The Charge Ratio of the Atmospheric Muons as Probe for Azimuthal Asymmetry

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Abstract

The charge ratio of the atmospheric muons is a quantity sensitive to hadronic interactions of cosmic rays and to the influence of the geomagnetic field. Experimental information is of current interest for tuning models used for the calculation of atmospheric neutrino fluxes. We report about experimental studies of the charge ratio based on the observation of the lifetime of the muons stopped in the absorber layers (aluminum support) of the detector WILLI, mounted in a rotatable frame and installed in IFIN-HH Bucharest (vertical geomagnetic cut-off rigidity of 5.6 GV). Measurements of the asymmetry of the muon charge ratio in the east-west direction, observed with a mean zenithal angle of 35°, results in values of the asymmetry of the charge ratio decreasing from 0.25 to 0.20 in the muon momentum range of 0.35-0.50 GeV/c, relevant to the atmospheric neutrino anomaly.

1. Introduction

The atmospheric flux of muons originating from the decay of charged pions and kaons produced by cosmic rays in the atmosphere is nearly isotropic. At lower energy the muon flux is influenced by of the local magnetic field in the atmosphere as well by the magnetic rigidity cut-off of the primary cosmic rays penetrating the Earth's atmosphere from the cosmos. The ratio of positive to negative atmospheric muons, called the muon charge ratio, $R_\mu = \mu^+/\mu^-$, maps the neutrino production and carries information on the hadronic interaction, used for the calculations of the fluxes. Super-Kamiokande [2,3] and other experiments find that the ratio of muon neutrinos to electron neutrinos is much smaller than the theoretical predictions. The measurements of the east-west effect of the muon charge ratio allows to check different models for the simulation of the atmospheric neutrino fluxes and to investigate the influence of the magnetic field [8].

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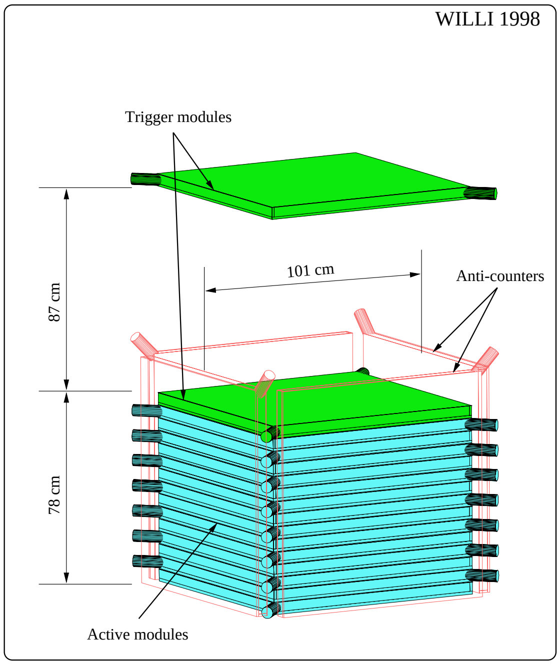

Fig. 1. Schematic view of the original WILLI detector (left) and the configuration in a rotatable frame (right)

2. Method and apparatus

The WILLI detector, built in IFIN-HH Bucharest [6] measures the muon charge ratio by the effective lifetime of stopped muons. Fig. 1 presents the initial configuration [7] and the new rotatable WILLI [1], using 16 scintillator modules for vertical measurements of the muon charge ratio, and 4 scintillator modules in vertical position as anticounters. All counters are made of a 1 cm thick aluminum plate and a plastic scintillator of 90 x 90 x 3 cm^3 closed by an aluminum cover of 2 mm.

A good event is induced by a particle triggering the telescope without penetrating to the bottom, together with the appearance of a delayed particle. From the time interval of incoming and decaying particle, the spectrum of the decay times is registered.

The total decay curve of all muons measured in the detector is a superposition of several decay laws, containing 3 detector dependent constants, accounting for the stopping power in the materials and the detection efficiencies, given by the detector geometry, laboratory walls, thresholds and angular acceptance, which have been determined by extensive detector simulations using the code GEANT. The muon charge ratio is obtained by fitting the measured decay spectrum with the theoretical curve.

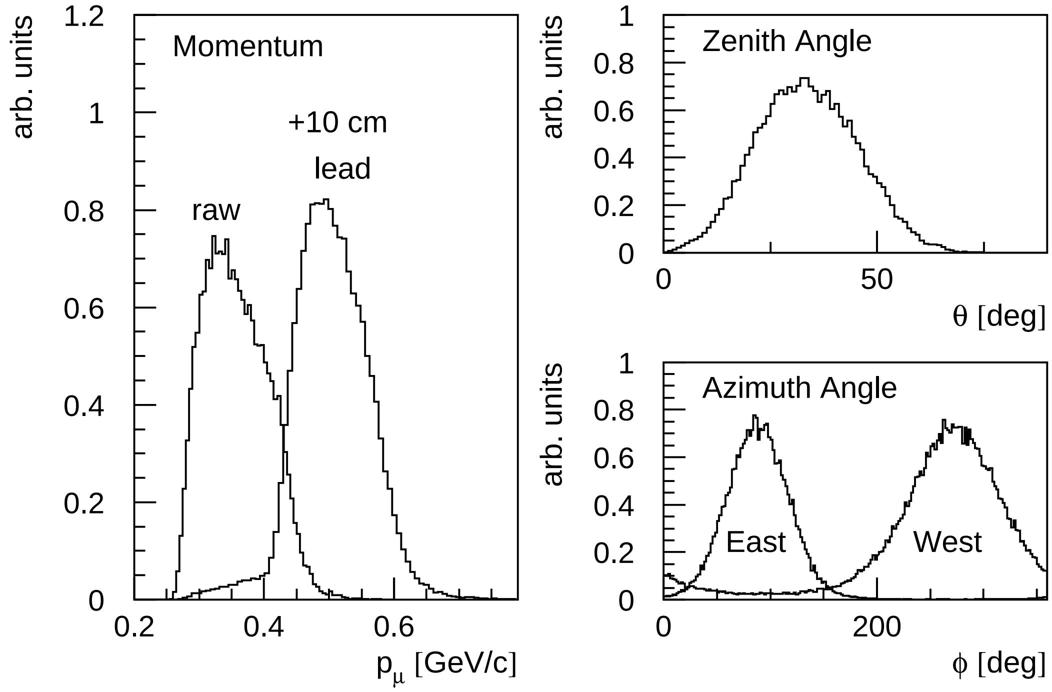

Fig. 2. Momentum, zenithal and azimuthal distributions of accepted events in the different set-ups.

3. Experimental results and azimuthal anisotropy

Fig. 2 shows the acceptance distributions of muons in momentum, zenith and azimuth angle. Introducing the azimuthal anisotropy $A_{EW} = \frac{R_W - R_E}{R_W + R_E}$, with R_E and R_W being the muon charge ratio measured in the east and west direction, the preliminary results show a pronounced east-west effect. Fig. 3 displays the measured values for the muon charge ratio compared with simulations [9] performed with CORSIKA [5] and the azimuthal anisotropy, confirming the east-west effect found in neutrino measurements [4].

4. Concluding remarks

Our method to determine the muon charge ratio by measuring the lifetime of muons stopped in the matter, overcomes the uncertainties appearing in measurements based on magnetic spectrometers, which are affected by systematic effects at low muon energies, due to problems in the particle and trajectory identification.

The results obtained with the rotatable WILLI detector, inclined at 45° (i.e. a mean zenith angle of detected muons of 35°) show a pronounced east-west

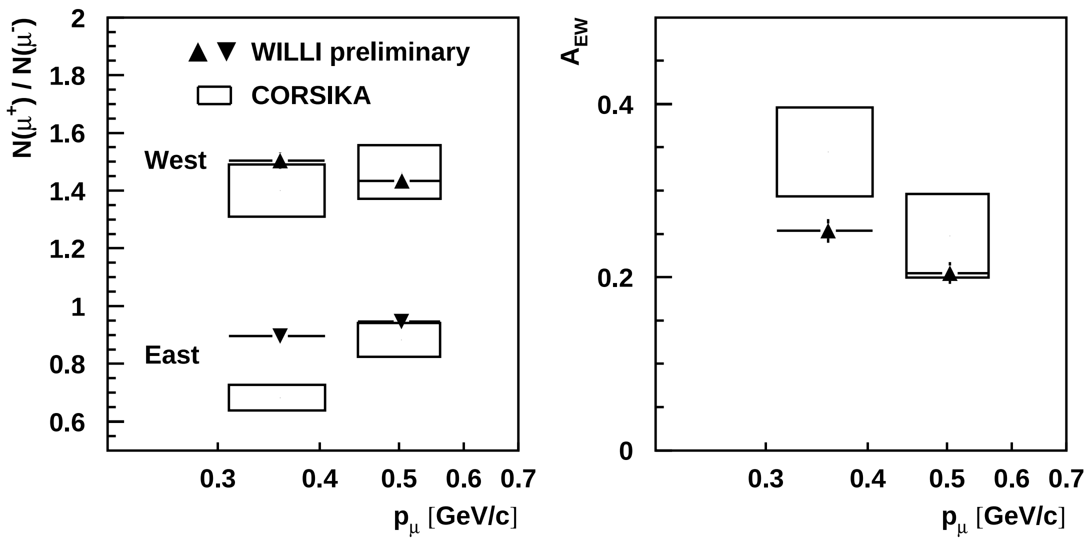

Fig. 3. Energy dependence of the east-west effect in the muon charge ratio.

effect, in good agreement with simulation results of CORSIKA. The values of the asymmetry of the charge ratio decreases from 0.25 to 0.20 in the muon momentum range of 0.35-0.50 GeV/c, relevant to the atmospheric neutrino anomaly.

5. References

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