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Author(s): V. D. Sandberg

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NEUTRINO CROSS SECTIONS ON $^{12}$C

V. SANDBERG (for the LSND Collaboration $^+$)

Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Measurements of the charged current reactions $^{12}$C($\nu_e$, $e^-$)$^{12}$N and $^{12}$C($\nu_\mu$, $\mu^-$)$^{12}$N for inclusive transitions to $^{12}$N excited states and exclusive transitions to $^{12}$N* are presented. The data presented represent three years of running of the LSND experiment and are from runs in 1993, 1994, and 1995 and total to 14772 Coulombs of protons on target. The $\nu_e$ scattering and $\nu_\mu$ exclusive scattering results are in good agreement with theoretical expectations, while the $\nu_e$ inclusive scattering results are smaller than expected from a continuum random phase calculation.

In this talk I will discuss the following neutrino-nucleus processes:

1. $\nu_e + ^{12}$C $\rightarrow e^- + ^{12}$N
2. $\nu_e + ^{12}$C $\rightarrow e^- + ^{12}$N*
3. $\nu_e + ^{12}$C $\rightarrow e^+ + ^{12}$N
4. $\nu_\mu + ^{12}$C $\rightarrow \mu^- + ^{12}$N*
5. $\nu_\mu + ^{12}$C $\rightarrow \mu^- + ^{12}$N

and report on measurements of the exclusive cross sections $^{12}$C($\nu_e$, $e$)$^{12}$N* and $^{12}$C($\nu_\mu$, $\mu^-$)$^{12}$N* and the inclusive cross sections to the $^{12}$N* excited states as measured by the LSND experiment. These processes are of interest on many fronts of current research, e.g.: The neutrino-nucleus scattering is sensitive to axial vector as well as vector nuclear currents and provide complementary information to electron-nucleus scattering. The inelastic cross sections are of importance to nucleosynthesis calculations. Finally, many detector systems rely on targets composed of carbon or oxygen and are thus dependent on knowledge of these cross sections. For neutrino oscillation experiments, the charged current scattering of $\nu_e$ and $\nu_\mu$ have an impact on the survival probabilities of the initial neutrino type.

electron-type neutrinos provides an independent method of determining the neutrino flux.

The experiment layout is shown in fig. 1, the neutrino source is shown in fig. 2, and the detector system is shown in fig. 3. The detector consists of 180 tons of mineral oil with 0.031 gm/l of butyl-PBD. This mixture is viewed by 1220 8" dia. photomultiplier tubes located at the inside surface of the tank. A data acquisition system continuously digitizes photocathode charge and time information every 100 ns and feeds this information to a trigger system. When a threshold of 300 hit tubes is crossed, the system records all activities (defined as greater than 19 hit tubes in any 100 ns interval) for the preceding 6 μs and the following 1 ms. The mineral oil scintillator mixture provides good particle identification. Cosmic ray muons are continuously monitored by a surrounding veto system.

The neutrinos come from the decay chain of pions and muons produced in the 30 cm long water target and copper beam stop. The majority of the pions and muons stop in the target or beam stop and decay at rest (DAR). A smaller fraction of the pions decay in flight (DIF) and produce a high energy neutrino beam. The spectra for this source are shown in fig. 4. The shape of the DIF spectrum is determined primarily by the source geometry. Data presented here are from runs in 1993, 1994, and 1995 and total to 14772 Coulombs of protons on target.

Process 1 is detected by the signature of a prompt electron followed in time by a positron. The $^{12}\text{N}^*$ decays with a lifetime of 15.9 ms and a maximum kinetic energy of 16. MeV. The energy, spatial, and temporal distributions for the electron and positron pairs are shown in fig. 5. The angular distribution of the electron and cross section for $\nu_e + ^{12}\text{C} \rightarrow e^+ + N_{g.s.}$ are shown in fig. 6. The flux averaged cross section for this process is $\langle \sigma \rangle = (9.1 \pm 0.4 \pm 0.9) \times 10^{-42} \text{ cm}^2$.

The reaction $^{12}\text{C}(\nu_e, e^+)^{12}\text{N}^*$ has only the prompt electron for a detection signature. It is distinguished from its backgrounds, primarily from other $\text{C}(\nu_e, e^+)$X processes and $\nu$-e elastic scattering, by means of the assumed energy and angular distributions. These are summarized in fig. 7. The flux averaged cross section for this process is $\langle \sigma \rangle = (5.7 \pm 0.6 \pm 0.6) \times 10^{-42} \text{ cm}^2$.

The forward peak in the angular distribution is from $\nu$-e elastic scattering. The backward peaking of the angular distribution is largely a result of the negative parity of the $\text{N}^*$ states expected to contribute.

The DIF processes (4 and 5) have a 123.7 MeV threshold for muon production. The analysis of these processes is in progress. Preliminary results are shown in fig. 8. The flux averaged cross section for $\nu_\mu + ^{12}\text{C} \rightarrow \mu^+ + N_{g.s.}$ is $\langle \sigma \rangle = (6.4 \pm 1.0 \pm 1.0) \times 10^{-41} \text{ cm}^2$ and agrees with theory. The inclusive reaction is lower than expected from a continuum random phase prediction.
Figure 1: Elevation view of the LSND experiment showing neutrino source and detector.

Figure 2: The A-6 beam stop and neutrino source

Figure 3: The LSND detector.

Figure 4: Source spectra for decay at rest (DAR) and decay in flight (DIF) neutrinos. The DAR spectra's abscissa is in terms of the fraction of the muon decay endpoint energy, 53.7 MeV.
Figure 5: Distributions in space and time for electron-positron events from DAR neutrinos.

Figure 6: Angular distribution and cross sections for $\nu_e + {}^{12}\text{C} \rightarrow e^- + N_{\text{g.s.}}$. 
Energy of $e'$ from $\nu_C - eN^*$

Angular distribution

Figure 7: Distributions for the inclusive process electrons from DAR neutrinos.

Cross section of $\nu_C - \mu N_{Ba}$

$\nu_C - \mu N_{Ba}$

Figure 8: Preliminary distributions for $\nu_\mu + ^{12}C$ processes.

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