Calorimeter Calibration Issues

J. Eric Grove
Naval Research Lab

What needs to be calibrated?

- Energy measurement.
  - Need relative calibration among crystals and overall absolute calibration.
  - Requirements for relative and absolute calibration?
    - My thoughts:
      1. Relative calibration to <1% (at all energies).
      2. Absolute calibration:
         - » Get pion bump in right place ⇒ at ~100 MeV, absolute knowledge to <10%.
         - » At 100 GeV, …?
         - » Goal: ~3% at all energies.
- Position measurement.
  - Need light asymmetry calibration in each crystal.
    - Bkg-rejection “requires” ~3 cm knowledge (~10% of crystal length).
      - ⇒ Need slope knowledge to ~10%.
    - Goal: Improve pointing for conversions in SuperGLAST.
      - ~3 mm knowledge ⇒ Want slope knowledge to ~1%.

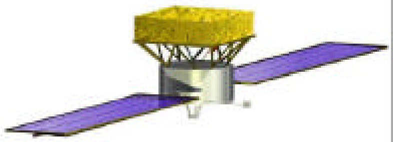
Calorimeter Calibration

Energy Calibration

- ❑ Need absolute calibration of each gain scale for each PIN.
- ❑ Calib process runs continuously.
- ❑ Method:
  - Use cosmic rays from H to Fe.
  - Trigger ID by ACD.
  - Tracked in TKR.
  - Useful event rate expected to be ~100 Hz.

Position Calibration

- ❑ End-to-end light asymmetry in CsI bar gives longitudinal position.
  - $x = (dx/dr)\ (R - L) / (R + L)$
  - Position determination is *independent* of energy deposition.
- ❑ Must calibrate each PIN.
- ❑ Method: Again, GCRs and Tracker trajectories.



Calorimeter Calibration

How often do calibration parameters need to be updated?

Timescales of Weeks.

- CsI light yield varies with radiation dose.
  - Test at NRL's ^{60}Co Irradiation Facility to ~20 kRad (~20 years or more on orbit) showed 25% degradation in light yield.
  - So ~1% per year, very long timescale.
- CsI light yield varies with temperature, ~1/2 % per deg C.
  - Large thermal mass $\Rightarrow$ no ΔT effect on orbital time scales.
  - Long-term ΔT possible from thermal surface degradation or seasonal exposure.
  - Active thermal control minimizes this effect.
- PIN diode bonds may degrade with time.
  - CLEO degradation was slow. Hamamatsu has fixed problem.
  - Failure on launch is more likely. Calibrate it out once.
- FEE gain and linearity may vary with radiation dose.
  - DMILL process is tolerant to relatively small dose on orbit.
  - Any change will be on long timescale.
- FEE gain and linearity may vary with temperature.
  - Again, thermal mass of calorimeter means timescale is long.

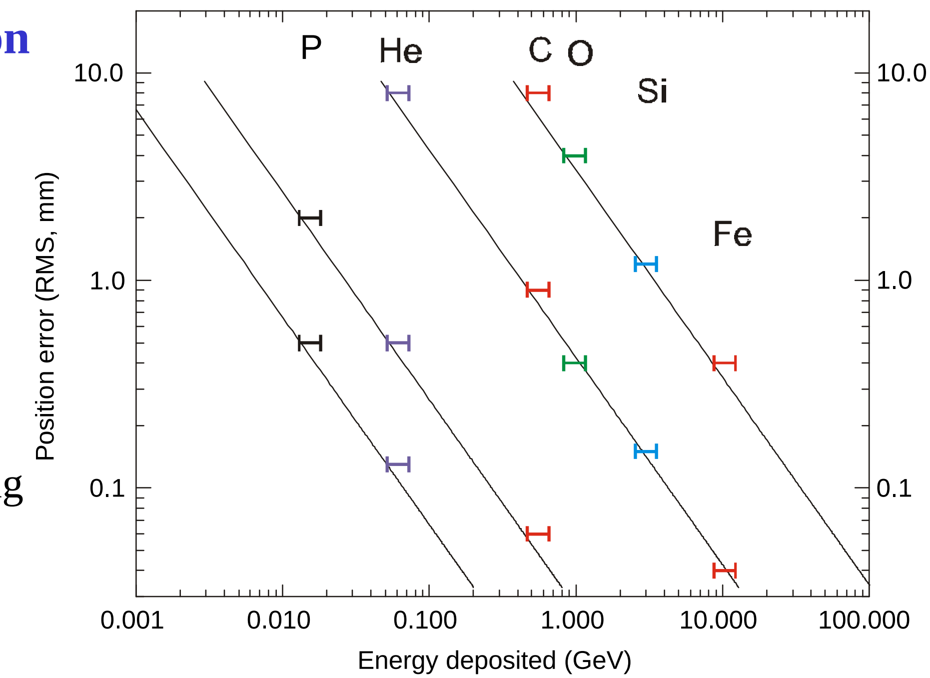
Calibration with Cosmic Rays

High flux of GCRs gives good calibration of full dynamic range.

- Concept:

1. ACD flags events > few MIPs.
2. ACD flags 1 in 1000 single-MIPs.
3. Accept only events with good TKR.
4. Accept only events with no charge-changing interactions in CAL.
5. Correct ΔE for pathlength in CsI bar.
6. Accumulate dE/dx in each bar.

- Derive calibration with statistical precision of better than few % each day over full dynamic range.

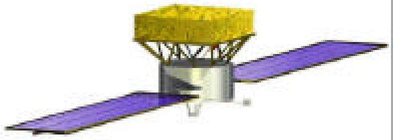


He: ~140 Hz
CNO: ~10 Hz ⇒ ~1100 per xtal per day
Si: ~0.4 Hz
Fe: ~0.8 Hz ⇒ ~70 per xtal per day

Calibration Process: S/W Needs

What software do we need for calibration process?

- **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. Identify charges.
  5. Identify charge-changing interactions.
  6. Identify mass-changing interactions.
  7. Fit dE/dx.
  8. Accumulate energy losses and light asymmetries.



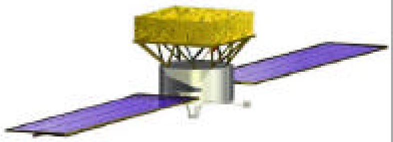
Calibration with Cosmic Rays

- **Questions for detector:**
    - What is magnitude, and dE/dx-dependence of scintillation efficiency, dL/dE?

- GSI beamtest for calorimeter.
    - Develop algorithms for
        1. Identifying charge-changing interactions.
        2. Identifying mass-changing interactions.
    - Derive dL/dE for heavy ions.
    - July 2000: C and Ni beams.

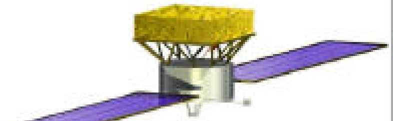
- **Questions for simulation:**
    1. What is rate of >few MIPs in ACD for everything but primary GCRs? Does this trigger add significantly to data volume?
    2. How well are CsI bars on outer edge of calorimeter covered by tracked GCRs?

- Is there a concern about calibrating above ~10 GeV?
    - Fe deposits ~10 GeV, but HE range goes to ~100 GeV.



Calibration with Cosmic Rays

- **Questions for simulation or analytic estimation:**
  1. What is rate of >few MIPs in ACD for everything but primary GCRs? Does this trigger add significantly to data volume?
  2. How well are CsI bars on outer edge of calorimeter covered by tracked GCRs? What is the rate of each species?
  3. How does rate of useful GCRs scale with geometry cuts?
     - Cuts with CsI bars. Cuts for good TKR geometry.
  4. What is the shape of ΔE distributions for useful GCRs? How well can they be centroided?
     - Finite width from dE/dx dependence on E_0, Landau fluctuations, and pathlength uncertainty.
  5. Calibration above ~10 GeV: Use long-pathlength Fe. What is rate? How well is pathlength known?



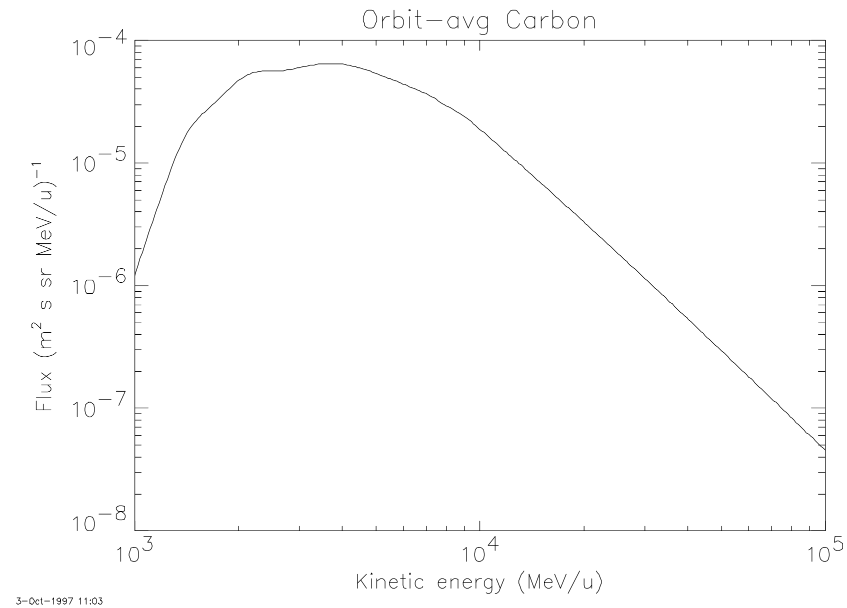
Calibration with Cosmic Rays

❑ Particle fluxes

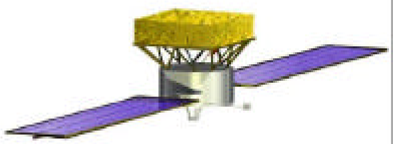
- CREME96 for 28.5 deg orbit for abundances and spectra.
- Conservative estimates: Required GCR to pass through upper and lower faces of CAL.

❑ Particle ranges

- At 2 GeV/n in CsI, ranges of C and Fe are 440 g/cm^2 and 110 g/cm^2, resp.
- All incident C will penetrate CAL ($9X_0$ = 76 g/cm^2).
- All but low-energy, large-angle Fe will penetrate.



Z range	Rate (s^{-1})
1 – 28	1020
6 – 28	12.4
10 – 28	3.6
24 – 28	0.7



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 ΔE 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!

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**.

GSI Beam Test for Calorimeter

- **From:** Grove, Eric
  Sent: Tuesday, October 19, 1999 9:07 AM
  To: Johnson, W. Neil; Phlips, Bernard
  Subject: thoughts on GSI beamtest
  Heavy ion beamtest goals:
  (1) Gain familiarity with heavy ions in scintillator.
  (2) Measure saturation for heavy ions in CsI.
  (3) Develop algorithms to identify charge and/or mass changing interactions in calorimeter.

- **What beams can GSI deliver and what do we want?**
  The SIS at GSI delivers 1 to 2 GeV/u beams. Species range at least from carbon to uranium.
  Range of beams:

	C	C	Fe	Fe	
E	1	2	1	2	(GeV/u)
R	180	440	45	110	(g/cm2)

- Thickness of calorimeter is 8 x 2.3 x 4.51 x sectheta = 83.0 sectheta g/cm2, so all C beams will penetrate without much slowing down (so without much change in dE/dx), while Fe beams can be made to slow and stop at several depths in the stack.

  We might also want to run with Fe beam and plastic upstream to increase spallation rate. This gives sub-Fe to test scintillation efficiency.

  Thus Fe is good to study change in saturation with changing dE/dx. We can compare to a C point, and maybe some intermediate species, like Ne, if they can deliver the beam. Fe is also good to develop algorithms to find spallation interactions.
- Presumably we should hit several points in the calorimeter to be sure to sample crystals from STCU and Crismatec from different batches, and presumably we should use the same points we hit at SLAC for cross-calibration. Presumably we should do several off-axis runs, since that always makes the algorithms more complicated, and more realistic.
- **Beam plan thought**
  Minimum beam plan to cover goals above.
  On axis:
  Three beams -- C at 2 GeV/u, Fe at 1 GeV/u and 2 GeV/u -- each at 9 or 16 positions. With Fe beam at 1 GeV/u, also add some positions with plastic upstream.
- ***From behind:***
  Two beams -- Fe at 1 GeV/u and 2 GeV/u -- each at 9 or 16 positions. Add plastic upstream to some 1 GeV/u positions. No need for C since it doesn't slow much.
- At an angle:
  One beam -- Fe at 2 GeV/u -- at several large angles and positions.
- ***Useful additions to the minimum test plan:***
  1. Ne beam (which energy?) to fill in intermediate dE/dx. On axis at several positions.
  2. C beam at an angle.
  3. C and/or Ne beam at 1 GeV/u with 100 g/cm2 of Pb upstream. This is a poor way to make a stopping lower-Z beam, but maybe the only easy way at GSI. This tests saturation at intermediate dE/dx.
- **What other hardware do we need?**
  Thin plastic scintillator upstream and downstream of stack to ensure we know the charge before and after the calorimeter. This is desireable, but not necessary. After all, we say we don't need the ACD in flight for this. Plastic 1 cm thick is more than adequate.
- If the beam spot is small, we don't need a hodoscope.

  Questions
  With current electron yield, which dE give good cross-calibrations between ranges? Do we really care, or do we just want to watch dE/dx?
- Still need to calculate run times in each configuration, given expected interaction probabilities. Still need to find out how complicated it is to switch beam species and energy.
-
- Eric