

# Combined Calorimeters Properties Part 1.

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## Introduction

Combined calorimeter means ECAL + HCAL + TCMT; and all their combination, such as:

ECAL + HCAL only: length is of about **5 nuclear interaction units** (conventional for ILD);

ECAL + HCAL + first 9 layers of TCMT: length is of about **6 nuclear interaction units** (proposed for ILD);

ECAL + HCAL + TCMT: full CALICE possible calorimeter length is of about **9 nuclear interaction units**.

### Position cuts

ECAL electromagnetic calibration check

HCAL electromagnetic calibration check

Muon stability check

Energy linearity

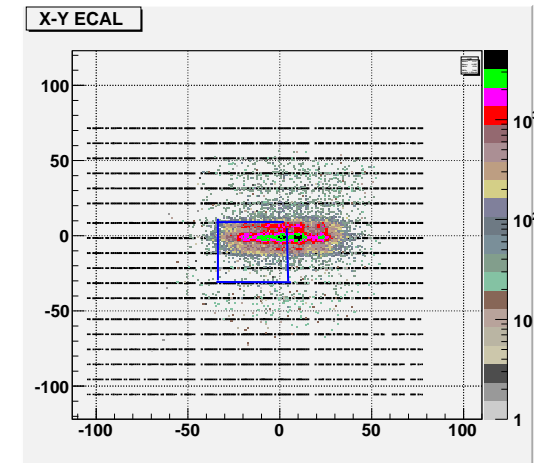
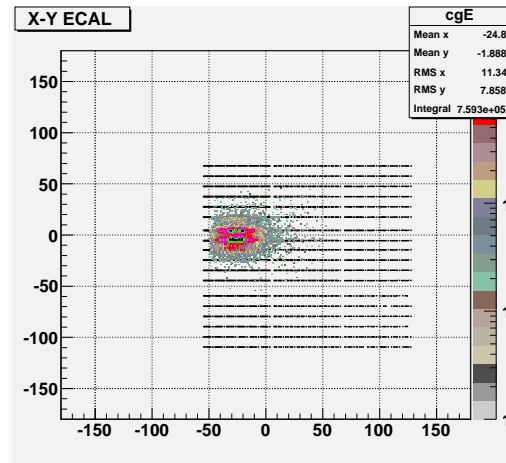
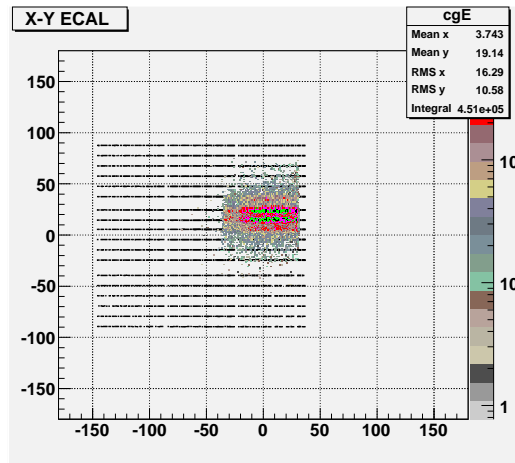
Energy resolution

Remark:

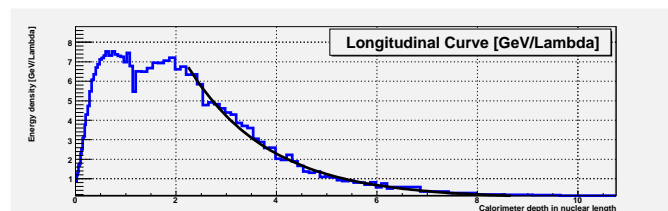
We will discuss of three different types of combined calorimeters to get a sense about a calorimeter length needed for ILD.

## Beam position cut

Pictures show different positions at different runs during CERN run beam-test period of data taking.



A small transverse size of the ECAL ( $18 \times 18 \text{ cm}^2$ ) in compare with hadron shower size leads to the shower energy losses at dead material surrounded of electromagnetic calorimeter. In the case of combined calorimeter such a losses are occurred near by the maximum of longitudinal distribution of hadron shower.

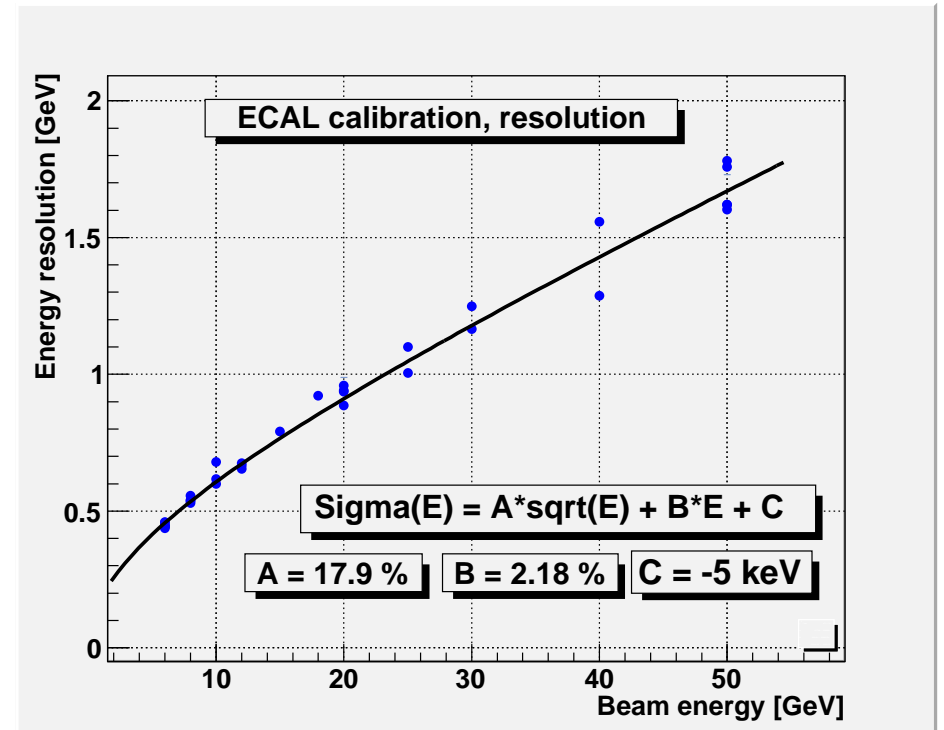
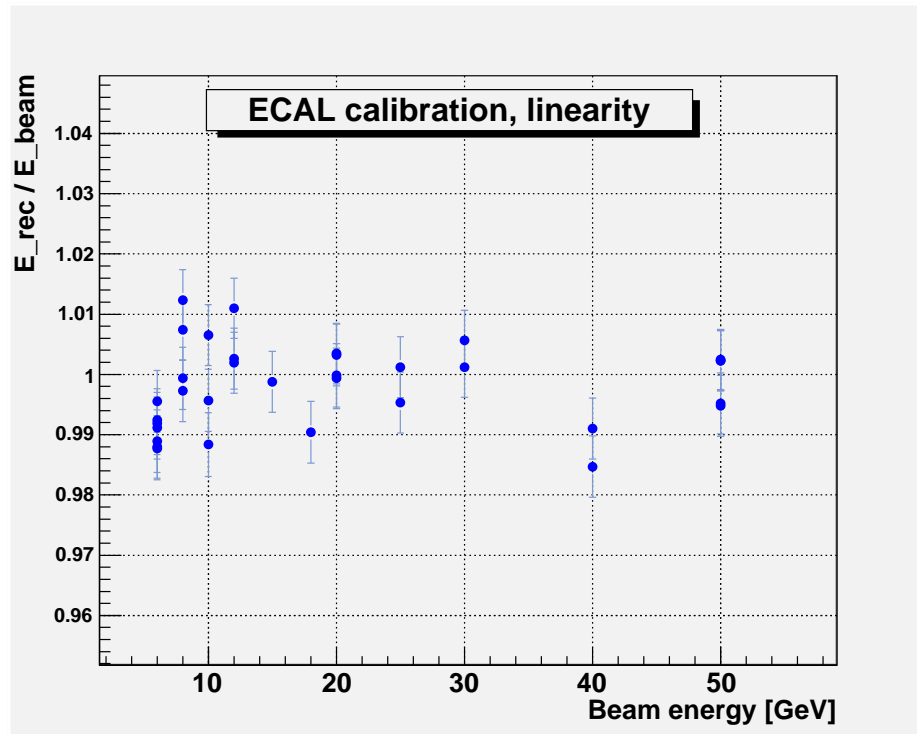


without position cut

A beam impact point was chosen to be at the center of ECAL sensors structure in small window  $4 \times 4 \text{ cm}$  to reduce an influence of energy losses. This cut is also slightly reduce of influence of gaps between ECAL wafers.

A position cut is the main reason of small statistics for many runs; these runs were dropped out.

## ECAL calibration check, individual runs



ECAL linearity is inside  $\pm 1\%$  of accuracy.

ECAL energy resolution is of about 18% with energy dependent term that is of about 2% and with zero noise term.

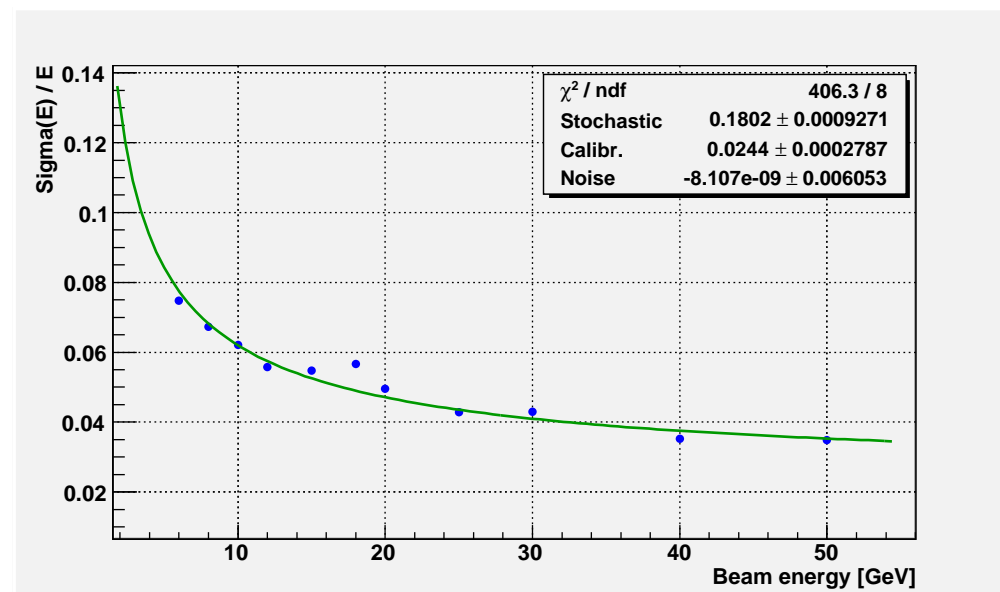
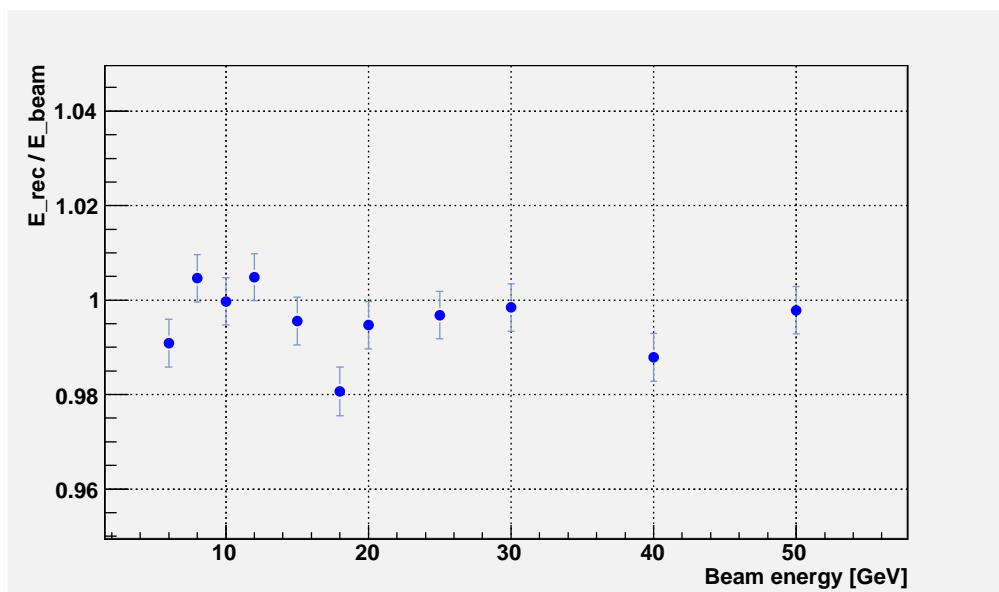
I do not understand a reason of spread of the resolution points. They are out of statistical accuracy.

Let say for now: that is an estimation of our systematical errors for the ECAL resolution for electrons.

It might be the effect of the beam particle type selection.

Need more investigation to be understood.

## ECAL calibration check, combined runs

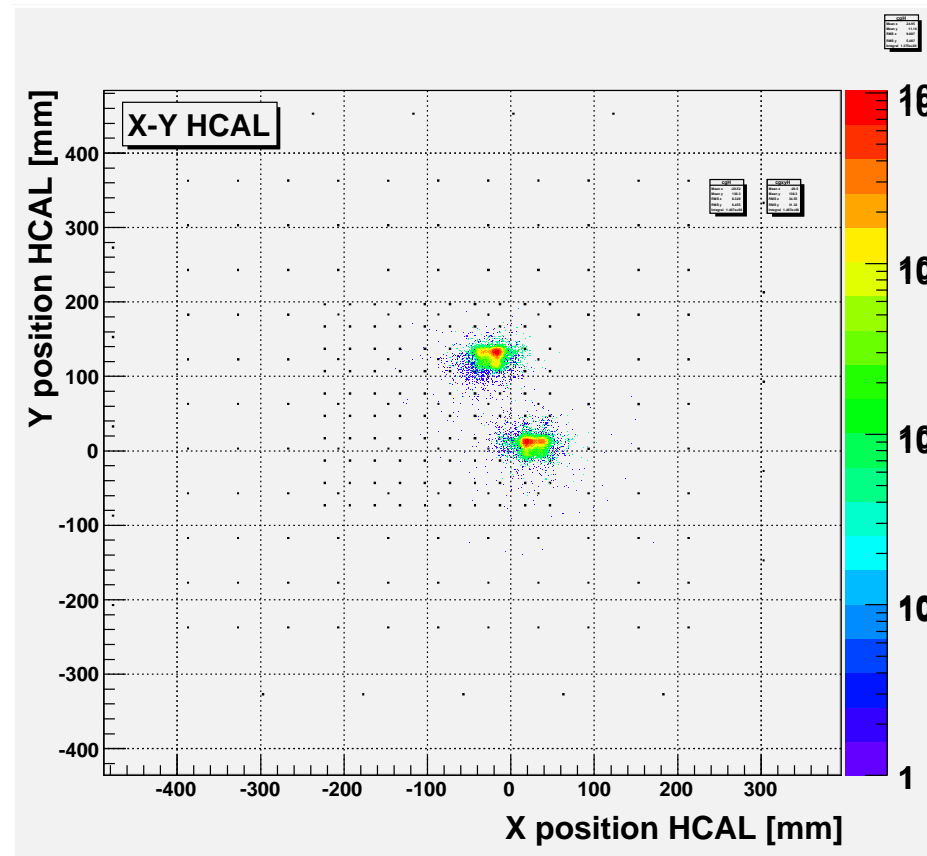


Combined runs means: one histogram was filled for all type of runs with the same beam energy.

## HCAL calibration check, individual runs

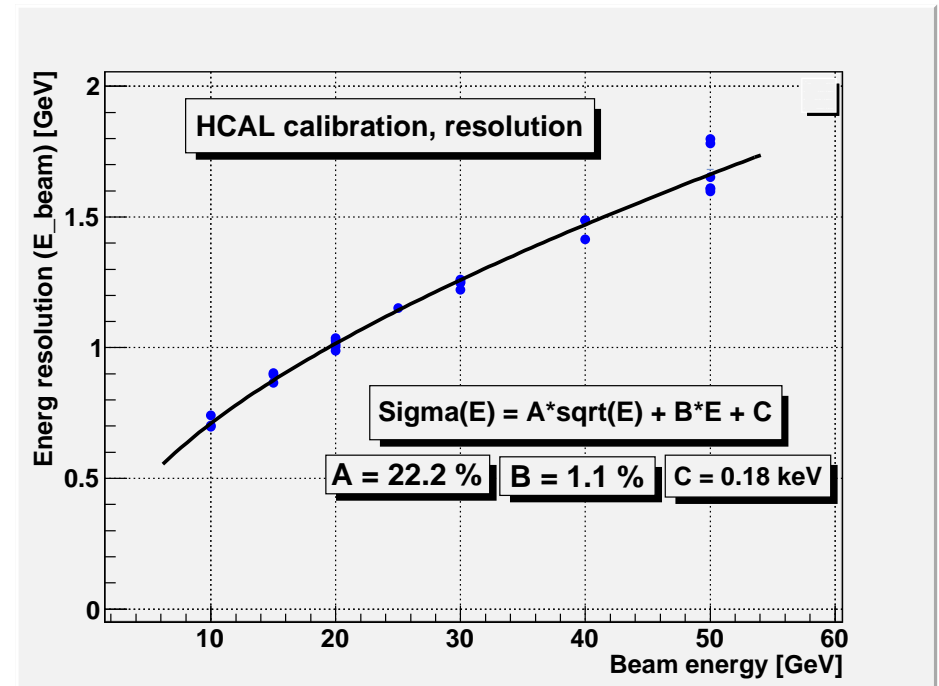
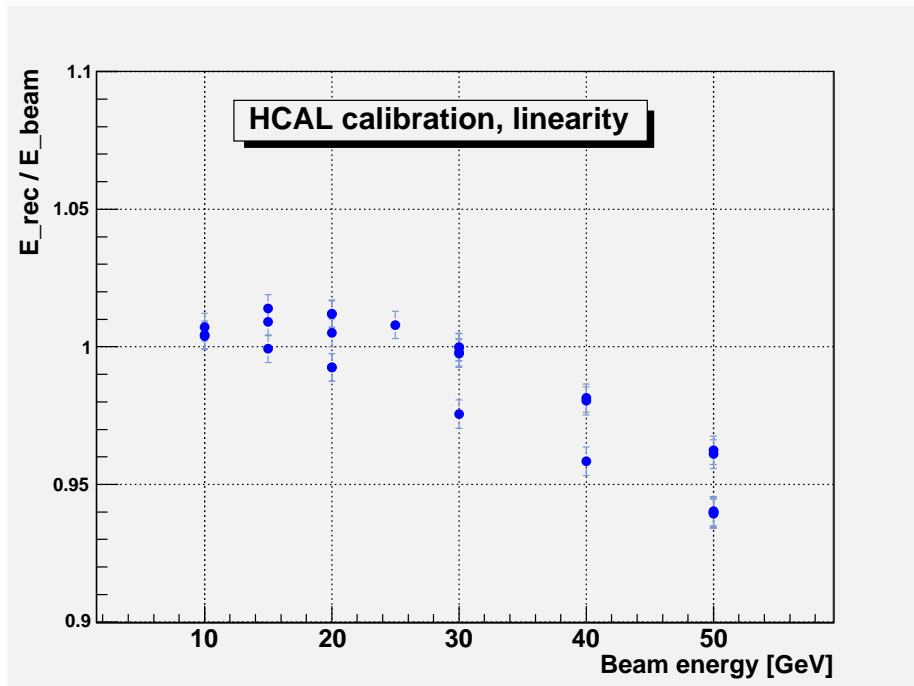
Electromagnetic shower energy for every particle was collected inside a cylinder around shower center with radius of 15 cm, and length of 20 HCAL layers to reduce an effect of HCAL  $1\text{m}^3$  noise.

Two beam position with the same beam energy at different runs.



Different sets of calorimeter cells are at work to get a positron shower energy. At some position the dead cells could be occurred near by the center of the electromagnetic shower in HCAL, at another one it is not the case.

## HCAL calibration check, individual runs

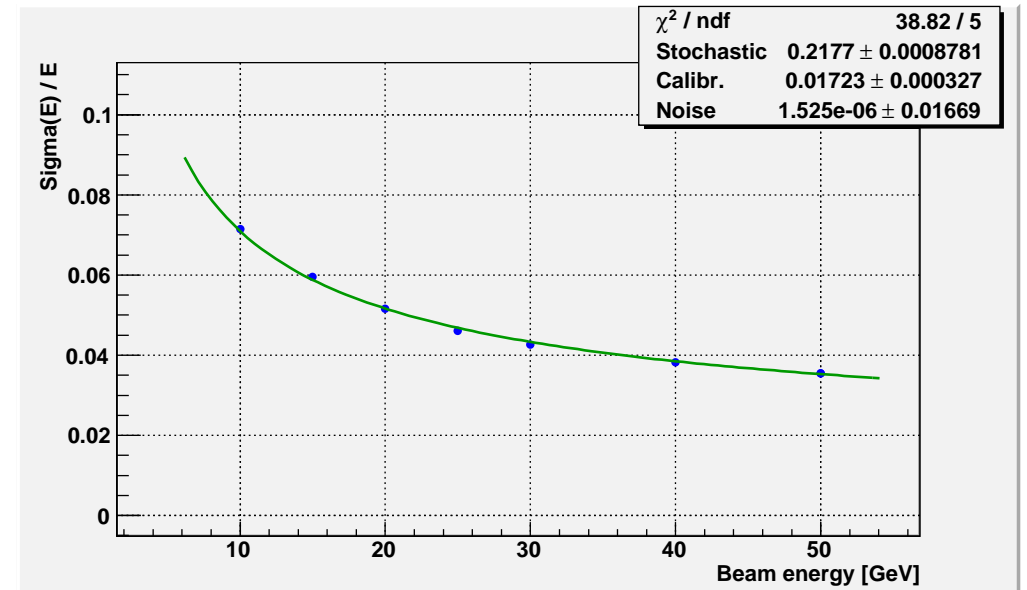
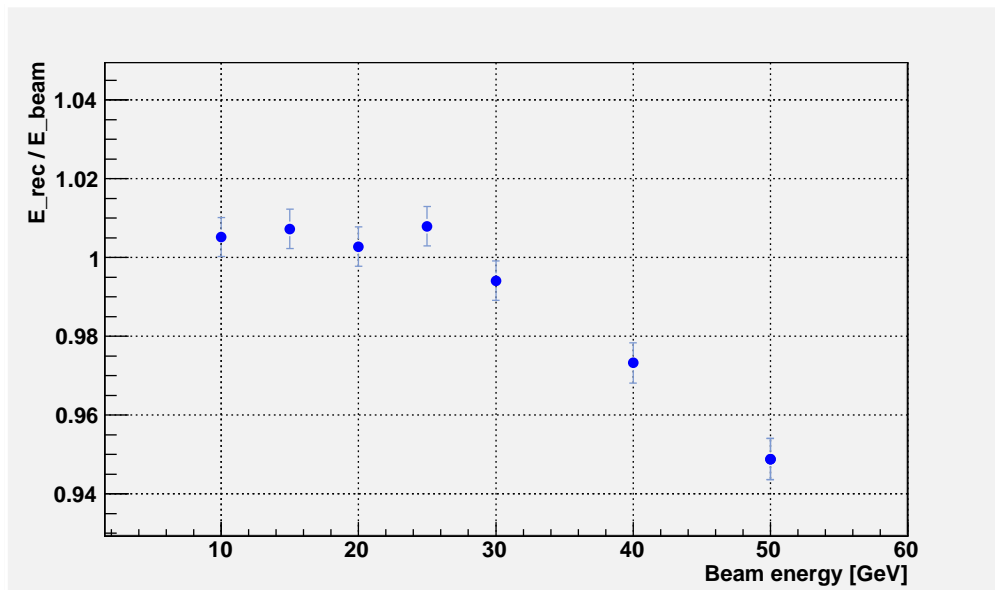


Two clear visible structures at the amplitude ratios are the consequence of the two different position of the beam spot. The effect is order of 2 percent in energy amplitude. (it is not so big). In the case of the hadron beam such an effect will be reduces by the spreading of the position of each individual electromagnetic shower inside the hadron one up to be neglected. Clear visible effect of SiPM saturation with high energy density.

**HCAL linearity is inside  $\pm 2\%$  of accuracy without saturation effect; and with systematics that is of about 2%.**

**HCAL energy resolution for positrons is of about 22% with energy dependent term that is of about 1% and with zero noise term.**

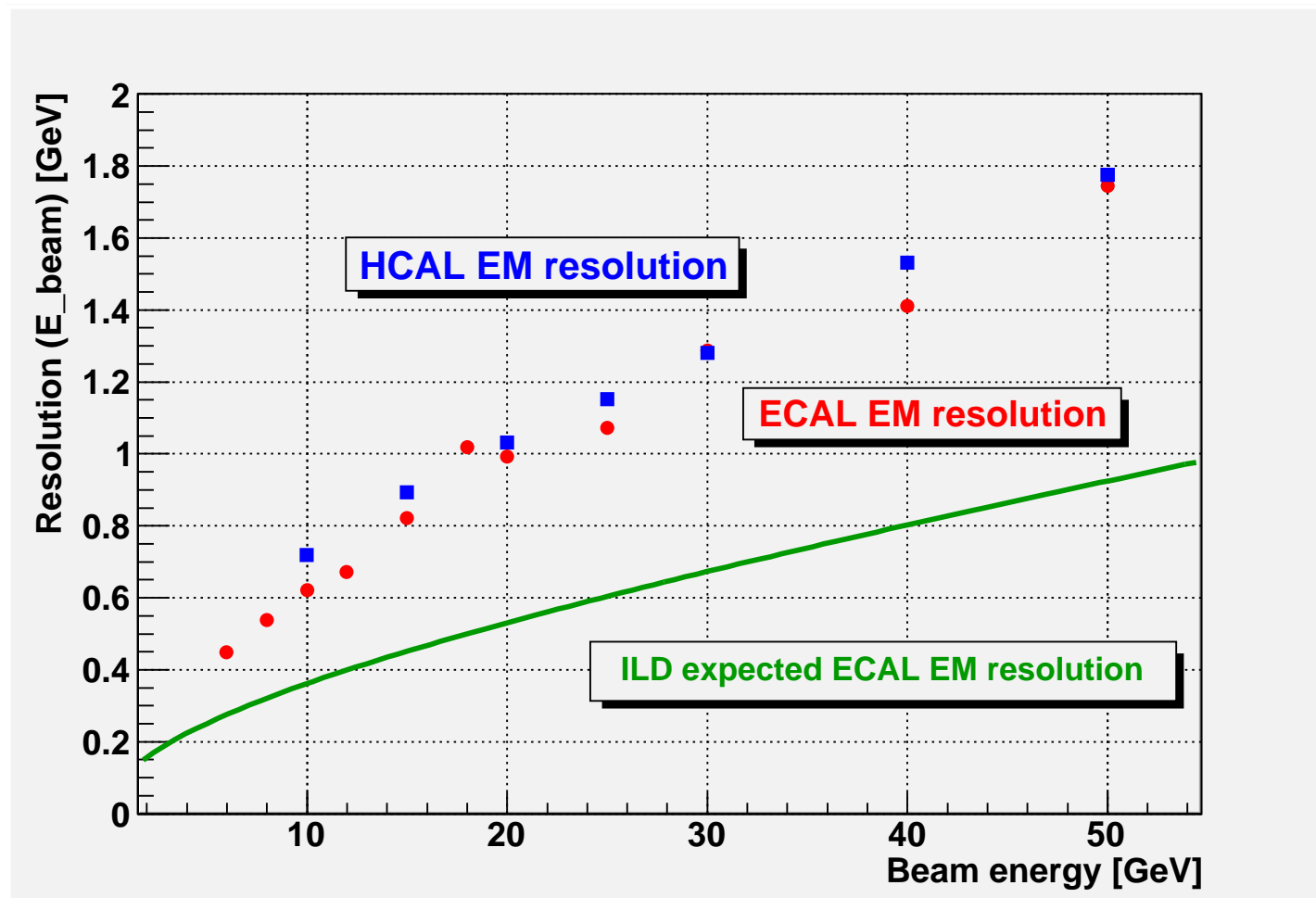
## HCAL calibration check, combined runs



Combined runs means: one histogram was filled for all type of runs with the same beam energy.

## ECAL and HCAL electron/positron resolution

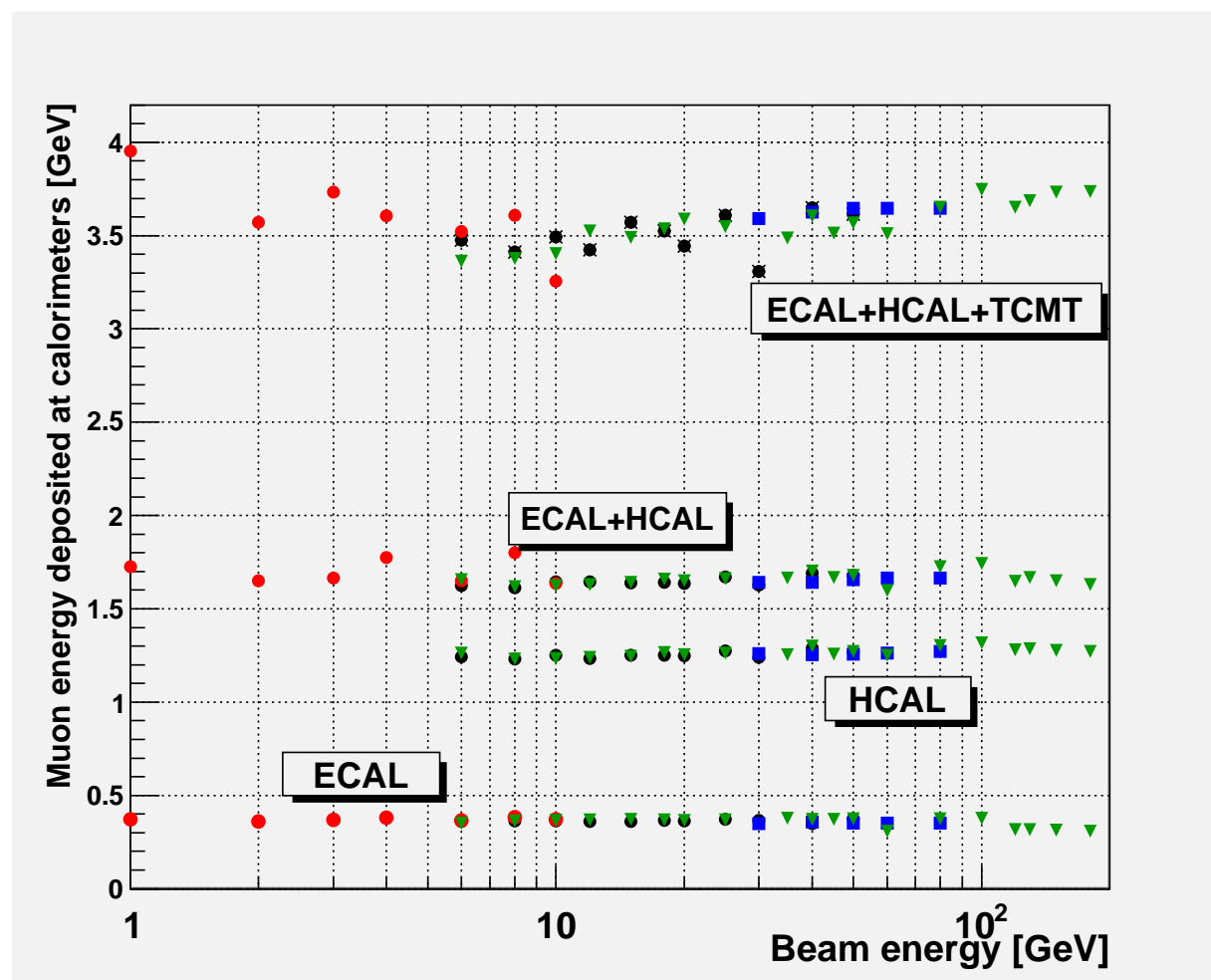
This picture should be never shown at public.



As the result: the resolution of combined calorimeter for hadrons will be much worse then expected.

## Muon energy deposition at calorimeters

Muon track energy for every particle was collected inside a cylinder around track center with radius of 7 cm at HCAL to keep a small noise contribution.



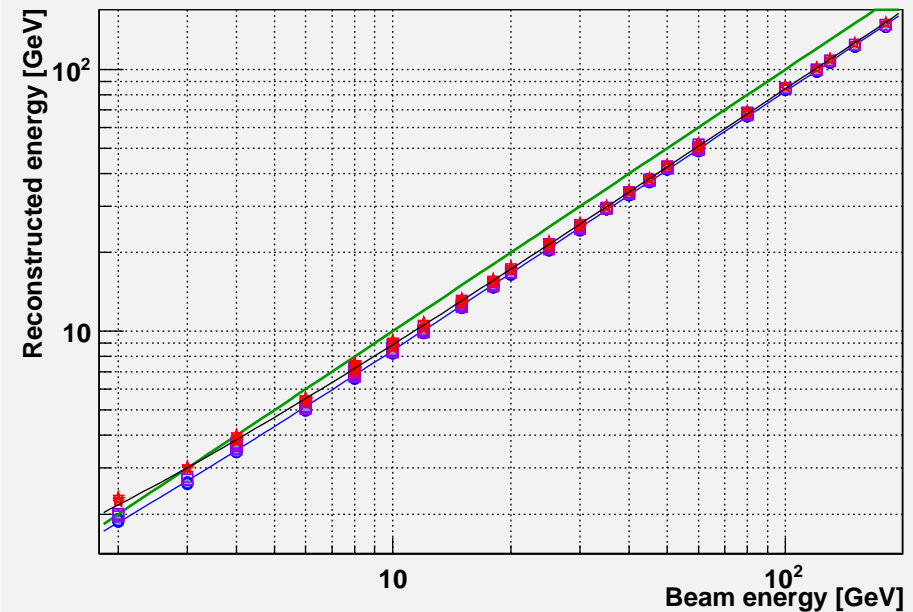
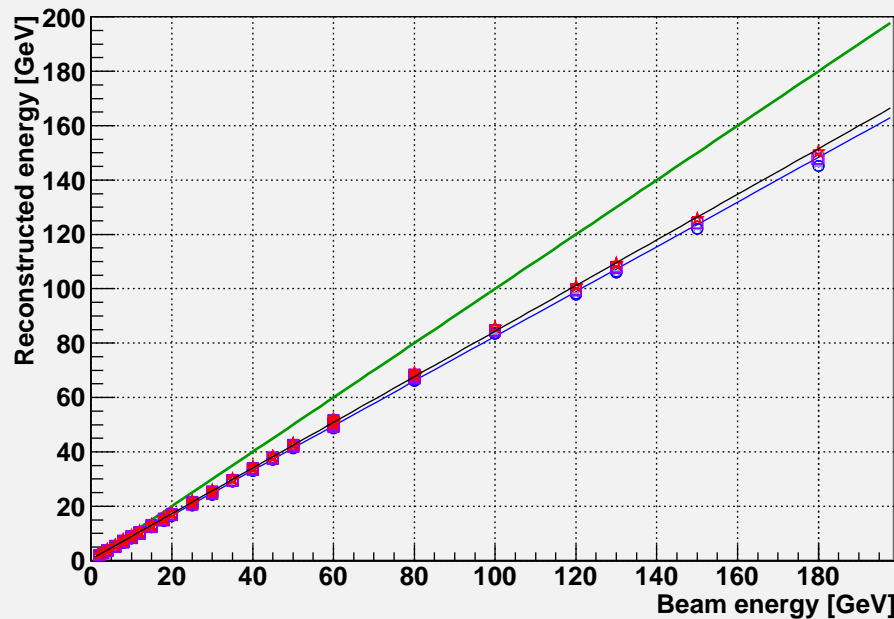
Different markers are different types of runs.

## Reconstructed energies with pure electromagnetic calibration

The energies are the simplest sum of the responses measured in different parts of the detector in GeV.

$$E_{sum} = E_{ECAL} [GeV] + E_{HCAL} [GeV] + E_{TCMT} [GeV]$$

Gaussian fit of this sum in range of  $\pm 2\sigma$  around maximum probable energy value was used to define reconstructed energy and its resolution.

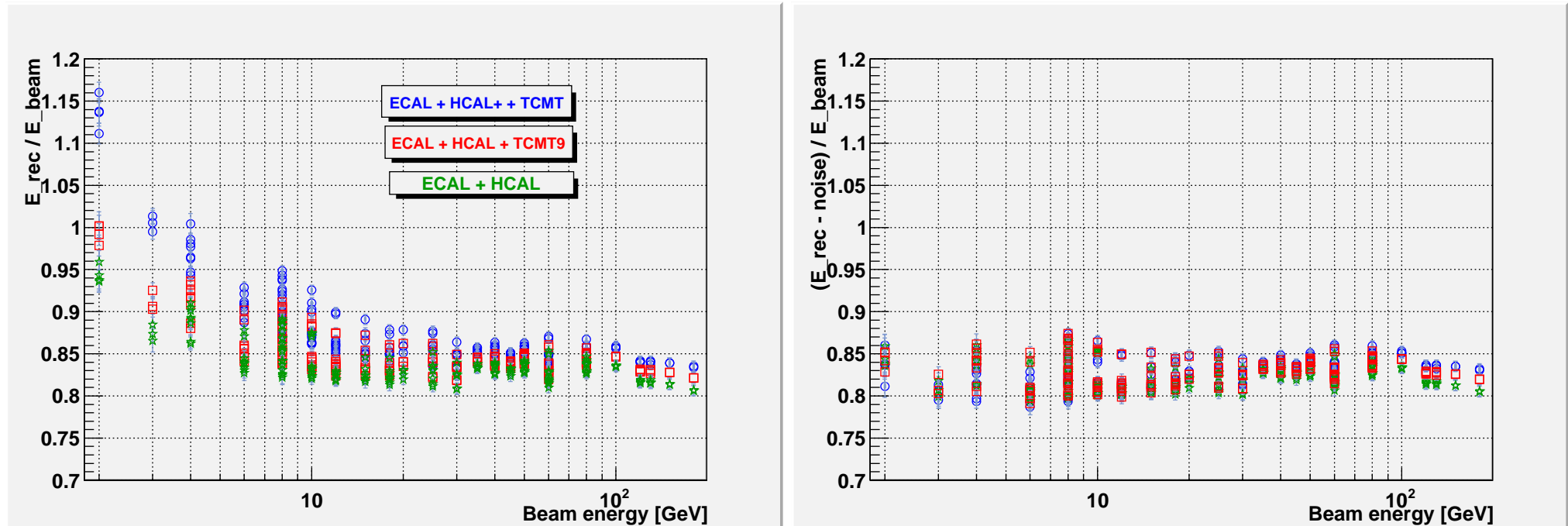


All three detectors show almost the same behaviour in term of linearity with a slope of about 0.8.

Later we will use this slopes to correct energy to the exact beam values.

Slightly smaller amplitude is visible for the shortest calorimeter; which is mostly affected by longitudinal leakage.

# Response linearity with pure electromagnetic calibration



Left plot shows an initial state without taking into account a noise in all calorimeters.

The right hand side plot shows the same amplitudes, but with subtraction of estimated noise (constant).

Noise for ECAL+HCAL calorimeter was taken as 0.2 GeV. !!!

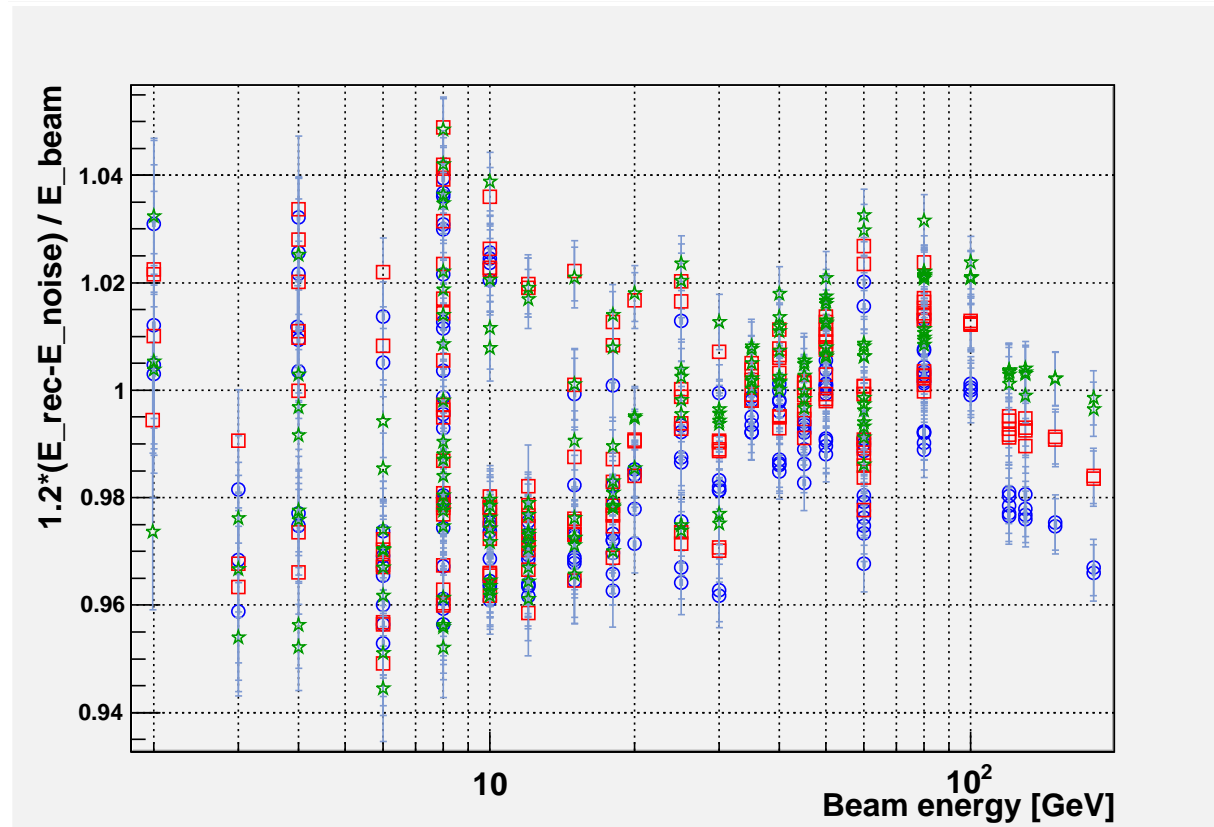
Noise for ECAL+HCAL+TCMT9 calorimeter was taken as 0.3 GeV. !!!

Noise for ECAL+HCAL+TCMT calorimeter was taken as 0.6 GeV. !!!

Dramatic changes in the linearity of the calorimeters at low energies are clear visible.

## Linearity: One factor = 1.2

Different calorimeters are marked by different colors.



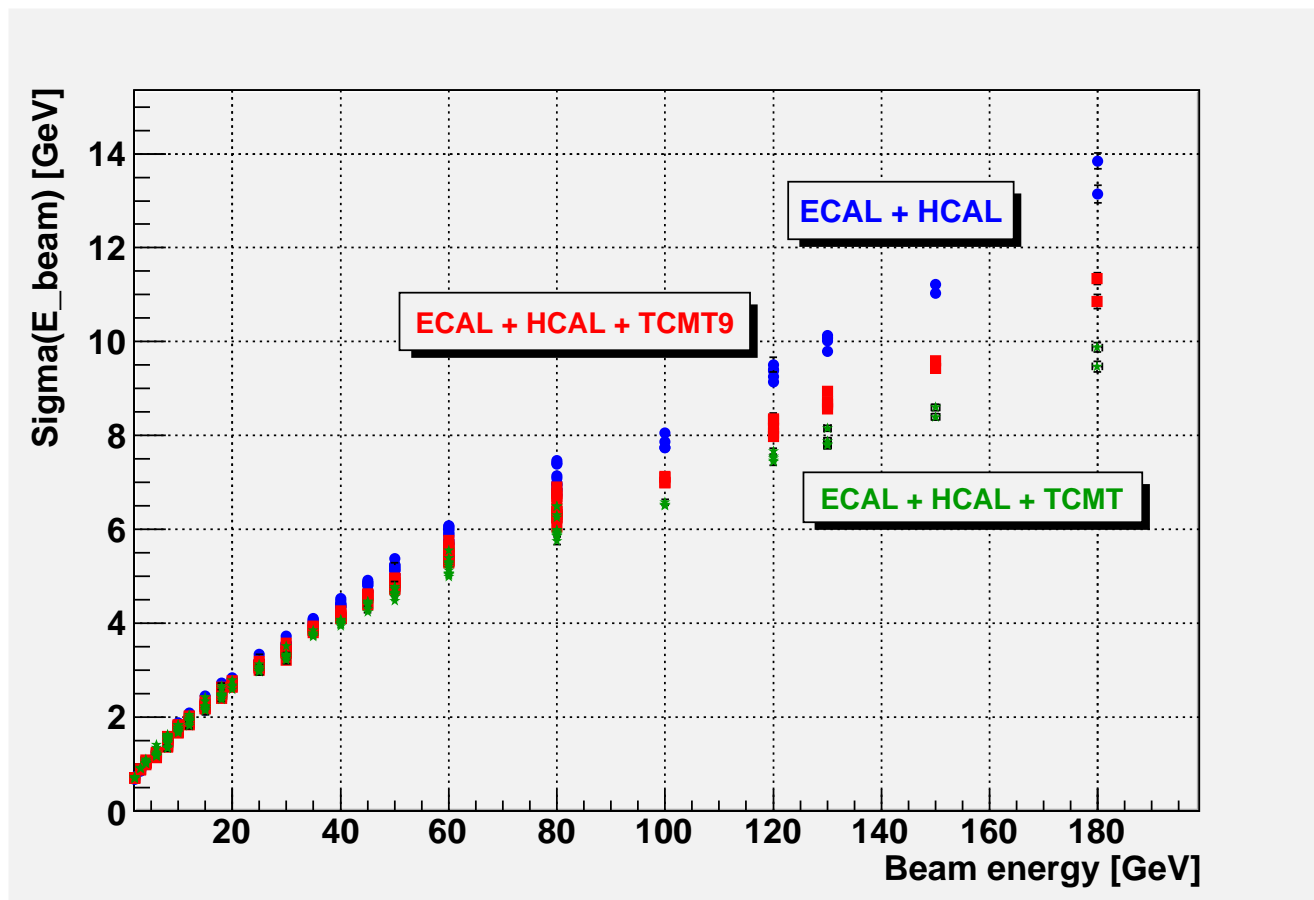
The spread are mainly the systematic uncertainties due to beam quality at particular run, HCAL temperature correction map (that is not perfect yet) and accuracy of calibration on muons.

A CALICE combined calorimeters (all of them) are linear in energy range 2 – 180 GeV at the level of 2–3% !

Here we do not see yet any difference between rather different calorimeter devices.

## Energy resolution in natural scale [GeV]

Different calorimeters are marked by different colors. One factor = 1.2.

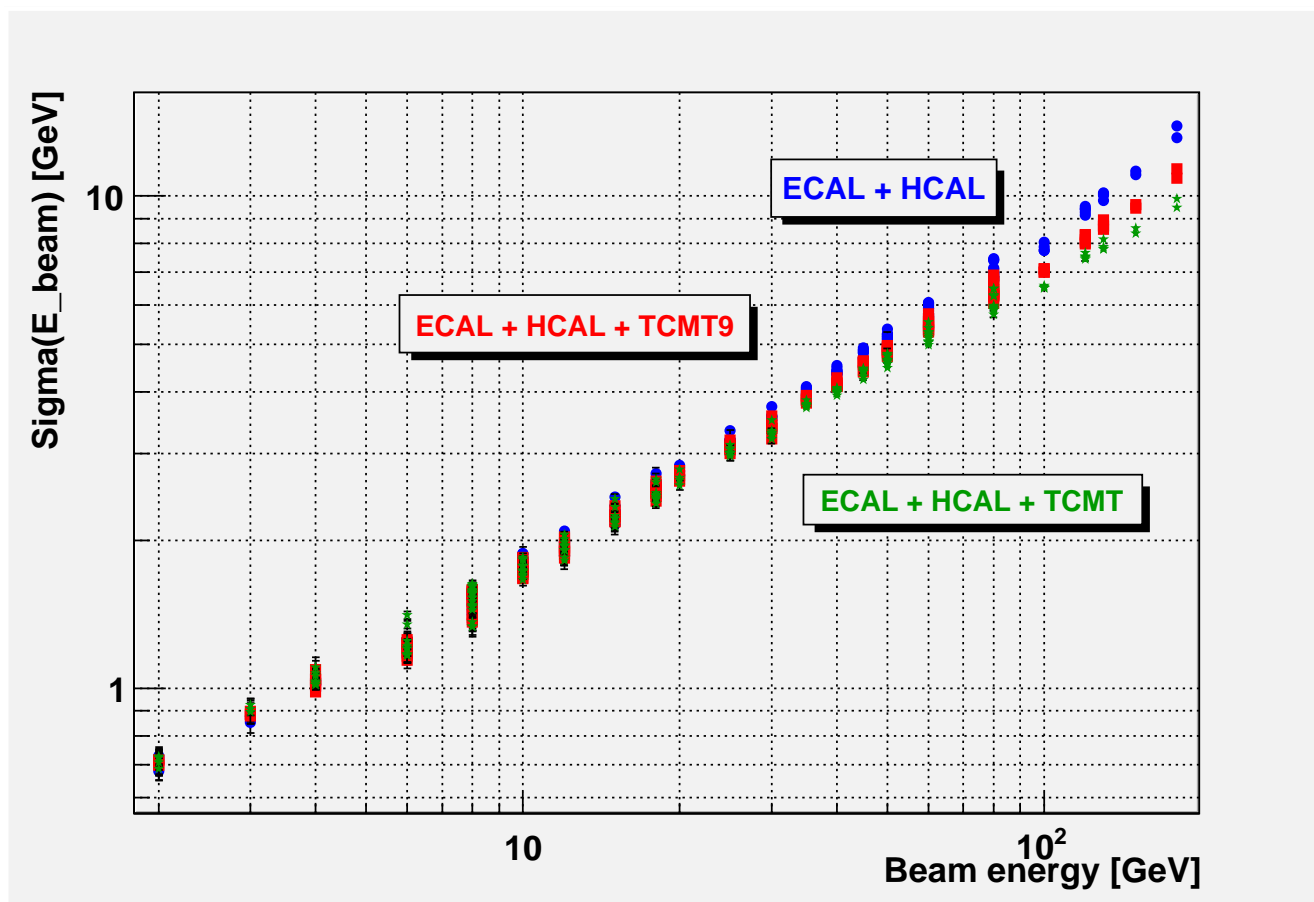


Resolution of shorter calorimeter is worse than resolution of the longer one, as it was expected.

Difference is significant at high energies and it is reaching almost 50% at 180 GeV in natural scale.

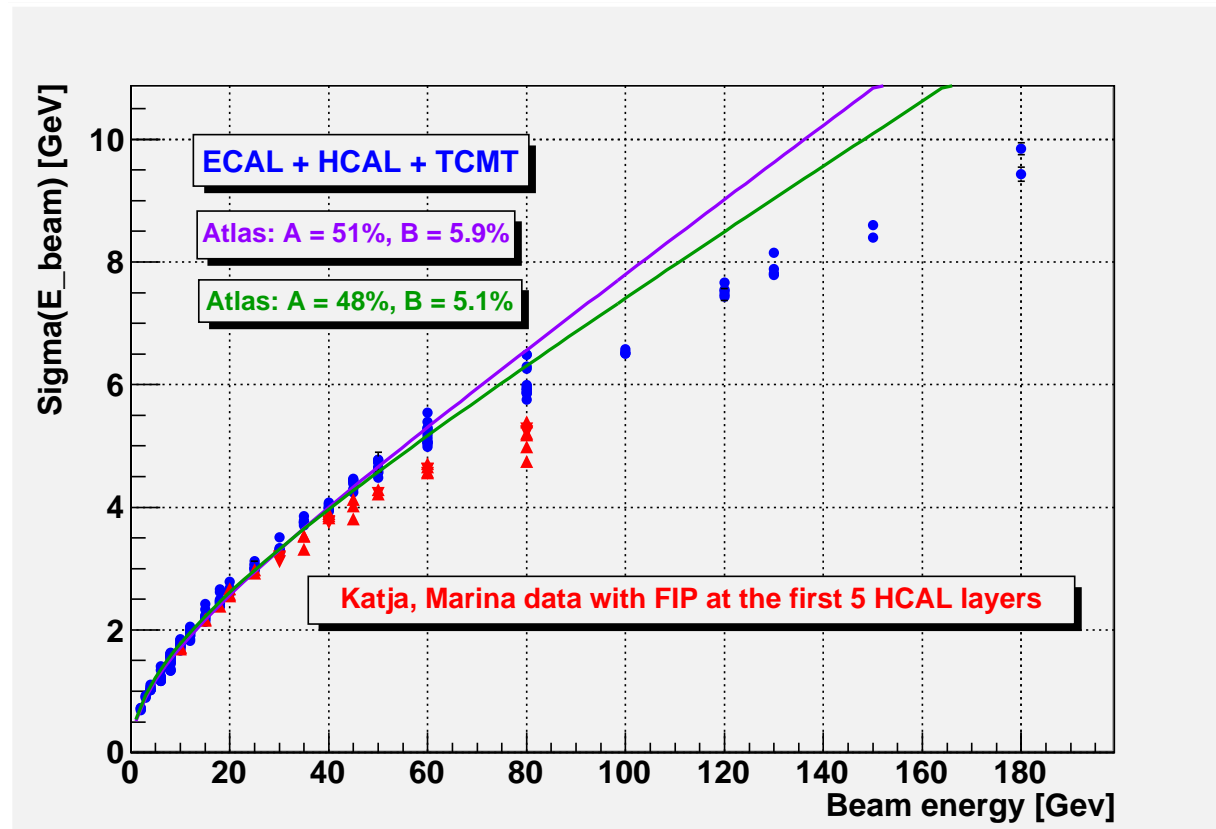
## Energy resolution

Different calorimeters are marked by different colors. One factor = 1.2.



The same picture as previous slide, to show: there is no difference at low energies, as it was expected.

## Energy resolution: comparison

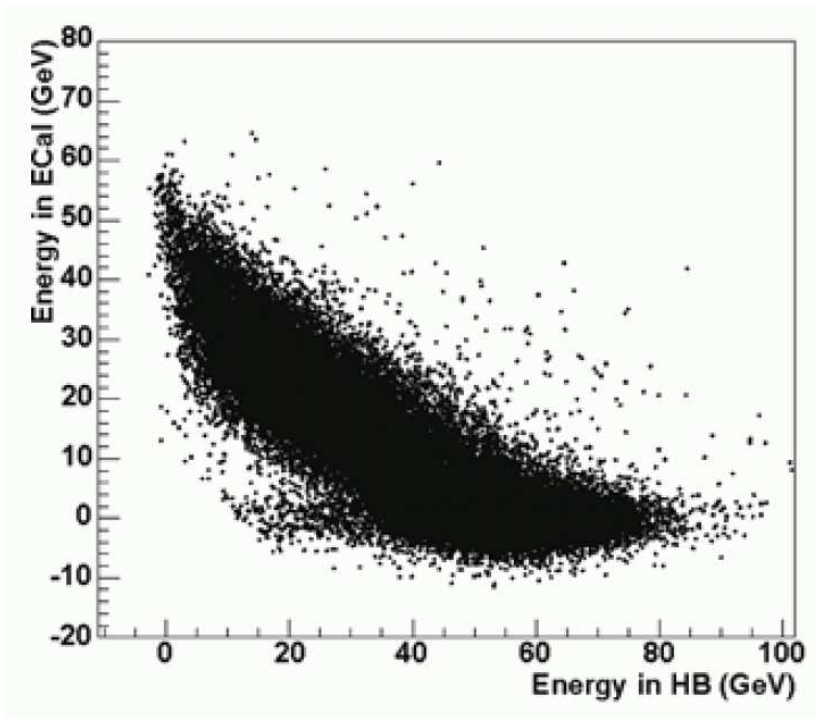


Katja and Marina data were collected for the same combined calorimeter configuration, i.e. ECAL+HCAL+TCMT, but for events with shower starting points at the first five layers of HCAL.

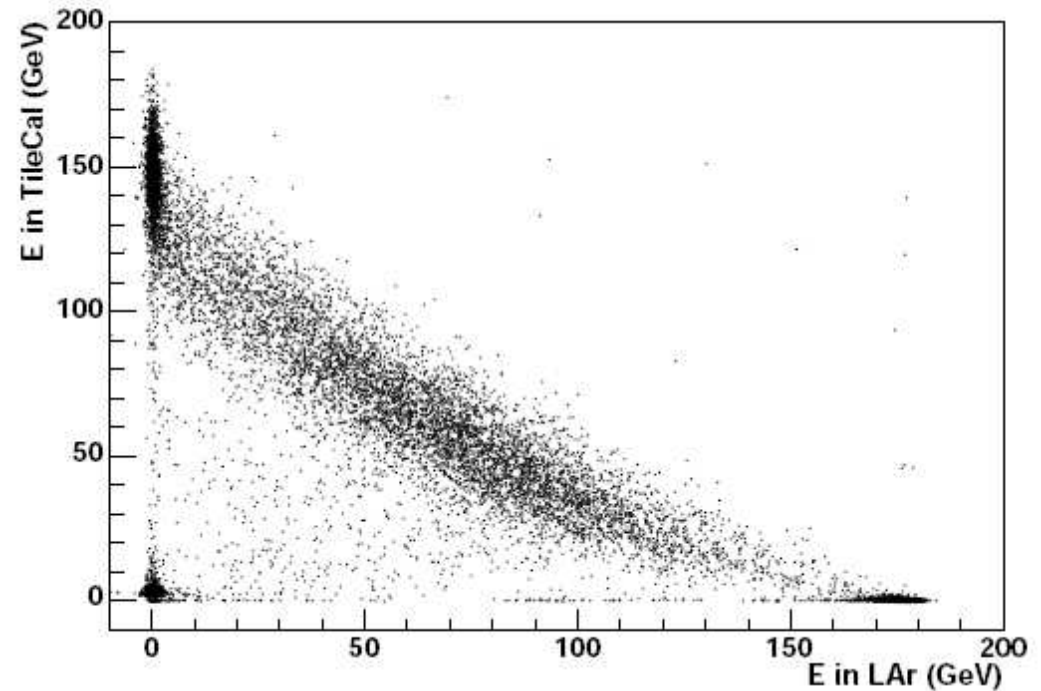
Longitudinal leakage at this case was minimized.

The significant effect of a leakage on the resolution at high energies is clear visible here.

## Combined calorimeters: CMS "banana" and ATLAS "line"

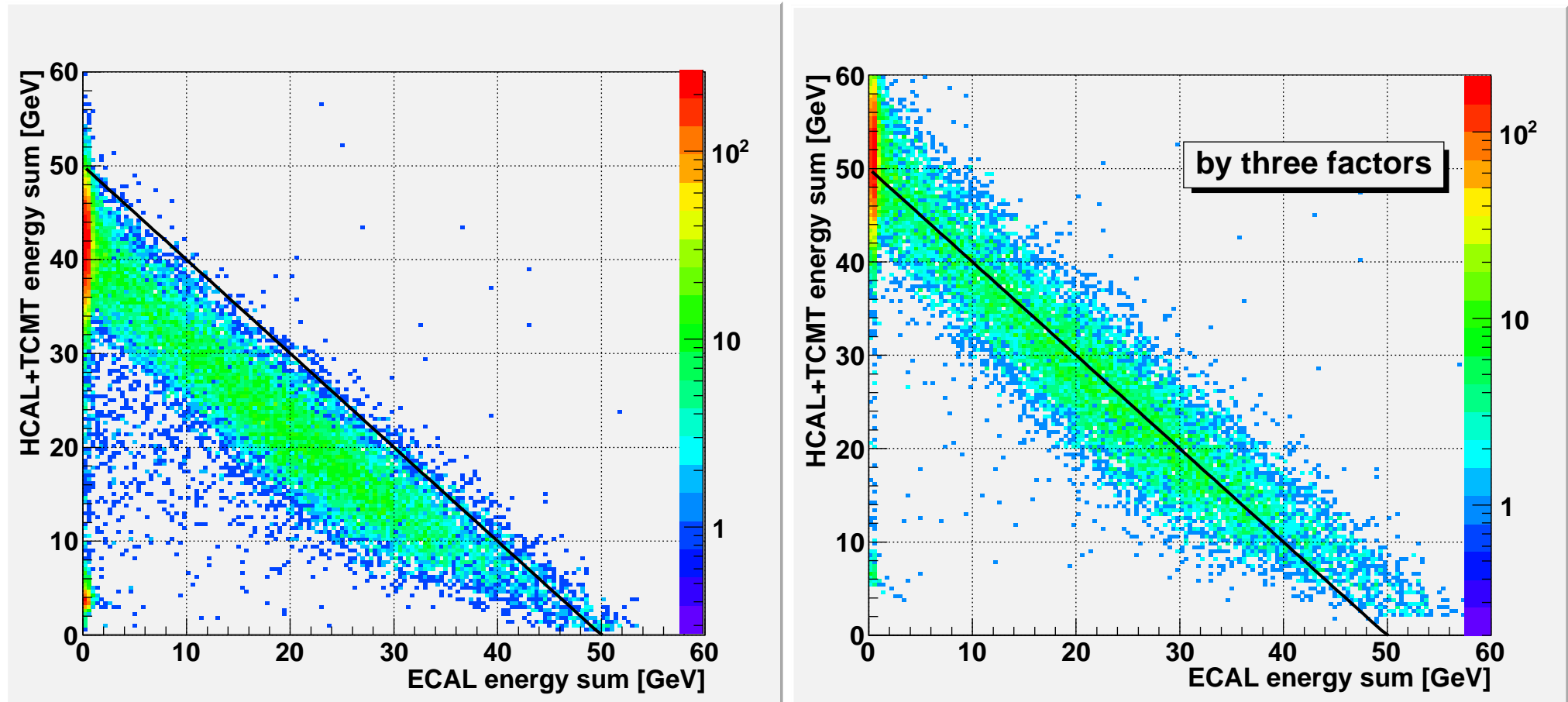


Energy measurement for 50 GeV pion in ECal vs. that in HB at CMS. "Understanding the performance of CMS calorimeter" by Seema Sharma at <http://www.springerlink.com/content/8h51hk42r626136x/>



Correlation between LAr and TileCal energy, 10 GeV pion "Study of the ATLAS central calorimeters response to pions in 2004 combined test beam" by V. Giangiobbe at <http://arxiv.org/pdf/physics/0610128>

## CALICE combined calorimeter "line"

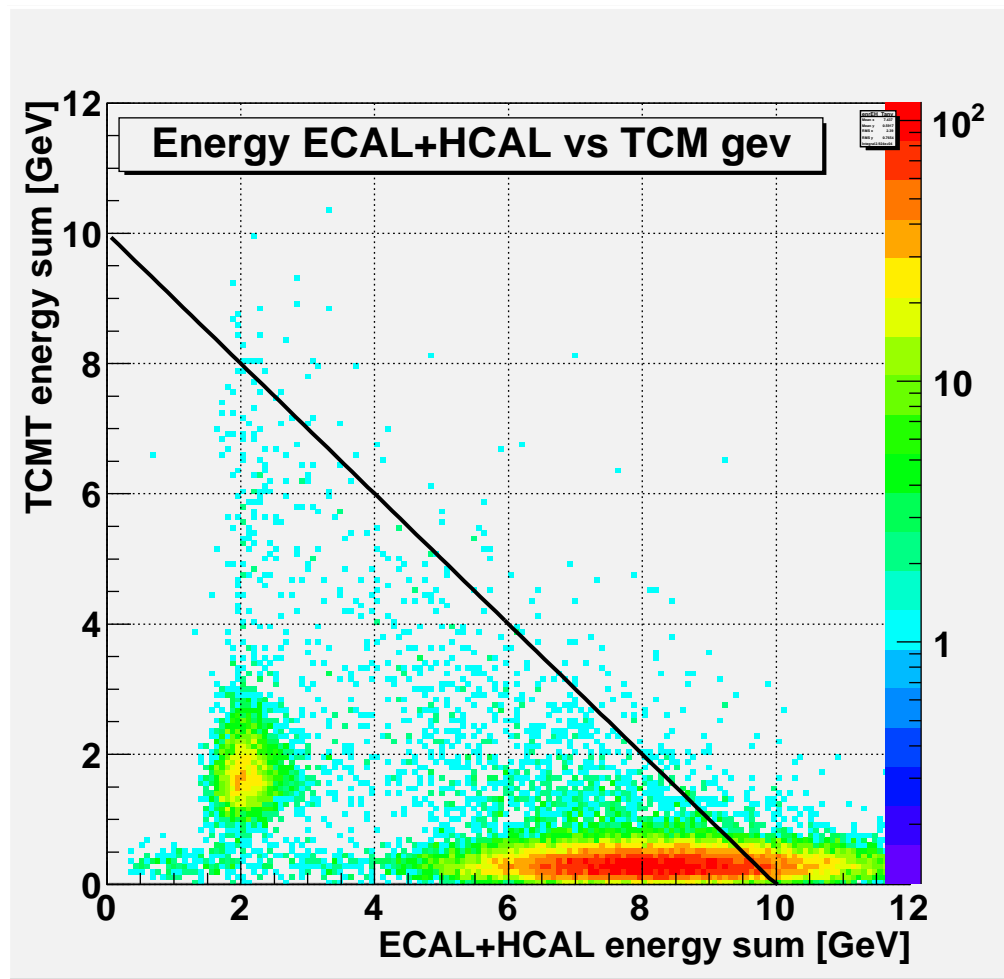


Individual coefficients are:  $C_{\text{ECAL}} = 1.1$ ;  $C_{\text{HCAL}} = 1.213$ ;  $C_{\text{TCMT}} = 1.3$  the same for any energy.

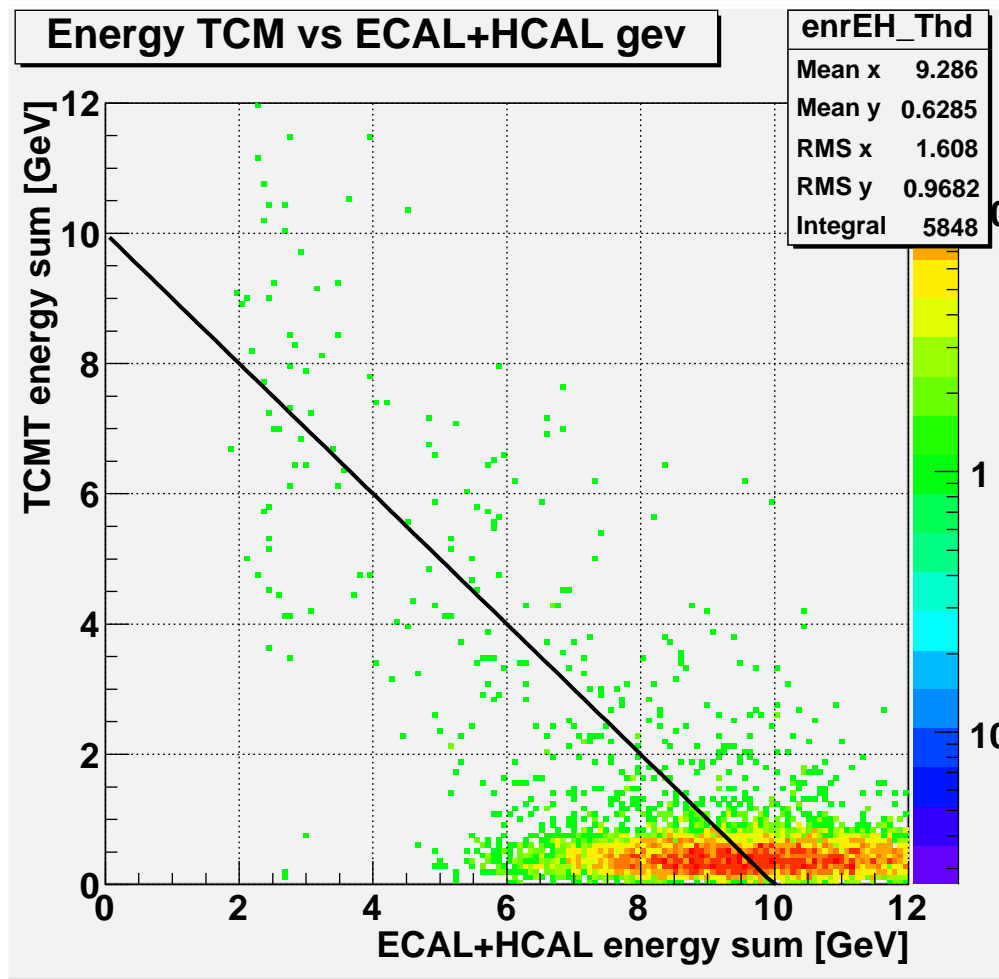
Technique of calorimeters weightings was developed for ILC whole detector.

See "Calorimeter energy calibration using the energy conservation law" at <http://www.springerlink.com/content/r4025526u46r8w67/>

# Energies correlations, 10 GeV, leakage

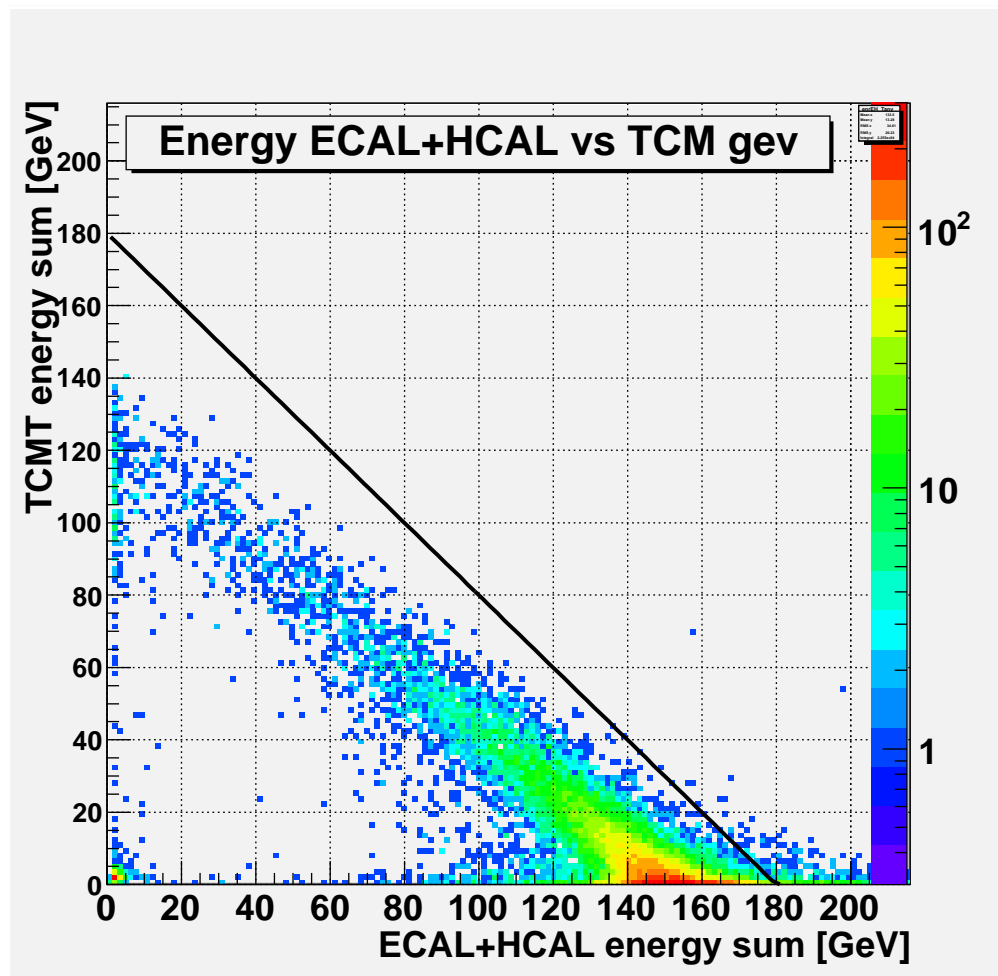


EM calibration only

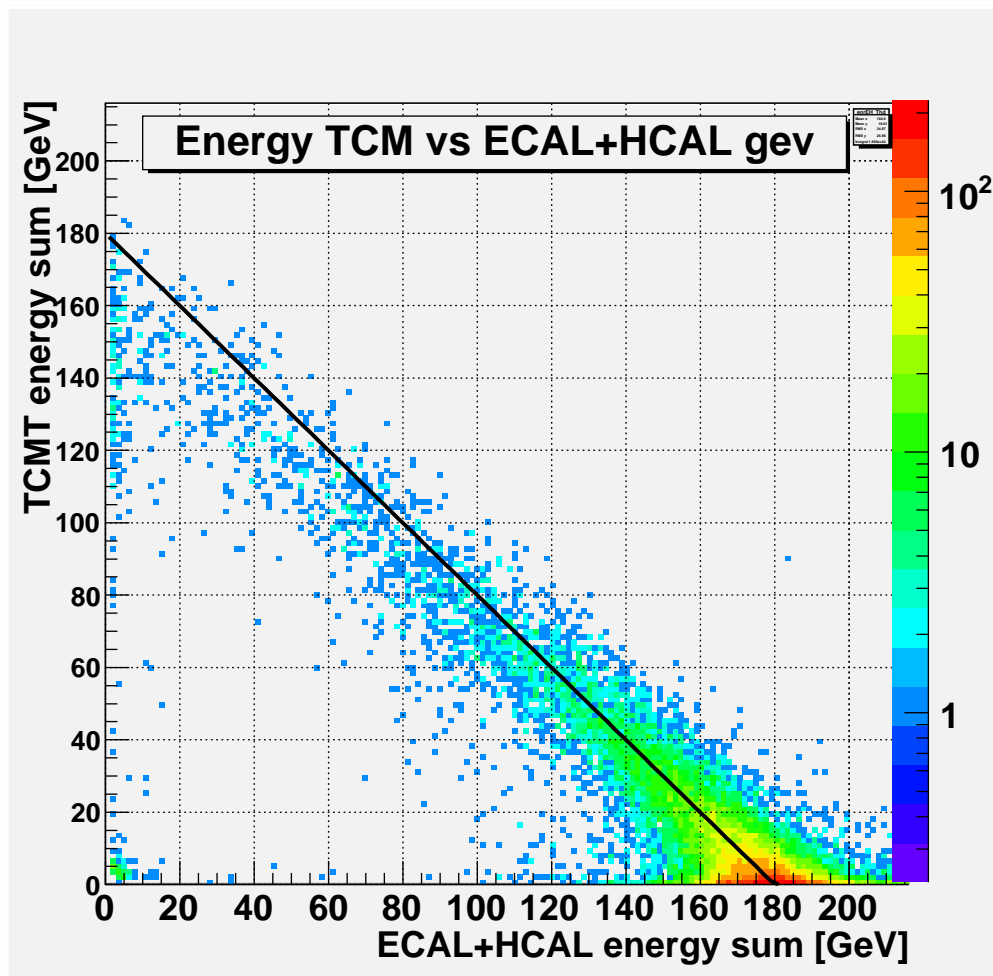


Weighting with 3 factors

## Energies correlations, 180 GeV, leakage

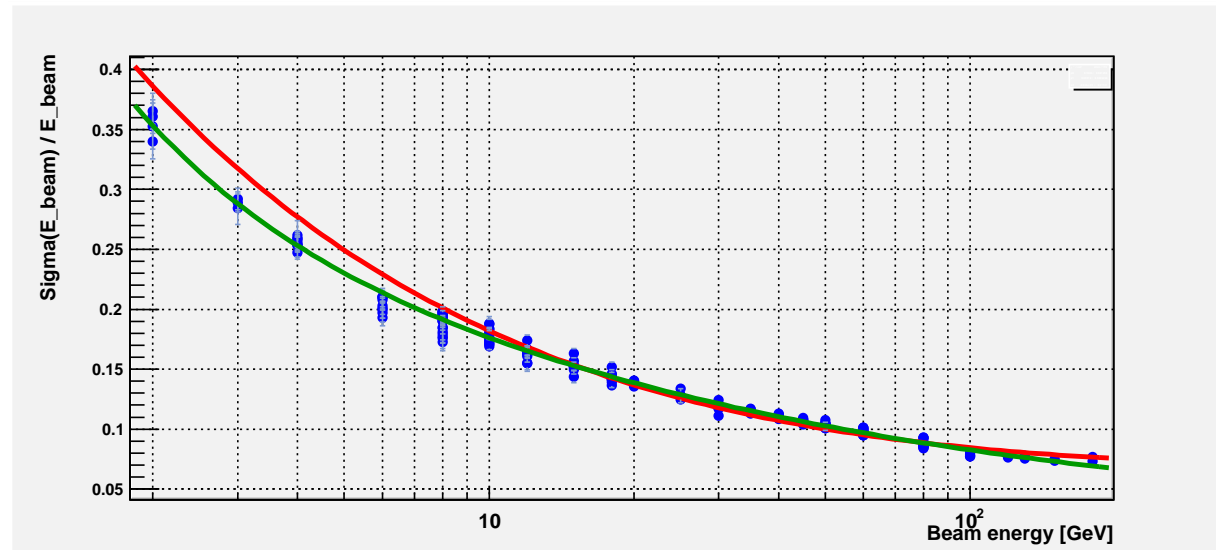


EM calibration only



Weighting with 3 factors

## About energy resolution fitting



Standard representation of energy resolution is  $\sigma(E)/E = A/\sqrt{E} \oplus B \oplus C/E$ , where:  $A$ ,  $B$  and  $C$  are dimensionless parameters; This equation (**red curve**) does not fit well to data at low energies.

**As a result: we cannot extract a correct parameters from this fit function.**

This is a property of a combined calorimeter with rather different sampling fractions of each part of it. A longitudinal motion of the maximum energy deposition to the ECAL with lowering energy of the beam leads to better stochastic term in common; and this fact we will try to reflect at the new equation for the energy resolution.

Let us make stochastic term to be dependent on the energy logarithmically.

$$\sigma(E)/E = (A + A_E * \log E) / \sqrt{E} \oplus B \oplus C/E \text{ (green curve).}$$

**This function is much better fit to the data.**

## **Instead of conclusion**

**This job is on going.**