Update of Λ polarization from Z decays

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Abstract

The measurement of Λ polarization from Z decays using the ALEPH detector has been updated with 1995 data and more Monte Carlo events. The measurement is compared with two models, one based on the simple quark model and one applying SU(3) flavor symmetry on the measured nucleon spin structure function. While the first model is in best agreement with the data, the second one is also consistent, given the uncertainties in the Λ production mechanism.

1 Measurement of the longitudinal polarization

The previously published measurement of the longitudinal polarization of Λ's from Z decay [1] has been updated by including data recorded by ALEPH during 1995. The data sample now comprises about 4 million events. The same procedure as in the previous analysis was used for selecting $\Lambda \to p + \pi^-$ decays in the data. A sample of 5.4 million Monte Carlo events was generated with JETSET [2], and passed through a full simulation of the ALEPH detector and the analysis chain. The momentum spectra of the simulated Λ's and K^0's were weighted so as to reproduce the observed spectra in the data, and the simulated specific ionization of V^0 tracks in the TPC was also explicitly tuned. After correcting the data for efficiency and background with the help of this Monte Carlo sample, the distribution of the decay angle $\cos\theta^*$ for

z	P_L^Λ
0.1 – 0.15	$-0.056 \pm 0.018 \pm 0.007$
0.15 – 0.2	$-0.106 \pm 0.024 \pm 0.014$
0.2 – 0.3	$-0.119 \pm 0.027 \pm 0.018$
0.3 – 0.4	$-0.264 \pm 0.044 \pm 0.029$
0.4 – 1.0	$-0.406 \pm 0.065 \pm 0.037$

Table 1: The longitudinal polarization of Λ's from Z decay in bins of $z = p_\Lambda/p_{\rm beam}$. The numbers are averages over Λ and $\bar{\Lambda}$ such that a positive sign on the longitudinal polarization refers to positive helicity for Λ and negative helicity for $\bar{\Lambda}$. The first of the quoted errors is statistical, including MC statistics, and the second systematic.

$\Lambda \rightarrow p\pi^-$ decays has a linear shape as shown in Figure 1. The slope of this distribution, divided by the decay parameter $\alpha = 0.642$, is the longitudinal polarization, shown as a function of momentum in Table 1. The χ^2 of the linear fit is good in each momentum bin. For $z > 0.3$ the new result is $P_L^\Lambda = -0.311 \pm 0.035 \pm 0.032$ - a significant improvement over the previous result: -0.31 ± 0.07.

Systematic errors arise from uncertainties in the background subtraction and efficiency correction involved in Figure 1. In Figure 2a the Λ mass distribution is shown before any direct cut on mass, and in Figure 2b is shown the pull of the specific ionisation of the proton track

$$R_I = \frac{\mathrm{dE/dx} - \langle \mathrm{dE/dx} \rangle_{\rm proton}}{\sigma_{\mathrm{dE/dx}}}$$

where $\langle \mathrm{dE/dx} \rangle_{\rm proton}$ is the expectation value of the dE/dx for a proton of the given momentum an polar angle and $\sigma_{\mathrm{dE/dx}}$ is its resolution. For the signal sample $R_I < 1.7$ is required. The tails of the distributions are dominated by pions from K^0 background and provide a check on the simulation of the background level. The most sensitive check is given by Figure 2b. Normalising the simulated R_I distribution to that of data in the region $R_I < 0$, the number of candidates in the region $R_I > 2$ is 2723 in data and 2738 in simulation. Another check is done by including all kinematically ambigous Λ/K^0

candidates in the selected sample, hereby doubling the background. The measured polarization then changes from -0.311 ± 0.035 to -0.312 ± 0.037.

The efficiency as a function of decay angle increases with $\cos\theta^*$ at high Λ energies. When $\cos\theta^*$ increases, the pion energy decreases and the spatial separation of the two decay tracks in the TPC becomes larger. Hence the efficiency becomes larger because of two-track resolution effects. Also the the χ^2 of the kinematic Λ fit is better for forward decays than for backward decays of high energy Λ's. As a check, the maximum $\chi^2/(ndf = 3)$ was therefore tightened from 8 to 2. The polarization for $z > 0.3$ then changed from -0.311 ± 0.035 to -0.298 ± 0.043. The effect of two-track resolution is weaker for K^0 decays (larger Q value, and therefore larger two-track separation), whereas it is very strong for γ conversions as shown in Figure 3. A systematic error in the simulation of two-track resolution would make the corrected distributions of the K^0 and γ decay angles depart from a constant. From Figure 3 the relative error in the slope of the efficiency, $\Delta s/s$, is limited to $\Delta s/s = 8\% \pm 15\%$ by the K^0 data, and to $\Delta s/s = -7\% \pm 5\%$ by the γ data. The systematic errors shown in Table 1 come about by adding in quadrature the effects of three variations: a shift in the background contamination by $\pm 5\%$, a shift in the efficiency slope by $\pm 10\%$, and inclusion of all kinematically ambigous Λ/K^0 candidates.

2 The Λ production mechanism

To predict the longitudinal Λ polarization, it is neccesary to know the details about the origins of Λ's in the hadronization process, and this is taken from the JETSET Monte Carlo with parameters tuned to fit ALEPH data. Recently a new parameter was activated which suppresses the creation of "first rank" baryons – exactly the kind of baryons expected to contribute most to the polarization. The parameter value of PARJ(19) = 0.57 forces the high momentum end of the simulated baryon spectra to agree better with data, and it could be viewed as a way of reproducing the influence of higher exited baryon states (for a review, see e.g. [3]). Since the simulated baryon momentum spectrum in the old MC is only in conflict with data at high momenta in the case of Z decays into light quarks, and not in the case of $b\bar{b}$ events, and since the Λ_b and Λ_c spectrum is well described without any suppression factor, the factor is only applied in light quark fragmentation. Therefore the

Λ's from Λ_c decay will contribute a larger fraction to the high momentum Λ's in the new MC. The effect of the changes in the fragmentation model is that the predicted polarization changes from -0.37 to -0.29 for $z > 0.3$ following the procedure of [1].

Other aspects of the Λ production mechanism were checked using the forward-backward asymmetry, the baryon number correlations between high energy Λ pairs and the Λ/p ratio. This checks the simulation of the fraction of Λ's containing a primary quark or a descendant of a heavy quark from weak decays. In all cases the checks show both the old and the new MC in good agreement with the data. For example, the measured forward-backward asymmetry for $z > 0.3$ is 0.081 ± 0.011, while the predicted forward-backward asymmetry is 0.074 with the old MC and 0.071 with the new MC.

3 Comparison with theoretical predictions

Two pairs of theoretical curves are shown together with the data in Figure 4. One pair of curves assumes the simple non-relativistic quark model [4] and the two tunings of JETSET described above (with and without leading bayon suppression), and the other pair assumes a Λ wave function as suggested in Reference [6] together with the same two hadronization models. In the second model SU(3) flavor symmetry is used to calculate the Λ spin dependent structure function from the measured spin dependent structure function of the nucleon:

$$\begin{aligned} \Delta u_\Lambda = \Delta d_\Lambda &= \Sigma - D \\ \Delta s_\Lambda &= \Sigma + 2D \end{aligned}$$

where $\Sigma = \Delta u + \Delta d + \Delta s = a_0 = 0.29 \pm 0.06$ [5] is the light quark fractional contribution to the proton spin, derived from the first moment of the spin dependent structure functions $g_1^{p(n)}(x, Q^2 = 5\ \mathrm{GeV}^2)$, and $D = 0.8$ is derived from the measured axial coupling constants in neutron and hyperon semileptonic decays (see e.g. [7]). Thus instead of the simple quark model prediction, $\Delta u = 0$ and $\Delta s = 1$, Reference [6] would expect $\Delta u = -0.17$ and $\Delta s = 0.63$. In all these calculations QCD effects are ignored, and in the following it is furthermore assumed the Δq's of the structure function also describe the spin transfer of the fragmentation functions.

The components of the Λ polarization are calculated as in [1]: The primary s quarks are assumed to have a polarization of -91%, and primary u quarks a polarization of -63%, including QCD radiative effects. The Λ's from Ξ's without a primary quark are given a polarization of -6.5%, as a consequence of the $\Xi \to \Lambda\pi$ decay having an asymmetry parameter of -0.44, and of the "trigger bias" preferentially selecting Λ's from forward decays. The same reasoning is applied to $\Lambda_c \to \Lambda + X$ decay, where the Λ gets a polarization of -25% assuming that the asymmetry parameter is -1 for all decays and that the Λ_c is unpolarized. The Λ's from Ξ's, Σ's and Σ^*'s with a primary quark are given a polarization as in [4].

In addition to the uncertainties arising from these assumptions (about 15% of the polarization), there is room for some 10% variation in the fraction of Λ's with a primary quark, and there is an uncertainty attached to the tuning of leading baryon suppression (about 6%). Thus the curves have a common theoretical relative uncertainty due to hadronization effects of at least 20%. The data seem to prefer the simple quark model, but given the various uncertainties, none of the two suggestions can be safely ruled out.

References

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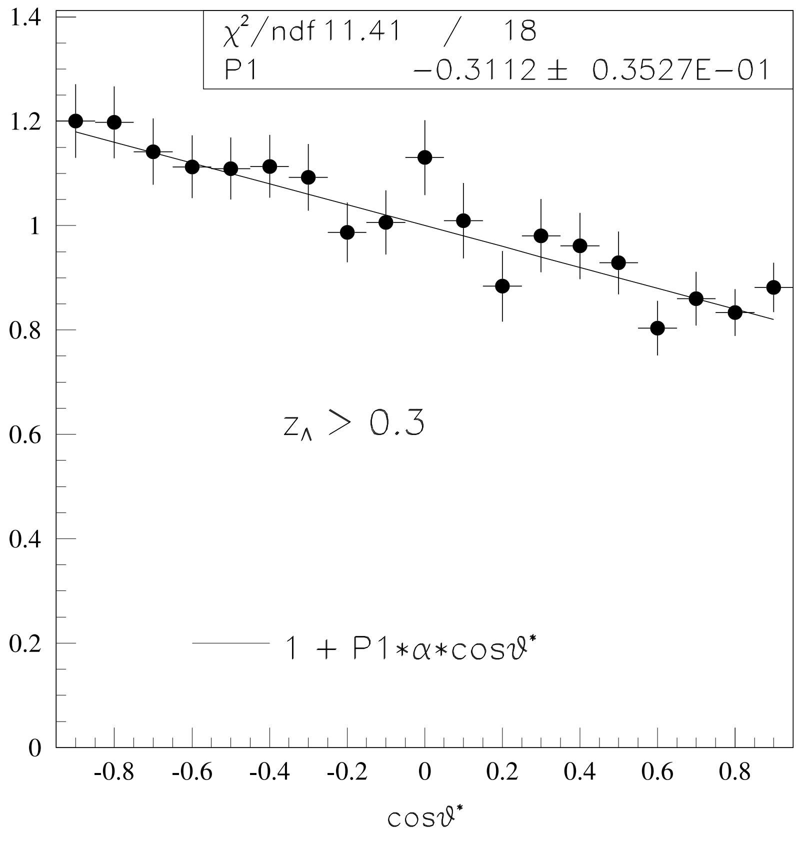

Figure 1: The corrected $\Lambda \to p + \pi^-$ decay angle distribution for $z_\Lambda > 0.3$.

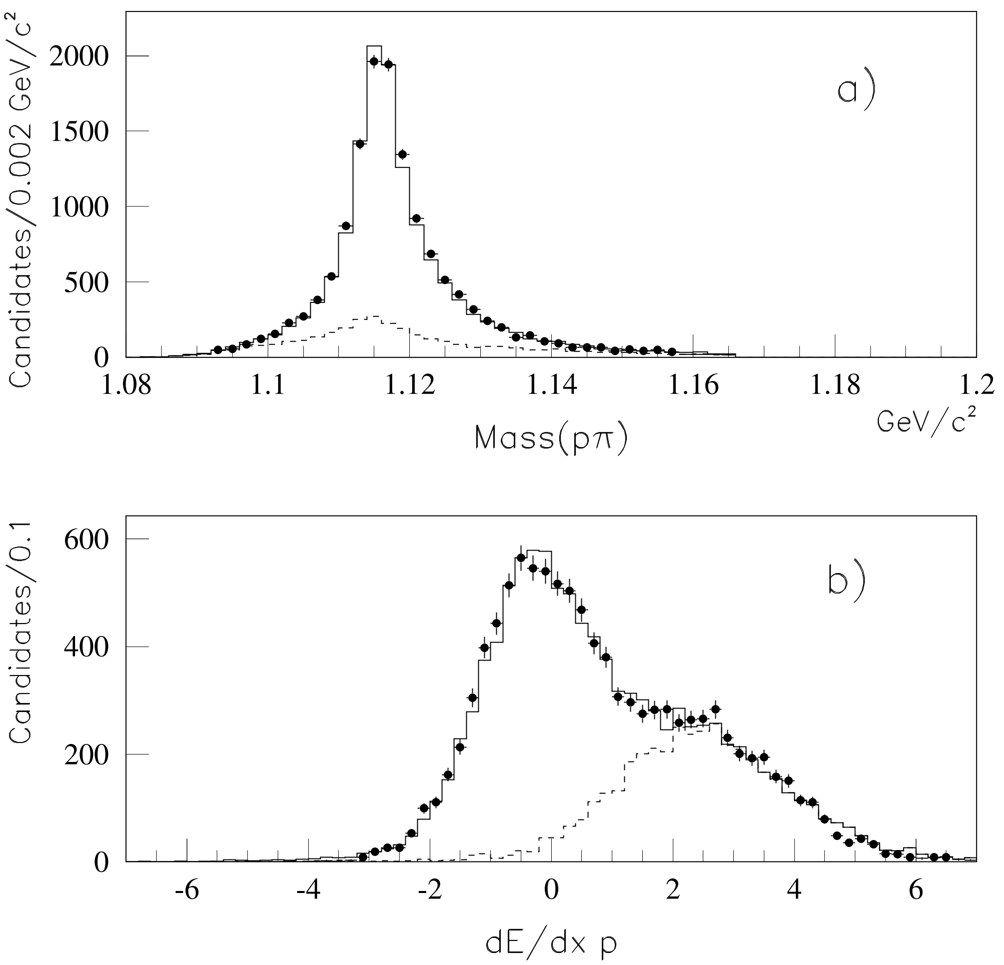

Figure 2: a) The invariant mass distribution of the $\Lambda \to p\pi$ sample before explicit mass cuts. b) The $\mathrm{d}E/\mathrm{d}x$ pull of the proton track before the cuts involving $\mathrm{d}E/\mathrm{d}x$.

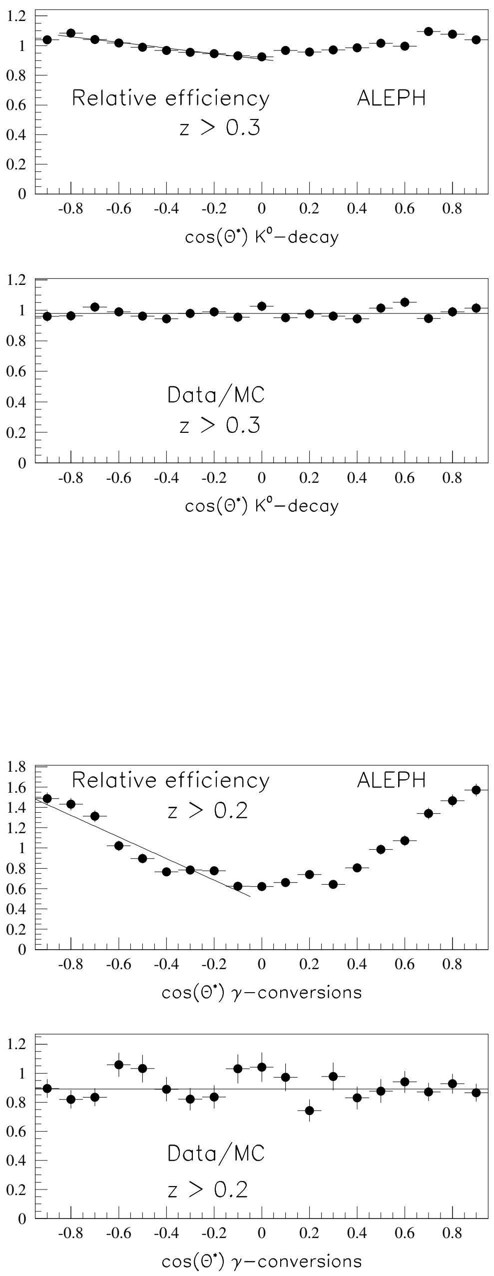

Figure 3: The relative efficiencies as a function of decay angle for selecting $\mathrm{K}^0 \rightarrow \pi^+\pi^-$ decays and $\gamma \rightarrow e^+e^-$ conversions. The Data/MC distributions are well described by a constant.

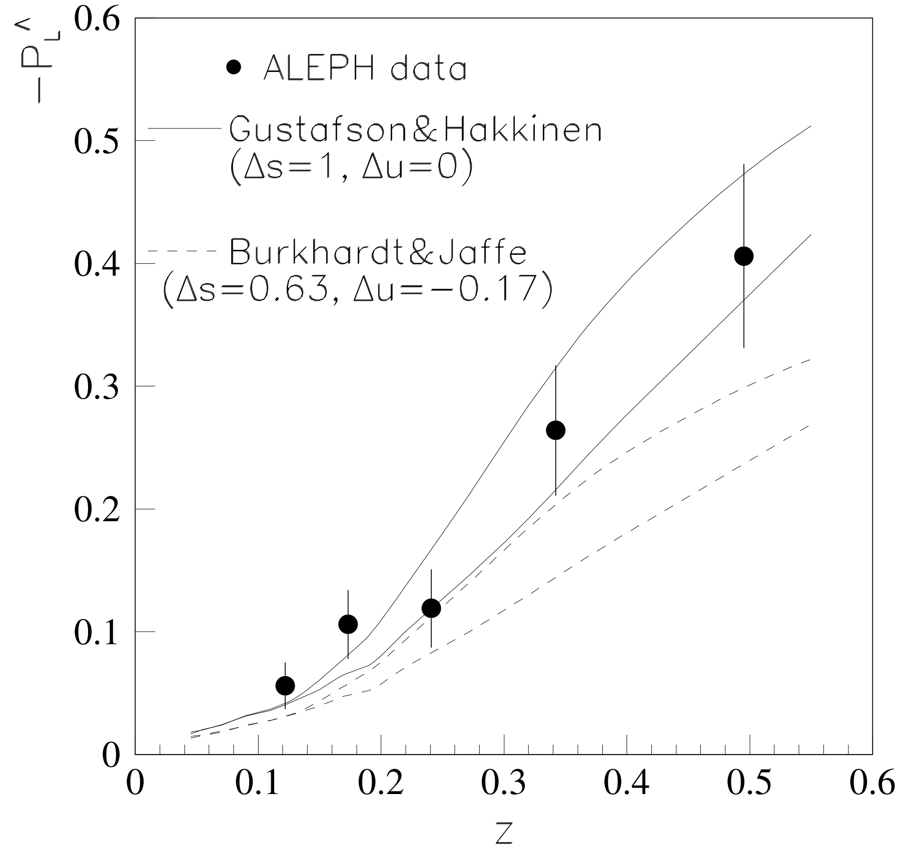

Figure 4: The measured longitudinal Λ polarization is shown as dots. Predictions based on [4] and [6] are shown as solid and dashed lines, respectively. The upper curve is for no "first rank baryon suppression" in JETSET, and the lower corresponds to the latest tuning. A theoretical uncertainty of about $\pm 20\%$ is common for all curves.