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Current status of the expanded GRAPES collaboration experiment at Ooty in India.

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Abstract: GRAPES-3 experiment employs a high-density array of scintillators and a large area tracking muon telescope. The GRAPES collaboration is being expanded with addition of several major facilities. These include a Cerenkov telescope and low frequency dipole array for the measurement of shower energy. Addition of several modules of muon telescopes to cover a larger area, expansion of the scintillator array with greater separation between detectors. Installation of a neutron monitor is also planned. The current status of the experiment would be summarized.

Introduction

The current GRAPES-3 experiment comprises a total of 400 (each 1 m^2) plastic scintillator detectors deployed with a separation of 8 meters, to record the density of particles in cosmic ray showers, making it the one of the highest density EAS arrays[1]. The GRAPES-3 experiment also has a large 560 m^2 area, tracking muon detector [2]. New results on the primary cosmic ray composition [3, 4] and on solar flares are being reported during this conference. It is proposed to enhance the sensitivity of this experiment by adding several new components and also by increasing the area covered by this array. In order to achieve this goal an expanded GRAPES collaboration has been formed with the participation of 9 new groups from within India. We invite enhanced participation of physicists from other countries. We have developed new instrumentation to carry out the expansion in a cost effective manner as detailed below.

Analysis of the data from the existing GRAPES-3 experiment shows excellent sensitivity to the composition of primary cosmic rays in the *knee* region (10^{15} - 10^{16}eV) using muon multiplicity distribution from the large area tracking muon detector. Already the sensitivity of present experiment requires tracking of changes in atmospheric pressure, at level of 0.1 mm of Hg, since it significantly affects the rate of detected cosmic ray showers. With the expanded GRAPES array it is hoped that a consistent picture of the hadronic interaction model and the nuclear composition of primaries should emerge in the *knee* region. A significant outcome of this exercise has been, the appearance of possible domination of iron and other heavier nuclei in the primary cosmic ray composition beyond 10^{15}eV.

GRAPES-3 has provided new information on various solar phenomena including Forbush decreases (Fds) and cosmic ray anisotropy. In particular Fd produced by a X17 class solar flare of 28 October 2003 [5] was studied in detail due to tracking feature of muon telescope, providing evidence for time evolution, during onset phase of this event. We were able to measure rigidity dependence of magnitude of Fd as a function of geomagnetic cutoff, from this single instrument.

A special workshop on Astroparticle physics in held in Ooty, India in December 2006 has recommended a major expansion of GRAPES-3 by utilizing present GRAPES-3 experiment as a nucleating centre for research in Astroparticle physics in India by a major infusion of new funding.

Physics goals and the expansion of the GRAPES experiment

Study of nuclear composition and energy spectrum of primary cosmic rays from well below the '*knee*' from 3×10^{13}) to ultra-high energy of 10^{18} can only done from ground based indirect observations with sophisticated air shower arrays. Measurements made with large arrays of detectors are expected to provide more definitive information on this subject.

It is proposed to expand GRAPES-3 shower array with detectors over an area of 1 km^2 in a graded manner using high quality plastic scintillators developed in-house. We also propose to more than double the area of muon detectors to 1200 m^2. It is also proposed to add detection of radio waves and Cerenkov component in showers using equipment developed within our collaboration. Almost all of electronics for signal processing and data recording is being designed within the group. Resulting in considerable cost savings.

This expansion would permit nuclear composition to be pinned down over an energy range from 3×10^{13} to 10^{18}eV, using this single instrument. An additional advantage of this approach is relative freedom from the systematic errors that crop up, when the data are combined from a number of experiments, located at different geographic sites on the globe. The configuration of the detectors at larger separation consisting of multiple scintillators would permit precision measurement of time spread of shower particles at large distances from the core. Thus each of these detectors would function as a mini-array and time spread is expected to provide an additional handle on the measurement of primary energy of the particle.

For a given initial energy, energy per nucleon is lower for a heavier nucleus as compared to the lighter nuclei. This results in production of larger number of pions and their subsequent decay gives rise to a greater flux of muons at observational level, compared to the lighter nuclei. Thus, muon content of a shower is an excellent tracer of mass of primary cosmic ray. Existing GRAPES-3 experiment has already demonstrated this capability of large area muon detectors, to measure the nuclear composition of primary cosmic rays. This is likely to get further enhanced with the addition of another 500-600 m^2 muon detector.

Since hadron component in a shower contains a significant fraction of total energy, measurement of hadronic component also provides an input for modeling hadron interactions in the forward region. Combined electron, muon and hadron information would provide a sharper handle to constrain the nuclear composition. It is proposed to install a 6-8λ deep, highly segmented (50cm$\times$50cm) iron-scintillator calorimeter to detect and measure the hadron component. Initially a 36 m^2 area calorimeter would be built which would be subsequently increased to 100 m^2.

Precision measurement of cosmic ray energy spectrum has the potential to detect fine spectral features in the energy spectrum. Although the '*knee*' in cosmic ray spectrum has been observed by a large number of groups, detailed studies of fine structure in the energy region 10^{15}-10^{16}eV are necessary to gain insights into the mechanism responsible for '*knee*'. Such studies on the size spectrum of air showers should provide valuable new information.

At present, primary energy is determined from a fit to measured lateral distribution of air shower at observational level, which suffers from significant uncertainties due to fluctuations in development of air shower. An excellent measurement of energy can be made from Cerenkov radiation in shower, as it represents a calorimetric measurement of total energy. We propose to add a Cerenkov detector to augment our array. At still higher energies $\geq 10^{17}$eV, electrons and positrons in a shower produce radio waves at low frequencies through Geosynchrotron emission in geo-magnetic field. We propose to set up an array of wide-band dipoles to detect this radio emission, which could provide an excellent measure of primary energy. Unlike a Cerenkov telescope, the dipole arrays have a much larger duty cycle.

We propose to also investigate solar phenomena such as Solar Flares, Coronal Mass Ejections (CMEs) and Cosmic Ray Modulation. Sun is the nearest astrophysical laboratory where almost all known processes of acceleration of particles involving shock acceleration, magnetic reconnection and various plasma instabilities operate, to produce the solar wind. Solar wind is being effectively monitored using a world-wide network of space- and ground-based instruments. The solar wind plays a crucial role in determining space weather.

During a major flares, huge transient fluxes of high energy particles are injected into interplanetary space including neutrons, protons and other nuclei. Solar particles above 20 GeV, produce muons in atmosphere, which are readily detected by ground based muon detectors. Study of solar flare particles through muons has become an important tool because of large area of tracking muon detectors. Lathough present studies have provided very valuable information on the physics of the solar flares with unprecedented precision, a lot is unknown about mechanism responsible for acceleration of particles during a flare. Round-the-clock high energy observations of solar flares using muons along with other information at lower energy is expected to shed new light on the functioning of the solar accelerator.

Global network of neutrons Monitors covering a range of geomagnetic latitudes and longitudes provide information on solar phenomenon on large scale due to their omni-directional response. In contrast muon telescopes such as those in GRAPES-3 have a better angular resolution and are better suited for study of small scale anisotropies in space. Thus these two instruments provide information, which is complementary. At present, only one Indian Neutron monitors is operating at Gulmarg. It is proposed to install neutrons monitors at Ooty to provide a better coverage. GRAPES-3 muon telescope with an angular resolution of $\sim 9^{circ}$, is well suited for study of episodic decreases (Fds) and for mapping interplanetary ejecta in 3-D responsible for these events. A combination of neutron monitors and tracking muon telescopes at Ooty would be a unique tool for study of; episodic modulation, 3-D features of Fds and interplanetary structures responsible for them, Precursor (e.g. loss cone) anisotropies, cosmic ray density gradients in space, effects of solar wind plasma and interplanetary magnetic field on high energy cosmic rays and the physics of solar modulation.

Episodic emission of ultra-high energy (UHE $>$50 TeV) radiation from periodic sources such as X-ray binaries and pulsars etc. is also an important component of this experiment. UHE photons are expected to be secondaries, produced in interaction of charged particles at sites of their acceleration. High energy electrons through bremsstrahlung and from decay of neutral pions produced in interaction of protons produce UHE photons in compact sources. Past observations have shown emission of episodes of sporadic emission of UHE radiation from X-ray binaries and radio pulsars. The operation of a large and sensitive expanded GRAPES-3 array should permit identification of episodic emission with much greater confidence by rejection of a large fraction of charged cosmic ray background using muon component in the shower.

Exotic phenomena such as bursts of ultra-high energy ($>3\times10^{13}$eV) radiation during γ-ray bursts, or during exploding phase of primordial Hawking black holes etc. may also be studied. Models of relativistic dust grains impacting Earth and producing γ-ray bursts have been proposed. Such models predict observation of γ-ray bursts over huge distances which could be detected by deploying a network of mini-GRAPES type arrays at several locations in India proposed by participating groups. Initial proposal envisages setting up of four such arrays at Darjeeling, Gulmarg, Guwahati besides at Ooty. This concept was also endored at the joint meeting of Indian funding agencies held in 2006.

Highest energy cosmic ray (CR) particles $>10^{20}$eV are expected to to produce a diffuse flux of 100 TeV γ-rays from their interaction with cosmic microwave background (CMB) photons resulting in 'GZK cutoff' in CR energy spectrum at $\sim10^{20}$eV. Experimentally it is difficult to distinguish γ- from CR induced showers with ground based observations. However, several groups in recent times have managed to place stringent upper limits on diffuse flux of γ-ray which seem to question the validity of certain models in the energy region from several tens of TeV to a PeV. It is known that the muon content of γ-ray showers, is $<5\%$ as compared to the proton/nucleus initiated showers. Therefore, showers unaccompanied by muons (μ-poor), provide an efficient mechanism for identification of γ-ray showers. Proposed expansion of muon detector would allow a separation between γ- and proton induced showers and determination of the ratio of γ-ray to protons (γ/p) to unprecedented precision.

Conclusions

Due to its dense detector configuration and the presence of a very large area tracking muon detector and its high altitude, and in view its proposed expansion the GRAPES array would offer advantages. These include enhanced ability to mesure cosmic ray composition, its spectral shape and sensitivity to episodic phenomena. For astrophysical observations unique location of Ooty near the equator offers a view of both northern and southern skies, including the galactic centre region. The latitude difference of about 5-6 hours relative to Europe and 10-12 hours relative to Americas, makes it possible to monitor certain UHE sources and other episodic or transient UHE emissions at a time when they are not in field of view of other experiments elsewhere. This makes GRAPES-3 experiment a valuable component of the international scene with great potential to contribute to the field of UHE astrophysics.

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