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Status of a Study of the Decay $K^+ \rightarrow \pi^+\nu\bar{\nu}$

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ABSTRACT

AGS-787, BNL-Princeton-TRIUMF, began taking data in February 1988 on rare K^+ decays into π^+ and non-interacting neutrals. Recent observations of B-$\bar{B}$ mixing have sharpened the branching ratio prediction of the three generation standard model, (SM), to ~ 1-5 × 10^{-10} for $\pi^+\nu\bar{\nu}$. The detector has 2π acceptance for this decay and 4π acceptance for background gammas. A very large window for viewing new physics exists between the SM value and the previous experimental limit of 1.4 × 10^{-7}. Several other predicted rare K^+ decays can be detected. The performance of the detector is described.

AGS Experiment 787 can yield an important constraint on the parameters of the SM, probe for new generations in SM, and explore for new physics beyond SM by seeking K^+ decays into π^+ and weak neutral(s).

The K^+ has a large kinematic window for π^+ emission and a large branching fraction window for $\pi^+\nu\bar{\nu}$ decays between 1.4 × 10^{-7}, the current limit[1,2], and ~ 10^{-10}, SM's prediction[3]. The appearance of more frequent decays into π^+ and non-interacting neutral particle(s) would be a clear signature for new physics beyond SM. AGS 787 is sensitive to decays involving a variety of neutral, light, and weakly interacting particles such as axions[4], familons[5], hyperphotons, Higgs, and the supersymmetric photino, goldstino, and scalar Higgs (Shiggs)[6], predicted by current theoretical models.

The observation of $\pi^+\nu\bar{\nu}$ at the SM value would constrain the mass of the top quark and the element linking the top and down quarks in the Kobayashi-Maskawa matrix. The decay's interpretation is free of uncertainties from light hadronic matrix elements and final state interactions. An extra generation of quarks and leptons in SM could modify the $\pi^+\nu\bar{\nu}$ decay rate considerably.

The experimental challenge of studying $\pi\nu\bar{\nu}$ decays to the 10^{-10} level requires high rates and rejection of many backgrounds from ordinary K^+ decays. The challenge is confronted with adequate segmentation in fully active tracking systems with redundant momentum, kinetic energy, range, and time measurements to select π^+ and reject μ^+ decays of K^+. The trackers are surrounded by "seamless" EM shower units to reject decays to photons.

At the AGS, Low Energy Separated Beam, LESB1 delivers an intense beam of 1 K^+/3 π^+ at 775 MeV/c. The K^+ are identified by a differential Cerenkov counter, tagged by fast wire chambers, marked by counter elements, degraded in beryllium oxide, and stopped at the center of the spectrometer in a segmented scintillating fiber degrader, that is called the "target". The isometric drawing of the magnetic spectrometer in Fig. 1 reveals the architecture of a collider experiment appropriate for K^+ decays at rest. More detail appears on the cross-section drawing in Fig. 2.

The cylindrical drift chamber and the 24 scintillator ranging sectors, the "range stack(s)", subtend 2π for π^+ decays from the target. A "seamless" 4π coverage for γ detection is provided by all-active tracking units surrounded by one barrel and the two endcap segmented EM shower units. The long active target segments provide γ veto coverage for the hole in the downstream endcap.

The decay π^+ gets three independent energy-momentum measurements: drift chamber arc in the one Tesla field, energy deposited in the target and range stack scintillator, and range in the segmented target and range stack. The preliminary rms resolution of momentum is ± 2.5 at 236 MeV/c, the "$K\mu2$" peak for μ^+ in $K^+ \rightarrow \mu^+\nu$ and ± 3% at 205 MeV/c, the "$K\pi2$" peak for π^+ in $K^+ \rightarrow \pi^+\pi^0$. The resolution of the π^+ mass calculated from a fit to momentum, energy and range is about ±8%.

Figure 3 shows the three sectors of a kaon's-eye view of the target. There are 9 × 14 clusters in each sector for a total of 378 segments. Every segment of the target is a triangular cluster of six state-of-the-art scintillating optical fibers 2 mm in diameter and 3.1 meters long. (The full length can register γ conversions.) For 2 meters the fibers are epoxied together to provide mechanical stability needed to locate each cluster and to help support the cantilevered stopping region. The six free ends are cemented to an optical mixing block. The blocks are fanned out to the back of a spherical surface supporting the 378 photomultiplier tubes. Six "I-counters" surrounding the 20 cm stopping region and the target elements, participate in the trigger logic. The target is instrumented with both ADC's and TDC's. Figure 4 is an xy drawing of the target, with K^+ and π^+ tracks from the run.

The drift chamber is designed to provide momentum resolution matched to scintillator range and energy resolution for background rejection of "$K\mu2$" ($K^+ \rightarrow \mu^+\nu$) and $K\pi2$ and to provide tracking to the segmented target. This is achieved in an active cylinder 50 cm long between radii of 12 and 43 cm containing five layers of six axial sense wire cells used to measure r-ϕ coordinates. The wires of layers 2 and 4 are at 3° and 4.5° stero angles for z position measurement. Graphite-epoxy cylindrical walls minimize scattering and inert material. High rate capability is achieved in short drifts (1 cm to 1.7 cm) with short memories (200 to 350 nsec). The inner layer sees one MHz rate spread over 36 cells. Reliability is enhanced by conservative selection of wires. The sense wires are 20 micron diameter gold-plated tungsten tensioned to 50 gm and the field wires are 170 micron diameter Be-Cu tensioned to 150 gm. There are 300 micron diameter field wires at the ends of the cells. The fields at the surface of the sensewires are in the range 270 kV/cm and the field wire surface fields are all less than 20 kV/cm to prevent whisker growth.

The range stack scintillator bars are read out at both ends to provide signal localization at high rates. Twenty four azimuthal sectors are each 40 cm thick. Each sector has 15 layers that are 2 cm thick in the stopping region. Two PWC's are imbedded after layers 4 and 8 in each range stack for tracking. The inner portion of the range stack below the Kπ2 peak is instrumented with TDC's and ADC's. The balance of the range stack is instrumented with ADC's, TDC's, and new 500 MHz transient digitizers designed and built for AGS 787. The transient digitizer captures the $\pi^+ \rightarrow \mu^+ \rightarrow e^+$ sequence in a charge-time plane whereby a π^+ is positively identified.

The barrel photon veto covers 360° in azimuth ϕ between 45 and 135° in polar θ. Photons from Kπ2 decays have between 20 and 225 MeV. The acceptance of the π^+ in the range stack forces most of the high energy photons into the barrel veto. For the $K^+ \rightarrow \mu^+\nu\gamma$ decay, 85% of the photons above 20 MeV enter the barrel. Seventy-five layers of 1 mm lead to 5 mm scintillator providing fourteen radiation length coverage is segmented into 4 radial layers in 48 azimuthal segments. The segmentation allows separation of the rare $K^+ \rightarrow \pi^+\gamma\gamma$ decay from the Kπ2. To achieve seamless coverage none of the cracks between the segments project back to the target.

The two endcap γ veto units also present 14 radiation lengths with the same 1 mm lead and 5 mm scintillator layers. The scintillator light is collected with BBOT wave length shifter bars. Mostly low energy photons fall on the end caps because of the restricted acceptance of the π^+ within the range stacks.

Triggering $\pi^+\nu\nu$ occurs in three levels (0,1,2). Level 0 signals the K^+'s stopping within the target and the decay π^+'s entering the first layer of a range sector, with appropriate π^+ range limit and γ veto condition met. The deadtime is about 40 ns. Level 1 involves memory lookup units that permit muon rejection by range and dip angle. The deadtime is seven microseconds. Level 2 software processing of transient digitizer data for the decay μ^+ from the π^+ and of target and range stack energy for a 135 MeV maximum occur in a SLAC Scanner Processor (SSP) over 500 microseconds. Parallel triggers selected "$\pi^+\mu^+\mu^-$" and $\pi^+\gamma\gamma$ decays.

Data is acquired in a microVAXII via FASTBUS and CAMAC bus networks. SSP's are distributed on FASTBUS networks servicingTDC's and the Transient Digitizers. ADC's and scalers are on CAMAC buses.

During the first engineering/data run from February to May, 1988, about twenty times the world sample of K^+ stops for $\pi\nu\bar{\nu}$ were written to tape. Most of the data were recorded at 130 thousand K^+ stops per AGS spill. Some running took place at 300 thousand K^+ stops per spill. The resolutions of all of the systems are approaching design values. The tails of distributions must be thoroughly understood. Data analysis is proceeding for decays into weak neutrals and π^+ above the Kπ2 peak.

Preliminary accounting of the data obtained by AGS 787 indicates that new limits can be obtained for the following decays for which present limits exist:

Decay	Sensitivity[7]	Present Limit
$K^+ \to \pi^+\nu\bar{\nu}$	$< 10^{-8}$	$(< 1.7 \times 10^{-7})^2$
$\to \pi^+X^0$	$< 3 \times 10^{-9}$	$(< 4 \times 10^{-8})^2$
$\to \pi^+\mu^+\mu^-$	$\leq 10^{-7}$	$(< 2.4 \times 10^{-6})^8$
$\to \pi^+\gamma\gamma$	$\leq 5 \times 10^{-7}$	$(< 8 \times 10^{-6})^8$

The goal of the present program is to press the study of $K^+ \to \pi^+\nu\bar{\nu}$ to a level of 2×10^{-10}.

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REFERENCES

1. G.D. Cable, et al., Phys. Rev. D8, 3807 (1973).
2. Y. Asano, et al., Phys. Lett. 107B, 159 (1981).
3. J. Ellis, J. Hagelin, S. Rudaz, Phys. Lett. 192B, 201 (1987).
4. R. Peccei and H. Quinn, Phys. Rev. Lett. 38, 1440 (1977) and Phys. Rev. D16, 1791 (1977); S. Weinberg, Phys. Rev. Lett. 40, 223 (1978); F. Wilczek, Phys. Rev. Lett. 40, 220 (1978).
5. F. Wilczek, Phys. Rev. Lett. 49, 1549 (1982).
6. R. Shrock. "The value of experiments on decays of the type K → π + missing neutral(s)", Snowmass Proceedings, 291 (1982).
7. L. Littenberg, private communication.
8. Particle Data Group, Phys. Lett. 170B April (1986).

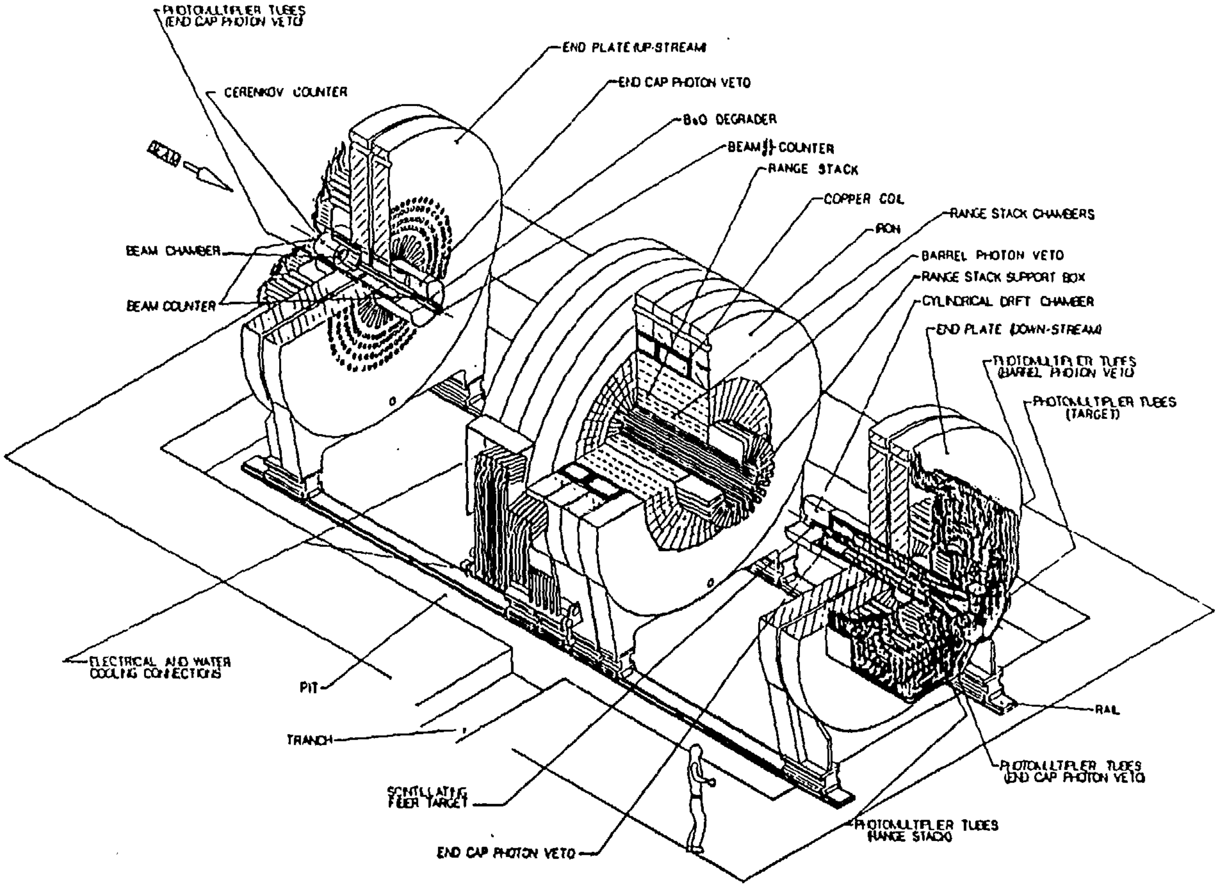

Fig. 1. Isometric Drawing of AGS 787 Spectrometer.

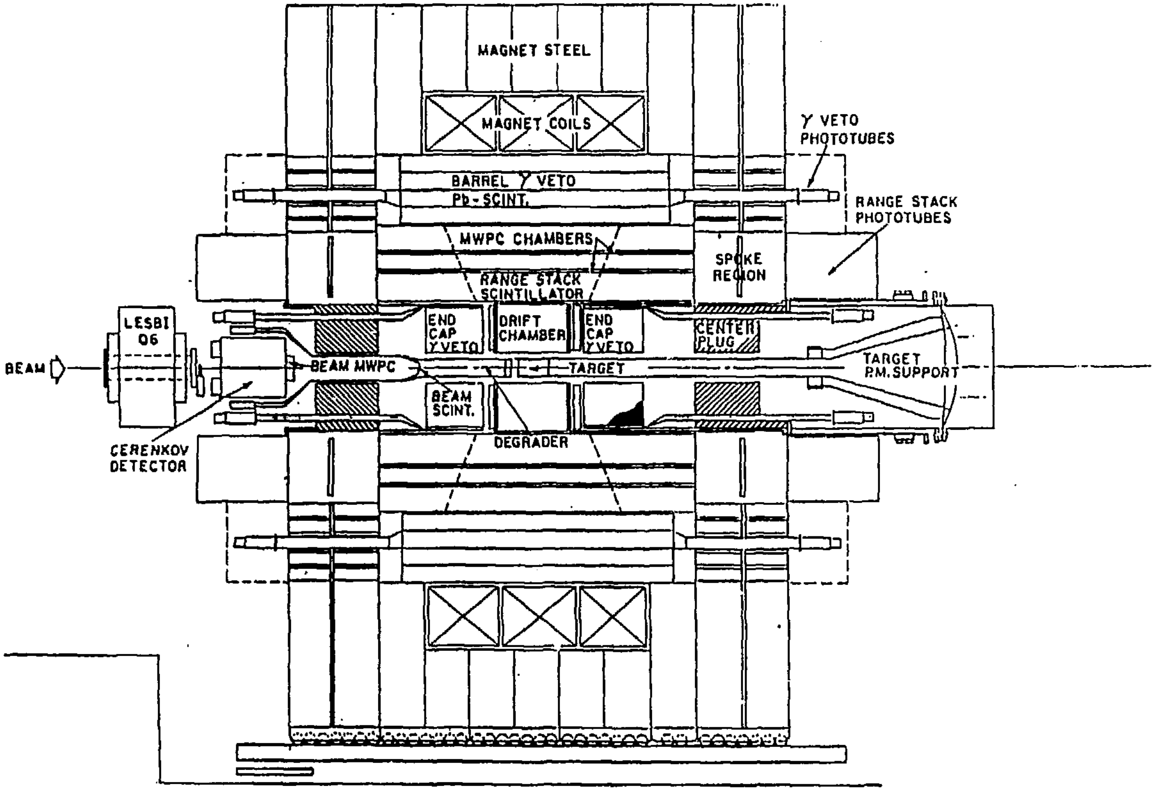

Fig. 2. AGS 787 Spectrometer Longitudinal Section.

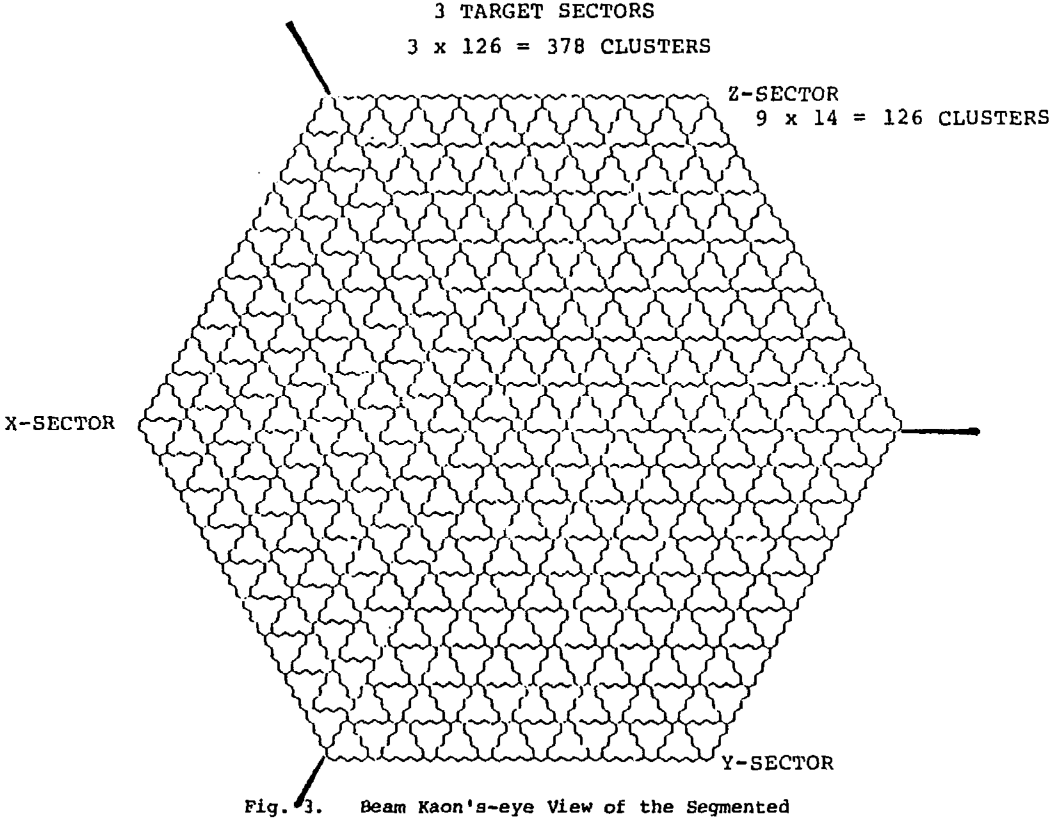

Fig. 3. Beam Kaon's-eye View of the Segmented Scintillating Fiber Target

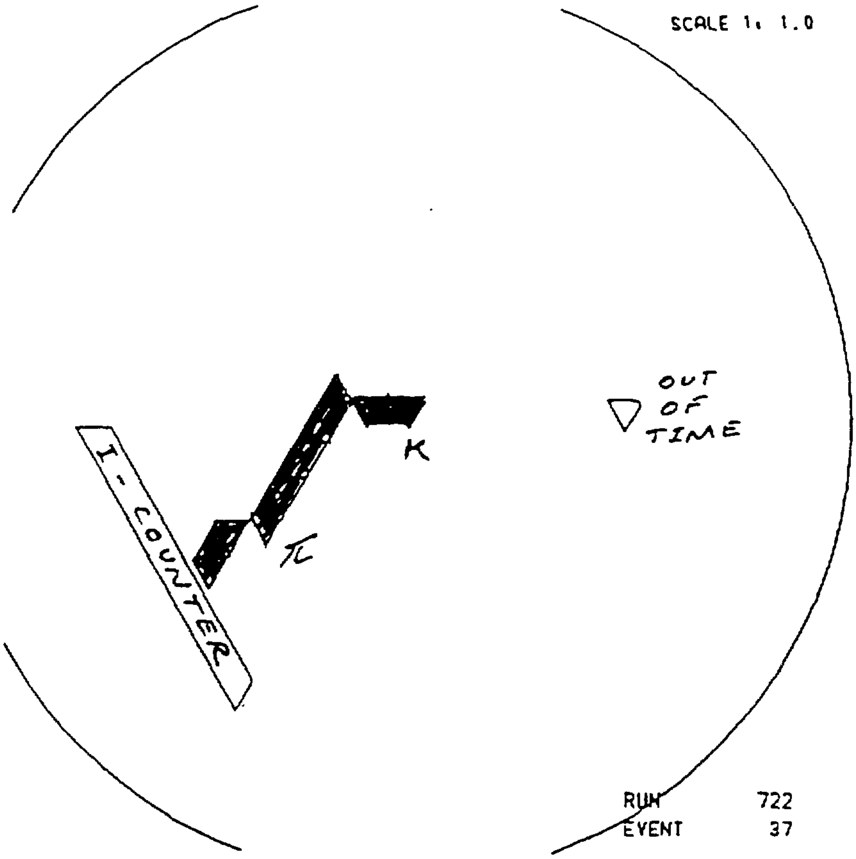

Fig. 4. $K^+ \to \pi^+ + \pi^0$ in the Target: K^+ visits 3 triangles coming to rest; π^+ visits 11 triangles and an I-counter; one triangle has out of time energy not associated with this decay. Each triangle of six scintillating fibers has time and energy recorded. Photons from π^0 decay convert in the barrel veto system. See text.

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