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SEARCH FOR TAU-NEUTRINO INTERACTIONS IN THE
BEBC BEAM DUMP EXPERIMENT

BEBC WA66 Collaboration

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ABSTRACT

A novel and efficient kinematic method is used to estimate the number of ν_τ charged current interactions with $E_\nu > 20$ GeV in the BEBC beam dump experiment. The result, -14 ± 12 ν_τ events, is consistent with zero. The ratio of D_s to D meson production in 400 GeV proton interactions in copper is estimated to be below 0.65 at 90% c.l. The oscillation probability $P(\nu_e \rightarrow \nu_\tau)$ averaged over the electron-(anti)neutrino spectrum is found to be below 18%. The hypothesis that ν_e and ν_τ are identical is excluded by about 6 standard deviations. A remarkable event is described: it contains a muon, a high p_T photon and a high p_T hadron.

1. INTRODUCTION

The nature of the lepton spectrum constitutes an old and still outstanding puzzle in elementary particle physics. Following the discovery of the third charged lepton τ of mass 1.78 GeV, there are strong experimental and theoretical reasons for supposing that there exists an associated neutrino, ν_τ .

At present however, there is no experimental evidence for the interactions of tau neutrinos. On the contrary, upper limits have been set on the production of tau neutrinos and on oscillations of muon and electron neutrinos into tau neutrinos based on the absence of tau-neutrino interactions in conventional neutrino beams^[1] and in beam dump experiments^[2-8].

The expected source of tau neutrinos in beam dump experiments is the decay of D_s mesons (previously called F) produced by interactions in the dump, for example

$$p + Cu \rightarrow D_s + \bar{D}_s + X \quad (1.1)$$

followed by the decays

$$D_s \rightarrow \tau + \nu_\tau \text{ and } \tau \rightarrow \nu_\tau + X. \quad (1.2)$$

The decay mode $D_s \rightarrow \tau \nu_\tau$ has not yet been observed but its rate can be predicted from the π -decay rate. Assuming zero mass for the ν_τ ,

$$\begin{aligned} \Gamma(D_s \rightarrow \tau \nu) / \Gamma(\pi \rightarrow \mu \nu) &= (f_{D_s} / f_\pi)^2 (m_\tau / m_\mu)^2 (m_{D_s} / m_\pi) \\ &\times \left((1 - (m_\tau / m_{D_s})^2) / (1 - (m_\mu / m_\pi)^2) \right)^2 \end{aligned} \quad (1.3)$$

Taking $m_{D_s} = 1971 \text{ MeV}^{[9a]}$, $m_\tau = 1784.2 \text{ MeV}^{[9a]}$, $\tau_{D_s} = (3.5^{+0.6}_{-0.5}) \times 10^{-13} \text{ s}^{[9b]}$ and assuming $(f_{D_s}/f_\pi)^2 = 4^{[10]}$ and using

$$\text{BR}(D_s \rightarrow \tau \nu)/\text{BR}(\pi \rightarrow \mu \nu) = (\tau_{D_s}/\tau_\pi) \Gamma(D_s \rightarrow \tau \nu)/\Gamma(\pi \rightarrow \mu \nu) \quad (1.4)$$

we obtain:

$$\text{BR}(D_s \rightarrow \tau \nu_\tau) = (3.9 \pm 0.7)\% \quad (1.5)$$

Given the small production cross-section expected for D_s mesons and this small $D_s \rightarrow \tau \nu_\tau$ branching ratio, the number of tau-neutrino events expected in a detector is very small. Sensitive detection techniques are therefore required to separate any ν_τ interactions from interactions of other neutrinos.

The ν_τ Charged Current (CC) reaction

$$\nu_\tau + N \rightarrow \tau + X \quad (1.6)$$

yields a charged τ lepton. This decays within a few millimetres of the primary vertex, its decay length being 0.06 mm/GeV for a lifetime of $3.5 \times 10^{-13} \text{ secs}$. About 35% of τ decays are purely leptonic and about 65% are semileptonic. The semileptonic modes contribute more events in a smaller background. These events have the appearance of Neutral Current (NC) events (i.e. they contain no identified μ or e).

In this paper, a novel and efficient kinematical method is used to determine the number of ν_τ CC interactions with semileptonic τ decays in a full sample

of NC candidates. This contains genuine NC events, unidentified CC events and neutral hadron interactions (e.g. interactions of incoming K_L^0 mesons or neutrons).

2. EXPERIMENTAL DETAILS

The data used in this analysis come from the beam dump experiment carried out at CERN in 1982 using the Big European Bubble Chamber (BEBC). Full details of the experimental conditions, event selection and analysis methods have been given elsewhere^[8]. The 400 GeV protons from the CERN SPS were extracted in a single turn (23 μ s) and dumped into a thick copper target (the beam dump) located 405.9 m from the centre of BEBC. Secondaries from the proton interactions were rapidly reabsorbed in the copper (attenuation length ~ 20 cm). Thus the flux of conventional neutrinos from the decays of long lived particles (π , K, Λ) was reduced by a factor of more than 10^3 relative to wide band neutrino beams. However, the decay length of particles with lifetime less than 10^{-11} s was generally less than their interaction length in the dump. Most of these therefore had time to decay, giving rise to the so-called prompt neutrinos. The source of the prompt neutrinos is assumed to be hadroproduction and decay of D or D_s mesons, Λ_c and other possible heavy particles.

Data were taken with a 'full density' beam dump, an ordinary copper block, and with a 'one-third density' dump in which air gaps were machined to reduce its average density to one-third that of copper. The flux of conventional neutrinos was about three times larger when the one-third density dump was used. The flux of prompt neutrinos was unchanged. So the signal to noise ratio was three times worse. Therefore only the data taken with the full

density dump are used in this analysis. After selection for good proton beam conditions, these corresponded to 1.91×10^{18} protons on target.

The neutrino interactions in the BEBC liquid (a neon-hydrogen mixture of 74 mole-% neon with a mean density of 0.69 g/cm^3 and radiation length of 43 cm) were photographed using four standard cameras (spatial resolution $\sim 600 \text{ }\mu\text{m}$) and one 'high resolution' camera (spatial resolution $\sim 200 \text{ }\mu\text{m}$). A fiducial volume of 16.6 m^3 was used. This corresponded to a target mass of 11.5 tonnes and subtended a solid angle of $46 \text{ }\mu\text{sr}$ as seen from the dump. About 10% of the observed events were within the reduced volume seen by the high resolution camera and could therefore be examined for tau decays or kinks very close to the event vertex.

An event was classified as a CC muon event if it contained a muon of more than 3 GeV/c momentum identified by two planes of the external muon identifier (EMI) in conjunction with the internal picket fence (IPF)^[11]. An event was classified as a CC electron event if any of the tracks from the event vertex was identified as an unpaired electron with two or more identifiers and with momentum above 0.8 GeV/c . If both an acceptable muon and an acceptable electron were present, the one with the larger transverse momentum relative to the beam determined the classification. If neither was present, the event was classified as an NC candidate. In all events the observed hadron energy was scaled up by a factor of 1.2 to account for missing neutrals. Only events with corrected total energies above 20 GeV were used in this analysis. These consisted of 364 CC muon events, 119 CC electron events and 141 NC candidates. These selections and their efficiencies are discussed further in ref. [8].

3. SEARCH FOR TAU NEUTRINO INTERACTIONS

3.1 ANALYSIS PROCEDURE

A tau-neutrino CC interaction resulting in a semileptonic tau decay will have no muon or electron. Thus it will be classified as a NC candidate. The analysis uses kinematic selection criteria and a maximum likelihood fit to separate such events from the other NC candidates. The latter comprise genuine NC events, unidentified CC events and neutral hadron interactions. The procedure uses the fact that hadrons from tau decay usually have large transverse momenta relative to the normal hadron (quark) jet.

In detail, the full procedure was the following:

1. The NC candidates were required to have a corrected hadron energy E_H above 20 GeV; this cut removes nearly all of the neutral hadron interactions.
2. For each retained event a final state hadron momentum vector $\vec{P}_H$ was constructed by summing the momentum vectors of the observed particles. Poorly measured particles, namely interacting neutral hadrons and charged hadrons interacting within 10 cm of the event vertex or having a fractional momentum error larger than 30%, were excluded from this sum. Leptons in unidentified CC events may simulate hadrons from tau decay by virtue of their large transverse momenta. Therefore the leaving track (if any) with the largest transverse momentum with respect to $\vec{P}_H$ was also excluded from the

sum; in addition, any photon collinear with this leaving track within ± 30 mr in dip and ± 100 mr in azimuth was also excluded (to remove photons due to inner or outer bremsstrahlung from unidentified leptons).

3. Of the remaining charged particles (now presumably all hadrons), the one with the largest momentum component P_1^t transverse to $\vec{P}_H$ was selected first. Then the one with the largest momentum component P_2^t transverse to $\vec{P}_H - \vec{P}_1$ was selected. Then the photon with the largest momentum component P_3^t transverse to $\vec{P}_H - \vec{P}_1 - \vec{P}_2$ was selected. If the required particle was absent, the corresponding P_i^t value was set to zero. Subtracting the $\vec{P}_1$ from $\vec{P}_H$ was done to avoid correlations between the P_i^t values.
4. The distributions of P_1^t , P_2^t and P_3^t were plotted (data points in Fig 1, see also last row in Table 1). They were then fitted to the sums of the P_i^t distributions expected from tau decay and from background, as explained below.

3.2 SIMULATION OF THE EXPECTED TAU SIGNAL DISTRIBUTIONS

The production and decay of D_s mesons and the resulting ν_τ interactions in BEBC were simulated in the following way. The D_s mesons were assumed to be produced according to:

$$\frac{d^3\sigma}{d^3p} \sim (1-|x|)^n e^{-2p_t} \quad (3.1)$$

where p , x and p_t are the momentum, Feynman x and transverse momentum of the D_s meson respectively and n was taken to be 5.7, similar to D meson

production^[8]. The effect of varying this choice is discussed later.

The decay $D_s \rightarrow \tau \nu_\tau$ followed by $\tau \rightarrow \nu_\tau + X$ yields two neutrinos, one from the D_s decay and one from the τ decay. The decay $D_s \rightarrow \tau \nu_\tau$ is isotropic. The expected angular distributions for $\tau \rightarrow \nu_\tau + X$ for zero ν_τ mass were taken from ref. [12]. The branching ratios for τ decay were taken from ref. [9a]. The calculated energy spectra of the neutrinos reaching BEBC are shown by the full lines in Fig.2; the ν_τ from D_s decay has a much softer spectrum (mean energy 13 GeV) than the ν_τ from τ decay (mean energy 45 GeV). As a result, most tau-neutrinos interacting in BEBC would come from τ decays.

The measured CC muon events were used in order to simulate ν_τ interactions in BEBC in detail:

- (a) In each event the muon was replaced by a tau of the same momentum and its semileptonic decays were simulated using multi-body phase space with the appropriate angular distributions^[12] and branching ratios^[9]. The simulation included $\rho^- \rightarrow \pi^- \pi^0$ and $\pi^0 \rightarrow \gamma\gamma$ decays, the interaction probabilities of the charged hadrons from tau decay, the detection efficiency for photons, and the hadron and photon momentum resolutions.
- (b) Weights were applied to correct the ν_μ spectrum to the ν_τ spectrum and to allow for the μ - τ mass difference assuming equal fluxes of ν_τ and $\bar{\nu}_\tau$ [13].

The distributions of P_1^t , P_2^t and P_3^t obtained by applying the procedure defined in Section 3.1 to these simulated ν_τ events are shown, normal-

ised to the data, in Fig 1 (full histograms). Table 1 lists their mean values for each decay mode separately, together with the corresponding weight based on present knowledge of branching ratios^[9].

3.3 SIMULATION OF THE EXPECTED BACKGROUND DISTRIBUTIONS

Backgrounds to the tau decay events arise from genuine NC events and from unidentified CC events. The NC background was simulated by ignoring the muon in CC muon events, together with any good inner bremsstrahlung candidates, i.e. any photons collinear with the muon within ± 30 mr in both dip and azimuth. The CC background was simulated by treating the muon as unidentified. In order to simulate the two backgrounds in the right proportion, appropriate weights were assigned to each sample. These weights were calculated from the number of unidentified CC events, estimated from the muon and electron identification inefficiencies, and from the corresponding number of genuine NC events.

Table 1 shows the mean values of P_1^t , P_2^t and P_3^t for the simulated NC and CC backgrounds separately. They are similar and are considerably lower than the mean values for tau decay events.

The $P_{1,2,3}^t$ distributions of the simulated NC and CC background events were very similar because the unidentified muon was indeed usually excluded from the initially constructed $\vec{P}_H$. Consequently the results given below are insensitive to the assigned weights. Similarly it was found to be unnecessary to simulate separately the unidentified CC events with leptons below the momentum cuts. The contribution of the neutral hadron interactions to the observed sample of NC candidates is very

small (3 ± 2 events)^[14] at hadron energies above 20 GeV. The P_i^t distributions for the background events are shown by the dashed histograms in Fig.1.

3.4 RESULT

To determine the relative proportion of tau decay events and background events in the observed NC sample, the distributions of P_1^t , P_2^t and P_3^t for the observed NC sample (the data points in Fig. 1) were fitted as sums of the corresponding tau decay distributions (full lines) and background distributions (dashed lines) using the maximum likelihood method. Because of the limited statistics in the background distributions, only one bin was used for $P_1^t > 1$ GeV/c, one for $P_2^t > 0.8$ GeV/c and one for $P_3^t > 0.6$ GeV/c.

The fraction of the observed NC sample that is due to tau neutrino CC events with subsequent semileptonic decay of the tau was thus estimated to be

$$\alpha = (-5.9 \pm 4.9)\% \quad (3.2)$$

The α values obtained from the P_1^t , P_2^t and P_3^t distributions separately were $(-6.2 \pm 6.4)\%$, $(-2.9 \pm 12.4)\%$ and $(-7.7 \pm 9.9)\%$ respectively.

There being 141 events in this NC sample, Eq. (3.2) corresponds to -8 ± 7 such events. Including (a) charged current ν_τ events lost below the 20 GeV cut because of the energy carried away by the ν_τ from the secondary τ decay and (b) charged current ν_τ events with purely leptonic

τ decay, this corresponds to a total of

$$N_{\tau}^{CC} = -14 \pm 12 < 17 \text{ at } 90\% \text{ c.l.} \quad (3.3)$$

charged current ν_{τ} interactions with $E_{\nu} > 20 \text{ GeV}$.

The error quoted includes the statistical errors of the simulations due to the finite number of CC muon events available. The upper limit quoted takes into account that α and N_{τ}^{CC} cannot have been negative, the 90% c.l. upper limit C_{90} on α being defined from

$$\int_0^{C_{90}} L(\alpha) d\alpha = 0.90 \int_0^1 L(\alpha) d\alpha \quad (3.4)$$

where $L(\alpha)$ is the likelihood function that was maximised. The result is insensitive to the n value assumed in the production formula for D_s mesons (Eq. 3.1); for example, changing n from 5.7 to 3.7 (see dashed curves in Fig.2) changed α only to $(-5.4 \pm 4.5)\%$.

The events giving at least one high value of P_i^t are the most likely ν_{τ} candidates. All their photographs were therefore carefully re-examined. None showed evidence of the presence of separate tau production and tau decay vertices.

3.5 COMPARISON WITH OTHER METHODS

No clear τ track connecting distinct production and decay vertices was seen among the 10% of events visible with the high resolution camera. This would give an upper limit of 23 CC ν_{τ} events (90% c.l.) if the

detection efficiency for τ decays were 100%. In reality, for 200 μm resolution and a lifetime of 3×10^{-13} secs, the efficiency is below 10% and the upper limit is in excess of 230 events.

The kinematic method of Ballagh et al^[1] looks for $\tau \rightarrow 3\pi^{\pm} + X$ semileptonic decays, amounting to 13.4% of all τ decays (Table 1), with an efficiency of 31% in their experiment falling to 28% in ours because of the softer ν_{τ} spectrum. Seeing no candidate would therefore have given an upper limit of 60 events: in fact there was 1 candidate, giving an upper limit of 100 events at 90% c.l.

The method of Poppe^[15] uses the scaling variable $\xi = p_T^2/p_L$, where p_T and p_L are the total transverse and longitudinal momenta of the observed hadron system. To apply it to our NC event sample, the ξ distributions expected for the tau signal and the background were simulated as above (Sections 3.2, 3.3); a maximum likelihood fit was then used to resolve the ξ distribution of the NC sample into these two components. The result was

$$\alpha = (26 \pm 21)\% \quad (3.5)$$

Correcting as for Eq (3.3), this corresponds to

$$N_{\tau}^{\text{CC}} = 63 \pm 52 \quad (3.6)$$

Since most ν_{τ} interactions appear as NC candidates, the apparent NC/CC ratio, after correcting for unidentified CC electron and CC muon events and neutral hadron interactions, measures the ν_{τ} rate if the true NC/CC

ratio is assumed to be the same for electron and muon neutrinos. This is the basis of the method used previously by this collaboration^[5,8]. For hadron shower energies E_H above 20 GeV, the apparent NC/CC ratio was measured to be $0.340 \pm 0.049 \pm 0.040$ ^[8,14]. The true NC/CC ratio expected for the mixture of ν and $\bar{\nu}$ CC events in these data is 0.348 ± 0.019 ^[16]. The excess, -0.008 ± 0.066 , corresponds to -2 ± 20 ν_τ interactions in the present NC candidate sample. Correcting again for (a) semileptonic CC ν_τ events lost below the 20 GeV E_H cut, (b) CC ν_τ events with purely leptonic τ decay, and (c) genuine ν_τ NC events, if any, this corresponds to

$$N_\tau^{CC} = -3 \pm 28 \quad (3.7)$$

Thus all these methods are less sensitive than our kinematic method. Combining results (3.3), (3.6) and (3.7) would give

$$N_\tau^{CC} = -9 \pm 11 < 17 \text{ at } 90\% \text{ c.l.} \quad (3.8)$$

which is not significantly better than (3.3) alone.

4. DISCUSSION

4.1 ESTIMATE OF THE D_s MESON PRODUCTION CROSS-SECTION

One can estimate the ratio of the D_s to D meson production cross sections from the ratio of ν_τ events to prompt ν_μ and ν_e events. To do this we assume the D_s meson to be the only source of tau neutrinos and the D meson to be the dominant source of prompt ν_e and ν_μ . These data

contain 220 ± 19 prompt ν_e and ν_μ CC events with $E_\nu > 20$ GeV^[8]. Correcting Eq. (3.3) for the kinematic suppression of the charged current ν_τ cross-section due to the large τ mass gives a weighted number

$$N_\tau^{\text{CC}} = -25 \pm 21 < 29 \text{ at } 90\% \text{ c.l.} \quad (4.1)$$

which can be compared directly with the numbers of ν_μ and ν_e events. Less than 13% of the integral energy-weighted prompt neutrino flux above 20 GeV through the detector is therefore due to ν_τ or $\bar{\nu}_\tau$. Assuming (a) a 3.9% branching ratio for $D_s \rightarrow \tau \nu_\tau$ (Eqn 1.5), (b) branching ratios for D into ν_e or ν_μ of 12% each (about equal rate of charged and neutral D mesons), and (c) production of D_s and D mesons according to (3.1) with the same n values, we obtain, after allowing for the softer energy spectrum of the ν_τ ,

$$\sigma(p+N \rightarrow D_s + X) / \sigma(p+N \rightarrow D + X) < 0.65 \text{ at } 90\% \text{ c.l.} \quad (4.2)$$

For a $\bar{D}$ production cross-section of 17 μb per nucleon^[8], for example, this gives a $\bar{D}_s$ production cross-section below 11 μb . These limits would increase (decrease) by about a factor of 1.7(1.4) for each unit of increase in the n value for D_s (D) production in Eq (3.1). They indicate only the degree to which this analysis is sensitive to the signal that might be expected.

4.2 LIMITS ON ν_e , ν_τ IDENTITY AND MIXING

If ν_e and ν_τ were identical, the $\nu_{e\tau}$ would have two CC channels ($\nu \rightarrow e$ and $\nu \rightarrow \tau$) available at full strength apart from kinematic suppression factors

The data used here contain 134 ± 12 ν_e and $\bar{\nu}_e$ CC events above 20 GeV, after all corrections^[8], versus -25 ± 21 weighted CC ν_τ and $\bar{\nu}_\tau$ events (4.1). If the ν_e and ν_τ were identical, these numbers would be equal. Therefore the hypothesis can be excluded by some 6 standard deviations.

From the same numbers we also conclude that the oscillation probability $P(\nu_e \rightarrow \nu_\tau)$ averaged over the electron (anti)neutrino spectrum above 20 GeV amounts to 18% at 90% c.l. This gives the limits

$$\sin^2 2\theta (\Delta^2 \text{ large}) < 0.36 \quad (90\% \text{ c.l.}) \quad (4.2)$$

$$\Delta^2 (\sin^2 2\theta \text{ large}) < 44 \text{ eV}^2 \quad (90\% \text{ c.l.}) \quad (4.3)$$

on the mixing angle θ and mass-squared difference Δ^2 between the ν_e and ν_τ . These limits, however, are less stringent than those already available from ν_e disappearance experiments^[17].

Similar but stronger limits to those deduced in this section have just been published by the E531 collaboration^[18] based on the non-observation of τ^- production in the FNAL wideband neutrino beam.

5. A REMARKABLE CC ν_μ EVENT

This analysis drew our attention to a remarkable CC muon event in our data. Table 2 gives its characteristics; Figure 3 shows the configuration of the tracks in the p_T plane. It contains a photon carrying 36 ± 8 GeV (track 4) whose momentum transverse to the beam direction exceeds 3 GeV/c, is balanced by that of an interacting positive hadron carrying 92 ± 2 GeV (track 3) and is also opposed by the muon (track 2). We have searched for other similar

events in data from other neutrino experiments having much larger statistics in the same energy range^[2,5,16,19], but none were found. We also ran the LUND Monte Carlo program^[20] and found that such a high p_T photon will not be generated by the normal fragmentation process. All rarer processes we considered would be expected to contribute falling p_T distributions of photons which should have been seen in the other experiments. We have been unable to find a convincing interpretation of this event. It is tempting to speculate that such a 'zoo' event is related to some interesting prompt source.

In the above search for ν_τ interactions, this event contributes to the tails of the expected background distributions. In order to estimate its effect on the calculated number of tau events, the analysis was repeated excluding this event from the background samples; the effect was found to be small [α became $-(4.1 \pm 4.8)\%$].

6. CONCLUSIONS

A novel kinematic method has been used to determine the number of ν_τ CC interactions with $E_\nu > 20$ GeV in the data of the BEBC beam dump experiment. The result, -14 ± 12 events, is compatible with zero. It is conservatively interpreted as an upper limit of 17 events at 90% confidence level. Other methods used before give weaker upper limits.

Using this upper limit, the ratio of D_s meson (previously called F meson) to D meson production cross-sections is estimated to be below 0.65 at 90% c.l. The oscillation probability $P(\nu_e \rightarrow \nu_\tau)$ averaged over the electron-(anti)neutrino spectrum is found to be below 18% at 90% c.l. The hypothesis that ν_e and ν_τ are identical is excluded at about the $6\text{-}\sigma$ level.

Details are given of a remarkable CC muon event to which this analysis drew our attention and for which we have no ready interpretation.

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TABLE 1

The Mean P_1^t Values and Weights of the Simulated ν_τ Events,
the Simulated Background Events
and the Observed Event Sample

Event Type	Weight	P_1^t (GeV/c) (first charged particle)	P_2^t (GeV/c) (second charged particle)	P_3^t (GeV/c) (photon)
$\tau^\pm \rightarrow \pi^\pm \nu_\tau$	0.108	0.911	0.393	0.218
$\tau^\pm \rightarrow \rho^\pm \nu_\tau$	0.237	0.798	0.412	0.444
$\tau^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \nu_\tau$	0.110	0.788	0.431	0.534
$\tau^\pm \rightarrow \pi^\pm \pi^0 \pi^0 \pi^0 \nu_\tau$	0.061	0.749	0.421	0.519
$\tau^\pm \rightarrow \pi^\pm \pi^+ \pi^- \nu_\tau$	0.081	1.038	0.647	0.250
$\tau^\pm \rightarrow \pi^\pm \pi^+ \pi^- \pi^0 \nu_\tau$	0.053	0.909	0.566	0.385
all simulated ν_τ events	0.650	0.850	0.459	0.403
simulated NC	0.62 ± 0.03	0.518 ± 0.014	0.343 ± 0.010	0.267 ± 0.013
simulated unidentified CC	0.38 ± 0.03	0.486 ± 0.010	0.304 ± 0.007	0.205 ± 0.007
all simulated background	1.00	0.506 ± 0.011	0.329 ± 0.008	0.244 ± 0.010
observed NC candidates		0.507 ± 0.020	0.325 ± 0.015	0.227 ± 0.016

TABLE 2**Kinematic Variables of the High p_T Photon Event (994/5358)**

$$E_{\text{vis}} = 234 \text{ GeV}, y_{\text{vis}} = 0.95, x_{\text{vis}} = 0.21, Q_{\text{vis}}^2 = 86 \text{ GeV}^2, W_{\text{vis}} = 18 \text{ GeV}$$

Track No	Particle	Momentum (GeV/c)	Dip Angle (mrad)	Azimuthal Angle (mrad)	Momentum PX	Momentum Components PY (MeV/c)	PZ	Identifi- cation
1	ν	>234	43 $\pm$ 2	40 $\pm$ 2		0	0	Beam
2	μ^-	8.33 $\pm$ 0.09	66 $\pm$ 1	6113 $\pm$ 1	8140	-1738	203	EMI
3	I^+	92.1 $\pm$ 2.3	48 $\pm$ 1	8 $\pm$ 1	92080	-2994	422	Interacts
4	γ_1	35.8 $\pm$ 8.2	34 $\pm$ 1	131 $\pm$ 1	35682	3256	-335	Converts
5	I^+	22.01 $\pm$ 0.37	69 $\pm$ 1	23 $\pm$ 1	21998	-381	572	Interacts
6	I^+	11.68 $\pm$ 0.23	22 $\pm$ 1	17 $\pm$ 1	11675	-267	-245	Interacts
7	I^+	7.39 $\pm$ 0.15	87 $\pm$ 1	26 $\pm$ 1	7380	-104	321	Interacts
8	I^+	>29 $\pm$ 3	41 $\pm$ 4	41 $\pm$ 4	29031	17	-83	Interacts
9	I^-	14.84 $\pm$ 0.19	37 $\pm$ 1	33 $\pm$ 1	14841	-111	-92	Interacts
10	I^-	3.79 $\pm$ 0.10	-9 $\pm$ 2	283 $\pm$ 2	3673	910	-194	Interacts
11	I^-	0.101 $\pm$ 0.009	-844 $\pm$ 51	1379 $\pm$ 85	12	65	-76	Interacts
12	I^+	0.474 $\pm$ 0.055	-261 $\pm$ 24	306 $\pm$ 18	436	120	-141	Interacts
13	P	0.305 $\pm$ 0.003	80 $\pm$ 34	4592 $\pm$ 24	-47	-300	26	P Stops
14	γ_2	1.67 $\pm$ 0.22	-45 $\pm$ 1	51 $\pm$ 1	1665	19	-147	Converts
15	γ_3	4.88 $\pm$ 0.89	25 $\pm$ 2	50 $\pm$ 1	4875	48	-91	Converts
16	γ_4	0.055 $\pm$ 0.006	56 $\pm$ 5	39 $\pm$ 2	55	0	1	Converts
17	γ_5	0.113 $\pm$ 0.019	-1 $\pm$ 5	43 $\pm$ 2	113	0	-5	Converts

FIGURE 1 P_i^t distributions for observed NC candidates (data points, see Section 3.1), simulated semileptonic tau decay events (full histograms, see Section 3.2) and simulated background events (dashed histograms, see Section 3.3). The distributions of the simulated event samples are normalised to the data.

FIGURE 2 The energy distributions of neutrinos traversing BEBC from (a) $D_s \rightarrow \tau \nu_\tau$ and (b) $\tau \rightarrow \nu_\tau X$ decay predicted using the assumptions given in Section 3.2.

FIGURE 3 Momentum components transverse to the beam direction of the tracks from the BEBC WA66 high p_T photon event 994/5358. The tracks labelled μ^- , I^+ and γ_1 are tracks 2 - 4 in Table 2.

FIGURE 1

FIGURE 2

FIGURE 3