Neutron and Muon Flux Measurements at BEO Moussala towards to Space Weather Research

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***Abstract*—The Basic Environmental Observatory BEO Moussala is located at 2925m above sea level and one of the main activities is connected with environmental monitoring and cosmic ray studies. In this work in details are presented the existing devices for neutron flux measurements and secondary cosmic ray muons at BEO Moussala observation level.**

The design of neutron flux meter based on SNM-15 detectors is shown and the simulations carried out with MCNP(x) code are presented. The estimations of the expected counting rate are obtained and preliminary studies of the influence of several environmental effects are studied. With MCNP(x) code is obtained the thickness of the moderator using the measured secondary cosmic ray neutron spectrum at Testa Grigia. The project for muon hodoscope is focused. The scientific potential of the existing and in development devices is discussed.

I. Introduction

The high mountain observatories have been exploited during the years for cosmic ray but also for environmental studies. The Basic Environmental Observatory BEO Moussala is located on the top of the highest mountain at Balkan peninsul. This is one of the most proper places in the region of Balkans and gives excellent possibility for high-mountain monitoring i.e. possibilities for measurements, experiments and monitoring for changes and processes in the atmosphere, as example the pollution, air-transport, aerosol investigations, changes of gamma-background, dose-rate from neutron flux, cosmic ray investigations etc… At the same time the analyses of collected data gives information about relation between very different kind of parameters and factors.

The connection between low energy cosmic ray and the Earth atmosphere is obvious. As example the variations of the cosmic rays which may be responsible for the changes in the large-scale atmospheric circulation associated with solar activity phenomena [1]. Thus the measurements of secondary cosmic ray neutrons and muons are very important. At the same time such type of measurements gives good basis for study of solar-terrestrial influences and space weather. Moreover the ability to forecast for long term space weather needs a precise knowledge of solar activity.

The space weather refers to conditions on the sun, solar wind and Earth's magnetosphere and ionosphere [2]. Several characteristic signatures in cosmic ray may be used for space weather applications [3] on the basis of neutron monitor data. Good examples are the solar proton events and Geomagnetic storms.

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II. Neutron measurements

As was mentioned above one of the main activities carried out at BEO Moussala is connected with secondary cosmic ray neutron measurements. The secondary cosmic ray neutrons are produced by interaction of primary cosmic ray protons or other nuclei with atmosphere nuclei, and the neutron production rate and energy distribution strongly depend on the atmosphere physical characteristics such as the chemical composition, humidity, cloud density. With this in mind neutron flux meter for absolute measurement of secondary cosmic ray neutron flux at BEO Moussala is constructed. The scientific potential of detector complex at high mountain altitude is huge. The relativistic cosmic rays both galactic and solar may be registered by neutron monitors and in our case neutron flux meters. They can play a useful key in space weather storms forecasting and in the specification of magnetic properties of coronal mass ejections, shocks and ground level enhancements [4]. Moreover the complex gives the possibility to register solar proton events and thus to investigate the time variation of atmospheric pressure and circulation [5]. Such type of events reflects on the atmospheric temperature [6].

The detector complex is based on gas filled detectors type SNM-15 with BF_3 enriched to 90% with B^{10}. The detectors are situated under the roof of the main building of BEO Moussala. The complex is divided in two modules each one of 3 detectors. In Fig.1 is shown the front panel inside the station of the first module. This detector configuration is without lead i.e. is only with neutron moderator. This is the main difference comparing to the usual neutron monitors.

The detailed and precise Monte Carlo modeling of the

Fig. 1. Front panel of the first module of the neutron flux-meter at BEO Moussala

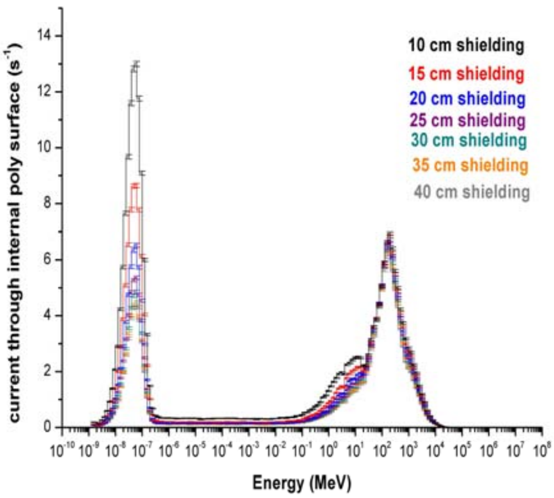

Fig. 2. Simulated total neutron current trough internal detector surface

detector response was carried out, the aim being to estimate the expected counting rate. First the moderator layer is estimated using the spectrum obtained from experimental measurements of neutron spectra at High Mountain Observatories in [7]. The results of the simulations as a total neutron current trough internal detector surface are presented in Fig.2. In this case the simulations were carried out using simplified spherical source, actually uniformly distributed neutrons in sphere and simplified geometry model of the detector. This permitted to choose the moderator layer to 12.5 cm.

The final design is with glycerin moderator with the same thickness. The moderator is contained in cylindrical tanks. An additional analysis and simulations are carried out aiming the total cross section for neutrons having different energies with polyetilen and glycerin comparison. Moreover the influence of the thickness of the stainless steal of detector was estimated. The results of this study are presented in Fig.3.

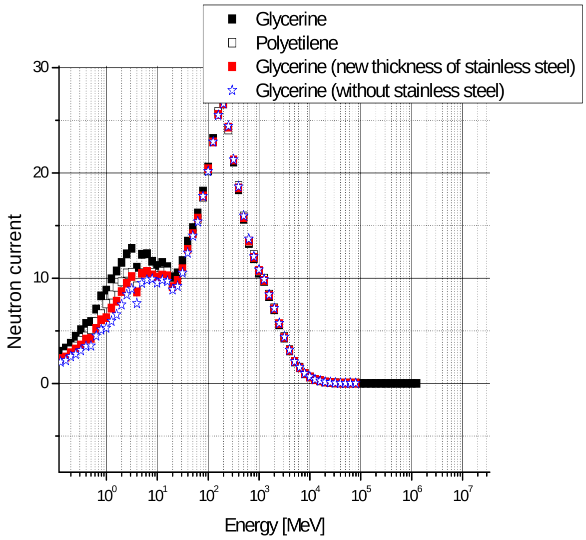

Fig. 3. Comparison of the neutron current with different moderators and taking into account the thickness of stainless steal

The cross section for elastic processes for glycerin and polyetilen in the energy range of interest is in practice with the same shape with difference less then 5%. The main result of the simulations shows that the use of glycerin moderator instead of polyetilen moderator is reasonable. Thus it is possible to provide measurements with similar quality as the usual polyetilen moderator.
The detector electronics within the data acquisition system was developed in INRNE-BAS. The differential spectrum of the detectors was obtained using neutron flux [8]. The estimated registration efficiency is between 0.5 and 3%.

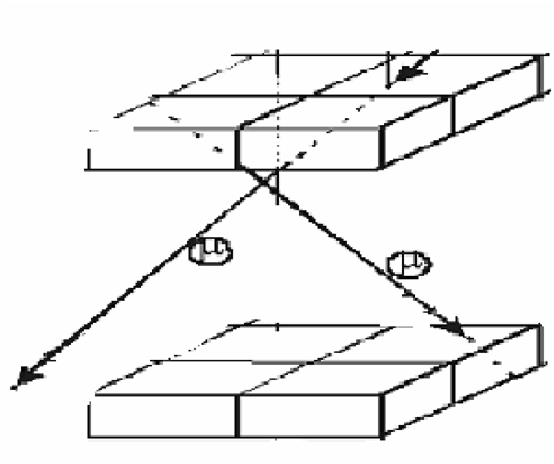

Fig. 4. Muon telescope based on water Cherenkov detectors

III. Muon Measurements

The constructed muon telescope is complementary to neutron flux meter Fig.4. The muon telescope is based on 8 water Cherenkov detectors. The water Cherenkov detector is a tank with 50x50x12cm with one photomultiplier Fig.5.

The principal aim is to investigate the variations of cosmic ray. Obviously it is possible to detect Forbush decrease. This permits to study the influence of galactic cosmic rays on the solar radiation input to the lower atmosphere, especially increases of the total radiation fluxes associated with Forbush-decreases in the galactic cosmic rays [9]. Moreover it is possible to investigate the variations of the pressure level heights, temperature profiles and wind characteristics in the troposphere and lower stratosphere during Forbush-decreases of the galactic cosmic rays [10]. The Forbush-decreases are accompanied by the pressure increase in the whole troposphere, the maximum of the effect taking place on the 3–4th day after the event onset. Simultaneously the temperature decrease is observed in the troposphere during the first few days of the Forbush-decreases. The pressure increase might be related to the changes of wind characteristics in the middle and upper troposphere. A possible mechanism of the observed effects seems to involve radiation budget changes in the atmosphere due to the cloudiness variations associated with

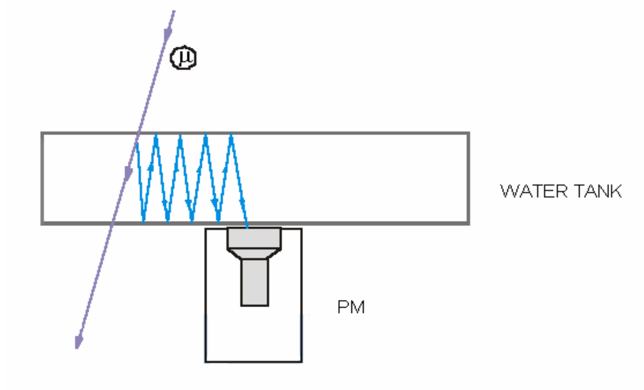

Fig. 5. Water Cherenkov detector with photomultiplier

Forbush-decreases of the galactic cosmic rays. Thus the simultaneous measurements of cosmic ray variations and atmospheric parameters at BEO Moussala are very important.

For real time researches of solar-terrestrial relations it is required to register simultaneously as more as possible of phenomena in heliosphere. In this connection it may be very useful to use ground-based muon hodoscope with high angular resolution that detects muons of cosmic rays with energy around 10GeV. Solar flares, scattering of protons by interplanetary shock waves, fluctuations of the air density distribution in the atmosphere will change ground level muon intensity. Amplitude of such variations can reach maximal value in various energy-active regions of the Earth near magnetic poles, tropics, sea coast of continents etc.

The muon hodoscope represents multi-channel device generally based on plastic scintillators. The original design of the hodoscope [11] is 512-channel large aperture muon hodoscope the aim being the investigation of solar-terrestrial physics. The estimated threshold of primary cosmic ray is 10 GeV. The estimated accuracy of measurement of cosmic ray muon directions is about 1-2 degree. The area of the

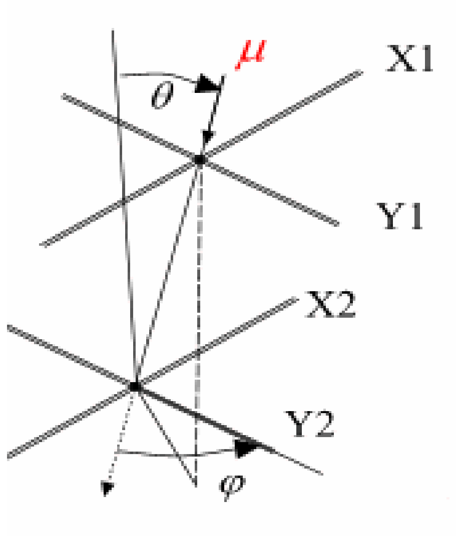

Fig. 6. Angles with detection principle of muon hodoscope.

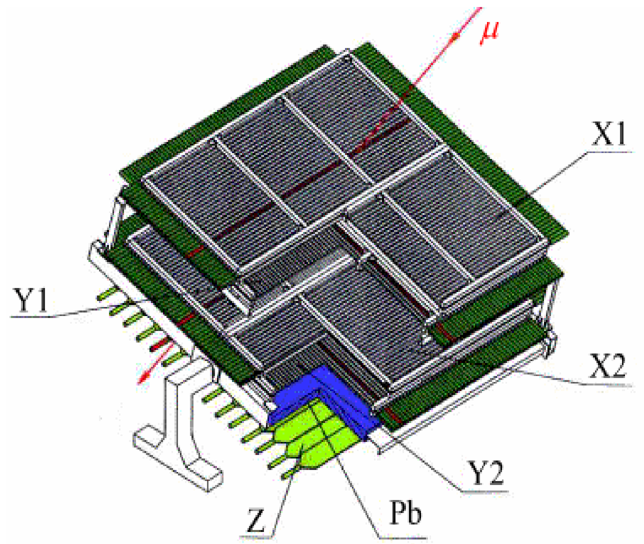

Fig. 7. General view of the muon hodoscope.

hodoscope is $9m^2$ and its counting rate is about a thousand events per second. The principle is shown in Fig. 6 and Fig.7.

The muon hodoscope is made of four layers. Each of the layers consists of 128 counters with a 2 mm iron sheet in front to reduce of the amount of knock-on electrons. The distance between the two pairs of layers is 1 meter. To reject the soft component, the 5 cm thick lead filter is used. In Fig. 7 are shown the upper X1, Y1 layers of counters, X2 and Y2 the lower counters and the trigger Z. The lead shielding layer is also shown. In the presented design instead plastic scintillator detectors we will use water Cherenkov detectors. The proposed design of the detector is a cylinder with 10 cm diameter and 1m length. The detector design is with one photomultiplier. The registration efficiency of the proposed water Cherenkov is estimated using modified version [12] of

EGS4 code [13]. The estimated registration efficiency is 91% assuming 5 GeV energy muons for threshold.

The scientific potential of the muon hodoscope is enormous. Starting from internal gravitational waves, measurement of the temperature field along height of the atmosphere, registration of acoustic waves [14] etc…

One of the possibilities is to exploit the barometric effect for muons in the atmosphere. This provides excellent possibility to study the internal gravitational waves. The internal gravitational waves represent transverse waves of density. Thee are passing above the muon hodoscope, and one can measure the intensity of muon streams for different angles in area 30x30 km^2 in the moment. Thus it is possible to observe the dimensional modulation of muon stream.

Similar technique is proposed for estimation of the

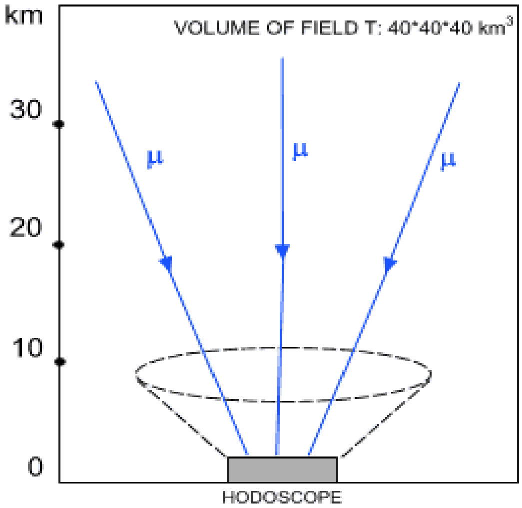

Fig. 8. Scanning of the atmospheric temperature using muon hodoscope

temperature field Fig 8. In this case one plays with the temperature effect for muons. The zenithal angular muon spectrum depends on distribution of temperature in the atmosphere before height of 30 km. On the basis of the assumption that the atmosphere is divided on several geo-potential layers with given fluctuation of the temperature. The temperature field is reconstructed of the solution of inverse problem with use of the muon spectrum measuring near the ground. The mean temperature is reconstructed using the integration of all angles. The different intensity of muons for varied angles corresponds to the temperature on varied geo-potential levels of atmosphere.

Another possibility is to study the shock waves in the interplanetary magnetic fields. Such type of waves is possible to detect on the basis of the modulation of cosmic muon stream after some hours to they arrive at the Earth. It is possible to measure the anisotropy and variations of galactic cosmic rays during generation and expansion of the shock waves. The front of the waves shocks the interplanetary magnetic field and produces modulation of galactic cosmic rays. This permits to study the space-time diagnostics and to make sounding of the structure of plasma turbulence in the Solar wind. The modulation moves and differentiate within "sight" of the Earth within the space of some days in the velocity of front = 400 - 1000 km/s Fig.9. The information obtained under the quiet Sun gives the possibility to investigate the anisotropy of galactic cosmic rays and such provides information about the value and behavior of the

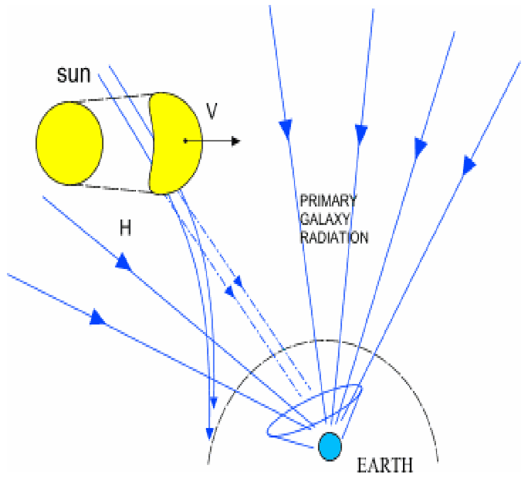

Fig. 9. Propagation of shock waves in the interplanetary magnetic fields

interplanetary magnetic field.

In this connection an additional possible study is the research of solar flashes. This study is based on registration of the energy and time spectra of ultra high energy, usually above some 10 GeV solar flashes. Presently the proposed models for acceleration of particles at the Sun predict possibility of generation of protons having energy of about 100 GeV and even more. In fact in present days the quality data are absent in this energy range. Moreover several results do not agree between it-self. Several recent models claimed the possibility of fast, in fact up to 0.1s process and slow, actually two and more steps process of the acceleration of protons. Indirect indications of reality some of the indicated gear exist. The obtained data in fact are complementary to the neutron flux meter data and gives the possibility for an additional analysis. Additionally it is possible the registration of high energy protons of the low-powered solar flashes. Because the protons energy of such type of events protons is roughly 10 GeV and such solar flashes take place than often the power solar flashes. Finally the registration of high energy direct neutrons having energy $E > 10$ GeV which are generated by power solar flashes permits the investigation of the time structure of the solar neutron events. Such events have been detected on the 22-year cycle events.

Using the muon hodoscope data together with the neutron flux meter gives the possibility for estimation of variability of the ozone layer thickness on height 10-30 km. The study is based on the difference of the effective night temperature of the atmosphere and the effective day temperature of the atmosphere on this height Fig.10.

The middle stratosphere heats owing to absorption of solar ultraviolet substantially. In the small thickness of ozone layer odds of the day and night temperature is small, but in the big thickness of ozone layer this odds is bigger. This problem can be resolved by the operations of frequent temperature measurements on stratosphere height during day over the time of all search time. Really, it will be make first wherewith the muon hodoscope in the operation of the continuous measurement of the angular distribution of cosmic muons.

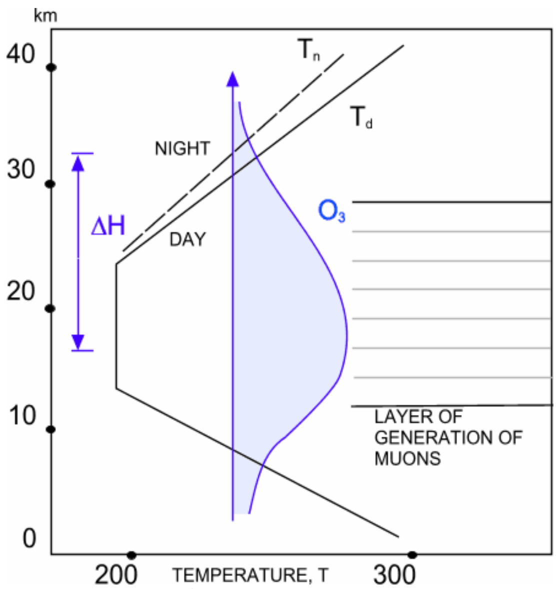

Fig. 9. Propagation of shock waves in the interplanetary magnetic fields

The hodoscope, neutron flux meter and muon telescope can provide continuous observation of the stratosphere ozone and control its season behavior and variability in dependence of a geophysical and technogenic factors. Moreover the additional information with gas analyzers at BEO Moussala observation level and the reconstruction of the vertical distribution of the ozone permits to adjust the model.

IV. Conclusion

In this work are presented several at BEO Moussala activities connected with secondary cosmic ray registration, especially the neutron and muon component. The neutron flux-meter is presented within some estimation concerning the final design. The muon telescope based on water Cherenkov detectors is shown. The muon hodoscope project proposal is described. The scientific potential of the devices is discussed.

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