Detection of Upward Air Showers with the EUSO Experiments

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Abstract

Upward-going showers in the atmosphere can be detected by an orbiting satellite having an appropriate instrumentation. If the method only uses directional Cherenkov radiation, it is difficult to discriminate the real shower events from the background noises of very short pulse. A spectroscopic polychromatic optical design can intentionally blur the focusing of photons at shorter wavelengths (300 - 330 nm), spreading the image size to 2×2 or 3×3 pixels. False triggers due to random chance coincidence of noises can be drastically reduced with a spectroscopic polychromatic, refractive telescope.

1. Introduction

High-energy air showers going upward in atmosphere send beams of Cherenkov light into space. The space-borne air shower observatory such as EUSO is suited for detecting such Cherenkov signals. Upward-going air showers can be generated by a part of earth-penetrating high energy particles that interact with earth's thin crust. These particles include tau-netrinos from 10^{15} to about 10^{17} eV, neutralinos, right-handed mirror-neutrinos, and other modestly-sterile, unknown particles at energies higher than 10^{17} eV. The cosmological sources of weakly interacting particles that have been discussed in the literature include AGNs, GRBs, and violent star-bursts of early universe, as well as mirror-particles oscillations.

The EUSO telescope, while designed to detect the fluorescence of extremely high-energy downward-going showers, has a capability to detect Cherenkov light as well. An appropriate modification of the imaging characteristics for the wavelengths shorter than 330 nm with a refractive optical design can allow a unique discrimination of upward Cherenkov signals from the backgrounds. We present

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a refractive optical means of exploring upward-going air showers with the EUSO telescope from space.

2. High Random Coincidence Rate for Single-pixel Short-pulse Events

Cosmic rays and trapped-belt proton radiation in space can hit the detector pixels for a very short duration of the order of sub-nanoseconds for a 5-mm $\times$ 5-mm $\times$ 10-mm pixel. The ballpark background rate may be 1/cm ^{2} s sr, although it varies orders of magnitude depending on the orbit and inclination of a satellite. The EUSO's gate time unit is about 1 microsec for a macro-cell of 48 $\times$ 48 pixels ($\sim$ 24 cm $\times$ 24 cm). Such a short-pulse background can substantially be ignored by the timing requirement for Cherenkov events that lasts 10 - 1000 ns. However, some radiation may escape from the built-in timing requirements and requires other independent and efficient rejection method. One cosmic ray hits a macro-cell at every 1.6 GTU's, which is 10^{13-15} times more frequent than the expected rate of upward showers by tau-neutrinos. However, the rate of the chance coincidence of backgrounds in four or nine circularly contiguous pixels is $(48^2)^{4-9} \sim 10^{13-30}$ times less than the single hit rate. Thus, the large imaging spot size for very short wavelengths ($<$ 330 nm) significantly helps reducing the false backgrounds.

Refractive telescope is inherently chromatic and a chromatic designing is possible for controlling an appropriate enlargement of the spot size at shorter wavelengths. The EUSO telescope requires nearly polychromatic nature for detecting fluorescent lights from air showers in the range 337 - 400 nm.

3. Spectroscopic Polychromatic Image Control by Double Fresnel Lenses.

The hardest task for refractive polymer lenses for fluorescence measurements was to achieve the polychromatic performance from 330 nm to 400 nm. While designing uniformly small spot sizes for wavelengths longer than 330 nm, EUSO lenses can easily controll the enlargement of the spot size for shorter wavelengths 300 - 330 nm.

Color controlling technique of fluorescence lines leads to a relaxation of achromaticity for more specifc science purpose. Such a spectrographic tweaking is possible only with refractive devices. With this idea in mind, the EUSO optics design team produced an advanced EUSO optics, particularly designed for a separate detection of Cherenkov signals at the same time of recording the major fluorescence signals. It is indeed necessary to have Cherenkov signals spread in several adjacent pixels in order to clearly suppress the random noise coincidence rate in observing Cherenkov signals from upward-going tau-neutrinos. Optimized advanced designs are compared in Table 1 below.

Two materials (TPX and CYTOP) satisfy the EUSO requirements without micro-grated surfaces. All materials satisfy the EUSO requirements when one or two Fresnel surfaces are micro-grated.

Table 1. Polychromatic Spectrograph. All the spot size values are for diameter and can further be reduced by a factor of >2-3 by micro-faceting on the first and last suraces of two double-sided Fresnel lenses.

	F/#	EPD (nm) (nm)	TTL (nm) (nm)	RMS Spot size (mm) for 357-391 nm (Fluorescence) [337 nm (Cherenkov)]				
				0°	10°	20°	25°	30°
TPX	1.252	1939.6	3552.2	4.4 [9.46]	4.94 [10.5]	5.98 [10.0]	5.57 [9.2]	5.8 [9.4]
CYTOP	1.25	1920	3490.3	4.42 [9.07]	4.9 [9.5]	5.1 [7.94]	5.05 [7.38]	5.39 [7.72]
∗ZEONEX grated	1.276	1920	3500	9.01 [20.2]	9.09 [22.0]	9.49 [21.3]	8.92 [19.7]	9.9 [19.4]
PMMA grade#000	1.00	being studied						

4. Conclusions.

Spectroscopic polychromatic designs have been tried. Several feasible designs allow discrimination of single-pixel event such as Cherenkov lights of upward showers from backgrounds.

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