COHERENT LOI 2: Far-Future COHERENT physics program at the SNS

COHERENT Collaboration

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NF Topical Groups:

☐ (NF1) Neutrino oscillations
■ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
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Abstract: We present a vision of a precision coherent elastic neutrino-nucleus scattering experimental program to take place at the Spallation Neutron Source. The beyond-the-standard-model searches that are envisioned aim to place tight constraints on neutrino properties, new mediators in neutrino-nucleus interactions, and sterile neutrinos.

Introduction

Coherent elastic neutrino-nucleus scattering (CEνNS) is a precisely theoretically-predicted cross-section, known to better than 0.5% for even-even nuclei in the Standard Model. Thus, full coherence precision measurements of the process can provide stringent tests of physics beyond the standard model (BSM); however, the interaction is challenging to detect. Due to the small weak charge of the proton, the coherence results in an enhanced neutrino-nucleon cross-section that is approximately proportional to N^2. Coherence is only satisfied when the initial and final states of the nucleus are identical, limiting this enhancement to neutral current scattering. The coherence condition, where the neutrino scatters off all nucleons in a nucleus in phase, is also only maintained when the wavelength of the momentum transfer is larger than the size of the target nucleus. High coherence for all scatters is only guaranteed for low momentum transfers. As a result, the experimental signature for the process is a difficult to detect keV-recoil for most nuclear targets, requiring a unique combination of the right source of neutrinos and detector technology.

Precision Neutrino-Nucleus Interactions

A precision CEνNS program will necessarily require high-statistics experimental configurations. The recent successes of the COHERENT collaboration of the first two CEνNS measurements (on CsI and Ar) [1, 2] with only $\sim$10 kg of detector mass each, still resulted in $\sim$100 counts each per year at the Spallation Neutron Source (SNS)—a stopped pion source that currently has the brightest pulsed neutrino flux available. The size of the current and next generation experiments is limited by the space available in *Neutrino Alley*, a narrow underground hallway at the SNS, which constrains the statistical precision for CEνS measurements that can be achieved. Fortunately, the SNS is currently planning for a Second Target Station (STS) to the facility–a process which could include the incorporation of a larger, dedicated experimental neutrino space [3]. With such a space, a true precision CEνNS program can be envisioned, but action must be taken soon to ensure a neutrino laboratory is included.

A diverse array of BSM searches is open to the precision-capable (<1%) experimental program of CEνNS measurements. A high-statistics measurement of the cross-section on multiple targets will test for non-standard neutrino interactions, which may depend on the quark makeup of the nucleus [4, 5]. The cross-section is sensitive to the magnitude of the nuclear weak charge at low momentum transfer [6]. A precision measurement of the cross-section that suppresses systematic uncertainties with a judicious choice of targets will be a sensitive test of physics above the weak scale. It is a sensitive probe for a hypothetical "dark" Z mediator–a possible explanation for the $(g-2)\mu$ anomaly–ultimately achieving a precision for the weak mixing angle comparable to other low-energy techniques. The interaction rate is sensitive to the magnitude of the neutrino magnetic moment [7] causing the recoil distribution to rise rapidly at the lowest energies for coherent scattering, a signature which provides a strong lever arm for improving experimental sensitivities. Furthermore, a measurement capable of separating CEνNS interactions from different flavor neutrinos has the potential to experimentally determine the effective neutrino charge radius [8]. Lastly, a high-statistics measurement at two baselines, possibly from two stopped-pion sources, would allow for a sensitive neutral current disappearance search for sterile neutrinos [9, 10].

The aim of the COHERENT collaboration is to build on the success of the current generation of experiments, to learn from the near-future experiments that are planned or are being built, and to leverage the opportunity of deploying to a larger space in the STS in order to reach the sub-% level precision. The time to engage with the SNS is now, during the developmental stage of this marquee facility before its expected commissioning in 2028.

Far-Future Experimental Program

The program described here should include a detector systems with very low energy thresholds and superior energy resolution, such as can be achieved with P-Type Point Contact germanium detectors, or cryogenic crystal scintillators. The experimental signatures in the recoil spectrum due to large neutrino magnetic moments or extra light Z' mediators is most dramatic at low nuclear recoil energies, which is also the region where coherence losses due to the finite size of the nucleus are minimal. Thus, large-mass, low-threshold detector systems that will be maximally sensitive near threshold are needed. Because the recoil energy spectrum for these signatures has only weak dependence on stopped-pion beam time structure, typically a timing response on the order of 1-2 μs in order to reject accidental backgrounds is required.

Precision tests of the magnitude of the CEνNS cross-section will require large monolithic detector systems for which the sensitive target mass can be well characterized, such as single-phase liquid argon or neon scintillation detectors. The use of light nuclei minimizes the impact of coherence-loss due to the nuclear form factor. Furthermore, even-even nuclei avoid the complication of the relatively poorly predicted axial component contributions to the cross-section. The timing resolutions of such systems facilitate the separation of the prompt ν_μ and delayed ν_e and $\bar{\nu}_\mu$, and are then also sensitive to flavor differences in the cross-section, such as may arise due to the effective neutrino charge radius.

Finally, any total cross-section measurement campaign must also account for the poorly understood production rate of neutrinos at the source–currently estimated with an uncertainty of 10%. This could be achieved with a larger deployment ($\sim$ 10T) of a flux-calibrator, an example of which is the D_2O system currently being planned [11]; although the theoretical precision on deuterium is currently limited at the 2-3%. Alternatively, this common systematic can be accounted for by measuring the ratio of the CEνNS cross-section in two light, even-even nuclei, such as neon and argon.

Summary

The COHERENT collaboration is looking beyond the next generation of CEνNS experiments ($\sim$1 T-scale) at the SNS in support of a multi-faceted program of precision BSM tests with $\sim$10 T-scale detectors [3]. Engagement with the SNS at this stage in the development of the STS is required while more precise detector and facility specifications are being developed to match the planned experimental goals with onsite capabilities.

1 References

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