Fermilab Proposal No. 361

Scientific Spokesman:

R. H. March
Physics Department
University of Wisconsin
Madison, Wisconsin 53706

FTS: 608 - 262-1234

Precision Measurement of $\Lambda \rightarrow e^- \nu p$ Decay Parameters

G. Bunce, R. Handler, R. March, L. Pondrom and M. Sheaff
University of Wisconsin

K. Heller and O. Overseth
University of Michigan

T. Devlin, R. Edwards and P. Yamin
Rutgers University

Date Received: November 11, 1974

Precision Measurement of $\Lambda \to e^- \nu p$ Decay Parameters

G. Bunce, R. Handler, R. March*, L. Pondrom and M. Sheaff
The University of Wisconsin
Madison, Wisconsin 53706

K. Heller and O. Overseth
The University of Michigan
Ann Arbor, Michigan 48104

T. Devlin, R. Edwards and P. Yamin
Rutgers University
New Brunswick, New Jersey 08903

ABSTRACT

Recent progress in gauge theory of the weak and electromagnetic interactions provides a motivation for improving the data on hyperon beta decays.[1] The Fermilab neutral hyperon beam is capable of producing a sample of Λ β-decays at least an order of magnitude larger than that used in existing world averages[2] per beam day. The experiment can be performed with the apparatus already in place for Experiment 8. Hadron rejection sufficient for the purposes of the experiment can be obtained by operating the E8 lead glass Cerenkov counter in the manner described by Appel et al.[3] for the study of direct lepton production. The experimental setup is compatible with that for the E8 Λp total cross section, so it can be run as a short (2-3 week) extension of this run.

---

*Principal spokesman

(1) Theory and Motivation

Until recently, the uncertainties in rates and form-factors for hyperon β-decays, which are of the order 5% to 10%, were well matched to theoretical uncertainties due to radiative corrections. The development of the SU(2) × U(1) gauge model permits a calculation of these corrections. Sirlin[1] finds them to be of the order 3% to 5%. They depend on the particular quark model chosen to represent the hadrons at about the 1% level. There is also a logarithmic dependence on the Z mass, amounting to 0.5% over the range $78 < M_Z < 200$ GeV. Sirlin argues that remaining uncertainties due to SU(3) symmetry breaking should be less than 1%.

Thus an improvement of our knowledge of hyperon β-decay parameters by an order of magnitude could provide a substantially improved test of Cabbibo universality. Alternatively, the results can be seen as a test of the gauge theories themselves, or as a means for getting an experimental "handle" on the details of the models employed.

Since the experiment can be performed with existing apparatus and a relatively modest expenditure of beam time, it seems worthwhile. We propose to collect a raw sample of $\sim 10^5$ events, to insure 4×10^4 after cuts, to determine the branching ratio to 0.5% and g_A/g_V to .01.

(2) Experimental Layout and Trigger Scheme

Figure 1 shows the experimental layout in the M2 beam. The arrangement is identical to that for the beam-survey portion of experiment #8, except that the lead glass Cerenkov counter has been

moved from the downstream end to the position shown and restacked so as to intercept all electrons from $\Lambda \rightarrow e^- \nu p$ that traverse the analyzing magnet. Here it will be employed in a manner similar to that described in reference (3) to reject hadrons.

The fast logic will require, in addition to the "electron" signal from the lead glass, an event that originates in the decay volume and deposits a positive particle in a relatively small area (25 cm × 20 cm) of the downstream proportional chamber. This logic is a strong selector for a Λ-decay with $E_p > 100$ GeV.

(3) Hadron Rejection and Electron Detection Efficiency

Appel et al.[3] have shown that a total-absorption lead glass Cerenkov counter can be operated in a mode that rejects hadrons by better than 2×10^4, while retaining an electron detection efficiency of better than 80%, over the range $20 < E < 80$ GeV. Their counter is preceded by two radiation lengths of lead and divided longitudinally into layers of depth 6, 6 and 12 radiation lengths, the shower being nearly complete in the first two layers. Hadrons are rejected by requiring:

(1) A signal substantially above minimum in a scintillation counter following the lead.

(2) A high signal at the 6 L_R depth in the Cerenkov counter, where the shower reaches maximum development.

(3) A cut on E/p, where E is the total shower energy and p is the magnetically determined momentum.

(4) Cuts on longitudinal shower development.

A loose threshold for criterion (3), plus criterion (2), already provides a trigger that rejects hadrons by a factor of about 1000.

Our lead glass counter may be conveniently rearranged into 5 layers of depth 3 L_R each. The range of electron energies covered is $5 < E < 50$ GeV, with a distribution that peaks between 20 and 25 GeV. Because bend angles in the magnet are an order of magnitude larger than decay angles, there is a strong energy-position correlation in the counter which may be exploited in trigger thresholds. Assuming that hadron rejection scales inversely as energy resolution, i.e. as $\sqrt{E}$, we should be able to match both the final rejection and trigger quality of reference (3) to within a factor 2. This is more than adequate for the experiment as it assures that even without kinematic analysis the $\Lambda \to p\pi^-$ background will be reduced to about 10% of the signal.

Hadron rejection will be monitored in real time by removing the trigger criteria for a prescaled fraction of the events. This will also provide a measurement of $\Lambda \to p\pi^-$ against our beam monitors, required to obtain the branching ratio. Our mass resolution ($\sim$5 MeV) is adequate to identify $\Lambda \to p\pi^-$ in the final data sample as an internal check. To avoid limiting systematic errors, hadron survival through all cuts must be determined to within about 2%, and monitor calibration to 0.3%. Both of these goals seem reasonable.

The limiting systematic error in the experiment probably comes from determining the electron detection efficiency of the Cerenkov

counter. This will be done by inserting in the beam a lead converter sandwiched between scintillators to convert beam γ's. The small opening angle of the pairs insures a beam sample of e^- that nearly matches the energy-position profile of e^- from Λ beta decay at the lead glass. We propose to perform such a calibration once on each data tape, i.e. at roughly 2-hour intervals. Operating in this mode for 10% of the run time should produce a sample an order of magnitude larger than the final data sample. If the efficiency of 80% reported in reference (3) is achieved, we must determine the electron "loss rate" to an accuracy of 2% to match our statistical error.

(4) Geometric Biases

Electrons that decay forward in the Λ center-of-mass have a high efficiency for entering our magnet aperture ($\sim$94%). Since the electrons are relativistic in the c.m. frame, the decay geometry is independent of the center-of-mass energy. The only c.m. spectrum bias comes from the elimination of electrons of less than 5 GeV, which are swept into the magnet coils. Approximately 5% of the electrons are lost this way, nearly all from the lowest quarter of the c.m. spectrum.

If events from the backward hemisphere are accepted, these efficiency figures drop to 68% and 80% respectively. They increase the data sample by only 15%, while necessitating accurate Monte-Carlo estimates of detection efficiency.

Because of the kinematic ambiguity in the O-C reconstruction of the events, for some fraction of the sample one solution will

lie in the forward hemisphere, the other in the backward. This, however, presents no serious difficulties in the final data analysis if the geometric cut is taken into consideration in the normalization of the distributions used in the likelihood function.

(5) Event Rates and Beam Time

The branching ratio[2] $(\Lambda \to e^- np)/(\Lambda \to \pi^- p) = 1.28 \times 10^{-3}$. The forward-hemisphere cut reduces this by a factor 2 and eliminates the distinction between detection efficiencies for the two modes. Assuming a hadron rejection (at trigger level) of 400 and an electron detection efficiency of 80%, we obtain a ratio of (π^- triggers)/(useful events) of 5/1.

The downstream chamber trigger insures a very clean sample of Λ decays (the observed singles rate in this chamber comes predominantly from protons from Λ decay). In particular, flux, decay kinematics and lifetime reduce the trigger rate from $K_L^o \to \pi^+ e^- \nu$ to 10^{-5} the Λ rate, or 2% of the "useful event" rate, and the gas Cerenkov counter eliminates these efficiently.

"Useless" triggers include accidentals, which at the proposed beam rate should be no more than a few percent, and events which are geometrically incomplete due to MWPC inefficiency. Assuming we can achieve efficiencies of no better than 97%, an assumption we regard as conservative, we would lose 15% of the sample. Thus it seems safe to assume that $\sim$70% of our triggers will come from geometrically reconstructable Λ-decays, giving data tapes that contain:

Useful events	8%
$\Lambda \rightarrow p\pi^-$	40%
Backward e^-, misc. triggers	2%
Prescaled "loose" triggers	25%
Useless triggers	25%

Our spectrometer is computer-limited to 250 triggers/pulse (data taking halted to wait for free buffer). This is well below the beam limit, so beam rate can be adjusted to give this many events on nearly every pulse. Assuming an average of 200 triggers/pulse, we should obtain 15 useful events per pulse. We can thus accumulate the desired sample in 7×10^3 pulses, or no more than a few days. Allowing a week or two for beam and trigger tuning, it should be possible to complete the experiment in three weeks of beam time, even if our rate estimates prove highly optimistic.

The experiment requires about 2×10^4 Λ-decays per pulse, which can be achieved with $\sim 5 \times 10^8$ ppp on target. The limit for the M2 beam is in the range 10^9-10^{10}.

The lead glass counter is not needed during the Λ total cross section run. Thus the lead glass can be restacked and tested in place while this run is in progress.

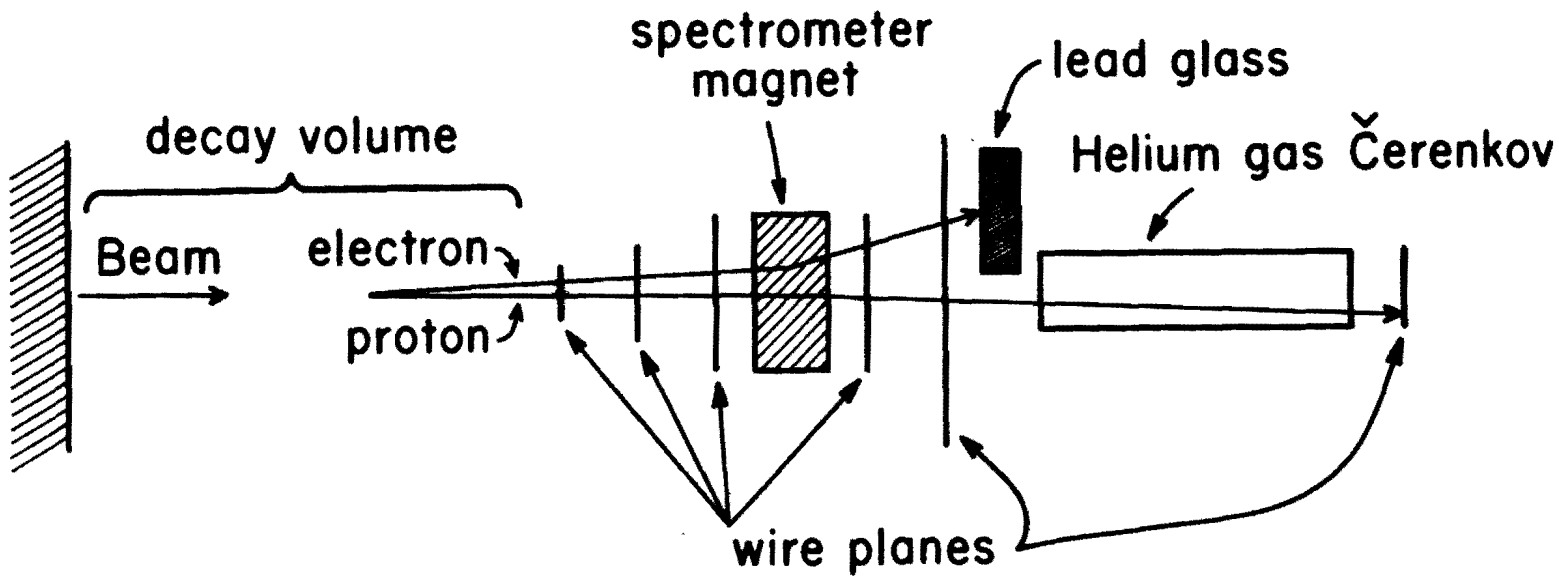
References

1 A. Sirlin, Nucl. Phys. B71, 29 (1974).

2 Particle Data Group, Phys. Letters 508, #1 (1974).

3 J. A. Appel et al., NAL-Pub-74/70-EXP, also private communication from members of this group.

Fig. 1 (transverse scale 8× longitudinal scale)



TO: T. Groves

FROM: L. Pondrom

SUBJECT: Addendum to Proposal #361, $\Lambda \to pe^-\nu$

1.) Reasons for this Addendum

The neutral hyperon beam in the M-2 line at the Meson Lab has been successfully operated, and yields for Λ°, and K_S° have been measured, allowing calculation of the $\Lambda^\circ \to pe^-\nu$ signal and the $K_L^\circ \to \pi^+ e^- \nu$ background rate. In addition the decay $\Xi^\circ \to \Lambda^\circ \pi^\circ$ has been detected in the beam, and the flux of Ξ°, which gives a daughter Λ° which is 40% polarized, is roughly known.

In the proposal the electron detection and hadron rejection are discussed in terms of the lead glass array, which would have to be moved from its present location 17 meters behind the spectrometer magnet (the last component in the apparatus) to a place about 4 meters behind the magnet, and would have to be re-stacked in a new configuration. It seems feasible to leave the glass as-is, use it for tagging those $\Lambda^\circ \to pe^-\nu$ which are daughters of $\Xi^\circ \to \Lambda^\circ \pi^\circ$ (the glass would detect the $\pi^\circ \to \gamma\gamma$ in the manner it now does), and to identify the e^- after the magnet by detecting the X-rays from synchrotron radiation in the magnet.

2.) Yield Data

The maximum available 300 GeV diffracted proton beam flux in the M-2 line is $10^8/10^{12}$. Even for the typical incident proton fluxes of $\sim 3\times10^{12}$, however, useable beam has been restricted to $\leq 10^8$ protons/pulse by background radiation of uncertain origin in the Meson Lab detector building. ~~The measured~~ yield is $(\Lambda^\circ \to p\pi^-) = 4000/10^8$, which gives $3\Lambda^\circ \to pe^-\nu\ /10^8$, compared to 15/pulse

quoted in the proposal. Such a rate is still substantial, giving $\sim 4\times10^5$ beta decays in 200 hours. The K_L° flux in the beam has been estimated from the measured $K_S^\circ \to \pi^+\pi^-$ decays to be $\sim 2000\ K_L^\circ/10^8$ at a mean momentum of 100 GeV. For a 10 meter decay volume, this leads to $(K_L^\circ \to \pi^+ e^- \nu)/(\Lambda^\circ \to p e^-\nu) \sim 1/2$. This background is no problem in the trigger rate. Suppression of $K_L^\circ \to \pi e \nu$ in the beta decay data sample must rely on kinematics and the π-p discrimination furnished by the threshold gas cherenkov counter already operating in the apparatus. This counter rejects protons below 160 GeV, while counting pions above 26 GeV with full efficiency. Further handles on the K_L° background are furnished by the decay vertex distribution and by the presence of the charge conjugate mode $K_L^\circ \to \pi^- e^+ \nu$, which can be separately isolated and studied. Some progress might be made with the $\bar{\Lambda}^\circ \to p^- e^+ \nu$ sample, which will be present at the 1% level relative to the Λ° decays.

3.) Electron Identification and Pion Rejection

A 10 GeV electron passing through the E-8 analyzing magnet ($p\theta$=1 GeV/c) loses $\Delta E_e \sim 750$ keV by synchrotron radiation, predominantly in the X-ray region between 1 and 100 ke V. This energy spectrum is similar to the one emitted in transition radiation when an electron passes through a stack of foils, and has been detected by several groups using MWPC's filled with Xe or Kr gas. A careful discussion of detection efficiencies has been given by Yuan.[1] To my knowledge no one has proposed combining synchrotron radiation with X-ray detection in MWPC's to identify electrons from a diffuse source, although the use of synchrotron radiation and scintillator detectors for electron beam tagging has been suggested by Busza, et al.[2] It seems quite feasible to use a Xe filled MWPC behind the analyzing magnet in place of one of the normal argon

chambers to detect synchrotron radiation X-rays with high efficiency and to exploit their number and pulse height as a trigger signal. The fact that these X-rays are in the plane of the electron orbit furnishes a further handle in background rejection. For example a 10 GeV electron will radiate about 16 X-rays between 4 and 100 KeV, and a 2 cm thick MWPC filled with Xe gas at STP should detect about 10 of these X-rays on the average. A 10 GeV pion will lose a total amount of energy $\Delta E_\pi = (m_e/m_\pi)^4 \Delta E_e$, which is completely negligible.

The expected detection efficiency for a fixed amount of Xe gas and various electron energies is now being calculated. Abundant electron data are in hand with the present set-up and argon gas in the MWPC's. Synchrotron X-rays are clearly visible in the chambers, although no effort was made to detect them when the data were being taken.

We now propose to replace the argon chamber (30 cm x 60 cm active area) immediately behind the spectrometer magnet by one filled with Xe, and to trigger on electrons by requiring the synchrotron radiation X-rays to ring up. The lead glass array would then remain in its present location to detect γ rays from π° decay.

4.) Ξ° Decay and Polarized Daughters

The decay chain $\Xi^\circ \to \Lambda^\circ \pi^\circ$, $\Lambda^\circ \to p\pi^-$, $\pi^\circ \to \gamma\gamma$ has been observed in the present apparatus at a level $\sim 10^{-3}$ relative to $\Lambda^\circ \to p\pi^-$. The detection of the two γ rays is about a factor of three below that expected, because of large hadronic splashes in the lead glass, which may be partly alleviated by removing one lead glass block. Optimistically, then, 1/300 of the detected $\Lambda^\circ \to pe^-\nu$ sample will have a 40% polarization, or about 1200 in 200 hours of data.

5.) Requested Running Time

Based on the present M-2 beam intensities, we request 300 hours to study $\Lambda^\circ \to pe^-\nu$, polarized $\Lambda^\circ \to pe^-\nu$, and $\bar{\Lambda}^\circ \to \bar{p}e^+\nu$. This should give 200 hours of good electron trigger data, resulting in approximately 4×10^5 Λ's, 1200 polarized Λ's and 400 $\bar{\Lambda}$'s.

References

1.) L.C.L. Yuan in Frascati 1973 International Conference on Instrumentation for High Energy Physics, p. 334.

2.) Busza, Chen, and Luckey, Nucl. Instr. & Meth. 105, 613 (1972).