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Simulation studies for muon charge ratio measured with WILLI in coincidence with a mini-array

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Abstract: The WILLI calorimeter, installed in NIPNE Bucharest, is operated since several years for measuring charge ratio of atmospheric muons at low energies (E $<$ 1 GeV), particularly exploring its directional dependence. Recently it was proposed to combine WILLI detector with a mini-array of 12 scintillators in order to measure muon charge ratio of the muon density of EAS lateral distributions. Such experimental studies could provide detailed information on the shower development under the influence of the geomagnetic field and probably also on hadronic interaction. As part of the proposed approach the ratio of the averaged μ^+ to μ^--densities of the radial and azimuthal lateral EAS distribution observed with folding with the finite WILLI angular acceptance, is investigated . The study is based on simulated showers generated for protons and various heavier primary nuclei by the Monte Carlo program CORSIKA in the energy range 10^{13}-10^{15} eV. The μ^+ to μ^-- ratio as registered in average by the WILLI device, thought to be triggered by a mini-array, is studied in dependence of the distance of the WILLI location from the shower core and of the azimuthal and zenithal directions of EAS incidence. The results exhibit the principal feasibility, but also some inherent problems of the WILLI device and of the considered experimental arrangement to explore the effects looked for.

Introduction

The ratio of the numbers of positive to negative muons in the atmospheric muon flux, which is dominated by the production of muons through low energy air showers (EAS) in the atmosphere, has been relatively often investigated. This muon charge ratio R_μ, whose value is governed by the proton excess in the flux of the primary cosmic rays, is dependent of the direction of observation, since the muon tracks are influenced by the geomagnetic field and differently bent in East and West direction. This influence leads to the well known East-West effect of the muon charge ratio of atmospheric muons (i.e with unspecified EAS origin) [1].

In contrast the charge ratio of the muon density of single EAS registered with well specified observation conditions (energy, direction of incidence, distance from the shower axis etc.) has been seldom considered and is experimentally unexplored. Recently the features of the charge ratio of the density of the EAS muon component have been extensively studied on basis of Monte Carlo simulations [2] revealing that the radial and azimuthal muon density distributions of EAS observed by surface detector are strongly influenced by the magnetic field of the Earth. The features depend on the direction of EAS incidence (zenith θ and azimuth Φ angles) relative to the geomagnetic field, in addition to the energy of the registered muons.

In this paper some considerations are presented, how the WILLI detector [3], when being triggered by EAS observation of a small detector array, may be used to explore some experimental information about the predicted features. It should be explicitely noted that WILLI does not allow the determination of R_μ of the observed EAS individually, but only counting the numbers of μ^+ and of μ^-, forming after observation of many showers an averaged value of R_μ.

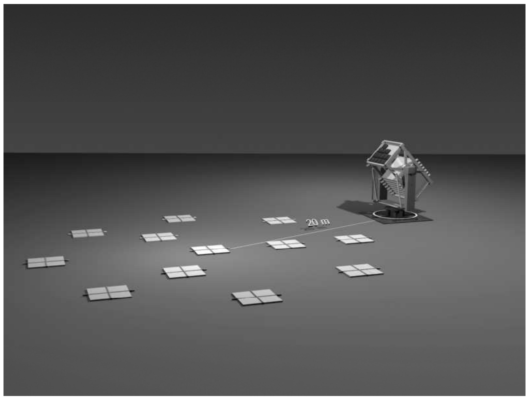

Figure 1: Sketch of the geometrical layout of a mini-array for triggering the nearby located WILLI device for muon detection by registering EAS [2].

Concept of an experimental arrangement

The WILLI detector [3, 4] installed for studying the muon charge ratio of atmospheric muons discriminates positive and negative muons by measuring the life time of muons stopped in the detector layers: Stopped positive muons decay with a lifetime of 2.2 μs, while negative muons are captured in atomic orbits, thus leading to an effectively smaller lifetime depending on the stopping material. From the adjustment of the measured decay curve to the actual mean value of the life time the value of R_μ can be deduced. Details of the method are described elsewhere [3]. It largely avoids the uncertainties due to different detection efficiencies and geometrical acceptances of muons of different charges which affect the results of magnetic spectrometers. In the present configuration the WILLI setup is able to get directed to a pre-chosen direction of muon incidence (zenith and azimuth angle) [4] for studies of the East-West effect of atmospheric muons [5] e.g..

The application of the WILLI device for experimental studies of the features of the radial and azimuthal variation of the charge ratio of the muon density distribution in EAS needs a link to the EAS registration by a nearby located detector array, specifying the characteristics (core location, direction of incidence etc.) of the triggering EAS. Fig.1 displays a highly schematic sketch of an eventual geometrical layout of a mini-array of 12 detector units, whose spatial distribution defines also the window of primary energies of the observed EAS.

The necessary simulation studies of the performance of such a mini-array and of the expected trigger rate (roughly estimated to be in the order of 1 event/min) are in progress. In particular, the layout studies must also include an adequate electronic system for triggering and data acquisition since only one stopped muon per shower can be handled in the present system. In the present studies we study, how the finite angular acceptance of the WILLI spectrometer, positioned at a particular accurately defined distance from the shower core and observing muons from a particular direction will affect the pronounced predicted variation of the charge ratio of the observed muon density.

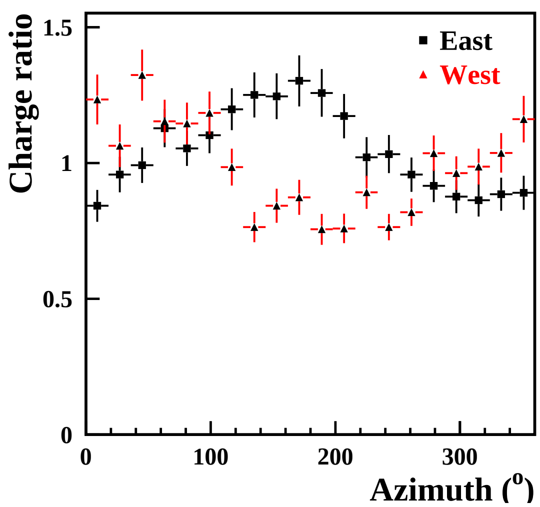

Figure 2: Dependence of the charge ratio on the azimuthal position of WILLI around shower core (radial distance: 150-200 m). Proton showers ($E=10^{15}$ eV, $\theta=45^o$) coming from East (squares) and from West (triangles). WILLI is oriented parallel to the shower axis.

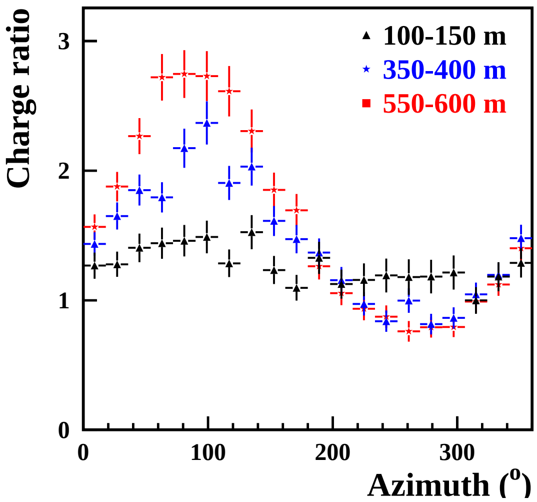

Figure 3: Dependence of the charge ratio on the azimuthal position of WILLI around shower core for various radial ranges. Proton showers (E=10^{15} eV, θ=45^o) coming from North. WILLI is oriented parallel to the shower axis.

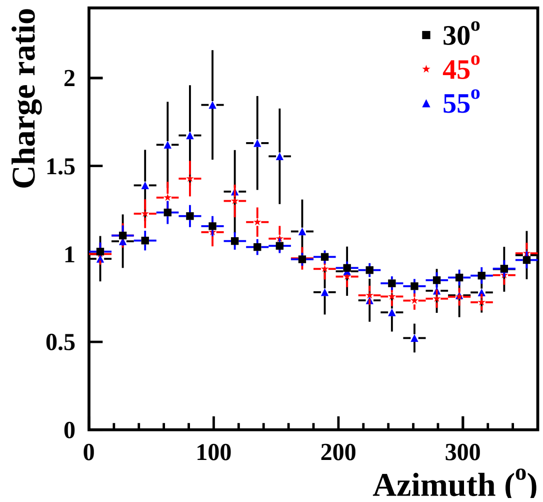

Figure 4: Dependence of the charge ratio on the azimuthal position of WILLI around shower core for proton showers (E=10^{15} eV) with several zenith angles coming from North. Radial distance: 200-250 m. WILLI is oriented parallel to the shower axis in each case.

Simulations of the charge ratio of the EAS muon density distribution as seen by WILLI

The following results, displayed in Figs. 2-6, are based on simulations by the EAS Monte Carlo simulation code CORSIKA (vers.6.0) [6] using finally the same set of simulations (about 60000 showers in total) as in [2], but including the criteria of muon registration by WILLI. For the present exploratory study the hardware triggering and vetoing conditions and the software cuts implemented in the WILLI data acquisition and analysis system were replaced by the condition that a single muon from a shower event hits WILLI. Furthermore this muon should have the energy E $<$ 1 GeV (with the threshold slightly dependent on the angle of incidence) and the incidence angle filtered with a gaussian angular acceptance with a dispersion similar to that determined in [3].

As expected from the theoretical studies [2] the figures indicate that the azimuthal variation of the R_μ gets more pronounced with increasing core distance. Actually the salient features are shown for core distances $\geq$ 100 m. The features at smaller distances follow the general trend, but need for demonstration a larger statistical accuracy, i.e. within the present procedure a larger number of analysed EAS, actually approaching the experimental reality. Differences of R_μ between iron and proton induced showers are small, at least at the energies studied in this work.

Concluding remarks

The application of the WILLI calorimeter as device for measuring the charge ratio of the EAS muon density needs some modifications of the apparatus, especially for triggering by the mini-array and the acquisition of the low energy muons [3]. EAS muons have an energy spectrum which is harder than that of atmospheric muons and less rich of muons which are able to get stopped in the actual WILLI device. This feature implies a serious limitation of the statistical accuracy of results of

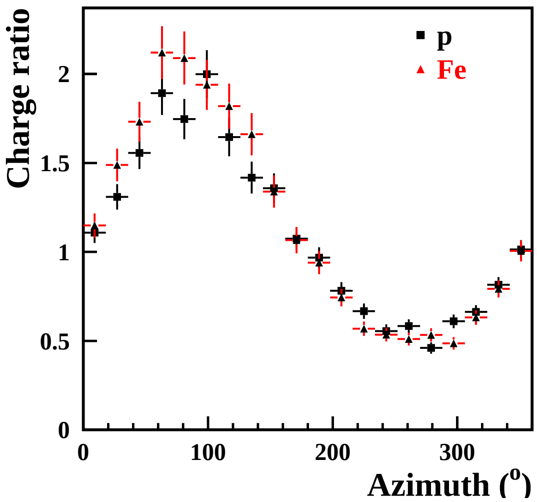

Figure 5: Dependence of the charge ratio on the azimuthal position of WILLI around shower core for proton (squares) and Fe (triangles) showers (E=10^{15} eV, θ=45^o) coming from North; radial distance: 450-500 m. WILLI is oriented parallel to the shower axis.

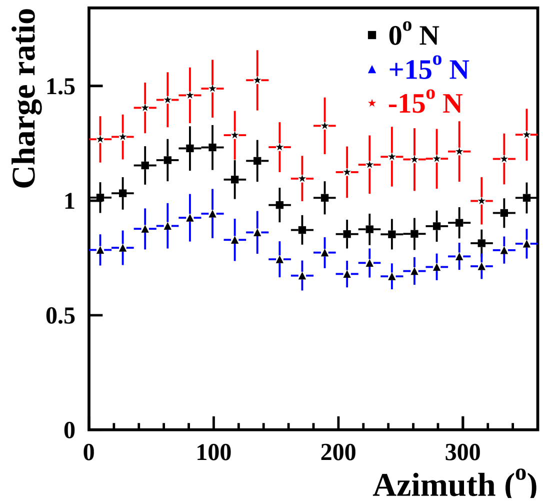

Figure 6: Dependence of the charge ratio on the azimuthal position of WILLI around shower core for proton showers (E=10^{15} eV, θ=45^o) coming from North. Radial distance: 200-250 m. WILLI is oriented parallel to the shower axis (squares), +15^o N (towards East, triangles) and -15^o N (towards West, stars).

WILLI. Hence the WILLI should to be additionally equipped with some absorber material for degradation of the muon energy in the direction of observation. For devising the mini-array (intended to be set up with 12 scintillator units from the former Central Detector of KASCADE in Forschungszentrum Karlsruhe) special attention should be put to the accuracy of the core location since inaccuracies of the core location are propagated in the azimuthal (and radial) position of the WILLI device with respect to the incoming shower and may smear out variations of the R_μ (azimuth). Therefore careful performance studies, optimising the layout of the planned mini-array are requested.

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