EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

B^* **Production in Z Decays at LEP**

The L3 Collaboration

Abstract

We present an improved measurement of B^* production in Z decays using the L3 detector. The analysis is based on 1.6 million Z decays collected in 1991, 1992 and 1993. A b enriched sample is obtained by a discriminator method which exploits event shape and lifetime information. The selection of B^* mesons is performed by identifying the photon emitted in the decay $\mathrm{B}^* \to \gamma\mathrm{B}$. The inclusive production ratio of B^* mesons relative to B mesons is determined from a fit to the photon energy spectrum in the B rest frame to be

$$\mathrm{N_{B^*}}/(\mathrm{N_{B^*}} + \mathrm{N_B}) = \mathbf{0.74 \pm 0.04 \pm 0.06.}$$

The first error is statistical and the second is systematic (preliminary result).

(Submitted to EPS and Lepton-Photon Conference 1995)

Introduction

Observation of the B^* meson was first reported by CUSB [2] and CLEO [3] in e^+e^- collisions at center-of-mass energies near the $\Upsilon(4S)$ resonance. Both experiments observed an excess of photons around 46 MeV and interpreted this as coming from the reaction $e^+e^- \rightarrow BB^*$, where $B^* \rightarrow \gamma B$. The mass splittings have been determined to be 46.0 ± 0.6 MeV [4] for B_d, B_u and 47.0 ± 2.6 MeV [2] for B_s. B^* production has also been measured in Z decays using either calorimetric [5] or converted photons [6,7]. Hard fragmentation of the b quark in Z decays yields b hadrons with high momenta and hence photons produced in the decay $B^* \rightarrow \gamma B$ are boosted to energies up to 800 MeV.

The inclusive[1)] production ratio of B^* mesons relative to B mesons $V/(V+P)$ was found to be consistent with a value of 0.75 [5–7]. This value is theoretically calculated based on spin counting or on Heavy Quark Effective Theory [8], both assuming infinitely heavy b quarks. Corrections to this limit due to the finite b quark mass are expected be small, and could be tested only with high precision measurements.

Here we present an improved measurement of B^* production using the same technique as described in reference [5] with the exception of a different b tagging method. The latter enables to reduce the statistical uncertainty by a factor of two compared to our previous publication.

B* Meson Selection

An inclusive selection of B^* mesons was performed by identifying the photon emitted in the decay $B^* \rightarrow \gamma B$. The B^* decay photons stand out as a peak above the background in the energy spectrum after a Lorentz transformation to the B meson rest frame. The B meson decay products were not explicitly reconstructed in this analysis. No distinction is made therefore between B_u^*, B_d^* and B_s^* since the mass splittings and production and decay kinematics for each of these excited meson states are approximately the same.

The analysis presented here is based on 1.6 million hadronic Z decays collected in the years 1991, 1992 and 1993. These events satisfied both the online trigger and offline hadronic event selection criteria [9] with an efficiency of better than 99% and negligible contamination.

The b tagging algorithm uses event shape as well as lifetime information. The first method exploits the large b quark mass and the hard b fragmentation. Various event shape variables were calculated from calorimtric information only and fed into a neural network [10].

The second method exploits the long b lifetime, which leads to large impact parameters with respect to the primary vertex (DCA) for decay tracks arising from b hadrons. A discriminator variable, normalized to the number of tracks per event, was calculated by comparing the DCA distributions from well reconstucted tracks of the event with the expected distributions for tracks coming from the primary vertex [11]. Both methods were finally combined in a single discriminator variable T_b (figure 1) and a value of T_b greater than 0.6 was chosen.

The momentum of each B candidate is then approximated in the following manner:

- The direction of the B momentum was taken as the jet direction.
- The magnitude of the B momentum was not estimated on an event by event basis, but was fixed to a common value $p_0 = 37$ GeV. This method exploits the hard fragmentation of b quarks, which has been shown [12] to produce a sharply peaked momentum distribution.

Additional kinematic constraints were applied to the jets to reduce background and to improve the B momentum estimate: each jet was required to have an energy of at least 20 GeV and to be reconstructed from no more than 13 calorimetric clusters. A total of 141 595 jets satisfied these selection criteria.

The b purity of the selected event sample was estimated to be 57%, with 9% of these events fragmenting to b baryons and the rest to B mesons.

1) Note that here and throughout the paper B^* refers to the b-flavored *mesons* as a mixture of B_u^*, B_d^* and B_s^*.

Photon candidates were selected from reconstructed clusters located in the central BGO calorimeter ($|\cos\theta| < 0.69$) and in the same hemisphere of the event as the B meson. Each cluster was required to have a lateral shower shape consistent with an electromagnetic energy deposition. The cluster energy was determined from a matrix of nine crystals with the most energetic crystal being at the center. Each cluster was required to have a total energy of at least 100 MeV.

Background from non-electromagnetic processes was reduced and the energy resolution for photons was improved by requiring that the central crystal contain at least 50% and not more than 80% of the total energy of the cluster. Minimum ionizing particles tend to deposit a larger fraction of the energy in the central crystal and hadronic showers tend to be distributed more evenly over all nine crystals. Charged particle background was further reduced by requiring that there be no TEC tracks matching within a 60 mrad angle of the cluster at the radius of shower maximum. An isolation of 100 mrad in opening angle was required between the cluster and the selected muon.

The energy of each photon candidate in the approximate B rest frame was determined by performing the Lorentz transformation: $E_{\mathrm{rest}} = E_{\mathrm{lab}}\gamma(1-\beta\cos\alpha)$. Here, α is the angle between the photon direction and the B direction and γ and β are defined in terms of the approximate B meson momentum: $\gamma \equiv \sqrt{(p_0^2 + M_{\mathrm{B}}^2)/M_{\mathrm{B}}^2}$ and $\beta \equiv \sqrt{(\gamma^2-1)/\gamma^2}$. Since $M_{\mathrm{B}^*} - M_{\mathrm{B}} \ll M_{\mathrm{B}}$, the recoil of the B is negligible and E_{rest} is a good approximation of the mass splitting.

Results

A maximum likelihood fit was performed to the data rest frame photon spectrum allowing both signal and background parameters to float freely.

A bifurcated Gaussian was used to describe the signal region. This four-parameter function has the form

$$f(x) = \frac{2A}{(\sigma_1+\sigma_2)\sqrt{2\pi}} \times \begin{cases} e^{-(x-x_0)/2\sigma_1^2} & \text{for } x < x_0, \\ e^{-(x-x_0)/2\sigma_2^2} & \text{for } x \geq x_0. \end{cases}$$

where A is the total area, x_0 is the peak position, σ_1 is the width of the function below the peak and σ_2 is the width of the function above the peak.

The background was parametrized by performing a logarithmic transformation of the energy spectrum and then applying a third order Chebyshev polynomial expansion. This method, described in Reference 15, was chosen for its suitability to fit a distribution close to threshold.

The fit to the data spectrum (figure 2) yields a signal with a peak position at $\mathrm{E}_\gamma = 46.8 \pm 1.2\,(\mathrm{stat})$ MeV. The number of B^* photons determined from the signal is

$$\mathrm{N}_{\mathrm{B}^*} = 5935 \pm 335\,(\mathrm{stat}).$$

The production rate was determined by comparing the number of B^* photons measured above with the number remaining in the Monte Carlo sample [13, 14] after applying the same selection. The Monte Carlo was normalized to the number of selected jets in the data. This procedure implicitly accounts for both the photon detection efficiency and the b purity.

The production ratio of B^* mesons to B mesons assuming a b-baryon fraction of $f_{\mathrm{baryon}} = 0.094$ is

$$\mathrm{N}_{\mathrm{B}^*}/(\mathrm{N}_{\mathrm{B}^*} + \mathrm{N}_{\mathrm{B}}) = 0.74 \pm 0.04\,(\mathrm{stat}).$$

Contributions to the systematic uncertainty of the B^* production measurement are presented in Table 1. The fraction of b quarks fragmenting to b baryons was varied between 0.07 and 0.13. The discriminator output T_b was varied between 0.6 and 0.8 to estimate the uncertainty in the b hadron purity.

The effect of the b hadron selection on the fit result was further studied by varying the kinematic constraints on the jet, including energy and constituent multiplicity.

Source of Systematic Error	Error on $N_{B^*}/(N_{B^*}+N_B)$
b baryon fraction	0.02
b purity	0.03
b hadron selection	0.02
b fragmentation estimate	0.02
photon selection	0.04
Total	0.06

Table 1: *Systematic errors in the* $N_{B^*}/(N_{B^*}+N_B)$ *measurement.*

Uncertainty in the B^* production ratio due to variations in the photon selection was estimated by systematically varying cut values while following the complete analysis chain for each selection combination. The B^* photon efficiency was determined from this procedure to vary by no more than 5%.

An additional study of the dependence of B^* photon efficiency on the selection was performed by measuring $\pi^0 \to \gamma\gamma$ signals in invariant mass spectra reconstructed from photon pairs in the selected events. One of the photons in each pair was required to satisfy the B^* photon cuts. The uncertainty of the B^* photon efficiency was checked by varying these cuts and comparing the π^0 rates for data and Monte Carlo.

The final systematic error was determined by adding in quadrature each of the individual uncertainties.

Conclusions

The relative production rate of B^* mesons to B mesons has been measured in $Z \to b\bar{b}$ decays at LEP. A b enriched sample of 141 595 jets was selected by performing a combined event shape and lifetime tag on 1.6 million hadronic Z decays. The production ratio, determined from a maximum likelihood fit to the photon energy in the B rest frame, is

$$N_{B^*}/(N_{B^*}+N_B) = 0.74 \pm 0.04\,(\mathrm{stat}) \pm 0.06\,(\mathrm{syst}).$$

This ratio is an average measurement of $V/(V+P)$ for a mixture of the states B_d, B_u and B_s.

Acknowledgments

We wish to express our gratitude to the CERN accelerator divisions for the excellent performance of the LEP machine. We acknowledge the contributions of all the engineers and technicians who have participated in the construction and maintenance of this experiment.

References

[1] CUSB Collaboration J. Lee-Franzini *et al.*, Phys. Rev. Lett. **65** (1990) 2947;
K. Han *et al.*, Phys. Rev. Lett. **55** (1985) 36.

[2] CUSB Collaboration J. Lee-Franzini *et al.*, Phys. Rev. Lett. **65** (1990) 2947;
K. Han *et al.*, Phys. Rev. Lett. **55** (1985) 36.

[3] CLEO Collaboration D.S. Akerib *et al.*, Phys. Rev. Lett. **67** (1991) 1692.

[4] Particle Data Group, Phys. Rev. **D45** (1992).

[5] L3 Collaboration M. Acciari *et al.*, Phys. Lett. **B 345** (1995) 589.

[6] DELPHI Collaboration P. Abreu *et al.*, CERN-PPE/95-53.

[7] ALEPH Collaboration S.Schael, Proceedings of the XXX. Rencontres de Moriond, QCD and High Energy Hadronic Interactions, Les Arcs, March 19-26, 1995.

[8] A. Falk and M. Peskin, Phys. Rev. **D49** (1994) 3320.

[9] L3 Collaboration, B. Adeva *et al.*, Z. Phys. **C51** (1991) 179.

[10] L3 Collaboration O. Adriani *et al.*, Phys. Lett. **B 307** (1993) 237.

[11] V. Monaco *B tagging by a DCA based algorithm* L3-Note 1461.

[12] L3 Collaboration, B. Adeva *et al.*, Phys. Lett. **B261** (1991) 177.

[13] T. Sjöstrand, Comp. Phys. Comm. **39** (1986) 347;
T. Sjöstrand and M. Bengtsson, Comp. Phys. Comm. **43** (1987) 367.

[14] The L3 detector simulation program is based on the GEANT program:
R. Brun *et al.*, "GEANT 3", CERN report **DD/EE/84-1** (1984) (Revised), September 1987.
Hadronic interactions in the detector were modelled with GHEISHA:
H. Fesefeldt, RWTH Aachen report **PITHA 85/02** (1985).
Events were corrected for the TEC, BGO and muon chamber inefficiencies obtained from the data.

[15] Numerical Approximations to Functions and Data,
Chapter 5: Curve Fitting by Polynomials in One Variable,
J.G. Hayes, University of London, The Athlone Press (1970).

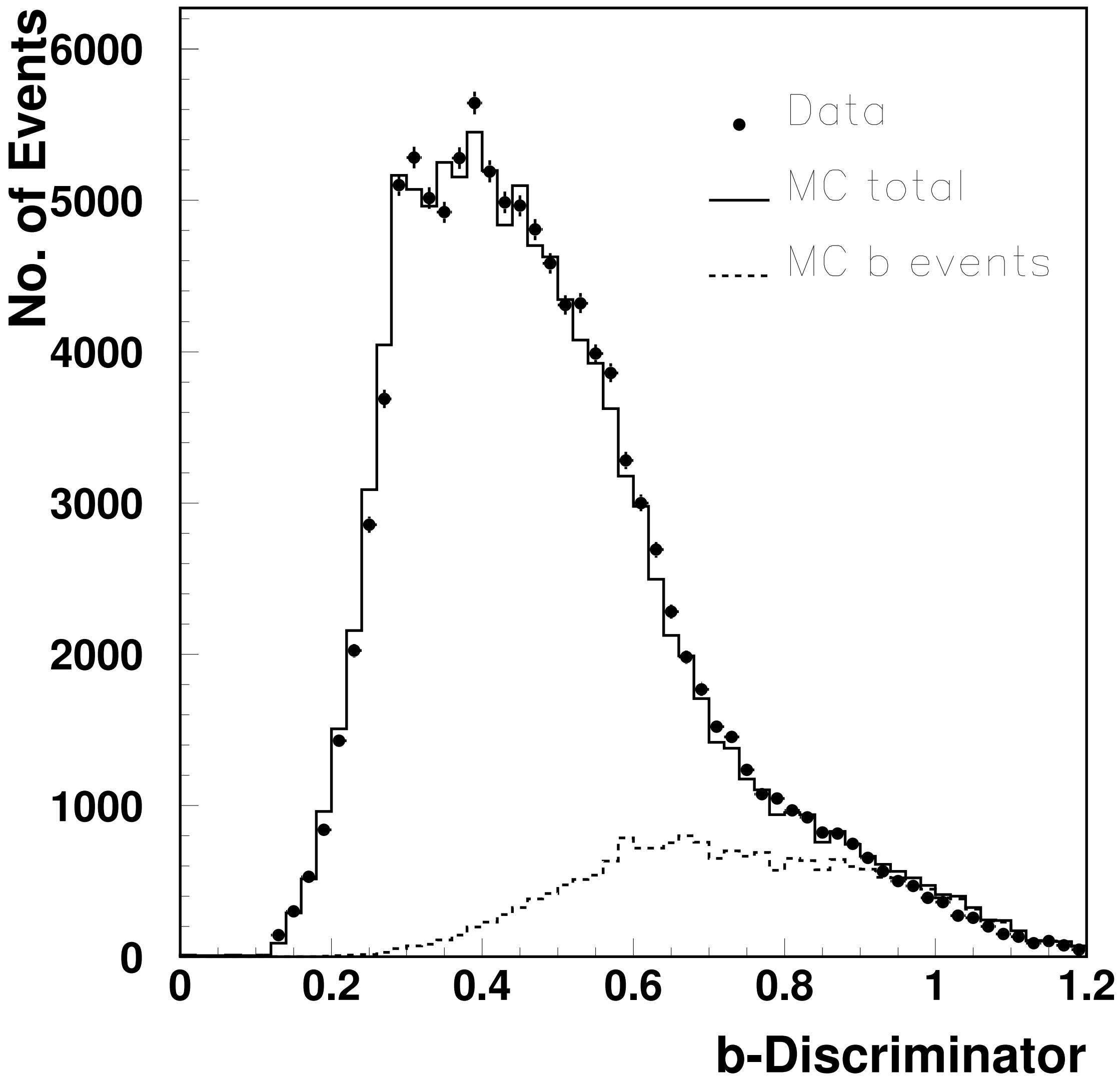

Figure 1: The discriminator output T_b, which combines event shape and lifetime information. The points are data, the full line shows the five flavor Monte Carlo and the dashed line the $b\overline{b}$ Monte Carlo.

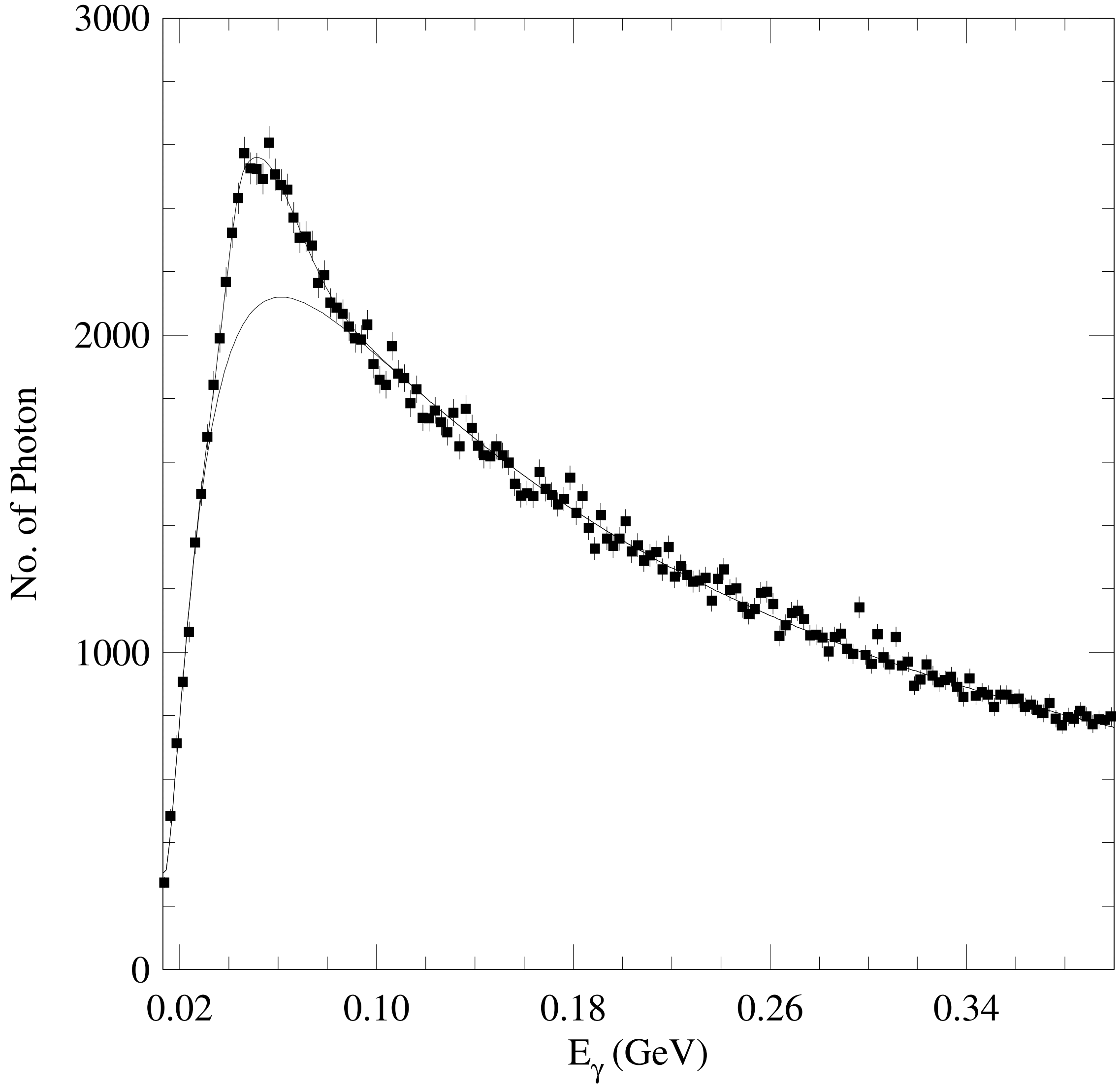

Figure 2: Likelihood fit to the data rest frame photon energy spectrum.