The Silicon Strip Tracker for the Gamma-ray Large Area Space Telescope

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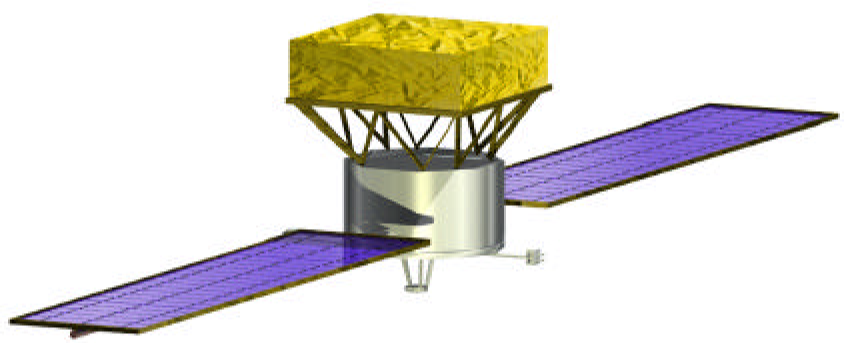
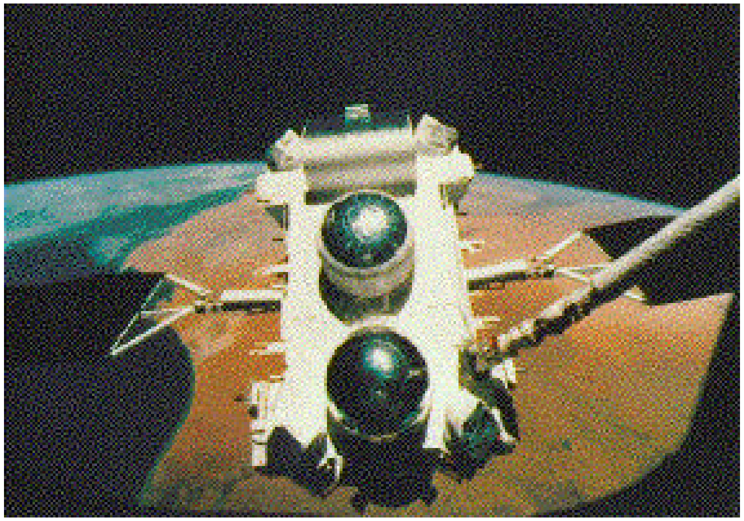


GLAST Silicon Tracker

Gamma-ray Astrophysics

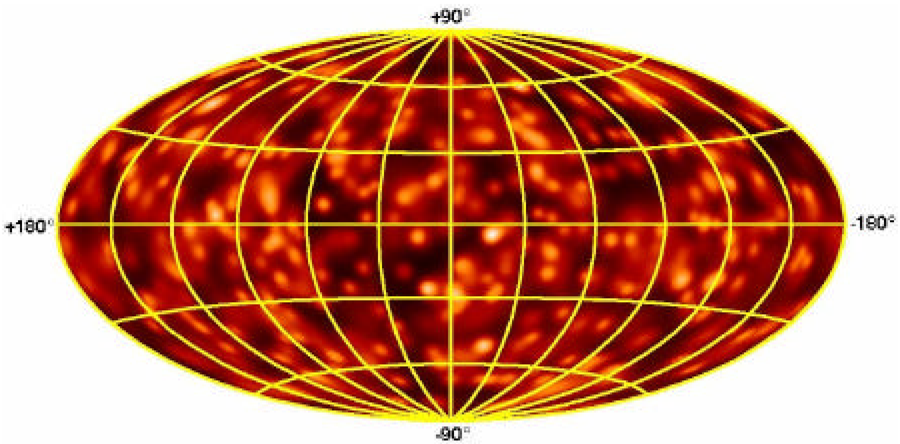
- **Gamma-Rays = Energy range 20 MeV-300GeV**
  - Studying the Nature largest accelerators.
  - Point directly back to the source.
- **There are incredible Objects in the Sky in this regime!**
  - They only can be studied with satellites.
  - Large discoveries by EGRET (90's):
    - γ's from Active Galactic Nuclei (Blazars)
    - γ's from pulsars
    - High energy γ's Gamma-Ray Bursts.
    - Unidentified sources.

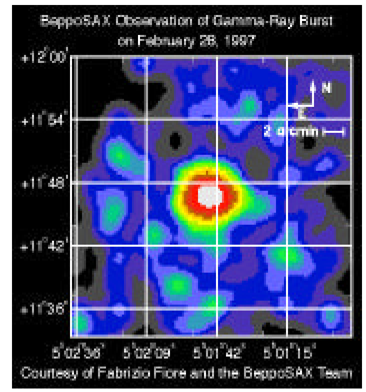


View of the NASA's Compton Gamma Ray Observatory.

- **GLAST is the new generation of gamma-ray satellite telescope:**
  - Improves the position resolution by a factor 10-100 (Silicon Detectors)
  - Enters in a UNEXPLORED region in Energy!
    - How many sources are waiting for discovery?
    - What are they?, Where are they?, How do they emit gamma-rays?

A glimpse of the Physics: Gamma-Ray Bursts





1.- BATSE results 1991: they are isotropic distributed

Cosmological Origin

2.- BeppoSAX june 1997: associate X-ray

GRB 970228 optical counterpart:galaxy.

<u>+2000 Gamma-ray bursts observed :</u> flashes of gamma-rays!

Release an enormous amount of energy (GRB 971214 $5\times10^{18}\ L_o$)

Varying times scales : 0.01-1000 s

Each one has an unique fingerprint!

What is the mechanism that produces this flashes of gamma-rays?

GLAST Silicon Tracker

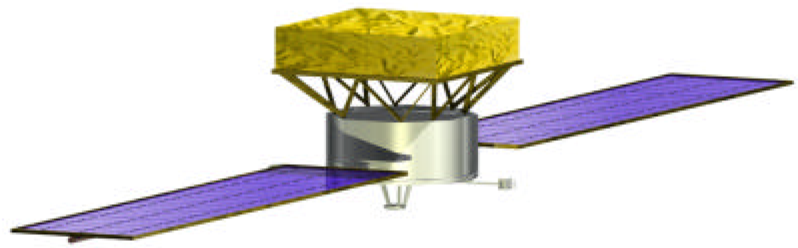
Gamma-ray Large Area Space Telescope

GLAST: detector technique

- E>10 MeV Pair conversion dominates!

$? \rightarrow e+ \ e$

- Measure the gamma direction and energy.



GLAST Physics Requirements:

- Large Effective Area 8000 cm^2
- Large Field of View 2.5 steradians
- Good timing resolution ~1 µs
- Good position resolution 3-0.05 deg
- Good comics-ray rejection $1{:}10^{-5}$
- Source sensibility (1yr) 4×10^{-9} ph/cm^2s

GLAST constraints: Space conditions:

Mass 3000 kg (500 kg Tracker)

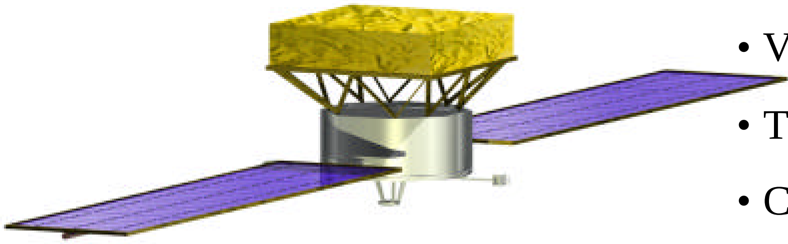
Power 650 W (250 W Tracker)

Reliability & DAQ Redundancy

Mechanical Stability and strength (for launch)

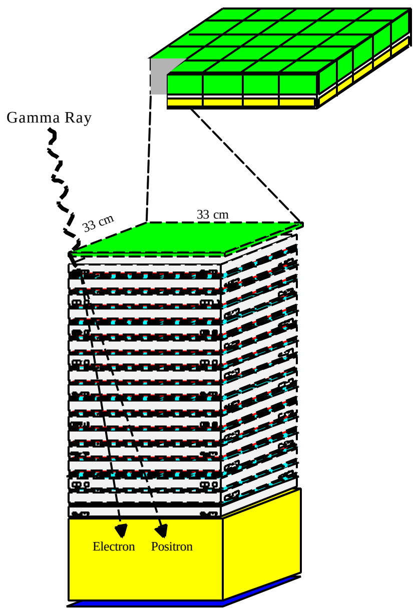
GLAST Silicon Tracker

GLAST Instrument



GLAST sub-detectors:

- Veto shield (against cosmic rays)
- Tracker (also it's the target)
- Calorimeter (additional target)
- DAQ & CPU boards

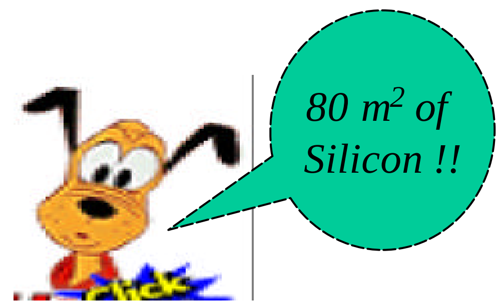


GLAST instrument: 5x5 Towers

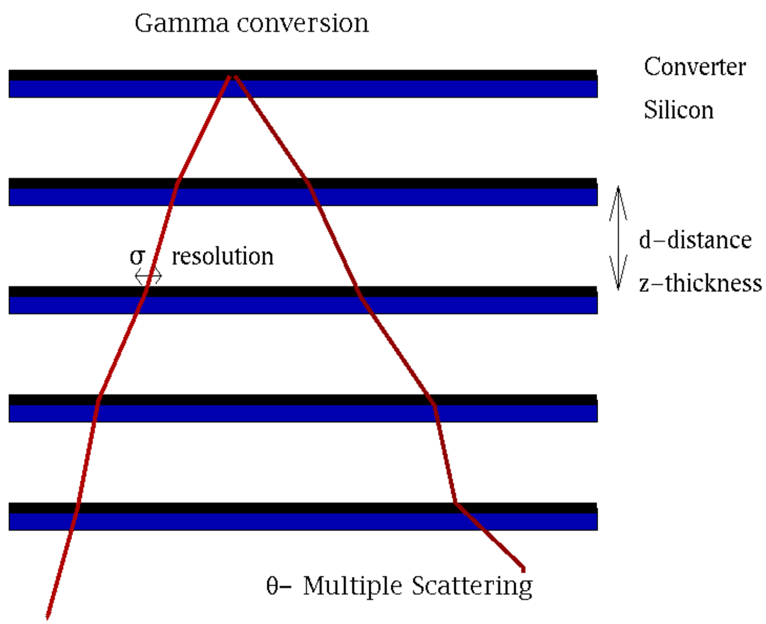
GLAST Tower:

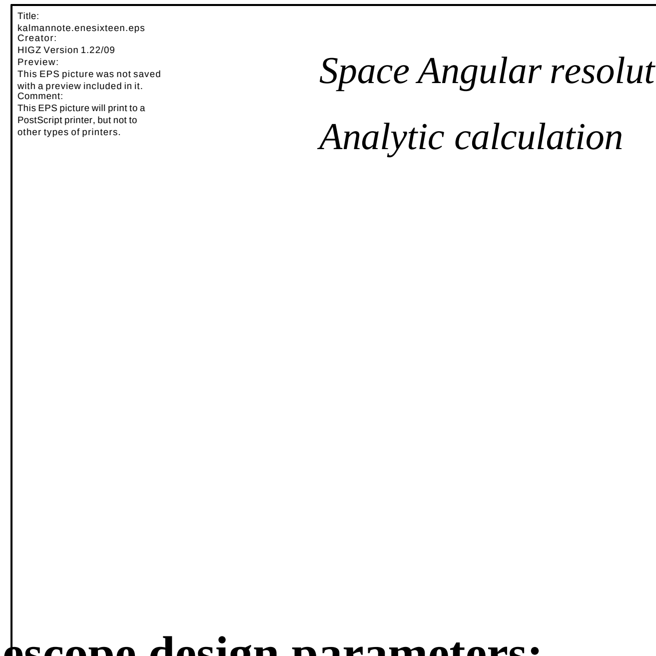
- Silicon Tracker: 16 XY planes

  Each tray:
  - Size 32×32 cm^2
  - 3.5% X_0 Pb (converter)
  - XY Single Sided Silicon Planes
- 10 X_0 CsI calorimeter
- DAQ board



GLAST tower: physics capabilities





Space Angular resolution

Analytic calculation

Telescope resolution parameters:

Number of planes	N
Multiple Scattering error	$J_0 \cong \frac{0.015 GeV}{p} \sqrt{z / X_0}$
Module angle resolution	$J_n = s \ / d$

Telescope design parameters:

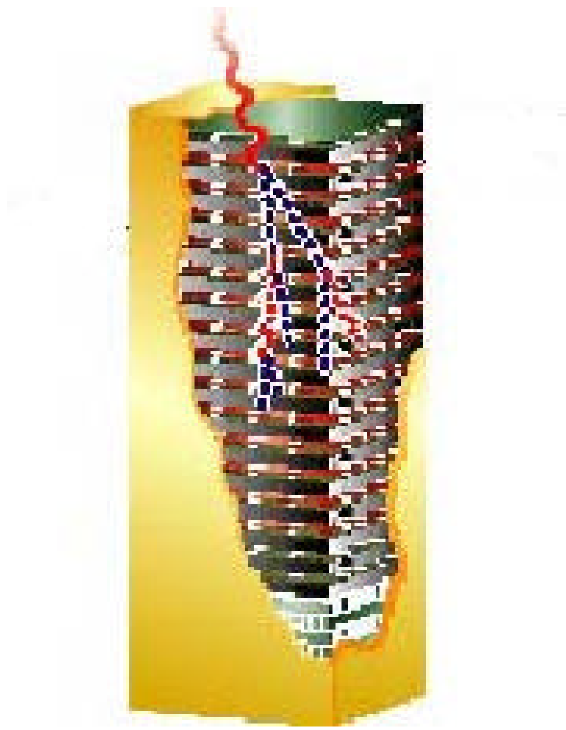
Optimized using full MC simulation GLASTSim

Number of γ's (Eff. Area) and Resolution

d = 3.2 cm, σ=60 μm ⇒ θ_n = 2.7 mrad

E ~ 1 GeV, $\theta_n \sim \theta_0$ ⇒ z = 3.5 X_0

GLAST Tower: technology requirements



Tracker Requirements, Why Silicon?

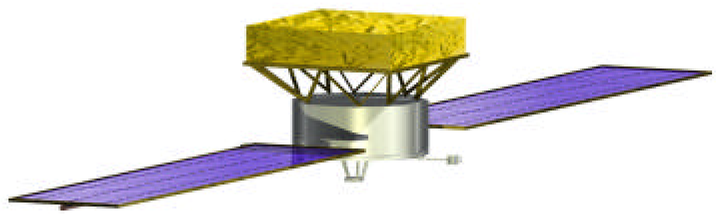
Mature and reliable technology	
No consumables (gas)	
Self triggering	
Relatively low voltage	100 Vols
Good resolution - two track separation	50-100 μm

Electronic Requirements:

Low power	200 μW/channel
Readout channels	1.3 Million
Occupancy	5×10^{-5}
Peaking time	1 μs
Capacitance Load	38 pF
Trigger Rate (1%dead)	10 kHz

GLAST collaboration

Ames Research Center,
Boston University,
Columbia University,
Ecole Polytechnique- France,
Goddard Space Flight Center,
Instituto Nazionale di Fisica Nucleare Trieste-Italy,
International Center for Theoretical Physics Trieste-Italy,
Kanagawa University-Japan,
Lockheed-Martin Research Laboratory,
Max Planck Institut für Extraterrestrische Physik- Germany,
Naval Research Laboratory,
SACLAY-France,
Sonoma State University,
Stanford University: HEPL & SLAC,
University of California Santa Cruz,
University of Chicago,
University of Rome- Italy,
University of Tokyo-Japan,
University of Washington



A DoE and NASA Collaboration !!

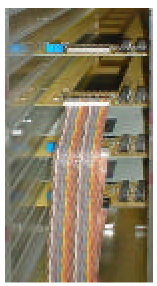
10 Astronomy + 10 HEP institutions

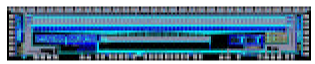
~90 collaborators

GLAST Status Report

GLAST Schedule:

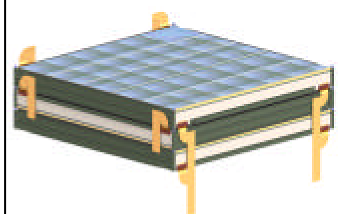
Sep 97- SLAC Test beam





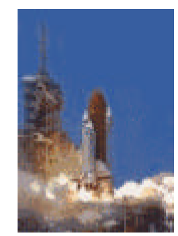
Jun 98: chips completed GTFE64, GTRC

Dec 98: First Tray



Oct 99 First Tower SLAC test-beam

2004 Launch



Current Status:

- 97 Test-Beam data, Occupancy and resolution studies, NIM paper in preparation.
- Testing and debugging the Front-End and Controller chips.
- Assembly of the first tray in progress.

The University of California, Santa Cruz on GLAST

Hardware: (Silicon + Electronics)

UCSC leading the Silicon Tracker Developpment:

- Silicon detector testing (UCSC/Japan).
- *Electronic design and Testing*:
  - Chips: GTFE64 (32,16) Front End- GTRC Controller.
  - Hybrids and cables.
- Mechanical design and assembly (SLAC, HITECH Inc.).
- Tray assembly, bonding and testing (SLAC).

Software: C++

- GLASTSim (GSFC, U. Washington).
- Tracking Reconstruction.
- MC analysis (i.e. background reduction).

SCIPP, UCSC

GLAST Silicon Tracker

GLAST Tray: components and mechanical issues

Tower: 17 trays

Each one rotated 180^0

Tensioned cables in the corners

Carbon-fiber walls to dissipate heat

Each Tray:

Light, thin closeout frame (Al)

Two Silicon Plane detectors XY

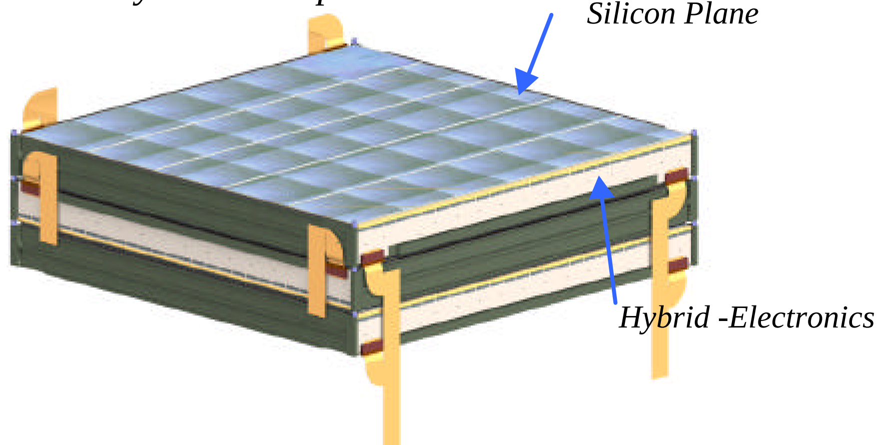
A 3.5% X_0 Pb converter

Electronics on the sides.

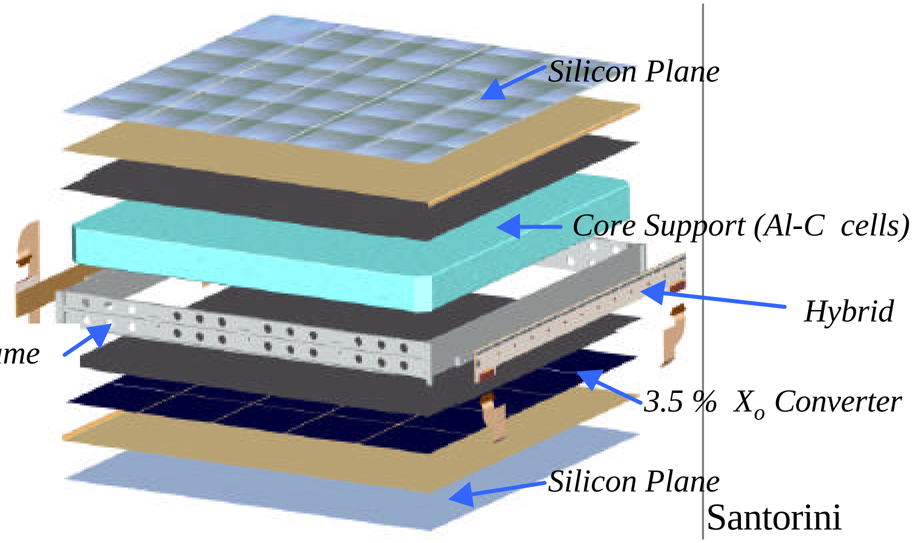
Each Silicon Plane

Plane dimensions	32 ×32 cm^2
Number of channels	1600
Number of Front End chips	25
Number of Detectors	5 ×5
Readout Pitch	195 µm

Three trays stacked up



Elements of the tray:



GLAST Silicon Tracker

Detectors: Single Sided Silicon Strip sensors

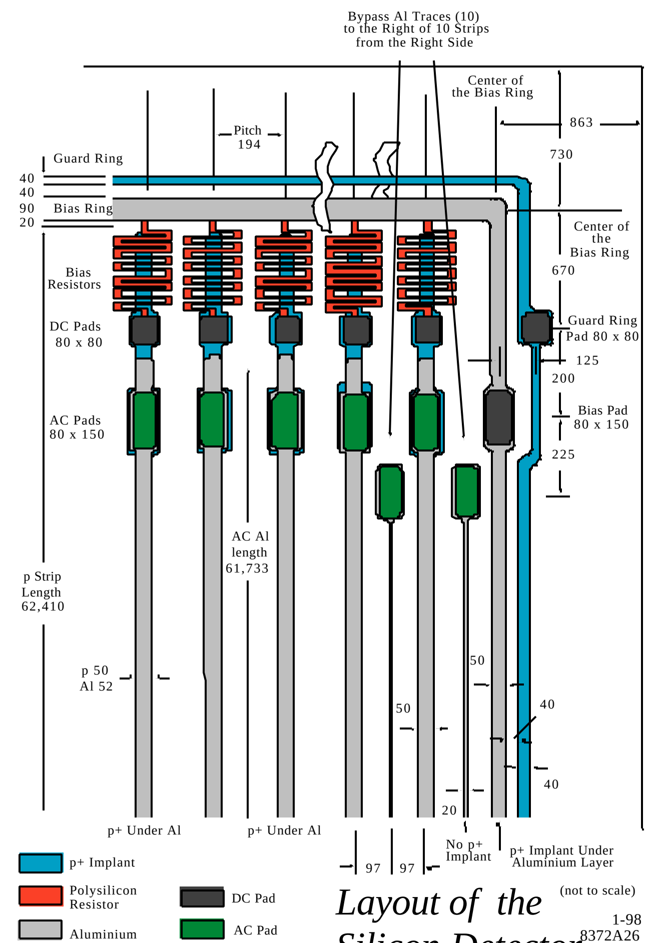
Single Sided Silicon Detectors

Hamamatsu Photonics 300 ordered/250 delivered

N-bulk , P-strip

AC coupled

Size	$6.4 \times 6.4\ cm^2$
Detector thickness	385 µm
Strip pitch	195 µm
Polysilicon Resister	64 MO
Depletion voltages	90 V
Leakage current	0.5 nA/strip
Fraction bad channels	2×10^{-4}

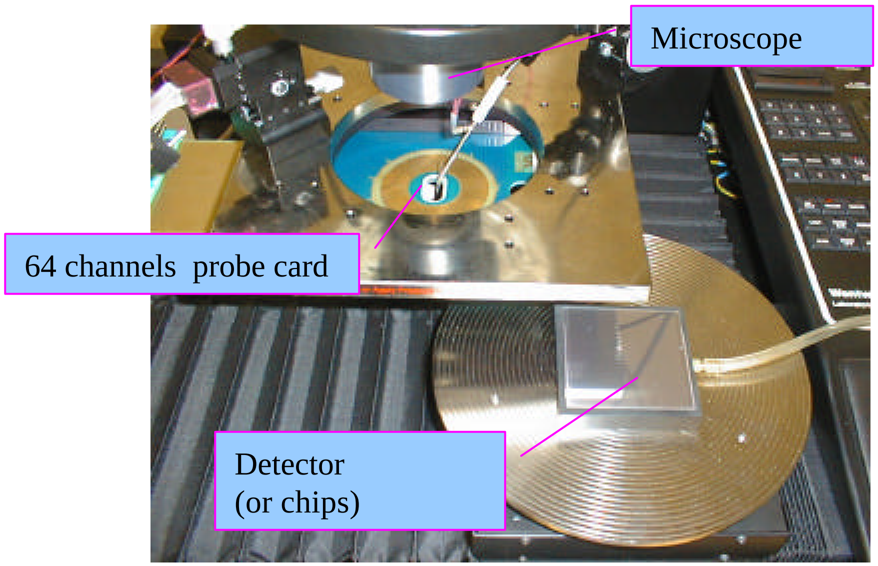


Layout of the Silicon Detector

Interested on the 6 inches wafers detectors 8 ´ 10.7 cm²

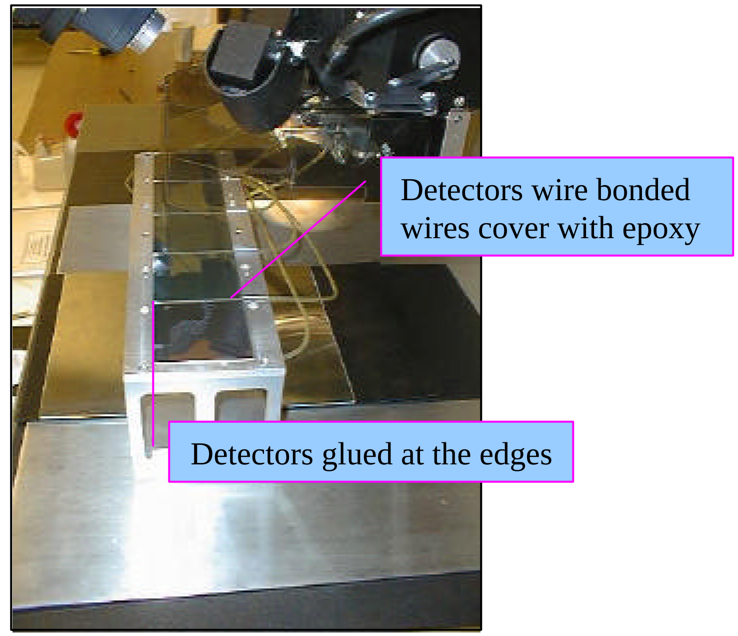
Equipment

Automatic Probe Station



Equipment: NRI grant from NSF

Automatic bonder



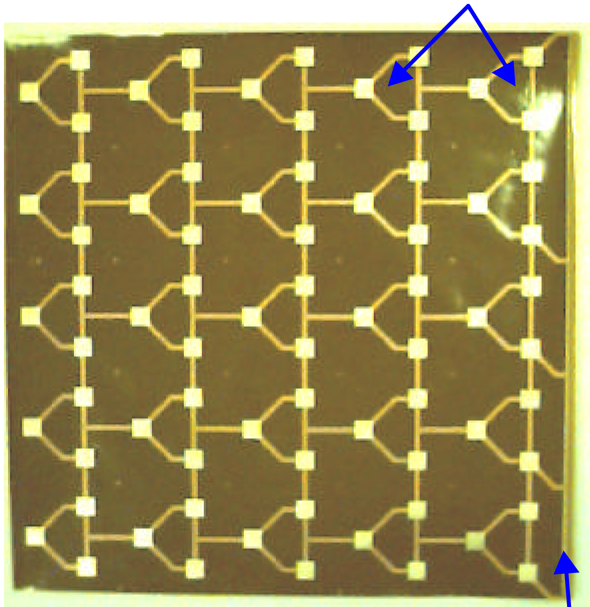
Ladder of 5 detectors

GLAST Silicon Tracker

Hybrids, connectors and other pieces

- **Kapton detector-interconnect flex circuit (32 cm)**

Bias for the detector 5x5 grid



1mm radius, 90^0 rotation

around the closeout edge.

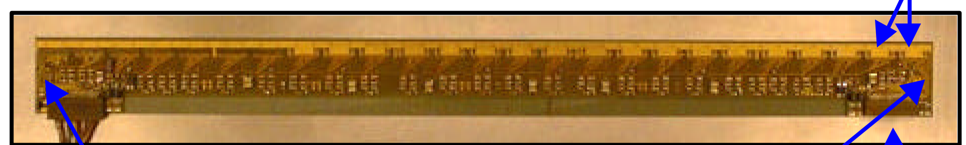
1600 gold traces: wire bonding

Detector-Trace

Trace - Electronic

- **Hybrid Printed Circuit Board (32 cm)**

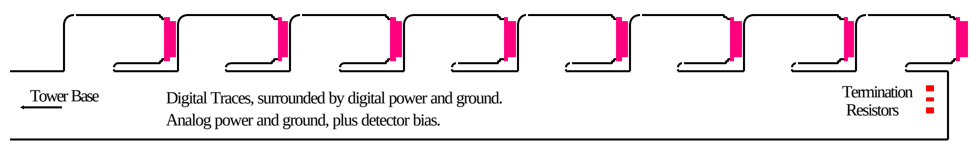
25 GTFE64 Front-End Chips, 64 channels/chip



2 GTRC Controller chips (redundancy)

2 Redundant Connectors

- **Kapton flex-circuit cables**



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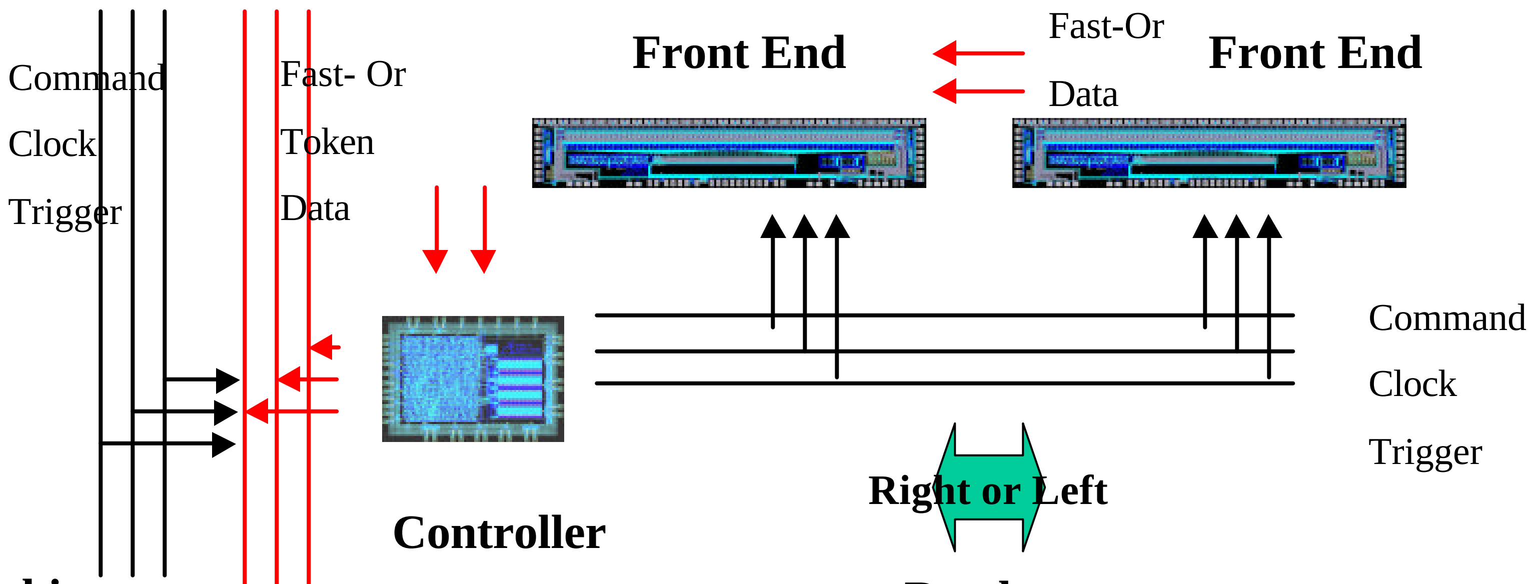
Readout architecture



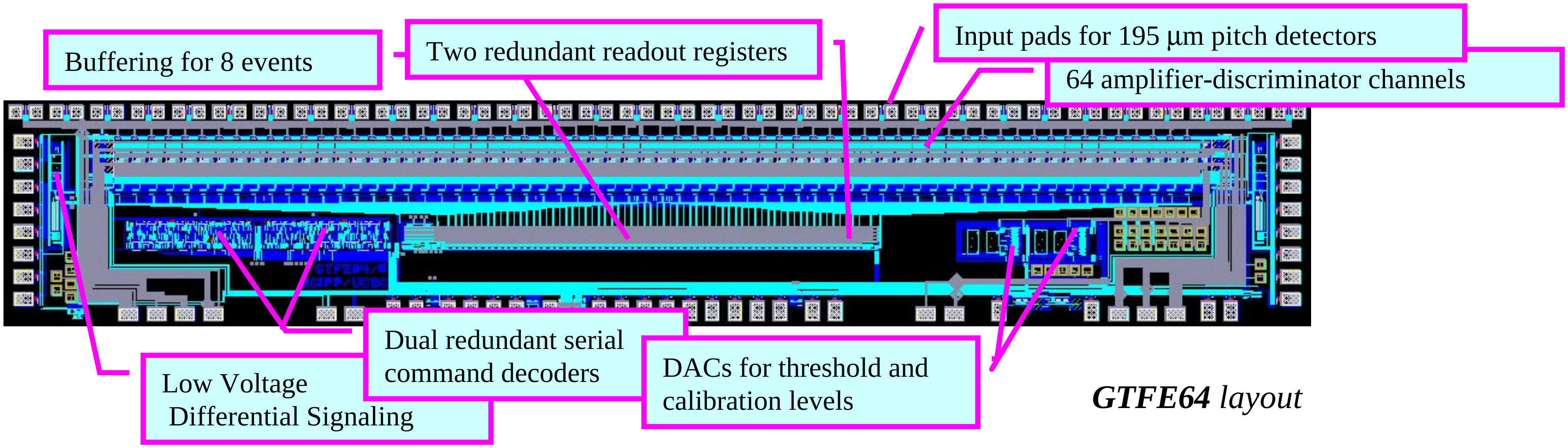
Architecture:

- 25 Front End chips GTFE64, 64 channels/chip.
- 2 controller chips *(redundancy Right/Left)*
- Low Voltage Differential Signals (0.2-0.4 V swing)
- Data shifted out at 20 MHz

Readout sequence

Fast-Or	Front End →Controller→Tower
Trigger	T → C → F
Read Event	T → C → F
Data	F → C
Token	C → T

GTFE64 GLAST Tracker Front End chip



***GTFE64** layout*

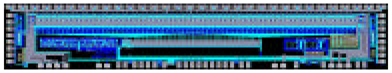
GTFE64 - Front End chip:

- 64 channels (Hewlett-Packard 0.8 µm CMOS process) chip.
- ASIC: Analog +Digital.
- Provides: Channel hit - Shaper-output signal crosses the threshold.

  Zero suppression - No data shifted out if there is not hit.

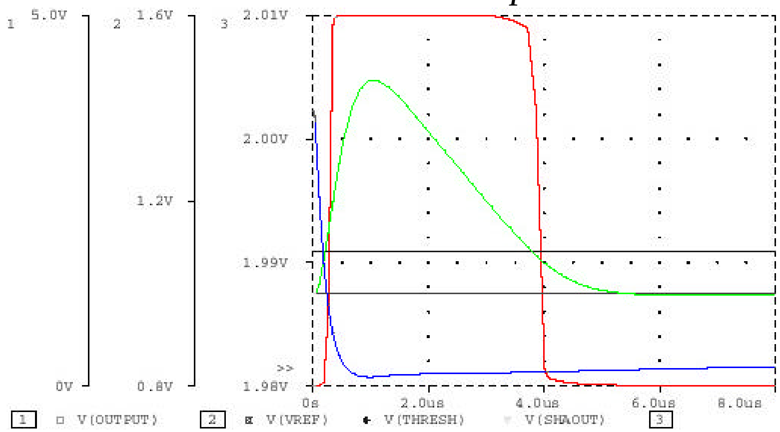
  Trigger (Fast-OR) - When any unmarked shaper-output signal crosses the threshold.
- Designed at UCSC.

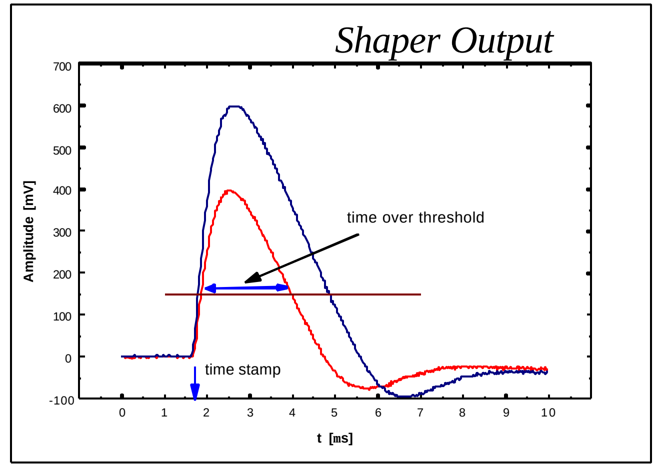
GLAST Silicon Tracker



GTFE64- Analog part

Spice simulation





Analog Part:

- Preamplifier - folded cascode - AC coupled to the Shaper

  The input transistor operates at 2 V to save power.

- Shaper Amplifier - cascode amplifier

  The decay shape is linear with the collected charge.

- Comparator - Slow diff. amplifier to stabilize output baseline

  The threshold is set by a DAC.

Noise Measurements:

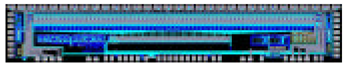
- ENC 280+28 ×Cp (Occupancy and external capacitor calibration)
- Cp=38 pF → 1350 ENC → 1/4 fC
- Gain 115 mV/fC

  Threshold ~ 150 mV → ~ 5/4 fC

  RMS Threshold 10 mV

- *mip* ~ 5.3 fC → ~ 5 σ

GLAST Silicon Tracker



GTFE64- Digital part

Digital Part:

- Decoding of serial commands (ie Read Event)
- Calibration:

  Calibration mask

  Internal Calibration DAC

  Calibration command

- Trigger:

  Fast Or = Or of all the comparators

  Trigger mask

  Threshold DAC

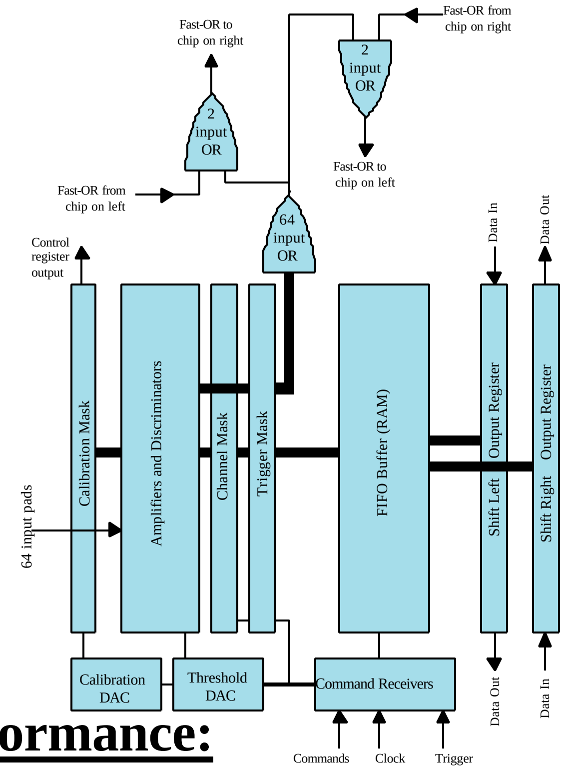
  Time Over Threshold a Input Charge

- Readout

  8 buffer FIFO's

  readout mask

- Flow direction for redundancy (Right/Left)



Performance:

- The digital part works perfectly .

- There is some *pick-up* feeding back to the preAmp when *the clock is switched on/off* or any command is sent to the decoder. => Isolate the digital ground from the substrate.

GTRC GLAST Tracker Readout Controller chip

GTRC controller chip:

- Talks with the Tower Board

  Receives commands, clocks, and token.

  Sends Trigger and Data.

  Data = chip ID + strip number

- Talks with the 25 chips in the tray:

  Sets the masks : Calibration, Trigger, Readout.

  Sets the Calibration DAC, and the threshold DAC

  Sets the direction Right/Left

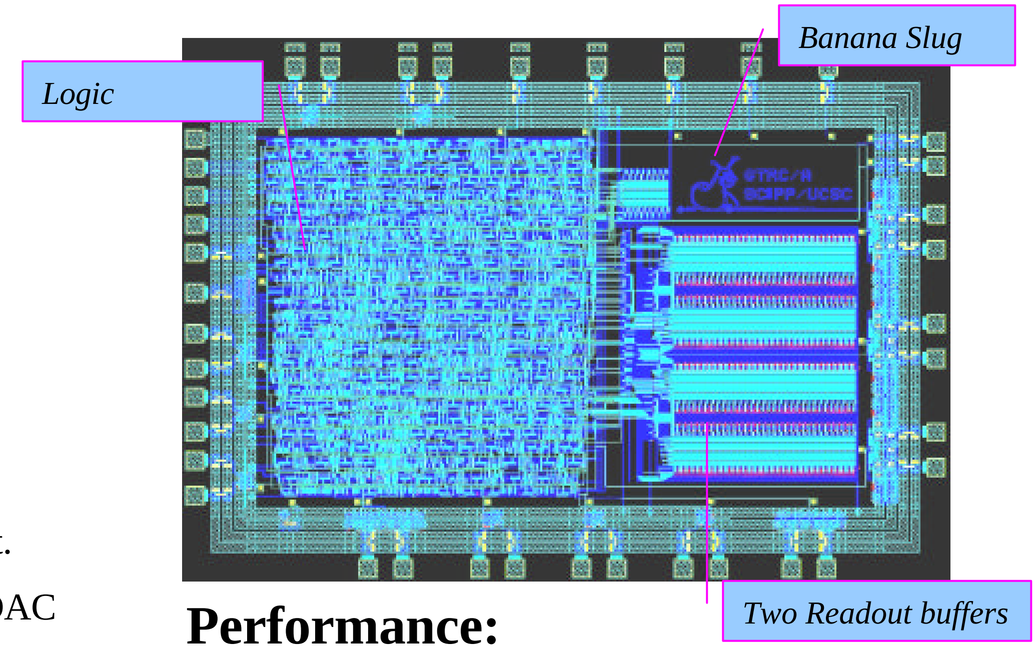
  Receives the Fast-Or

  Sends the Trigger.

  Sends commands (ie *Read Event*)

  Receives the Data.

  Store the data (2 readout buffer's)



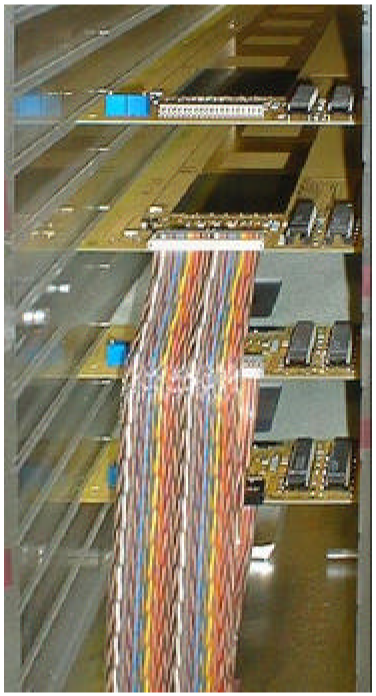
Performance:

- The chip works perfectly.
- Only one bug:

The UCSC mascot (a banana slug) connected to the power line to the substrate, making it a nice ~ 50Ω resistor; it was not a power low slug!

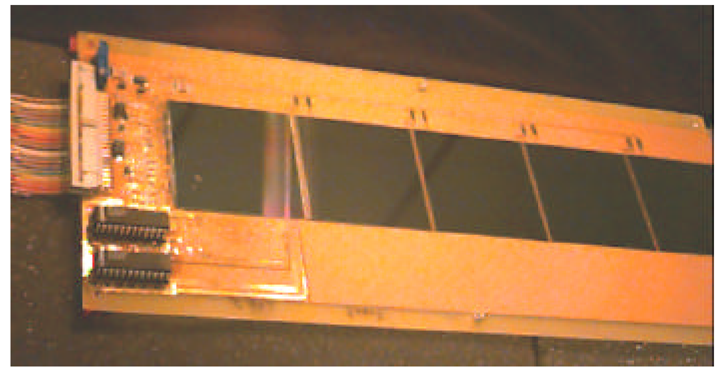
The Oct'97 SLAC Beam Test

Oct 97 SLAC Test Beam:



- Oct 98 at SLAC
- Electron and photon beams 50 MeV-30 GeV
- 12 planes of detectors
  (6*x* and 6*y*)
  + CsI calorimeter
  + anti-coincidence system.
- Only one 5 detector module.
- Different Pb thickness.

One 5 detector module:



- GTFE32 (previous Front-End version)
- Detectors: punch-though bias
  500 μm thickness.

GLAST Silicon Tracker

Oct’97 SLAC Test Beam results

Inefficiency:

Extrapolation of the track to the 5 detector module

Title:
eff.eps
Creator:
HIGZ Version 1.22/09
Preview:
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with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers.

Noise Occupancy:

At 1-1.5 fC threshold the occupancy is < 5×10^{-5}

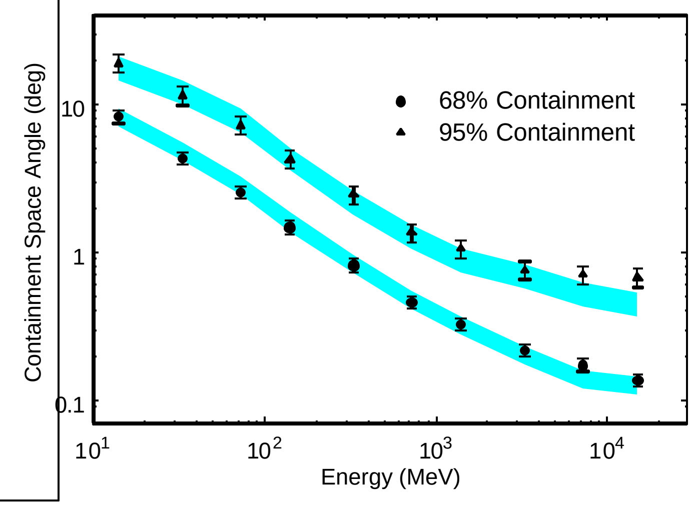
Satisfies the requirements!

Title:
occ_good_chan.eps
Creator:
HIGZ Version 1.22/09
Preview:
This EPS picture was not saved
with a preview included in it.
Comment:
This EPS picture will print to a
PostScript printer, but not to
other types of printers.

Space angle photon reconstruction:

Excellent agreement between Data and MC.

Validation of the MC simulation



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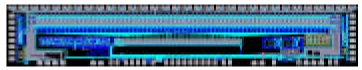
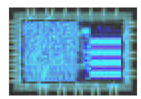
Power consumption results

GTFE64 chip:



	Analog 2 V	Analog 5 V	Digital 3 V	Total Power
Input transistor bias	1.4 mA			2.80 mW
Amplifiers and bias circuit		1.43 mA		7.15 mW
Quiescence state			0.423 mA	1.27 mW
Readout sequence at 12.5 KHz (100 clock cycles)			0.160 mA	0.48 mW

GTRC chip:



	Digital 3 V	Total Power
Quiescence	4.6 mA	13.80 mW
Readout 6 chips at 20 MHz clock	3.3 mA	9.90 mW

Power per channel:

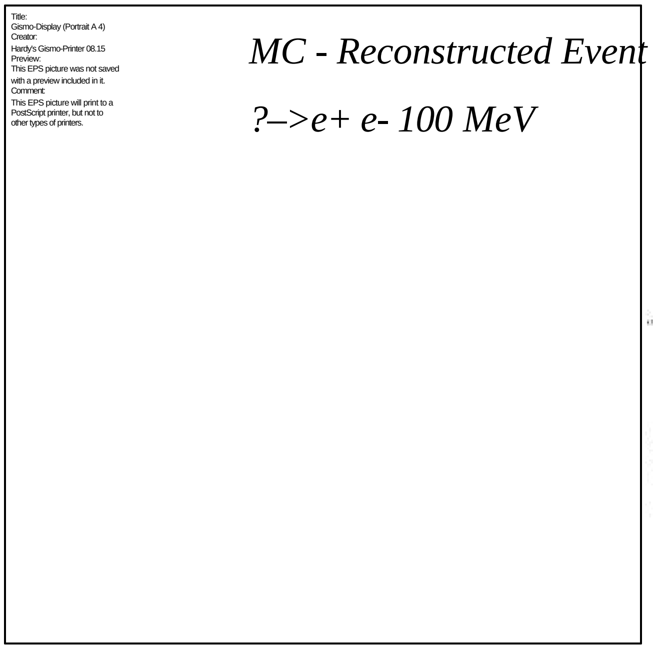
GTFE64	GTRC	Total Power/channel
193 μW	30 μW	213 μW

The initial goal was to have < 300 μW/channel

GLAST Silicon Tracker

GLAST simulation, Tracking Reconstruction

GLASTSim:



- C++ code
- Based in GIZMO (Atwood and Burnett)
- Mature code

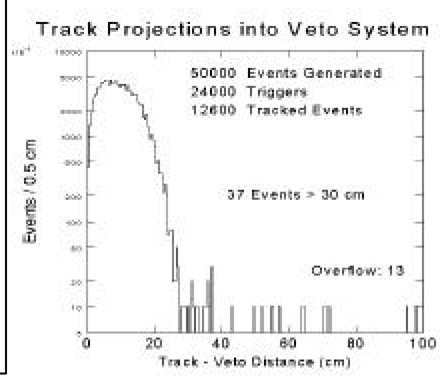
UCSC software involved:

- Detector design optimization:

  Present Baseline performance

  Studies with 40x40 cm2 towers (Silicon 6'' wafers)

- Analysis: Background Rejection ($1:10^{-5}$ needed!)



Cosmic rays	2×10^{6} generated
ACD (veto)	10^{-3} rejection
Calorimeter	18 S/N
Tracking shape	15 S/N

2 events survived!

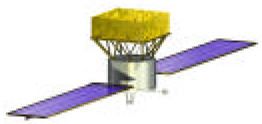
- Tracking Reconstruction:

  Kalman Filter implementation.

  Event basis pattern recognition.

Conclusions

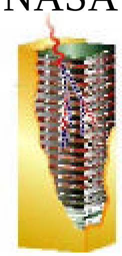
- **GLAST(2004) will provide abundant high quality data for research and**



discoveries in high energy astrophysics.

- **Much progress has been made on an integrated instrument design using robust, well understood technology from HEP.**

    - Design concept has been validated by MC simulation
    - Oct'97 SLAC test-beam validated the tracker electronics and the technologies as well as the MC.
    - NASA ATD funding began this year for construction of a full prototype tower.



        - All electronics prototypes in hand.
        - First completely functional tray in Dec'98
        - First Tower and Test beam at SLAC, Dec'99.
    - NASA is preparing for the mission.
        - Currently in the budget planning.