Ultra High Energy Photon and Neutrino Search with the Telescope Array Fluorescence Detector

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Abstract: The Telescope Array is a hybrid detector consisting of an array of scintillator detectors and fluorescence telescope stations. The detector measures incoming cosmic ray induced air showers over about 700 sq km of desert in Central Utah. We search for ultra high energy photons and neutrinos using this detector. We use the depth of shower maximum (X_{max}) to select photon candidates since photon induced air showers should be significantly deeper in the atmosphere than hadronic induced showers. We also search for neutrino induced air showers by searching for upward going showers. We report the results of these analyses.

Keywords: telescope array, ultra-high energy cosmic ray, photon, neutrino.

1 Introduction

Ultra High Energy (UHE) cosmic rays have been researched with several approaches, such as energy spectra, primary composition, and arrival directions. Nevertheless, their origin is still unknown. UHE photon and neutrino studies can support these analyses and give us insight into the origin of UHE cosmic rays. UHE photon and neutrino emission is predicted by some UHE cosmic ray source models. There are basically two types of models. One is the non-acceleration model, or so-called "top-down" scenarios. For instance, decay/annihilation of the relic Topological Defects (TD) [1] and Super Heavy Dark Matter (SHDM) [2], or resulting from resonant production of Z boson (Z-Burst, ZB) [3], or QCD fragmentation [4]. In contrast, the another type of model involves acceleration and is known as the "bottom-up" scenario. In this scenario, UHE photons and neutrinos are produced by the GZK process from π^0 decays. These scenarios are distinguished by the different flux of UHE photons and neutrinos. For the top-down model, UHE photon flux is significantly higher than bottom-up scenario. Also, within these scenarios we can examine the ratio of UHE photons to other UHE cosmic rays. This ratio has the possibility of probing the GZK mechanism, but it is challenging because the expected fraction is very small: Only of 1% or below[5]. On the other hand, if we would identify only a few UHE photon or neutrino events, its arrival direction is strongly correlated with the source. In this work, we search for UHE photons and neutrinos using the air shower profile observed by Fluorescence Detectors (FDs) in the Telescope Array (TA) experiment. The air showers initiated by UHE photons deeply penetrate the atmosphere, allowing their identification using the depth of shower maximum (X_{max}). We also search for neutrinos by searching for upward going showers.

2 Telescope Array experiment

The Telescope Array (TA) is the largest aperture cosmic ray observatory in the northern hemisphere, located in a
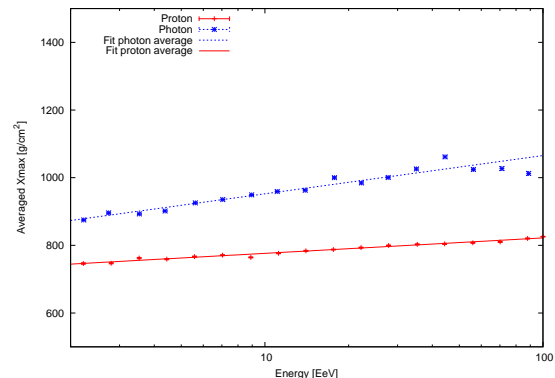

Fig. 1: Averaged X_{max} of protons and photons through the monocular reconstruction. Blue points show the averaged X_{max} of photons and red points indicate protons. The lines are a fit to the averaged X_{max}

desert in the western part of Utah, USA, to explore the origin of ultra-high energy cosmic rays, photons, and neutrinos. TA employs two types of detectors to observe air showers generated by cosmic rays in the atmosphere: the first is an array of Surface Detectors (SDs) deployed on a square grid of 1.2 km spacing and covering area of about 700 km^2 to measure shower particles on the ground. The second is Fluorescence Detectors (FDs) installed in three stations to observe fluorescence light, caused by air shower particles, from the atmosphere above the SD array. The TA detectors have been in operation since May 2008.

3 Photon selection

The air showers induced by UHE photons deeply penetrate the atmosphere and the X_{max} is significantly deeper than iron and even proton induced air showers. Thus, we used the X_{max} to select "photon like" events. The selection criteria is determined by CORSIKA simulation. Fig. 1 indicates
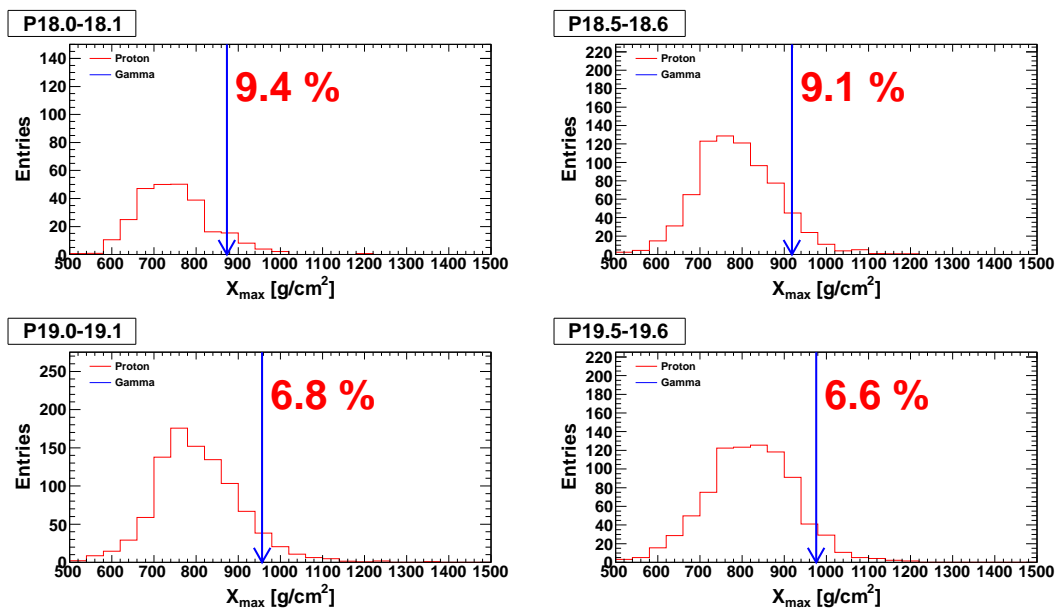
Fig. 2: Contamination from proton X_{max} distributions. Histograms show the X_{max} distribution of protons. Blue arrows show the averaged X_{max} of photon in the energy range. The percentage shown on each figure is the proton contamination.

the averaged X_{max} of proton and photon through the FD monocular reconstruction procedures. We use the averaged X_{max} of photons as the selection criterion of photon-like events. By this selection criteria, there is expected to be some contamination from protons which have deep X_{max} due to fluctuations. But this effect is small and we can evaluate the effect. Fig. 2 shows the contamination from protons. we applied this criteria to FD monocular data sets.

4 Data and Analyses

The data set was collected from June 2008 to September 2011, and consists of those events observed by TA FD monocular. To determine the shower parameters accurately, we applied the following quality cuts to the data set. The data must have (1) The number of PMT used in the reconstruction greater than 10, (2) track length of observed event is greater than 10 degrees, (3) the time extent of the signal is greater than 2 μs, (4) the distance between the FD and shower axis is grater than 0.5 km, (5) the reduced χ^2 of the longitudinal fit is less than 10, (6) X_{max} is observed in the field of view. In addition to these standard cuts, we apply following more strict cuts to cancel the bias on averaged X_{max}: (1) zenith angle less than 55 degrees, (2) minimum viewing angle greater than 20 degrees, (3) shower axis angle on shower detector plane is less than 120 degrees, (4) starting depth of observed shower is greater than 150 g/cm^2 and less than 700 g/cm^2, (5) the observed shower track must penetrate greater than 150 g/cm^2, and (6) the end point of observed shower is greater than 900 g/cm^2. Only the data which passed all of these cuts were adopted to following analysis. After these cuts, we search for photon like events in the data set using X_{max} mean value of photons as the selection criterion Fig. 3. As a result, 88, 36, 18, and 5 events with energy grater than 2, 3, 5, and 10 EeV satisfy the criterion. The respective fractions to the number of all data are 6.3, 5.1, 6.1, and 5.3 %. It is to be noted that these events are not "photon" but only "photon like" events

and include the contamination from proton X_{max} fluctuation.

To compare the results, we applied the same criteria to the proton simulation and we got the fractions 6.0, 5.4, 4.3, and 3.2 %. The observed data has an excess over the proton simulation at energies greater than 5 and 10 EeV. Therefore we checked the significance of this result by simulation. The simulated data sets were made from X_{max} distributions of simulated protons.

First, for the simulation, we divide the energy range between log(E[eV]) = 18.0 and 20.0 by 0.1 division, and in each energy range picked up the same number of events as the observed data set from the proton X_{max} distributions. Then, we randomly selected events to follow a distribution with spectral index of -3.1 in each energy division. As a result of these simple simulations, we got a simulated data set of proton X_{max} with the same number of events as the observed data set. This simulation was repeated 10,000 times and we calculated the probability that the number of selected photon-like events exceeds the observed number. Fig. 4 shows the results. The highest significance is 2.5 σ at an energy greater than 5 EeV, which is not highly significant and could be explained by proton fluctuation.

5 Summary and further analyses

We searched for UHE photons above 2 EeV observed by the TA FD. To search for the "photon like" events from the data set, we applied the selection criteria which is the averaged X_{max} calculated from photon simulation. The result of this selection is that, fractions of the photon like events are 6.3, 5.1, 6.1, and 5.3 % with energy greater than 2, 3, 5, and 10 EeV. We calculated the significance of this result by using 10,000 times simulations which has the same number of events as the observed data set and the largest significance is 2.5 σ. This is not sufficiently significant and could be explained by proton fluctuation. We will calculate the photon fraction upper limit from this result and will apply the same type of analysis to data which is reconstructed
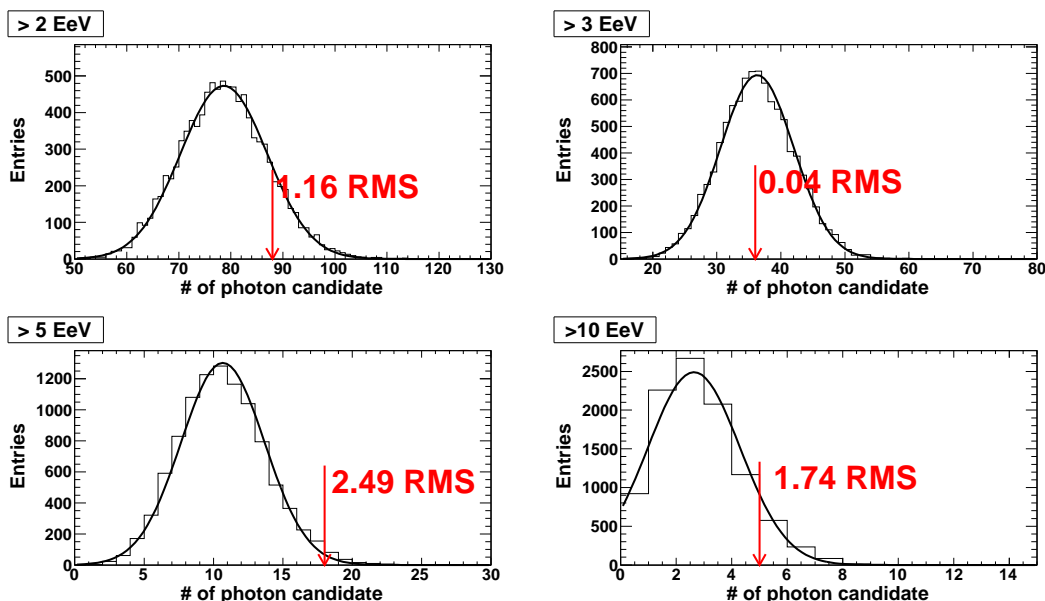
Fig. 4: Significance of the number of selected photon like events. Histograms show the distributions of the number of selected photon like events from proton simulations. Red arrows show the number of photon like events from observed data set and the significance is indicated in each figures.
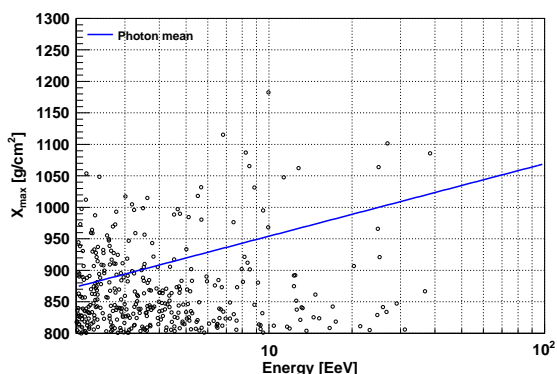

Fig. 3: Application of the selection criterion to the data set. Blue line shows the averaged X_{max} of photons and black points show observed X_{max} in the data set.

by stereoscopic mode and hybrid mode. Stereoscopic mode and hybrid mode provide substantial improvement in reconstruction accuracy and the contamination from proton will be reduced.

Also, a neutrino search is in progress.

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