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# New Detection Methodologies for Dark Matter Measurements

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**Abstract:** ***Scintillator detectors filled with liquefiable noble gas are very low background and high efficiency and high resolution detectors. Traditionally they have been used to search for very weakly interacting particles. Hypothetical particles like Weakly interacting massive particles (WIMPs) are conjectured to constitute Dark Matter. In this article we shall be encompassing such detector development presently used for such studies and further propose new configurations.***

**Keywords:** Detectors, Dark Matter

## 1. Introduction

Our universe is gravitationally influenced by a class of non-baryonic invisible matter known as the Dark Matter (DM) [1, 2, 3]. DM accounts for approximately 85% of the matter, and 25% of the energy density of the universe. The primary evidence of existence and effects of DM are observed in astronomical scales where structure of many astronomical objects such as galaxies and clusters reveal the invisible glue that holds their shape.

DM could also be baryonic, where the invisible matter could be attributed to the brown dwarfs or similar dense formation, collectively known as massive compact halo objects, or MACHOs. MACHOs also can be large objects like black holes [4], dead stars and all the massive objects that are hard to see.

However the general view seems to favor the non-baryonic scenario, where DM could be exotic particles, such as axions or weakly interacting massive particles or WIMPS.

DM is postulated to play an important role during the formation of galaxies. Interestingly, the DM percentage in a galaxy could be variable, in-fact a recently discovered galaxy called NGC 1052-DF2 [5] is completely devoid of it. This absence gives us a indication that there is a dynamic play of ordinary matter and DM during the formation of the galaxies.

Most of the experimental efforts towards DM detection have so far been directed towards WIMPs, and to a lesser extent towards axions. Scientists Goodman and Witten suggested [1] that elastic scattering of WIMPs on detectors will leave behind the recoiling nuclei having large enough kinetic energy such that the energy deposited by such recoiling nuclei in the detector medium can henceforth be detected. The real signals are heavily affected by the background particles such as cosmic rays, gamma rays and electrons passing through the detector medium. That's why the WIMP search experiments are typically performed in deep underground laboratories to reduce the background from cosmic rays.

But even at those experimental sites the backgrounds due to gamma ($\gamma$) rays and electrons ($\beta$) originating from decay of radioactive contaminants within the detector material as well as the environment surrounding the detector keep affecting the real signal. Extreme purification procedure of the detector medium and background signal veto using passive shielding is used to reduce the unwanted signals. In the light of recent multimessenger approach [6] for DM search, many complementary experiments are underway, probing cosmic rays and accelerated particles at high energy. At the Large Hadron Collider the studies at TeV energies using detectors at forward rapidities are ongoing [7, 8, 9]. The DM searches and possibilities in Beyond Standard Model (BSM) scenarios [2] using forward detectors are discussed in ref [9] for LHC energies. The paper is organised to start with a brief introduction on DM and the ongoing experimental facilities summarized in Section-2. Section 3 is devoted for the discussion on design and working procedures for new detector configurations. Finally, we summarise by pointing out the challenges that lie ahead.

## 2. Present Facilities

Since we do not know what dark matter is, we need a diverse pool of instruments and approaches to detect it [10, 11]. These techniques used in the experiments (like LUX [12], PandaX-II [13], PICASSO [14], PICO [15], DAMA [16, 17] to name a few) are known as direct detection methods. Here, a detector is constructed on Earth with a massive target to increase the odds of an interaction with the dark matter that exists in our Galaxy. The current experiments employ one of the two strategies for detecting dark matter. The first strategy is to look for a variation in the total event rate or event direction that is expected due to Earth's motion through the galaxy. The difficulty with this method is that one looks for a small, time-varying signal on top of a huge background. It requires a large detector volume along with a stable nonfluctuating background. The advantage is that one does not need to know the characteristics of the background as long as it is not time-varying. The other strategy is to substantially reduce the background to near zero and detect WIMP-nucleon interactions. The difficulty with this approach lies in understanding the backgrounds [18, 19] and achieving an extremely low-background experimental environment.

There are varied detector mediums used including crystals such as Ge, Si, $CaWO_4$, NaI and CsI (as used in experiments like DAMA/LIBRA [16], KIMS [20] etc) along with superheated fluids and gels such as $C_3F_8$, $CF_3$ and $C_4F_{10}$ and liquid noble gasses such as Xe and Ar. There are three observables that result from the interactions of WIMPs in these mediums: ionization, phonons produced from the interaction of the WIMP with a nucleon in the crystal lattice, and scintillation. Experiments composed of these mediums use one or two of these observables to understand and differentiate between the candidate signal events and the extended background [18].

Dark matter candidates and neutrons are assumed to interact with the target's nucleus producing nuclear recoils while most background particles (gamma-rays and electrons) interact with electrons surrounding the nucleus producing electron recoils. Experiments that use two observables have excellent discrimination between candidate signal events and backgrounds can be obtained from the fractional energy (i.e. ionization energy divided by phonon energy). This quantity is known as "yield". Another class of experiments uses superheated bubbles or gels to observe the interactions of WIMPs in the target medium.

Mediums used by these experiments (like PICASSO [14], PICO [15] etc) include $CF_3I$, $C_3F_8$ or $C_4F_{10}$. In the case of LUX [12] and PandaX-II [13], the dark matter particles leave behind traces of light which the sophisticated sensors will probably manage to detect.

## 3. New Proposed Configurations

In this detector design proposal we want to lay down the concepts for new type of detectors. During the first phase we envisage a detector that has broad usage in nuclear physics, high energy and astro-physics observations. In the second and final phase we shall concentrate our efforts on the construction of a DM detector. This proposal has several key aspects as detailed here in this section.

The first phase construction plans are as follows:

1. A kilogram class detector, that can do tracking and can act as a accurate large volume, high efficiency detector, for various energy ranges of few keVs to GeVs.
2. Accurate characterization and calibration of the prototype detector. The detector should be characterized with all the standard type of calibration sources, beta, gamma, neutron, charged particles. It is also important that the characterization is done for all the possible entry angles of the detector.
3. Development of integrated electronic circuit with extremely low footprint will be also pursued. We would aim for high granularity and high fidelity. Tracking will be one of the essential features of this detector. Polarization measurement of the photons from catastrophic astronomical events is also one of the features of this detector and for future goals, where if such a detector is placed in a satellite.

### 3.1 Design

This detector is cylindrically shaped and will have several concentric shells, where each are filled with hexagonal light collecting chambers that tapers into individual Silicon Photo-Multiplier(SiPM). Each hexagon is independent in terms of light collection, but are connected through the volume. The electronic signals are collected and are taken out from the flat bottom side of the cylinder. Each shell also acts as an energy filter and a given detection can be accurately determined. The infilled scintillation material is liquid Xe/Ar, depending on the availability.

The top part of the detector has a configurable aperture for testing and calibration.

The details of the aperture are explained as follows:

- Beta particle only acceptance: In this mode the electron-path can be focused and bent by the Einzel lens type of system or a electrostatic quadrupole. Other type of radiations and particles will be stopped by appropriate shielding along the path. Calibration will be performed using electron gun.

- Neutron acceptance only: The gamma radiation can be stopped in the aperture using lead shielding. One can also use roman era lead for extremely low background requirements. The stray charged particles can be deflected using various electrostatic elements.

- Gamma acceptance only: Borated paraffin is the shield to be used to cover the opening of the aperture. With proper electrostatic setting, only gamma can travel to the bulk of the detection volume.

- Extremely low cross section acceptance mode: Usually in this case the whole detector would be shielded by using uncontaminated lead, paraffin blocks and vetoed by a plastic scintillator container. The confined detector volume would remain pristine and signal less, till a weakly interacting particle decays inside. The larger the volume of the detector, higher the probability of the interaction.

### 3.2 Working

Such a detector is a broadband tracking detector. It will continuously record signals and background signals in the range 10 keV to 10 MeV. We plan to record the data over a long period as the Sun and the solar system.

Moves around the galactic centre with an approximate velocity of 8,28,000 km/hr ($V_{sun}$). We broadly think of two types/sets of data, one where the Earth's orbital velocity of 1,10,000 km/hr ($V_{earth}$) is towards the Sun's orbital velocity and other type where it is away.

This detector working together with other DM detectors in an "open" mode operation, i.e., accepting signals both from the lower and higher energy range and hence might be able to see a diffused interaction of the DM with the scintillator material. These detectors should be perfectly timed using atomic clock and the signals should be synchronized to get meaningful result.

## 4. Summary and Outlook

Liquid scintillator detectors provide a pristine medium to look for extremely weak signals from particle-particle interaction. These detectors with latest tracking technologies and devices can reproduce accurate energy deposited in the medium. A multi shell detector structure optimized to characterize such events are envisaged to open up the realm of the detection of WIMPs.

For the first time we are proposing to record a synchronised broadband signal from the available DM detectors as we move around the galactic centre at about $V_{sun}$ + $V_{earth}$ velocity. Any unaccounted variation in the background signal strength (amplitude) might hint at scattering centres or particles that are yet to be discovered.

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## Conflict of Interests

India and IGDORE, Sweden. "The authors declare that there is no conflict of interest regarding the publication of this paper."

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