ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Catania

INFN/AE-04/01
16 Gennaio 2004

A PROPOSAL FOR COSMIC RAY STUDIES INVOLVING COLLABORATIONS BETWEEN HIGHER EDUCATION, RESEARCH SITES AND LOCAL AREA HIGH SCHOOLS

Barbara Famoso[1], Francesco Riggi[1,2]

[1)]Dipartimento di Fisica e Astronomia, Università di Catania, I-95129 Catania, Italy
[2)]INFN-Sezione di Catania, Catania, Italy

Abstract

This is a proposal for a collaboration between the INFN, the Department of Physics and Astronomy of the University of Catania, and local area high schools, aimed at carrying out experimental studies in cosmic ray physics. The purpose of the collaboration is to investigate the possible involvement of high schools sites in studies related to nuclear and high energy experimental physics, and the educational aspects of such involvement. According to the idea outlined in the present proposal, the INFN/University Department site will act as a central data collection and processing institution, managing an array of scintillator-based detectors. Each high school joining the project could handle its own detector for cosmic muons, with the overall set of detectors resulting in a large array allowing the study of both local properties of the cosmic muon flux and large area correlations as well. A basic introduction to the different physics items which could be investigated in this framework is given in the present document, together with some technical aspects on how to carry out such measurements. The role of the educational aspects of the proposal is also stressed.

PACS.: 01.10.-m, 96.40.-z

*Published by **SIS–Pubblicazioni***
Laboratori Nazionali di Frascati

1 INTRODUCTION

This document outlines a proposal for possible joint collaborations between the INFN, the Department of Physics and Astronomy of the University of Catania, and local area high-schools, in the field of cosmic rays. The idea is to install and use suitable cosmic ray detectors at the Physics Department site and in several high-schools, for continuous muon counting and for detection of extensive air showers. The collected data are to be accessible through internet to all participating institutions.

The main aim of such project is educational, trying to involve high-school teachers and students in real experiments and data analysis. There is however some possibility to contribute to cosmic ray physics as well, ranging from the study of the local muon flux and its relation with solar events, to the search for large scale correlations between muons from an air shower or even among individual air showers.

Some interest in cosmic ray studies from collaborations involving high-school and university/research centers has arisen in recent years in several laboratories (1-6).

A large project (ALTA, Alberta Large area Time coincidence Array) was pioneered in Canada (1), with the University of Alberta acting as a central institution and several high-schools participating to the activity. This project resulted in an even larger collaboration, the NALTA (North American Large-scale Time-coincidence Array) consortium (2), whose members are several University Institutions and local area high-schools in USA and Canada. The consortium was founded in the year 2000 as a result of the *Workshop on Cosmic Ray Physics with School-Based Detector Networks*, held at the University of Washington/Seattle. An educational air shower array is under construction at the Stockholm AlbaNova University Center (3). This will be extended by the inclusion of local schools in the Stockholm area. The Preston College in United Kingdom has been working in this field since many years, developing an extended array of cosmic ray detectors (4). Another on-going project is localized at the University of Adelaide (Australia), operating a cosmic ray muon telescope for astronomy teaching and several related activities (5). A similar project is operating in Portugal at the Laboratory of Instrumentation and Experimental Physics of Lisboa (6).

It is likely that similar projects are under construction, or even operating, in other institutions worldwide. In addition to these studies, which are concerned with several aspects of the cosmic ray physics, a number of educational and environmental experiments are running in several places to monitor the muon flux and to correlate such variations to the atmospheric behaviour or to solar phenomena. As an example, a set of scintillators was used in Belgrade for years-long monitoring of cosmic muons (7).

In most cases, various combinations of scintillator-based detectors have been used for such experiments. With proper electronics and data acquisition techniques, the information from each individual detector can be collected on a local basis, and in some cases correlations between data collected at individual sites may be searched for, by the use of GPS technology.

The study of cosmic rays offers to university and high-school students a relatively easy approach to the field of experimental high-energy physics. Not only can individual or groups of students carry out physics experiments with some help from their supervisors, but, in addition, they can be introduced to the use of sophisticated equipment (similar to what really in use in larger high-energy physics experiments), of data analysis methods, simulation procedures, computer resources and so on.

In our Country, a dissemination of the scientific research concerned with nuclear and high-energy physics carried out at INFN and University sites is highly desirable even in the context of the normal curricular activity which teachers and students pursue in their high-school institutions. For such reasons, projects similar to that discussed in the present document may help to establish better links between INFN, University Centers and high-schools. Such links may include lectures and seminars concerned with various aspects of the research activity, stages of students in the framework of some selected activity planned by research groups, joint projects for experiments and/or data analysis, outreach activities and so on. Preliminary contacts with physics teachers from local high-schools point out that a positive response is generally expected.

After a short recall of some of the basic properties of cosmic rays which can be useful in this context (Sect.2), a discussion of possible physics and interdisciplinary items which may be addressed by such activity is presented in Sect.3. The experimental techniques and detector arrangements to be used are discussed in Sect.4. Finally, Sect.5 reports some considerations concerned with the educational aspects of the proposal, and a list of specific activities which can be undertaken within high-school projects.

2 COSMIC RAYS AND AIR SHOWERS

Cosmic Rays (CR) are particles which bombard the Earth's atmosphere from space (8-9). The largest part of cosmic ray particles in space are charged nuclei. The mass composition of primary particles reflects the nuclear abundances found in nature, with H nuclei (protons) dominating, and some excess of light nuclei (Li, Be, B). Heavier nuclei, up to Fe, are also part of the cosmic rain. They have energies which vary from a few MeV up to more than 10^{20} eV.

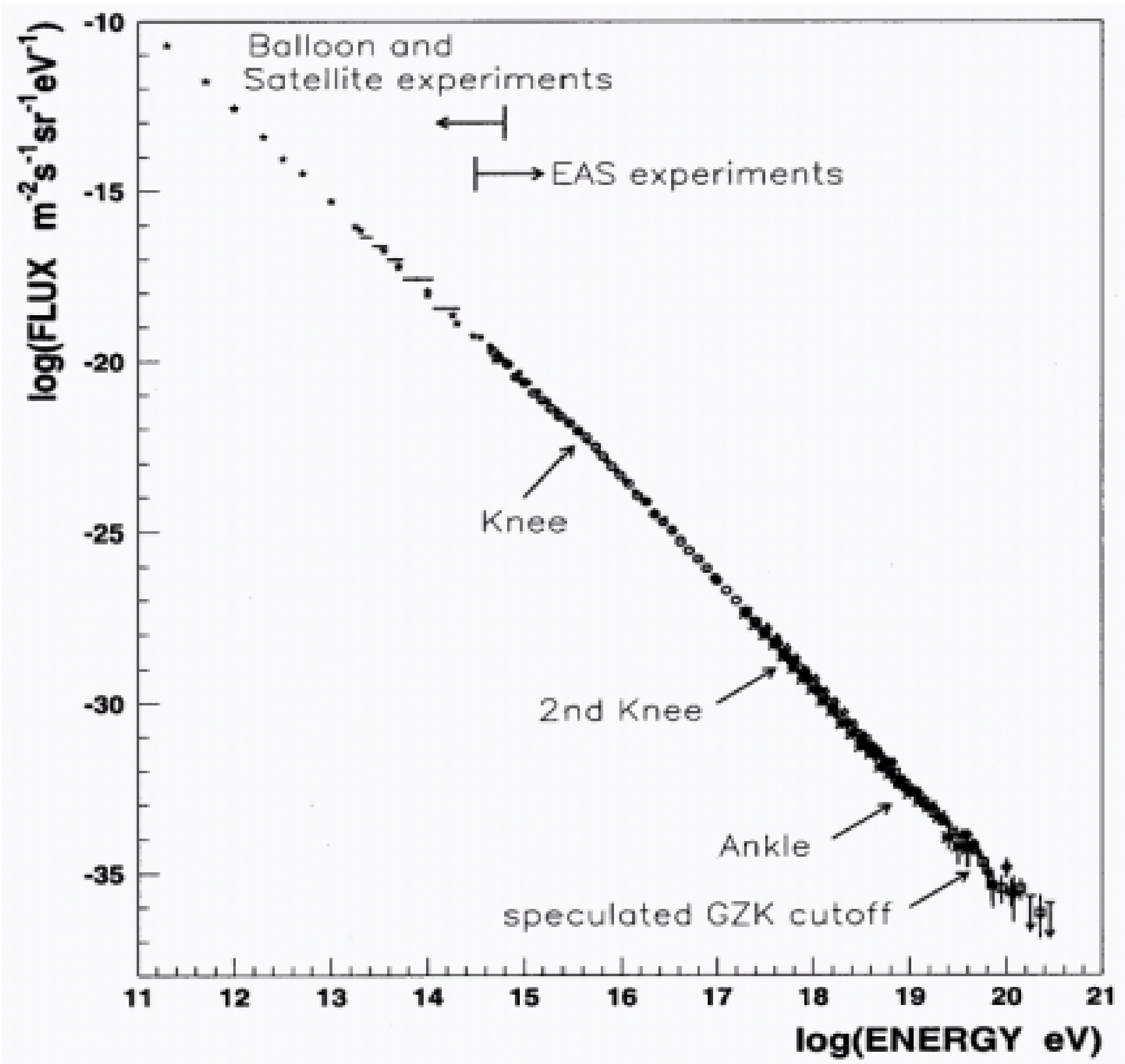

FIG.1: Energy spectrum of primary cosmic rays

The cosmic ray energy spectrum can be described by a power law, $dN/dE = const\ E^{-\gamma}$, with γ=2.7 up to 3 x 10^{15} eV. Above this energy, and up to 10^{19} eV the spectrum steepens, with a value of γ=3.1 (the so-called *knee*). At energies above10^{19} eV, up to the highest energy ever observed (3 x 10^{20} eV) the spectrum flattens again (the so-called *ankle*). These sudden changes in the spectral index near these two energies are believed to originate from a change in the propagation of the particles in the interstellar medium and/or in the acceleration mechanisms.

Most cosmic rays come from within our galaxy, with a low fraction of them (below a few GeV for protons) originating from the Sun atmosphere (flares). While the majority of cosmic rays have a homogeneous distribution in space and time, those related to the Sun activity reflect the eleven-years solar cycle.

Several theoretical approaches have shown that the large observed energies of primary cosmic particles cannot be accounted for by a single acceleration mechanism. Moreover, for the highest energies observed, no convincing mechanism has been up to now demonstrated. The very existence of these large energies is still a puzzle, and at present it is not known whether an energy cut-off actually exists (the Greisen-Zatsepin-Kuzmin, or GZK cut-off) (10).

From the time of the discovery of cosmic rays, at the beginning of last century, a lot of experiments have been carried out to understand their properties. The cosmic radiation provided also the source for the observation of new particles in the middle of last century, leading to the discovery of the positron, the muon, the pion and the first strange particles. With the advent of particle accelerators, which allowed to control the energy and nature of beam particles, cosmic rays were studied less extensively. The development of astroparticle physics in the last 20 years however has renewed the interest in cosmic ray experiments.

Up to an energy of 10^{14} eV the flux of primary cosmics is high enough to allow direct measurements with detectors located in balloons or satellites outside or at the top of the atmosphere. However, above this energy the flux becomes too small to detect a significant number of events with such detectors. At the knee energy for instance the flux is limited to 1 particle/(m^2 sr) per year (see fig.1), and only arrays with very large areas can detect an adequate number of events. The measurement of high-energy cosmics is then carried out with surface arrays at the sea level, or underground. This is an indirect measurement, since the primary is not detected directly but through the shower of particles it creates in the atmosphere.

An air shower is created each time a high-energy primary cosmic particle interacts with a nucleus in the upper layers of the atmosphere. The interaction produces a set of secondary particles, which can in turn interact again with other nuclei, or decay, according to the various cross-sections of the relevant processes and their lifetimes. In any case, a cascade of secondary particles is created, whose directions reflect that of the original primary particle. The mean energy of the particles in the shower decreases as the shower develops in the atmosphere, and when the energy falls below the threshold for production of additional particles, the energy will gradually be lost by ionization and other processes. The lateral extent of the shower increases as a function of depth, and depends upon the energy of the primary particle. If the particle initiating the shower has hadronic nature, strong interactions happen with the nuclei in the atmosphere, producing a shower whose main component is hadronic. However, this hadronic component generates mesons, which by decay can create leptons, giving rise to the electromagnetic and muonic components in the shower. If the primary is a photon, the shower mainly develops by bremsstrahlung and pair creation into an electromagnetic component, with a much less reduced presence of muons.

The muonic component is the most penetrating part of the shower. Muons are created mainly by pion and kaon decay. Due to their large energy, relativistic effects increase their lifetime (which is 2.2 μs) , allowing them to reach the Earth's surface.

Muons constitute then the most abundant charged cosmic ray component reaching the Earth's surface. Detailed muon measurements at the ground level provide information on the primary cosmic ray fluxes as well as on the interaction mechanism of high-energy particles in the atmosphere. In spite of the great experimental efforts devoted so far, the muon flux and energy distribution at the ground level have still to be measured with precision. As a matter of fact, the available measurements show discrepancies up to 15-20 % in the region between 10 GeV/c and 1 TeV/c, mainly due to systematic errors not properly taken into account. The charge ratio between positive and negative muons is larger than unity, showing a weak dependence around 1.25-1.30 on the muon momentum in the region 10 GeV/c – 1 TeV/c. Even for such data, there is still a large margin of uncertainty and discrepancy between different experiments.

A recent paper (11) reports a compilation and combination of all published measurements concerning the vertical atmospheric muon flux and charge ratio.

While most of the educational experiments are not able to measure the energy and charge state of the muons, which would require magnetic spectrometers, the overall muon flux depends on several factors, all of which can be used for educational studies. Apart from the influence of the local environment and of the atmospheric conditions, which can be corrected to some extent, the resulting variations in the muon flux reflect the state of the eliosphere and the solar wind, and are in general related to solar events.

In the following section, several possible items of educational interest are outlined and briefly discussed, with respect to cosmic rays investigations which can be carried out with simple apparata.

3 PHYSICS AND INTERDISCIPLINARY ITEMS OF INTEREST

3.1 Monitoring the muon flux for diurnal variations

One of the simplest investigation which can be performed is the study of the small variations in the muon counting rate along the day, reflecting the diurnal variation of the pressure (see fig. 2). The determination of the pressure/muon rate correlation is usually very interesting to students, and may be investigated in a quantitative manner by a continuous monitoring of the muon flux with a sufficiently high number of events in order to reduce the statistical errors above the expected variations. The atmosphere acts as an absorber for the muons, so that a higher pressure above the detector is associated with a larger absorber and a lower detection rate.

The barometric coefficient is in the order of 0.2% variation per mbar. As an estimate, with a detector counting about 10 particles per second, one could carry out measurements in one hour steps to have statistical errors in the order of 0.5%, which should allow to see even fine variations (3-5 mbar) in the pressure. For such measurements, it is preferable to have a parallel recording of the local pressure, which can be done by simple apparata, or may be included as part of the muon data acquisition. Pressure data are often available even from Meteorological services through their Web sites.

Data analysis of such measurements will offer a good opportunity to discuss and use correlation techniques, and will introduce – through a simple example – to the need of correcting the data in a physics experiment, before to search for more sophisticated phenomena. The variation of the local atmospheric pressure is also a topic of interest for interdisciplinary discussions in the classroom.

Such measurements may be performed on a local basis from each high-school joining the project, with the use of dedicated equipment allowing a sufficiently high counting rate. However, the possibility to have more sites performing the same measurements in different locations permits to correlate the data obtained at different sites, and in some cases to increase the overall statistics, in which case smaller detectors may be locally used.

It should be added that in case of small variations to be observed, a detector design made by two scintillators in coincidence, instead of a single counter, will be of great help in order to reduce random fluctuations and experimental effects which could mask the small variation to be investigated.

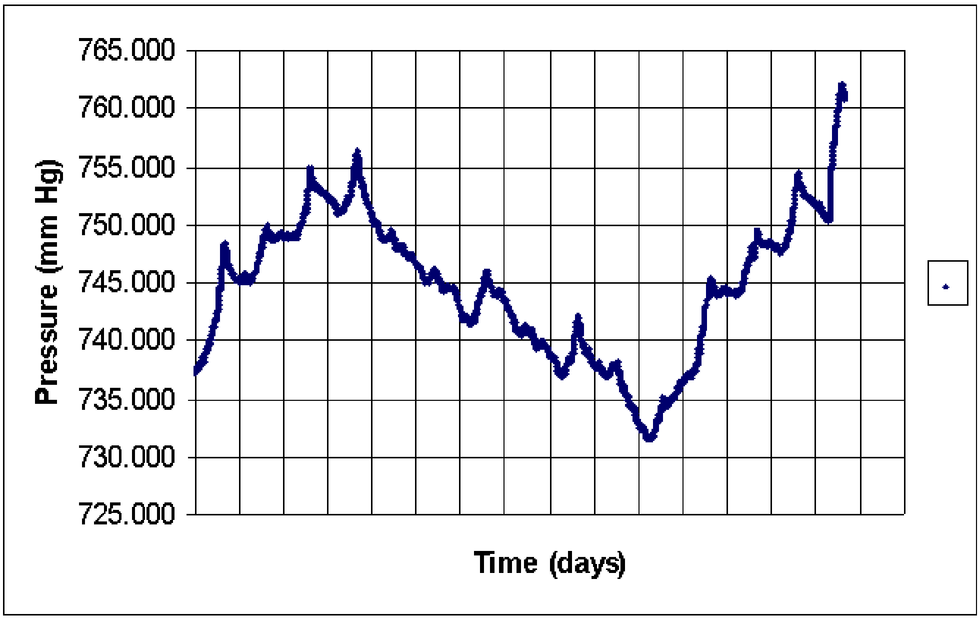

FIG.2: Variation of the local atmospheric pressure monitored in Catania along a period of approximately 15 days.

3.2 Study of the influence of atmospheric conditions on the muon flux

Apart from the (small) diurnal variations – in the order of a few mbar - of the atmospheric pressure, medium term variations (up to 40 mbar) of the pressure result in a larger – and more easily detectable – variation of the muon counting rate. Since variations in the order of 3-4 % may be observed in the local pressure (see figs.2 and 3), with a time scale which can last several days, this will give the possibility to carry out medium-term measurements (from a few days to 1-2 weeks) basically with the same approach depicted in 3.1. In such case, if one is not interested in the fine details of the time variations, longer runs may be performed, with a small statistical error. Again, the possibility to exchange data with other sites could largely improve these measurements and their subsequent analysis through correlation methods.

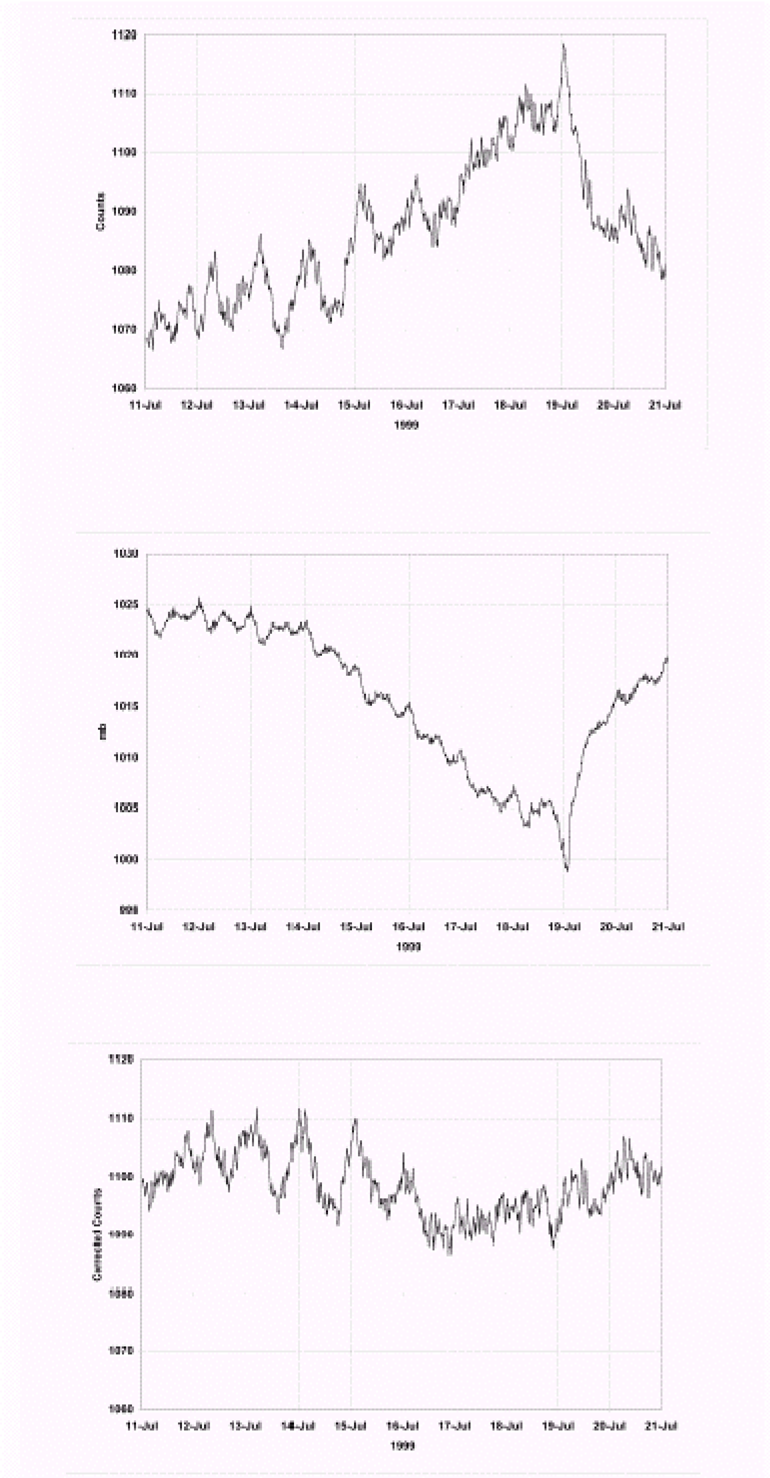

FIG.3: Correlation between the pressure and the muon rate. From Ref.(5).

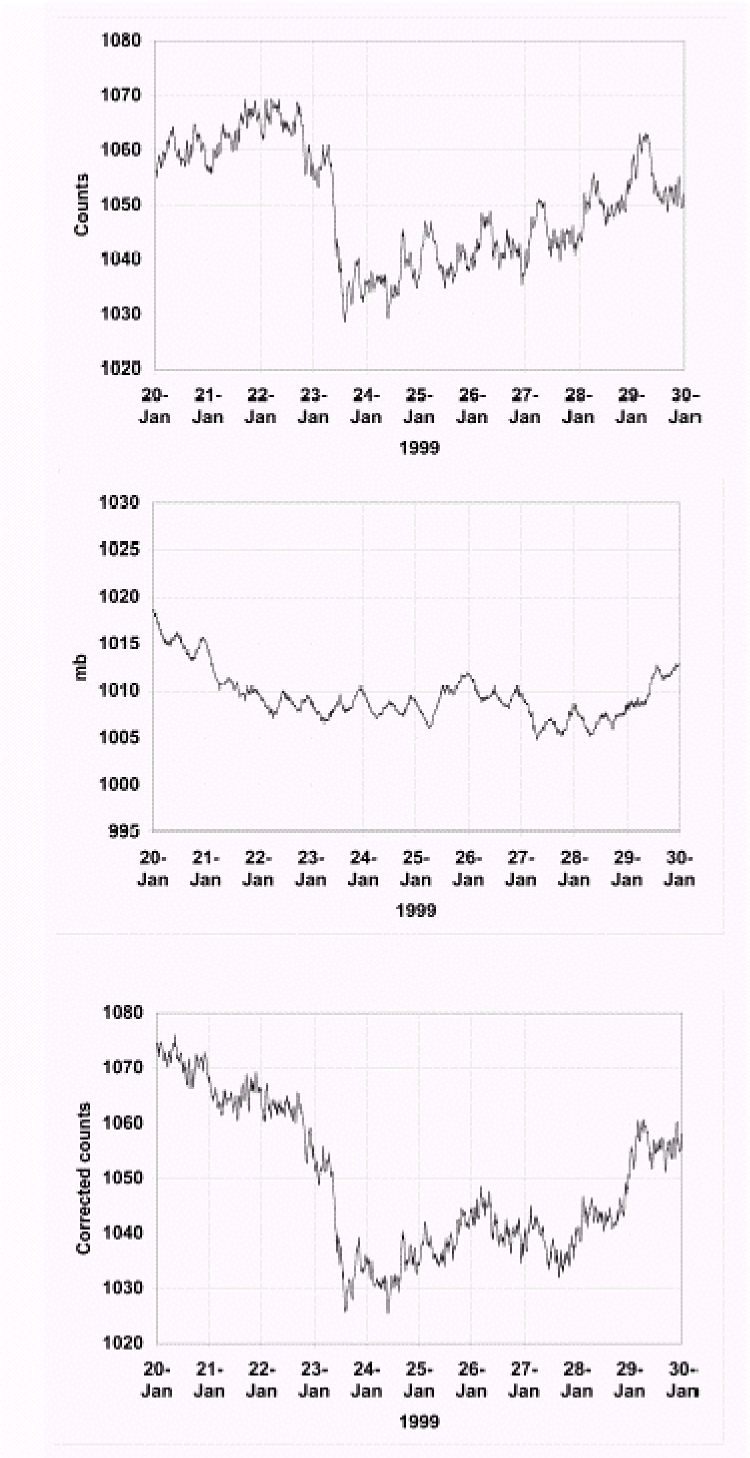

FIG.4: Forbush decrease in the muon rate. From Ref.(5).

3.3 Investigate the Forbush decrease of the muon flux

Once corrections for the pressure (and maybe laboratory temperature as well) have been made, monitoring the muon flux on a continuous basis will offer several possibilities to study physical aspects related to astronomical events. One of these is the so-called Forbush decrease (12),which is a rapid, short-term variation resulting from solar flares and mass ejection activity from the Sun corona. Such variations may result in a decrease of a few percent in the muon counting rate, followed by a characteristic recovery period of a few days (see fig.4). Such events are also seen by other radiation detectors around the world, and solar data confirm that a strong Sun activity is associated with the Forbush decrease periods. Since these events happen randomly, a continuous monitoring over extended periods of the muon flux must be carried out to have some chance to observe one of such events and study its correlation with other data available from other monitoring sites.

3.4 Correlate the muon flux to other solar events

In many cases the rapid change in cosmic ray intensity is due to the solar activity and to variations in the solar wind. Especially after violent solar events, a change in the muon flux at the sea level may be expected, with a time delay of the order of a few days. Such solar events are usually observables through several methods. They can be searched in visual solar flare data, or looking at several effects which change the state of the magnetic field of the Earth. Most of these data are made available through Web resources, and may then be used by students to understand the origin of the observed (if any) variations in what has been measured through the muon detector.

Neutron detectors are frequently used to monitor the state of the eliosphere. Neutron detectors respond better to lower energy cosmic rays which are more influenced by eliospheric changes. Also the data from some neutron monitor station is made available through the Web and can be used as a reference. As an example, the Inuvik neutron monitor station in Canada has 18 cosmic ray counters, arranged in three units, and it is continuously monitoring the neutrons associated to cosmics since 1965, showing an anticorrelation in the neutron rate with the number of sunspots, with the typical 11 years cycle. Other events recorded by neutron monitors include the Forbush decreases and solar flares.

3.5 Study the angular dependence of the muon flux

Two scintillators may be arranged in order to constitute a muon telescope, similarly to an optical telescope. When a cosmic muon will pass through both of them with a proper time difference, this will roughly define an orientation for such muon. The size of each individual detector and their distance will define the solid angle of the telescope, and hence its counting rate, together with the uncertainty in the orientation itself.

The expected muon zenith angular distribution varies with the zenithal angle θ with roughly a $\cos^2\theta$ shape, while a uniform azimuthal distribution is expected. However some discrepancy from the ideal behaviour may be found, due to the location of the muon telescope and the natural and artificial environment around it. In some cases one could take advantage of the muon absorbtion in the materials surrounding the telescope to discuss such effects and relate them to the muon energy loss.

In order to measure only the most penetrating part of the flux, a convenient (i.e. a few cm of lead) absorber could be inserted between the two components of the telescope.

The muon counting rate may be converted into absolute units of muon flux (counts per second, per steradian per unit area of the lower detector), to compare results with those obtained at different sites.

Most of the considerations reported in the previous subsections (3.1 – 3.4) for the overall counting rate may also be investigated with a specific selection of the muon orientation. For instance the muon flux can be monitored along the vertical direction, or one can search for specific behaviours along selected orientations, including the horizontal direction. Due to the $\cos^2\theta$ distribution, measurements close to the horizontal direction may require long runs.

3.6 Measure muon coincidences between separate detectors some meters apart

The use of additional muon detectors placed horizontally as the main detector, and separated by some distance, makes it possible to carry out significant new experiments. No coincidences due to a single muon are possible in such condition, and the detected coincidences originate from different, related, particles. Such coincidences were first investigated in the second half of 1930's and it was found that coincident events could be observed even when the detectors were hundreds of meters apart, although with a very low rate. When two detectors are operated in coincidence, the coincidence rate between the two detectors is a rapid decreasing function of the detector separation. Such dependence of the counter coincidence rate upon the detector separation is called the decoherence curve.

The measurement of the decoherence curve may be done within a few meters distance between the detectors, and may be found that the coincidence rate decreases dramatically as the separation of the detectors increases, for instance by a factor 5 when going from 0.5 to 2 m (see fig.5). The result is much steeper than the characteristic shower width expected on the basis of the Molière radius, which amounts to about 80 m at sea level. This sharp decrease is due to the central shower core which has a lateral spread of only a few meters. For larger separations between the two detectors, in the order of 10-50 m, the observed decrease is not so steep, and a relatively constant coincidence rate may be observed in this range. However the absolute counting rates are much lower than those observed in the range 0.5-2 m, by a factor which exceeds two orders of magnitudes.

In order to carry out such experiments, at least two detectors are needed, which can be moved in the same horizontal plane. For distances up to a few meters, the experiments are easier, since the two detectors may be placed inside the same lab, and the counting rates are relatively manageables. However, for larger separations, some better organization of the detector set-up is needed, in order to have two detectors working at tens of meters distance (power supplies, attenuation of the signal in the cables, timing between the two detectors,…). Moreover, the counting rates will be very low, requiring running times in the order of a few days to get adequate statistics.

As an example, fig.5 reports some data which were obtained at the Preston college as a part of extracurricular physics activity, with two 30 cm x 60 cm x 2 cm plastic scintillators, viewed by large photomultipliers (4). The single count rate was about 17/s for each scintillator. Even with a single count rate of about 1/s however, a few coincidences per hour may be expected at 2 m distance.

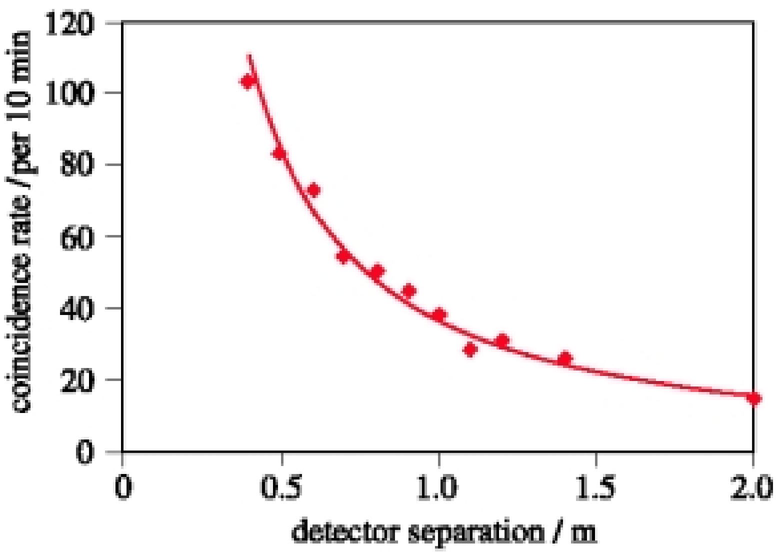

FIG.5: Decoherence curve at small separation distance. From Ref.(4).

3.7 Investigate large distance correlations

Even larger separations between detectors may be employed for the study of high energy primary cosmics. The use of large shower arrays of detectors is the base for the investigation of ultra high energy cosmic rays, as addressed by professional dedicated experiments, like the Auger experiment (14), which will investigate extensive air showers associated to energies up and possibly beyond 10^{20} eV.

While the aim of educational experiments is only to provide some insight of the problems currently addressed by frontier experiments, some quantitative investigation could be carried out even in this respect, depending on the number of available detectors and associated equipments, detector size and separation.

As an example, detector separations of the order a few hundred meters could be achieved within the same campus by placing the detectors inside close buildings. Simulations of extensive air showers allow to correlate the energy of the primary with the particle density at sea level. For instance the educational shower array in Stockolm (3) which has 3 detector stations located at about 150 m relative distance, could detect coincidences between at least two of the three detector stations originating from primary cosmic rays with energies in the order of 10^{16} eV.

Even higher energies could be addressed by the use of detectors placed at larger distances, of the order of some km, as it is the case for typical distances between the university departments and local area high school within the town. Possible involvement of several high-schools located within distances of a few km could then mimic the organization of the largest world experiments dedicated to high-energy cosmic rays. As an example, typical interdetector distances in the Auger experiment are 1.5 km.

When the distances between the detectors become very large, it is not practical to have a centralized control of the detectors and a unique data acquisition set-up. In such cases it is preferable to have an independent running of the detectors, with some timing device (usually GPS-based) to correlate the information from individual detectors (see section 4 for further experimental details).

It must be observed that through this basic technique, and employing only four detector stations located some 100 km apart in Switzerland, a time correlation was searched for between primary cosmic rays (not particles from the same shower) (15). Such correlations could originate from hypothetical events far outside of the Earth's atmosphere.

Due to the existence of similar projects in the world, some of which already started data taking on a regular basis, and the possibility that some network will be established also in different part of Italy in the future, there is hope to search for correlated events even at very large distances (hundred of km) or to become a member of large world collaborations with detectors spread out worldwide. In such case a database of events with their time-stamps derived from GPS timing could be built, and information could be accessed from any user for checks, comparison and analysis.

3.8 Estimation of the time spread in the shower front

Particles belonging to an air shower all travel with a speed which is very close to that of light. The time spread in the shower front is very small, only a few nanoseconds wide. This time width may be estimated by a comparison between the spread of the time coincidence spectrum between two detectors placed above each other, and the spread observed when the two detectors are placed side by side on the same horizontal plane. In both cases, all the time uncertainties related to scintillators/photomultiplier and electronics are the same, so that subtraction in quadrature of the two measured time widths will give an estimate of the shower time front.

3.9 Shower direction

While the zenith angular distribution of single muons can be measured (see previous subsection 3.5) in a relatively easy way, and its dependence on the zenithal angle θ is roughly $\cos^2 \theta$, the dependence of the shower as a whole has a stronger dependence on the angle (13). This is caused by different attenuation lengths of the muon and of the electromagnetic component. The measurement of the shower direction is much more difficult than for single muons which can be traced through an orientable muon telescope with a narrow solid angle. An estimate of the shower direction distribution can be done by a set of measurements of the time coincidence peak as a function of the horizontal spacing between two detectors. From such measurements, the centroid and the width of the time difference may be extracted. When the spacing between the detectors is increased, the centroid of the distribution remains constant, while the width increases, since the time difference is given by the delay between the passage of the shower front through the first and the second detector. For a fixed incoming direction, this difference is proportional to the distance between the detectors. The detailed shape of the time difference may give information about the distribution of the different arrival directions. However a simulation is usually required, starting from some hypotheses concerned with the zenith angle distribution and comparing the results of the simulations with the observed time spectrum.

3.10 Simulation and theoretical approaches

There are several aspects of cosmic ray physics, at the undergraduate level, or even at high-school level, which can be of interest from the point of view of simple theoretical or phenomenological approaches.

The evaluation of cosmic ray trajectories in a magnetic field is an important step in the understanding of some aspects of the observable phenomena. Both analytical and numerical approaches are possible, to understand the effect of the galactic and of the Earth's magnetic fields.

Statistics of counting a small number of events, and the related problems of uncertainty, reduction and controlling the statistical errors, the Poisson distribution,… provide a good set of topics to be discussed, and lot of real data to be used.

Also the role of computer simulation may be exploited both in the understanding of the detector response and the development of the air shower array in the interaction of a primary nucleus with the atmosphere. Simple computer simulations may be also undertaken to introduce students to the problem of understanding the response of a detector when it depends on several variables, and no simple analytical solution exists. In some cases more sophisticated Monte Carlo methods, or even full GEANT simulations may be discussed.

4 EXPERIMENTAL TECHNIQUES

4.1 Possible detector configuration and design

A common laboratory exercise for introductory studies on cosmic muons is the use of a simple Geiger counter to record the number of counts in fixed amounts of time, to examine the properties of the Poisson distribution. Although some attempts have been made for educational purposes, the effective area of a Geiger counter is usually too small to allow the study of intensity variation in the muon flux, and to permit coincidences between different counters. For most of the investigations concerned with these projects, people have generally used plastic scintillators, where the light produced is detected by conventional photomultipliers. Single muons which pass through the detector will loose energy by ionization, with an energy loss rate dE/dx of about 2 MeV/(g cm^{-2}). Since most of the muons roughly come from the vertical direction, the amount of material traversed by the incoming muons is nearly constant. In such case the spectrum of the deposited energy will show a broad peak corresponding to the average energy deposition, the so-called single-particle peak.

In order to maximize the muon count rate, scintillators with not too small areas are required. In such case however, one is faced with the problems related to the light collection from extended scintillators and with non-uniform efficiency along the scintillator surface. The detailed shape of the signal spectrum is a convolution of different factors, including the zenithal angular distribution of the incoming muons, the light collection efficiency over the entire scintillator surface and the properties of the Landau distribution for the energy deposition. With sufficient statistics, the spectrum will show up counts also in the high signal region, many times higher than the single particle peak, reflecting in a complicated way the particle density at the detector and then the structure of the primary particle energy spectrum (16).

Several implementations of this basic technique may be used, depending on the available material and resources. Plastic scintillators are very common in high-energy physics experiments, so that in principle some surplus material may be found.

Many experiments use scintillation detectors with a surface 0.1-1.0 m^2 and a thickness in the order of 1 cm or more, viewed from the top by a single, large size, photomultiplier. The whole scintillator/photomultiplier combination is enclosed in a light-tight box, which is either cubic or pyramidal with the photomultiplier at the apex. In other cases a smaller size scintillator may be optically coupled to a photomultiplier through a suitable light guide.

The insertion of absorbing material above the detector will reduce the muon counting rate, since the muons loose energy through ionization processes in all the traversed materials. Absorbers may be layers of lead (a few cm thickness) or the very same presence of the building. Quantitative investigation of the absorption of muons may be carried out by different layers inserted above the detector, or even putting the detector in different floors inside the same building.

For the prototype we intend to study, we will use extended scintillators with the shape of a disc (R=20 cm, thickness 3 cm), viewed by six photomultipliers localized around the disc. Such detectors were used in a previous experiment (17) for neutron detection at LBL, and allow in principle the evaluation of the hit position along the disc by a proper comparison of the timing information from several photomultipliers. The principle of the method is described in detail in Ref.(17) Even without the position information, the use of several photomultipliers increases the detection efficiency, resulting in a larger count rate.

For a better definition of the main trigger we propose to use two of such discs superimposed on the horizontal plane, with a coincidence between the two. Depending on the available electronics, one photomultiplier per disc may be used, requiring only 2 discriminators and a coincidence unit, or up to 6 photomultipliers per disc, requiring 12 discriminators, 2 six-fold logic fan-in units and again a coincidence unit.

FIG.6: Possible configuration of a two-scintillator muon detector

While such configuration is sensitive to muons coming from any direction, spanning a solid angle close to 2 π, a cosmic muon telescope may be built by the use of the same discs separated by some distance. A suitable mechanical structure with an equatorial or alto-azimuthal system could allow alignment of the muon telescope along a fixed orientation, in order to measure the angular distribution.

Additional detectors with the same size could be located at some distance from the main detector, in order to exploit coincidences between them. A small array of detectors placed at distances varying from some meters to a few tens of meters may be envisaged within the same building. Up to such distances, detectors may be handled from a unique control station, both for what concerns the power supply and for data signals.

4.2 Electronics and data taking

The use of a muon detector requires some electronics, power supply and data acquisition. The amount of material required depends on the configuration which is being developed and the measurements to be carried out. For a two scintillators system (for instance a muon telescope, or two detectors on the same horizontal plane), the basic electronics which is needed includes power supplies, discriminators, and a coincidence unit, together with some delay line. A counter and some logic fan-in/fan-out units are also useful. All this material is relatively easy to find in INFN/University research sites, together with NIM crates to handle the electronics. Concerning the data acquisition, a standard CAMAC-based acquisition set-up may be used, which requires a CAMAC crate, TDC and ADC modules (usually one module has several channels), and some crate controller + PC interface card to connect the CAMAC crate to a PC running an acquisition program. A trigger unit is also useful to provide different trigger configurations. Many systems like this are normally in use in research or even in teaching laboratories. Some of them are based on commercial available materials, while in several cases small acquisition systems have been developed from the users for the requirement of an experiment or as a part of the advanced teaching laboratory courses. The expected counting rate from detector configurations as those depicted above is not very high (usually less than 10 Hz), so that the data acquisition does not need to be very powerful in terms of acquisition rate. Graphical monitoring of spectra, counting rate, peak finding and the standard tools of an acquisition system are however useful.

In general, within the environment of a research/university site, it should be relatively easy to find out what is required to set-up a proper detector configuration to carry out at least some of the experiments outlined above, and build a prototype. An exception could be the use of a GPS-based timing device, in order to assign to each event an absolute time with the desired precision, usually in the range of tens of ns. The use of such devices is not so common in standard experiments with beams. Some GPS timing modules exist, which fulfill the CAMAC standard, providing timing precision between 10 and 100 ns, depending on the number of GPS satellites which can be accessed from the antenna.

The situation is of course much different for a high-school, which does not have at disposal basic or spare materials such as those required by these experiments. The cost of buying all what is required even for a simple two-detectors system could be in the order of 30000-40000 Euro. In such conditions, it is clear that a collaboration with high-schools may only be started with the help from INFN/University sites or within specific school projects which can be prepared as part of their developing strategies. In some cases, alternative technical solutions could be exploited by the school if the necessary knowledge is available, leading to more economical choices. As an example, DC/DC converters could be used instead of standard NIM power supply for photomultipliers, and even a GPS timing device could be built with good electronics know-how. This possibility could especially be exploited by collaborations with technical high-schools.

The addition of other detectors to the main one in the same location does not increase the cost very much, since a large part of the cost is related to the basic equipment (crates, data acquisition system, GPS module,…).

Due to the above mentioned dependence of the muon flux on the atmospheric conditions, a weather station which collects data (at least temperature and pressure) is required. These informations may be inserted in the main data acquisition procedure or collected through some separated equipment, since there is no need to exactly synchronize these informations with the muon events. Data loggers which allow the acquisition of physical variables from different types of sensors are now available on the market, and all of them may transmit the data to a PC for recording and analysis.

4.3 Data Analysis

The amount of data collected in such experiments depends very much on the detector configuration, on the number of detector stations involved and on the amount of running time. For a station with four scintillators, providing a number of CAMAC parameters of the order of 10, and a counting rate in the order of 10 Hz, 200 bytes/s will be collected. For a continuous running, this means approximately 15 Mbytes/day. If the data taking goes on continuously for several months, up to several Gbytes can be collected. Some organization of the data is then required to efficiently handle these data, organize the files, make them available to different users, transmit the data from a location to another (for instance from each individual school to a central unit), copy the data into back-up devices, and so on.

To analyze the collected data, several activities can be envisaged. Various correlation techniques can be efficiently used in order to extract relevant informations. Numerical and analytical methods may give rise to classroom activities at a sophisticated level. Comparison with model predictions and detector simulations will provide an additional topic of study and research. Computer programming and efficient use of computer tools for data handling is another aspect of interest.

5 EDUCATIONAL ASPECTS

The main educational aspect of such proposal is to involve a number of high-school institutions in real research projects concerned with some of the activities of interest to INFN and University centers. Physics teachers and associated groups of students would be trained in this field, to understand the underlying physics, to set-up and to run the experiment, and to participate to the analysis of real data.

The data from this collaboration could contribute to some aspects of cosmic ray physics, especially in view of possible participation to larger projects, and the activity could become part of the physics curriculum in the participating schools, as well as to provide interesting items for degree theses at the university level. There are also several technical aspects of a project like this which can be of interest to high-schools.

Here follows a list of school activities and investigations related to this project. Some of them are concerned with the understanding of physics phenomena, others to the experimental activity and data analysis. The detailed organization of this activity is to be defined together with the interested collaborators from high-school institutions.

1) Learn about cosmic ray physics, their main properties, the open problems, and the present status of knowledge in the field.

2) Understand the specific contribution to cosmic ray physics which can be given by the experimental set-up in the school or through the data collected at different sites joining the project.

3) Understand the basic principles of muon detection and the use of the different particle detectors.

4) Learn about the different radiations and how they interact with matter.

5) Understand the basic data which can be extracted by the experimental set-up and compare with expectations.

6) Learn about how computers can control an experiment and how data can be collected from detectors and stored on disk.

7) Learn about the basic electronics needed in such experiments, including timing signals, coincidences and the use of an oscilloscope.

8) Learn about the Global Positioning System (GPS) and how it works.

9) Learn about the principles of computer simulations of an experiment and carry out simple simulations.

10) Participate to muon monitoring campaigns and extract the relevant information from the data.

11) Measure coincidences between different detectors, possibly a decoherence curve, and understand the results.

12) Analyze specific sets of data, for instance the muon flux versus time, or the muon rate/pressure correlation.

13) Disseminate results to other people in the classroom, in form of oral presentations, written reports, Web-based informations.

14) Participate to joint discussions and presentation of results with other school teams in informal meetings.

6 CONCLUSIONS

It has been shown that simple cosmic ray muon detectors can be built within the resources of a typical INFN/University site and locally used to investigate several aspects of cosmic ray physics. The possibility to set-up collaborations with local area high-schools for educational projects related to cosmic ray physics has been discussed in detail.

There is hope that a participation in a scientific project could give to teachers and students a real feeling of the nature of research in nuclear and high-energy physics, offering to many students a direct way to verify their interest to start a career in the physical sciences.

A prototype of a possible experimental set-up for such studies would include a main detection system located at INFN/Physics Department site in Catania and a small number of detectors placed in neighbouring high-schools. If enough resources may be found to support the participation of a larger number of high-schools to the project, this could result in the creation of a large cosmic ray detector, which could allow specific measurements to be carried out locally, and the search for rare events in correlated data.

7 AKNOWLEDGMENTS

We warmly thank all the collaborators of the MUFFINS experiment for their kind permission to use part of their equipment for the purpose of the present proposal.

8 REFERENCES

(1 The ALTA project, http://csr.phys.ualberta.ca/nalta
(2 The NALTA consortium, http://www.phys.washington.edu/~walta/NALTA.html
(3 M.Pearce et al., The Stockholm Educational Air Shower Array, 28th Int.Cosmic Ray Conference
(4 P.Dunne et al., Physics Education **36,** 322, (2001).
(5 R.W.Clay et al., A cosmic ray muon detector for astronomy teaching, Electronic Publication of the Astronomical Society of Australia **17**, 171, (2000).
(6 http://www.lip.pt/experiments/trc
(7 J.Puzovic et al., Analysis of continuous cosmic-ray measurements in Belgrade, 5th General Conference of the Balkan Physical Union, August 25-29, 2003; http://www.phy.bg.ac.yu/~cosmic
(8 M.Nagano and A.A.Watson, Rev.Mod.Phys. **27**, 689, (2000).
(9 T.K.Gaisser, Cosmic Rays and Particle Physics, Cambridge University Press (1990).
(10 K.Greisen, Phys.Rev.Lett. **16**, 747, (1966); G.T.Zatsepin and V.A.Kuzmin, JETP Lett. **4**, 78, (1966).
(11 T.Hebbeker and C.Timmermans, Astroparticle Physics **18**, 107, (2002).
(12 K.Nagashima et al., Planetary Space Sci. **40** , 1109, (1992).
(13 D.Ciampa and R.W.Clay, The zenith angle distribution of extensive air showers at sea level, J.Phys. G: Nucl.Phys. **14** , 787, (1988).
(14 The Auger project, http://www.auger.com
(15 O.Carrel and M.Martin, Observation of time correlations in cosmic rays, Physics Letters **B325** , 526, (1994).
(16 D.B.Swinson and J.R.Prescott, The density spectrum of extensive air showers at 1575 m and 4300 m, Canadian Journal of Physics **46** , S292-S295, (1968).