29th International Cosmic Ray Conference Pune (2005) **3**, 425-428

CREST: A Cosmic-Ray Electron Synchrotron Telescope to measure TeV Electrons

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The Cosmic Ray Electron Synchrotron Telescope (CREST) instrument is a balloon payload designed to measure the flux of primary cosmic ray electrons at energies greater than 1 TeV. As electrons at these energies lose energy very rapidly during propagation through the interstellar medium, their detection would indicate the existence of sources that are nearby on a Galactic scale. In order to obtain the large exposure time and detector aperture required for this measurement, we use an approach based on the detection of synchrotron photons emitted by electrons in the Earth's magnetic field. These photons have energies in the x-ray and gamma-ray region, and to detect them CREST employs an array of inorganic scintillators. The effective detection area using this technique is significantly larger than the actual detector array size, and has the desirable feature of increasing with electron energy, due to the energy dependence of synchrotron radiation intensity.

The CREST project has two phases: CREST-1 is a prototype array of 96 BGO and BaF_2 crystals designed to validate the technique, and is scheduled for balloon flight in summer 2005. The full detector, CREST-2, will be a long duration instrument based on a 1600 crystal array.

1. Introduction

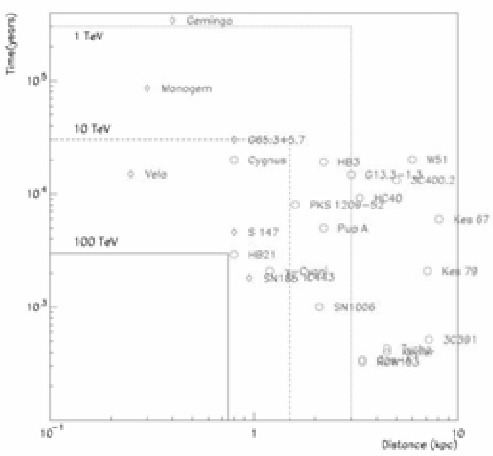

Figure 1. Distance and age of nearby SNRs and pulsars (Compilation by Swordy [2]).

The study of the electron component of the cosmic rays has provided a wealth of information concerning the source of cosmic rays and their propagation in the interstellar medium. The existence of TeV electrons in the vicinity of supernova remnants (SNRs) is inferred by observations of non-thermal x-rays and TeV gamma-rays associated with these objects [1]. However, their propagation from these sources to the point of observation is constrained by energy loss in the interstellar medium, an effect which increases with increasing electron energy. Consequently, high-energy electrons (E>1 TeV) must originate from sources at distances less than 1 kpc. In Figure 1 we show a cross-correlation of distance and age of several nearby SNRs and pulsars. The lines illustrate limits for energies that an electron observed locally can have if it originates from any of these sources.

Based on these considerations it is reasonable to expect the electron spectrum at energies greater than 1 TeV to depart significantly from a simple power law continuation of the spectrum at lower energies, and that the form this spectral distortion takes will depend in detail on the distribution and age of nearby cosmic ray sources, as discussed in ref. [1]. Hints of a threshold in the electron energy spectrum at energies of roughly 2 TeV are seen in recent ATIC data [3], but it is clear that further measurements with increased sensitivity are needed.

2. Detection Method

The CREST instrument is designed to measure the UHE electron spectrum in the energy range 1-50 TeV, an energy range within which one expects the electron spectrum to depart dramatically from an extrapolation of the electron spectrum at sub-TeV energies, as discussed above. The CREST detector concept is presented in Figure 2. The CREST instrument detects the primary electron through observation of the synchrotron radiation generated by the electron in the Earth's magnetic field. This technique has been suggested over the years [4, 5] but has never been fully exploited. It allows very large detector apertures, since the instrument need only intersect a portion of the line of photons, which extend over hundreds of meters of space, and not necessarily the electron itself. Conceptually, the detector in Figure 2 has an effective area determined by the spatial extent of the synchrotron x-rays, and not the physical size of the detector. To separate these events from background photons, two characteristics of the radiation must be exploited - the formation of a line of photons at the detector, and the very short time interval over which these photons are detected. These requirements drive us to propose a spatially segmented detector with good (i.e., <2ns) timing resolution.

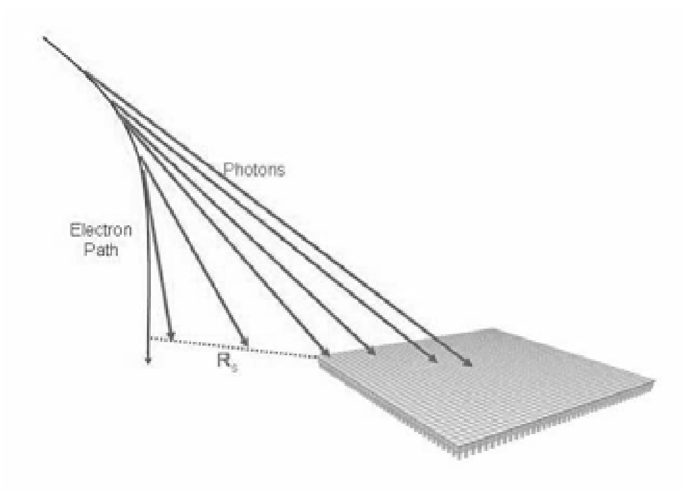

Figure 2. CREST detection concept. The effective area, R_s, of the detector is much larger than the actual physical size of detector.

3. Instrumentation (CREST-1)

The primary objective of the CREST-1 flight is the direct measurement of the x-ray background count rate and energy spectra as a function of atmospheric depth, validating simulation-based estimates of the background to the measurement of the UHE electron spectrum in CREST-2. CREST-1 consists of an array of 96 scintillator crystals (50 mm dia. x 10 mm) surrounded by a veto system used to reject signals due to penetrating charged particles, as shown in Figure 3. Each scintillator crystal is optically coupled to a photomultiplier tube (PMT) and is read out by custom electronics that measures signal amplitude from 1 keV to 10 MeV and relative timing to 250 ps. A multilevel trigger level selects events for analysis. Events with energies greater than 20 keV are sent to a multiplicity logic which selects n events in ~ 5 ns. Each multiplicity level n is prescaled up to n>3. Both BGO and BaF_2 crystals are being tested in the CREST-1 detector.

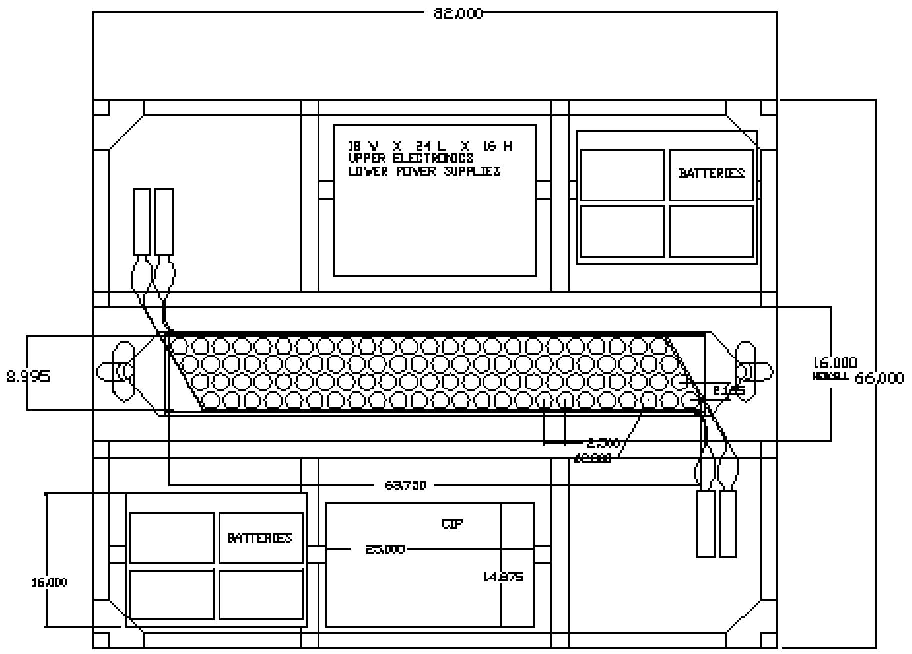

Figure 3. The CREST-1 instrument (dimensions in inches)

BGO provides excellent conversion efficiency at relatively low cost, but exhibits a slow fluorescence decay time that is not ideal in this application. BaF_2 has excellent timing properties but scintillates in the UV, traditionally requiring the use of expensive UV-sensitive photomultiplier tubes. To address this issue we have developed a new technique for vacuum depositing a wavelength shifter (diphenyl stilbene) directly on the surface of the BaF_2 crystal, allowing for the first time the use of regular bi-alkali window PMTs in reading out BaF_2. The relative performance of BGO and BaF_2 will be compared using data obtain from the CREST-1 test flight. CREST-1 will be flown in late August, 2005 from Ft. Summer, New Mexico.

4. CREST-2

Following a successful demonstration of the CREST concept by the CREST-1 instrument, the CREST-2 instrument will be engineered and constructed over a 2 year period. CREST-2 will consist of a 1600 element crystal array, and will be designed either as a ULDB or LDB instrument, depending upon available balloon craft capabilities at that time. Simulations indicate that for a 100 day exposure as many as 250 electrons with energies greater than 2 TeV will be detected. Figure 4 shows the expected results for a 100 day flight, for two assumed UHE electron source distributions. Table 1 shows the expected number of events vs. primary electron energy, assuming a uniform electron source spatial distribution.

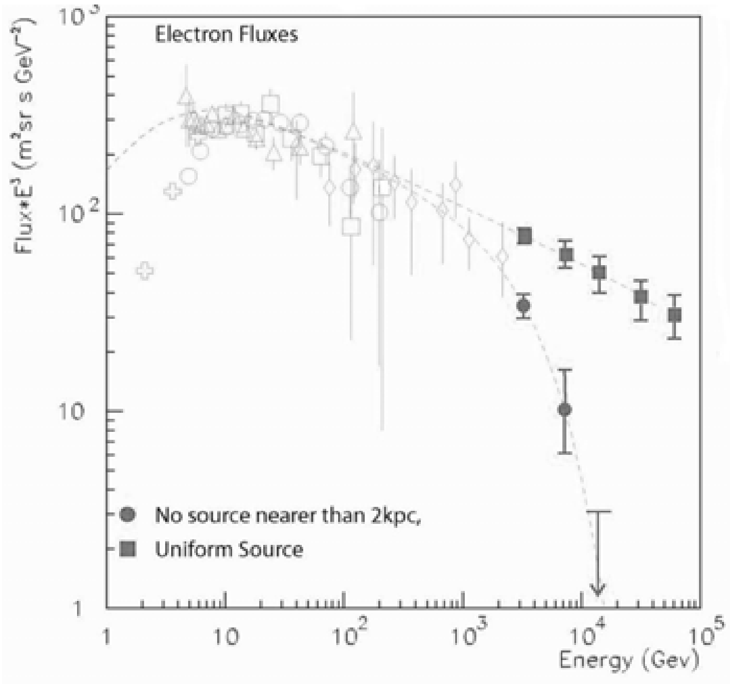

Figure 4. Electron flux spectrum

Table 1. Expected number of electrons

Electron Energy [TeV]	Number of Electrons in a 100 (20) day flight
2 -5	116 (24)
5 - 10	56 (14)
10 - 20	31 (8)
20 - 50	21 (5)
> 50	20 (5)

5. Acknowledgements

We thank J. Ameel, M. Gebhard, R. Northrop, and C. Smith for their support in the construction of the CREST-1 experiment.

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