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Experimental Investigations in Particle Physics at Intermediate Energies

Performance Report

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Disclaimer

Abstract

The major emphasis of this project continues to be on fundamental symmetries and parameters of the Standard Model. We have also been able to mount a test of a quark model prediction. The projects in the current period have been: LSND, a neutrino oscillation experiment at LAMPF; E791, a search for the decays $K_L^0 \to \mu e$ and $K_L^0 \to ee$; E871, tests and preparations for an upgrade proposal; and E888, a search for the H dibaryon.

The LSND (Large Scintillator Neutrino Detector) is under construction at this time. Progress in the construction schedule has been accelerated with the expectation of being ready to accept beam in March 1993. Our automated system for testing photomultiplier tubes is in full production and should be able to certify a full complement of tubes for installation by October 1992. Results of an earlier LAMPF experiment, E764, on the interaction of muon-neutrinos with carbon nuclei have been submitted for publication.

A thorough 'blind' analysis of the E791 data set has just been brought to completion. Final results for the upper limits (90% C.L.) on the branching ratios for the decays $K_L^0 \to \mu e$ and $K_L^0 \to ee$ are 3.3×10^{-11} and 4.1×10^{-11}, respectively. The final result for the branching ratio for $K_L^0 \to \mu\mu$ from all our data (720 events) is $(7.0 \pm 0.4 \pm 0.2) \times 10^{-9}$.

The potential of the E791 detector for rare K decays has reached its limit. Before disassembling it, we have used it to mount a search (E888) for a possible long-lived six-quark state, the H. At the same time studies have been made of an upgraded version of the experiment (E871) that will make use of a portion of the existing apparatus.

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

Contents

1 Neutrino Physics

The major goal of the LSND experiment is the search for the oscillation of muon neutrinos into electron neutrinos. The probability for this transition is given by:

$$P = \sin^2 2\theta \sin^2(1.27\Delta m^2 R/E_\nu) \tag{1}$$

where Δm^2 is the mass squared difference of the two neutrino types in $(\text{eV})^2$, θ is the mixing angle, R is the flight distance in meters and E_ν is the energy of the neutrino in MeV. An advantage of experiments at LAMPF as opposed to higher energy accelerators is the much lower average value of E_ν. The experiment will be sensitive at mixing angles as small as $\sin^2 2\theta = 0.0001$ at $\Delta m^2 = 1$ eV^2, rising to 1 as $\Delta m^2 \rightarrow 0.01$ eV^2. Other goals of the experiment include studies of neutrino interactions with C nuclei and with protons.

The LSND detector is a cylindrical tank filled with Britol 6NF HP white mineral oil of index of refraction 1.47 into which is mixed 0.03 g/l of t-butyl PBD ($C_{24}H_{22}N_2O$) liquid scintillator. The PBD produces isotropic scintillation light to help detect and distinguish between particles that are above or below Cerenkov threshold in the oil. The light will be detected by 1200 photomultiplier tubes (PMT's) suspended inside the tank. An active cosmic ray veto shield surrounds the tank, which is located inside a tunnel downstream from the LAMPF beamstop.

The efforts of our group on the LSND experiment have been in the following areas:

1. Photmultiplier preparation and testing
2. Scintillator tests
3. Laser calibration system
4. Production of tank parts
5. Event reconstruction and Monte Carlo

1.1 Photomultiplier testing

Photomultiplier tube (PMT) testing is now in full production. Of the 480 R1408 Hamamatsu 8" PMT's which have been received, 444 have been tested, 384 have been accepted, and 60 were rejected. The rejected PMT's are set aside to be replaced, the others are potted with a protective coating in readiness for installation into the detector. The delivery schedule calls for the remaining 830 PMT's to be delivered over the next three months bringing the total to 1250. At a testing rate of 8 per day, with concurrent potting, all PMT's should be ready for installation by late October.

For so many tubes, testing is a major operation that requires a systematic production line approach. Figure 1 shows a layout of the PMT testing, potting, and storage facility D. Works and C. Athanassopoulos have built at LAMPF. The southwest corner of the room has been cleared for delivery. Nearby benches are used for PMT inspection and soldering the base to the flying leads The test setup consists of eight 55 gallon drums, each housing one PMT. Testing is automated and takes 23 hours to complete, leaving one hour in the daily cycle for PMT exchange. A list of the accepted PMT's must be sent to Hamamatsu within one month of the delivery date. The potting room, built in the center of the room, acts as a large fume hood. It holds up to 42 PMT's for potting base and stem in Hysol, a protective coating. The PMT's are dipped twice in the Hysol and left for two days to cure before storage. In the future stored PMT's will be binned by operating voltage in order to make the transition from storage to detector easier.

The 55 gallon drums are equipped with light pulsers. The PMT's are held in a frame at the bottom of the drum and face upward towards the light pulser which is fastened to the drum lid. An aluminum foil box shields the light pulser to prevent rf pickup. The light pulser sits 10" from the photocathode and is made up of two light sources, a green LED for charge tests, and an avalanche transistor for timing tests. Diffusion paper in front of the LED provides for full face illumination. The LED emits a 100 ns burst of light and the avalanche transistor emits a short (< 1 ns) burst of blue light, both at the single photoelectron level. Diffusion paper cannot be used with the avalanche transistor because of the low light level. Testing is controlled by a Macintosh II computer interfaced to CAMAC. Figure 2 is a block diagram of the test electronics. Figure 3 is an example of the report produced by the system for each tube.

Before testing begins, the PMT's sit in darkness under voltage for 8 hours. After the 8 hour warm up period, charge spectra are taken at voltages 100 V above and below the nominal Hamamatsu voltage for a 5×10^6 gain. From these measurements the gain is calculated and the actual operating point for 5×10^6 gain determined. It is generally within 50 V of that given by Hamamatsu. A measure of the occupancy is given with each charge histogram. Occupancy is the percentage of nonzero counts and gives a rough estimate of the quantum efficiency. The light from each LED is filtered to give an average occupancy of around 60%. The occupancy is used along with Poisson statistics to determine the mean number of photoelectrons, which is then divided into the mean charge to determine the gain. Each charge spectrum requires 4 hours to comlete. Then a timing test is done at the Hamamatsu operating voltage using the avalanche transistor as a light source. About 10,000 samples are taken for each PMT, requiring 5 hours to complete.

The final step is a noise and signal rate plateau determination. The dark rate and the LED generated rate are measured while the PMT voltage is ramped from 900 V to 2500 V in 40 V steps. PMT's which perform well have a flat plateau with at least a 2 kHz separation between the signal and noise rates. The plateau takes 2 hours.

After testing, an acceptable PMT is prepared for potting. The glass stem and pigtail are cleaned with isopropyl alcohol and the PMT is put in a holder which supports the PMT at the widest part of the bulb allowing base, stem, and pigtail to be dipped in Hysol. Hysol PC18 is a solvent-based one-component urethane coating which is cured at room temperature. With a dielectric strength of 1200 Volts/mil, it is especially designed for printed circuit boards. When cured, Hysol is extremely tough and solvent resistant. Tests have shown Hysol to have no poisoning effects on the scintillator and not to degrade the mineral oil attenuation length. The thickness of one coat is < 0.2 mm. Although there is no evidence of light emission from the

PMT glass stem, as a precaution 1 gram of black pigment is added to every liter of Hysol. All potting takes place in a room designed as a large fume hood. An exhaust fan sits on top of the room and draws air through the windows at a rate of 100 cubic feet per minute, keeping the level of toluene diisocyanate, the hazardous component of Hysol, below 5 parts per billion. Respirators are worn while potting.

Figures 4–7 show results for the 384 accepted PMT's at a gain of 5×10^6. Figure 5 shows the voltage distribution, ranging from 1668 V to 2445 V. Only those below 2500 V are accepted. Figure 5 shows the distribution of dark rates, ranging from 1045 Hz to 23,400 Hz, with 3570 Hz as the mean. Retesting of 4 potted PMT's has shown the dark rate reduced by an average of 30%. The reason for this reduction is unknown, but may be due to glass charging effects. This reduction was seen in earlier tests with the PMT covered in cloth. Figure 6 shows the timing jitter, ranging from 2.2 ns to 4.2 ns FWHM, with a mean of 3.0 ns. These results are about 0.5 ns lower than Hamamatsu's specifications. It may be that the avalanche transistor does not illuminate the full photocathode adequately. We are planning tests to understand this aspect. No PMT's have been rejected due to timing problems. Figure 7 shows the charge resolution in terms of the one-photoelectron peak-to-valley ratio. The average is 1.2, with a few as high as 1.5.

Overall PMT performance is below Hamamatsu's specifications, but in order to be assured that 1220 usable PMT's will be installed in the detector by the end of 1992 many substandard PMT's will be kept. For example, PMT's with dark rates above 8500 Hz and with peak/valley below 1.15 do not meet specs but have been accepted. Although it has been assumed in testing that the PMT's will operate at 5×10^6 gain, a 20% – 40% reduction in gain would decrease dark rates up to 50% and increase charge resolution slightly. A decision has recently been made to use a gain of 4×10^6. Dark rates will be reduced further since the detector will be kept 10°C below the testing temperature of 25°C. Tests at 0°C cut dark rates in half.

1.2 Scintillator tests

Studies in a test beam of the properties of various mixtures of scintillator and mineral oil were undertaken to understand the correct mixture to use in the detector. These results have been readied for publication.[3] A draft of the paper is included in Appendix A. On this basis the final mixture of 0.03 grams per liter of PBD was chosen. The plan is to add the scintillator gradually to the pure oil in the tank and adjust the mixture if it seems advisable.

1.3 Laser calibration system

The purpose of the laser system is to calibrate the times of the 1200 photomultiplier tubes within the main LSND tank. By providing a standard light flash at an accurately known time and position, the individual transit times and cable delay times for each tube can be determined and compensated for. For these time offsets to contribute negligibly to the uncertainty in the timing, it is desirable to determine them with sub-nanosecond accuracy. The system parameters have been chosen to be consistent with this goal.

The need for a fast, triggerable laser determines the choice of a pulsed nitrogen laser. The LN203C from Laser Photonics has an advertised pulse width of 500 psec and is TTL triggerable (via an internal thyratron) at rates up to 50 Hz with a jitter of 3 nsec. The pulse energy of 70 microjoules, the smallest power level of available nitrogen lasers, is calculated to be more than adequate — we expect to have to attenuate the light by a factor of nearly one million.

A tunable dye module allows us to choose the wavelength of the light flash to be 450 nm, a value better adapted to available optics and more central to the experimental light spectrum than the 337 nm of nitrogen. We are experimenting with dyes to find a suitable dye solution. Although intended primarily as a time reference, the advertised stability of the laser gives it the potential to serve as a secondary standard for gain calibration. At the very least, clusters of similarly positioned tubes can be used to bootstrap a gain reference throughout the tank. The additional ability to scan the wavelength makes it possible to determine relative gains as a function of wavelength.

The laser flash, after attenuation, will be divided among the three legs of a slica fiber splitter. Each leg then has further trim attenuation and passes a computer controlled shutter before being refocused onto the 200 micron 10 meter-long field cables that run to the tank. Multimode step-index fiber was chosen as being more robust than graded index fiber and less sensitive to connections than single mode fiber. The time dispersion in these cables will degrade the pulse time somewhat, but this can be compensated by averaging over a sufficient number of pulses. At the tank the light passes through optical feedthroughs to interior cables from which diffusers are suspended. The field cables and splitter have been delivered and checked out; the feedthroughs and interior cables are on order from General Fiber Optics.

Following up on an idea used at Kamiokande, the diffusers are flasks of Ludox, a commercial suspension of silica spheres in water. Because the diameter of the spheres is small compared to the wavelength of light, light is scattered in a purely Rayleigh pattern. This $(1+\cos^2\theta)/2$ pattern is further randomized by multiple scattering since the flask must be several mean free paths in radius to attenuate the beam. The use of three scattering centers ensures that all tubes receive photons and provides redundancy. The relative timing from three accurately located scattering centers should provide useful cross checks on the timing.

Using ordinary CW lasers at 634 and 543 nm, studies of two varieties of Ludox, 12 nm HS-40 and 22 nm TM, have determined the mean free paths of each. We will use the latter variety, which has a satisfactory mfp of 1.7 cm when scaled to 450 nm. This mfp is nevertheless nearly an order of magnitude longer than that calculated theoretically. Further study of diluted samples is being undertaken to understand this discrepancy. We believe it must be due to the correlations among the closely packed spheres, as opposed to the independent scatterers assumed by the theory. Understanding the scattering cross section, besides its intrinisc interest, is desirable for predicting the possible consequences of breaking one of the spheres within the

LSND fluid. Thorough mixing of a spilled flask in the 50,000 gallons of oil should give a scattering mean free path of about 1200 m at 450 nm and 120 m at 250 nm — long compared to that from other processes of scattering and absorption in the oil.

1.4 Tank work

The Temple shop has manufactured the port covers through which the signal/HV cables for the 1200 tubes enter the tank. The covers have been delivered to a contractor who will insert cables through the individual holes and pot each group of cables to make the assembly oil tight. The cables will be cut to length and connectorized after assembly in the tank.

The shop has also produced blank cover plates for the cable ports so that pressure testing can be carried out as soon as the tank is ready and while the cable potting is still in progress. Finally, they have produced special recessed covers for the calibration ports. The limited clearance above the tank (1.9"), the limits on bending radius (4") for a fiber optic cable, and the size of the connectors and feedthroughs combine to require that the cable be attached to the tank several inches below the normal tank surface. All of these items were on the critical path toward the goal of accelerating the experiment schedule — in particular toward having the tank positioned in its tunnel by September. Everything installed through the ports must be completed before that move can be made.

1.5 Track reconstruction and Monte Carlo

P. Hermida has been working on the muon reconstruction algorithm which will be used in the on-line processors to distinguish between cosmic ray muons that pass through the fiducial volume of the detector and muons from cosmic rays or from neutrino interactions that stop and decay in the detector. A quick and efficient algorithm will give us the ability to reject uninteresting cosmic ray events that have evaded the cosmic ray veto.

The information the algorithm has to work with are the time, pulse height and location of PMT's receiving a signal. The pulse height will generally saturate for tubes hit by the Cerenkov cone. Clusters of these tubes are used to determine the entrance and exit position of the track, the distinction between entrance and exit being based of course on timing. There are several categories of cosmic ray events that must be distinguished in the algorithm: Upward and downward traveling muons, both throughgoing and stopping, and those that only clip an edge of the detector.

The algorithm is being tested using cosmic ray events generated by the Monte Carlo simulation written by A. Eisner, D. Smith, and D. Whitehouse, which generates realistic PMT signals. Figures 8–14 show distributions of the differences between the reconstructed and the Monte Carlo generated entrance and exit positions and angles. Off-line analysis of events that pass the on-line analysis can use more lengthy and elaborate calculations to further sharpen the reconstructed tracks.

In Philadelphia, we are engaged in installing the analysis software on a local DECstation.

1.6 E764

The final paper on a previous neutrino experiment at LAMPF (E764) has been submitted for publication.[2] A draft of this paper on muon-neutrino interactions with carbon nuclei is included in Appendix A.

2 Rare kaon decays

2.1 E791

This experiment is now substantially complete, the analysis of the entire data set having been undertaken in a comprehensive manner. S.Kettell and J. Belz have taken a major role in the μe and ee analysis [4, 5] and to the writing of a μe paper. A copy of the draft paper [6] on the μe analysis is included in Appendix A.

With the increased statistics of the total data sample, backgrounds could be seen encroaching on the signal region. Careful study was required to understand the apparatus thoroughly and determine which cuts could be tightened to reject background without greatly reducing the acceptance. A new 'blind' analysis technique was used for the μe and ee data: a signal 'box' was defined in reconstructed mass $(491.7 < m_{\mu e} < 503.7 MeV/c^2)$ and transverse momentum $(\mathrm{P}_T^2 < 144(MeV/c)^2)$ and only events outside this box were studied in determining the cuts to apply to the data. Only after the final set of cuts were chosen, was the box opened; no events were found in either the μe or the ee sample. Because no cuts were chosen exclusively to eliminate any signal events, no bias from a selective tuning of cuts is introduced into the final branching ratio limit.

During the course of our analysis of the μe data we realized that the most troublesome source of background has been from K_{e3} decays in which the pion decayed and we incorrectly resolved an ambiguity in the drift chambers. The final state particles (μ and e) are identical to $K_L^0 \longrightarrow \mu e$, and the pion decay and ambiguity can conspire to raise the measured mass above the kinematic endpoint of 489 MeV/c^2. A tighter set of cuts was introduced for events that have an ambiguity in the x-view (the momentum determining view).

A significant improvement in the analysis has been the enhancement of one of the fitting programs to use all 5 available degrees of freedom in creating the χ^2. This fitting routine introduces kink angles in the y-view (non-bend) of the track at drift chambers 2, 3 and 4 and forces the swimming routine to pass the track trajectory through the actual hit positions at all chambers. The magnitudes of the kink angles then contribute to the χ^2. The kink angle at the fourth chamber $(\Delta\theta_4)$, downstream of the second magnet, has proved very useful in selecting against background in the μe sample. By requiring a good match of the momentum as measured in the two magnets, we are able to discriminate against pion decays if the decay introduces a kink in the track in the x-view If we also have atrack ambiguity in the x-view, however, a pion decay and an incorrect resolution of the ambiguity can lead to a good momentum match (and a high $m_{\mu e}$). A cut on $\Delta\theta_4$ reduces this background as the pion decay is likely to introduce a kink in the y-view in addition to the kink in the x-view of the track.

We found a significant source of track ambiguities that had not been appreciated previously. In addition to events where only one wire is hit or where two wires are hit but do not form a good time sum, another class of events has three wires hit and forms two good time sums. This additional class of events occurs with half the frequency of the other classes and so contributes significantly to the background to μe.

A tighter cut on the difference between the expected range of the muon and its actual range was found to be a powerful means of rejecting background of this type. We now require the actual range to be no less than 90% of the expected range (vs. 70% previously). This cut our background sample in half with only a 2% loss in efficiency.

The analysis of the ee data has been carried forward primarily by Temple, since it will be the subject of J.Belz's thesis. Several important enhancements have been introduced. The decay $K_L^0 \rightarrow eeee$ has been included in the Monte Carlo and we see good agreement with the data. In fact this decay is perhaps the most significant source of background in the ee analysis. A new cut has been introduced to reduce this background — if an event has extra tracks in the first two drift chambers that point back to the event vertex, the event is cut. This has a small efficiency loss and eliminates one quarter of the events above a mass of 475 MeV/c^2. A plot of θ^2 vs. m_{ee} for events passing all cuts, except the extra track cut and the 'same charge' cut, is shown in Figure 15. No events fall within the kinematic box and all of the remainder on the plot fail some other criterion. Nine of the events have one track above π theshold in the Cerenkov counter, four events have extra track stubs, and seven events have the same charge.

The analysis of the ee data is nearly finished and the thesis and a draft paper will be forthcoming, with an upper limit of 4.1×10^{-11}. This will be the most sensitive search yet done for this allowed but very rare decay. The analysis has shown that future experiments that attempt to go down another order of magnitude to the unitarity limit will face background limitations from the Dalitz and double Dalitz modes unless the experiment is specifically designed to reject them.

The final analysis of all the $\mu\mu$ data is progressing and a draft paper will be available soon. The branching ratio from the total sample of 720 events is $(7.0 \pm 0.4 \pm 0.2) \times 10^{-9}$.

2.2 E871

The proposed upgrade from E791 to E871[7] requires that ways be found to handle a much more intense beam with low deadtime and high pattern recognition efficiency. First of all a parallelism trigger between two separated hodoscopes will hold down the trigger rate. Secondly the beam will be stopped in the single analyzing magnet so that downstream K decays will not contribute to the accidental triggers. Downstream detectors will be able to span the beam line and the overall acceptance will be larger. Higher rate tracking detectors will be necessary, preferably with reduced sensitivity to the low energy neutrons and photons coming from the beam plug. The old apparatus will be used wherever feasible, supplemented or replaced by new designs as needed.

The E791/E871 groups have carried out studies of the design of an adequate beam plug design over the last two years, including this spring. Rates in the existing detectors, in prototype detectors, and in special flux monitoring detectors were measured. The outcomes indicate that the scheme is workable.

Temple assumed responsibility for the design and construction of the first level trigger for E871. The trigger requirements cannot be met with commercially available units, so we are building eight new module types (typically 3-5 of each type). These modules will be made with ECL 10E series chips to reduce timing dispersion compared to that available with commercial units. Several of the boards have highly specialized designs to meet the requirements of keeping accidental rates low and the efficiency high.

The L0 trigger has two module types: an X-X coincidence unit that imposes a parallelism requirement between two hodoscopes in the trigger and an X-Y coincidence unit that provides an effective meantiming of the X signals. The Y counters also serve to reduce the rate from accidentals. The design, layout and prototype construction have been completed for the L0 X-Y coincidence board. A logic diagram for this unit is shown in Figure 16 and the layout diagram is shown in Figure 17. It is a standard CAMAC board and uses ECL 10E surface mount chips. Testing of this board is underway. The design of the second board, the L0 X-X coincidence, is nearing completion and will soon go out to be manufactured. We anticipate that the remaining boards will be completed by the end of the 1992 calender year.

Temple took the responsibility for coordinating between the E871 experiment and BNL for the first half of FY1992. In this capacity we coordinated design activty for a new vacuum tank, a new spectrometer magnet and the reconfiguration of the muon range finder. In addition we organized the preparation for the 1992 running periods for experiments E871 and E888.

3 E888: Search for the H

Experiment E888[8] is a search for the H, the six quark, strangeness -2, zero charge state suggested by Jaffe[9] as a necessary consequence of the quark theory. It was proposed by V. Fitch (Princeton) that the E791 equipment could be used with only minor modification to search for this state. A proposal to fit in a quick run before the E791 equipment is disassembled in July to make way for E871 was defended before the BNL PAC in January. It was estimated that about two weeks of data could make a significant contribution. The proposal was approved and at this time the run has been mounted and has gone well. Two techniques are being used to cover a wide range of possible quark binding energy.

3.1 Decay search

Most calculations of the binding suggest that the mass would be less than that of two Λ's, with the consequence that it would be stable against strong decay. Decaying only weakly, the lifetime should be such as to let it, like the hyperons, propagate a finite distance from a production target. A. Schwartz (Princeton) studied the minimum bias data tapes taken in E791 and found that Λ's from the target, decaying to $\pi^- p$, are readily identified. A subset of the Λ's is identified as coming from Ξ^o production in the target with subsequent decay to $\Lambda\gamma$. We therefore believe that Λ's from the decay $H \rightarrow \Lambda n$ should be detectable if the H lies in the mass range between Λn and $\Lambda\Lambda$ and if the liftime is of the order 10^{-10} sec.

Sources of background include neutrons scraping the collimators and interacting with the residual gas in the decay volume. The former should be identifiable by projecting the Λ momentum back to specific planes along the beam direction. Gas interactions have been greatly suppressed as compared to E791 by improving the vacuum a factor of 10^3 from 10^{-2} torr to 10^{-5} torr. Data have been taken at much higher pressure to look for gas background; preliminary analysis indicates that there is none at our sensitivity.

K_{e3} and $K_{\mu 3}$ decays give neutral V's which may be mistaken for Λ's. These are mostly suppressed kinematically in the Level-3 trigger algorithm and off-line, but the trigger rate must be held down by the particle identification counters. One background is the misidentification of a π^+ as a proton and an e^- as a π^-. To improve the veto efficiency for this mode we lowered the pion threshold in the left Cerenkov counter, which tends to see the positive particles, from 8 GeV to about 3.2 GeV by filling it with Freon 12. This required some effort by the Temple group to reduce some previously inconsequential leaks and to replumb the gas supply system to provide either or both of He/N_2 mixture or Freon and to measure interferometrically either of the widely different indices. The interior optics were also re-aimed on the basis of Monte Carlo simulation of the signal.

During the run, the beam rates were mostly so low that the left Cerenkov could be left out of the trigger and used off-line. At higher beam rates putting the counter into the trigger as a veto reduced the rate by about a factor two. Figure 18 shows how the Λ sample is cleaned up by it; the dashed line is the approximate level of leptonic background without using the Cerenkov information. (Higher masses are suppressed by an on-line calculation.) As usual, hardware design and maintenance of the trigger was a Temple responsibility and carried out by S. Kettell. The Texas group took over the maintenance of the muon hodoscope during the run.

3.2 Diffractive dissociation

Donoghue, Golowich, and Holstein[10] have calculated the binding and lifetime of the H and conclude that it might have a lifetime more like the K^+ in the 10^{-8} range (but not so long as to enable it to travel from Cygnus X-3, as has been speculated.) In this case, the rate will be too slow to be detectable by the decay technique. This is also the case in the unlikely event that the binding is so strong as to reduce the mass below that of nn, rendering the system stable.

For these reasons, we also are taking data in which the long- lived H's dissociate into $\Lambda\Lambda$ after diffraction on the protons in an active scintillator target. This target will veto most inelastic events and events which have charged secondaries. The associated production background of ΛK^o made by neutrons in the target, with the K^o misidentified as a Λ, is again reduced by the Freon filled Cerenkov counter. Since the Λ's will be strongly forward peaked while the soft pions bend considerably in the magnet, the counters were relocated to cover the phase space of interest. Chambers also had to be rearranged — three of them moved into the beam just downstream of the dissociator and one of them rotated for ambiguity resolution. This means that, unlike the decay search, a new pattern recognition program will have to be written before data analysis can proceed effectively.

4 Other work

As part of an effort to understand in detail the E791 Cerenkov counters, the Temple group participated in some tests at Fermilab for a prototype gas Cerenkov counter for the SDC detector. The results of this study are being prepared for publication.[11] This work was supplemented by bench studies of reflective materials and of the effect of first dynode voltage on PMT photoelectron efficiency as a function of wavelength.

V. Highland and R. Cousins (UCLA) continued a study, which arose from the E791 rare decay experiments, of the appropriate statistical technique for including systematic errors into an upper confidence limit. It appears that there is no satisfactory solution to this problem except by using both 'classical' and Bayesian statistical ideas. A paper[12] giving these results is now in press.

5 Investigators' time and budget

The investigators spent the expected time on the contract. L. B. Auerbach and V. L. Highland worked on the project full time for two summer months and had one-third released time during the academic year. Auerbach concentrated on the LSND experiment, while Highland divided his time between the LSND calibration system and the H experiment. K. McFarlane remained on study leave from the University through the 1991-92 academic year. At the end of the year he has decided to resign his position to take up a new one at the SSC. He has remained involved in the Brookhaven work and as J. Belz's thesis adviser, but did not draw salary from the contract.

S. Kettell has worked full time at Brookhaven as a Post-Doctoral Research Investigator. C. Guss left the contract upon the completion of the last budget year. We are seeking a replacement Post-Doc who would focus on the LAMPF work in the immediate future. G. Daniel has continued his work as Senior Research Technician, supported by the University.

Graduate students working full time on the project included J.Belz, who has led the analysis of the $K_L^o \to ee$ data as his thesis project. D. Works has been in charge of testing the LSND phototubes in Los Alamos, assisted since the beginning of the calendar year by C. Athanossopoulos. At the same time P. Hermida went to Los Alamos to be more closely involved with preparations for data acquisition.

During the summer, Y. Xiao has worked on the Mont Carlo DECstation at Temple. A. Trandafir spent two months at Brookhaven assisting with the H experiment. An undergraduate, W. Filler, has worked part time on the optics of the laser calibration system.

Travel expenses for the group exceeded expectations.

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

6 Publications and References

Publications and reports are listed in section 6 as references [2], [3], [6], [11], and [12].

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A.P. Heinson, J. Horvath, C. Mathiazhagen, W.R. Molzon *(U.C., Irvine)*,
K. Arisaka, R.D. Cousins, T.Kaarsberg, J. Konigsberg, P. Rubin, W.E. Slater, D.L. Wagner *(UCLA)*,
W.W. Kinnison, D.M. Lee, R.J. McKee, E.C. Milner, G.H. Sanders, H.J. Ziock *(Los Alamos)*,

P. Knibbe, J. Urheim *(University of Pennsylvania)*, K.A. Biery, M.V. Diwan, G.M. Irwin, K. Lang, J. Margulies, A. Schwartz, S. Wojcicki *(Stanford)*, L.B. Auerbach, J. Belz, P. Buchholz, C. Guss, V.L. Highland, S.H. Kettell, W.K. McFarlane, M. Sivertz *(Temple)*, G.W. Hoffmann, P.J. Riley, J.L. Ritchie, A. Yamashita *(University of Texas)*, M.D. Chapman, M. Eckhause, J.F. Ginkel, A.D. Hancock, J.R. Kane, C.J. Kenney, Y.Kaung, W.F. Vulcan, R.E. Welsh, R.J. Whyley, R.G. Winter and M.T. Witkowski *(William and Mary)*, to be submitted to Phys. Rev. Lett.

[7] E871 collaboration (for 1992): D. Connor, J. Cortese, W. R. Molzon *(U.C., Irvine)*, M. Diwan, G.M. Irwin, D.A. Ouimette, S.G. Wojcicki *(Stanford)*, J. Belz, S. Kettell, W.K. McFarlane *(Temple)*, G.W. Hoffmann, J. McDonough, P.J. Riley, J.L. Ritchie, A. Yamashita *(University of Texas)*, M. Eckhause, D. Hancock, J.R. Kane, Y. Kuang, R.E. Welsh, R.G. Winter, and M. Witkowski *(William and Mary)*, Proposal E871 submitted to BNL, approved Sept. 1991.

[8] E888 collaboration: M. May, S. White *(BNL)*, D. Connor, J. Cortese, W. R. Molzon *(U.C., Irvine)*, R.D. Cousins, *(UCLA)*, V. L. Fitch, J. Klein, A.J. Schwartz *(Princeton)*, M.V. Diwan, K. Ecklund, G.M. Irwin, S. Wojcicki *(Stanford)*, J. Belz, V.L. Highland, S.H. Kettell, W.K. McFarlane *(Temple)*, C.A. Allen, G.W. Hoffmann, K. Lang, M.R. Marcin, J. McDonough, C.T. Nguyen, P.J. Riley, J.L. Ritchie, B. Ware, S. Worm *(University of Texas)*, M. Eckhause, A.D. Hancock, C. Hoff, J.R. Kane, Y.Kaung, R.E. Welsh, and R.G. Winter *(William and Mary)*.

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[12] Incorporating Systematic Uncertainties into an Upper Limit, Robert. D. Cousins and Virgil L. Highland, Temple report DOE-ER40389-69 (March 1991, Revised February 1992). Nucl. Inst. and Meth., in press.

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7 List of Figures

R220 floor plan; PMT testing, potting, and storage. 9/24/91

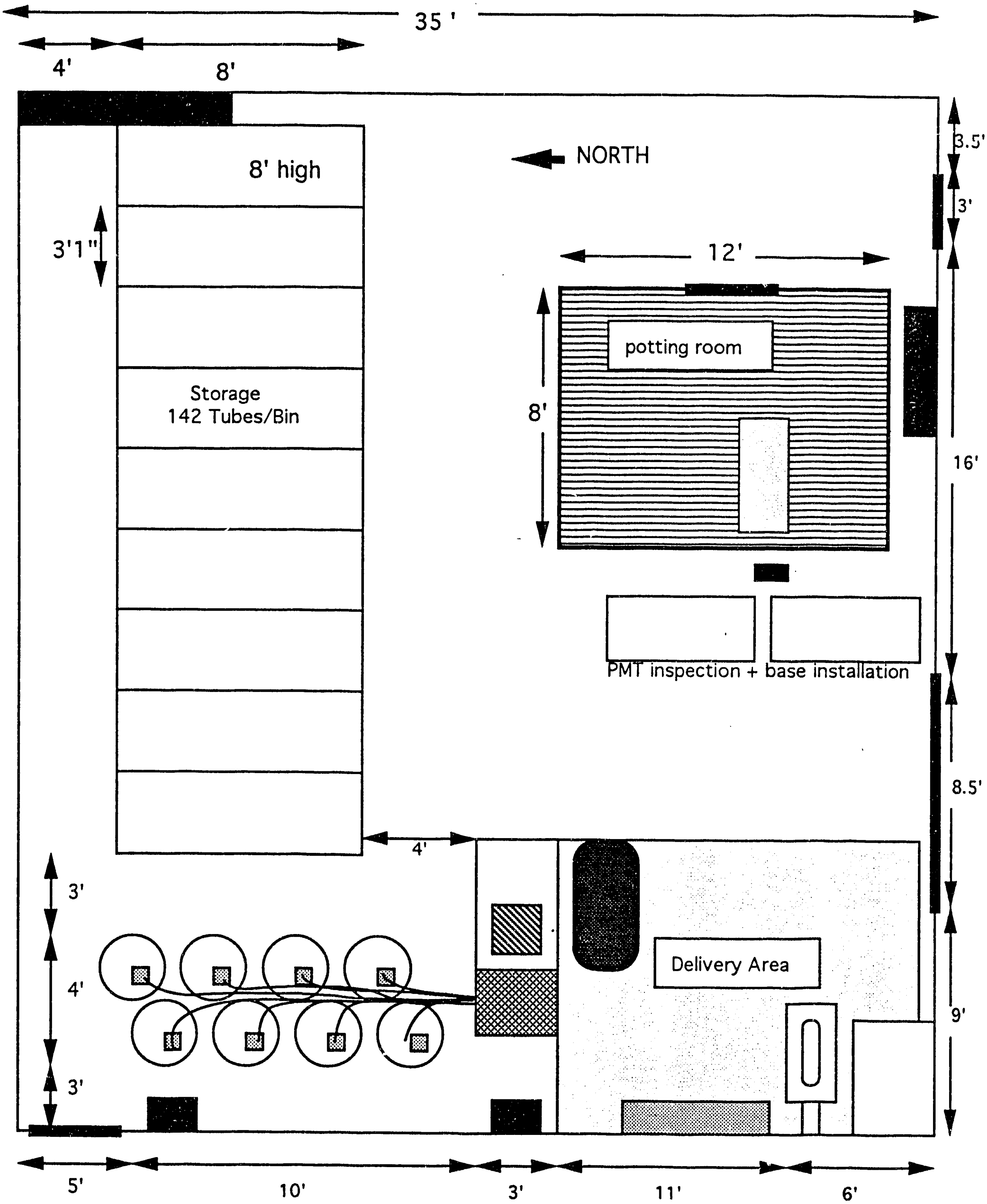


Fig. 1

PMT test electronics 10/23/91

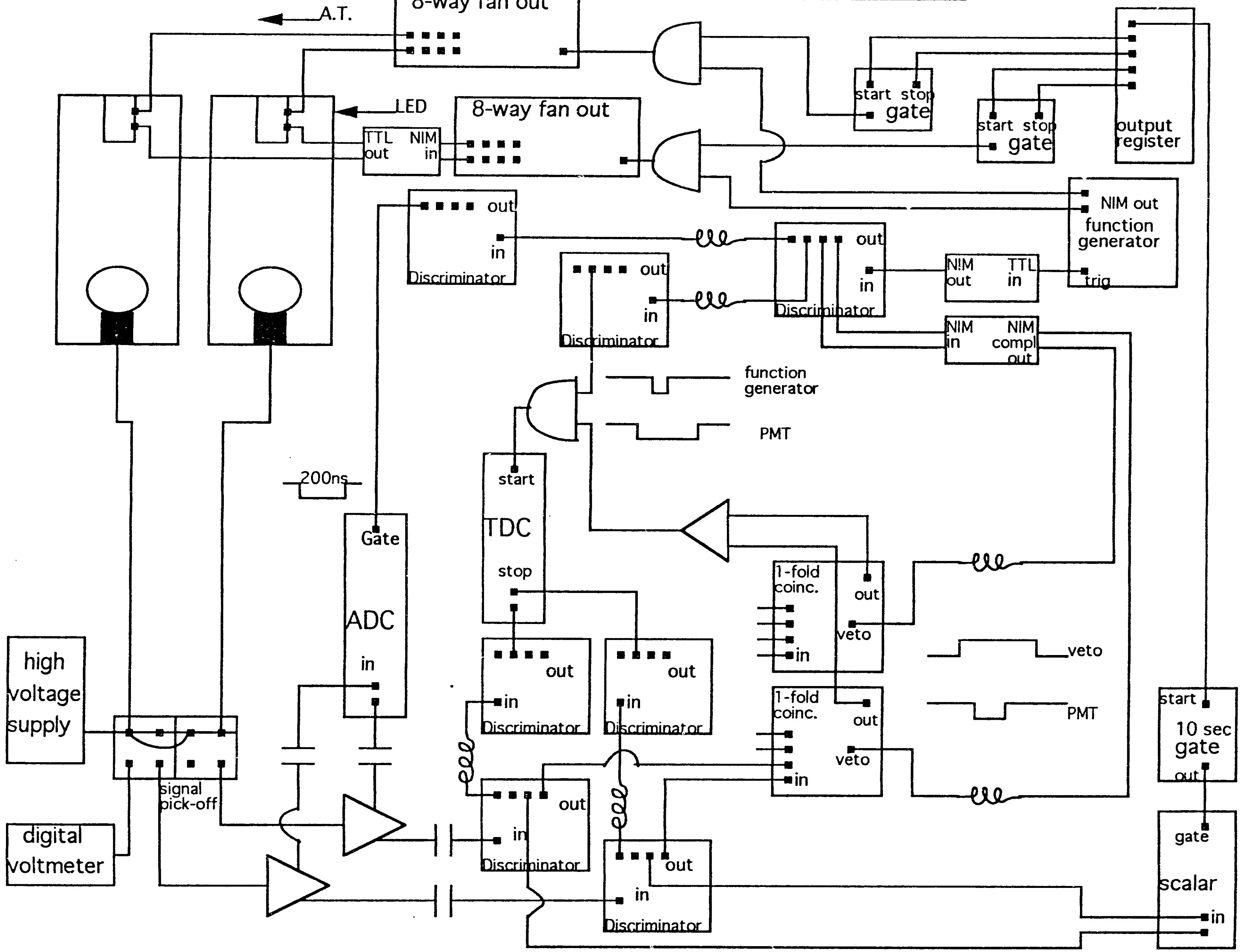


Fig. 2

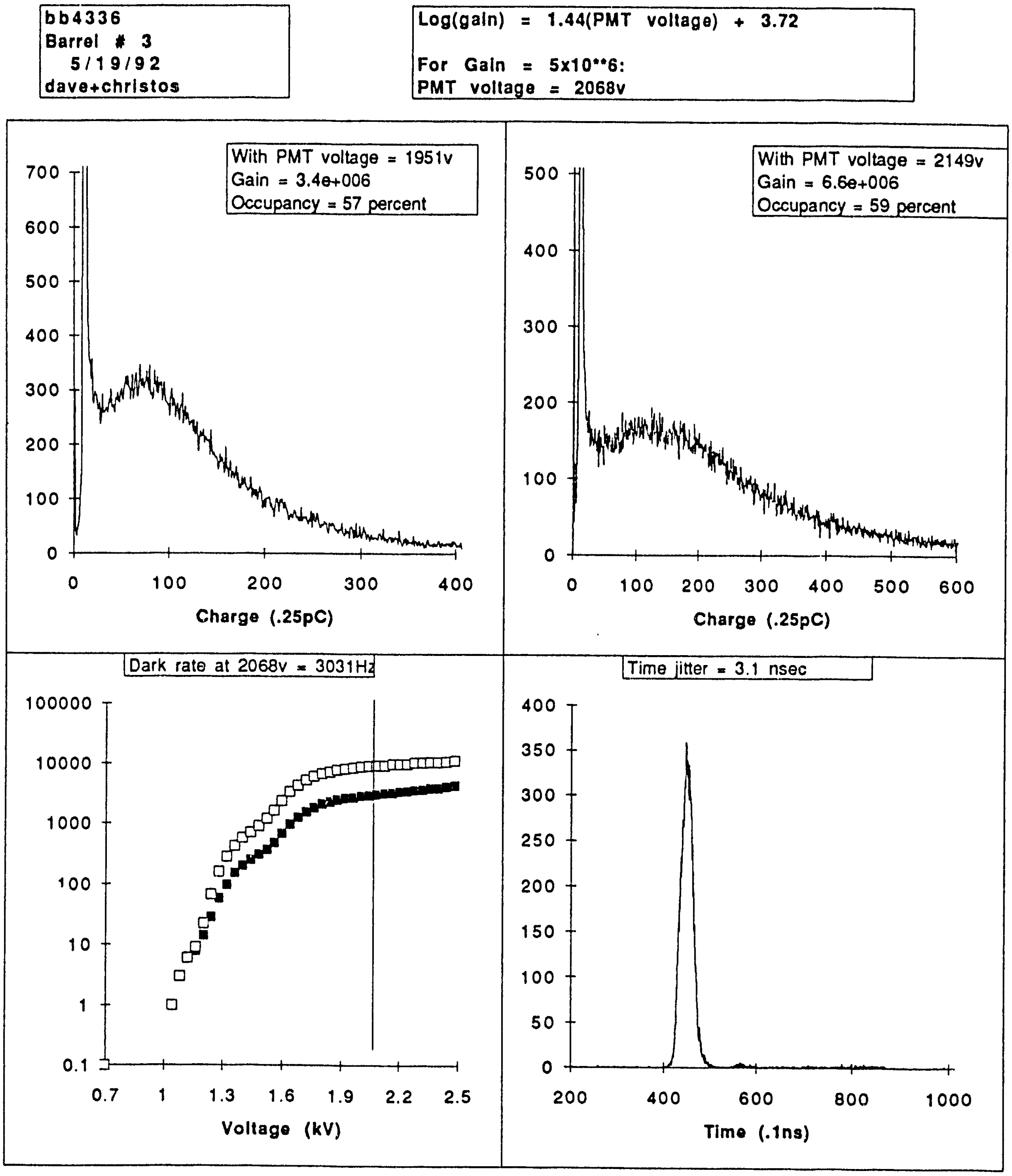

bb4336
Barrel # 3
5/19/92
dave+christos
Log(gain) = 1.44(PMT voltage) + 3.72
For Gain = 5x10**6:
PMT voltage = 2068v
With PMT voltage = 1951v
Gain = 3.4e+006
Occupancy = 57 percent
700
600
500
400
300
200
100
0
0
100
200
300
400
Charge (.25pC)
With PMT voltage = 2149v
Gain = 6.6e+006
Occupancy = 59 percent
500
400
300
200
100
0
0
100
200
300
400
500
600
Charge (.25pC)
Dark rate at 2068v = 3031Hz
100000
10000
1000
100
10
1
0.1
0.7
1
1.3
1.6
1.9
2.2
2.5
Voltage (kV)
Time jitter = 3.1 nsec
400
350
300
250
200
150
100
50
0
200
400
600
800
1000
Time (.1ns)

Fig. 3

Dark Rates for 5x10**6 Gain, 384 PMT's

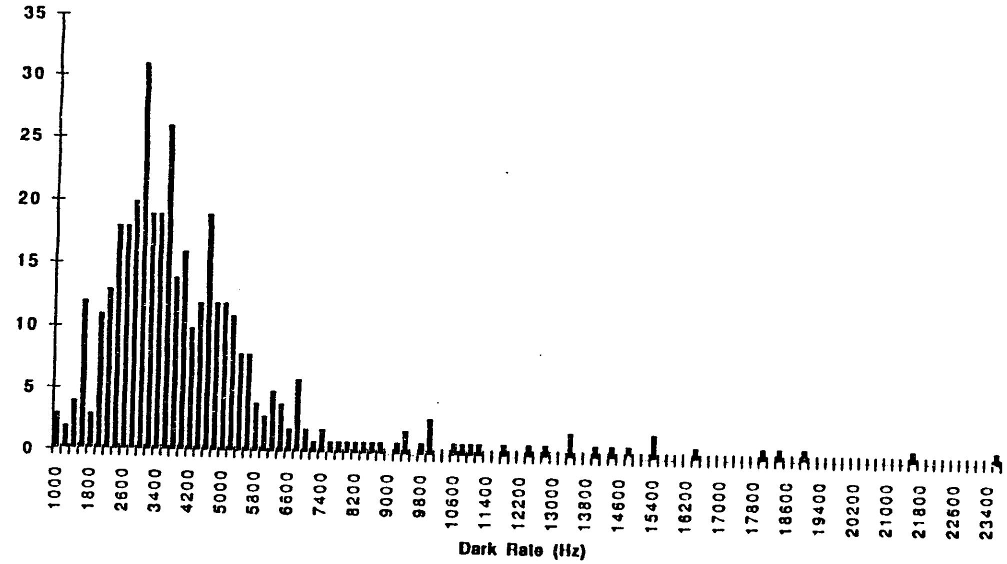


Fig. 5

Operating Voltages for 5x10**6 Gain, 384 PMT's

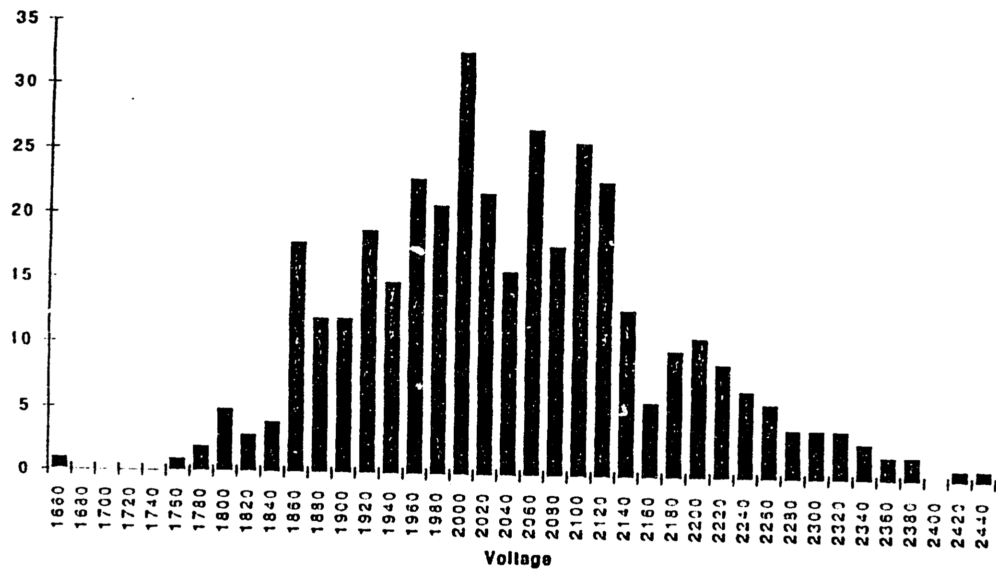


Fig. 4

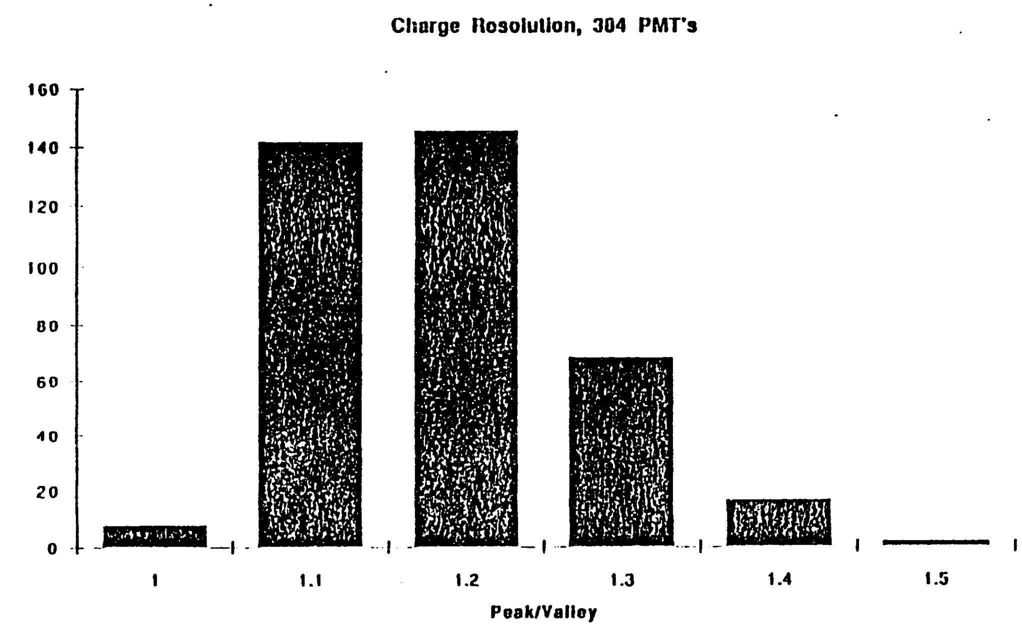

Charge Resolution, 304 PMT's
160
140
120
100
80
60
40
20
0
1
1.1
1.2
1.3
1.4
1.5
Peak/Valley

Fig. 7

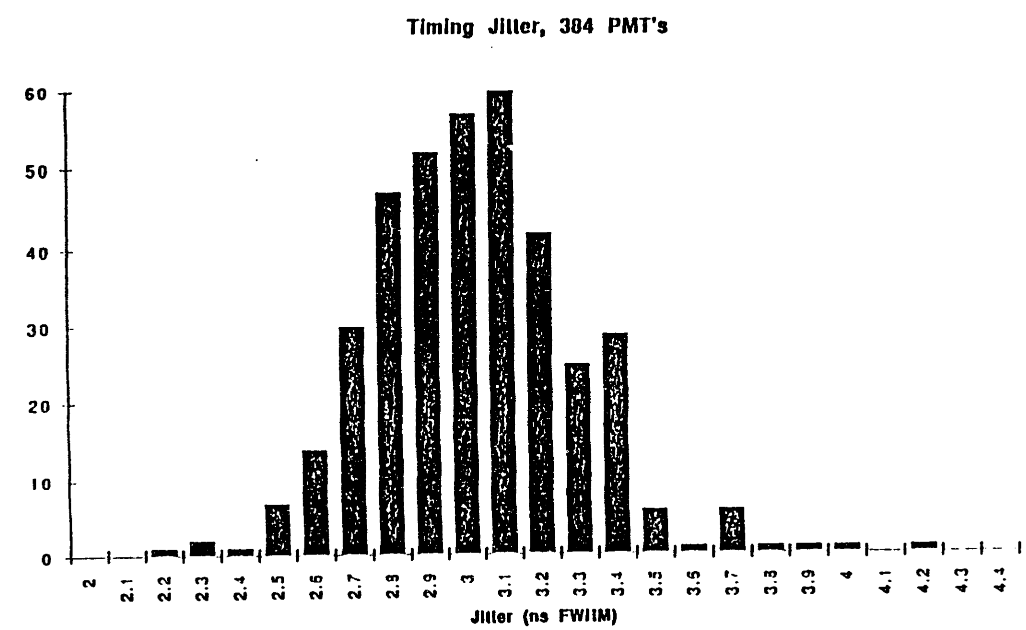

Timing Jitter, 304 PMT's
60
50
40
30
20
10
0
2
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4
4.1
4.2
4.3
4.4
Jitter (ns FWHM)

Fig. 6

Fig. 9 Exit error thrugoing

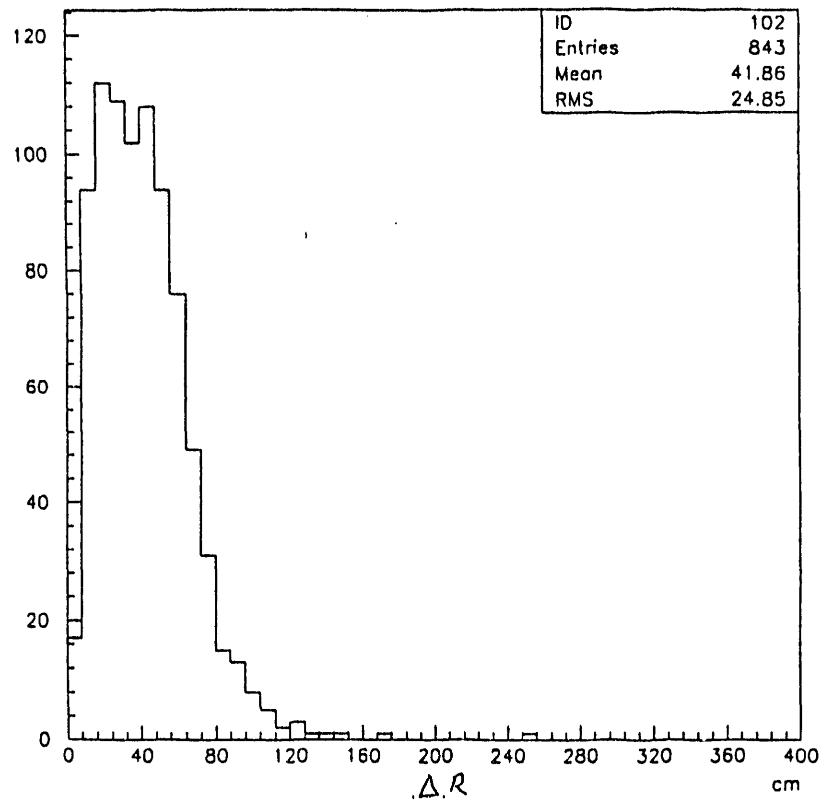


Fig. 8 Entrance error thrugoing

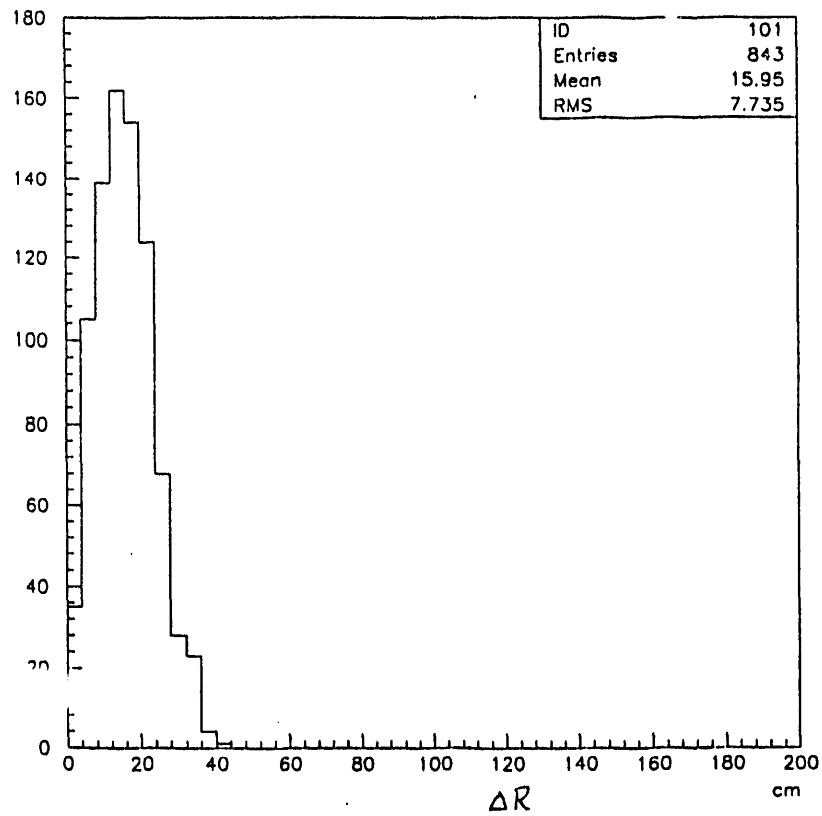


Fig.11 Timing error thrugoing

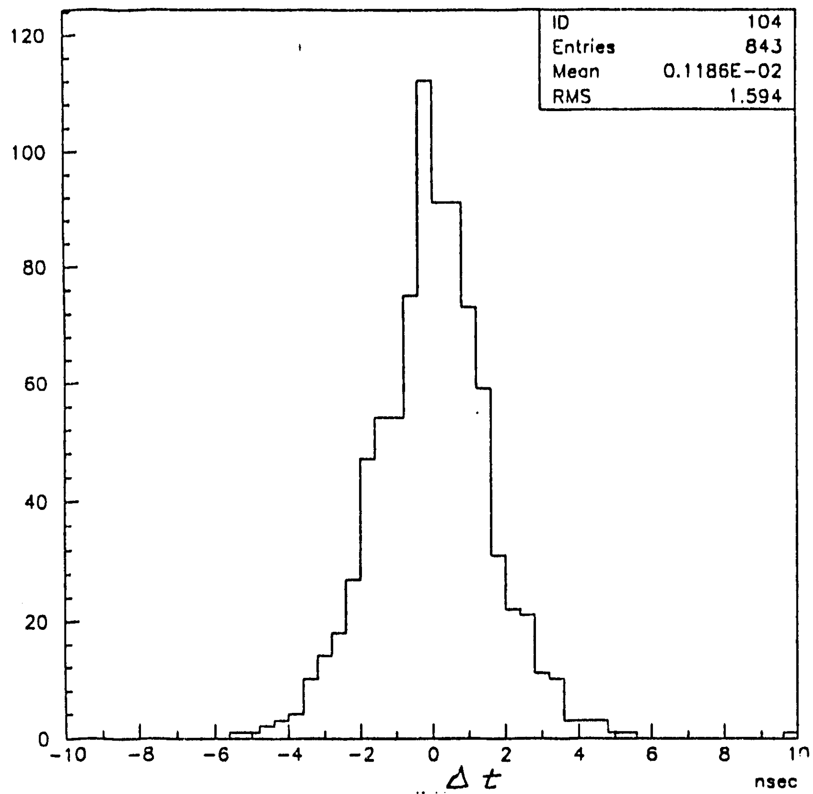


Fig.10 Angle error thrugoing

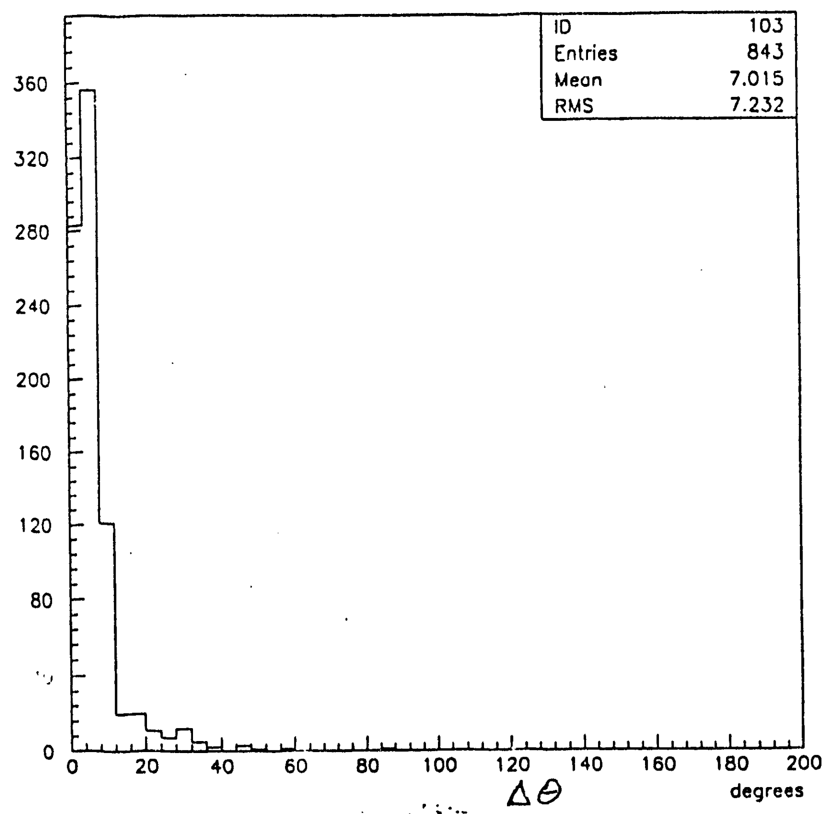


Fig. 13 Exit error stopping

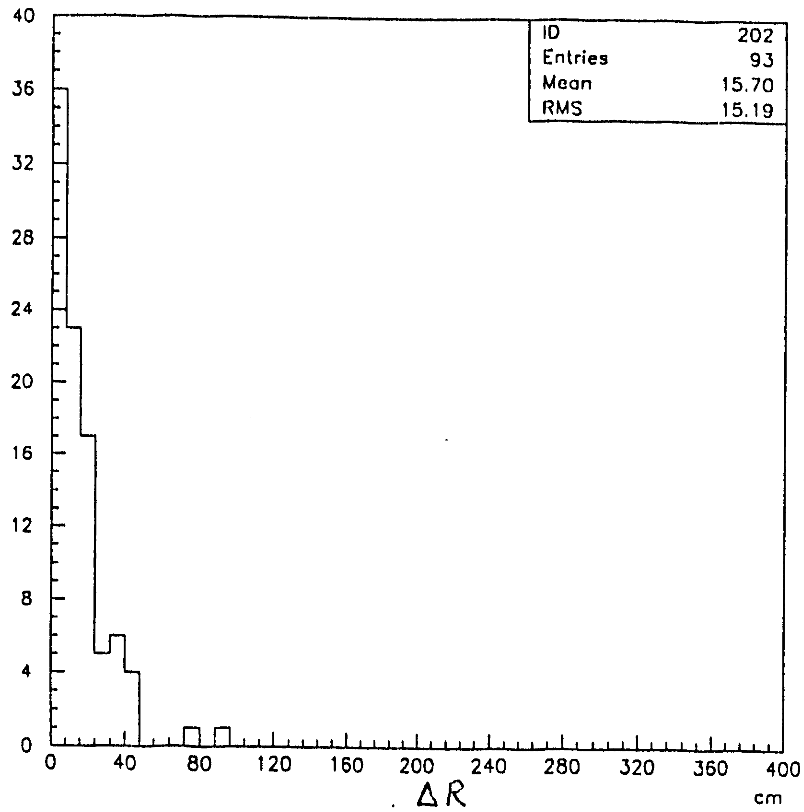


Fig 12 Entrance error stopping

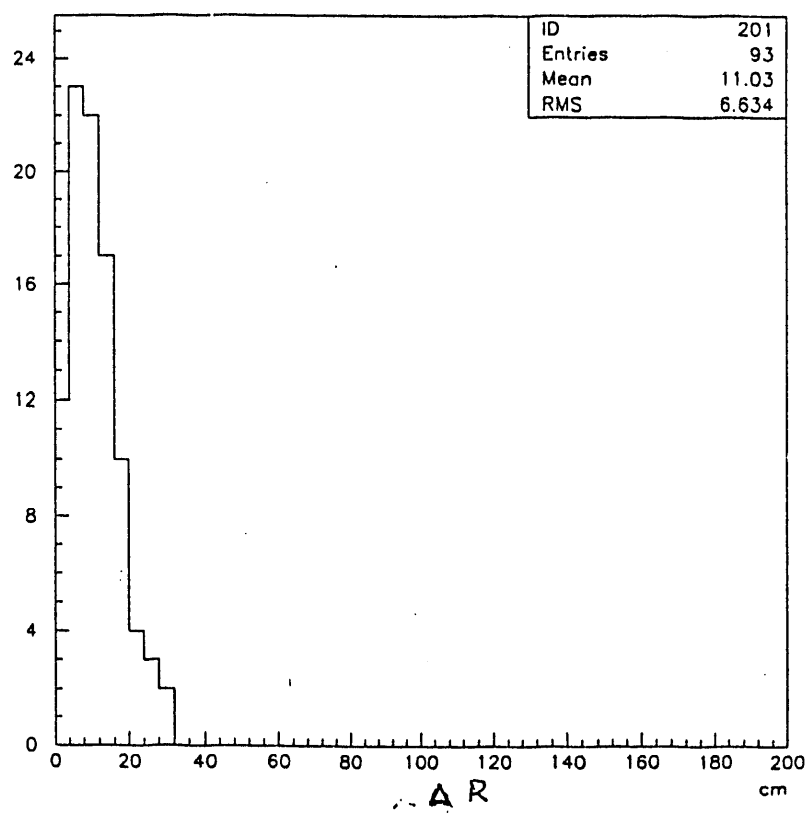
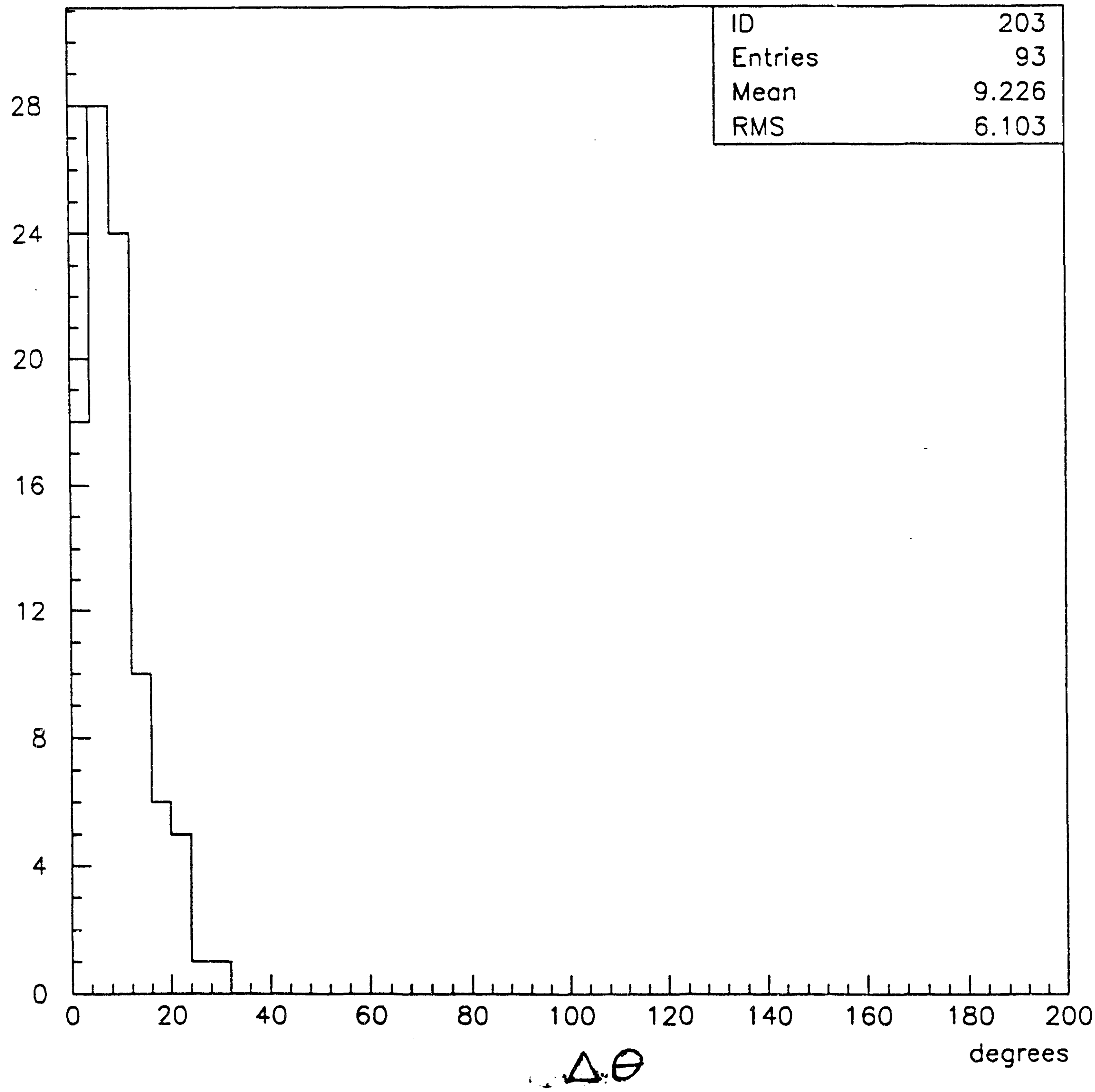


Fig. 14 Angle error stopping



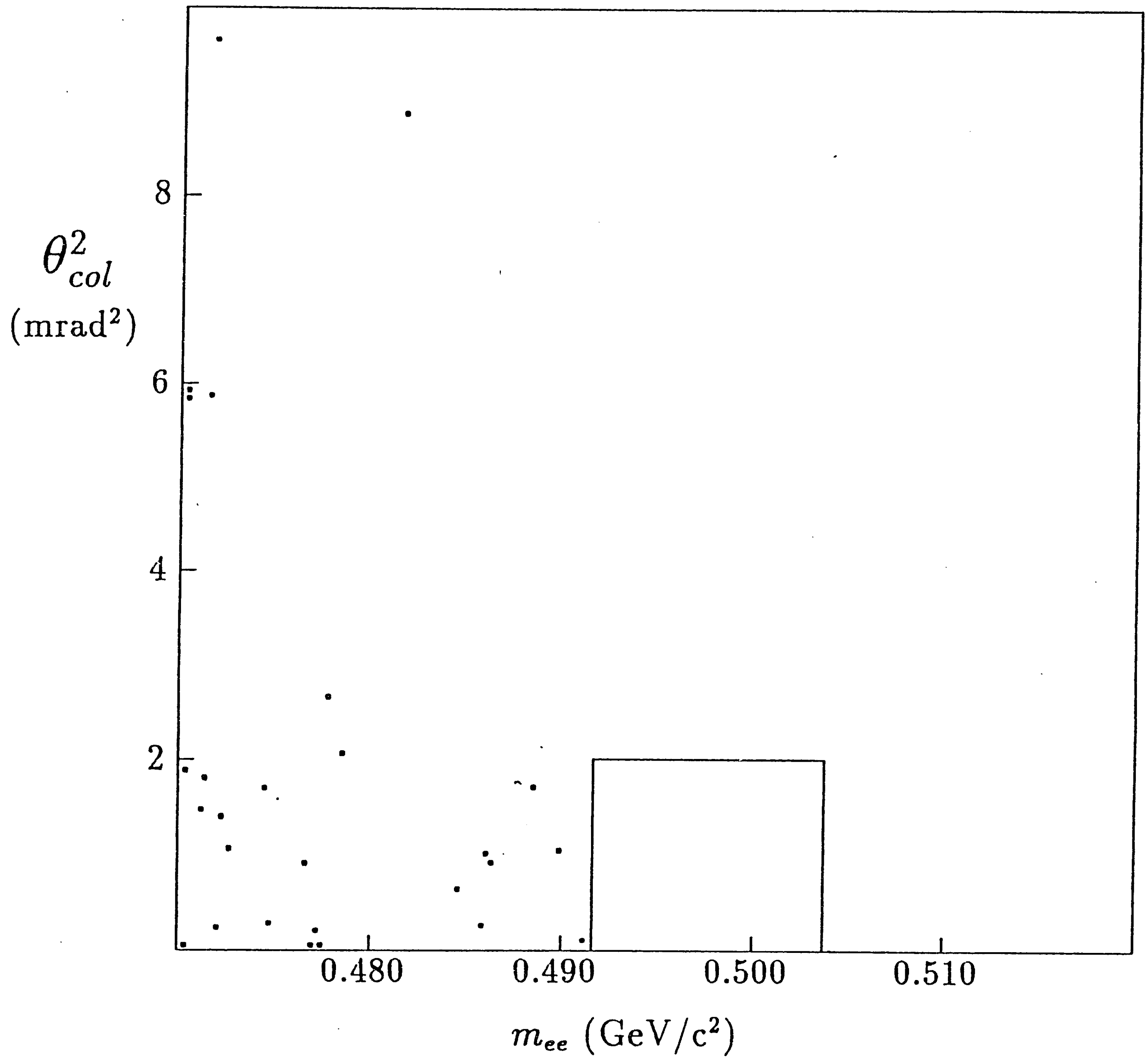
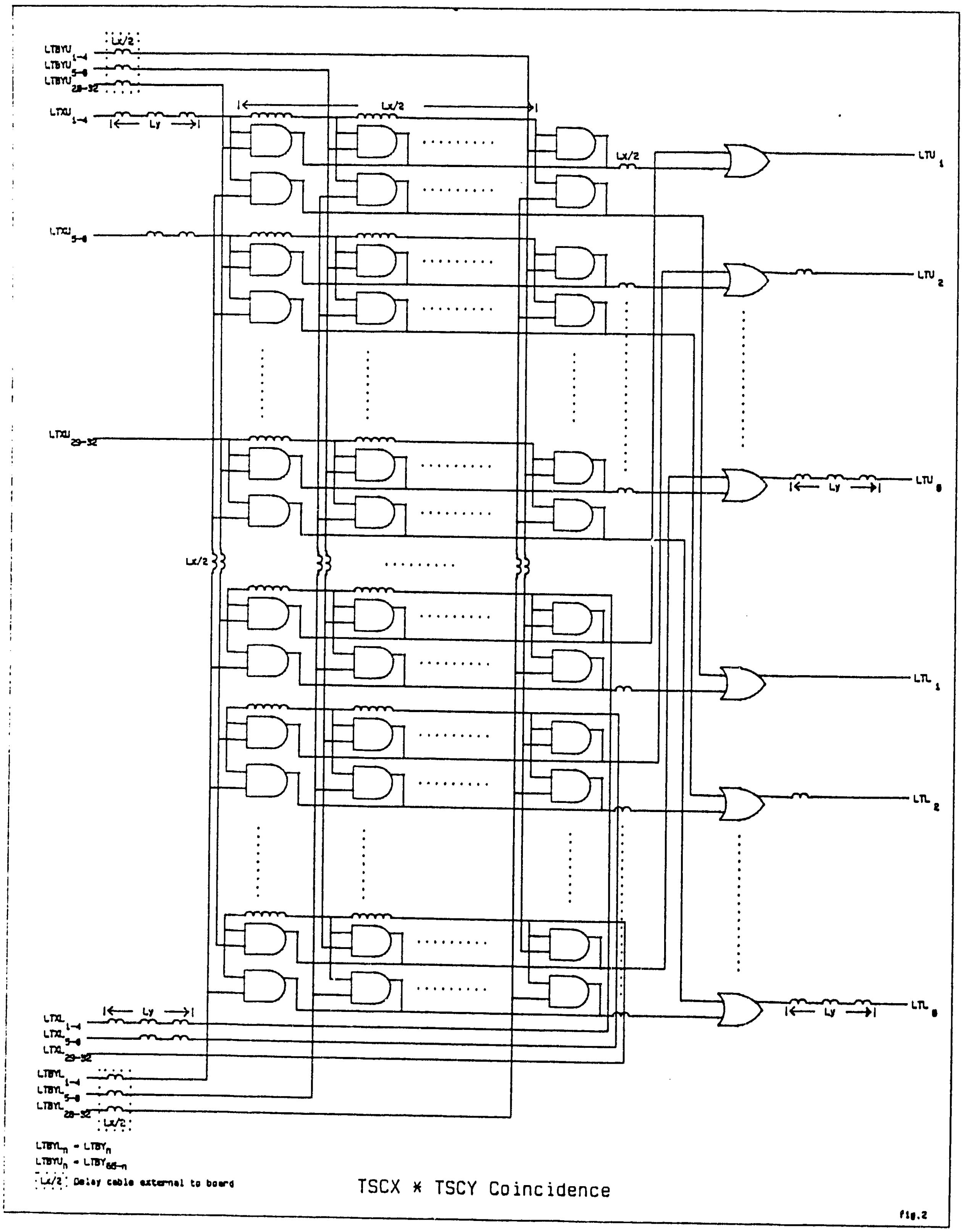


Fig 15



LTBYU 1-4
LTBYU 5-8
LTBYU 29-32
LTXU 1-4
LTXU 5-8
LTXU 29-32
Lx/2
Ly
LTU 1
LTU 2
LTU 8
LTL 1
LTL 2
LTL 8
LTXL 1-4
LTXL 5-8
LTXL 29-32
LTBYL 1-4
LTBYL 5-8
LTBYL 29-32
LTBYL_n = LTBY_n
LTBYU_n = LTBY_65-n
Lx/2 Delay cable external to board
TSCX * TSCY Coincidence
Fig.2

Fig. 16

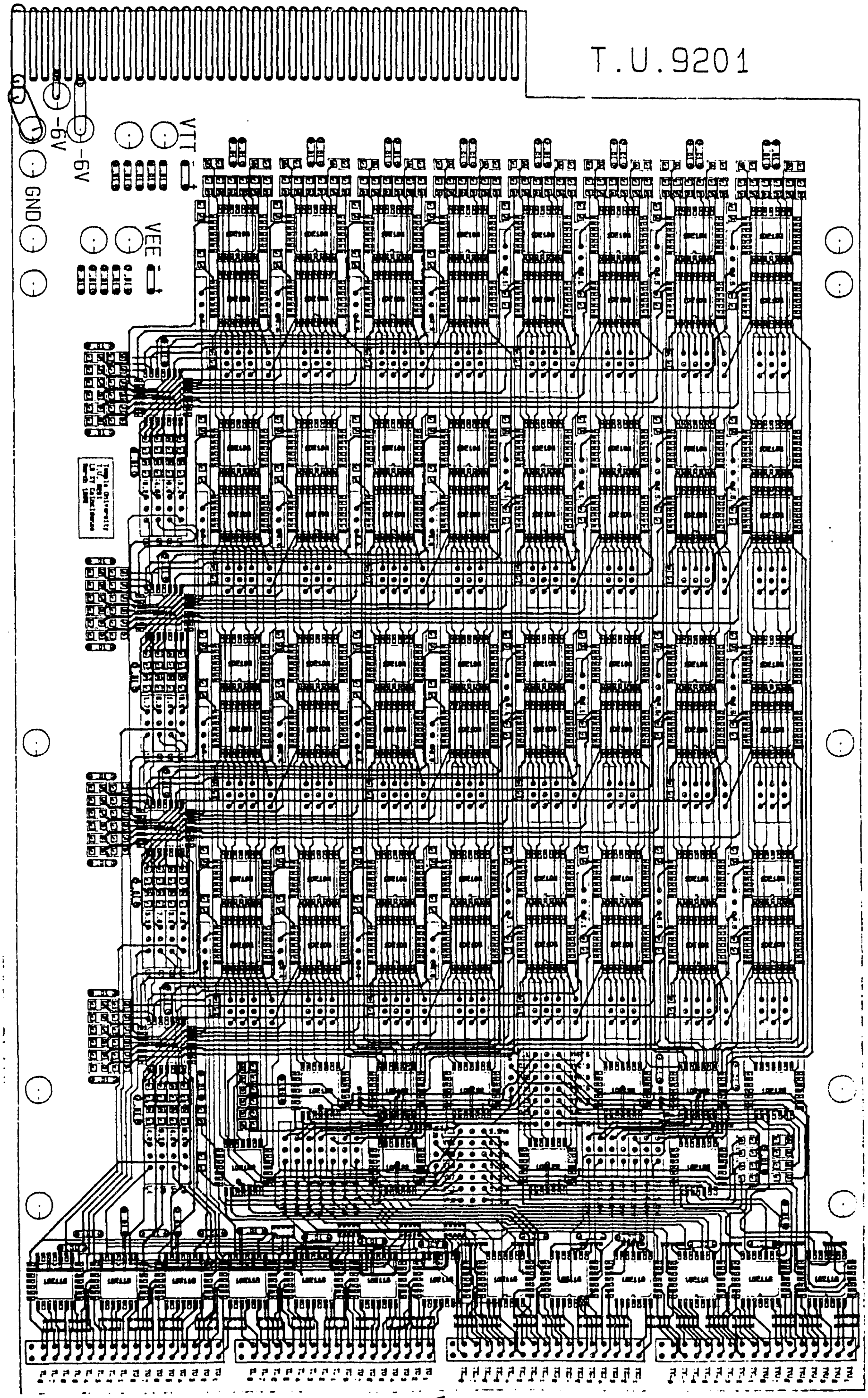
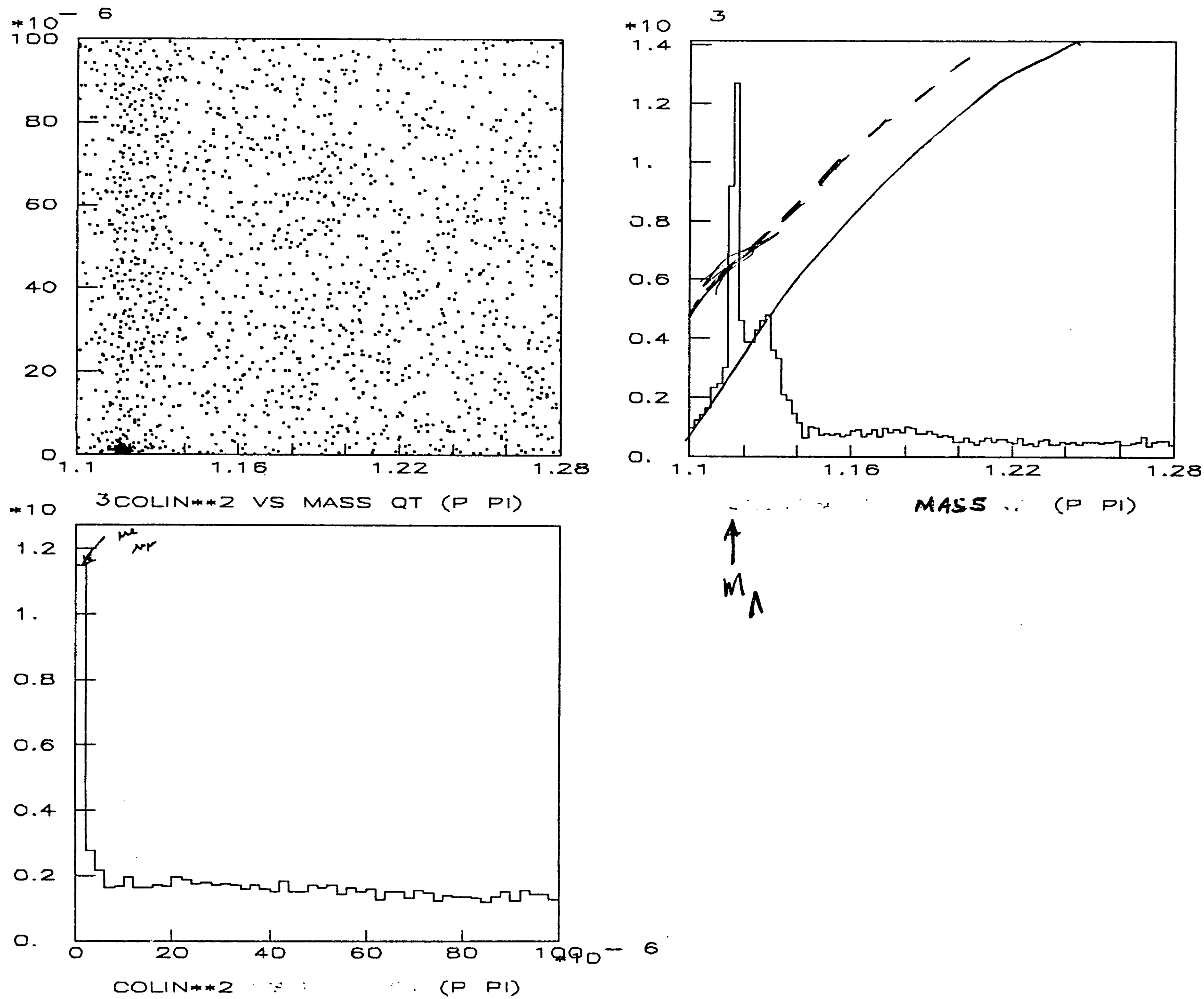


Fig 17



*10⁻ 6
100
80
60
40
20
0
1.1
1.16
1.22
1.28
3COLIN**2 VS MASS QT (P PI)
*10 3
1.4
1.2
1.
0.8
0.6
0.4
0.2
0.
1.1
1.16
1.22
1.28
MASS (P PI)
M Λ
*10
1.2
1.
0.8
0.6
0.4
0.2
0.
0
20
40
60
80
100
*10⁻ 6
COLIN**2 (P PI)

Fig 18

8 Appendix A

1. Final draft of submitted paper on E764.
2. Draft paper on LSND scintillator studies.
3. Draft paper on E791 μe results.

Preprints removed

END

DATE FILMED

12/1/92