E949 Technote #K042
Can E949 measure the K^+ lifetime?

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Abstract

Recent published results from the FermiLab KTeV collaboration on the decay of the K_L has disagreed with old previously accepted results. This has caused an interest in reassessing of all the properties of the neutral and charged kaons including their lifetimes. We have been studying data taken by E949 during our production run during 2002 to determine if we might be able to determine the K^+ lifetime to test previously published measurements. These studies should be regarded as a 'feasibility' study, rather than a test of the ultimate sensitivity that can be achieved. Using current analysis code, we have determined that it is likely that we can measure the K^+ lifetime to better than the 1% level. This survey suggests that the analysis path chosen is causing the limitations on the systematic uncertainty, and may dominate other effects like the effects of the trigger and the high detector rates. We suggest code modifications to do better. In addition, the Letter of Intent for using the E949 detector to search for the Pentaquark state opens the possibility of acquiring a new data set in the near future that would enable us to make an accurate K^+ lifetime measurement in a controlled manner.

Introduction

The current Particle Data Book lists the K^+ lifetime as 12.384+-0.024 ns (0.2%). The most precise measurement of the K^+ lifetime [Ott et al. PR**D3**(1971)52] has 3M events with a minimal detector (inactive degrader, inactive target, 2-fold scintillator telescopes for K^+ and decay product, K^+ Cerenkov). We have a very sophisticated detector; under proper conditions, we should be able to utilize this complexity to solve many problems and test levels of systematic uncertainty. Unfortunately, complexity can make life difficult, and if the complexity causes systematic problems, it can make a precision lifetime measurement impossible.

To measure the kaon lifetime, one needs a) a sufficient number of K^+ decays to have interesting statistical accuracy; b) a method to measure and calibrate the time scale with sufficient accuracy; and c) a method of acquiring and analyzing the data so that the level of systematic effects may be tested and do not dominate the lifetime determination. We believe that to be interesting (publishable), the lifetime determination must be better than 0.5%, and 0.1% would be quite interesting, indeed.

Conceptually, we had 500 MHz CCDs instrumenting each element of the target and beam systems, as well as several 'veto' systems. Measurements in the scintillating fiber target measure time for both the stopping kaon and the charged decay products. Thus, the '0' time as well as the decay time are measured in each event by the same system of CCDs.

Over all the sample decays that we measured, any individual target element, viewed by individual CCD channels, could measure either the incident kaon time or the subsequent decay time. A single clock provided the time scale for all the CCD channels. The following sections describe the methods that we used.

Concept and Methods

A pass2 executable was created in which all CCD hits for the kaon and pion Cerenkov counters (14 channels each) were saved to ntuples. In addition, all CCD hits for the target channels were saved. Joe Mildenberger ran this code on the rarek cluster at TRIUMF and processed all the km21 and kp21 monitors from the 2002 'good run list'. In addition about 5% of pnn1or2 triggers (runs in which the AGS 93MHz RF modulation were most significant) were analyzed with this executable.

The number of events in the Km21 data set provided sufficient statistics to get to the level of ~0.1-0.2% statistical error; the Kp21 set gets to ~0.3% statistical precision on the lifetime. There is a lot of additional statistics available (probably more than a factor of 2), if we were to include runs that were not listed in the stdmix good run list, and even more, under more diverse beam conditions if we use our 'tune-up' data early in the 2002 run, or from the 2001 run.

The idea was to use information from the pion and kaon Cerenkov counters to eliminate events in which accidental beam particles, or their decay products, might influence the trigger, or might affect the reconstruction efficiency. The Cerenkov counters are located ~2m upstream of the stopping target, and the kaon Cerenkov counter in particular should be quite insensitive to byproducts from kaon decays originating in the stopping target. In addition, the information from the CCDs, over a wide time interval, might allow a calibration check of the absolute time scale of the CCDs by observation of the AGS 93 MHz RF frequency.

Absolute determination of the time scale

The CCDs are driven by a single clock within a Fluke 6070A/6071A synthesized signal generator. The frequency of this clock may be set through front panel controls in the range of 0.2 to 519.999999 MHz, with a resolution of 1 Hz, and generally has stability levels of better than 1 part in 10^5. Thus, in principle, if we know the setting of the CCD clock frequency, the reference clock cycle time should be known and stable to this level. (I plan to not check this until the analysis is complete in to eliminate a potential bias.)

We have another way of determining the absolute time scale. The AGS has a natural beam modulation that occurs at a rate of 93.142 MHz. This is known to a level of better than 1 part in 10^5; it is a fundamental frequency of the AGS, governed by the dimensions of the accelerator itself. Although we generally requested that the magnitude of this modulation be reduced by AGS control, it was often visible in our data. In fact, for some data that we took, this modulation was a dominant feature in our beam counters. Fig. 1 below plots the number of events vs. hit time in the CCDs in one of the pion Cerenkov tubes in one run of pnn1or2 events in the stdmix trigger; in red is plotted the time in the target for fibers with >~5 MeV. Fig.2 below plots a ‘peak to valley’ ratio of one of the kaon Cerenkov counter hits as a function of Run number in the ‘good run list of standard-mix’ runs during our 2002 run. This ratio provides a ‘figure of merit’ of how much the AGS RF was visible.

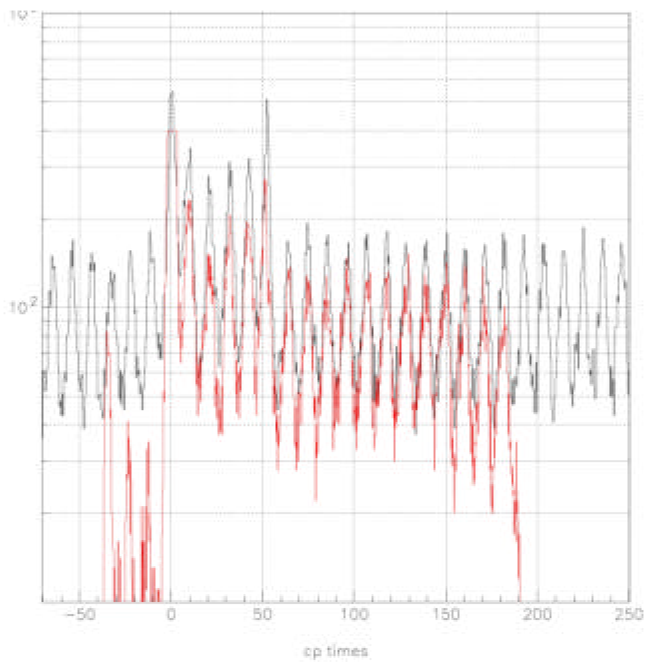

Fig. 1. Number of hits vs. time for one Pion Cerenkov tube time (ns) pnn1or2 triggers, run 49217. Also shown in red are the target times in the CCDs for hits >~5 MeV. The AGS RF structure is clearly seen in the target CCDs and in the Cerenkov CCDs.

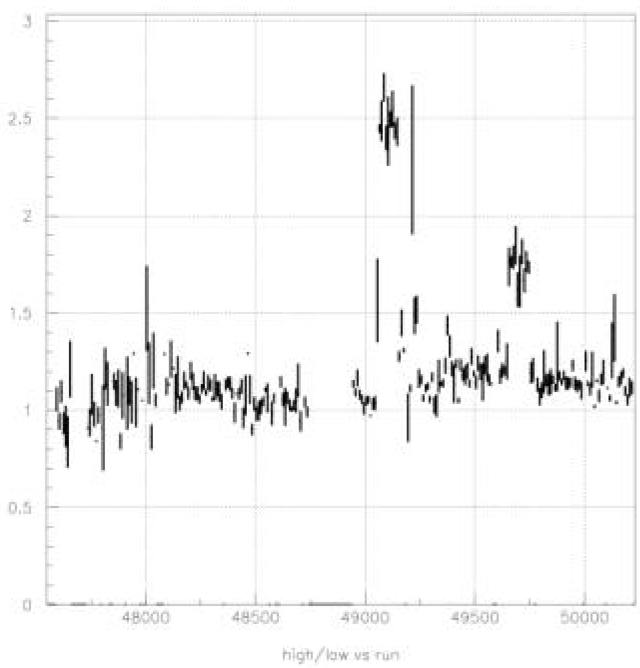

Fig. 2. Cerenkov modulation vs. run. Ratios near 1.0 show little 93 MHz RF modulation. Run 49217 had the highest modulation (4.2), which was taken during KOPIO beam tests, while the AGS was working to maximize the modulation.

It appears that it should be easiest to check the CCD clock frequency against the AGS 93MHz frequency when the modulation is high (and the modulation was high only for short times during our 2002 run). However, we get good agreement of the Cerenkov tube times even when the modulation was rather small. A fit to a Gaussian plus constant background was fit to each of the timing peaks from -110ns to +340. The background level for each of the peaks was separately determined. The resulting time of the peaks was fit to a straight line. For the 14 pion Cerenkov tubes, the slope was 10.728+-.004 combining the km21 monitors in runs 49056-49148, where the average modulation was ~2.5. The result was 10.731+-.004 for km21 monitors in runs 49751-499983, where the average modulation was ~1.2. The error bars represent the standard deviation of the slopes for the ensemble of the 14 pion Cerenkov tubes. The slopes are the same in the two sets of data to ~0.03%.

The scale of the average slope, 10.73, is the number of "ccd_ns" between AGS RF spikes. Were no other problems found, and if the CCD clock was set to 500.000 MHz, then "ccd_ns" = ns. I have not yet determined the setting of the CCD clock, either from inspection now, 2 years after the data was taken, nor from any contemporaneous records recorded at the time of the run. In this Tech Note, the time units in 'ns' and the time units for the reciprocal lifetime have not yet been calibrated.

A similar procedure was followed fitting for the target CCDs peaks from 0 to 200ns. (The full range for the beam-system CCD channels was ~512ns, whereas it was ~256ns in the target-system CCD channels; the same clock set the time scale for both systems.) Using hits with CCD area above ~5 MeV, we find that the peaks are not very well defined in runs in which the RF modulation was low. All target channels were merged to gain sufficient statistics. The result for km21 monitors in runs 49056-49148 was 10.579+-.039, were the error bar here is the uncertainty in the fit; for km21 monitors in runs 49648-49750 (during which the AGS RF modulation figure of merit number was ~ 1.7) the result was 10.687+-0.039. Thus, the fitted RF frequency from these two run sets disagree with each other by 1% (a 2σ effect), and furthermore, the average of these disagrees with the results from the pion Cerenkov counters by 1%.

To gain insight into what might be the cause of this disagreement, Fig #3 plots the deviation in ns from the straight line fit for the individual tubes in the pion Cerenkov counters for the two sets of analyzed runs.

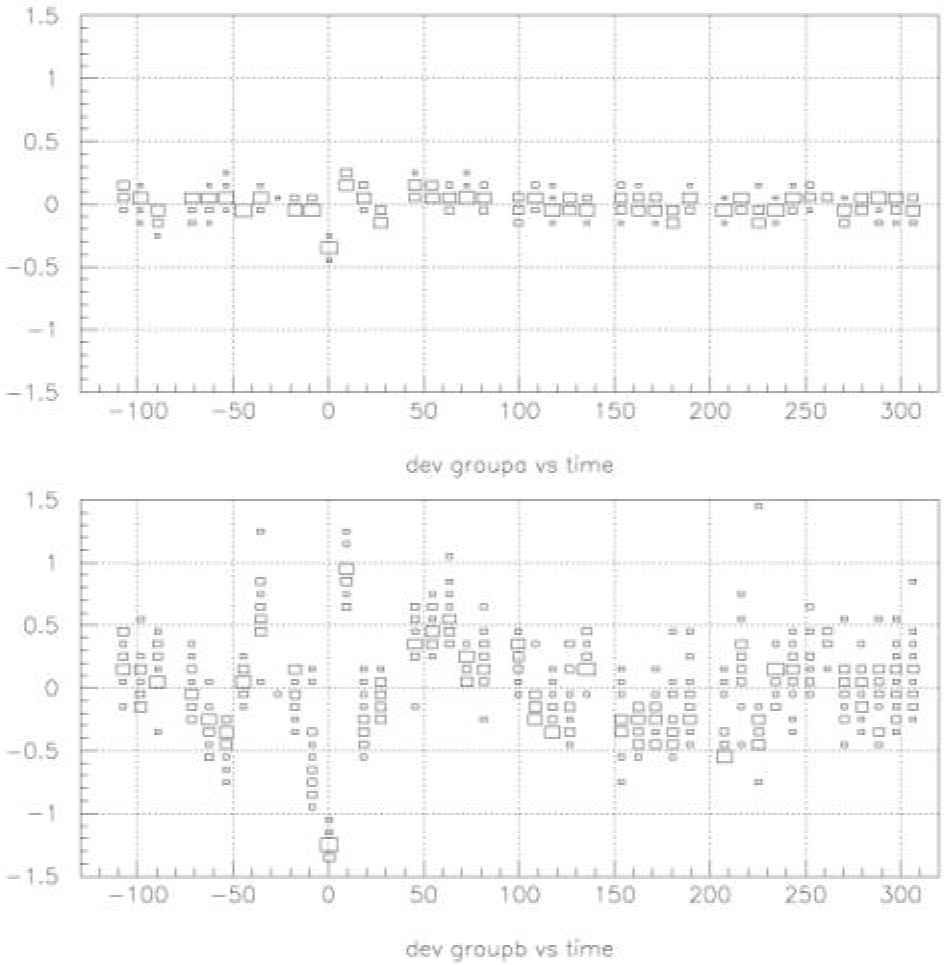

Fig 3. Top plot: Deviation from straight line fit in the pion Cerenkov counters in ccd_ns vs time (in ccd_ns) for km21 monitor runs 49056-49148 top plot (AGS RF modulation figure of merit ~2.5); Bottom plot, same for runs 49751-499983 (AGS RF modulation figure of merit ~1.2)

Two things are apparent. First, although the average slopes found from these two run sets agree to better than a few parts in 10^4, the position of the peaks is much more uniform in the runs where the RF modulation figure-of-merit was higher. Second, there are obvious systematic effects in the position of each fitted peak as a function of time, especially noticeable in times near 0. Similar structure is apparent in the target CCD peak fits.

The structure as a function of time is pointing out a systematic problem. It is showing that there are different intervals between successive time peaks. It could be caused from the trigger (the beam strobe starts the CCD gate and all channels are aligned pretty much the same in each channel, and synchronized to the 500 CCD clock); it could be from differing signal/background ratios; it could be demonstrating a differential non-linearity in the CCD system; it could be something else. My favorite, but as yet untested reason, is that the times are determined from code which calculates the CCD time based upon a linear fit to the pulse shape in the region where the pulse is rising, and this may beat, at some level, against the 500 MHz CCD clock. In addition, it is likely dependent upon the pulse height, even though the linear fit should reduce this dependence. It is possible to study this further to try to understand the source of this problem, and hopefully to correct for it. However, at present, the systematic uncertainty of the time scale in the CCDs seems to be at about the 1% level.

Tests of the K^+ lifetime determination

Putting aside the absolute calibration, and possible non-linearity of the CCDs, it is worthwhile to see if there are other systematic or statistical problems that limit the precision of the K^+ lifetime. As discussed previously, we took data at relatively high rates, and did not deliberately change the beam rates by large factors. In this analysis, we attempted to overcome the effects of high rate by vetoing any event in which there might have been additional particles. We chose very limited 'set-up' cuts in order to keep small any analysis effects that might bias the lifetime determination. All of these are subject to question and what systematics they cause, but they provided a starting point.

The initial setup cuts were: itgqualt=0; |tk|<3ns; 100<pdc<290; 0<tpi-tk<50; |tpi-trs|<4. These were applied to all events.

A) Removing accidentals

The first check was to determine how much the apparent background caused by accidentals could be reduced by imposing cuts on Cerenkov counter activity. By studying the coincidence level of the pion and kaon Cerenkov CCD hits, a coincidence level of 6 or more hits in either the kaon or pion Cerenkov system (out of 14 counters each) within +-4ns of each other provided a reasonably efficient flag that some particle was incident. So, an event needed to have 6 or more kaon Cerenkov hits within 4 ns of tk, and was rejected if it had more than 5 pion Cerenkov hits within 4 ns of tk.

In order to monitor accidental activity, the rate of T.2 coincidences was measured. The analysis eliminated those T.2 hits coincident with the trigger T.2; the level of coincidences was examined in the range from 5 to 45 ns after tpi. Km21 monitor data was analyzed, and the events were divided into 4 classes: a) those which had a total kaon Cerenkov counter energy (summing all tubes)>40 [This cut was found to be weakly correlated with 2 beam kaons incident at about the same time]; b) those which had either a incident pion or kaon from 4ns to 60ns after tk [as flagged by Cerenkov activity]; c) those events which had an incident pion or kaon from -4 to -60ns before tk [also as flagged by Cerenkov activity; and d) those events the Cerenkov counters indicated one and only one kaon in the window between -60 to +60 ns [i.e. all events that satisfied the setup cuts, had 6 or more kaon tubes fire within 4ns of tk, had fewer than 6 pion tubes fire within 4ns of tk, and didn't satisfy either of the conditions a-c, above].

Normalizing by the number of events in each of the 4 categories, we find:

a) 1422 T.2 hits/ns in 589,539 events = .00241;

b) 2763 T.2 hits/ns in 1,078,445 events = .00256;

c) 138 T.2 hits/ns in 464,548 events = .00030; and

d) 145 T.2 hits/ns in 1,030,517 events = .00014.

This shows that the T.2 rate is reduced by a factor of up to 18 by imposing cuts on the accidental Cerenkov counter activity. Note that even after eliminating all events that were seen in the Cerenkov counters, the accidental T.2 rate was not 0. The residual rate may come from incident particles that missed the Cerenkov counters or had too few tubes hit. In addition, there must be an ambient rate of accidental activity as a product of the pi->mu->e decay chain. This rate may be calculated from Monte Carlo studies.

B) Discussion of the stability of lifetime determination

In order to demonstrate that we can determine the K^+ lifetime in our apparatus, we have to show that the lifetime we determine does not change as a function of any cuts that we impose. Indeed, the first studies of the lifetime stability: the lifetime as a function of the number of pions demonstrated a problem introduced by SWATHCCD. This target reconstruction program uses the UTC extrapolation into the target and hits found by the CCD system, ADCs, and TDCs to determine target parameters for each event. A second hit in each fiber is allowed in the current version of the program, and the probability of finding a second hit (like a pion hit in the same fiber as a kaon hit) varies strongly with time. In addition, the ~80ns width of the ADC gate in the target (gated by the beam strobe) causes an apparent change in the pion energy as a function of time. A correction factor may be applied (see Fig 4), but there will be fibers, especially where pions just clip a corner, which will fail to be seen by the ADC or TDC. (The CCD threshold is about 0.5 MeV, and so will also miss many of these corner clips.) Therefore, it is not surprising that the number of pion fibers varies as a function of the time after the beam-strobe. Fig. 5 shows a plot of the reciprocal of the K^+ lifetime as a function of the number of pion elements.

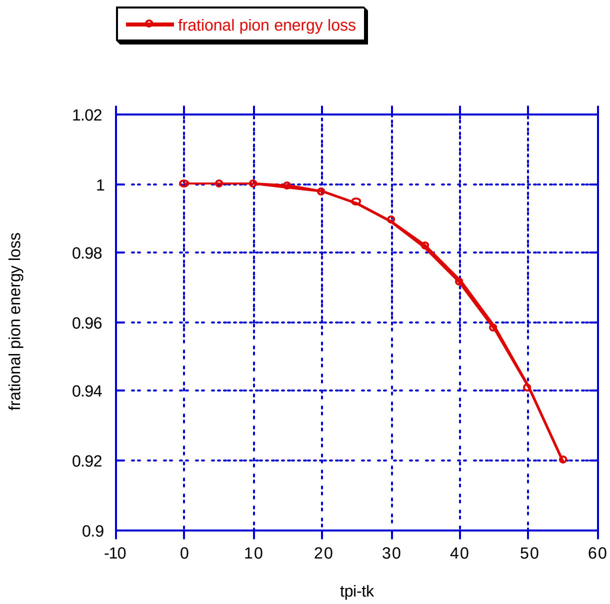

Fig. 4. Fractional change in observed pion energy as a function of time. This is caused by the pulse tail that occurs after the target ADC gate.

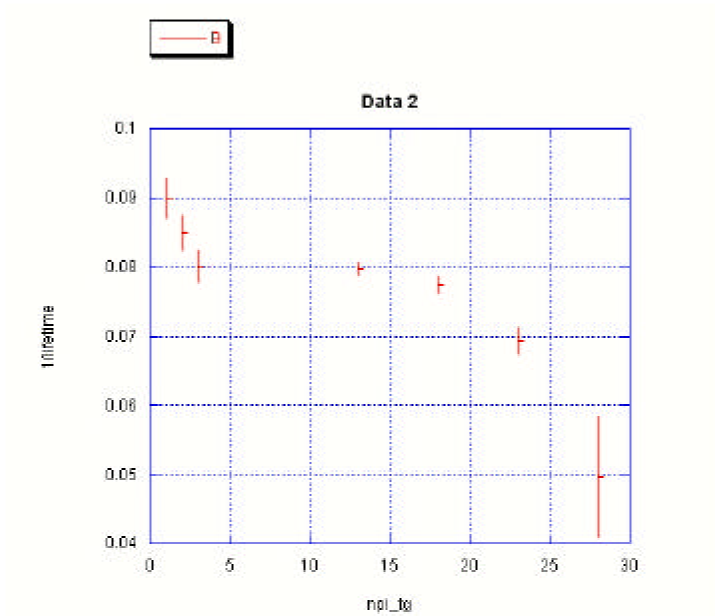

Fig. 5. The reciprocal of the K^+ lifetime as a function of the number of fibers associated with the pion. Not all values of npi_tg are plotted, but the trend is clear.

The version of SWATHCCD that was used for most of these studies eliminated the 2nd pulse possibility for reconstructed pions. However, a possible modified version of SWATHCCD (that uses only first hits in the CCDs, and does not use ADC information) may be tested in the future. The time-slew correction introduced in the TDC unpacking routines is also suspect, since it links the TDC time to the non-uniform response of the ADCs.

Aside from biases that may be introduced in the analysis code, there may be biases that originate from the various triggers. Aside from KBEAM triggers, most calibration data that we took which can be analyzed for the K^+ lifetime required Ck, B4, the target energy sum, as well as the I-counters, T.2, and other parts of the detector either in positive or veto mode. The KBEAM trigger used the beam gate to strobe the rest of the detector and the current pass2 analysis fails when there is no 'detector strobe' and the kaon decay occurred more than ~20ns after the beam strobe. (The 'detector-strobe' came from IC.T.2 coincidences which were not imposed for the KBEAM trigger.) A special analysis code has already been written (constructed by others in order to study the T counter efficiency), but it has not yet been used in these lifetime studies. So far, studies have utilized the complete 'good-run list' of the km21 and kp21 monitor streams, and a limited number of pnn1or2 events. Comparison of these different streams, with significantly different trigger conditions and backgrounds should provide a test of the stability of any K^+ lifetime determination.

C) Tests of lifetime stability in km21, kp21, and pnn1or2 triggers

After imposing the setup cuts, a study was made of the effect of applying Cerenkov counter accidental cuts. The reciprocal of the K^+ lifetime was calculated using the PAW command hi/fit x(5.:45.) e L. (log-likelihood calculation from 5<tpi-tk<45). For all events that passed the cuts, the histogrammed quantity was tpi-tk, where both of tk and tpi came from SWATHCCD. The initial results were:

Table 1

Trigger and Cuts Condition	Reciprocal lifetime	Rel. error (%)	# events ($x10^6$)	Chisq/df	1-ratio to first row (%)
Km21 after cuts	.07977+-.000124	0.155	1.24	231/79	
Km21 (1)	.07930+-.000167	0.211	0.69	143/79	0.59+-0.26
Km21 (2)	.07772+-.000124	0.160	1.23	310/79	2.54+-0.22
Km21 (3)	.07832+-.000186	0.237	0.54	120/79	1.82+-0.28
Kp21 after cuts	.07895+- .00022	0.279	0.39	159/79	1.03+-0.32
Kp21 (1)	.07824+- .00030	0.383	0.22	97/79	1.92+-0.41
Kp21 (2)	.07639+-.00022	0.288	0.39	159/79	4.43+-0.33
Kp21 (3)	0.7760+-.00034	0.438	0.17	111/79	2.72+-0.46

Here Condition (1) means events that were cut by high energy in Ck at tk; (2) events that were cut by accidental Ck or Cpi from slightly after tk to tk+60ns; (3) events that were cut by accidental Ck or Cpi from hits slightly earlier than tk to tk -60ns. Events in each of the rows are independent, and only events that remained after cut [i] were examined by cut [i+1]. The rows labeled 'after cuts' include only events that survived the setup cuts as well as all 3 sets of Cerenkov counter cuts.

From the above table, I point out two items: a) the lifetime is sensitive to the accidental cuts imposed at the several percent level, and b) even after imposing the accidental cuts, the lifetime from kp21 triggers differs from km21 triggers by 1.03%, a 3σ effect.

After looking at some distributions of other variables, I found that there was evidence of misreconstructed events that survived the setup cuts. In order to eliminate some of these, I decided to add a few more 'setup' cuts. |tgz|<15.; radius of decay vertex.le.5.; and 150<ptot<260. These removed about 15% of the events.

Table 2

Trigger and Cuts Condition	Reciprocal lifetime	Rel. error (%)	# events ($x10^6$)	Chisq/df	Ratio to first row (deviation from 1.) %
Km21 after cuts	.08036+-.00013	0.17	1.07	176/79	
Km21 (1)	.07966+-.00018	0.23	0.59	137/79	0.88+-0.29
Km21 (2)	.07811+-.00013	0.17	1.04	309/79	2.89+-0.24
Km21 (3)	.07890+-.00020	0.25	0.46	94/79	1.82+-0.30
Kp21 after cuts	.07990+- .00025	0.31	0.32	103/79	0.58+-0.35
Kp21 (1)	.07901+- .00033	0.42	0.18	83/79	1.71+-0.45
Kp21 (2)	.07703 +-.00025	0.33	0.32	222/79	4.32+-0.37
Kp21 (3)	.07862 +-.00037	0.47	0.14	92/79	2.16+-0.50
pnn1or2 after cuts	.07671+-.00026	0.34	0.25	130/79	4.76+-0.38
Pnn1or2 (1)	.04692+-.00027	0.58	0.20	*	*
Pnn1or2 (2)	.02161+-.00018	0.87	0.36	*	*
pnn1or2 (3)	.08105+-.00040	0.49	0.11	105/79	0.86+-0.52

The cuts were defined in Table #1. Here are a few comments about Table 2: a) the kp21 and km21 triggers now give K^+ lifetimes consistent with each other (1.66σ), but the pnn1or2 is highly inconsistent (12.5σ); b) the calculated lifetimes for pnn1or2 are highly dependent upon the accidental cuts imposed (a factor of 2-3 different!), whereas the km21 or kp21 triggers show a couple of percent differences; c) even for km21 triggers, there was a significant change in K^+ lifetime with the additional setup cuts (the change is 0.74%, but the 172k events that were removed had a lifetime of .07606 +- .00033, which represents a change of (4.9 +-0.5)% from the number listed in Table 1; d) the fit to an exponential isn't too bad for pnn1or2 triggers when the accidentals are vetoed using the Cerenkov counter activity. However, examining the pnn1or2 events which fail the accidental cuts shows the 93 MHz RF beam modulation, so therefore the exponential fit is lousy.

Looking at some additional information in the km21 data set: a) There is no significant run dependence to the lifetime (chisq/df = 4.8/9), nor dependence as a function of the radius of the stopping point (chisq/df = 3.3/4), nor as a function of ztg (chisq/df = 6.8/5); nor as a function of ptot (8.0/5). ; b) the lifetime may be calculated from tpi_tg – tk (tpi in each of the 413 target fibers, rather than tpi – tk (tpi for each event). The average reciprocal lifetime, and the standard deviation of the 413 measurements is .07985 +- .00087. The spread of the lifetimes is consistent with the average uncertainty in the fit (.00084); however, the average differs from the value obtained tpi –tk (.08036 in Table 2) by 0.6%.

In the pnn1or2 data set, the ratio of the calculated lifetime at the Kpi2 ptot peak to the calculated lifetime at the Kmu2 ptot peak was 1.022+-.0075 (3σ). In addition, in the momentum bins excluding the Kpi2 and Kmu2 peaks, there was evidence of some significant non-exponential component in the tk-tpi plot, in the range from 5 to 45 ns. This provided some evidence that there was still some significant background in the pnn1or2 data set which was not eliminated by the Cerenkov counter accidental cuts, or the (still loose) setup cuts. From the kp21 data set, the ratio of the calculated lifetime at the Kpi2 peak (ptot) to the calculated lifetime at the Kmu2 peak was 1.0059+-.0068.

After imposing these rather minimal set of cuts, the agreement in the lifetime as found from the km21 and kp21 data set provides some confidence that the analysis is stable. There are some indicators of problems, however. It appears that the pnn1or2 data set was demonstrating that the lifetime analysis result is not free of bias at the several percent level. A series of tests was made to try to understand the discrepancy between the km21 and kp21 results and the pnn1or2 results.

First, a new set of accidental cuts was created. This rejected events in which there was high energy in the target CCDs from -50 to +60ns that was not associated with the fibers assigned to the kaon or pion track. The cut was made on raw CCD energy > 500 (approximately 5 MeV). This should have removed events that were not flagged by the Cerenkov counter cuts. One can imagine a small bias in the tk-tpi distribution as a result of this cut. A small percentage of photons have more than 5 MeV in a target fiber. If the time of this photon is close to tk, and is contiguous with it, then it might be incorrectly merged with the kaon in SWATHCCD. Fitting tpi-tk>5 should effectively remove this possible bias.

Examining the events that were removed from the sample by the target CCD energy cut in **Table 3**, we find

Data sample	Fraction of evts removed	1/lifetime of removed events	1/lifetime of remaining events
Km21	4.9%	.07039+-.00058	.08089+-.00014
Kp21	6.9%	.07106+-.00091	.08056+-.00026
Pnn1or2	12.6%	.06314+-.00067	.07891+-.00028

Note that the lifetime of the 'removed events' is quite different than that of the remaining events. This demonstrates that the accidental cuts and/or the 'setup' cuts were not tight enough to achieve a stable lifetime measurement.

Therefore, a tighter set of accidental cuts was imposed. The summed energy of the kaon tubes at prompt time was reduced from 40 to 35, and accidentals which had at least 4 pion or kaon Cerenkov tubes were eliminated. (The minimum number of kaon tubes at prompt time remained at 6.) This eliminated ~20% of the surviving events. Now, repeating the stability test of Table 3, but with the tighter set of Cerenkov counter tests, the results are tabulated in **Table 4** (the kp21 was not analyzed).

Data sample	Fraction of evts removed	1/lifetime of removed events	1/lifetime of remaining events
Km21	4.7%	.06980+-.00066	.08085+-.00015

Kp21			
Pnn1or2	12.6%	.06267+-.00077	.07884+-.00032

As before, adding additional target cuts on CCD activity changes the lifetime significantly in the pnn1or2 data set as well as in the km21 data set. Comparing the results in the last column of Table 4 to those in Table 3 shows that the additional events removed by the tighter cuts on the Cerenkov counter did not change the lifetime after imposing the target CCD cuts. This seems to imply that there are high energy hits in the target that physically miss the Cerenkov counters. Both km21 and pnn1or2 results were stable, though they do not agree with each other (differ by 2.55+-0.45%).

It is tempting to disregard the lifetime obtained from the pnn1or2 data set, since the trigger was complex (e.g. delco, refined-range, hextant cuts, level_1.2, etc.), and one can speculate that these may be quite sensitive to the time between the beam strobe and the detector strobe. As a test, the delco bit was required in the km21 data set. Results are shown in Fig. 6.

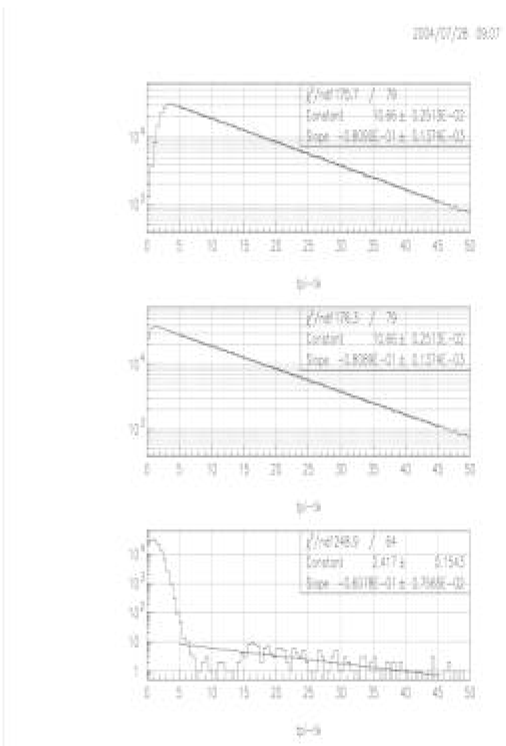

Fig. 6. Plot of tpi-tk for km21 data after (top) and before (middle) DELCO bit was required. The bottom plots only the difference.

Fig 6. shows the effect of imposing the delco bit in software on the km21 data set. The difference shows that the delco bit acceptance varies strongly with tpi-tk in the fit region (5.:45.) However, the difference does not affect enough events to explain the difference in lifetime between the km21 and the pnn1or2 data sets. A similar test of the hextant bit showed no significant change in the lifetime. Analysis tests of other tests of parts of the pnn trigger requirement will cause large losses in statistics on the km21 data set, and tests of the refined range will be very lossy in either the km21 or kp21 data set. These additional tests have not been done.

The issue of lifetime-dependent effects in the trigger provides a potentially serious systematic uncertainty. Potentially, the IC.T.2.TTSUM requirement for all detector-strobe triggers can have biases from the recovery time of the various discriminators that are set for each of the subsystems. To check this, the range of time of activity in the Cerenkov counters was varied. Recall that the analysis removes events if there was accidental Cerenkov activity from -60 to +60 ns from tk. The early time range was varied in the next study, and summarized in **Table 5**. (The accidental target CCD activity veto remained fixed at -50 to +60ns. The strobe time into the target CCD crates does not allow us to remove earlier hits.)

Veto if Cerenkov activity is in range (km21 data set)	Reciprocal lifetime	Relative error (%)	Number events (km21)	Reciprocal lifetime on events cut from previous row
-60 to +60	.08087+-.000140	.17	981496	
-90 to +60	.08140+-.000157	.19	783996	.07883+-.00030
-120 to +60	.08147+-.000177	.22	616088	.08110+-.00034
-140 to +60	.08114+-.000200	.25	483221	.08269+-.00038

Table 5. Lifetime fit of tk-tpi from 5 to 45 ns as a function of times of accidental Cerenkov activity.

This indicates that the lifetime calculation from the km21 data set has approached a stable value when one blocks out very early accidental activity. The range of the Cerenkov CCD data extends to ~-140ns for most of the data, so we can go no further in removing very early accidentals. For pnn1or2, cut from -140 to +60, the reciprocal lifetime was .07975+-.00040; for the kp21 data set, also cut from -140 to +60, the reciprocal lifetime was .08105+-.00038.

A few tests of stability of the lifetime calculation (events with accidental Cerenkov hits from -120 to +60 ns are eliminated, as well as events with extra target CCD energy>5 MeV) is found in **Table 6**.

Data set	Range of fit (ns)	Reciprocal lifetime	Chisq/df	Constant bkg
Km21	5 – 45	.08147+-.000177	138/79	-
Km21	5 – 25	.08149+-.000334	95/39	-
Km21	25 – 45	.08131+-.000432	45/39	-
Km21	5 – 49	.08141+-.000167	145/87	-
Km21	5 – 45, +const bkg	.08144+-.000454	138/79	-1.3 +-17.3
Km21	5 – 49, +const bkg	.08158+-.000373	144/87	+6.4+-12.2
Km21	5 – 45 kmu2 ptot	.08149+-.000180	139/79	-
Kp21	5 – 45	.08111+-.000342	81/79	-
Kp21	5 – 45 kp2 ptot	.08182+-.00044	63/79	-
Kp21	5 – 45 kmu2 ptot	.08042+-.00057	88/79	-
Pnn1or2	5 – 45	.07973+-.00036	93/79	-
Pnn1or2	5 – 45 kp2 ptot	.08246+-.00065	73/79	-
Pnn1or2	5 – 45 kmu2 ptot	.07820+-.00048	91/79	-

In this table, we note that the pnn1or2 data set gives a lifetime that is 2.2+-.5% different than that from the km21 data set. The pnn1or2 data also has a poor chisq/df as a function of ptot (42.4/5df), and the lifetime at the kp2 and km2 peaks differ by 5.4+-1.0%. It is interesting to note in the kp21 data set, the kp2 and km2 peaks differ by 1.7+-0.9%. This taken on its own is not significant; but because it is in the same direction as that seen in the pnn1or2 data set, it may indicate that there is some systematic effect not yet studied.

Summary, Conclusions, and Next Steps

It is encouraging that the K^+ lifetime measurement as seen in the km21 data set appears to be approaching stability with a statistical precision of 0.2%. Additional systematic checks are needed. Indications that there may be significant systematic effects are: a) the poor chisq/df; b) the nagging problem that the pnn1or2 results are different from that in the km21 at the ~2% level; c) and the overall issue of possible absolute time calibration and differential non-linearity of the CCD times. It is possible that differential non-linearity could be the cause of the poor chisq/df. The effects from high average detector rates are considerably reduced by the imposition of cuts on accidental coincidences in the Cerenkov counters and extra target energy in the CCD system. However, these are costly in terms of acceptance (<20% survive).

Following are some suggestions for a next pass at the data: a) change TDCUNP to eliminate the slewing correction; b) remove the adc threshold check on ccd pulses; c) save all target and Cerenkov counter TDC hits, in addition to the CCD hits; d) save b0, wire-chamber, AD hits (not just those that are near beam time or detector time e) rationalize the bin size for all ntuple times. The first several of these suggestions address the problem caused by the short ADC gate which builds in a time-bias, and adds the TDC system to check the CCD system. The KBEAM and B0 trigger sets need to be analyzed; for these data sets, the analysis must create its own detector strobe time for the range stack and UTC analysis, since none was required in the trigger. We may also wish to make a version of SWATHCCD that does not use the ADCs in any way (except, perhaps for the kaons near t=0), which would use the CCD energy only. A more ambitious and speculative analysis can be conducted by using the accidental kaons that arrive AFTER the detector-strobe. (The entire data set could be used, including the pnn1or2 triggers.) Using the TDC and CCD information in the target, one can analyze the RS and UTC by feeding in a fake detector strobe to match the pion time in the target (This analysis would begin with Benji's TGRECON program or the like, get times for the possible kaon and the pion, and then use those times to force the analysis to use these as the beam and detector strobe times. These times would feed back to the UTC reconstruction, and then SWATHCCD could be used, in principle.)

If we can get future running time, I would propose a low incident kaon rate (~10^4/sec) that can be varied; a deliberately high level of 93 MHz RF structure of the beam; a time-in-spill clock with good resolution fed by the AGS; a Ck trigger and a random trigger; deliberate variation of the strobe time into the CCDs; deliberate change in the target gains. With a tuned-up detector, less than 1 week of beam time should get us to the level of ~0.1% on the K^+ lifetime.