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STUDIES OF THE HIGH ENERGY MUON FLUX IN UNIREA SALT MINE FROM SLANIC PRAHOVA*

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Abstract. The muons represent the EAS penetrating component and carry information about the mass and the energy of the primary cosmic particle, under the influence of the Earth magnetic field. The study of the high energy muon flux brings new informations regarding the muon multiplicities and the hadronic interaction models. The high energy muons represent, also, the main contribution at the natural radiation dose in underground which is important for low background measurements. A new experimental facility for studies of high energy muons is proposed as underground facility in a salt mine in Slanic Prahova, Romania. Simulation studies using CORSIKA and MUSIC codes estimate the expected muon rate at aprox. 600 mwe (meter water equivalent). The energy cut off is estimated to be 150–200 GeV. A new mobile laboratory which permit measurements at surface and in underground is in construction. For the future a muon experiment (MUON-UG) is planned to get installed in the mine to study hadronic interaction features as revealed by the flux and the multiplicities of high energy muons.

Key words: muons, underground.

1. INTRODUCTION

The muons represent the EAS penetrating component and originate from the decay of charged pions and kaons produced by cosmic ray in the atmosphere:

$$\pi^{\pm} \to \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}),\ 99.9\%,\ \tau = 26\ \text{ns}, \quad (1)$$

$$K^{\pm} \to \mu^{\pm} + \nu_{\mu}(\bar{\nu}_{\mu}),\ 63.5\%,\ \tau = 12\ \text{ns}. \quad (2)$$

Muons have a relatively large lifetime (τ = 2.2 μs) and decay in:

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$$\mu^{+} \rightarrow e^{+} + \nu_{e} + \overline{\nu}_{\mu}, \tag{3}$$

$$\mu^{-} \rightarrow e^{-} + \overline{\nu}_{e} + \nu_{\mu}. \tag{4}$$

Taking into account that IFIN-HH is building an underground laboratory in a salt mine for gamma and dosimetric measurements at low background, we propose to build a MUON-UG (UnderGround) detector in the salt mine. We will check if the flux of the penetrating muons, determined with the MUON-UG detection system, is consistent with the fluxes measured by other underground laboratories.

In order to find the optimum configuration of MUON-UG system, Monte-Carlo simulations were performed. The validity of the simulations was checked by ground level measurements of muon charge ratio and muon flux performed with WILLI detector.

As a result of setting up of the underground laboratory in Slanic Prahova, IFIN-HH was invited to participate to the consortium of FP7 project 212343 – "Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics", acronym LAGUNA [1]. A huge volume detector (min 100,000 m^3) is planned to be installed in an underground site that will be chosen from 7 different locations from Europe. Three different types of detectors are investigated: LENA (liquid scintillators), MEMPHYS (water) and GLACIER (liquid argon).

2. GROUND LEVEL MEASUREMENTS OF MUON FLUX

In order to test the validity of the simulations, measurements of the low energy (< 1 GeV) muon flux and muon charge ratio were performed using the WILLI detector [2, 3] which is a compact, modular rotatable system (see fig. 1). Each module is formed by a plastic scintillator layer of 3 cm thickness, in 1 cm Al frame box. The detector was used to measure the muon charge ratio and the muon flux, for different azimuthal direction (N,S,E,W) for a mean zenithal angle of 35 ^{o}. The results were compared with Monte-Carlo simulations performed with CORSIKA [4] code.

2.1. THE MUON CHARGE RATIO MEASUREMENTS

The muon charge ratio, $R_{\mu}(\mu^{+}/\mu^{-})$, of atmospheric muons provides a sensitive test of the simulation of the fluxes as the primary and secondary component of cosmic rays are influenced by the geomagnetic field. The WILLI detector (see Fig. 1) determines the muon charge ratio by measuring the life time of stopped muons in the detector layers, avoiding the uncertainties of measurements of low

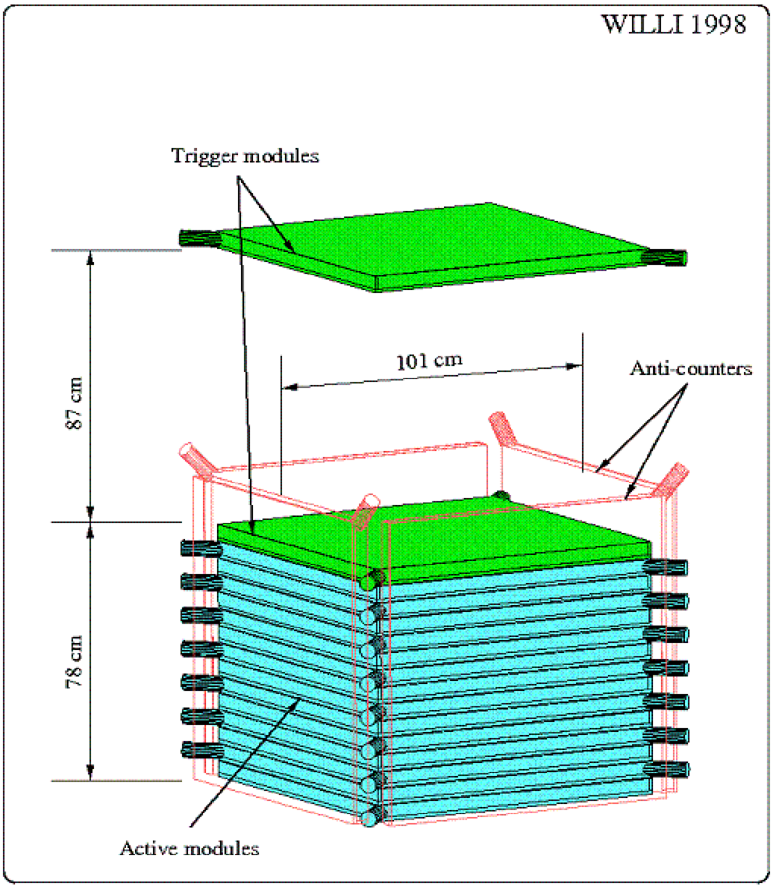

Fig. 1 –The WILLI detector.

energy muons. The detector determines the charge ratio of atmospheric muons by measuring the life time of stopped muons in the detector layers: the stopped positive muons decay with a lifetime of 2.2 μs, while negative muons are captured in the atomic orbits, leading to an effectively smaller lifetime depending on the stopping material. The WILLI detector, transformed in a compact rigid detector with rotation facilities in zenith and azimuthal direction, allows studying the influence of the Earth's magnetic field on the trajectories of charged particles. Fig. 2 compares the muon charge ratio data measured separately in East and West direction for muons of inclined incidence (of a mean value of 35°).

Figure 2 displays the good agreement between the experimental data and Monte-Carlo simulation performed with CORSIKA, showing a pronounced East-West effect in the muon energy range of < 1GeV.

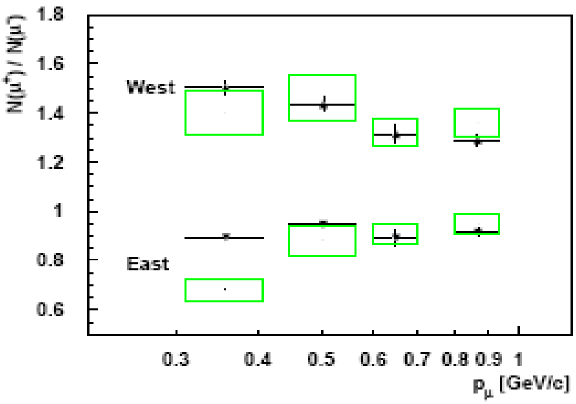

Fig. 2 – The East-West effect of the muon charge ratio as a function of μ momentum (*P*μ) measured with WILLI compared with CORSIKA simulations.

2.2. THE MUON FLUX

The simulations of the atmospheric muon flux have been done with the standard CORSIKA version using the planar atmospheric model for a zenith angle < 30°, and with the "curved" CORSIKA version for the simulations of the East-West effect of the atmospheric muons. The simulations of the atmospheric muon flux have been performed using the precise geographical parameters, like the local geomagnetic cut-off and the altitude of the different sites.

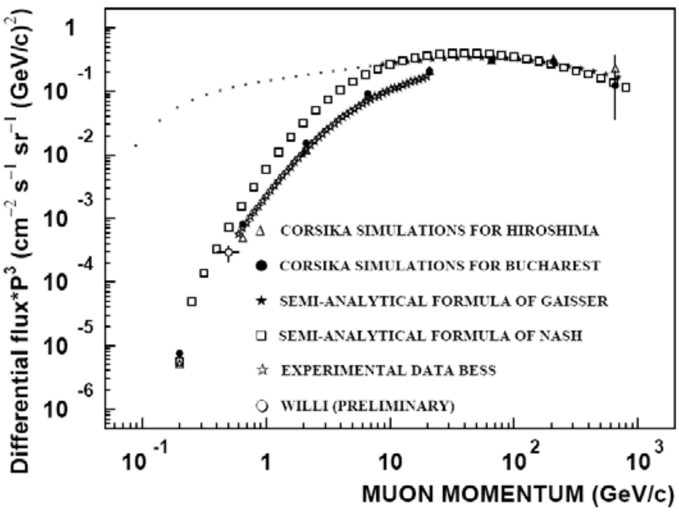

Fig. 3 – Comparison of the muon flux obtained with CORSIKA with the experimental data (BESS and WILLI) and semi-analytical formulas.

In view of detailed geomagnetic effects, the muon fluxes have been calculated [5] for two different locations with different geomagnetic cut-off: Hiroshima (34 N, 132 E) with the geomagnetic cut-off 11.6 GV and Bucharest (44 N, 26 E) with geomagnetic cut-off of 5.6 GV [6]. For Bucharest and Hiroshima Fig. 3 compares the muon flux calculated with CORSIKA, with the semi-analytical formula of Nash [7] and Gaiser [8], and the experimental data of BESS [9] and WILLI.

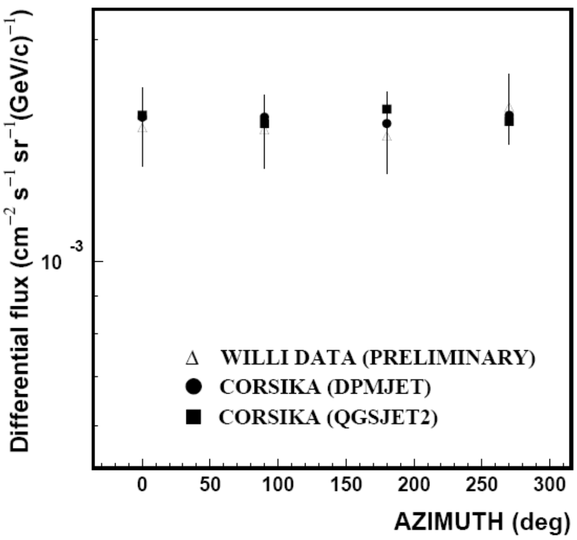

Fig. 4 – The azimuthal variation of muon flux measured by WILLI compared with CORSIKA simulations

Figure 4 shows the muon flux measured by WILLI compared with CORSIKA simulation using 2 hadronic interaction models QGSJET2 and DPMJET.

3. MUON-UG (UNDERGROUND)

Though the intensity of the underground muon flux is several orders of magnitude lower than on sea level and requires more patience, such an attempt seems to be worthwhile with respect to the information about the muon origin, with contributions from pion and from kaon decay [10, 11], the hadronic interaction models and muon multiplicities.

Due to the direct relation between the muon flux and the atmospheric neutrino flux (eqs. 1–3) the study of the underground μ flux can provide informations about the neutrino fluxes.

The study of neutrino properties represents one of the hottest physics research domains since, on one side, fundamental properties of neutrinos as its absolute mass and its nature (is it a Dirac or a Majorana particle?) are still unknown and, on the other side, because the neutrinos are key particles in many physical processes from nuclear and elementary particle physics, astrophysics and cosmology. That is why the detailed knowledge of the neutrino properties would give us essential information about the formation and the evolution of the universe and of the other astrophysical objects as stars, planets, Supernovae, galaxies. There are three types of experiments (with the corresponding theoretical calculations) for the determination of the neutrino properties:

– *direct measurements* of the neutrino mass: tritium decay and double beta decay. From the double-beta decay experiments the most stringent upper limit for the neutrino mass: 0.39 eV (result not yet confirmed) has been deduced; this value also shows the present experimental and technological limits for the measurement of the neutrinoless double-beta decay half-lives [12],

– *neutrino oscillation experiments*: these brought compelling evidence in favor of massive neutrinos [13],

– *cosmological data*: from which one can derive lower limits for the sum of the neutrino masses; presently this value is around 1 eV [14].

The present situation in the neutrino physics research is a challenging one, since by combining the experimental data and the theoretical calculations the next future double-beta decay experiments will be able to check the actual limits of the neutrino masses. On the other side, it would be meaningfully to know the real mechanism by which the neutrinoless double-beta decay occurs, because, in this way, one could verify some of the fundamental hypothesis advanced by the Grand Unification theories: nonconservation of the lepton number, existence of the SUSY particles and existence of the right handed components of the weak currents, etc.

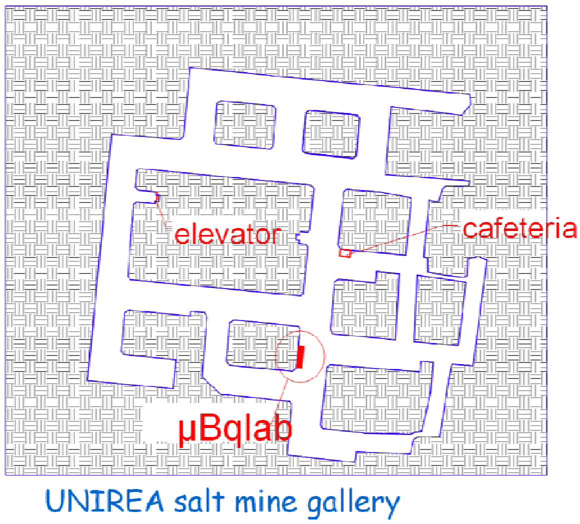

Fig. 5 – The map of UNIREA mine from Slanic.

During the last 3 years a new laboratory for low background measurements was build by IFIN-HH in UNIREA salt mine from Slanic Prahova.

Another reason for measuring underground muons from cosmic rays arrises from the neccesity of a well known radioactive background for Slanic site. This is important in order to establish very accurate the mwe (metter water equivalent) thickness of Unirea site. The site for LAGUNA experiment will be established taking into account the depht of each site and the possibility to install a large volume detector inside (min 100,000 m^3). Slanic site has a huge volume of material allready excavated (2,900,000 m^3), but the shallow depht could be a problem. It seems that the GLACIER experiment is the only one feassible for Slanic, but the exact depht (mwe) of Unirea mine should be measured.

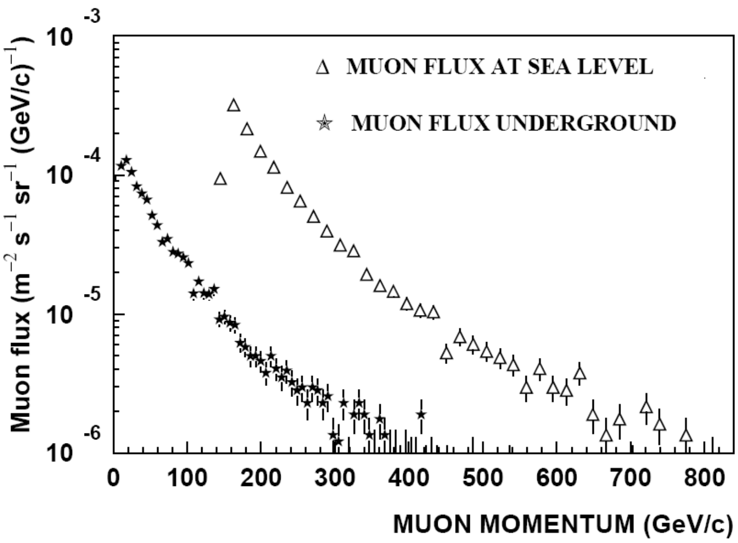

Fig. 6 – The simulated muon flux at the surface (only the muons that rich the underground level) and in underground.

Simulation studies using CORSIKA (sea level muons) and MUSIC [15] (underground flux) codes estimate the expected muon rate at aprox. 600 mwe (meter water equivalent). The energy cut off is estimated to be 150-200 GeV (see Fig. 6). For the future a muon experiment (MUON-UG) is planned to get installed in the mine to study hadronic interaction features as revealed by the flux and the multiplicities of high energy muons. It is planned that the construction will start in the second part of 2009 and would be operational at the end of 2010.

A new mobile device for measuring the muon flux is in construction and will be used for measuring the muon flux at the surface and in underground. A self-consistent and fast measurement of mwe depht of Slanic site will be performed till the end of 2009.

4. CONCLUSIONS

Measurements of muon charge ratio at about 200 GeV, could bring information about the kaon contributions to atmospheric muons; this will need the installation of a magnetic spectrometer.

The feasibility of studies of muon bundles and muon lateral and angular distributions, by measuring muon flux at different places from the salt mine should be investigated. Measurements of muon flux in deep underground could give the possibility to investigate the hadronic interaction models at very high energy.

The European experiment LAGUNA could be immediately installed in Unirea mine from Slanic Prahova, due to the huge excavated volume, but an accurate parameterisation of the mwe depth of the site should be determined.

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