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A Proposal
to Search for the Rare Kaon Decay Mode $K_L \rightarrow \pi^0 e^+ e^-$

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ABSTRACT

We propose to search for the rare kaon decay $K_L \rightarrow \pi^0 e^+ e^-$ with a sensitivity of $\sim 1 \times 10^{-11}$. Theoretical predictions of the branching ratio range from 0.4×10^{-12} to 0.6×10^{-9}. Within the Standard Model, this decay mode may have a sizable CP violating decay amplitude such that $\varepsilon'_{\pi ee}/\varepsilon \sim 1$. A high sensitivity search for this decay will test different models and provides a new window to explore the question of direct CP violation.

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1) Physics Background

The amplitude for $K_L \rightarrow \pi^0 e^+ e^-$ is composed of a CP conserving part and a CP violating part. The leading CP-conserving amplitude proceeds through two-photon exchange while the CP-violating one may proceed via one-photon exchange [1,4]. Within the framework of the Standard Model (SM) where CP violation comes from the phase δ in the Kobayashi-Maskawa matrix [2], $K_L \rightarrow \pi^0 e^+ e^-$ may have a sizable $\Delta S=1$ CP-violating effect ($\varepsilon'_{\pi ee}/\varepsilon \sim 1$). The Superweak Model [3] predicts $\varepsilon'_{\pi ee}$ to be zero.

In terms of the CP eigenstates K_1 (even) and K_2 (odd), K_L is written as $(K_2 + \varepsilon K_1)$ and one may describe the contributions to the $K_L \rightarrow \pi^0 e^+ e^-$ decay amplitude as follows: (a) the CP conserving amplitude via two photons exchange $K_2 \rightarrow \pi^0 \gamma^* \gamma^*$, where γ^* is an off-shell photon; (b) the mass matrix 'indirect' CP violation amplitude which comes from the small K_1 impurity of K_L; and (c) the 'direct' CP violation amplitude ε' from the 1-photon exchange $K_2 \rightarrow \pi^0 \gamma^*$ part of K_L. Within the Standard Model, part (c) could be described by the 'electromagnetic penguin' diagram (Fig.1) and is comparable to or larger than part (b) in magnitude. Theoretical estimation of the 'size' of this penguin is under active pursuit by our theoretical colleagues. While the predictions [1] of the branching ratio in general are around 10^{-11}, the Weinberg Model [5] predicts the branching ratio as high as 0.6×10^{-9}.

The $K_L \rightarrow \pi^0 e^+ e^-$ decay is an attractive avenue for the observation of 'direct' CP violation, particularly should detailed studies of the 2π decays of the neutral kaon (ε'/ε) prove inconclusive [6,7].

2) Current Experimental Status and the Branching Ratio Limit of $K_L \rightarrow \pi^0 e^+ e^-$ from E-731

Currently there are two other efforts to search for $K_L \rightarrow \pi^0 e^+ e^-$, one at BNL (Proposal 845) and the other one at KEK. Both have been approved and are currently under construction with the goals of 10^{-10} sensitivity. There were three recent experimental results on the limit of branching ratio of $K_L \rightarrow \pi^0 e^+ e^-$. The BNL,CERN and FNAL results [9,10,8] are $<3.2 \times 10^{-7}$, $<4 \times 10^{-8}$ and $<4.2 \times 10^{-8}$ respectively.

In this section we describe the FNAL result [8] obtained with 20% of the E-731 data; together with the detector performance, the trigger, and the reconstruction method.We then describe the needed changes for the proposed experiment in the following sections.

Figure 2 shows the detector layout. Two neutral K_L beams (1/2 x 1/2 mrad^2) were created at 4.8 mrad by 800 GeV protons striking a Be target. The data was taken within one month of running time (80 hours/week) with 0.7×10^{12} proton per spill. One of the two beams always hit a regenerator for the 2π ε'/ε measurement and is not relevant in this discussion. The drift chamber system with eight x-planes and eight y-planes (2000 wires total) measured the positions and momenta of the charged particles. These planes had a position resolution of about 100 μm and were at least 98% efficient. The singles rate in the chambers was about 20 kHz on the hottest wire. The 804 circularly stacked leadglass array measured the positions and energies of electrons and photons. Each block is 5.82 cm (H) x 5.82 cm (W) x 60.2 cm (L), giving a depth of 19.2 radiation lengths. There were two holes (11.6 cm x 11.6 cm) separated vertically by 11.6 cm at the center of the array for the beams to pass. The position and energy resolution for electrons were about 2 mm and $1\% + 5\% / \sqrt{E/(\mathrm{GeV})}$ respectively. For online triggering purposes, we instrumented each of the leadglass phototube outputs with a 60 MHz flash ADC. These comprised the front-end electronics for a two-dimensional cluster finding trigger processor, while also serving to suppress out-of-time photons. A cluster was defined as a 'neighbor-connected' island of leadglass blocks each with more than 1 GeV.

The E-731 neutral trigger required exactly four clusters, 30 GeV or more energy deposited in the leadglass, and no hit in the 'trigger plane' (z=137m, see Fig.2). Hence this trigger was sensitive to $\pi^0e^+e^-$ candidates in the downstream decay region. The momenta of the e^+ and e^- and the decay vertex of the candidates were determined by the drift chamber spectrometer. The e^+ and e^- were identified by matching the tracks with the clusters, and requiring $0.85 < E/P < 1.15$, where E is the cluster energy and P is the track momentum. Figure 3 shows the E/P distribution for electrons from calibration data. The π^0 mass resolution was about 4 MeV (Fig.4) and the $\gamma\gamma$ mass was required to be within 10 MeV of the nominal π^0 value. By then constraining the $\gamma\gamma$ mass to the nominal value, the reconstructed kaon mass ($M_{\pi ee}$) would have a resolution of about 4.5 MeV. The square of the transverse momentum (P_t^2) of the $\pi^0e^+e^-$ system with respect to the line connecting the decay vertex and the production target had a resolution of about 50 MeV^2. The candidates are shown in a two dimensional $M_{\pi ee}$ vs P_t^2 plot (Fig.5). A candidate is defined to have $P_t^2 < 200$ MeV^2 and $489 < m_K < 507$ MeV; these cuts include about 95% of the signal. No candidate is found in the signal region and there is virtually no background.

The acceptance is 9.5% for a fiducial downstream decay volume of 22.2 meters and kaon energy between 30 and 150 GeV, assuming a uniform three-body phase space distribution. The upper limit B.R.($K_L \to \pi^0e^+e^-$) $< 4.2 \times 10^{-8}$ (90% confidence) is obtained by normalizing to a sample of 58.8×10^3 $K_L \to 2\pi^0$ decays. This result corresponds to 20% of the E-731 data sample.

E-731 had better resolution and lower background than the experiments performed so far. Most of the merits come from the higher kaon energy spectrum. The complete E-731 data set which is being analyzed currently, has $\sim 8\times10^{-9}$ sensitivity and we expect to have our result within the next few months.

3) Run Plan

We describe below the changes and needs to our current detector and Meson Center beamline for the proposed ~1×10^{-11} sensitivity search with two Fixed Target Tevatron periods. A 'Phase I' two month run has ~2×10^{-10} sensitivity and a 'Phase II' five month run has ~1×10^{-11} sensitivity.

i) Phase I (1989-1990)

We need:

a) 2×10^{12} protons per spill for a two month period (assumes 80 hrs/week) for data taking and two weeks for tuning, calibration, rate studies etc.;

b) to move the lead-mask photon veto plane (see Fig. 2) from the current position z=120m to z=100m to increase decay fiducial region;

c) to remove the vacuum 'trigger planes';

d) to implement four modules of TRD for additional π/e rejection;

e) to instrument the two small beam holes at the leadglass with electromagnetic calorimeters to increase acceptance;

f) to implement a tracking trigger processor to reduce trigger rate.

Items b),c),d),e), and f) are discussed in the next section.

The Meson Center beam line configuration need not be changed. We will reduce the amount of upstream beam absorber (from the current 3" of Pb and 18" of Be to only 3" of Pb) so that the kaon yield increases by 2.5, although the neutron flux then increases by a factor of five. We gain an additional factor of 6 with 2×10^{12} protons per spill and using both K_L beams (scaled from our published result which was obtained with 7×10^{11} pps and one K_L beam). The K_L flux per spill will then be ~8×10^{7}, and the neutron to K ratio in the beam will be ~2:1.

The acceptance of the detector was calculated as follows. Kaons are generated with an energy spectrum in accordance to Malensek's formula [11] for a decay volume of 59 meter from z=100 m to the first drift chamber (z=159 m) and energy from 20 to 220 GeV. These events passed the hardware trigger requirement and were fed through the analysis with the cuts described ($M_{ee} > 150$ MeV, 125 MeV $< m_{\pi^0} <$ 145 MeV, 489 MeV $< m_K <$ 507 MeV and $P_t^2 <$ 200 MeV^2). The acceptance for a decay fiducial length of 59m and kaon energy from 30 to 150 GeV is 10%. This calculation assumes the instrumentation of the two beam holes at the leadglass with a high rate and radiation resistant calorimeter (a gain of 2 in acceptance). Figure 6 shows the acceptance vs M_{ee} without the $M_{ee} > 150$ MeV cut.

Scaling from our current E-731 result with a two month run, we obtain a sensitivity $\sim 2.0 \times 10^{-10}$ at 90% confidence. This run is also essential for detector engineering and development for the subsequent search.

ii) Phase II (1991-1992)

We need:

a) 3×10^{12} proton per spill for five months (assumes 80 hours/week) for data taking and one extra month for calibration, tuning etc.;

b) the neutral beam production collimator and associated elements of the Meson Center beam line need to be reconfigured from the current two 1/4" x 1/4" holes to one 1" x 1" hole;

c) the projected beam size at the leadglass array is 16" x 16"; therefore a similar size high rate, radiation resistant fine-segmented calorimeter is needed.

The kaon flux essentially scaled as the area of the beam, i.e. a gain of eight compared to Phase I or $\sim 6 \times 10^{8}$ per spill. The sensitivity is $\sim 1.0 \times 10^{-11}$ for the run.

4) Current Detector and New Hardware

We need the following changes and additions to our detector:

a) The 'trigger plane' counters (z=137m), which are two 40cm (W) x 60cm (H) x .1cm (T) scintillation counters in vacuum are a source of accidentals from beam interaction. It will be removed in Phase I. There will be no material in the decay region until the vacuum window (z=159m). The lead mask, which is located at z=120m, will be moved to z=100m to increase the decay fiducial length. The operations involved for the movement are straight forward.

b) The Transition Radiation Detector (TRD) provides non-destructive particle identification. The main properties of transition radiation from the detector viewpoint could be summarized as follows: i) the practical detected energy interval of TR photons is 3-20 KeV with the peak at ~10 KeV; ii) the photon yield of realistic radiators is low (~0.1γ/cm); and iii) the emission angle of TR is very small, so that TR is always detected together with ionization losses of the particles in TRD; dE/dx is the main background for TR detection, unless the particle is deflected by a magnetic field. The usual TRD structure is of the multi-layer radiator/detector type. A π/e rejection ratio of ~100 (with 90% electron efficiency) [17,18] has been achieved with four modules of TRD. Each module will consist of the transition radiator material layer followed by a xenon filled wire chamber. For easy handling and construction, the radiator under consideration is polypropylene fibers 20-40 μm diameter and 60-80 mm long compressed to a density of ~0.1 gm/cm^3 and ~ 7-10 cm in thickness. This radiator compares favorably with the Li foils and polyethylene foils in TR yield. The xenon filled 1.8m (W) x 1.8m (H) x 1.5 cm (D) chambers have 1cm sense wire spacing and need only x or y plane readout. Each sense wire will be instrumented with a 100 MHz, 8-bit FADC's to record the pulse height profile so that the 'cluster-counting' technique [19] could be performed. The radiation length is about 1% per module. Developmental work on a full size prototype (Fig.8) which includes front-end and readout electronics, wire chamber design, and Monte Carlo calculation (TR yield and signal analysis) is being carried out by the collaboration. We project the full implementation in Phase I.

(c) The calorimeter covering the central region is required to be fast in order to reduce accidental overlaps and to withstand 30 krad/week of radiation without sacrificing good resolution (large light output) and good two-cluster separation (short Moliere radius). Two candidates are being considered:

i) BaF_2 scintillator has a fast emission component with 0.6 ns decay time at 220 nm as well as a slow component at 310 nm [20]. Using a UV broad-band filter (35% transmission at the peak), the fast component alone can be selected. It has been shown that BaF_2 survives a radiation exposure of order 10^7 to 10^8 rad, and that the recovery of transmission with time is good especially for the fast component [21]. The Moliere radius is about 80% of that for F2 leadglass.

ii) the PbF_2 Cerenkov counter has been neglected for 20 years until very recently, when it attracted attention due to its fast timing, short radiation length (1cm), small Moliere radius (50% of F2), and possible radiation hardness [22]. The light output per GeV and per unit wavelength is about 60% that of F2 leadglass; the transmission range, however, extends down to 270 nm, and in the end it may give better resolution than F2.

We plan to test these calorimeters by installing them in each of the two holes in the Phase I run. The successful candidate will replace the central region (about 18"x18") for the Phase II run. Figure 9 shows the test assembly for the BaF_2. The division into front and back halves will allow us to improve the energy resolution for photons.

(d) A Track-Processor is under design and construction for E-773 [23]. This processor has several INMOS T800 Transputers (a 10 MIPS RISC CPU chip) to calculate quantities from the drift chamber hit patterns to reduce trigger rate. This upgrade constitutes an important part of our triggering abilities for both E-773 and this experiment.

(e) We have twelve planes of photon veto counters (Fig.2) located at various positions of the detector. Background with accidentals (see section 6) from $K \rightarrow 3\pi^0$ decays will be further reduce by strategically positioning additional upstream (z<100m) photon veto counters to detect photons that fall outside the calorimeter acceptance.

The current leadglass array does suffer from radiation damage (~ 6 rad/week for the worst block which translated to ~2% loss in gain). A high intensity UV light source was used to 'cure' the damage (>90% recovery). The procedure typically took about 24 hours. The group has accumulated a vast amount of experience on this subject. The source of the damage is also under active pursuit and there are indications that it largely comes from hadron interactions in the vacuum 'trigger counters' which will be removed.

The singles rate of the drift chambers is muon flux dominated. The chambers were operated with 2×10^{12} pps for four months during the 1987-1988 run. We have confidence that they will perform as well in this experiment.

5) Trigger and Data Acquisition

In Phase I, by requiring the total energy in the leadglass array to be more than 25 GeV and four clusters found by the trigger processor in the leadglass array, the trigger rate scaled from E-731 is estimated to be 10 KHz. Requirement of two tracks in the drift chambers (hodoscope B has more than 1 hit and the track processor finds two tracks) will further reduce the rate to 600 Hz. The trigger rate largely comes from $K_L \rightarrow \pi^+\pi^-\pi^0$ decays. With the hodoscope located behind the lead wall in veto and one out of the four TRD modules in the trigger, the rate drops to ~100 Hz. The current date acquisition system, which is FASTBUS based, has an event deadtime of <1 msec. The projected system live-time is ~90%.

In Phase II, with the modified collimator with 3×10^{12} protons on target, the trigger rate will be ~ 800 Hz. We anticipate to employ an ACP system online to calculate kinematic quantities such as event invariant mass and E/P for tracks and be able to veto the $K_L \rightarrow \pi^+\pi^-\pi^0$ decays. The group has extensive experience with the ACP for offline analysis.

6) Background Sources

The background to $K \rightarrow \pi^0 e^+ e^-$ decay, if assumed to be coming from other K decay, could be categorized into combinations of three effects; namely, 1) missing final state photons, 2) particle mis-identification and 3) overlays with accidentals. In this section, we shall describe the various background sources and the corresponding levels predicted by Monte Carlo calculations. The Monte Carlo program used is the same one as used in the 2π ε'/ε measurement and includes very detailed simulation of the detector responses and resolutions. Various modes of K and π decays were generated with the corresponding form factors. With a cut of $0.9<E/P<1.1$ on the charged particles, the π/e rejection ratio is about 100. We also assumed a π/e rejection ratio of 100 with four modules of Transition Radiation Detector. The cuts applied to define a good event are the same as used in the acceptance calculation.

The backgrounds which involved accidentals were simulated with the Monte Carlo generated decay overlaid with the 'accidental trigger' data taken during the E-731 run. This data measured the true detector response weighted by the instantaneous proton intensity. The 'accidental' data used corresponds to $2\text{x}10^{12}$ pps on target.

The various backgrounds shown below could be expressed as,

$$\frac{\text{Event}_{\text{pass}}}{\text{Event}_{\text{gen}}} \text{ x } \Pi\,(\text{br}_i) \text{ x } \Pi\,(\text{reject}_i) \text{ x } \frac{1}{\text{acceptance}}$$

where $\text{Event}_{\text{pass}}$ is the number of simulated events that pass all cuts, $\text{Event}_{\text{gen}}$ is the equivalent number of events generated, br_i are branching ratios involved, reject_i are π/e rejection of the detector, and acceptance is 10% for signal as described previously in section 3.

We list below various simulated backgrounds and their corresponding predicted levels:

i) and ii)

$$K_L \rightarrow \pi^0\pi^0\pi^0 \quad \llcorner\!\!\rightarrow e^+e^-\gamma$$

$<1.0\text{x}10^{-15}$

i) $K_L \to 3\pi^0$ with a π^0 undetected and another π^0 Dalitz decay with the γ undetected or fused with others; and ii) $K \to 3\pi^0$ with a π^0 undetected and another π^0 double Dalitz decay with one of the two pairs undetected. Both cases have a missing π^0, thus the reconstructed K mass is at most 363 MeV; these backgrounds are negligible.

iii)

$K_L \to \pi^0\pi^0\pi^0$

$\qquad\qquad \hookrightarrow e^+e^-\gamma$

$\qquad\quad \hookrightarrow e^+e^-\gamma$ [$<2.6\times10^{-10}$ (90%CL)]

$K_L \to 3\pi^0$ with two π^0 each Dalitz decay of which the two γ fused with others or undetected and also two of the four electrons undetected: B.R.($K_L \to 3\pi^0$)=0.21, B.R.($\pi^0 \to ee\gamma$)=0.012; with 2.63 million events generated, none was reconstructed. Although the background is then calculated to be only $<2.6\times10^{-10}$ at 90% confidence level, it is only limited by amount of computing time accessible.

This decay requires that both e^+e^- pairs have to decay asymmetrically, the correct four bodies detected out of a eight-body final state decay and small energy loss from the undetected particles. It is unlikely that this background is significant, but a high statistics Monte Carlo calculation will be performed.

iv)

$K_L \to \pi^0\pi^0$

$\qquad\quad \hookrightarrow e^+e^-\gamma$ $<1.\times10^{-13}$ (90%CL)

$K_L \to 2\pi^0$ with a π^0 Dalitz decay with the γ undetected or fused: the background is negligible with the cut of $M_{ee}>150$ MeV made. Figure 7 shows the M_{ee} spectrum of the π^0 Dalitz decay.

v)

$$\begin{array}{l} K_L \to \pi^0\pi^0 \\ \qquad\quad \hookrightarrow e^+e^-e^+e^- \end{array}$$

$<4.\mathrm{x}10^{-13}$ (90%CL)

$K_{L)}2\pi^0$ with a π^0 double Dalitz decay with two of the four electrons undetected: with B.R.($K_L \to 2\pi^0$)=0.1% and B.R.($\pi^0 \to eeee$)=$3.2\mathrm{x}10^{-5}$; no event survived with 1.82 million generated. The background is $<4.\mathrm{x}10^{-13}$ at 90% confidence.

vi)

$$\begin{array}{l} K_L \to \pi^0\pi^0 \\ \qquad\quad |\;\; \hookrightarrow e^+e^-\gamma \\ \qquad\quad \hookrightarrow e^+e^-\gamma \end{array}$$

$<3.3\mathrm{x}10^{-12}$ (90%CL)

$K \to 2\pi^0$ with both π^0 Dalitz decay and two out of the four e^+/e^- undetected: B.R.($K_L \to 2\pi^0$) =0.1%, B.R.($\pi^0 \to ee\gamma$)=1.2%; no event survived with 1 million events generated. The background is $<3.3\mathrm{x}10^{-12}$ at 90% confidence.

vii)

$$\begin{array}{l} K_L \to \pi^0\pi^0 \\ \qquad\quad \hookrightarrow e^+e^- \end{array}$$

[$1.8\mathrm{x}10^{-11}$]

$K \to 2\pi^0$ with a π^0 decay to e^+e^- : B.R.($K \to 2\pi^0$)=0.1% and B.R.($\pi^0 \to e^+e^-$) =$0.18\mathrm{x}10^{-6}$; with 10% acceptance,we should be able to observe this at $1.8\mathrm{x}10^{-11}$ level but it could be easily handled because M_{ee} would be reconstructed as π^0 mass with 2 MeV resolution.

viii)

$$K_L \to \underset{\substack{\downarrow\,\downarrow\\(e^+e^-)}}{\pi^+\pi^-}\pi^0 \qquad\qquad <1.\mathrm{x}10^{-13}\ (90\%\mathrm{CL})$$

$K\to\pi^+\pi^-\pi^0$ but with both charged pions misidentified as electrons : B.R.($K\to\pi^+\pi^-\pi^0$) =0.124; pion rejection ratio of $(10^{-4})^2$; no event survived out of 0.287 million generated; the background is $<1.\mathrm{x}10^{-13}$ at 90% confidence.

ix)

$$K_L \to \underset{\substack{\downarrow\\(e^+)}}{\pi^+}\pi^0 e^-\nu \qquad\qquad <1.6\mathrm{x}10^{-13}\ (90\%\mathrm{CL})$$

$K\to\pi^+\pi^0 e^-\nu$ with the charged pion misidentified as electron : B.R.($K_L\to\pi^+\pi^0 e\nu$) = $6.2\mathrm{x}10^{-5}$ and 10^{-4} pion rejection; no event survived with 0.91 million generated. With 90% confidence, this background is $<1.6\mathrm{x}10^{-13}$.

x)

$$K_L \to e^+e^-\gamma + \gamma_{acc} \text{ or}$$
$$K_L \to e^+e^-\gamma + 2\gamma_{acc} \qquad\qquad 5.3\mathrm{x}10^{-12}$$

$K\to e^+e^-\gamma$ (K Dalitz decay) overlaps with one or two accidental γ : B.R.($K_L\to e^+e^-\gamma$) $=1.7\mathrm{x}10^{-5}$; equivalent to 32.4 million decays was generated and overlapped with the 'accidental' data, one event survived. The background is $5.3\mathrm{x}10^{-12}$.

xi)

$$K_L \to \underset{\substack{\downarrow\,\downarrow\\(e^+e^-)}}{\pi^+\pi^-}\gamma + \gamma_{acc} \qquad\qquad 2.2\mathrm{x}10^{-13}$$

$K \to \pi^+\pi^- \gamma$ (radiative 2π) overlaps with an accidental γ and with both charged pions misidentified as electrons: B.R.($K_L \to \pi^+\pi^- \gamma$, γ threshold at 30 MeV) = $4\text{x}10^{-5}$, pion rejection ratio of $(10^{-4})^2$; 30 events passed all cuts out of 11.4 millions generated, the background is $2.2\text{x}10^{-13}$.

xii)

$$K_L \to \underset{\substack{\downarrow \\ (e^+)}}{\pi^+} e^- \nu\gamma + \gamma_{acc} \qquad\qquad 2.2\text{x}10^{-12}$$

$K \to \pi^+ e^- \nu \gamma$ (radiative K_{e3}) overlaps with an accidental γ and with the charged pion misidentified as electron: B.R.(K_{e3})=0.387 and 5% of which a γ is emitted with center of mass energy greater than 5 MeV, pion rejection of 10^{-4}; 10 events survived all the cuts out 9.45 millions generated. The estimated background level is $2.2\text{x}10^{-12}$.

xiii)

$$K_L \to \underset{\substack{\downarrow \\ (e^+)}}{\pi^+} e^- \nu + 2\gamma_{acc} \qquad\qquad <7.3\text{x}10^{-12} \text{ (90\%CL)}$$

K_{e3} decay with two accidental γs and the charged pion misidentified as electron: with B.R.(K_{e3})=0.387, pion rejection of 10^{-4}; no events survived with the equivalent of 122 million generated and overlapped with the 'accidental' data. The estimated background is $<7.3\text{x}10^{-12}$ with 90% confidence.

The background that involve accidentals could be further suppressed if one assumes the extra one or two photons actually come from $K \to 3\pi^0$ decay by vetoing on the five or four otherwise undetected photons with the veto planes (see section 4(a) and (d)).

7) Summary

We propose to search for the $K_L \rightarrow \pi^0 e^+ e^-$ decay mode with a Phase I run during the next Fixed Target period (1989-1990) following the scheduled E-773 (a CPT violation test in neutral kaon system [22]) run period. With 650 hours of 2×10^{12} pps, no change to the existing beamline and a modest upgrade of the current E-731 detector, this run will yield $\sim 1 \times 10^{-10}$ sensitivity.

A Phase II run (1991-1992) with 1600 hours of 3×10^{12} pps and a modest modification to the MC beam configuration will yield a $\sim 1 \times 10^{-11}$ sensitivity. We hope we have convinced the readers of the technical feasibility to perform the experiment at Fermilab. The $K_L \rightarrow \pi^0 e^+ e^-$ decay mode besides providing a test of Standard Model, offers an attractive alternative to explore CP violation which is a central issue in elementary particle physics. We feel that if the decay is observable within the experimental sensitivity, we should see it first.

Appendix I. The $\pi^0 \rightarrow e^+e^-$ decay and other Rare Kaon Decays

We describe some other rare decay modes which are also within the experimental reach of the proposed experiment. Besides providing a very interesting physics playground, these decays also serves as 'calibration' at different sensitivity level.

a) $\pi^0 \rightarrow e^+e^-$

Basically this decay could be described by a fourth order electromagnetic diagram (Fig.10) and the branching ratio is calculated to be > 4.8×10^{-8} (the unitarity limit). The published B.R. ($\pi^0 \rightarrow e^+e^-$) = $(1.8 +/- 0.7) \times 10^{-7}$, comes from two measurements [13,14]; but there is mild controversy on the validity of the results. A new technique was used to search for this decay in the current E-731 data. We have collected about 15 million reconstructed $K \rightarrow 3\pi^0$ decay with the 'six-cluster' trigger data. The signature of $\pi^0 \rightarrow e^+e^-$ is then two tracks matched with the leadglass showers and reconstructed a π^0, the four extra clusters reconstructed as $2\pi^0$, and all six clusters reconstructed as a kaon coming from the target. Figure 11 shows the scatterplot of M_{ee} vs $M_{3\pi}$ for 30 % of the total sample and corresponds to a limit of $<2.5 \times 10^{-7}$ (90% confidence). There is no background and we believe this 'tagged pion' technique could be exploited much further and a definite measurement could be made.

(b) $K_L \rightarrow \pi^0 \gamma\gamma$

The predicted branching ratio of $K_L \rightarrow \pi^0 \gamma\gamma$ [1,12] is $\sim 7 \times 10^{-7}$. The current experimental limit [24] is B.R.($K_L \rightarrow \pi^0 \gamma\gamma$) < 2.4×10^{-4}. This decay is interesting in the context of Chiral Perturbation Theory and is crucial for the theoretical prediction of the amount of CP violation in $K_L \rightarrow \pi^0 e^+e^-$ decay. We plan to search for the decay via the π^0 Dalitz decay. The e^+e^- vertex, reconstructed π^0 mass and K_L mass provides an unambiguous signature.

(c) $K_L \rightarrow e^+e^- \gamma$ (K_L Dalitz decay)

The world total observed number of these decay was four and the published branching ratio [16] is $(1.7 +/- 0.9) \times 10^{-5}$. Twelve events were reconstructed from a partial E-731 data set. Figure 12 shows the reconstructed kaon mass vs electron pair mass distribution. The kaon mass resolution is about 8 MeV and the mass peak is well separated from the low mass events (from radiative K_{e3}). We estimate about 100 events from the entire data set. There is theoretical interest [15] in the distribution of the e^+e^- invariant mass.

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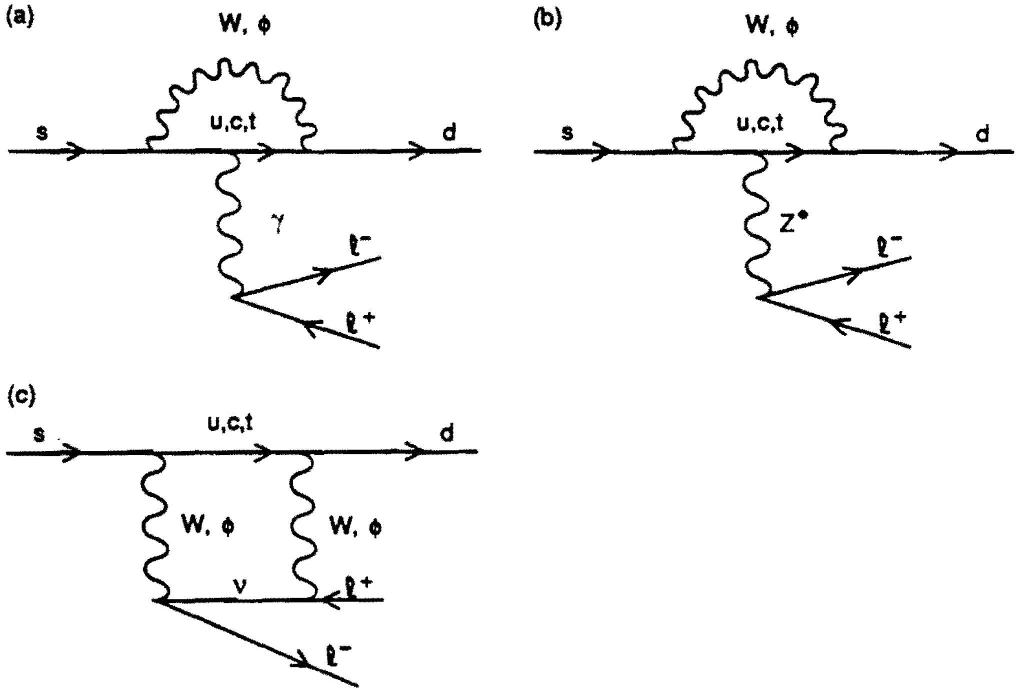

Figure 1 Three diagrams giving a short distance contribution to the process $K \to \pi l^+ l^-$: (a) the 'electromagnetic penguin', (b) the 'Z penguin', (c) the 'W box'. (From C.O.Dib,I.Dunietz,and F.Gilman of ref.1)

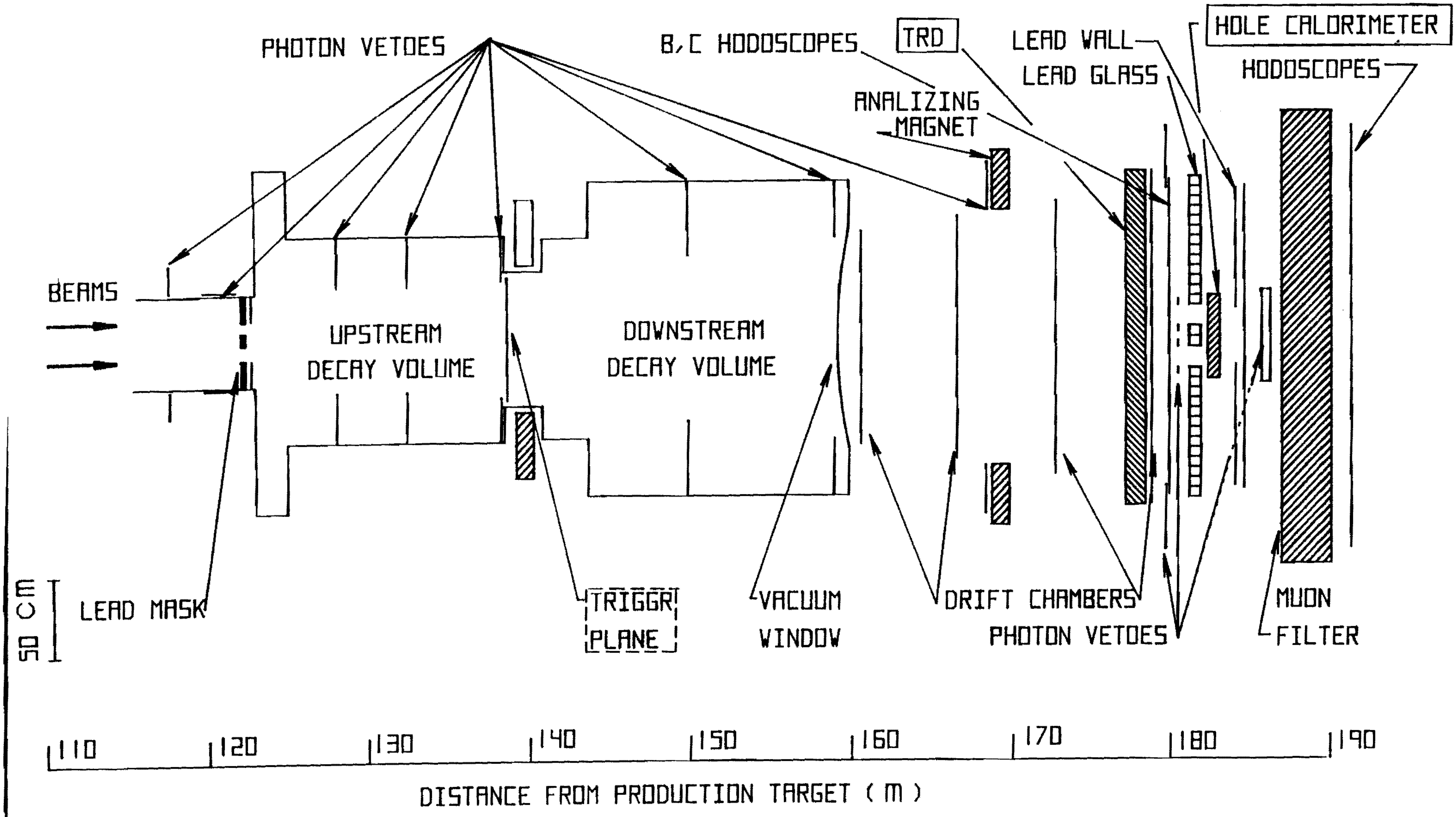

Figure 2 Schematic of the detector in the Meson Center beamline. *Items labelled with boxes are new equipment. The 'Trigger*

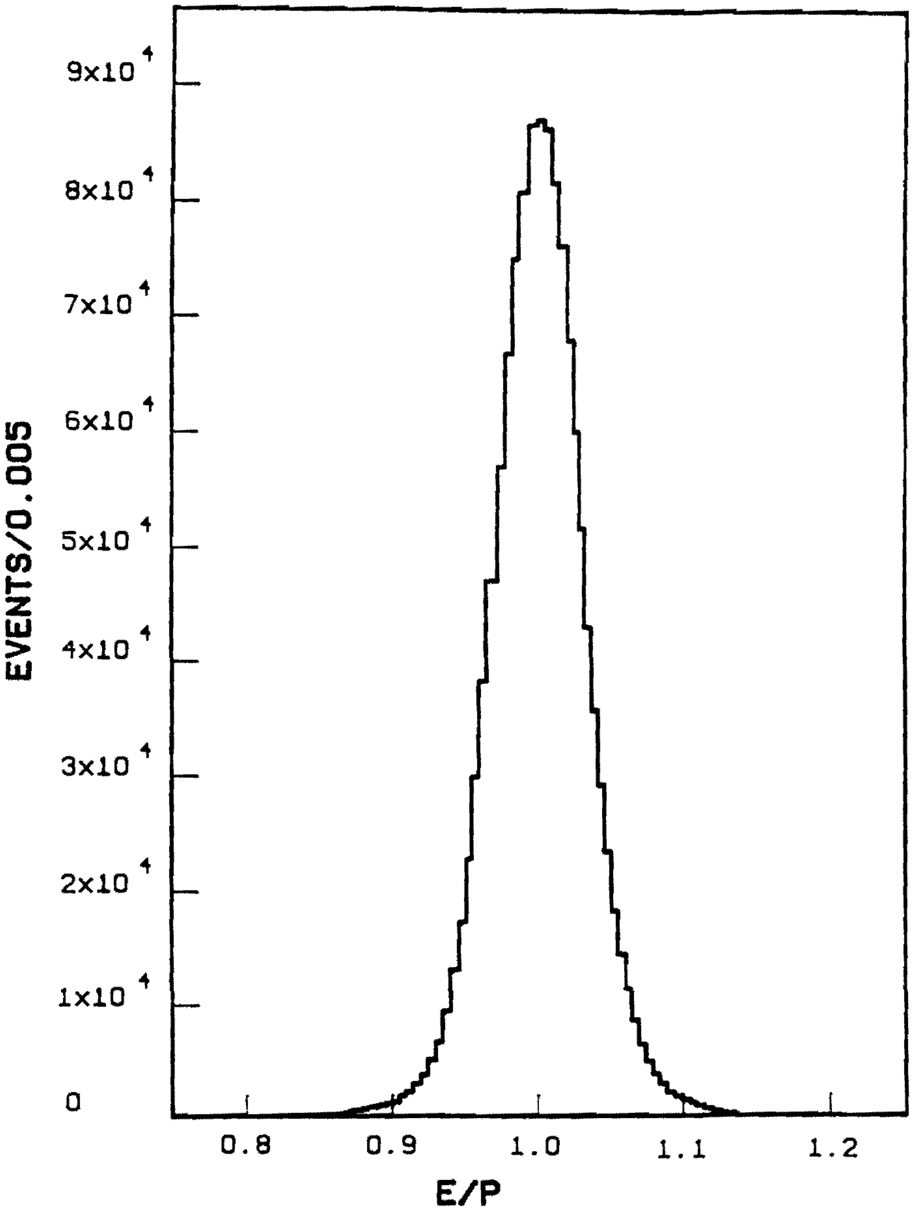

Figure 3 Distribution of E/P in the leadglass from the electron calibration data. The resolution is about 4% rms.

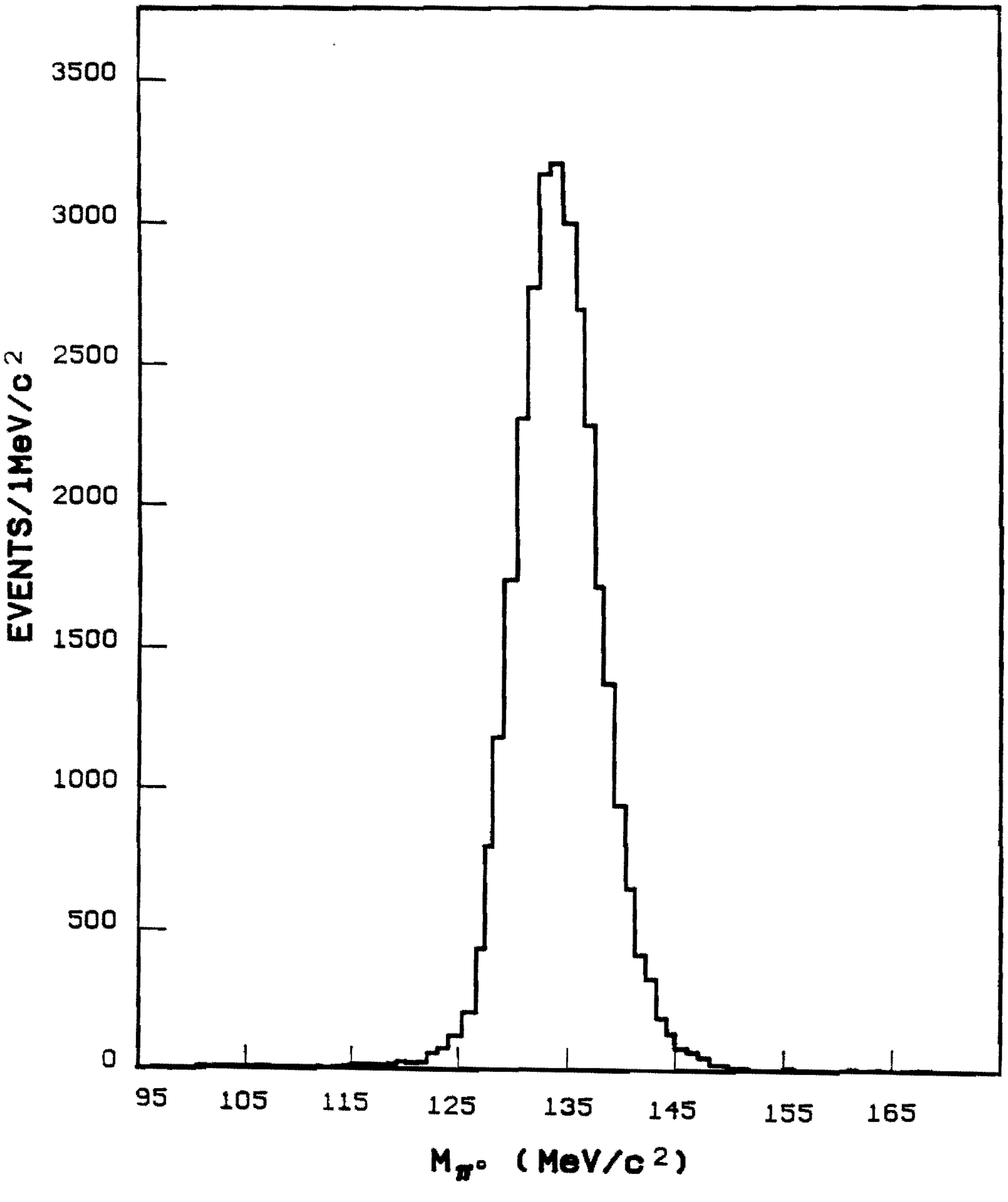

Figure 4 Distribution of the π° mass reconstructed from $K_L \to \pi^+ \pi^- \pi^\circ$ decays. The resolution is 4 MeV/c^2.

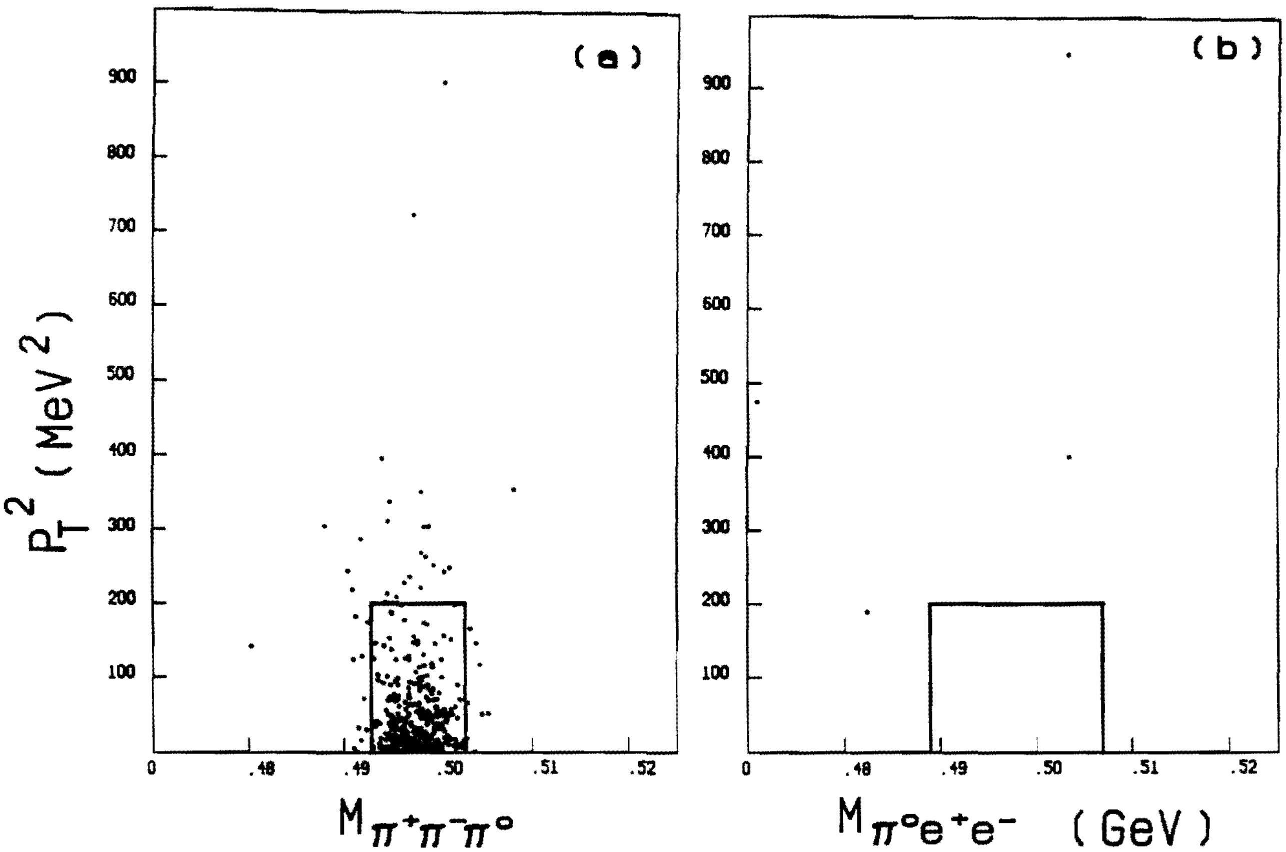

Figure 5 Reconstructed kaon mass vs. the square of the transverse momentum for (a) $K_L \to \pi^+\pi^-\pi^\circ$ and (b) $K_L \to \pi^\circ e^+e^-$. The events in the plots were selected with a π° mass cut of 2.5σ and the boxes represent the signal region.

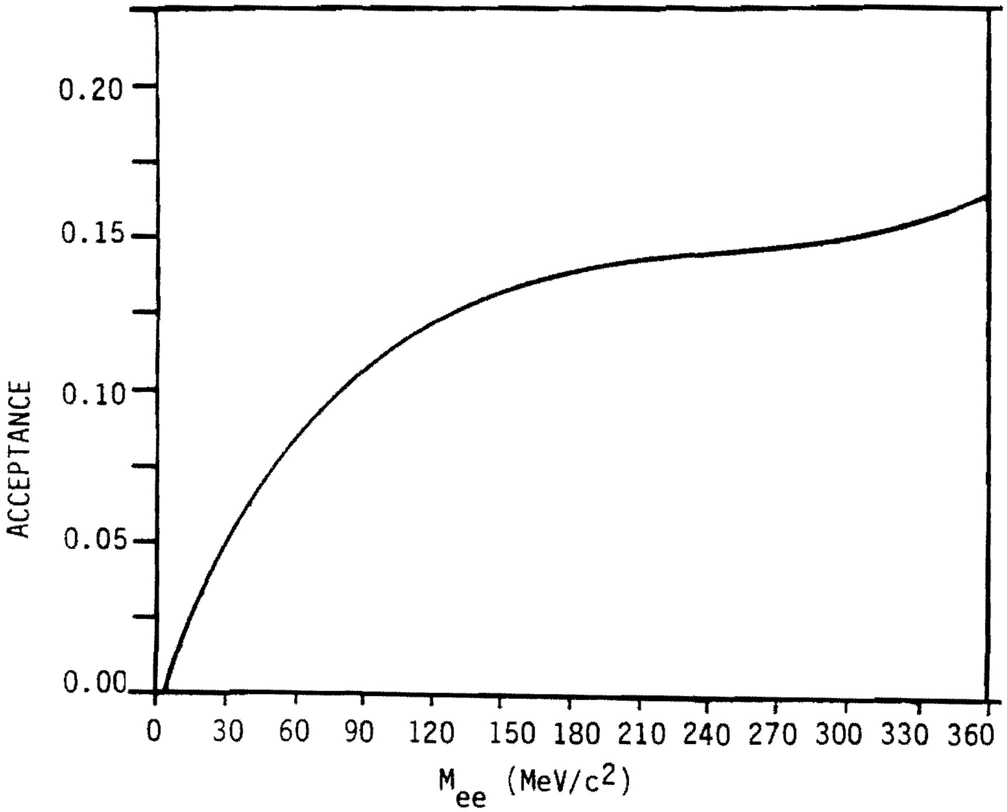

Figure 6 The acceptance of the $K_L \to \pi^0 e^+ e^-$ vs. M_{ee}

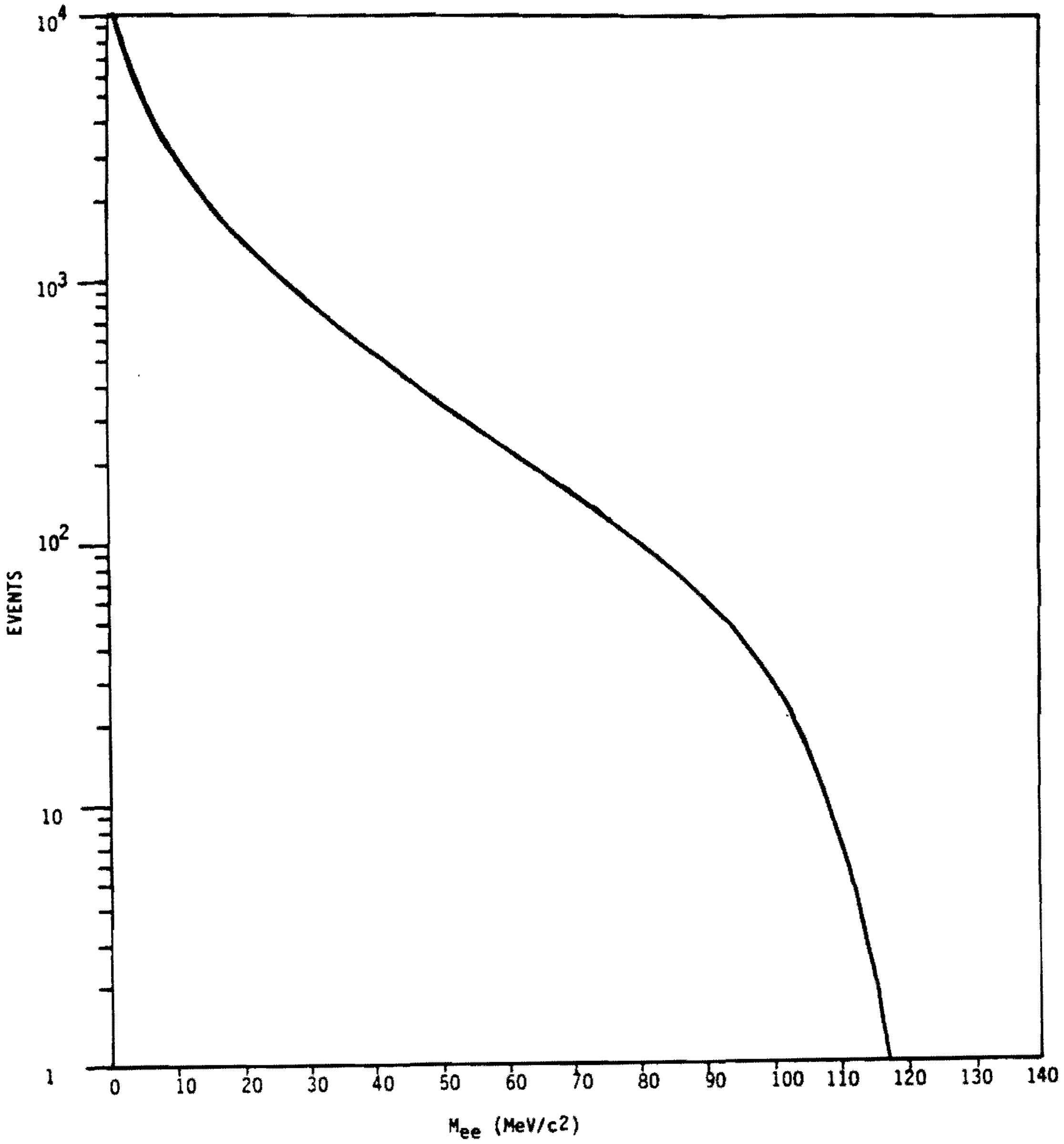

Figure 7 The M_{ee} distribution for the π° Dalitz decay.

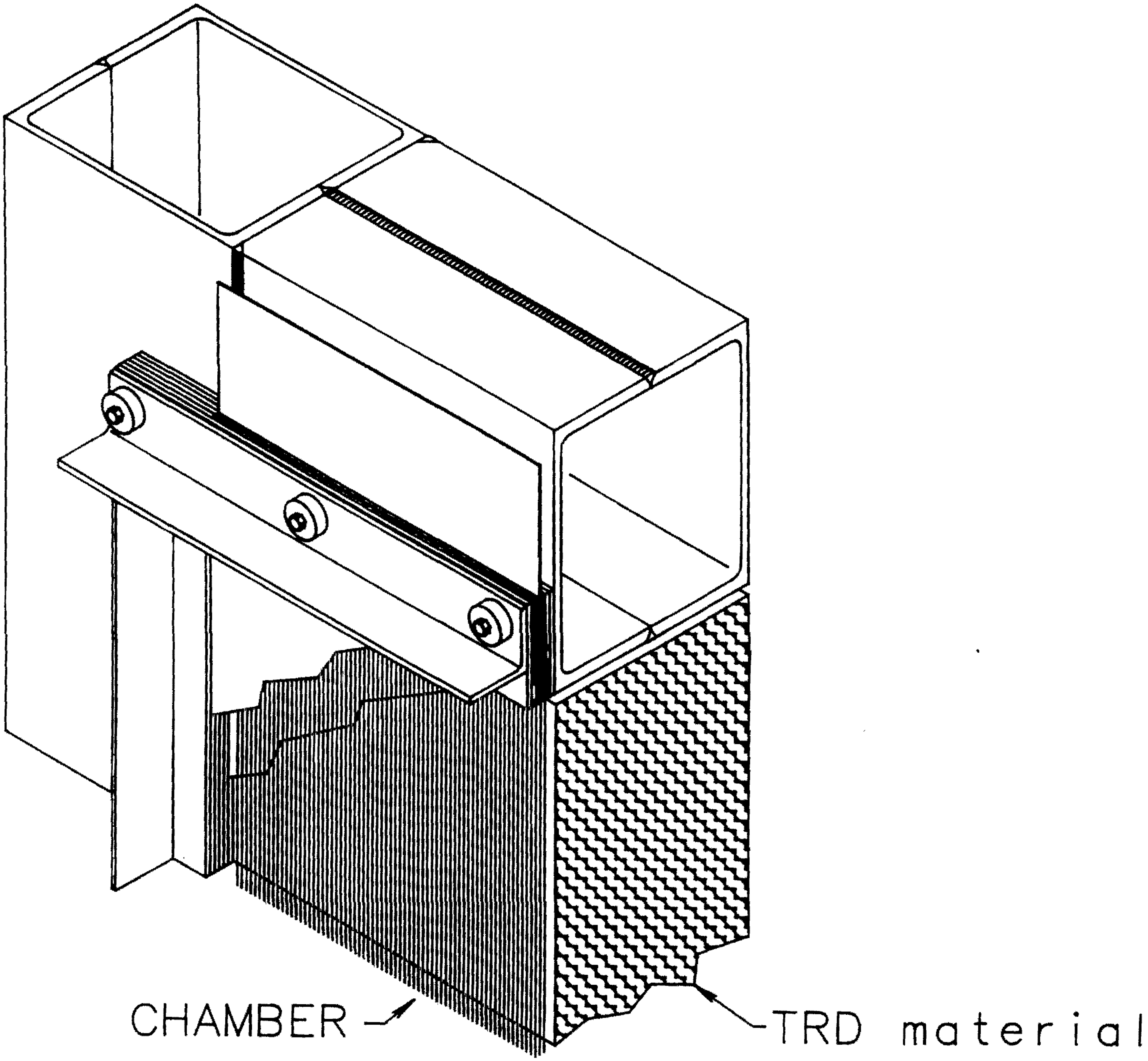

Figure 8 The Transition Radiation Detector. The size is 1.8 m x 1.8 m x 10 cm.

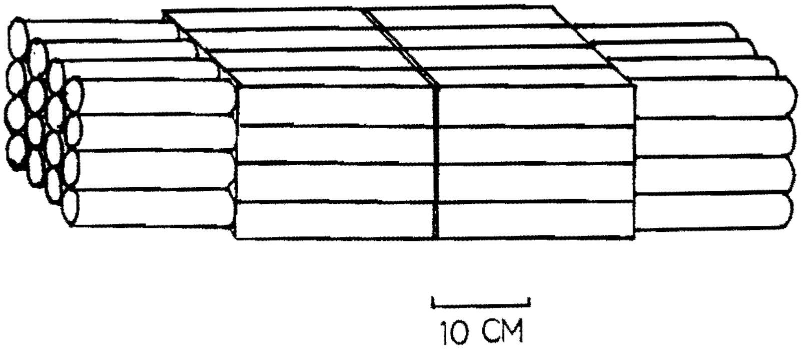

Figure 9 The beam hole calorimeter.

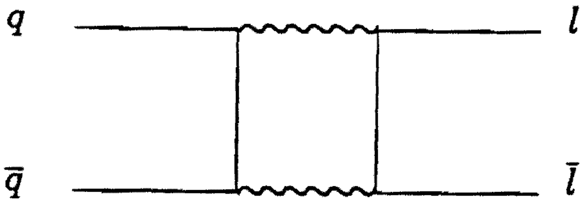

Figure 10 The Feynman diagram of $\pi^\circ \rightarrow ee$ decay.

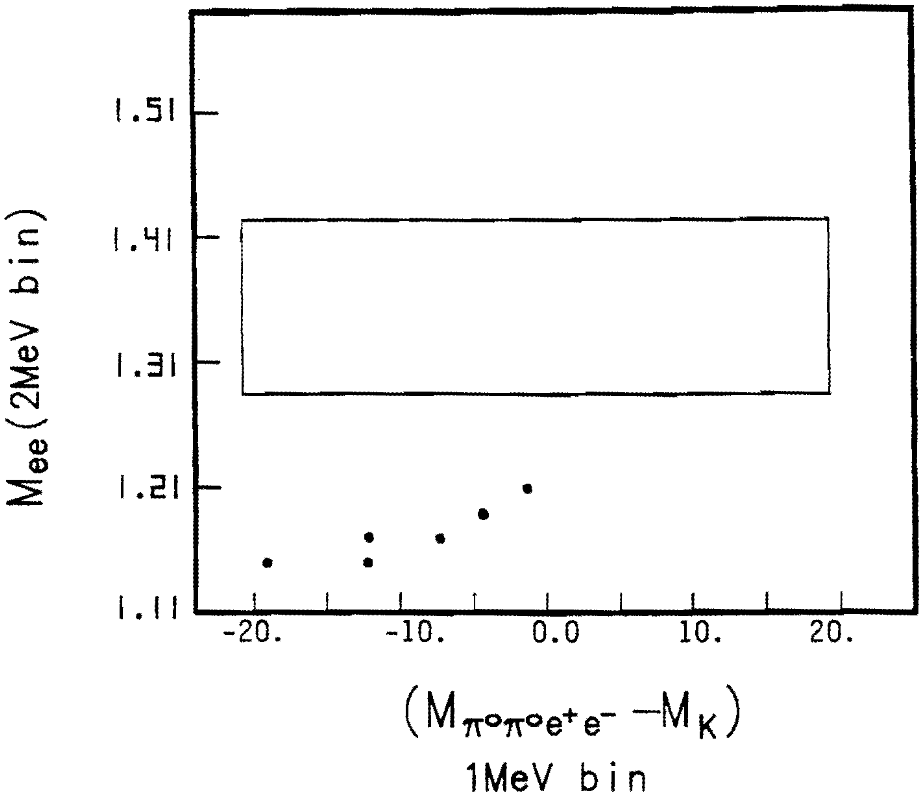

Figure 11 Reconstructed e^+e^- invariant mass vs. kaon mass for the 'six-cluster' trigger data. The box represent 90% confidence signal region.

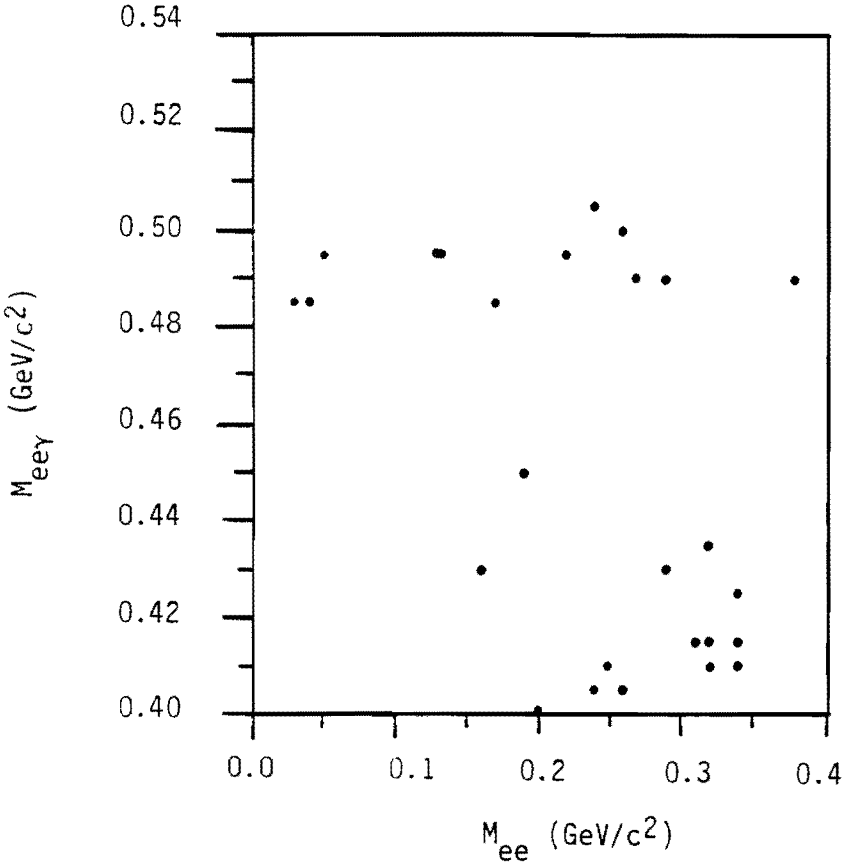

Figure 12 $M_{ee\gamma}$ vs. M_{ee} of K_L Dalitz decay. The mass resolution is 8 MeV. The low $M_{ee\gamma}$ events are due to radiative K_{e3} .

DRAFT

September 16, 1993

Memorandum of Understanding
among
Fermilab KTeV Colaborators
and
Fermi National Accelerator Laboratory

TABLE OF CONTENTS

1. INTRODUCTION

This Memorandum of Understanding describes the KTeV collaboration of members of the Fermilab Accelerator Division(AD), Computing Division(CD), ES&H Section(ES), Physics Department(PD) and Research Division(RD) in the KTeV detector/facility project at Fermilab. The purpose of this collaboration is the design, fabrication, operation and scientific exploitation of the KTeV detector at FNAL to study rare kaon decays and CP violation. The present state of the design of the detector is described in the KTeV Design Report (January, 1992 FN-580) and in design notes filed in the KTeV library.

The organization, leadership, operating procedures and the present membership of the KTeV Collaboration are described in the KTeV Project Management Plan, dated July 1993, which will be approved by Fermilab. This management plan will also be updated as necessary.

This is a Memorandum of Understanding among the Fermilab KTeV collaborators and FNAL. It represents our best understanding of the plans for the implementation of those items in KTeV that Fermilab is responsible for; it does not constitute a legal contractual obligation on the part of either of the parties.

2. SCIENTIFIC PERSONNEL

2.1 List of Personnel

Participating scientists committed to KTEV experiments with fraction of research time on KTeV if it has been negotiated and becomes available:

Accelerator Division:	
Rick Coleman	50%
Computing Division:	
Ruth Pordes	
ES&H Section:	
Kamran Vaziri	20%
Physics Department:	

Yee Bob Hsiung(Fellow)	100%	
Hogan Nguyen(PD)	100%	
Stephen Pordes		
Erik Ramberg(PD)		
Robert Tschirhart(Fellow)	80%	Until completion of E799-I
	100%	Beginning 1/1/94
Julie Whitmore(PD)	100%	
Research Division:		
Greg Bock	100%	
Sam Childress	90%	
Mike Crisler	100%	
Rick Ford		
Doug Jensen	100%	
Tom Kobilarcik		
Ron Ray	90%	
Herman White		

We will likely add new research associates and scientists to KTeV as the project progresses.

2.2 Other Research Commitments

E. Ramberg and R. Tschirhart will be involved in finishing the analysis and publication of results from the 1991 run of Fermilab E773 and E799-I. S. Pordes and R. Ray will be involved in finishing the analysis and publication of results from Fermilab E760 and some modest involvement in E835. Except postdocs and fellows, Fermilab staffs generally will have other assigned laboratory duties or responsiblities.

Until the commitments described in section 3 are fulfilled, new research commitments by any members of the group are strongly discouraged and in any case must be made with the knowledge to KTeV Collaboration Council.

Other Fermilab Senior Scientists may join the group, subject to approval by the KTeV Collaboration Council. Research Associates, Fellow and Junior Scientists can join at the discretion of the Fermilab KTeV group.

2.3 Representative to the Collaboration Council

Y.B. Hsiung and R. Tschirhart will be the Representative of the Fermilab group on the KTeV Collaboration Council.

3. FABRICATION RESPONSIBILITIES

3.0 General Description and KTeV Project

Fermilab has a number of responsibilities in the KTEV collaboration. These are: construction of primary beamline (3.1); secondary beamline (3.2); vacuum system for the decay region (3.3) including regenerator mover; vacuum ring vetoes (3.4); analysis magnet (3.5); TRD chambers and recirculating gas system (3.6); CsI crystal procurement (3.7); CsI PMT base mechanical design and CsI block house (3.8); CsI laser calibration system (3.9), CsI digital PMT base (3.10), CsI digital pipeline readout system (3.11); TDC, FERA ADC and Latch system (3.12); DAQ system (3.13); Steel muon shield and hadron veto lead wall (3.14); HV and delay cables (3.15); new KTeV experimental facility (3.16).

To coordinate the management of the budget, construction, facility and schedule of the KTeV experiments, an organization of KTeV Project has been formed in the Research Division. The description of the KTeV Project, detector/facility subsystems and organization will be detailed in the "KTeV Project Management Plan". The current KTeV Project management consists of:

KTeV Project Head:	Bruce Winstein
Deputy Head:	Greg Bock
Technical Coordinator:	Mike Crisler
Facility Coordinator:	Sam Childress
Project Engineer:	Dave Pushka

3.1 Primary Beam

3.1.1 Coordination and Progress Reporting (Primary Beam)

The KTeV System Manager for Primary Beam is Gaston Guitierrez (RD/OP Beams Group). The work of Fermilab on the KTeV Primary Beam will be done under his general direction. The progress of the design, fabrication and testing of the beamline components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress of the entire Primary Beam to the KTeV Management.

3.1.2 Help and Collaboration from Other Group (Primary Beam)

All design and construction related to the Primary Beam will be carried out in close communication and collaboration with other groups working on this and related subsystems. KTeV collaborators will provide necessary specifications and adequate requirements to the Beams Group.

3.1.3 Contribution of Manpower (Primary Beam)

Currently, Rick Ford, Tom Kobilarcik and Gaston Guitierrez are the Primary Beam opticians for designing the primary proton beam transport system to NM2 target enclosure.

Fermilab RD will also provide:

Mechanical engineer - 1 man-mos. (magnet supports and installation)

Mechanical technicians - 2 man-mos. (magnet supports and installation)

Electrical engineers - 5 man-mos. (DC power, instrumentation and controls)

Electrical technicians - 4 man-mos. (interlocks, instrumentation and controls)

Radiation Safty officers - 4 man-mos. (primary and secondary beams) during the design, testing and commissioning stages.

3.2 Secondary Beam

3.2.1 Coordination and Progress Reporting (Secondary Beam)

The KTeV System Manager for Secondary Beam is Rick Coleman. The work of KTeV secondary collimation system, target/dump pile, muon sweeper, absorbers etc. will be done under his general direction. The progress of the design, fabrication and testing of the Secondary Beam components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Secondary Beam to the KTeV Management.

3.2.2 Help and Collaboration from Other Group (Secondary Beam)

All design and construction related to the Secondary Beam will be carried out in close communication and collaboration with other groups working on this and related subsystems. Bill Slater at UCLA will provide the physics simulation to evaluate the input to the performance on the halo/radiation damage to CsI for the Secondary Beam design. RD/OP Beams Group will provide the simulation of muon halo and radiation dosage at the experiment and site boundary to ensure the safe of running KTeV experiments.

3.2.3 Contribution of Manpower (Secondary Beam)

Fermilab RD will provide:

Beamline physicists - 8 man-mos.
Mechanical engineers - 14 man-mos.
Draftspersons - 8 man-mos.
Mechanical technicians - 4 man-mos.
Rigging/TM - 8 crew months
Alignment Crew - 3 man-mos.
Radiation Oversight - 6 man-mos.
Electrical Engineers - 1 man-mos.
Electrical technicians - 2 man-mos.

during the design, fabrication, installation and comissioning.

3.3 Vacuum System of Decay Region

3.3.1 Coordination and Progress Reporting (Vacuum System of Decay Region)

The KTeV System Manager for Vacuum System of Decay Region is Doug Jensen. The work of KTeV vacuum vessels, vacuum pump system, regenerator tank and mover, z-calibrator and vacuum window, etc. will be done under his general direction. The progress of the design, fabrication and testing of the components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Vacuum System to the KTeV Management.

All the vacuum mechanical design have to be reviewed and approved by the RD safty review committee, chaired by Joel Meisek.

3.3.2 Help and Collaboration from Other Group (Vacuum System of Decay Region)

All design and construction related to the Vacuum System of Decay Region will be carried out in close communication and collaboration with other groups working on this and related subsystems. Rutgers will provide the Regenerator and PMT/base readout system. Fermilab Physics Department will provide the Vacuum Ring Vetoes, UCLA will provide the Mask Anti.

3.3.3 Contribution of Manpower (Vacuum System of Decay Region)

Fermilab RD will provide the following people:

Physicist - Doug Jensen
Engineers - Ron Currier, Ed Chi, Dave Pushka, Andrew Szymulanski.
Technicians - from MAB and vacuum group for mechanical assembly, vacuum testing and operation

during the design, procurement, assembly, testing and commisioning stages.

3.4 Vacuum Ring Vetoes

3.4.1 Coordination and Progress Reporting (Vacuum Ring Vetoes)

The KTeV System Manager for Vacuum System for Decay Region is Doug Jensen. The work of KTeV vacuum ring vetoes will be done under his general direction. Y.B. Hsiung will be responsible for the vacuum ring vetoes design, engineering and fabrication at Fermilab. The progress of the design, fabrication and testing of the components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the Vacuum System to the KTeV Management.

3.4.2 Help and Collaboration from Other Group (Vacuum Ring Vetoes)

All design and construction related to the Vacuum Ring Vetoes will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity.

3.4.3 Contribution of Manpower (Vacuum Ring Vetoes)

Fermilab RD and PD will provide:

Physicists - Y.B. Hsiung (50%), H. White (30%)
Engineer - Don Goloskie, Dave Pushka (5%)

Procurment - John Korienek

PD will also provide the fabrication facility and technical support for the scintillator fabrication at Lab 8 CAD/CAM/Thermwood, WLS fiber aluminized sputtering at Lab 7 polishing and vacuum sputtering, and the assembly and testing at Lab 6. The assembly project manager is Karen Kephart, who will coordinate the assembly operation between Lab 6, 7 and 8. RD will provide the vacuum tech for leak checking and vacuum test. PD E-shop will provide the PMT bases for all veto detectors. The PMT test facility at WH10E will be used for PMT test.

3.5 Analysis Magnet

3.5.1 Coordination and Progress Reporting (Analysis Magnet)

The KTeV System Manager for Analysis Magnet is Doug Jensen. The work of KTeV Analysis Magnet will be done under his general direction. The progress of the design, fabrication and testing of the components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the Analysis Magnet to the KTeV Management.

3.5.2 Help and Collaboration from Other Group (Analysis Magnet)

All design and construction related to the Analysis Magnet will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. We expect other KTeV collaborators will involve in the magnet field mapping and analysis.

3.5.3 Contribution of Manpower (Analysis Magnet)

Fermilab RD and PD will provide:

Physcists - Doug Jensen, Stephen Pordes
Engineers - Ron Fast, Don Mitchell, Chuck Grozis, Bob Wands, Ang Lee
Draftspersons/Technicians

for the design, simulation, assembly and testing of the magnet, as well as the ZIPTRACK facility for field mapping.

3.6 TRD Chambers and Gas System

3.6.1 Coordination and Progress Reporting (TRD Chambers and Gas System)

The KTeV System Manager for Particle ID (PID) is Y.B. Hsiung. The work of Fermilab KTeV TRD system will be done under his general direction. The TRD project is a collaboration between Fermilab Physics Department and Univ. of Chicago KTeV group. The TRD group (Y.B. Hsiung, E. Ramberg, J. Krider and R. Tschirhart) at Fermilab will be responsible for the design, engineering and fabrication of the TRD chambers and gas system. The progress of the design, fabrication and testing of the components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire PID to the KTeV Management.

3.6.2 Help and Collaboration from Other Group (TRD Chambers and Gas System)

All design and construction at Fermilab related to the TRD system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. Univ. of Chicago will provide the raidator for the chamber and the TRD readout and trigger electronics.

3.6.3 Contribution of Manpower (TRD Chambers and Gas System)

Fermilab PD will provide:

Physicists - Erik Ramberg, Y.B. Hsiung (30%), R. Tschirhart (10%)
Engineering Physicists - John Krider
Engineer - 1 for detailed mechanical design and support
Technicians - Gene Beck, Brian Lavoy

PD will provide a clean room in Lab 7 for the TRD chamber R&D, construction and testing, wire chamber winding facility at Lab 6 and necessary tech support. TRD chamber and recirculation system will be designed by John Krider with close collaboration with both PD and Univ. of Chicago KTeV group.

3.7 CsI Crystal Procurment

3.7.1 Coordination and Progress Reporting (CsI Crystal Procurment)

The KTeV System Manager for CsI Calorimeter is Bruce Winstein. The work of Fermilab CsI crystal procurement will be done under his general direction. The progress of the procurement and visiting vendor will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire CsI project to the KTeV Management.

3.7.2 Help and Collaboration from Other Group (CsI Crystal Procurment)

The procurement at Fermilab related to the CsI crystals will be carried out in close communication and collaboration with the Univ. of Chicago KTeV group working on the CsI crystal testing/assembly.

3.7.3 Contribution of Manpower (CsI Crystal Procurment)

Fermilab physicist Ron Ray will spend about 20% of his time to work with Fermilab contract office, vendors and Univ. of Chicago KTeV group to ensure the success of the crystals delivery.

3.8 CsI Block House and PMT/Base Mechanical

3.8.1 Coordination and Progress Reporting (CsI Block House and PMT/Base Mechanical)

The KTeV System Manager for CsI Calorimeter is Bruce Winstein. The work of Fermilab CsI Block House and PMT/Base Mechanical will be done under his general direction. Ron Ray will be responsible for the CsI block house and PMT/base mechanical design, engineering and fabrication at Fermilab. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire CsI project to the KTeV Management.

3.8.2 Help and Collaboration from Other Group (CsI Block House and PMT/Base Mechanical)

All design and construction at Fermilab related to the CsI Block House and PMT/Base Mechanical will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. Chicago will provide the stacked CsI array. Osaka will provide the PMTs and HV divider design as well as collar anti. UCSD will provide the ET trigger system. Fermilab will provide the digital PMT bases, laser calibration sysem and the related mechanical supports for the crystal and readout, as well as the humidity and temperature control system.

3.8.3 Contribution of Manpower (CsI Block House and PMT/Base Mechanical)

Fermilab RD and PD will provide:

Physicists - R. Ray (70%), M. Crisler (20%), R. Tschirhart (10%), H. Nguyen (10%)

Engineers - D. Pushka (5%), P. Wheelwright (50%), R. Woods (90%), C. Lindenmeyer (20%), Don Goloskie (20%) and one electrical engineer from PD for 3 man-mos.

Draftspersons - 1-2

during the design, construction and testing of the CsI block house, PMT/Base mechanical design and support, as well as digital PMT readout.

Fermilab will also provide machine shop time to make prototype and the use of PD PMT test facility at WH10E for R&D testing.

3.9 CsI Laser Calibration System

3.9.1 Coordination and Progress Reporting (CsI Laser Calibration System)

The KTeV System Manager for CsI Calorimeter is Bruce Winstein. The work of Fermilab CsI laser calibration system will be done under his general direction. H. Nguyen will be responsible for the CsI laser calibration design, engineering, and fabrication at Fermilab. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire CsI project to the KTeV Management.

3.9.2 Help and Collaboration from Other Group (CsI Laser Calibration System)

All design and construction at Fermilab related to the CsI laser calibration system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. Chicago will provide the CsI test array and Osaka will provide the PMTs. Fermilab will provide the high power YAG laser and quartz fibers system.

3.9.3 Contribution of Manpower (CsI Laser Calibration System)

Fermilab RD and PD will provide:

Physicists - M. Crisler, H. Nguyen (70%), R. Ray, K. Vaziri (20%)
Engineering Physicist - John Krider
Engineers - Don Goloskie
Technicians - Tim May

during the R&D, design and setup 125 channels test array, construction and installation.

PD will also provide the tech support of machine shop, E-shop and the use of PMT test facility at WH10E.

3.10 CsI Digital PMT Base

3.10.1 Coordination and Progress Reporting (CsI Digital PMT Base)

The KTeV System Manager for CsI Calorimeter is Bruce Winstein. The work of Fermilab CsI digital PMT base (DPMT) project will be done under his general direction. R. Tschirhart and J. Whitmore will be responsible to the design, engineering and fabrication of the DPMT at Fermilab. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire CsI project to the KTeV Management.

3.10.2 Help and Collaboration from Other Group (CsI Digital PMT Base)

All design and construction at Fermilab related to the CsI DPMT system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity.

3.10.3 Contribution of Manpower (CsI Digital PMT Base)

Fermilab physicists involved in the DPMT group are:

R. Tschirhart (50%), J. Whitmore (90%), R. Ray, M. Crisler, Y.B. Hsiung.

The DPMT project requires engineering expertise from several groups at Fermilab. Development and thorough testing of the current splitter chip will be a collaborative effort between the KTeV DPMT group, Bill Foster, Al Baumbaugh (RD/SDC), Ray Yarema (RD/EE) and his group.

The Physics Department is responsible for the following:

a) The mechanical/electrical interface between the digital PMT bases and the pipeline system, including the transmission cable.
b) The RF, low-voltage, and calibration control signals for the entire system.
c) Test stand and testing for production DPMT cards.
d) Commissioning of the Fermilab test array and the KTeV calorimeter.

Research Division Ray Yarema's group (RD/EE), Bill Foster and Al Baumbaugh (RD/SDC) will provide the following:

a) Design and layout of the full ranging current splitter test board.
b) Preliminary testing of the full-ranging current splitter device and for developing the digital base board.
c) Support studies and development of an on-chip electronic calibration system.
d) Support studies and development of a nine bit folding flashing encoder.

List below is the engineering time commitment necessay for the digital base project.

PD E-shop:	Sten Hansen (50%)
	Dan Graupman (25%)
	Claudio (25%)
	1 technician (50%)
RD/EE-group:	Ray Yarema (25%)
	Tom Zimmerman (50%)
	Kelly Knickenbocker(25%)
	Mahur (50%)
	1 technician (10%)
RD/SDC group:	Bill Foster (25%)
	Al Baumbaugh (25%)

3.11 CsI Digital Pipeline Readout System

3.11.1 Coordination and Progress Reporting (Digital Pipeline Readout System)

The Digital Pipeline system interfaces the output of the DPMT system that instruments the CsI calorimeter to the DART data acquisition system. The KTeV System Manager for Front-end Electronics is R. Tschirhart. The work of Fermilab CsI digital pipeline readout system will be done under his general direction. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Front-end Electronics to the KTeV Management.

3.11.2 Help and Collaboration from Other Group (Digital Pipeline Readout System)

All design and construction at Fermilab related to the digital pipeline readout system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity.

3.11.3 Contribution of Manpower (Digital Pipeline Readout System)

The project is a collabrative effort between the Research Division RD/EE group, the Computing Division OLS group, and the Physics Department. The project is lead and managed by Mark Larwill (RD/EE group), and the bulk of the design, testing and implementation will be supported by (RD/EE). The Physics Department will specify, test and install the input pipeline cables. In addition, PD KTeV personnel will provide system requirements and specifications and contribute to the design, testing and implementation of the system. The CD OLS group will contribute to the diagnostics, testing and comissioning of the final system. A description of the pipeline requirements can be found in the "Minimal KTeV Pipeline Requirements" internal KTeV memo. The conceptual design report of the pipeline system can be found in the "Conceptual Design of the KTeV Pipeline" internal KTeV memo.

Fermilab RD, PD and CD will provide the following personnel:

RD/EE group:	(System Design, testing, comissioning)
M. Larwill	Engineer (Project leader)
C. Rotolo	Engineer
M. Bleadon	Engineer
S. Chappa	Techinician
T. Fitzpatrick	Technician
C. Needles	Technician
PD group:	(System Design, testing, comissioning)
R. Tschirhart	KTeV physicist
new postdoc	KTeV physicist
CD OLS group:	
R. Pordes	KTeV/OLS
J. Anderson	OLS/DAH
O. Trevizzo	OLS/DAH

3.12 TDC , FERA ADC and Latch System

3.12.1 Coordination and Progress Reporting (TDC, FERA ADC and Latch System)

The KTeV System Manager for Front-end Electronics is R. Tschirhart. The work of Fermilab TDC, FERA ADC and latch system will be done under his general direction. The distribution and function of these channels can be found in the "Overview of KTeV Trigger and Front-end Electronics Requirements" internal

KTeV memo. Specification, testing and implementation of the non-CsI ADC system is a collaborative effort between Fermilab CD, PD and UCLA KTeV group. The ADC channels will be instrumented with the LeCroy FERA system. The TDC channels will be instrumented with CAMAC TDCs designed by the Fermilab Physics Department. The latch channels will be instrumented with CsI pipeline modules that can be configured as a 144-channel latch module. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Front-end Electronics to the KTeV Management.

3.12.2 Help and Collaboration from Other Group (TDC, FERA ADC and Latch System)

All design and construction at Fermilab related to the TDC, FERA ADC and latch readout system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. UCLA will provide students to test and comissioning the FERA ADC system. We expect other KTeV collaborators will involve the testing and comissioning of the system.

3.12.3 Contribution of Manpower (TDC, FERA ADC and Latch System)

Personnel from Fermilab:

CD/OLS/DAH: Large contingent, available for consultation and hardware (PREP) support.

CD/OLS/DAS: Large contingent, available for consultation and support for testing and PREP support.

KTeV: R. Pordes and R. Tschirhart for the system design, testing and comissioning.

3.13 DAQ System

3.13.1 Coordination and Progress Reporting (DAQ System)

The KTeV System Manager for Trigger/DAQ is T. Barker. The work of Fermilab DAQ system will be done under his general direction. The progress of the design, integration and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Trigger/DAQ to the KTeV Management. The development and design of the KTeV DAQ system is a collaborative effort between the CD DART project, Osaka and FNAL DART collaborators.

3.13.2 Help and Collaboration from Other Group (DAQ System)

All design and construction at Fermilab related to the DAQ system will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. We expect other KTeV collaborators will involve the testing and comissioning of the system.

3.13.3 Contribution of Manpower (DAQ System)

Personnel from Fermilab:
CD/OLS/DAH: Large contingent of Online Hardware Support.
CD/OLS/DAS: Large contingent of Online Software Support.
KTeV: R. Pordes, new associate scientist (CD/OLS)
R. Tschirhart, H. Nguyen, Y.B. Hsiung (PD)

3.14 Steel Muon Shield and Hadron Veto Lead Wall

3.14.1 Coordination and Progress Reporting (Steel Muon Shield and Hadron Veto Lead Wall)

The KTeV System Manager for Particle ID (PID) is Y.B. Hsiung. The work of Fermilab KTeV muon shield and hadron veto lead wall will be done under his general direction. The muon and hadron veto project is a collaboration between Fermilab and Rutgers KTeV group. The progress of the design, fabrication of the components will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire PID to the KTeV Management.

3.14.2 Help and Collaboration from Other Group (Steel Muon Shield and Hadron Veto Lead Wall)

All design and construction at Fermilab related to the steel muon shield and hadron veto lead wall will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. Rutgers will provide the scintillator hodoscope for hadron veto, muon veto and muon trigger banks and the requirements on the muon steel and lead wall design.

3.14.3 Contribution of Manpower (Steel Muon Shield and Hadron Veto Lead Wall)

Fermilab will provide:

Engineers - Dave Pushka
Draftspersons - 1-2
Technicians and riggers for installation.

Fermilab PD will also provide all the bases for hadron veto, muon veto and muon trigger counters. The PMT test facility will be used for PMT test.

3.15 HV and Cables

3.15.1 Coordination and Progress Reporting (HV and Cables)

The KTeV System Manager for Front-end Electronics is R. Tschirhart. The work of HV and cables will be done under his general direction. Fermilab will provide all the HV systems and cables. The progress of the design, fabrication and testing will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire Front-end Electronics to the KTeV Management.

3.15.2 Help and Collaboration from Other Group (HV and Cables)

The design and testing of all HV and cables will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity. We expect other KTeV collaborators involve in the testing, installation of this system.

3.15.3 Contribution of Manpower (HV and Cables)

Fermilab will provide electricians and technicians for the installation.

3.16 KTeV experimental Facility

3.16.1 Coordination and Progress Reporting (KTeV experimental Facility)

The KTeV System Coordinator for experimental facility is S. Childress. The work of KTeV facility design and construction will be done under his general direction. The progress of the design and construction will be reported on a weekly basis to the KTeV System Manager, who in turn will report progress on the entire KTeV Facility to the KTeV Management.

3.16.2 Help and Collaboration from Other Group (KTeV experimental Facility)

The design of the KTeV facility will be carried out in close communication and collaboration with other groups working on this and related subsystems to ensure the integrity.

3.16.3 Contribution of Manpower (KTeV experimental Facility)

The design and construction of the KTeV experimental facility will be contract out to the outside A/E firm and contractors. Fermilab will provide personnels from RD, FESS, BSS as planned in the "KTeV Construction Project" to ensure the success of the timely completion of the facility.

4. FACILITIES, EQUIPMENT AND SOFTWARE DEVELOPEMENT

4.0 Services

The services of the Fermilab Contract, Purchasing, Expediting, and Receiving as well as the Administration Staff will be available to the KTeV project to the degree required to carry out the fabrication responsibilities of the Fermilab KTeV group.

4.1 Facilities and Equipment

The following Fermilab facilities and equipment will be made available to the KTeV project to the degree necessary to carry out the fabrication responsibilities of the Fermilab group.

Physics Department E-shop WH9E, machine shop at WH9W and PMT test facility at WH10E.
Lab 6 - PD assembly/test area, winding machine and RD shop.
Lab 7 - Clean room, Scintillator shop, Vacuum sputtering facility, Fiber polishing machine.
Lab 8 - CAD/CAM and Thermwood machine for scintillator fabrication.
NMUON - staging and assembly area and counting room.
PREP - NIM, Camac, Fastbus and VME electronics, HV and LV power supplies.

Computing - WH9X DAQ testing facility, Fermilab central computer clusters, Physics clusters and workstations.

4.2 Operational Costs

Fermilab and the appropriate DOE grants will fund the normal operating expenses of the Fermilab group working on the KTeV project. These normal operating expenses are not considered as contributions to the detector fabrication program.

4.3 Software Development

Common software development will be done under the general direction of the System Manager for Software, E. Cheu. All KTeV software development will be done within the framwork established by the software group to define design and specification of code, choice of programming language, coding standards, and use of tools. Software assignments will be estabilished after discussion with the Software System Manager. They will usually be planned out for no more than a 6-12 month period. The KTeV experiment will develope its software to be run on UNIX platforms as well as DEC-VAX machine running VMS. The Fermilab group will utilize SGI or IBM UNIX installation for code development and data analysis. Fermilab CD will maintain the HEP networks with other HEP institutions for their software developement and physics analysis effort.

5.COSTS AND FUNDING

Detailed cost estimate for KTeV detector, beam and facility are summarized in the current KTeV project budget plan with Work Breakdown Structure (WBS) classification in "KTeV Project Managenet Plan". The cost of design, fabrication, staging, installation and comissioning will be funded through Fermilab DOE grants.

6. ADMINITRATIVE DETAILS

7. SCHEDULES AND MILESTONES

The schedules for the fabrication of the KTeV detector are contained in the KTeV Design Report and the KTeV Management Plan. Fermilab will make every effort to carry out their fabrication responsibilities consistent with these schedules. These schedules may have to be changed as the project progresses. Changes taht affect the scheduling of components to be fabricated at Fermilab will be noted Appendices to this MOU.

The following are the milestones for each system:

7.1 Primary Beam

10/1/93	Conceptual Design Report written
1/1/94	Engineering design final
3/1/94	Procurement complete
8/1/94	Installation in beamline
10/1/94	Motion control and power test done, ready for beam

7.2 Secondary Beam

10/1/93	Conceptual Design Report written
3/1/94	Complete design, fabriaction and preparatory work for target and dump magnets, colimators and Mu-sweeper II
6/1/94	Remove NM2 and MC target piles
9/1/94	Complete KTeV target pile installation
10/1/94	Complete Target magnet, Mu-Sweeper II instalation
12/1/94	Motion control and power test done, ready for beam.

7.3 Vacuum System of Decay Region

9/15/93	Downstream vacuum tanks ordered
12/1/93	Complete redesign of regenerator tank and mover, and vacuum window test
3/1/94	Upsteam decay region design and vacuum system design final
6/1/94	Vacuum tank delivery
8/1/94	Regenerator tank delivery
12/1/94	Installation start
2/1/95	Installation complete

7.4 Vacuum Ring Vetoes

9/15/93	RC7 assembly complete, cosmic ray and vacuum test
1/1/94	RC6 assembly complete, cosmic ray and vacuum test

3/1/94	RC8 assembly complete, cosmic ray and vacuum test
6/1/94	RC9 assembly complete, cosmic ray and vacuum test
9/1/94	RC10 assembly complete, cosmic ray and vacuum test
2/1/95	Installation complete

7.5 Analysis Magnet

9/15/93	Coil ordered
11/1/93	Manufacturing plan complete
9/30/94	Coil delivery
12/1/94	Installation start
1/15/95	Magnet test and field mapping
2/15/95	mapping finished
3/15/95	field map ready for on-line and offline analysis

7.6 TRD Chambers and Gas System

11/1/93	Conceptual Design Report written
1/1/94	Mechanical design complete, parts ordered
3/1/94	First chamber build and ready for test
2/1/95	Tenth chamber build and ready for test
5/1/95	Installation complete

7.7 CsI Crystal Procurement

9/30/93	Contract signed for final 20% of crystals
9/30/94	Complete delivery on first 80% from QS and Bicron
12/1/94	Complete delivery of last 20% from Horiba

7.8 CsI Block House and PMT/Base Mechanical

1/1/94	Complete engineering and drafting of blockhouse and CsI stand
6/1/94	Complete CsI stand fabrication
12/1/94	Complete pre-assembly of blockhouse
1/1/95	Begin blockhouse assembly in experimental hall
2/1/95	Installation of blockhouse and CsI stand complete
5/1/95	Complete installation of PMT/Bases

7.9 CsI Laser Calibration System

7/15/93	Complete setup long term monitoring of single fiber-CsI test
7/15/93	Ordered Nd:YAG laser
10/1/93	Setup 125 channels laser monitoring system
1/1/94	Complete fiber bundle and light distribution design
2/1/94	YAG laser delivery and order fibers

3/1/94	Construction light distribution boxes and masking system
5/31/94	Fiber delivery and ready for installation
5/1/95	Complete installation of fibers and laser system

7.10 CsI Digital PMT Base

9/1/93	Evaluate 8-bit encoder & FIFO complete, order parts
10/1/93	Evaluate Multi-ranging ASICs and test board complete
1/31/94	Finish fabrication & study for test array
2/1/94	Order ASICs and final mother boards
4/1/94	SLAC beam test
12/1/94	Complete assmebly and test all DPMT boards

7.11 Digital Pipeline Readout System

10/1/93	Finish design all prototype modules
12/1/93	Finish layout on all prototype modules
3/1/94	Start prototype test
5/1/94	Redesign and layout of prototype modules
7/1/94	Start production pipeline modules
10/1/94	Start comissioning of pipeline system
1/1/95	Finish debugging, system ready

7.12 TDC, FERA ADC and Latch System

8/1/93	Finish FERA ADC system test, order to LeCroy placed
10//1/93	Finish Physics Department TDC test, order parts
12/1/93	All miscelaneous system components designed
2/1/94	Complete testing of miscelaneous system components
4/1/94	ADC and TDC system assembled
6/1/94	ADC and TDC system are fully comissioned
10/1/94	Latch system assembled
12/1/94	Latch system are fully comissioned

7.13 DAQ System

1/15/94	Single stream, single event builder VME plane assembled running DART V1.0 to test control of data taking, data flow and analysis on a single CPU processor, no tape logging.
4/1/94	Complete 2 stream, 2 VME planes DAQ system to test plane swithing and event building feasures.
10/1/94	Complete full multi-stream, multi-plane DAQ system with multi-processor filtering, monitoring and tape logging.
1/1/95	Full DAQ system be installed for commissioning at NMUON

	3/1/95	Move full DAQ system to KTeV counting room
7.14	Steel Muon Shield and Hadron Veto Lead Wall	
	12/1/93	Start engineering design of the muon shield and lead wall
	2/15/94	Complete design and supports
		All EMI PMTs delivered and bases fabrication complete
	7/1/94	Pre-assembly in NMUON
	1/1/95	Install in KTeV experimental hall
7.15	HV and Cables	
	8/31/93	HV ordered
	2/1/94	All cables ordered
7.16	KTeV Experimental Facility	
	8/15/93	A/E conceptual design complete, Title-I approved
	10/1/93	EA approved by DOE
	10/31/93	Site Prep out for bid
	11/15/93	Detector hall and counting house 90% review
		Ground breaking
	11/30/93	Detector Hall and counting house out for bid,
		KTeV enclosure 90% review
	1/15/94	KTeV enclosures out for bid
	2/15/94	Detector Hall and counting house construction start
	3/15/94	KTeV enclosure construction start
	8/15/94	KTeV enclosure complete
	9/15/94	Crane installation and fire protection complete
	11/1/94	Detector hall and counting room complete
	12/15/94	construction project close out

8. SCIENTIFIC PARTICIPATION IN KTeV