GeoSynchrotron Radiation from Earth Skimming Tau Neutrino Shower

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Introduction

Profile of earth-skimming tau neutrino induced showers

Geosynchrotron radiation generated by shower particles

Summary and prospect
Introduction

- Neutrino telescopes (e.g., IceCube and ANITA) are emerging recently to detect high energy neutrinos from the deep universe by measuring induced showers.
- *Earth-skimming tau* neutrinos will induce horizontal air showers.
- Showers are *simulated* using CORSIKA code.
- *Radio* emissions are produced by charged shower particles gyrating the *geomagnetic* field.
- Radiation is calculated in the *coherent geosynchrotron model*. (Huege and Falcke, A&A, 2003)
neutrino
Tau
Shower
Radio wave
Cherenkov radiation
Fluorescence light
Charged particles
The shower comes from electromagnetic cascades of tau decay products, dominantly $e^\pm$, $\mu^\pm$, and $\pi^\pm$.

We simulate electron showers at energies of $10^{16.5}$, $10^{17}$, $10^{17.5}$, $10^{18}$ and $10^{18.5}$ eV, corresponding to cosmogenic neutrinos.

Shower structure, lateral and energy distribution, has universal feature.

The pattern of the radiation field and the radio pulse are presented.
Shower Structure:

Lateral profile

Blue is fitting curve
Red is simulated curve

\[-25.04 + 2.34 \times E \times e^{-0.002823 \times E} + \left(3^{2 \times (E-16.5)}\right) \times \left(70 \times 100 - 560 \times x + 1.180 \times x^2\right)\]
Shower Structure:
particle energy distribution

Lorentz factor distribution

Normalized unit

Lorentz factor

10^{18.5}
10^{18}
10^{17}
10^{16.5}
10^{16}
Shower Structure:
particle energy distribution

Relative ratio vs. Lorentz factor for different energy ranges:
- $10^{18.5}$ eV
- $10^{18.0}$ eV
- $10^{17.5}$ eV
- $10^{17.0}$ eV
- $10^{16.5}$ eV
Shower Structure:
Angle of Emission

Theta angle distribution

Normalized unit

Theta angle
The strength of radiation has interference patterns due to the finite size of the shower maximum.

The strength and particle number scale as the shower energy.

Adapting 30-80MHz filter, the expected pulses are evaluated.
Geometry

Front of shower max.

\[ \eta = 0 \]

1000m

10km

observation distance \( R \)

off distance \( d \)

\[ R(\vartheta, \varphi) \]

\[ \theta(\vartheta, \varphi) \]

\[ \varphi \]

\[ \vartheta \]
Dependence on distance for $10^{17}$ eV shower

Antenna distance $d$

$R = 10$ km

- 50MHz
- 75MHz
- 100MHz

Distance from shower core (m)
Dependence on distance for 50 MHz

Antenna distance $d = 10 \text{km}$
Radiation Spectra

Synchrotron frequency dependence

- $R = 10\text{km}$
- $d = 0$

- $10^{16.5}\text{eV}$
- $10^{17}\text{eV}$
- $10^{17.5}\text{eV}$
- $10^{18}\text{eV}$

| Energy ($10^{x}\text{eV}$) | Line Color | Line Style |
|---------------------------|------------|------------|
| $10^{16.5}$               | Blue       | Solid      |
| $10^{17}$                 | Pink       | Solid      |
| $10^{17.5}$               | Yellow     | Solid      |
| $10^{18}$                 | Green      | Solid      |

Synchrotron frequency (MHz)

$|E(2\pi\nu)| (\mu\text{N m}^{-1}\text{MHz}^{-1})$
Scaling Behavior

Graph showing the relationship between shower energy and the particle number. The graph includes data points for different distances:
- $d=500m$
- $d=1000m$

The x-axis represents shower energy, and the y-axis represents the absolute value of the energy density ($|E(2\pi v)|/\mu V m^{-1} MHz^{-1}$). The graph also indicates that the data is at the center.
Pulse Expectation

Expected pulse at core

- $10^{17}$ eV
- $10^{17.5}$ eV
- $10^{18}$ eV

- $R = 10$ km
- $d = 0$
Pulse Expectation

Expected pulse of $10^{17}$eV shower

Antenna distance $d$

- at core
- 500m
- 1000m

$R=10\text{km}$
Pulse Expectation

Pulse strength $|B| (\mu V/m)$ vs. offdistance from center (m)

Antenna distance $d$

Observation distance $R$

Distance intervals: 10km, 15km, 20km, 30km, 40km
Summary & Prospect

- We analyzed the structure and the radio property of tau neutrino induced showers.
- The coherent geosynchrotron model rendered a picture for detecting tau neutrino by radio emissions.
- The universal feature of the shower profile should benefit in developing a realistic simulation of the geosynchrotron radiation.
- It also is a good reference for experiments design.