Snowmass2021 - Letter of Interest

Instrumentation and R&D for the Global Argon Dark Matter Collaboration

Thematic Areas: (check all that apply □/■)
■ IF1: Quantum Sensors
□ IF2: Photon Detectors
□ IF3: Solid State Detectors and Tracking
□ IF4: Trigger and DAQ
□ IF5: Micro Pattern Gas Detectors (MPGDs)
□ IF6: Calorimetry
□ IF7: Electronics/ASICs
■ IF8: Noble Elements
■ IF9: Cross Cutting and Systems Integration
□ (Other) *[Please specify frontier/topical group]*

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Abstract: Great interest attaches to the possibility of dark matter direct detection experiments combining large sensitive mass with sensitivity to the directions of detected WIMPs. Members of the GADMC are engaged in continuing experimental and theoretical research to explore how this might be achieved in liquid argon. Possible methods could involve applying different drift fields, extending the recoil energy range, modifying the electron thermalization with additives to the LAr [1], or other methods suggested by theory/simulation.

Snowmass Letter of Intent
Recoil Directionality as a Definitive Signature of Particle Dark Matter

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The nature of the dark matter is one of the major outstanding problems of both astrophysics and particle physics [2].

Direct detection experiments aim to detect hypothesised WIMP dark matter particles via their elastic scattering off of target nuclei in the laboratory. Specifically, experiments look for the tiny energy deposited in the detector material by the recoil nucleus. Like any counting experiment, there are backgrounds which are indistinguishable event-by-event from the sought after WIMP signal.

An unambiguous detection of dark matter in the form of WIMP particles requires a definitive signature connecting the observed signal to the cosmos, and excluding neutron interactions or other backgrounds. Various possibilities for such a signature exist. For a simple, nucleon-spin-independent WIMP-nucleus interaction, the energy-integrated recoil event rate is proportional to the square of the neutron number [3]. The recoil energy spectrum also has a definite dependence on target mass number. Therefore one widely discussed potential sinature would be the consistency of integrated event rates and/or spectra measured in two or more experiments with different target nuclei, suitably corrected for detector threshold response [4]. Making unambiguous inferences from this signature would require a large number of events with both targets, a thorough understanding of the respective background environments, and accurate calculations of the respective nuclear form factors.

Other signatures result from the WIMP velocity distribution in the rest frame of the Earth [5, 6]. In the default isothermal sphere halo model, the WIMPS have a thermal velocity spectrum with zero average velocity and zero net rotation in the rest frame of the galaxy. Since the solar system revolves around the galactic center while the Earth revolves around the Sun and rotates on its axis, this model (or any other model with a WIMP halo that does not follow the Earth around) predicts other potential signatures due to the motion of the Earth relative to the halo.

At any instant of time, antiparallel to the resultant velocity of the Solar System around the Galactic Center there blows a "WIMP wind" on Earth, a preferred direction in galactic coordinates from which the WIMPs appear to emanate. At the present epoch, this wind should appear to originate from a point in the constellation Cygnus.

The wind is stronger (and hence the WIMP flux is higher) at times when the orbital speed of the Earth around the Sun is parallel to that of the solar system around the Galactic Center, and lower when these are antiparallel. The flux modulation should give rise to an (<10%) annual modulation of the WIMP-nucleus interaction rate. The DAMA/LIBRA collaboration has has in fact reported such a modulation. Despite ample statistics, as well as amplitude, frequency, and phase consistent with the expectations of the isothermal sphere halo model, that measurement has not been widely interpreted by the physics community as evidence for dark matter. This is partly because of the possibility that the modulation could be due to annual modulation of some unidentified background, rather than WIMP flux. It is clear that the wide acceptance of a dark matter detection claim requires a less ambiguous signature.

A possible origin for such a signature was discussed long ago [5, 6]. The rotation of the Earth on its axis causes the WIMP wind direction to rotate in the lab at the sidereal rate, just as stars in the sky appear to rise and set daily. If a measurable signal disclosing this direction could be found, it would provide the most robust signature currently known for the Galactic origin of a WIMP signal [7]. No known background can mimic this signal.

A number of projects are underway to seek recoil direction signatures by measuring the recoil tracks in gaseous detectors [8]. The present project seeks instead to leverage the large sensitive masses available with liquid noble gases and to find a direction-sensitive signature for these detectors [9]. We will search for an experimental signature of the recoil direction for WIMP-like interactions (principally neutron elastic scattering) in condensed media (principally liquid argon).

WIMP directional information is potentially available in dual-phase liquid noble gas Time Projection Chambers by exploiting columnar recombination [1]. Models suggest that the magnitude of the recombination effect should vary with the angle between the applied electric field (TPC drift field) and the recoil direction [10]. In liquid argon (LAr), energetic particles with track lengths of order $\sim$ mm are known to exhibit measurable signal variations depending on the track angle with respect to the drift field [11]. U.S. signers of this LOI were principals in the SCENE experiment [12], which searched for this effect in LAr at energies and track lengths characteristic of WIMP recoils ($\sim$10's of KeV and $\sim$100's of Angstroms), finding no unambiguous positive result within its limitations of statistics, recoil energy, and field strength. To continue these studies, we have participated in building a small, dedicated LAr-TPC called ReD [13] which is being operated by Italian groups at neutron beam facilities to extend the electric field studies. Future work searching for effects allowing direction-sensitive detection of WIMP recoils and could be carried out either in Italy or in the U.S.

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