Hadronic Showers:

Energy Decomposition, Correlations and Calibration Factors

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The copy of this talk one can find at the http://www.desy.de/˜morgunov

Introduction

In Monte–Carlo simulation programs, formally, we know everything about energy deposition during hadronic cascade treatment.

But, in practice, it is not easy to extract useful and meaningful information to record it for further comparison with the beam data or for cross–comparison of different MC–programs.

I would like to discuss a concrete scheme of energy recording during simulation; and application of such a data to events analysis, in addition to that was done upto now.

Talk consists of a lot of technicalities.

I can discuss of each histogramm separately, but I will nod do this now.

I simply wanted to highlight the problem we will collide with, just after we are finishing the calibration steps.

I will not discuss GEANT4, because of different intrinsic data representation, but analysis scheme may by the same.

There are more questions than ansewrs here – issue for further work.

Path to Hadron Data Analysis

Hadronic shower simulation has been done for several different intranuclear cascade models in GEANT3

Namely: GHEISHA (H.Fesefeldt), FLUKA (J.Ranft), GCALOR (T.Gabriel)

Whole energy deposition in calorimeter volume was recorded for each event and for each kind of particles separately, as well as for scintillator volume.

Energy of π^0s and gammas that have produced in hadronic interactions were recorder as well.

Calorimeter volume means exactly whole volume including as absorber as scintillator, (pure true information about energy deposition).

The ratio between energy deposited in whole calorimeter volume to the energy deposited in scintillator is called sampling factor. (may be defined for different kind of particles separately)

Electromagnetic energy (EM) of cascade is defined as energy deposited by photons (under threshold), electrons and positrons.

Electromagnetic energy that surroundings of any charged hadron track will called TRKem.

Hadronic–Electromagnetic energy (HEM) of cascade is defined as energy deposited by π^0s and gammas that were born in nuclear interactions.

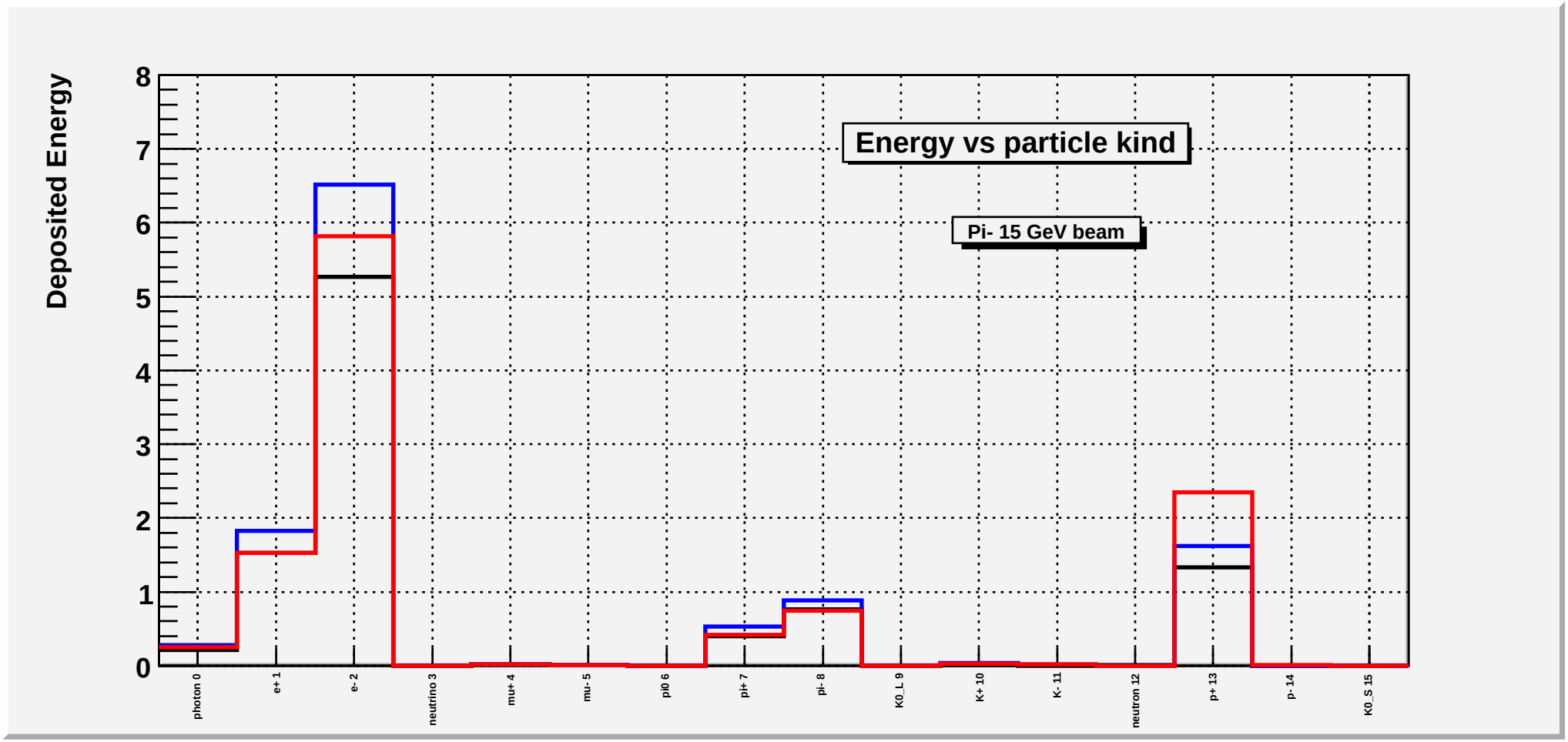
Visible energy digitization used the tile map for CALICE HCAL prototype with half of MIP threshold.

Deep Analysis of Hadronic Shower was used for reconstruction of energy decomposition.

Draft scheme of hadronic shower analysis to compare different Monte–Carlo simulation programs as one another as with experimental data.

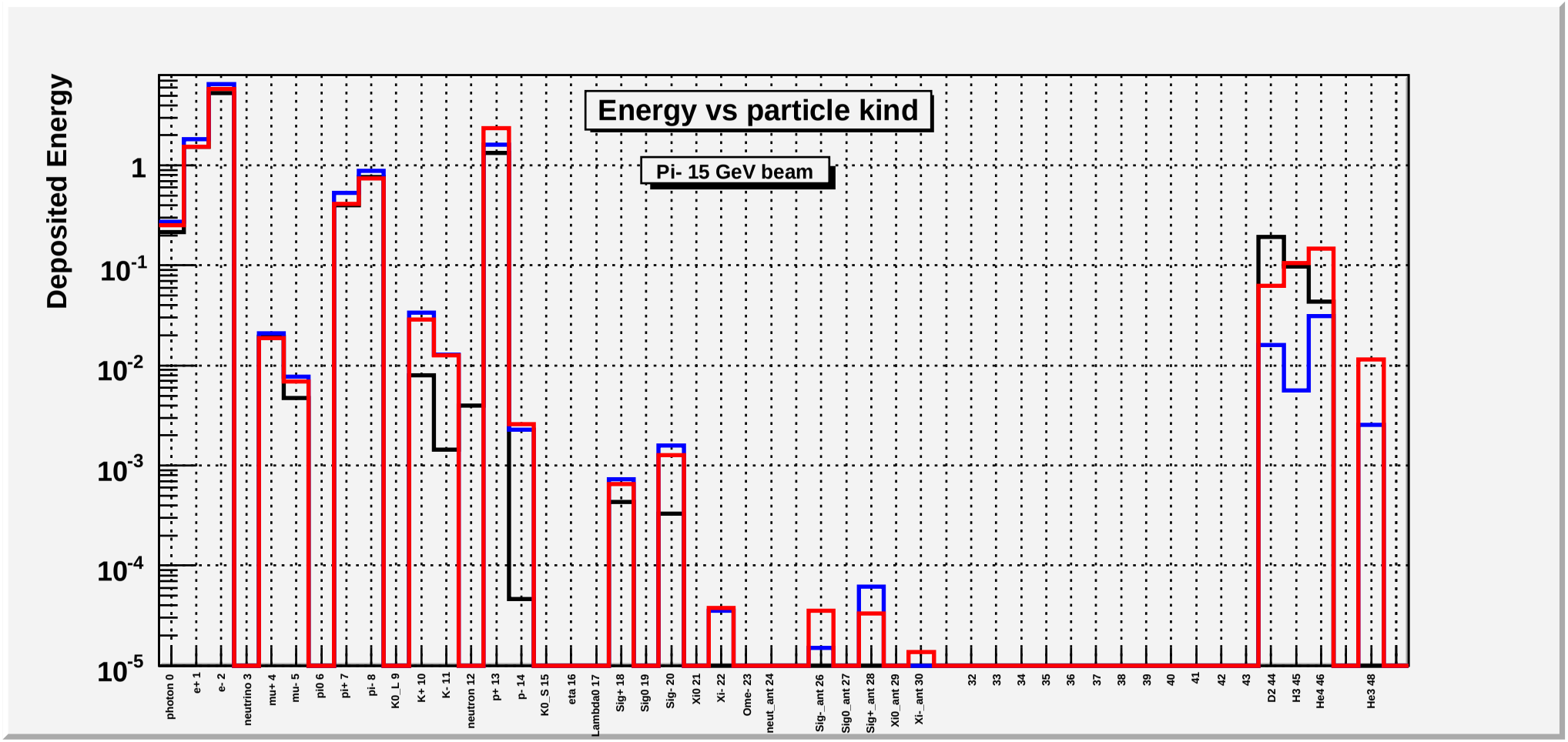
There is not a well established procedure, just a sketch of the way to ...

Simulated Energy: Decomposition (linear scale)



GHEISHA, **FLUKA**, **CALOR**

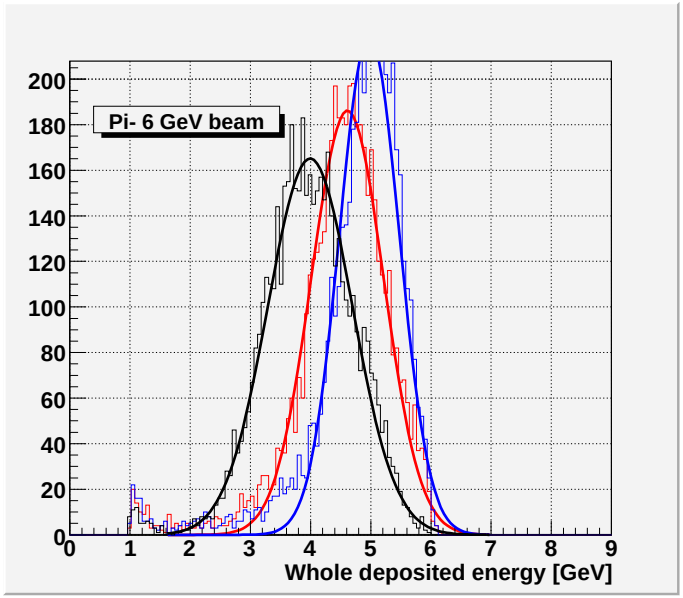
Simulated Energy: Decomposition (log scale)

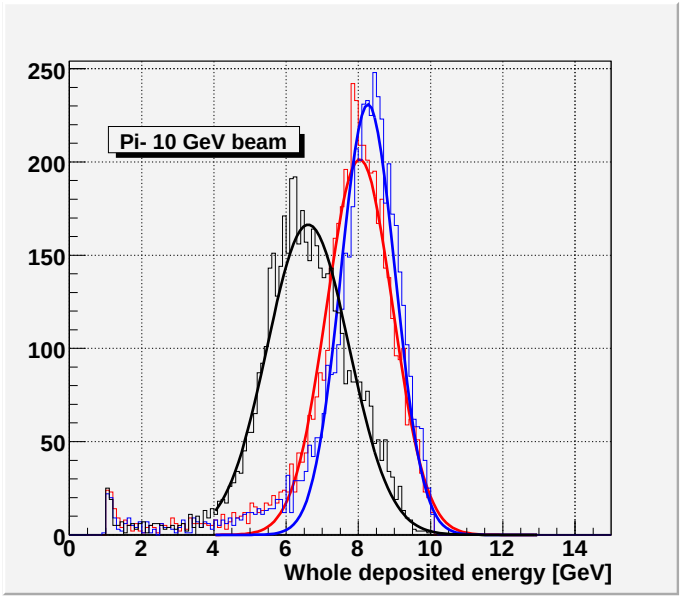


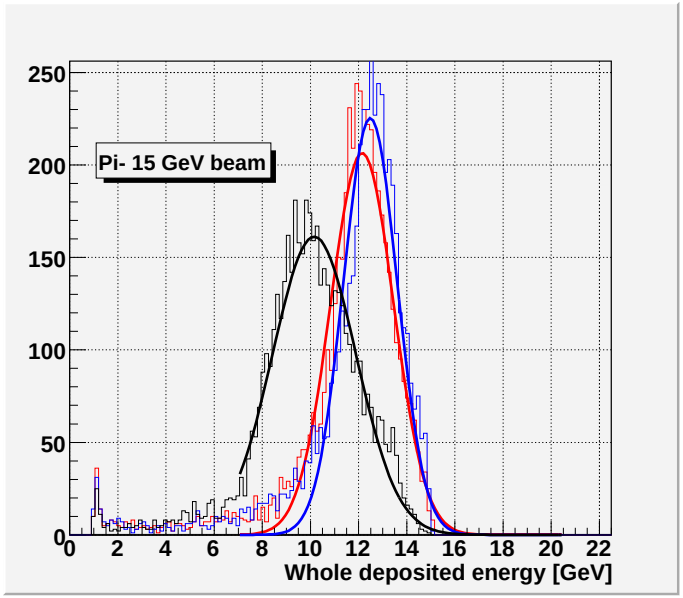
GHEISHA, **FLUKA**, **CALOR**

Whole Deposited Energy in Calorimeter Volume

GHEISHA, **FLUKA**, **CALOR**







Sum of energies deposited by all particle in the whole calorimeter volume strongly (dramatically) depends on the hadronic shower model in GEANT3.

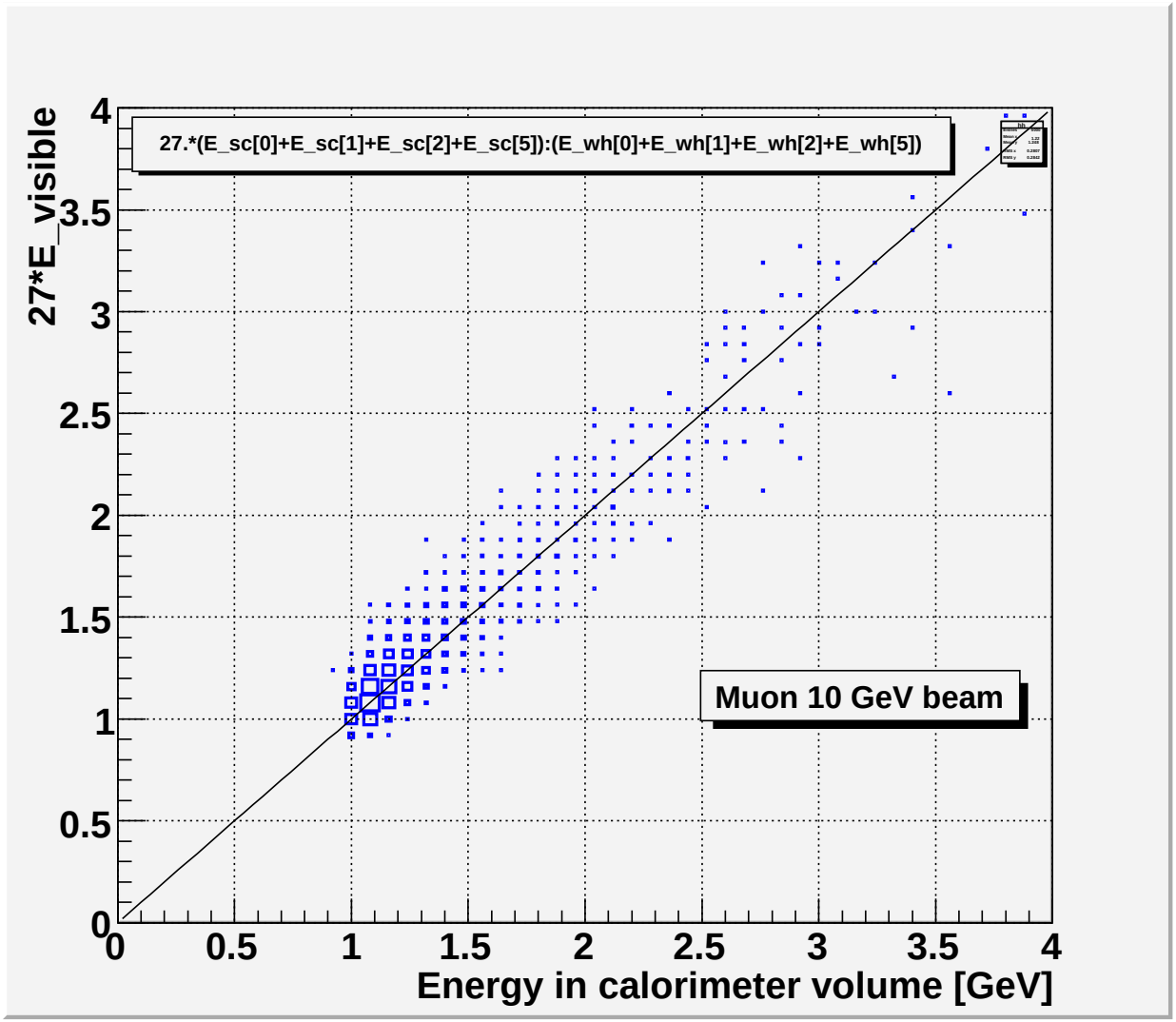
The questions are:

What do we measure in the calorimeter? **What is proportional to beam energy?**

What is the REAL energy deposition in hadronic cascade in our calorimeter?

I did not say any words about energy resolution yet...

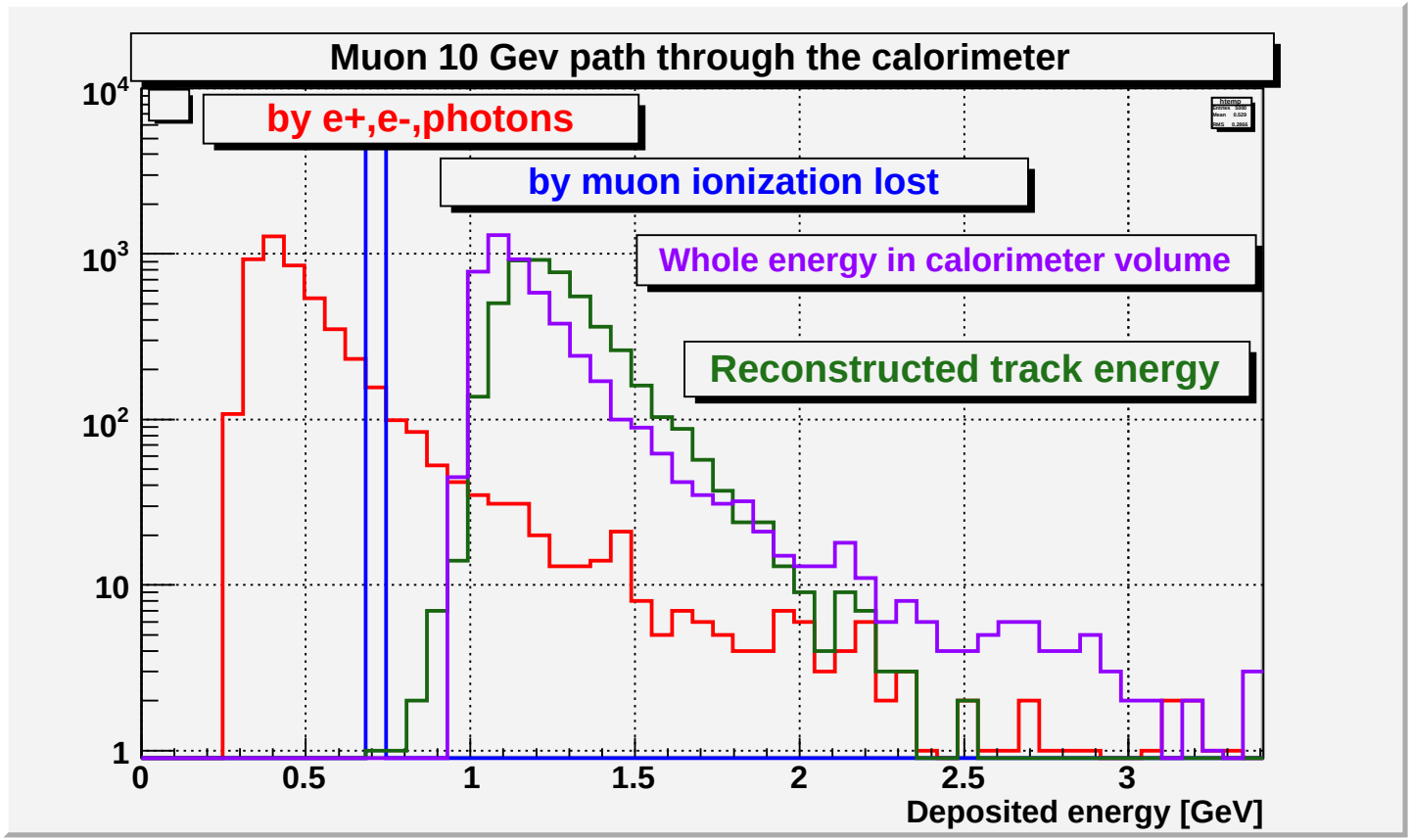
Simulated Muons: Energy Correlation, Sampling Factor = 27.0



Detectable energy losses correlate well with whole energy deposited by muon track.

That is the basis for sampling calorimetry.

Decomposition of Muon Energy in HCAL



Ionization losses is about constant, because of small energy changes; and they are of about half of whole losses

Bremsstrahlung and delta–electrons creates a Landau distribution (depends on the simulation program settings)

Reconstructed energy is energy losses in scintillator by sampling factor (= 27 in the case of muon)

The same kind of energy decomposition will be true for any charged hadron track (radiative and ionization losses).

Decomposition of Simulated Energy in HCAL

It is not easy to extract of pure hadronic part of electromagnetic energy (HEM) of cascade. Simple procedure to decompose energy into hadronic and electromagnetic pieces of hadronic shower by particle type will not work, because of any charged hadron track is surrounded by some electromagnetic activity, as we saw in muon case.

Let us call energy surrounding charged hadron tracks as TRKem.

It is reasonably to split a true EM part of shower from HEM (hadronic) part of shower (recall: π^0s and gammas that were born in nuclear interactions) and only this energy.

Another reason is the DeepAnalysis program. It extracts the dense electromagnetic clusters presented in hadronic shower, and it split them from the tracks and neutron's signal. In this algorithm track consists of both parts as TRKem as pure ionization signal. The same we are measuring in the real calorimeter when we measure one track.

Decomposition of Energy in Whole Volume

$EM = \sum_{i=0}^{i=2} E_i = E_{e^+} + E_{e^-} + E_\gamma;$ (this includes all EM activity in the calorimeter volume)

$TRK_{ioniz} = \sum_{i=3}^{i=50} E_i \ \ for\ i > 2;$ (i.e. excluding EM energy; 50 is the last particle number in GEANT3)

$HEM = E_{\pi^0} + E_{dex\gamma};$ (gammas come from deexitation of nuclei after hadronic interaction)

$TRK_{rad} = EM - HEM;$ (this is possible for whole volume, because of full energy conservation in EM cascade)

$HAD = TRK_{ioniz} + TRK_{rad};$ (both pieces belong to the same hadronic tracks activity)

Finaly we will use HEM as elecromagnetic part and HAD as hadronic part of hadronic shower in calorimeter

Separation and extracting signal from neutrons are still unreachable.

Now, we are almost ready to go to the correlations in hadronic cascade.

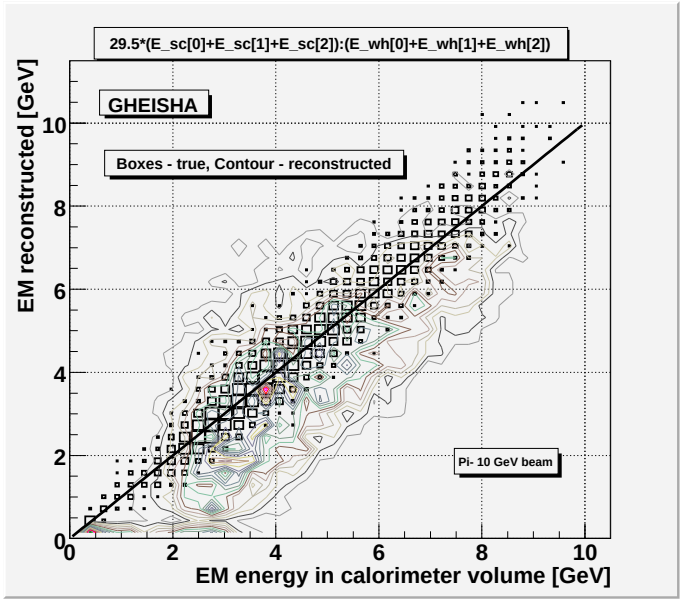
BUT, one more things before ...

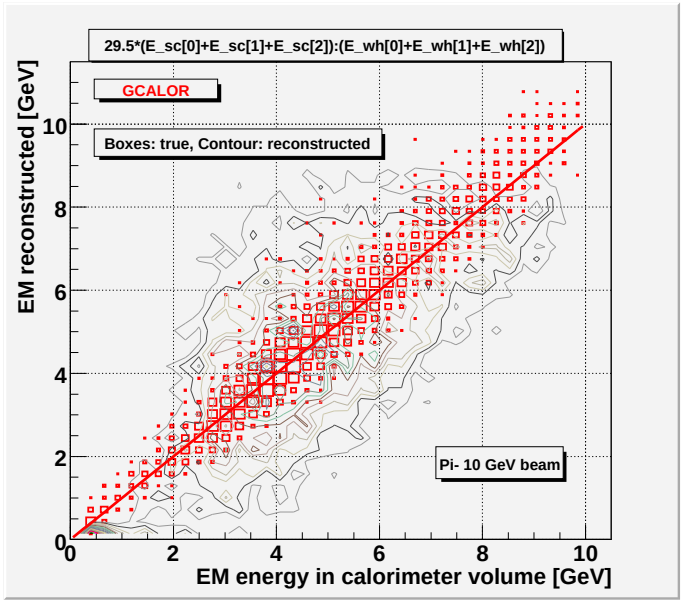
Sampling Factors:

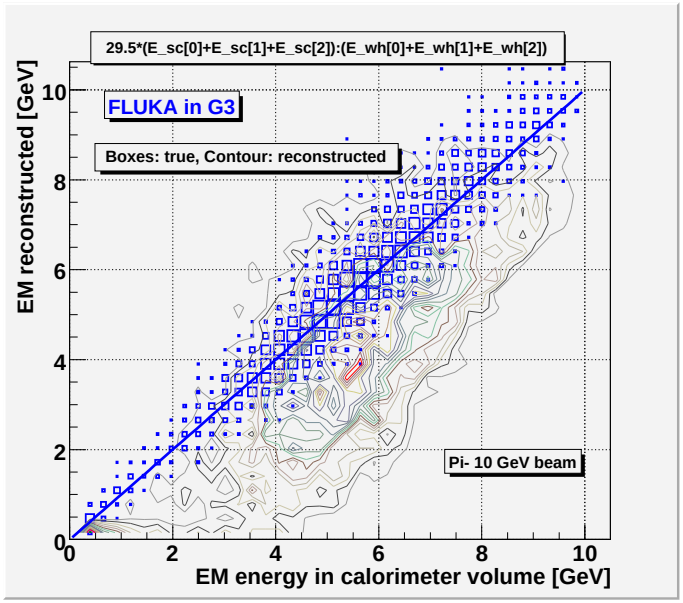
For muon we saw factor 27 to convert visible energy into whole deposited energy.

Is it the same for electromagnetic cascades in the HCAL sampling structure?

EM Energy Correlations, Sampling Factor = 29.5



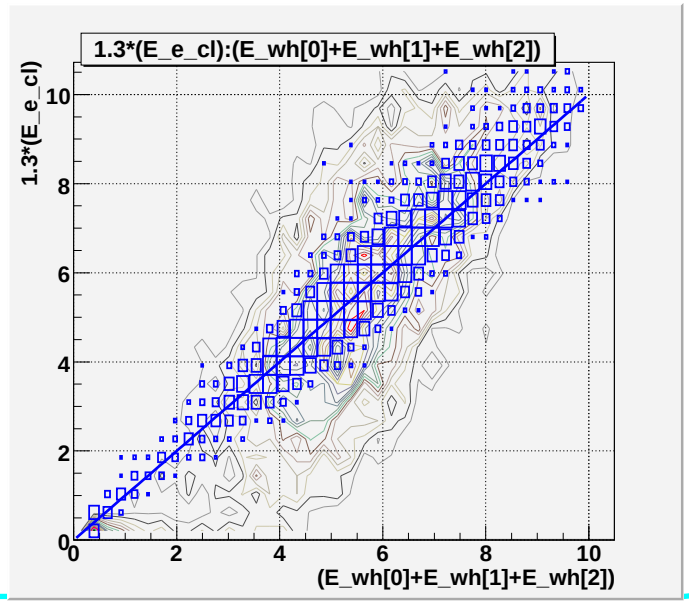




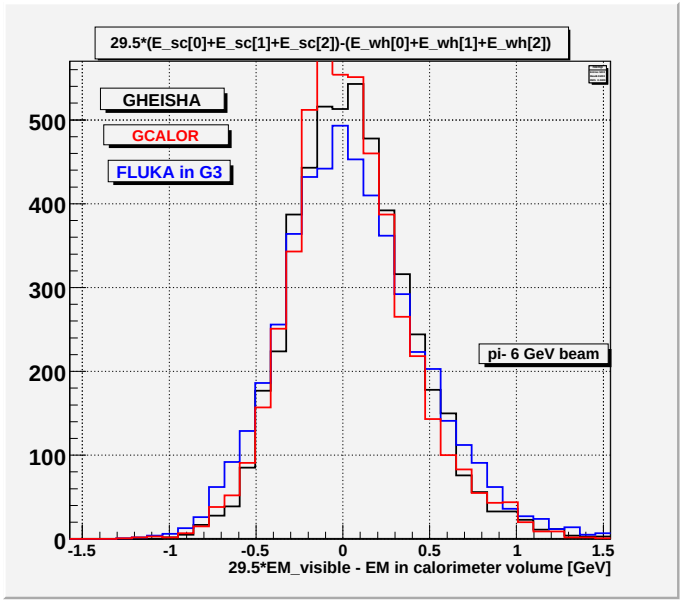
The ratio between energy deposited in whole calorimeter volume and in the scintillator volume for electromagnetic cascades are the same in all programs.

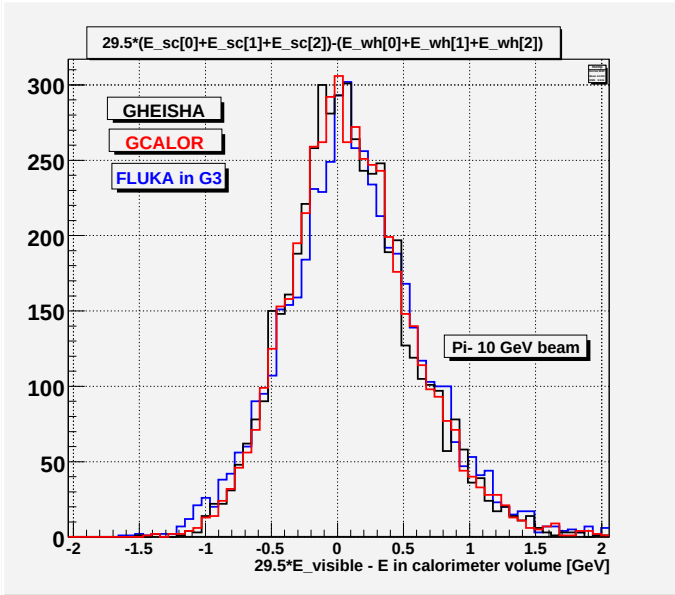
The reason is, the same QED formulae in all these programs, that have an accuracy of about 1 percent.

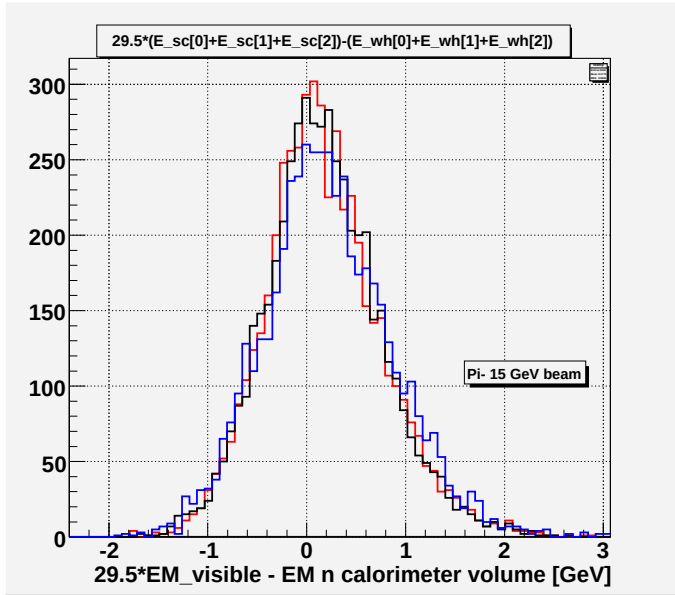
This sampling factor should work well for pure electron beam goes into CALICE HCAL.



Visible Energy, Sampling Factor = 29.5







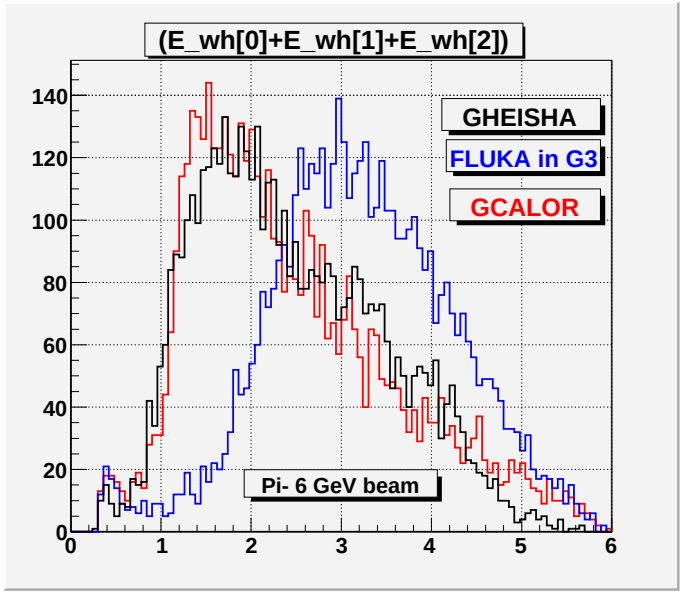
The visible energy well correlated with whole energy.

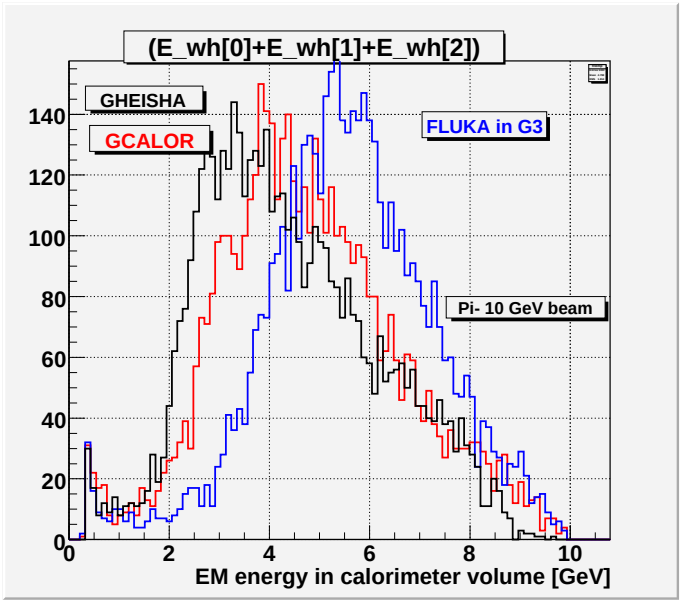
And what we see here as a width of these distributions is proportional to the stochastic term of HCAL energy resolution for pure electromagnetic cascade.

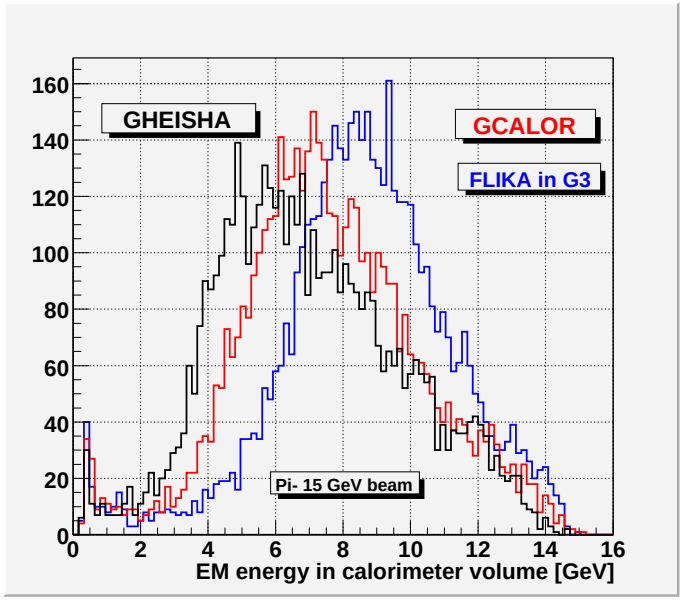
(Do not forget – all of these curves had taken from hadronic cascades, so they are not Gaussian, because many different EM cascades, with different energies are presented in histograms.)

Predicted EM energy resolution does not depend on the program.

Whole Deposited EM Energy







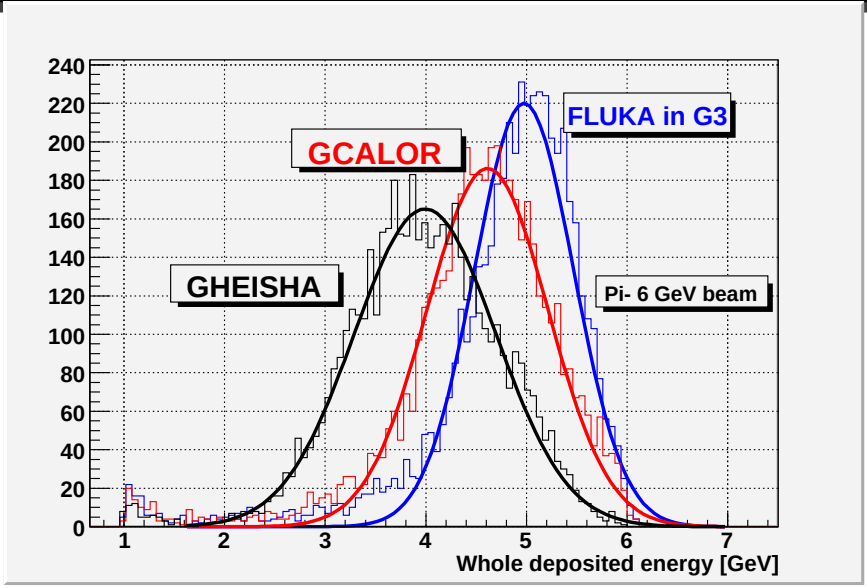
Different intranuclear cascade programs give a different containment of electromagnetic energy in hadronic shower.

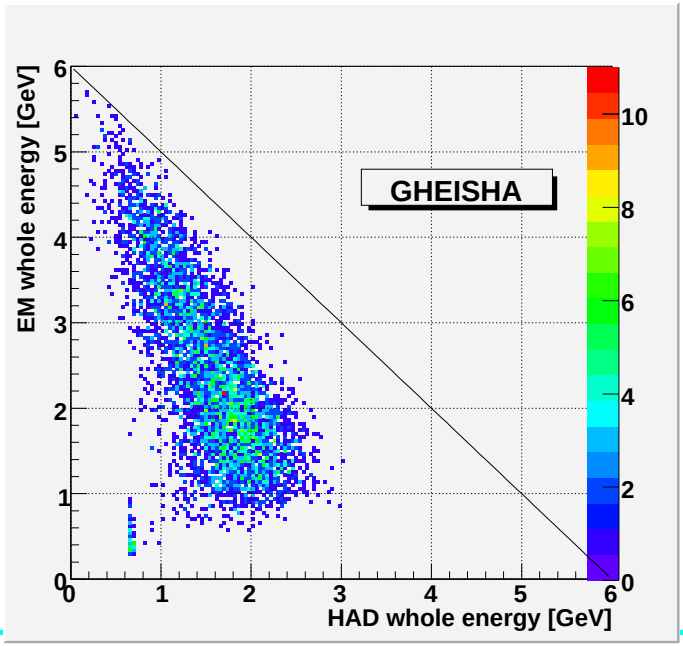
CALICE HCAL was designed to judge which is correct.

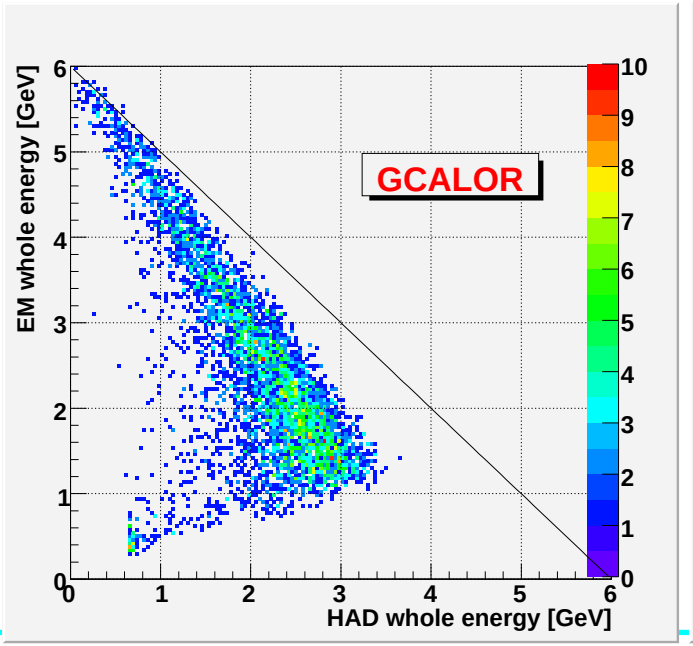
There is well known than the hadronic activity in a cascade strongly depends on the energy part that goes into π^0s, mainly at the first nuclear interaction of beam particle.

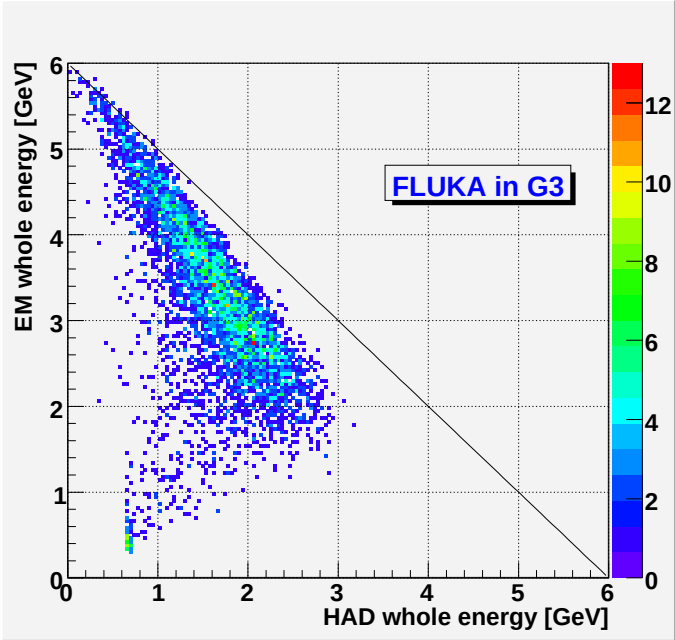
This is the reason of increasing of calorimeter e/π ratio with increasing of beam energy (see T.Gabriel, NIM 1995).

Whole Energy and Correlations π^- 6 GeV beam

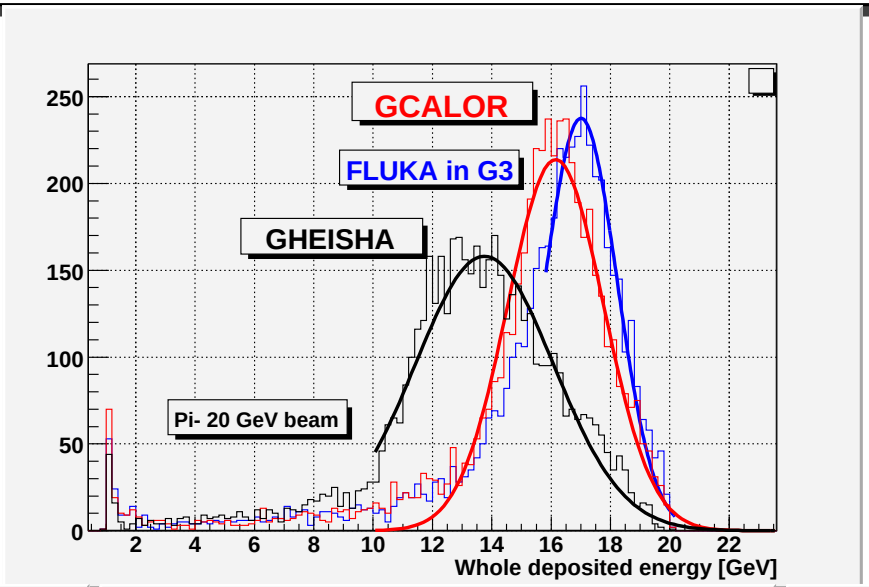


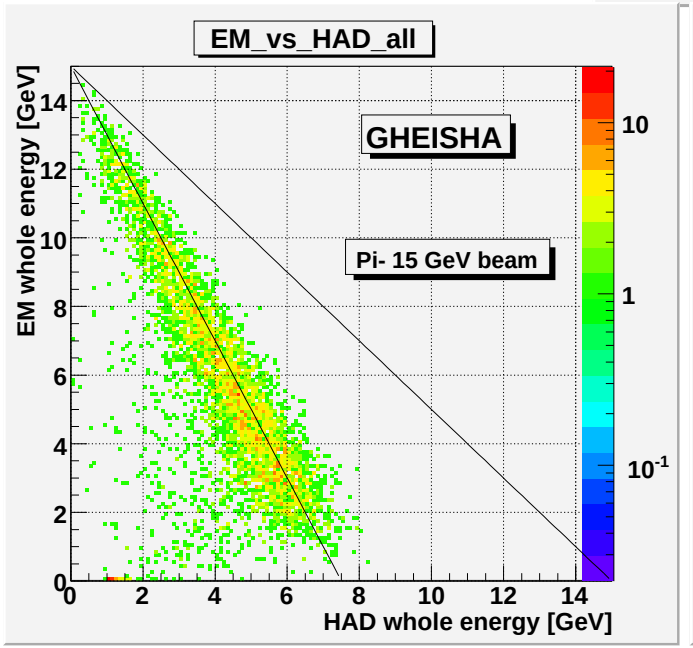


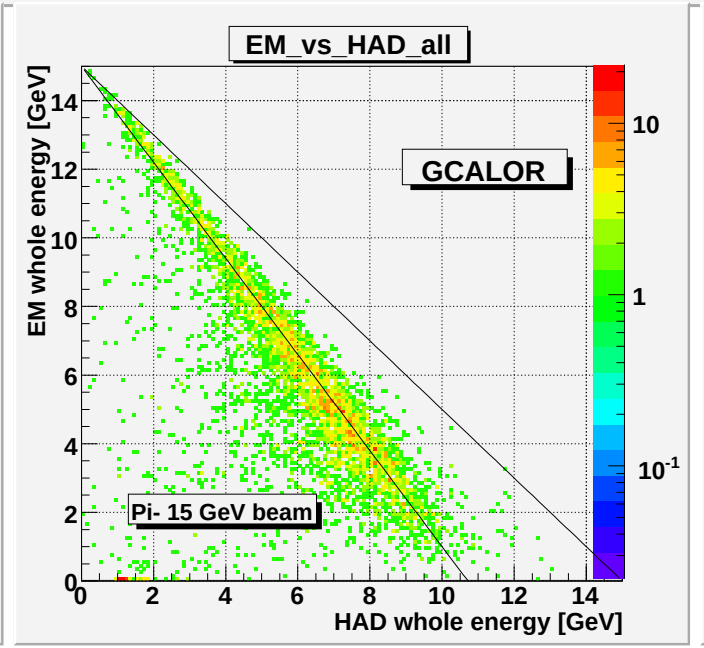


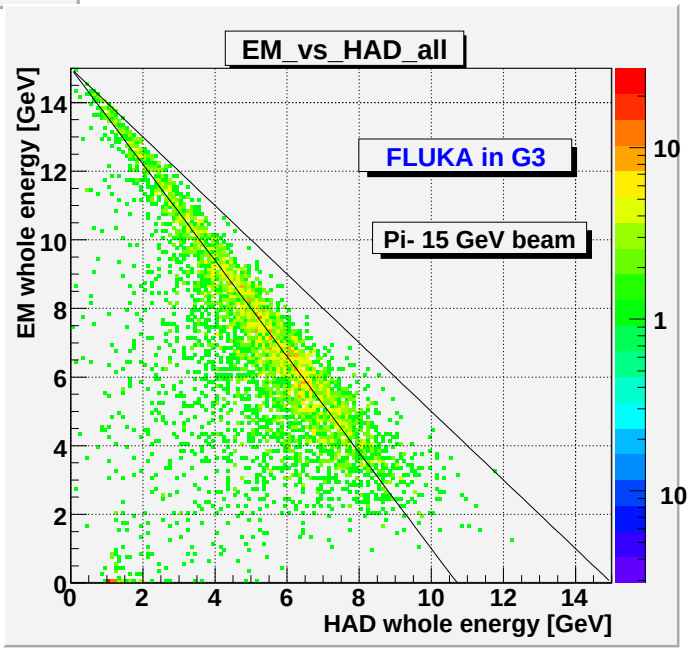


Whole Energy and Correlations π^- 15 GeV beam

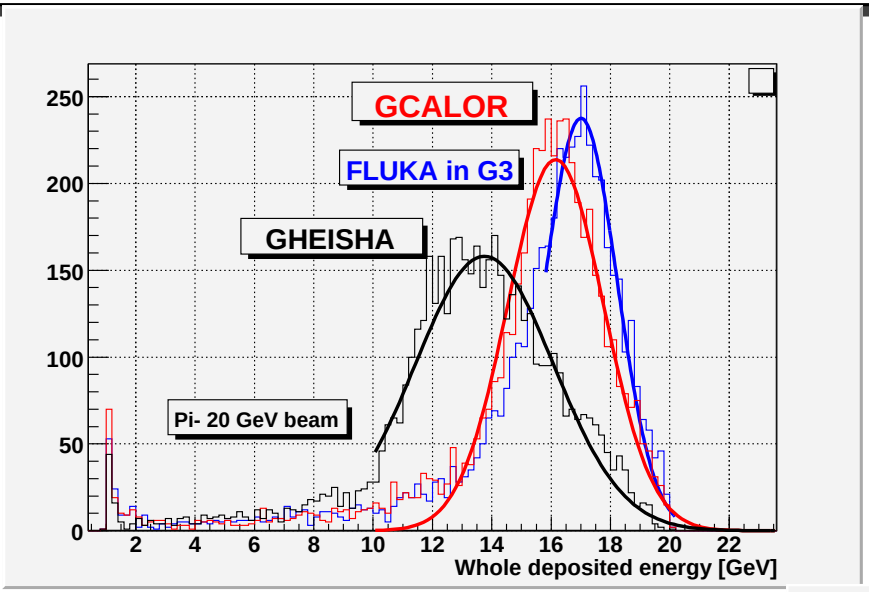


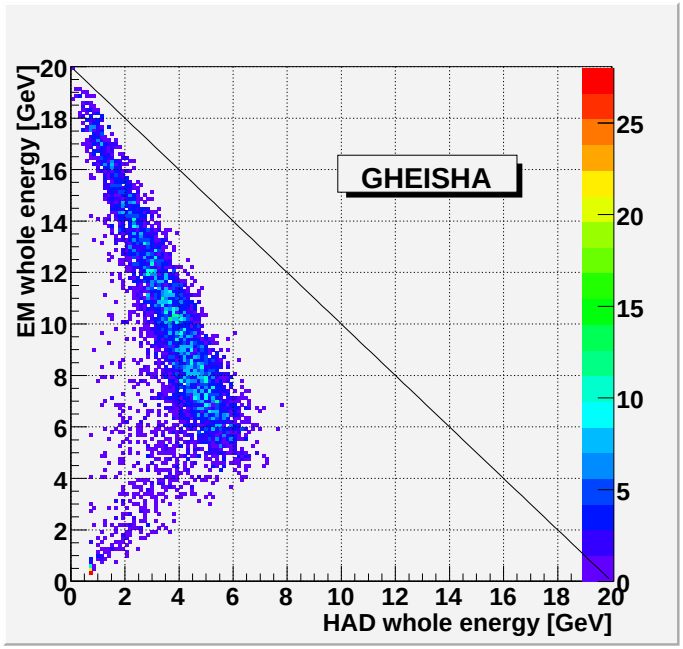


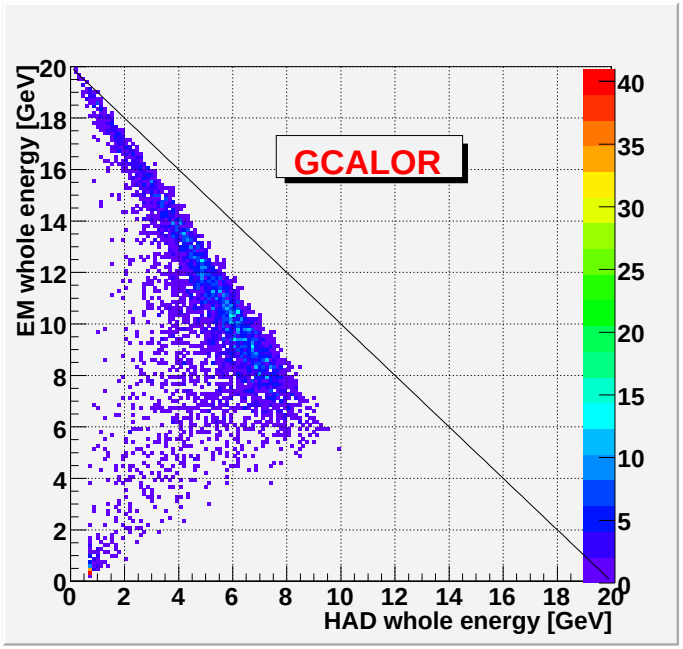


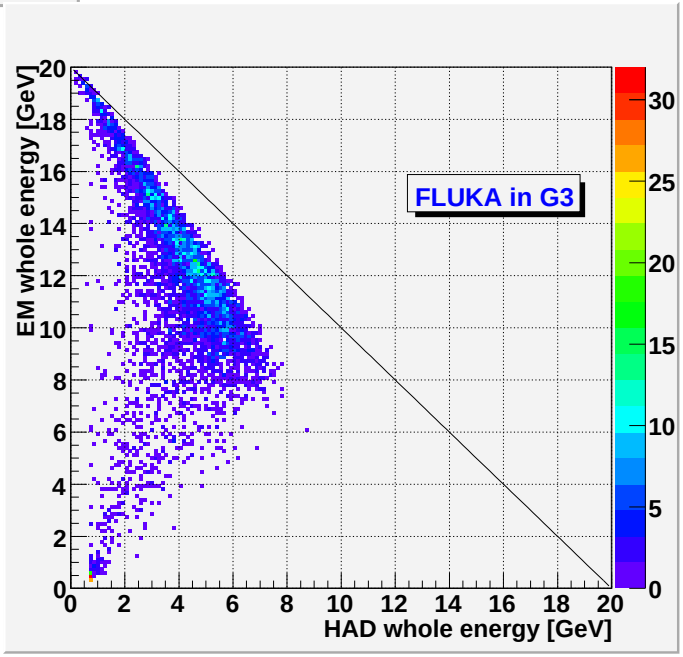


Whole Energy and Correlations π^- 20 GeV beam

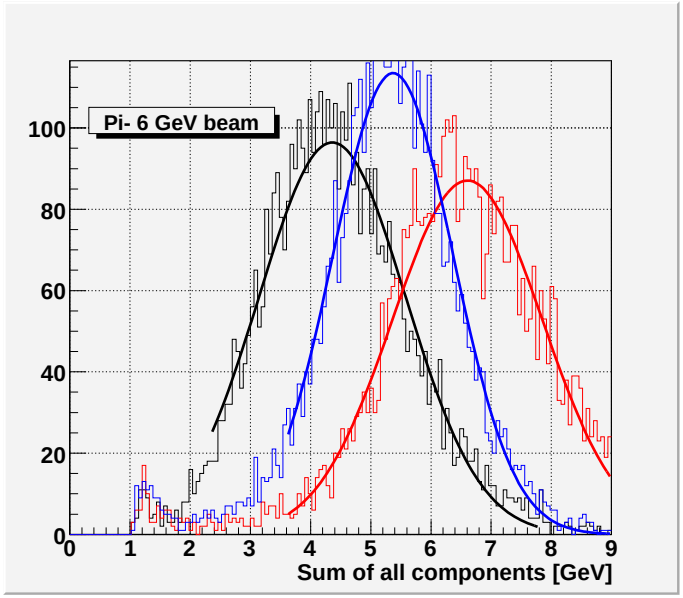


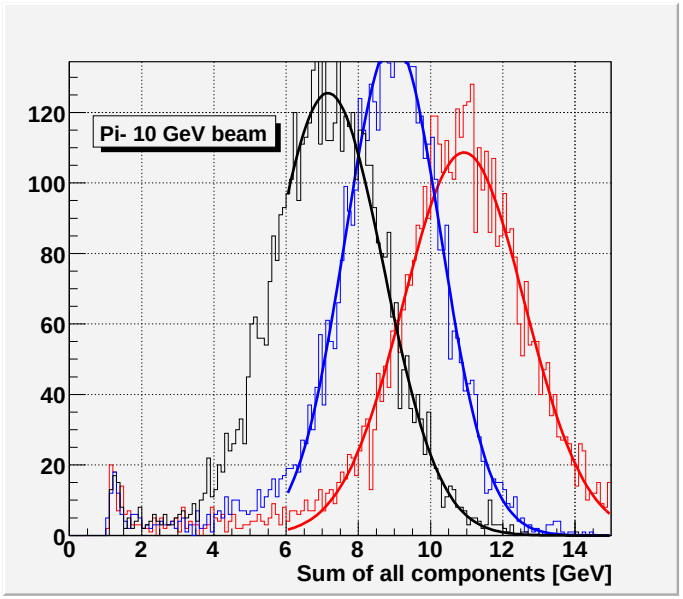


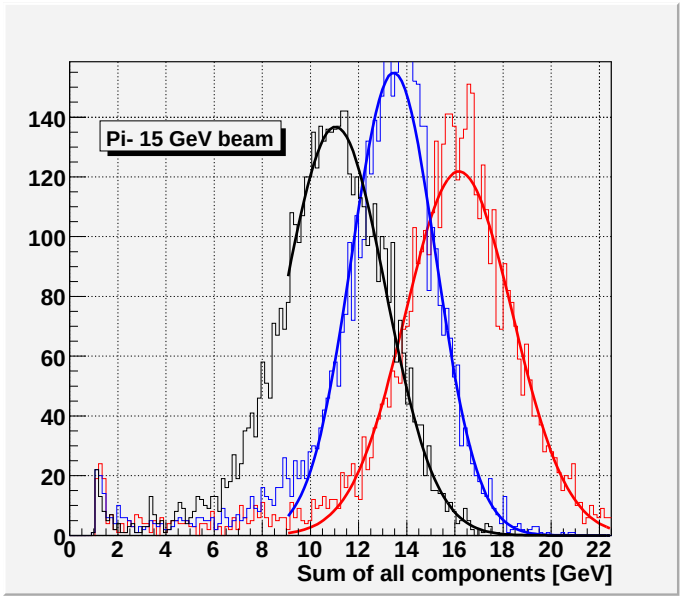


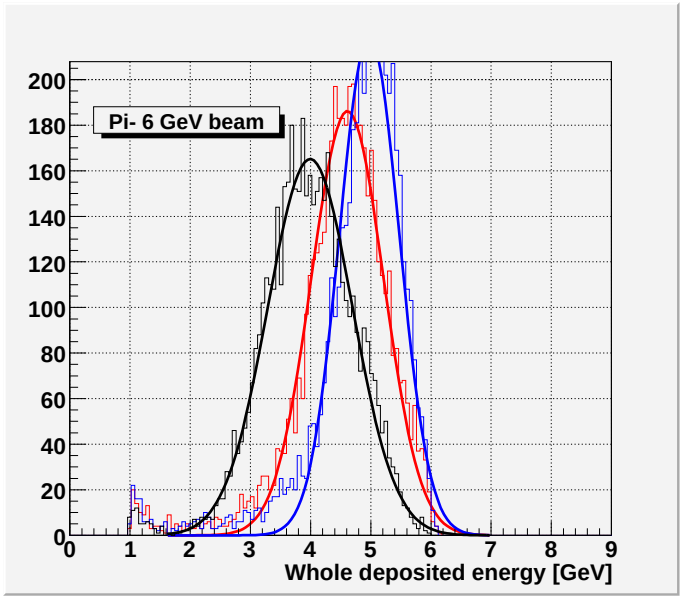


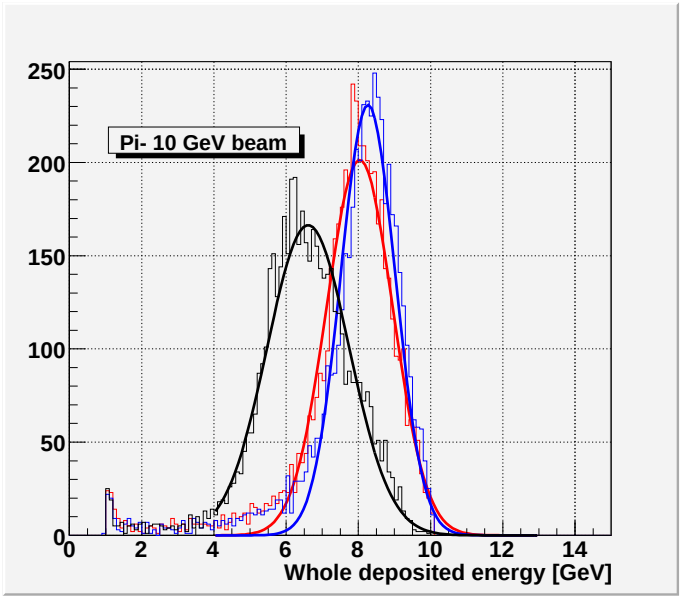
Reconstructed Energy, Sampling Factor = 29.5

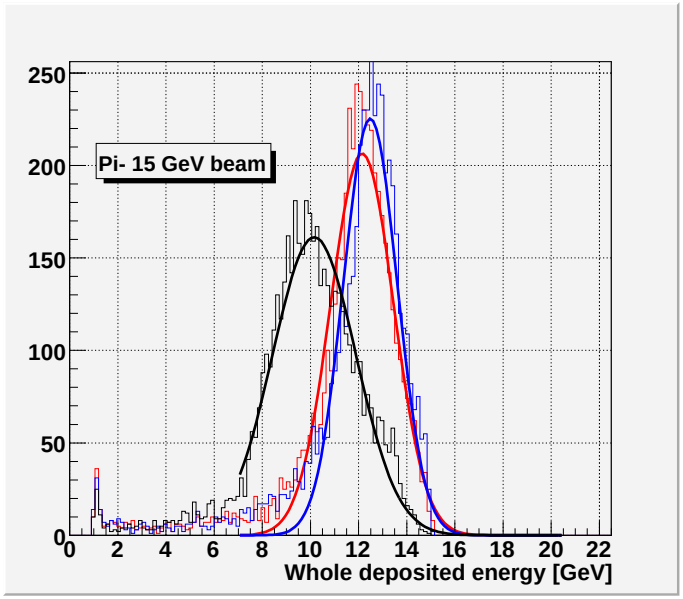




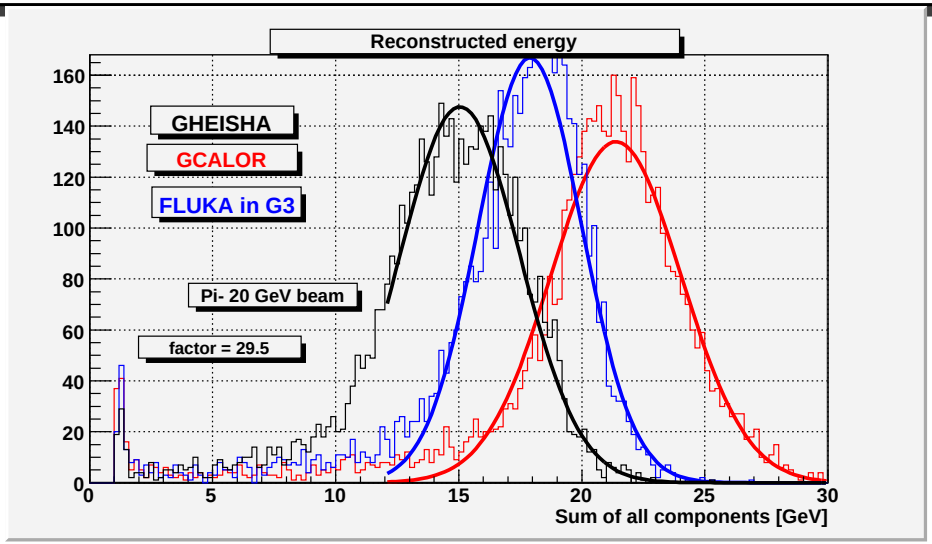




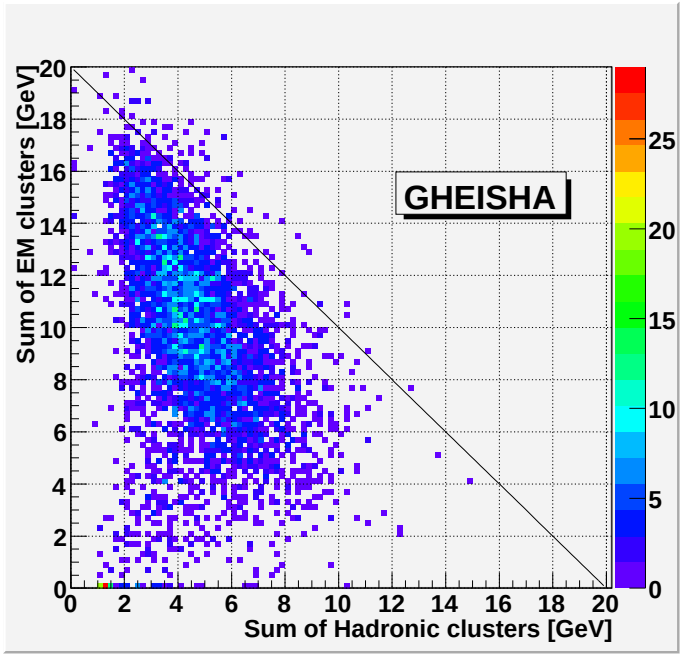


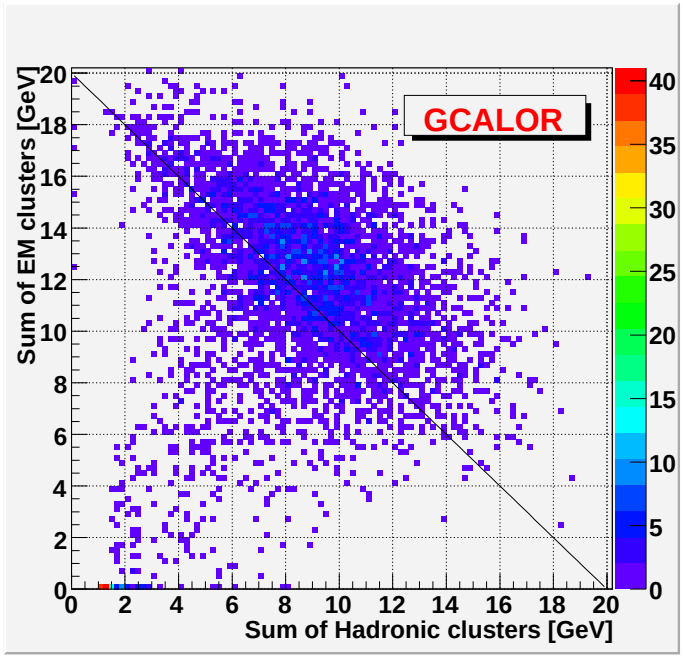


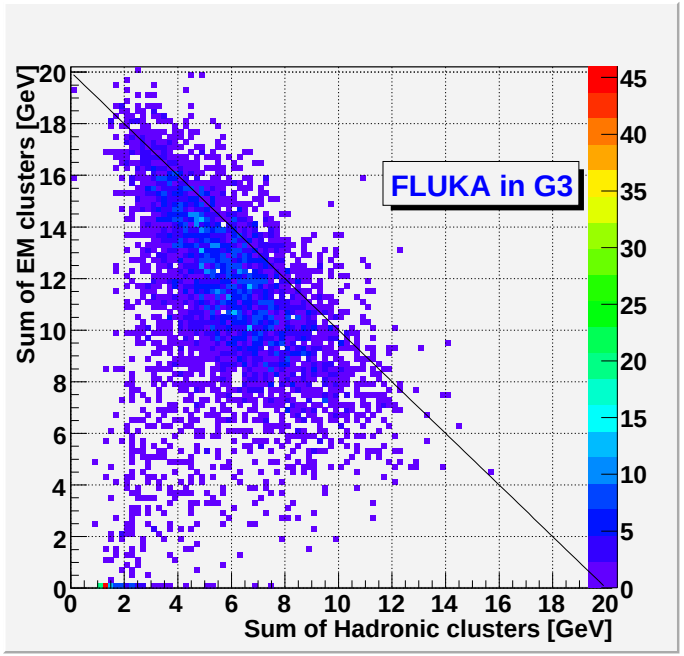
Reconstructed Energy and Correlations π^- 20 GeV beam



The same factor = 29.5







Last remarks

Actual program to collect energies for all kinds of particle is of about 20 strings in GUSTEP,
and 10 more strings to collect π^0s and gamma energies for every event.

Reconstruction (by DeepAnalysis) was made during a simulation step.

Results are in Root trees (easy to read), may be used by everybody.

Used statistics: 4 programs, 4 energies of π^- beam, 5000 events each run.

In common: $4 \times 4 \times 5000 = 80K$ *events, simulation (including reconstruction) took one day at my laptop CPU.*

One of the aims of this talk was to show a complexity of the future tasks.

Do not relax after a beam data taken, its lot of work ahead.

Will need a spy program for both GEANTs to collect neutron signals.