Polarization of Ω^- Hyperons Produced in 800 GeV Proton-Beryllium Collisions

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The polarization of 103 211 Ω^- hyperons produced in 800 GeV proton-beryllium inclusive reactions has been measured. Between $0.3 < x_F < 0.7$ and $0.5 < p_t < 1.3$ GeV/c, the Ω^- polarization is found to be consistent with zero, with a mean value of -0.01 ± 0.01 at $\langle x_F \rangle = 0.5$ and $\langle p_t \rangle = 0.95$ GeV/c. This behavior is similar to that of $\bar{\Lambda}^0$, which also does not have any quarks in common with the incident proton, but is different from $\bar{\Xi}^+$, which is significantly polarized in the same kinematic region.

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Since the discovery that Λ^0 hyperons produced by protons were polarized at high energies [1], polarization measurements have been made on most of the stable baryons. A nonzero polarization was also observed for the Ξ^0, Ξ^-, Σ^+, Σ^0, and Σ^- hyperons [2-7]. As required by parity conservation in strong interactions, the resulting polarization is in the direction perpendicular to the production plane of the hyperon. Typically the magnitude of the polarization is of the order of 10% at x_F of 0.5 and p_t of 1 GeV/c. A polarization consistent with zero was found for the $\bar{\Lambda}^0$ in the same kinematic region [8].

Since the $\bar{\Lambda}^0$ does not have any valence quarks of the incident proton, its zero production polarization agrees with models in which the hyperon polarization is a consequence of the recombination of at least one leading quark from the projectile with the sea quarks [9]. However, the recent discovery that $\bar{\Xi}^+$ antihyperons created by protons exhibit a polarization comparable to that of Ξ^- has cast doubts on the validity of polarization models that incorporate the leading quark effect [10]. The Ω^- is a baryon yet, like the antihyperons, it does not have any valence quarks in common with the incoming protons. Determining the polarization of Ω^-'s produced by protons should improve our understanding of the quark production process via the strong interaction. This paper reports the first statistically significant measurement of the Ω^- polarization.

The result is based on a sample of 103 211 reconstructed Ω^-'s produced by 800 GeV protons incident on a beryllium target at Fermilab. The Ω^- hyperons were detected through the $\Omega^- \to \Lambda^0 + K^-$ and $\Lambda^0 \to p + \pi^-$ decay sequence. The apparatus of this experiment, E-756, has been described in some detail elsewhere [11]. After emerging from the target, the Ω^-'s passed through a 7.3 m long bending magnet, M1. The Ω^-'s and their decay products were then detected by a spectrometer consisting of silicon microstrip detectors, multiwire proportional chambers, scintillators, and an analysis magnet, M2. Data were taken with a vertical production angle of 2.4 mrad at five different M1 field integrals. The production angle was reversed regularly to change the sign of any possible polarizations in order to minimize the effects of any apparatus asymmetries. The field of the momentum analyzing magnet was also reversed periodically for the same reason. A right-handed coordinate system was chosen with the y axis vertical up, and the z axis along the designed path of a 500 GeV Ω^- originating from the center of the target and emerging into the spectrometer through the centers of the collimator. The x axis was normal to the y and z axes. Any precession of the Ω^-

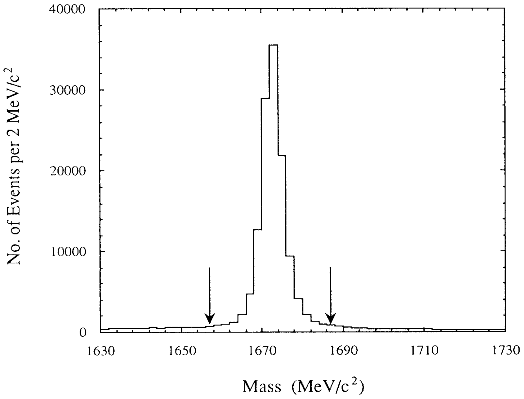

FIG. 1. Λ^0-K^- invariant mass of the final data sample. Events with mass between the arrows are used in the polarization analysis.

spin due to its magnetic moment in the magnetic field of M1 would yield a polarization in the x-z plane when the Ω^- decayed in the spectrometer.

Event selection was based on both geometric and kinematic criteria in the off-line analysis. Invariant masses of each event were calculated under the Λ^0-π^- and Λ^0-K^- hypotheses. Most of the reconstructed events were $\Xi^- \rightarrow \Lambda^0 + \pi^-$ decays that were recorded along with the Ω^- decays in a ratio of about 75 to 1. By requiring the Λ^0-π^- invariant mass of the event to be greater than 1.345 GeV/c^2, more than 99% of the $\Xi^- \rightarrow \Lambda^0 + \pi^-$ decays were rejected. Additional requirements imposed on the data for selecting $\Omega^- \rightarrow \Lambda^0 + K^-$ events are described in detail elsewhere [12]. The Λ^0-K^- invariant mass distribution of the final data sample is shown in Fig. 1. Only events with the Λ^0-K^- invariant mass between 1.657 and 1.687 GeV/c^2 were used in the polarization analysis. The estimated background in the selected mass region was about 3%. These background events were primarily $\Omega^- \rightarrow \Xi^0 + \pi^-$ decays or poorly reconstructed $\Xi^- \rightarrow \Lambda^0 + \pi^-$ decays.

The nonleptonic weak decay, $\Omega^- \rightarrow \Lambda^0 + K^-$, can be described by three decay parameters, α, β, and γ, with the constraint that $\alpha^2 + \beta^2 + \gamma^2 = 1$. Assuming time-reversal invariance and no final-state interactions, β is taken to be zero [13]. The parameter α is also consistent with zero [12,14], thus preventing us from determining the Ω^- polarization from the Λ^0 distribution in the Ω^- rest frame. However, when averaged over the sample, the vector polarization of the Ω^-, $\mathbf{P}_\Omega$, is related to the daughter Λ^0 polarization, $\mathbf{P}_\Lambda$, by the following equation [12]:

$$\mathbf{P}_\Lambda = [1/2(j+1)][1+(2j+1)\gamma]\mathbf{P}_\Omega \, , \tag{1}$$

where γ is chosen to be $+1$, since the decay is predominantly parity conserving [15], j is the spin of the Ω^- and is assumed to be $\frac{3}{2}$. In the rest frame of the Λ^0, $\mathbf{P}_\Lambda$ can be measured by examining the distribution of the decay proton along a spatial axis i which is given by

TABLE I. Mean Ω^- momentum, components of the polarization, and biases as a function of the M1 field integral, and the field polarity of M2.

M1 field integral (T-m)	Field Polarity of M2	Mean Ω^- momentum (GeV/c)	Comp.	$\alpha_\Lambda P_\Lambda$	Bias
-15.3	+	316	x	-0.041±0.021	0.034±0.021
			y	-0.042±0.022	0.000±0.022
			z	0.000±0.031	0.028±0.031
	-	330	x	0.023±0.019	-0.013±0.019
			y	-0.008±0.021	-0.003±0.021
			z	0.070±0.026	-0.023±0.026
-19.5	+	379	x	0.000±0.013	0.014±0.013
			y	0.014±0.014	-0.007±0.014
			z	-0.010±0.017	-0.031±0.017
	-	389	x	-0.025±0.010	-0.016±0.010
			y	0.018±0.011	-0.009±0.011
			z	-0.014±0.013	-0.023±0.013
-22.2	+	418	x	-0.001±0.014	0.014±0.014
			y	-0.012±0.014	0.001±0.014
			z	-0.006±0.017	-0.010±0.017
	-	428	x	-0.001±0.017	0.034±0.017
			y	0.041±0.018	-0.006±0.018
			z	-0.026±0.020	-0.007±0.020
-24.3	+	452	x	-0.045±0.037	0.044±0.037
			y	0.021±0.037	0.061±0.037
			z	-0.004±0.040	-0.025±0.039
	-	459	x	0.011±0.027	0.046±0.027
			y	0.023±0.029	-0.003±0.029
			z	0.051±0.033	0.006±0.033
-25.5	+	465	x	0.020±0.034	0.026±0.034
			y	0.006±0.035	-0.072±0.034
			z	-0.023±0.037	-0.017±0.037
	-	473	x	0.032±0.023	0.019±0.023
			y	-0.028±0.024	-0.070±0.024
			z	-0.036±0.028	-0.027±0.028

$$\frac{dN}{d\cos\theta_i} = \tfrac{1}{2}(1+\alpha_\Lambda P_{\Lambda i}\cos\theta_i)\,, \qquad (2)$$

where θ_i is the angle between the momentum of the proton and the axis i. In practice this distribution is modified by the acceptance of the spectrometer which was unfolded with an improved hybrid Monte Carlo method [16]. In this technique, ten Monte Carlo Λ^0's were generated for each reconstructed Λ^0 from the Ω^- decay in the final data sample. The simulated Λ^0's had the same momentum and decay position as the real Λ^0, but the cosine of the decay angle of the proton in the Λ^0 rest frame was randomly varied. These Monte Carlo events were reconstructed in the same way as the real events and subjected to the same selection criteria.

The measured signal is a sum of the polarization, $\alpha_\Lambda P_\Lambda$, and any bias which results from a combination of the apparatus and the reconstruction of events not fully reproduced in the Monte Carlo simulation (e.g., events with small opening angles). Because a parity conserving polarization must be perpendicular to the production plane ($\mathbf{p}_p \times \mathbf{p}_{\Omega^-}$), the y-z plane at the target, it reverses when the production angle changes sign, but the bias will remain unchanged. Data taken with positive and negative production angles can thus be used to determine both the polarization signal and the bias. Table I shows the components of the Λ^0 polarization measured in the spectrometer, $\alpha_\Lambda P_\Lambda$, and bias as a function of the momentum of the Ω^-. Most of the biases were less than 2 standard deviations from zero, indicating that the Monte Carlo simulation could unfold the acceptance of the experiment in the x, y, and z directions reasonably well. As shown in Fig. 2, the y components of the polarization were consistent with zero, with a mean of 0.00 ± 0.01, as required by parity conservation in strong interactions. The other two polarization components were also not significantly different from zero. Since the results of the samples with an equal and opposite M2 field agreed to the precision of the measurement, they were combined in the following analysis.

The Ω^- polarization at the target, P_{tgt}, is related to the x and z components of its polarization in the spectrometer by $P_{\Omega x} = P_{\mathrm{tgt}}\cos\phi$ and $P_{\Omega z} = P_{\mathrm{tgt}}\sin\phi$, where $P_{\Omega x}$ and $P_{\Omega z}$ are determined from the Λ^0 polarization with Eq. (1) and ϕ is the spin precession angle relative to the Ω^- momentum in the magnetic field of M1:

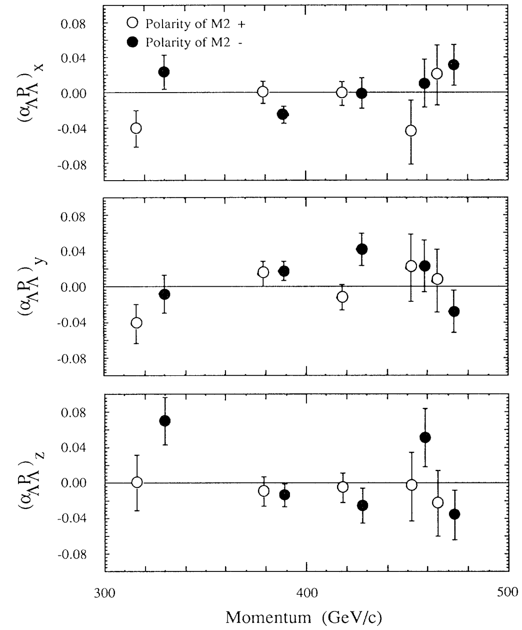

FIG. 2. Components of the polarization as a function of the field polarity of M2 and momentum of the Ω^-.

$$\phi = \frac{2}{\beta_v}\left[\mu_\Omega - \frac{q_\Omega}{2m_\Omega c}\right]\int B\,dl\,, \qquad (3)$$

where q_Ω and m_Ω are the charge and the mass of Ω^-, respectively, $\beta_v = v/c \approx 1$ in this experiment, μ_Ω is the Ω^- magnetic moment given in nuclear magnetons (μ_N) and $\int B\,dl$ is the field integral of M1 in units of T m. With μ_Ω constrained to $(-1.94 \pm 0.22)\mu_N$ [17], a fit using the measured asymmetries yielded P_{tgt} and the biases as a function of momentum [18]. The χ^2 for this procedure was 8.7 for 4 degrees of freedom. The Ω^- polarization at the target as a function of the Ω^- momentum is shown in Table II [19]. The average Ω^- polarization was determined to be -0.01 ± 0.01 at a mean x_F of 0.5 and p_t of 0.95 GeV/c. The biases determined with this method were consistent with zero. The mean helicity was -0.00 ± 0.01, again consistent with zero as required by parity conservation.

Figure 3 is a comparison of the polarizations of Ω^-, $\bar{\Lambda}^0$, $\bar{\Xi}^+$, and Ξ^- when produced by protons in inclusive

TABLE II. Ω^- polarization at target as a function of momentum. The decay parameter γ is taken to be +1.

Mean Ω^- momentum (GeV/c)	Number of events	Mean transverse momentum (GeV/c)	Ω^- polarization at target
323	15 735	0.776	0.011 ± 0.023
385	47 722	0.925	-0.029 ± 0.014
424	25 685	1.02	-0.014 ± 0.018
457	5 976	1.10	0.013 ± 0.036
471	8 098	1.13	0.020 ± 0.033

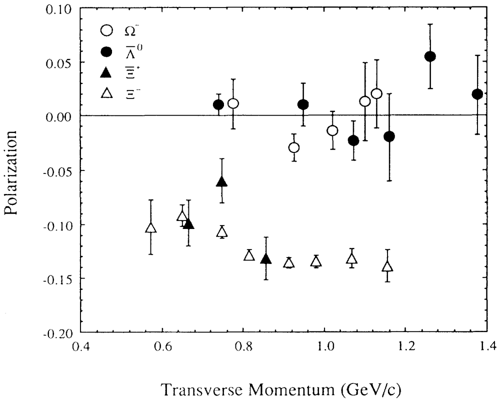

FIG. 3. Comparison of the Ω^- polarization with those of the $\bar{\Xi}^+$, $\bar{\Lambda}^0$, and Ξ^- as a function of the transverse momentum. For a given transverse momentum, the average x_F of the $\bar{\Lambda}^0$ is slightly lower than that of the Ω^-. The Ξ^- and $\bar{\Xi}^+$ data are from this experiment (see Refs. [4] and [10]), and the 400 GeV/c $\bar{\Lambda}^0$ results are taken from Ref. [8].

reactions as a function of the transverse momentum [4,8,10]. The $\bar{\Lambda}^0$ data, taken at 400 GeV/c, cover a similar x_F range as the Ω^-, Ξ^-, and $\bar{\Xi}^+$ results from this experiment. Even through Ω^- is a baryon, it has no valence quarks in common with the proton. Its zero polarization seems to indicate that having at least one quark is common with the beam, like Ξ^-, is necessary to produce a polarized particle. This agrees with the zero polarization measured for the $\bar{\Lambda}^0$, but is distinctly different from the nonzero polarization of $\bar{\Xi}^+$. The conflicting behavior of the production polarization among the Ω^-, $\bar{\Lambda}^0$, and $\bar{\Xi}^+$ is puzzling. As far as we know, no existing model of particle production can accommodate the Ω^-, $\bar{\Lambda}^0$, and $\bar{\Xi}^+$ results.

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