EMC in Fast Simulation

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Introduction

- The main goals of the fast simulation projection of the SuperB
  - Detector optimization : beam pipe/tracker configuration; detector options (forward PID, backward EMC, etc.)
  - Physics analysis : physics reach studies of the benchmark channels.
- The simulation has been developed within the BaBar framework.
- Simulation is “fast” (goal ~ 100Hz) and expected to change frequently, so no event persisting; physics is run inline with simulation.
- Provide track, cluster, PID objects functionally equivalent or literally identical to their BaBar counterparts.
- Geometry, layout, and response parameters are easily modifiable by non-expert.

Basic design

- Simulation process is broken up into 5 steps:
  1. Particle (4-vector) generation (EvtGen)
  2. Detector material simulation
  3. Detector response simulation
  4. Detector reconstruction simulation
  5. Physics (Beta) candidate creation
- These processes are roughly sequential, though some recursion is needed to handle of daughter particles produced in decay or material interaction.
- This talk focuses on EMC response simulation.

Geometry and detector description

- Particle trajectories are described with piecewise trajectories (helices and straight lines), which allow scattering and energy loss.
- Position and momentum changes are recorded at every point where a particle interacts with material or a sense layer.
- Detector elements are described with cylinders (axis=z-axis), and planes (normal || z-axis)
    - Cone is more difficult because its intersection with a helix results in a transcendental equation.
    - For the moment, EMC forward endcap is represented with a plane, not a cone.

Geometry and detector description (II)

- Detector elements are modeled as quasi two-dimensional objects with an effective thickness instead of full volumes.
  - e.g., cylinder is described by radius and z limits.
  - Intersection is easier to calculate.
- Path length through the element is calculated with its thickness and local incidence angle.
  - Edges are ignored.
  - Curving of the particle trajectory is ignored.
- Probability of interaction and momentum change of a particle passing through an element are calculated at one shot (macroscopically).
- Other details, see SuperB wiki.

Interaction of particles with matter

- Normal charged particle interactions
  - Ionization energy loss sampled from a truncated Landau distribution
  - Deflection angle sampled from a double-Gaussian
- EM interaction (pair production, Compton scattering, showering)
  - Probability calculated from radiation length
  - For "thin" layers, original particle may or may not survive, extra particles may be produced (⇐ not yet fully implemented)
  - For "thick" layers, shower is initiated. Some energy is allowed to pass through the element (longitudinal profile) (⇐ not yet fully implemented; particle always loses all its energy)
- Hadronic interactions (nuclear scattering, showering...)
  - Situation similar to EM interaction, but more difficult to parameterize.

EMC layout

- Barrel: a cylinder
- Forward endcap: a plane
- Range defined by polar angles
- Crystals arranged in rings, and perfectly projective.
- Each ring is segmented uniformly in φ.

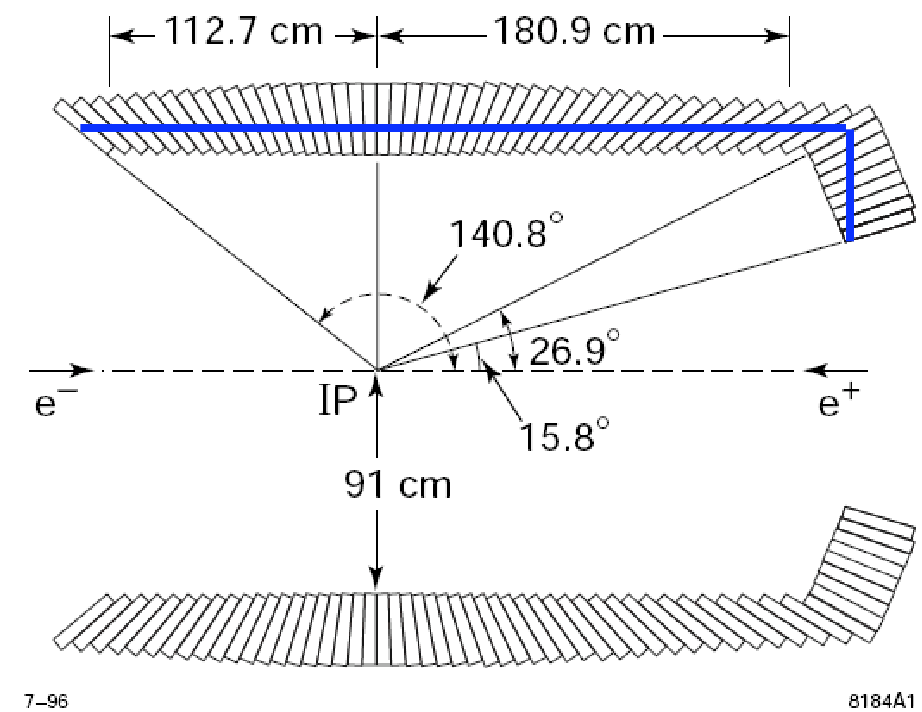


Figure 3-11. *The EMC layout: Side view showing dimensions (in mm) of the calorimeter barrel and forward endcap.*

- Segmentation in θ is not uniform but in pseudo-rapidity $\eta=-\ln(\tan(\theta/2))$ is.
- Polar angle ranges, radius, thickness, #rings, #crystals in rings, etc. are all easily configurable.

EMC clusters

- An EMC cluster is represented by the class `PacEmcCluster`, which contains a list of `PacEmcDigi`. The latter represents the energy deposition in a single crystal.
- Both classes mimic the respective classes in BaBar, but no calibration, timing, and data flow information is represented.

Shower library abandoned

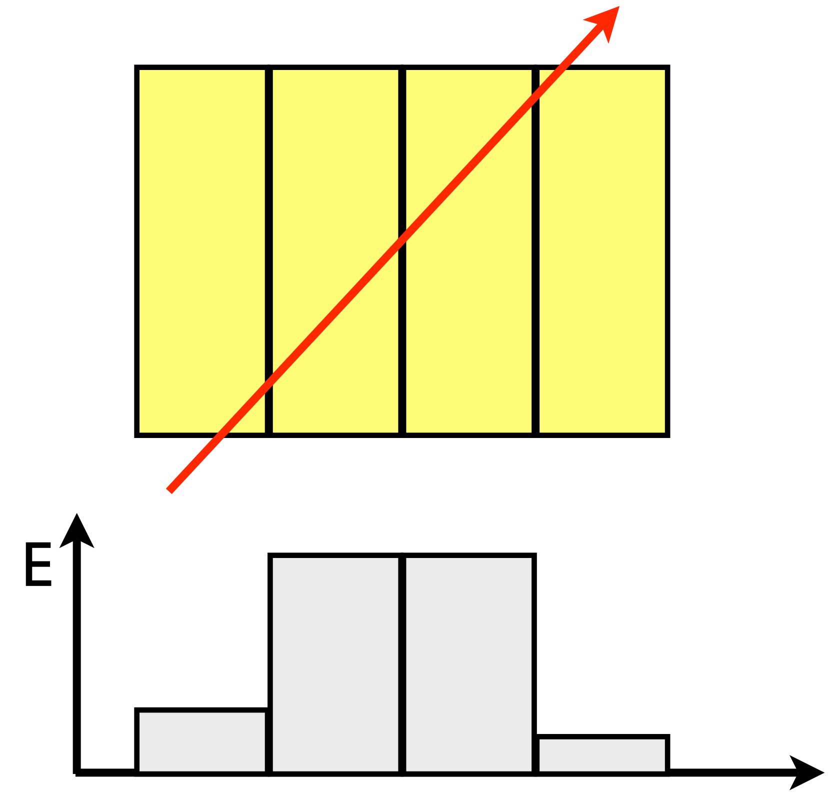
- At Elba we proposed using a shower library generated from full simulation, from which we sample an appropriate cluster to simulate detector response, in order to faithfully reproduce the correlation between crystals, especially for hadron shower.
- We later realized that the shower library is not easy to implement. A complete implementation requires large space, non-trivial look-up scheme, and running full simulation each time when geometry or material is changed.
- We have basically abandoned the shower library idea, and try to also parametrize hadronic shower. (see later).

Ionization

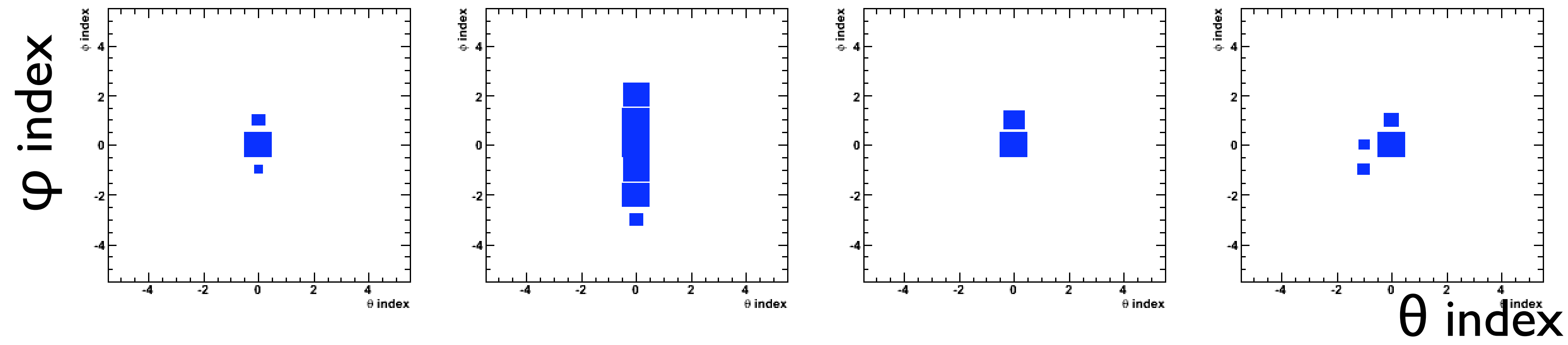
- If a particle is determined to be only interacting with the EMC "normally" (see p.6), we simply distribute the energy loss to the crystals it passes through. Energy is proportional to the path length in each crystal.
- Curving inside the EMC is ignored.
- Energy in each crystal is then smeared according to

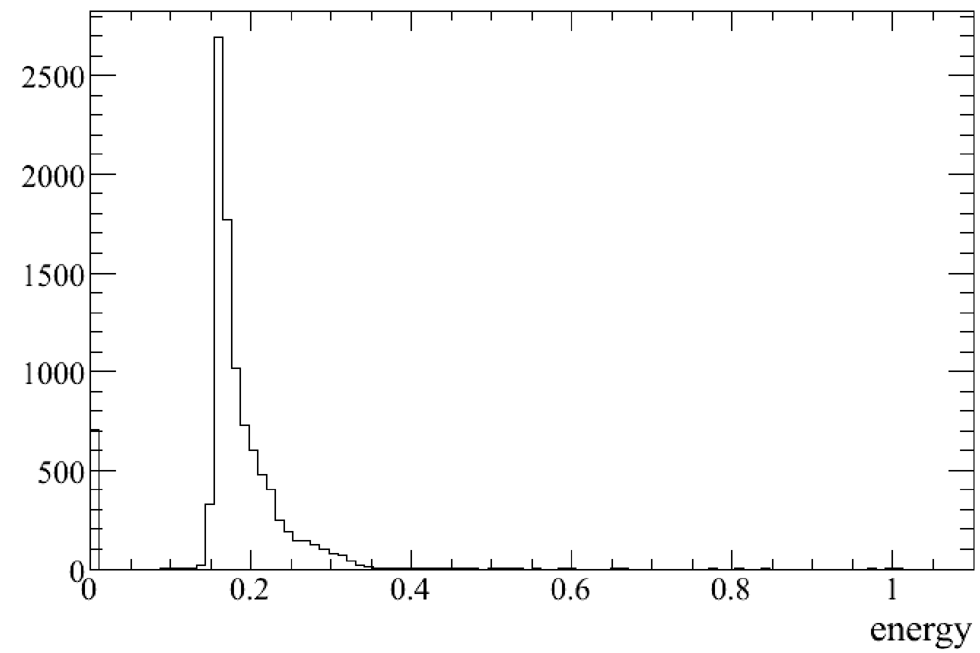
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt[4]{E(\mathrm{GeV})}} \oplus b$$

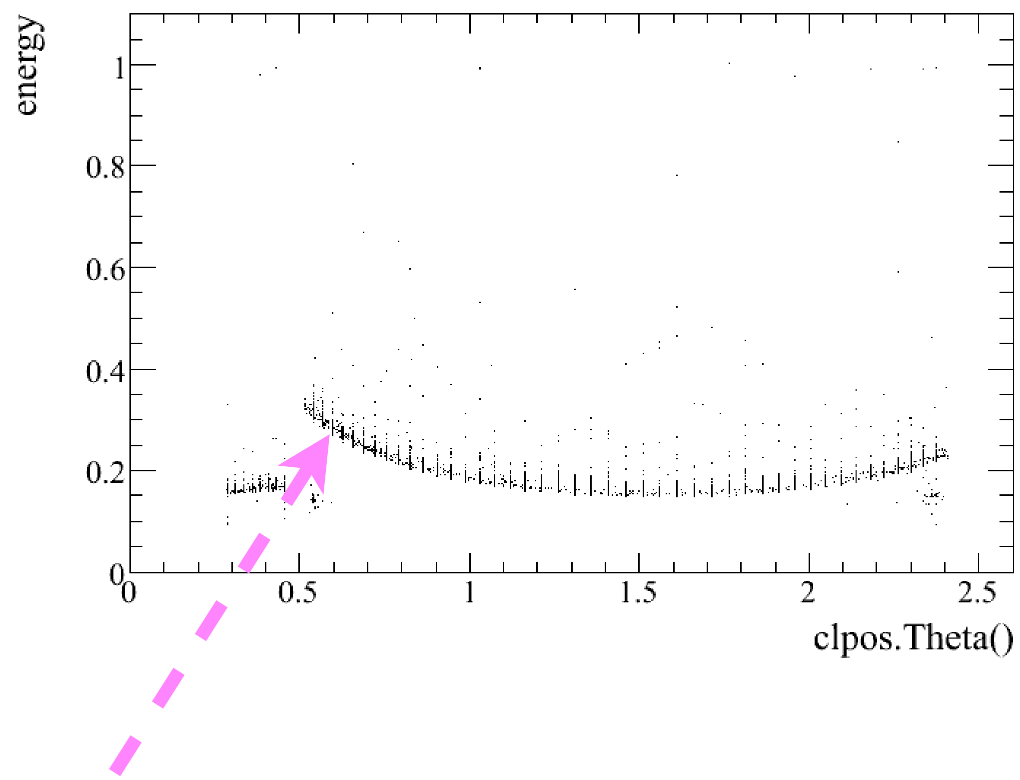
In the following, I use
a= 1% ; b= 1.2%



One-GeV/c muons







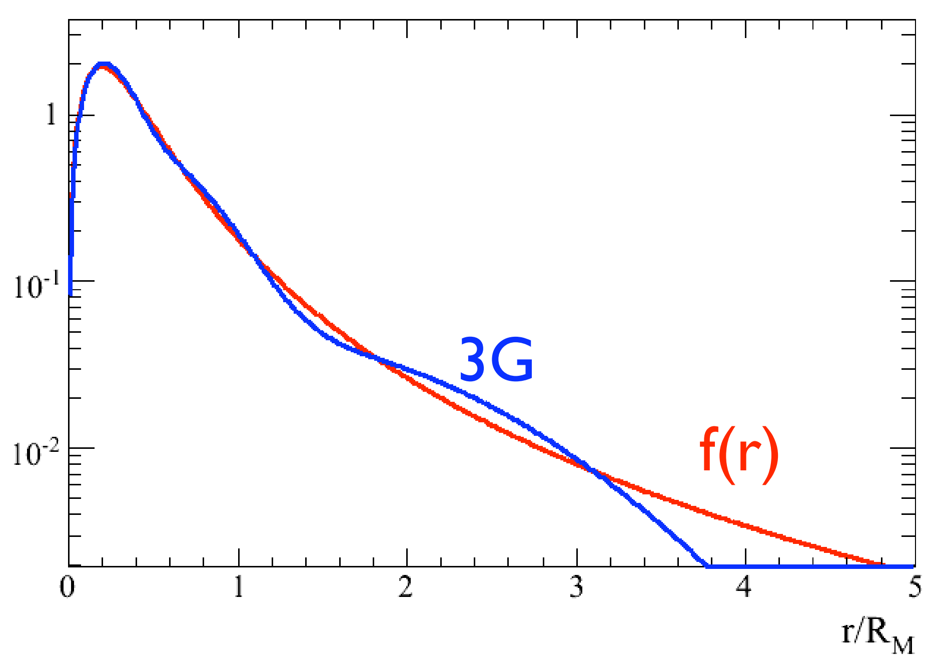
- Path is longer at shallow angle in barrel because the thickness is assumed uniform; need fix.

EM shower

- The lateral shower development is assumed to be symmetric
- On average 10% of the deposited energy lies outside R_M, and about 1% outside 3.5 R_M.
- The radial distribution can be modeled phenomenologically with

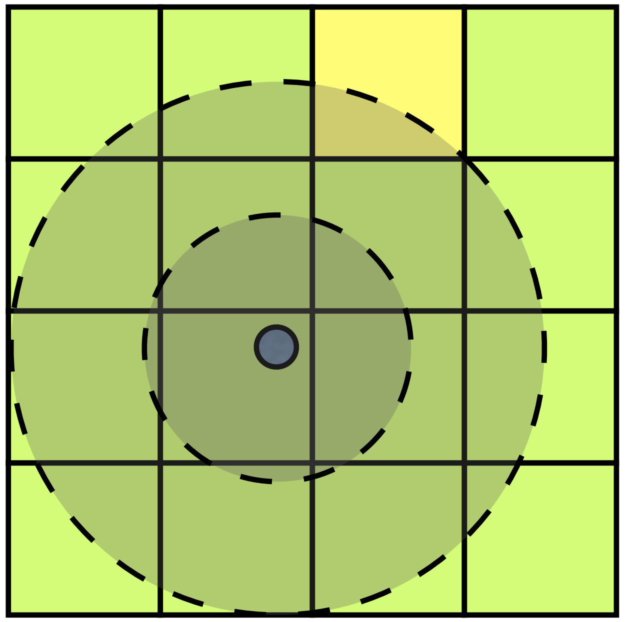
$$f(r) = \frac{2rR}{(r^2 + R^2)^2}$$ [PDG2008 Sec. 27.5]

- Modeled with a sum of three Gaussians
- Scaled with the Moliere radius R_M.



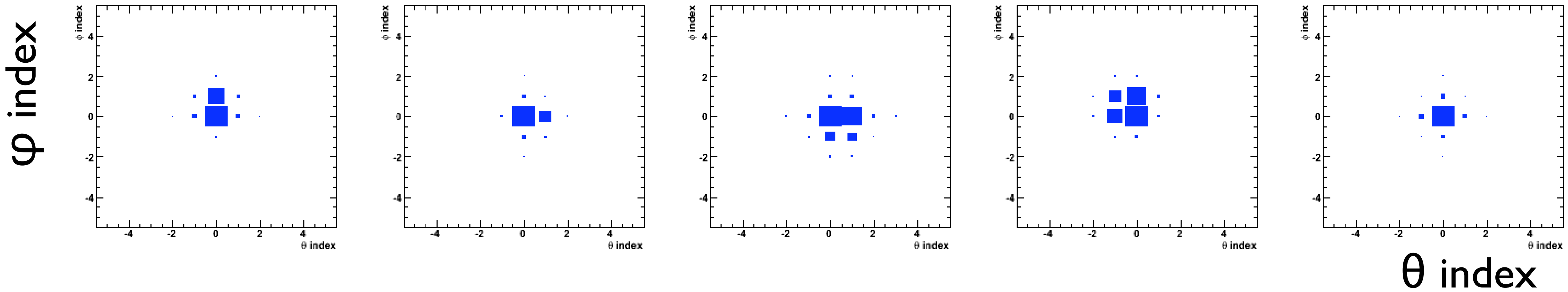
The integral of 3G from R_M to inf is 0.9% and from $3.5R_M$ to inf is 0.15%

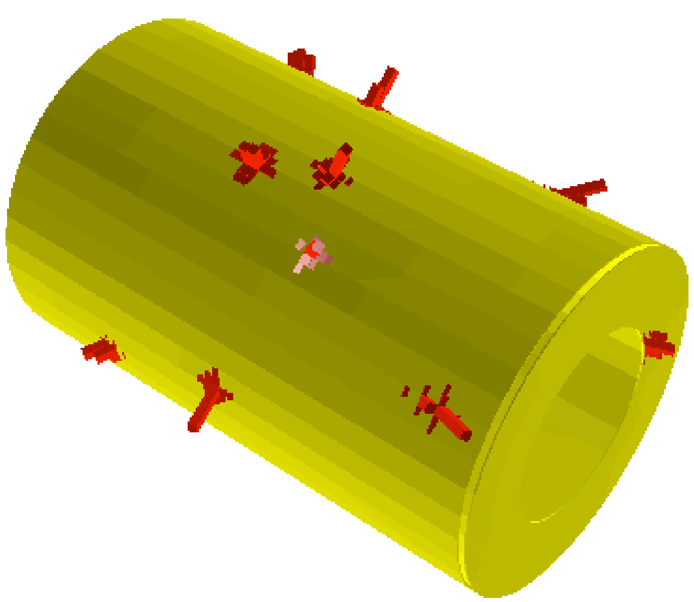
EM shower (II)



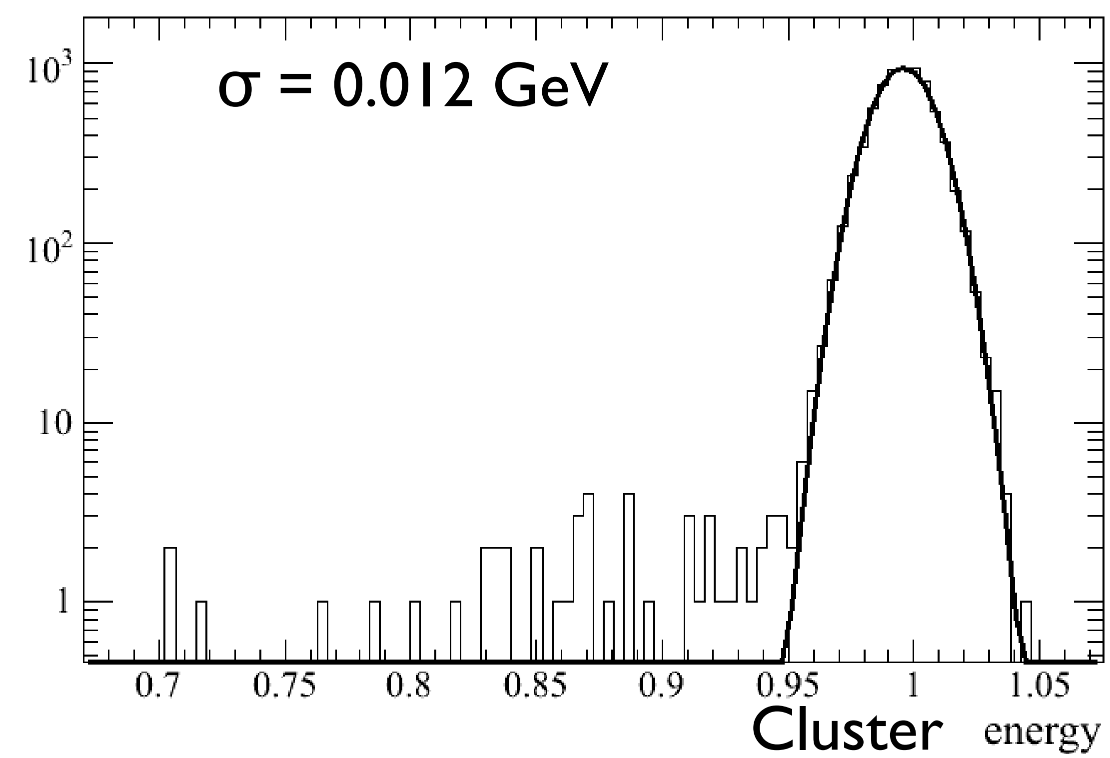
- Starting with the crystal a particle hits, calculate the integral of f(r) [3Gaussian] over each crystal.
- Energy is distributed over crystals according to the integral.
- Here I use R_M=3.7cm, and allow it to fluctuate by 10%.
- Energy in each crystal is fluctuated by $$\frac{\sigma_E}{E} = \frac{a}{\sqrt[4]{E(\mathrm{GeV})}} \oplus b$$

One-GeV photons



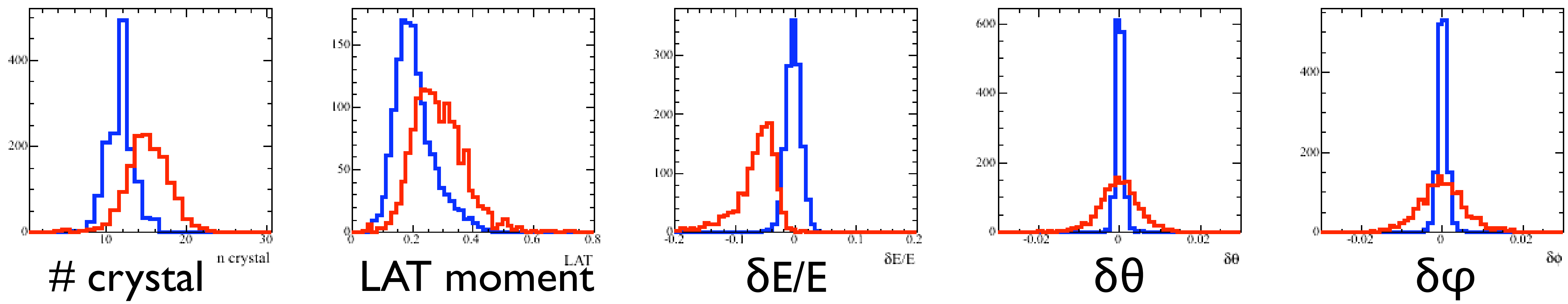


“event display”

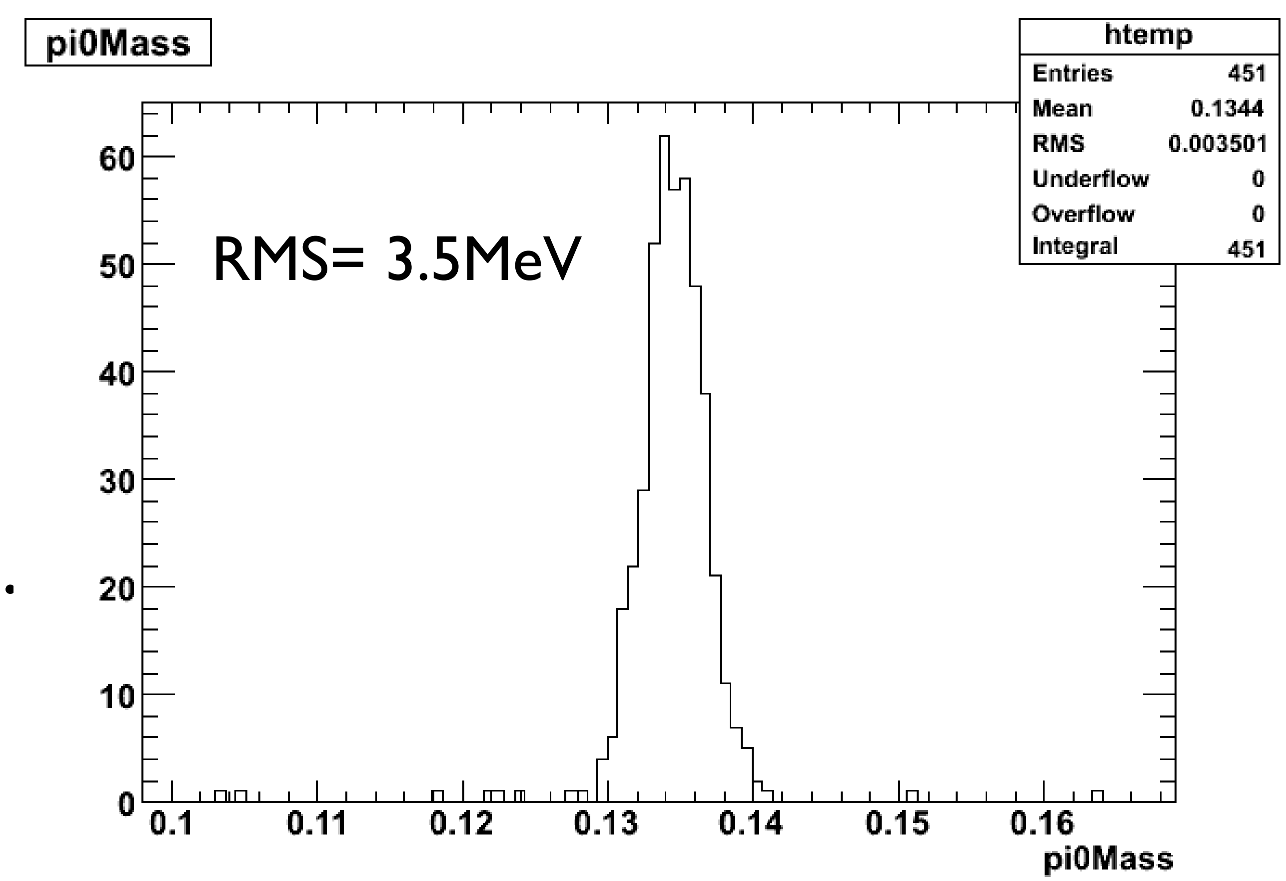


Performance

- One-GeV photons: Blue= FastSim; Red= full Sim



- π0 from B → π+ π0 simulation



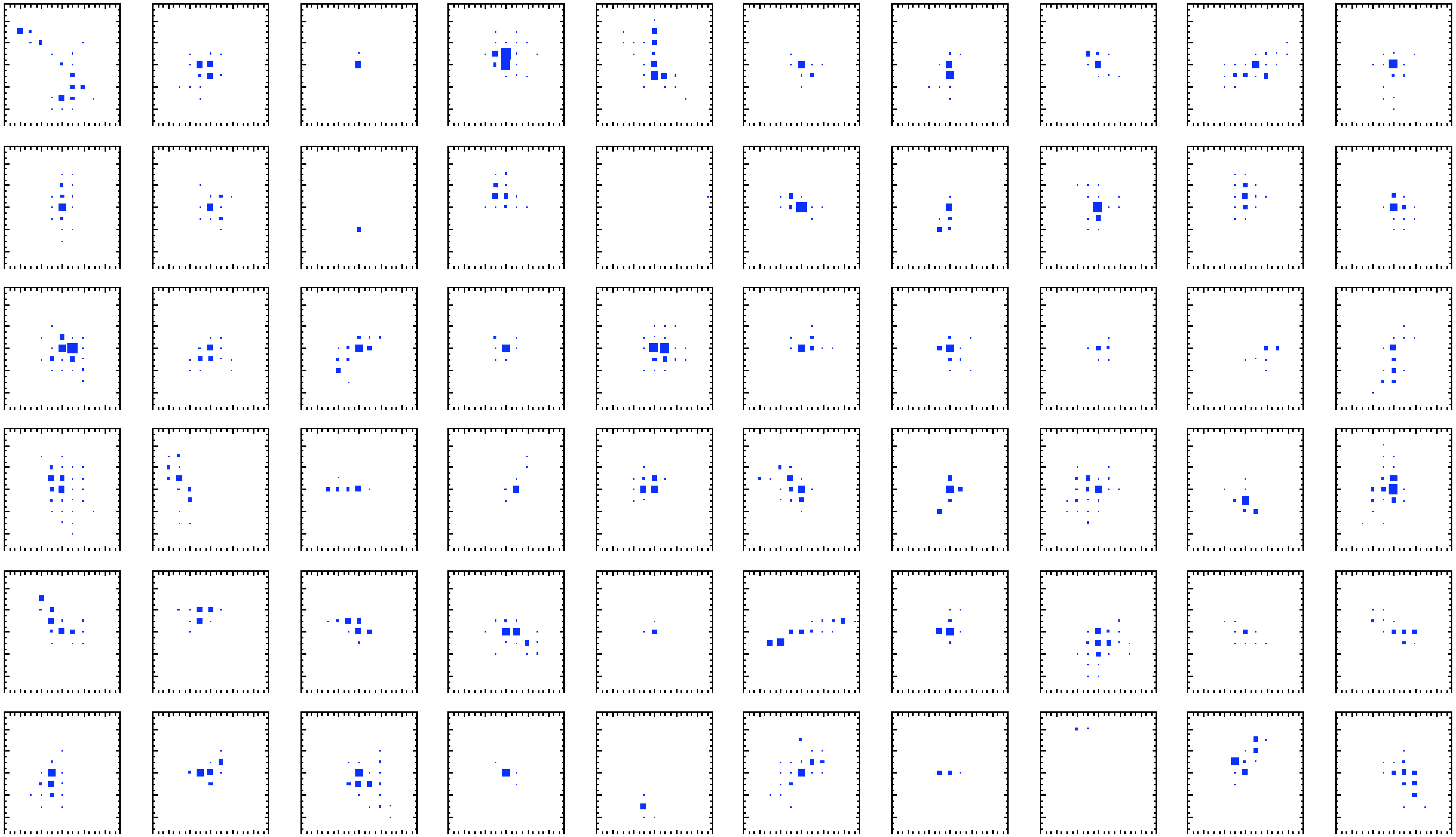
- Resolution is clearly too good.
- Does not simulate energy leaks.
- Need some more “noise”.

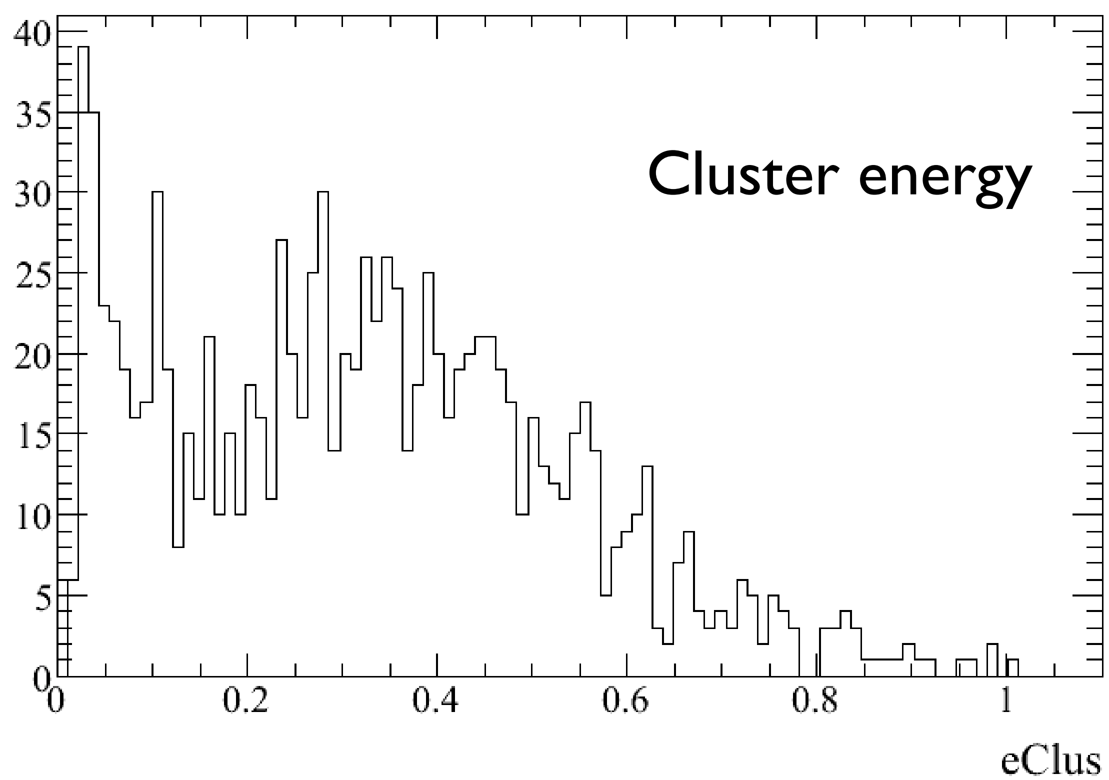
Hadronic shower

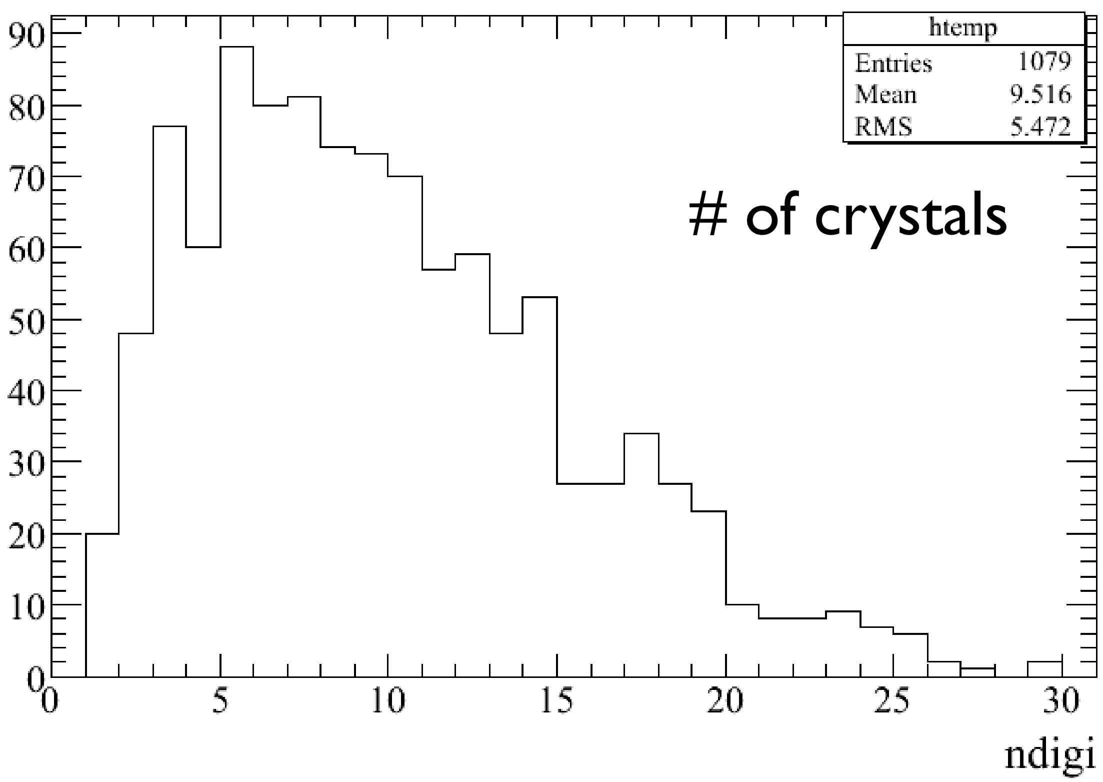
- Hadronic showers are irregular and difficult to model with simple parametrization.
- New idea: use random walk to navigate through crystals and create large fluctuation to create irregular patterns.

What hadronic showers look like

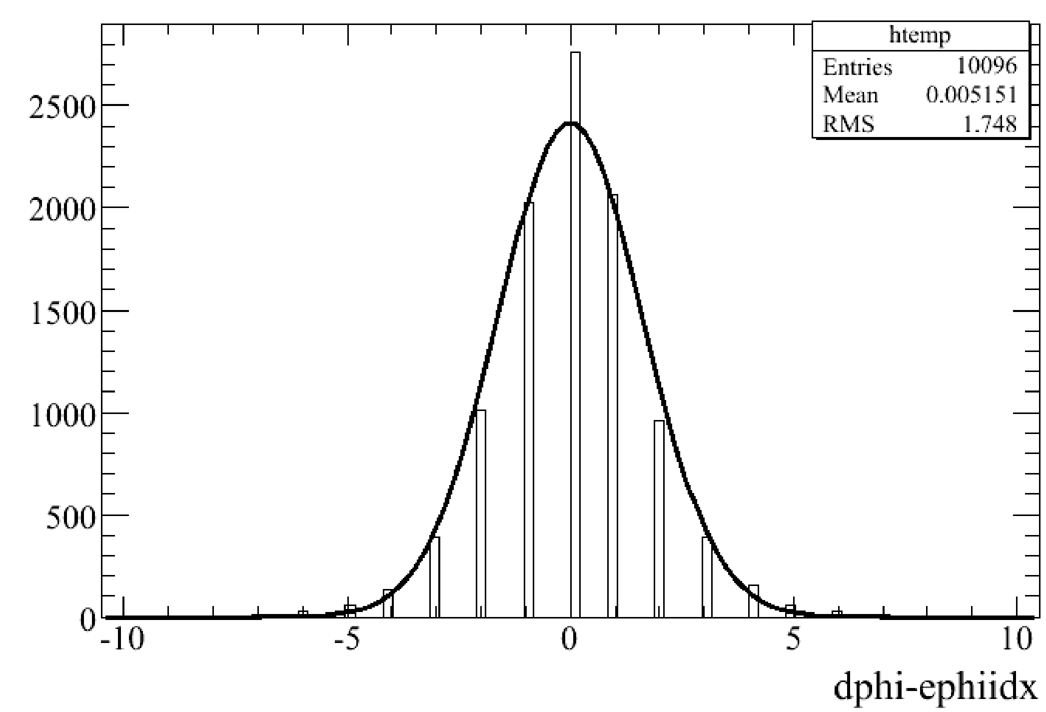
- Samples of 1GeV/c KL shower shapes from Babar full simulation (only about 1/2 of all KL leave a cluster in Babar EMC)







- Energy distributed in a wide range.
- Average shower shape is very close to a Gaussian (central limit theorem).



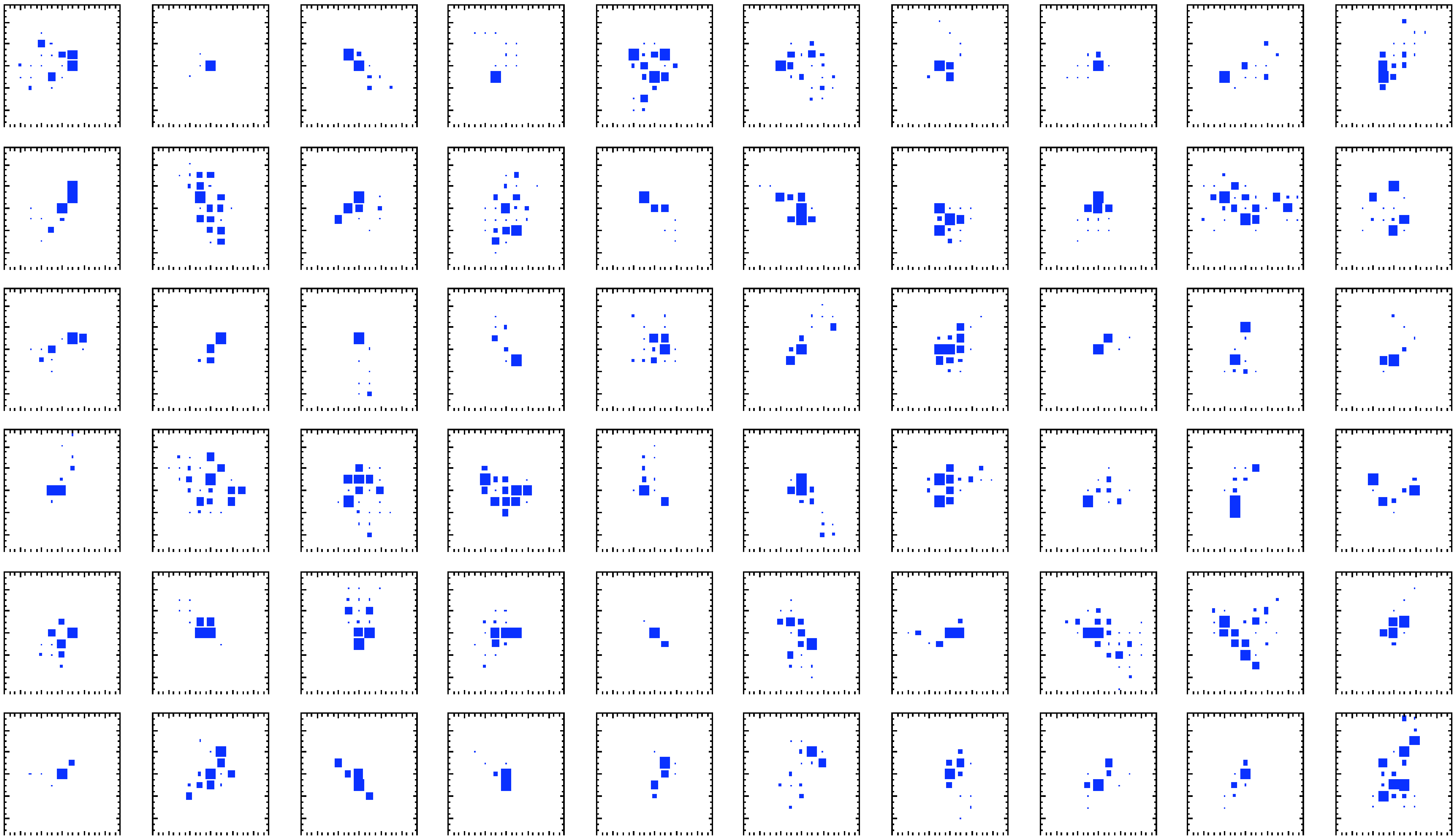
Hadronic shower modeling procedure

1. Determine the total deposited energy E.
2. Start from the crystal (i,j) where a hadron enters.
3. Determine the average energy Eij in that crystal (a fraction of E) based on an integral of a 2D Gaussian.
4. Fluctuate Eij using a Poisson with a large quanta.
   - Eij = TRandom::Poisson(Eij/quanta) * quanta
   - and then smear it : Eij = Eij + TRandom::Gaus(0,σ_E)
5. Fill that crystal with Eij, and reduce E by Eij.
6. Random walk to a nearby crystal (i', j'). If (i', j') has already been dealt with, walk again.
7. Repeat step 3 until E <= 0 or has walked too far.

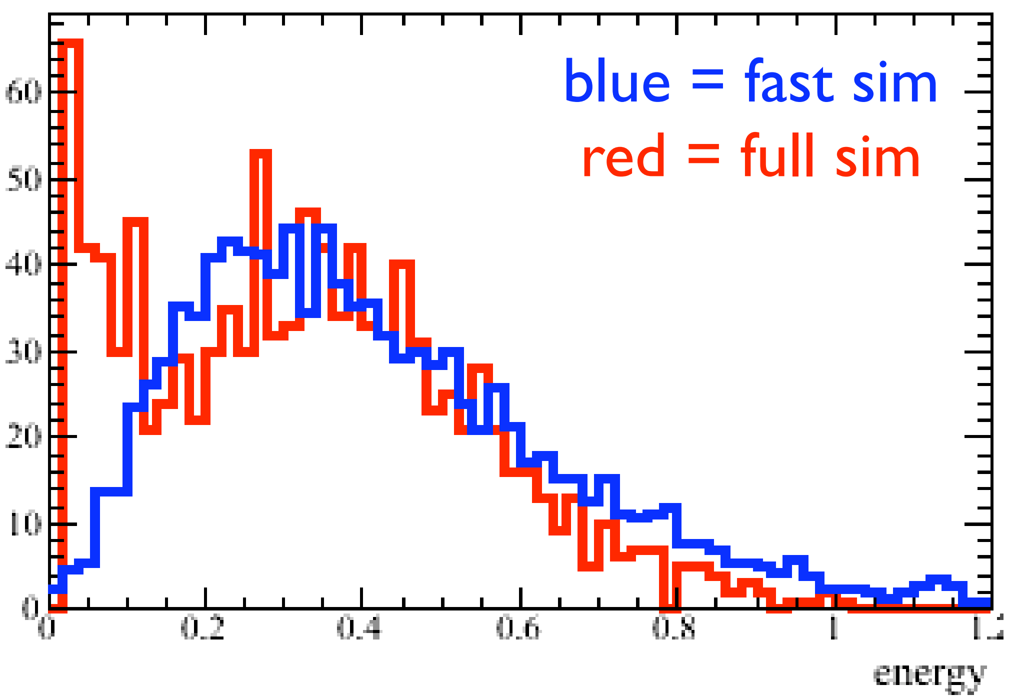
Test with 1 GeV/c K_L^0

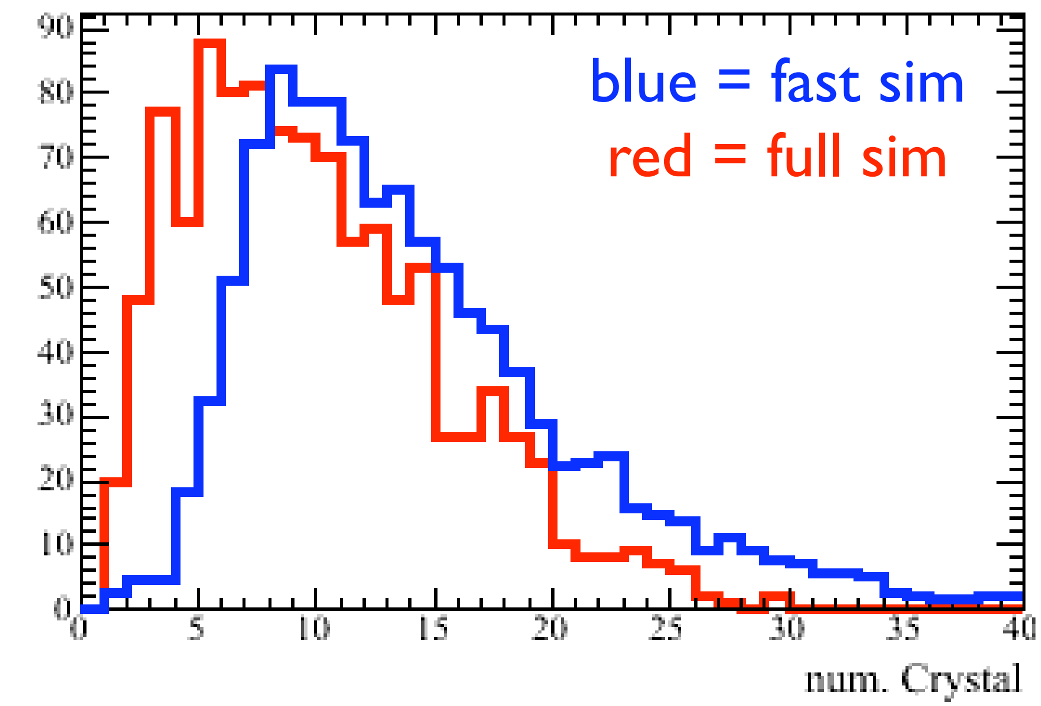
- Parameters:
  - Overall profile σ= 8 cm
  - Maximum distance: 30 cm
  - Energy “quanta” = 50 MeV
  - Extra fluctuation σ_E = 10 MeV
  - Minimum energy = 1 MeV
- Caveat: currently in fastSim when KL interacts, all its energy is lost in that detector element. So we always end up with 1 GeV to begin the process described in the previous page.
  - In the future, energy leaks beyond EMC will be allowed.

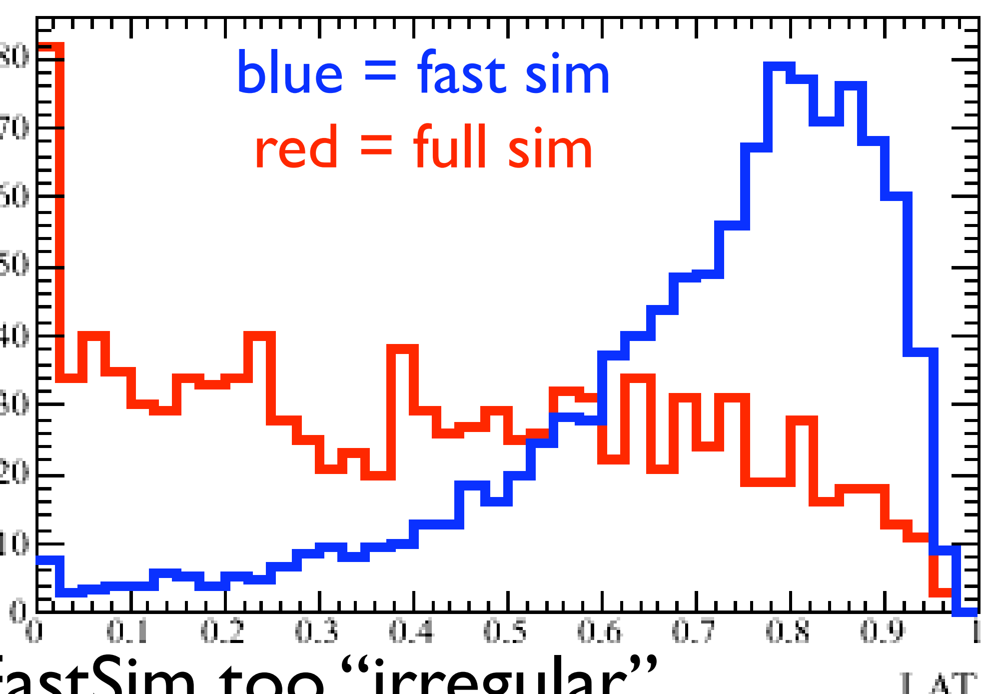
Test examples



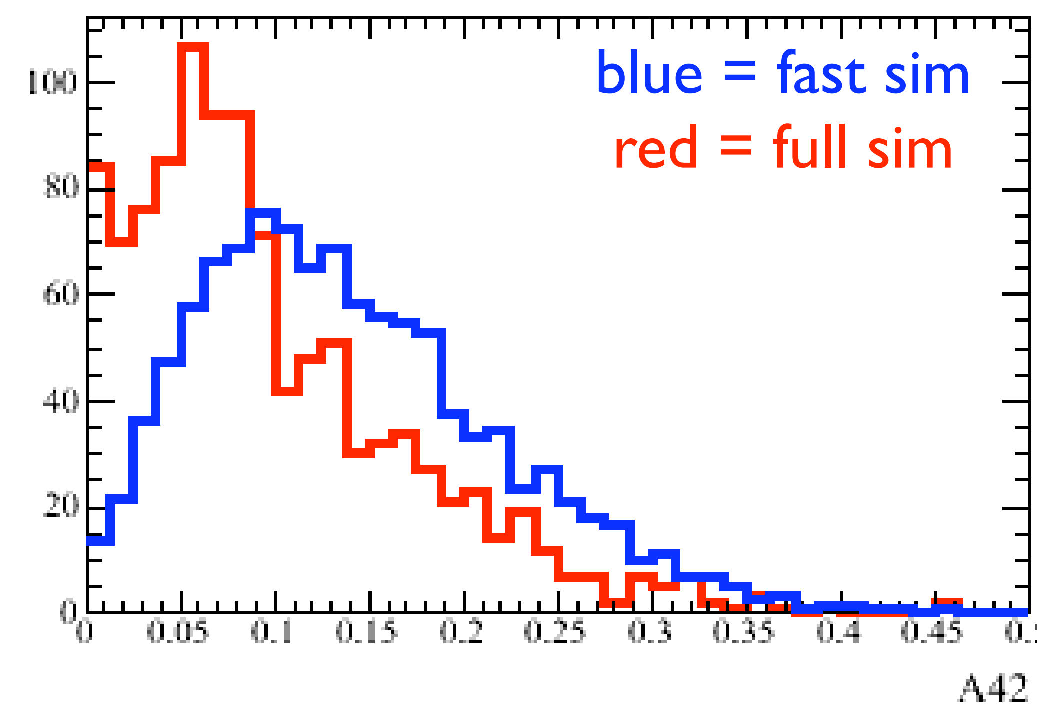
Compare with full simulation







FastSim too “irregular”



Conclusions

- We are making progress in SuperB FastSim project.
- It is able to simulate tracking and basic DIRC, EMC and IFR responses.
- EMC is able to simulate MIPs, EM showers and hadronic showers.
- Shower library is abandoned (for now at least).
- It is possible to generate very irregular shower shape with random walk.
- We haven't spent any time tuning parameters. Performance does not match full simulation yet.
- Many still need to be done:
  - track-cluster matching, dealing with new material (LYSO), cluster merging/splitting, validation plots macros, etc...