Searches for $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\gamma$, and $\pi^0 \to \nu\overline{\nu}$ in K^+ decay at rest.

Peter S. Cooper[1]
(for the BNL E949 Collaboration)

Fermi National Accelerator Laboratory, MS 234 PO Box 500, Batavia, IL, 60510

Abstract. E949 is a high rate K^+ decay at rest experiment with the primary goal of determining $|V_{td}|$ via a measurement of the branching ratio of the ultra-rare charged kaon decay $K^+ \to \pi^+\nu\overline{\nu}$. I report here related limits from the decays $K^+ \to \pi^+\gamma\gamma$, $K^+ \to \pi^+\gamma$ and $\pi^0 \to \nu\overline{\nu}$ from an analysis of the full E949 dataset.

PACS: 13.20.Cz, 14.40.Aq, 14.60.St

INTRODUCTION

The E949 detector is a kaon decay at rest spectrometer in the low energy separated beamline (LESB II) at AGS at Brookhaven. It is an upgraded version of the original E787 experiment which discovered the ultra-rare charged kaon decay $K^+ \to \pi^+\nu\overline{\nu}$. While the detector was designed primarily to observe this ultra-rare decay mode other rare decays are accessible particularly those with photons in the final state.

An incoming $\sim 700 MeV/c$ charged beam with kaons tagged by Cherenkov and dE/dx counters is stopped in an active target. The apparatus has high geometrical acceptance for all kaon decay products with momentum analysis in a $10Kg$ magnetic field. Charged daughters are measured by range, energy and observation of the $\pi \to \mu \to e$ decay chain. Photon detectors surround everything. The apparatus was upgraded for E949 (shown in blue in Fig 1). Particularly, the photon detectors were strengthened. These upgrades improved the performance for searches like $K^+ \to \pi^+\gamma\gamma$ reported here.

Twelve weeks of data, of 60 originally approved, were taken in 2002 corresponding to $\sim 2 \times 10^{12}$ live kaon stops. The accelerator had some problems, the apparatus and upgrades worked well. Results from the $K^+ \to \pi^+\nu\overline{\nu}$ search are reported elsewhere [1].

$K^+ \to \pi^+\gamma\gamma$

The $K^+ \to \pi^+\gamma\gamma$ decay mode is a sensitive test of $O(p^6)$ corrections in chiral perturbation theory (ChPT). Results from E787 showed a some evidence for $O(p^6)$ corrections [2]. We focused near the decay spectrum endpoint (Fig 2(left)) where these corrections dominate. Our results are shown in Fig 2(right). With 8 times the sensitivity of

[1] Talk presented at the Particles and Nuclei Int ernational Conference (PANIC05), October 24-28, 2005, Santa Fe, New Mexico, USA.

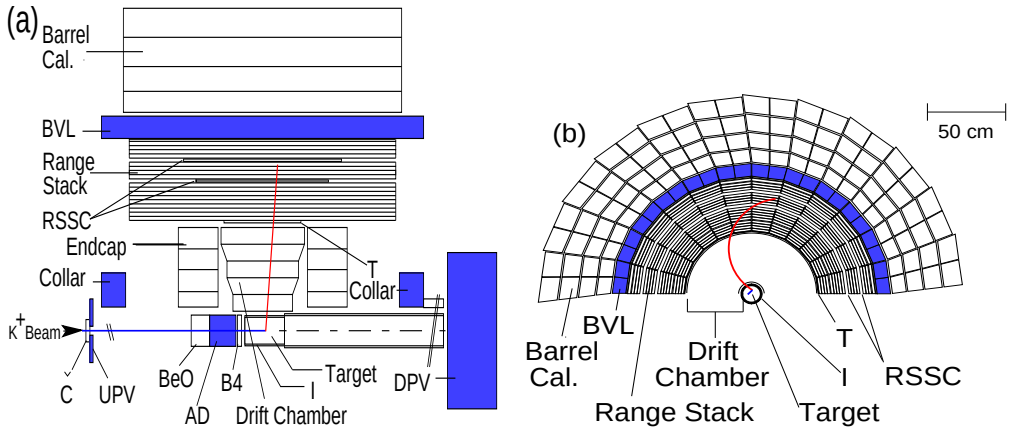

FIGURE 1. E949 apparatus (upgrades from e787 are shown in blue)

E787 we still observe only an upper limit of Br($K^+ \to \pi^+\gamma\gamma$) $< 8.3\times10^{-9}$ (90% CL) for $P_\pi > 213 MeV/c$ and can neither confirm nor rule out these corrections. the fully approved data set would have resolved this issue. The same data and analysis are used to set an improved limit on the $K^+ \to \pi^+\gamma$ decay mode which violates both angular momentum conservation and gauge invarience. Our limit of Br($K^+ \to \pi^+\gamma$) $< 2.3\times10^{-9}$ (90% CL) is a factor of 160 improvement over E787. These results are now published [3].

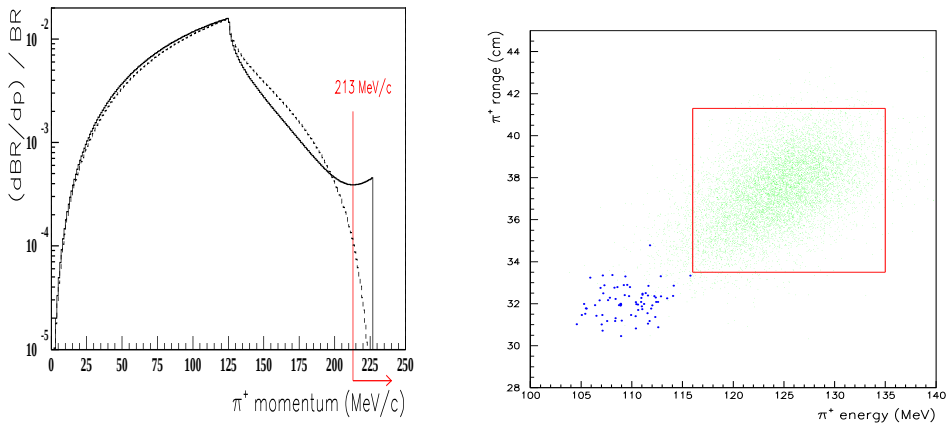

FIGURE 2. (left) ChPT predictions for the π^+ momentum spectrum with and without $O(P^6)$ unitarity corrections(UC). (right)E949 search results. No signal events are in seen the signal box. Light pointss are the MC signal prediction.

$\pi^0 \to \nu\overline{\nu}$

The $\pi^0 \to \nu\overline{\nu}$ decay mode is forbidden by angular momentum conservation if W's and neutrinos are purely left-handed. With massive neutrinos the limit from the present neutrino mass limits is Br($\pi^0 \to \nu\overline{\nu}$) $< 1.1\times10^{-9}$ for $m(\nu_\tau) < 18.2 MeV/c^2$ [4]. The best previous direct search limit, Br($\pi^0 \to \nu\overline{\nu}$) $< 8.3\times10^{-7}(90\%CL)$, is from E787 [5].

Our technique is to use the copiously observed mono-energetic π^+s from $K^+ \to \pi^+\pi^0$ decays to cleanly tag π^0 decays. We look for events with no other activity observed in the detector. This sample comes in on the main $K^+ \to \pi^+\nu\overline{\nu}$ trigger. We select $K^+ \to \pi^+\pi^0$ events and apply the tightest possible photon veto cuts to reject $\pi^0 \to \gamma\gamma$, etc. In a blind analysis we tune the cuts on $1/3$ of the data sample and use the other $2/3$ for the search.

The effective π^0 rejection as a function of acceptance is shown in Fig 3 (left). The value of the acceptance cut set from the $1/3$ data sample was 0.117. The π^+ momentum distribution for increasing photon cut levels are shown in Fig 3 (right). After all cuts 99 events survive. We presume these to the $\pi^0 \to \gamma\gamma$ events with undetected photons. A background subtraction would require an independent measurement of the photon inefficiency at a level beyond our ability to measure it. The corresponding branching ratio upper limit is $\mathrm{Br}(\pi^0 \to \nu\overline{\nu}) < 2.7 \times 10^{-7}(90\%CL)$, a factor of 3 improvement beyond E787. These results are now published [6].

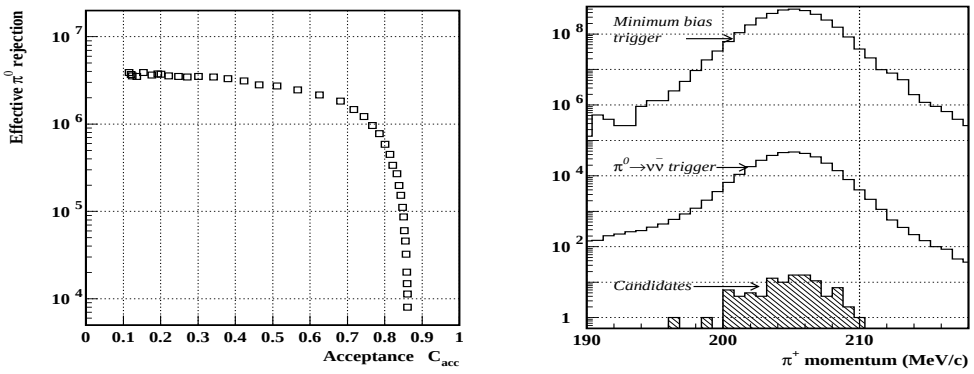

FIGURE 3. (left) The effective π^0 rejection as a function of acceptance. (right) The π^+ momentum distribution for increasing photon cut levels. The 99 surviving events are hashed.

ACKNOWLEDGEMENTS

This was work supported by several US, Canadian, Japanese and Russian funding agencies and laboratories whose contributions are gratefully acknowledged [1, 3, 6] .

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