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Preliminary

DELPHI Collaboration

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Abstract

A measurement of the cross-section ratios for flavour tagged events in e^+e^- annihilation at centre-of-mass energies of 183 and 189 GeV has been performed with the DELPHI experiment at LEP, including the data taken in 1997 and 1998 corresponding to an integrated luminosity of 53 and 158 pb^{-1}, respectively. Hadronic events were selected and classified as bottom, charm and light quark events on the basis of the silicon tracker information. The cross-section ratios, defined as the ratio of the cross-section for one quark flavour to the total hadronic cross-section, measured for bottom and *uds* quark events were compared to the Standard Model expectations.

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1 Introduction

Since the autumn of 1995 the centre-of-mass energy of the LEP accelerator was upgraded, thus allowing to test the Standard Model predictions in an unexplored energy region between 130 and 189 GeV. In particular an observation of any deviation between the measured and predicted cross-sections for the production of quark-antiquark pairs of definite flavour would indicate some new physics beyond the Standard Model like the contact interactions [1] or the production of an exotic heavy particle [2].

The present study was devoted to the measurement of the cross-section ratios of flavour tagged $q\bar{q}$ pairs in the energy range between 183 and 189 GeV (the analogue results concerning the energy range 130-173 GeV have been published in [3]). The information provided by the silicon tracker about the presence of long-lived particles coming from the decays of heavy flavours allowed to split the data into subsamples enriched in bottom, charm and light quark-pair events. From the fraction of bottom (uds quark) tagged events the ratio $R_b = \sigma_b/\sigma_h$ ($R_{uds} = \sigma_{uds}/\sigma_h$) was extracted, respectively (σ_h denotes the total hadronic cross-section).

2 Data sample

The DELPHI detector is described in [4]. The data sets which have been analyzed correspond to the full sample of 53 pb^{-1} collected in 1997 in the centre-of-mass energy of 183 GeV and of 158 pb^{-1} gathered in 1998 with $\sqrt{s} = 189$ GeV.

3 Track selection

Charged particles were selected if they satisfied the following criteria:

- polar angle with respect to the beam axis between 20 and 160 degrees;
- momentum greater than 0.4 GeV;
- relative error on the momentum measurement less than 100 %;
- distance of track's closest approach to the beam-spot less than 4 cm in the plane perpendicular to the beam axis and less than 10 cm along it;
- track length larger than 30 cm.

While neutral particles were demanded to pass the following cuts:

- energy of the shower detected in calorimeters (either hadronic or electromagnetic or Small Angle Tile Calorimeter (STIC)) of more than 1.5 GeV;
- energy deposits of showers in the STIC calorimeter to be concentrated in more than one cell.

4 Event selection

The selection of hadronic events coming from the process $e^+e^- \to q\bar{q}(\gamma)$ is based on the global event features which were deduced from the set of selected particles. The selection criteria were as follows:

- at least nine charged particles;
- at least seven charged particles seen in the silicon tracker;
- at least 18 % of the centre-of-mass energy was carried by charged particles;
- the rejection of Bhabba events in the forward region was obtained by the requirement that the variable $\sqrt{E_A^2 + E_C^2}$ was less than 90 % of the beam energy where E_A and E_C were the energies in the respective endcaps A and C of the forward calorimeter;
- the polar angle of the thrust axis of the event had to be in the range between 25 and 155 degrees (the thrust axis was evaluated from both charged and neutral particles of the event);
- most of the hadronic events coming from the process $e^+e^- \to W^+W^-$ was removed by requiring at most three jets reconstructed in the event (using the LUCLUS algorithm with the cut on the invariant mass set at 5 GeV);
- in addition only events in which all jets contained at least three particles were accepted;
- the rejection of the events with so called Z^0 radiative return was obtained by the cut on the effective centre-of-mass energy $\sqrt{s'}$, calculated using the SPRIME package [5]: $\sqrt{s'}/\sqrt{s} > 0.85$. These events come from the radiative corrections to the $q\bar{q}$ production in e^+e^- collisions where, due to the photon radiation in the initial state, the invariant mass of the fermion pair is close to the mass of the Z^0.

This procedure yielded 1051 (2481) events selected at $\sqrt{s}$=183 (189) GeV, respectively. The simulated data samples of the processes $e^+e^- \to q\bar{q}(\gamma)$ and $e^+e^- \to W^+W^-$ have been subjected to the same selection criteria. They have been generated by the PYTHIA 5.7 generator [6] with DELPHI tuning [7], simulated in the DELPHI detector [8] and passed the same algorithm of event reconstruction as the data. The number of simulated events was 15 times larger than the data. The yield of W^+W^-events in the data sample was estimated from the simulation to be of the order of 3.8 (4.1) % for the energy of 183 (189) GeV, respectively. The contribution of other processes like the production of ZZ pair or $\gamma\gamma$ interaction was found negligible.

5 Tag of events with different quark flavours

Due to the relatively long lifetime of charmed and beauty particles (typically 0.4 and 1.5 ps, respectively) the events in which the heavy flavours were produced are characterized by the presence of secondary vertices. The information provided by the silicon tracker [9] of DELPHI was used to split the data into three subsamples enriched in bottom, charm and light quarks, respectively. The variable used to discriminate among these three data sets was the probability $\mathcal{P}_E^+$ for the hypothesis that all tracks detected in the silicon tracker come from the primary vertex [10]. It was evaluated per event and using only charged tracks with a positive lifetime. The sample enriched with bottom quarks which will be called since now *b-tagged* had to satisfy the requirement $\mathcal{P}_E^+ < 0.002$. For the one classified as *c-tagged* the $\mathcal{P}_E^+$ probability had to cover the range between 0.002 and 0.1. Events of the third sample containing mostly the light quarks and labelled as *L-tagged* had to fulfill $\mathcal{P}_E^+ > 0.1$ (in the following the light quarks u, d and s will be noted L). The cuts were chosen to maximize the separation between the quark flavours. The respective efficiencies and purities of the different tags are summarized in Table 1.

The differences between data and simulation for the different tags were studied using the data collected the same year at a centre-of-mass energy corresponding to the Z^0 peak. At the Z^0 the Standard Model fractions for bottom, charm and light quark events were assumed giving rise to the correction factors collected in Table 2 which were applied to the simulation sample at high energy. The Z^0 data were also used to check the mistag rates (a mistag is e.g. a charm (light quark) event that is tagged as a bottom). This was done dividing the events into two hemispheres and applying the b, c and uds tag per hemisphere. In this way data and simulation were compared selecting a b (c, uds) tag in one hemisphere and looking at the bottom, charm and light quark tags in the other one. It was found out that all the mistag rates agree to better than 5 %.

6 Cross section ratios for different flavours

The numbers of events belonging to the different tagged categories were divided by the total number of selected hadronic events in order to obtain the cross-section ratios. They were denoted as R_y^x where the upper index distinguishes between the data and the simulation of the process $e^+e^- \to q\bar{q}(\gamma)$ and the lower one labels different subsamples. It was assumed that the cross-section ratios obtained for the simulation sample correspond to the values expected in the Standard Model. The predictions from the simulation were obtained using the correction factors given in the Table 2. The variable defined as $(R^{data} - R^{SM})/R^{SM}$ was defined for each tag separately as a measure of possible deviations from the Standard Model. Its values are presented in Table 3.

The systematic error had four components. The first one came from the statistical uncertainty in the estimation of the correction factors (shown in Table 2). The second uncertainty was the largest one and came from the modelling of the mistag rates discussed in the previous section. A systematic error on the mistag efficiency of 10 % was propagated into the expected number of events. The last two (less pronounced) components were due to the presence of the W^+W^-background and from the systematic effects coming from the reconstruction of the effective centre-of-mass energy $\sqrt{s'}$ (contamination of non-radiative sample from double radiative events which where misinterpreted by the SPRIME package). The quadratic sum of these four components is quoted (cf Table 3) as the total systematic error which turned out to be small with respect to the statistical uncertainties.

As an additional check of consistency the cross-section ratios were evaluated in the same way for the data corresponding to the Z^0 radiative return $(0.43 < \sqrt{s'}/\sqrt{s} < 0.57)$ (cf Table 3). No significant discrepancy between the cross-section rates resulting from the data and the Standard Model predictions has been found both for non-radiative and Z^0

radiative return events

The cross-section ratios R_b and R_L (defined as the ratio of the quark cross-section σ_q to the total hadronic cross-section σ_h) were extracted from the event rates measured for flavour-tagged subsamples according to the formula:

$$R_q = \frac{\sigma_q}{\sigma_h} = R_q^{SM}(1 + \frac{N_q^{obs} - N_q^{exp}}{N_q^{exp} P_q}) \tag{1}$$

where q denotes b and uds quarks, R_q^{SM} refers to the Standard Model expectation as given by ZFITTER version 6.10 [11], N_q^{obs} (N_q^{exp}) to the observed (expected) number of events for a given q enriched tag and P_q to the q purity for a q enriched tag (cf Tables 1 and 3). The result for the 183 GeV can be summarized as:

$$R_b = 0.153 \pm 0.017(stat + syst) - 0.18\,(R_c - 0.250) - 0.03\,(R_{uds} - 0.581) \tag{2}$$

$$R_{uds} = 0.576 \pm 0.031(stat + syst) - 0.07\,(R_b - 0.169) - 0.64\,(R_c - 0.250). \tag{3}$$

while the one for the 189 GeV reads:

$$R_b = 0.167 \pm 0.012(stat + syst) - 0.21\,(R_c - 0.252) - 0.03\,(R_{uds} - 0.581) \tag{4}$$

$$R_{uds} = 0.571 \pm 0.022(stat + syst) - 0.07\,(R_b - 0.167) - 0.63\,(R_c - 0.252). \tag{5}$$

The cross-section R_c was not given as the c-enriched sample was not pure/efficient enough to perform a direct measurement (it can be recuperated from the relation $R_c = 1 - R_b - R_{uds}$). The results for R_b and R_{uds} are summarized in Table 4 and plotted in Fig 1 together with the predictions from ZFITTER (Fig 1 presents results in the full energy range between 130 and 189 GeV including earlier results from [3]).

7 Summary

The cross-section ratios have been measured in $q\bar{q}$ hadronic events collected at centre-of-mass energies of 183 and 189 GeV. A preliminary comparison with the Standard Model did not show any significant deviation from its predictions.

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Table 1: Efficiences and purities (in %) of quark flavours for the two subsamples defined in the text. The quoted errors are statistical from the simulated sample.

Efficiency (%)			
$\sqrt{s}$ (GeV)		183	189
b enriched	$b\bar{b}$ events ($\epsilon^b_{b\bar{b}}$)	78.1 ± 1.1	81.0 ± 1.2
	$c\bar{c}$ events ($\epsilon^b_{c\bar{c}}$)	14.1 ± 0.3	16.7 ± 0.4
	LL events ($\epsilon^b_{L\bar{L}}$)	1.9 ± 0.1	2.3 ± 0.1
c enriched	$b\bar{b}$ events ($\epsilon^c_{b\bar{b}}$)	15.8 ± 0.4	13.8 ± 0.4
	$c\bar{c}$ events ($\epsilon^c_{c\bar{c}}$)	34.4 ± 0.5	34.7 ± 0.5
	LL events ($\epsilon^c_{L\bar{L}}$)	16.4 ± 0.2	17.8 ± 0.2
L enriched	$b\bar{b}$ events ($\epsilon^L_{b\bar{b}}$)	6.0 ± 2.0	5.3 ± 2.0
	$c\bar{c}$ events ($\epsilon^b_{c\bar{c}}$)	51.5 ± 0.7	48.7 ± 0.7
	LL events ($\epsilon^L_{L\bar{L}}$)	81.7 ± 0.6	79.9 ± 0.6

Purity (fraction) (%)			
$\sqrt{s}$ (GeV)		183	189
b enriched	$b\bar{b}$ events ($f^b_{b\bar{b}}$)	74.2 ± 1.1	71.1 ± 1.0
	$c\bar{c}$ events ($f^b_{c\bar{c}}$)	19.7 ± 0.4	22.1 ± 0.5
	LL events ($f^b_{L\bar{L}}$)	6.1 ± 0.2	6.8 ± 0.2
c enriched	$b\bar{b}$ events ($f^c_{b\bar{b}}$)	13.1 ± 0.3	10.9 ± 0.3
	$c\bar{c}$ events ($f^c_{c\bar{c}}$)	41.7 ± 0.7	41.6 ± 0.7
	LL events ($f^c_{L\bar{L}}$)	45.2 ± 0.7	47.6 ± 0.7
L enriched	$b\bar{b}$ events ($f^L_{b\bar{b}}$)	1.7 ± 0.1	1.5 ± 0.1
	$c\bar{c}$ events ($f^L_{c\bar{c}}$)	21.2 ± 0.3	21.1 ± 0.3
	LL events ($f^L_{L\bar{L}}$)	77.1 ± 0.6	77.4 ± 0.6

Table 2: The correction factors accounting for the difference in the distribution of the tagging variable $\mathcal{P}_E^+$. The quoted errors are statistical from the Z^0 data sample.

$\sqrt{s}$ (GeV)	183	189
b enriched sample	1.011 ± 0.013	1.006 ± 0.010
c enriched sample	1.029 ± 0.014	1.052 ± 0.011
L enriched sample	0.989 ± 0.005	0.984 ± 0.004

Table 3: Summary of deviations in the cross-section ratios ($r_x = (R_x^{data} - R_x^{SM})/R_x^{SM}$, $x = b, L$) between the data and the Standard Model predictions as given by simulation splitted into flavour tagged subsamples. The upper (lower) tables correspond to non-radiative events and Z^0 radiative return, respectively.

non radiative $\sqrt{s'/s} > 0.85$					
tag	data	simulation			r_x
	obs. events	exp. events	stat. error	syst. error	
$\sqrt{s} = 183$ GeV					
b enriched	179	192.4	1.8	3.5	$-0.070 \pm 0.064 \pm 0.006$
c enriched	242	224.7	1.9	4.6	$+0.077 \pm 0.062 \pm 0.010$
L enriched	630	633.9	3.2	5.3	$-0.006 \pm 0.025 \pm 0.006$
$\sqrt{s} = 189$ GeV					
b enriched	481	480.4	4.4	8.8	$+0.001 \pm 0.042 \pm 0.008$
c enriched	577	557.9	4.7	12.8	$+0.034 \pm 0.039 \pm 0.014$
L enriched	1423	1442.7	7.6	12.1	$-0.014 \pm 0.017 \pm 0.008$

Z^0 radiative return $0.43 < \sqrt{s'/s} < 0.57$					
tag	data	simulation			r_x
	obs. events	exp. events	stat. error	syst. error	
$\sqrt{s} = 183$ GeV					
b enriched	412	400.4	2.6	3.5	$+0.029 \pm 0.046 \pm 0.007$
c enriched	394	362.8	2.5	4.8	$+0.086 \pm 0.050 \pm 0.010$
L enriched	1223	1265.9	4.6	6.9	$-0.034 \pm 0.018 \pm 0.006$
$\sqrt{s} = 189$ GeV					
b enriched	832	855.0	6.0	10.1	$-0.027 \pm 0.031 \pm 0.008$
c enriched	786	823.0	5.9	13.5	$-0.045 \pm 0.032 \pm 0.013$
L enriched	2780	2720.1	10.8	14.9	$+0.022 \pm 0.012 \pm 0.008$

Table 4: The derived quark cross-section ratios for bottom and *uds* quarks at energies 183 and 189 GeV with $\sqrt{s'/s} > 0.85$ (the total error is given).

$\sqrt{s}$ (GeV)	R_b		R_{uds}	
	exp.	obs. (stat. + syst.)	exp.	obs. (stat. + syst.)
183	0.169	0.153 ± 0.017	0.581	0.576 ± 0.031
189	0.167	0.167 ± 0.012	0.581	0.571 ± 0.022

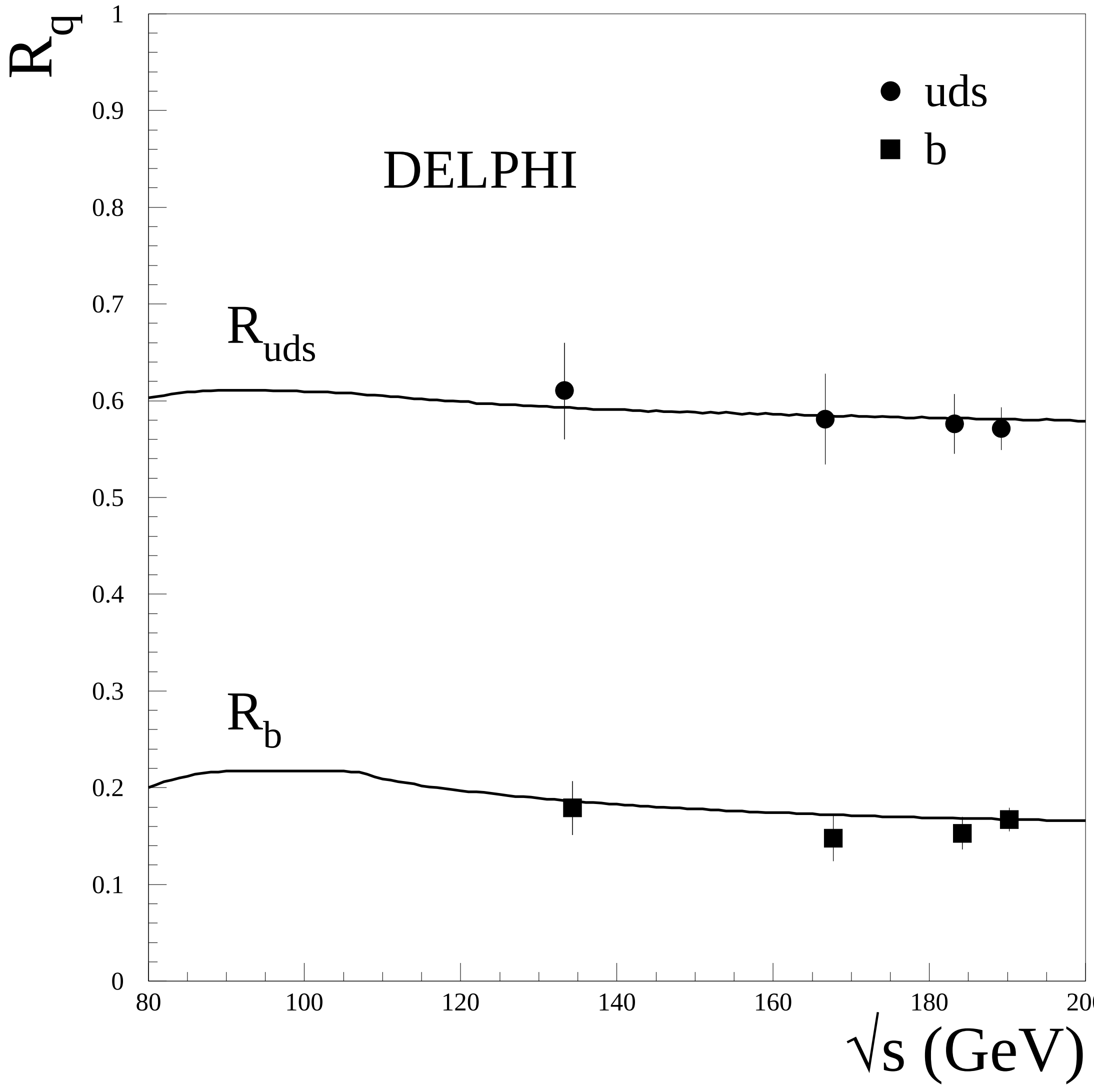

Figure 1: The measured cross-section ratios for bottom and *uds* quarks as a function of centre-of-mass energy, together with the prediction from ZFITTER