A PRECISION MEASUREMENT OF THE Ω^- MAGNETIC MOMENT

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The structure of baryons can be probed at long range by measuring their magnetic moments. The particularly simple valence quark structure (three strange quarks with their spins aligned) of the Ω^- should make a precise measurement its magnetic moment a useful test of models of baryon structure. The only previous measurement of the Ω^- magnetic moment(Ref. 1), to a precision of 10%, could not clearly differentiate between these models.

Polarized Ω^-s used for this measurement were produced using two different techniques: the spin transfer technique from a polarized neutral beam (PNB), which was used in the previous Ω^- magnetic moment measurement(Ref. 2), and a new technique that used an unpolarized neutral beam (UNB)(Ref. 3). In both cases a neutral beam containing Λ and Ξ^0 hyperons, as well as γs, neutrons, and K^0s, was produced by an 800-GeV/c proton beam in the inclusive reaction p+Be → (neutral particle) + X. In the unpolarized neutral beam mode, the protons struck an upstream target at 0 mrad. The resulting particles passed through a collimator embedded in a sweeping magnet with a 1.8 T field. This neutral beam was then targeted at vertical production angles of ± 1.8 mrad on a second Be target to produce Ω^-s primarily by the reaction $(\Lambda,\Xi^0) + \mathrm{Be} \rightarrow \Omega^- + X$. The polarized neutral beam was produced by targeting the proton beam at vertical targeting angles of ± 1.8 mrad producing polarized Ξ^0 and Λ(Refs. 4,5). Since the sweeping magnet field was perpendicular to the production plane, the spins of the neutral particles were not precessed as they passed through the channel. The Ω^-s were then produced by targeting the polarized neutral beam at 0 mrad. Table 1 shows the average polarizations for each of these modes. The Ω^- yield per incident proton for unpolarized neutral beam production was roughly three times that for polarized neutral beam production.

The Ω^- production target (Be, $5.14\times5.28\times147$ mm^3) was located 55 cm upstream of the spin-precession/momentum selection magnet. The magnet was

Production method	Precession field integral (T·m)	Sample size 10^4 events	P_{Ω^-}
Unpolarized neutral beam	-24.36 ± 0.26	16.7	0.044 ± 0.008
Unpolarized neutral beam	-17.48 ± 0.17	5.02	0.036 ± 0.015
Polarized neutral beam	-24.36 ± 0.26	1.83	-0.069 ± 0.023

Table 1: The sample sizes and average polarizations measured for the three Ω^- samples used in this analysis. The initial polarization is in the $\pm\hat{x}$ direction in a right-handed coordinate system defined by the Ω^- momentum direction ($\hat{z}$) and the vertical ($\hat{y}$).

7.315 m long with a field in the $-\hat{y}$ (where $\hat{y}$ is the vertical) direction. The magnet was fitted with a curved brass-tungsten channel(Ref. 6), with a total bend of 18.7 mrad in the x-z (where $\hat{z}$ is along the Parent particle momentum and $\hat{x} = \hat{y} \times \hat{z}$) plane and a defining aperture of 5.08 mm× 5.08 mm. The curved channel selected negatively charged particles with a momentum range of 300 to 550 GeV/c when the magnet was operating at a field of 3.33 T. The field integral was measured using a Hall probe(Ref. 1) and checked by measuring the Ξ^- magnetic moment. It was found to be accurate to better than 1%.

The parent Ω^- and its charged daughters for the decay $\Omega^- \rightarrow \Lambda K^-$ and $\Lambda \rightarrow p\pi^-$ were tracked by a spectrometer consisting of 8 planes of silicon microstrip detectors with 100 μm pitch, 12 multiwire proportional chambers with 1 and 2 mm wire spacing, and an analyzing magnet consisting of two dipole magnets which gave a deflection of 1.45 GeV/c to the daughter p, π^-, and K^-(Ref 7). Signals from scintillation counters and wire chambers were used to form a trigger that required at least one positively charged and one negatively charged track.

This trigger produced a reasonably unbiased data sample which contained 3.4% Ξ^- and 0.035% Ω^- with a spectrometer live time of 70%. Approximately 1.35×10^9 triggers were processed by a multi-pass offline reconstruction program which fit the three-track, two-vertex topology with an overall efficiency of 97%(Ref. 3,6). Selected events were required to fit the topology of the parent/daughter hyperon decay with the parent hyperon pointing back to within 8 mm of the center of the target in x and to within 9 mm in y. Ω^- candidates were also required to have a Λ-K^- invariant mass between 1657 and 1687 MeV/c^2. The $\Xi^- \rightarrow \Lambda\pi^-$ decays reconstructed under the ΛK^- hypothesis which satisfy that mass criterion occupy a small range of decay angles in the Ω^- rest frame. All events in this range of decay angles were removed from the data sample which reduced the Ξ^- background to the 0.6% level(Ref. 7). The predominant remaining background, $\Omega^- \rightarrow \Xi^0\pi^-$ decays, was at the 2.4% level. The Λ-K^- invariant mass distribution for the final Ω^- sample is shown in Figure 1.

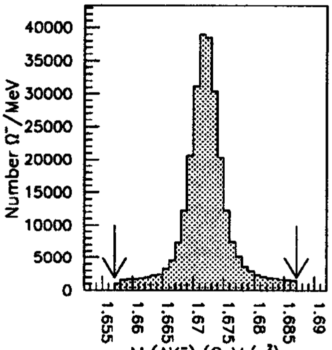

Figure 1 The ΛK^- invariant mass.

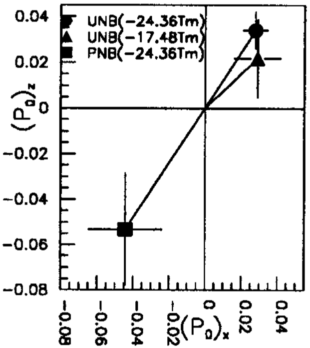

Figure 2 The measured x and z polarization components.

Assuming $\gamma_{\Omega^-} = +1$, the vector polarization of the Ω^-, $\vec{P}_\Omega$, is related to the daughter Λ polarization, $\vec{P}_\Lambda$, by $\vec{P}_\Omega = \vec{P}_\Lambda$(Ref. 7). The Λ polarization was determined by measuring the decay asymmetry of the proton in the Λ rest frame(Ref. 9). This measured asymmetry was corrected for acceptance by a a hybrid Monte Carlo analysis(Ref. 9). The resulting proton distributions were then fit to a linear function in $\cos\theta$ for each component of the asymmetry.
For a hyperon H with spin J (in units of $\hbar$) passing through a precession field perpendicular to the initial polarization, the precession angle relative to its momentum direction is given by

$$\Phi = \frac{e}{\beta m_H c}\left(\frac{m_H \mu_H}{2J m_p \mu_N} + 1\right)\int B dl, \tag{1}$$

where Φ is the precession angle in radians, e is the magnitude of the electron charge, β = v/c, m_p is the mass of the proton, μ_N is the nuclear magneton, m_H and μ_H are the hyperon's mass and magnetic moment, and $\int Bdl$ is the precession field integral in T·m. Because parity is conserved in strong interactions, the initial polarization direction must be perpendicular to the production plane. In this case the measured polarization components are given by $P_x = P_0\cos\Phi$ and $P_z = P_0\sin\Phi$, where $\hat{z}$ is parallel to the Ω^- momentum, $\hat{y}$ is the vertical, $\hat{x} = \hat{y} \times \hat{z}$, and P_0 is the initial hyperon polarization at the target. The precession angle is given by $\Phi = \tan^{-1}\left(\frac{P_z}{P_x}\right) + n\pi$ where n is an integer. The x and z components of the polarization signals, shown in Figure 2, were significantly different from zero, while the y component for each sample was consistent with zero. Table 2 gives the precession angles and magnetic moments for the three samples for this experiment as well as the two samples from the

Neutral beam type	Precession field integral (T·m)	Φ (radians)	μ_Ω (nuclear magnetons)
Unpolarized neutral beam	–24.36±0.26	0.88±0.17	–2.023±0.065
Unpolarized neutral beam	–17.48±0.17	0.65±0.43	–2.03 ±0.23
Polarized neutral beam	–24.36±0.26	0.88±0.32	–2.02 ±0.12
Polarized neutral beam(Ref. 1)	–19.53±0.19	0.58±0.42	–1.96 ±0.20
Polarized neutral beam(Ref. 1)	–14.77±0.14	0.34±0.46	–1.90 ±0.29

Table 2: The precession angles and magnetic moments measured for the three samples used in this analysis and the two samples from the previous measurement of μ_Ω.

previous experiment(Ref. 1).

Using the three data samples of this experiment we found μ_Ω by minimizing,

$$\chi^2 = \sum_{ij} \left(\frac{P_{x_{ij}} - P_{0_{ij}} cos\Phi_j}{\sigma_{x_{ij}}} \right)^2 + \left(\frac{P_{z_{ij}} - P_{0_{ij}} sin\Phi_j}{\sigma_{z_{ij}}} \right)^2 \tag{2}$$

with Φ_j given by Eq. 1. $P_{0_{ij}}$ is the initial polarization which depends on production method. $P_{x_{ij}}$ and $P_{z_{ij}}$ are the measured x and z polarization components, and $\sigma^2_{x_{ij}}$ and $\sigma^2_{z_{ij}}$ include uncertainties from $P_{x_{ij}}$ and $P_{z_{ij}}$. The subscript i indicates the production method, and the two precession field values are represented by the sum over j. The observed polarization at the target depends on the field integral since the momentum spectrum of the particles entering the spectrometer changes with the field value. Minimizing the χ^2 from Eq. 2 gave $\mu_{\Omega^-} = (-2.024 \pm 0.056)\mu_N$ with a χ^2 of 1×10^{-3} for two degrees of freedom. The uncertainty for the combined result is given by the variation in the magnetic moment which changes the χ^2 by one. This uncertainty is equal to the uncertainty obtained when the statistical uncertainties of the three sample are combined by standard methods. The momentum averaged magnetic moments for the three samples as well as μ_Ω vs momentum for the largest data sample are shown compared to the constrained fit result in Figure 3.

The Ω^- magnetic moments measured independently for all the samples including those of the previous measurement agree to within their measurement uncertainties. To remove the ambiguity of the precession angle due to rotations by an additional $n\pi$ a linear fit for Φ as a function of the precession field, constrained to include $\Phi = 0$ for zero field, was made. The best fit for the points shown in Figure 4 was for $n = 0$ with a $\chi^2 = 0.3$ for four degrees of freedom; the next best fit had $\chi^2 = 10$ for $n = 1$.

Using the spin precession technique on polarized samples of Ω^- produced by both polarized and unpolarized neutral beams, we have measured the magnetic

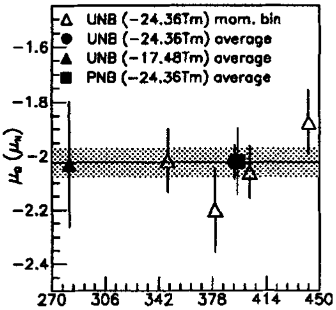

Figure 3 μ_Ω vs. Ω momentum. The line and shaded area indicate fit value and error of the result.

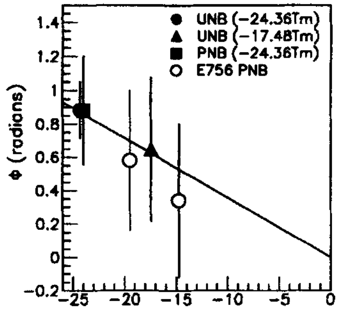

Figure 4 Φ vs. ∫Bdl including two points from the previous measurement Fermilab E756.

moment of the Ω^- to be $\mu_{\Omega^-} = (-2.024 \pm 0.056)\mu_N$ which is in agreement with the previous measurement of $\mu_{\Omega^-} = (-1.94 \pm 0.17 \pm 0.14)\mu_N$. Combining our result with the previous measurement gives a world average of $\mu_{\Omega^-} = (-2.019 \pm 0.054)\mu_N$ including the systematic uncertainty of the previous measurement. The line shown in Figure 4 corresponds to this value of the magnetic moment. This measurement disagrees with the static quark model value of $-1.84\mu_N$ at the 3σ level and all other models known to the authors which sucessfully predict other magnetic moments. It is hoped that this measurement will provide a stringent test for future models of baryon structure.

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