GLAST Large Area Telescope: Technical Status

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Outline

- Context: flow of requirements, definitions, design drivers
- Instrument overview, simulation, early tests
- Overview of technical status since January
  - Mechanical/Thermal
  - Tracker (TKR)
  - Calorimeter (CAL)
  - Anti-Coincidence Detector (ACD)
  - Electronics and Flight Software
  - Integration and Test (I&T)
  - Science Analysis Software (SAS)
- Work in progress to CDR
- Summary
Simplified Requirements Flow

Science Requirements Document (SRD)

Mission System Specification (MSS)

Interface Requirements Document (IRD)

Mission Assurance Requirements (MAR)

Design Trade Study Space

LAT Performance Specifications

LAT Subsystem Requirements

Level II

Level III
Aside: some definitions

**Effective area**
(total geometric acceptance) • (conversion probability) • (all detector and reconstruction efficiencies). Real rate of detecting a signal is (flux) • $A_{\text{eff}}$

**Point Spread Function (PSF)**
Angular resolution of instrument, after all detector and reconstruction algorithm effects.

[2-dimensional 68% containment ~ $1.5\sigma$ (1-dimensional error) if purely Gaussian response. Non-Gaussian tail characterized by the 95% containment, which would be 1.6 times the 68% containment for a perfect Gaussian response.]
### Science Performance Requirements Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>SRD Value</th>
<th>Present Design Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Effective Area (in range 1-10 GeV)</td>
<td>&gt;8000 cm²</td>
<td>10,000 cm² at 10 GeV</td>
</tr>
<tr>
<td>Energy Resolution 100 MeV on-axis</td>
<td>&lt;10%</td>
<td>9%</td>
</tr>
<tr>
<td>Energy Resolution 10 GeV on-axis</td>
<td>&lt;10%</td>
<td>8%</td>
</tr>
<tr>
<td>Energy Resolution 10-300 GeV on-axis</td>
<td>&lt;20%</td>
<td>&lt;15%</td>
</tr>
<tr>
<td>Energy Resolution 10-300 GeV off-axis (&gt;60º)</td>
<td>&lt;6%</td>
<td>&lt;4.5%</td>
</tr>
<tr>
<td>PSF 68% 100 MeV on-axis</td>
<td>&lt;3.5°</td>
<td>3.37° (front), 4.64° (total)</td>
</tr>
<tr>
<td>PSF 68% 10 GeV on-axis</td>
<td>&lt;0.15°</td>
<td>0.086° (front), 0.115° (total)</td>
</tr>
<tr>
<td>PSF 95/68 ratio</td>
<td>&lt;3</td>
<td>2.1 front, 2.6 back (100 MeV)</td>
</tr>
<tr>
<td>PSF 55º/normal ratio</td>
<td>&lt;1.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Field of View</td>
<td>&gt;2sr</td>
<td>2.4 sr</td>
</tr>
<tr>
<td>Background rejection (E&gt;100 MeV)</td>
<td>&lt;10% diffuse</td>
<td>6% diffuse (adjustable)</td>
</tr>
<tr>
<td>Point Source Sensitivity(&gt;100MeV)</td>
<td>&lt;6x10⁻⁹ cm⁻²s⁻¹</td>
<td>3x10⁻⁹ cm⁻²s⁻¹</td>
</tr>
<tr>
<td>Source Location Determination</td>
<td>&lt;0.5 arcmin</td>
<td>&lt;0.4 arcmin (ignoring BACK info)</td>
</tr>
<tr>
<td>GRB localization</td>
<td>&lt;10 arcmin</td>
<td>5 arcmin (ignoring BACK info)</td>
</tr>
</tbody>
</table>

**LAT meets all requirements** [see January review]
Experimental Technique

- Instrument must measure the direction, energy, and arrival time of high energy photons (from approximately 20 MeV to greater than 300 GeV):
  - photon interactions with matter in GLAST energy range dominated by pair conversion:
    - determine photon direction
    - clear signature for background rejection
  - limitations on angular resolution (PSF)
    - low E: multiple scattering => many thin layers
    - high E: hit precision & lever arm

Energy loss mechanisms:

- must detect γ-rays with high efficiency and reject the much larger (~10^4:1) flux of background cosmic-rays;
- energy resolution requires calorimeter of sufficient depth to measure buildup of the EM shower. Segmentation useful for resolution and background rejection.
IRD and MSS Constraints Relevant to LAT Science Performance

- Lateral dimension < 1.8m
  
  Restricts the geometric area.

- Mass < 3000 kg
  
  Primarily restricts the total depth of the CAL.

- Power < 650W
  
  Primarily restricts the # of readout channels in the TKR (strip pitch, # layers), and restricts onboard CPU.

- Telemetry bandwidth < 300 kbps orbit average
  
  Sets the required level of onboard background rejection and data volume per event.

- Center-of-gravity constraint restricts instrument height, but a low aspect ratio is already desirable for science.

- Launch loads and other environmental constraints.
Overview of LAT

- **Precision Si-strip Tracker (TKR)**
  18 XY tracking planes. Single-sided silicon strip detectors (228 µm pitch)
  Measure the photon direction; gamma ID.

- **Hodoscopic CsI Calorimeter (CAL)**
  Array of 1536 CsI(Tl) crystals in 8 layers.
  Measure the photon energy; image the shower.

- **Segmented Anticoincidence Detector (ACD)**
  89 plastic scintillator tiles.
  Reject background of charged cosmic rays; segmentation removes self-veto effects at high energy.

- **Electronics System**
  Includes flexible, robust hardware trigger and software filters.

*Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.*
Gamma Conversion Material

TKR tungsten converter thickness profile:

“FRONT”: 12 layers of 3% $X_0$
“BACK”: 4 layers of 18% $X_0$
followed by 2 layers with no converter

- Large $A_{\text{eff}}$ with good PSF and improved aspect ratio for BACK.
- Two sections provide measurements in a complementary manner: FRONT has better PSF, BACK greatly enhances photon statistics.

TKR has $\sim 1.5 \ X_0$ of material.
Combined with $\sim 8.5 \ X_0$ CAL provides 10 $X_0$ total.
LAT design based on detailed Monte Carlo simulations.

Integral part of the project from the start.

- Background rejection
- Effective area and resolutions
- Trigger design
- Overall design optimization

Simulations and analyses are all C++, based on standard HEP packages.

Detailed detector model includes gaps, support material, thermal blanket, simple spacecraft, noise, sensor responses...

Instrument naturally distinguishes gammas from backgrounds, but details matter.
Monte Carlo Modeling Verified in Detailed Beam Tests

High-level performance parameters (e.g., PSF)

Detailed detector characteristics (e.g., hit multiplicities)

1997 SLAC beam test (photons, positrons)
Demonstrate silicon conversion telescope principle
Published in NIM A446

1999-2000 SLAC beam test (photons, positrons, protons)
flight-scale tower
Published in NIM A474

S. Ritz
LAT Balloon Flight: Goals

Purpose of balloon test flight: expose prototype LAT tower module to a charged particle environment similar to space environment and accomplish the following objectives:

- Help validate the basic LAT design at the single tower level.
- Demonstrate the ability to take data in the isotropic background flux of energetic particles in the balloon environment.
- Record events for use as a background event data base.

All Objectives met by Balloon Flight on August 4, 2001 (3 hrs at 38 km float)

All subsystems performed properly.
Trigger rate <1.5 kHz, well below BFEM 6 kHz capability.
Calibration Strategy

- Every LAT science performance requirement has a draft defined test.
- LAT energy range and FOV are vast. Beam tests are used to sample the performance space and to verify the detailed simulation; analysis with the simulation is used to verify the full range of performance parameters.
- Every LAT science performance requirement can be verified in this manner. All the science performance requirements can be verified in beam tests using four towers. Full-LAT tests are functional tests.
## Summary of Subsystem Status from January Review

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>pass PDR</th>
<th>ready for Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1.1 Management</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.2 System Engineering</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.4 Tracker</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.5 Calorimeter</td>
<td>✓</td>
<td>N</td>
</tr>
<tr>
<td>4.1.6 AntiCoincidence Detector</td>
<td>✓</td>
<td>N</td>
</tr>
<tr>
<td>4.1.7 Electronics, DAQ &amp; Flight Software</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.8 Mechanical Systems</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>4.1.9 Inst. Integration &amp; Test</td>
<td>✓</td>
<td>N</td>
</tr>
<tr>
<td>4.1.A Performance &amp; Safety Assurance</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.B Inst. Operations Center</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.C Education &amp; Public Outreach</td>
<td>n/a</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.D Science Analysis Software</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4.1.E Suborbital Flight Test</td>
<td>n/a</td>
<td>✓</td>
</tr>
</tbody>
</table>
LAT Mechanical Design Overview

- ACD, Thermal Blanket / Micrometeoroid Shield
- TKR Towers
- GRID
- CAL Modules
- Radiator, Heat pipes
- Electronics (underneath)
Mechanical/Thermal Technical Status

• January review: mechanical designs technically ready; thermal subsystem design judged not ready “due to a recently directed change to repackage the radiators to allow…the maximum number of potential spacecraft vendors to bid for the spacecraft contract.”

• Action items from the review
  – Re-evaluate thermal interface requirements DONE
  – Investigate alternate design implementations DONE
  – Add specific items to test plans DONE
  – Conduct delta review NOW

• Mechanical/Thermal Design changes summary:
  – Observatory accommodations in radiator layout
  – Thermal management (improved radiator emissivity, added heat pipes, change TKR sidewall material for better conductivity)
Impacts of Mechanical/Thermal Changes on LAT System Are Limited

• I&T
  – Re-routing of heat pipes requires LAT to undergo thermal verification testing “on its side” (+X-axis pointing down). Included in Verification Test Plan and LAT-Spacecraft Interface Requirements Document.

• TKR
  – Higher conductivity sidewalls cost increment, in baseline.

• CAL
  – No impact

• ACD
  – No impact

• Electronics
  – No impact

Implications of the redesign for mass, cost, and testing are taken into account in the baseline project plan.

The Mechanical/Thermal System is ready for delta review.
TKR Technical Status

• January review: Tracker technically ready.
• Progress since January review:
  – Mechanical prototype construction and testing
  – ASICs:
    • Second run of the readout controller and front end chips had design rule error. Fixed, verified, and resubmitted.
    • Resubmitted chips come back in August. Baseline schedule: one more submission after that for flight parts. Chips coming back in August have all functionality for flight.
  – Electronics testing facilities set up; parts qualification for poly-switches and HV caps in progress.
  – Engineering Model tooling and production facilities setup
TKR Mechanical Prototype

Mechanical prototype program conducted to reduce risk in the engineering model development.

Evaluated manufacturing, tooling, finite element model, environmental testing.

Systematic progression:
- early test articles (tray concept)
- beam test/balloon flight tower
- mechanical prototype
- engineering model
- qual towers
- flight towers
TKR Mechanical Prototype Testing Results

- Thermal and vibration testing of prototype trays successful (LAT-TD-00793).
- Two tower-level vibration tests were performed. Improvements in TKR tower mount design required (primarily affects bottom tray):
  - Formal review team commissioned by LAT project management
  - Key elements in plan:
    - detailed FEM analysis and margins assessment;
    - redesign and analysis;
    - assemble and load-test new bottom tray (9/25);
    - start EM assembly; EM test complete (11/6).
  - Underlying problems identified and corrective actions defined. No modifications to the baseline critical path for the EM and flight production are necessary at this time, preserving schedule float.

Details in Tracker subsystem breakout session
Calorimeter Technical Status

- January review: CAL technically ready.
- Environmental testing (vibe and thermal) of CAL module prototypes successfully completed (LAT-TD-00850).
- Crystal Detector Element (CDE) development program initiated at NRL
  - support French program in developing manufacturing process
  - provide alternate source of CDE for the Engineering Model
- Modifications to CsI crystal, PIN diode and mechanical structure dimension specs.
- Qualification testing of PIN diodes
- PIN diode-crystal bonding procedure developed and tested (LAT-PS-00385).
- Prototype ASICS, front-end boards fabricated, tested, used for interface testing.
ACD Technical Status

- January review: ACD technically ready.
- Technical action items from the January review:
  - Finalize tile and fiber layout, build mock-up
  - Test light yield of full optical system
  - Demonstrate electronic noise is low
    - Use first engineering board - Sept. 2002
  - Thermal cycle tile assemblies
  - Plan for calibration of ACD system
    - Basic approach verified, draft complete
  - Improve ASIC schedule margin

- ACD Electronics Module: EM1 version designed, built, and tested; EM2 version (interfaces, functions, and components as flight-version) in design.
Electronics/Flight Software Technical Status

- January review: technically ready.
- Tower Electronics Module (TEM)
  - Built and tested EM1 version
  - EM2 version [all functions, components, interfaces as flight model] under development.
- Flight-Processors (selection by April 2004)
  - Received cPCI BAe750 processor board, being evaluated
  - NRL cPCI 603e-based processor board in preliminary design phase
- Power supplies
  - Prototype of most challenging converter (1.5V for TKR) built and tested. Evaluated with TKR electronics to verify no observable impact on noise.
- Designed TEM enclosure and mounting system
- Interface functionality tests (hardware and flight software)
  - TEM/AEM used to control and readout subsystem front-end electronics.
Electronics/Flight Software Technical Status (II)

- Event format from front-end electronics decided.
  - demonstrated readout on the bench using prototype hardware from subsystems.
  - new format improves event size, event access time
  - software written to transform Monte Carlo event data to this format. Used to study filtering process.

- Event filtering code approaching production quality
  - processing time optimized (currently <15 µs/event)
  - rejection rate currently 98%
  - completion, documentation, and review of filters prior to October collaboration meeting.

- Finer estimate of CPU requirements
  - benchmark BAE 750 board, matches earlier estimates
  - major pieces of filter algorithm coded
  - generous amount of CPU cycles left for processing final 2% of background.
I&T Technical Status

• January review: I&T technically ready
• Planning for Engineering Model I&T testbed
• Technical Plan Documents:
  – LAT Performance Verification Plan (LAT- MD-00408) in final review
  – Science Verification and Calibration Plan (LAT-MD-00446) complete and reviewed.
  – I&T Contamination Control Implementation Plan draft complete [contained in the LAT Contamination Control Plan (LAT-MD-00404)].
  – Particle Test Plan (LAT-TD-00440) draft complete.
  – Airplane Cosmic Ray End-to-End Test Plan (LAT-TD-00550) draft complete.
• Test support equipment (EM1 EGSE Release 1) has been delivered to subsystems.
Science Analysis Software Technical Status

- January review: SAS judged to be technically ready.
- New version of the simulation packages: GLEAM
  - beta release in June; first user release in October
  - Geant4 for particle transport
  - revised reconstruction with many improvements underway
- Support for calibrations planning
  - infrastructure under development
  - database implementation underway. TKR hot/dead strip lists being used as first client
- Science tools support
  - joint sit-down working meeting with GLAST Mission Science Support Center (SSC) in June; LAT-SSC working group telecons regularly since February.
  - defining requirements for higher level analysis tools. Review in September, prior to collaboration meeting.
Analysis Group Formed

• Initial purposes and tasks:
  – grow the base of people using the simulation and reconstruction
  – as organized users, important interactions with SAS: quick feedback on functionality, documentation, usability, etc.
  – evaluate, improve, parameterize instrument performance
  – background rejection analysis improvements
  – calibration/verification tasks simulations
  – GLEAM higher-level checkout
  – onboard filtering studies support
  – instrument issues as they arise

• Participation from across LAT team. Meets regularly.
Work in Progress to Critical Design Review

• Subsystems building engineering models and designing production facilities and procedures.

• Flight-quality science analysis software packages under construction (particle fluxes, instrument simulation, reconstruction), to be ready prior to Critical Design Review.
  – validation of calibration tasks and verification testing
  – science tools planning
  – updated instrument performance calculations

• Test and verification plans being completed and reviewed.

• ICDs being finalized.
Summary

- Action items from the January review have been addressed.
- When new technical issues arise (e.g., recent TKR mechanical prototype tests), formal and open processes are immediately put into place to evaluate and resolve the issues efficiently.

- **Overall technical status of LAT:**
  - ready for this delta review
  - moving forward toward Critical Design Review and LAT fabrication.