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Baryon Production in ALEPH

Presented on behalf of the ALEPH Collaboration by

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Abstract

Several recent results of the ALEPH Collaboration covering different aspects of baryon production on the Z resonance are presented. In particular production rates of hyperons, the full kinematical reconstruction of the Λ_b, observation of Ξ_b in its semileptonic decay, and the measurements of the polarization of Λ and Λ_b baryons are discussed.

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1 Introduction

Baryon production in quark fragmentation is still poorly understood. The existing models reproduce the available data quite well. To distinguish between these models and to come to a more fundamental understanding of the production mechanism of baryons more experimental input is needed. Results of the ALEPH Collaboration on hyperon and b – baryon production in Z decays are reported here. Whenever possible, not only the overall production rates but also the momentum spectra of baryons have been investigated and compared to Monte Carlo predictions.

While the number of produced hyperons is quite large the production rate of b – baryons is low. Only few of them have been observed by LEP experiments so far. The full reconstruction and mass determination of the Λ_b and the observation of the Ξ_b through Ξ – lepton correlations will be described.

Z decays provide many possibilities to test the Standard Model. Quarks produced in Z decays are expected to obtain a strong longitudinal polarization due to parity violation in the electroweak interaction. While mesons always cascade down to spin zero pseudoscalar states retaining no polarization information, baryons might preserve a large fraction of the initial quark polarization. Recent measurements of the Λ and Λ_b polarizations are presented here.

The data sample used for these studies has been taken with the detector ALEPH at the LEP storage ring at a center of mass energy of about 91 GeV. The detector and its performance are described in detail elsewhere [1].

2 Hyperon production

ALEPH has studied recently the inclusive production rates of several octet and decuplet hyperons: $\Sigma^{\pm}(1385)$, Ξ^-, $\Xi^0(1530)$ and Ω^-[2]. Except for the Ω^- also the energy spectra have been measured. The four hyperons have been reconstructed in their decays:

$$\begin{array}{lcl} \Sigma^{\pm}(1385) & \rightarrow & \Lambda\pi^{\pm} \\ \Xi^- & \rightarrow & \Lambda\pi^- \\ \Xi^0(1530) & \rightarrow & \Xi^-\pi^+ \\ \Omega^- & \rightarrow & \Lambda K^- \end{array}$$

where the Λ candidates are tagged in the decay channel $\Lambda \rightarrow p\pi^-$. The resulting mass distributions are shown in Fig. 1a - d.

Except for the Ω^- (due to low statistics) the energy spectra have been determined and compared with Monte Carlo predictions from JETSET 7.3[6] and UCLA[7] (Fig.2). The agreement is quite reasonable with slight preferences for JETSET.

The mean multiplicities per Z decay have then been determined using JETSET to extrapolate into the inaccessible low energy region.

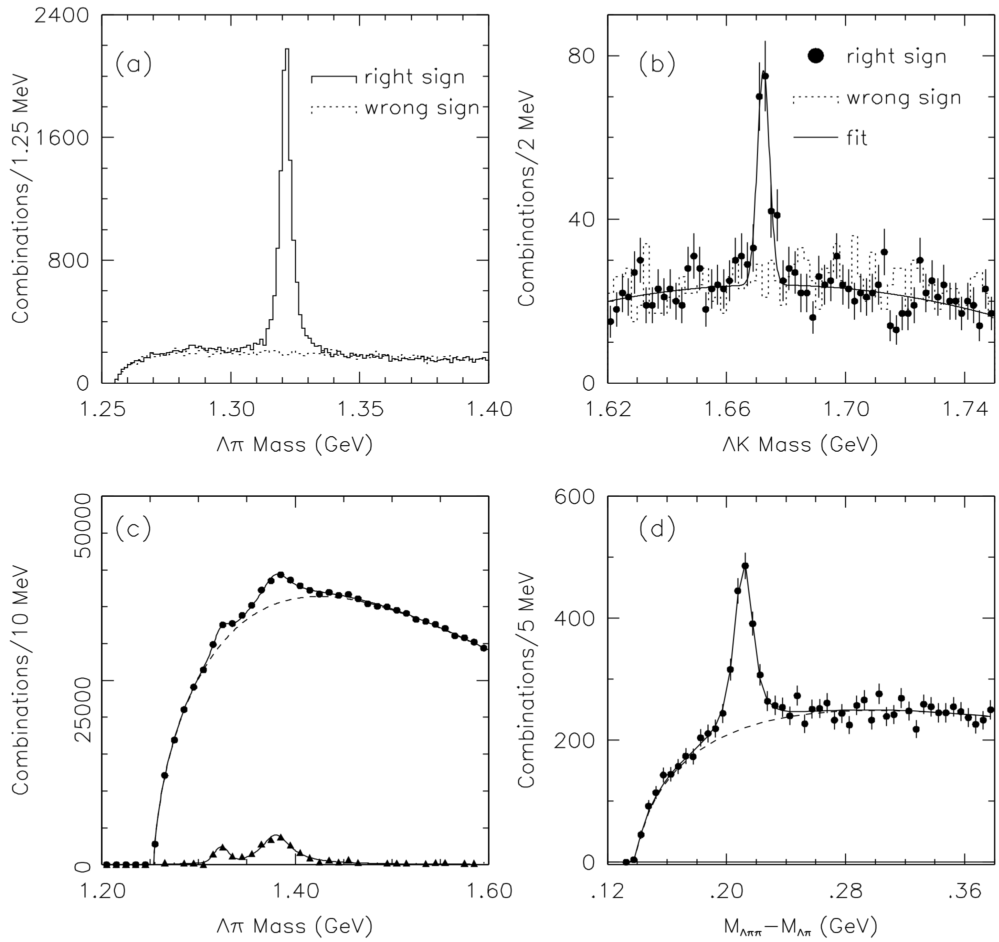

Figure 1: (a) *The signal for* $\Xi^- \to \Lambda\pi^-$. *(b) The signal for* $\Omega \to \Lambda K^-$. *(c) The mass spectrum for* $\Sigma^\pm(1385) \to \Lambda\pi^\pm$*, fit to a background shape, a* Ξ^- *contribution, plus a Breit – Wigner resonance. Also shown is the background – subtracted spectrum. (d) The mass – difference spectrum for* $\Xi^0(1530) \to \Xi^-\pi^+$ *candidates, fit to the background shape plus a Breit – Wigner resonance convolved with a gaussian.*

The preliminary results are:

$$\begin{aligned}
\langle N_{\Xi^-}\rangle + \langle N_{\bar{\Xi}^+}\rangle &= 0.0285 \pm 0.0007 \pm 0.0020 \\
\langle N_{\Xi^0(1530)}\rangle + \langle N_{\bar{\Xi}^0(1530)^0}\rangle &= 0.0072 \pm 0.0004 \pm 0.0006 \\
\langle N_{\Sigma^\pm(1385)}\rangle + \langle N_{\bar{\Sigma}(1385)^\pm}\rangle &= 0.065 \pm 0.004 \pm 0.009 \\
\langle N_{\Omega^-}\rangle + \langle N_{\bar{\Omega}^+}\rangle &= 0.0010 \pm 0.0002 \pm 0.0002
\end{aligned}$$

While our measurement of the $\Sigma^\pm(1385)$ rate is in good agreement with the Monte Carlo prediction it is nevertheless about 1.7 times higher than the corresponding measurements from DELPHI and OPAL[3],[4],[5]. Fig.3 gives an overview about the hyperon production rates at LEP[8].

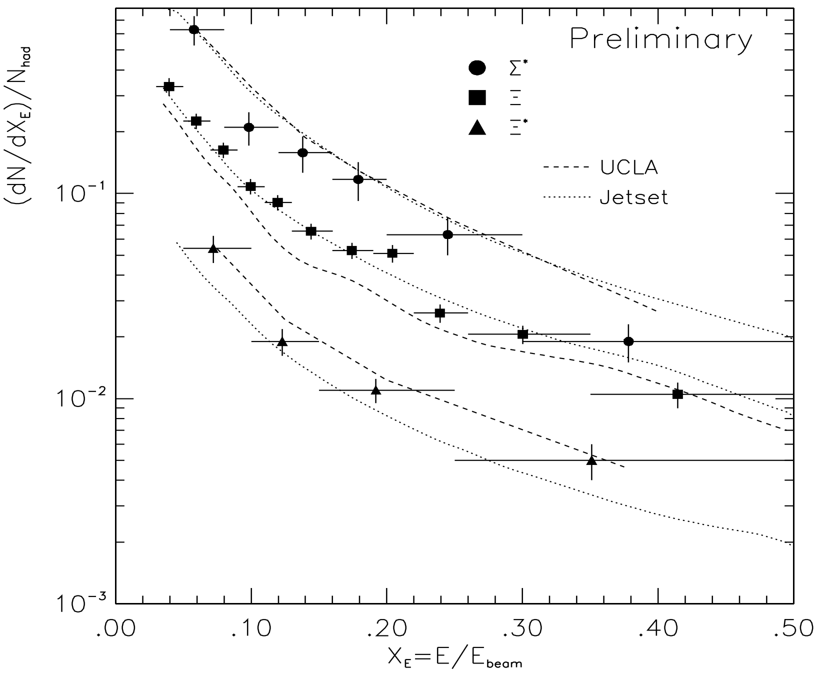

Figure 2: *The measured x_E distribution for $\Sigma^{\pm}(1385)$, Ξ^-, and $\Xi^0(1530)$ (with antiparticles included), compared with predictions from the UCLA and JETSET 7.3 models.*

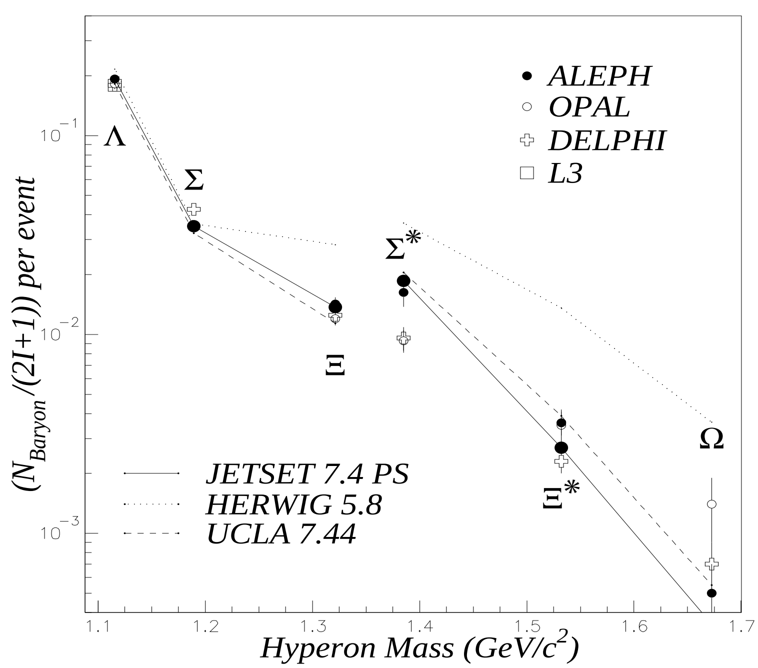

Figure 3: *Production rates of hyperons at LEP together with predictions of JETSET, HERWIG and UCLA models. Lines are drawn to guide the eye.*

3 b – baryons

The situation in the sector of heavy baryons containing a b – quark is quite different. Due to their low production rates combined with small branching ratios (in the order of a few %) and long decay chains only very few b – baryons have been observed at LEP so far, namely the Λ_b, Ξ_b (which will be presented here) and Σ_b, Σ_b^* by the DELPHI Collaboration [9].

3.1 The Λ_b

The Λ_b has been observed indirectly since several years in Λl^- and $\Lambda_c^+ l^-$ correlations (where l = muon or electron). Its production rate has been determined by e.g. ALEPH to be $Br(b \to \Lambda_b) \cdot Br(\Lambda_b \to \Lambda_c^+ l \bar{\nu} X) = (0.76 \pm 0.15 \pm 0.13) 10^{-3}$[10] but its mass remained only poorly known. Now the Λ_b has been fully reconstructed in its decay channel $\Lambda_b \to \Lambda_c^+ \pi^-$ with $\Lambda_c^+ \to pK\pi$, $p\bar{K}^0$ or $\Lambda\pi\pi\pi$. Several cuts have been applied to reduce the background. The result is shown in Fig.4

The background has been estimated to be 0.38 ± 0.05 entries leaving us with a statistical significance of the observed peak at the $3.3\,\sigma$ level, not taking into account the mass clustering of the four events. The Λ_b mass has been found to be $(5614 \pm 21(stat.) \pm 4(sys.))$MeV/c^2[11]. This is in good agreement with the recent measurements of DELPHI $(5668 \pm 16 \pm 8)$MeV/c^2[12] and CDF $(5623 \pm 5 \pm 4)$MeV/c^2[13] and the PDG94 value (5641 ± 50)MeV/c^2[14].

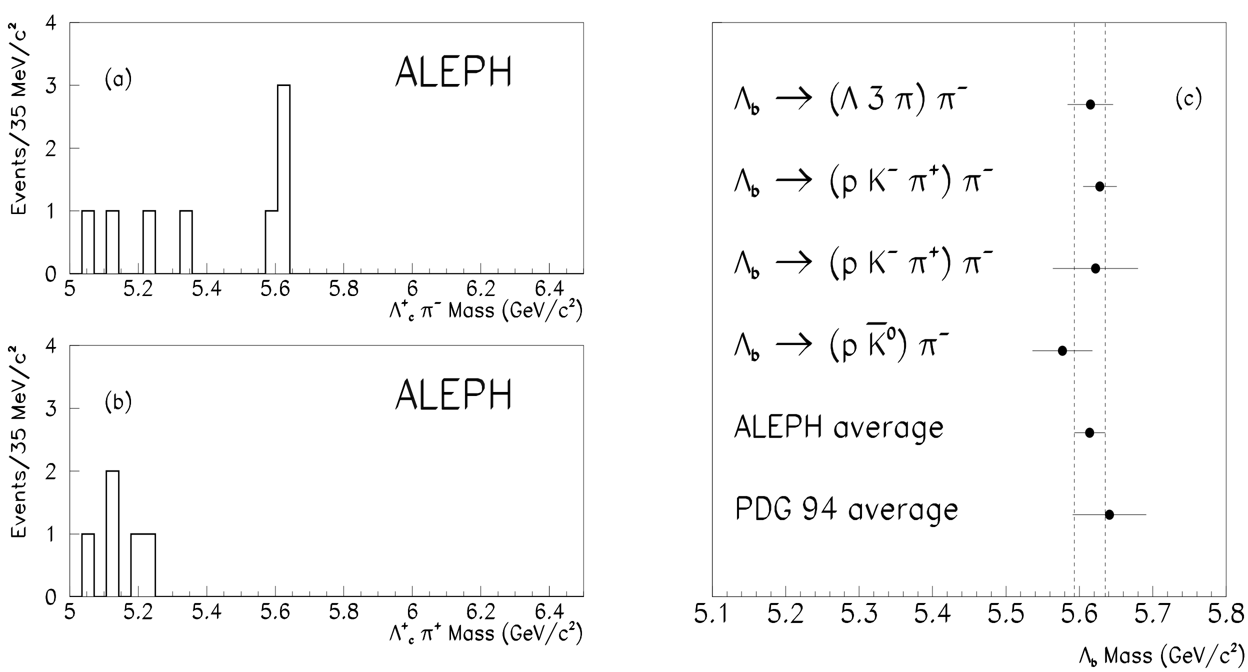

Figure 4: *(a) $\Lambda_c\pi$ invariant mass distributions for the right – sign combination and (b) for the wrong – sign combinations. (c) Λ_b invariant masses for the four selected candidates. The dotted lines indicate the $\pm 1\sigma$ values around the ALEPH average measurement.*

3.2 The Ξ_b

A search for $\Xi^- l^-$ correlations (again l stands for muon or electron) in the same hemisphere of the detector has been made to find evidence for Ξ_b production. After correcting for other possible sources of $\Xi^- l^-$ pairs as e.g. Λ_b B or accidentals an excess of 22.5 ± 5.7 like−sign combinations with respect to opposite−sign combinations has been observed. It is therefore interpreted as from the semileptonic decay of the Ξ_b and can be translated into the following product of branching fractions:

$$Br(b \to \Xi_b) \cdot Br(\Xi_b \to \Xi^- l^- \bar{\nu} X) = (5.3 \pm 1.3 \pm 0.7) 10^{-4}$$

per lepton species[15]. This value is in good agreement with the DELPHI result[16].

4 Polarization

Polarization of the primary quarks coming from Z decays is due to the parity violating inequality of the Z coupling to right and left handed fermions. Ignoring mass effects and gluon radiation (which may depolarize the quarks by about 3% [17]) the expected polarization can be written as

$$P_L^q = \frac{-2 g_v g_a}{g_V^2 + g_A^2}$$

where g_v and g_a are the vector and axial vector coupling constants of the Z to the quark. With $\sin^2 \vartheta_W = 0.23$ a polarization of -94% for downtype quarks is expected according to the Standard Model, but may be diluted substantially during the hadronization phase due to spin−spin forces.

Mesons always cascade down to spin zero pseudoscalar particles which do not retain any polarization information. In contrast baryons are expected to preserve a sizeable fraction of the initial quark polarization which, however, gets smaller if the weakly decaying ground state baryon is produced in the decay of a higher resonance[18],[19]. Therefore the mean measureable polarization will depend on the production rate of these resonances and will thus give additional information about the hadronization phase.

4.1 The Λ polarization

The polarization of Λ hyperons can be measured by investigating the decay angle ϑ^* in their decay $\Lambda \to p\pi^-$. Here ϑ^* is defined as the angle between the proton momentum in the Λ restframe and the Λ boost direction. The ϑ^* distribution is expected to follow $R(\vartheta^*) = 1 + \alpha P_L^\Lambda \cos\vartheta^*$ with the asymmetry parameter $\alpha = 0.642 \pm 0.013$ [14] and the Λ polarization P_L^Λ. The observed Λ polarization is diluted with respect to the primary s−quark polarization by those Λ baryons which do not contain a primary quark. To derive a Monte Carlo prediction of P_L^Λ, first the fraction of Λ's containing a primary quark has been determined in the data by measuring the Λ forward−backward asymmetry and the correlation of back−to−back $\Lambda\bar{\Lambda}$ pairs. The differences between data and MC have been used as correction factors for all possible sources of polarized Λ's (see [21] for details). Then the fraction of Λ baryons coming from e.g. Λ_b, Σ etc. has been corrected, and the expected polarizations [20] have been added up. The ALEPH measurement is shown in Fig.5 together with the expectation. For Λ's with $z = p(\Lambda)/P_{Beam} > 0.3$ the polarization has been determined to be $P_L^\Lambda = -0.32 \pm 0.07$ [21], in good agreement with the JETSET prediction of -0.39 ± 0.08.

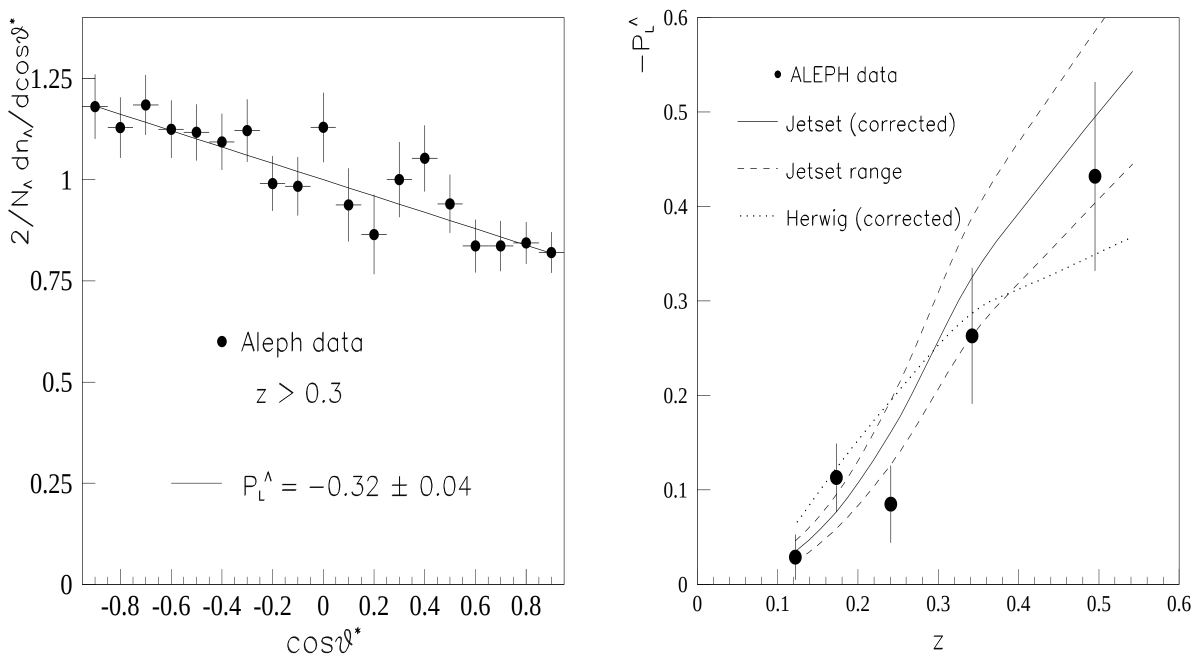

Figure 5: **Right**: *Fit of the longitudinal* Λ *polarization to the decay angle distribution for* $z > 0.3$ *.*
Left: *The measured longitudinal* Λ *polarization is shown as as function of z together with the JETSET prediction after multiplying by the correction factor (shown as solid line). The dashed lines indicate the estimated uncertainty of the JETSET prediction. The HERWIG prediction after multiplication by the correction factor is shown as dotted line.*

4.2 The Λ_b polarization

There is no need to estimate the 'primary' Λ_b fraction since b−quarks nearly always originate directly from Z decays. It has been suggested for some time to measure the Λ_b polarization (which is equal to the b−quark polarization in the heavy quark limit) in its semileptonic decay[22].

Apart of the interest in the polarization itself, weak decays of polarized b−quarks provide another interesting aspect. It has been pointed out by Gronau and Wakaizumi [23] that the left handedness of the b−quark coupling to the charged weak current has never been proven. They have shown that, assuming the same handedness for the leptons involved in the decay, the chirality could not be determined in b−meson decay . Amundsen et. al. [24] suggested to resolve this ambiguity through an investigation of the semileptonic decay of *polarized* b−quarks which are available in Λ_b's from the Z resonance. When deriving the polarization from the lepton spectra, a V+A coupling would result in a change of sign of the measured with respect to the true polarization. This is in principle analogous to the determination of the Michel parameter ξ in τ decays.

The ALEPH analysis of the Λ_b polarization [25] has followed a suggestion of Bonvicini and Randall [26] who proposed to study the ratio y of the mean energies of charged leptons and neutrinos from semileptonic Λ_b decays. This procedure offers several advantages: Independence from the Λ_b fragmentation function, greater sensitivity than the charged lepton alone and more statistics than any exclusive decay.
For this purpose $\Lambda\pi^+ l^-$ pairs have been selected. The neutrino energy is calculated from the visible amount of energy in the detector: $E_\nu = E_{tot} - E_{vis}$, with $E_{tot} = \sqrt{s}/2 + (M^2_{same} - M^2_{oppo})/2\sqrt{s}$. Here M_{same} (M_{oppo}) is the invariant mass in the same (opposite) hemisphere. Biases due to selection cuts and neutrino energy reconstruction have been corrected with Monte Carlo simulations.

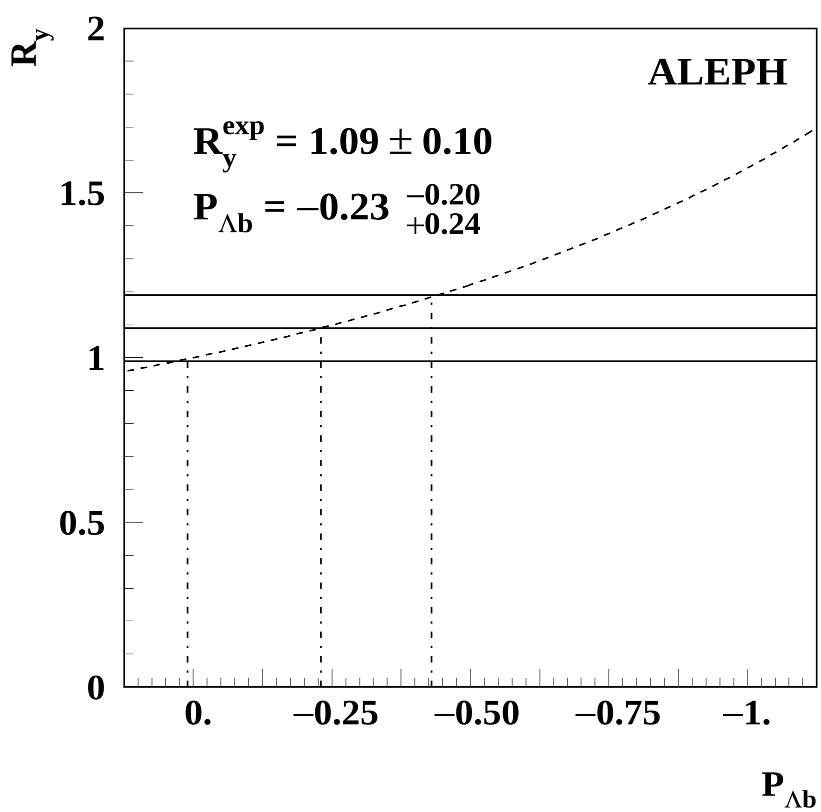

Figure 6: *The method to extract the Λ_b polarization value: Comparison between the measured R_y^{exp} value and the theoretical prediction R_y*

The polarization in the data is extracted by comparing $R_y^{exp} = y_{data}/y_{MC}(P = 0)$ (where $y_{MC}(P = 0)$ is the expected ratio between lepton and neutrino mean energy without any polarization) with the expected R_y curve and correcting for differences between Data and Monte Carlo (Fig.6):

$$\mathcal{P}^{\Lambda_b} = -0.23^{+0.24}_{-0.20}(stat.)^{+0.08}_{-0.07}(syst.)$$

This result can be compared with an expectation of about -0.73 estimated from [19] together with the $\Sigma_b^{(*)}$ production rates measured by DELPHI [9]. It is quite low (but consistent with the expectation), indicating additional depolarization effects during hadronization.

References

[1] D. Decamp et al., ALEPH Collaboration, Nucl. Instrum. Meth. **A 294** (1990) 121
D. Buskulic et al., ALEPH Collaboration, Nucl. Insttrum. Meth. **A 360** (1995) 99

[2] D. Buskulic et al., ALEPH Collaboration, *Hyperon production in Z decays*, contributed paper to EPS−HEP 95, Brussel,Belgium

[3] P.D. Acton et al., OPAL Collaboration, Phys. Lett. **B 291** (1992) 503

[4] P. Abreu et al., DELPHI Collaboration, CERN - PPE/96 - 12, Submitted to Z. Phys. C

[5] P.D. Acton et al., OPAL Collaboration, Proceedings of the August 1994 meeting of the APS Divison of Particles and Fields, Albuquerque, N.M.; OPAL Physics Note PN138

[6] M. Bengtson and T. Sjöstrand, Phys. Lett. **B 185** (1987) 435; T. Sjöstrand, CERN−TH.6488/92 (1992)

[7] S.B. Chun and C.D. Buchanan, Phys. Lett. **B 308** (1993) 153. Curves obtained from C.D. Buchanan by private communication.

[8] Numbers taken from P.V. Chliapnikov and V.A. Uvarov, Phys. Lett. **B 345** (1995) 313

[9] P. Abreu et al., DELPHI Collaboration, contributed paper to EPS−HEP, Brussel,Belgium

[10] D. Buskulic et al., ALEPH Collaboration, Phys. Lett. **B 357** (1995) 685

[11] D. Buskulic et al., ALEPH Collaboration, CERN - PPE/96 - 28, submitted to Phys. Lett. B

[12] P. Abreu et al., DELPHI Collaboration, Phys. Lett. **B 374** (1996) 351

[13] G. Bauer, talk given at the 2nd Rencontres du Vietnam, Ho Chi Minh City, October 21-28, 1995, CDF/PUB/BOTTOM/PUBLIC/3562

[14] Particle Data Group. Phys. Rev. **D 50** (1994) 1173

[15] D. Buskulic et al., ALEPH Collaboration, CERN - PPE/96 - 81, submitted to Phys. Lett. B

[16] P. Abreu et al., DELPHI Collaboration, Z. Phys. **C68** (1995) 541

[17] J. Körner, A. Pilaftsis, and M.M. Tung, Z. Phys. **C63** (1994) 575

[18] F. Close, J. Körner, R.J.N. Phillips, and D.J. Summers, J. Phys. **G 18** (1992) 1716

[19] A.F. Falk and M.E. Peskin, Phys. Rev. **D 49** (1994) 3320

[20] G. Gustafson and J. Häkkinen, Phys. Lett. **B 303** (1993) 350

[21] D. Buskulic et al., ALEPH Collaboration, Phys. Lett. **B 374** (1996) 319

[22] J. Körner and M. Krämer, Phys. Lett. **B 275** (1992) 495
T. Mannel and G.A. Schuler, Phys. Lett. **B 279** (1992) 194
G. Altarelli and B. Mele, Phys. Lett. **B 299** (1993) 345
J.F. Amundson, J.L. Rosner, M. Worah, and M.B. Wise Phys. Rev. **D 47** (1993) 1260

[23] M. Gronau and S. Wakaizumi, Phys. Rev. Lett. **68** (1991) 1814

[24] J.F. Amundson, J.L. Rosner, M. Worah, and M.B. Wise, Phys. Rev. **D 47** (1993) 1260

[25] D. Buskulic et al., ALEPH Collaboration, Phys. Lett. **B 365** (1996) 437

[26] G. Bonvicini and L. Randall, Phys. Rev. Lett. **73** (1994) 392