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Calorimeter energy calibration using the energy conservation law

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Abstract. A new calorimeter energy calibration method was developed for the proposed ILC detectors. The method uses the center of mass energy of the accelerator as the reference. It has been shown that using the energy conservation law it is possible to make ECAL and HCAL cross calibration to reach a good energy resolution for the simple calorimeter energy sum.

Keywords. calorimeter, calibration, energy conservation

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1. Calibration procedure

The calorimeters (ECAL and HCAL) of Large Detector Concept (LDC) at the ILC were designed to get the best jet energy resolution using particle flow approach with minimal number of different sampling structures to reduce the number of calibration coefficients [1].

Both calorimeters of LDC will have three sampling structures, so three calibration coefficients to convert the visible energy in the calorimeters into the physical energy scale are needed. Let us define $C^{conv} = E_{whole}/E_{visible}$ for each sampling structure, which is the usual sampling fraction coefficients. For the moment it can be taken from Monte–Carlo; later on it can be defined from cosmic–muon calibration runs. In comparison with the usual calorimeter calibration procedures [2] the proposed procedure is much more simple and it will work for the real detector as well as for simulated events.

Ideally the energy reconstructed by the calorimeters for each event should give $E_{Ecal} + E_{Hcal} = E_{CM}$. In reality this is not the case as seen in Figure 1. The red line corresponds to the ideal calibration, while the black line fits to actually measured points if one uses the sampling fraction coefficients.

To calibrate the detector the black line needs to be rotated on the red line by rescaling the coefficients of energy conversion [1]. The equation for the black line is:

[1]"Rotation" actually means of the affine transformation of this 2–D.

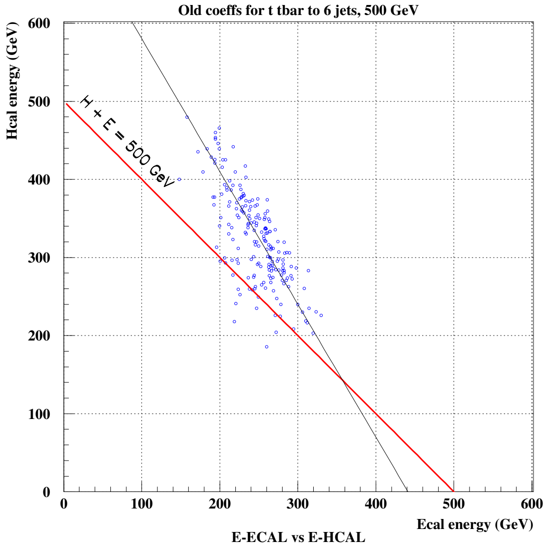

Figure 1. Simple sampling fraction coefficients do not give us the energy conservation for the whole event.

$$a_0 E_{Ecal} + E_{Hcal} = a_0(c_1 E_{vis1} + c_2 E_{vis2}) + c_3 H_{vis} = E_0$$

where: c_1, c_2 and c_3 are an initial energy conversion coefficients, a_0 is the slope which give us the minimal energy width and E_0 is some constant – the line should come through the most probable value of the initial energy sum [2].

The red line equation is: $E^{calib}_{ECAL} + E^{calib}_{HCAL} = E_{CM}$, which is the energy conservation law. Let us require $E_0 = E_{CM}$ and $a_0 = 1$ exactly. Then we get the new coefficients: $c^{calib}_1 = f a_0 c_1, \;\; c^{calib}_2 = f a_0 c_2 \;\; and \;\; c^{calib}_3 = f c_3$; where: $f = E_{CM}/E_0$;
and $c^{calib}_1 E_{vis1} + c^{calib}_2 E_{vis2} + c^{calib}_3 H_{vis} = E_{CM}$ along the most probable line.

These new coefficients contain all the properties of the LDC calorimeters as well as the flavor's containment of the jets. Only these three coefficients will be applied later on to each hit in the particular sampling regions of the calorimeter for any event.

2. Results

This calibration procedure was checked for a number of energies 91.2, 360, 500 GeV and 1000 GeV. The calculations were done with three conversion coefficients only.

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[2]If the initial coefficients were bad fitted to the intrinsic mutual calorimeter properties (bad inter–calibration), one will never get the sharp top right edge of the energy distribution as well as the clean most probable line!

The results of rescaling can be seen in the Figures 2–5. Shown is the energy measured by the HCAL (sum of hit energies) versus energy measured by the ECAL [3].

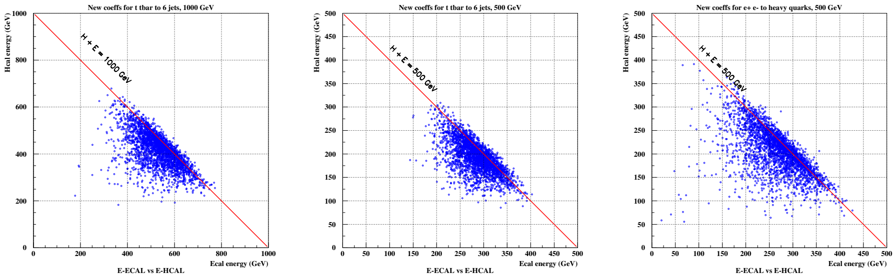

Figure 2. E_{HCAL} versus E_{ECAL} for heavy quarks , 1000 GeV and 500 GeV

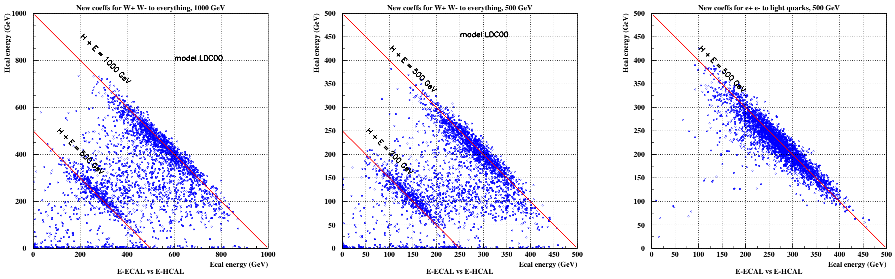

Figure 3. E_{HCAL} versus E_{ECAL} for W and light quarks , 1000 GeV and 500 GeV

A more accurate comparison of the results of rescaling with true information will allow us to estimate the pure calorimetric energy resolution. To do this one has to compare the energy which is available to be measured by the calorimeters on the event to event basis.

Events for all these plots were generated without a luminosity curve and without ISR, so, the total sum of energy in HEP record is equal of the center of mass energy of accelerator exactly.

To calculate the available energy for the calorimeters one should subtract from E_{CM} the sum of neutrino energies, as well as the energies of particles which are lost in the very forward direction; and the energies carried by muons out of calorimeter (each muon leaves about 1.6 GeV in the calorimeter). So, the estimated energy to be measured by the calorimeters for each event is: $E_{available} = E_{CM} - E_{neutrinos} - E_{to\ tube} - E_{muons} + N_{muons} \times 1.6\ GeV$. Table 1 shows the results of a gaussian fit of the distributions shown at Figures 2–5 and of fitting the distributions of the difference between measured energy sum and energy available in calorimeters (for more detailed pictures see a conference talk [3]).

[3]Events were simulated by full simulation code Mokka 5–4 based on GEANT 4.8

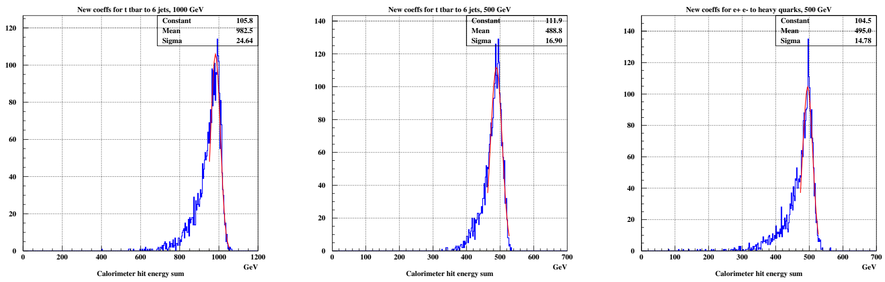

Figure 4. E_{ECAL} + E_{HCAL} for heavy quarks , 1000 GeV and 500 GeV

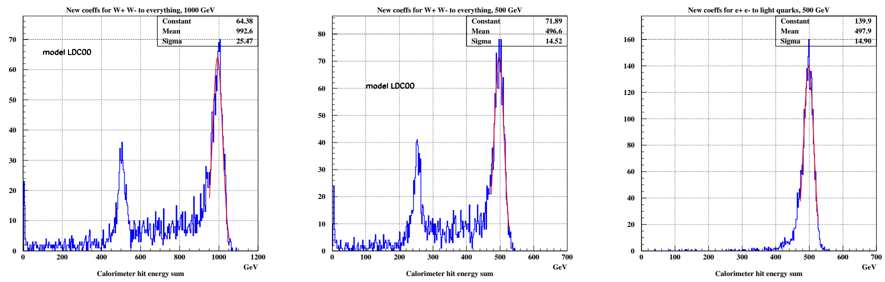

Figure 5. E_{ECAL} + E_{HCAL} for W and light quarks , 1000 GeV and 500 GeV

The last column of Table 1 shows the reachable energy resolution of LDC calorimeters extracted only from the simple sum of hit energies. Any reconstruction program/procedure should not get a worse resolution than the simple energy sum.

References

[1] http://www.ilcldc.org/documents/dod/outline.pdf
[2] R.Wigmans, Calorimetry, Oxford University Press, 2000.
[3] http://indico.cern.ch/contribAuthorDisplay.py?
authorId=morgunov+vasiliy+vasiliy.morgunov%40desy.de&confId=568

Table 1. Summary Table, model LDC00

	Whole calorimeter sum		Check plots	
Process e+ e- into , at energy	Energy mean [GeV]	Energy sigma [GeV]	Difference [GeV]	Estimated energy resolution [GeV]
t tbar, 1000 GeV	982.3	24.6	0.19	18.7
W+ W-, 1000 GeV	992.6	25.5	2.7	17.4
t tbar, 500 GeV	488.8	16.9	1.8	12.6
W+ W-, 500 GeV	496.6	14.5	1.6	10.9
heavy quarks, 500 GeV	495.0	14.8	-0.5	12.8
light quarks, 500 GeV	497.9	14.9	-1.1	14.3
t tbar, 360 GeV	356.4	14.0	5.5	10.0
Z pole, 91.2 GeV	90.4	4.67	-0.06	4.25