Charm Counting in b and c Events at LEP

M.Elsing [1]

[1] CERN, CH-1211 Geneva 23, Switzerland

E-mails: markus.elsing@cern.ch

Abstract

In this article the current status of the partial width R_c^0 of the $Z^0 \to c\bar{c}$ and of the multiplicity n_c of charm quarks per b decay are discussed. Final results presented by the LEP experiments using their full LEP 1 data sets lead to a more precise determination of both quantities. The new LEP and SLC averages are $R_c^0 = 0.1674 \pm 0.0038$ and $n_c = 1.149 \pm 0.036$.

1. Charm counting analysis

R_c^0 and n_c can be obtained from the sum of all weak decaying charm hadron rates in $Z^0 \to c\bar{c}$ and $Z^0 \to b\bar{b}$ events. ALEPH and DELPHI presented final updates based on their full LEP 1 data set. The rates of D^0, D^+, D_s^+ and Λ_c are extracted from the invariant mass signals of exclusive reconstructed decays. The contributions from b and c events need to be separated after subtraction of background and $g \to c\bar{c}$. ALEPH uses a high purity b tag veto in the hemisphere opposite to the reconstructed charm hadron and applies an energy cut of $X_E > 0.5$ to select a 79 % pure c sample. DELPHI uses a combined fit to the b tagging and to the charm hadron energy spectra to simultaneously measure the rates in b and c events with a small correlation of -35 %. They remove the charm hadron decay products from the event to improve the separation power of the b tagging, especially for the D^+ channel.

2. Charm counting results for c events

The measured rates for D^0, D^+, D_s^+ and Λ_c are divided by the PDG [1] branching ratios for the corresponding decay modes. The Λ_c rates are corrected by 15 ± 5 % for Ω_c and Ξ_c production assuming strange baryon production ratios. From the sum ALEPH [2] and DELPHI [3] obtain:

$$R_c^0 = 0.1738 \pm 0.0047 \pm 0.0113(A) \quad (1)$$

$$R_c^0 = 0.1692 \pm 0.0047 \pm 0.0097(D), \quad (2)$$

respectively. A previous result from OPAL [4] using only data up to 1993 gives $R_c^0 = 0.1670 \pm 0.0110 \pm 0.0130$.

The systematic uncertainty due to the branching ratio uncertainty dominates the total error of the individual measurements, especially for D_s^+ and Λ_c. Using the branching ratio error in the calculation of the averages would bias the results towards small rates, because the branching ratio enters as a factor and hence the constant relative error of the branching ratio results in smaller absolute errors for downwards fluctuating measurements. This problem is present in the current LEP electroweak working group average which includes these measurements.

3. The DELPHI R_c^0 double tagging result

DELPHI has presented a final update of the R_c^0 measurement using reconstructed D^{*+} in the decay mode $D^{*+} \to (K^-\pi^+)\pi^+$. The same b/c separation method as for the charm counting analysis was applied to obtain the rates in c and b events [3]:

$$R_c P_{c\to D} BR_{D^{*+}\to D^0\pi^+} BR_{D^0\to K^-\pi^+} = 0.01089 \pm 0.00027 \pm 0.00039 \quad (3)$$

$$R_b P_{b\to D} BR_{D^{*+}\to D^0\pi^+} BR_{D^0\to K^-\pi^+} = 0.01315 \pm 0.00035 \pm 0.00053 \quad (4)$$

with a correlation of -34 %. The rate $P_{b\to D} BR_{D^{*+}\to D^0\pi^+}$ was determined using a double tagging method. In one event hemisphere a 81 % pure charm sample was selected using exclusively reconstructed D mesons from 7 different decay modes and applying a b tagging veto. In the opposite hemisphere the rate of slow pion from the decay $D^{*+} \to D^0\pi^+$ was determined from the p_t^2 spectrum. From this rate DELPHI obtains [5]:

$$P_{b\to D} BR_{D^{*+}\to D^0\pi^+} = 0.174 \pm 0.010 \pm 0.004. \quad (5)$$

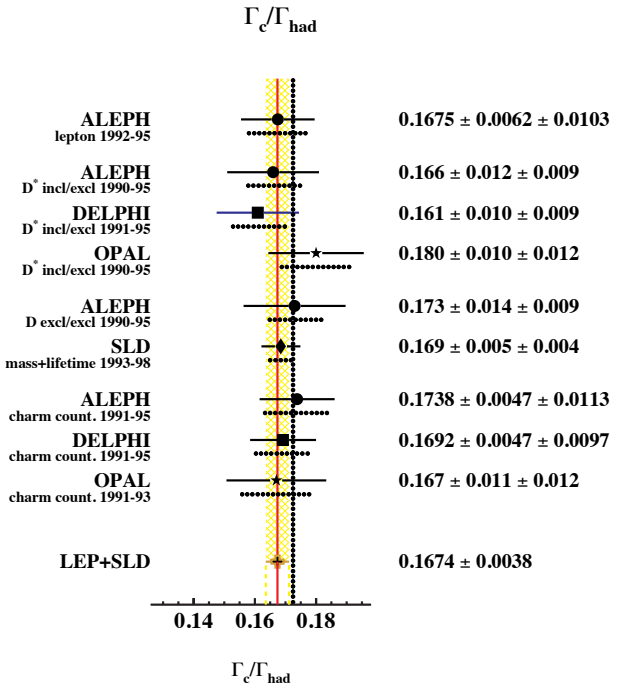

Figure 1. Summary of results on R_c^0 from LEP and SLC.

Combining both results and using the PDG $BR_{D^0\to K^-\pi^+}$ [1] yields:

$$R_c^0 = 0.1610 \pm 0.0104 \pm 0.0088. \quad (6)$$

4. LEP and SLC results on R_c^0

A summary of the LEP and SLC results on R_c^0 is given in figure 1. Good agreement of the results with the Standard Model prediction of 0.172 is found. Using the charm counting results the fractions of different charm hadrons per c quark are determined to be :

$$f(D^+) = 0.240 \pm 0.016 \quad (7)$$
$$f(D_s^+) = 0.118 \pm 0.025 \quad (8)$$
$$f(\Lambda_c) = 0.084 \pm 0.022, \quad (9)$$

assuming $f(D^0) = 1 - f(D^+) - f(D_s^+) - f(\Lambda_c)$. The LEP combined value for $P_{c\to D^{*+}} BR_{D^{*+}\to D^0\pi^+}$ is 0.1652 ± 0.0053.

5. Charm counting results for b events

The measured rates of D^0, D^+, D_s^+ and Λ_c in b events are divided by the PDG [1] branching ratios for the corresponding decays modes. Using $R_b^0 = 0.21642 \pm 0.00073$ [6] one obtains the probabilities $P_{b\to D}$ for a b to produce a charm hadron. Charmonia states have been measured at LEP [7]. Assuming $\eta_c : J/\psi : \chi_c : \psi_c' = 0.57 : 1 : 0.27 : 0.31$ [8] the charmonia states contribute 4.0 ± 1.3 % to the charm rate per b decay. The branching ratio of B into Ξ_c has been measured by CLEO [9]. One needs to add 4.0 ± 1.6 % to the charm rate taking Ξ_c production from B_s and Λ_b into account. The new DELPHI result [3] is:

$$n_c = 1.166 \pm 0.031 \pm 0.049 \pm 0.054(BR). \quad (10)$$

This compares to previous results $n_c = 1.190 \pm 0.034 \pm 0.065(sys + BR)$ from ALEPH [10] and $n_c = 1.137 \pm 0.048 \pm 0.084(sys+BR)$ from OPAL [4]. The correlated LEP average over all charm counting results is:

$$n_c = 1.151 \pm 0.022 \pm 0.022 \pm 0.051(BR). \quad (11)$$

6. Inclusive n_c measurement

DELPHI has performed an inclusive measurement of the rate of double open charm n_{2c} and no open charm n_{0c} decays per b. The analysis was based on the high purity impact parameter b tagging. By tagging one hemisphere a 84 % pure b sample was selected, while in the opposite hemisphere the different impact parameter signatures of the additional production of charm hadrons from open charm was used to separate the classes. After subtraction of the light quark background and using the normalisation to fix the single charm rates DELPHI obtains [11] rates of $n_{0c} = 3.3 \pm 2.1$ % and $n_{2c} = 13.9 \pm 4.2$ %. From this they deduce an upper limit on the rate of charmless b decays of 3.5 % at 95 % CL. From this measurement DELPHI obtains:

$$n_c = 1.147 \pm 0.041 \pm 0.008. \quad (12)$$

7. Exclusive double charm

Two measurements of exclusive double charm have been performed so far. CLEO [12] uses D-lepton correlation and obtains $\Gamma(B \to DX)/\Gamma(B \to \bar{D}X) = 0.100 \pm 0.031$, which translates into a branching ratio for upper vertex charm of $BR_{B\to\bar{D}X} = 7.9 \pm 2.2$ %. This measurement corresponds to $BR_{b\to c\bar{c}s} = 21.9 \pm 3.7$ %, taking D_s^+, charmonia and baryon production into account. ALEPH [13] measures exclusively reconstructed double D decays and finds $BR_{b\to D(s)\bar{D}(s)X} = 20.9 \pm 3.0 \pm 2.4 \pm 3.7$ %. Adding charmonia this corresponds to $BR_{b\to c\bar{c}s} = 22.1 \pm 3.1$ %. If one uses the Standard

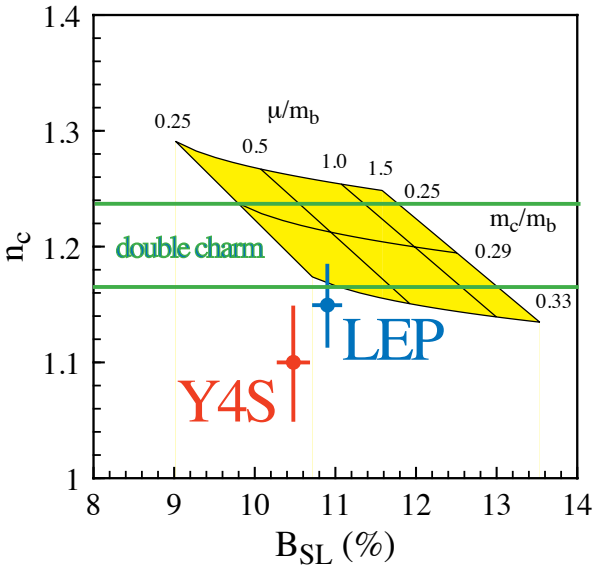

Figure 2. $Y4S$ and LEP results on n_c and B_{SL} compared to HQET predictions. The band is given by the indirect result from exclusive double charm measurements.

Model upper limit of 2 % [14] for charmless b decays one obtains a combined indirect measurement of:

$$n_c = 1.201 \pm 0.037. \qquad (13)$$

A check on these results can be obtained from a recent DELPHI result of $BR_{b\to\bar{c}\to l} = 1.68 \pm 0.46$ % [15]. Using the results above and the PDG charm semileptonic branching ratios one can deduce $BR_{b\to\bar{c}\to l} = 1.67 \pm 0.57$ % [16].

8. n_c vs $BR(B \to l)$

Figure 2 shows the HQET predictions [17] after correction for spectator effects for the charm counting in b decays and the B semileptonic branching ratio for different values of μ/m_b and m_c/m_b. The combined LEP average of the charm counting analyses and the inclusive DELPHI result on the number of charm quarks per b decay is:

$$n_c = 1.149 \pm 0.036. \qquad (14)$$

The LEP average for the semileptonic branching ratio $BR_{b\to l} = 10.63 \pm 0.17$ [18] needs to be corrected by $B_{SL} \simeq \tau_B/\tau_b \times BR_{b\to l}$ to account for the different b hadron production at LEP.

The $Y4S$ results are $n_c = 1.10 \pm 0.05$ [9] and $B_{SL} = 10.45 \pm 0.21$ % [1]. The band in figure 2 is given by the indirect result from the exclusive double charm production. No major disagreement between the measurements and the HQET prediction is found within errors.

References

[1] C.Caso et al., Eur. Phys. J. **C3** (1998) 1
[2] R.Barate et al., ALEPH Coll., CERN-EP/99-94
[3] P.Abreu et al., DELPHI Coll., CERN-EP/99-66
[4] G.Alexander et al.,OPAL Coll., Z. Phys. **C72** (1996) 1
[5] P.Abreu et al., DELPHI Coll., CERN-EP/99-67
[6] J.Mnich, *Tests of the Standard Model*, Proceedings EPS-HEP'99
[7] P.Abreu et al., DELPHI Coll., Phys. Lett. **B341** (1994) 109, D.Buskulic et al., ALEPH Coll., Phys. Lett. **B295** (1992) 396
[8] J.H.Kühn, S.Nussinov, R.Rückl, Z. Phys. **C5** (1980) 117
[9] L.Gibbons el at., CLEO Coll., Phys. Rev. **D56** (1997) 3783
[10] D.Buskulic et al., ALEPH Coll., Phys. Lett. **B388** (1996) 648
[11] P.Abreu et al., DELPHI Coll., Phys. Lett. **B426** (1998) 193
[12] T.E.Coan, CLEO Coll., Phys. Rev. Lett. **80** (1998) 1150
[13] R. Barate et al., ALEPH Coll., Eur. Phys. J. **C4** (1998) 387
[14] G.Buchalla, I.Dunietz, H.Yamamoto, *Hadronization of $b \to c\bar{c}s$*, FEMILAB-PUB-95/167-T
[15] P.Abreu et al., DELPHI Coll., *Measurement of the semileptonic b branching ratios in Z decays*, HEP'99 # 5_ 522
[16] D.Abbaneo et al., LEP Heavy Flavour Electroweak Working Group, LEPHF/98-01
[17] M.Neubert, C.T.Sachrajda, Nucl. Phys. **B483** (1997) 339
[18] P.Gagnon, *Semileptonic b branching fractions at LEP*, Proceedings EPS-HEP'99