Directional direct Dark Matter searches with gaseous TPCs

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Abstract

The presence of DM in the Universe is nowadays established, but still unexplained mystery. The determination of the incoming DM direction can provide an astrophysical correlation that offers an unique key for unambiguous identification of DM. Time Projection Chambers can supply the best observables for a directional DM searches and are today a mature technology aiming at the ton-scale. We will review current directional R&Ds effort and the CYGNUS proto-collaboration concept towards a large scale multi-site directional galactic observatory.

1 Introduction

The existence of an unknown gravitational source in the Universe, commonly referred to as Dark Matter (DM), has been extensively demonstrated through a plethora of astrophysical measurements (from cosmic microwave background to cluster and galaxy rotations, lensing and Big Bang nucleosynthesis and so on [1]). Among the different explanation, the existence of unidentified Weakly Interactive Massive Particles (WIMPs) is still a well motivated interpretation of these experimental observations. WIMPs can potentially be observed by three complementary approaches: they can be produced at particle colliders, their annihilation can give an indirect signal in astrophysics experiments or they can be directly detected on Earth through their elastic scattering with the common matter, due to our motion around the centre of the Galaxy.

The main experimental challenge of direct DM searches is to detect the very low energy (1-100 keV) expected DM-nuclear recoils and discriminate them from interactions induced by other particles, which have typically 10^6-10^9 higher rates. Classical background minimisation techniques are operation in deep underground laboratories (to suppress cosmic rays), use of radio-pure components (to avoid natural radioactivity) and active or passive shielding of the detector. Additionally, experiments exploit the different materials response to energy deposit of different particles to discriminate nuclear from electron recoils. Neutral particles, unfortunately, produce a detector response nearly identical to WIMPs, unless some additional topology or directional handle is employed for further discrimination. In large detectors with heavy dense targets, fast neutron with O(cm) mean free path can be suppressed by rejecting multiple scattering events and defining an internal fiducial volume, but at the price of reducing the active material sometimes even of 50%. Neutrinos, on the other hand, can not be shielded, nor are expected to multiple scatter. Current Xe-based experiment [2] (and several next generation detectors [3, 4]) will be sensitive to a new background coming from solar, atmospheric and diffuse supernovae neutrinos, that they will not be able to discriminate from WIMPs.

In this context, the incoming direction of the DM particle could provide an unique tool for DM identification, together with rejection of such annoying backgrounds [5]. The ordinary, luminous galactic matter in fact, including planets and stars and our Solar system as well, is concentric to the DM halo and rotating with an average orbital velocity of $\sim$ 220 km/s: this implies an apparent WIMP wind for an observer on the Earth, that creates two effects.

In its rotation around the Sun, the Earth orbital velocity is antiparallel to the DM wind in summer and parallel in winter, creating a seasonal modulation of the observed DM rates inside the detector. Unfortunately, since the Earth's orbital speed is small compared to the Sun speed with respect to the Galaxy rest frame, this modulation is expected to be only a few % and therefore very difficult to disentangle from systematic effects, such as possible seasonal dependence of the background rates. Consequently, its detection requires a large mass detector, able to stay very stable over a long period of time and to strongly suppress any background. The DAMA/LIBRA claim of DM observation [6] is based on the measurement of such annual asymmetry of the rate inside the detector.

A much more robust signature comes from the diurnal directional modulation of the DM signal. This originates from the orientation of solar system motion around the centre of our Galaxy, which happens to point towards the constellation Cygnus. Due to the Earth rotation around its axis, an observer on our planet would see the average direction of the WIMPs changing of $\sim 90^o$ for every 12 sidereal hours. This is a directional correlation with an astrophysical source that no background whatsoever can mimic. A detector sensitive to direction and sense of the arrival of particles can therefore hold the key to an unambiguous, positive observation of a DM signal. This holds true even in presence of an unknown amount of isotropic background, such as neutrons from environmental or detector materials radioactivity [7]. Directionality allows also to positively identify the Solar neutrinos thanks to the correlation with the Sun position in the sky, transforming this background (usually referredto as a "Floor") into an opportunity rather than a nuisance [8, 9]. Directionality information can furthermore discriminate between various DM halo models and provide constraints on WIMP properties, like no other non-directional detector [5, 10].

2 The case for directional DM searches with gaseous TPC

The main experimental challenges of DM detectors aiming at directional sensitivity are to instrument a large volume with high enough granularity to infer recoiling tracks direction down to low energy, while staying background-free. The spatial resolution required is ultimately set by the density of the target material, since it determines the characteristic length of a WIMP induced recoil, which in turn fixes the minimum energy threshold for which the track direction and orientation can be inferred and the electrons discriminated from nuclear recoils using topology information.

Although inherently challenging, gaseous TPCs constitute therefore the natural approach to directional DM searches and can potentially provide the best architecture and the best observables for the following reasons:

- A measurement of the total ionisation indicates the energy of the recoil. α particles and electrons can be easily identified comparing their track topology to the energy released along the path (i.e. dE/dx), providing excellent background rejection;

- The track itself indicates the axis of the recoil and the charge measured along its path encodes the track orientation, providing an additional powerful observable (usually referred to "head-tail" asymmetry, given that most charge is released at the start of the track at these energies). It has been in fact demonstrated how this information improves by a factor 10 the directional sensitivity of a detector, while a pure axial signal (the track orientation via 2D or 3D reconstruction) can in practice be washed-out by the WIMP velocity distribution [11];

- The active target volume can be made free of background-producing material: it contains only the gases, which can be purified of Radon (Rn) and recirculated. Large choice of gases can be employed in a TPC, from light to heavy nuclei, with both odd and even spins, therefore sensitive to both SI and SD interactions also in the low WIMP mass region;
- Only one wall of the detector needs to be instrumented with an amplification and readout systems, and the other with a cathode, leading to favourable cost-volume scaling and to reduced radioactive contamination due to the detector materials. Radon Progeny Recoils (RPRs) from such sources constitute, indeed, one of the most dangerous backgrounds for direct DM searches [12]. This happens when ^{222}Rn from internal detector radioactivity decays into ^{218}Po and the unstable positively charged ion ^{218}Po^{+} (80% of times), drifts and plates out on the cathode with the emission of a 6.11 MeV α particle. The geometry of this process implies an high probability for the α to be completely embedded in the cathode, leaving only the ^{218}Po recoiling in the fiducial volume and mimicking a WIMP interaction. In order to reject these events, the full 3D position of the track, including along the drift direction, needs to be reconstructed (a technique usually referred to as "fiducialization");
- TPCs up to 100 m^3 of active volume have already been sucessfully operated at the ALICE LHC experiment [13] and up nearly 20000 m^3 approved for construction in the neutrino field [14], showing the feasibility of very large detectors with large active masses;

In the following, we will review the current status of experimental R&D efforts for the development of TPCs for directional DM searches at large scale, and how these are working together as proto-collaboration towards the development of CYGNUS, a multi-site, multi-target Directional Galactic Recoil Observatory of DM and neutrinos at the ton scale.

3 Current R&D efforts

3.1 DRIFT: multi-wire proportional chambers with negative ion drift

The DRIFT collaboration [15] at the Boulby Underground Laboratory has pioneered since 2001 the construction and operation of the only existing directional DM TPC at 1 m^3 scale. The DRIFT II detector is composed of 2 back-to-back TPCs, each with 50 cm drift length, separated by 0.9 μm thick texturised mylar cathode, conveniently shaped to minimise recoils induced by materials radioactivity [16]. Gas amplification and readout is obtained with Multi Wire Proportional Chambers technique. DRIFT employs a 30:10:1 Torr CS_2:CF_4:O_2 gas mixture to obtain negative ion drift (NID).

NID is a peculiar modification of the TPC principle, suggested in 2000 by J. Martoff [17], in order to overcome the restrictions due to electron diffusion (since all DM TPCs lack of the magnetic field typically present in experiments at colliders). When an highly electronegative dopant is added to the gas mixture, primary electrons liberated by the track while ionising the gas are captured at very short distances $\leqslant$ 10-100 μm by the electronegative molecules, creating negative ions. These anions drift to the anode, where their additional electron is stripped and gives rise to a standard electron avalanche. Thanks to the anions mass being much larger than electrons, their diffusion is reduced to the thermal limit without the need of magnetic fields, achieving a dispersion of $\sim$1 mm/m (to be compared to $\sim$ 20 mm/m expected for conventional electron drift). This characteristic allows for the use of longer drift distances, combined with improved tracking performances. Recently, a new remarkable feature has been observed in negative ion gas mixtures: the presence of multiple charge carriers in the time signal, with different masses [18]. Since anions mobility depends on the mass, the difference in time of arrival of different anions effectively provides a measurement of the absolute position of the event along the drift direction. This feature allows to reject backgrounds coming from detector surfaces (an action typically referred to as *fiducialization*), a procedure not possible in self-triggering TPCs. The combination of the complete electron rejection (2×10^{-5} at 20 keV) with the fiducialization offered by the minority charge carriers in a negative ion TPC, allowed DRIFT to put the most stringent constraint from a directional detector on SD WIMP-nucleon proton coupling [19].

SF_6 has been recently demonstrated to work very well as negative ion gas between 20 and 100 Torr, including the possibility of high gains and fiducialization via minority SF_5^- charge carriers [20]. Recently, the feasibility of NID operation at nearly atmospheric pressure with He:CF_4:SF_6 at 360:240:10 Torr with triple thin GEMs amplification has also been demonstrated [21]. Compared to the high vapour pressure, low flash point and low explosive mixture in air of the CS_2 employed by DRIFT, SF_6 has the substantial advantages of much more safer handling, combined with easier Radon purification and recirculation [22], while at the same time increasing the target Fluorine mass.

Given the stronger avalanche fields required at the anode plane to achieve field ionisation with SF_6 with respect to CS_2 due to its higher electron affinity, DRIFT recently moved to development of an hybrid readout through the combination of 1 mm Thick GEMs (ThGEM, where the field ionization of the anions occur) with low capacitance 100 μm multi-wires at 1 mm pitch (through which the induced charge signals are readout) [23].

The detector used in this work has a 2 cm $\times$ 2 cm readout for 5 cm drift distance. The signal multiplication was induced by setting the opposite (induction) side of the ThGEM to a positive potential and biasing the wire at 0 V, in order for the avalanche electrons to induce equivalent current on the wires [24, 25]. These induced charge signals were used as avalanche electrons can reattach to SF_6 to form anions while drifting from the induction side of the ThGEM to the charge collection wires.

With X-rays produced by a ^{55}Fe source, gas gain was measured in the range of 1120 $\pm$ 90 to 2470 $\pm$ 160 at a reduced drift field E/N range of 56 Td (10$-$17 V cm^2) to 93 Td (10$-$17 V cm^2) in 20 Torr of pure SF_6 gas. αs from an ^{241}Am source allowed to determine drift velocity and reduced mobility of SF_6 anions in this same E/N range and found compatible with previous results.

Hence, the ThGEM-Multiwire technology has the potentials to serve as a robust, economic, low noise charge readout for future development of large scale directional TPCs.

3.2 NEWAGE: micro-pixelated chambers with single GEM amplification

The NEWAGE experiment main peculiarity is the use of micro-pixels chambers (μ-PIC) coupled to GEM to amplify and detect the track ionisation cloud [26]. μ-PIC can be built on monolithic, 100 μm thick printed circuit boards allowing easy scalability. μ-PIC gas amplification structures (70 μm-diameter anode electrodes with a 400 μm pitch) act also as a 2D pixel readout, thanks to the circular cathode strips with 260 μm diameter around them. The GEM is built onto a 100 μm-thick liquid crystal polymer, and the hole size and pitch are 70 μm and 140 μm, respectively. NEWAGE developed a custom DAQ system based on FPGA to record two data types: “charge” and “track”. An amplifier-shaper-discriminator chip collects the analog signals from the cathodes, grouping them into four channels. A flash ADC (FADC) records the waveforms from the four channels with 100 MHz sampling and from the summed waveforms (FADC-sum) the energy deposition of a charged particle is extracted (“charge”). The “track” data are extracted as the addresses and time-over-threshold (TOT) of all strips hit by an event.

The current version of the detector NEWAGE-0.3b” at the Kamioka Observatory has a readout area of 30.7 $\times$ 30.7 cm^2 coupled to a 31.0 $\times$ 32.0 cm^2 GEM, with 41 cm drift length. The target gas is pure CF_4 at 76 Torr and the gas gain with this setup is about 2500. NEWAGE-0.3b” demonstrated directional capability down to $\sim$ 50 keV (with head-tail sensitivity in the range 70-400 keV on a statistical basis) and $\sim 2.5 \times 10^{-5}$ gamma rejection at the same energy [27]. NEWAGE-0.3b” has been more recently equipped with an improved, low radioactivity version of μ-PIC, LAμ-PIC, developed to reduce the αs emission from the surface [28]. This was achieved substituting the surface exposed to the detection volume (originally made of polyimide reinforced with a glass cloth-sheet) with a new material combining polyimide and epoxy, which is a factor of hundred times less contaminated by ^{238}U and ^{232}Th. This allowed to reduce the background in the region [50, 100] keV of a factor 30 [29].

While LAμ-PIC contributed to a significant background reduction, ^{210}Po decay on the detector surface were still observed with an emission rate of (2.1 $\pm$ 0.5) $\times$ 10^{-4} α/cm^2/hr, contributing to backgrounds mainly located around the GEM, LAμ-PIC and cathode. These could be removed if the absolute Z coordinate of the track was measured, a feature not available with pure CF_4 in self-triggering TPCs. For this reason, NEWAGE collaboration recently developed a negative ion micro time projection chamber (NIμTPC) with detection volume of 12.8 $\times$ 25.6 $\times$ 144 mm^3 to study full 3D tracking, including fiducialization, with NID and SF_6 (see Sec.3.1). With αs from a ^{241}Am source and exploiting SF_5^- minority carriers, the NIμTPC showed capability of reconstructing the absolute Z coordinate between 39 mm and 139 mm distance from the anode with 16 mm uncertainty [30]. With the same setup, 3D tracking with absolute Z determination was demonstrated for the first time, with a spatial resolution of 130 μm for single hits. The NIμTPC results are therefore extremely promising in expanding the reach of directional DM searches.

Another very interesting recent advancement from the NEWAGE collaboration is the development of an innovative approach to field cage manufacturing, using a commercial resistive sheet [31]. Typical field cage are composed of field-shaping electrodes connected through a resistor chain. This design, however, causes some non-uniformity of the electric field near the borders, at a distance of about the width of the electrode. Moreover, the electrodes material (typically Cu) and the ceramic in the resistors exhibit an amount of radioactivity that can be dangerous for rare event searches. The material used for this study, Achilles-Vynilas, was selected among several candidates because of the better uniformity along 1 m, with a resistivity of 3.3 $\pm$ 0.3 $\times$ $10^{10}\Omega/\square$. Achilles-Vynilas foils are thin (200 μm), transparent, of easier assemble and with 2-3 order of magnitude less radioactivity than typical resistors. The measurement with cosmic muons showed a good tracking-performance even in the volume close to (20 mm) the field cage. This innovation can significantly benefit any TPC development, not only for DM searches.

3.3 D^3: pixel and Micromegas readout with thin GEMs amplification

The D^3 project is based on the use of a double (or more recently triple) thin GEM charge amplification coupled to ATLAS FE-I4B ASIC pixels readout (50 x 250 um^2 pixel size with 40 MHz sampling) [32]. Preliminary results with very small prototypes and Ar/He:CO_2 gas mixtures at 1 bar show the possibility of 150-200 um single point resolution for cosmic muons, few degrees angular resolution for α tracks and gain resolution of $\sim$ 9% at 5.9 keV$_{ee}$ [33]. With a 2.0 $\times$ 1.68 cm^2 pixel readout area for 15 cm drift length in a 70:30 mixture of He:CO_2, they demonstrated also the capability of extracting absolute Z measurement in electron drift gases with αs [32]. This is possible using charge cloud topology information and fitting it to extract the track diffusion during drift (from which the distance between the original track and the GEMs, i.e. absolute Z, is recovered). The precision achieved over mm-length α track segments is of $\sim$ 1 cm uncertainty over 15 cm drift distance.

Eight devices similar to this named BEAST TPCs, with 2.0 $\times$ 1.68 cm^2 readout area for 10 cm drift, are currently operating as fast neutron detectors at the Belle II experiment at SuperKEKB [34]. In this context, BEAST TPCs were optimized for the directional detection of fast neutrons, and operated at low gain in order to maximize operational stability in the high-background and high magnetic fields environment at SuperKEKB. As fast neutron detectors, BEAST TPCs demonstrated excellent angular resolution, energy resolution, and long term stability, exceeding all design goals [34]. Two recent PhD theses [35, 36] demonstrated that even at such low gain, the detectors have a nuclear recoil energy threshold of $\sim$ 10 keV and good particle identification capabilities above $\sim$ 10-20 keV.

Very recently the D^3 project started developing a scale up of the BEAST TPC to be operated as directional DM detector, with two back-to-back TPCs with 50 cm drift and 20 $\times$ 20 cm^2 readout area for a 40 L fiducial volume filled with He:CF_4:C_4H_{10}/CHF_3 mixtures at 1 bar and equipped with resistive strip Micromegas readout by SRS CERN system [37].

3.4 CYGNO and INITIUM: optical 3D readout with CMOS cameras and PMTs

The distinctive traits of the CYGNO and INITIUM approaches to directional DM detection is the optical readout of the secondary scintillation light produced together with electron avalanches by a triple thin GEMs amplification stage and the use of He:CF_4(:SF_6) mixtures at 1 bar for simultaneous sensitivity to both SI and SD interaction at O(GeV) WIMP masses. Tracks are reconstructed in 3D combining an high granularity 2D projection on the X-Y plane imaged by CMOS cameras with relative Z measurement offered by signal waveforms from PMTs [38]. The advantages of the using CMOS cameras resides in the lower noise with respect to CCDs (about 1/3), the single photon sensitivity and the possibility to decouple it from the target and image large areas with a single device by proper optics. The ERC Consolidator Grant INITIUM goal is to explore the feasibility of NID within such optical approach with a very modest doping of SF_6, and its development is therefore highly synergic with CYGNO's (which is on the contrary based on electron drift).

The larger prototype developed with this approach (LEMON) has 7 L active volume, with 20 $\times$ 24 cm^2 triple thin GEMs amplification and 20 cm drift length. In this configuration, the CMOS camera Orca Flash (2048 $\times$ 2048 pixels with an area of 6.5 $\times$ 6.5 μm^2 each) equipped with a Schneider lens (25 mm Focal Length, 0.95 aperture), is placed at a distance of 52.5 cm, so that each pixel images an effective area of 130 $\times$ 130 μm^2. LEMON results in the following have been all obtained with He:CF_4 60:40 gas mixture at 1 bar. Studies are on-going to develop NID within this context.

In order to estimate the energy threshold and resolution, the sensor electronic noise and the response to ^{55}Fe was studied with LEMON [39]. For the first, the distribution of the number of pixels counting fake clusters (i.e. ghosts) reconstructed in data collected with the camera shutter closed was studied. From this, a threshold of a total of 400 photons collected was established, in order to ensure a fake events rate $\leqslant$ 10 per year. From the study of ^{55}Fe events, LEMON response is measured to be 1200 photon/cluster, i.e 1 photon each 5 released eV, with 15% energy resolution at 5.9 keV$_{ee}$. Therefore, the 400 photons threshold extracted from the noise study, with such 0.2 photon/eV sensitivity determined with ^{55}Fe, represent an energy threshold of 2 keV. By visual inspection of the fake clusters, is moreover easy to see how pattern recognition algorithms could easily reject a significant portion of ghosts, effectively lowering the energy threshold estimated in this way.

With LEMON, the possibility to determine the absolute Z position of the event in electron drift was studied with 450 MeV electrons from the Frascati BTF facility, extracting from the recorded CMOS images and PMT waveforms the track diffusion during drift (a technique similar to the one discussed in Sec.3.3). The transverse recorded light profile, in fact, possess a Gaussian shape with the total light being proportional to $\sigma_{light} \times$ A$_{light}$ (where σ_{light} is the sigma and A$_{light}$ the amplitude of the Gaussian). The ratio $\eta_{light} = \sigma_{light}/\mathrm{A}_{light}$ is found to increases linearly with the drift distance and can be therefore used to evaluate the absolute Z with about 15% uncertainty over 20 cm drift distance [40].

In order to study within the CYGNO/INITIUM approach the nuclear recoils reconstruction efficiency at low energies and the capability to distinguish them from electron recoils, Ambe and ^{55}Fe sources were employed in LEMON. The iDBSCAN algorithm with multiple iteration (based the well-known Density-Based Spatial Clustering of Applications with Noise) was developed to select track with different ionization patterns. With iDBSCAN and exploiting very simple topological information, a natural radioactivity background rejection in the energy region around 5.9 keV$_{ee}$ of 10^{-3} was obtained, with 40% nuclear recoil efficiency [41]. While these results are already encouraging, the collaboration is working on a more sophisticated multivariate approach, with which rejection can significantly be improved.

The CYGNO/INITIUM collaboration recently manufactured a larger, 50 L prototype (LIME), imaged by a single sCMOS and a 4 small PMT and with same dimensions (33 $\times$ 33 cm^2 readout area for 50 cm drift) of a single module of the 18 foreseen for the CYGNO/INITIUM 1 m^3 detector (already funded). LIME goals are in fact to verify in an underground environment and on realistic dimensions the performances expected for 1 m^3 detector, while at the same time test part of the materials and construction techniques and also provide a precise, spectral and directional measurement of the underground environmental neutron flux. Overground commissioning of LIME is ongoing, and already established detector stability at nominal operational values similar to LEMON and an energy resolution of 15% along the whole drift volume at 5.9 keV$_{ee}$ from ^{55}Fe events.

4 CYGNUS: a multi-site, multi-target Directional Galactic Recoil observatory of DM and Neutrinos at the ton scale

The CYGNUS project is a new international collaboration formed by nearly all the members of the experimental efforts described in Sec. 3. CYGNUS aim is to develop a large modular Galactic Recoil Observatory that could test the DM hypothesis beyond the Neutrino Floor and measure galactic Neutrinos. The key features of the proposed experiment is a modular design of recoil sensitive TPCs filled with He:SF_6(:CF_4) (low and high pressure operations envisaged, as well as electron or negative ion drift) with full fiducialization and energy and directional threshold at O(keV) and installation in multiple underground sites (including the Southern Hemisphere) to minimise location systematics and improve sensitivity. A coordinated R&D effort to optimise technologies and gas mixture choices is currently undergoing in several laboratories in the participating countries, as can be seen by the studies discussed in each subsection of Sec. 3.

The proto-collaboration recently developed an comprehensive feasibility study for a 1000 m^3 detector, based on MC simulation backed up by experimental measurements [42]. In this, in addition to the DM and Neutrinos physics cases, a detailed simulation of six different charge readout options with NID and the study of their electron recoil discrimination and directional capabilities are discussed. Furthermore, foreseen external and internal backgrounds and engineering requirements are examined. From a cost/benefit study, taking into account costs, directional performance at low recoil energies and intrinsic radioactivity content, the strip readout technologies emerges as the best choice in a NID context with SF_6 as dopant.

The simulations presented in [42] indicate moreover the possibility of electron rejection down to 1 keV_{ee} in an atmospheric pressure He:SF_6 mixture. By simply exploiting the measured track length versus energy released, background discrimination can exceed 10^6 at 5 keV_{ee} for fluorine, and 10 keV_{ee} for helium. A preliminary investigations with deep learning neutral networks suggest that this can be improved upon by several orders of magnitude. A ton-scale 'Cygnus-1000' detector, with the characteristics discussed in [42], would have a non-directional sensitivity to WIMP-nucleon cross sections significantly extending to sub-10 GeV WIMP masses for SI coupling, whereas for SD interactions even a 10 m^3 scale would compete with generation-two (G2) detectors currently under construction, and would breach the Xe Neutrino Floor. Final recommendations suggest to experimentally demonstrate on prototypes with full drift length and high readout resolution all energy-dependent performances and to continue pursuing alternative approaches, based on electron drift with optical or high granularity charge readout.

5 Conclusions

The determination of the incoming direction of WIMP particles can offer a very powerful handle for a positive, unambiguous identification of a DM signal, together with an excellent capability of rejection of the annoying backgrounds, including neutrons and neutrinos. Gaseous Time Projection Chambers, constituting the most natural, although inherently challenging, approach to directional DM searches, have nowadays reached the technological maturity to aim at 1 ton scale experiment. In this context, several R&Ds are on-going to found the best technologies and gas mixtures choices to this goal. A coordinate endeavour among such experimental efforts is in progress, as a new international proto-collaboration called CYGNUS, that recently presented a detailed feasibility study for a modular, multi-target ton scale experiment. From these studies, a 'Cygnus-1000' detector would be able to put significant constraints to both SD and SI interactions extending the expected reach of G2 detectors, while at the same time measure Solar Neutrinos.

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