PRECISION MEASUREMENT OF MAGNETIC MOMENTS OF Σ^+ AND $\overline{\Sigma}^-$ HYPERONS (E761 experiment, FNAL)

N. F. Bondar, A. S. Denisov, A. V. Dobrovolsky, V. L. Golovtsov, V. T. Grachev, A. V. Khanzadeev, N. P. Kuropatkin, V. M. Samsonov, V. A. Schegelsky, N. K. Terentyev, I. I. Tkatch, L. N. Uvarov, A. A. Vorobyov, R. A. Carrigan[1)], P. S. Cooper[1)], J. Lach[1)], A. Morelos[1)], Li Yunshan[2)], Tang Fukun[2)], Lang Pengfei[2)], Li Chengze[2)], Shi Huanzhang[2)], Zhao Wenheng[2)], Dai Lisheng[2)], Zheng Shuchen[2)], Zhong Yuanyuan[2)], Yan Jie[2)], M. A. Kubantsev[3)], S. Timm[4)],T. Dubbs[5)], E. McCliment[5)], C. Newsom[5)], I. F. Albuquerque[6)], C. O. Escobar[6)], H. Gottshalk[6)], P. Gouffon[6)], J. R. P. Mahon[6)], M. Foucher[7)], M. Luksys[8)], A. M. F. Endler[9)], M. C. Pommot Maia[10)], D. Chen[11)], V. J. Smith[12)]

[1)] *Fermi National Accelerator Laboratory, Batavia, Illinois USA*
[2)] *Institute of High Energy Physics, Beijing, People's Republic of China*
[3)] *Institute of Theoretical and Experimental Physics, Moscow, Russia*
[4)] *Carnegie Mellon University, Pittsburgh, Pennsylvania USA*
[5)] *University Of Iowa, Iowa City, Iowa USA*
[6)] *Universidade de Sao Paulo, Sao Paulo, Brazil*
[7)] *J.W.Gibbs Laboratory, Yale University, New Haven, Connecticut USA*
[8)] *Universidade Federal da Paraiba, Paraiba, Brazil*
[9)] *Centro Brasileiro de Pesquisas Fisicas, Rio de Janeiro, Brazil*
[10)] *Conselho Nacional de Pesquisas, Rio de Janeiro, Brazil*
[11)] *State University of New York at Albany, Albany, New York USA*
[12)] *H.H. Wills Physics Laboratory, University of Bristol, Bristol, United Kingdom*

High energy proton nucleus interactions have provided us with high intensity sources of polarized hyperons and antihyperons. These polarized beams have made possible precise measurements of hyperon magnetic moments which offer insights into the quark structure

of the baryons. In a previous publication [1] we have shown that both the Σ^+ and $\overline{\Sigma^-}$ are produced with significant polarization. Here we present measurements of the Σ^+ and $\overline{\Sigma^-}$ magnetic moments [2]. These measurements were performed as part of Fermilab experiment E761 whose primary goal was the measurement of the asymmetry parameter [3] in the weak radiative decay $\Sigma^+ \to p\gamma$.

The configuration and experimental resolutions are the same as in the polarization measurements [1]. We show an expanded view of the part of the E761 apparatus (Fig.1) emphasizing those aspects of particular relevance to these magnetic moment measurements. Protons of 800 GeV/c were steered and focused onto the hyperon production target. The charged hyperon beam originated from a one interaction length Cu target in the upstream end of a 7.3 m long hyperon magnet (M1 in Fig.1) which deflected and collimated the 375 GeV/c hyperon beam. The targeting angle was varied over the range ± 5 mrad in the vertical (YZ) plane. This allowed the hyperons to be produced, in a controlled manner, with polarization direction perpendicular to the vertical (Y) magnetic field of the hyperon magnet. This condition corresponds to maximal spin precession in the magnet. The currents in all of the magnets shown in Fig.1 could be reversed thus allowing selection of a positive or negative beam containing Σ^+ or $\overline{\Sigma^-}$, respectively. The beam traversed a second magnet (M2) where the magnetic field was also in the vertical direction but opposite in sign to M1. Thus the spin precession of M1 is partially cancelled by M2. This experimental configuration of magnets was dictated by the requirements of asymmetry parameter measurement [3].

This study used the $\Sigma^+ \to p\pi^0(\overline{\Sigma^-} \to \bar{p}\pi^0)$ decay mode (52% branching fraction) for analysis of the $\Sigma^+(\overline{\Sigma^-})$ magnetic moment. The detection apparatus consisted of a hyperon spectrometer to measure the hyperon momentum, a baryon spectrometer to measure the $p(\bar{p})$ momentum and a photon spectrometer to detect the photon decay products of the π^0 (see detailes in the previous publication [1]). The reconstructed neutral particle (X^0) missing masses squared for the decays $\Sigma^+ \to pX^0(\overline{\Sigma^-} \to \bar{p}\overline{X^0})$ are shown in Fig.2a and Fig.2b, respectively. Events whose reconstructed neutral mass, assuming a decay $K^+ \to \pi^+X^0\,(K^- \to \pi^-X^0)$, was near the π^0 mass have been rejected.

Data were collected at pairs of complementary targeting angles as shown in Table. The targeting angles were of equal magnitudes but opposite signs thus allowing the polarization direction to be periodically reversed to separate the asymmetry from instrumental biases. The asymmetry and polarization are related by $\vec{A} = \alpha\vec{P}$ where α for the $\Sigma^+ \to p\pi^0$ decay is -0.98 [4]. Note that the measured A_y components are small, consistent with initial polarization only in the X direction.

The spin precession angle, ξ, of the $\Sigma^+(\overline{\Sigma^-})$ after it traverses the magnets is

$$\xi = \frac{q}{2\beta m_\Sigma c^2}(g-2)\int Bdl \tag{1}$$

where q is the hyperon charge, β (is equal to 1 to a very good approximation) is the relativistic velocity divided by the speed of light, and $\int Bdl$ is the field integral of M1 and M2. The magnetic moment μ_Σ is related to g, the gyromagnetic ratio, by

$$\mu_\Sigma = \frac{g m_p}{2m_\Sigma}\mu_N, \tag{2}$$

where $m_p(m_\Sigma)$ is the proton (Σ^+) mass and $\mu_N = e\hbar/2m_pc$ is the nuclear magneton.

Shown in Table are the three components of the Σ^+ and $\overline{\Sigma}^-$ decay asymmetry $\vec{A}$. An earlier measurement [5] demonstrated that 2π rad must be added to the measured angles to bring them into agreement with previous measurements. This implies that $\xi = \tan^{-1}(|(A_x/A_z|) - 3.5\pi$. Shown graphically in Fig.3 are the polarization vectors, initially in the positive X direction, then rotated in the XZ plane due to M1 and M2 magnetic fields. We measure ξ for the Σ^+ and $\overline{\Sigma}^-$ decays to be -10.937 ± 0.022 and -10.72 ± 0.24 rad, respectively, where the uncertainties are statistical only.

Table

Measured Σ^+ and $\overline{\Sigma}^-$ decay asymmetries

Particle	Angle, mrad	Events	A_x	A_y	A_z
Σ^+	± 2.9	249863	0.0094 ± 0.0036	-0.0055 ± 0.0036	0.1598 ± 0.0037
$\overline{\Sigma}^-$	± 2.9	11806	-0.0191 ± 0.0166	-0.0227 ± 0.0167	-0.0678 ± 0.0171

The hyperon trajectories in M1 were constrained by a precision tungsten collimator inserted between its steel pole tips. A measurement of the magnetic field in M1 presented a particular challenge since a precision of $\approx 10^{-3}$ is needed and at its narrowest point the collimator has a width of only 1.4 mm. The measurement of the field integral of M1 was done by mapping the field with a special miniature Hall probe which was calibrated with a NMR probe. Although the magnetic field of M2 was also measured with a Hall probe, its final field integral was more precisely fixed by using the known masses and the angular distribution of the protons in the $\Sigma^+ \rightarrow p\pi^0$ decay. The produced hyperons experienced a field integral of -25.215 ± 0.031 Tm in M1 and $+4.750 \pm 0.007$ Tm in M2.

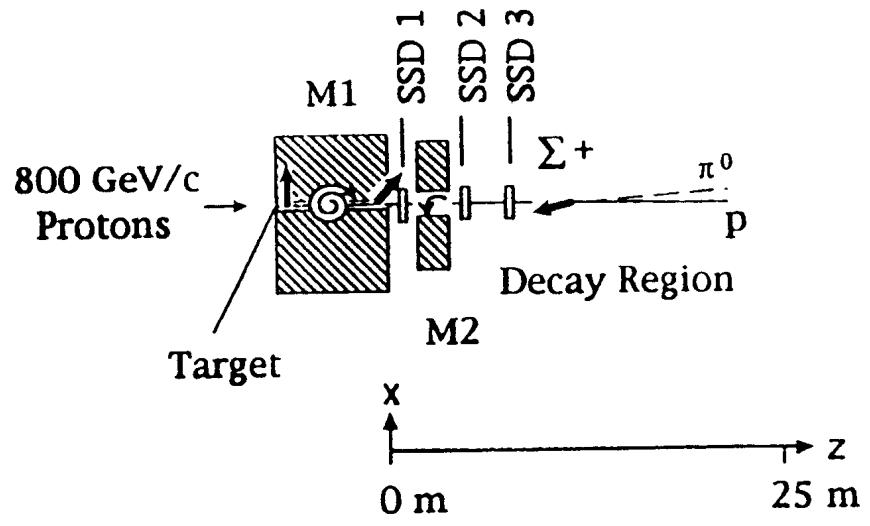

Fig.1. Plan view of the apparatus showing the incident proton beam and hyperon spectrometer. Depicted are the precession angles in M1 and M2 magnets. The bold arrows indicate the spin directions of the Σ^+. SSD1 — SSD3 are silicon strip detectors

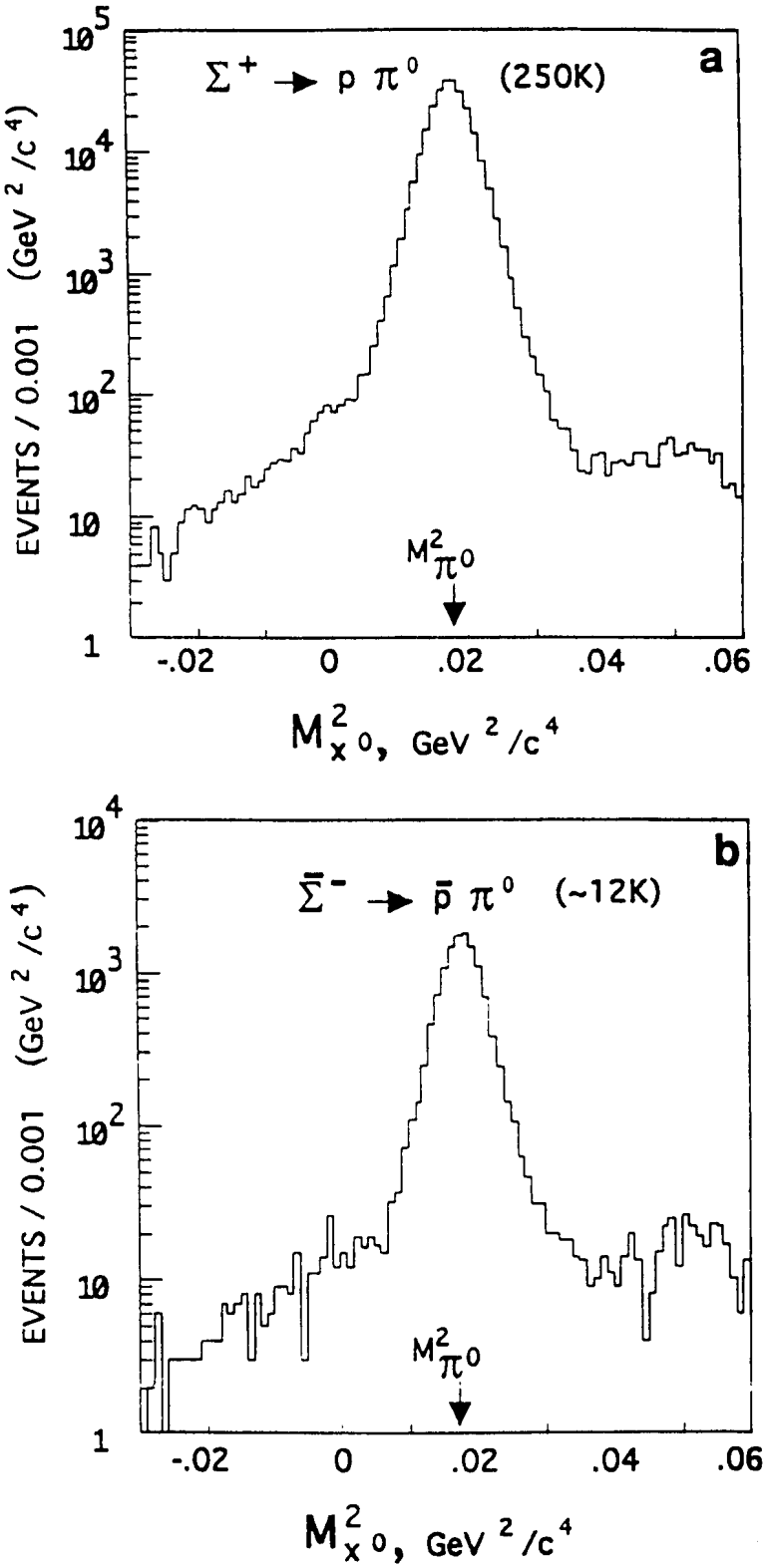

Fig.2. Event distributions of the mass squared of the missing neutral particle X^0 for the hypothesis: a) $\Sigma^+ \rightarrow pX^0$; b) $\overline{\Sigma}^- \rightarrow \overline{p}\overline{X}^0$

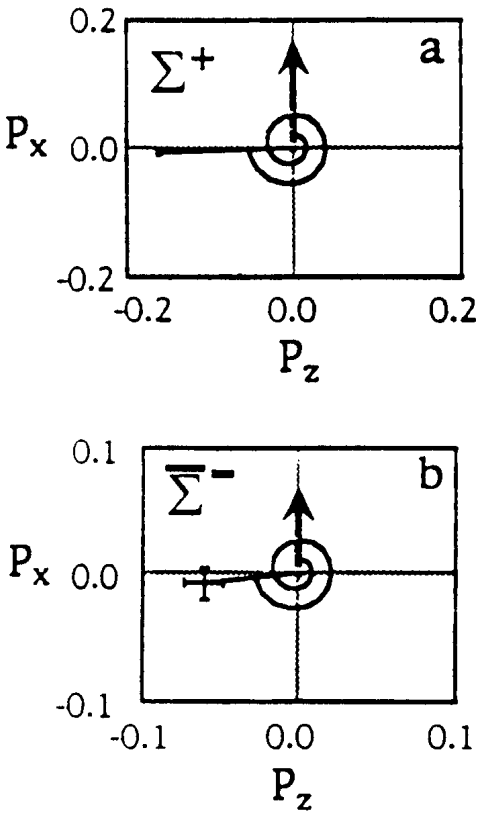

Fig.3. Rotation of the polarization vectors of the Σ^+ and $\overline{\Sigma}^-$. The initial polarization is produced in the $+X$ direction and precesses into $-Z$ direction for each of the two hyperons

We measured the Σ^+ and $\overline{\Sigma}^-$ magnetic moments to be $(+2.4613 \pm 0.0034 \pm 0.0040)\mu_N$ and $(-2.428 \pm 0.036 \pm 0.007)\mu_N$, respectively. The stated uncertainties are statistical and systematic. The combined errors for each of these measurements give an uncertainty $(\Delta\mu_\Sigma/\mu_\Sigma)$ in the Σ^+ and $\overline{\Sigma}^-$ magnetic moments of 0.21% and 1.52%, respectively. The magnetic moment of $\overline{\Sigma}^-$ is determined for the first time. The Σ^+ and $\overline{\Sigma}^-$ magnetic moments are consistent in magnitude but opposite in sign as required by CPT invariance.

REFERENCES

1. *Morelos A. et al.* //Phys.Rev.Lett., 1993. V.71. P.2172.
   See also this PNPI Research Report 1992–1993. St.Petersburg., 1994. P.8.
2. *Morelos A. et al.* //Phys.Rev.Lett., 1993. V.71. P.3417.
3. *Foucher M. et al.* //Phys.Rev.Lett., 1992. V.68. P.3004.
4. *Hikasa K. et al. Particle Data Group* Phys.Rev., 1992. V.D45. N°11. Part II.
5. *Ankenbrandt C. et al.* //Phys.Rev.Lett., 1983. V.51. P.863.