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IMPLICATIONS OF THE CERN BEAM DUMP PROGRAM RELATING TO NEUTRINO OSCILLATIONS

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ABSTRACT

The underlying concept of a beam dump experiment is that the neutrinos which arise from ordinary long lived particles are suppressed relative to those which are produced by short lived parents by interacting the parents in a dense medium before they decay. The arrangement at the CERN Laboratory in Geneva, Switzerland is shown schematically in Figure 1. The "prompt" component of the ν flux is produced by the decay of the new hadrons (charm, top, bottom, etc.). The "non-prompt" component is produced by ordinary long lived pions, kaons and hyperons which decay before interaction despite a large dense absorber.

A serendipitous coincidence resulted in the beam dump/target being located far from the detectors (820 m to 910 m as shown in Figure 1). Thus the (1.27 L/E) figure for the experiment which is the paramount parameter for neutrino oscillation tests is .05-.01. I will use the by-now-familiar notation which relates the probability of a neutrino produced as type 1 and interacting as type 2 to mixing parameter $\sin^2 2\theta$ and the difference in mass-squared Δ.

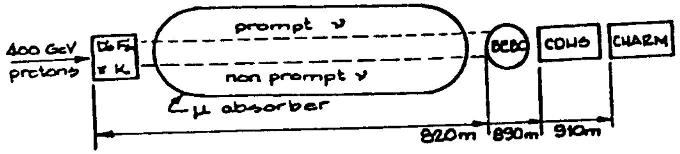

Figure 1) Schematic diagram of the CERN Beam Dump experiment.

$$P(\nu_1 \rightarrow \nu_2) = |\delta_{12} - \sin^2 2\theta \sin^2 (\frac{1.27\Delta L}{E})|$$

where $\Delta = |m_1^2 - m_2^2|$ in eV^2

L = drift distance in m, E = energy of neutrino in MeV

The extraction of the prompt ν flux is done in two ways. The direct experimental procedure is to measure the neutrino flux using dump/targets of differing density. As shown in Figure 2 when extrapolated to infinite density (zero absorption length) the "prompt" ν flux is identified. Alternatively, the "non-prompt" contribution can be calculated using knowledge of π, K production spectra, geometry, etc. The prompt component is the remainder after subtraction of this calculated background flux.

The experiment performed in 1977 and 1979 utilized 0.25 x 10^{18} protons on a 1/3 density copper target and 0.67 x 10^{18} protons on a full density copper target.[1] The three detectors used have been documented elsewhere.[2,3,4] They run the gamut of sensitivity and mass. The CDHS detector is ∿ 470 tons of homogeneous magnetized iron calorimeter. In this detector electron neutrinos cannot be distinguished from neutral weak current interactions. However, because of its large mass it has recorded the largest number of events. The large bubble chamber (BEBC) filled with 14 tons of a Neon-hydrogen mixture had the fewest events albeit with the most detailed information concerning identification of ν_e charged current events, $\bar{\nu}_e$ charged current events, and neutral current events, as well as ν_μ ($\bar{\nu}_\mu$) interactions. The CHARM detector of mass ∿ 100 tons is intermediate both in rate and in ability to identify ν_e interactions.

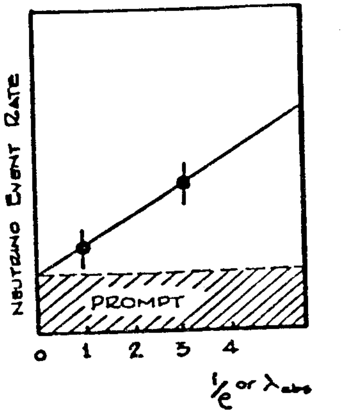

Figure 2) The variation of ν event rate with the target absorption length. The intercept determines the prompt rate.

In the following discussion I assume the available experimental data restrict the possible range of $\nu_\mu \to \nu_e$ oscillations well below levels attainable in the beam dump experiments.[5] The important remaining possibility is a two component oscillation of the ν_e flux. The experimental measurements made are:

- 1 μ consisting of $\nu_\mu(\bar{\nu}_\mu)$ interactions producing $\mu^-(\mu^+)$ in the final state.
- 1 e consisting of $\nu_e(\bar{\nu}_e)$ interactions producing $e^-(e^+)$ in the final state.
- 0 μ consisting of neutral current events (although the 1 e events are included in this category for the counter experiments).

In Figure 3 the 1 μ prompt flux is shown obtained by extrapolation using data from all three experiments.[6,7,8] Although the agreement between experiments is in general good, there is an indication of discord in the measurements of the μ^+ rate at low target density.

The energy distribution of the ν_μ events observed in the CDHS detector from a full density dump is shown in Figure 4. Although a large fraction of the events occur at large L/E (∿.05 to .01) the remainder are at such small values of L/E that they contain negligible information on neutrino oscillations. Figure 5 shows the neutrino energy distribution for the $\nu_e(\bar{\nu}_e)$ observed in the CHARM detector. For electron neutrinos virtually the entire flux has L/E values in the range .05 to .01.

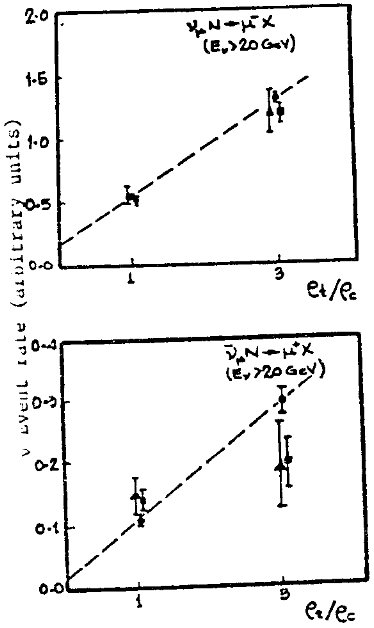

Figure 3) The rate of ν_μ CC events observed in the CDHS detector (ɪ), the CHARM detector (ɪ) and the BEBC detector (ɪ) at two target densities (ρ_t/ρ_c = target density/density of copper) showing the extrapolation to determine the prompt ν_μ flux.

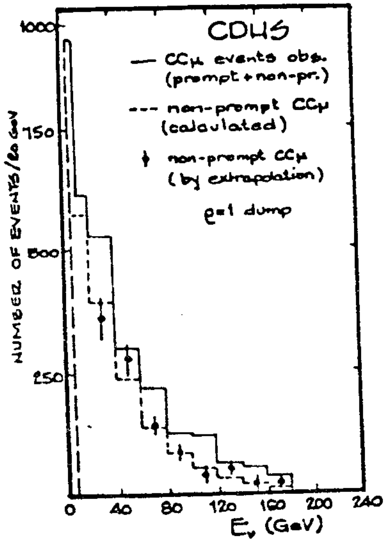

Figure 4) Distribution of the energy of muon neutrino's observed in the CDHS detector.

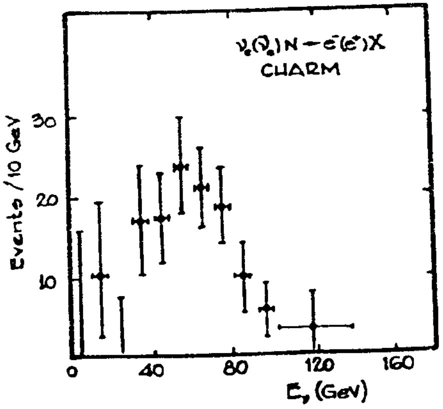

Figure 5) Energy distribution of $\nu_e(\bar{\nu}_e)$ events observed in the CHARM detector.

Consider the possibility that $\nu_e \rightleftarrows \nu_\tau$. This reaction would manifest itself as an anomalous ratio of 1e/1μ events. This ratio can be written as:

$$R(\frac{e}{\mu}) = \frac{\phi(1-P)\sigma_{cc} + 0.17\phi P\sigma^\tau_{cc}}{\sigma_{cc} + 0.17\phi P\sigma^\tau_{cc}}$$

where P = probability of $\nu_e \rightarrow \nu_\tau$

$\phi = \nu_e$ flux/ν_μ flux

The assumption that charmed particles produce the prompt ν_e and ν_μ flux implies $\phi = 1$. Thus the expected value for R if $P = 0$ is 1. A deviation from this value could be interpreted as an indication of neutrino oscillation among a number of possible explanations. In Table I the results of the three detectors are presented.

Table I
Beam Dump Results Concerning the 1e/1μ Ratio

Detector	R by extrapolation	R by subtraction	Energy
CDHS	0.77±0.18±0.24	0.58±0.07±0.19	> 20 GeV
CHARM	0.49±0.21	0.44±0.11±0.10	> 20 GeV
BEBC		$0.59^{+0.35}_{-0.21}$	> 10 GeV

If two errors are given, the first is statistical, the second systematic.

These results do indeed deviate from 1 and, if they are interpreted as oscillation, would mean a value of $\Delta \gtrsim 100$ eV^2.

Another possible avenue of detection is through the measurement of the ratio of neutral current to charged current events. The ratio can be written:

$$R(\frac{NC}{CC}) = \frac{\sigma_{cc}R + \phi\sigma_{cc}(1-P)R + 0.66\phi\sigma^\tau_{cc}P + \phi\sigma^\tau_{cc}R_\tau P}{\sigma_{cc} + \phi\sigma_{cc}(1-P) + 0.34\phi\sigma^\tau_{cc}P}$$

where P = probability of $\nu_e \rightarrow \nu_\tau$

R = ratio of NC/CC observed in ν_μ interactions

ϕ = 1e flux/1μ flux

Again if $P = 0$, the expected value of R(NC/CC) is 0.32. The BEBC group reports a value 0.28±0.07 in good agreement, but the CHARM collaboration reports an anomalous excess inferred from their measured ratio 0.64±0.16±0.13.

Thus there is marginally credible evidence for something not incorporated within the current understanding of beam dump physics. That these anomalies are related to neutrino oscillations is not established at all. To buttress this conclusion I can report the results on the ratio of antineutrino events to neutrino events which have no bearing on the question of neutrino oscillations. In Table II the values of $R(\bar{\nu}/\nu)$ obtained in the CERN program are presented:

Table II

Values of the ratio of antineutrino events to neutrino events

	Type	R by extrapolation	R by subtraction
CDHS	μ^+/μ^-	0.06±0.10±0.06	0.28±0.05±0.07
CHARM	μ^+/μ^-	0.86±0.53	$0.62\pm0.24^{+0.19}_{-0.10}$
BEBC	μ^+/μ^-		0.36±0.22
	e^+/e^-		0.32±0.17
	$\frac{(e^+/\mu^+)}{(e^-+\mu^-)}$		0.35±0.15

The expected value is $R = 0.48$, the ratio of charged current cross sections assuming equal fluxes $(\phi(\bar{\nu}) = \phi(\nu))$. The experiments are in disarray. The BEBC results are in good agreement with the expected value, the CDHS results appear to be on the low side, whereas the CHARM collaboration deviates to the high side. My point is that one should refrain from interpreting similar fluctuations in R(e/μ) or R(NC/CC) as neutrino oscillations when the internal consistency of the results from the various detectors are in question.

Several interpretations of the beam dump results are possible.

i) The precision of the experiments is too poor to draw definitive conclusions.
ii) The assumptions $(\phi(\nu_e) = \phi(\nu_\mu)$ or $\phi(\bar{\nu}) = \phi(\nu))$ are in error
iii) Neutrino oscillations exist
iv) All (or none) of the above

I note one additional experiment at CERN which has presented limits on ν_e oscillation derived from a study of electron neutrino interactions using BEBC in a "narrow band" or dichromatic beam.[9] In this experiment the parent mesons which produce the neutrino beam are selected by sign of their charge and their momentum before being allowed to decay. Only π^+/K^+ or π^-/K^- parents remain after this selection. Since the ν_e flux derives from $K^\pm_{e3}$ decay, it is straightforward to relate this flux to the ν_μ flux from $K^\pm_{\mu 2}$.

The experimenters calculate the relative ν_e/ν_μ flux by use of the measured branching ratios and a geometrical factor to account for the differences between a three body decay and a two body decay. Based on their observation of ν_μ interactions they predict that 70±2 ν_e events should have been detected in their experiment. They observed 73±10 ν_e events, which have an energy distribution as shown in Figure 6. From this null measurement of $P(\nu_e \to \nu_e)$ they can exclude a range of the parameters $\sin^2 2\theta$ and Δ as shown in Figure 7.

In conclusion, little evidence of neutrino oscillations can be obtained from beam dump experiments to date. The fluxes are poorly known and results are inconsistent and inconclusive. If new phenomena are being observed in the beam dump experiments, it is probably not attributable to ν oscillations. The most credible experiment is the BEBC narrow band bubble chamber experiment at CERN which, if interpreted as a measurement of the probability that a ν_e remains a ν_e $P(\nu_e \to \nu_e)$, excludes $\Delta \gtrsim 35$ eV^2 and $\sin^2 2\theta \gtrsim 0.2$.

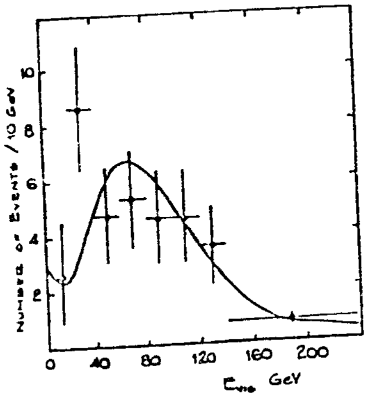

Figure 6) Energy distribution of electron neutrino events observed in the BEBC narrow-band experiment.

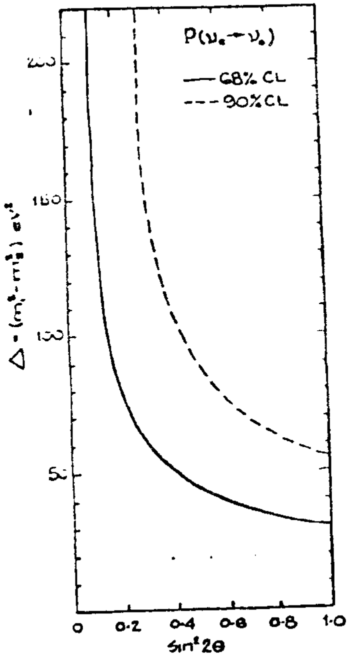

Figure 7) The resultant limit on ν_e oscillation obtained by the BEBC narrow band experiment. The unshaded region shows the values of $\sin^2 2\theta$ and Δ excluded at the confidence level indicated.

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