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Λ_b^0 POLARIZATION AT LEP*

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Theoretical predictions and experimental aspects of the Λ_b^0 baryon polarization measurement at LEP are briefly presented. In the typical LEP process $e^+e^- \to Z^0 \to f\bar{f}$ down-type quarks are born with a high (≈ -0.94) longitudinal polarization. In case of a heavy b quark its almost full transfer to the ground baryonic state Λ_b^0 makes an important prediction of the HQET (**H**eavy **Q**uark **E**ffective **T**heory). At LEP the Λ_b^0 polarization is experimentally accessible in its semileptonic decay mode through the lepton energy spectra. Moreover, since neutrino is predicted to be the decay product most sensitive to polarization its energy reconstruction is essential for the described method. First result on Λ_b^0 polarization coming from the ALEPH collaboration is presented.

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LEP is an excellent accelerator for exploring reactions in which b quarks take part. A $b\bar{b}$ pair is produced in a high fraction (15.4%) of Z^0 decays, and the b hadrons have large boost, making them more easily identifiable in the relatively clean environment of e^+e^- collisions.

In particular the analysis of baryons containing heavy quark b has been of growing interest to all LEP experiments over last few years. So far only the lightest baryonic state of this type — Λ_b^0 — has been explored in detail. The first observation of Λ_b^0 was made by the UA1 collaboration in 1991 [1] and its mass was determined to be $(5640 \pm 50 \pm 30)\mathrm{MeV}/c^2$. Subsequently, the substantial majority of results on b-baryons have come from LEP experiments.

Already this lightest ground baryonic state gives a unique possibility of investigating some phenomena inaccessible in case of the far more frequently

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occurring heavy mesons. One of such interesting effects is a Λ_b^0 strong longitudinal polarization being a direct consequence of polarization of the primary b quark coming from a Z^0 decay. The latter is precisely predicted in the framework of the Standard Model. For the typical LEP process $e^+e^- \to Z^0 \to f\bar{f}$ the formula for the primary fermion longitudinal polarization as a function of θ-production angle reads:

$$P_f = -\frac{A_f(1+\cos^2\theta) + 2A_e\cos\theta}{1+cos^2\theta + 2A_eA_f\cos\theta}, \quad \text{where} \quad A = \frac{2c_Vc_A}{c_V^2+c_A^2}. \qquad \text{(Ref. [2])} \tag{1}$$

For the down-type quarks polarization given in (1) is fairly stable along the whole range of production angle. Having averaged over this angle we are left with the mean b polarization:

$$\langle P_b\rangle = -A_b \cong -0.94 \quad \text{assuming} \quad \sin^2\Theta_W = 0.23\,. \tag{2}$$

In a meson system the information about the heavy quark spin state is lost since the mass and spin meson eigenstates are not identical. However, in case of the hadronization to a ground baryonic state full b polarization transfer to a Λ_b make an important prediction of the Heavy Quark Effective Theory. In the HQET approximation the degrees of freedom of a heavy quark are decoupled from a spin-zero light diquark. However, the indirect hadronization through heavier Σ and Σ^* states:

$$\begin{aligned} &b \longrightarrow \Sigma_b \longrightarrow \Lambda_b + \pi\,,\\ &b \longrightarrow \Sigma_b^* \longrightarrow \Lambda_b + \pi\,,\\ &b \longrightarrow \Sigma_b^* \longrightarrow \Sigma_b + \gamma \longrightarrow \Lambda_b + \pi + \gamma\,, \end{aligned} \tag{3}$$

are predicted to lead to a substantial depolarization of the heavy quark. The detailed discussion of different scenarios of indirect hadronization is given in [3]. This discussion shows that the Λ_b polarization measurement should give an important hint about heavy baryon hadronization processes and constitutes a subsequent test of HQET.

So far only the semileptonic Λ_b decay mode with a Λ_s in the final state has been accessible at LEP with a reasonable statistics and purity. Hence most of the analyses are based on the following decay channel:

$$\Lambda_b^0 \to \Lambda_c^+ + l^- + \bar{\nu}_l \to \Lambda_s^0 + l^- + \bar{\nu}_l + X \to p^+ + \pi^- + l^- + \bar{\nu}_l + X \tag{4}$$

and the charge coupled one. Here the letter l stands for either an electron or muon. There are two additional reasons for choosing semileptonic decays. First of all, there is a relatively easy way of Λ_b^0 tagging through Λ_s lepton correlations. Secondly, for the semileptonic decay there is a precise Standard

Model prediction on the double-differential (θ angle and energy) distribution of decay products in the Λ_b^0 rest frame. In the Born approximation the formula reads:

$$\frac{d^2\Gamma}{dy d\cos\theta} = \frac{d\Gamma}{dy}\tfrac{1}{2}[1 + P\alpha(y)\cos\theta]\,, \quad \text{(Ref. [4])} \tag{5}$$

$$\alpha_l(y) = \frac{(1-2y)(1-y) - \epsilon(1+y)}{(3-2y)(1-y) + \epsilon(3-y)}\,, \qquad \alpha_\nu(y) = 1\,,$$

$$\text{where} \quad y = \frac{2E}{m_b} \quad \text{and} \quad \epsilon = \frac{m_c^2}{m_b^2}\,.$$

Here E is the decay product energy in the Λ_b^0 rest frame and P is the Λ_b^0 polarization. m_b and m_c denote a free b and c quark mass respectively.

The first order QCD corrections for process (4) have been calculated [5] and are fortunately of the order of a few percent. Therefore comparing to our present experimental accuracies they are negligible and are not taken into account in this discussion.

From the form of the α coefficients one can see that for neutrino the angular dependance factorizes from the energetic one and hence the neutrino turns out to be the decay product most sensitive to polarization [6]. Unfortunately from the experimental point of view the charged lepton is over three times less sensitive to Λ_b^0 polarization. Its angular distribution is rather weakly altered by the polarization. Moreover, since we are not able to fully reconstruct the Λ_b^0 we are effectively limited to the LAB frame observables. Fortunately, the Λ_b^0 is fairly prompt in the LAB frame and the asymmetry in the above double differential distributions can be relatively easily expressed in terms of the energy spectra mean values:

$$\langle E^{\rm LAB}\rangle = \langle\gamma\rangle\langle E^{\rm CM}\rangle + \langle\gamma\beta\rangle\langle p^{\rm CM}_{\rm long}\rangle \cong \langle\gamma\rangle\left(\langle E^{\rm CM}\rangle + \langle p^{\rm CM}_{\rm long}\rangle\right)\,, \tag{6}$$

where $E^{\rm CM}$ and $p^{\rm CM}_{\rm long}$ are respectively the energy and the longitudinal momentum in the Λ_b^0 rest frame.

From the data we are able to extract the energy of both the charged lepton and the neutrino. The latter is reconstructed using the hemisphere missing energy method and hence carries with it considerable error.

Since the mean values of charged lepton and neutrino spectra are respectively correlated and anticorrelated with polarization the variable defined as:

$$y = \frac{\langle E_l\rangle}{\langle E_\nu\rangle} = \frac{\langle E_l^{\rm CM}\rangle + \langle p^{\rm CM}_{l_{\rm long}}\rangle}{\langle E_\nu^{\rm CM}\rangle + \langle p^{\rm CM}_{\nu_{\rm long}}\rangle}\,, \tag{7}$$

turns out to be highly sensitive to Λ_b^0 polarization [7]. Moreover, this observable is to a good approximation independent on fragmentation uncertainties since in the ratio the γ factor drops out. This crucial fact allows us to overcome the substantial problem of Λ_b^0 energy reconstruction. Similarly, a variable $\tilde{y}$ defined as:

$$\tilde{y} = \frac{E_l - E_\nu}{E_l + E_\nu} \tag{8}$$

has same advantages and additionally can be used for histogramming on the event-by-event basis.

The first measurement of the Λ_b^0 polarization at LEP based on the analysis of energy spectra of both leptons has been performed by ALEPH collaboration [8]. Using the hemisphere missing energy method described by the set of simple kinematical equations (9) ALEPH obtains for the single measurement σ_{E_ν}=2.8 GeV/c^2.

$$\begin{aligned} E_\nu &= E_{\rm tot} - E_{\rm vis}\,, \\ E_{\rm vis} &= E_{\rm char} + E_\gamma + E_{\rm neut.hadr.}\,, \\ E_{\rm tot} &= \frac{\sqrt{s}}{2} + \frac{M^2_{\rm same} - M^2_{\rm oppo.}}{2\sqrt{s}}\,, \end{aligned} \tag{9}$$

where

$E_{\rm char}$ = sum of all charged particle energies in the Λ_b hemisphere,
E_γ = sum of all neutral electromagnetic (γ) energies in the Λ_b hemisphere,
$E_{\rm neut.hadr.}$ = sum of all neutral hadronic energies in the Λ_b hemisphere,
$M_{\rm same}$ = mass of the Λ_b hemisphere calculated using both neutral and charged particles,
$M_{\rm oppo.}$ = mass of the opposite hemisphere calculated using both neutral and charged particles.

In the mean value of the energy spectrum it leads to an error of less then 200 MeV/c^2 ($\approx$260 Λ_b candidates). The final result on the Λ_b^0 polarization from the ALEPH analysis is:

$$P_{\Lambda_b} = -0.30^{+.32}_{-.27}({\rm stat.}) \pm 0.04({\rm sys.})\,. \tag{10}$$

This result, although not precise, indicates existence of a strong depolarization mechanism in the Λ_b^0 hadronization process. The analysis has been based on over 1.5 million Z^0 events coming from 1991–1993 data-taking periods.

The DELPHI collaboration is also working on beauty baryon analyses. So far the lifetime and production rate measurements have been completed [9]. Currently we are progressing with the polarization analysis based on methods similar to the ones used by ALEPH. We have already performed extensive analysis based on pure LUND generations and DELPHI Monte-Carlo. For this purpose a sample of about 20,000 polarized Λ_b^0 events (semileptonic decays) has been generated in the frame of the DELPHI full simulation program. We are significantly suffering from low efficiency for Λ_s^0 reconstruction caused by fairly small TPC – our main tracking device. There is still hope in more statistics coming from 1994 data-taking period which should almost double the statistics available at present ($\approx$ 1.5 million Z^0).

Besides our experiment has a unique proton identification capability thanks to the RICH (**R**ing **I**maging **CH**erenkov detector). This opens a possibility for future exploration of different channels like inclusive p^+l^- correlations or fully reconstructed $\Lambda_c \to p^+K^-\pi^+$.

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