EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

LEP2FF/01-01

ALEPH 2001-039 PHYSIC 2001-013
DELPHI 2001-108 PHYS 896
L3 note 2663
OPAL TN690

16 May 2001

Combination of the LEP II $\mathrm{f\bar{f}}$ Results

LEPEWWG $\mathrm{f\bar{f}}$ Subgroup

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Abstract

Preliminary combinations of measurements of the 4 LEP collaborations of the process $\mathrm{e^+e^-} \rightarrow \mathrm{f\bar{f}}$ at LEP II are presented, using the latest results from 2000 data taking where available. Cross-sections and forward-backward asymmetry measurements are combined for the full LEP II data set. Combined differential cross-sections $\frac{\mathrm{d}\sigma}{\mathrm{d}\cos\theta}$ for muon-pair and tau-pair final states are presented. Measurements of the production of heavy flavours are combined. The combined results are interpreted in terms of contact interactions, exchange of $\mathrm{Z'}$ bosons and the exchange of leptoquarks.

Results Prepared for Winter Conferences 2001

1 Introduction

Since the start of the LEP II program LEP has delivered collisions at energies from ~ 130 GeV to ~ 209 GeV. The 4 LEP experiments have made measurements on the $e^+e^- \rightarrow f\bar{f}$ process over this range of energies, and a preliminary combination of these data is discussed in this note.

In the years 1995 through 1999 LEP delivered luminosity at a number of distinct centre-of-mass energy points. In 2000 most of the luminosity was delivered close to 2 distinct energies, but there was also a significant fraction of the luminosity delivered in, more-or-less, a continuum of energies. To facilitate the combination of the data, the 4 LEP experiments all divided the data they collected in 2000 into two energy bins: from 202.5 to 205.5 GeV; and 205.5 GeV and above. The nominal and actual centre of mass energies to which the LEP data have been averaged for each year are given in Table 1.

A number of measurements on the process $e^+e^- \rightarrow f\bar{f}$ exist and have been combined. The preliminary averages of cross-section and forward-backward asymmetry measurements are discussed in Section 2. The results presented in this section update those presented in [1]-[3]. In Section 3 an average of the differential cross-sections measurements, $\frac{d\sigma}{d\cos\theta}$, for the channels $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ is presented. In Section 4 an update of the combinations of heavy flavour results R_b, R_c, A_{FB}^b and A_{FB}^c from LEP II is presented. Complete results of the combinations are available on the web page [4].

In Section 5 the combined results are interpreted in terms of contact interactions, the exchange of Z' bosons and the exchange of leptoquarks.

The results are summarised in section 6.

2 Averages for Cross-sections and Asymmetries

In this section the results of the preliminary combination of cross-sections and asymmetries are given. The individual experiments' analyses of cross-sections and forward-backward asymmetries are discussed in [5]. Cross-section results are combined for the $e^+e^- \rightarrow q\bar{q}$, $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ channels, forward-backward asymmetry measurements are combined for the $\mu^+\mu^-$ and $\tau^+\tau^-$ final states. The averages are made for the samples of events with high $\sqrt{s'}$. The combination followed the procedure described in detail in [1] and [2].

As in [1], the averages were performed using a χ^2 minimisation technique. The data were split into 3 sets: data taken at energies from 130–189 GeV, data taken during 1999, and data taken in 2000. Averages were performed separately for each of these data sets. This procedure ignores correlations between the 1999 and 2000 data and also correlations between these two sets of data and the data taken at 130–189 GeV. This procedure was adopted because the 1999 and 2000 data are still preliminary, whereas the 130–189 GeV averages are based on mostly published data. Inclusion of these correlations would have only a small effect on the results.

The results for the averages of the 130–189 GeV and 192-202 GeV data have not been updated. Results can be found in [1] and [3]. Results for the more preliminary data taken during 2000 are not given in numerical form but are shown in Figures 1 and 2 which show the LEP averaged cross-sections and asymmetries (based on definition 1 of [1]), respectively, as a function of the centre-of-mass energy, together with the SM predictions.

The χ^2 per degree of freedom for the average of the LEP II $f\bar{f}$ data is 173/180. The correlations are rather small, with the largest components at any given pair of energies being between the hadronic cross-sections. The other off-diagonal terms in the correlation matrix are smaller than 10%.

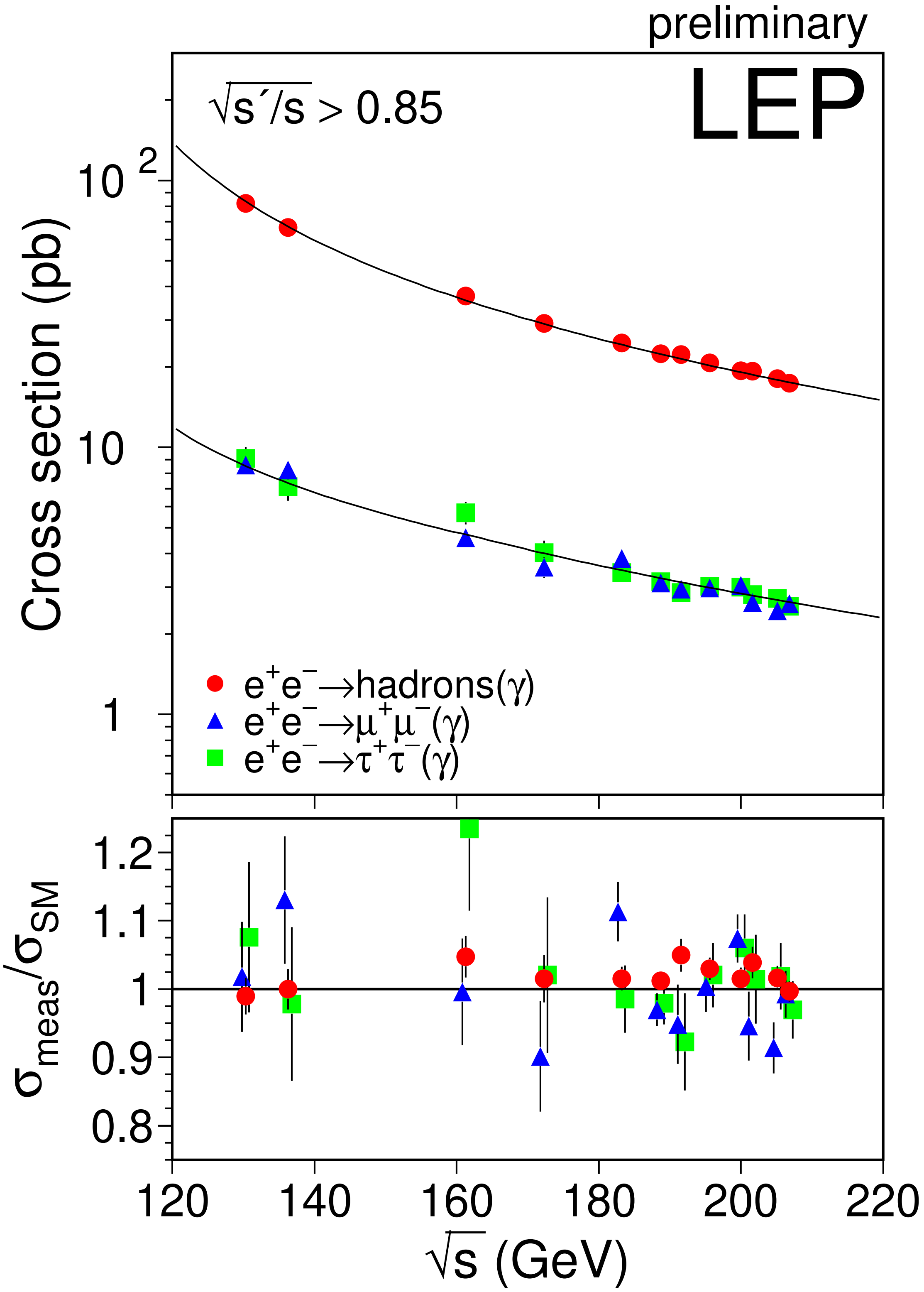


Figure 1: *Preliminary combined LEP results on the cross-sections for* $q\bar{q}$, $\mu^+\mu^-$ *and* $\tau^+\tau^-$ *final states, as a function of centre-of-mass energy. The values at 130–189 GeV are taken from [3]. The expectations of the SM, computed with ZFITTER [6], are shown as curves. The lower plot shows the ratio of the data divided by the SM.*

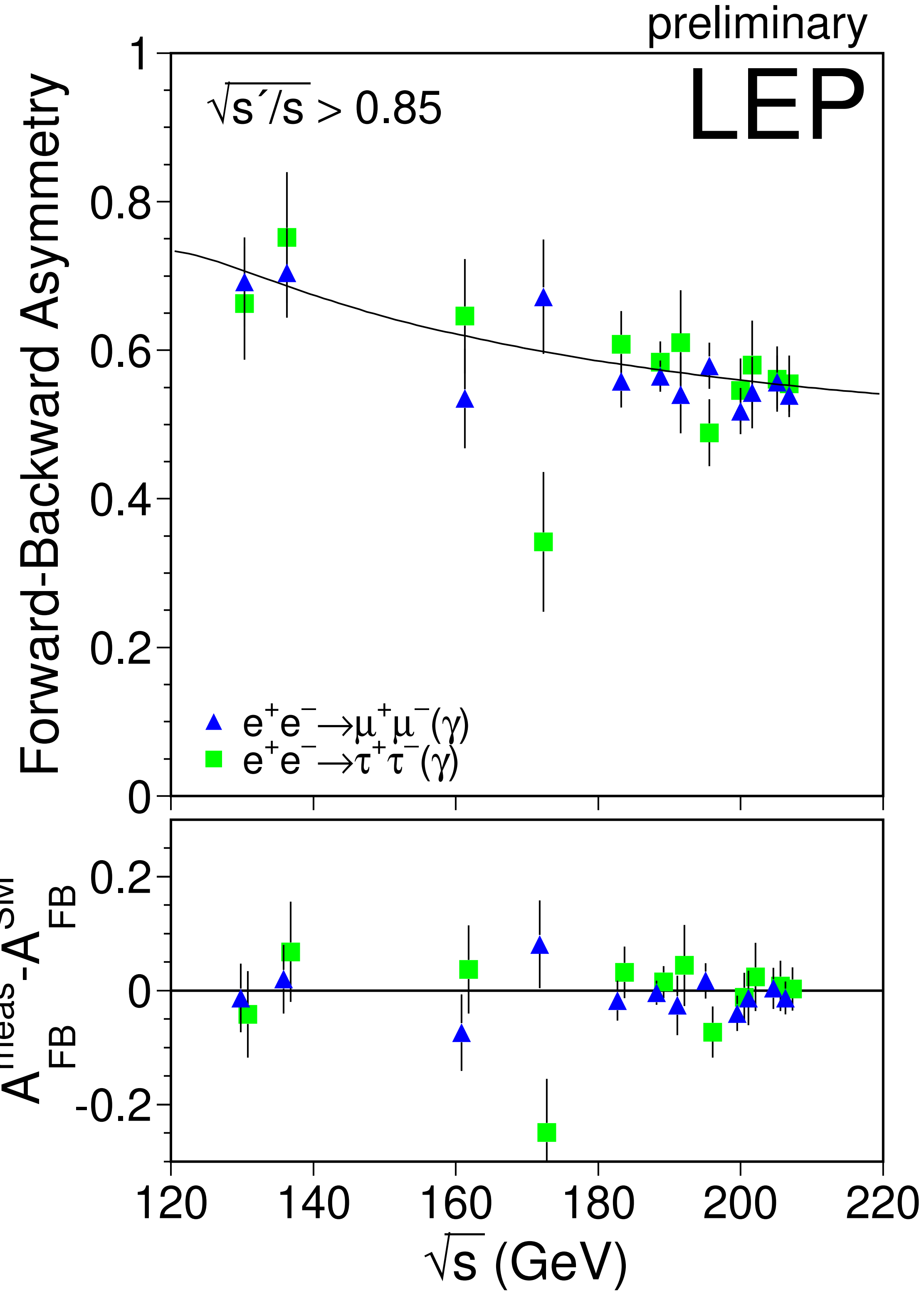


Figure 2: *Preliminary combined LEP results on the forward-backward asymmetry for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states as a function of centre-of-mass energy. The values at 130–189 GeV are taken from [3]. The expectations of the SM computed with ZFITTER [6], are shown as curves. The lower plot shows differences between the data and the SM.*

There is good agreement between the SM expectations and the measurements of the individual experiments and the combined averages. The cross-sections for hadronic final states at most of the energy points are somewhat above the SM expectations. Taking into account the correlations between the data points and also assigning an error of $\pm 0.5\%$ [7] on the absolute SM predictions, the difference of the cross-section from the SM expectations averaged over all energies is approximately a 1.8 standard deviation excess. It is concluded that there is no significant evidence in the results of the combinations for physics beyond the SM in the process $e^+e^- \rightarrow f\bar{f}$.

3 Averages for Differential Cross-sections

The LEP experiments have measured the differential cross-section, $\frac{d\sigma}{d\cos\theta}$, for the $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ channels for samples of events with $\sqrt{s'/s} > 0.85$. These results have been combined using the procedure discussed in [1]. The ranges in $\cos\theta$ for the measurements of the individual experiments and the average are given in Table 2.

The combination included data from 183 to 207 GeV, but not all experiments provided data at all energies. The data received are summarised in Table 3.

Three separate averages were performed one for 183 and 189 GeV data, one for 192–202 GeV data and for 205 and 207 GeV data. The averages for the 183–189 and 192–202 GeV data sets have not been updated with respect to [1]. The results of the averages are shown in Figures 3 and 4. The χ^2 per degree of freedom for the average is 375/320.

The correlations between bins in the average are less that 2% of the total error on the averages in each bin. Overall the agreement between the averaged data and the predictions is good, with a χ^2 of 158 for 160 degrees of freedom. At 202 GeV the cross-section in the most backward bin, $-1.00 < \cos\theta < 0.8$, for both muon and tau final states is above the predictions. For the muons the excess in data corresponds to 3.3 standard deviations. For the taus the excess is 2.3 standard deviations, however, for this measurement the individual experiments are somewhat inconsistent, having a chi-squared with respect to the average of 10.5 for 2 degrees of freedom.

4 Averages for Heavy Flavour Measurements

This section presents a combination of both published [8] and preliminary [9] measurements of the ratios* R_b and R_c and the forward-backward asymmetries, A_{FB}^b and A_{FB}^c, from the LEP collaborations at centre-of-mass energies in the range of 130 to 209 GeV. Full details concerning the combination procedure can be found in [10].

Table 4 summarises the inputs that have been combined, yielding the results presented in Table 5 and Figures 5 and 6. A list of the error contributions from the combination at 189 GeV is shown in Table 6. The results are consistent with the Standard Model predictions of ZFITTER.

5 Interpretation

The combined cross-sections and asymmetries and results on heavy flavour production have been interpreted in a variety of models. The cross-section and asymmetry results have been used to place limits on the mass of a possible additional heavy neutral boson, Z', in several models.

*Unlike at LEP I, R_q is defined as $\frac{\sigma_{q\bar{q}}}{\sigma_{had}}$.

Year	Nominal Energy GeV	Actual Energy GeV	Luminosity pb^{-1}
1995	130	130.2	~ 3
	136	136.2	~ 3
	133*	133.2	~ 6
1996	161	161.3	~ 10
	172	172.1	~ 10
	167*	166.6	~ 20
1997	130	130.2	~ 2
	136	136.2	~ 2
	183	182.7	~ 50
1998	189	188.6	~ 170
1999	192	191.6	~ 30
	196	195.5	~ 80
	200	199.5	~ 80
	202	201.6	~ 40
2000	205	204.9	~ 80
	207	206.7	~ 140

Table 1: *The nominal and actual centre-of-mass energies for data collected during LEP II operation in each year. The approximate average luminosity analysed per experiment at each energy is also shown. Values marked with a * are average energies for 1995 and 1996 used for heavy flavour results. The data taken at nominal energies of 130 and 136 in 1995 and 1997 are combined by most experiments.*

Experiment	$\cos\theta_{min}$	$\cos\theta_{max}$
ALEPH	-0.95	0.95
DELPHI ($e^+e^- \to \mu^+\mu^-$183)	-0.94	0.94
DELPHI ($e^+e^- \to \mu^+\mu^-$189 $-$ 207)	-0.97	0.97
DELPHI ($e^+e^- \to \tau^+\tau^-$)	-0.96	0.96
L3	-0.90	0.90
OPAL	-1.00	1.00
Average	-1.00	1.00

Table 2: *The acceptances for which experimental data are presented and the acceptance for the LEP average. For DELPHI the acceptance is shown for the different channels and for the muons for different centre of mass energies. For all other experiments the acceptance is the same for muon and tau-lepton channels and for all energies provided.*

$\sqrt{s}$(GeV)	ALEPH	DELPHI	L3	OPAL
183	-	F	-	F
189	P	F	F	F
192-202	P	P	-	P
205-207	P	P	-	P

Table 3: *Differential cross-section data provided by the LEP collaborations for combination at different centre-of-mass energies. Data indicated with* F *are final, published data. Data marked with* P *are preliminary. Data marked with a* - *were not supplied for combination.*

$\sqrt{s}$ (GeV)	R_b				R_c				A_{FB}^b				A_{FB}^c			
	A	D	L	O	A	D	L	O	A	D	L	O	A	D	L	O
133	F	F	F	F	-	-	-	-	-	F	-	F	-	F	-	F
167	F	F	F	F	-	-	-	-	-	F	-	F	-	F	-	F
183	F	P	F	F	F	-	-	-	F	-	-	F	P	-	-	F
189	P	P	F	F	P	-	-	-	P	P	F	F	P	-	-	F
192 to 202	P	P	P	-	-	-	-	-	P	P	-	-	-	-	-	-
205-207	-	P	P	-	-	-	-	-	-	P	-	-	-	-	-	-

Table 4: *Data provided by the ALEPH, DELPHI, L3, OPAL collaborations for combination at different centre-of-mass energies. Data indicated with* F *are final, published data. Data marked with* P *are preliminary. Data marked with a* - *were not supplied for combination.*

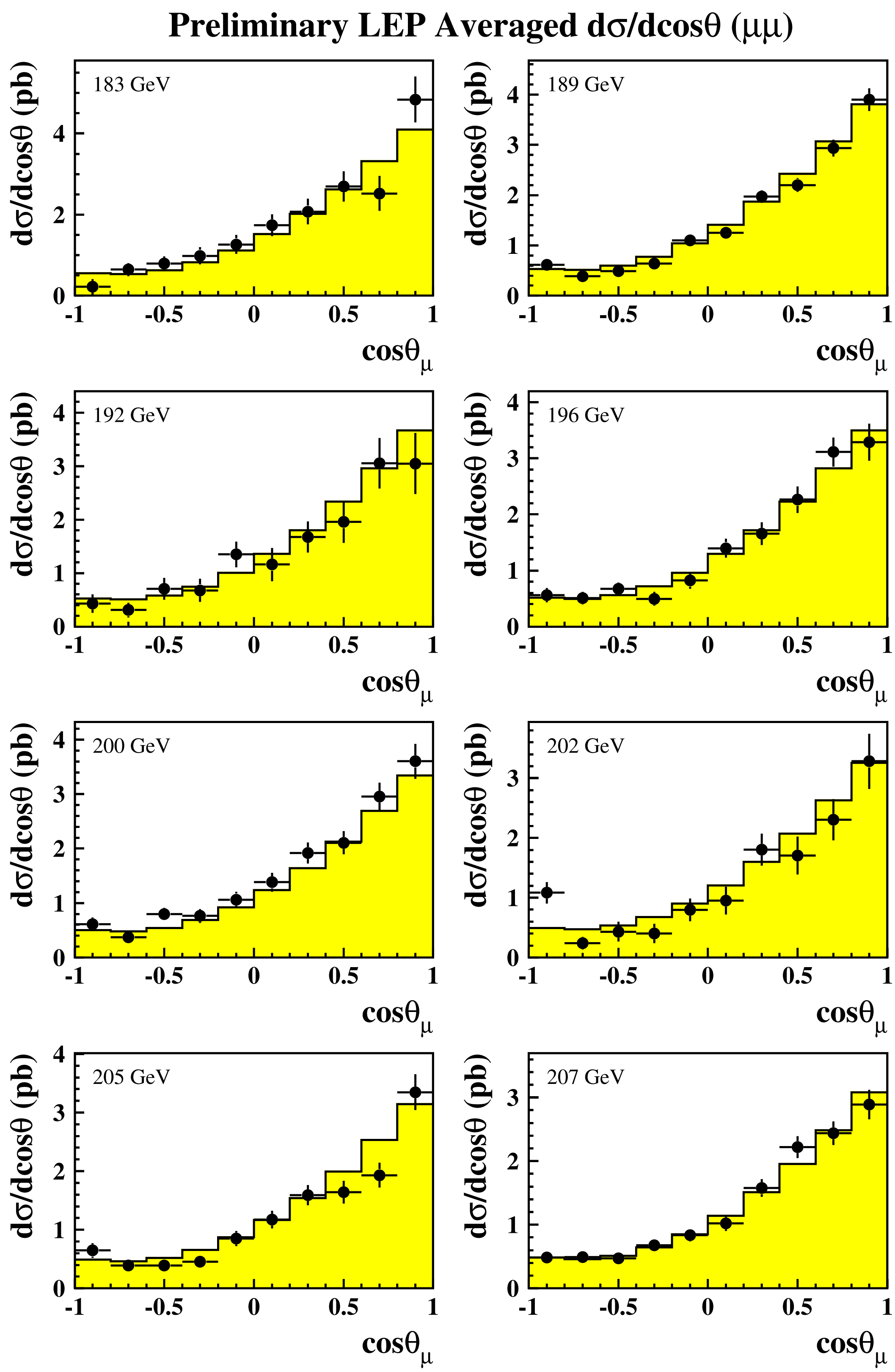


Figure 3: *LEP averaged differential cross-sections for* $e^+e^- \rightarrow \mu^+\mu^-$ *at energies of 183-207 GeV. The SM predictions, shown as solid histograms, are computed with ZFITTER [6].*

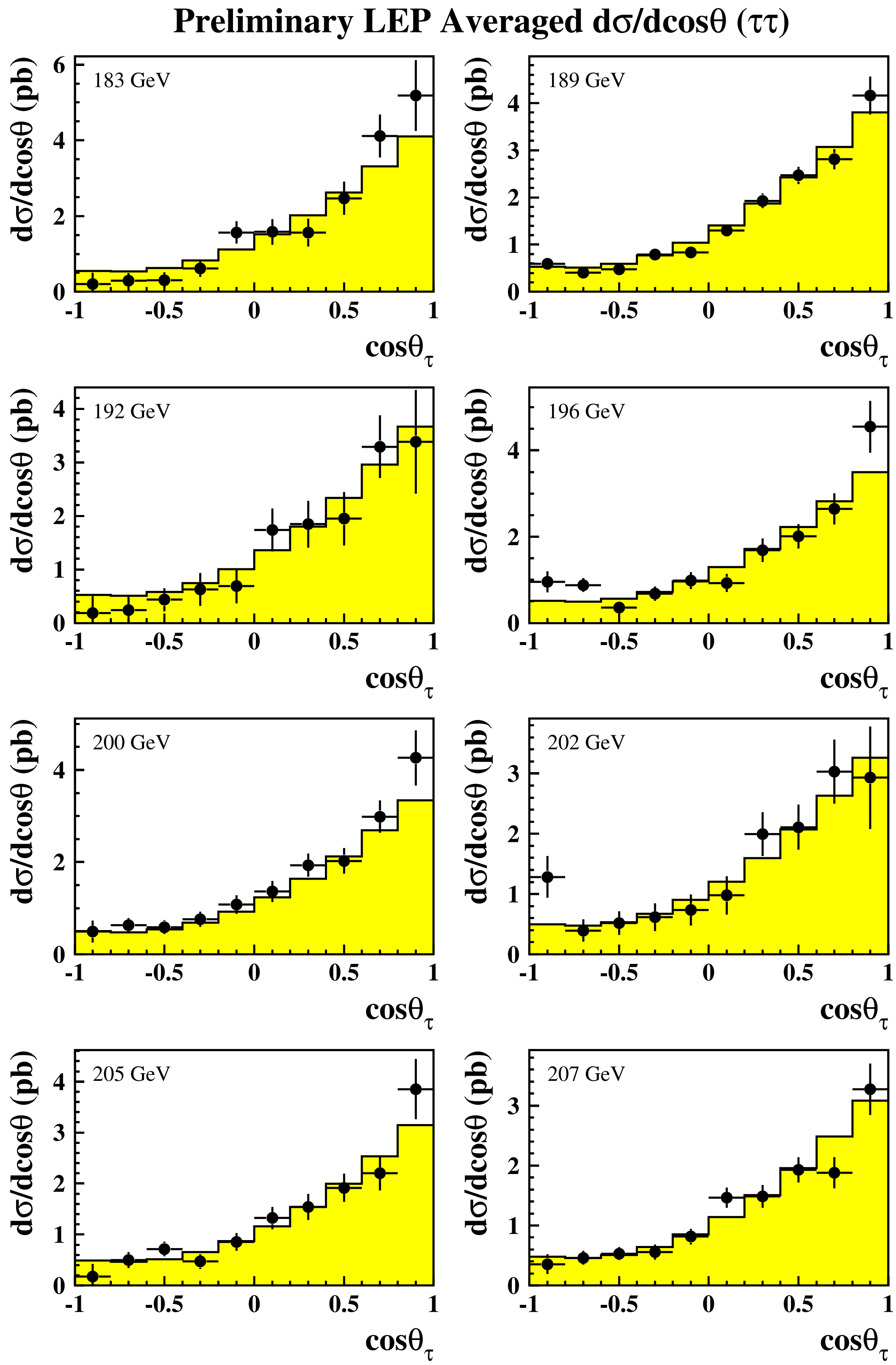


Figure 4: *LEP averaged differential cross-sections for* $e^+e^- \to \tau^+\tau^-$ *at energies of 183-207 GeV. The SM predictions, shown as solid histograms, are computed with ZFITTER [6].*

$\sqrt{s}$ (GeV)	$\mathrm{R_b}$	$\mathrm{R_c}$	$\mathrm{A_{FB}^b}$	$\mathrm{A_{FB}^c}$
133	0.1811 ± 0.0132 (0.1853)	- -	0.358 ± 0.251 (0.487)	0.577 ± 0.314 (0.681)
167	0.1484 ± 0.0127 (0.1708)	- -	0.620 ± 0.254 (0.561)	0.915 ± 0.344 (0.671)
183	0.1619 ± 0.0101 (0.1671)	0.269 ± 0.043 (0.250)	0.528 ± 0.155 (0.578)	0.658 ± 0.209 (0.656)
189	0.1562 ± 0.0065 (0.1660)	0.240 ± 0.023 (0.252)	0.488 ± 0.094 (0.583)	0.446 ± 0.151 (0.649)
192	0.1541 ± 0.0149 (0.1655)	- -	0.422 ± 0.267 (0.585)	- -
196	0.1542 ± 0.0098 (0.1648)	- -	0.531 ± 0.151 (0.587)	- -
200	0.1675 ± 0.0100 (0.1642)	- -	0.589 ± 0.150 (0.590)	- -
202	0.1635 ± 0.0143 (0.1638)	- -	0.604 ± 0.241 (0.593)	- -
205	0.1588 ± 0.0126 (0.1634)	- -	0.728 ± 0.258 (0.594)	- -
207	0.1680 ± 0.0108 (0.1632)	- -	0.447 ± 0.200 (0.593)	- -

Table 5: *Results of the global fit, compared to the Standard Model predictions, computed with ZFITTER [11], for the signal definition in parentheses. Quoted errors represent the statistical and systematic errors added in quadrature. Because of the large correlation with* $\mathrm{R_c}$ *at 183 GeV and 189 GeV, the errors on the corresponding measurements of* $\mathrm{R_b}$ *receive an additional contribution which is absent at the other energy points.*

Error list	$\mathrm{R_b}$ (189 GeV)	$\mathrm{R_c}$ (189 GeV)	$\mathrm{A_{FB}^b}$ (189 GeV)	$\mathrm{A_{FB}^c}$ (189 GeV)
statistics	0.00606	0.0179	0.0884	0.1229
internal syst	0.00232	0.0123	0.0296	0.0481
common syst	0.00082	0.0078	0.0138	0.0735
total syst	0.00246	0.0145	0.0327	0.0878
total error	0.00654	0.0231	0.0942	0.1510

Table 6: *Error breakdown at 189* GeV

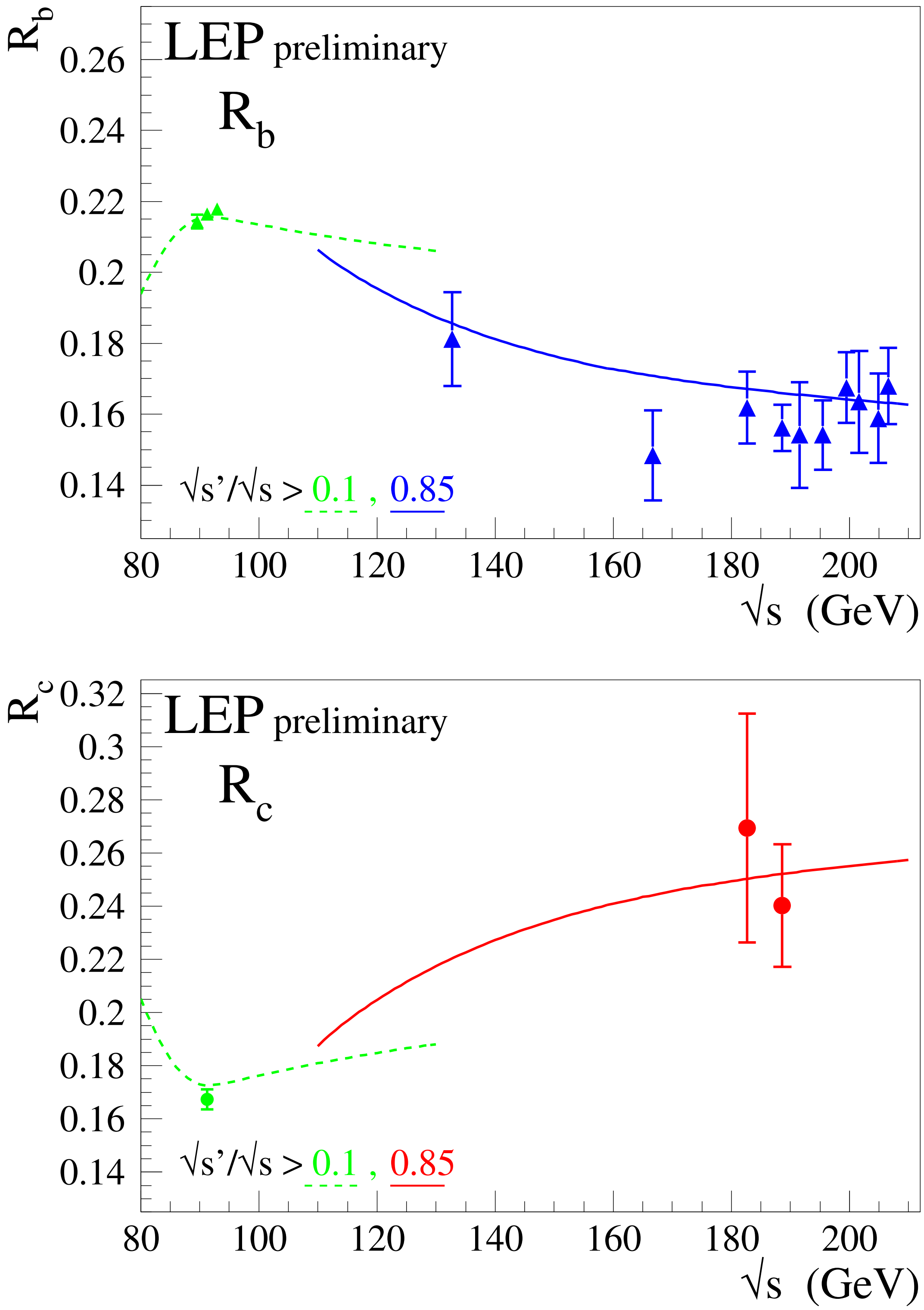


Figure 5: *Preliminary combined LEP measurements of* $\mathrm{R_b}$ *and* $\mathrm{R_c}$*. Solid lines represent the Standard Model prediction for the signal definition and dotted lines the inclusive prediction. Both are computed with ZFITTER[11]. The LEP I measurements have been taken from [12].*

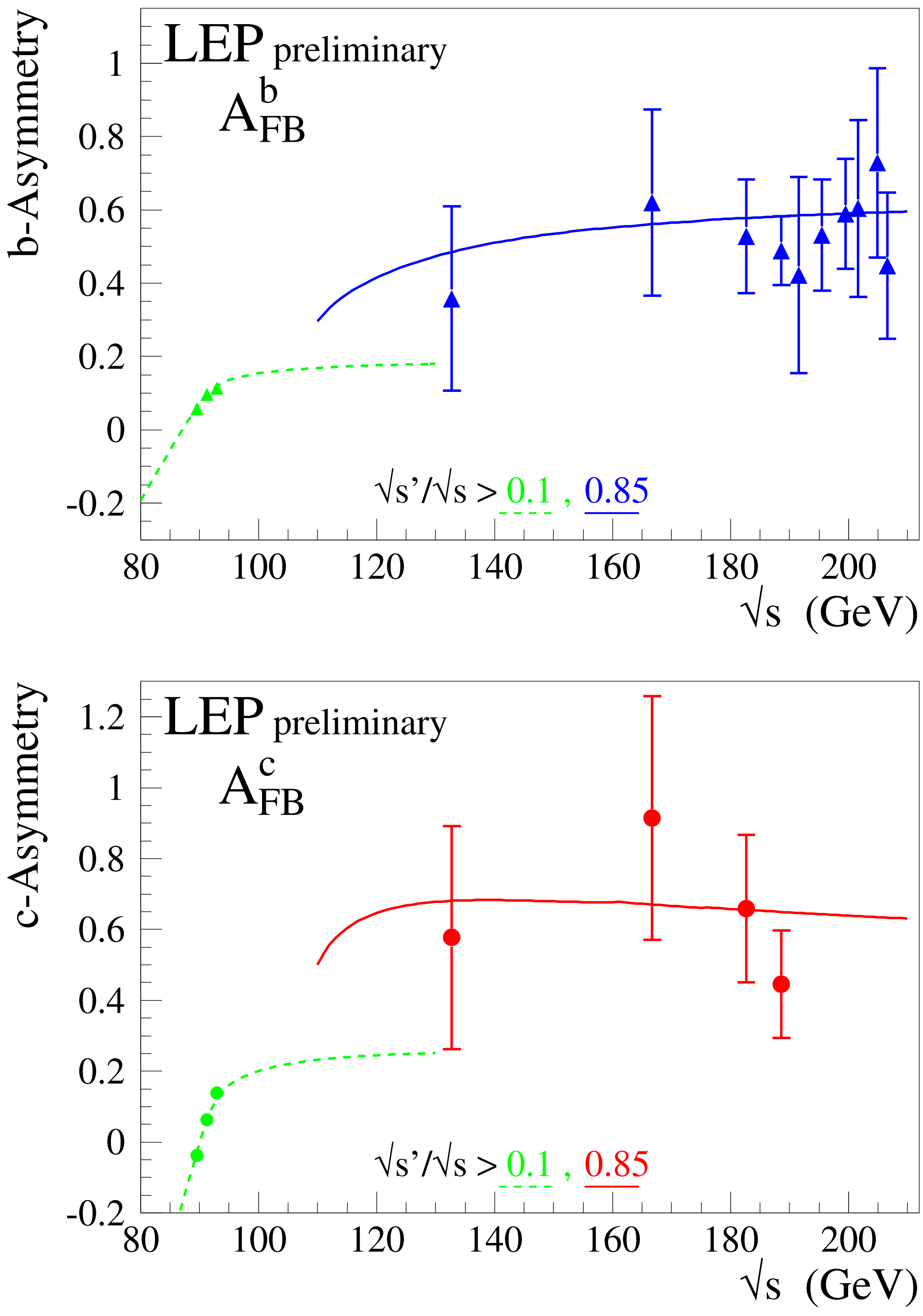


Figure 6: *Preliminary combined LEP measurements of the forward–backward asymmetries* A^b_{FB} *and* A^c_{FB}*. Solid lines represent the Standard Model prediction for the signal definition and dotted lines the inclusive prediction. Both are computed with ZFITTER[11]. The LEP I measurements have been taken from [12].*

Model	χ	ψ	η	L-R	SSM
$\mathrm{M}_{\mathrm{Z}'}^{limit}$ (GeV/c^2)	715	478	454	862	2090

Table 7: *95% confidence level lower limits on the* Z' *mass and* χ, ψ, η, *L-R and SSM models.*

Limits on contact interactions between leptons and on contact interaction between electrons and b and c quarks have been obtained. The results update those provided in [1].

Limits are also provided on the masses of leptoquarks.

5.1 Models with Z' Bosons

The combined hadronic and leptonic cross-sections and the leptonic forward-backward asymmetries were used to fit the data to models including an additional, heavy, neutral boson, Z' within a variety of models [13] and [14]. See [1] for further details.

No evidence was found for the existence of a Z' boson in any of the models.

95% confidence level lower limits on $\mathrm{M}_{\mathrm{Z}'}$ were obtained, by integrating the likelihood function†. The lower limits on the Z' mass are shown in Table 7, these are obtained for the mixing angle between the Z and Z', $\Theta_{\mathrm{ZZ}'} = 0$.

5.2 Contact Interactions between Leptons

Following [15] and [16] the averages of cross-sections and forward-backward asymmetries for muon-pair and tau-lepton pair final states have been used to search for contact interactions between leptons. See [1] for further details.

The values of ϵ extracted for each model were all compatible with the Standard Model expectation $\epsilon = 0$, at the two standard deviation level. These errors on ϵ are typically a factor of two smaller than those obtained from a single LEP experiment with the same data set. The fitted values of ϵ were converted into 95% confidence level lower limits on Λ. The limits are obtained by integrating the likelihood function over the physically allowed values, $\epsilon \geq 0$ for each Λ^+ limit and $\epsilon \leq 0$ for Λ^- limits. The fitted values of ϵ and the extracted limits are shown in Table 8. Figure 7 shows the limits obtained on the scale Λ for the different models assuming universality between contact interactions for $\mathrm{e^+e^-} \rightarrow \mu^+\mu^-$ and $\mathrm{e^+e^-} \rightarrow \tau^+\tau^-$.

5.3 Contact Interactions from Heavy Flavour Averages

Limits on contact interactions between electrons and b and c quarks have been obtained. These results are of particular interest since they are inaccessible to $\mathrm{p\bar{p}}$ or ep colliders. See [1] for further details.

The fitted values of ϵ and their 68% confidence level uncertainties together with the 95% confidence level lower limit on Λ are shown in Table 9. Figure 8 shows the limits obtained on the scale, Λ, of models with different helicity combinations involved in the interactions.

†To be able to obtain confidence limits from the likelihood function it is necessary to convert the likelihood to a probability density function; this is done by multiplying by a prior probability function. Simply integrating the likelihood is equivalent to multiplying by a uniform prior probability function.

$e^+e^- \to \mu^+\mu^-$			
Model	ϵ (TeV^{-2})	Λ^-(TeV)	Λ^+(TeV)
LL	$-0.0056^{+0.0040}_{-0.0040}$	8.6	14.7
RR	$-0.0077^{+0.0053}_{-0.0030}$	8.3	14.1
VV	$-0.0014^{+0.0016}_{-0.0017}$	15.3	22.4
AA	$-0.0036^{+0.0027}_{-0.0013}$	11.8	20.4
LR	$0.0014^{+0.0043}_{-0.0061}$	7.8	9.3
RL	$0.0014^{+0.0043}_{-0.0061}$	7.8	9.3
V0	$-0.0036^{+0.0025}_{-0.0014}$	12.1	20.2
A0	$0.0008^{+0.0020}_{-0.0031}$	12.7	12.9

$e^+e^- \to \tau^+\tau^-$			
Model	ϵ (TeV^{-2})	Λ^-(TeV)	Λ^+(TeV)
LL	$-0.0016^{+0.0054}_{-0.0047}$	9.4	10.6
RR	$-0.0008^{+0.0049}_{-0.0060}$	9.0	10.2
VV	$-0.0002^{+0.0016}_{-0.0023}$	15.2	17.5
AA	$-0.0004^{+0.0032}_{-0.0025}$	13.2	13.8
LR	$-0.0014^{+0.0075}_{-0.2283}$	2.1	8.6
RL	$-0.0014^{+0.0075}_{-0.2283}$	2.1	8.6
V0	$-0.0003^{+0.0023}_{-0.0030}$	13.0	14.7
A0	$-0.0008^{+0.0038}_{-0.0046}$	9.9	11.9

$e^+e^- \to l^+l^-$			
Model	ϵ (TeV^{-2})	Λ^-(TeV)	Λ^+(TeV)
LL	$-0.0042^{+0.0035}_{-0.0027}$	10.0	16.1
RR	$-0.0046^{+0.0037}_{-0.0033}$	9.6	15.3
VV	$-0.0009^{+0.0011}_{-0.0013}$	17.2	25.3
AA	$-0.0025^{+0.0019}_{-0.0012}$	13.9	21.8
LR	$0.0014^{+0.0036}_{-0.0062}$	9.0	10.7
RL	$0.0014^{+0.0036}_{-0.0062}$	9.0	10.7
V0	$-0.0020^{+0.0017}_{-0.0018}$	13.9	22.3
A0	$0.0008^{+0.0018}_{-0.0031}$	13.8	15.0

Table 8: *Fitted values of ϵ and 95% confidence limits on the scale, Λ, for constructive (+) and destructive interference (−) with the Standard Model, for the contact interaction models discussed in the text. Results are given for* $e^+e^- \to \mu^+\mu^-$, $e^+e^- \to \tau^+\tau^-$ *and* $e^+e^- \to \ell^+\ell^-$, *assuming universality in the contact interactions between* $e^+e^- \to \mu^+\mu^-$ *and* $e^+e^- \to \tau^+\tau^-$.

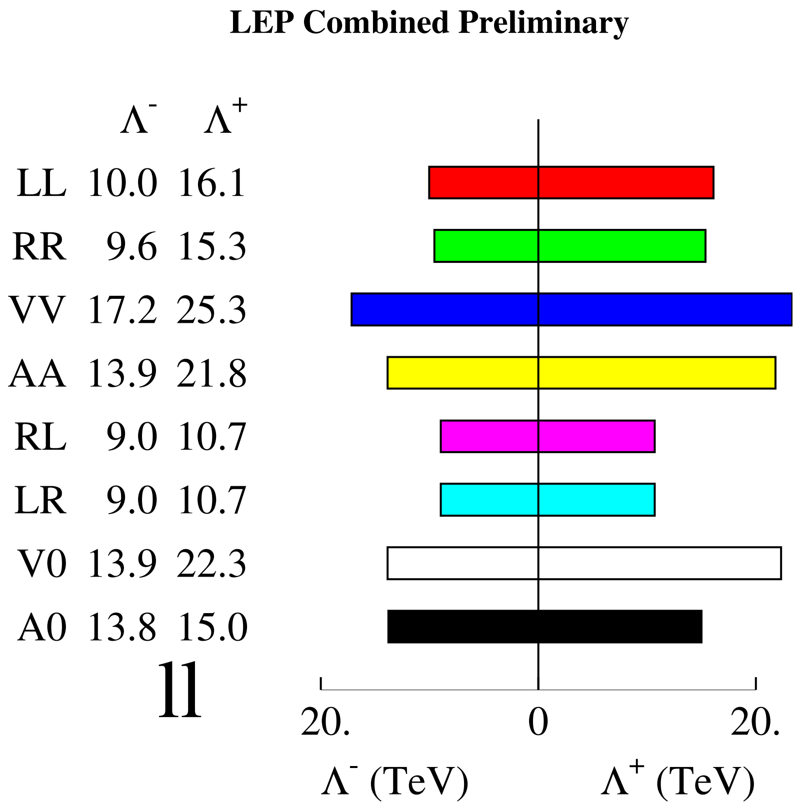
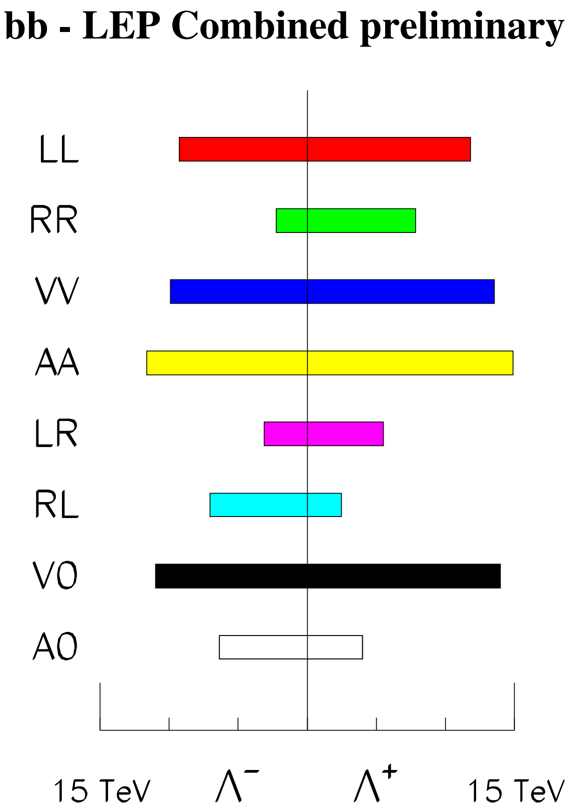


Figure 7: *The limits on* Λ *for* $\mathrm{e^+e^-} \to \ell^+\ell^-$ *assuming universality in the contact interactions between* $\mathrm{e^+e^-} \to \mu^+\mu^-$ *and* $\mathrm{e^+e^-} \to \tau^+\tau^-$.

$e^+e^- \to b\bar{b}$			
Model	ϵ (TeV^{-2})	Λ^- (TeV)	Λ^+ (TeV)
LL	$-0.0032^{+0.0047}_{-0.0047}$	9.3	11.8
RR	$-0.175^{+0.163}_{-0.158}$	2.2	7.9
VV	$-0.0029^{+0.0038}_{-0.0040}$	9.9	13.6
AA	$-0.0019^{+0.0029}_{-0.0031}$	11.6	14.9
RL	$-0.0475^{+0.0526}_{-0.0395}$	3.1	5.5
LR	$0.0071^{+0.1408}_{-0.0149}$	7.0	2.5
V0	$-0.0023^{+0.0034}_{-0.0034}$	11.0	14.0
A0	$0.0294^{+0.0235}_{-0.0329}$	6.4	4.0

$e^+e^- \to c\bar{c}$			
Model	ϵ (TeV^{-2})	Λ^- (TeV)	Λ^+ (TeV)
LL	$0.010^{+0.595}_{-0.024}$	5.2	1.3
RR	$0.040^{+0.385}_{-0.052}$	4.5	1.4
VV	$-0.000^{+0.010}_{-0.010}$	7.2	6.8
AA	$0.006^{+0.017}_{-0.015}$	6.4	5.1
RL	$0.091^{+0.112}_{-0.128}$	3.4	2.0
LR	$0.152^{+0.091}_{-0.091}$	2.8	2.5
V0	$0.028^{+0.016}_{-0.013}$	6.7	1.4
A0	$0.516^{+0.076}_{-0.080}$	3.9	2.5

Table 9: *Fitted values of ϵ and 95% confidence limits on the scale, Λ, for constructive (+) and destructive interference (−) with the Standard Model, for the contact interaction models discussed in the text. From combined $b\bar{b}$ and $c\bar{c}$ results with centre of mass energies from 133 to 209 GeV.*



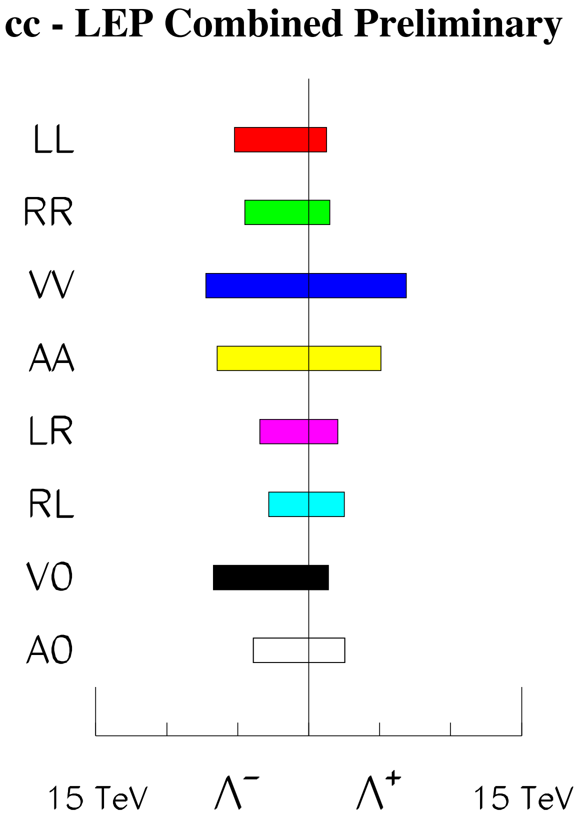


Figure 8: *95% CL limits on the scale of Contact Interactions in* $e^+e^- \to b\bar{b}$ *and* $e^+e^- \to c\bar{c}$ *using Heavy Flavour LEP combined results from 133 to 209 GeV.*

LQ type	$m_{\mathrm{LQ}}^{min}(\mathrm{GeV}/c^2)$	LQ type	$m_{\mathrm{LQ}}^{min}(\mathrm{GeV}/c^2)$
$S_0(\mathrm{L}) \to \mathrm{eu}$	789	$V_{1/2}(\mathrm{L}) \to \mathrm{ed}$	305
$S_0(\mathrm{R}) \to \mathrm{eu}$	639	$V_{1/2}(\mathrm{R}) \to \mathrm{eu},\ \mathrm{ed}$	227
$\tilde{S}_0(\mathrm{R}) \to \mathrm{ed}$	210	$\tilde{V}_{1/2}(\mathrm{L}) \to \mathrm{eu}$	176
$S_1(\mathrm{L}) \to \mathrm{eu},\ \mathrm{ed}$	364	$V_0(\mathrm{L}) \to \mathrm{e\bar{d}}$	1070
$S_{1/2}(\mathrm{L}) \to \mathrm{e\bar{u}}$	189	$V_0(\mathrm{R}) \to \mathrm{e\bar{d}}$	167
$S_{1/2}(\mathrm{R}) \to \mathrm{e\bar{u}},\ \mathrm{e\bar{d}}$	240	$\tilde{V}_0(\mathrm{R}) \to \mathrm{e\bar{u}}$	497
$\tilde{S}_{1/2}(\mathrm{L}) \to \mathrm{e\bar{d}}$	–	$V_1(\mathrm{L}) \to \mathrm{e\bar{u}},\ \mathrm{e\bar{d}}$	664

Table 10: *95% confidence level lower limits on the LQ mass assuming $g_{L,R} = \sqrt{4\pi\alpha}$. For $\tilde{S}_{1/2}$(L) no limit can be set.*

5.4 Leptoquarks

Leptoquarks (LQ) mediate quark-lepton transitions. They carry fermion numbers, $F = L + 3B$. Following the notations in Reference [17, 18], scalar leptoquarks, S_I, and vector leptoquakrs,V_I are indicated based on spin and isospin I. Isomultiplets with different hypercharges are denoted by an additional tilde. It is assumed that leptoquark couplings to quark-lepton pairs are flavour-diagonal and preserve baryon- and lepton-number. The couplings refer to g_L, q_R, according to the chirality of the lepton. In the process $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}$ leptoquarks can be exchanged in u- or t-channel (F=2 or F=0).

For convenience, one type of leptoquarks is assumed to be much lighter than the others. Further, experimental constraints on the product $g_L g_R$ allow separate studies of $g_L \neq 0$ or $g_R \neq 0$.

Asuuming a coupling of electromagnetic strength, $g = \sqrt{4\pi\alpha_{em}}$, (where α_{em} is the fine structure constant), limits on the masses of leptoquarks are derived by integrating the likelihood functions obtained from comparisons of the theoretical predictions for the hadronic cross-section to the LEP II averaged measurments.

The 95% confidence level lower limits on masses m_{LQ} are summarized in Table 10. These results complement the leptoquark searches at HERA [19] and exceed the reach of direct searches for some types of leptoquark.

The exchange of scalar quarks existing in R-parity breaking theories modifies the hadronic cross section in the same manner as leptoquarks. Right-handed down-type scalar quarks couple like left-handed S_0 leptoquarks and left-handed up-type squarks like the $\tilde{S}_{1/2}$. The corresponding limits for squarks assuming $\lambda'_{1jk} = \sqrt{4\pi\alpha_{em}}$ can be obtained from Table 10.

6 Summary

A preliminary combination of the LEP II $\mathrm{e^+e^-} \to \mathrm{f\bar{f}}$ cross-sections (for hadron, muon and tau final states) and forward-backward asymmetries (for muon and tau final states) from LEP running at energies from 130 to 209 GeV has been made. The results from the four LEP experiments are in good agreement with each other.

The results for energies between 192 and 202 GeV are given in [1]. Results for 130–189 GeV are available in [3]. Further information is available at [4]. The averages for all energies are shown graphically in Figures 1 and 2. Overall the data agree with the Standard Model predictions of ZFITTER, although the combined hadronic cross-sections are on average 1.8 standard deviations above the predictions.

Differential cross-sections, $\frac{d\sigma}{d\cos\theta}$, for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ were combined. Results are shown in Figures 3 and 4.

An average of results on heavy flavour production at LEP II has also been made for measurements of R_b, R_c, A_{FB}^b and A_{FB}^c, using results from LEP centre-of-mass energies from 130 to 209 GeV. Results are given in Table 5 and shown graphically in Figures 5 and 6. The results are in good agreement with the predictions of the SM.

The averaged cross-section and forward-backward asymmetry results together with the combined results on heavy flavour production were interpreted in a variety of models. The LEP II averaged cross-sections were used to obtain lower limits on the mass of a possible Z' boson in different models. Limits range from 450 to 2090 GeV depending on the model. Limits on the scale of contact interactions between leptons and also between electrons and $b\bar{b}$ and $c\bar{c}$ final states have been determined. A full set of limits are given in Tables 8 and 9.

Limits on the masses of leptoquarks have been derived from the hadronic cross-sections. The limits range from 167 to 1070 GeV depending on the type of leptoquark.

Acknowledgements

The analysis and interpretation of the high energy $f\bar{f}$ data requires the theoretical input from Monte Carlo programs to compute efficiencies, from programs to compute the luminosity and programs which make Standard Model predictions. We would like to acknowledge the work of all the authors of these programs. In particular we are grateful to D. Bardin, S. Jadach, G. Passarino and B. Ward for their direct contributions to our work.

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