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GLUON SPLITTING RATE INTO HEAVY FLAVOURS AT THE Z PEAK

ANDREA GIAMMANCO
Scuola Normale Superiore
piazza dei Cavalieri 7
56126 Pisa, Italy
E-mail: andrea.giammanco@pi.infn.it

The available measurements of the rates of gluon splitting to heavy quarks in hadronic Z^0 decays are described and the results are compared to theoretical predictions.

1 Introduction

In hadronic events at e^+e^- colliders, charm or bottom quarks can be produced either directly, or by *gluon splitting* ($g \to Q\bar{Q}$, where $Q = c, b$). At the Z^0 peak it is customary to define the rate $g_{Q\bar{Q}}$ for the latter process per hadronic Z^0 decay as $g_{Q\bar{Q}} = \frac{\Gamma(Z^0 \to q\bar{q}g, g \to Q\bar{Q})}{Z^0 \to hadrons}$

Theoretical predictions of $g_{c\bar{c}}$ and $g_{b\bar{b}}$ are available at leading and next-to-leading logarithmic approximation [1], yielding rates of order percent for $g_{c\bar{c}}$ and permille for $g_{b\bar{b}}$.

Typical experimental signatures for $g \to c\bar{c}$ and $g \to b\bar{b}$ are three and four jets events, respectively. In the first case the clustering is optimized so that c and $\bar{c}$ products are mainly in the same jet (which tends to be the broadest and softer), while b and $\bar{b}$ are resolved in separate jets.

2 Gluon splitting to $c\bar{c}$

2.1 Methods based on D^* reconstruction

OPAL [2] and ALEPH [3] reconstruct $D^{*\pm}$ mesons looking for the decay $D^{*\pm} \to D^0\pi^\pm$ followed by $D^0 \to K^\mp\pi^\pm$. The smallness of the phase space available to the background ($M(D^*) - M(D^0) \approx M(\pi)$) compensates the limited statistics available for this channel.

After the selection of a sample of $D^{*\pm}$ candidates OPAL extracts the $g_{c\bar{c}}$ value from a fit to the meson energy spectrum. Signal events are mainly contributing to the low momentum side of the distribution.

ALEPH divides the event in two hemispheres separated by a plane orthogonal to the thrust axis. The $D^{*\pm}$ mesons from gluon splitting are preferentially found in the hemisphere with the larger invariant mass, while the mesons from direct $c\bar{c}$ production are found with equal probability in both hemispheres. The $g_{c\bar{c}}$ value is extracted from a fit to the difference in mass between the hemispheres.

The results for the two analyses are:

OPAL	$(4.08 \pm 1.22(stat.) \pm 0.79(syst.))\%$
ALEPH	$(3.23 \pm 0.48(stat.) \pm 0.53(syst.))\%$

2.2 Methods based on leptons in three-jet events

OPAL [2], L3 [4] and ALEPH [5] identify leptons from charm decays and assume the lowest-energetic jet as the "gluon jet".

Leptons from $g \to c\bar{c} \to Xl\nu$ have a softer spectrum than leptons coming from primary charms, so momentum is used in the selection. The largest background comes from decays of primary b and c hadrons. Further signal/background discrimination is provided by the invariant mass of the "gluon jet" (which in gluon splitting events contains the remnants of two heavy quarks) [2] [4] or from the projection of missing momentum along the "gluon jet" direction (which comes mostly from neutrinos from c decay in signal events) [5].

The main systematic errors which are characteristic of this method are the uncertainty on the semileptonic branching ratios of heavy quarks and the uncertainty on the rejection of the fake leptons, due to the soft spectrum of the leptons from gluon splitting charm quarks. This mainly concerns the muon sample, which suffers the contamination from misidentified π's and K's and from muons produced in $\pi, K \to \mu\nu$ decays.

The results for these analyses, separately for electron and muons, are:

OPAL (e)	$(3.03 \pm 0.28(stat.) \pm 0.41(syst.))\%$
OPAL (μ)	$(3.53 \pm 0.37(stat.) \pm 0.79(syst.))\%$
L3 (e)	$(3.14 \pm 1.14(stat.) \pm 0.85(syst.))\%$
L3 (μ)	$(3.06 \pm 1.76(stat.) \pm 0.83(syst.))\%$
ALEPH (e)	$(3.32 \pm 0.28(stat.) \pm 0.42(syst.))\%$
ALEPH (μ)	$(2.99 \pm 0.38(stat.) \pm 0.72(syst.))\%$

2.3 Measurement based on event shape variables

L3 [4] performs an analysis using a neural network having as inputs several global event shape variables, such as three different Fox-Wolfram moments [6] and the mass difference between the heaviest and the other two jets, in three-jet events enriched in heavy quarks.

The weakness of the method is in the difficulty to obtain a high purity, even with a tight cut on the neural network output; nevertheless, this is largely compensated by the high statistics as all the hadronic decays of the c quarks are used.

The main systematics are related to the incorrect modeling of the input distributions, which has an influence during the training of the neural network. The result is:

L3 $(2.27 \pm 0.30(stat.) \pm 0.59(syst.))\%$

3 Gluon splitting to $b\bar{b}$

The available $g_{b\bar{b}}$ measurements can be classified as *"2b"* and *"4b"*, where the first category refers to searches of two b-jets in four jet events with the typical gluon splitting topology, while the latter looks for $Z^0 \to b\bar{b}g, g \to b\bar{b}$ events, which have a cleaner signature (the reconstruction of three good b-jets is sufficient to tag the event as a "4 b") but suffer from lower statistics. The second method measures the rate $R_{4b} \equiv \frac{Z^0 \to b\bar{b}b\bar{b}}{Z^0 \to hadrons}$, from which $g_{b\bar{b}}$ is extracted using a tree-level QCD prediction for $\frac{g_{b\bar{b}}}{R_{4b}}$ which takes in account the interference term between primary and secondary b quarks.

3.1 "2b" measurements

The analyses performed by ALEPH [7], DELPHI [8] and SLD [9] all follow similar strategies. In four jet events, two jets are required to have low energy and small opening angle, and to have a good probability to contain the decays of B hadrons.

In OPAL [11] two jets are considered as gluon splitting candidates if they can most easily clusterize into a single jet. The events are selected according to the presence of secondary vertices in the candidate jets, and a fit is performed on the acoplanarity distribution of those which pass the selection.

The results are:

DELPHI	$(2.1 \pm 1.1(stat.) \pm 0.9(syst.)) \times 10^{-3}$
ALEPH	$(2.77 \pm 0.42(stat.) \pm 0.57(syst.)) \times 10^{-3}$
SLD	$(2.44 \pm 0.59(stat.) \pm 0.34(syst.)) \times 10^{-3}$
OPAL	$(3.07 \pm 0.53(stat.) \pm 0.97(syst.)) \times 10^{-3}$

3.2 "4b" measurements

DELPHI [10] bases this analysis on three-jet events, all three required to have a b-tag.

ALEPH [7] "4b" analysis uses the same four jets than "2b" analysis. Only the first three, in lifetime ordering, are required to be good b-jets.

The results are:

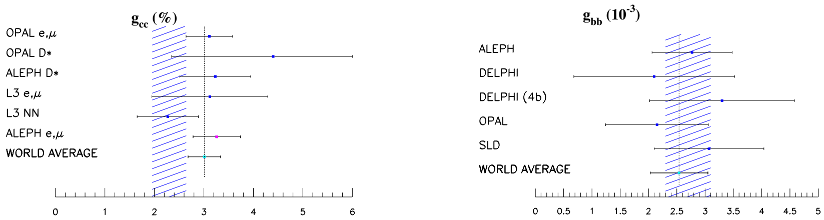
DELPHI	$(3.0 \pm 1.0(stat.) \pm 0.8(syst.)) \times 10^{-3}$
ALEPH	$(3.6 \pm 0.6(stat.) \pm 0.8(syst.)) \times 10^{-3}$

4 Averaging procedure and combined results.

The $g_{c\bar{c}}$ and $g_{b\bar{b}}$ measurements are combined [12] taking into account the correlations between different measurements of the same quantity, and the fact that $g_{c\bar{c}}$ is an input to $g_{b\bar{b}}$ and *vice-versa*.

An iterative method is used, yielding

$$g_{c\bar{c}} = (2.96 \pm 0.38)\%$$
$$g_{b\bar{b}} = (2.54 \pm 0.51) \times 10^{-3}$$



(a) (b)

Figure 1. Results for (a) $g_{c\bar{c}}$ and (b) $g_{b\bar{b}}$. Shaded areas correspond to the theoretical predictions.

The experimental results are consistent both for $g_{c\bar{c}}$ and $g_{b\bar{b}}$. While the $g_{b\bar{b}}$ average is in excellent agreement with the theoretical predictions, the $g_{c\bar{c}}$ average is 1.1σ away from the upper edge of the theoretical interval.

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