Current status of different detector technology in the searches of dark matter events

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Abstract. In this article, we review the possible candidates of dark matter and their proposed properties. We have focused on different methods used for the detection of the dark matter candidates such as, search of WIMPs at the accelerators, indirect and direct detection of WIMPs. We have highlighted the different detector technologies such as, charge collection after ionization, bubble formation in superheated liquid by charge particle, scintillation produced due to the incident radiation, cryogenic detection technique, noble liquid as detector material, time projection chamber, which are used by different experimental collaborations worldwide.

Keywords- Dark matter candidates, different detector technology used in the search of dark matter candidates.

1. Introduction
In the whole universe, we have a special ability to think the facts which surprise us. One of such query is “how the universe was formed?” In search of the answer to this question various theories were proposed [1] by scientists and in order to verify various experiments are proposed and performed [1-2]. One of such theory is ΛCDM (Lambda Cold Dark Matter) or Lambda-CDM model [1-2], here the term ‘Λ’ represents the cosmological constant. With the help of this model we are able to understand the mysteries of universe (such as dark matter, dark energy, the formation of large-scale structure of galaxies, the expansion of the universe etc.), while this model have some issue at small scale [1-2].

Long time ago, scientists were started observing distant part of the universe, like galaxies, stars, nebula etc, we can see these object due to electromagnetic interaction. In 1933 Zwicky studied on Coma cluster [3] and suggested the presence of few orders more mass than the observed luminous mass [3], while at that time no one took this invisible mass in a serious note. The observation of rotation curve of spiral galaxies by Vera Rubin [4], and other cosmological and astronomical evidences were also suggesting the presence of a large amount of mass which does not interact via electromagnetic interaction while its presence can be observed by the gravitational effect and coined a term dark matter [4-5]. Based on the observations and models[6], calculations shows that nearly ~26% of the critical energy density of the universe is consists of dark matter where as visible matter

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consists only ~ 4% and rest ~ 70% is the dark energy. The detection of dark matter is a challenging task because of its mode of interaction with normal matter is still a puzzle [5].

The observations [6] suggest that the possible dark matter candidates may have following properties:

(i) **Non-interacting nature:** As we have seen in the case of bullet cluster, when two clusters collide, no interactions happen between the dark matters, suggesting the non-interacting nature of the dark matter particle [7].

(ii) **Stable:** From the observations, we know that dark matters are non-interacting, thus they must remain the same from the time of the formation of the universe. This reveals that the dark matter candidates have life time at least larger than the present age of the universe [6-7]. So they may be considered as being stable.

(iii) **Non-Relativistic:** As the universe formed in the bottom up way, it must consist of cold dark matter (CDM), which support that the candidate must be non-relativistic in nature (i.e. their kinetic energy must be lower than the rest mass energy) [7]. As evident that the dark matter candidate should be non-relativistic in nature its mass must be greater than its temperature at the time of radiation and mass decoupling [7, 12]. It is also evident that only non-relativistic nature of dark matter particles may strongly support the formation of large scale structure formation in the galaxies.

(iv) **Non-Baryonic:** The observations from the results of cosmic microwave background (CMB) [6-7] and big bang nucleosynthesis, shows that the baryonic matter density is very low in the universe. Therefore the dark matter candidates must be non baryonic in nature.

(v) **Massive:** If the dark matter candidates are produced in the thermal equilibrium of the early universe then these particles needs to be fairly massive only then it can explain the large scale structure of the universe [6, 12].

(vi) **Classical:** If dark matter is not treated as classical its confinement in the galaxy cannot be explained. We can compute the bound on the mass of the dark matter candidate if it is bosonic or fermionic in nature using galaxy density, size, velocity, dispersion etc. For boson mass $m \geq 10^{-22}$ eV are rarely confined and for Fermionic consideration its mass should the order of $m \geq 25$ eV [6-7].

2. Possible dark matter candidates

Based on the properties explained in the above section I, scientists assume some extension in the standard model of particle physics and predicted some models to explain the dark matter candidates. The dark matter particles may interact in weak interaction scale similar to the standard model weak scale, one of the most important candidates of the dark matter is Weakly Interacting Massive Particles (WIMPs) [6-8, 12]. These particles are important because it produces the relic density (i.e. the density of a specific particle at the time of freeze-out) of dark matter very well. Various experiments all over the world are running in search of WIMPs [14, 12, 37]. Other proposed candidates of the dark matter particles are Axions [7-9], Massive Astrophysical Halo Object (MACHOs) [9], Kaluza-Klein particles [10-11] etc. Now the challenges with these particles are to observe them and answer whether these particles are able to produce the correct relic abundance of dark matter? or whether it could be able to explain other observed cosmological and astrophysical phenomena’s? [6-8].

**WIMP** is a well-accepted candidate for dark matter particles [6-8]. Weakly interacting means cross-section of interaction with the present standard model particle is extremely low, possibly non-zero. For selecting the candidate of dark matter we have to keep in mind that the relic density predicted by these models must be matching with the current relic abundance of the dark matter and also it must be electrically neutral [6-7, 12]. For calculation of the relic abundance, physicists are using the formula given by the Boltzmann. The relic density has different relation with the mass and interaction cross-section for the particle, which is created in the phase transition and for the particle which created in the thermal equilibrium [12]. Thermal equilibrium means, after the Big Bang all the standard model candidates and the dark matter candidates are in thermal equilibrium with each other. The temperature
of the universe at that time was extremely high they used to make a plasma as the atoms could not formed at that much hot bath. As the temperature of universe start to falls off, the number of both photon and dark matter candidate start to fall and after a certain temperature the production of the WIMPs get off due to the fact as the expansion of the universe is started and it starts to get cooled [6,12]. WIMPs eventually freeze-out of equilibrium from the thermal plasma of hot particles and the reason for decoupling happen [6, 12]. When the WIMP annihilation rate became roughly less than the expansion rate of the universe eventually the annihilation stops and this mechanism of the WIMPs production is known as freeze-out mechanism and this mechanism is very well accepted in explaining the WIMPs production [6,12]. Because of this fact, the WIMPs number density falls exponentially from that time till now. If the universe is still in equilibrium, we might have a very less number of WIMPs as they all might get annihilated. Due to which, the light (photons) present in the universe should be more in number than the current time. While the thing is quite different as the number of WIMPs starts decreasing and therefore the number density is also start to become low and due to this the probability of getting annihilation get decreased. This is one of the reasons today we have large number of WIMPs present in the universe [6, 12]. There are many more mechanisms rather than freeze-out [12] for explaining WIMP production.

**AXION** is also a most promising candidate for the cold dark matter [13]. It is basically a hypothetical particle, which is proposed to solve the strong CP problem of the standard model of particle physics [9, 13]. According to the theoretical predictions, made by the quantum chromodynamics (QCD) [8], there should be a violation of the CP symmetry while the experimental observations [9] shows that it is not evident that CP symmetry is broken in strong interaction. There were many solutions provided to solve this problem [8, 13] but the best one is the Peccei-Quinn solution for the strong CP problem. From this theory we get the axions as the solution of the discrepancy [8-9, 13]. Axions are cold dark matter and pseudoscalar particle, they are produced non-thermally and as they have large decay constant, these particles at cosmological scale are collision less [13]. Axion particles have very small (lower bound) mass of the order of μeV[13]. Detecting axions is a challenging task because of the feeble coupling with standard model particle [8, 13].

**MACHOs** are also a proposed candidate for the dark matter particles [9]. It was proposed in the earlier time when scientists just started to think about the possibility of the dark matter candidates. Primordial black hole, neutron star, white dwarf, brown dwarf are considered as the candidates of the MACHOs. As we know that there emission tendency is extremely low that’s why it is very hard to find them [9]. WIMPs are non-baryonic in nature while MACHOs are baryonic in nature [6, 9]. Presence of this kind of matter is very much evident from the observed gravitational effect such as gravitational lensing [9]. Gravitational lensing is the phenomenon which observed in the universe, whenever light is passing nearby of the massive object and the light bends due to gravitational effect of that heavy mass [9]. After so many observations it was seen that MACHOs are basically remnants of dead or dying star and they are not remains much possible and interesting candidate for the study of dark matter candidates [9].

### 3. Detection of Dark matter candidates

In introduction section, we have elaborated about the concept of dark matter and their properties. In section II, we shed light on the proposed candidates of the dark matter. So it can be concluded that the dark matter is present in the universe and it cannot be explained by the theory of the known particles, which are listed in the list of standard model of particle physics [5-9]. Now we will focus on how physicists are trying to verify these theories and in which way they have to set the detector or how much accurate detector technology needs to be building for accurate detection of the proposed candidates of the dark matter. For the detection of the dark matter candidates firstly, we must have to understand the interactions mechanism of dark matter candidates with the ordinary matters [7] or standard model's particles.

**A. Detection of WIMPS**
The experimental searches of WIMPs as dark matter candidates are classified in three categories [6].

First one is the direct detection of WIMPs, in direct detection experiments we measure recoil energy deposited on a nucleus recoiling from a WIMP-nucleus scattering [5-7, 12]. Second is indirect detection of WIMPs, in which we basically looks for the WIMP-WIMP annihilation product at distant location [7]. Third one is the creation or production of WIMPs using high energy accelerator, in this study scientists are trying to create a similar atmosphere, like when the universe was created [12] and looks for the missing energy and momentum in a complete event. This idea is based on the concept that the annihilation of dark matter particles may produce standard model particles then reverse is also possible.

a) **Searches of WIMPs at the Collider Experiments**

As we know that the confirmation of any new particle is always done through the detection using its basic predicated properties. The accelerator accelerates and collide two opposite circulating rings of particles (e.g: CERN) at a fix space and time. If WIMPs are real they have a certain chance to produce in that collision [5]. These sensitive particle detectors will sense all standard model particles, however as WIMPs is weekly interacting in nature; it will manage to escape from the detectors without leave any signature there. In collider experiments, momentum and energy are always conserved. Scientists look for the missing momentum and energy carried out by the WIMPs and confirms the case. If the dark matter candidates are Kaluza-Klein particle collider can be used for detection [10-11].

Due to weak interaction with the SM particles, DM particles will not produce a visible signal in collider experiments such as CMS and ATLAS, which constitute the detectors. Therefore conservation of the transverse momentum will be a good parameter to conclude the presence of DM particles in LHC experiments. SUSY has been a standard benchmark for collider experiments for the searches of the WIMP DM candidate. DM at LHC offers a rich spectrum of possible signals. The LHC has concluded that delivery of only around 1% of the data set planned for its running period up to 2035 [47]. This is an evident that the search for WIMP DM at LHC experiments has only just started [47].

b) **Indirect detection of WIMPs**

We would expect WIMP-WIMP annihilation in the region of high WIMP density such as core of the sun because super-symmetric WIMPs are Majorana particles [5]. Indirect detection of WIMPs dark matter basically looks for the annihilation of WIMPs. If WIMPs are Dirac particle, we can expect annihilation only when we have comparable amount of particle and antiparticle [5, 36]. We can trace the annihilation in dense body from the extremely high energy particles and rays including neutrinos production [12]. Prospects for indirect detection of WIMP dark matter are as below:

1. In the places like galactic centers, or perhaps the center of the Sun is gravitationally highly dense. We may expect greater rate of annihilation for larger density, thus have better chance of seeing them is also increased [36].

2. The product of annihilation should reach to the earth without any deflection and it must be unaffected by the background radiation [5]. Here background radiation basically means that particles and radiations like neutrino, gamma ray, and electron positron pair that is coming from the astrophysical source and that has nothing to do with dark matter but they produce background to the annihilation signal [36].

There are mainly three types of indirect search experiments.

1. When WIMPs annihilation occurred inside a very dense object, then we expect extremely high energy neutrino as the final product. To detect these final state particles requires large detectors such as Super-Kamiokande, Ice Cube, etc.

2. When WIMPs annihilation is occurring in the free space other type of radiation can be detected. To detect a dark matter differently from other cosmic radiation specific characteristics need to be found.
3. If WIMPs annihilated directly into gamma rays, one could expect a line or box shaped in the observed gamma ray spectrum depending on the production of gamma.

One of the famous indirect DM detection experiment Fermi Gamma-Ray Space Telescope (FGST), which is equipped with Large Area Telescope (LAT) recently have published there data of 10 years gamma ray event observation from the sun. They have constrained the cross section limit on DM nucleus scattering for long-lived mediator case for spin-independent cross section lies in the range $10^{-48}$-$10^{-47}$ cm$^2$ and for spin-dependent case cross section lies between the range $10^{-46}$-$10^{-45}$ cm$^2$ for DM mass range from 3 to 150 GeV, these limits have several dependency factors [36]. In recent day’s neutrino detectors playing a major role in providing new limits on the DM searches, as neutrino could be a viable candidate of DM annihilation or decay [12]. As their rate of interaction is very much low we have to take a look on the regions where the abundance of DM particle is very much high (e.g., Galactic center, galaxy clusters, Sun etc.). In search of DM particles one must be very careful about the production spectra and propagation from center of celestial body in their way to earth [12, 39].

Muonium counters and water Cherenkov detectors are the main two technologies used in neutrino telescope. In this article we will discuss results and prospects of the IceCube [41], and SuperK [38, 39-40] experiments based on Cherenkov detectors. Super-Kamiokande (SK) is a famous indirect detection experiment with the 50 Kton water Cherenkov detector, installed in University of Tokyo taking data from 1996 and in 2018 completed its fourth run. They are basically looking for the neutrinos produced in the annihilation of WIMPs [38, 40]. They have studied solar, earth, and galactic halo WIMP induces neutrinos but not find any significant amount of excess in events while for each annihilation channel they proved the self annihilation cross section with 90% C.L. [38]. The SK planned for a upgradation to SK-Gd by adding 0.1% Gd to their existing detector in two phases, firstly 10 ton of Gd$_2$(SO$_4$)$_3$ to be added to enhance 0.01%Gd, then in order to improve further the neutron capture efficiency 90% to 50% they planned (90% to 50% or it should be 50% to 90%. Please check) to add 90 ton of Gd$_2$(SO$_4$)$_3$ in order to tag anti-neutrino from inverse beta decay with a 8 MeV gamma anti-coincidence from the neutron capture of Gd, which will improve their background to detect Supernova Relic Neutrinos (SRN) [39]. The IceCube Neutrino Observatory also providing a good footprint towards the sterile neutrino sector as it also could be a strong particle of DM, they have taken simplest “3+1” model of sterile neutrino and their second analysis result provide a good class limit in the region $\Delta m^2_{31} \geq 10$ eV$^2$ from approximately $0.012 \leq \sin^2(2\theta_{31}) \leq 0.16$ and $0.024 \leq \sin^2(2\theta_{34}) \leq 0.54$ [41].

In X-Ray emission signal around 3.5 KeV was observed while observing adjacent galaxies and galaxy clusters. This could be possible DM decay signal of sterile neutrino at mass 7 KeV, so observation of milk way halo must be produce this signal if it’s true signal of DM [45]. Many experiments worldwide are trying to verify this event, Chandra observed the cosmic X-ray background and reported event in 3.5 KeV with 2.5-3.0e, in accordance with their previous work of ~7 keV sterile neutrino [46], while in recent publication XMM-Newton (X-ray MultiMirror Mission) analyzed there observation of milky way halo and suggested of no evidence of the event and set the decay upper limit in this mass range [45]. Majority of indirect detection results seems to be better bounds in the cross section and mass space parameters, however their calculations are highly model dependent. This is one of the reasons why scientists are focusing their strong efforts on direct detection.

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c) Direct detection of WIMPs

If WIMPs produced and annihilating into standard model particles or produced in thermal equilibrium, we can expect to be directly interacting with the ordinary matter through Feynman diagram [5]. We also can expect that WIMPs, which are gravitationally bound to our Milky Way galaxy [5, 36] will interact with the SM’s particles. From the measurement of escape speed curve for Galactocentric radii ranging from ~5-10.5 kpc [28], the local Galactic escape velocity at the Sun’s position was estimated to be $v_e(r) = 580 \pm 63$ km s$^{-1}$, and it increase towards the Galactic centre[28]. From this escape velocity, we can measure that WIMPs can transfer energy of the order of eV to a rest electron which is of very low energy whereas the energy transfers to the atomic nucleus is of the order of 10 KeV [5, 12] and
also WIMPs are considered as the non-relativistic particles, therefore the de-broglie wave length associated with it will be of the order of the nuclear dimension.

Thus, in direct detection, we have to focus on the nuclear recoil instead of electron recoil. However, the cross section for the WIMP - nucleus elastic scattering is very feeble [14] due to weak nature. From the theoretical predictions nuclear spin can couple with WIMPs. For this case the scattering amplitude arises from (what) because opposite spin can cancel out due to coherence [5]. Nucleus having unpaired nucleon and high spin factor are favourable for spin-dependent interaction. Having a feeble interaction rate this detection required long measurement time and larger detector mass, while in low mass region interaction is little high compared to the high mass region [7,14].

**B. Detection of Axions**

Now let us see how we can detect the other hypothetical particle which comes as the Peccei-Quinn solution of the strong CP problem [7, 8] and known as Axion. As we have seen earlier it has very low mass and it couple very much weakly with the ordinary radiation and matter [7]. For searching the existences of this particle there are so many experiments running world-wide, most of them are looking at a particular concept of the Primakoff effect [13], which is very effective and sensitive way to detect the Axions. When two photons interact in which one of them may a virtual photon then Axions are produced in charged plasma due to the coulomb field [5] then these Axions converted coherently into photons under the influence of magnetic field produced in the laboratory [8]. Also there are other techniques like microwave cavity experiment based on this technique Axion search experiment ADMX have collected data [5, 8]. CERN axion solar telescope (CAST) is mainly focused in axion-photon coupling strength at lower mass region ($m_a \leq 0.02$ eV) and able to set improved limit compared to their previous result which started data taking at 2003, from recent data (2013-2015) they set limit for coupling constant $g_a < 0.66 \times 10^{-10}$ GeV$^{-1}$ at 95% C.L. [15]. Lately GERDA collaboration, which is basically aiming towards the $0\nu\beta\beta$ decay detection, have produced limit in AxionLike Particle’s (ALP) coupling to electron. These interactions are basically cognate photoelectric effect and known as Axion electric effect [42]. For mass of 150 keV/c$^2$ the most stringent direct limits for the dimensionless couplings of axion like particles electrons is $g_{ae} < 3 \times 10^{-12}$ [42].

**I. Detection Procedure**

In this section we focus on the detection techniques of the dark matter candidates. As we know that if the WIMPs annihilate or interact with standard model particle, thus it can be trace by the known physics as:

1. Production of ionization in the detecting material and we can study the ionization current for understanding the event [14].
2. Particle can take the atoms of detecting material to an excited state due to which scintillating light can be produced during de-excitation. We can use this scintillation for detection to know the incident energy [16].
3. Also the incident particle can interact with the atomic chain of the solid detecting material due which lattice vibration will be created [33].

The experiments running all over the world for detection of proposed candidates of dark matter using different detection techniques such as ionization technique [14], scintillation and lattice vibration [16-17, 33, 37]. Some of the experiments use combination of the above process to enhance their detection efficiency and background discrimination [22-25].

**A. Charge collection after Ionization**

Ionization technology has a wide spread acceptance all over the world. In this technology the basic concept is that the incident interactions will create ionization in the detecting material. Due to this the ionization process will be generated from the ionized particle and these secondary charged particles were collected by the electrode due to the applied electric field and a signal pulse is formed. Studying the properties of these pulses we can have the idea of incident energy and other
properties of the interacting particle [14, 37]. The detecting material that is used by majority of different experiments running all over the world is semiconductor [18, 20]. In solid semiconductor detector, germanium is highly preferable. Now these germanium detectors are used in different types of configuration such as broad energy germanium detector [18], ultra-low energy germanium detector [18], coaxial germanium detector [14,18], p-type point contact germanium detector [20], n-type point contact germanium detector [14] etc, each of them has their own advantages [14]. These kinds of detection technologies are used by the various worldwide collaborations for dark matter search, few of them are TEXONO [14, 18], IGEX [19],CDEX [20, 29]. CDEX collaboration in their recent work have excluded the DAMA/LIBRA and COGeNT allowed region with 90% (C.L.) and provides improved limit on both spin dependent and spin independent WIMP - nucleon scattering cross section as $3 \times 10^{-36}$ and $8 \times 10^{-42}$ cm$^2$, respectively for the WIMP mass of 5 GeV. The CDEX-10 experiment has achieved 160 eV$_{el}$thresholds and 2 cpkd background levels in 2.4 keV region with 102.8 kg.day exposure [29]. Due this low threshold, they opened the low mass WIMP detection window to explore.

**B. Bubble formation in superheated liquid by charge particle**

This is also a very effective technique and is used in various dark matter search experiments for detecting cold dark matter particles in the spin independent sector of direct detection [21]. Most effective side of this technique is that it is insensitive to gamma ray, beta ray around the operation temperature and by these properties we will get very good background discrimination inherently [21]. Firstly this technique was used by a project in the Canada to search for super-symmetric objects (PICASSO) experiment. In which, they have used bubble of the superheated liquid droplets of Perfluorobutane (C$_4$F$_{10}$) inside a polymerized acrylamide in an ambient temperature and pressure. Whenever a charged radiation having energy greater than the critical energy incident on this bubble then due to the occurrence of the phase transition, a gas bubble created which explode and create an audible or ultrasonic pulse, which could be easily detectable by the help of piezoelectric transducers. To enhanced sensitivities of spin dependent WIMP interaction the presence of $^{19}$F is required [21, 30]. Later this technique is modified slightly and, named as Chicago land observatory for underground particle physics (COUPP),instead of using liquid droplets they used liquid as the bulk detecting material [21]. In this experiment the used liquid is CF$_3$I. Latter these two collaborations evolved as a more developed experiment which is named as PICO. Their latest result PICO-60 raises the temperature of C$_4$F$_3$ from (13.9±0.1)℃ to (19.9±0.1)℃ with superheated pressure 25 psia due to this (1.20±0.08) KeV threshold achieved. At this lower threshold, events are mostly dominated by the electron recoil and event rates get increased. There data from 2017 with 1404 kg-day exposure shows that they achieved 2.45 keV thresholds, which is lower than the previous 3.3 keV threshold. With enhanced exposure, they improve the result by one order in the region of 3-5 GeV WIMP mass. That translates the precise limit $3.2 \times 10^{-31}$ cm$^2$ on spin-dependent cross section for WIMP mass of 25 GeV [21, 30]. This collaboration is also aiming towards a larger size experiment as PICO-500.

**C. Scintillation produced due to the incident radiation**

This is a very widespread detection technique in the case of particle detection and used in both detecting standard model as well as beyond standard model particles [16]. In this technology various kind of material is used as detector’s material among which inorganic scintillator is one of the most favoured in particle detection in which NaI(Tl), CsI(Tl) and CaF$_2$(Eu) crystals are used for detection of the dark matter candidate [16]. Scintillation property with more light is necessary for these types of detectors. These two NaI(Tl) and CsI(Tl) detectors along with high purity germanium detector are very good tool for detecting direct WIMP interaction in spin dependent and spin independent both cases [16]. During the growth of these detectors’s crystal small amount of activator doping is added to bring the transition in visible range. These detectors are very much efficient at room temperature region after adding the doping. The CaF$_2$(Eu) is one of the best scintillation detector in which fluorine is used [16]. There are several experiments running all over the world based on this technology such as
DAMA / LIBRA [16] use NaI(Tl) scintillation, MiniBooNE [16] use liquid scintillation detector. COSINE also use NaI(Tl) detector and is designed to search the validity of the annual modulation signature claimed by the DAMA / LIBRA experiment, though there claim is not consistent with other experiments results. The COSINE used model independent approach in their latest analysis keeping the same detecting material NaI(Tl) used by DAMA. The ANAIS [16] and KIMS [16] also aimed to check the DAMA excluded region with model independent approach [16, 31]. In both, isospin conserving and non-conserving spin independent data from COSINE exclude the DAMA allowed 3σ region at 90% C.L. and the same is true for spin dependent sector [32].

D. Cryogenic detection technique
This is also good detection technique for detecting the dark matter candidate. This technique is basically depending on the properties which can be achieved when the temperature of the material is taken around absolute zero [17]. At this temperature limit the specific heat for the metal is very low as is vary with T^3 and also the property of superconductivity can be used [17]. This kind of detector is very good in separating the nuclear recoil and electronic recoil events which is the main need of dark matter direct detection. Around the globe there are so many collaborations running with this technique like Cryogenic Dark Matter Search (CDMS) [17] then some improvisation is made in this detector and known as CDMS-2 [17] after that super CDMS [17] became as successor [17]. The EDELWEISS [17] and CRESST collaborations are also using cryogenic technique and this experiment was able to make a clear footprint in direct DM search in the sub-GeV region after their CRESST-II result published in 2015. To give more prominent limits on sub-GeV in 2016 July phase-I data taking was started for CRESST-III, the acceptance region is extended from 100eV to 400 KeV. They analyze their data of 2.39 kg.day of threshold 100 eV, placed sensitivity for dark matter particles mass of 500 MeV with improvement by one order, and also improved their reach to 350 MeV [33].

E. Noble liquid as detector material
So far we have seen that dark matter candidates are extremely weakly interacting and detecting them is a highly challenging task. Up to that point we have gone through many detector technologies but as we have seen that all these type of detectors are of very small in size and limited in mass. To enhance the probability of interaction we need a large mass and size detector keeping this fact in mind scientists started fabricating large size detector but one of the big challenge is keep the background event rate low [22, 34]. Since we know that as the mass increases the radioactivity which is present inherently also increases. So at the time of crystal growth and fabrication of large detector we must have to use very good purification techniques and background discrimination techniques [5, 22]. Now when ionizing radiation passes through the detecting material it creates scintillation [16]. Based on this technique there are so many experiments running worldwide such as zoned proportional scintillation in liquid nobel (ZEPLIN) [23] uses Xenon as scintillation detector material also by the time improvisation is done by this collaboration and ZEPLIN-2 [23], ZEPLIN-3 [22] created. Also the latest one is LUX-ZEPLÍN (LZ) [23] which assumed to start taking data from 2020. The liquid argon is also used as the detecting material in the ArDM collaboration [24]. The XENON1T using this technique and they have published a recent result in which they claimed “observation of excess event from 7 KeV which increasing with the decrement of energy, and have peak at 2-3KeV” expected event was 232±15 but observed is 285 [34]. Observed events can be best accounted for solar axion model on the basis of spectral shape alone with 3.5σ, but this could decrease to 2σ if additional background is considered from tritium [34].

F. Time Projection Chamber
In electron-positron collider, to reconstruct the events this type of detector technology is established, with help this technology we can track the particle as well as measure the momentum and can get a three dimensional information by multiple ionization sampling in a compact detector [25]. In this kind of detector technology gases or / and liquids are used as the active material. From this detection
technique, we can have 3D information about the events. Such detector records complete information about events along with position coordinates [25]. These types of detectors have a very good track detection capability. The DarkSide collaboration [26] used liquid argon as detecting material. The TREX-DM [27] is an experiment which uses time projection chamber and argon or neon gas as the detecting material and have great discovery potential of low mass WIMPs [35]. The XENON1T [34] also uses this technique.

4. Background and its reduction techniques
Different experiments are dealing with different types of backgrounds. The DM detection is a background sensitive experiment. Backgrounds are basically arises from the shielding materials due the presence of radioactivity or due to the activation by the cosmic ray or by any means. The U/Th decay chain is the leading background source, along with $^{60}\text{Co}$, $^{209}\text{Po}$, $^{209}\text{Bi}$, $^{55}\text{Mn}$, $^{40}\text{K}$ etc. [34, 43]. Also direct detection techniques basically have to face different backgrounds arising from gamma ray (from different decay chain of radioactive isotope), neutron background (fast neutron capable of mimicking nuclear recoil events) [43]. Various types of veto systems are designed and used over the time in order to veto the background. Active shielding helps in tagging the events from unwanted sources while the passive shielding works as safeguards to the detector from the background source but not used in active data taking. Different types of tagging like coincidence, anti-coincidence, delayed tagging etc. also have different aspects of usefulness. Coincidence tagging helps to detect events which give signature in various detectors those events are truly unacceptable when we are aimed to DM particle detection, as these particles very feeble interaction strength [3-10]. Anti-coincidence is use full in tagging gamma etc. When there is chance of decay of some isotope like $^{77}\text{Ge}$ this technique is important [44]. There are also some other process like pulse shape discrimination, pulse rise information used in suppressing backgrounds [43]. In XENON1T experiment main sources of backgrounds are $\beta$ decay of $^{214}\text{Pb}$, $^{212}\text{Pb}$, $^{85}\text{Kr}$. A cryogenic distillation technique is used in removing these isotopes along with different theoretical models are used in predicting the $\beta$ spectra [34]. In TREX-DM experiment Micromegas used as read out with different technologies like bulk Micromegas and microbulkMicromegas as they have very low intrinsic radioactivity. Also they provide good information to discriminate background from expected signals [35]. The CAST experiment is also used microbulkMicromegas readout and achieved the best background level [15]. In PICO multiple bubble produce definitive neutron signature possible background source [30]. Background prediction can also performed by the GEANT-4 software using Monte Carlo simulation [15, 30, 35, 43].

5. Summary and outlook
In the above sections, we established the presence of dark matter and it's possible candidates strongly supported by various theories. We described the detection techniques currently in use by good number of experiments either operational or proposed around the world. Current limit on cross section and WIMP mass parameters is majorly limited by the intrinsic background coming from the long lived decay series of U and Th, and cosmogenic background. To minimize such background majority of proposed experiments are covering their detectors with a tens of meter thick pure water column so that they may accurately tag the background events. Proposed experiments are also focusing on the detector material purification. These approaches will give better results if proposed detection techniques should consider various effective parameters instead of measuring either ionization or phones.

References
[1] M. Rezaei et al., “A Bayesian comparison between CDM and phenomenologically emergent dark energy models”, Eur. Phys. J. C, 80, 374 (2020).
[2] Antonino Del Popolo et al., “Small scale problems of the ΛCDM model: a short Review”, Galaxies 2017, 5, 17; doi:10.3390/galaxies5010017 (2017).
[3] F. Zwicky, “The redshift of extragalactic nebulae”, Gen Relativ Gravit, 41, 207 (2009).
[4] Vera C. Rubin et al., “Extended Rotation Curves of Highly Luminosity Spiral Galaxies IV
Systematic Dynamical Properties $\text{Sa} \rightarrow \text{Sc}$", *The Astrophysical Journal*, 225, L107 (1978).

[5] Wolfgang Rau, “Dark Matter Search Experiments”, arXiv:1103.5267v1 [astro-ph.CO] (2011).

[6] S. Profumo et al., “An Introduction to Particle Dark Matter”, arXiv:1910.05610v1 [hep-ph] (2019).

[7] Edward A. Baltz, “Dark Matter Candidates”, *SLAC Summer Institute on Particle Physics* (SSI04), 2004.

[8] Andreas Ringwald, “Alternative dark matter candidates: Axions”, arXiv:1612.08933v1 [hep-ph] (2016).

[9] Paul H. Frampton, “Theory of Dark Matter”, arXiv:1705.04373v1 [hep-ph] (2017).

[10] Hsiao-Chia Cheng et al., “Kaluza-Klein Dark Matter”, arXiv:1707.02071v2 (2002).

[11] Jeroen van Donge et al., “Einstein and the Kaluza-Klein particle”, arXiv:gr-qc/0009087v1 (2000).

[12] Leszek Roszkowski et al., “WIMP dark matter candidates and searches – current status and future prospects”, arXiv:1707.06277v2 [hep-ph] (2018).

[13] Leanne D. Duffify et al., “Axions as Dark Matter Particles”, arXiv:0904.3346v1 [hep-ph] (2009).

[14] A.K. Soma et al., “Characterization and performance of germanium detectors with sub keV sensitivities for neutrino and dark matter experiments”, *Nuclear Instruments and Methods in Physics Research A*, 836, 67 (2016).

[15] V. Anastassopoulos et al., “New CAST limit on the axion–photon interaction”, DOI: 10.1038/NPHYS4109.

[16] S K Kim et al., “Scintillator-based detectors for dark matter searches I”, *New Journal of Physics*, 12, 075003 (2010).

[17] Daniel A. Bauer, “Dark Matter Detection with Cryogenic Detectors”, *FERMILAB-CONF-08-406-E*.

[18] M K Singh et al., “Background rejection of TEXONO experiment to explore the sub-keV energy region with HPGe detector”, *Indian J. Phys.*, 91(10), 1277 (2017).

[19] C. Amole et al., “PICASSO, COUPP and PICO - search for dark matter with bubble chambers”, *EPJ Web of Conferences* 95,04020 (2015).

[20] D.-M. Mei et al., “Cryogenic Large Liquid Xenon Detector for Dark Matter Searches”, *Journal of Physics: Conference Series* 400, 052021 (2012).

[21] Kudryavtsev, Vitaly A., "Recent Results from LUX and Prospects for Dark Matter Searches with LZ" *Universe*, 5(3), 73 (2019).

[22] P Agnes et al., “Direct Search for Dark Matter with DarkSide”, *Journal of Physics: Conference Series* 650, 012006 (2015).

[23] F. J. Iguaz et al., “TREX-DM: a low-background Micromegas-based TPC for low-mass WIMP detection”, *Eur. Phys. J. C.*, 76, 529 (2016).

[24] G. Monari et al., “The escape speed curve of the Galaxy obtained from Gaia DR2 implies a heavy Milky Way”, *A&A* 616, L9 (2018).

[25] C. Amole et al., “Dark matter search results from the complete exposure of the PICO-60 C3F8 bubble chamber”, *Physical Review D* 100, 022001 (2019).
[31] G. Adhikari et al., “Search for a Dark Matter-Induced Annual Modulation Signal in NaI(Tl) with the COSINE-100 Experiment”, PHYSICAL REVIEW LETTERS 123, 031302 (2019).
[32] Y. J. Ko et al., “Comparison between DAMA/LIBRA and COSINE-100 in the light of Quenching Factors”, arXiv:1907.04963v3 [hep-ex] (2019).
[33] F Petricca et al., “First results on low-mass dark matter from the CRESST-III experiment” arXiv:1711.07692v1 [astro-ph.CO] (2017).
[34] E. Aprile et al., “Observation of Excess Electronic Recoil Events in XENON1T”, arXive:2006.09721 [hep-ex].
[35] J. Castel et al., “Background assessment for the TREX dark matter experiment”, Eur. Phys. J. C, 79, 782 (2019).
[36] M. N. Mazziotta et al., “Search for dark matter signatures in the gamma-ray emission towards the Sun with the Fermi Large Area Telescope”, PHYSICAL REVIEW D 102, 022003 (2020).
[37] Katherine Freese et al., “Annual Modulation of Dark Matter: A Review”, arXiv:1209.3339v3 [astro-ph.CO] (2013).
[38] Katarzyna Frankiewicz, for the Super-Kamiokande collaboration, J. Phys.: Conf. Ser. 888 012210 (2017).
[39] Y. Takeuchi, Recent results and future prospects of Super-Kamiokande, Nuclear Inst. and Methods in Physics Research, A, 952, 16134 (2018), https://doi.org/10.1016/j.nima.2018.11.093.
[40] K. Hagiwara et al. “Search for Astronomical Neutrinos from Blazar TXS 0506+056 in SuperKamiokande”, The Astrophysical Journal Letters, 887, L6, (2019).
[41] M. G. Aartsen et al., “Searching for eV-scale sterile neutrinos with eight years of atmospheric neutrinos at the IceCube neutrino telescope”, arXiv:2005.12943v2 [hep-ex] (2020).
[42] M. Agostini et al., “First Search for Bosonic Superweakly Interacting Massive Particles with Masses up to 1 MeV/c2 with GERDA”, PHYSICAL REVIEW LETTERS 125, 011801 (2020).
[43] M K Singh et al., “Background rejection of TEXONO experiment to explore the sub-keV energy region with HPGe detector”, Indian J. Phys., 91(10),1277 (2017).
[44] Christoph Wiesinger et al., “Virtual depth by active background suppression: revisiting the cosmic muon induced background of GERDA Phase II”, Eur. Phys. J. C., 78, 597 (2018). https://doi.org/10.1140/epjc/s10.
[45] Christopher Dessert et al., “The dark matter interpretation of the 3.5-keV line is inconsistent with blank-sky observations”, Science 367, 1465 (2020).
[46] Nico Cappelluti et al., “Searching for the 3.5 keV Line in the Deep Fields with Chandra: The 10 Ms Observations”, The Astrophysical Journal, 854, 179, (2018).
[47] Oliver Buchmueller et al., “Search for dark matter at colliders”, NATURE PHYSICS, 13, 217 (2017).