Background in Tau Neutrino Detection

Cosmic muon background

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TREND Neutrino Simulation Weekly @ NAOC

Outline

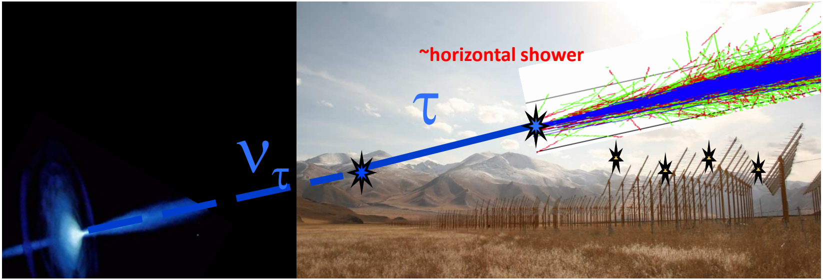
- Introduction
- Tau Neutrino – Full simulation chain
  - Neutrinos converting to tau leptons
  - Tau propagation in rocks and air
  - Tau decay in air
  - Extensive air shower
  - Radio detection
  - Antenna Response
  - Trigger Conditions
- Background to Neutrino Detection
- Summary and TO-DO

Motivation

- Ultra High Energy Cosmic Rays (UHECR):
  - Most energetic particles in the Universe
    - Energy $> 10^{16}$ eV
  - What are the possible sources of UHECR?
- Ultra High Energy Neutrinos:
  - Several models for origin of highest energy cosmic rays also predict significant neutrino fluxes
  - Neutrinos have their straight-line propagation out of the galaxy.
    - very 'clean' probe (no deflection / no interaction)
- Advantage of Radio Detection:
  - Low price + stable setup
    - Easy to maintain
    - Easy to extend and built large array for sensitivity needed
  - Maximum observation cycle, independent of weather condition

TREND: Radio Detection of Neutrinos from Behind the Tianshan Mountain

- Detection mechanism for the tau Neutrino (ν_τ):
  - Earth-skimming ν_τ penetrates the Earth
  - ν_τ interacts in rocks to produce tau lepton (τ)
  - τ propagates in rocks
  - τ escapes the Earth and decays in the atmosphere
  - Extensive Air Shower (EAS) generated in the atmosphere
  - Radio Array detects the air shower



Neutrino Simulation

- Full Simulation Chain
  - ν_τ Interacts with earth rock
  - τ lepton escapes from earth surface
  - τ lepton decays in air
  - τ EAS radio simulation
  - Antenna response to radio signal
  - Trigger condition

Neutrino Sensitivity Estimation: Simulation Scheme

Simulation scheme from the neutrinos to the radio detection of EAS:

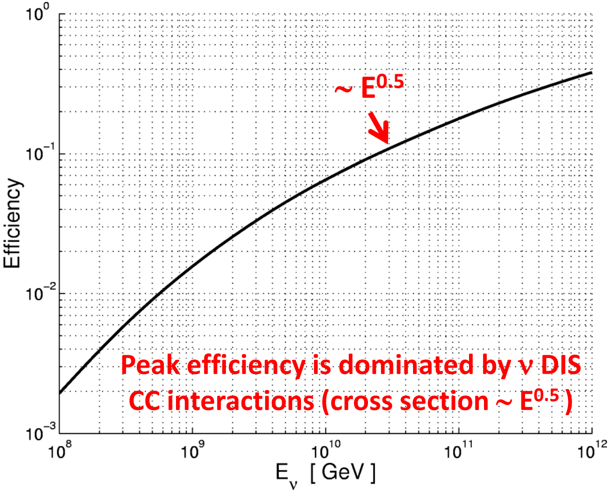
- Earth-skimming tau neutrinos:
  - ν_τ enters the Earth
  - Simulation of the topology of TREND site
  - Their interactions in the Earth rocks
    - Charge Current (CC) interaction
    - Neutral Current (NC) interaction
  - Their conversion to τ leptons in rocks
- Tau leptons:
  - τ propagation and energy loss
  - τ escape to air and decay in flight
  - Produce a cascade of secondary particles - air shower
- Radio Detection of extensive air shower (EAS)
  - Quasi-horizontal EAS in the atmosphere
  - Radio simulation at large zenith angle
  - Antenna response

Geometry simulation: Ulastai Site Topology

- Modeling of the topology of the site:
  - data from the NASA SRTM survey
  - Select an area of 200x200 km^2, centered on the TREND site
  - data point in a grid of 90 m steps
  - Assume standard rock composition with a density of 2.65 g/cm^3
  - Take into account of the Earth curvature
  - The altitude profile deformed from the local vertical direction
- Neutrinos:
  - Inject neutrinos at the boundaries of the simulation medium
  - For each neutrino trajectory in rocks, back-propagate to the atmosphere

Physics Simulation: ν_τ Interactions in Rocks

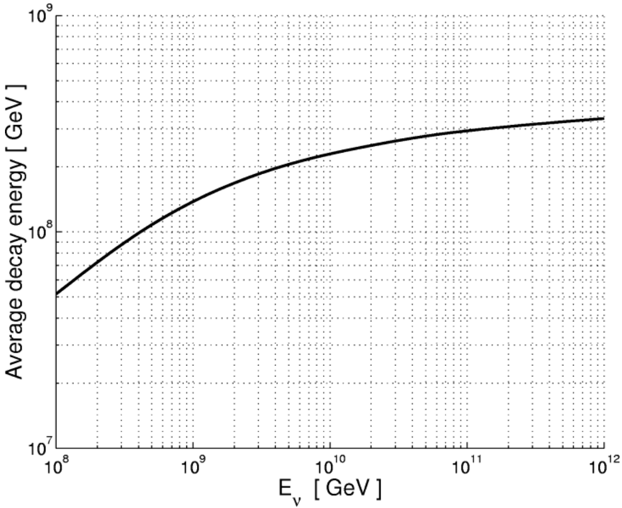
- Neutrino interaction in rocks:
  - Integrated cross-sections from Gaudi *et. al* (CTEQ4-DIS)
  - Inelasticity randomized with Pythia 6 + CTEQ5D-DIS LHAPDF
- Keep track of neutrinos until:
  - $E_\nu < E_{min} = 10^{15}$ eV from Neutral Current (NC) interactions
  - or it escapes the rock
  - or it converts to a τ lepton by Charge Current (CC) interactions



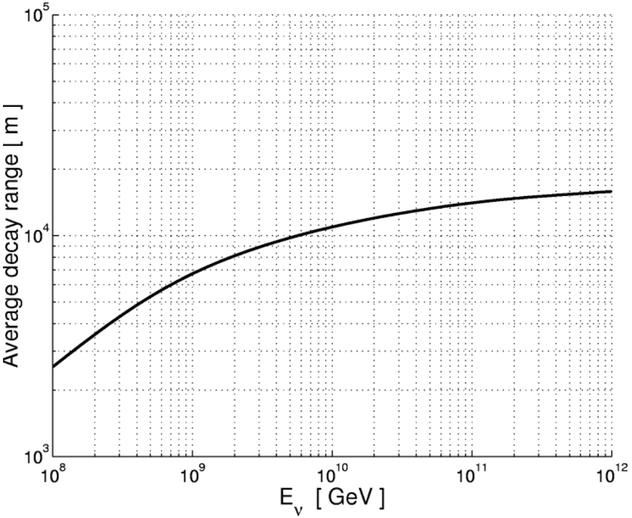
Neutrino conversion efficiency to τ decaying in the air, calculated by Valentin

Physics Simulation: τ Leptons Simulation

- τ Propagation and energy loss in rocks
  - GEANT4
  - Dominant energy loss for UHE τ:
    - Photonuclear interactions of tau leptons with nuclei:
      - via virtual photon exchange
    - Cross section following *Dutta et al.*
- Keep track of the τ lepton in rock and air until:
  - It lives its entire lifetime and disintegrates
  - $E_\tau < E_{min} = 10 TeV$
  - It escapes the simulation medium
- τ Decays in the air:
  - Use Pythia + TAUOLA
  - Record:
    - Energy transferred to shower daughter particles
    - Location of the decay vertex

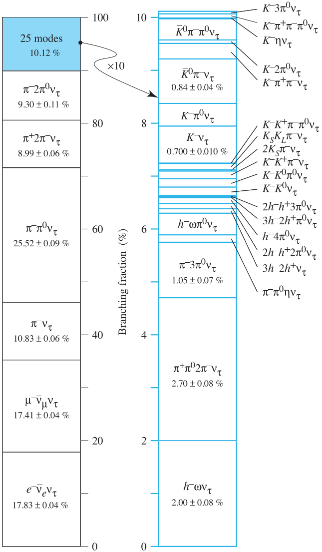


Energy spectrum of τ at decay as a function of neutrino energy (by Valentin)



Flight distance in the air of the decaying τ (by Valentin)

τ decay branching ratio



J.Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001 (2012).

Summary on Part I: Neutrino Simulation

- Introduction
- TREND future path: tau neutrinos
- Full simulation chain:
  - Neutrinos converting to tau leptons
  - Tau propagation in rocks and air
  - Tau decay in air
  - TO-DO in simulation:
    - Extensive air shower
    - Radio detection
    - Antenna Response
    - Trigger Conditions
- Background to Neutrino Detection

Next Talk on Simulation: Signal Computation

Signal computation:

- from the radio emission to the sampled voltage

Radio Emission:

- Follow the MGMR model with the full formalism by Werner *et.* al
- Take into account the 3 dominant sources of emission:
  - Drift current
  - Charge excess
  - Dipole moment
- Use EVA package

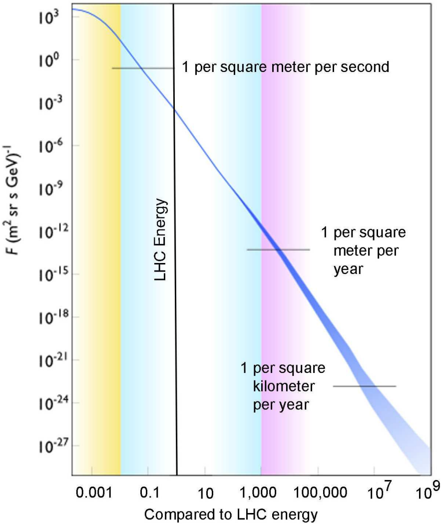
Part II: Backgrounds to Neutrino Detection

- Irreducible background:
    - Cosmic muons
- Reducible background:
    - Man-made radio noise
- ...

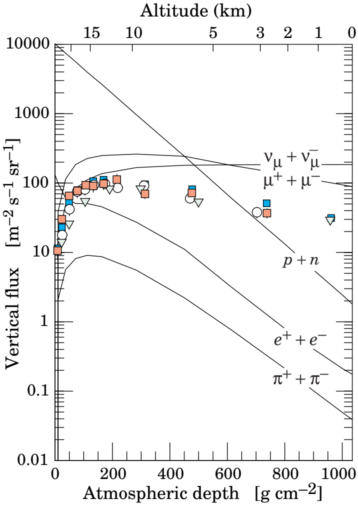
Flux of Ultra High Energy Cosmic Rays, comparing to LHC @ 8TeV

by Don Lincoln, FermiLab Today, Sep 27th, 2013.

NS130927_Figure01.jpg (JPEG Image, 1200 × ... http://www.fnal.gov/pub/today/archive/archive_...



Vertical fluxes of cosmic rays in the atmosphere with E>1GeV estimated from the nucleon flux



The points show measurements of negative muons with $E_\mu > 1$ GeV.

J.Beringer et al. (Particle Data Group), Phys. Rev. D 86, 010001 (2012).

Backgrounds to Neutrino Detection

Simple estimations (By Valentin)

- the flux of muons between 0 -10 deg elevation:
  - order of 1 $m^{-2}s^{-1}sr^{-1}$
  - agree well with Chirkin's parametric model (arXiv:hep-ph/0407078)
- the integrated flux of muons over the solid angle between 0-10 deg elevation
  - 1 muon per m^2 per s
    - dorminated by 'low energy' muons: 0.1-1 TeV, not detected by an antenna
    - at ultra high energies (UHE), flux much smaller ==> O(5) muons per m^2 per year above 10^{16} eV
- probability for an UHE muon to decay in the air above the detector
  - 1.5 $e^{-7} * (L/km)/(E_\mu/1PeV)$, L is the detector extent
- flux of muons with $E_\mu \geq 10^{16} eV$ decaying above the detector:
  - F = 0.1* (L/km) per km^2 per year
  - for L = 100 km, F = 10 per km^2 per year

Reference I: Neutrino Detection and Simulation

- "Radio Detection of Neutrinos from Behind a Mountain":
  - by O. Brusova, L. Anchordoqui, T. Huege, K. Martens
  - http://arxiv.org/pdf/0708.3824v1.pdf
- "Ultra High Energy ν_τ Detection Using Cosmic Ray Tau Neutrino Telescope"
  - -Used in Fluorescence/Cerenkov Light Detection
  - by Z. Cao, M. A. Huang, P. Soolsky, Y. Hu
  - http://arxiv.org/pdf/astro-ph/0411677.pdf
- "Neutrino Interactions at Ultrahigh Energies":
  - by Raj Gandhi, Chris Quigg, Mary Hall Reno, Ina Sarcevic
  - Phys. Rev. D 58, 093009 (1998)
- "Propagation of muons and taus at high energies":
  - by S.I. Dutta, Y. Huang, M. H. Reno
  - Phys. Rev. D 72, 013005 (2005)
- NASA SRTM survey: T.G. Farr, *et. al*, Rev. Geophys. 45 (2007).

Reference II: Radio Simulation

- "Macroscopic treatment of radio emission from cosmic ray air showers based on shower simulations":
  - by K. Werner, O. Scholten
  - Astropart. Phys. 29, 393 (2008)
- *REAS3: Monte Carlo simulations of radio emission from cosmic ray air showers using an "end-point" formalism* :
  - by M. Ludwig, T. Huege
  - Astroparticle Physics 34 (2011), 438-446