Experimental Investigations
in Particle Physics
at Intermediate Energies
Performance Report

for December 1st, 1990 to November 30th, 1991

L.B. Auerbach, V.L. Highland, C.J. Martoff
K.W. McFarlane, C. Guss and S. Kettell
Physics Department, Temple University
Philadelphia, PA 19122

September 30, 1991

Prepared for
The U.S. Department of Energy
(Division of High Energy and Nuclear Physics)
Under Contract No. DE-FG02-88ER-40389

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Disclaimer

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Abstract

The major emphasis of this project continues to be on fundamental symmetries and parameters of the Standard Model. The projects in the current period have been BNL E791 (a search for the decay $K_L^0 \rightarrow \mu e$, which would violate the rule of separate lepton number conservation), test of an upgrade proposal (E871), and LSND, a neutrino experiment at LAMPF.

For E791, data taking was completed in June 1990, and preliminary results are now available for the decays $K_L^0 \rightarrow \mu e$ and $K_L^0 \rightarrow \mu\mu$ from the entire data set. The data for the decay $K_L^0 \rightarrow ee$ are still being analysed. These are an upper limit for the branching fraction for $K_L^0 \rightarrow \mu e$ of 3.5×10^{-11} (90% C.L.). From the 1990 data alone, we have a new (preliminary) value of the branching fraction for $K_L^0 \rightarrow \mu\mu$ of $(6.96 \pm 0.4 \pm 0.22) \times 10^{-9}$, with a sample of 349 events. Combining this with earlier data gives $(6.96 \pm 0.34) \times 10^{-9}$, by far the most precise value. The limit on the decay $K_L^0 \rightarrow \mu e$ places a lower limit on the mass of a new particle mediating such decays of 85 TeV.

The LSND (Large Scintillator Neutrino Detector), a search for neutrino oscillations at LAMPF, has been approved, and is now underway. Other neutrino work at Los Alamos, E764, has resulted in a final publication. This includes the best measurement of ν -nuclear scattering, in ν_μ ^{12}C inclusive cross sections. The measurement of the cross section for the exclusive reaction ν_μ $^{12}\text{C} \rightarrow \mu^-$ ^{12}N is unique.

In a new development, Dr. Martoff has established a facility for fabrication of superconducting detectors of nuclear radiation; the equipment has been funded and is partly installed. Planned uses include searching for 'Dark Matter.'

In summary, the objectives for this year have been met.

Contents

Title page	i
Disclaimer	ii
Abstract	iii
Contents	iv
List of figures and tables	v
1 Introduction	1
2 Neutrino interactions at LAMPF	2
2.1 Neutrino oscillations – LSND, Experiment 1173	2
2.1.1 PMT Testing Facility	2
2.1.2 Laser-Driven Light-pulser system for time calibration	4
2.1.3 Monte Carlo Studies of the Detector Response	5
2.1.4 Completion of LAMPF Experiment 764	5
3 Rare K_L^0 decays – BNL E791/871	6
3.1 BNL E791	6
3.2 E871	8
4 PILAC	12
5 π^0 work	12
6 Detector Developments	12
7 Investigators' Time and budget	14
8 Publications and References	15

List of Figures

1	Photomultiplier Test Setup.	3
2	Schematic of Timing Calibration Light pulser	9
3	Plots of $M_{\mu e}$ vs P_T^2 and $M_{\mu\mu}$	10
4	Invariant mass distribution for $\mu\mu$ candidates for all runs.	11

List of Tables

1 Introduction

We have continued to work on the structure of fundamental interactions, particularly on their basic symmetries and conservation laws. Our emphasis in the last year has been moving from the rare K_L^0 decay experiment at Brookhaven National Laboratory to the LSND work at Los Alamos, and, for the longer range, work at the SSC.

The BNL experiment is intended to look for lepton non-conservation, which is an assumption of the Standard Model without any theoretical basis. This work is in collaboration with six other institutions [10]. Good progress has been made on this work: the data taking is complete and papers on the 1989 and 1990 runs have been published [2, 1, 3], analysis of the 1990 data is almost complete and the work of combining the three runs (1988, 1989 and 1990) is almost complete. The follow-on experiment for the AGS "Booster Era," E871, has been approved following a successful test of the beam plug in 1990. One of the investigators (K. McF) is participating in E871, and has begun to participate in SSC work.

The 'Large Scintillator Neutrino Detector' (LSND - LAMPF E1173) [13] to search for neutrino oscillations has been approved. In the case of other neutrino work at LAMPF (E764), a final paper (on $\nu - C$ interactions) has been published.

A proposal to the DOE University Research Instrumentation program was funded and work has begun on this project [14]. The aim of the project is to fabricate nuclear radiation detectors of much higher sensitivity than existing types. The detectors will use superconducting tunnel junctions, and the technique is expected to have many applications, including the search for Dark Matter. Additional funding for this work (primarily by Dr. C.J. Martoff) has come from Temple University and the Texas National Research Laboratory Commission.

Details of the work on rare kaon decays are given in section 3, of the work on LSND and LCD in section 2. The detector development effort led by Prof. Martoff is described in section 6. An outline of effort and funds expended is in section 7. Finally, publications resulting from the work are listed in section 8.

2 Neutrino interactions at LAMPF

[This section was prepared by L.B. Auerbach]

2.1 Neutrino oscillations – LSND, Experiment 1173

This is a proposal [13] to search for neutrino oscillations using a smaller-scale prototype of LCD and an existing neutrino area at LAMPF that is equipped with a cosmic-ray veto shield. Its intent is to use LCD technology in a physics experiment, both as a development tool for the LCD project and to improve limits on neutrino oscillations by an order of magnitude over existing results. The LCD technology to be used consists of several elements: large PMT's immersed in a Cherenkov medium (with the addition of some scintillator but using both types of light), the data acquisition electronics, and similar reconstruction algorithms. A detailed description was submitted with our Continuation Application. This experiment is be a high-sensitivity search for neutrino oscillations in the appearance mode in the channels $\nu_\mu \rightarrow \nu_e$, $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$; it will also yield measurements of the reactions $\nu_e C \rightarrow e^- N$ and $\nu C \rightarrow \nu C^*$ (15.11 MeV γ). It will be a major improvement over Expts. 645 and 764 which were done previously at LAMPF.

The Temple group working on LSND (Experiment 1173, search for neutrino oscillation at LAMPF) has focussed its attention on three primary tasks:

- Establishing a semi-automated testing facility for the photomultipliers tubes (8" Hamamatsu tubes) that line the walls of the detector tank.
- Designing and building a laser-driven light pulser that will serve as an ongoing time-calibration for the 1200 photomultipliers in the detector.
- Using the Monte-Carlo code for the experiment to study the detector response to the divers particles produced within.

2.1.1 PMT Testing Facility

A photomultiplier tube testing setup has been built in preparation for the 1250 8" Hamamatsu tubes which will be delivered to LSND beginning in September. The setup is capable of testing 8 tubes each day, enough to easily stay ahead of the delivery schedule of 144 per month. Each of the 8 tubes is held in a steel 55 gallon drum equipped with light pulser. The testing, which measures the dark counting rate versus voltage, gain, and time jitter, is fully automated, and takes 21 hours to

complete. A block diagram of the test setup is shown in Figure 1. The electronics are

Figure 1: Photomultiplier Test Setup.

held in a NIM bin and controlled via a CAMAC crate with a GPIB crate controller by a Macintosh II computer. The light pulser, which sits 9" from the photocathode to ensure full face illumination, contains two light sources, one an avalanche transistor for timing, and the other a green LED for charge analysis. A NIM pulse starts the avalanche transistor which emits a short burst (FWHM ≈ 1 ns) of blue light at the single photoelectron level. A TTL pulse turns the LED on for 100ns, the light is filtered such that a single photoelectron results about 40% of the time. Control of the light pulser is through the output register, which by opening an AND gate, allows

pulses to be sent to the desired light source at 10 kHz with a function generator. The phototubes are tested at positive high voltage, thus the signal must be picked-off the high voltage line before being amplified. After amplification the signal is sent to an ADC which receives a 200ns gate each time the LED is turned on. A TDC measures the time between firing of the avalanche transistor and the arrival of a phototube pulse at the amplifier. The function generator starts the TDC whenever the avalanche transistor and phototube fire in loose coincidence; the TDC is then stopped by the phototube signal. A scaler is used to measure the rate on each tube. The automatic data collection and testing begins by allowing the tubes to sit in darkness under voltage for 6 hours. The dark counting rate is recorded every minute to ensure that the tubes have settled down enough to continue testing. Next dark counting rate and LED efficiency curves (plateaus) are done. Starting at 900v, the voltage is increased to 2000v in 40v steps. At each step the rate is recorded when the photocathode is fully illuminated with the LED, and when it sits in darkness. The plateau test takes 2 hours. Next a charge spectrum is taken at two voltages using the LED as a light source. Data is collected from the ADC each time the LED is turned on until 100,000 samples have been taken. Around 40% of these samples correspond to single photoelectrons, while most of the rest represent zero charge. From this data a plot of number of counts versus charge can be made showing clearly the single photoelectron peak which is then used to determine the gain of the tube. The ADC test takes 8 hours. The final test uses the avalanche transistor to determine the time jitter. If any one of the eight tubes fires when the avalanche transistor is pulsed, the TDC is started with the avalanche transistor, and stopped with the tube. Around 10,000 samples are taken for each tube, which gives a peak in timing plot whose FWHM is taken as the time jitter. The TDC test takes 5 hours.

When the testing is finished a data sheet is made up for each tube. A sheet displays plateau, ADC, and TDC plots, along with the relevant tube parameters: phototube voltage for a gain of 10^7 , the dark counting rate at this voltage, and the time jitter.

2.1.2 Laser-Driven Light-pulser system for time calibration

The basic design of the light pulser is shown in Fig. (2). The nitrogen laser will, when triggered by an external pulse, produce a pulse of light, the intensity rising and falling symmetrically, with a FWHM of approximately 300 picoseconds. The light will be transmitted through optical fibers to diffuser-balls in the detector, and the computer

will regulate the shutters so that only one diffuser will operate at a time. The laser will be externally triggered at between 30 and 40 Hz., and the firing will continue until enough pulses are recorded from each of the PM's in the appropriate sector of the tank gets enough counts to give a well defined time spectrum. The photo-diodes will monitor the actual firing time of the laser for each pulse, and their outputs will constitute the zero-time for each bank of phototubes. The whole system will be computer-driven on command by the main computer for the experiment. Light levels will be adjusted so that most of the PM's will be working at the one-photoelectron level, thus simulating the actual running conditions of the experiment. The various components of the system are all identified. As of this writing, the design is nearing its final form, and will probably be complete in two months. There is an additional phase to the calibration, which is the question of precisely how to obtain an energy calibration at about 5 and 10 MeV. We have some preliminary designs for this aspect, and will probably have a final design in about three months.

2.1.3 Monte Carlo Studies of the Detector Response

We will study the response of the detector to protons, neutrons, gammas and electrons. We have started running the Monte-Carlo (the M. C. currently resides at LAMPF) The liquid in the detector is taken to be mineral oil, with a small addition of PBD scintillating material, so that the light produced by a charged particle is both scintillation light and Cerenkov light, with 4 times as much scintillation light as Cerenkov light. The latest version of the Monte Carlo is almost complete, and we will install the new version on the DEC Workstation that we'll have here at Temple. Two of the Graduate Students will devote all of their efforts this Fall to getting things working in that area.

2.1.4 Completion of LAMPF Experiment 764

The final paper on expt. 764 is now in nearly final form, and will be submitted to Phys. Rev. C in about a month. The title is, "A Study of the Inclusive Muon-Neutrino-Carbon Charged-current Interaction in the Energy Range just above Muon Threshold." Since the abstract is in final form, it is given below.

A measurement of the muon-neutrino-carbon charged-current cross section, $\nu_\mu + C \rightarrow \mu^- + X$ was performed using the in-flight pion-decay neutrino source at the LAMPF accelerator. At an average neutrino energy of 202 MeV, we measured an inclusive cross-section of $(15.6 \pm 2.6 \pm$

$3.1) \times 10^{-39} \text{cm}^2$. We have compared this cross section with theoretical predictions and find it in agreement with predictions of the Fermi Gas Model and in disagreement with a previous experiment and with subsequent calculations that yielded substantially lower cross sections. We also isolated a small sample of events in which the final state nucleus was in the ground state of ^{12}N . Our measured cross section for this reaction is $(0.8 \pm 0.3 \pm 0.2) \times 10^{-39} \text{cm}^2$, or about $(5 \pm 2)\%$ of the total event rate. This is within the errors of the predicted rate near 2%.

3 Rare K_L^0 decays – BNL E791/871

BNL E791 and E871 are searches for the lepton-number non-conserving decay $K_L^0 \rightarrow \mu e$; the apparatus is also sensitive to the decays $K_L^0 \rightarrow \mu\mu$ and $K_L^0 \rightarrow ee$. This work is being carried out at the Brookhaven AGS by the E791/E871 collaboration.[11, 12] Our main goal is to search for separate lepton-number non-conservation (SLNC) at a new level of sensitivity. Some extensions of the Standard Model predict SLNC; the decay $K_L^0 \rightarrow \mu e$ is a critical test of such theories. Other goals proposed were a search for the decay $K_L^0 \rightarrow ee$, the CP-violating decay $K_L^0 \rightarrow \pi^0 ee$, a precise branching fraction for the decay $K_L^0 \rightarrow \mu\mu$, and the CP-violating polarization in $K_L^0 \rightarrow \mu\mu$.

Details of the physics goals and the design of the experiment are given in the original proposal [12]. In this section, we outline our progress to date, and give current results.

3.1 BNL E791

[adapted from talk by S.H. Kettell]

Here we describe the preliminary results from our 1990 data sample of a search for the decay $K_L^0 \rightarrow \mu e$. This decay is forbidden by the conservation of the separate additive quantum numbers for electrons and muons. Any observation of this decay mode would be evidence of physics beyond the Standard Model. We will also briefly discuss our measurement of the $K_L^0 \rightarrow \mu\mu$ branching ratio[4].

This experiment was performed at the B-5 beamline of the Alternating Gradient Synchrotron (AGS) at BNL. An average of 4.5×10^{12} protons per spill at 24 GeV are incident on a 1.3 interaction length Cu target. The E791 spectrometer and neutral beam line are described in previous papers.[5, 6]. The spectrometer consists of 5 drift chamber stations and 2 magnets with equal and opposite 300 MeV/c kicks. Immediately downstream of the drift chambers are two pairs of trigger scintillator

hodoscopes (TSC) and the particle identification detectors (PID). Electron particle ID consists of a threshold gas Cerenkov counter (CER) and a lead-glass array (PBG). Muon identification, downstream of 0.9 m of iron, consists of a scintillator hodoscope (MHO) and a muon range finder (MRG) with 10% range sampling.

The hardware trigger consists of an overlap coincidence of the trigger scintillators and the upstream drift chambers. A 'minimum bias' trigger is simply prescaled and a di-lepton trigger is formed from a coincidence with the CER and MHO. These L1 triggers are then processed further on-line in 3081E processors. The upstream drift chambers and first magnet are used to calculate the reconstructed 2-body mass and the colinearity angle (θ_C). The colinearity angle is defined as the difference between the kaon direction (defined by the target and vertex positions) and the reconstructed 2-body system direction. Events passing this L3 trigger are then written to tape.

Offline events are pattern recognized using the full spectrometer to reconstruct tracks with a common vertex. Pattern recognized tracks are then fit to determine more accurately their kinematic quantities and cuts are placed on mass, θ_C and the track and vertex χ^2 . In addition, cuts are applied to require the decay vertex to lie within the vacuum region and to require that the tracks do not traverse large amounts of material.

Tracks are projected to the PID detectors and their response recorded. Efficiencies of the cut on the CER time and PBG energy are measured with K_{e3} electrons to be 0.913 and 0.957 respectively. The muon detectors efficiencies are 0.965 for the MHO and 0.975 for the MRG, measured with $K_{\mu3}$ decays.

Potential source of background are of two types: 1) 'double mis-ID', where the pion from K_{e3} decays is identified as an electron and the electron is identified as a muon. The kinematic endpoint for this process is above the kaon mass so good particle ID is essential. 2) 'single mis-ID', where the pion from K_{e3} decays is misidentified or decays to a muon. The kinematic endpoint is 8 MeV below the kaon mass, so excellent kinematic resolution is essential. It is also essential to minimize possible mistakes in position measurement due to ambiguities resulting from missing hits.

The analysis of the μe data proceeded by studying the background events outside of a region defined by $\pm 6 \text{ MeV}/c^2$ around the kaon mass and with $\theta_C > 2 \times 10^{-6} \text{ mrad}^2$. In order not to bias our choice of cuts no events inside of this signal region were analyzed until after the final cuts had been chosen.

The experiment is normalized to $K_L^0 \rightarrow \pi\pi$ decays. The total number of $\pi\pi$ events passing the μe analysis cuts is $N_{\pi\pi} = 27845 \pm 308$. Figure 3 shows the final sample of $K_L^0 \rightarrow \mu e$ candidates plotted with mass vs P_T^2 ($P_T \equiv \theta_C \times P_K$). No events passing

all cuts remain in the signal region defined by $492.7 \leq M_{\mu e} \leq 502.7 \text{ MeV}/c^2$ and $P_T^2 \leq 144(\text{MeV}/c)^2$.

Since no $K_L^0 \rightarrow \mu e$ events are observed the 90% confidence limit on the branching ratio is given by

$$B(K_L^0 \rightarrow \mu e) < 2.3 \times \frac{B(K_L^0 \rightarrow \pi\pi)}{4000 \times N_{\pi\pi} \times \xi_{K_S}} \times \frac{A_{\pi\pi}}{A_{\mu e}} \times \frac{\epsilon_{\pi\pi}}{\epsilon_{\mu e}} \times \left(\frac{\epsilon_{\pi\pi}}{\epsilon_{\mu\mu}}\right)^{L3} \times \left(\frac{1}{\epsilon_{\mu\mu}}\right)^{L1}. \quad (1)$$

The $K_L^0 \rightarrow \pi\pi$ branching ratio $B(K_L^0 \rightarrow \pi\pi)$ is $2.03 \pm 0.04 \times 10^{-3}$, the correction due to the K_S contamination of the $\pi\pi$ sample is $\xi_{K_S} = 0.989 \pm 0.005$, $\epsilon_{\pi\pi} = 0.97 \pm 0.01$ is the correction for pion interactions, $\epsilon_{\mu e} = 0.837 \pm 0.003$ is the μe PID efficiency, the ratio of acceptances is $A_{\pi\pi}/A_{\mu e} = 1.40 \pm 0.010$, the L3 efficiency correction $(\epsilon_{\pi\pi}/\epsilon_{\mu e})^{L3}$ is 1.01 ± 0.01 and the L1 lepton trigger efficiency $\epsilon_{\mu e}^{L1}$ is 0.988 ± 0.003 .

The resulting 90% confidence limit on the branching ratio $B(K_L^0 \rightarrow \mu e)$ is 7.1×10^{-11} . We estimate the systematic uncertainty on the normalization of this preliminary result to be 10%. If the 1990 result is combined with our earlier result the limit is $B(K_L^0 \rightarrow \mu e) < 3.3 \times 10^{-11}$.

Also shown in Fig. 2 is a plot of $M_{\mu\mu}$ for all events passing the $\mu\mu$ analysis cuts. We find 349 ± 20 background subtracted $\mu\mu$ events in the peak and the $K_L^0 \rightarrow \pi\pi$ normalization sample contains 32576 ± 300 events[4]. Our preliminary 1990 result is $B(K_L^0 \rightarrow \mu\mu) = 6.96 \pm 0.40(\text{stat}) \pm 0.22(\text{syst}) \times 10^{-9}$, which agrees with earlier results[5, 6, 7, 8].

3.2 E871

The plug test in Spring 1991 went well: rates in the detectors near the plug were higher than without the plug, but within acceptable limits. The proposal underwent a Technical Review by a BNL panel in August, and was approved by the full Program Committee. E871 will likely proceed to an engineering run in 1993, with first physics data in 1994.

During his stay at SSCL, K. McFarlane undertook a study of how to measure the low-momentum spectrum of kaons in the beam. E871 uses kaons down to 2 GeV/c in contrast to E791 which begins at 4 GeV/c. Since the kaon spectrum at BNL is essentially unmeasured, it was a source of uncertainty in predicting the rate for E871. This study [15] showed how the region relevant for E871 could be measured with the E791 apparatus. This measurement was carried out and the data (analyzed by Y. Kuang of Wm. and Mary) showed that the prediction we had been using was adequate.

Figure 2: Schematic of Timing Calibration Light pulser

Figure 3: Plots of $M_{\mu e}$ vs P_T^2 and $M_{\mu\mu}$.

Figure 4: Invariant mass distribution for $\mu\mu$ candidates for all runs.

4 PILAC

K. McFarlane contributed to the PILAC proposal by preparing a paper analyzing the physics motivation for a precise measurement of pion beta decay (the current most accurate experiment was done by a group including Temple at LAMPF), commenting on the precision needed and the design possibilities for an actual experiment.[16]

5 π^0 work

[The following two sections were provided by Prof. C.J. Martoff in a report on his activities which formed part of our 1990-93 Renewal Proposal. K. McF]

The ante for pi zero decay experiments was raised greatly by the measurements of H. Fonvielle et al, Phys. Lett B 233, 65 (1989) (December 28 issue!). These people did a rather high statistics (32,000 Dalitz decays) experiment which confirmed the negative slope of the form factor and obtained a value which is in the expected (i.e. boring) range. Further improvement in this measurement would not come without improved methods of handling radiative corrections, as well as higher statistics. [So this project has been dropped.]

IUCF [Indiana University Cyclotron Facility] has put the large acceptance cooler detector for rare decays on the back burner. That is, there is no fabrication money for it in their FY 91-94 plan.

6 Detector Developments

[This section describes work by Prof. Martoff on nuclear radiation detector fabrication. This work has been funded by this grant, by a DOE Universities Research Instrumentation Grant with matching funds from Temple University and by the Texas National research Laboratory Commission. Several commercial companies have provided free or lost-cost services. As can be seen, the devices under development have applications spanning a wide range of basic and applied physics. K. McF.]

I am continuing to work on very thin and rad hard tracking using the Texas money, with fabrication at Hypres to start this month. The mask designs for a variety of strip-type detectors with pitch down to 40 microns are complete. These are to be fabricated in Ti for free at Solarex under an informal agreement with their management. Progress there has been slow for three months due to their workload; you get what you pay for. I am now planning to incorporate some of these designs

in another test chip which will be fabricated for pay by Hypres. This test chip will include in addition several pixel-type geometries (close packed hexagons from 100 - 2000 microns in height, as well as square arrays). These will be fabricated in a novel structure with the detectors on one layer and the wiring on a separate layer, insulated from the first by a SiO₂ layer. The metal used will be Nb, which is known to be rad hard to the megarad level, and which has a very high critical current even in thin film form. This will make for a faster detector with larger signal sizes than the Ti devices, which are optimized for sensitivity. The only part of this mask design not yet complete is the wiring layer for the 100 micron hexagons; it is surprisingly difficult geometrically to wire large arrays of this small pitch.

We have also been working on thin film AuGe thermistors. These are to offer an alternative to the neutron-transmutation doped Ge thermistors now used by Sadoulet et al for calorimetric dark matter detectors. The NTD Ge thermistors are small, they must be mechanically bonded to the absorber crystal (which causes lots of problems with excess heat capacity and poor coupling), they have a problem with thermal decoupling of the lattice (where the heat from the absorber winds up) from the electrons (which give rise to the resistivity change that provides a signal), and they are radioactive. My student has produced thin film AuGe devices with good responsivity ($d(\log R)/d(\log T) \simeq 5$) and reasonable resistivity. We have not come up with a way to passivate these, so each test requires making new devices. This has slowed things down, but work is continuing.

The cryogenic Si diode fabricated in collaboration with Quantrad worked well inside the vacuum of a frozen hydrogen target at TRIUMF in June for a muon catalyzed fusion experiment. Energy spectra of fusion helions were obtained which agreed with Monte Carlo. This technique is to be used to measure fusion cross sections as a function of muD kinetic energy in a setup using TOF on the muD. There is another run scheduled in February for which I will provide a detector. Measurement of the charged fusion products in good geometry is also useful to provide a measure of absolute fusion yields which is more reliable than currently available data from neutron detectors located outside the cryostat.

We have continued to test Ti transition edge devices fabricated by Barbara Neuhauser at SF State. We have detected alpha particles with several of these devices, and mapped out their performance curves as function of temperature and bias current. A group at the Oxford conference I went to 4-7 Sept described a new theoretical analysis of transition edge device functioning which I am exploring with a student. Some mysteries remain as to why devices from the same lot do not appear

to have similar superconducting transition temperatures. The Solarex people have made films for me by DC sputtering (Barbara uses e-beam evaporation) , which all superconducted just fine and quite uniformly.

[This describes a The clean room air circulation system is complete and the room has been certified by an outside contractor. Essentially all utilities are in and the mask aligner has been installed. The only major system still not running is the hyperpure water supply. This appears to be having problems with bad deionizer cartridges. These are being replaced by Millipore. The room will be in operation this month or next. I will put two people in there at first, one to determine sputtering conditions for best film uniformity and one to work up photolithography procedures. Consultants (students of Barbara's with experience, or laid-off personnel from Solarex) may be used to speed up the initial process development.

Increasing sensitivity for all these detectors will require cold preamps nearby the detectors. I have one student working on the thermal aspects of preamp design according to heat flow calculations of mine, and another building the circuit on the bench. I am trying to use a dual FET cascode, but am having trouble setting up a stable operating point. This type of amplifier should be fast and sensitive, but comparable performance is available with other designs if I can't get the bugs out of this.

7 Investigators' Time and budget

The investigators spent the expected time on the contract, with a slight modification. V.L. Highland worked on the project full time for two summer months and had one-third released time during the academic year. L.B. Auerbach's involvement was slightly reduced: one-third time during the academic year, and *one* summer month. K. McFarlane had a leave for the academic year 89-90 and devoted full time to the project from July 1st 1989 till June 30th 1990, with half salary from Temple and half from DOE. Beginning July 1st 1990, he worked at the SSC Laboratory, devote 30% of his time to this project. Salary will come 40% from Temple, 60% from the SSC.

In September 1988, C.J. Martoff joined the Physics Department at Temple as a Visiting Associate Professor. He has worked (about one-sixth time during the academic year and one month in the summer) on the LCD and CEBAF parts of this project, while preparing an independent proposal. He has now been appointed to a tenure-track position and has submitted independent proposals.

We have been fortunate in attracting excellent Post-Doctoral Research Investi-

gators: S. Kettell (Ph.D. from Yale on muonium work at Los Alamos) and C. Guss (Ph.D. from Northwestern on σ_{tot} for $p\bar{p}$ at 1.8 TeV, at Fermilab).

G. Daniel has played an important role as Senior Research Technician; he is University supported.

Students working on the project included John Belz, on E791, and Y. Zhang, T. Garzarella, C. Fuller, X. Wang on the superconducting detector development; D. Works and two more students (P. Hermida and Y. Xiao) work on LSND.

Travel was in excess of what was planned.

A detailed financial report will be filed at the appropriate time.

8 Publications and References

Publications and reports are listed in section 8 as references [1],[2],[3], [9], [15] and [16],[17].

References

- [1] Higher-statistics Measurement of the Branching Ratio for the Decay $K_L^0 \rightarrow \mu\mu$
A.P. Heinson, J. Horvath, C. Mathiazhagan, W.R. Molzon, K. Arisaka, R.D. Cousins, T. Kaarsberg, J. Konigsberg, P. Rubin, W.E. Slater, D.L. Wagner, W. W. Kinnison, D. M. Lee, R. J. McKee, E. C. Milner, G. H. Sanders, H. J. Ziock, P. Knibbe, J. Urheim, K. A. Biery, M.V. Diwan, G. M. Irwin, K. Lang, J. Margulies, D. A. Ouimette, A. Schwartz, S. G. Wojcicki, L. B. Auerbach, J. Belz, P. Buchholz, V. L. Highland, W. K. McFarlane, M. Sivertz, J. L. Ritchie, A. Yamashita, M. D. Chapman, M. Eckhause, J. F. Ginkel, A. D. Hancock, J. R. Kane, C. J. Kenney, Y. Kuang, W. F. Vulcan, R. E. Welsh, R. J. Whyley, R. G. Winter, Physical Review **D44**, R1-R4 (1991)
- [2] Measurement of $B(K_L^0 \rightarrow \mu\mu)$: New Results from BNL E791.
A.P. Heinson, J. Horvath, C. Mathiazagen, W.R. Molzen, K. Arisaka, R.D. Cousins, T.Kaarsberg, J. Konigsberg, P. Rubin, W.E. Slater, D.L. Wagner, W.W. Kinnison, D.M. Lee, R.J. McKee, E.C. Milner, G.H. Sanders, H.J. Ziock, P. Knibbe, J. Urheim, K. Biery, M.Divan, G. Irvin, K. Lang, J. Margulies, D. Ouimette, A. Schwartz, S.Wojcicki, L. Auerbach, J. Belz, P. Buchholz, V. Highland, W.K. McFarlane, M.Sivertz, M. Chapman, M. Eckhause, J.Ginkel, D. Hancock, J. Kane, C. Kenney, Y.Kaumg, W. Vulcan, R. Welch, R. Whyley,

- R. Winter. Proceedings of the Fourth Conference on the Intersection Between Particle and Nuclear Physics, 13 June 1991.
- [3] An improved Upper Limit on the Branching Ratio $B(K_L^0 \rightarrow \mu e)$ and a measurement of $B(K_L^0 \rightarrow \mu\mu)$. S.H. Kettell, to be published in the proceedings of the Particles and Fields Conference, Vancouver, B.C. (July 1991).
 - [4] A. Schwartz, Proceedings of the 4th Conf. on the Intersections between Particle and Nuclear Physics, June (1991).
 - [5] A.P. Heinson, *et al*, Phys. Rev. **D44**, R1(1991).
 - [6] C. Mathiazhagan, *et al*, Phys. Rev. Lett. **63**, 2185(1989).
 - [7] T. Inagaki, *et al*, Phys. Rev. **D40**, 1712(1989).
 - [8] T. Inagaki, 1991 Lepton Photon Conference.
 - [9] New Search for the Spontaneous conversion of Muonium to Antimuonium, B.E. Matthias, H.E. Ahn, A. Badertscher, F. CHmely, M. Eckhause, V.W. Hughes, K.P. Jungmann, J.R. Kane, S.H. Kettell, Y. Kuang, H.-J. Mundinger, B. Ni, H. Orth, G. zu Pulitz, H.R. Schaeffer, M.T. Witkowski, and K.A. Woodle, Phys. Rev. Lett. **66**, 2716 (1991).
 - [10] E791 collaboration:
 C. Mathiazhagan, W.R. Molzon
University of California, Irvine, California 92717
 K. Arisaka, R. D. Cousins, T. Kaarsberg, J. Konigsberg, J. Kubic, P. Rubin, W. E. Slater, D. Wagner
University of California, Los Angeles, California 90024
 G. W. Hart, W. W. Kinnison, D. M. Lee, R. J. McKee, E. C. Milner, G. H. Sanders, H. J. Ziock
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
 P. Knibbe, J. Urheim
University of Pennsylvania, Philadelphia, Pennsylvania 19104
 K. A. Biery, G. M. Irwin, K. Lang, J. Margulies, D. A. Ouimette, S. G. Wojcicki
Stanford University, Stanford, California 94309
 L. B. Auerbach, P. Buchholz, C. Guss, V. L. Highland, S. Kettelll, W. K. McFarlane, M. Sivertz
Temple University, Philadelphia, Pennsylvania 19122

J. L. Ritchie, G. Hoffman, P. Riley

University of Texas at Austin, Austin, TX 78712

M. D. Chapman, M. Eckhause, J. F. Ginkel, A. D. Hancock, J. R. Kane, C. J. Kenney, W. F. Vulcan, R. E. Welsh, R. G. Winter

College of William and Mary, Williamsburg, Virginia 23185

- [11] Cousins, R.D., P. Melese, (UCLA); J.F. Frank, W. Kinnison, J.W. Lillberg, R. McKee Jr., G. Sanders, (LANL); W.R. Molzon, W.D. Wales (U of Pennsylvania); J.F. Greenhalgh, (Princeton U); G.M. Irwin, J.L. Ritchie, S.G. Wojcicki (Stanford U); L.B. Auerbach, V.L. Highland, W.K. McFarlane (Temple University). Added after submission: J. Konigsberg, W. Slater, P. Rubin, (UCLA); D.M. Lee, C. Milner, H. Ziock (LANL); K. Arisaka, J. Urheim, P. Knibbe (U of Pennsylvania); K. Lang, S. Axelrod, J. Margulies, (Stanford); P. Buchholz, M. Sivertz (Temple U); and R. Welsh, M. Eckhause, R. Winter, C. Kenney, M. Chapman, J. Ginkel, R. Whyley, P. Guss, D. Joyce, J.R. Kane (College of Wm. and Mary), Proposal to AGS: Study of Very Rare K Decays. Submitted January 1984, approved by BNL as E791, June 1984.
- [12] E871 collaboration (for 1991):
A. Heinson, W. R. Molzon (*University of California, Irvine, CA 92717*), M. Diwan, G.M. Irwin, D.A. Ouimette, S.G. Wojcicki (*Stanford University, Stanford, CA 94305*), J. Belz, C. Guss, S. Kettell, W.K. McFarlane (*Temple University, Philadelphia, PA 19122*), G.W. Hoffmann, J. McDonough, P.J. Riley, J.L. Ritchie, A. Yamashita (*University of Texas at Austin, Austin, TX 78712*), M. Eckhause, D. Hancock, J.R. Kane, Y. Kuang, R.E. Welsh, R.G. Winter, M. Witkowski (*College of William and Mary, Williamsburg, VA 23185*), Proposal E871 submitted to BNL in 1990, approved Sept. 1991.
- [13] A proposal to Search for Neutrino Oscillations with High Sensitivity in the Appearance Channels $\nu_\mu \rightarrow \nu_e$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$, X.-Q. Lu *et al.*, UC Irvine, UC Riverside, CEBAF, Los Alamos Nat. Lab., Louisiana State U, UNM, U. of Penn., and Temple U. June 30th 1989 and Dec. 1st 1989. LAMPF proposal E1173
- [14] Facility for Development of Superconducting Detectors for Nuclear Radiation, C.J. Martoff, J. Crow and K.W. McFarlane, DOE proposal and Temple report DOE-ER40389-63

- [15] K. McFarlane, "Measuring the low-momentum kaon spectrum," E791 internal report KL-325.
- [16] K. McFarlane, "Pion beta decay at PILAC," Contribution to the PILAC proposal, Technical Report DOE-ER40389-68 (April, 1991).
- [17] Incorporating Systematic Uncertainties into an Upper Limit, R.D. Cousins and Virgil L. Highland, Temple report DOE-ER40389-69 (March 1991). Submitted to Nucl. Inst. and Methods.

END

**DATE
FILMED**

2 / 07 / 92