GLAST Calorimeter
ATD Program Review
20 March 2000

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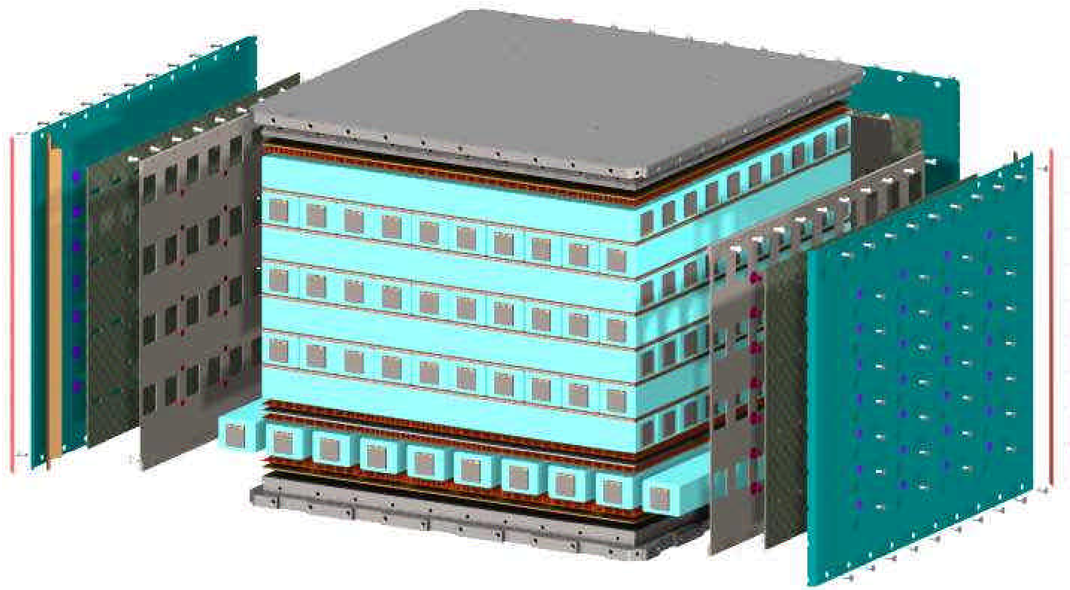
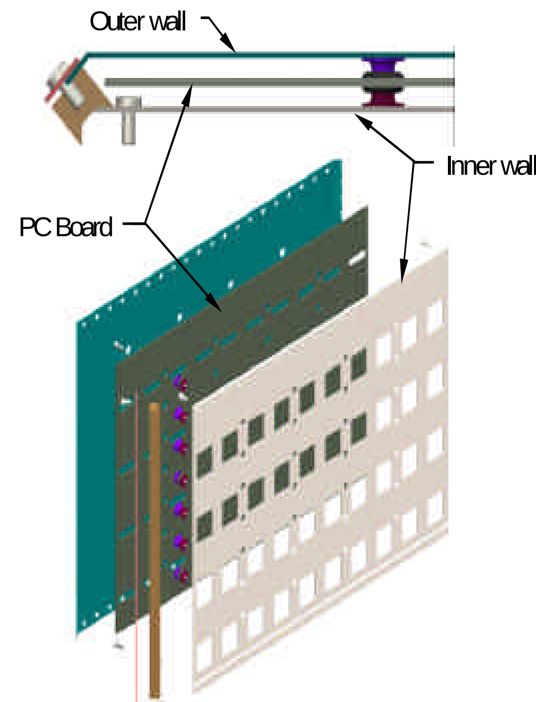
Naval Research Lab

Calorimeter Technology Program

- Program Elements
  - Science performance verification and optimization through simulations - examine several concepts and configurations.
  - CsI(Tl) and PIN photodiode detector module performance and packaging.
  - Low-power, analog and data acquisition electronics.
  - Mechanical design and packaging of the calorimeter.
- Program Goals
  - Identification of key performance drivers
  - Full scale prototype
  - Beam test performance demonstration
- Major Participants
  - NRL (mgmt, detectors, electronics, assembly, GSE and test)
  - GSFC (custom analog ASIC design and test, simulations)
  - Hytec, Inc. (mechanical design and fab)
  - France - IN2P3 (alternate concepts, simulations, beam tests)

Calorimeter Prototype Concept

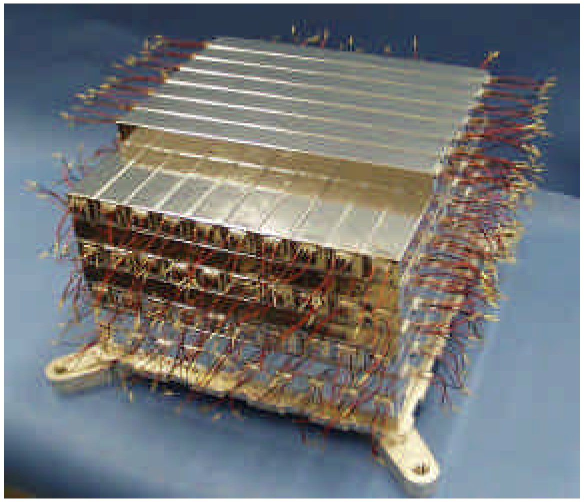


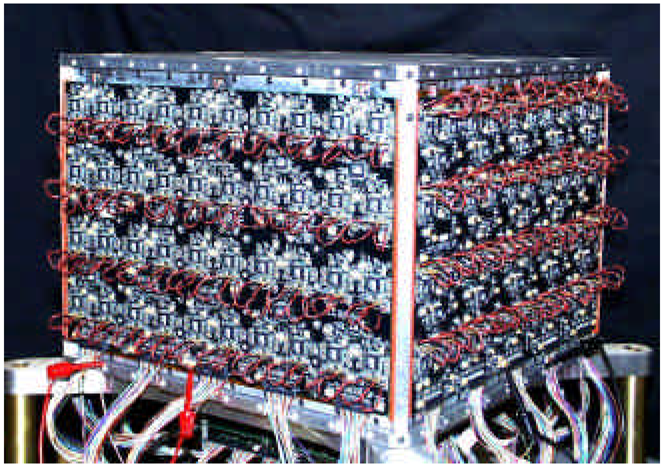


- 8 layers of 10 CsI Crystals
  - Crystal dimensions: 30 x 23 x 310 mm
  - Hodoscopic stacking - alternating orthogonal layers
- Dual PIN photodiode on each end of crystals.
- Mechanical packaging - compression cell.

- Dual side-walls form stiff side support
- Inner side-wall holds compression (1 mm Al)
- Outer wall is EMI shield as well.
- Electronics are supported between walls

Prototype Calorimeter Assembly





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Derived Calorimeter Requirements

Calorimeter Depth	10 (8.5) radiation lengths
Number of CsI Crystals	80 (96) (8 layers of 10 [12])
Crystal Dimensions	30 × 23 × 310 mm (28 × 20 × 352)
Number of Electronics Channels:	320 (384) / tower (each CsI xtal, both ends, 2 PIN each)
Dynamic Range:	5×10^5 (noise to max signal)
Noise goal:	1 MeV RMS (3×10^3 e^-)
A to D Range:	~2 MeV – 100 GeV
Trigger Rate: (GLAST)	Ave: 5500 Hz (2000 Hz w/ ADC veto) Peak: 9000 Hz (3400 Hz w/ ACD veto)
Self trigger delay:	< 1 μsec
Trigger Dead time:	20 μsec
Power:	5 (6) watts / tower (conditioned)
Mass	~ 98 kg/ tower
Nominal Operating Temperature	~ 0 – 10 deg C, in orbit ~0 – 30 deg C, in ground test
Storage Temperature Range (survival range)	~ –20 to +50 deg C

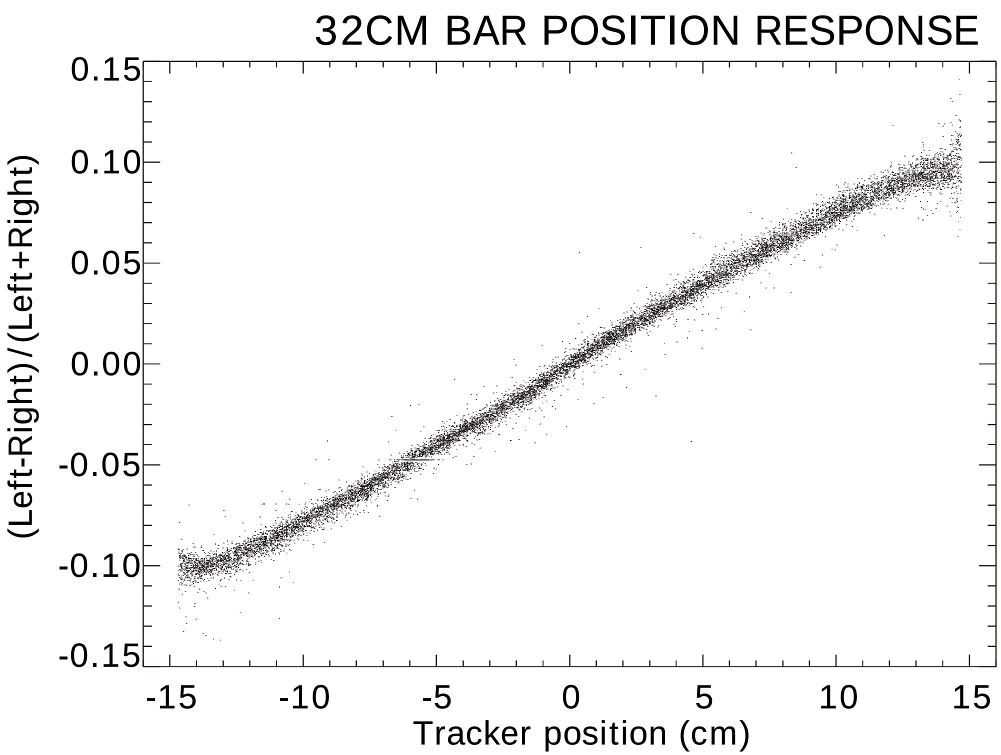
Numbers in parenthesis (red) are for flight design 38-cm towers.

Derived Calorimeter Requirements (Divide and Conquer)

- Achieve dynamic range with 4 PIN diodes per log and 2 gain ranges in preamp and subsequent processing (640 chans/tower)
  - Low Energy Range: 2 - 800 MeV
  - High Energy Range: 100 MeV - 100 GeV
- Custom front end ASIC
  - 1 preamp, 3 shaping amps, 2 peak/hold per PIN
  - mux'ed output to ADC
- Use COTS (commercial off the shelf) ADC
  - 12 bit, successive approximation
- The dual PIN photodiode for GLAST from Hamamatsu.
  - Based on 3590 PIN, 180 μm thick (active)
  - Package is 15.5 mm x 16.5 mm ceramic carrier
    - Large diode area - 96 mm^2, ~70 pf
    - Small diode area - 24 mm^2, <20 pf
  - Ceramic carrier has been selected for lowest noise and cross-talk

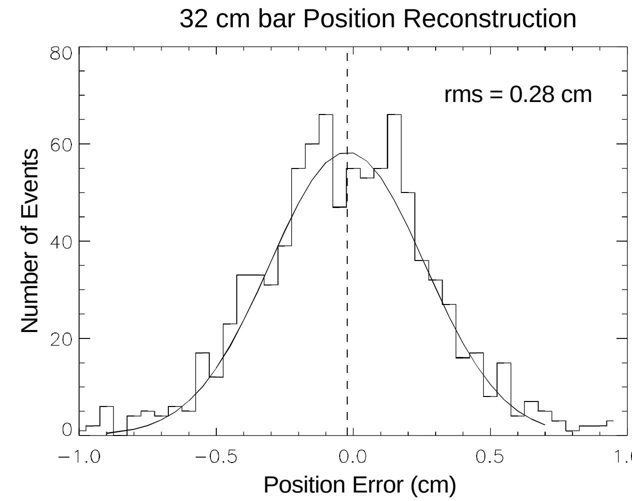
Custom Dual PIN
96 / 24 mm Areas

Positioning with Light Asymmetry



SLAC e⁻ beam, 2 GeV

ΔE ~ 130 MeV

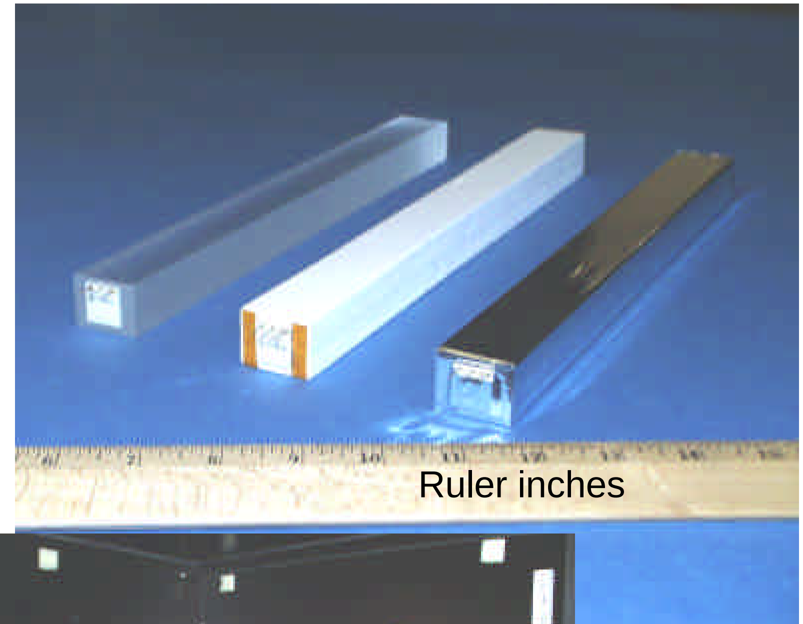


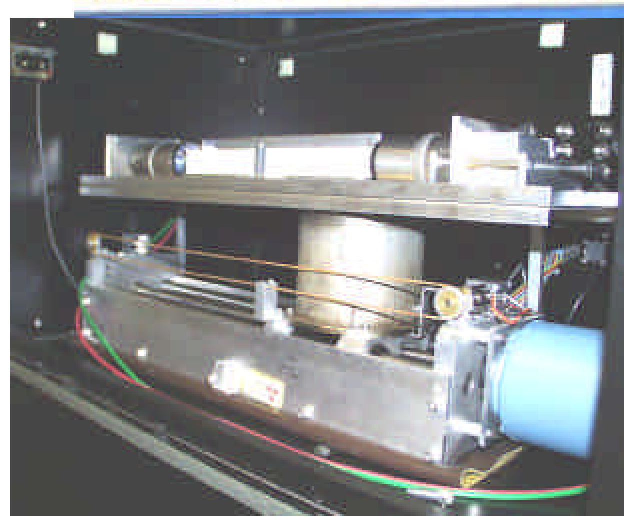
Imaging Calorimeter

- Support background rejection.
- Improve energy resolution by shower profile fitting.
- Imaging events without supporting tracker direction.

CsI Crystal Selection

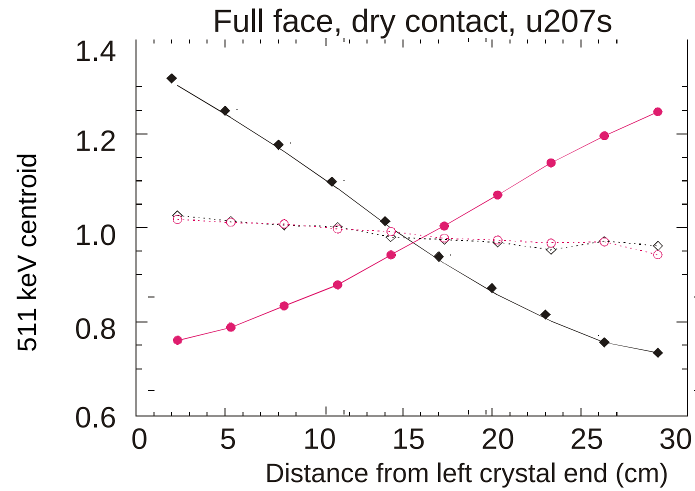
- Identify sources of CsI crystals and their ability to deliver material to specification.
  - Two vendors (Crismatec & ISC Kharkov) were used, both found acceptable.
  - 90 crystals purchased and tested.
- Map crystal response as a function of position.
  - ^{22}Na source scanned along length of crystal.
  - Red-sensitive PMTs at both ends.
  - Fully automated scanner acquires map in 40 minutes.
  - After required processing, the light yield of the ISC Kharkov crystals were indistinguishable from the Crismatec crystals.

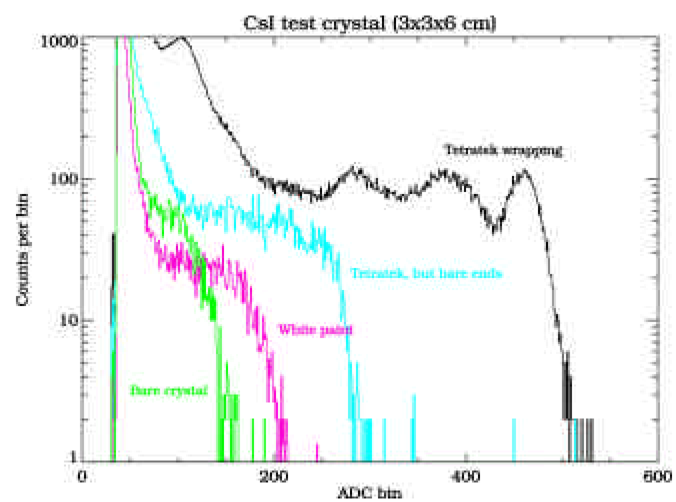




CsI Crystal Processing and Wrapping

- Identify controlling parameters for light attenuation or light tapering along length of crystal.
  - ISC Kharkov crystals were polished. NRL applied light tapering with sanding.
  - Black ends improve light tapering uniformity at the expense of lost light.
- Test light yield for crystals of GLAST geometry and identify wrapping and packaging drivers to light yield.
  - Tetratek and Tyvek wraps best.
  - Don't wet surface.
  - No wrap is x2 loss in light.

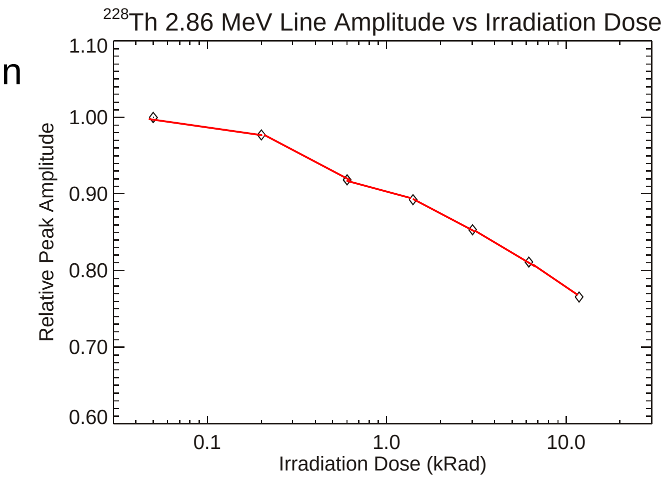


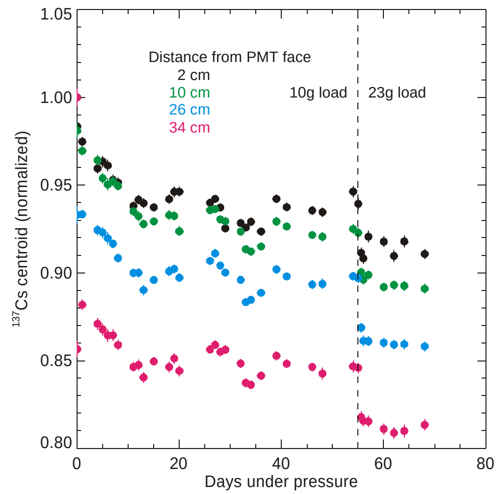


CsI Light Yield vs Environment

- Determine environmental influence on light yield - temperature, radiation damage, compression aging.
  - 0.5% loss / deg C drop in temperature,
  - 25% loss of light after 10 kRad,
  - relatively quick loss of ~ 5-10% which then appears to stabilize.
- Study bonding techniques for PIN diode to crystals and impact on light yield.
  - Need bond - air gap is x2 loss in light.
  - Hard epoxies are fine but problem w/ CTE of CsI over temperature - bonds break.
  - Silicone pads best.

Radiation





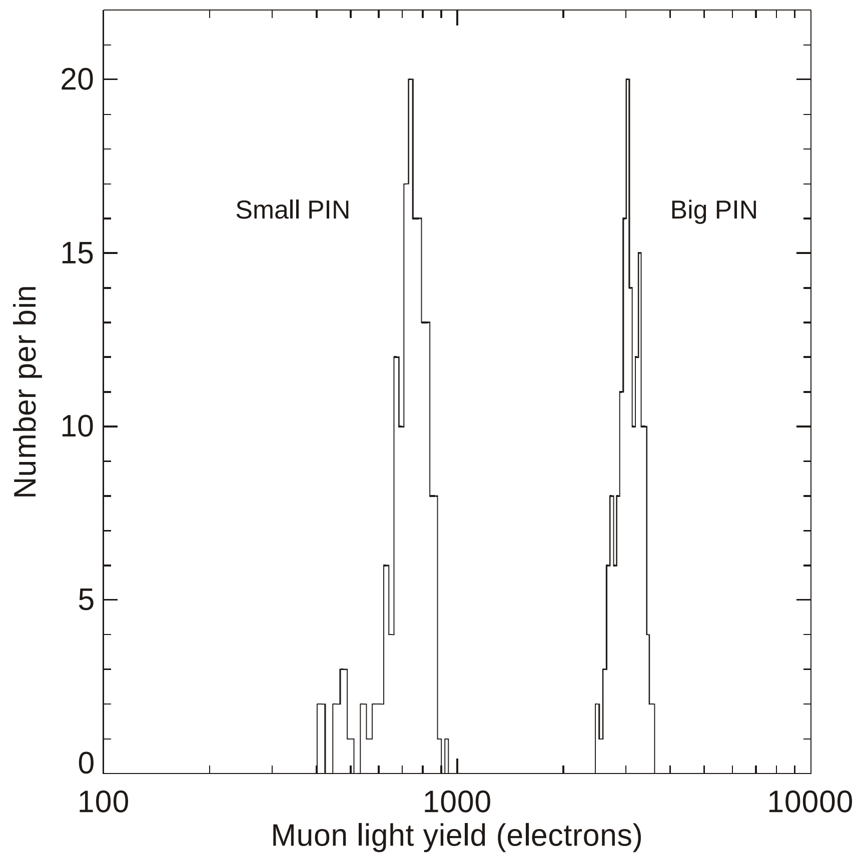
Compression

CsI Crystal Processing

- Acceptance testing.
  - inspection, metrology.
  - light yield vs position w/ ^{22}Na source (PMT dry mount, both ends).
- Surface processing (Ukrainian crystals only, Crismatec delivered with light taper).
- Crystal resizing (Ukrainian only).
- End treatment.
  - blacken with aperture for PIN photodiode or
  - white Tetratek.
- Light yield vs position w/ ^{22}Na source.
- Mount PIN photodiodes.
- Final optical wrap.
  - Tetratek (2 x 10 mil).
  - Aluminized mylar with adhesive.
- Muon testing (and ^{228}Th source).

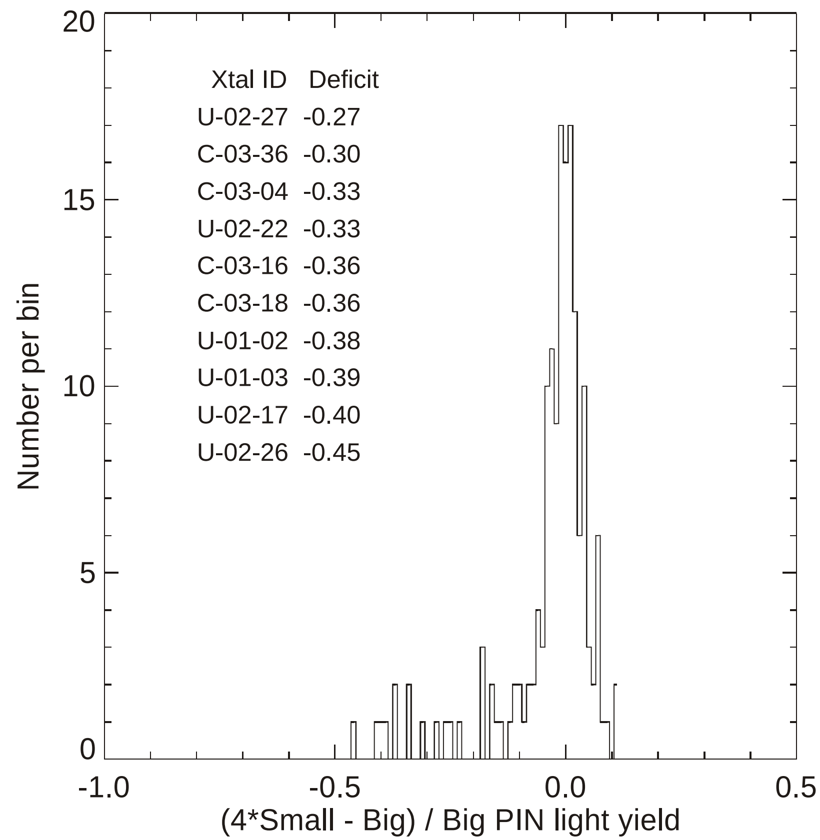
Distribution of Light Yields

- Light yield of Crismatec and Amcrys bars, with final surface treatment and final wrap.
  - Variation from bar to bar is small.
    - rms light yield in big PIN = 4%.
    - Crismatec and Amcrys bars are *indistinguishable*, despite the obvious difference in optical opacity: Crismatec bars are clear, while Amcrys bars are milky!
  - Mean yield
    - in 1-cm^2 PIN = 3000 e/MeV.
    - in ¼-cm^2 PIN = 750 e/MeV.
  - Note crystals with low yields in small PIN…



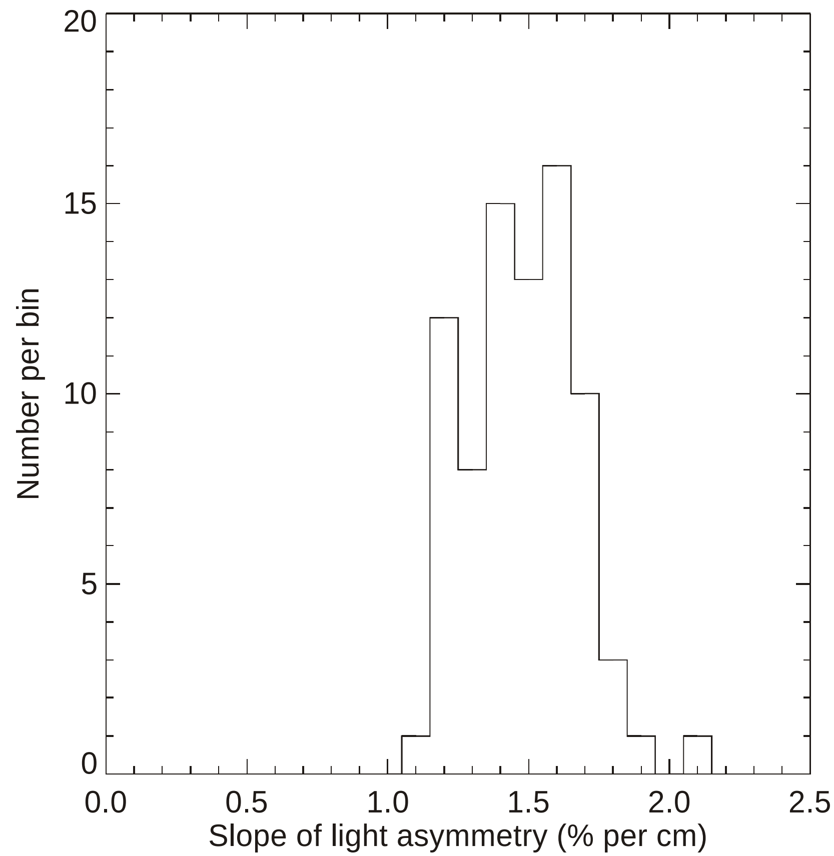
Distribution of Light Yields

- Some optical bonds to small PIN were poor.
  - Poor bonds not detected in bench checkout because [228]Th photopeak is not detectable in small PIN.
  - Next time: check all bonds with muons immediately.
  - Fractional difference in yield in small PIN relative to corresponding big PIN:
    - $f = (4Y_S - Y_B) / Y_B$
    - Factor of 4 accounts for difference in geometric area.
    - Rejected crystals based on this ratio, or placed them in top of BTEM calorimeter, where small PIN is less useful.



Distribution of Slopes (Light Attenuation Lengths)

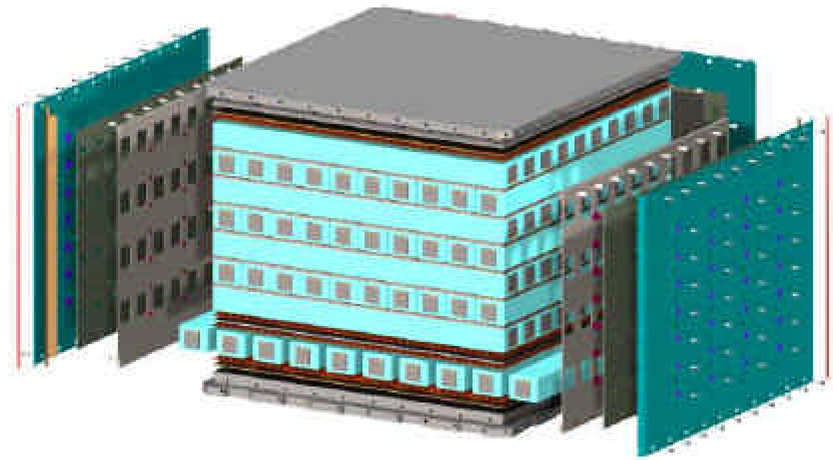
- ❑ Fit linear model to light yield as a function of position for each end of crystal.
- ❑ Crismatec and Amcrys bars with final surface treatment and wrap.
  - Mean slope = 1.5% per cm
  - rms of slope = 0.3% per cm
    (20% of mean slope)
  - Mean slope corresponds to end-to-end attenuation of ~0.4, i.e. response at far end is 40% of response at near end.



- Compression cell design provided by Hytec, Inc in collaboration with NRL.
- Design problem is dealing with large CTE of CsI relative to mechanical structure in expected temperature variations during ground handling, test, and launch.

Solution: compression cell with elastomeric pads. Used extensively in CGRO/OSSE.

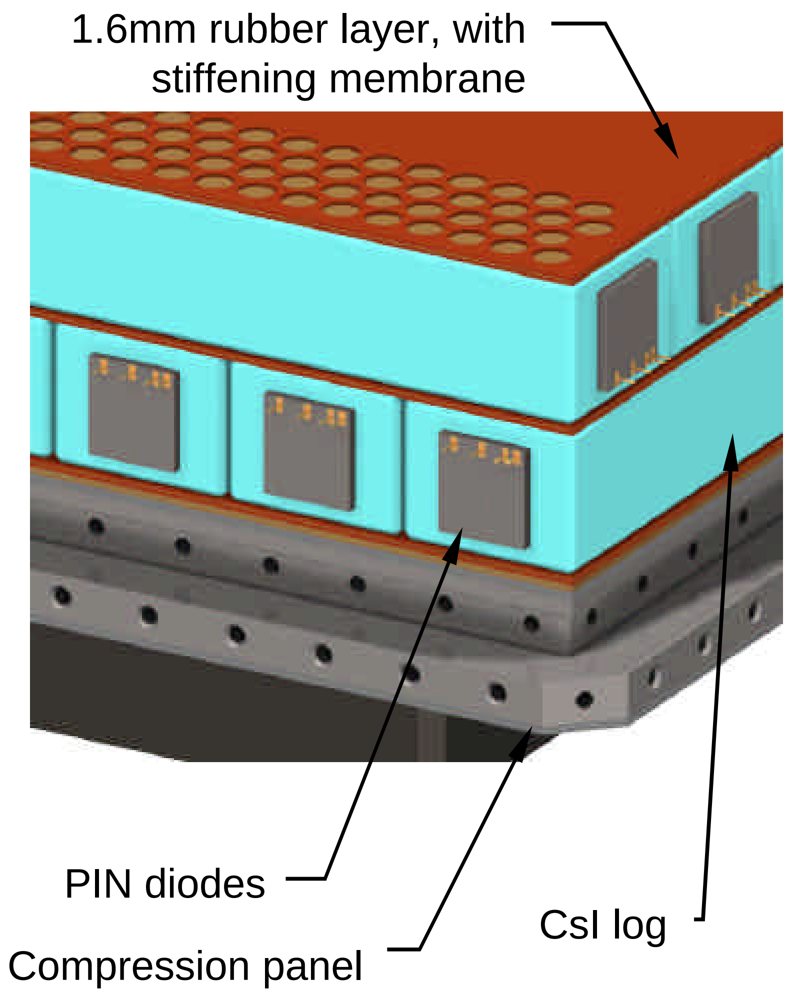
- Compression is applied vertically.
- Friction against rubber pads constrains the crystals horizontally. Side walls provide “backstop” in the event of motion.



Program: Fabricate two compression cells.

- Populate one with dummy crystals and perform acceptance level vibration testing.
- Build beam test prototype with other.

Mechanical Design (cont'd)

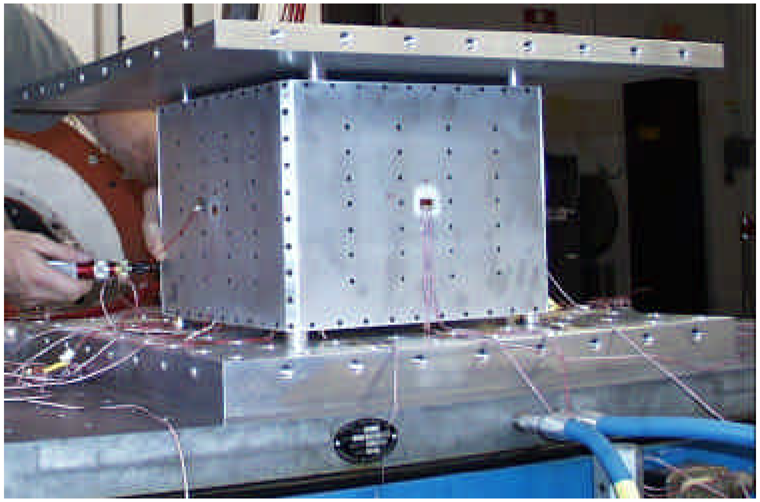


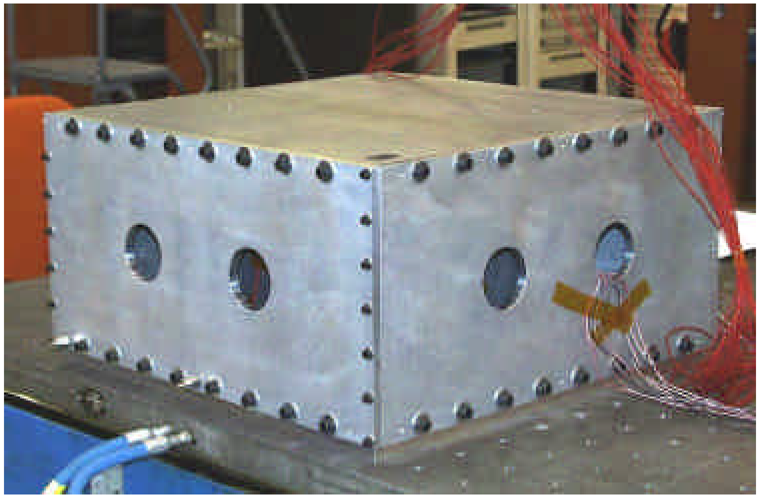
- ❑ Top and bottom compression panels are honeycomb with face-sheets
- ❑ Inner side-wall holds compression
- ❑ Rubber sheet with holes is placed above and below each layer to provide for thermal variation in CsI depth (CTE mismatch of x4).
- ❑ Al shim between layers of rubber is used to set initial compression.

Mechanical Assembly

- Crystals stacked with alignment fixture (Dummy crystals shown here.)
- Compression applied and shims are adjusted to get the correct compressed height.
- Side compression containment panels are attached. External compression is released.

Vibration Test Setup





- Vibration tests performed at NRL
  - 2 axes - thrust axis (z-axis) using vertical shaker, transverse axis using horizontal shaker.
  - 25 accelerometers
- Test fixture simulated mounting configuration for flight:
  - 4 points on bottom and 4 points on top
- Tests
  - low-level random
  - qualification level sine burst
  - random vibration levels as specified in the General Environmental Verification Specification (GEVS)

GLAST Calorimeter

Modal Analysis Results

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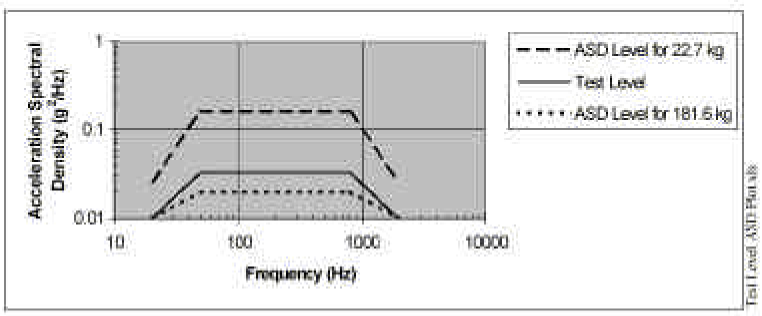
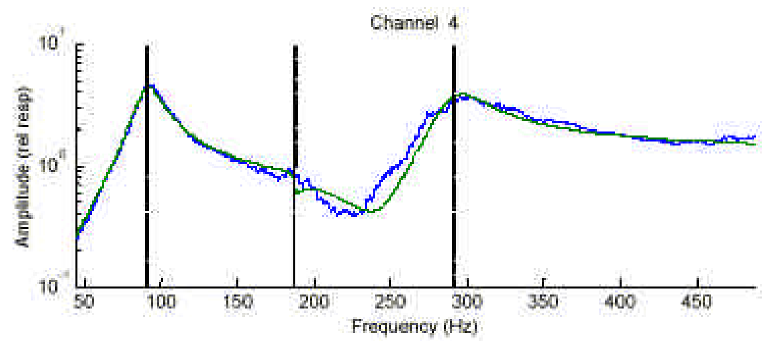
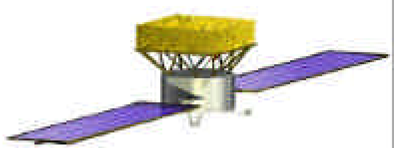
Mode	Matlab	Experimental		
	FREQ (Hz)	**FREQ (Hz)**	**Damp Ratio**	**Quality Factor**
1st Trans Shear	88.1	91	9.3%	5.4
2nd Trans Shear	172.5	187	1.9%	26.3
3rd Trans Shear	251.2	292	6.1%	8.2
1st Vertical (Accordian)	305.4	218.5	4.1%	12.2
2nd Vertical (Accordian)	598.9	524	1.4%	35.7





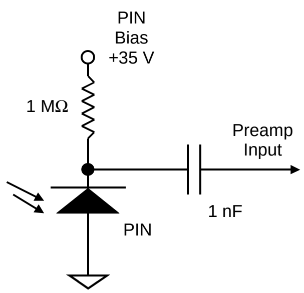
Blue line is Experimental Transfer function and green line is estimated transfer function

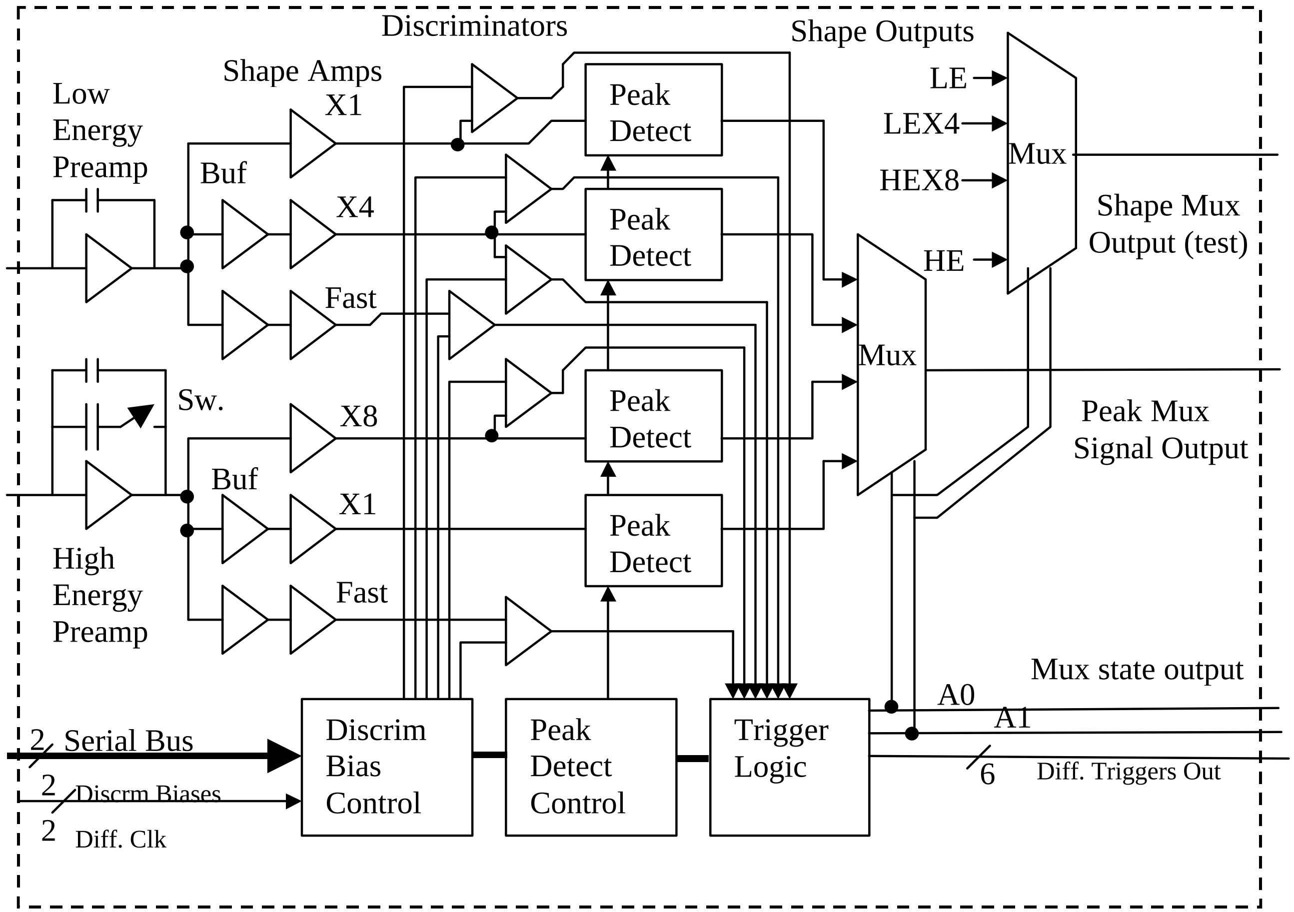


Calorimeter Electronics Development
Electronic Challenges

- Large dynamic range (~3 x 10^5)
  - break into multiple gain ranges - 2 PINs per crystal end
  - custom ASIC that breaks each PIN signal into two gain ranges to get desired ADC resolution on each.
  - Total of four gain ranges covering 2 MeV - 300 GeV
- Low power allocation per detector (~30 mW per crystal end including digital readout)
  - custom CMOS ASIC for front end analog processing
  - COTS low-power successive approximation ADCs
- Low event processing time (dead time) requirement (< 20 μsec)
  - simultaneous digitization of 160 signals from the crystal ends.
  - High bandwidth transfer to DAQ using multiple serial links.
- Performance monitoring and Calibration on the ground and in orbit.
  - Internal charge injection calibration system
  - test gain setting
  - low threshold for cosmic muon testing
  - in flight calibration with high Z cosmic rays.

Analog ASIC Signal Chain

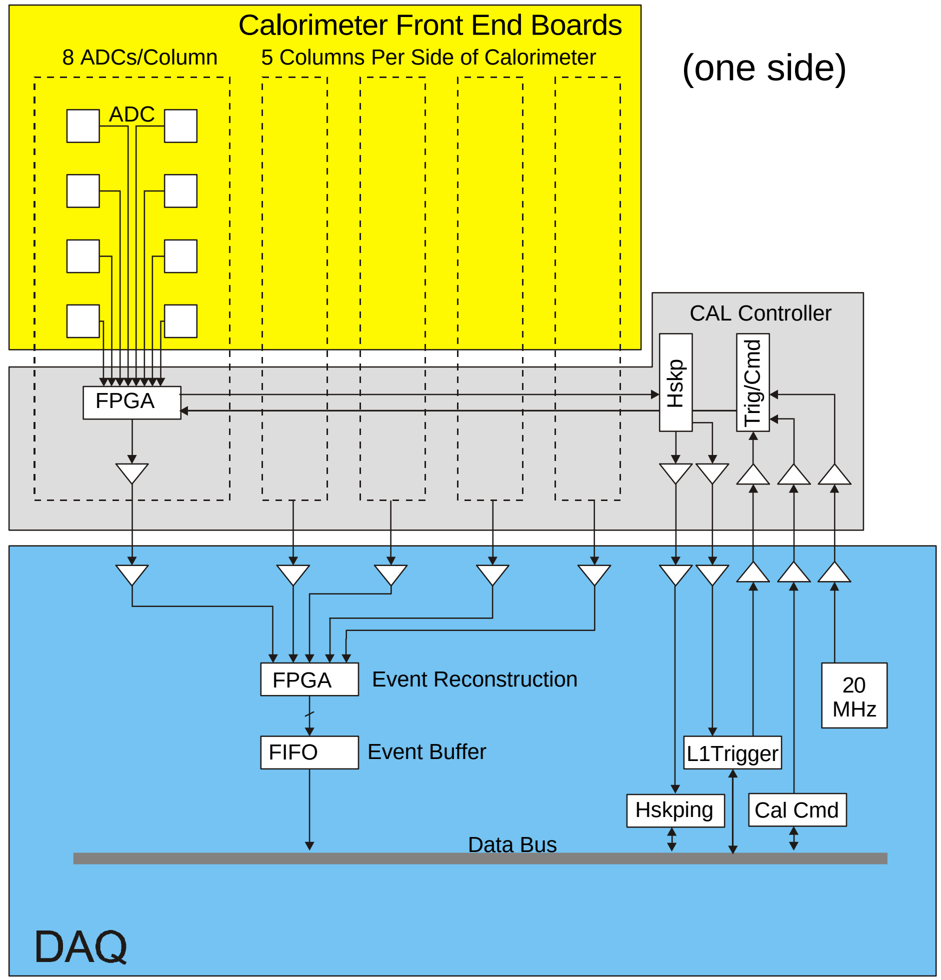




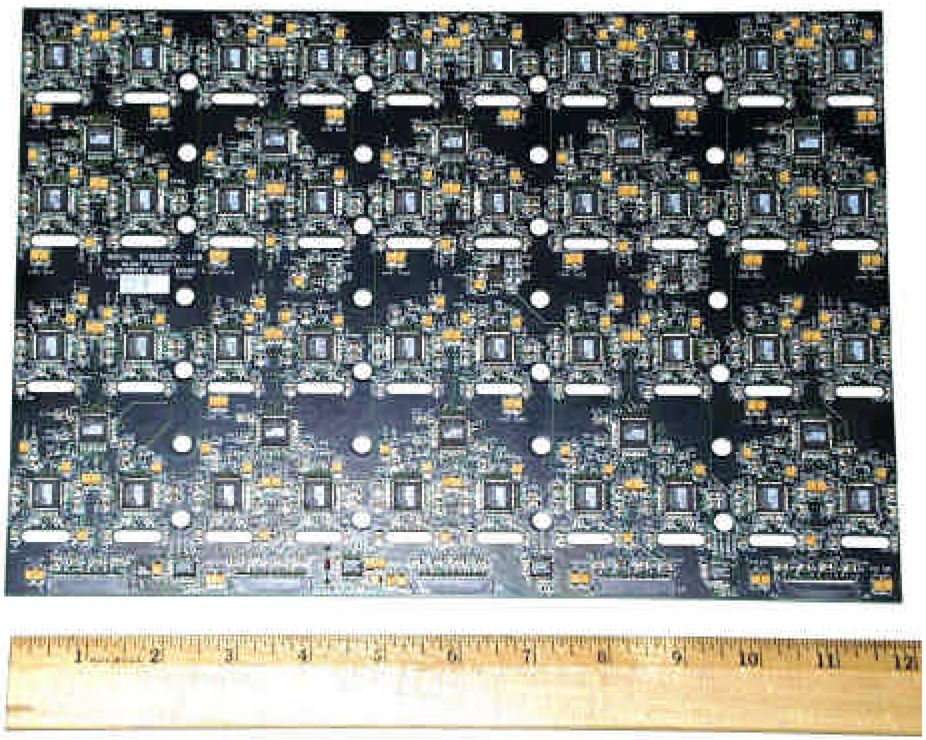
GSFC prototype ASIC demonstrated all analog functionality. DACs, cmds and other digital control need to be added.

Prototype Calorimeter Trigger Event Data Readout

- 160 ADCs readout simultaneously to cal controller
  - Xfer time ~ 3.5 µsec (3 - 4 MHz)
  - form 20 “columns” of 8 ADC values with flags
- 20 Columns transferred simultaneously to DAQ
  - 128 bit messages at 20 MHz (6.4 µsec)
  - transfer can overlap acquisition of new event
- DAQ I/F merges 20 columns into ordered sequence of 160 16-bit words
  - load into event buffering FIFOs
- DAQ performs event sparsification for readout

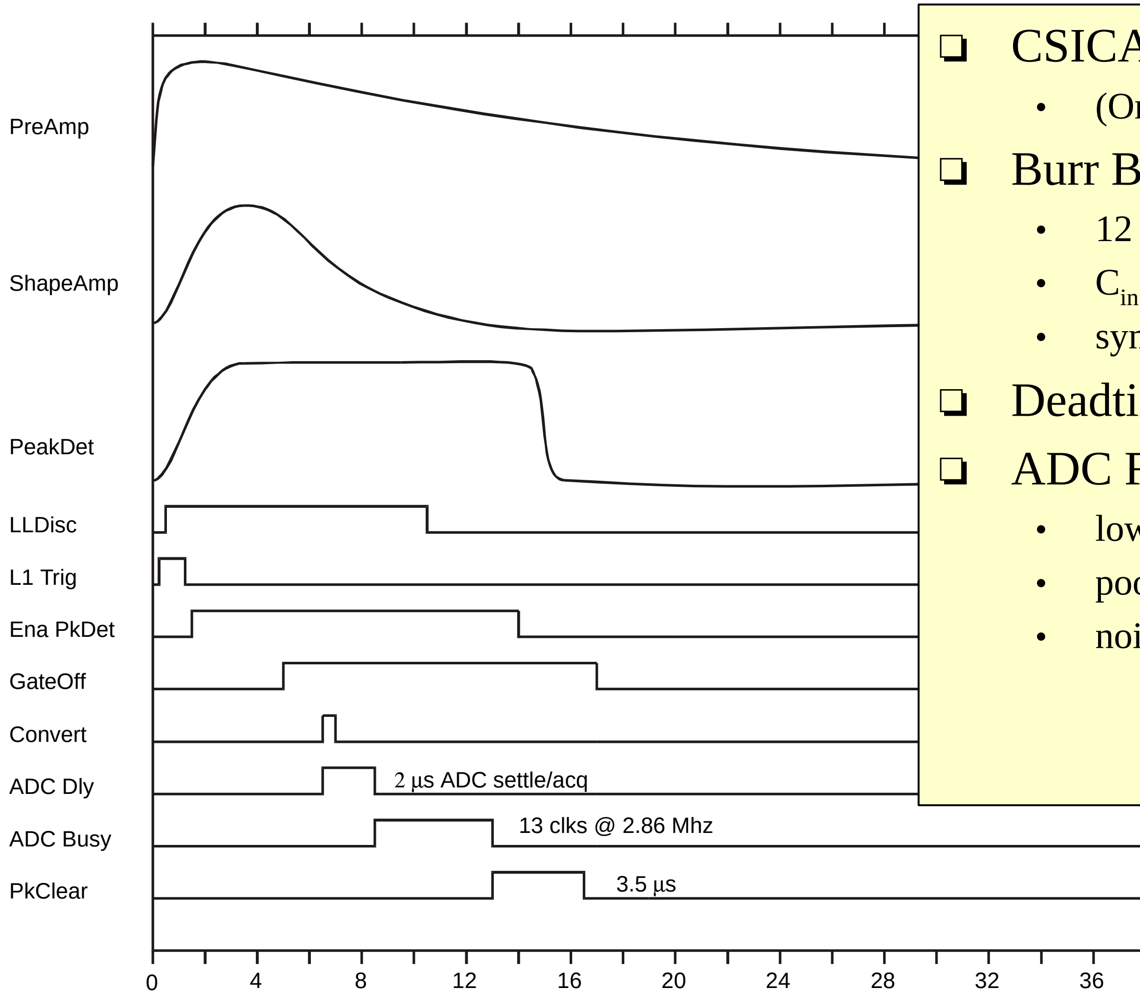


AFEE Circuit Card



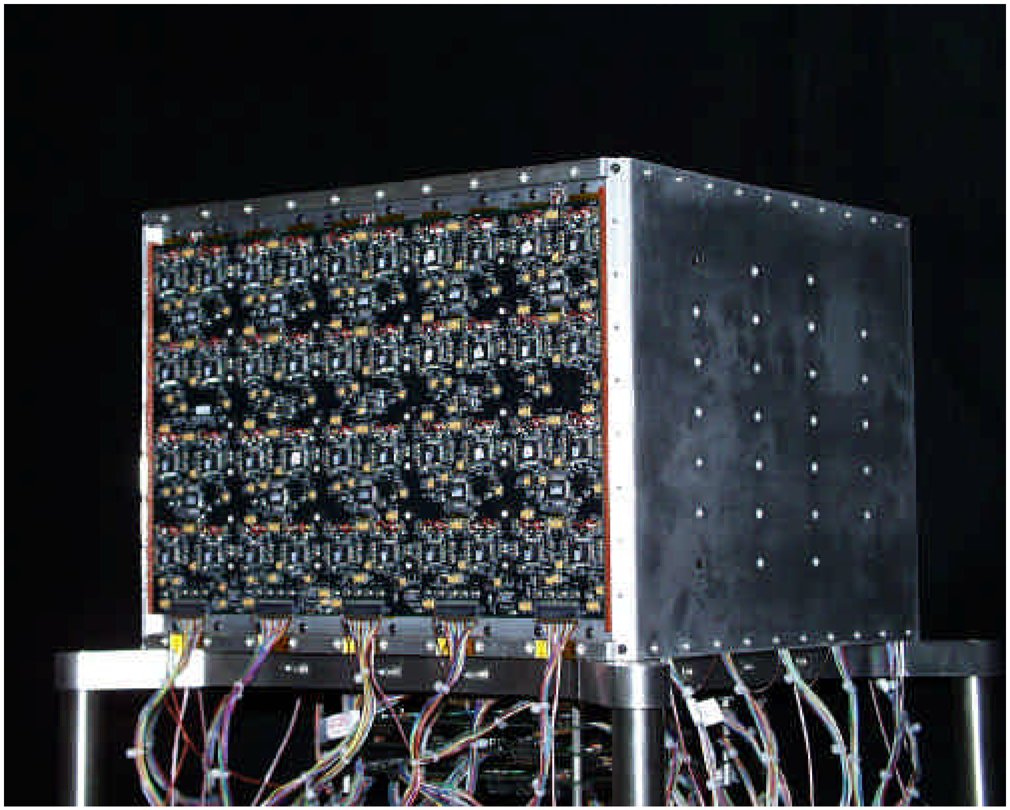
- 16 Layer board
- 40 CsICAL ASICs, 80 PIN diodes connections
- 10 V-I/I-V ASICs
- 40 ADCs
- 16 DACs
- Misc buffers, biasing, filters
- 5 Nanonics connectors
- Total of ~ 1400 components on both sides.

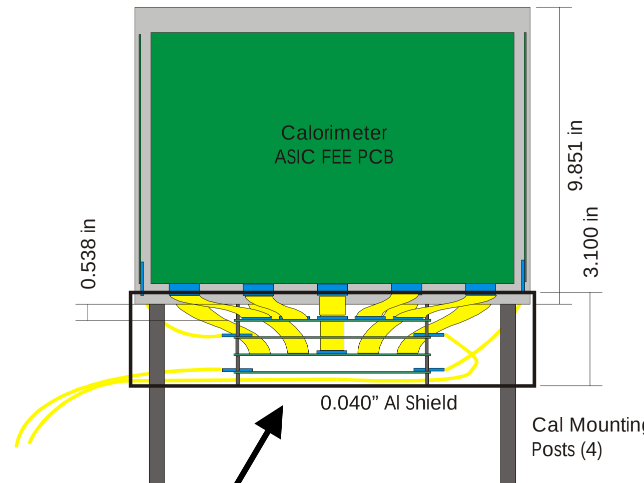
Dead Time
Front End Data Capture - BB



- CSICAL2-2 ASIC (GSFC)
  - (Orbit 1.2 µm, 5 V process)
- Burr Brown ADS 7816
  - 12 bit, low power
  - C_{in} ~ 25 pf
  - synchronous serial readout
- Deadtime: ~17 µsec per event
- ADC Features
  - lowest power (+++)
  - poorest performance (---)
  - noisy environment, ext clock (---)

Partially Assembled BTEM Calorimeter



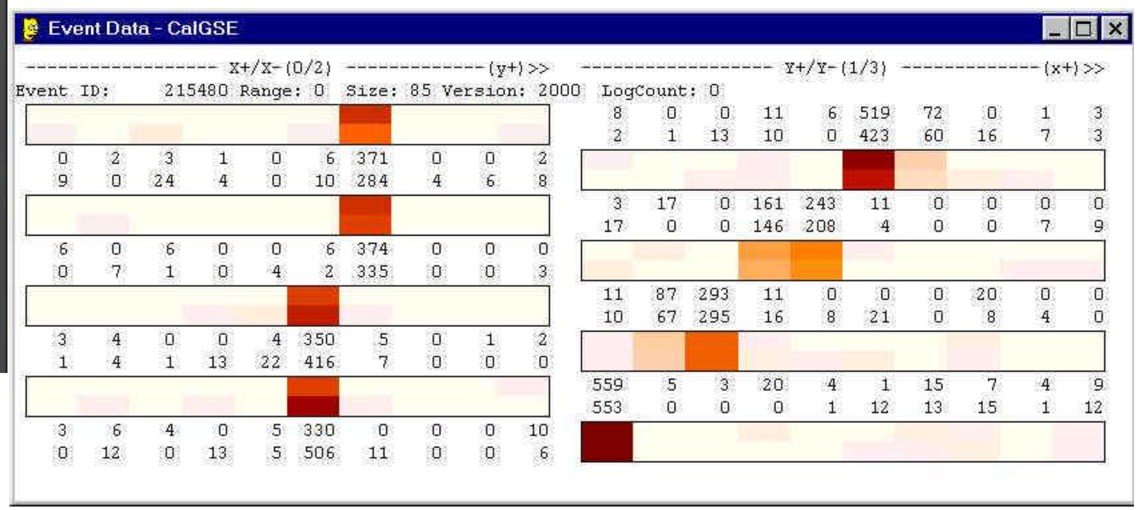


Calorimeter controller PCBs (one per side) are mounted below calorimeter. Four cables mate to DAQ system.

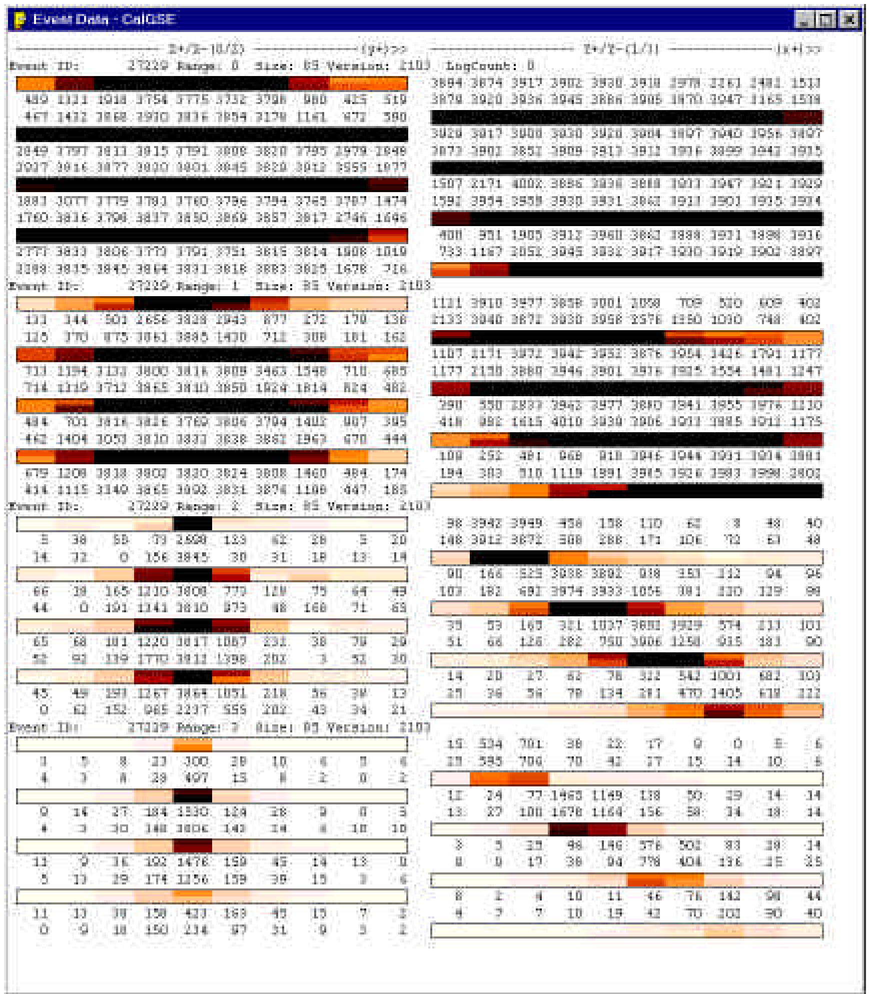
Assembled Calorimeter

- Completed Assembly
  - mass: 98 kg
  - power: 5 watts

Tracking cosmic muons

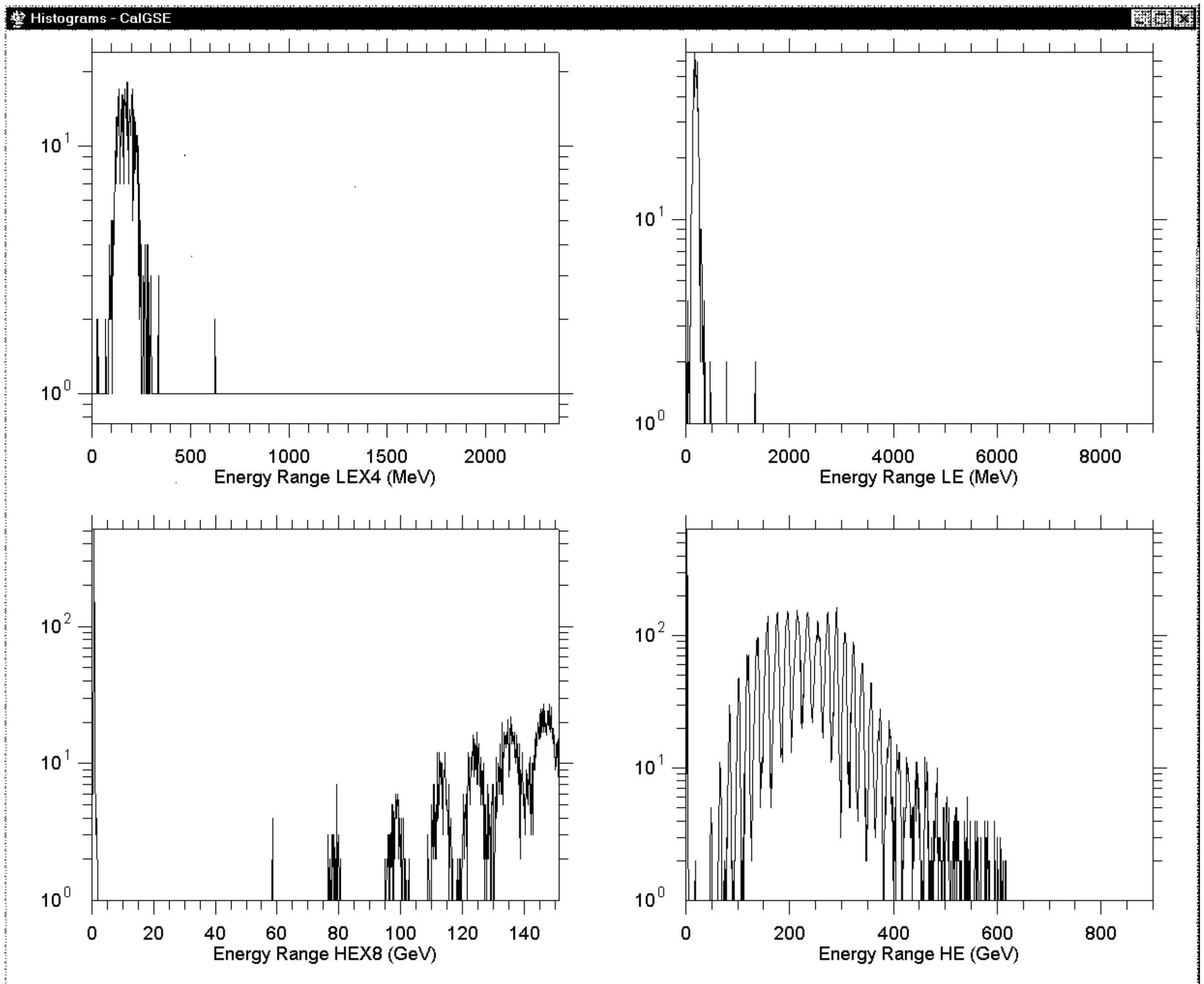


Beam Test Performance



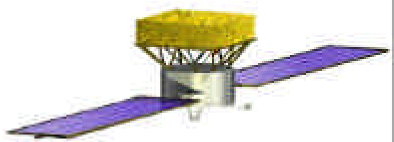
- ❑ Display shows all four energy ranges.
  - Both crystal ends are shown.
  - Color code indicates energy deposition.
- ❑ Incident beam is ~12 positrons in a single pulse from 20 GeV beam
- ❑ Beam incident at ~ 50 deg angle
- ❑ Lowest range is saturated
- ❑ Highest range not saturated

Multi-Particle Energy Spectra



Running self-triggered

- See muons in low energy range
- See multiplicity of particles up to 600 GeV
- Each peak in the lower two plots represents a integer multiplicity of positrons. Average multiplicity was varied between ~10 and 30 during this run of 10 GeV positrons.



Conclusions

- Design of calorimeter meets the requirements for flight system
- Some modifications to design are required
  - Calorimeter size and depth have changed in flight unit - modest impact.
  - More functionality is required in analog ASIC - digital control, internal DACs and autoranging to be designed by CEA/Saclay.
  - Compression adjustment capability prior to launch is desired.
  - PIN bonding with silicone pads requires modification to PIN mounting.
  - DAQ and interface to DAQ are under review; calorimeter data compression (zero suppression) is desired.
- Alternate mechanical design for the calorimeter is being considered - IN2P3/Ecole Polytechnique.