Calorimeter Calibration

J. Eric Grove
NRL

Calibration Needs

- Reference document (LAT-???)
  - In progress by Eduardo do Couto e Silva
  - Input from subsystems (including CAL!)
  - Gives calibration/test matrix
    - i.e. which test, when, h/w required
  - Describes each calibration quantity
- 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 (TBR).
- Where do the data come from?
  - Ground calibration of EM, QM, CU, FM
  - 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.
    - Required accuracy is TBD; goal is TBD.
    - Pedestal centroid and width for 12288 channels.
  - Electronic gain: eCalib shall generate a linear gain model for each gain range for each PIN diode.
    - Required accuracy is TBD; goal is TBD.
    - Gain slope (bins/fC), slope uncertainty, offset, offset uncertainty for 12288 channels.
  - Integral non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - Required accuracy is TBD; goal is TBD.
    - ~50 ordered pairs (pulse input, ADC output) for 12288 channels.
  - Differential non-linearity: eCalib shall generate look-up table for each gain range for each PIN diode.
    - Required accuracy is TBD; goal is TBD.
    - ~4000 values (ΔADC output) for 12288 channels.

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.
    - Required accuracy is TBD; goal is 3%.
    - TBD (~5) coeffs and uncertainties.
  - Light yield: GCRCalib shall calculate the light yield (i.e. electrons per MeV) at the center of each log for each PIN diode.
    - Required accuracy is TBD; goal is 3%.
    - Light yield, statistical error, systematic error for 6144 diodes.
  - 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.
    - Required accuracy is 10%; goal is 1%.
    - TBD (~6) coeffs and uncertainties for 9216 maps.
  - Light asymmetry: GCRCalib shall produce maps of light asymmetry (i.e. (P-M)/(P+M) as a fcn of longitudinal position) for each log.
    - Required accuracy is 10%; goal is 1%.
    - TBD (~6) coeffs and uncertainties for 3072 xtals.

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

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 ~ monthly?
  - 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

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 ~ monthly?
  - 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

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

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.

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.

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

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

Performance State

- In addition to the calibrations, we need to track status of each channel:
  - Failures
  - Noisy channels
- Performance State database (or whatever)
  - Allows Recon to interpret CAL data stream and give optimal event reconstruction.
  - Documents data modes, anomalous conditions.
  - Functional requirements
    - Contents (there should be a corresponding Flight s/w doc)
      - Hot log list
      - Failed gain range list
      - Tower State
        - » Failed towers
        - » Failed CAL sides/signal chains
      - Pointer to entry in CAL Calibration Parameter Database

Appendix: 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: 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: 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: 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: Balloon flight GCRs

- **GCR rates for Palestine balloon flight**
  - Require passage through uppermost full Si layer and bottom of CsI
  - Used CREME96 for 35km above Palestine in 2001, from H to Ni

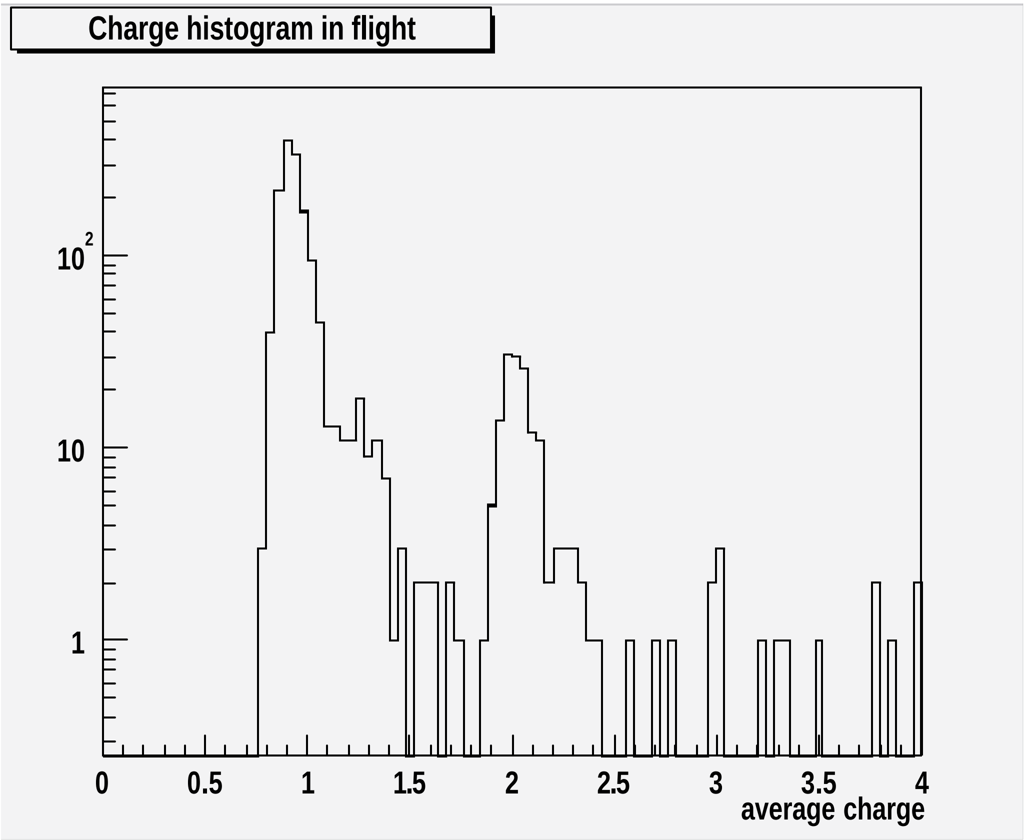
We wanted 8 hrs at float
~4000 CNO
~900 Ne, Mg, and Si
~250 Fe
to play with.

We got 3% of 3 hrs at float
~40 CNO
~10 Ne, Mg, and Si
~3 Fe
to play with.

Species	Total rate (per hr)	Non-fragmenting rate (per hr)
C	220	63
N	58	15
O	220	55
Ne	35	8
Mg	46	10
Si	35	7
Fe	29	4

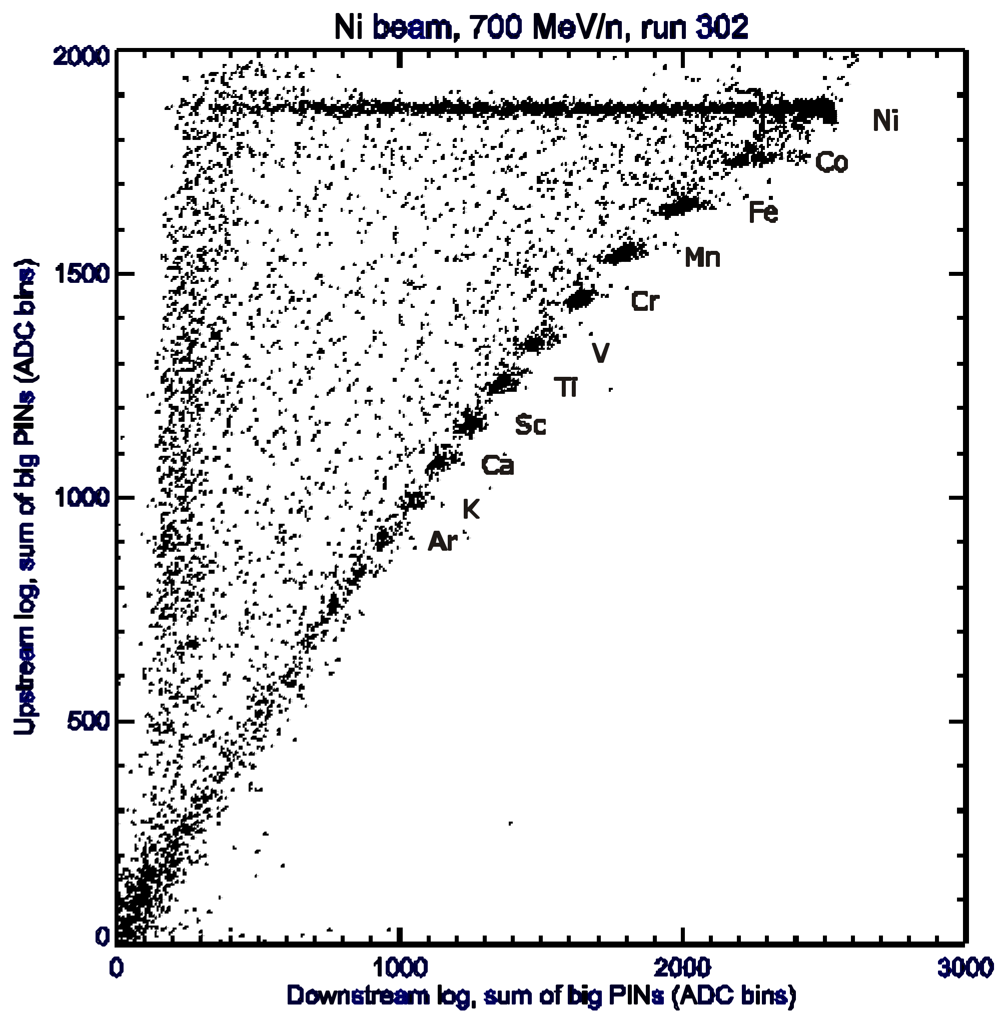
Playing with Balloon Data

- Charge histogram from BF
- Looked for non-interacting GCRs in LEX4
  - (Carbon would saturate)
  - Required each layer to be roughly constant fraction of total ΔE
  - Corrected for pathlength with TKR trajectory
- Since $dE/dx \propto Z^2$,
  $Z \propto (\Delta E)^{1/2}$
- Analyzed with ROOT



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.



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.