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SIGNALS FOR TAU NEUTRINO INTERACTIONS IN A BEAM DUMP EXPERIMENT

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ABSTRACT

We propose a test which can be used in beam dump experiments to observe, for the first time, the sequential neutrino ν_τ associated with the τ lepton. The test relies on the ability of new detectors to measure the direction of the hadron spray and hence test for missing transverse momentum and determine certain azimuthal angle correlations.

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The nature of the lepton spectrum constitutes an old and still outstanding puzzle in elementary particle physics. A major step forward in this area has been provided by the recent discovery of a third charged lepton τ^- of mass 1.78 GeV at SPEAR[1,2] and its subsequent confirmation at DORIS[3]. There are strong experimental and theoretical reasons for supposing that there exists a neutrino ν_τ associated with the τ. In this paper we shall accept it as tentatively established that ν_τ is a sequential neutrino (i.e. distinct from ν_e and ν_μ) and shall propose a practical test for its production and interaction in neutrino beam dump experiments to be carried out in the near future by the FNAL-MIT-MSU-NIU (FMMN)[4] and CERN-Hamburg-ITEP-INFN (CHII)[5] collaborations. The basic test is to trigger on an outgoing muon, apply the standard cuts on the muon and hadron energies, and search for substantial missing transverse momentum. A positive signal, we shall argue, would result only from the reaction $\overset{(-)}{\nu}_\tau + N \to \tau^\pm + X$, followed by the leptonic decay $\tau^\pm \to \overset{(-)}{\nu}_\tau \, \mu^\pm \overset{(-)}{\nu}_\mu$. This test makes crucial use of the fact that the detectors for these experiments will have the ability to measure the direction of the hadron spray produced in the above reaction, and hence to determine whether or not there is missing transverse momentum. It should be stressed that from a purely empirical point of view the existence of ν_τ is presently an inference, albeit a strongly supported one. An experiment which performs the test proposed here and finds a positive signal could claim to have observed directly, for the first time, a $\overset{(-)}{\nu}_\tau$. It would thus play a historic role analogous to the classic experiments[6,7] which first observed the interactions of free $\bar{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ when their existence was still an inference from decay data.

Let us first review the evidence for the existence of ν_τ. Most directly, experimental data on τ decay[1,2,3] indicates missing energy and momentum.

In semileptonic τ decay this implies an outgoing neutrino ν_τ associated with the τ; in leptonic decays the same conclusion follows if one uses the principle of lepton family number conservation.* The main theoretical argument for the existence of ν_τ begins with the observation that the Weinberg-Salam[8] (WS) $SU(2)_L \otimes U(1)$ theory of weak and electromagnetic interactions, with the generalized Glashow-Iliopoulos-Maiani[9] (GIM) mechanism incorporated, is at present the most successful model in its confrontation with the experimental data on weak decays and charged and neutral current reactions. In this model the requirement of the absence of tree-level strangeness-changing neutral currents, and its extension via the principle of quark-lepton universality to natural flavor conservation by the neutral current, implies that all fermions of a given charge and chirality must have the same weak T and T_3.[10] For leptons this is also implied by the requirement of natural suppression of μ- and e-number nonconservation, if it exists at all.[11] Hence, given the phenomenological success of the model, with SU(2) doublet assignments for left-handed fermions, the τ must also be placed in a doublet $\begin{pmatrix}\nu_\tau \\ \tau\end{pmatrix}_L$. This is independently required by anomaly cancellation, given the analogous assignment of the T-constituent quark b to a doublet $\begin{pmatrix}t \\ b\end{pmatrix}_L$ (which, of course, presupposes the existence of a t quark). Based on these and other experimental and theoretical grounds,† we shall assume in this paper that ν_τ is a sequential neutrino which couples to τ in the manner specified by the above doublet assignment. We allow for the possibility that there are more than three doublets of leptons and quarks; our test is a specific test for ν_τ and will not confuse it with other new (sequential) neutrinos, even if they exist.

In order to check the feasibility of this test, one needs to have a rough estimate of the flux of $\overset{(-)}{\nu}_\tau$ relative to that of $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ to be expected in a beam dump experiment, since the latter types of neutrinos produce the only significant background reactions. The main source of $\overset{(-)}{\nu}_\tau$ will presumably be the process $p + N \to F^+F^-$, $F^\pm F^{*\mp}$; $F^\pm \to \tau^\pm \overset{(-)}{\nu}_\tau + (\ell^\pm \overset{(-)}{\nu}_\ell$ or hadrons), where $\ell = e$ or μ. The production cross section for F versus D mesons should be in a ratio similar to that of K versus π which, for 400 GeV incident proton energy, is ~ 0.1.[12] The branching ratio $B(F^\pm \to \tau^\pm \overset{(-)}{\nu}_\tau) \sim 0.03$, if one uses $f_F = f_K$ and a nonleptonic enhancement factor determined so as to reproduce the measured quantity[13] $B(D \to e^+ X) \simeq 0.1$. In a beam dump composed of a reasonably high Z material, if one assumes a hadronic charm production cross section[14] of ~ 60 μb, the main source of $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ will be the (semi)leptonic decays of charmed mesons.** In addition to $F^\pm \to \tau^\pm \overset{(-)}{\nu}_\tau$ decay, the other sources of $\overset{(-)}{\nu}_\tau$ are (1) Drell-Yan production of $\tau^+ \tau^-$ followed by their decays, and (2) $D\bar{D}$ production and leptonic decay. We estimate that the flux of $\overset{(-)}{\nu}_\tau$'s from these two sources, taken together, is of order $\sim 10^{-2}$ of the flux from $F\bar{F}$ production and decay. Because of the associated nature of hadronic charm production, the outgoing neutrino fluxes will satisfy $N(\nu_i) \simeq N(\bar{\nu}_i)$, $i = e, \mu, \tau$. Then $N(\overset{(-)}{\nu}_\tau)/N(\overset{(-)}{\nu}_\ell) \simeq \left[\sigma(pN \to F\bar{F}X)/\sigma(pN \to D\bar{D}X)\right] \times \left[2B(F^\pm \to \tau^\pm \overset{(-)}{\nu}_\tau)/B(D^\pm \to e^\pm X)\right] \simeq 0.06$, where $\ell = e$ or μ. This estimate depends only on the ratio of the $F\bar{F}$ to $D\bar{D}$ hadronic production cross sections and not on the actual charm production cross section, given that neutrinos produced by π and K decays in the dump are unimportant. This estimate of the ratio of $\overset{(-)}{\nu}_\tau$ to $\overset{(-)}{\nu}_\ell$ fluxes should be accurate to within factors of a few. The actual ratio would of course vary as a function of neutrino energy and angular position of the detector relative to the direction of the primary proton beam. To determine the shape of the $\overset{(-)}{\nu}_\tau$ flux distribution as a function of energy, and the precise size of the flux, one would have to carry out a complicated and model-dependent Monte Carlo simulation, folding in the geometry of each particular experiment.** Since this is not feasible here we shall simply use the FNAL horn neutrino spectrum as a rough approximation to the expected $\overset{(-)}{\nu}_\tau$ flux. Our results do not depend sensitively on the shape of the assumed $\overset{(-)}{\nu}_\tau$ flux distribution.

The reactions initiated by an incident $\overset{(-)}{\nu}_\tau$ include the neutral current process

$$\overset{(-)}{\nu}_\tau + N \rightarrow \overset{(-)}{\nu}_\tau + X \tag{1}$$

and, given that E is sufficiently large, the charged current processes

$$\overset{(-)}{\nu}_\tau + N \rightarrow \tau^\pm + X \tag{2a}$$

$$\hookrightarrow \begin{cases} \overset{(-)}{\nu}_\tau + \text{hadrons} & \\ \overset{(-)}{\nu}_\tau + e^\pm + \overset{(-)}{\nu}_e & \quad (2b) \\ \overset{(-)}{\nu}_\tau + \mu^\pm + \overset{(-)}{\nu}_\mu & \quad (2c) \end{cases}$$

Reactions (1), (2a), and in a conventional detector which cannot distinguish electrons from hadrons, also reaction (2b), would appear to be neutral current processes. Since reactions (1) and (2a) are thus indistinguishable from $\overset{(-)}{\nu}_e$ - and $\overset{(-)}{\nu}_\mu$- induced neutral current reactions, we shall focus our attention on the charged current processes. Furthermore, even in experiments (such as those of the FMMN and CHII groups) which can often separate electrons from hadrons, the scattering angle and energy of the scattered lepton can be measured more accurately for a muon than for an electron. Accordingly, we shall actually restrict our treatment to reaction (2c).

Our test for $\overset{(-)}{\nu}_\tau$ production and interaction in a beam dump experiment is based on the following fundamental property of ν_τ: it couples via the usual charged current to τ, which is short-lived and hence will certainly decay within the detector (indeed, typically within $\sim$ a cm of its production vertex). By requiring an outgoing muon, one selects events due to the reaction $\overset{(-)}{\nu}_\tau$ $N \rightarrow \tau^\pm X$, followed by the leptonic decay $\tau^{\pm} \to \overset{(-)}{\nu}_{\tau}\ \mu^{\pm}\overset{(-)}{\nu}_{\mu}$, so that there are two missing neutrinos. One would expect, and our Monte Carlo calculations verify, that in general these two neutrinos carry off substantial momentum transverse to the (experimentally known) incident $\overset{(-)}{\nu}_{\tau}$ direction, $\hat{n}_b$. The test, then, consists of the following steps: (1) trigger on a single, unaccompanied outgoing muon; (2) apply the standard cuts used in counter neutrino experiments, on E' (the scattered muon energy), E_H (the hadronic energy deposition), and optionally, Θ_{μ} (the muon scattering angle); and (3) from $\hat{n}_b$ and the measured muon and hadron spray momenta $\vec{p}_{\mu}$ and $\vec{p}_H \equiv E_H\hat{p}_H$, test to determine if, within the accuracy of the experiment, (a) $(\vec{p}_{\perp})_{missing} \equiv -\left[(\vec{p}_{\mu}) + (\vec{p}_H)\right]_{\perp}$ (where $\vec{p}_{\perp} \equiv \vec{p} - \vec{p}\cdot\hat{n}_b\hat{n}_b$) is nonzero, i.e. there is missing momentum transverse to the beam direction, and/or (b) $(\vec{p}_T)_{missing} \equiv -\left[(\vec{p}_{\mu})_T + (\vec{p}_H)_T\right]$ is nonzero, where $\vec{p}_T \equiv \vec{p}\cdot\hat{n}_{pp}$, and $\hat{n}_{pp} \equiv (\hat{n}_b \times \hat{p}_{\mu})/|\hat{n}_b \times \hat{p}_{\mu}|$ is the normal to the apparent production plane. In the $\overset{(-)}{\nu}_{\tau}$-induced process (2c) which is selected by the trigger, $(\vec{p}_i)_{missing}$ will of course be equal to $(\vec{p}(\overset{(-)}{\nu}_{\tau}) + \vec{p}(\overset{(-)}{\nu}_{\mu}))_i$, where $i = \perp$ or T. For events in which there is significant missing transverse momentum, two further key diagnostic quantities to analyze are the (independent) azimuthal angles $\Delta\phi_{\mu H} \equiv \sin^{-1}\left[(\hat{p}_{\mu})_{\perp} \times (\hat{p}_H)_{\perp}\right]$ and $\Delta\phi_{mH} \equiv \sin^{-1}\left[(\hat{p}_{\perp})_{missing} \times (\hat{p}_H)_{\perp}\right]$ (where "m" stands for "missing"). For reaction (2c) $\Delta\phi_{mH}$ is the azimuthal angle between $(\vec{p}(\overset{(-)}{\nu}_{\tau})+p(\overset{(-)}{\nu}_{\mu}))_{\perp}$ and $(p_H)_{\perp}$. Until the present time no counter experiment would have been able to perform this test since none was able to measure with reasonable accuracy the direction $\hat{p}_H$ of the hadronic spray. However, the new FMMN[4] and CHII[5] experiments have detectors which do have this capability and hence can carry out our proposed test. Although both experiments are multipurpose, they intend to spend a significant portion of their running time in the beam dump mode. Thus the above test can feasibly be performed in the near future.*†

Let us now describe quantitatively the observable distributions which are associated with this test. Note first that the sign of the outgoing muon determines whether the event was induced by an incident ν_τ or $\bar{\nu}_\tau$. We plot in Fig. 1(a) the distribution of events from reaction (2c) as a function of $|\vec{p}_\perp|_{missing}$, i.e. $dN/d(p_\perp)_{missing}$, and in Fig. 1(b) the $dN/d(p_T)_{missing}$ distribution. The solid and dashed curves in Figs. 1 - 2 represent incident ν_τ and $\bar{\nu}_\tau$, respectively. In the Monte Carlo calculations **we have applied the cuts** $E' > 4$ GeV and $E_H > 5$ GeV. One can observe from the ν_τ curves that the $(p_\perp)_{missing}$ distribution peaks at about 0.75 GeV, but extends all the way out to 5 GeV, while the $(p_T)_{missing}$ distribution peaks at zero and extends outward to about 3 GeV. For incident $\bar{\nu}_\tau$ the $(p_\perp)_{missing}$ and $(p_T)_{missing}$ distributions are shifted to slightly higher values, as a result of the fact that the τ^+ carries a somewhat larger fraction of the incident $\bar{\nu}_\tau$ energy than the τ^- does for an incident ν_τ. Our studies of possible backgrounds (see below) indicate that they do not yield so large values of $(p_i)_{missing}$, where $i = \perp$ or T, as the signal, process (2c), does. Thus, to isolate the $\overset{(-)}{\nu}_\tau$ events from possible backgrounds, one could make either or both of the cuts $(p_\perp)_{missing} > 1$ GeV or $(p_T)_{missing} > 1$ GeV. As can be seen from Ref. 4, for example, the experimental uncertainty in the measurement of $\vec{p}_\mu$ and $\vec{p}_H$ produces a resultant error in $(p_\perp)_{missing}$ which is expected to be small compared to the typical values of this quantity for events generated by incident $\overset{(-)}{\nu}_\tau$.

In Fig. 2 we accordingly impose the previous cuts on E' and E_H, and, in addition, the cut $(p_\perp) > 1$ GeV. The distributions in $x_{vis}=Q^2_{vis}/(2ME_H)$ and $y_{vis} = E_H/E_{vis}$ are shown in Figs. 2(a) and 2(b), respectively. Here $Q^2_{vis} = 4E_{vis}E'\sin^2(\Theta_\mu/2)$, where $E_{vis} = E' + E_H$. It is a general kinematic characteristic of heavy lepton production reactions that x_{vis} tends to be **small** while y_{vis} is large.[15] Quantitatively, x_{vis} is confined to very small values ($\langle x \rangle_{vis} \simeq 0.08$), while y_{vis} is sharply peaked at $y_{vis} \simeq 0.8$ and 0.6 for incident ν_τ and $\bar{\nu}_\tau$, respectively.

Next, Figs. 2(c) and 2(d) show the azimuthal angle distributions $dN/d(\Delta\phi_{\mu H})$ and $dN/d(\Delta\phi_{mH})$. These are both peaked at 180^o, as expected from the requirement of transverse momentum balance among the totality of final state particles. The $\Delta\phi_{\mu H}$ distribution decreases to small values for $\Delta\phi_{\mu H} < 90^o$, while the $\Delta\phi_{mH}$ distribution is very sharply peaked, falling to zero for $\Delta\phi_{mH} \lesssim 120^o$. This difference is a result of the necessity of transverse momentum balance, together with the fact that the $\Delta\phi_{\mu H}$ correlation only involves one outgoing lepton, whereas $\Delta\phi_{mH}$ involves two such leptons. These important characteristics provide the basis for two further cuts which can be used to distinguish genuine $\overset{(-)}{\nu}_\tau$-induced events from possible backgrounds, namely $\Delta\phi_{\mu H} > 90^o$ and $\Delta\phi_{mH} > 120^o$.

In order to conclude that an observed sample of events which satisfy the trigger and cuts on E', E_H, θ_H, $(p_\perp)_{missing}$, $\Delta\phi_{\mu H}$, and $\Delta\phi_{mH}$ is due to incident $\overset{(-)}{\nu}_\tau$, it is necessary to show that no background processes could have produced a significant fraction of these events. The main backgrounds arise from the $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ coming from the beam dump. The first of these is comprised of neutral current reactions in which very slow π's and K's in the leptonic spray decay leptonically (or, for K's, semileptonically). This is a negligible background, since in order to decay in the volume of the detector the π's and K's would have to have energies so low that the resultant muon energies would fail the cut $E' > 5$ GeV, and furthermore, $(p_\perp)_{missing}$ would fail its respective 1 GeV cut. Moreover, since the $\mu^\pm$ and $\overset{(-)}{\nu}_\mu$ will follow the direction $\hat{p}_H$, $\Delta\phi_{\mu H}$ and

$\Delta\phi_{mH}$ will both be small and would fail the special cuts $\Delta\phi_{\mu H} > 90^{o}$ and $\Delta\phi_{mH} > 90^{o}$. Other standard techniques for eliminating this background are the measurement of the longitudinal uniformity of candidate events in the detector and variation of the density of the target material.

A second possible source of background arises from neutral current $\overset{(-)}{\nu}_e$ or $\overset{(-)}{\nu}_\mu$ reactions, accompanied by associated charm production, in which one of the charmed hadrons decays (semi)leptonically, yielding $\mu^{\pm}\overset{(-)}{\nu}_\mu$ + possible hadrons. Again, this process is negligible because, as has been shown experimentally and theoretically, the rate of associated charm production and single semileptonic decay is of order $\gtrsim 10^{-4}$ relative to the corresponding neutral (or charged) current process.[16] We estimate that before special cuts are imposed, the rate for this background, relative to the signal, is $\lesssim 10^{-2}$. Furthermore, the characteristics of these events are distinctively different from those of the signal. Most notably, $\Delta\phi_{\mu H}$ and $\Delta\phi_{mH}$ are peaked toward 0^{o}, as was the case with the first type of background, so that this already small source of background can be further severely reduced by the cuts $\Delta\phi_{\mu H} > 90^{o}$ and $\Delta\phi_{mH} > 120^{o}$. Secondly, E_H should be noticeably larger for reactions involving charm production than for the τ production reaction.

The third and most important background consists of the charged current reactions $\nu_{\ell 1} + (s \text{ or } d) \rightarrow \ell_1^- + c$ and $\bar{\nu}_{\ell 1} + \bar{s} \rightarrow \ell_1^+ + \bar{c}$ followed by $\overset{(-)}{c} \rightarrow \overset{(-)}{s} + \ell_2^{\pm} + \overset{(-)}{\nu}_{\ell 2}$, where (ℓ_1, ℓ_2) = (a) (e, μ) or (b) (μ, e). These reactions will sometimes satisfy the trigger and usual cuts on E', E_H, and Θ_μ, if the muon energy is sufficiently high and the electron shower overlaps, or is obscured by, the hadron spray, in which case the experiments would not be able to tell if the electron were present. This background will produce events which simulate genuine $\overset{(-)}{\nu}_\tau$-induced events at a relative rate $R = \left[N(\overset{(-)}{\nu}_\ell)/N(\overset{(-)}{\nu}_\tau)\right]\left[\{\sigma(\overset{(-)}{\nu}_\ell N \rightarrow \ell^\pm X_c)\, B(X_c \rightarrow \ell^\mp X)\varepsilon_\mu^{(b)}\delta_e\}/ \{\sigma(\overset{(-)}{\nu}_\tau N \rightarrow \tau^\pm X) B(\tau^\pm \rightarrow \overset{(-)}{\nu}_\tau \mu^\pm \overset{(-)}{\nu}_\mu)\varepsilon_\mu^{(\tau)}\}\right]$ where $N(\overset{(-)}{\nu}_\ell)$, X_c, $\varepsilon_\mu^{(\tau)\text{or}(b)}$ and δ_e denote, respectively, the $\overset{(-)}{\nu}_\ell$ flux (where ℓ = e or μ), a charmed hadronic final state, the detection efficiency for the muon from the τ or background, and the probability that the electron will not be detected. Using our estimate for the $\overset{(-)}{\nu}_\ell$ versus $\overset{(-)}{\nu}_\tau$ flux, the measured dimuon to single muon production ratio $\sigma(\overset{(-)}{\nu}_\mu N \rightarrow \mu^\pm \mu^\mp X)/\sigma(\overset{(-)}{\nu}_\mu N \rightarrow \mu^\pm X) \sim 0.5\%$ (which of course includes the factors for the semileptonic charm branching ratio and muon detection efficiency), $\varepsilon_\mu^{(\tau)} \approx 1$, and $\delta_e = 0.1$ and 1 for cases (a) and (b), respectively, we find $R \approx .05$ and 0.5 for these two types of reactions, (a) and (b).[††] This general background can be strongly suppressed by the cut $\Delta\phi_{mH} > 120^\circ$. Furthermore, E_H will be distinctively larger, and, $(p_\perp)_{missing}$ will be substantially smaller,[17] than for genuine $\overset{(-)}{\nu}_\tau$ events, so that the cut $(p_\perp)_{missing} > 1$ GeV will further reduce this background.

Any exclusive charm production channels will contribute only a small fraction of the inclusive cross section which has just been discussed above. For example, we estimate the rate, relative to the signal, for the diffractive process $\overset{(-)}{\nu}_\ell N \rightarrow \mu^\pm F^* X$ (where ℓ = e or μ); $F^* \rightarrow F\gamma$; $F^\pm \rightarrow \tau^\pm \overset{(-)}{\nu}_\tau$; $\tau^\pm \rightarrow \overset{(-)}{\nu}_\tau X$ to be $\lesssim 1\%$. This small rate can be further suppressed by the cut $\Delta\phi_{mH} > 120^\circ$ and, optionally a cut on Q^2_{vis}.

In addition to these conventional backgrounds, it is also necessary to show the candidate $\overset{(-)}{\nu}_\tau$ events could not be due to additional sequential neutrinos ν_i, i = 4, 5.., or to possible effectively stable neutral heavy leptons. It is easy to see that $\nu_{4,...}$ would not confuse our test, since they would have to be produced in conjunction with the corresponding heavy leptons ℓ_i, i = 4, 5... . The production of $\ell_{4,...}$ would be severely suppressed relative to that of τ since they could not arise from decays of charmed hadrons, but rather would have to come from Drell-Yan production or the decays of b-flavored, or heavier hadrons.

Hence, simply for kinematic reasons, the flux of any additional new neutrinos would be tiny compared to that of $\overset{(-)}{\nu}_\tau$. To show that the signal does not arise from possible effectively stable neutral heavy leptons one could use a recently proposed test[18] which relies upon precise timing relative to the RF structure of the proton pulses from the accelerator. The same technique could be used to show that the mass of ν_τ is consistent with zero.

Thus our analysis indicates that the test proposed here can be used, hopefully in the near future, to observe for the first time the (anti)neutrino $\overset{(-)}{\nu}_\tau$ associated with the τ lepton.

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FOOTNOTES

* These conclusions depend on the facts that $\nu_\tau \neq \bar{\nu}_e$ or $\overset{(-)}{\nu}_\mu$ and the strongly supported inference that $\nu_\tau \neq \nu_e$. See the following footnote.

† The following are other grounds for this assumption: (1) $\nu_\tau \neq \overset{(-)}{\nu}_\mu$ since $\overset{(-)}{\nu}_\mu + N \not\to \tau^\pm + X$; (2) τ cannot be a paralepton, i.e. $N(\tau^-) \neq N(e^+)$ or $N(\mu^+)$ (see Ref. 1); hence $\nu_\tau \neq \bar{\nu}_\mu$ or $\bar{\nu}_e$; (3) even in enlarged gauge models it is very difficult to arrange that ν_e, e, and τ are in the same multiplet without contradicting the experimental fact that $B(\tau \to eX)=B(\tau \to \mu X)$. Hence there is good reason to assume that $\nu_\tau \neq \overset{(-)}{\nu}_e$ or $\overset{(-)}{\nu}_\mu$.

** The $\overset{(-)}{\nu}_e$ and $\overset{(-)}{\nu}_\mu$ fluxes from conventional sources and from charm have been analyzed by S. Mori and B. Roe (unpublished). The expected $\overset{(-)}{\nu}_\tau$ flux is being computed by S. Mori.

*† A different kind of test for new neutrinos, based on the apparent neutral to charged current cross section ratio, has been proposed recently in V. Barger and R. Phillips, Phys. Lett. 74B, 393 (1978). Our test has the advantage of featuring specific cuts which can be used, on an event-by-event basis, to isolate the $\overset{(-)}{\nu}_\tau$ signal from the background.

†† We thank J. Friedman and F. Taylor for providing estimates of δ_e in the FMMN experiment.

FIGURE CAPTIONS

Fig. 1. Distributions in (a) $(p_\perp)_{missing}$ and (b) $(p_T)_{missing}$, for the reactions $\overset{(-)}{\nu}_\tau$ $N \to \tau^\pm X$; $\tau^\pm \to \mu^\pm X$. The solid and dashed curves apply for ν_τ and $\bar{\nu}_\tau$ respectively. The units on the vertical scale are arbitrary.

Fig. 2. Distributions in (a) x_{vis}; (b) y_{vis}, (c) $\Delta\phi_{\mu H}$, and (d) $\Delta\phi_{mH}$, for the reactions $\overset{(-)}{\nu}_\tau$ $N \to \tau^\pm X$; $\tau^\pm \to \mu^\pm X$ (solid and dashed curves, respectively); scales of graphs (a)-(d) are marked in arbitrary units.

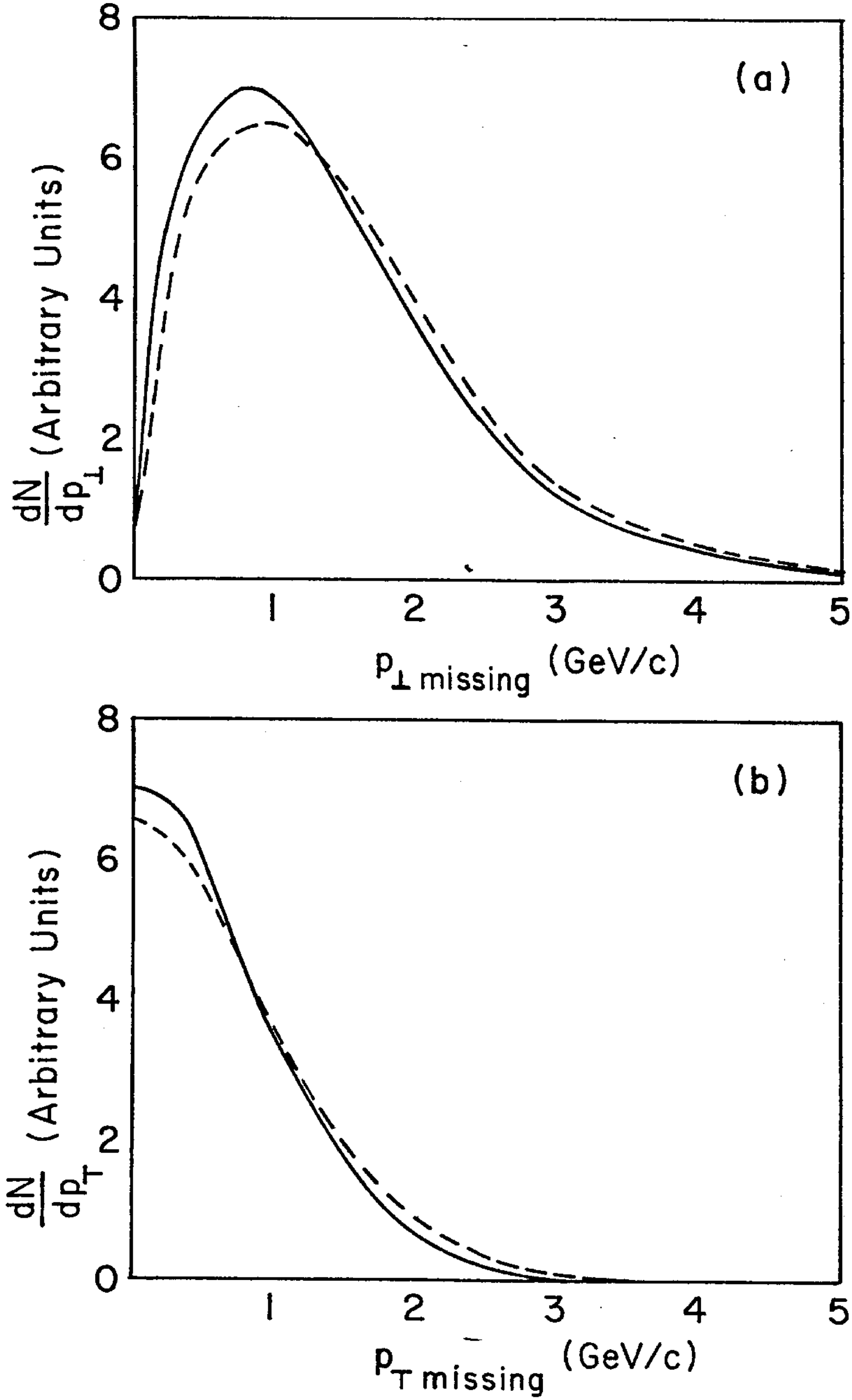
(a)
8
6
4
2
0
1
2
3
4
5
dN/dp⊥ (Arbitrary Units)
p⊥ missing (GeV/c)
(b)
8
6
4
2
0
1
2
3
4
5
dN/dpT (Arbitrary Units)
pT missing (GeV/c)

Fig. 1

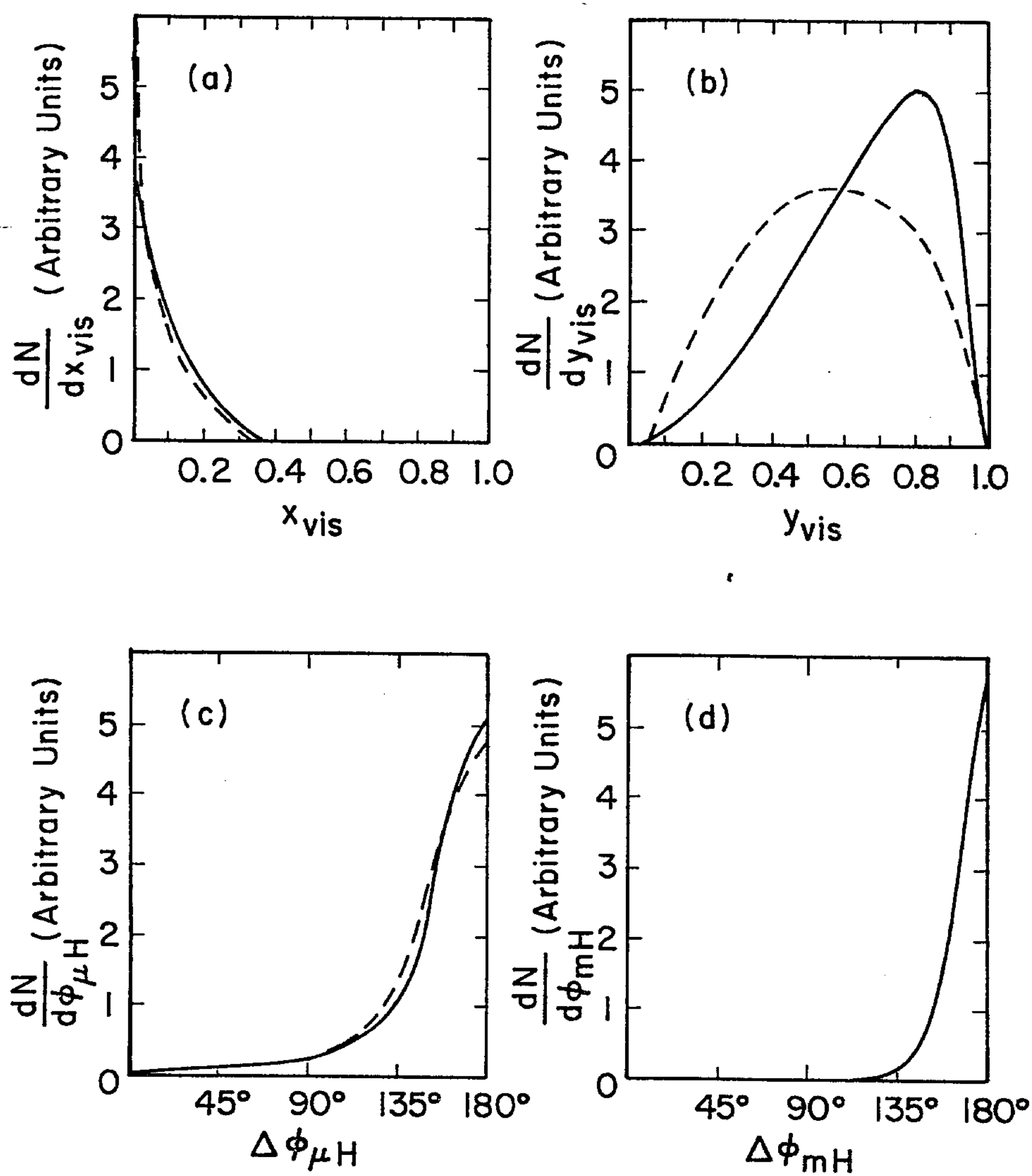
(a)
dN/dx_vis (Arbitrary Units)
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
x_vis
(b)
dN/dy_vis (Arbitrary Units)
0
1
2
3
4
5
0.2
0.4
0.6
0.8
1.0
y_vis
(c)
dN/dφ_μH (Arbitrary Units)
0
1
2
3
4
5
45°
90°
135°
180°
Δφ_μH
(d)
dN/dφ_mH (Arbitrary Units)
0
1
2
3
4
5
45°
90°
135°
180°
Δφ_mH

Fig. 2