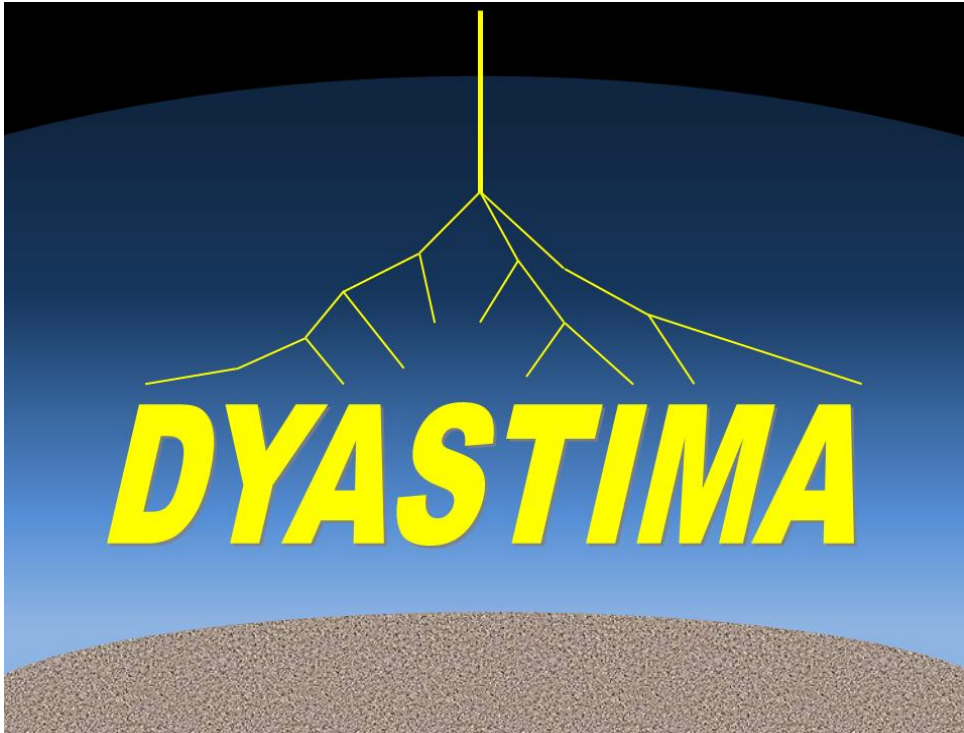


User Manual



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2016

1. Versioning

DYASTIMA v1.0: first GUI-based version

DYASTIMA v1.1: minor bug fixes

2. Brief Description

DYASTIMA is a standalone application for the simulation of the showers that are produced in the atmosphere of a planet due to the cosmic rays. The application makes use of the well known Geant4 simulation toolkit. The last version of DYASTIMA allows extensive parameterization via a friendly graphical user interface and provides a lot of information regarding the shower. DYASTIMA is free to be used by the scientific community with the only requirement being a reference to:

- P. Paschalis, H. Mavromichalaki, L.I. Dorman, C. Plainaki, D. Tsigrikas: "Geant4 software application for the simulation of cosmic ray showers in the Earth's atmosphere", *New Astronomy*, 33, 26-37, 2014
- Agostinelli S., Allison J., Amako K., Apostolakis J. et al. for the Geant4 collaboration, "Geant4 - a simulation toolkit", *NIM A*, Volume 506, Issue 3, pp. 250-303, 2003
- Allison J., Amako K., Apostolakis J., Araujo H. et al. for the Geant4 collaboration, "Geant4 developments and applications", *IEEE Transactions on Nuclear Science*, vol.53, no.1, pp. 270-278, 2006

3. Requirements

DYASTIMA is a GUI-based application that is developed in Microsoft Visual Studio. As a result, a Microsoft Windows operating system and the .NET library are required. The Geant4 library and Geant4 datasets are also required. DYASTIMA can automatically download all the required files of Geant4 and set the necessary environmental variables. The current version of DYASTIMA uses the version 9.6.p04 of Geant4 and the corresponding datasets.

For the execution of DYASTIMA, it is optimal to use an over mid-range computer. Commonly, the results of a simulation run require about 100 MB of disk space. However, the required disk space may be increased in case of several tracking layers and/or in case the horizontal position of the particles is recorded.

4. Input and output

The simulation requires several input parameters that may be categorized as following:

- general characteristics of the planet (radius, surface type, surface magnetic field, surface pressure and surface gravitational acceleration)

- settings regarding Geant4 and the simulation geometry (simulation area width, geometry model, division of the atmosphere, physics list, production range cut, beam altitude)
- structure of the atmosphere (composition, temperature profile)
- altitudes in which the tracking of particles is performed
- spectra (particle types, flux, zenith and azimuth range)
- optional energy cuts for the production, simulation or tracking of particles

The simulation scenario is described by using a GUI. There are help buttons that guide the user for the correct input of the parameters.

Regarding the output, DYASTIMA executes the simulation of a specific scenario for a user defined number of primary cosmic ray particles (events). Resume of a finished or a stopped run is also supported. The output is presented in table 1.

Altitude (m)	Particle Type (name)	Energy Log Bin (eV)	Density of Produced Particles (#/m ³)	Counted Particles (#)		
Altitude (m)	Particle Type (name)	Energy Log Bin (eV)	Flux of Particles (#/m ²)	Counted Particles (#)		
Altitude (m)	Particle Type (name)	Time Log Bin (s)	Flux of Particles (#/m ²)	Average Energy (eV)	Counted Particles (#)	
Altitude (m)	Particle Type (name)	Zenith Angle 5-degrees Bin	Azimuth Angle 5-degrees Bin	Flux of Particles (#/m ²)	Average Energy (eV)	Counted Particles (#)
Altitude (m)	Particle Type (name)	Longitude 1-km Bin	Latitude 1-km Bin	Flux of Particles (#/m ²)	Average Energy (eV)	Counted Particles (#)
Altitude (m)	Particle Type (name)	Ionizing Energy Deposit (eV/m ³)	Non Ionizing Energy Deposit (eV/m ³)	Counted Particles (#)		

Table 1: output of DYASTIMA

Finally, the user can test the simulation scenario and geometry by simulating one event for a specific particle, energy and incoming direction. The geometry test creates a .heprep file that can be viewed by the HepRApp browser.

Link: <http://www.slac.stanford.edu/~perl/HepRApp/>

5. Models and algorithms

5.1. Geometry

The simulation volume contains the atmosphere and the surface of the planet. There are two models available, the "FLAT" and the "SPHERE" model. In the "FLAT" model the atmosphere is a rectangular box while in the "SPHERE" model it is a spherical shell in order to represent the curvature of the planet. The "FLAT" model provides speed while the "SPHERE" model provides accuracy. In order to represent the density and pressure decrease with the altitude, the atmosphere is divided in slices with decreasing density. The division of the atmosphere is performed in such a manner, that the density decrease within a slice is smaller than a user defined percentage. The cosmic ray particles are emitted from a point source at the top of the atmosphere (or at a user defined altitude), following a cosine law angular distribution. This equals to an isotropic flux that reaches the top of the atmosphere. For the interactions of the particles, the reference physics lists of geant4 are used. A magnetic field is applied within the atmosphere for the divergence of the tracks. The magnetic field is supposed to be a dipole and the magnitude is decreased with $1/R^3$.

5.2. Data handling and normalization

The data that are collected during the simulation are flushed to a sqlite database every 3 minutes. This approach provides optimal data handling and storage and it allows the user to resume a finished or stopped simulation. In order to ensure the integrity of the results, the flushing is performed by using transaction. While a transaction is being executed, a temporary journal file is generated. The temporary journal file is automatically deleted after the changes are committed. In case the simulation is stopped while the transaction is in progress, the journal file remains in the folder and is used for rolling back the database on the next access. The user should not delete the journal files.

The data that are collected should be normalized in order to be transformed to physical units. Since the primary particles are emitted from a point source at the top of the atmosphere, the collected particles at a specific altitude can be considered as the particles per area unit that are collected if the whole atmosphere is illuminated with particles. More accurately, in the case of FLAT model, if the total flux of primary particles at the top of the atmosphere is J_{total} then the normalization factor that should be applied to the results is:

$$Normalization_{FLAT} = \frac{J_{total}}{simulated\ events}$$

In case of SPHERE model, since the particles are distributed in a spherical shell, the area of which is $\sim R^2$, the normalization factor becomes:

$$Normalization_{SPHERE} = \frac{J_{total}}{simulated\ events} \cdot \frac{(Spectra\ Altitude + Planet\ Radius)^2}{(Tracking\ Altitude + Planet\ Radius)^2}$$

6. Usage

For better description of the usage, the figures show a testing simulation scenario. The Graphical User Interface (GUI) of DYASTIMA is shown in figure 1.

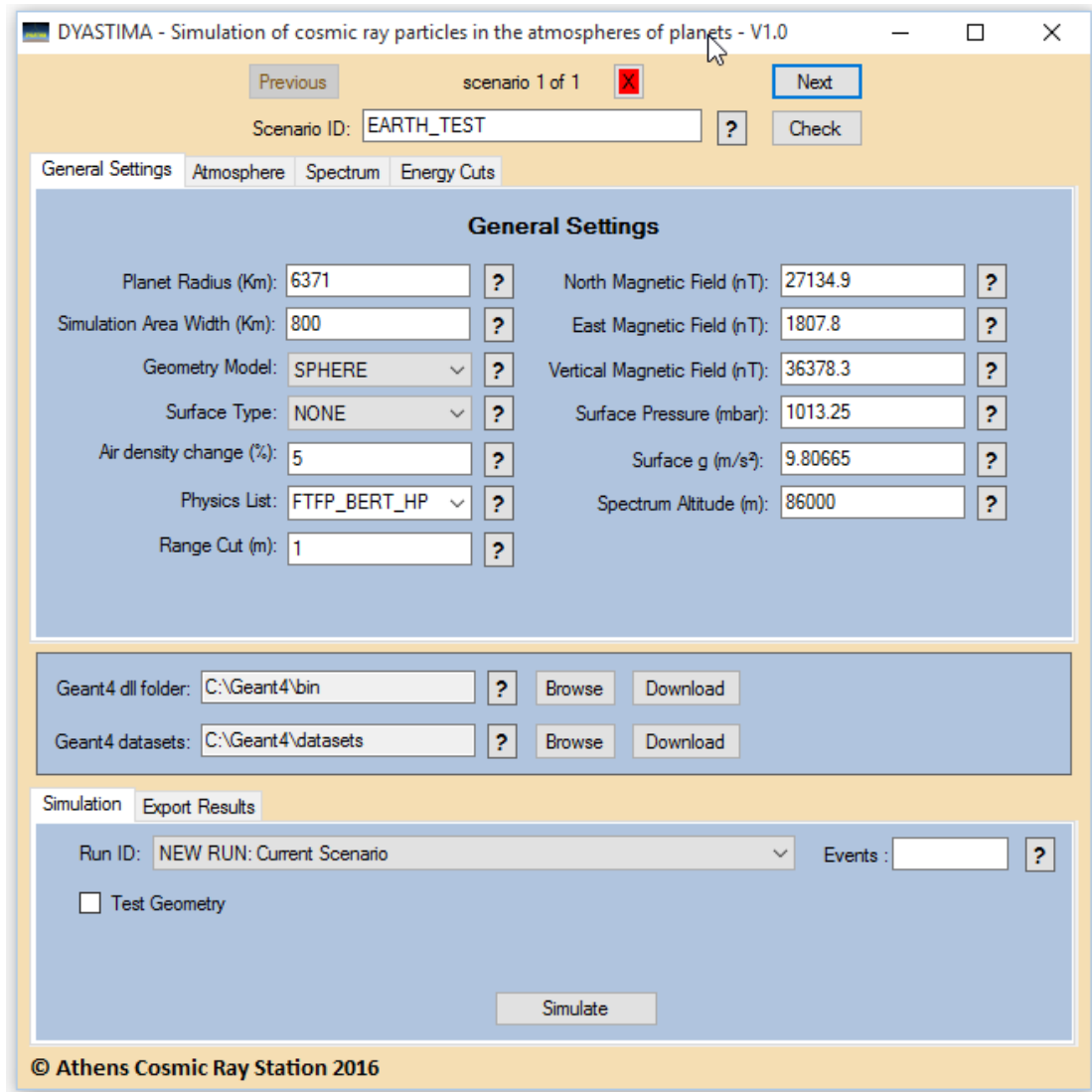


Figure 1: Graphical User Interface of DYASTIMA

The user can describe several simulation scenarios by using the buttons at the top of the form, as shown in figure 2. Each simulation scenario should have an ID. There is a button for checking the validity of the parameters that describe the scenario.

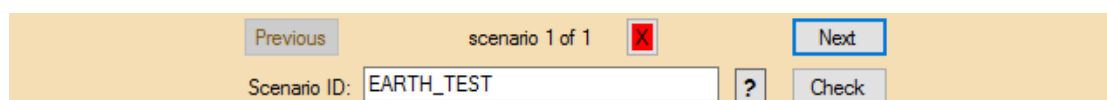


Figure 2: Buttons for navigation among the different simulation scenarios

6.1. Description of the simulation scenario

For a simulation scenario the user should define the required parameters that are distributed in four tabs.

General Settings tab

Parameter	Value
Planet Radius (Km)	6371
Simulation Area Width (Km)	800
Geometry Model	SPHERE
Surface Type	NONE
Air density change (%)	5
Physics List	FTFP_BERT_HP
Range Cut (m)	1
North Magnetic Field (nT)	27134.9
East Magnetic Field (nT)	1807.8
Vertical Magnetic Field (nT)	36378.3
Surface Pressure (mbar)	1013.25
Surface g (m/s ²)	9.80665
Spectrum Altitude (m)	86000

Figure 3: General settings tab

Planet Radius: the radius of the planet in kilometers

Simulation Area Width: the horizontal dimension of the simulation area in Km. Representative value is 500-800 Km.

Geometry Model: Selection between FLAT - SPHERE for the shape of the atmosphere. See 5.1. for more info.

Surface Type: The surface type of the planet beneath the atmosphere. Selection among NONE - GROUND – SEA.

Air Density Change: Percentage decrease (%) of the density within the layers, used for the division of the atmosphere in slices. Representative value is 5%.

Physics: Reference physics list of Geant4 that is used in the simulation. Optimal physics lists are predefined (FTFP_BERT_HP, QGSP_BERT_HP, QGSP_BIC_HP). The user can declare another reference physics list than the predefined ones.

Range Cut: Production range cut of the particles in meters. Particles of a range smaller than the range cut are not produced. Optimal value is 1m. Small values increase accuracy with a trade off to performance.

North Magnetic Field¹: North-South component of the magnetic field in nT. Positive values are towards the North direction.

East Magnetic Field¹: East-West component of the magnetic field in nT. Positive values are towards the East direction.

Vertical Magnetic Field¹: Downward-Upward component of the magnetic field in nT. Positive values are towards the downward direction.

Surface Pressure: Surface pressure of the planet in mbar.

Gravitational Acceleration: Surface Gravitational acceleration in m/s².

Spectrum Altitude: Altitude of the particle source in meters.

Atmosphere tab

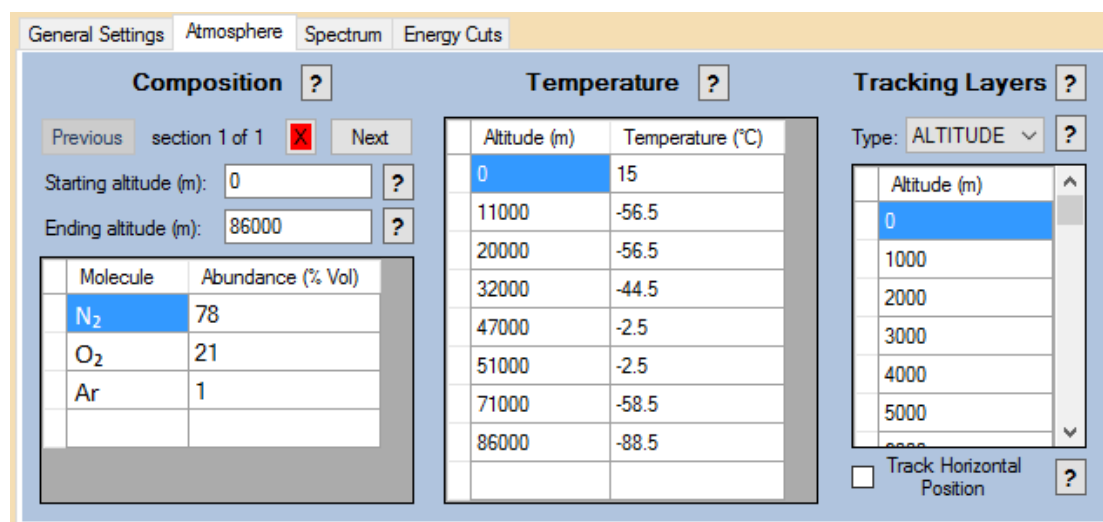


Figure 4: Atmosphere tab

Composition: The user should define sequential sections from the bottom to the top of the atmosphere. For each section the user should define:

- the starting and the ending altitude of the section in meters.
- the composition of the section in Molecule type - Abundance(%Vol) pairs. Abundances in each layer should sum to 100%.

Temperature: The user should define Altitude(m) - Temperature(°C) pairs from the bottom to the top of the atmosphere.

¹ Values can be found in <http://www.ngdc.noaa.gov/geomag/>

Tracking Layers: Altitudes in which the tracking of particles is performed. The layers can be defined either in altitude (m) or in atmospheric depth (g/cm^2).

Track Horizontal Position checkbox: Enables the tracking of horizontal position. This is useful only when a directional beam of primary particles is used, in order to study the dimension of the shower. In case of a wide angular distribution of primary particles the tracking of horizontal position has no physical meaning (see 5.2. for more information).

Spectrum tab

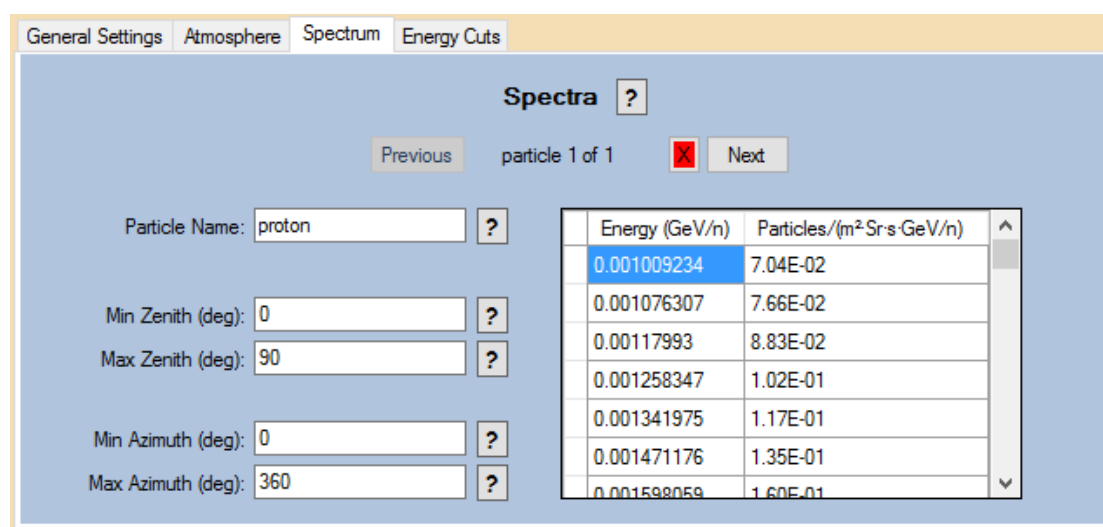


Figure 5: Spectrum tab

The spectrum of several particles can be defined. For each spectrum the user should define:

- the particle name according to Geant4 notation
- the minimum and maximum zenith and azimuth angles of the incoming particles in degrees
- the differential spectrum in Energy/nucleon - Flux pairs. Units are GeV/n - Particles/(m²·Sr·s·GeV/n) respectively.

Notice: The differential spectrum is integrated numerically in order to calculate the total flux that is used in the normalization of the results (see 5.2.). Linear interpolation is considered during the integration so, for accurate results, the user should define the points of the spectrum densely.

Energy Cuts tab

Production Cut ?	
Particle Name	Cut Energy (MeV)

Simulation Cut ?	
Particle Name	Cut Energy (MeV)

Tracking Cut ?	
Particle Name	Cut Energy (MeV)

Figure 6: Energy Cuts tab

Optional energy cuts for the production, simulation and/or tracking of particles. Particles with energy smaller than the defined one are excluded from the production, simulation and/or tracking respectively. The user should define pairs of Particle name (Geant4 notation) - Energy (MeV). A negative energy value excludes the particles completely.

6.2. Required files of Geant4

The user should declare the folders in which the Geant4 dlls (bin folder) and Geant4 datasets are located. The user can download the necessary files from Geant4's webpage or download them by using the form. DYASTIMA is based on Geant4 version 9.6.p4 http://geant4.web.cern.ch/geant4/support/source_archive.shtml

Geant4 dll folder:	<input type="text" value="C:\Geant4\bin"/>	?	Browse	Download
Geant4 datasets:	<input type="text" value="C:\Geant4\datasets"/>	?	Browse	Download

Figure 7: Geant4 library and datasets

6.3. Execution of the simulation

The user should select from the drop-down menu the scenario that will be simulated. The drop-down menu shows the "NEW RUN: Current Scenario" choice and the previous simulations that may exist. The user can select to start a new run of the current scenario or

to continue a previous one. The user can define the number of events for the simulation (figure 8) or to test the geometry of the scenario for a specific particle, energy and direction (figure 9).

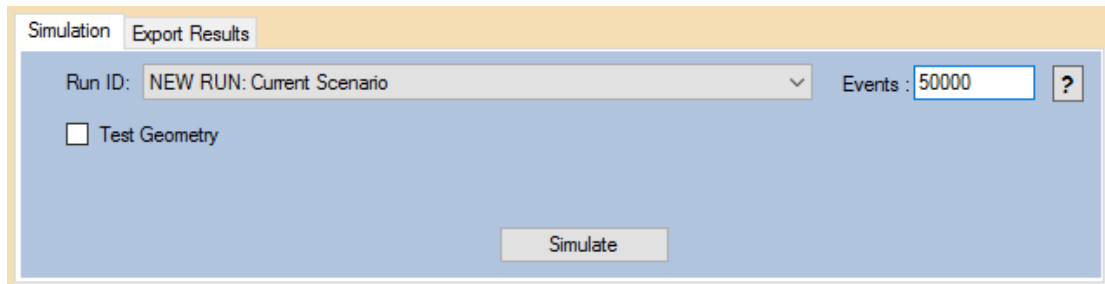


Figure 8: Starting or resuming a simulation

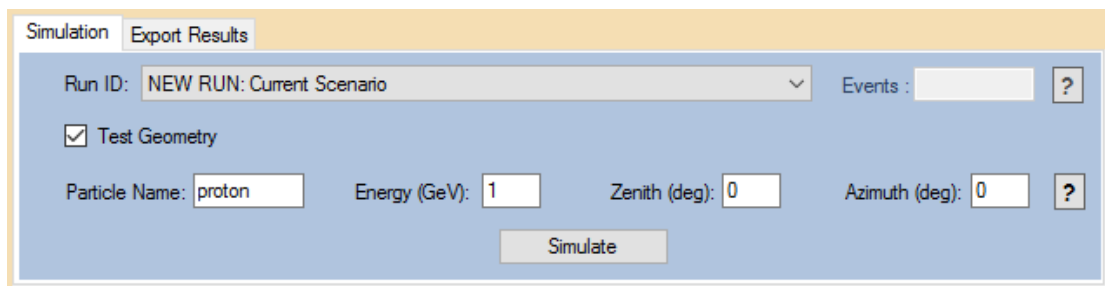


Figure 9: Testing geometry

In the case that a new run is selected, when the simulation button is pressed the current scenario is checked. Possible errors or invalid parameters are indicated to the user. In the case of a valid scenario, the scenario id is concatenated with the current date and time and a new folder with this name is created in the /results folder of DYASTIMA. In this folder, three files exist (figure 10):

- the sqlite database file
- a .txt file containing the parameters of the scenario
- a .txt file containing the output of Geant4

Name	Date modified	Type	Size
EARTH_TEST_31-01-2016_22-08-15.db	31/1/2016 22:08	DB File	42 KB
EARTH_TEST_31-01-2016_22-08-15_output.txt	31/1/2016 22:08	Text Document	0 KB
INFO_EARTH_TEST_31-01-2016_22-08-15.txt	31/1/2016 22:08	Text Document	48 KB

Figure 10: Files created for the simulation

The simulation procedure is performed via a console application (figure 11). For each event the application indicates the particle that enters the atmosphere, the energy, the time spent for the processing of the event and the estimated remaining time. The results of the simulation are flushed every 3 minutes in .db file while any message from Geant4 is written in the output .txt file. In case of testing the geometry, the simulation is performed for the one particle and a .heprep file is generated in the folder of the run.

```

DYASTIMA RUN ID: EARTH_TEST_31-01-2016_22-08-15
-----
DYASTIMA: COSMIC RAY SIMULATION IN ATMOSPHERE BY USING GEANT4
University of Athens - Physics Department - Cosmic Ray Station

Reference:
1) P. Paschalis et al., "Geant4 software application for the
simulationof cosmic ray showers in the Earth's atmosphere",
New Astronomy, Volume 33, 26-37, 2014

Based on Geant4 toolkit:
1) Geant4 collaboration, "Geant4 - a simulation toolkit",
NIM A, Volume 506, Issue 3, 250-303, 2003
2) Geant4 collaboration, "Geant4 developments and applications",
IEEE Transactions on Nuclear Science, Volume 53, No.1, 270-278, 2006
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Geant4 is being initializing. This may take a few seconds

$G4NEUTRONHPDATA
Processing Event 1/50000 ----- Particle: proton , Energy: 2.66513 GeU
Event took 0.406 seconds ----- Estimating remaining time 20299.6 seconds

Processing Event 2/50000 ----- Particle: proton , Energy: 23.6391 GeU
Event took 3.266 seconds ----- Estimating remaining time 91796.3 seconds

```

Figure 11: Simulation procedure

6.4. Export of the results

The results of a simulation run are collected at the corresponding file of the sqlite database. There are VIEWS defined in the database that transform the results according to the format of table 1. The experienced user can use any sqlite browser and access the results by sending simple SQL queries. However, DYASTIMA provides functionality for exporting the results to .csv files (figure 12). The user has to select the ID of the simulation, the category of the results, the altitude and the particle. Since several records may be available and in order to avoid creating huge .csv files that are not functional, the user has to define the line limit after which the .csv file will be split. The .csv files are stored in folder /CSVs of the simulation folder.

Figure 12: Exporting results from database