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); π^-: 5.55 (Had).
- Towers: projective (EM and Had).
- Number of cells in $\theta \times \phi$: 840×1680 (EM); 600×1200 (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.

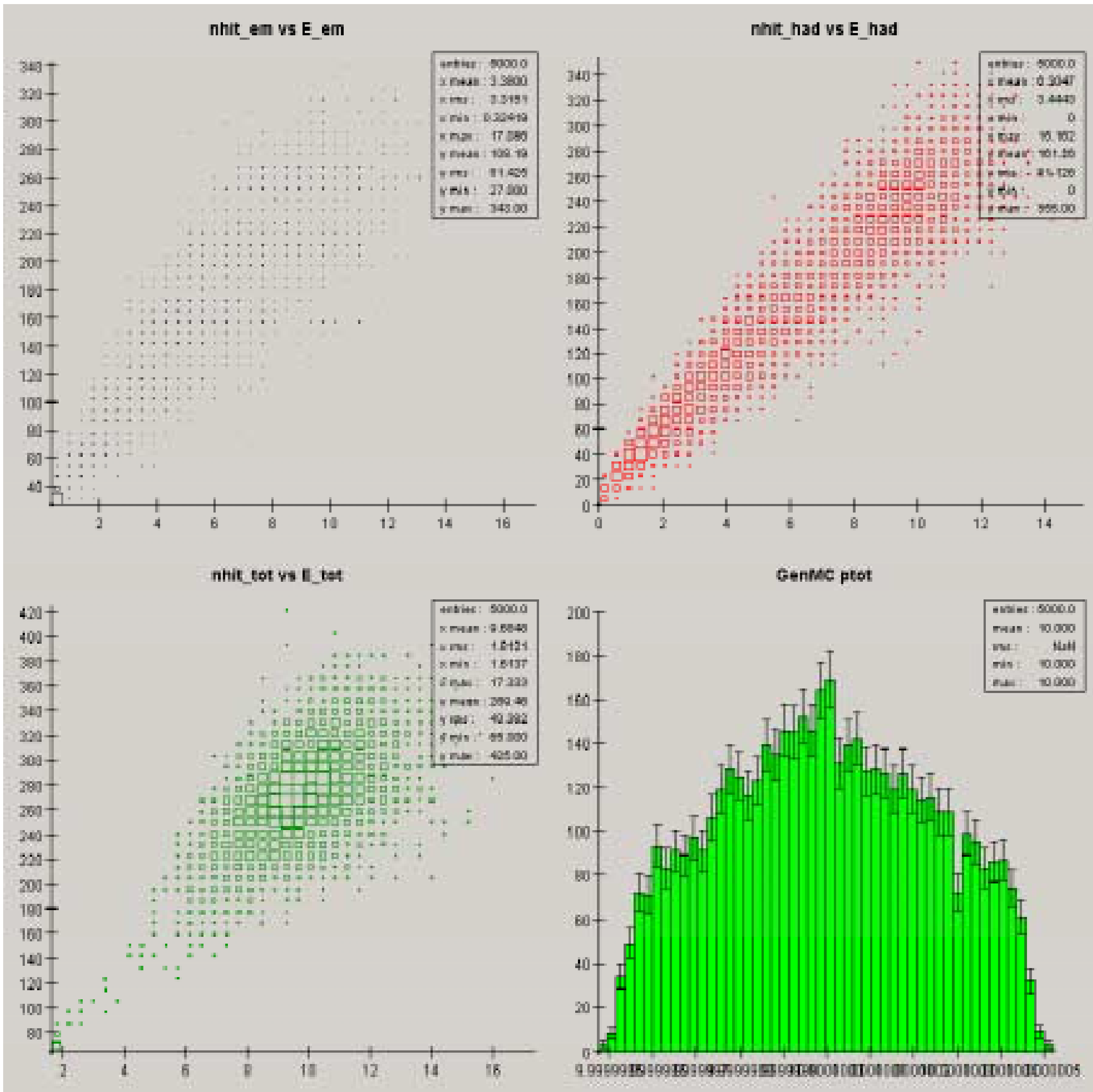
Monte Carlo samples:

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

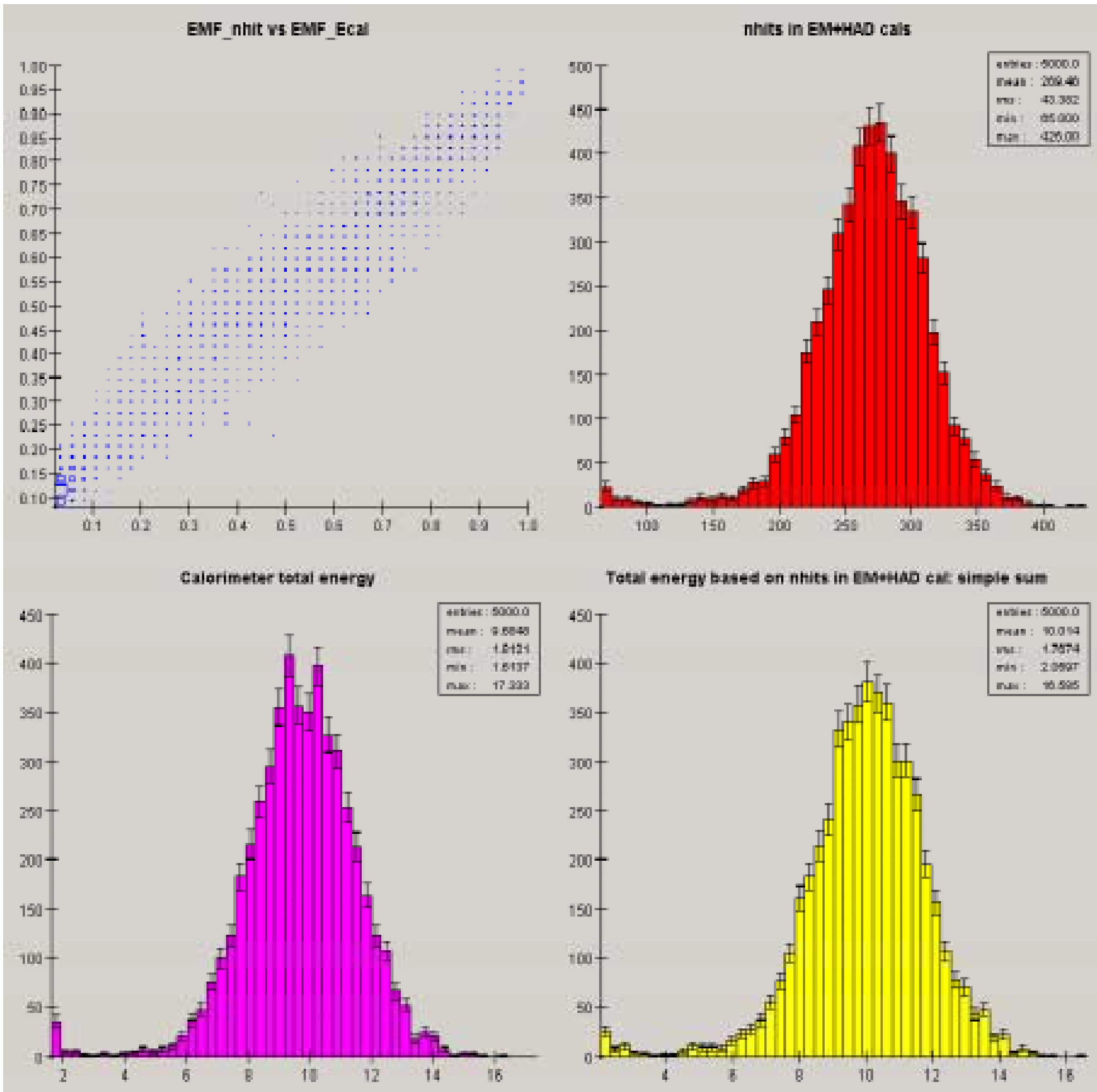
Reconstruction:

- 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.

A few plots with 10 GeV π^-s



A few plots with 10 GeV π^-s [contd.]

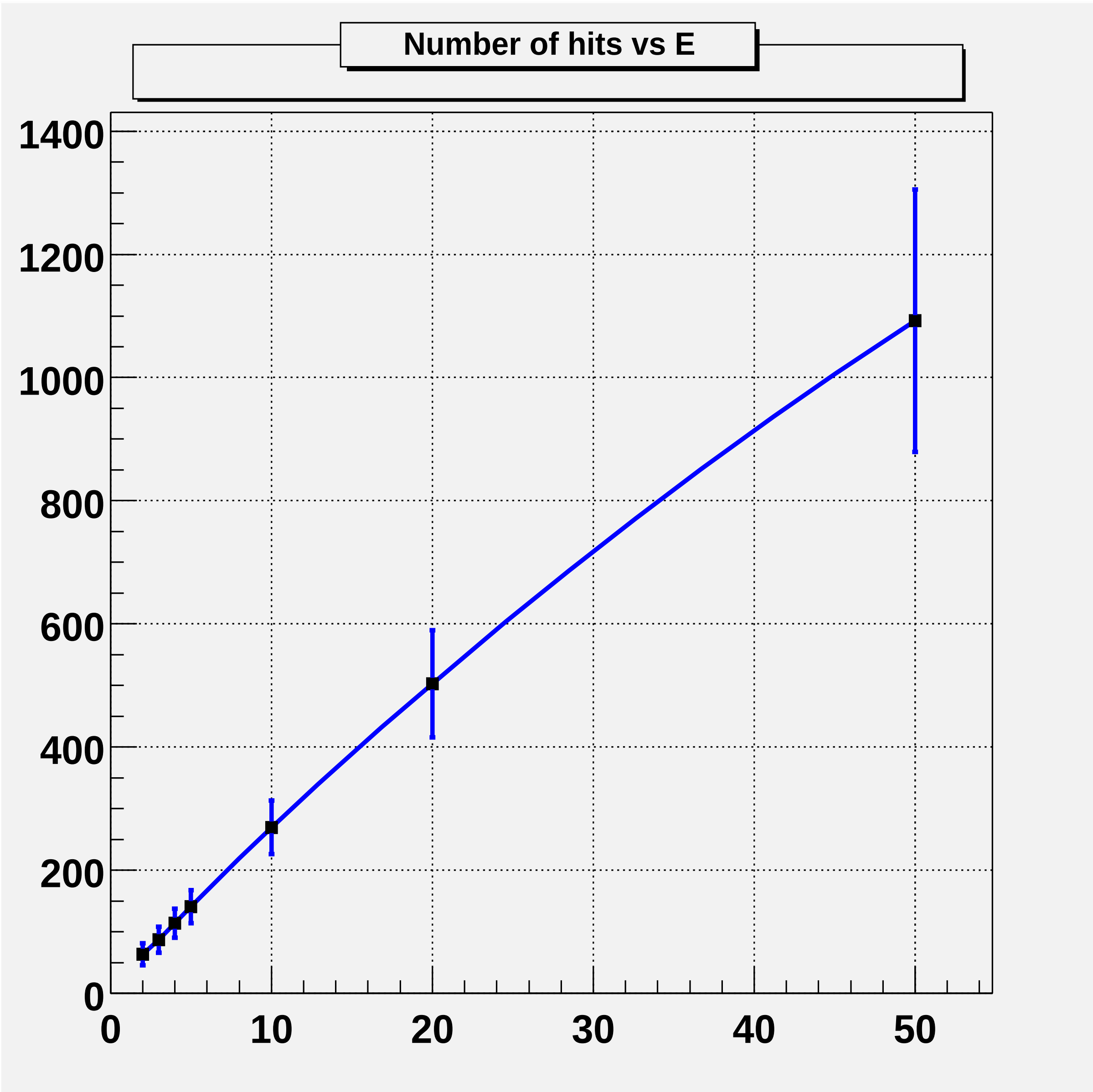


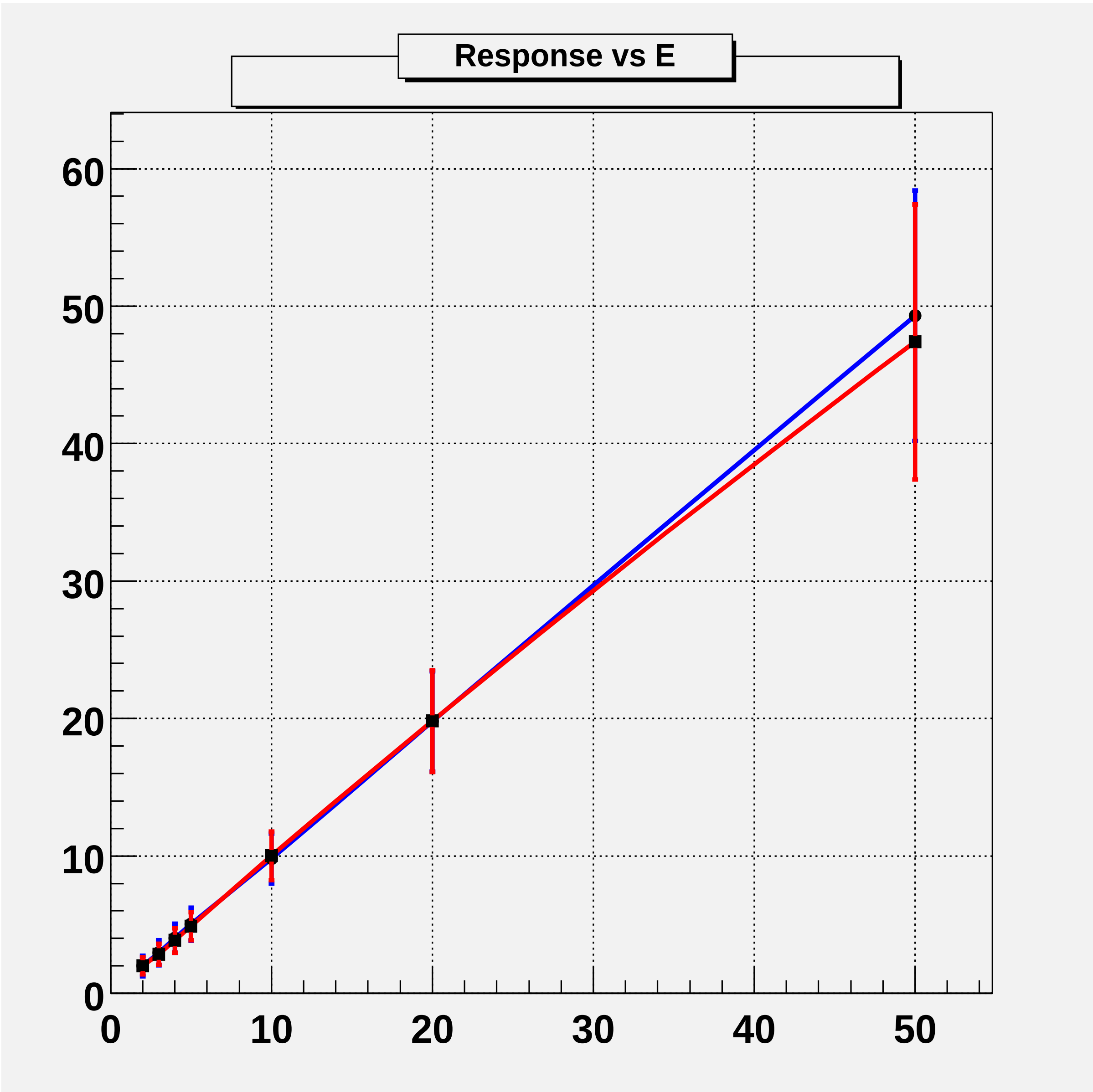
Digital measurement of E (cell-counting):

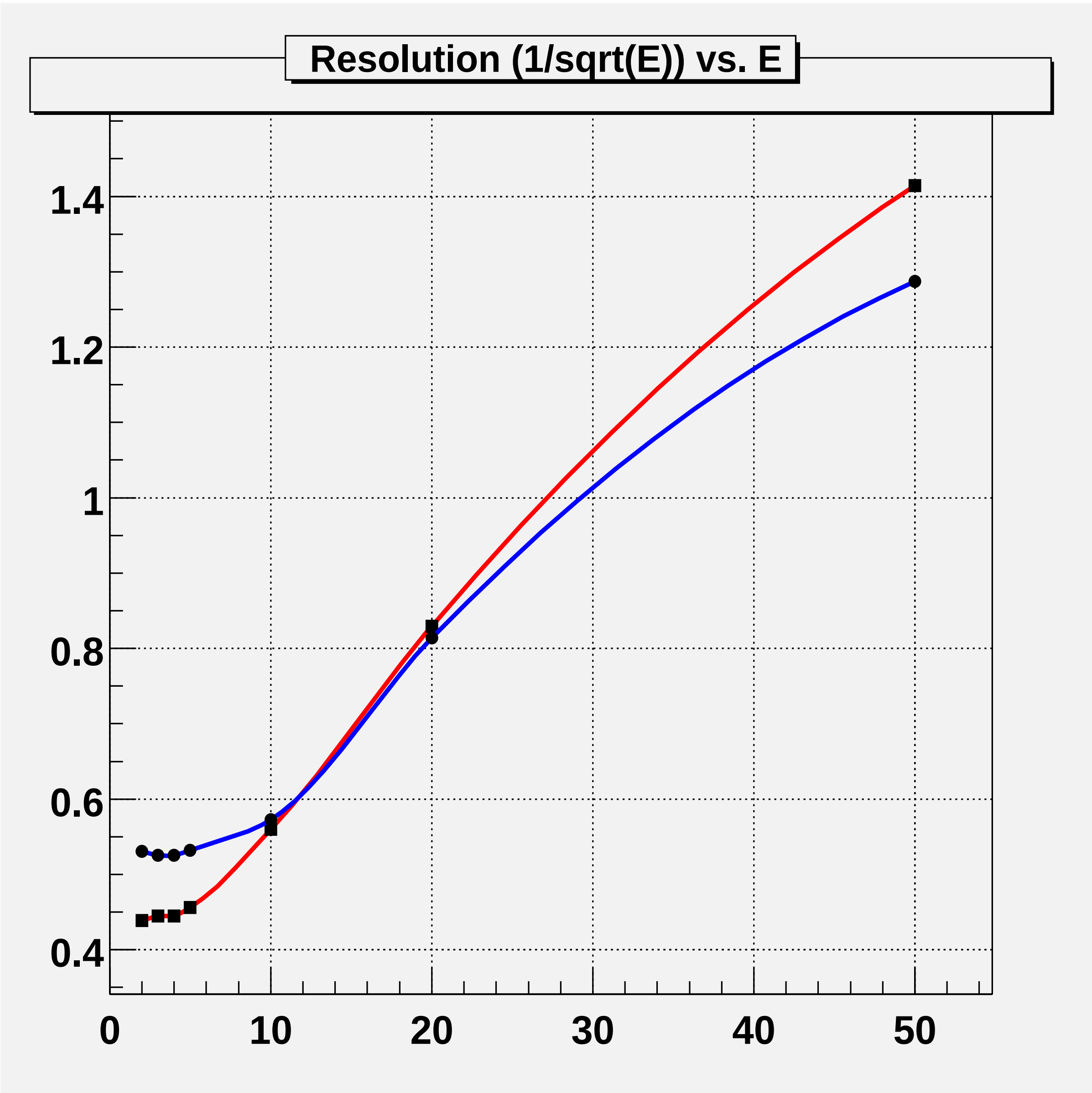
- Count the number of cells hit in the EM and Hadronic sections of the calorimeter.

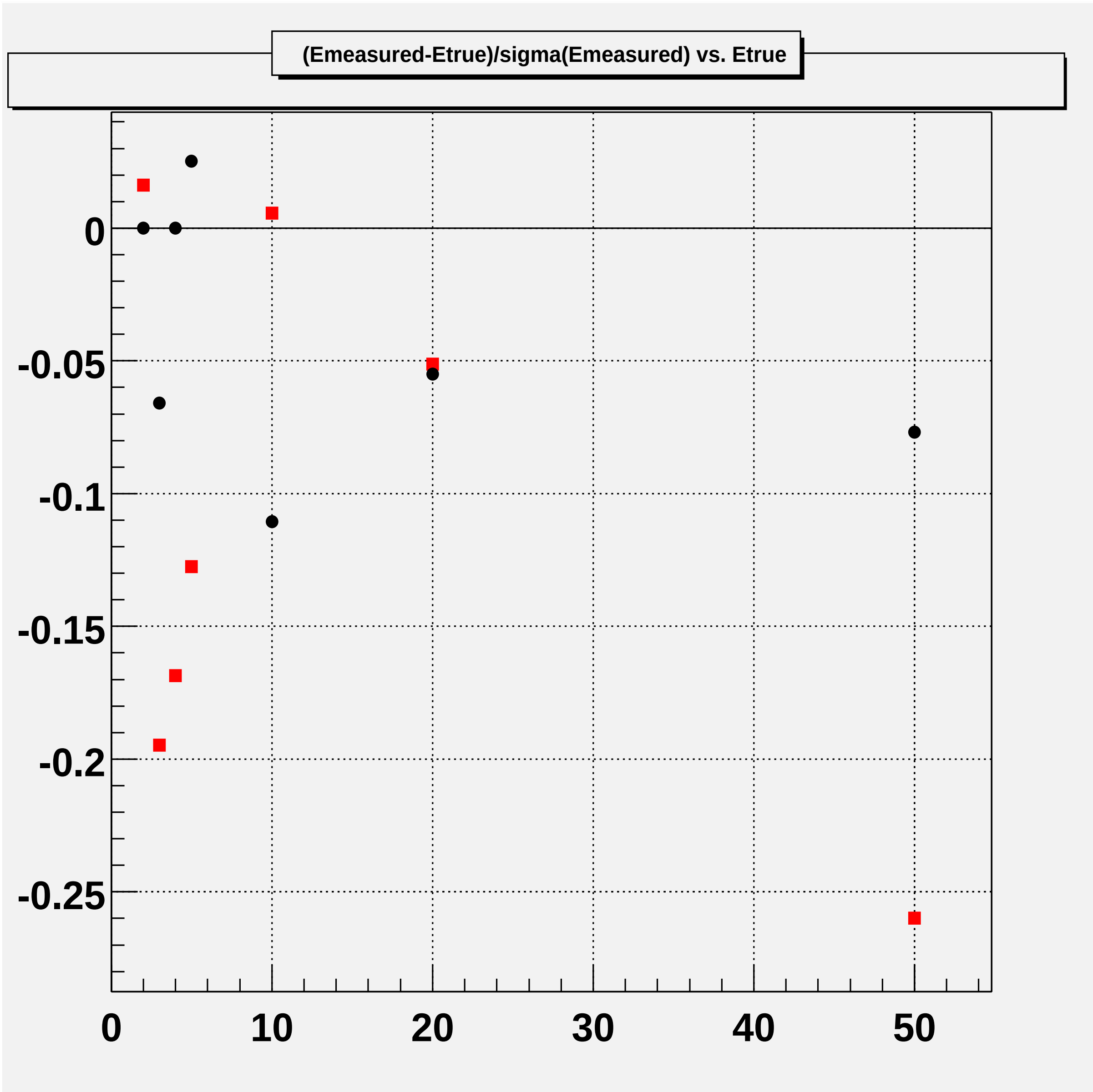
- Did not perform any rigorous function minimization, but tried a few ways, both linear and non-linear, of combining n_{hit}(EM) and n_{hit}(Had), with manual tuning of parameters.

- 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.)


Number of hits vs E
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50


Response vs E
0
10
20
30
40
50
60
0
10
20
30
40
50


Resolution (1/sqrt(E)) vs. E
1.4
1.2
1
0.8
0.6
0.4
0
10
20
30
40
50


(Emeasured-Etrue)/sigma(Emeasured) vs. Etrue
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
10
20
30
40
50

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

- $$E = \left(\frac{n_{\text{hit}}}{< n_{\text{hit}}(2 \text{ GeV}) >} \right)^{\frac{1}{\log_{10} c}},$$

  where

  $$c = \frac{< n_{\text{hit}}(20 \text{ GeV}) >}{< n_{\text{hit}}(2 \text{ GeV}) >} = \frac{503}{63.3} \approx 7.95.$$

- 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 ~ 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 parametes, if favorable and practical.