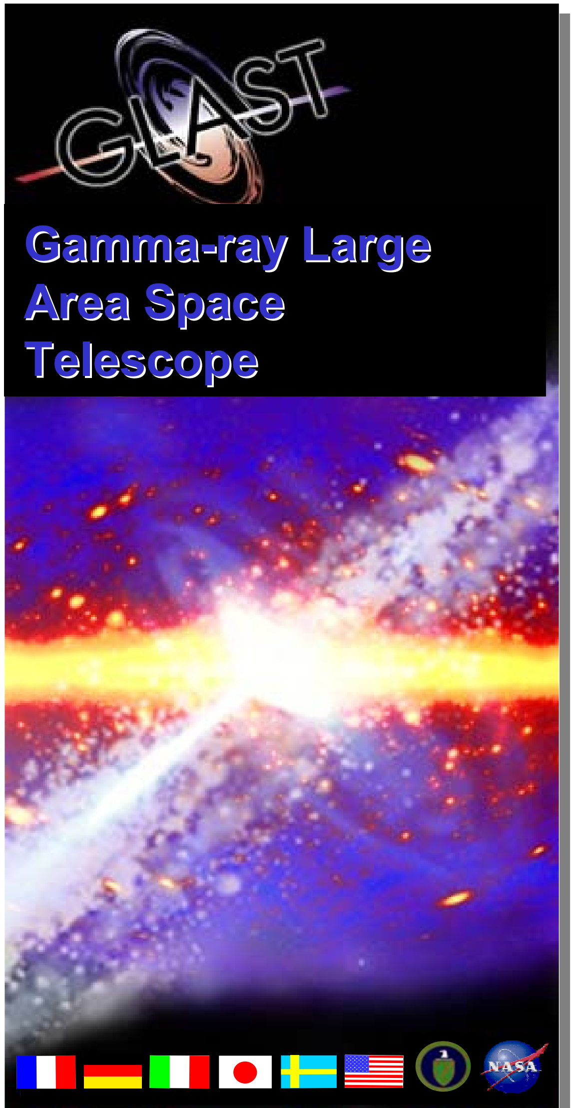


GLAST Large Area Telescope:

Calorimeter Ground Software

J. Eric Grove
Naval Research Lab, Washington DC
Calorimeter Ground Software Manager
grove@gamma.nrl.navy.mil

Outline

- Organization and Manpower
- Scope of Task
  - Energy reconstruction
  - Direction reconstruction
  - Calibration
- Work Plan

- Supporting materials

CAL Software Organization

- Calorimeter Subsystem Manager
  - W.N. Johnson (NRL)
- CAL Software Manager
  - J.E. Grove (NRL)
  - A. Djannati-Atai (CdF)
- CAL software team at NRL
  - Manpower
    - Scientists 1.25 FTE
    - Data Analyst 0.4 FTE
- CAL software team in France
  - Manpower
    - Scientists 1.5 FTE
    - Grad students 1.0 FTE
- Given 4.1 FTE in CAL team, WAG levels of effort allocation
  - Design & Doc (50%) 2.0 FTE
  - Coding (15%) 0.6 FTE
  - Testing/Running (35%) 1.5 FTE
  - Total 4.1 FTE
  - Note: not including CAL work at GSFC, SLAC, WU, …

Scope of Software Task

- Primary Responsibilities
  - CAL event reconstruction
    - Energy reconstruction
    - Direction reconstruction
  - CAL calibration
    - Electronic calibration
    - GCR calibration
- Secondary or Supporting Responsibilities
  - Simulation
  - Background rejection
  - State tracking
    - Performance state (e.g. dead channels)
    - Failure remediation
  - Instrument Response Function
    - Spectral deconvolution

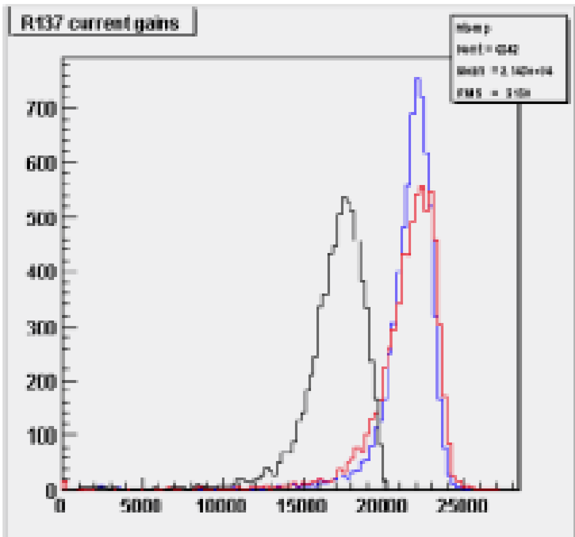
Energy Reconstruction

- Primary scientific function of calorimeter is to measure energy of incident photons
  - By design, segmentation of CAL provides opportunity to improve knowledge of photon E
  - To first order, incident energy is sum of signals in CsI
  - Several correction factors:
    - Energy loss in TKR
      - Dominant at low E (~100 MeV)
      - Correction: count hits in Si, scale by magic factor
      - Status: algorithm in use, but should be improved
        - » Work in progress in France
        - » Future work in coordination with TKR team
    - Longitudinal leakage
      - Dominant at high E (~100 GeV)
      - Correction: shower profiling or leakage correlation
      - Status: good algorithms in use

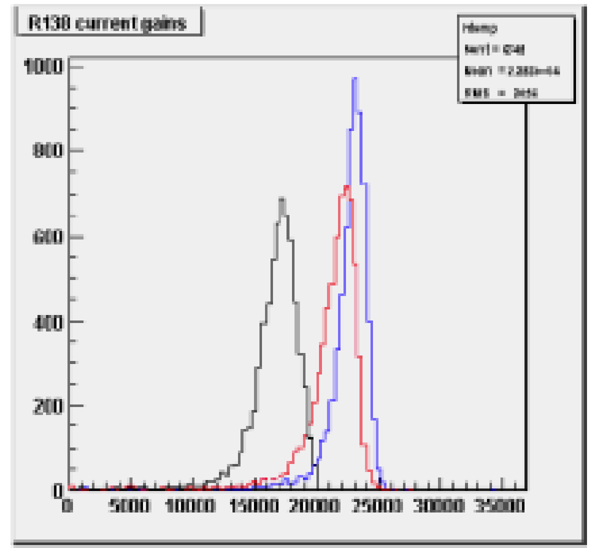
Energy reconstruction

- More correction factors...
  - Side leakage
    - ~10-20% of Aeff has significant escape out the side
    - Correction: same algorithms as longitudinal leakage
      - » Special cases, different coefs for leakage correlation
    - Status: in development in France
  - Passive material in CAL
    - Most important contributor: grid walls
    - Correction: change in profiling or correlation coefs
    - Status: in development in France
  - Direct deposition in PIN diodes
    - Small correction
    - Status: future work
- Iterative procedure
  - TKR needs CAL energy to seed its direction finder, and CAL needs TKR direction to generate correction factors
    - Status: algorithm exists, but will be rewritten

Energy Resolution



sum	7%
profile fitting	5.3%
correlation	3.9%



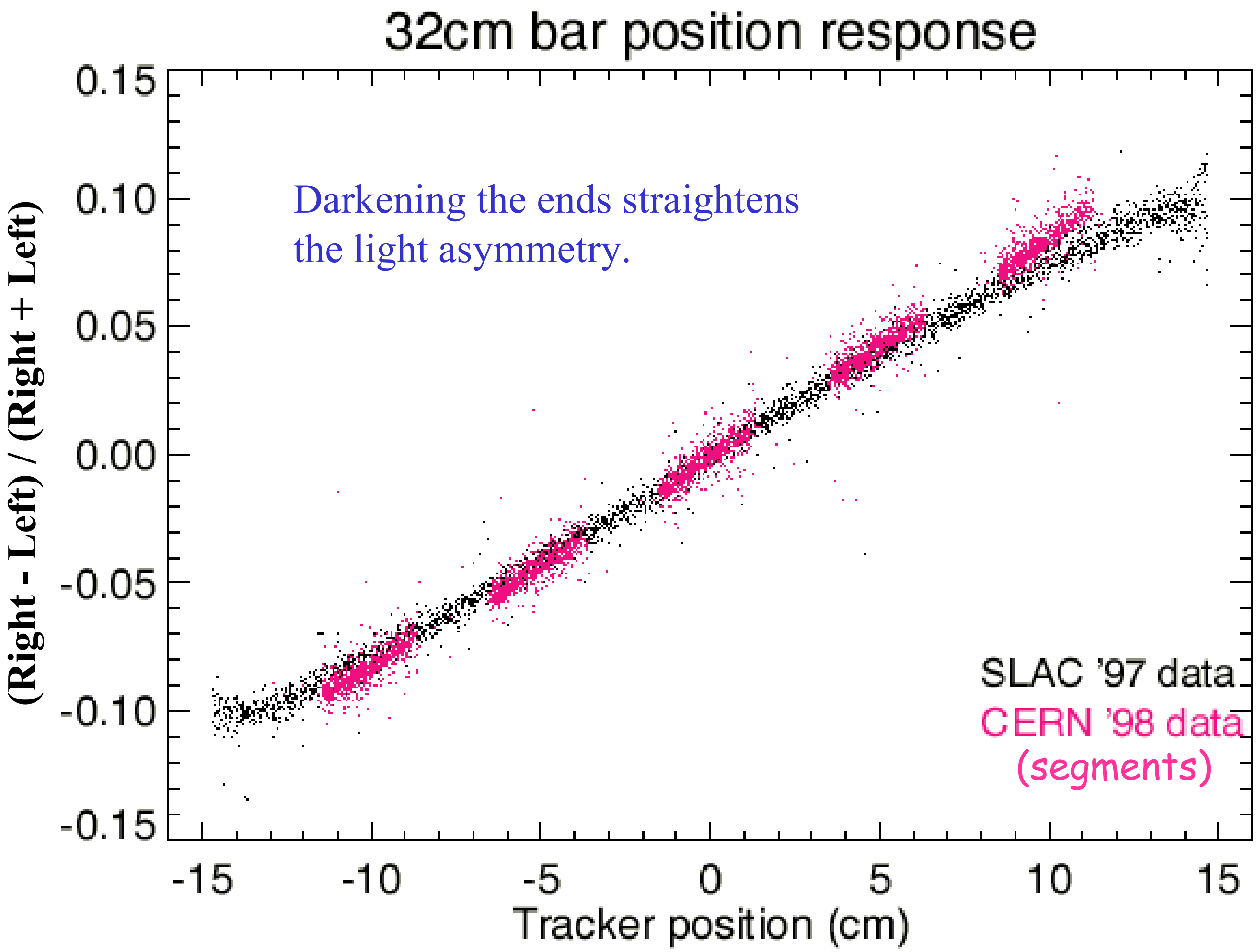
sum	7.2%
profile fitting	4.8%
correlation	3.8%

- How well does it work?
  - Beam test of prototype CAL

Direction reconstruction

- By design, the CAL is hodoscopic
  - Useful for
    - Background rejection
    - Calorimeter-only trajectories
  - Shower passage through xtal has three coordinates, two from xtal ID and a third at the Center of Light (CoL) position
    - Use light asymmetry to measure CoL
      - Status: good algorithm in use
        - » Depends on good asymmetry maps, to be updated
    - Ensemble of position measurements gives incident direction
      - Status: basic algorithm in use
        - » Two 2D projections
        - » Future work on other algorithms

Positioning by “light asymmetry”



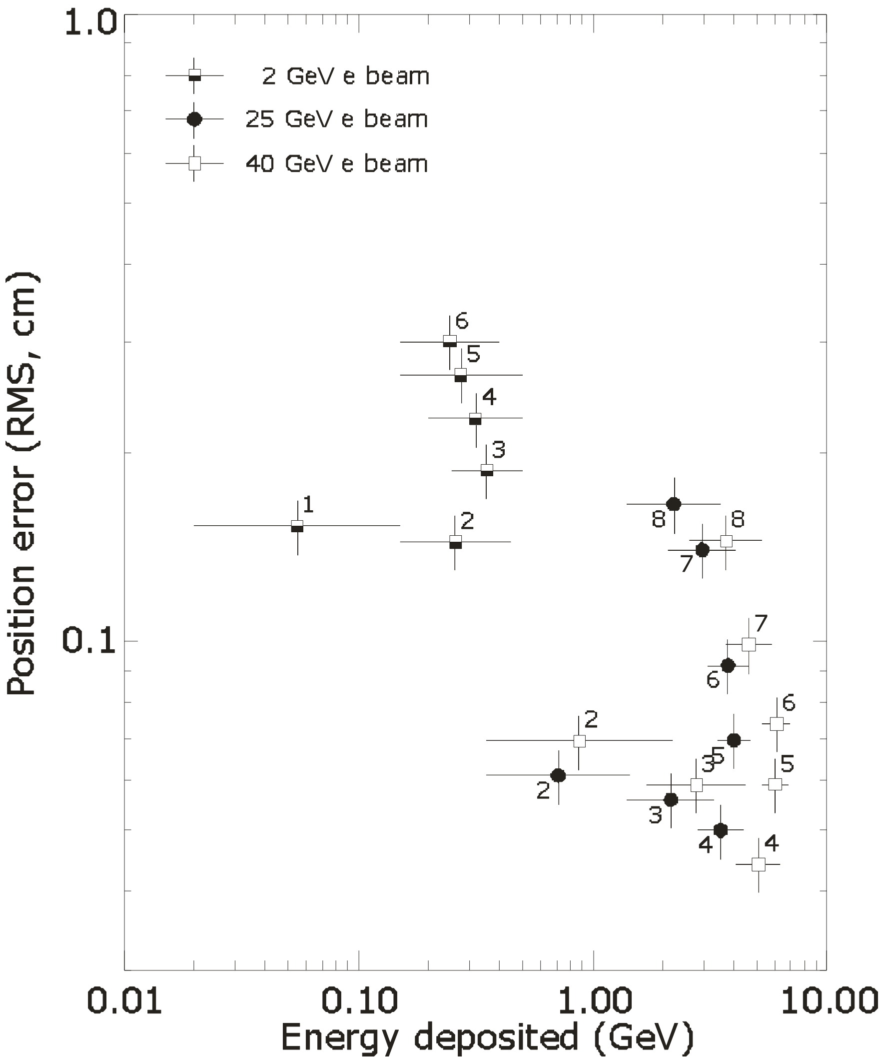
Position Resolution, SLAC ’97 Beam

Longitudinal position resolution:

- σ_x = 0.04 cm - 0.4 cm.
- 3 × 3 × 19 cm crystals.

Position resolution is a function of:

- Slope of asymmetry measure;
- Energy deposited in crystal;
- Shower multiplicity;
- Transverse shower development.



Calibration Needs

- What needs to be calibrated?
  - CAL needs to make energy and position measurements
    - Gain scale (conversion of ADC bins to MeV)
    - Map of scintillation response
- How often?
  - Timescales likely to be ~ months to year (TBR).
- Where do the data come from?
  - Ground calibration of Engineering Model (EM), Qual Module (QM), Calibration Unit (CU), Flight Modules (FMs)
  - Beam tests of EM, CU
  - In-flight calibration of FM

Calorimeter Calibration

- Functional requirements (top level)
  - Pedestals: FSW shall generate the pedestal centroid and width for each gain range for each PIN diode.
    - Pedestal centroid and width for 12288 channels.
    - Code exists, in use; need similar flight s/w process.
  - Electronic gain: eCalib shall generate a linear gain model for each gain range for each PIN diode.
    - Gain slope (bins/fC), slope uncertainty, offset, offset uncertainty for 12288 channels.
    - Prototype code exists, in use.
  - Integral non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - ~50 ordered pairs (pulse input, ADC output) for 12288 channels.
    - Prototype code exists, in use.
  - Differential non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - ~4000 values (ΔADC output) for 12288 channels.
    - No code exists.

Calorimeter Calibration

- Functional requirements (top level)
  - Scintillation efficiency: pre-flight beam tests shall determine scintillation efficiency (i.e. light yield as fcn of GCR charge) for sample crystals.
    - TBD (~5) coeffs and uncertainties.
    - No code exists
  - Light yield: GCRCalib shall calculate the light yield (i.e. electrons per MeV) at the center of each log for each PIN diode.
    - Light yield, statistical error, systematic error for 6144 diodes.
    - Prototype code exists, in use.
  - Light attenuation: GCRCalib shall produce maps of light attenuation (i.e. light yield as a fcn of longitudinal position) for each face (P, M) and the sum of faces (P+M) for each log.
    - TBD (~6) coeffs and uncertainties for 9216 maps.
    - Prototype code exists, in use.
  - Light asymmetry: GCRCalib shall produce maps of light asymmetry (i.e. (P-M)/(P+M) as a fcn of longitudinal position) for each log.
    - TBD (~6) coeffs and uncertainties for 3072 xtals.
    - Prototype code exists, in use.

Work Plan

- High priority, short term
  - Calibration s/w (ground calibration) Due 5/02
  - Simulation support: Due 5/02
    - Digi algorithms (ideal and realistic instrument)
    - Add heavy ion physics to G4 package
  - On-going support for sim and recon
- Moderate priority, intermediate term
  - Iterative recon Due 10/02
  - Generalizing leakage-correlation algorithm
  - GCR calibration s/w
- Low priority, long term
  - On-going support for sim and recon
  - State tracking, failure mitigation in recon

Supporting Materials

- Appendix 1: Energy reconstruction
- Appendix 2: Direction reconstruction
- Appendix 3: Iterative recon
- Appendix 4: Calibration requirements
- Appendix 5: Cosmic ray calibration
- Appendix 6: State tracking
- Appendix 7: Spectral deconvolution

Appendix 1: Energy Reconstruction

- Primary scientific fcn of CAL is to measure energy of incident photons.
  - Much of the incident energy escapes the calorimeter
    - At low E, small fraction of E reaches CAL.
      - For Einc = 100 MeV, <Eobs> ~ 50 MeV
    - At high E, most E blows out the back.
      - For Einc = 100 GeV, <Eobs> ~ 40 GeV
- By design, segmentation of CAL provides opportunity to improve knowledge of incident energy of photon.

- Functional requirements (top level)
  - Energy per xtal: Recon shall calculate the energy deposited within individual CsI xtals.
  - Incident energy: Recon shall estimate the incident photon/particle energy.

Appendix 1: Energy Reconstruction

- Correcting for energy escaping out the back of the CAL
  - Simplest: Geometric correction.
    - Look-up table corrects deposited energy and shower pathlength to typical incident energy.
      - Derived from mean shower profiles.
      - Resulting incident total energy will have low tail from shower fluctuations, late-starting showers.
  - More advanced: Shower-profile fitting.
    - Mean longitudinal profile is well-described by gamma distribution:

$$\frac{dE}{dx} \propto \frac{1}{\lambda}\left(\frac{x}{\lambda}\right)^{\alpha-1} e^{-x/\lambda}$$

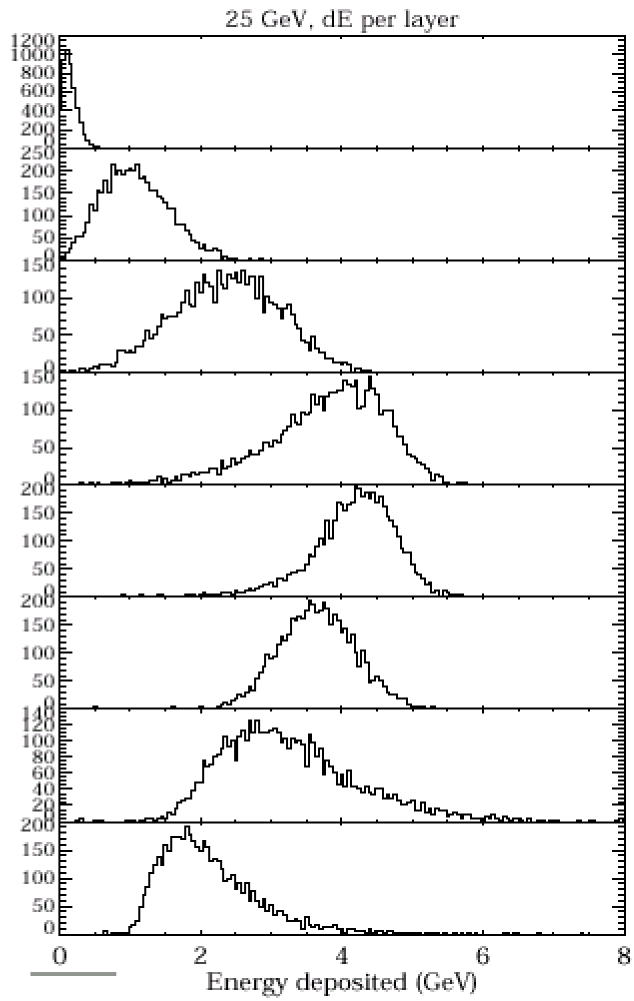
    - Profile fitting corrects the low E depositions of late-starting showers, i.e. it removes some of the low-energy tail
    - Shower fluctuations are *still* significant, shower leaks out the back of calorimeter.

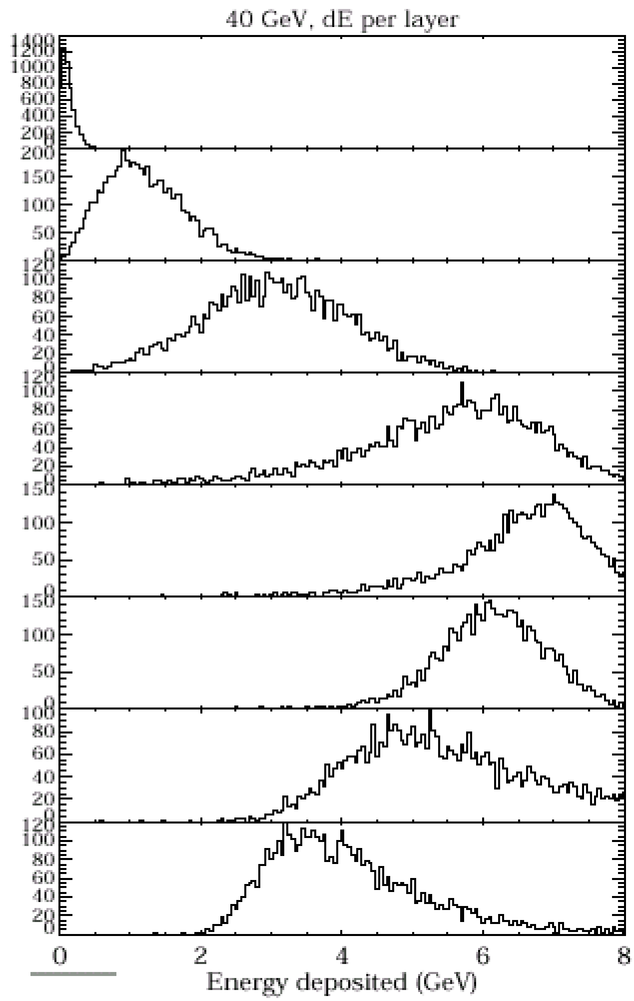
Appendix 1: Energy Reconstruction

- **Leakage correlation method**
  - Alternative to shower profile fitting
  - Amount of energy leaking out the back of the CAL is related to the number of daughters escaping the last layer.
    - Best estimate of number of daughters escaping is energy deposited in last layer.
      - $Einc = Esum + \beta(Esum) \times Elast$
      - $\beta(Esum) \approx 1.1 + 0.56 \times Esum[GeV]$
  - Works as long as shower maximum is within CAL.
    - Gives better energy resolution than shower profiling.

Appendix 1: Energy Reconstruction

- Shower profile fitting
  - Mean longitudinal profile is well-described by gamma distribution: $$\frac{dE}{dx} \propto \frac{1}{\lambda}\left(\frac{x}{\lambda}\right)^{\alpha-1} e^{-x/\lambda}$$
  - Code exists and is in use
- Leakage correlation
  - Amount of energy leaking out back of CAL is related to number of daughters escaping last CAL layer.
    - Best estimate of number of daughters is energy deposited in last layer
      - $\text{Einc} = \text{Esum} + \beta(\text{Esum},\theta) \times \text{Elast}$
  - Code exists, is in use, needs generalization
- Leakage correlation generally gives better resolution than profiling


25 GeV, dE per layer
Energy deposited (GeV)
0
2
4
6
8


40 GeV, dE per layer
Energy deposited (GeV)
0
2
4
6
8

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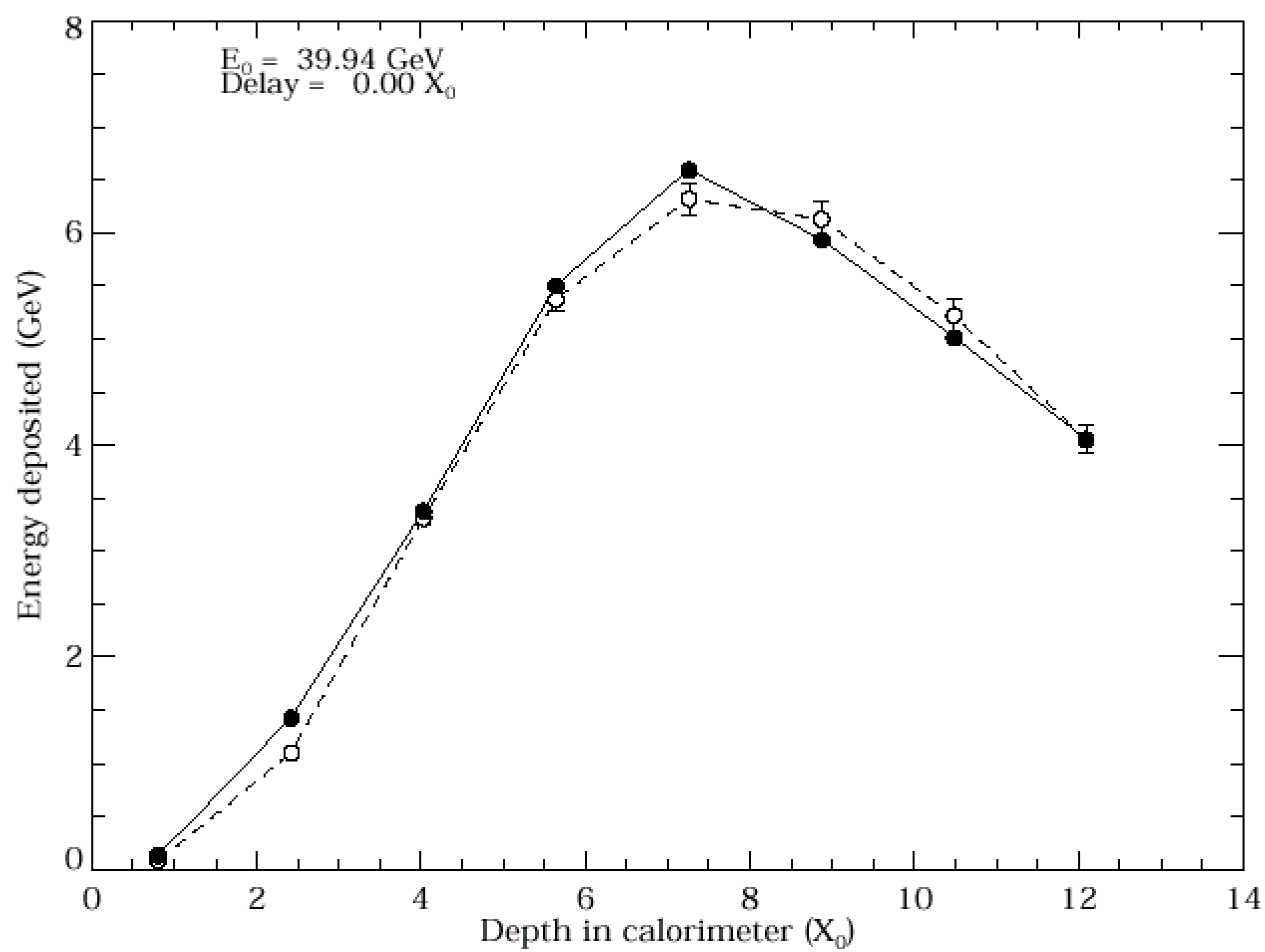
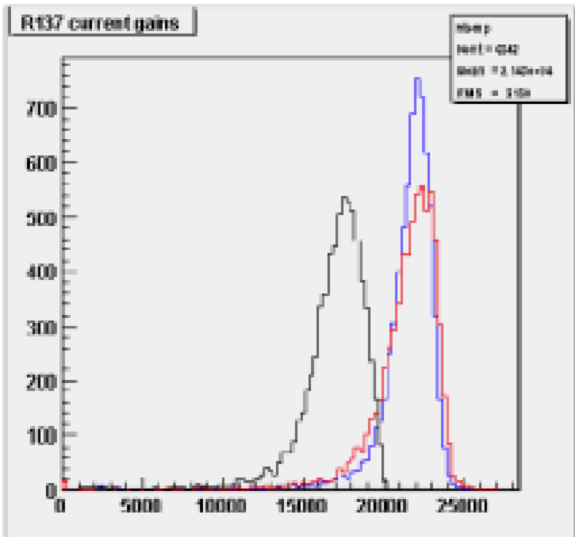


Appendix 1: Energy Resolution



sum	7%
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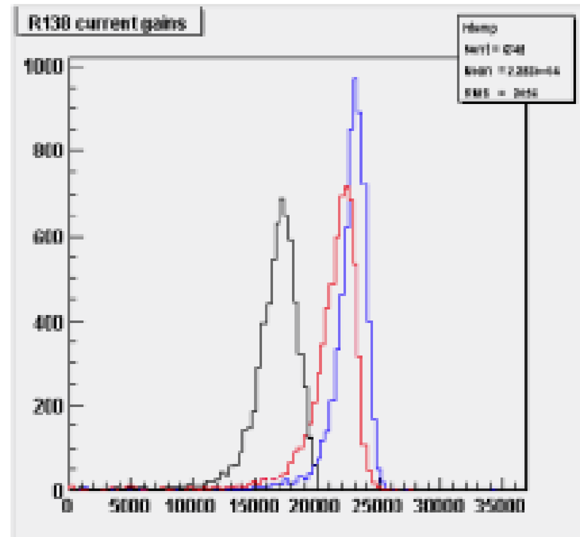


sum	7.2%
profile fitting	4.8%
correlation	3.8%

- ❑ **How well does it work?**
  - **Beam test of prototype CAL**

Appendix 1: Energy Reconstruction

- **Energy loss in TKR**
  - To increase the effective area (by increasing the pair-conversion efficiency), the last layers of the TKR have thicker radiators.
  - Below ~200 MeV, significant energy is lost in TKR ***before*** CAL.
  - How can we correct for energy loss in passive material?
    - Idea: Energy lost in radiators is related to number of hits in Si layers surrounding them.
      - $\Delta E_{Tkr} = \sum \alpha_{lay} \, Nhits_{lay}$
    - Better idea: TKR event reconstruction connects the hits in Si; thus they could estimate number of particles *and* pathlength through radiator.

Appendix 2: Direction Reconstruction

- Calorimeter-only trajectories
  - By design, the CAL is hodoscopic
    - Shower passage through xtal has three coordinates, two according to xtal ID and a third at the Center of Light position
    - Ensemble of position measurements gives incident direction
  - TKR has primary responsibility of shower imaging, but
    - Conversion deep in TKR can benefit from CAL information
    - Low-E photons may benefit from CAL clustering (i.e. energy per pair daughter)
    - CAL-only imaging may be useful in some cases (e.g. timing studies)

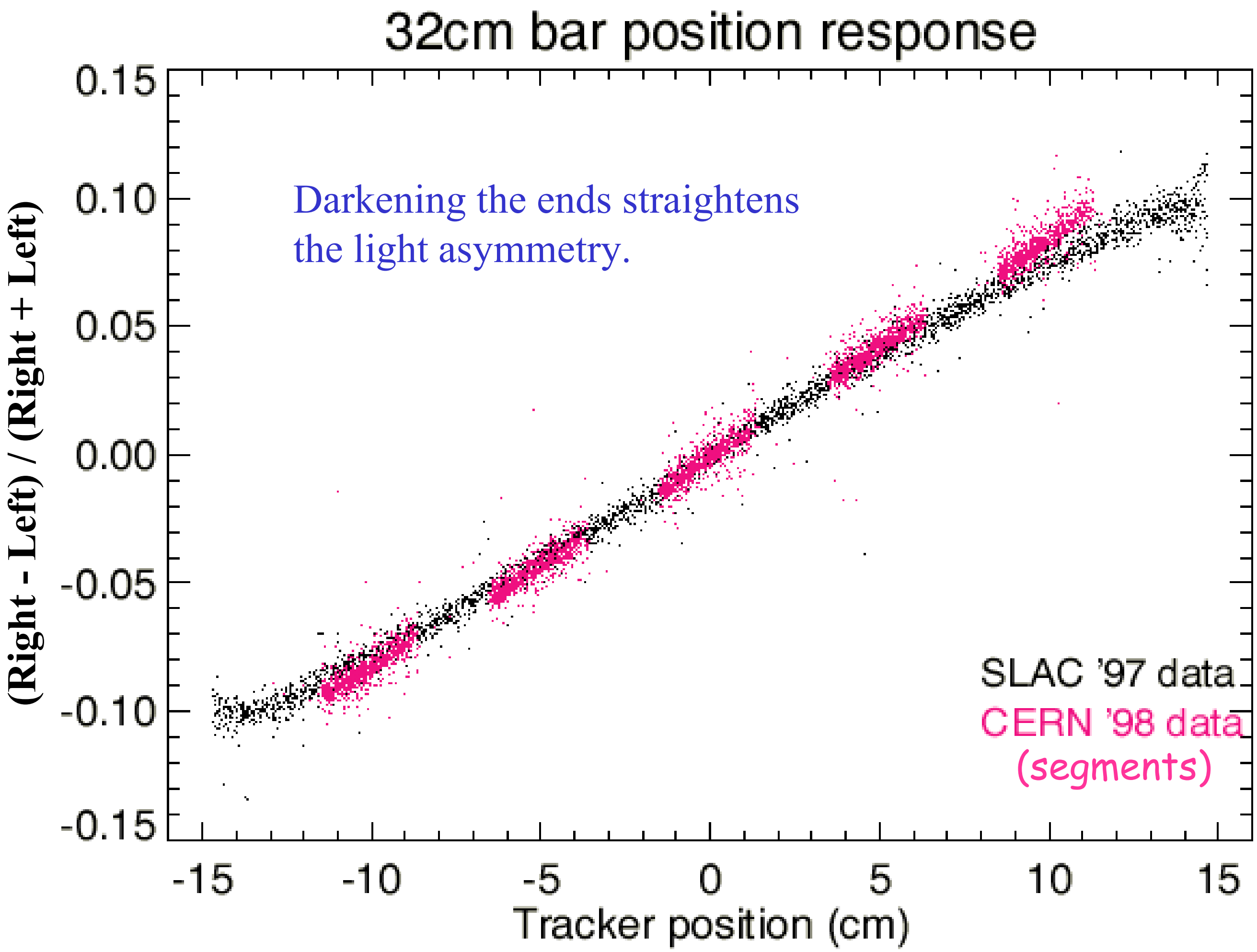
- Functional requirements (top level)
  - Position calculation: Recon shall calculate positions of interactions within individual CsI xtals.
  - Direction calculation: Recon shall estimate the incident photon direction from CAL information, and support TKR direction recon.

Appendix 2: Position Reconstruction

- Each crystal provides three spatial coordinates for ΔE.
  - Xtal ID gives two coordinates, z and x or y.
    - Gives resolution $\sigma_z = 20/\sqrt{12} = 6$ mm and systematic bias to center of xtal
  - Difference in signal between ends of xtal gives third coordinate.
    - "Longitudinal" position
    - Gives much better resolution, $\sigma_x = 0.4 - 3$ mm, and no bias.
    - Resolution is fcn of ΔE, spread of shower, and shower multiplicity
- Longitudinal position determination
  - If light falls linearly with distance along xtal, then position is *proportional* to difference in signals at two ends.
  - Scaling the difference by the total light removes the energy dependence from the position.
  - Thus, the "light asymmetry measure"

$$A = \frac{(Right - Left)}{(Right + Left)}$$

App 2: Positioning by "light asymmetry"



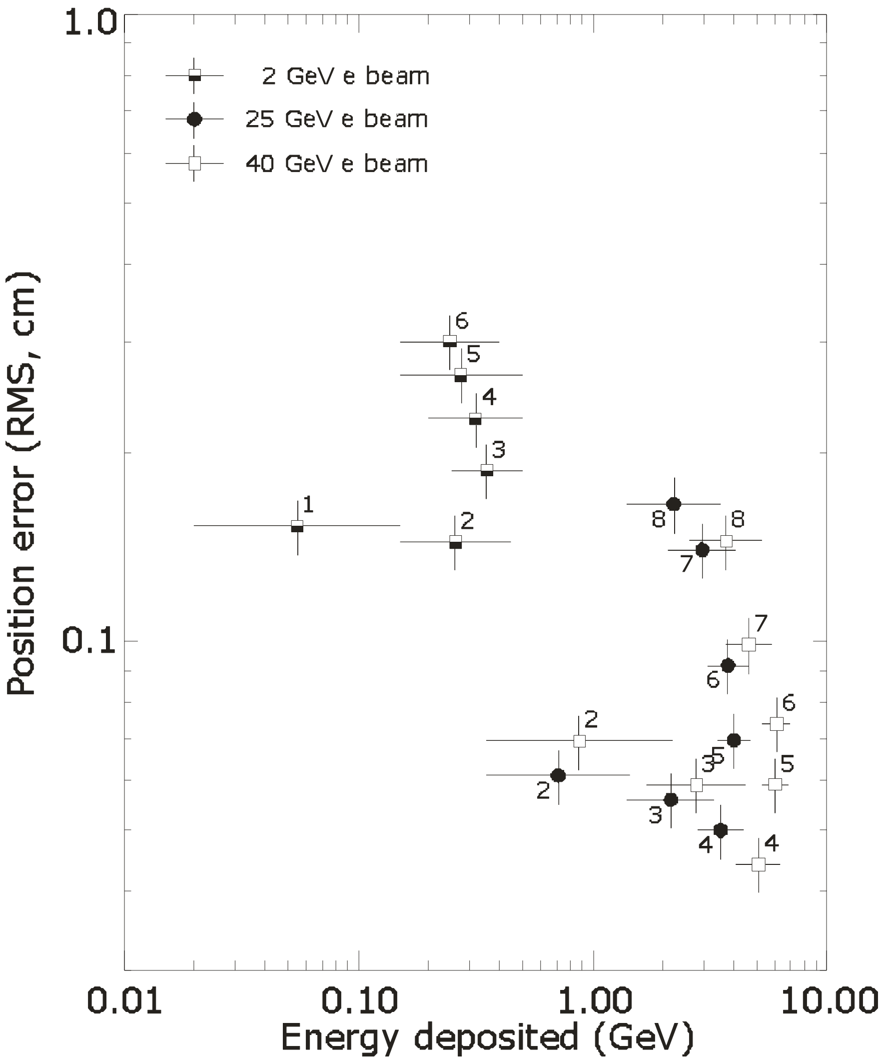
App 2: Position Resolution, SLAC '97 Beam

Longitudinal position resolution:

- σ_x = 0.04 cm - 0.4 cm.
- 3 × 3 × 19 cm crystals.

Position resolution is a function of:

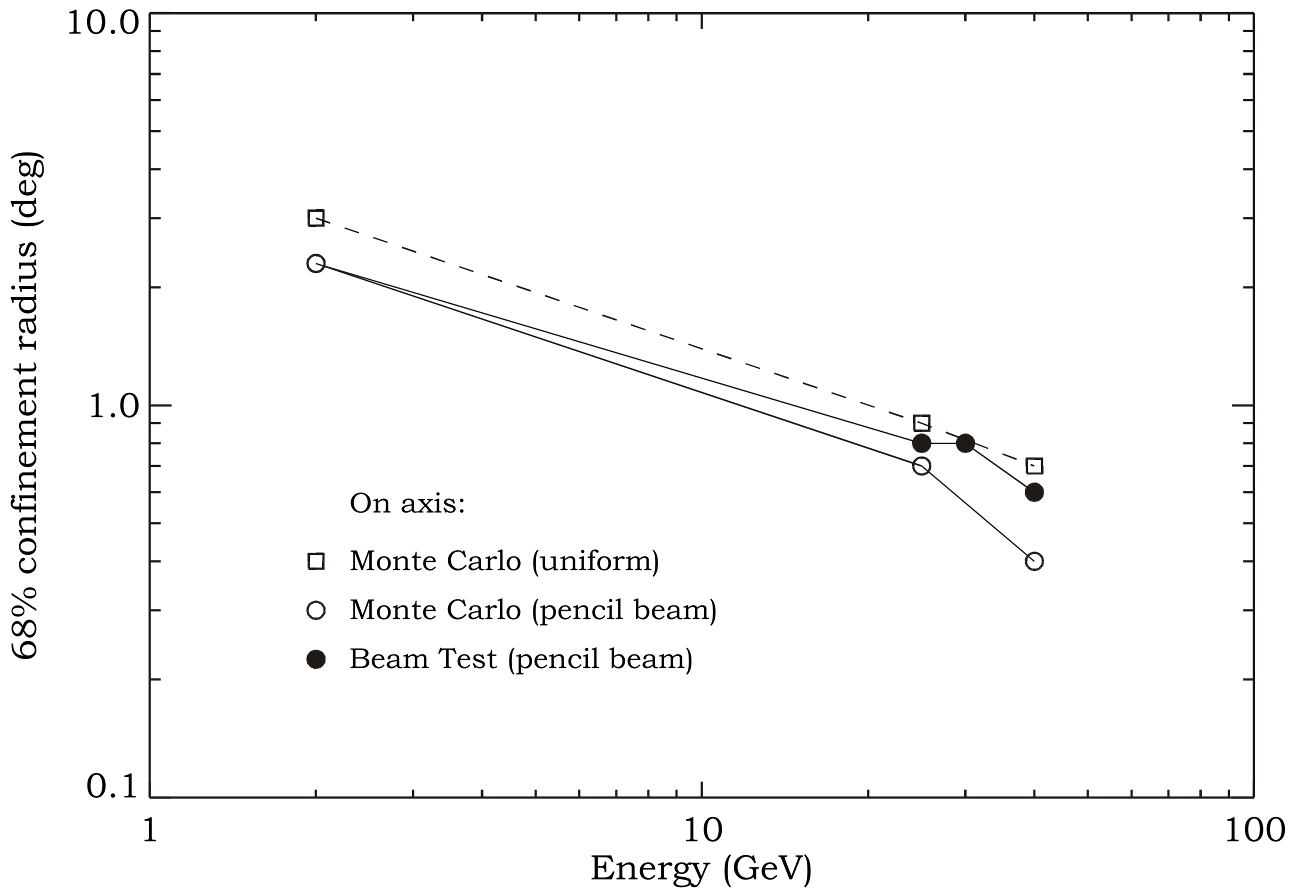
- Slope of asymmetry measure;
- Energy deposited in crystal;
- Shower multiplicity;
- Transverse shower development.



Appendix 2: Direction Reconstruction

- How should we convert the positions in the xtals into an incident direction?
  - Typical number of xtals hit is ~30 (recall 8 layers).
  - Cloud of spatial coordinates with differing weights.
- Candidate algorithms
  - Minimize squared perpendicular distance to track axis
    - Uses longitudinal and xtal ID positions, uneven weights
    - Requires numerical search in 4-D parameter space
  - Minimize squared distance to each layer crossing
    - May use only longitudinal positions (which are more precise, unbiased)
    - Analytic solution in xz and yz planes. Very fast.
  - Connect the dots, top and bottom
    - Works quite well on corn-rows
  - And others…

CAL Angular Resolution, SLAC '97 Beam



Appendix 3: Iterative Recon

- Outline of process

1. CAL: Convert to charge units
   – Use electronic calib. Convert from ADC bins to charge at FEE.
2. CAL: Calculate energy in each xtal
   – Convert to MeV at center of xtal. Assume position = center of xtal.
3. CAL: Calculate total energy deposited
   – Simple xtal sum
4. CAL+TKR: Make simple energy corrections
   – Scale by avg-profile correction, f(Eobs,θ)?
   – Add simple TKR energy correction, i.e. scale by num hits?
5. CAL: Simple energy centroid
   – Calculate centroid in XZ and YZ planes using logID positions.

Appendix 3: Iterative Recon

- Outline of process (cont.)

5. TKR: Direction recon
   - Insert the real TKR stuff.
6. TKR: Energy recon
   - Do the best TKR energy-loss correction, following daughters or whatever.
7. CAL: Recalculate energy in each xtal
   - Use TKR direction. Accounts for failures and light tapering maps.
8. CAL: Recalculate total energy deposited
   - Total all xtal energies, having accounted for failures and taper.
9. CAL: Recalculate simple energy centroid
   - Repeat simple centroid, having accounted for failures and taper.

Appendix 3: Iterative Recon

- Outline of process (cont.)

10. ACD+CAL+TKR: Particle ID (necessary here, or later?)
    – Some complicated algorithms to confirm photon or particle.
11. TKR(+CAL): Direction recon
    – Do the real TKR direction recon. Use CAL info to improve direction for late conversions, if possible.
12. CAL+TKR: Energy recon
    – Use best CAL and TKR information to estimate incident energy.
    – Use profiling, leakage correlation, TKR info, whatever.
13. Iterate steps 10-12 as necessary

Appendix 4: Calibration Requirements

- Pedestal Calibration
  - Pedestals: FSW shall generate the pedestal centroid and width for each gain range for each PIN diode.
    - Pedestal centroid and width for 12288 channels.
  - Generated when?
    - Module Assy & Test at NRL
    - Instrument I&T at SLAC
    - S/C integration and end-to-end at ??
    - Flight
      - Updated ~ monthly?
  - Generated how?
    - Flight s/w process (or TEM simulator) histograms, fits centroid and width, telemeters centroid and width. Diagnostic mode telems histograms.
  - Data volume
    - 2 x 12288 floats = 103kB per month
  - Status
    - Prototyped in IDL, find_pedestals.pro, and ROOT
    - Needed for EM

Appendix 4: Calibration Requirements

- Electronic Gain Calibration
  - Electronic gain: eCalib shall generate a linear gain model for each gain range for each PIN diode.
    - Gain slope (bins/fC), slope uncertainty, offset, offset uncertainty for 12288 channels.
  - Generated when?
    - Module Assy & Test at NRL
    - Instrument I&T at SLAC, CU at SLAC etc.
    - S/C integration and end-to-end at ??
    - Flight
      - Updated ~ quarterly?
  - Generated how?
    - Data created by on-board chg-calib process, telem in calib mode.
    - GSW identifies two fiducial charge peaks, fits line.
  - Data volume
    - 4 x 12288 floats = 200kB per month
  - Status
    - Prototyped in IDL, fit_intlin_fits.pro
    - Needed for EM

Appendix 4: Calibration Requirements

- Integral Non-Linearity Calibration
  - Integral non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - ~50 ordered pairs (pulse input, ADC output) for 12288 channels.
  - Generated when?
    - Module Assy & Test at NRL
    - Instrument I&T at SLAC, CU at SLAC etc.
    - S/C integration and end-to-end at ??
    - Flight
      - Updated ~ quarterly?
  - Generated how?
    - Data created by on-board chg-calib process, telem in calib mode.
    - GSW fits all charge peaks, matches with input charge.
  - Data volume
    - ~100 x 12288 long integers = 5.2MB per month
  - Status
    - Prototyped in IDL, fit_intlin.pro
    - Needed for EM

Appendix 4: Calibration Requirements

- Differential Non-Linearity Calibration
  - Differential non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - ~4000 values (ΔADC output) for 12288 channels.
  - Generated when?
    - Module Assy & Test at NRL
    - Instrument I&T at SLAC
    - Flight
      - Updated ~ annually or less often
  - Generated how?
    - Ground: ramp the charge injector, look for steps in output.
    - Flight: look for steps in CDB, make it smooth.
  - Data volume
    - ~4000 x 12288 long integers = 200MB per year
  - Status
    - Not started, conceptual only
    - Not needed for EM, but will test

Appendix 4: Calibration Requirements

- Scintillation Efficiency Calibration
  - Scintillation efficiency: pre-flight beam tests shall determine scintillation efficiency (i.e. light yield as fcn of GCR charge) for sample crystals.
    - TBD (~5) coeffs and uncertainties. How many xtals?
  - Generated when?
    - Calibration Unit
    - Other xtal samples?
    - Never updated.
  - Generated how?
    - Heavy ion beam tests of CU and maybe test crystals.
    - Fit dL/dE, a fcn of Z.
  - Data volume
    - I dunno. Not much. Never updated.
  - Status
    - No serious code exists yet, just some playing in IDL.
    - Not needed for EM. Will be measured with EM.

Appendix 4: Calibration Requirements

- **Light Yield Calibration**
  - **Light yield:** GCRCalib shall **calculate the light yield** (i.e. electrons per MeV) at the center of each log for each PIN diode.
    - Light yield, statistical error, systematic error for 6144 diodes.
  - Generated when?
    - Module Assy & Test at NRL, with muons
    - Instrument I&T at SLAC, CU at SLAC etc., with muons & nuclei
    - S/C integration and end-to-end at ?? With muons
    - Flight, with GCRs
      - Updated ~ monthly?
  - Generated how?
    - From muons, heavy ion beams, or GCRs, telemetered in calib mode.
    - For muons, define beam geometry through xtals, select MIPs, and fit Landau.
    - For GCRs, complicated process described elsewhere.
  - Data volume
    - 3 x 6144 floats = 80kB per month
  - Status
    - For muons, prototyped in IDL, mu_checkout.pro
    - For GCRs, algorithm outlined but not coded or tested.
    - Needed for EM.

Appendix 4: Calibration Requirements

- Light Attenuation Calibration
  - Light attenuation: GCRCalib shall produce maps of light attenuation (i.e. light yield as a fcn of longitudinal position) for each face (P, M) and the sum of faces (P+M) for each log.
    - TBD (~6) coeffs and uncertainties for 9216 maps.
  - Generated when?
    - Module Assy & Test at NRL, with muons. This is best dataset.
    - Instrument I&T at SLAC, CU at SLAC etc., verification
    - Flight, with GCRs
      - Updated ~ annually?
  - Generated how?
    - For muons, define beam geometry through xtals, select MIPs, and fit Landau.
    - For GCRs, complicated process described in Appendix.
  - Data volume
    - ~12 x 9216 floats = 450 kB per month
  - Status
    - Prototyped in IDL, mu_checkout.pro and find_slopes.pro
    - Needs more sophisticated attenuation model. GCR process needs work.
    - Needed for EM

Appendix 4: Calibration Requirements

- Light Asymmetry Calibration
  - Light asymmetry: GCRCalib shall produce maps of light asymmetry (i.e. (P-M)/(P+M) as a fcn of longitudinal position) for each log.
    - TBD (~6) coeffs and uncertainties for 3072 xtals.
  - Generated when?
    - Module Assy & Test at NRL, with muons. This is best dataset.
    - Instrument I&T at SLAC, CU at SLAC etc., verification
    - Flight, with GCRs
      - Updated ~ annually?
  - Generated how?
    - For muons, define beam geometry through xtals, select MIPs, and fit Landau.
    - For GCRs, complicated process described in Appendix.
  - Data volume
    - ~12 x 3072 floats = 150 kB per month
  - Status
    - Prototyped in IDL, mu_checkout.pro and find_slopes.pro, and ROOT.
    - Needs more sophisticated asymmetry model. GCR process needs work.
    - Needed for EM

Appendix 5: GCR Calibration

Cosmic Ray Calibration (new)

- High flux of GCRs gives good calibration over full dynamic range (see Appendix).
- Derive calibration with statistical precision of better than few % each day over full dynamic range.

He: ~140 Hz
CNO: ~10 Hz □ ~1100 per xtal per day
Si: ~0.4 Hz
Fe: ~0.8 Hz □ ~70 per xtal per day

- Flight s/w flags and telemeters GCR data in Calibration Mode (4-Range Mode).
  - Might be pre-scaled to reduce data volume.
    - This would give longer times between calibration.

❑ **Functional Requirements**

- GCRCalib shall process Calibration Mode telemetry.
- GCRCalib shall query Perf State to modify algorithms, fault tolerance.
- GCRCalib shall identify non-interacting GCRs with clean TKR trajectories through logs.
- GCRCalib shall accumulate energy loss and light asymmetry maps in GCR DB.
  - See algorithms.

Appendix 5: GCR Calibration Process

- Algorithms
  - Physics inputs:
    - dE/dx for heavy ions. Code expressions from the literature.
    - dL/dE for heavy ions. Measure it, then code it. Analytic expr. exist.
  - Elements of calibration process:
    1. Extract multiMIP events.
    2. Identify likely GCRs, reject obvious junk.
    3. Fit tracks.
    4. Accept events with clean track through log, no edges or glancing hits.
    5. Identify charges.
    6. Identify charge-changing interactions.
    7. Identify mass-changing interactions.
    8. Fit dE/dx.
    9. Accumulate energy losses and light asymmetries.

Appendix 5: Calibration with Cosmic Rays

- Nuclear interactions
  - Majority of GCRs suffer nuclear interactions as they pass through calorimeter.
  - Interaction lengths:
    - $\lambda_{N,CsI}$ = 86 g/cm^2
    - $\lambda_{Fe,CsI}$ = 58 g/cm^2
  - GCR at 45 deg traverses ~100 g/cm^2 of CsI
    - ~30% of CNO group and ~20% of Fe survive without interacting.
- How many per day in each CsI bar?
  - ~1100 non-interacting CNO.
  - ~70 non-interacting Fe.

- Scintillation efficiency
- Light output of CsI(Tl) is not strictly proportional to DE for heavy ions.
  - dL/dE, the light output per unit energy loss, decreases slowly with increasing dE/dx for heavy ions, but is constant for EM showers.
  - dL/dE is fcn of dE/dx, rather than charge of the beam.
  - Magnitude (in NaI!!):
    - ~0.9 near minimum ionizing.
    - ~0.3 near end of range.

- Need to measure in heavy ion beam!

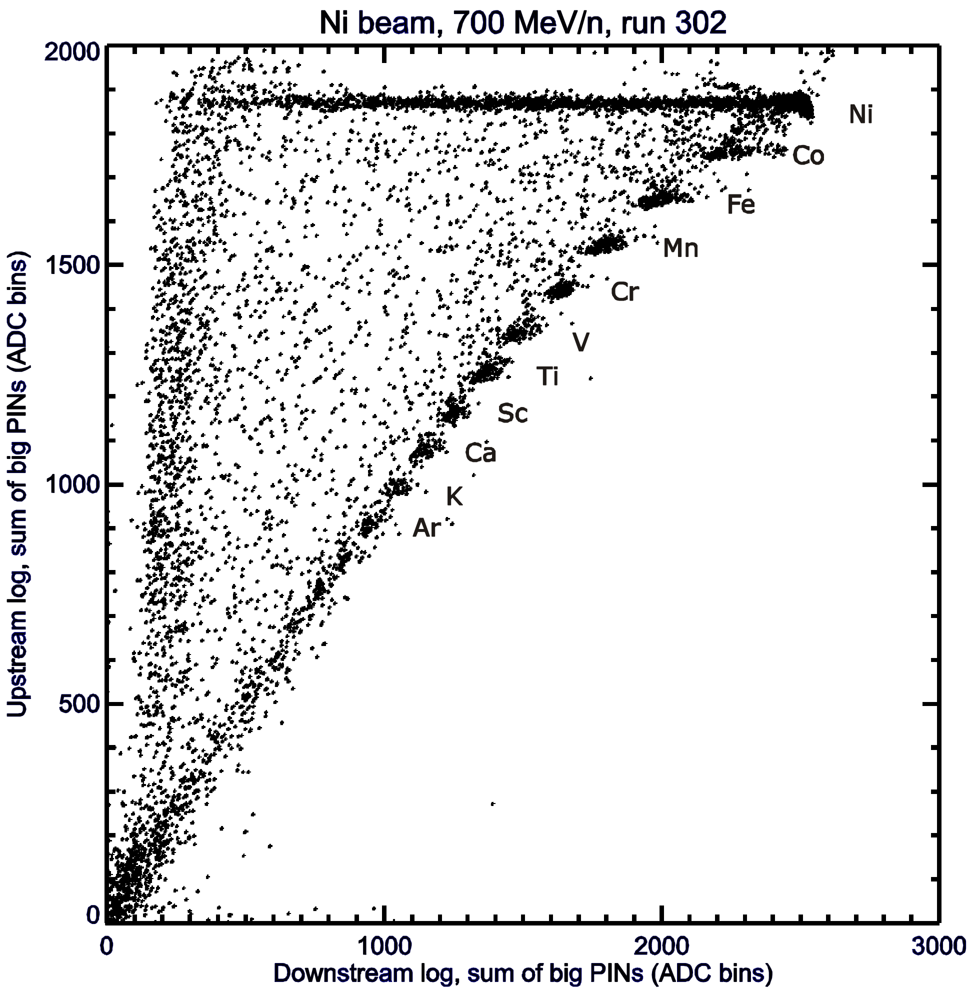
Appendix 5: Calibration with Cosmic Rays

- Calibration Uncertainty
- Need to bin GCRs by estimated ΔE. This is uncertain for following reasons:
  - Uncertainty in initial energy.
    - ΔdE/dx ~ 10% over 2-6 GeV/n.
  - Landau fluctuations.
    - σ_L < 5% for CNO near 5 GeV/n.
    - σ_L < 5% for Fe near 5 GeV/n
  - Unidentified nuclear interactions.
    - p-stripping from C is hard to miss.
    - p-stripping from Fe.
      - ΔE < 10%.
  - Uncertainty in dL/dE.
    - Guess < few %.
- Adding in quadrature gives rms < 20%.
- With ~1000 CNO per bar per day, statistical precision of ~1% per day is achievable.

- Practice, create algorithms
  - Heavy ion beam tests
    - GSI, Summer 2000
  - Balloon flight
    - Palestine, Summer 2001

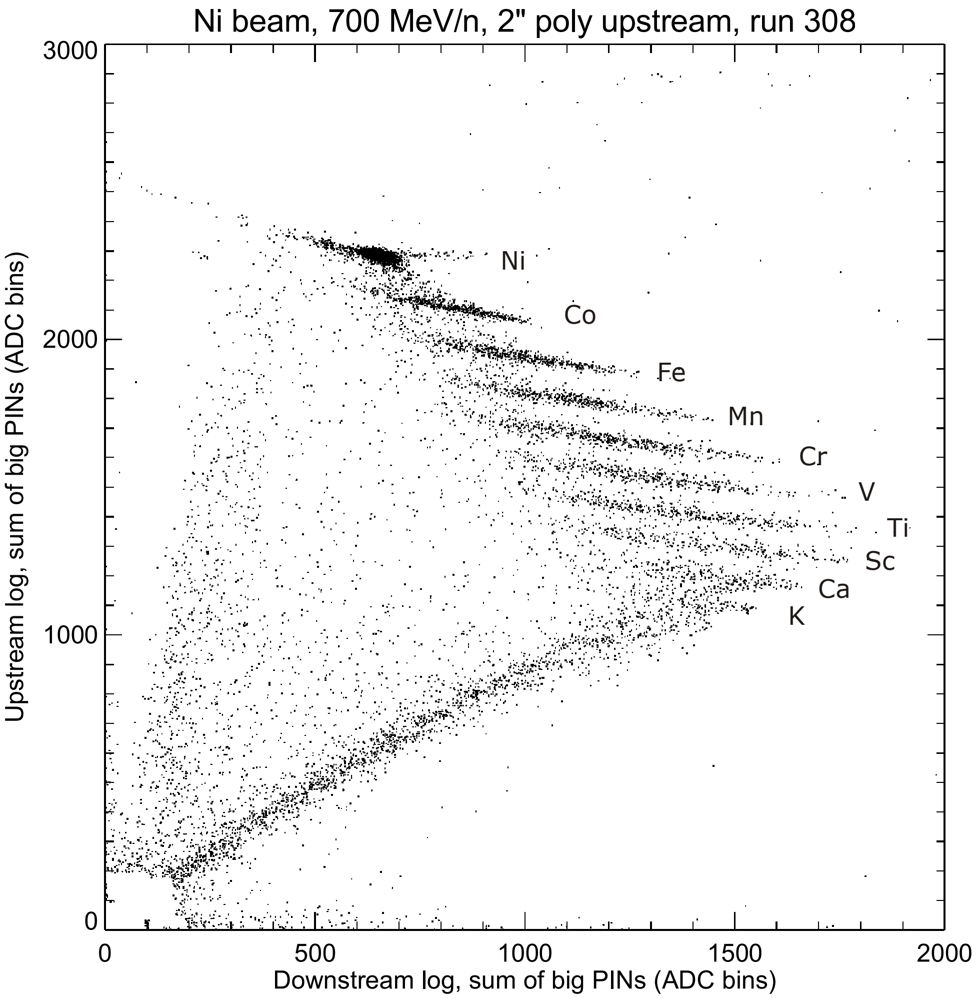
Appendix 5: Ni beam at GSI

- Ni beam into test box
  - Test box xtals are 37 cm, dual PIN with Sylgard bond.
  - Fragments are created in beam monitor
    - 1 cm plastic paddle upstream
  - At this energy, all species penetrate both CsI layers, but there is slowing down (note downstream signal is bigger than upstream).
  - Similar plot for C and daughters.
- Charges are easy to identify.



Appendix 5: Ni beam at GSI

- **Same Ni beam, same crystals, but added material upstream**
  - **2" polyethylene slows down primary beam and creates fragments with varying energies (from varying depths of creation).**
  - **Ni through Ti stop in second CsI layer.**
  - **Sc and smaller penetrate second CsI layer.**
- **Demonstrates that identifying charges in CsI is quite simple, even in the presence of a spectrum of incident energies.**



Appendix 6: State Tracking

State Tracking

- **Level 1 PDA must track the state of the instrument**
  1. **Command State**
     - **The verified configuration of the h/w.**
     - **Analysis needs to know data modes, etc.**
     - **Created by first-pass L1 processing, MOPS tasks.**
  2. **Performance State**
     - **Documents performance or anomalous conditions not described by Cmd State: dead logs, bad gain ranges, etc.**
     - **Created by first-pass L1 processing.**
     - **Output feeds into Cal Recon, allows fault tolerance in Recon.**
  3. **Calibration State**
     - **Created by Calibration in L1 processing.**
     - **Output feeds into Cal Recon, Cal Calib Parameter DB.**

- **Develop in concert with TKR, ACD. System-wide service.**

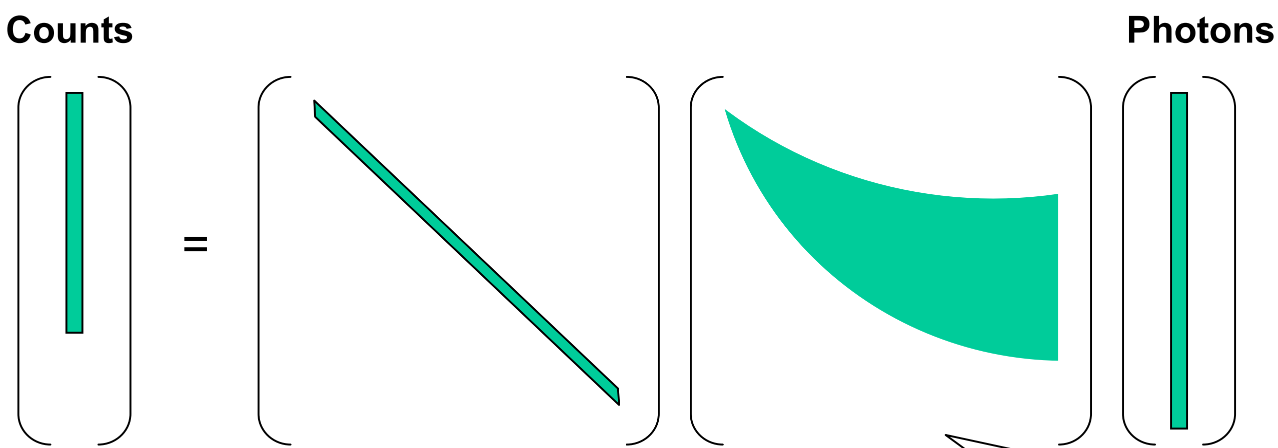
Appendix 7: Spectral Deconvolution

- **Resolution broadening is important for steep spectra.**
  - **More-abundant low-energy photons look like high-energy photons.**
  - **Observed spectrum is artificially flattened.**
  - ***So even if you make your best guess of the energy of each photon, you can still get the wrong spectral index.***
  - ***Still need to do resolution deconvolution.***

- **Spectral deconvolution is more than just energy reconstruction.**
  - **Shower profiling helps correct observed ΔE into incident photon energy, but …**
  - **Need to account for**
    1. **resolution broadening, which can be *increased* by profiling.**
    2. **conversion efficiency (cm^2)**
    3. **livetime.**

Appendix 7: Spectral Deconvolution

- Instrument response matrix.
  - **Conversion of incident photon flux to observed count spectrum.**



Effective Area matrix.
- Geometric area x conversion efficiency.
- Livetime weighted over all aspects to src.

Energy redistribution matrix.
- Incident high-energy photons are observed as lower energy.
- Includes resolution broadening.
- Livetime weighted over all aspects to src.

Appendix 7: Spectral Deconvolution

Spectral deconvolution

- Forward-Folding Deconvolution from an ensemble of detected gamma rays.
  - Create Instrument Response Matrix
    - Transforms measured energy deposition into incident energy as a function of zenith and azimuth.
    - Columns of response matrix are Green's functions at a large number of incident energies.
      - » i.e. the spectra that should be produced by monoenergetic beams
  - Candidate incident spectrum is multiplied by the response matrix and compared to the observed spectrum.
  - Parameters of the candidate spectrum are varied to minimize χ^2.