ESWW-2

Israeli semi-underground great plastic scintillation multidirectional muon telescope (ISRAMUTE) for space weather monitoring and forecasting

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Now in the frame of Israel Cosmic Ray and Space Weather Center under construction is semi-underground great plastic scintillation multidirectional muon telescope (ISRAMUTE) with more than two thousand single telescopes in vertical and many inclined directions at different zenith and azimuthally angles. By ISRAMUTE will be determined for each hour the cosmic ray distribution function out of the Earth's magnetosphere (by using spectrographic method and coupling functions), and estimate the moving from the Sun CME and interplanetary shock wave for about 15-20 hours before they captured the Earth (i.e. before the start of big geomagnetic storm). The scintillators of ISRAMUTE will be used also for continue measuring of electron-photon and muon EAS arriving in vertical and at different inclined directions. This will expand the spectrum of measured primary cosmic rays up to very high energies. By using ISRAMUTE in complex with other cosmic ray data (available in real time scale from Internet) we plane to realize the program of continue monitoring of space weather and forecasting dangerous situations.

1. Introduction

The Israel Cosmic Ray and Space Weather Center (ICR&SWC) and Israeli-Italian Emilio Segre' Observatory (ESO) were established in 1998, with affiliation to Tel Aviv University, to the Technion (Israel Institute of Technology, Haifa) and to the Israel Space Agency (under the aegis of the Ministry of Science). The mobile CR Neutron Monitor was prepared by the collaboration of Israeli scientists of ICR&SWC /ESO (headed by Prof. Lev Dorman) with Italian scientists of CR Group of Roma-Tre University (headed by Prof. Nunzio Iucci) and of the Cosmic Radiation Sector IFSI/CNR (headed by Dr. Giorgio Villoresi), and transferred in June 1998 on Mt. Hermon (33°18' N, 35°47.2' E, 2,025 m above sea level, vertical cut off rigidity R_c = 10.8 GV). The results of measurements (data taken at one minute intervals of CR neutron total intensities at two separate 3NM-64 sections, as well as similar one minute data about the intensities relating to neutron multiplicities m = 1, 2, 3, 4, 5, 6, 7 and ≥ 8) are stored in the computer. Similar one minute data relating to the atmospheric electric field, wind speed, three components of geomagnetic field, air temperature outside, and humidity and temperature inside the CR Observatory are also recorded and archived. Each month one hour data of ESO are sent to the World Data Center in Boulder (USA, Colorado) and to many CR Observatories in the world. An automatic electric power supply using Uninterruptible Power Supply (UPS) and a diesel generator guarantees continuous power for ESO. There is a direct radio connection in real time from ESO on Mt. Hermon to the Central Laboratory of ICR&SWC in Qazrin, and to the Internet. To extend the experimental basis of ICR&SWC ESO on Mt. Hermon (see in [1]) and a great semi-underground plastic scintillation multidirectional muon telescope are now under construction, with more than two thousand two-coincidences channels for vertical and inclined directions at different zenith and azimuthal angles together with EAS installation in a former bomb shelter in Qazrin, which will be described shortly below.

2. Description of semi-underground multi-directional muon telescope in Qazrin

A semi-underground multi-directional muon telescope is presently under construction in collaboration with the CR Group of the University New Mexico (headed by Prof. H. Ahluwalia). Figure 1 shows the scintillation detector for this underground muon telescope.

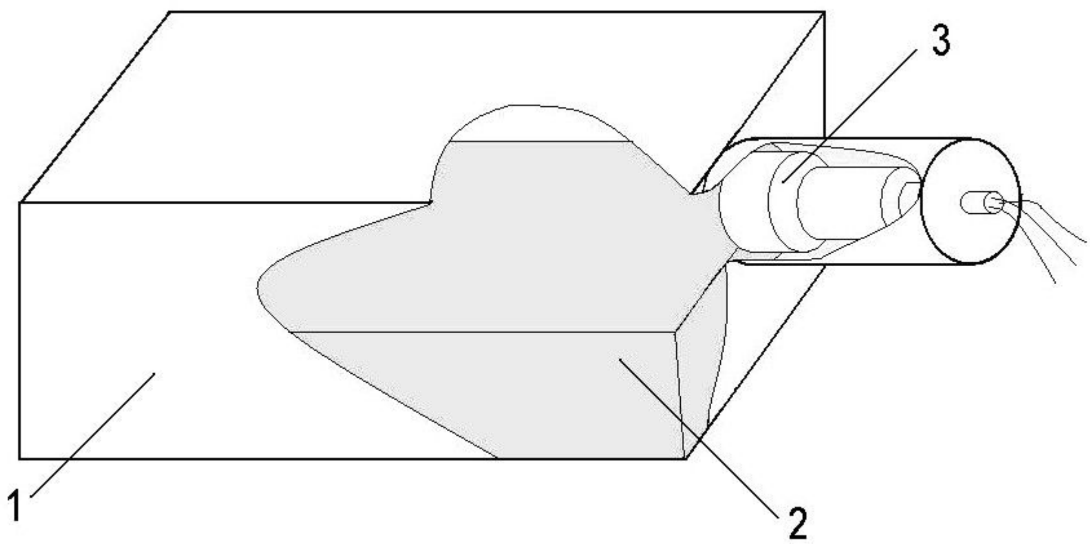

Figure 1. Scintillation detector for the semi-underground multi-directional muon telescope in Qazrin (Israel). 1 – box with reflector, 2 – plastic scintillator 50 cm × 50 cm × 10 cm, 3 – photomultiplier.

Figure 2 depicts the planned underground multidirectional muon telescope that will start to work in Qazrin in near future.

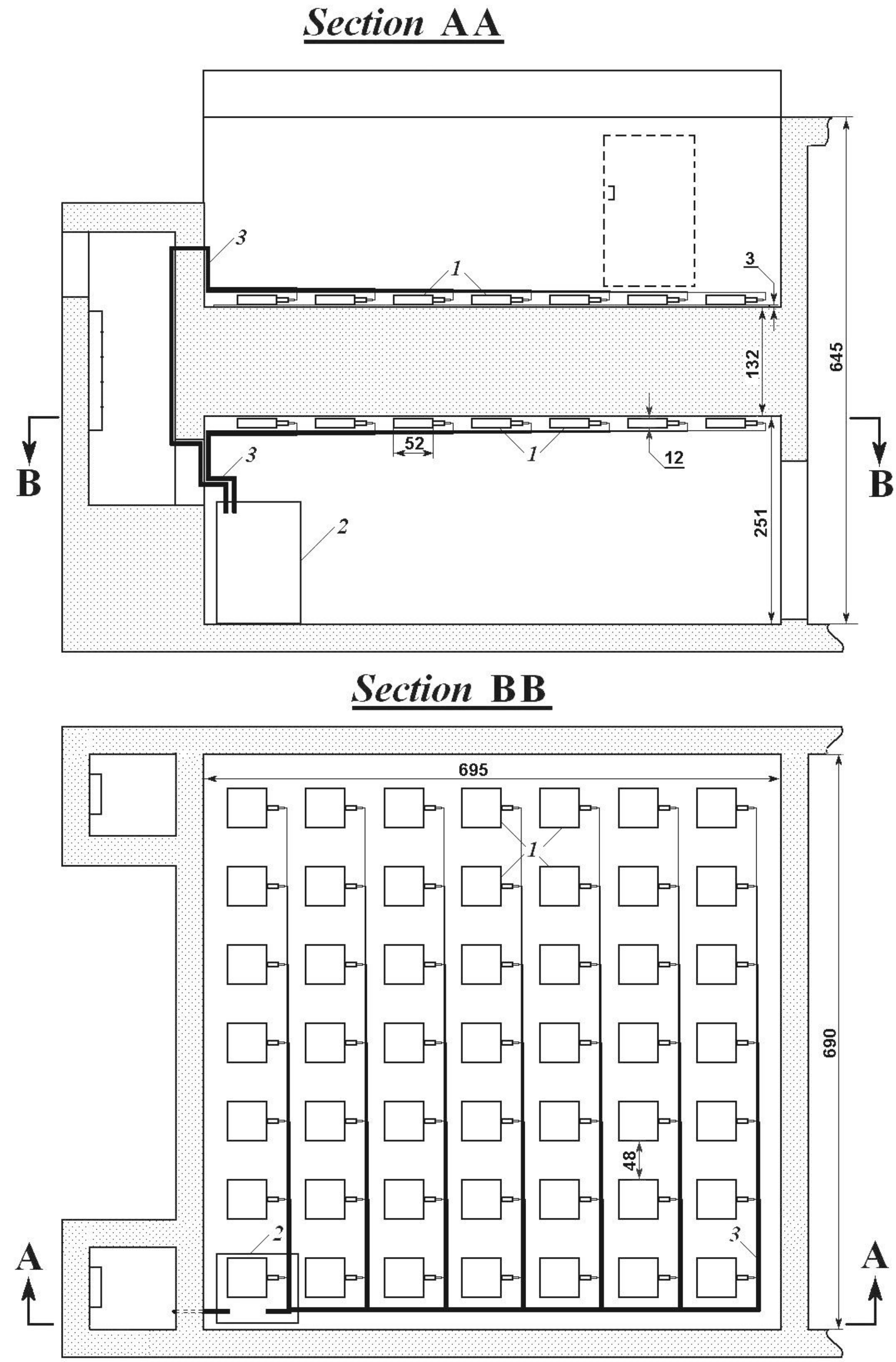

Figure 2. The disposition of the semi-underground multidirectional muon telescope in the in a former bomb-shelter in Qazrin, Israel (with characteristics partly listed in Table 1). 1- scintillation detectors (see Figure 1); 2- acquisition system and computers; 3 – connection and power feeders. Dimensions are given in cm.

In Table 1 is given short information only for 997 double-coincidence telescopes from total 2401. The counting rates of double-coincidence telescopes at the same zenith and azimuth direction are summarized.

Table 1. Channels of planned semi-underground multi-directional muon telescope in ICRC/ESO.

No.	Channel title	Azimuth angles, degree	Zenith angle, degree	Number of telescopes in each direction	Expected counting rate per hour	Statistical error for 1 hour, %
1	Vertical		0	49	1782878	0.07
2	N1, W1, S1, E1	0, 90, 180, 270	31.8	42	574890	0.13
3	NW1, SW1, SE1, NE1	45, 135, 225, 315	41.3	36	236011	0.21
4	N2, W2, S2, E2	0, 90, 180, 270	51.1	35	77619	0.36
5	NW2, SW2, SE2, NE2	45, 135, 225, 315	60.3	25	13373	0.86
6	N3, W3, S3, E3	0, 90, 180, 270	61.8	28	11427	0.94
7	N4, W4, S4, E4	0, 90, 180, 270	68.1	21	2078	2.19
8	NW3, SW3, SE3, NE3	45, 135, 225, 315	69.2	16	1165	2.93
9	N5, W5, S5, E5	0, 90, 180, 270	72.1	14	424	4.86
10	N4W4, S4W4, S4E4, N1E4	45, 135, 225, 315	74.1	9	138	8.50
11	N6, W6, S6, E6	0, 90, 180, 270	75.0	7	78	11.36
12	N5W5, S5W5, S5E5, N5E5	45, 135, 225, 315	77.2	4	18	23.91
	Total in 45 directions			997	5451767	0.04

3. Description of EAS array combined with semi-underground multi-directional muon telescope in Qazrin

By coincidences in different combinations of upper scintillators, we obtain counting of EAS (electron-photon component). This array can be considered as local because the distances between detectors are much smaller than the effective radius of EAS on the level of observations. In this case, on passage of EAS of density ρ (mean number of particles per 1 m^2) the probability that not a single particle will pass through a detector of effective area σ will be $\exp(-\rho\sigma)$. The probability of at least one particle crossing through a detector will be $\omega = 1 - \exp(-\rho\sigma)$. The particle distribution in EAS may be represented in the form $\rho(r) = u(r)N_e$, where r is the distance from the EAS axes, N_e is the total number of particles in electron-photon component of EAS, and $u(r)$ is the function satisfying the normalization condition and has the form:

$$2\pi \int_0^\infty u(r) r dr = 1 ; \qquad u(r) = \begin{cases} ar^{-1} \exp(-r/r_o) & \text{if } r \le r_o, \\ u(r) = br^{-2.6} & \text{if } r \ge r_o . \end{cases} \tag{1}$$

Here r_o is the effective radius of the shower (r_o = 55 m for sea level observations, and r_o = 80 m for mountain observations on the level about 3 km). Coefficients a and b are determined from the condition of normalizing and of tie-in of the function $u(r)$ at the point $r = r_o$. It gives on the basis of Eq. (1):

$$a = er_o^{-1}\left[2\pi(e(1-1/e)+1/0.6)\right]^{-1} = 0.12781 \times r_o^{-1}; \; b = r_o^{0.6}\left[2\pi(e(1-1/e)+1/0.6)\right]^{-1} = 0.04702 \times r_o^{0.6} \quad . \tag{2}$$

Eq. (2) gives for the level of mountain (altitude 3 km, r_o = 80 m) a = 1.598×10^{-3} m^{-1}, b = 0.6518 m$^{0.6}$; for Mt Hermon (altitude 2 km, r_o = 72 m) a = 1.775×10^{-3} m^{-1}, b = 0.6119 m$^{0.6}$; for sea level (r_o = 55 m) a = 2.3324×10^{-3} m^{-1}, b = 0.5206 m$^{0.6}$;

Let us suppose that the axis of EAS with total number of particle N_e crossed the observation level in some point P and actuated simultaneously any n detectors of array with total m detectors (meaning that through each of these n detectors crossed at least one particle from total number N_e in EAS) and not actuated other any $m - n$ detectors. Let the distance from point P to the detector i is r_i (i = 1, 2, … m). In this case the probability to detect this EAS will be

$$\omega_{nm}(P) = C_m^n \prod_{i=1}^{n}(1-\exp(-\rho_i\sigma)) \prod_{i=n+1}^{m}\exp(-\rho_i\sigma) \approx C_m^n (1-\exp(-u(r)N_e\sigma))^n \exp(-(m-n)u(r)N_e\sigma) \quad (3)$$

where $C_m^n = m!(n!(m-n)!)^{-1}$. In Eq. (3) we take into account that in our case the distances between detectors $<< r_o$, therefore we can put for all $r_i \approx r$, where r is the distance from point P to the center of installation. Let us take into account also that $N_e \approx 0.3E_o^s$, where E_o is the energy of primary particle in GeV, and $s \approx 1.1$ at mountain level 3 km, and $s \approx 1.2$ at sea level. Because P may be elsewhere, the total probability to detect EAS with N_e particles (generated by primary particle with energy E_o) simultaneously by any n detectors of the local installation with total m detectors will be in the unity of time

$$\omega_{nm}(N_e, r_o, \sigma)dN_e \approx 2\pi C_m^n D(N_e)dN_e \int_0^\infty (1-\exp(-u(r)N_e\sigma))^n \exp(-(m-n)u(r)N_e\sigma) r dr; \quad (4)$$

$$\omega_{nm}(E_o, r_o, \sigma)dE_o \approx 2\pi C_m^n D(E_o)dE_o \times$$

$$\times\left\{\int_0^{r_o}\left(1-\exp\left(-0.03834 r_o^{-1} r^{-1}\exp(-r/r_o)E_o^s\sigma\right)\right)^n \exp\left(-0.03834 r_o^{-1} r^{-1}(m-n)\exp(-r/r_o)E_o^s\sigma\right) r dr + \right.$$

$$\left. + \int_{r_o}^{\infty}\left(1-\exp\left(-0.01411 r_o^{0.6} r^{-2.6} E_o^s\sigma\right)\right)^n \exp\left(-0.01411 r_o^{0.6} r^{-2.6}(m-n)E_o^s\sigma\right) r dr \right\}, \quad (5)$$

where $D(N_e)$ and $D(E_o)$ are differential spectrums of EAS, and E_o is in GeV, r_o is in m, σ is in m^2. The expected counting rate $I_{nm}(r_o, \sigma)$ (i.e. number of detected EAS per unity of time by any n coincidences from total m detectors with effective area σ each) will be

$$I_{nm}(r_o, \sigma) = \int_0^\infty \omega_{nm}(N_e, r_o, \sigma)dN_e = \int_0^\infty \omega_{nm}(E_o, r_o, \sigma)dE_o. \quad (6)$$

The coupling functions characterized the sensitivity of installation to detect EAS will be

$$W_{nm}(N_e, r_o, \sigma) = \omega_{nm}(N_e, r_o, \sigma)/I_{nm}(r_o, \sigma); \; W_{nm}(E_o, r_o, \sigma) = \omega_{nm}(E_o, r_o, \sigma)/I_{nm}(r_o, \sigma). \quad (7)$$

It is easy to see that these coupling functions are normalized for any E_o, σ, n and m:

$$\int_0^\infty W_{nm}(N_e, r_o, \sigma)dN_e = \int_0^\infty W_{nm}(E_o, r_o, \sigma)dE_o = 1. \quad (8)$$

The differential energy spectrum of primary CR can be represented by (in units $m^{-2}sec^{-1}GeV^{-1}sr^{-1}$):

$$D(E_o) = \begin{cases} 2.2\times10^4 \times E_o^{-2.7}, & \text{if } E_o \le 3\times10^6\, GeV \\ 3.8105\times10^7 \times E_o^{-3.2}, & \text{if } E_o \ge 3\times10^6\, GeV \end{cases} \tag{9}$$

The expected dependence of counting rate in dependence of n is shown in Figure 3. The coupling functions for sea level for different n at $m = 45$ are shown in Figure 4.

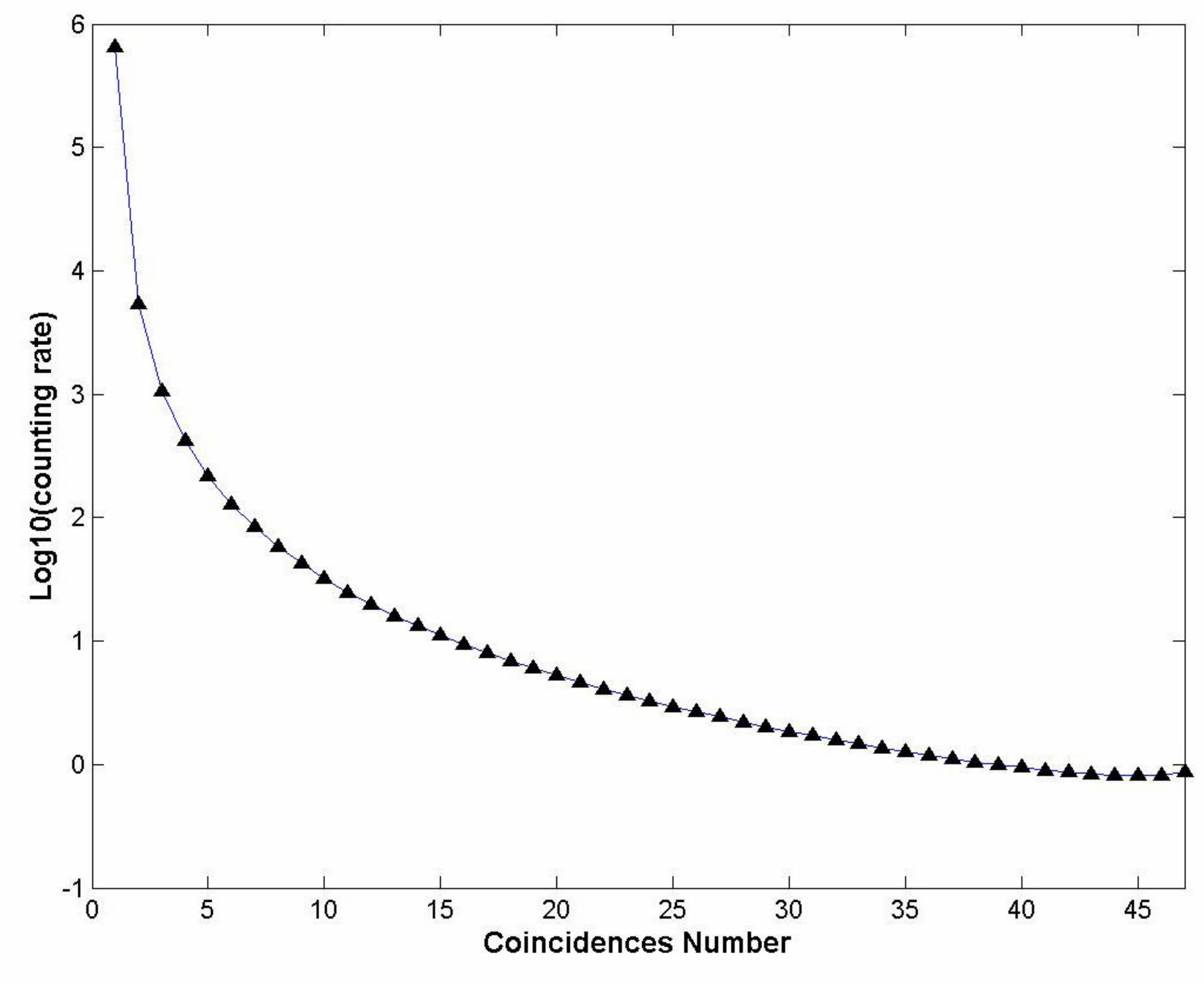

Figure 3. The expected dependence of counting rate of EAS per sec in dependence of n for the EAS installation in the bomb-shelter in Qazrin.

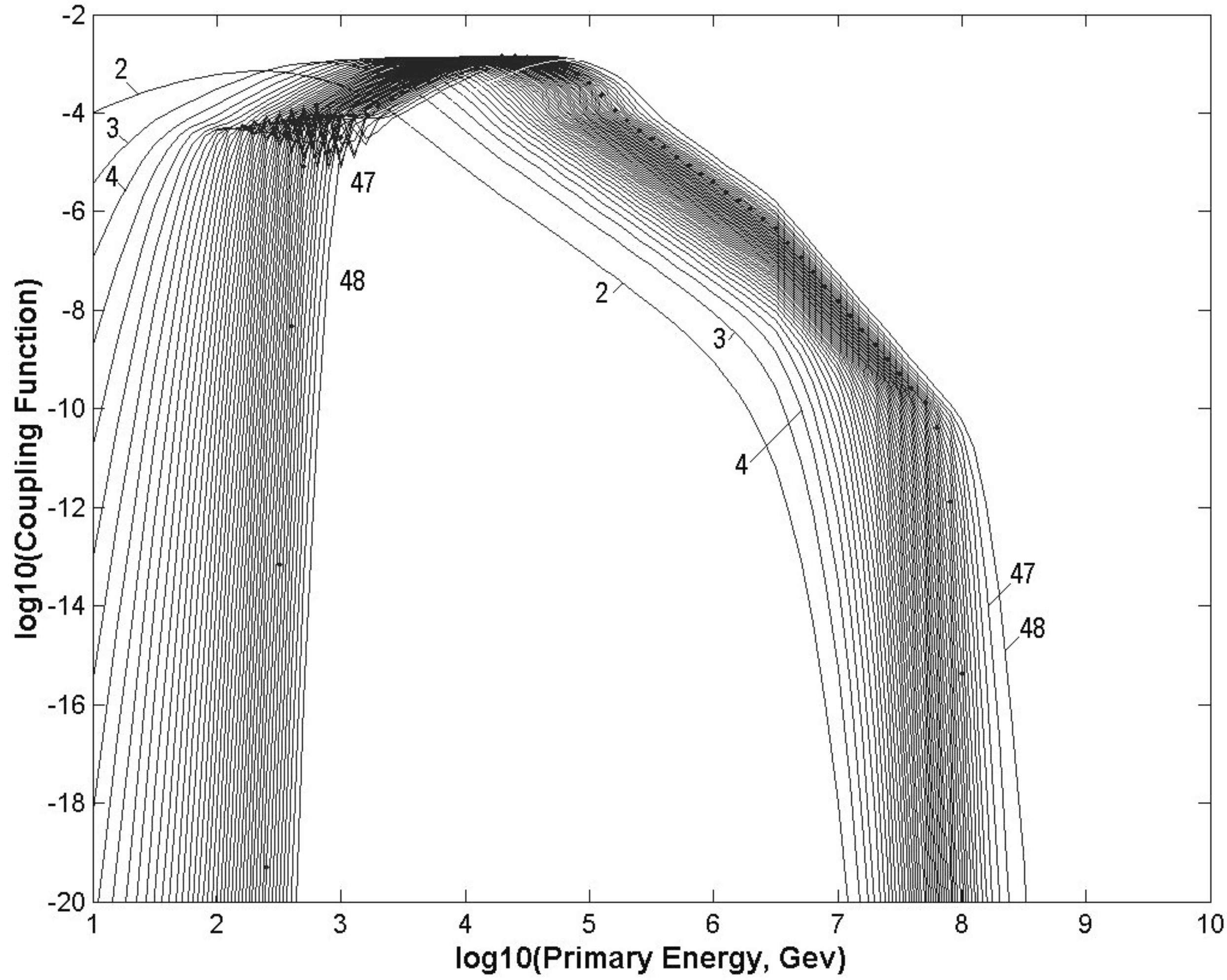

Figure 4. The coupling functions for sea level for different *n* at *m* = 45 for the EAS installation in the bomb-shelter in Qazrin. From right to left for *n* from 2 up to 48.

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