Modeling the Cerenkov Signals from $\nu_\mu$ and $\nu_\tau$ Events

Chih-Ching Chen
National Taiwan University
LeCosPA
For OSU Simulation Workshop
Goal of this Talk

• Neutrino interaction and lepton propagation
• Mu tau novel signal
• 3D model of radio signal for simulation
Mu, Tau Propagation

• $\mu, \tau$ loss energy into medium (GQRS, Dutta, Bugaev.....)
• Bremsstrahlung processes
• $e^+ e^- \text{--pair production processes}$
• Photonuclear processes
• Stochastic caustic energy loss
Ultra-High Energy Muon, Tauon in Ice

Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos

Chih-Ching Chen
$10^{19}$ eV Tau propagate in ice

Hadronic shower

Photonuclear loss

Pair production loss

EM shower

Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos
Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos
10^{19}eV Hadronic Shower in Ice

Chih-Ching Chen

Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos
Electron $10^{19}$eV in ice

Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos

Chih-Ching Chen
Energy Loss of EeV muon

At ultra-high energies, muon energy loss consists of two components:

\[
\left[ \frac{dE}{dx} (E) \right]_{\text{Total}} = \left[ \frac{dE}{dx} (E) \right]_{\text{Shower}} + \left[ \frac{dE}{dx} (E) \right]_{\text{Cont.}}
\]

Shower signal
Energy loss of EeV Muon

At 5EeV Muon (th:10^{-3}):

\[ \frac{dE}{dx}_{total} = \frac{dE}{dx}_{shower} + \frac{dE}{dx}_{cont} \]

\[ \frac{dE}{dx}_{total} \sim 1.25 \text{ EeV/km} \]

\[ \frac{dE}{dx}_{shower} \sim 1 \text{ EeV/km} \]

\[ \frac{dE}{dx}_{cont.} \sim 0.25 \text{ EeV/km} \sim 0.25 \text{ PeV/m} \]

They are comparable!

• Based on shower simulations, we know that the number of moving net charges from continuous energy loss is \( \sim 10^5 \text{ e}^- \)
Near-Field Effects of Cherenkov Radiation Induced by Ultra High Energy Cosmic Neutrinos

Chih-Ching Chen

Shower Energy v.s. Total Net Charge Track Length

Integration of net charges number is Proportional to energy
\[ \int N(x)dx = \text{INX} = E/15\text{MeV (\#*meter)} \]
Radiation form Cherenkov angle

- Log(A(t'))
Hadronic shower $10^{16}$-$10^{20}$ eV
EM Shower
Askereyan Signal

\[ A(r, t) = \frac{\mu_0}{4\pi} \int \frac{J_t(r', t' = t - R/c)}{R} dV \]

\[ J_t(r, t) = \frac{1}{4\pi} \nabla \times \nabla \times \int \frac{J(r', t)}{R} dV \]

\[ \vec{E} = -\nabla \Phi - \frac{\partial \vec{A}}{\partial t} \]

\[ A = \text{Int}(J_t/r \, dr) : \text{vector potential in radiation gauge} \]
Signal form constant moving charge (1D)

20m long constant charge
Detection location: 300 m on Cerenkov angle
Arrived time for 2D pancake

later

early Cherenkov angle
Signal form 2D lateral moving charge snapshot (arrived time)
Signal for 2D constant moving charge

later

early

Cherenkov angle
Signal form constant moving charge with 2D lateral profile

Charge trace: 60m
Lateral radius: 1m;
detection location 500m
Signal form NKG shower with 2D lateral profile

Shower size: 10m
Lateral radius: 1m;
detection location 500m

Asymmetry from shower long. profile
We will focus on shower energy loss

- lepton energy loss

\[
\left[ \frac{dE}{dx} (E) \right]_{Total} = \left[ \frac{dE}{dx} (E) \right]_{Shower} + \left[ \frac{dE}{dx} (E) \right]_{Cont.}
\]
Ratio of Hadronic/EM energy deposits

Assumptions:
1. $(dE/dx)_{\text{s\lowercase{hower}}}$ can be determined

2. Hadronic and EM showers are distinguishable by waveform.
Energy loss of mu, tau through showers with $E_{\text{shower}} > 10^{17}$ eV
Muon energy loss through different types of showers

![Graph showing energy loss versus lepton energy for different types of showers.](image-url)
Tau energy loss through different types of showers

![Graph showing energy loss vs lepton energy for different types of showers.](image)
Ratio of Had./EM loss for muon

[Graph showing the ratio of hadronic to electromagnetic loss for muons as a function of lepton energy (log(eV)). The ratio decreases from approximately 0.6 to 0.15 as the log(eV) increases from 18 to 22.]
Ratio of Had./EM loss for tauon

Ratios for tau and mu are at least an order of magnitude different and should therefore be distinguishable.
Total energy loss!

$10^{19.5}$ Tau vs $5 \times 10^{18}$ Muon!
The distribution of Hadronic / EM shower ratio
1000 events mu and tau

1000 events of mu (blue) and tau (white)
Conclusion

• Signal from const current of mu and tau
• 3D current radiation model
• Hadronic shower model
• EM shower model (developing....)