Opportunities for Neutrino Physics at the Spallation Neutron Source

A. Bolozdynya, F. Cavanna, G. Greene, Y. Efremenko, A. Hatzikoutelis, R. Hix, J. M. Link, W. C. Louis, D. Markoff, P. Mueller, K. Patton, K. Scholberg, C. Virtue, J. Yoo

We point out here unique opportunities for physics using the neutrino source provided by the Spallation Neutron Source (SNS). While designed as a neutron source, neutrinos are produced as a free by-product, and this neutrino source is of exceptional quality. The SNS protons on target produce numerous pions, which stop in the target and decay at rest, yielding monochromatic 30 MeV ν_μ from pion decay at rest, followed on a 2.2-μs timescale by $\bar{\nu}_\mu$ and ν_e with a few tens of MeV from μ decay; there should be very little contamination from decay-in-flight pions, and hence the spectral uncertainties are small. Flavor content uncertainties are also small, as the fraction of neutrinos originating from π^+ is high. The expected ν flux is $\sim 10^7$ cm^{-2}s^{-1} per flavor. The short-pulse time structure is excellent for neutrino experiments, with 60 Hz of sub-μs pulses providing a 10^{-3}-10^{-4} background rejection factor [1].

A rich program of physics is possible with such a stopped-pion ν source. One possibility is a search for sterile neutrino oscillation, a topic of recent interest [2, 3]; this is addressed in a separate contribution. We point out here additional measurements, complementary to the sterile oscillation studies (and potentially sharing resources) [4].

The SNS is ideal for measurements of ν-nucleus cross sections in the few tens-of-MeV range in a variety of targets relevant for supernova neutrino physics. This territory is almost completely unexplored: so far only ^{12}C has been measured at the $\pm 10\%$ level [5, 6]. The ν spectrum matches the expected supernova spectrum reasonably well (see Fig. 1); the slightly harder stopped-pion spectrum makes for higher event rates.

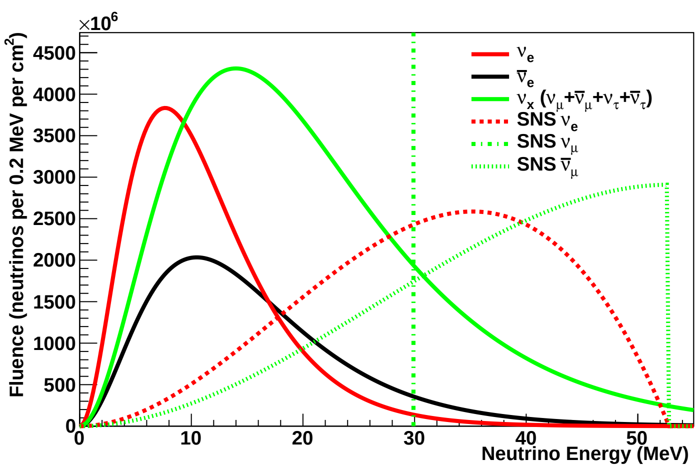

Figure 1: Left: Typical expected supernova spectrum; fluence integrated over the $\sim$15-second burst. Right: SNS spectrum; integrated fluence for one day at 30 m from the SNS target.

Understanding of ν-nucleus interactions in this regime is vital for understanding of supernovae: core-collapse dynamics and supernova nucleosynthesis are highly sensitive to ν processes. Neutrino-nucleus cross section measurements will furthermore enhance our ability to extract information about ν mixing properties (in particular, mass hierarchy) from the observation of a Galactic supernova ν burst, via understanding of both the supernova itself and of the ν detection processes. The highest-priority targets for which to measure cross sections are argon (relevant for current and planned detectors like Icarus, MicroBooNE and LBNE), lead (relevant for the new detector HALO), water (relevant for water Cherenkov detectors) and carbon (relevant for scintillator detectors).

Such measurements have previously been proposed for the SNS [7], which offers the excellent duty factor desirable for rejection of background. Recently interest is reviving for measurements there [8].

Another interesting possibility for a stopped-pion source is the detection of nuclear recoils from coherent elastic ν-nucleus scattering, which is within the reach of the current generation of low-threshold detectors [9]. This reaction is also important for supernova processes and detection. This measurement also has excellent prospects for Standard Model tests; even a first-generation experiment has sensitivity beyond the current best limits on non-standard interactions of neutrinos and quarks [10].

What major scientific discoveries have occurred in your research area since the 2007 LRP was drafted?

There have in fact been no neutrino-nucleus interaction measurements in the tens-of-MeV energy regime in the past few years. However, these measurements are more motivated than ever, given the huge recent progress in core collapse simulation [11], and new prospects for large underground detectors for supernova neutrinos. In particular, the new lead detector HALO is now online [12], and argon has been chosen as the technology for LBNE. There has also been as yet no successful detection of coherent neutrino-nucleus scattering, although dark matter detection technology, sensitive to low-energy recoils, has made enormous progress in the past decade [13].[1]

What compelling and unique science is to be done in the next 5 years?

The next five years could see the first measurements of charged-and neutral-current neutrino-nucleus interactions in several nuclei, with modest-scale experiments (*e.g.* [14, 12, 15]), as well as the first detection of coherent elastic neutrino-nucleus scattering (*e.g.* [16, 17]) and new constraints on (or discovery of) beyond-the-Standard-Model physics. There are also interesting prospects for hidden sector experiments [18].

What science would you expect to pursue in the program in 2020 and beyond?

Beyond the next five years, we could pursue upgrades to the experiments listed above. For supernova-relevant interactions, the list of potential targets will likely not be exhausted for measurements at better than the 10% level.[2] There are furthermore possibilities to test the Standard Model (*e.g.* [14, 19]) with precision cross-section measurements. For coherent elastic scattering, second-generation experiments at the $\sim$ton scale could probe nuclear physics, and potentially measure neutron density distributions [20, 21].

What is the international context, and how does it affect your vision?

There is broad community interest in the topic of supernova neutrinos, and a number of international collaborations would be "customers" for cross-section measurements [22].

There is no existing program for measurements, although the J-PARC spallation source could potentially host an experiment (beam timing characteristics are worse), as could the planned European Spallation Neutron Source, for which there have been some discussions [23]. The DAEδALUS program now under development also plans cyclotrons dedicated to producing stopped-pion neutrinos for physics including the topics above [24]. However the high duty factors expected for DAEδALUS would make surface neutrino experiments challenging. There is no other high-intensity short-pulse source planned for the near future. **The SNS is currently the world's best neutrino source of this nature and will likely remain so for at least a decade.**

[1] We note that for sterile oscillation searches are now highly motivated by several recent results.

[2] We note that the occurrence of a nearby core-collapse supernova would increase the urgency for precision measurements of relevance for interpreting the signal.

References

[1] F. T. Avignone and Yu. V. Efremenko. "Neutrino nucleus cross-section measurements at intense, pulsed spallation sources." *J. Phys.* **G29**, 2615–2628 (2003).

[2] K.N. Abazajian, M.A. Acero, S.K. Agarwalla, A.A. Aguilar-Arevalo, C.H. Albright, *et al.* "Light Sterile Neutrinos: A White Paper." (2012). `arXiv:1204.5379`.

[3] OscSNS Collaboration URL `http://www.phys.ufl.edu/~hray/oscsns/`.

[4] Yu. Efremenko and W.R. Hix. "Opportunities for Neutrino Physics at the Spallation Neutron Source (SNS)." *J.Phys.Conf.Ser.* **173**, 012006 (2009). `arXiv:0807.2801`.

[5] L. B. Auerbach *et al.* (LSND). "Measurements of charged current reactions of ν_e on C-12." *Phys. Rev.* **C64**, 065501 (2001). `hep-ex/0105068`.

[6] B. Armbruster *et al.* (KARMEN). "Measurement of the weak neutral current excitation C-12(ν_μ,ν'_μ)C*-12(1+,1,15.1-MeV) at E(ν_μ) = 29.8-MeV." *Phys. Lett.* **B423**, 15–20 (1998).

[7] NuSNS collaboration. "The νSNS Experiment." (2005). URL `http://www.phy.ornl.gov/nusns/`.

[8] "Workshop on Neutrinos at the Spallation Neutron Source." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop`.

[9] K. Scholberg. "Prospects for measuring coherent neutrino nucleus elastic scattering at a stopped-pion neutrino source." *Phys. Rev.* **D73**, 033005 (2006). `hep-ex/0511042`.

[10] K. Scholberg, T. Wongjirad, E. Hungerford, A. Empl, D. Markoff, *et al.* "The CLEAR Experiment." (2009). `arXiv:0910.1989`.

[11] R. Hix. "Why core-collapse people like the SNS." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/hix.pdf`.

[12] C. Virtue. "The merits of lead as a supernova neutrino target." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/virtue.pdf`.

[13] V. Chepel and H. Araujo. "Liquid noble gas detectors for low energy particle physics." (2012). `1207.2292`.

[14] Y. Efremenko. "Neutrinos at the SNS." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/efrementko.pptx`.

[15] F. Cavanna. "Supernova neutrino detection in LAr-TPC and the quest for ν-Ar cross-sections." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/cavanna.pdf`.

[16] J. Yoo. "Coherent elastic scattering in argon." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/yoo.pdf`.

[17] A. Bolozdynya. "Neutrino coherent scattering in liquid xenon." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/bolozdynya.pdf`.

[18] A. Hatzikoutelis. "Hidden sector particles at the SNS." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/hatzikoutelis.pdf`.

[19] V. Gudkov. "Test of the standard model and neutrino-deuteron cross-sections." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/gudkov.pdf`.

[20] P.S. Amanik and G.C. McLaughlin. "Nuclear neutron form factor from neutrino nucleus coherent elastic scattering." *J.Phys.G* **G36**, 015105 (2009).

[21] K. Patton. "Neutrino-nucleus coherent scattering as a probe of neutron density distributions." (2012). URL `http://www.phy.duke.edu/~schol/sns_workshop/talks/patton.pdf`.

[22] K. Scholberg. "Supernova Neutrino Detection." (2012). `arXiv:1205.6003`.

[23] "Workshop on Neutrino, Neutron, Nuclear, Medical and Muon Physics at ESS." (2009). URL `http://indico.hep.lu.se/conferenceDisplay.py?confId=896`.

[24] J. Alonso, F.T. Avignone, W.A. Barletta, R. Barlow, H.T. Baumgartner, *et al.* "Expression of Interest for a Novel Search for CP Violation in the Neutrino Sector: DAEδALUS." (2010). `arXiv:1006.0260`.