Generation-3 Direct Detection Dark Matter Experiments

A summary of the US direct detection community discussions

Description: “Generation-3” direct detection searches for Weakly Interacting Massive Particles (WIMPs) were defined by PASAG in 2009 as reaching at least 10^{-47} cm^2/nucleon (spin independent cross section typically in the 50 to 100 GeV/c^2 mass region). Given the evolution of the theoretical and experimental landscape, the class of experiments proposed here is more generally described as a follow-up to the “Generation-2” (G2) experiments either currently being built (Xenon1T, DEAP3600, XMASS 1 ton fiducial upgrade) or in advanced R&D for selection by DOE and NSF in the coming year.
The results of these G2 experiments should be available in the 2017–2020 time frame. Three scenarios are possible: i) If particle dark matter has been discovered in direct detection, acquiring large statistics will be essential to establish the nature of those particles (e.g., through their mass and cross section), link the signal to the galaxy with modulation (or even better directionality) and measure the velocity distribution in the galactic halo. ii) If LHC or indirect experiments (gamma ray satellites and Atmospheric Cerenkov arrays, Ice Cube) have provided evidence for a signal for dark matter and no complementary signal is seen in G2 experiments, direct detection detectors of improved sensitivity would be necessary to help in characterizing the origin of such a signal. iii) If no convincing signal has been obtained anywhere, detectors of, say, an order of magnitude greater sensitivity than the G2 experiments will have to be built to confirm or reasonably exclude the general concept that dark matter is due to physics at the TeV scale (the sensitivity is likely to be limited by solar or atmospheric neutrinos).
The exact focus of Generation-3 will depend on the positive or negative experimental evidence gathered in the coming five years at the LHC, and in direct and indirect dark matter searches and on the shifts of paradigm that these results may induce. Recent theory developments have increased the likely range of dark matter particle masses and suggested that the phenomenology (e.g., dependence on the target nucleus) may be more complex than for the simple WIMP scenarios. We may then need significantly more than two Generation-3 detectors worldwide. Ideally, they would use different technologies with complementary capabilities and different susceptibility to background. There should be enough sensitivity overlap to have at least a second experiment able to cross-check any claim. In order to maximize our scientific investment, and maintain our historical leadership, we believe that the development of at least **two** such detectors (combined or in separate experiment) should be led by the US. While there is broad agreement about this approach, the details will have to be filled in by the ongoing Snowmass studies.
In all these cases, it would be scientifically desirable to have these experiments ready for operation in the early 2020’s requiring the start of a selection process in the next five years and a construction decision in some eight years from now.

Science: The nature of the ubiquitous dark matter in the universe is a central problem of cosmology and the possibility that it is made of particles produced in the early universe remains an attractive concept, which would further unite the physics at small and large scale. The direct detection of the scattering of dark matter particles in a terrestrial target would provide unambiguous proof of such a scenario and hints at its physical origin. The 2011 NRC report “An Assessment of the Deep Underground Science and Engineering

Laboratory" provided a strong endorsement: "The direct detection dark matter underground experiment is of paramount scientific importance and will address a crucial question upon whose answer the tenets of our understanding of the Universe depend."
Apart from axions or sterile neutrinos, not considered here, the recent theoretical discussions focused on two scenarios: i) The Weakly Interacting Massive Particles proper whose existence and density are explained by new physics at the weak scale (e.g., supersymmetry). The favored mass scale is above 50 GeV/c^2. ii) A dark sector either with symmetric or asymmetric dark matter, which could self-interact for instance through a light mediator and exhibit a complex structure. For a dark particle-antiparticle asymmetry similar to that of the baryons, a mass in the few GeV/c^2 would be favored.
Whatever the scenario, direct detection, indirect detection and the LHC are complementary. In particular, direct and indirect detection experiments may be able to bring additional information on signals that could be observed at the LHC (e.g., help break ambiguities). If no new physics is observed at the LHC, direct and indirect particle dark matter detection could help pin down the scale for new physics, since, contrary to colliders, the astrophysics searches are not restricted by sharp production thresholds.

Collaboration and Funding: The G2 down selection is likely to lead to a substantial reorganization of the collaborations. Moreover, a consolidation of the efforts worldwide may lead to significant foreign contribution if the decision process in the US is effective and timely. Thanks to the support of NSF and DOE, the US has been a leader in the development and demonstration of the most powerful technologies currently being deployed for WIMP searches. Moreover, US scientists involved in WIMP direct detection represent some 40% of the worldwide community. This strongly argues for the US taking responsibility for at least two detectors, which would have considerable advantage scientifically in terms of breadth and cross-checks and would decrease the technological risks. Note that conversely, US leadership may be undermined by delays in decision and funding, which may lead US teams to join foreign-led projects.

Cost: Engineering studies made in the context of DUSEL indicated a cost on the order of $100M per Generation-3 detector, leading to a total of ~$200M for two detectors (with generous contingency). Foreign participation may decrease this number by ~30%.
This assumes that these experiments can be housed in existing labs in the US (Homestake), Canada (SNOLAB) or around the world (Modane, Gran Sasso, and Jin Ping). The physical size of the experiment or lack of space may require the excavation of a new cavity in one of the existing underground laboratories. Depending on the location and sharing of infrastructure with other experiments, this may require an additional investment of $50M to $200M (to be amortized over the duration of the facility).

Science Classification and Readiness: The Generation 3 Direct Detection Dark Matter program is *absolutely central* to the goals of the Cosmic Frontier and is in advanced R&D phase. The G2 experiments will likely provide the demonstration of the basic technologies to be used for the G3 program. Additional R&D will be needed to optimize the sensitivity and threshold of the detectors. Unless a light "WIMP" with a large cross section is discovered, it is unlikely that directional detectors can be scaled to the needed target mass in the next five years, but active R&D remains necessary.