Status of ATLAS liquid argon calorimeter simulations with GEANT4

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Abstract

We present the status of ATLAS liquid argon electromagnetic calorimeter and hadronic end-cap calorimeter simulations with the GEANT4 toolkit. Comparisons with test beam data and GEANT3 simulations are performed. The first experience of "accordion" calorimeter implementation in GEANT4 is discussed. A new type of GEANT4 volume is under investigation.

Keywords: simulation,calorimeter,ATLAS,GEANT4

1 Introduction

The GEANT3.21 [1] system of detector description and simulation tools was used to design and optimize the ATLAS detector for the Large Hadron Collider (LHC), and to develop and test the reconstruction and analysis programs. In 1999 we started evaluating a new simulation package, the GEANT4 toolkit [2], based on advanced software engineering techniques and object-oriented technology.

This status report describes the first high-statistics study of the ATLAS hadronic end-cap calorimeter simulations and the first implementation tests of the ATLAS electromagnetic barrel calorimeter with GEANT4.

Most of the simulations presented in this paper were performed with version GEANT4.0.1. A few runs were re-done with the version GEANT4.1.0, released in December 1999, and no significant difference in results was noticed.

2 Hadronic end-cap calorimeter

Each hadronic end-cap calorimeter (HEC) consists of two independent wheels (assembled from parallel plates), of outer radius 2.03 m [3]. The first wheel is built out of 25 mm copper plates, while the second one uses 50 mm plates. In both wheels the 8.5 mm liquid argon (LAr) gap between consecutive copper plates is equipped with three parallel electrodes. The geometries of the full HEC and of the HEC test beam set-up [4] have been described using the standard set of GEANT4 (G4) shapes in the same manner as in GEANT3 (G3).

When comparing G4 with G3 one should take into account the difference in cuts on particle tracking and production. In G3, there are tracking cuts given in energy units, which can be redefined individually for a given tracking medium. In G4, there is no tracking cut: once created, the particles are tracked down to zero kinetic energy. There is, however, a cut in G4 on particle production: a threshold for producing secondary particles expressed in range, which is universal for all media (though it can be redefined individually for some particles and some media). This range cut is converted to an energy cut for each kind of particle and for each material used in the detector description.

We have used four different values of the range cut (0.5, 1.0, 2.0 and 4.0 mm) to investigate its influence on G4 simulation results. The standard ATLAS set of cuts has been used in the G3 simulations (those relevant for EM showers are CUTGAM = CUTELE = 0.1 MeV).

Simulations for positive muons have been performed for one energy $E_\mu = 120$ GeV, with statistics of 50 000 events for each value of the range cut [5]. The energy deposited by a muon in different read-out segments of the HEC has been studied. The ratios between the mean energy in a read-out segment and the mean energy in the whole calorimeter are given in Table I. G4, as well as G3, described the test beam (TB) data well within error bars (which are around 0.01 for the values in Table I).

Table I: The ratio between the mean energy deposited by a muon in a read-out segment and the mean energy deposited by a muon in the whole HEC.

	Segment 1	Segment 2	Segment 3	Segment 4
TB HEC	0.180	0.416	0.196	0.207
G3	0.175	0.413	0.205	0.207
G4, 0.5 mm	0.177	0.408	0.207	0.208
G4, 1.0 mm	0.178	0.408	0.210	0.205
G4, 2.0 mm	0.180	0.403	0.209	0.207
G4, 4.0 mm	0.177	0.413	0.206	0.206

Simulations have also been made for positrons for each of the range cuts given above, and for different energies, $E_e = \{20, 60, 80, 100, 119, 147, 193\}$ GeV, with statistics of 1000 events in each case [5]. Checking the linearity, we found that the residuals of linearity are inside a bound of $\pm 0.1\%$ for both G4 and G3. The simulation of different energies allowed investigation of the energy dependence of the resolution. The energy resolution values for G4, G3 and TB data are shown in Fig.2 together with standard quadratic sum fits $\sigma/E = a/\sqrt{E} \oplus b$. The values of fit parameters are given in the Table II.

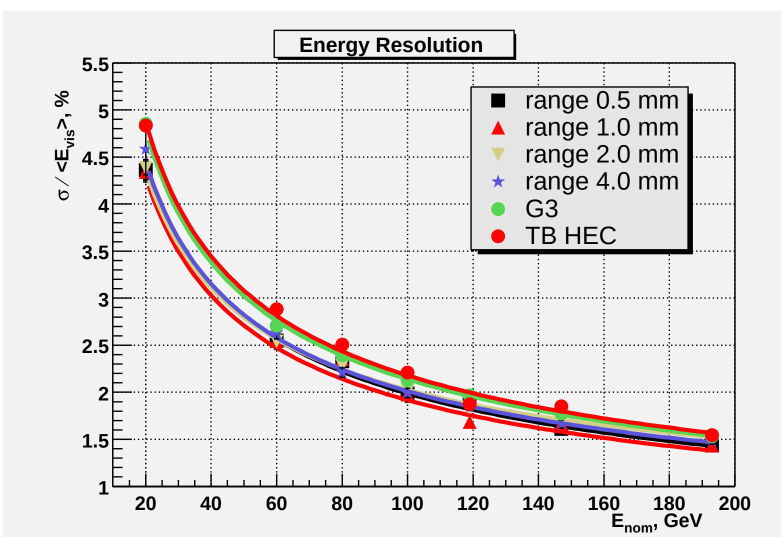

Figure 1: Comparison of the energy resolutions. The solid lines show the result of the fit.

Table II: The energy resolution fit results

	Sampling term a (%)	Constant term b (%)	χ^2/N$_{d.f.}$
TB HEC	21.79 ± 0.11	$0. \pm 0.02$	25.8/5
G3	21.37 ± 0.09	$0. \pm 0.03$	4.9/5
G4, 0.5 mm	19.87 ± 0.20	$0. \pm 1.$	4.2/5
G4, 1.0 mm	19.16 ± 0.14	$0. \pm 1.$	36/5
G4, 2.0 mm	19.25 ± 0.32	0.6 ± 0.1	1.8/5
G4, 4.0 mm	19.82 ± 0.55	0.34 ± 0.26	1.6/5

While G3 describes the TB data quite well, the results from G4 are below both the TB data and G3 for all values of range cut. The investigation of this difference is being pursued.

3 Electromagnetic calorimeter

The shapes of the plates in the ATLAS highly granular EM calorimeters are much more complicated then the HEC plate shape [3]. Twisted trapezoids were used in the G3 description of the end-cap EM calorimeter with a so-called 'Spanish fan' geometry. Such twisted trapezoids are not included in the standard set of G4 shapes. However the accordion-like plates of the barrel EM calorimeter can be constructed from parts of tubes and non-twisted trapezoids. We have investigated three versions of the barrel accordion geometry description. Each of them describes the calorimeter in full detail (as in the official ATLAS G3 simulation model used to-date).

The first one - STATIC GEOMETRY [A] - describes the two basic accordion plates (absorber and read-out electrode) as a set of standard pieces. It needs 64 such pieces for one absorber plate and 31 pieces for one read-out electrode. All pieces for the 2×1024 barrel plates are positioned in mother volume filled with liquid argon. About 110 Megabytes of memory are required to implement the full barrel geometry in this version. The CPU time is 9.5 seconds$\times$SPECint95/GeV, close to the speed of G3 barrel accordion simulations.

Trying to decrease the amount of required memory, we investigated a second geometry description - PARAMETERIZED GEOMETRY [B] - which uses a specific method from G4: the solid volume's type, dimensions, material, and transformation matrix can all be parameterized as a function of the copy number. The user implements the desired parameterization function and the program computes and updates automatically at run time the information associated to each physical volume. Here a set of about a hundred parameters is enough to provide G4 with the shape and position of each piece of the absorber and electrode plates of the barrel. The CPU time, however, is about 1500 seconds$\times$SPECint95/GeV. In this version, volumes in the vicinity of any hit are recalculated each time by G4; this explains the huge increase in CPU time.

The memory required in version [A] is so large because each piece is treated as if it has unique shape and position. This approach is justified if all volumes indeed have different shapes and sizes. But the active part of any calorimeter is usually a quite regular structure. By design any calorimeter consists of a number of similar cells. The mechanical structure which supports this logical subdivision also consists of the similar elements repeated many times. To navigate in such a regular surrounding one may used specialized algorithms which can be more effective than the general approach. This new idea is implemented in the third version - TAILORED GEOMETRY [C] - of the barrel description. A new type of solid, G4Accordion, is introduced, since the G4 design "allows users to describe any solid they desire"[6].

One instance of the G4Accordion class describes all the thick absorbers at once, a second instance describes all thin absorbers, and a third instance describes all read-out electrodes. For example, all thick absorbers are described as parts of one solid volume positioned by G4PVPlacement as a physical volume in a mother volume filled with LAr. The parts of this physical volume are disconnected in space; however from the G4Navigator point of view, they represent all together just one physical volume with the same material in all its parts. Only three volumes: thick absorbers, thin absorbers and read-out electrodes are used to describe the whole regular part of the barrel accordion. As a result, version [C] requires only 8 Megabytes of memory to describe the entire barrel calorimeter. A geantino scan was used to check that the geometry of version [C] is equivalent to the geometry of version [A]. The CPU time for version [C] is currently 11.5 seconds$\times$SPECint95/GeV, and optimization of this version is continuing. CPU profiling of these two versions shows that voxel navigation routines are responsible for a large fraction of the processing time in version [A], whereas member functions of the G4Accordion class are among of the most CPU intensive components of version [C].

The energy deposit in the LAr is 17.3 - 17.4 % of the initial energy of the EM shower for all three G4 versions. For comparison, the corresponding energy deposit in LAr was 17.1% with the last GEANT3.21 version of G3. The G4 results on energy resolution of EM barrel calorimeter (for 10 GeV EM showers) are in good agreement with G3 results, which described the TB data well.

Work on simulation of the charge collection in a realistic electric field has been started in parallel with the geometry implementation tests. Current sharing between calorimeter cells, electronics and pile-up noise simulation, and a digital filtering method will be implemented in G4 as it was in the ATLAS G3 code.

4 Conclusions

Intensive work on GEANT4 simulations of the ATLAS LAr calorimeters has started. The first results on EM shower simulations are close to test beam and GEANT3 results, but more work is needed to understand the differences. GEANT4 performance comparable to that of GEANT3 can be achieved. The design of GEANT4 allows a user to extend GEANT4 functionality. This helps to implement the new idea of “tailored” geometry description that can be used for high performance simulation of any calorimeter or other regular structure.

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