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MASTER

Proposal for

AN EXPERIMENT FOR THE STUDY OF THE RADIATIVE $K_{\pi 2}^+$ DECAY MODE

TO BE PERFORMED AT THE ZERO GRADIENT SYNCHROTRON

ARGONNE NATIONAL LABORATORY

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3. Description of Experiment

a. Introduction

The slow rate of $K^+ \rightarrow \pi^+ \pi^0$ is apparently due to the strength of the $\Delta I=1/2$ selection rule, which forbids this mode of decay. The fact that 20% of K^+ 's do decay by this mode indicates that the selection rule is broken (perhaps electromagnetically) by some part of the interaction. If the selection rule is broken electromagnetically, decays of the form $K^+ \rightarrow \pi^+ \pi^0 \gamma$ should be observed.⁽¹⁻⁴⁾ Specifically, such decays into that region of phase space in which the π^+ has momentum >133 MeV/c (upper end of τ') and <180 MeV/c (approaching $K_{\pi 2}$ at 205 MeV/c) could have a branching ratio up to 8×10^{-4} .

The amplitude for this process of direct emission from the decay vertex can be confused with, and can interfere with the amplitude for internal bremsstrahlung from the π^+ and/or K^+ . The above branching ratio assumes constructive interference with the (calculable) inner bremsstrahlung amplitude. The energy spectra of π^+ expected with (a) only inner bremsstrahlung, (b) destructive interference between (a) and direct amplitude, (c) constructive interference, are shown in Fig. 1, together with the preliminary data of Cline and Fry.⁽⁵⁾ Their complete sample of events^(5a) shows the same behavior. It is probable that constructive interference does not occur, but beyond this no statement can be made, other than one would like to see the $\pi^+ \gamma$ angular correlation.^(5, 5a)

Note that these 63 events were all obtained in the following way. Stopped K^+ gives single anomalously short range π^+ (identified by the sequence), but not short enough for $K_{\pi 3}$ (τ'). Care is taken to make sure the K^+ was stopped, but the 3 γ 's are not converted.

There are clearly 2 questions to be answered, viz:

- (1) Are these events really $K^+ \rightarrow \pi^+ \pi^0 \gamma$?
- (2) To what extent is the γ from inner bremsstrahlung?

We propose to perform an experiment in January 1968, to study this process using counters and spark chambers.

3b. Experimental Arrangement

--General

Figure 2 shows a plan view of the experimental apparatus. We propose to use the stopping K^+ beam described in our proposal P-153 (quod vide). The kaons stop in a scintillator block which is subdivided to provide a characteristic stopping signal and some information about the location of the decay vertex within the stopping target. Surrounding the stopping target, in as close to a 4π geometry as can be obtained, are lead plate spark chambers approximately 2 radiation lengths thick. These are designated $\Gamma_1 - \Gamma_6$ in the diagram. The spark chamber Γ_1 will have in it

750 MeV/c
ENRICHED K^+ BEAM

Figure 2.

NOTES:

- ① THE GAMMA RAY CHAMBER Γ_4 HAS BEEN REMOVED.
- ② THE STOPPING SCINTILLATOR S IS STRATIFIED $\perp$ TO K^+ BEAM DIRECTION AS WELL AS $\perp$ TO π^+ EXIT DIRECTION.

a thin plate region which will allow the charged particle to pass through without severe multiple scattering or significant energy loss. The charged particle is deflected approximately 90° by the magnet and enters a range chamber. Counters placed just in front of the range chamber will permit anticoincidence on charged particles having momentum less than 130 MeV/c or greater than 190 MeV/c. The arrangement illustrated, in which the charged particle aperture is at 90° to the incoming beam-line was chosen to minimize the loss of events due to gammas emitted into the solid angle near the degrader where one cannot hope to detect the π^0 gammas.

-- The Stopper Target

The K^+ beam will be degraded in momentum from the transport momentum of 750 MeV/c in a graphite block, as shown in Figure 2, and stopped in plastic scintillator. The technique of designing stopping targets is discussed in detail in appendix C of our P-153. The stopper scintillator will be almost in contact with the end of the degrader, and will be 8 cm high x 6 cm thick x 10 cm along the K beam direction. Its stopping efficiency will be about 40%.

It will be composed of 30 vertical slabs, 1 cm x 2 cm x 8 cm. as shown below:

These will be fanned-in (probably optically) in rows and columns. The sequence of increasing amplitude column pulses will indicate a stopping K^+ , and the sequence of row pulses will indicate (together with the first momentum chamber track direction) the K^+ decay vertex.

-- Momentum and Range Measurement on π^+

From Figure 3 it is seen that the charged particle can be identified by observing first its momentum, and then its range. The range momentum relationship for pions and muons can each be seen as a line on Figure 3. The pion line is very faint, as there should be almost no events between the upper end of the τ' spectrum (lower left corner - note suppressed zeroes) and the θ point. Figure 3 is taken from Auerbach et al (reference 6). Their momentum resolution was $\pm 2.5\%$ and their range chamber was designed so that at each momentum, there were 5 gaps between the pion line and the muon line. Such a chamber turns out to be quite conveniently built from magnesium and aluminum jig-plates ranging in thickness from 0.5 to 2.0 g/cm³.

Figure 3.

In Figure 2 we show how the momentum measurement can be accomplished using BM-112 at 12 KG. The arrangement shown provides an aperture of $\sim 1\%$ of 4π , and provides a momentum focus for 205 MeV/c (P_0) at the entrance to the range chamber. This allows a veto of π^+ 's from $K_{\pi 2}$. Since the stopper scintillator is not a point, the clean rectangular window in the range-momentum veto shown in Figure 3 will have fuzzy edges, and we expect some triggers from both the τ and θ decay modes. Numerical estimates of this contamination are given in section 3d., where other sources of background are also discussed.

-- Gamma Ray Detectors

Each gamma ray detector module will consist of an array of lead plate spark chambers and scintillators in the configuration illustrated below.

Five plates in each chamber consist of 1 mm of lead, clad on both sides by 0.5 mm aluminum plates. The two plates on the target side of the inner chamber are 1 mm aluminum. The first two gaps serve as verification of the anticoincidence scintillator.

The gamma rays of interest (both those in the π^0 decay and the bremsstrahlung gamma) will be in the energy range of 40-150 MeV. We have performed Monte Carlo calculations in an attempt to estimate the intrinsic detection efficiency of such an arrangement. The results of these calculations are indicated in Figure 4. The curve labelled "untriggered" represents the probability that, if a photon of the energy indicated enters one of the detectors, then a visible shower will be produced in which tracks are seen in at least two gaps. The curve labelled "triggered" gives the probability that not only will the "untriggered" criterion be satisfied but also that an electron of at least 12 MeV kinetic energy passes through one or both of the trigger scintillators (t_1 , t_2 in the above diagram).

We intend to study the properties of one of these modules this summer using a low energy tagged photon facility.

FIG. 4.

Pb PLATE SPARK CHAMBER EFFICIENCIES;
TWO RADIATION LENGTH
AT NORMAL INCIDENCE.

-- Spark Chamber Trigger

The requirement for spark chamber trigger will be as follows:

- (1) A particle enters the stopping target and produces a large pulse in two adjacent segments of the target and does not leave the down stream end. This will discriminate strongly against pion contamination in the beam. These pions will have energies up to 280 MeV at the stopping target.
- (2) No pulse is observed in the anticoincidence scintillators in front of the gamma chambers.
- (3) A signal is observed from one or more of the gamma trigger counters imbedded in the gamma ray chamber array.
- (4) A particle is observed to pass through the scintillator placed in front of the range chamber.
- (5) No anti pulse is received from either the momentum veto counter or the range veto counter. This requirement will suppress $K_{\pi 2}$ and $K_{\pi 3}$ contamination.

3c. Expected Event Rate

We have calculated that we should be able to obtain approximately 110 good events in the 40 shifts of operation requested. The calculation was performed in the following fashion:

The geometric detection efficiency of the apparatus illustrated in Figure 2 was calculated by assuming that the aperture of the momentum-range apparatus was $.01/4\pi$. It was further assumed that any of the three gamma rays would not be detected if they were emitted from the decay vertex within a cone of half angle 25° centered on the incoming beam line or within a cone of the same half angle centered about the π^+ direction. If the gamma rays did enter the gamma detectors it was assumed that they would be detected with an intrinsic efficiency of 45% (for each gamma). The requirement for detection of an event, then, was that all 3 gamma rays be detected and that the π^+ enter the momentum range aperture. The results of these calculations are illustrated in Figure 5.

With these efficiencies, the integral of efficiency times branching ratio over the interval of π^+ energies from 55 to 91 MeV was calculated:

$$\langle B\epsilon \rangle = \int_{55 \text{ MeV}}^{91 \text{ MeV}} \int_{k_{\min}}^{k_{\max}} \frac{d^2 B}{dTdk} \epsilon(T,k) dk dT$$

FIGURE 5

Typical geometric detection efficiencies

— for $P_{\pi^+} = 130 \text{ Mev./c}$ ($T = 51 \text{ Mev}$)

- - - for $P_{\pi^+} = 170 \text{ Mev./c}$ ($T = 81 \text{ Mev}$)

vertical lines show kinematic limits

$\epsilon(T, k) \times 10^2$

where $K_{\min}$ and $K_{\max}$ are the kinematic limits on the gamma ray energy appropriate to the particular value of T . We used the formulas of Costa and Kabir, reference 3, for this calculation. The quantity

$\frac{d^2 B}{dTdk}$ is the differential branching ratio $\frac{(K^+ \rightarrow \pi^+ \pi^0 \gamma)}{(K^+ \rightarrow \pi^+ \pi^0)}$. A summary of

the event rate calculation is given in the following table:

1. Number of stopping K^+ per ZGS pulse 2000
2. $\langle B\varepsilon \rangle$, average geometric efficiency times
branching ratio relative to $K_{\pi 2}$ branching ratio . . . 0.90×10^{-5}
(Here we assume the entire contribution arises
from inner bremsstrahlung.)
3. Intrinsic detection efficiency of gamma detectors
is 0.45 per gamma detector thus the overall
intrinsic efficiency is 0.091
4. $K_{\pi 2}$ branching ratio 0.21

The above calculations leads to an expected event rate of about 3.4×10^{-4} per pulse, or approximately 2.8 per shift.

The significance of these data can be expressed in the following way: If one assumes that the p-wave and s-wave $\pi^+ \pi^0$ scattering phase shifts are equal and that the amplitude of the magnetic dipole intrinsic

bremsstrahlung is 0 ($x_m = 0$, in the notation of reference 3) then the parameter x_e , representing the contribution of the electric dipole intrinsic bremsstrahlung relative to the internal bremsstrahlung, can be determined to an accuracy of ± 0.05 . This has been determined by calculating the sensitivity of the spectrum shape to this parameter in the region in which we are sensitive. It does not assume that we make an absolute measurement of this branching ratio but only that we fit the P_{π^+}, K spectrum shape.

3d. Background

Although the branching ratio for $K_{2\pi\gamma}^+$ is very small (2.2×10^{-4}), we hope to be able to isolate these events by their unusual signature. This will be accomplished in two stages: viz. in the triggering stage, by demanding at least one gamma conversion as well as an outgoing positively charged particle within the range and momentum window; and then in the scanning stage, by demanding 3 gamma conversions.

Note that the above implicitly assumes that the ambient γ background is not high. This may not quite be the case. Assume for example,

- (1) π^+/K^+ ratio may be as bad as $10^0/1$ before degrader.
- (2) 1 incident π^+ results in .35 π^0 's (assume these all decay inside the Γ chamber array, which is not quite true).

So with $10^5 \pi^+$ in 500 msec. we get .07 π^0 's decaying per microsecond; hardly a problem for the (fast) trigger, but certainly a problem at the SCAN level. If the spark chamber's latent image lasts 1 μ sec, then, even with a lead sheath around the degrader, 1 to 5% of the pictures will have an extra gamma ray showing. This gives rise to two effects:

1. 1 to 5% of $K^+ \rightarrow \pi^+ \pi^0 \gamma$ will scan like $K^+ \rightarrow \pi^+ \pi^0 \pi^0$ (τ' decay)
2. 1 to 5% of other K^+ decays with a π^0 and a charged particle will scan like $K^+ \rightarrow \pi^+ \pi^0 \gamma$.

The loss of good events by effect (1) is small, and hopefully can be recovered by fitting events with 4 gammas converted first to the τ' hypothesis, and then to the $\pi^+ \pi^0 \gamma$ hypothesis.

The effect (2) will allow some of the pictures to pass the 3 γ scanning critereon as shown in Table I.

TABLE I

Mode	Branching Ratio	Relative number of triggers* (events photographed)	Relative number to be measured (assuming 5% have chance γ 's)
$K_{\pi 2}$	21%	52,000	<2000
$K_{\mu 3}$	3.6%	30,000	< 850
$K_{e 3}$	4.9%	24,000	< 670
$K \rightarrow \pi^+ \pi^0 \gamma$	.022%	360	100
(There will also be a contribution from τ ' decays due to imperfect lower momentum cut off in the trigger system. This mode provides its own ambient gamma rays)			
$K^+ \rightarrow \pi^+ \pi^0 \pi^0$	1.7%	3,000	<3000
Total pictures taken $\sim 110,000$		Number to measured ≤ 6500	

* The relative aperture of the range-momentum window for $K_{\mu 3}$ and $K_{e 3}$ was taken to be 50% and 30% respectively, from consideration of the data of Auerbach et al. (ref. 6) some of which is shown in Figure 3. Pion decay in flight before and during the momentum measurement also takes its toll: losing us about 15% of our good events, and causing about 7.5% of $K_{\pi 2}$'s to enter the range-momentum window. This contamination due to $K_{\pi 2}$ decays was increased to a possible 15%, to allow for leakage into the window due to finite stopper target size effects.

It is clear from Figure 3, which shows the K^+ decay data (charged particle only observed) of Auerbach et al, that the muons and the bulk of the pions have a well defined (and distinct) range-momentum relation. Electron ranges are very much straggled and tend to be much longer than muon ranges. Pion ranges are all shorter than muon ranges, and a few are much shorter due to nuclear interaction. This range-momentum relationship will separate off the modes leading to charged leptons.

The remaining pictures (<5000) contain about 100 good events. These latter will lie on or below the "pion line" (see Figure 3) with momentum $P_{\theta\gamma}$ such that $P_{\max}(\tau') < P_{\theta\gamma} < P(\theta)$. From the experience of Auerbach et al we can predict that there will only be a few hundred events on the pion line in this momentum region, and those showing 3 gammas will mostly be $K^+ \rightarrow \pi^+ \pi^0 \gamma$. For all such events a fit will then be tried to $K_{\pi 2\gamma}$ kinematics. Since knowing the K vertex, the three γ vertices, and the π^+ momentum vector overdetermines the kinematics (2C fit) the $K_{\pi 2\gamma}$ events can now be easily extracted.

Background due to K^+ 's which decay in flight in the neighborhood of the stopper scintillator will be precluded by the absence of a stopping signal sequence from the stopped scintillator stack. The second line of defense (in case a hard δ -ray fakes the stopping signal) lies in the 90° geometry. In this case $P_{\max}(\tau')$ cannot easily be pushed up into our region of interest.

Monte Carlo calculations to test the design against all these sources of background are planned, and the results will be submitted as an addendum as soon as they are available.

4. Accelerator Operation

We have designed this experiment to use an external proton beam of 2×10^{10} per pulse on a 6 cm long, 8.5 mm diameter copper target. The beam spill should be >400 msec at a repetition rate ≥ 20 per minute. The experiment can accommodate a less intense beam, shorter spill and lower repetition rate with corresponding increase in the running time estimates made in section 8.

5. Beam

This experiment requires an enriched stopping K^+ beam, yielding at least 2×10^3 stopped K^+ 's per pulse. The source of K 's will be a $1/2 L_c (\approx 6 \text{ cm})$ long copper rod, $1/3''$ in diameter, placed in the extracted proton beam (E.P.B.) at Z.G.S. The intensity striking this target should be at least 2×10^{10} per pulse, at 12.5 BeV, and the spill length should be 400 msec.

The beam will be transported at 750 MeV/c through a single stage electrostatic separator (Argonne 10ft separator) to the experimental region. Preliminary studies show that at some expense in momentum recombination, this can be accomplished with a somewhat shorter and simpler beam than that of Kalmus and Romanowski (see ref. 8).

The results of detailed studies now in progress will be forwarded as an addendum to this proposal. One of the possibilities being considered is a suggestion due to A. Roberts and P. Livdahl that we target early and transport to the west side of the E.P.B. tunnel. It is already clear however, that the basic beam parameters will not be much different from those presented in P-153, viz: $\Delta p/p \approx \pm 1\%$, $\Delta \Omega \approx 10^{-3}$ steradians. The length will be about 550 inches. This beam is being designed by one of us (W.R.F.), apparently not in collaboration with other groups, as stated earlier in P-153.

6. Experimental Equipment

Aside from the beam transport elements and the 10 foot separator, the major piece of experimental equipment needed is the π^+ spectrometer magnet, BM112.

7. Schedule

The first gamma ray chamber is presently under construction and should be completed by the end of June 1967. Following tests with this chamber we will proceed to construct other chambers necessary for the experiment. We estimate this construction time to be 4 months maximum.

We feel that the apparatus will be ready to move onto the ZGS floor on or about 15 December 1967. Therefore, we estimate that we would be able to use beam on or about 15 January 1968.

8. Machine Time Required

It was stated in Section 3c (page 9) that with 2×10^3 K^+ 's stopping per pulse, we could collect just over 100 completely reconstructed events in 40 shifts, and that these events would constitute a significant experiment. A conservative estimate (see P-153, Appendix B, p 32) shows that the above stopping rate of K^+ 's can be obtained with 2×10^{11} full energy external beam protons per pulse on $1/2 L_c$ of copper target. We anticipate the need for 8 shifts of preliminary runs, and would also like to add a 30% contingency factor to the final run. This brings the total time requested to 60 shifts, at 2×10^{11} (external) per pulse.

9. Data Analysis

We intend to use a computer-controlled flying spot scanner device for measuring and perhaps scanning the film from this experiment. This machine has been designed and partially constructed at Case during the last year. Presently all hardware is on hand and it is being interfaced with our IBM 1802. It is anticipated that an experiment* which produces film of a rather simple format and topology will be analyzed on this machine prior to the experiment described in this proposal. The machine is designed to measure the position of points on film with a nominal precision of 1 part in 1000 and to operate at a speed such that one frame could be examined in a few seconds. If the machine performs as we expect then data analysis could proceed quite rapidly, being measured as fast as it is produced. We recognize, however, that it may not so perform. In such an event we are prepared to have the film scanned and measured by hand and have the personnel and equipment necessary to do so. Adequate computing facilities exist at Case for any data analysis problem arising from this experiment.

* to be performed this summer at the AGS by a group from Harvard, Cornell and Case.

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