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Proposed Design for a Photomultiplier Tube Testing Facility

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ABSTRACT

We present a plan for testing photomultiplier tubes for the D0 experiment at Fermilab. The photomultiplier tubes will be used to detect light from scintillator modules through fiber optics bundles in the Inter Cryostat Detector. About 800 photomultiplier tubes have to be tested during the next 8 months. Each tube will be tested for a period of 1 week to satisfy performance and calibration requirements. A fully automated system under computer control is proposed to test all the tubes in such a short period of time. The facility will be designed, built and operated at the University of Michigan. The project completion date is expected to be the end of August, 1990.

1. Introduction

Monte Carlo studies[1] show that the energy resolution of the D0 calorimeters is degraded in the pseudorapidity region between .8 and 1.4. As much as 60% of average shower energy may be lost in dead materials. The major sources of dead material are the cryostat walls and material in the region between the central and endcap calorimeters. There is limited readout in this region from the central calorimeter, while the endcap calorimeter readout occurs too late in shower developement. A scintillator tile Inter Cryostat Detector (ICD) was designed to provide an intermediate reading in this eta region between the two cryostats. With the additional sampling provided by the ICD, we expect to significantly improve the energy resolution and hermeticity of the D0 detector.

The ICD was designed to preserve the D0 tower structure. Each module spans .1 in eta and .1 in phi. A module consists of a scintillator tile with embedded wavelength shifting optical fibers to transmit light to photomultiplier tubes (PMT). There are $6 \times 64 \times 2 = 768$ ICD modules. Therefore, we need to test and calibrate the response of about 800 PMT's. According to the current schedule for the D0 detector, the task of testing the PMT's must be completed by the summer of 1990, that is in 8 months.

Three ICD modules of adjacent eta are housed in one box and share a single high voltage (HV) power supply. This common HV puts special performance constraints on the PMT's. One of the major tasks of the PMT testing stations will be to find matching sets of three PMT's.

Another major task of the testing facility is to help in the design of the online calibration system. We plan to use a nitrogen laser with fiber optics light distribution to calibrate the gain of each ICD module during the run. The PMT test facility will test many of the elements of this calibration system.

The main goals for the PMT testing facility are summarized as follows:

1. Certify and calibrate each PMT. Test temperature dependence, linearity, high rate effects and short term stability. Create a database with all test results, including gain-voltage characteristics, and dark currents for each PMT.
2. Match PMT's with similar characteristics in groups of three, since a single HV supply feeds three tubes in the same ICD box.
3. Use the test facility to design and benchmark the online calibration system for the ICD.

2. Performance Criteria

The specific performance limits for the PMT's have not been decided yet. We will describe here broad guidelines, which will serve as design crietria for the test stations. Once a decision is made on the tube type and we have preliminary test results from the first sample of tubes, we will freeze the performance limits for all the tubes. In addition, the criteria for matching three tubes cannot be specified till we have some experience with testing a large sample of tubes. The test stations therefore need to have flexible design. Some of the criteria and techniques used in designing the D0 test chambers are based on the CDF PMT testing experience.[2]

As described below, it will take about 1 week to test each tube. Since we wish to accomplish all testing in 6 months, we need to test 34 tubes per week. We plan to test some of the tubes for the entire duration of 6 months. Therefore, we propose to simultaneously test 48 tubes each week under computer control. This number also includes a few slots needed for monitoring light levels. To keep the size of the test chamber manageable, we plan to build 2 test chambers, each capable of handling 24 tubes.

From Monte Carlo studies,[3] and from recent test beam results from CERN,[4] we expect the ICD tiles to be exposed to a range between 1 minimum ionizing particle (MIP) to several hundred MIP's. The test facility will exercise the PMT's in this range.

We require a minimum resolution of 1 MIP in each ICD tile. From a Monte Carlo simulation[5] we expect about 40 photons per MIP. Therefore, we plan to test each PMT for exposures between 20 to 20,000 photons. The light pulsers have to be capable of providing photons in these numbers.

Since it would take too long to determine the gain-voltage characteristics for each tube individually, we plan to establish these characteristics in the test station using a programmable high voltage power supply. Once the gain-voltage curve is established, the operating voltages of the phototubes will be set to achieve the best operating range in the ADC's. We will also measure the dark current for each tube.

During the high intensity running of the accelerator, a 500 KHz crossing rate may be achievable. Assuming 7 particles per eta for a minimum biased event,[6] and assuming that 14 tiles are exposed in each event, we calculate that each tile will be exposed at a maximum rate of 5 KHz. These high rates will be simulated in the test chambers through lighting from a combination of light emitting diodes (LED) and Tungsten Halogen Quartz (THQ) filament lamps. The THQ lamps will also be used to simulate constant DC level background noise.

We plan to test each PMT for a large fraction of the full range of temperatures that is expected during normal running conditions at D0. A ciculating water system can achieve a range of 40 to 100 degree fahrenheit. The water supply will be cooled with ice and heated with electric coils.

3. General Layout

The general setup of the PMT test station with all its light sources is shown in Figure 3.1 . Each PMT testing station consists of a light tight aluminum box, inside which is a supporting structure for 24 phototubes, as shown in Figure 3.2 . Optical fibers from each of the light sources are brought into the box and attached to scintillator cookies. The cookies will be viewed by the PMT's to be tested. The design allows for easy exchange of the PMT's and reproducibility of the light contact between the PMT and the cookie. A circulating water heating and cooling system is attached to the box. The air temperature at several points inside the box will be monitored.

Independent light tight boxes are planned for each light source. The laser box, shown in Figure 3.3 , will be copper shielded to minimize noise. The intensity of the laser light will be controlled by a filter wheel under computer control. The intensity of the LED and THQ sources will be controlled by the computer through their power supplies. A temperature sensor will monitor the temperature inside the LED box. Numerous photodiodes will monitor the intensities of all three light sources. In addition, the absolute gain will be monitored by two radioactive Am-241 sources imbedded in NaI crystals.

The laser box with its optical fiber fanout and computer controlled filter wheel is designed as a smaller test version of the online calibration system. In the online calibration system we will need a fanout of 684 fibers for the ICD only, compared to the 48 fibers in the test facility. In addition, it will be controlled by VME instead of CAMAC. Otherwise, the two systems are identical. We plan to test and debug the laser system during the PMT test, so that we can evolve a workable design for the main ICD calibration system.

Both NIM and CAMAC modules will be used to control, monitor and acquire data from the test stations. A full rack with HV power supplies, 2 NIM crates, 1 CAMAC crate and patch panels is planned.

4. Data Acquisition and Trigger

We propose to use a generic PC clone for data acquisition and on-line analysis. CAMAC modules will be used for maximum compatibility and support from Fermilab. With a DSP Technologies 6002 crate controller and PC004 interface, we can achieve CAMAC cycles of 50 μseconds and maximum DMA transfer rates of 800 KHz. Such a system should be adequate for running two test stations, and additionally provide considerable cost savings compared to a VAX data acquisition system.

The heart of the trigger is a Jorway 221 timing module. This module can repeat a sequence of up to 4096 TTL pulses of specified duration for 12 output channels. The minimum pulse spacing is 1 μsecond. With appropriate pulse shaping and delays, we can control all the PMT test sequences with the Jorway 221. The nitrogen laser light source, LED's and charge ADC's will be triggered by the Jorway 221. The effect of high rates can also be simulated and tested quite easily.

The Jorway 221 module outputs TTL pulses with the help of a Jorway 222 power driver. The laser and the LED will then use the TTL pulses for trigger. A TTL-NIM level convertor with fanout is necessary to create the ADC gates.

In the normal data taking mode, the computer will trigger the laser and ADC's simultaneously using the Jorway 221, wait for the ADC's to complete digitization, and then read the data from the ADC's. Next the ADC's will be triggered to get pedestal readings. The read cycle will be repeated many times to increase statistics. Intermittent readings will be taken from the photodiodes and the temperature sensors. To increase throughput, the data could also be read in a synchronized listen only mode, where the Jorway 221 is programmed to execute many triggers, while the computer reads the data without reissuing commands to the 221.

Two different triggers are envisioned to study rate effects. First, triggers will be generated to pulse the LED's in between each laser pulse. The LED's will simulate minimum bias background at rates up to 1 KHz at each PMT. The laser will simulate high p_t D0 events recorded at a 1 Hz rate. Second, we will investigate the effect on resolution of having 2 triggers from two consecutive beam crossings. By varying the delay between the LED pulse and the laser pulse, we can study the effect of a second trigger within the tail of the pulse from the first trigger. All the special triggers needed to study rate effects can be generated with the Jorway 221. In addition, a constant DC level background can be simulated with the THQ light source.

5. PMT Charge and Dark Current Measurements

The operating voltage for each PMT will be determined in the test chambers to accomodate the minimum resolution of 1 MIP and the maximum response of 500 MIP's within the range of the ADC's used. For later use in D0, we will also create a database with the gain-voltage characteristics of each tube. We plan to use a LeCroy 1440 programmable high voltage system with a CAMAC interface to control and monitor the power supply to each tube.

In order to estimate the number of shower particles passing through the ICD, we plan to collect and digitize the charge accumulated in each PMT during a light pulse. For the test facility, we plan to use LeCroy 2249W 11-bit wide-gate charge ADC's. Even though a 15 bit ADC would be preferable to test a larger operating range of the PMT's, in the absence of a commercial 15-bit product, we have decided to use the 11-bit ADC. The pulse output from the photodiodes will also be digitized with the same ADC's.

The output from the PMT's will pass through double pole double throw Form-C relays to allow measurement of the dark current. A Jorway 40 TTL level ouput register will switch the relays under CAMAC computer control to either measure charge in the ADC's, or measure the dark current in a Keithley 485 picoammeter. The signal from the picoammeter will be digitized and recorded through a Joerger ADC3216 16-bit scanning ADC.

6. Monitoring Ambient Conditions

We will monitor the temperature inside the test chambers and the LED box with integrated chip temperature sensors LM35A from National semiconductors. The output from the LM35A's will be digitized with the 32 channel Joerger ADC3216, a 16-bit scanning ADC, also used for digitizing the dark current measurements. The per channel cost for this system is very low and the one quarter degree centrigrade resolution over our operating range is more than adequate.

Two Hamamatsu S1722-02 ultrafast PIN silicon photodiodes with extended sensitivity in the ultra-violet region will be used to monitor the light intensity from the laser. Two or three less expensive S1336-18BQ photodiodes will monitor the light from the LED's and the THQ lamp. A few more similar photodiodes will monitor the light behind scintillator cookies in the test chambers. A LeCroy 2249W ADC will be used to digitize the charge from the photodiodes. This is the same ADC used for the PMT's, except for a wider gate to accomodate the light from different sources.

The reverse bias supply for the photodiodes, power supply for the LM35A, power supply for the LED pulser, the power supply for the THQ lamp and the power supply for the filter wheel motor may also be monitored by the computer through the scanning ADC.

7. Outline of Test Cycle

The complete test cycle for each phototube will consist of the following steps as shown in Figure 7.2 :

1. A burn-in period during which the PMT's are subjected to a high output DC light source. The current in the tubes will be monitored. The level of light and burn-in duration for all the tubes will be determined after the first batch of tubes have been tested. We expect a 24 hour burn-in period.
2. Turn off all light sources and measure the dark current from all the tubes, after a sufficient recovery time in darkness.
3. Measure PMT gain versus voltage. Before the first batch of PMT's to be tested are loaded into the test chambers, we plan to map the light output at each postion in the test chambers with a reference phototube. This map will be recorded in the computer and used to calculate the absolute gain vs voltage for each PMT. Of course, we will be measuring the product of quantum efficiency and gain. We will use the quantum efficiency measured by the tube manufacturer to estimate the gain from our measurements. No separate tests to measure the quantum efficiency are planned.
4. Next we will test the linearity of each PMT by cycling through different light levels from the laser. We will also use the THQ lamp to simulate a DC noise level, and test linearity under such conditions.
5. The effects of high rates will be simulated with the trigger described before. Readings will be recorded for various LED background rates. The effect of two pulses close together will also be studied by using a delay between the LED and the laser pulses.
6. For the remainder of the 1 week test period the PMT's will be exercised by varying the temperature and the light levels. The temperature coefficients

will be calculated and stored during this period. Short term stability of the tubes will also be examined.

8. Conclusion

We have designed a facility to rigorously test 800 photomultiplier tubes in a short period of time. During the tests, we will collect necessary calibration data on each phototube to help us in matching them in groups of 3, and to create a database of hardware information for later use in D0. We will also test and study the design of the ICD online calibration system. We hope to acquire the necessary equipment soon to start testing the phototubes and finish the task on schedule.

REFERENCES

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FIGURE CAPTIONS

Figure 3.1: General Setup of PMT test station

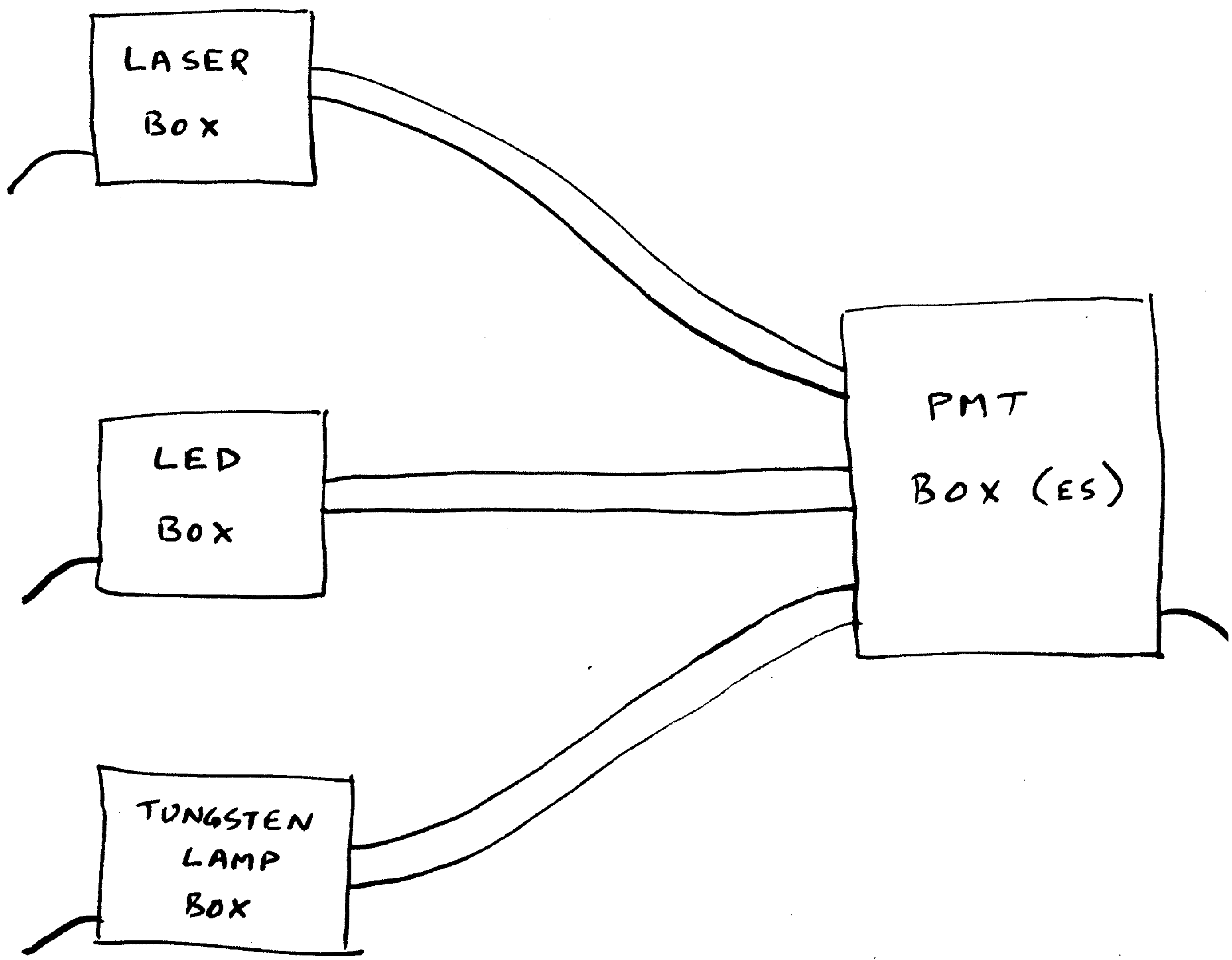
Figure 3.2: PMT test chamber cutout.

Figure 3.3: Laser box cutout.

Figure 7.1: PMT test sequence.

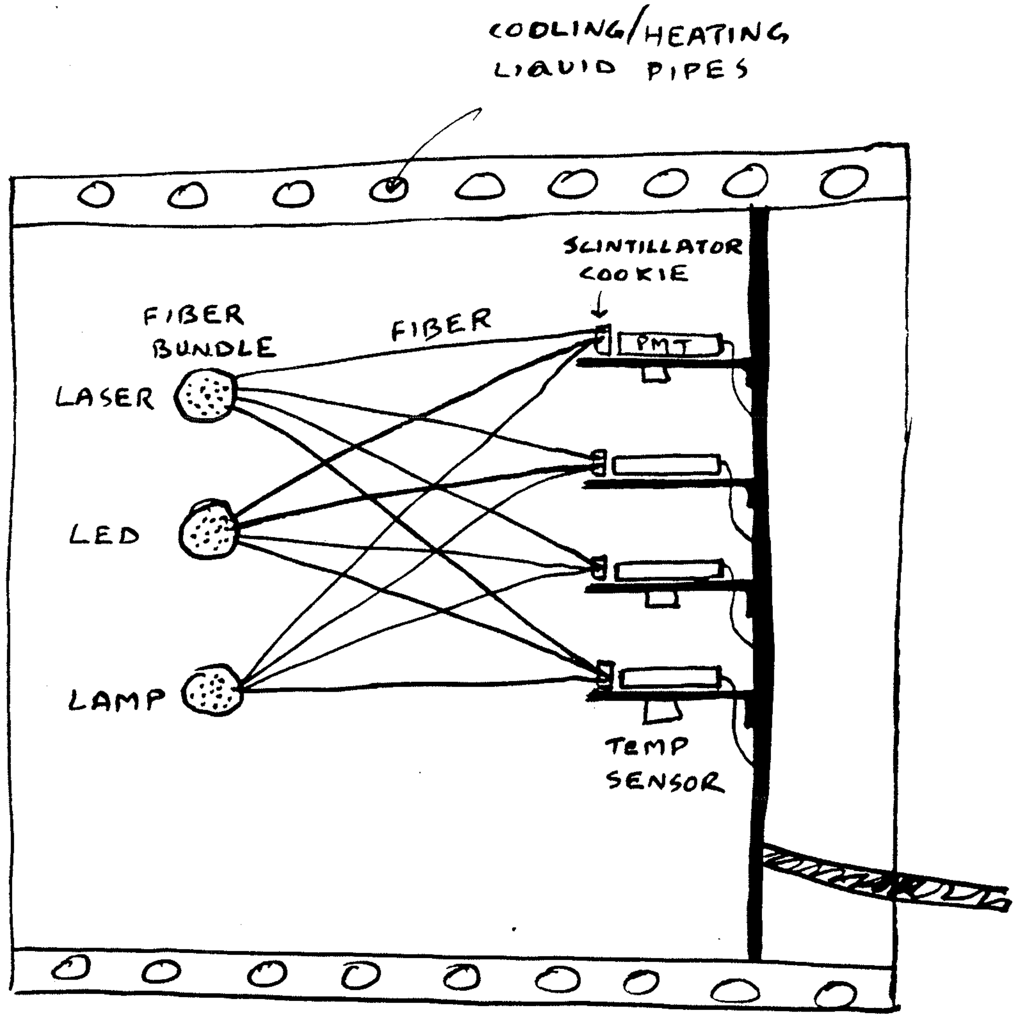
Figure 7.2: PMT Test Plan

PMT Testing
11/6/89



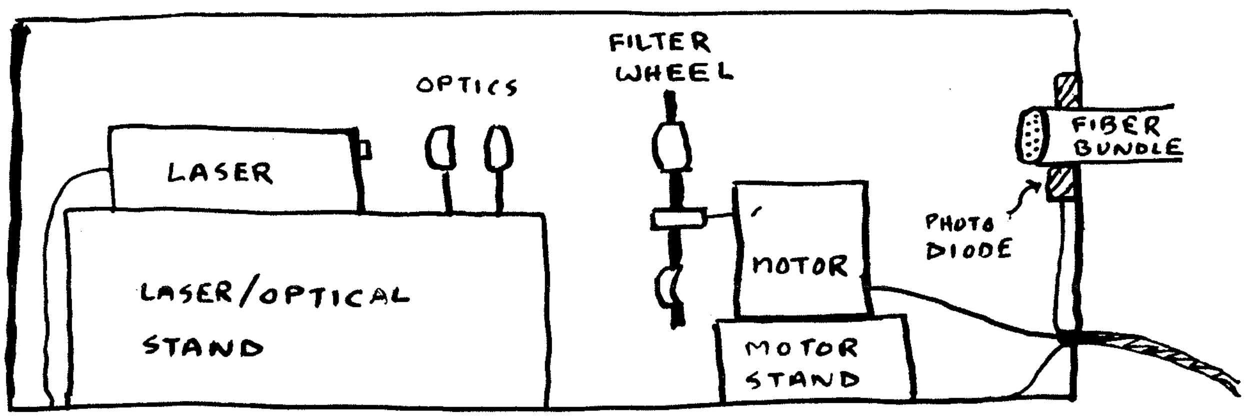
GENERAL SETUP

PMT Testing
11/20/89



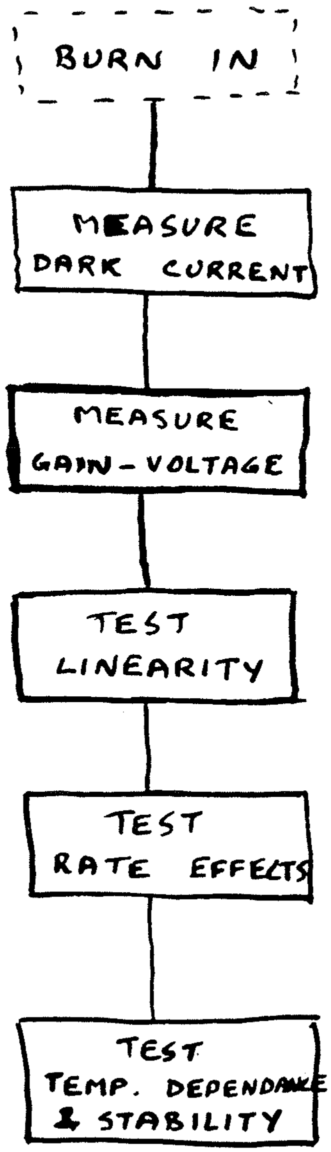
PMT Box

PMT Testing
11/10/89



LASER BOX

PMT Testing
11/20/89



PMT TEST PLAN