ELO: The ELectron Observatory, an Instrument to Measure High-Energy Cosmic-Ray Electrons

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Abstract

The ELectron Observatory (ELO) is a calorimeter designed to extend current data on the energy spectrum of cosmic-ray electrons to over 10 TeV, with the potential of detecting predicted structures imprinted on the electron flux by the acceleration process. We present a detailed description of the design and expected performance of the ELO instrument and on the plans for future implementation.

1. Introduction

Electrons are the only component of the cosmic radiation for which there is direct evidence (synchrotron X-rays) of acceleration in supernova remnants (SNRs) [1]. Their energy loss during propagation is dominated by synchrotron and inverse Compton processes, and the loss rate is proportional to the square of the energy of the electron. This places strict limits on the lifetime of high energy events and on the distance to their sources. As a consequence, the energy spectrum of high energy electrons observed at Earth should exhibit structure [2] and possibly up to 20% anisotropy [3].
The direct measurement of high energy electrons is a difficult one due to the relative paucity of these particles and the abundance of background events. As a result, only about 15 electrons over 1 TeV have been observed by balloon borne instruments so far [4].

2. ELO Design

The ELO detector concept is a space based silicon-tungsten (Si-W) sampling imaging calorimeter, optimized to identify electrons and measure their energy spectrum and arrival direction in the energy range from 100 GeV to 10 TeV. The development of ELO was guided by Monte Carlo simulations based on GEANT 3.21 + FLUKA. Its design builds on the longstanding experience of

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Table 1. *Expected number of electron events for the ELO mission, extrapolated from the spectra of [4, 8] by assuming a three-year exposure*

Energy (TeV)	Galactic	Vela SNR
0.1-0.3	160,000	
0.3-1	13,000	
1-3	800	720
3-10	65	120
> 10	4	16

the WiZard collaboration with similar balloon borne and spacecraft based Si-W detectors [5,6].

The ELO calorimeter consists of 24 active Si detector layers. The top four layers have no absorber material between them and are used for charge measurement and gamma-ray rejection. The remaining layers are interleaved with 20 W absorbers. Each absorber is 7 mm (i.e. 2 radiation lengths, X_0) thick. The total thickness of ELO is thus 40 X_0, or about 1.5 proton interaction lengths, λ_I. The active area of the calorimeter is 40×40 cm^2 and its physical height is about 21 cm. This configuration maximizes both the geometric factor and the e/p separation.

Each Si layer is a mosaic of 25 8×8 cm^2 wide and 380 μm thick Si microstrip detectors. Each detector is divided into 32 Si microstrips, with a pitch of 2.4 mm each (this pitch is 1.2 mm for the four top Si layers). The strips of adjacent detectors are daisy chained to each other, and the readout is performed at the edge of the Si layer. The strips of subsequent Si layers are oriented orthogonally to each other, providing double coordinate x-y readout [6,7].

The effective geometric factor for electrons of ELO, determined by our Monte Carlo code, is 0.31 m^{2}sr. We assumed an exposure time of three years and estimated the expected number of events for ELO both by extrapolating the power law fit to the low energy electron spectrum [8] and by considering the contribution from nearby SNRs above 1 TeV [4]. Results are displayed in table 1.

3. Resolution

The ELO calorimeter provides a full longitudinal containment of electromagnetic showers. Energy resolution $\delta E/E$ at ELO energies is dominated by sampling error. ELO achieves $\delta E/E = 3.4\%$ at 1 TeV, an excellent figure for spectral measurements, which further improves at higher energies [9]. In addition, the correlation between measured energy (dE/dx energy deposit in the Si layers) and incident energy (actual energy of the electron) in the range 0.1 TeV to 10 TeV is linear. We also estimated the directional response of ELO, by reconstructing the trajectory of the primary electron from the straight line fit to the peaks of the lateral spread of the dE/dx deposits in each Si layer. At 1 TeV, the angular difference between actual trajectory and reconstructed trajectory is of the order of 1 degree.

As a secondary science goal, ELO will also measure the energy spectra of cosmic-ray protons and light nuclei up to 10^{15}eV. In this case, the effective geometric factor is 0.28 m^{2}sr for protons and in excess of 0.40 m^{2}sr for light nuclei. Identification of individual elements is achieved by ELO's charge detector. As far as energy resolution, ELO achieves only a partial containment of hadronic showers and the main source of fluctuations in the $\delta E/E$ comes from longitudinal leakage. Thus, on average $\delta E/E = 40\%$ for protons and $\delta E/E = 30\%$ for helium [9], which are still acceptable for power-law spectrum measurements [10].

4. Background Rejection

The rejection of gamma-rays and nuclei is easily achieved by the ELO charge detector (the top four Si layers). The most challenging aspect of ELO is the accurate identification of electrons against the proton background, at energies where the proton-to-electron ratio is 10^4.

We performed extensive Monte Carlo simulations to compare the calorimeter's response to protons and electrons. Typically, electromagnetic showers begin high in the calorimeter, are very collimated and are fully contained within 25-35 X_0 (figure 1). In contrast, the starting point of hadronic showers is statistically tied to the number of λ_I the particle travels through and hence tends to vary. Proton induced showers are widely spread around the central axis and a large fraction of such showers leaks through the bottom of the detector (figure 2). We have developed a set of four energy independent selection criteria, based both on the topology of the shower extracted from the calorimeter and on its longitudinal containment [9]. From our current Monte Carlo statistics we find that these four criteria combined with the high lateral and longitudinal segmentation of ELO achieve a rejection power of better than 10^5, together with an efficiency for electrons of better than 97%.

5. Conclusions

Under the most conservative assumptions, our analysis shows that ELO is capable of measuring the cosmic-ray electron spectrum up to 10 TeV. The weight of this detector is contained within 520 kg, while the total power needs are estimated at 100 W. ELO is designed to operate as a free-flyer in a circular orbit of 575 km initial altitude and 28.5^0 inclination, with an expected mission lifetime of

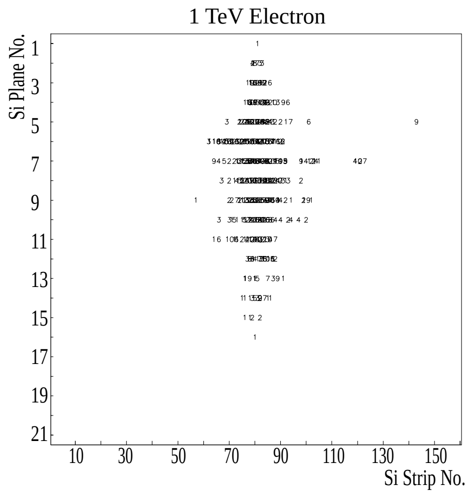

Fig.1 *1 TeV electron as seen by the ELO calorimeter. The numbers within the graph represent the number of mips (minimum ionizing particles) recorded by each strip.*

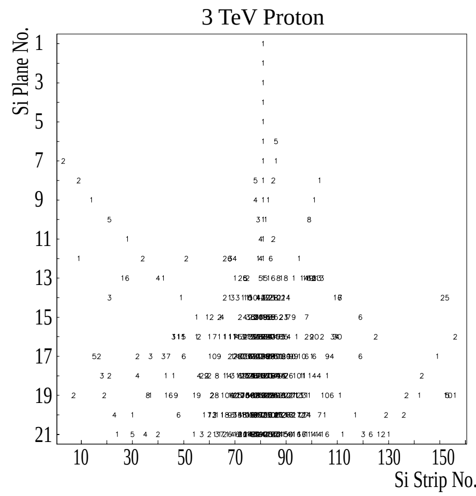

Fig.2 *Typical 3 TeV proton as seen by the ELO calorimeter.*

two to four years. Given the large field of view of ELO, this orbit will provide an almost complete sky coverage. An ideal launch vehicle that meets all mission requirements is the Taurus 2110 rocket. The cost analysis shows that the whole mission falls within the current cap for Small Explorers (SMEX) under the NASA Explorer Program. This makes the ELO experiment an ideal candidate for SMEX.

6. References

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