NAL PROPOSAL No. 60

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VERY HIGH ENERGY K°_{L} EXPERIMENTS AT NAL

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Abstract

This is a proposal to do four experiments. Several can be run simultaneously. The experiments are:

Experiment A is to simultaneously check both of the predictions of the Pomeranchuk theorem that either the total cross sections for particles and anti-particles approach the same constant at very high energies, or that the ratio of the real to imaginary amplitudes should increase as ln(E). The measurement consists of two parts; determining the regeneration amplitude of $K_L^o + p \rightarrow K_S^o + p$ (in hydrogen) and also measuring the interference phase between the regenerated K_S^o decay to $\pi^+\pi^-$ and the CP-violating decay, $K_L^o \rightarrow \pi^+\pi^-$. The technique employs wire spark chambers, counter hodoscopes and a magnet.

Experiment B is to measure the diffraction regeneration in hydrogen by observing the recoil proton in coincidence with a decay $K_S^o \rightarrow \pi^+\pi^-$. The motivation is to study the t dependence of $d\sigma/dt$ as a function of s. The angle and range of the recoil proton will be measured in a combination of multiwire proportional counter and range hodoscopes.

Experiment C is to try to observe the electromagnetic regeneration $K_L^o + e \rightarrow K_S^o + e$ by directly measuring the recoil electrons in coincidence with the $K_S^o \rightarrow \pi^+\pi^-$ decays. It would be an attempt to check the theoretical predictions for this cross section which includes determining the charge radius associated with the transition.

Experiment D is to determine the K° spectrum and the neutron spectrum. The latter through the reaction $p + N \rightarrow p + N^*$ and $N^*(1470) \rightarrow \pi^- p$, using essentially the same geometry and targets and apparatus as in the above experiments.

The feasibility of carrying out these various measurements depends upon a collaboration with others. A simultaneous measurement of several quantities needs the same set up effort on the part of NAL and during the same running time additional experiments can be performed at NAL

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II. PHYSICS JUSTIFICATION

At the present time it is proposed to measure the following:

A) The interference of the coherent regeneration of K°_S from K°_L in hydrogen: This is a sensitive check on whether the total cross sections for particles and anti-particles are approaching the same value. It will also check the predictions of the Pomeranchuk theorem regarding the energy dependence of the ratio of the real to imaginary forward scattering amplitude.

B) The diffraction regeneration of K°_S from K°_L in hydrogen (if it exists): This is to study the s dependence of $d\sigma/dt$ as a function of t.

C) The forward recoil electrons (in coincidence with $K^\circ_S \rightarrow \pi^+\pi^-$) from the reaction $K^\circ_L + e \rightarrow K^\circ_S + e$. The motivation is to directly observe the reaction and to measure the (transition) charge radius of the K° mesons.

D) The K°_L flux and spectrum and the neutron spectrum.

Several of these measurements can be made simultaneously by using alternate triggering requirements, thus maximizing the use of the machine time. However additional special equipment is required for B, C. and D; the feasibility of such simultaneous measurements depends upon there being collaborators. The physics justification and method of measurement for each of the above is discussed below.

A. The Coherent Regeneration and Regeneration Phase for $K^\circ_L + p \rightarrow K^\circ_S + p$.

The recent Serpukhov data (Phys. Letters 30B, p. 300 (1969)) on K^-p total cross sections at high energies seems to show that they are approaching a constant. The K^+p data at lower energies seems to have already approached a constant and the two constants differ by about 2 to 3 millibarns. Our naive understanding of the Pomeranchuk theorem had led us to expect the two cross sections should become equal at very high energies; however, if one goes back to the basic Pomeranchuk theorem one finds there are three alternatives. They can be summarized as follows:

1) If the total cross section for K^+p and the total cross section for K^-p each approach a constant (C_{K^+} and C_{K^-}) as $s \to \infty$, and if the phase of the forward elastic scattering amplitude is constrained by

$$\frac{\mathrm{Re}\ f_o}{\ln E\ \ \mathrm{Im} f_o} \to 0 \qquad \text{as } E \to \infty$$

then the equality $C_{K^+} = C_{K^-}$ follows.

2) If the total cross sections for K^+p and K^-p increase with energy as $E \to \infty$, thenthe difference is not allowed to increase with energy (by unitarity) and either the cross sections approach each other or the ratio $\frac{\mathrm{Re}\ f_o}{\mathrm{Im}\ f_o}$ must increase with energy as $\ln E$

3) The total cross sections could oscillate indefinitely as $E \to \infty$, in which case nothing has yet been proven about their equality.

The regeneration in the reaction $K_L^o + p \to K_S^o + p$ is a direct measure of the differences of the forward scattering amplitudes and the imaginary part is therefore a direct measure of the differences of the particle and anti-particle total cross sections on protons. By studying the decay $K^o \to \pi^+\pi^-$ as a function of time following the regenerator, one can measure the interference between the regenerated K_S^o and the CP violating decay $K_L^o \to \pi^+\pi^-$ and thus determine the regeneration phase, ϕ_R. For a very thin sample,

$$\phi_R = \arctan \frac{\mathrm{Re}[f_o(K^o p) - \bar{f}_o(\bar{K}^o p)]}{\mathrm{Im}[f_o(K^o p) - \bar{f}_o(\bar{K}^o p)]}$$

where $f_o(K^o p)$ and $\bar{f}_o(\bar{K}^o p)$ are the forward scattering amplitudes ($t = 0$) for $K^o + p$ and $\bar{K}^o + p$ respectively.

Lorella Jones (private communication) has investigated the consequences of the Pomeranchuk theorem for regenerations experiments where one is measuring the differences of forward scattering amplitudes. She finds that the conditions on the differences of the forward scattering amplitudes are similar to those given above, namely in case 1) if the total cross sections approach the same constant, i.e. the regeneration cross section is approaching zero at high energies then

$$\frac{\mathrm{Re}[f_o - \bar{f}_o]}{\ln E \ \mathrm{Im}[f_o - \bar{f}_o]} \to 0 \quad \text{as } E \to \infty$$

In case 2), namely that the total cross sections K^+p and K^-p are both increasing with energy as $E \to \infty$ and the difference does not increase with energy, then

$$\frac{\mathrm{Re}[f_o - \bar{f}_o]}{\mathrm{Im}[f_o - \bar{f}_o]} \quad \text{increases with } \ln E.$$

Therefore it is important to determine the energy dependence of the regeneration phase as well as the regeneration at the highest energies possible. Even though cross sections may still differ, a determination of the energy dependence of the ratio of the real to imaginary parts would indicate which of the various alternatives of the Pomeranchuk theorem may exist in asymptopia.

We assume that the formalism for an interference regeneration experiment is well known and therefore we will only briefly state the expressions involved. The number of decays into $\pi^+\pi^-$ as a function of time (or distance) is given by the expression (neglecting background)

$$\text{Number of } \pi^+\pi^- =$$

$$|A(K_S^o) \to \pi^+\pi^-|^2 \left[|R|^2 e^{-\Gamma_S t} + 2|R||\eta_\pm| e^{-(\Gamma_S + \Gamma_L)t/2} \cos(\delta m t + \Delta\phi) + |\eta_\pm|^2 e^{-\Gamma_L t} \right].$$

where $A(K_S^o) \to \pi^+\pi^-$ is the decay amplitude of $K_S^o \to \pi^+\pi^-$, Γ_S and Γ_L are the decay constants for K_S^o and K_L^o respectively, $\eta_\pm$ is the CP-violation decay ratio of amplitudes:

$$|\eta_\pm| = \frac{A(K_L^o \to \pi^+\pi^-)}{A(K_S^o \to \pi^+\pi^-)} = 1.92 \times 10^{-3} \text{ and } \phi_{\eta_\pm} \simeq 43°$$

where $\delta m = m(K_L^o) - m(K_S^o) = 0.469\ \Gamma_s$, $\Delta\phi = \phi_R - \phi_{\eta_\pm}$, and $R = |R|e^{i\phi_R}$ is the regeneration amplitude

$$|R| \simeq \Lambda N \frac{\Delta\sigma_{eff}}{4} e^{-L/2\lambda} \left| \frac{e^{-L/2\Lambda} - e^{i\Delta kL}}{\frac{1}{2} - i\frac{\delta m}{\Gamma_S}} \right|$$

where Λ is the decay length in the laboratory for K_S° ($\simeq$ 5.5 meters for 100 BeV/c), N is the number of atoms/cm^3, L is the length of the sample, Λ is the interaction mean free path in the sample, and

$$\Delta\sigma_{eff} = \left| -i\frac{Re[f_o - \bar{f}_o]}{Im[f_o - \bar{f}_o]} + 1 \right| [\sigma_{Total}(K^\circ p) - \sigma_{Total}(\bar{K}^\circ p)]$$

The difference of the total cross-sections is 2 to 3 millibarns at about 30 GeV. The sensitivity of the method would allow us to measure a $\Delta\sigma_{eff}$ of the order of 0.1 millibarns. If $\Delta\sigma_{eff}$ is 0.3 millibarns or greater, it appears feasible to determine a change in the regeneration phase of about 5% as the energy is increased by a factor of 3. An example of the types of results that one might obtain are shown in Figs. 1 and 2. (We assumed very high energy, $\Lambda >> L$ and we neglected the attenuation). Fig. 2 is for a condition where we have set the regeneration amplitude equal to the CP-violating parameter $|\eta_\pm| = 1.92 \times 10^{-3}$. If $\Delta\sigma_{eff}$ is greater than 0.3 millibarns, the same conditions as shown on the curves can be achieved by going to a shorter target. This choice of conditions is to accent the measurement of the interference phase in the first four lifetimes, in order to optimize the spread in the energy of K° in one measurement.

Experiences with measurements of charged particle cross sections and ratios of real to imaginary parts indicate that it is not feasible to achieve the accuracies which can be obtained by the direct measurement of the differences by the regeneration method. We understand that it may not be until after 1975 that it would be feasible to do such experiments at the highest energies available at this accelerator in the experimental areas along the external proton beam. In discussions with the NAL staff, it appeared feasible to set up a neutral beam which looks directly at a target in a straight section of the magnet ring, and this would allow us to run these experiments using the highest energy available at the machine at an exceedingly early date. This coherence experiment, along the road to asymptopia, and the experiment on the K_0 electron scattering both become much more significant at the highest energies.

B. Diffraction Regeneration.

Fred Gilman (Phys. Rev. 171, 1453 (1968)) has pointed out that the study of both regeneration at t = 0 and dσ/dt as a function of t are of interest to those using the Regge Pole model. He also points out that the ω trajectory plays a major role in the process $K_L^o + p \to K_S^o + p$. If one assumes that the dσ/dt varies as exp[a + b ln(s)]t and that the parameters will be similar to those of the ρ trajectory, then at about 100 BeV one expects dσ/dt ≃ exp(11t). The measurement would consist of observing the proton recoil in coincidence with the K_S^o meson decay. The desire to observe the recoil will probably limit us to a $|t_{min}|$ of 0.05. The initial measurements should certainly be made simultaneously with the coherent regeneration measurements, and the apparatus will limit us to a $|t_{max}|$ of approximately 0.4 $(GeV/c)^2$. The recoil protons will be in an angular range for about 83° to 70° relative to the beam direction.

It is of great interest to see whether dσ/dt has a simple exponential shape at these high energies or a more complicated shape; these possibilities are discussed by Gilman. Information on the s dependence should be obtained over a range of energies that vary by about a factor of 3.

At the present time a collaboration of John Hopkins, Maryland, and Cal Tech are involved in a similar measurement at SLAC, and they should get some indication of the dσ/dt as a function of t. Similar measurements may be made at Serpukhov probably up to about 30 or 40 GeV/c; therefore the major interesting feature would be in the highest energy behaviour.

C. The Direct Observation of The Recoil Electrons From The Reaction $K_L^o + e \to K_S^o + e$.

G. Feinberg (Phys. Rev. 109, 1381 (1957)) first pointed out that the electromagnetic contact interaction would lead to the regeneration reaction $K_L^o + e \to K_S^o + e$. Ya. B. Zel'dovich (JETP 36, 984 (1959)) calculated the cross section of this reaction in a non-relativistic approximation and obtained a cross section of the order of 2×10^{-35} cm.^{2}; his result was energy independent. Kroll, Lee and Zumino (Phys. Rev. 157, 1376 (1967)) using vector dominance point out that Zel'dovich's value is probably high. Gormley and Jones have separately performed perturbation calculations in the relativistic case and find that the cross section varies as γ_K^2, namely as the square of the energy of the K meson. The total cross section at 100 BeV is the order of 10^{-33} cm.^{2}. If this calculation is correct and if our estimate is correct that we can observe approximately 40% of the spectrum of these forward recoiling electrons, then it will be possible to measure the $K_L^\circ \rightarrow K_S^\circ$ "transition electromagnetic form factor" (or transition charge radius of the K° meson). The electrons come out essentially in the forward direction and we will deflect them by a magnet placed right after the end of the hydrogen target into an electron detecting system (described in Section III) and also require the electrons are coincident with an appropriate $K_S^\circ \rightarrow \pi^+\pi^-$ decay.

There is also the method of Foeth et al., (Phys. Letters, Vol. 30B, 276 (1969)) who performed a search for the coherent regeneration from electrons. Their method is based on a comparison of the regeneration cross section obtained from diffraction scattering in copper and lead compared with the regeneration cross section obtained from forward coherent scattering. The coherent regeneration includes a contribution from Z electrons in each atom whereas the diffraction scattering is purely nuclear. They obtained that $\langle R^2 \rangle = -(0.5 \pm 1.3) \times 10^{-27}$ cm.^{2}. The forward scattering amplitude from the electrons varies directly as the energy of the K mesons, therefore the coherent regeneration from electrons should be enhanced as one goes to higher energies. However the width of the diffraction regeneration decreases with energy so that the measurement becomes more difficult in this sense. It is also subject to an appreciable number of corrections such as inelastic events (e.g. K* production and $K^* \rightarrow K_S^\circ + \pi$) which increase in number at higher energies. We consider it much more appealing to directly observe the recoil electrons. This cross section should be measured not only to check our belief in understanding the interaction, but also because there are some interesting theoretical questions, e.g. should one Reggeize exchange particles if one vertex is not a strong interaction. There are neutrons in the same beam; hence there is the very fascinating possibility of comparing the charge radius of the K° meson and of the neutron for the same momentum transfers in the same beam. Calculations of the experimental feasibility of the neutron experiment have not been completed at the present time.

D. Measurement Of The Spectrum Of K_L° Mesons And Neutrons

In the measurement of the coherent regeneration from hydrogen, it is planned to run with and without hydrogen targets; hence we will obtain the spectrum of the K_L° mesons. We would also like to determine the spectrum of neutrons with the same equipment in the same beam. It is believe that at high energies there will be a constant cross-section for those reactions in which no quantum numbers are exchanged. The reaction N + p → p + N*(1470) appears to be an excellent candidate.

(We are very grateful to Lorella Jones for the calculations on the theoretical aspects and for exceedingly helpful discussions concerning the above experiments.)

III. EXPERIMENTAL ARRANGEMENT

There are many calculations, tables, and graphs that constitute the bases for the decisions for the experimental arrangements and this section would have become exceedingly long and difficult to follow. Therefore we have stressed an understanding of the problems and the conclusions we have reached. We include some typical values to provide a quantitative feeling. Obviously we would be very pleased to provide those detailed calculations, tables and figures which are desired. The organization of the material in this section is the following:

A) Basic Detector for $K^\circ \to \pi^+\pi^-$ as a function of time
   1) Equipment and triggering scheme
   2) Efficiency
   3) Resolution
   4) Backgrounds

B) Additional Equipment for Diffraction Regeneration.

C) $K^\circ_L + e \to K^\circ_S + e$ Experimental Arrangement
   1) Kinematics and Additional Equipment
   2) Background

D) Additional Equipment for Neutron Spectrum

E) Beams and Estimates of Fluxes
   1) From Internal target
   2) In Experimental Area II.

F) Targets, Rates, and Running Time.

G) Data Analysis.

A) Basic Detector for $K^\circ \to \pi^+\pi^-$ as a function of time

A-1) Equipment and triggering scheme:

The basic detecting scheme for studying the time dependence of $K^\circ \to \pi^+\pi^-$ is shown in Fig. 3; this set up is for K° mesons in the energy range 60 - 180 GeV/c and is limited to the first four lifetimes at 180 GeV/c. If the experiment is performed in the range 30 - 90 GeV/c, the dimensions along the beam should be cut in half. The opening angle, decay vertex, and momentum of the decay pions are determined by four wire spark chambers before and four wire spark chambers after the magnet. The triggering depends on an extensive veto system which is detailed below, and hodoscopes consisting of crossed counters before the magnet and after the last wire spark chamber. Exactly two events are required in each of the hodoscopes.

(The distances involved will lead to an additional 170 nanosecond delay in firing the chambers, if we use standard cable from the veto system. By using special (homemade) conductors we can reduce this to 100 nanoseconds additional to the conditions we have had in previous experiments, - namely the order of 300 nanoseconds; we will reduce the latter to compensate for the additional delay.)

A set of counters will be placed around the target in order to veto low energy secondaries and recoil protons from such processes as diffraction production and scattering.

The coplanarity, opening angle, and momentum of the 2π decays overdetermine and give a clean kinematic identification of the processes of interest in the spark chamber data. However, there are about six hundred times as many 3-body decays, and we can not afford the additional computation time which would be involved. We wish to keep 3-body and false triggers relative to events of interest at a ratio of less than 10 to 1 and preferable 4 to 1. Therefore an efficient veto system is incorporated to eliminate the 3-body decays $K^{\circ}_{3\pi}$, K°_{3e}, and $K^{\circ}_{3\mu}$. The π° in the $K_{3\pi}$ decay will be vetoed by means of a shower counter hodoscope about four radiation lengths thick. Unfortunately about 10% of the π's give false vetoes due to nuclear interactions, and we will lose of the order of 20% of our good decays. Due to the intense neutron beam there will have to be a hole through the center of this hodoscope about 7" in diameter in order not to get an appreciable number of accidental vetoes. This same hodoscope will also serve to eliminate triggers from K°_{e3} decays. The efficiency of our shower detectors will be calibrated in an electron machine.

Experiences at CEA on the efficiency combined with our geometrical loss lead to an estimated efficiency of better than 98% for the electrons, and better than 93% for each of the γ-rays to the π° decay. Additional upstream shower chambers outside the vacuum tank and in the vicinity of the magnet will also help eliminate the $K^{\circ}_{3\pi}$ decay triggers. The veto for the $K_{\mu 3}$ decay will consist of observing the penetration of the μ meson through a block of steel behind the rest of the system. Some initial studies for the selected sample of good $K^\circ \to \pi^+\pi^-$ decays will have to be made to determine the energy dependence of the very high energy π's to create a cascade which penetrates through this steel. The above veto system leads to about a 10 to 1 3-body to 2-body trigger ratio, with the K_{e3} the main culprit. Therefore additional reductions will be obtained from limitations on acceptable hodoscope triggers. There is a rather limited range of the combination of boxes which are allowed between the first hodoscope and the second hodoscope. It appears possible with present day fast solid state components to convert the hodoscope information into binary form and to chose an allowable range of acceptable combinations. We have both the expertise and the shop facilities to build this special project. The additional delay time due to such special logic and its effect on the resolution of the chambers needs to be determined. If it cannot be incorporated in the trigger, it can be indicated on the magnetic tape that these are not events of interest.

A-2) Efficiency:

The geometrical losses for different momentum K's arise from kinematics and the apertures. In $K^\circ \to \pi^+\pi^-$ decay the invariant quantity is $p\theta$ = .206(GeV/c) radians for decays at 90° in the center-of-mass, and for the same momentum K's, a useful rule is that the angle in the laboratory increases by 16% for every increment of 10° in the center-of-mass. Therefore to obtain a useful efficiency over a range of a factor of three in the momentum of the K's, one must cut off the total path length and limit the number of K_S° lifetimes for the highest energy particles. We have chosen four K_S° lifetimes for 180 GeV/c.

With the dimensions shown in Fig. 3, K_S° with 60 GeV/c have a 20% efficiency for being observed in the first lifetime; 180 GeV/c K's have an efficiency of being observed of over 70%. The cut off of lowest energies arises from the size of the vacuum system and/or the aperture in the magnet. This is already an enormous vacuum system and constitutes a major engineering problem. A magnet with this type of aperture exists at Harvard; if this magnet is not used in this experiment and if one is not available from NAL, the SCM-105s at Argonne National Laboratory have about a 32" height and a wider aperture. For this part of the experiment the field requirements are quite modest - namely we wish about 7 kilogauss meters in order to bend the 90° center-of-mass decays in the horizontal plane back to parallelism for one polarity; those with the opposite polarity will have their divergence doubled. The hodoscope has to be designed so that the minimum boxes do not allow the two particles from the highest energy K°'s and the longest lifetimes to enter the same box in the counter hodoscope. For this purpose, the center parts of the hodoscope will consist of 2" x 2" boxes. The outer extremes will consist of 10" x 10" boxes. In the center of the beam where there are neutrons, we intend to make these center counters either 1 mm thick or 1/2 mm thick.

The overall efficiency is estimated to be above 60% for the highest momentum K°'s and about 15% for the decay of 60 GeV/c K° mesons. However the empty target runs with the CP-violating decay mode will give us an experimental determination of the relative calculated efficiencies.

A-3) Resolution:

Most of us use arrangements with about four wire spark chamber gaps to determine angles and this corresponds to eight wire planes. It turns out that the basic limitation in resolution is essentially set by the multiple scattering in these wire planes. One calculates the probability of zero hits, one hit, two hits, three hits, etc. times the mean deflection. We find a mean deflection of the order of 0.5 milliradians per GeV/c for 0.008" aluminum wire spark chambers with 30 to the inch. Decreasing the spacing or going to copper with diameter greater than 0.003" makes this worse. We have set the resolution of our system so as to be slightly less than the multiple scattering errors. Our spatial resolution is about 0.3 millimeters and we have set our chambers about 20 meters apart to work with pions which have a momentum of about 100 GeV/c.

The data after corrections for efficiency and attenuation can be plotted as shown in Fig. 2, namely as a function of t/τ_s. Two factors enter into the determination of t/τ_s: one is the location of the vertex downstream from the hydrogen target and the other is the determination of the energy of the K, namely γ_K. For the 60 GeV/c K°'s the errors in the vertex are about .14(τ_s). For K°'s of 180 GeV/c, in the first lifetime, the error is about .13(τ_s) and in the fourth lifetime, about .06(τ_s). J. H. Smith (Vol 3, 1968 Summer Study, p.1) has done an analysis of the error in determining γ_K for such experiments. Rather interestingly, one finds that the fractional error is independent of the momentum of the K's. For the conditions specified, namely a field of about 7 kilogauss meters and with our resolutions, we obtain that the uncertainty due to γ_K gives us about an error in t/τ_s of about (0.20). Therefore the resultant uncertainty in the proper time from the combination of the error in the vertex position and the error in the momentum is $0.24(\tau_s)$ for most of the decays. Increasing the field to about 12 kilogauss meters would reduce the overall error to a value of about $0.20.(\tau_s)$. However one then loses the capability of rejecting some of the 3-body decays in the triggering system.

A-4) Backgrounds:

An analysis of the diffraction regeneration by K°'s and of peripheral production of K*'s and other inelastic reactions leading to forward K_S^o production was covered by Smith and Wattenberg (Vol. 3, 1968 Summer Study Group, p. 35). It was shown that despite a veto counter system on the front, back and sides of the hydrogen target to eliminate reactions accompanied by charged particles, there would still remain about 10 background events per pulse. However all of these events are accompanied by π^o mesons, which should be vetoed by the shower counters outside the acceptable cone of K_S^o decays and in back of the detecting system.

It is estimated by J. H. Smith (Vol. 2, 1968 Summer Study Group, p. 121) there are of the order of 10^2 to 10^3 times as many neutrons in the beam as K°'s. If the intensity of available K°'s is an order of magnitude greater than required by the statistical accuracy desired, we would like to reduce the ratio of neutrons to kaons by inserting a LiH plug in the beam upstream of the collimator. The average cross section for K_L^o is the order of about 19 millibarns per nucleon, whereas the average cross section for neutrons is about 39 millibarns and in a lithium nucleus the shadowing loss is only about 20%. Specifically, a plug of LiH of 276 grams would reduce the K° flux by 1/20th and the neutron flux by about 1/400th. It was estimated in the Summer Study of 1968 (Smith and Wattenberg, Vol. 3, p. 35) that if one looked at just the K_S^o decays, without asking for interference, one could very well have a signal which is 10 times the regeneration intensity, therefore the mere observation of K_S^o following a target is no indication that there is really regeneration. For example, the K°'s will be produced in peripheral neutron reactions. What is uncertain in the estimates is the extent to which one will veto a forward going charged particle, a sidewise recoiling charged particle, or the γ-rays from the π°'s. Therefore among the early studies that one needs to make, even if there is not superflous intensity, is the effect of putting in a LiH plug to get a measure of the K°'s in the forward direction which are arising from neutron events rather than K_L° particles.

B) Additional Equipment for Diffraction Regeneration.

If the diffraction regeneration is of the form $d\sigma/dt$ = constant e^{-t/t_o}, then the ratio

$$\frac{\text{Diffraction regeneration}}{\text{Coherent regeneration}} = \frac{|t_o|}{(\hbar c)^2\ 4\pi Nx}$$

where N is the number of atoms/cm^2 and x is the length in centimeters. For a one meter long hydrogen target using $|t_o| = \frac{1}{11}$, one finds that the diffraction regeneration will be about 4.5 times the coherent regeneration. This means if the difference that exists in the Serpukhov results has not dropped by more than a factor of 10 at 100 BeV, there will be more than an adequate number of events, and one can trade intensity to improve the angular resolutions.

For regeneration or other peripheral processes with a recoil proton, a convenient relationship between the deviation of the angle of recoil from 90° is $\psi \simeq \frac{\sqrt{|t|}}{2M_p}$ (The approximation used is that the energy of the recoil proton is classical.) Unfortunately there will be a great number of recoil protons from peripheral processes with these t values. Conventional wire spark chambers do not have adequate resolving times, especially when operated at this large a distance from the downstream hodoscope trigger. Our multiwire proportional counters with 1 mm spacing have a resolving time of 40 nanoseconds. Therefore, we plan as the extra apparatus for this experiment: three vertical planes of multiwire proportional counters each separated by 30 cm. combined with a scintillation counter range hodoscope with ranges from 0.1 gm/cm^2 to 100 gms/cm^2. After the first 3 gm^3/cm^2 of plastic scintillator, there will be a plastic (isolite) Čerenkov detector to veto higher energy particles and lower mass particles. Sandwiches of aluminum and plastic scintillators interspersed will make up the remainder of the range hodoscope. As mentioned previously, we will be operating in the range of $.05 < |t| < .50$. Our multiwire proportional counters are attached to circuits which convert to binary logic and we can determine if the correct angle and range relationship exists in a total operating time of under 200 nanosecond. This time is in parallel with other logic and is not an additional delay. At the end of the other electronic logic it would demand that there be a $K_S^\circ \to \pi^+\pi^-$ decay observed in the downstream hodoscopes without any accompanying other charged particles or π° decays. Each of the multiwire proportional counters will contain about 300 wires. We have previously successfully built them 8" long. We assume we can get to 30 cm. without any difficulty and with further development work even larger. The 30 cm. height would give us a solid angle efficiency of about 4%. The angular resolution of our K° detecting system will create uncertainty in the hydrogen targets in the radial direction of the order of 6 centimeters or about .4 gms/cm^2. Therefore the range information will not be a sensitive check at small ranges. However the angle and momentum of the K° should be in agreement with the $|t|$ value obtained from the angle measured in the multiwire proportional counter system.

$$|\Delta t| = 2|t| \frac{\Delta\psi}{\psi}$$

$\Delta\psi$ is the order of .01. At $|t| = .05$, ($\Delta\psi = .11$) and at $|t| = .5$ ($\psi = .36$), we will have resolutions $|\Delta t| = .01$ and $|\Delta t| = .03$ respectively.

The major background will be from peripheral neutron reactions or very wide angle π mesons production. In the most pessimistic case, we estimate that a background within the recoil proton detector system will lead to an accidental rate of the order of 5%. The requirement for $K_S^\circ \to \pi^\circ\pi^-$ (and no π°'s or other charged particles) combined with the kinematical requirement in the recoil proton trigger, should lead to a triggering ratio of good events to others of better than two to one.

C) $K_L^\circ + e \to K_S^\circ + e$ Experimental Arrangement.

C-1) Kinematics and Additional Equipment:

The cross section for this reaction is independent of t and is approximately $d\sigma/dt = 3 \times 10^{-5}$ millibarns/(GeV/c)^2. The range of t's go from 0 to t_{max} where

$$|t_{max}| = 4 \frac{E_K^2 m_e^2}{s}$$

specifically for K mesons of 100 GeV/c, the total cross section is 0.86×10^{-33} cm^2, (at 40 GeV/c it is 1.6×10^{-34} cm^2). At 100 GeV/c the electrons are essentially emitted forward. The maximum angle of deflection is 6 milliradians. The relationship between the laboratory momentum of the electrons and the $\cos\theta_{cm}$ is shown in Fig. 4. From this figure we can see that by measuring the electrons from about 14 to 4 GeV/c we will obtain about a 40% efficiency. With this efficiency and a flux of K mesons of about 10^6 with the 3 meter target, one would expect to see one event every two hundred pulses. The K_S^o triggering rate is the order of 10/pulse; it would not be serious to have a trigger with electrons of 1/pulse; however the final electron and kinematic identification must be redundant and satisfy the relationship in Fig. 4.

Fig. 5 shows a tentative redundant detection system for these electron events which are to be in coincidence with $K_S^o \rightarrow \pi^+\pi^-$ at the appropriate angle and energy. (This sytem has not been optimized in regard to angles of deflection and rates.) The electrons are deflected in a 20 kilogauss meter magnet placed in a gas-tight helium filled box 30 cm. high and 10 meters long (this will be tested at an electron machine) which is used as a Čerenkov detector by means of a curved mirror which focuses the light back onto a series of photomultipliers. It is sensitive to electrons and not to pions with energies below 14 GeV. (People have been discouraged from using helium as a Čerenkov detector because it is known to scintillate; however Koester and Yuan (private communication) have found that the scintillations are quenched by the addition of a minute amount of oxygen.) At the downstream end of the box leaving a foot clearance in the beam line are shower detectors as a second electron detector. To determine the trajectory of the electrons through the magnet we are planning a set of three or four hodoscopes of thin (1 mm) plastic scintillators in a fast coincidence circuit.

C-2) Background:

We will get electrons from pairs that are produced by γ-rays from π^o mesons. The hodoscope in the magnet and at the downstream end should eliminate these pairs. Additional veto counters will be placed on the positron side to eliminate inefficiencies due to time jitter. What will determine the feasibility of this experiment is our ability to determine and eliminate sources of background which give spurious triggers.

There are some alternative approaches for observing this reaction other than the one described here. If additional study indicates they are better, supplementary material will be submitted describing them.

D) Additional Equipment for Neutron Spectrum

To measure the neutron spectrum we intend to use the reaction $N + p \rightarrow p + N^*(1470)$ and $N^*(1470) \rightarrow p^+\pi^-$. When the magnet is set at about 9 kilogauss meters there are a set of decays near the horizontal plane, in which both the π and proton have the same momenta and angles of deviation. They will then be bent to parallelism. This corresponds to approximately 45° decays in the center-of-mass and is independent of the energy of the N* at high energies. This requires the addition of about 24 more counters, each 2" x 30" high, placed behind the manget. We will accept for the pion $36° < \theta_{cm} < 54°$ at $\pm$ 30° in ϕ_{cm}, to give a solid angle detecting efficiency of 1.6%. After leaving the magnet, these ranges result in deviations from parallelism to the beam of the order of 10^{-5} E_{N^*} radians. (e.g. for 100 GeV/c, the deviation is 1 mr and in 20 meters it is 2 cm.) We also wish to demand that only one of the particles have $\gamma > 118$ to discriminate against protons (or anti-protons) in a 10 meter He Čerenkov detector.

It is estimated that the cross section for this reaction should be constant, the order of 100 microbarns at high energies. $N^* \rightarrow \pi^- p$ one third of the time; combining this with a 1.6% geometrical efficiency, we get the order of one event/pulse for every 5 x 10^5 neutrons, from the one meter target. If one uses the geometry of Fig. 3, the technique would be good for neutrons with energy above 80 GeV/c. If one uses the geometry associated with the alternative experiment in Area No. 2, it would be good for neutrons with energies above 40 GeV/c. To measure the spectrum of lower energy neutrons one needs to place the hydrogen target closer to the first spark chamber and to use mixtures of N_2 and He in the Čerenkov detector. Unfortunately, we expect the neutron intensity to be well above 10^6 per pulse.

E) Beams and Estimates of Fluxes

E-1) From internal target:

We hope that as increasing data becomes available from Serpukhov that the uncertainties in the fluxes to be expected at high energies at various angles will be reduced. Table II gives the flux of K_L^o's estimated to be in a 6 milliradian beam from a thin internal target subject to multiple traversals of 10^{12} protons. 2 x 10^{-7} steradians was assumed as the solid angle, that is about a 6" diameter opening at 1000 ft. The yields in the column labeled "1968 Estimates" were based on curves given by Hagerdorn and Ranft (J. H. Smith, NAL Summer Study 1968, Vol. 2, p. 121). The values in the column "1969 Estimates" are based on modifications of the Hagerdorn and Ranft curves by Nezrick (NAL Summer Study 1969, Vol. 1, p. 403). For purposes of making estimates of rates and running times, we have binned in intervals of $\pm$ 20 GeV, using the 1969 estimates; these fluxes are given in the last column of Table IV.

The 6 milliradian beam is one that would originate at the upstream end of a straight section and just clear the top of the first downstream magnets. It will be slightly to one side of vertical so as to pass through the tunnel wall where the tunnel changes from being 12 ft. to 10 ft. in diameter. This possibility was suggested by Tom Collins of the NAL staff. It could be installed after the tunnel and earth fill around it have settled. 2" to 4" of lead are put in neutral beams before the collimator to remove the γ rays. The collimator should be fairly far upstream and needs to be followed by a sweeping magnetic field. One does not need an exceedingly large number of kilogauss meters if it is fairly far upstream and Telegdi has pointed out that one could use a permanent (Alnico) magnet to avoid the need for bringing power lines and water. Beyond the clearing field the beam should be passing through a vacuum.

We urge that very serious consideration be given to this possibility of our performing these experiments at the highest energy of the machine at the earliest possible time. The interest in the experiment is to get as far as possible along the road to asymptopia.

E-2) Beam in Experimental Area 2.

If it is not feasible to obtain a beam directly from the internal target of the machine, at 400 GeV/c, then we would propose to perform the experiment in Area 2. Table III gives the fluxes based on the 1969 estimates previously mentioned; the values are given for three situations. One with a beam that makes an angle from the target of 5 milliradians and the second at 10 milliradians. In the first two cases we have indicated 3 x 10^{12} protons on an optimum target, this is effectively 10^{12} interacting protons. For the production of the highest energy particles the optimum target length is one mean free path and the yield is e^{-1} compared to a thin target with multiple traversals.

Table II

Estimated fluxes of K_L^o of various energies from 10^{12} protons of 400 GeV/c momentum in a beam at 6 mr with $\Delta\Omega = 2 \times 10^{-7}$ steradians

K_L^o Momentum GeV/c	(1968 Estimates) with $\Delta p = 1$ GeV/c	(1969 Estimates) with $\Delta p = 1$ GeV/c	(1969 Estimates) with $\Delta p = 40$ GeV/c
80	1.8×10^5	1.4×10^4	$5. \times 10^5$
120	$5. \times 10^4$	$3. \times 10^3$	1.1×10^5
160	1.3×10^4	$5. \times 10^2$	$2. \times 10^4$
200	2.2×10^3	$6. \times 10^1$	$2. \times 10^3$
Total Neutrons	2×10^7 (1968)		

Table III

Estimated fluxes of K_L^o of various energies from 200 GeV/c protons with $\Delta\Omega = 2 \times 10^{-7}$ and $\Delta p = \pm 10$ GeV/c (Based on Nezrick's estimates 1969 Summer Study)

K_L^o Momentum GeV/c	3×10^{12} protons on an optimum target		10^{13} protons on an optimum target and 276 gms/cm^2 LiH plug
	at 10 mr	at 5 mr	at 5 mr
40	4.8×10^5	1.8×10^6	$3. \times 10^5$
60	1.2×10^5	$8. \times 10^5$	1.4×10^5
80	2.8×10^4	$3. \times 10^5$	$5. \times 10^4$
100	4.4×10^3	1.1×10^5	1.8×10^4
Total Neutrons	2.5×10^7	0.8×10^8	$2. \times 10^5$

If 10^{13} protons or more are available, to be put on target, we would propose to use the extra intensity to decrease the neutron to K ratio. The last column of the table shows the fluxes one could obtain at 5 mr. with a 276 gms/cm^2 plug of lithium hydride in the beam. The ratio of neutrons to kaons were taken from the curves of J. H. Smith (ibid.). His curves show that the ratio of neutrons to kaons rises to the order of several thousand if one tries to go to smaller angles than 5 mr. If Nezrick's figures are correct, angles larger than 10 mr are a disaster for performing these experiments with kaons with energies above 60 GeV; although such beams will be useful for other experiments. The NAL experimental planning group has under consideration the possibility of making the targeting angle (in the target box for Experimental Area 2) a variable over a small angular range. We strongly urge that this idea be implemented in order to optimize the kaon to neutron ratio in K_L^o experiments to be run in that area. When higher proton fluxes become available, the values in the last column of Table III can be obtained.

F) Targets, Rates and Running Times

We wish to run with 2 hydrogen targets that differ in length by about a factor of three and with an empty target. One motivation is that when one puts in the background and the diffraction scattering, the time distribution of decays has these as an additional term multiplied by $e^{-\Gamma_s t}$. The background and diffraction regeneration both vary linearly with the length of the target, whereas the coherent regeneration term varies as the square of the length. The background arises from such things as K_S^o production by neutrons and K* production by K_L^o. Obviously the mere observation of K_S^o from a K_L^o beam is not evidence for regeneration. The ratio of coherent regeneration to diffraction regeneration is independent of the regeneration cross section and at very high energies depends only on the lengths of the target and the experimental resolution. For a one meter target $\frac{\text{Coherent}}{\text{Diffraction}} \simeq 1/2$ and for a three meter target is less than 1/20 for our experimental resolution. The limitation on the resolution arises from the multiple scattering, namely the amount of material in the detectors times its Z. Under these circumstances, I doubt if one will want to go to a target that is shorter than one half a meter, at which point the $\frac{\text{Coherent}}{\text{Diffraction}} \simeq 1$.

In order to enhance the interference term in the first four lifetimes, we have chosen the regeneration amplitude = $|\eta_\pm|$. This is the condition which actually applied in drawing Fig. 2 and it was only to give some idea of the values that we specified $\Delta\sigma_{eff}$ = 0.3 mb and a target of 3 meters length. We trustthat from the Serpukhov data we will be able to have a better indication of the actual length of targets to be used. There is obviously the hope that we will see some energy dependence in the regeneration amplitude and so therefore the smallest target should probably correspond to the condition last seen at Serpukhov and the longer target would then make feasible the observation of a smaller cross section which might exist at higher energies.

Since there is a good deal of uncertainty in the actual fluxes that will be available, both due to machine intensity and the extrapolation of the known yields of kaons, the rates are calculated using the last column of Table II (using the lower 1969 estimates) (Nezrick).

As an example take 120 GeV/c where we have 1.1×10^5 kaons in a bin of $\pm$ 20 GeV/c. From Fig. 2 one sees that the average number of decays from regeneration during the first four lifetimes is $1.5|\eta_\pm|^2$ per τ_s time intervals. If one thinks of binning the data in one lifetime intervals, this gives us

$$\text{flux} \times 1.5 \times |\eta_\pm| \times \text{efficiency} = 1.1 \times 10^5 \times 1.5 \times 3.6 \times 10^{-6} \times 0.6 \simeq 0.4$$

events per pulse per bin. At higher energies the efficiency is the same; at lower energies, it decreases. From Table II, one sees that at about 160 GeV/c the event rate will be approximately one fifth of this or .08 events/pulse/bin. We assume that during the first year the accelerator will have a 50% efficiency and give an average of about 6000 pulses/day. With this assumption for 160 GeV/c we get about 500 events per day/bin. One wants 10,000 events per bin. This is 20 days of running for each of the targets; which leads to an estimated running time of about sixty days. The diffraction regeneraton experiment and the electron-regeneration should run simultaneously with the coherent regeneration experiment.

The above time estimate has the product of several pessimisms in it. If we have been overly pessimistic then despite Table II, we may have statistically significant data for K_L° with momenta of 200 GeV/c. From a simple analysis we estimate that we should be able to measure <u>changes in the regeneration phase</u> of about 5° between 60 GeV/c and 180 GeV/c.

In the neutron flux measurement, there should be 10^4 to 10^5 events in one day. It is probably sensible to assume that the measurements may take about three days (if you give us more time we could have a lot of fun looking for other N^*_{11} states).

In regard to the time needed for testing, we hope we are the first ones who will be trying to use such beams at NAL. Besides testing our own equipment, we would like to try to do everything possible to minimize backgrounds and to be sure the effects we are observing are from K_L^o mesons and not neutrons. Under the circumstances we would certainly start off using a carbon regenerator and want to run with and without a lithium hydride plug in the beam. The important thing will not be the statistics in such cases, but the rapid reduction of the data while we are running. We would like to have about ten days to study the beam conditions and about two weeks to study the functioning of the parts and any spurious triggers in our apparatus. We would also need about ten days to study the feasibility of C.

CONCLUSION: Total time for running and testing, about 100 days of machine operation, with an average of about 5000 useful pulses per day and an average intensity of 10^{12} interacting protons per pulse.

G) Data Analysis

The University of Illinois group has a Sigma 2 computer with a disc for fast storage and a tape unit. There is no difficulty in storing the data and transferring the data to tape at the rate of 100 events/pulse. As we are currently using this computer in an experiment which studies $K^o \rightarrow \pi^+\pi^-$ as a function of distance, we already have some of the software. We can process about 1 event/second on-line, as well as transferring other events to magnetic tape. During the period when one is trying to get rid of backgrounds and false triggers, it is important to have immediate feedback. For example, one may be trying to reduce the number of false triggers, and one wishes to know what the effect of a specific change is. For this reason we feel that there are great advantages to using our own computer and existing software.

The reduction of the backgrounds and other sources of false triggers was dictated by the amount of off-line computing that one can afford. We expect to get the order of 500,000 useful events from all the runs, therefore if there are five false triggers or three body decays for every good event, we would have to analyze the order of 2.5×10^6 events. At the present time we operate our own 7094, and it is reasonable for us to process this quantity and type of data in six months. If there are 5×10^6 triggers, it might take a year to perform the analysis.

IV. APPARATUS

WE NEED:

1) From NAL, a 40 meter long large vacuum system. The larger section is 60 ft. long and 48" in diameter. The other 60 ft. should be about 24" in diameter. We would like it in two 30 ft. sections which could be joined together or used separately.
2) From NAL (or possibly from a collaboration with Harvard), a magnet with a total field length of 12 kilogauss meters and an aperture at least 48" horizontally and preferably 48" vertically. If it is unavailable from NAL or Harvard, it might be possible to borrow an adequate magnet from another National Laboratory.
3) From ANL (or by borrowing from another National Laboratory), two hydrogen targets probably 3 ft. and 9 ft. long, 6 inches in diameter. The 3 ft. long should have thin side walls on at least one side. The density in the hydrogen target should be controlled reasonably, namely we can stand fluctuations of several per cent. The actual lengths of the targets will be better known after some anticipated results from Serpukhov.
4) From NAL, <u>with a strong preference</u>, a neutral beam from an internal target in the machine at as small an angle as possible, i.e. 5 or 6 mr and 400 GeV/c protons. If the former is not available, a neutral beam line in Experimental Area 2, preferably with a variable angle of targeting in the range from 5 mr to 10 mr.

WE HAVE:

1) Our own on-line computer, a Sigma 2 with a disc for fast storage and a tape unit to which the information from the disc can be transferred.
2) Already constructed, one half of the wire spark chambers that are needed and one quarter of the hodoscope that is needed for Part A of the experiment, namely the coherent interference regeneration.
3) The electronic logic.

EQUIPMENT WHICH WILL NEED TO BE CONSTRUCTED:

This depends upon the collaboration. We can mount and carry out A and D alone without collaborators. With a collaboration equivalent to our own group, we would like to do A, D, and C if it is feasible. If there is a 3rd equivalent collaborating group, and we all have similar interest, we would like to do A, B, C, and D.

If we go it alone, it would take us a year to build the rest of the hodoscopes, including the veto shower counters. If we are collaborating with one group, we would like to test the components for Part C and could complete either the hodoscopes or the remaining spark chambers in six months.

If C were not feasible or not of interest to the collaborators, as an alternative we could construct the detector for the recoil protons, including the multiwire proportional counters, the range telescope and the special high speed logic. We have already built and used multiwire proportional counters; we have many of the printed circuits for the logic and it is mainly a metter of producing more and a larger system. We believe this job alone will take about nine months. However our systems engineer will not be available until about October.

CONCLUSION: Depending on which of the above choices are made, the equipment needed should be completed during the fall of 1971.

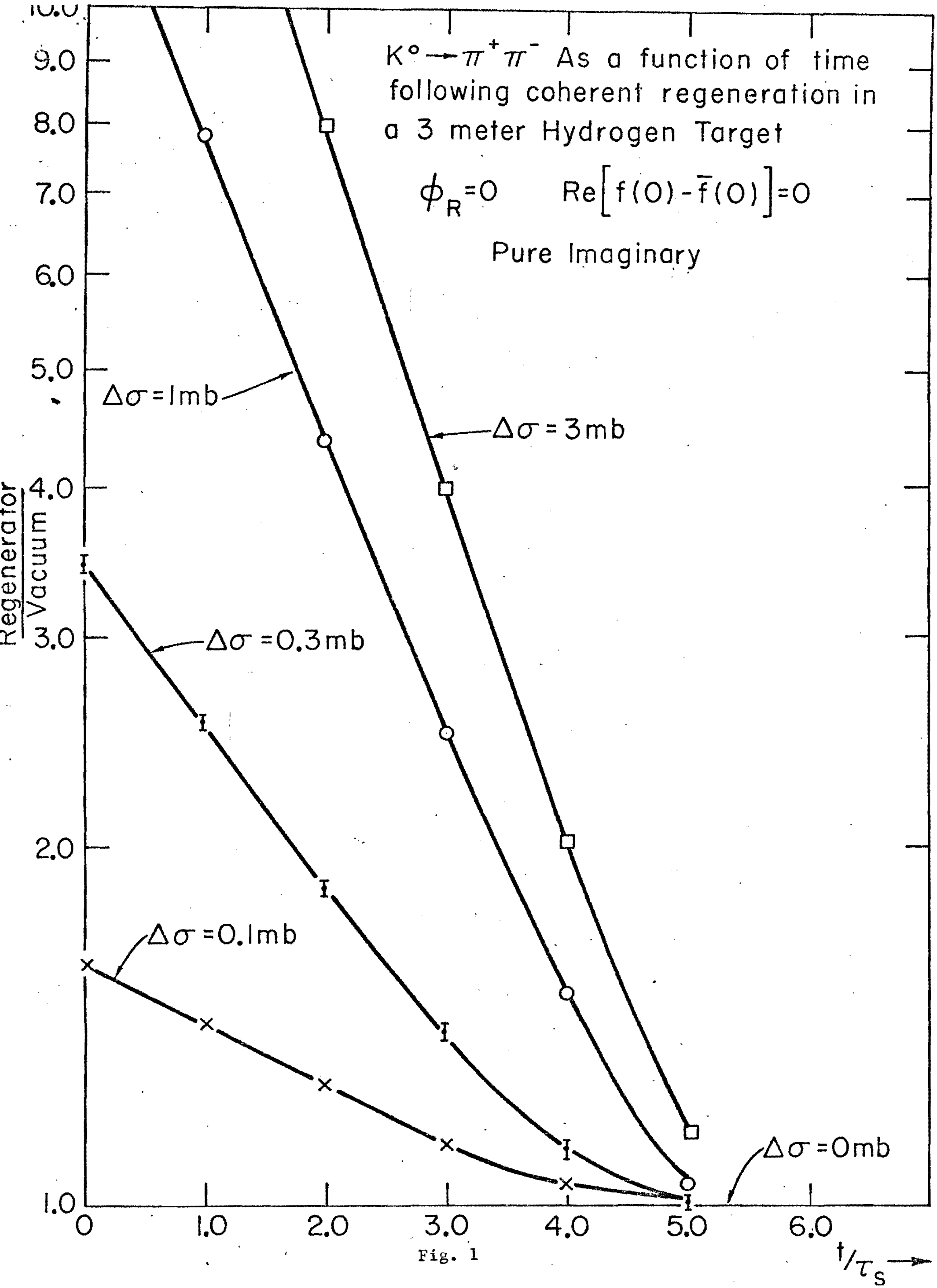
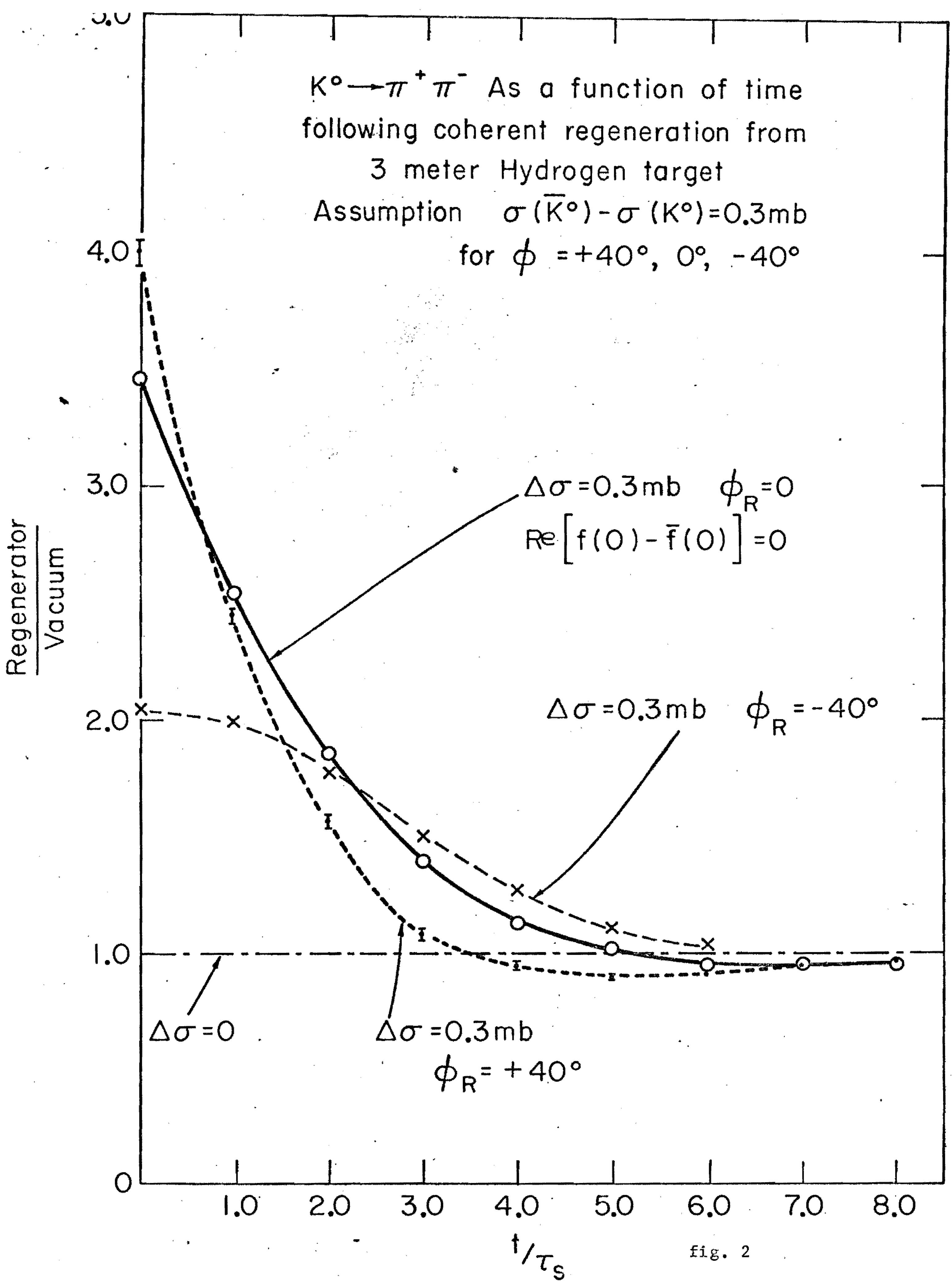

$K^\circ \rightarrow \pi^+\pi^-$ As a function of time following coherent regeneration in a 3 meter Hydrogen Target
$\phi_R = 0$ $\mathrm{Re}\left[f(0) - \bar{f}(0)\right] = 0$
Pure Imaginary
$\Delta\sigma = 1\,mb$
$\Delta\sigma = 3\,mb$
$\Delta\sigma = 0.3\,mb$
$\Delta\sigma = 0.1\,mb$
$\Delta\sigma = 0\,mb$
Regenerator / Vacuum
t/τ_S
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
0
1.0
2.0
3.0
4.0
5.0
6.0

Fig. 1



$K^\circ \rightarrow \pi^+\pi^-$ As a function of time following coherent regeneration from 3 meter Hydrogen target
Assumption $\sigma(\bar{K}^\circ) - \sigma(K^\circ) = 0.3$mb
for $\phi = +40°, 0°, -40°$
$\Delta\sigma = 0.3$mb $\phi_R = 0$
Re$[f(0) - \bar{f}(0)] = 0$
$\Delta\sigma = 0.3$mb $\phi_R = -40°$
$\Delta\sigma = 0$
$\Delta\sigma = 0.3$mb
$\phi_R = +40°$
Regenerator / Vacuum
t/τ_S
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0

fig. 2

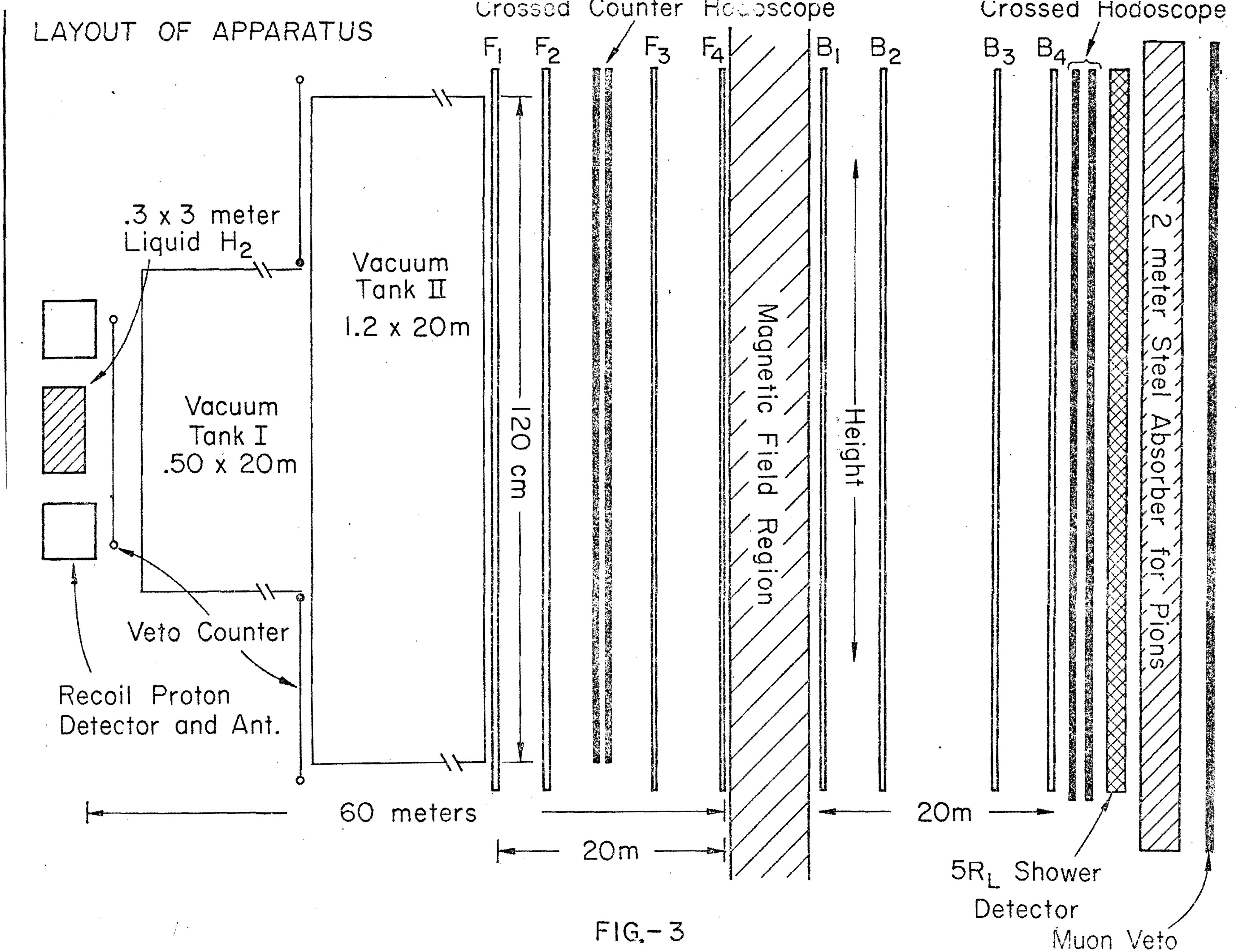

LAYOUT OF APPARATUS
Crossed Counter Hodoscope
Crossed Hodoscope
F1
F2
F3
F4
B1
B2
B3
B4
.3 x 3 meter
Liquid H2
Vacuum
Tank II
1.2 x 20m
Vacuum
Tank I
.50 x 20m
120 cm
Magnetic Field Region
Height
2 meter Steel Absorber for Pions
Veto Counter
Recoil Proton
Detector and Ant.
60 meters
20m
20m
5RL Shower
Detector
Muon Veto

FIG.-3

$K_L^o + e \longrightarrow K_S^o + e$

Relationship of Recoil Momentum of Electron and Center of Mass Angle

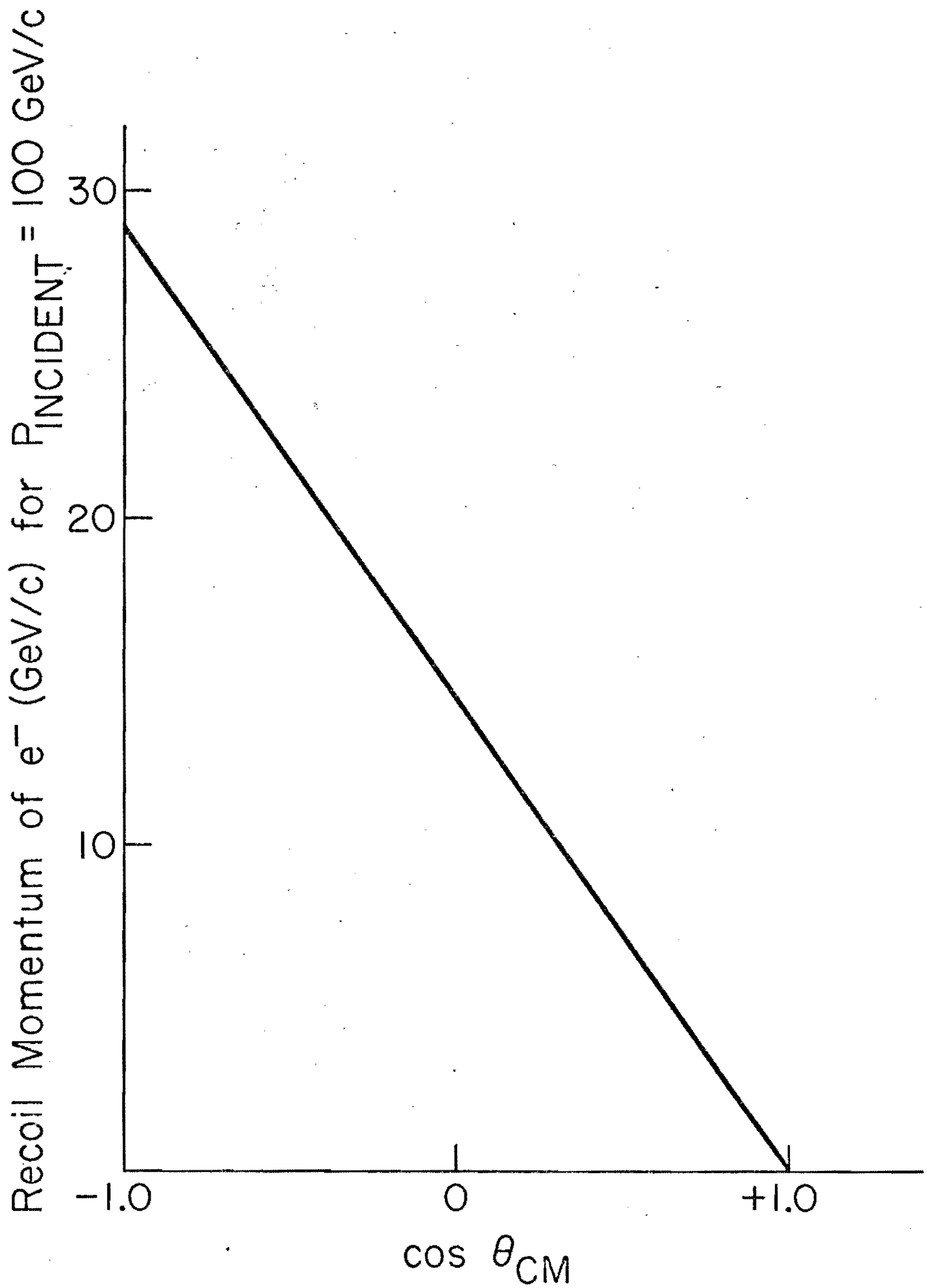


FIG.-4

Arrangement for Detecting Electrons

from $K_L^o + e \rightarrow K_S^o + e$

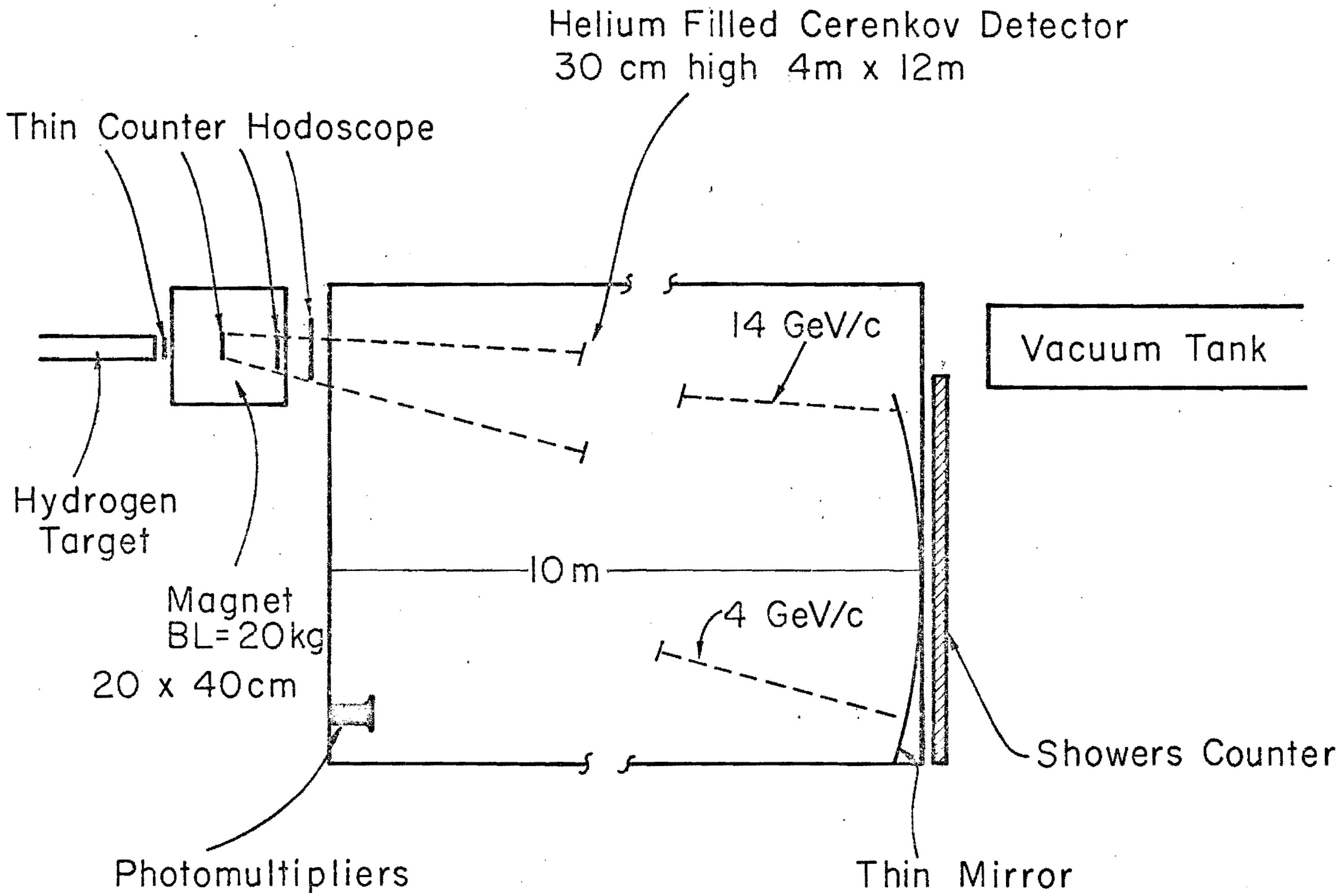


FIG.-5