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School Cosmic Ray Outreach Detector (SCROD)

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Abstract. We report on our studies of applying novel detector technologies developed for LHC-era experiments to cosmic ray detection. In particular, we are investigating usage of scintillating tiles with embedded wavelength-shifting fibers and avalanche photodiode readout as part of a robust, inexpensive cosmic air shower detector. In the near future, we are planning to deploy detector stations based on this technology at area high schools and colleges as part of an outreach and education effort, known as SCROD.

1 Introduction

The project we describe here, known as *SCROD* for *S*chool *C*osmic *R*ay *O*utreach *D*etector, is based on a idea which is simple but has great potential: install cosmic ray detectors suitable for continuous muon counting and detection of building-sized (or larger) extensive air showers in high schools and relay collected data via the internet to a central repository which is accessible to all participating schools. The principle aim of the project is education, but there is potential for contribution to cosmic ray physics as well. Involving students in a project making real measurements in a living field appears to be more likely to spark an interest in physics than the usual ritual of repeating century old experiments whose conclusions are foregone. A number of groups are pursuing similar programs (CROP, CHICOS, ALTA, WALTA) [1] using various approaches and recycling equipment to various degrees. Here we discuss our approach and the current status of the work.

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[1]Relevant web pages are:
http://www.unl.edu/physics/crop.html
http://www.chicos.caltech.edu/
http://csr.phys.ualberta.ca/~ alta/
http://www.phys.washington.edu/~ walta/
http://www.hep.physics.neu.edu/scrod/

2 Physics Potential

There are a number of topics which can be addressed with an array of detectors of the type we are proposing, ranging from searches for long-range correlations among air showers (perhaps the primary goal) to other topics in astrophysics.

Our pilot phase will take place in Boston, which, with its dense population of schools, is naturally conducive to a reasonably granular detector. In this phase, therefore, SCROD will function somewhat like earlier experiments such as AGASA and CASA, sampling the shower front with scintillators.

Depending on what the highest energy cosmic rays actually are, it is conceivable that there exist long-range correlations among the air showers they produce. Either observation or non-observation of such correlations would be an important result which cannot readily be obtained except by geographically extensive experiments.

Several processes could give rise to very long-range correlations. One is the Gerasimova-Zatsepin (GZ) effect (Gerasimova and Zatsepin, 1960; Medina-Tanco and Watson, 1999; Epele, Mollerach and Roulet, 1999), in which a high energy atomic nucleus approaches the earth and dissociates on an optical photon from the sun. The (two or more) nuclear fragments can then reach the earth at distant locations, but close together in time. Since the composition of high energy cosmic rays is unknown, and its determination from single extensive air showers is complicated by sensitivities of observables to details of the hadronic interaction model chosen, it would be interesting to search for such events.

In the GZ effect, the distance by which nuclear fragments are separated upon arrival at the earth depends on their deflection in the magnetic field of the solar system. Recent analysis (Medina-Tanco and Watson, 1999) for iron nuclei has indicated that very large separations are to be expected. For iron nuclei with energy around 1 EeV, for example, most separations wll be in excess of 100 km. Clearly, extensive detectors are required to observe such events. Figure 1 shows roughly the expected rate for various separations (see the appendix for more detail).
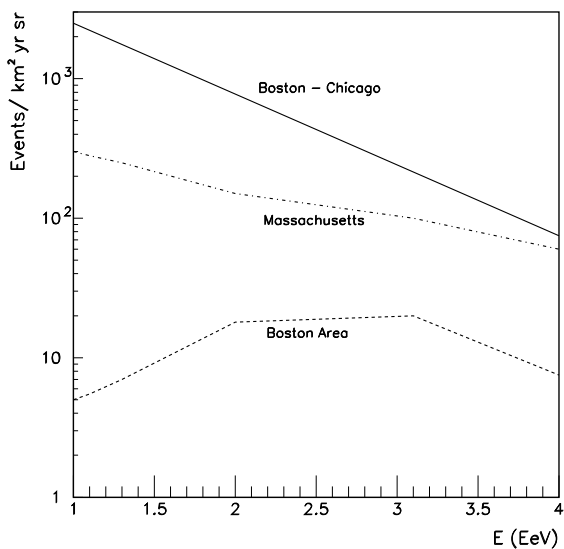
Fig. 1. Expected rates versus energy for correlated events due to iron nuclei disintegrating on solar photons. This figure is for the case of events arriving from a direction close to the sun. The three lines show approximate rates characteristic of the separations attainable in different geographical areas (the Boston area, the entire state of Massachusetts, and a separation of roughly the distance from Boston to Chicago.)

There are also other conceivable mechanisms to produce a similar effect. For example highly energetic dust grains could dissociate and give rise to widely-separated showers (Anchordoqui , 2000). One might also conceive of dramatic cosmic events that may also pepper the globe with many high energy cosmic rays all at about the same time. With the GPS timing information, it will be possible to compare and correlate data taken with SCROD with those taken at neutrino and gravitational radiation detectors. Finally we note that there is already some suggestion of experimental evidence for long range correlations in the literature (Wada et al., 1999; Carrel and Martin, 1993).

The primary background for genuine long-range correlations will arise from random coincidences of low energy showers. This can be controlled by detector spacing, which effectively sets an energy threshold, and possibly pulse-height analysis of the scintillator signals.

3   Education Goals

The goal is that students, under the advisement of professional physicists and their teachers, will be responsible for the day-to-day running of the experiment, for the data analysis and search for time correlations, and will in some cases devise unique projects using their station. We are also consulting with area teachers to begin developing ways to use the apparatus to catalyze related classroom activities. At the

current prototype phase, we are involving a few high school students and beginning undergraduates directly in the development efforts. Aside from its value to the students, this helps us to ascertain which aspects of the project will have to be kneaded into a more pedagogically usable form.

4   Detector Description

The hardware proposed for the detector sites consists of the following main components: 1) a set of plastic scintillating tiles with wavelength-shifting fibers; 2) avalanche photodiodes to read out the fibers; 3) a GPS-based system to time-stamp the signals; 4) a personal computer (PC) for local data acquisition and 5) the Internet to provide an inexpensive wide-area data acquisition system. A single station will be equipped with 3–5 separate scintillators, arranged on the school rooftop. We plan to procure new detector equipment (scintillators and fibers) while recycling computers, which otherwise would be the single most expensive component of the system. In this way we can deliver a quality detector at reasonable cost.

4.1   Scintillating Tiles with APD Readout

The scintillator we use is adapted from technology developed for the LHC-b pad/preshower detector (LHC-b Collab. , 1998), and comprises a 30×30 cm plastic scintillator slab with two circular grooves machined in it. Three wavelength–shifting fibers (Bicron BCF-91) are embedded in the grooves, 1 in the inner grove, 2 in the outer, to shift the scintillation light into the sensitive region of the readout apparatus and to serve as a light guide. The scheme is illustrated in Figure 2. The entire assembly is wrapped in white Tyvek [2] paper to increase light collection efficiency.
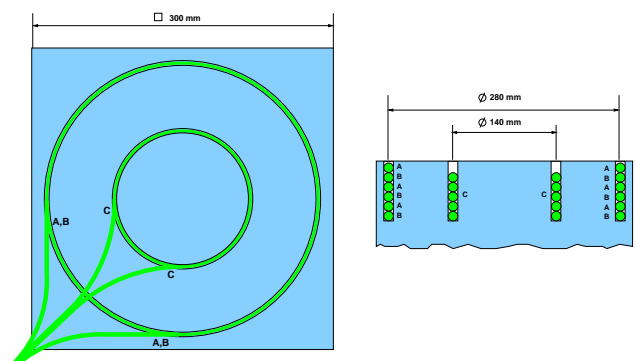

Fig. 2. Schematic representations of scintillators with embedded wavelength-shifting fibers.

To read out the fibers, we use an avalanche photodiode (APD). APDs are essentially photodiodes with an internal gain mechanism. They can have high quantum efficiencies, exceeding those of photomultiplier tubes. They are also mechanically robust (Baccaro, et al., 1999; Musienko, et al.,

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[2]Tyvek is a trademark of DuPont.

2000; Marler, et al., 2000) and easy to use, requiring a supply of only a few hundred volts, a current-limiting resistor, and a preamplifier. Furthermore, they require only a few hundred nanoamperes of current to function; an apparatus which presents no risk of electric shock is attractive for deployment at schools.

Using a low-noise amplifier we have designed together with the scintillator-fiber-APD assembly yields a very clean signal, as shown in Figure 3.
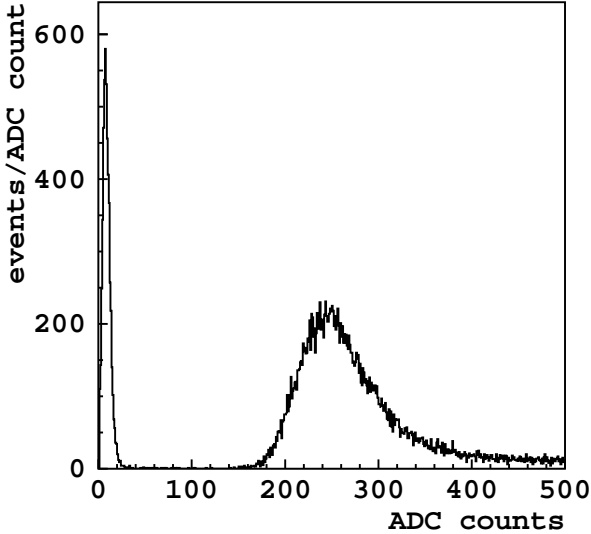

Fig. 3. Signal due to single muons passing through the scintillator using APD readout.

4.2 GPS Timestamp and Data Acquisition

In the current prototype version, the amplifier signal is passed through a discriminator to generate a TTL pulse, which is used to latch the time of each hit. The time is broadcast from a central board comprised of two sets of counters, one of which records the number of pulses delivered by the GPS receiver's 1 pulse per second (1PPS) line, while the other is clocked by an on-board 100 MHz oscillator and reset each second by the 1PPS line. The timing resolution offered by the fast rising edge of the 1PPS signal is about 40 ns. Each scintillator has its own time latching circuitry which converts the time to serial RS-232 signals and relays it to a serial port in the computer; there is one serial port for each scintillator. This design is reasonably modular so that a given site can easily attach another scintillator, or in principle any other piece of hardware which records data that should be timestamped. The basic scheme is illustrated in Figure 4.

This design also allows for very simple electronics. Our prototypes were constructed by first-year undergraduate students using quite inexpensive off-the-shelf components.

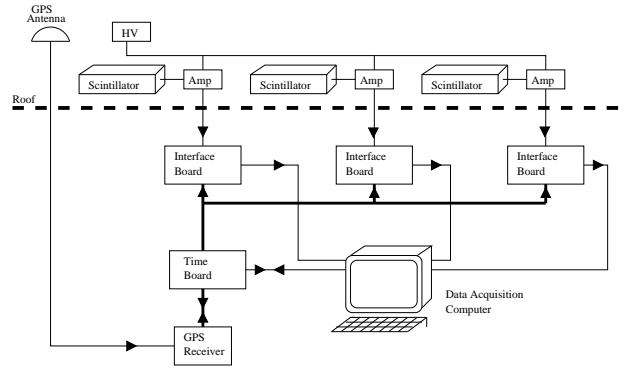To the extent possible, we are devising a purely offline

Fig. 4. Readout scheme for a SCROD station. The Time Board broadcasts the time count, using the 1PPS signal from the GPS receiver to stay synchronized to universal time. The Interface Boards latch the time upon receipt of a signal from a scintillator, then relay it to the computer.

software trigger; all hits are stored in their respective serial ports and accessed by reader programs running as separate threads on the PC. A triggering module can access the data from the different threads and apply trigger logic. This allows students to develop their own triggering schemes in a very easy manner, and it also will facilitate future upgrades and uniformity among all the stations. Changing the trigger will only entail uploading a new piece of code, instead of altering the hardware at numerous sites.

5 Summary

We are adapting detector technologies from our work on LHC experiments to develop inexpensive cosmic air shower detectors suitable for deployment at high schools. The primary goal is to interest students in physics by involving them directly in a project which has the potential to make some meaningful measurements. The essential ingredients have been designed and tested (partly by students) and construction of a station for deployment is underway.

Appendix A

The rate of occurrence of these kind of events is given by the cosmic ray flux, the fragmentation probability, and the fraction of GZ events with separation distance $d < d_{\max}$, $f_{d_{\max}}$. The rate of events above a given energy E for a surface detector of area S and solid angle Ω reads,

$$\text{Rate}(E_{\text{CR}} > E) \sim \Phi(E_{\text{CR}} > E)\, \eta_{\text{GZ}}(E)\, f_{d_{\max}}\, S\,\Omega, \quad \text{(A1)}$$

where $\eta_{\text{GZ}}^{\text{Fe}}(E) \sim 10^{-5} - 10^{-4}$ is the fragmentation probability, and

$$\Phi(E_{\text{CR}} > E) \sim 47 \left(\frac{\text{EeV}}{E}\right)^2 \text{km}^{-2}\,\text{yr}^{-1}\,\text{sr}^{-1}, \quad \text{(A2)}$$

is the measured cosmic ray flux above the knee ($E_{\text{CR}} > 3 \times 10^{15}$ eV).

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LHC-b Collab. Technical Proposal is available at `http://lhcb-tp.web.cern.ch/lhcb-tp/`

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