Detecting Dark Matter with the Light Dark Matter eXperiment

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On Behalf of the LDMX Collaboration
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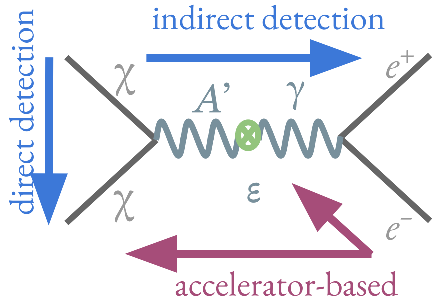
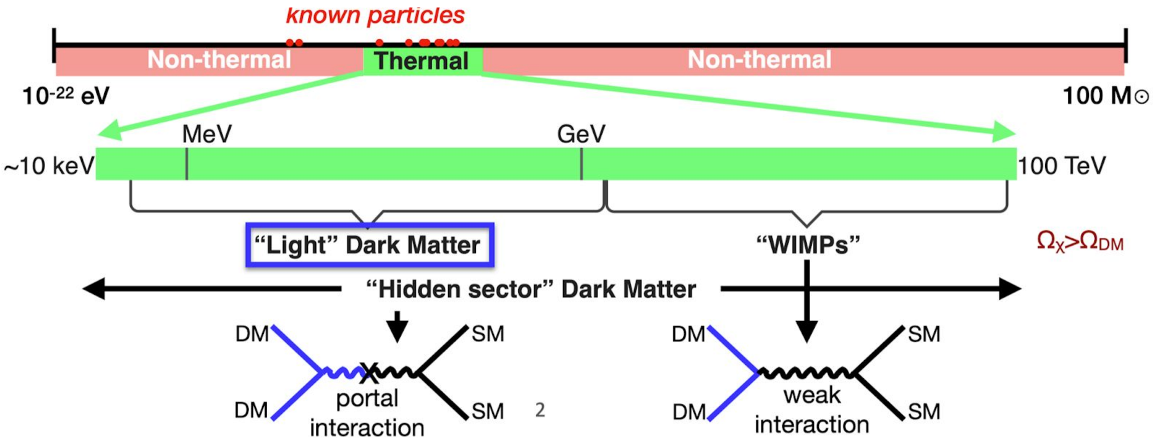
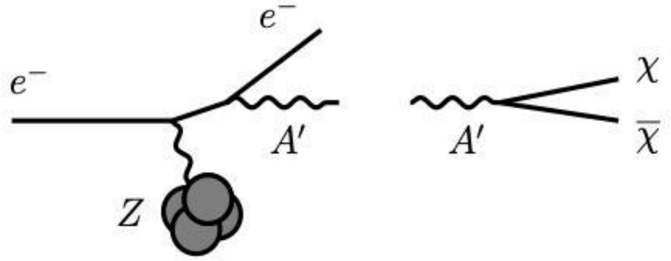
Light Dark Matter

- General interest in expanding dark matter (DM) search to sub-GeV range
  - Thermal relic DM model works for keV to TeV range
- Two categories for thermal dark matter: WIMPs & LDM
  - Accessible parameter space for WIMPs is dwindling, leading to the rise of "light" dark matter research
- Simplest prediction has dark photon (A') mix with SM photon
- Accelerators provide a generic probe for light dark matter in fixed-target measurements

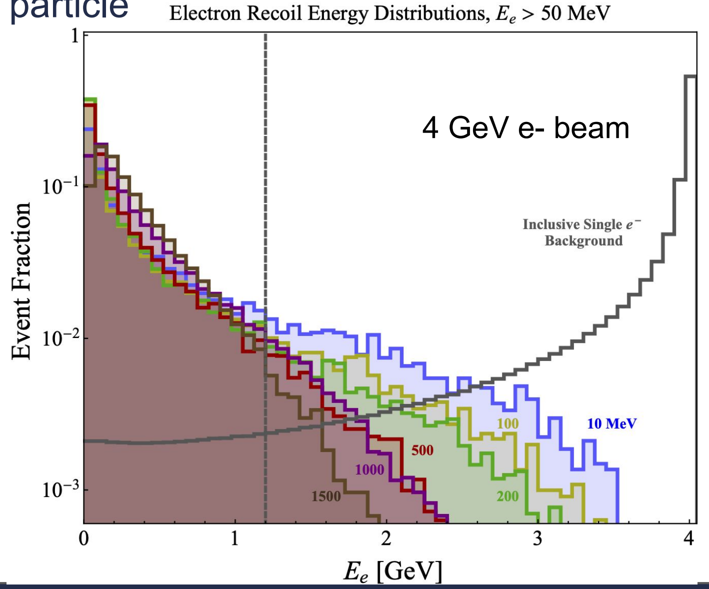




DM Production & Kinematics

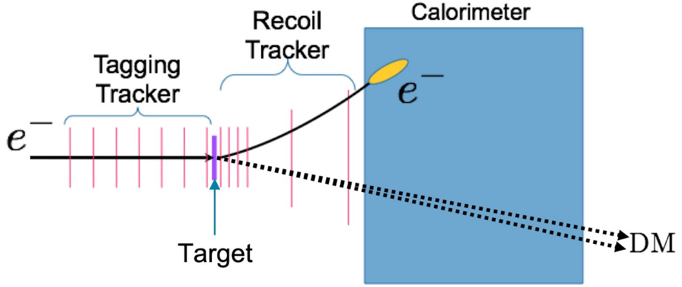


- Few DM signal characteristics for a fixed target
  - A's being produced by "dark" bremsstrahlung process
  - Large drop in energy of beam electron (taken away by A' production)
  - Leads to a "soft" recoil electron, the only visible final state particle



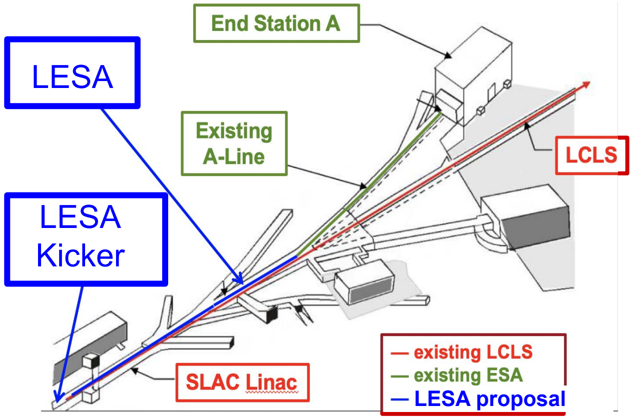
- Can probe these with missing momentum search! Just need:
  - High momentum resolution
  - High veto efficiency for SM backgrounds

LDMX Concept



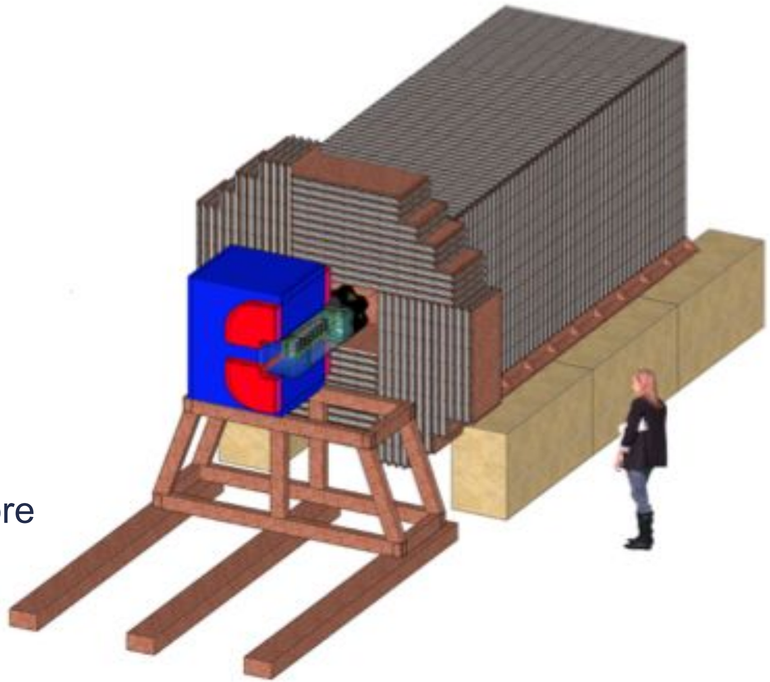
- Look for missing momentum and energy in recoil electron
  - Also use detectors to identify the missing momentum & energy → DM production!
  - Particle ID
  - Transverse momentum of recoil e^- used as discriminator/identifier

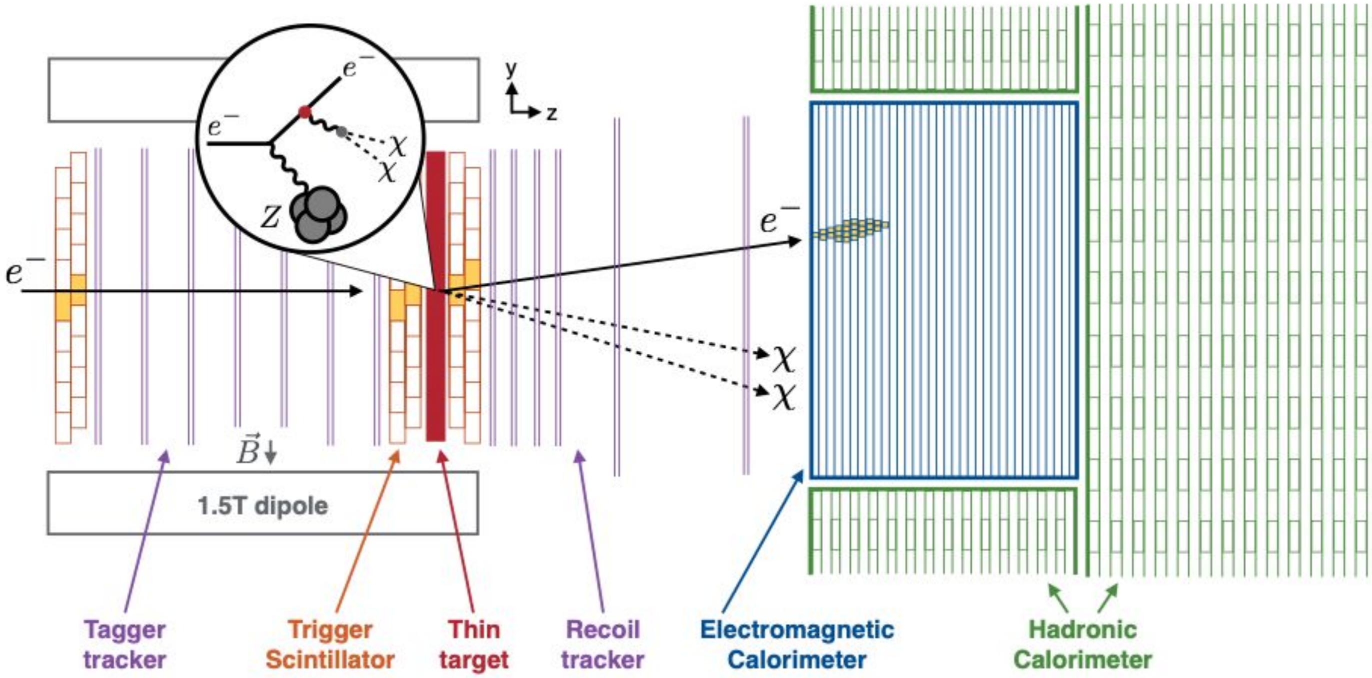
- e^- beam provided by SLAC
  - Planning on 4 GeV and 8 GeV runs
- Must be able to tag and reconstruct every electron
  - Do this for up to 1e16 electrons
  - Use low current, high repetition rate of 37 MHz, μ = 1



LDMX Design

- Detector must be designed to withstand high radiation doses and high rates
- Missing energy trigger at E < 1.5 GeV
- Optimized detector for main search technique (missing momentum), but is also sensitive to:
    - Displaced visible signatures (dark sector physics - more on that later)
    - Electronuclear measurements (neutrino physics)





<u>Tagging and Recoil Tracker</u>

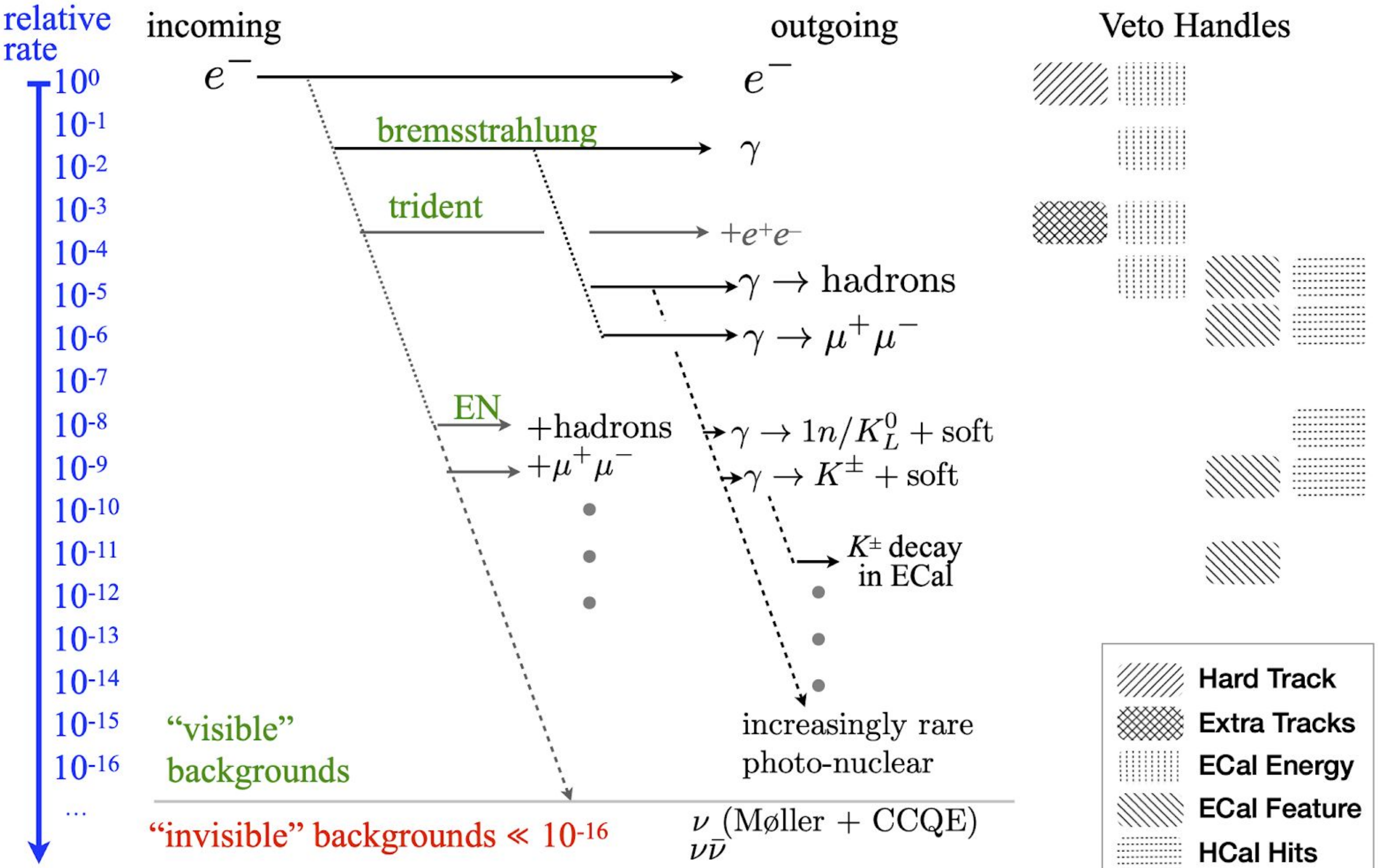
Simplified version of Silicon Vertex Tracker from HPS at JLab (visible dark photon search)

<u>Electromagnetic Calorimeter</u>

Draws on design of CMS Si-W HGCal (fast, radiation hard, dense, with high granularity for MIP tracking)

<u>Hadronic Calorimeter</u>

Inspired by Mu2e Cosmic Ray Veto (plastic scintillator with steel absorber: ~16 interaction lengths, optimized for veto of neutral hadrons)


relative rate
10^0
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incoming
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outgoing
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bremsstrahlung
γ
trident
$+e^+e^-$
$\gamma \to$ hadrons
$\gamma \to \mu^+\mu^-$
EN
+hadrons
$+\mu^+\mu^-$
$\gamma \to 1n/K_L^0$ + soft
$\gamma \to K^\pm$ + soft
$K^\pm$ decay in ECal
increasingly rare photo-nuclear
"visible" backgrounds
"invisible" backgrounds ≪ 10^{-16}
ν (Møller + CCQE)
$\nu\bar{\nu}$
Veto Handles
Hard Track
Extra Tracks
ECal Energy
ECal Feature
HCal Hits

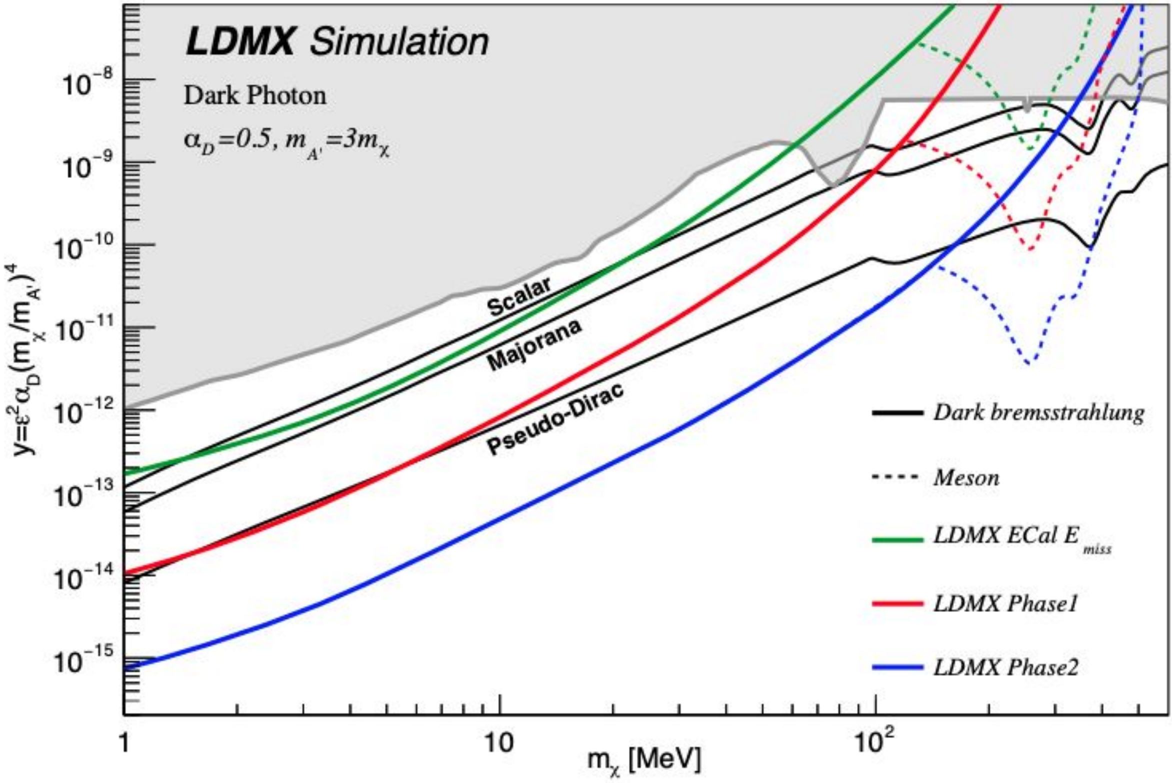
Backgrounds

- With all systems combined, < 1 background event
  - Signal efficiency of ~30%-50% for O(1e14) electrons on target (EoT)
- Recall that transverse momentum of recoil electron is another discriminator for backgrounds
- See LDMX Photon Veto Paper for more information: arXiv:1912.05535

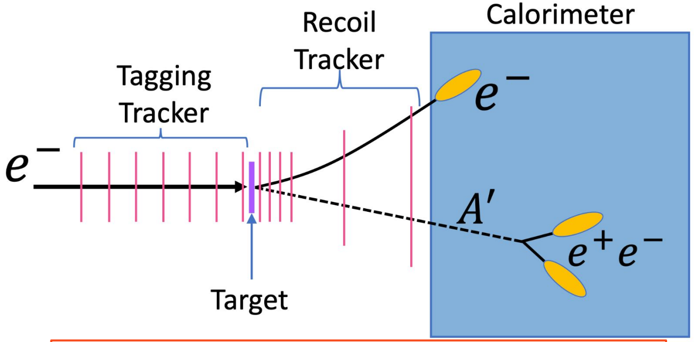
	Photo-nuclear		Muon conversion	
	Target-area	**ECal**	**Target-area**	**ECal**
EoT equivalent	4×10^{14}	2.1×10^{14}	8.2×10^{14}	2.4×10^{15}
Total events simulated	8.8×10^{11}	4.65×10^{11}	6.27×10^{8}	8×10^{10}
Trigger, ECal total energy < 1.5 GeV	1×10^{8}	2.63×10^{8}	1.6×10^{7}	1.6×10^{8}
Single track with $p < 1.2$ GeV	2×10^{7}	2.34×10^{8}	3.1×10^{4}	1.5×10^{8}
ECal BDT (> 0.99)	9.4×10^{5}	1.32×10^{5}	< 1	< 1
HCal max PE < 5	< 1	10	< 1	< 1
ECal MIP tracks = 0	< 1	< 1	< 1	< 1

Sensitivity

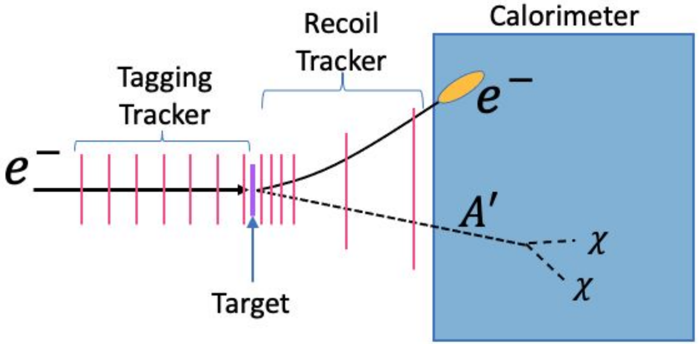
- Benchmark thermal relics are in black
- "Phase 1" corresponds to 4×10^{14} EoT and 4 GeV beam
- "Phase 2" corresponds to 10^{16} EoT and 8 GeV beam
- See more in LDMX Snowmass paper: arXiv:2203.08192



Visible Signatures



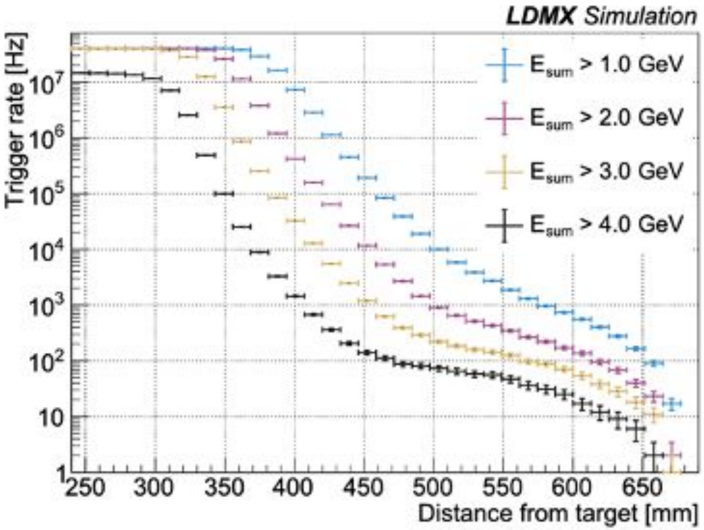
$m_{A'} < 2m_\chi \rightarrow$ visible decays



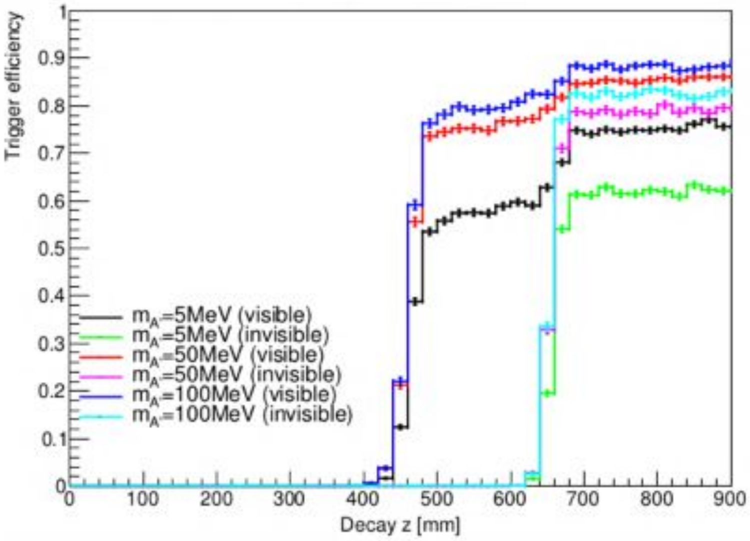
$m_{A'} > 2m_\chi \rightarrow$ invisible decays

- LDMX also able to constrain visible decays
- Plenty of technical challenges
  - Background studies - not expected to be a background-free analysis
  - Determining the best visibles trigger for a high efficiency and low rate

Visibles Trigger - High Efficiency, Low Rate



Visibles and standard LDMX trigger efficiencies for different A' masses

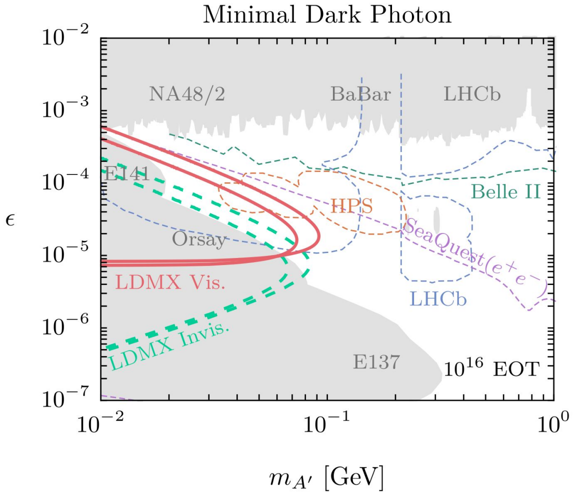


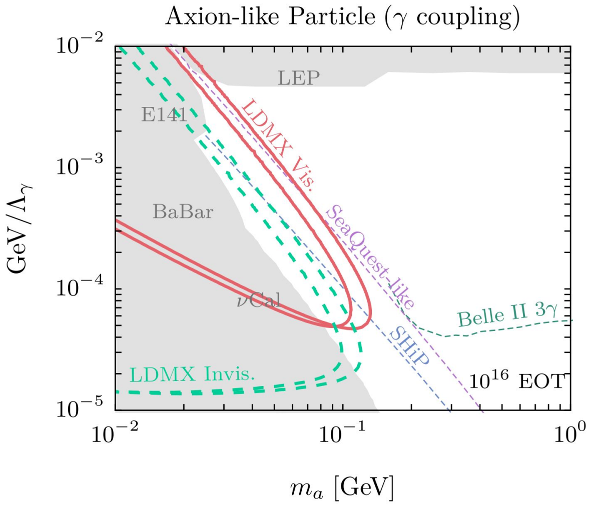
Courtesy of Tyler Horoho

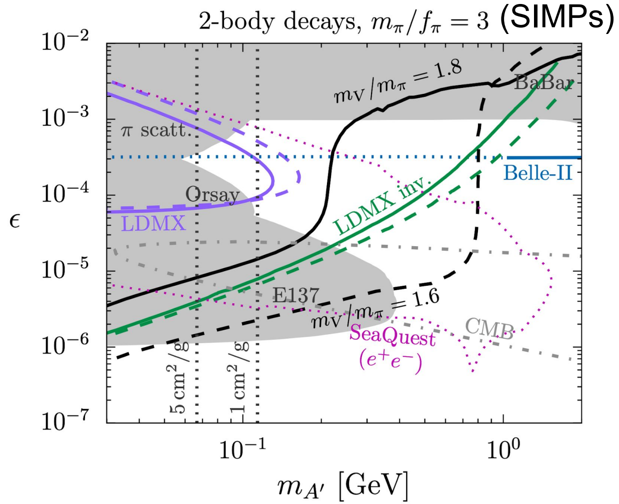
- For standard search, already have missing energy trigger
  - This will not capture visible A' decays
- Goal is to have 100 Hz trigger rate for visibles search

- Progress in this trigger at UVA
- Current work shows that a visibles trigger with a low rate and high efficiency is viable

- Displaced visible decays can be explored with LDMX
  - Reach plots below, for 8 GeV and 16 GeV beam
  - Minimal dark photon, ALPs, SIMPs, etc.
- Background studies need to be completed
  - Most concerned about hard neutrons (from PN) and late secondary photon conversions
- See more in LDMX Pheno Paper: arXiv:1807.01730







Conclusion

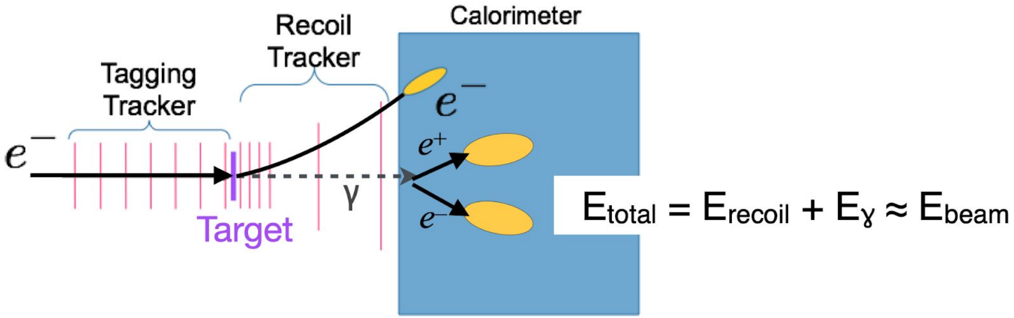
- Thermal relic models hold great promise for discovering dark matter
  - Phase space covered by WIMPs shrinking quickly
  - Sub-GeV mass range is becoming increasingly popular area to search as complement to WIMPs
- LDMX will be well equipped to find signature of dark matter
- Also able to probe other areas of interest to the community
  - Displaced visible signatures
  - Electronuclear measurements (possibly useful to experiments like DUNE)

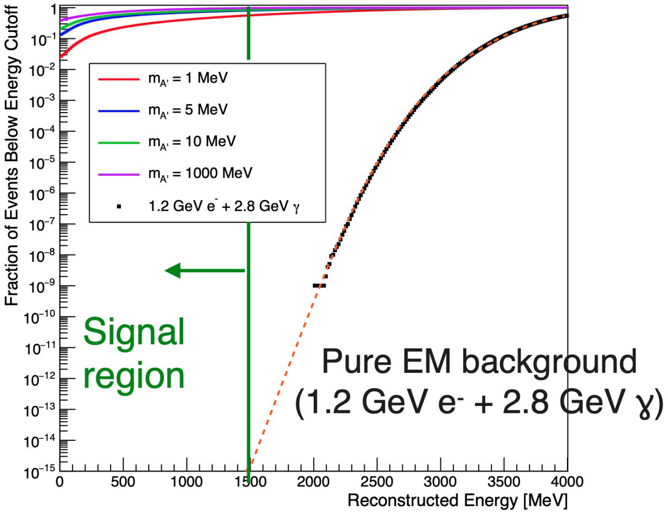
2020	2023	2025	2027
Detector R&D	Construction	Phase I data taking	Phase II construction & operation

Proposed LDMX baseline schedule

Missing Energy Trigger (Backup)

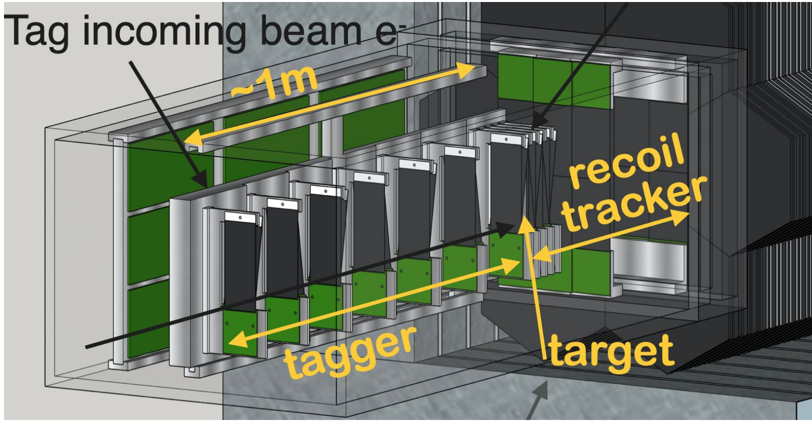
- Requiring a low energy deposition trigger sufficiently mitigates the largest backgrounds (bremsstrahlung conversions, tridents, etc.)
- Missing Energy Trigger has large signal efficiency





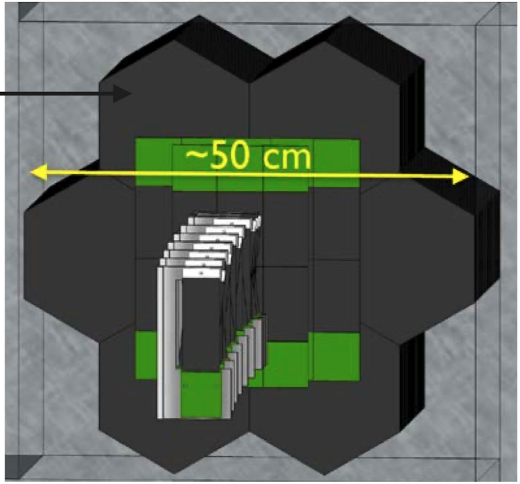
Tracker and Trigger Scintillator (Backup)

- Tagging tracker
  - Measures incoming beam electron
- Recoil tracker (based on HPS design)
  - Measures recoil electron and vetoes extra particles
- Trigger Scintillator
  - Arrays of scintillator bars provide fast count of incoming electrons
  - Used an input to the missing energy trigger

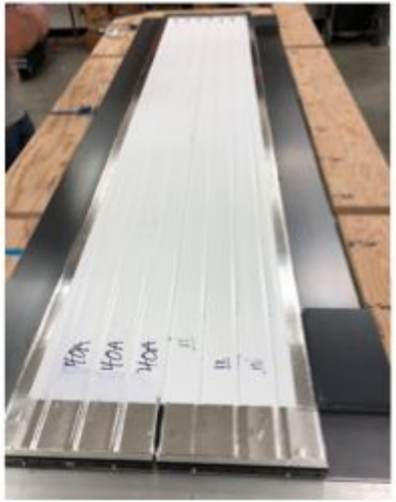


Electromagnetic Calorimeter (Backup)

- $40\ X_0$ Si-W sampling calorimeter (based on CMS High Granularity Calorimeter upgrade)
  - Ideal because it is dense, radiation hard, and has full shower containment
  - Provides the fast missing energy trigger
    - Recoil electron energy < 1.5 GeV
  - Capable of MIP tracking
  - High granularity uses both transverse and longitudinal shower shapes to reject backgrounds
  - Typical backgrounds vetoed are photons and charged particles



Hadronic Calorimeter (Backup)



- Layered absorber (steel) and scintillator (plastic) calorimeter
  - Scintillators are read out using wavelength-shifting fibers and SiPMs
    - Based on Mu2e Cosmic Ray Veto design
  - Highly efficient and optimized veto for photonuclear processes that produce neutral hadrons
    - Strive for 1e-6 rejection
  - Side Hcal (part around the Ecal) rejects wide-angle bremsstrahlung and $\gamma \rightarrow \mu^+\mu^-$
  - Back Hcal rejects neutral particles

A’ Simulations (Backup)

- Plots from simulation where A’ are produced at target and have a uniform chance of decaying at any point along the path
  - Mass of A’ = 50 MeV in this simulation
- Full A’ acceptance in both Ecal and Hcal
  - Based on known sizes of both calorimeters