DUMAND—Deep Underwater Muon and Neutrino Detection

September 15, 1980

Hawaii DUMAND Center
University of Hawaii
2505 Correa Rd.
Honolulu, HI 96822
808 - 948-7391

HAWAII DUMAND NOTE 80-21

To: DUMAND Gang

From: John Learned

Subject: A Golden Tag for UHE τ's in DUMAND: Incoming Particle with Characteristic dE/dx, Very Large Burst and No Muon Out

This is just a short note to ask the question of whether we might discern τ's from μ's at high energies. τ's with energy > 2.6×10^{15} eV (for handbook upper limit of 2.3×10^{-12}s) would travel ∿ 1 km before decaying. (If $\tau_\tau = 3 \times 10^{-13}$s, $E_{1\ km} = 2 \times 10^{16}$ eV.) They would traverse the array with light ionization,* devoid of much brem and pair production bursting, lose little energy (they'll almost never range out), and decay in a large flash to a cascade of particles (∿ 5/6 of the time) without any muons. This seems to be a unique signature. If true, what use is it? Where could τ's come from and how to use them? I see three possibilities.

I) Charged current ν_τ interactions will make τ's. The volume for detecting these τ's must be very large. If the τ range were 1000 km·w.e., the volume for DUMAND G would be $10^6\ m^2 \times 10^6\ m = 10^{12}$ tons!! (We are helped by the greater earth density, $\rho \gtrsim 5.5$, which cuts the light time to the detector for more target volume than water, $\rho = 1$.)

Why should there be ν_τ's? For terrestrial c.r. production they should arise from direct production (e.g., heavy flavors, heavier than charm). If they were comparable to the atmospheric ν_e's and ν_μ's at this high energy (which are mostly from direct production at this energy), the rate would still be small, even in 10^{12} tons, extrapolating from a direct production crossover at 50 TeV. For extraterrestrial ν's we would expect to be dominated by ν_μ's and ν_e's unless there are neutrino oscillations which then take ν_μ's and ν_e's to τ's with their saturation mixing for any astrophysical distance.

II) Are substantial extraterrestrial $\bar{\nu}_e$'s at the Glashow resonance energy [$\sqrt{s} = \sqrt{2m E_\nu^G} = m_W$ or $E_\nu^G = (78.1\ \text{GeV})^2/2 \times 5.11 \times 10^{-4}\ \text{GeV} = 6 \times 10^{15}$ eV]? Here

$$\bar{\nu}_e + e^- \rightarrow W^- \rightarrow \tau^- + \bar{\nu}_\tau$$

*At this high energy they radiate $\sim(m_\mu/m_\tau)^2 = 1/250$ less per unit distance than muons of the same energy.

we get the resonance production increase in rate of W^- production but not much extra range. (We get τ^-'s from W^- decay.) Suppose the volume is 10^{10} tons and rate is up by 1000, then the rate would be just barely visible from direct atmospheric ν's. (Or is it?)

III) Perhaps we'll get τ's, just like μ's, directly from the primary or cascade interaction (20 km flight would require at least 5.2×10^{16} eV, or 4×10^{17} eV if the lifetime is 3×10^{-13}s). Should there be something to the quark matter bag model, predicting strange quark "droplets," and should they be excited by heavy primary (Fe-air) interactions, the decay/fragmentation of these objects will be most complex. Perhaps it would include a substantial fraction of τ's (weak decays of heavy states?). In this (highly) speculative scenario, it could turn out that we can use τ's as unique probes of the interactions. There are $\sim$ 6000 primaries/year > 10^{17} eV over DUMAND per year, but only 20/year over 10^{18}. Thus the likelihood of seeing an incoming charged particle decay, dumping something like 10^{17} eV in DUMAND from a muon arriving from the surface is very small. Any such event is a τ! And we may have dE/dx information to nail it down. It may be then that we have a nice tag for any UHE mechanism making τ's.

This is surely a preliminary speculation. I'm really asking you to think about the question and posing it as an agenda item for further discussion. Specific questions to be addressed:

1) What is the τ lifetime? 3×10^{-13}s seems inescapable.

2) What does its average dE/dx look like versus energy and in comparison to muons? (Given the total energy, how good is the μ/τ separation?)

3) Can we tell τ's from μ's in DUMAND by dE/dx vs. distance alone (given a τ of $E \gtrsim 10^{16}$ eV, otherwise it would have decayed)? Is the stopping rate discernably different?

4) Having seen a charged particle coming in, observed its dE/dx, seen the (too large for a μ) decay burst and no muon out, do we have a golden τ signature? I think so.

5) What in fact is the effective volume for a DUMAND detector for τ's (of energy, say, $\geq 10^{17}$ eV) arising from ν_τ charged-current interactions? Given neutrino oscillations will DUMAND be a ν_e telescope at small energies (10 GeV-10 TeV), a ν_μ telescope at high energies (10 TeV-10^{16} eV), and a ν_τ telescope at UHE?

6) Now the tough question, where might these τ's as ν_τ's come from? Are I-II at all sensible? Do you think of others?