Xerox Documate 152

LA-UR- 09-06610

Approved for public release; distribution is unlimited.

Title: Neutrino Physics at OscSNS

Author(s): Geoffrey B. Mills

Intended for: NuINT 09 PROCEEDINGS

Los Alamos
NATIONAL LABORATORY
EST. 1943

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (7/06)

Neutrino Physics at OscSNS

Geoffrey B. Mills

Physics Division
Los Alamos National Laboratory
Los Alamos, NM, 87544
USA

Abstract. The SNS will be on the the most prolific sources of neutrinos in the world in the next few years. It will enable experiments to make significant advances in neutrino science. The SNS will have significant advantages over the old standard, the LAMPF at Los Alamos, owing to the time-compressed beam pulse relative to LAMPF. The 500 *ns* long pulse will be over 1000 times shorter than the old LAMPF beam pulse of 700 μs. This article describes some of the possibilities for measurements in neutrino physics made possible by the SND facility.

Keywords: Neutrino,SNS,LSND,MiniBooNE
PACS: 13.15.+g,14.60.Pq,14.60.St,25.30.Pt,26.30.Jk

INTRODUCTION

The Spallation Neutron Source (SNS), located at the Oak Ridge National Laboratory in Tennesee, USA will produce be of the most intense terrestrial sources of neutrinos. These neutrinos are the by-product of producing an intense beam of neutrons for the study of materials. Hence those neutrinos will be produced whether or not they are used to study neutrino properties.

At the SNS, a 1.2 MW proton beam with proton kinetic energy of up to 1.3 GeV will impact a liquid mercury (Hg) target. The pulses of ^{-}H delivered from a linac at 60 Hz are compressed in a time compression ring to a pulse length of 695 ns. Those pulses are extracted in a single turn and directed onto the Hg target.

The SNS neutrino beam will be unique in energy range, time structure, and flavor composition, and thus will provide a setting to study neutrinos found no where else in the world.

THE SNS NEUTRINO SOURCE

The neutrinos from the SNS are produced in the decays of π mesons and their daughter μ mesons. Roughly 11.6% of the protons impinging on the target produce a π^+ and nearly all of those will decay to a ν_μ neutrino and a μ^+. The π^+ decay occurs quickly with a proper lifetime of 26ns. The daughter μ^+ also decays, but much more slowly with a proper lifetime of 2.2 μs, into a positron, a ν_e, and a $\bar{\nu}_\mu$. Since the beam pulse is only 695 ns, much shorter than the μ^+ lifetime, the prompt, nearly monoenergetic, 29.5 MeV ν_μs from π^+ decay are separated in time from the subsequent neutrinos from μ^+ decay.

The production rate of π^- mesons is much smaller than for π^+ mesons. When π^- mesons stop they are rapidly absorbed onto the Hg nuclei. The few π^- that manage to decay in flight will produce a μ^-, which will capture most of the time on a nucleus. The beam is thus nearly devoid of $\bar{\nu}_e$ from μ^- decay.

Two notable experiments, KARMEN and LSND[1], have already operated in at stopped muon neutrino sources, ISIS and LAMPF respectively, however OscSNS will have significant advantages over both of those experiments. While the time structure of ISIS was comparable to SNS, the KARMEN detector was an order of magnitude smaller than OscSNS and the ISIS flux was only one fifth of the expected SNS flux. LSND was also a factor of five smaller and suffered from significant cosmic ray backgrounds in neutrino reaction channels that did not have a coincidence requirement (e.g. a subsquent beta decay or neutron capture).

TABLE 1. Flux averaged cross sections for various DAR processes.

Process	Flux Averaged Cross Section $\times 10^{-40} cm^2$
$^{12}C(\nu_e, e^-)^{12}N_{GS}$	0.093
$^{12}C(\nu_e, e^-)^{12}N^*$	0.06
$^{12}C(\nu, \nu)^{12}C(1511)$	0.027
$^{13}C(\nu_e, e^-)^{13}N(GS+*)$	1.1
$^{12}C(\bar{\nu}_e, e^+)^{12}B_{GS}$	0.085
$e(\nu, \nu)e$	0.008
$p(\bar{\nu}_e, e^+)n(\mu^- \; decay)$	0.72
$p(\bar{\nu}_e, e^+)n(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$	0.94

OSCSNS

The OscSNS experiment[2] will be based on the technology used in the Liquid Scintillator Neutrino Dectector[3] (LSND), which allowed excellent separation of electromagnetic photon or electron events from neutron induced events. The detector will be located roughly 60 meters from the SNS proton target. with the beam entering the target area at 12:00, OscSNS would be placed at 10:00, so in the backward direction from the target.

The detector will consist of a 12 meter diameter steel tank, similar to MiniBooNE[4], with a 50 cm thick veto region which surrounds the fiducial volume which is seperated by an optical barrier. The fiducial volumes outer surface is lined with 3502 10 inch photomultiplier tubes whose photocathodes cover 25% of the surface area. The tank is under three meters of earth overburden to suppress the rate of cosmic rays entering the tank.

The target material will be organic mineral oil (CH_2) which contains carbon in the naturally occuring stable isotopes, ^{12}C (98.9%)and ^{13}C (1.1%). The mineral oil will be lightly doped with bPPD wave shifter to enhance scintillation light from non-relativistic particles.

The detector is able to discriminate between electrons (or gammas) and neutrons with high efficiency by looking for a Cherenkov cone in the prompt light and the overall level of delayed scintillator light.

Neutrino Processes

There are a number of neutrino processes of interest that will occur in the OscSNS detector. Table 1 lists some of them and their respective DAR flux averaged cross sections. The simplest is νe elastic scattering[5], whose cross section is known from the standard model. That process will allow the determination of the overall flux of neutrinos from the target with very little theorectical uncertainty.

There are also a number of reactions involving the carbon nuclei. The ^{12}C nucleus, a 0^+ state, will transition to the ground states of ^{12}N and ^{12}B via neutrino and anti-neutrino charged current reactions respectively. Those ground states will subequently decay and readily identify the reaction uniquely. The the nuclear matrix element for those processes is well determined by the inverse beta decay rate, and thus they will serve as a good constraint on the flux of neutrino and anti-neutrinos in the beam.

In the inclusive electron/positron spectrum from neutrino interactions, the dominant component will be events due the ground state ^{12}N transition, the next highest rate will be due to excited ^{12}N states, which are unstable to proton emission. Finally, there are a small fraction of the events due to νe elastic scattering which are easily distinguished by their alignment with the beam direction. Here, OscSNS would have a significant advantage over LSND because of the absence of cosmic rays due to the extremely small duty ratio at the SNS.

Neutrino Oscillation Measurements

Neutrino number of oscillation searches could be performed with OscSNS by using the SNS neutrino source. There are two measurements where the OscSNS experiment could significantly advance the knowledge in the area of neutrino

oscillations. The first is in repeating the LSND $\bar{\nu}_e$ with much higher statistics, and the second is to perform the first ν_μ disappearance search using the mono-energetic, 29 MeV ν_μs from π^+ decay at rest.

The most sensitive measurement to date was performed by the LSND experiment[6], where and unexplained excess of $\bar{\nu}_e$ events was observed in the inverse neutron decay $\nu_e p \rightarrow e^+ n$. The data was analyzed under the hypothesis of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$where an oscillation probability of 0.26% was observed.

The OscSNS, with a duty ratio 1000 times smaller, 5 times more fiducial mass, 2 times higher flux, and almost no decay-in-flight background, would make a far more sensitive measurement than LSND in the $\bar{\nu}_e$ appearance mode.

The mono-energetic ν_μ neutrinos from π^+ decay at rest are seperated in time[2] from most of the neutrinos of μ^+ decay at rest. With an energy of 29 MeV they are well below the threshold for charged current interactions. They can however interact through the neutral current reaction, $\nu_\mu^{12}C \rightarrow \bar{\nu}_\mu^{12}C(1511)$.

This is a unique situation in the sense that one could observe a neutral current reaction and at the same time know precisely the energy of the neutrino causing it. Any oscillations between active neutrinos do not disturb the rate of NC interactions, which are independent of flavor. However, should there be a transition to a sterile state, it is possible to observe this as a function of distance by merely observing the interaction rate as a function of distance from the source, i.e. every distance corresponds to a unique L/E or quantum mechanical phase advance of the neutrino mass state.

CONCLUSION

In conclusion, the OscSNS experiment would be able to measure a number of interesting neutrino cross sections and explore non-statndard oscillation scenarios in a relatively background-free environment as compared to LSND. The neutrinos will be produced regardless of whether or not a neutrino experiment is present to utilize them.

REFERENCES

1. E. D. Church, K. Eitel, G. B. Mills and M. Steidl, Phys. Rev. D **66**, 013001 (2002) [arXiv:hep-ex/0203023].
2. G. T. Garvey *et al.*, Phys. Rev. D **72**, 092001 (2005) [arXiv:hep-ph/0501013].
3. C. Athanassopoulos *et al.* [LSND Collaboration], Nucl. Instrum. Meth. A **388**, 149 (1997) [arXiv:nucl-ex/9605002].
4. A. A. Aguilar-Arevalo *et al.* [MiniBooNE Collaboration], Nucl. Instrum. Meth. A **599**, 28 (2009) [arXiv:0806.4201 [hep-ex]].
5. L. B. Auerbach *et al.* [LSND Collaboration], Phys. Rev. D **63**, 112001 (2001) [arXiv:hep-ex/0101039].
6. A. Aguilar *et al.* [LSND Collaboration], Phys. Rev. D **64**, 112007 (2001) [arXiv:hep-ex/0104049].