Measurement of α_Ω in $\Omega^- \to \Lambda K^-$ Decays

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Abstract. The *HyperCP* experiment (E871) at Fermilab has collected the largest sample of hyperon decays in the world. With a data set of over a million $\Omega^- \to \Lambda K^-$ decays we have measured the product of $\alpha_\Omega \alpha_\Lambda$ from which we have extracted α_Ω. This preliminary result indicates that α_Ω is small, but non-zero. Prospects for a test of *CP* symmetry by comparing the α parameters in Ω^- and $\overline{\Omega}^+$ decays will be discussed.

INTRODUCTION

In the quark model, the Ω baryon is predicted to have spin $J = 3/2$. The spin of it has not yet been determined experimentally, but measurements made by Deutschmann *et al.* [1] and Baubillier *et al.* [2] have ruled out $J = 1/2$ and found consistency with $J = 3/2$. Angular momentum conservation allows the ΛK system in the decay $\Omega \to \Lambda K$ to be P and D, corresponding to parity conserving and parity violating amplitudes respectively. Parity violation is characterized by the parameter α_Ω defined as $\alpha_\Omega = 2Re(P^* D)/(|P|^2 + |D|^2)$ [3]. A non-zero α_Ω is the signature of parity violation in this decay.

Although the main goal of the *HyperCP* experiment at Fermilab is to search for *CP* violation in $\Xi \to \Lambda\pi \to p\pi\pi$ decays with a precision at the 10^{-4} level, the topological similarity of $\Omega \to \Lambda K \to p\pi K$ decays to $\Xi \to \Lambda\pi \to p\pi\pi$ decays has enabled us to

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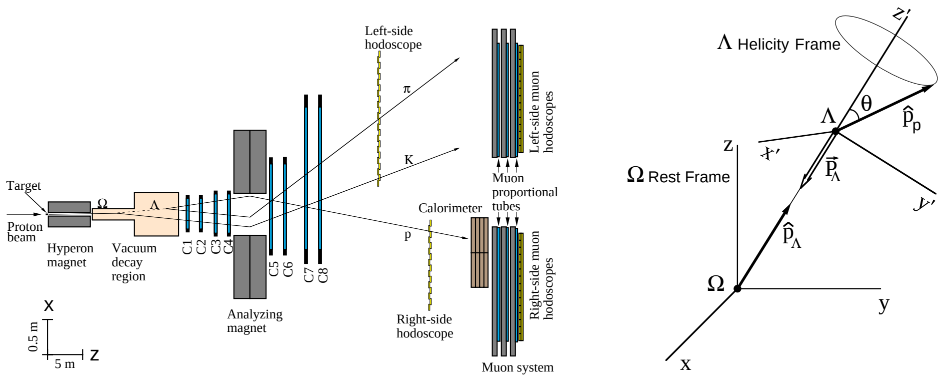

FIGURE 1. (a) Plan view of the *HyperCP* spectrometer. (b) Proton direction in the Λ helicity frame.

collect a large sample of Ω events [4]. Nineteen million Ω^- and $\overline{\Omega}^+$ were acquired during RUN-I (1997) and RUN-II (1999), allowing us to measure α_Ω for both Ω^- and $\overline{\Omega}^+$ decays at the 10^{-3} level. A difference between $|\alpha_\Omega|$ and $|\alpha_{\overline{\Omega}}|$ would be evidence of *CP* violation in $\Omega \to \Lambda K \to p\pi K$ decays.

THE *HYPERCP* SPECTROMETER

Figure 1 (a) shows the spectrometer used in the *HyperCP* experiment. Hyperons are produced by 800-GeV protons from the Tevatron striking a target. Omegas and other charged particles travel through a curved magnetic channel (collimator) followed by a vacuum decay pipe. The trajectories of the K from the Ω decay and the proton and π from the Λ decay are measured by four proportional wire chambers upstream of the analyzing magnet. The K and the π are deflected to the left side of the spectrometer, and the proton is deflected to the right side in the field of the analyzing magnet. After four downstream proportional wire chambers the K and the π strike the Left-side Hodoscope, and the proton strikes the Right-side Hodoscope before depositing energy in the calorimeter. Two muon stations are located downstream of the calorimeter. These are used to identify muons from rare kaon and hyperon decays. The Left-side Hodoscope, Right-side Hodoscope, and the calorimeter were used to form the triggers, which had a rate of $50 \sim 80$ KHz. The samples of Ω and $\overline{\Omega}^+$ were taken alternatively by switching the sign of the Hyperon Magnet and the Analyzing Magnet.

ANALYSIS METHOD

For unpolarized Ω, the angular distribution of the proton in $\Omega \to \Lambda K \to p\pi K$ decays is expressed as

$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1+\alpha_\Omega\alpha_\Lambda \cdot \cos\theta), \quad \alpha_\Lambda \equiv \frac{2Re(S^*P)}{|S|^2+|P|^2}, \tag{1}$$

where θ is the polar angle of proton in the Λ helicity frame, and α_Λ is the decay parameter for $\Lambda \to p\pi$ decays. As illustrated in Figure 1 (b), $\vec{P}_\Lambda$ represents the Λ polarization, $\hat{p}_\Lambda$ is the Λ momentum, and $\hat{p}_p$ is the unit momentum of the proton in the Λ helicity frame. In reality, the proton $\cos\theta$ distribution is distorted by the spectrometer acceptance. To correct for the acceptance we use a Hybrid Monte-Carlo method (HMC) [5] in our data analysis. We take all variables from each real event except $\cos\theta$, generate Monte-Carlo events (to distinguish them from normal Monte-Carlo events, we call them HMC fake events) with uniform $\cos\theta$, and then let all the HMC fake events go through the software spectrometer, triggers, event selection cuts, etc. to simulate the behavior of real events in the experiment. Assuming the Monte-Carlo code describes the spectrometer perfectly, the distortion by the acceptance of the proton angular distribution of fake events should be exactly the same as for real events.Matching the fake event $\cos\theta$ distribution to the real event $\cos\theta$ distribution by minimizing the χ^2 in Eq. (2), without explicitly computing the acceptance correction, gives us the unknown $\alpha_\Omega\alpha_\Lambda$,

$$\chi^2(X) = \sum_{k=1}^{20} \frac{[N_r(k) - N_f(X,k)]^2}{\sigma_k^2}, \tag{2}$$

here $X \equiv \alpha_\Omega\alpha_\Lambda$, $\sigma_k^2 = N_r(k) + N_f(X,k)$, and $N_r(k)$ and $N_f(X,k)$ are numbers of real events and fake events in bin k respectively.

RESULTS

To select good $\Omega \to \Lambda K \to p\pi K$ decays, we require events to meet the topology of three tracks and two vertices. The initial filtering process, which is a geometric fit, gets rid of most events that have the wrong topology. All three-track combinations in an event are required to have a Λ vertex and a Ω vertex under the hypothesis of $\Omega \to \Lambda K \to p\pi K$ decay. Those three tracks that best match the $\Omega \to \Lambda K \to p\pi K$ hypothesis are kept for the further study. If the $p\pi$ invariant mass and ΛK invariant mass are ± 50 MeV of the Λ and Ω PDG masses, we consider this event as a Ω decay candidate. Additional cuts are required to get a clean Ω sample including: 1) cuts on z positions of Λ and Ω vertices, 2) Λ vertex downstream of the Ω vertex, 3) x-projection and y-projection of the Ω track at the target within the xy-dimension of the target, 4) a cut on $K \to 3\pi$ mass, and 5) a cut on the geometric fit χ^2.

We have obtained a preliminary result for the Ω^- from the RUN-I data. Figure 2 (a) shows the ΛK invariant mass of 1.2 million events after all event selection cuts. Under the signal region (marked by arrows), the ratio of background to signal is 0.7%. The raw $\alpha_\Omega\alpha_\Lambda$ before background correction, defined as S_m, is measured to be $(1.32 \pm 0.29) \times 10^{-2}$. The comparison of proton angular distributions of real and fake events after the matching is shown in Figure 2 (b). The bias from the background was investigated using the side bands of the ΛK invariant mass. A careful study shows that the contributions from the side bands at low mass region and high mass region are essentially the same, and the mean value is $S_b = (21.77 \pm 1.80) \times 10^{-2}$. Assuming the background under the mass peak has the same shape as side bands, we use the formula $\alpha_\Omega\alpha_\Lambda = N_m S_m / N_s -$

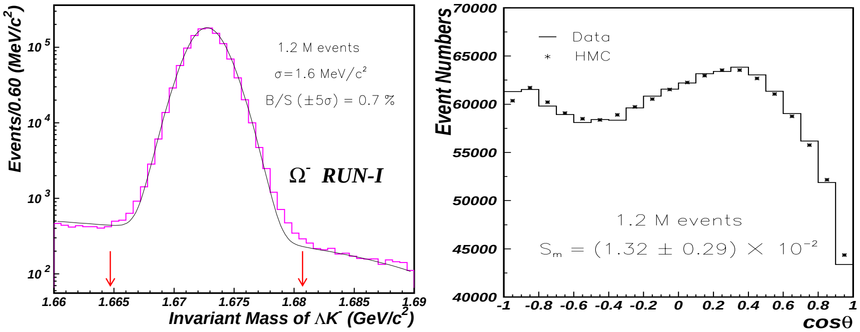

FIGURE 2. (a) ΛK invariant mass. (b) The $\cos\theta$ distributions after matching.

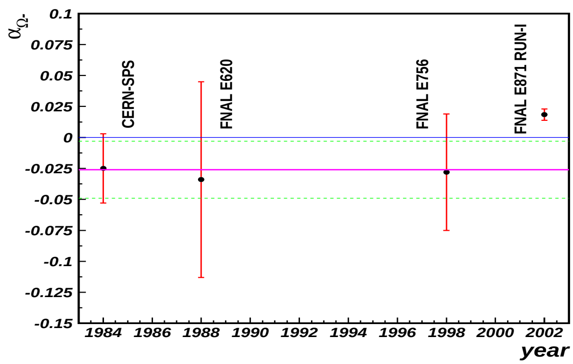

FIGURE 3. Different measurements of α_Ω for Ω^-. The lower solid line is for PDG value and the error is marked by the two dashed lines. The upper solid line marks the position of zero.

N_bS_b/N_s to obtain the $\alpha_\Omega\alpha_\Lambda$, where N_m, N_s, and N_b are numbers of measured events, signal events, and background events respectively. With this background correction, our preliminary result is: $\alpha_\Omega\alpha_\Lambda = [1.18 \pm 0.29\ (\mathrm{stat})] \times 10^{-2}$. Using PDG value for α_Λ (0.642 ± 0.013 [6]), α_Ω is extracted:

$$\alpha_\Omega = [1.84 \pm 0.46\ (\mathrm{stat}) \pm 0.04\ (\mathrm{sys\ PDG})] \times 10^{-2}, \tag{3}$$

where 0.04×10^{-2} is the error propagated from the error of α_Λ. The stability of our result with different cuts and different data samples indicates that the systematic error is expected to be smaller than the statistical error. However, the systematic errors are still under investigation. The small but non-zero of α_Ω value indicates parity violation in $\Omega^- \to \Lambda K^-$ decays. Figure 3 shows the comparison of our preliminary measurement from RUN-I data with previous experimental results which are all consistent with zero within the error bars.

Analysis of Ω^- and $\overline{\Omega}^+$ data samples from RUN-II have just begun. With similar event selection cuts, we get about 4.6 million Ω^- and 1.9 million $\overline{\Omega}^+$. The measured raw $\alpha_\Omega\alpha_\Lambda$ before background correction are $S_m = (1.41 \pm 0.11) \times 10^{-2}$ and $S_m =$

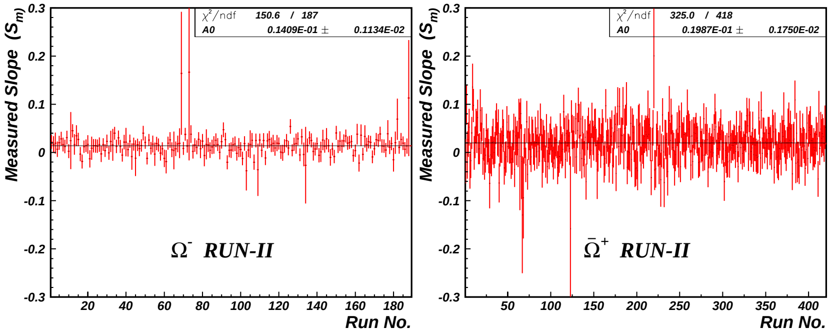

FIGURE 4. Raw $\alpha_\Omega\alpha_\Lambda$ versus run number (RUN-II data).

$(1.99 \pm 0.18) \times 10^{-2}$ for Ω^- and $\overline{\Omega}^+$ respectively. The Ω^- result is consistent with RUN-I data with over two times smaller statistical error. Figure 4 shows the raw $\alpha_\Omega\alpha_\Lambda$ versus different run number of RUN-II data for both Ω^- and $\overline{\Omega}^+$.

By measuring the difference of $\alpha_\Omega\alpha_\Lambda$ between Ω^- and $\overline{\Omega}^+$, which is defined as

$$\Delta(\alpha_\Omega\alpha_\Lambda) \equiv \alpha_\Omega\alpha_\Lambda - \alpha_{\overline{\Omega}}\alpha_{\overline{\Lambda}} \quad \text{or} \quad A_{\Omega\Lambda} \equiv \frac{\alpha_\Omega\alpha_\Lambda - \alpha_{\overline{\Omega}}\alpha_{\overline{\Lambda}}}{\alpha_\Omega\alpha_\Lambda + \alpha_{\overline{\Omega}}\alpha_{\overline{\Lambda}}} \approx A_\Omega + A_\Lambda, \tag{4}$$

we can test CP-violation in $\Omega \to \Lambda K \to p\pi K$ decays. The statistical precisions of $\Delta(\alpha_\Omega\alpha_\Lambda)$ and $A_{\Omega\Lambda}$ are estimated to be 2×10^{-3} and 9×10^{-2} respectively for RUN-II data. Systematic errors are expected to be very similar between Ω^- and $\overline{\Omega}^+$ and should almost cancel in this comparison.

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REFERENCES

1. M. Deutschmann *et al.*, Phys. Lett. 73B, (1978) 96.
2. M. Baubillier *et al.*, Phys. Lett. 78B, (1978) 342.
3. T. D. Lee and C. N. Yang, Phys. Rev. 108, (1957) 1645.
4. E.C. Dukes, K.B. Luk, *et al.*, Fermilab Proposal P-871 (1994).
5. G. Bunce, Nucl. Instr. Meth. 172, (1980) 553.
6. Particle Data Group, Phys. Rev. D66, (2002) 010001-821.