Neutrino Nucleon Scattering

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(References:Phys.Rev.D87:013002,2013 and arxiv:1303.4332[hep-ph])

Introduction......

- We consider charged current interactions involving a charged Higgs and a W' gauge boson in the scattering processes $\nu_\tau + N \rightarrow \tau^- + X$ and $\bar{\nu}_\tau + N \rightarrow \tau^+ + X$
- The reaction $\nu_\tau + N \rightarrow \tau^- + X$ is relevant for experiments like Super-Kamiokande(Super-K) and OPERA that seek to measure $\nu_\mu \rightarrow \nu_\tau$ oscillation by the observation of the τ lepton
- The above interaction is also important for the DONuT experiment(arXiv:0711.0728 [hep-ex]) which measured the charged-current (CC) interaction cross section of the tau neutrino

Model Independent Analysis......

The measurement of the atmospheric mixing angle θ_{23} relies on the following relationship

$$N(\nu_\tau) = P(\nu_\mu \to \nu_\tau) \times \Phi(\nu_\mu) \times \sigma_{\rm SM}(\nu_\tau)$$

and

$$P(\nu_\mu \to \nu_\tau) \approx \sin^2 2\theta_{23} \cos^4 \theta_{13} \sin^2(\Delta m^2_{23} L/4E)$$

In the presence of new physics we have

$$N(\nu_\tau) = P(\nu_\mu \to \nu_\tau) \times \Phi(\nu_\mu) \times \sigma_{\rm tot}(\nu_\tau)$$

where $\sigma_{\rm tot}(\nu_\tau) = \sigma_{\rm SM}(\nu_\tau) + \sigma_{\rm NP}(\nu_\tau)$, where $\sigma_{\rm NP}(\nu_\tau)$ refers to the additional terms of the SM contribution towards the total cross section.Hence, $\sigma_{\rm NP}(\nu_\tau)$ includes contributions from both the SM and NP interference amplitudes, and the pure NP amplitude. Assuming θ_{13} to be small

$$\sin^2 2(\theta_{23}) = \sin^2 2(\theta_{23})_{SM} \frac{1}{1 + r_{23}}$$

Model Independent Analysis......contd....

where $\theta_{23} = (\theta_{23})_{SM} + \delta_{23}$

$$r_{23} = \sigma_{NP}(\nu_\tau)/\sigma_{SM}(\nu_\tau)$$

The reactor neutrino experiments can determine the mixing angle θ_{13} from the oscillation probability, P($\bar{\nu}_e \to \bar{\nu}_\tau$).The probability of the tau antineutrino appearance $\bar{\nu}_e \to \bar{\nu}_\tau$ can be used to extract θ_{13}.

$$N(\bar{\nu}_\tau) = P(\bar{\nu}_e \to \bar{\nu}_\tau) \times \Phi(\bar{\nu}_e) \times \sigma_{\rm tot}(\bar{\nu}_\tau)$$

where

$$P(\bar{\nu}_e \to \bar{\nu}_\tau) \approx \sin^2 2\theta_{13} \cos^2\theta_{23} \sin^2(\Delta m^2_{13} L/4E)$$

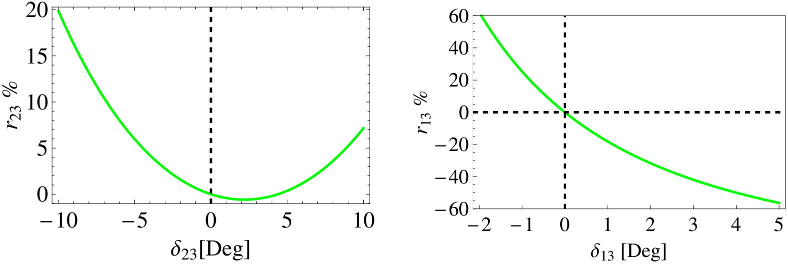
and

$$\sin^2 2(\theta_{13}) = \sin^2 2(\theta_{13})_{SM} \frac{1}{1+r_{13}}$$

and r_{13} is given as

$$r_{13} = \sigma_{NP}(\bar{\nu}_\tau)/\sigma_{SM}(\bar{\nu}_\tau)$$

Model Independent Analysis......contd....



$$r_{23} = \left[\frac{\sin 2(\theta_{23})_{SM}}{\sin 2((\theta_{23})_{SM} + \delta_{23})}\right]^2 - 1$$

$$r_{13} = \left[\frac{\sin 2(\theta_{13})_{SM}}{\sin 2((\theta_{13})_{SM} + \delta_{13})}\right]^2 - 1$$

Quasi-Elastic Scattering......

For the process $\nu_l(k) + n(p) \to l^-(k') + p(p')$ we have the following

$$\langle p| \,(p')|J^+_\mu|n(p)\,|\rangle = V_{ud}\,\langle p|\,(p')|(V_\mu - A_\mu)|n(p)\,|\rangle$$

The expressions for the vector and axial-vector hadronic currents

$$\langle p|\,(p')|V_\mu|n(p)\,|\rangle = \bar{u}_p(p')\left[\gamma_\mu F_1^V + \frac{i}{2M}\sigma_{\mu\nu}q^\nu F_2^V + \frac{q_\mu}{M}F_S\right]u_n(p)$$

$$-\langle p|\,(p')|A_\mu|n(p)\,|\rangle = \bar{u}_p(p')\left[\gamma_\mu F_A + \frac{i}{2M}\sigma_{\mu\nu}q^\nu F_T + \frac{q_\mu}{M}F_P\right]\gamma_5 u_n(p)$$

The diferential cross-section is

$$\frac{d\sigma_{SM}(\nu_l)}{dt} = \frac{M^2 G_F^2\cos^2\theta_c}{8\pi E_\nu^2}\left[A_{SM} + B_{SM}\frac{(s-u)}{M^2} + C_{SM}\frac{(s-u)^2}{M^4}\right]$$

Quasi-Elastic Scattering......contd

For the process $\bar{\nu}_l(k) + p(p) \rightarrow l^+(k') + n(p')$

$$\langle n|\,(p')|J^-_\mu|p(p)\,|\rangle = \langle p|\,(p)|J^+_\mu|n(p')\,|\rangle\,\dagger$$

$$\frac{d\sigma_{SM}(\bar{\nu}_l)}{dt} = \frac{M^2 G_F^2 \cos^2\theta_c}{8\pi E_\nu^2}\left[A_{SM} - B_{SM}\frac{(s-u)}{M^2} + C_{SM}\frac{(s-u)^2}{M^4}\right]$$

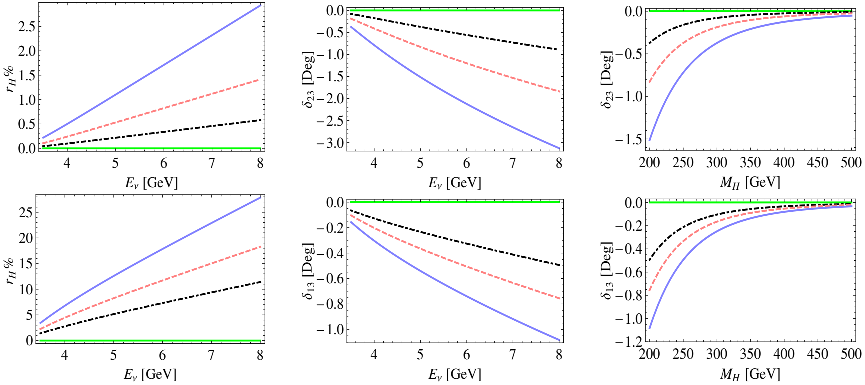
The charged Higgs contribution to $\nu_\tau + n \rightarrow \tau^- + p$ is seen as

$$\frac{d\sigma_{SM+H}}{dt} = \frac{M^2 G_F^2 \cos^2\theta_c}{8\pi E_\nu^2}\left[A_H + B_H\frac{(s-u)}{M^2} + C_{SM}\frac{(s-u)^2}{M^4}\right]$$

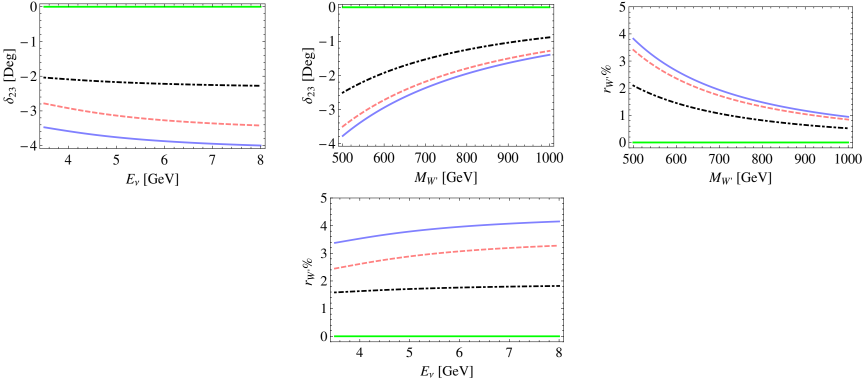
and the $W^{'}$ contribution to $\nu_\tau + n \rightarrow \tau^- + p$ is

$$\frac{d\sigma_{SM+W'}(\nu_\tau)}{dt} = \frac{M^2 G_F^2 \cos^2\theta_c}{8\pi E_\nu^2}\left[A' + B'\frac{(s-u)}{M^2} + C'\frac{(s-u)^2}{M^4}\right]$$

Results(Quasi-Elastic Scattering)......

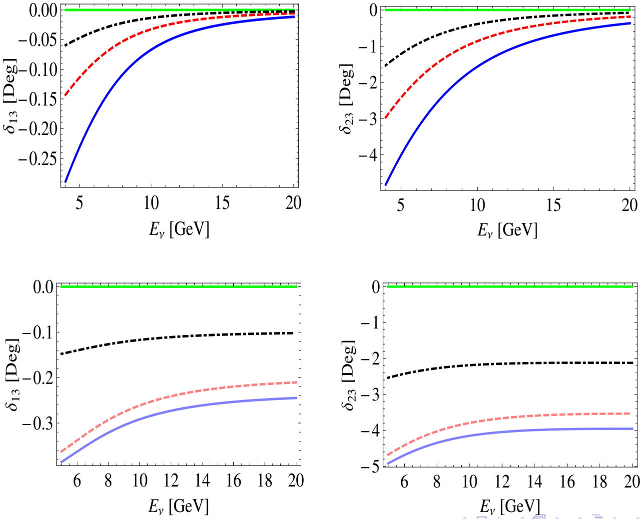


Results(Quasi-Elastic Scattering)......



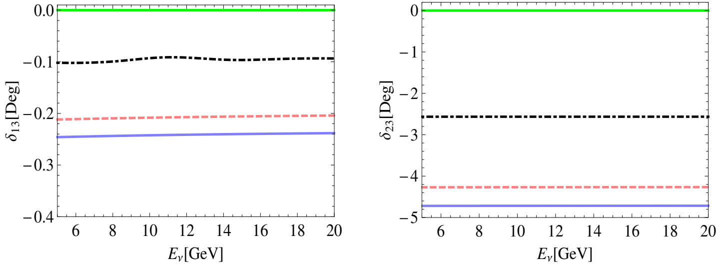
Results(Δ Resonance Scattering)......

For the charged Higgs(top) and for the W' (bottom)we have respectively



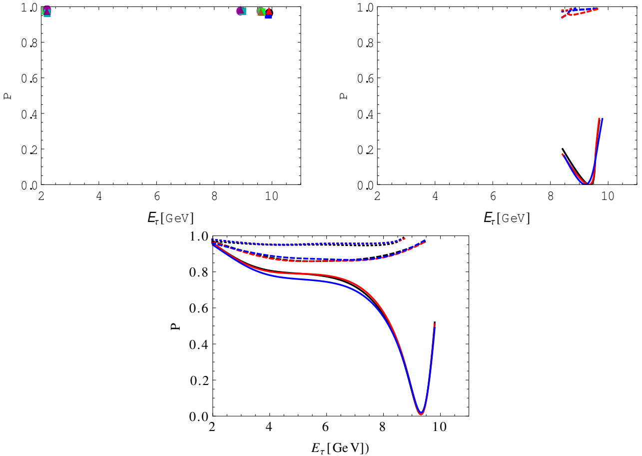
Results(Deep-Inelastic Scattering)......

For the W' we have



Tau Polarization......

The degree of τ polarization P with E_τ in the QE, Δ-RES, and DIS scattering for 0 degree, 5 degrees, 10 degrees respectively.



Conclusion......

- When a charged Higgs is involved $\delta_{23,13}$ are negative. For $W^{'}$ the contribution to δ_{23} could be both positive and negative, but is mostly negative.
- In the Δ Resonance case, the charged Higgs contribution gives negative deviations in $\delta_{23,13}$ and so does the $W^{'}$ contribution.
- For the Deep-inelastic case the charged Higgs does not produce any deviation, whereas the $W^{'}$ contribution were negative.
- When the τ was polarized we did not find any significant effects in any of the above cases.