Sampling and Sampling Fluctuations Studies

A. Para, January 9, 2007

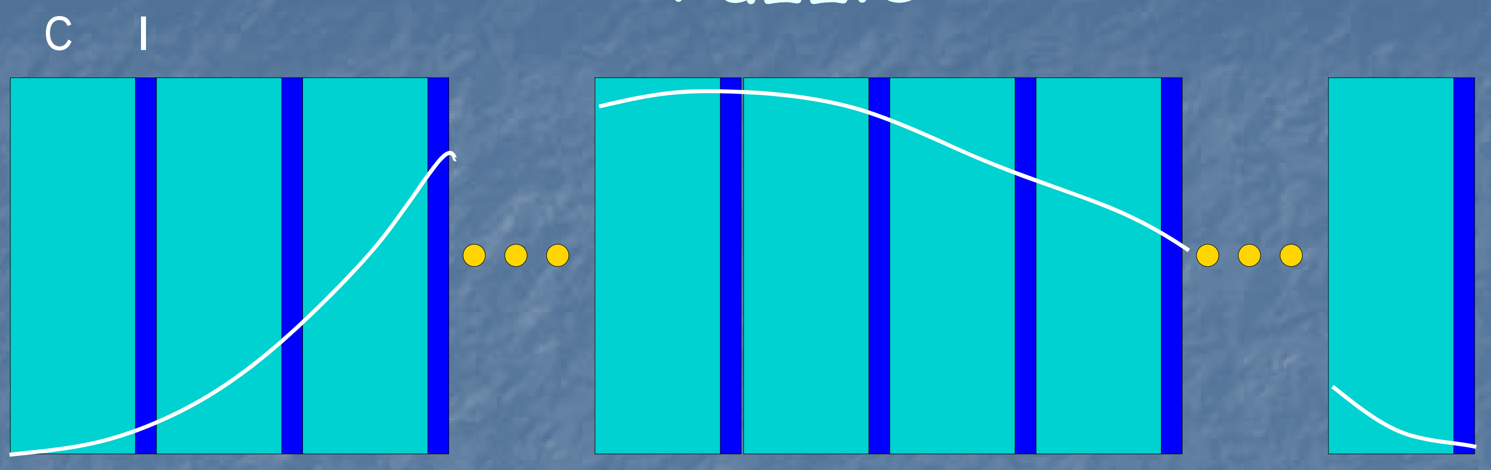
Motivation

- Homogenous calorimeter with dual readout (Cherenkov + ionization) offers a prospect of high resolution hadron calorimetry. But physical realization of a dual readout is rather difficult.
- Natural implementation of a dual readout concept: two-component calorimeter (for example lead glass/scintillator). In such a calorimeter both components are sampled, hence undergo sampling fluctuations
- Sampling fluctuations must be well understood to optimize the detector design and segmentation

Sampling Fluctuations Studies

- In calorimeters with different materials in different sections (realistic case) the energy sharing between the materials may be different for different components of the shower (electrons/photons, pions/neutrons, etc..)
- It seems natural to develop understanding of sampling fluctuations in a configuration with both, the Cherenkov radiator and the ionization detector, made of the same material (like lead glass). [It may be, in fact, a possible design of a calorimeter if a scintillating glass can be used in practice]

GEANT4?/Sampling? Long Standing Puzzle



- Naïve expectation: when detector thicknesses are small compared to the shower size the sum ionization energy depositions in the I(onization) layers and C(herenkov) layers should be proportional to the thicknesses of these layers:

$$\sum I_i \frac{t_I + t_C}{t_I} = \sum C_i \frac{t_I + t_C}{t_C} = \sum I_i + C_i$$

GEANT 4 results (Eiko): this is true as long as the absolute thickness of the I layers is bigger than ~ 1 mm. For very thin I layers, like 100μ, a relative enhancement of 6-10% is observed.

New Developments (Hans+Eiko)

- The initial version of the simulation gave only the total energy deposition in the I and C layers.
- December version:
  - Ionization energy deposition for individual C and I layers stored and available in the analysis
  - This is the version used in the following
- January version (Hans):
  - Cherenkov energy deposition in the individual layers available

Tracing the Anomaly

- Test (case A): use 1 GeV electrons, 25 mm radiator (C layer) , 0.1 mm 'active' (I layer)

'Corrected' energy deposition in the I layers = 1.06. Same as always.

- Fine granularity detector: simulate a calorimeter with 10,000 lead glass layers, 0.1 mm thick each. Given that all layers are made of the same material, the shower development ought to be the same as in a single large block of lead glass. Or in any arbitrary combination of C and I layers. In particular..
- (case B) Define 250 layers followed by 1 layer as C and I layers. It should be identical to the case A.

The result: 'Corrected' energy deposition in the I layers = 1.0 [In fact it is slightly less than 1, the exact value depending on the actual thicknesses of C. This is expected from the fact that shower profile has some curvature.]

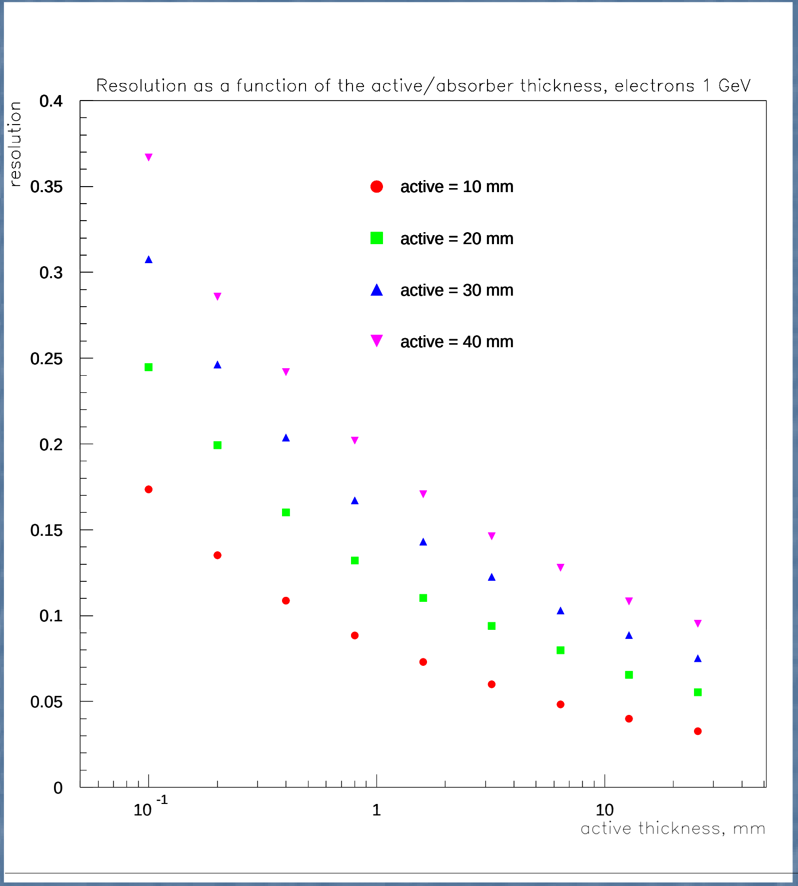
What does it mean?

- The cases A and B are conceptually identical. The only difference is hat the case B the actual step size used by GEANT to trace particles is limited to 0.1 mm, whereas it can be longer in the case A. But GEANT should optimize the step sizes, forcing them to be shorter should lead to the increase of the running time but not to a difference in the results. Bug/feature in GEANT4? Perhaps.. But..
- Check the influence of energy cut-offs first. Imagine that we have a cutoff corresponding to 1 mm path length. If such a particle is produced within 0.1 mm thin layer the entire energy of the particle will be 'deposited' in the thin layer. Such an effect may lead to a systematic overestimate of the energy in the thin layers. Need to be checked.. (Hans)

Optimizing Sampling for Dual Readout

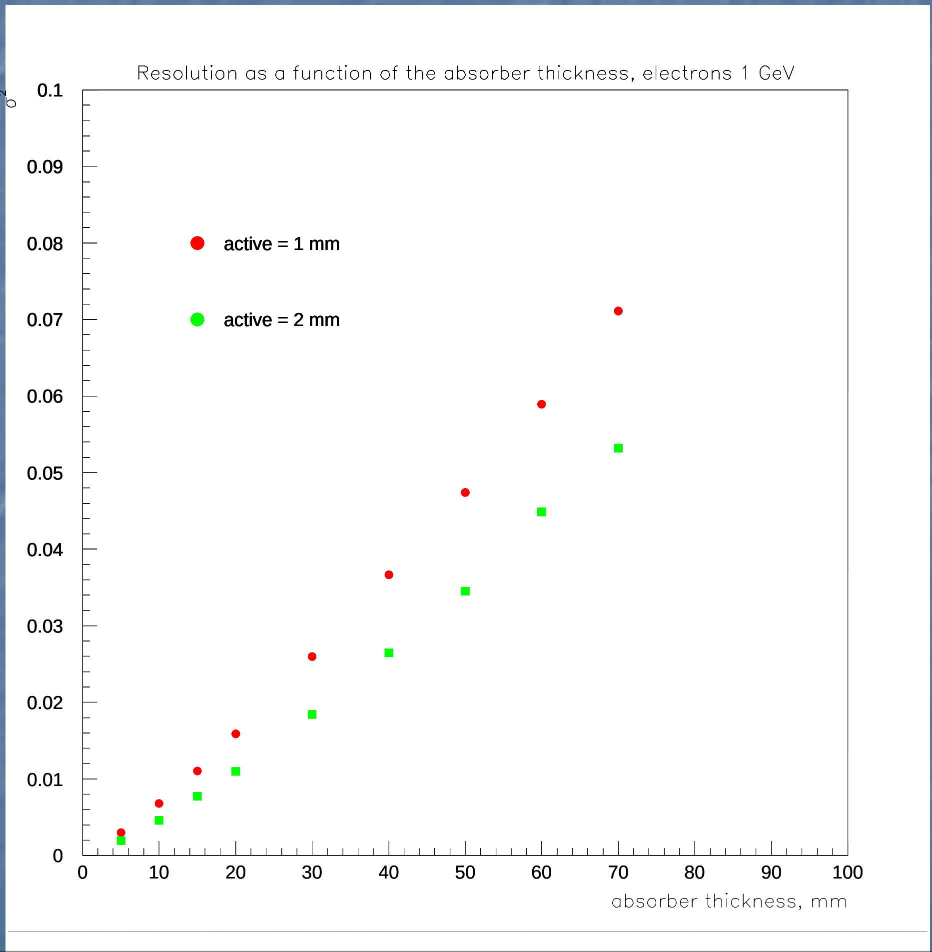
- Common wisdom : $(\Delta E/E)_{sampling} \sim \surd d$ where d is the thickness of the 'absorber'
- In our case the calorimeter layers are simultaneously the active detectors and absorbers:
- $(\Delta E/E)_{ionization} \sim \surd d_C$
- $(\Delta E/E)_{Cherenkov} \sim \surd d_I$
- The scale of d is the absorption length or the radiation length (for hadronic/electromagnetic showers)
- How adequate is the standard wisdom once we enter high precision calorimetry regime?

Some Initial Look at the Sampling Fluctuations



- Using the very fine sampling calorimeter and 1 GeV showers one can simulate a wide range of possible detector arrangements.
- Here: energy resolution for four different thicknesses of the Cherenkov radiator: 1, 2, 3 and 4 cm as a function of a thickness of the 'active' layer.
- This is ionization measurement only, for a given thickness of 'absorber' how does the enrgy resolution depend on the thickness of the 'active' layer?
- Active layer thickness dominates the energy resolution when the thickness is 'very small'

Resolution vs absorber thickness



- For a 'sensible' thickness of the active layer (1 mm of lead glass ~ 4 mm of scintillator)
  - σ^2 does not scale linearly with thickness
  - Resolution different for 1 and 2 mm lead glass 'active'
- Naïve guess:

$$\sigma \approx \sqrt{\sigma_{sampling}^{2} + \sigma_{active}^{2}}$$

Does not describe well the 'data'.

Probably due to the fact that changing the thickness of either layer we move the sampling along the shower profile.

Optimizing the Resolution

We have the tools. GEANT 4.8.2 is out and it is almost as fast as 4.7. Let's try to outline the program:

- Validate the tools:
  - Energy conservation
  - Cuts setting
- Compensation scheme for the sampled detector.
  - Use Ionization/Cherenkov ratio per layer
  - Transverse segmentation (10 x 10 cm) (need further code enhancement)
- Start with lead glass/lead glass to simplify the case (avoid the problem of neutrons) to understand the contribution of sampling?

Strawman Proposal

- Take I layer (for example 2 mm LG). Vary C layer: 1/2/4 cm. Run 1,2,5,10,20 GeV pions and electrons (need electrons for calibration of the procedure).
- Develop the procedure to minimize the energy resolution and keep $e/\pi = 1$.
- Run the above but for I = 1 mm and 4 mm
- Run the above but for the transversely segmented layers (10 x 10 cm ?)
- Run the above but using I = 5 mm scintillator
- Analysis time likely to dominate over the event generation. Generate all these samples and store in the afs space.
- For the segmented calorimeters the file size is proportional to the number of layers. Cannot afford too many readout channels. Use total length of 3 m? Same for the transverse segmentation – use 10 x 10 cm? (coarser segmentation can be simulated by summation)