

CORELib: COsmic Ray Event LIBrary

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CORELib is a library of simulated events that is meant for open access to satisfy a broad range of needs. The physical parameters of CORELib production are set to achieve a general purpose high statistics production.

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1. INTRODUCTION

Cosmic rays are a source of background for many astroparticle and astronomy experiments. The computing time needed to simulate air showers increases exponentially with the energy of the primary cosmic ray. The main focus of CORELib is to provide a collection of simulated showers induced by cosmic rays and a common framework to produce and manage such large production. Originally developed for the Research Infrastructures (ESFRI) in ASTERICS, especially KM3NeT, CORELib is potentially useful also outside of the astronomical community. For example, simulations of air showers induced by high energy primary cosmic rays are very interesting for muon radiography, which is employed both to study the inner structures of volcanoes and for archaeological investigations of big monuments such as pyramids.

The production is obtained by using the widely used CORSIKA-7.5000 as generator and the GRID infrastructure as computational resources. The KM3NeT's VO (Virtual Organization) has been used, mainly the computational and storage resources located in the Naples university.

2. CORSIKA

Initially developed to run simulations for the KASCADE experiment, CORSIKA (Cosmic Ray Simulation for KASCADE) [1] is a detailed Monte Carlo program to follow step by step the evolution of extensive air showers (EAS) produced by the interaction of cosmic rays with the atmosphere. EAS induced by protons and light nuclei up to Fe or photons can be simulated. The interactions with air nuclei produce secondary particles that are tracked along their trajectories and their parameters are stored in files when a set observation level is reached. Each simulation run produces two types of output files:

- Control output file: a text file in which all the standard output of the corresponding run is stored, first of all the datacards of the event;
- Particle list: a compressed binary file that contains:
 - all the information about the secondary particles;
 - photons produced by the Cherenkov effect (if this option has been selected).

3. CORELib

Each event collected in CORELib represents a different simulated shower. The showers produced are generated by primary cosmic rays with zenith angle between 0 and 89 degrees. The observation level is placed at sea level, while the Standard European Atmospheric Model is used. The selected parameters of simulation are available and easily accessible to the user, encoded in a CORSIKA datacard. The choice of the parameters has been done with the KM3NeT Simulation and Analysis Working Groups [2].

In order to work out the best selection in terms of computation time and quality of production, a “**pilot production**” of CORELib has been made. Only showers induced by protons were considered and the simulated energy spectrum has a power law with spectral index -2.

The “**full scale production**”, instead, consists of several kinds of primary cosmic rays: showers induced by protons and heavy nuclei (He, C, N, O, Fe) are simulated (Table 1).

For proton-induced showers, two productions are available: with and without Cherenkov radiation (Table 2).

Besides the energy spectrum tested in the pilot production, a flat energy spectrum (spectral index = 0) to increase the statistics at high energy has been evaluated (Table 2).

The aim is to that enhance event samples with features that are worth studying. Both productions are made with different high energy hadronic interaction models: QGSJET01 with the CHARM option selected to enable the treatment of charmed states, QGSJETI and EPOS with the TAULEP option selected to enable the treatment of tau. GHEISHA has been chosen as a common low energy model.

Heavy nuclei (He-CNO-Fe) induced showers						Proton induced showers								
High Energy Model	Low Energy Model	Option		Cherenkov Radiation		STATUS	High Energy Model	Low Energy Model	Option		Cherenkov Radiation		STATUS	
		TAULEP	CHARM	with	without				$\alpha = -2$	$\alpha = 0$				
QGSJET01	GHEISHA		x		x	DONE	QGSJET01	GHEISHA		x	x	x	DONE	DONE
QGSJET01	GHEISHA	x			x	DONE	QGSJET01	GHEISHA	x		x	x	DONE	DONE
QGSJET II-04	GHEISHA	x			x	DONE	QGSJET II-04	GHEISHA	x		x	x	DONE	DONE
EPOS	GHEISHA	x			x	DONE	EPOS	GHEISHA	x		x	x	DONE	70% DONE

Table 1(left): Summary of heavy nuclei induced showers produced. Currently only the production without contribution of Cherenkov radiation is completed. **Table 2 (right):** Summary of the proton-induced showers produced. The production with $\alpha = -2$ is completed while the flat spectrum production is ongoing

The production of each model is divided in 7 energy bins, equally logarithmically spaced from 10^3 GeV to 10^9 GeV. The number of events in each energy range has been chosen according to the computing load (Table 3).

Energy range (GeV)	Number of events
200-100	10000000
10^3-10^4	10000008
10^4-10^5	1000002
10^5-10^6	100000
10^6-10^7	10000
10^7-10^8	1000
10^8-10^9	100

Table 3: Number of simulated events for each energy bin.

The computing time (fig. 1) and the size of the output files (fig. 2) increase with the energy of the primary cosmic ray.

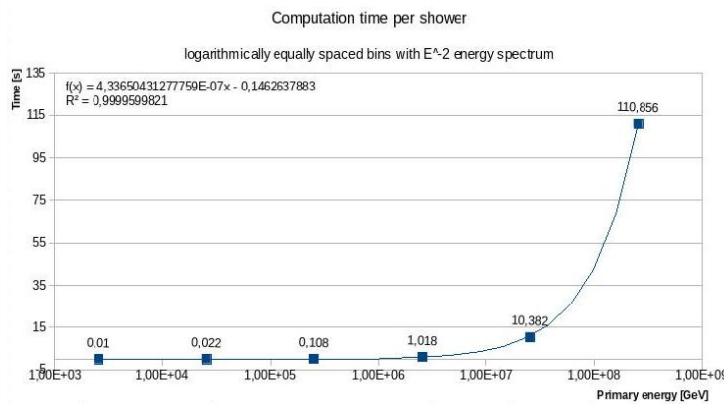


Figure 1: The computing time is the difference between the last and the first “PRESENT TIME” UTC date in the standard output of CORSIKA; the uncertainty in the computing time is of the order of 2 seconds.

All the information about every single shower is stored in a SQLite database that can be queried by the user. In order to simplify the access to the library, the information about secondary

cosmic rays is extracted from CORSIKA output files and put in separated ASCII files (electromagnetic component, muons, neutrinos, hadrons+tau), but only for showers simulated without Cherekov effect.

We use a dedicated tool named CORANT, originally developed and maintained by T. Chiarusi, L. A. Fusco and C. Pellegrino and later improved by B. Spisso and S.M. Stellacci for this purpose.

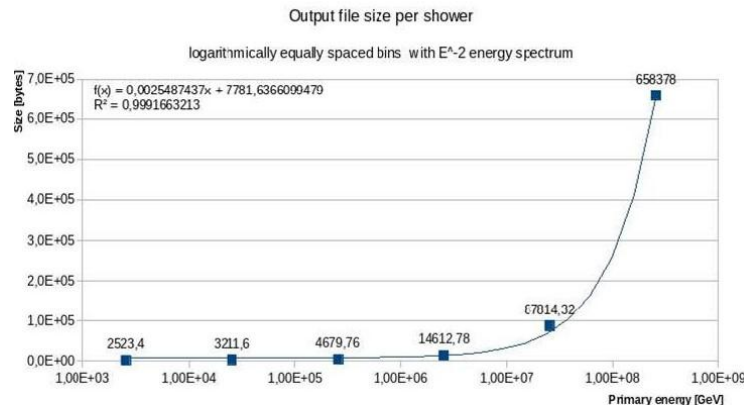


Figure 2: Average size in each energy bin.

The productions completed so far (March 2019) are stored at CNAF, the Information Technology National Center of INFN (Italian Institute for Nuclear Physics). They can be downloaded through gridFTP with an X509 certificate.

4. CONCLUSIONS

CORELib results from a big computation effort to feature large statistics of cosmic ray showers. Because of the wealth of simulated data, the productions can be used by a large community of researchers. The inherent flexibility of CORSIKA allows easy extension of the production to specific case, if requested. Last but not least, the dedicated access through X509 certificate is both open and secure

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References

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