QWG3 CsI-2

• Why CsI?
• Care & Feeding
• Get Ready for Physics

LEPP
LABORATORY FOR ELEMENTARY-PARTICLE PHYSICS
Care & Feeding

Outline

- Sparsification of readout
- Simulation
- Calibrations
  - ECal: Electronic channel level
  - XCal: Crystal level
- Reconstruction
Sparsification

- Cannot read out every crystal every event
  - Which ones?
  - Don’t compromise E resolution!

Possible algorithms
- All above a threshold (e.g. $1\sigma_{\text{Noise}}$)
- nxn around local maxima (n=3,4,5?)
- More sophisticated?

Answer depends on noise level
Sparsification: How?

- Fixed threshold works against maintaining E resolution over a wide dynamic range...
  - $1\sigma_{\text{Noise}}$ implies $\sim 15\%$ read out every event... too many!
  - Higher threshold hurts too much

- Fixed nxn around local maxima dangerous
  - Need to preserve information from low energy showers
Neighbor-seed strategy

Define “seed” threshold well above noise but below smallest shower energy of interest (e.g. 5~MeV)

Define “neighbor” threshold at a lower value (e.g. $1\sigma_{\text{Noise}}$

For any seed, keep it & all nbers and next-near neighbors around it (recursive)

Requires all crystals read out into a common buffer every event for this to work – no decisions made at the TDC/ADC or even the crate level.
Seed-Neighbor Example

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>0.1</th>
<th>0.9</th>
<th>0.1</th>
<th>4</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td>0.4</td>
<td></td>
<td>80</td>
<td>300</td>
<td>200</td>
</tr>
<tr>
<td>0.3</td>
<td>2</td>
<td>1</td>
<td>25</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td></td>
<td>0.6</td>
<td>29</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>4</td>
<td>7</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.1</td>
<td>0.2</td>
<td>0.9</td>
<td>0.1</td>
<td>1</td>
<td></td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>3</td>
<td></td>
<td>0.5</td>
<td>4</td>
<td>0.1</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td></td>
<td>6</td>
<td>0.4</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>0.9</td>
<td>2</td>
<td>1</td>
<td>0.8</td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.3</td>
</tr>
</tbody>
</table>

Seed: 5.0 MeV
Nbr: 0.5 MeV
RED xtals are read out
Sparsifying Readout

Seed-neighbor strategy preserves options for how many crystals will be summed during reconstruction.

Also keeps total # low enough (hundreds).
C&F: Simulation

GEANT3 works very well, does most of the work (probably GEANT4 does too)

γ, e± cutoffs (CUTELE, CUTGAM)

- So it knows when to stop the cascade
- Throws away particle below threshold
- Strongly affects CPU time but also accuracy
- Choice strongly affects MC energy scale...fix it & never change it!
- Choice strongly affects accuracy of simulation in energy resolution & shower shape
- We found no improvement in simulation below 1 MeV values, but deterioration above 1 MeV
- Stayed with 1 MeV; you might want to verify!
Readout Simulation

- Must insert electronic noise
  - CLEO smears by pedestal widths from pulser calibration runs, but found this was not smearing enough. Had to increase by ~50%. Not understood.
  - Coherent noise important too, difficult to measure. Estimate instead?

- Must simulate digitization, ADC scale selection
- Must simulate sparsification
Event “Noise” Simulation

- Not referring to elec Noise, which is msd w/Ecals
- Showers from beam & cosmics
  - Varies with machine conditions
- Not specific to calorimeter
- CLEO merges random triggers from the simulated run into each MC evt

Single most difficult challenge to the software framework to naturally accommodate this feature
C&F: Calibrations

**ECal**: Electronic channel level
- Disabled diode compensation
  - CLEO has 4 diodes/crystal, can disable & compensate via downloadable settings to crates
  - Output gets amplified up accordingly
  - After 14 yrs, CLEO has 251/7784 crystals w/ ≥1 diodes off because they died or became noisy
    - 240 (1 disabled), 11 (2 disabled), 0 (3 or 4 disabled)
  
- Pedestals & Gains on each range

**XCal**: Crystal level

**SCal**: Shower level Energy Scale

**Rcal**: Run (time) dependence
Crystal Energy

\[ E_i = \frac{(Digi_i - Ped_i^r)}{G_i^r \times C_i \times C_0} \]

where

- \( E \) = energy (GeV)
- \( i \) = crystal identifier (1-N)
- \( r \) = digitization range
- \( Digi \) = digitization, \( Ped \) = pedestal
- \( G_i \) = electronic gain
- \( C_i \) = relative crystal calibration
- \( C_0 \) = overall factor to set energy scale
Goal is to preserve the measurement of $E=0$ (via pedestals) & stability of an ADC/TDC count (via electronic gains) from one day to the next

- Remove temperature/environmental variation effects
- Remove effects of changing a card
- Involves ONLY electronics, not crystal!

Usually taken with pulser trigger with no beam

Pedestal widths useful for monitoring noisy channels & for insertion into MC

CLEO takes ECal ~weekly but if no changes, not every ECal is used in reconstruction (introduces unnecessary scatter)
C&F: XCal

Goal is to obtain a conversion from counts to GeV for each crystal that is stable with time.

First guess from source testing on the bench.

Second guess from cosmic ray tests prior to data.

Best estimate from Bhabhas.
Bhabha Calibration

- Assume linearity of light ↔ energy
- Obtain a single constant per crystal
- Select e^+e^- evts: each e^± has ~E_{beam}
- Minimize shower energy resolution
- Define \( q_i = \frac{(\text{Digi}_i - \text{Ped}_i^r)}{G_i^r} \)
- \( E_{bha} \) = energy of e^± at that \( \theta, \phi \)
  - Accnt for crossing angle (~2 mrad @ CESR)
- \( c_i = \frac{1}{C_i} \) (crystal gain)
Bhabha Selection

- Two showers, each $E > 45\% E_{\text{beam}}$
- Total other shower energy $< 10\% E_{\text{beam}}$
- Acollinearity in polar angle $< 50$ mrad
- Endcap bhabhas are prescaled by 8 in trigger: flattens polar angle distribution
  - Proved that there is no bias from this procedure: same answer with flat or normal, steep Bhabha $\theta$-distribution
- Need $>10$ showers/crystal (max in shower)
Matrix Equation

Minimize \( \chi^2 = \sum_{bha} \left\{ (\sum_i c_i q_i) - E_{bha} \right\}^2 \)

\[\Rightarrow \sum_i c_i (\sum_{bha} q_i q_j) = \sum_{bha} q_j E_{bha}\]

\[Q \ c = r\]

c = vector of the unknown crystal gains

r = vector of known

Q is 7784x7784 sparse matrix (non-zero near diagonal only)

MA28 sparse-matrix solver (Harwell pkg)

- Took ~10 hours to solve in 1990
- Takes ~5 minutes to solve today
Bhabha Cal Results

Crystal #

$\theta$

$\phi$

$\langle E_{sh}/E_{bm} \rangle$

$\langle E_{sh}/E_{bm} \rangle$

$\sigma_{E}/E = 1.4\%$

@5 GeV

e$^+e^- \rightarrow \gamma\gamma$

$E_{shower}/E_{bea}$

CsI: QWG3 Topical School, B Heltsley, Oct 2004
**XCal Conclusions**

- Procedure is robust, stable after a few iterations
- Large Bhabha cross section makes this possible to redo very often
- But how often do we need it?
- **CLEO**: every few months. Why?
Slow, Progressive Deterioration

BBCal gains vs time: 12 yrs of CLEO

What's happened?

Jan 1990

CLEO III
Barrel Losses

Crystals appear to migrate from the top band to the bottom band, then stabilize.
The Good, the Bad,...

Gain /1st Month

- 534 Crystal Above Average
- 466 Barrel Crystal Below Average

Error bars show spread of avg

Time (months)
...and the Ugly

Worst crystal
Lessons from Endcaps

- Endcaps removed & repackaged for CLEO III - allowed access unlike barrel
- Looked at crystals that had lost light output
  - Glue joint had opened up!
    - Between acrylic light guide & CsI
    - Can’t go anywhere: mechanically held in place
    - Loss from traversing air gap
    - Seems to explain largest losses
    - Endcap crystals reglued; stuck with barrel losses
A Tale of Two CsIs

- Belle was luckier: discovered problem in time to reglue all crystals
- Problem was differential thermal expansion of photodiode & CsI
- Discovered in Novosibirsk beam test

Chgd size at diff rates; caused acrylic to peel off

CLEO has 6mm thickness so problem was different
C&F: Reconstruction

**Input**
- Run Info: Peds, gains, geometry...
- List of crystal id’s & digitizations

**Output**
- 3-vector momentum & errors
- Shower shape (for splitoff rejection)

**Simple task, but… challenges await!**
- Optimize E, \( \phi \) resolution
- Find & separate nearby showers, share crystal energies correctly
**Bump Hunting**

- Look for local maxima ("bumps") > 10 MeV
- Gather nbrs (nr & next-nr)
- Share crystal energies between nrby showers
  - Wt by bump energy ratio & proximity to respective bumps?

<table>
<thead>
<tr>
<th></th>
<th>17</th>
<th>18</th>
<th>29</th>
<th>90</th>
<th>45</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>2</td>
<td>40</td>
<td>100</td>
<td>45</td>
<td>400</td>
<td>325</td>
</tr>
<tr>
<td>9</td>
<td>10</td>
<td>19</td>
<td>39</td>
<td>18</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Can get much more sophisticated and deal with more complicated situations.
Thank you for sharing…

Crystal $i$ near-nbr of 1, near-nbr of 2:

- $E_i(1) = E_i \times \frac{b1}{b1+b2}$
- $E_i(2) = E_i \times \frac{b2}{b1+b2}$

Same for $i$ next-near of 1, next-near of 2

For $i$ near-nbr of 1, next-near of 2

- $E_i(1) = E_i \times \frac{b1}{b1+b2/10}$
- $E_i(2) = E_i \times \frac{(b2/10)}{(b1+b2/10)}$

Very crude

I’m sure you can do better
How many to sum?

Monte Carlo ($\sigma_l = 0.62, \sigma_c = 0.26$)

Data ($\sigma_l \approx 0.5, \sigma_c \approx 0.2$)

Monte Carlo ($\sigma_l = 0.31, \sigma_c = 0.13$)

Monte Carlo (No Noise)

---

$\sigma_E / E(\%)$

Number of Blocks Summed

100 MeV $\gamma$'s
Shower Energy

Balance: adding **noise** with adding **true energy**: must cut off somewhere?

Order crystals assigned to shower by $E_i$

Then, apply the “highest-$N$” algorithm:

- Find $N(E_A)$, $E_A$ = sum of All crystal energies
- Sum the first $N$ of the ordered list, applying whatever non-integral fraction to the next:
  - If $N=9.3$, $E_{shower} = E_1 + E_2 + \ldots + E_9 + 0.3 \times E_{10}$
  - Only these crystals used for energy & position
Highest N(E)

Better resolution than:
- neighboring crystals above some fixed threshold
- $3 \times 3$ or $5 \times 5$

Graph showing number to sum versus energy (GeV)
Correction to centroid:
• ~0 at ctr
• ~0 at boundaries
• not symmetric due to 50-mrad tilt away from vertex-pointing & staggering of front faces
• smaller effect at larger energy because shower spreads more, which helps centroid accuracy
• peak correction typically 5-10 mm
Performance

(a) 
\[ \frac{\sigma_E}{E} (\%) \]
- $\tau(3S) \rightarrow \gamma X$
- $\pi^0 \rightarrow \gamma \gamma$
- $e^+e^- \rightarrow \gamma \gamma$
- $e^+e^- \rightarrow e^+e^-\gamma$
- $e^+e^- \rightarrow \mu^+\mu^-\gamma$
- GEANT Monte Carlo $\gamma$

(b) 
\[ \sigma_\gamma (\text{photons}) \]
- $\pi^0 \rightarrow \gamma \gamma$
- $e^+e^- \rightarrow \gamma \gamma \gamma$
- GEANT Monte Carlo $\gamma$
$\pi^0$ Resolution

$\sigma_{M(\gamma\gamma)} \sim 5.5$ MeV

$\mu = 134.3$ MeV
$\sigma = 5.4$ MeV

$\mu = 133.8$ MeV
$\sigma = 5.6$ MeV

$M_{\gamma\gamma}$ (GeV)
Care & Feeding: Recap

- Sparse Readout of data
- MC Considerations
- ECal & XCal described
- Reconstruction issues aired
- We now have reconstructed showers – what to do with them?