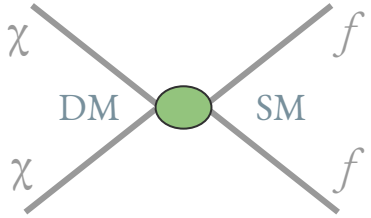
Caltech Fermilab Lunds Universitet University of Minnesota UCSB University of California Santa Barbara SLAC National Accelerator Laboratory Stanford University Texas Tech University University of Virginia

The Light Dark Matter eXperiment, LDMX

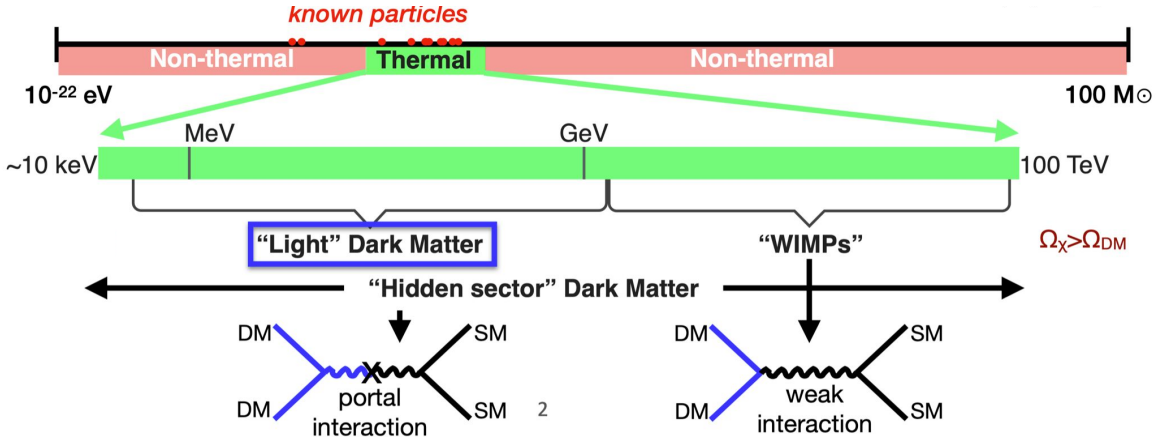
August 16, 2021

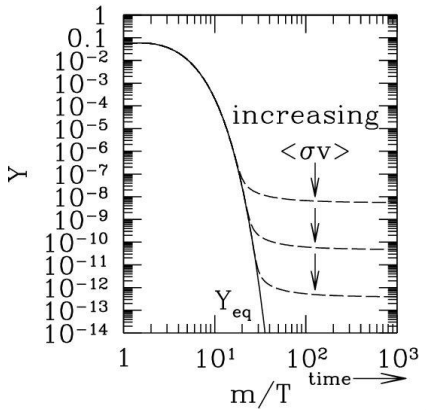
Matt Solt, University of Virginia
On behalf of the LDMX Collaboration

A Thermal Relic



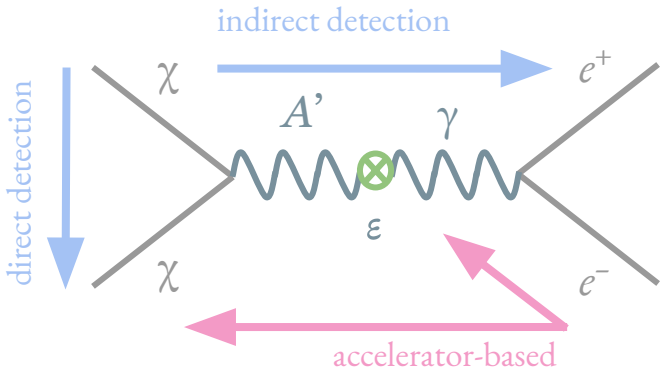
- A thermal relic - simple and predictive model of dark matter (DM)
- WIMPs are popular, but accessible parameter space is running out of room
- Increasing interest in expanding the thermal DM search to “Light” DM in the MeV-GeV mass range

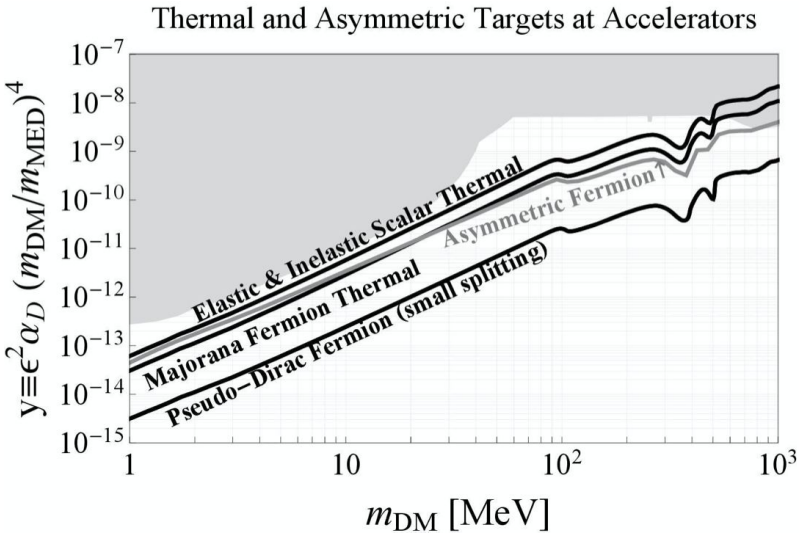




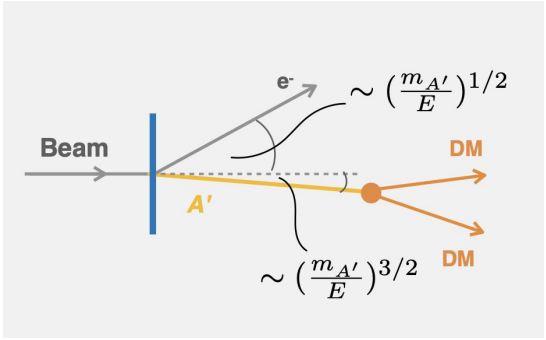
Light Dark Matter

- Simplest prediction includes a dark photon (heavy photon or A’) that mixes with the SM photon
- Thermal prediction targets make attainable predictions with accelerators

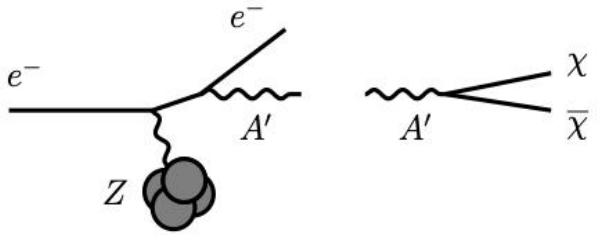


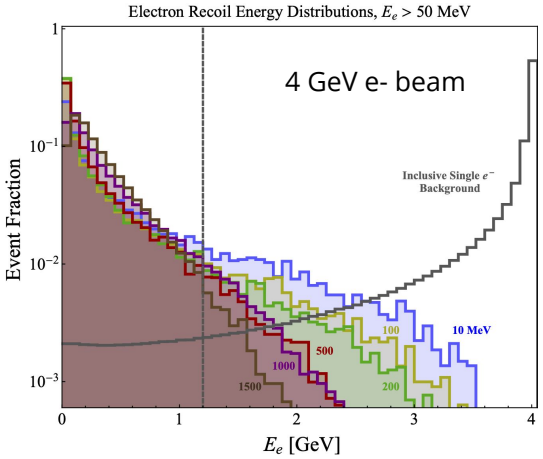


DM Production and Kinematics



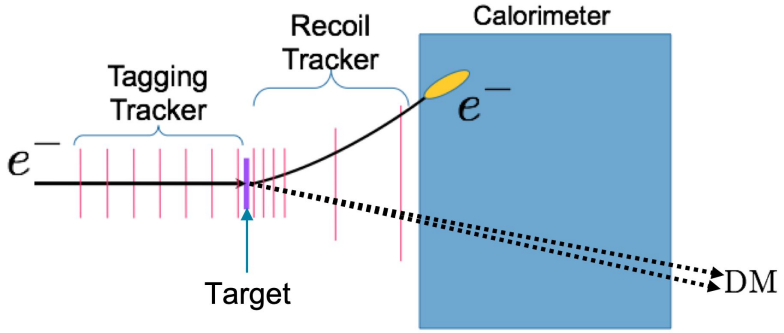
- Fixed Target Signal Characteristics:
  - Dark bremsstrahlung A’ production
  - A’s take most of the beam energy
  - Only visible final state particle is a soft recoil electron



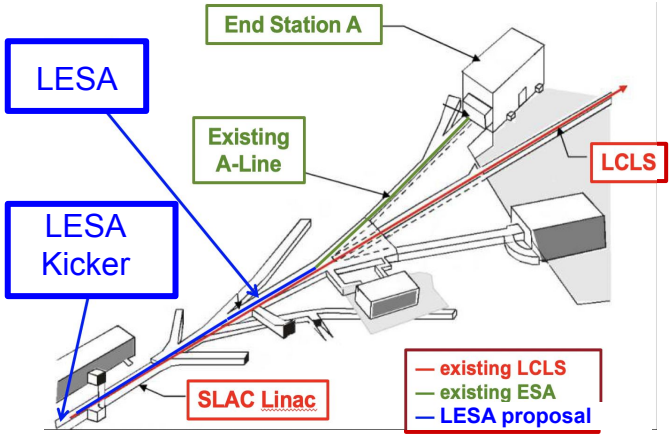


- Can probe this mechanism through a missing momentum search. We need…
  - High momentum resolution
  - High veto efficiency of Standard Model backgrounds

LDMX Concept



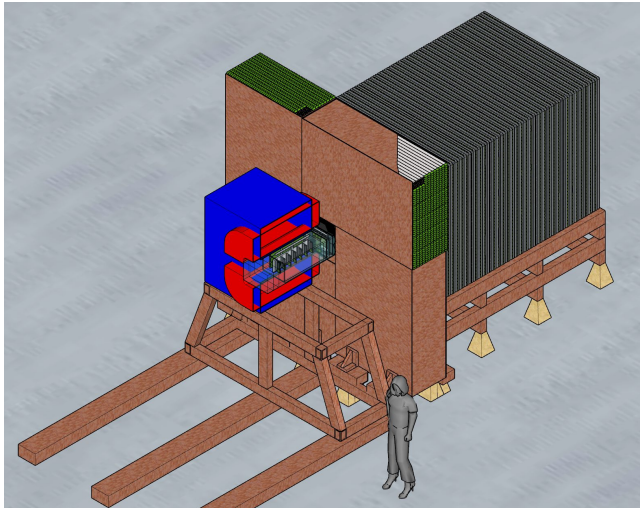
- Missing momentum and energy approach
  - DM production identified by missing energy/momentum in detector
  - Equipped for particle ID e/gamma
  - Recoil pT used as discriminator/identifier

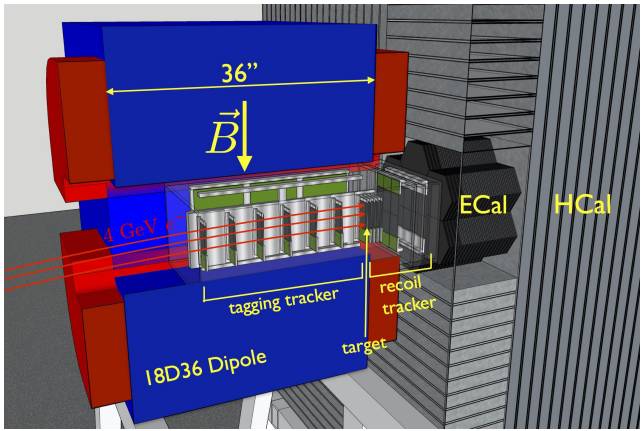


- 4 and 8 GeV e- beam provide by SLAC
  - Parasitically use the LCLS II beam with a dedicated transfer line (LESA)
  - Individual tagging and reconstruction of up to 1e16 electrons
  - Low current, high repetition rate 37 MHz, μ = 1

LDMX Design

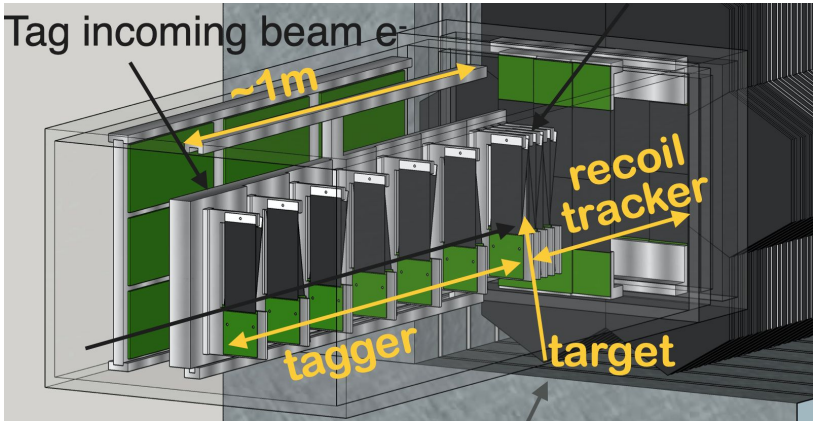
- Detector designed for high rates and high radiation doses
  - **Tagging/recoil tracker**: fast with high momentum resolution and large acceptance
  - **Electromagnetic calorimeter**: fast, good energy resolution, and high granularity
  - **Hadronic calorimeter**: high veto efficiency of neutral hadrons
- Detector optimized for missing momentum search, but also sensitive to…
  - Displaced visible signatures (dark sector physics)
  - Electronuclear measurements (neutrino physics)

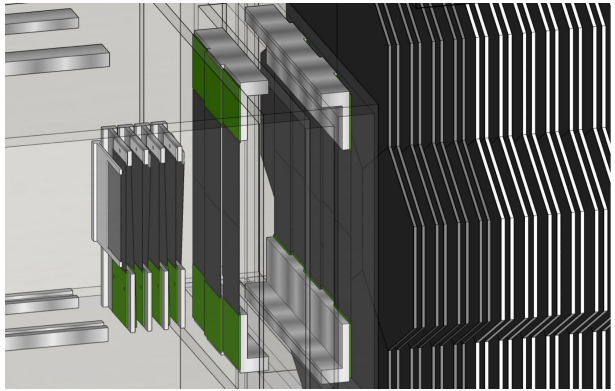




Tracker and Trigger Scintillator

- 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

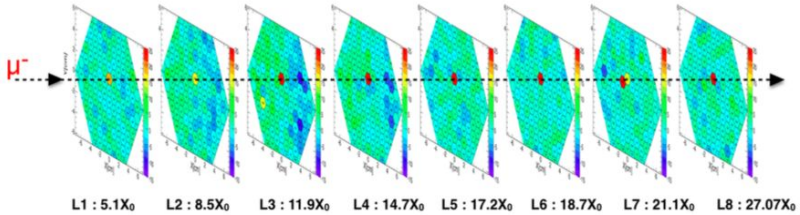


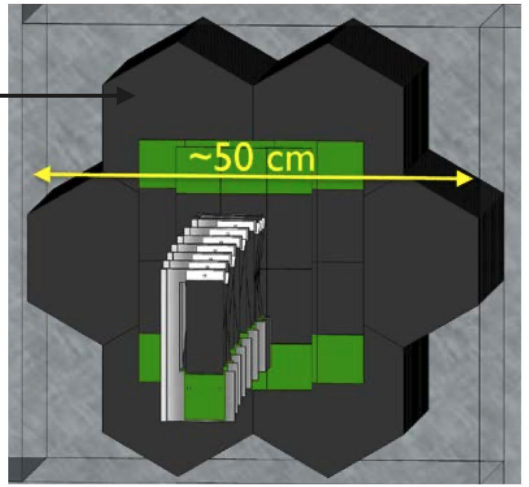


Electromagnetic Calorimeter

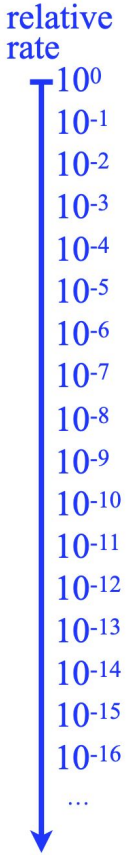
- 40 X0 Si-W sampling calorimeter (based on CMS HGCal upgrade)
  - Provides fast missing energy trigger
  - Dense, radiation hard, full shower containment
  - High granularity exploits both transverse/longitudinal shower shapes to reject background
  - Capable of MIP tracking

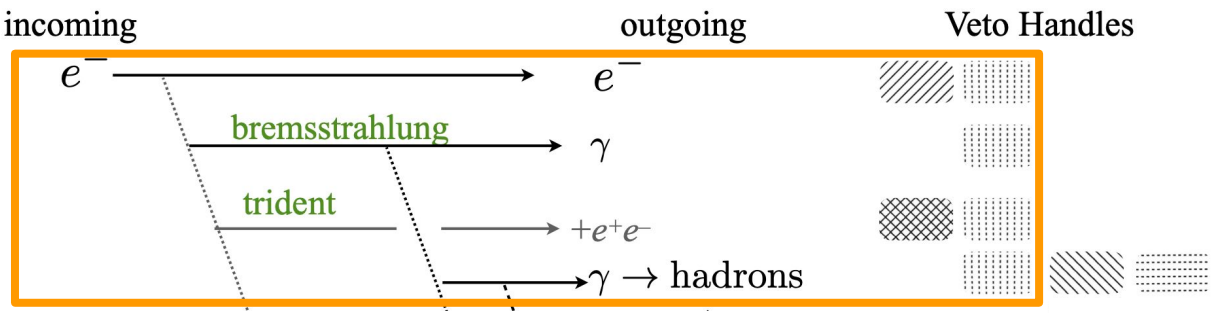
A.Martelli on behalf of CMS, arXiv:1708.08234

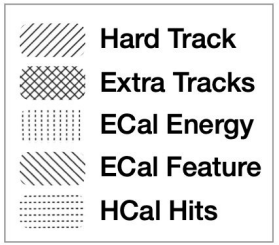




Backgrounds

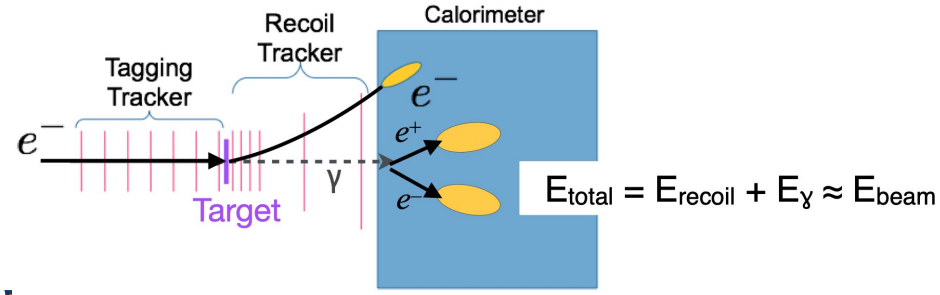


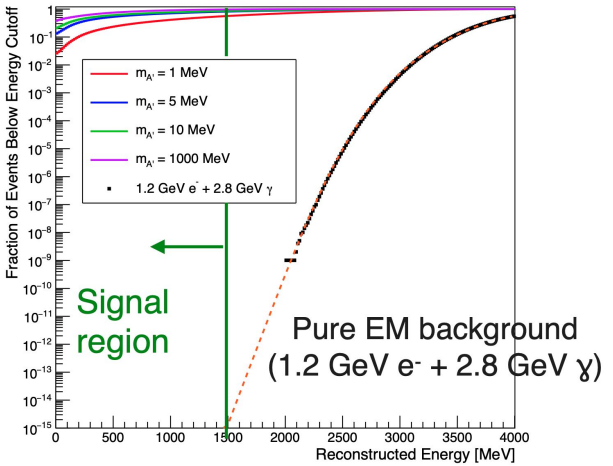




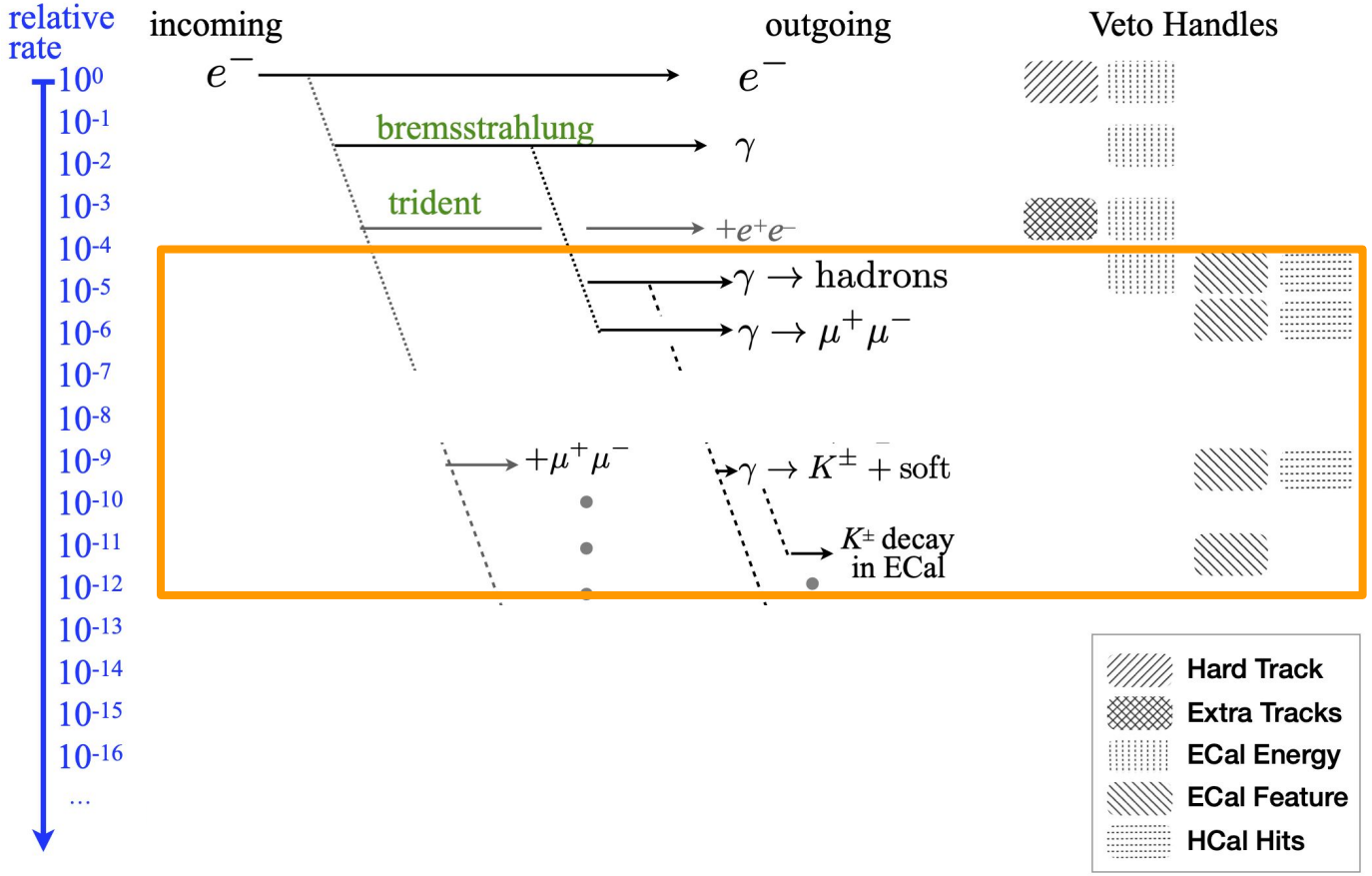
Missing Energy Trigger

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



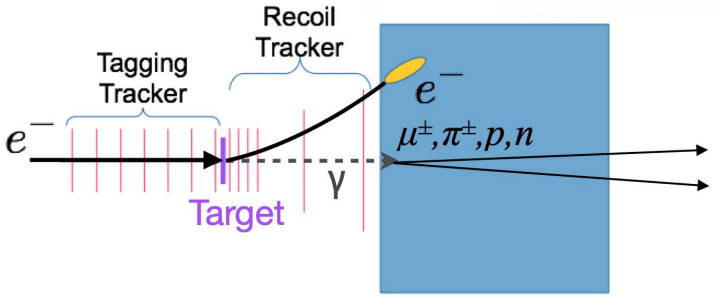


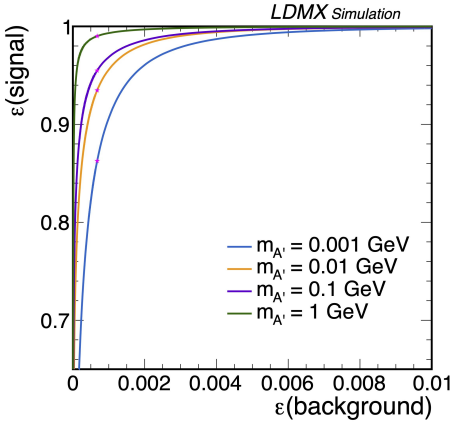
Backgrounds

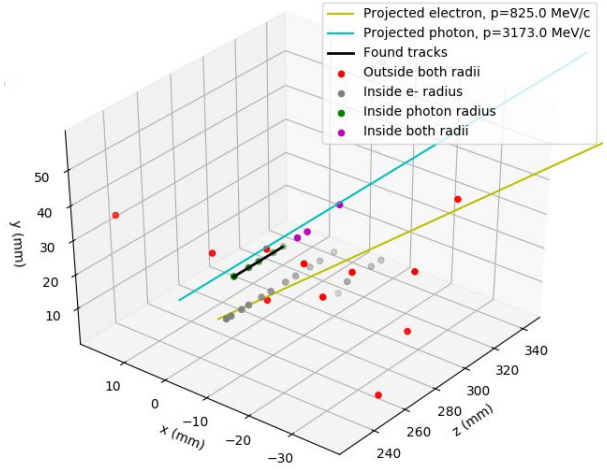


Ecal Veto

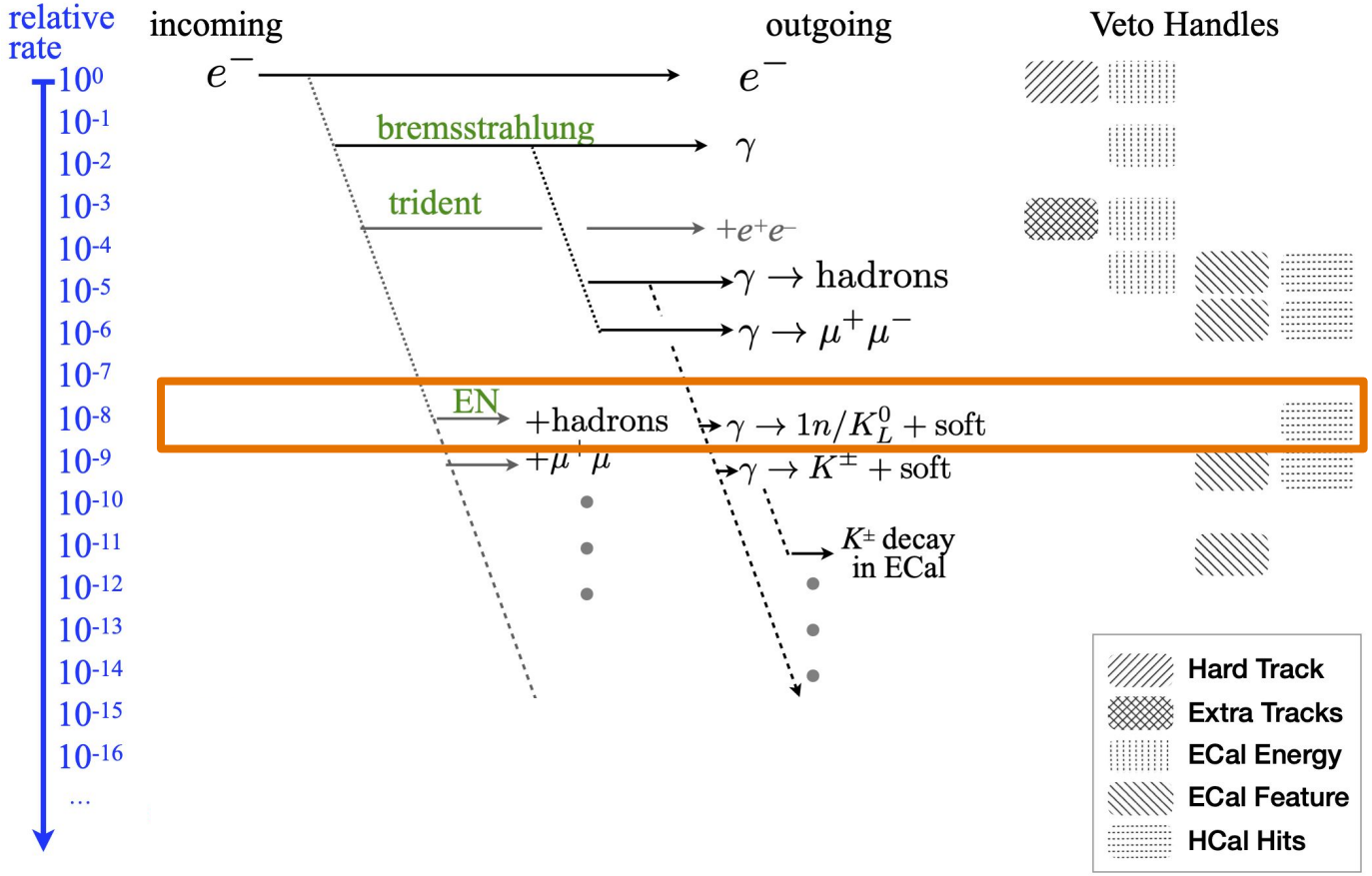
- More difficult to veto: Rare photon reactions that deposit low energy in the Ecal
  - Exploit longitudinal/transverse shower shapes and train a boosted decision tree (BDT)
  - High granularity Ecal enables MIP tracking





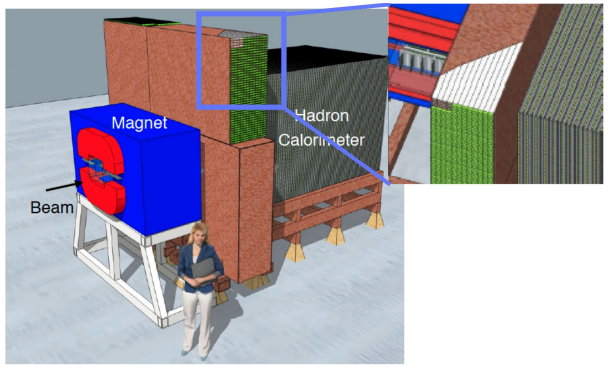


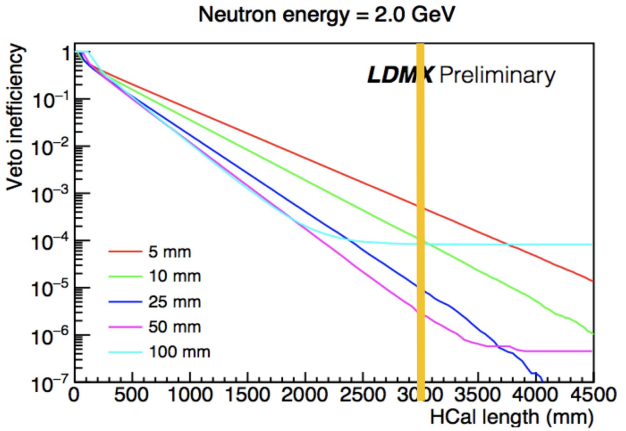
Backgrounds



Hadronic Calorimeter

- Segmented plastic/steel calorimeter
  - Readout by wavelength shifting fibers and SiPMs (based on the Mu2e Cosmic Ray Veto design)
  - Highly efficient veto for PN processes that produce neutral hadrons. Desire 1e-6 rejection
  - Side HCal rejects wide angle bremsstrahlung and γ→μ+μ-
  - See Tyler Horoho's talk next!

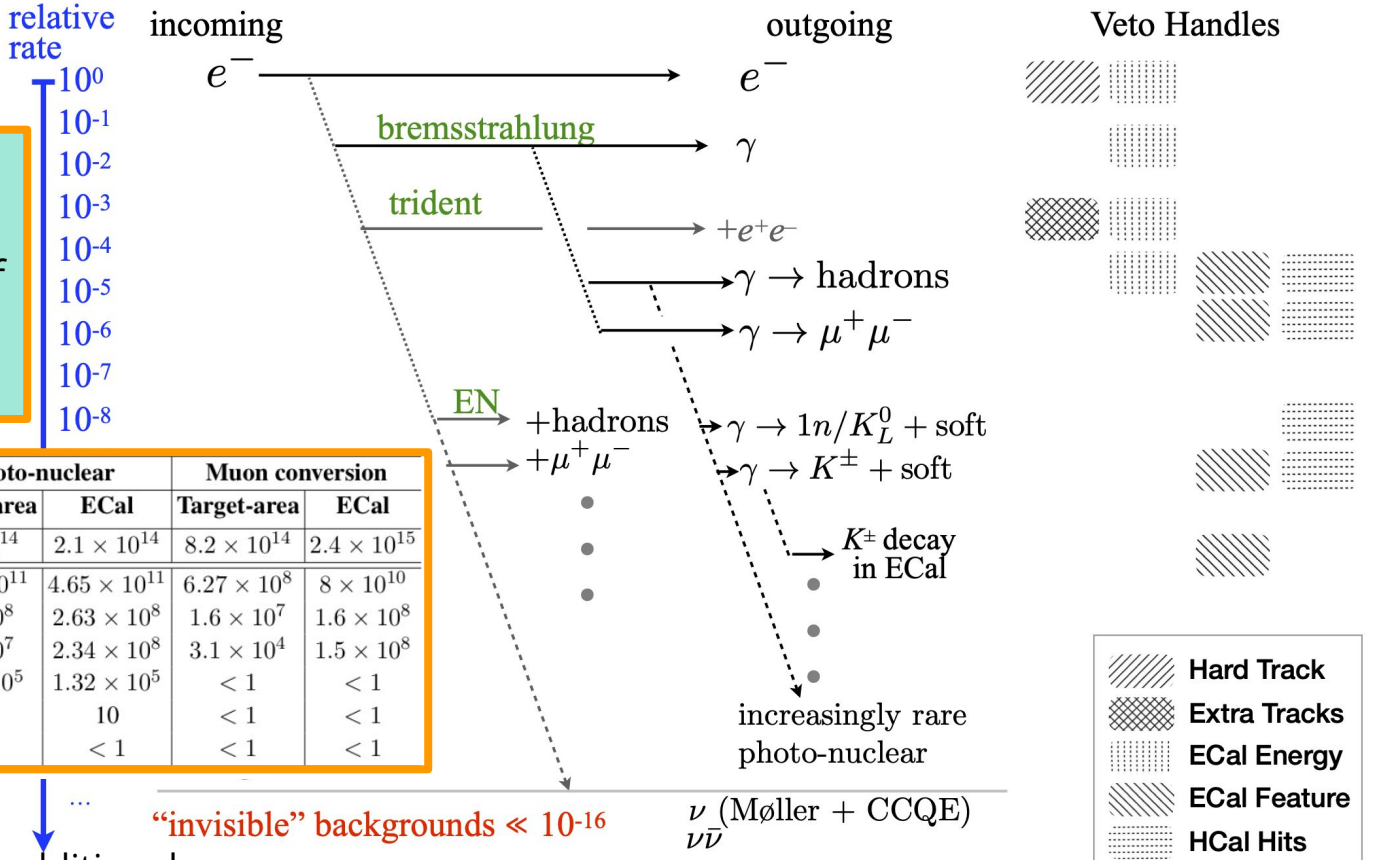




Backgrounds

All systems combined: < 1 background event with signal efficiency of ~30-50% for O(1e14) EoT!

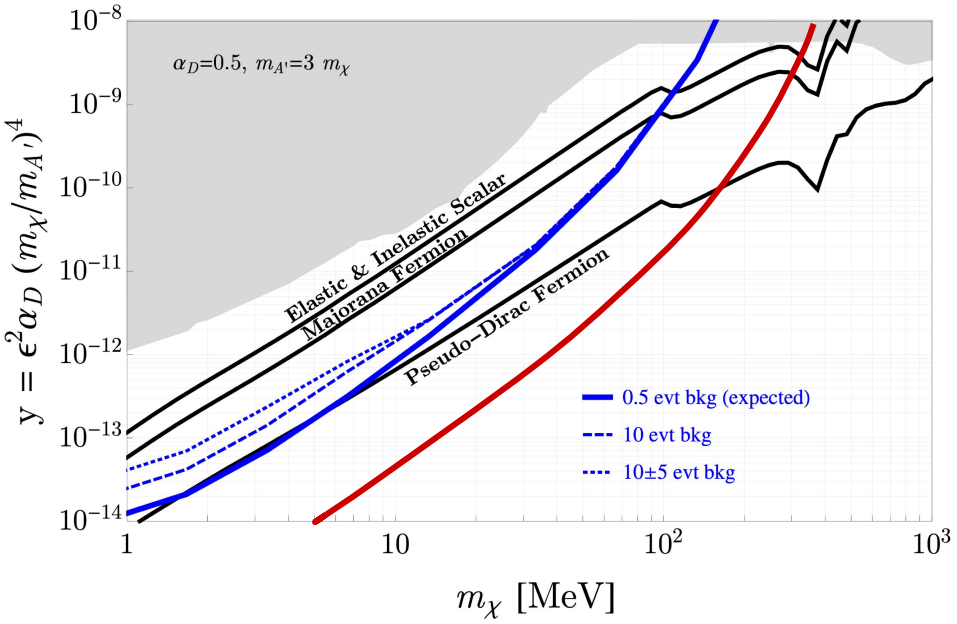
	Photo-nuclear		Muon conversion	
	Target-area	ECal	Target-area	ECal
EoT equivalent	4×10^{14}	2.1×10^{14}	8.2×10^{14}	2.4×10^{15}
Total events simulated	8.8×10^{11}	4.65×10^{11}	6.27×10^{8}	8×10^{10}
Trigger, ECal total energy < 1.5 GeV	1×10^{8}	2.63×10^{8}	1.6×10^{7}	1.6×10^{8}
Single track with $p < 1.2$ 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



Recoil e- pT is an additional discriminator on backgrounds

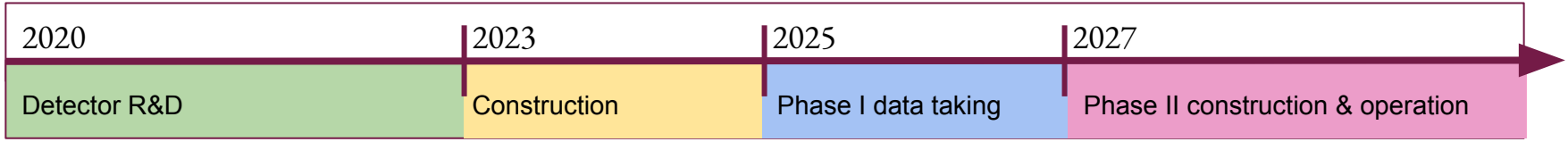
arXiv:1912.05535

Sensitivity



Phase 1: 4 GeV, 10^{14} electrons
Phase 2: 8 GeV, 10^{16} electrons

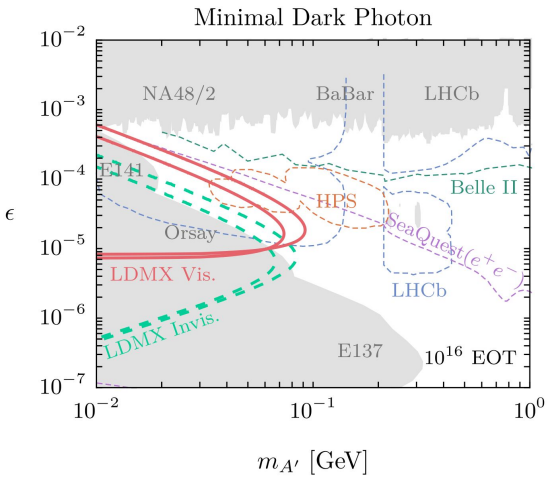
arXiv:1808.05219

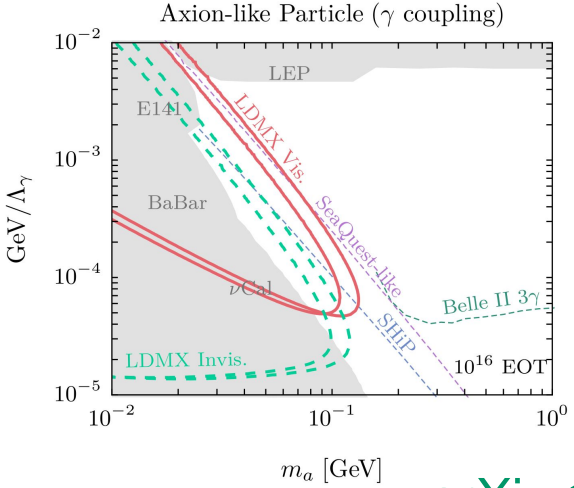


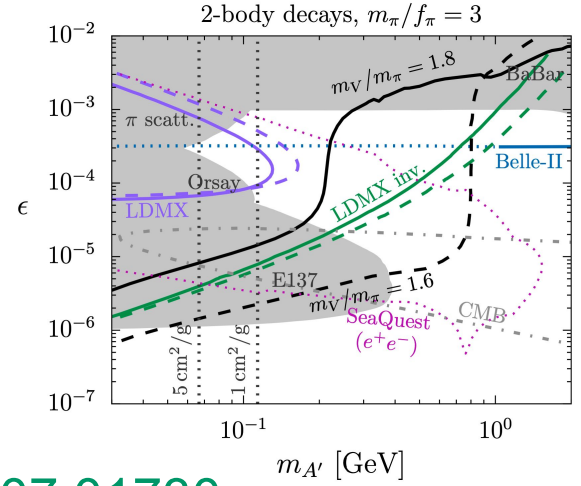
Proposed LDMX baseline schedule

Visible Signatures

- Broad physics potential for LDMX beyond missing momentum search
  - Displaced visible decays - minimal dark photon, ALPs, SIMPs, etc.
  - Electronuclear measurements for neutrino physics - see Laura Zichi's talk.







Projections are for 8 GeV and 16 GeV beams

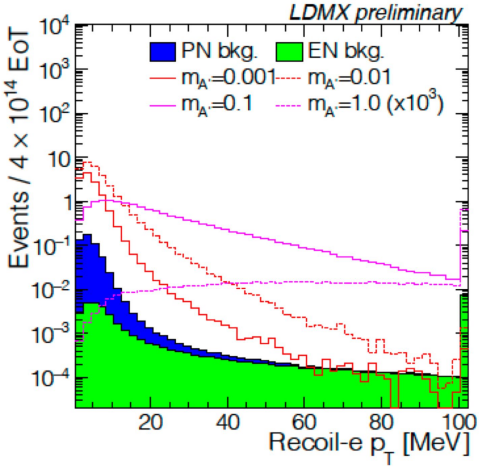
arXiv:1807.01730

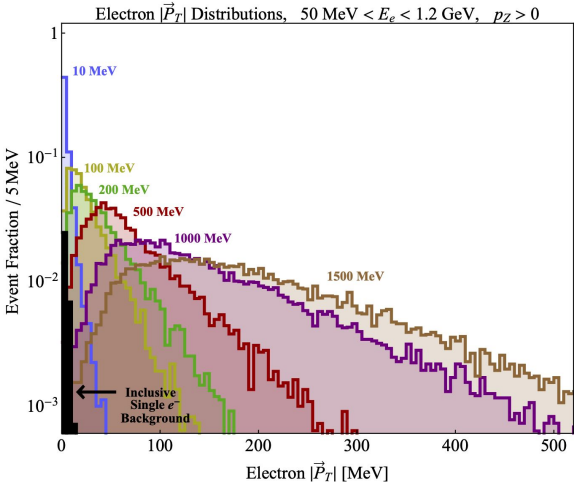
Conclusion

- Thermal relic models offer plausible and predictive models of dark matter
- LDMX can conclusively probe such models in the sub-GeV mass range through a missing momentum search
- Beyond the missing momentum search, LDMX can probe displaced visible signatures and electronuclear measurements that are useful for neutrino experiments arXiv:1807.01730
- Other LDMX talks at New Perspectives:
  - Tyler Horoho, Laura Zichi, & Chloe Greenstein

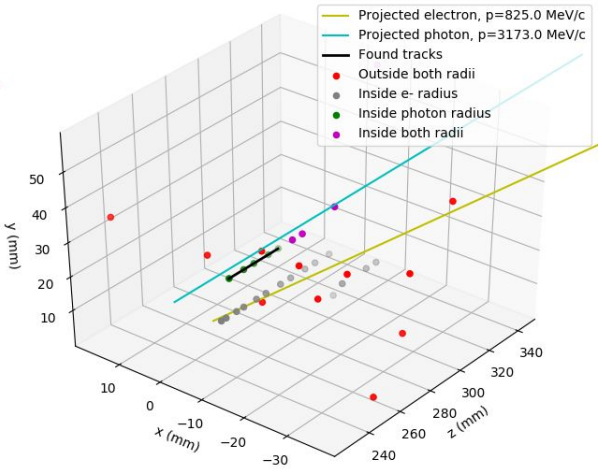
Signal Kinematics

- Transverse momentum of recoil election is the last veto handle
- Currently not used in veto efficiency estimates, but as a backup discriminator
- Transverse momentum can also be used to estimate/constrain DM mass scale

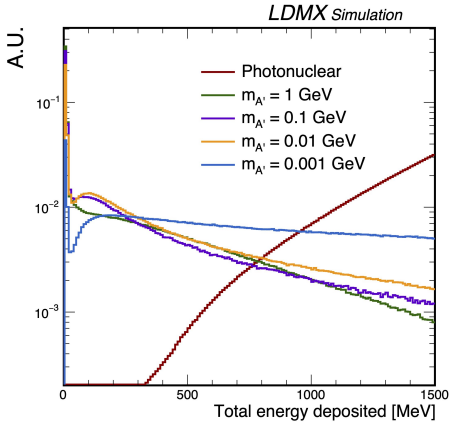


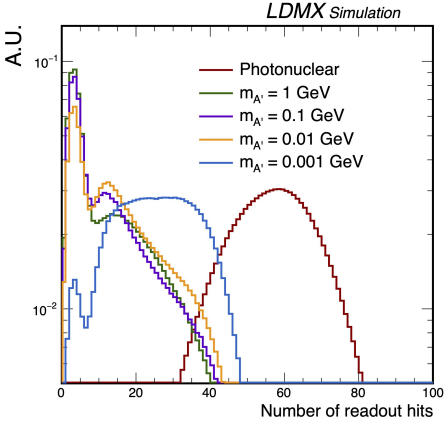


Ecal BDT

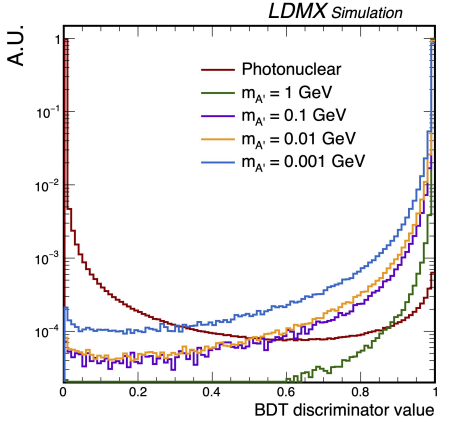


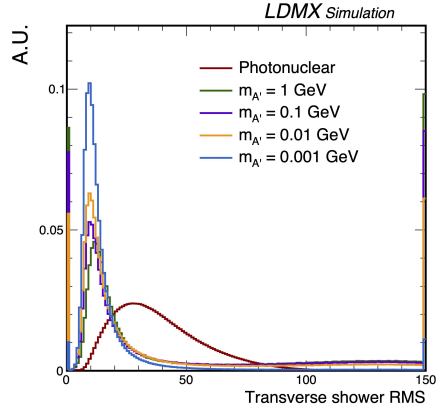
MIP Tracking





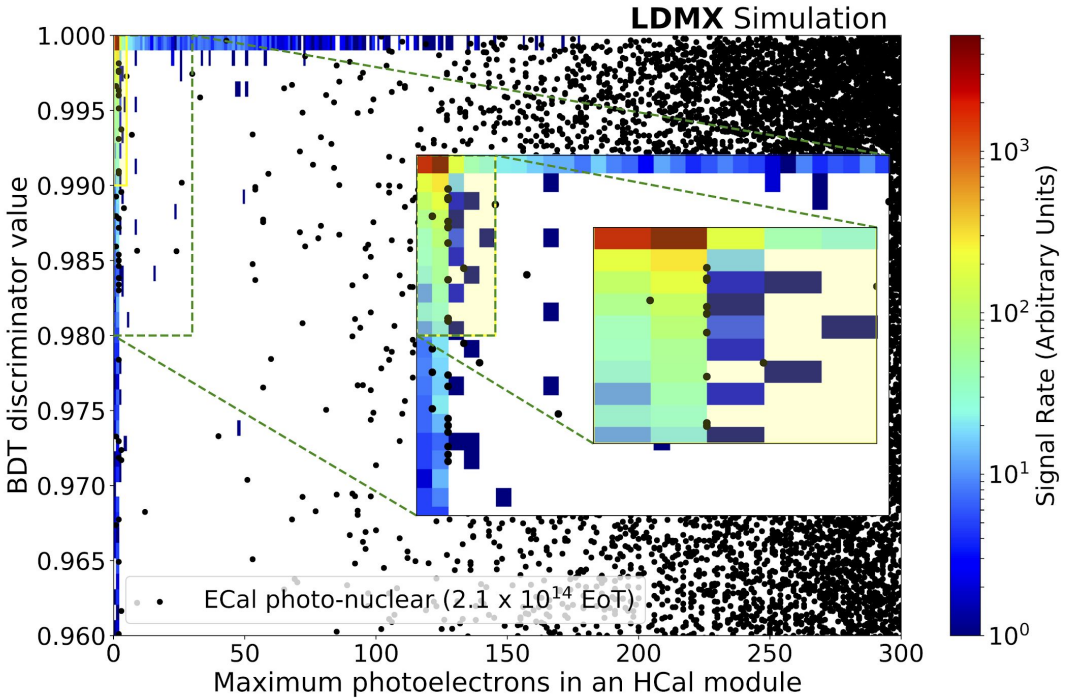
BDT Variables





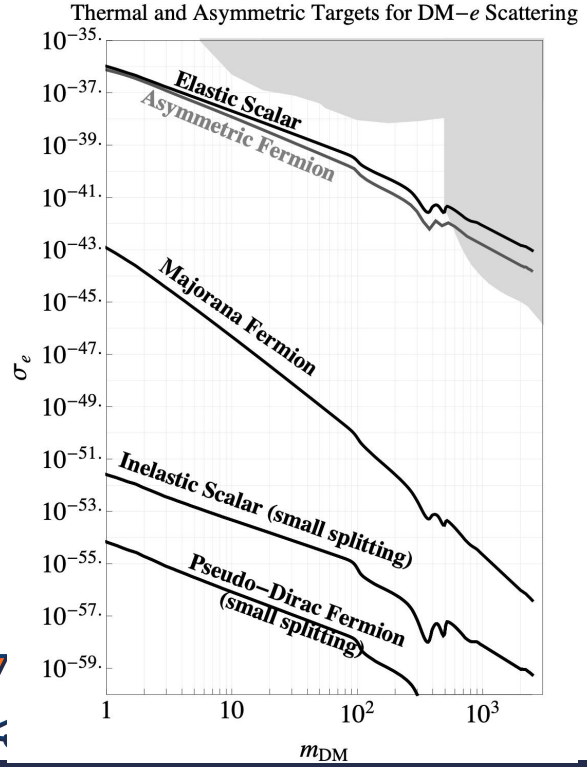
Ecal/Hcal Vetoes

- Ecal BDT > 0.99
- Hcal max PEs is > 5

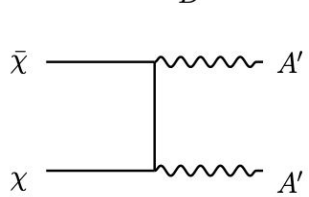


Advantage of DM Production at Accelerators

Non-relativistic vs semi-relativistic DM scattering



$\sigma v \propto \alpha_D^2$



$\sigma v \propto \epsilon^2 \alpha_D$