GLAST Calorimeter Design and Front End Electronics Dec 10, 1998

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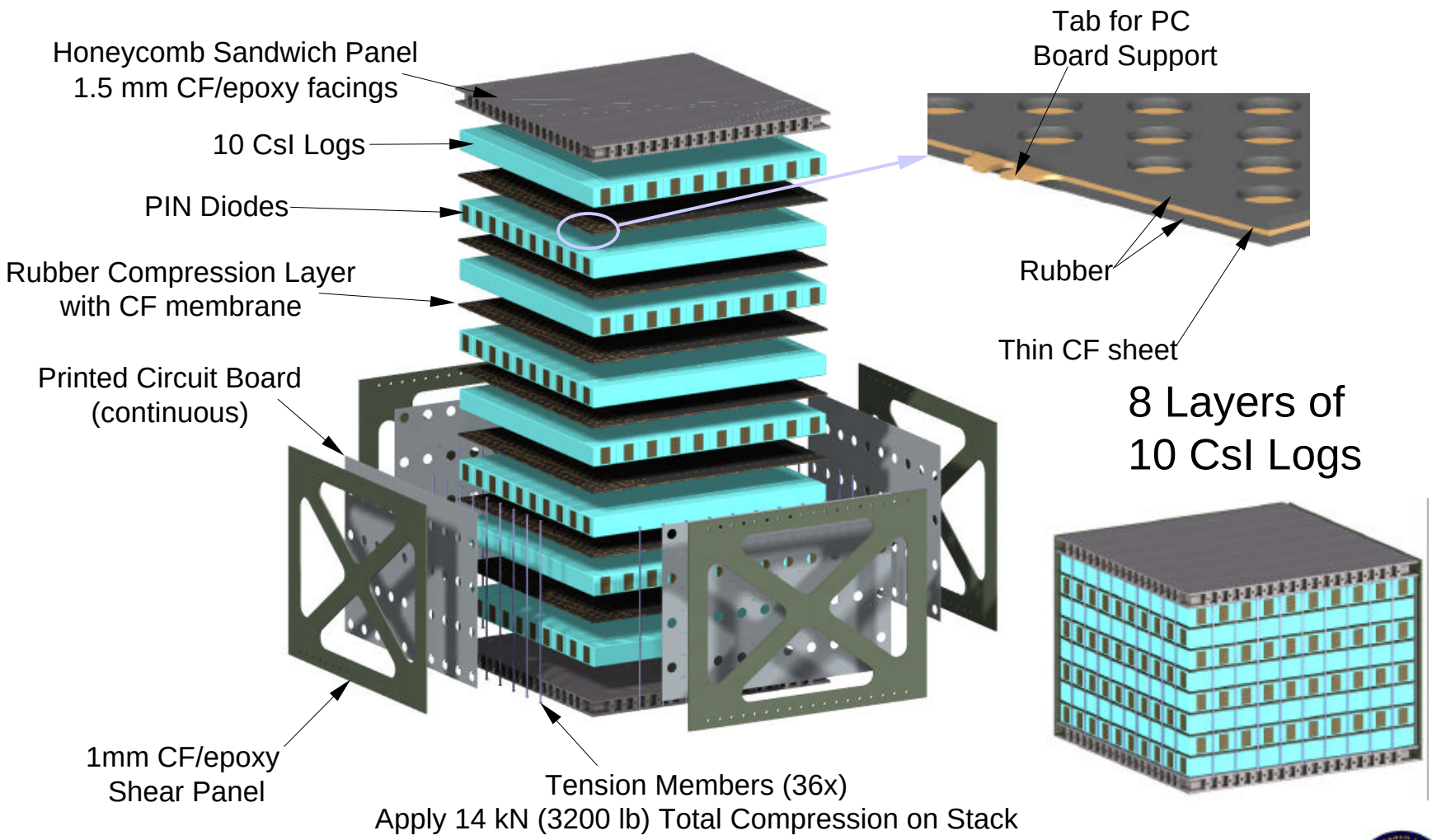
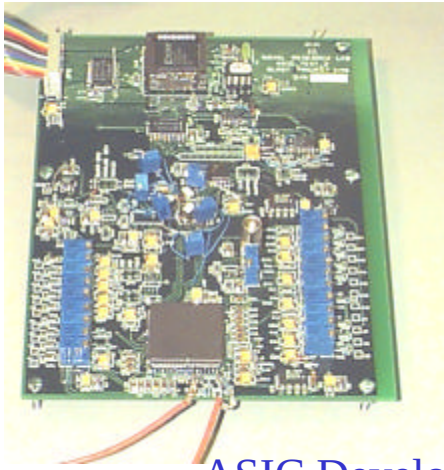
32 cm Calorimeter Concept



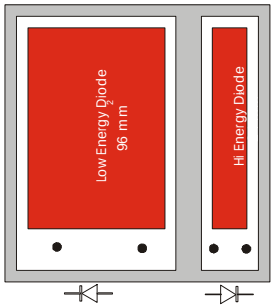
Calorimeter Design

Number of Channels:	160 / tower (80 CsI blocks, both ends)
Dynamic Range:	5×10^5
Noise goal:	0.4 MeV (2×10^3 e^-)
A to D Range:	2 MeV – 100 GeV
Power:	5 watts / tower
	~ 62 mW / CsI block

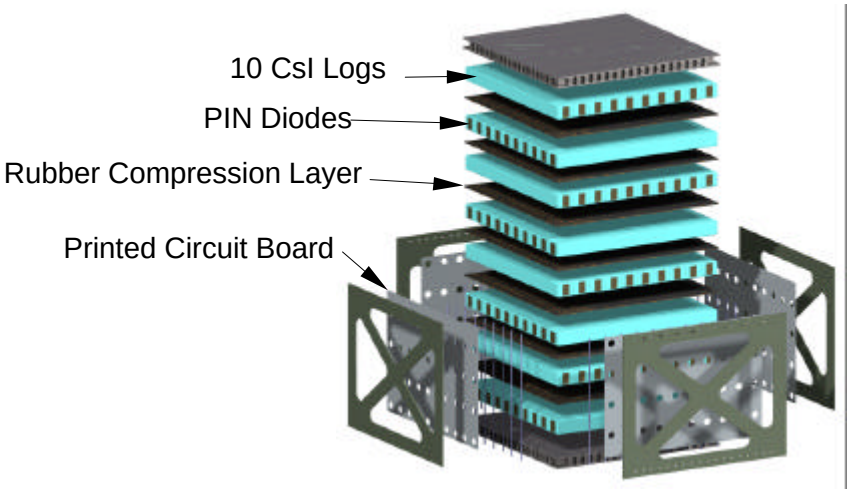
Achieve dynamic range, noise and power performance with dual PIN photodiodes and custom low-power application specific integrated circuit (ASIC) with multiple energy ranges.



ASIC Development - prototype test board



Custom Dual PIN photodiode



Aspects of GLAST Calorimetry

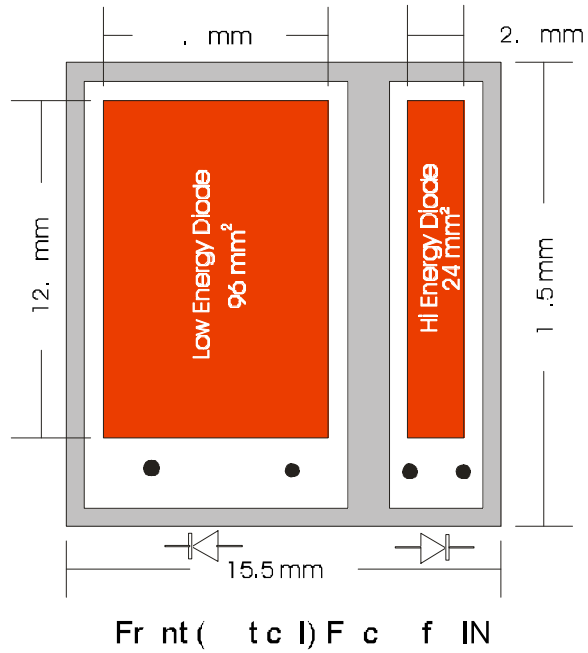
- Mass - 89 kg/tower
- Low Power (5 Watts/tower)
  - includes preamp, shaping, discrimination, and A to D conversion, compression, transfer, and housekeeping
- Large dynamic range: 3×10^5
  - energy range for spectroscopy: 2 MeV to 300 GeV
  - single CsI crystal spectroscopy: 2 MeV to 100 GeV
- Self-triggering mode
  - large energy losses in calorimeter trigger readout of GLAST tracker
- Low deadtime
  - calorimeter pulse height analysis and buffering complete in 10 μsec (goal)

Calorimeter Electronics Requirements

Number of Channels:	160 / tower (80 CsI blocks, both ends)
Dynamic Range:	3×10^5
Noise goal:	0.4 MeV (2×10^3 e^-)
A to D Range:	~2 MeV – 100 GeV
Electronic Resolution:	~ 1% (except at threshold)
Trigger Rate: (GLAST)	1200 Hz (Trkr, orbit ave)
	+250 Hz (Cal, orbit ave)
	4000 Hz (peak)
Self trigger delay:	< 1 μsec
Trigger Dead time:	10 μsec (goal)
Power:	5 watts / tower
	~ 62 mW / CsI block

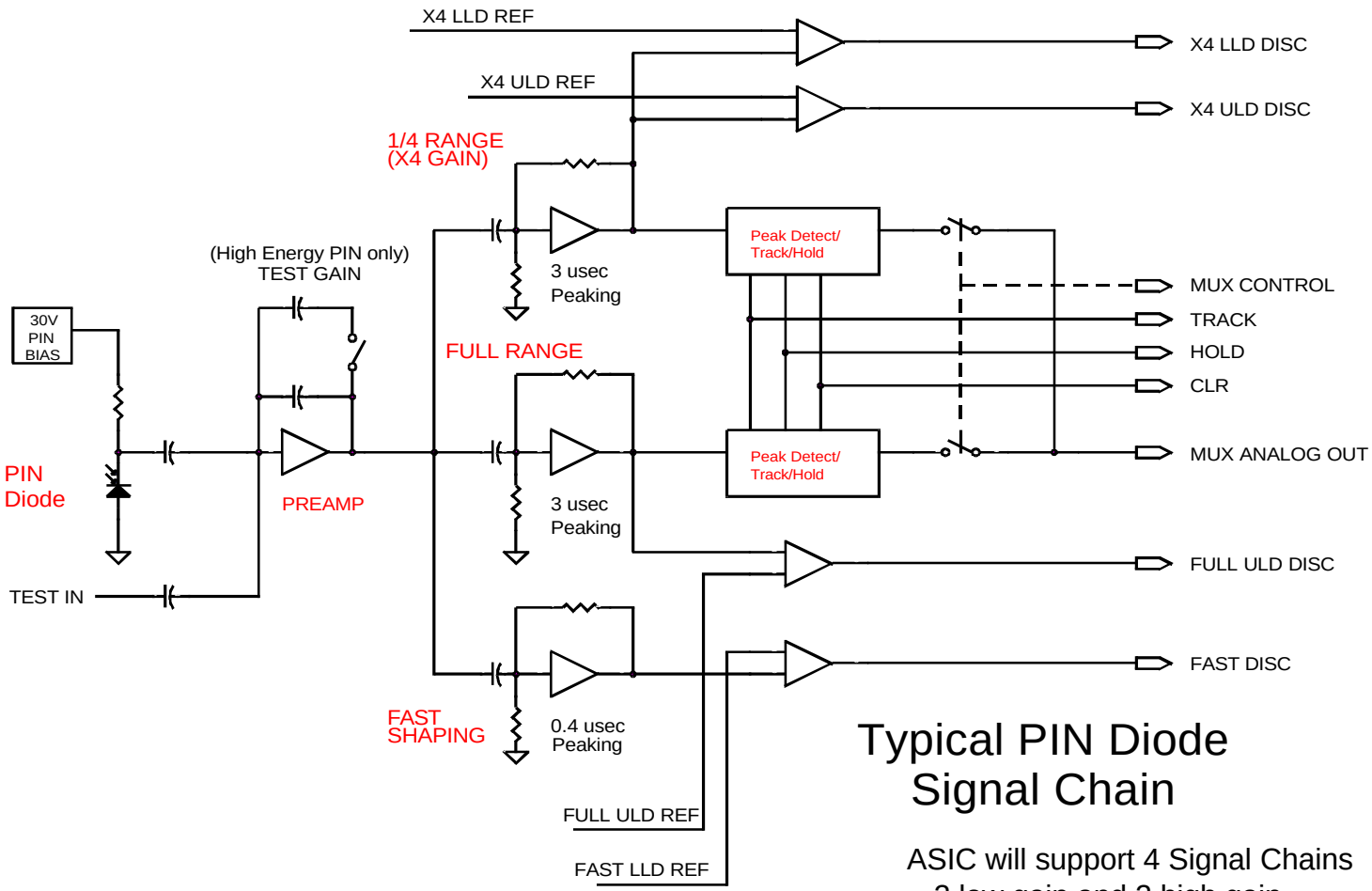
Derived Calorimeter Requirements (Divide and Conquer)

- 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: 40 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
  - 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

Prototype ASIC PIN Signal Chain



Typical PIN Diode Signal Chain

ASIC will support 4 Signal Chains
- 2 low gain and 2 high gain.

GLAST Calorimeter ASIC Baseline Functionality

Each ASIC supports 2 CsI Detectors - 2 high energy and 2 low energy PINs.

- **Low Energy PIN channel functionality (1 - 800 MeV)**
  - PIN area ~96 mm^2, ~0.8 fC/MeV
  - Net gain ~ 5.5 mV/fC
  - PreAmp input C ~ 80 pf
  - Noise goal: <2000 e^- (0.4 MeV)
  - ×4 Shaper, ~3.5 μsec peaking
    - Programmable lower level discriminator (LLD)
    - Fixed upper level discriminator
    - Peak detect and hold
  - Full Range Shaper, ~3.5 μsec peaking
    - Fixed upper level discriminator
    - Peak detect and hold
  - Fast Shaper, ~0.5 μsec peaking
    - Range: ~ 50 - 800 MeV
    - Programmable lower level discriminator (FLLD)

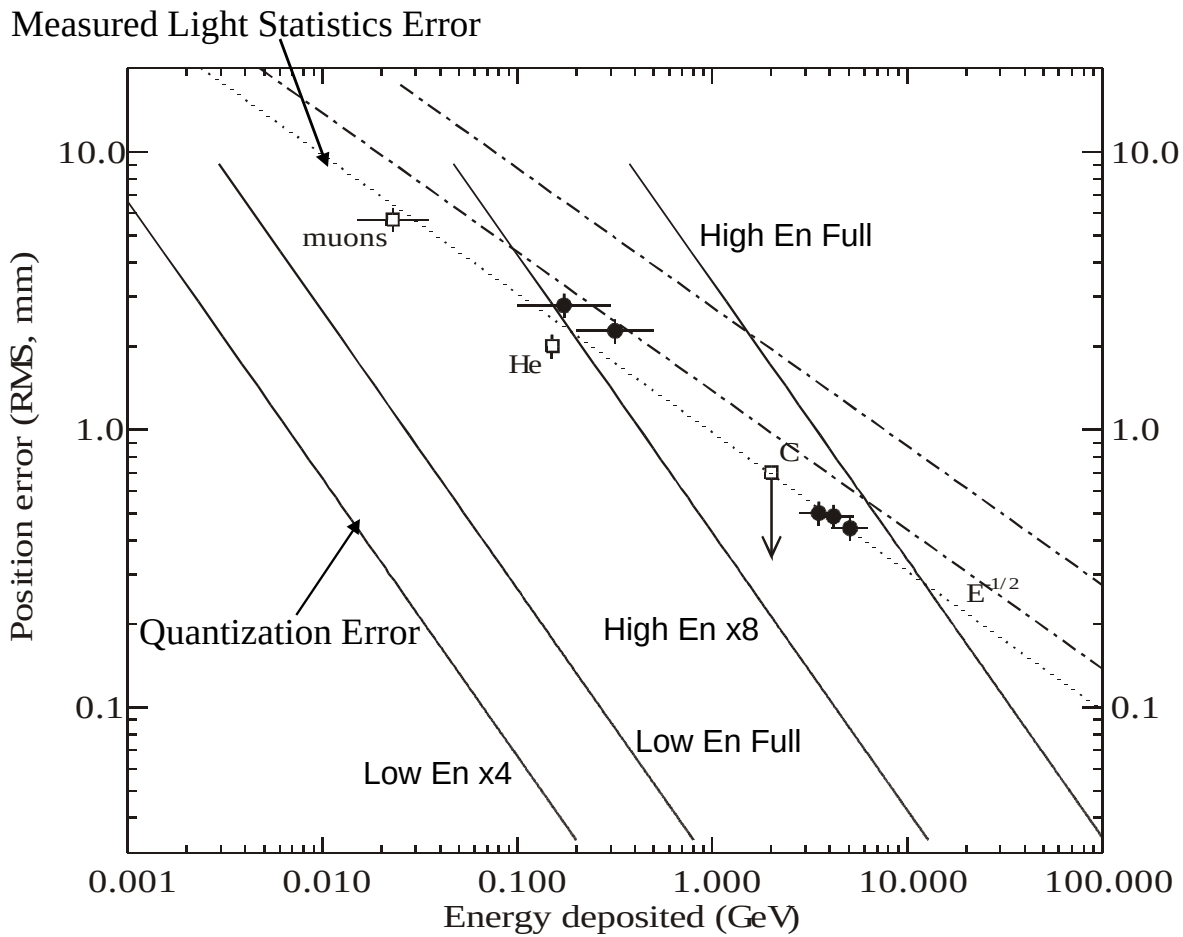
GLAST Calorimeter ASIC Baseline Functionality (cont)

- **High Energy PIN channel functionality (800 MeV - 100 GeV)**
  - Pin area 24 mm^2, ~0.2 fC/MeV
  - Net gain ~ 175 µV/fC
  - PreAmp input C ~ 30 pf
  - Noise goal: < 20000 e^- (16 MeV)
  - ×8 Shaper, ~3.5 µsec peaking
    - Programmable lower level discriminator (LLD)
    - Fixed upper level discriminator
    - Peak detect and hold
  - Full Range Shaper, ~3.5 µsec peaking
    - Fixed upper level discriminator
    - Peak detect and hold
  - Fast Shaper, ~0.5 µsec peaking
    - Energy Range: 500 MeV - 100 GeV
    - Programmable lower level discriminator (FLLD)

GLAST Calorimeter ASIC Baseline Functionality (cont)

- **Test/Calibration Features**
  - Analog Test inputs
  - Programmable voltage step charge injection on command
  - Test gain mode for low gain range to raise gain to same as high gain range
  - Calibration mode can digitize all gain range signals of an event in sequence for cross calibrations.
- **Programmability**
  - Discriminator level setting
  - Preamp/shaping amp gain adjust
  - channel enable, trigger enable
- **On-Orbit Calibrations**
  - Use Cosmic Rays (p, C, N, O, Fe) to calibrate
  - Organization of gain ranges largely determined by the on-orbit calibration and cross comparisions

Baseline Energy Ranges

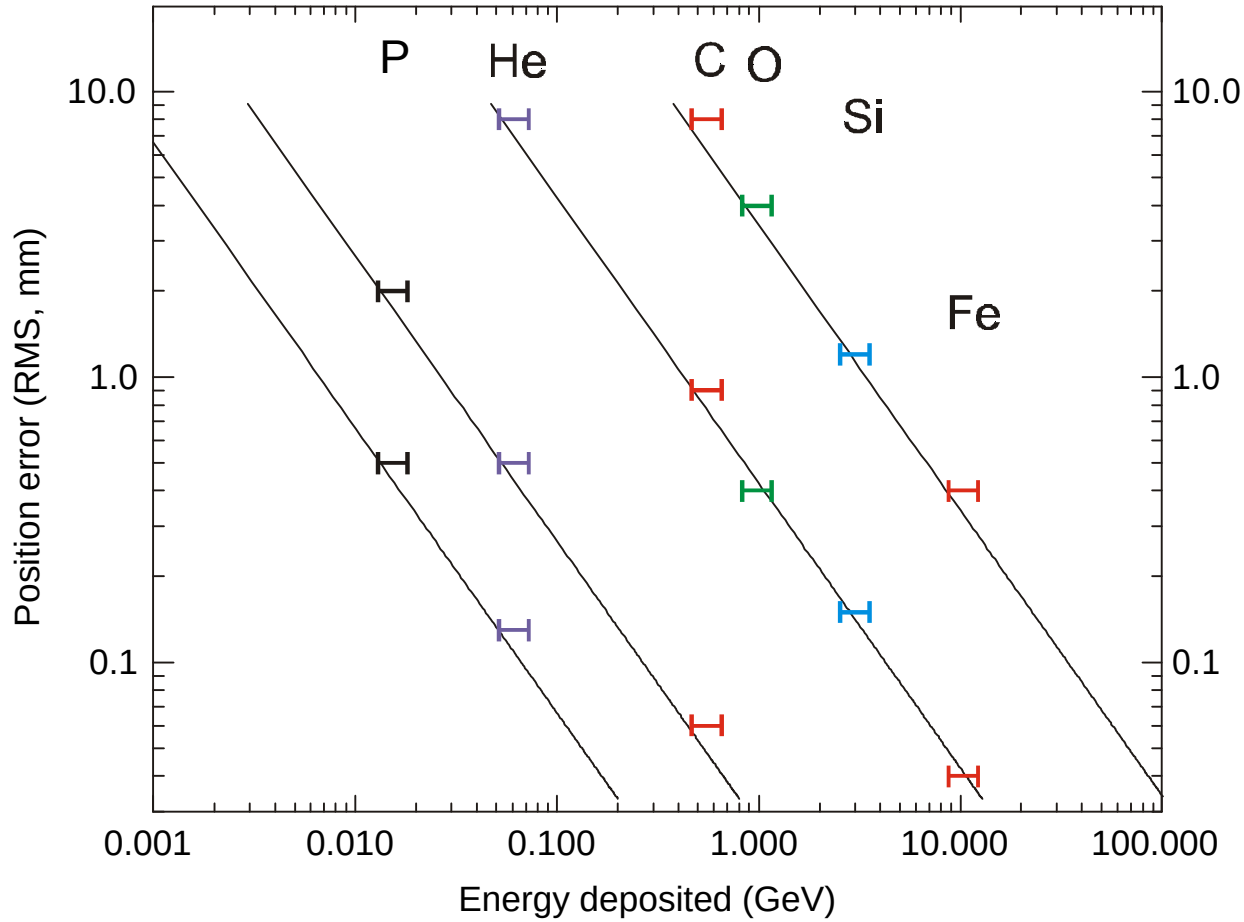


Four Energy Ranges

- Low Energy Range
  - x4, 2 - 200 MeV
  - Full, 200 - 800 MeV
- High Energy Range
  - x8, 0.8 - 13 GeV
  - Full, 13 - 102 GeV

Energy Range Calibration with Cosmic Rays

He: ~140 Hz
CNO: ~10 Hz
Si: ~0.4 Hz
Fe: ~0.8 Hz



Calorimeter ASIC Gain Scale Summary

	High Gain X4	High Gain Full	Low Gain X8	Low Gain Full
Max Energy	200 MeV	800 MeV	12.8 GeV	102 GeV
Chan Width	0.049 MeV	0.19 MeV	3.1 MeV	25 MeV
Threshold	2 MeV	80 MeV	300 MeV	12 GeV
Noise Estimate (Simulation)	3000 e^- rms (0.60 MeV)	2400 e^- rms (0.48 MeV)	Need Simulation	Need Simulation
Quantization Error @ Thresh	2%	0.1%	1%	0.2%
Chan # of 1 MIP	254/4096	63/4096	3/4096	0
Chan # of ^{12}C	**	2294/4096	143/4096	17/4096

Photo Electron Yield Estimate

SLAC and MSU tests @ 21 deg C, 19 cm logs:

PIN collects 12,000 - 15,000 e^- / MeV

Reductions:

- Operation at 0 deg C, reduce by factor ~ 0.9 (Blucher et al., CLEO)
- Radiation effects (10 kRad), reduce by factor ~ 0.75
- Channel gain variation in ASIC (+/- 10%), reduce by factor ~ 0.9
- Light output variation in crystals and wrapping (+/- 20%), reduce by factor ~ 0.8

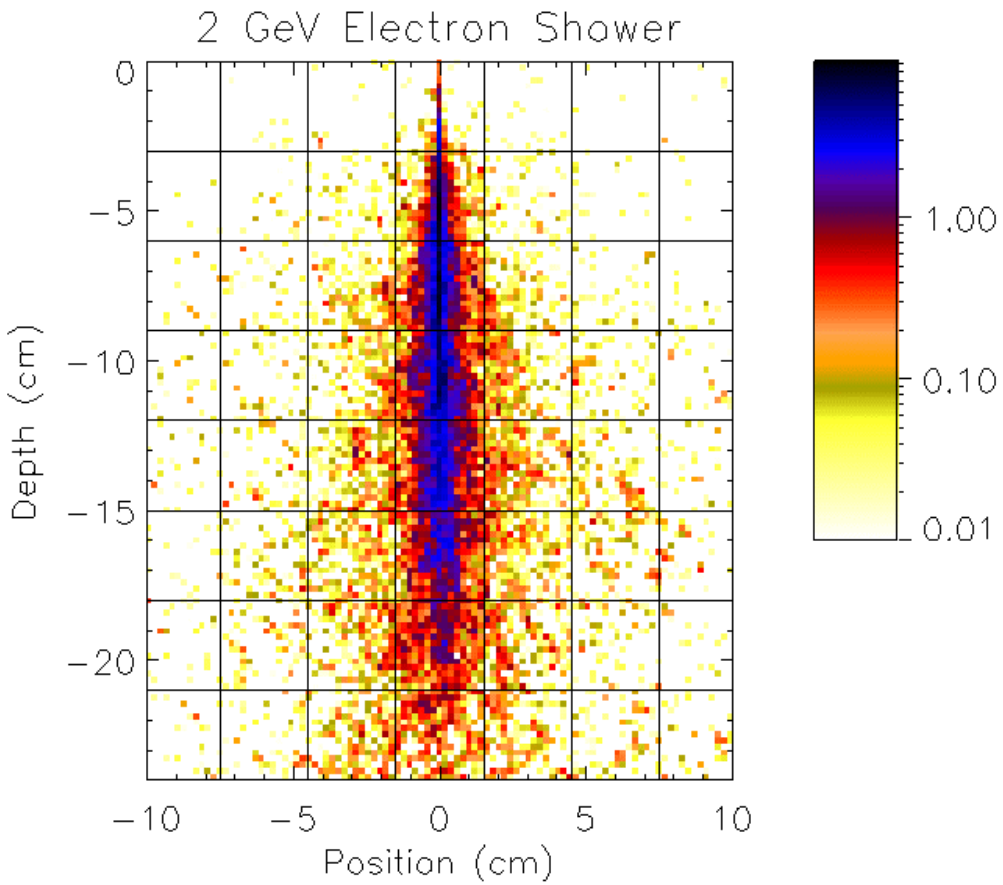
Result:

6,000 - 8,000 e^- / MeV (prototype ASIC designed at 10,000 e^- / MeV)

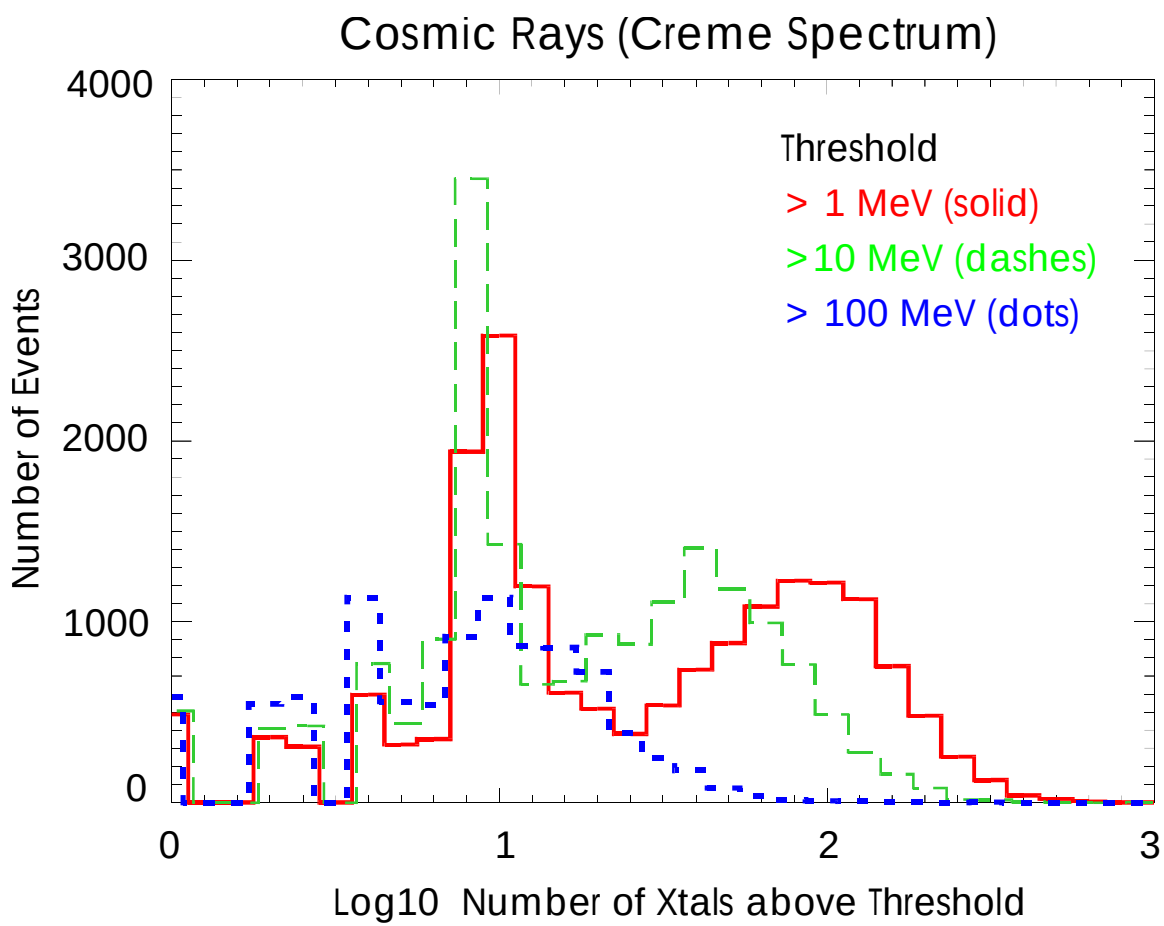
Other Issues: Custom PIN diode active area

Development of Electromagnetic Shower in the GLAST Calorimeter

- Simulation of 2 GeV electron entering calorimeter from the top.
- Grid represents the segmentation of the calorimeter into 3 cm blocks
- Color coding shows the projected total energy deposited in 2 mm voxels in MeV.
- Maximum energy loss rate (shower max) occurs at depth of 10 cm.



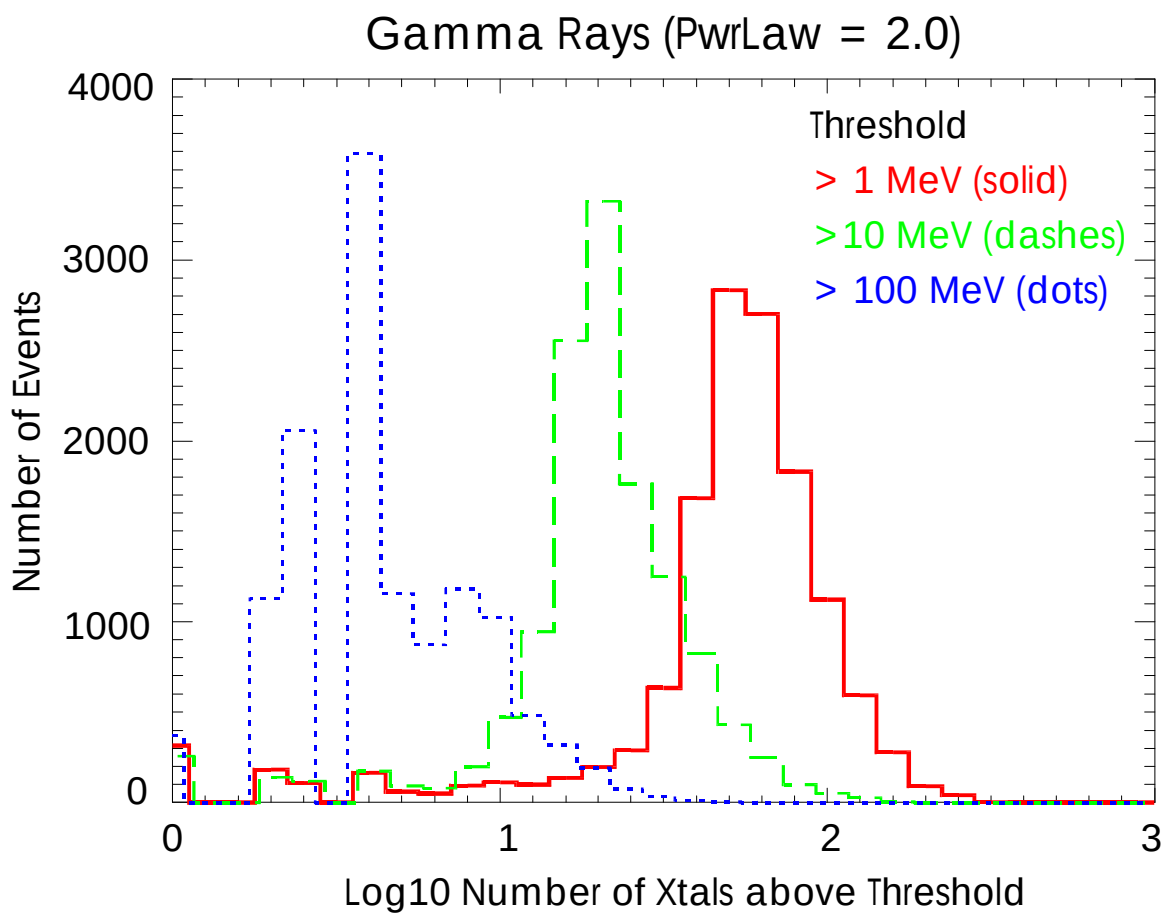
Cosmic Ray Event Multiplicity



Mean Multiplicity
63 Xtals/event

Gamma Ray Event Multiplicity

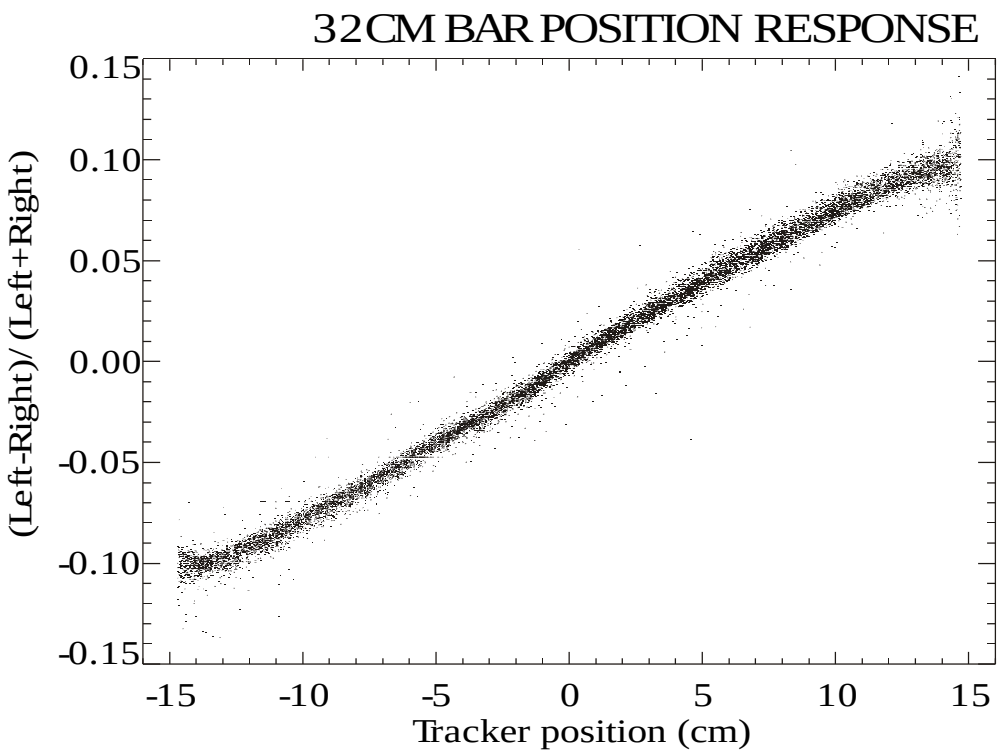
Mean Multiplicity
71 Xtals/event



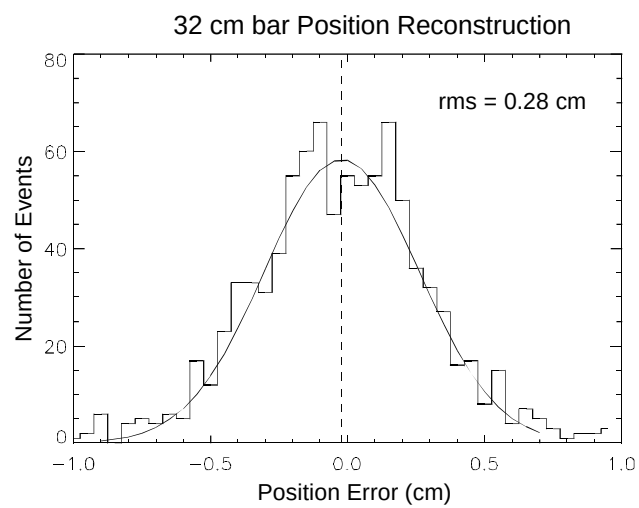
Expected Calorimeter Event Rate

- Calorimeter Event Rate dominated by Galactic Cosmic Rays
- Other important components
  - Trapped protons in earth's magnetic field
  - Earth albedo particles (protons & neutrons)
  - Earth albedo gamma rays
- Net Rate for total GLAST is 4,000 s^{-1} (orbit average), 16,000 s^{-1} (max)
  - This is essentially all GCRs
- From Monte Carlo (GLASTSIM) simulations
  - Cosmic ray crystal multiplicity is mean ~ 60, max ~ 300
  - Gamma ray crystal multiplicity is mean ~ 70, max ~160.
- Orbit Average Threshold rate is 4000 $s^{-1} \times 60$ mult / 2000 crystals = 120 s^{-1}
- Peak Threshold rate is 16,000 $s^{-1} \times 60$ mult / 2000 crystals = 480 s^{-1}

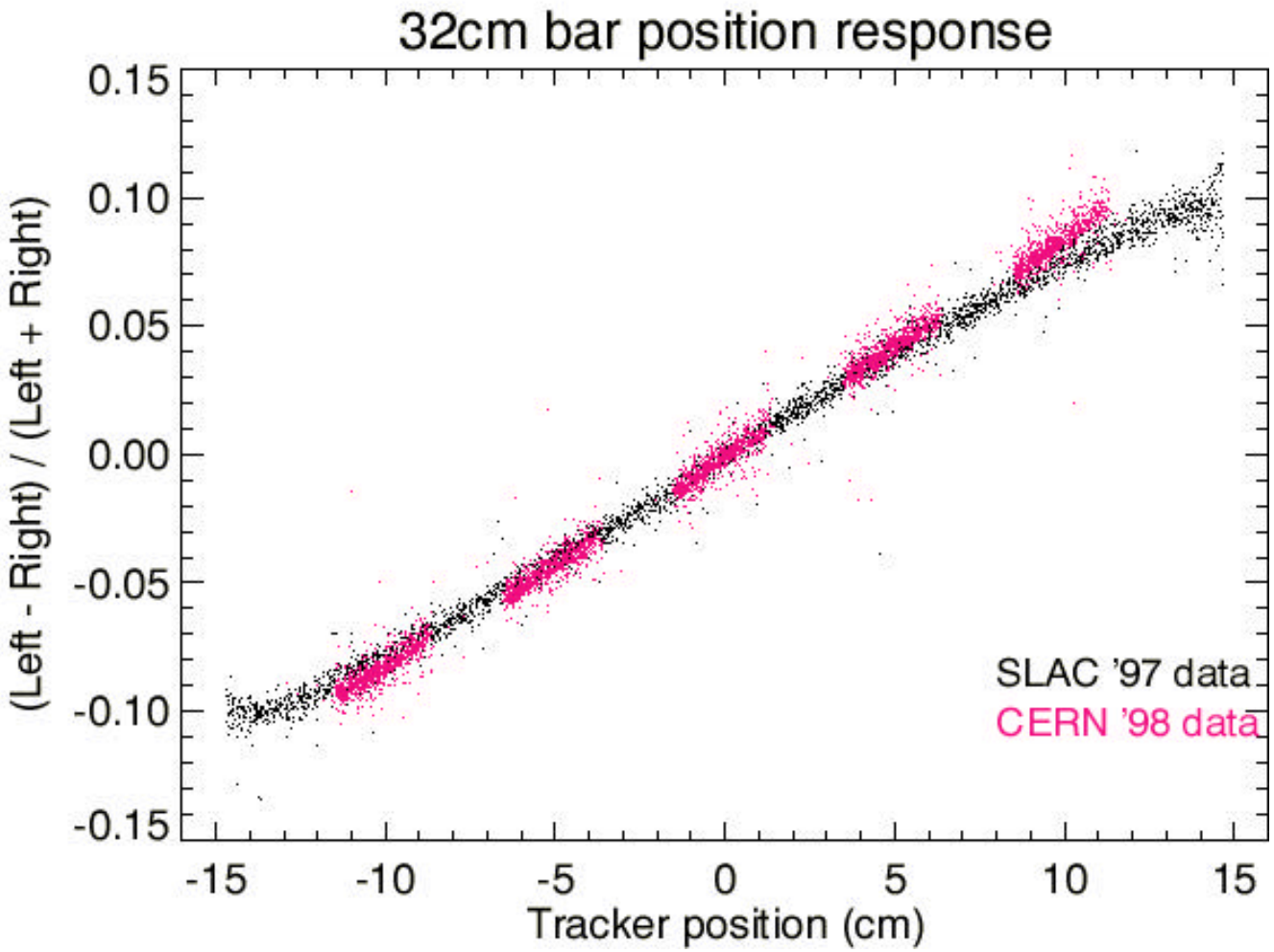
Positioning with Light Amplitude Ratio



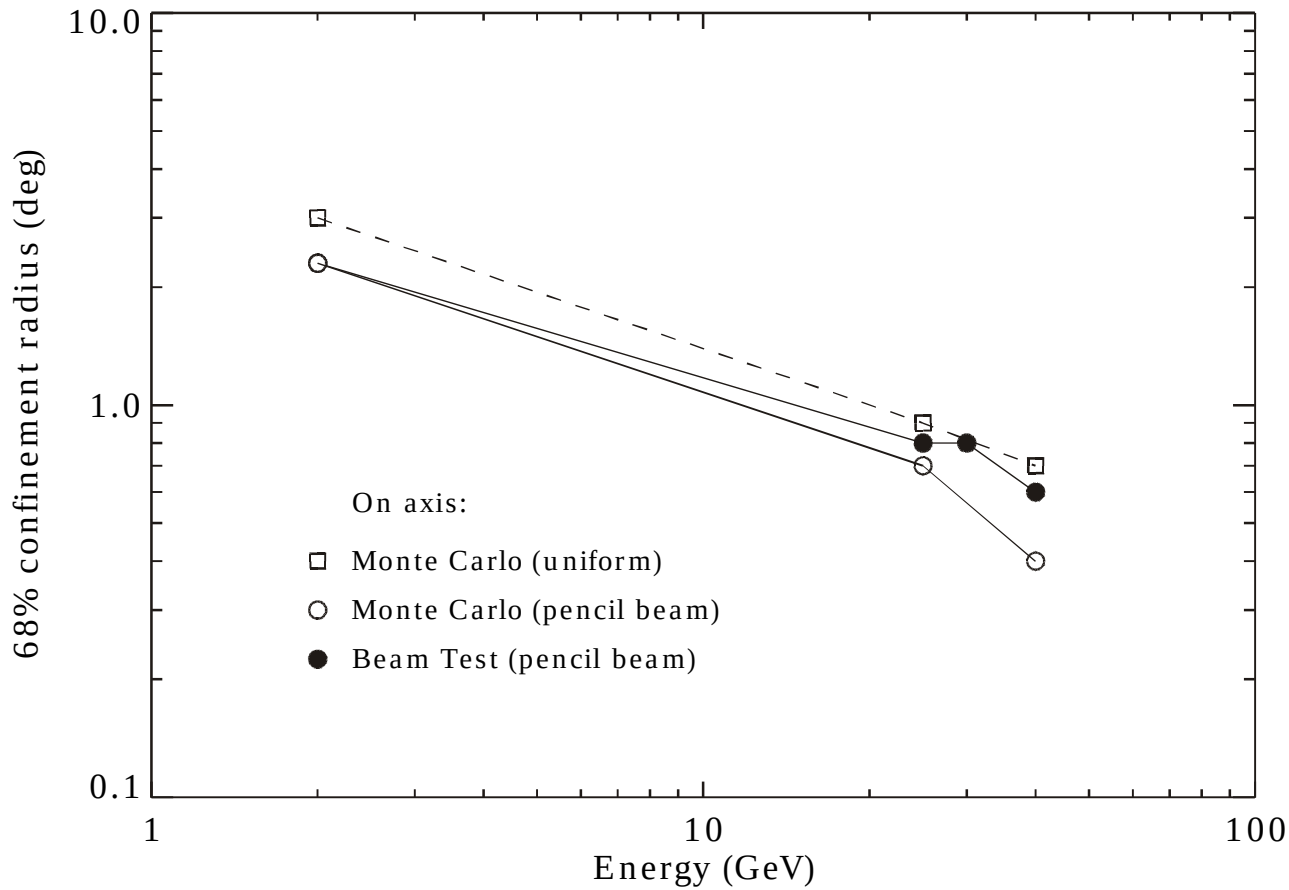
- SLAC e^- beam, 2 GeV
- $\Delta E \sim 130$ MeV



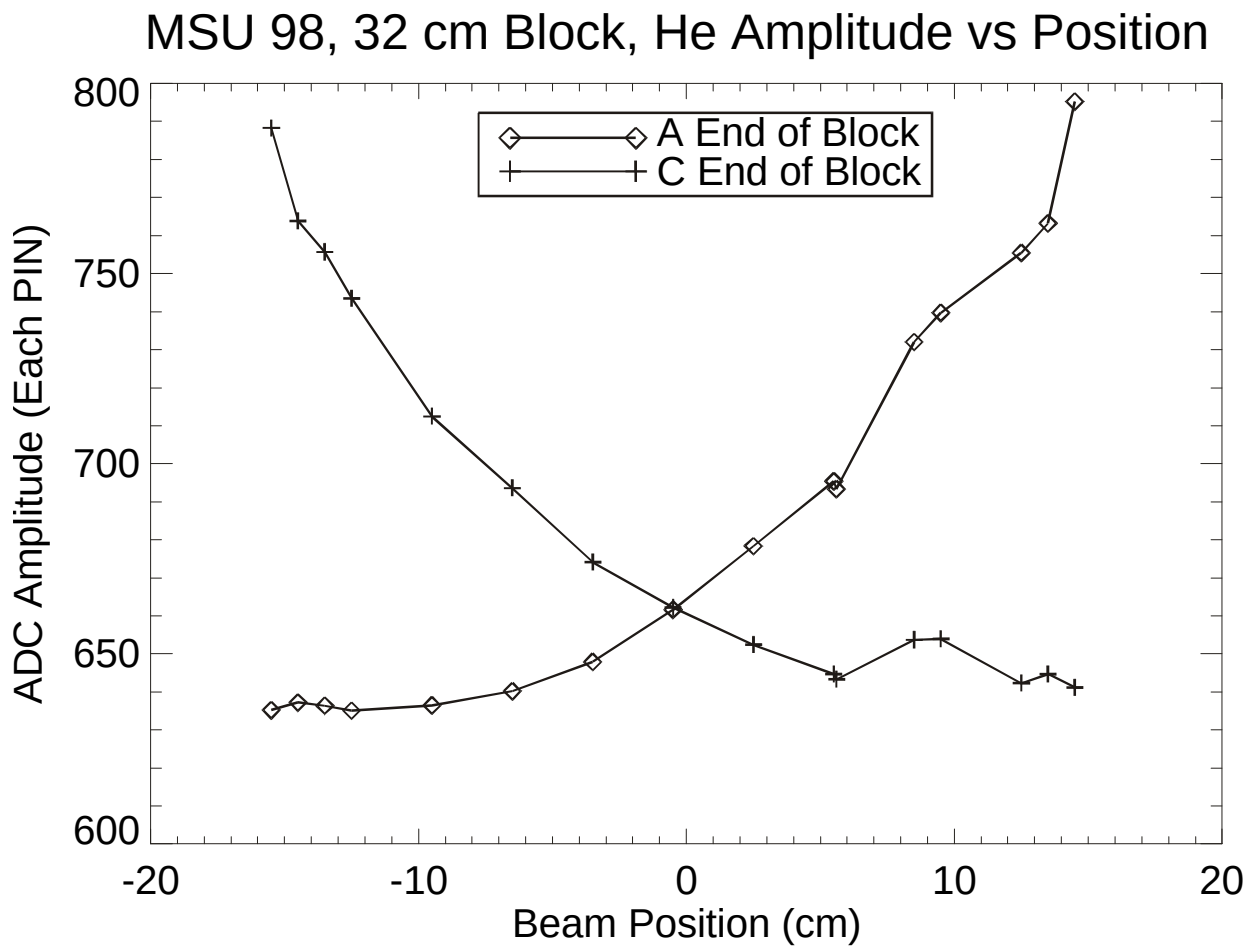
CERN Beam Test '98



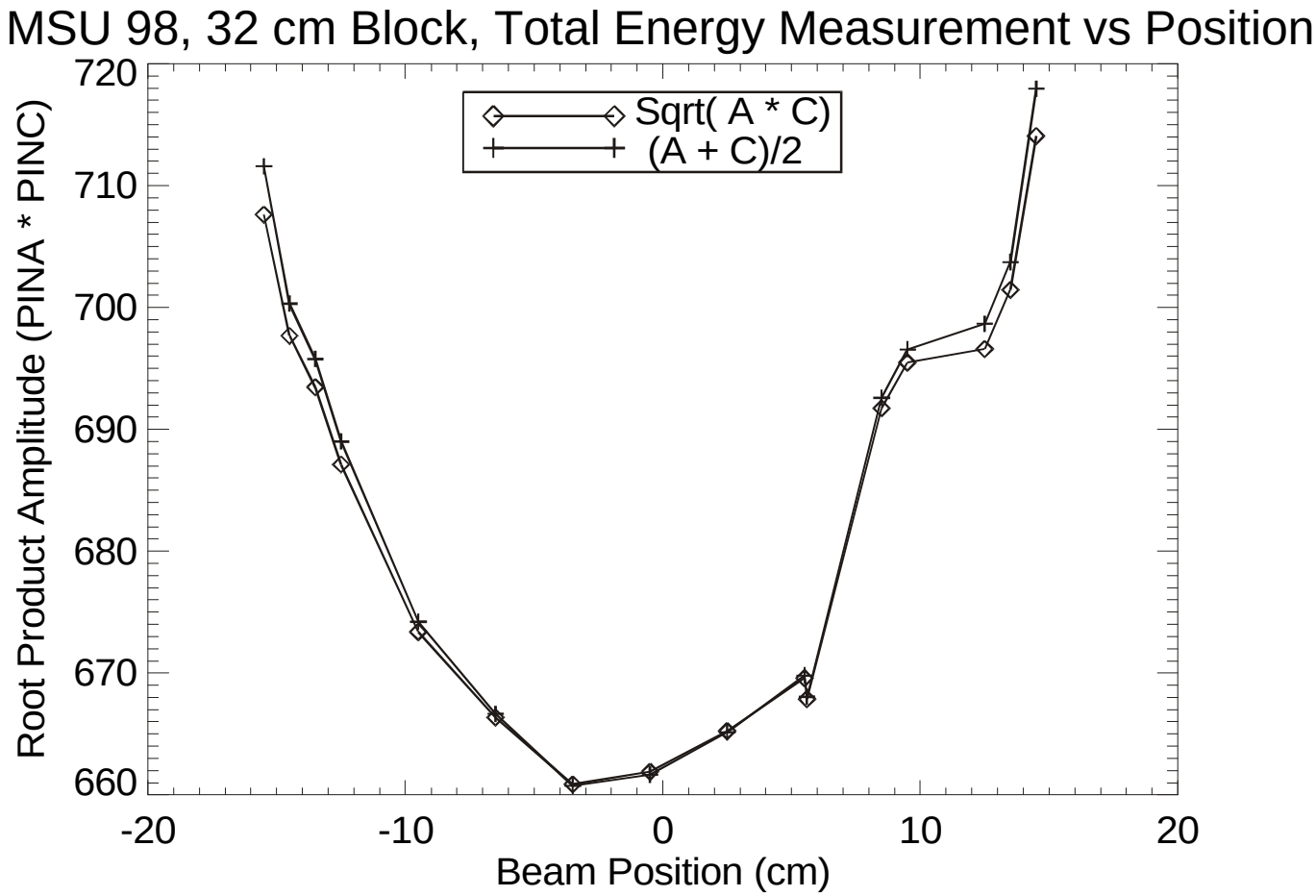
Prototype Calorimeter Angular Resolution



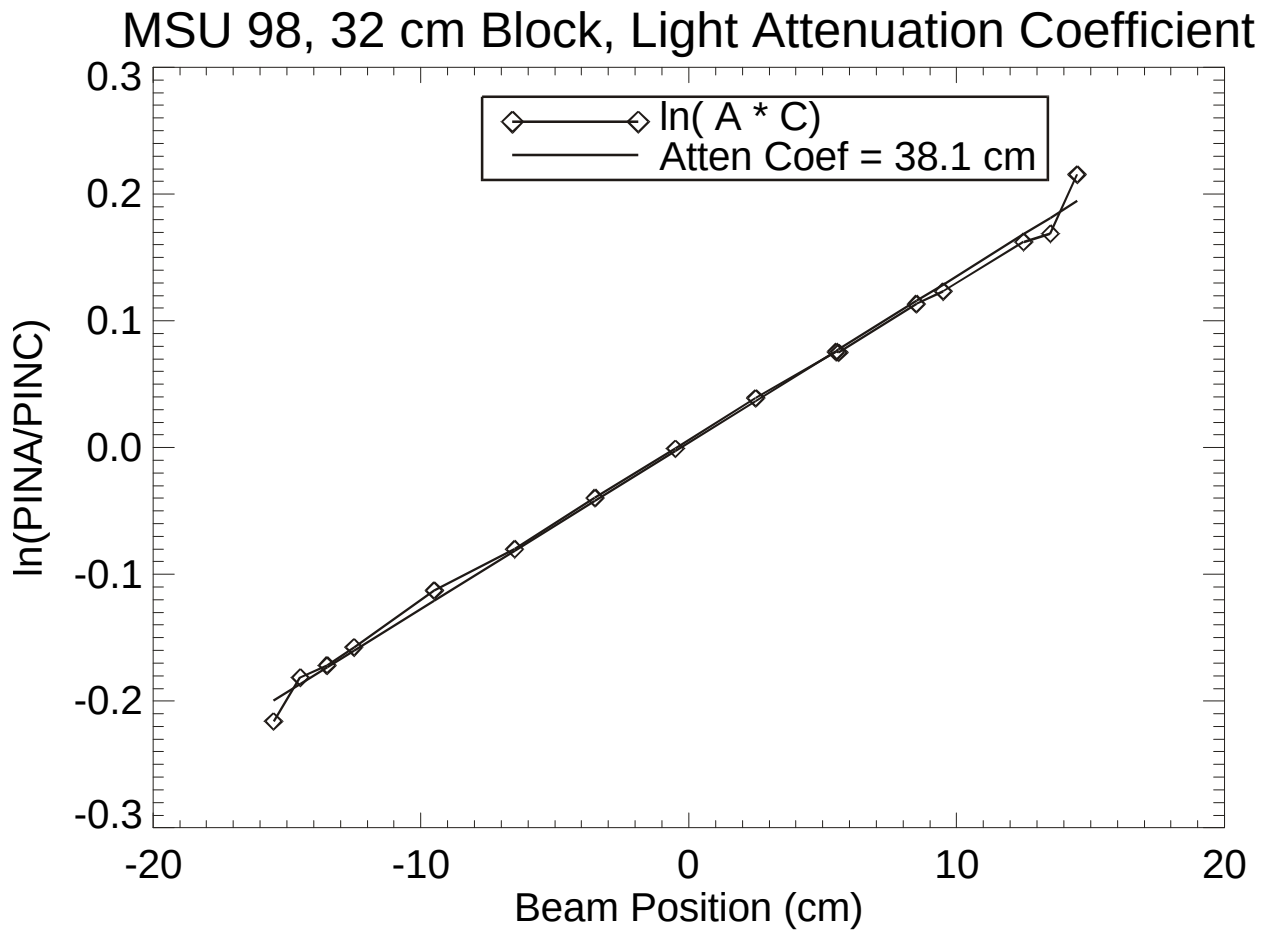
MSU Beam Test '98 - He Beam Amplitude vs Position

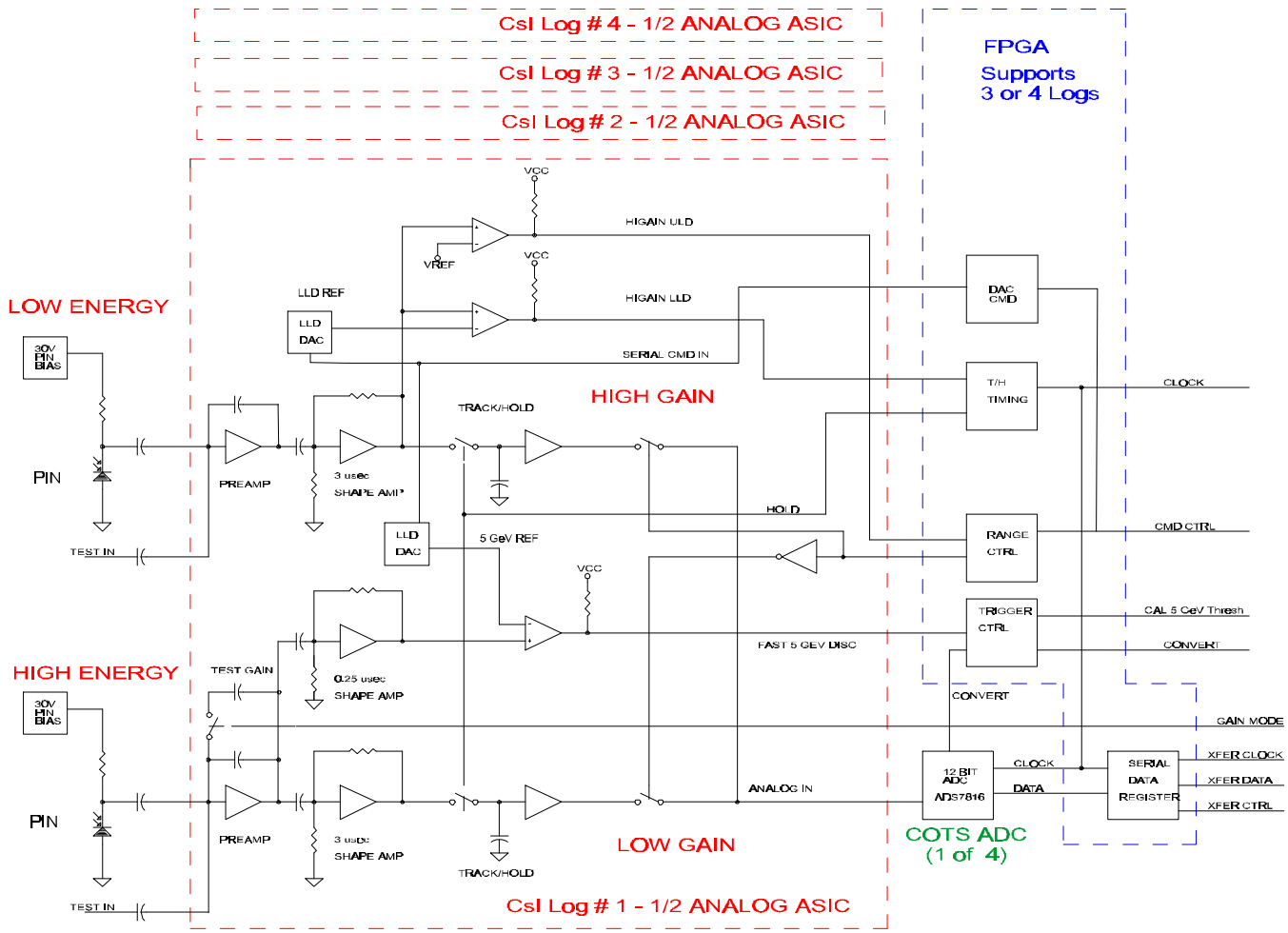


MSU Beam Test '98 - He Beam Total Amplitude vs Position



MSU Beam Test '98 - He Beam Light Attenuation Coefficient



Calorimeter Front End Electronics Concept

April '97 Concept