OBSERVATION OF NEUTRINO-LIKE INTERACTIONS WITHOUT MUON OR ELECTRON IN THE GARGAMELLE NEUTRINO EXPERIMENT

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Events induced by neutral particles and producing hadrons, but no muon or electron, have been observed in the CERN neutrino experiment. These events behave as expected if they arise from neutral current induced processes. The rates relative to the corresponding charged current processes are evaluated.

We have searched for the neutral current (NC) and charged current (CC) reactions:

$$\text{NC} \quad \nu_\mu/\bar{\nu}_\mu + \text{N} \rightarrow \nu_\mu/\bar{\nu}_\mu + \text{hadrons}, \qquad (1)$$

$$\text{CC} \quad \nu_\mu/\bar{\nu}_\mu + \text{N} \rightarrow \mu^-/\mu^+ + \text{hadrons} \qquad (2)$$

which are distinguished respectively by the absence of any possible muon, or the presence of one, and only one, possible muon. A small contamination of $\nu_e/\bar{\nu}_e$ exists in the $\nu_\mu/\bar{\nu}_\mu$ beams giving some CC events which are easily recognised by the e^-/e^+ signature. The analysis is based on 83 000 ν pictures and 207 000 $\bar{\nu}$ pictures taken at CERN in the Gargamelle bubble chamber filled with freon of density 1.5×10^3 kg/m^3‡. The dimensions of this chamber are such that most

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‡ A more detailed account of the analysis of this experiment appears in a paper to be submitted to Nuclear Physics.

hadrons are unambiguously identified by interaction or by range-momentum and ionisation. Any track which could possibly be due to a muon has consigned the event to reaction (2).

Analysis of the signal. To estimate the background of neutral hadrons coming from neutrino interactions in the shielding and simulating reaction (1), events where a visible charged current interaction produces an identified neutron star in the chamber (associated, AS, events) were also studied. To obtain a good estimate of the true neutral hadron direction from the direction of the observed total momentum a cut in visible total energy of >1 GeV was applied to the NC and AS events, as well as to the hadronic part of the CC events.

We have observed, in a fiducial volume of 3 m^3, 102 NC, 428 CC and 15 AS in the ν run and 64 NC, 148 CC and 12 AS in the $\bar{\nu}$ run. Using these numbers without background substraction the ratios NC/CC are then 0.24 for ν and 0.42 for $\bar{\nu}$, whilst the NC/AS ratios are 6.8 and 5.3 respectively.

The spatial distributions of the NC events have been compared to those of the CC events and found to be similar. In particular, the distribution along the beam direction of NC (fig. 1) has the same shape as the CC distribution. In contrast the observed distribution of low energy neutral stars shows a typical exponential attenuation as expected for neutron background. The distributions of radial position, hadron total energy, and angle between measured hadron total momentum and beam direction are also indistinguishable for NC and CC.

Using the direction of measured total momentum of the hadrons in NC and CC events, a Bartlett method has been used to evaluate the apparent interaction mean free paths, λ_a, for NC and CC which are found to be compatible with infinity. For the NC events we find $\lambda_a > 2.6$ m at 90% CL; this corresponds to 3.5 times the neutron interaction length for high energy (>1 GeV) inelastic collisions in freon.

Evaluation of the background. Since the outgoing neutrinos cannot be detected in reaction (1), the NC events may be simulated by neutral hadrons coming from the ν beam or elsewhere.

As a check for cosmic ray origin, the up-down asymmetries of NC events in vertical position and momenta have been measured and found to be (3 ± 8)% and (-8 ± 8)% respectively. In addition, a cosmic ray

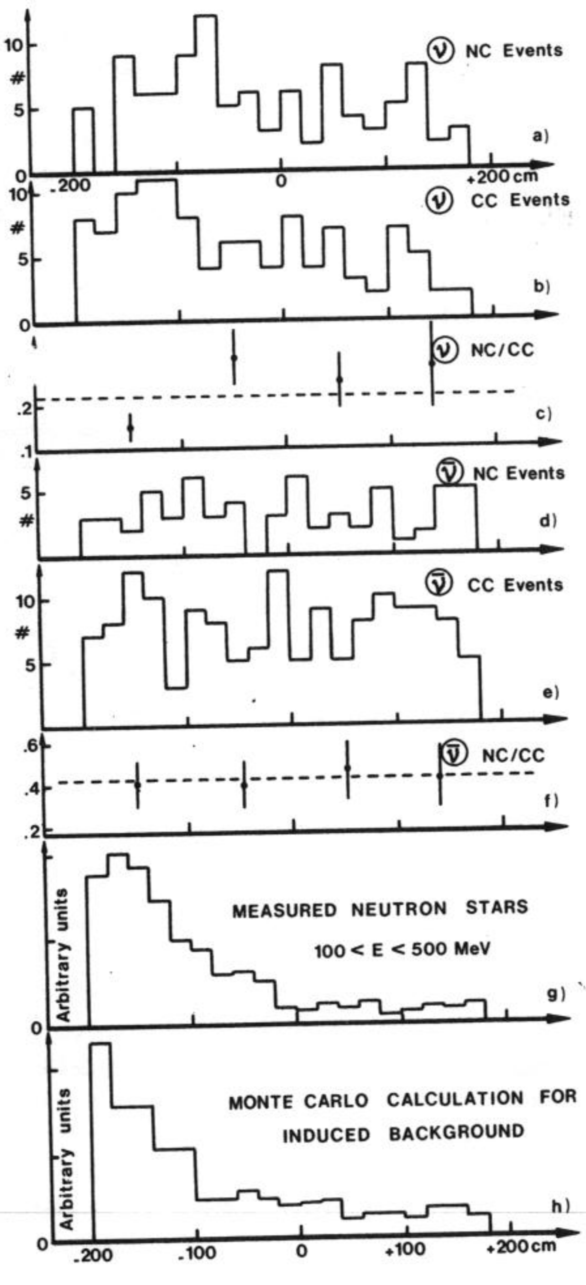

Fig. 1. Distributions along the ν-beam axis. a) NC events in ν. b) CC events in ν (this distribution is based on a reference sample of ~ 1/4 of the total ν film). c) Ratio NC/CC in ν (normalized). d) NC in $\bar{\nu}$. e) CC events in $\bar{\nu}$. f) Ratio NC/CC in $\bar{\nu}$. g) Measured neutron stars with $100 < E < 500$ MeV having protons only. h) Computed distribution of the background events from the Monte-Carlo.

exposure of 15 000 pictures shows no NC type event satisfying the selection criteria. We conclude that the cosmic background is negligible.

The low energy muons (< 100 MeV/c) captured at rest in the ν run could be mistaken as protons. A study of the observed muon spectrum in CC events, as well as a theoretical estimate of the low end of this spectrum shows that the correction to be applied is 0 ± 5 events.

Interactions of neutral hadrons produced by the primary protons up to and including the target should produce events at an equal rate in ν and $\bar{\nu}$ runs. On the contrary, we observe an absolute rate 4 times larger in the ν run than in the $\bar{\nu}$ run. If the neutral hadrons are due to defocussed secondary pions and kaons, the disagreement is larger since we expect $1-2$ times more events in $\bar{\nu}$ than in ν. Since the whole installation is shielded from below by earth we should again expect up-down asymmetries in the NC events. This is not observed.

The most important source of background is the interaction of neutral hadrons produced by the undetected neutrino interactions in the shielding. The high elasticity (0.7) of the neutrons causes a cascade effect in propagation through the shielding. The neutron energy spectrum at production can, in principle, be obtained from the AS events together with available nucleon-nucleus data. Due to the limited statistics in the AS events we make the extreme assumption that all the NC events are neutron produced an use their observed energy spectrum to calculate the neutron spectrum from neutrino interactions. This gives an energy dependence described by E^{-2}. The effective interaction length λ_e of neutrons in the shielding is then found to be 2.5 times the inelastic interaction length, λ_i. A smaller effective interaction length is found for K_L^o although the background from this source must be negligible since we find no examples of Λ^o hyperon production among the NC events.

From the absolute value of the number of AS events, we can calculate the number of background events. This has been done by Monte-Carlo generation of events in the shielding surrounding the fiducial volume according to the radial intensity distribution of the beam. The ratio of background events (B) to AS events is found to be $B/AS = 0.7$ for $\lambda_e = 2.5\,\lambda_i$. If the NC sample has to be explained as being entirely due to neutral hadrons, the Monte-Carlo requires $\lambda_e/\lambda_i > 10$, instead of the best estimate of 2.5. Both ratios would predict distributions along the beam direction in the chamber in strong disagreement with those observed.

Another evaluation of this type of background has been made using the simple assumption that an equilibrium of neutral hadrons with neutrinos exists throughout the entire chamber/shielding assembly. For a radially uniform ν flux it gives $B/AS < 1.0$ which confirms the Monte-Carlo prediction.

Conclusion. We have observed events without secondary muon or electron, induced by neutral penetrating particles. We are not able to explain the bulk of the signal by any known source of background, unless the effective interaction length of neutrons and K_L^o is at least 10 times the inelastic interaction length. These events behave similarly to the hadronic part of the charged current events. They could be attributed to neutral current induced reactions, other penetrating particles than ν_μ and ν_e, heavy leptons decaying mainly into hadrons, or by penetrating particles produced by neutrinos and in equilibrium with the ν beam.

On subtraction of the best estimate of the neutral hadron background, and taking into account the $\nu(\bar{\nu})$ contamination in the $\bar{\nu}$ (ν) beam, our best estimates of the NC/CC ratios are

$$(NC/CC)_\nu = 0.21 \pm 0.03$$

$$(NC/CC)_{\bar{\nu}} = 0.45 \pm 0.09$$

where the stated errors are statistical only. If the events are due to neutral currents, these two results are compatible with the same value of Weinberg parameter, $\sin^2\theta_W$ [1–3] in the range 0.3 to 0.4.

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