Status Report of DONUT Experiment

Direct Observation of Nu Tau

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Outline

Motivation/Goals
Experimental Setup
Data Analysis Status
Present Work
  Individual Event Probabilities
  Location Efficiency
  Cross Section Measurement
Conclusions
Motivation/Goals

Old Results:


Upper limit on tau neutrino magnetic moment, $\mu_{(\nu_\tau)} < 3.9 \times 10^{-7} \mu B$ (Phys. Lett. B 513(2001) 23-29) (Reinhard Schwienhorst)

Preliminary Results:

Extended data set from 203 to 437

Observed 3 more tau neutrino interactions (total 7 candidates)

Calculated individual event probabilities (Jason Sielaff 2002)

Working on interaction cross section measurement

Is tau neutrino standard model particle?

Two theses down (Sielaff, Schwienhorst), two to go (Erickson, Maher)
directly observe cc interactions of the $\nu_\tau$

$$\nu_\tau + N \rightarrow \tau + X$$

$\nu_\tau$ + $N$ $\rightarrow$ $\tau$ + $X$

Experimental Setup – Block Diagram

- BEAM DUMP
- SHIELDING
- EMULSION TARGET
- SPECTROMETER

- 800GeV
- $D_s$ $\tau$
- $\nu_\tau$

- $c\tau$ = 0.09mm
- $\sim 3.5 \times 10^{17}$ protons for 433 $\nu$ interactions
- $\sim 5\%$ $\nu_\tau$
Data Analysis Status – Then and Now

- 6.6×10^6 triggers
- 1026 predicted vertices from spectrometer
- 878 within fiducial volume
- 647 digitized emulsion data exists
- 647 emulsion vertex location attempted
- 451 vertex found
- 437 systematic decay search
- 264 ντ candidates
- 4 candidates
- 7 charm candidates
- 59% Location efficiency
Messy Event – No Emulsion Data
Typical Event – Emulsion Data, Not Located
New $\nu_\tau$ Candidates

Event analysis not complete
Individual Event Probabilities - Observables

Use 3-parameter or 5-parameter analysis to assign probabilities to event interpretation.

Parameters

- Track production angle $\theta$
- Event angular symmetry $\Delta \phi$
- Track decay length $L$
- Daughter momentum
- Daughter decay angle

View perpendicular to $\nu$ direction

Vector sum of all hadrons
Individual Event Probabilities
Jason Sielaff’s Thesis

Single Prong Event Parameters

- Track production angle
- Event angular symmetry
- Track decay length
- Daughter decay angle
- Daughter momentum $\nu_{\tau}$ cc
- $\nu$ + charm
- $\nu$ + hadron scatter

Probability all events are background = $5 \times 10^{-5}$

<table>
<thead>
<tr>
<th></th>
<th>$\nu_{\tau}$ cc</th>
<th>$\nu$ + charm</th>
<th>$\nu$ + hadron scatter</th>
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<td>3024.30175</td>
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</table>
# Individual Event Probabilities

## Trident Event Parameters
- Track production angle
- Event angular symmetry
- Track decay length

## Probability
- All events are background
  \[= 2.2 \times 10^{-7}\]

## 3 parameter analysis

<table>
<thead>
<tr>
<th>Single Prong</th>
<th>Tridents</th>
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</table>
| \(\nu_\tau\) cc | 0.87  
| \(\nu\) +charm | 0.13  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.99  
| \(\nu\) +charm | 0.01  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.06  
| \(\nu\) +charm | 0.03  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu\) +charm | 0.14  
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| \(\nu_\tau\) cc | 0.99  
| \(\nu\) +charm | 0.01  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.96  
| \(\nu\) +charm | 0.03  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.89  
| \(\nu\) +charm | 0.01  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.91  
| \(\nu\) +charm | 0.73  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.01  
| \(\nu\) +charm | 0.03  
| \(\nu\) + hadron scatter | 0.00 |

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| \(\nu_\tau\) cc | 0.10  
| \(\nu\) +charm | 0.01  
| \(\nu\) + hadron scatter | 0.00 |
Cross Section Measurement

Check to see if the number of tau neutrino charged current interactions DONUT observed agrees with theory – check lepton universality

Cross section can be calculated in different ways

- Calculate an absolute expected number of tau neutrino charged current interactions using first principles and measured cross sections, relating event yield to protons on target
- Normalize expected number against number of electron and muon neutrino charged current interaction observed by DONUT

The following quantities are necessary:
- Must define specific cuts to create data set
- Must know efficiencies (trigger, selection, location, lepton id)
Conclusion

• Increasing event sample continues
  – From 203 to 437
    • Problems are getting harder
    • Located 4 events in the last month

• Better understanding of efficiencies and more tau and charm events
  – Improved understanding of backgrounds and systematics

• Better discrimination of tau neutrino interactions and background events

• First Cross Section Measurement of tau neutrino

• Improving technology for future detectors to study short lived particles.
• trigger
• muon ID
• electron ID
• momentum calibration
• vertex location
**Individual Event Probabilities**

\[ P(x \text{ event}_i) = \frac{A_i \times \text{PDF}_i(x)}{\sum_j A_j \times \text{PDF}_j(x)} \]

\[ P = \text{The probability of a set of observables, } x, \text{ being a result of event } i, \text{ where } \{\text{charm, hadronic scatter}\}. \]

Two inputs for each event type:

1. **A**\(_i\) **prior probability:**
   
   Knowledge of the likelihood of each event \(i\)

   **Relative Normalization (aka N_{signal}, N_{charm \ bkg}, N_{int. \ bkg}),**

2. **PDF**\(_i(x)\): **probability density function**

   Probability of finding event in \((x, x+\Delta x)\)

   where \(x\) is a 3- (for trident events) or 5- (for single prong events) tuple of parameters specific to the individual event