Construction and Performance of the Si Tracker for the GLAST Beam Test Engineering Module

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GLAST Gamma-Ray Large Area Space Telescope

An Astro-Particle Physics Partnership Exploring the High-Energy Universe

Design Optimized for Key Science Objectives

- Understand particle acceleration in AGN, Pulsars, & SNRs
- Resolve the $\gamma$-ray sky: unidentified sources & diffuse emission
- Determine the high-energy behavior of GRBs & Transients

Proven technologies and 7 years of design, development and demonstration efforts

- Precision Si-strip Tracker (TKR)
- Hodoscopic CsI Calorimeter (CAL)
- Segmented Anticoincidence Detector (ACD)
- Advantages of modular design
- NASA, DoE, DoD, INFN/ASI, Japan, CEA, IN2P3, Sweden

Challenges of Science in Space

- Launch
- Limited Resources
- Space Environment

Resolving the $\gamma$-ray sky
Gamma-rays convert into $e^+e^-$ pairs, are tracked and their energy measured. Gamma is reconstructed from $e^+e^-$ tracks.

- Charged particle tracking detectors
- Calorimeter (energy measurement)
- Conversion foils
- Anticoincidence shield

Converter Thickness $t$
Conversion Probability $\sim t$
Pointing RMS $\sim \sqrt{t}$

Maximize Number of Converters
Overview of TKR Baseline Design

- 16 towers, each with 37 cm × 37 cm of Si (78m² in all)
- 18 x,y planes per tower
  - 19 “tray” structures
    - 12 with 2.5% Pb on bottom
    - 4 with 25% Pb on bottom
    - 2 with no converter
  - Every other tray rotated by 90°, so each Pb foil is followed immediately by an x,y plane
    - 2mm gap between x and y

- Trays stack and align at their corners
- The bottom tray has a flange to mount on the grid
- Carbon-fiber walls provide stiffness and the thermal pathway to the grid

- Electronics on the sides of trays
  - Minimize gap between towers
  - 9 readout modules on each of 4 sides

One Tracker Tower Module

Carbon thermal panel

Electronics flex cables
The BTEM Tracker, (~1/16 of the flight instrument) for the SLAC test beam (11/99 – 1/00)
- 2.7m² silicon, ~500 detectors, 42k channels
- all detectors are in 32 cm long ladders.

Si Detectors used:
HPK  296 (4”), 251 (6”)
Micron  5 (6”)
Leakage I: 300 nA/detector (HPK)
Bad strips: about 1 in 5000
Silicon-Strip Detectors (SSD)

GLAST SSD:
Simple, reliable, cheap

- 400 μm thick, single sided
- 8.95 cm × 8.95 cm (6” wafers)
- Strip pitch: 228 μm
- AC coupled with polysilicon bias (~50MΩ)
- Prototypes from HPK, Micron, STM

GLAST Needs:
- ~10k detectors from 6” wafers
- ~ 1M readout channels
- > 5M bonds

Schematic layout of the detector.
- Square detectors
- Bypass strips will not be used.
- DC pads will increase in size.
- A second AC pad will be added on each strip, for probing and for a second chance at wire bonding.
Assembly of BTEM Tracker at SCIPP

2 trays and 2 observers

4 trays, 10 eyes & 10 hands

All done and all smiles.

17 trays!
Assembly Challenge: QA, Yield, Alignment

Bad Channels Fraction: 0.06%

<table>
<thead>
<tr>
<th>Number of defective strips</th>
<th>Al open</th>
<th>Al short</th>
<th>Coupling short</th>
<th>Total</th>
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</thead>
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<tr>
<td>Al open</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Al short</td>
<td>11</td>
<td>8</td>
<td></td>
<td>19</td>
</tr>
<tr>
<td>Coupling short</td>
<td>2</td>
<td>13</td>
<td>19</td>
<td>25</td>
</tr>
</tbody>
</table>

Leakage current on 32cm long ladders after assembly

Start with good SSD’s QC during Assembly
End up with good ladders

Simple Mechanical Alignment: RMS: 8um

Assembly Yield: 98%

<table>
<thead>
<tr>
<th>Description</th>
<th>4 inch</th>
<th>6 inch</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good quality detectors</td>
<td>289</td>
<td>251</td>
<td>540</td>
</tr>
<tr>
<td>Runaway or unstable leakage current</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Unstable current after ladder assembly</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Losses due to accident</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>296</td>
<td>254</td>
<td>550</td>
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</table>
IEEE2000 : GLAST

Installation of the BTEM at SLAC

Beam Test in SLAC’s Endstation A (Dec 1999/Jan 2000)

- Test Fabrication Methods
- Verify Performance
  - Resolutions
  - Trigger
  - MC Programs

CsI Calorimeter

Silicon Tracker

ACD
Beam Test at SLAC 1999/2000: $e^+$ and $\gamma$ in BTEM

High efficiency (99.9%), low noise occupancy ($\approx 10^{-5}$)

Conversion Point
Challenge: Tracker Noise and Efficiency

- Noise occupancy determines the noise rate of the LVL1 trigger, a coincidence of 6 OR’d layers.
- Noise RMS $\sigma = 130 + 21 \times C/pF \ [e^-]$ , $\tau = 1.3 \mu s$
- Hit efficiency was measured using single electron tracks and cosmic muons.
- The requirements were met: 99% efficiency with $<<10^{-4}$ noise occupancy.

**Hit efficiency versus threshold for 5 GeV positrons.**

Noise occupancy and hit efficiency for Layer 6x, using in both cases a threshold of 170 mV. No channels were masked.
Determine Conversion Point

Time-over-Threshold ToT is a Measure of the Pulse Height

ToT of Tracks away from the Conversion Point:
Single MIP’s Follow a Landau curve

ToT at the Conversion Layer:
2 tracks in one strip:
2MIP Signal
Follow Tracks after Conversion

After Gamma Conversion, Electron-Positron Pair develop Showers

Distribution of # of hits along the track of a 5GeV positron agrees well with prediction at the Start of the track and End of the track.
Effective Area:
Vertex Distribution reflects the Converter Distribution shows expected Attenuation of the $\gamma$ Beam

Back Section:
3 layers of thick Efficient Conversion before calorimeter

Front Section:
10 layers of thin converters: Precision Tracking

~ 6% R.L

~ 25% R.L
After successful Beam Test and Verification of Prediction:
Finalize the design
Build Engineering Model
Start Construction