EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

L3 Note 2763
July 1, 2002

Preliminary L3 Results on Fermion-Pair Production

The L3 Collaboration

Abstract

In this note we present preliminary measurements of e^+e^- annihilation into hadrons and leptons pairs. The data have been collected with L3 detector at LEP at centre-of-mass energies between 130 and 208 GeV, corresponding to a total integrated luminosity of about 705 pb^{-1}. Measurements of total hadronic and leptonic cross sections and leptonic differential cross sections and forward-backward asymmetries are presented. Published data are combined with recent preliminary results. The measurements are interpreted in the S–Matrix framework.

Submitted to the 31^{st} *International Conference on High Energy Physics*
Amsterdam, Netherlands, 24-31 July 2002.

Introduction

This note summarises the Z–boson parameters derived, in the S–Matrix framework. We use the published measurements performed at the Z resonance [1] and at centre–of–mass energies between 130 and 189 GeV on data taken from 1995 to 1998 [2, 3], as well as preliminary measurements at centre–of–mass energies between 192 and 208 GeV taken in 1999 and 2000.

At centre–of–mass energies above the Z resonance cross sections and forward-backward asymmetries are measured for two event samples. For s-channel processes, events at high effective centre–of–mass energies, $\sqrt{s'}$, (so-called *high-energy* events) are selected by requiring $\sqrt{s'} > 0.85\sqrt{s}$. The *inclusive* samples include also the events where initial-state radiation, ISR, lowers the initial centre–of–mass energy substantially. It is defined by requiring $\sqrt{s'} > 60$ GeV for hadronic events and $\sqrt{s'} > 75$ GeV for lepton-pair events. For Bhabha scattering a cut is applied on the acollinearity angle, ζ, of the final-state e^+ and e^-. In this case, the inclusive and high-energy samples are defined by requiring $\zeta < 120°$ and $\zeta < 25°$, respectively.

The uncertainties on the beam energy for 161 to 189 GeV are the range from 20 to 30 MeV [4]. Currently, a 50 MeV uncertainty is assigned to the beam energy values used for the 192 to 208 GeV data. and a 20 MeV uncertainty for the 130 to 140 GeV data. The effect of these uncertainties on the fit result is estimated to be negligible.

Cross Section and Forward–Backward Asymmetry Measurements

Preliminary results from hadron cross section and lepton cross section and forward–backward asymmetry measurements are used in the S–Matrix analysis. The event selection for the four final states is the same as described in our last publication [3]. Figure 1 shows the distributions for the most important selection cuts for each final state.

The distributions of the effective centre–of–mass energies for the different s-channel processes and of the acollinearity for Bhabha events are shown in Figure 2.

Cross section and leptonic forward–backward asymmetries are measured for both, the inclusive and the high-energy event samples. The results are compared to the Standard Model predictions as calculated with the ZFITTER program [5] for s-channel processes and the TOPAZ0 program [6] for Bhabha scattering in the Figures 3 to 6. We also determine the differential cross sections for the Bhabha scattering and for Muon pair-production. They are shown in Figures 7 to 9.

Fits in the S–Matrix Framework

The fits in the S–Matrix framework [7] which makes a minimum of theoretical assumptions are updated. For details on this fitting approach see References [1, 8].

A particularity of the S–Matrix approach is the fact that the hadronic γ/Z interference term, $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$, is not taken from the Standard Model but is left free in the fit. Due to a strong correlation with the Z boson mass the error on m_{Z} in this fit is significantly enlarged compared to fits where the hadronic γ/Z interference term is fixed to its Standard Model value. The γ/Z interference terms are constrained using cross section and asymmetry measurement far away from the Z peak. Hence the cross section and forward–backward asymmetry measurements at high effective centre–of–mass energies obtained during the LEP runs at high energies (130 GeV

$\leq \sqrt{s} \leq 189$ GeV) [3] and during 1999 and 2000 LEP running (192 GeV $\leq \sqrt{s} \leq 208$ GeV) are included into the fits.

The S–Matrix parameters as obtained from fits to all data using the program SMATASY [9] are listed in Table 1. Their correlations are given in Tables 3 and 2 for the two fits with and without assuming lepton universality. The parameters obtained for the individual lepton types are compatible with each other and support this assumption. The results of the fits to Z data only [1] are used as constraints in the fits while for high energy data the cross section and forward-backward asymmetry measurements are used. Correlations between measurements taken close to the Z resonance and measurements at high centre–of–mass energies are estimated and their influence on the fit results is found to be negligible. Correlations between different measurements at high centre–of–mass energy are taken into account in the fits.

Since in the S–Matrix ansatz the definition of the Z–boson mass and width are slightly different a correction is applied so that they correspond to the usual definitions as used in the standard Breit–Wigner ansatz.

The solid line in Figure 10 shows the correlation contour between m_{Z} and $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ obtained from the fit to all data assuming lepton universality. For comparison, the dashed contour is obtained using only data taken in the vicinity of the Z pole.

Comparing the results for m_{Z} obtained with fixed hadronic interference term and in the S–Matrix approach one finds that the experimental uncertainty on $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ adds an uncertainty of approximately ± 2.1 MeV to the error on m_{Z}. Our measurement of the hadronic interference term agrees with results from data taken at energies below the Z resonance [10]. Adding the low energy measurements to the fits we obtain:

$$
\begin{aligned}
\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}} &= 0.156 \pm 0.076(\mathrm{exp}) \pm 0.015(\mathrm{th})\,, \\
m_{\mathrm{Z}} &= 91\,190.5 \pm 3.1(\mathrm{exp}) \pm 1.4(\Delta \mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}) \pm 0.3(\mathrm{th}) \quad \mathrm{MeV}\,.
\end{aligned}
$$

and a correlation between $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ and m_{Z} of -0.37. The theory uncertainty is due to the uncertainty of 0.5% [11] on the calculation of cross sections for $\sqrt{s} > 130$ GeV of the ZFITTER program.

References

[1] L3 Collab., M. Acciarri *et al.*, Measurements of Cross Sections and Forward-Backward Asymmetries at the Z Resonance and Determination of Electroweak Parameters, Preprint CERN-EP/2000-022, CERN, 2000, accepted by E. Phys. J. C.

[2] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 407** (1997) 361.

[3] L3 Collab., M. Acciarri *et al.*, Phys. Lett. **B 479** (2000) 101.

[4] LEP Energy Working Group, Evaluation of the LEP centre-of-mass energy for data taken in 1998, Preprint LEP Energy Working Group 99/01, CERN, 1999.

[5] ZFITTER version 6.36 is used.
D. Bardin *et al.*, Preprint hep-ph/9908433; Z. Phys. **C 44** (1989) 493; Nucl. Phys. **B 351** (1991) 1; Phys. Lett. **B 255** (1991) 290. For the comparison with our measurements, the following ZFITTER flags have been changed from their default values: `FINR` = 0, `INTF` = 0, and `BOXD` = 2.

[6] TOPAZ0 version 4.4 is used.
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VENUS Collab., K. Yusa *et al.*, Phys. Lett. **B 447** (1999) 167.

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[20] we use the average top quark mass as given in Reference [12].

Parameter	Treatment of Charged Leptons		Theory	Standard
	Non–Universality	Universality	uncertainty	Model
m_{Z} [MeV]	91189.2 ± 3.7	91188.7 ± 3.7	0.6	—
Γ_{Z} [MeV]	2502.7 ± 4.1	2502.4 ± 4.1	0.1	$2492.7\,^{+3.8}_{-5.2}$
$\mathrm{r}^{\mathrm{tot}}_{\mathrm{had}}$	2.9852 ± 0.0092	2.9847 ± 0.0092	0.0003	$2.9584\,^{+0.0088}_{-0.0119}$
$\mathrm{r}^{\mathrm{tot}}_{\mathrm{e}}$	0.14314 ± 0.00075	—	0.00002	
$\mathrm{r}^{\mathrm{tot}}_{\mu}$	0.14281 ± 0.00079	—	0.00002	
$\mathrm{r}^{\mathrm{tot}}_{\tau}$	0.14371 ± 0.00102	—	0.00002	
$\mathrm{r}^{\mathrm{tot}}_{\ell}$	—	0.14318 ± 0.00059	0.00002	$0.14242\,^{+0.00035}_{-0.00049}$
$\mathrm{j}^{\mathrm{tot}}_{\mathrm{had}}$	0.26 ± 0.11	0.26 ± 0.11	0.04	0.21 ± 0.01
$\mathrm{j}^{\mathrm{tot}}_{\mathrm{e}}$	-0.027 ± 0.042	—	0.002	
$\mathrm{j}^{\mathrm{tot}}_{\mu}$	-0.010 ± 0.025	—	0.002	
$\mathrm{j}^{\mathrm{tot}}_{\tau}$	0.053 ± 0.029	—	0.002	
$\mathrm{j}^{\mathrm{tot}}_{\ell}$	—	0.011 ± 0.018	0.002	0.0041 ± 0.0003
$\mathrm{r}^{\mathrm{fb}}_{\mathrm{e}}$	0.00174 ± 0.00111	—	0.000002	
$\mathrm{r}^{\mathrm{fb}}_{\mu}$	0.00329 ± 0.00064	—	0.000002	
$\mathrm{r}^{\mathrm{fb}}_{\tau}$	0.00450 ± 0.00092	—	0.000002	
$\mathrm{r}^{\mathrm{fb}}_{\ell}$	—	0.00331 ± 0.00047	0.000002	0.00255 ± 0.00023
$\mathrm{j}^{\mathrm{fb}}_{\mathrm{e}}$	0.685 ± 0.073	—	0.001	
$\mathrm{j}^{\mathrm{fb}}_{\mu}$	0.791 ± 0.033	—	0.001	
$\mathrm{j}^{\mathrm{fb}}_{\tau}$	0.738 ± 0.041	—	0.001	
$\mathrm{j}^{\mathrm{fb}}_{\ell}$	—	0.761 ± 0.024	0.001	0.799 ± 0.001
χ^2 /d.o.f.	65.9/56	68.1/64		—

Table 1: Results of the fits in the S–Matrix framework with and without the assumption of lepton universality. The theory uncertainty is due to the uncertainty of 0.5% on the calculation of cross sections for $\sqrt{s} > 130$ GeV of the ZFITTER program. The Standard Model expectations are calculated using $m_{\mathrm{Z}} = 91\,189.8 \pm 3.1$ MeV, $m_{\mathrm{t}} = 175.0 \pm 5.0$GeV, 112. GeV $\leq m_{\mathrm{H}} \leq 1$ TeV, $\Delta\alpha^{(5)}_{had} = 0.02761 \pm 0.00036$, $\alpha_s(m^2_{\mathrm{Z}}) = 0.119 \pm 0.002$ [1, 14–17].

	m_Z	Γ_Z	r^{tot}_{had}	r^{tot}_{e}	r^{tot}_{μ}	r^{tot}_{τ}	j^{tot}_{had}	j^{tot}_{e}	j^{tot}_{μ}	j^{tot}_{τ}	r^{fb}_{e}	r^{fb}_{μ}	r^{fb}_{τ}	j^{fb}_{e}	j^{fb}_{μ}	j^{fb}_{τ}
m_Z	1.00	0.06	0.09	–0.07	0.02	0.02	–0.52	–0.12	–0.13	–0.12	–0.04	0.08	0.03	–0.02	–0.05	–0.03
Γ_Z		1.00	0.91	0.54	0.52	0.40	–0.02	–0.02	0.01	0.01	–0.00	0.02	0.02	–0.01	0.04	0.03
r^{tot}_{had}			1.00	0.56	0.53	0.41	–0.02	–0.04	0.01	0.01	0.00	0.02	0.02	–0.01	0.04	0.03
r^{tot}_{e}				1.00	0.33	0.25	0.05	0.04	0.03	0.02	0.13	–0.01	0.00	–0.02	0.03	0.02
r^{tot}_{μ}					1.00	0.23	–0.02	–0.02	0.09	0.01	0.00	0.03	0.01	–0.01	0.10	0.02
r^{tot}_{τ}						1.00	–0.02	–0.02	0.02	0.08	0.00	0.01	0.03	–0.01	0.02	0.10
j^{tot}_{had}							1.00	0.11	0.10	0.10	0.04	–0.04	–0.03	0.02	0.04	0.02
j^{tot}_{e}								1.00	0.03	0.03	0.00	–0.01	–0.01	0.33	0.01	0.01
j^{tot}_{μ}									1.00	0.02	0.01	0.07	–0.00	0.00	0.32	0.01
j^{tot}_{τ}										1.00	0.00	–0.01	0.04	0.00	0.00	0.20
r^{fb}_{e}											1.00	–0.01	0.00	0.02	0.00	0.00
r^{fb}_{μ}												1.00	0.01	–0.00	0.12	–0.00
r^{fb}_{τ}													1.00	–0.00	–0.00	0.10
j^{fb}_{e}														1.00	0.00	0.00
j^{fb}_{μ}															1.00	0.00
j^{fb}_{τ}																1.00

Table 2: Correlation of the S–Matrix parameters listed in Table 1 not assuming lepton universality.

	m_Z	Γ_Z	r^{tot}_{had}	r^{tot}_{ℓ}	j^{tot}_{had}	j^{tot}_{ℓ}	r^{fb}_{ℓ}	j^{fb}_{ℓ}
m_Z	1.00	0.07	0.08	–0.00	–0.51	–0.21	0.05	–0.06
Γ_Z		1.00	0.92	0.69	–0.02	0.00	0.02	0.04
r^{tot}_{had}			1.00	0.71	–0.02	–0.01	0.03	0.04
r^{tot}_{ℓ}				1.00	0.01	0.06	0.04	0.08
j^{tot}_{had}					1.00	0.17	–0.03	0.05
j^{tot}_{ℓ}						1.00	0.04	0.28
r^{fb}_{ℓ}							1.00	0.10
j^{fb}_{ℓ}								1.00

Table 3: Correlation of the S–Matrix parameters listed in Table 1 assuming lepton universality.

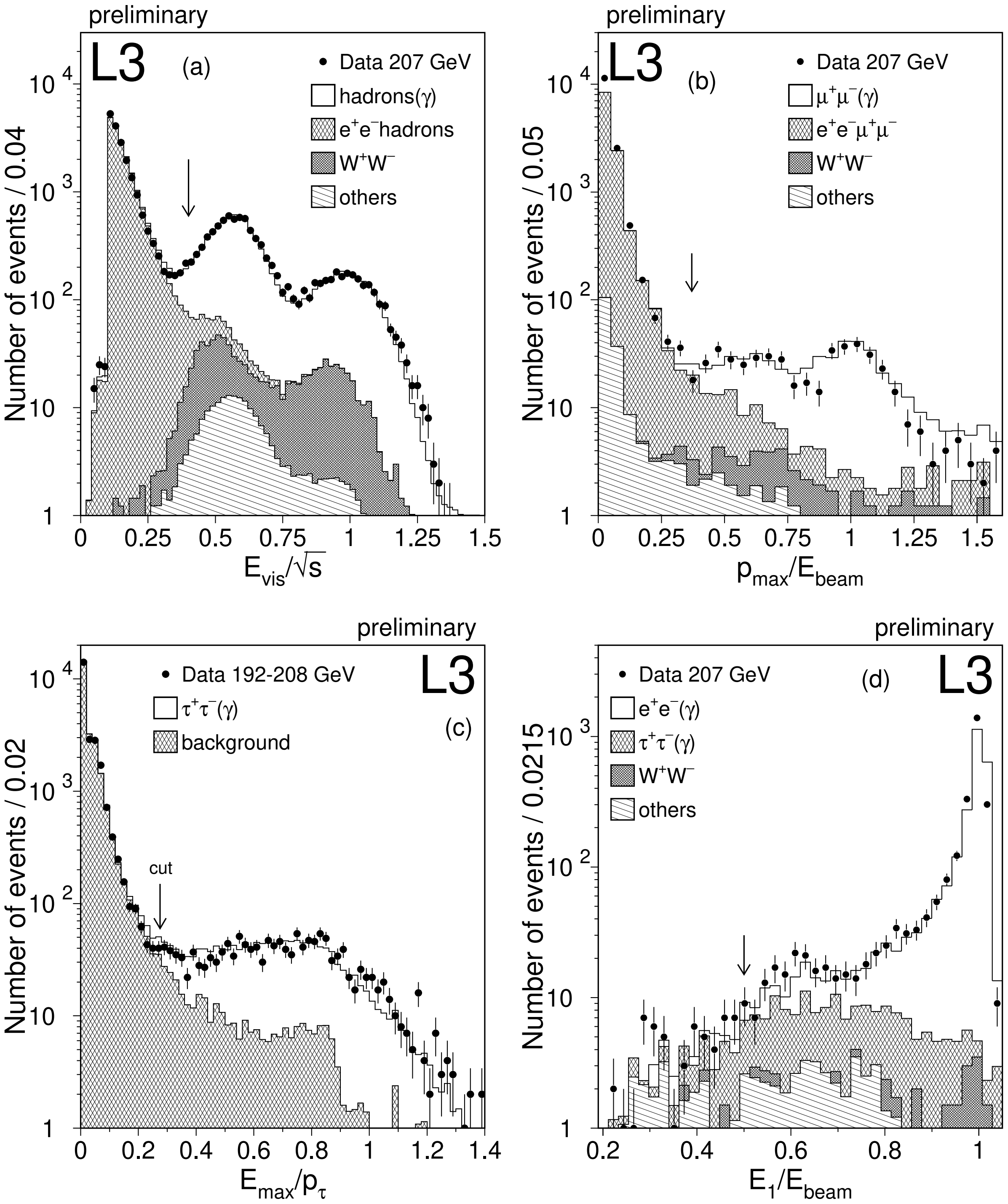

Figure 1: (a) The total visible energy normalised to the centre–of–mass energy, $\sqrt{s}$, for the selection of $e^+e^- \to$ hadrons $+\,\gamma$ events, (b) highest muon momentum normalised to the beam energy for the selection of $e^+e^- \to \mu^+\mu^-(\gamma)$ events, (c) highest tau jet energy normalised to the beam energy for the selection of $e^+e^- \to \tau^+\tau^-(\gamma)$ events, and (d) highest electron energy normalised to the beam energy for the selection of $e^+e^- \to e^+e^-(\gamma)$ events. The arrows indicate the cut values.

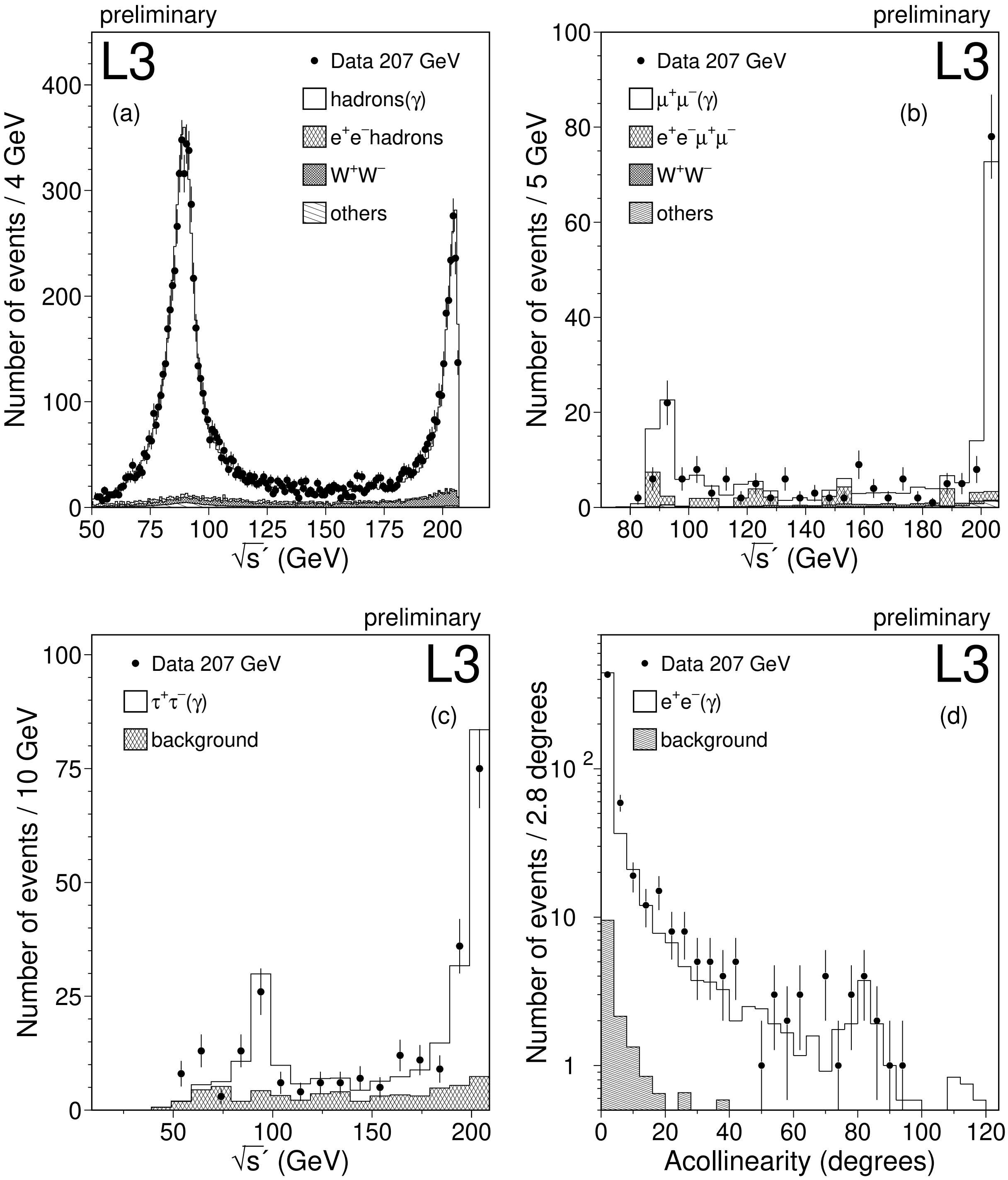

Figure 2: The reconstructed effective centre–of–mass energy, $\sqrt{s'}$, for the selection of (a) $\mathrm{e^+e^-} \rightarrow$ hadrons$+\gamma$ events, (b) $\mathrm{e^+e^-} \rightarrow \mu^+\mu^-(\gamma)$ events, (c) $\mathrm{e^+e^-} \rightarrow \tau^+\tau^-(\gamma)$ events and the acolinearity angle, ζ, for (d) $\mathrm{e^+e^-} \rightarrow \mathrm{e^+e^-}(\gamma)$ events.

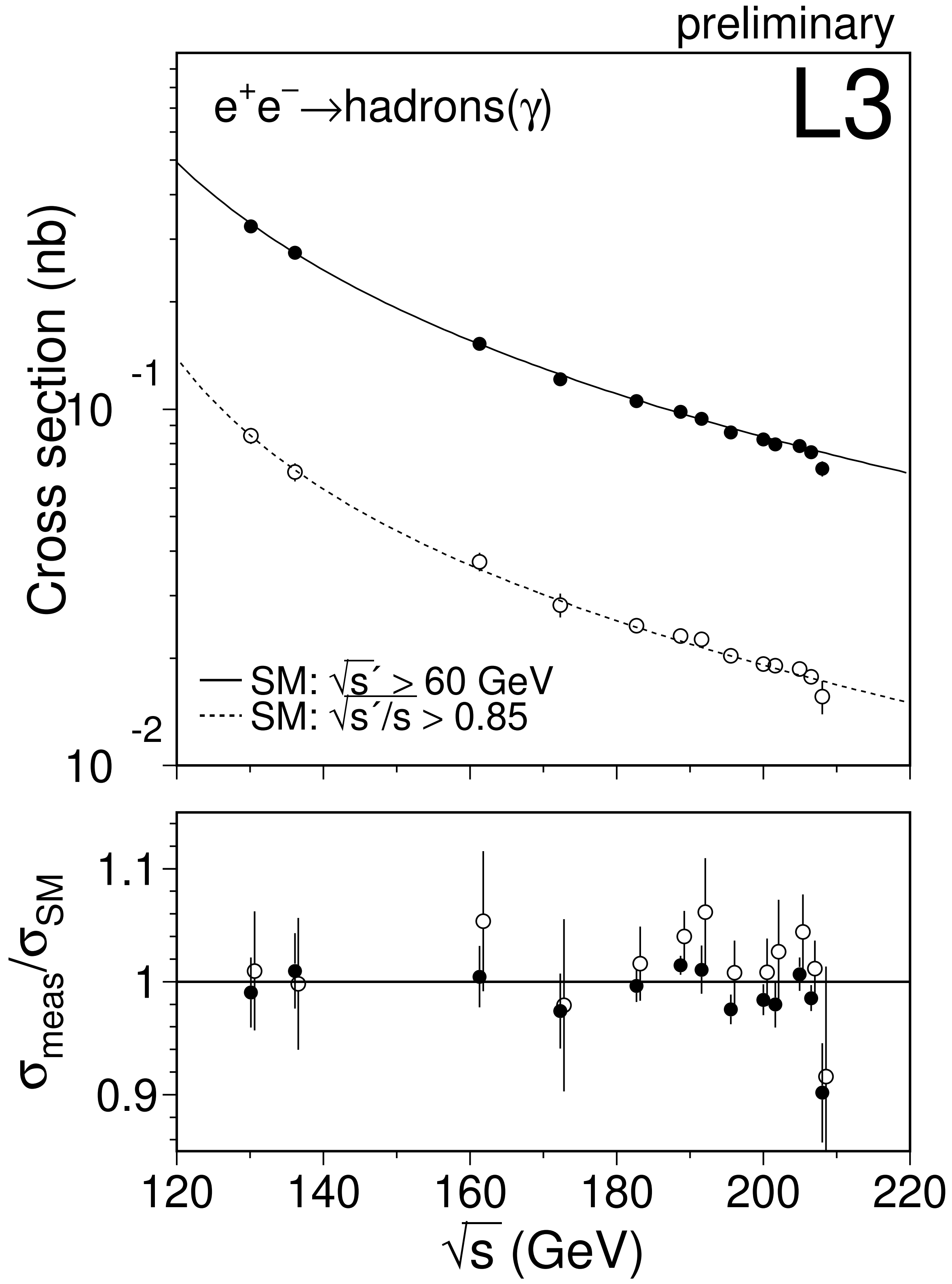

Figure 3: Comparison of hadron cross section measurements at centre–of–mass energies above the Z resonance to the Standard Model prediction.

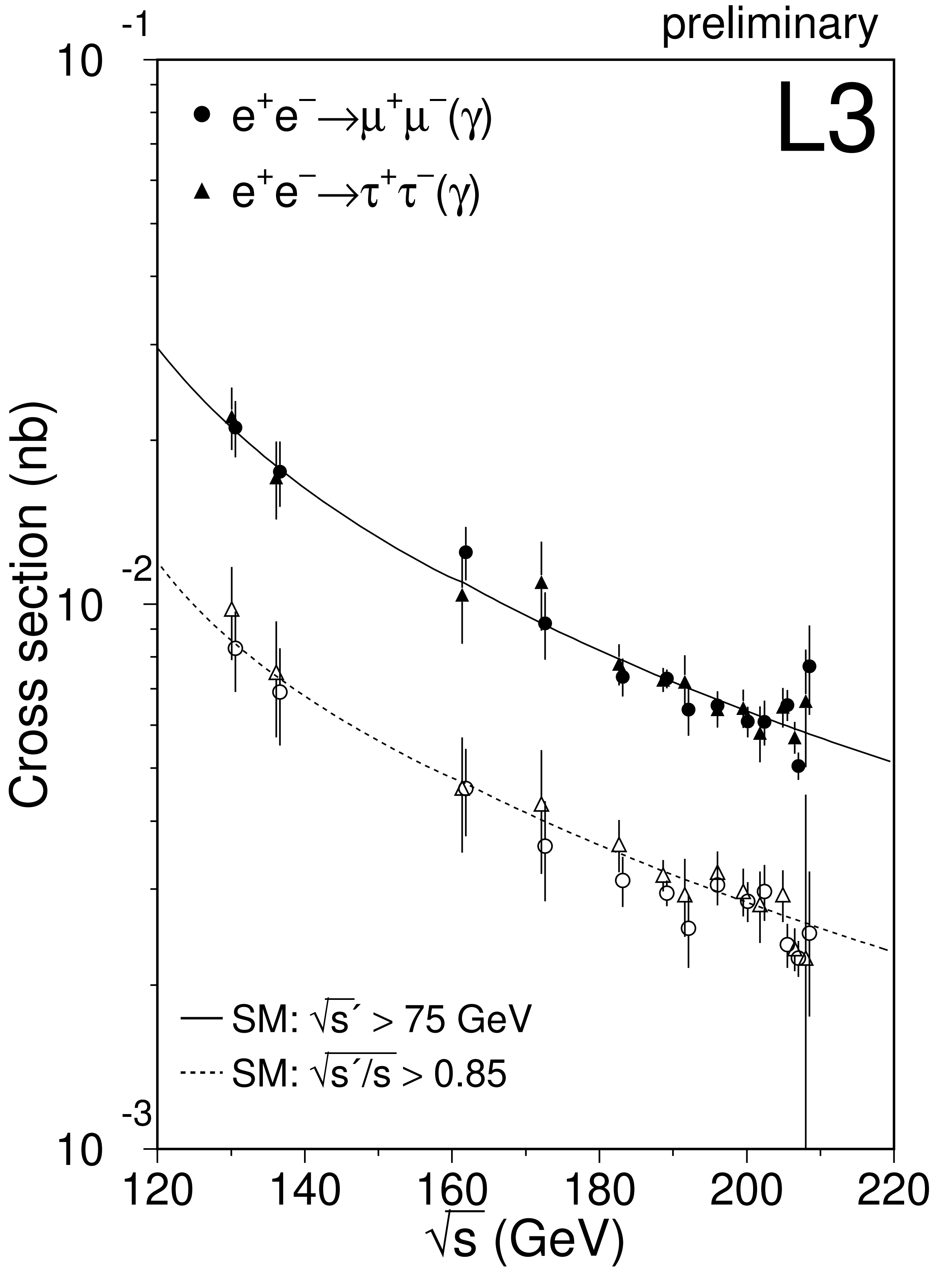

Figure 4: Comparison of muon– and tau–pair cross sections at centre–of–mass energies above the Z resonance to the Standard Model prediction.

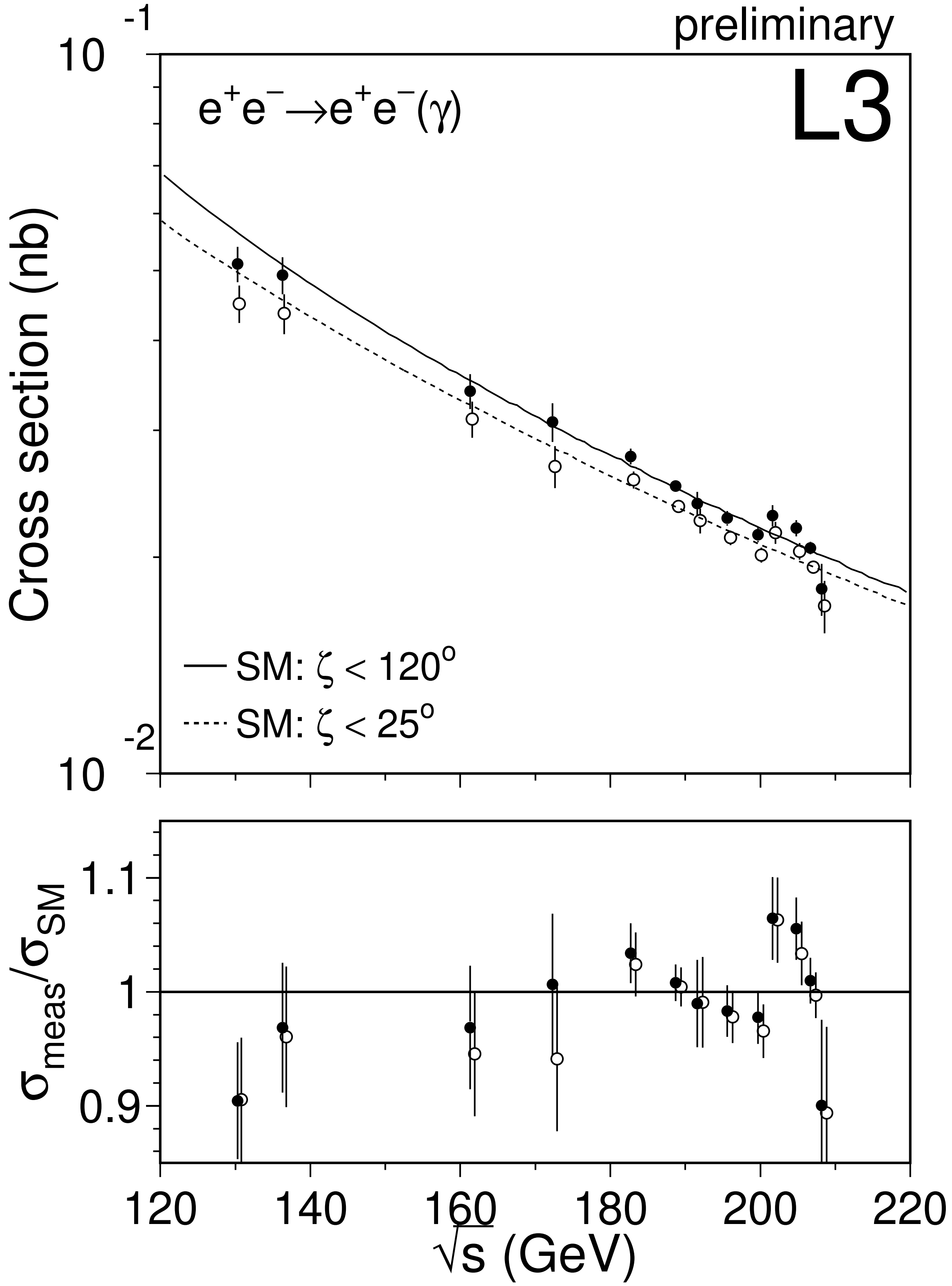

Figure 5: Comparison of Bhabha cross section measurements at centre–of–mass energies above the Z resonance to the Standard Model prediction.

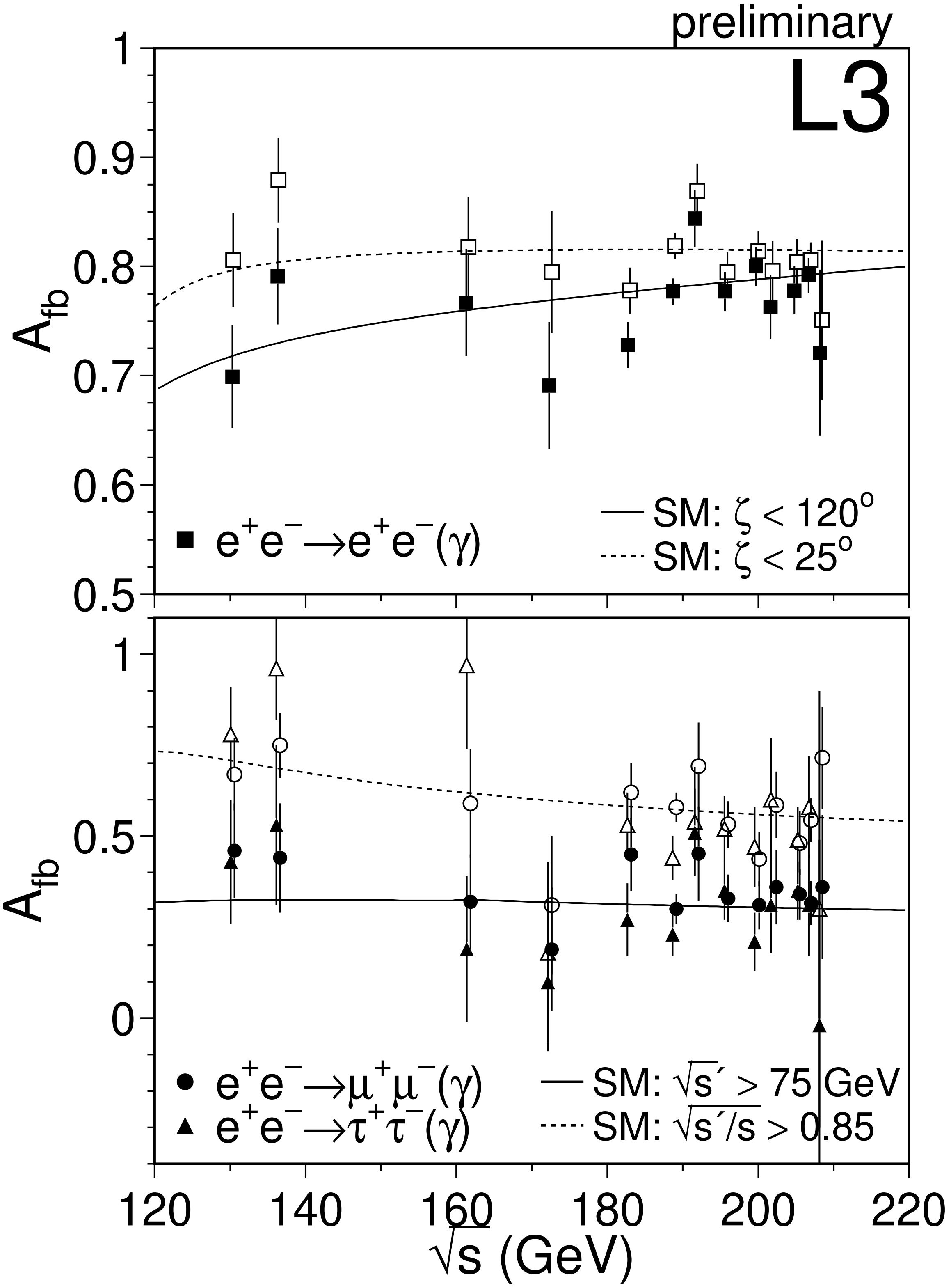

Figure 6: Comparison of muon– and tau–pair asymmetry measurements (bottom) and of electron–pair forward–backward asymmetry measurements (top) to the Standard Model prediction.

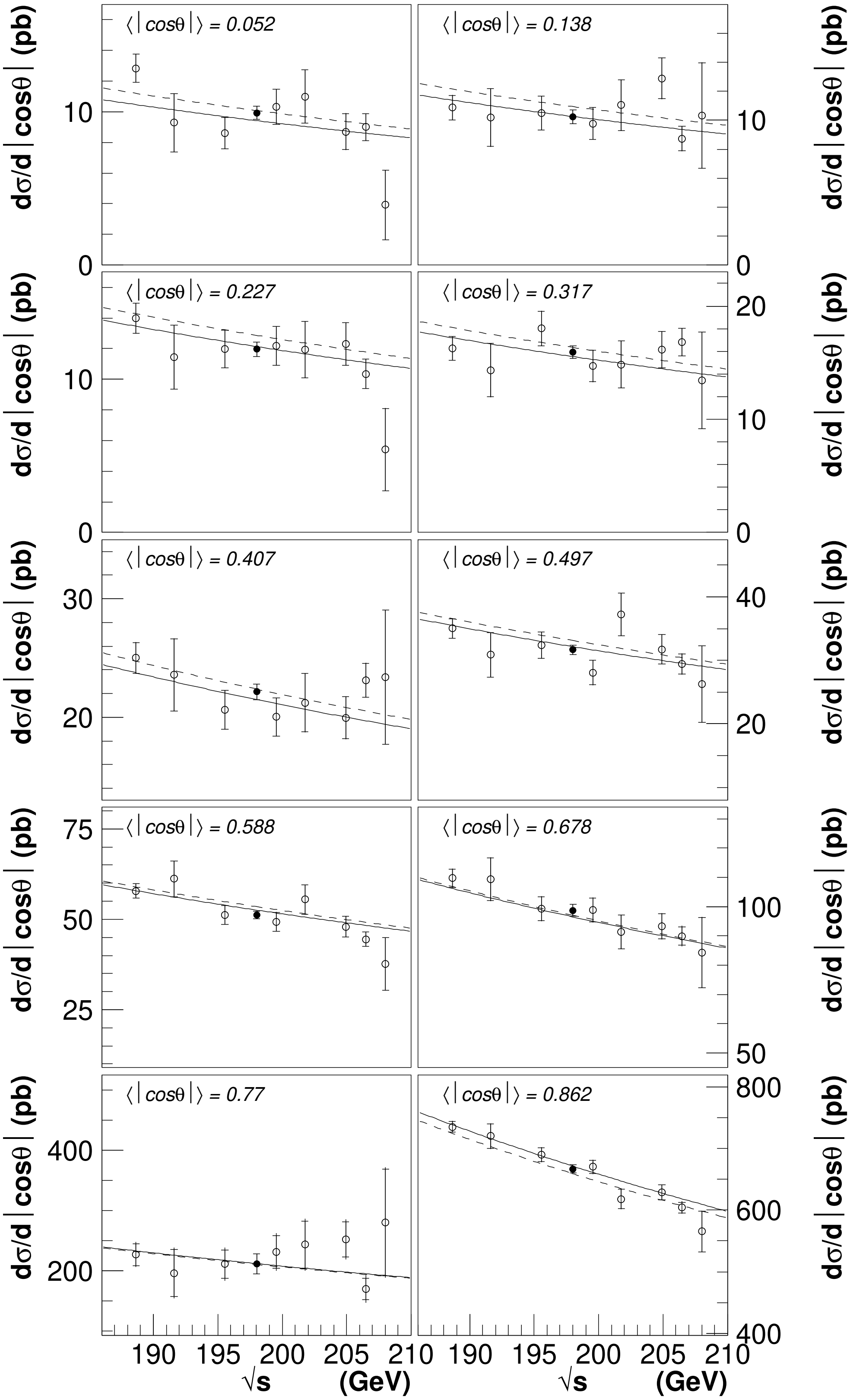

Figure 7: Comparison of the measured differential coss sections of Bhabha production at centre–of–mass energies above the Z resonance to the Standard Model prediction (solid line) and to the Born cross section (dashed line).

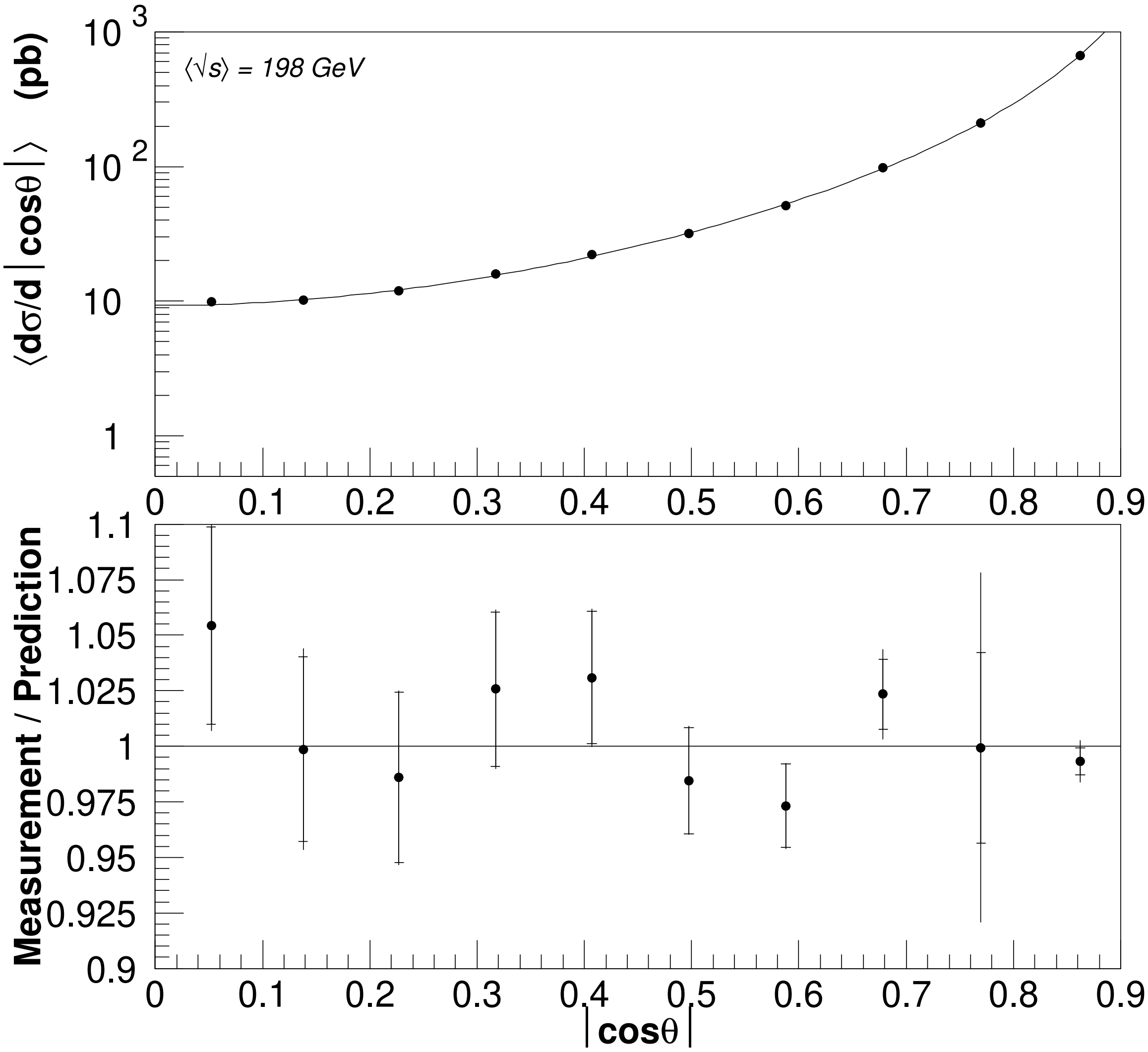

Figure 8: Comparison of the measured differential coss sections of Bhabha production. Data from all centre–of-mass energies have been combined to an average energy of 198 GeV.

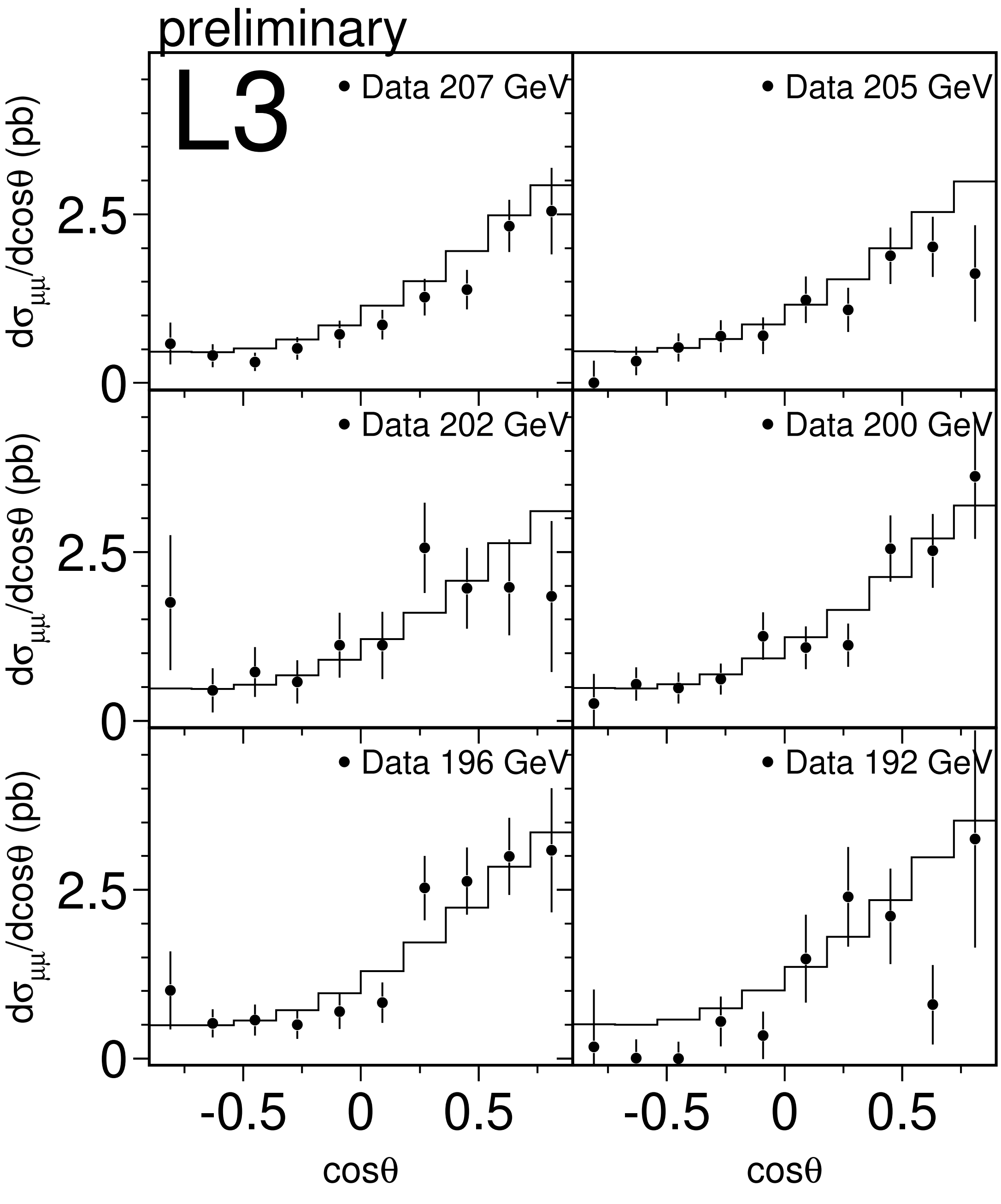

Figure 9: Comparison of the measured differential coss sections of muon production. The histograms correspond the the Standard Model prediction.

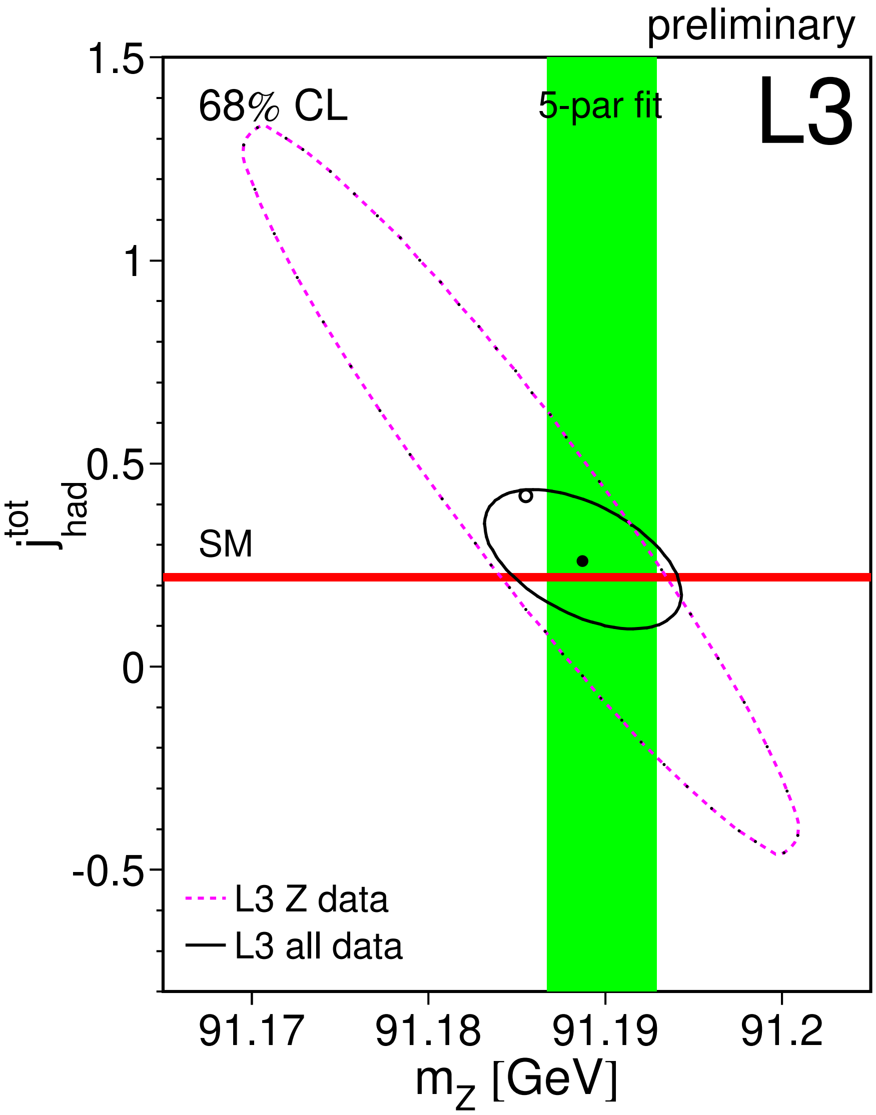

Figure 10: Contours in the (m_{Z}, $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$) plane at 68% confidence level under the assumption of lepton universality. The dashed line is obtained from Z data only; the inclusion of 130 GeV to 208 GeV data gives the solid line. The circle (Z data) and the solid dot (all data) indicate the central values of the fits. The Standard Model prediction for $\mathrm{j}_{\mathrm{had}}^{\mathrm{tot}}$ is shown as the horizontal band. The vertical band corresponds to the 68% confidence level interval on m_{Z} in a fit assuming the Standard Model value for γ/Z interference.