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An Experiment Studying $K_L - K_S$ Interference to Test CPT Conservation at the Planck Scale

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Abstract

We have begun planning for a Fermilab Main Injector experiment designed to maximize the interference between K_L and K_S mesons near their production target. This situation would allow a program of K_S and interference experiments to be performed. Of the many accessible physics topics, one of the most interesting is a test of CPT symmetry conservation sensitive to the Planck scale. In this report we describe that test. The experiment will use an RF-separated K^+ beam striking a target at the entrance to a hyperon magnet to make the K^0 beam by charge exchange. The decay region and magnetic spectrometer follow immediately to observe interference between K_L^0 and K_S^0 near the target. We describe in this report a measurement of the difference in phase between η_{+-} and ϵ, which is sensitive to CPT violation at the Planck scale. The measurement of several previously unmeasured (or poorly measured) CP violation parameters, and of the branching ratios of rare K_S decays will also be possible in this experiment.

Proposal Gift AAF 1894

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I. INTRODUCTION

We have begun planning for a Fermilab Main Injector experiment to test CPT symmetry conservation, study CP violation, and study rare decays of the K_S meson. Our goal is to design the optimal experiment to study interference between K_L and K_S mesons near the production target. We have chosen to make our neutral kaon beam from a K^+ beam by charge exchange because then the dilution factor is 1, its largest possible value. The dilution factor, $D = (K^0 - \overline{K}^0)/(K^0 + \overline{K}^0)$, multiplies the interference term between K_L and K_S. In a regenerator experiment the role of the dilution factor is taken by the regeneration amplitude which, by comparison, is about 0.1 at Main Injector energies. We use a hyperon magnet (a thinner version of the magnet in the Fermilab Proton Center beam line) to define the neutral beam and get as close to the target as possible. This "closed geometry" method of beam definition is excellent for handling high rates and collecting large amounts of data. The detector consists of a standard Vee spectrometer and an electromagnetic calorimeter.

The result of this design is an experimental arrangement that makes possible a program of measurements in this area. A rich harvest of Ph. D. theses would result from this program, a very different situation from experiments measuring only one number.

Of all the physics topics accessible to this experiment, we choose in this report to concentrate on only one: searching for CPT symmetry violation with sensitivity at the Planck scale. A preliminary version of a growing list of other physics topics is included.

The RF separated K^+ beam described below will be useful for other experiments as well. An experiment searching for the rare decay $K^+ \rightarrow \pi^+ \nu \overline{\nu}$ would find it ideal. The experiment proposed by P. Cooper, R. Tschirhart, M. Crisler, and J. Ritchie needs only 1/10 of the intensity that can be achieved with our design. In addition, with a few modifications, the K^+ beam could be turned into a $\overline{p}$ beam, making other types of experiments possible.

II. THEORY

The CPT theorem is based on the assumptions of locality, Lorentz invariance, the spin-statistics theorem, and the assumption of asymptotically free wave functions. All quantum field theories (including the standard model of the elementary particles) obey CPT symmetry invariance. The $K^0 - \overline{K}^0$ system is a natural place to search for CPT symmetry violation since it exhibits C, P, and CP symmetry violation (and is the only place to date where CP violation has been seen). In the final analysis, the conservation or violation of CPT symmetry is an experimental question, and the search for this effect is of the utmost interest.

There is a theoretical hint of the level at which CPT symmetry might be violated. This comes from the fact that gravity can't be included in quantum field theory. Many physicists think that there must be a more general theory that has quantum field theory embedded in it. In this more general theory CPT symmetry may be violated.

One expects to see effects of quantum gravity at what is called the Planck scale: at energies of $M_{Planck}c^2 = \sqrt{\hbar c^5/G} = 1.2 \times 10^{19}$ GeV, or at distances of the order of 10^{-33} cm. Since it is hard to see such effects in ordinary processes, one would look in a place where quantum field theories predict a null effect, then if something is observed it could be ascribed to quantum gravity. Therefore, it would be very interesting to test CPT symmetry conservation at the Planck scale.

In K^0 physics, one can observe CPT violating effects through mixing or decays (called indirect or direct CPT violation). In mixing, one introduces a parameter Δ which is both CP and CPT violating:

$$\begin{cases} K_S = K_1 + (\epsilon + \Delta)K_2 \\ K_L = K_2 + (\epsilon - \Delta)K_1 \end{cases} \tag{1}$$

All CP violation seen to date has been through the $(\epsilon - \Delta)$ term of the K_L. One can also have direct CPT violation, for example in semileptonic decays, where an amplitude y_l is introduced that is CPT violating [1]:

$$\begin{cases} \langle \pi^- l^+ \nu | T | K^0 \rangle = F_l(1 - y_l) \\ \langle \pi^+ l^- \overline{\nu} | T | \overline{K^0} \rangle = F_l^*(1 + y_l^*) \end{cases} \tag{2}$$

There are several measurements that would signify CPT violation: a difference between the phase of ϵ and the phase of η_{+-}, a difference between the phases of η_{+-} and η_{00}, certain interference terms between K_L and K_S in semileptonic decays, or evidence for a non-zero Δ in the Bell-Steinberger relation. In this report we will concentrate on the first method, measuring the phase of η_{+-} and comparing it to the calculated value of the phase of ϵ.

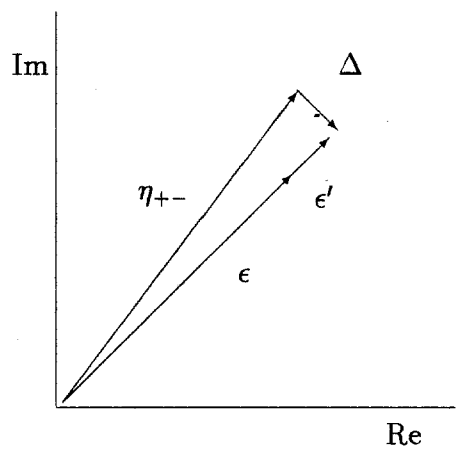


Fig. 1. The Wu-Yang Diagram

Fig. 1 shows the relationships between $\epsilon, \epsilon', \Delta$, and η_{+-}. ϵ' and Δ are shown greatly enlarged for clarity. The size of $|\epsilon'/\epsilon|$ is of order 10^{-4}, and the phase of ϵ' is very close to that of ϵ, so the phase of the vector $\epsilon + \epsilon'$ is the same, to good accuracy, to the phase of ϵ. We can see from the figure that the component of Δ perpendicular to ϵ, $\Delta_\perp$, is

$$\Delta_\perp = |\eta_{+-}|(\phi_{+-} - \phi_\epsilon) \tag{3}$$

where ϕ_{+-} (ϕ_ϵ) is the phase of $\eta_{+-}(\epsilon)$. In general, in terms of the elements of the kaon decay matrix Γ and mass matrix M, Δ is given by [2]:

$$\Delta = \frac{(\Gamma_{11} - \Gamma_{22}) + i(M_{11} - M_{22})}{(\Gamma_S - \Gamma_L) + 2i(M_L - M_S)} \tag{4}$$

The mass term has a phase perpendicular to ϵ and the decay term is parallel to ϵ. We can solve Eqns. 3 and 4 for $M_{11} - M_{22}$, which is the mass difference between the K^0 and $\overline{K^0}$ mesons:

$$\frac{|M_{K^0} - M_{\overline{K^0}}|}{M_{K^0}} = \frac{2(M_L - M_S)}{M_{K^0}} \frac{|\eta_{+-}|}{\sin\phi_{SW}} |\phi_{+-} - \phi_\epsilon| \tag{5}$$

where $\tan\phi_{SW} = 2(M_L - M_S)/(\Gamma_S - \Gamma_L)$.

In Eqn. 5, $(M_L - M_S)$ is 10^{-6} eV, and when one divides by M_{K^0} the ratio is of order 10^{-15}. $|\eta_{+-}|$ is of order 10^{-3}. **These factors let us approach the Planck scale at current accelerator energies.**

One might think that string theory, as a candidate for the more general theory that has quantum field theory embedded in it, would give us guidance. G. Veneziano built CPT conservation into the first string theory, and in mainstream string theory it is still there: conventional string theory is CPT conserving to all orders of perturbation theory [3]. Kostelecky and Potting [4] wrote down a string-like theory with spontaneous CPT violation, and found that the largest CPT violating effect was a change in quark propagators that had the opposite sign for antiquarks. This led to a nonzero value of $|M_{K^0} - M_{\overline{K^0}}|$ coming from indirect CPT violation, with $\Delta \perp \epsilon$. This is exactly the signature that a measurement of $|\phi_{+-} - \phi_\epsilon|$ would search for.

There have also been speculations about the violation of quantum mechanics leading to CPT violating effects that would be seen in the $K^0 - \overline{K^0}$ system. J. Ellis **et al.** [5] introduced three new CPT violating parameters, α, β, and γ, describing this effect. In a recent analysis [6], Huet pointed out that measurements of the magnitude and phase of η_{+-} and of the semileptonic charge asymmetry would be able to separately measure the three parameters. The experiment we will describe in this report would be the world's most sensitive in this area.

Some of the present authors (SRS, SVS, and GBT) were part of Fermilab experiment E773. In this experiment we placed the limit (at 90% confidence level) [7],

$$\frac{|M_{K^0} - M_{\overline{K^0}}|}{M_{K^0}} < 1.3 \times 10^{-18} \tag{6}$$

By the Planck scale we mean

$$\frac{|M_{K^0} - M_{\overline{K^0}}|}{M_{K^0}} = \frac{M_{K^0}}{M_{Planck}} = 4.1 \times 10^{-20} \tag{7}$$

so the result of Ref. 7 stands at 31 times the Planck scale.

In the KTeV experiment we expect to make an improvement of a factor of 3 to 5. But the interference term from which ϕ_{+-} is measured, $2|\eta_{+-}||\rho|\cos(\Delta mt + \phi_\rho - \phi_{+-})\exp(-t/2\tau_s)$, is reduced by the regeneration amplitude $|\rho| \simeq 0.03$, and ϕ_{+-} and ϕ_ρ are hard to disentangle. Using the regeneration method will be difficult beyond the KTeV level.

III. THE EXPERIMENT

A. General Description

After the KTeV experiment we expect to stand a factor of 6 to 10 above the Planck scale. To close that gap we will want to do an interference experiment near the kaon production target. The interference term is then $2D|\eta_{+-}|\cos(\Delta mt - \phi_{+-})\exp(-t/2\tau_s)$. Here ϕ_{+-} appears alone, and $|\rho|$ is replaced with the dilution factor, $D = (K^0 - \overline{K}^0)/(K^0 + \overline{K}^0)$ at the target. To maximize D and hence the interference, we choose to make our K^0 beam from a K^+ beam by charge exchange. Then at medium to high Feynman x, $D \simeq 1$. The charge exchange cross section is large, about 20% of the total cross section. To maximize the flux of K^+ made from the 120 GeV/c protons from the Fermilab Main Injector we choose a K^+ momentum of 25 GeV/c. We would use a hyperon magnet to define the K^0 beam, similar to the one in the Proton Center beam line. In the calculations described below we will assume the use of elements of the KTeV spectrometer.

In Ref. 7 we measured ϕ_{+-} to 1 degree accuracy. To reach the Planck scale we must achieve 0.03 degree accuracy.

In what follows we will calculate the statistical sensitivity of the experiment, estimate some of the systematic uncertainties, describe an RF separated K^+ beam, a possible design for a collimator in the hyperon magnet, and estimate singles rates and trigger rates.

B. Sensitivity of the Experiment

In this experiment we measure ϕ_{+-}, but we must calculate ϕ_ϵ. We first describe some corrections to this calculation.

Assuming CPT invariance, the phase of ϵ' is known to be (48 ± 4) degrees [8]. Its magnitude is unknown, but if we assume it to be the central value from E731 we find that the maximum possible change of ϕ_ϵ from this source is 0.003 degrees, an order of magnitude smaller than the contribution of CPT violation at the Planck scale.

The full formula for ϕ_ϵ is

$$\tan\phi_\epsilon = \frac{2\Delta m}{\Gamma_S - \Gamma_L}\cos\xi + \frac{\sin\xi}{\delta} \tag{8}$$

where $\xi = \arg(\Gamma_{12}A_0\overline{A}_0{}^*)$ and $\delta = 2Re(\epsilon)$. Here A_0 is the isospin 0 part of the $\pi^+\pi^-$ decay amplitude. In the Wu-Yang phase convention, A_0 is real, and Γ_{12} gives contributions from two sources: semileptonic decays through $Im(x)$, the $\Delta S = \Delta Q$ violation parameter, and 3π decays through $Im(\eta_{+-0})$ and $Im(\eta_{000})$.

In the standard model we expect $x \simeq 10^{-7}$, which is much smaller than we need worry about, but $Im(x)$ is known experimentally only to an accuracy of ± 0.026. This results in an uncertainty in ϕ_ϵ of 1.7 degrees. To prove that an observed difference between ϕ_{+-} and ϕ_ϵ were due to CPT violation one would have to measure $Im(x)$ about 50 times more accurately than today's level. The way to do this is described below.

The contribution to ϕ_ϵ from the 3π modes in the standard model is 0.017 degrees, which is about 1/2 of the contribution of CPT violation at the Planck scale. But if one takes into account the current world's knowledge, the uncertainty these decay modes contribute is 2.2 degrees. So they have to be measured better also.

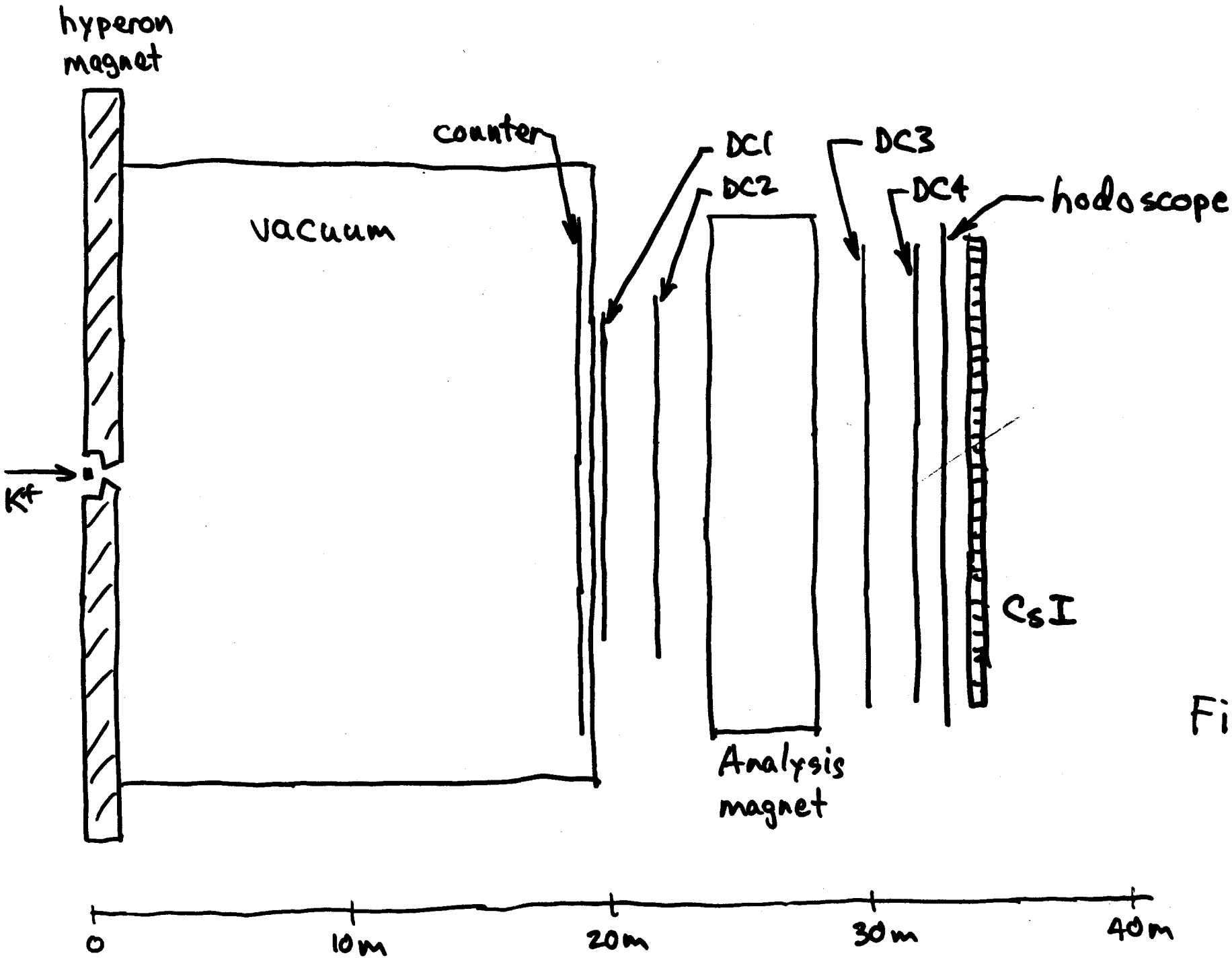
The experimental approach to measuring these three quantities, x, η_{+-0}, and η_{000}, is the same. One would choose an experiment with high dilution factor and observe interference between K_L and K_S close to the target; i.e. the experiment described here. So these measurements should be thought of as being an important part of this experiment. We have

not had time to perform a complete calculation of the sensitivity of this experiment for these quantities, but we estimate that we can reach at least the required sensitivity. We conclude for now that we can calculate ϕ_ϵ to the required accuracy.

We have calculated the statistical sensitivity of the experiment making the following assumptions:

- A beam of $2 \times 10^8 K^+$ per spill, striking a 10 cm tungsten target at 9 mrad, for 1×10^7 seconds, with the spill structure of the Fermilab Main Injector.
- The measured charge exchange cross sections.
- A solid angle of 36 μster for the K^0 beam, the same as in beams described in the KAMI Design Report.
- A hyperon magnet 1.3 meters thick.
- A decay region 17.3 meters long, followed by elements of the KTeV spectrometer. Fig. 2 shows the hyperon magnet, decay region, and spectrometer.

We calculated the acceptance using a Monte Carlo program. Fig. 3 shows the momentum spectrum of kaons exiting from the target, and of K_S and K_L decaying in the decay region. Fig. 4 shows the proper time distribution of the events. The figure shows the actual proper time distribution and also what the distribution would look like if there were no interference. The second part of the figure shows the ratio of those two curves. Between 5 and 20 K_S lifetimes the interference is first a 40% destructive effect then is a 65% constructive effect. We calculated the distribution of events in momentum and proper time for the resulting 11 billion events. We fit this distribution using MINUIT. The fitting parameters were $|\eta_{+-}|, \phi_{+-}, D$, and a normalization constant. The uncertainty in ϕ_{+-} was 0.02 degrees. This is 50% better than what is needed to place a 90% confidence limit on CPT symmetry violation at the Planck scale.


hyperon magnet
counter
DC1
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K^+
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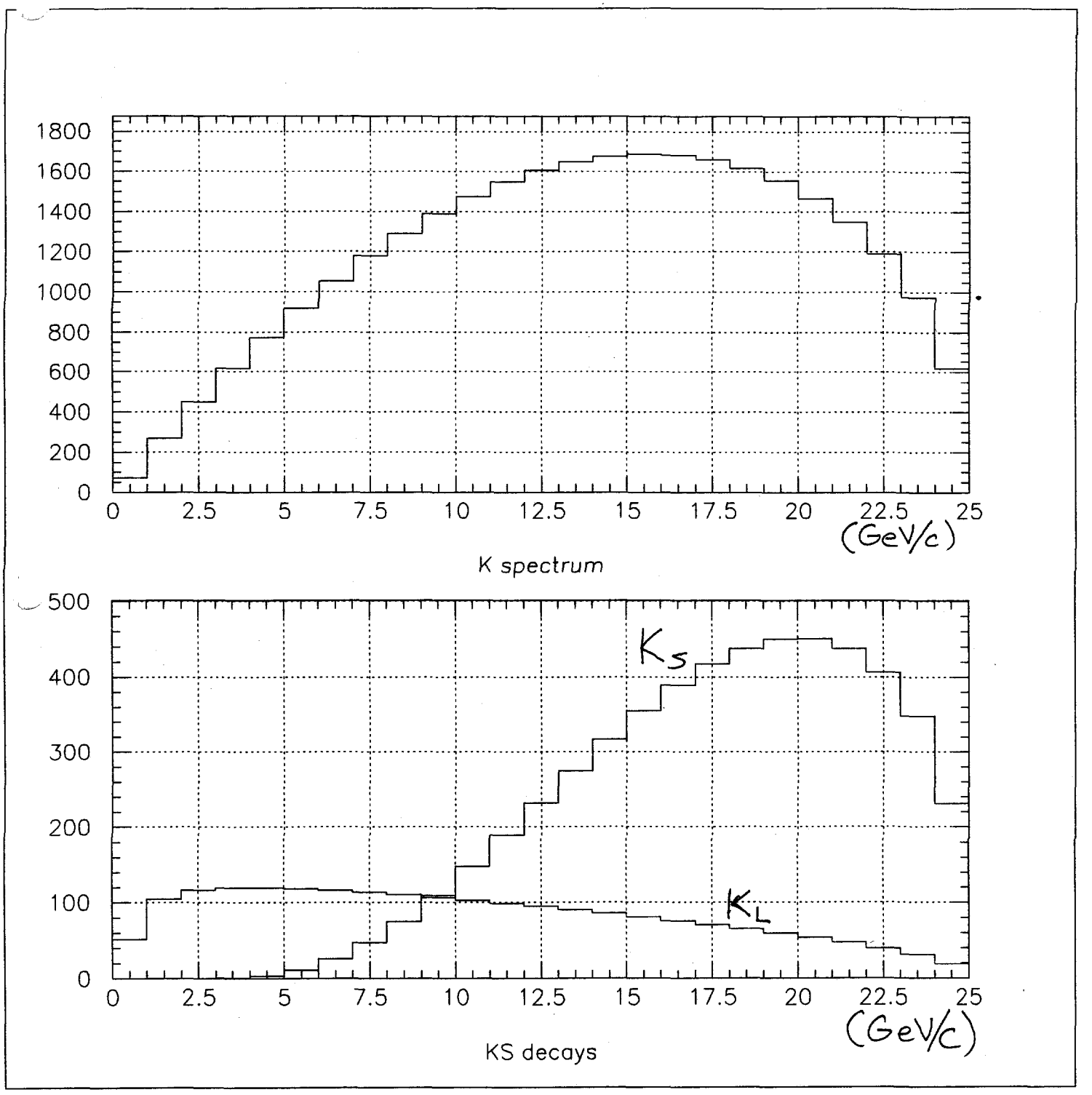
Fig. 2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(GeV/c)
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200
100
0
K_S
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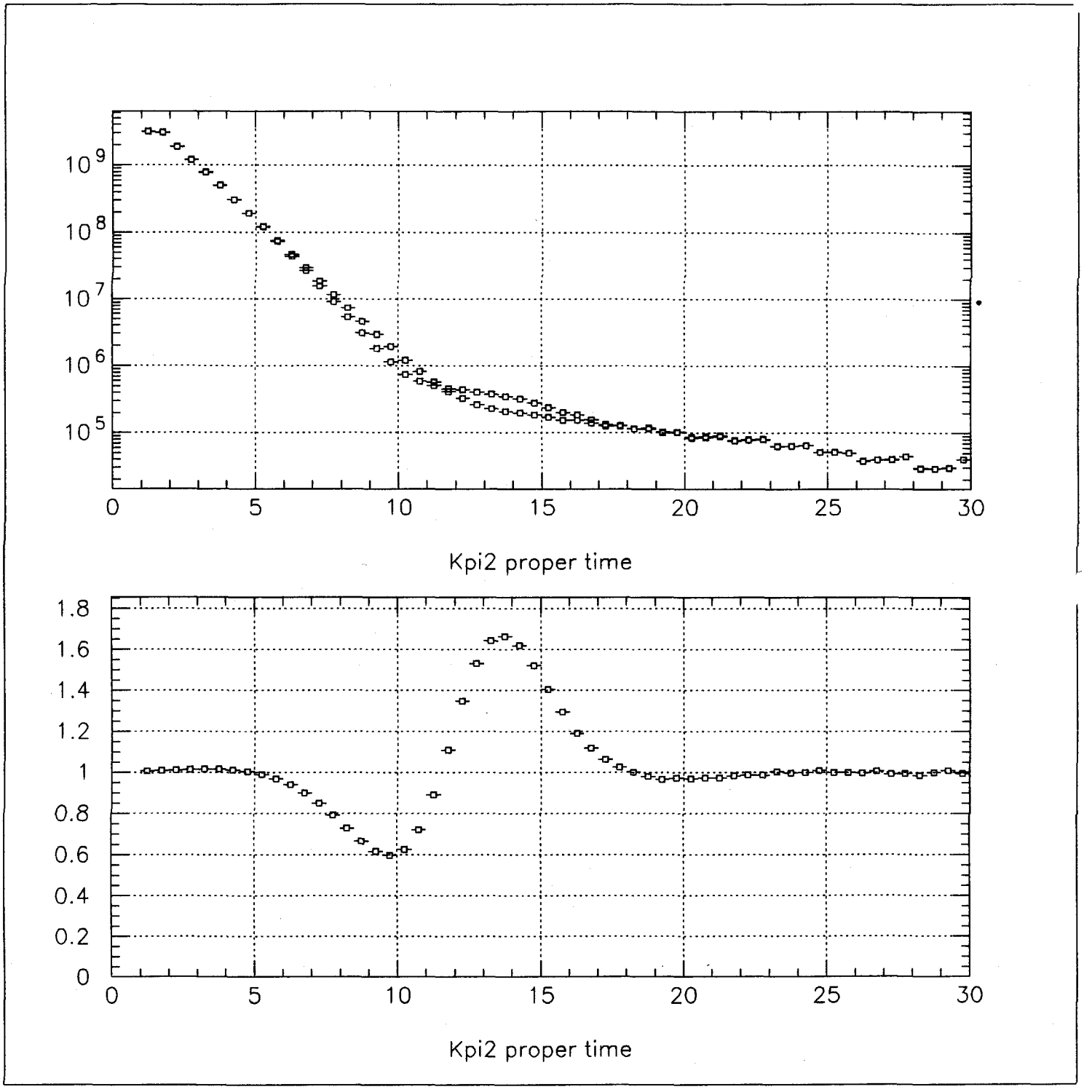
KS decays

Fig. 3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Kpi2 proper time
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0.2
0
0
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30
Kpi2 proper time

Fig. 4

C. Systematic Uncertainties

We have estimated some of the systematic uncertainties we will have to confront in this experiment.

To deal with the possible background due to semileptonic decays, particularly K_{e3}'s, we have calculated that we must correct for this effect to the 0.1% level. This is less stringent than the 0.02% level that will be achieved in the KTeV experiment. However the differences in particle momenta and in distance from target to decay vertex are big enough that we must perform a more complete calculation of detector resolution to confirm this simple scaling. We plan to perform this calculation soon.

The accuracy with which one must know the acceptance is an important parameter of the experiment. We estimate that 0.1% knowledge is required. This is also a less stringent requirement than we expect to achieve in the KTeV experiment. Here also we will be performing more detailed calculations soon.

If the phase of η_{+-} were to change by 0.03 degrees, the interference term would shift in space, for the average momentum kaon, by a distance of 1 mm. We must know the decay point and t=0 point (on the average) to better than this distance. For the decay point, we estimate that we can determine drift chamber wire positions to 0.2 mm, as well as measuring the location of the center of the target to that accuracy. We are helped in this area by the fact that the incoming K^+ and outgoing K^0 are being absorbed in the target with the same cross section, making the center of the target the average production point. But one wonders, at this level, if scattering of the K^0's in the target could contribute to a change of the average production point. To test this we wrote a Monte Carlo program that follows individual K^+ mesons through the target, produces K^0's through charge exchange, and allows the K^0's to scatter elastically. The outgoing K^0 then has a different energy than when it was produced, so when we observe it and calculate the production point as the center of the target we are making a small error. In performing this Monte Carlo calculation we learned that there is a solid angle effect which moves the average production point downstream by 0.9 mm, but

that the scattering effect we were concerned with is only an 0.3 mm effect. It is clear that we must understand the size and divergence of the beam to good accuracy to be able to perform this experiment. Measurements of these quantities must be part of our experiment. Running with two different target thicknesses would provide a good test of our target-length correction calculation.

One parameter that is a factor in the interference term and is unknown is the dilution factor, D, and we must measure it. In our fits to the simulated $K_{\pi 2}$ data we have included a parameterization for D, and have found that the fit picks out the correct value for the parameter, and that the correlation between it and ϕ_{+-} is very low, only 0.6%. So measuring D should be possible. One can also do it using K_{e3} decays.

D. K^+ Beam Design

One of us (J. D.) designed an RF separated K^+ beam for the TRIUMF KAON accelerator [9], and has modified his design for the present experiment's needs. Our design has C-band RF cavities, operating at 5.79710 GHz to perform the separation. In the past S-band cavities have been used successfully to make K^+ beams, both at BNL and at the Argonne ZGS, and a separated K+ beam using C-band cavities was once planned at CERN.

In general, the way the RF separation works is that the first cavity imposes a transverse momentum kick on the beam of 5 MeV/c per meter of cavity length, creating a waving-fan of particles exiting from it. The second RF cavity is located 75 m downstream, and in between is a system of quadrupoles with a transformation matrix of (-1). The phase of the second cavity is tuned so π^+ mesons arrive with the same phase that they had in the first cavity. Since the quadrupoles have reversed the π^+ momenta and they get the same kick from the second cavity, the π^+ end up with no net kick. With this design choice of RF frequency and distance between the cavities, π^+ and protons are 360 degrees out of phase at the second cavity, so protons also receive no net kick. K^+ mesons are 90 degrees out of phase from the π^+ so they get a net bend of 1.2 mrad in our design. A beam plug downstream of the second

cavity destroys the π^+ and protons, and passes most of the K^+. So our design separates K^+ from both π^+ and protons. We choose the direction of the RF cavities' kick to be vertical to decouple from the momentum selection, which is in the horizontal direction.

Fig. 5 shows the beam elements and size in x and y, as a function of z. The first quad triplet collects the K^+'s and focuses them at horizontal focus HF1. Magnet B1 performs the momentum analysis. The momentum slits and proton dump are located at HF1. Bending magnet B2 has equal but opposite field from B1 to keep the beam approximately straight to fit in Fermilab tunnels. With the first three quad triplets the large y' acceptance is transformed into a small divergence (0.6 mrad) so the 1.2 mrad kick of the RF cavities dominates the particles' angles. They also focus the beam at RF1, the first RF cavity. Two (-1) matrix quadrupole strings follow which give a net (+1) transformation, and the second RF cavity (RF2) is actually run at opposite phase (for pions) from the first. The quad triplet after RF2 focuses the beam on the stopper, and after that the beam is cleaned up with bending magnets and focused on the K^0 production target.

This is a highly symmetric design which minimizes higher order aberrations. Using the TRIUMF Monte Carlo program REVMOC, which has been tested to give identical results to DECAY TURTLE, we calculated the acceptance of the beam, taking into account kaon decays. Fig. 6 shows the y coordinate of pions and kaons at the location of the stopper. It can be seen from the figure that the physical size of the stopper should be about 15 mm, and that about half of the kaons are transported past it. With 5×10^{12} protons per pulse at 120 GeV/c striking the target at 0 mrad, we got a flux of 3.4×10^8 kaons per pulse, more than the assumption of 2×10^8 we made in our statistical significance calculation. In building such a beam one would want to have an safety factor of 2 or so on paper, and this design gives it.

There are two aspects of this beam which we have not yet had time to give serious thought to. One is the dump for the proton beam, but it should fit easily in the area around HF1. The other, and more important, is the final focus at the target in the hyperon magnet. We will be doing this soon. With the exception of these two questions, we want to emphasize

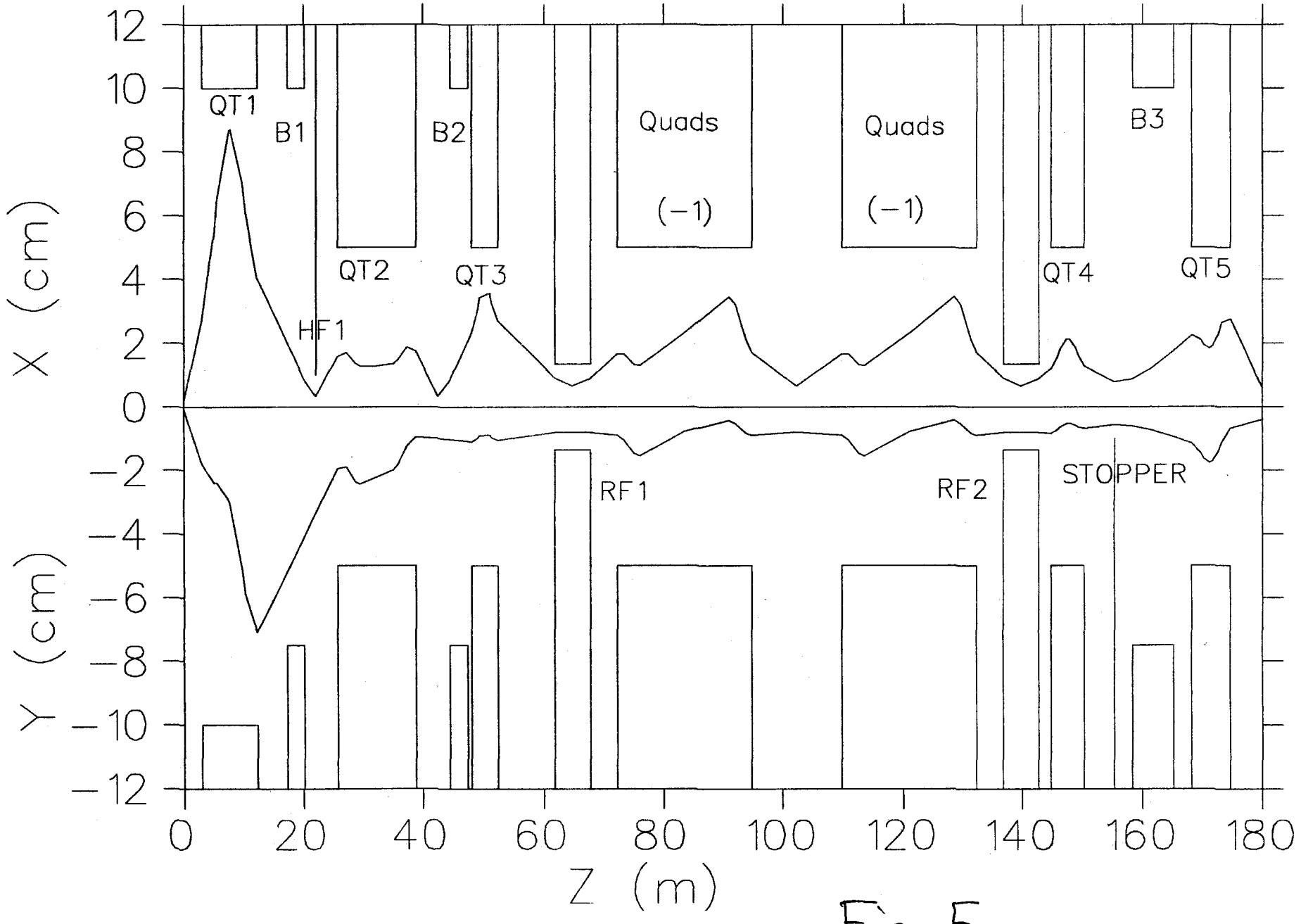
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Fig. 5

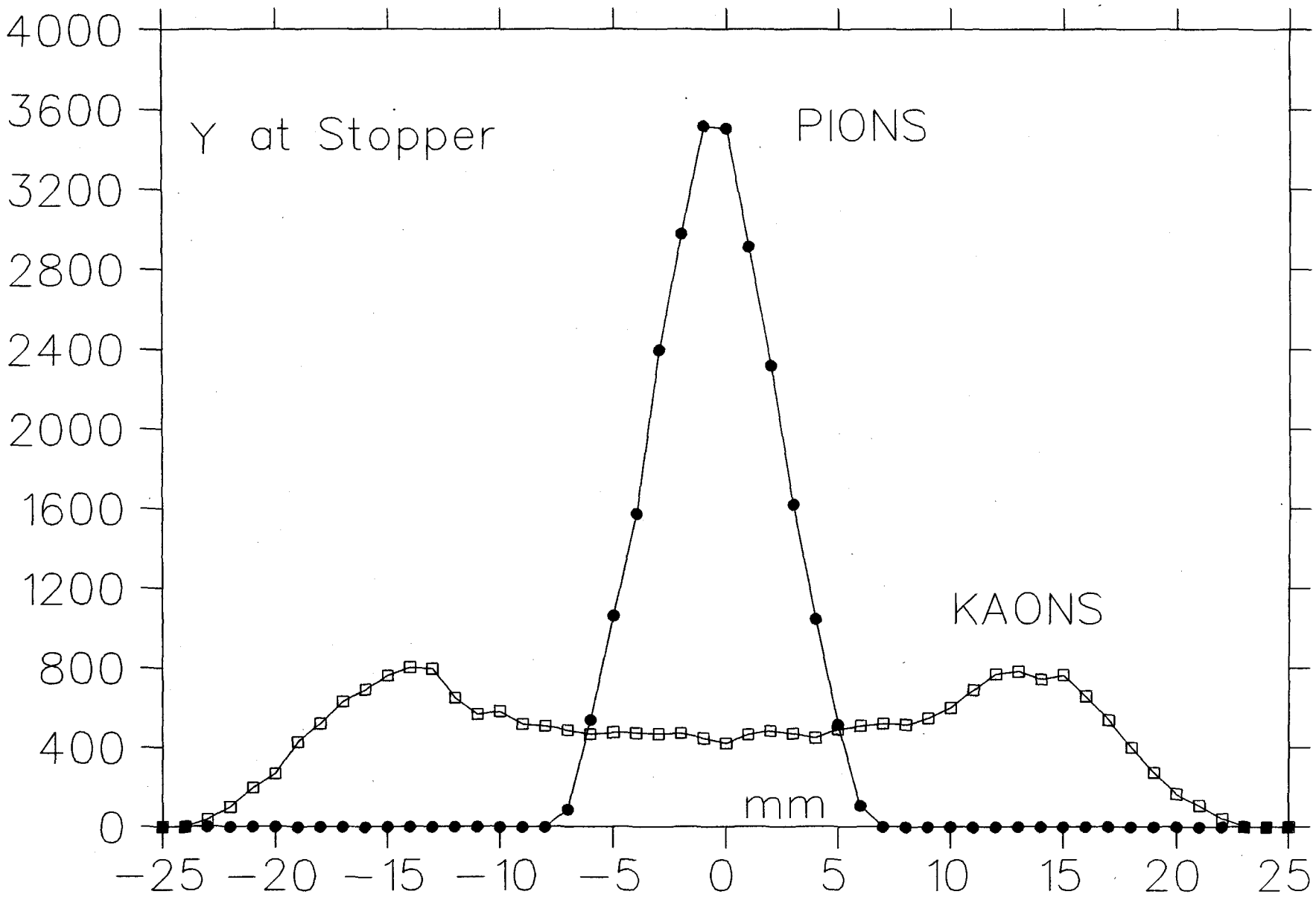
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Fig. 6

that the beam design is substantially in its final form.

E. Hyperon Magnet Design

For the hyperon magnet, which cleans up the region where the K^+ beam strikes the K^0 production target, we have chosen a design similar to that of the working hyperon magnet now in the Fermilab Proton Center beam. This conventional magnet uses tapered pole pieces to make a 35 kGauss field in its central region. A plan view of the collimator in this magnet is shown in Fig. 7. The K^+ beam strikes a 10 cm tungsten target, and follows the path shown to be destroyed in the collimator. Neutral particles follow the straight path shown to form the beam. While this design is not final, it is one that would do the job, as shown below.

F. Rates and Triggering

Using the hyperon magnet design shown above we have performed a GEANT calculation of resulting beam and particle intensities. First, GEANT reproduces the kaon flux described above in our subsection on the sensitivity of the experiment. We calculated the rates in the first drift chamber, which is the detector that will be exposed to the largest particle flux. With 2×10^8 K^+/second the first drift chamber will see 560 kHz of charged particles, approximately evenly distributed over its face (which adds up to less than 1 Hz per centimeter of sense wire). This rate is considerably lower than that expected in KTeV. In addition there is 1.4 MHz of γ-rays, most less than 10 MeV, striking it in the beam region. These are the remnants of electromagnetic showers in the high-Z target. Taking account of the material in the front end of the spectrometer, this leads to 8 kHz of conversions, or 75 Hz per centimeter of sense wire. This is much less than the space charge limit of 20 kHz per centimeter of sense wire. Both the charged particle and the γ-ray rates will be improved as we perform more fine-tuning on the hyperon magnet collimator design.

D. Hyperon magnet

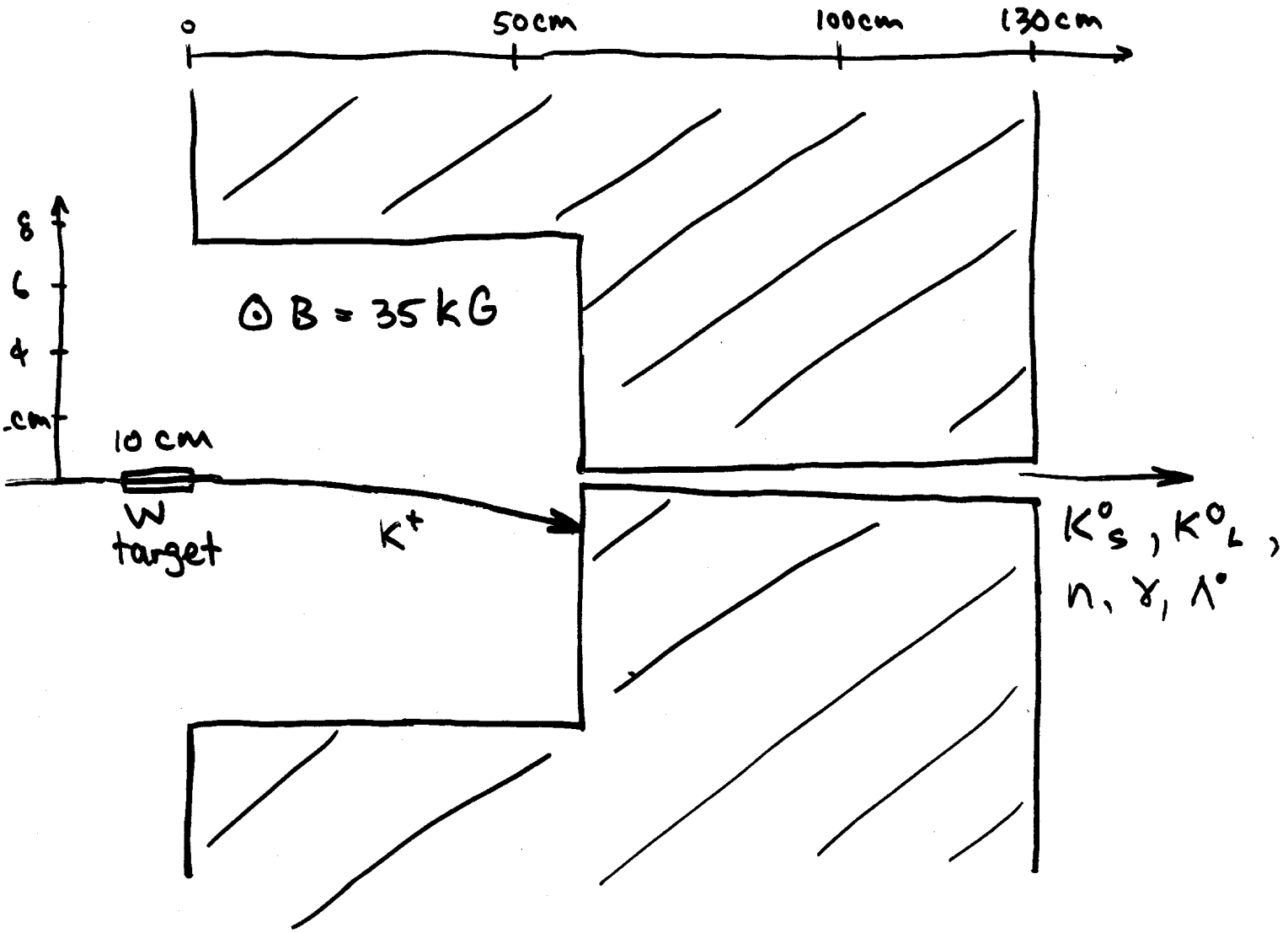

Fig. 7

The neutron/K_L ratio is 1.8 (with average neutron momentum about 1 GeV/c), about 3 times better than KTeV. The Λ/K_S ratio is 0.1 (with average Λ momentum of 3 GeV/c), which is much lower than previous K_S experiments at Fermilab.

At these low rates the correct strategy would be to trigger on all 2-track events. This would result in 3.4 kHz of $K_{\pi 2}$ events per spill, and a data volume of about 2 MBytes/second. Again using KTeV for comparison, this is 1/10 of its capabilities. We must add about 10% for Λ's, 30% for K_L decays, and perhaps 30% more for triggers that do not reconstruct into good Vees.

This leads to a serious problem. **The rates are too low.**

If we increase the proton beam intensity by a factor of 4, to 2×10^{13} protons per pulse (the Main Injector is expected to produce 3×10^{13}), all rates would still be less than those expected for KTeV, and the 12 months of data collection time would become only 3 months. This would be an important running consideration.

It was suggested to us by Gaston Gutierrez of Fermilab that if the Main Injector protons could be bunched at the C-band RF frequency we could gain up to a factor of 3 in K^+ intensity per proton, due to fewer K^+'s striking the beam stopper and in being able to shorten the beam and have fewer K^+ decays. We have approached Steve Holmes, the head of the Fermilab Main Injector project to see if this is possible. If so it would make a big difference in Fermilab proton economics.

IV. PLANS FOR THE FUTURE

There are several aspects of the $\phi_{+-} - \phi_\epsilon$ measurement that could use more work. Matching the K^+ beam design to the needs of targeting at the hyperon magnet has yet to be done. Useful improvements could be made to our acceptance calculation, for example to resolve resolution questions in K_{e3} backgrounds, and to further investigate sources of systematic uncertainty.

Other CPT violation signals remain to be investigated.

- As we have excellent sensitivity to ϕ_{+-} we also will be able to measure ϕ_{00} very well. A nonzero difference between them is a signal of direct CPT violation.

- In the interference between K_L and K_S decays to $\pi e \nu$ and $\pi \mu \nu$ final states there are CPT violating terms proportional to $Re(\Delta)$ and $Im(\Delta)$ that we will search for.

- The Bell-Steinberger relation [10] is a statement of the conservation of probability in $K^0 - \overline{K}^0$ decays, in which, through Eq. 1, Δ appears. The biggest uncertainties [11] in the Bell-Steinberger relation at this time come from η_{000}, x (the $\Delta S = \Delta Q$ violation parameter), and δ_l (the charge asymmetry in K_L semileptonic decays). We will be able to make excellent measurements of these quantities. For the next level of accuracy in the Bell-Steinberger relation the uncertainties in $|\eta_{+-}|$ and $|\eta_{00}|$ must be improved. We will have good sensitivity for these measurements also.

In addition there are several other very interesting physics topics that we will be able to address in this experiment.

- Through our technique we should be able to measure η_{+-0} and η_{000}, which describe CP violation in K_S decays to three pions. These decays are expected to have contributions from direct CP violation on the order of 10%, and are the places where CP violating beyond-the-standard-model effects are largest.

- $\eta_{+-\gamma}$ describes CP violation in the radiative K_L decay, and has the biggest product of (difference from ϵ) $\times$ (branching ratio) of all K^0 decays. The world's data on this decay [12] stands within about a factor of 3 of finding this difference from ϵ. We should make a powerful measurement of $\eta_{+-\gamma}$.

- With 11 billion $\pi^+\pi^-$ events we should have good sensitivity for the CP conserving decay $K_S \rightarrow \pi^0 e^+ e^-$, which is expected to have a branching ratio between 5×10^{-10} and 5×10^{-9}. The branching ratio for this decay can be used to predict the indirect CP violation contribution to the branching ratio for the $K_L \rightarrow \pi^0 e^+ e^-$ decay. The

latter decay is one of the main candidates for finding direct CP violation in a rare K^0 decay.

- It is worth mentioning that an extension of this experiment with higher flux would be a good vehicle for finding direct CP violation in the $K_L \to \pi^0 e^+ e^-$ decay through $K_L - K_S$ interference. In this method the "Greenlee background" (the K_L radiative Dalitz decay) is not a problem as it is in a conventional K_L experiment.

V. CONCLUSION

We have described an experiment to search for CPT symmetry violation in the decays of K^0 mesons that has the sensitivity to reach the Planck scale. In addition the experiment will measure many other topics in kaon physics as well, including CP violation parameters never measured before, and rare kaon decays. Perhaps the best way to describe the experiment is as a systematic program of experiments in $K_S - K_L$ interference physics.

Our design uses protons from the Fermilab Main Injector to make an RF separated K^+ beam. With this we make a tertiary neutral kaon beam created in just the way to maximize the interference between K_S and K_L while maintaining high flux. We use a "closed geometry" hyperon magnet for beam definition. A standard Vee spectrometer, with drift chambers and an electromagnetic calorimeter, is used to make the measurement.

It is worth considering one alternative to this design, the KLOE experiment at the Frascati DAΦNE Φ factory. This is an "open geometry" experiment limited by e^+e^- beam luminosity. They expect to achieve a sensitivity to the fractional $K^0 - \overline{K}^0$ mass difference 30 times worse than what is proposed here [13].

The purpose of this progress report is to summarize work we have been doing at Rutgers and TRIUMF on this experiment. Our plans are to continue this work and write a proposal to Fermilab to carry out this experiment.

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