

Search for Correlated High Energy Cosmic Ray Events with CHICOS

R. D. McKeown^a, B.E. Carlson^a, E. Brobeck^a, C.J. Jillings^a, M.B. Larson^a, T.W. Lynn^a, J.E. Hill^b, B.J. Falkowski^c, R. Seki^c, J. Sepikas^d and G.B. Yodh^e

(a) W.K. Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, CA 91125, USA.

(b) Department of Physics, California State University at Dominguez Hills, Carson, CA 90747, USA.

(c) Department of Physics and Astronomy, California State University at Northridge, Northridge, CA 91330, USA.

(d) Department of Astronomy, Pasadena City College, Pasadena, CA 91106, USA.

(e) Department of Physics and Astronomy, University of California at Irvine, Irvine, CA 92697-4575, USA.

Presenter: R. D. McKeown (bmck@krl.caltech.edu), usa-mckeown-R-abs2-he13-oral

We present the results of a search for time correlations in high energy cosmic ray data (primary $E > 10^{14}$ eV) collected by the California High school Cosmic ray ObServatory (CHICOS) array. Data from 69 detector sites spread over an area of 400 km² were studied for evidence of isolated events separated by more than 1 km with coincidence times ranging from 1 microseconds up to 1 second. We report upper limits for the coincidence probability as a function of coincidence time.

1. Introduction

Correlations between spatially separated cosmic ray events would indicate that the particles have some common history. Extensive air showers are well-known to produce correlated signals on the earth's surface over distances of several kilometers. However, it is possible that isolated primary cosmic ray events separated by > 1 km could arrive in time coincidence. Such correlated cosmic ray events could result, for example, from the photodisintegration of heavy nuclei (*i.e.*, iron) by solar photons [1]. In a previous study [2], there was some episodic evidence for time correlations up to 10^{-3} s in events separated by ~ 100 km. More recently, LAAS [3] searched for correlated events at large distances ~ 500 km and found a few candidate events. However, these events were consistent with interpretation as accidental coincidences between uncorrelated events. We have studied data obtained with the CHICOS array during January 2003 through June 2005 and searched for evidence of correlated air shower events separated by > 1 km with energy threshold 10^{14} eV.

2. CHICOS

The California High school Cosmic ray ObServatory (CHICOS) observes cosmic ray induced air showers with an array of detector sites located on school roofs in the Los Angeles area (Lat. 34.1° , Long. -118.1° , average 250 m above sea level). The sites are separated by distances of typically 2 – 3 kilometers, with the overall array covering an area of ~ 400 km². During this study, the number of operational sites increased from 31 to 66. Each detector site contains two plastic scintillator detectors, separated by ~ 3 meters. The detector typically has ~ 1 m² area and 5 – 10 cm thickness. Data are stored on local hard disk and automatically transferred to Caltech via internet every night by the computer located at each site.

“Trigger” events are defined as those where both detectors at a site record signals greater than 2 single vertical particles within a 100 ns time window. Most trigger events are isolated single events (*i.e.*, no nearby sites are hit) which are generated by low energy showers with a threshold of about 10^{14} eV. The rate of these triggers (about 1000 per day per site) is comparable to expectations based on the previously measured flux [4] and computer simulations of air showers with the AIRES code [5].

Large showers that generate a trigger at one site with coincident single hits at several neighboring sites must

have extremely high energies of $> 10^{18}$ eV. We do observe such large air shower events with the CHICOS array, presently at a rate of about one per month. However, even the largest air showers with primary energy $E \sim 10^{20}$ eV would not generate 2 triggers in sites separated by more than 1 km. In this work we search for double trigger events where two sites, separated by more than 1 km, both record trigger events within a certain coincidence time. Such a signal could indicate the existence of isolated correlated cosmic ray events separated in distance by up to 60 km (the largest distance between two CHICOS sites).

3. Correlation Analysis

The data sample for this analysis is the time-stamped sequence of trigger data from the operational sites, which forms a complete record of all the events detected by the array with sufficient energy to trigger a single site. In order to examine these data for time correlations, a randomized data set was constructed directly from the real data, as in [2], by offsetting the sequence of triggers at each site by some integer number of seconds relative to the other sites. Since a shift of several seconds is small compared to the time for drift in the average trigger rate, the randomized data should reproduce all aspects of the real data associated with accidental coincidences. Deviations of correlations observed in the real data relative to the randomized data could be indications of significant correlations (*i.e.*, not accidental) in the data.

Given a coincidence time interval Δt , we define N_{excess} as the number of excess event pairs (relative to the randomized data sample) with that time difference, which may be positive or negative. If both members of a successive pair are from the same site, that pair is not counted (to eliminate instrumental effects such as PMT afterpulsing).

In order to search for correlations on any time scale less than 1 second, we compute the probability of an excess coincidence per site for the cumulative time interval $\{0, \tau\}$ according to

$$P_{\text{excess}}(\tau) = \frac{N_{\text{excess}}(\Delta t < \tau)}{N_{\text{trig}} (\langle N_{\text{sites}} \rangle - 1)} \quad (1)$$

in which $\langle N_{\text{sites}} \rangle$ is the average number of operational sites and N_{trig} is the total number of trigger pairs. We

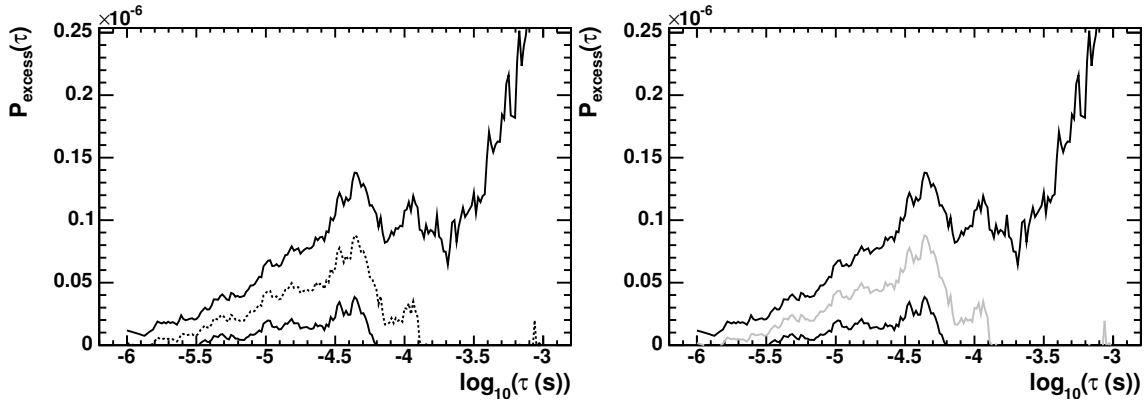


Figure 1. Probability of an excess trigger coincidence per site plotted vs. cumulative coincidence time scale. The upper plot shows the results for short time scales $\tau < 10^{-3}$ s and the lower plot shows the longer time scales $10^{-3} < \tau < 1$ s. The lines drawn are the upper end (solid), center (dotted) and lower end (solid) of a 90% Feldman-Cousins confidence interval. The upper curve is interpreted as an upper limit for the probability per site of real coincidences for the corresponding time scale.

compute a 90% confidence interval for $P_{\text{excess}}(\tau)$ using the method in [6], and interpret the upper limit as the 90% confidence level upper limit for the excess probability per site for the interval $\{0, \tau\}$. The results, for 17 months of data from January 2003 through July 2004 are shown in Fig. 1 [7].

As discussed in [7], the data in Fig. 1 indicate an excess of events at time scales of order $\sim 10^{-4.5}$ s, or $\sim 30 \mu\text{s}$. The excess heals itself at larger τ as we add more data that show (apparently) no correlations. To study this possible signal further, we have repeated this analysis with an independent data set from August 2004 through May 2005. In Fig. 2 we show the results of the analysis of the new data. It is clear from the new data that there is no evidence of the apparent excess displayed in Fig. 1. Therefore, the excess in the earlier dataset is interpreted as a statistical fluctuation.

4. Conclusions

A search for time correlations in cosmic ray data collected by the CHICOS project has been performed. The results are consistent with a lack of any real correlation between isolated events. Earlier observations that indicated an excess of events at shorter times are interpreted as a statistical fluctuation. The excess coincidence probabilities displayed in Fig. 1 can be properly interpreted as 90% CL upper limits for the incidence of correlated pairs of cosmic rays above 10^{14} eV separated by distances between 1 and 60 km.

5. Acknowledgements

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¹<http://www.chicos.caltech.edu/collaboration/collaboration-list.html>

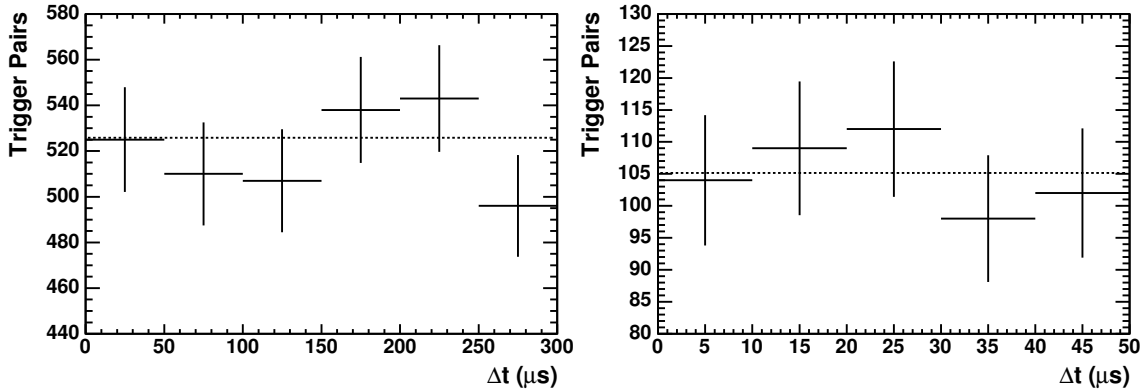


Figure 2. Trigger pair time distribution for the new dataset (August 2004 through May 2005) with $\Delta t < 300 \mu\text{s}$ and with $\Delta t < 50 \mu\text{s}$. Plotted points with error bars are real data and the horizontal dotted line indicates the expectation from random coincidences.

References

- [1] G. A. Medina-Tanco and A. A. Watson, *Astropart. Phys.* **10**, (1999) 157.
- [2] O. Carrel and M. Martin, *Physics Letters* **B325**, (1994) 526.
- [3] N. Ochi, *et al.*, *J. Phys. G: Nucl. Part. Phys.* **29** (2003) 1169.
- [4] M. Nagano and A. Watson, *Rev. Mod. Phys.* **72**, (2000) 698.
- [5] AIRES Webpage:
<http://www.fisica.unlp.edu.ar/auger/aires/>
- [6] G. Feldman and R. Cousins, *Phys. Rev.* **D57**, (1998) 3873.
- [7] B. E. Carlson, *et al.*, *Journ. Phys. G: Nucl. Part. Phys.* **31**, 409 (2005).