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STUDY OF NEUTRINO PROTON ELASTIC SCATTERING

IN THE "GARGAMELLE" FREON EXPERIMENT

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ABSTRACT

The cross section ratio of the elastic neutral current reaction $\nu p \rightarrow \nu p$ to the quasi-elastic charged current reaction $\nu n \rightarrow \mu^- p$ has been measured in the kinematical region $0.3 \leq q^2 \leq 1.0 \text{ (GeV/c)}^2$. The measured value is $R_M = 0.17 \pm 0.08$. Model dependent corrections are applied and the result is compared to various models.

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A study has been made of the neutral current elastic reaction

$$\nu p \rightarrow \nu p \quad (1)$$

observed in the large heavy liquid bubble chamber Gargamelle exposed to the wide-band neutrino beam of the CERN PS, the intensity of which was increased by the use of the Proton Synchrotron Booster. A comparison with the corresponding charged current reaction

$$\nu n \rightarrow \mu^- p \quad (2)$$

has been made.

The chamber was filled with heavy freon CF_3Br (radiation length 0.11 m, interaction length ~ 0.6 m). The experimental conditions were similar to previous runs [1], except that some extra shielding was added upstream of Gargamelle to reduce as much as possible the background due to the process

$$np \rightarrow np . \quad (3)$$

An upper limit of the ratio of the cross sections of the reactions (1) and (2) has been reported previously [2] and such a reaction has been observed in other experiments [3-4].

The present result is based on the analysis of a total of 138 000 pictures, which were scanned for stopping protons inside the visible volume. A projected length greater than 3 cm on the scanning table (~ 120 MeV kinetic energy) was required. The stopping proton could be either isolated (neutral current candidate NC), or accompanied by one negative muon candidate (corresponding charged current reactions CC). There had to be no other interacting vertex in the frame. The vertex had to be "clean", i.e. without any visible short (less than 2 mm) track, in order to reduce the contamination from pionic channels, as well as the effect from the possible intra-nuclear cascade of the proton. After two scans, the scanning efficiency was found to be 0.98 ± 0.04 for each topology.

For the analysis a fiducial volume of 1.57 m^3 and an "external" volume of about 2.5 m^3 have been used. The fiducial volume is a cylinder

of 50 cm radius ($R \leq 50$ cm) defined by $-50 \leq x \leq 150$ cm along the beam direction. The external volume is defined by $-50 \leq x \leq 150$ cm and $R > 50$ cm.

Protons were retained having a kinetic energy between 150 and 500 MeV, corresponding to the cuts $0.3 \leq q^2 \leq 1.0$ (GeV/c)². The upper cut ensures that the proportion of stopping protons is almost 100% inside the fiducial volume and 70% inside the external volume. After these cuts, the number of events are respectively 153 isolated protons in the external volume, and 100 isolated protons and 264 μ^-p candidates in the fiducial volume.

The most important source of background to reaction (1) is reaction (3), which may be induced by neutrons of two kinds: skyshine neutrons and equilibrium neutrons.

Skyshine neutrons come partly from cosmic rays, and partly from the beam line. They can only penetrate the chamber by the two ends, since the 1.5 m magnet yoke protects the chamber on the sides by more than 15 interaction lengths. Pictures taken in previous runs without the additional shielding in front of the chamber show this background to be of low energy and concentrated at the beginning of the chamber. Extrapolation of this result to our present sample obtained with the improved shielding shows that with the cuts in volume (which imposes three interaction lengths of free visible liquid upstream) and in q^2 this type of background is less than 6% and therefore can be neglected.

The equilibrium neutrons are generated by neutrino interactions in the material surrounding the visible volume. The genuine neutral current signal should decrease with increasing radius, according to the beam shape as the charged current signal does, whereas the background of incoming neutrons from the sides increases with radius. This is shown in fig. 1. It should be noted that the fall in the observed distribution for $R > 60$ cm is due to lost protons leaving the visible volume. Monte-Carlo techniques [5] were used to simulate the production of neutrons and their cascade through the detector and its surroundings. The generation of equilibrium neutrons in the Monte-Carlo was done using the angular distribution of the neutrons and the momentum distribution of the protons produced in neutrino interactions studied in previous exposures.

Fig. 1(a) shows that the Monte-Carlo prediction for the R^2 distribution gives a good agreement with the shape of the observed distribution in the external volume, where the neutron background dominates.

In order to get rid of the difficult calculation of the absolute neutron flux, the Monte-Carlo results were used only for computing the ratio of the number of background events in the fiducial volume to the number in the external volume. The corresponding ratio expected for neutrino events was obtained easily from the shape of the ν beam. Comparison of these ratios with the experimental number of events gives directly the percentage of background. Fig. 2 shows a comparison between the Monte-Carlo predictions and the observed distributions in distance x along the beam axis and in kinetic energy for events in the external volume.

The final background estimate is (62 ± 16) events in the fiducial volume, where the quoted error includes also the uncertainties on the Monte-Carlo input data and on the identification probability for the proton. This result is independent of the definition of the external volume. Also any variation within four standard deviations of the Monte-Carlo input parameters, produces a change in the predicted background not larger than five events.

Corrections also have to be applied for the presence of contaminations from the pionic channels $\nu N \rightarrow \mu^- \pi^+ p$ and $\nu N \rightarrow \nu \pi^+ p$, where the pion is subsequently absorbed or remains undetected. The calculation of this background has been made using our published data on one pion production [6], the hypothesis of $\Delta(1232)$ dominance, the probability that a pion is absorbed (~ 0.12), the probability that this topology appears "clean" according to the scanning criteria (< 0.50), the probability that the event survives the q^2 cuts ($\lesssim 0.40$) and the π^0 detection probability (0.86). This contamination is found to be less than 10% in both NC and CC samples and so the overall effect on the ratio NC/CC is negligible compared with the other corrections.

After background subtraction and corrections for the excess of target neutrons in freon ($n/p = 1.19$), the following ratio is obtained:

$$R_M = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)} = 0.17 \pm 0.08 .$$

The reaction $\nu n \rightarrow \nu n$ is very likely to exist as well as the reaction $\nu p \rightarrow \nu p$. It would be exceedingly difficult to detect. Nevertheless, it can contribute to the isolated proton sample, through nuclear reinteraction of the neutron. The correction for this reaction can only be done with the help of a model, since there exists no experimental information on it. A Monte-Carlo calculation [7], in which the nucleus is described as a Fermi gas has been performed to estimate the probabilities that a proton produced within the cuts remains in the sample in spite of reinteraction inside the parent nucleus (0.77) and that a neutron produces, via reinteraction either inside or outside the parent nucleus, a proton accepted in the sample (respectively 0.13 and 0.025). The multiplicative correcting factor f to be applied to R_M is found to be

$$f = \frac{0.77}{0.77 + (0.13 + 0.025) \times 1.19 r} , \text{ where } r = \frac{\sigma(\nu n \rightarrow \nu n)}{\sigma(\nu p \rightarrow \nu p)} .$$

Since f depends on r , which in turn is model dependent, the theoretical predictions R_{th} from various models [8] for the ratio

$$\frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}$$

are displayed in table 1, taking into account the applied q^2 cuts, the shape of the neutrino spectrum, the effect of the Fermi momentum, and assuming the value of M_A , the mass associated with the axial form-factor, to be [9] $0.92 \text{ GeV}/c^2$. The experimental result is compatible with the predictions of these models. In the framework of the Salam Weinberg model, which predicts a value for the ratio r of the order of 1.5 for $\sin^2 \theta_W = 0.32 \pm 0.05$ [1], the following ratio is found:

$$R = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)} = f \times R_M = 0.12 \pm 0.06 .$$

In conclusion, the ratio R_M although obtained with very different experimental techniques is in agreement with the previous measurements [3-4] and is consistent with the Salam-Weinberg predictions, as well as for those of other models.

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TABLE 1

Model	$\sin^2 \theta_W$	R_{th}^2 $0.3 \lesssim q \lesssim 1$	r	$f^{-1} \times R_{th}$
Salam-Weinberg	$= 0.3$	$= 0.101$	1.5	0.14
Vector	$= 0.4$	$= 0.115$	$1/3$	0.12
Gursey-Sikivie (B)	$= 0.4$	$= 0.170$	$1/3$	0.18

FIGURE CAPTIONS

- Fig. 1 (a) The R^2 distribution of the isolated protons vertices. The dashed curve is the Monte-Carlo prediction for equilibrium neutron induced events, normalised to the observed number of events with $R^2 > 2500 \text{ cm}^2$.
- (b) The R^2 distribution of the vertices of μ^-p events. The dashed curve represents the beam shape corrected for detection efficiency.
- Fig. 2 Comparison between Monte-Carlo predictions for background and the observed NC distributions in the external volume:
- (a) x coordinate;
- (b) proton kinetic energy.

FIG.1a

FIG.1b

FIG. 2a

FIG. 2b