Double-Cascade Events and New Physics: IceCube prospects

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Double bang events

- Standard signature of $\nu_\tau$ at very high energy
  - $\nu_\tau$ CC interaction produce a $\tau$ and a shower (1 shower)
  - $\tau$ decay (2 shower)
  - $\tau$ emits cherenkov radiation

- Not detected yet

Double bang signals to look for heavy sterile neutrinos

- 1st shower $\nu$ interaction
- 2nd shower $N$ decay
- No cherenkov radiation in between

$$\nu_{\alpha L} = \sum V_{\alpha m} \nu_{m L} + V_{\alpha 4} N_{4 L}$$
New physics scenario: Heavy sterile neutrino

In the presence of $\nu - N - Z$ interaction: strongs bounds on the mixing between N and $\nu_e, \nu_\mu$

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The double bang signal comes from

$$\nu_\tau + N \rightarrow N_4 + W$$

$$N_4 \rightarrow \text{visible} + \text{invisible}$$

- The decay length depends on $m_4$ and on $|V_{\tau 4}|^2$

- Cross section calculated with GENIE (Coherence + Resonance + DIS)
  - Proportional to mixing parameter $|V_{\tau 4}|^2$
- Minimum distance between showers $\geq 20\text{m}$ between showers.

- Energy threshold of 5GeV per shower

- Maximum distance covered by light of 36m

- Simulation include DOMs position and triggers

- Background
  - Coincident atmospheric cascades
  - $10^{-11}/\text{year}$
Results

\[ |V_{\tau 4}|^2 \]

IceCube/DeepCore \((N_{ev}>1)\)

IceCube/DeepCore \((N_{ev}>10)\)

CHARM

DELPHI

\[ m_4 \text{ (GeV)} \]

\[ 10^{-5} \quad 10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 1 \]

Double-Cascade Events

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• Double Bang signals can probe new physics in IceCube

• Sterile neutrino via neutral current

• IceCube is sensitive to $m_4 \in [0.1, \sim 2.5] GeV$ and $|V_{\tau 4}|^2 \in [10^{-5}, 1]$
Thank you very much!
Back up
We are interested in a transition magnetic moment

Weak constraints

\[ \mathcal{L} \supset -\mu_\nu \tilde{N}_4 \sigma_{\mu\nu} P_L \nu_\alpha F^{\mu\nu} \]

The main contribution to our signal events comes from DIS on nucleons

\[ \frac{d^2\sigma_N}{dxdy} = \alpha^2 \nu \left( \sum_q e_q^2 f_q(x) \right) \left( \frac{(2-y)^2}{y} - y \right) \]

The decay length \( N \to \nu_i \gamma \)

\[ \Gamma = \frac{\mu_\nu^2 M_4^3}{16} \]
\( \nu_\mu - N \) transition

\[
\begin{align*}
\nu_\mu - \gamma \text{ decoupling} &> \text{MeV} \\
\text{IceCube/DeepCore}(N_{\text{ev}}>10) \\
\text{IceCube/DeepCore}(N_{\text{ev}}>1) \\
\text{Borexino} \\
\text{GEMMA} \\
\text{CHARM-II} \\
\text{NOMAD}
\end{align*}
\]
$\nu_\tau - N$ transition

\begin{figure}
\centering
\includegraphics[width=\textwidth]{plot.png}
\caption{Plot showing the $\nu_\tau - N$ transition with different experimental results and theoretical predictions.}
\end{figure}

- Borexino
- GEMMA
- DONUT
- ALEPH
- IceCube/DeepCore ($N_e > 1$)
- IceCube/DeepCore ($N_e > 10$)

$\mu_{tr}/\mu_B$ vs. $m_N$ (GeV)