EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-PPE/95-76
17 May 1995

B Quark Fragmentation *

Michael Feindt
CERN, 1211 Geneva 23, Switzerland
E-mail: FEINDT @ CERNVM.CERN.CH

Abstract

New experimental results from LEP experiments on b quark fragmentation are reviewed. These comprise measurements of the b fragmentation function, inclusive particle production in b jets, precision analyses of B^* production and decay as well as the recent discoveries of the orbitally excited mesons B^{**} and B_s^{**} and the baryon states Σ_b and Σ_b^*.

*Invited talk given at the XXX. Rencontres de Moriond, QCD and High Energy Hadronic Interactions, Les Arcs, Savoie-France, March 19-26, 1995

1 Introduction

The abundant production of $b\bar{b}$ pairs in Z^0 decays makes it possible to study the mechanism of b hadron formation at LEP and their properties in detail. Large event rates, high resolution silicon vertex detectors and new inclusive reconstruction methods allow high statistics analyses that overcome the usual difficulties resulting from small exclusive B branching ratios. This article will summarize the qualitatively new results obtained in the last year at LEP. Due to lack of space the relevant plots from the OPAL and ALEPH collaborations will appear elsewhere is these proceedings [1, 2].

2 Overview

The picture emerging from the new observations can be summarized as shown in fig. 1: A high energy (around 45 GeV at LEP) b-antiquark fragments into a primary b-hadron, in about 90% by picking up a quark from the vacuum to form a primary B-meson, and the remaining 10% an anti-diquark to form a B-antibaryon. The mean energy carried by the primary hadron in b-jets is found to be 70% of the b-quark energy, more than in charm jets and much more than in light quark jets. The fractional momentum distribution (the fragmentation function) can approximately be described by a Peterson function (fig.1, top left). About 30% of the B-mesons formed are orbitally excited (L=1) (generally called B^{**}), (see fig. 1, middle left [3] and [4, 2]) and 70% in the ground state (without orbital angular momentum). All B^{**} states decay strongly into ground state B mesons. The latter are the pseudoscalar B meson and the vector meson B^*, which is just 46 MeV heavier and can only decay via photon emission (fig.1, middle right). The ratio of B^* to all B (including those from B^* decay) production rates is found to be large (around 72%) [5, 6, 2]. Disentangling the (small) effect from B^{**} decays [6], the ratio of primary B^* to primary B meson production is 3:1, in accordance with the naive spin counting picture (there are 2J+1 helicity states for a spin J meson, and all of them are equally populated). This again is in contrast to the charm and especially the light quark sector, where the vector meson contribution is suppressed. The ratio of helicity ± 1 to helicity 0 states of the B^* is found to be 2:1, again in agreement with naive spin counting. (The b-quark polarisation in Z^0 decays leads to an asymmetry between $\lambda = +1$ and -1, but the ratios 3:1 and 2:1 are unaffected.)

The quark picked up from the vacuum may be of flavour u,d or s. The latter is probably suppressed by a factor $\approx 1/3$, as in light quark fragmentation. There exists a further suppression mechanism for B_s mesons due to production and decay of B_s^{**} mesons: The decay of $B_s^{**} \rightarrow B_s\pi$ is forbidden by isospin conservation, and since the decay $B_s^{**} \rightarrow B_{u,d}^{(*)}K$ has been found to be kinematically allowed (fig.1, bottom left and [4]), it will dominate. Thus there will be about 30% less B_s than expected without B^{**} production, which is bad for the prospects to measure B_s oscillations.

Most of the b-baryons created will finally decay into the weakly decaying Λ_b, i.e. the spin 1/2 bud state with the ud-diquark in the J=0,I=0 state. There is first evidence for the spin 1/2 $\Sigma_b^{\pm}$ and the spin 3/2 $\Sigma_b^{*\pm}$ (both with quark content buu and bdd) decaying into $\Lambda_b\pi^{\pm}$ (fig.1 top right,[7]). First evidence for the bsu and bsd states Ξ_b is found in $\Xi^- l^-$ correlations [8, 9, 10].

3 B spectroscopy

During the last months the development of inclusive b-reconstruction methods (see e.g. [6] for a detailed description of the "rapidity algorithm" applied by DELPHI and ALEPH) lead to a wealth of qualitatively new results on both B spectroscopy and understanding of B fragmentation. The general technique is to look for enhancements in the invariant mass $m(Bx)$ of inclusively reconstructed B-hadrons and a single well reconstructed particle $x = \gamma, \pi^{\pm}, K^{\pm}$. Since the B-hadron is not well measured, one actually looks at the mass difference Δm by subtracting the reconstructed B-mass $m(Bx) - m(B)$, which gives a better resolution. In some analyses (B^{**}, B_s^{**}) one does not know whether the inclusive b-hadron is a B or B^*, what one can really reconstruct is the $Q-$value of the decay. To obtain a mass one then has to employ a model for the relative $B^{**} \rightarrow B^*/B$ yields. The

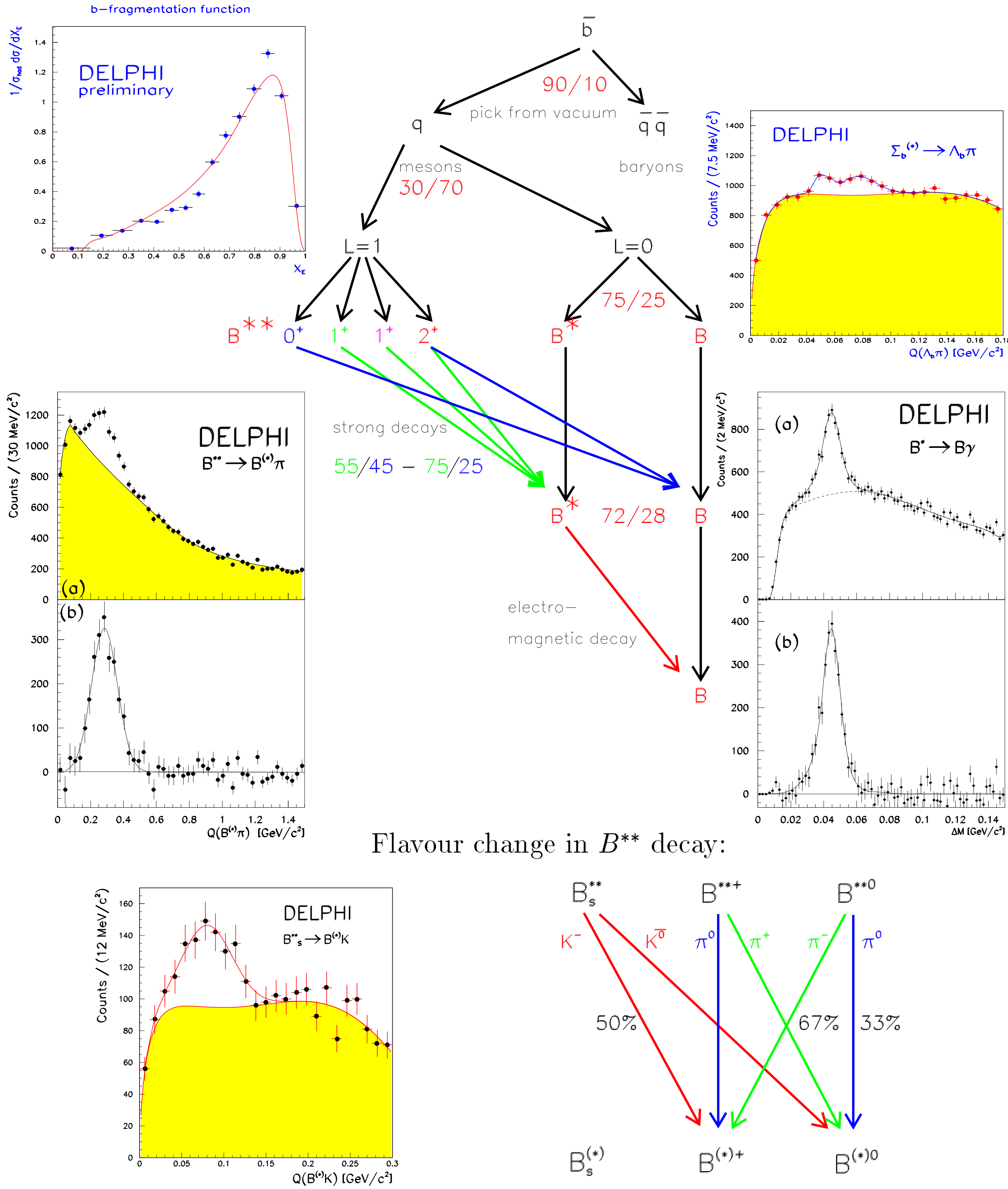

Figure 1: Scheme of b-quark fragmentation according to DELPHI data

Quantity	Experiment	Measurement	Comments
$\Delta M_{B^*/B}[MeV]$	L3	46.3 ± 1.9	[5]
	DELPHI	$45.5 \pm 0.3 \pm 0.8$	[6]
	ALEPH	$45.2 \pm 0.4 \pm 0.9$	preliminary [2]
	PDG 94	46.0 ± 0.6	[11]
	average	45.7 ± 0.4	average value
$\|\Delta M_{B^+} - \Delta M_{B^0}\|$ [MeV]	DELPHI	< 6.0 at 95 % c.l.	[6]
$\|\Delta M_{B_s} - \Delta M_{B^{0,+}}\|$ [MeV]	DELPHI	< 6.0 at 95 % c.l.	[6]
	PDG 94	1.0 ± 2.6	[11] CUSB II
$B^*/(B^* + B)$ production rate	L3	$0.76 \pm 0.08 \pm 0.06$	[5]
	DELPHI	$0.72 \pm 0.03 \pm 0.06$	[6]
	ALEPH	$0.74 \pm 0.03 \pm 0.06$	preliminary [2]
	average	0.74 ± 0.04	average value
helicity analysis $\sigma_L/(\sigma_L + \sigma_T)$	DELPHI	$0.32 \pm 0.04 \pm 0.03$	[6]
	ALEPH	$0.33 \pm 0.06 \pm 0.06$	preliminary [2]
	average	0.32 ± 0.04	average value
$\langle X_{B^*} \rangle$	DELPHI	$0.695 \pm 0.009 \pm 0.013$	[6]

Table 1: Summary of LEP B^* results

single analyses are:

$B + \gamma \to B^*$: L3 [5] is using photons reconstructed in the BGO calorimeter, DELPHI [6] and ALEPH [2] converted photons. The results are summarized in table 1.

$B + \pi^\pm \to B^{**}_{u,d}$: Shortly before Christmas 94 both OPAL [4] and DELPHI [12, 3] independently announced the discovery of orbitally excited B-mesons. ALEPH [2] confirms their findings. B^{**} mesons decaying strongly, the pion must originate from the primary vertex and not from the B-decay vertex. To reduce combinatorial background all three experiments use their silicon vertex detectors to perform vertex fits and to select candidate pions from the primary vertex. The signal is broader than expected from detector resolution, it may either come from a single broad resonance or be an overlap of several narrow and broad states, as expected in HQET [13]. With the present methods no separation between the states is possible. The results are summarized in table 2, where the signal is interpreted as a single broad resonance.

$B + K^\pm \to B^{**}_s$: Combining identified kaons with inclusive B-mesons, OPAL [4] and DELPHI (fig.1 bottom left) have found evidence for B^{**}_s meson production, see table 3

$\Lambda_b + \pi^\pm \to \Sigma_b, \Sigma_b^*$: Employing the same analysis as for the B^{**}, but enriching the b-hadron sample in Λ_b content by demanding an identified proton or reconstructed Λ among the decay products, DELPHI has found first evidence for the beautiful baryons Σ_b and Σ_b^*, see fig. 1 top right. Two Gaussians for spin 1/2 Σ_b and spin 3/2 Σ_b^* with detector resolution are fitted on top of a smooth background. The observed widths are consistent with the experimental resolution, i.e. the natural width of the Σ_b states is small. As a cross check the baryon enrichment cut is reversed, in this case no excess is visible. The preliminary results, summarized in table 4, are in good agreement with quark model expectations [14, 15].

4 B fragmentation function

Using the rapidity algorithm and applying a regularised unfolding procedure for correcting for the finite and non-Gaussian resolution [16], the b fragmentation function has been determined with hitherto unknown statistical precision. Fig. 1 top left shows the preliminary DELPHI result along with the JETSET 7.4 prediction. The mean fractional b-hadron energy is determined to be $\langle x_E \rangle = 0.708 \pm$

$B^{**}_{u,d}$	OPAL[4]	DELPHI[3]	ALEPH [2]
Mass [MeV]	5712 ± 11	$5732 \pm 5 \pm 20$	$5730 \pm 3 \pm 16$
Γ [MeV]	116 ± 24	148 ± 28	–
$BR(b \to B^{**}_{u,d})/BR(b \to B_{u,d})$	$(27 \pm 6)\%$	$(35 \pm 2 \pm 8)\%$	$(18.3 \pm 1.0 \pm 3.8)\%$

Table 2: Summary of LEP B^{**} results. The published OPAL mass [4] has been shifted upwards by 31 MeV by the author in order to account for the $B^{**} \to B^*$ contribution, the error does not contain the uncertainty on this procedure.

B^{**}_s	OPAL	DELPHI	ALEPH
Mass [MeV]	5884 ± 15	$5882 \pm 5.6 \pm 15$	seen
Γ [MeV]	47 ± 22	≈ 55	–
$BR(b \to B^{**}_s)/BR(b \to B_s)$	$(17.5 \pm 5.2)\%$	$(34 \pm 6.2 \pm 10)\%$	–

Table 3: Summary of LEP B^{**}_s results. The published OPAL mass [4] has been shifted by 31 MeV by the author to account for $B^{**}_s \to B^*$, the error does not contain the uncertainty on this procedure.

Quantity	Σ_b	Σ^*_b	Reference
$Q[MeV]$	51 ± 2	76 ± 4	DELPHI
	$(57 \pm 20)^a$		^{a} A. Martin 1981 [14]
	$(60 \pm 20)^b$	$(90 \pm 20)^b$	^{b} R. Roncaglia et al. 1995 [15]
$\mathcal{P}(b \to \Sigma_b, \Sigma^*_b)$	0.041 ± 0.007		DELPHI
	$(0.026)^c$		^{c} JETSET 7.4
$< \Sigma_b/(\Sigma_b + \Sigma^*_b) >$	0.27 ± 0.16		DELPHI
	$(0.33)^c$		^{c} JETSET 7.4

Table 4: Preliminary DELPHI results on Σ_b and Σ^*_b compared with expectations

0.003 ± 0.015, the shape cannot be well described by the JETSET parton shower Monte Carlo with Peterson fragmentation. With $\approx 30\%$ B^{**} rate $\langle x_E \rangle$ of the primary B hadron is expected to be larger than that of the weakly decaying B hadron by approximately 0.010. This may be compared with the average B^* energy $\langle x_{B^*} \rangle = 0.695 \pm 0.009 \pm 0.013$. Both are consistent with previous measurements using very different methods, for a review see e.g. [17].

5 Inclusive particle production in b jets

Inclusive cross section studies for identified particles have recently been extended to identified b events. The difference between the charged multiplicity in b- and light quark events is found to be $\delta_{bl} = 3.02 \pm 0.05 \pm 0.79$ (OPAL [18]) and $\delta_{bl} = 3.12 \pm 0.09 \pm 0.67$ (DELPHI [19]).

Separation of b-hadron decay and fragmentation contributions is achieved using secondary vertices

particle X	$q\bar{q}$	$b\bar{b}$	$n(B \to X)$	reference
charged		43.42 ± 0.56	5.51 ± 0.51	OPAL [18]
charged	20.71 ± 0.77	23.32 ± 0.51	5.84 ± 0.39	DELPHI [19]
K^0_S	0.98 ± 0.03	1.08 ± 0.06	0.29 ± 0.029	DELPHI [19]
$K^{\pm}$	2.26 ± 0.15	2.74 ± 0.50	0.88 ± 0.19	DELPHI [19]
p	1.07 ± 0.14	1.14 ± 0.27	0.141 ± 0.061	DELPHI [19]
Λ	0.357 ± 0.017	0.338 ± 0.0047	0.059 ± 0.011	DELPHI [19]
π^0	9.3 ± 1.5	10.0 ± 1.6	1.91 ± 0.44	DELPHI [20]

Table 5: Inclusive production rates in $q\bar{q}$ and $b\bar{b}$ events and per b-hadron decay at LEP

(OPAL) or rapidity distributions (DELPHI). This allows to determine the average production rate per b-hadron decay (see table 5). These are found to be consistent with $\Upsilon(4s)$ results, where only B^+ and B^0 contribute, apart for a higher Λ and p rate which can be attributed to Λ_b decays.

6 Summary

Lifetime b-tags and inclusive B reconstruction methods have revealed many new and interesting results in a short time. New and precise fragmentation function measurements are available. Inclusive cross sections for identified particles become available in $b\bar{b}$ events. Precision measurements of B^* production and decay properties have been performed. The excited B states B^{**},B_s^{**} as well as the beautiful baryons Σ_b and Σ_b^* have been discovered. All measurements show a good agreement with predictions – the B system is a good Heavy Quark Effective system.

7 Acknowledgements

I like to thank the organizers of this workshop for their excellent work creating such a pleasant and creative atmosphere. I further want to thank my colleages in DELPHI, especially O. Podobrin and C. Kreuter for the good cooperation, and M. Jimack and B. Kowalewsi (OPAL), A. Nippe (L3) and S. Schael (ALEPH) for providing material.

REFERENCES

[1] OPAL Coll., C. Shepherd-Themistocleous, these proceedings

[2] ALEPH Coll., S. Schael, these proceesings and priv. comm.

[3] DELPHI Coll., P. Abreu et al., Phys. Lett. **B 345** (1995) 598

[4] OPAL Collaboration, R. Akers et al., *Observations of $\pi - B$ charge-flavor correlations and resonant $B\pi$ and BK production*, CERN-PPE/94-206 (1994)

[5] L3 Collaboration, M. Acciarri et al., Phys. Lett. **B345** (1995) 589

[6] DELPHI Coll., P. Abreu et al., *B^* Production in Z^0 Decays*, CERN-PPE/95-53 (1995)

[7] DELPHI Coll., M. Feindt, C. Kreuter and O. Podobrin, *First Evidence for the beauty-baryons Σ_b and Σ_b^**, Note for the 1995 winter conferences

[8] DELPHI Coll., P. Abreu et al., *Production of strange B-baryons decaying into $\Xi^{\mp} - \ell^{\mp}$ pairs at LEP* , CERN-PPE/95-28 (1995)

[9] ALEPH Coll., *Search for strange B baryons through Ξ lepton correlations*, conference paper no. 590, 27th ICHEP, Glasgow, July 1994

[10] OPAL Coll., *Search for Strange b-Flavoured Baryons Using Ξ^- lepton Correlations*, OPAL Physics Note 1672, Feb. 1992

[11] Particle Data Group, Phys. Rev. D50 (1994)

[12] M. Feindt, *New Inclusive Bottom Physics Results from DELPHI*, Talk at the 138. WE-Heraeus-Seminar on Heavy Quark Physics, Bad Honnef, Germany, December 1994; to appear in the proceedings

[13] E.J. Eichten, C.T. Hill and C. Quigg, Phys. Rev. Lett. **71** (1993) 4116

[14] A. Martin, Phys. Lett. **B 103** (1981) 51

[15] R. Roncaglia et al., Phys. Rev. **D 51** (1995) 1248

[16] V. Blobel, *Unfolding in High Energy Physics*, Procs. CERN School of Computing, Aiguablava (Spain), Sept. 1984. CERN, Geneva, 1985, p.88.

[17] A. de Angelis, *Properties of $Z^0 \to b\bar{b}$ events*, CERN-PPE-94-174

[18] OPAL Coll., R. Akers et al., Z.Phys. C61 (1994) 209

[19] DELPHI Coll., P. Abreu et al., *Production of charged particles, $K_s^0, K^{\pm}, p$ and Λ in $Z^0 \to b\bar{b}$ events and in the decay of b hadrons* , CERN-PPE/95-01 (1995)

[20] DELPHI Coll., P. Abreu et al., *Measurement of Inclusive π^0 Production in Z^0 Decays*, DELPHI-draft 0108