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Tau neutrino discovery

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ABSTRACT

A total of 337 neutrino interactions was located in emulsion target and analyzed to find ν_τ interactions by DONUT experiment. Seven tau neutrino ineteractions have been detected with an estimated background of 1.2 events.

1 Introduction

In the last summer [1],the DONUT experiment (Fermilab E872) confirmed the existence of tau neutrino,which is the last fundamental particle in the Standard Model. A charge current ν_τ ineteraction is identified by observing the tau particle from the interaction. A nuclear emulsion was used as the vertex detector as well as the interaction target,because the flight length of the τ particle is very short.($\gamma c\tau \sim 2mm$).

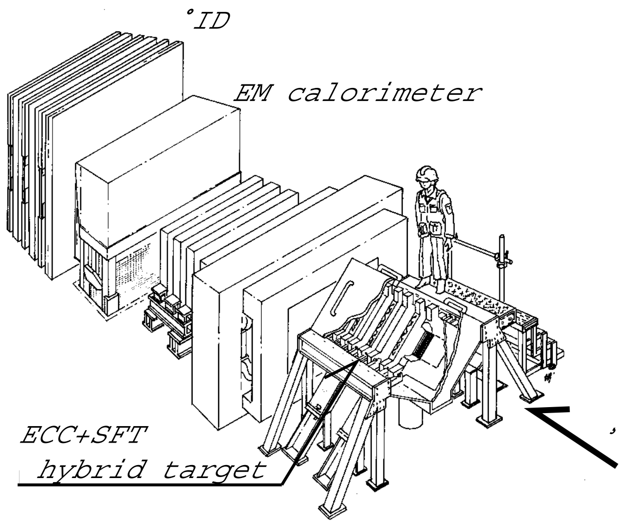

Figure 1: *A schematic view of the DONUT detector.*

Tau neutrinos were produced via the consecutive decay of D_s produced in the 800 GeV/c proton-tugsten beam dump interactions, i.e. $D_s \rightarrow \tau^+ \nu_\tau$, $\tau^+ \rightarrow \overline{\nu}_\tau X$. The mean energy of ν_τ is 111 GeV/c. The expected abundance of $\nu_\tau(\overline{\nu_\tau})$ is about 5% in the ν beam. DONUT detector was mounted at a distance of 37m downstream from the beam dump. A magnet just after beam dump target swept out muons from charged particle decays. Fig.1 shows a schematic view of the DONUT detector. The most important part of the detector is the Emulsion Cloud Chamber(ECC) and the sintilation fiber tracker (SFT) hybrid target. Behind them,the EM calorimeter and the μID were followed.

2 Event Location

Three types of ECC target were used in DONUT. First type consisted of iron plates(thickness=1.0mm) and emulsion plates($100\mu m$ emulsion layers were coated on both sides of a 200 μm thick plastic base). Second type consisted of iron plates(thickness=1.0mm) and emulsion plates with different plastic base thickness($800\mu m$). And the last type consisted of only emulsion plates($350\mu m$ emulsion layers on both sides of a $90\mu m$ thick plastic base). Using the SFT hit information,vertex position were predicted .(Fig.2) In the volume around the

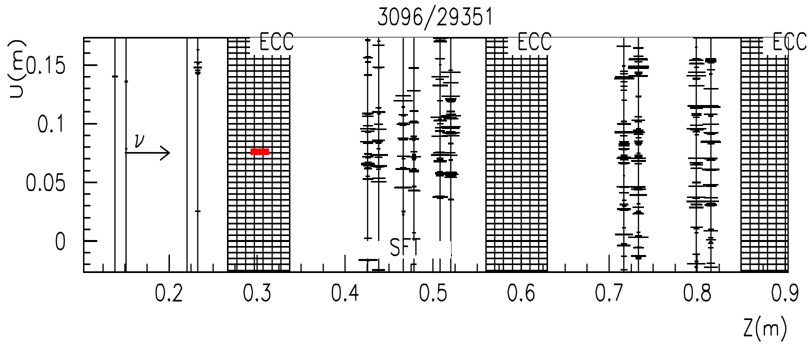

Figure 2: *Example of triggered event in DONUT.The meshed boxes show ECC targets, and the vertical lines between ECCs show the SFT.The horizontal lines on the SFT show the signals . In this case ,about seven charged particles passed through the SFT.*

predicted point,typically 5mm x 5mm x 20mm, the coordinates and the slopes of all tracks in the volume were measured by the Ultra Track Selector(UTS) , which is the present version of the automated emulsion read-out system developed by NAGOYA university group. [2]) The UTS can read out track information by a speed of $1cm^2/hour$. Track recognition efficiency is around 99% for tracks which have the incident angle within 0.4rad . Fig.3-(a) shows the scatter plot of all recognized tracks in $5x5mm^2$. In this area,about 20000 tracks were recognized. In the figure ,the line length shows the track slope. In the succeeding 8 emulsion plates ,all tracks within 0.4 rad were readed out ,and reconstructed. About 10000 tracks were reconstructed in this volume.(Fig3-(b)) Of these ,penetrating tracks were rejected. After this selection,820 tracks were remained.(Fig.3-(c)) And by rejecting low momentum tracks ,83 tracks were selected for further analysis.(Fig.3-(d)) After small impact parameter ($\leq 5\mu m$) between the remained tracks was requested in order to reconstruct a vertex, only 1 vertex candidate was identified in this volume.(Fig.3-(e)) Then the vertex was located. This method is called 'NETSCAN location'.

In DONUT ,about 800 events are selected as triggered neutrino interactions. Until now,566 events were searched by the NETSCAN location,and 337 events were located in the ECC targets. For some events ,it was difficult to predict the vertex position precisely, when electromagnetic shower grows earlier in the ECC target.(maximum material $\sim 3X_0$) Vertex position distribution

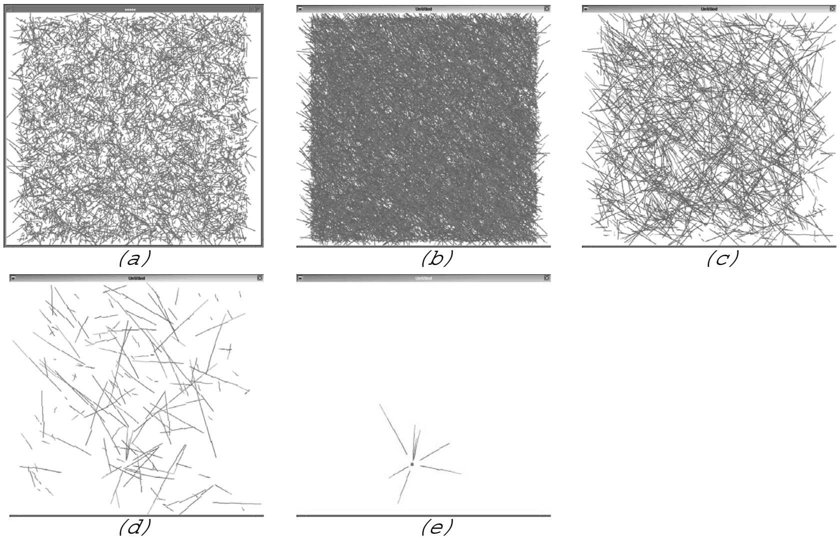

Figure 3: *NETSCAN location(DONUT 3267/24207). (a)Recognized tracks by UTS in one plate.The line length shows track slope. (b)Reconstructed tracks in the succeeding 8 emulsion plates. (c)After rejecting the penetrating tracks ,about 800 tracks were remained. (d)After rejecting the low momentum tracks ,83 tracks were selected. (e)After requesting the small impact parameter between the tracks,only 1 vertex candidate were identified.*

for found events and predicted events are shown in Fig.4-(a). The position is the distance between the SFT and the predicted vertex. The event location efficiency reached to 85% for events which were predicted nearby the SFT. But at the far side ,it drops down to less than 40%. Fig.4-(b) shows one example event which was failed to locate . Those kind of events will be analyzed near future using the next generation of the track selector by enlarging the scanning volume.

Another reason of the failure of the vertex location is that the number of shower tracks from the neutrino interaction is not enough to reconstruct a vertex. At present,NETSCAN location requires at least 2 charged particles from the 1ry vertex. So some events would be lost because of this requirement.

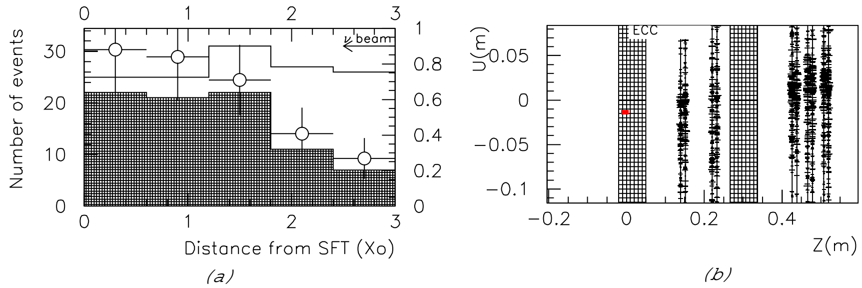

Figure 4: *(a) Dependence of the vertex location efficiency on the amount of materials between the vertex and the SFT. White and black histograms show the number of tried and found events,respectively. And the dots shows the efficiency of the vertex location calculated from them. It is clear that the location efficiency becomes worse when the material increases. This indicates that for upstream events the accuracy of the prediction become worse. (b) Example which was failed to locate the vertex in the ECC.*

3 Momentum measurement by Multiple Coulomb Scattering

The position resolution of $0.3\mu m$ by NETSCAN allows the momentum measurement of the tracks by detecting the position displacement caused by Multiple Coulomb Scattering(MCS). 942 tracks generated from 269 neutrino interactions were tried to measure the momentum. For this ananlysis ,all of the tracks generated from the located vertex were followed. The tracks were followed about 0.5 radiation length . Fig.5 shows the result of this momentum measurement. The error of the momentum measurement is estimated to be $\Delta(1/P)/(1/P) \simeq 35\%$ up to 20 GeV/c. We have compared the results with a result from a MC in order to confirm this method. PYTHIA 5.7 was used for event generation and momentum of the tracks were smeared by the measurement error. The data is consistent with the MC up to 20 GeV/c.(Fig.5)

4 ν_τ^{cc} event search

New set of scanning data was taken around the interaction point again to detect τ decay with larger scanning volume. The scanning volume is defined as 2.6x2.6 mm^2 (transverse) and 10mm(longitudinal). About 90% of τ will decay in this volume.

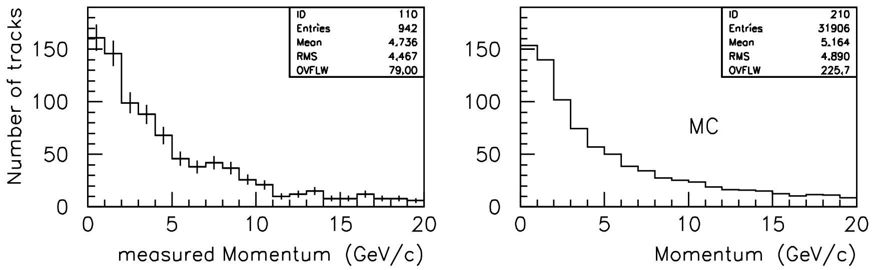

Figure 5: *Measured momentum distribution of tracks from primary vertex.Left is the data measured by MSC.Right is the MonteCalro result. The DATA is in good agreement with MC expectation.*

The mean flight length of the τ is 2$\sim$3mm in DONUT, so about 75% of τ track can be measured in the emulsion layer. In this case ,kink angle and kink position can be measured strictly. Remained 25% of the events,the τ track cannot be recognized in the emulsion layer. In this case ,ν_τ events can be recognized by detecting the non-zero impact parameter of daughter track to the primary vertex. The former analysis is called long flight decay search,and the latter is short flight decay search.

4.1 Long flight decay search

The τ decay search have been applied to 337 located events. Requirements for τ candidates are shown in Table.1.

From kink decay search ,35 candidates were selected in 337 events,and Fig.6 shows the Pt distribution of them. And from trident topology ,2 candidates were detected. After this selection , if there is no lepton from primary vertex,that event is identified as ν_τ^{cc} interaction. Table.2 and table.3 show the decay information of 6 kink topology candidates and 2 trident candidates ,respectively. About these candidates ,existence of a lepton from the primary vertex have been checked. In one candidate ,μ from primary vertex were confirmed by the downstream μ detector, and another candidate has an electron from the primary vertex which were confirmed in the ECC, therefore these two events were identified as charm production in the ν_μ^{cc} and the ν_e^{cc} interactions,respectively. As a result,6 τ candidates have been detected.

Table 1: *Selection for long flight decay search. In this table, θ_{kink} is the angle difference between the parent track and the daughter tracks. Pt is defined as $P \cdot sin\theta_{kink}$ where P is the daughter momentum.*

Kink topology	Trident
Kink angle $\theta_{kink} \geq 5mrad$	Kink angle $\theta_{kink} \geq 5mrad$
Daughter IP to primary vertex $\leq 500\mu$m	Daughter IP to 1ry $\leq 500\mu$m
Daughter momentum $\geq 1GeV/c$	Daughter momentum $\geq 1GeV/c$
$Pt \geq 100MeV/c$ if daughter's hadron	
$Pt \geq 250MeV/c$ if daughter's lepton	

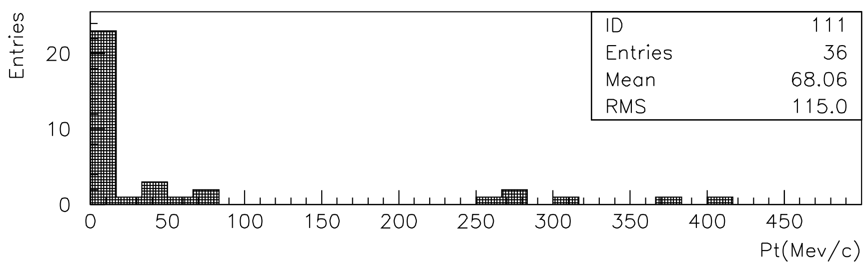

Figure 6: *Pt distribution*

If the lepton ID from primary vertex is failed, the ν_μ^{cc} or the ν_e^{cc} with the charm production or hadronic interaction becomes the background for ν_τ^{cc} candidate. The efficiency of μ-ID is 80% and the efficiency of e-ID is 70%. So the probability of missing the primary lepton is 25% on average. The background from charm produced events is estimated to be 0.32 events for kink topology,and be 0.47 for trident topology. The background from hadronic interactions is estimated to be 0.23 events in total.

4.2 Short flight decay search

For the short flight decay search,all combinations of the event-related tracks were examined whether they have a meaningful non-zero impact parameter or not. If significant impact parameter was observed ,momentum of the related tracks were measured by MCS ,and Pt_{min} was evaluated . Pt_{min} is calculated by assuming that the decay point is located at the most downstream position of the iron plate where the primary interaction occures. If $Pt_{min} \geq 0.08GeV/c$

Table 2: *Event list(kink) selected by long flight decay search.*

Run/event	θ_{kink} (mrad)	$Pt(MeV/c)$	Lepton from 1ry	Daughter of τ	ID
3024/30175	93	265^{+135}_{-69}	No	electron	ν_τ^{cc}
3039/01910	90	414^{+144}_{-81}	No	hadron	ν_τ^{cc}
3263/25102	127	246^{+285}_{-90}	No		ν_τ^{cc}
3333/17665	13	278^{+187}_{-83}	No	electron	ν_τ^{cc}
3065/03238	250	276^{+102}_{-59}	electron		ν_e^{cc}
3073/22977	89	319^{+349}_{-114}	μ		ν_μ^{cc}

Table 3: *Event list(trident) selected by long flight decay search.*

Run/event	θ_{kink} (mrad)	Daughter's P (GeV/c)	Invariant mass	Lepton from 1ry	ID
3334/19920	93	$7.8^{+3.6}_{-1.9}$ $3.3^{+1.2}_{-0.7}$ $18.9^{+20.7}_{-6.8}$	$\geq 550MeV$	No	ν_τ^{cc}
3296/18816	90	$2.3^{+1.3}_{-0.6}$ $1.3^{+2.1}_{-0.5}$ $0.9^{+1.0}_{-0.3}$	$\geq 560MeV$	No	ν_τ^{cc}

and there is no lepton from the primary vertex,this event was identidied as ν_τ^{cc} candidate. Until now, this analysis has been applied to 203 events out of the 337 located events. [1)] After the requirment of Pt_{min} condition,2 candidates were remained. Table.4 shows some details of these 2candiates . One τ and one charm candidate were detected. The number of background is estimated to be 0.13 from the charm decay 0.09 and from the secondary interaction.

4.3 *Detail on new candidate events*

Here some details of the newly detected ν_τ^{cc} events are shown.[1]

[1]Five tau candidates have already reported in NOW2000. [1)]

Table 4: *event list selected by short flight decay search candidates.*

Run/event	min. θ_{kink}	Daughter's P	Pt_{min}	ID
3356/17099	27mrad	$3.4^{+1.6}_{-0.8}$ GeV/c	0.091 GeV/c	ν_τ
3245/22786	41mrad	$4.8^{+7.9}_{-2.0}$ GeV/c	0.2 GeV/c	ν_μ

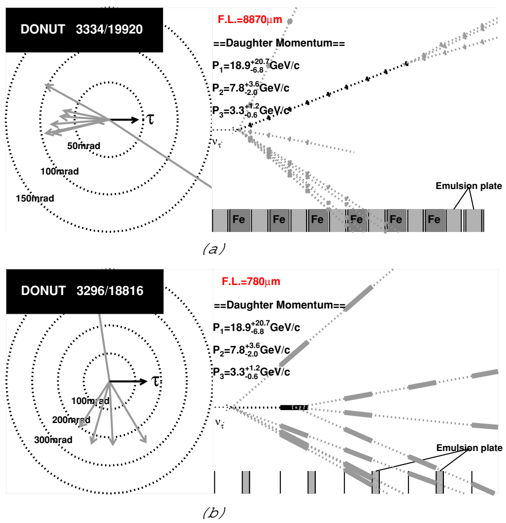

Figure 7: *$\nu_\tau CC$ candidates.Left figure is view from beam direction,Right is side view.*

4.3.1 EVENT 3334-19920

Fig.7-(a) shows the topology of this event. From primary vertex 9 charged tracks are generated. One steep track, which goes to the opposite side against the other particles ,decayed into three charged particles in the plastic base. The flight length is measured to be 8870 μm. The momentum of the daughters are measured to be 7.8GeV/c,3.3GeV/c and 18.9GeV/c,respectively, by MCS method. By this information,the invariant mass of the parent track is estimated to be more than 0.55GeV/c. From EM calorimeter information ,the total energy of this event was estimated to be 53GeV/c. So,about half of the energy of this event was carried by these daughters.

Table 5: *Summary for the decay search.*

Decay analysis	Number of analyzed events	Number of τ	Estimated BG from Charm	Estimated BG from 2ry int.
Long flight	337	6	0.79	0.23
Short flight	203	1	0.13	0.09

4.3.2 EVENT 3296-18816

The event topology of this event is shown in Fig.7-(b). This event has also trident decay topology. Six charged tracks were generated from the 1ry vertex. And after the short flight path of 780 μm,it decayed into 3 charged tracks. The decay vertex was observed in the emulsion. The measured momentum of three daughters are measured to be 2.3GeV/c,1.3GeV/c and 0.89Gev/c,respectively. The invariant mass was estimated to be more than 0.56 MeV/c. Among the remained 5 charged tracks from the primary vertex,no μ was identified. One track of these five are out of acceptance of the μ detector. So,the probability of the charm particle is not zero for this event. This probability of the failure of 1ry lepton is considered into the background estimation.

5 Conclusion

As a summary,since the publication in ICHEP2000 [3],two new τ candidates were found. From long flight decay search,6 τ decay candidates were detected in a set of 337 located neutrino interactions. From short flight decay search,one candidate was detected in a set of 203 located neutrino interactions. The expected number of τ events among our sample are 6.1 and 0.8 for the long and the short flight decay search ,respectively. On the other hand,the background were estimated to be 1.02 and 0.22 ,respectively.(Table.5)

About 800 triggered ν interactions were stored in DONUT ECC targets. Until now only 337 events of them were located . As discussed in section 2,one reason of this discrepancy is in the small scaninng volume respect to the vertex prediction accuracy especially for the events occured at the upstream of the ECC target. These upstream events will be tried to locate again,after constructing S-UTS which speed of data acquisition becomes 20 times faster than the current UTS.

6 References

References

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