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Magnetic Moments of the Hyperons A Short Experimental Review*

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The advent of high energy hyperon beams, the discovery that hyperons produced by the interaction of high energy protons are polarized, and the realization that this polarization vector can be readily precessed to yield their magnetic moments¹ has allowed us to test quark models of the baryons to an astonishing level of sophistication. This has all happened in the last dozen years². Let me review where these measurements are now and what the future directions might be.

OVERVIEW

The first figure shows the baryon octet and decouplet. Intrinsic to each of these particles is an associated magnetic moment. Many of these particles have allowed strong decay modes making their lifetimes so short that their magnetic moments will be widened similar to their mass broadening. Measurement of these magnetic moments are far beyond our present experimental reach.

Figure 1 The baryon octet and decouplet

The Σ^0 decay is electromagnetically dominated resulting in a short (but still well defined) lifetime of 5×10^{-20} seconds. This magnetic moment is also well beyond our reach. That is the discouraging news. The good news is that all of those baryon states forbidden to decay via the strong or electromagnetic forces have now had their magnetic moments measured. This includes a new measurement of the Ω^- moment, the first and probably only, member of the decouplet that can be

expected to have its magnetic moment measured in the foreseeable future. I have circled those that have been measured in Figure 1. Except for refinements, we have gone about as far as we can with the ground state baryons containing only u, d, and s quarks. However, the states which include heavier quarks are untouched and many have lifetimes that, at least in principle, make them accessible to measurement.

The electromagnetic decay, $\Sigma^0 \rightarrow \Lambda^0 \gamma$, is a magnetic dipole transition and has associated with it a transition magnetic moment. This transition moment is described by the same formalism as the static magnetic moments and amenable to the same quark model predictions. It has been measured¹ by the Primakoff³ method. The Primakoff technique can also be used to investigate electromagnetic transitions involving excited baryon states thus gaining insight into their quark structure. The measurement of the transition rate $\Sigma^+(1385) \rightarrow \Sigma^+ \gamma$ is of particular interest since it is forbidden in SU_3 but allowed in SU_6 . With present day hyperon beams a measurement of this rate is feasible and was proposed as part of an abandoned Fermilab proposal, P734.

MEASUREMENT TECHNIQUES

Most hyperons produced at $P_t \approx 1$ GeV/c by high energy unpolarized protons have polarizations of 10-25%. This has become the standard mechanism to produce polarized hyperons whose polarization directions have then been rotated by a magnetic field. The direction of the polarization vector is determined through the parity violating asymmetries of the subsequent weak decay. The sensitivity of this measurement is limited by the product of the intrinsic weak decay asymmetry and the hyperon polarization, αP . If either of these parameters is small, the more challenging becomes the measurement. As they approach zero, the measurement becomes impossible.

The only other method that has been used to measure hyperon magnetic moments is through the formation of an "exotic" atom containing a negative hyperon captured near rest by a nucleus. X-rays from the exotic atom transitions are detected with high resolution solid state detectors and from the hyperfine splitting the hyperon magnetic moment can be inferred. So far this technique has only been applied to the measurement of the Σ^- magnetic moment. Complications occur because the captures are usually done in heavy elements, there are significant atomic physics corrections, and one is not able to resolve all of transition lines.

NEW RESULTS

The first attempt⁴ to measure the Ω^- magnetic moment using 400 GeV incident protons found a value of $P=0.12 \pm 0.08$. Taking this at face value led to a Ω^- magnetic moment of $-2.1 \pm 1.0 \mu_N$. A recent further analysis⁵ of the same data led the experimenters to conclude that the polarization was not sufficiently different from zero to place a significant constraint on the Ω^- magnetic moment.

A new measurement of the Ω^- magnetic moment was presented at this meeting by the Fermilab E756 group⁶. This group attempted to measure the Ω^- polarization and magnetic moment as was done by Luk et al⁴ (but with 800 GeV incident protons) and found, with higher statistics, that the polarization was consistent with zero. However they were able to modify the apparatus to first produce a neutral beam containing polarized Λ^0 and Ξ^0 and then targeted them to produce Ω^- . They were able to determine that the produced Ω^- had significant polarization. This spin transfer technique has allowed them to obtain a measurement of the Ω^- magnetic moment of $-2.0 \pm 0.2 \mu_N$. This value is preliminary and does not contain systematic errors. This was an important demonstration of the strength of the spin transfer technique. Further measurements of spin transfer using a variety of projectiles and targets over various kinematic regions should be extremely useful to probe the mechanisms of the spin process.

Figure 2 Σ^- Magnetic Moment

Figure 2 shows the recent history of measurements⁷⁻¹⁰ of the Σ^- magnetic moment. I have tabulated the magnetic moment values starting with the initial operation of the Fermilab hyperon beams and apologize to the authors of earlier works, but the data is really dominated by results from the start of this period. Since the last spin conference the only new result is from the group working at

Brookhaven National Laboratory (BNL) using the exotic atom technique¹⁰. Note that in Figure 2, two values are given. The later value comes from the same data sample but from a more mature analysis and differs only slightly from the earlier version¹¹. The other points on Figure 2 come from three Fermilab hyperon beam experiments. The one with the highest precision⁹ represents a combination of measurements at two momenta and two final states ($\Sigma^- \rightarrow n\pi^-$ and $\Sigma^- \rightarrow ne^-\nu$). The final value from the exotic atom measurement differs from it by 1.7σ ; the agreement being reasonable. The weighted mean of these measurements yields a Σ^- magnetic moment of $-1.156 \pm 0.014 \mu_N$. No new measurements are under way or planned to improve on this number.

Figure 3 Ξ^- Magnetic Moment

Two new measurements of the Ξ^- magnetic moment have been presented at this meeting^{12,6}. Their measured values are $-0.661 \pm 0.036 \mu_N$ and $-0.64 \pm 0.01 \mu_N$ and they are from Fermilab experiments, E715 and E756 respectively. Both are preliminary and the stated errors are statistical only. They are both plotted on Figure 3 with their errors increased to include a systematic error estimated

to be the same as the statistical error. They are both in excellent agreement with the earlier dominant hyperon beam measurement¹³. The E715 measurement represents the complete data sample from that experiment. However, the E756 result is only part of a considerably larger sample and this is the experiment which is expected to eventually provide the most precise measurement. The weighted mean of these three measurements is $-0.651 \pm 0.017 \mu_N$ for the Ξ^- magnetic moment.

OLD RESULT, OLD PROBLEM

The satisfactory status of the Σ^- and Ξ^- measurements is contrasted with the unsatisfactory state of the two most precise Σ^+ measurements^{14,15}. They are from Fermilab experiments E497 and E620 respectively and are shown in Figure 4. These two nominally 1% measurements differ by 3.1σ indicating one or both of them probably have errors larger than the stated ones. This is a well known problem and it has been handled by increasing the error so that the mean is $2.419 \pm 0.022 \mu_N$. Although this discrepancy is not crucial for the confrontation of existing models, it may be important in the future. Certainly it is a loose end which should be tidied up.

Figure 4 Σ^+ Magnetic Moment

SUMMARY

There are no new results on neutral hyperon magnetic moments or on the $\Sigma^0 \rightarrow \Lambda^0 \gamma$ decay since the last review in this conference series¹⁶. Table 1 summarizes the current status of the baryon mag-

netic moments. Also tabulated are the customary predictions from the simple quark model where we assume as input the p, n, and Λ^0 moments. The sign of the $\Sigma^0 \rightarrow \Lambda^0$ transition moment is taken from the quark model. The Ω^- moment is taken as three times the Λ^0 moment.

The quark model predictions reproduce all the signs correctly. In magnitude the worst disagreement is about $0.25 \mu_N$. This agreement makes you feel you are on the right track. However this is far from the complete story as a glance at the column showing the deviations in σ , or the % difference will attest. The Ξ^- , with a $\approx 30\%$ deviation, is striking. The quality of the hyperon magnetic moment measurements has steadily improved and they will continue to be an important constraint on model builders (see presentations of L. Brekke and J. Franklin this conference).

Table 1

Baryon	Magnetic Moment μ_N	Quark Model μ_N	Difference μ_N	σ	% Dif
p	2.7928444 ± 0.0000011	input			
n	$-1.91304308 \pm 0.00000054$	input			
Λ^0	-0.613 ± 0.004	input			
Σ^+	2.419 ± 0.022	2.67	-0.251 ± 0.022	11.41	-9.40
Σ^-	-1.156 ± 0.014	-1.09	-0.066 ± 0.014	4.71	6.06
$\Sigma^0 \rightarrow \Lambda^0$	-1.61 ± 0.08	-1.63	0.02 ± 0.08	0.25	-1.23
Ξ^0	-1.253 ± 0.014	-1.43	0.177 ± 0.014	12.64	-12.38
Ξ^-	-0.651 ± 0.017	-0.49	-0.161 ± 0.017	9.47	32.86
Ω^-	-2.0 ± 0.2	-1.84	-0.16 ± 0.20	0.80	8.70

Figure 5 is a plot of the differences. Here the error on the Λ^0 moment is plotted to illustrate the precision of the Λ^0 compared to the others. The larger errors on the $\Sigma^0 \rightarrow \Lambda^0$ transition moment and Ω^- moment distinguish them from the rest.

Figure 5 Comparison with Quark Model

FUTURE PROSPECTS

In the near future, before the next spin conference, we should expect to see final results from E756 on the Ω^- moment and from E715 on the Ξ^- moment although they are not expected to change in any major way from the results presented at this meeting. The completion of the E756 Ξ^- moment analysis using their full data sample should make that a definitive measurement.

In the more distant future, we might expect to see new data on the Σ^+ magnetic moment from Fermilab E761. This experiment will measure hyperon radiative decays ($\Sigma^+ \rightarrow p\gamma$ and $\Xi^- \rightarrow \Sigma^-\gamma$) in the next Fermilab fixed target running period. They also expect to collect a large sample of $\Sigma^+ \rightarrow p\pi^0$ decays from which they will be able to extract a measurement of the Σ^+ magnetic moment. Hopefully they will be able to resolve the two present conflicting measurements of the Σ^+ magnetic moment.

This same experiment will also attempt to see the rotation of the Σ^+ polarization by channeling Σ^+ with a bent crystal. The use of such crystals for the deflection of a 800 GeV beam has recently been demonstrated¹⁷. This technique has been suggested as a possible way of measuring the magnetic moment of short lived baryons containing heavy quarks¹⁸.

Members of the Fermilab E756 group (renamed E800) plan to run again to improve the statics (perhaps by as much as a factor of 5-10) of their Ω^- moment measurement. The time for this run has not yet been scheduled.

Approved programs exist at CERN¹⁹, Fermilab²⁰, and at UNK²¹ for significant new hyperon beam programs. These are mainly aimed at studying the production of heavy quark baryonic states. It is these long range programs that will continue to make the field exciting.

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