Measurement of the Ξ^- Magnetic Moment

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The magnetic moment of the Ξ^- hyperon has been measured to be $\mu(\Xi^-) = -0.69 \pm 0.04 \pm 0.02$ nuclear magnetons, where the uncertainties are statistical and systematic, respectively.

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The discovery of inclusive polarization in both neutral and charged hyperons by high-energy protons[1-5] has given rise to a series of successful measurements of hyperon magnetic moments.[3,5-9] Precise measurements of both $\mu(\Lambda)$ and $\mu(\Xi^0)$ were achieved with use of the inclusive polarization.[6,7] While the measured value of $\mu(\Lambda)$ is in excellent agreement with the colored-quark-model prediction,[10] such calculations for other hyperon moments are less successful. The measured value of $\mu(\Xi^0)$ differs by $0.2\mu_N$ from the prediction. Similar differences between theoretical calculations and experimental measurements are observed for the Σ^- and Σ^+ magnetic moments.[3,8-11]

The present experiment is a high-statistics determination of $\mu(\Xi^-)$. The Ξ^-'s were produced by 400-GeV protons in the M2 beam at Fermilab in the process $p + \mathrm{Be} \to \Xi^- + X$. The apparatus and coordinate system are shown in Fig. 1. Details of the beam transport system are given by Deck *et al.*[3] Data were taken at production angles of ±5.0 and ±7.5 mrad. The polarization vector at production was normal to the production plane in the parity-allowed direction given by $\hat{k}_{\mathrm{in}} \times \hat{k}_{\mathrm{out}}$, where $\hat{k}_{\mathrm{in}}$ is the direction of the incident proton and $\hat{k}_{\mathrm{out}}$ is the direction of the outgoing hyperon. The magnetic field in M_2 was used to precess the Ξ^- spin as well as to transport the negative beam through a 10-mrad curved, momentum-selecting channel. A multiwire-proportional-chamber spectrometer was configured to observe the

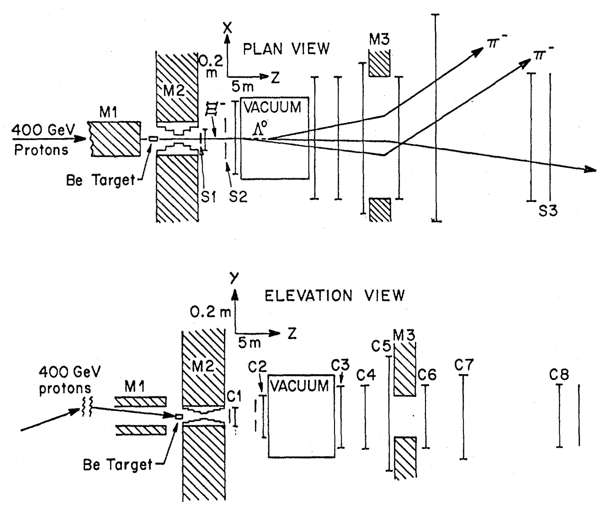

FIG. 1. Plan and elevation views of the apparatus. The Ξ^- hyperons were produced in a $\frac{1}{2}$-interaction-length, 6-mm-diam, Be target. With the M_1 steering magnets, the incident angle of the proton beam could be varied through positive and negative production angles in the vertical (y-z) plane. The Ξ^- beam was defined by a brass collimator, with a central limiting aperture of 4 mm diam embedded in the 5.3-m-long magnet, M_2. The spectrometer consisted of a dipole magnet, M_3, and a set of multiwire proportional chambers, C_1–C_8. It was used to observe the Ξ^- decay sequence which is shown in the plan view. Prompt signals from C_3, the left half of C_7, and the right half of C_8 were used in the trigger logic. S_1–S_3 were scintillation counters. S_1 covered the beam emerging from M_2, S_2 was used to veto halo around the beam, and S_3 covered the area irradiated by protons from Λ decay. The event trigger was $S_1C_3C_{7L}C_{8R}S_3S_2$.

charged products of the decays $\Xi^- \to \Lambda\pi^-$ and $\Lambda \to p\pi^-$. Details of the spectrometer have been described previously.[12,13]

The acceptance of the apparatus for Ξ^-, which does not play a role in the present calculation, is shown in Ref. 14. The Λ acceptance, which is important here, is a well understood property of the detection system and nearly identical to that shown in Fig. 9 of Ref. 12.

The final sample had 218 043 events. Event selection was based on the geometric and kinematic fit of the charged tracks to the Ξ^- decay sequence. The Ξ^- decay vertex was required to be downstream of the precession magnet, and its momentum was required to project within 6.6 mm of the target center. These criteria insured that the Ξ^- did not decay in the precession field, nor was it produced in the collimator. Data were taken under the following conditions: 6.60 ± 0.01 T$\cdot$m field integral in M_2 and 5.0 mrad production angle (a final sample of 145 526 Ξ^- in the momentum range 125–290 GeV/c); 5.13 ± 0.01 T$\cdot$m and 5.0 mrad (43 095 Ξ^- in the range 105–270 GeV/c); and 5.13 ± 0.01 T$\cdot$m and 7.5 mrad (29 422 Ξ^- in the range 105–255 GeV/c).

The Λ and Ξ^- invariant-mass distributions are given in Ref. 14. The background measured outside the Ξ^- mass peak and interpolated under the peak is 0.7%. The sources of most of this background are understood, and the most drastic assumptions about asymmetries in all the background yield negligible correction to the final result.

The magnetic moment was determined from the precession of the polarization, $\vec{P}_\Xi$, in the M_2 field. The direction of $\vec{P}_\Xi$ after precession was obtained from $\vec{P}_\Lambda \cong \alpha_\Xi \hat{k} + \gamma_\Xi \vec{P}_\Xi$,[15] where $\vec{P}_\Lambda$ is the Λ polarization, $\hat{k}$ is the Λ momentum direction in the Ξ^- rest frame, $\alpha_\Xi = (-0.472 \pm 0.012)$, and $\gamma_\Xi = (0.882 \pm 0.006)$.[16] Each of the three components of $\vec{P}_\Lambda$, and hence $\vec{P}_\Xi$, was determined from the asymmetry of the proton distribution in the Λ rest frame.[17] Throughout the data taking the production angle was alternated between positive and negative values. This reversed the direction of $\vec{P}_\Xi$ while leaving apparatus- and software-induced asymmetries (biases) unchanged. Biases were measured and eliminated by this procedure. For the full data set, the magnitude of $\vec{P}_\Xi$ was -0.10 ± 0.01, the average Ξ^- momentum was 170 GeV/c, and the average y asymmetry, which is expected to be zero, was -0.001 ± 0.004. For one of the data samples, Fig. 2 shows the raw asymmetries (along the x and z axes for each production angle) from which the polarization vector was computed. The fits which produced the raw asymmetries had typical χ^2 per data point of 1.4 for P_x and 2.2 for P_z. The higher values for the P_z fits result from confusion of the two negative tracks for a small fraction of the events with $|\cos\theta_z|$ near 1.0. This occurs also for Monte Carlo samples, and has no significant effect on the final result.

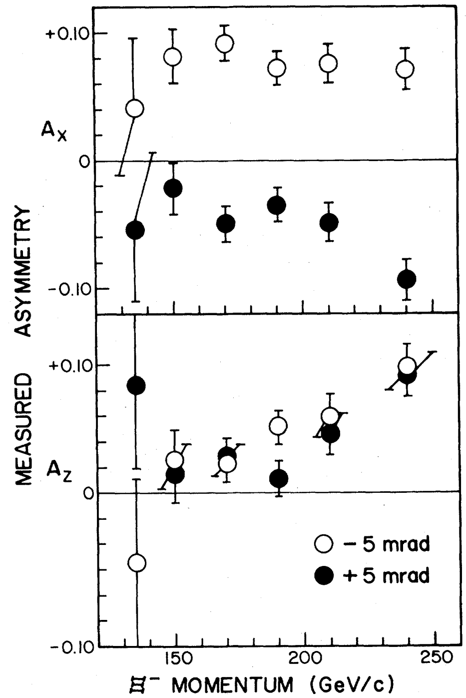

FIG. 2. The asymmetries, $A_i(\pm 5 \text{ mrad}) = \alpha_\Lambda \gamma_\Xi P_i + B_i$ ($i = x, z$), computed from the data taken with a precession field of 6.6 T$\cdot$m, and corrected for acceptance by the hybrid Monte Carlo method of Ref. 17. Reversing the production angle reverses the polarization, P_i, whereas the detector, and any biases, B_i, not matched by the acceptance calculation, remain unchanged. The differences in the x asymmetries when the angle is reversed indicate a significant P_x, whereas the z asymmetries show P_z to be consistent with zero.

The x and z components of $\vec{P}_\Xi$ after precession were used to determine the precession angle, $\theta = \tan^{-1}[P_z/P_x] + n\pi$, where n is an integer corresponding to possible combinations of the initial direction of $\vec{P}_\Xi$ $(\pm\hat{x})$ and the sense of precession. Measurements of θ at two values of $\int B dl$ in M_2 were used to determine the value of n and the magnetic moment.

Both the Ξ^- polarization and momentum were perpendicular to the magnetic field in M_2. Under these conditions the spin precession angle, θ,

TABLE I. Precession angles (degrees) for the four lowest-order solutions to the precession equation.

n	Initial polarization direction	Precession sense	Precession angles in degrees for $\int B\,dL =$ 5.13 T m	6.60 T m	$g/2-1$	$\mu(\Xi^-)/\mu_N$	χ^2 (1 d.f.)
0	$-\hat{x}$	...	-5 ± 8	$+5\pm5$	-0.03 ± 0.05	-0.69 ± 0.04	1.0
+1	$+\hat{x}$	(+)	$+175\pm8$	$+185\pm5$	-2.25 ± 0.05	$+0.88\pm0.04$	12.0
+2	$-\hat{x}$	(+)	$+335\pm8$	$+365\pm5$	-4.46 ± 0.05	$+2.45\pm0.04$	64.0
−1	$+\hat{x}$	(−)	-185 ± 8	-175 ± 5	$+2.18\pm0.05$	-2.26 ± 0.04	30.2

measured relative to the momentum direction, is given by the sum of the Larmor precession of the spin in the particle's rest frame, the cyclotron rotation of the momentum vector, and the Thomas precession of the particle's rest-frame coordinates relative to the laboratory coordinates. This sum yields

$$\theta = (q/\beta M_\Xi c^2)(g/2-1)\int B\,dl$$
$$= -(13.00\ \mathrm{deg/T\cdot m})(g/2-1)\int B\,dl.$$

For the Ξ^-, $q=-e$, $M_\Xi = 1.321\ \mathrm{GeV}/c^2$, and $\beta=1$. The magnetic moment is $\mu(\Xi^-) = (-g/2)(M_p/M_\Xi)\,\mu_N$ where M_p is the proton mass and μ_N is the nuclear magneton ($e\hbar/2M_p c$). The two precession angles measured in this experiment are listed in Table I for $n=-1$, 0, +1, and +2. Other values of n imply unreasonable solutions for $\mu(\Xi^-)$. A fit of θ vs $\int B\,dl$ for each of the initial conditions indicates that only the choice $n=0$ has acceptable χ^2, giving $\mu(\Xi^-) = (-0.69\pm0.04)\,\mu_N$.

The moment was tested for stability against variations in the geometric and kinematic selection criteria and found to be stable to within 0.5σ. The data were separated into five momentum bins, and the moment was calculated for each. The χ^2 for these values fitting $\mu(\Xi^-) = -0.69$ was 8.9 for 5 degrees of freedom. A similar calculation for the moments computed from six different subsets of the data with small differences in the experimental conditions yielded $\chi^2 = 10.1$ for 6 degrees of freedom. No clear pattern of nonstatistical fluctuations was observed, but we have assigned to the magnetic moment a systematic uncertainty of $0.02\,\mu_N$.

The result of this experiment improves the precision in the measurement of $\mu(\Xi^-)$.[18,19] The new world average is $\mu(\Xi^-) = (-0.69\pm0.04)\,\mu_N$, dominated by this experiment with the statistical and systematic uncertainties combined. This result now differs from the colored-quark-model prediction, $-0.49\,\mu_N$,[10] by $0.2\,\mu_N$. It is interesting to note that the sum, $\mu(\Xi^0) + \mu(\Xi^-) = (-1.94\pm0.06) \times \mu_N$, is in excellent agreement with the colored-quark prediction of $-1.92\,\mu_N$, indicating that the deviations from the model are equal and opposite for Ξ^0 and Ξ^-.

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