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MEMORANDUM

To: Rethinking Dark Matter attendees

From: Peter Fisher

Subject: A terminal nuclear recoil experiment

Date: Friday, April 21, 2016

LIGO's recent success shows what can be accomplished with the long term Federal support of an important scientific project. The two interferometers that first observed gravitational radiation were scaled from 1.5 m and 40 m prototypes at MIT and Caltech, representing more than a factor of 100 scaling. Initial LIGO was built with the near certain knowledge that it would not be able to observe the expected gravitation radiation, but the proponents made convincing arguments for the project's importance, ensuring nearly thirty years of support from the NSF. This memo considers a terminal nuclear recoil experiment from a similar view point.

We have a good idea of the Standard Model processes that would mediate elastic scattering between a dark matter particle and target nucleus. Assuming no new interactions appear in the coming years, the question is, "What are the characteristics of a nuclear recoil experiment able to exhaust most of the parameter space assuming *only* a new weakly interacting massive particle with known forces mediating the elastic scattering with a nucleus?" Based on $\sigma_n = 10^{-49}\text{cm}^2$ as reported in the meeting, and dark matter particle mass of up to 10 TeV, some first thoughts follow.

Adopting the notation of Lewin and Smith, *Astroparticle Physics* 6 (1996) 87, the total event rate per kilogram of target material A is $R_o = N_A \sigma_o n_o < v > /A$. We assume t is ten years of operation. If the experiment is truly background free *and the experimenters know it*, the needed detector mass is then $1/R_o t$, referred to as the single event mass.

Reality intrudes: in their first paper, LUX managed a background rate of 0.0036 counts/keV-kg-day in the signal region 0.9-5.5 keV$_{ee}$. For their 85 day run, they had 160 counts in their analysis window. At $m_\chi = 45$ GeV, where LUX is most sensitive, their 118 kg target mass allowed a cross section limit of 10^{-45}cm^2, or fewer than 6 counts. Their limit actually comes from a fit to the signal region taking into account the expected signal spectrum and reasonable assumptions about the background spectrum. Fitting buys LUX a factor of thirty over the simple Gaussian five standard deviation limit (i.e. fewer than 160+1.65$\times\sqrt{160} = 181$ as the 95% c.l. upper limit on the number of counts).

A terminal background free xenon experiment running for ten years would have single event mass of 70 tons.

Radiation sources inside and outside the fiducial volume comprise the background. Contaminants in the xenon itself causes the former and necessarily scales with mass and exposure time. Fiducialization is really using the xenon outside the fiducial region as a shield against outside

	10 TeV		5 GeV	
Target Element	Single Event Mass (tons)	E_or (keV)	Single Event Mass (tons)	E_or (keV)
Helium	2,430,000	7.4	3,700,000	2.4
Oxygen (Water)	38,100	30	301	1.9
Argon	2,460	74	87	1.0
Germanium	412	135	42	0.6
Xenon	70	239	22	0.4

Table 1: Single event sensitivity masses for candidate target elements.

sources outside and this background scales with a lower power of the xenon mass. If the xenon itself is the primary source of the background, a terminal experiment requires 4 million tons of xenon, representing the worst possible case. Using a fit as LUX did may lower the mass requirement to 135,000 tons. A higher threshold may save another factor of ten in target mass while not losing much signal. If the background could be reduced by a factor of 20, the resulting target mass would be comparable to DUNE, about 100 tons.

Table 1 gives the single event masses for several candidates that have been used in recoil experiments. It first thought, xenon presents the best path forward; a few hundred tons could be a realizable amount. Oxygen in water could be interesting if a way of detecting low energy recoils could be found; the IceCube Neutrino Observatory contains around a billion tons of target material.

For WIMPs with masses below 10 GeV, the threshold plays an essential role. Table 1 shows detecting WIMPs with masses below 5 GeV requires thresholds below 1 keV for the most attractive elements. hep-ph:1512.04533 outlines a possible approach using the breaking of Cooper pairs in a super conductor by dark matter elastic scattering.

Consideration of a terminal dark matter experiment would be a good topic for a Radcliffe Institute Meeting. Topics would be,

1. Developing a road map to develop the factor of 20 background mitigation for a realizable experiment.
2. An industry study for the production of the needed material for the best target element and handling systems for deploying them.
3. Readout schemes for detector built of different candidate elements, including accessing the mass region below 5 GeV.

I believe deploying a terminal dark matter experiments with a 100 ton target mass is technically possible. Agencies could support such an endeavor if the argument that a terminal experiment would close out dark matter with weak interactions and with masses that could conceivably be probed by a collider up to 10 TeV. One could argue that doing a terminal dark matter experiment would be a necessary precursor to a 100 TeV proton-proton collider – evidence for a particle in the 10 TeV mass range would guarantee interesting physics at such a machine.

If something shows up at the LHC in the coming years, the imperative for a terminal experiment becomes obvious.