Light Dark Matter eXperiment (LDMX)

Owen Colegrove,[1] Bertrand Echenard,[2] Norman Graf,[3] Joshua Hiltbrand,[4] David Hitlin,[2] Joseph Incandela,[5] John Jaros,[3] Robert Johnson,[6] Gordan Krnjaic,[7] Jeremiah Mans,[4] Takashi Maruyama,[3] Jeremy McCormick,[3] Omar Moreno,[3] Timothy Nelson,[3] Philip Schuster,[3,8] Natalia Toro,[3,8] Nhan V Tran,[7] and Andrew Whitbeck[7]

[1] *University of California, Santa Barbara, Santa Barbara, CA 93106, USA*
[2] *California Institute of Technology, Pasadena, CA 91125, USA*
[3] *SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA*
[4] *University of Minnesota, Minneapolis, MN 55455, USA*
[5] *University of California at Santa Barbara, Santa Barbara, CA 93106, USA*
[6] *Santa Cruz Institute for Particle Physics, University of California at Santa Cruz, Santa Cruz, CA 95064, USA*
[7] *Fermi National Accelerator Laboratory, Batavia, IL 60510, USA*
[8] *Perimeter Institute for Theoretical Physics, Waterloo ON N2L 2Y5, Canada*

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I. INTRODUCTION

The "Light Dark Matter eXperiment" (LDMX) described in this note aims to precisely measure missing momentum and energy in electron-nuclear collisions with unprecedented sensitivity. The most prominent applications of these measurements include a decisive test of (direct annihilation) thermal dark matter scenarios in the sub-GeV mass range, exploration of well-motivated mass and coupling parameter space for light scalar and vector mediators, as well as searches for milli-charged particles. In addition, a variety of electro-nuclear and photo-nuclear reactions of broader interest can be measured by LDMX. To achieve high statistics, LDMX proposes to use a low-current ($\sim$pA) but high-repetition electron beam. For example, a beam with 10^8 electrons/second on target and energy in the 4 to 10 GeV range can explore most of the sub-GeV dark matter parameter space, while remaining below threshold for production of neutrinos, which are an irreducible background. The DASEL beamline at SLAC is ideal for this purpose, though the Jefferson Lab CEBAF could be adapted for this purpose. We show reach estimates for running LDMX in SLAC's End Station A.

An electron beam incident on a thin target can produce dark matter particles through a "dark bremsstrahlung" process in which most of the incident electron's energy is typically carried away by the invisible dark matter. To search for this process, LDMX reconstructs the kinematics of each beam electron both up- and down-stream of the target. The up-stream tracker tags the incoming beam electrons while the down-stream tracker selects the low-energy, moderate transverse-momentum recoils of the beam electrons. The calorimetry then vetoes events with an energetic forward photon or any additional forward-recoiling charged particles or neutral hadrons. For the first-phase experiment described here, the total required luminosity is a modest 0.2 pb^{-1} corresponding to 10^{14} tagged electrons on target. Nonetheless, because each electron passes through the detector, the experiment must contend with high event rates in the tracker and electromagnetic calorimeter. Therefore, LDMX uses low-mass tracking that provides high-purity tagging for incoming electrons and clean, efficient reconstruction of recoils in a high-rate environment. The calorimetry for LDMX will be fast enough to support this high rate of background events, most of which can be rejected on the basis of their high electromagnetic energy deposition, and sensitive enough to reject rare but subtle processes where a hard bremsstrahlung photon undergoes a photo-nuclear reaction in the target or in the calorimeter itself. These simultaneous requirements call for a high-speed, high-granularity Silicon calorimeter with extremely high MIP sensitivity, that can identify most photo-nuclear interactions. It will be used in conjunction with a hadron calorimeter that experiences much lower event rates. The LDMX concept plans to meet these challenges by leveraging technology under development for the HL-LHC and experience from the HPS experiment.

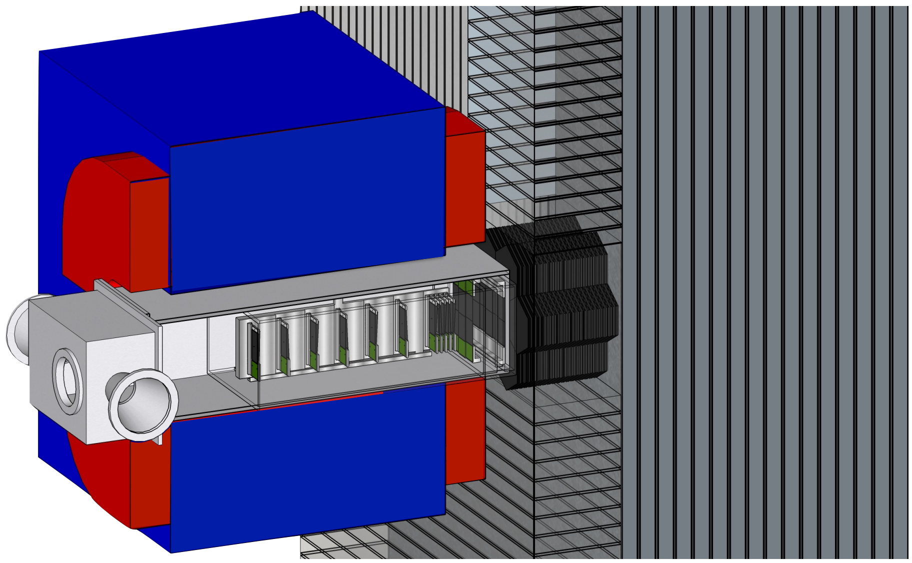

FIG. 1: A cutaway overview of the LDMX detector showing, from left to right, the trackers and target inside a vacuum chamber in the spectrometer dipole, the forward ECAL, and the HCAL. The size and configuration of the HCal necessary to effectively veto rare photonuclear events is still under study.

II. SCIENCE GOALS

As highlighted above, a primary goal of LDMX is to search for dark matter particles in the sub-GeV mass range — a region that is simultaneously well motivated by the thermal freeze-out hypothesis for the origin of dark matter and experimentally open territory. In simple models, a thermal origin for dark matter (via direct annihilation) implies a *minimum* interaction strength between dark and ordinary matter (as does any thermal contact between dark and ordinary matter in the early Universe) — the "thermal relic target". While many recent experimental efforts aim to explore dark matter in this mass range, LDMX will have unprecedented sensitivity. In particular, for DM masses below a few hundred MeV LDMX aims in its first phase to *fully* explore the scalar and Majorana fermion thermal DM parameter space, and the pseudo-Dirac fermion and inelastic scalar thermal DM parameter space in its second phase, as shown in Figure 2. Together with already approved experiments, LDMX is similarly capable of covering the entire allowed parameter space for asymmetric dark matter coupled through vector mixing in the sub-GeV mass range, as shown in Figure 3. LDMX will also explore a broad range of well-motivated parameter space for new light mediator particles, as shown (for the vector case) in Figure 4. Exploring light dark matter physics to the level of sensitivity achieved by LDMX is among the science priorities recently highlighted in the Dark Sectors 2016 community report [1], and resonates with the dark matter priorities emphasized in the P5 report [2].

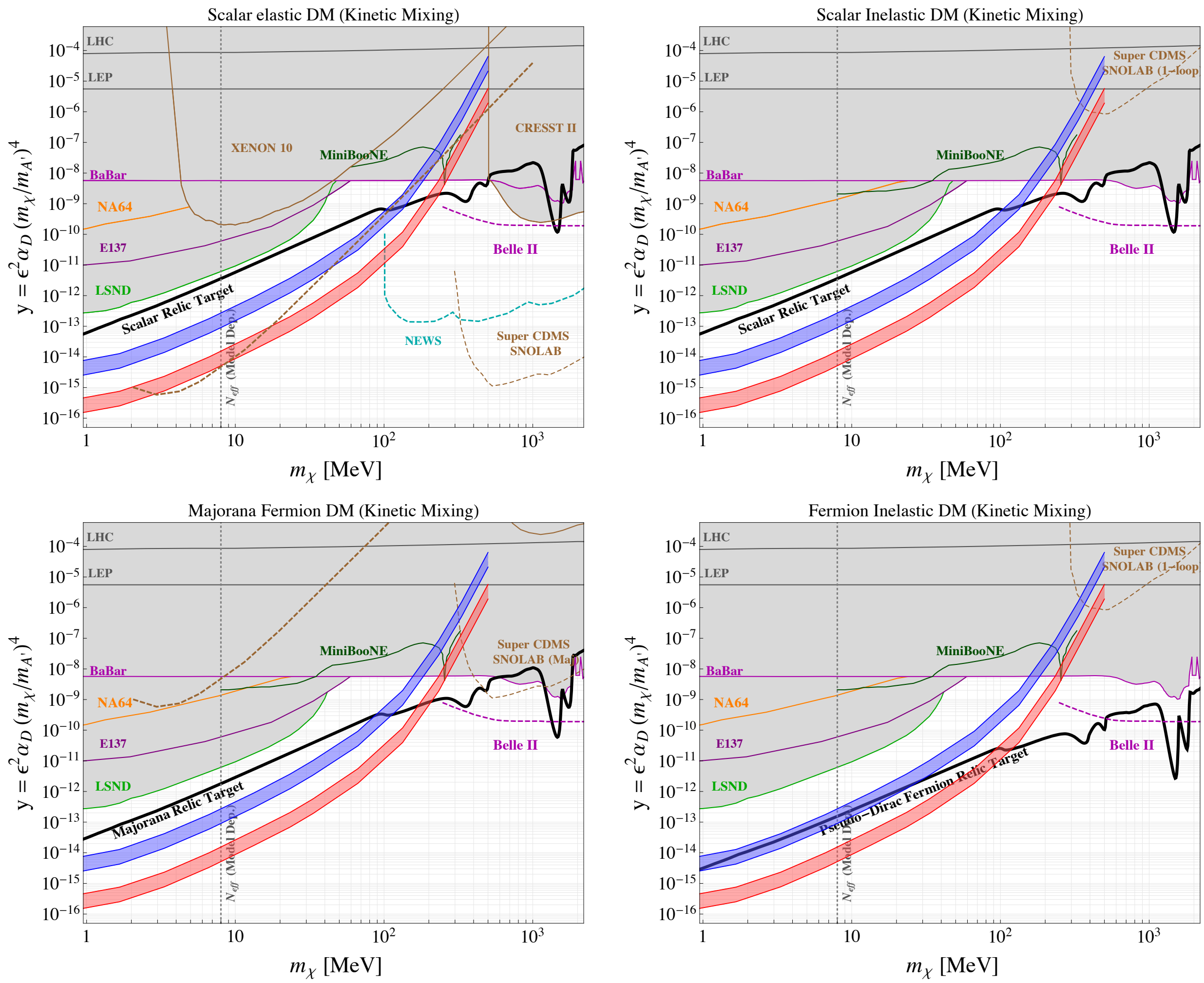

FIG. 2: The reach of the LDMX experiment for Phase I (4×10^{14} EOT, blue band) and Phase II (10^{16} EOT, red band) for the four (direct annihilation) thermal relic DM scenarios allowed by CMB observations. The large momentum transfer of dark bremsstrahlung production in electron-nuclear collisions allows LDMX to decisively probe all thermal relic models with similar sensitivity (a unique strength of LDMX), in contrast to non-accelerator based approaches that must contend with dramatic low-energy velocity or kinematic suppression of interaction cross-sections. Together with Belle II and G2 direct detection experiments, LDMX reaches the targets for thermal relic abundance over nearly the entire mass range.

[1] J. Alexander et al. (2016), 1608.08632, URL `http://inspirehep.net/record/1484628/files/arXiv:1608.08632.pdf`.

[2] S. Ritz et al. (HEPAP Subcommittee) (2014).

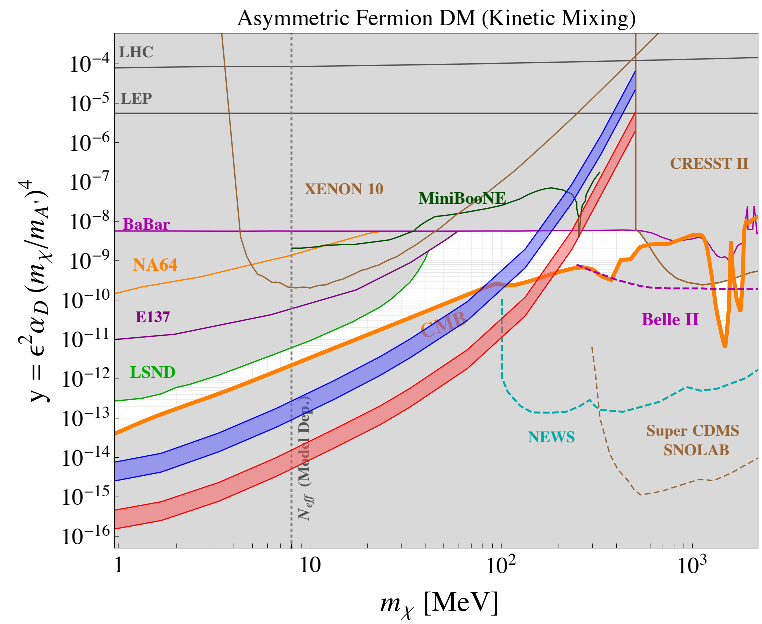

FIG. 3: The reach of the LDMX experiment for Phase I (4×10^{14} EOT, blue band) and Phase II (10^{16} EOT, red band) for asymmetric dark matter coupled through light vector mixing. Together with Belle II, LDMX covers nearly the entire allowed parameter space, which is all equally motivated.

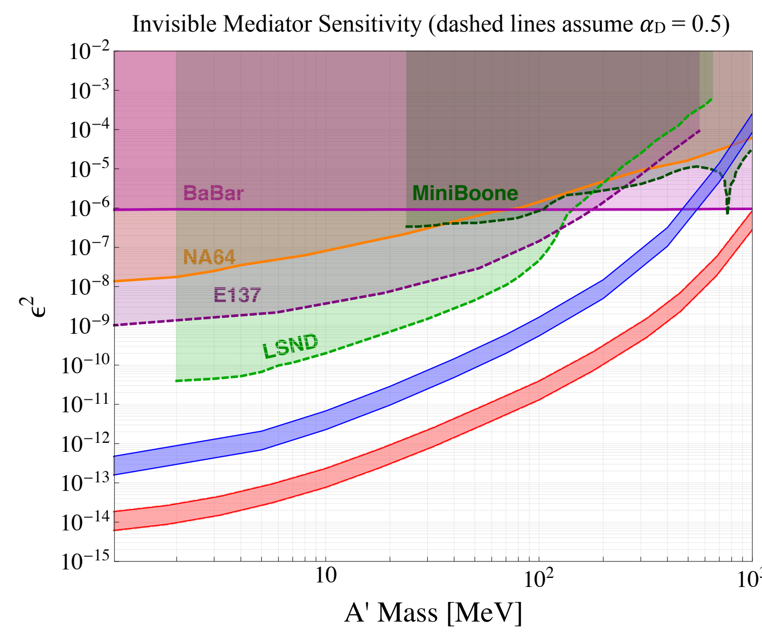

FIG. 4: The reach of the LDMX experiment for Phase I (4×10^{14} EOT, blue band) and Phase II (10^{16} EOT, red band) to a new light vector mediator. The coupling range $\epsilon^2 \sim 10^{-12} - 10^{-6}$ is especially well-motivated as vector mixing is naturally generated at one- or two-loop level. This range of coupling strength would be uniquely explored by LDMX.