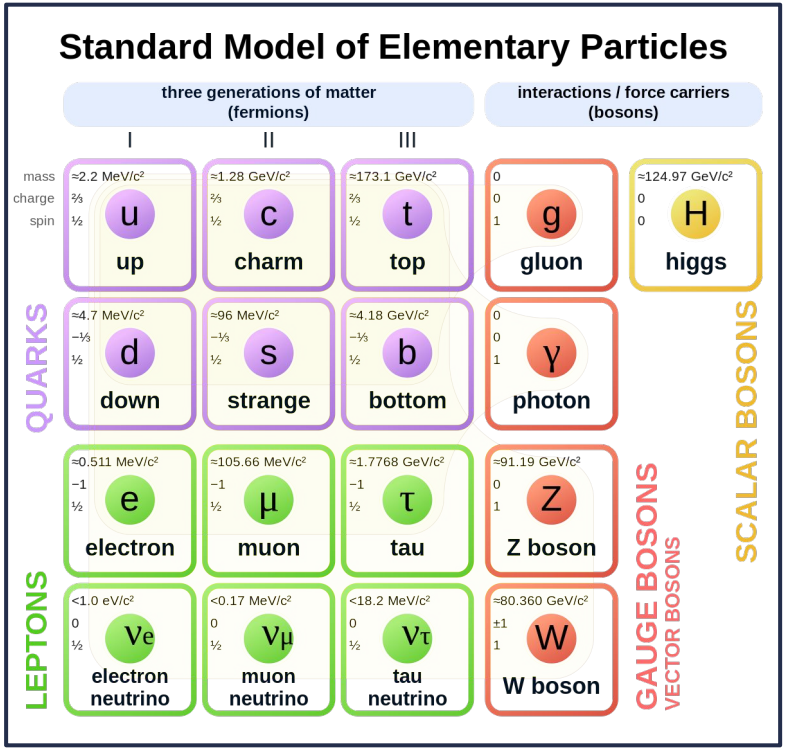
Introducing the Light Dark Matter eXperiment (LDMX)

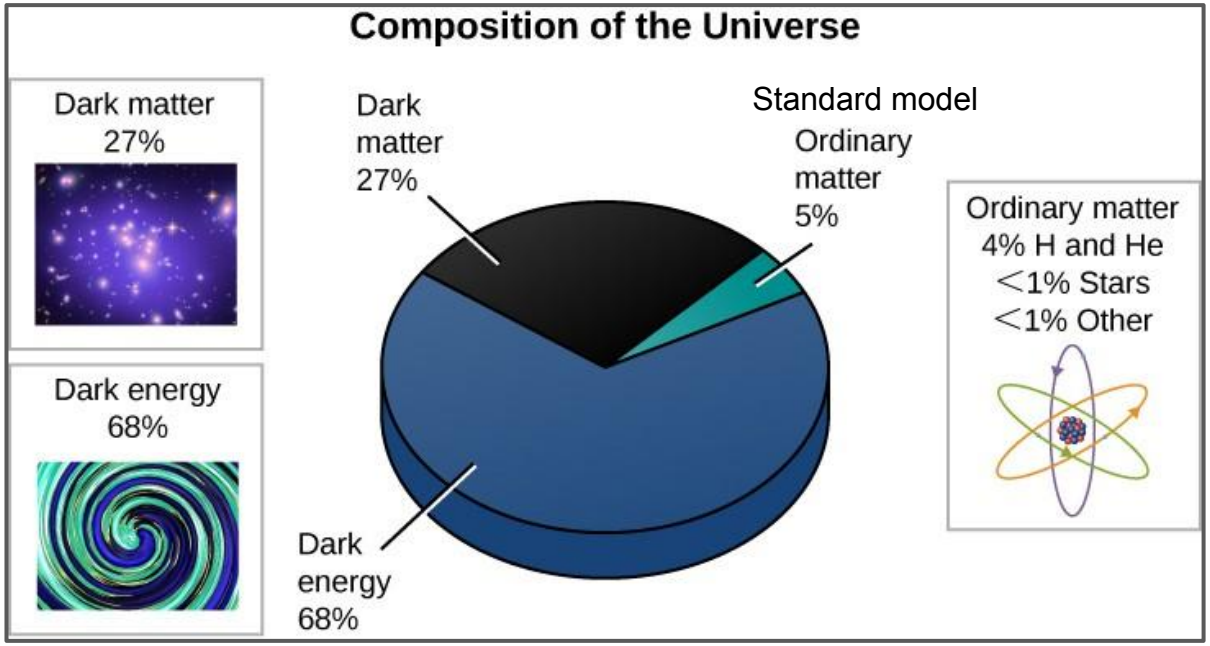
Jessica Pascadlo
on behalf of the LDMX collaboration
May 25, 2023

Standard Model of Particle Physics

- Characterizes fundamental particles and how they interact with one another
  - Describes all regular matter in the universe
- Each of these particles have been observed experimentally
  - Second and third columns almost exclusively observed during high energy collisions
- If we have the Standard Model (SM), why do we care about searching for dark matter?



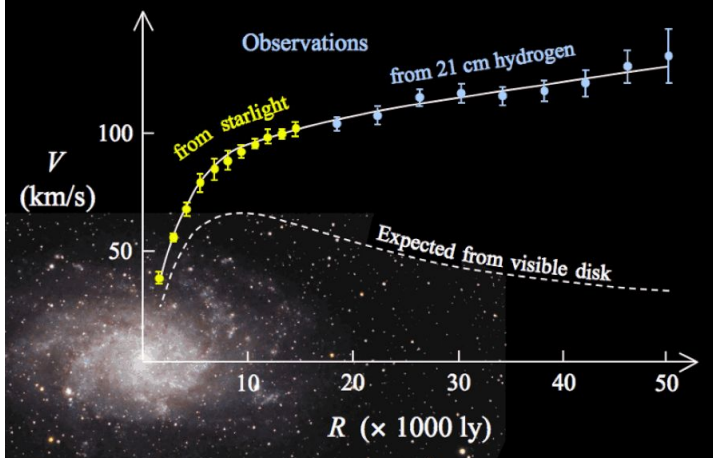
Why Dark Matter?

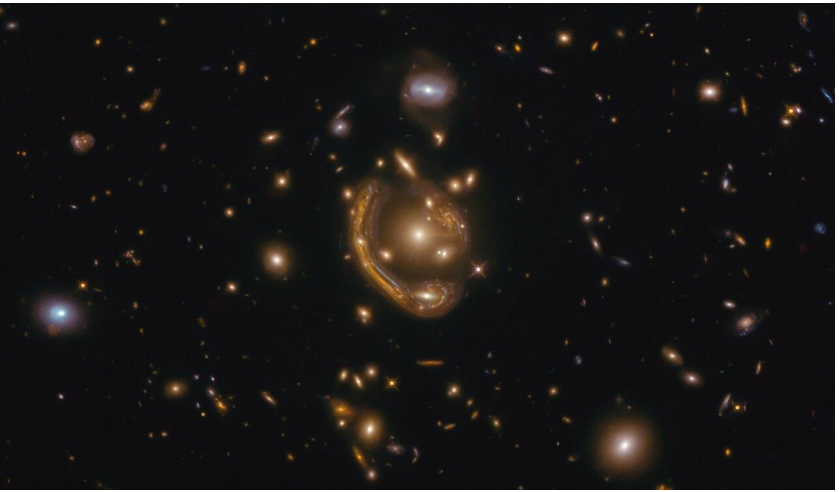


- We don't understand about 95% of the Universe's composition!
  - The current Standard Model (SM) must not be complete
- Understanding dark matter could help answer other fundamental questions about the Universe

Evidence for Dark Matter

- Strong case for the existence of dark matter (DM)
  - Galaxy rotation curves
  - Gravitational lensing
  - Cosmic Microwave Background anisotropy

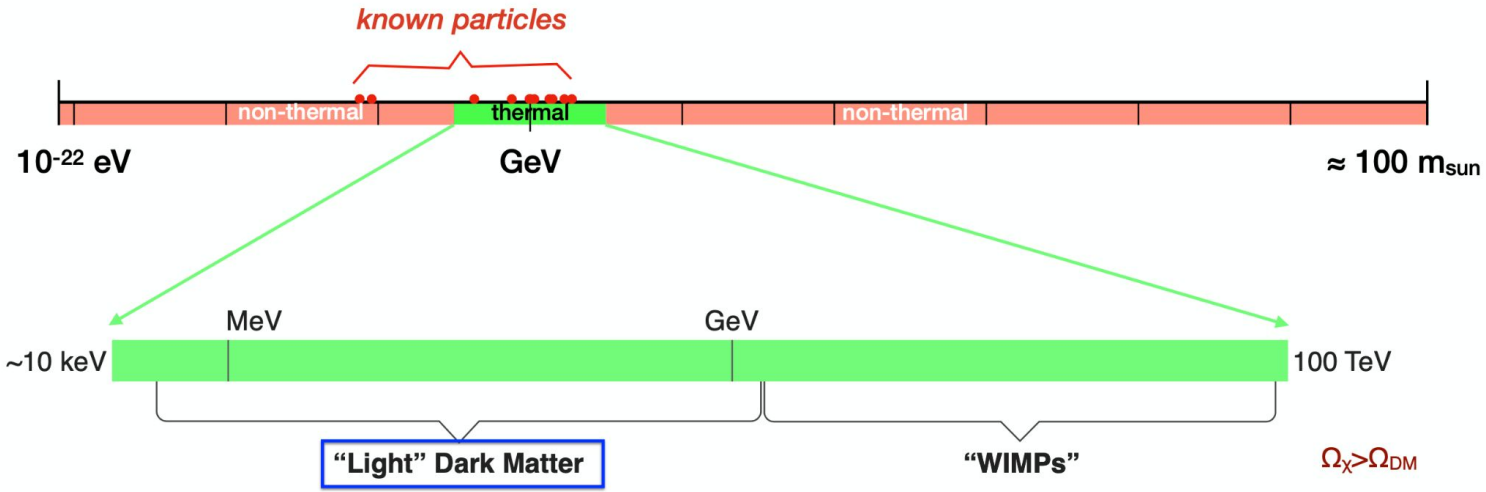




- No detection (yet!) - the origin and nature of DM is a key puzzle for particle physics
  - Standard model does not include dark matter
  - How do we narrow down a search region to determine what DM is?

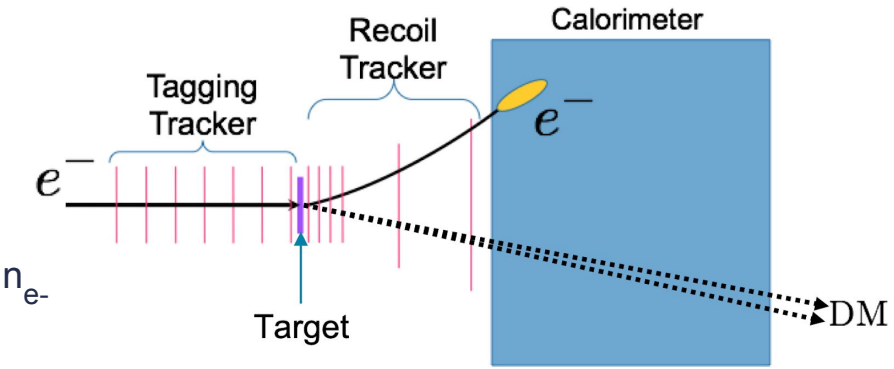
Light Dark Matter

- Thermal relic dark matter is well motivated
  - Accessible experimental parameter space for candidates with mass greater than a proton (about 1 GeV) is dwindling
- General interest in expanding DM search to a mass scale similar to the electron and proton



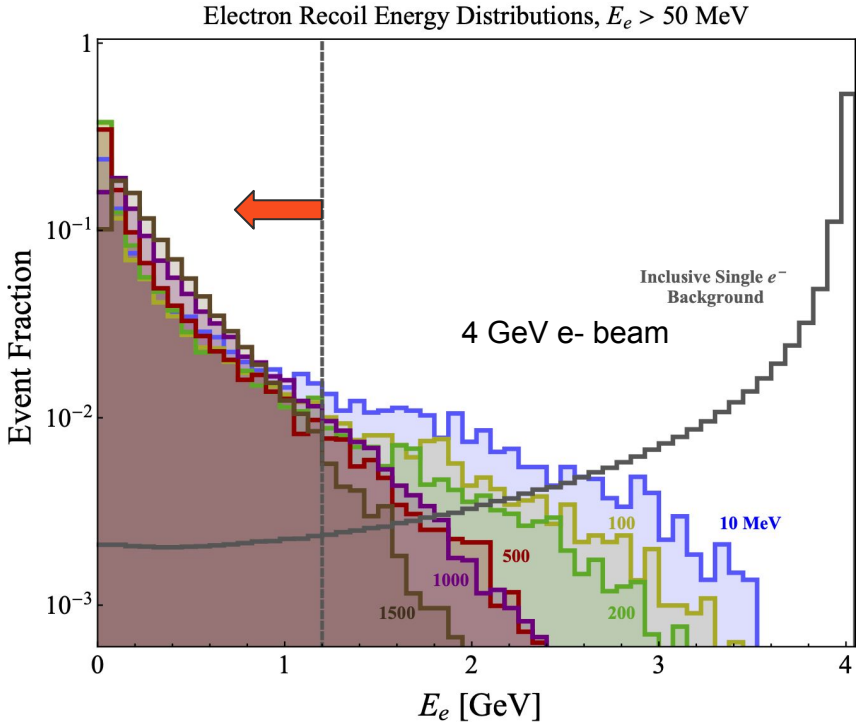
LDMX Concept

- From conservation of momentum, if “invisible” dark matter is produced, the signature would be some momentum missing from the recoil electron!
- e^- beam provided by Stanford Linear Accelerator Center (SLAC)
  - Planning on 4 GeV and 8 GeV runs
- Must be able to tag and reconstruct every electron
  - Do this for up to 10^{16} electrons
  - Use low current, high repetition rate of 37 MHz, $n_{e-} = 1$

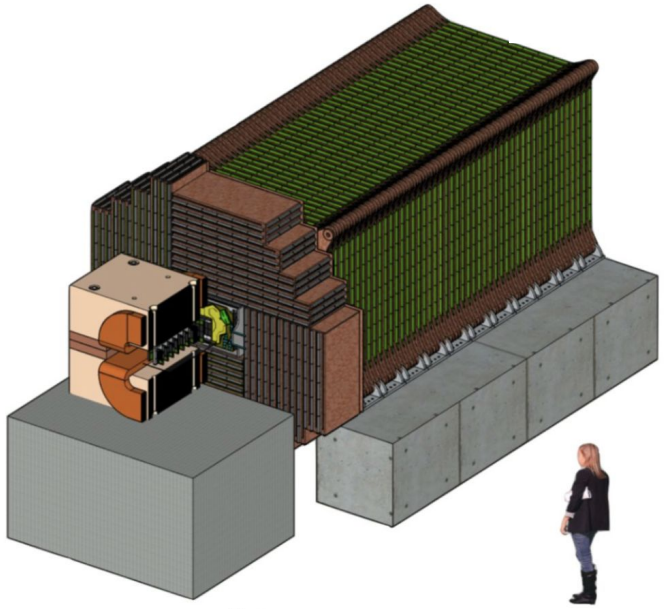


DM Production & Kinematics

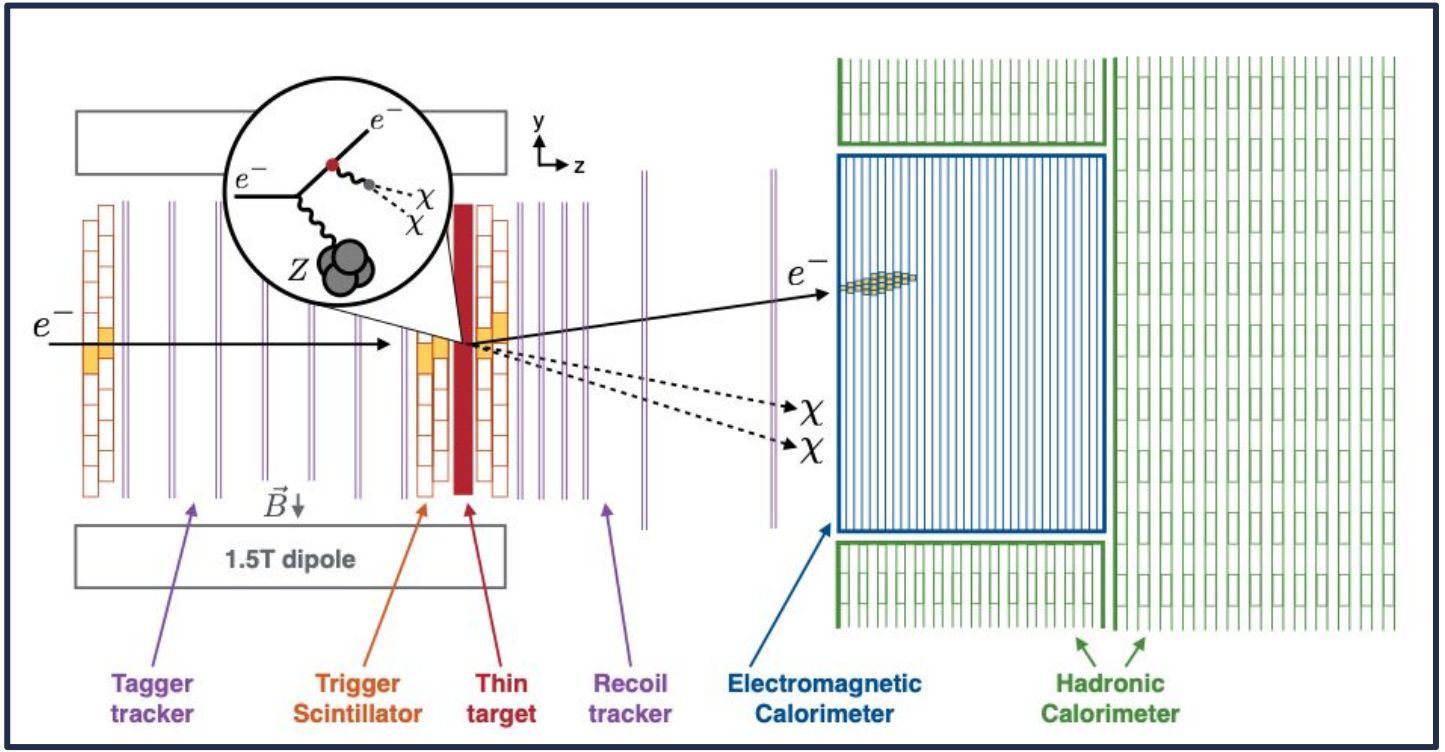
- Few DM signal characteristics for fixed target experiment
  - Dark photon (A') produced by "dark" photon radiation (bremsstrahlung) process
  - Large drop in energy of beam electron (taken away by A' production)
  - Leads to a "soft" recoil electron, the only visible final state particle
- Main background comes from SM bremsstrahlung process



LDMX Design



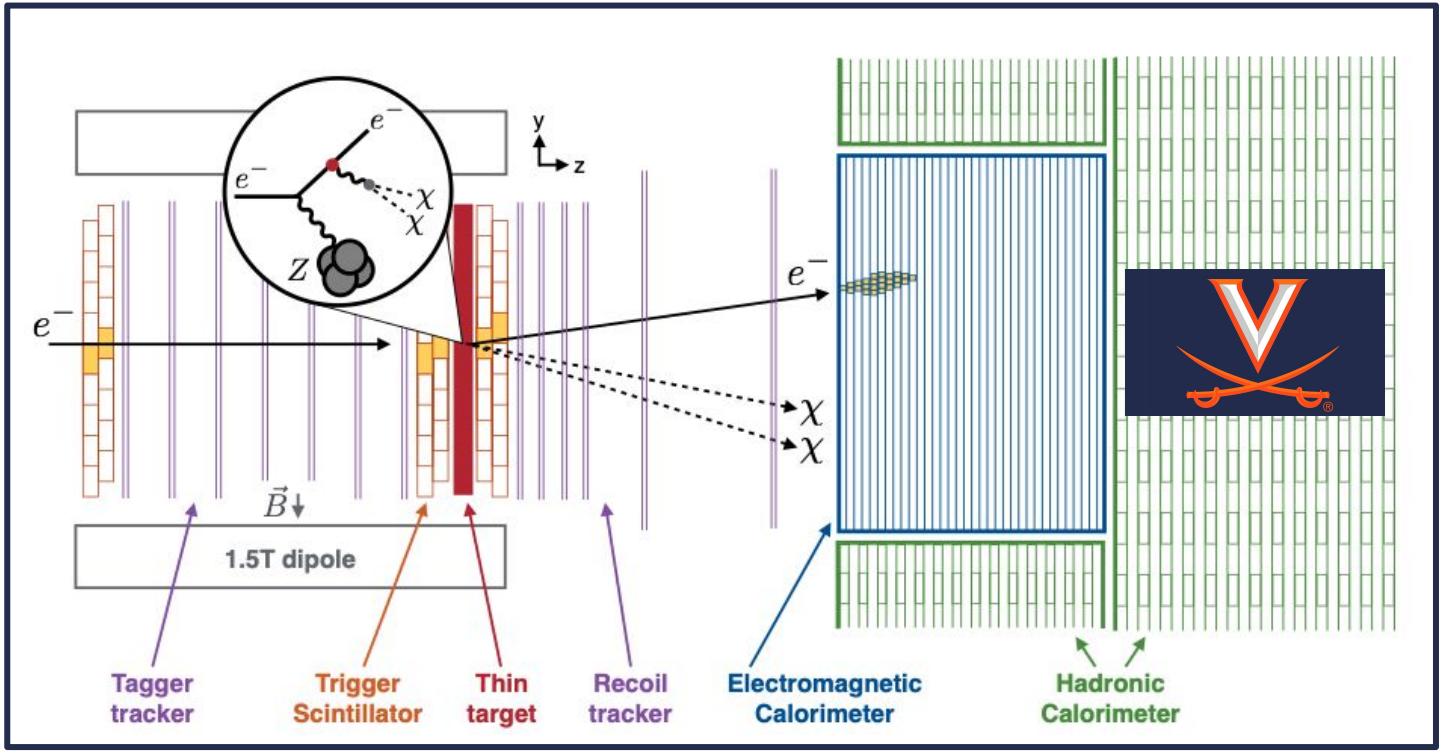
- Detector must be designed to withstand high radiation doses and high rates
- Missing energy trigger at electron energy less than (about) 30 percent of the beam
  - With 10^{14} - 10^{16} electrons, we can't keep data on all events!
  - Have to select events that look more signal-like → set a simple energy cut/trigger for standard search
- LDMX builds on previous, proven designs from other experiments
  - **Hadronic Calorimeter** – Muon-to-Electron Conversion Experiment (Mu2e) Cosmic Ray Veto
  - **Tagging and Recoil Tracker** – Heavy Photon Search (HPS)
  - **Electromagnetic Calorimeter** – Compact Muon Solenoid (CMS) High Granularity Calorimeter Upgrade



Tagging and Recoil Tracker
Fast with high momentum resolution and large acceptance

Electromagnetic Calorimeter
Fast, radiation hard, good energy resolution, high granularity (useful for calibration)

Hadronic Calorimeter
High veto efficiency of neutral hadrons.



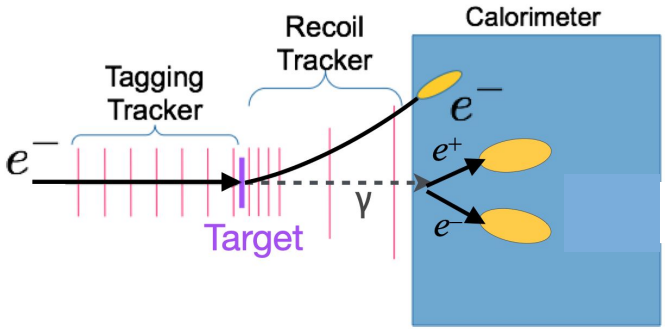
Tagging and Recoil Tracker
Fast with high momentum resolution and large acceptance

Electromagnetic Calorimeter
Fast, radiation hard, good energy resolution, high granularity (useful for calibration)

Hadronic Calorimeter
High veto efficiency of neutral hadrons.
Will be built at the University of Virginia!

Backgrounds

- Detector designed to veto SM backgrounds
- With all systems combined, simulations predict < 1 background event!
  - Signal efficiency of ~30%-50% for O(1e14) electrons on target (EoT)
- See LDMX paper for more information: arXiv:1912.05535



Bremsstrahlung background

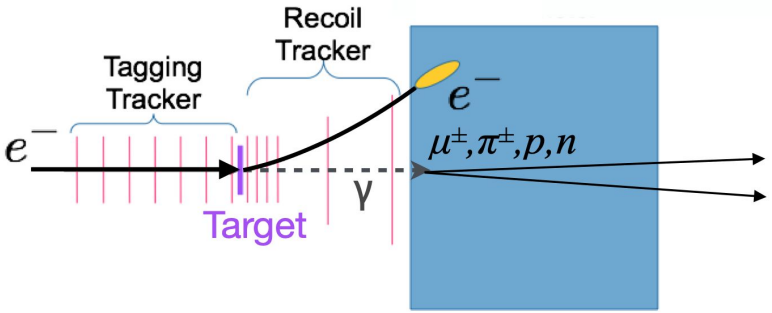
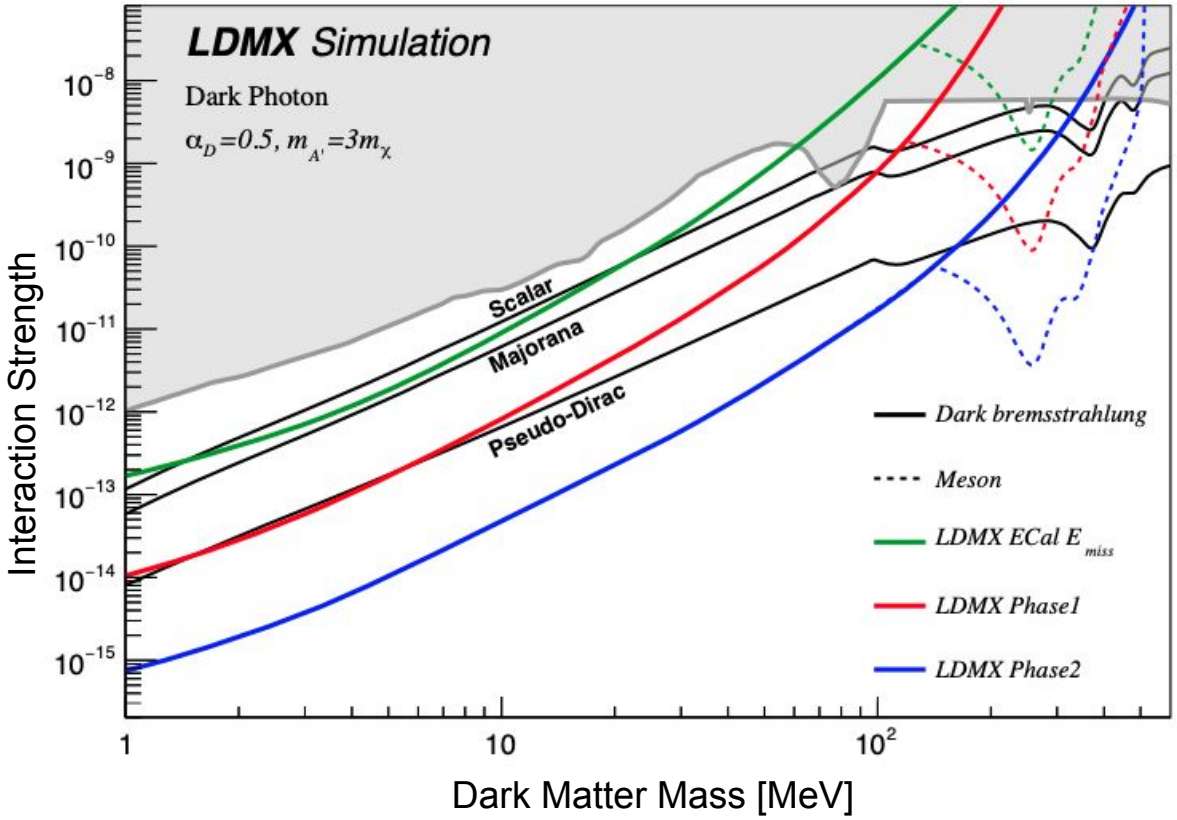


Photo-nuclear backgrounds

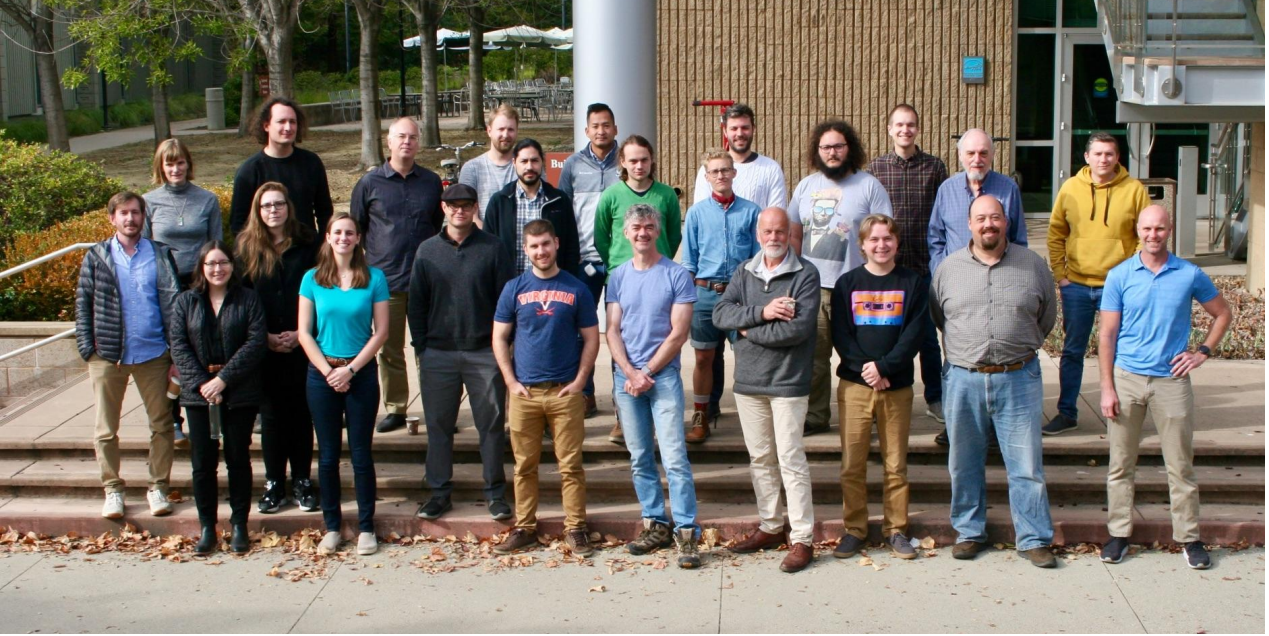
Sensitivity

- Benchmark thermal relics are in black
- “Phase 1” corresponds to 4 x 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



Conclusion

- Discovering dark matter would be an incredibly exciting achievement for the scientific community!
  - Low mass range of thermal relic model is becoming increasingly popular area to search
- LDMX will probe full low-mass range with unprecedented sensitivity
  - Can be taking data in a few years once a funding profile is established
- Also able to explore other areas of interest to the community
  - Displaced visible signatures – Stick around for Lincoln's talk next!



Thank you!

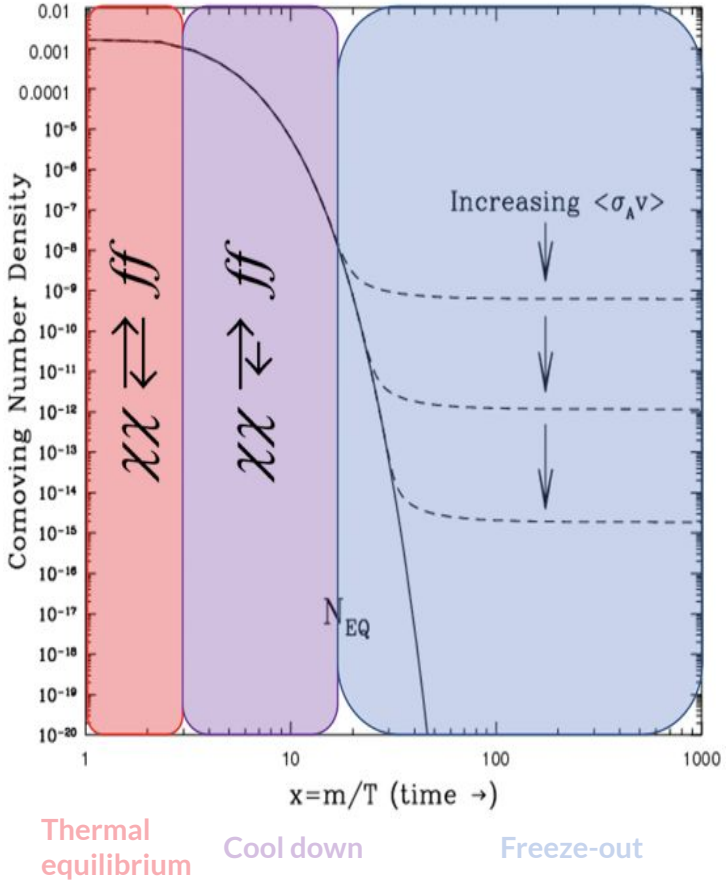
Caltech
Fermilab
Lunds Universitet
University of Minnesota
UCSB University of California Santa Barbara
Carnegie Mellon University
SLAC National Accelerator Laboratory
Stanford University
Texas Tech University
University of Virginia

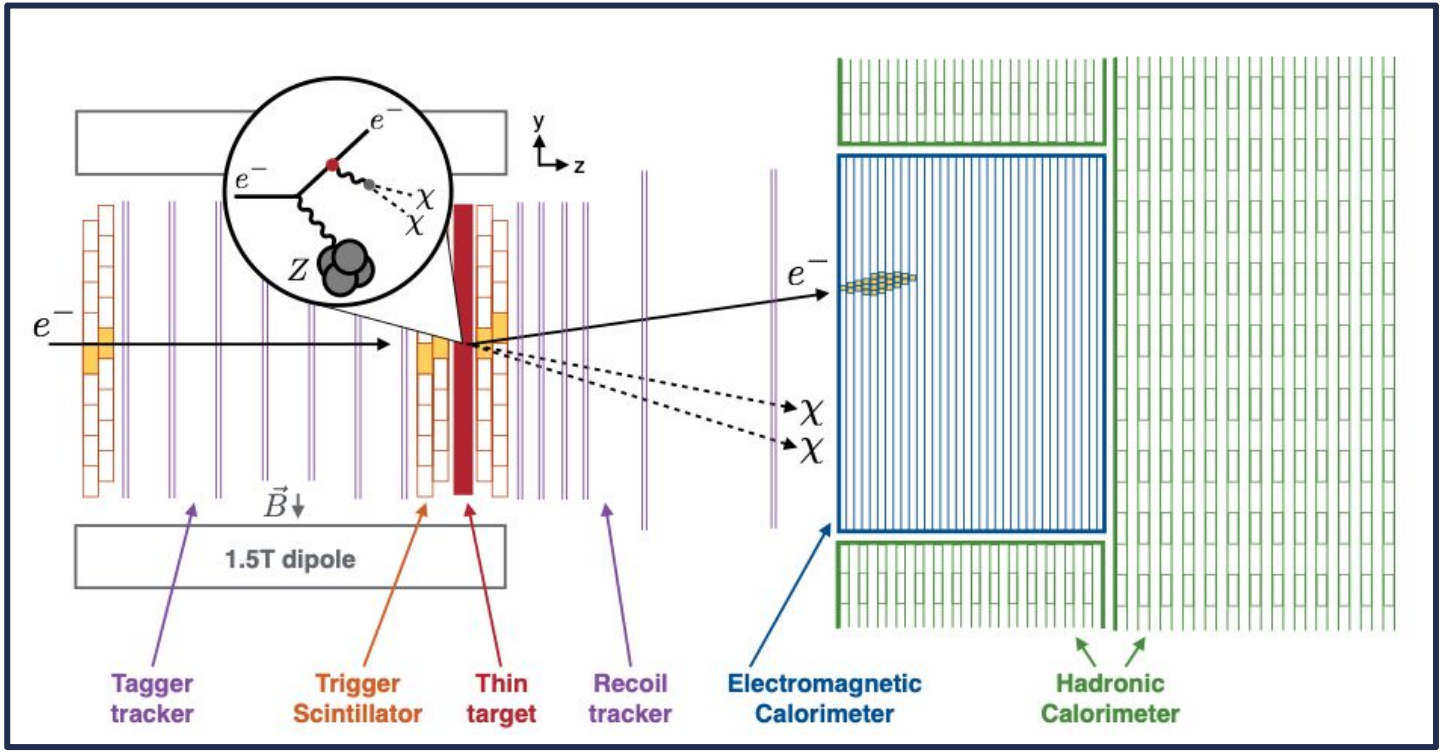
Backup

Thermal Dark Matter

- Assume that DM is in thermal equilibrium with SM in very early universe
- Thermal DM as relic of the hot early Universe is one of the most compelling paradigms
  - Generic: only non-gravitational interactions between DM and SM
  - Predictive: current relic density suggests interaction strength at accelerators
- The current relic density Ω_χ is related to the annihilation cross section

$$\Omega_\chi \propto \frac{1}{\langle \sigma v \rangle} \qquad \langle \sigma v \rangle = 3 \times 10^{-26} \frac{\mathrm{cm}^3}{\mathrm{s}}$$





Tagging and Recoil Tracker

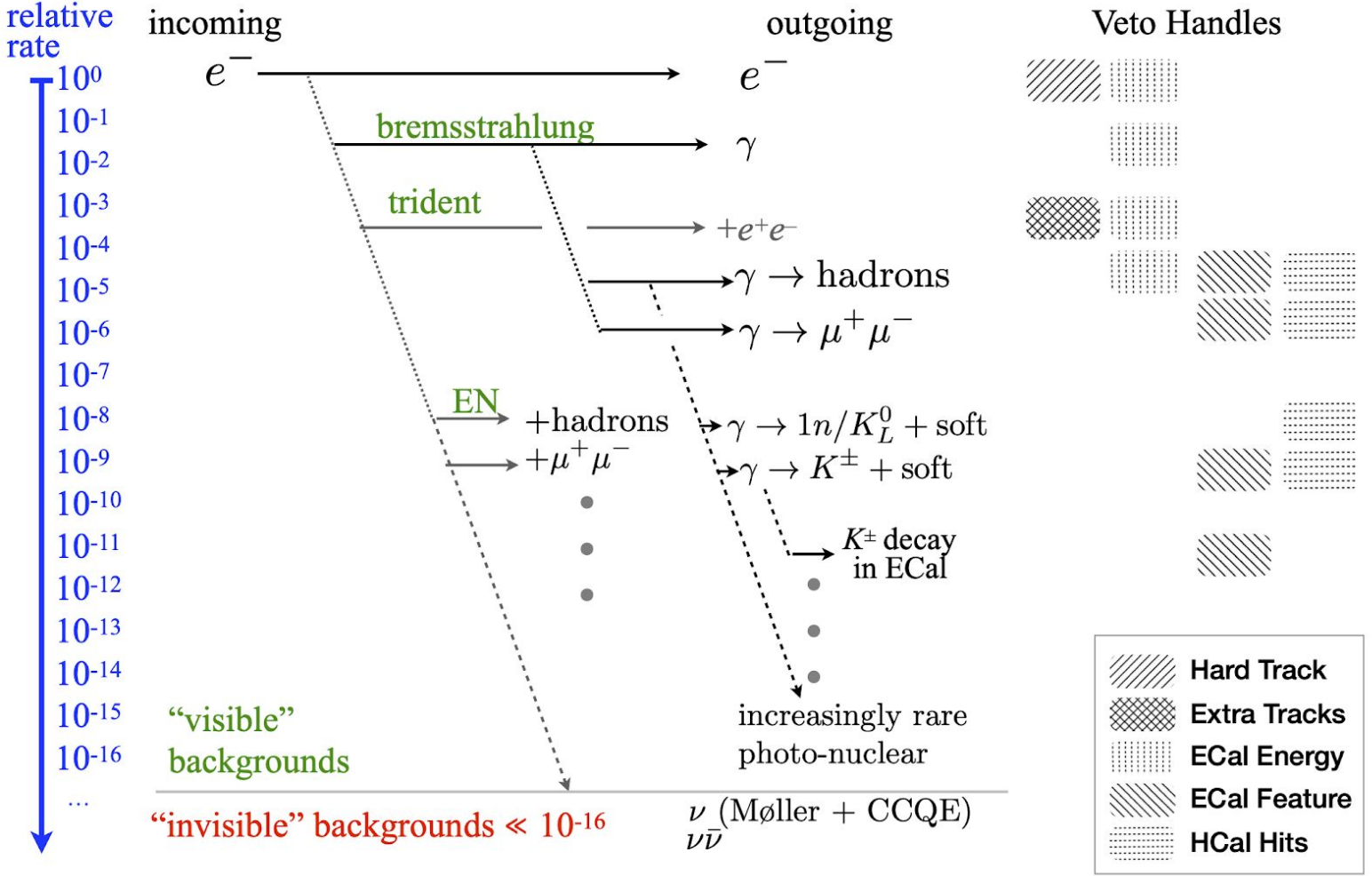
Simplified version of Silicon Vertex Tracker from HPS at JLab (visible dark photon search)

Electromagnetic Calorimeter

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

Hadronic Calorimeter

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


relative rate
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
...
incoming
outgoing
e^-
e^-
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
"visible" backgrounds
increasingly rare photo-nuclear
"invisible" backgrounds $\ll 10^{-16}$
ν (Møller + CCQE)
$\nu\bar{\nu}$
Veto Handles
Hard Track
Extra Tracks
ECal Energy
ECal Feature
HCal Hits