1. Conceptual Design

The E-872 experiment was proposed to directly observe the charged current interaction of the tau neutrino, ν_τ. Tau neutrinos are produced predominantly from the leptonic decay of the D_S meson in the decay sequence

$$D_s \rightarrow \tau + \nu_\tau$$
$$\tau \rightarrow \nu_\tau + X.$$

In this experiment D_S mesons are produced by 800 GeV protons interacting in a tungsten beam dump. Both the D_S and the daughter τ decay in the dump, each decay producing one ν_τ (or $\bar{\nu}_\tau$; they are used interchangably in this discussion). The number of ν_τ per incident proton produced in the beam dump through this process is estimated to be 1.68×10^{-4}. [1]

Observation of a ν_τ interaction is made by observing the τ lepton, produced in the charged current interaction $\nu_\tau + N \rightarrow \tau^\pm + X$, and the subsequent decay of the τ in an active target. The τ lepton has a $c\tau$ of 0.087 cm and therefore will decay within a distance of ~5mm ($<\gamma c\tau_\tau>$ ~ 2.5 mm). Eighty-six per cent of the τ decays have only one charged track (a "kink" decay). This implies that a very high spatial resolution on tracks near the vertex is required. Since such capabilities are possible with nuclear emulsion, it was chosen as the neutrino interaction target. Emulsion provides the very high resolution necessary to resolve τ decays and at the same time is of sufficient density to provide enough mass so that there can be a reasonable event rate. The ν_τ interaction candidates are recognized by the topology of the tracks associated with the neutrino interaction vertex. The primary characteristics of the decay which can be measured with an emulsion target are the direction of the tau with respect to the incoming neutrino, the decay length of the tau, the angle(s) between the tau and it's daughter(s), and the momentum of the daughter(s). Monte Carlo distributions characteristic of the τ and its decay are shown in Figure [].

The number of ν_τ charged-current interactions that occur per centimeter of target material is determined by the ν_τ energy and interaction cross section. Because the ν_τ interaction cross section depends on the energy of the ν_τ, the neutrinos from each of the decays ($D_S \rightarrow \tau + \nu_\tau$ and $\tau \rightarrow \nu_\tau$) have different interaction probabilities. For the purposes of estimating expected event rates we have used an effective interaction cross section of 0.42×10^{-37} cm^2.[2] Using the solid angle acceptance of the E872 target was ±7.1 mr, we predict 5.0×10^{-18} ν_τ charged-current interactions per centimeter of emulsion (ρ=3.72g/cm^3) per proton. Taking into account τ sources other than D_S, such as B meson decays, $D^\pm$ decays, Drell-Yan and secondary production from charm, increases the predicted yield by 14% to 5.8×10^{-18} ν_τ charged-current interactions per centimeter of emulsion per proton.

The target configuration described in Section 4 was chosen to optimize the number of interactions while retaining the ability to find and measure the events with high efficiency. An added constraint was the high cost of the nuclear emulsion, ~$300K per 100 kg.

While an emulsion target is "active" in the sense that it records the tracks produced at the interaction vertex, it is passive in the sense that it has no electronic output indicating when an interaction has occurred. Rather, it simply integrates all tracks that are produced in it, or pass through it during the time in which it is exposed to the beam. In order to distinguish interesting interactions from the background, an electronic spectrometer is used to trigger a data acquisition system which records the signals from the particles which emerge from the emulsion targets. The electronic spectrometer, in conjunction with the emulsion target is called a hybrid emulsion spectrometer (HES). As a consequence of cost and schedule constraints as well as opportunity, many of the components used in the E-872 HES were recycled from previous Fermilab experiments. A plan view of the E-872 HES is shown in Figure [].

The major task of the electronic spectrometer is to reconstruct tracks from the neutrino interaction vertex. The location of the primary interaction in the emulsion requires at minimum, a single non-interacting reconstructed spectrometer track projected to a vertex candidate in the emulsion, where an emulsion vertex is defined as one or more tracks *originating* in the emulsion target. The configuration of the electronic spectrometer provides a series of particle tracking devices which optimize acceptance and position resolution. To do this detectors with large acceptance but poor resolution are placed at the downstream end of the spectrometer. Smaller, but high resolution tracking is placed in the upstream section, allowing for precision tracking into the emulsion modules. In addition to the emulsion target modules the major components of the HES are :

- emulsion sheets that are frequently changed out to keep the track density very low for clear event identification. These "changeable sheets" (at 8 locations) were replaced about once every week.
- a 60,000 channel scintillating fiber detector arranged in 44 tracking planes. It has sufficient resolution to point tracks from the wire chambers to special emulsion sheets
- three planes of scintillation counters to provide signals for a trigger
- a large aperture dipole magnet to provide a 225 MeV/c p_T kick for momentum analysis (ROSIE)
- drift chamber tracking upstream and downstream of the analysis magnet
- electromagnetic calorimeter to aid in the identification of electrons and contribute to the measurement of the total energy in the event
- a muon tagging system using range to screen out hadrons and provide identification of muons

The range of tracking resolution for the major components of the electronic spectrometer are shown in Figure [].

Subsequent sections of this paper will describe the configuration and performance of each system in detail.

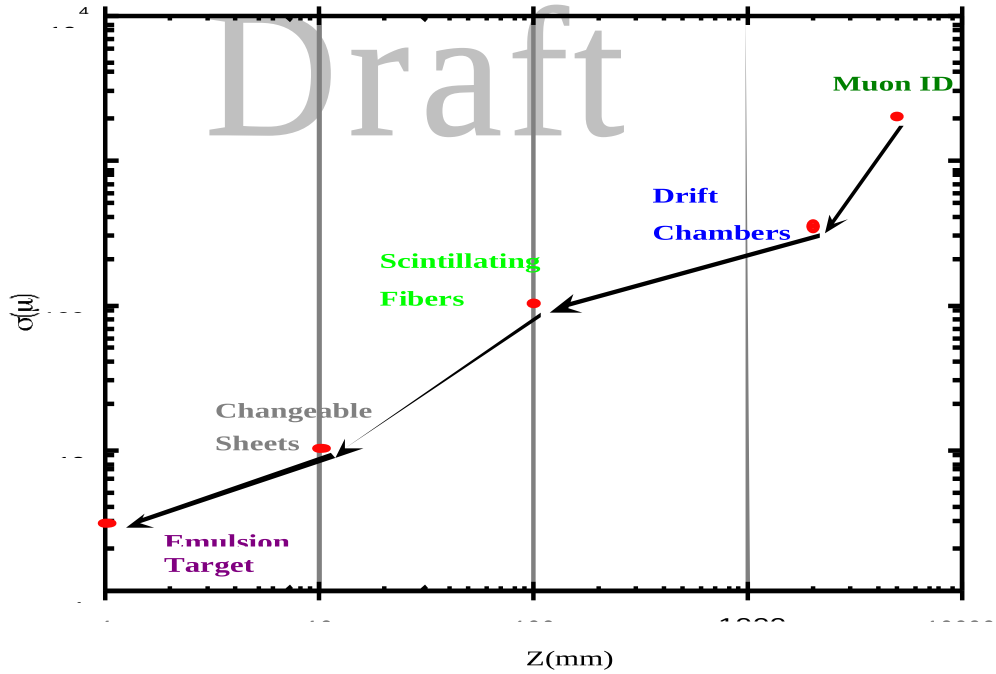

Figure 1. Order of magnitude of tracking resolution for major components of the hybrid emulsion spectrometer.

---

[1]B. Lundberg *et al.*, P872, Measurement of the τ Lepton Production from the Process $\nu_\tau + N \rightarrow \tau$, Proposal for Fermilab E872 (1994)

[2] *Ibid.*