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LAT ACD Photomultiplier Tube Quality Plan and Acceptance Tests</td></tr>
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Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

ACD Photomultiplier Tube Quality Plan and Acceptance Tests

DRAFT

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CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes

1. Purpose

This document provides a quality plan for the GLAST ACD photomultiplier tubes.

Definitions and Acronyms

ACD	The LAT Anti-Coincidence Detector Subsystem
ADC	Analog-to-Digital Converter
AEM	ACD Electronics Module
ASIC	Application Specific Integrated Circuits
BEA	Base Electronics Assembly
CAL	The LAT Calorimeter Subsystem
DAQ	Data Acquisition
EGSE	Electrical Ground Support Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FM	Flight Module
FMEA	Failure Mode Effect Analysis
FREE	Front End Electronics
GAFE	GLAST ACD Front End – Analog ASIC
GARC	GLAST ACD Readout Controller – Digital ASIC
GEVS	General Environmental Verification Specification
GLAST	Gamma-ray Large Area Space Telescope
HVBS	High Voltage Bias Supply
ICD	Interface Control Document
IDT	Instrument Development Team
I&T	Integration and Test
IRD	Interface Requirements Document
JSC	Johnson Space Center
LAT	Large Area Telescope
MGSE	Mechanical Ground Support Equipment
MLI	Multi-Layer Insulation
MPLS	Multi-purpose Lift Sling
PCB	Printed Circuit Board
PDR	Preliminary Design Review

PMT	Photomultiplier Tube
PVM	Performance Verification Matrix
QA	Quality Assurance
SCL	Spacecraft Command Language
SEL	Single Event Latch-up
SEU	Single Event Upset
SLAC	Stanford Linear Accelorator Center
TACK	Trigger Acknowledge
TDA	Tile Detector Assembly
T&DF	Trigger and Data Flow Subsystem (LAT)
TBD	To Be Determined
TBR	To Be Resolved
TSA	Tile Shell Assembly
TSS	Thermal Synthesizer System
TKR	The LAT Tracker Subsystem
VME	Versa Module Eurocard
WBS	Work Breakdown Structure
WOA	Work Order Authorization

2. Applicable Documents

Documents relevant to the ACD Photomultiplier Quality Plan include the following.

1. LAT-SS-00016, LAT ACD Subsystem Requirements – Level III Specification
2. LAT-SS-00352, LAT ACD Electronics Requirements – Level IV Specification
3. LAT-SS-00437, LAT ACD Mechanical Requirements – Level IV Specification
4. LAT-MD-00039-01, LAT Performance Assurance Implementation Plan (PAIP)
5. LAT-MD-00099-002, LAT EEE Parts Program Control Plan
6. LAT-SS-00107-1, LAT Mechanical Parts Plan
7. LAT-MD-00078-01, LAT System Safety Program Plan (SSPP)
8. ACD-QA-8001, ACD Quality Plan
9. LAT-TD-00760-D1 Selection of ACD Photomultiplier Tube

10. LAT-DS-00739-1 Specifications for ACD Photomultiplier Tubes
11. LAT-TD-00438-D2 LAT ACD Light Collection/Optical Performance Tests
12. LAT-TD-00720-D1 ACD Phototube Helium Sensitivity
13. LAT-DS-00740-1 Temperature Characteristics of ACD Photomultiplier Tubes
14. Response to RFQ 5-09742, Hamamatsu Photomultiplier Tube Proposal

4. Introduction

The ACD Subsystem uses photomultiplier tubes (also called phototubes or PMTs) as the sensors for the light that originates in the Tile Detector Assemblies (scintillator tiles with embedded waveshifting fibers). These vacuum tubes are electronic parts, covered by the EEE Parts Plan, but they have characteristics (such as being made individually, not in batches) that require special quality considerations. The phototubes will be purchased from Hamamatsu Corporation, a leading supplier of phototubes for both ground and space applications. Many of the tests for the ACD photomultiplier tubes are carried out as part of the procurement, so that GSFC is responsible principally for the acceptance tests, performance monitoring, and careful handling of the flight tubes.

5. ACD Photomultiplier Tube Purchase from Hamamatsu

Photomultiplier tubes have a long and successful history in space, dating back some 40 years. The Compton Gamma Ray Observatory instruments, for example, carried over 300 phototubes. Generically, phototubes can be considered a well-established space technology. They are relatively rugged, and they are not damaged by radiation at the level expected for the LAT or by temperature changes over a fairly wide range. Known risks to phototubes are breakage (glass envelope), helium diffusion through the glass, and high temperatures (above 50 C).

Based on studies of our optical requirements (LAT-TD-00438-D2 LAT ACD Light Collection/Optical Performance Tests) and other constraints (LAT-TD-00760-D1 Selection of ACD Photomultiplier Tube), we developed specifications for the photomultiplier tube to be used in the ACD (LAT-DS-00739-1 Specifications for ACD Photomultiplier Tubes). The competitive procurement for the phototubes provided a clear choice, the R4443 tube made by Hamamatsu Corporation (Response to RFQ 5-09742, Hamamatsu Photomultiplier Tube Proposal). Hamamatsu Corp. has substantial experience in building flight phototubes, including the R647 on HEXTE (the R647 is the commercial version, unruggedized, of the R4443) and the R4444 on SOHO and EVRIS (identical to the R4443 except for the photocathode material).

Under the specifications for the phototubes, much of the testing for the ACD phototubes is carried out by Hamamatsu before delivery. Only those tubes meeting our specifications are delivered to us. These tests include visual inspections, burn-in, and random vibration, along with a variety of performance tests. Temperature cycling tests and radiation tests were not deemed essential, because the phototubes were expected to operate within the standard range for these conventional photomultipliers. As part of its proposal, Hamamatsu defined its Quality Plan, which included a detailed description of these tests, plus information about the manufacturing process (ISO 9001, all processes documented by procedures), failure definitions, and failure analysis reporting. The Hamamatsu Quality Plan appears to be consistent with the LAT and ACD Quality Plans (LAT-MD-00039-01, LAT Performance Assurance Implementation Plan (PAIP), ACD-QA-8001, ACD Quality Plan). The tubes are delivered with both electronic and paper copies of the test reports.

6. Performance/Acceptance Testing of the Phototubes

Although the characteristics of the delivered PMTs are documented by Hamamatsu, it is essential to verify that the phototubes actually meet the ACD requirements. The essential performance requirements, listed in the Level III and Level IV documents (LAT-SS-00016, LAT ACD Subsystem Requirements – Level III Specification, LAT-SS-00352, LAT ACD Electronics Requirements – Level IV Specification) are the efficiency for detection of charged particles and the signal size for charged particles passing through an ACD scintillator, quantities that depend on the assembled scintillator/waveshifting fiber/phototube system. These requirements are not, therefore, directly measurable properties of the phototube. The basic principle of the testing by the ACD team is therefore to compare the tube performance with that of other tubes that have demonstrated the performance requirements in a complete assembly. We establish two tests:

1. Performance. The phototube is attached to a reference scintillator, and a triggering telescope is used to identify cosmic ray muons (Minimum Ionizing Particles, or MIPs), which produce the same signals that the ACD requirements specify. An LED is used to determine the number of detected photoelectrons. The actual efficiency for detection of charged particles can also be determined as a function of threshold for the pulse height. The procedure is "ACD Phototube Performance Test Procedure." (Appendix A outlines the procedure. Appendix C shows results for the qualification phototubes.)

2. Inspection. This is a visual inspection to insure that no damage has taken place during shipment, also to verify that the physical properties of the phototube, as shown on the manufacturer control drawing LAT-TD-00744-1 are met this verification will be performed using the "ACD Phototube Inspection Procedure." (Appendix B)

In practice, the damage inspection will be done first, followed by the performance test and then the measurement of the dimensions. (If the tube does not meet our performance requirements, then it does not matter whether it is the correct size).

7. Quality Assurance for the Phototubes

As with all flight hardware for the ACD, the photomultiplier tubes will be handled, processed, and controlled under the provisions of the PAIP (LAT-MD-00039-01, LAT Performance Assurance Implementation Plan) and the LAT ACD Quality Plan (ACD-QA-8001, ACD Quality Plan). Some aspects (not intended to be a exhaustive list) of these plans as applied specifically to the phototubes are:

1. All work will be documented with a Work Order Authorization (WOA), GSFC Form 4-30. This WOA will remain with the phototube as a traveler until the phototube is integrated into the ACD electronics assembly, after which it will be retained as a reference document.
2. All work on flight phototubes will be done by certified technicians.
3. All work will be inspected by a representative of the Product Assurance group.
4. The phototubes will be stored in a locked facility except while actual work on them is in progress.
5. Because phototubes can suffer degraded performance after excessive exposure to helium, the areas where phototubes are stored or being worked on will be kept free of helium sources. If there are known helium sources, helium monitoring will be provided. If the concentration of helium near the phototubes exceeds 10 ppm, the phototubes will be bagged and purged with a gas having less than 5 ppm helium concentration.
6. When the phototubes are assembled into their housings, the serial number of the phototube will be transferred to the housing in a permanent and visible marking.
7. The performance characteristics of the phototubes measured during the acceptance tests will be recorded in a database. Subsequent duplicate tests will be performed after integration of the resistor network and again after the assembly of the tube into the Base Electronics Assembly. These results will be recorded in the same database. For any tube with sensitivity change greater than 10%, a Nonconformance Report (NCR) will be written.
8. Except for helium, there are no special environmental conditions for the photomultiplier tubes. Normal laboratory conditions are acceptable.

Appendix A - ACD Phototube Performance Test Procedure Outline

In this procedure, the phototube sensitivity for detection of charged particles is measured, and the number of photoelectrons for a MIP is measured using an LED. Reference LAT-TD-00843-D2, Design Qualification Tests for ACD TDA and Phototubes.

1. Sensitivity test

   1.1 This test uses the temporary tube base that comes with the phototube. It should be run before the base is removed from the tube.

   1.2 Connect the tube base to a reference socket (used for testing all tubes) and the socket to a high voltage power supply (0-1500V).

   1.3 Install PMT under test in Tile T, which is placed between triggering tiles T1 and T2

   1.4 Run the test at HV = 900V, 1000V, 1050V, and 1100V, collecting around 2,000 events in each run (takes 5-7 min. each). Save each run in a file.

   1.5 Analyze the data by fitting the pulse height histogram to a Landau distribution, and find the channel number at maximum. Plot these values vs. the HV; this is a sensitivity plot

2. Photoelectron (p.e.) test

   2.1 Disconnect the PMT from the tile and connect to the LED fixture. LED is driven by a pulse generator.

   2.2 Set HV=900V and collect the data at 3 different values of pulse amplitude. Check them by starting the CAMAC for a short time – the max of the histogram for one value of the pulse amplitude should be close to that for muons at the same HV, and two others should be smaller and larger by 30-70 channels. This will allow drawing a curve line for the p.e. yield calibration.

   2.3 Analyze every run by fitting the histogram by a gaussian, finding the peak position.

   2.4 Repeat 2.2 for 1000V and 1050 V

   2.5 Calculate the number of photoelectrons by dividing the peak channel (after pedestal subtraction) by the value of sigma, which is given by the fitting routine. The square of this number is a p.e. estimate.

   2.6 Make a plot (number of p.e. vs. the peak position) with 3 lines corresponding to the three voltages used. Draw vertical lines on this plot at the MIP peak position obtained earlier for each HV value. The intersection of the vertical lines with data lines gives the number of p.e. corresponding to a single MIP.

3. Efficiency measurement (optional – carried out for a sample of phototubes)

   3.1 Use setup as in 1, but adding two more 32cm by 32cm triggering tiles.

   3.2 Use the top and bottom tiles to trigger the readout, and read out the data from two other triggering tiles and the one under test (which is connected to the PMT under test). All the signals should be sent to CAMAC for digitization.

   3.3 Collect 20,000-30,000 events at HV=1,000V.

Appendix C shows the acceptance test results for the qualification phototubes.

Appendix B - ACD Phototube Inspection Procedure

In this procedure, the phototube is visually inspected for conformance to physical specifications and absence of shipping damage. All tests are pass/fail.

Damage Inspection

Item #	**Parameter**	**Pass/Fail**
1	Window material free of visible bubbles, inclusions, scratches, and edge chips	
2	Phototube glass free of bubbles larger than 1 mm diameter or other surface irregularities including cracks, chips, or scratches	
3	Phototube free of loose particles (0.5 mm max for metallic particles, 1 mm max for nonmetallic particles, 1.5 mm max for accumulations of particles	
4	Internal structure free of visible defects (compared to a known tube)	

Dimensions

Item #	**Parameter**	**Dimensions**	**Pass/Fail**
1	Diameter of phototube	14.5 ± 0.7 mm	
2	Diameter of photocathode	≥10 mm	
3	Length of body of phototube	61 ± 2 mm	
4	Length of glass nipple at back of phototube	≤ 13 mm	
5	Length of semiflexible leads	≥ 33 mm	
6	Length of untinned portion of semiflexible leads from phototube	≤ 5 mm	
7	Angle between phototube face and sides	89°≤angle≤91° or ≤ 1 mm from square across the top of the tube	

Appendix C - Acceptance tests for Qualification Hamamatsu R4443

The acceptance test is to be performed on each R-4443 PMT delivered to GSFC before the tube is assembled with the resistor network and housing. We trust the tests and measurements done at Hamamatsu, and the goal of the acceptance tests is to test whether the PMT successfully survived the transportation from Japan to USA. The test method is to compare the basic PMT performance parameters measured here with those measured at Hamamatsu. Since we cannot perform the same tests, we have to find the reliable but indirect way to measure them.

Cosmic ray muons will be used to measure the sensitivity of PMT. The sensitivity for each PMT is measured by finding the maximum of the pulse-height distribution for muons detected by a standard scintillator tile, 32 cm by 32 cm. This sensitivity is the product of the PMT gain and its photocathode quantum efficiency. The experimental setup places the standard tile, with the PMT under test attached, between two triggering tiles, each 20cm by 20cm.

The quantum efficiency of the PMT photocathode can be estimated by measuring the photoelectron (p.e.) yield. The fastest way to do that is to use an LED and measure the width of the pulse height distribution; this assumes that the width of the distribution is determined solely by photoelectron statistics. After measuring the p.e. yield, the relative gain can be found by dividing the sensitivity by the p.e. yield.

Data obtained for the 10 qualification PMTs is shown in the Table, and also in figures. There are two plots per PMT, one showing sensitivity measurement results (MIP peak position), and the second showing calibration of p.e. yield for 3 or 4 HV values.

For the acceptance tests, I suggest running four HV values for sensitivity measurements (10 min. each run, 1 hour in total per PMT); and three HV values for p.e. yield calibration, with 3 LED pulse height values per each HV value (9 points in total, with 5 min. each, 2 hours in total). The total time required to test each PMT is thus approximately 3 hours. An efficiency measurement can also be performed with an additional 1.5-2 hours.

The table shows that the gain measurement (which actually is a combination of sensitivity and quantum efficiency) correlates well with the measurements at Hamamatsu (line 10 in the table); my measurements placed PMTs at the proper order (ordering by the gain value). The p.e. measurement does not correlate as well (lines 8 and 9). So using gain data, we can at least find faulty PMTs, and test them more carefully. Figure 1 is a plot of the ratio between the relative gain (measured by Alex) and the absolute gain from the Hamamatsu datasheet. If we establish the requirement that acceptable PMTs must be within 7% of the initial Hamamatsu gain, all 10 qualification PMTs would be accepted. uspicious PMTs can be tested more carefully.

PMT S/N	0882	0609	0610	0879	0883	0896	0885	1088	1085
Measured Sensitivity									
At 900 V	209	142	264	219	249	283	148	59	247
At 1000 V	480	340	609	512	569	619	330	146	578
At 1050 V		491	879			932	490	217	810
Measured p.e. yield at 900V-1050V	26-28.3	21.5-23.5	22.5-26	24-27	27-28	25-29	23-24	19-23	20-21.5
Measured p.e. average, (order)	27.1 (2-3)	22.5 (7)	24.3 (5)	25.5 (4)	27.5 (1)	27 (2-3)	23.5 (6)	21 (8-9)	21 (8-9)
Measured p.e. yield at sensitivity of 600 channels, (order)	28 (1)	24 (6)	24.5 (5)	25.5 (4)	27.5 (2)	27 (3)	23.5 (7)	21 (8-9)	21 (8-9)
QE, from datasheet (hereafter DS), (order)	16.0 (5-6)	16.0 (5-6)	15.4 (7)	16.9 (2)	16.8 (3)	17.6 (1)	16.1 (4)	15.0 (9)	15.2 (8)
Measured Gain = Sensitivity(1000V)/p.e. average, (order)	17.7 (6)	15.1 (7)	25.0 (2)	20.1 (5)	20.7 (4)	22.9 (3)	14.0 (8)	7.0 (9)	27.5 (1)
Gain, from datasheet, (order)	7.91 (6)	6.19 (8)	10.40 (2)	8.66 (5)	9.11 (4)	10.10 (3)	6.42 (7)	3.00 (9)	11.44 (1)
p.e. average / QE(DS)	1.69	1.41	1.58	1.51	1.64	1.53	1.46	1.40	1.38
p.e.(600) / QE(DS)	1.75	1.50	1.59	1.54	1.64	1.53	1.52		1.38
Gain at 1000V/Gain(DS)	2.24	2.44	2.40	2.32	2.27	2.27	2.18	2.33	2.40

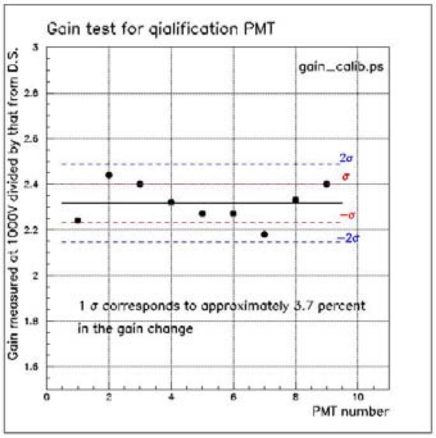
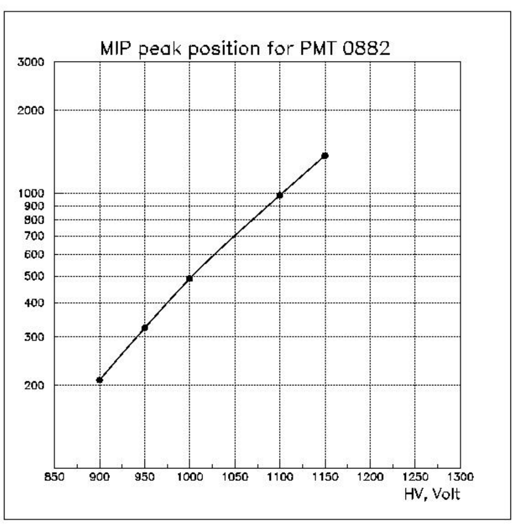
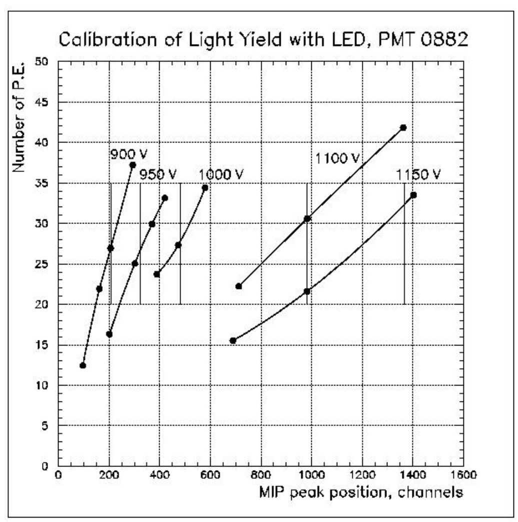


Fig.1. Comparison of measured relative gain for qualification PMTs with absolute gain from datasheet.





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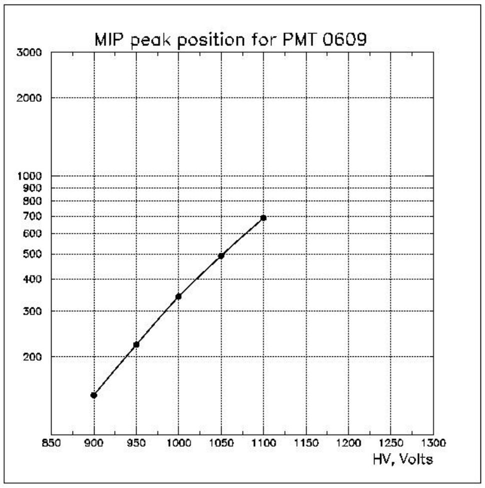

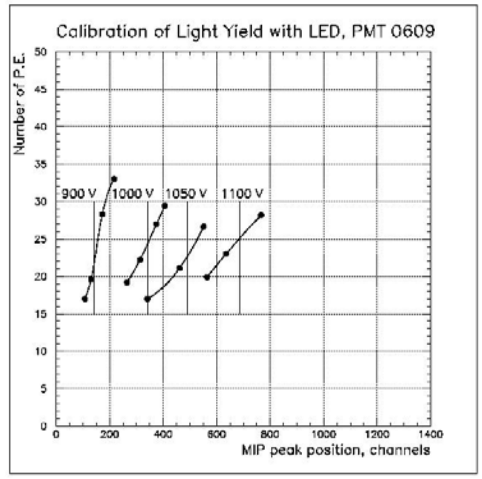

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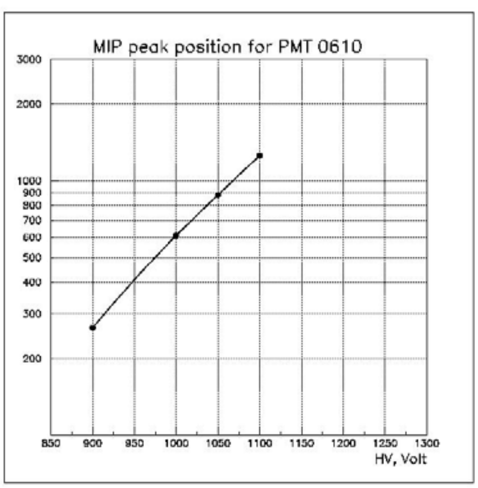

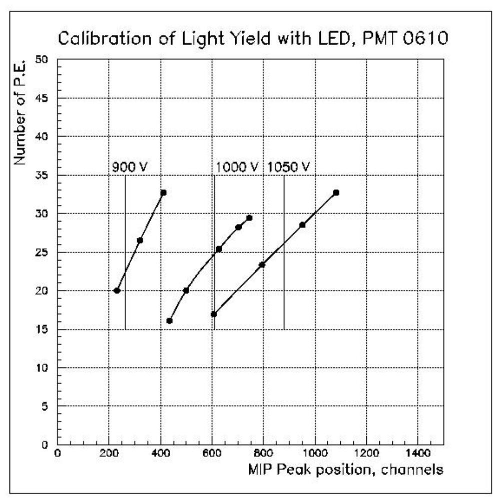

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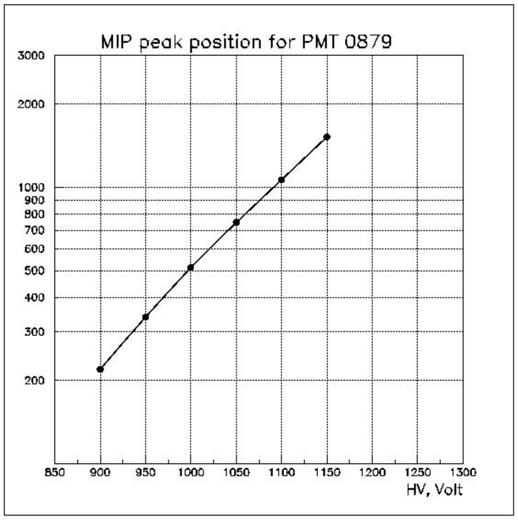

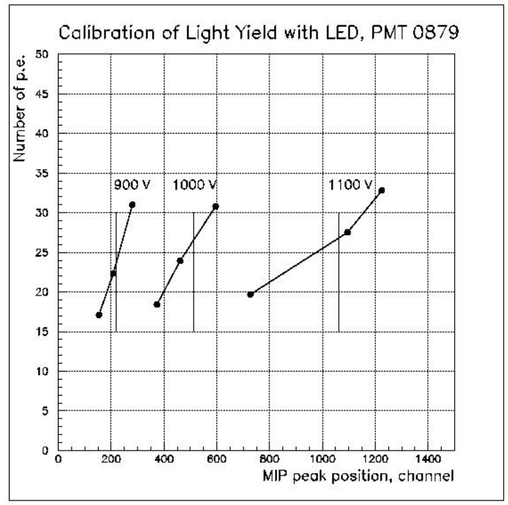

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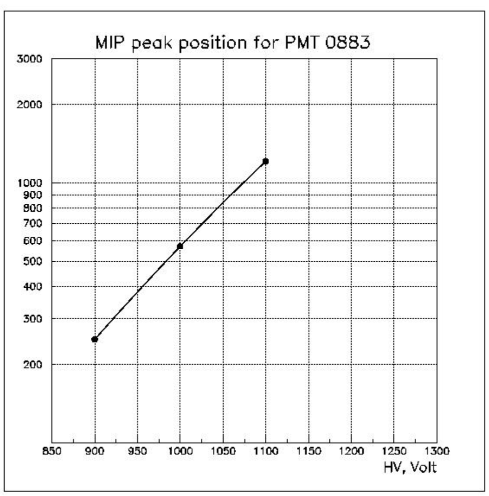

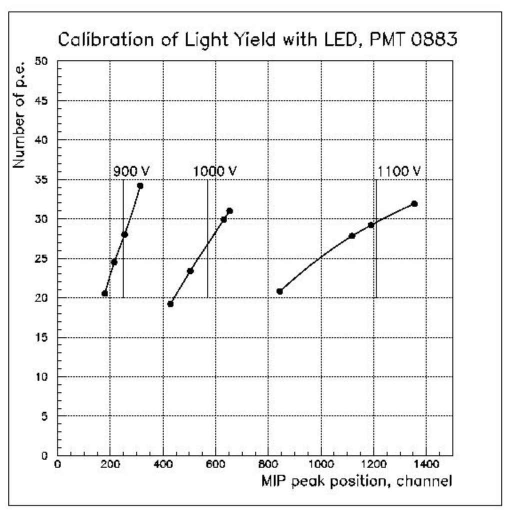

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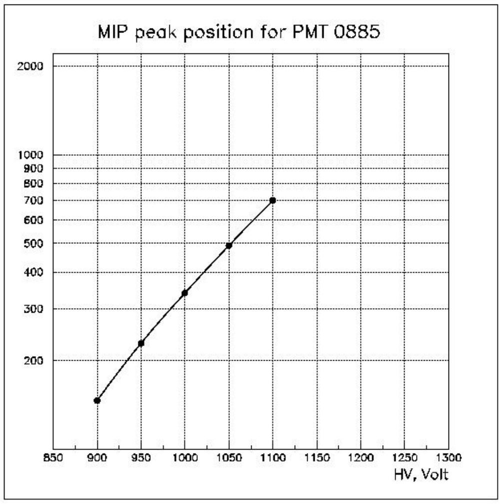

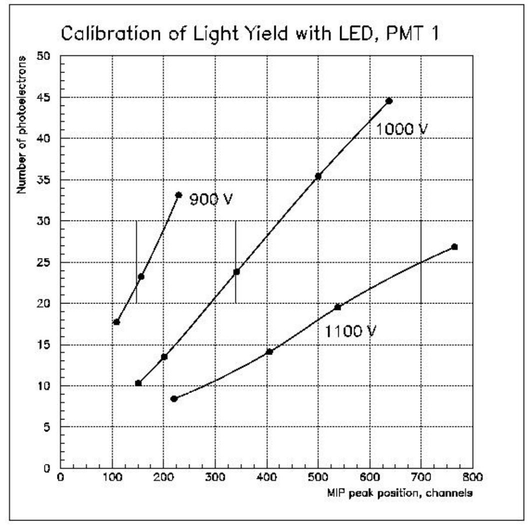

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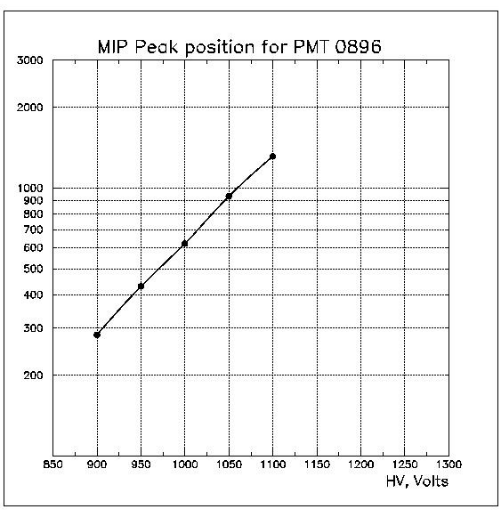

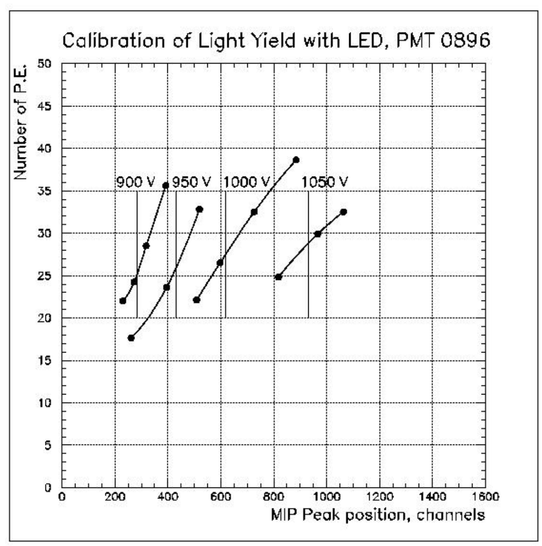

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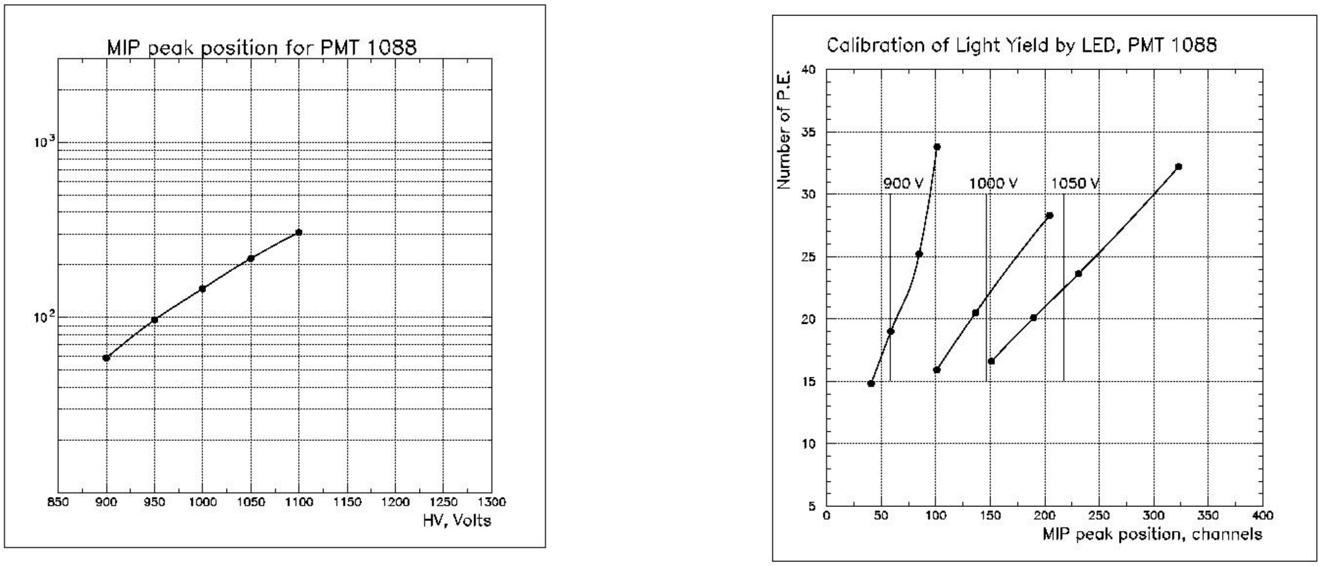

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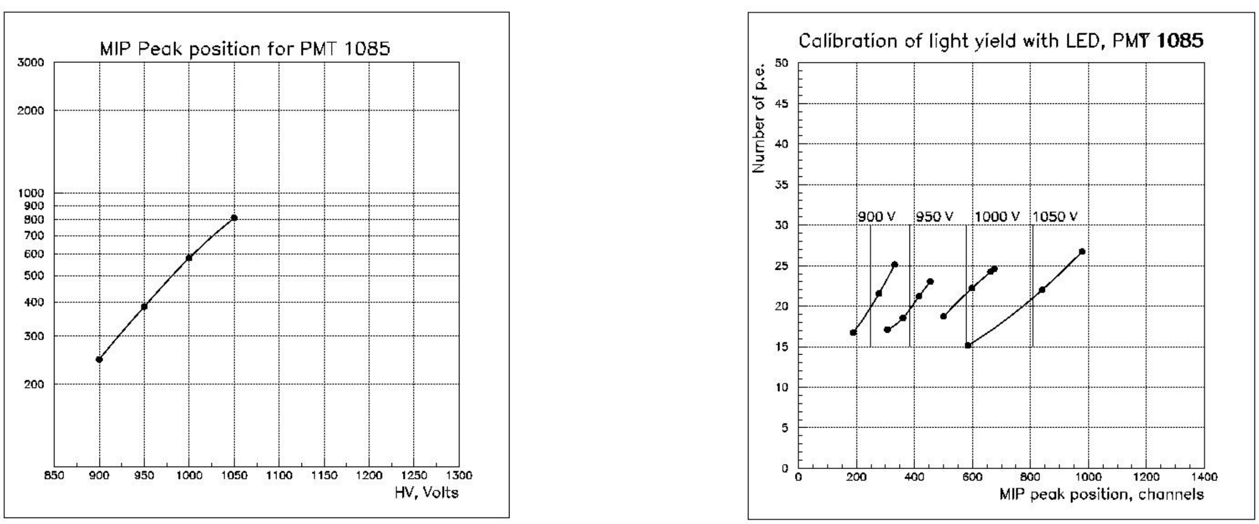

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