Ultradhigh Energy Neutrinos with a Mediterranean Neutrino Telescope

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Why to detect UHE$\nu$ at a 1 Km$^3$ Neutrino Telescope?

- The extragalactic contribution dominates: extragalactic astronomy

- It is possible to measure simultaneously the neutrino flux and the $\nu$-Nucleon cross section, at energies and kinematical regions never tested. Events $\nu_\tau$ and $\nu_\mu$ induced.
The rate of $\tau$-$\mu$ events in 1 Km$^3$

$$\frac{dN_l}{dt} = D \sum_a \int d\Omega_a \int dS_a \int dE_v \frac{d\Phi_v(E_v)}{dE_v d\Omega_a} \int dE_l \varepsilon(E_l) \cos(\theta_a) k_a(E_v, E_l; \vec{r}_a, \Omega_a)$$

Same calculation for Auger in PLB634:137-142,2006

Probability that an incoming $\nu$, with energy $E_v$ and direction $\Omega_a$, crossing the earth or the water, produces a lepton $l$ which enters the fiducial volume with energy $E_l$, through the lateral surface $dS_a$ at the position $\vec{r}_a$.

Fiducial volume, no experiment characteristics, just able to recognize $\tau$-$\mu$

$a = W, E, S, N, U, D$
Nemo experiment

Digital Elevation Map (DEM)

- Site Location
  36°21' N, 16°10' E

- Average Depth
  ~3500 m
  (3424 in our simulation)
Apertures for $\tau$ tracks crossing the rock in Nemo Matter Effect!

\[
\frac{dN_\tau}{dt} = \sum_a \int dE_\nu \Phi_\nu(E_\nu) A_a(E_\tau)
\]
Disentangling flux from cross section

The number of rock/water events is a good estimator of $\nu$ flux and $\nu$-Nucleon cross section.
Lepton energy loss in the detector

- $\mu$ and $\tau$ contributions summed and real observable considered, that is the energy deposited in the detector.

$$\Delta E_l \cong \lambda(\vec{r}_a, \Omega_a) \beta_l E_l \rho_w$$

- Detected events properly binned for energy loss and arrival direction to constrain flux and cross section.

$$N_{ij} = T \sum_{\alpha=\mu,\tau} \sum_a \int_{X_i} d(\Delta E) \int d\Omega \int dS_a \int dE_v \frac{d\Phi_v(E_v)}{dE_v d\Omega_a} \frac{\cos(\theta_a)}{\lambda(\vec{r}_a, \Omega_a)} k_a(E_v, E_l; \vec{r}_a, \Omega_a)$$

$X_i$=energy loss bin
$Y_j$=direction bin
Constraining parameters

- Waxman-Bahcall neutrino flux

\[
\frac{d\Phi_\nu(E_\nu)}{dE_\nu d\Omega_{\alpha}} = C \cdot 1.3 \cdot 10^{-8} E_\nu^{-2} \text{GeV}^{-1} \text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1}
\]

- Generalization of standard cross section (change in energy slope)

\[
\frac{\sigma^{\nu N}_{CC}}{10^{-33} \text{cm}^2} = \begin{cases} 
0.677 \cdot 10^{-3} \frac{E_\nu^{0.492}}{E_1} & E_\nu \leq E_1 \\
0.344 \left(\frac{E_\nu}{E_1}\right)^{0.492} & E_\nu > E_1
\end{cases}
\]

- Multi-Poisson likelihood analysis, with \( L = \exp(-\chi^2/2) \) and

\[
\chi^2 = 2 \sum_{ij} \left[ (N_{ij}^0 - N_{ij}) + N_{ij}^0 \ln \left( \frac{N_{ij}^0}{N_{ij}} \right) \right]
\]

\( N_{ij}^0 = \# \text{ of events for the reference model} \)

\( N_{ij} (A,C,D) = \# \text{ of events in the i energy and j direction bin} \)

\( E_1 = 10^{5.5} \text{ GeV} \)


Marginalized likelihoods and contour plots for two energy and three angular bins and an exposure time of 5 years.

\[ 0.6 \leq A \leq 1.1 \text{ (68\% CL)} \quad -0.1 \leq \log C \leq 0.2 \text{ (68\% CL)} \]
Marginalized likelihoods and contour plots for two energy and three angular bins and an exposure time of 5 years.

\[ 0.95 \leq D \leq 1.15 \ (68\% \ CL) \]

\[ -0.1 \leq \log C \leq 0.2 \ (68\% \ CL) \]
Marginalized likelihoods and contour plots for two energy and three angular bins and an exposure time of 5 years.

\[ 0.6 \leq A \leq 1.1 \text{ (68\% CL)} \]

\[ 0.95 \leq D \leq 1.15 \text{ (68\% CL)} \]
Conclusions and outlook

• UHE $\nu$ detection allows for extragalactic $\nu$-astronomy, and makes possible the simultaneous measurements of the $\nu N$ cross section at energy ranges never explored before (New Physics?), and the value of astrophysical neutrino flux. This can be done using the different behavior of the number of events in different energy and arrival direction bins.

• Simple parameterizations of flux and cross section have been considered, but work is in progress for more general expressions.