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THE DARKLIGHT EXPERIMENT - A STATUS REPORT

James R. Boyce
On behalf of the DarkLight Collaboration
Jefferson Lab, Newport News, VA 23606, USA

Abstract

Interest in probing physics Beyond the Standard Model (BSM), has led to incorporating accelerator technologies such as Superconducting RF (SRF) and Energy Recovery Linacs (ERL) into experiments searching for evidence of dark matter in laboratory settings. Three experiments will use JLab's accelerators, CEBAF and FEL, to explore complimentary regions of parameter space seeking evidence of a hypothesized gauge boson, the A'. This is a status report on the DarkLight effort using the FEL.

1 Introduction

As summarized by Jaeckel [4] and illustrated in Figure 1, many groups have searched for evidence of dark matter. In early 2006 the LIPSS Collaboration [1] showed that Jefferson Lab's accelerators, using superconducting RF (SRF) and

Energy Recovery Linac (ERL) technologies, could be used to explore regions of parameter space heretofore unreachable.

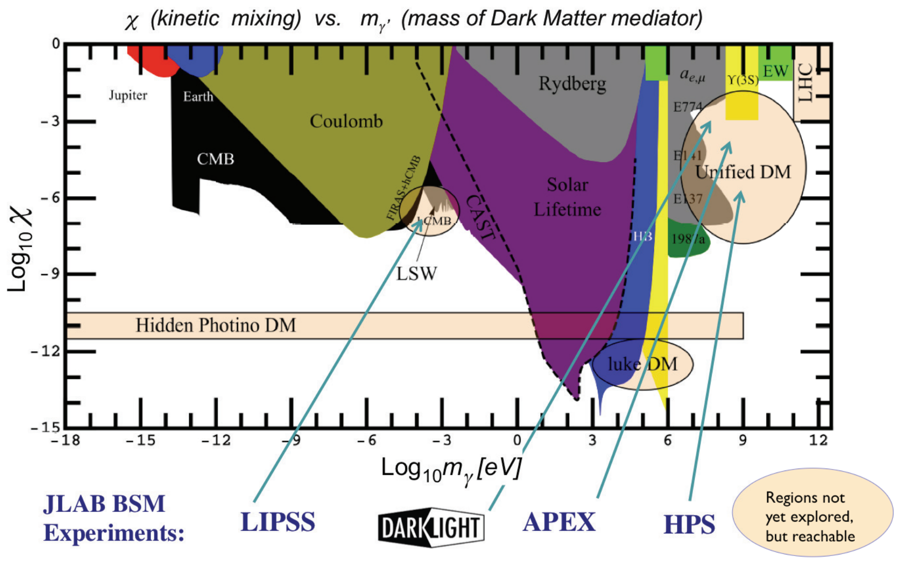

Figure 1: *Many experiments have explored parameter space and have established regions - in color - where dark matter evidence is excluded. Jefferson Lab experiments examine the regions indicated by light blue arrows.*

The high quality electron beam capabilities of JLab's accelerators, CEBAF and FEL, [5] have been incorporated into proposals based on predictions of Freytsis. [3] These experiments will search for the A′ scalar boson in the mass region 10 MeV to 1.0 GeV. Three collaborations (APEX, HPS, and DarkLight) are setting up to explore complementary parameter space regions indicated in Figure 1. The DarkLight Collaboration [1] search for the A′ [2]

[1] J. Balewski, J. Bernauer, W. Bertozzi, J. Bessuille, B. Buck, R. Cowan, K. Dow, C. Epstein, P. Fisher, S. Gilad, E. Ihloff, Y. Kahn, A. Kelleher, J. Kelsey, R. Milner, C. Moran, L. Ou, R. Russell, B. Schmookler, J. Thaler, C. Tschalaer, C. Vidal, A. Winnebeck *Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA 02139, USA and the Bates Research and Engineering Center, Middleton MA 01949 USA*

will use the electron beam of the FEL facility to scatter off a gaseous hydrogen target.

2 DarkLight - The Basic Idea

The DarkLight experiment will use the FEL facility's high current ($\approx$ 10mA), low energy ($\approx$ 100 MeV) electron beam to scatter off a diffuse hydrogen gas target. Figure 2 shows the interaction diagram, parameter space to be explored by DarkLight, and the experiment concept. Hydrogen gas is fed into a gas chamber with coaxial windowless entrance and exit channels. Hydrogen gas escaping the chamber into the vacuum beam pipe is removed by pumping stations before and after the interaction region. Electron beam bunches are focused through the channels, interact with the hydrogen gas, and reaction products are recorded for analysis. Evidence for the hypothesized $A^{'}$ would consist of a narrow resonance on a large QED cross section.

S. Benson, C. Gould, G. Biallas, J.R. Boyce, J. Coleman, D. Douglas, R. Ent, P. Evtushenko, H. C. Fenker, J. Gubeli, F. Hannon, J. Huang, K. Jordan, R. Legg, M. Marchlik, W. Moore, G. Neil, M. Shinn, C. Tennant, R. Walker, G. Williams, S. Zhang *Jefferson Lab, 12000 Jefferson Avenue, Newport News, VA 23606, USA*

M. Freytsis *Physics Dept., U.C. Berkeley, Berkeley, CA, USA*

R. Fiorito, P. OShea *Institute for Research in Electronics and Applied Physics University of Maryland, College Park, MD, USA*

R. Alarcon, R. Dipert, *Physics Department, Arizona State University, Tempe, AZ, USA*

G. Ovanesyan *Los Alamos National Laboratory, Los Alamos NM, USA*

T. Gunter, N. Kalantarians, M. Kohl, *Physics Dept., Hampton University, Hampton, VA, USA*

I. Albayrak, M. Carmignotto, T. Horn *Physics Dept., Catholic University of America, Washington, DC 20064, USA*

D. S. Gunarathne, C. J. Martoff, D. L. Olvitt, B. Surrow, X. Li *Physics Dept., Temple University, Philadelphia, PA 19122 USA*

E. Long *Physics Dept., Kent State University, Kent, OH, 44242 USA*

R. Beck, R. Schmitz, D. Walther, *University Bonn, D - 53115 Bonn Germany*

K. Brinkmann, H. Zaunick II. *Physikalisches Institut Justus-Liebig-Universitt Giessen, D-35392 Giessen Germany*

W.J.Kossler *Physics Dept., College of William and Mary, Williamsburg VA 23185, USA*

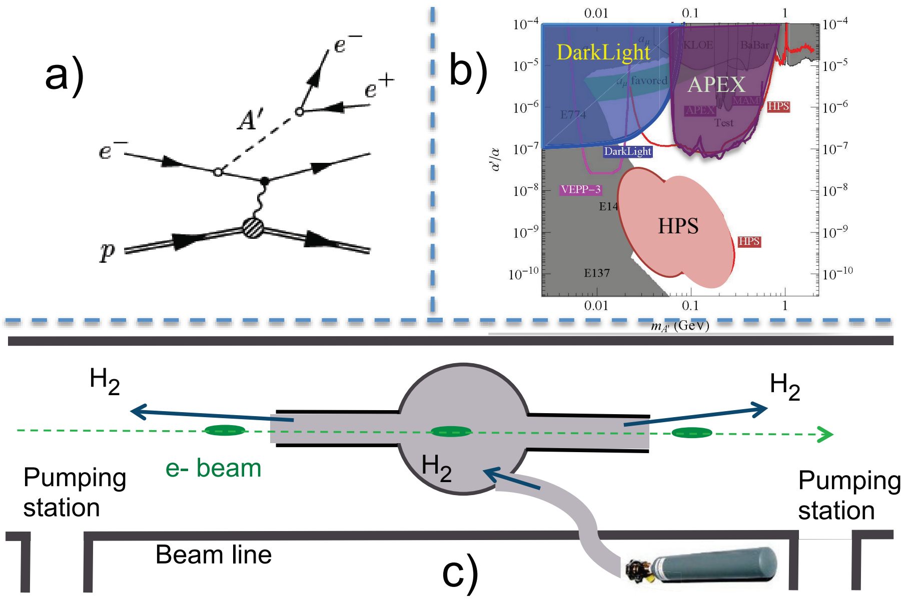

Figure 2: a) The hypothesized reaction, b) the parameter space to be explored by upcoming JLab experiments DarkLight, APEX and HPS, and c) The DarkLight experiment concept.

3 Proposed Detector System Design

The detector system for the DL experiment surrounds the windowless gas target and is inside a 0.5 T solenoid magnet surrounding the electron beam line, detectors, and windowless gas chamber at the interaction region. A candidate location for this system is in the the FEL's UV beam line, indicated in Figure 3, which is a schematic layout of the FEL's ERL accelerator system. TheDarkLight system is contained in a cylindrical space about 1.7 meters long and 1 meter in diameter fitting around the the accelerator beam line. Figures 4 and 5 show the present detector system design concept. The diameter of the input and output channels (≈ 2 mm) was chosen by balancing the requirement of a constant density of Hydrogen in the interaction chamber, against the need to maintain good vacuum in the accelerator beam line. Hence the pumping stations before and after the DL system.

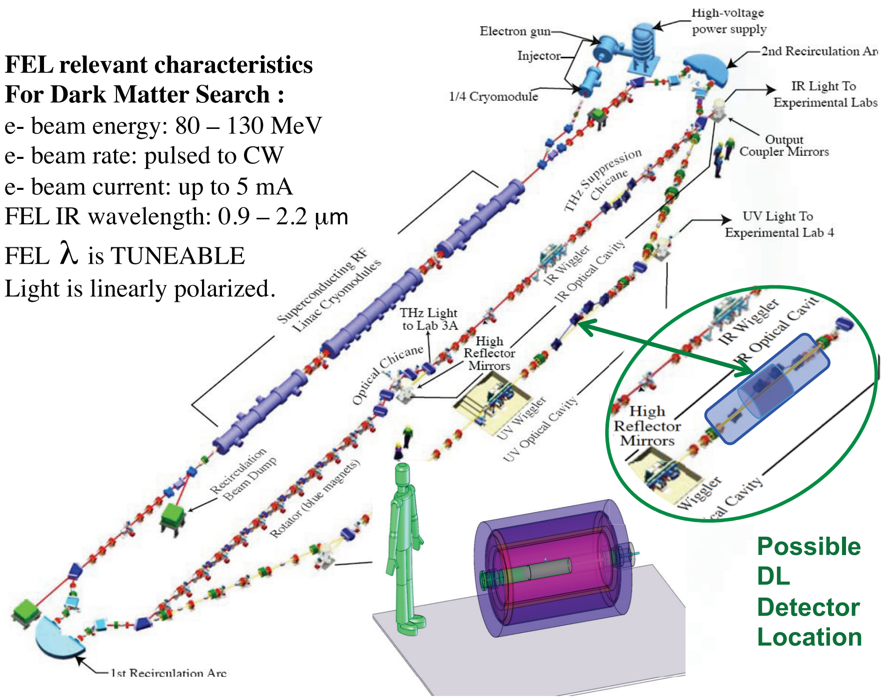

Figure 3: Jefferson Lab's FEL is an Energy Recovering Linac (ERL) in a 60 meter long racetrack configuration. An inset cartoon illustrates the size of the DarkLight detector system relative to a green manikin. Also shown a location for the DarkLight Experiment and relevant FEL characteristics for Dark Matter experiments.

However, this design calls for clean transmission of 10 mA of a 100 MeV electron beam through the DL system. Cleanly threading a 1 MW beam and then cleanly maintaining it through such a system has never been done before and is a challenging task for the FEL beam opticians and operators.

Prior to more detailed design considerations, three topics needed further examination: 1) background ambient radiation in the detector location, 2) radiation caused by scraping of the electron bunch along the in/out channels, and 3) excessive RF heating of the target region induced by the beam. These topics were addressed in 2012 by extensive modeling and by measurements with the FEL.

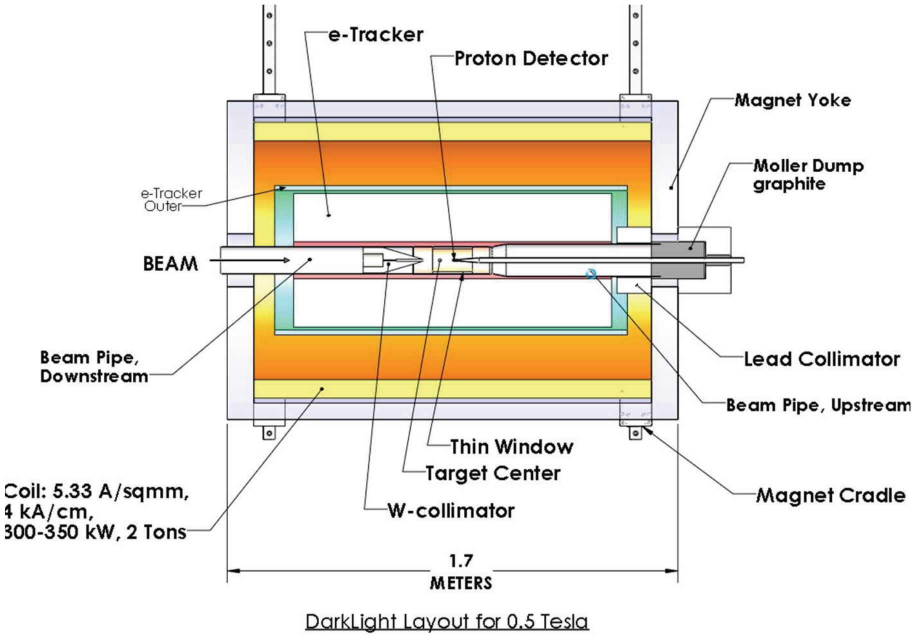

Figure 4: A cross section of the DL system shows the solenoid surrounding detectors surrounding the windowless gas chamber - the interaction region.

4 Background Radiation

Ambient vault radiation was measured outside the vacuum beam line while the beam-target interaction studies required installing an insertable system in the beam-line. Results of these studies will be used to establish shielding requirements and beam bunch size requirements.

4.1 Beam-Target radiation.

The 2-mm diameter constraints on the entrance/exit channels along with the beam current and energy means putting 1MW of power through the chamber. Two items of concern needed to be addressed: beam scraping and RF induced hot spots. Figure 6 shows the setup used to address these diameter concerns. A solid block of Al with three holes of progressively smaller diameters (6 mm, 4 mm, and 2 mm) was mounted on a standard vacuum chamber/cube and at-

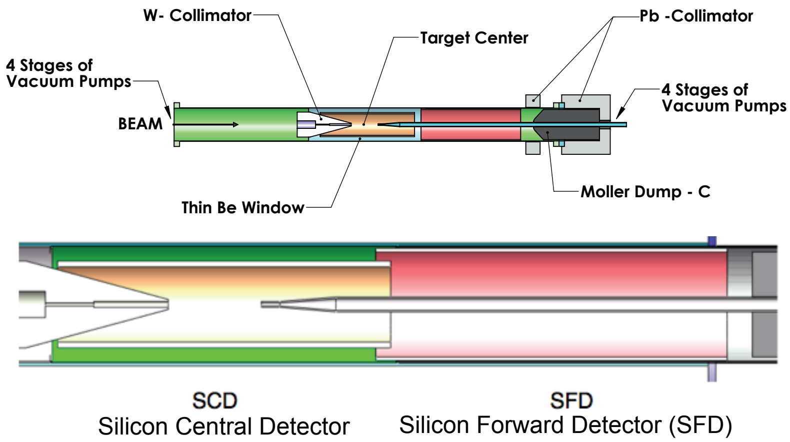

Table: Gas target specifications for the DarkLight experiment.

Outflow channel diameter	D=2 mm
Outflow channel length	l= 5 cm
Mach number at channel entrance	$\eta = 0.18$
Reynolds number at channel entrance	$R_e = 250$
Target pressure	$p = 12$ Torr
Target thickness	$t = 10^{19}$ atoms/cm^2
Gas outflow rate in each channel	$Q = 15$ Torr-liter/s

Figure 5: An enlarged view of the target chamber and the initial design considerations.

tached to a remotely controlled precision stepper motor. The cube was then mounted in the IR beam line along with insertable viewers before and after the target block. The beam-target test consisted of sending the the beam through each of the three holes and measuring the temperature and radiation as a function of beam current and hole size. First, with the Al block retracted, the FEL beam was established with low rep rate and bunch charge. Then the block was inserted to each hole's position co-axial to the beam and the beam current was progressively increased while the radiation levels and block temperature were monitored and recorded.

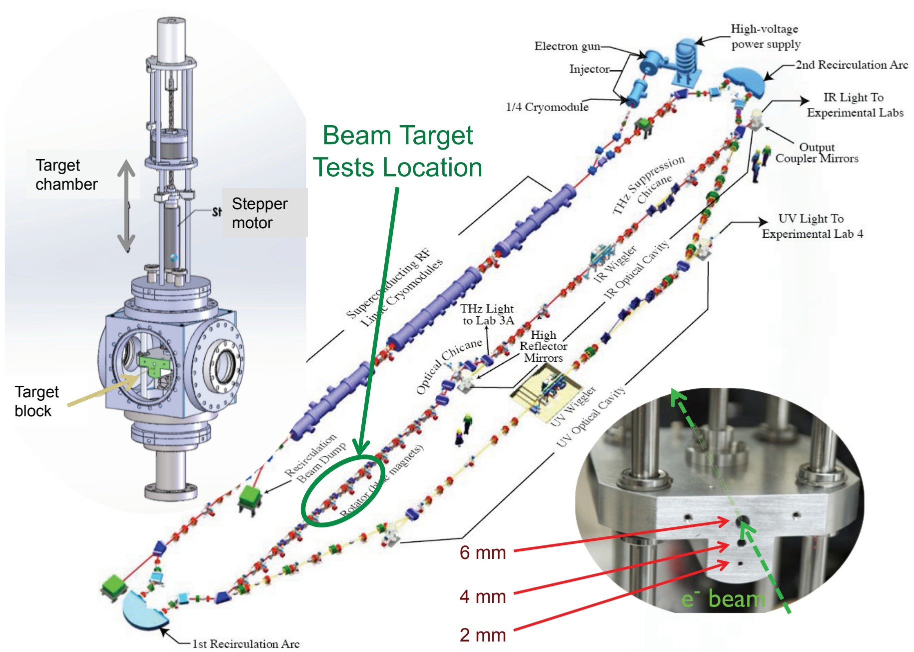

Figure 6: The actual beam-target tests setup. The tests verified that the electron beam can be successfully threaded through input and exit regions of the windowless gas target without excessive scraping off the walls. Radiation from and temperature of the block were recorded as a function of beam conditions.

4.2 Induced RF Heating.

Using an RDT temperature sensor mounted on the Al block, the power deposited in the block was determined by measuring the rise and fall of the Al block temperature. These measurements were taken during an eight hour long run. Bottom Line: there was a loss of between 3 and 7 ppm from a 0.45 MW beam, well below the original tolerable limit of 1E-05 loss due to beam halo scraping.

It is well known that unhealthy levels of radiation can be produced by SRF accelerator cryomodules of the type used in the FEL. Measurements of the vault's ambient radiation was conducted parasitically with an experiment needing UV lasing, i.e., an electron beam of 130 MeV. This would establish an upper limit on the radiation doses of photons and neutrons. Figure 7 shows

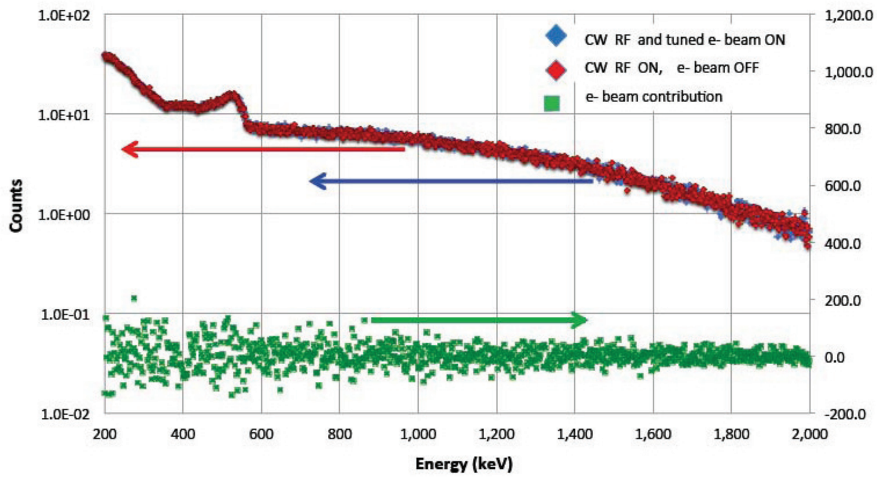

Figure 7: Typical photon spectra in the FEL vault recorded during UV lasing operations. The arrows indicate which scale is appropriate for the data points. The important conclusion from these measurements is that the ambient radiation in the FEL vault is solely from the accelerating cryomodules, providing the electron beam is well tuned and energy recovered.

typical photon spectra taken under these conditions using a NaI/PMT system inside a two-inch thick Pb enclosure. The red spectrum was taken during UV lasing. The blue spectrum was taken immediately after the electron beam was turned off. The green spectra is the difference between the red and blue. These data clearly establish an important fact: a properly tuned electron beam does not contribute to the ambient radiation field in the FEL vault.

In addition to the NaI/PMT detector system, two unshielded, calibrated detector systems measured the flux of neutrons and gammas in the vault. Figure 8 shows the fluxes as function of RF accelerating voltage as the voltage is shut down from the last accelerating cavity back to the injector. At maximum SRF voltages, neutrons contribute about 1/4 of the total radiation. The good news is that since DarkLight does not require maximum SRF voltage, the individual cryomodules can be tuned such that 100 MeV is achieved while at the same time the accelerating SRF voltages are under the threshold for pesky field emission-causing background.

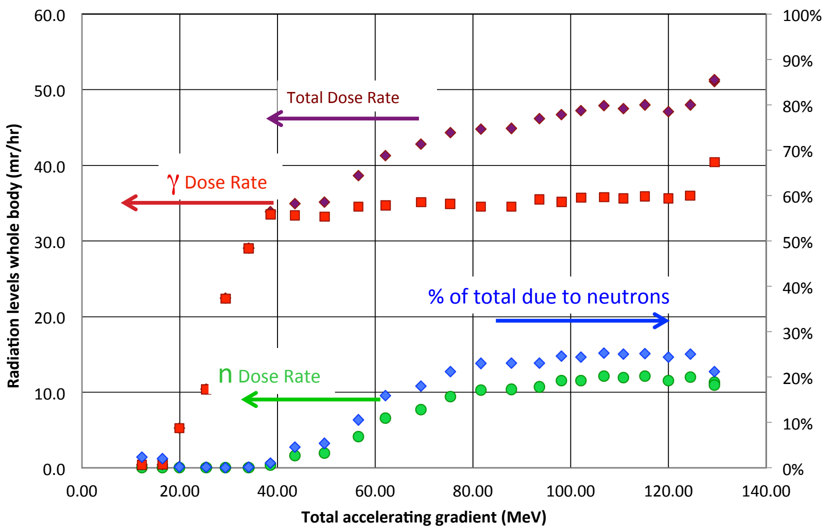

Figure 8: Photon and neutron dose rates recorded during UV lasing operations. The electron beam energy was 130 MeV. These points were recorded as the RF on the three cryomodules was shut down starting with the cavities at the end of the third cryomodule and sequentially shutting down each section back towards the injector. The arrows indicate the appropriate scale for each set of data points.

5 Discussion and Path Forward

To summarize the DarkLight effort to date, we have made background radiation measurements, modeled beam-target and moller scattering, measured actual ambient radiation, designed, constructed, calibrated, and conducted tests with the actual FEL beam. We have established upper level background radiation doses for both neutrons and photons, as well as their sources. We have established that the tight constraints on the electron beam in terms of stability, current, and energy are achievable.

With the successful studies conducted in 2012, the collaboration has the

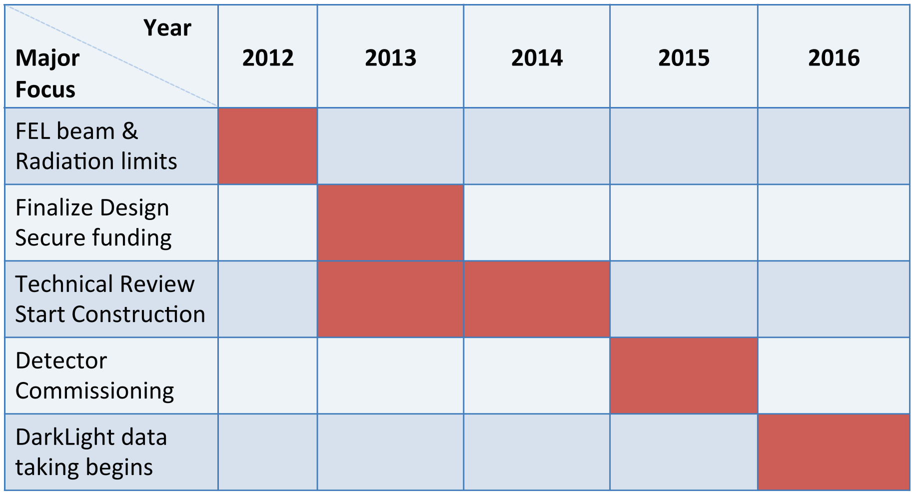

Figure 9: With the information gathered to date, the collaboration's focus for calendar year 2013 will shift over to seeking funding support. Once secured, the design, construction and commissioning of the DarkLight system will start. The estimated start of the experiment will occur in 2016.

information needed to complete the design, construct and commission the the Detector system, and install and run the DarkLight Experiment. The anticipated timeline is shown in Figure 9.

6 Acknowledgements

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References

1. A. Afanasev, O.K. Baker, K.B. Beard, G. Biallas, J. Boyce, et al. New Experimental limit on Optical Photon Coupling to Neutral, Scalar Bosons. *Phys.Rev.Lett.*, 101:120401, 2008.

2. P. Fisher and Milner R. A proposal for the darklight experiment at the je erson laboratory free electron laser. Program Advisory Committee - 37 PAC PR-11-008, Jefferson Lab, 12000 Jefferson Ave., Newport News, VA 23606, USA, December 2010.

3. M. Freytsis, G. Ovanesyan, and J. Thaler. Dark Force Detection in Low Energy e-p Collisions. *JHEP*, 1001:111, 2010.

4. J. Jaeckel and A. Ringwald. The Low-Energy Frontier of Particle Physics. *Ann.Rev.Nucl.Part.Sci.*, 60:405–437, 2010.

5. G.R. Neil, C. Behre, S.V. Benson, M. Bevins, G. Biallas, et al. The JLab high power ERL light source. *Nucl.Instrum.Meth.*, A557:9–15, 2006.