RESULTS OF A BEAM DUMP EXPERIMENT
AT THE CERN SPS NEUTRINO FACILITY

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SUMMARY

We report results from a beam dump experiment performed at the CERN SPS facility. An excess of electron- and muon-neutrinos has been observed. This new source of prompt neutrinos gives 2 10^{-7} ν_e or $\bar{\nu}_e$ per incident proton with E_ν > 20 GeV and neutrino angle smaller than 1.85 mrad. A possible explanation would be the pair production of charmed meson $D\bar{D}$ with an inclusive cross section of the order of 40 μb.

RESUME

Dans une expérience de Beam Dump utilisant un des faisceaux du SPS au CERN, nous avons observé un excès de neutrinos-électron et de neutrinos-muon. La nouvelle source de neutrinos ainsi mise en évidence donne 2 10^{-7} ν_e par proton incident pour une énergie de neutrino supérieure à 20 GeV et un angle de production inférieur à 1,85 milliradians. L'explication la plus probable est la production en paire de mésons charmés $D\bar{D}$ avec une section efficace inclusive de l'ordre de 40 microbarns.

1. INTRODUCTION

The Beam Dump experiment [1,2,3] at the CERN SPS Neutrino facility was performed to search for long-lived neutral particles promptly produced at the target.

New types of penetrating particles could be produced either directly in the primary interaction in the target or in the decay of short-lived particles.

Such processes had been suggested recently by several experiments :

i) Part of the dimuon and trimuon events detected in high energy neutrino experiments [4] might be explained as due to the interaction of new neutrinos, coupled to new heavy leptons.

ii) The existence of the τ lepton [5] implies the existence of a τ neutrino. A large production of ν_τ in the Dump would give an abnormal ratio of muonless to charged current events.

Axion production [6] might also be detected in such an experiment.

To be sensitive to such a small source of prompt neutrinos, one has to suppress the conventional beam component of ν_μ induced by π and K decay.

This was obtained by using a large copper target where the secondary pions and kaons were absorbed so that the ν fluxes were reduced by $\sim$ 3000 [7].

The CDHS detector [8] recorded events provided the energy deposition was larger than $\sim$ 7 GeV.

Events were retained if they occured in a fiducial volume (9.3 m of iron, 1.6 m Ø) corresponding to a target mass of $\sim$ 580 tons. In the final sample a cut in visible energy was applied above 20 GeV. In these conditions and after double scan for event selection, we obtain the final event numbers summarized in Table I.

2. MULTIMUON EVENTS

We observed 6 dimuon events in the fiducial volume. The rate of dimuons relative to charged current interactions above 30 GeV is

Table I

Summary of event numbers

Number of protons E > 20 GeV		
Single muon events	μ^-	850
	μ^+	187
Dimuon events*		6
Trimuon events		0
Muonless events**		372

* $E_{vis} > 30$ GeV

** Fiducial cuts and selection criteria are different from single muon analysis.

The quoted numbers differ from those of a previous publication[15) because of some data overlooked in a first scan.

Table II

Summary of muonless event numbers

Observed muonless events	372 ± 30
Expected NC events from ν_μ (435 * 0.3)	130 ± 10
Expected muonless events from known ν_e in the beam	45 ± 15
New source	197 ± 35

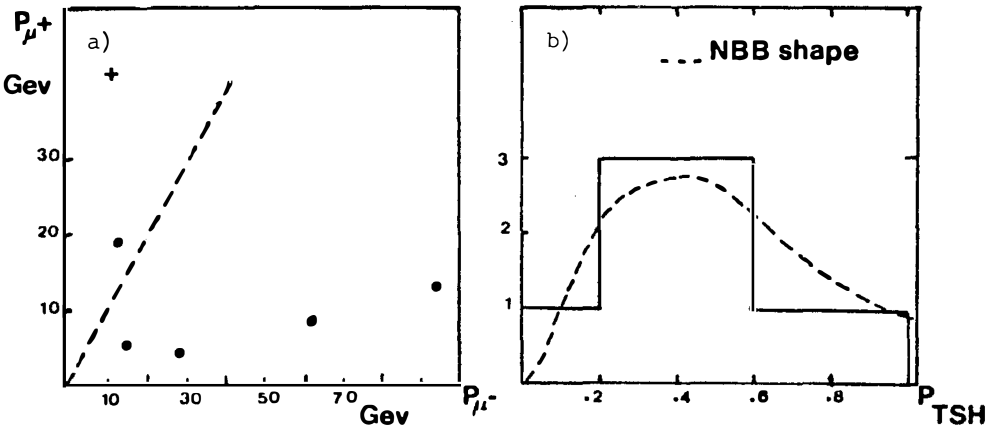

Figure 1 a) $P_{\mu-}$ versus $P_{\mu+}$ plot of the dimuon events.
b) Transverse momentum of the non-leading muon relative to the shower axis. The dashed line is the distribution observed in the narrow Band Beam data[4].

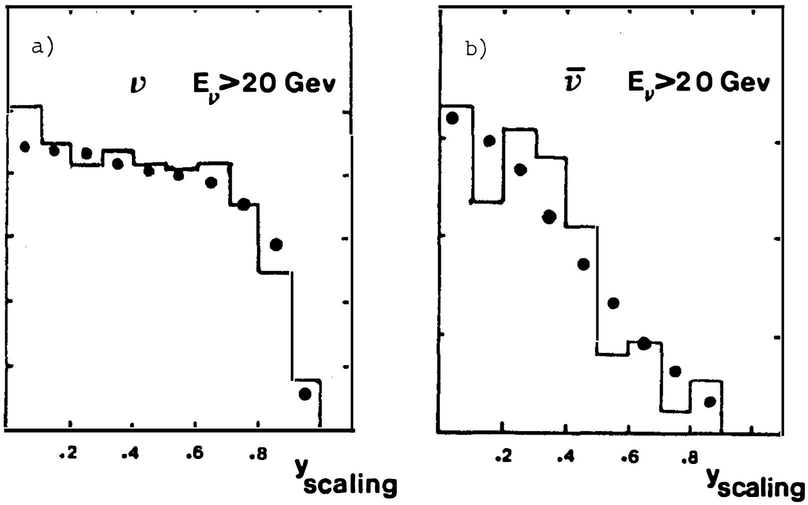

Figure 2 Y distribution of the neutrino (a) and antineutrino (b) single muon events. The dots show the prediction of a Monte-Carlo simulation including 16 % antiquarks.

$$\frac{N(\mu^+\mu^-)}{N(\mu)} = (0.7 \pm 0.3)\ \%$$

This ratio is not in disagreement with the measured rate in the Narrow Band Beam Data [9]. The kinematical distributions of the dimuon events are shown in Fig. 1.

We do not observe any trimuon event. In order to give upper limits on multimuon production by new neutrinos, we compare the rate of multimuons in the Beam Dump and in the Wide Band Beam running.

In the same detector, using the same trigger and the same energy of the primary protons (400 GeV), we have recorded :

$\sim$ 1500 dimuons and 12 trimuons

corresponding to 2.10^{17} protons on the target [10].

We can conclude that, in the Wide Band Beam sample, less than 0.3 % of the dimuons and less than 10 % of the trimuons (90 % CL) are due to prompt neutrinos.

3. SINGLE MUON EVENTS

A total number of 850 μ^- charged current and 187 μ^+ charged current interactions with $P_\mu > 5$ GeV/c has been selected. The x and y scaling distributions are compatible with those observed in other neutrino beams (Figure 2).

The energy spectrum of the single muon events is drawn in Figure 3. The expected neutrino and antineutrino fluxes due to the remaining background of π and K decay+) are also shown. Absolute flux is difficult to compute. However, we think that the relative flux of antineutrinos to neutrinos is estimated with a reasonable accuracy. The expected ratio (0.14 ± 0.015) is not compatible with the measured ratio (0.22 ± 0.02). This shows an excess of antineutrino interactions which has to be attributed to prompt antineutrinos. In the following we will see that there is a reason to believe that this new source gives as many neutrinos as antineutrinos. If this is assumed and if we use the experimental cross section ratio [11] $\sigma_{\bar{\nu}}/\sigma_\nu = 0.48$, we find of prompt signal of $210 \pm 86\ \nu_\mu$ and $91 \pm 40\ \bar{\nu}_\mu$.

+) We wish to thank Dr. H. Wachsmuth for making these calculations available to us.

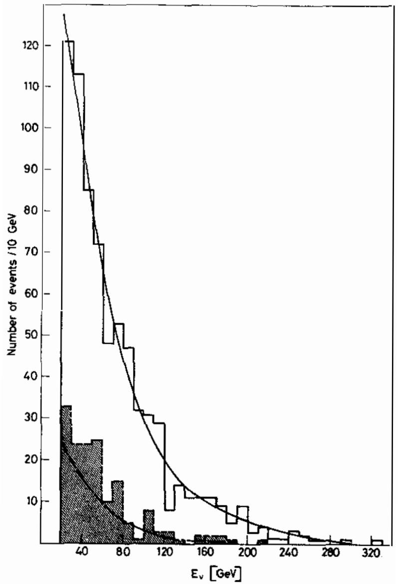

Figure 3 :

Total visible energy spectra for single μ^- (upper histogram) and single μ^+ events (shaded histogram) compared to the expectations from π- and K-decay neutrinos normalized to the total number of negative muons.

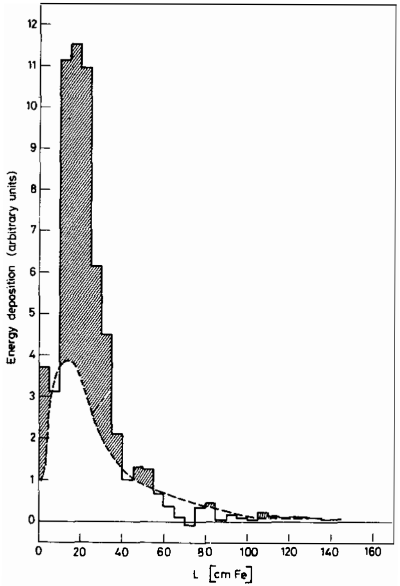

Figure 4 :

Longitudinal shower development in the iron calorimeter for excess muonless events compare to the shape of hadronic showers (dashed curve) as measured by single muon events.

4. MUONLESS EVENTS

Muonless events have been analysed using the standard technique already used in our detector [12] : without any requirement on muon reconstruction, all events with shower energy larger than 20 GeV are classified according to their penetration length in iron. The fiducial volume is $\sim$ 70 % of the one used in the single muon analysis.

We find 372 $\pm$ 30 muonless events and 435 $\pm$ 27 muon events giving a ratio

$$R = \frac{\text{muonless}}{\geq 1 \text{ muon}} = 0.86 \pm 0.08$$

This ratio has to be corrected for the interaction of $\nu_e/\bar{\nu}_e$ in the beam due to Ke_3 and hyperon decays. However this correction cannot account for the difference with respect to the ratio R = 0.30 $\pm$ 0.01 measured in ν_μ beam [12].

The known contributions to the signal are summarized in Table II. It can be seen that there remain 197 $\pm$ 35 muonless events which are not ν_μ or $\bar{\nu}_\mu$ neutral current events. These events could be interpreted as :

i) ν_e interactions due to a prompt source :
In our detector electrons induce electromagnetic showers which are seen as muonless events,

ii) ν_τ interactions :
Charged current interactions of ν_τ produce τ leptons which decay with emission of either hadrons, electrons or muons : [5]

$$\begin{aligned} \nu_\tau + N \rightarrow \tau + X & \\ \rightarrow \text{hadrons} + \nu_\tau & \quad \sim 60\ \% \\ \rightarrow e + \nu_e + \nu_\tau & \quad \sim 20\ \% \\ \rightarrow \mu + \nu_\mu + \nu_\tau & \quad \sim 20\ \% \end{aligned} \quad \left.\begin{matrix} \\ \\ \end{matrix}\right\} \text{80 \% muonless events}$$

iii) If axions [13] exist, with properties similar to those of π°'s, their interaction in iron would produce hadrons much as neutral current events of neutrinos.

It is important to note that in the case i) a large fraction of the energy is transferred to the electromagnetic shower. On the contrary in hypotheses ii) and iii) most of the energy goes into the hadronic part.

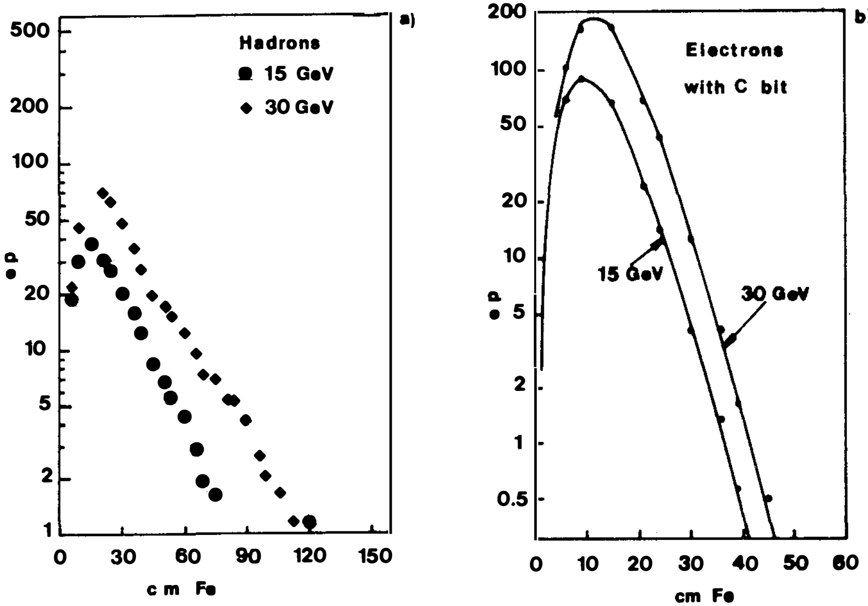

Fig. 5A

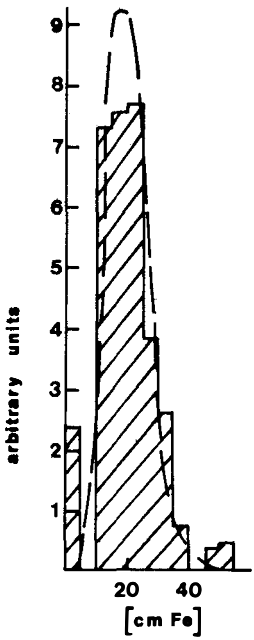

Fig. 5B

Figure 5A :

Longitudinal development of hadronic showers induced by π^-(a) and electro-magnetic showers induced by electrons (b) at 15 and 30 GeV in the test calorimeter[10]

Figure 5B :

Comparison of the pulse height not due to hadronic showers with the shape of purely electromagnetic showers.

In iron, as the radiation length (1.7 cm) is substantially smaller than the interaction length (18 cm), the longitudinal shower development looks different for electromagnetic and hadronic showers. We have compared the shower development of the excess events (solid curve in Figure 4) to that observed in ν_μ charged current interactions (dashed curve). The early shower development is clearly different : normalizing the two plots for thicknesses above 40 cm, we find that only 57 % of the visible energy can be attributed to hadron showers (including π° component). The remaining 43 % (dashed area) can be attributed to electromagnetic showers. The shape of this excess is in agreement with the development observed for electron induced showers measured with a test calorimeter [14] in an electron beam (Figure 5).

This large fraction of electromagnetic energy is expected from ν_e ($\bar{\nu}_e$) interactions and in disagreement with the ν_τ and axion hypotheses.

Using the ratio R = 0.3 and taking into account the cut $E_{shower} > 20$ GeV, we conclude that we observe a prompt signal of 171 ± 31 charged current (e^+, e^-) events and 26 ± 5 neutral current (ν_e, $\bar{\nu}_e$) events.

5. SUMMARY

Adjusting the muonless sample to the same fiducial volume as for the single muon sample, we obtain :

$$N_{\nu_e} + N_{\bar{\nu}_e} = 236 \pm 40$$

$$N_{\nu_\mu} + N_{\bar{\nu}_\mu} = 301 \pm 126^{+)} \ .$$

The magnitudes of the two signals are compatible with equal fluxes of prompt muon and electron neutrinos. If we assume further an equal number of prompt ν_e and $\bar{\nu}_e$ in the beam, then taking into account the difference in the cross section

$$N_{\nu_e} = 158 \pm 27 \ , \qquad N_{\bar{\nu}_e} = 78 \pm 14 \quad .$$

The absolute number of prompt ν_e within the angular acceptance of the detector (1.85 mrad) and with the cut $E_{shower} > 20$ GeV may be computed on the basis of this result, the neutrino cross-section

+) This number is obtained assuming equality of prompt ν_μ and $\bar{\nu}_\mu$ fluxes, see section 3.

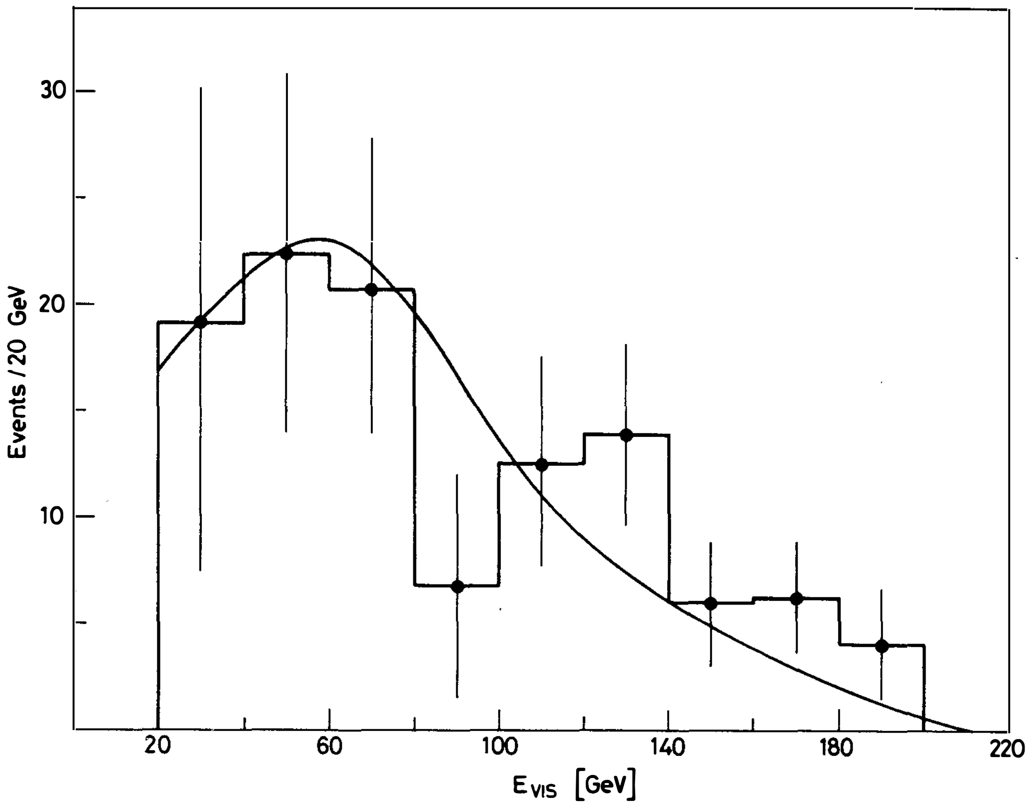

Figure 6 : Total visible energy distribution for the charged current events from prompt ν_e and $\bar{\nu}_e$. The line shows the prediction of our charm pair production model.

and the measured proton flux :

$$N_{\nu_e}/\text{incident proton} = (1.9 \pm 0.4)\ 10^{-7}$$

The prompt flux may also be compared to ν_μ flux from K decay. We attribute to $K_{\mu 2}$ decay 367 ± 39 events so that

$$N_{\nu_e}/N_{\nu_K} = 158/367 = 0.43 \pm 0.09$$

6. INTERPRETATION

The only known process, which might be the origin of this prompt neutrino flux, is the production of charmed particles. Approximately 20 % of charmed mesons decay semi-leptonically, giving equal fluxes of electron and muon neutrinos, as supported by the data.

In order to make cross-section estimates, we need additional assumptions on production mechanisms as our detector covers only a small fraction of the phase space in the forward direction.

We have used a simple model for $D\bar{D}$ pair production :

- invariant cross section [16)]

  $$\frac{d^2\sigma}{dx_F\ dp_T^2} \propto (1 - x_F)^3\ e^{-\alpha p_T^2}$$

  where x_F is the Feynman variable and $\langle p_T \rangle = 0.7$ GeV/c
- equal branching ratio

  BR $(D \to K\mu\nu)$ = BR $(D \to K^*\mu\nu)$ = 10 %

  BR $(D \to Ke\nu)$ = BR $(D \to K^*e\nu)$ = 10 %

The computed energy spectrum of the neutrinos is in agreement with the visible energy distribution of the excess muonless events (Figure 6).

Then, using the observed ratio of ν_μ from K decay to prompt ν_e events, we can give an estimate of the inclusive cross section for $pp \to D\bar{D}$ relative to kaon production at 400 GeV :

$$\sigma(pp \to D\bar{D}) = \frac{N_{\nu_e}}{N_{\nu_K}} * \frac{\varepsilon(\nu_\mu K)}{\varepsilon(\nu_e D)} * \sigma(pp \to K) \qquad \text{where } \varepsilon \text{ is the acceptance of the detector}$$

$$\simeq 3.10^{-3} * \sigma(pp \to K)$$

Using $\sigma(pp \to K) = 13$ mb we find that the charm production cross section is of the order of 40 μb per nucleon. If we assume different production mechanisms, this number may easily change by a factor two.

One should note that $\sigma(pp \rightarrow K)$ infers a $A^{2/3}$ dependence for the cross-section.

Finally, the data can be used to set upper limits on axion production. From geometric acceptance of our detector for π°, we obtain

$$\sigma(pN \rightarrow a^\circ) * \sigma(a^\circ N \rightarrow X) < 10^{-67} \text{ cm}^4 \quad (90\ \%\ \text{CL}).$$

The production rate of axions relative to π° would be

$$\left(\frac{n_{a^\circ}}{n_{\pi^\circ}}\right) < 0.5\ 10^{-8} \quad (90\ \%\ \text{CL}).$$

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