L3 Note # 1809
July 14, 1995

Electroweak Update including Preliminary 1993/94 Data

The L3 Collaboration

Submitted to the EPS and Lepton/Photon Conferences, July 1995

I. L3 Data

(a) Events

Details of the events used for this update are given below.

Table 1

	No. of Evts 1990 + 91	No. of Evts 1992	No. of Evts 1993	No. of Evts 1994
Data type	7 point scan	Peak only	3 point scan	Peak only
Luminosity (pb^{-1})	18.4	22.4	32	45
$q\bar{q}$	416 K	678 K	654 K	1362 K
e^+e^-	16 K	22 K	25 K	47 K
$\mu^+\mu^-$	14 K	21 K	21 K	42 K
$\tau^+\tau^-$	10 K	15 K	15 K	34 K

(b) Systematic Errors on Cross sections (%):

Table 2

	1990	1991	1992	1993	1994
$q\bar{q}$	0.3	0.15	0.15	0.08	0.2
e^+e^-	0.4	0.3	0.3	0.3	0.4
$\mu^+\mu^-$	0.8	0.5	0.5	0.3	0.6
$\tau^+\tau^-$	0.9	0.7	0.7	0.8	1.5

(c) Systematic Errors on lepton asymmetries:

Table 3

	1990	1991	1992	1993	1994
e^+e^-	0.004	0.004	0.002	0.004	0.004
$\mu^+\mu^-$	0.005	0.002	0.002	0.001	0.002
$\tau^+\tau^-$	0.005	0.005	0.003	0.004	0.006

(d) Systematic Errors on Luminosity:
Systematic errors on luminosity are determined to be 0.6% for 1990-1992, 0.2% for 1993 and 0.22% for 1994. These values include a theoretical systematic error of 0.16%.

II. LEP Energy Errors

The LEP Energy Group has come out with a final determination of the uncertainties in LEP energy for the year 1993 (R. Assmann et al, CERN-PPE/95-10, CERN-SL/95-02, dated January 20, 1995, Z. Phys. C66 (1995) 567).

(a) the LEP energy covariance matrix for the 1993 scan is provided. The average error on the determination of M_Z and Γ_Z due to LEP energy uncertainties are estimated as 1.4 and 1.5 MeV respectively for 1993 data. **Using only 1993 L3 data we have carried out fits switching on/off the LEP errors and confirm that the errors on M_Z and Γ_Z due to LEP energy uncertainties are 1.5 and 1.7 MeV respectively.**

(b) the average value of the beam energy spread is determined to be 55$\pm$5 MeV for 1993. This value was 51$\pm$ $\sim$5 MeV for the 1991 data (L. Arnaudon et al, CERN-PPE/92-125, CERN-SL/92-37(DI), dated July 31, 1992). Using L3 data we have carried out fits using values of beam energy spread increased/decreased by 5 MeV. **We find that this $\pm$5 MeV error results in an additional error on Γ_Z of $\pm$1 MeV.**

(c) Assmann et al confirm that the LEP energy errors for the years 1990-1992 stay as they were and furthermore they are UNCORRELATED with the 1993 LEP errors during the energy scan. (To recapitulate: the overall LEP energy errors are: i) 26 MeV for 1990, ii) 18 MeV for 1991 data prior to Aug 14, 1991, 5 MeV for 1991 data thereafter, iii) 18 MeV for the 1992 data and iv) 18 MeV for the first 1993 run on the peak which is uncorrelated with all other data)

(d) For the 1994 run preliminary estimate of the overall LEP energy error from the LEP Energy Group is 4 MeV; it is to be taken as UNCORRELATED with the earlier LEP energy errors.

III Results

(a) Fits to cross section data alone

Table 4

Parameter	Fitted/derived Value*	March 1995 (Moriond)
M_Z	91193.7 ± 3.6	91193.4 ±3.7
Γ_Z	2502.0 ± 5.3 ± 1.0	2503.8 ± 5.3
R_e	20.892 ± 0.116	20.911 ± 0.117
R_μ	20.800 ± 0.115	20.847 ± 0.125
R_τ	20.745 ± 0.168	20.725 ± 0.171
$\sigma^\circ_{\mathrm{had}}$	41.478 ± 0.108	41.41 ± 0.11
Γ_{ee}	83.90 ± 0.29	83.87 ± 0.29
Γ_μ	84.27 ± 0.53	84.12 ± 0.56
Γ_τ	84.50 ± 0.73	84.62 ± 0.74
Γ_{hadron}	1752.9 ± 6.2	1753.7 ± 6.4
R_l	20.818 ± 0.077	20.842 ± 0.081
Γ_{lepton}	84.06 ± 0.23	84.01 ± 0.23
Γ_{hadron}	1749.9 ± 5.1	1750.9 ± 5.4
$\Gamma_{\mathrm{invisible}}$	500.1 ± 4.4	501.1 ± 4.6
N_ν	2.984 ± 0.024	2.995 ± 0.025

* Units are MeV for mass and widths, nano barn for cross section

(b) Fits to cross section plus lepton F/B asymmetry data

Table 5

Parameter	Fitted/derived Value*	March 1995 (Moriond)
M_Z	91193.6 ± 3.6	91193.5 ± 3.7
Γ_Z	2502.2 ± 5.3 ± 1.0	2504.0 ± 5.3
$\sigma^\circ_{\mathrm{had}}$	41.483 ± 0.108	41.411 ± 0.11
R_e	20.893 ± 0.115	20.911 ± 0.117
R_μ	20.803 ± 0.115	20.851 ± 0.124
R_τ	20.727 ± 0.167	20.712 ± 0.171
$A^{\circ,e}_{\mathrm{FB}}$	0.0125 ± 0.0070	.0125 ± 0.0070
$A^{\circ,\mu}_{\mathrm{FB}}$	0.0168 ± 0.0038	.0164 ± 0.0041
$A^{\circ,\tau}_{\mathrm{FB}}$	0.0287 ± 0.0064	.0305 ± 0.0073
R_l	20.812 ± 0.076	20.836 ± 0.080
$A^{\circ,l}_{\mathrm{FB}}$	0.0186 ± 0.0030	0.0183 ± 0.0032
g^l_A	-0.5013 ± 0.0007	−0.5012 ± 0.0007
g^l_V	-0.0398 ± 0.0032	−0.0395 ± 0.0034
ρ	1.005 ± 0.0029	1.005 ± 0.0029
$\sin^2\theta^{\mathrm{eff}}_{\mathrm{w}}$	0.2302 ± 0.0016	0.2303 ±0.0017

* Units are MeV for mass and widths, nano barn for cross section

Correlation matrix for 5 parameter fit with
$M_Z,\Gamma_Z,\sigma^{\circ}_{had},R_l,A^{\circ,l}_{FB}$

Table 6

	1	2	3	4	5
1	1.000	.053	−.068	−.019	.086
2	.053	1.000	−.317	−.038	.000
3	−.068	−.317	1.000	.148	.004
4	−.019	−.038	.148	1.000	−.008
5	.086	.000	.004	−.008	1.000

Correlation matrix for 9 parameter fit with
$M_Z,\Gamma_Z,\sigma^{\circ}_{had},R_e,R_\mu,R_\tau,A^{\circ,e}_{FB},A^{\circ,\mu}_{FB},A^{\circ,\tau}_{FB}$

Table 7

	1	2	3	4	5	6	7	8	9
1	1.000	.053	-.067	-.026	-.004	-.004	.053	.062	.033
2	.053	1.000	-.316	-.034	-.024	-.005	-.004	.002	.002
3	-.067	-.316	1.000	.071	.117	.072	.034	-.009	-.005
4	-.026	-.034	.071	1.000	.058	.040	-.107	.014	.011
5	-.004	-.024	.117	.058	1.000	.039	.000	.016	.000
6	-.004	-.005	.072	.040	.039	1.000	-.001	.000	.014
7	.053	-.004	.034	-.107	.000	-.001	1.000	-.004	-.004
8	.062	.002	-.009	.014	.016	.000	-.004	1.000	.008
9	.033	.002	-.005	.011	.000	.014	-.004	.008	1.000

(c) Fits to cross section plus lepton F/B asymmetry data plus P_τ plus P_τ asymmetry data

Table 8

Parameter	Fitted/derived Value*	March 1995 (Moriond)
g_A^e	-0.5009 ± 0.0009	-0.5008 ±0.0009
g_A^μ	-0.5021 ± 0.0017	-0.5017 ±0.0018
g_A^τ	-0.5027 ± 0.0022	-0.5030 ±0.0022
g_V^e	-0.0395 ± 0.0036	-0.0395 ±0.0041
g_V^μ	-0.0360 ± 0.0088	-0.0349 ±0.0095
g_V^τ	-0.0397 ± 0.0032	-0.0397 ±0.0040
g_A^l	−0.5013 ± 0.0007	−0.5012 ±0.0007
g_V^l	−0.0391 ± 0.0021	−0.0388 ±0.0024
ρ	1.0054 ± 0.0028	1.0049 ± 0.0028
$\sin^2\theta_w^{eff}$	0.2305 ± 0.0010	0.2306 ± 0.0012

(d) L3 Summary on $\sin^2\theta_{\mathrm{w}}^{\mathrm{eff}}$ using various data

Table 9

Using	Derived $\sin^2\theta_{\mathrm{w}}^{\mathrm{eff}}$	March 1995 (Moriond)
$A_{FB}^{\circ,l}$	0.2302 ± 0.0016	0.2303 ± 0.0017
A_e+ A_τ	0.2307 ± 0.0013	0.2309 ± 0.0016
$A_{FB}^{\circ,b}$	0.2335 ± 0.0021	0.2335 ± 0.0021
Average	0.2311 ± 0.0009	0.2313 ± 0.0010

IV S-Matrix Approach

A simple model-independent ansatz to determine the properties of the Z boson is given by the S-Matrix formalism [1]. This ansatz allows to vary the γZ interference terms for cross sections and asymmetries independently from the couplings describing the pure Z exchange. The total cross section, $\sigma^0_{\mathrm{tot}}(\mathrm{e^+e^-} \to \mathrm{f\bar{f}})$, as a function of center-of-mass energy $\sqrt{s}$ is given by:

$$\sigma^0_{\mathrm{tot}}(s) \quad = \quad \frac{4}{3}\pi\alpha^2\left[\frac{\mathrm{g_f^{tot}}}{s} + \frac{s\mathrm{r_f^{tot}} + (\mathrm{s} - \overline{\mathrm{m}}_{\mathrm{Z}}^2)\mathrm{j_f^{tot}}}{(s-\overline{\mathrm{m}}_{\mathrm{Z}}^2)^2 + \overline{\mathrm{m}}_{\mathrm{Z}}^2\overline{\Gamma}_{\mathrm{Z}}^2}\right] . \tag{1}$$

Defining the forward-backward asymmetric cross section, σ^0_{fb}, by:

$$\sigma^0_{\mathrm{fb}}(s) \quad = \quad \frac{4}{3}\pi\alpha^2\left[\frac{s\mathrm{r_f^{fb}} + (\mathrm{s} - \overline{\mathrm{m}}_{\mathrm{Z}}^2)\mathrm{j_f^{fb}}}{(s-\overline{\mathrm{m}}_{\mathrm{Z}}^2)^2 + \overline{\mathrm{m}}_{\mathrm{Z}}^2\overline{\Gamma}_{\mathrm{Z}}^2}\right] , \tag{2}$$

the forward-backward asymmetry is given by:

$$A_{\mathrm{fb}}(s) \quad = \quad \frac{3}{4}\frac{\sigma^0_{\mathrm{fb}}(s)}{\sigma^0_{\mathrm{tot}}(s)} . \tag{3}$$

The S-Matrix parameters r, j and g scale the Z exchange, γZ interference and photon exchange contributions, respectively. The photon-exchange contribution g, which is fixed by QED, vanishes in asymmetric cross sections. In particular, the hadronic γZ interference term for total cross sections, $\mathrm{j^{tot}_{had}}$, is now a free parameter. In the fits presented in previous sections, $\mathrm{j^{tot}_{had}}$ is fixed to its Standard-Model prediction.

We use the program SMATASY 4.9 [2] to perform S-Matrix fits to the L3 data set. Not assuming lepton universality, the results summarized in Table 10. The results derived under the assumption of lepton universality are listed in Table 11, together with the Standard Model predictions for the S-Matrix parameters. The matrices of correlation coefficients are given in Tables 12 and 13, respectively.

Table 10

Parameter	Value	Error
$\overline{m}_Z$ (GeV)	91.161	0.013
$\overline{\Gamma}_Z$ (GeV)	2.5005	0.0058
r_{had}^{tot}	2.980	0.014
r_e^{tot}	0.1426	0.0011
r_μ^{tot}	0.1430	0.0010
r_τ^{tot}	0.1439	0.0013
j_{had}^{tot}	0.08	0.71
j_e^{tot}	0.008	0.064
j_μ^{tot}	-0.001	0.057
j_τ^{tot}	0.066	0.063
r_e^{fb}	0.0021	0.0015
r_μ^{fb}	0.00311	0.00076
r_τ^{fb}	0.0050	0.0012
j_e^{fb}	0.70	0.10
j_μ^{fb}	0.822	0.066
j_τ^{fb}	0.664	0.087

S-Matrix parameters derived from L3 data without the assumption of lepton universality.

Table 11

Parameter	Value	Error	SM Prediction
$\overline{m}_Z$ (GeV)	91.162	0.013	—
$\overline{\Gamma}_Z$ (GeV)	2.5002	0.0058	2.4948
r_{had}^{tot}	2.979	0.014	2.965
r_e^{tot}	0.14304	0.00083	0.14269
j_{had}^{tot}	0.06	0.70	0.22
j_e^{tot}	0.020	0.044	0.004
r_e^{fb}	0.00332	0.00059	0.00272
j_e^{fb}	0.749	0.047	0.799

S-Matrix parameters derived from L3 data with the assumption of lepton universality; and Standard-Model predictions for these parameters.

Table 12

1.00	-.39	-.35	-.18	-.23	-.16	-.96	-.52	-.57	-.50	.13	.22	.10	-.02	-.01	.00
-.39	1.00	.85	.53	.57	.43	.41	.19	.24	.22	-.05	-.06	-.02	.01	.04	.02
-.35	.85	1.00	.59	.62	.47	.38	.15	.21	.20	-.03	-.05	-.02	-.01	.04	.03
-.18	.53	.59	1.00	.40	.30	.20	.10	.11	.11	.08	-.04	-.01	-.03	.03	.02
-.23	.57	.62	.40	1.00	.32	.24	.10	.24	.13	-.02	-.02	-.01	.00	.07	.02
-.16	.43	.47	.30	.32	1.00	.17	.07	.10	.21	-.01	-.02	.02	.00	.02	.06
-.96	.41	.38	.20	.24	.17	1.00	.51	.56	.49	-.12	-.21	-.10	.02	.01	.00
-.52	.19	.15	.10	.10	.07	.51	1.00	.30	.27	-.07	-.12	-.06	.17	.00	.00
-.57	.24	.21	.11	.24	.10	.56	.30	1.00	.29	-.07	-.11	-.06	.01	-.05	.00
-.50	.22	.20	.11	.13	.21	.49	.27	.29	1.00	-.07	-.11	-.04	.01	.00	-.03
.13	-.05	-.03	.08	-.02	-.01	-.12	-.07	-.07	-.07	1.00	.02	.01	.04	.00	.00
.22	-.06	-.05	-.04	-.02	-.02	-.21	-.12	-.11	-.11	.02	1.00	.03	.00	.23	.00
.10	-.02	-.02	-.01	-.01	.02	-.10	-.06	-.06	-.04	.01	.03	1.00	.00	.00	.19
-.02	.01	-.01	-.03	.00	.00	.02	.17	.01	.01	.04	.00	.00	1.00	.00	.00
-.01	.04	.04	.03	.07	.02	.01	.00	-.05	.00	.00	.23	.00	.00	1.00	.00
.00	.02	.03	.02	.02	.06	.00	.00	.00	-.03	.00	.00	.19	.00	.00	1.00

Matrix of correlation coefficients not assuming lepton universality.

Table 13

1.00	-.39	-.35	-.26	-.95	-.73	.26	-.01
-.39	1.00	.85	.69	.41	.30	-.08	.04
-.35	.85	1.00	.76	.38	.27	-.06	.05
-.26	.69	.76	1.00	.28	.25	-.02	.06
-.95	.41	.38	.28	1.00	.72	-.25	.01
-.73	.30	.27	.25	.72	1.00	-.18	.01
.26	-.08	-.06	-.02	-.25	-.18	1.00	.18
-.01	.04	.05	.06	.01	.01	.18	1.00

Matrix of correlation coefficients assuming lepton universality.

Remarks:

1) The S-Matrix ansatz uses a constant Z width in the Breit-Wigner propagator. Thus, the S-Matrix results for the mass and total width of the Z Boson must be shifted by +34.1 MeV and +0.9 MeV, respectively, in order to compare them to the results of the other fits.

2) The largest correlation (−95%) arises between the mass of the Z Boson and the hadronic γZ interference term for the total cross section (parameter $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$). As the Z mass is essentially determined by the hadronic lineshape, the error on the Z mass is increased in fits where this parameter is left free (see Figure 1, solid contour). The error on the hadronic γZ interference term $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$, and consequently the error on $\overline{\mathrm{m}}_{\mathrm{Z}}$, is reduced by using total cross section measurements far away from the Z peak [1, 3]. The TOPAZ collaboration at TRISTAN (KEK) has recently performed a measurement of the hadronic total cross section at $\sqrt{s} = 57.77$ GeV, $\sigma^0_{\mathrm{tot}} = 143.6 \pm 1.5(stat.) \pm 4.5(syst.)$ pb [4]. If we include this measurement, the error on $\overline{\mathrm{m}}_{\mathrm{Z}}$ decreases from 13 to 5.8 MeV, and the correlation between $\overline{\mathrm{m}}_{\mathrm{Z}}$ and $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ is reduced to −76% (Figure 1, dashed contour):

Data	L3		L3+TOPAZ	
Parameter	Value	Error	Value	Error
$\overline{\mathrm{m}}_{\mathrm{Z}}$ (GeV)	91.162	0.013	91.1596	0.0058
$\overline{\Gamma}_{\mathrm{Z}}$ (GeV)	2.5002	0.0058	2.5006	0.0054
$\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$	0.06	0.70	0.18	0.25

3) The energy dependence of the leptonic forward/backward asymmetries is described by the parameters $\mathrm{j}_{\ell}^{\mathrm{fb}}$. Within the errors, our measurements are compatible with the Standard-Model prediction.

V Standard Model based Fits

We carry out fits in the standard model framework to determine best values of $\mathrm{M}_{\mathrm{top}}$, α_{s} and $\mathrm{M}_{\mathrm{Higgs}}$. The ZFITTER4.9 package is used for this purpose. The fits given below use the value of

$$1/\alpha(M_z^2) = 128.894 \pm 0.090$$

as now used by the LEP Electroweak Working Group based on a recent paper by Eidelman and Jegerlehner [5]. The 0.09 error on this results in an additional ~5 GeV error on $\mathrm{M}_{\mathrm{top}}$ and corresponding increased error on $\mathrm{M}_{\mathrm{Higgs}}$.

The input data for these standard model fits consists of the 5 parameter fit results (lepton universality) given in tables 5 and 6, the L3 values of $\mathrm{A}_{\mathrm{e}}= 0.156\pm0.017$, $\mathrm{A}_{\tau}= 0.152\pm0.013$, $\mathrm{R}_{\mathrm{b}}= 0.222\pm0.008$ and the $\sin^2\theta_{\mathrm{w}}^{\mathrm{eff}}= 0.2335\pm0.0021$ from $\mathrm{A}_{\mathrm{FB}}^{\mathrm{o,b}}$.

1. Allowing both M_{top} and α_s to be free parameters we obtain:

$$M_{top} = 194^{+16}_{-18} \pm 16 \text{ GeV}, \quad \alpha_s = 0.127 \pm 0.008 \pm 0.002$$

   the central value corresponding to M_{Higgs}= 300 GeV and the second error being due to variation of M_{Higgs} from 60 to 1000 GeV

2. To obtain best value of M_{top} we constrain α_s to 0.123 $\pm$ 0.006, from event shape measurements. We obtain:

$$M_{top} = 196^{+15}_{-16} \pm 17 \text{ GeV}$$

   and the various derived parameters to be

$$\begin{aligned} \Delta r &= 0.031 \pm 0.007 \pm 0.001 \\ M_W &= 80.46 \pm 0.11 \ ^{+0.02}_{-0.01} \\ \sin^2\theta_w &= 0.2215 \pm 0.0021 \ ^{+0.0002}_{-0.0003} \\ \sin^2\theta_w^{eff} &= 0.2312 \pm 0.0006 \ ^{+0.0001}_{-0.0002} \end{aligned}$$

   If we include the CDF and D0 values of M_{top}: 176$\pm$13 GeV and 199$\pm$30 GeV in the fit, we obtain

$$\begin{aligned} M_{top} &= 180 \pm 11 \quad \text{GeV} \\ M_{Higgs} &= 68^{+249}_{..} \quad \text{GeV} \end{aligned}$$

References

[1] A.Leike, T.Riemann, J.Rose, Phys.Lett. B273 (1991) 513;
T.Riemann, Phys.Lett. B293 (1992) 451;
and references therein.

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[3] G.Isidori, Phys.Lett. B314 (1993) 139;
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M.Grünewald, S.Kirsch, CERN preprint CERN-PPE/93-188.

[4] The TOPAZ Collaboration, K.Miyabayashi et al., Phys.Lett. B347 (1995) 171.

[5] S. Eidelman and F. Jegerlehner, Preprint PSI-PR-95-1, BudkerINP 95-5, January 1995.

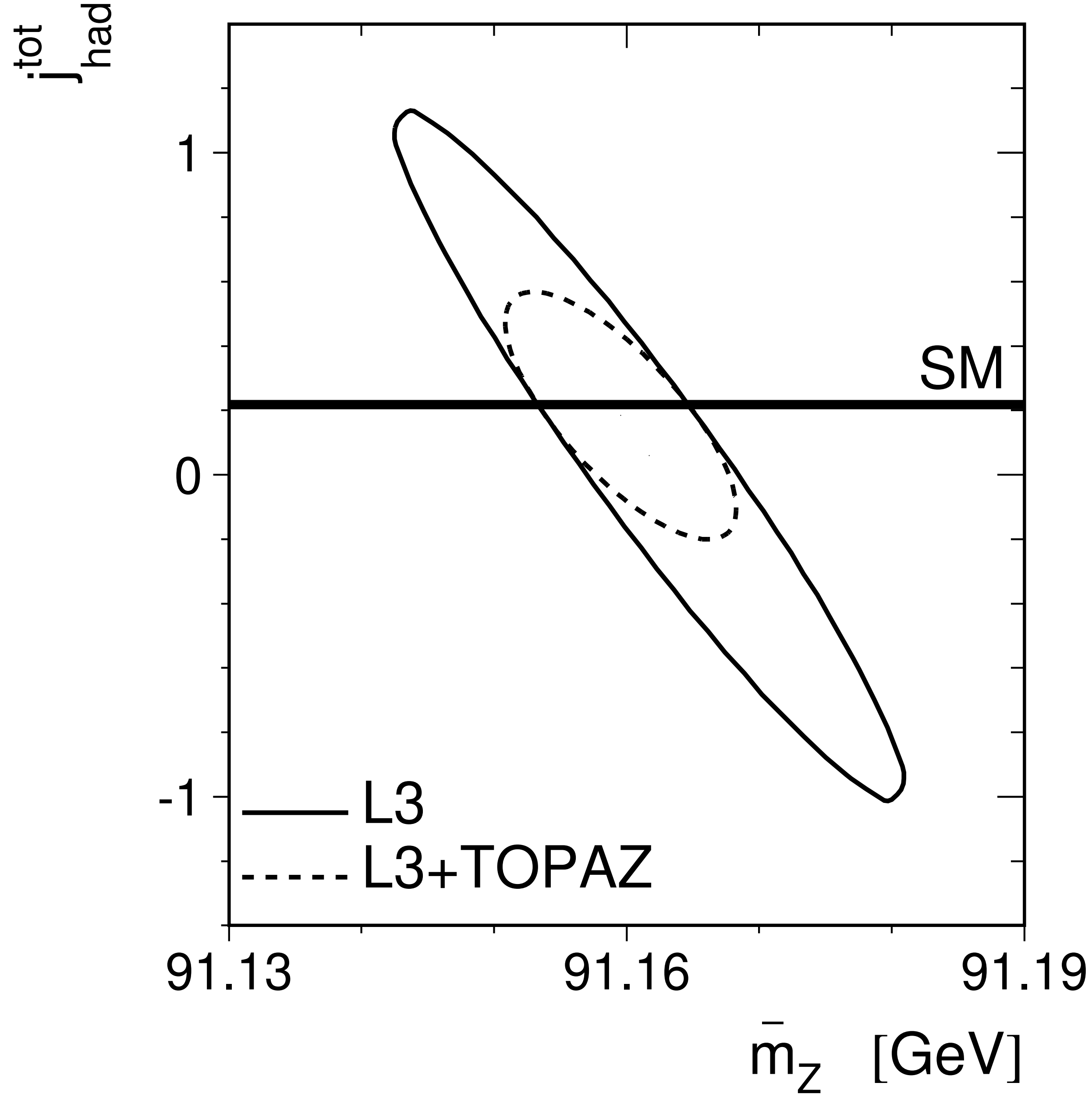

Figure 1: 68% correlation contour between the mass of the Z boson in the S-Matrix approach, $\overline{m}_Z$ ($= M_Z - 34.1$ MeV), and the hadronic γZ interference term for total cross sections, j_{had}^{tot}. The solid contour corresponds to L3 data only, the dashed contour is obtained by including the TOPAZ measurement. The Standard-Model prediction for j_{had}^{tot} is shown as the solid band.

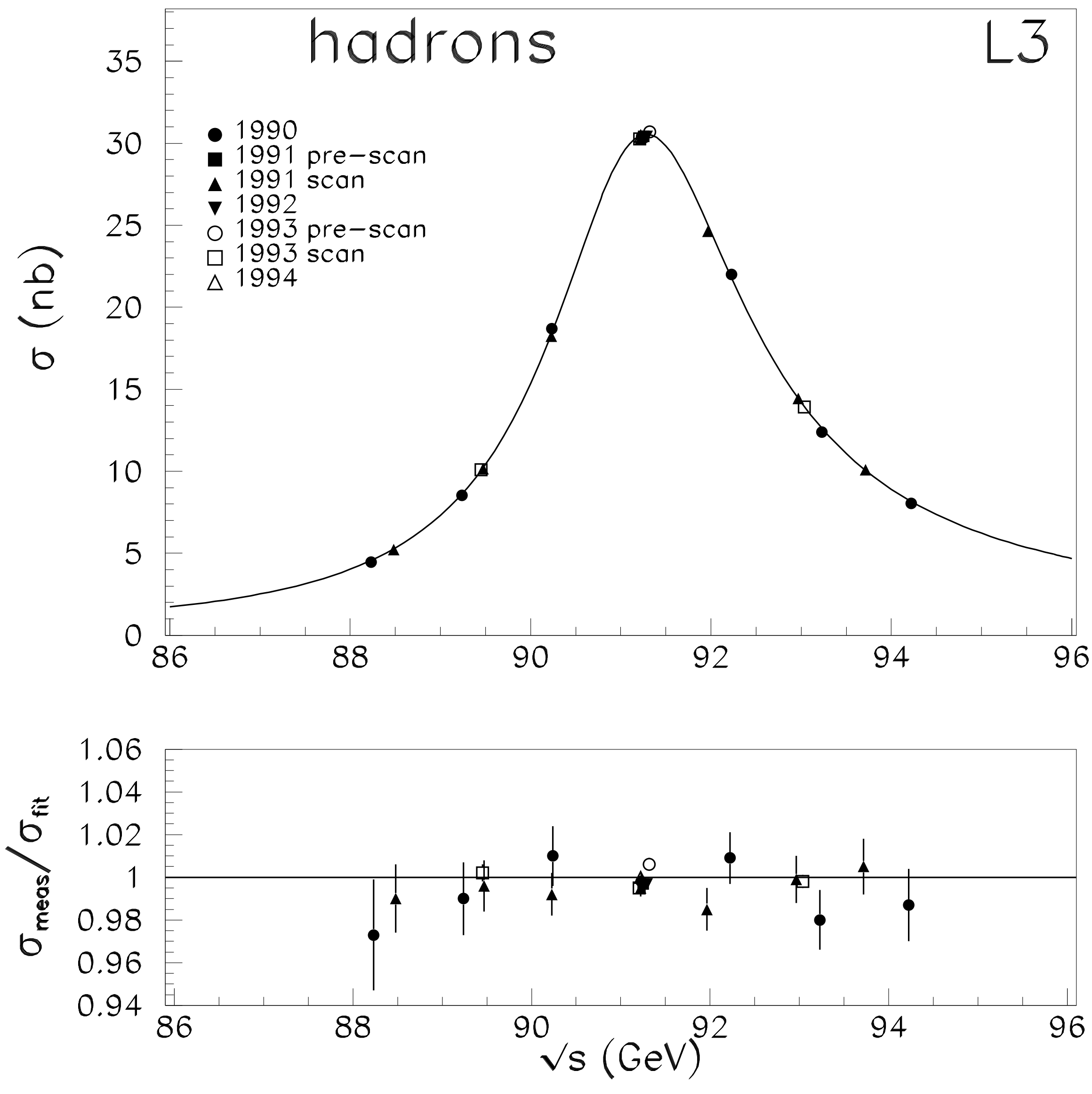

Figure 2: Hadron lineshape with lepton universality fit superimposed.

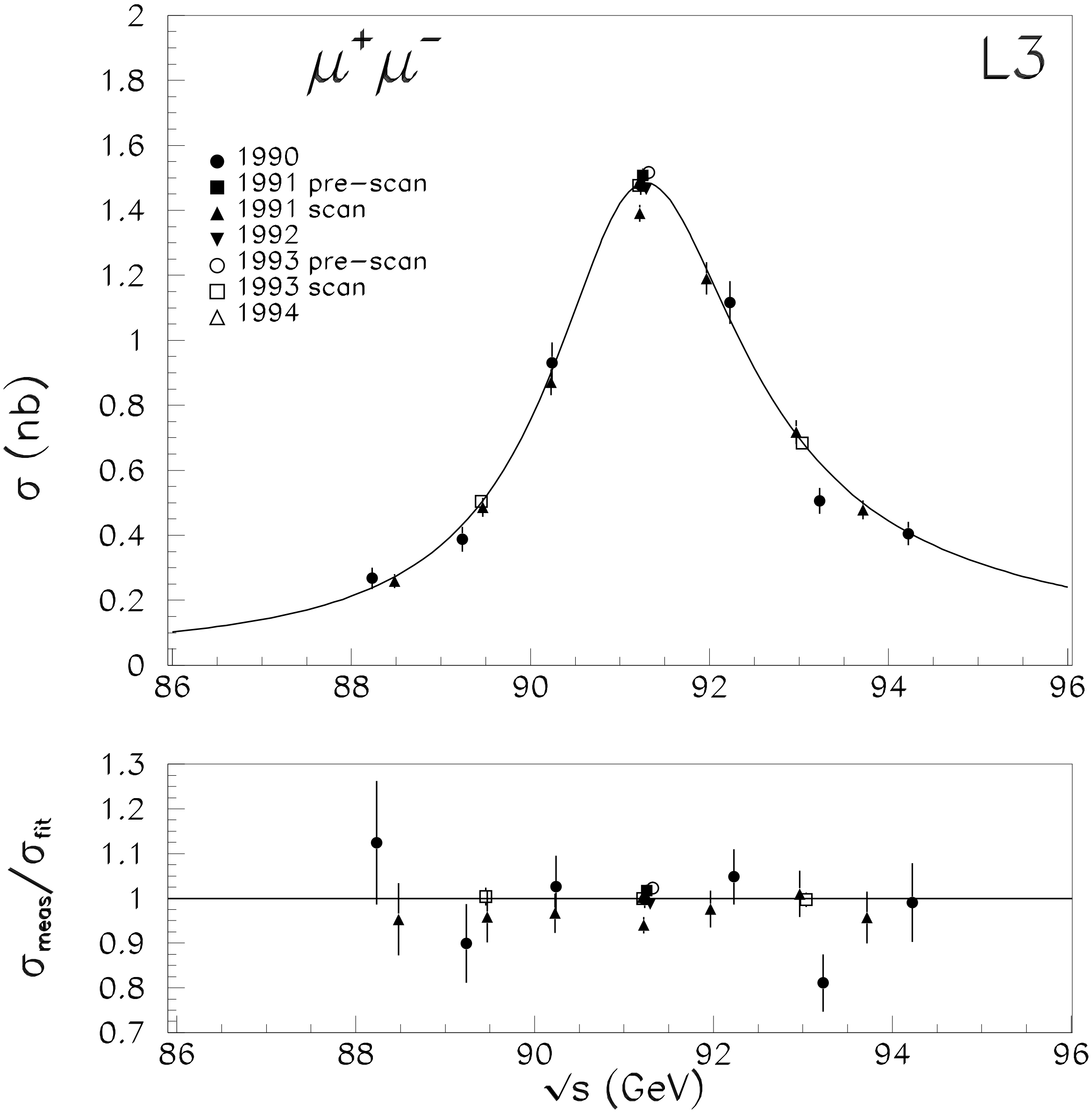

Figure 3: Muon lineshape with lepton universality fit superimposed.

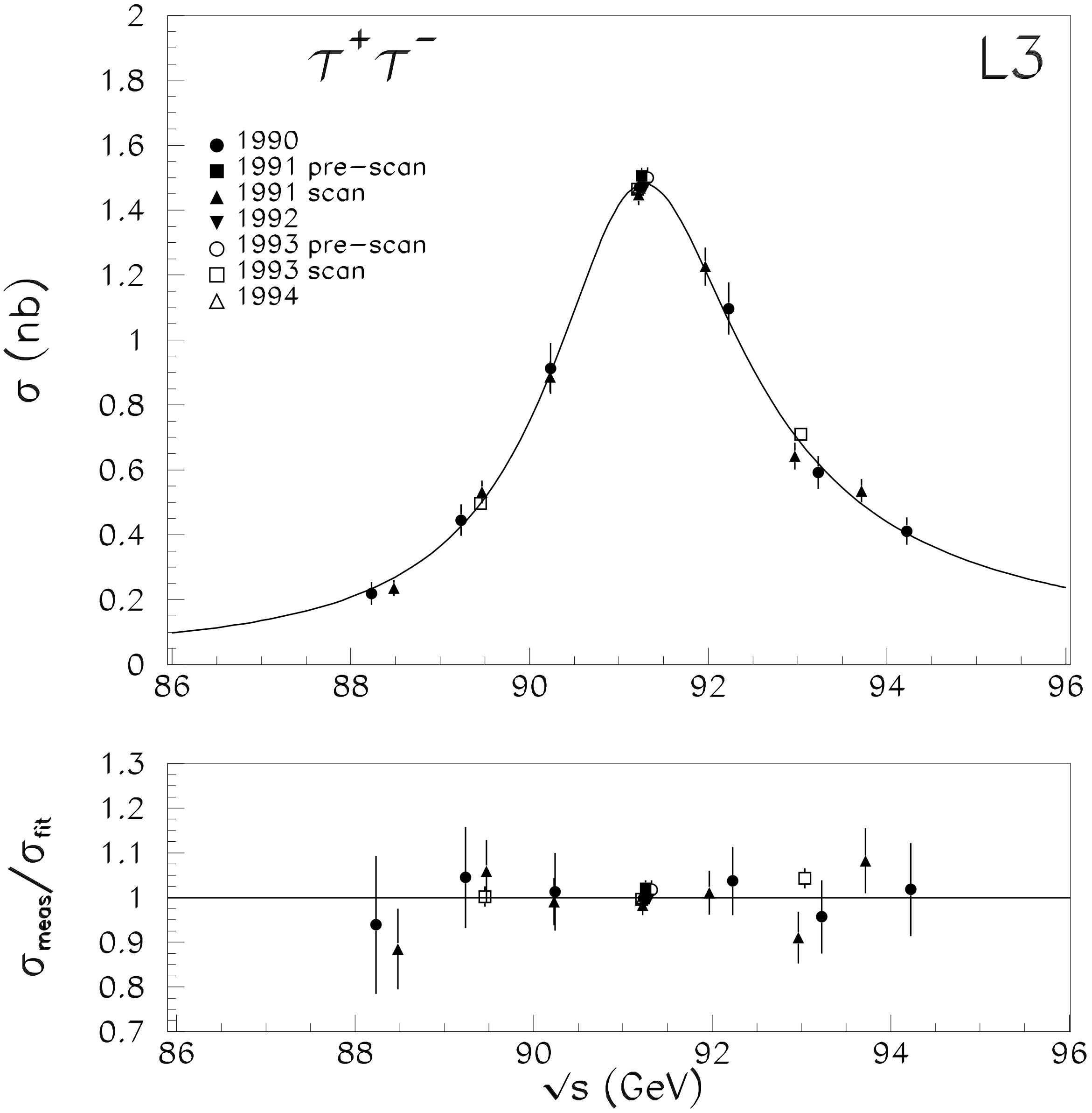

Figure 4: Tau lineshape with lepton universality fit superimposed.

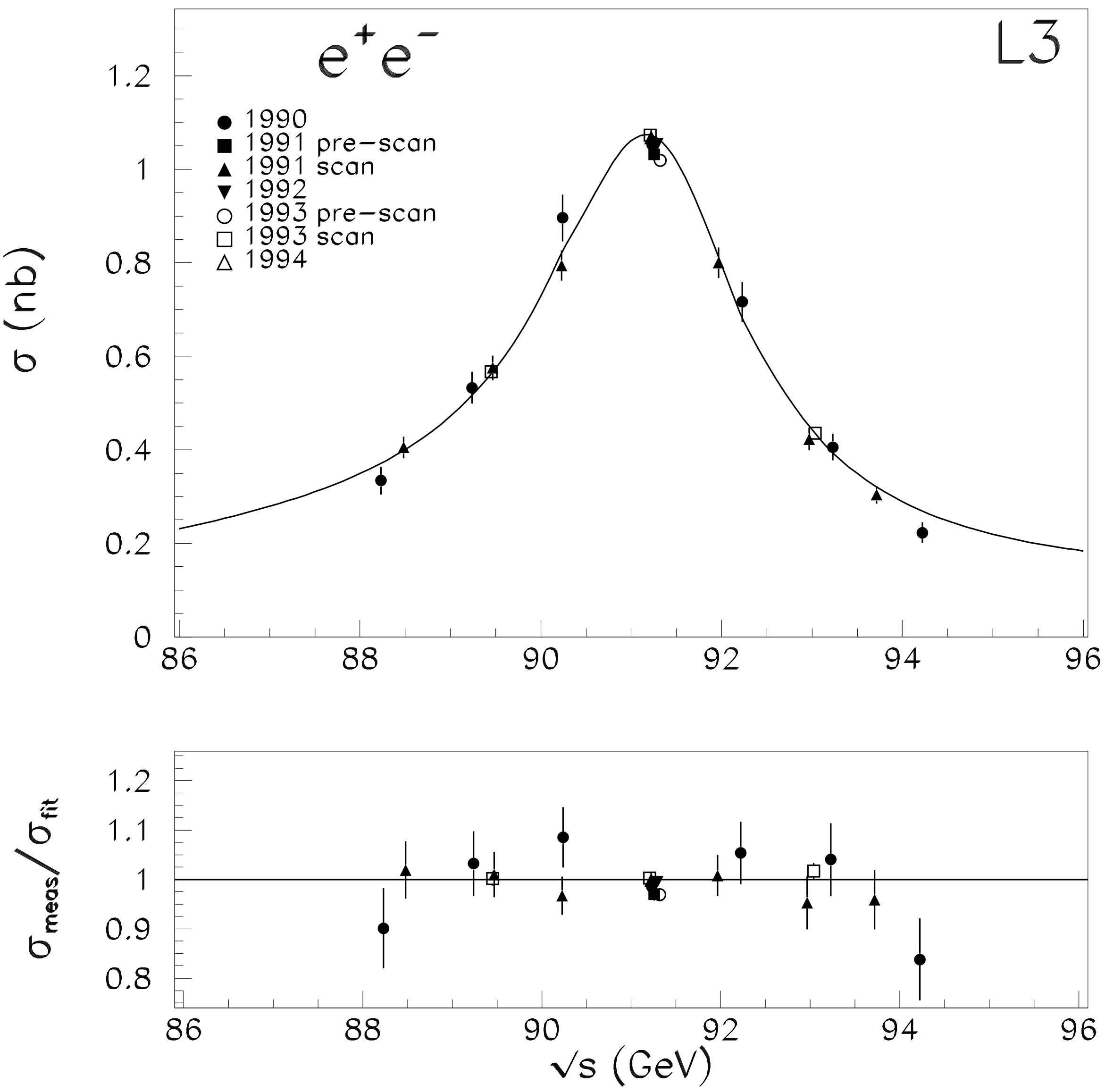

Figure 5: Electron lineshape with lepton universality fit superimposed.

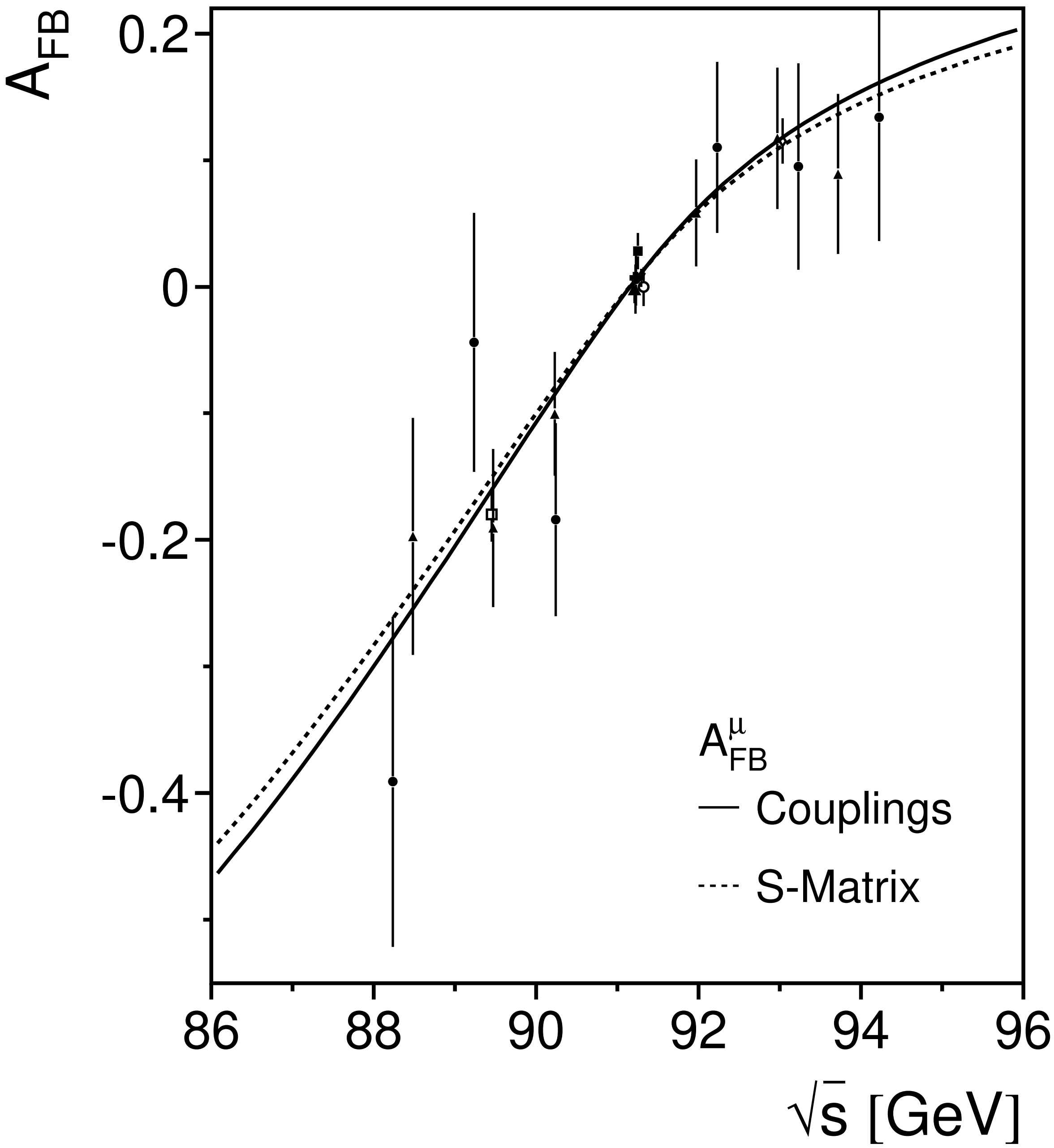

Figure 6: Muon forward-backward asymmetry with lepton universality couplings and S-Matrix fits superimposed.

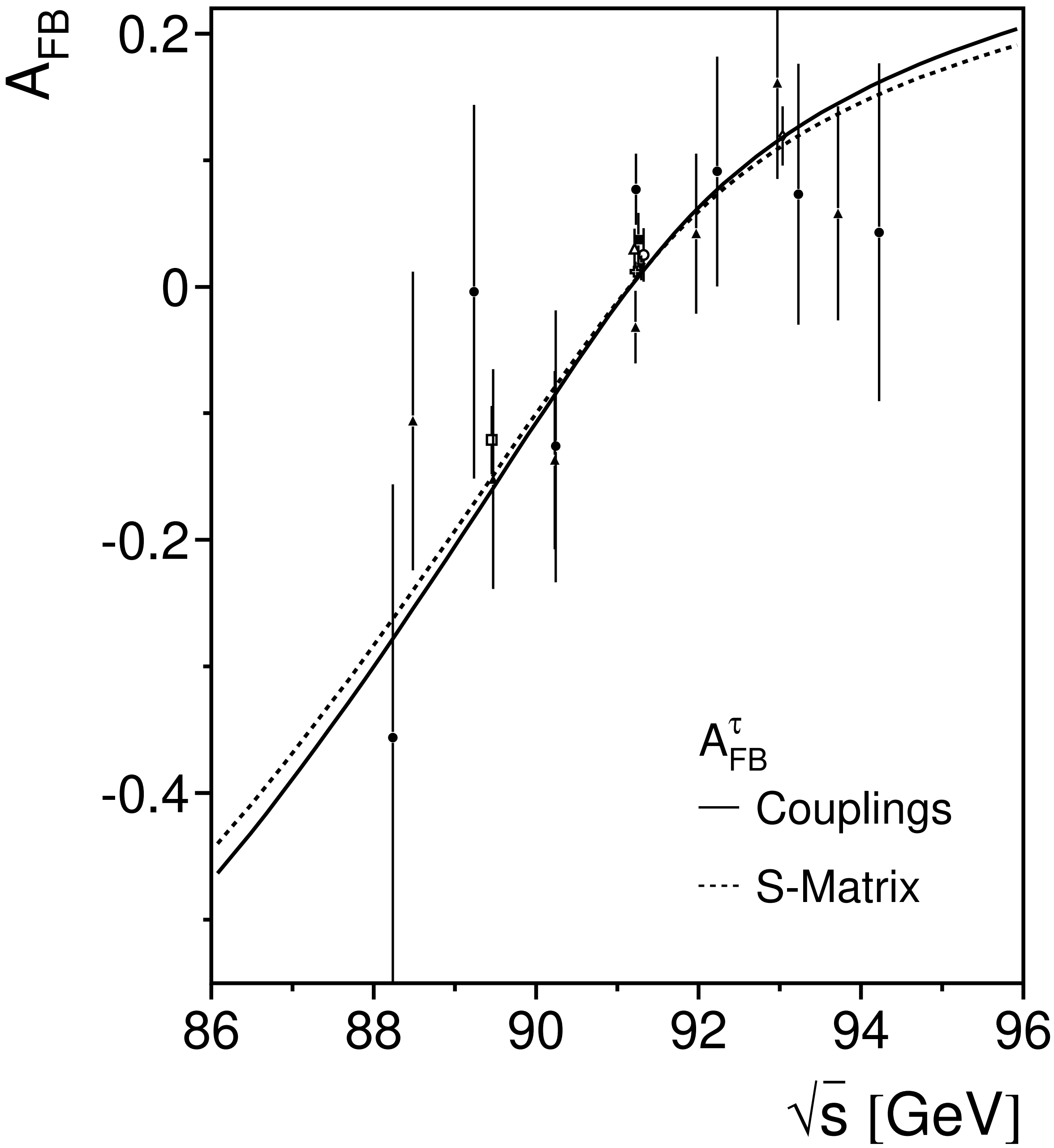

Figure 7: Tau forward-backward asymmetry with lepton universality couplings and S-Matrix fits superimposed.

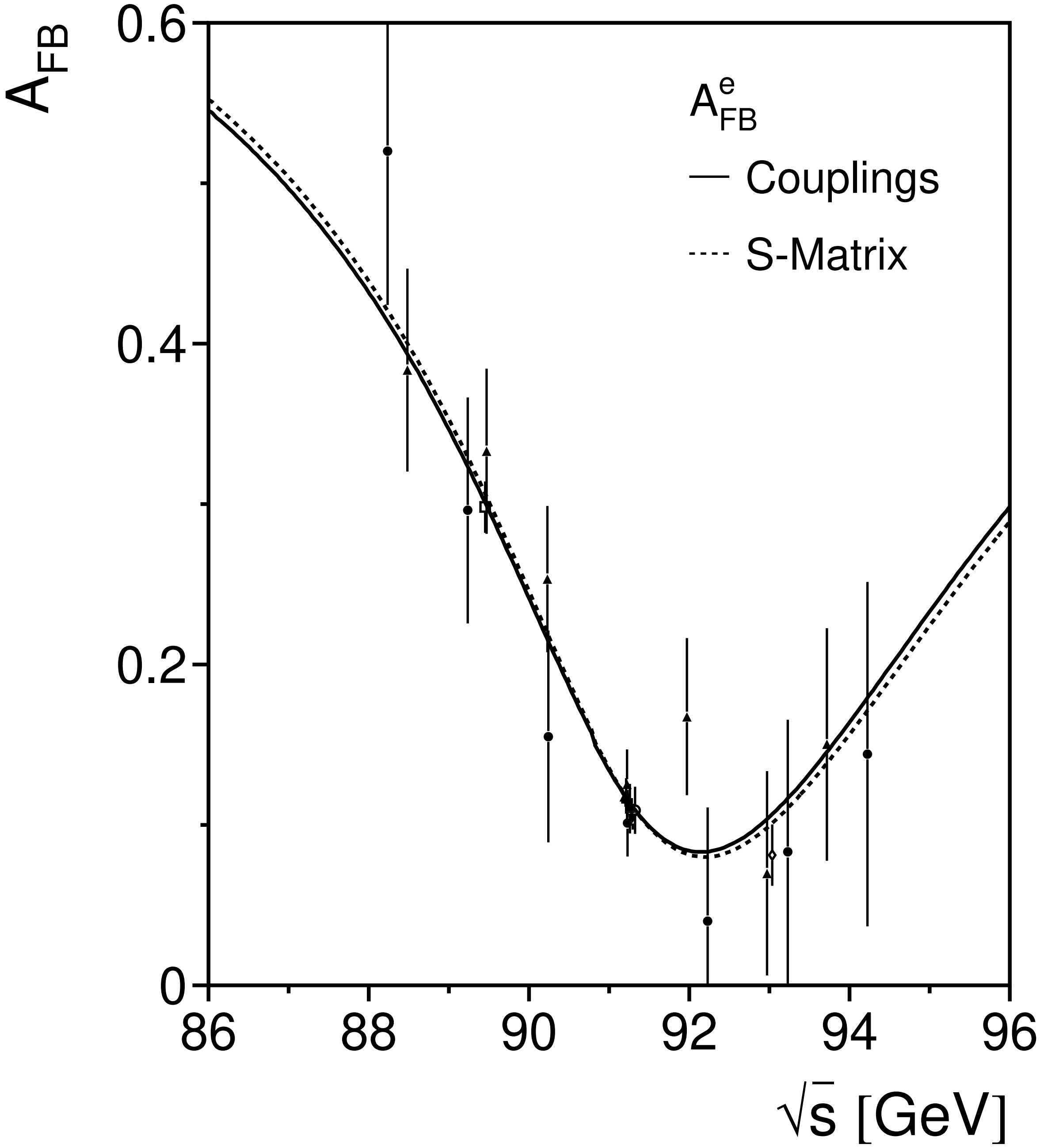

Figure 8: Electron forward-backward asymmetry with lepton universality couplings and S-Matrix fits superimposed.