Fermi National Accelerator Laboratory

FERMILAB-Conf-00/058

Hyperon99 Experimental Summary: A 40 Year Perspective

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March 2000

Presented at and to appear in the Published Proceedings of the *Hyperon Physics Symposium (Hyperon99)*, Fermilab, Batavia, Illinois, September 27-29, 1999

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

Hyperon99 Experimental Summary: A 40 Year Perspective

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Summaries of the experimental results for the Hyperon 99 Symposium at Fermilab are given in this article. An attempt is made to view these results in a larger framework so that an idea of future experimental priorities can be obtained.

1. INTRODUCTION

The Hyperon 99 Symposium was held in a very timely fashion and place. Fermilab is likely making the last 800 GeV fixed target run for a very long time. As has been true since Fermilab began, hyperon physics continues to play an important role in the fixed target program. Both of the active fixed target experiments, KTeV and HyperCP, have strong hyperon physics programs, and both have reported results at this symposium. In addition, it should be pointed out that both experiments have strong kaon physics programs. This linkage of kaons and hyperons is, of course, not coincidental, but mirrors the gradual discovery of strangeness through associated production of kaons and hyperons in the early 1950's.[1] As an overview of the long history of hyperon physics, Vince Smith gave a very thorough presentation of the CERN hyperon physics program and showed how it relates to the work done at Brookhaven and Fermilab.

I have arranged this summary in five sections. The first three correspond to the way in which hyperons are studied: they exist (with static properties such as mass and lifetime), they are produced (with production properties such as polarization) and they decay (with decay properties such as form factors). I then summarize some of the data presented at the symposium reflecting strangeness in other baryonic forms of matter than the standard hyperon. In the last section I try to summarize what I believe are the important future measurements we should make in the field of hyperon physics.

2. HYPERONS EXIST

The static properties of hyperons have historically been an incredible hotbed of experimental activity. Fortunately, this data is of great quality and is challenging theoretical models to this day. Unfortunately, it doesn't leave eager experimentalists much to do on this front. Nontheless, many significant new measurements were presented.

Peter Cooper gave an excellent overview of hyperon static properties, such as magnetic moments, mass and lifetimes. In magnetic moments, he pointed out that there are no new measurements, but this is to be expected since no theory can test the precision in the current set of measurements. He presented the CERN NA48 experiments' new result on the mass of the Ξ°. This value is $m_{\Xi^\circ} = 1314.83 \pm 0.06 \pm 0.20$, bringing the error on this poorly measured mass in line with other hyperon mass measurements. The Coleman-Glashow relation[2] is now tested at a more significant level:

$$\begin{aligned} M_n - M_p + M_{\Xi^-} - M_{\Xi^\circ} + M_{\Sigma^+} - M_{\Sigma^-} \\ = 0 \ (Theory) \\ = -0.30 \pm 0.25 \ (Experiment) \end{aligned} \quad (1)$$

Peter also presented what he called "the new last results from E761", namely a new measurement of the lifetimes of the Σ^+ and its antiparticle. The result for the fractional difference in lifetimes is:

$$\frac{\Delta\tau}{<\tau>} = -0.06 \pm 1.12\% \quad (2)$$

making it the best baryon lifetime CPT test. The Ξ° lifetime is still poorly measured, but this should (MUST!) be measured by NA48 and KTeV in the near future.

Henning Krueger showed how the charm baryon experiment, SELEX, at Fermilab has made significant new measurements with its hyperon beam. The total cross section for $\Sigma^- N$ interactions at $\sqrt{s} = 34$ GeV has been measured and matches very well a prediction of Harry Lipkin's from 1975.[3] A cross check has been made by also measuring the π^- total cross section and this matches well the trend in previous lower energy data. As well, SELEX has measured the charge radius of the Σ^-, along with the proton and π^-. The latter two match previous measurements, while the former is the first such measurement. It shows that the Σ^- has a slightly smaller charge radius than the proton.

3. HYPERONS ARE PRODUCED

There is one word in hyperon production that tends to overshadow the others: polarization. It is an unexpected phenomenon, hard to explain and there is always another measurement that can be made. This symposium saw a plethora of new results in hyperon polarization, as well as other production properties such as hyperon-antihyperon asymmetries. Even if there is no comprehensive theoretical model that adequately challenges the current data set, measuring new aspects of this phenomenon is like putting money in the bank - it most assuredly will be taken out and used when the time is right.

To begin with, Ulrich Miller showed the WA89 result for polarization of Λ's produced by several different incident particles. The statistically significant result is for Σ^- production of Λ, with a systematically increasing positive polarization as you increase x_F, and relatively flat in p_T. Vince Smith also showed WA89 results, this time for Σ^- production of Σ°, showing a rather large negative polarization of about -40%.

Ed McCliment showed two new polarization results from SELEX. The first was the production polarization of Σ^+ hyperons. Although lower in statistics than E761, SELEX extends the p_T range to 2 GeV/c and the x_F range to 0.67, with a substantial positive polarization still seen at these limits. The second result was the polarization of Λ hyperons using an incident Σ^- beam, similar to the WA89 data. The SELEX data and WA89 data both show that Λ's produced in this way have the opposite polarization from proton production.

Al Erwin showed KTeV's new result on Ξ° polarization from 800 GeV proton production. These results agree very well with the 400 GeV data at twice the targeting angle, indicating that there is no energy dependence in this mode. KTeV saw no indication of polarization for the anti-Ξ°.

In a very intriguing result, Dave Christian showed new exclusive Λ polarization data from E690. For a $\Lambda - K^+$ final state, the data is rather irregular in p_T and x_F bins. However, if binned in terms of the effective mass, there is a simple monotonic behavior ranging from positive to negative 50%. This data confirms and extends a previous result.[6]

In his fine overview of polarization phenomena, Lee Pondrom discussed the issue of regularities in exclusive reactions, as reported in BNL E766 this year.[7] For four different exclusive $\Lambda - K^+$ final states, they can characterize the Λ polarization as a simple linear combination:

$$P_\Lambda = -a x_F p_T \tag{3}$$

Pondrom showed how this functional form fits the 400 GeV inclusive data for the lower values of p_T, but overestimates the polarization at higher values. Clearly this kind of synthesis between exclusive and inclusive reactions needs further study, especially for exclusive production of hyperons other than the Λ.

As a final note on polarization, Milind Purohit showed an impressive first result on Λ_c charm baryon polarization from E791, using a sample of almost 1000 decays. There seems to be an increasingly negative polarization with respect to p_T, much like the normal Λ data. More statistics will tell.

Beyond polarization, Joao Anjos presented other E791 results on production distributions of many hyperons (2.5 million Λ's, 1 million Ξ^-, etc). There are significant Λ decay statistics beyond a production p_T of 3 GeV/c, enough to show an enhancement above most theoretical models. He also showed large hyperon-antihyperon production asymmetries as a function of x_F and p_T^2, whose magnitude and shape are clearly not predicted by the Pythia/Jetset models.

4. HYPERONS DECAY

Hyperons, due to their low mass, have a fairly simple set of final states into which they decay. For the most part there is the standard non-leptonic weak decay, the beta decay and the weak radiative decay. Each of these three had significant exposure at this symposium.

One of the most ambitious hyperon experiments has to be HyperCP at Fermilab, which is continuing to run this year. Ken Nelson reported on the status of the search for CP violation in the normal mode decay of the Ξ^- hyperon and its antiparticle. They have an astounding 1997 sample of 245 million anti-Ξ^- decays, with 4 times that number for the particle counterpart. They expect a statistical sensitivity on the CP violation parameter of

$$\delta A_{\Xi\Lambda} = 2 \times 10^-4 \tag{4}$$

with 4 times more events in 1999! Ken presented evidence that systematic effects such as residual targeting angles do not show up in the ultimate center of mass angular distributions. Although most models of hyperon CP violation predict effects smaller than HyperCP's ultimate sensitivity, the latest results on ϵ' in the kaon sector show that Standard Model predictions of CP violation in even the simplest systems may turn out wrong.

Uwe Koch reviewed the status of hyperon radiative decays. The weak radiative decays have been a theoretical puzzle for many years, with an unexpected large negative asymmetry showing up in the decay $\Sigma^+ \to p\gamma$. Unfortunately, that is about as far as the experimental situation goes, while the theory has developed somewhat more.[8] Uwe showed KTeV's new result on the asymmetry in the decay $\Xi^\circ \to \Sigma^\circ\gamma$, which also shows a large negative value. KTeV also has on the order of 1000 events of the $\Lambda\gamma$ decay mode of the Ξ°, although with no measurement of the asymmetry yet. Lest KTeV rest on its laurels, Uwe showed NA48's plans for dedicated K_S running in the spring of 2000. Because their K_S production target is quite close to their detector, as compared to KTeV, their yield for hyperons is significantly greater. They may reach 50,000 events of both types in 30 days of running. Uwe also showed preliminary observations at KTeV of the decay $\Sigma^\circ \to \Lambda e^+e^-$, tagged from the rare decay $\Xi^\circ \to \Sigma^\circ\gamma$. Although this decay has been seen in bubble chambers, this has the potential to be the first measurement of its branching ratio and angular distribution properties.

Steve Bright continued the KTeV presentation by showing their new result on the first observation of Ξ° beta decay, with measurement of its branching ratio and form factors. With almost 500 candidate events, the branching ratio matches exactly the straight Cabibbo Theory prediction, with no SU(3) correction. Steve also showed that the form factor results, obtained from center of mass angular correlations, coincide quite precisely with the straight Cabibbo Theory. Since with two strange quarks you would expect significant SU(3) effects, this result is somewhat surprising.

Ashkan Alavi-Harati gave an overview of the experimental side of hyperon beta decays, where the KTeV result was put in perspective with the other hyperon beta decays. All of the experimentally accessible hyperon beta decays have now been observed. The Σ° and Ξ^- decays suffer from very small branching ratios. Ashkan discussed how global fits to the beta decay data set have been affected by large shifts in the neutron data. The search for SU(3) symmetry breaking is rather elusive and Ashkan showed how a case can be made that any such symmetry breaking is minimal in hyperon beta decays.

5. BEYOND HYPERONS

The hyperon is a well known beast which has been tamed over the course of decades. This symposium saw a hint of perhaps new exotic animals, related to the hyperon, but excitingly different.

Rene Bellwied gave a comprehensive overview of strange quarks in nuclear matter. One of the key signatures for the elusive quark-gluon plasma is an enhancement in anti-hyperon to hyperon production ratio. He showed evidence from NA35 and NA49 of net strangeness enhancement in nuclear collisions-perhaps another signature. Rene then discussed the plans for such measurements at the new RHIC nuclear collider at Brookhaven. With 10,000 charged particles per collision, they have their work cut out for them. Rene also showed preliminary results from several searches for the H dibaryon, containing 2 each of u,d and s quarks. This 6 quark semi-stable state will decay into a Λ, proton and π if its mass is below the di-Λ threshold. Several experiments from Brookhaven see an enhanced production in this mass region. Not shown at this conference is the new KTeV result on a search for the H dibaryon, which found no effect.[9]

Another hypothetical particle is 'diquarkonium', which contains 2 quarks and 2 anti-quarks. Ulrich Muller discussed how WA62 saw a mass peak in several final states containing a Λ, an anti-proton and two or three π's. There is also some confirming evidence from the BIS-2 experiment at Serpukhov. Ulrich showed WA89's new result on a search for this final state, with no observation at a sensitivity level where they should have seen it. As scientisits are always fond of saying: "we need more data".

Finally, Leonid Landsberg perked everyone up by showing an intriguing observation of a new resonance obtained from diffractive proton production at SPHINX in Serpukhov. In both the coherent region and at higher p_T^2 a significant resonance structure is apparent in the $\Sigma^\circ K^+$ mass region around 2 GeV/c^2. The interesting aspect of this state is its narrow width (less than 100 MeV/c^2) and the fact that its decay into the strange final state is greater than its decay into the normal nucleon isobar final state. Both of these facts make it a serious candidate for the pentaquark exotic baryon ($uuds\bar{s}$). Leonid also showed how Primakoff production from the Σ^- beam in SELEX gives a slight enhancement at this same mass value for the $\Sigma^- K^+$ final state. This work will be extended with a new SPHINX run and we are all looking forward to the results.

6. THE FUTURE

Besides showcasing the latest results in hyperon physics, which I have tried to summarize above, the symposium has given experimentalists, theorists and accelerator physicists a chance to meet and discuss the potential future of this field. The key questions are 1) what remains to be done and 2) how can we accomplish it?

Both KTeV and NA48 have plans to finish out their round of neutral hyperon measurements. HyperCP is also running again and will obtain incredible amounts of data on many decays of the charged hyperons. We are all looking forward to the results from that experiment. If a signal of CP violation is seen in their hyperon data sample then this may give a great impetus to further studies. Unfortunately, the calorimeter in that experiment is insufficient to reconstruct photons and electrons in the final state, so beta and radiative decays will not be analyzed.

Looking further afield, a panel met to discuss the possibilities of future experiments. It seems that a major criteria for a new hyperon experiment, or any new high energy phyics experiment for that matter, is that it should have a measurable and interesting goal in mind. A few relevant issues in hyperon physics that stand out in my mind as meeting this criteria are:

- $\Sigma^+ \rightarrow \Lambda e^+ \nu$ decay: As many speakers pointed out, this decay has been very poorly measured, with only 21 events ever seen.[4] Besides measuring the branching ratio to test the Cabibbo theory prediction, this decay is interesting in that it can resolve the issue of whether there is isospin mixing between the Σ and the Λ, as discussed in this symposium by Gabriel Karl.[5] After all this time, do we really know what a Λ is?
- Weak Radiative Decays: Now that new high statistics samples of the Ξ° weak radiative decays have been obtained, it is time to close the door on the experimental side of weak radiative hyperon decays. The decays $\Xi^- \rightarrow \Sigma^- \gamma$ and $\Lambda \rightarrow n\gamma$ are eminently measurable, especially considering that the latter can be measured in an experiment for the former by tagging the plentiful $\Xi^- \rightarrow \Lambda\pi^-$ decay.
- Polarization in anti-hyperons: To my mind, the observation of polarization in anti-hyperons (the $\bar{\Xi}^+$ and $\bar{\Sigma}^-$) is an amazing fact and the most telling of all polarization results. If it is possible to polarize sea quarks, then all of the current models are wrong and we MUST reconsider this interesting phenomenon. The anti-hyperon results must be repeated and studied in more detail.

Please note that these three examples are really all aspects of a single well-designed hyperon experiment - a multipurpose high intensity charged hyperon experiment with good tracking and calorimetry. The main sticking point is how and where to make the beam? If we think about such an experiment at Fermilab, it is clear that an 800 GeV fixed target beam will have to wait for completion of the collider Run II in 2006 or so. Even then it would have to justify competing against a collider run. The 120 GeV Main Injector beam is available for fixed target experiments, but several members of the panel were concerned at the prospect of losing the advantage that higher energy gives for hyperon physics. And Bill Foster urged us to consider a new Fermilab 3 TeV machine as the obvious candidate. To my mind, the Main Injector option should be considered as the default candidate until it can be shown as unworkable. Although I've always been a Fermilab regular, I would urge that this kind of dedicated charged hyperon experiment also be considered for other laboratories.

7. CONCLUSION

I call this summary a 40 year perspective partly because the oldest reference to experimental hyperon data in the Particle Data Book is from 1959 - a measurement of the branching ratio of $\Lambda \to p\pi^-$.[4] But another reason is that I turned 40 years old myself during this symposium. My hope is that I have matured in high energy physics as gracefully as the field of hyperon studies. And my sincerest wish and belief is that the future is promising for us both.

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In general, an experimental situation contains, first, the system itself, and, second, a model or models of the system. Whatever else is involved, it is an essential part of the experimenter's task to test the properties of the model against the properties of the real system. In principle, our model will ineviÂ tably be incomplete and inaccurate. For example, let us return to the problem of ordering paint for the wall. If as blind painters we test the properties of rectangles with increasing precision against those of the actual wall, we inevitably reach a point at which we begin to find Radiative Hyperon Decays an Overview. Uwe Koch University of Mainz NA48 Collaboration CERN. Hyperon 99, Sept. 27 - Sept. 29, 1999. Contents.Â Experimental Results till 1998. NA48 - Experiment. â€¢ main goal: measurement of Re(Îµ`/Îµ) â€¢ 2 collinear beams for KS and KL Mesons â€¢ Lifetimes for KS Meson and Hyperons in same range (~10-10s) â€¢ => Hyperons from Ks Target â€¢ Spectrometer, excellent mass and vertex resolution â€¢ Liquid Krypton calorimeter with excellent energy resolution. NA48 - The Beam Lines. NA48 - The Detector. NA48 - Hyperon Selection.Â Same final state as the decay mode Îž âˆ'> Î› Ï€0 (99.95 %) can be distinguished by Î›Î³ and Î³Î³ mass use Îž âˆ'> Î› Ï€0 for normalization. Preliminary: BR(Îž âˆ'> Î£0 Î³) = (3.0 Â± 0.05 Â± 0.2) âˆ— 10 âˆ'3. KTeV - Îž -> Î£. 99,477. 80.39. 2. 0.000290. 99,327. 74.48. 0.000209. 99,443. 79.42. 3.Â Note: The period life expectancy at a given age for 2017 represents the average number of years of life remaining if a group of persons at that age were to experience the mortality rates for 2017 over the course of their remaining life. The Social Security area population is comprised of (1) residents of the 50 States and the District of Columbia (adjusted for net census undercount); (2) civilian residents of Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Northern Mariana Islands; (3) Federal civilian employees and persons in the U.S. Armed Forces abroad and their dependents; (