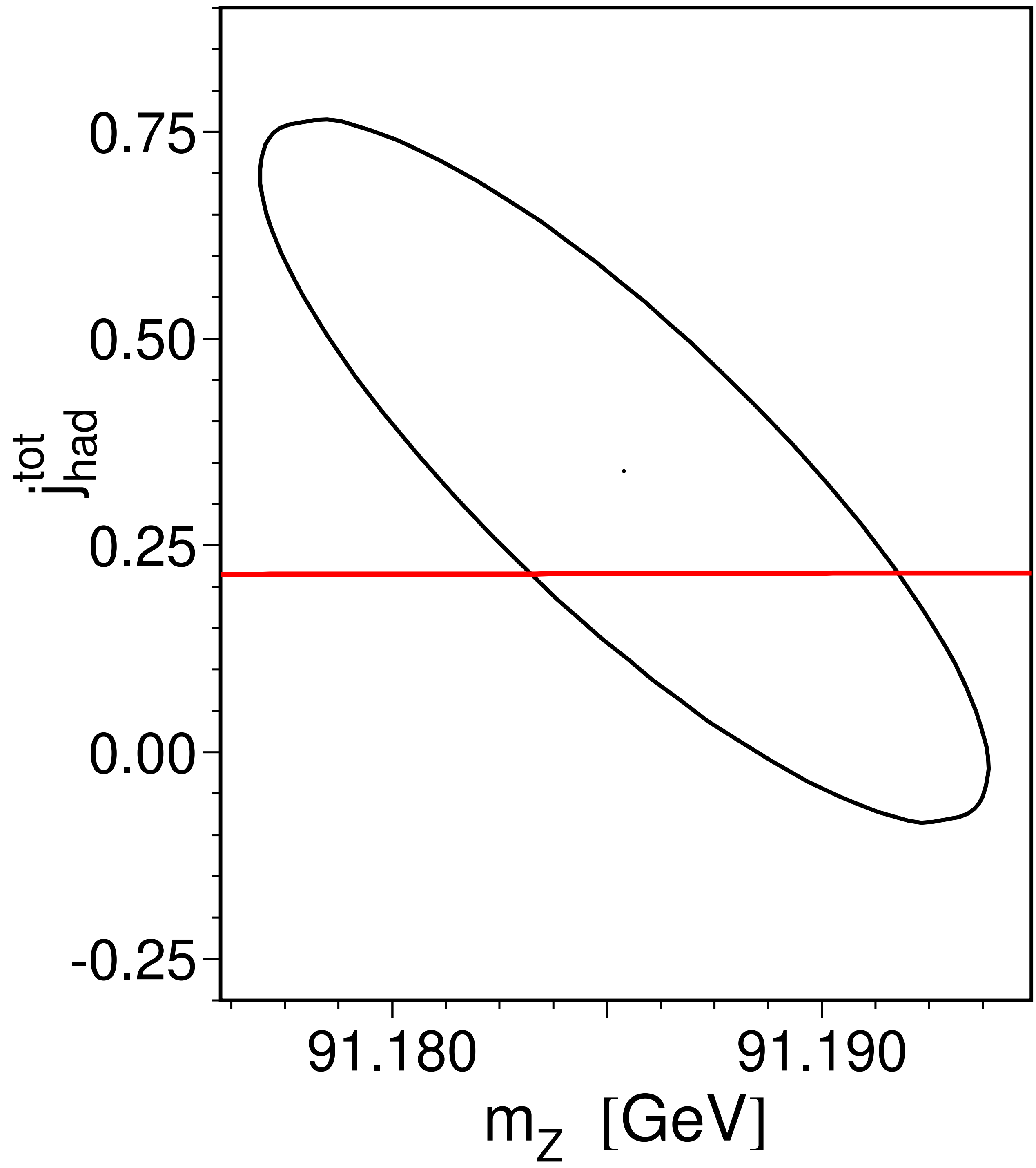

Figure 9: Contour in the m_Z–$j^{\rm tot}_{\rm had}$ plane obtained from the S–Matrix fit assuming lepton universality.

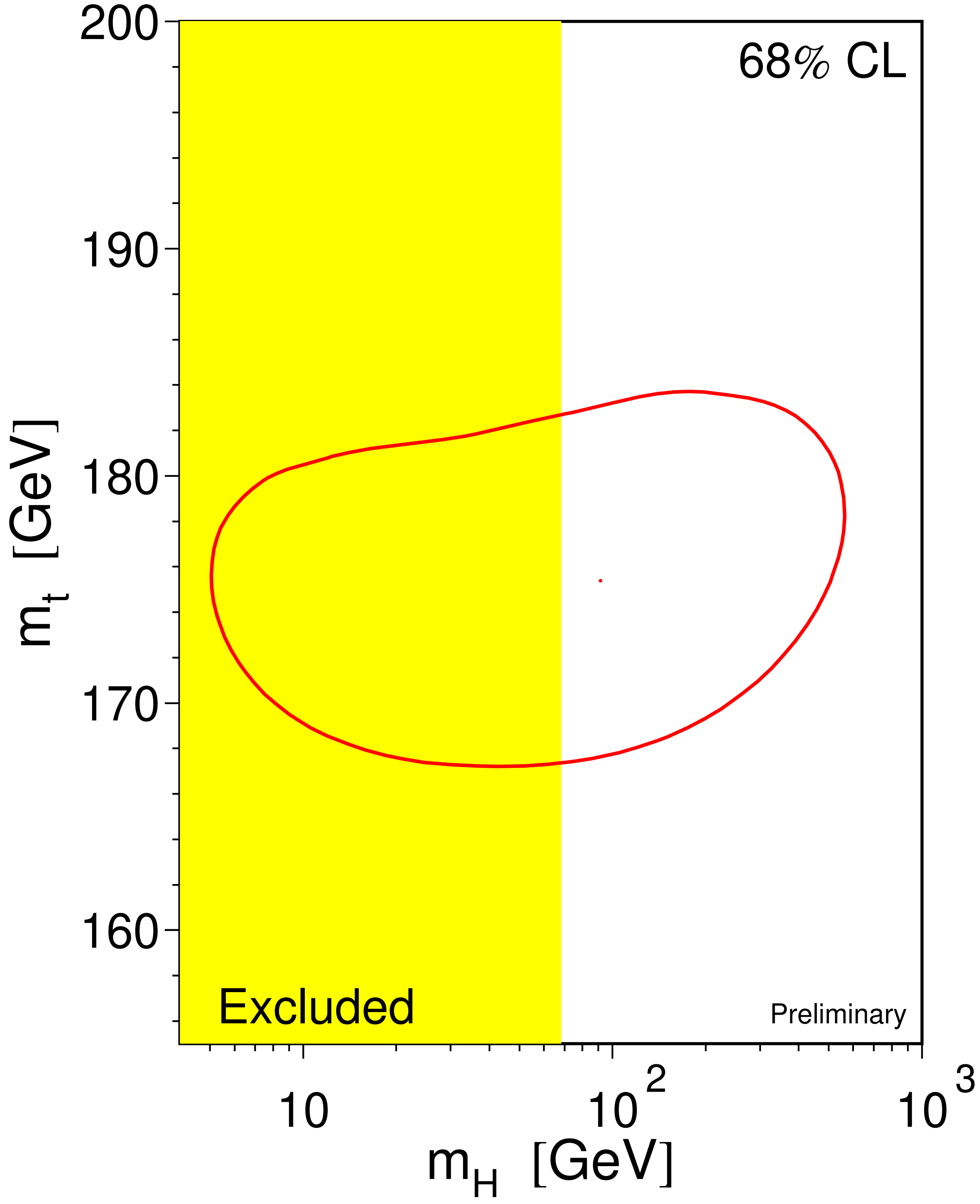

Figure 10: Contour in the m_t–m_H plane obtained from the SM fit.