A first look at
Digital Hadronic Calorimetry
for the NLC detector

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Can we replace traditional analog (proportional) hadronic calorimetry with a digital one at the Next Linear Collider Detector?

A study based on a current NLCD design and available datasets.

SD geometry (March 2001):

- Active layer, thickness: Si, 0.04 cm thick (EM); Polystyrene, 1 cm (Had).
- Inactive layer, thickness: W, 0.25 cm (EM); Stainless steel, 2 cm (Had).
- Number of layers: 34.
- Radiation length, interaction length: $\sim 20$, $\sim 0.8$ (EM); $\sim 40$, $\sim 4$ (Had).
- Sampling fraction: $e^-$: 2.22 (EM); $\pi^-$: 5.55 (Had).
- Towers: projective (EM and Had).
- Number of cells in $\theta \times \phi$: $840 \times 1680$ (EM); $600 \times 1200$ (Had).
- Inner radius: 142 cm (EM); 153 cm (Had).
- Max $z$: 210 cm (EM); 213 cm (Had).
- Magnetic field: 5 Tesla.
- No cracks.
- No noise or inefficiency.
Monte Carlo samples:

- Single $\pi^-$s, 5000 events each at $E = 2, 3, 4, 5, 10, 20, 50$ GeV.
- Uniform in $\phi$, all at $\theta = \frac{\pi}{2}$ (i.e., all going through a cell boundary).

Reconstruction:

- EM scale = $\frac{1}{0.016}$, Had scale = $\frac{1}{0.06}$ for proportional, no constant term.
- No attempt made to account for energy losses upstream or downstream of calorimeters.
- No attempt made to utilize tracking information.
- No clustering done.
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A few plots with 10 GeV $\pi^-$s

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A few plots with 10 GeV $\pi^-$s [contd.]
Digital measurement of E (cell-counting):

- Count the number of cells hit in the EM and Hadronic sections of the calorimeter.
- Did not perform any rigorous function minimization, but tried a few ways, both linear and non-linear, of combining $n_{hit}(EM)$ and $n_{hit}(Had)$, with manual tuning of parameters.
- Adding $n_{hit}(EM)$ and $n_{hit}(Had)$ with equal weights gave the best energy resolution, although it is not obvious why it should. (This needs further study.)
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Number of hits vs E

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Response vs E

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Resolution (1/sqrt(E)) vs. E

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\( \frac{E_{\text{measured}} - E_{\text{true}}}{\sigma(E_{\text{measured}})} \) vs. \( E_{\text{true}} \)

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Digital measurement of $E$ (cell-counting): [contd.]

\begin{equation}
E = \left( \frac{n_{\text{hit}}}{\langle n_{\text{hit}}(2 \text{ GeV}) \rangle} \right)^{\frac{1}{\log_{10} c}},
\end{equation}

where

\[ c = \frac{\langle n_{\text{hit}}(20 \text{ GeV}) \rangle}{\langle n_{\text{hit}}(2 \text{ GeV}) \rangle} = \frac{503}{63.3} \approx 7.95. \]

Some alternatives gave better resolution at some energies, but none was found to be clearly superior to the simple sum across the board.
Conclusions:

- Cell-counting gives better energy resolution than summing energies for lower energies ($E < 20$ GeV), and comparable up to the highest energies tested (50 GeV).

- The issue of position resolution has yet to be addressed.

- We’ve just begun, there’s much room for improvement:
  
  – Tracking information needs to be exploited.

  – Analog information from the EM calorimeter may be useful, particularly in defining clusters and improving position resolution.

  – Detailed pattern-recognition must be investigated.
Plans:

- More complete samples of single $\pi^\pm$ have been requested:
  - Uniform in $\frac{\pi}{6} < \theta < \frac{5\pi}{6}$ (barrel).
  - $E = 2, 5, 10, 20, 50, 100, 200$ GeV.
  - $N_{\text{layer}} = 128$ (to study longitudinal profile and leakage).
  - Additional coarser longitudinal and lateral segmentations (to optimize granularity under practical constraints which may set a lower limit on limit the average cell size at $\sim 10$ cm$^2$ and increase the thickness by 25%).

- We’ll use these to study shower development, containment, E-flow for the Jan ’02 workshop.
Plans: [contd.]

- Rigorous studies based on real physics processes and more realistic detector description, and using more information will follow. Will collaborate in implementing and testing these in the GEANT4-based simulation.

- Aiming to do a detailed feasibility study for a digital HCAL for the NLCD, and determine optimal design parameters, if favorable and practical.