A PRECISE MEASUREMENT OF THE NON-LEPTONIC WEAK DECAY PARAMETERS α AND ϕ IN THE SPIN 3/2 DECAY $\Omega^- \to \Lambda^0 + K^-$

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To get a physical feeling for the non-leptonic weak decay parameters α_Ω and $\Phi_\Omega = tan^{-1}(\beta/\gamma)$, and to understand how they manifest themselves in the decay of the spin 3/2 baryon $\Omega^- \to \Lambda^0 + K^-$, we first consider the more familiar (and topologically identical) case of the spin 1/2 hyperon decay sequence $\Xi^- \to \Lambda^0 + \pi^-$, $\Lambda^0 \to \pi^- + p$. The polarization of the daughter baryon $(\vec{P}_\Lambda)$ is related to the polarization of the parent $(\vec{P}_\Xi)$ as:

$$\vec{P}_\Lambda = \frac{(\alpha_\Xi + \hat{\Lambda} \cdot \vec{P}_\Xi)\hat{\Lambda} + \beta_\Xi(\vec{P}_\Xi \times \hat{\Lambda}) + \gamma_\Xi(\hat{\Lambda} \times \vec{P}_\Xi) \times \hat{\Lambda}}{1 + \alpha_\Xi \hat{\Lambda} \cdot \vec{P}_\Xi} \qquad (1)$$

where $\hat{\Lambda}$ is a unit vector defining the momentum direction of the daughter Λ in the Ξ rest frame. $\hat{\Lambda}$ and the vector cross-products that appear in the expression are mutually orthogonal and can be used to construct a very natural coordinate system known as the helicity axes.

$$\hat{X} = \frac{\vec{P}_\Xi \times \hat{\Lambda}}{\left|\vec{P}_\Xi \times \hat{\Lambda}\right|}, \qquad \hat{Y} = \frac{\hat{\Lambda} \times \left(\vec{P}_\Xi \times \hat{\Lambda}\right)}{\left|\hat{\Lambda} \times \left(\vec{P}_\Xi \times \hat{\Lambda}\right)\right|}, \qquad \hat{Z} = \hat{\Lambda} \qquad (2)$$

The parameters β and γ thus provide information about the strength of the daughter Λ's polarization as projected onto the $\hat{X}$ and $\hat{Y}$ helicity axes. Note that if the parent Ξ is unpolarized, α_Ξ is seen as the helicity of the Λ (i.e., from (1), with $\vec{P}_\Xi = 0$, $\vec{P} = \alpha_\Xi \hat{\Lambda}$).

The decay parameters α_Ξ, β_Ξ, and γ_Ξ also appear in the expressions for the distributions of the proton (from the Λ decay) as seen in the Λ rest frame. These expressions reduce to their simplest form when calculated with respect to the helicity axes.

$$I(\hat{X} \cdot \hat{p}) = \frac{1}{2}(1 - \gamma_\Xi[\frac{\pi}{4}\alpha_\Lambda P_\Xi \hat{Y} \cdot \hat{p}]) \qquad (3)$$

$$I(\hat{Y} \cdot \hat{p}) = \frac{1}{2}(1 + \beta_\Xi[\frac{\pi}{4}\alpha_\Lambda P_\Xi \hat{Y} \cdot \hat{p}])$$

$$I(\hat{\Lambda} \cdot \hat{p}) = \frac{1}{2}(1 + \alpha_\Xi[\alpha_\Lambda \hat{\Lambda} \cdot \hat{p}])$$

where $\hat{p}$ is the momentum direction of the proton in the rest frame of the parent Λ. Each of the decay parameters is a measure of the asymmetry of its associated distribution and indicates the strength of the parity violation taking place in the particular weak decay. The corresponding expressions in the spin-3/2 case of $\Omega^- \rightarrow \Lambda^0 + K^-$, $\Lambda^0 \rightarrow \pi^- + p$ are (Ref. 1):

$$I(\hat{X} \cdot \hat{p}) = \frac{1}{2}(1 - \gamma_\Omega[\frac{3\pi}{10}\alpha_\Lambda \hat{X} \cdot \hat{p}(P_\Omega - \frac{5}{16}\sqrt{\frac{7}{5}}t_{30}])) \qquad (4)$$

$$I(\hat{Y} \cdot \hat{p}) = \frac{1}{2}(1 + \beta_\Omega[\frac{3\pi}{10}\alpha_\Lambda \hat{Y} \cdot \hat{p}(P_\Omega - \frac{5}{16}\sqrt{\frac{7}{5}}t_{30}]))$$

$$I(\hat{\Lambda} \cdot \hat{p}) = \frac{1}{2}(1 + \alpha_\Omega[\alpha_\Lambda \hat{\Lambda} \cdot \hat{p}])$$

The most striking difference between the spin-1/2 case and the spin-3/2 is that the asymmetry parameters β and γ are now tangled up with a tensor polarization term t_{30}. Thankfully, this term cancels in the calculation of ϕ_Ω. To see this, first note that the dot products of the momentum direction of the proton in the Λ rest frame with each of the helicity axes are just cosines, and so the distributions plotted as a function of these cosines should be linear with slope

$$\hat{X}: \qquad -\gamma_\Omega \quad [\frac{3\pi}{10}\alpha_\Lambda(P_\Omega - \frac{5}{16}\sqrt{\frac{7}{5}}t_{30})] \qquad (5)$$

$$\hat{Y}: \qquad \beta_\Omega \quad [\frac{3\pi}{10}\alpha_\Lambda(P_\Omega - \frac{5}{16}\sqrt{\frac{7}{5}}t_{30})]$$

$$\hat{\Lambda}: \qquad \alpha_\Omega \quad [\alpha_\Lambda]$$

In calculating the ϕ parameter, we use only the *ratio* of the slopes involving β and γ, which is independent of t_{30}. This ratio is also independent of the magnitude of the polarization $\vec{P}_\Omega$, though the direction of $\vec{P}_\Omega$ is necessary in constructing the helicity axes. Since each distribution is a linear function of a particular $cos\theta$, our job as experimentalists is easy: we measure the distribution of the proton in the Λ rest frame (eg. Fig 1), find its slope (properly corrected for the acceptance), and extract α_Ω and ϕ_Ω.

We can estimate the magnitude of the asymmetry parameters by expressing them in terms of the p-wave (B_p) and d-wave (B_d) amplitudes as

$$\alpha = \frac{2Re(B_p{}^*B_d)}{(\mid B_p \mid^2 + \mid B_d \mid^2)}, \quad \beta = \frac{2Im(B_p{}^*B_d)}{(\mid B_p \mid^2 + \mid B_d \mid^2)}, \quad \gamma = \frac{\mid B_p \mid^2 - \mid B_d \mid^2}{(\mid B_p \mid^2 + \mid B_d \mid^2)} \qquad (6)$$
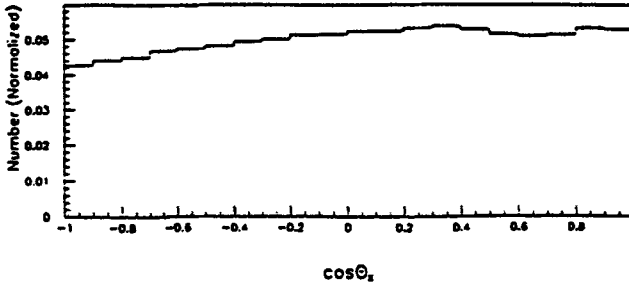
Figure 1: Distribution of protons in the Λ rest frame with respect to the X-helicity axis

with

$$\alpha^2 + \beta^2 + \gamma^2 = 1 \tag{7}$$

Since B_d is suppressed with respect to B_p by a factor of $(M_{\Xi^0} - M_\Lambda)/(M_{\Xi^0} + M_\Lambda) \sim 0.08$ (Ref. 2), we would expect that $\alpha_\Omega \sim 0$, $\beta_\Omega \sim 0$, and $\gamma_\Omega \sim 1$, so that $\phi_\Omega \sim 0$.

The E800 spectrometer at Fermilab was a simple particle tracking device consisting of (Fig. 2): 12 Multi-Wire Proportional Chambers (MWPCs) shown as C1-C12 in the figure, 8 Silicon Strip Detectors (SSDs), 4 scintillation counters (S1,S2, and veto counters V1 and V2), and 2 analysis magnets (PC4AN1 and PC4AN2). Polarized Ω^-s (and Ξ^-s) were produced upstream of the spectrometer using both polarized and unpolarized neutral beams (Ref. 3) in conjunction with two magnets (PC3SW and PC3ANA) and two targets (TGT1 and TGT2). The hardware trigger ensured that the parent particles accepted were traversing the zero-line of the spectrometer and that their decay products evinced the characteristic V-topology associated with the decay of the Λ hyperons. This loose trigger configuration allowed us to write 1.35×10^9 events to tape, although only $\sim 3\%$ of these proved to be good three-track events. Of these three-track events, most were Ξ^-s with an admixture of about 1% Ω^-s.

To extract a small Ω signal buried amidst the deluge of Ξ background, we employed several kinematic selection criteria in addition to the set of cuts used to garner the good three-track events. In reconstructing the events, the mass of the parent particle was calculated twice: once assuming the event was an $\Omega^- \rightarrow \Lambda^0 + K^-$ and again assuming it was a $\Xi^- \rightarrow \Lambda^0 + \pi^-$. Some Ξ^-s reconstructed both as good Ξ^-s and as good Ω^-s and could be eliminated from the Ω sample by requiring that $cos\theta_K > 0.775$, where θ_K is the angle made by the daughter kaon in the Ω rest frame with respect to the $\hat{z}$ axis of the spectrometer. Moreover, a subset of Ξs which decayed in the charged particle collimator and whose decay products were bent in the fringe field of the
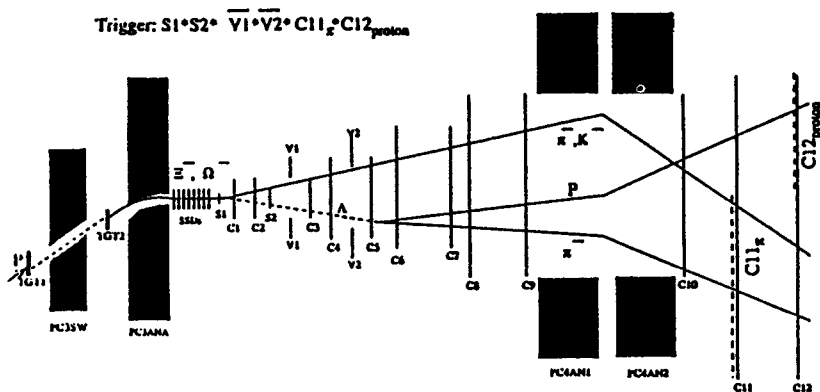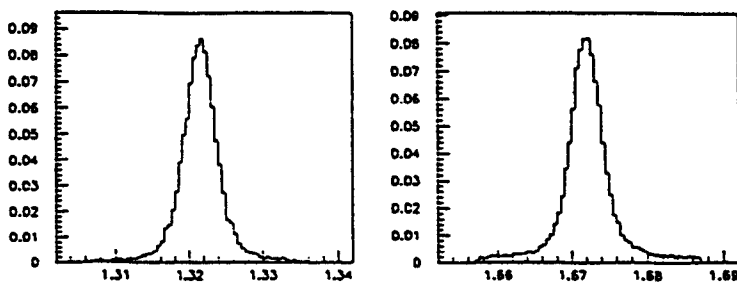
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Figure 2: The E800 spectrometer

Figure 3: The Cascade (left) and Omega (right) mass peaks (scale in Gev.)

the PC3ANA magnet also reconstructed as good Ω^- candidates. Imposing a second kinematic cut, $\cos\theta_K > (|\ 0.008125 \times \phi_K\ | -1.8125)$ (where ϕ_K is the azimuthal angle associated with θ_K) expunged these events from the Ω^- event sample. Monte carlo studies indicated that these cuts removed only $\sim 5\%$ of the Ωs while reducing the background by 99.9%. The final data sample used for this analysis contained 252×10^3 $\Omega^- \rightarrow \Lambda^0 + K^-$ events. Figure 3 shows the cleanliness of the cascade and omega mass peaks.

The most critical element in the measurement of α_Ω and ϕ_Ω was the accuracy with which we could reconstruct the decay angle in the Λ rest frame (i.e., $cos\theta$). The bin size used in the analysis was 0.1 (20 bins from -1.0 to +1.0). We fed monte carlo data into the reconstruction algorithms to determine the percentage of reconstructed events that were within a bin width of the known monte carlo value; the results indicated that 99.8% were reconstruced into the bins from which they came.

To correct for the non-uniform acceptance of the spectrometer and reconstruction programs, we used a hybrid monte carlo (Ref. 4) which used all of the
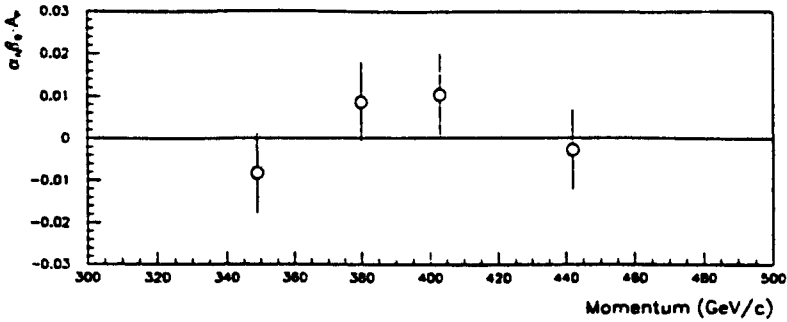
Figure 4: A systematic study of the asymmetry involving β_Ω vs momentum

characteristics of the real events except those associated with $cos\theta$, which was generated randomly. In essence, the hybrid monte carlo allowed us to require that every good event could have had any value of $cos\theta$ and still have been accepted by the spectrometer and reconstruction.

Data collection at opposite production angles at the target allowed us to use a bias cancellation technique to help eliminate any systematic effects. For the α_Ω measurement, we studied the data as a function of momentum, uncertainty in the bias measurement, run type, time and selection criteria to estimate the magnitude of the systematics. For ϕ_Ω, the polarization direction was also studied. In all cases, the systematic errors were negligible when compared with the statistical errors. A sample is shown in Figure 4.

The final answers are:

$$\alpha_\Lambda \alpha_\Omega = 0.0126 \pm 0.0042 \tag{8}$$
$$\alpha_\Omega = 0.0196 \pm 0.0066$$
$$\phi_\Omega = -3.4° \pm 10.3° \tag{9}$$

E800's measurement of α_Ω is almost four times more precise than the previous world average value of -0.026 ± 0.026 (Ref. 5) and shows this parameter to be inconsistent with zero. This is the first measurement of the parameter ϕ_Ω.

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