Results from DONUT

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The DONUT experiment has analyzed a sample of 203 neutrino interactions recorded in nuclear emulsion targets. Two decay search methods has done for long and short flight tau decay. Evidence of four tau neutrino interactions with an estimated background of 0.41 events and one with background of 0.22 events.

1. Introduction

Since the discovery of the τ lepton in 1975[1], the existence of τ neutrino has been believed. But there had been no direct evidence for 25 years. The DONUT experiment (Fermilab E872) was designed to observe the charged current interactions of the ν_τ by identifying the τ lepton as the only lepton created at the interaction vertex. ν_τs were produced via the consecutive decay $D_s \rightarrow \tau^+\nu_\tau, \tau^+ \rightarrow \bar{\nu_\tau}X$ in the beam dump of 800GeV proton.

Neutrinos were exposed to emulsion target module. The size of emulsion module is 500mm by 500mm perpendicular to the beam. Three kinds of stacks were used, ECC200,ECC800 and BULK. ECC(Emulsion Cloud Chamber) had alternating sheets of 1mm thick stainless steel and emulsion. The emulsion sheets had $100\mu m$ emulsion layers on each side of a plastic base. The thickness of the plastic base was $200\mu m$ and $800\mu m$ for ECC200 and ECC800 respectively. And BULK is a set of $350\mu m$ thick emulsion on the both side of $90\mu m$ thick plastic base. Each module has 2 to 3 X_0 in the cascade length and 60 to 100kg weight. The information of charged tracks in an emulsion plane was read out by automatic read-out systems developed at Nagoya University[2]. A track segment has angle and position information. Its position accuracy is about $0.3\mu m$ which is enough to detect τ's kink, to estimate the momentum by measuring magnitude of multiple scattering and to identify electron by detecting electromagnetic shower in the emulsion target module.

The SFT(Scintillating Fiber Tracker) followed the emulsion target module to support the neutrino interaction location. The SFT consists of 40 U,V-projection planes and 4 X-projection planes. X-projection is inclined at 45 degrees to U and V. A plane of U,V-projection is made from 2 layer of $500\mu m$ diameter scintillating fibers. The position accuracy is measured to be $\sim 130\mu m$[3].

$\mu - ID$ system was made up of 3 steel walls and 3 set of proportional tube plane.

2. Event Analysis

The exposure was done from April to September 1997 with 3.54×10^{17} POT. The expected number of neutrino interactions is 1100 ± 200 which contains about 5% of ν_τ interactions. 698 events were selected as neutrino interactions in the fiducial volume from 4.0×10^6 triggers. To locate the primary vertex in the emulsion target module we developed "Net scan" technique. SFT predicted the vertex position up to typically $5 \times 5 \times 15mm$. All track segments in the predicted volume are read out and reconstructed. The tracks from the vertex must start in the volume and have small impact parameter with each other. Primary vertex location has been attempted for 499 events with 262 events successfully located.

New set of scanning data was taken around the located position for the decay search. 203 events of 262 satisfied the criteria for the tight alignment. The volume for the decay search is defined by a transverse area of $2.6mm \times 2.6mm$ centered on the located vertex with a longitudinal dimension of $\sim 12mm$ of the vertex.The mean flight length of τ is 2mm in DONUT.

τ typically decays with kink (single charged particle) topology. They are classified into two groups. One is "long flight decay" in which τ has at least one track segment in the emulsion data. The other is "short flight decay" in which τ decays before the first emulsion plane.

After picking out "kink" topology in the decay search volume, two requests characterize a kink as a τ decay. One request is low value cut for daughter momentum and Pt to reject hadronic interactions. Pt is defined as $Pt \equiv P \times sin\theta_{kink}$ where P is the daughter particle momentum and θ_{kink} is the angle difference. In the case that the daughter particle was identified as lepton, we can relax the cut. The other request is no lepton comes out from Primary vertex to reject charm particle decay. The $\mu - ID$ efficiency is 79% and $e - ID$ efficiency is 75%.

For "long flight decay", Fig.1 shows the Pt distribution of 52 kink candidates. We requested $Pt \geq 0.25GeV/c$ to reject hadronic interactions. In this condition 0.20 ± 0.06 hadronic interactions are expected as τ-kink background.
5 events satisfied this cut. One of them had electron from the primary vertex and identified as a charm production in ν_e^{CC}. We have 4 long τ-kink candidates and 2 of them are decayed into electron. The background from charm is estimated to be 0.21 ± 0.04 events.

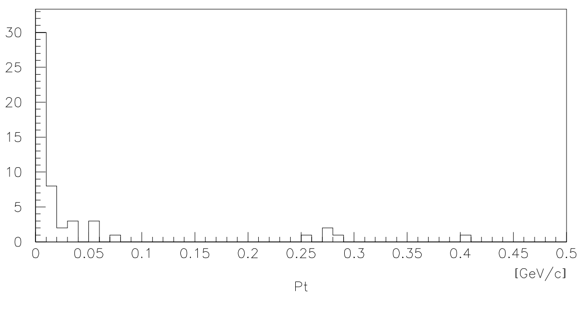

Figure 1. Pt distributions of long kink candidates

For "short flight decay", we selected pairs of tracks which has a large impact parameter to each others compared to the expected value. Fig.2 shows the σ distribution for all pairs except with very small impact parameter. σ is defined as impact parameter divided by expected value which was came from measurement error and multiple scattering. In Fig.2, there are 6 events satisfied $\sigma \geq 4$. For short flight decay candidates, we evaluated Pt_{min} instead of Pt. Pt_{min} is defined as Pt assuming the kink point is the most downstream. After $Pt_{min} \geq 0.08GeV/c$ cut, 2 events were remained. One of them has a μ at the primary. Then it's identified as a charm production in $\nu_\mu^C C$. For the other event, the emulsion data were added to get better momentum resolution. The Pt_{min} is $0.09^{+0.04}_{-0.02}GeV/c$ and no lepton comes from the primary vertex. The number of background were estimated 0.13 from the secondary interaction and 0.09 from charm decay.

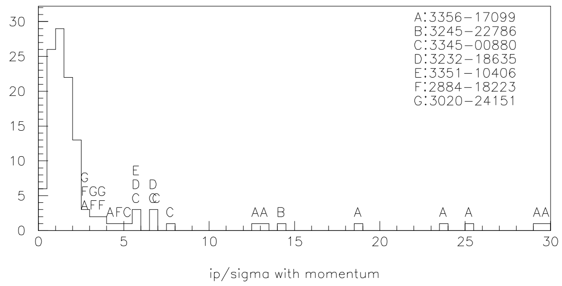

Figure 2. σ distribution in short flight decay search. 18 pairs are greater than $\sigma \geq 4$ from 6 events. The alphabets indicate each event.

3. ν_τ Events

Here the details of each τ events are shown.

3.1. Event 3024-30175

This event is shown in Fig.3. Three tracks were found from the primary vertex. The track that is near the neutrino direction has a 0.093 rad kink, 4.5mm from the primary vertex in the plastic base of emulsion plate. No other tracks including nuclear evaporation tracks from this kink vertex are recognized. The kink daughter track was identified as an electron, because of the existence of an electron pair accompanying this track, and a shower seen in the SFT planes. The momentum was estimated $2.9^{+1.5}_{-0.8} GeV/c$ by measuring multiple scattering. But this value should be considered as a lower limit, because electron looses energy by pssing through the material. The Pt is estimated to be $\geq 0.27^{+.14}_{-.69}\ GeV/c$.

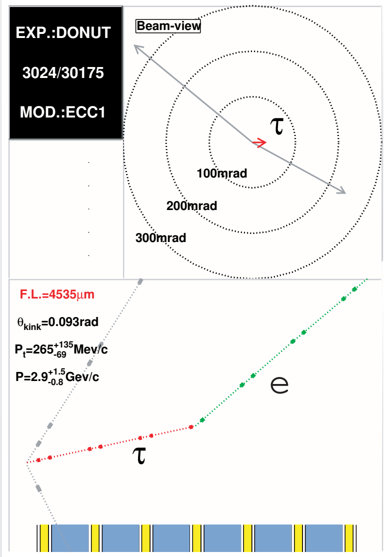

Figure 3. ν_τ CC interaction candidate event.

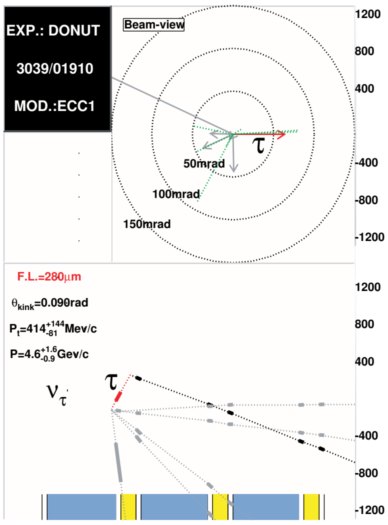

Figure 4. ν_τ CC interaction candidate event.

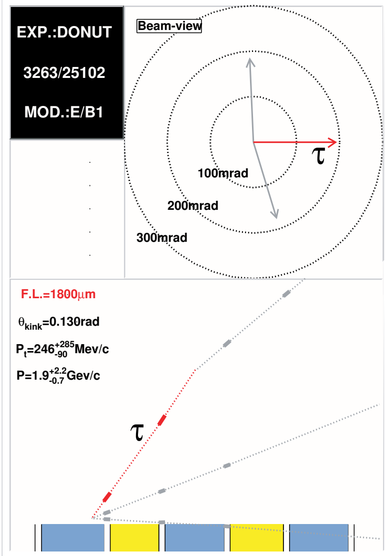

Figure 5. ν_τ CC interaction candidate event.

3.2. Event 3039-01910

As shown in Fig.4 there is an isolated track that shows a 0.090 rad kink after 280μm flight length. This track is isolated from the other charged tracks and is emitted opposite to the other tracks in the plane perpendicular to the beam. The decay occurs in the plastic base (200μm thickness). The daughter momentum was measured to be $4.6^{+1.6}_{-0.9}$ GeV/c in Emulsion. The estimated decay p_T is $0.41^{+0.14}_{-0.08}$ GeV/c. The daughter track was identified as a hadron because a secondary interaction is seen after 1.5cm flight.

3.3. Event 3263-25102

The event topology is shown in Fig.5. One track shows a kink topology after 1.8mm flight length. The decay point is in the Iron plate. The kink angle is measured to be 0.130rad and the daughter momentum is estimated to be $1.9^{+2.2}_{-0.7}$ GeV/c. The corresponding p_T is $0.25^{+0.29}_{-0.09}$ GeV/c.

3.4. Event 3333-17665

Fig.6 shows the event topology. The track nearest to the beam direction has a kink 0.013 rad. The daughter is identified as an electron. The momentum of the electron was measured to be 21^{+14}_{-6} GeV/c by multiple scattering measurement. Because of the continuous energy loss of the electron, this value must be considered as a lower limit. The corresponding decay p_T is $\geq 0.28^{+0.19}_{-0.08}$ GeV/c.

3.5. Event 3356-17099

This is a short flight decay candidate. Fig.7 shows the event topology. The primary vertex is inside of the iron 900μm upstream from the first emulsion layer. One track has 23μm impact parameter and its momentum is $3.2^{+1.3}_{-0.73}GeV/c$ measured by multiple scattering. So minPt is greater than 0.09GeV/c.

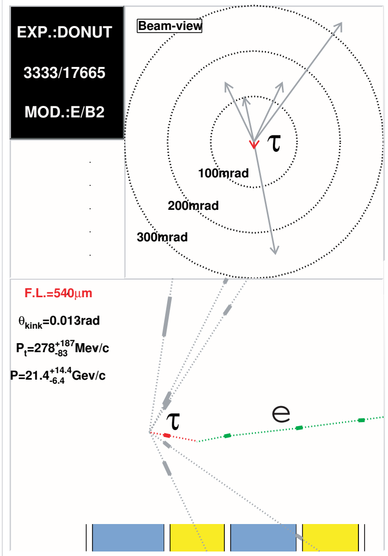

Figure 6. ν_τ CC interaction candidate event.

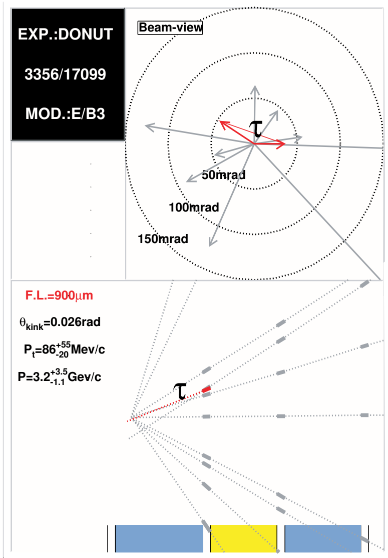

Figure 7. ν_τ CC interaction candidate event(short flight decay).

4. Conclusion

Four long flight τ decay candidates and one short flight τ decay candidate were detected in a set of 203 located neutrino interactions. The expected value are 4.1 and 0.8 events for long and short respectively by 5% ν_τ to all ν. The background were estimated 0.41 and 0.22 for long and short respectively. The probability that all events are from background source is 1.9×10^{-4}, and we conclude that these events are evidence that tau neutrino charged current interactions have been observed.

REFERENCES

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