Quark Mass Effects at NLO

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Introduction

☞ Recent QCD precision measurements

❶ α_s measured with a 2-3% precision

❷ α_s universality tested to 1% level

❸ b-quark mass has been measured (with 500 MeV/c^2 accuracy)

❹ Colour factors from quark and gluon jets ($C_A/C_F = 2.25 \pm 0.14$)

❺ $g \to c\bar{c}$ and $g \to b\bar{b}$ measured $\mathcal{O}(10^{-3})$

☞ Theoretical calculations have followed

❶ NLO 3-jet rate for massive quarks

Bilenky, Rodrigo, Santamaria, Phys Rev Lett 79(1997)193

Bernreuther, Brandenburg, Uwer, Phys Rev Lett 79(1997)189

❷ Event shapes for massive quarks at NLO

Nason and Oleari, Phys. Lett B407(1997)57

❸ Improved jet algorithm (Cambridge)

Dokshitzer et al. JHEP 9708:001

Massive NLO event shapes

✎ OPAL pa 1#25: "Test of flavour independence of α_s using NLO calculations for heavy quarks"

uds	**events**	☞	**N_{sig}=0**	⇨	35% eff.
b	**events**	☞	**$N_{sig} \geq 5$**	⇨	23% eff.
c	**events**	☞	**D***	⇨	2% eff.

Massive $\mathcal{O}(\alpha_s^2)$ calculations of event shape observables:

(1-T), $M_H/\sqrt{s}$, B_w, Durham y_{23} and C.

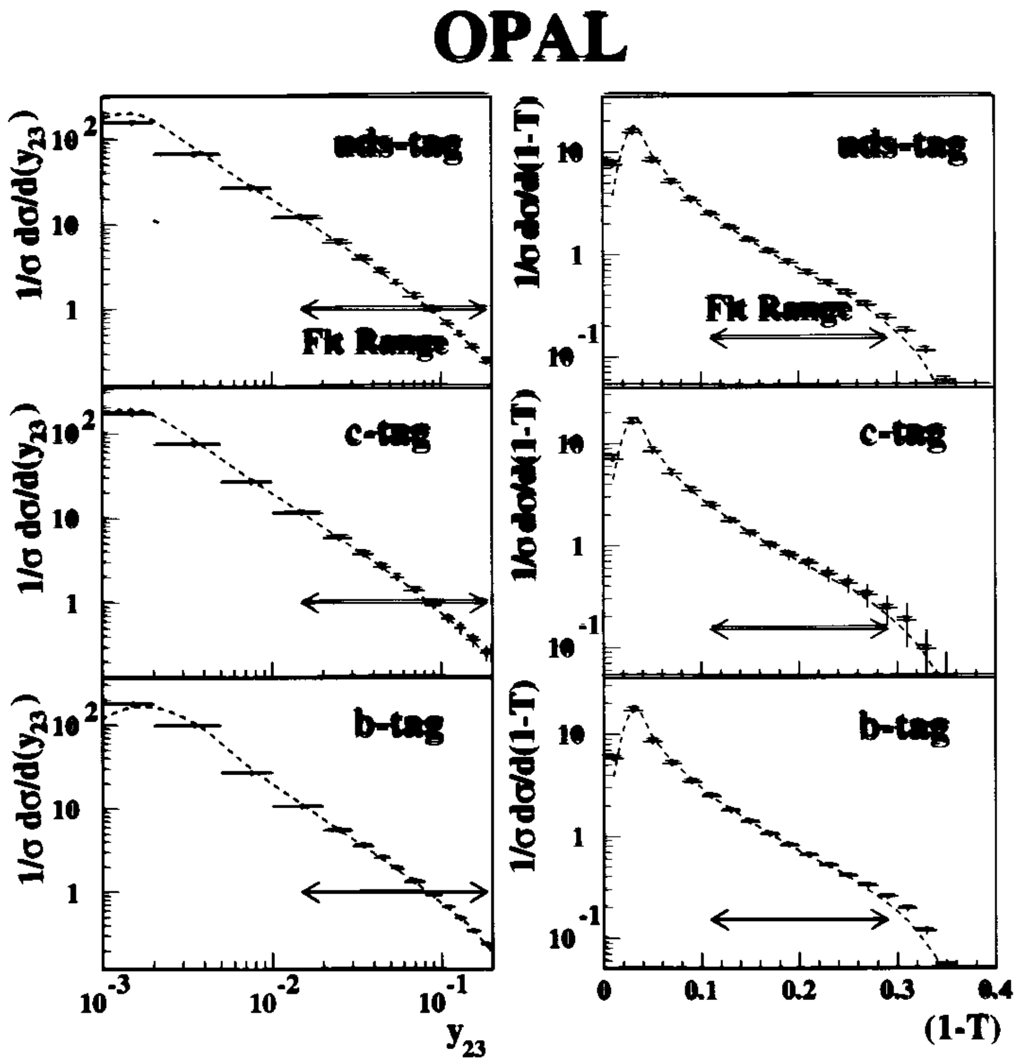
Fit Procedure:

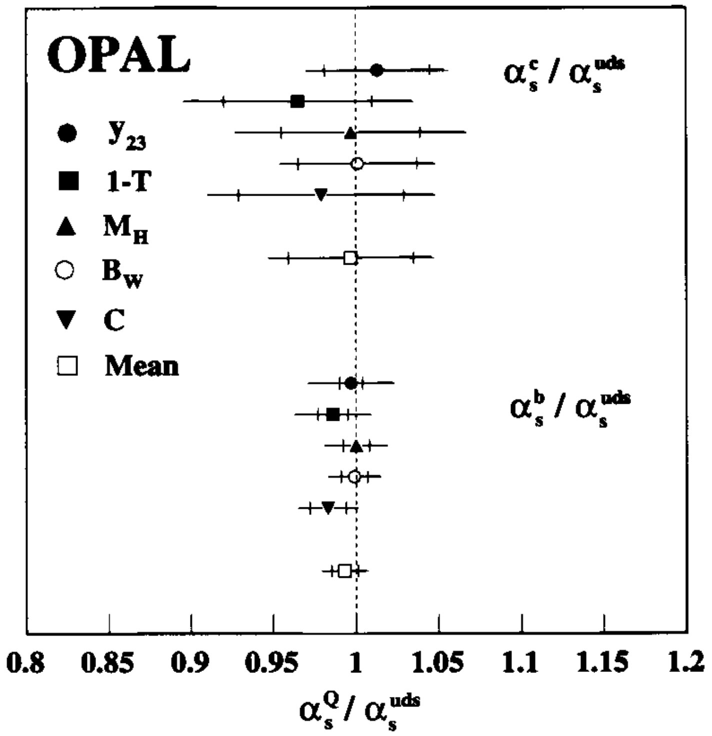
$$\left(\frac{1}{\sigma_{tot}}\frac{d\sigma}{dy}\right)^{q-tag} = f_{uds}^{q-tag} R(y)^{uds} \left(\frac{1}{\sigma_{tot}}\frac{d\sigma}{dy}\right)^{uds,th} + f_c^{q-tag} R(y)^c \left(\frac{1}{\sigma_{tot}}\frac{d\sigma}{dy}\right)^{c,th} + f_b^{q-tag} R(y)^b \left(\frac{1}{\sigma_{tot}}\frac{d\sigma}{dy}\right)^{b,th}$$

M_c=1.35 GeV/c^2 **and** M_b = 5.0 GeV/c^2

f_i^{q-tag} are flavour composition factors and $R(y)^i$ hadronization corrections ($\sim 10\%$).

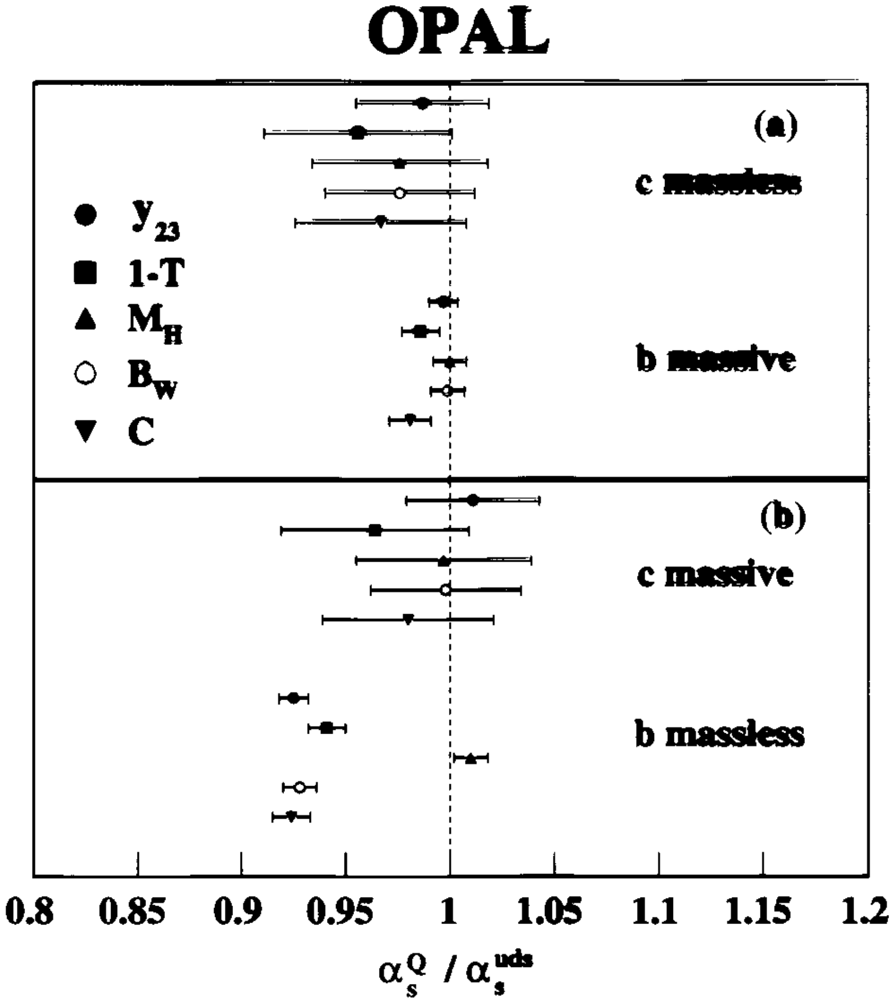
☞ Three parameter fit: α_s^{uds}, $\frac{\alpha_s^c}{\alpha_s^{uds}}$ and $\frac{\alpha_s^b}{\alpha_s^{uds}}$


OPAL
uds-tag
c-tag
b-tag
Fit Range
1/σ dσ/d(y23)
1/σ dσ/d(1-T)
y23
(1-T)


OPAL
y23
1-T
MH
BW
C
Mean
αsc / αsuds
αsb / αsuds
αsQ / αsuds

OPAL: α_s flavour independence

❶ The effect of a b-quark with a pole mass of 5.0 GeV/c^2 is $\approx$ 7%

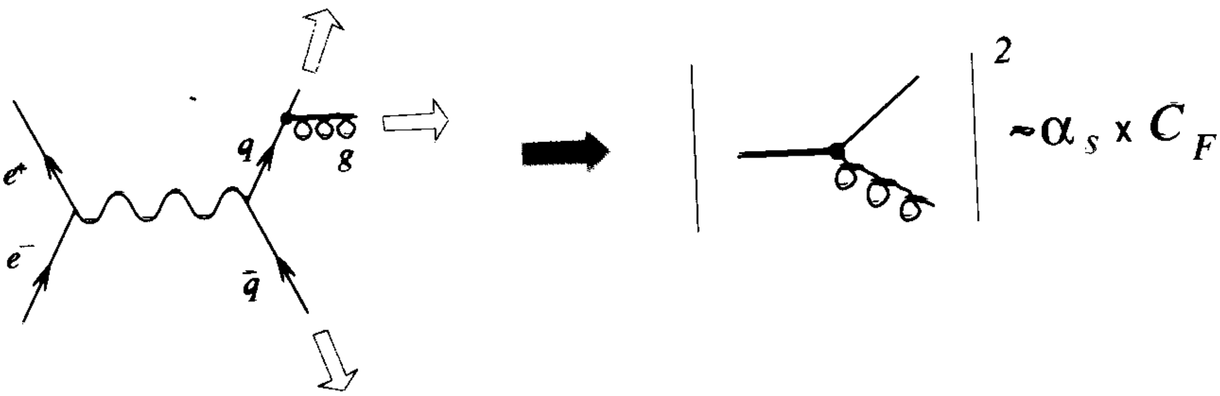


❷ α_s universality tested for massive quarks

$$\frac{\alpha_s^c}{\alpha_s^{uds}} = 0.997 \pm 0.038(\text{stat}) \pm 0.030(\text{syst}) \pm 0.012(\text{theo}$$

$$\frac{\alpha_s^b}{\alpha_s^{uds}} = 0.993 \pm 0.008(\text{stat}) \pm 0.006(\text{syst}) \pm 0.011(\text{theo}$$

DELPHI: α_s flavour independence



At LO: $$\Gamma_{3j}(y_c) = \frac{\alpha_s}{\pi} A(y_c)$$

$$\frac{\alpha_s^b}{\alpha_s^\ell}(y_c) = R_3^{b\ell}(y_c) - M(m_b)$$

At NLO:

$$\frac{\alpha_s^b}{\alpha_s^\ell}(y_c) = \left[R_3^{b\ell}(y_c) - M(m_b)\right] + 1.94\frac{\alpha_s}{\pi}\left[R_3^{b\ell}(y_c) - M(m_b) - 1\right]$$

Using the Cambridge jet finder

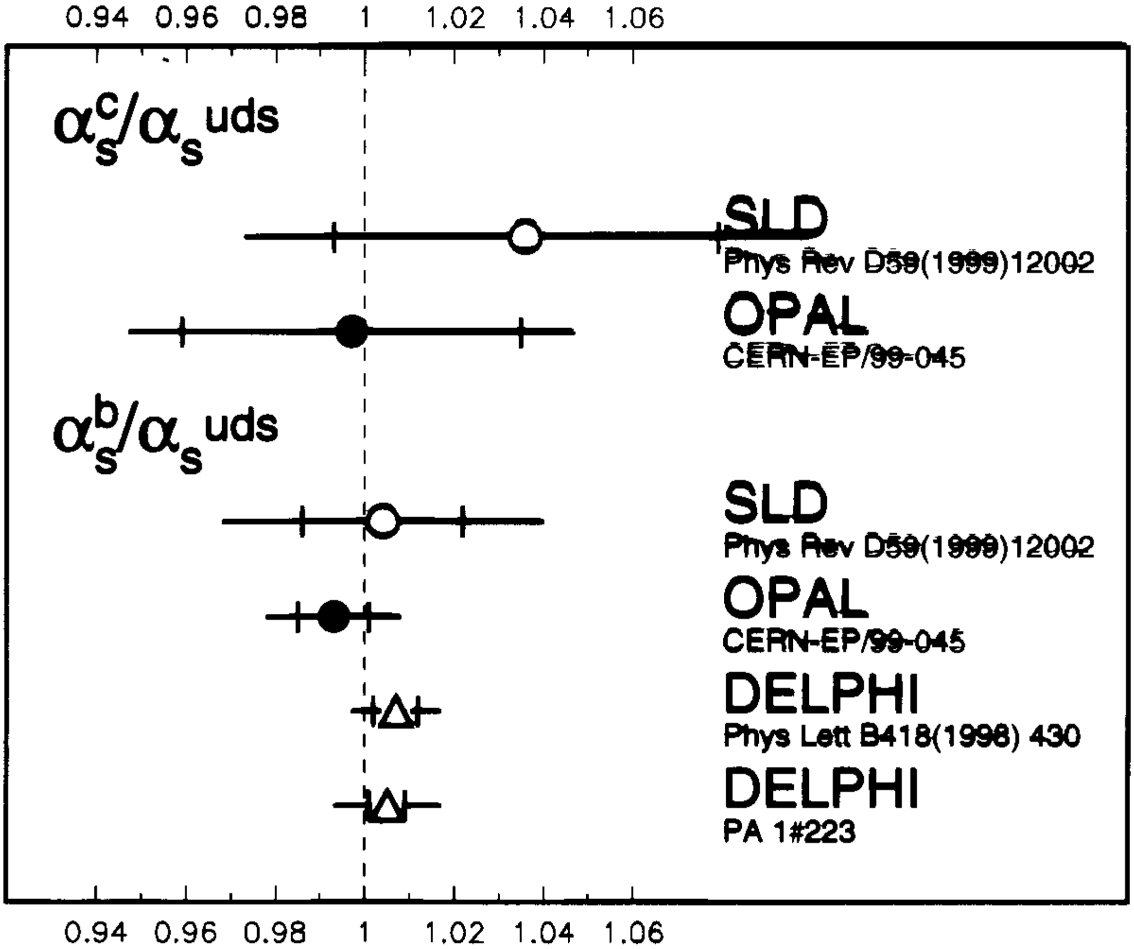
$$R_3^{b\ell}(0.005) = 0.965 \pm 0.004(\text{stat}) \pm 0.011(\text{syst})$$

$$M(m_b) = \mathbf{-0.036 \pm 0.007(theo)}$$

DELPHI obtains

$$\frac{\alpha_s^b}{\alpha_s^\ell} = 1.005 \pm 0.004(\text{stat}) \pm 0.011(\text{syst}) \pm 0.007(\text{theo})$$

Summary of α_s universality at NLO

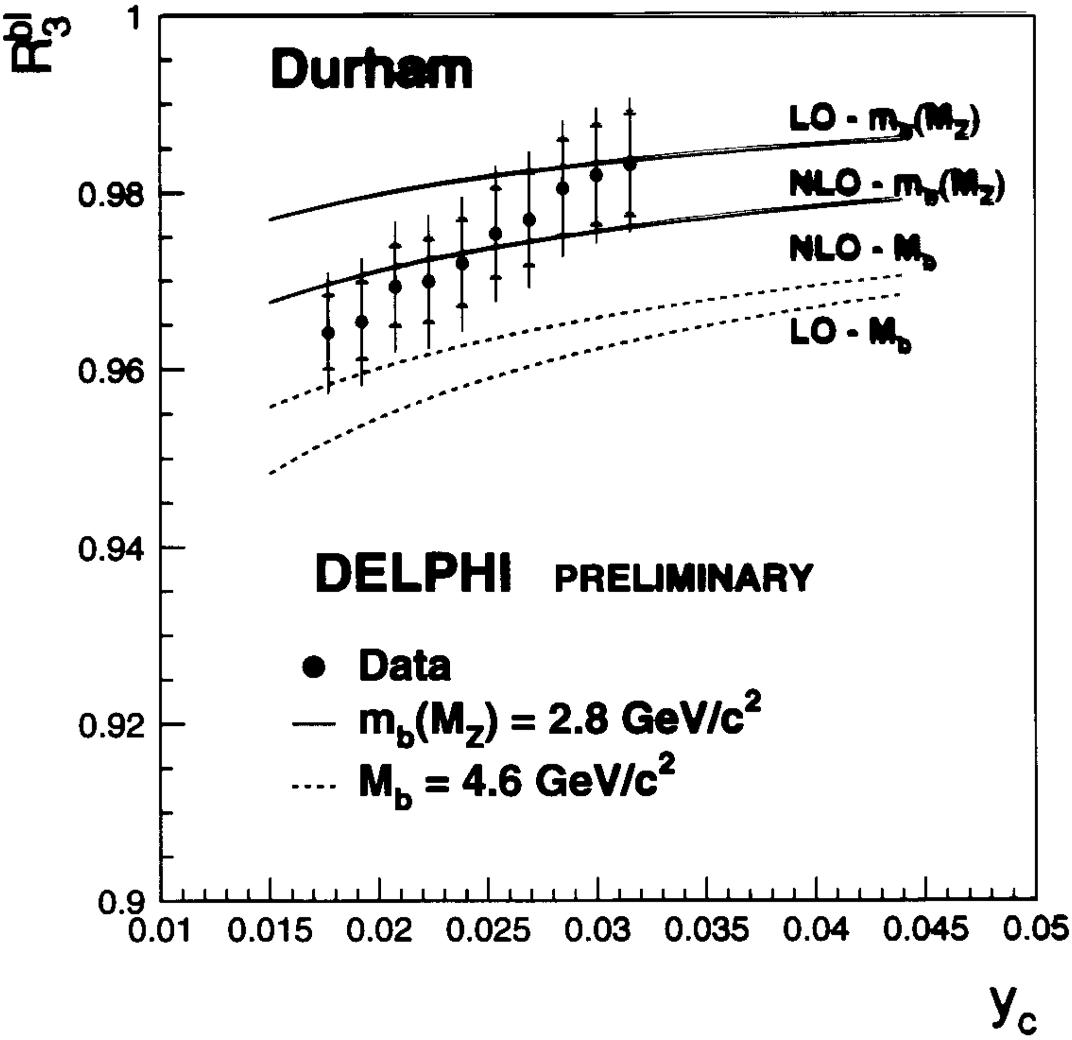


✌ Flavour independence of α_s tested at NLO with massive quarks expresions to $\sim$ 1% level

Mass effects and the NLO 3-jet rate

✎ DELPHI pa 1#223: "Three- and four- jet heavy b-quark production rates in e^+e^- annihilation at the Z peak"

$$R_j^{b\ell}(y_c) = \frac{[\Gamma_j(y_c)/\Gamma_{tot}]^{Z\to b\bar{b}}}{[\Gamma_j(y_c)/\Gamma_{tot}]^{Z\to \ell\bar{\ell}}} \qquad j = \textbf{3,4 jets}$$



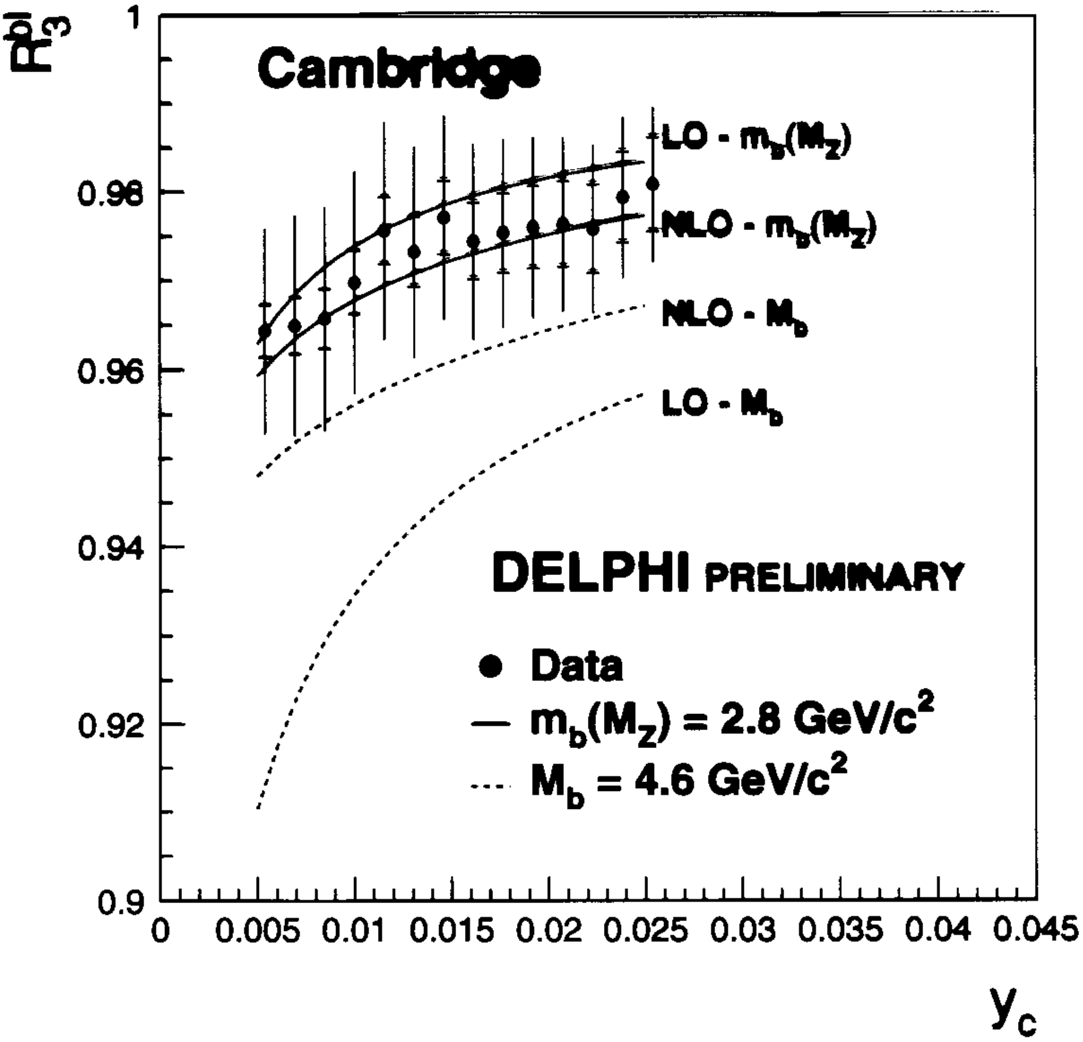
➊ LO pole mass almost 2σ away from data

➋ LO running mass only $\sim 1\sigma$ away

☞ Mass effects and radiative corrections seen

Mass effects and the NLO 3-jet rate

⇨ Cambridge jet finder has a better description of the soft gluon bremsstrahlung



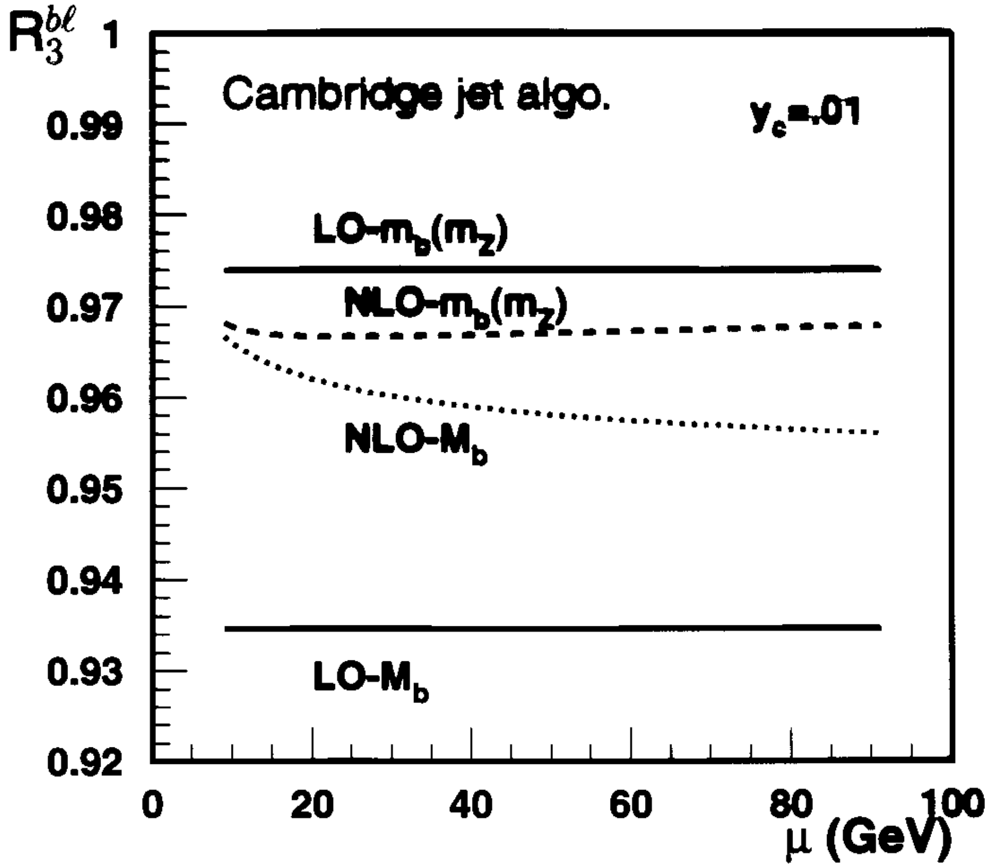
❶ LO pole mass almost 5σ away from data

❷ LO running mass only $\sim 1\sigma$ away

Cambridge $R_3^{b\ell}$

❶ NLO corrections with massive quarks are available for the Cambridge jet finder

M. Bilenky et al. hep–ph/9812433, Subm. to Phys. Rev. D



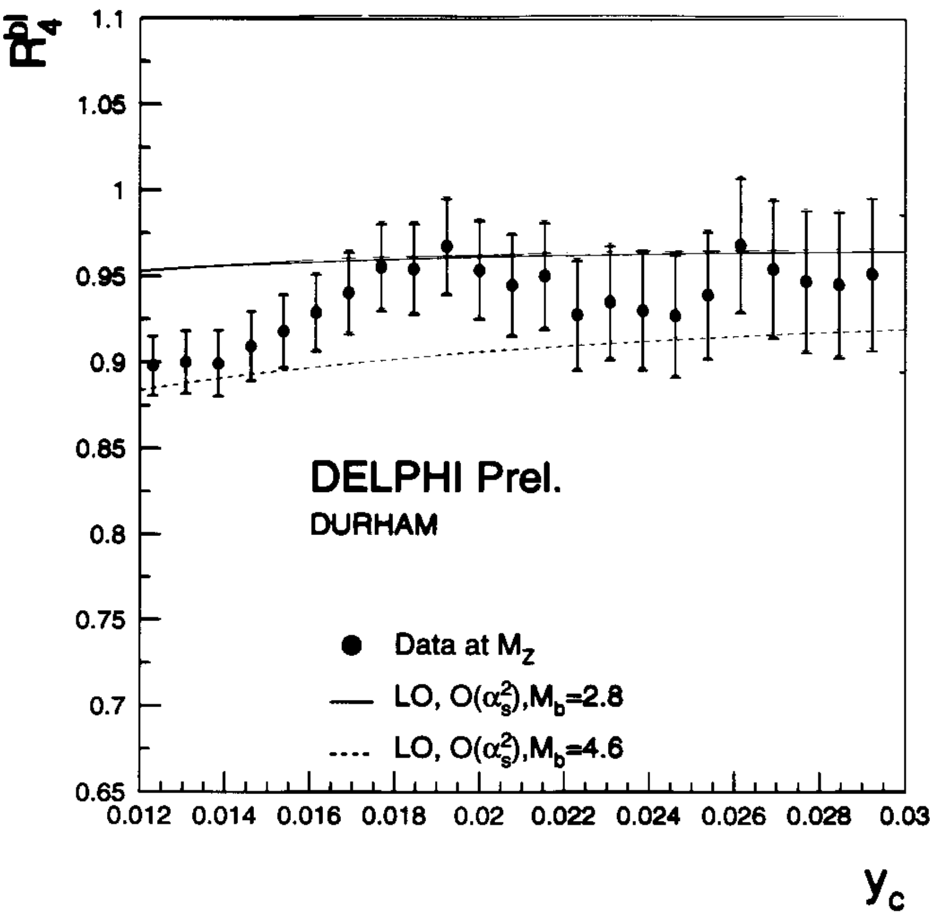
❷ NLO corrections are smaller when expressed in terms of the running mass

❸ NLO corrections expressed in running mass have low dependence with process scale μ

☞ Most of the H.O. corrections are absorbed in the running

b quark mass and the NLO 4-jet rate

❶ b-quark mass effects have been also seen in the 4-jet rates ($R_4^{b\ell}$). They are more important than for the 3-jet rate.



❷ Data points lay in the region between LO-pole mass and LO-running mass.

☞ Same scenario as for the 3-jet rate.

ALEPH m_b analysis

✎ ALEPH pa 1#384: "Investigations on the b-quark mass from hadronic Z decays"

❶ Study of the 1st and 2nd momentum of event shape variables:

T, C, y_3, B_T and B_W

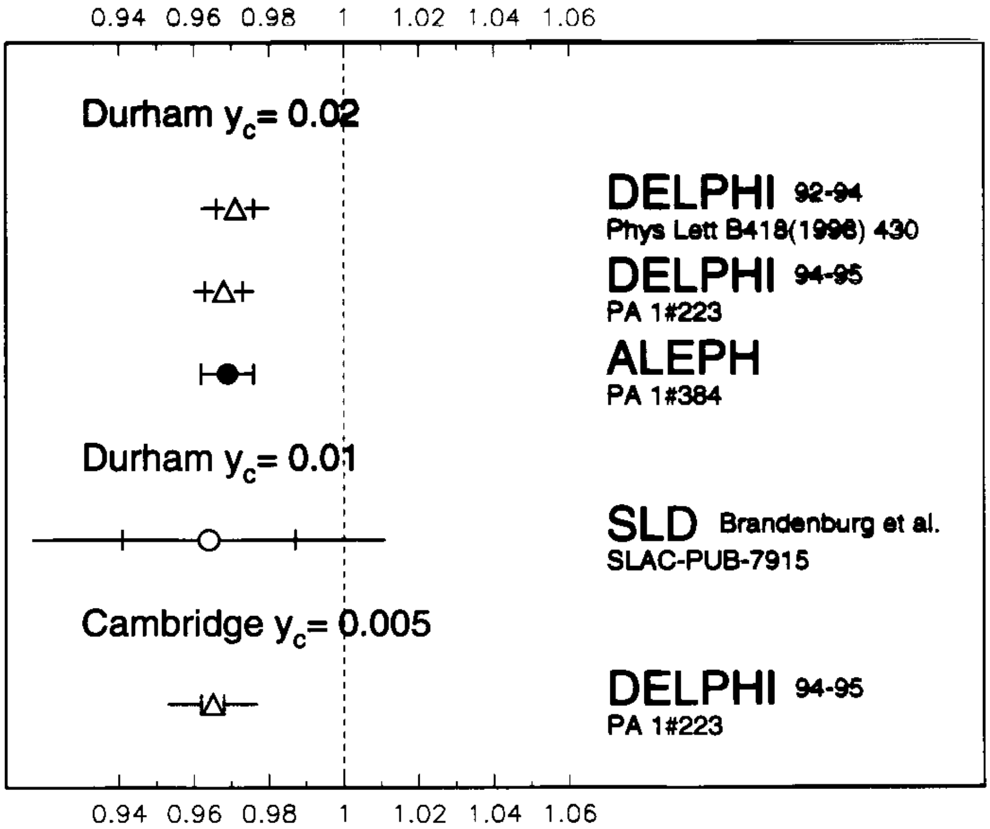
Obser.	Hb/ℓ	NLO/LO	$R^{b\ell}$
T_1	1.142	0.53	0.904± 0.003
T_2	1.139	1.90	0.901± 0.006
C_1	1.175	0.50	0.890± 0.002
C_2	1.181	1.86	0.887± 0.004
y_{31}	1.029	0.22	0.942± 0.007
y_{32}	0.990	0.20	0.981± 0.015
B_{T1}	1.302	0.05	0.832± 0.001
B_{T2}	1.333	3.11	0.825± 0.003
B_{W1}	1.142	0.73	0.903± 0.002
B_{W2}	1.093	0.44	0.928± 0.004
$R_3^{b\ell}$(D)	0.989	0.25	0.969±0.007

⚠ ALEPH shows that observables with low hadronization and NLO corrections perform better.

Summary of $R_3^{b\ell}$ results

✎ **DELPHI, SLD, ALEPH have measured the three-jet rate in b- and ℓ-quark events**

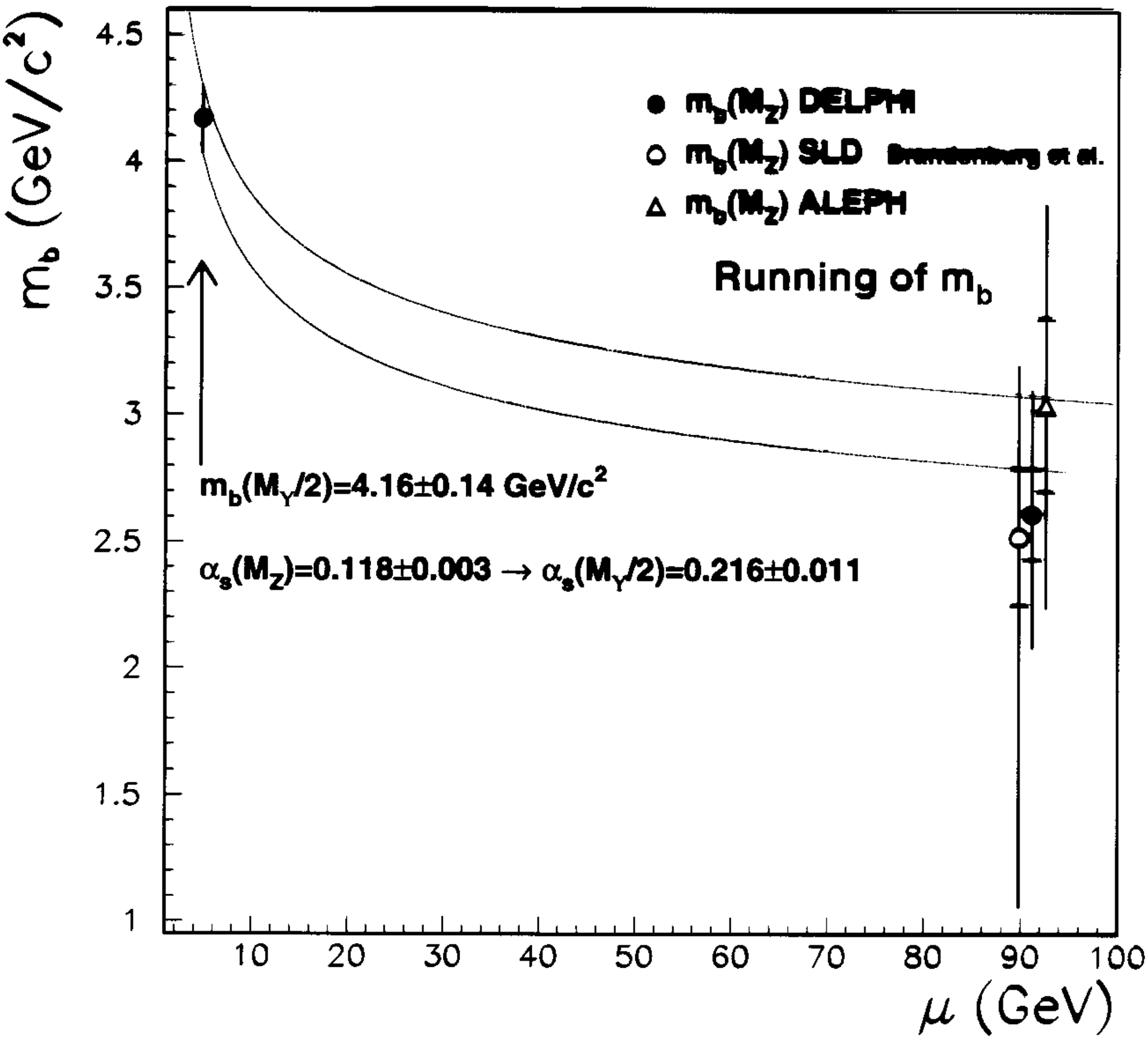
$$R_3^{b\ell}(y_c) = \frac{[\Gamma_3(y_c)/\Gamma_{tot}]^{Z\to b\bar{b}}}{[\Gamma_3(y_c)/\Gamma_{tot}]^{Z\to \ell\bar{\ell}}}$$



✌ DELPHI, SLD, ALEPH are in agreement

b-quark mass from $R_3^{b\ell}$

✎ DELPHI, SLD, ALEPH have measured of the running mass of the b-quark at the Z scale, $m_b(M_Z)$, using $R_3^{b\ell}$.



✌ DELPHI, SLD, ALEPH are in agreement with the QCD prediction

Summary and conclusions

❶ DELPHI, OPAL, ALEPH and SLD experiments have seen the b-quark mass effects and compared observables to NLO massive calculations

❷ The different observables being studied have different sensitivity to the mass effects and different massive NLO corrections.
☞ **The ideal observable has to have large sensitivity to mass effects and low massive NLO corrections.**

❸ b-quark mass effects at NLO can be studied in terms of either the pole mass or the running mass.
☞ **The b-quark 3-jet rate is better described in terms of the running mass.**