DUNE NuTau Meeting

CC-ν_τ Cross Section in DUNE

Barbara Yaeggy
(03/25/2021)

UNIVERSITY OF Cincinnati

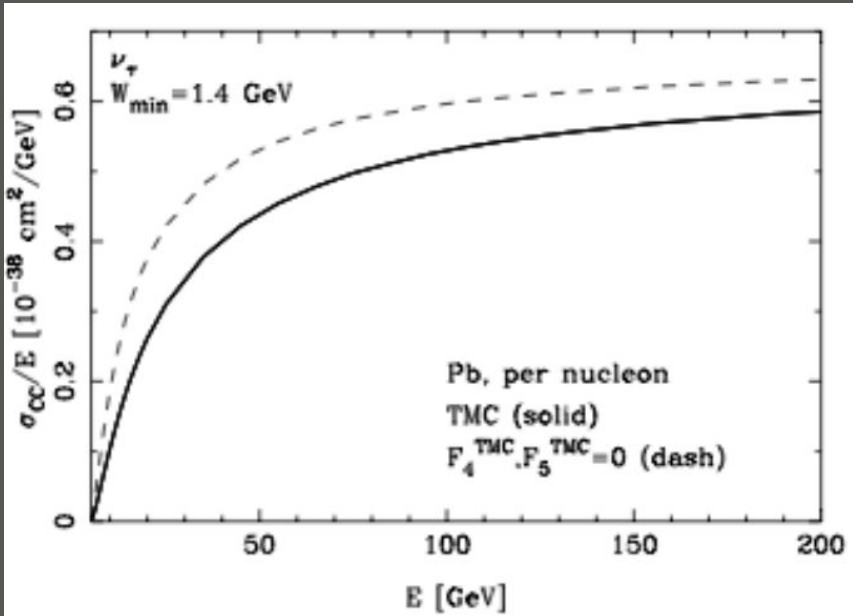
DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

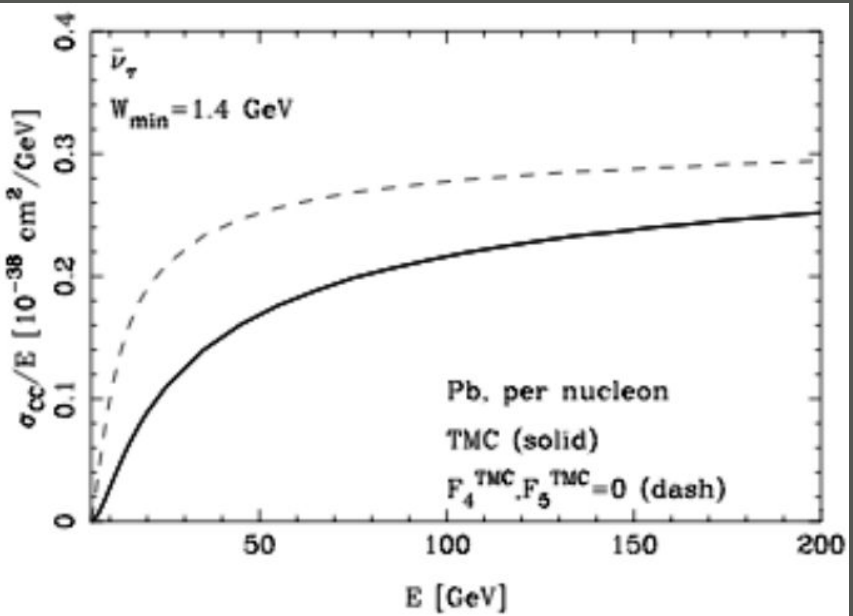
Fermilab

Previously it catch our attention

The SHip Proposal showed the hypothesis of $F_4 = F_5 = 0$ would result in an increase of the ν_τ and $\bar{\nu}_\tau$ charged-current DIS cross-sections and consequently, of the number of expected ν_τ and $\bar{\nu}_\tau$ interactions.

ν_τ **SM prediction (solid)** **F4=F5=0 hypothesis (dashed)** $\bar{\nu}_\tau$





Notice **the difference** between the cross-sections in the **$F_4 = F_5 = 0$ hypothesis** and the **SM prediction** **is larger for lower neutrino energies.**

Differential Cross-Section

arXiv:2008.03527

The structure functions **F4 and F5**, are pointed out by **Albright and Jarlskog** **are neglected in muon neutrino interactions** because of a suppression factor depending on the square of the charged lepton mass divided by the nucleon mass times neutrino energy.

$$\frac{d\sigma}{dQ^2}(Q^2, E_\nu) = \frac{c_{qq'}^2}{16\pi}\frac{M^2}{E_\nu^2}\left[(\tau + r^2)\,A(Q^2) - \nu B(Q^2) + \frac{\nu^2}{1+\tau}C(Q^2)\right], \tag{5}$$

where $r = m_\ell/(2M)$ with the lepton mass m_ℓ, incoming neutrino energy E_ν and variable $\nu = E_\nu/M - \tau - r^2$. The structure-dependent factors A, B, and C are given by

$$A = \tau\left(G_M^V\right)^2 - \left(G_E^V\right)^2 + (1+\tau)F_A^2 - r^2\left(\left(G_M^V\right)^2 + F_A^2 - 4\tau F_P^2 + 4F_A F_P\right), \tag{6}$$

$$B = 4\eta\tau F_A G_M^V, \tag{7}$$

$$C = \tau\left(G_M^V\right)^2 + \left(G_E^V\right)^2 + (1+\tau)F_A^2, \tag{8}$$

Structure Functions F4 and F5

Given the higher mass value of the τ lepton, **F_4 and F_5 contribute**, instead, to the **tau neutrino cross-section.**

$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\left((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1 - \frac{m_\tau^2}{4E_\nu^2}) - (1 + \frac{Mx}{2E_\nu})\right]F_2 \right.$$
$$\left. \pm \left[xy(1 - \frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2 + Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\right),$$

At leading order, in the limit of massless quarks and target hadrons, ***F4 = 0* and *2xF5 = F2***, where *x* is the Bjorken-x variable. **NLO show that *F_4 ~ 1% of F_5*** arXiv:hep-ph/0605295

Premise: the energy distribution can be modified based on Osc.Parameters but also XSec.Parameters

- **How do we expect our distribution to change in the TRUE way as we change the XSec. Model?**

- **Get the XSec.** → a basic idea on how the TRUE energy spectrum will change.
- **Get a basic smearing** → an idea of what the reconstruction spectrum would be.

- **Is there a way to re-weight events based on the changes on the structure functions?.**

Starting Point: LBNF/DUNE CDR

The Decay of Tau Leptons Produced in Neutrino-Nucleon Scatterings arXiv:1606.09550 describes the proposed physics program and experimental design at the conceptual design phase.

- The purpose was provide the results of these simulations to the community to facilitate phenomenological studies of long-baseline oscillation at LBNF/DUNE.

- Additionally, they include GDML of the DUNE single-phase far detector for use in simulations.

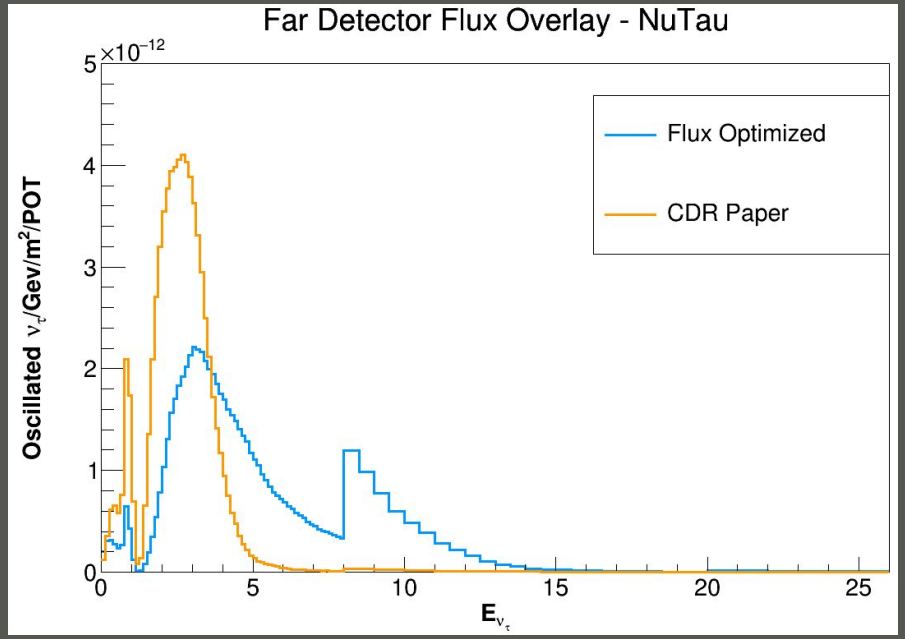
- **Genie 2.8.4**

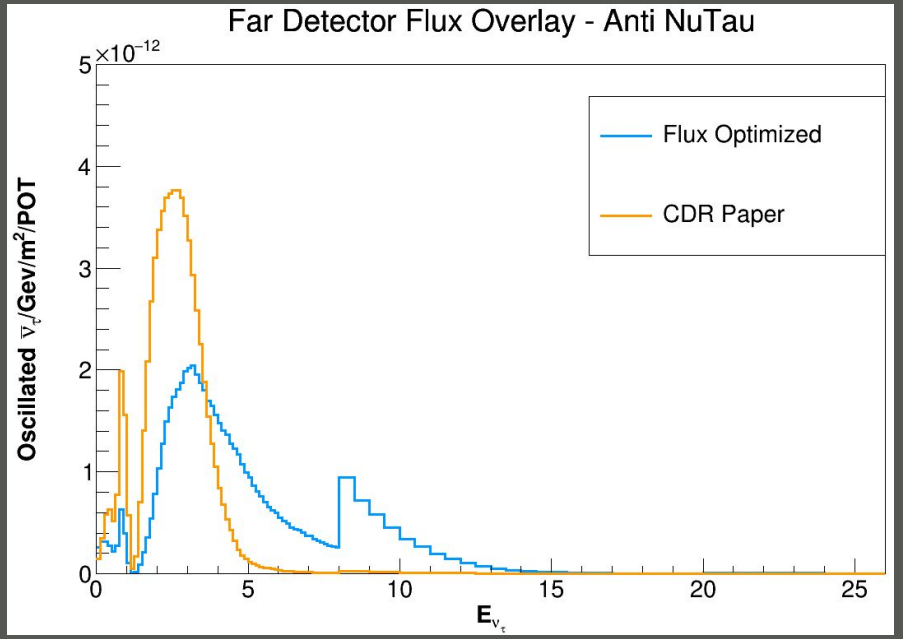
There are differences between the flux inputs...

The one that I used is the DUNE Far Detector Tau Optimized
https://home.fnal.gov/~ljf26/DUNEFluxes/TauOptimized/

The one used on the CDR paper

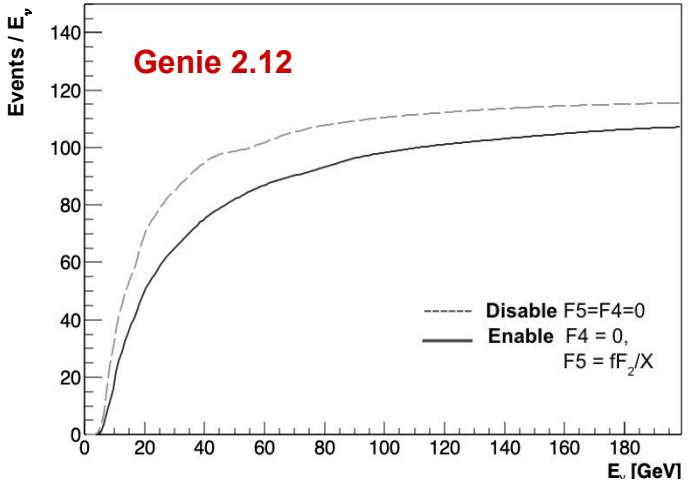
https://arxiv.org/abs/hep-ph/0503050

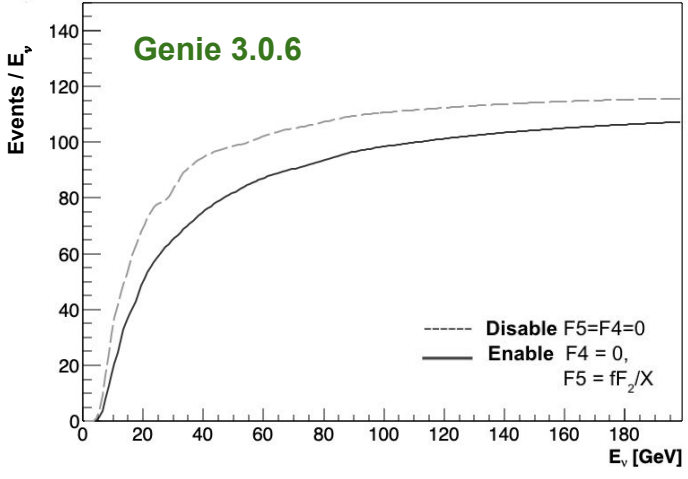




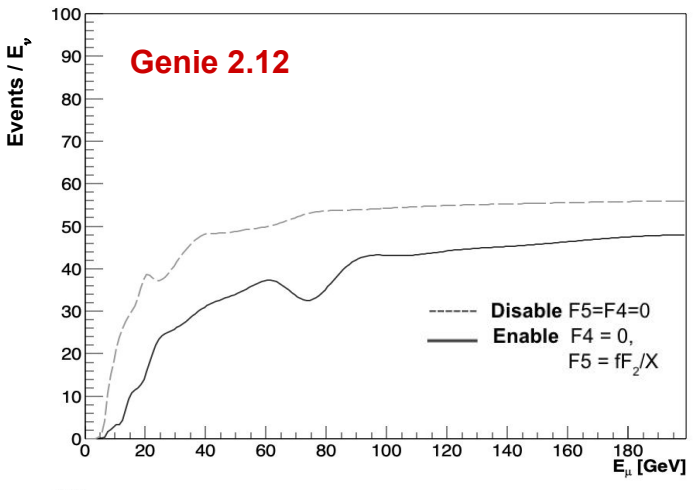
There are differences between the Genie versions

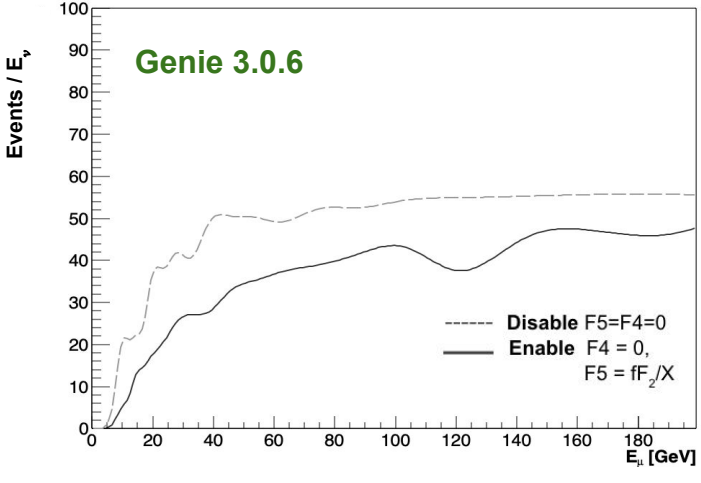
GENIE DIS Splines ν_τ + Ar40





GENIE DIS Splines. $\overline{\nu}_\tau$ + Ar40





Why such differences ?

So far it point to be from the **CKM quark mixing values**

Genie 2.12 /Genie 2.8.4

`config/UserPhysicsOptions.xml`

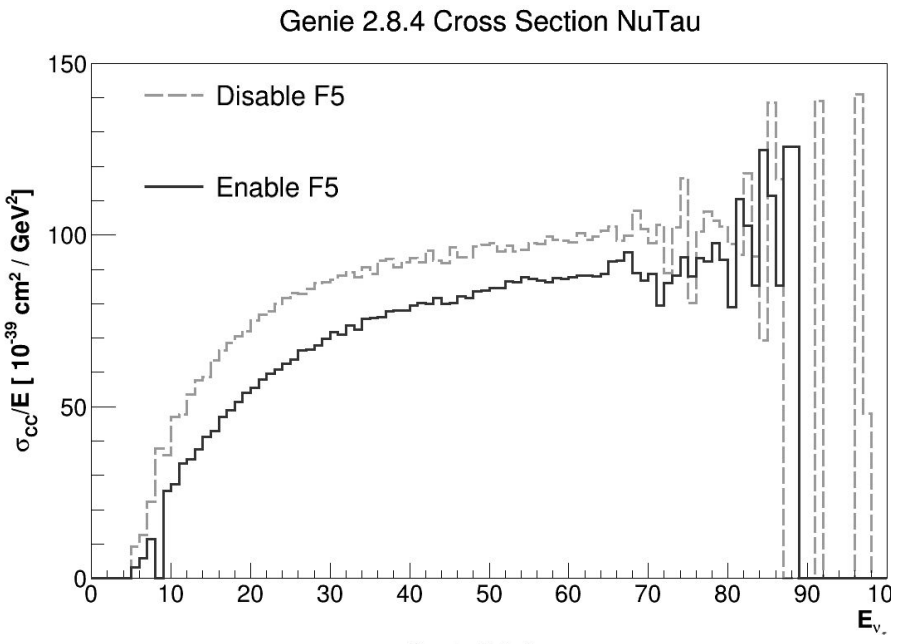
Use values listed at the July 2006 particle physics booklet.

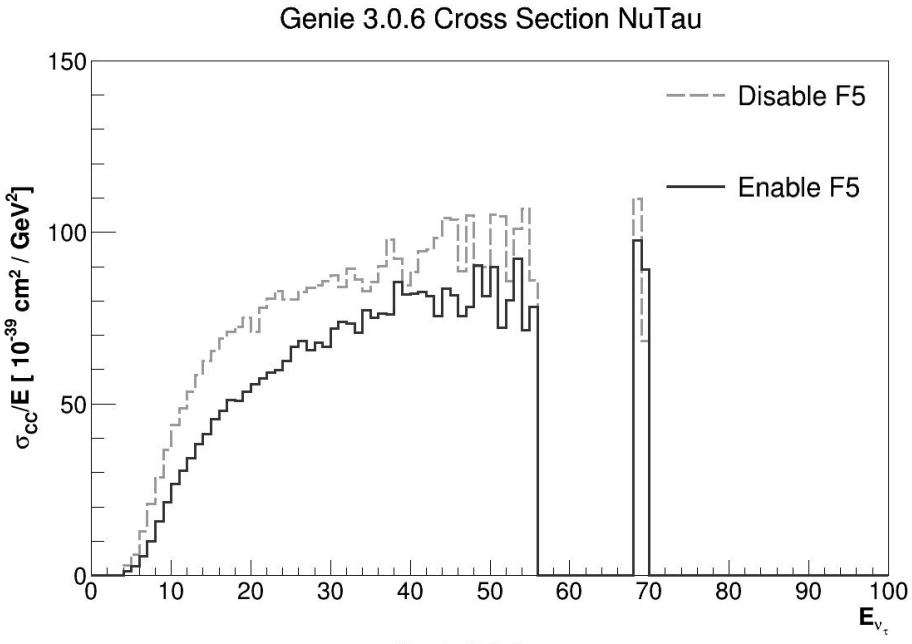
Genie 3.0.6

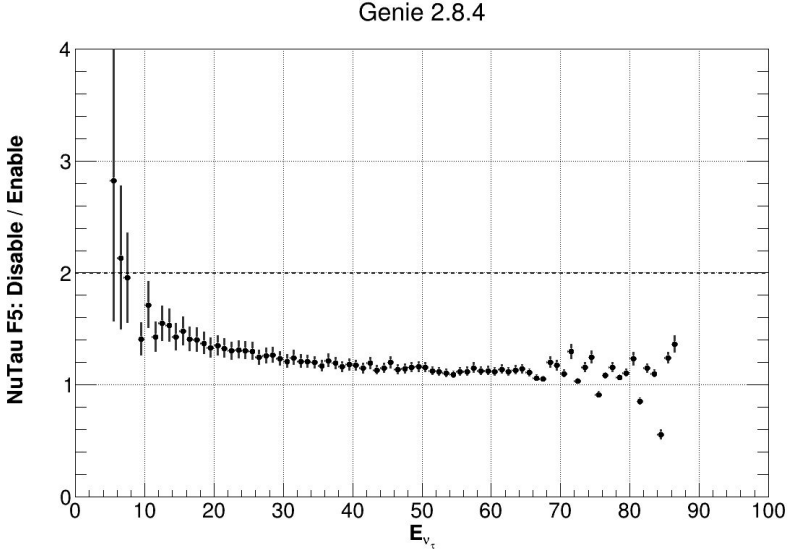
`config/CommonParam.xml`

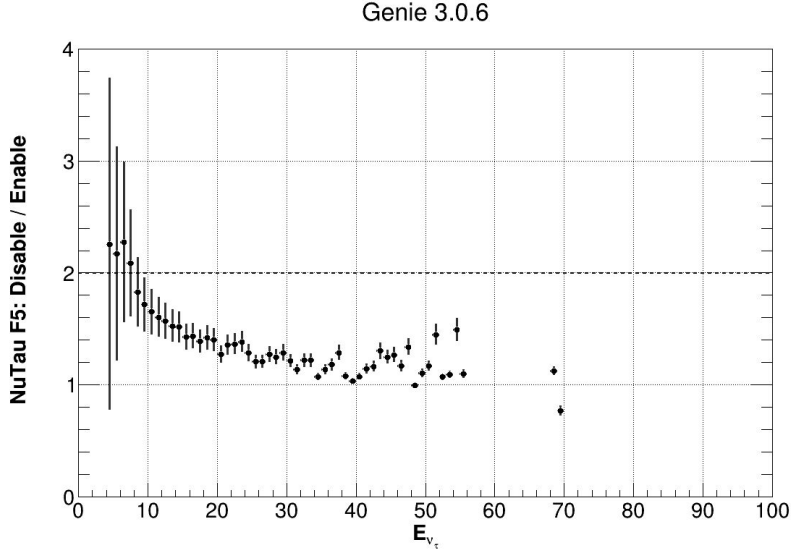
Use values listed at the Chinese Physics C Vol.40, No. 10 (2016) 100001 Review of Particle Physics

ν_τ Cross Section: Genie 2.8.4 vs Genie 3.06

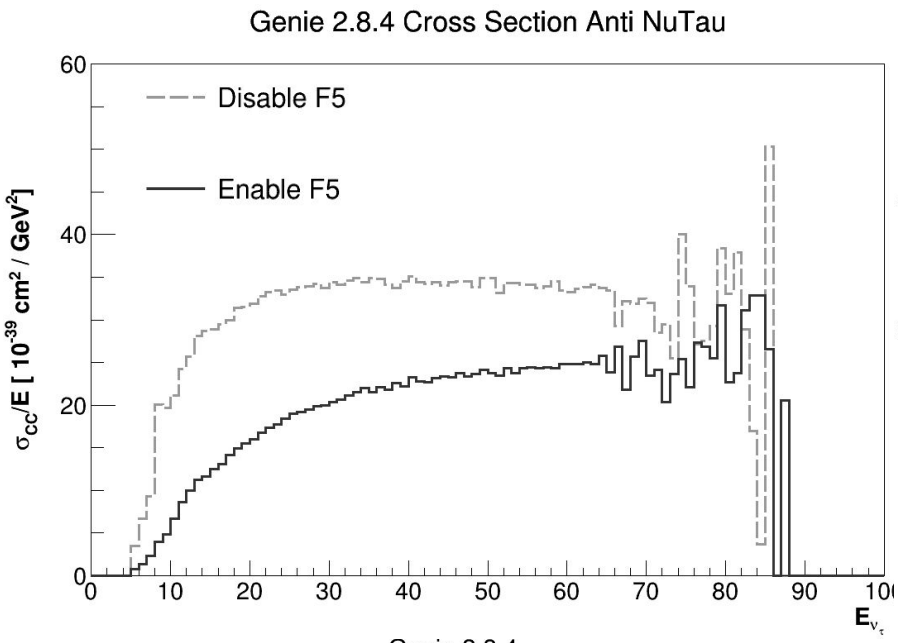


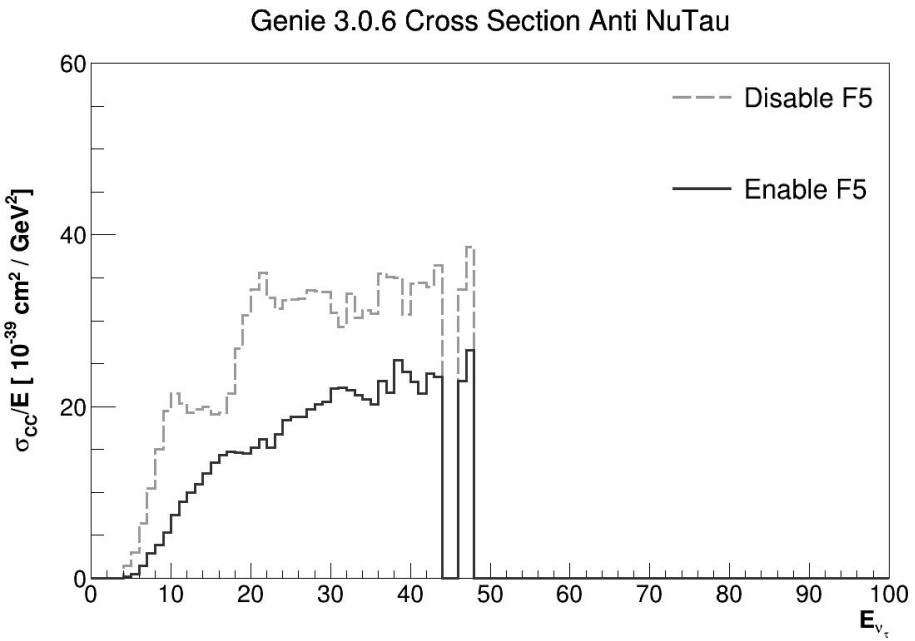


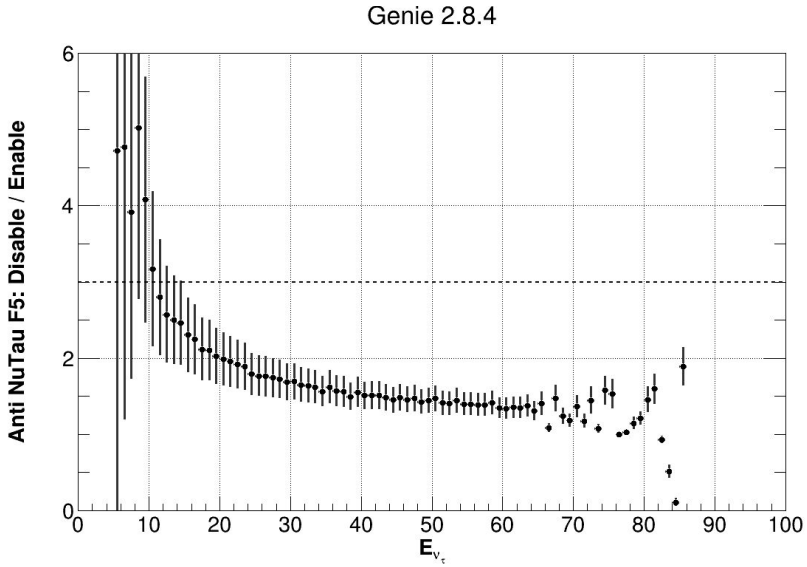


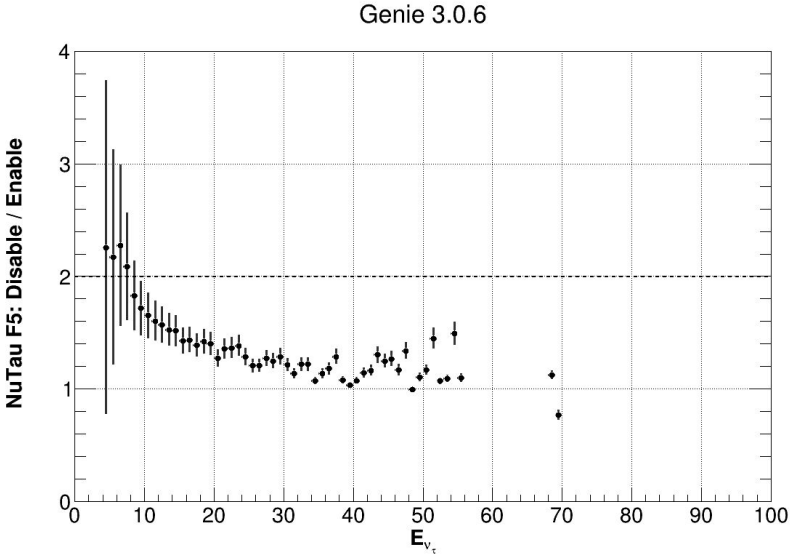


$\bar{\nu}_\tau$ Cross Section: Genie 2.8.4 vs Genie 3.06

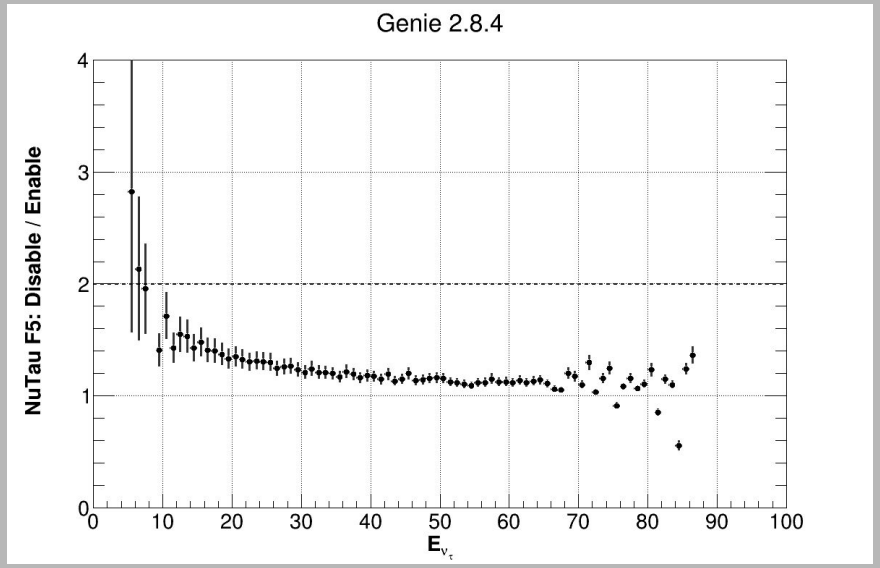


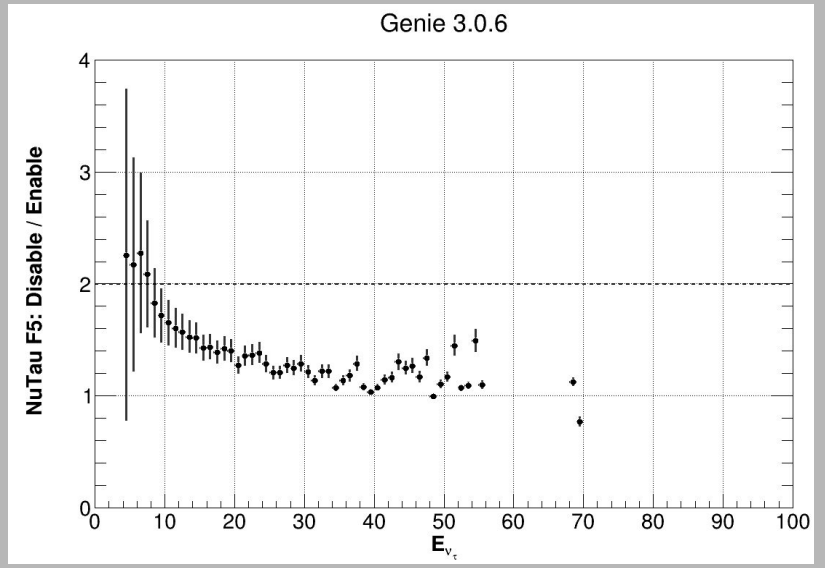


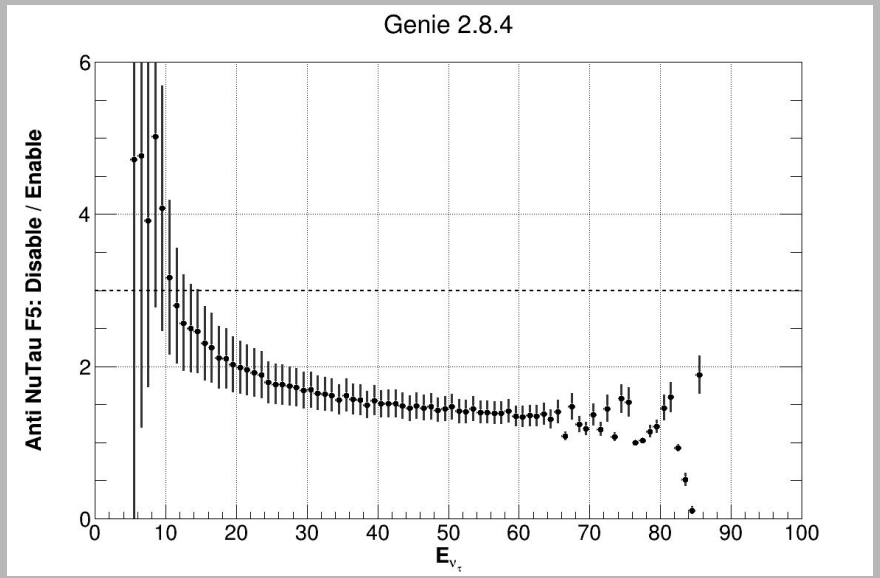


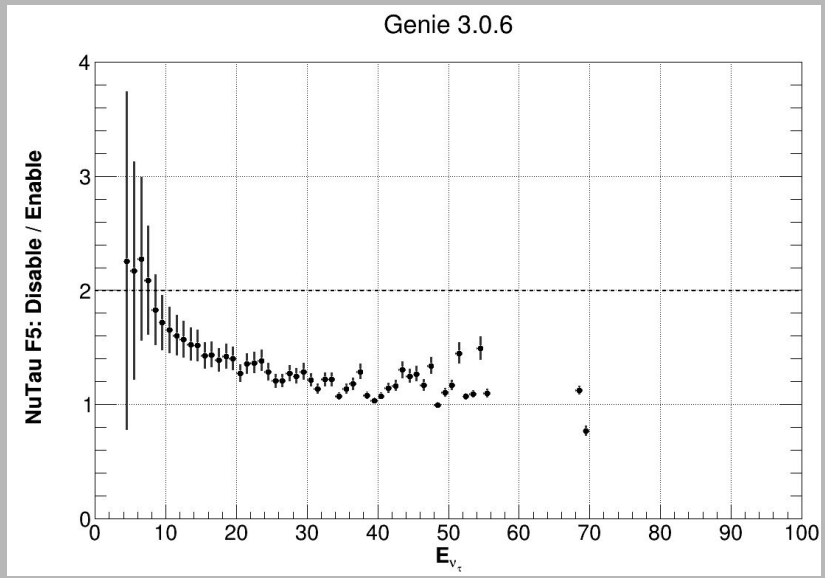


Ratio Disable/Enable Cross Sections



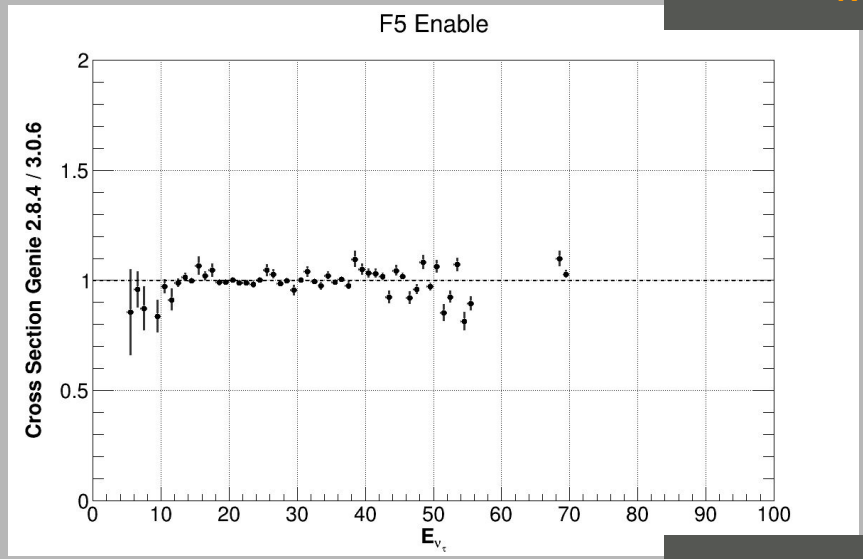


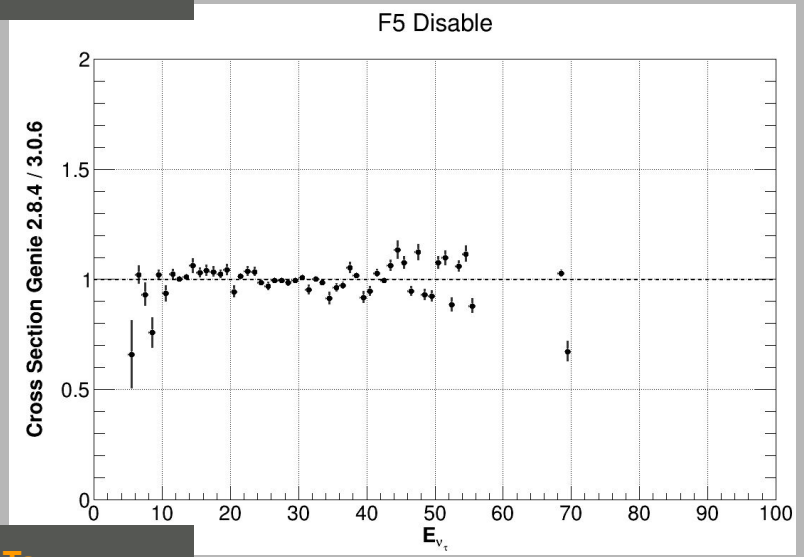




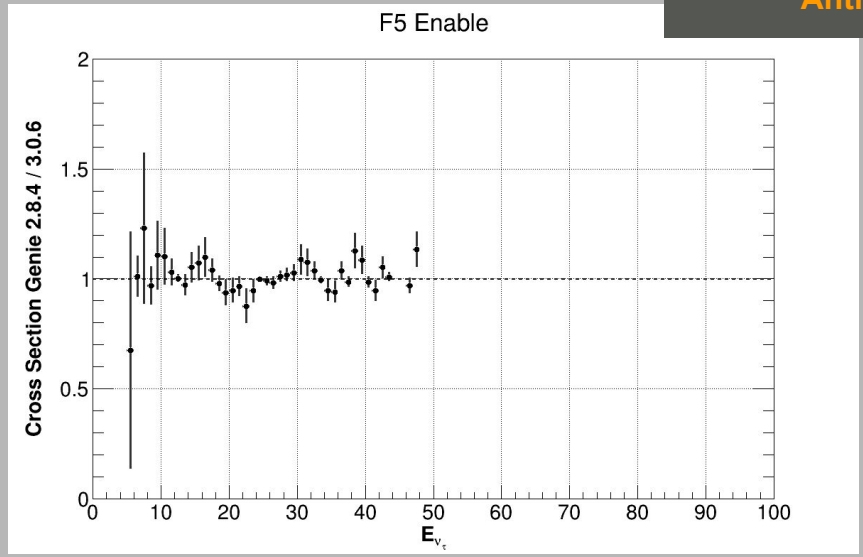
Ratio Cross Section Genie 2.8.4 / Genie 3.06

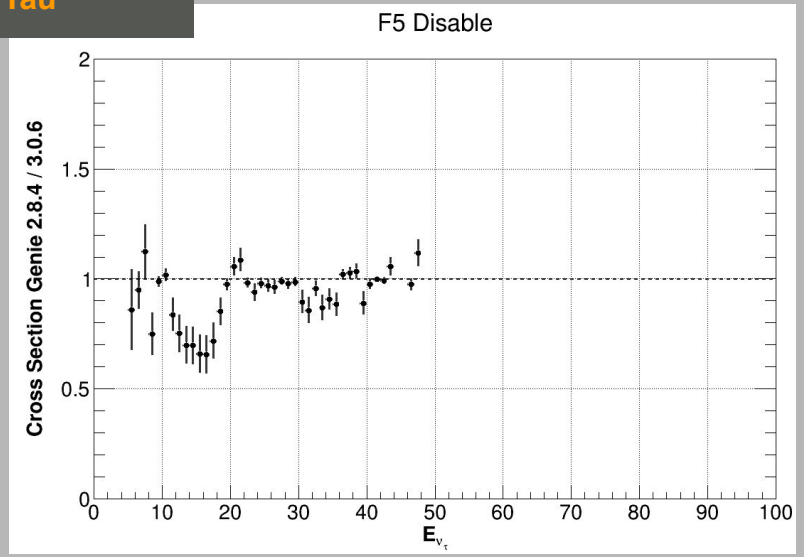
Nu Tau





Anti Nu Tau





For the corrections

The idea is:

- Correct Genie 2.8.4 by Genie 3.0.6 } Ratios Slides 9-10

Default ⇝ Disable FS ← Numerator (N) / Enable FS ← Denominator (D)

$$\text{Correction}_{(N)} = N\_\text{Genie 2.8.4} * \text{Weight}_{(N)}$$

$$\text{where: } \text{weight}_{(N)} = \frac{N\_\text{Genie 3.0.6}}{N\_\text{Genie 2.8.4}}$$

} DISABLE FS

$$\text{Correction}_{(D)} = D\_\text{Genie 2.8.4} * \text{Weight}_{(D)}$$

$$\text{where: } \text{weight}_{(D)} = \frac{D\_\text{Genie 3.0.6}}{D\_\text{Genie 2.8.4}}$$

} ENABLE FS

Before jump into get the corrections/weights...

Confirm if the differences between Genie versions come from:

1) Differences between the CKM parameters
2) Models (changes on the DIS model?)
3) Both

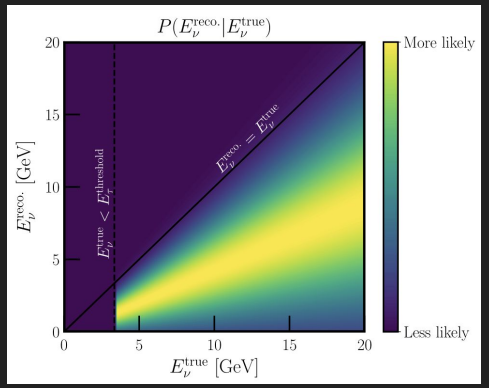
Comments?

Milky Way and Volcan de Fuego , Guatemala

Backup

CC-ν_τ scattering in DUNE

- Up to today, 14 ν_τ have been identified by DONuT (decay of Ds mesons) and OPERA ($\nu_\mu \rightarrow \nu_\tau$ oscillations)
- **DUNE will combine bubble chamber quality data with calorimetry and large statistics.**
- It will therefore provide an unprecedented opportunity to study the ν_τ sector



Migration matrix for hadronically decaying τ leptons produced via ν_τ charged-current interactions. PhysRevD.100.016004

Due to the large mass of the τ ± relative to the e ± and μ ±, the threshold for this process to occur is 3.5 GeV.

INTERESTING BECAUSE...

- **To test the Standard Model predictions and check the validity of the lepton universality hypothesis.**
- **Interaction studies** are also required to better **understanding of the neutrino oscillation parameters (SHiP, DsTau experiments).**
- The interaction cross sections for all three flavors of neutrinos should be known to high accuracy requiring better measurements of the ν_τ /ν_τ XSec.
- IceCube plan to explain the mechanism for production of high-energy neutrinos from astrophysical sources and for the MC simulation of the events, a **good control on the cross-section estimated is required.**