Methods of hadronic shower energy classification in Geant4

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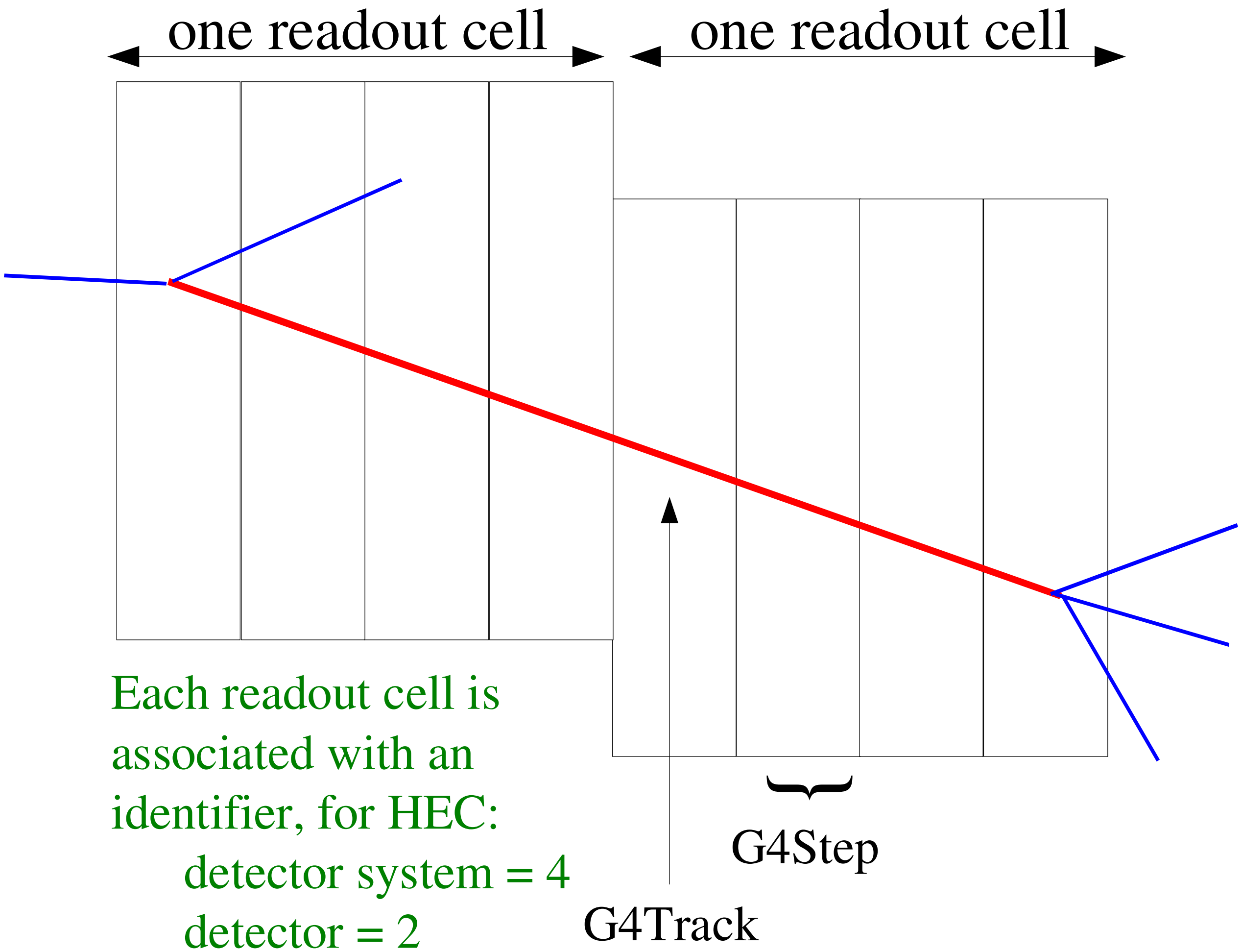
Calibration hits - Bill Seligman will discuss this

- LArHit
  - Readout identifier
  - Energy deposited in liquid argon
  - Time

- LArCalibrationHit
  - "Dead material" identifier
  - Readout identifier for inactive material in readout cell (IM cell)
    - IM cell boundaries should be defined (for accordion, FCAL, ...)
  - A separate energy field for each of the following:
    - EM energy ($e^{\pm}$, γ)
    - non-EM energy
    - "invisible" energy
    - escaped energy (in addition to standard requirement)

Access to Information in Geant4



Each readout cell is associated with an identifier, for HEC:

- detector system = 4
- detector = 2
- sampling = 2
- region = 0
- eta = 4
- phi = 14

A G4Step points back to its G4Track.

A G4Track points back to:

- the physics process that created it
- the kinematics at its starting point (x,y,z,t), (**p**,E)
- the logical and physical volume at its starting point

Access to information at each step of particle tracking:

ProcessDefinedStep is one of the physics processes or
a process “transportation” on volume boundaries.

```
processDefinedStepName = step->GetPostStepPoint()->
                         GetProcessDefinedStep()->GetProcessName();
```

The whole visible energy deposited on the step:

```
G4double dEStepVisible = step->GetTotalEnergyDeposit();
```

We extract also the particle name, mass, PDG code, ...
We calculate energy loss: dEkinStep = EkinPreStep - EkinPostStep
and dEkinNonDeposited = dEkinStep – dEStepVisible.

dEkinNonDeposited = 0 for electromagnetic (EM) processes.

How to separate visible energy from EM processes ?

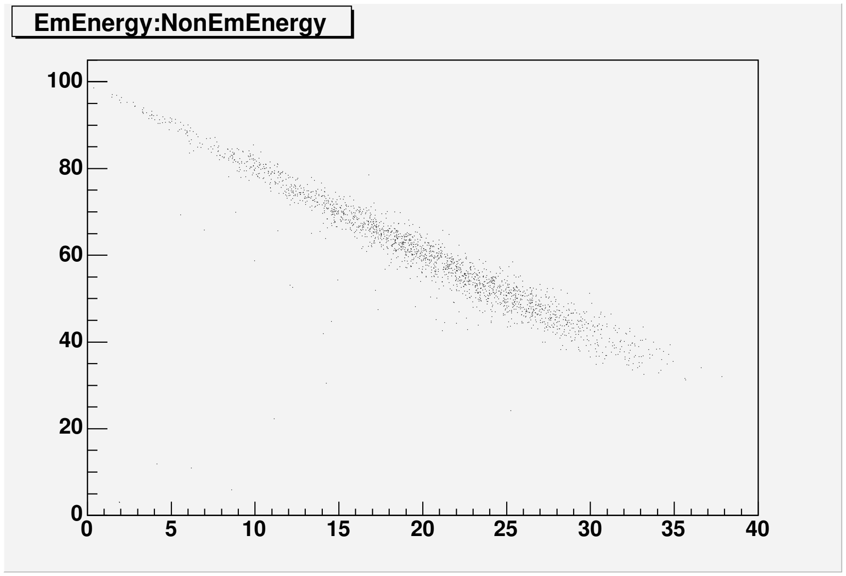
At first we looked for processName: eIoni, eBrem, eTrans, eMsc, phot ..., then we realized that the particle names e- and e+ give us clear and compact solution:

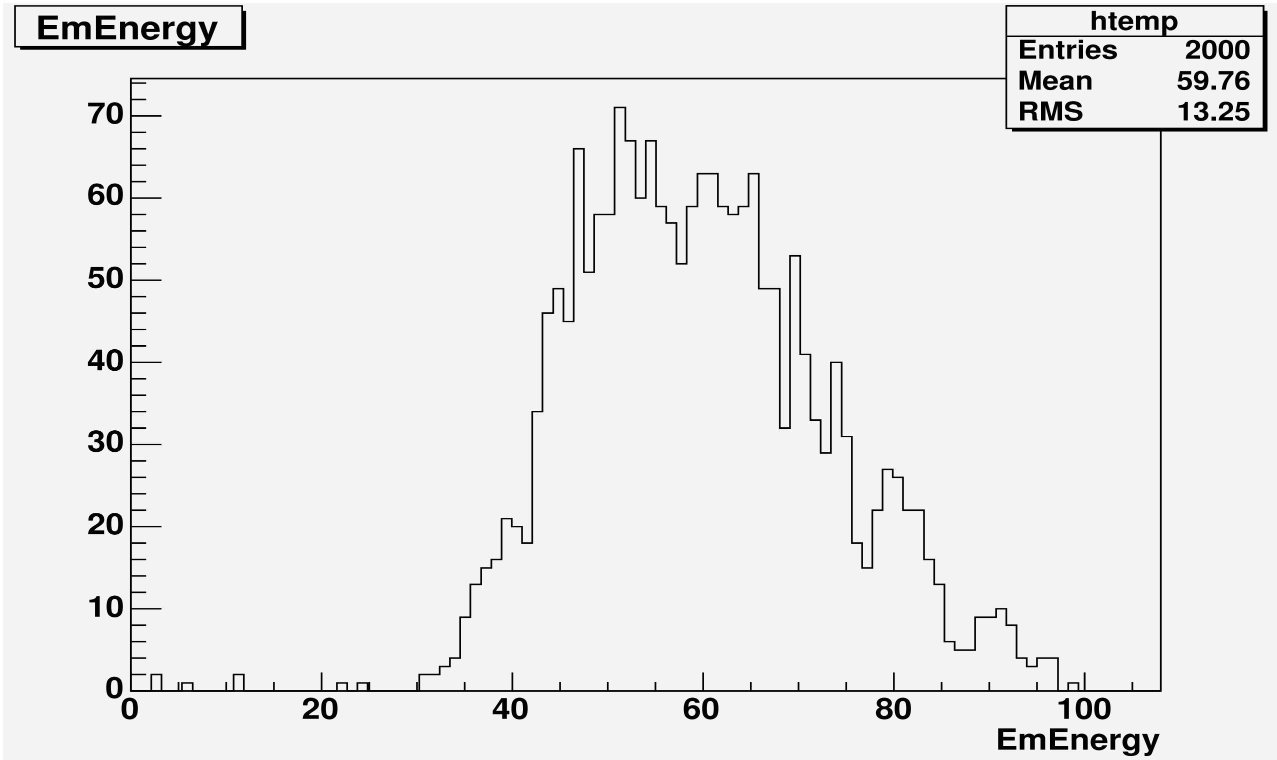
```
if (particleName == "e-" || particleName == "e+" ||
    processDefinedStepName == "phot")
   {
     result.energy[kEm] = dEStepVisible;
   }
else {
     result.energy[kNonEm] = dEStepVisible;
  }
```

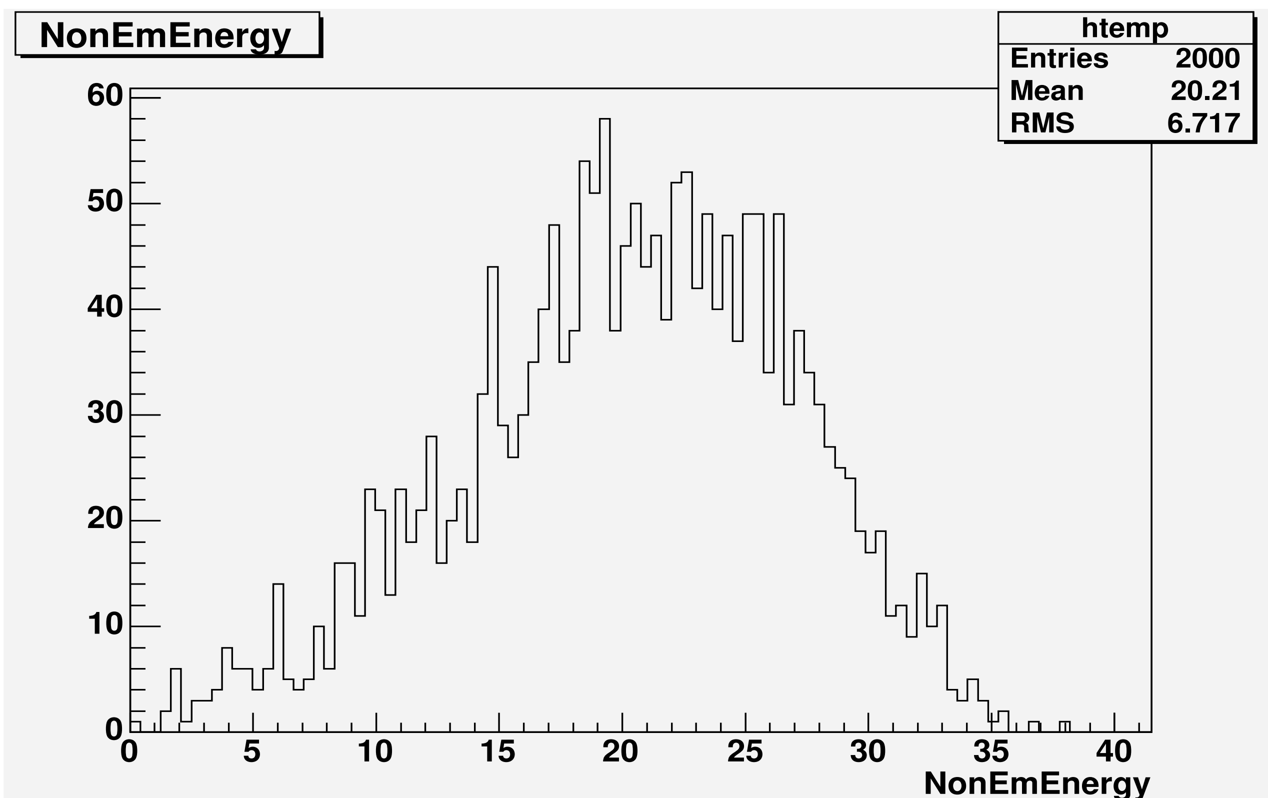
The visible energy from EM processes separated from energy deposits from all other particles (including muons) by this code – let us call it Method 1.

Visible EM and non-EM in HEC

- Hadronic shower from 100 GeV pion+ in HEC
- 2000 events




EmEnergy
htemp
Entries 2000
Mean 59.76
RMS 13.25
0
10
20
30
40
50
60
70
0
20
40
60
80
100
EmEnergy


NonEmEnergy
htemp
Entries 2000
Mean 20.21
RMS 6.717
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40
NonEmEnergy

Invisible energy

- Break up of nuclei, nuclear excitations, when part of energy dissipates via nuclear collisions.
- P.Loch summarized the experience of calculating the invisible energy for hadronic calibration purposes as the energy mismatch between the particle entering the interaction and the particles (secondaries) coming out of the interaction in Note
  http://www.nevis.columbia.edu/~lelchuk/CalibrationHits/P.Loch_Note.txt
- The implementation of these ideas for Geant3, shown in this Note, was a good example for our code for Geant4, in particular the method of the measurable energy calculation and energy balance calculation.

Measurable Energy

- The concept from P.Loch Note: Rest masses of stable particles do not give rise to a signal in the calorimeter. The measurable energy is obtained by subtracting the rest mass from the total energy for these particles and those particles which may decay into them.
- For antiparticles the rest mass has to be added due to annihilation processes.
- The invisible energy associated with a step can be found as a difference between incoming energy and measurable energies of secondaries. It is called Invisible0 (which means: Version 0) in the current code.
- For comparison we used in G4 also a difference between incoming kinetic energy and kinetic energies of secondaries as another possible definition of the invisible energy (called Invisible1) and modified version of measurable energy (which results in Invisible2).
- We would like to continue this comparison.

Geant4 does not make many of its internal process information easily available. V.Ivantchenko showed that the simplest way to get at the data on the secondaries is to inherit a class from G4SteppingVerbose, in order to gain access to its protected members.

```
class SimulationEnergies : public G4SteppingVerbose

  CopyState(); // access to secondaries via G4SteppingVerbose

  G4int tN2ndariesTot = fN2ndariesAtRestDoIt +
                        fN2ndariesAlongStepDoIt +
                        fN2ndariesPostStepDoIt;

  // loop through secondary particles which were added at current step
  // to the list of all secondaries of current track:
  G4int loopStart = (*fSecondary).size() - tN2ndariesTot;
  size_t loopEnd  = (*fSecondary).size();
```

This code is our Method 2.

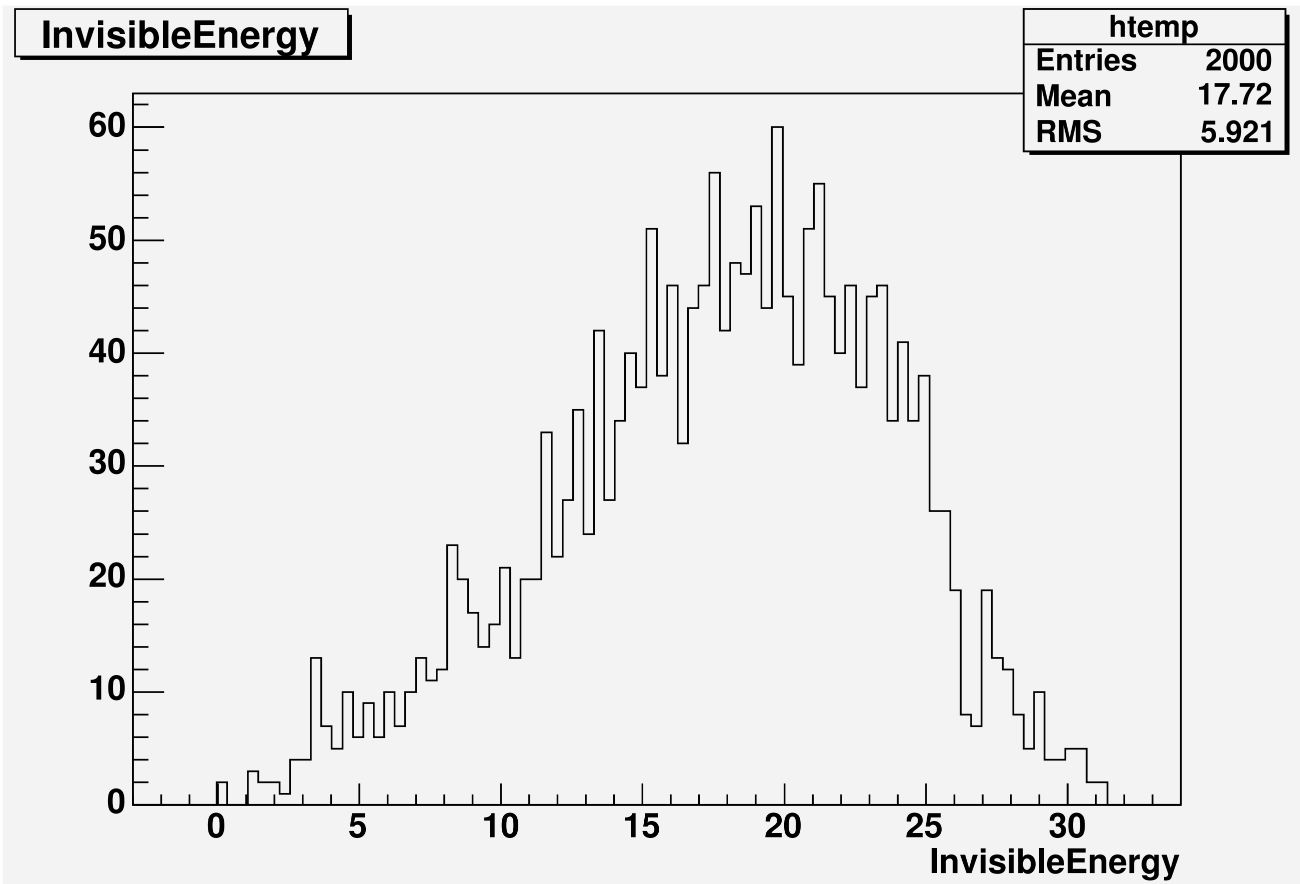
Invisible energy location

- The visible and invisible energy loss along the step is assigned to the readout cell whose volume contains the (x,y,z) hit location.
- Usually we assume that the (x,y,z) hit location is the location of the middle of the step but more detailed description can be done in each calorimeter calculator code.
- Cell by cell in-out energy balance is an automatic result of correct positioning of energy loss on each step.

Negative invisible energy

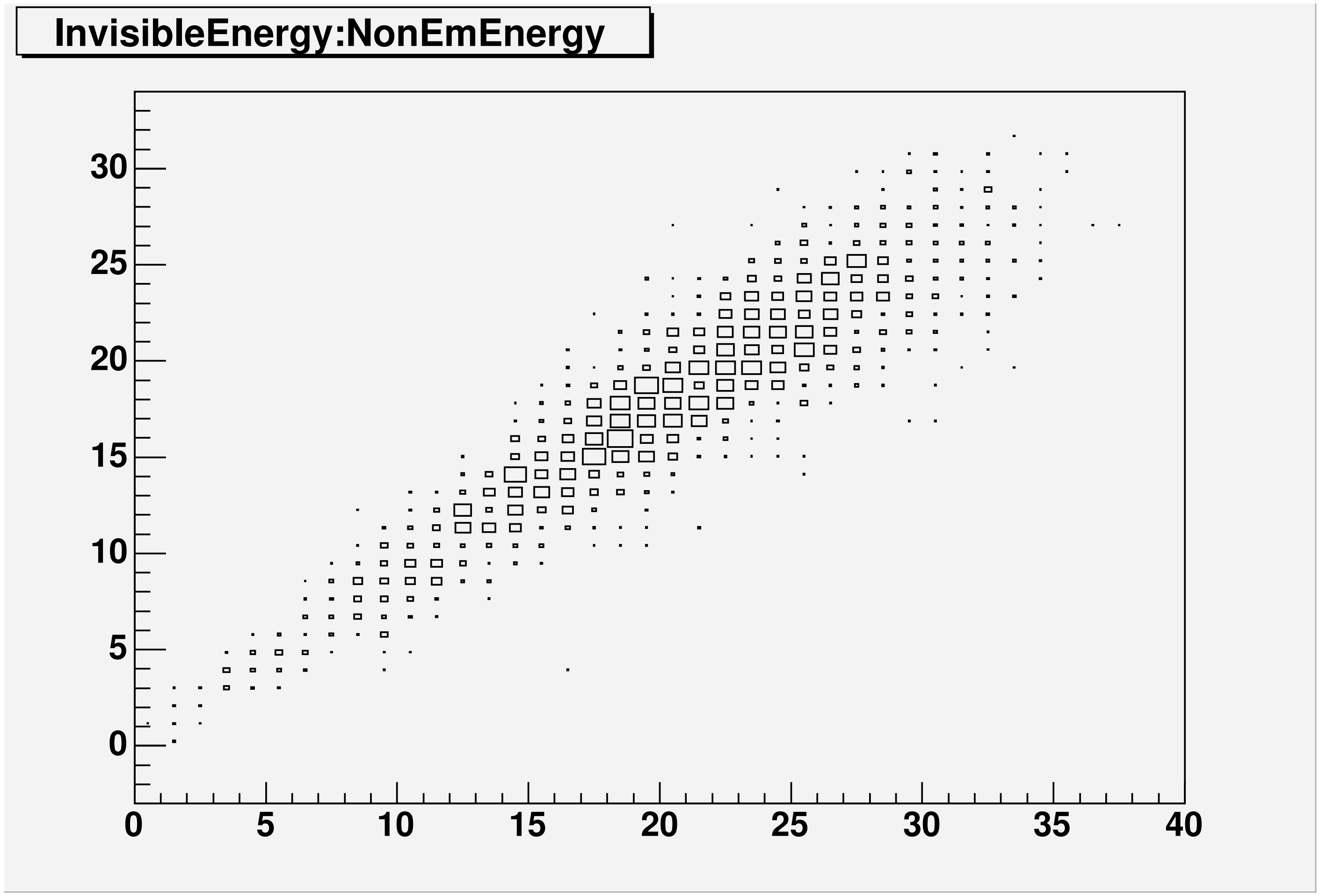
- A visible energy in any cell should be positive. This is not the case for invisible energy which calculated as a difference between incoming energy and energies of secondaries.
- Example: Some fraction of nuclear binding energy loss is recuperated when neutrons get captured by other nuclei. This simulated by G4LCapture class with creation of one or two photons.
- Kinetic energy of incoming neutron may be in keV range, but photons are in MeV range. A neutron can travel a lot and then it is finally captured in one of the cell. Appearance of photons with measurable energy leads to negative invisible energy in this cell.

Total invisible E in HEC



- 100 GeV pion+

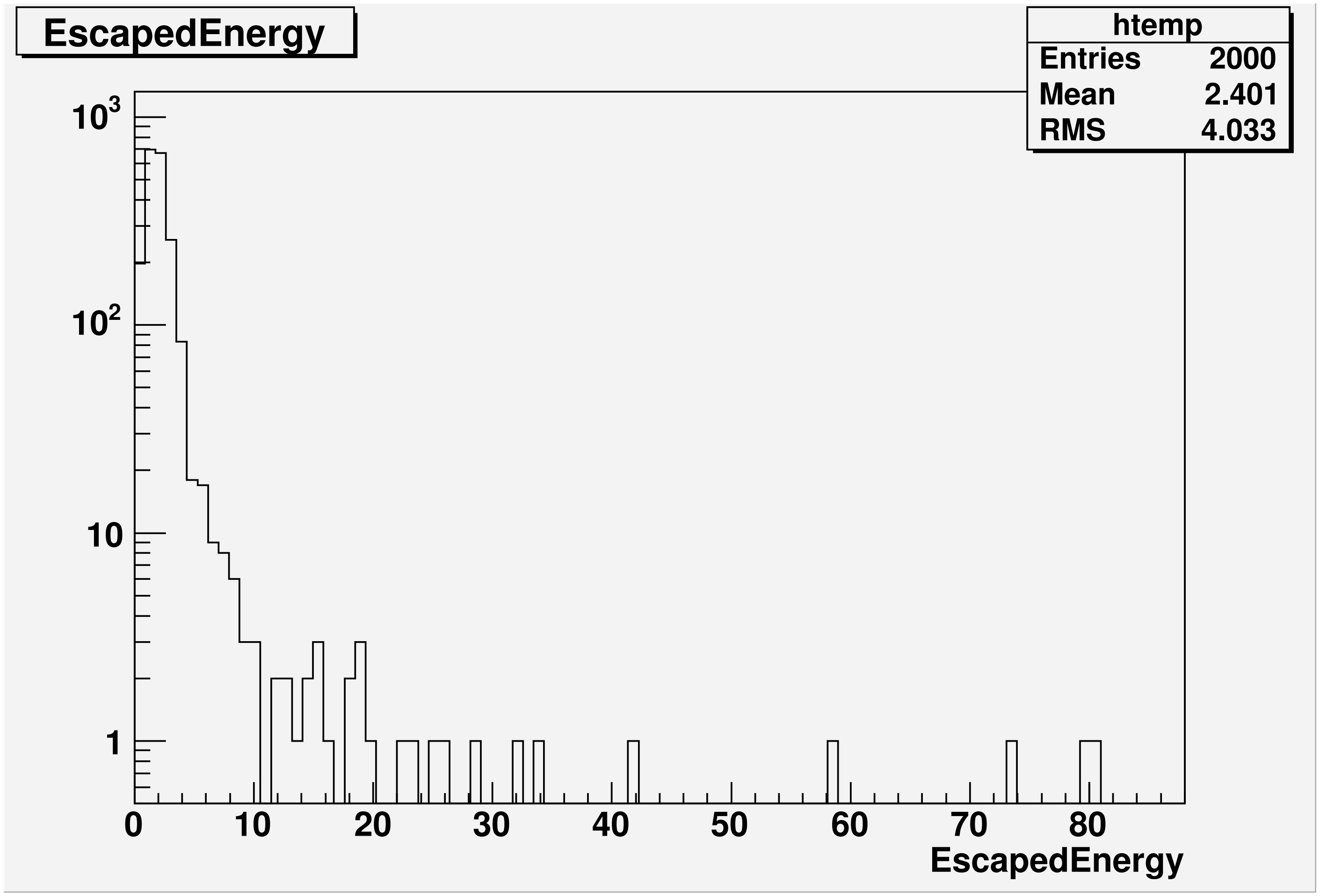
...correlated with non-EM



Escaped energy

- Neutrinos, high-energy muons, some neutrons and photons may escape the calorimeter. Neutrino component of escaped energy ~ (1.3-1.7)%
- we associate the escaped energy with the volume in which the G4Track originated so it can be summed with invisible energy loss of that cell

Escaped E


EscapedEnergy
htemp
Entries 2000
Mean 2.401
RMS 4.033
10^3
10^2
10
1
0
10
20
30
40
50
60
70
80
EscapedEnergy

proton with initial Ekin=100 GeV   in Toy calorimeter

	Evis	Esum	EM	NonEM	InvE	InvEV2	InvEV1	EscE	neutrino
cut=0.02 :									
Mean:	76.69	100	54.46	22.23	21.03	21.03	21.06	2.28	1.70
RMS:	5.52	3.06e-5	9.61	4.91	4.59	4.59	4.58	3.29	0.56
cut=0.7 :									
Mean:	76.37	100	52.66	23.71	21.09	21.09	21.13	2.54	1.70
RMS:	5.52	2.01e-5	10.29	5.36	4.74	4.74	4.72	4.50	0.57

Value at 0.02 - Value at 0.7:

	Evis	Esum	EM	NonEM	InvE	InvEV2	InvEV1	EscE	neutrino
	-0.32		- 1.80	1.48	0.06			0.26	

| 4 basic components |

cut=0.02 mm 5000 events   7.2 s/event on Xeon Processor 2.4 GHz

cut=0.70 mm 4999 events   4.9 s/event

1 event Aborted ->G4ParticleChangeForMSC::CheckIt

(see Known Problems)

References

- Some preliminary results and notes are collected on Web site

  http://www.nevis.columbia.edu/~lelchuk/CalibrationHits

- A description of the "dead material" identifiers can be found at:

  http://www.nevis.columbia.edu/~lelchuk/DeadMaterials/Version_1.7.txt

- Implemented by Fairouz Malek-Ohlsson, Fabienne Ledroit in release7.5.0

The physics lists

- Geant4.6.0 has a few physics lists available. We choose QGSP for initial work.
- The code that separates the energy deposits into different categories uses particle name, process name, track status. It does not rely on any parameter specific to a particular physics list - this allows to change the physics list without any change in the energy classification code.

Plans

- Tests with “Toy” calorimeter.   Done
- Package with example code in release 7.5.0 Done
- Tests based on HEC have been started.
- Update Web site.
- Each calorimeter experts will apply example code to real calorimeter description.
- Work on IM cell boundaries (calculators,...) .
- Extend to dead materials starting from cryostats.