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On Fast Simulator.

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Abstract

Large numbers of simulated events are necessary for opimization of the STAR detector and for planning the future data analysis. Due to the high event multiplicity and sophisticated detector geometry, the requirements for the computational time become a major problem for mass production of simulated events.

The Fast Simulator for electromagnetic calorimeters is considered as a possible solution of this problem. In this paper, experience on the creation of a prototype of a Fast Simulator for EEMC is summarized. Using standard techniques, good agreement between Fast Simulator results and GEANT calculations was achieved. The computational technique is described in detail, and simplifications and assumptions are explained.

Also, the magnitude of possible acceleration of GEANT simulations due to EMC Fast Simulator is estimated. It is found that for the simulations with full STAR geometry, the maximum possible gain is only 2.2 times. It is pointed out that a EMC Fast Simulator, probably, is not able to reduce seriously the simulation CPU time, so other approaches should be studied.

1 FSim : the expectations.

For high energies of the RHIC beams and for projectiles with large atomic numbers, the multiplicity of the interactions will be enormously high. Thus, for $AuAu$ central collisions at the energies $\sqrt{s}$=200 A GeV, the multiplicity of 5–6 thousand particles is what we could expect in the STAR detector. Moreover, the secondary interactions inside the detector create more particles with a large variety of kinematical characteristics.

To study the response of various STAR subsystems, for optimization of STAR configuration and for trigger studies – a large number of simulated events is required for the STAR project.

In pp–interactions, the number of produced particles is smaller. At the same time, the polarization studies assume the observation of small asymmetries in relatively rare processes. These studies also require a large number of simulated events to be processed through the data processing chain.

At the moment, the GEANT simulation of one $AuAu$–event (in full geometrical configuration) takes one–two hours, and the large number of events hardly could be processed through GEANT in a reasonable period of time. This is the bottleneck of all the current simulation projects. The simulation of showers in STAR Barrel– and End-cap– Electromagnetic Calorimeters (**BEMC and EEMC**) takes a considerable amount of processing time, in comparison to simulation of particle propagation through other STAR subsystems.

That was the reason why the idea of a Fast Simulator of showers in the EMC was considered in the software community of the Collaboration. It was expected that the implementation of a procedure for fast shower simulation could significantly increase the statistics. This would be especially important for the members of the Collaborations possessing limited computational resources.

2 FSim : methods and references.

There are several methods of fast shower simulation.

• The most "expensive" and space–consuming method is the creation of a "shower library", which contains a large number of fully simulated showers – for all energies, angles of incidence and types of particles. This method is not widely used and has very limited area of application.

• In another method, the speed of calculations is accelerated by increasing the cut–off energy for secondary particles. Only a few generations of shower particles are simulated; when the energy of a shower particle drops below the cut–off energy, the particle is replaced by a sample shower. This method requires some amount of pre–generated and stored "frozen" showers, but this number is relatively small. As several "frozen" showers are used to complete the development of a shower, the realistic statistical fluctuations of the showers could be reproduced.

• The most popular method is the replacing of each single shower by its parametrization. The assumption is as follows : **each single shower could be described by the same functional form.** *But the parameters in the formula can fluctuate, and they are different for different showers.*

A large number of papers are devoted to fast simulations of showers. The analytical description of shower development was published long before the practical use of calorimeters [1]. At the end of this paper, a number of references is given. They were chosen from the bigger set of papers as, probably, being the most useful for our studies.

The method based on recombination of pre–generated showers is fairly well described in paper [2].

The "hybrid" simulation technique was proposed in [19]. This algorithm follows the shower development down to a certain energy, and then superimposes a combination of pre–generated showers.

Many papers are specially devoted to the parametrization of the electromagnetic (EM) showers. Most of the methods use Γ–distributions [1] with the minimal set of parameters for the approximation of the *longitudinal* profile of the shower and its fluctuations [14].

Some models give the complete three-dimensional shower parametrization [17], successfully using approximation of transverse shower development.

In paper [16] the complete algorithm for the EM showers is described : simulation of

[1]As follows from "Approximation B" by Rossi [1]. In this approximation, electrons lost a constant amount of energy ϵ per radiation length X_o; and the results are identical for all substances if thickness is measured in X_o units and energies in ϵ units.

longitudinal and transverse profiles, their fluctuations and the correlations between the fluctuations. The complete EM shower is described by 15 parameters (!). This paper contains many interesting suggestions and useful ideas.

A sampling calorimeter can be replaced by a homogeneous medium. This makes the calculations much simple, though introduces some distortions of the shower shape. The limitations of the method are discussed in [12].

A parametrization of *hadronic showers* was successfully implemented in the UA1 experiment [3]; still, it is the most often cited paper on this subject. The similar methods are described in [14, 18]. Another algorithm, making use of multivariate statistical analysis, is presented in [6, 10].

The most accurate and complete discussion of the processes in sampling EM calorimeters and various approaches to shower parametrization can be found in [22, 23, 26].

The *full* simulation of showers in the EMC calorimeters of the STAR detector would be very desirable. It means that not only the energy response of the calorimeter (with correct fluctuations) should be simulated, but also the realistic spatial distribution of hits in sensitive layers of the calorimeter should be simulated as well. There are several reasons for detailed simulation of the showers :

• The Shower Max Detector (SMD) information is used to separate one– and two–photon events, and simulations of the SMD response and the SMD profiles should be done as detailed as possible.

• BEMC and EEMC are not the uniform media. The realistic geometrical description includes a number of gaps, cracks and ineffective regions. All these irregularities distort the shower development and cause energy leakage from the calorimeter. These could significantly influence the resolution of the detector and its efficiency to detect some selected processes. To take these effects into account, the simulated spatial distribution of shower hits is required.

• Many effects give contributions to the response of the EMC : photostatistics, light collecting efficiency variations inside a sensitive layer, dead channels, slightly different thicknesses of scintillating plates inside one tower, etc. To estimate their cumulative influence to the EMC response, the simulation of layer–to–layer shower profiles is beneficial.

3 DFSim : preparations.

There are two different types of showers observed in the EMC :
–"electromagnetic" (initiated by γ's and electrons), and
–"hadronic" (initiated by $\pi^{\pm}$–mesons, protons, etc.).

The physical processes underlying the development of showers of these two types, are different. The electromagnetic showers can be approximated by relatively simple formulas. At the same time, the description of hadronic showers should be necessarily done using more sophisticated and less accurate formulas. The reasons for this are the following :
– a number of π^0–mesons are produced at the early stages of the hadronic interactions. Their decays give rise to the electromagnetic component of the shower, which contributes to about half of the measured shower energy;
– a large number of physical processes involved in the hadronic shower development result in large energy and spatial fluctuations;
– hadronic showers have much larger attenuation lengths as compared to electromagnetic showers. Both the BEMC and the EEMC have thicknesses smaller than one interaction length. This means that a hadronic shower, even if started, will never deposit all its energy inside the EMC. Both EEMC and BEMC were not designed as hadronic calorimeters. Nevertheless, the hadronic showers give signals in the EMC and should be simulated.

To study the performance of a Fast Simulator and its possible limitations, the software prototype of a Fast Simulator was created. Below, it is referred to as "Dirty Fast Simulator" **(DFS)**. "Dirty" means that it is not implemented in the STAR GEANT yet, though it has all the features of a Fast Simulator. DFS was made specially for the End–cap Electromagnetic calorimeter.

To check the analytical expressions for DFS shower parametrizations and to get the numerical value of parameters in the formulas, "test" showers should be simulated in GEANT. For this purpose, an input file with test particles was prepared. It consisted of "test" particles : γ, e at 1 GeV ,

2 GeV,

5 GeV,

10 GeV,

20 GeV.

The total number of particle was 2,000, at normal angle of incidence ($\theta = 0^o$). At normal incidence the showers have symmetric shapes that are much easier to fit. The EEMC design, however, does not allow particles from the interaction region with $\theta < 15^o$ to hit the calorimeter.

To obtain the showers produced by particles at normal incidence, the geometry namelist file for EEMC was slightly changed. The size of the central hole was set to zero, so the EEMC was represented in GEANT as the set of alternating lead and scintillating disks. All the cracks and radial support walls were deleted (*only in this special geometry file*). (For BEMC these changes in geometry are not necessary, as the position of the BEMC allows the particles to hit the calorimeter at normal angle.

This allows one to obtain a set of "ideal" EM showers having minimal distortions. The characteristics of these shower profiles depends only on particle energies and the thicknesses of the lead/scintillator layers.

This set of test particles was processed through GEANT, and complete information on each hit of a shower was kept. The distributions of deposited energy in the EEMC for γ's of different energies are shown in Fig.1.

4 DFS : longitudinal profiles. Fit and fluctuations.

Mean longitudinal profiles of EM showers in the EEMC are shown in Fig.2. as functions of shower depth (in units of radiation length X_o). All profiles have the similar shape: rapid growth, maximum around 5–7 X_o (where SMD will be installed) and tails until 22 X_o.

Of course, even for the particles of the same energy, each individual EM shower profile is sufficiently different from the mean. Fig.3 gives an idea about the magnitude of fluctuations in EM showers.

For this study, the longitudinal approximation was taken in the form [14]:

$$f_i(x) = \frac{x^{\alpha_i - 1} e^{-x}}{\Gamma(\alpha_i)},$$

where x = β_it (t - depth in units of radiation length X_o) [2].

The incoming particle does not necessarily start to shower immediately at the first layer. To get the correct fit results, the "vertex" of each simulated shower profile was shifted to the point $t = 0$.

Each single longitudinal EM profile was fit to this formula [3]. Each single EM profile can be fit with good accuracy, as the average total number of hits in the EEMC scintillator layers is $\sim$ 55 hits/GeV, so for 10 GeV γ this gives $\sim$ 500 hits concentrated mostly in the first 12 layers, so the errors in each bin (layer) are reasonably small. For higher X_o, several bins (layers) should be combined to get reasonable statistics in each bin.

The fit procedure gives for each individual EM shower profile a pair of parameters (α_i, β_i). The distributions of parameters is shown in Fig.4. The parameters are correlated; the correlation coefficient was calculated as $\rho = \mathbf{0.76 - 0.86}$.

In the subsequent simulations, this value was fixed ρ=0.82.

The distributions of parameters α_i and β_i are smooth gaussian–like curves (though they are not exact gaussians). The distributions of $ln(\alpha_i)$ and $ln(\beta_i)$ are more close to normal distributions, as shown in Figs.5a and 5b.

The mean values and dispersions of these distributions are dependent on the γ's energy. These dependences are shown in Fig.5c, and in first approximation, can be represented as the linear functions of $ln(E_\gamma)$:

$<\alpha> = \alpha_o + K_\alpha lnE;$

$<\beta> = \beta_o + K_\alpha lnE;$

[2]The third parameter - normalization factor – is not included in the formula. The reason is that each shower was normalized to 1. before the fit.

[3]The standard fitting procedure DFUNFT (D501 in CERNlib) was used. Please note : at rsgi machines it is available only as "double precision function", so its usage requires some accurate preparations.

$\sigma_\alpha = \sigma_{\alpha_o} + K_{\sigma_\alpha} lnE;$

$\sigma_\beta = \sigma_{\beta_o} + K_{\sigma_\beta} lnE.$

Therefore, the procedure of simulating the longitudinal profile is as follows (just a piece of code as an example to make it clear !) :

```
     ................
* -- one single gamma-shower profile

      cor_coef = 0.82

      alpha_av     = 2.017 + 0.525 * alog(Egamma)
      sig_alpha    = 0.910 - 0.074 * alog(Egamma)

      beta_av      = 0.303 + 0.049 * alog(Egamma)
      sig_beta     = 0.271 - 0.068 * alog(Egamma)

      call NORMCO(alpha, beta,
     &   alpha_av, beta_av, sig_alpha, sig_beta, cor_coef )  ! a correlated pair

* --- Check for stupid values ( gaussian distributions are broad ! )

      if(alpha.lt.0.1 ) go to 100
      if( beta.lt.0.02) go to 100
    ..................
```

Using the generated pair of parameters (α_i, β_i), the single longitudinal shower profile (as the function of depth in units of radiation length) is calculated using the above formula for $f_i(x)$.

This procedure is illustrated by Figures 6–8. In Fig.6, the distributions of pairs of correlated parameters, obtained from DFS, are presented. Figures 7 and 8 show the DFS–reproduced mean profiles and the showers profile fluctuations.

5 DFS: lateral distribution of EM showers.

The longitudinal profile of an EM shower is a function of one variable – depth t (in units of radiation length). The lateral profile f_T of a shower is a more complicated case, as it is the function of both the shower depth t and radius R : $f_T(t, R)$. The shape of the lateral distribution is changing as the shower develops deeper in the calorimeter [4], Fig.9.

[4]The lateral spread of a shower is mainly due to a multiple scattering of the electrons being produced during the shower development.

The discussion on the parametrization of lateral profile can be found in papers [8, 16, 17].

Traditionally, the lateral shower profile [5] is presented by the sum of two exponential functions. In an attempt to find the formula with least number or parameters to be fitted, we chose the formula :

$$f_T(t,R) = \frac{1}{2\lambda_R}\frac{R}{\lambda_R}^{\alpha_R/2-1}\frac{e^{-\sqrt{R/\lambda_R}}}{\lambda_R\Gamma(\alpha_R)},$$

(where t - depth in units of radiation length X_o).

Each single distribution (for each scintillator layer) cannot be fitted so easily as was done for longitudinal profiles. The reason is that the number of hits (and data points to be fitted) for each single histogram is small – so wide bins in R should be used, and several layers should be combined in one t–interval.

The variations of parameter λ_R are small, and for simplicity, it can be fixed to constant, so the lateral profiles can be described with only one free parameter α_R. The simulated lateral profiles are shown in Fig.10. There is good agreement between the DFS–, and the real (GEANT) distributions shown in Fig.9. The parameter α_R depends both on shower depth t and the particle energy E. These dependencies are linear, as shown in Fig.11.

Comment: The fluctuations of lateral profiles are simulated by the same method as being done for longitudinal profiles. The longitudinal parameters α_i, β_i and lateral parameter α_R are correlated. The details can be found in [16, 17].

6 EEMC response, resolution and number of "spots".

The stochastic nature of shower development lead to the fluctuations of the deposited energy in the EMC active layers. In a sampling calorimeter, the dominating factor is "sampling fluctuations", i.e. the fluctuations of the total number of electron and positron tracks crossing the sensitive planes [6].

In the Fast Simulator, the conversion from the deposited energy in the calorimeter to the measured fraction in active layers, should be performed. This means that the appropriate number of sampling points (spots) which simulate the energy hits in the active volumes of the calorimeter, should be distributed over the parametrized shower shape. The

[5] integrated over t !

[6] This is the reason why resolution $\sigma(E)/E$ is proportional to the inverse square root of the incident energy. The dependence of sampling fluctuations on the detector structure is a complicated but interesting question; see, for example, discussions in [27, 28].

suitable choice of the number N_{spot} of sampling points allows one to reproduce the observed fluctuations of energy in the active layers. The number of points can be rather accurately estimated as :

$$\frac{\sigma_E}{E} = \frac{0.16}{\sqrt{E}} = \frac{\sqrt{N_{spot}}}{N_{spot}},$$

where 0.16 (16%) is the known resolution of the EEMC [29]. This gives the number $N_{spot} \simeq 35$ "spots"/GeV (GeV – of energy of incident particle) in the active layers of the EEMC.

It is known [29], that the ratio between deposited energy in active layers and total deposited energy in EEMC is $E_{active-layers}/E_{total} \simeq 0.073$. Therefore, for the whole calorimeter (for both lead and scintillator layers), the number of spots $N_{spot} = 35 \times (1./0.073) \simeq$ **480 spots/GeV.** The spots are of equal energy, i.e. the energy of one spot (representing one hit in the calorimeter) is 2.08 MeV.

For each active layer of the EEMC, its depth t_i (in units of X_o) is known.

In DFS, the positioning of hits in active layers was performed in the following steps :

◇ The number of spots was calculated : $N_{spot} = 480 \times E_\gamma$.

◇ According to the simulated longitudinal shower profile, a relative weight w_i was assigned to each active layer (as its t_i is known) [7], and the total number of spots were redistributed between layers $N_{spot}i = N_{tot} \times w_i$.

◇ For each active layer, the $N_{spot}i$ spots were then distributed according to the lateral parametrization $f_T(t_i, R)$.

◇ Finally, each spot was *randomly* deleted (with the probability (1-0.073), or left (with the probability 0.073). This is the most important part of the procedure, as this allows one to introduce the correct energy fluctuations.

The DFS results are shown in Fig. 12. The simulated energy resolution is in good agreement with GEANT results, presented in Fig.1.

Comment: Before, we mentioned that the GEANT result is $\simeq$ 55 hits/GeV in active layers. This is larger than the 35 spots/GeV in DFS, because the energy distribution (E_{loss}) for GEANT hits has the clear rise toward zero, i.e. many GEANT hits have small energies. This is the reason why the number of spots (each of the same energy of 2.08 MeV) is smaller, than the number of GEANT hits.

[7] $w_1 + w_2 + ...w_{26} = 1$!

7 DFS : hadronic showers.

The number of hadrons in acceptances of BEMC and EEMC is comparable to the number of γ's. They pass through the EMC, give a signal and can interact inside the EMC.

The development of hadronic showers is a complicated process, and the simple approximations do not exist. The characteristic length of the hadronic shower development is the *nuclear interaction length* λ_I. For lead, $\lambda_I \simeq 17$ cm, that is larger than the total thickness of the calorimeter. This means that incoming hadrons *can* interact inside the EEMC, but also with a fairly high probability *might not*. Also, a hadronic shower (opposite to EM shower) will never deposit all its energy inside EEMC, as most of the secondary particles leave it. This is illustrated in Fig.13, where the distributions of deposited energy in the EEMC are presented. It is clearly seen that most pions leave only the minimal energy in the EEMC. Some others have an interaction inside the EEMC and hence the magnitude of energy fluctuations is large.

Several attempts are available in the literature on parametrizing the shower profiles in large hadronic calorimeters. The common parametrization [3, 23] looks like :

$dE = k[ws^{a-1}e^{-bs} + (1-w)t^{c-1}e^{-dt}]dx$, where

s = x/X_o depth in radiation length;

t = x/λ depth in absorption length;

a,b,c,d – parameters to be fitted, a=c ;

w, 1-w – relative weights; k – normalization constant;

a = a_o + $K_a ln(E)$, etc.

The first term describes the development of the electromagnetic part of hadronic showers (due to decays of π^o's and η's), the second term describes the pure hadronic component. The average number of secondary π's in hadronic interactions is small, so the fluctuations are large. As mentioned in [3], there is no satisfactory approach to simulate the fluctuations for the individual hadronic shower.

The typical hadronic profiles in the EEMC are presented in Fig.14. There is no hope to find any reasonable parametrization for the *individual* profile, as was done for EM showers. In DFS, the parametrization of hadronic showers was not implemented. The reasons will be explained later.

Comment: If one decides to parametrize the hadronic showers in the (E)EMC, this could be done in the following way. First, one again should prepare the special geometrical description of the calorimeter. The "test" calorimeter should be several times thicker than the real one. The standard estimate [23] gives for hadronic median length :

$x_{med} = (0.54 \cdot ln[E(GeV)] + 0.4)\lambda_o,$

$\mathrm{L}(95\%) = 2.5 x_{med} \quad \simeq 75$ cm.

This means that the "test" calorimeter should be about 1 meter long to obtain the full shower profiles. Practically, it means that one should made the geometrical description of the EMC consisting of about 120 lead and scintillator layers.
For hadronic showers, the number of hits per active layer is much smaller than for EM showers. To get the satisfactory fit for 5 parameters, several active layers should be combined to form one data point with relatively small statistical error.

The hard problem is the simulation of fluctuations in hadronic showers, as the *complicated* correlation matrix of parameters should be calculated from the data and subsequently simulated.

8 DFS : more improvements.

During the DFS tuning (and for DFS–simulated showers), the showers are assumed to have an origin at the very first layer of the calorimeter, at $t \simeq 0.X_o$. The origins of the real showers are distributed according to an exponential law with the attenuation length X_o or λ_I for electromagnetic and hadronic showers, respectively. When the profiles of the showers are simulated, they should be shifted according to these distributions [8].

If a particle enters the calorimeter at normal incidence, each active layer of the EEMC at depth t_i will contain only the hits corresponding to the part of longitudinal distribution $f_L(t_i)\Delta t$. The simulation of showers for other angles of incidence requires a more accurate

[8] For γ's, 7/9 X_o should be also added (the average conversion length).

procedure. In homogeneous media this looks simple : the simulated (at normal incidence) shower profile is rotated to corresponding angles in space, so an active layer, crossing the shower profile at an angle, will contain the hits corresponding to *different* t_i in the distribution $f_L(t)F_T(t,R)$. For homogeneous media, this could be done using simple geometrical considerations.

EEMC consists of alternating layers of "light" and "heavy" materials. The presence of light material (scintillator) led to the broadening of the lateral shower profile. The larger the angle of incidence, the larger the effective thickness of scintillator (as seen by the incoming particle). There is no common formulae or simple receipt on correcting the lateral broadening of the shower. In all the references the discussion of this problem is usually avoided.

In DFS, this problem is not so terrible, as the DFS was tuned already using lateral profiles from the active layers, i.e. the broadening of lateral profiles was accounted for from the very beginning, and fitted values of parameters reflect this phenomena (at $\theta = 0^o$).

For the EEMC, the maximal angle of incidence is $\theta = 38^o$. For this angle, the unaccounted relative lateral broadening of the EM shower could reach 20%.

9 FSim and GEANT : the limits.

Some showers cannot be simulated accurately in DFS.

• If the electron or γ has the energy $E_{e,y} < 1$ GeV, the fluctuations of the shower shape are relatively large, and the shower profile seriously deviates from the known parametrizations [9].

• If the shower axis is close to the boundary of the tower, to a gap, crack or wall, the shower development could be seriously perturbed, as well as the calorimeter response. For these showers, all above parametrizations are incorrect. The characteristic radius of an EM shower is $R_{Moliere} \simeq 1.6$ cm, and distortions of the shower profile become sufficient if the distance between shower axis and the boundary is less than 2 cm. As it was shown in [29], about 20% of all EM showers in the EEMC are distorted due to their position close to the boundaries.

[9] As the particle propagation starts deviate from Rossi Approximation B .

• The characteristic radius for hadronic showers is much large then $R_{Moliere}$. The lateral profile of hadronic showers is described as the sum of two gaussian–like curves with the characteristic FWHM $\sim 0.3\lambda_I$ and $\geq \lambda_I$. Moreover, the width of a hadronic shower grows linearly with the shower depth. This means that with a high probability a hadronic shower will occupy more than one tower of the calorimeter [10], and the influence of the boundary effects will be significant.

Now, we would like to discuss an important question :

How fast could the Fast Simulator be ?

To estimate the relative part of the CPU time used by GEANT for simulations of showers in both the EEMC and the BEMC, the following test was performed. The same AA–event with the multiplicity of 1000 tracks was processed through GEANT, each time in a different geometrical configuration.

#1. Full geometrical descriptions of all STAR subsystems : SVT, TPC, CTF, VPD, XTP, BEMC, EEMC, MAG were used. All electromagnetic and hadronic showers were fully simulated in GEANT. The GEANT simulation of the complete event *in the full geometry* took **1200** seconds. The simulated event is shown in Figure G1.

#2. At the next step, we excluded both electromagnetic calorimeters : BEMC and EEMC. We left only the EEMC and BEMC envelopes filled with air – so no showers were produced in EMC's. To avoid particle cascading [11] in the iron yoke of the magnet, it was also replaced by the empty envelope. GEANT simulation of the event in the configuration without both BEMC and EEMC took **420 seconds**. The simulated interaction is shown in Figure G2.

A Comment. Of course, the comparison of #1 and #2 is not quite correct. Looking at Fig.G1, there are clearly some showers in the magnet. In case #2, the BEMC, the EEMC *and* the magnet were excluded, but all of the CPU time reduction was attributed to the BEMC and EEMC not being present. This means, that we took off from GEANT more showers, then could be, in principle, processed by the Fast Simulator. Therefore, the possible estimated gain from FSim is not $1200/420 \simeq 3$, but even smaller.

[10] Which has the typical size of a tile $16 \times 12 cm^2$.

[11] ...which before were cascading in the BEMC or the EEMC.

Nevertheless, the calculations for the Case #1 were redone, for full STAR configuration, *excluding magnet*. The CPU time used was almost the same 1200 seconds, so our comparison of Cases #1 and #2 stays reasonable.

#3. Though at the previous step EEMC, BEMC and magnet were excluded, GEANT spent its time tracing the particles through empty volumes, until the particle left *CAVE*. At the third step, the radius of the *CAVE* was reduced to avoid useless tracing. This is illustrated by Figure G3. Now, the processing of the whole event took **310** seconds [12].

These estimates lead us to the conclusion : even *if* the *ideal* Fast Simulator for BEMC and EEMC could exist, the simulation of a complete event in full STAR geometry could be accelerated no more than (1200'/310') $\simeq$ **4 times**. It is the best estimate, because we assumed that the Fast Simulator can accurately simulate both electromagnetic and hadronic showers, do it also in the regions of cracks and walls, and do it *very* fast.

The more realistic estimate gives the smaller number :

1. The fast simulator cannot accurately reproduce the showers of particles with energies less than 1 GeV. The number of "slow" particles is not small.
In Fig.15, the spectra of γ's and $\pi^{\pm}$ in AuAu–interactions at $\sqrt{s}$ = 200 A GeV, are shown. Only 25% of γ's have the energy $E_\gamma > 1$ GeV, but the simulation of showers for these 25% of γ's takes 80% of all time required for simulation of electromagnetic showers [13].
For $\pi^{\pm}$ mesons, the particles with $E_\pi > 1$ GeV include 45% of all $\pi^{\pm}$'s.

Therefore, whether low–energy particles will be processed in GEANT or simulated in Fast Simulator, the maximal possible gain in CPU time is about 20%.

The reasonable solution would be : not to simulate the low–energy particles in the Fast Simulator, but to process them through GEANT and get results one can trust.

2. An electromagnetic shower requires more time for simulation in GEANT, than a hadronic shower of the same energy. The ratio is : $T_\gamma^{GEANT}/T_\pi^{GEANT} \simeq 5$.
In simulated AuAu–events at $\sqrt{s}$ = 200 A GeV, the number of charged pions and the

[12] This was done on *sirius* SuN station. The absolute values of CPU time can differ for different computers, though the ratio between them shall be the same .

[13] The simulation time an for EM shower is roughly proportional to E_γ.

number of γ's (including those from π^o decays) are of the same order :
$N_\gamma(E > 1GeV)/N_\pi(E > 1GeV) = 0.65$.

This leads us to the conclusion : whether the hadrons will be processed in Fast Simulator or not, the possible gain in CPU time is small (about 15%). It would be reasonable not to simulate the hadronic showers in the Fast Simulator *at all.* This would allow one to avoid all the difficulties of approximating the hadronic showers, and to obtain accurate GEANT results.

3. The ineffective regions of the EEMC, where the development of the shower is seriously distorted by the boundary effects and cannot be reproduced by the Fast Simulator, are 20% of all the EEMC volume. Therefore, it would be reasonable not to try to simulate these showers in Fast Simulator, but process them through GEANT.

Summary :

All hadrons should be processed through GEANT in order to obtain results we could believe in.

The low–energy γ's should also be processed through GEANT.

20 % of all particles cannot be simulated in the Fast Simulator due to the boundary effects.

These assumptions lead to a decrease of the Fast Simulator efficiency, and the estimate of total CPU time gain (GEANT+FSim vs GEANT) is *only* $\sim$ *2.2 times.*

Comment 1: If the simulations are performed for the BEMC or EEMC *only*, without other STAR subsystems, the gain in CPU time due to the Fast Simulator could be significant. But the mass production of Monte Carlo events will be done with the full STAR configuration.

Comment 2: The serious acceleration of the simulations in GEANT could be done using another technique : increasing the standard GEANT energy cuts. This requires special study, as increasing the cut–off energies could lead to some decrease of accuracy in the simulation results.

10 FSim : summary and conclusion.

In this paper, the results on the EEMC Fast Simulator prototype performance are presented. Using standard techniques, the electromagnetic showers were simulated, and the results are seen to agree quite well with GEANT calculations.

At the same time, the Fast Simulator procedure necessarily has several limitations. Some particles should not be simulated in the Fast Simulator but should be processed through GEANT. Otherwise, the simulation results cannot be reasonably reproduced and trusted.

The maximal possible gain in CPU time due to the EMC Fast Simulator is estimated as 2.2 times only (for full STAR configuration in GEANT). The further increase is impossible without similar Fast Simulation procedures for other STAR subsystems.

Another solution, such as increasing the GEANT cut–off energies, might solve the problem of accelerating the GEANT calculations in a less expensive and complicated way.

* * *

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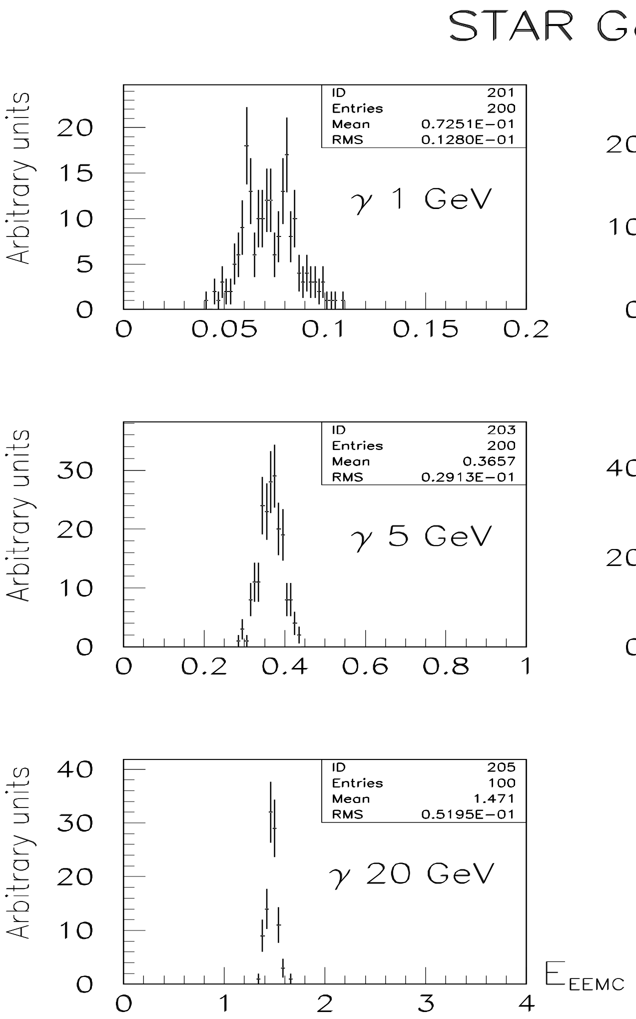

Figure 1. *Deposited energy distributions in the EEMC from GEANT–simulated electromagnetic showers.*

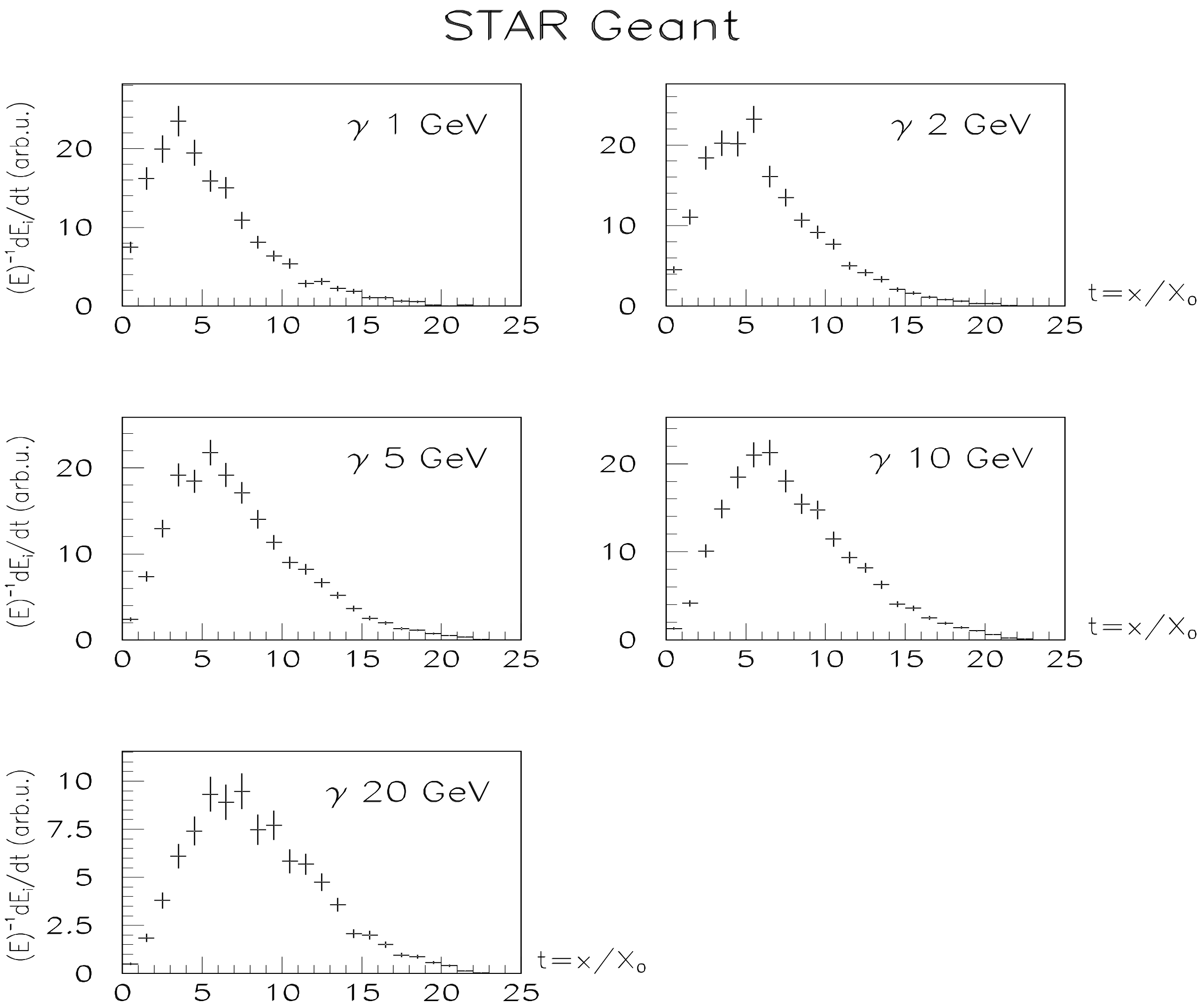

Figure 2. *Mean longitudinal profiles of electromagnetic showers in the EEMC. Profiles are shown as a function of depth t (t – in units of radiation length).*

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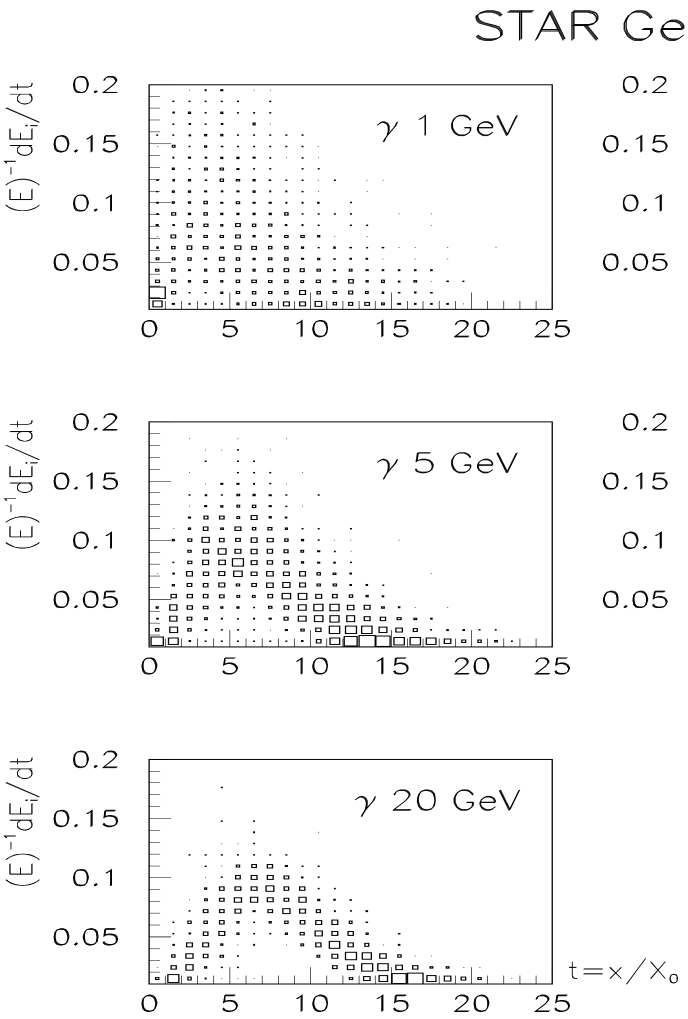

Figure 3. *Longitudinal profiles of electromagnetic showers in the EEMC. Profiles are shown as a function of depth t (t – in units of radiation length). As comparing to Figure 2., this picture gives the idea about the magnitude of fluctuations of EM showers. As the vertex positions of the simulated showers are different, the simulated showers were shifted to common point t=0 at Figures 2 and 3.*

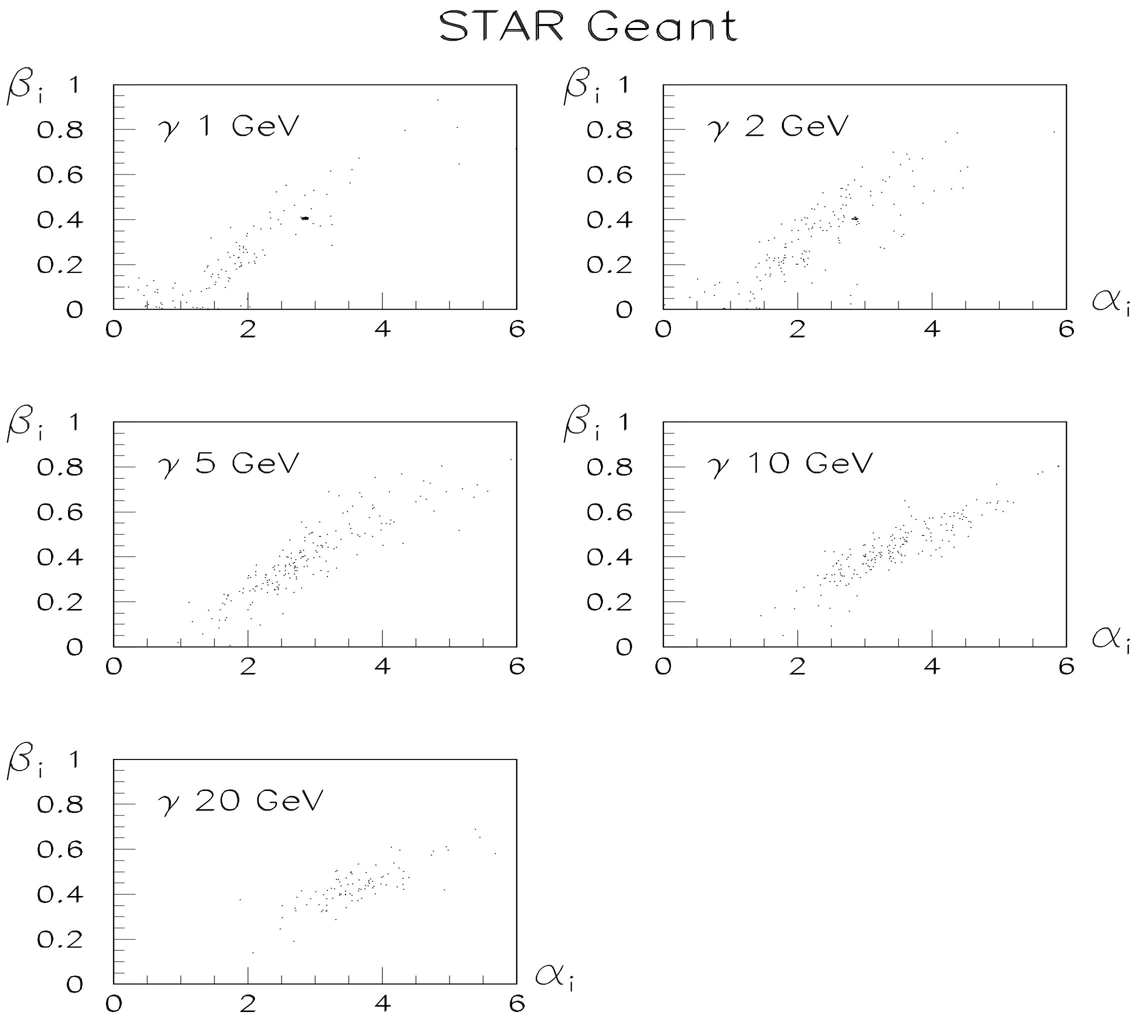

Figure 4. *Each single longitudinal profile of electromagnetic showers is described by two parameters : α_i and β_i. The picture shows the correlation between these parameters for showers initiated by γ's of various energies.*

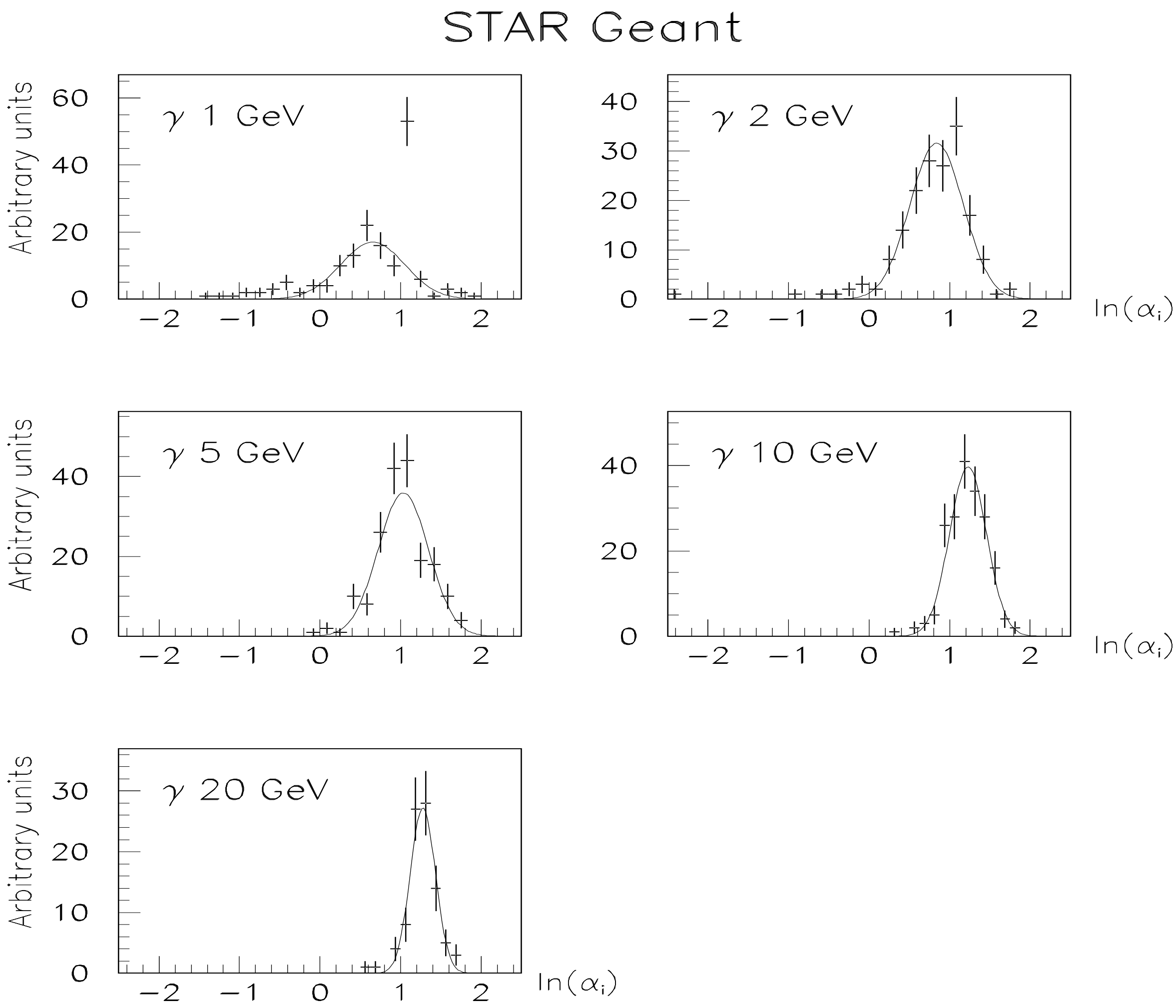

Figure 5a. *Distributions of ln(α_i). For the Fast Simulator, each distribution can be approximated by gaussian curve.*

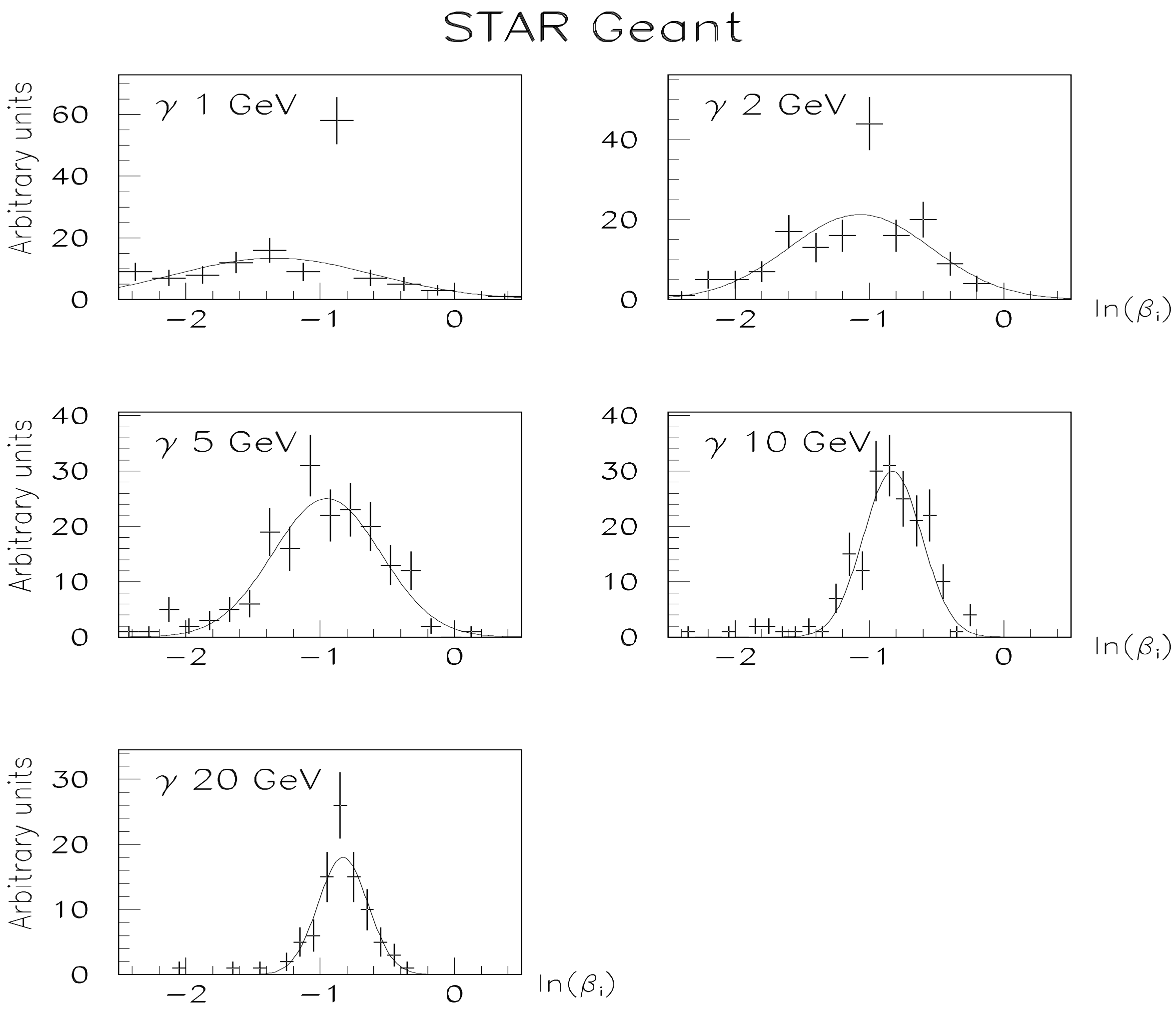

Figure 5b. *Distribution of ln(β_i). For the Fast Simulator, each distribution can be approximated by gaussian curve.*

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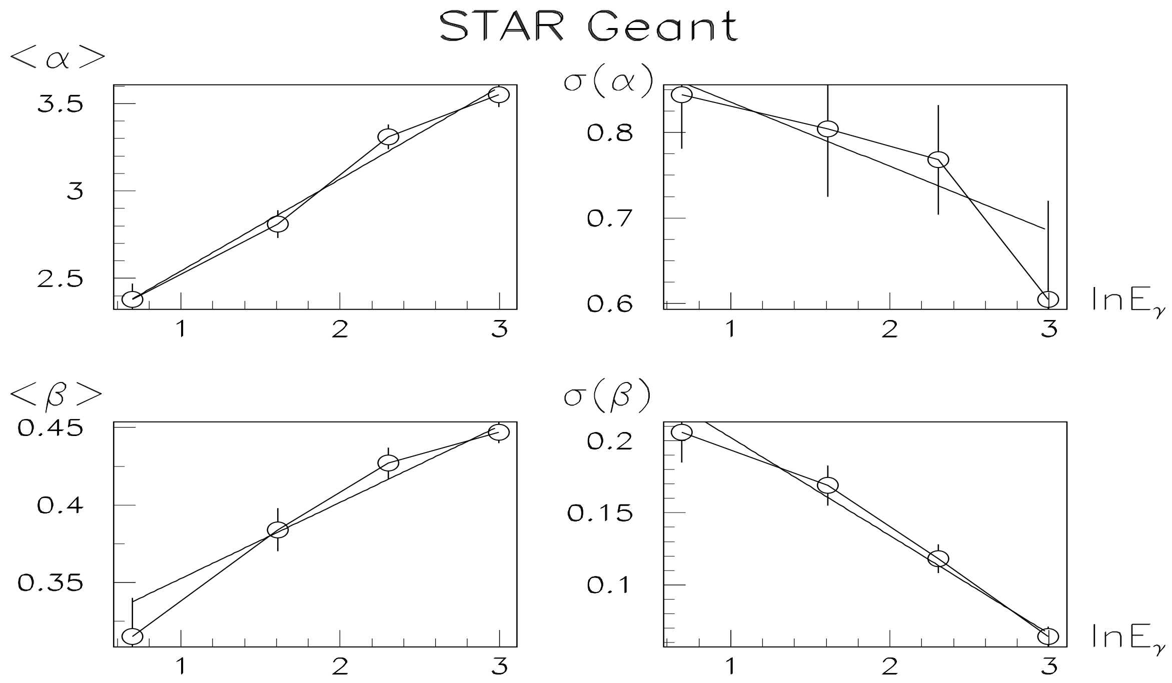

Figure 5c. *Dependences of parameters α and β and their variations are shown as linear functions of ln(E_γ). The data points for E_γ=1 GeV are excluded from the consideration.*

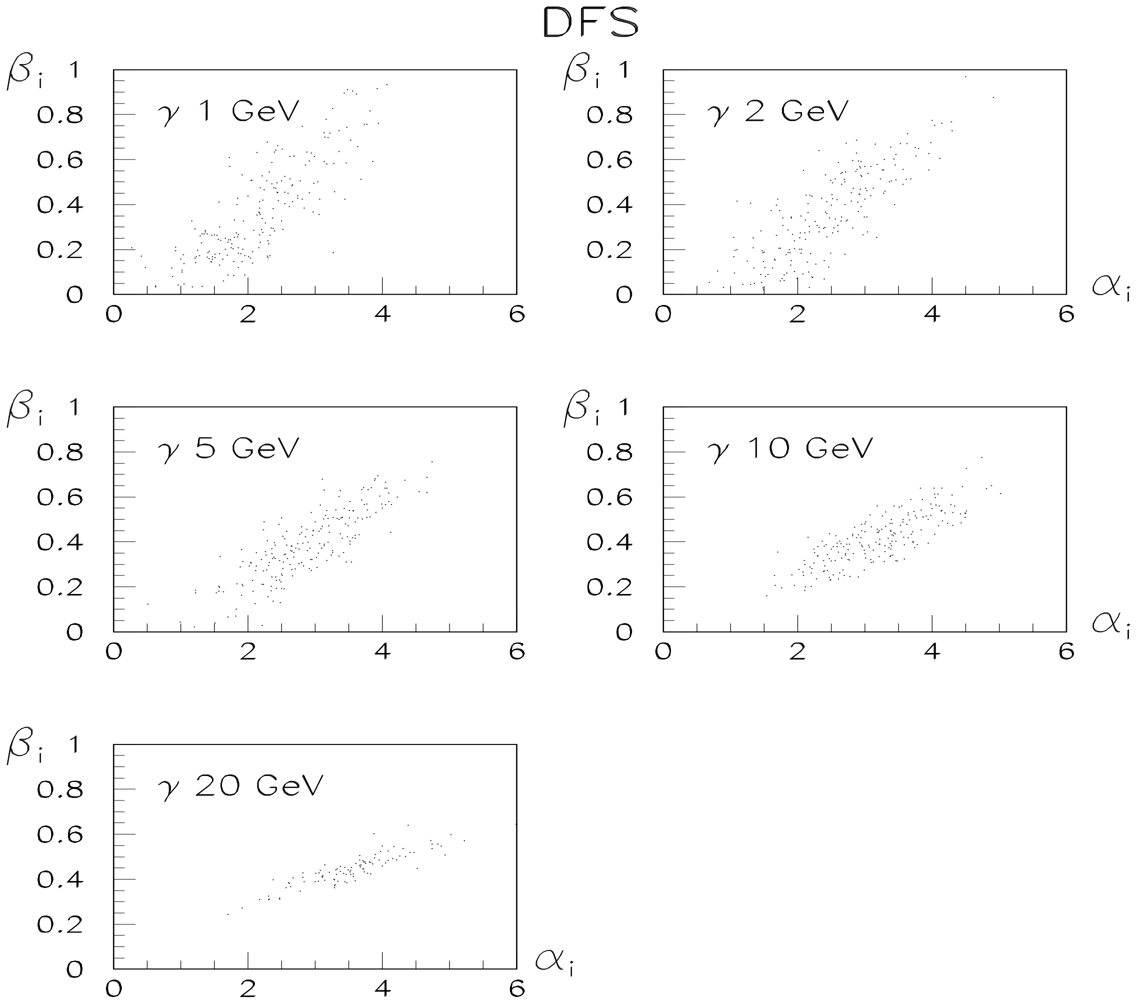

Figure 6. *The distributions of pairs of correlated parameters (α_i, β_i). Each pair of parameters is used to simulate a single longitudinal profile of EM shower in DFSim.*

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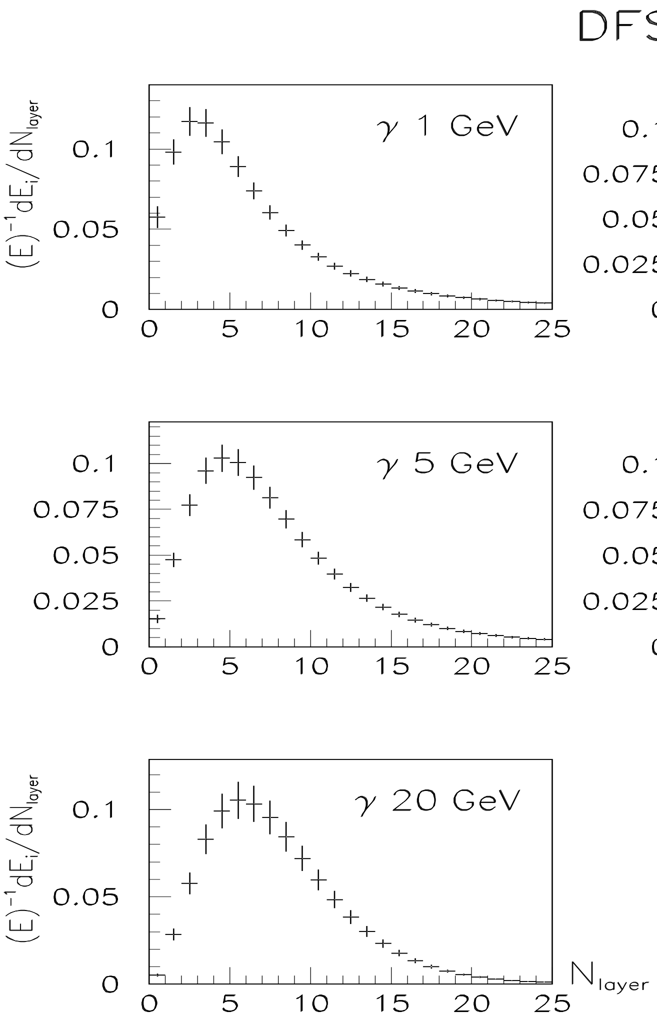

Figure 7. *Mean longitudinal profiles of electromagnetic showers in the EEMC. The individual profiles were simulated in DFSim.*

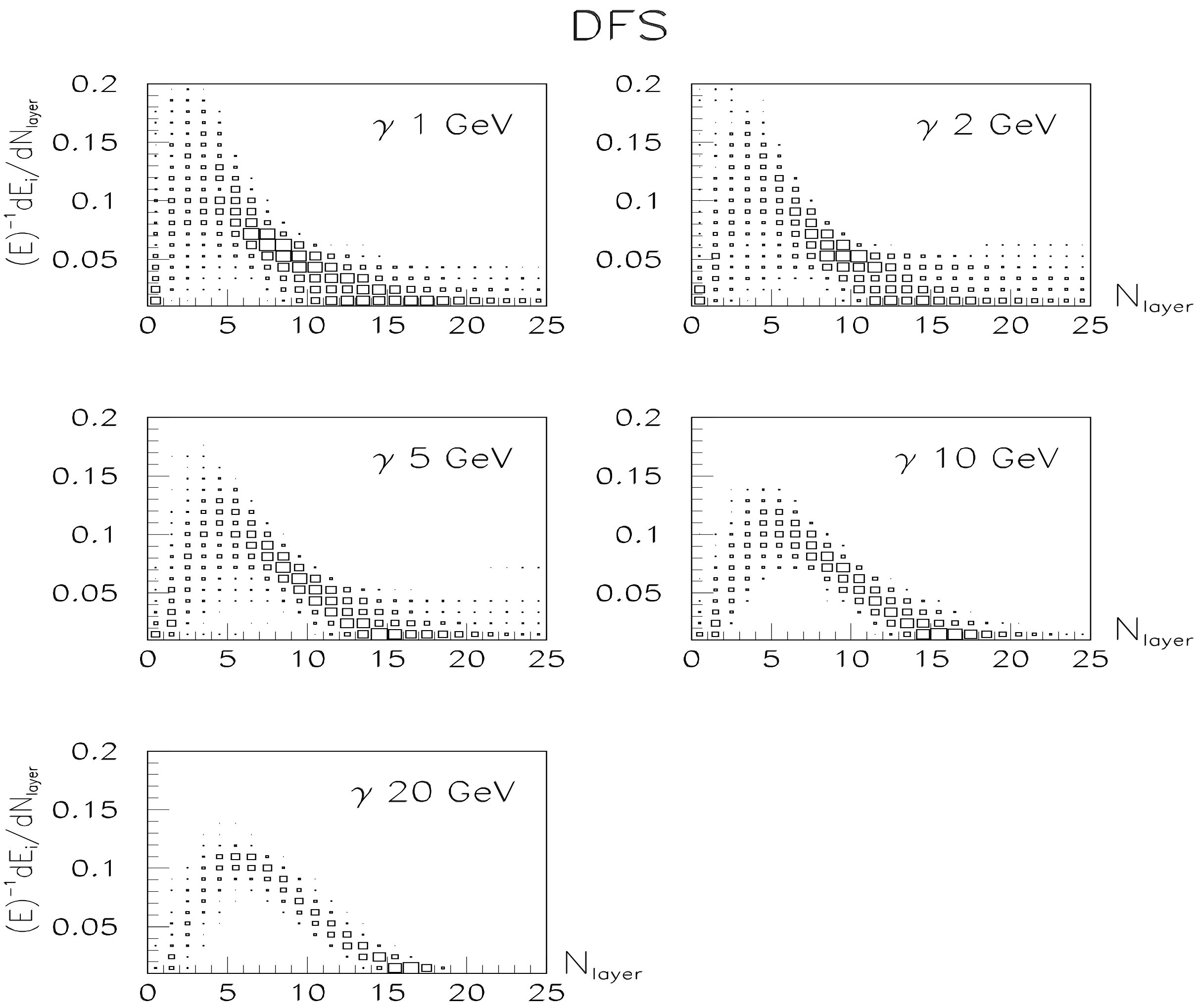

Figure 8. *The same as Figure 3. – Longitudinal profiles of electromagnetic showers in the EEMC. Individual profiles were simulated in DFSim. The distribution at E_γ=1 GeV deviates from the original one at Figure 2.*

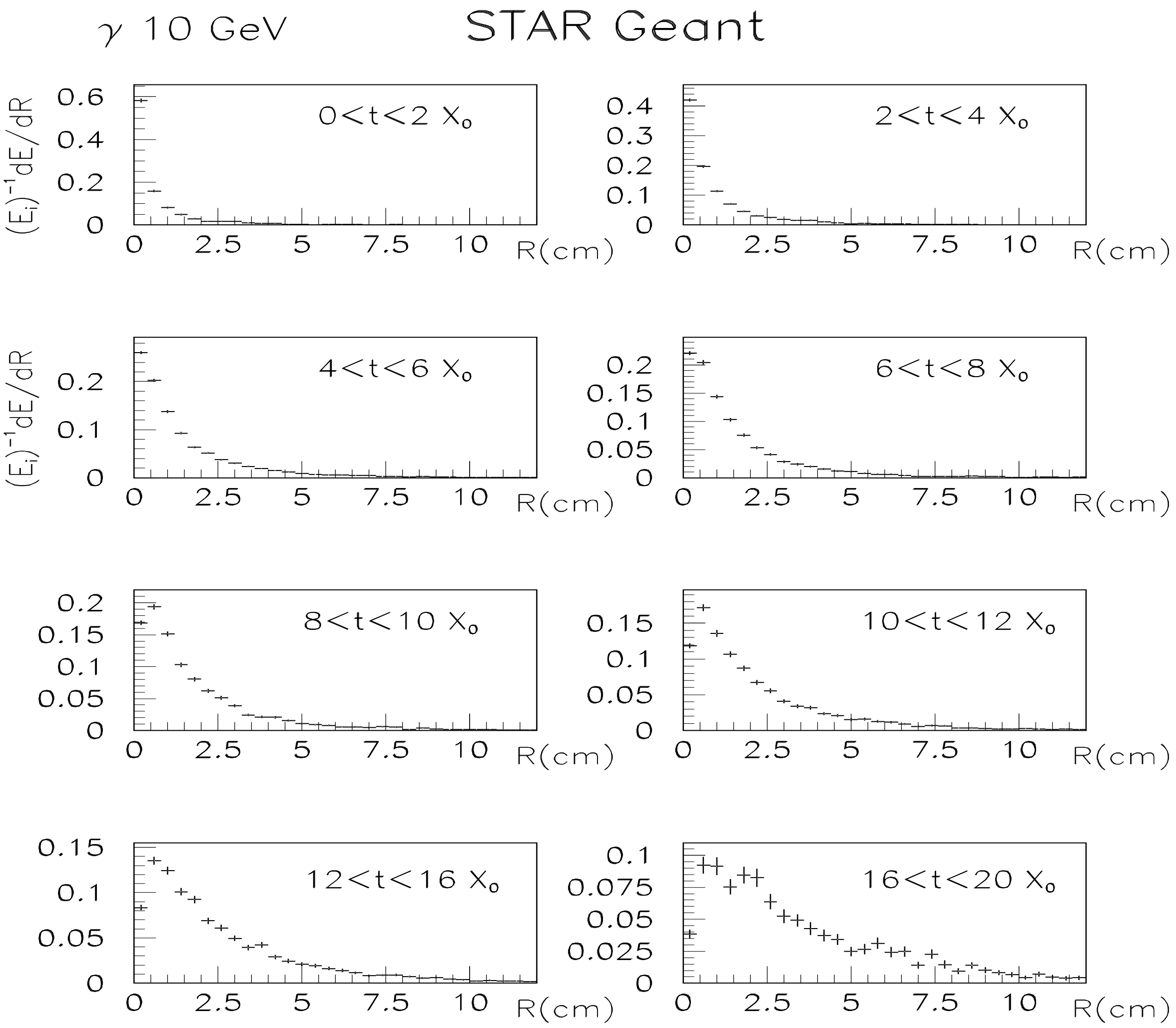

Figure 9. *Lateral distributions of electromagnetic showers in the EEMC for E_γ=10 GeV (GEANT results). Lateral profiles are shown in various intervals in depth t (in units of radiation length).*

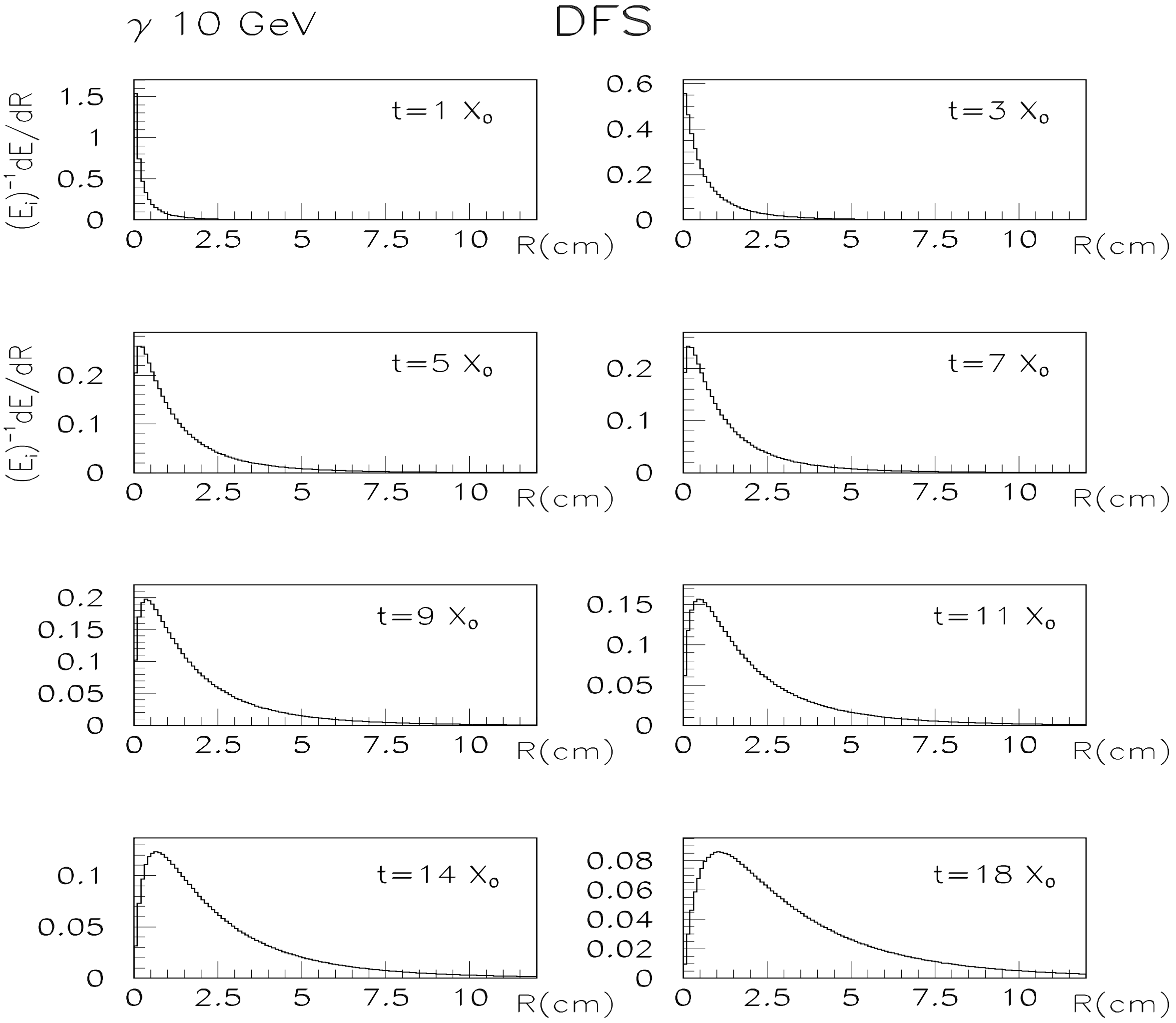

Figure 10. *Approximations of lateral distributions of EM showers in the EEMC for E_γ=10 GeV (DFSim results).*

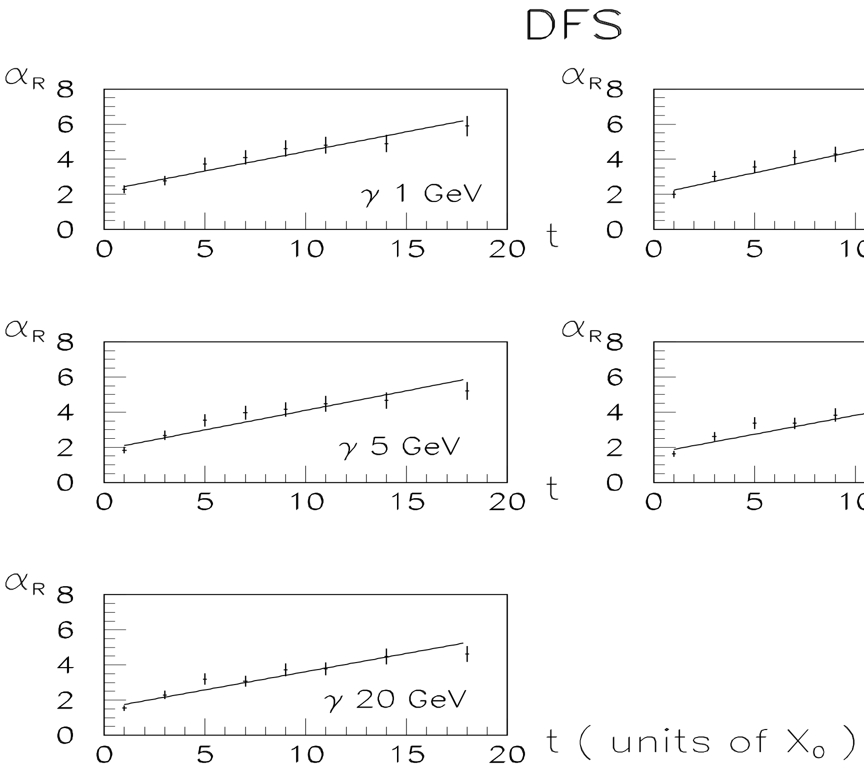

Figure 11. *With a very good accuracy, lateral profiles of EM showers could be approximated using only one parameter α_R. The parameter α_R is a linear function of shower depth t (in units of radiation length). The slopes are slightly depend on E_γ.*

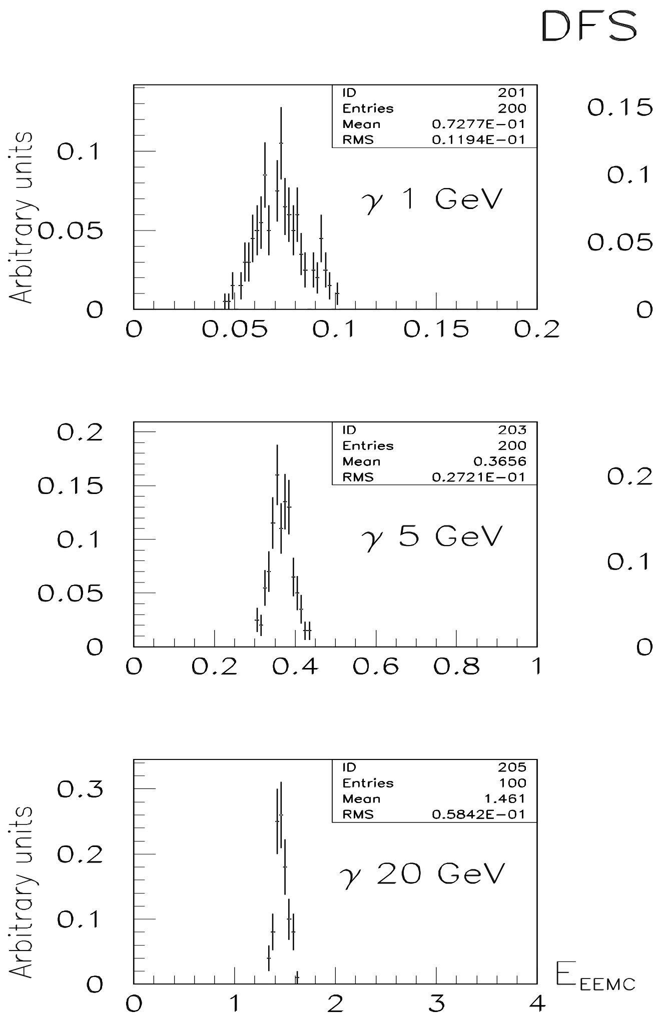

Figure 12. *Distributions of deposited energy in the EEMC. The distributions were obtained from DFSim. They are in a good agreement with the original results from Geant simulation (see Figure 1.). The EEMC resolution is quite well reproduced.*

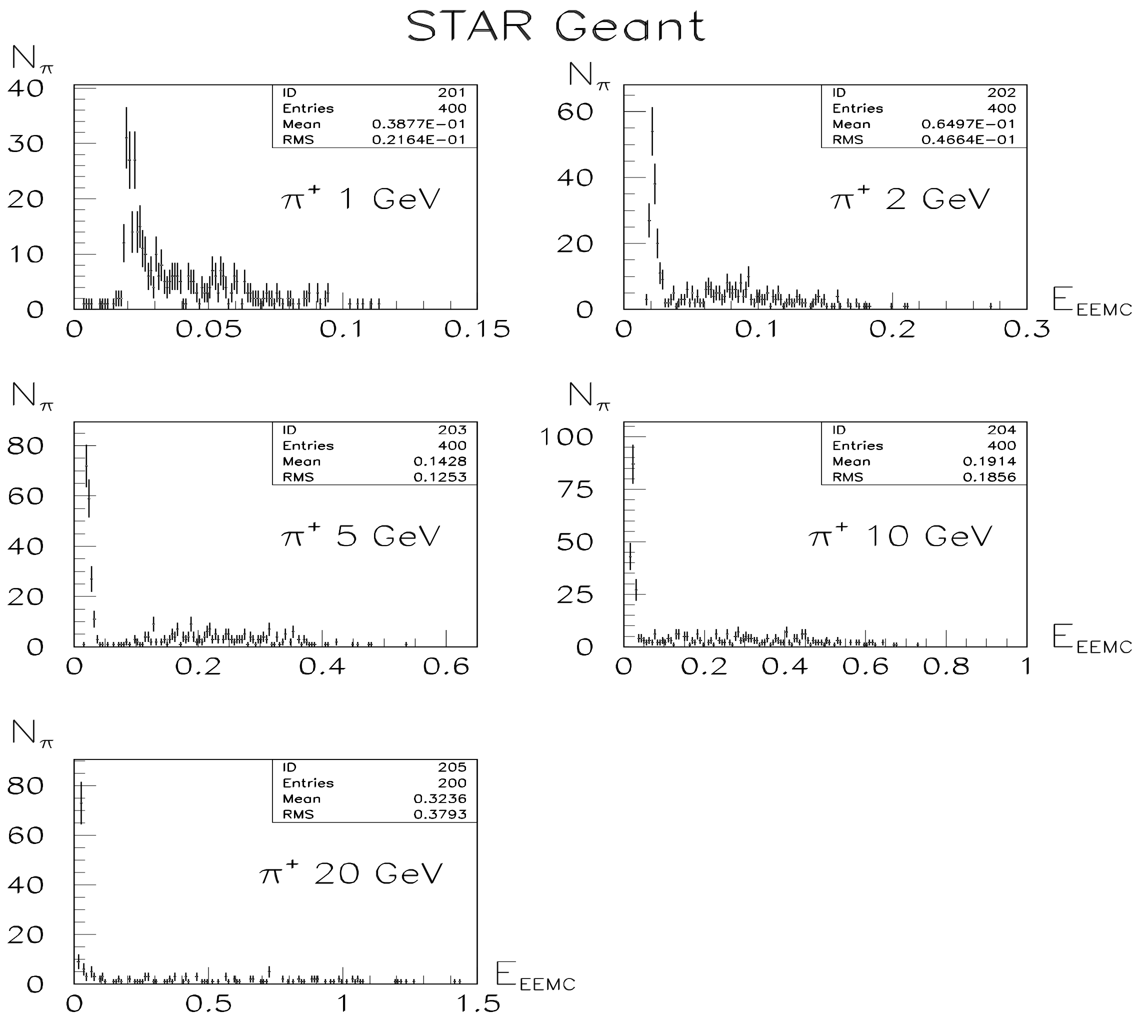

Figure 13. *Distributions of deposited energy of hadronic showers in the EEMC. Most pions leave only the minimal energy into EEMC. The broad tails – are the results of hadronic interaction in EEMC. The magnitude of energy fluctuations is much higher than for EM showers (see Figure 1.).*

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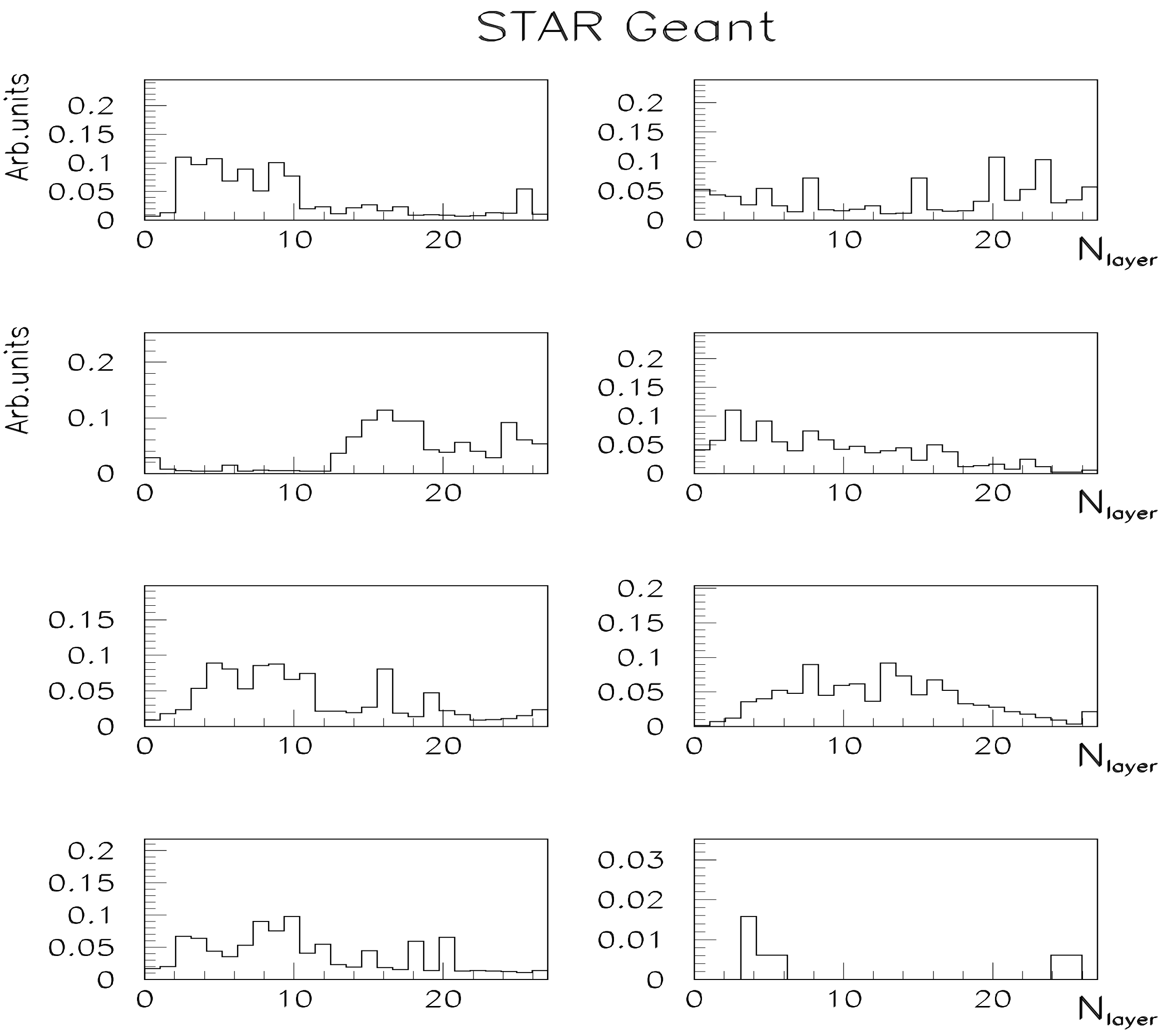

Figure 14. *Profiles of hadronic showers in the EEMC. These are the good examples , – when pions have an interaction inside the EEMC, and showers start close enough to the first EEMC layer. In most cases, the profiles look much poor (see lower right picture). Most of the hadronic energy is dissipating somewhere outside the EEMC.*

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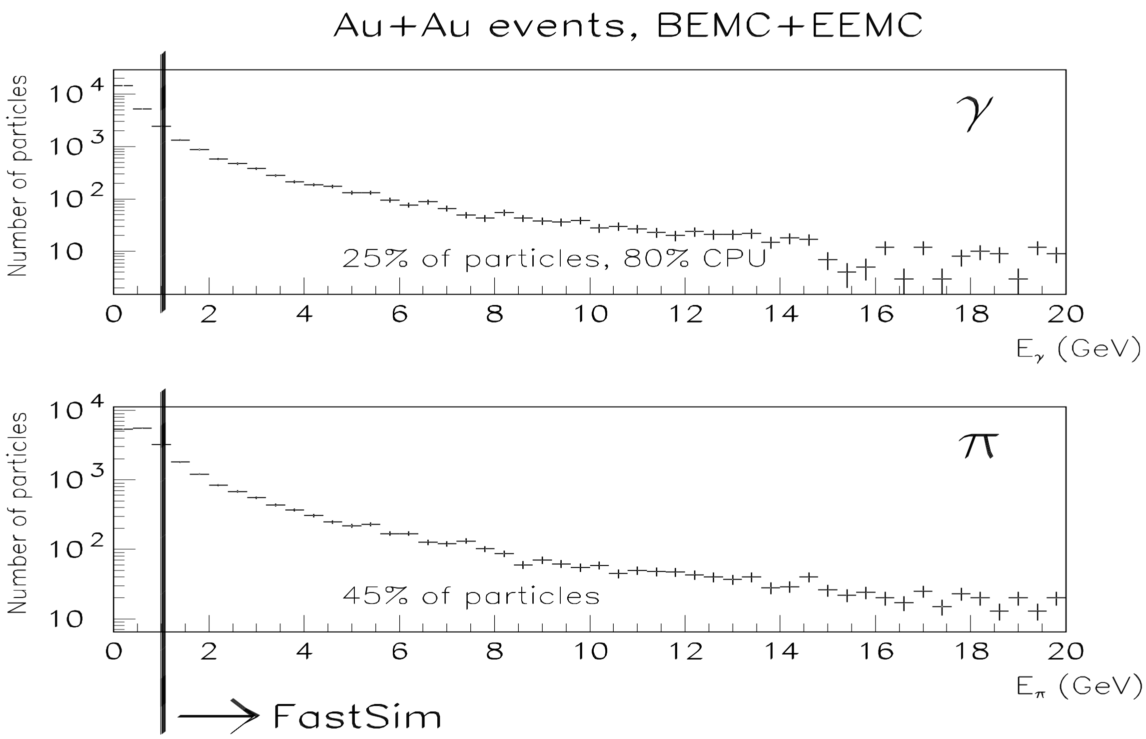
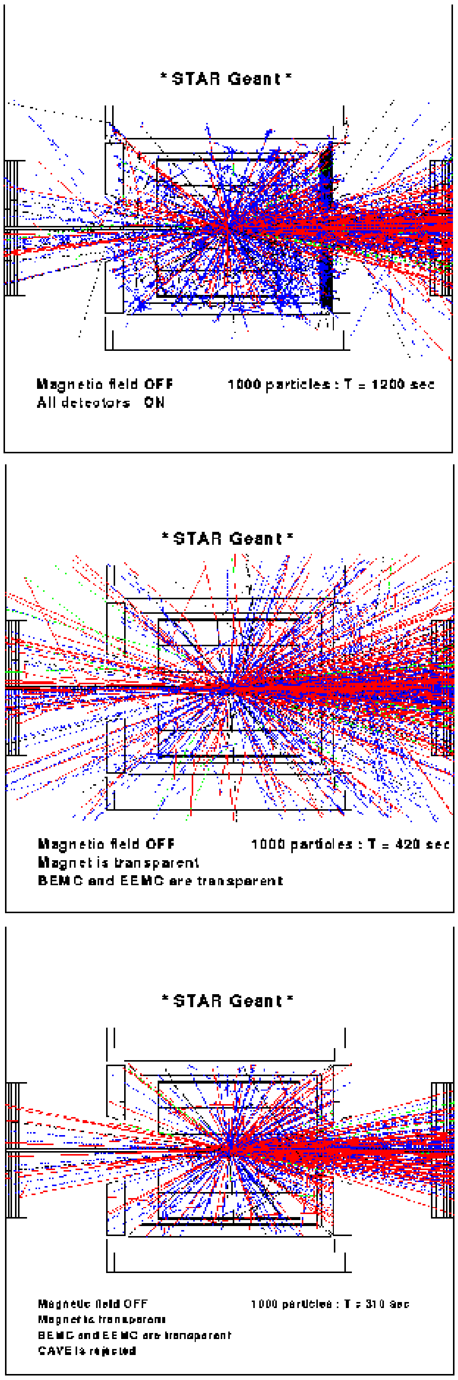


Figure 15. *Spectra of charged pions and γ's (including those from π^o decays) in acceptance of BEMC and EEMC.*

$N_\gamma(E > 1.0\ GeV) = 25\%$ *of all* γ*'s.*

$N_{\pi^\pm}(E > 1.0\ GeV) = 45\%$ *of all* $\pi^\pm$*'s.*



Figures G1, G2, G3. *AA–interaction (1000 tracks) is simulated in full GEANT. Various geometrical configurations are used, as explained in the text.*
The full–scale pictures could be copied from ~medved/public/fsim/pic_geant_1.ps (also pic_geant_2.ps and pic_geant_3.ps) at RHIC cluster.