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The AUGERHIT Option of the Air Shower Simulation Program CORSIKA

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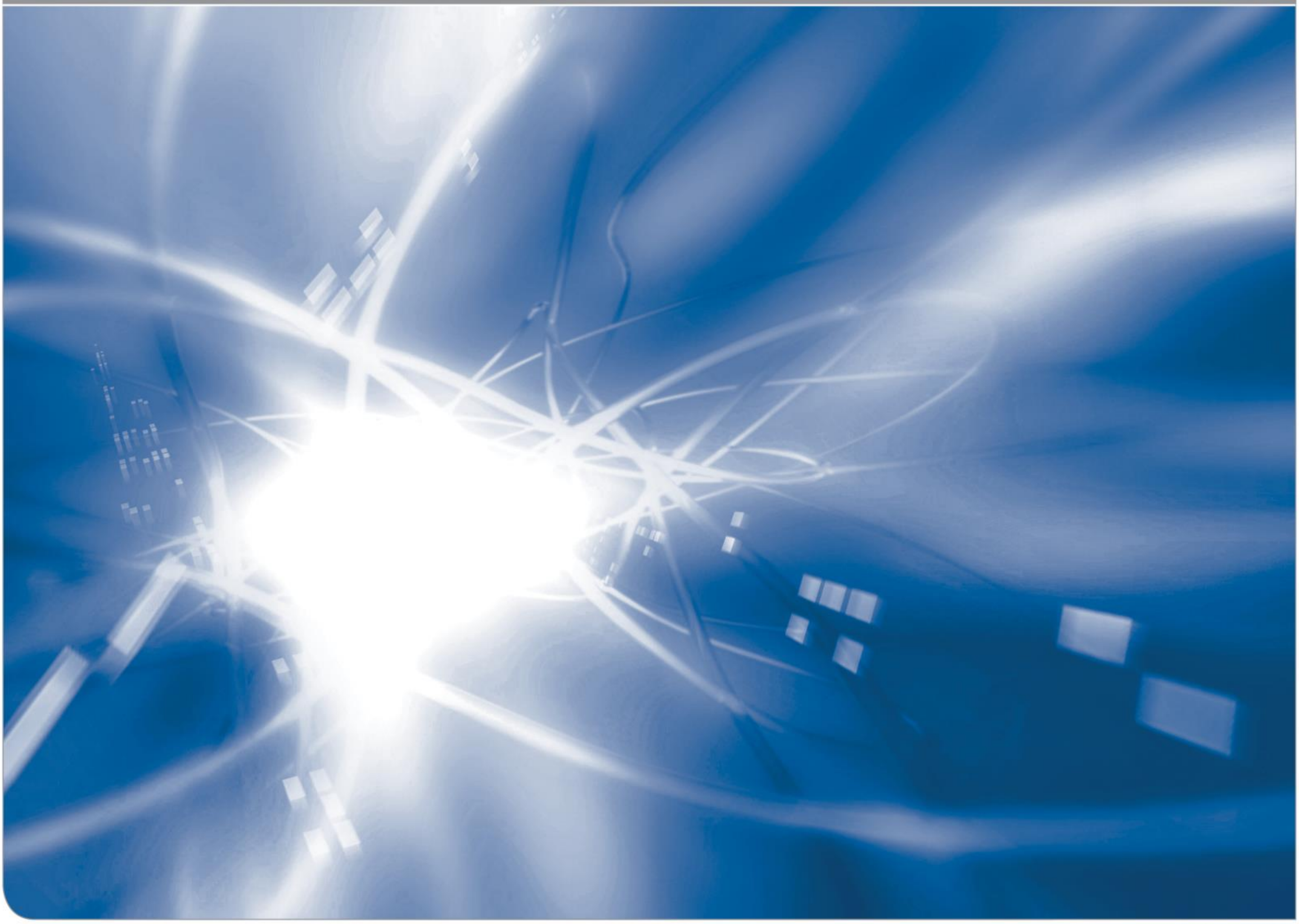

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Abstract

The AUGERHIT Option of the Air Shower Simulation Program CORSIKA

This report describes the size reduction of the particle data output file(s) for Auger simulations. This reduction is achieved by a (random) selection of the shower core position relative to the triangular grid of detectors, as for all shower particles in the observation plane it is checked whether they arrive in the neighbourhood of a corresponding detector position. Only hitting particles are kept for the output. All other particles falling onto the Argentinian pampa far from any detector are skipped.

Zusammenfassung

Die AUGERHIT-Option des Luftschauer-Simulationsprogramms CORSIKA

Dieser Bericht beschreibt die Reduzierung der Größe der Teilchenausgabedatei(en) bei Auger-Simulationen. Diese Reduzierung wird durch eine (zufällige) Wahl der Lage des Schauerzentrums relativ zu dem Dreieck-Gitter der Detektoren erreicht, weil für alle Schauerteilchen in der Beobachtungsebene geprüft wird, ob sie in der Nähe einer passenden Detektorposition niedergehen. Nur solche Teilchen werden in die Ausgabedatei geschrieben. Alle anderen Teilchen, die in die argentinische Pampa weitab von einem Detektor fallen, werden weggelassen.

Contents

1 Introduction

Recently the CORSIKA Extensive Air Shower simulation code [1] has been extended for parallel processing [2, 3] on multi-node machines. This development enables the full simulation (without *thinning* procedures) of even the highest energies for the Pierre Auger Observatory (PAO) [4] in elapsed times of less than a day. At energies above 10^{19} eV the number of particles reaching the observation level exceeds $5 \cdot 10^9$ resulting in a particle data output file size above a TeraByte.

This file size is too large for an easy handling, especially when the outputs of the different CPU-slaves of a parallelized run have to be merged into one particle data output file.

With respect to a precalculated core position within the triangular grid structure of the PAO all particles falling outside of detectors will be skipped and only the particles hitting detectors will be written to the particle data output file. By these means a significant reduction of the particle data output file size to about 0.1% can be achieved.

2 Core Selection

Before starting the simulation the shower core position relative to the triangular grid of the PAO-detectors has to be defined. To reduce the overall computing time up to 20 core locations can be chosen for each single shower event with a quasi-random distribution using a SOBOL random generator [5]. Correspondingly the array of PAO-detectors is placed up to 20 times in the observation plane relative to the shower center and the coordinates of all particles hitting close to a detector are stored. Instead of selecting the core positions at random, alternatively they can be selected in the steering input using the additional keyword AUGHIT (see [6], parameters x$_{shcore}$, y$_{shcore}$ in meters). Up to 20 shower core positions may be selected by separate input lines in arbitrary sequence. For the random selection the first parameter MAUGPOS of the keyword AUGSCT (see [6], default value 20) defines how often each shower is used. The x- and y-coordinates of all core locations are stored within the event header of the particle data output file because they must be available in the analysis of the simulated shower.

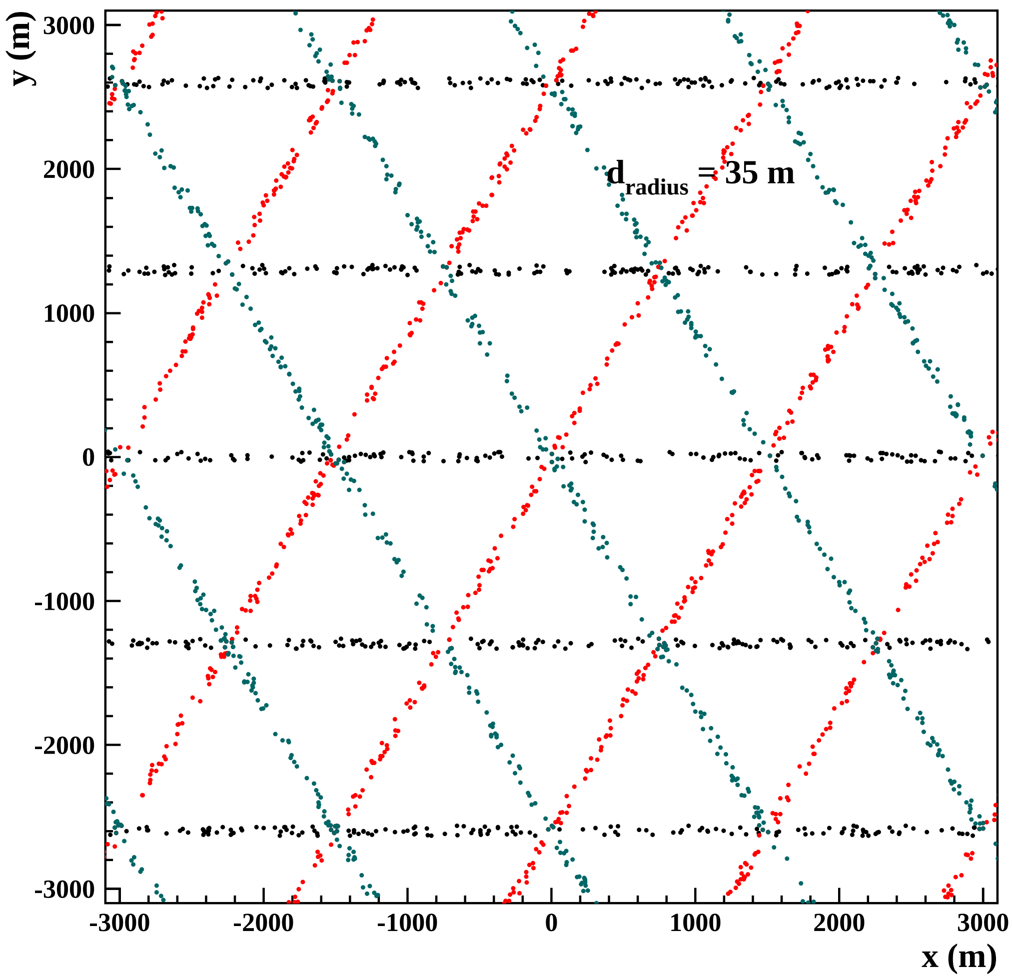

Figure 1: Traces of hits on the three stripes parallel to the detector rows. The width of the stripes is $2\,d_{radius}$ = 70 m, the distance between the detectors (at the crossing point of the traces) amounts to 1500 m.

3 Hitting Particles

The decision whether a particle may hit a detector of the PAO uses a simple and fast procedure to keep the simulation time as low as possible. Without controlling the directional details of each particle it is sufficient to require that it falls onto a circular area with a radius of $d_{radius} = 35$ m (default value of the second parameter of the keyword AUGSCT) around the detector center. With the dimensions of the active volume of the PAO-detector tanks with 1.2 m height and 3.54 m diameter this area is touched by particles with a zenith angle up to $\approx 88°$ for skimming the tank volume at its upper circular edge.

With the triangular structure of the detector array it may be favourable to look for each particle to fall onto a stripe of width $2\ d_{radius}$ which connects the detectors on the x-axis (West-East) of the coordinate system. Equivalently it may hit onto a stripe parallel to this axis in the distance $rowdist$ between the detector rows. See the black traces in Fig. 1. With the distance between the detectors r = 1500 m this row distance calculates to

$$rowdist = r \cdot \sqrt{3}/2 \approx 1299 \text{ m} \ .$$

In a second step it is checked whether the particles fall on one of the parallel stripes which are rotated by $60°$ counter-clockwise relative to the x-coordinate. These hits are marked in red in Fig. 1. The third parallel stripe pattern (in green in Fig. 1) is rotated by $60°$ clockwise. If the particles simultaneously hit all three stripe patterns the area of hits results in a hexagon around a detector. This is drawn in Fig. 2. By this method it is guaranteed that all particles landing within a maximum distance of d_{radius} to a detector are kept for the particle data output file, while the bulk of particles falling outside are discarded from writing.

4 Shower Core

Particles close to the shower core at distances less than 200 m (default of the third parameter CUTRAD of the keyword AUGSCT, see [6] for details) are discarded, as at such small distances the detectors become overloaded and therefore cannot register any hitting particle. A similar suppression of particles too close to the shower core is already available in CORSIKA in the *thinning* option [6].

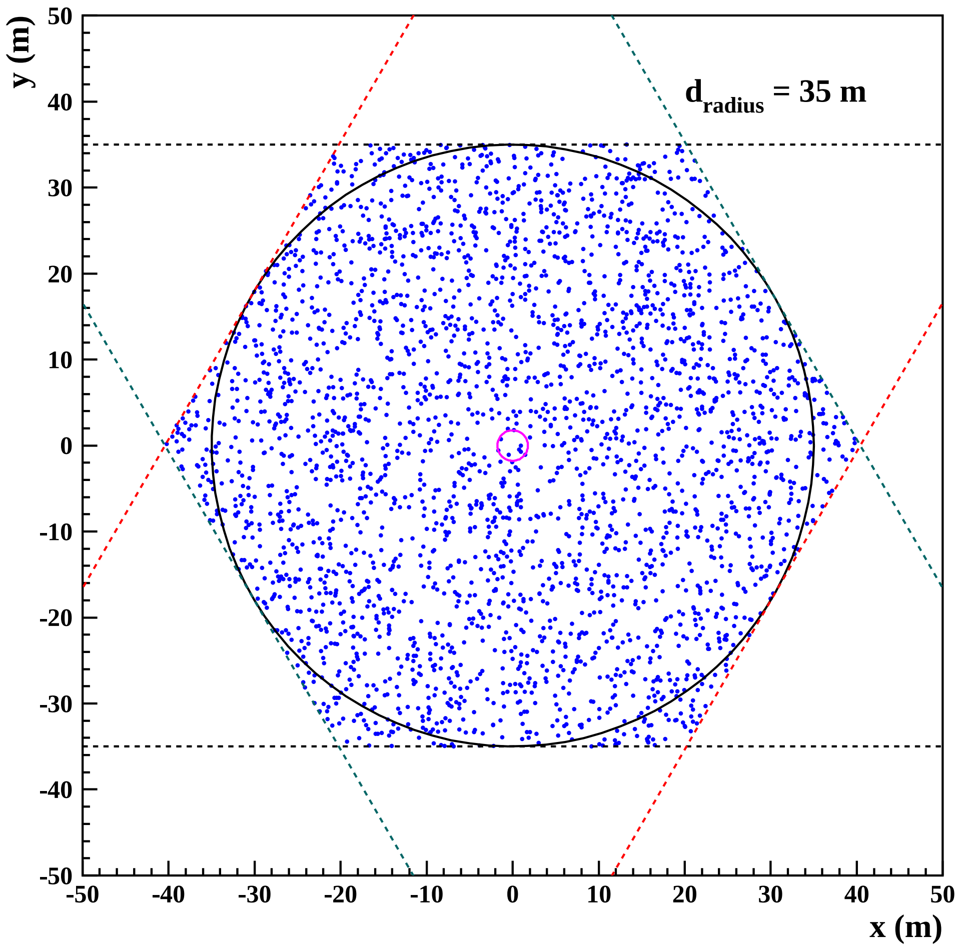

Figure 2: Traces of hits on the hexagonal area around a detector. The detector diameter (drawn in pink) amounts to 3.54 m. The diameter of the black circle inscribing the hexagon amounts to $2\ d_{radius} = 70$ m. The width of the stripes is indicated by the limiting dotted lines in black (West-East), red ($60°$ rotated counter-clockwise), and green ($60°$ rotated clockwise).

5 File Size Reduction

For particles with uniform distribution on the surface detector array the size reduction of the particle data output file may be calculated from the ratio of the active hexagon area F (see the area filled with blue dots in Fig. 2) to the total area between the detectors. It is sufficient to use only the sixth part of the active hexagon and to consider the area A of one triangle spanned by three detector stations at its corners (see Fig. 1):

$$A = 0.5 \cdot r \cdot rowdist = 0.5 \cdot r \cdot r \cdot \sqrt{3}/2 = 0.25 \cdot r^2 \cdot \sqrt{3} \ ,$$

with r the triangles side length and $rowdist$ the triangles height. Within each corner of such a triangle we have 1/6 portion of an active hexagon area, within which a circle of radius d_{radius} may be inscribed (see black circle in Fig. 2)

$$F/6 = d_{radius}^2/\sqrt{3} \ .$$

As we have to consider 3 such portions (one in each corner of the triangle with detectors at the corners) the reduction ratio $ratio$ results in

$$ratio = \frac{A}{3 \cdot F/6} = \frac{0.25 \cdot r^2 \cdot \sqrt{3}}{3 \cdot d_{radius}^2/\sqrt{3}}$$

which simplifies to

$$ratio = 0.25 \cdot r^2/d_{radius}^2 \ .$$

With the distance between the detectors of $r = 1500$ m and the default size of the active hexagon ($d_{radius} = 35$ m of inscribed circle) a reduction ratio of ≈ 460 is attained for uniformly distributed particles.

Moreover, as in the direct neighbourhood of the shower core up to a distance (radius) of 200 m (default value) all particles are rejected from output (because of overload of the detectors) in practical cases the reduction ratio will even be markedly higher. But this reduction ratio has to be divided by the number of the selected core positions, which is restricted to 20. Adopting the default values of the detector geometry and the sensitive area and using each shower with 20 different core positions relative to the triangular PAO-detector grid structure the particle data output file size will be reduced at minimum by a factor of 23.

6 Example

As example we used a shower with the specifications listed in Table 1 employing the PARALLEL option of CORSIKA without *thinning*. Each shower is used 20 times with the shower core locations distributed at random. The scatter of the 20 shower core locations is shown in Fig. 3. By the usage of the SOBOL pseudo-random generator [5] events with overlapping detector areas are prohibited.

Table 1: Parameters of simulated example.

parameter		value
primary particle		proton
primary energy		$10^{18.5}$ eV
zenith angle		18°
azimuth angle		-63.4°
observation level		1452 m
energy cuts	hadrons	100 MeV
	muons	50 MeV
	electrons	250 keV
	gamma	250 keV
magnetic field	horizontal	19.5 μT
	vertical	-14.17 μT
interaction models	high energy	QGSJET-II-4
	low energy	GHEISHA
AUGSCT parameters	number of scatters	20 (randomly selected)
	stripes half width d_{radius}	55 m
	core cut radius	200 m
For all other parameters default values have been used		

The results of the simulations without/with the AUGERHIT option are summarized in Table 2. With identical random seeds the two runs produce the same particles arriving at ground. The markedly different accumulated processing times have to be attributed to the different number of WRITE commands to be executed in the two cases. Most stringent is the reduction of the summed particle data utput file size shrinking from 392 GB without the AUGERHIT option to only 6.9 GB with the AUGERHIT option. Even for the larger radius of $d_{radius} = 55$ m the attained reduction factor of ≈ 57 reaches more than the double of the prognosis calculated in Sect. 5.

Table 2: Properties of example simulated with a multi-core processor system.

	without	with
	AUGERHIT option	
used processors	128	128
accumulated processing time	40.5 d	22.7 d
summed particle data output file size	392.1 GB	6.9 GB
reduction factor	56.8	

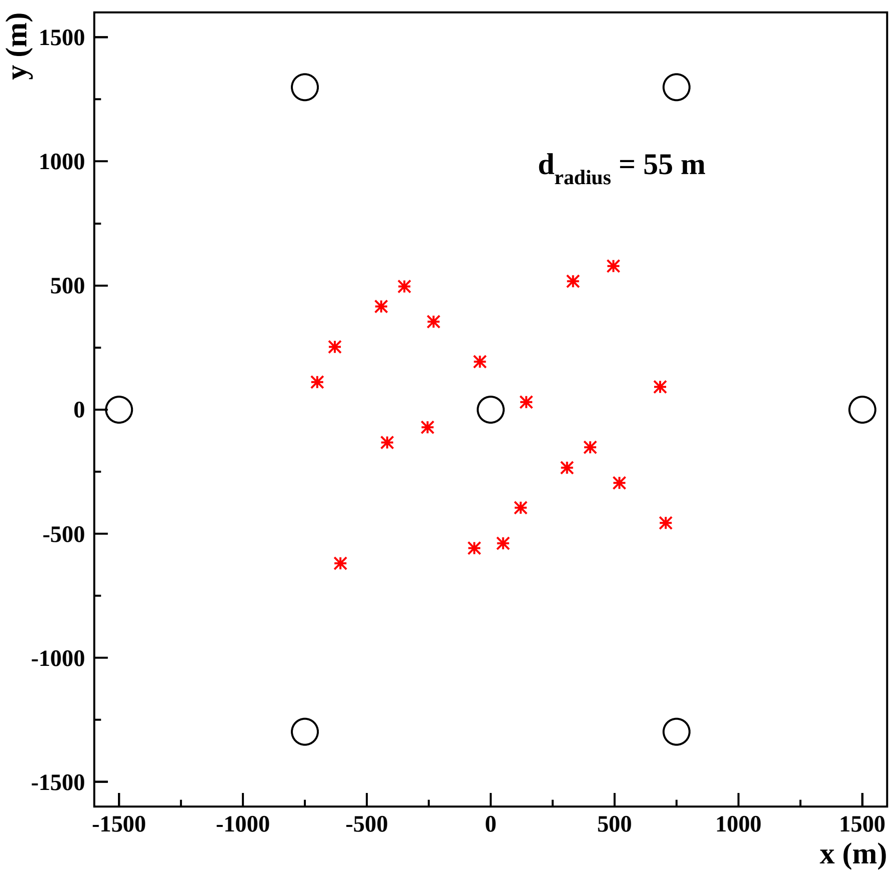

Figure 3: Scatter positions (red crosses) of the shower center relative to the hexagonal grid of detectors (black circles with $2\ d_{radius} = 110$ m diameter).

References

[1] D. Heck, J. Knapp, J.N. Capdevielle, G. Schatz, and T. Thouw, *CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers*, Report **FZKA 6019**, Forschungszentrum Karlsruhe (1998), available from: `https://web.ikp.kit.edu/corsika/physics_description/corsika_phys.html`

[2] D. Heck, R. Engel, T. Pierog, G. Thiara, S. Karla, H. Singla, G. Poghosyan, D. Seldner, and F. Schmitz, *Challenges of simulating air showers at ultra-high energy*, Proc. of Workshop *Computational Methods in Science and Engineering* (SimLabs@KIT 2010), Karlsruhe (Germany), (2010) 87; `http://digbib.ubka.uni-karlsruhe.de/volltexte/documents/1794913`

[3] S. Sharma, G. Poghosyan, T. Pierog, D. Heck, J. Oehlschläger, and R. Engel, *MPI-Runner for CORSIKA Simulations (Algorithms)*, available with the CORSIKA files in subdirectory `doc/MPI-Runner_PHYSICS.pdf`; S. Sharma and G. Poghosyan, *User Guide of MPI-Runner for parallel CORSIKA simulations on computing systems supporting Message Passing Interface*, available with the CORSIKA files in subdirectory `doc/MPI-Runner_GUIDE.pdf`

[4] J. Abraham et al. (Auger Coll.), *Properties and performance of the prototype instrument for the Pierre Auger Observatory*, Nucl. Instr. Meth. **A 523** (2004) 50; *Trigger and aperture of the surface detector array of the Pierre Auger Observatory*, Nucl. Instr. Meth. **A 613** (2010) 29

[5] W.H. Press, S.A. Teukolsky, W.T. Vetterling, and B.P. Flannery, *Numerical Recipes in* FORTRAN *77: The Art of Scientific Computing*, 2^{nd} ed., Cambridge University Press, Cambridge (U.K.), (1992)

[6] D. Heck and T. Pierog, *Extensive Air Shower Simulations with CORSIKA: A User's Guide*, available from: `https://web.ikp.kit.edu/corsika/usersguide/corsika_tech.html`

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