PROPOSAL FOR A MEASUREMENT OF THE 
$\bar{\Xi}^- + \Lambda^0(\Xi^0) + e^- + \nu$ DECAy RATE

J. Duclos, D. Freytag, J. Heintze,
H. Rieseberg, K. Schlüpmann and V. Soergel

We wish to do an experiment on $\Xi^-$ produced by a $K^-$ beam in a
CH$_2$ target, having as three main topics of research in mind:

1) the determination of the $\Xi^-$ Beta decay rate;
2) a more precise determination of the decay parameters $\alpha$, $\beta$
and $\gamma$;
3) a determination of the $\Xi^-$ spin by an Adair analysis.

This proposal deals with the Beta decay only. We will submit later a
discussion on the two other points.

The $\Xi^-$ has three possible modes of leptonic decays:

\[ \Xi^- \rightarrow \Lambda^0 + e^- + \nu \quad 5 \times 10^{-4} \quad \text{I} \]
\[ \Lambda^0 + \mu^- + \nu \quad 1.5 \times 10^{-4} \quad \text{II} \]
\[ \Sigma^0 + e^- + \nu \quad 8 \times 10^{-5} \quad \text{III} \]

The branching ratios predicted by Cabibbo's theory have been worked out by
Breue et al.\textsuperscript{1}

A measurement of these leptonic decay rates is very desirable as
a test of Cabibbo's theory. It could extend the knowledge on Hyperon decays
to the $S = 2 \rightarrow S = 1$ transitions. The decay modes I and II have the
particular feature that the D and F couplings nearly cancel and that the
decay is therefore almost a pure vector transition, a prediction which
under the hypothesis of CVC can be tested by even a rough rate measurement.

Three events of type I, observed in a Hydrogen bubble chamber, had
been reported earlier\textsuperscript{2).} Two of them are meanwhile considered to be of other
origin\textsuperscript{3).} The one event which seems to be certain gives a branching ratio of
$5 \times 10^{-4}$.

We have studied the possibility of doing a counter-spark chamber
experiment which could give the combined rate of decay modes I and III.

Below we describe a set up which should be capable, at the predicted
rate, to detect 1 event per $6 \times 10^{8}$ K$^{-}$ of 1.8 GeV/c of the decay modes I and
III with a background of less than 10%. At the present intensity of the m$_{4}$
beam, which is quoted to be $\sim 2 \times 10^{4}$ K$^{-}$ per burst, one would then obtain $\sim 1$
event per day. This rate, although admittedly not very encouraging, seems to
us to be high enough to make this experiment feasible.

**Kinematics of $\Xi^{-}$ production and decay**

Fig. 1 shows the angular distribution of the K$^{+}$ in the reaction

$$K^{-} + p \rightarrow K^{+} + \Xi^{-}$$

at a K$^{-}$ momentum of 1.8 GeV/c; where the cross section is 120 \( \mu \)b\textsuperscript{4).} The
dashed curve gives the fraction of K$^{+}$ which can be stopped, the others being
lost by nuclear interactions and by decay in flight. For \( \Xi^{-} \) identification by
detection of the decay of stopped K$^{+}$, evidently only the angular range around
the backward peak is useful.

Fig. 2 gives the energy spectrum of the K$^{+}$ and its range spectrum
in the angular region from 54$^{\circ}$ to 110$^{\circ}$.

In Fig. 3 and 4 the angular distribution and energy spectrum of the
decay products for the $\Xi^{-} \rightarrow \pi^{-} + \nu + \Lambda^{0}$ and for the $\Xi^{-} \rightarrow p + \pi^{-}$
$\rightarrow \pi^{+} + \Lambda^{0}$ decays are shown.

The $\Xi^{-}$ produced have a momentum of 1.8 GeV/c corresponding to 7 cm
decay length.
The apparatus is shown in Fig. 5. The $\Xi^-$ are produced in a CH$_2$ target of 10 cm length. The K$^+$ is detected by slowing it down and bringing it to rest in one of the water tanks (K$_1$ through K$_3$) and looking for the delayed Čerenkov light of its decay products. The K$^+$ detectors are designed to cover the angular region from 60$^\circ$ to 110$^\circ$ and to stop the K$^+$ energies occurring within this angular range.

The particles taking part in the reaction and the charged decay products of the $\Xi^-$ and the subsequent $\Lambda^0$ will be detected in a "vertex" spark chamber and in spark chambers in front of the water counters. For making visible the $\Xi^-$ track and for background discrimination the target is subdivided into $\sim$13 pieces of 8 mm each with spark gaps inserted between them.

A gas Čerenkov counter, made of 15 cells, will distinguish between electrons and pions. The light of each cell is focussed by a parabolical or elliptic mirror onto a RCA C 70133 photo-tube with bialkali photo-cathode. According to the specifications, this tube with its very high quantum efficiency (28% in the peak) and its extremely low noise should allow us to keep the accidental coincidence rate sufficiently low. We envisage the possibility to cool the gas and therefore the photo-cathode to further suppress PM noise. It seems to us feasible to make the mirrors large enough so to cover with the Čerenkov counters at a flight path of 1 m an angular range from 10$^\circ$ to 50$^\circ$ towards the axis of the apparatus. 54% of the electrons from $\Xi^- \rightarrow e^- + \nu + \Lambda^0$ decay fall into this angular range (Fig. 3).

The entrance window of this counter must be very thin in order to suppress $\pi^-$ charge exchange. Therefore, the counter can only be operated at atmospheric pressure. However, with a gas of high-refractive index as freon 122 ($n - 1 = 1.4 \times 10^{-3}$), an efficiency of 80% should be obtained. For additional discrimination against $\pi^-$'s and against pairs from $\gamma$-ray conversion, a spark chamber having two radiation lengths of 2 mm iron plates is placed behind the gas Čerenkov counter.

From those $\Xi^-$, which decay outside of the target, particles emitted at angles larger than the maximum emission angle of $\pi$'s ($\sim 60^\circ$) with respect
to the $\pi^-$ momentum) can be identified as electrons by the additional requirement of a reasonable high pulse in the corresponding cell of the water Čerenkov counter of the $K^+$ detector. 40% of the electrons are emitted into this angular range and they can be analyzed for 50% of the $\pi^-$. 

**Background**

We have considered four classes of possible background sources:

1. $\pi^- \rightarrow \pi^- + \Lambda^0$ decay;
2. production of $\Xi^-$ (1530) and its decay into $\pi^0 + \Xi^-$;
3. $\Xi \rightarrow \Lambda^0 + \gamma$ decay;
4. other sources.

1. The $\pi^-$'s may produce light in the Čerenkov counter either by charge exchange and subsequent conversion of the $\gamma$ rays or by decay in flight. Knock on electrons are below the Čerenkov threshold at the $\pi^-$ energies in question, products of nuclear stars as well.

The $\pi^-$ charge exchange is dangerous only, if it occurs in the target or in the frame of the spark chamber. The probability that a $\pi^-$ in one cm of CH$_2$ makes charge exchange and one of the $\gamma$ rays is converted in the same cm CH$_2$, is $1.2 \times 10^{-4}$, assuming for the charge exchange a cross-section of 40 mb. At the $\gamma$ ray energies in question, ~40% of the conversion is due to Compton effect. Assuming that for 90% of the pairs both electrons are seen, we have for a $\pi$ traversing 1 cm CH$_2$ a probability of $2.4 \times 10^{-5}$ to simulate an electron. This number is further reduced by making use of the angular distribution of the $\pi^-$'s and the conversion electrons by at least a factor 10.

From the 50% of the $\Xi^-$, which decay within the target region, the $\pi^-$'s will traverse in the average $3 \times 1$ cm of CH$_2$, therefore giving rise to a background of $7.5 \times 10^{-6}$. About 24% of all $\pi^-$'s go through the frame of a spark chamber, traversing $\sim 3$ cm of plexiglas. This gives an additional background of $2.5 \times 10^{-5}$. Therefore, the normal $\Xi^-$ decay simulates a Beta decay in the angular range of the gas Čerenkov counter with a probability of $\sim 3 \times 10^{-5}$.

The $\pi^-$'s may decay in flight by the modes $\pi^- \rightarrow e^- + \nu$ and $\pi^- \rightarrow \mu^- + \nu$, giving rise to Čerenkov light producing electrons. In the available flight path of 1.5 m, 16.5% of 150 MeV/c $\pi^-$'s would decay. With the branching ratio $1 \times 10^{-4}$, the $\pi^- \rightarrow e^- + \nu$ decay gives therefore
1.6 x 10^{-5} electrons/pion. The \( \pi^- \to \mu^- \to e \) decay gives \( \sim 2 \times 10^{-4} \) electrons/pion at this momentum. The angular selection of the electrons by the gas Čerenkov counter and the spark chamber behind it should reduce this number by at least a factor 10. The \( \pi \) momentum chosen for this consideration is near the lower limit of \( \pi \)'s entering the gas counter, therefore the number given is an upper limit.

2. \( \Xi^- (1530) \) are produced with \( \frac{1}{6} \) of the cross-section for \( \Xi^- \) production, and \( \frac{2}{3} \) of them decay into \( \pi^0 + \Xi^- \). A \( \gamma \) ray of the \( \pi^0 \) is converted in the same cell of the gas counter which is traversed by the \( \pi \) from the \( \Xi^- \) decay, with a probability of \( 2 \times 10^{-5} \). The actual background is much lower as the \( \pi^- \) and the conversion electrons are distinguished in the spark chamber behind the Čerenkov counter.

3. This is a major trouble in the bubble chamber, but is strongly suppressed even at a poor performance of the \( \Xi^- \) trigger. The contribution of this process is furthermore easily controlled by identifying \( \Sigma \to N + \pi \) decays. We expect background from \( \Sigma \to \Lambda \omega \) decay to be small compared to the background from \( \Xi^- \to \pi \Lambda \) decay.

4. We discussed in this class processes like

\[
K^- + p \to \text{Hyperon} + 2K
\]

\[
K^- \text{ nucleon} \to 2 \text{ charged particles} + V^0 (\Lambda^0 \text{ or } K^0) + m\pi^0
\]

\[
\pi^- \text{ nucleon} \to K^+ + \text{Hyperon} + \pi.
\]

The background expected of all these sources is again small compared to the one from \( \Xi^- \to \pi \Lambda \) decay, if the electron is identified by the gas counter. For the large angle events which represent \( \sim 20\% \) of the expected data, we have no estimate of this background yet.

Therefore, the total background of the Beta decay events should be less than 10\%. The background coming from \( \Xi^- \to \pi \Lambda^0 \) decay which should give the main contribution, can be tested experimentally.
Efficiency

1. Efficiency of the \$K^+\$ detector
   a) Fraction of the \$K^+\$ which stop in the water tank and decay into \$\mu^+ + \nu\$ or \$\pi^+ + \pi^0\$.
      \[0.14\]
   b) Decays detected with 4ns delay, assuming 70% detection efficiency.
      \[0.070\]
   \[0.50\]

2. Reduction of the efficiency of the pattern requirements
   For a good \$\Xi^-\$ pattern we require \$\Xi^-\$ path length \(\geq 3\) cm, \(\Lambda\) path length \(\geq 3\) cm, and the \(\Lambda\) decay into charged particles.
   \[0.32\]

3. Leptonic decay detection efficiency
   a) The gas \(\xi\) Cerenkov counter, having an estimated efficiency of 80%, accepts 54% of the electrons.
      \[0.43\]
   b) The \(K\) detector accepts 24% of the big angle electrons, half of which are coming from the useful \$\Xi^-\$ decay region.
      \[0.55\]
      \[0.12\]

Rates

Assuming 120 \(\mu\)b production cross-section, a CH\(_2\) target of 10 g/cm\(^2\) effective length with \(2 \cdot 10^3\) effective protons/cm\(^2\), \(2 \cdot 10^4\) \(K^-\)/burst and \(3 \cdot 10^4\) burst/day, we get the rates summarized in the following table.

| \(\Xi^-\) produced in the target | \(2.4 \cdot 10^{-4}\) | 140,000 |
| \(\Xi^-\) triggers | \(1.7 \cdot 10^{-5}\) | 10,000 |
| \(\Xi^-\) detected with good decay pattern | \(5.4 \cdot 10^{-6}\) | 3,200 |
| Detected Beta decay events assuming a branching ratio (I+III) = \(5.8 \cdot 10^{-4}\) | \(1.7 \cdot 10^{-9}\) | 1.0 |

It would evidently be useful to have a higher beam intensity which seems to be obtainable in the east area.
Data recording

All spark chambers will be photographed. (We envisage the possibility to digitize 2 planes of the vortex chamber for easier data handling.)

In addition, we will record on magnetic tape and on oscilloscope pictures the pulses of the gas Čerenkov counters and the counters of the $K^+$ detector.

Trigger rate

We hope that the $K^+$ detector can be made selective enough as to give one $\Sigma^-$ for two $K^+$ like coincidences observed in the $K^+$ detector. In this case, we would use the $K^+$ signal as trigger for our data recording system and take $\sim 20,000$ triggers per day, containing $\sim 10,000$ $\Sigma^-$'s. The candidates for Beta decay could easily be selected by the requirement of a pulse in the gas counter or a prompt pulse in a $K^+$ detector which are stored on magnetic tape. The large number of $\Sigma^-$ would, of course, be very useful for the other topics of the experiment.

If the $K^+$ detector is not selective enough and gives too high a trigger rate, the electronical requirement for electron detection can, of course, be required in the trigger already.

Machine time required

In order to get for the first approach 10-20 Beta decay events, we like to ask for 10-20 days running at $2 \times 10^{-4}$ $K^-$ per burst. The total number of $\Sigma^-$ recorded in this time would be $\sim 10^5$. 

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REFERENCES


2) See Chuvilo, Dubna conference report on weak interactions of strange particles.

3) Ticho, discussion remark at the Argonne conference of weak interactions, October 1965.

4) Miller, Strange particle physics, Dubna conference report.
FIGURE CAPTIONS

Fig. 1 K^+ angular distribution in the reaction
K^- + p → K^+ + Σ^- at a K^- momentum of 1.8 GeV/c.

Solid curve: Free protons, dotted curve: Fermi motion taken
into account. In the rate calculation, 2.6 effective protons
per carbon nucleus were assumed.

It is indicated which fraction of the K^+ can be stopped, the
others being lost by interactions and decay in flight.

Fig. 2a K^+ energy spectrum for the angular range accepted by the
K^+ detector for free protons and protons with Fermi motion.

Fig. 2b K^+ range distribution.

Fig. 3 Angular distribution of charged particles from Σ^- decay with
respect to the direction of the incoming K^-.

Fig. 4 Energy spectra of charged particles from Σ^- decay.

Fig. 5 Apparatus – The beam counters are not shown. A gas Čerenkov
counter in the beam will reject incoming π^-.
$K^- + P \rightarrow K^+ + \Xi^-$

$K^+$ angular distribution

--- Fermi motion effect

--- Reduction due to absorption and decay in flight

$\theta_{K^+, K^-} \text{ (lab)}$ degrees

$K^+$ energy spectrum

for $55^\circ < \theta_{K^+, K^-} < 105^\circ$

Fig: 1

Fig: 2a
Range distribution of $K^+$ in Carbon
from $K^- + p \rightarrow K^+ + \Xi^-$ at 1.8 GeV/c

Fig: 2b
\[ K^- + P \rightarrow K^+ + \Xi^- \]
\[ \rightarrow \Lambda + e^- + \nu \]
\[ \rightarrow \pi^- + p \]

**ANGULAR DISTRIBUTION**

of

1: electrons
2: pions
3: protons

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pions from \( \Xi^- \rightarrow \pi^- + \Lambda \)

**per cent/n degrees**

- electrons: \( n = 6 \)
- pions: \( n = 3 \)
- protons: \( n = 1.5 \)
$K^- + P \rightarrow \Xi^- + K^+ \quad (55^\circ < \theta_{K,K^-} < 105^\circ)$

\[ \begin{align*}
\pi^- + \Lambda \\
\Lambda + \rho^- + \nu \\
\pi^- + P
\end{align*} \]

Energy spectrum

$12^\circ < \theta_{lab} < 55^\circ$

$55^\circ < \theta_{lab} < 100^\circ$