AntiCoincidence Detector (ACD) for GLAST

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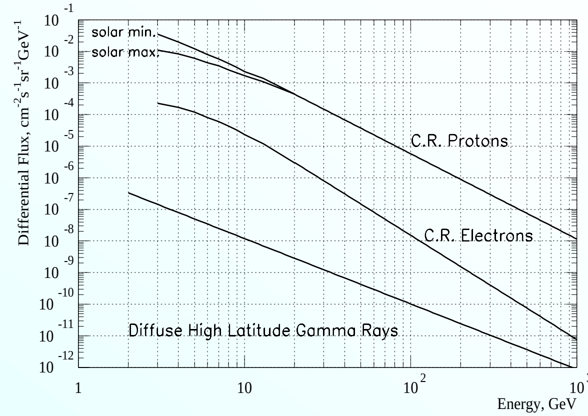
Description

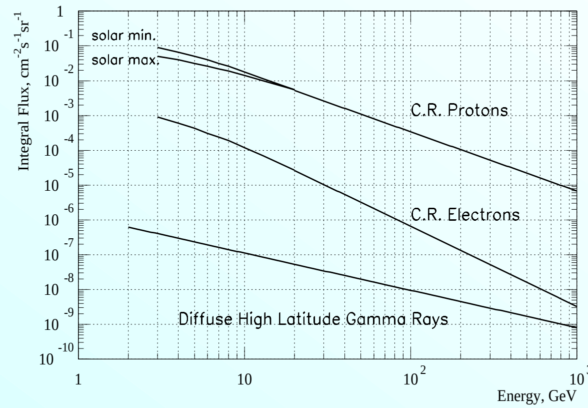
- The Anticoincidence Detector (ACD) is the outermost active detector on GLAST. It surrounds the top and sides of the tracker.
- The purpose of the ACD is to detect incident cosmic ray charged particles, which outnumber cosmic gamma rays by more than 5 orders of magnitude. Signals from the ACD can be used to either veto an event trigger or be considered later in the data analysis.
- The ACD for GLAST is based on the heritage of the SAS-2, COS-B and EGRET telescopes. GLAST will be studying gamma radiation up to 300 GeV. Gamma-rays of such high energy create a huge number of secondary particles in the calorimeter of the telescope; some of them may interact in the ACD, causing self-veto and reducing dramatically the efficiency of the instrument for the detection of high energy photons. Instead of a monolithic scintillator dome as used in previous missions, the Anticoincidence Detector for GLAST is subdivided into smaller tiles to avoid the efficiency degradation at high energy.

Science requirements

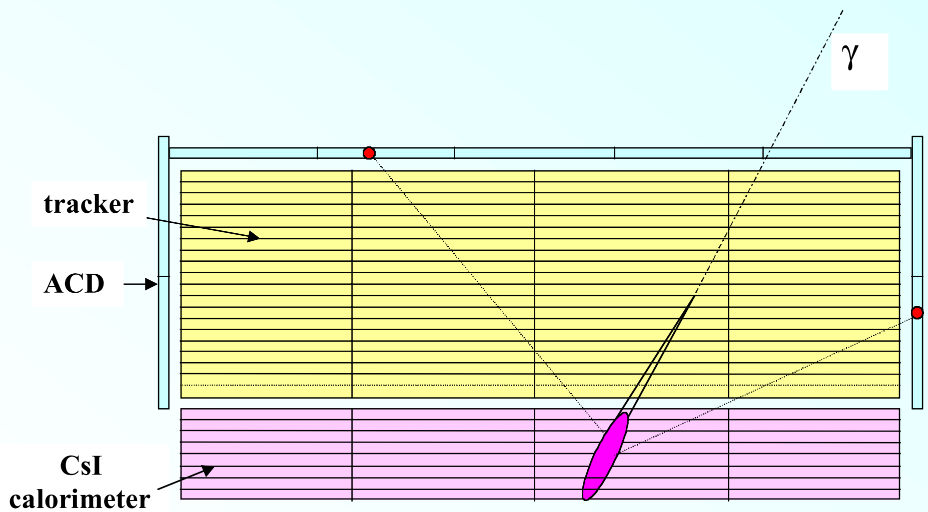
Charged particle background rejection 10^5 :1 at system level. ACD should be able to reject at least 3×10^3 of them; additional rejection is provided by tracker+calorimeter. This requirement is determined mainly by the ratio of 10-20 GeV cosmic ray electrons to high latitude diffuse gamma rays.

- **calorimeter can discriminate photons from cosmic ray protons, but not from electrons which create showers in the calorimeter identical with photon showers. Only the ACD with the help of the tracker protects against electrons**
- **thus, the required efficiency for charged particles (detector efficiency + hermeticity) is > 0.9997**
- **we expect one additional "9" from the top tracker layer to meet the system level requirement**

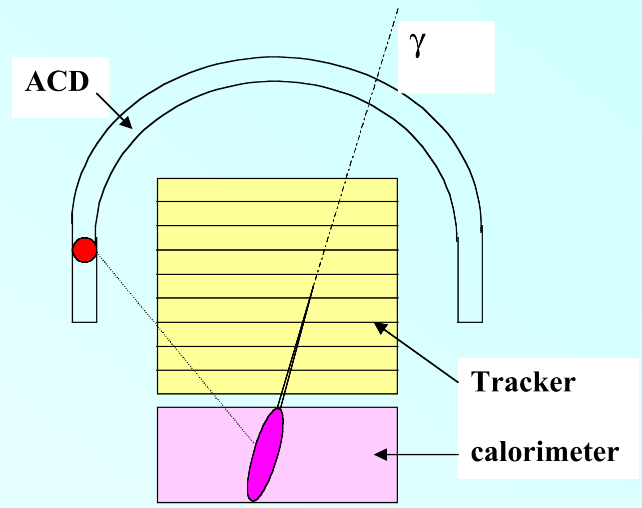




Description (cont.)



GLAST



EGRET

Science requirements (cont.)

Backsplash avoidance

- **High energy gamma rays incident on the calorimeter produce showers with backsplash (mainly 0.2-2 MeV photons). Such photons can Compton scatter in the ACD producing a "hit" signal comparable to the energy deposit by a minimum ionizing particle (aka *mip)*. If the location of the ACD hit cannot be distinguished from the arrival direction of the gamma ray (determined by the tracker), then the event may be self-vetoed.**
- **Such backsplash reduced the EGRET effective area by 50% at 10 GeV compared to 1 GeV**
- **Requirement: segment the ACD such that the backsplash effect gives a "false" veto for *not more than 20%* of good gamma ray events over the entire energy range up to 300 GeV**

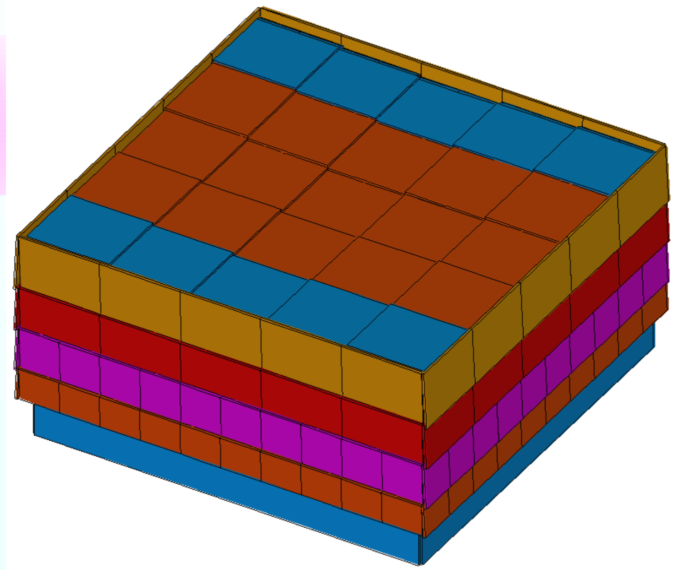
Mechanical Constraints

- Mass 175kg +54 kg reserve
- Electrical Power » 29 W + 26 W reserve
- Outer dimensions 167cm × 167cm × 76cm: covers the top and the sides of the tracker
- Maintain overall dimensions of 173cm × 173cm (thermal blanket and micrometeoroid shield included)
- Minimize the inert material outside the ACD to prevent locally generated gamma-ray background.
- Minimize inert material inside the ACD (structural) to reduce the fraction of gamma rays converted in non-optimal locations
- Robust to launch loads

Monte Carlo studies

- **Need separate trigger for high energy photons from calorimeter**
- **ACD must cover whole side of tracker**
- **Simple cuts on number of ACD tiles are used at L3 for background rejection and can be used at L1 if there are rate problems**
- **Developed idea of "nearest neighbor" coverage**

Design Approach



- Segmented plastic scintillator (Bicron-408) with wave-shifting fibers (BCF-91MC) + PMT (Hamamatsu R1635, R5900) readout; each segment (tile) has a separate light tight housing.
- segmentation localizes backsplash
- separate tile housings provide resistance to accidental puncture by micrometeoroids; the loss of one tile will lead to <10% increase in event rate (both EGRET and COS-B would have lost the entire ACD and consequently the defense against cosmic rays if this had happened)
- wave-shifting fiber readout provides the best light collection uniformity within the space constraints and minimizes the inert material
- ACD "hat" covers the top and the sides of the tracker down to the calorimeter, covering the gap between tracker and calorimeter where the massive grid is located.
- size of the tiles is such that self-veto due to backsplash does not exceed 20% at 300 GeV
- possible gaps between tiles should not align with the gaps between tracker towers for hermeticity

ACD Parts and Fabrication

Element	Parts & materials	Fabrication & Assembly
Scintillators/fibers	Bicron-408 scintillator Bicron 91A/MC WSF	Bicron subcontractor cuts high-quality grooves for embedding the fibers into the scintillators. GSFC/LHEA bonds the fibers
Wrapping	TYVEK, opaque wrap	TYVEK for light reflection, opaque layer to isolate tiles in case of penetration by micrometeoroid
Phototubes	Hamamatsu R1635 or R5611 space-qualified	Magnetic shielding. Hamamatsu can build bases with voltage divider or Cocroft-Walton HV supplies, potted for vaccum
HV	Hamamatsu HV supply or Cocroft-Walton converters	Purchase as part of PMT assembly or custom design
Front-end ASIC and related electronics	Custom design by GSFC	Process TBD, based on best available; design by GSFC group doing Swift MIDEX and analog design for beam test tower
FPGA logic	Actel	Common buy for all subsystems; programming by GSFC engineer based on beam test experience
Support structure	Composite, low-density, high-strength space-qualified rigid foam for spacing	GSFC Mechanical Engineering/Composites Group design, parts manufactured by local contractor, assembly by GSFC in-house
Outer shielding (thermal and micrometeoroid protection)	Nextel ceramic fabric Solimide foam Kevlar MLI	High-strength fabric bumper layers, as used on the ISS. Low-density, flexible foam for spacers, used on Shuttle Backing shield, good penetration resistance GSFC blanket group will handle assembly, similar to the EGRET

Summary of Measurements and Laboratory Developments

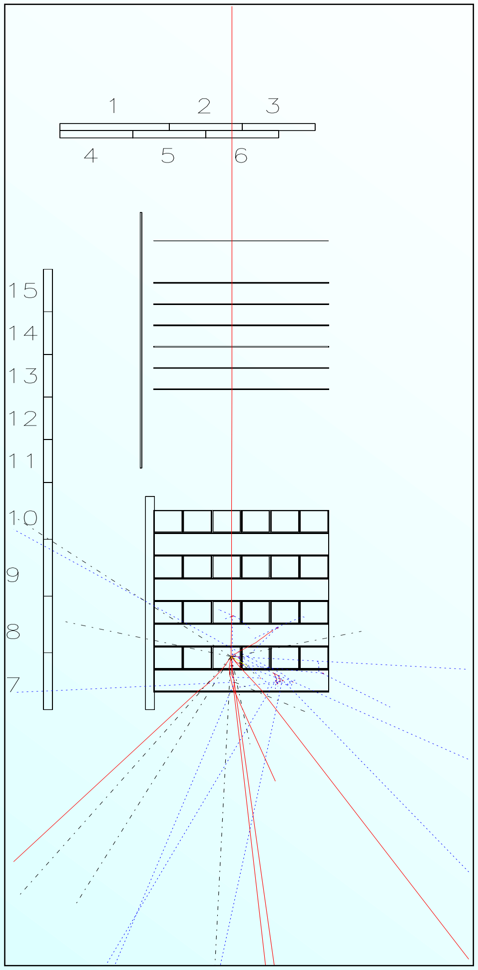
1997 beam test at SLAC

<u>Goals:</u>

- verify choice of wave-shifting fibers for light collection
- study angular distribution and energy spectrum of backsplash
- measure the ACD efficiency for electrons (minimum ionizing particles)
- test use of 2 layers
- validate Monte Carlo estimates of backsplash

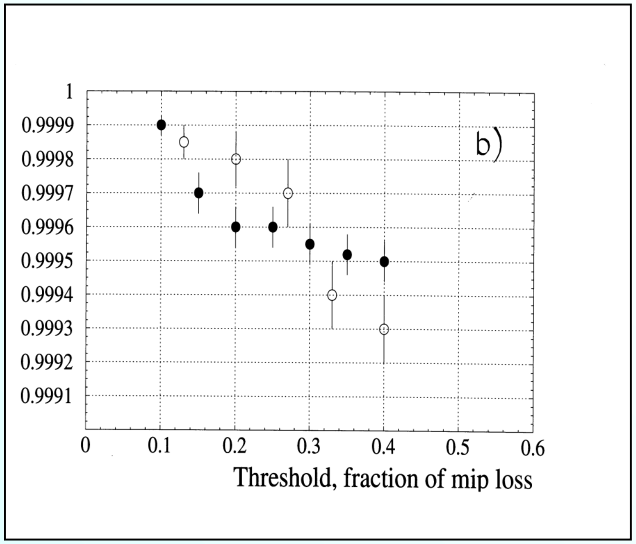
1999 beam test at CERN

- to extend the backsplash measurements to higher energies
- used refurbished hardware and similar experimental setup



Summary of Measurements and Laboratory Developments (cont.)

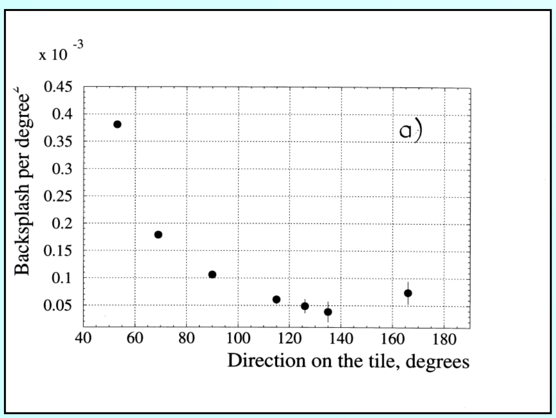
Efficiency of electron detection depends on the discriminator threshold. It was measured in an electron beam (SLAC-97, filled circles) and in the laboratory using cosmic ray muons (open circles). Measurements agree with estimates based on photoelectron statistics and indicate the detection of 30 photoelectrons for a mip traversing the detector with normal incidence. These measurements are consistent with the pulse height distribution widths made with BTEM paddles built this year (see chart 17).

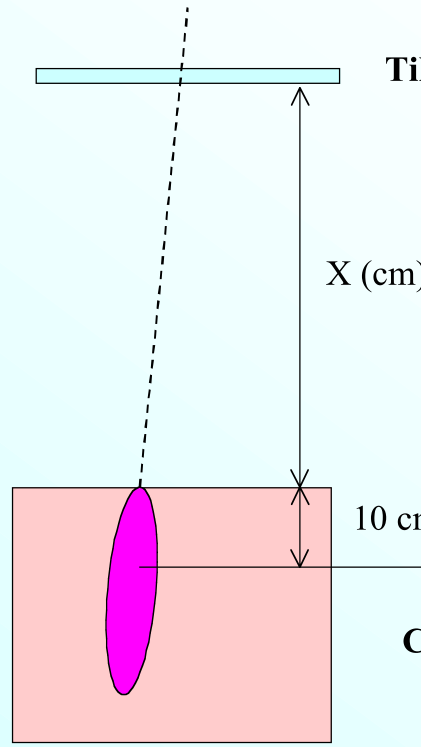


Summary of Measurements and Laboratory Developments (cont.)

Backsplash measurements:

- directional distribution of events accompanied by backsplash above 0.2 of the mip loss is shown for the incident 20 GeV photons (SLAC-97)





Summary of Measurements and Laboratory Developments (cont.)

- **The fraction of events with backsplash above a given discriminator threshold for the energy range from SLAC energies (5 GeV) to CERN energies (300 GeV) are given on the right. It resulted in the empirical formula for backsplash:**

$$P_{bs} = \left(0.85 \times \frac{0.3}{E_{thr}} + 0.15\right) \times 10^{-3} \times \frac{A}{144} \times \left(\frac{55}{x+10}\right) \times E^{0.75}$$

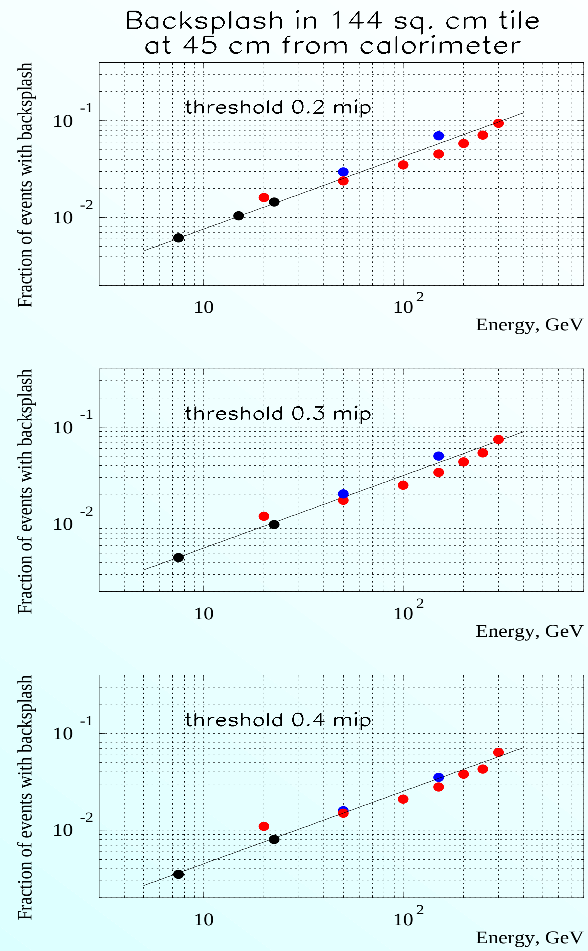
where E is the energy of incident electron/photon in GeV,

E_{thr} is the threshold value in units of mip

X is the distance from the top of calorimeter in cm

A is an area in cm²

P_{bs} is the probability that there was an energy deposition above E_{thr} in 1cm thick scintillator



Summary of Measurements and Laboratory Developments (cont.)

Conclusions:

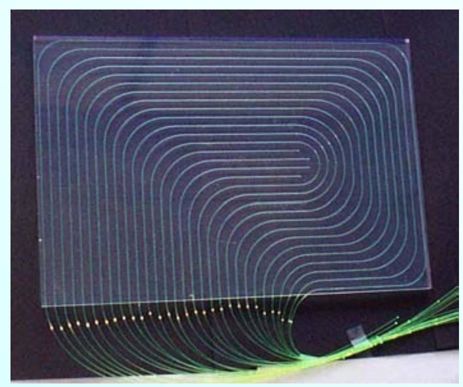
- An efficiency for a mip >0.9995 is achievable, with discriminator setting of »15-20% of a mip. This threshold avoids any problems from noise (majority of which is well below 5-10% of the mip) and reduces backsplash effect
- The angular distribution of backsplash has a broad minimum of $\pm 60^0$ around backward direction, consistent with the isotropization of low energy particles in the shower. We can use these results for predicting backsplash on any size tile and at any location within that cone at any energy. With »1000 cm^2 tiles on the top of the tracker the relative efficiency for GLAST will be degraded by no more than 20% at the highest accessible energy.
- GEANT and GLASTSIM simulations, performed for the beam test configuration, predict less backsplash that measured in beam test. We have used the beam test results to estimate the self-veto probability.
- Two layer design gives a factor of only 2-3 reduction in the self-veto (beam test data). We determined that a single layer is adequate. It avoids use of the much more complicated 2-layer design that requires significant additional mass and power.

ACD Trade Studies and Simulations

Combining the extensive Monte Carlo simulations and the beam and laboratory test results allowed us to define the flight unit specifications and requirements:

- ACD tile area required: »1000 cm^2 on the top. For the sides specification varies with distance of the tile from calorimeter and is science driven.
- 1 tile layer vs. 2 tile layers (on top): 1 layer is acceptable (charged particle detector efficiency requirement can be met with only 1 layer and certain gap size between adjacent tiles)
- Gap width: < 2mm gap, overlap of tiles is desirable (simulations show that the efficiency requirements are marginally met for this gap)
- Tile gap alignment with respect to Towers: Misalignment recommended (Simulations have shown that misaligning the tile gaps with the tower gaps allows the first tracker layer to provide backup for particles coming through the gaps between ACD tiles, improving the leakage performance of the ACD from 10^{-3} to 10^{-4})
- Importance of Efficiency and Leakage requirements: < 10^{-3} required (Simulations and investigations have shown that additional factor of ten needed to reject electrons can be obtained by combining the ACD information with tracker information)

1999 SLAC beam test (BTEM)



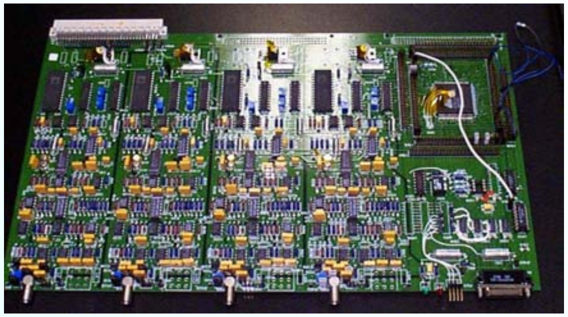
Primary Goals:

- **verify ACD design - physics, mechanics, electronics**
- **verify simulations of the ACD design - efficiency, leakage, backsplash avoidance**
- **test and validate DAQ interface design concepts**

Secondary Goals:

- **study possible high-voltage electromagnetic interference with other components**
- **study bending, routing, and mounting of wave-shifting fibers**
- **test attachment of scintillators to structure**
- **test methods of building light-tight housings**

1999 SLAC beam test (cont.)



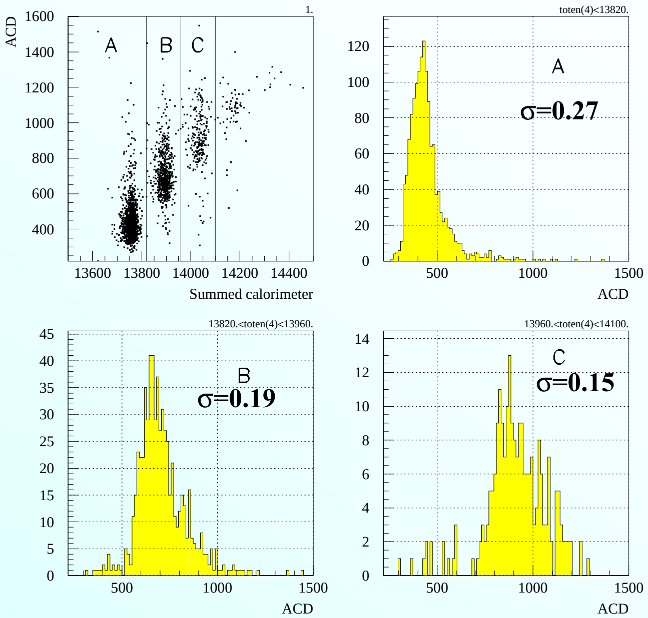
The BTEM/ACD design can be summarized as follows:

- **ACD is a separate unit (aka a "hat") that covers the tracker part of the tower**
- **All scintillating tiles (12 in total) are viewed by Hamamatsu R1635 phototubes through multicladding BC-91MC wave-shifting fibers**
- **Top ACD is divided into four tiles with some gaps in between with the goal to study the efficiency degradation around possible gaps in real design; these top tiles are bent with embedded fibers**
- **some PMTs are hidden under side scintillators, others are not so that the impact of cascades from the calorimeter hitting the PMTs can be evaluated**
- **to measure the direct detection of splash radiation from calorimeter, one PMT was not attached to a scintillator**
- **Lower side tiles have a curved fiber groove pattern designed to minimize the space for the PMT**

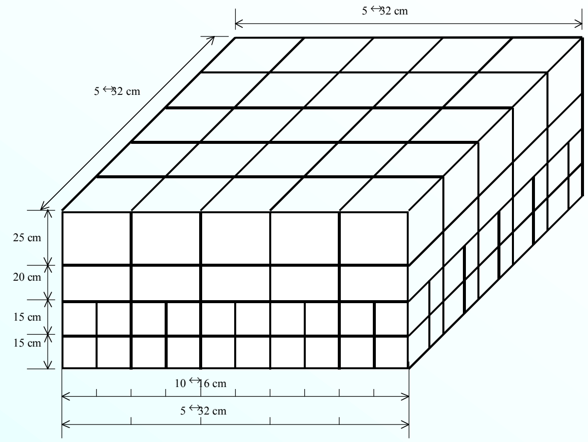
1999 SLAC beam test (cont.)

Beam test results:

- **Preliminary tests showed that all the tiles worked as expected**
- **The data collected in 5 GeV electron run is shown. The left upper panel shows the ACD pulse-height vs. the calorimeter summed pulse-height. Events with 1, 2, 3 and 4 particles are clearly separated. The ACD data applying calorimeter selections are shown.**
- **Variation of the resolution with signal obtained is consistent with about 36 photoelectrons, indicating the expected improvement in light collection over the earlier units.**
- **Detailed analysis of the collected experimental data is just beginning.**



Flight ACD Design



Competed studies and measurements combined with the scientific goals for GLAST motivate the following design specifications for the GLAST ACD:

- ACD must be >0.9997 efficient to the singly charged mip and have leakage < 3×10^{-4}. This drives the requirement for light production and collection - the thickness of scintillator, the fiber frequency and placement, and uniformity of response
- Efficiency degradation due to backsplash-caused self-veto should be not more than 20% over the entire energy range up to 300 GeV.
- Redundancy needs to be carefully considered. All critical elements are to be redundant.
- Optimized footprint of GLAST dictates very limited room for the ACD on the sides; design studies show that this can be less than 5 cm (excluding thermal blanket)
- Resistance of the ACD to accidental puncture by a micrometeoroid requires each tile to be independently enclosed and light tight. Rate studies show that failure of a 1000 cm^2 tile will increase rate by <10%.
- Unique possibility to detect high energy gamma-ray lines, possibly originating from dark matter annihilation, would be improved if we use off-angle events with long paths in the calorimeter. To maintain the self-veto at the level of <20%, we have to set the size of the tiles on the tracker sides.

Next steps for beam test data

- **Data analysis**
  - **Study response near edges and determine overlap for flight unit**
  - **Revalidate backsplash measurements**
  - **Study stability and location of threshold settings**
- **Laboratory measurements using muons to compare with beam data**
  - **Efficiency**
  - **Threshold settings**
  - **Noise**

Other studies

- **Improve light collection by 30%**
  - **Degradation study**
- **PMT - HV system**
  - **Cockroft-Walton**
  - **Distributed HV**
- **Segmentation of tiles on side**
  - **Current design based on use of photons entering through sides at >70^{o}**