Measurement of Relative Cross-Section of ν_τ to ν_μ Part 1

Emily Maher

16 June 2004

Relative Cross Section Formula

To derive a formula for the cross section of the charged current interaction of the ν_τ, begin with the following:

$$\langle N_{\nu_\tau} \rangle = \int N_{\nu_\tau} \cdot \epsilon_{\nu_\tau} \cdot \sigma^{cc}_{\nu_\tau}(E) \cdot n \cdot dE \qquad (1)$$

where $\langle N_{\nu_\tau} \rangle$ is the observed number of ν_τ interactions observed, N_{ν_τ} is the number of ν_τ's that traverse the target, ϵ_{ν_τ} is the total efficiency (selection, trigger, location, identification), $\sigma^{cc}_{\nu_\tau}(E)$ is the cross section of the ν_τ per energy, and n is the number of scattering centers per cm^2 in the target.

To calculate the relative cross section, use the following equation:

$$\frac{\langle N_{\nu_\tau} \rangle}{\langle N_{\nu_\mu} \rangle} = \frac{\int N_{\nu_\tau} \cdot \epsilon_{\nu_\tau} \cdot \sigma^{cc}_{\nu_\tau}(E) \cdot n \cdot dE}{\int N_{\nu_\mu} \cdot \epsilon_{\nu_\mu} \cdot \sigma^{cc}_{\nu_\mu}(E) \cdot n \cdot dE} \qquad (2)$$

Since n is the same regardless of the neutrino type, it cancels.

The charged current cross section for ν_μ at the typical energies in this experiment ($>$ 5 GeV) is assumed to be linear in energy, so it can be rewritten as:

$$\sigma^{cc}_{\nu_\mu}(E) = E_{\nu_\mu} \cdot \sigma^{cc}_{\nu_\mu \text{ const}} \tag{3}$$

where E_{ν_μ} is the energy of the ν_μ and $\sigma^{cc}_{\nu_\mu \text{ const}}$ is the constant part of the cross section. The cross section for the ν_τ can be written in terms of the ν_μ cross section:

$$\sigma^{cc}_{\nu_\tau}(E) = K_F(E) \cdot \sigma^{cc}_{\nu_\mu}(E) \tag{4}$$

where $K_F(E)$ is a kinematic term that is necessary because of the finite mass of the tau lepton. Equations 3 and 4 can be combined:

$$\sigma^{cc}_{\nu_\tau}(E) = K_F(E) \cdot E_{\nu_\tau} \cdot \sigma^{cc}_{\nu_\tau \text{ const}} \tag{5}$$

If the ν_τ is a standard model particle, then:

$$\sigma^{cc}_{\nu_\mu \text{ const}} = \sigma^{cc}_{\nu_\tau \text{ const}} \tag{6}$$

Substituting equations 3 and 5 into 2:

$$\frac{\langle N_{\nu_\tau}\rangle}{\langle N_{\nu_\mu}\rangle} = \frac{\int N_{\nu_\tau} \cdot \epsilon_{\nu_\tau} \cdot K_F(E) \cdot E_{\nu_\tau} \cdot \sigma^{cc}_{\nu_\tau\ \text{const}} \cdot dE}{\int N_{\nu_\mu} \cdot \epsilon_{\nu_\mu} \cdot E_{\nu_\mu} \cdot \sigma^{cc}_{\nu_\mu\ \text{const}} \cdot dE} \tag{7}$$

Simplifying this equation:

$$\frac{\langle N_{\nu_\tau}\rangle}{\langle N_{\nu_\mu}\rangle} = \frac{\epsilon_{\nu_\tau} \cdot \sigma^{cc}_{\nu_\tau\ \text{const}} \cdot N_{\nu_\tau} \cdot \int K_F(E) \cdot E_{\nu_\tau} \cdot dE}{\epsilon_{\nu_\mu} \cdot \sigma^{cc}_{\nu_\mu\ \text{const}} \cdot N_{\nu_\mu} \cdot \int E_{\nu_\mu} \cdot dE} \tag{8}$$

Solving for $\sigma^{cc}_{\nu_\tau\ \text{const}}$:

$$\sigma^{cc}_{\nu_\tau\ \text{const}} = \frac{\langle N_{\nu_\tau}\rangle \epsilon_{\nu_\mu} N_{\nu_\mu} \sigma^{cc}_{\nu_\mu\ \text{const}} \int E_{\nu_\mu} dE}{\langle N_{\nu_\mu}\rangle \epsilon_{\nu_\tau} N_{\nu_\tau} \sigma^{cc}_{\nu_\tau\ \text{const}} \int K_F(E) E_{\nu_\tau} dE} \tag{9}$$

Questions

- How do I handle neutrinos vs. anti-neutrinos? I cannot distinguish ν_τs from $\bar{\nu}_\tau$s, so any cross section I measure will be the average of $\sigma^{cc}_{\nu_\tau}$ and $\sigma^{cc}_{\bar{\nu}_\tau}$. There should be an equal number of each for ν_τs, but is this true for ν_μs? If I do a relative measurement, this becomes important.

- How should I handle prompt vs. non-prompt ν_μs? These two have different energy distributions and efficiencies. I could use Patrick's ratio of prompt to non-prompt and do each part separately.

Calculating Parameters

- Observed Number of Neutrino Interaction

  This number comes from the data. Currently the observed numbers are:

  $$\langle N_{\nu_\tau} \rangle = 6 \qquad (10)$$

  and

  $$\langle N_{\nu_\mu} \rangle = 162 \qquad (11)$$

- Constant Part of ν_μ Charged Current Cross Section

  The measured value for total cross section in muon neutrino charged current interactions is:

  $$\sigma^{cc}(\nu_\mu N) = 0.677 \pm 0.0014 \times 10^{-38} cm^2 GeV^{-1} \qquad (12)$$

  $$\sigma^{cc}(\bar{\nu}_\mu N) = 0.334 \pm 0.008 \times 10^{-38} cm^2 GeV^{-1} \qquad (13)$$

Calculating Parameters Cont.

- Efficiency

  Four different efficiencies should be considered: $\nu_{\mu\ \text{prompt}}$, $\nu_{\mu\ \text{non-prompt}}$, $\nu_{\tau\ \text{kink}}$, and $\nu_{\tau\ \text{trident}}$. Each efficiency is the product of the trigger, the selection, the location, and the identification efficiencies. The following table summarizes the efficiencies from Patrick and Jason's thesis and a note which Niki wrote called, "Calculation of the Expected Number & Type of Neutrino Interactions" :

ν_μ prompt			
Type	Jason	Patrick	Niki
Trigger	94	93	96
Selection	80	80	75
Location	78	79	
Identification	73	73	
Total	43	43	

ν_μ non-prompt			
Type	Jason	Patrick	Niki
Trigger	67	76	89
Selection	76	76	75
Location	67	70	
Identification	56	49	
Total	19	20	

ν_τ kink			
Type	Jason	Patrick	Niki
Trigger	97	97	95
Selection	80	80	75
Location	73	73	
Identification	51	52	
Total	29	29	

No one has done any work on the trident efficiency. I assume the trigger, selection, and location efficiencies will be the same as kink events. The identification is only dependent on the condition that the tau decay within 10mm.

ν_τ trident	
Type	Efficiency
Trigger	97
Selection	80
Location	73
Identification	90
Total	51

- Number of Neutrinos that Traverse the Target

  The number of neutrinos that hit the target is the product of the number of neutrinos that are produced multiplied by the target acceptance:

$$N_{\nu_\tau}(E) = N_{\nu_\tau \text{ produced}}(E) \cdot \eta \qquad (14)$$

  where η is the target angular acceptance, which is:

$$\eta = 0.064 \qquad (15)$$

  according to Niki's note.

  The number of neutrinos produced is a function of the number of charm particles (and light mesons for non-prompt ν_μ) produced. This is a function of the charm production (and light meson production) cross section for 800 GeV protons on a tungsten target.

Since we are interested in the ratio, we can use the following equation:

$$\frac{N_{\nu_\tau}}{N_{\nu_\mu}} = \Big[\sum_j \sigma(pN \to C_j X) BR(C_j \to \nu_\tau X)\Big]$$
$$\div \Big[\sum_i \sigma(pN \to C_i X) BR(C_i \to \nu_\mu X) +$$
$$\sum_k \sigma(pN \to L_k X) BR(L_k \to \nu_\mu X)\Big] \quad (16)$$

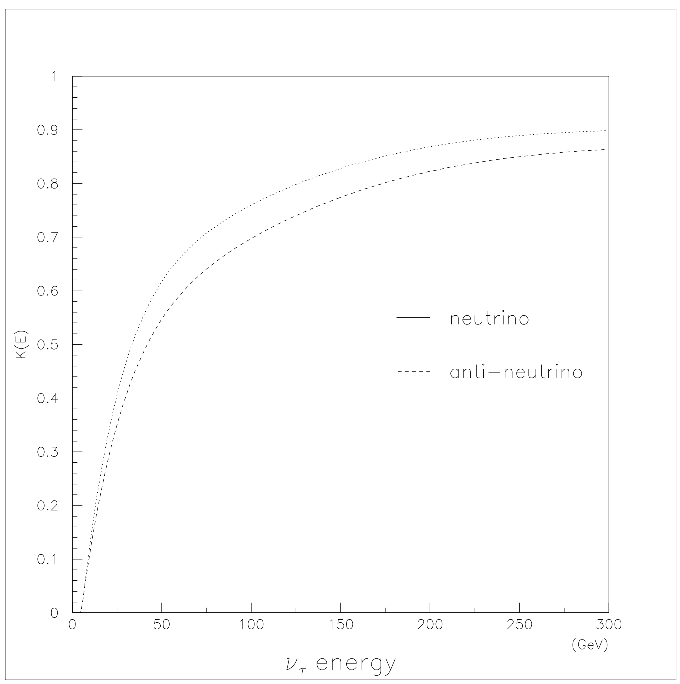
where $C_{i,(j)}$ are the relevant charm particles that produce ν_τ's (ν_μ's), $\sigma(pN \to C_{i,(j)}X)$ are the charm production cross sections for 800 GeV protons, $BR(C_{i,(j)} \to \nu_\tau X)$ is the branching ratio for these charm particles to $\nu_\tau + X$ $(\nu_\mu + X)$, L_k are the relevant light mesons that produce nu_μ's, and $BR(L_k \to \nu_\mu X)$ are their branching ratios to $\nu_\mu + X$. C_i can be D_s and $D^\pm$; C_j can be D_s, $D^\pm$, D^0, and Λ_c; L_k can be π and K.

800 GeV Production Cross Sections	
$\sigma(pN \to D_s X)$	5.2 ± 0.8 μbarn
$\sigma(pN \to D^{\pm} X)$	11.3 ± 2.2 μbarn
$\sigma(pN \to D^0 X)$	27.4 ± 2.6 μbarn
$\sigma(pN \to \Lambda_c X)$	5.4 ± 2.1 μbarn
$\sigma(pN \to \pi X)$	
$\sigma(pN \to K X)$	

Branching ratios	
$BR(D_s \to \nu_e X)$	8 ± 5.5 %
$BR(D_s \to \nu_\mu X)$	8 ± 5.5 %
$BR(D_s \to \nu_\tau X)$	6.4 ± 1.5 %
$BR(D^{\pm} \to \nu_e X)$	17.2 ± 1.9 %
$BR(D^{\pm} \to \nu_\mu X)$	16.0 ± 3.0 %
$BR(D^{\pm} \to \nu_\tau X)$	7×10^{-4}
$BR(D^0 \to \nu_e X)$	6.9 ± 0.3 %
$BR(D^0 \to \nu_\mu X)$	6.5 ± 0.8 %
$BR(\Lambda_c \to \nu_e X)$	2.1 ± 0.6 %
$BR(\Lambda_c \to \nu_\mu X)$	2.0 ± 0.7 %
$BR(\pi \to \nu_\mu X)$	99.9 %
$BR(K \to \nu_\mu X)$	63.4 ± 0.17 %

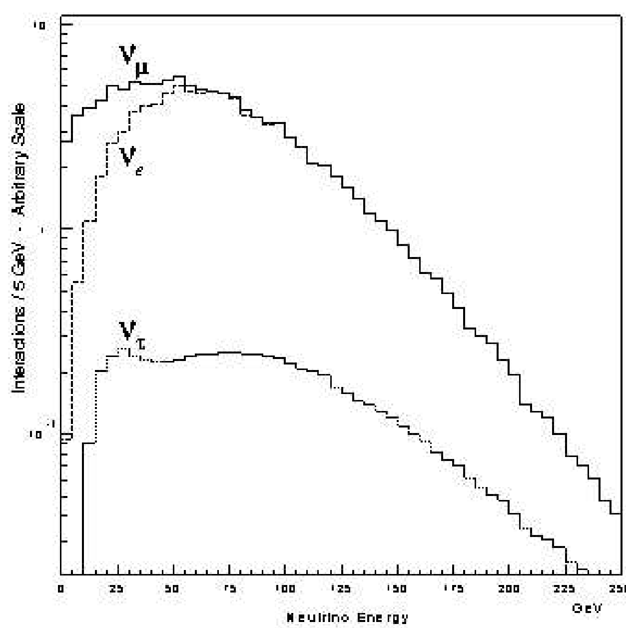
- Kinematic Factor

  K_F can be calculated numerically, shown by Albright and Jarlskog:



- Energy

  The neutrinos are produced with the spectrum of energy shown here:



So I normalize this spectrum and integrate over the spectrum for ν_μ. For ν_τ, I must integrate over this spectrum and the spectrum for K_F.