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Signature for ν_τ interactions in a high-energy proton-beam-dump experiment

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We propose a method for observing the as yet undetected τ neutrino in a proton-beam-dump experiment at the high-energy accelerators of the next generation (UNK, LHC, SSC). The technique relies on the observation in a fine-grained calorimeter of events with a single charged hadron coming from the quasielastic reaction $\nu_\tau N \rightarrow \tau N'$, with the subsequent decay $\tau \rightarrow \pi\nu_\tau$. Computations showing a favorable signal-to-background ratio are presented for the special case of a hypothetical experiment at UNK.

To date, no experiment has been able to provide direct evidence for interactions induced by the ν_τ. At the high-energy accelerators of the next generation [the Accelerating and Storage Complex at Serpukhov (UNK), the CERN Large Hadron Collider (LHC), the Superconducting Super Collider (SSC) (Ref. 1)] a proton-beam-dump experiment will yield a relatively large amount of ν_τ's, coming from the decay of the charm meson F produced in the dump. The detection of deep-inelastic, charged-current (CC), ν_τ interactions via the direct observation of the τ decay would be the best proof of the existence of the ν_τ. However, such an experiment would need a dedicated detector, combining a large fiducial mass with a very high spatial resolution. Here we discuss the possibility of detecting the ν_τ with a more conventional calorimetric detector, via the observation of the quasielastic process

$$\nu_\tau N \rightarrow \tau N' , \tag{1}$$

with the subsequent decay $\tau \rightarrow \pi\nu_\tau$ (throughout this paper, where not explicitly stated, both charge-conjugate states are also implied). In a fine-grained sampling calorimeter, part of the events produced in reaction (1) will appear as a minimum-ionizing track, at a small angle with respect to the beam direction, producing a hadronic shower after a path of length L_t. This L_t will depend on the interaction length typical of the target material. Events with such a topology can be identified. They will give a valid proof of the existence of the τ neutrino, provided that the background generated by events with the same signature coming from ν_e and ν_μ interactions be small and known with good precision. A direct and precise measurement of the background will be possible by selecting events with the proposed signature in an exposure of the calorimeter to a standard neutrino wide-band beam (WBB) where the ν_τ component is negligible. In the following, we will show that a sizable signal with a small background can be expected in a realistic experiment.

Both signal and background will depend, of course, on the characteristics of the beam and the detector. As an example, we shall compute the expected numbers for the hypothetical case of a proton-beam-dump experiment at the 3-TeV fixed-target accelerator UNK. For the detector, we shall take a calorimeter of the type of the CHARM II detector[2] with ≈ 500 ton of fiducial mass and with a longitudinal sampling thickness of about one-tenth of λ_π, the interaction length for pions.

To evaluate the signal rate we shall refer to the detailed calculations, given elsewhere,[3] of the neutrino fluxes from a proton beam dump at UNK. It has been assumed that the source of τ neutrinos is the charm F meson produced in proton-nucleon interactions, yielding two ν_τ's via the decays $F \rightarrow \nu_\tau \tau$ and $\tau \rightarrow \nu_\tau X$. While the decay properties of the τ lepton are well known,[4] assumptions have to be made for the total (σ_c) and differential charm cross section, for the probability p_F of the c quark to fragment into F, and for the branching fraction of the decay $F \rightarrow \nu_\tau \tau$. In Ref. 3 the following values were adopted: $\sigma_c = 100\ \mu$b per nucleon at $s = 6000$ GeV^2; $p_F = 0.1$; branching ratio $B(F \rightarrow \nu_\tau \tau) = 4\%$. The differential F-meson cross section was parametrized in terms of x_F, the Feynman x variable, and p_t, the transverse momentum, as $(d^2\sigma)/(dx_F dp_t^2) \propto \exp(-ap_t^2)(1-|x_F|)^5$ with $a = 1$ GeV^{-2}. The values adopted are consistent with recent estimates, such as those given by Altarelli *et al.*,[5] Tavernier,[6] and De Rújula and Rückl[7] for the total and differential charm cross section and by Talbezadeh *et al.*[8] for the leptonic branching ratio of the F meson. The main source of uncertainty affecting the event rates is the charm-production cross section. Based on Refs. 5–7, we estimate that the chosen value $\sigma_c = 100\ \mu$b cannot be lowered by more than 40%.

The ν_τ flux from Ref. 3(a), assuming an angular acceptance of 2 mrad, is shown in Fig. 1. The average ν_τ energy is about 240 GeV. Scaling from Ref. 3(a), the number of CC interactions observed in the detector in a run with 2×10^{19} protons will be

$$0.9\times 10^7 \ (\nu_\tau \, \mathrm{CC}) , \tag{2a}$$

$$10\times 10^7 \ (\nu_e \, \mathrm{CC}) , \tag{2b}$$

$$20\times 10^7 \ (\nu_\mu \, \mathrm{CC}) . \tag{2c}$$

A suppression of 0.9 of the ν_τ cross section at an average energy of 240 GeV is taken into account.

We have scaled the number of ν_τ CC events to the number of detectable events of reaction (1) with the procedure described next. First we had to evaluate the cross section

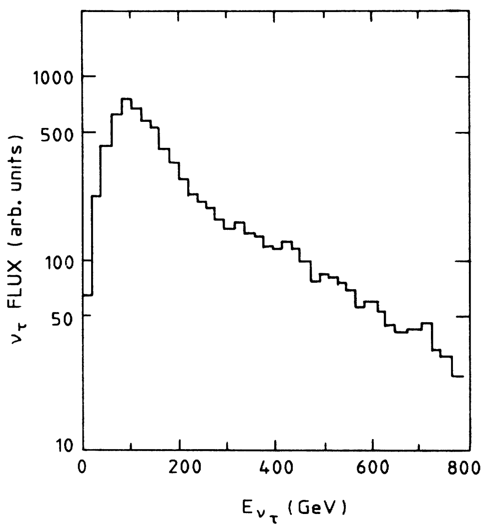

FIG. 1. Expected ν_τ flux from a 3-TeV proton beam dump at UNK [taken from Ref. 3(a)].

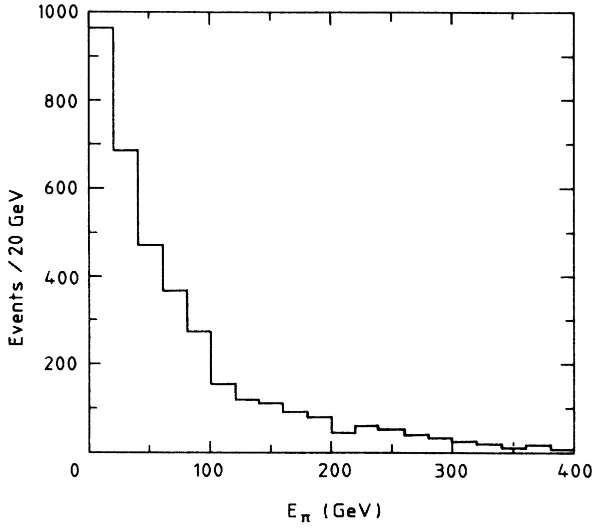

FIG. 2. Energy spectrum of the pion coming from the two-body decay of the τ meson produced in the quasielastic reaction $\nu_t N \rightarrow \tau N'$.

for process (1). The "visible" cross section will depend on the experimental technique used to isolate the events, i.e., on which level of activity around the vertex is tolerated in addition to the minimum-ionizing track emerging from the τ decay. We have assumed a visible cross section per nucleon of $\sigma = 0.5 \times 10^{-38}$ cm^2, energy independent, and equal for ν_τ and $\bar{\nu}_\tau$. This is a rough estimate based on the consideration that, depending on the selection criteria, some of the $\nu_\tau N \rightarrow \tau N'$ events will be lost, while some of the events with N^* or Δ production, together with low-y deep-inelastic events, will be included.

It is important to note that in real life one can measure in a standard neutrino WBB the rate of muon-neutrino-induced events which survive a given set of selections. The efficiency for events induced by the τ neutrino will then be known, assuming equal cross sections for ν_μ- and ν_τ-induced events.

Using the ν_τ energy spectrum shown in Fig. 1, the quoted cross section per nucleon, $\sigma = 0.5 \times 10^{-38}$ cm^2, for reaction (1), and simulating the decay angular distribution of the τ, we obtain for the energy of the π the spectrum shown in Fig. 2. Normalizing to the quoted number of ν_τ CC events (0.9×10^7), we obtain 3100 events with $E_\pi \geq 20$ GeV (the reason for this cut will be explained later). This number takes into account the branching ratio $B(\tau \rightarrow h\nu_\tau(h = \pi, K)) = 0.115$.[1] The $\nu_\tau K$ decay mode has been included since K and π behave essentially in the same way.

Finally, one has to take into account the fact that to isolate reaction (1) it is necessary to observe the hadron as a single track for a certain number of samplings; requiring the shower vertex to lie at a distance of one λ_π or more from the primary vertex (i.e., at least 10 samplings) reduces the signal by a factor $e^{-1} = 0.37$.

To summarize, in our hypothetical experiment one would identify about 1150 events coming from reaction (1). This corresponds to a fraction 1.3×10^{-4} of the CC events induced by the ν_τ.

Turning now to the background, we first recollect the characteristics of the signal which we are looking for: (i) single minimum-ionizing track producing a hadronic shower after a path $L_t \geq \lambda_\pi$; (ii) track length L_t before the shower following a distribution of the form $\exp(-L_t/\lambda_\pi)$; (iii) angle of the track θ_t with respect to the beam direction equal to the angle of the hadronic shower θ_s ($\theta_t = \theta_s$); (iv) low values of the transverse momentum of the hadron ($p_T \leq 1$–2 GeV/c; convolution of the p_T of the quasielastic scattering and the p_T in the τ decay); and (v) absence of outgoing muons.

Two classes of events produced by ν_e and ν_μ interactions can show these characteristics: events with back-scattering and neutral-current (NC) events with the production of a single charged hadron. We have tried to estimate the rate of these two processes. However, we stress that the proof of the existence of the τ neutrino relies on the direct measurement of the background, to be performed by the experiment using a WBB in the same energy domain of the neutrinos coming from the proton-beam dump.

Concerning back-scattering we note that the correct signature can only be produced by events without a primary muon, showing a back-scattered proton with a momentum of the order of 1.5 GeV/c or more; this is because a track length of the order of one λ_π is required. An estimate for the rate of production of protons this fast can be obtained using the existing analysis of data on hadron-nucleus interactions. Following Komarov and Muller,[9] we evaluated a rate of the order of 10^{-4} per event. This rate is further reduced by the requirement $\theta_t = \theta_s$. Assuming an isotropic distribution for the back-scattering angle, the reduction is 5×10^{-4} if the resolution on the shower angle is 25 mrad (as, for example, in Ref. 10 for hadronic showers of 100 GeV). The combined reduction factor is then 5×10^{-8} of the muonless events, leading to a background of about 10 events, i.e., 1% of the signal.

The second source of background is due to NC interactions producing a single charged hadron. Isolated protons or pions of low energy can be produced in elastic and quasielastic NC interactions. For this reason the cut on the energy of the hadron is needed ($E_h \geq 20$ GeV/c).

Data on the production of a single charged hadron of high energy in neutrino NC interactions do not exist. However, the production of a single energetic π^0 in NC interactions and that of a charged pion in CC interactions have been studied both experimentally[11] and theoretically.[12] The latter process is currently interpreted in terms of the interaction of the isovector axial-vector current, whose longitudinal part behaves like a pion which scatters elastically on the nucleus. To compute the cross section for production of a single charged pion in NC interactions we have adopted the same formalism as in Rein and Sehgal[12] and simply replaced the elastic π^0-nucleon cross section with the charge-exchange cross section (σ_{CEX}). We derived σ_{CEX} for π^0's using the compilation[13] of $\pi^{\pm}N$ charge-exchange cross sections. With this method we calculated that the background from single charged-pion production in NC interactions consists of 50 events ($\approx 5\%$ of the signal), once the energy cut and the track-length requirement are applied.

To summarize, our hypothetical experiment at UNK will collect a signal of 1150 events induced by ν_τ interactions. The predicted background is of the order of 60 events. Because of the lack of experimental data, the background estimate is affected by large uncertainties but a precise measurement of it will be possible in the same experiment.

Our conclusion is that the new proposed technique gives a good chance of allowing the detection, with a good signal-to-background ratio, of the τ neutrino in a fairly conventional experiment. The experiment will be able to measure directly both the efficiency for collecting the signal and the level of background. Our quantitative predictions refer to the special case of an experiment at UNK, because of the availability of detailed calculations of the expected ν_τ flux. However, it is clear that most of the considerations are valid for any beam-dump experiment performed in a similar energy domain.

The author has developed the idea presented in this paper while working at the CHARM II experiment. It is therefore a pleasure to thank all the members of the collaboration and in particular A. Rosanov, who contributed useful suggestions.

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[1] Particle Data Group, G. P. Yost *et al.*, Phys. Lett. B **204**, 1 (1988).

[2] K. De Winter *et al.*, Nucl. Instrum. Methods Phys. Res. Sect. A **277**, 83 (1989).

[3] (a) CHARM II Collaboration–IHEP–Berlin–Zeuthen, Letter of Intent submitted to the UNK Committee, 1989, contact person, V. Khovansky, ITEP, Mocow; (b) A. E. Asratyan, Report No. ITEP 3-89, Moscow, Atominform, 1989 (unpublished).

[4] B. C. Barish and R. Stroynowski, Phys. Rep. **157**, 1 (1987).

[5] G. Altarelli *et al.*, Nucl. Phys. B **308**, 724 (1988).

[6] S. P. K. Tavernier, Rep. Prog. Phys. **50**, 1439 (1987).

[7] A. De Rújula and R. Rückl, Report No. ECFA 84/85, CERN 84-10, 1984, p. 573.

[8] M. Talebzadeh *et al.*, Nucl. Phys. **B291**, 503 (1987).

[9] V. I. Komarov and H. Muller, JINR Dubna Report No. E2-12439, 1979 (unpublished).

[10] J. Dorenbosch *et al.*, Nucl. Instrum. Methods A **253**, 203 (1987).

[11] P. Marage *et al.*, Z. Phys. C **31**, 191 (1986); F. Bergsma *et al.*, Phys. Lett. **157B**, 469 (1985).

[12] D. Rein and L. M. Sehgal, Nucl. Phys. B **223**, 29 (1983).

[13] V. Flaminio, W. G. Moorehead, D. R. O. Morrison, and N. Rivoire, CERN-HERA Report No. 83-01, 1983.