HADRON SPIN PHYSICS AT OPAL

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Spin alignment of inclusive vector mesons and longitudinal polarization of Λ and Λ_b hyperons have been measured in a sample of 4.3 million hadronic Z^0 decays from the OPAL experiment at LEP. Leading, light vector mesons have been found to populate preferentially the helicity-zero state, a result which has no firm theoretical explanation. The values of off-diagonal elements of the helicity density matrix are in agreement with a model based on coherent fragmentation. The longitudinal polarization of the Λ (Λ_b) hyperons is well described by a model in which the constituent strange (beauty) quark carries all of the hyperon spin.

The primary quarks from Z^0 decay at LEP are produced with high longitudinal polarization (approximately -0.94 for down-type quarks). The polarization of leading hyperons composed of a heavy quark and a light diquark is expected to reflect this fact directly. However, it is still an open question as to what part, if any, the polarization of primary quarks plays in determining the helicities of leading vector mesons.

The present analyses are based on a sample of some 4.3 million multihadronic Z^0 decays recorded at the OPAL detector[a] at LEP 1 between 1990 and 1995. We have studied the helicity density matrices for inclusively produced B^*, $D^*(2010)^\pm$, $\phi(1020)$ and $K^*(892)^0$ mesons, concentrating on large values of meson momentum, where the mesons have a high probability to contain a primary quark from Z^0 decay. We have also studied the polarization of Λ hyperons and b baryons and compared the measurements with Monte Carlo models based on a simple constituent quark picture.

The formalism for the OPAL analyses of vector-meson helicity density matrices has been described fully in [2]. B^* mesons were studied in $B+\gamma$ decay mode [3]. The B meson candidates were reconstructed inclusively in jets containing a secondary vertex[4], and the photons, which for kinematic reasons had laboratory momenta below 800 MeV/c, were measured by their conversion in the material of the OPAL detector. The B^* signal was identified using the peak in the distribution of mass difference between the B^* and B candidate track combinations. From the angular distribution of the decay photons, we measured $\rho_{00} = 0.36 \pm 0.09$.

[a] For a general description of the OPAL detector and relevant sub-detectors see [1].

Details of our reconstruction of D^* candidates are described in [5,6]. For the spin analysis [2], only those combinations with scaled energy $x_E > 0.2$ were used. The D^* signal was identified as the peak at around 145 MeV$/c^2$ in the spectrum of the mass difference between D^* and D^0 candidate track combinations. The density matrix elements were measured using a maximum likelihood fit to the decay angular distributions, with the element ρ_{00} evaluated separately in the fit for $c \to D^*$, $b \to D^*$ and background events. The charm component included both directly produced D^* mesons and those from excited charm hadron decays. The results for the charm component were: $\rho_{00} = 0.40 \pm 0.02$ and $\mathrm{Re}\,\rho_{1-1} = -0.039 \pm 0.014$. So the OPAL data show enhanced production of D^* in the state of zero helicity, and a small negative value of $\mathrm{Re}\,\rho_{1-1}$.

In the $\phi(1020)$ analysis [2], inclusive K^+K^- pairs with scaled momentum $x_p > 0.7$ were identified using the $\mathrm{d}E/\mathrm{d}x$ measurements, and mass spectra were formed for three bins of the polar and azimuthal decay angles. Fits to these mass spectra to determine the $\phi(1020)$ intensities as functions of decay angles gave $\rho_{00} = 0.54 \pm 0.08$, again indicating preferential occupation of the helicity zero state. As in the case of the D^*, the off-diagonal element was found to have a small negative value, $\mathrm{Re}\,\rho_{1-1} = -0.11 \pm 0.07$.

For the inclusive $K^*(892)^0$ analysis [7], which had much higher statistics than the other channels, it was possible to fit $K^{\pm}\pi^{\mp}$ mass spectra and measure the K^{*0} cross sections in six bins of decay angles for twelve ranges of x_p. The results, given in figure 1, show clear deviations from $\rho_{00}= 1/3$ and $\mathrm{Re}\,\rho_{1-1}= 0$ at large momentum where the K^* is most likely to contain a primary quark from the Z^0 decay. Our measured value for the ratio $\mathrm{Re}\,\rho_{1-1}/(1-\rho_{00})$ is -0.19 ± 0.05 for $x_p > 0.3$, in reasonable agreement with the prediction [13] of -0.10 based on coherent fragmentation and some plausible assumptions about hadronization.

Figure 2 summarizes our measurements of the matrix element ρ_{00} for the four vector mesons. Apart from the B^*, all leading vector mesons have $\rho_{00} > 1/3$, and there is some evidence that the deviation from equal population of the three helicity states is larger for the lighter vector mesons.

Longitudinal polarization P_L^{Λ} of Λ hyperons was measured [8] using the angular distribution of $\Lambda \to p\pi$ decay in the rest frame of the hyperon, for nine ranges of scaled Λ energy x_E. P_L^{Λ} increases from around zero at small x_E to $-32.9\pm7.6\%$ for $x_E > 0.3$, in agreement with the value reported by ALEPH [9] over the same x_E range, and the expectations of the JETSET Monte Carlo program with different models of baryon production. Transverse polarization of Λ was found to be consistent with zero.

Semileptonic decays of b baryons with a Λ in the final state have been used to measure average polarization of weakly decaying b baryons. The ratio of

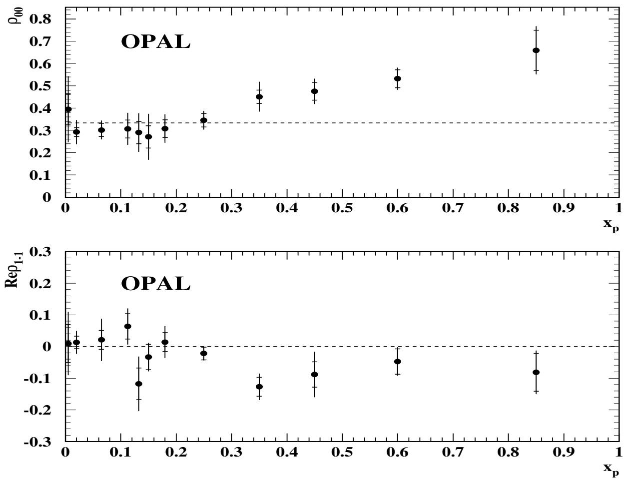

Figure 1: Measured K^{*0} helicity density matrix elements, ρ_{00} and $\mathrm{Re}\,\rho_{1-1}$, as functions of x_p. The error bars are statistical and systematic combined in quadrature, with the tick marks giving the statistical errors only.

the neutrino energy (estimated from missing energy measurements) and the charged lepton energy was found to be a sensitive observable, resulting in the measured value of the average b baryon polarization [10], $P_L^{\Lambda_b} = -0.56^{+0.20}_{-0.13} \pm 0.09$. Once again, this agrees well with simple Monte Carlo expectations, and is larger than, but consistent with an ALEPH measurement [11].

So, the OPAL vector meson measurements, together with some recent DELPHI [12] results, clearly establish that leading vector mesons, other than the B^*, are spin-aligned with a preference for the helicity-zero state. A number of models relevant to these observations are discussed in [2,12,13]. In the firmly-based and generally successful Lund string model of hadron formation, no spin alignment of vector mesons is expected, and the same is true of the cluster model of HERWIG. So although these QCD models have enjoyed a good measure of success in describing the LEP 1 data, the results on vector meson spin alignment still await a firm theoretical interpretation.

The OPAL measurements of small, negative values of the off-diagonal element $\mathrm{Re}\,\rho_{1-1}$ are in agreement with coherence in the primary $q\overline{q}$ production and fragmentation. In the case of the K^*, the numerical values are in agreement with a recent theory [13] based on the standard model.

While the vector meson spin-alignment results remain to be explained, the measurements of Λ and Λ_b polarization in the Z^0 decay data are consistent

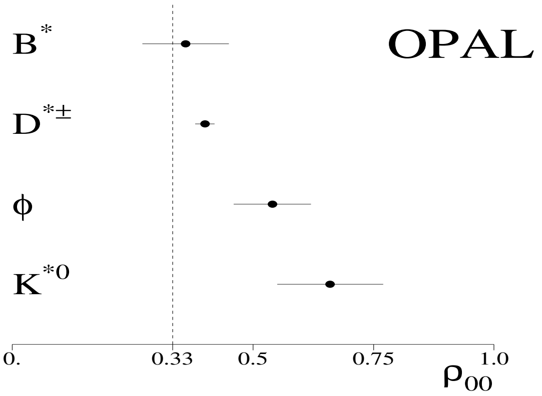

Figure 2: Values of helicity density matrix element ρ_{00} for four vector mesons. The D* result is for mesons produced by primary c quarks only. The results for ϕ and K* are for leading particles with $x_p > 0.7$. The dashed line corresponds to no spin alignment.

with a simple constituent quark model whereby primary quark polarization is transferred to a final state hyperon during hadronization.

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