SEARCH FOR THE $\Delta S = 2$ DECAY $\Xi^o \rightarrow p\pi^-$

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ABSTRACT

An experiment is proposed to search for the $\Delta S = 2$ decay $\Xi^o \rightarrow p\pi^-$, using a neutral hyperon beam. With 10^{10} protons per pulse on target, if the Ξ^o/Λ production rate is as high as 10^{-3}, a test in the range 10^{-6} to 10^{-7} seems feasible, if the background and false-trigger problems can be solved by suitably optimizing the design of the detector. The detector uses a modest number (40 to 60) of wire planes and a fairly small spectrometer magnet (32 in. $\times$ 80 in. with an 8 in. gap).

I. INTRODUCTION

The absence of direct $|\Delta S| = 2$ transitions is one of the more striking features of weak interactions. The fact that the $K_S^o - K_\ell^o$ mass difference is of the same order of magnitude as the K_S^o lifetime indicates that a direct $|\Delta S| = 2$ transition from K^o to $\overline{K}^o$ cannot be much stronger than the second-order weak transition through a 2π intermediate state. There have been no tests of this selection rule with comparable sensitivity in other transitions.

The decay $\Xi^o \rightarrow p\pi^-$ seems an excellent candidate for this test. It is a two-body decay with an enormous Q value (p_{cm} = 300 MeV/c) that gives it a clean kinematic "signature" even in very high energy beams.

The present upper limit on this decay mode is of the order of 1%. To push this limit down to 10^{-5} to 10^{-6} would provide a test of the selection rule comparable to that from the K^o mass difference. A "superweak" $|\Delta S| = 2$ transition could come in several orders of magnitude higher. We choose as our target figure the range 10^{-6} to 10^{-7}. Assuming a "reasonable" experiment of 10^5 data-gathering pulses, from 10 to 100 Ξ^o decays per pulse will satisfy this requirement. This seems within the capabilities of the neutral hyperon beam described elsewhere in this study.[1]

II. EXPERIMENTAL DESIGN

The experimental layout is depicted in Fig. 1. The Ξ^o decays are sampled in the first few meters after the shield. Starting 2 m from the shield, wire spark-chamber planes placed as close to the beam as possible, at intervals of one meter, measure the angles of the decay products. A spectrometer magnet with a gap of 8 in. × 32 in. and 80 in. long is placed 7 m from the shield to measure their momentum. Three horizontal wire planes covering 5 m behind the magnet complete the spectrometer. A single horizontal plane inside the magnet is needed to resolve charge ambiguity and pick up low-momentum π^-. All the other wire planes can be magnetostrictive. If a conservative design is chosen, with all planes doubled for maximum efficiency, a total of 36 horizontal and 24 vertical planes is required, ranging in size from 2 in. × 2 in. at the front end, 8 in. × 10 in. at the magnet entrance, to 60 in. × 20 in. at the back end. This seems well within the capability of current technology.

The beam has a width $\Delta\theta$ = 0.5 mrad, for a total solid angle of 0.8 μsr. The wire planes diverge from the beam line at 1.5 mrad, allowing several millimeters beam clearance. Since a "typical" $\Xi^0 \rightarrow p\pi^-$ decay will have an opening angle of 20 mrad, the beam direction is well defined. The kinematics of Ξ^0 decay determine the spectrum of decaying particles, which will be peaked at 120 GeV/c with a full width at half-maximum of 75 GeV/c, unless the production spectrum is dropping rapidly in this region, which seems unlikely.

The layout has an angular resolution of from 0.10 to 0.25 mrad, and momentum resolution of from 3% to 0.1% over the useful range, assuming existing wire-chamber resolution of 0.5 mm. These two figures are well matched and provide mass resolution of 10 to 20 MeV over the range of detectable decay momenta and configurations. This is the unconstrained mass resolution; it is not assumed that the beam direction is known, so that it is possible to reject particles from the beam halo or secondary processes.

The logic for the trigger system includes two pairs of counters defining the following conditions:

1. $1.5 < \theta_p < 6.5$ mrad
2. $\theta_\pi > 8$ mrad
3. Conditions (1) and (2) satisfied on opposite sides of the beam line.

The first condition is defined 2 m ahead of the magnet to guarantee a usable proton-angle measurement. This is not necessary for the pions, so is best defined at the magnet for maximum efficiency.

The configuration shown has not been computer optimized, but is offered merely to show that the experiment is feasible even without such optimization. The actual system should be much better.

III. RATES, BACKGROUNDS, AND BEAM REQUIREMENTS

The fraction of solid angle determined by the spectrometer and defining counters for Ξ^o of various momenta is plotted in Fig. 2. The integrals of these curves along the beam line give a weighted or effective decay length:

$$\int \frac{\Delta\Omega(x)}{4\pi}\, dx = \begin{array}{l} 1.4 \text{ m at } 180 \text{ GeV} \\ 1.0 \text{ m at } 150 \text{ GeV} \\ 0.55 \text{ m at } 120 \text{ GeV}, \end{array}$$

for an average of 1.0 m over the expected spectrum. The decay length τ/mc is the same for Ξ^o and Λ^o. Let the ratio of Ξ^o to Λ^o production in this portion of the spectrum be R. Using the production curves in the report on the neutral beam,[1] we have a Λ^o decay rate of 13/m sr inc. proton in the sensitive region. Thus our rate is

$$R \times 13 \times 1.0 \times 0.8 \times 10^{-6} \times N = 10^{-5}\, RN,$$

where N is the number of interacting protons per pulse. If R is as large as 10^{-3} the experiment is feasible at the desired rate at the design proton beam intensity of 10^{10}. Otherwise we must settle for a slower rate, and thus a longer experiment or higher limit.

It is likely, however, that the real data rate will be determined by false triggers from other processes in the beam. The dominant backgrounds in the trigger logic are from $\Lambda \to p\pi^-$ and $K^o_S \to \pi^+\pi^-$. Though the system rejects these at high momenta above 80 GeV/c, lower momentum decays can produce triggers. Evaluating the solid angle-length integral for these decays and folding in the decay spectrum gives trigger rates compared to Ξ^o sampled of

$$\left.\begin{array}{l} 0.06/R \text{ for } \Lambda \\ 0.04/R \text{ for } K^o \end{array}\right\} \text{ total } 0.1/R\ .$$

Other sources of triggers, such as 3-body K^o modes and neutron interactions, are harder to estimate but are one to two orders of magnitude lower.

With a long spill, perhaps 20 triggers per pulse can be tolerated as an upper limit. Thus for $R = 5 \times 10^{-3}$ or less it is the trigger rate that limits the experiment.

Fortunately, there are several ways to reduce the trigger rate:

1. Moving up the minimum angle for proton trigger drops the Λ's very fast, at a small sacrifice in Ξ^o sensitivity.

2. The K^o_S can be eliminated, though less rapidly, by the same device.

3. Both the K_S^o and Λ that satisfy trigger requirements will have typical momenta of 60 GeV/c with the positive track at 45 GeV/c. This is about half the comparable value for Ξ^o. Since the difference in deflection of the average positive tracks in the magnet is about 10 mrad, while the width of the positive "beam" is only 5 mrad, a simple scintillation counter trigger can probably reduce the false trigger to Ξ^o ratio by an order of magnitude.

It must be emphasized that, because of the high mass resolution, false triggers are an equipment problem rather than a true background. Detailed Monte Carlo simulation is necessary to determine the actual background, but a rough guess indicates that the desired 10^{-6} to 10^{-7} level can be achieved.

The false triggers have one positive effect; the kinematics of slow Λ^o and K^o are sufficiently close to that for fast Ξ^o to use these modes to calibrate the detection efficiency of the system.

For the experiment to be feasible, it is necessary that the beam be "high-quality," which means that the defining slit in the magnetic shield must not produce an excessive beam halo. Because the mass resolution of the system is high even without knowing the beam direction, the halo is not a source of true background. But the high neutron background of the beam must be kept out of the close-in wire planes.

IV. DATA HANDLING

The fast logic requirements for the system seem modest, requiring perhaps a dozen scintillation counters. Suitable readout is required to accommodate the wire plane inside the magnet (if this proves a problem two shorter magnets can be substituted). But each trigger represents perhaps 100 words of counter and wire-plane readout. If a trigger rate of 20 per pulse is accepted, a PDP-8 type computer can handle the load of tape writing, but there will be about a foot of tape per pulse. The number of reels of tape resulting is of the order of 100. To reduce this number, one could either

1. Reduce the trigger rate, or

2. Provide a computer with enough real-time computing capacity to "edit" the triggers, passing through only a random sample of obviously false triggers by testing on total momentum.

REFERENCE

[1] R. H. March, A Short-Lived Neutral Beam, National Accelerator Laboratory 1969 Summer Study Report SS-3, Vol. I.

APPENDIX A. EQUIPMENT LIST

1. One spectrometer magnet, 80 in. long with a gap of 8 in. × 32 in.

2. One on-line small computer, either PDP-8 quality or something with about 4 times the computer power

3. About 60 magnetostrictive wire planes and associated power supplies, readout, and interfacing to the computer

4. One wire plane with readout capability in a magnetic field, (or else two magnets capable of being placed within 24 in. of one another, each 40 in. long)

5. About 12 scintillation counters with power supplies and logic circuits.

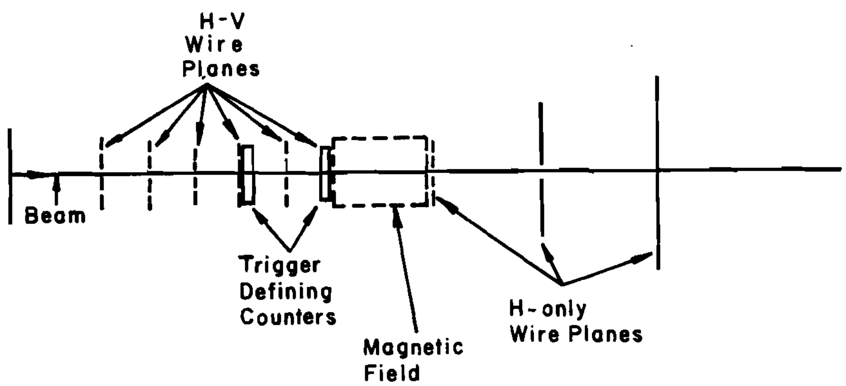

Fig. 1. Beam layout for hyperon decay experiment.

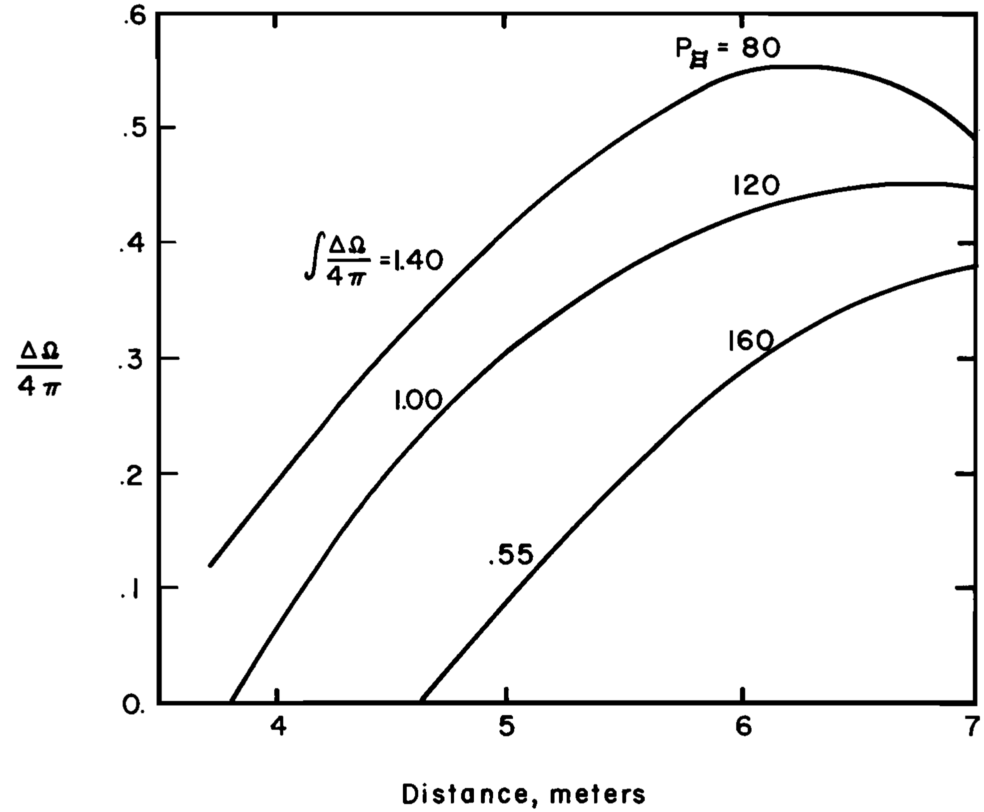

Fig. 2. Solid angle as a function of decay position and hyperon momentum.