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Measurements of R_{b} at $\sqrt{s} \geq 192$ GeV

The L3 Collaboration

Abstract

The preliminary measurements of $R_{\mathrm{b}} = \sigma(\mathrm{e^+e^-} \to \mathrm{b\bar{b}})/\sigma(\mathrm{e^+e^-} \to \mathrm{q\bar{q}})$ at centre–of–mass energies of 192 GeV, 196 GeV, 200 GeV and 202 GeV are presented. High energy events, with an effective centre–of–mass energy $\sqrt{s'/s} > 0.85$, are selected. The single-tag method is used, exploiting the relatively large decay length of b-quarks.

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Introduction

The ratio R_{b},

$$R_{\mathrm{b}} = \frac{\sigma(\mathrm{e^+e^-} \to \mathrm{b\bar{b}})}{\sigma(\mathrm{e^+e^-} \to \mathrm{q\bar{q}})}$$

is relevant for precision tests of the Standard Model [1] and sensitive to new physics phenomena [2]. To measure R_{b} [3] hadronic events have to be selected and $\mathrm{b\bar{b}}$ final states have to be separated from other hadronic final states. Therefore a three-dimensional b-tagging algorithm is performed. This algorithm is based on the decay length of b-quarks which is significantly larger than for other quark flavours [4]. The b-tagging algorithm performs the calculation of the probability for reconstructed tracks not to originate from the primary vertex. High energy events are selected, with an effective centre–of–mass energy, $\sqrt{s'/s} > 0.85$. These measurements are performed according to the single-tag-method.

Event selection

The data are collected with the L3 detector at 192 GeV, 196 GeV, 200 GeV and 202 GeV [5] centre–of–mass energies. The centre–of–mass energies and the corresponding integrated luminosities are summarized in Table 1.
In the following the selection of hadronic events is described. The effective centre–of–mass energy is required to be $\sqrt{s'/s} > 0.85$ and the visible energy is required to be larger than 70% of $\sqrt{s}$ in order to reject radiative events. The number of clusters, $N_{Cluster}$, in the hadron calorimeter is required to be larger than 20. The transverse energy imbalance is required to be less than 0.3 in order to have well balanced events. The quantity y_{34} of the DURHAM algorithm [6] that determines the transition from three to four jets in an event, is required to be less then $y_{34} < 0.006$ to reduce non-$\mathrm{q\bar{q}}$ background. The absolute value of $\cos\Theta$, were Θ is the polar angle of the event thrust, is required to be less than 0.8 to have the jets within the SMD [7] and the barrel region of the TEC. This provides a reliable b-tagging performance due to excellent track reconstruction. The width of the broad jet, wbj, is the angular information of jet broadening and is required to be less then 0.6 to reduce the $\mathrm{W^+W^-}$ background. Electron energy is required to be less than 50 GeV in order to reduce background events with semileptonic decay channels. All quantities used for hadronic event selection are listed in Table 2.

Monte Carlo processes

All background processes that have been studied are listed in Table 3 with Monte Carlo event generators. The numbers of events for the different centre–of–mass energies for data and Monte Carlo are listed in Table 4. The contribution of non-$q\bar{q}$ background processes are listed in Table 5. The non-$\mathrm{q\bar{q}}$ background is under 5% for all centre–of–mass energies of which the contribution from W-pairs dominates. The background of remaining events with ISR is 8% to 9% for all investigated centre–of–mass energies. The increasing non-$\mathrm{q\bar{q}}$ background contribution is due to increasing cross section of the process $\mathrm{e^+e^-} \to \mathrm{W^+W^-}(\gamma)$ while the cross section of $\mathrm{e^+e^-} \to \mathrm{q\bar{q}}(\gamma)$ is decreasing with increasing centre–of–mass energies.

R_{b}-Measurement

After hadronic events are selected, the number of $\mathrm{b\bar{b}}$-events in the sample are determined using the three-dimensional b-tag algorithm. The three-dimensional b-tagging algorithm is based on a decay length tag [4]. Due to low statistics the single-tag-method is applied [3]. Hence the entire event is tagged to be a $\mathrm{b\bar{b}}$-event while using the double-tag-method the event is divided in two hemispheres and each hemisphere is tagged separately. For each reconstructed track the probabilitity, P_{Track} to originate from the primary vertex is calculated. The event probability P is obtained by combining all values P_{Track} for each event separately. One obtains a so-called discriminant variable D, $D = -\log_{10}P$. Events with high D value are most likely $\mathrm{b\bar{b}}$-events that originate from secondary decay vertices. A cut on D ($D = 2.6$) has been applied to the selected sample in order to obtain high purity (75%) and sufficient high tagging efficiency for b-quarks (more than 40%). Since the number of tagged background events have to be taken into account, R_{b} can easily be derived from the following formula;

$$R_{\mathrm{b}} \;=\; \frac{1}{\varepsilon_b - \varepsilon_{uds}} \left[\frac{N^t_{obs} - N^t_{bkg}}{N_{obs} - N_{bkg}} - \varepsilon_c R_{\mathrm{c}} - \varepsilon_{uds}(1 - R_{\mathrm{c}}) \right] \tag{1}$$

The tagging efficiencies ε_b, ε_c and ε_{uds} are derived from Monte Carlo for all different quark flavours and listed in Table 6. R_{c} is calculated by ZFITTER 6.21 [8] as Standard Model expectation for all centre–of–mass energies.

Statistical and Systematic Errors

Since the number of tagged events is a sub-sample of the number of selected events, the calculation of the statistical error is performed according to binomial error transition law. For the number of selected events, N_{sel}, out of a sample of known number N the statistical errror is given by

$$\Delta N_{sel} = \sqrt{N\varepsilon(1-\varepsilon)} \tag{2}$$

whereas ε is the selection efficiency. The statistical error for the selection efficiency taken from Monte Carlo is then calculated by

$$\Delta\varepsilon = \sqrt{\frac{\varepsilon(1-\varepsilon)}{N^{MC}}} \tag{3}$$

The systematic errors have been investigated by varying the corresponding cut-quantities within reasonable ranges. The systematic error on R_{b} resulting from finite Monte Carlo statistics for tagging efficiencies is obtained by varying the efficiencies corresponding to their statistical errors and to take the variation of R_{b} as systematic error. Systematic errors from quark modelling are obtained by using data taken on the Z-resonance and reweigthing the events according to errors of the modelling parameters like lifetime, branching fractions etc. Since these quantities are almost independent from the centre–of–mass energy the obtained errors are propagated to high centre–of–mass energies and summed in quadrature. The error contributions resulting from tracking effects are obtained by tuning the b-tag again. For this purpose the values for DCA shifts and multiple scattering effects are smeared by their errors and the tuning is done again for each quantity separately. R_{b} is anti-correlated with R_{c} and the dependence can be parametrised as

$$\Delta R_{\mathrm{b}} = a(R_{\mathrm{c}})(R_{\mathrm{c}} - {R_{\mathrm{c}}}^{SM}). \tag{4}$$

The values for $a(R_{\mathrm{c}})$ are listed in Table 7 together with the values of ${R_{\mathrm{c}}}^{SM}$. Table 8 gives an overview on the systematic uncertainties from all quark modelling parameters. The summary of all error contributions is listed in Table 9. Table 10 presents the preliminary results of the R_{b} measurement with L3 detector in 1999 for the high energy sample. The measured values of R_{b} are shown in figure 2 together with the measured points of the published analysis from 130 GeV to 189 GeV.

References

[1] S. L. Glashow, Nucl. Phys. **22** (1961) 579–588.

[2] L3 Collab., M. Acciarri *et al.*, L3 note 2543, (2000).

[3] L3 Collaboration M. Acciarri *et al.*, CERN-EP-2000-054, submitted to Phys. Lett. B (2000).

[4] L3 Collaboration M. Acciarri *et al.*, Phys. Lett. **B411** (1997) 373.

[5] J. A. Bakken *et al.*, NIM **A275**, (1989) 81;
S. Lanzano *et al.*, NIM **A289**, (1990) 335;
O. Adriani *et al.*, NIM **A302**, (1991) 53;
B. Adeva *et al.*, NIM **A323**, (1992) 109;
K. Deiters *et al.*, NIM **A323**, (1992) 162;
M. Chemarin *et al.*, NIM **A349**, (1994) 345;
M. Acciarri *et al.*, NIM **A351**, (1994) 300;
G. Basti *et al.*, NIM **A374**, (1996) 293;
A. Adam *et al.*, NIM **A383**, (1996) 342..

[6] S. Catani and Yu. L. Dokshitzer and M. Olsson and G. Turnock and B. R. Webber, Phys. Lett. **B269**, (1991) 432;
S. Bethke and Z. Kunszt and D. E. Soper and W. J. Stirling, Nucl. Phys. **B370**, (1992) 310.

[7] M. Acciarri *et al.*, Nucl. Instrum. Meth. **A351** (1994) 300–312.

[8] D. Bardin *et al.*, ZFITTER v.6.21: A semi-analytical program for fermion pair production in e+ e- annihilation, hep-ph/9908433, 1999.

[9] S. Jadach and B. F. L. Ward and Z. Was, The precision Monte Carlo event generator KK for two- fermion final states in e+ e- collisions, hep-ph/9912214, 1999.

[10] T. Sjøstrand, Comput. Phys. Commun. **82** (1994) 74–90.

[11] S. Jadach and B. F. L. Ward and Z. Was, Comput. Phys. Commun. **79** (1994) 503–522.

[12] R. Engel, Z. Phys. **C66**, (1995) 203;
R. Engel and J. Ranft, Phys. Rev. **D54**, (1996) 4244.

[13] M. Skrzypek and S. Jadach and W. Placzek and Z. Was, Comput. Phys. Commun. **94**, (1996) 216;
M. Skrzypek and S. Jadach and W. Placzek and Z. Was, Phys. Lett. **B372**, (1996) 289.

$\sqrt{s}$/ GeV	$\mathcal{L}_{int}$/pb^{-1}
191.6	29.72
195.5	83.69
199.5	82.72
201.7	37.13

Table 1: The centre–of–mass energies and integrated luminosities that have been investigated.

Quantity	Number
$\sqrt{s'/s}$	> 0.85
$E_{vis}/\sqrt{s}$	> 0.70
$N_{Cluster}$	> 20
N_{Track}	> 6
E_{trans}/E_{vis}	< 0.3
y_{34}	< 0.006
$\lvert\cos\Theta\rvert$	< 0.8
wbj	< 0.6
$E_{electron}$	< 50 GeV
$Acollinearity$	> 2.8

Table 2: Selection criteria for events with $\sqrt{s'/s} > 0.85$.

Background Process	MC Generator
$e^+e^- \to q\bar{q}(\gamma)$	KK2F [9]
$e^+e^- \to ZZ$	PYTHIA [10]
$e^+e^- \to Zee$	PYTHIA
$e^+e^- \to \tau^+\tau^-$	KORALZ [11]
hadronic two-photon collisions	PHOJET [12]
$e^+e^- \to We\nu$	EXCALIBUR
$e^+e^- \to W^+W^-(\gamma)$	KORALW [13]

Table 3: Background processes and corresponding Monte Carlo event generators.

$\sqrt{s}$/ GeV	data/expected in MC
192	391/397.8
196	1086/1061.0
200	833/883.2
202	446/437.7

Table 4: Numbers of high energy events selected from data and expected number of events in Monte Carlo.

Process	192 GeV	196 GeV	200 GeV	202 GeV
$e^+e^- \to ZZ(\gamma)$	1.44(8.8%)	4.14(8.8%)	3.73(9.3%)	1.88(9.3%)
$e^+e^- \to Zee(\gamma)$	0.41(2.5%)	1.52(3.2%)	1.20(3.0%)	0.66(3.3%)
$e^+e^- \to \tau^+\tau^-(\gamma)$	0.18(1.1%)	–	–	–
hadronic two-photon collisions	0.42(2.5%)	1.19(2.5%)	–	–
$e^+e^- \to We\nu$	0.50(3.0%)	1.44(3.1%)	1.25(3.1%)	0.65(3.2%)
$e^+e^- \to W^+W^-(\gamma)$	13.44(82.0%)	38.50(82.3%)	34.03(84.8%)	17.07(84.4%)
total	16.39	46.79	40.21	20.26

Table 5: Absolute(relative) background contribution for all centre–of–mass energies.

$\sqrt{s}$/ GeV	ε_b	ε_c	ε_{uds}
192	0.481 ± 0.010	0.0564 ± 0.004	0.0213 ± 0.002
196	0.484 ± 0.008	0.0475 ± 0.003	0.0217 ± 0.001
200	0.449 ± 0.008	0.0495 ± 0.003	0.0181 ± 0.001
202	0.460 ± 0.011	0.0459 ± 0.004	0.0204 ± 0.002

Table 6: Efficiencies for all studied centre–of–mass energies for b, c and light quark flavour.

$\sqrt{s}$/ GeV	$a(R_c)$	${R_c}^{SM}$
192	-0.0764	0.2536
196	-0.0558	0.2548
200	-0.0729	0.2560
202	-0.0580	0.2565

Table 7: Coefficients $a(R_c)$ for all centre–of–mass energies and the corresponding values for ${R_c}^{SM}$ calculated by ZFITTER 6.21 taking initial final state radiation interference and an angle cut ($\cos\Theta < 0.8$) into account.

Source	ΔR_{b}			
	192 GeV	196 GeV	200 GeV	202 GeV
b fragmentation parameter:				
$\langle x_E(b) \rangle$	0.0016	0.0014	0.0014	0.0020
b decay parameters:				
b lifetime τ_b	0.0004	0.0004	0.0004	0.0005
b decay multiplicity	0.0013	0.0011	0.0011	0.0016
Fractions in $c\bar{c}$-events:				
D^+	-0.0003	-0.0003	-0.0003	-0.0003
$\mathrm{D_s}$	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Λ_{c}	0.0001	0.0001	0.0001	0.0001
Gluon splitting in $c\bar{c}$-events:				
$g \to c\bar{c}$	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$g \to b\bar{b}$	< 0.0001	< 0.0001	< 0.0001	< 0.0001
c decay parameters:				
D^0 lifetime	< 0.0001	< 0.0001	< 0.0001	< 0.0001
D^+ lifetime	-0.0001	-0.0001	-0.0001	-0.0001
D^+ lifetime	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Λ_{c} lifetime	< 0.0001	< 0.0001	< 0.0001	< 0.0001
c decay multiplicity:				
$\mathrm{D}^+ \to 1$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D}^+ \to 5$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D}^0 \to 0$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D}^0 \to 4$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D}^0 \to 6$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D_s} \to 1$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D_s} \to 5$ prong	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$\mathrm{D_s} \to K^0_S$	-0.0001	-0.0001	-0.0001	-0.0001
c fragmentation parameter:				
$\langle x_E(c) \rangle$	-0.0002	-0.0002	-0.0002	-0.0002
Fractions in uds-events:				
$K^0 and \Lambda$	-0.0003	-0.0003	-0.0003	-0.0003
Gluon splitting in uds-events:				
$g \to c\bar{c}$	< 0.0001	< 0.0001	< 0.0001	< 0.0001
$g \to b\bar{b}$	< 0.0001	< 0.0001	< 0.0001	< 0.0001
total b, c physics modelling uncertainty	0.0021	0.0019	0.0020	0.0027

Table 8: Systematic error contribution from quark modelling. The negative sign indicates the anti-correlation between these quantities and R_{b}. The total modelling uncertainty is the quark-modelling error in Table 8.

Source	ΔR_{b}			
	192 GeV	196 GeV	200 GeV	202 GeV
Event selection	0.005	0.003	0.002	0.003
quark-modelling	0.002	0.002	0.002	0.003
finite MC stat.	0.005	0.003	0.003	0.006
Tracking effects.	0.003	0.003	0.003	0.003
Total	0.008	0.006	0.005	0.008

Table 9: Systematic error contribution from all investigated sources.

$\sqrt{s}$/ GeV	${R_{\mathrm{b}}}^{meas.}$	${R_{\mathrm{b}}}^{SM}$
192	$0.169 \pm 0.025 \pm 0.008$	0.1647
196	$0.150 \pm 0.014 \pm 0.006$	0.1640
200	$0.144 \pm 0.014 \pm 0.005$	0.1634
202	$0.201 \pm 0.026 \pm 0.008$	0.1630

Table 10: Preliminary results of R_{b} measurements for selected high energy events. In comparison the Standard Model expectation for ${R_{\mathrm{b}}}^{SM}$ calculated with ZFITTER 6.21 taking initial final state radiation interference and an angular cut ($\cos\Theta < 0.8$) into account. Statistical and systematic errors are given.

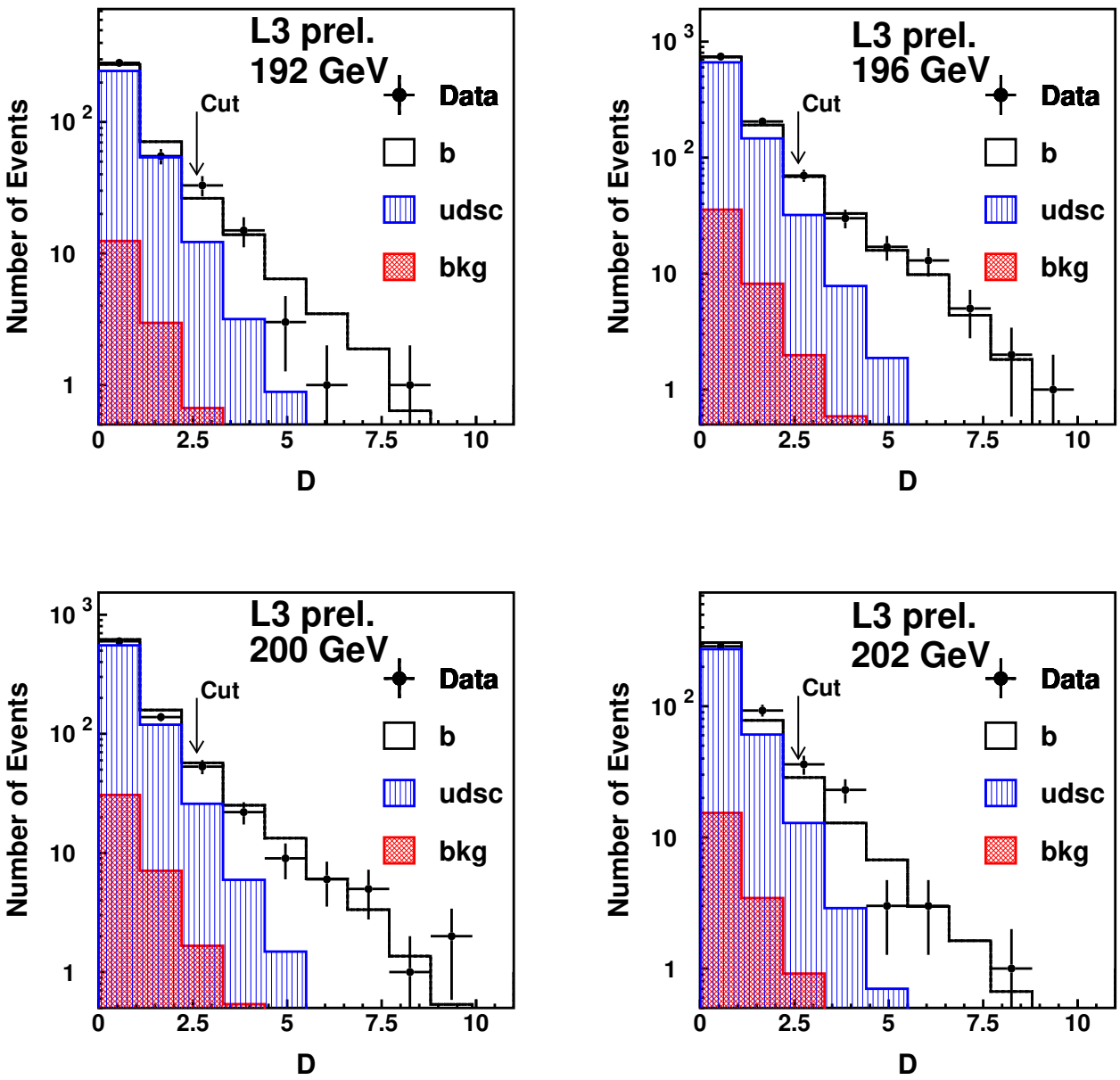

Figure 1: Discriminant distributions for all four centre–of–mass energies. The black dots are the data, the open histograms are all Monte Carlo generated events and the hatched histograms are the light quark and the non-$q\bar{q}$ background contributions.

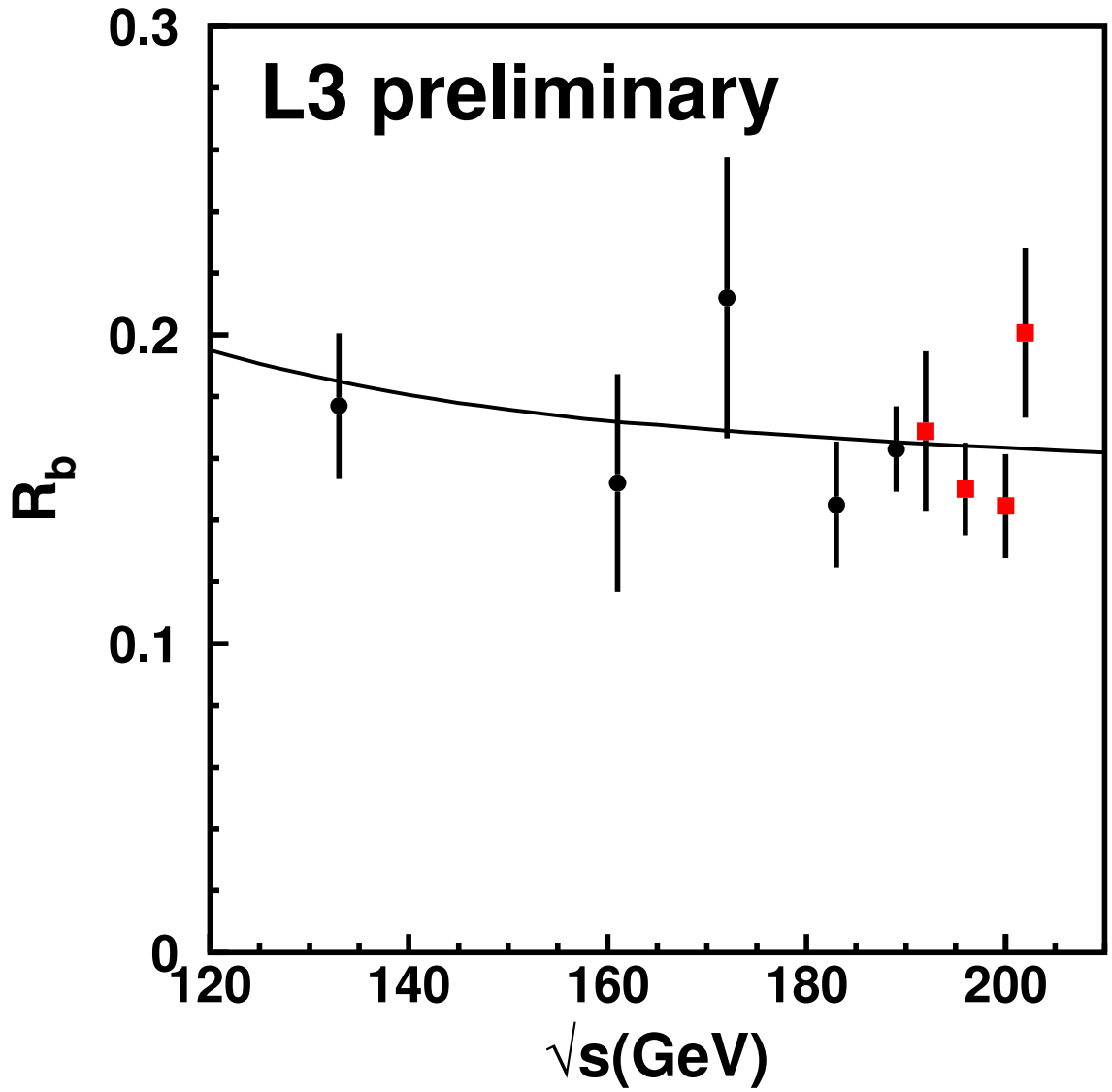

Figure 2: The R_b measurements in comparison to SM expectation. The black dots represent the published measurements from 130 GeV to 189 GeV [3]. The squares represent the results of this analysis.