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Underground Facilities for the Cosmic Frontier

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2.1 Direct detection of particle like dark matter

2.1.1 Introduction: drivers for underground dark matter experiments

Refer to Cosmic Frontier report and reiterate the prime science driver of the search for dark matter.

2.1.2 Current experiments

The current *classes* of experiments and their solutions for the experimental needs.

2.1.3 Future experiments and their need

General needs for dark matter experiments include:

- depth, space
- environmental radiation monitoring (muon, neutron, radon, Kr/Ar etc.)
- muon and neutron veto: water or liquid scintillator
- calibration sources, including gaseous source, neutrons
- material screening (this is covered in UF4)
- local support, machine shop, living accommodation

Below are needs for specific type of experiments: large noble liquids experiments, cryogenic bolometers and other technologies.

2.1.3.1 Noble liquids

The next generation noble liquid experiments will use 50 to 300 tons of liquid xenon or argon to probe heavy WIMPs into the "neutrino fog". Maintaining this large amount of cryogenic liquid in a stable cold liquid and its supporting systems, such as distillation columns, require a significant continuous cooling power, which can result in heat-loads to the underground facility which must be carefully considered. Liquid nitrogen cooling can be supplied in addition to industrial cryogenic cooling. For example, the XENONnT infrastructure features a 30 tonne LN_2 tank underground, serving several subsystems. A ten times larger LN_2 tank supplying the need for the next generation liquid xenon will be needed.

The future noble liquid dark matter experiments, both LAr and LXe, would benefit greatly from on-site isotopic separation ability, to mitigate for example a small air leak or cosmogenically-activated radioisotopes at surface, introducing a trace amount of noble radioisotopes (e.g. ^{37}Ar, ^{39}Ar, or ^{85}Kr), and to reduce the radioactive radon emanating from the detector inner surfaces. This can be achieved using on-site cryogenic distillation columns, such as use in XENON1T [1] and XENONnT. The XENON1T/nT distillation column, requires 5.5 m of height, and releases some 10s of kW of heat into the cavern. The XENONnT radon distillation column [5] is 3.8 m in height and requires a few kW of cooling power. Both the height and heat load requirement of a distillation column should be considered when siting future large noble liquid DM experiments.

Muon-induced neutron background should be reduced to a negligible level combining the deep underground rock overburden and sufficiently-thick active shield. Both LZ and XENON1T/nT [6] liquid xenon detectors use water, with about 10 m in diameter and height, as the shield for external and muon-induced neutrons. Further neutron background from the detector material is realized by using either liquid scintillator or gadolinium doped in the water. Safe handling of these shielding liquids shall be taken into consideration in regard of the environmental concerns.

At a shallow depth, cosmogenic activation of certain isotopes, such as Xe-137, will be a concern if the liquid xenon target will be used to search for ^{136}Xe $0\nu\beta\beta$ signals. Typically, ^{37}Ar activation in liquid xenon at the surface will decay away in several months of storage at underground. Further reduction of ^{37}Ar in xenon can be achieved using cryogenic distillation column as used in XENON1T/nT.

2.1.3.2 Cryogenic bolometers

Many future experiments will focus on DM nuclear recoils of sub-keV energy, with a signal either largely or entirely in the phonon or heat channel. Such experiments rely on mK temperatures for this sensitivity, achieved via 3He/4He dilution refrigeration. The 3He/4He dilution refrigeration technology enforces a space constraint on such experiments, particularly in the vertical direction. Even if the target masses themselves are small (e.g., <1 kg) the experiment as a whole requires significant vertical space for the opening and closing of the fridge and the shielding external to the cryostat. A vertical space of at least 4m is highly beneficial. It is possible to configure a dilution-refrigerator-based experiment to require less vertical space, but at the cost of increased complexity and decreased cooling power.

The vibration environment is a second item of concern for many cryogenic bolometer technologies. The target mass of such experiments are held in some fashion to the support structure, and a slip in this holding, even a slip at the atomic scale, can induce a visible 'dark rate' of signal into the phonon system. While multiple groups are investigating mitigation methods either through alternative target holding methods or vibrational isolation [2], the environment itself must also be considered. A typical environmental goal may be to keep these vibrations below $10^{-7}\mathrm{g}\sqrt{\mathrm{Hz}}$ at all frequencies.

Many bolometric sensors require a quiet electromagnetic environment as well. Superconducting electronics (e.g. SQUID amplifiers) are highly sensitive to noise across a wide range of frequencies, and are also sensitive to a DC magnetic field. Faraday cage mitigations and cold filtering can help, but the E&M environment should be kept in mind when selecting underground sites and what experiments can share a facility.

As the threshold of bolometric technologies continues to be pushed to lower and lower energies, the reduction of backgrounds specific to sub-keV energies is now an active complementary research area. At these low energies, backgrounds include Cherenkov or luminescence backgrounds from insulators near the detectors [3], and also heat-only events which are still mysterious in origin [4]. Given that very low-threshold experiments are currently dominated by non-cosmogenic backgrounds, it is difficult to assess the depth requirement of future low-threshold experiments until that R&D is more mature.

2.1.3.3 Other technologies

This part needs community input.

2.2 Conclusions

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