Gluon Splitting into $c\bar{c}$ and $b\bar{b}$

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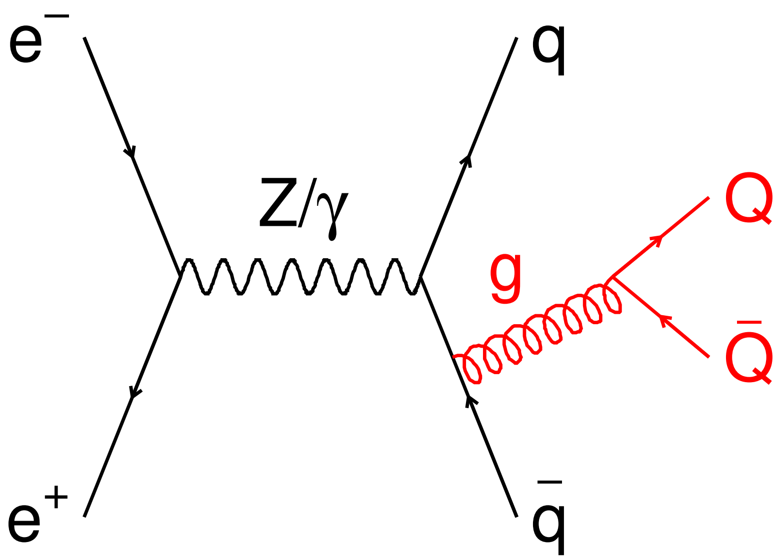
Rate of Heavy Quark Pairs from Gluon Splitting

$$g_{Q\overline{Q}} = \frac{N_{(Z\to q\bar{q}g, g\to Q\overline{Q})}}{N_{(Z\to \mathrm{hadrons})}} \qquad Q = \mathrm{b}, \mathrm{c}$$



Theory (Miller, Seymour: hep-ph/9805414):

$$g_{c\bar{c}} = 2.007\%; \qquad g_{b\bar{b}} = 0.175\%$$

Why is it interesting?

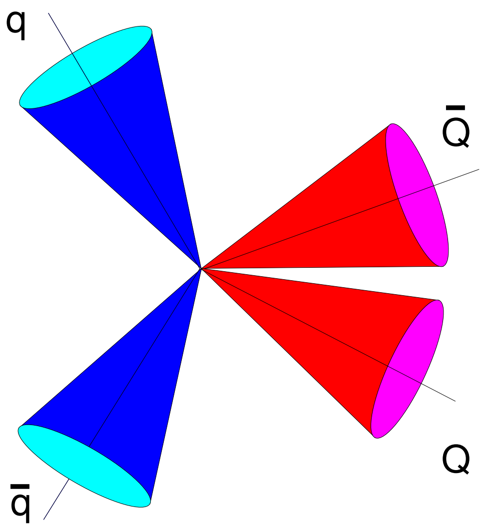
- test perturbative QCD
- process well predicted by perturbative QCD
- infrared safe: natural cut-off for heavy quarks
- experimentally: HF tagging well established
- major rôle in uncertainty on R_b measurement

Start with a Hadron Analysis

large and balanced energy in detector

high particle multiplicity

introduces no biases later



(A) Direct Approach (high statistic,low purity)

identify the jets from gluon splitting

with flavour tagging and cut on topology

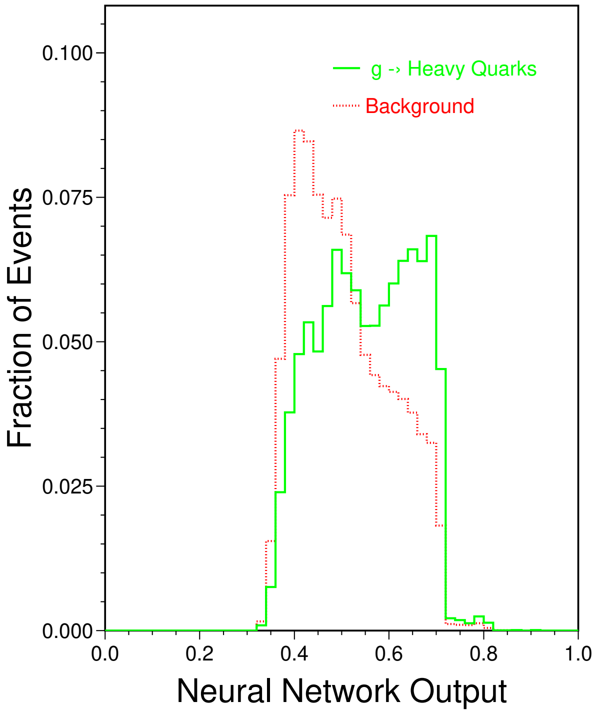
or use a Neural Net instead

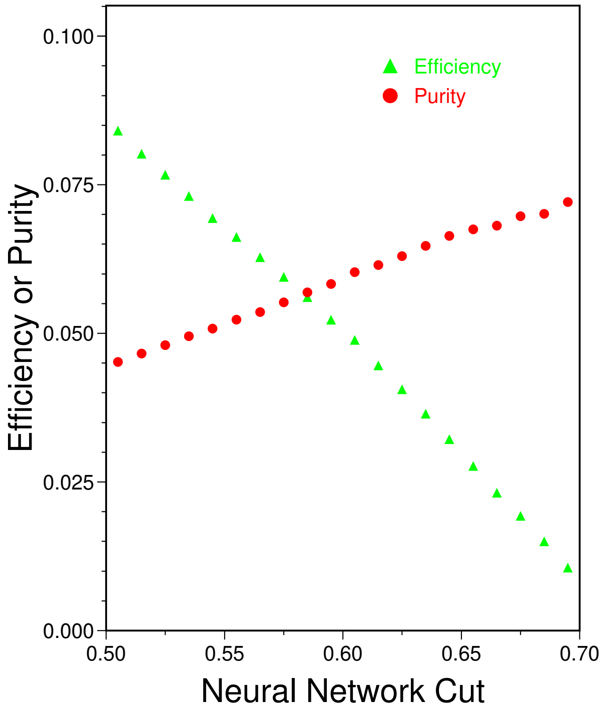
(B) Indirect Approach (high purity,low statistic)

measure R_{4b} by flavour tag on three jets

derive $g_{b\bar{b}}$ from R_{4b}

L3: Measurements of $g_{c\bar{c}}$





Neural Net, 5 Event Shape Variables as Inputs

9520 events selected: $\varepsilon, \pi \approx 5.5$ %

NN: $$g_{c\bar{c}} = \frac{\varepsilon_{DA} - \varepsilon_N}{(\varepsilon_B - \varepsilon_N)\, R + (\varepsilon_C - \varepsilon_N)}$$

$$g_{c\bar{c}}^{NN} = 2.05 \pm 0.19(stat) \pm 0.48(syst)\ \%$$

Lepton: $$g_{c\bar{c}} = \frac{\varepsilon_{DA}}{(1 + R\varepsilon_B/\varepsilon_C)\, 2\, \mathrm{Br}(c \to X\ell\nu)\, \varepsilon_C}$$

$$g_{c\bar{c}}^{\ell} = 2.68 \pm 0.64(stat) \pm 0.59(syst)\ \%$$

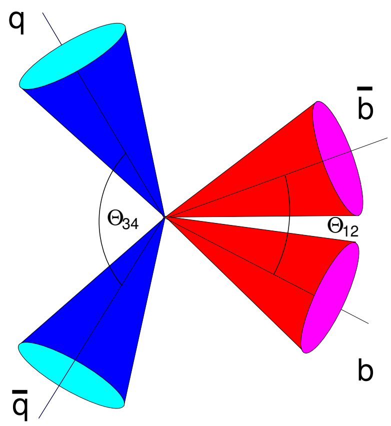
L3 Combined Value

$$g_{c\bar{c}} = 2.22 \pm 0.18(stat) \pm 0.44(syst)\ \%$$

from theory $R = g_{b\bar{b}}/g_{c\bar{c}} = 0.155 \pm 0.028$

ALEPH: Measurement of $g_{b\bar{b}}$

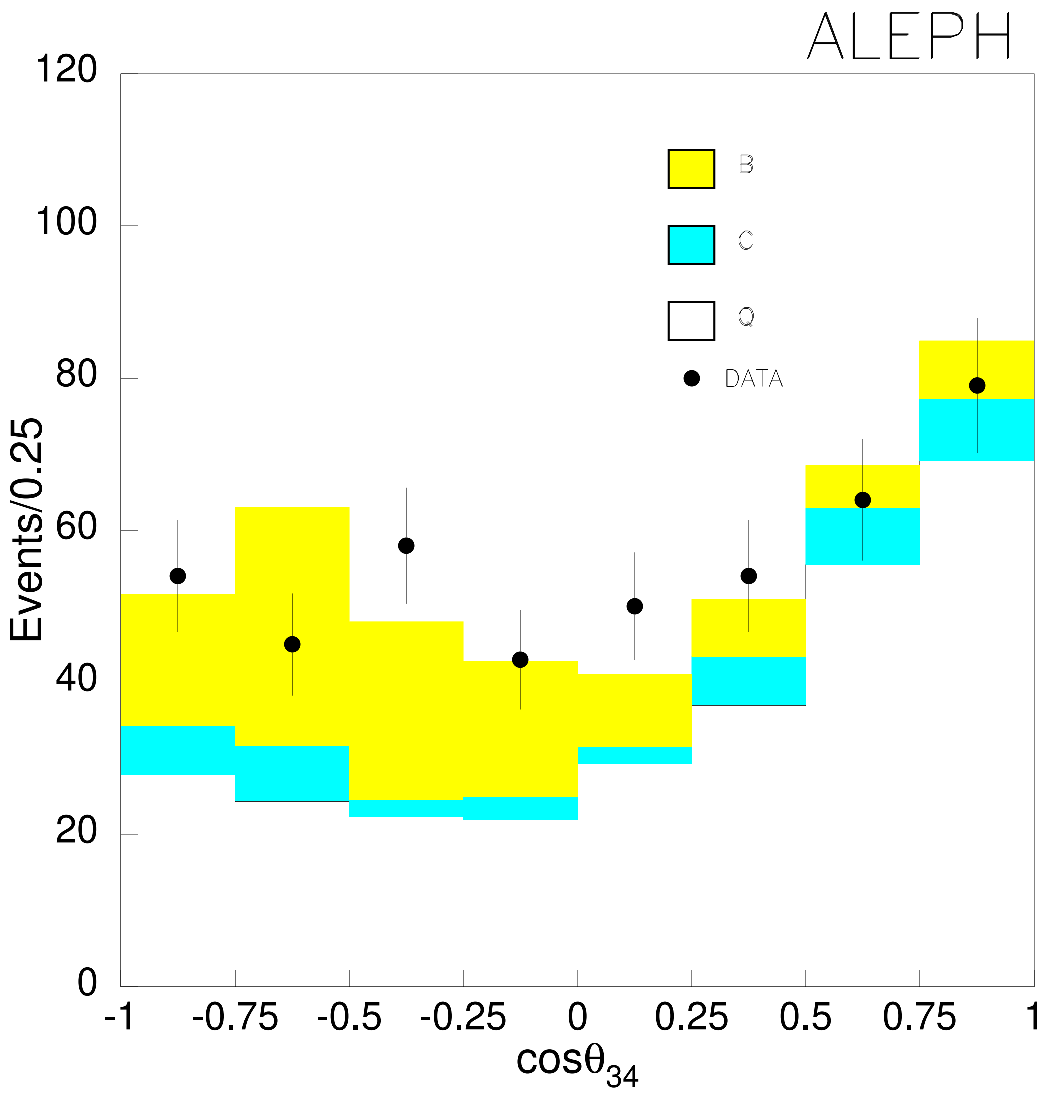
Lifetime Tag and Topology Cuts



3.7 million events analysed

222 events selected

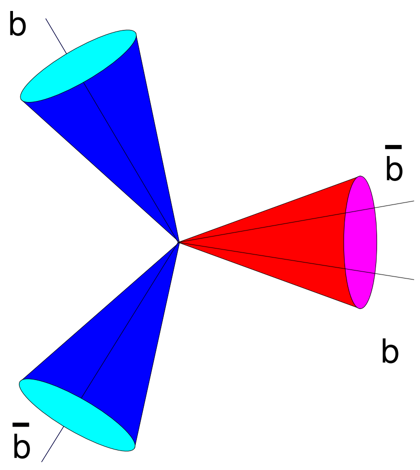
122 background



$$g_{b\bar{b}} = \frac{\varepsilon_{DA} - (1 - g_{c\bar{c}})\varepsilon_N - g_{c\bar{c}}\varepsilon_C}{(\varepsilon_B - \varepsilon_N)}$$ with $g_{c\bar{c}} = 2.38 \pm 0.48\%$

$$g_{b\bar{b}} = 0.277 \pm 0.042(stat) \pm 0.057(syst)\ \%$$

DELPHI: Measurement of $g_{b\bar{b}}$

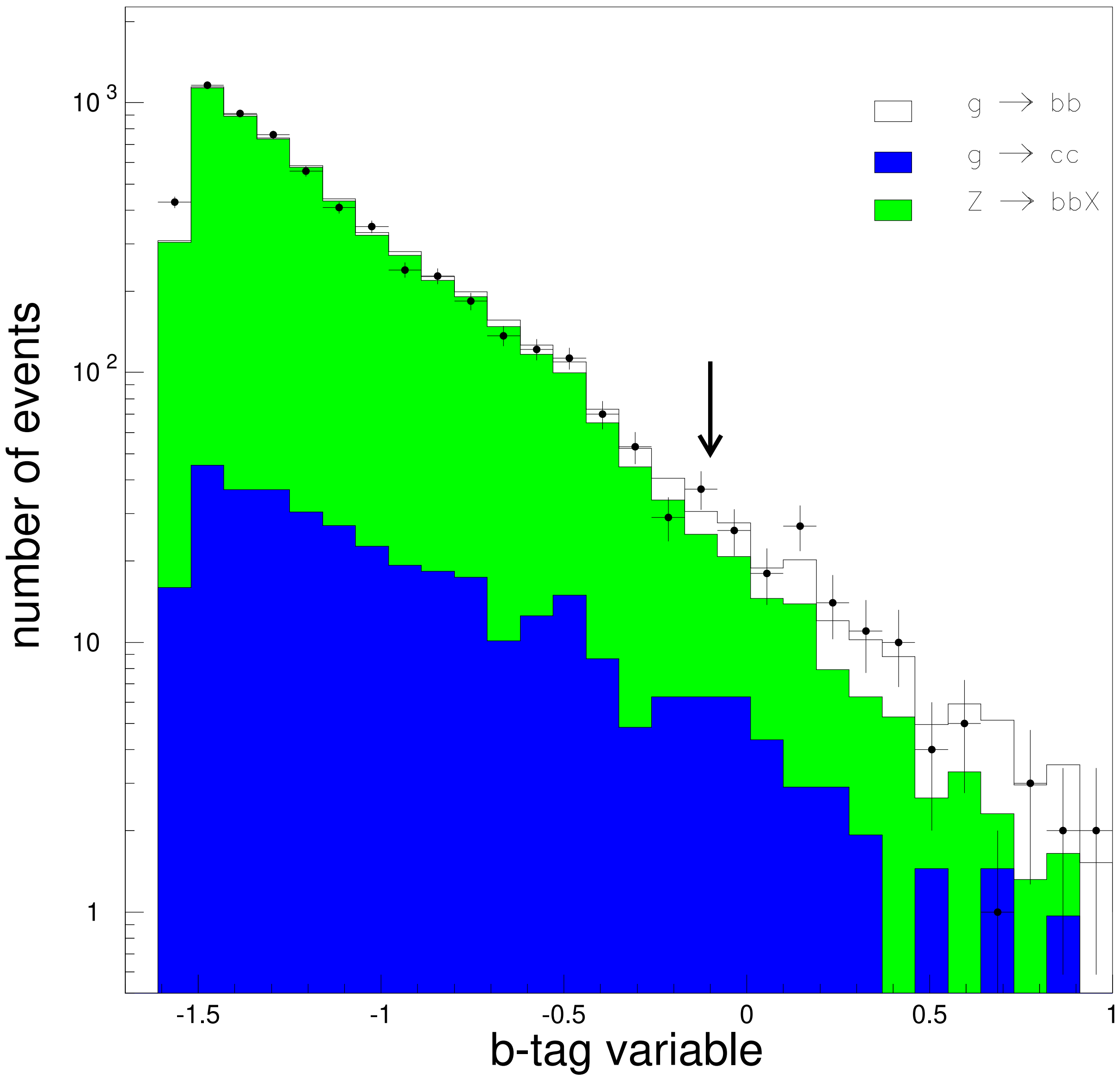


Reject 2 Jet Events

Other Events forced to 3 Jets

Enhanced Impact Parameter tag on each Jet

- Topology not important
- No Cutoff on Gluon Mass
- Interference Effects enhanced



DELPHI: Measurement of $g_{b\bar{b}}$

From 2 million events 140 Events selected

$R_{4b} = \frac{\varepsilon_{DA} - \varepsilon_Q - R_b[g_{c\bar{c}}(\varepsilon_C - \varepsilon_{2B}) + \varepsilon_{2B} - \varepsilon_Q]}{(\varepsilon_{4B} - \varepsilon_{2B})}$ with $g_{c\bar{c}} = 2.38 \pm 0.48\%$

$$R_{4b} = 0.054 \pm 0.0018(stat) \pm 0.0015(syst)\%$$

Due to Interference between primary and secondary $b\bar{b}$ production

$$R_{4b}/R_b \neq g_{b\bar{b}}$$

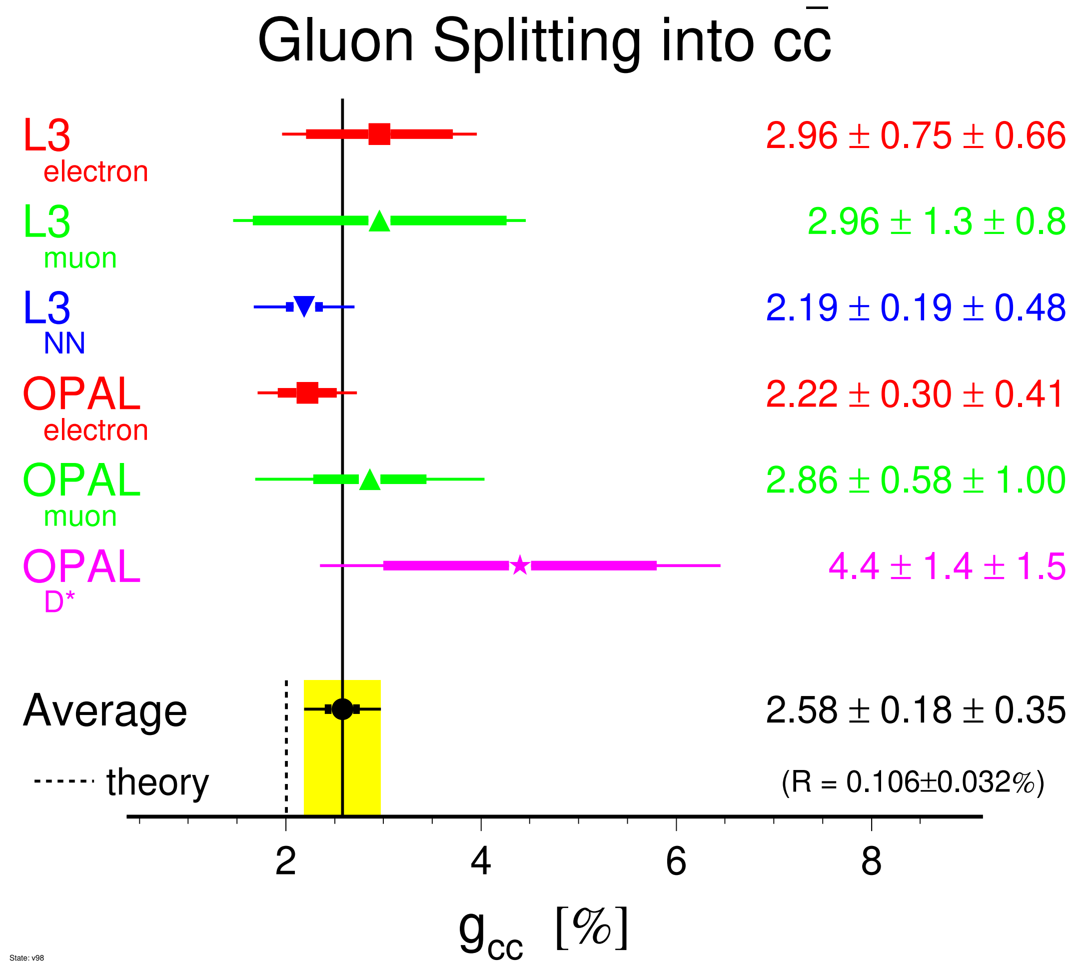
Extraction of $g_{b\bar{b}}$ from R_{4b}:

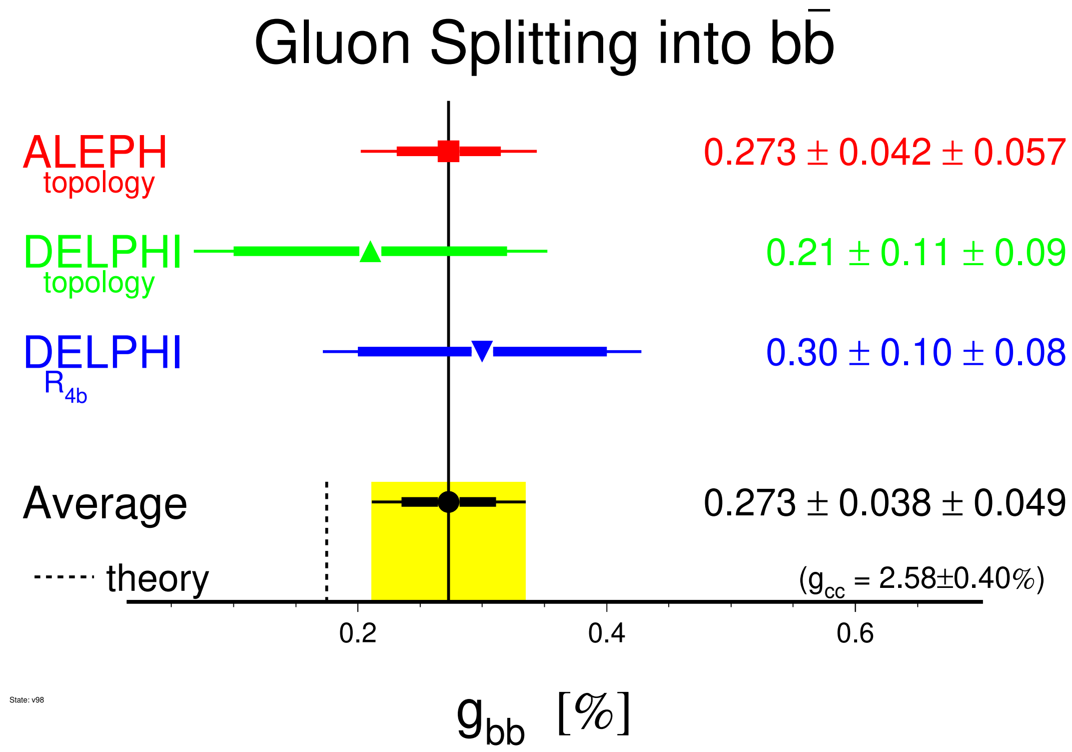
$g_{b\bar{b}} = \frac{\sigma(Z \to q\bar{q}g, g \to b\bar{b})}{\sigma(Z \to b\bar{b}b\bar{b})} R_{4b} = R_{th}\, R_{4b}$ with $R_{th} = 5.457 \pm 0.008$

$$g_{b\bar{b}} = 0.30 \pm 0.10(stat) \pm 0.08(syst)\%$$

Systematics in all Analyses:

- y_{cut} jet clustering parameter
- uncertainties in bottom and charm physics
- fragmentation parameters
- semileptonic branching ratios ($g_{c\bar{c}}$)
- detector systematics, background simulation
- MonteCarlo statistics


Gluon Splitting into $c\bar{c}$
L3 electron
2.96 ± 0.75 ± 0.66
L3 muon
2.96 ± 1.3 ± 0.8
L3 NN
2.19 ± 0.19 ± 0.48
OPAL electron
2.22 ± 0.30 ± 0.41
OPAL muon
2.86 ± 0.58 ± 1.00
OPAL D*
4.4 ± 1.4 ± 1.5
Average
2.58 ± 0.18 ± 0.35
theory
(R = 0.106±0.032%)
2
4
6
8
g_{cc} [%]
State: v98


Gluon Splitting into $b\bar{b}$
ALEPH topology
0.273 ± 0.042 ± 0.057
DELPHI topology
0.21 ± 0.11 ± 0.09
DELPHI R_{4b}
0.30 ± 0.10 ± 0.08
Average
0.273 ± 0.038 ± 0.049
theory
(g_{cc} = 2.58±0.40%)
0.2
0.4
0.6
State: v98
g_{bb} [%]

Conclusion

New Measurements of Gluon Splitting into $c\bar{c}$ and $b\bar{b}$

$g_{c\bar{c}} = 2.22 \pm 0.18 \pm 0.44\%$ (L3)

uses $R = 0.155 \pm 0.028$

$g_{b\bar{b}} = 0.277 \pm 0.042 \pm 0.057\%$ (ALEPH)

$g_{b\bar{b}} = 0.30 \pm 0.10 \pm 0.08\%$ (DELPHI)

uses $g_{c\bar{c}} = 2.38 \pm 0.48\%$

New Averages (no Theory Input)

$g_{c\bar{c}} = 2.58 \pm 0.18 \pm 0.35\%$

$g_{b\bar{b}} = 0.273 \pm 0.038 \pm 0.049\%$

corresponds to $R = 0.106 \pm 0.022 \pm 0.023$

Consistent with perturbative QCD predictions

$g_{c\bar{c}} = 2.007\%$

$g_{b\bar{b}} = 0.175\%$

Error on R_b from Gluon Splitting reduced