Fermion pair production at LEP2 from 130 to 196 GeV

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Abstract

The $e^+e^- \to f\bar{f}$ cross sections and asymmetries are presented for data taken at centre of mass energy between 130 and 196 GeV, including the events recorded in the early summer 99 at 192 and 196 GeV by the ALEPH, DELPHI, L3 and OPAL collaborations. After a brief recall of the fermion pair production features above the Z resonance, the combined 4-Lep experiment cross-sections and asymmetries are given and their major systematics discussed, including heavy quark flavour production and the associated tagging methods. Finally the searches for the flavour changing neutral current process $e^+e^- \to t\bar{c}(\bar{u})$ are summarized.

1. Introduction

Since 1995 LEP is operating at center-of-mass energy well above the Z resonance. In addition to the data already collected at center-of-mass energies of 130.2 and 136.2 GeV (1995 and 1997), 161.3 and 172.1 GeV (1996), 182.7 GeV (1997), preliminary results from recently collected data at 188.6 GeV (1998), 191.6 and 195.6 GeV (1999) were reported to the conference[1][2][3][4]. In Table 1 the integrated luminosity taken by each experiment at the different energies are summarized, the 1999 results being based upon the available statistic at the conference time.

Table 1. Integrated luminosity per experiment for the different centre-of-mass energies. For 1999 the expected final luminosity at 192 and 196 GeV are given in brackets.

Year	$\sqrt{s}$ GeV	$\int \mathcal{L}$ dt /exp pb^{-1}
1995, 1997	130/136	6/6
1996	161/172	10/10
1997	183	55
1998	189	175
1999	192/196	27/30 (30/80)

2. Fermion pair production at high energies

Around the Z-pole, at the Born level, the fermion pair production is dominated by the on shell s-channel Z exchange, while well above the Z resonance the s-channel γ exchange dominate and the γ/Z interference contribute at a few per mil level but is responsible for the large asymmetries in all channels. One of the remarquable effect at LEP2 energies is the importance of the radiative processes due to ISR radiation of incoming particles, which reduces the available centre-of-mass energy s' down to the Z resonance and enhanced the di-fermion born cross-section by a factor five as shown on Figure 1, where the reduced centre of mass energy s' is defined from the direction of the two fermions.

The correspondence between the experimental definition of s' and the theoretical one is treated differently among the experiments. The original reduced centre of mass energy can be defined either as the s-channel propagator mass or from the invariant mass of the di-fermion final state; in the first case the existence of large contribution from ISR/FSR interference graphs leads to an ambiguous definition, therefore the second definition is usually choosen for leptons; however for $q\bar{q}$ final state, the possibility of gluon radiation before the emission of a FSR photon makes difficult the definition of the bare $q\bar{q}$ invariant mass; in addition, it is difficult to experimentally identify an FSR photon from the quark jet fragments, and experiments refer in

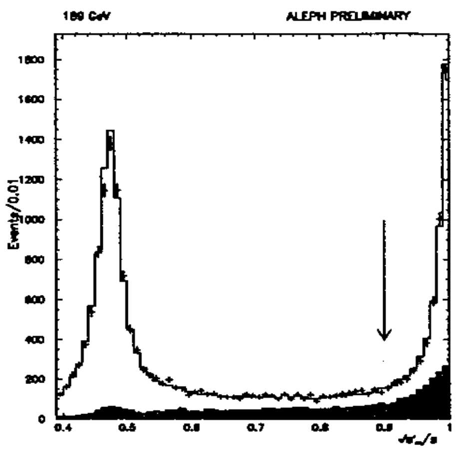

Figure 1. Distribution of the effective centre-of-mass energy as measured by ALEPH.

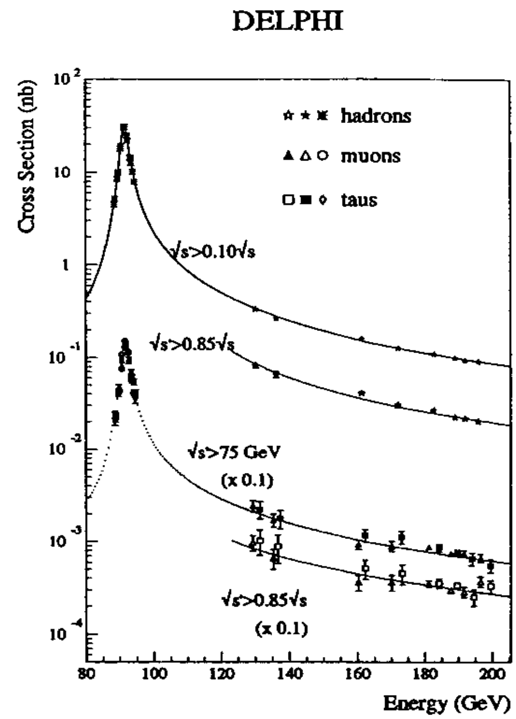

Figure 2. Delphi cross section measurement from Z resonance to 196 GeV.

the quark case to either definition. A further complication comes from the dropping efficiency at small polar angle in particular for leptonic final states for which ISR/FSR interference contribution at small angle is a source of important systematical error ; therefore the experimental measurements may be given for a reduced acceptance or extrapolated using theoretical calculations.
The four LEP experiments measure the inclusive cross section ($\sqrt{s'}/\sqrt{s}$ >0.1) and exclusive sample ($\sqrt{s'}/\sqrt{s}$ >0.85)for the following channels $e^+e^- \rightarrow q\bar{q}(\gamma), \mu^+\mu^-(\gamma), \tau^+\tau^-(\gamma), e^+e^-(\gamma)$ up to 196 GeV. The average efficiency and purity for these channels are summarized in Table2 for 189 GeV together with the statistical error and systematic achieved.

The main background sources for the inclusive sample come from $\gamma\gamma$ events and 4 fermions processes; these backgrounds are generally removed by the selection procedure for the exclusive sample, however ISR photon splitting into a low invariant mass fermion pair is considered as signal while the production of two real Z is accounted as background. On Figure 2 is summarized the inclusive and exclusive DELPHI masurements from 130 to 196 GeV.

The averaged cross-section measurements for exclusive samples of di-fermions($q\bar{q}, \mu^+\mu^-, \tau^+\tau^-$) performed [8] is shown on Figure 3 where ZFITTER [6] predictions have been used to correct the experimental definition choice. The asymmetries for muons and taus pair channel are summarized on Figure 3. The measurements are in good agreement with the Standard Model expectactions for which a 1% uncertainty is quoted among which only 0.12% comes the improved theoretical luminosity error [5]; the current work of the LEP2 Monte-Carlo work-

$\sqrt{s'}/\sqrt{s}$	flavour	ϵ %	Purity %	stat. %	sys. %
	$q\bar{q}$	85	87	0.5	~ 0.5
>0.1	$\mu^+\mu^-$	75	95	3	~ 1.5
	$\tau^+\tau^-$	43	85	4	~ 1.5
	$q\bar{q}$	87	90	2	~ 0.5
>0.85∼0.9	$\mu^+\mu^-$	90	98	5	~ 1.5
	$\tau^+\tau^-$	60	90	6	~ 1.5

Table 2. Average efficiency and purity achieved for the di-fermion channels at 189 GeV.

shop will give improved predictions in the near future [7].

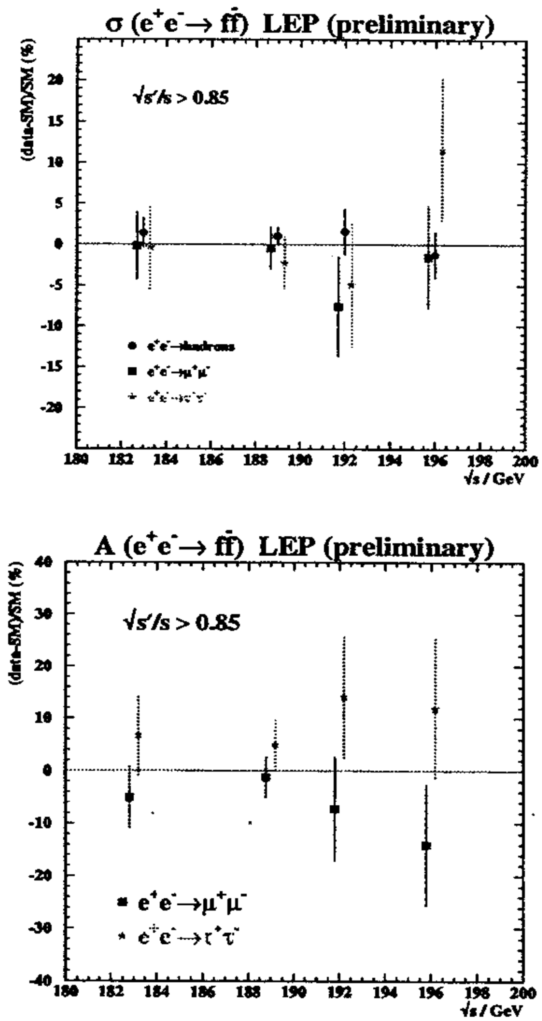

Figure 3. Deviations of the 4 LEP experiments combined results on cross-sections and asymmetries from 183 to 196 GeV to the standard model predictions.

3. Heavy flavour cross-sections and asymmetries

The four LEP experiments apply also flavour tagging on the exclusive hadronic events sample and give measurements of R_b, R_c, R_{uds}, jet charge and forward-backward asymmetries in $b\bar{b}$ and $c\bar{c}$ production [1][9][10][11]. The tagging procedure makes use in neural net techniques of the long b lifetime, of the kinematic and of identified lepton, kaon or D* from b or c decays. The cross-section measurements agree well with the predicted centre of mass energy dependence for all flavour as displayed in Figure4. At 189 GeV a combined value for $R_b = 0.161 \pm 0.0057$ is obtained in good agreement with the expected standard model expectation of 0.162.

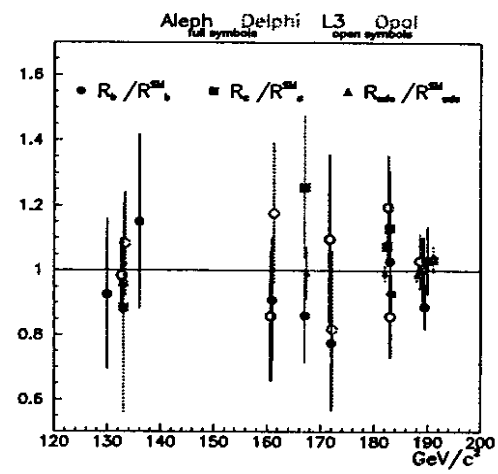

Figure 4. Partial cross-section for b,c uds flavour from 130 to 189 GeV.

A 10% precision is achieved at 189 GeV for $b\bar{b}$ asymmetries and 30% for $c\bar{c}$, the measured deviation to the standard model predictions are summarised on Figure 5, all measurements agree within 1.5 sigma with the SM expectations.

4. Search for flavour changing neutral current

At 189 GeV searches are made for Flavour Changing Neutral Current process as $e^+e^- \rightarrow t\bar{c}(\bar{u})$ where $t \rightarrow Wb$, the W decaying into two quark

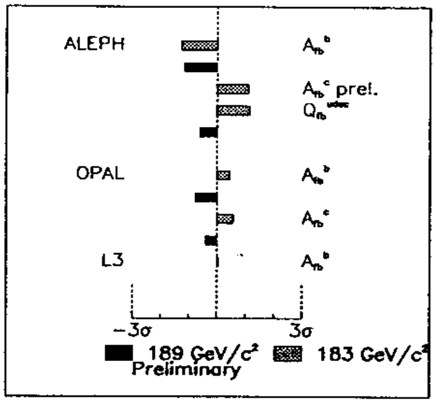

Figure 5. Asymmetry deviations from SM expectations for heavy quark at 183 and 189 GeV.

or semileptonically. Such processes are forbidden at the tree level however they can exist at the loop level with highly suppressed rates(10^{-9}pb), as flavour changing vertices are present in many SM extensions [12] they will enhanced top quark production.

Aleph[13] and Delphi[14] have looked for 2 jets events(with a b candidate), lepton and missing energy or 4 jet events (with one b candidate). They use in discriminant analysis the expected kinematic features as the quark pair or the lepton-neutrino mass, and the b jet energy. The expected backgrounds and efficiency for this processes as well as the observed events are summarized in Table 3.

	Hadronic W(Aleph)	Leptonic W(Aleph)	Leptonic W(Delphi)
W^+W^-	1.54	0.95	0.59
Zee			0.19
ZZ	0.59	0.01	
$q\bar{q}$	6.43		
Total	8.55	0.96	1.00
ϵ	12.25%	5.35%	6.62%
Observed	16	2	0

Table 3. Analysis performance for the hadronic and leptonic channel from both experiment

From the above table a 95%CL upper limit of 0.60pb on the single top production is derived by the Aleph collaboration, while Delphi derive a 0.3pb limit at 95%CL for a top mass of 175 GeV, assuming 100% of top decay in Wb. The excess seen by Aleph is compatible with being a statistical fluctuation.

5. Acknowledgements

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References

[1] ALEPH Collab., CERN-EP/99-042 (submitted to Euro. Phys J. C);
ALEPH Collab., ALEPH-CONF/99-013, contribution #6_694 to EPS-HEP.

[2] DELPHI Collab., DELPHI-MORIO-CONF-247, contribution #6_362 to EPS-HEP.

[3] L3 Collab., L3 note 2398, contribution #6_262 to EPS-HEP.

[4] OPAL Collab.,Euro. Phys. J. C6 (1999) 1;
OPAL Collab.,contribution #20 to EPS-HEP conference.

[5] W.Placek et al,CERN-TH 99/07.

[6] D. Bardin *et al.*, CERN-TH 6443/92; http://www.ifh.de/~riemann/Zfitter/zf.html .

[7] LEP2 Monte Carlo Workshop: http://www.to.infn.it/~giampier/lep2.html .

[8] LEP EWWG subgroup: http://www.cern.ch/LEPEWWG/lep2/ .

[9] DELPHI collab.,DELPHI-CONF-286, contribution #6-219 to EPS-HEP.

[10] L3 collab., L3-note 2417, contribution #5-283 to EPS-HEP.

[11] OPAL collab., Note PN380,contribution #6-20 to EPS-HEP.

[12] C-S Huang et al, hep-ph/9901369, January 1999.
R.D. Peccei et al, Nucl.Phys.B337(1990) 269.
T.Han et al, Nucl.Phys.B454(1995) 527.

[13] ALEPH collab., ALEPH-CONF 99-023,contribution #6-418 to EPS-HEP.

[14] DELPHI collab., DELPHI 99-85 CONF 272,contribution #6-216 to EPS-HEP.