Proceedings of ICRC 2001: 877 

ICRC 2001

# Cosmic-ray air-shower timing experiment: A small prototype ‘Linsley-effect’ detector

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**Abstract.** A new, small-scale, detector utilizing the finite thickness of air-shower “pancakes” has been developed and operated on the roof of the physics building at the University of Minnesota. (MR. CRATE = Minnesota Rooftop Cosmic-Ray Air-shower Timing Experiment) The work started before the author was aware of the extensive work of Linsley and others with such detectors. The experiment will be expanded to three detectors operating in coincidence to look at showers from $10^{17}$ to $10^{19}$ eV and develop techniques for using a compact array in coincidence with underground detectors. Preliminary results and design will be discussed.

## 1 Introduction

With the motivation of using a small, compact cosmic-ray air-shower detector to measure showers whose core fell outside of the detector, a rooftop detector was installed on the Physics Building at the University of Minnesota. The initial plan was to rely upon fast timing to measure the extended thickness of the shower front from high-energy air-showers.

## 2 Hardware & data collection

The prototype detector consists of 2m$^2$ of 12.7mm thick Bicron BC-408 scintillator arranged in four 1/2m$^2$ tiles, each read out by a fast XP-2020 photomultiplier tube. (Three of the tubes are hand-selected XP-2020-UR models.) Data readout is CAMAC-based, with NIM discriminators and low-level coincidences requiring three out of four of the tiles to have minimal signals (corresponding to about 30 particles/m$^2$ in the shower). After the initial coincidence and discriminators are set, the data are fed into LeCroy 1.3GSa/s waveform analyzers (FADCs) and then read out to a acquisition PC via GPIB.

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Final trigger formation is handled offline via a software time-over-threshold discriminator. About 14000 events were recorded during 2405 hours of livetime during the six month period November 2000–May 2001. Of these, 2459 were reconstructed using the first pass software

## 3 Preliminary data & analysis

Analysis of the data was based on empirical formulations for the shower event time envelope (thickness) and on Monte Carlo simulations of extensive air showers using the AIRES simulation code. Figure 1 shows the empirical template for timing t distance for a moderate $N_e$. The points on the plot are taken from Monte Carlo simulations. Vertical errors arise from timing errors in measurement and horizontal errors from the distribution of possible solutions. This distribution is due to the unresolved angular dependence of the air-showers (averaged over shower production) and the intrinsic shower-to-shower fluctuations.

A crude, first-pass attempt at an all-particle spectrum is shown in Figure 2. Note that there is no geometrical factor (or acceptance) calculated for these data—only the raw number of reconstructed events versus reconstructed energy is plotted.

Figures 3 and 4 show two sample events from the analyzed data set. Figure 3 is a relatively nearby shower of about $10^{18}$ eV recorded about 200m from impact. Errors on the energy are estimated at the 75% level and on the impact parameter at the 30% level. Figure 4 is one of the highest energy events—it reconstructed to about $5 \times 10^{18}$ eV at a distance of approximately 400m from the core.

## 4 Conclusions & future plans

The detector will be expanded to three units operating in coincidence and separated by about 20m on an equalateral triangle. The total detector area will be about 7.5m$^2$ with each element consisting of two paddles. Triggers will be formed

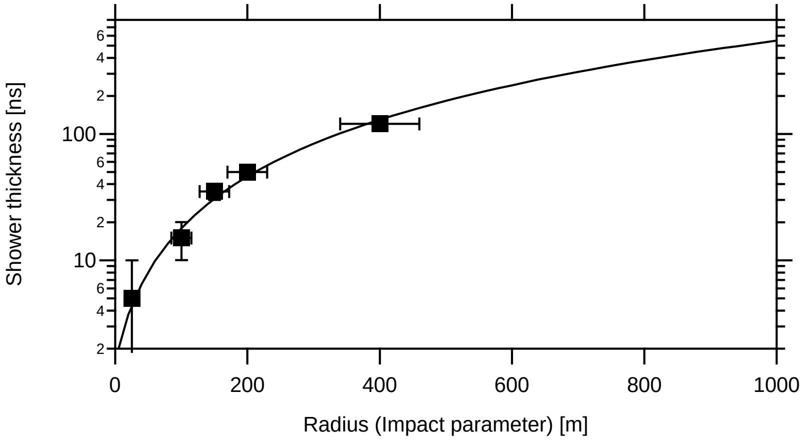


**Fig. 1.** The shower “pancake” thickness to radius curve for showers of near $10^18$ eV. The curve is the empirical formulation of Linsley (1986) and the square markers are the results from a Monte Carlo (AIRES) simulation combined with a detector & electronics simulation. Vertical errors are representative of finite statistics errors in timing and the horizontal errors reflect the systematic spread of possible solutions.

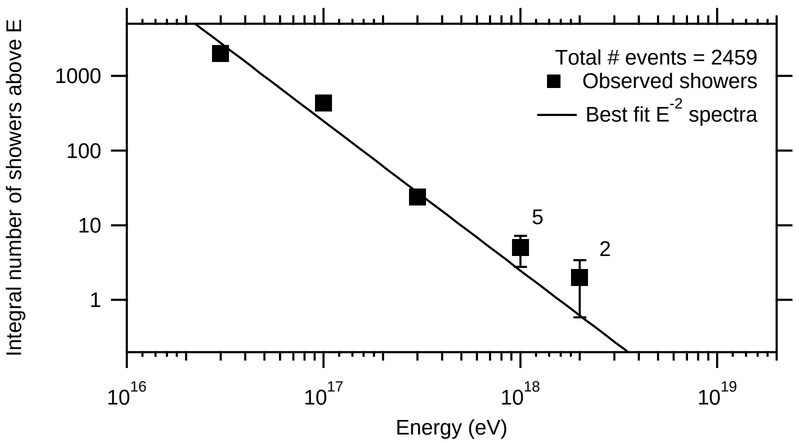


**Fig. 2.** Of the approximately 14000 events recorded during 2405 hours of livetime over six months, 2459 had energies and impact parameters reconstructable in this first analysis pass. Displaying the integral number of events as a function of energy yields data which are not inconsistent with a power-law spectrum. A full Monte Carlo has not been performed, but simple calculations seem to show a roughly constant aperature over the $10^{16.5}$ – $10^{18.5}$ eV range. The number of events is indicated for the last two bins.

by majority logic of the three elements each of which will require a two-fold coincidence of scintillator paddles. By measuring relative timings between elements as well as time-above-threshold at each scintillator, most of the geometric uncertainty of reconstruction can be removed. Software for the automated processing of events will also be finalized.

An additional development goal for this detector system is to operate it in coincidence with a cosmic-ray RF detector system also under development at the University of Minnesota. The timing detector allows for triggering on large air showers from a relatively compact array—ideal for development work on RF detectors for which the largest, highest energy showers should have the most prominent signals.

*Acknowledgements.* This work has been supported by institutional funds at the University of Minnesota. Thanks also to Jim Beatty, Jim Cronin, Keith Ruddick, and Mike Thayer for suggestions and fruitful discussions.

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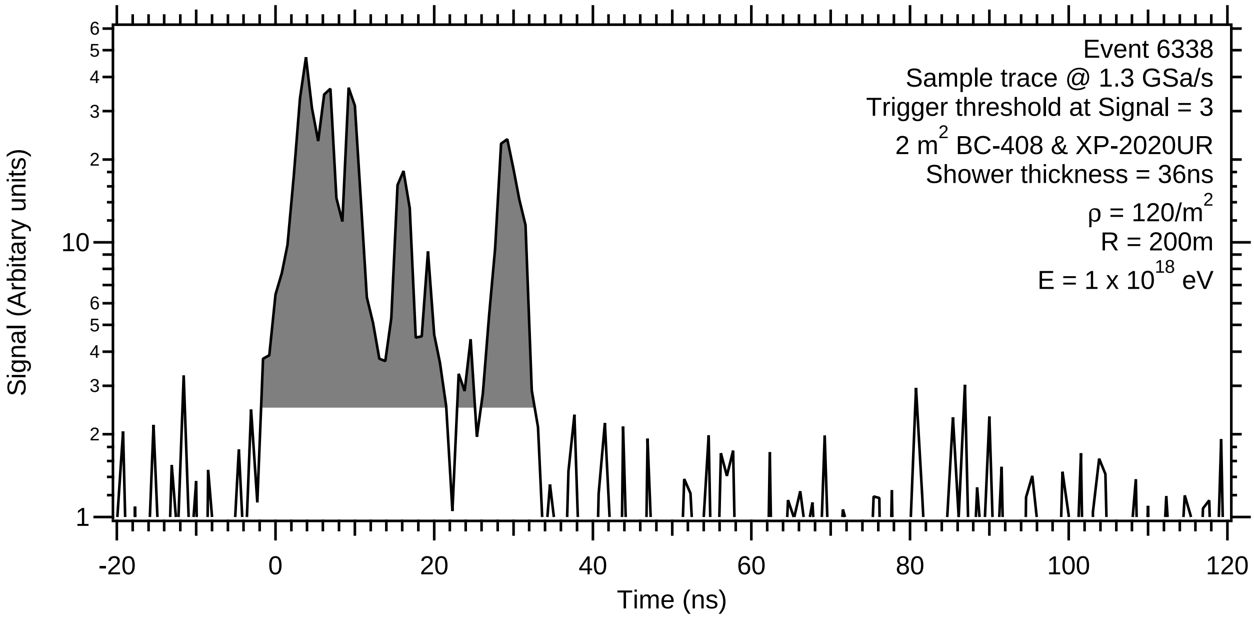


**Fig. 3.** This is an example of a relatively close high-energy shower. It was inferred to be of about $10^{18}$ eV from the shower "pancake" thickness and with impact parameter 200m from the energy and the particle density. Reconstruction is highly preliminary and reflects averaged angle shower parameters due to the use of a single detector paddle. The trigger is a time-over-threshold coupled to a box-car integrator. For this run, a constant threshold was set, signals were required for 20ns minimum, and the time-over-threshold fraction needed to be above 50%.

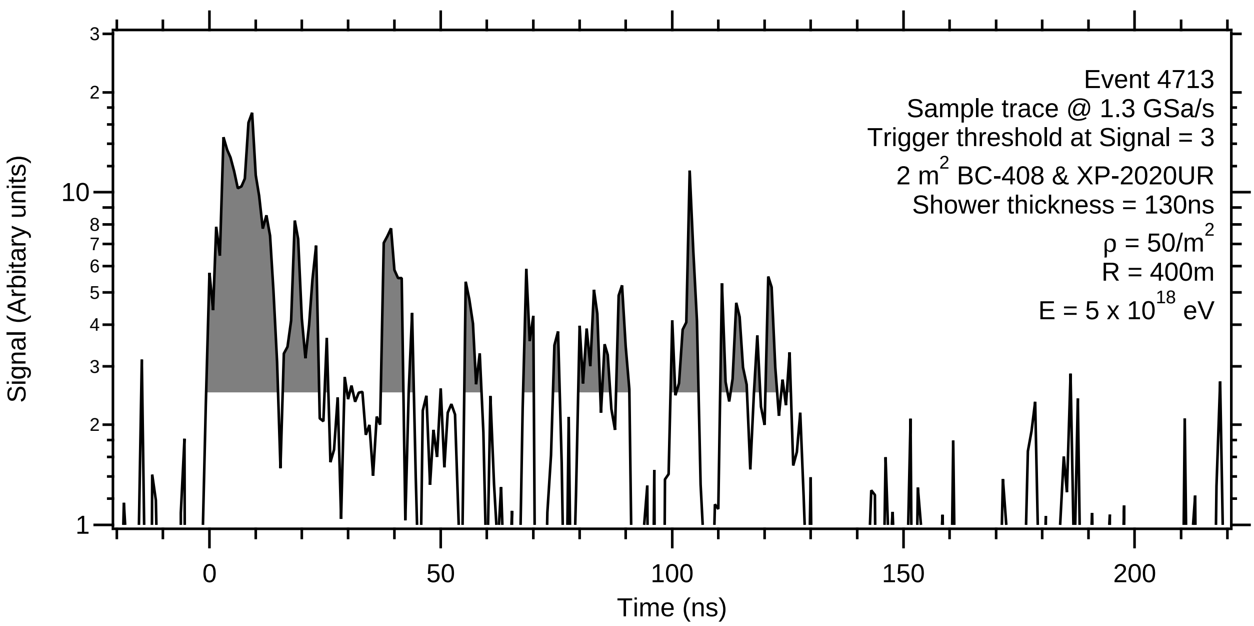


**Fig. 4.** In the preliminary reconstruction, this event (number 4713) appeared with the highest energy (about $5 \times 10^{18}$ eV, with uncertainties of about 75%). This event was seen at about 400m from the core with a particle density of about 50/m$^2$. The noise in the detector consists primarily of low-energy showers, single ground-level particles, and a fairly high dark current on the phototube.