Title of the Proposed Project: Germanium Detector with Sensitivity to MeV-Scale Dark Matter
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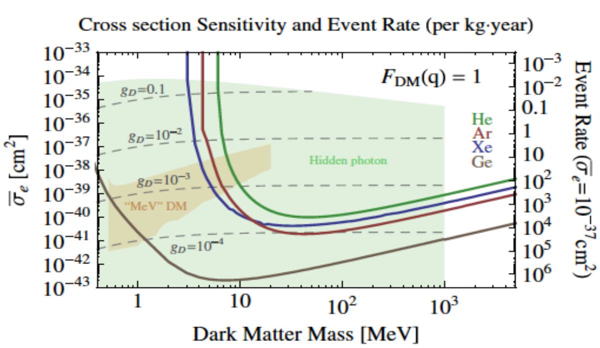
List Participating Institutions: University of Alabama (UA); University of South Dakota (USD, lead); University of Tennessee at Knoxville (UTK); Black Hills State University (BHSU); Industry Partner – Klytec (NJ); Institute of Physics, Academic Sinica, Taiwan; Tsinghua University, China; Sichuan University, China; Yangtze University, China.

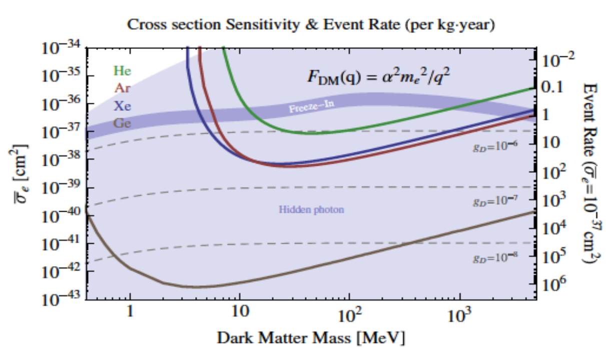
Primary Physics Goals: In the past decade, light, MeV-scale dark matter has risen to become an exciting dark matter candidate even though its low mass makes it unreachable by any current experiment. The one of the technologies with strong potential for sensitivity to MeV-scale dark matter is internal amplification with impact ionization of impurities. We intend to develop state-of-the-art germanium (Ge) detectors with internal amplification enabling an ultra-low energy threshold of ~0.1 eV for detecting low-mass dark matter particles in MeV range at the Sanford Underground Research Facility (SURF). Development of a Ge detector that employs internal amplification will possess not only discovery potential in science but also a great innovation that could expand the use of Ge detectors into ultra-low energy radiation detection.

Experimental Approach: Utilizing the grown crystals developed at USD, planar detectors of internal amplification with impact ionization of impurities can be developed. As suggested by Starostin and Beda (Phys.Atom.Nucl. 63 (2000) 1297-1300), we will develop Ge detectors with internal amplification and appropriate doping level of impurity to achieve an effective threshold of 0.1 eV to prove this technology. In high-purity Ge with a sensitivity volume of ~200 cm^3, the critical electric field, E_{cr}, can be obtained at a level of greater than 10^4 V/cm for a planar detector. The amplification factor can be estimated as $K = 2^{h/l}$ where h is the length of avalanche region and l is the free electron path of inelastic scattering. The value of l in Ge at 77 K is about 0.5 μm and h can be 5 μm for planar detector 3 cm thick. Thus, it is possible to achieve a value of $K = 10^3$ with a threshold as low as ~0.1 eV.

Existing and Future Physics Results: USD's unique Ge crystal growth facility enables zone refining, crystal growth and characterization, and includes a Hall-effect system and a photothermal ionization spectroscopy (PTIS) instrument. Detector experts Mark Amman (LBNL), Yulan Li (Tsinghua), and Rupak Mahapatra (Texas A&M) have successfully fabricated Ge detectors with the crystals grown at USD. To leverage and advance these capabilities, we will develop a planar detector for a mass of ~1 kg with internal amplification to prove the detector technology and obtain initial results at SURF.

Experimental Sensitivity: According to R. Essig, J. Mardon, and T. Volansky, Phys. Rev. D 85 (2012) 076007, the sensitivity for a germanium detector is shown below.





Timescale of Future Plans: The first prototype detector will be fabricated and tested in 2018. The first low-background detector will be built at USD in 2019. This detector will be installed at SURF in 2020.

Rough Estimate of Budget: A rough budget for R&D for three years is ~\$600K. A 10 kg experiment would cots about \$1.5M. A 100 kg experiment would cost about \$10M.