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Gamma-ray Large Area Space Telescope (GLAST)

Large Area Telescope (LAT)

ACD On-Ground Science Performance Calibration and Monitoring

ACD-PLAN-0003321 Rev-

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CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes

1. Purpose

This document provides a Plan and Procedures for ACD On-Ground Science Performance Calibration and Monitoring

1.1 Definitions and Acronyms

ACD	The LAT Anti-Coincidence Detector Subsystem
ADC	Analog-to-Digital Converter
AEM	ACD Electronics Module
CFC	Clear Fiber Cable Extension
DAQ	Data Acquisition
EGSE	Electrical Ground Support Equipment
GASU	
GLAST	Gamma-ray Large Area Space Telescope
HVBS	High Voltage Bias Supply
I&T	Integration and Test
LAT	Large Area Telescope
MIP	Minimum Ionizing Particle (*mip*)
MLI	Multi-Layer Insulation
PMT	Photomultiplier Tube
QA	Quality Assurance
SLAC	Stanford Linear Accelorator Center
TDA	Tile Detector Assembly
T&DF	Trigger and Data Flow Subsystem (LAT)
TBD	To Be Determined
TSA	Tile Shell Assembly
TKR	The LAT Tracker Subsystem
WOA	Work Order Authorization

2. Applicable Documents

Documents relevant to the ACD Science Performance Calibration and Monitoring 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-00078-01, LAT System Safety Program Plan (SSPP)
6. ACD-QA-8001, ACD Quality Plan
7. LAT-TD-00760-D1 Selection of ACD Photomultiplier Tube
8. LAT-DS-00739-1 Specifications for ACD Photomultiplier Tubes
9. LAT-TD-00438-D2 LAT ACD Light Collection/Optical Performance Tests
10. LAT-TD-00843-D1 Design Qualification Tests for ACD TDA and phototubes
11. ACD-PROC-000059 Fabrication and Assembly Procedure for the ACD TDA
12. ACD-PLAN-000162 LAT ACD Tile Detector Assembly Quality Plan, Acceptance and Light Yield Tests
13. ACD-PROC-000294 LAT ACD Clear Fiber Cable Post-Installation Procedure
14. ACD-PROC-000224 LAT ACD Fiber Ribbon Acceptance Test Procedure
15. LAT ACD Light Budget Table

3. Required equipment

- NIM crate ORTEC 401A
- 12-channel PM 10X amplifier LeCroy 612A
- Dual gate generator LeCroy 821
- Coincidence unit LeCroy 465
- High Voltage power supply Tennelec TC 952 (NASA M143205)
- Customer made triggering scintillating tile with PMT attached - 2
- Customer made NIM-to-LVDS signal converter
- Set of necessary connecting cables

4. Quality Assurance for the Tile Detector Assemblies

1. All work will be documented with a Work Order Authorization (WOA). QA shall be contacted 24 hours prior to the start of the tests
2. All work will be inspected by a representative of the Product Assurance group.
3. The ACD performance characteristics measured during the tests will be recorded in a database

5. Input information about the ACD In-Ground Science Performance Calibration and Monitoring

5.1. Introduction

Of the many parameters that characterize the ACD, the scientific performance is largely determined by two level III requirements: (1) the efficiency for signaling the passage of charged particles (requirement 0.9997 averaged over the surface except for the lowest row of side tiles); and (2) the ability to reject backsplash effects at high energies (< 20% loss at 300 GeV). The other requirements on the ACD are essentially all related to obtaining these performance characteristics. By contrast, parameters like energy resolution and point spread function, which are critical in the tracker and calorimeter, are largely irrelevant to the ACD. The focus of testing and in-flight calibration is on monitoring the ACD performance in these two critical areas.

5.2. Detection Efficiency and Related Parameters

Although the charged particle detection efficiency is the crucial parameter, this quantity is fairly difficult to measure in flight, requiring analysis of track fits. It is also not something that is directly adjustable. For this reason, the related measurable quantities of rate, pedestal, electronics response to known charge, Minimum Ionizing Particle (MIP) peak position, MIP peak Full Width Half Maximum (FWHM), threshold, and HV need to be tracked (threshold and HV being the commandable ones that may require adjustment). The position of the MIP peak in particular is a good measure of the end-to-end performance. Many of these parameters are directly read out or easily derived, so that they could be included in a monitoring (on-line, or EGSE) system. The derived parameters are ones that require additional analysis and would be thought of as calibration parameters.

The ACD average efficiency over its area should be not less than 0.9997 with the threshold set to 0.3 *MIP*. During a flight it can be measured directly as a fraction of charged particles events which created the L1T but were vetoed by the ACD (a signal in the VETO_HITMAP, the only readout that has the full efficiency). Also ACD efficiency can be derived from the performance of each ACD component (TDA, ribbon) placed in ACD simulation (see notes "Flight ACD Performance verification", AM, 11/18/2004). What is needed for a given tile is a large sample of triggers for which a single charged particle hits the tile within restricted range of angles. The procedure of efficiency determination in on-ground tests is given in section 6.

We have to remember that the ACD efficiency is not uniform – it is lower around the tile edges than in the center. But still the performance of the entire ACD can be derived from the performance of its parts – electronics, tiles, and the fiber ribbons.

For monitoring in real-time, we expect to have data display pages and graphics, with formats to be defined. For calibration, we will maintain tables of these parameters (averaged over each tile by tube) as a function of time. Fig.1 shows how we might obtain each of these.

Rate (Hz) - This simple parameter, which is sampled and read out by the AEM for each tube, is a surprisingly powerful diagnostic of first-order changes in performance. The first thing we will want to look at in every test is the set of rates from the tubes, comparing them with a reference set and with each other. This parameter is used in both real-time monitoring and in calibration.

Since these rates vary a lot over an orbit, and also over a day, some care is needed to compare with a reference set. Perhaps use averages over ~5 minutes, then use for comparison the minimum during a 24-hour period. The maximum is less attractive because of solar flares and trapped particle precipitation. Even the minimum could be distorted if a flare occurs around the time the minimum should occur.

Pedestal (in units of PHA or ADC channels) – We may need a special mode for this test where the Zero-Suppression will be shut down. Accumulate a pulse height analysis (PHA) spectrum for each tube, under any operating condition. Fit a gaussian to the large peak in the lowest non-zero channels. The pedestal is the mean value of the fitted gaussian. Remark: after the qualification test of electronics we will determine the limitations on the pedestal's sigma and on the range of pedestal value change (significant pedestal shift will signal that something is changing in the system).

Electronics response (in units of PHA channels) - Run the ACD in charge injection mode for 3-5 minutes (perhaps during one SAA passage per TBD) with HV for the phototubes turned down. Inject charge nominally corresponding to 1 MIP. Record the channel(s) where this peak appears in the PHA spectrum for each tube, and the width of this peak. Note that this mode requires an ACD-only trigger for the LAT.

MIP Position and MIP FWHM (in units of PHA channels) - During normal operation, most of the triggers that contain useful information for determining these parameters will not be sent to the ground (majority of detected charged particles will be removed on-board). These needed PHA spectra will be accumulated on board using "ACD trigger" when L1T is created by the pulse from any ACD tile or by the one of ACD coincidence combinations (see section 6 for more details). For each target tile, define one or more trigger tiles that are approximately in a normal direction to the given tile. Collect PHA values for the target tile (each tube separately) only for those triggers in which a signal is seen in one of the tubes on the trigger tiles. Fit the accumulated PHA spectra with a Landau function to determine the peak and Full Width Half Maximum. An alternative approach using processed data would be to accumulate the PHA spectra for tiles to which the tracker shows a single straight track pointing, but in this approach not all ACD tiles can be calibrated due to the LAT geometry (e.g. bottom side tiles). The calculated values can go into the calibration data base.

Threshold (in PHA channels) - This is a commanded value. If the command units are mV, convert to channels using the scaling for that tube. The commanded value can be displayed in real time. In addition to the command, we need to determine the actual threshold, in channels (see 6.1.4. for the details.

High Voltage (in V) - This is a commanded value. It is also read back. We shall monitor both the command and the value read back. The alert shall be issued if HV value changes by more than 1% of that set.
Both the command and the readback should be included in real-time monitoring displays and in the calibration database.

5.3. Backsplash Rejection

This parameter should be derivable from the standard data products. Recognized gamma-ray events with high energy are likely to be accompanied by backsplash signals in some ACD tiles. Events in which the backsplash hits the entering tile will be rejected, but many events will be seen in which the backsplash is seen only in other ACD tiles. From those we should be able to confirm the backsplash energy spectrum (at least that visible above tube noise) and angular distribution. This analysis is probably only practical offline. Remark: we probably need some sort of guideline for how the VETO threshold affects the backsplash rejection. Such information will be obtained during the beam calibrations using the ACD Calibration Unit, but it can also be derived from the PHA data during routine operations.

5.4. Other Calibration Data

5.4.1 ADC linearity.

ADC linearity for each tube is done by charge injection in 64 charge value steps. Eduardo suggests a table. The calibration input pulse height is defined in terms of TCI counts and the output is expressed as an average PHA value of the muon peak. The conversion is accomplished by using a look-up table where adjacent points are linearly interpolated. This procedure is described in details in ACD Comprehensive Test Plan (ACD-PLAN-000038).

5.4.2. Timing parameters

These parameters should not change often, but they need to be recorded for the calibration.

Some of them (TACQ, TACK delay) can be determined only at the LAT level and will be given in the appropriate document. The ACD internal parameters are determined during ACD Comprehensive test and described in ACD Comprehensive Test Plan (ACD-PLAN-000038).

Channel	Hold	VETO	Hitmap	Hitmap	Hitmap	TACQ	TACK Delay

	Delay	Width	Width	Deadtime	Delay		(for ACD trigger)
0-000							
1-000							
(195 rows)							
0-603							
1-603							
Unused channels							

Table 1. ACD Timing Parameters

5.4.3. Temperatures and voltages.

PMT, electronics, and scintillator responses changes with temperature and electronics supply voltage; therefore a table of temperatures and voltage is needed as a function of time.

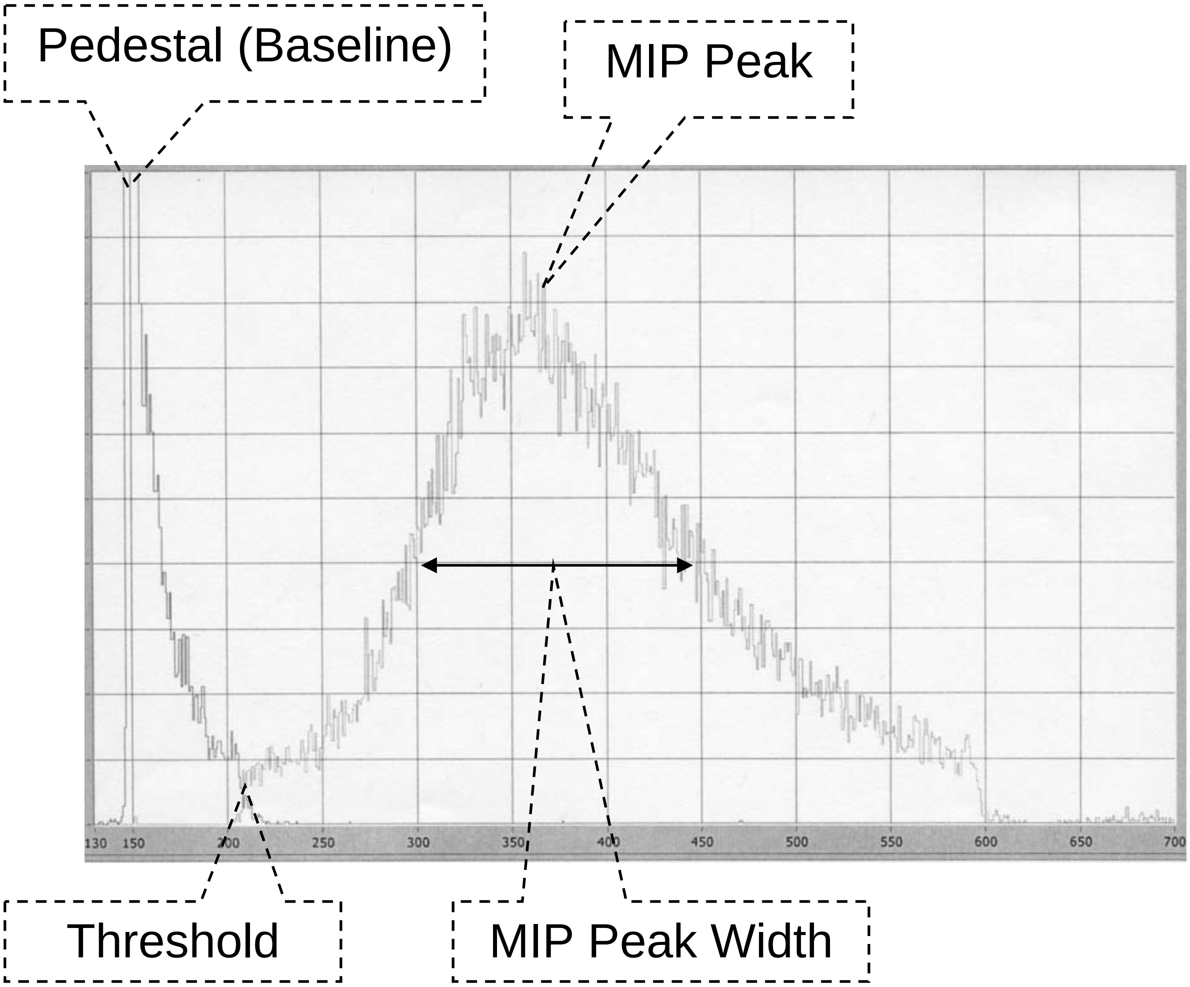

Fig. 1 – Schematic of some calibration parameters derived from the ACD data, particularly the Pulse Height Analysis (PHA).

Header: Date, time
ACD setup (position, special conditions)
Trigger
Temperatures

PMT (channel)	Average Rate, Hz	ADC Pedestal /width, bins	MIP peak position /width, measured, bins (pedestals subtracted)	MIP peak position correction factor (directional part)	MIP peak position correction factor (ADC gain change part)	MIP peak position for normal incidence, derived, bins	MIP peak position, reference, bins	MIP peak position change ratio	Light Yield, reference, p.e.	Light yield, current, derived, p.e.	High Voltage, readout / HV nominal, Volts
	Determined in this test	Determined in this test. Width is monitored	Determined in this test	Provided by ACD group	Determined in this test in electronics test	Determined in this test. Used for VETO threshold setting	Provided by ACD group	Determined in this test, monitored	Provided by ACD group	Determined in this test. Used for efficiency calculation	Readout determined in this test; nominal provided by ACD group
A	B	C	D	E	F	G	H	I	J	K	L
0-000	350	120/3	380/72	0.94	1.02	364	370	0.984	18.4	18.1	780/780
1-000		170/3	420/78	0.94	1.05	414	412	1.005	19.5	19.6	779/780
0-001		250/4	340/66	0.96	0.97	317	310	1.023	20.2	20.7	782/780
1-001		520/4	395/76	0.96	1.	379	386	0.982	18.8	18.5	780/780
……….											

"G" = "D" × "E" × "F"
"I" = "G" / "H"
"K" = "J" × "I"

Table 2. ACD calibration table (values are given for the example). Also the product of ACD calibration is the set of calibration plots for "ADC bin vs. VETO threshold setting" dependences.

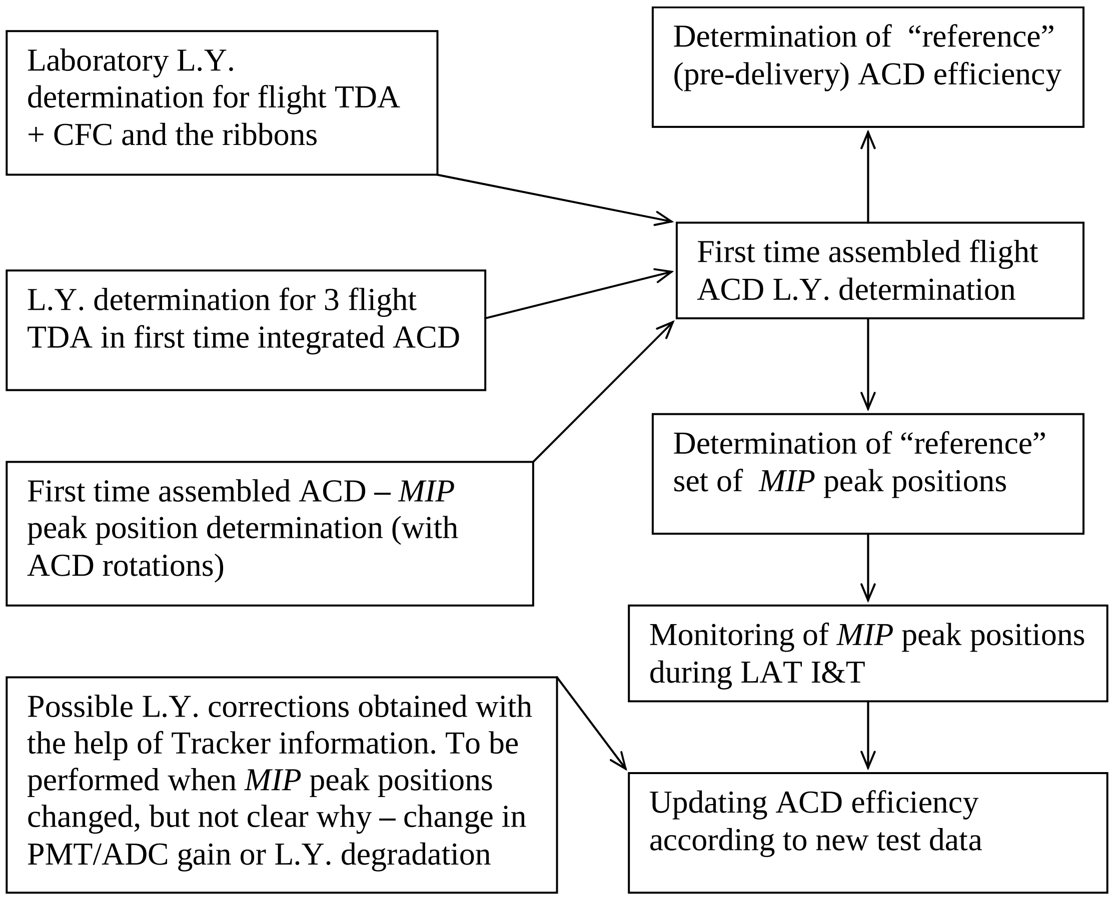

Fig. 2 Logical Scheme of ACD efficiency monitoring

6. Approach to the ACD In-Ground Science Performance Monitoring and Calibration (see fig.2)

6.1. Utilization of ACD trigger

VETO signals are used here as the triggers . The VETO thresholds for all ACD detectors are set to their minimal possible values, to be just above the noise (unless stated otherwise).

This approach is used to:

a) monitor ACD performance for standalone ACD or when the LAT/tracker information is not available,
b) determine the values of VETO threshold settings (L1T trigger may not provide needed vertical tracks for some of side TDA's)

As mentioned above, the main ACD parameter to be monitored is the charged particle detection efficiency. The efficiency is obtained by the simulations using measured performance (in particular the light yield) of every ACD detector (see notes "Flight ACD performance verification", AM, 11/18/2004). **Required efficiency** is achieved by performing the **ACD performance stability monitoring** and **calibration of VETO threshold setting.**

The steps in ACD efficiency provision and monitoring:

a) measurement of light yield for every ACD detector in the laboratory according to ACD-Plan-000162 “LAT ACD Tile Detector Assembly Quality Plan, Acceptance and Light Yield tests”. Results are given in TDA Light Budget Table, column “M”
b) measurement of the initial light yield for every ACD detector when all detectors are integrated in ACD (see below, in “Initial Light Yield measurement for flight configuration”). In order to complete this, the actions described in 6.1.2 have to be performed
c) regular performance of tests described in “ Following tests for standalone ACD”. They provide us the information about the current performance (in particular light yield) of every ACD detector and allows us to determine the current values for the VETO threshold values.

6.1.1. Initial Light Yield measurement for flight configuration

Light yield of ACD Tile detectors and ribbons is measured once in the Laboratory before ACD integration (see “Light Budget Table”). After that it has to be measured after all detectors are integrated in ACD. There are two ways how to do it:

Method 1 (preferable)

a) run the efficiency test for 3 top TDA’s using external triggering hodoscope (see fig.3). From this test determine the **light yield (LY) for each of tested TDA’s**. Notice that the Light Yield here is an “effective” light yield, which is a product of the amount of light reaching the PMT photocathode and quantum efficiency of this PMT. In other words, it is the number of photoelectrons generated in a specific PMT.
b) Determine the average sensitivity of flight ADC (in units of ADC bins per number of electrons at the GAFE input . Notice that all high voltages have to be set to the nominal values. We assume that the sensitivities of all flight ADC is within 2-3% of its average value. For 3 tested TDA’s the average flight ADC sensitivity A_{fl} can be found from

$$A_{fl} = \frac{1}{6} \times \sum_{i=1}^{6} \frac{P_i}{LY_i \times G_{i,fl}}$$, where P_i and $G_{i,fl}$ are correspondingly the

measured *MIP* peak position (in ADC bins) and gain for each of six (i=1, 6) tested TDA PMT (all five tested TDAs have 2 PMT’s)

c) Run *MIP* peak position test (see “*MIP* peak position determination”) for every TDA. Determine the Light Yield LY for every TDA (PMT) as

$$LY = \frac{P}{A_{fl} \times G_{fl}}$$, where A_{fl} is the ADC sensitivity determined above, and P is

the *MIP* peak position (in ADC bins) determined for this TDA PMT with the gain G. Obtained values for LY are to be inserted in the efficiency determination program.

d) Compare obtained values of LY with that obtained in the Laboratory tests (given in “Light Budget Table”), not forgetting to correct for the quantum efficiency of flight PMT and the PMT used in the laboratory tests.

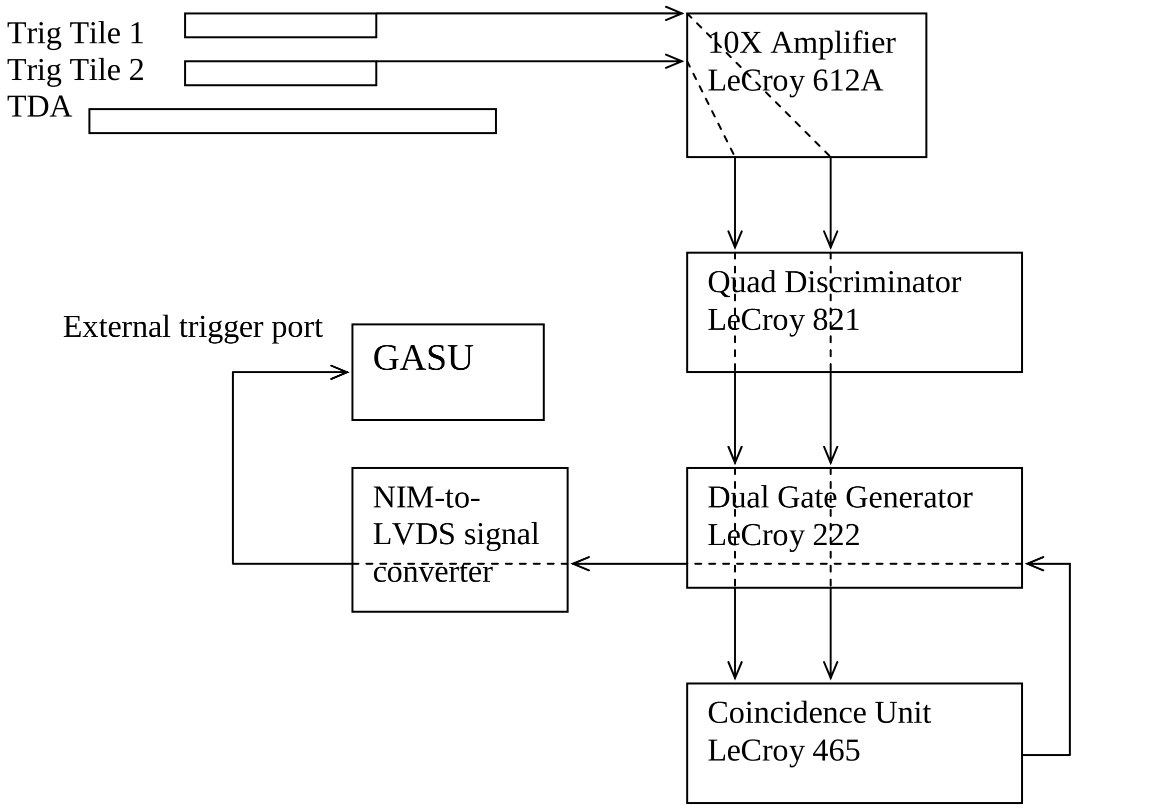

Fig.3 Setup for the use of external ACD trigger.

<u>Method 2.</u>

a) this method is used if the direct measurement of flight TDA light yield is not possible for some reasons

b) The MIP peak position P measured by ADC with sensitivity A, for the ACD channel (TDA+PMT) with the number of photons reaching the PMT photocathode N and PMT gain G and quantum efficiency Q, can be expressed as the product:

$$P = A \times Q \times N \times G \,,$$

and after some simple operations (index i denotes the current PMT being tested, denominations "fl" and "lab" stand correspondingly for the tests performed on the same TDA PMT in flight integrated ACD and in the laboratory)

$$\frac{P^{fl}{}_i \times Q^{lab}}{LY_i^{lab} \times G^{fl}{}_i \times Q^{fl}{}_i} = A_{fl} \times \frac{N_i^{fl}}{N_i^{lab}} \,,$$

One can notice that the right side of this expression is proportional to the change in the light yield of the channel (TDA) which occurred since TDA was tested in the laboratory. So, the left side of this expression should be constant, and deviations of this constant for some TDA channels will reveal those where the TDA performance has changed since the tests in the laboratory. Consequently, the light yield for this TDA channel, given in the "Light Budget Table", has to be corrected according to the obtained result.

6.1.2. *MIP* peak position determination.

When the ACD integration is complete, the *MIP* peak position in a PHA histogram for every channel (TDA PMT) has to be determined at nominal value of High Voltage (TBD). This test is critical, since the value obtained for *MIP* peak position will be used all of the time later on, to monitor the ACD performance. The *MIP* peak position is to be measured in the units of ADC bins, with ADC pedestal subtracted.

The problem is that the MIP peak position in a histogram depends on the angular distribution of the incident particles. The light yield measurements are done for the about vertical angular distribution of incident particles, and the same has to be inserted in efficiency simulation program. So, if the test was done for not-vertical incident particles (for example, if we run muon test and ACD is positioned with top pointed to the zenith, the side tiles will be exposed to the incident muons arriving at large angles in respect to the tile plane), obtained PHA histogram has to be corrected for the arrival angle.

During the first test, when ACD is integrated, the ACD shall be rotated to expose every ACD side to the vertical muon flux. The following operations shall be done:

a) Perform a muon run for 3 top tiles (HV set to nominal – TBD) using external trigger (one scintillator). Collect 5K events per each tile. This operation provides us the knowledge about muon peak position on a histogram for vertical muon flux. Laboratory test demonstrated that for the ground muon flux the muon peak position obtained with external triggering is the same as for the self-triggering mode, if the trigger threshold for self-triggering mode is chosen properly. So, the purpose of this test is to confirm this statement for the flight configuration.

b) Perform a muon run with ACD in “normal” position with top pointed to the zenith and all HV set to nominal (TBD) values. Use “any ACD tile” trigger (use of prescale is OK). Collect ~500K events in total (~30 min at 500Hz rate). This provides the data for the top tiles performance monitoring in self-triggering mode (P^{top}_{self}). Compare obtained values of MIP peak position on each 6 histograms obtained in a) with corresponding values obtained here. Make sure they are the same otherwise apply correction factors.

c) Perform a muon run using ACD trigger ROI1 & ROI2 (ROI1 is a coincidence of any tile on side +X with any tile on side –X; ROI2 is a coincidence of any tile on side +Y with any tile on side –Y). Collect ~200K events in total (takes ~ 2 hours with the rate of 20Hz). The result is the values of MIP peak position $P^{\pm X}_{co}$ and $P^{\pm Y}_{co}$ obtained for each of PMT for the side TDA’s in the side coincidence mode.

d) Perform a muon run using ACD trigger ROI3 (ROI3 is a coincidence of any tile on the top with any tile on any side). Collect ~ 200K events (~ 15min assuming rate 250Hz). The result is the values of MIP peak position P^{top}_{co} obtained for each of PMT for the top tiles in the side coincidence mode.

e) Rotate ACD to point +X side to the zenith. Perform a muon run using ACD trigger from any tile. Collect ~500K events (~30 min in total assuming 500Hz rate). This provides the data for the performance monitoring of the tiles on +X and -X sides (gives the MIP peak position for vertical muon incidence). The result is the values of MIP peak position P^X_{self} for each PMT on +X and –X sides.

f) Rotate ACD to point +Y side to the zenith. Perform a muon run using ACD trigger from any tile. Collect ~500K events (~30 min in total assuming 500Hz rate). This provides the data for the performance monitoring of the tiles on +Y and -Y sides (gives the MIP peak position for vertical muon incidence). The result is the values of MIP peak position P^Y_{self} for each PMT on +Y and –Y sides.

Results of the performed tests are:

- the values of MIP peak position for every PMT for **vertical** muon flux – consequently P^{top}_{self} , P^X_{self} , and P^Y_{self}. They are used in 2.1.1. (Method 1) to obtain initial light yields and as reference values for all future tests.
- the values of correction factors K, which will be applied to the MIP peak position values obtained in the side coincidence mode, to correct them to the values obtained for vertical flux (here obtained in self-triggering mode). These correction factors are consequently

$$K^{top} = \frac{P_{self}^{top}}{P_{co}^{top}}, \; K^{\pm X} = \frac{P_{self}^{\pm X}}{P_{co}^{\pm X}}, \; and \; K^{\pm Y} = \frac{P_{self}^{\pm Y}}{P_{co}^{\pm Y}}$$

They will be used in all future ground tests when the ACD is in the "normal" position (ACD sides are exposed to the off-vertical flux) to convert obtained MIP peak position values to that for the vertical incidence particles. Vertical incidence is needed to determine "normal incidence single MIP" signals and from them to determine the values for the VETO thresholds.

6.1.3. Tests for standalone ACD

These tests shall be performed any time when the ACD performance monitoring is needed. It is assumed that the ACD will be in "normal" position (no more instrument rotation). All High Voltages have to be set to the nominal values.

a) Perform a muon run using ACD trigger "any **top** TDA". Collect ~100K events.
b) Perform a muon run using ACD trigger ROI1 & ROI2. Collect ~ 200K events
c) Perform a muon run using ACD trigger ROI3. Collect ~ 200K events
d) Compare obtained values of MIP peak positions on the histograms with "reference" ones.
e) Use correction factors K^{top}, $K^{\pm X}$, and $K^{\pm Y}$ to convert obtained MIP peak position values to that for normal incidence in order to determine VETO threshold values

6.1.4. VETO threshold setting calibration.

In order to properly set VETO thresholds for their use in L1T, the dependence "ADC bin vs. VETO threshold setting" has to be found for each TDA channel. The basic idea is to run the ACD with "any ACD tile" trigger, changing the VETO threshold settings for every TDA channel with the steps of 3 (TBD) of 64, and looking at the corresponding histogram in what ADC bin this threshold is. The problem here is that there will be almost no events at the threshold level 0.1-0.2 MIP, where we want to do the calibration. The approach is to run ACD with low high voltages – 300V lower than nominal (corresponds to approximately factor of 5 lower gain, with MIP peak moving to ~ 0.2 MIP position at nominal HV)

a) Set ACD detectors high voltage 300V lower than their nominal values. Perform a set of muon runs with "any ACD tile" trigger and setting VETO thresholds to consequently 2, 5, 8, 11, 14, 17, …, 63. Collect ~200K events in each run
b) Determine on each histogram the threshold position (in ADC bin units). The threshold position corresponds to the bin in the middle of the left tail (see fig.2). Plot the threshold position (in units of ADC bin) against the VETO threshold setting for each TDA channel (PMT).

6.1.5. Ribbon performance determination.
Ribbon performance determination actually requires the use of the tracker information about trajectory of detected particle. The way to determine it for the standalone ACD is the following:

a) For the ACD in "normal" position run four efficiency runs with external triggering hodoscope placed on the top TDA's in the positions shown in fig.3 (in the middle between adjacent tiles 020 and 021, 021 and 022, 022 and 023, 023 and 024) to have the ribbon in the middle)
b) Set HV values to the nominal.
c) Collect ~100K events in each run
d) Determine the efficiency of the area with two tiles and the ribbon in the center between them; put the results in the simulation code with known values of the light yield for the TDA's used in this test, and from this determine the ribbon light yield.
e) For the ACD with +X side pointed to the zenith – run similar four efficiency tests, placing triggering hodoscope between TDA's consequently 300 and 301, 301 and 302, 302 and 303, and 303 and 304. Analyze the data appropriately
f) For the ACD with +Y side pointed to the zenith – run similar four efficiency tests, placing triggering hodoscope between TDA's consequently 400 and 401, 401 and 402, 402 and 403, and 403 and 404. Analyze the data appropriately
g) Insert obtained ribbon light yield values in the efficiency simulation code

6.2. ACD efficiency determination using the information from the tracker

Use of the information about particle trajectory, provided by the tracker, provides the direct measurement of ACD efficiency. We have to remember that ACD is required to demonstrate 0.9997 efficiency over its entire area for the isotropic flux. Ground cosmic muon flux is not isotropic, and ACD efficiency test with ground muons **gives lower ACD efficiency** value than that for the isotropic flux.

a) Perform a muon run with LAT in "normal" position. ACD HV and VETO thresholds are set to nominal values (actually VETO settings shall not affect the results since ACD VETO is disabled). Use LAT "3-in-a-row" trigger (ACD VETO disabled) and collect ~200K muon events.
b) Data analysis: apply obtained in "ACD standalone" tests VETO threshold values to all ACD detectors and plot the ACD efficiency against applied VETO threshold (in the units of fraction of MIP peak position).
c) Results of this test can also be used to study the edge effect in the TDA efficiency and gap effect, as well as ribbon performance, for the top TDA's. For this analysis larger event statistics is desirable - ~500K events.

d) In order to determine the ribbons performance, select the events which crossed the ribbons (by the tracker) and analyze their histograms to determine the light yield.

Appendix 1. Procedure of the Initial Performance Test

1. Light Tightness test
    1.1. ACD in "normal" position. Set all HV and VETO thresholds to the initial values
    1.2. Run the ACD. Check the rates. Cover the ACD by light tight blanket. Check the rates again – they should be within 10% of that for open ACD.

2. Selected TDA efficiency measurement
    2.1. Install "External trigger telescope #1" (small) on the top of TDA 021 (at its center)
    2.2. Set HV to the nominal (could be different from initial values). Run the muon test using "ACD external trigger". Collect 100K muon events
    2.3. Install "External trigger telescope #1" on the top of TDA 012 (at its center). Run the muon test using "ACD external trigger". Collect 100K muon events
    2.4. Install "External trigger telescope #1" on the top of TDA 033 (at its center). Run the muon test using "ACD external trigger". Collect 100K muon events
    2.5. Using obtained test data, determine the efficiency for each channel (PMT) and corresponding light yield values. Derive average ADC sensitivity from obtained light yield values (per 2.1.1. of the main document, Method 1)

3. MIP peak position determination for TDA's and ribbons
    3.1. ACD in "normal" position (top TDA's are pointed to the zenith)
    3.2. Set all HV to the nominal values. It is critical for this test, because obtained data will be used as the reference data, and have to be taken at the same HV.
    3.3. Using ACD "external trigger telescope #2" (large) perform muon runs for the same tiles on the top – 021, 012, and 033. Collect 5K events in every run.
    3.4. Ribbon test: Install "external trigger telescope #2" (large) on the top of TDA 020 and 021 (in the middle of them). Collect 100K triggers
    3.5. Repeat step 3.4 setting trigger telescope in the middle of TDA pairs 021 and 022, 022 and 023, 023 and 024. Collect 100K triggers in every run.
    3.6. Measurement of MIP peak positions for all tiles in self-triggering mode: Set Veto thresholds to their lowest possible values (just above the noise). Perform a muon run using "any ACD tile" trigger. Collect 500K events.
    3.7. Measurement of MIP peak position for all side TDA's in the coincidence mode: Set Veto thresholds to their lowest possible values (just above the noise). Perform a muon run using ROI1 & ROI2 ACD trigger. Collect 200K events.
    3.8. Measurement of MIP peak position for all top TDA's in the coincidence mode: Set Veto thresholds to their lowest possible values (just above the noise). Perform a muon run using ROI3 ACD trigger. Collect 200K events.
    3.9. Rotate ACD to point +X side to the zenith.

3.10. Measurement of MIP peak position for ±X sides TDA's in the self-triggering mode: Set Veto thresholds to their lowest possible values (just above the noise). Perform a muon run using "any ACD tile on sides +X and –X" trigger. Collect 500K events.
3.11. Ribbon test. Install external trigger telescope consequently on the top of TDA 300 and 301, 301 and 302, 302 and 303, 303 and 304. Collect 100K triggers in every run.
3.12. Rotate ACD to point +Y side to the zenith.
3.13. Measurement of MIP peak position for ±Y sides TDA's in the coincidence mode: Set Veto thresholds to their lowest possible values (just above the noise). Perform a muon run using "any ACD tile on sides +Y and –Y" trigger. Collect 500K events.
3.14. Ribbon test. Install external trigger telescope consequently on the top of TDA 400 and 401, 401 and 402, 402 and 403, 403 and 404. Collect 100K triggers in every run.
3.15. Using data obtained in 3.4 – 3.10, determine the reference mip peak positions for self-triggering mode (vertical muon flux) for all PMT's
3.16. Determine reference light yield for all PMT's, using data obtained in 3.11

4. VETO threshold setting calibration
   4.1. ACD in normal position (top TDA's are pointed to the zenith)
   4.2. "Any ACD tile" trigger is used for these runs
   4.3. Set all HV's ~300V lower that the nominal values are. Check if the muon peak moves to the ADC bin where ~0.2 mip peak for the nominal HV would be. Adjust HV if needed
   4.4. Perform a set of muon runs setting VETO thresholds to consequently 2, 5, 8, 11, …, 63. Collect ~200K events in each run

Appendix 2. Procedure of Standalone ACD Performance Test

1. ACD in normal position (top TDA's are pointed to the zenith)
2. Set all HV's to the nominal values
3. Set all VETO thresholds to its minimal values (just above the noise)
4. Perform a muon run using "any ACD **top** tile" trigger. Collect ~ 100K muon events
5. Perform a muon run using ACD trigger ROI1 & ROI2. Collect ~200K muon events
6. Perform a muon run using ACD trigger ROI3. Collect ~200K muon events
7. Fill out the ACD Calibration Table with the obtained results

Appendix 3. Procedure of ACD Performance Test using information from LAT

1. LAT in normal position (top ACD TDA's are pointed to the zenith)
2. Set all HV's and VETO thresholds to the nominal values
3. Perform a muon run using LAT "3-in-a-row" trigger (ACD VETO disabled). Collect 500K-1M muon events for the full test (direct

measurement of ACD efficiency). Collect ~200K for the short test to monitor ACD performance