Fermilab Proposal No. 353

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VERY STRANGE HYPERON DECAYS

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I. Introduction

We propose a comprehensive program to study decays of charged hyperons with an emphasis on the properties of the Ω^-. This emphasis derives from the unique ability of the Fermilab machine to produce usable fluxes of rare short lived particles. Many of the decay modes which are accesible at Fermilab will provide information on the nature of the low q^2 V-A Weak Interaction theory while others pertain to questions which are more speculative in nature. The experimental technique which we propose, however, allows most decay modes of interest to be studied simultaneously, thus allowing us to search for exotic effects without neglecting the less speculative part of the program.

This survey of hyperon decays is a natural extension of our group's work at Brookhaven National Laboratory (BNL)[1] and of the technical developments we have been pursuing for approved experiments E69 and E97. In fact, the apparatus needed to carry out the program proposed here requires rather few additions and variations to the apparatus for E97 (Elastic Scattering of Hyperons). Thus, we propose that this study of hyperon decays be carried out immediately following E97 in the charged hyperon beam.

Two methods of detection and identification of hyperons are proposed. One is a pair of superconducting quadrupoles and a high resolution gas Cerenkov counter placed immediately after the magnetic channel to directly tag the hyperons. The other consists of using a double magnetic spectrometer to

reconstruct the beam particle mass from the kinematics of the charged decay products. In almost every decay mode of interest, the reconstructed event is overconstrained.

We will be sensitive to hyperon decays leading to a wide variety of final states, both leptonic and non-leptonic. Often, a chain of decays will be of interest where the final state contains a Λ^{o}. In other cases, the final state contains a neutron. Our work at BNL has given us experience in the detection and analysis of such events.

While most of our effort will be devoted to decays of negative hyperons or decays of lambdas coming from Ξ^{-} decay, we hope to spend some effort studying leptonic decays of the Σ^{+}.

We envisage this experiment as being done just after E97 using the apparatus of E97 with the addition of detectors for electrons and possibly gamma rays. Many of these new detectors can be tested during the running of E97. As we have pointed out in the E97 proposal, the magnetic channel design there is not adequate for decay experiments using the rarer hyperons. In this proposal we require a channel embodying superconducting quadrupole magnets which would make the beam better matched to the acceptance of the Cerenkov counter described in the E97 proposal. This improved acceptance channel would also enhance the capabilities of E97 and we would also use it there. We estimate 600 hours of beam time would be needed for the data taking part of the program described here.

II. Which Decay Modes are Interesting and Why

A. Flux Measurements

The cross section for production of Σ^-, Σ^+, Ξ^- and Ω^- by protons can be determined either with the high resolution Cerenkov counter or from the predominant 2-body decays with the indicated number of constraints

$\Sigma^- \to n\pi^-$	1 C
$\Sigma^+ \to n\pi^+$	1 C
$\Xi^- \to \Lambda^o\pi^-$, $\Lambda^o \to \pi^- p$	4 C
$\Omega^- \to \Lambda^o K^-$, $\Lambda^o \to \pi^- p$	4 C
$\Omega^- \to \Xi^o\pi^-$, $\Xi^o \to \pi^o\Lambda$, $\Lambda \to \pi^- p$	1 C
$\Omega^- \to \Xi^-\pi^o$, $\Xi^- \to \pi^-\Lambda$, $\Lambda \to \pi^- p$	1 C

These flux measurements are part of the approved E97 program and are a common part of both experiments. A comparison of the hyperon production cross sections measured at BNL and Fermilab will test scaling in the single particle inclusive reactions

$$p + \text{Nucleon} \to Y^{\pm} + \text{anything}$$

Figure 1 is a compilation of these inclusive hyperon cross sections as measured at BNL and CERN.

B. Ω^- Physics

Since Fermilab is uniquely suited for the production of useful beam fluxes of Ω^-, we expect the major thrust of this program to be the study of the decays of the Ω^-. Such a program would be of interest with a sample of a few hundred Ω^- events. As will be discussed in a later section, a sample of thousands of events is quite likely to be obtained in a few hundred running hours at Fermilab. The use of the beam Cerenkov counter to tag Ω^- will be essential in studying some of the rare decay modes described below.

i) $\Omega^- \to \Lambda^o K^-$, $\Lambda^o \to \pi^- p$: This mode is a 4C fit. In addition to its use in measuring the Ω^- flux, its lifetime can be determined. The Ω^- lifetime is now known only to about 25%.[2] If the Ω^- are produced aligned as might be expected for 0° production, the decay angular distribution can be used to measure the spin of the Ω^-. Such a measurement, if successful, would confirm the SU_3 assignment of the Ω^- to the decouplet.

ii) $\Omega^- \to \Xi^o \pi^-$, $\Xi^o \to \Lambda^o \pi^o$, $\Lambda^o \to \pi^- p$;
$\Omega^- \to \Xi^- \pi^o$, $\Xi^- \to \Lambda^o \pi^-$, $\Lambda^o \to \pi^- p$:

These decay modes are 1C fits even with no π^o detection. Their branching ratios are probably of order tens of percents so that adequate samples could be obtained. These branching ratios, while interesting on their own, provide a nice test of the $\Delta I = 1/2$ rule in decuplet to octet transitions. As is well known, the $\Delta I = 1/2$ rule in octet to octet transitions can

arise from cancellation of $\Delta I = 3/2$ terms by neutral currents (perhaps the neutral currents are then cancelled by charmed currents if the correct algebra is SU_4). In the case of decuplet to octet transitions, the Clebsch-Gordan coefficients are <u>not</u> such to allow cancellation of $\Delta I = 3/2$ terms. As a result, significant $\Delta I = 3/2$ amplitudes may appear in Ω^- decays. No data exists on the validity of the $\Delta I = 1/2$ rule in decuplet to octet transitions. If the rule is valid the ratio of these decay modes is expected to be 1/2 with small modifications for phase space factors.

iii) $\Omega^- \to \Lambda^o \pi^-$, $\Lambda^o \to \pi^- p$; $\Omega^- \to n\pi^-$: These decays, if they occur, are 4C and 1C respectively. The high resolution Cerenkov counter would be used to tag beam Ω^- to reduce background from Σ^- and Ξ^- 2 body decays. These Ω^- decays are, of course, forbidden in that they are $\Delta S = 2$ and $\Delta S = 3$ respectively. These selection rules could be verified to about 10^{-4} in rate in this experiment. There are no data on the existence of decays with $\Delta S = 2$ in decays from the decuplet to the octet, and, of course, no limits on $\Delta S = 3$ transitions.

C. Leptonic Decays

A high statistics sample of overconstrained leptonic decays of hyperons would give a clean test of the Cabbibo picture of semileptonic decays of the baryon octet. If the currents responsible for these decays are members of an SU_3 octet of currents, and the vector currents are conserved then the vector and axial vector form factors of such decays can be described by only two

parameters, F and D, and the Cabbibo angle. With the fluxes available in a negative hyperon beam at FermiLab, it would be possible in 100 hours of beamtime to obtain about a thousand events of the overconstrained decays

$$\Xi^- \to \Lambda^o e^- \bar{\nu} \quad \text{and} \quad \Sigma^- \to \Lambda^o e^- \bar{\nu}$$
$$\hookrightarrow \pi^- p \qquad\qquad \hookrightarrow \pi^- p$$

With adequate experimental resolution on the directions and momenta of the charged decay products, these decays would yield information on form factors from Dalitz plot distributions and from correlations with the Λ^o polarization. In addition, it would be possible to study several thousand overconstrained leptonic decays of polarized lambdas ($\Lambda^o \to pe^-\bar{\nu}$).

Lambdas of known polarization are obtained from the 2-body decay of the Ξ^-. By detecting the decay π^- from the Ξ^-, the momentum of the Λ^o is known. The Ξ^- will be unpolarized due to its production at zero degrees, and the resulting decay Λ^o's have a polarization equal to the asymmetry parameter, 0.4, in the decay $\Xi \to \Lambda^o\pi^-$. Subsequent leptonic decays ($\Lambda^o \to pe^-\bar{\nu}$) are once overconstrained.

Previous experiments to study leptonic decays of hyperons namely $\Sigma^- \to ne^- \bar{\nu}$, have suffered from a loss of precision due to the square root ambiguity associated wiht not having overconstrained events and with the resulting uncertainty in background levels and systematic problems. With the method described here, these problems are avoided by the ability to reconstruct the Λ^o mass. The form factors can then be determined independently from the

asymmetry parameters of the p, e^- and $\bar{\nu}$ with respect to the Λ^o polarization and from the Dalitz plot distribution. This gives a nice check on the consistency of the results. This data has some sensitivity to the presence of SU_3 violating second class currents. With the numbers of events projected, the accuracy of the form factor ratio g_A/g_V obtained from each of these methods should be better than $\Delta(g_A/g_V) = .07$.

We would, of course, make the usual checks for scalar and tensor components to the matrix element, especially in the decay $\Xi^- \rightarrow \Lambda^o e^- \bar{\nu}$ where very little information exists. The decay $\Lambda^o \rightarrow pe^- \bar{\nu}$ will provide a test of T invariance in the presence or absence of a term $\sigma_\Lambda \cdot (\vec{P}_p \times \vec{P}_e)$ in the matrix element.

Our group is currently studying the question of the feasibility of high statistics measurements of hyperon leptonic decays. The fluxes are certainly adequate for such measurements. The questions which must be answered concern whether or not sufficient resolution can be achieved on the decay kinematics and whether leptons can be efficiently identified in the trigger while discriminating against decay mesons to 1%. If these questions are answered in the affirmative the apparatus need only be modified by the addition of the lepton detectors between the two spectrometer magnets. (See IV H).

D. Decays of the Σ^+:

i) $\Sigma^+ \rightarrow n\pi^+$: This decay, which gives a 1C fit, is used to survey the Σ^+ flux and to measure its production cross section.

ii) $\Sigma^+ \to \Lambda^o e^+ \nu, \Lambda^o \to \pi^- p$; The $\Delta S = 0$ decay of the Σ^+ is once overconstrained. The most important information obtained from this decay mode is the ratio

$$R = \frac{\Gamma\ (\Sigma^+ \to \Lambda^o\ e^+\ \nu)}{\Gamma\ (\Sigma^- \to \Lambda^o\ e^-\ \bar{\nu})}$$

In the absence of second class currents, R = .30. Any observed deviation from this ratio indicates a direct observation of such G parity violating currents in the Weak Interaction. With the projected event rates (Table IV), it would be possible to determine this ratio to about 15%. Systematic errors would be minimized by using the same detection apparatus for $\Sigma^+ \to \Lambda^o\ e^+\nu$ as for $\Sigma^- \to \Lambda^o\ e^-\ \bar{\nu}$.

iii) $\Sigma^+ \to ne^+\ \nu$: Observation of this decay indicates a direct violation of the $\Delta S = \Delta Q$ selection rule. It is forbidden by the Octet Current hypothesis. A search for this decay or the decay $\Xi^- \to ne^-\ \bar{\nu}$ would require a complex neutron detector which is capable of determining the neutron angle in order to reconstruct the decay. Such a detector was successfully used by our group at BNL.[1] With the fluxes expected, a limit on $(\Delta S = -\Delta Q)/(\Delta S = \Delta Q)$ of 10^{-5} might be obtained.

The program outlined above is a broad and comprehensive study of hyperon decays with the primary goal of measuring the properties of the Ω^- and probing the Weak Interaction selection rules. Such a program is clearly well suited for FermiLab and can be accomplished with relatively little new hardware beyond that required for Exp. 97. If it appears feasible to study leptonic decays and so further test the octet current hypothesis, electron detectors (possibly shower counters, lead glass or transition detectors) would be constructed.

III. Expected Intensities

A. Production Cross Sections

A great deal of new information is available on secondary particle yields at high energies since the writing of the E97 proposal. We will now update these flux estimates in the light of measurements at FermiLab of production cross sections of $\pi^{\pm}$ and protons[3] and measurements of Σ^- and Ξ^- yields at BNL[1] and CERN.[4] The existing measurements of the invariant cross sections for hyperons are shown in Fig. 1. Here they are plotted as a function of α which is the ratio of the laboratory hyperon momentum to the maximum kinematic laboratory momentum. At the energies of interest for us this is very close to the laboratory hyperon momentum divided by the incident proton momentum. Table I shows the non invariant cross sections at $\alpha = 0.6$ and $\alpha = 0.8$ for 200 and 300 GeV/c incident protons.

Let us consider first the fluxes of negative particles. We

note that for $\alpha = 0.8$ the cross section ratio of Σ^- to π^- is near one so this is a desirable operating point when doing Σ^- physics. However the Ξ^- cross section is much higher at $\alpha = 0.6$ then at $\alpha = 0.8$ so for Ξ^- studies $\alpha = 0.6$ is more desirable in spite of the higher π^- cross section. As in our BNL experiment we should be able to vary α by varying the magnetic field in the hyperon channel in order to optimize the flux of the desired hyperon with a minimum of background. We arrive at the Ω^- fluxes by assuming the production cross section ratio for Ξ^-/Ω^- is the same as that measured for the ratio Σ^-/Ξ^-. Note from Fig. 1 that this is a strong function of α. Since little is known about Ω^- fluxes this could be an optimist estimate. Existing data place an upper limit of $10^{-2 \pm 1}$ for the Ω^-/Ξ^- ratio.

No measurements are available on high energy Σ^+ production but an estimate has been made using the Hagedorn-Ranft model[5] at an incident proton energy of 200 GeV/c. This also shown in Table I as well as a value at 300 GeV/c based on the assumption that the corresponding invariant cross section has reached its scaling limit. The Σ^+ cross sections are about a factor of seven greater than the corresponding Σ^- cross sections which seems reasonable since one would expect the positive charge of the proton projectile to enhance forward Σ^+ production relative to Σ^- production. The estimated proton and π^+ yields are from the data of Baker et al.[3]

B. Flux Estimates

Based on the cross sections of Table I we have computed

the fluxes available at the beginning of our decay region, a distance of 15 m from the production target. In this 15 m are included the 6 m hyperon channel described in E97, a quadrupole doublet of total length 4 m to render the beam parallel and a 5 m Cerenkov counter for particle identification. These are described in more detail in Section IV. The fluxes of particles surviving after the Cerenkov counter are shown in Table II. Included in the calculation are the solid angle and momentum acceptance of the channel as well as the hyperon decay losses. The number of interacting protons has been chosen to give $5 \cdot 10^5$ total particles at the start of the decay region and is listed separately for the positive and negative setting.

For the negative settings we note that 60,000 Σ^- per pulse is achievable at $\alpha = 0.8$ and 300 GeV/c incident protons. This flux is about 300 times greater than the usable flux achieved at our BNL hyperon experiment. The expected Ξ^- flux is also about two orders of magnitude larger than our BNL flux. The Ω^- flux estimate is more uncertain but leads us to expect almost five per pulse at $\alpha = 0.6$ and 300 GeV/c incident protons. With this flux we would exceed the present world sample of Ω^- in ten machine pulses! The number of protons interacting in our target is modest and ranges from 10^9 to a few times 10^{10} per pulse. Since this is the number of interacting protons and no targeting efficiency has been included we would require a factor of about three more than the above for our incident proton flux.

Part of the uncertainty in the Ω^- flux stems from our lack of knowledge of its lifetime. The lifetime is presently measured to be $1.3^{+0.3}_{-0.2} \cdot 10^{-10}$ seconds.[2] If the lifetime were in fact to be one standard deviation above the present value our fluxes of Ω should be increased by almost a factor of three.

On the other hand if the real lifetime were one standard deviation lower our fluxes should be decreased by a similar amount. Needless to say this experiment should provide as a by product an improved measurement of the Ω^- lifetime.

For the possible study of Σ^+ the number of interacting protons required is on the order of a few times 10^8. Here we are limited by the large proton fluxes energing from our channel. However if we limit the proton flux on our target to a level which gives us $5 \cdot 10^5$ total particles (mostly protons) emerging from our channel we still have a Σ^+ flux which measures up to a few thousand per pulse. This Σ^+ flux is larger than the Σ^- flux used in our BNL hyperon experiment!

In Table III we tabulate the expected number of hyperon decays in ten hours of accelerator operation. We have taken a fiducial region which extends from 15 to 25 m from the production target. We assume the accelerator operates with a six second period. We believe these substantial fluxes to be the input to a very rich physics program.

C. Event Rates

We list in Table IV the expected detected number of events in a 100 hour accelerator run as a function of hyperon and decay mode. The fluxes from Table III for $\alpha = 0.6$ and 300 GeV/c incident protons have been assumed. Included is a flat detection efficiency of 10% for all decay modes. This would include the tagging efficiency of the entering hyperon by the

Cerenkov counter as well as the detection efficiency of the hyperon decay products. We believe this estimate to be conservative.

IV. Hyperon Beam and Detector

A. Introduction

Figure 2 is a schematic diagram of the beam and detector proposed for Expt. 97 with the additions needed for this proposal. A beam of 300 GeV protons impinges on a target of cross section 1 mm x 1 mm and one interaction length in the beam direction. High energy negative particles produced in the forward direction are transmitted by a magnetic channel. Following the channel approximately 9 m is available to insert a superconducting quadrupole doublet, high precision ($\sigma \sim 70$ μm) proportional wire chambers and a focusing Cerenkov counter for tagging Ω^- in the beam. Such a quadrupole doublet would require 4 meters along the beam line. A decay region followed by the first analyzing magnet, A1, is located after the high resolution chambers. This magnet allows a determination of the momentum of the low energy particles, mesons and leptons. produced in hyperon decays of interest. (An array of counters for lepton tagging in the trigger could be located between A1 and the second spectrometer magnet, A2) The high momentum neutrons (125-180 GeV/c) produced through a decay chain such as

$$\Sigma^- \rightarrow n\pi^-$$

are tagged for the trigger by an iron scintillator calorimeter located 75 m downstream from the A2 magnet on the neutral beam line. Standard BNL 18D72 magnets provide adequate aperture to be used as spectrometer magnets for Expt. 97 and for this proposal. For A1 the gap required is 12"; for A2, 8" would be adequate. A hadron calorimeter downstream of A2 will aid in identifying fast protons from Λ^{o} decays thereby eliminating accidental triggers due to muons.

We would now discuss in more detail the components of the hyperon beam and detection apparatus. Immediately after the target is a magnetic dipole channel, quadrupole doublet and Cerenkov counter. The acceptances of these elements must be carefully matched and their total length kept to a minimum because of the short hyperon lifetime. Careful attention must also be given to shielding the detection apparatus from the proton beam striking our target.

B. Shielding, Activation and Muon Background

In our design of the magnetic channel for Expt. 97 we have attempted to evaluate the problems of target and magnet activation as well as radiation shielding for incident proton intensities of several times 10^{10} per pulse. It appears that there are no problems at these intensities and most likely the problems are even tolerable up to 10^{11} protons per pulse with a small increase in the shielding of the dump. Our experience in the design and operation of the BNL hyperon beam indicates that with a properly designed magnetic channel, muon problems are not severe. The conclusion is especially true if one uses proportional wire chambers and drift chambers as detectors because of their relatively short memory time with

respect to spark chambers used in the BNL experiments. With fluxes of 10^{11} protons, some additional muon shielding may be needed downstream of the experiment.

C. The Magnetic Channel

The channel used for this set of experiments can be identical to that designed for Expt. 97. It is 6m long with an exit aperture of 10mm x 6mm. The momentum bite is 10% but a measurement of the beam particle position and angle at the exit of the downstream quadrupole doublet using high resolution proportional wire chambers will determine the momentum to 0.5% and angle to 0.02 mr. The same magnet that is being used to sweep out charged particles for the neutral hyperon experiment (E8) would be suitable for our magnetic channel with the insertion of properly shaped pole pieces and shielding.

D. Superconducting Quadrupole Magnets

In order to increase the acceptance of the high resolution Cerenkov counter we will install a superconducting quadrupole doublet immediately upstream from the counter. A design for such a set of magnets has already been made by R. McCracken.[6] The magnets will be 2 meters and 1.5 meters long, respectively, with a one inch bore. With such magnets, the beam will be sufficiently parallel to increase the Cerenkov acceptance to at least 50%. Such a system was successfully implemented in the CERN P.S. hyperon beam in conjunction with a DISC counter.

A free space of 4 m is incorporated into our design for these magnets. We would request that FermiLab undertake the construction of such magnets.

E. High Resolution Cerenkov Counter

A Cerenkov counter designed to separate protons, Σ, Ξ and Ω giving a definite trigger for one of the particles would be located just downstream of the quadrupole doublet. The beam is made to have negligible divergence vertically by the doublet, but has a 3 mr horizontal spread due to the 10% momentum aperture. When the Cerenkov light is focused to a ring, the angle spread of the beam causes a spread in the center of the ring. Therefore a single ring aperture and light collection system will not see all of the beam momentum aperture. We propose making a multi channel differential Cerenkov counter, which will be able to accept a large momentum aperture and high flux. Any attempt to recombine the beam in angle so a single aperture could be used, would involve more magnets and a higher decay loss.

The Cerenkov light would be focused to a ring at a focal plane with about 30 apertures (defined by either mirror segments or light pipes) leading to separate phototubes. The apertures would be segments of the ring displaced horizontally with respect to each other and collecting about one half of the light. The proportional chambers on either side of the counter determine the particle's angle through the counter and hence which aperture the light is expected to fall in. A fast electronics box would calculate the aperture and gate the

corresponding phototube signals giving the particle trigger. We believe the counter would work up to 180 GeV/c with the following parameters: Length 5 m, Cerenkov Angle 12 mr, Cerenkov Angle bin aperture 0.13 mr, number of photo electrons 4, and efficiency > 50% for $\Delta P/P = 10\%$. FermiLab physicists would undertake the construction of this counter using Physics Department facilities.

F. High Resolution PWC

Members of the team submitting this proposal have successfully constructed proportional wire chambers with 2.5 wires/mm for use in Expt. 69. These chambers have high efficiency and an effective resolution (standard deviation) of 70 μm when operated as staggered pairs. These chambers are easily adapted for use in determining the beam particle momentum and direction in hyperon experiments.

The chambers operate at 4 atmospheres pressure using a 90% argon, 10% isobutane, .7% Freon gas mixture. The chambers give a minimum pulse amplitude of 1mv with a rise time of ~ 10 ns. They are read out with a commercial hybrid chip (LeCroy) containing an amplifier, discriminator and one-shot. A preamplifier with a gain of 10 is used at the front end. These chambers and their readout have been adequately tested in conjunction with their use in Expt. 69.

G. Drift Chambers

Members of the team working on Expt. 97 are currently designing drift chambers[7] and their readout electronics for use in hyperon experiments. Drift chambers of adequate sensitive area and resolution have already been constructed at other laboratories. A prototype chamber and readout has been

constructed by our group using a novel field shaping method. This chamber has been studied using the E69 apparatus. Intrinsic resolutions of about 100 μm have been achieved exclusive of digitization errors. The use of drift chambers should allow us to run with high intensities (10^{11} protons/pulse) with virtually no background problems from muons or limitations in data acquisition rates.

H. Lepton Trigger Elements

Compared to AGS energies, the FermiLab hyperon beam has the disadvantage that the decay electrons cannot be as readily distinguished from pions by Cerenkov detectors; the energies are too high. However, at FermiLab energies the distinction between electromagnetic and hadronic cascades serves the same purpose. The pions, muons and electrons from hyperon decay have similar spectra, ranging from 5 to 50-60 GeV/c in the laboratory. In this energy region muons can be effectively distinguished by range. (We note that in studying $\Sigma^- \rightarrow n\ell^-\bar{\nu}$ decays there would be some advantages in detecting the muonic mode-fewer radiative corrections compared to electronic modes and a sensitivity to induced pseudoscalar form factors. Muon detection may thus be considered at a later stage.) The electron-pion distinction by pulse height in an array of lead-scintillator sandwiches, judging from experience at lower energies, may allow discrimination against pions by a factor of 100. Additional discrimination, though not necessary, might be achieved by vetoing on the high energy cascades which will develop strongly beyond the electromagnetic cascade in high - Z materials. We are currently initiating discussions with other physicists who have had experience in lepton identification at

FermiLab energies. Perhaps it will be concluded that lead-glass arrays would best do the job. The point which must be emphasized, however, is that the lepton trigger elements need only identify particles for triggering purposes - no information about their energy is required.

I. Triggers

The triggering scheme for these experiments consists in being able to tag electrons, decay mesons, high energy neutrons and high energy protons from Λ^o decay in the downstream apparatus. By requiring the correct combinations of these tagging triggers, a clean trigger for each decay mode of interest can be achieved. In addition, for studying forbidden Ω^- decays the high resolution Cerenkov counter is required to tag the Ω^- to prevent the prevalent Σ^- and Ξ^- decays from flooding the trigger. To illustrate this scheme we consider the leptonic decay trigger. Here the relevant decay modes are

$$\Sigma^- \to \Lambda \ell^- \bar{\nu}$$
$$\quad \hookrightarrow \pi^- p$$
$$\Xi^- \to \Lambda \ell^- \bar{\nu}$$
$$\quad \hookrightarrow \pi^- p$$
$$\Xi^- \to \Lambda \pi -$$
$$\quad \hookrightarrow p \ell^- \bar{\nu}$$

In each case there is a proton and electron in the final state. Thus, even with 10^4 Σ^-/pulse and 100 Ξ^-/pulse the requirement of a high energy proton should greatly suppress all other Σ^- decays and the presence of an electron should reduce the

Ξ^- triggers to less than 1/pulse. For Ω^- events, the high resolution Cerenkov reduces the trigger rate to the level of beam Ω^-. Only in the case of $\Sigma^- \rightarrow n\pi^-$ and $\Xi^- \rightarrow \Lambda\pi^-$ will the trigger rate be excessively high, but in these cases the trigger is essentially pure and so can be scaled down to a convenient level. In cases where several decay modes have identical triggers, the trigger rates are low and there are kinematic constraints to separate the decays. The triggering scheme described here was successfully used in our BNL hyperon experiments.

V. Hyperon Decay Kinematics and Resolutions

The decay angles for decays scale approximately inversely with the beam momentum so that hyperon decay angles are an order of magnitude smaller than at the BNL hyperon beam. The most critical measurement in reconstructing these decays is the determination of the initial hyperon angle which is accomplished by high resolution (70μm) PWC's spaced approximately 5 m apart. Such a system defines the hyperon momentum to 0.5% - the required order of magnitude increase in accuracy over the BNL experiment.

Decay mesons and leptons have momenta in the range 5-60 GeV/c while decay protons from Λ^0 have momenta from 120-180 GeV/c for 300 GeV incident protons and $\alpha = 0.6$. If we use BNL 18D72 magnets as the spectrometers A1 and A2 with drift chambers of spatial resolution of about 250 μm we can determine the decay product momenta to about 5%. Such a system would give a

resolution in the reconstructed hyperon mass of the order of 10-20 MeV/c^2. This should be more than adequate for the purpose of separating overconstrained decay modes with identical trigger configurations.

VI. Summary of Beam and Equipment Requirements

We require a beam of approximately 10^{11} protons per pulse of energy 300 GeV focused to a spot of 1 mm in cross sectional area. This beam and the hyperon channel could be identical to that used for Expt. 97 except for the addition of the quadrupole doublet. The diffracted proton beam (M2) in the Meson Laboratory would be suitable.

The detection apparatus is identical to that used for Expt. 97 except for the lepton trigger detectors which will be supplied by the experimenters. We would require the use of additional electronics required to read out these detectors (CAMAC ADC'S) and the additional fast logic required to form the many classes of triggers. It should be noted that when E97 was proposed the technology of proportional wire chambers was in its infancy and we proposed to do E97 using high resolution spark chambers developed by this group for our BNL hyperon experiment. It is now clear that the proportional wire chamber technology developed by this group for E69 would greatly enhance the physics potential of E97 and we plan to equip both this experiment and E97 entirely with drift and proportional wire chambers.

The two 18D72 magnets or their equivalents which will be used for Expt. 97 have adequate apertures for our purpose. We also request continued use of the data acquisition system, counting house and computer links used in Expt. 97. Some minimal amount of rigging may also be required to slightly reconfigure the apparatus of Expt. 97 in order to optimize it for our purposes. About 600 hours of beam time will be needed for the data taking part of this experiment.

The estimated event rates can be read from Table IV for a given number of beam hours and proton beam intensity. Presumably a minimal amount of test time will be needed due to our experience with beam and apparatus during Expt. 97.

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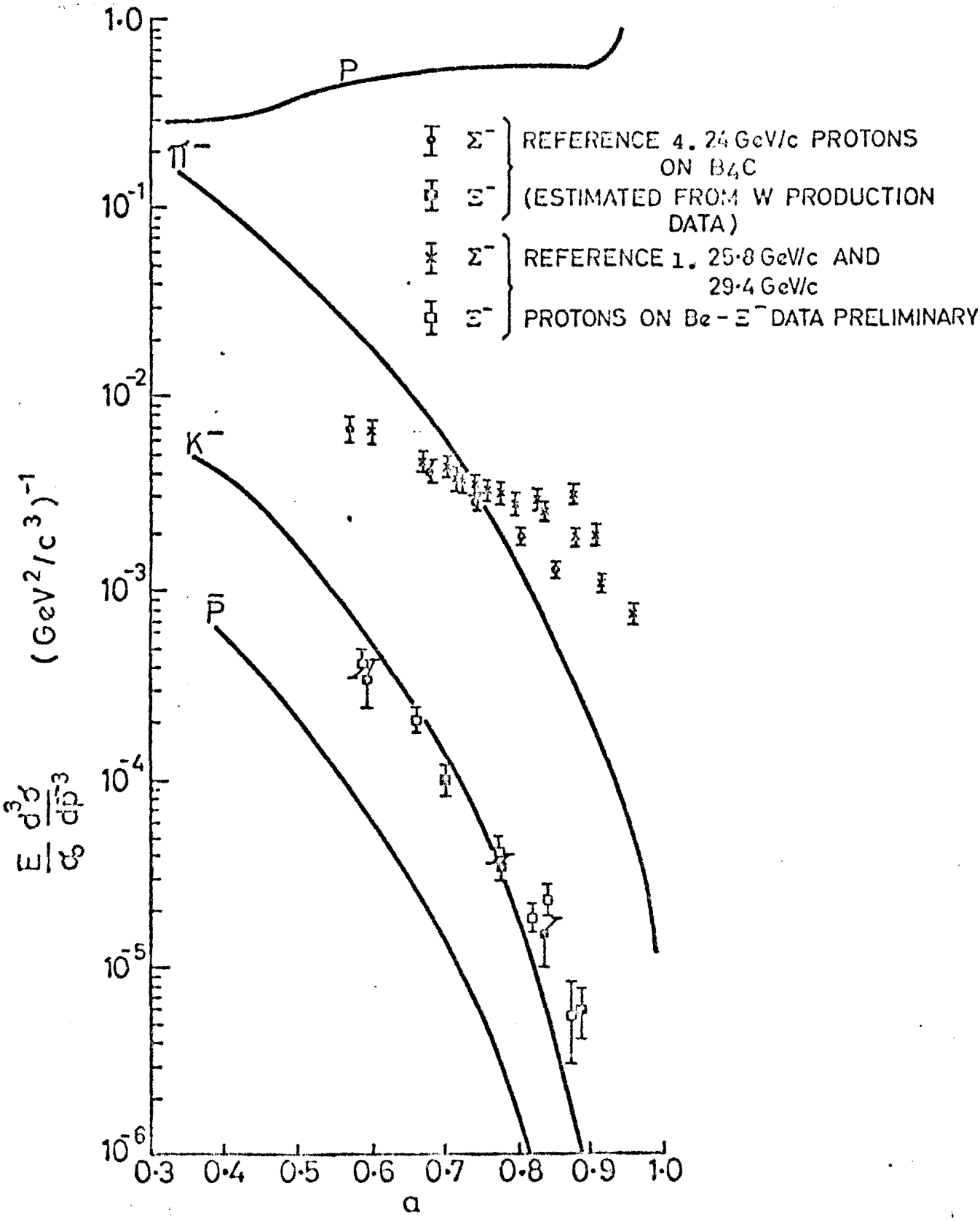
Figure 1



The invariant inclusive cross-section plotted as a function of the longitudinal laboratory momentum normalized to its kinematic limit for various particles produced in proton-Be collisions.

TABLE I

Particle production cross sections in Berylium. These cross sections are for the forward direction and the units are number of secondary particles per GeV/c per steradian per interacting proton at the target.

	200 GeV/c Incident		300 GeV/c Incident	
	120 GeV/c	160	180	240
	$\alpha=0.6$	$\alpha=0.8$	$\alpha=0.6$	$\alpha=0.8$
Σ^-	0.79	0.46	1.18	0.69
Ξ^-	$3.7\cdot10^{-2}$	$3.8\cdot10^{-3}$	$5.6\cdot10^{-2}$	$5.7\cdot10^{-3}$
Ω^-	$1.8\cdot10^{-3}$	$3.2\cdot10^{-5}$	$2.6\cdot10^{-3}$	$4.8\cdot10^{-5}$
π^-	4.15	0.71	6.22	1.07
Σ^+	5.2	3.3	7.8	4.9
π^+	2.4	0.20	3.5	0.30
P	23.6	20.3	35.5	30.4

TABLE II

Particle fluxes passing through hyperon channel and surviving to 15 m downstream of target. The number of protons interacted in the target was adjusted to give $5 \cdot 10^5$ particles emerging from the channel.

	200 GeV/c Incident		300 GeV/c Incident	
	120 GeV/c $\alpha=0.6$	160 $\alpha=0.8$	180 $\alpha=0.6$	240 $\alpha=0.8$
Σ^-	$3.3 \cdot 10^3$	$2.6 \cdot 10^4$	$1.0 \cdot 10^4$	$6.0 \cdot 10^4$
Ξ^-	$1.6 \cdot 10^2$	$1.8 \cdot 10^2$	$4.1 \cdot 10^2$	$2.2 \cdot 10^2$
Ω^-	.96	.37	4.5	1.3
π^-	$5.0 \cdot 10^5$	$5.0 \cdot 10^5$	$5.0 \cdot 10^5$	$5.0 \cdot 10^5$
p int.	$3.6 \cdot 10^9$	$2.1 \cdot 10^{10}$	$1.6 \cdot 10^9$	$9.3 \cdot 10^9$
Σ^+	$2.03 \cdot 10^2$	$7.67 \cdot 10^2$	$1.59 \cdot 10^3$	$3.59 \cdot 10^3$
π^+	$4.54 \cdot 10^4$	$4.94 \cdot 10^3$	$4.53 \cdot 10^4$	$4.91 \cdot 10^3$
p	$4.54 \cdot 10^5$	$4.94 \cdot 10^5$	$4.53 \cdot 10^5$	$4.91 \cdot 10^5$
p int.	$5.8 \cdot 10^8$	$7.3 \cdot 10^8$	$2.6 \cdot 10^8$	$3.23 \cdot 10^8$

TABLE III

Expected number of hyperon decays in fiducial region in ten hours of accelerator operation.

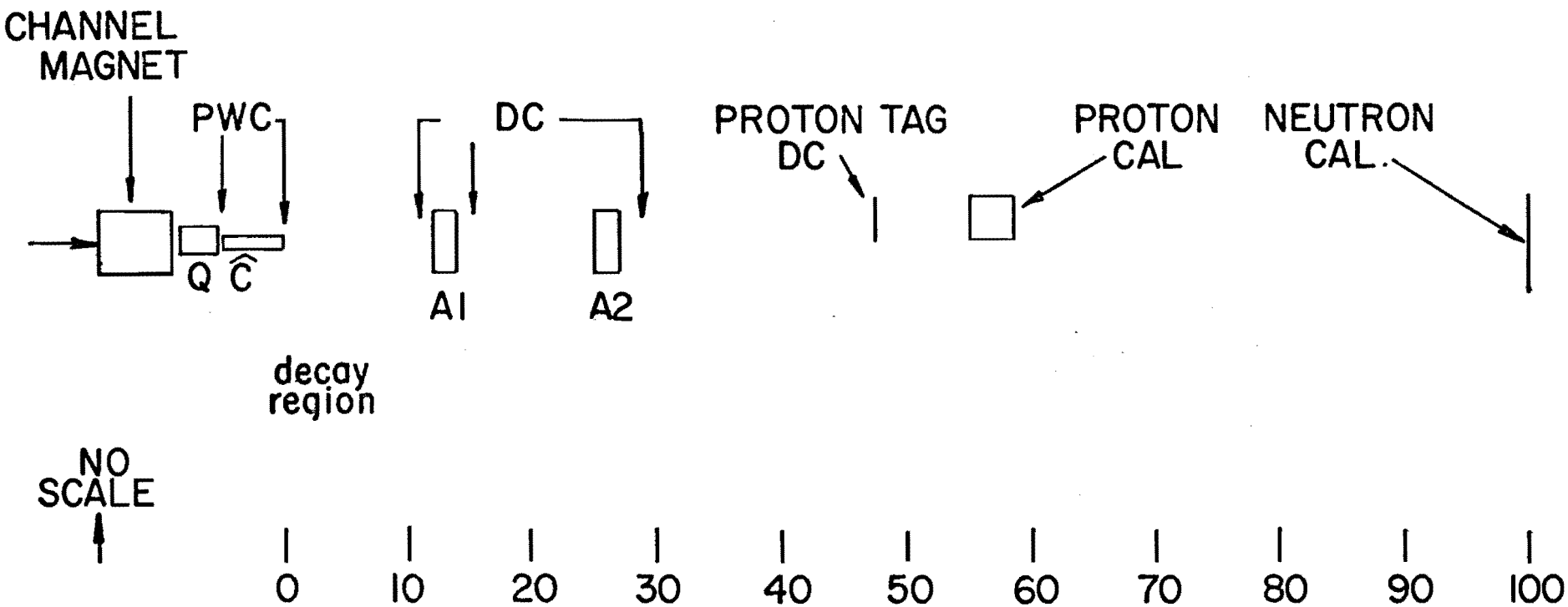
	200 GeV/c Incident		300 GeV/c Incident	
	120 GeV/c	160	180	240
	$\alpha=0.6$	$\alpha=0.8$	$\alpha=0.6$	$\alpha=0.8$
Σ^+	$1.2\cdot10^6$	$4.6\cdot10^6$	$9.5\cdot10^6$	$2.1\cdot10^7$
Σ^-	$1.8\cdot10^7$	$1.3\cdot10^8$	$4.7\cdot10^7$	$2.4\cdot10^8$
Ξ^-	$8.5\cdot10^5$	$8.7\cdot10^5$	$1.9\cdot10^6$	$8.9\cdot10^5$
Ω^-	$5.6\cdot10^3$	$2.1\cdot10^3$	$2.5\cdot10^4$	$6.4\cdot10^3$

TABLE IV

Estimated Event Rates for 100 Accelerator hours. We assume the fluxes of Table III at 300 GeV incident and $\alpha=0.6$ An overall detection efficiency of 10% has also been included.

Channel	Branching Ratio	Detected Events	Branching Ratio Limit
$\Sigma^- \to n\pi^-$	1	$4.7\cdot10^7$	
$\Sigma^- \to \Lambda^o e^- \bar{\nu}$ $\hookrightarrow \pi^- p$	$(0.60\cdot10^{-4})(0.642)=3.9\cdot10^{-5}$	$1.8\cdot10^3$	
$\Sigma^- \to ne^-\nu$	$(1.08\cdot10^{-4})$	$5\cdot10^4$	
$\Sigma^+ \to n\pi^+$	0.484	$2.2\cdot10^6$	
$\Sigma^+ \to \Lambda^o e^+ \nu$ $\hookrightarrow \pi^- p$	$(2.02\cdot10^{-5})(.642)=1.3\cdot10^{-5}$	60	
$\Sigma^+ \to ne^+\nu$	0	0	$\sim10^{-5}$
$\Xi^- \to \Lambda^o \pi^-$ $\hookrightarrow \pi^- p$	$(1.)(0.642)=0.64$	$1.2\cdot10^6$	
$\Xi^- \to \Lambda^o e^- \bar{\nu}$ $\hookrightarrow \pi^- p$	$(0.70\cdot10^{-3})(0.642)=4.5\cdot10^{-4}$	$8.5\cdot10^2$	
$\Xi^- \to n\pi^-$	$< 1.1\cdot10^{-3}$	0	$\sim10^{-5}$
$\Xi^- \to ne^-\bar{\nu}$	$< 1\%$	0	$\sim10^{-5}$
$\Omega^- \to \Lambda^o K^-$ $\hookrightarrow \pi^- p$	$\sim(0.6)(0.642)=0.39$	$9.6\cdot10^3$	
$\Omega^- \to \Xi^o \pi^-$ $\hookrightarrow \Lambda^o \pi^o$ $\hookrightarrow \pi^- p$	$\sim(0.1)(1.0)(0.642)=0.064$	$1.6\cdot10^3$	
$\Omega^- \to \Xi^- \pi^o$ $\hookrightarrow \Lambda^o \pi^-$ $\hookrightarrow \pi^- p$	$\sim(0.2)(1.)(0.642)=0.13$	$3.2\cdot10^3$	
$\Omega^- \to \Lambda^o \pi^-$ $\hookrightarrow \pi^- p$	0		$\sim10^{-4}$
$\Omega^- \to n\pi^-$	0		$\sim10^{-4}$

HYPERON BEAM LAYOUT



DC: DRIFT CHAMBER

PWC: PROPORTIONAL CHAMBER

A1 12"GAP, 18" WIDTH, 6' LONG

A2 8"GAP, 18" WIDTH, 6' LONG

5 m