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EXPERIMENTAL DIRECT DARK MATTER SEARCH

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Abstract

Dark Matter is one of the most challenging puzzles of modern physics. Its indisputable evidence so far comes solely from its gravitational interaction, but it is believed to have particle nature. The Weakly Interacting Massive Particle (WIMP) still remains the best-motivated candidate. After a brief introduction and motivation to the WIMP paradigm, the WIMP direct detection principles will be explained, and a review of the leading experiments and their recent results will be given.

1 Introduction

The solution to the Dark Matter puzzle is surely one of the main challenges of modern particle and astroparticle physics. Strong observational evidences provide a picture of a Universe in which Dark Matter constitutes about 85%

of the total matter. Yet Dark Matter has not been directly detected. In this review the Dark Matter problem will be discussed and the approaches to directly detect it, in the form of a special category of particles, will be presented.

The evidence of Dark Matter comes from astrophysical observations at different scales and with completely different techniques. From galactic to cosmological scale [1, 2, 3, 4] all evidences strongly suggest that more than 95% of the Universe is made of invisible and unknown types of matter and energy.

1.1 Particle Dark Matter

The existence of Dark Matter having been assessed, one question arises: what are the Dark Matter characteristics and nature? Moving from experimental evidences and astronomical observations, with the help of theoretical predictions we can attempt to depict the "identikit" of an hypothetical Dark Matter particle.

As already highlighted above, the Dark Matter interacts gravitationally, meaning that it is constituted by **massive** particles that are definitely **non-baryonic** and **electrically neutral** (being invisible to any radiation sensitive device). Furthermore, having been there also at the time when the Universe became transparent to light, as measured from the cosmic microwave background, Dark Matter particles have to be **stable** or at least have a lifetime longer than the age of the Universe.

Dark Matter candidates may be classified as 'hot' (relativistic) or 'cold' (non-relativistic) according to their energy at the time when they decoupled from the rest of the Universe. The observations on the present Universe suggest Dark Matter being predominantly cold, i.e. **non-relativistic**. This is derived from the relation between the tiny fluctuations in the matter-density of the early Universe and the large scale structures observed nowadays: if Dark Matter were hot it would not be able to assemble in confined regions and the Universe structures observed today would have been much more isotropic.

1.2 WIMPs and their Miracle

The evolution of the number density of any particle χ over the age of the Universe t follows the Boltzmann equation [5] in which annihilation and creation of χ is modeled in terms of the temperature (i.e. kinetic energy) of the particle species and of the Universe expansion rate. In the early instants the temperature is high enough that the production rate equals the annihilation rate and $n_\chi = n_\chi^{eq}$. As soon as the thermal kinetic energy of χ particles falls below their mass ($= m_\chi$) the production is suppressed and n_χ decays exponentially until the expansion term starts dominating and there is no more annihilation.

At this point in time the total density of χ particles (Ω_χ) is then found to be: $\Omega_\chi = 1.66\ g^{1/2} \frac{T_0^3}{\rho_c m_{Pl} \langle \sigma_A |v\rangle}$. Substituting $T_0 = 2.35 \cdot 10^{-4}$ eV (the current Universe temperature), $\rho_c \simeq 1 \times 10^4\ h^2$ eV$\cdot$ cm^{-3} (the critical density), $m_{Pl} = 1.22 \cdot 10^{28}$eV (Planck mass) and $g^{1/2} \sim 1$, we obtain:

$$\Omega_\chi h^2 = \frac{m_\chi n_\chi}{\rho_c} \simeq \frac{3 \cdot 10^{-27} cm^3 s^{-1}}{\langle \sigma_a v\rangle}$$

Therefore, in the case of Dark Matter particles we find that $\langle \sigma_a v\rangle \sim 10^{-26} \div 10^{-25}$cm^{3}s^{-1}. Incidentally this value is very close to what is expected from a "weak-scale" ($m_\chi \sim 100$ GeV c^{-2}) particle interacting through electroweak force ($\langle \sigma_a v\rangle \sim 10^{-25}$cm^{3}s^{-1}), therefore dubbed "**Weakly Interacting** Massive Particle" (WIMP). Many supersymmetric extensions of the Standard Model of particle physics predict the existence of a particle with similar characteristics. For this reason this coincidence of Cosmology and Particle Physics predictions is not seen as actually "accidental", rather as a *(WIMP) miracle*.

1.3 Detection of WIMPs

Dark Matter particles can be searched via three different methods:

1. **Indirect detection:** by looking for excesses of standard model particles in large, heavy astrophysical objects (galaxies, stars, etc...), possibly coming from Dark Matter annihilation;
2. **Collider production:** by searching for missing energy at colliders, possibly coming from Dark Matter production;
3. **Direct detection:** by detecting signals of low energy deposits coming from Dark Matter particle scattering off nuclei in low background detectors placed underground.

2 Direct Dark Matter Detection

If WIMPs exist and are the dominant constituent of Dark Matter, they must be present also in the Milky Way [6] and, though they very rarely interact with conventional matter, should nonetheless be detectable in sufficiently sensitive experiments on Earth. Assuming a local density of $\rho_0 = 0.3$ GeV$\cdot$ cm^{-3} and a WIMP mass of $m_\chi = 100$ GeV$\cdot$ c^{-2}, the WIMP flux on Earth is expected to be of the order of 10^5 cm^{-2}s^{-1} [7], large enough to allow the detection of a significant number of nuclear recoils caused by their elastic scatterings off target nuclei of Earth based detectors [8]. Direct Dark Matter search experiments, indeed, aim to detect the interactions of WIMPs in dedicated low background detectors, by measuring the rate, R, the energy, E_R and possibly, in directional experiments, the direction of the WIMP-induced nuclear recoils. Since the WIMP$-$nucleon relative velocity v is non-relativistic, the recoil energy E_R can be expressed in terms of the scattering angle in the center of mass frame, θ as [9]:

$$E_R = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2_{\chi-N} v^2}{m_N}(1 - \cos\theta), \tag{1}$$

where m_N and m_χ are the masses of the target nucleus and of the WIMP respectively, $|\vec{q}| = \sqrt{2m_N E_R}$ is the momentum transfer and $\mu_{\chi-N} = \frac{m_\chi m_N}{m_\chi + m_N}$ is the WIMP-nucleus reduced mass.

2.0.1 The Rate

The differential nuclear recoil rate induced by the WIMPs can be written as:

$$\frac{dR}{dE_R}(E_R, t) = \frac{\rho_0 \sigma_0}{m_N m_\chi} \int_{v_{min}}^{v_{esc}} v \cdot f(\mathbf{v}) \cdot F^2(E_R, \mathbf{v}) \cdot d^3v. \tag{2}$$

Here E_{th} is the energy threshold of the detector, ρ_0 is the local Dark Matter density, σ_0 is the cross section at zero momentum transfer, $f(v)$ is the WIMP velocity distribution in the halo, v_{min} is the minimum velocity required for the WIMP to generate the recoil energy E_R and v_{esc} is the galactic escape velocity. $F^2(E_R)$ is the nuclear form factor, that accounts for the fact that the de Broglie wavelength associated with the momentum transfer is of the same order as the nuclear dimensions; thus the bigger the nucleus the stronger its effect.

The main astrophysical uncertainties lie in the velocity distribution $f(v)$ (commonly assumed to be Maxwellian) and in the local Dark Matter density ρ_0 (usually assumed equal to 0.3 GeVc^{-2}cm^{-3}). Detecting the direction of the WIMPs would provide a viable solution to the velocity distribution function problem.

2.0.2 The Cross Section

In order to provide an interpretation of the outcome of a Dark Matter direct detection experiment some assumption on the specific particle-physics model needs to be made. If WIMPs are neutralinos, i.e. Majorana fermions, for example, they can have only scalar or axial coupling with quarks, which, in this specific non-relativistic regime, translates into a spin-independent coupling and a coupling between the neutralino spin and the nucleon spin. In the spin-independent case, the full coherence results in a cross section $\sigma_0 \propto A^2$, for a target nucleus of mass number A, while in the spin-dependent case the cross section is dominated by the total net spin of the nucleus. In most cases, the coherent term will dominate because of the A^2 enhancement. However, neutralinos with dominantly gaugino or higgsino states, for example may only couple through the spin-dependent term.

In the generalized framework of non-relativistic effective field theories (EFT), the WIMP-baryon possible couplings can be worked out. In this case six possible nuclear response-functions are present, described by 14 different operators [10, 11, 12].

2.0.3 The Modulation of the Rate

As a result of the Earth motion relative to the WIMP halo, the event rate is expected to modulate with a period of one year with the maximum on the 2$^{\text{nd}}$ of June. To detect this characteristic modulation signature, large masses are required, since the effect is of the order of $\sim 3\%$ with respect to the total event rate [13]. A stronger diurnal direction modulation of the WIMP signal is also expected. The Earth rotation about its axis, oriented at an angle with respect to the WIMP "wind", changes the signal direction by 90 degrees every 12 hours, with a resulting 30% modulation with respect to the total rate [14].

2.1 General experimental considerations

Several experimental effects are in common with all the technologies employed for direct detection of Dark Matter, some due to the nature of the interaction and others related to the common sources of background. In the remaining part of this section some general experimental considerations are discussed to help the understanding of the case, while specific detector related effects need to be considered separately in the discussion of the individual experimental approach.

Nuclear recoils induced by WIMPs are detected exploiting the three basic phenomena associated with the energy loss of charged particles in target media: scintillation, ionization and heat. All the detectors used to perform this rare event search are also sensitive to the environmental radiation associated with cosmic rays and radioactivity in construction materials and the environment. At the current limits [15] the expected WIMP rate is ~ 1 event per ton per year and significant SUSY parameter space still exists down to such rates that will be accessible by upcoming multiton-scale detectors with nearly vanishing backgrounds.

Because of such small expected signal rates, Dark Matter search experiments are usually located in deep-underground sites, where the cosmic muons' flux is attenuated by a factor 10^5 to 10^8 with respect to the surface. In addition, such detectors are typically enclosed in thick layers of (active or passive) shielding materials, in order to reduce the contribution to signals from environmental (background) radiation. Moreover shielding and detector components have to be selected with the lowest possible radioactivity.

The signals recorded by a WIMP-search experiment are of two types: nuclear recoils **(NR)** and electronic recoils **(ER)**.

NR are the looked-for-signals, but can also be induced by (background) fast neutrons. Such neutrons may either be the product of spontaneous fission and/or (α, n) reactions from environmental and detector construction materials (mainly induced by natural primordial radionuclides ^{238}U and ^{232}Th), or arise from the hadronic showers produced by the highly energetic residual cosmic ray muons. The neutron contribution to the signal is usually modeled via Monte Carlo simulations including detector response, detailed detector and surrounding geometry and using, for the global normalization scaling, the cosmic muon flux and spectrum, and measurements of the radioactivity content of the materials surrounding the detector. Coherent scattering of solar, diffused supernovae and atmospheric neutrinos off target nuclei will also soon become an important background that mimics the DM signal [16].

ER are the dominant background in direct WIMP search experiments and are produced by the interaction of γ-rays originating from the decays of the uranium and thorium chains as well as from other radioactive isotopes present in the vicinity of the detector. Techniques for background reduction need to be employed in order to be able to isolate the signal in sensitive experimental data. In the following a general discussion on background reduction and ER rejection is given. For a more detailed description of background sources and reduction techniques the reader is referred to reference [17].

Since the mean free path of a high energy γ-ray or of a fast neutron is of the order of centimeters, while the mean free path of a WIMP is of the order of light-years, the identification of multiple scatters, sometimes referred to as multi-site events, constitutes a powerful background rejection tool. Moreover some detectors have the advantageous ability of reconstructing the interaction verteces, allowing volume fiducialization, that helps both with self-shielding and with rejection of spurious events coming from surface contamination. Finally in many Dark Matter direct search experiments background discrimination mechanisms are used, based on the fact that nuclear recoils (signals) and electronic recoils (backgrounds) have different signatures in the detector, due to their different nature. Electronic recoil rejection techniques are mainly based on the principle that NR have much denser energy losses than ER. Therefore one can exploit this effect either with hardware solutions or with software (analysis) active rejection. In particular a detection technology that is not sensitive to weakly ionizing charged particles is employed in superheated liquid detectors (see section 3.2). Two main analysis approaches are used in off-line software rejection: *pulse shape discrimination* and *combination of two detection channels* (ionization and scintillation, for example).

Dedicated calibrations are used to define the signal (neutron source) and background (γ or β source) regions in the parameter space usually defined by the readout signals.

3 A biased selection of WIMP search experiments

A large variety of experiments aiming at direct WIMP detection are deployed in underground laboratories all around the world. Many have finished their research program and several ton or multi-ton scale are currently under construction. In this review it is not possible to give count of all and only a small selection of them is presented that should provide an overview of the current status and the direction the field is taking. For more details the reader is referred to a more general review. One of the most complete of the recent reviews of the field is [18]; however being relatively old it misses some of the most recent results and proposed experiments.

The technologies employed in this experimental research field are: NaI(Tl) scintillator crystals (see section 3.1 for details), other scintillators [19], ionization germanium detectors [20, 21, 22], cryogenic bolometers [23, 24, 25], liquid noble elements-based detectors (see sec. 3.3), superheated liquid detectors (see sec. 3.2), directional detectors [26], gas based detectors [27, 28], paleo-detectors [29]. The above list is probably not completely exhaustive and the author apologizes in advance in case some experiment or technology is not listed or not present in the provided bibliography.

3.1 DAMA/Libra: a longstanding, controversial signal

In a review of this type a mention is deserved by the DAMA/Libra longstanding claim [30] of a significant annually modulated signal, compatible (in period, phase and energy spectrum) with Dark Matter detection.

The project was designed in early 1990s by an Italian group, in collaboration with Chinese and French colleagues, and installed at Gran Sasso underground laboratory [31]. The detector (DAMA) was initially based on nine 9.7 kg of highly radio-pure NaI(Tl) scintillators shielded from radioactive background. The collaboration has then increased the sensitive mass to about 250 kg of NaI(Tl) (LIBRA). The threshold provided for both experiments was 2 keV.

More recently the LIBRA detector was upgraded [32] by replacing all the photomultiplier tubes (PMTs) with new ones with higher quantum efficiency and lower radioactivity. This upgrade resulted in a lower software threshold of 1 keV as well as a better energy resolution and a higher acceptance efficiency near the threshold.

The DAMA experiment belongs to the first generation of dark matter direct detection experiments, with no background rejection, therefore requiring a large detector exposure. Although the NaI(Tl) scintillator provides some discrimination between nuclear recoils and electronic recoils based on pulse shape, the collaboration published its data without any background reduction. Using a total exposure (2.46 ton$\times$year), combining old and new data the collaboration reported a 12.9σ C.L annual modulation in the energy range $[2, 6]$ keV. The modulation analysis carried out using a simple sinusoidal function

$A(t) = A_0 \cos[\omega(t - t_0)]$ results in the following outcome:
$A_0 = 0.0103 \pm 0.0008$ cpd/kg/keV
$t_0 = 145 \pm 5$ days
$T = \frac{2\pi}{\omega} = 0.999 \pm 0.001$ years

The DAMA/LIBRA evidence for the annual modulation is clear but only in the lowermost energy bins (2-6 keV corresponding to a nuclear recoil energy of 22-66 keV for interaction on Iodine nuclei) where the understanding of the efficiencies is particularly important. The origin of this clear modulation and its interpretation continue to be widely disputed, although many studies have been performed by the collaboration regarding various possible systematic effects.

The DAMA/LIBRA result is in strong tension with all other more sensitive WIMP search experiments employing different detection technologies, even when they give up any ER rejection [33]. Therefore several experimental efforts have started in different underground laboratories in order to confirm or refute the DAMA/LIBRA signal using the same NaI detection medium. The main challenge is to obtain crystals of kg-scaled sizes with the same (or lower) radioactive contamination as the DAMA/LIBRA crystals. An intensive investigation on low radioactive samples of NaI powder and on clean crystal growth procedures have led to the development of a specific process that has become a standard between all these experiments [34, 35]. There are NaI-based dark matter search experiments in operation (DM-Ice17 [36], ANAIS [37, 38]) or under development (DM-Ice [39], Kam-LAND-PICO [40], SABRE [41, 34], COSINUS [42]). These detectors are/will be located in both Northern and Southern hemispheres; therefore possible seasonal or site effects can be disentangled from the dark matter modulation. Definitive results are expected in the next three to five years.

3.2 Superheated liquid detectors

After their invention in 1952 [43] and the successful years of applications in accelerator experiments in 1960s and 1970s, classical bubble chambers have been outclassed by other detection technologies and for several decades they have been almost forgotten. However the relatively large use of superheated liquid "droplet" detectors in neutron dosimetry has likely inspired their application in the context of direct Dark Matter search [44].

In this technology the target is kept in liquid phase in a superheated state slightly below its boiling point. Proto-bubbles are created by the thermal spikes of released heat on a particle track. The growth of such bubbles is dumped by various thermal processes. Therefore macroscopic liquid-to-vapor phase transitions can happen only if an amount of energy larger than a certain critical value (E_c) is deposited within a thermal spike length $L < 2R_c$, where R_c is the "critical radius", i.e. the minimal radius that the proto-buble should have to nucleate. Therefore the superheated liquid thermodynamical conditions can be tuned in such a way that only particles with $dE/dx > 50$ keV/μm (like scattered nuclei) can nucleate a bubble. In this way the detector is extremely insensitive to electronic recoil events ($> 10^{10}$ rejection power), since all other background particles (muons, γ-rays, X-rays and βs) are well below the nucleation threshold. The energy threshold for recoiling nuclei can be set as low as a few keV. Precautions are being taken in order to reduce the inhomogeneous bubble nucleation by mildly superheating the liquid. The bubbles forming in these detectors are usually photographed with CCD cameras, while the acoustic shock waves that accompany the nucleation are detected with piezoelectric transducers.

WIMP-search experiments using superheated liquids usually employ fluorine reach targets (CF_3I, C_2ClF_5, C_3ClF_8 and $C4F_{10}$). Fluorine has an unpaired number of protons and is, thus, sensitive to spin-dependent interactions. A notable source of background are the α particles from naturally occurring radioactive radioactive isotopes, mainly ^{222}Rn and its progenies, emanating from surfaces. However since α-particles have a louder acoustic emission they can efficiently ($< 99.3\%$) be rejected. Moreover, since the location of the nucleation is known with mm precision, efficient fiducialization can be applied in order to select only events in the inner core of the detector.

Five different experiments have been operating over the last years using bubble chamber (COUPP [45]), PICO [46]) and MOSCAB [47])) and droplet detector (PICASSO [48]) and SIMPLE [49])) technologies.

PICO-60 is a 60 liter bubble chamber detector based on C_3F_8, located at SNOLAB. It ran for a few years until 2017. The experiment "set the most stringent direct-detection constraint to date on the WIMP-proton spin-dependent cross section at 3.4×10^{-41} cm^2 for a 30-GeV c^{-2} WIMP" [46]).

The low background achievements and the technological developments in bubble chambers detectors for WIMP direct detection are remarkable. However some specific effects limiting their sensitivity have been evidenced in the past 5 years that need to be addressed. In particular it has been shown by PICO-60, for example, that particulate contamination can create bulk bubbles that constitute a background signal for Dark Matter search. Although the mechanism remains largely uncertain, there are good indications that it is the interaction of the particulate with the buffer fluid to produce such events. Therefore future plans for bubble chamber detectors for WIMP search (PICO-40L, PICO-500 and MOSCAB [47]) moved from pressure (mechanical) to temperature stabilization. In this way after each event the detector-reset to the initial state is automatic. This determines the absence of any moving parts, reducing (if not eliminating) any possible particulate detachment.

3.3 Liquid noble elements based detectors

Liquid noble elements such as argon and xenon are excellent media to be used for non-segmented, homogeneous, compact and self-shielding detectors. Liquid xenon (LXe) and liquid argon (LAr) are good scintillators and have good charge conduction properties. The characteristic wavelength of the scintillation light is 175 nm and 128 nm for LXe and LAr respectively [50]. While LAr scintillation wavelength needs to be shifted to (usually blue) longer values to make this light detectable by traditional photo-sensors, that of LXe is in a relatively near ultraviolet region that allows quartz/fused silica photo-sensor transparent windows. Moreover the singlet (short-) and triplet (long-lived) states that generate the luminescence in such media are populated at different levels depending on the type of ionizing particle [51]. This provides a NR to ER discrimination tool based on pulse shape that is particularly efficient in LAr for which the characteristic times of the two components are 6 ns and 1.6 μs. For LXe the pulse shape analysis is not as effective since the lifetimes of the two components are much closer in value (4 ns and 22 ns). In order to profit of pulse shape discrimination a large number of measured photons is needed and therefore a higher threshold has to be used, making LAr based detectors mainly sensitive to relatively high mass WIMPs ($\gtrsim$ 20 GeV c^{-2}).

Moreover as already discussed above, the simultaneous detection of ionization and scintillation signals provides an additional rejection tool for ER events. This is possible when operating noble elements based detectors in dual phase time projection chambers (TPCs). In this configuration the detector has a cylindrical geometry defined by a tube of reflective material and three optically transparent electrodes (cathode, anode and "gate grid") that define two regions with separately tunable electric field values. The liquid fills most of the volume and is the sensitive medium. The gas phase in thermal equilibrium with the liquid is above a well defined level between the gate grid and the anode. Two arrays of photo-sensors on top and bottom are usually present to detect the primary scintillation signal (S1) from particle interactions. Moreover the ionization electrons resulting from the same interaction are drifted along the electric field lines to reach the liquid-gas interface; in this region the electric field applied between gate grid and anode is strong enough to extract the electrons to the gas phase and accelerate them such that they can generate a secondary scintillation signal (S2) that is proportional to their number. In addition the 3D position of an interaction can be determined by measuring z from the time distance between S1 and S2 and $x - y$ from the S2 hit pattern on the top photo-sensor array.

LXe dual phase TPCs have shown the best performances and are leading the direct WIMP search field providing the most stringent limit on spin-independent WIMP-nucleon interaction [15]. Noble liquid elements based detectors that just finished operation successfully (or will be ending soon) are: (LAr) DarkSide-50 [52], DEAP-3600 [53], DarkSide-20k and Argo [54], (LXe) LUX [55], XMASS-I [56], PandaX-II [57], PandaX-4T [58], XENON1T and XENONnT [15, 59].

4 Beyond the WIMP paradigm

Although WIMP still remains a very well motivated Dark Matter candidate, the lack of convincing signal, combined with the increasingly stringent limits set by LHC searches for new physics has motivated in the recent years a large effort by the Dark Matter community to explore a broader set of dark matter candidates [60]. A big effort has brought to the development of innovative ideas in terms of theoretical results as well as new experimental concepts. In particular an extension of the sensitivity of current or purposely designed new detectors to lower energy deposits allows to probe DM with masses between meV to GeV scale. In Figure 4.1 the theoretical predictions from different models of a possible Dark Matter candidate mass are schematically shown, along with some of the experimental ideas for direct detection of low-mass DM

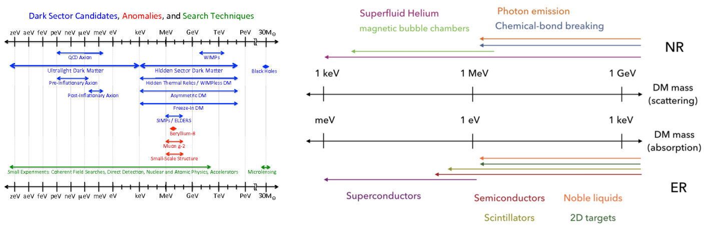

Figure 1: "Mass ranges for dark matter and mediator particle candidates, experimental anomalies, and search techniques described in this document" (left). Some new ideas on how to probe low mass Dark Matter with scattering or absorption (right). From [60]

via scattering off, or absorption by, nuclei (NR) or electrons (ER).

4.1 Low Energy Threshold: a possible reality

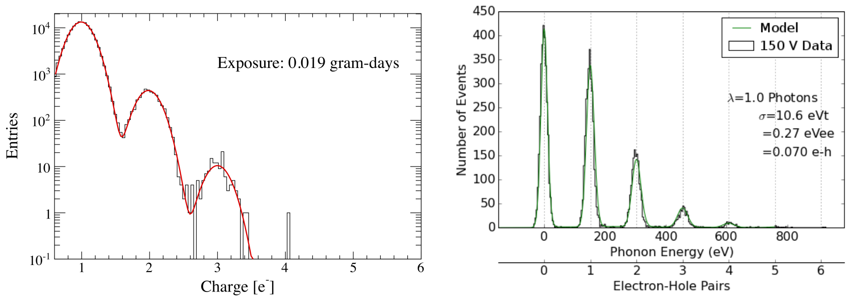

Figure 2: Recorded spectrum by the SENSEI experiment in a surface run at FermiLab [61] (left). Laser calibration data showing individual electron-hole pair sensitivity of a single crystal of silicon [62]

The low energy threshold required for low-mass Dark Matter direct detection is the main challenge in this new field. However the technology is mature to allow very low energy deposits. In particular two experiments have demonstrated single electron-hole pair sensitivity in silicon (see Figure 4.1), which constitute a solid base for any future investigations.

5 Conclusions

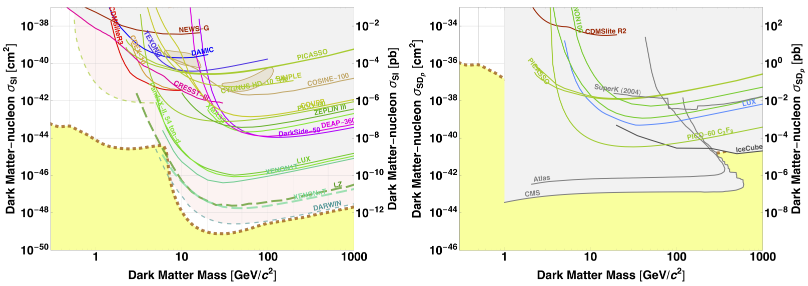

Figure 3: Limits from current experiments and DAMA/Libra allowed region and projected sensitivity of future direct WIMP search experiments. Spin-independent WIMP-nucleon (left) and spin-dependent WIMP-proton (right) cross section vs WIMP mass parameter space. Plot generated from [63]

The cold dark matter explaining all cosmological and astrophysical observations could be made of WIMPs, thermal relics from an early phase of our Universe. This hypothesis is testable with different approaches: direct detection, indirect detection and at accelerators. However so far it escaped detection in the laboratory. Liquid xenon experiments offer excellent prospects for discovery with an increase in WIMP sensitivity by ~ 2 orders of magnitude in the next decade The neutrino background will soon be on reach. Figure 5 summarizes the present status and future reach of this very competitive field. Should a future observation be made in one experiment a confirmation from at least another experiment would be required, preferably employing a different experimental technique, as well as cross checks from indirect and collider searches. Other direct searches of Dark Matter in a different lower mass particle form has already started, building on the technological achievements of past and current WIMP search experiments, but moving from nuclear to electronic scatters.

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