HEAVY-QUARK MASS EFFECTS AND IMPROVED TESTS OF THE FLAVOUR-INDEPENDENCE OF α_s

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Review of:

152: DELPHI: *New determination of the b-quark mass using improved jet clustering algorithms*

253: SLD: *An improved test of the flavor independence of strong interactions*

295: OPAL: *A test of the flavor independence of α_s using next-to-leading order calculations including mass effects*

(and earlier results)

Motivation

Physics

- **Flavour independence of strong interactions a fundamental ansatz of QCD (Ward Identity)**

- **Especially interesting to test for b-quark:**

  new physics may couple strongly to b

  recent excitement in EW sector (R_b, A_b)

  $\Rightarrow$ cross-check strong dynamics of b

- **Interesting + non-trivial mass effects**

  $\Rightarrow$ affect jet observables in $b\bar{b}g$ events

Technology

- **New O(α_s^2) calculations:**

  Bernreuther *et al.* PRL 79 (1997) 189

  Rodrigo *et al.* PRL 79 (1997) 193

  Nason, Oleari PLB 407 (1997) 57

$\Rightarrow$ possibility to determine $m_b(M_Z)$

Strategy

Choose $b\bar{b}g$ observable(s) to measure

Compare with QCD predictions

Two possible philosophies:

1. Input mass effects (now available at $O(\alpha_s^2)$):

$\Rightarrow$ Test flavour independence of α_s

2. Assume flavour independence:

$\Rightarrow$ Test $O(\alpha_s^2)$ calculations + determine m_b

1. TEST OF FLAVOUR INDEPENDENCE

A) METHOD

- **Select $e^+e^- \to q\bar{q}$ events,**
- **Tag events of different flavours i, j**
- **Measure IR-safe 3-jet observable X, *eg.* $R_3(y_c)$**
- **Correct for:**

  Detector acceptance + resolution

  Tagging bias + flavour composition

  Hadronisation

- **From**

$$\frac{X^i}{X^j} = \frac{A^i(X)\,\alpha_s^i + B^i(X)\,(\alpha_s^i)^2}{A^j(X)\,\alpha_s^j + B^j(X)\,(\alpha_s^j)^2}$$

measured **QCD calculation**

A (B) are LO (NLO) mass-dependent coefficients

$$\Rightarrow \quad \frac{\alpha_s^i}{\alpha_s^j}$$

- **Many systematics cancel in ratio**

B) FLAVOUR TAGGING

Separation of $b\bar{b}$ from $u\bar{u}$ +$d\bar{d}$ +$s\bar{s}$ events based on lifetime + decay multiplicity of B hadrons:

		b-tag		uds-tag	
		ϵ (%)	Π (%)	ϵ (%)	Π (%)
DELPHI:	**Prob. method**				
2.8M events					
b-tag	$P \leq 0.005$	**55**	**85**		
uds-tag	$P > 0.2$			**80**	**80**
OPAL:	**# sig. tracks**				
4.4M events					
b-tag	$N_{sig} \geq 5$	**23**	**96**		
uds-tag	$N_{sig} = 0$			**35**	**86**
c-tag	**D^***	**(2)**	**(55)**		
SLD:	**vtx mass, mom**				
150k events					
b-tag	$M_{vtx} > 1.8$ ...	**62**	**90**		
uds-tag	**No vtx,** $N_{sig} = 0$			**56**	**91**
c-tag	$M_{vtx} < 1.8$, $P_{vtx} > 5$ ...	**(19)**	**(64)**		

C. RESULTS

DELPHI: $R_3(y_c = 0.02)$, Durham jet-finder

(Calcs. of Rodrigo *et al.*)

$$\frac{\alpha_s^b}{\alpha_s^{uds}} = 1.007 \pm 0.005(\text{exp.}) \pm 0.007(\text{frag.}) \pm 0.005(\text{theor.})$$

OPAL: D_2, $1-T$, M_H, B_T, B_W, C event shapes

(Calcs. of Nason + Oleari)

$$\frac{\alpha_s^b}{\alpha_s^{uds}} = 0.988 \pm 0.005(\text{stat.}) \pm 0.004(\text{syst.}) \pm 0.011(\text{theor.})$$

$$\frac{\alpha_s^c}{\alpha_s^{uds}} = 1.002 \pm 0.017(\text{stat.}) \pm 0.025(\text{syst.}) \pm 0.009(\text{theor.})$$

SLD: $R_3(y_c)$, E, E0, P, P0, D, G jet-finders

(Calcs. of Bernreuther *et al.*)

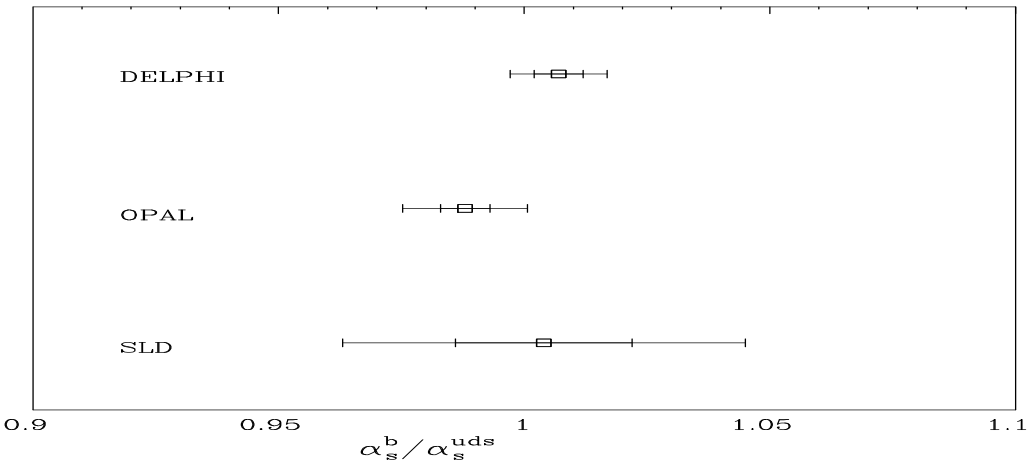
$$\frac{\alpha_s^b}{\alpha_s^{uds}} = 1.004 \pm 0.018(\text{stat.})^{+0.026}_{-0.031}(\text{syst.})^{+0.018}_{-0.029}(\text{theor.})$$

$$\frac{\alpha_s^c}{\alpha_s^{uds}} = 1.036 \pm 0.043(\text{stat.})^{+0.041}_{-0.045}(\text{syst.})^{+0.020}_{-0.018}(\text{theor.})$$

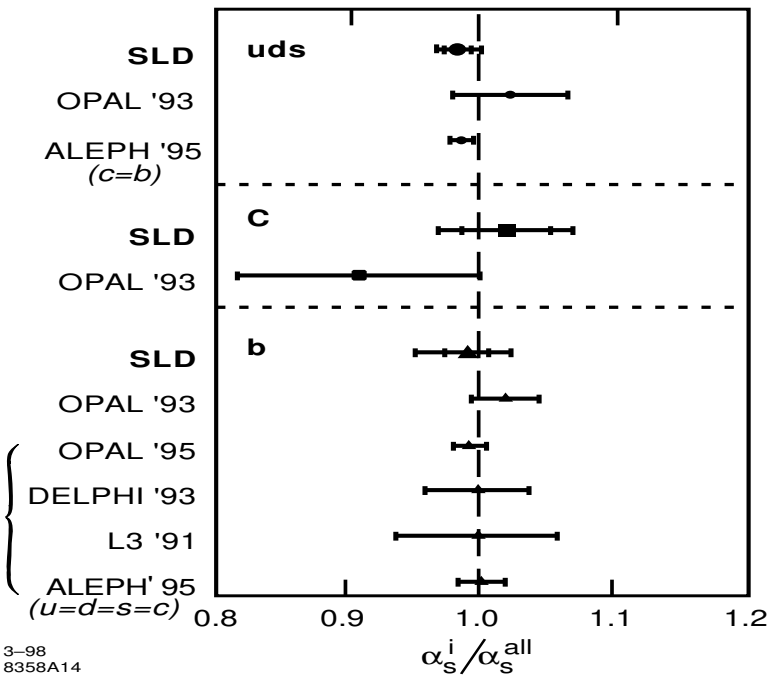
(analysis with 3$\times$ data and new VXD in progress)

D. SUMMARY OF Z^0 MEASUREMENTS

$\alpha_s^b/\alpha_s^{uds}$ including mass effects at NLO

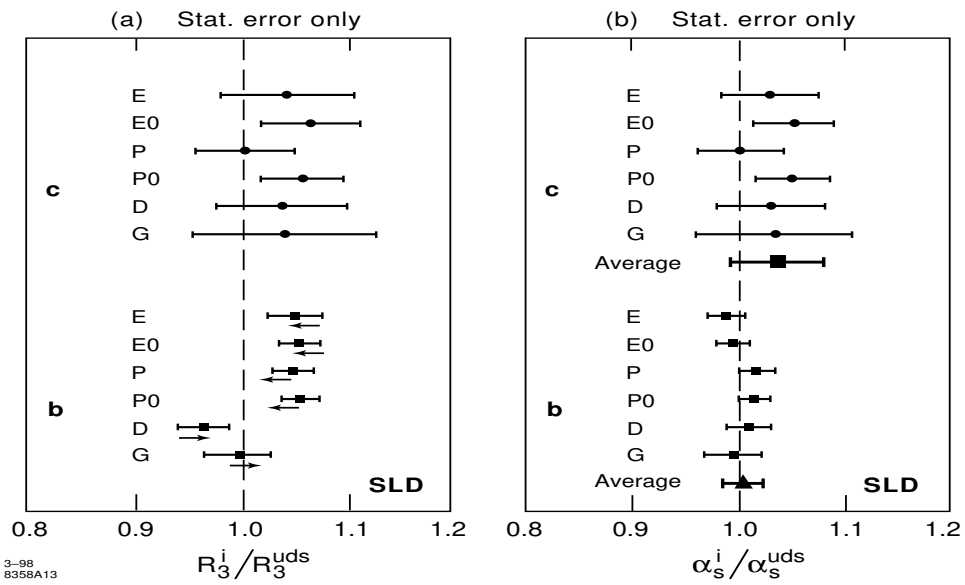


$\alpha_s^i/\alpha_s^{all}$ including mass effects at LO



2. HEAVY QUARK MASS EFFECTS

- **Non-zero b mass clearly visible in data:**



- **Effect is jet-algorithm dependent:**

R_3^b/R_3^{uds} $>$ 1 **for E, E0, P, P0 jet-finders**

$<$ 1 **for D, G jet-finders**

- **Two sources:**

(i) Phase-space SUPPRESSION of gluon radiation:

$\Rightarrow R_3^b < R_3^{uds}$

DOMINATES for Durham, Geneva algorithms

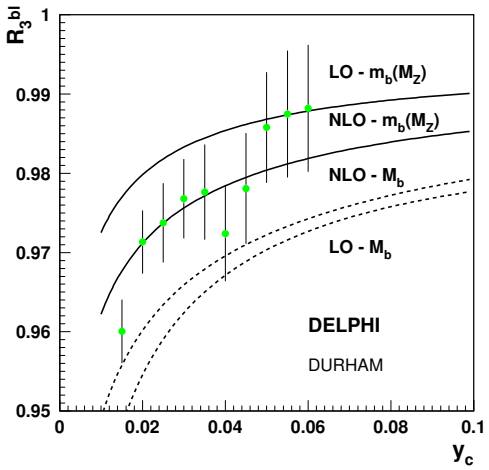
(ii) Kinematic ENHANCEMENT of quark-gluon inv. mass:

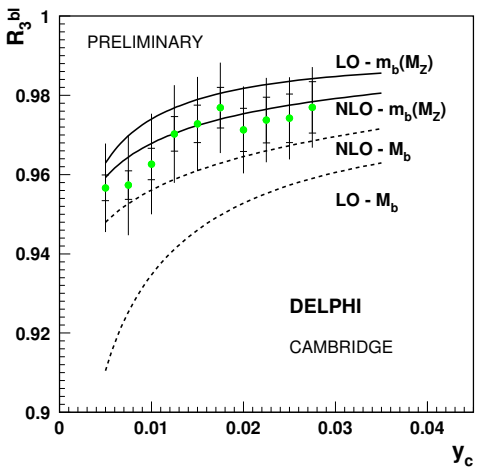
$\Rightarrow R_3^b > R_3^{uds}$

DOMINATES for inv. mass based E, E0, P, P0 algorithms

DELPHI Analysis

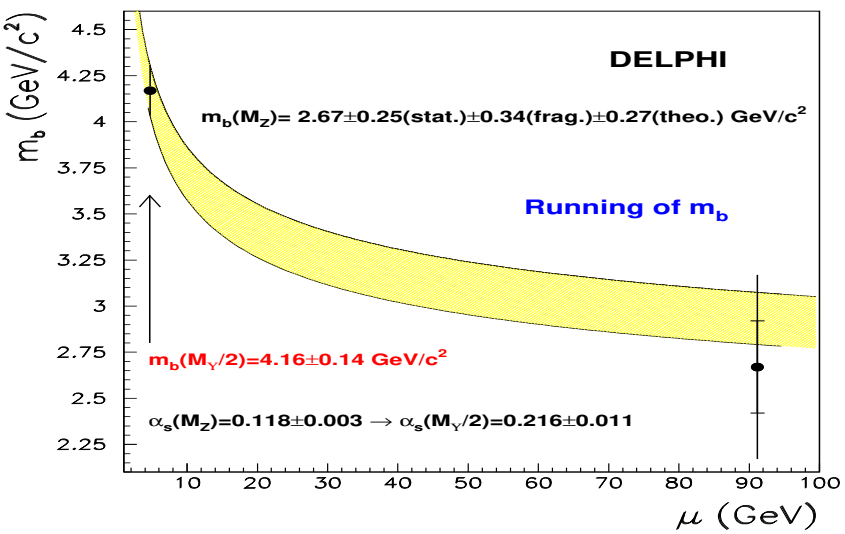
(PLB 418 (1998) 430; ICHEP98 #152)





- **Durham algorithm, $y_c = 0.02$**
- **Calculations of Rodrigo *et al.***

$$m_b(M_Z) \;=\; 2.67 \pm 0.25(\text{exp.}) \pm 0.34(\text{frag.}) \pm 0.27(\text{theor.})\ \text{GeV}/c^2$$

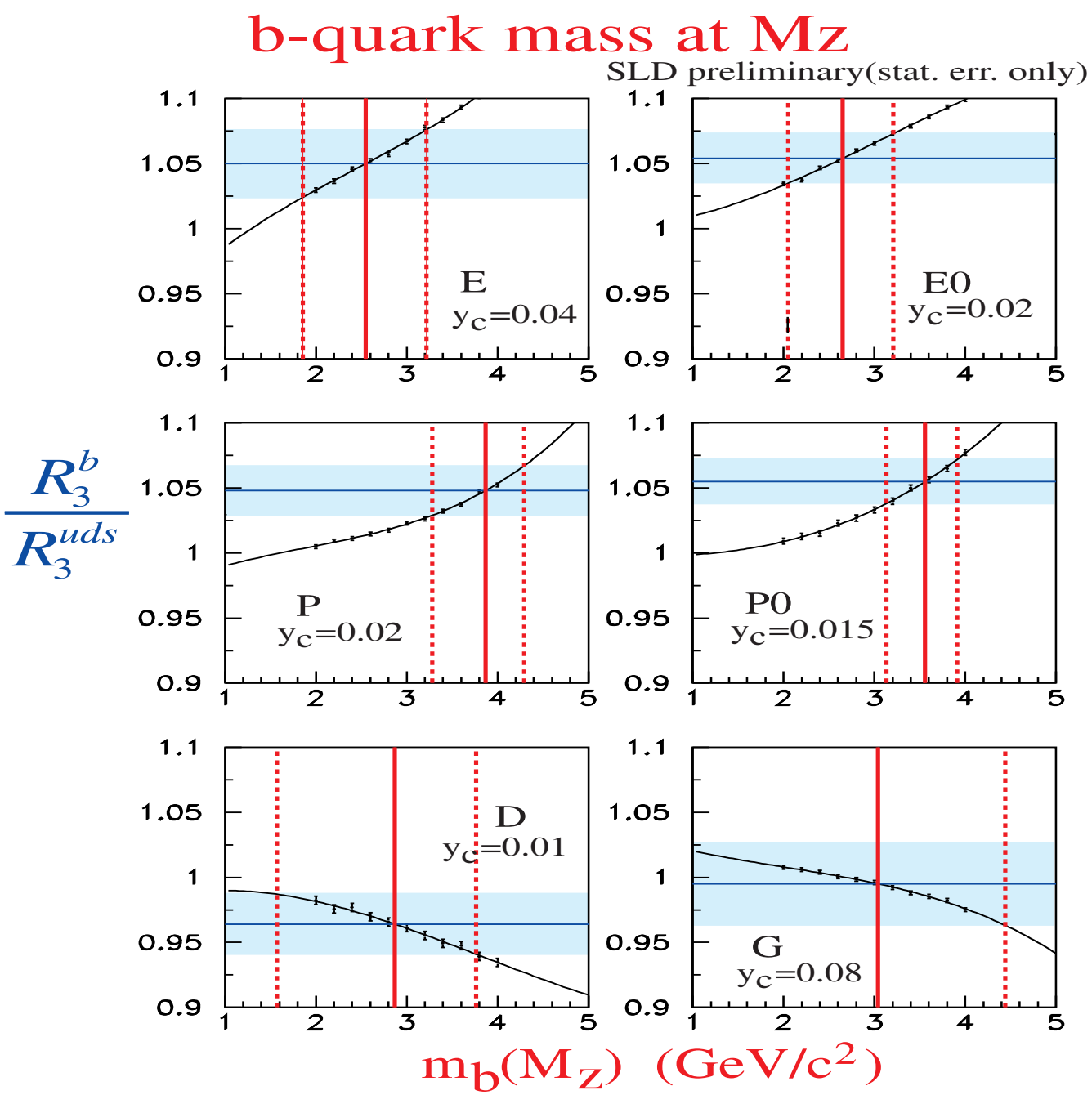


$$\Rightarrow \quad m_b(M_Z) - m_b(M_\Upsilon/2) \;=\; -1.49 \pm 0.52\ \text{GeV}/c^2$$

Analysis using SLD Data

(A. Brandenburg, P. Burrows, N. Oishi, P. Uwer)

Parametrised m_b-dependence based on calculations by Bernreuther *et al.*: 6 jet algorithms (E, E0, P, P0, D, G)



Analysis using SLD Data (contd.)

- **Very different m_b-dependence of calculations for different algorithms**

- **Significant scatter among $m_b(M_Z)$ fitted values:**

  $\Rightarrow$ **r.m.s.** $= \quad \pm 0.49$ **GeV**$/c^2$

- **Significant hadronisation uncertainties (ex. Durham):**

  $\Rightarrow$ **as large as** $+0.5\ -1.7$ **GeV**$/c^2$

- **Simple weighted average over 6 algorithms:**

$$m_b(M_Z) \;=\; 3.23^{+0.56}_{-0.72}(stat.)^{+0.81}_{-1.28}(syst.)^{+0.28}_{-1.05}(theor.) \pm 0.49(r.m.s.)$$

PRELIMINARY

(Analysis not optimised for m_b)

SUMMARY + CONCLUSIONS

1. FLAVOUR INDEPENDENCE OF α_s

- **New results from DELPHI, OPAL and SLD**
- **Tests at ~1% level:** $\alpha_s^b/\alpha_s^{uds}$

  ~5% level: $\alpha_s^c/\alpha_s^{uds}$

  (few measurements of α_s^c!)

2. HEAVY QUARK MASS EFFECTS

- **New results from DELPHI and SLD**
- **Clearly see non-zero b mass effects in** R_3^b/R_3^{uds}
- **New O(α_s^2)** $b\bar{b}g$ **calculations from 3 groups**

  $\Rightarrow$ **allow measurement of** $m_b(M_Z)$
- **Using Durham,** y_c**=0.02:**

  DELPHI $\Rightarrow m_b(M_Z) = 2.67 \pm 0.50$ **GeV**$/c^2$
- **Using E, E0, P, P0, D, G:**

  SLD data $\Rightarrow m_b(M_Z) = 3.23^{+1.02}_{-1.81}$ **GeV**$/c^2$

  and SIGNIFICANT algorithm-dependence: $\pm$**0.5 GeV**$/c^2$
- **Further studies: DELPHI: Cambr. alg, SLD: new data**