DETECTING NEUTRINOS FROM AGNS AND
TOPOLOGICAL DEFECTS WITH NEUTRINO TELESCOPES

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We evaluate neutrino-nucleon cross section for energies up to $10^{21}$ eV in light of new information on the small-$x$ behavior of parton distributions. We give predictions for large underground neutrino telescope event rates for ultrahigh-energy neutrinos from Active Galactic Nuclei and from the decay of topological defects formed in the early Universe.

Active Galactic Nuclei (AGNs) are the most powerful sources of high-energy gamma rays. If these gamma rays originate in the decay of $\pi^0$, then AGNs may also be prodigious sources of high-energy neutrinos. Neutrinos are undeflected by magnetic fields and have long interaction lengths, so they may potentially provide valuable information about astrophysical sources. Gammas, on the other hand, are absorbed by a few hundred grams of material. As underground neutrino telescopes achieve larger instrumental areas, prospects for measuring fluxes from AGNs become realistic.

The diffuse flux of AGN neutrinos, summed over all sources, is isotropic, so the event rate is $A \int dE_\nu P_\mu(E_\nu, E^{\text{min}}_\mu) S(E_\nu) dN_\nu/dE_\nu$, given a neutrino spectrum $dN_\nu/dE_\nu$ and detector area $A$. Attenuation of neutrinos in the Earth, described by a shadowing factor $S(E_\nu)$, depends on the $\nu_\mu N$ cross section through the neutrino interaction length, while the probability that the neutrino converts to a muon that arrives at the detector with $E_\mu$ larger than the threshold energy $E^{\text{min}}_\mu$, $P_\mu(E_\nu, E^{\text{min}}_\mu)$ is directly proportional to the charged-current cross section.

Here we present predictions of event rates for several models of the AGN neutrino flux. We also compare the predicted rates with the atmospheric neutrino background (ATM). These rates reflect a new calculation of the neutrino-nucleon cross section that incorporates recent results from the HERA ep collider.

The classic signal for cosmic neutrinos is energetic muons produced in charged-current interactions of neutrinos with nucleons. To reduce the background from muons produced in the atmosphere, we consider upward-going muons produced in and below the detector in $\nu_\mu N$ and $\bar{\nu}_\mu N$ interactions. We

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Table 1: Number of upward $\mu + \bar{\mu}$ events per year per steradian for $A = 0.1$ km$^2$.

| Flux      | $E_{\mu}^{\text{min}} = 1$ TeV | $E_{\mu}^{\text{min}} = 10$ TeV |
|-----------|---------------------------------|----------------------------------|
| AGN–SS    | 82                              | 46                               |
| AGN–NMB   | 100                             | 51                               |
| AGN–SP    | 2660                            | 760                              |
| ATM        | 126                             | 3                                |

Table 2: $\bar{\nu}_e \rightarrow W^-$ events per year per steradian for a detector with effective volume 1 km$^3$ and the downward (upward) background from ($\nu_\mu, \bar{\nu}_\mu$)N interactions above 3 PeV.

| Mode                 | AGN–SS | AGN–SP |
|----------------------|--------|--------|
| $W \rightarrow \bar{\nu}_\mu \mu$ | 6      | 3      |
| $W \rightarrow$ hadrons       | 41     | 19     |

We also give predictions for downward-moving (contained) muon event rates due to $\bar{\nu}_e e$ interactions in the PeV range and for neutrinos produced in the collapse of topological defects.

In Table 1 we show the event rates for a detector with $A = 0.1$ km$^2$ for $E_{\mu}^{\text{min}} = 1$ TeV and 10 TeV. The CTEQ–DIS rates are representative of the new generation of structure functions. The older rates derived from the EHLQ structure functions are given for comparison. If the most optimistic flux predictions are accurate, the observation of AGNs by neutrino telescopes is imminent.

Only in the neighborhood of $E_\nu = 6.3$ PeV, where the $W$-boson is produced as a $\bar{\nu}_e e$ resonance, are electron targets important. The contained event rate for resonant $W$ production is $(10/18)V_{\text{eff}} N_A \int dE_\mu \sigma_{\bar{\nu}_e \nu_e}(E_\nu) S(E_\nu) dN/dE_\mu$. We show event rates for downward resonant $W$-boson production in Table 2. (The Earth is opaque to upward-going $\bar{\nu}_e$s at resonance.) We note that a 1-km$^3$ detector with energy threshold in the PeV range would be suitable for detecting resonant $\bar{\nu}_e e \rightarrow W$ events, though the $\nu_\mu N$ background is not negligible.

Another possible source of UHE neutrinos is topological defects such as monopoles, cosmic strings, and domain walls, which might have been formed in symmetry-breaking phase transitions in the early Universe. When topological defects are destroyed by collapse or annihilation, the energy stored in them...
Table 3: Downward $\mu^+ + \mu^-$ events per steradian per year from $\langle \nu_\mu, \bar{\nu}_\mu \rangle N$ interactions in a detector with effective volume 1 km$^3$, for the BHS$_{p=1.0}$ flux from topological defects.

| Parton Distributions | $E_\mu_{max}$ GeV | $E_\mu_{min}$ GeV |
|----------------------|-------------------|-------------------|
| CTEQ–DIS             | 10                | 6                 |
| CTEQ–DLA             | 8                 | 4                 |
| MRS D$_-$             | 12                | 8                 |
| EHLQ                 | 6                 | 3                 |

is released in the form of massive $X$-quanta of the fields that generated the defects. The $X$ particles can then decay into quarks, gluons, leptons, and such, that eventually materialize into energetic neutrinos and other particles.

Table 3 shows rates induced by the neutrino flux from the collapse of cosmic-string loops, in a model that survives the Fréjus bound at low energies. We take this flux as a plausible example to consider the sensitivity of a km$^3$ detector to fossil neutrinos from the collapse of topological defects.

For our nominal set (CTEQ-DIS) of parton distributions, the BHS$_{p=1.0}$ flux leads to 10 events per steradian per year with $E_\mu > 10^7$ GeV, far larger than the rate expected from “conventional” pion photoproduction on the cosmic microwave background. This is an attractive target for a 1-km$^3$ detector, and raises the possibility that even a 0.1-km$^3$ detector could see hints of the collapse of topological defects.

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