R_b measurements at centre-of-mass-energy above the Z pole at LEP

On behalf of the LEP Collaborations

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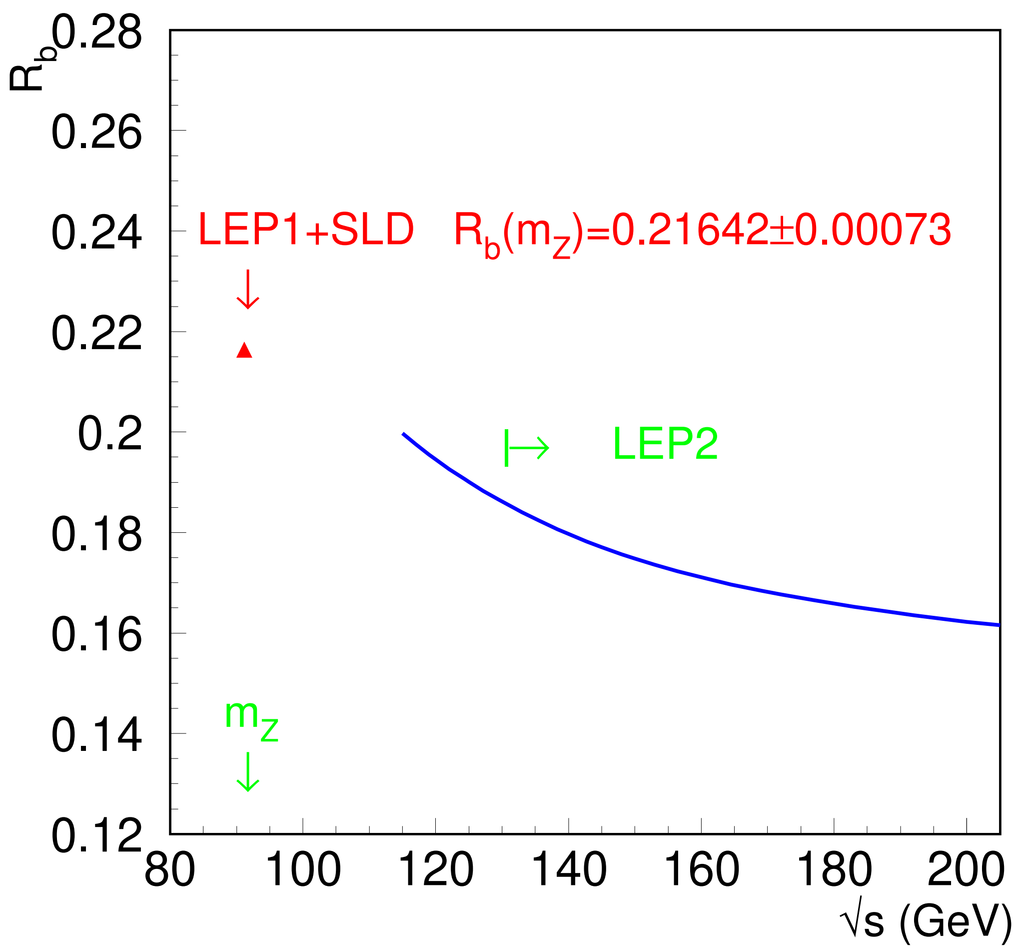
OUTLINE

- Definition of R_b
- b-tagging algorithms
- R_b measurement
- Combination of LEP R_b measurements
- Conclusions

DEFINITION

- Process studied ⇨ $e^+e^- \rightarrow Z/\gamma^* \rightarrow b\bar{b}$
- Definition of R_b ⇨ $R_b = \dfrac{\sigma(e^+e^- \rightarrow b\bar{b})}{\sigma(e^+e^- \rightarrow q\bar{q})}$



DATA ANALYZED

- Luminosity for each experiment:

Year	$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})
1995 & 1997	130	6
1995 & 1997	136	6
1996	161	10
1996	172	10
1997	182.7	55
1998	188.6	180
1999	191.6	28
1999	195.6	77
1999	199.6	83
1999	201.6	40

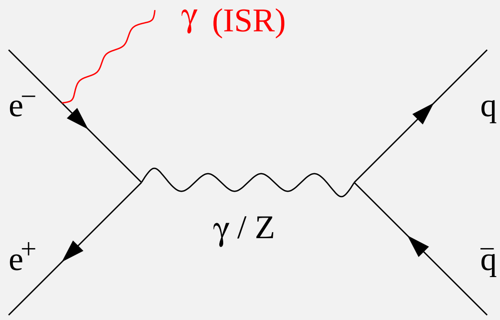
- Total integrated luminosity collected by each experiment from 1995 to 1999 above the Z pole:

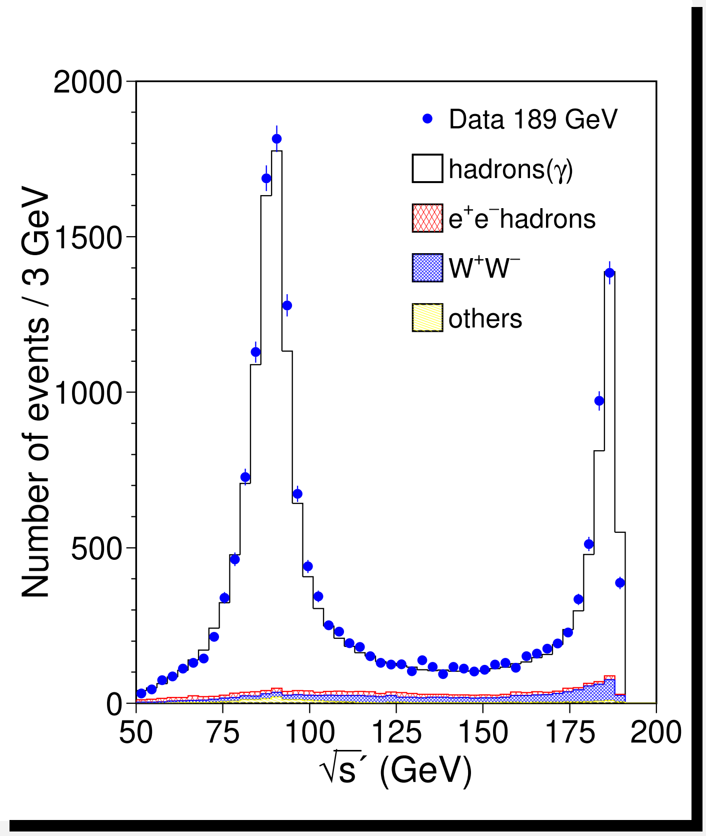
$$\boxed{\mathcal{L}_{\mathrm{tot}} \simeq 500 \ \mathrm{pb}^{-1}}$$

SIGNAL DEFINITION

☞ **Hadronic Selection:**

❶ ISR rejection:



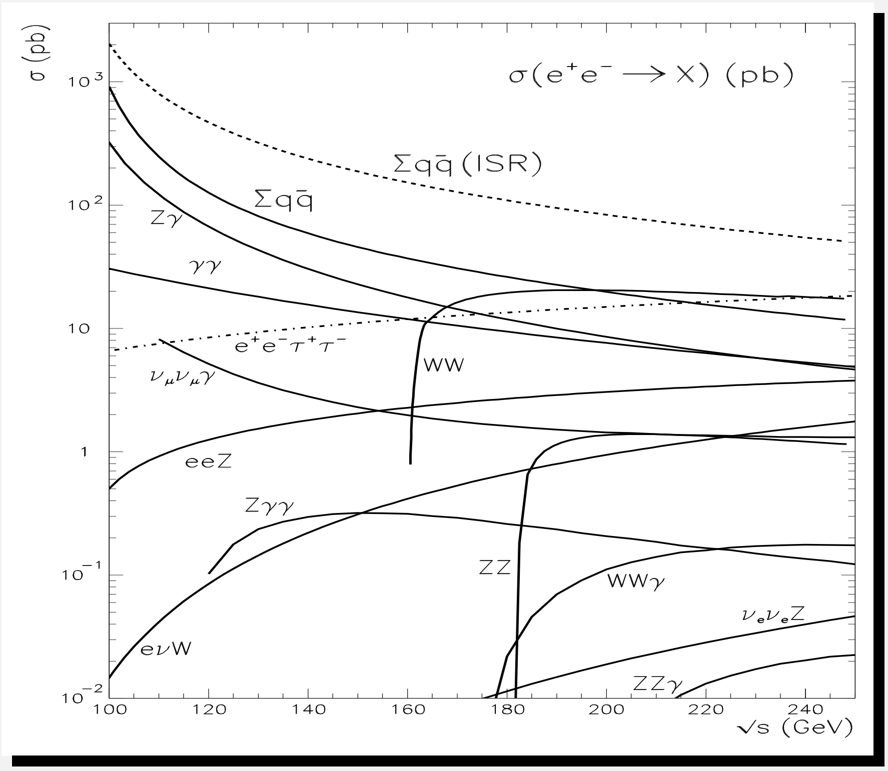


$$\sqrt{s'} > 0.85\sqrt{s}$$

SIGNAL DEFINITION

☞ Hadronic Selection:

❷ 4f rejection: $\begin{cases} e^+e^- \to W^+W^- & (\sqrt{s} > 161\ \text{GeV}) \\ e^+e^- \to ZZ & (\sqrt{s} > 183\ \text{GeV}) \end{cases}$



☞ $b\bar{b}$ selection: ➠ **b-TAGGING**

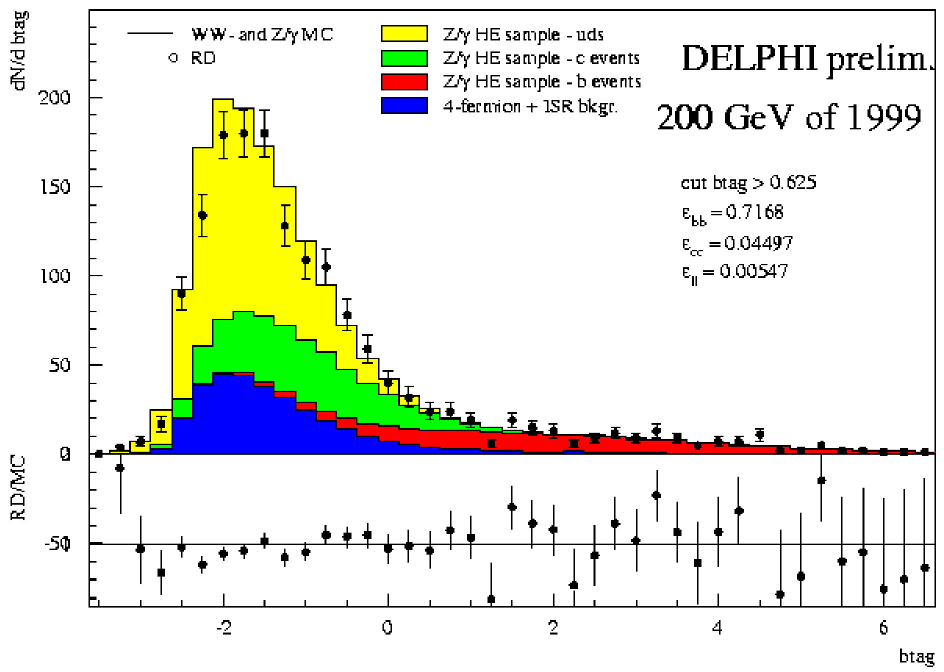
b-TAGGING

ALEPH

- 3-D impact parameter significance of tracks.

DELPHI

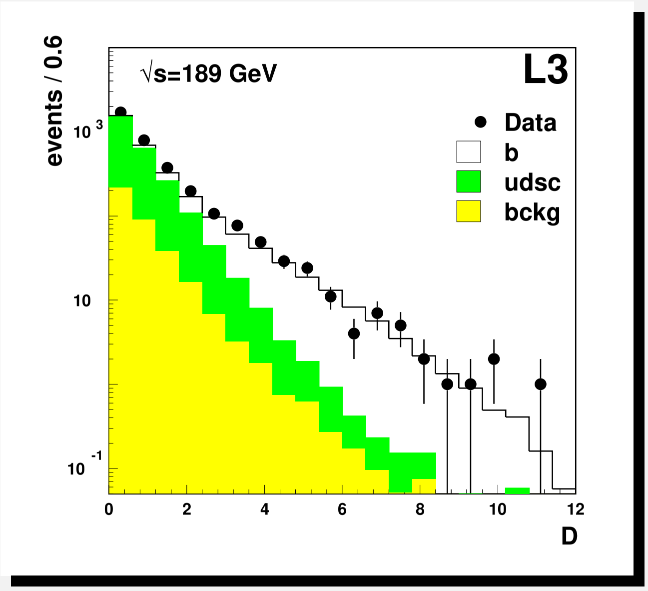
- 3-D impact parameter significance of tracks.
- Mass of the secondary vertex (if present).
- Rapidities of tracks from the secondary vertex or jet.



b-TAGGING

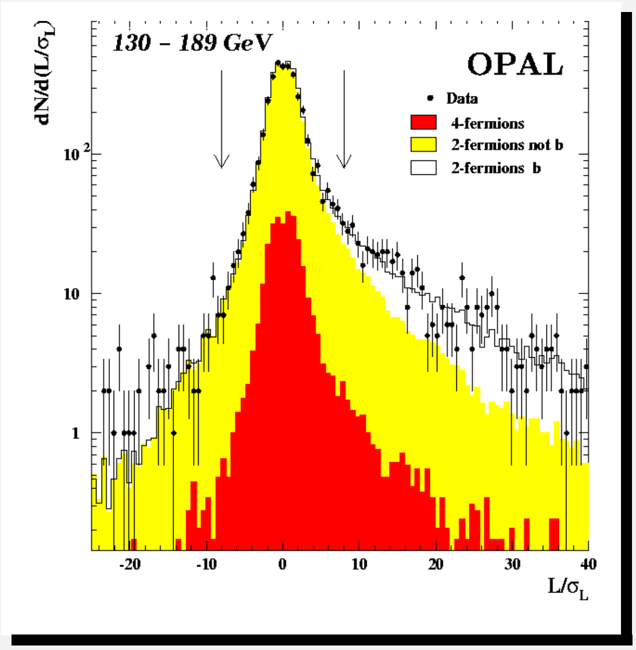
L3

➢ 3-D impact parameter significance of tracks.



OPAL

➢ Distance of secondary vertex from primary vertex.



$\mathrm{R_b}$ MEASUREMENT

- Limited statistics (189 GeV $\sim 3300\ q\bar{q}$) ⇨ It is not possible to use a Double Tagging technique.

- ## Tagging Techniques

  ☞ **Event tag** $\boxed{\mathbf{N^{q\bar{q}}_{tag} = N^{q\bar{q}}_{tot}[R_b\epsilon_b + R_c\epsilon_c + (1 - R_b - R_c)\epsilon_{uds}]}}$ $\left\{ \begin{array}{l} \textbf{ALEPH} \\ \textbf{DELPHI} \\ \textbf{L3} \end{array} \right.$

  - $\mathbf{N^{q\bar{q}}_{tot/tag}}$ ➠ Number of total and tagged events subtracting 4f and ISR total and tagged background ($\sim 10/15\%$, $\sim 10\%$)
  - $\epsilon_\mathbf{c}$, $\epsilon_\mathbf{uds}$ ➠ non $\mathbf{b\bar{b}}$ tagging efficencies estimated from MC.
  - $\epsilon_\mathbf{b}$ ➠ $\mathbf{b\bar{b}}$ tagging efficency estimated from $\mathbf{q\bar{q}}$ MC (**ALEPH & L3**) or by measurement at Z calibration data sets using event tag and assuming $\mathbf{R_b}$ at Z (**DELPHI**).

R_b MEASUREMENT

☞ **Folded tag** $\boxed{N - \bar{N} = 2N_{tot}[R_b\tilde{\epsilon}_b + R_c\tilde{\epsilon}_c + (1 - R_b - R_c)\tilde{\epsilon}_{uds}]}$ **OPAL**

- N_{tot} ➠ Number of total events subtracting 4f background
  N ➠ Number of tagged hemispheres subtracting 4f background
  $\bar{N}$ ➠ Number of anti-tagged hemispheres subtracting 4f background

- $\tilde{\epsilon}_q = \epsilon_q - \bar{\epsilon}_q$ where:
  ϵ_q ➠ $q\bar{q}$ tagging efficency estimated from MC
  $\bar{\epsilon}_q$ ➠ $q\bar{q}$ anti-tagging efficency estimated from MC.

- Correction for **ISR** contamination estimated from MC.

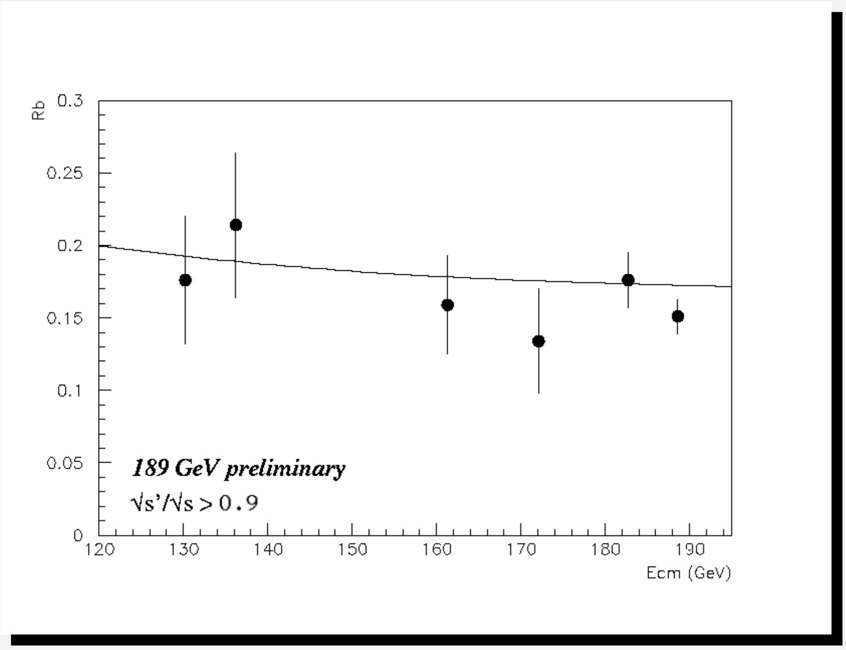
❑ $\boxed{R_c}$ calculated from **ZFITTER**.

❑ Energy points analyzed

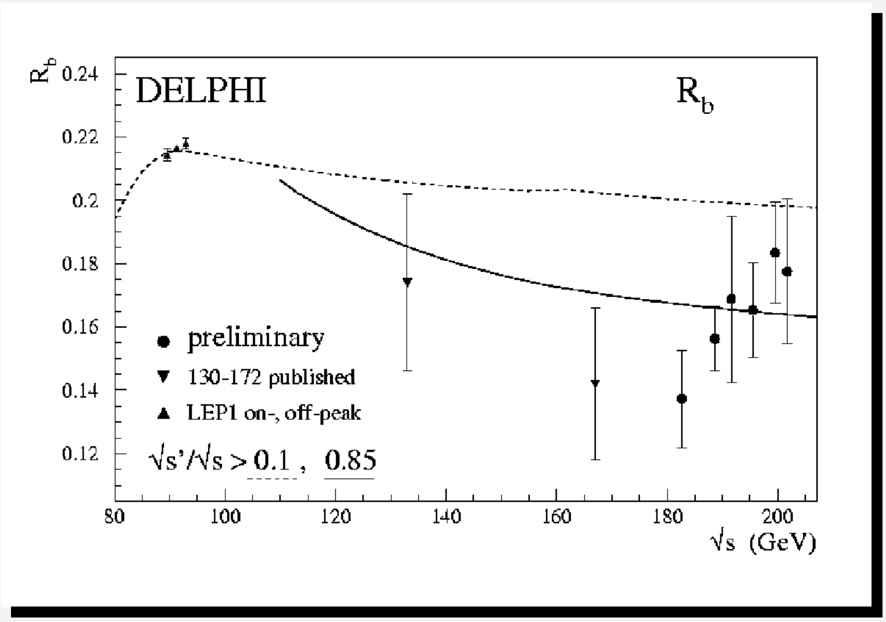
– **ALEPH** ➠ **130 ÷ 189 GeV** (189 Preliminary)
– **DELPHI** ➠ **130 ÷ 202 GeV** (183 ÷ 202 Preliminary)
– **L3** ➠ **130 ÷ 202 GeV** (192 ÷ 202 Preliminary)
– **OPAL** ➠ **130 ÷ 189 GeV**

R_b RESULTS

ALEPH $R_b(189\ \text{GeV}) = 0.151 \pm 0.011^{+0.002}_{-0.004}$



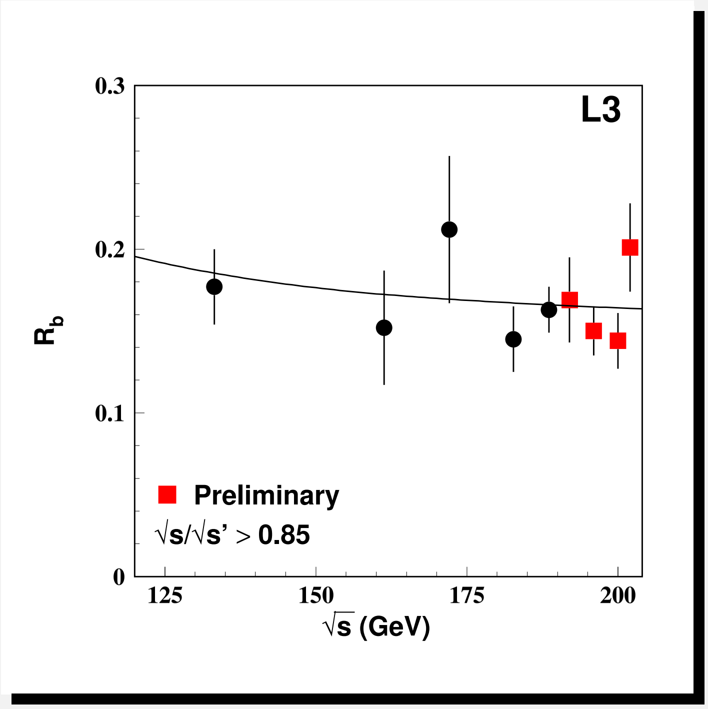
DELPHI $R_b(189\ \text{GeV}) = 0.156 \pm 0.010 \pm 0.004$



R_b RESULTS

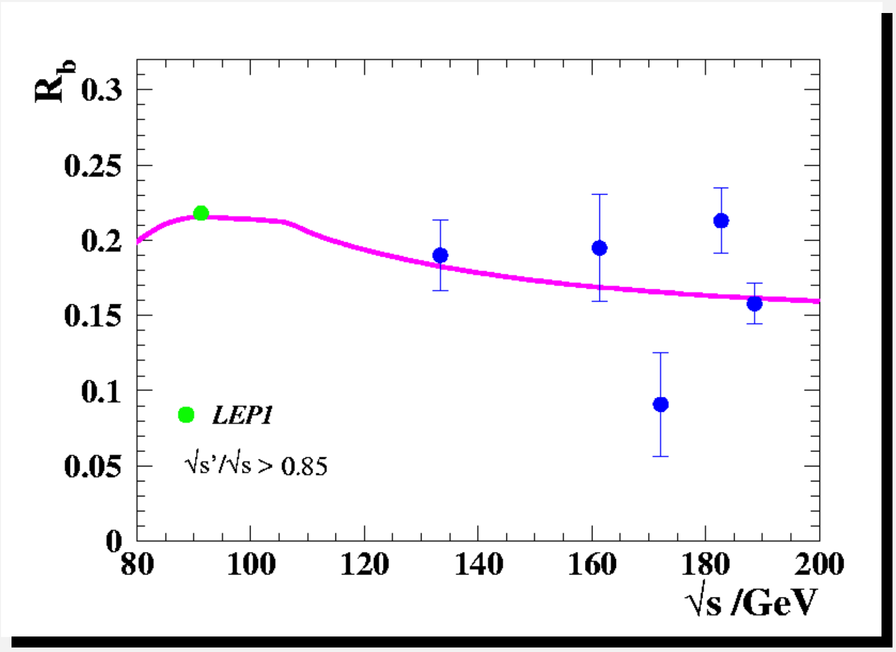
L3

$$R_b(189\ \mathrm{GeV}) = 0.163 \pm 0.013 \pm 0.005$$



OPAL

$$R_b(189\ \mathrm{GeV}) = 0.158 \pm 0.012 \pm 0.007$$



SYSTEMATIC UNCERTAINTIES

b, c, uds physics modelling

- Systematics on ϵ_b are studied by **L3** & **OPAL** varying at **Z** peak:
  - b fragmentation parameter
  - b decay multiplicity
  - b hadron composition
  - b lifetime

  ⇨ $\sim 1.5\%$

  ALEPH uses an inclusive method to estimate the ϵ_b **MC** uncertainties.

  DELPHI quotes ϵ_b error as statistical one on **Z** calibration data sets.
- Systematics on ϵ_c and ϵ_{uds} are evaluated by all **four experiments** studying **c** decay properties. ⇨ $\sim 0.5\%$

Detector resolution

- Variation of b-tagging parameters . ⇨ $\sim 1 \div 3\%$

R_c dependence

- $\Delta R_b = a(R_c)\Delta R_c$ $\quad a(R_c) \sim -0.06/-0.1$

COMBINATION OF MEASUREMENTS

☞ **Averaging procedure**

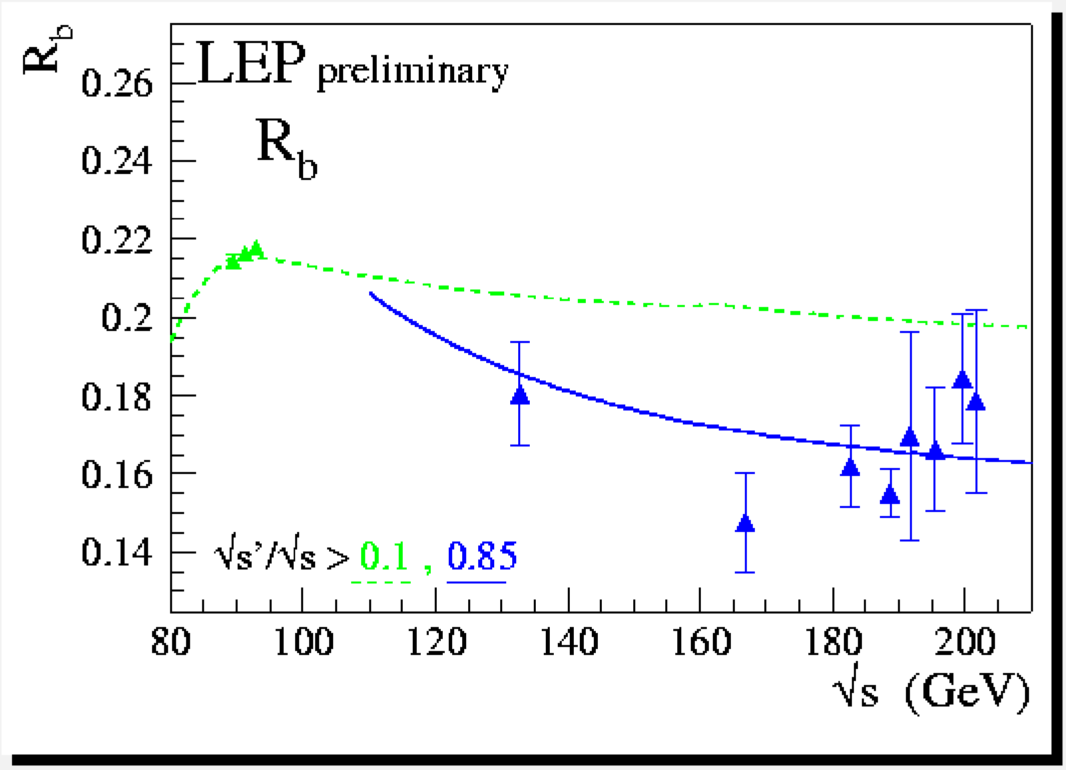
- Common signal definition
- Energy points:
  - 130 & 136 GeV ➪ 133 GeV
  - 161 & 172 GeV ➪ 167 GeV
  - 183 GeV
  - 189 GeV
  - 192 GeV **(DELPHI)**
  - 196 GeV **(DELPHI)**
  - 200 GeV **(DELPHI)**
  - 202 GeV **(DELPHI)**
- Input variables:
  - $\mathbf{R_b}$
  - $\mathbf{R_c}$
  - Forward-backward $\mathbf{b\bar{b}}$ asimmetries.
  - Forward-backward $\mathbf{c\bar{c}}$ asimmetries.

- Systematic errors
  - Uncorrelated (MC statistics, Detector effects, ...).
  - Correlated between energy points.
  - Correlated between energy points and experiments (b, c, uds physics modelling, ...).

COMBINATION OF MEASUREMENTS

☞ **RESULTS**

Energy (GeV)	R_b	R_b^{SM}
133	0.181 ± 0.013	0.1853
167	0.148 ± 0.013	0.1708
183	0.162 ± 0.010	0.1671
189	0.155 ± 0.006	0.1660
192	0.170 ± 0.027	0.1655
196	0.166 ± 0.016	0.1648
200	0.185 ± 0.017	0.1642
202	0.179 ± 0.023	0.1638



CONCLUSIONS

☞ ALEPH, DELPHI, L3 and OPAL have performed R_b measurements above the Z pole in an energy range between 130 and 202 GeV.

☞ Several b-tagging techniques based on relatively large lifetime of b hadron have been used to obtain high purity b samples.

☞ Combined LEP results still preliminary (work in progress).

✌ R_b values measured are in agreement with Standard Model predictions.