Heavy Flavour Measurements at LEP2

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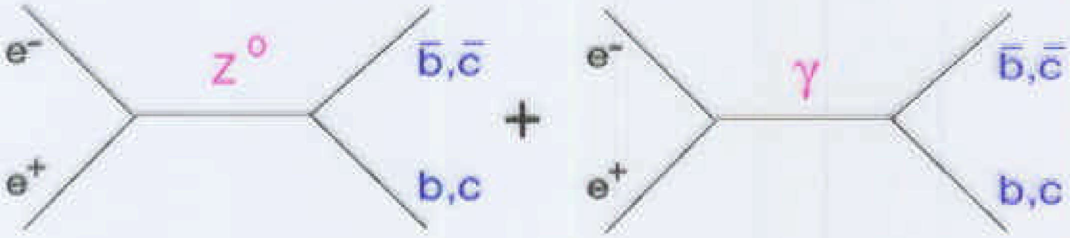
Introduction

Study beauty and charm quarks production in
$e^+e^- \rightarrow Z^\circ/\gamma \rightarrow q\bar{q}$ events:



Heavy quark observables:

- Cross-Section Ratios:

$$R_{b,c} = \frac{\sigma_{b,c}}{\sigma_{had}}$$

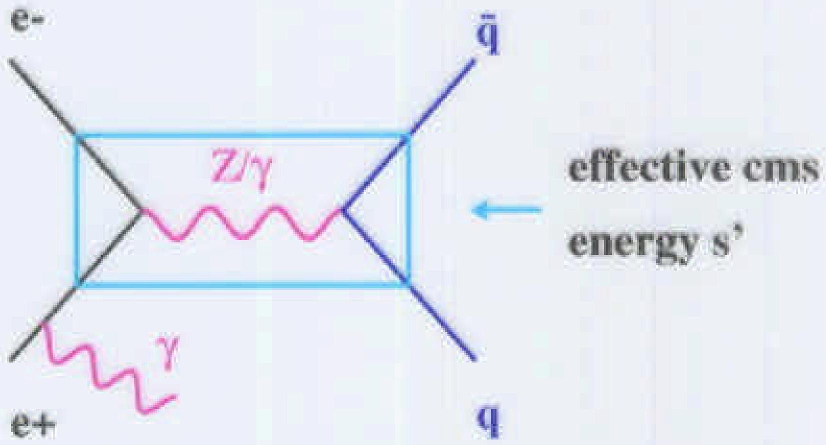
- Forward-Backward Asymmetries:

$$A_{FB}^{b,c} = \frac{\sigma_{b,c}^F - \sigma_{b,c}^B}{\sigma_{b,c}^F + \sigma_{b,c}^B}$$

Test of the Standard Model above the Z°
specific to heavy quark sector

Selection of Hadronic Events

Radiative return to the Z dominates:

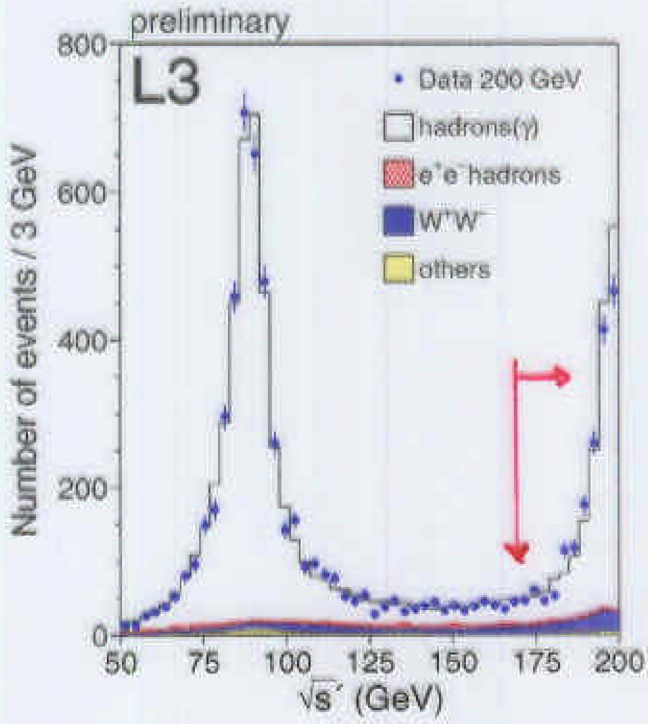


Select events with effective $\sqrt{s'}$ close to full centre-of-mass energy:

Typical cut:

$\sqrt{s'/s} > 0.85$

Residual ISR background $\approx$ 5-10%



W-pair background rejected on the basis of topological information. Residual contamination $\approx$ 5-15%

R_b and R_c Measurements

Identification of b and c events based on:

- "Lifetime-Tag"; presence of secondary vertices significantly displaced from primary vertex, large impact parameters.
- "Lepton tag"; presence of high p, p_t leptons (e,μ) from semileptonic b,c decays

After flavour identification and ISR, WW background subtraction, R_b or R_c are derived from the tagged fraction:

$$\frac{N_{tag}}{N_{had}} = \epsilon_b \cdot R_b + \epsilon_c \cdot R_c + \epsilon_{uds} \cdot (1 - R_b - R_c)$$

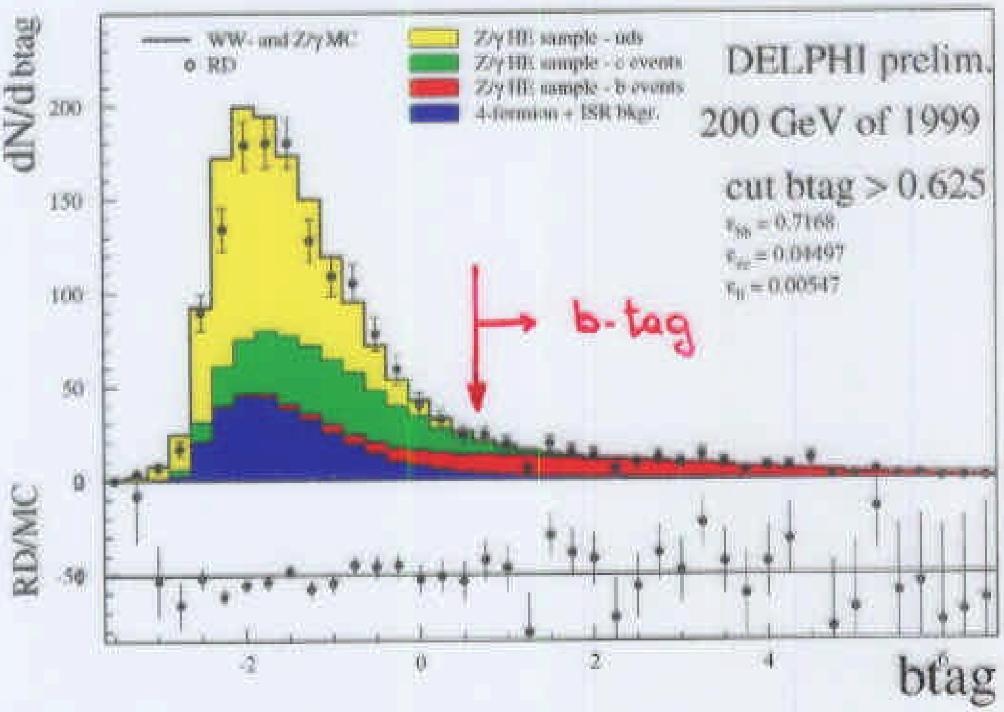
Cross-sections much smaller than at the Z^o peak:

- "Single tag" techniques, rely on MC for the estimate of all efficiencies
- Maximise tagging efficiency

DELPHI - R_b

Tagging variable based on:

- Track impact parameters
- Mass of the secondary vertex
- Rapidity of tracks in the jets



Very efficient and pure technique:

$$\epsilon_b = 72\%, P_b = 90\%,$$

Measurements from 130 to 206 GeV. At 200 GeV:

N_{had}	N_{tag}	R_b	R_b^{SM}
1633	206	$0.183 \pm 0.016 \pm 0.005$	0.166

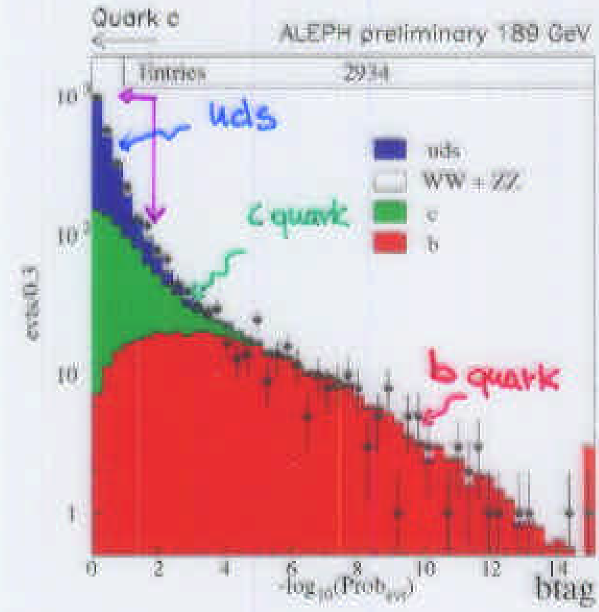
ALEPH -R_c

Measurements at 183 and 189 GeV. First step:

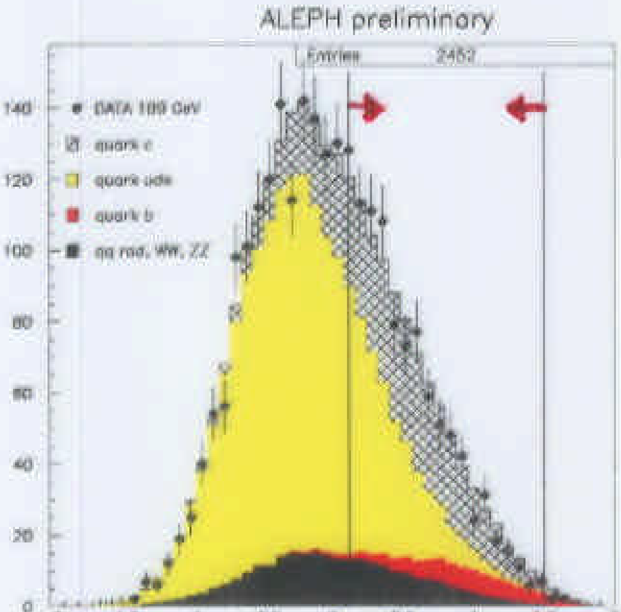
b-antitag:

80% b-rejection

86% efficient for c



Second step: c-tagging ($\epsilon_c = 59\%$, $P_c = 41\%$) with a NN based on lifetime information and high momentum leptons/kaons to discriminate against light flavours:



ALEPH R_c at 189 GeV:

$0.242 \pm 0.017(\mathrm{stat}) \pm 0.016(\mathrm{sys})$

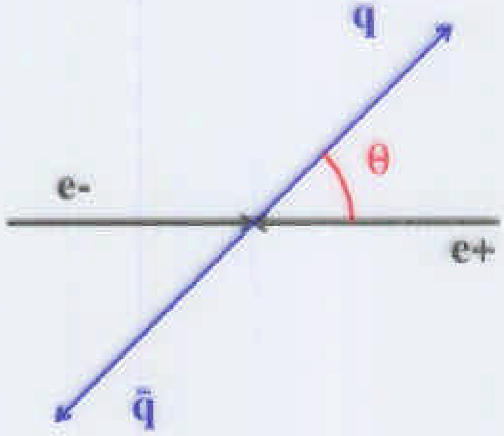
$R_c(\mathrm{SM})=0.25$

Asymmetry Measurements

After flavour tagging, need to determine the direction signed by the charge of the final state quark:

$$\frac{dN}{dx} = 1 + x^2 + \frac{8}{3} \cdot A_{FB} \cdot x$$

$$x = -Q \cdot \cos\theta$$



- Use "Jet charge" for lifetime tagged events; this technique has $\approx 30\%$ mistagging probability.

- Lepton charge in lepton tagging; unambigous charge ID compensates lower efficiency $\rightarrow$ similar sensitivity

- Event thrust axis taken as the quark direction (events have back-to-back jet topology)

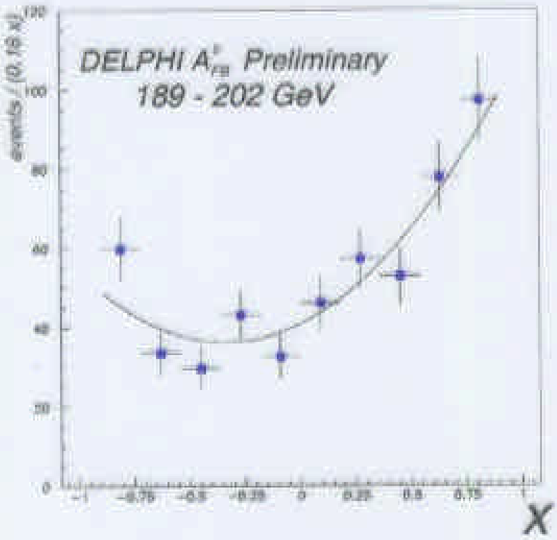
DELPHI and OPAL - A_{FB}^{b}

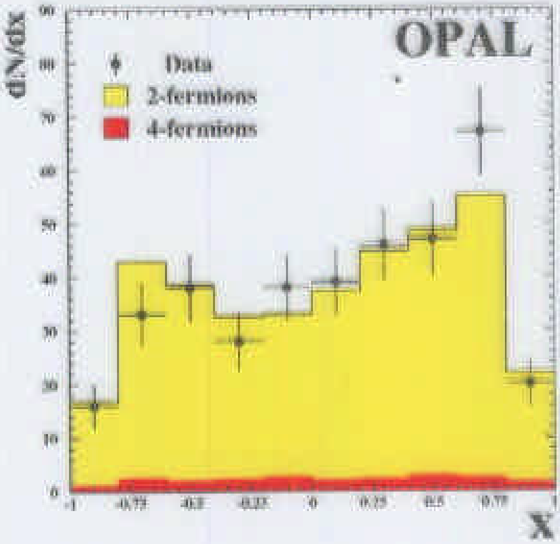
Use lifetime tagged events and divide the event in two hemispheres:

- Calculate charge flow Q_{FB}, probability P_b of correct quark charge ID $\approx$ 65-75%:

$$Q_{FB} = Q_F - Q_B, \quad Q_{F(B)} = \frac{\sum q_i |p_i|^k}{\sum |p_i|^k} \quad k = 0.4/0.6$$

- Measure observed asymmetry from fit to $x = -\text{sign}(Q_{FB}) \cdot \cos\theta_T$ distribution





$$A_{FB}^{b} = \frac{A_{obs} - \sum_{q=udsc} s_q(2P_q - 1)A_{FB}^{q} F_q}{(2P_b - 1)F_b}$$

Flavour fractions, charm/light quarks asymmetries and charge ID probabilities taken from MC. At 189 GeV:

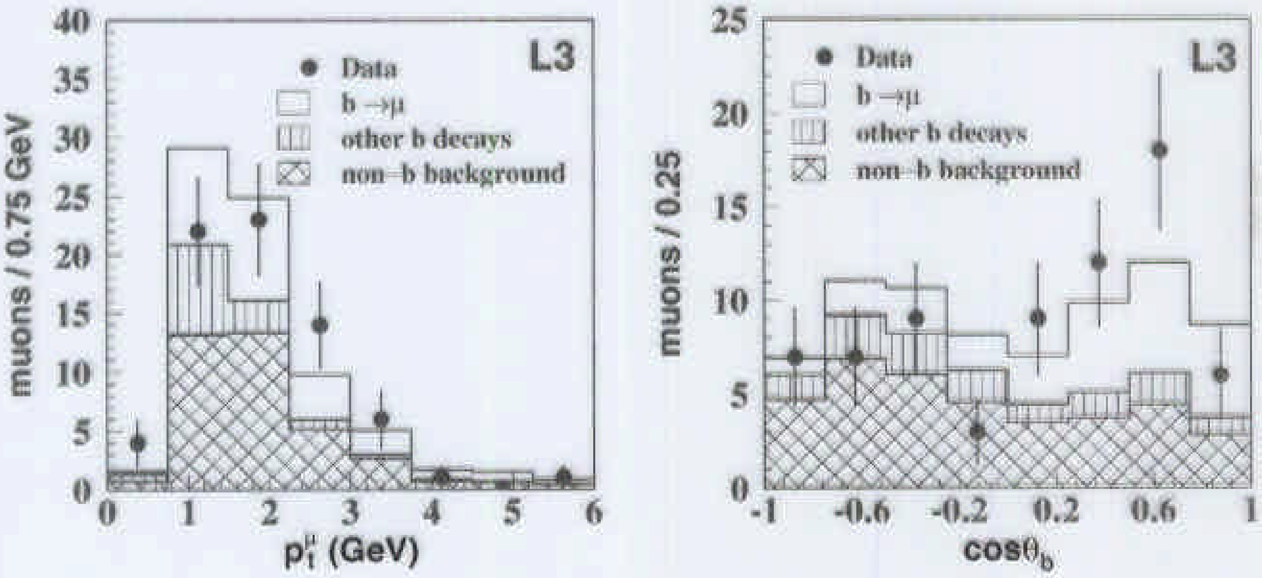
DELPHI $\quad 0.50^{+0.13}_{-0.14}(\text{stat}) \pm 0.05(\text{sys}) \quad \text{SM} = 0.58$

OPAL $\quad 1.22^{+0.28}_{-0.24}(\text{stat}) \pm 0.08(\text{sys})$

L3 - A_{FB}^{b}

b-tagging with high p, p_t electrons and muons:

- Efficiency $\approx$ 20% for direct b $\rightarrow$ l decay
- Purity $\approx$ 20-30% (charm and fake lepton contamination)
- "Perfect" quark charge identification



b asymmetry derived from a likelihood fit accounting for the different b semileptonic decays and background. At 189 GeV:

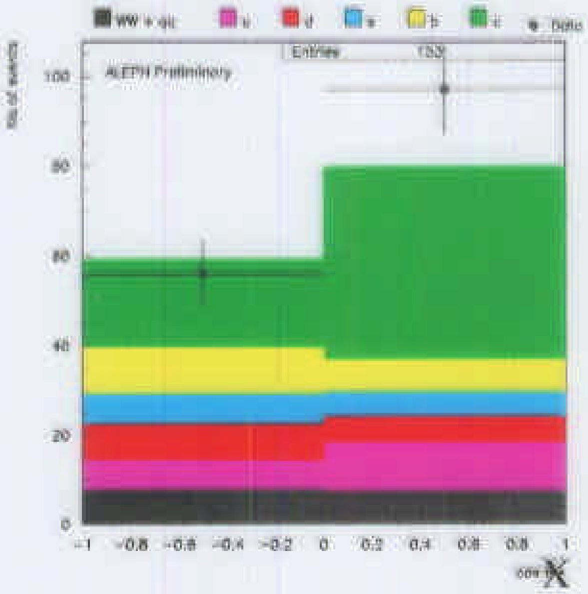
$$A_{FB}^{b} = 0.61 \pm 0.18(\text{stat}) \pm 0.09(\text{sys}) \quad \text{SM} = 0.58$$

ALEPH and OPAL-A_{FB}^{c}

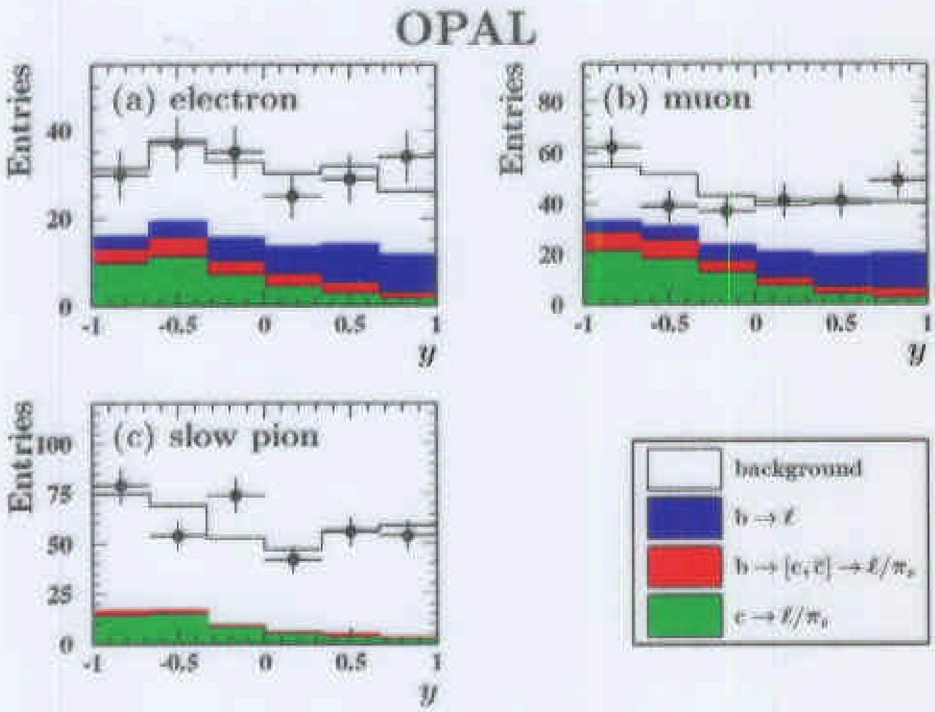
ALEPH at 183 GeV:

Same tagging as for R_c
Charge ID with NN based on:

- jet charge
- e, μ, K, π charge
- charge of leading particles



$$A_{FB}^{c}(183\ \mathrm{GeV}) = 0.95 \pm 0.27(\mathrm{stat})^{+0.11}_{-0.09}(\mathrm{sys}) \quad \mathrm{SM}=0.66$$



OPAL 130-189 GeV:

Use leptons and slow pions
NN to separate:

- $b \rightarrow l$,
- $b \rightarrow c \rightarrow l/\pi$
- $c \rightarrow l/\pi$

Measure both A_{FB}^{b}, A_{FB}^{c}

$$A_{FB}^{c}(183\ \mathrm{GeV}) = 0.56^{+0.27}_{-0.28}(\mathrm{stat}) \pm 0.11(\mathrm{sys})$$

Systematic Errors

Systematic errors mainly come from:

- Understanding of the detector resolution, which is studied using calibration data collected at the Z° peak (1%-3% on R_b)

- Uncertainties on b and c-decay physics modelling (1%-3% on R_b), which are totally correlated between experiments:
  - b,c fragmentation
  - b,c hadron fractions
  - b,c hadron lifetimes
  - b,c hadron decay multiplicity
  - b,c semileptonic BR's and decay model

  Their effect is estimated varying these inputs according to the prescriptions of the LEP HFWG

- Contamination from radiative $q\bar{q}$ and W-pair events (1%-2% on R_b)

All the measurements are still limited by statistics

LEP Averages (preliminary)

cms energy GeV	R_b	R_c	A_{FB}^b	A_{FB}^c
130-136	A D L O	- - - -	- D - O	- D - O
161-172	A D L O	- - - -	- D - O	- D - O
183	A D L O	A - - -	A - - O	A - - O
189	A D L O	A - - -	A D L O	- - - O
192-202	- D L -	- - - -	- D - -	- - - -
205.5	- D - -	- - - -	- D - -	- - - -

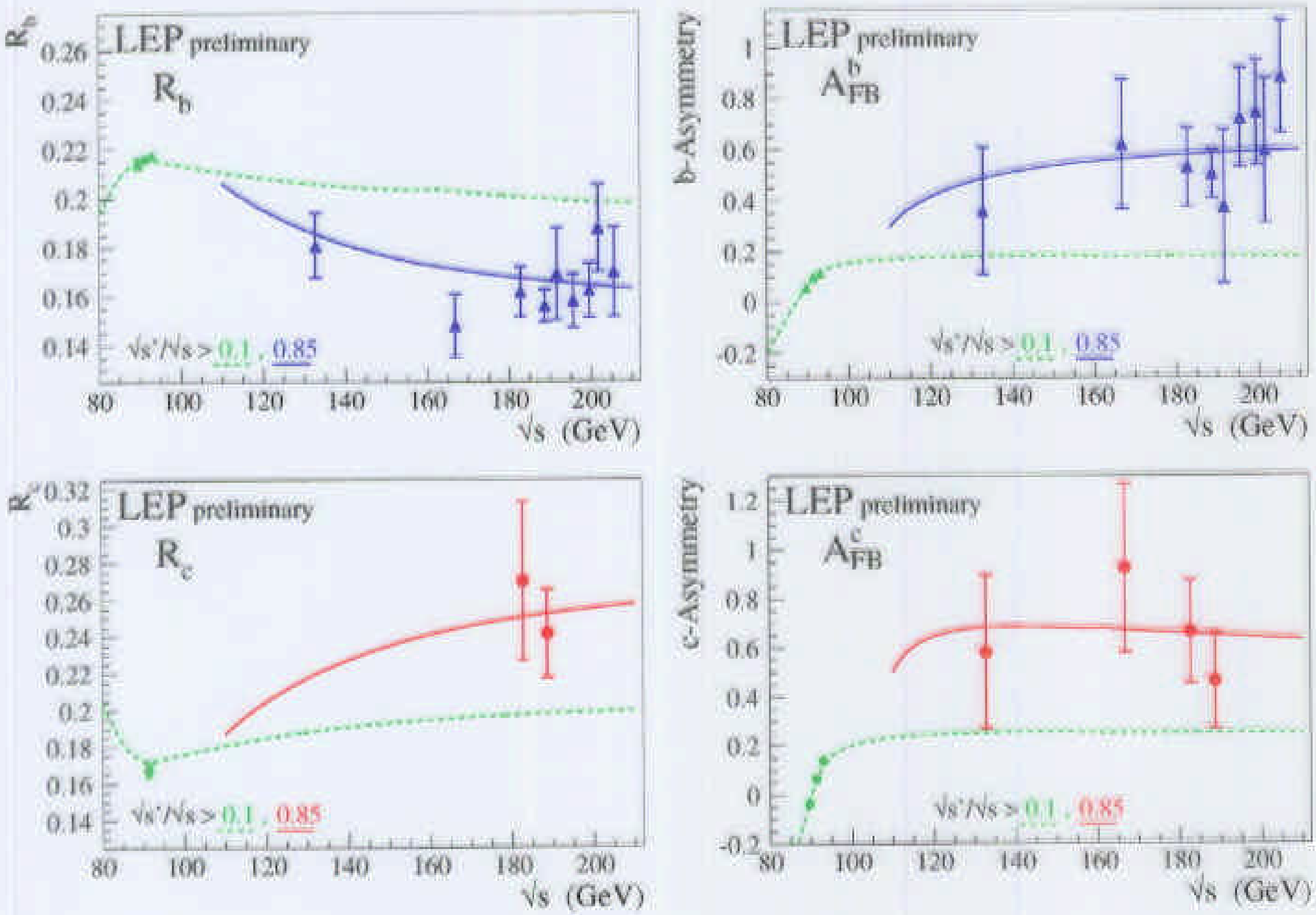
Averages performed on data taken from 130-206 GeV, either published or preliminary:

- Convert all measurement to a common signal definition (i.e. full angular acceptance)

- Correlated systematic errors among experiments and among measurements at different centre-of-mass energies in each experiment are taken into account

- The mutual dependence of the measurements (for example the dependence of the R_b measurement on the assumed value of R_c) are also taken into account

LEP Combined Results (preliminary)



Measurements are in agreement with the Standard Model predictions. Use combined results to:

- Constrain the Standard Model parameters above the Z° → S-matrix fit
- Set limits on New Physics → Contact interaction

S-Matrix fit

Use combined $R_{b,c}$, which are converted into cross sections, and $A_{FB}^{b,c}$ together with S-matrix results using LEP1+LEP2 data up to 172 GeV to constrain Standard Model parameters specific to b and c:

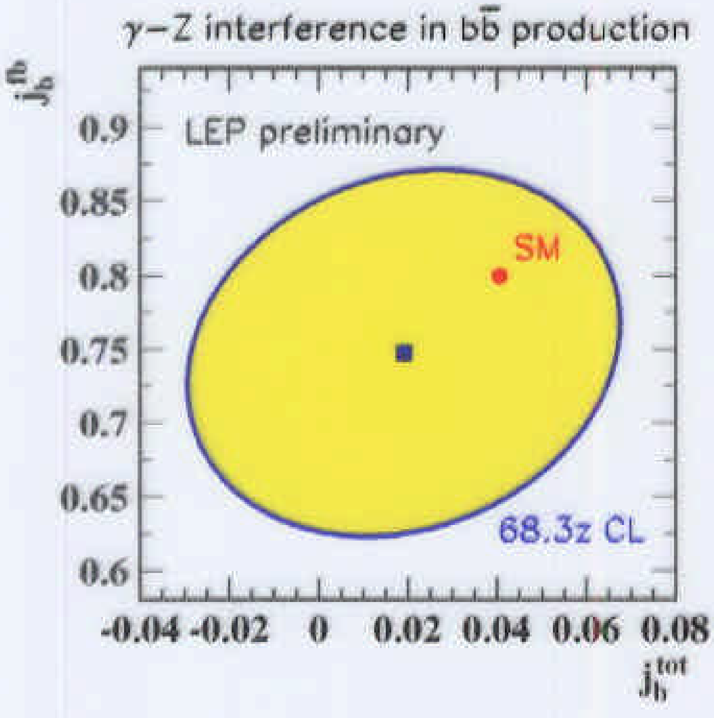
$$\sigma^{tot,fb}(s) \propto \frac{g^{tot,fb}}{s} + \frac{j^{tot,fb}(s - M_Z^2) + r^{tot,fb}s}{(s - M_Z^2)^2 + M_Z^2\Gamma_Z^2}$$

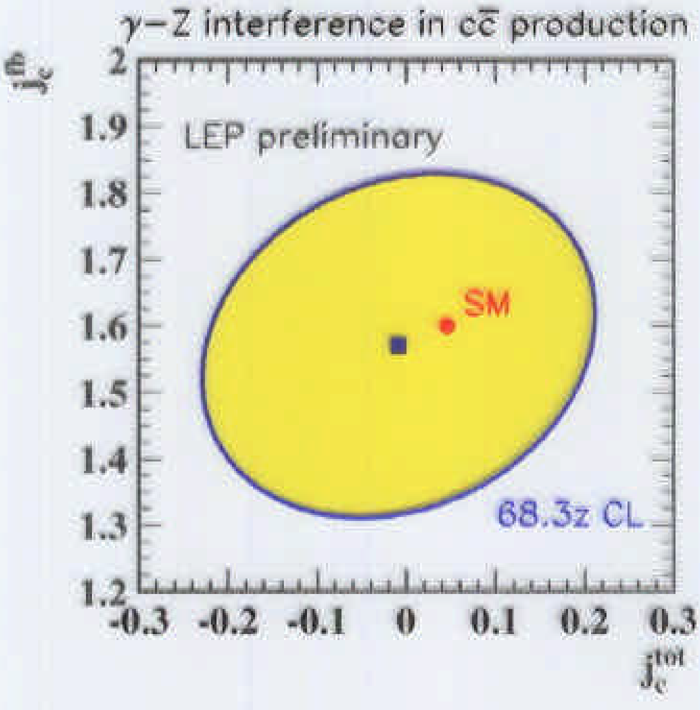
$$A_{FB}(s) \propto \frac{\sigma^{fb}}{\sigma^{tot}}$$

$g^{tot,fb} \rightarrow$ pure γ

$j^{tot,fb} \rightarrow$ $Z\gamma$ interference

$r^{tot,fb} \rightarrow$ pure Z

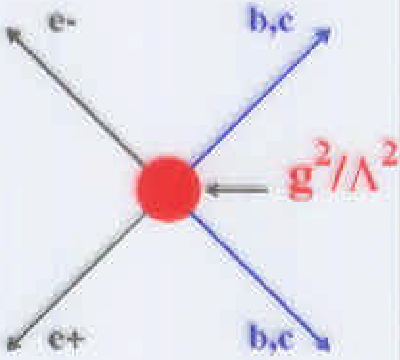




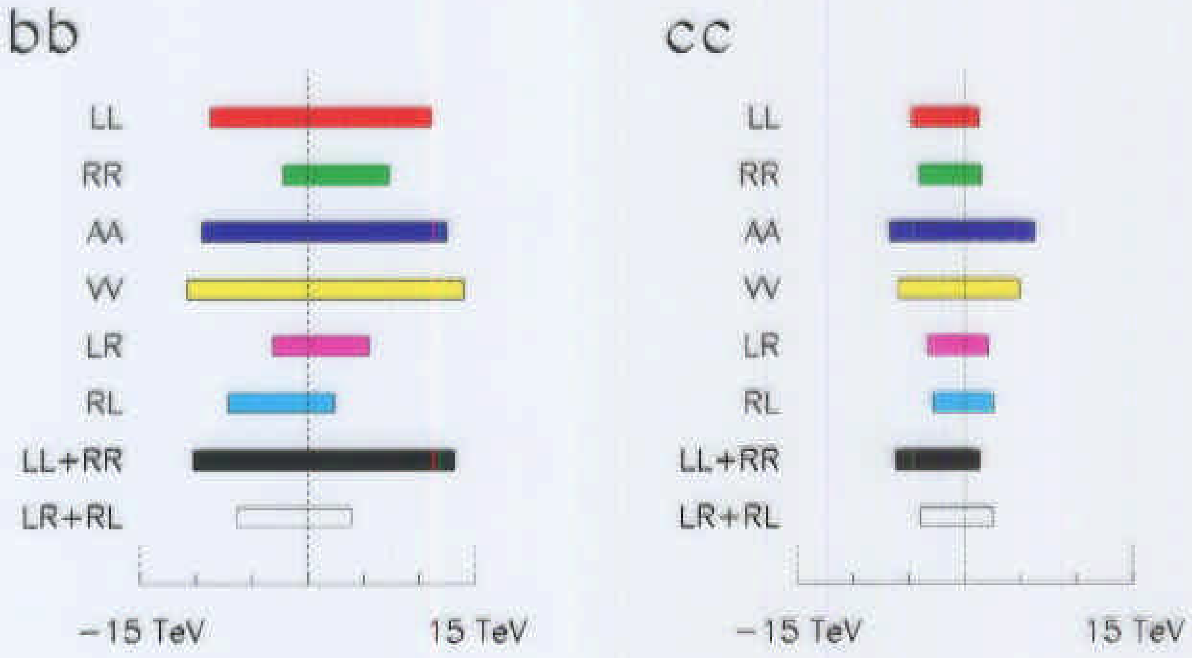
Measurement of the $Z\gamma$ interference

Limits on New Physics -Contact Interaction

Effective pointlike interaction characterized by an energy scale Λ.



Predicted effects on $b\bar{b}$ and $c\bar{c}$ cross sections and asymmetries depend on the helicity structure of the interaction $\rightarrow$ different limits on Λ:



Limits in the 2-14 TeV range

Conclusions

Heavy quark production measured at LEP2, in a wide range of centre-of mass energies, 130-206 GeV.
Measurements are consistent with the Standard Model.

- Measurement of the Standard Model parameters above the Z° resonance, particularly the $Z\gamma$ interference

- No evidence of anomalies $\rightarrow$ limits are derived on possible New Physics involving the heavy quark sector