GLAST Large Area Telescope: 
I & T Peer Review

Particle Test

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Outline

- Flow of Requirements to/From Subsystems
- LAT Particle Tests
- Cosmic Rays and Van de Graaff
- Calibration Unit Beam Test
**LAT Functional Performance (SE and I&T)**

- **Structural and Mechanical Tests** (cosmic ray survey)
- **Thermal Verification Tests** (cosmic ray survey)
- **Instrument Monitoring** (cosmic ray, Van de Graaff)
- **End-to-end test** (cosmic rays at ~35,000 ft in a jet airplane during transport to NRL for environmental tests) (TBR)

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**Produce a Working Instrument**
Science Performance (SE, IS, and I&T)

- Particle tests (beam test, cosmic rays, Van de Graaff)
- Calibration (beam test, cosmic rays)
- Science verification tests (beam test, cosmic rays, Van de Graaff)

Produce a Scientifically Working Instrument
<table>
<thead>
<tr>
<th>Req’t #</th>
<th>Req’t Title</th>
<th>1. Parameter</th>
<th>Verification Method</th>
<th>Beam Tests relevant to the Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2.1</td>
<td>Energy Range/Effective Area</td>
<td>At Normal Incidence: &gt; 300 cm² @ 20 MeV &gt;3000 cm² @ 100 MeV &gt;6400 cm² @ 300 GeV</td>
<td>T=Test A=Analysis T and A</td>
<td>1) Van de Graaff 17.6 MeV γ 2) Tagged photons 100 to 1500 MeV, norm incidence 3) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.</td>
</tr>
<tr>
<td>5.2.2</td>
<td>Energy Resolution</td>
<td>On axis: ≤ 50 % 20–100 MeV ≤ 10 % .1-10 GeV ≤ 20% 10-300 GeV ≤ 6% &gt;10 GeV, Incidence&gt;60°</td>
<td>T and A</td>
<td>1) Van de Graaff 17.6 MeV γ 2) Tagged photons 100 to 1500 MeV, norm incidence 3) Positrons 1,2,5,10,28, 45 GeV, variety of angles and transverse positions</td>
</tr>
<tr>
<td>5.2.3</td>
<td>Peak Effective Area</td>
<td>&gt;8000 cm²</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.</td>
</tr>
<tr>
<td>5.2.4</td>
<td>Effective Area Knowledge ΔA/A, 1σ</td>
<td>＜50% 20-50 MeV ＜25%.05-300 GeV</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.</td>
</tr>
<tr>
<td>5.2.5</td>
<td>Single Photon Angle Resolution 68% (on-axis)</td>
<td>＜3.5° front @ 100 MeV ＜6° back ＜0.15° front @ 10-300 GeV ＜0.3° back</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 2) Tagged photons 100 to 1500 MeV, norm incidence</td>
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<tr>
<td>5.2.6</td>
<td>Single Photon Angle Resolution 95% (on-axis)</td>
<td>＜3 x 0°, On-Axis</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions. 2) Tagged photons 100 to 1500 MeV, norm incidence</td>
</tr>
<tr>
<td>5.2.7</td>
<td>Single Photon Angle Resolution (off axis at 55°)</td>
<td>＜1.7 times on-axis</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.</td>
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<tr>
<td>5.2.8</td>
<td>Field of View</td>
<td>＞2 sr</td>
<td>T and A</td>
<td>1) Brems beam, simultaneously all γ energy bins from 20 MeV to 28 GeV, variety of angles and transverse positions.</td>
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<tr>
<td>5.2.11</td>
<td>Time Accuracy</td>
<td>Better than 10 usec relative to S/C time</td>
<td>T and A</td>
<td>1) All Beam Test events record time from Linac RF</td>
</tr>
<tr>
<td>5.2.12</td>
<td>Background Rejection</td>
<td>＞10:1 (TBR)</td>
<td>T and A</td>
<td>1) 200 K protons (Pattern rejection) 2) Cosmic rays on the ground (ACD rejection)</td>
</tr>
<tr>
<td>5.2.13</td>
<td>Dead Time</td>
<td>＜100 usec per event</td>
<td>T and A</td>
<td>1) Ground cosmics 2) All Beam Test runs</td>
</tr>
</tbody>
</table>
Beams

- Cosmics rays on the ground
  - EM, CU, LAT
- Van de Graaff (17.6 Mev $\gamma$)
  - EM, CU (TBR), LAT (TBR)
- End Station A positrons (1-45 Gev)
  - CU
- End Station A tagged photons (~100-1000 Mev)
  - CU
- End Station A brems photons (> 20 Mev – 28 Gev)
  - CU
- End Station A protons (~12 Gev)
  - CU
- Cosmic rays in airplane (25,000 - 35,000 feet) (few hours) (TBR)
  - LAT
Ground Cosmic Rays (Examples)

- Each tower as it becomes available at SLAC
  - \(\sim 10^6\) muons/day x 3 days (TBR) (use 3 in-a-row tracker trigger)
  - Natural cosmic solid angle distribution. External muon telescope.
- Four Tower Calibration Unit
  - Inter tower survey.
- Full LAT
  - \(\sim 10^8\) muons/day (using 3 in-a-row tracker trigger)
  - Inter tower survey
  - Calibrate individual CsI xtals
    - ADC chans/MeV
    - Positional dependence
  - Calibrate tracker
    - Dead and noisy strip map
    - Straight tracks survey relative tray and tower positions
  - Calibrate ACD
    - ADC chans / MeV
    - Calibrate discriminator thresholds
    - Efficiency vs position
- Trigger and DAQ
  - Efficiency vs position

For a full list of calibrations see LAT-MD-00446.
BGO Detector Array

BGO crystal array used to calibrate the energy of the tagged photon beam.

Elements of Scintillator Telescope to identify Cosmic Rays.

BGO crystals

Phototubes
Van de Graaff Installed

Heritage from previous use in Crystal Ball experiment by members of I&T. This VDG was used for 8 years at SLAC and then shipped to DESY (Hamburg, Germany). During this time it was used routinely for CB calibration using $\gamma$ lines produced by the VDG.
1) The **points** are data (3335 events) from the Crystal Ball for the gammas from the reaction p+Li7.

2) The **black solid curve** is the sum of a Breit-Wigner ($E_{\text{resonance}} = 12$ MeV, FWHM $\Gamma = 5$ MeV) and a Gaussian ($E_{\text{resonance}} = 17.6$ MeV, $\Gamma \sim 10$ keV, $\sigma_{\text{resolution}} = 1.3$ MeV). The two curves have equal area and add up to the total number of counts in the data.

3) The **red solid curve** is what the EM would see with the GLAST LAT required resolution, assuming a sum of two Gaussians ($\sigma = 50\%, 50\%$, relative efficiency $= 0.7, 1.0$).

4) The Li target produced 1060 Hz of gammas ($E > 7$ MeV) into $4\pi$ solid angle (Measured in February with the Van de Graff and BGO calorimeter in Bldg 33).
Absolute normalization of VDG Flux

• VDG Absolute Flux needs to be known if VDG used to establish < 100 MeV Science requirements.
  – Required to establish > 300 cm² effective area for LAT @ 20 MeV (TBR)

• BGO normalization of the γ flux during EM, CU, LAT Measurements
  – The γ angular distribution from the target is expected to be isotropic. Measurements at 0 and 45 degrees have initially confirmed this.
  – **Primary normalization method:** The BGO calorimeter will be placed at ~135 degrees to the beam direction (i.e., behind the target) while the target is in front of the EM, CU, or LAT. Simultaneously counting the photons into the solid angle of the BGO will yield the number of photons going into the solid angle of the EM, CU, or LAT.
  – Secondary normalization method (less accurate): The Van de Graaff operator will keep the energy and current of the accelerator constant during the run, and then use the flux versus current calibration to calculate the number of photons going into the solid angle of the EM, CU, or LAT.
Simulated Energy Spectrum from the VDG source

90 000 MC signal events
(0.5 h of data taking
50 Hz rate from VDG)

Used as input to the MC

Linear Scale !!!

$E_{B-W} = 12$ MeV, FWHM $\Gamma = 6$ MeV and a Gaussian
$E_{\text{resonance}} = 17.6$ MeV, $\Gamma \sim 10$ keV)

N$_{ent} = 1635$
Mean = 15.55
RMS = 3.16

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**TKR - Number of TRACKS**

Differential distribution

**TKR - number of CLUSTERS**

Differential distribution

**Cuts: TKR trigger**

- Signal dominates
- Negative values are not shown

- Negative values are not shown

<table>
<thead>
<tr>
<th>Nent</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1479</td>
<td>0.8749</td>
<td>0.127</td>
</tr>
<tr>
<td>-1586</td>
<td>4.722</td>
<td>2.598</td>
</tr>
</tbody>
</table>
EM Energy Spectrum (TKR only)

EM MC

Photons only

<table>
<thead>
<tr>
<th>N_{ent}</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1160</td>
<td>10.57</td>
<td>3.257</td>
</tr>
</tbody>
</table>

TKR energy (MeV)
True MC Spectrum
Breit-Wigner (mean 11.4, FWHM = 6 MeV)
Delta function (17.6 MeV)
Event ratio 1:1

MC Reconstructed spectrum

Cuts: TKR trigger, TOT>0 below conversion layer, ECAL>0

EM Energy Spectrum (CAL+TKR) in MeV

Photons only

N_{ent} = 998
Mean = 16.51
RMS = 3.427

90 000 MC signal events
(0.5 h of data taking)
Beam Test Measurement Strategy

- First, calibrate Four Tower Calibration Unit energy response
  - 1–45 Gev e+ with variety of x,y,θ (6 days) (small extrapolation to γ with MC).
  - Calibrate tagged photon beam with BGO array (energy calibrated with VDG).
  - 100-1500 Mev tagged photons at normal incidence (2 days).
  - 17.6 MeV γ from Van de Graff (< 100 MeV) TBR.
- Second, take photon data for testing the Monte Carlo (use CU for energy measurement).
  - Bremsstrahlung γ beam at one e+ energy (28 Gev) (20 days)
  - Simultaneously measures all γ energies from 20 Mev to 28 GeV
  - Bremsstrahlung spectrum has equal numbers of γ per % width energy bin.
  - The already energy calibrated LAT bins the photons into ±25% energy bins.
  - An example of bin edges= [GeV]
    - .017, .026, .038, .057, .086, .129, .19, .29, .44, .65, .98, 1.5, 2.2, 3.3, 5.0, 7.4, 11, 17, 25 GeV
- Third, take hadron data for testing the simulation and measuring the pattern cut rejection factor.
  - ~200 K protons @ .0044 /pulse x 30 Hz x 30 days x .58 accelerator efficiency
  - This is the number of protons we recorded in 30 days in Beamtest 99.
EXTRA SLIDES
**Background Rate**

Trigger rate = # of triggered events x 60000 cm² x 1.67 /cm²/s /1,000,000 generated events

- Vertical Position (3-in-a-row only) = 15.33 Hz
- Vertical Position (W cut) = 13.94 Hz
- Horizontal Position (W cut) = 2.54 Hz

W cut = 3-in-row reconstructed events that Converted inside the W foil (130.15 to 130.25 mm)
Highest Photon flux
Highest Trigger efficiency

Highest CR flux
Highest Trigger efficiency

YZ Plane:
Trade off between Flux and Trigger efficiency

XZ Plane:
No Trade off between Flux and Trigger efficiency rate is dominated by trigger efficiency

For cosmic rays
TOT right below the converter where conversion happens

We should be able to see this difference in the VDG test if the TOT is working.

MC

We need to “calibrate” the TOT with muons

\[ X - \text{axis} = TOT \cos \theta_z \]

Cuts: TKR trigger, TOT>0 below conversion layer. Found track along Z direction, needed to normalize to normal incidence.
TOT “Calibration” with Muons Tower Vertical - MC

This is the TOT one expects for Muons in a given TKR layer from Monte Carlo Simulations

Muons: 1 Mip ~ 33 to 37 counts

Cuts: TKR trigger, 1 track and 1 vertex
TOT “Calibration” from muons - DATA

(using EGSE and the GTRC chip v3 that is in the EM! At SLAC)

Muons: 1 Mip ~ 15-20 counts

This is the TOT already working with real data!

<table>
<thead>
<tr>
<th>h1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
</tr>
<tr>
<td>1451</td>
</tr>
<tr>
<td>38.22</td>
</tr>
<tr>
<td>42.32</td>
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