THREE-JET HEAVY b-QUARK PRODUCTION RATES IN e^+e^- ANNIHILATIONS AT THE Z PEAK APPLIED TO TEST THE FLAVOUR-INDEPENDENCE OF STRONG INTERACTIONS USING NLO QCD CALCULATIONS.

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NLO theoretical calculations including mass effects allow performing experimental tests of QCD. Precise determinations of the ratio $\alpha_s{}^b/\alpha_s{}^{uds}$ performed by DELPHI, SLD and OPAL collaborations have confirmed the flavour independence of the strong interactions. Two compatible values of the b-quark running mass, $m_b(M_Z)$ as defined in the $\overline{MS}$ scheme at the M_Z scale have been extracted by DELPHI and SLD.

1 Theoretical overview

Theoretical calculations at Next-to-Leading order (NLO) in QCD perturbation theory allow for improved experimental tests of QCD [1,2,3]: the study of the universality of strong interactions and the measurement of the b-quark running mass $m_b(M_Z)$ in the $\overline{MS}$ renormalization scheme. Both of them have important theoretical implications: QCD just as it is formulated needs α_s to be quark-flavour independent to preserve the properties of gauge invariance and renormalizability. A dependence of α_s with the quark flavour could be interpreted as a signature of a flavour dependent anomalous quark chromomagnet moment that would modify the emission rate of gluons for different quark flavours [4]. The running of α_s has been experimentally tested many times by different experiments[5]. At LEP energies, the b-quark is the best candidate and QCD the proper scenario to test the running of quark masses. The measurement of the b-quark running mass $m_b(M_Z)$ at the scale $\mu_1 = M_Z$, provided by DELPHI (LEP) [6] and SLD (SLC) [7], together with the value at the b quark production threshold scale $\mu_2 = M_{\Upsilon/2}$, extracted form the Υ bound states with QCD sume rules[8] and QCD lattice calculations[9] constitute a set of two independent measurements at distant scales that allows to test the running of $m_b(\mu)$ in QCD. This running has important fenomenological implications in Higgs searches given that the parameter $m_b(M_H)$ governs the decay $\Gamma(H \to b\bar{b})$, dominant for $m_H \leq 100$ GeV[10]. Besides, $m_b(M_Z)$ is a basic input parameter to test $m_b - m_\tau$ unification predicted by many GUT models. In fact, the running $m_b(M_Z) - m_b(M_{\Upsilon/2})$ is a large part of the running $m_b(M_{GUT} \sim 10^{16} GeV) - m_b(M_{\Upsilon/2})$ responsible of the $m_b - m_\tau$ unification[11,12].

2 The experimental strategy

DELPHI, OPAL and SLD collaborations followed the same strategy: they measured a 3-jet observable with huge samples of hadronic Z decays that were classified into tagged quark-flavor subsamples taking advantage of the improved flavour tagging techniques based on the lifetime-impact parameter of the charged tracks in the event and in the particular case of SLD the invariant mass of topologically-reconstructed long-lived hadron heavy-decays vertices. However they have choosen two posible ways for the comparison of data and NLO predictions taking mass effects into account. The test of flavour independence of α_s is performed with LEP/SLC data and NLO-QCD predictions as theoretical input, including mass effects that contain an accurate knowledge of the b-quark mass extracted from independent measurements at low scales[8,9]. In the second way, the hypothesis of the α_s flavour independence is assumed. The perturbative series is cut at $\mathcal{O}(\alpha_s^2)$ and it is discussed wich scheme better describes the data, the pole mass M_b scheme followed in calculations[1,2] or the $\overline{MS}$ scheme in calculations[1,3]. In this $\overline{MS}$ scheme it will be extracted the value of the b-quark mass.

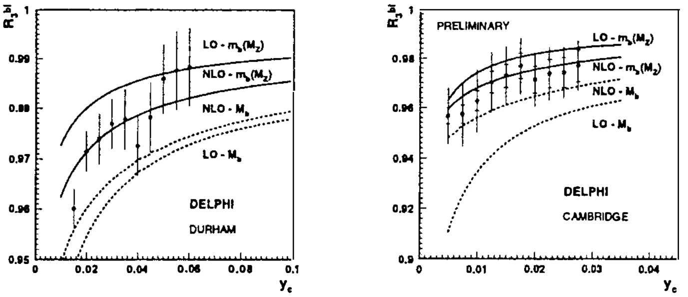
DELPHI considered the ratio 1 of the normalized three-jet rates for b to light ℓ quarks:

$$R_3^{b\ell}(y_c) = \frac{\Gamma_{3j}^{Z^0 \to b\bar{b}g}(y_c)/\Gamma_{tot}^{Z^0 \to b\bar{b}}}{\Gamma_{3j}^{Z^0 \to \ell\bar{\ell}g}(y_c)/\Gamma_{tot}^{Z^0 \to \ell\bar{\ell}}} \tag{1}$$

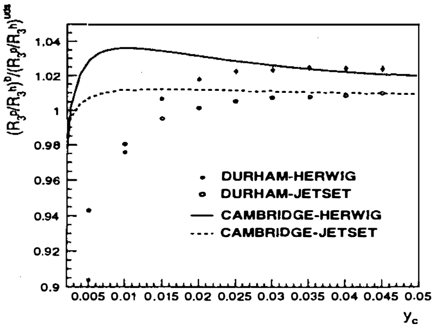
and calculations[1] in both $\overline{MS}$ and pole mass M_b schemes. Using Durham algorithm for jet reconstruction it was found that the calculation at Leading Order LO did not provide an acceptable description of data using both values: $M_b = 4.6\ GeV/c^2$ and $m_b(M_Z) = 2.83\ GeV/c^2$. The DELPHI analysis confirmed that the QCD radiative corrections including mass effects were needed to correctly describe the data. The NLO corrections resulted to be larger in terms of the running mass $m_b(M_Z)$ than in terms of the pole mass M_b. Although the candidate description for a given observable is that which minimizes the size of the NLO corrections it was found that the data prefered to be described at NLO with Durham algorithm in terms of the running mass $m_b(M_Z)$ (see left side of figure 2). The b-quark running mass was extracted: [6] $m_b(M_Z) = 2.67 \pm 0.50$ (stat. + syst.) GeV/c^2 and a net change in its value between M_Z and low scales was observed with almost three standard deviations: $m_b(m_\Upsilon/2) - m_b(M_Z) = 1.49 \pm 0.52$ GeV/c^2 The Cambridge algorithm improved the teoretical scenario: that time the NLO correction was smaller in terms of $m_b(M_Z)$ and its dependence with the μ scale was very stable. The data were well described at NLO in terms of $m_b(M_Z)$ and at LO only the description using the value of $m_b(M_Z)$ was acceptable (see right side of fig 2).

The hadronization corrections to the observable $R_3^{b\ell}$ were evaluated using two different fragmentation models: the cluster decay fragmentation (HERWIG) and the lund string fragmentation (JETSET). The difference in the hadronization correction factors depending on the choice of the fragmentation model was considered an aditional source of systematics, in fact the largest contribution to the total error of the $m_b(M_Z)$ measurement. The interval of validity for the jet resolution parameter y_c to perform the measurement was connected with the region where the behaviour of the fragmentation corrections was flat and the 4-jet contribution small ($\leq 2\%$ for Durham and $\leq 5\%$ for Cambridge). That region was extended (from $y_c \geq 0.015$ for Durham to

005 for Camjet) to low y_c values where the relative sensitivity to the mass correction was ed (see the figure 2).



1: Corrected data values of $R_3^{b\ell}$ (grey points) for Durham (on the left) and Cambridge (on the right) in ison with the LO and NLO theoretical predictions in terms of the pole mass M_b (dashed curves) and the running mass $m_b(M_Z)$ (solid curves).



2: Hadronization corrections to the $R_3^{b\ell}$ observable calculated with HERWIG and JETSET generators, and Durham and Cambridge jet algorithms.

D[7] studied also the observable $R_3^{b\ell}$ with six different jet algorithms: E, E0, P, P0, Durham eneva and considered NLO predictions in term of $m_b(M_Z)$[3]. They found a b-quark mass dependent on the jet algorithm: $R_3^{b\ell} \geq 1$ for E,E0,P,P0 that enhanced the invariant mass cal quark-gluon pair, and $R_3^{b\ell} \leq 1$ for D and G, where the dominant mechanism was the space suppresion of soft gluon emission. The results of $m_b(M_Z)$ for the six algorithms had d of $\approx$ 0.5GeV, similar to the total error of the DELPHI result with Durham algorithm. arge spread of values could be produced by the different of high-order QCD effects in O calculation affecting each algorithm[11]. The best estimate of $m_b(M_Z)$ was obtained into account statistical correlations as well as correlations in the systematic error and isation uncertainties.

AL[15] fitted the global event shape distributions y_{23}, $1-T$, M_H, B_W and C to $\mathcal{O}(\alpha_s^2)$ tions taking into account mass corrections for the c and b-quark in terms of the pole s[2] in a three parameter fit: α_s^{uds}, $\alpha_s^c/\alpha_s^{uds}$, $\alpha_s^b/\alpha_s^{uds}$. When massless QCD calculation was t was observed a reduction ~8% in the ratio $\alpha_s^b/\alpha_s^{uds}$ due to the b-quark mass effect. The shape observable M_H was not sensitive to the b-quark mass.

3 Summary of results

The mass effects of the b quark were clearly detected in LEP and SLC data at the Z peak and quantified through theoretical calculations of perturbative QCD at NLO including heavy quark mass effects. At NLO, data prefered to be described by corrections in terms of the running mass $m_b(M_Z)$ [1,3] rather than in terms of the pole mass M_b [1,2]. The ratios studied were found to be compatible with unity indicating the flavour independence of α_s:

$$\left(\alpha_s^b/\alpha_s^{uds}\right)_{DELPHI} = 1.007\pm0.005(stat.)\pm0.007(frag.)\pm0.005(theo.) \quad (2)$$

$$\left(\alpha_s^b/\alpha_s^{uds}\right)_{OPAL} = 0.993\pm0.008(stat.)\pm0.006(syst.)\pm0.011(theo.) \quad (3)$$

$$\left(\alpha_s^b/\alpha_s^{uds}\right)_{SLD} = 1.004\pm0.034(exp.)\pm0.029(theo.) \quad (4)$$

$$\left(\alpha_s^c/\alpha_s^{uds}\right)_{OPAL} = 0.997\pm0.038(stat.)\pm0.030(syst.)\pm0.012(theo.) \quad (5)$$

$$\left(\alpha_s^c/\alpha_s^{uds}\right)_{SLD} = 1.036\pm0.061(exp.)\pm0.019(theo.) \quad (6)$$

Two compatible determinations of the running b-quark mass $m_b(M_Z)$ were performed by DELPHI (7) and SLD (8) respectively:

$$m_b(M_Z) = 2.67 \pm 0.25 \text{ (stat.)} \pm 0.34 \text{ (frag.)} \pm 0.27 \text{ (theo.) GeV/c}^2, \quad (7)$$

$$m_b(M_Z) = 2.52 \pm 0.27 \text{ (stat.)}^{+0.33}_{-0.47}\text{(syst.)}^{+0.54}_{-1.46}\text{(theo.) GeV/c}^2 \quad (8)$$

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