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# GAMMA-400 space gamma-telescope mathematical model with engineering elements included

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**Abstract**

Mathematical model creation is a necessary stage in scientific apparatus development. The mathematical model of gamma-ray telescope GAMMA-400 is used to emulate transport of various elementary particles through the apparatus. The new iteration of the model is based on precise technical drawings and includes all the elements of the real gamma-telescope. It is created in Geant4 environment. This model allows calculation of energy deposition not only in detectors, but in any part of the apparatus, including construction elements. Moreover, it supports creation of virtual sensitive volumes, allowing determination of the number and properties of particles passing through an arbitrary part of the construction.
Software for automated creation of Geant4 model based on technical drawings in STEP 3D Model format was developed. This software is capable of making models of other apparatus based particularly on scintillation and strip detectors.

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*Keywords:* gamma-ray telescope; hadron and electromagnetic showers; gamma rays; cosmic rays; space experiments, mathematical model, Geant4

## 1. Introduction

GAMMA-400 is a space gamma-ray telescope, which is currently under development. Its main scientific objectives include study of high energy and diffuse cosmic rays, galactic and extragalactic gamma-ray sources, gamma-ray bursts and dark matter [1-4]. Mathematical model creation allows quantitative studying of elementary

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particle interactions with detector materials and spacecraft structural materials. This data is later used in order to optimize apparatus construction.

The latest technical GAMMA-400 drawing consists of more than 14000 detectors and individual engineering elements, such as beams, fasteners, racks, etc. Since the design of scientific equipment has to be finally approved by the testing results, it is necessary to be able to quickly modify the mathematical model to make it comply with up-to date technical drawings.

## 2. Geometry import

The source technical drawings in STEP 3D Model (*STandard for Exchange of Product model data)* format are converted to STL (*STereoLithography*) format with the help of open source program "FreeCad". This approach was taken due to the usage of a tool to import STL geometry to Geant4 environment ("CADMesh") [5]. However, due to difference in standards, a single STEP file is usually converted into a large number of STL files. Such a large number of files is required because an STL file is only capable of storing a single element, while a STEP file usually contains a large number of elements. For instance, the STEP file with GAMMA-400 geometry was converted into more than 14 000 STL files.

As it is impractical to create such a large number of files by hand, an automated conversion program was made via "FreeCad" - supported Python script. Moreover, the existing version of "CADMesh" only allows import of a single element at a time [5]. Therefore, "CADMesh" had to be partially modified in order to correctly import a multitude of objects into Geant4 environment.

Unfortunately, STL files contain only geometry descriptions. It means that material parameters such as chemical composition and density have to be specified separately. In the present mathematical model, a table of correspondence between element types and materials was created by hand based on technical drawing information and Geant4 Material Database. Afterwards, GAMMA-400 elements in Geant4 environment were assigned correct materials based on their type by a specially written program using the hand-crafted materials table.

## 3. GAMMA-400 mathematical model geometry

Gamma-telescope GAMMA-400 is made of the following detecting systems [1-4]:

- anticoincidence system (AC, consists of ACtop and AClat);
- converter-tracker (C);
- time-of-flight system (TOF, consists of S1 and S2);
- position sensitive calorimeter (CC1);
- electromagnetic calorimeter (CC2);
- scintillation detectors of Calorimeter (SDC, consists of S3 and S4);
- calorimeter lateral detectors (LD);
- neutron detector (ND);
- star sensors (SS1, SS2);
- magnetometers (M1, M2).

Fig. 1a and 1b shows the 3D model of GAMMA-400 in STL format and Geant4 environment correspondingly.

## 4. Particles and physical processes used by the mathematical model

The list of particles, models and physical processes used in this simulation (the so-called PhysicsList) is the same as was used in GLAST telescope modeling [6]. The following elementary particles are included: leptons, gamma-quanta, unexcited hadrons (mesons and baryons) both first generation and strange.

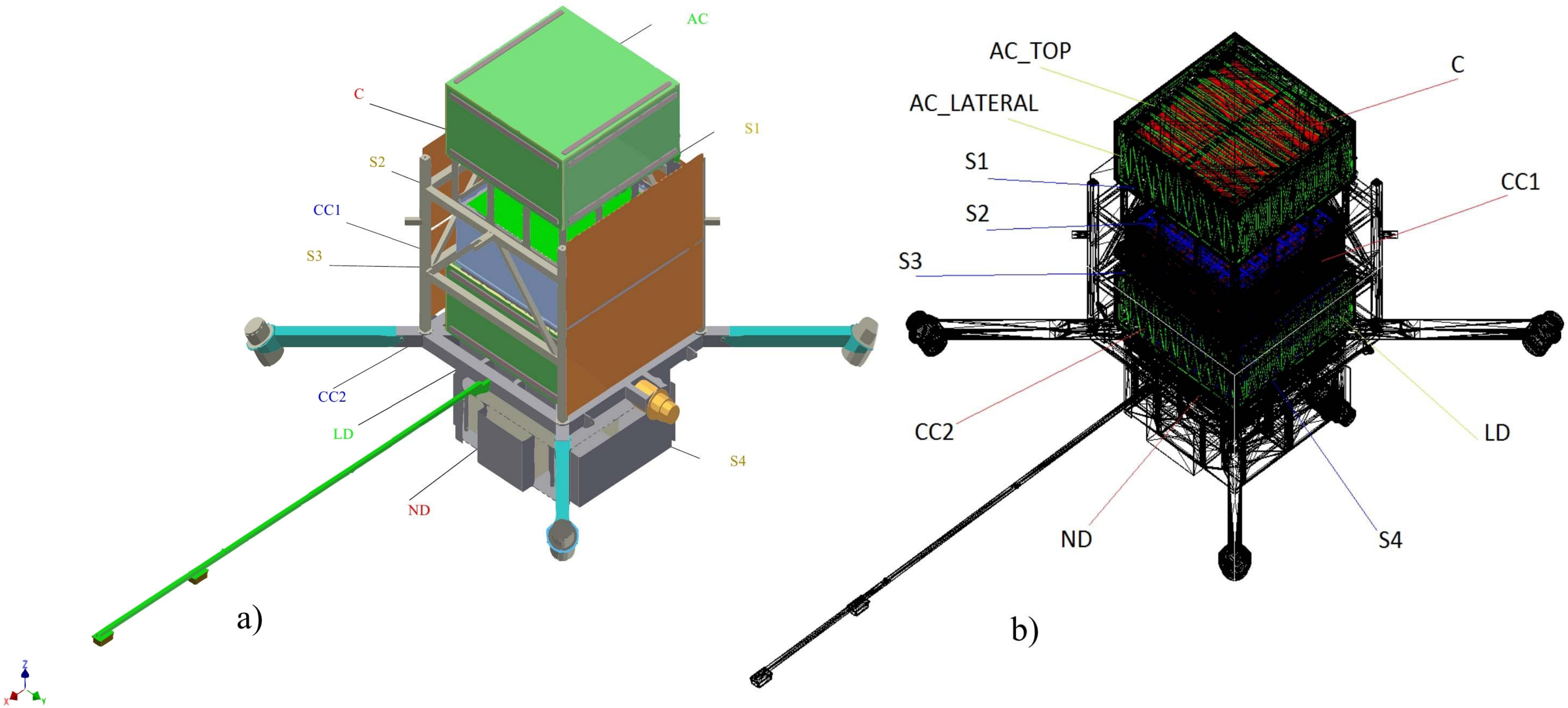


Fig. 1. 3D model of GAMMA-400 in a) STL format   b) Geant4 environment

The following processes were modeled:

- ionization by electrically charged particles;
- multiple scattering of electrically charges particles;
- annihilation of antiparticles in matter;
- photoelectric effect;
- electrically charged particles bremsstrahlung;
- photo- and electronuclear processes;
- leptons pair generation;
- Compton scattering;
- elastic and inelastic hadrons scattering;
- hadrons capture by nuclei;
- meson capture into mesoatoms;
- short-lived particle decay.

## 5. Output data format

Currently, the modeling data is output as a set of files, including:

- Processlist.txt, containing the list of processes which were used by this simulation run and their internal id codes;
- Manifest.txt, containing the list of all binary files generated by the model, as well as any comments left by user;
- a number of binary files (1 per 100 primary particles) consisting from data sequences identical to the one shown in Table 1.

Table 1. The sample of output data file.

| Address | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | A | B | C | D | E | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0000 | 41 | 0D | 00 | 00 | 00 | 00 | 00 | 00 | 16 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 0010 | 48 | 0D | 00 | 00 | 01 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 |
| 0020 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 00 | 70 | A7 | 40 |
| 0030 | 00 | 00 | 00 | 00 | 00 | 84 | 77 | 40 | 00 | 00 | 00 | 00 | 00 | 00 | 69 | 40 |
| 0040 | 33 | 33 | 33 | 33 | 33 | 47 | 93 | C0 | 2B | B8 | A8 | DE | 4F | 8B | F3 | 3F |
| 0050 | 00 | 00 | 00 | 00 | 00 | 00 | 99 | C0 | | | | | | | | |

Each data sequence (Table 1) consists of:

- one variable of C "long" type containing the sensitive volume id (address 0000-0007);
- six variables of C "int" type containing: particle type id (as defined by Particle Data Group encoding convention (PDGE)) (address 0008-000B), the number of secondary particles within the shower (address 000C-000F), the number of primary particles (address 0010-0013), current internal track id (address 0014-0017), the track id of progenitor particle (address 0018-001B), current simulation step process id (address 001C-001F);
- seven variables of C "double" type, containing: total energy deposition of the current particle during the current simulation step (MeV) (address 0020-0027), total energy of the particle at the end of the current simulation step (MeV) (address 0028-002F), global x (address 0030-0037), y (address 0038-003F), z (address 0040-0047) coordinates of the particle at the end of the current simulation step (mm), global time since the creation of the primary particle to the end of the current step (ns) (address 0048-004F), global z coordinate where the current particle was generated (mm) (address 0050-005F).

These sequences are appended to the binary file currently being written each time a particle interacts within a sensitive volume. While typically only detectors are declared as sensitive volumes, any element can be declared as one. All the variables are explicitly converted from internal Geant4 format to standard C types. In order to be used, the data is typically further processed by specialized programs.

## 6. Virtual surfaces

Virtual surfaces can be used to control particle passage through specific areas of model. These surfaces have zero density and can be set up both inside and outside existing model elements. Their only function is generation of OnHit event each time a particle track crosses one of them. In no way do these virtual surfaces alter the behavior of particles or other model elements. Each time a particle causes an OnHit event, data is recorded as described in section 5 of this article. Virtual surfaces can be used to determine amount of particles passing through gaps between detectors.

## 7. Energy deposition in construction elements

In order to determine maximum energy deposition in construction elements, transport of electrons and gamma-quanta with various starting energies was modeled. These particles were generated directly above the cross-shaped intersection point of two polycarbonate honeycomb panels in the middle of converter-tracker (Fig. 2) and flew normally to the frontal surface of GAMMA-400. For each combination of particle type and starting energy 10000 runs were performed. The results are in Table 2 (gamma-quanta) and Table 3 (electrons). Based on the resulting data maximal energy loss for high-energy electrons and gamma-quanta is no more than 5%.

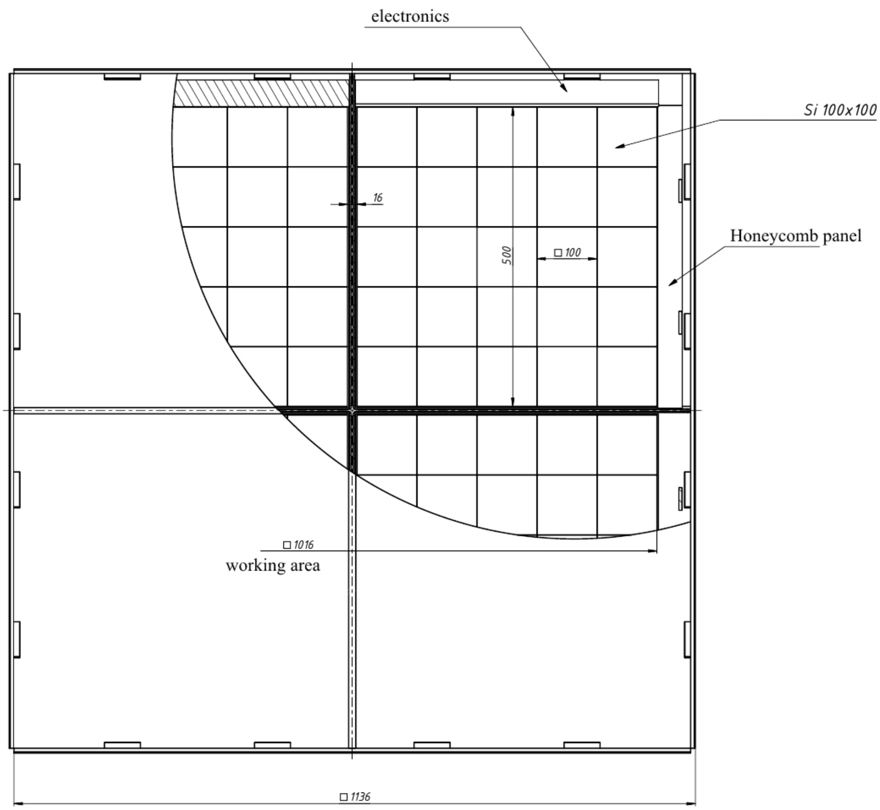


Fig. 2. Converter-tracker top view.

Table 2. Energy deposition results for gamma-quanta

| Starting energy, GeV. | Minimal energy loss, % | Maximal energy loss, % | Average energy loss, % |
|---|---|---|---|
| 1 | 0.2 | 33.1 | 10.4 |
| 10 | 0.7 | 13.1 | 4.0 |
| 50 | 0.9 | 7.5 | 2.3 |
| 100 | 1.0 | 4.7 | 1.9 |

Table 3. Energy deposition results for electrons.

| Starting energy, GeV. | Minimal energy loss, % | Maximal energy loss, % | Average energy loss, % |
|---|---|---|---|
| 1 | 1.1 | 35.6 | 14.8 |
| 10 | 1.1 | 13.8 | 5.8 |
| 50 | 1.2 | 7.2 | 3.0 |
| 100 | 1.1 | 5.0 | 2.4 |

## 8. Conclusion

The present mathematical model can be used to simulate particle passage through the gamma-telescope GAMMA-400 providing data to determine optimal settings for its detector systems. This model fully conforms to the current technical drawings. The developed software package can be used to quickly make corrections to the model in the case of technical drawings change. Moreover it can be used to make mathematical models of other scintillation and strip detector apparatus based on technical drawings in STEP format and materials table.

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