We show that with GLAST there will be the possibility to detect, within the UHECR skimming the Earth atmosphere, the showers generated by very high energy upward and horizontal Tau. The effective area, thanks to the large area covered by the showers at 550 Km, is less than that of AUGER, but its efficiency is comparable because the lower detection threshold and the consequent event rate may lead to a few EeV and-or few Glashow resonant signals within a decade.

1 Introduction

Ultra high energy neutrinos UHE $\nu_{\tau}$, $\bar{\nu}_{\tau}$ and $\bar{\nu}_e$ at EeV’s up to GZK energies ($\geq 10^{19}$ eV) can hit the earth crust at the horizon leading to UHE $\tau$ which may decay in flight at high altitude. The consequent UHE air showers might be observable by next generation gamma-ray space missions like GLAST.

Here we show the expected fluence and time signature considering two different complementary signals: the upward $\tau$ air shower (UpTau) near the vertical at PeV energies and the horizontal $\tau$ air shower (HorTau) at 1.4 $10^{19}$ eV.

1.1 Upward $\tau$ air shower

Assuming a given altitude ($h_1 \sim 575 K m$) for the circular orbit of the satellite, the distance between the detector and the edge of the earth crust can be written as

$$d_{1U} = (R + h_1) \sin(\theta_{1U}) - \sqrt{(R + h_1)^2 \cdot \sin^2(\theta_{1U}) - [(R_\oplus + h_1)^2 - R_\oplus^2]}$$

where $\theta_{1U} \sim 70^0$ is the angle of the shower from the horizontal. In first approximation

$$d_{1U} \sim h_1 / \sin \theta_{1U} \sim 612 Km$$
Figure 1: A schematic picture (not in scale) of the possible detection method

A pictorial view of the detection method is shown in figure 1.

Now we can calculate the area $A_U$ of the corresponding front of the upward $\tau$ showers that is given by:

$$A_U = \frac{\pi}{4} \Delta \theta_{sh}^2 \theta_{1U}^2 \approx 90 \text{Km}^2$$

where $\Delta \theta_{sh} \sim 1^\circ$ is the typical opening angle for showers.

The lateral density profile is, of course, more dense near the inner part, and here we assume that $\sim 90\%$ of the gammas are contained in a narrow angle of $1/4$ of degree, leading to a reduces area:

$$A_{Ur} = 5.62 \text{Km}^2$$

This areas allow us to calculate the secondary gamma-ray flux.

We considered $\nu_\tau$'s with a primary energy of the order of $\sim 4 \cdot 10^{15}$ eV because at greater energies they are suppressed by the earth opacity, while at lower energies the cross section and the $\tau$ propagation length are smaller [1]. Indeed the probability $P(\theta, E_\nu)$ of escaping from the earth is approximately

$$P(\theta_{1U}, E_\nu) \approx e^{-\frac{2B_{\nu,\tau} \sin \theta_{1U}}{R_{\tau}(E_\tau)}} (1 - e^{-\frac{B_{\nu,\tau}(E_\nu)}{R_{\nu,\tau}(E_\nu)}}).$$

where $\theta_{1U}$ is nearly the complementary angle of the direction of the upcoming $\tau$ angle with the zenith, $R_{\tau}$ is the interaction length of the $\tau$ and $R_{\nu,\tau}$ is the $\nu$ interaction length.

The $\tau$ energy is typically $\sim 20\%$ less then the $\nu_\tau$ one's.
Figure 2: Lepton $\tau$ (and $\mu$) Interaction Lengths for different matter densities: $R_{\tau_{\nu}} = c \cdot \tau_{\nu} \cdot \gamma_{\tau}$ is the free $\tau$ length, $R_{\tau_{\nu \omega}}$ is the New Physics TeV Gravity interaction range at corresponding densities, $R_{\tau_{\nu \nu \omega \rho}}$ [1], see also [3], is the combined $\tau$ Ranges keeping care of all known interactions and lifetime and mainly the photo-nuclear interaction. There are two slightly different split curves (for each density) by two comparable approximations in the interaction laws. Note also the neutrino interaction lengths above lines $R_{\text{Weak}} = L_{\nu}$ due to the electroweak interactions at corresponding densities (see also [3]) [1].
The number of gamma \( N_{\gamma s} \) with energies around 100 MeV in the showers is in first approximation

\[ N_{\gamma s} \sim \frac{E_\tau}{E_c} \sim 4 \cdot 10^6 \]

for \( E_c = 100 \text{MeV} \) with the assumption of the energy equi-partition between \( \gamma \), electron pairs (\( \sim 33\% \) each component), as well as taking in account a partial (\( \sim 33\% \)) opacity of the atmosphere for the \( \tau \) shower.

The number of photons per unit reduced area at the altitude of GLAST is then:

\[ \Phi_{\gamma r} = \frac{N_{\gamma s}}{A_{U r}} = 7.14 \cdot 10^{-5} \text{cm}^{-2} \]

in the inner \( \Delta \theta = 1/4^\circ \) core and

\[ \Phi_{\gamma} = 4.4 \cdot 10^{-6} \text{cm}^{-2} \]

in the wider \( \Delta \theta = 1^\circ \) cone shower.

The characteristic time structure of the shower is \( t_s \sim \frac{L_s}{c} \geq 10^{-4} \text{s} \)
where \( L_s \) is the shower attenuation length at altitude \( \sim 23 \text{Km} \), where upward \( \tau \) take place. (see ref.[2]).

Assuming the lateral GLAST detector area, \( A = 1.3 \cdot 10^4 \text{cm}^2 \), an efficiency \( \eta = 0.5 \), the total effective area is \( A_{eff} = A \cdot \eta \cdot \cos \theta = 2.3 \cdot 10^3 \text{cm}^2 \) the number of photons for each event is, respectively for narrow and large view angle:

\[ N_{\gamma r}(E \sim 100 \text{MeV}) = \Phi_{\gamma} \cdot A_{eff} \sim 0.16 \]
\[ N_{\gamma}(E \sim 100 \text{MeV}) \sim 10^{-2} \]

So we conclude that GLAST can measure upward \( \tau \) only in coincidence with the GRB monitor approximately one over 6 upward \( \tau \) showers. Therefore the high energy \( \gamma \) detection alone is not an effective way to discriminate upward Tau Air-Showers (UpTaus) by GLAST.

### 1.2 Horizontal \( \tau \) air shower

We can now use the above procedure to calculate the rate of events for the Horizontal \( \tau \) air shower. The distance between the detector and the edge of the earth crust is in this case

\[ d_{hH} = (2R_{\oplus} h_1)^{1/2} \cdot (1 + \frac{h_1}{2R_{\oplus}})^{1/2} \sim 2768 \text{Km} \]

for the same altitude of 575 Km and where the angle of the shower from the horizontal is \( \theta_{hH} = \arctan((2h_1/R_{\oplus})^{1/2} \cdot (1 + \frac{h_1}{2R_{\oplus}})^{1/2}) \sim 23.5^\circ \). However the Tau decay in flight and the HorTau appearance takes place at great distance (\( \sim 600 \text{ km} \)) from the Earth...
and the HorTau Shower has a characteristic distance of \( (\simeq 200 \text{ km}) \) making the real distance from the Shower front to the satellite reduced to \( d_{h,\text{HorTau}} \sim 2500 \text{ km} \).

Now we can calculate the area of the corresponding front of the showers given by:

\[
A_H = \frac{\pi}{4} \Delta \theta_{sh}^2 d_h^2 \sim 1510 \text{Km}^2
\]

This area is comparable with future AUGER experiment area. In analogy to previous UpTaus scenario we also consider inner Shower cone of a nominal beam angle 1/4 of degree obtaining a reduced area

\[
A_{Hr} = \frac{\pi}{4} \Delta \theta_{sh}^2 d_h^2 \sim 94.4 \text{km}^2
\]

This areas allow us to calculate the secondary gamma-ray flux.

The optimal observable primary neutrino energy is \( 1.1 \cdot 10^{19} \text{ eV} \) because of the earth crust slant depth combined with the horizontal atmospheric opacity [1].

The number of gamma \( N_\gamma \) with energies around 100 MeV in the showers is in first approximation

\[
N_\gamma \sim \frac{E_\gamma}{E_e} \sim 3.3 \cdot 10^{10}
\]

with the same assumption of the energy equi-partition between \( \gamma \), electron pairs but without the opacity of the atmosphere for the \( \tau \) shower because in this case we are at the maximum of the shower with nearly no atmospheric suppression.

The number of photons per unit area (or reduced area) at the altitude of GLAST is then:

\[
\Phi_\gamma = \frac{N_\gamma}{A_{Ur}} = 2.18 \cdot 10^{-3} \text{cm}^{-2}
\]

\[
\Phi_{\gamma \gamma} = \frac{N_{\gamma \gamma}}{A_{Ur}} = 3.5 \cdot 10^{-2} \text{cm}^{-2}
\]

The characteristic time structure of the shower is \( t_s \sim L_s/c \geq 10^{-3} \text{ s} \)

where \( L_s \approx 200 \text{ km} \), is the shower attenuation length at high altitude \( \sim 23 \text{km} \), where air is much diluted (see ref.[2]).

Assuming as before the lateral area of the detector \( A = 1.3 \cdot 10^4 \text{cm}^2 \), an efficiency \( \eta = 0.5 \), the total effective area is \( A_{eff} = A \cdot \eta \cdot \cos \theta \sim 0.6 \cdot 10^4 \text{cm}^2 \).

the number of photons for each event is for \( \Delta \theta_{\text{Sh}} = 1^\circ, 1/4^\circ \):

\[
N_\gamma(E \sim 100 \text{MeV}) \sim 13.1
\]

\[
N_{\gamma \gamma}(E \sim 100 \text{MeV}) \sim 210
\]
1.3 HorTau Event rate in GLAST

The number of events may be estimated by scaling the EUSO experiment event rate at the horizons, keeping care of the different beaming angle and of the different horizontal area and duty cycle life-time $\eta_{EUSO} \simeq 0.1$ respect the GLAST one $\eta_{GLAST} \simeq 1$, for a nominal three years of recording. These event rate are scaled assuming a minimal, guaranteed GZK (Greisen, Zatsepin, Kuzmin) neutrino fluence $\Phi_{\nu_{GZK}} \simeq \Phi_{UHECR} \simeq 3 \cdot 10^{-18} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ produced by observed Ultra High Cosmic Rays, UHECR, during their photopion scattering on Cosmic Big Bang Radiation within the GZK cut-off volumes:

$$N_{\text{GLAST}} = \frac{A_{\text{GLAST}}}{A_{\text{EUSO}}} \frac{1}{360^o} \cdot \frac{1}{\eta_{\text{EUSO}}} N_{\text{EUSO}} \frac{1}{2} \sim 0.398 N_{\text{EUSO}} \sim 15 \leftrightarrow 30$$

The consequent reduced area (narrower beamed) event number is:

$$N_{\text{GLAST}^r} = \frac{A_{\text{GLAST}}}{A_{\text{EUSO}}} \frac{1}{5760^o} \cdot \frac{1}{\eta_{\text{EUSO}}} N_{\text{EUSO}} \frac{1}{2} \sim 0.0248 N_{\text{EUSO}} \sim 1 \leftrightarrow 2$$

1.4 HorTaus versus Other High Altitude Showers

Among these Upward-Horizontal Showers by $\tau$ we must consider the competitive signals of more common and known UHECR showers at horizons: Horizontal High Altitude Shower Hias [2] are observed by satellites above the horizons ($\theta \geq 0.8^\circ$) and they behave as a background signal respect to HorTau below the Horizons ($\theta \leq 0.05^\circ$). Indeed their event number in three years (at the same GZK energies $10^{19}$ eV, and flux $\Phi_{UHECRs}$ as in previous section : $\Phi_{UHECRs} \simeq 3 \cdot 10^{-18}$ eV) is

$$N_{\text{GLAST}} \sim 247$$

The consequence of this expected signal above the horizons is the necessary presence of a background Ultra High Cosmic Rays at a rate comparable to present AGASA and HIRES records. The very natural advantage is the general calibration of this UHECR physics on ground with this high quota Showering in Space. The drawback is the need of a clear angle discriminator between HorTaus and Hias. Because at the distances we are dealing the split angle is nearly one degree we may expect that a dozen or more gamma events will be enough to estimate the arrival direction within a needed accuracy (a few tenth of degree).

In summary the Glast thresholds are described in the included figure below.

1.5 GLAST

The Gamma-ray Large Area Space Telescope (GLAST) [5], has been selected by NASA as a mission involving an international collaboration of particle physics
and astrophysics communities from the United States, Italy, Japan, France and Germany for a launch in the first half of 2006. The main scientific objects are the study of all gamma ray sources such as blazars, gamma-ray bursts, supernova remnants, pulsars, diffuse radiation, and unidentified high-energy sources. Many years of refinement has led to the configuration of the apparatus shown (see figure 4), where one can see the 4x4 array of identical towers each formed by: • Si-strip Tracker Detectors and converters arranged in 18 XY tracking planes for the measurement of the photon direction. • Segmented array of CsI(Tl) crystals for the measurement the photon energy. • Segmented Anticoincidence Detector (ACD). The main characteristics are an energy range between 20 MeV and 300 GeV, a field of view of ~ 3 sr, an energy resolution of ~ 5% at 1 GeV, a point source sensitivity of 2x10^{-9} (ph cm^{-2} s^{-1}) at 0.1 GeV, an event deadtime of 20 µs and a peak effective area of 10000 cm^2, for a required power of 600 W and a payload weight of 3000 Kg.

The list of the people and the Institution involved in the collaboration together with the on-line status of the project is available at [http://www-glast.stanford.edu](http://www-glast.stanford.edu).

The important number for our estimate is the lateral area of the tracker for each of the four sides that is A = 60cm \times 170cm = 1.02 \times 10^4 cm^2.
Figure 4: Scheme of the lateral view of GLAST with the arrival directions of horizontal and upward $\nu\tau$ shower.

The projected total area is $4 \cdot A \cdot \cos(\theta_{1U}) = 1.4 \cdot 10^4$ where $\theta_{1U} = 70^\circ$ is the angle between the arrival $\tau$ shower and the horizon constrained by the geometry of the servicing modules that do not allowed to see upward showers (see figure 4).

2 Conclusion

The gamma-ray space experiment GLAST is just in orbit. Its clear detection of Cosmic rays secondaries, mostly single gamma and electron pairs as well as muons must take place at a high rate (thousands of events a year). Most muons pairs will hit the detector at 400 GeV energies. More rare bundle of X-$\gamma$ and 0.4 TeV $\mu$ as well as UHE (tens GeV) neutrons (with and without gamma-X traces) might be also observable soon. PeVs-EeVs cosmic rays air-showering at the terrestrial atmosphere edge must occur at daily-weekly rate in GLAST. The first neutron-gamma-electrons and or muon-gamma-electrons at associated bundles must flash soon opening a new road to UHECR astrophysics. Moreover with a high angular resolution (below 0.5$^\circ$) it might be even possible in a future to reveal first EeV persistent gamma source as well as rarest PeVs-EeVs upgoing tau. This signals are to be distinguished from background noises whose single event or whose rare pair structure in different from rarest (tens) bundles of X-gamma-muons or X-Gamma neutron burst at 0.1 millisecond time structure.
This upgoing airshowers will be the most exciting signal of the long waited UHE Neutrino Astronomy. Similar results, but an order of magnitude below, maybe applied to AGILE detector.

3 Acknowledgments

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