ICRC2021 (Berlin, online) ID725

COSMOS X as a general purpose air shower simulation tool

T. Sako,[a] T. Fujii,[b,c] K. Kasahara,[d] H. Menjo,[e] N. Sakaki, [f] N. Sakurai,[g] A. Taketa,[h] Y. Tameda[i] for the COSMOS X development team

[a] Institute for Cosmic Ray Research, the University of Tokyo, [b] Hakubi Center for Advanced Research, Kyoto University, [c] Graduate School of Science, Kyoto University, [d] Faculty of Systems Engineering and Science, Shibaura Institute of Technology, [e] Institute for Space-Earth Environmental Research, Nagoya University, [f] Computational Astrophysics Laboratory, RIKEN, [g] Graduate School of Science, Osaka City University, [h] Earthquake Research Institute, University of Tokyo, [i] Osaka Electro-Communication University, Department of Engineering Science

ABSTRACT: An air shower simulation package COSMOS was born in 1970's and has been continuously developed. A recent major update enables particle tracking not only in the atmosphere but also in arbitrary gas, liquid and solid materials by combining with the EPICS detector simulation package. This paper describes the properties of this **extended version of COSMOS, namely COSMOS X**. Combination of gas, liquid and solid materials in spherical shells with a common center can be defined as environment. Users can also arbitrary define the electric and magnetic fields. These features allow shower simulations even in the soil, concrete, sea and ice. Also simulations at the Sun and the Mars are possible applications. Flexible input/output control since the previous versions of COSMOS, a set of user hook functions, is also available. In the predefined user functions, information of each particle in transportation can be easily accessed and users can extract information from them. General introduction to COSMOS and new functions of COSMOS X together with some interesting application cases will be presented in this paper.

Introduction

Importance of air shower MC tool is increasing in the modern cosmic-ray experiments in the following aspects

- Importance of particle ID (mass, γ, ν)
- New knowledge of hadronic interaction especially from LHC [1]
- Muon puzzle from the air shower experiments [2]
- Wide application to non-air materials, thunder clouds [3], non-Earth environments, …

Based on the COSMOS lasting since 1970', a new package COSMOS X is developed. Main features and interesting applications of COSMOS X are presented.

What is COSMOS?

COSMOS is an air shower MC simulation package like CORSIKA written in FORTRAN. The codes can be compiled by GFortran and Intel compilers and tested on Linux and Mac OS X platforms.

The scheme of COSMOS is shown in Fig.1..

- Users control the settings from 'param' file
- Users define the primary spectra and composition by 'primary' file
- Users define the actions at various steps in 'chook.f' function.

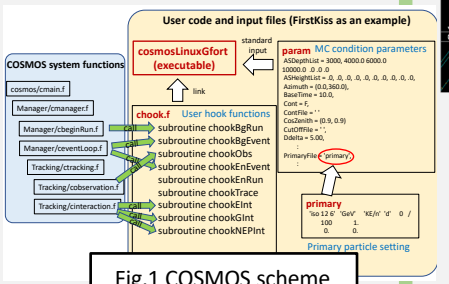

Fig.1 COSMOS scheme

Through chook functions, flexible access to the shower particles and outputs are realized.

COSMOS X and Applications

COSMOS X was born as a marriage of the COSMOS 9 air shower MC package and the EPICS detector simulation package. Important features of COSMOS X are

- Non-air gas, solid and liquid materials can be defined as environment
- Shape of the materials is limited as a spherical shell with a common center, which enables simulations at non-Earth stars like Sun and Mars
- Arbitrary electric and magnetic fields can be defined
- Compiled by CMake tool, which reduced the environment dependence

Some examples of application are introduced

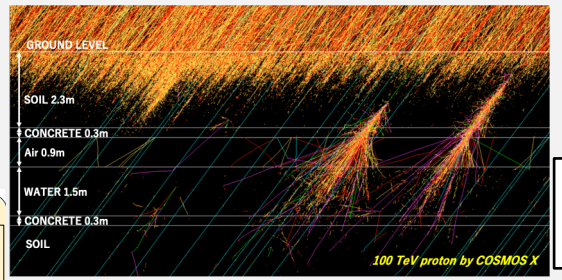

Fig.2 A 100TeV proton shower above and below the ground

Figure.2 demonstrates an air shower of 100TeV proton primary above and below the ground. Attenuation of electromagnetic particles (red and orange) and penetration of muons (blue) are clearly seen. Two hadronic showers produced in the ground are also identified. Strong absorption of electromagnetic components in the soil is used for the principle of the hadron/γ separation using underground muon detectors in the Tibet ASγ experiment [4].

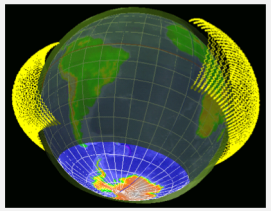

Fig.3 Trajectory of a charged particle trapped in the geomagnetic field

Fig.4 Tracking of a 10TeV proton in the solar atmosphere

Figure.3 and 4 are examples of non-traditional usage. Figure.3 tracks a charged particle in the geomagnetic field, but without collisional interaction. Figure.4 is a 10TeV proton air shower but in the solar atmosphere with a toy solar magnetic field model. Very different behavior from our familiar air showers is visible. This application is important to study the recent observations of solar gamma rays [5].

Though some COSMOS functions are not migrated, a β version of COSMOS X is public. Questions and comments are welcome.

http://cosmos.icrr.u-tokyo.ac.jp/COSMOSweb/

REFERENCES:

[1] H.Dembinski, Review talk in ICRC2021
[2] D. Soldin, ICRC 2021, ID 856
[3] J. W. Belz et al., JGR Atmosphere, 125, e2019JD031940 (2020).; J. Remington, ICRC 2021, ID848
[4] T. K. Sako, K. Kawata, M. Ohnishi, A. Shiomi, M. Takita and H. Tsuchiya, Astropart. Phys., 32 (2009) 177-184.
[5] T. Linden, B. Zhou, J. Beacom, A. H. G. Peter, K. C. Y. Ng, and Q.-W. Tang, Phys. Rev. Lett., 121, 131103 (2018).