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Monte-Carlo Simulation of Hadronic Showers

Part 5: Simulations in the Atmosphere

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Նախնատիպ ԵՖԻ-1385(15)-92

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ՀԱԴՐՈՆԱՅԻՆ ՀԵՂԵՂՆԵՐԻ ԽԱՂԱՐԿՈՒՄԸ ՄՈՆՏԵ-ՔԱՐԼՈ ԵՂԱՆԱԿՈՎ

ՄԱՍ 5. ԽԱՂԱՐԿՈՒՄՆԵՐ ՄՔՆՈԼՈՐՏԻ ՄԵՋ

MARS10 ծրագրի օգնությամբ կատարված է մքնոլորտի մեջ պրոտոնի սկզբնավորած հեղեղների եռաչափ Մոնտե-Քարլո խաղարկում: Ուսումնասիրված են բարձր էներգիայի սկզբնական պրոտոնից սերված լայնատարած մքնոլորտային հեղեղների (ԼՄՀ) միջին բնութագրիչները: Ստացված է ԼՄՀ-ի էներգիայի անջատման բաշխումը մքնոլորտի 615գ/մ^2 խորության վրա շարված սցինտիլյատորների շերտի մեջ 0.1-100ՏէՎ էներգիայի միջակայքի համար: Կատարված է համեմատություն Նիշիմուրա-Կամատայի լայնական ստրուկտուրային ֆունկցիայի հետ:

ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ

ԵՐԵՎԱՆ 1992

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1. Cascade Simulations

The simulations of proton induced showers in the atmosphere up to ANI facility [1-4] altitude on mountain Aragads were carried out by the MARS10 code [5-7]. The code was written by N. V. Mokhov in mid 70-ies and has been extensively modified and tested by the IHEP (Serpukhov) group over the past years. A weighted Monte-Carlo algorithm is used in MARS, so that only the average characteristics of the shower can be estimated. Typical computing times are of the order of an hour and very logarithmically with the incident energy.

In MARS10 the tabulated values of hadron-nucleus interaction cross sections are used for $E_0 \leq 20$TeV. The simulations for $E_0 > 20$TeV were fulfilled by using the interaction cross section for 20TeV. The simulations were performed in cylindrical geometry - the Z-axis pointed downwards to the center of a R=500m, 5cm thick scintillator array located 615g/cm^2 deep in the atmosphere. The number of shower histories run for each primary energy was 5000. The cutoff energy was set to 10MeV. The primary was a perpendicularly incident proton.

The tabulated values of the atmosphere density as a function of its depth were taken from ref. [8].

The energy dependence of the total deposited energy - E_{tot} is presented in figure 5.1. The EAS energy deposition in the scintillator array - E_{sc} as a function of primary energy is given in figure 5.2. It can be fitted by the formula:

$$E_{sc}(\text{MeV}) = 0.9(\pm 0.2)E_0^{1.2(\pm 0.03)}(\text{GeV}), \qquad (5.1)$$

where

E_0(in GeV) is the primary proton energy. The reduced longitudinal EAS profiles -

$$E/(\rho_i \Delta h_i),$$

where

ρ_i – is the atmosphere density in the Δh_i depth, for 1, 5, 10, 20, 50 and 100TeV incident protons are given in figure 5.3. The reduced lateral EAS profiles –

$$(1/E_{sc})(\Delta E_{sc}/2\pi R\Delta R),$$

where

E_{sc} –is the total energy deposited in the scintillator,

ΔE_{sc} – is the energy deposited within [R,R+ΔR] in the scintillator,

R – is the distance from the EAS core, for 1, 10, 20 and 50TeV primary energies are presented in figure 5.4. The comparison of 20TeV proton induced shower profile with the same energy lateral structure function of electromagnetic showers –

$$(1/r_1)^2 f(R/r_1,s),$$

where

r_1 – is the Moliere unit, s – is the age of shower, is also given in figure 5.4. The last function is evaluated from the tabulated values of the Nishimura – Kamata approximate formulae [9] using an interpolation. The numerical values are taken from ref.-s [10] and [9]. Longitudinally integrated reduced lateral profiles –

$$(1/E)(\Delta E/2\pi R\Delta R),$$

where

E – is the total energy deposited in the atm.,

ΔE – is the energy deposited within [R,R+ΔR] in the atm., for 1, 5, 10, 20, 50 and 100TeV primary energies are presented in figure 5.5.

The leakage energy and the number of leakage particles from the simulating region are presented in Table 5-1.

ACKNOWLEDGEMENTS

We would like to thank Dr.-s N. Mokhov and A. Uzunyan from IHEP(Serpukhov) who made available for us the 10-th version of MARS code.

TABLES

Table 5-1. Leakage of EAS from the simulating region.

Incident Energy, TeV	Leakage Energy, GeV						Number of Leakage Particles		
	Hadrons			Low-Energy Neutrons	Photons and Electrons	Total			
	Backward	Forward	Side				Backward	Forward	Side
0.1	0.002	8.	31.	0.21	22.	61.	0.035	4.	63.
0.2	0.004	18.	47.	0.35	44.	110.	0.043	8.	99.
0.5	0.003	60.	87.	0.67	110.	258.	0.044	21.	188.
1.	0.004	145.	138.	1.04	235.	520.	0.057	44.	333.
2.	0.003	289.	204.	1.73	469.	964.	0.053	128.	454.
5.	0.005	776.	383.	3.37	1314.	2477.	0.140	160.	1039.
10.	0.005	1643.	612.	5.62	2990.	5251.	0.075	368.	1654.
15.	0.004	2734.	738.	7.24	4798.	8278.	0.072	541.	2065.
20.	0.010	3365.	854.	9.20	6658.	10887.	0.194	685.	2392.
50.	0.006	9259.	1620.	14.95	19000.	29894.	0.081	1355.	4695.
100.	0.002	13990.	2493.	22.63	37580.	54086.	0.067	1919.	6866.

Table 5-1. (Continuation).

Incident Energy, TeV	Number of Leakage Particles: The Rear Plane, 16750m p	n	$\pi^{\pm}$	The External Cylinder, 500m p	n	$\pi^{\pm}$
0.1	1.	1.	2.	10.	28.	25.
0.2	2.	2.	4.	15.	44.	40.
0.5	3.	7.	11.	26.	89.	73.
1.	6.	14.	24.	38.	173.	122.
2.	10.	60.	58.	64.	213.	177.
5.	25.	39.	96.	146.	527.	366.
10.	61.	118.	189.	223.	821.	610.
15.	60.	134.	347.	285.	1070.	710.
20.	111.	159.	415.	266.	1150.	976.
50.	136.	353.	866.	565.	2590.	1540.
100.	284.	395.	1240.	896.	3780.	2190.

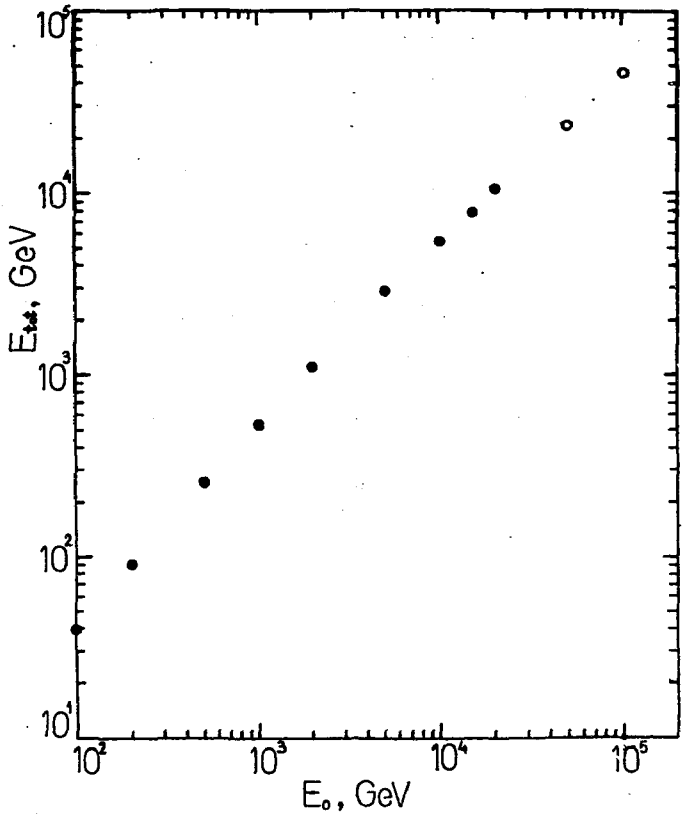

Fig. 5.1

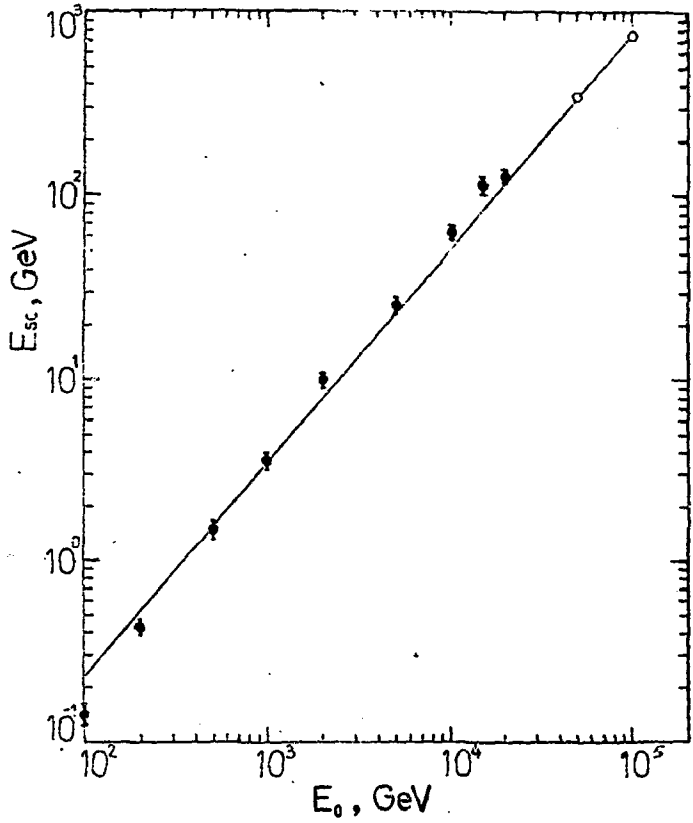

Fig. 5.2

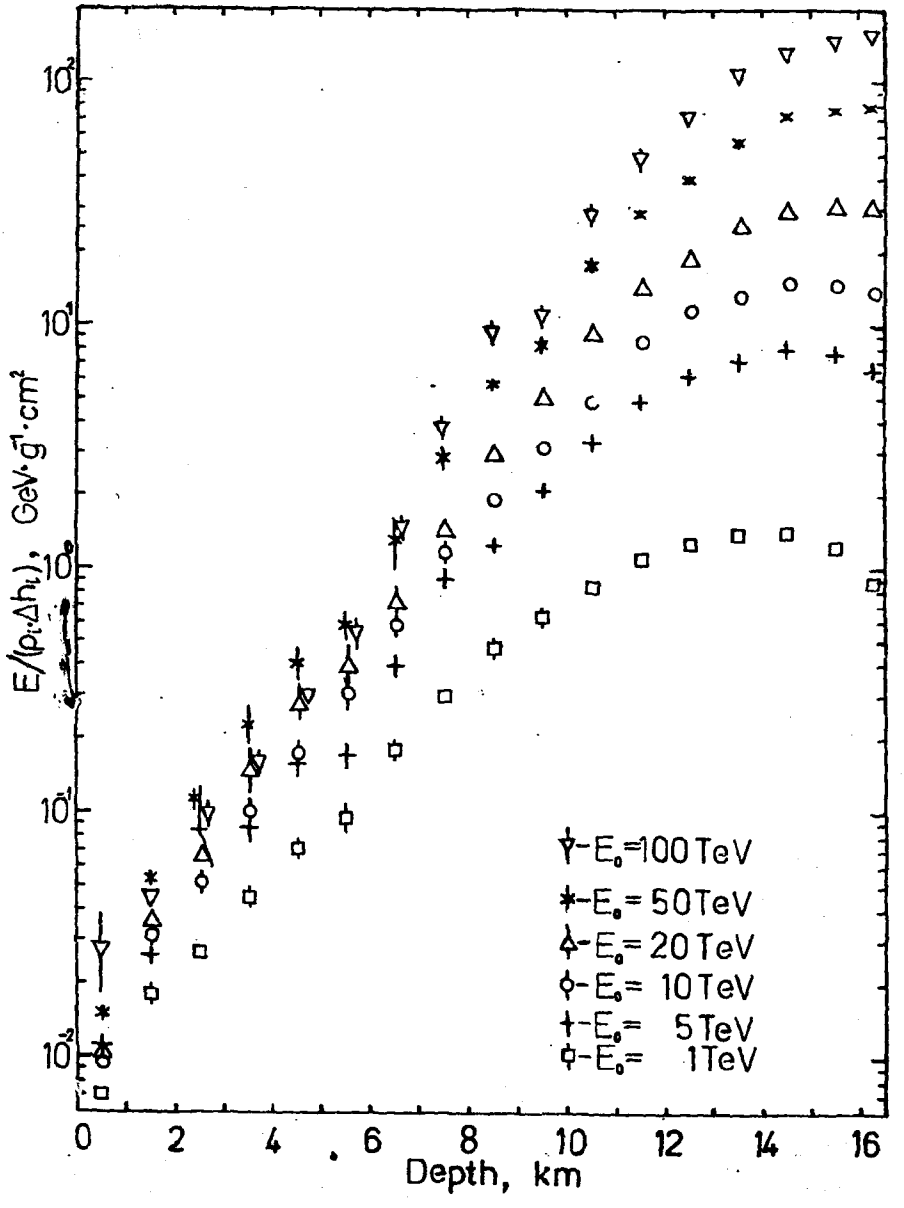
10^2
10^1
10^0
10^{-1}
10^{-2}
$E/(\rho_i \cdot \Delta h_i)$, GeV·g^{-1}·cm^2
0
2
4
6
8
10
12
14
16
Depth, km
∇-E_0=100 TeV
*-E_0= 50 TeV
Δ-E_0= 20 TeV
o-E_0= 10 TeV
+-E_0= 5 TeV
□-E_0= 1 TeV

Fig. 5.3

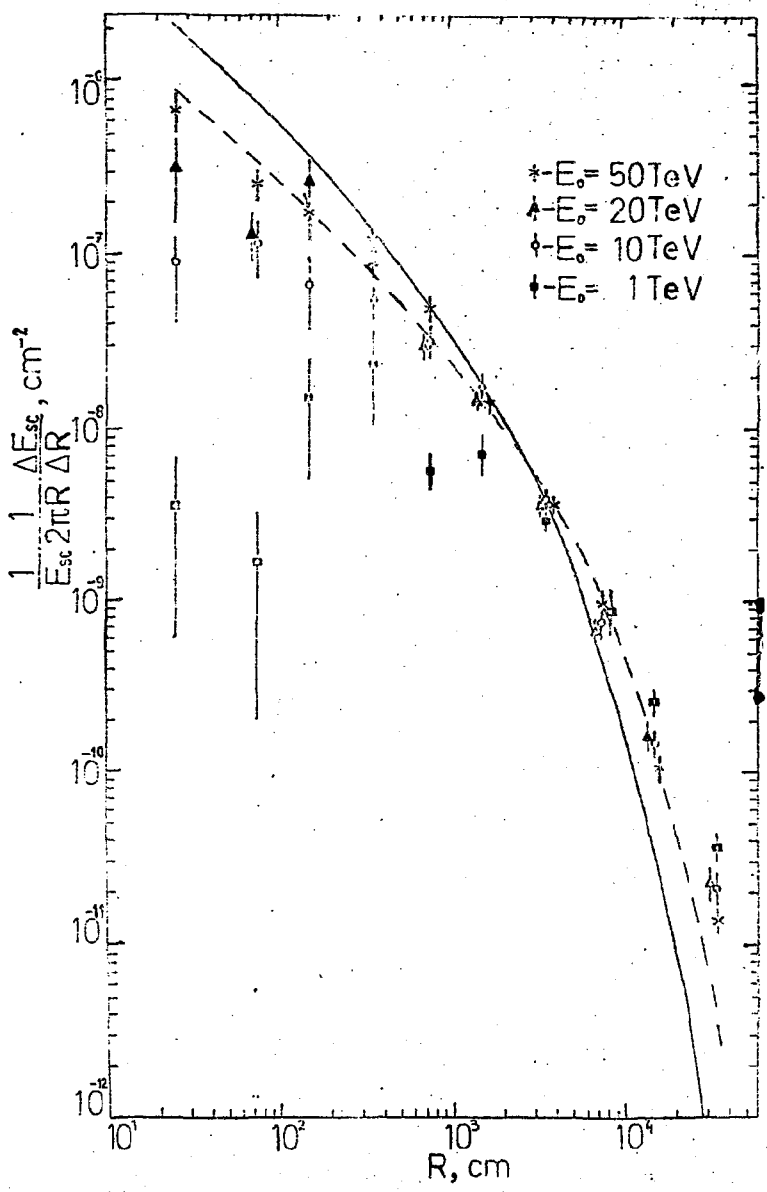
*-E₀= 50TeV
▲-E₀= 20TeV
◆-E₀= 10TeV
♦-E₀= 1TeV
$\frac{1}{E_{sc}}\frac{1}{2\pi R}\frac{\Delta E_{sc}}{\Delta R}$, cm⁻²
R, cm

Fig. 5.4

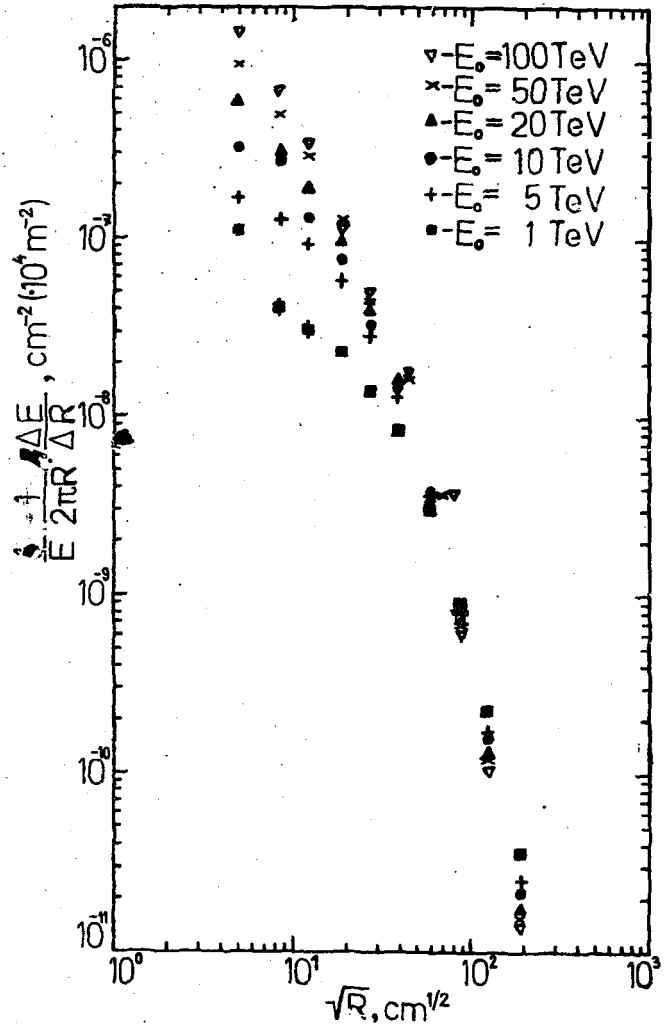
▽-E₀=100TeV
×-E₀= 50TeV
▲-E₀= 20TeV
●-E₀= 10TeV
+-E₀= 5TeV
■-E₀= 1 TeV
$\frac{1}{E}\cdot\frac{1}{2\pi R}\cdot\frac{\Delta E}{\Delta R}$, cm⁻²(10⁴m⁻²)
√R, cm^1/2

Fig. 5.5

FIGURE CAPTIONS

Fig. 5.1. Dependence of total deposited energy on primary energy.

Fig. 5.2. Dependence of EAS energy deposition in the scintillator array on primary energy. ♦ and o - MARS10, solid line - is a fit (formula (5.1)).

Fig. 5.3. Reduced longitudinal EAS profiles.

Fig. 5.4. Reduced lateral energy deposition of EAS in the scintillator array. ♦, ▲, ◊ and ■ - MARS10; solid and dashed lines - are the Nishimura - Kamata structure function in Approximation B at E_0 = 20TeV for three- and one- dimensional cascades respectively.

Fig. 5.5. Reduced lateral EAS profiles.

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МОДЕЛИРОВАНИЕ АДРОННЫХ ЛИВНЕЙ МЕТОДОМ МОНТЕ-КАРЛО
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