Calculating the Probability of Tau Neutrino Trident Events Using Event Parameter Analysis

PRELIMINARY RESULTS

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10.07.2002

1 Event Parameters

The three parameters used in this analysis are θ, the angle between the initial beam direction (the z - direction) and the tau track, $\Delta\phi$, which is the asymetry of the produced tracks' polar angles, and the decay length, L (the length of the tau track). The value of θ is obtained by measuring the z distance of the track and the projection of the track in the plane perpendicular to the beam direction. With these two sides, the angle is calculated using inverse tangent. The value of $\Delta\phi$ is obtained by measuring the polar angle for each track (where each track is the the normalized unit momentum vector transverse to the neutrino direction), and calculating the angle between the tau track and the average polar angle of the other tracks (the average of the polar angles of the other tracks is the vector sum of unit transverse momentum of all other tracks from the interaction). L is measured from the data. The values of these parameters are summarized in a table below.

Event	θ	$\Delta\phi$	L
3334_19920	39.8 mrad	2.88 rad	0.88 mm
3296_18816	141 mrad	0.977 rad	0.78 mm

2 Analysis

The probability that an event happens using Bayesian analysis is given by (1).

$$P(i) = \frac{PP_i\Pi(i)}{PP_i\Pi(i) + \Sigma_{bkg}PP_{bkg}\Pi(bkg)} \qquad (1)$$

where i is either a tau neutrino event, a charm event, or a hadronic interaction, and the background term, $\Sigma_{bkg}PP_{bkg}\Pi(bkg)$, is the sum over the other two possibilities. PP_i is the prior probabilty of the event being an i type event. $\Pi(i)$ is the probabilty density function evaluated at a set of measured values of event type i.

PP_i is the aprior knowledge of the likelihood of event type i. In this paper, the expected number of each type of event was calculated. The expected number is just the $PP_i * N$, where N is the number of events in the data set; $N = 429$ events for this data set.

$\Pi(i)$ is calculated using simulated data for each hypothesis. This is measured by calculating the fraction of simulated events which reside in a region of parameter space. This parameter space is centered on the θ, $\Delta\phi$, and L values for the event.

2.1 Calculating Prior Probabilities

The prior probability is the expected number of a certain type of event divided by the total number of events. The expected number is first calculated for each kind of event, and then the prior probability is calculated from the expected number.

Prior Probability of ν_τ event

The expected number of ν_τ trident events, $N_{\nu_\tau\mathrm{trid}}$, is calculated using equation (2).

$$N_{\nu_\tau trid} = N_{\nu_\tau}P(\tau \to \text{trident}), \qquad (2)$$

where N_{ν_τ} is the number of ν_τ interactions in the data and $P(\tau \to \text{trident})$ is the probability that a τ will decay to 3 charged particles. $P(\tau \to \text{triden}t)$ $= 0.1457$ [1]. N_{ν_τ} is the number of tau neutrino interactions expected in the data set. This is the number of ν_τ interactions measured from the number of ν_e and ν_μ interactions found in the data set, the predicted rates of the each neutrino flavor in the beam, and the total efficiency in locating each kind of neutrino interaction (which comes from simulated data). The total number of ν_τ interactions expected in the 203 data set is 8.2 events or 4.0 % of the neutrino interactions are expected to be ν_τ interactions [2]. The expected number of ν_τ interactions in the 429 data set is 17.32 neutrino events and $N_{\nu_\tau trid}$ is 2.52 events.

The $PP_{\nu_\tau} = 5.92\text{x}10^{-3}$.

Note the efficieny of locating the secondary vertex here is assumed to be 100 %. This number assumes once the primary vertex is found in the emulsion, the secondary vertex is always found for trident events. This is something that will be investigated further.

Prior Probability of charm interaction

The expected number of background charm events is given by equation (3).

$$N_{\text{charm trid}} = \sum_i N_{\text{charm}_i} P(\text{charm}_i \to \text{trident})\xi, \tag{3}$$

where N_{charm_i} is the expected number of charm particles of type i in the data set, $P(\text{charm}_i \to \text{trident})$ is the probability that a charm particle of type i will decay to produce 3 charged particles, and ξ is the probability that the primary lepton is not identified. The expected number of charm particles of type i is calculated using equation (4).

$$N_{\text{charm}_i} = N_{cc} F \alpha_i, \tag{4}$$

where N_{cc} is the number of charged current events, F is the average charm particle production fraction, and α_i is the fraction of time that the charm quark will produce a charm particle of type i, where i is D, D_s, or Λ_c. In the 203 data set, the number of charged current interactions is 154 [2]. If the ratio of charged current events/neutral current events stays constant for the 429 data set, then the 429 data set should contain 326 charged current events. For E872's energies, the fraction F is 0.066 [2]. This result comes from the results of E531, CCFR μ^-, and CCFR μ^+ data. The following table summarizes α_i for each charm particle: [3]

Particle	α
D	0.24
D_s	0.09
Λ_c	0.10

The expected number produced for each type of charm particle is listed in the following table along with $P(\text{charm}_i \to \text{trident})$ [1], ξ, and the expected number of background charm events:

Particle	N_{charm}	$P(\text{charm}_i \to \text{trident})$	ξ	PP_{charm}
D	5.16	0.3656	0.3	0.57
D_s	1.94	0.3234	0.3	0.19
Λ_c	2.15	0.1988	0.3	0.13
Total				0.881

The $PP_{\text{charm}} = 2.05\text{x}10^{-3}$.

Note 100% location efficiency of both the primary and secondary vertices was assumed here. This assumption will be investigated further.

Prior Probability of Hadronic Interaction

The expected number of hadronic interation background events is calculated using equation (5).

$$N_{\text{scatter}} = \sum_i L_i P(\text{scatter})_i \xi, \tag{5}$$

where L_i is the total length of all the hadron tracks through material i, where i can be iron, acrylic base, or emulsion. $P(\text{scatter})_i$ is the probability that the hadrons will interact to produce 3 charged paticles in material i per length, and ξ is the probability that the primary lepton was not found (0.3) [2]. The total length was found by taking the total length of the hadron tracks in the 203 data set in iron is 1717 mm, in acrylic base is 887 mm, and emulsion is 1335 mm. Dividing these lengths by 203, an average length per event is calculated. The average length a hadron tranverses per event is 8.46 mm/event for iron, 4.37 mm/event for arcylic base, and 6.58 mm/event for emulsion. These numbers were multiplied by 429 (the number of events in the present data set) to find the total length of all the hadron tracks in each material: 3629 mm in iron, 1874.7 mm in acrylic base, and 2821.2 in emulsion. Note this method was used becuase the information on all of the events in the present data set is unavailable. Then a Monte Carlo was used to simulate a list of typical hadrons occuring in the data. This was done separately for muon events or electron events, for charged current events or neutral current events, and for prompt or non-promt muon events.

The next step is to simulate the propagation of these hadrons through 5 mm of iron, emulsion, and acrylic base using GEANT to determine the number of interactions which result in 3 charged final state particles. This will yield a probability of interacting to produce 3 charged particles per length for each material. $P(\text{scatter})_i$ was calculated for each of the 6 classes of events in each of the 3 materials and the values are summarized in this table number ***:

$P(\text{scatter})_i$			
Type of File	Iron	Acrylic Base	Emulsion
Electron CC Events	0.00215	0	0
Electron NC Events	0.00204	0	0
Muon CC Prompt Events	0.00186	0	0
Muon NC Prompt Events	0.00216	0	0
Muon CC Non-Prompt Events	0.00166	0	0
Muon NC Non-Prompt Events	0.00200	0	0

The highest $P(\text{scatter})_{\text{iron}}$ is used to calculate prior probability.

The expected number and prior probabilities for each type of event are summarized in this table:

Type	N_{exp}	PP_i
Tau Neutrino	2.54	5.92 x 10^{-3}
Charm	0.88	2.05 x 10^{-3}
Interaction	2.35	5.48 10^{-3}

2.2 Calculating Probability Densities

$\Pi(i)$ is calculated using simulated data for each hypothesis. This is measured by calculating the fraction of simulated events which reside in a region of parameter space. This parameter space is centered on the θ, $\Delta\phi$, and L values for the event.

Probability Density of Tau Event

A list of simulated tau neutrino interactions was generated using GEANT. This list gives the weight, θ, $\Delta\phi$, and the momentum of each. Events which fit into a certain $\Delta\theta$ and $\Delta(\Delta\phi)$ were selected from the list.

The next step of this process is to find events which pass a decay length cut. For each event which passed the angle cut, the momentum was used to produce a decay length spectrum. A decay length was then choosen from this spectrum. Each event, therefore, will have a decay length associated with it, and a cut is made on this decay length. The following tables lists the results for the fraction of events which passsed the angle cut and the legnth cut.

Event	Angle Cut	Length Cut
3334_19920	0.132	0.0329
3296_18816	0.000596	0.0102

To calculate the probability density, these two percentages are multiplied together, and the value must be divided by $\Delta\theta\Delta(\Delta\phi)\Delta L$.

Event	$\Pi(\tau)$
3334_19920	9.983
3296_18816	0.00526

Probability Density of Charm Event

This is very similar to the caluculation above. The difference, of course, is a list of simulated charm events is used. The same $\Delta\theta\Delta\phi\Delta L$ are used. The table below lists the fraction of events which passed the angle cuts and the length cut.

Event	Angle Cut	Length Cut
3334_19920	0.0354	0.0279
3296_18816	0.00414	0.0149

The probability density for each event is listed in the table below.

Event	Π(charm)
3334_19920	2.26
3296_18816	0.045

Probability Density of Scatter Event

For this calculation, the files of simulated hadrons were used. The same $\Delta\theta$ and $\Delta\phi$ are used. The table below summarizes the fraction of events which passed the angle cuts for each of the six files.

Fraction that Passed Angle cuts		
Type of File	3334_19920	3296_18816
Electron CC Events	0.0199	0.0104
Electron NC Events	0.0055	0.0123
Muon CC Prompt Events	0.0107	0.0122
Muon NC Prompt Events	0.0060	0.0169
Muon CC Non-Prompt Events	0.0293	0.0113
Muon NC Non-Prompt Events	0.0039	0.0139

Since the interaction probability in iron is constant, the events which passed the angle cuts are propagated through 1 mm of iron. The fraction that interact within 1 mm of iron is calculated to give a probability of interaction per 1 mm of iron. The vales are summarized in a table below.

Fraction that Interacted (1/mm)		
Type of File	3334_19920	3296_18816
Electron CC Events	0.0036	0.0038
Electron NC Events	0.0025	0.0038
Muon CC Prompt Events	0.0043	0.0029
Muon NC Prompt Events	0.0046	0.0031
Muon CC Non-Prompt Events	0.0027	0.0023
Muon NC Non-Prompt Events	0.0027	0.0033

The fraction which passed the angle cuts is multiplied by the fraction that passed the decay length cut. This number is then divided by $\Delta\theta\Delta(\Delta\phi)\Delta L$. Below the probability density is listed for each type of file (in 1/rad^{2}mm):

Π(interaction/scatter)		
Type of File	3334_19920	3296_18816
Electron CC Events	0.0527	0.0145
Electron NC Events	0.0046	0.0172
Muon CC Prompt Events	0.0169	0.0130
Muon NC Prompt Events	0.0101	0.0193
Muon CC Non-Prompt Events	0.0291	0.0096
Muon NC Non-Prompt Events	0.0039	0.0169

The highest value is taken to give an upper limit for the probabiltiy density of an interaction/scatter event.

The probability densities for each type of event are summarized in this table (in 1/rad^{2}mm):

$\Pi(i)$		
Type	3334_19920	3296_18816
Tau Neutrino	9.98	4.48 x 10^{-3}
Charm	2.26	7.34x 10^{-1}
Interaction	0.0527	1.93 x 10^{-2}

3 Results

The probabilities were calculated for each type and are listed below.

Probability		
Type of Event	3334_19920	3296_18816
Tau Neutrino	.92	0.02
Charm	.07	0.92
Interaction/Scatter	0	0.06

4 Future Work

4.1 Possible Improvements

I should explore the following: the efficiency of finding the secondary vertex of a ν_τ event, the efficiency of locating charm particles both the primary and secondary vertices, the lengths of the hadron tracks for the 429 data set in iron, acrylic, and emulsion, and the number of charge-current events in the 429 data set. As data on all of these events is gathered for the phase 2 paper, I believe these numbers will be easier to explore. I will wait to do further investigation of these issues.

References

[1] Particle Data Group: (2002)

[2] Jason Sielaff: Ph.D. Thesis (2002)

[3] T. Bolton: hep-ex/9708014v1 (1997)