COHERENT LOI 3: COHERENT Sensitivity to Dark Matter

COHERENT Collaboration

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NF Topical Groups:

☐ (NF1) Neutrino oscillations
☐ (NF2) Sterile neutrinos
■ (NF3) Beyond the Standard Model
☐ (NF4) Neutrinos from natural sources
☐ (NF5) Neutrino properties
☐ (NF6) Neutrino cross sections
☐ (NF7) Applications
■ (TF11) Theory of neutrino physics
■ (NF9) Artificial neutrino sources
■ (NF10) Neutrino detectors
■ (CF1) Dark Matter: Particle-Like

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Abstract: Since the COHERENT experiment made the first observation of coherent elastic neutrino-nucleus scattering (CEvNS) in 2017, we have continued to better understand neutrino scattering at low-Q^2. Additionally, detectors made to study CEvNS are capable of pursuing compelling dark matter constraints. We outline here the strategy for using low threshold detectors to search for an accelerator-produced dark matter flux consistent with the cosmological dark matter concentration. This detection method is most sensitive for dark matter masses ∼15 MeV/c^2.

1 Introduction

Known standard model particles only account for roughly 20% of gravitationally-interacting matter [1]. The particle nature of the remaining dark matter is yet to be determined. Experiments searching for astrophysical WIMPs have consistently improved constraints, but typically lose sensitivity at dark matter masses below $\sim$1 GeV/c^2 [1]. However, these lower masses are easily accessible with terrestrial laboratories, leading to several efforts to detect a sub-GeV mass WIMP at accelerators.

Apart from studying CEvNS, accelerator-based experiments capable of detecting low-energy nuclear recoils are also sensitive to such dark matter particles [2]. A flux of dark matter particles would interact leaving a nuclear recoil signature but with a spectrum characteristically different from CEvNS in recoil energy and time. Further, at low energy transfer, the interaction is coherent, analogous to the CEvNS signal, giving a large cross section which allows for ambitious constraints using a detector of modest scale.

2 Dark Matter at the Spallation Neutron Source (SNS)

Below masses of $\sim$1 GeV/c^2, WIMP dark matter interacting directly with matter is not viable [3]. However, it is possible for such light dark matter particles to interact with matter through a new force, mediated by a "portal" particle, V, [4]. The SNS produces neutrinos in high intensity $p-$Hg collisions through the decay at rest of $\pi^+ \to \mu^+\nu_\mu$ and $\mu^+ \to e^+\nu_e\bar{\nu}_\mu$, yielding a prompt flux of ν_μ coincident with the SNS beam pulse, FWHM = 340 ns, and a flux of ν_e and $\bar{\nu}_\mu$ delayed by $\tau_\mu = 2.2$ μs. The neutrino flux from these decays-at-rest is isotropic. Portal particles may be frequently produced at the SNS, predominantly through the decay $\pi^0 \to V\gamma$, which would in turn decay to a pair of dark matter particles. As dark matter is produced through decay in flight, any observed scatters would be coincident with CEvNS from the prompt ν_μ flux.

Within this benchmark model [2], the relic abundance of observed dark matter can be calculated and directly tested. Further, this scheme would directly detect dark matter particles, allowing for the scattering properties of any detected DM-like excess to be compared against theoretical predictions.

CEvNS scatter from the ν_μ flux and beam-uncorrelated backgrounds are the dominant backgrounds to the dark matter search. The beam-uncorrelated background can be measured directly using data out-of-time with the beam. Systematic uncertainties on the neutrino flux and detector modeling can be constrained using CEvNS from the delayed flux [5]. This improves understanding of the ν_μ CEvNS background in the prompt dark matter ROI giving a convenient control sample for understanding beam background in-situ in a manner unique to this detection method.

3 COHERENT Plans for Constraining Dark Matter

We propose a phased approach for searching for dark matter using two successive argon scintillation calorimeters to be designed and deployed the SNS. The ultimate sensitivity of this approach to a accelerator-produced dark matter flux is beyond the flux that would be expected from the cosmologically observed dark matter concentration within the benchmark model for dark matter masses between 4 and 100 MeV/c^2 with optimal sensitivity at 15 MeV/c^2. These detectors will allow parallel investigation and precision tests of CEvNS on argon. Argon is an attractive detection material due to its $\sim$20 keV$_{\text{nr}}$ threshold, relatively low background, and scalability.

For the first stage, a designed argon detector with 610 kg of fiducial mass would be built and assembled at the SNS. Next, this detector would be upgraded by filling with underground argon [6], which can reduce the largest background, ^{39}Ar decay, by over two orders of magnitude.

The final stage involves a 10 ton detector in conjunction with the commissioning of the second target station (STS) at the SNS [7]. The detector would be placed on the axis of the STS utilizing the forward bias of the dark matter flux [5]. If dark matter is detected, the two target stations at the SNS would allow simultaneous measurement of the dark matter scatter rate from two different off-axis angles. This would give an invaluable test of the angular dependence of the excess which could differentiate between a boosted dark matter flux and the isotropic neutrino flux. This detector would require the construction of a shielded experimental hall with no open-air connection to the neutron source location. We continue to interface with ORNL to plan a suitable site. The ultimate reach of this detector can test the couplings required to explain the relic dark matter flux for scalar dark matter masses between 3 and 100 MeV/c^2 [6].

4 References

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