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

D.P. Ciampa$^a$, P.M. Border$^a$, Y.T. Gao$^{b,e}$, G. Guglielmo$^{a,f}$, K.J. Heller$^a$, K.A. Johns$^c$, M.J. Longo$^b$, R. Rameika$^d$, N.B. Wallace$^a$, D.M. Woods$^a$

$^a$School of Physics and Astronomy, University of Minnesota, Minneapolis, MN 55455
$^b$Department of Physics, University of Michigan, Ann Arbor, MI 48109
$^c$Department of Physics, University of Arizona, Tucson, AZ 85721
$^d$Fermi National Accelerator Laboratory, Batavia, IL 60510
$^e$now at Lanzhao University, Lanzhao, China
$^f$now at University of Oklahoma, Norman, Oklahoma

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

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

where $\hat{\Lambda}$ is a unit vector defining the momentum direction of the daughter $\Lambda$ in the $\Xi$ 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.

$$\hat{X} = \frac{\vec{P}_\Xi \times \hat{\Lambda}}{|\vec{P}_\Xi \times \hat{\Lambda}|}, \quad \hat{Y} = \frac{\hat{\Lambda} \times (\vec{P}_\Xi \times \hat{\Lambda})}{|\hat{\Lambda} \times (\vec{P}_\Xi \times \hat{\Lambda})|}$$, \hspace{1cm} (2) \hspace{1cm} \hat{Z} = \hat{\Lambda}

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

The decay parameters $\alpha_\Xi, \beta_\Xi$, and $\gamma_\Xi$ also appear in the expressions for the distributions of the proton (from the $\Lambda$ decay) as seen in the $\Lambda$ rest frame. These expressions reduce to their simplest form when calculated with respect to the helicity axes.

$$I(\hat{X} \cdot \vec{p}) = \frac{1}{2} \left(1 - \gamma_\Xi\left[\frac{\pi}{4} \alpha_\Lambda \vec{P}_\Xi \hat{Y} \cdot \vec{p}\right]\right)$$  \hspace{1cm} (3)

© 1995 American Institute of Physics

692
where \( \hat{p} \) is the momentum direction of the proton in the rest frame of the parent \( \Lambda \). 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):

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

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

The most striking difference between the spin-1/2 case and the spin-3/2 is that the asymmetry parameters \( \beta \) and \( \gamma \) are now tangled up with a tensor polarization term \( t_{30} \). Thankfully, this term cancels in the calculation of \( \phi_\Omega \). To see this, first note that the dot products of the momentum direction of the proton in the \( \Lambda \) 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

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

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

\[
\hat{\Lambda} : \quad \alpha_\Omega \left[ \alpha_\Lambda \right]
\]

In calculating the \( \phi \) parameter, we use only the ratio of the slopes involving \( \beta \) and \( \gamma \), which is independent of \( t_{30} \). This ratio is also independent of the magnitude of the polarization \( P_\Omega \), though the direction of \( P_\Omega \) 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 \( \Lambda \) rest frame (eg. Fig 1), find its slope (properly corrected for the acceptance), and extract \( \alpha_\Omega \) and \( \phi_\Omega \).

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

\[
\alpha = \frac{2Re(B_p^*B_d)}{(|B_p|^2 + |B_d|^2)}, \quad \beta = \frac{2Im(B_p^*B_d)}{(|B_p|^2 + |B_d|^2)}, \quad \gamma = \frac{|B_p|^2 - |B_d|^2}{(|B_p|^2 + |B_d|^2)}
\]
with

$$\alpha^2 + \beta^2 + \gamma^2 = 1 \quad (7)$$

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 $\Omega^-$s (and $\Xi^-$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 $\Lambda$ hyperons. This loose trigger configuration allowed us to write $1.35 \times 10^9$ events to tape, although only $\sim 3\%$ of these proved to be good three-track events. Of these three-track events, most were $\Xi^-$s with an admixture of about $1\% \Omega^-$s.

To extract a small $\Omega$ signal buried amidst the deluge of $\Xi$ 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 $\Xi^-$s reconstructed both as good $\Xi^-$s and as good $\Omega^-$s and could be eliminated from the $\Omega$ sample by requiring that $\cos \theta_K > 0.775$, where $\theta_K$ is the angle made by the daughter kaon in the $\Omega$ rest frame with respect to the $\hat{z}$ axis of the spectrometer. Moreover, a subset of $\Xi$s which decayed in the charged particle collimator and whose decay products were bent in the fringe field of the
the PC3ANA magnet also reconstructed as good $\Omega^-$ candidates. Imposing a second kinematic cut, $\cos \theta_K > (|0.008125 \times \phi_K| - 1.8125)$ (where $\phi_K$ is the azimuthal angle associated with $\theta_K$) expunged these events from the $\Omega^-$ event sample. Monte carlo studies indicated that these cuts removed only $\sim 5\%$ of the $\Omega$s while reducing the background by $99.9\%$. The final data sample used for this analysis contained $252 \times 10^3 \Omega^- \rightarrow \Lambda^0 + K^-$ events. Figure 3 shows the cleanliness of the cascade and omega mass peaks.

The most critical element in the measurement of $\alpha_\Omega$ and $\phi_\Omega$ was the accuracy with which we could reconstruct the decay angle in the $\Lambda$ 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 reconstructed 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
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 $\alpha_\Omega$ 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 $\phi_\Omega$, 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:

$$\alpha_A \alpha_\Omega = 0.0126 \pm 0.0042$$
$$\alpha_\Omega = 0.0196 \pm 0.0066$$
$$\phi_\Omega = -3.4^\circ \pm 10.3^\circ$$

E800's measurement of $\alpha_\Omega$ is almost four times more precise than the previous world average value of $-0.026 \pm 0.026$ (Ref. 5) and shows this parameter to be inconsistent with zero. This is the first measurement of the parameter $\phi_\Omega$.

This work was supported by the U.S. Department of Energy and the National Science Foundation.

3. K. Johns, these proceedings.