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UCRL-TR-230895

Cosmic Ray induced Neutron and Gamma-Ray bursts in a Lead Pile

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May 11, 2007

Disclaimer

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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The neutron background is created primarily by cosmic rays interactions. Of particular interest for SNM detection is an understanding of burst events that resemble fission chains. We have been studying the interaction of cosmic rays with a lead pile that is efficient at creating neutron bursts from cosmic ray interactions. The neutron burst size depends on the configuration of the lead. We have found that the largest bursts appear to have been created by primaries of energy over 100 GeV that have had a diffractive interaction with the atmosphere. The large events trigger muon coincidence paddles with very high efficiency, and the resulting interactions with the lead pile can create over 10, 000 neutrons in a burst.

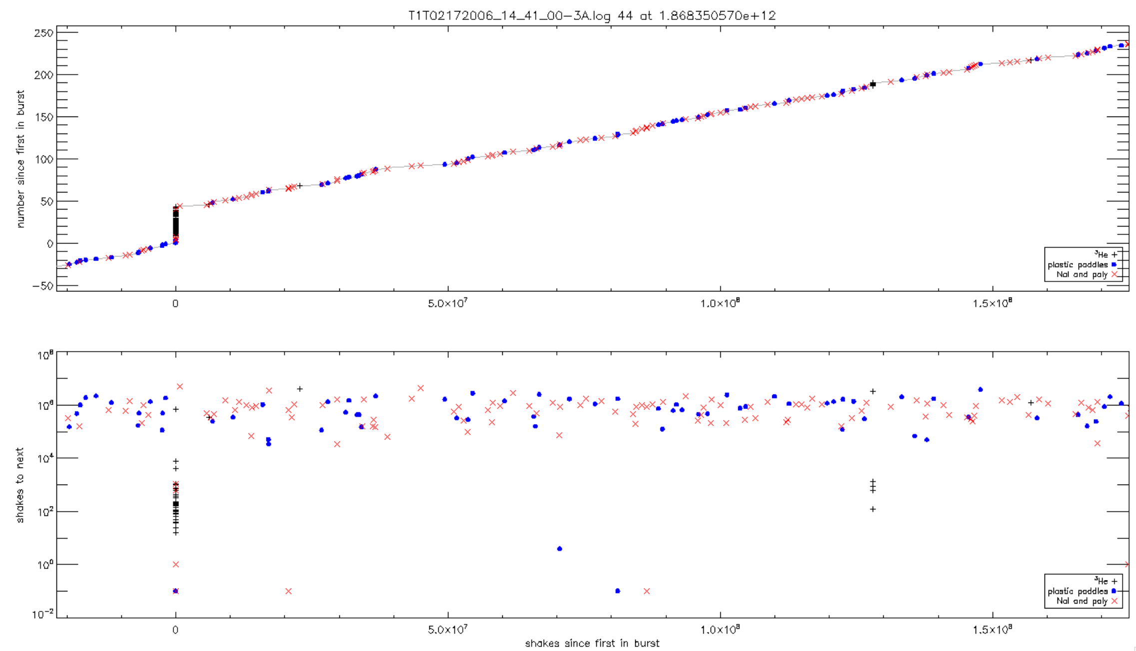

Figure 1: The top panel shows the accumulated number of counts verses time (in shakes, 1 shake $= 10^{-8}$ seconds), the total duration is about 2 seconds. On average there is a roughly constant slope, but near a bust there is a rapid increase in the number of counts in a short time. The bottom panel shows the time intervals between adjacent counts versus the time of the first count. The data acquisition system had 1 shake time resolution, and the synchronization between detectors is about that scale, so time intervals less than a few shakes are essentially simultaneous. The time intervals between typical background events, gamma-ray background and cosmic rays, is about 10^{-2} seconds. The time intervals between events in a burst are between about 1/10 microsecond and 100 microseconds. (Neutrons independently diffuse in the ^{3}He detector before capture, with a 40 microsecond time scale.)

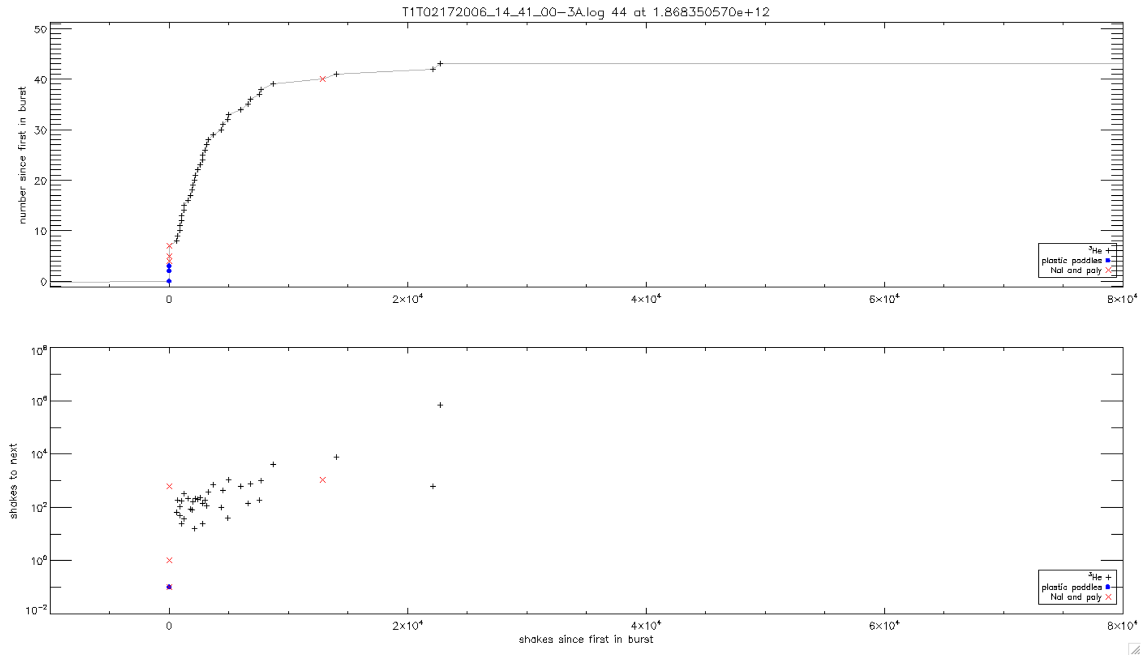

Figure 2: This Figure shows a shorter time snapshot of Figure 1. The total time is now less than a millisecond. The upper panel shows the accumulation of counts from the burst in a little over 200 microseconds. Three kinds of detectors show events. The event was triggered by muon paddles (three paired paddles) and by NaI, followed by neutron counts, and a few gamma-ray counts. The lower panel plots time intervals between adjacent counts, and shows that neutrons counts are typically separated by microseconds. A few gamma-ray counts separated from neighbors by about 10 microseconds could be neutron capture gamma-rays (or possibly intervening background).

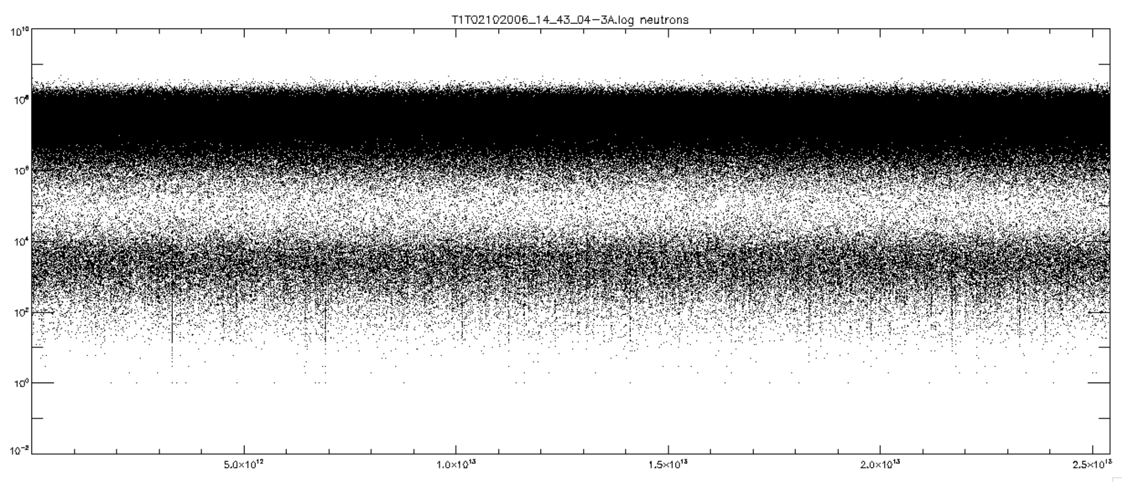

Figure 3: The Figure shows about 3 days of neutron time intervals. The dark band at the top has characteristically the time intervals less than a second. This is the dominant neutron background. The lower band, from about 1/10 microsecond to 100 microseconds, is from correlated events. The large showers show as long streaks.

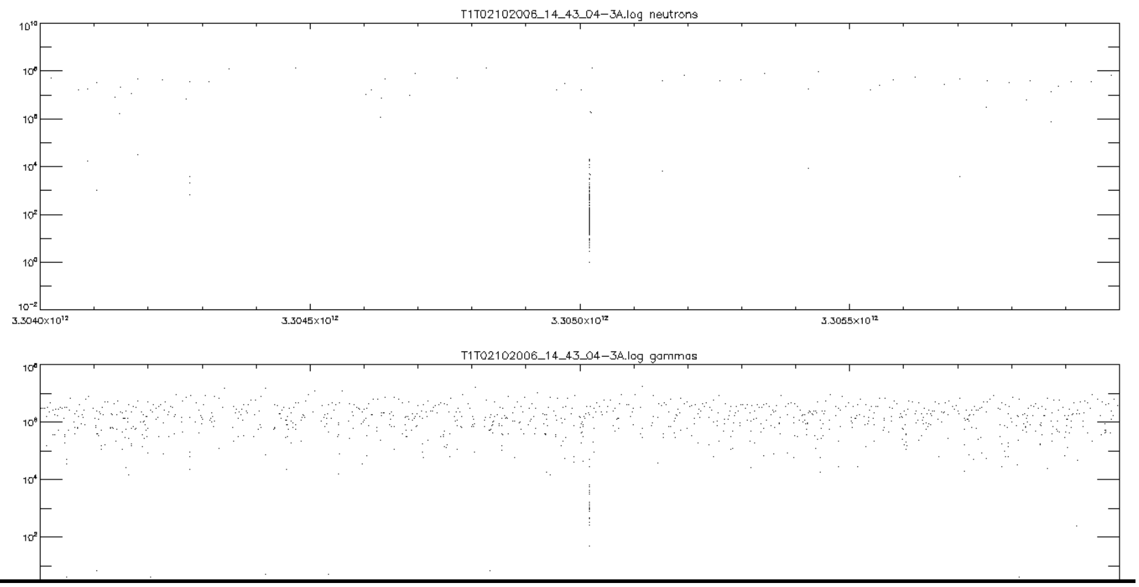

Figure 4: The Figure shows the large streak near the left of Figure 3, on a shorter time scale. This upper panel shows the neutron burst (in the ^{3}He detector), the lower panel shows the burst in neutron capture gamma-rays (counted in the NaI detectors). There was 1 foot of polyethylene between the Pb pile and 3 NaI detectors (4" x 4" x 16").

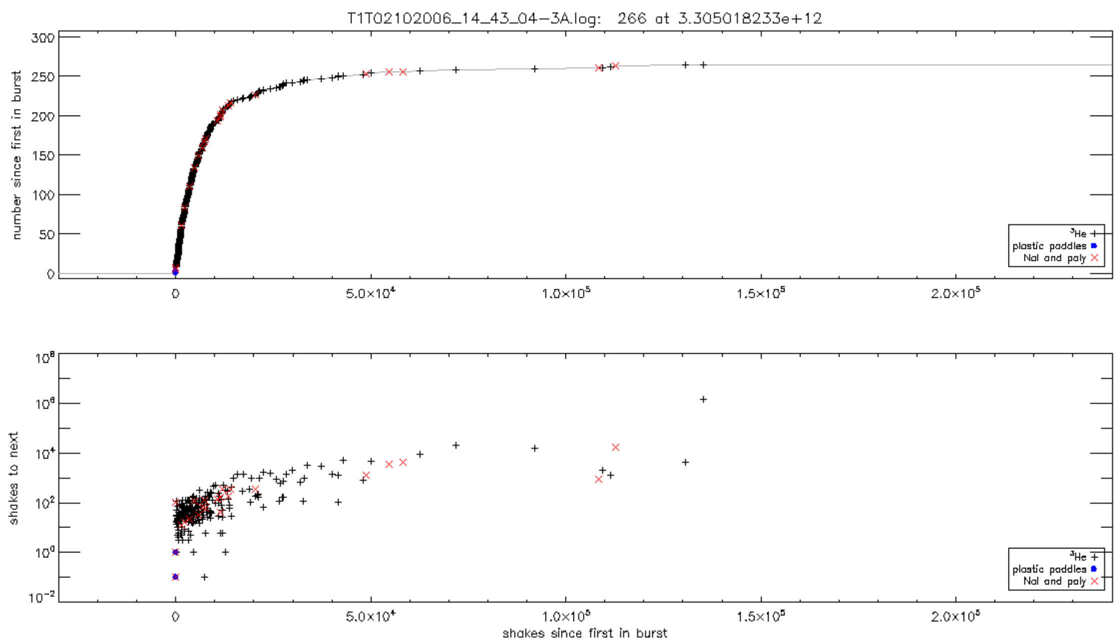

Figure 5: This Figure shows about 2 1/2 milliseconds of data near the burst of Figure 4. The upper panel shows the accumulated counts, beginning with a muon tag, followed by neutrons and (n, gamma) events. The lower panel shows the time intervals.

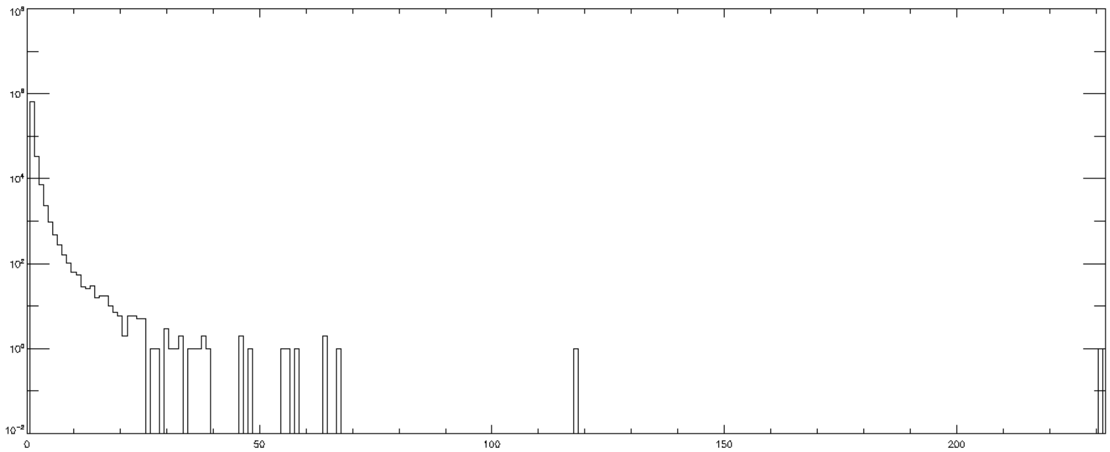

Figure 6: The Figure shows the number of occurrences of neutron burst events of different size from the 3 day run of Figure 3.

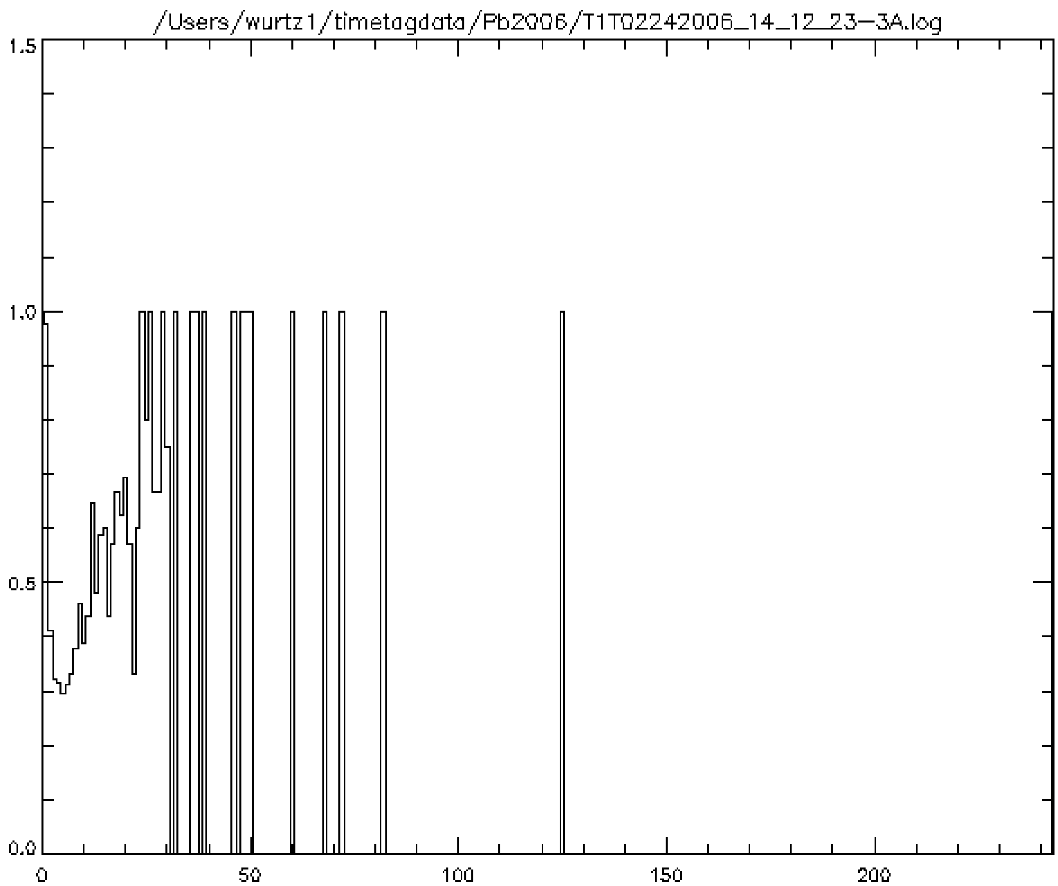

Figure 7: This Figure shows the probability that the bursts were triggered by the muon paddles, depending on the size of the burst. The large bursts are always triggered, but the smaller ones have lower triggering probability.

Discussion

The largest bursts are probably from protons or neutrons of energy greater than 100 GeV that create FermiLab-like fixed target events followed by cascade showers in the lead. The Pb pile is about half an atmosphere thick. Given the ~ 2% efficiency of the neutron counter, the event recorded in Fig 5 with about 250 counted neutrons had to have produced more than 10,000 neutrons. That kind of event is probably not due to muons. Each captured muon creates only about 2 neutrons in lead. High density showers can create at most hundreds of muons per square meter. The time dependence of the burst in Figure 5 is consistent with all neutrons in the event hitting the detector on a time scale less than a microsecond, because the neutrons independently diffuse in polyethylene before being captured by the ^{3}He. There are 14 separate ^{3}He tubes in the detector so it is possible to get several counts in less than a microsecond if in separate tubes.

The primary cosmic rays responsible for the largest events are probably nucleons that have undergone a diffractive scattering process that leaves a nucleon in the final state with a large fraction of the incident energy, and possibly charge exchange. This interpretation is supported by the fact that half the nucleons at sea level above 10 GeV are neutrons, and we have perfect muon (or charged particle) tagging efficiency for large bursts, implying a high density of muons accompanying the nucleon.

We also repeated the experiment with the lead spread one brick flat. In a similar three day count we observed a distribution of showers that cut off at about 25 neutron counts (there was one event with 45 counts. Compared to the distribution shown in Figure 6, there were relatively very few events with more than 10 counts. This implies the neutrons are multiplied by secondary interactions where spallation neutrons hit other Pb nuclei in the pile. Spallation neutron sources, such as SNS at Oak Ridge National Lab, with 1 GeV proton beams create over 20 neutrons per proton on a Hg target.

When the Pb bricks were scattering around the room more than two meters away from the detectors, a three day count gave only one event with over 8 counts in a burst. That single event gave 90 counts, however.

Acknowledgement

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract W-7405-Eng-48. We would also like to thank Richard Bionta and Mark Rowland for lending us the detectors and data acquisition systems used in these experiments.