# Visible Signatures of Dark Photon Decays in LDMX

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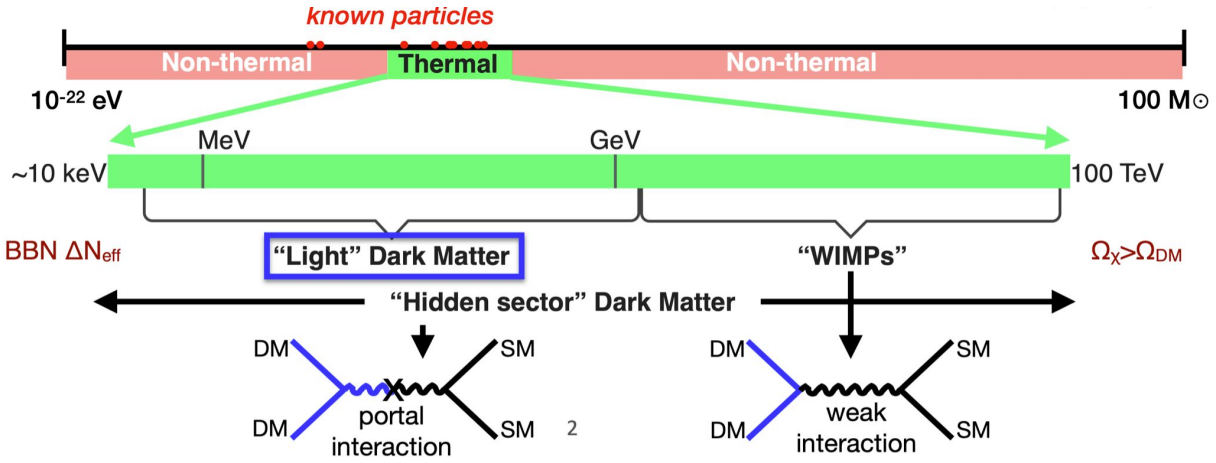
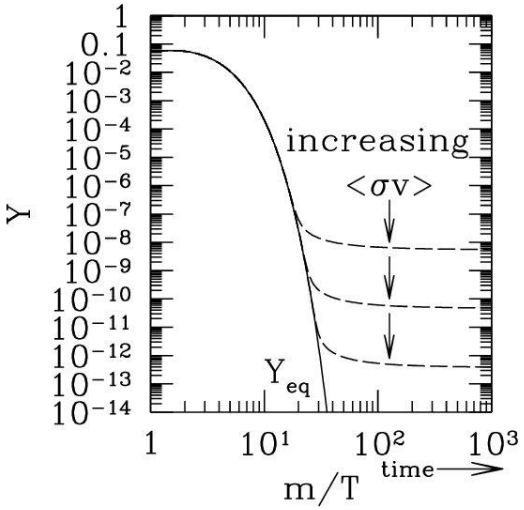
Phenomenology Symposium 5/9/2023


# Thermal Relic Dark Matter

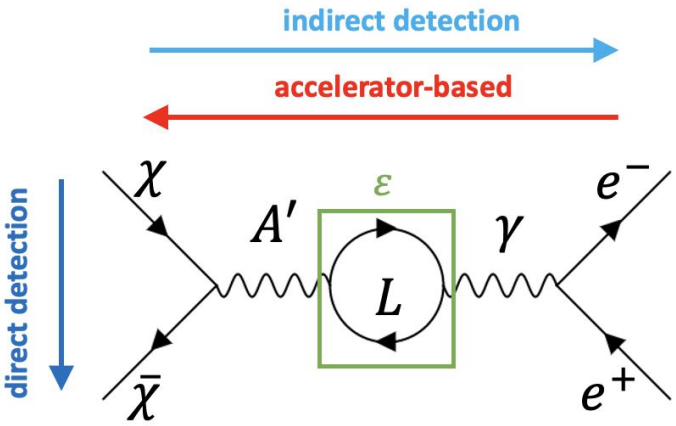
- A simple and predictive model of dark matter
- Dark matter and ordinary matter were in thermal equilibrium in the early universe, and there was a "freeze out" as the universe expanded and cooled
- WIMPs are well-motivated, but the accessible parameter space is shrinking



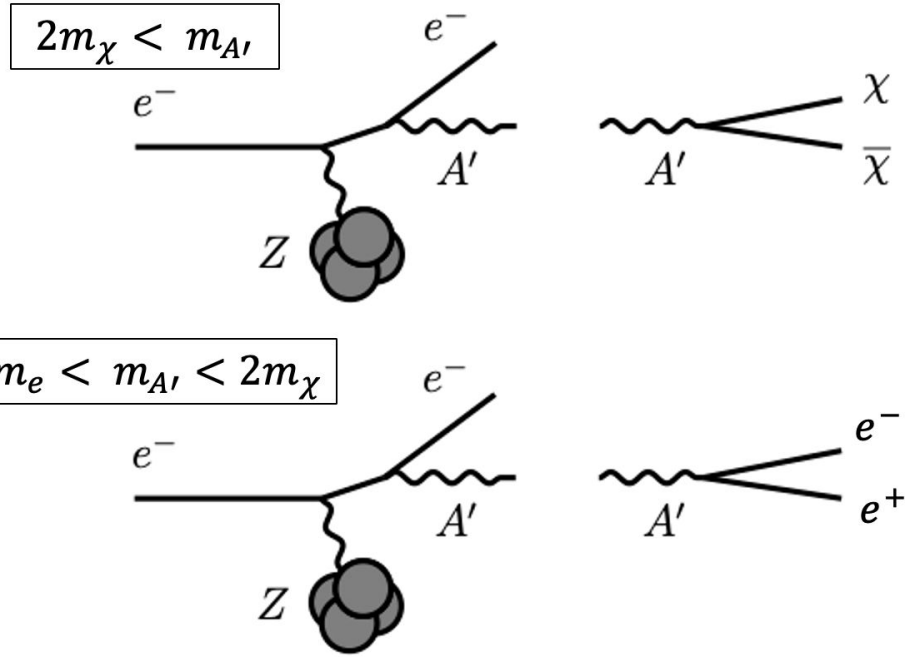



# Light Dark Matter

Simplest prediction includes a new broken U(1) symmetry (generating a dark photon, A′) that kinetically mixes with the standard model photon.

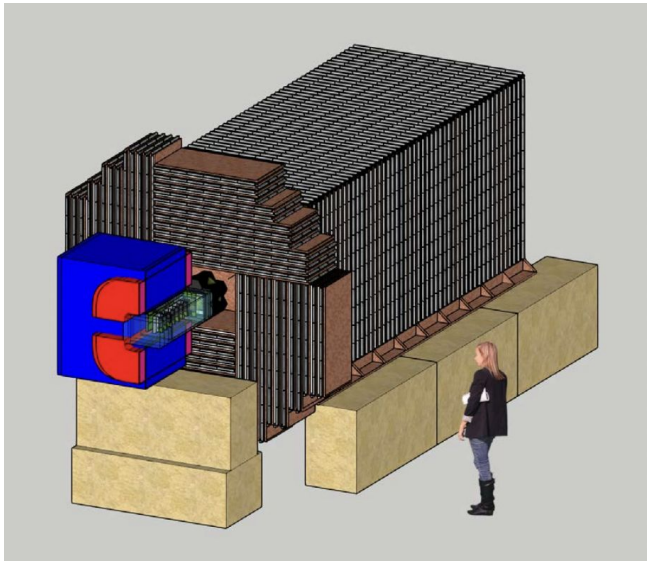


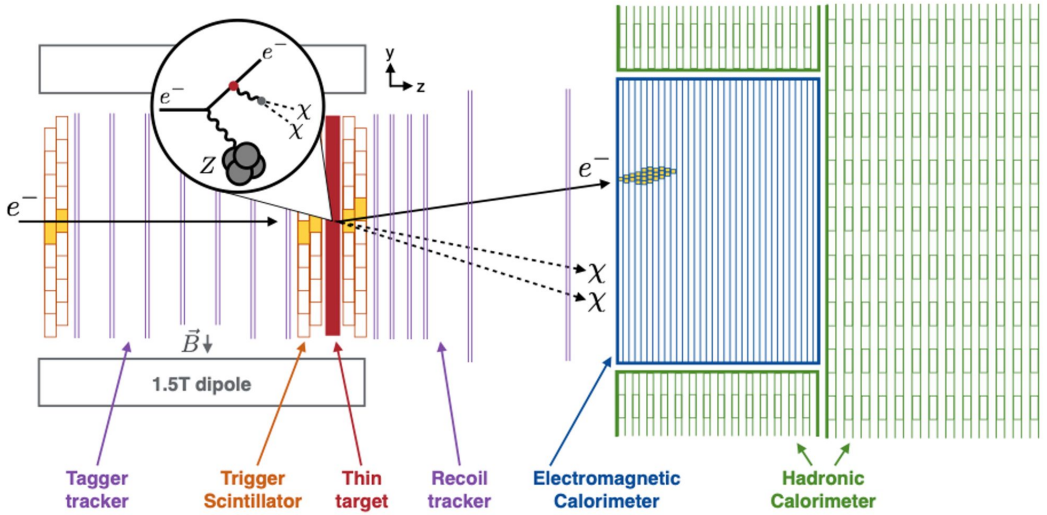

Heavy charged leptons $L$ carrying $U(1)_d$ charge



# LDMX: The Light Dark Matter eXperiment

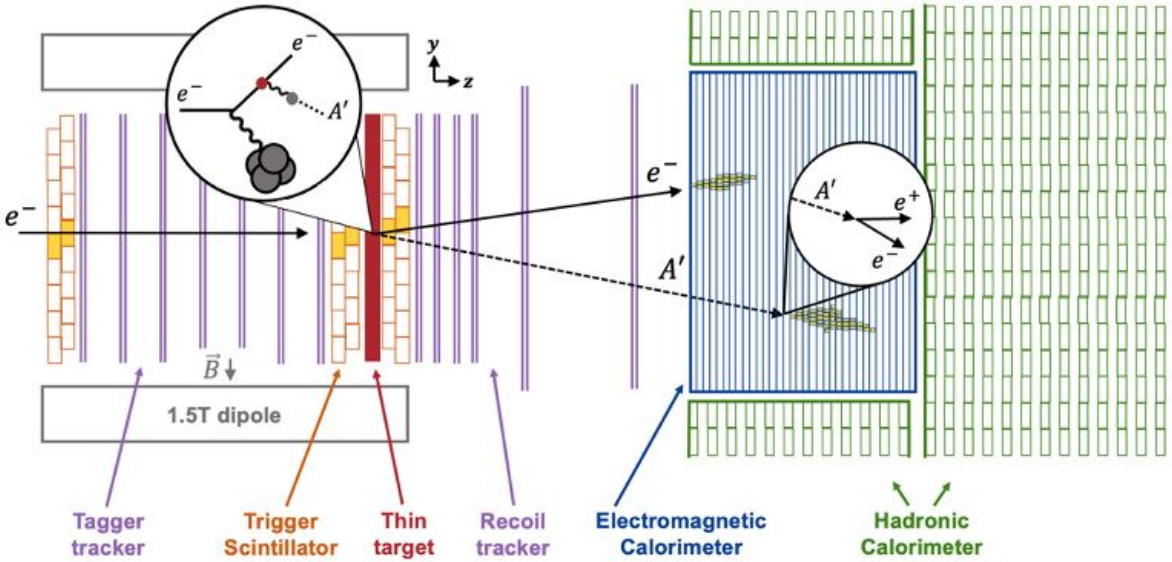
- DM production identified through missing energy/momentum in the detector
- 4 GeV and 8 GeV e- beam provided by SLAC
- For more info on the missing momentum search at LDMX, see V. Dutta's talk in BSM VIII
  - This talk already happened, but slides are posted!





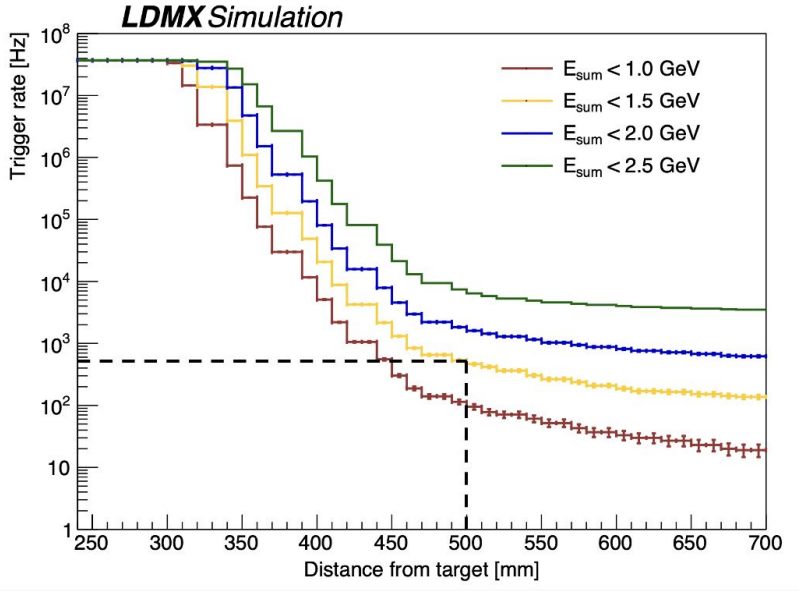
# Visible signatures in LDMX

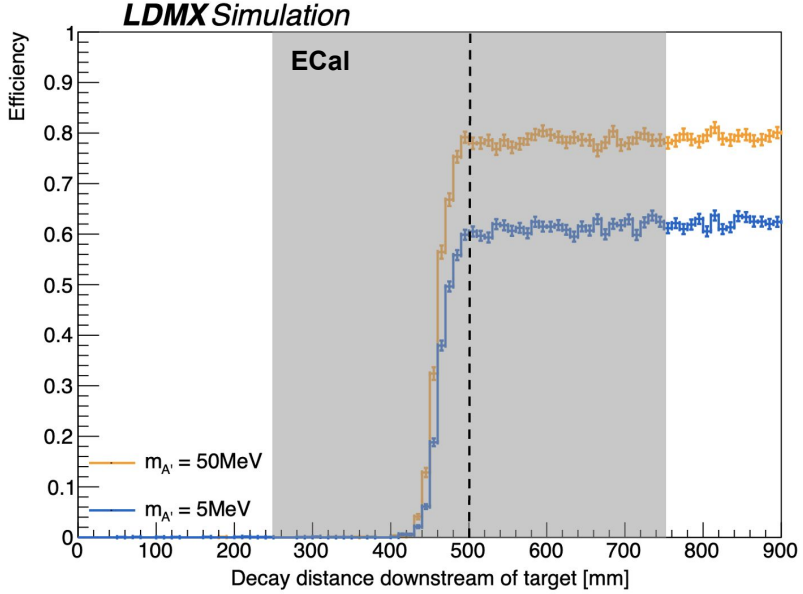
- As a compliment to the missing momentum search, LDMX is capable of searching for the sudden appearance of energy/momentum in the calorimeter
  - Sensitive to broad range of models – minimal dark photon, ALPs, SIMPs, etc.
  - Viable decay channel if $2m_e < m_{A'} < 2m_X$



# A trigger for visible signatures

- Looking for low background rate, high signal efficiency set of conditions
- Trigger on <1.5 GeV upstream of some ECal layer for 4 GeV beam energy
  - LDMX missing energy search triggers on <1.5 GeV in whole ECal



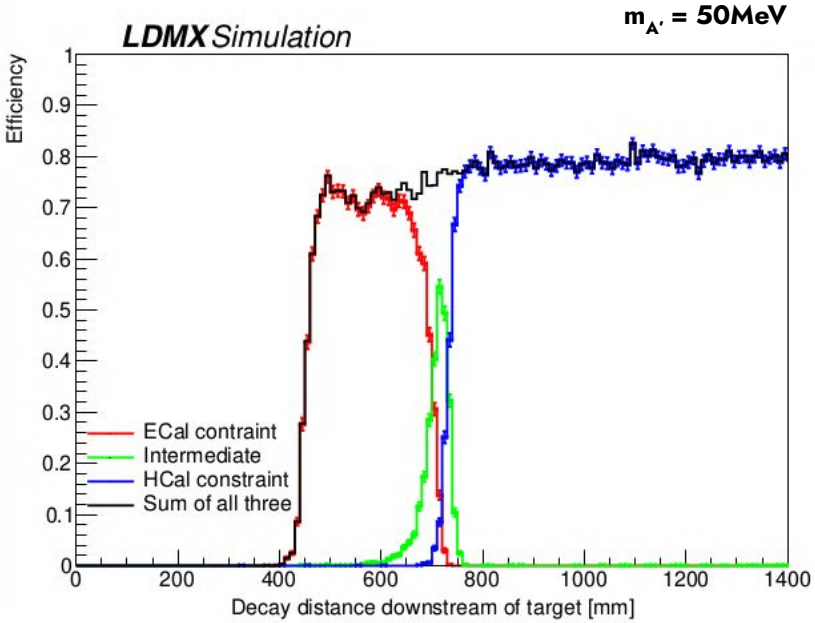



# A′ decays in the ECal/HCal

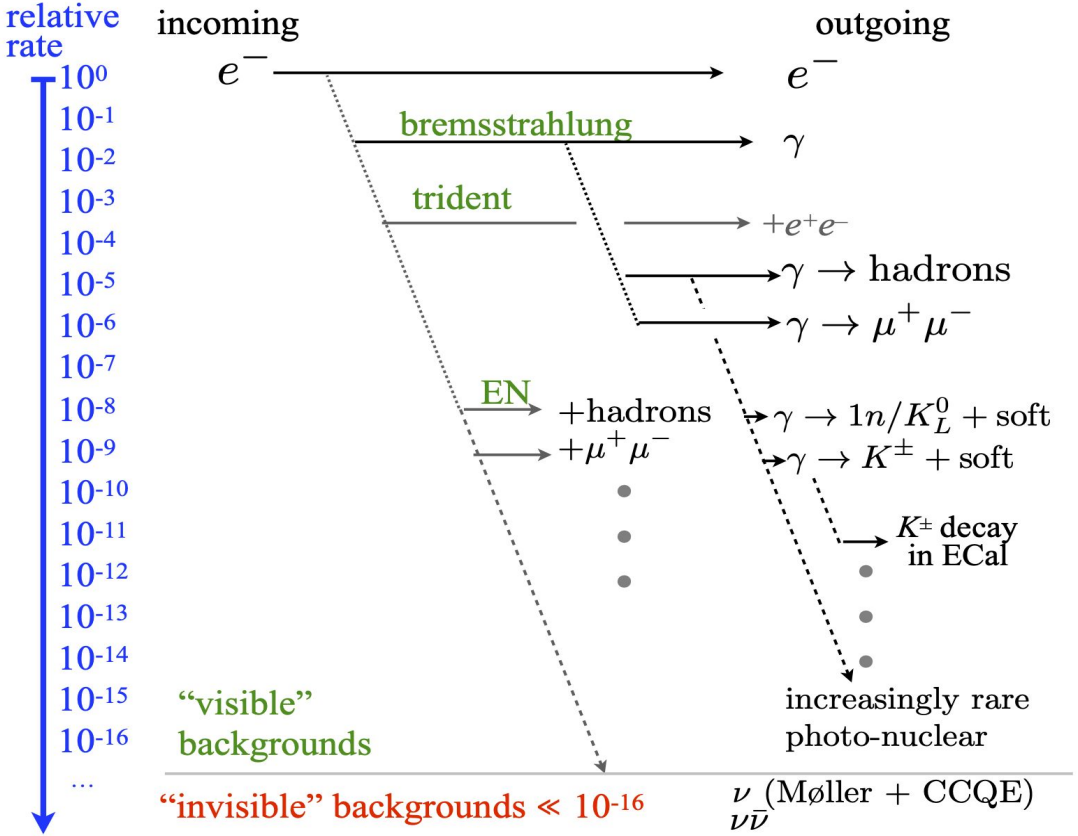
After trigger, we break up the analysis into three parts based on energy constraints in the detector subsystems due to different backgrounds to veto in ECal/HCal.
ECal region probes more interesting region of parameter space.

| | $ECal_{back\ half}$ | HCal | $ECal_{back\ half}$ + HCal |
|---|---|---|---|
| ECal | >2.5 GeV | <2.5 GeV | — |
| HCal | <2.5 GeV | >2.5 GeV | — |
| Intermediate | <2.5 GeV | <2.5 GeV | >2.5 GeV |

This talk will focus on the ECal analysis



# Backgrounds to veto



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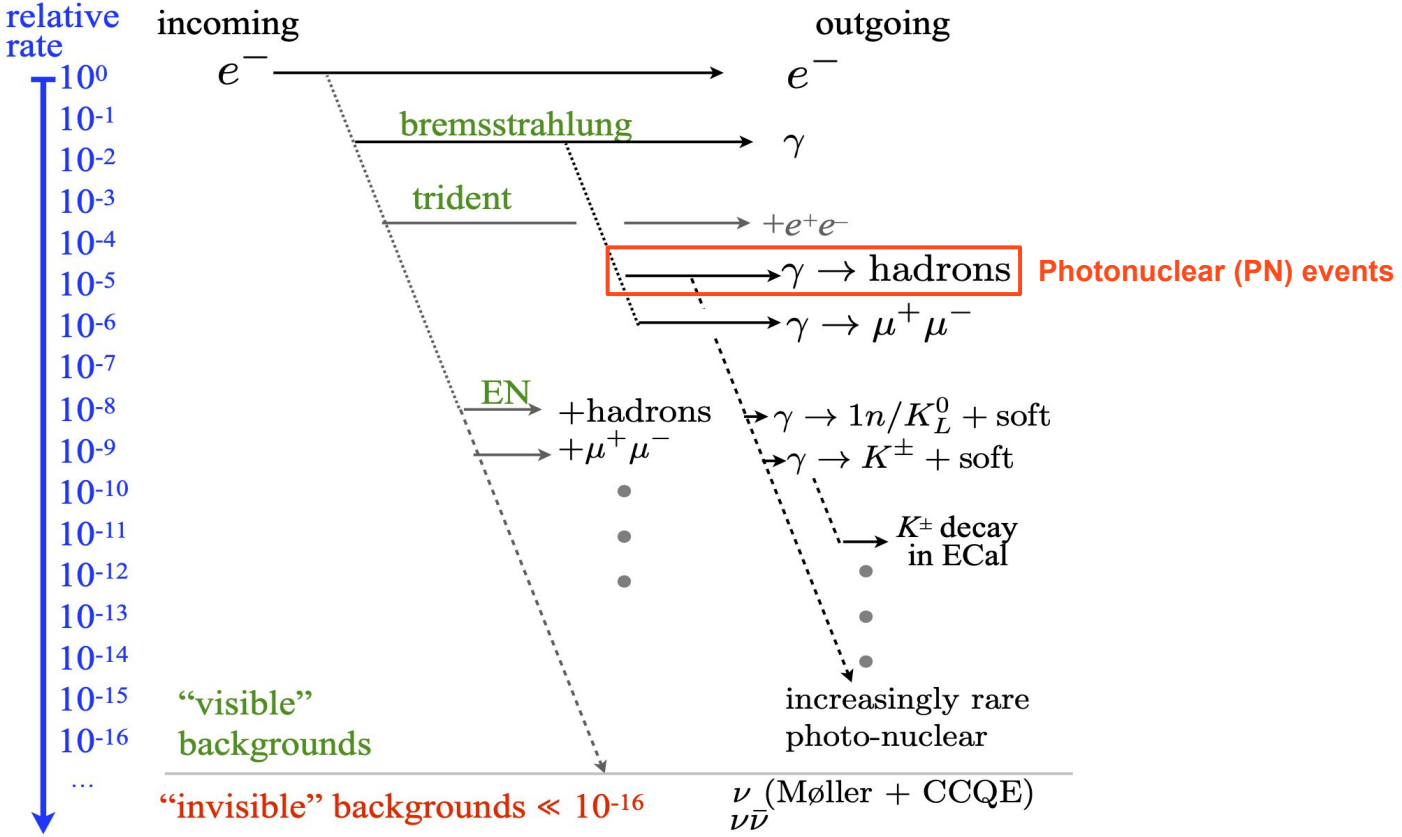
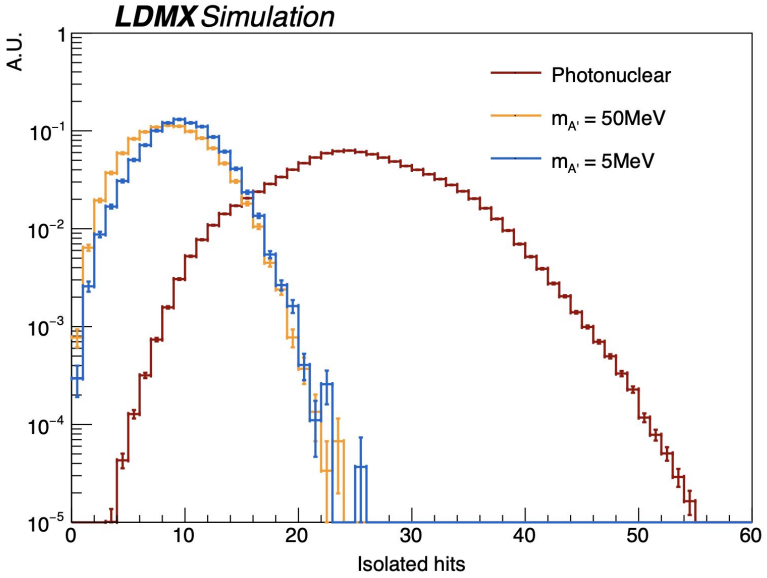
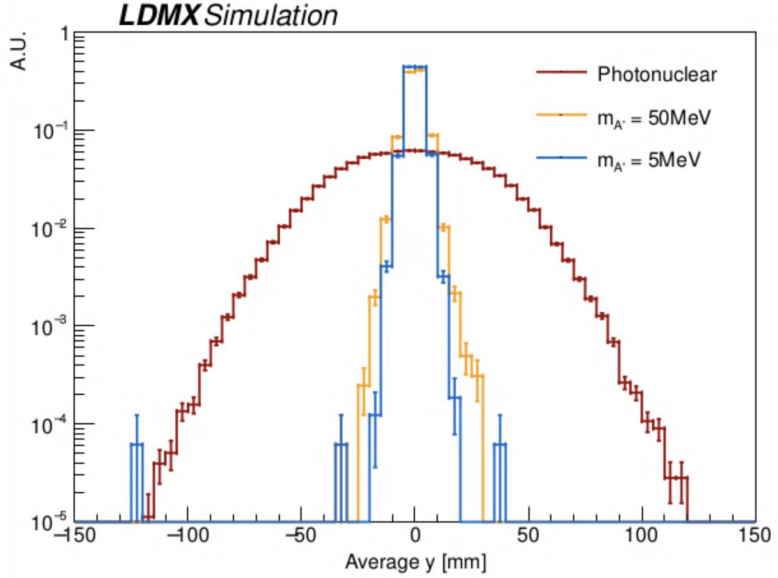


# A BDT for vetoing PN events in the ECal

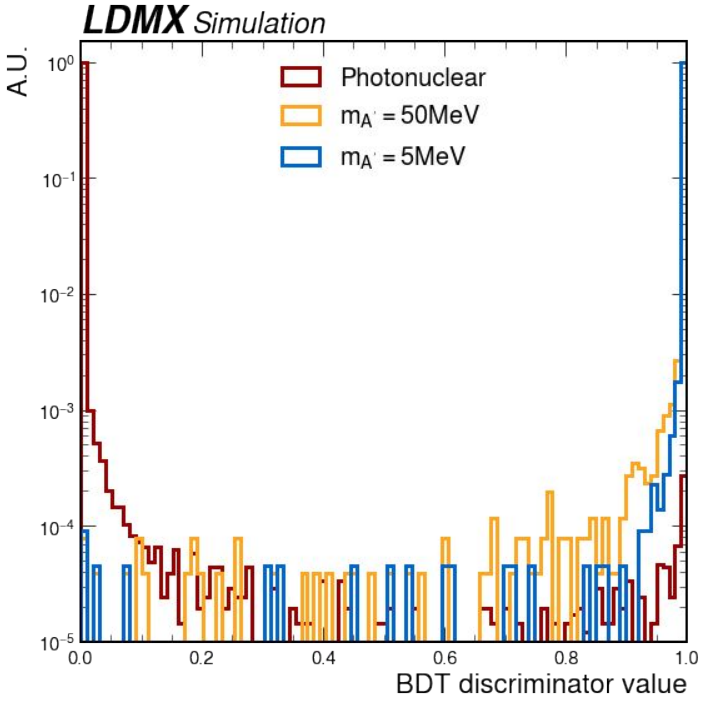
- Trained a boosted decision tree on 21 input features from simulated photonuclear background events and signal events with two A′ masses (5, 50 MeV)
  - All input events pass visibles trigger and have >2.5 GeV deposited in $ECal_{back\ half}$
  - Input features were a mix of spatial distributions of hits and energy deposition / # of hits

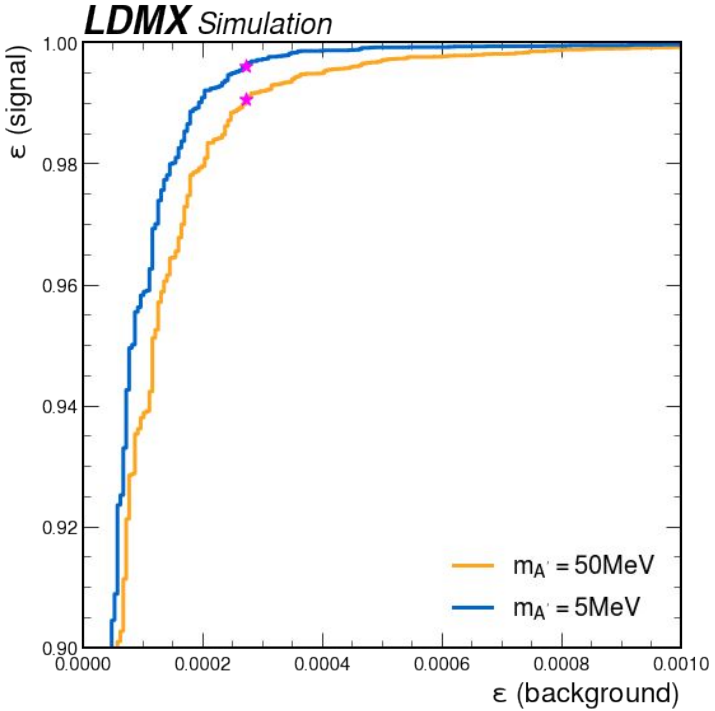


# BDT veto performance

Histogram of BDT output for signal and background (left). Signal efficiency vs background efficiency with BDT discriminator threshold of 0.99 shown as star (right).



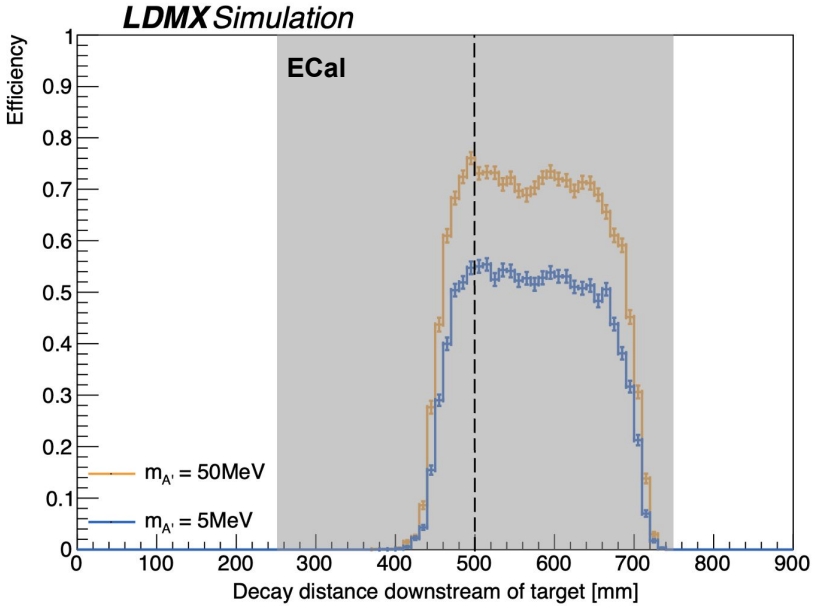



# Signal efficiency and background rejection

A high signal efficiency can be maintained over a large region of the ECal while achieving a $10^5$ level of photonuclear background rejection.
Other veto handles will be required to remove remaining background (recoil pT, information from HCal, etc.). This is still a work in progress!

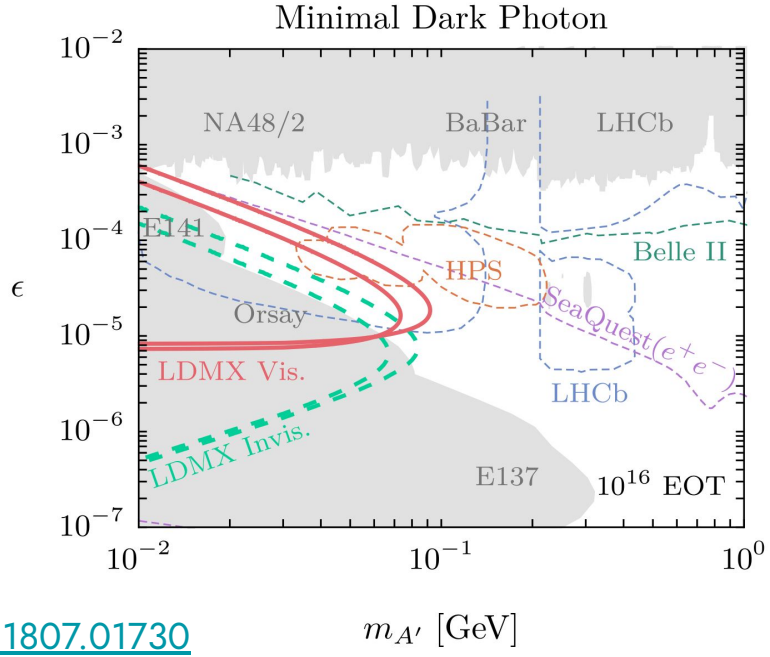
| | ECal Photonuclear |
|---|---|
| Electrons on Target (EoT) equivalent | $2.1 \times 10^{11}$ |
| Trigger, < 1.5GeV upstream of z=500mm | $3.4 \times 10^{6}$ |
| ECal downstream energy > 2.5GeV | $2.0 \times 10^{5}$ |
| Single track in tracker with 50MeV < $p$ < 1.5GeV | $1.8 \times 10^{5}$ |
| ECal BDT (> 0.99) | 36 |

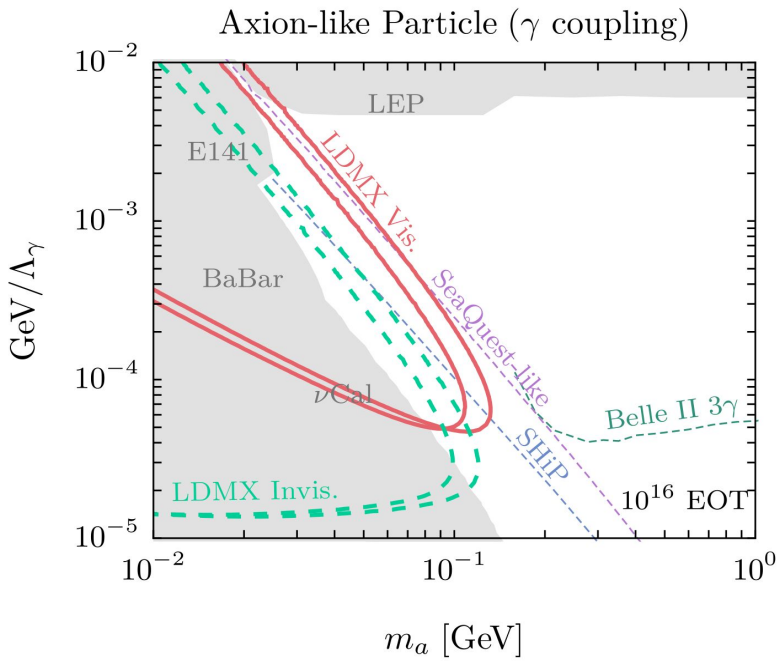
Zero background not expected for visibles search.



# Reach Projections

- Projection assumes 9 background events (and 14 signal events) after full run
  - We will have more concrete reach projections when all backgrounds have been studied
  - We still have competitive reach with some level of background




arXiv: 1807.01730

# Summary

- With WIMP dark matter accessible parameter space shrinking, there is a growing demand for searches at sub-GeV particle masses
- LDMX is a high sensitivity probe of sub-GeV thermal relic dark matter with sufficient background vetoing
- A proof of concept of a low-rate, high-efficiency trigger for displaced visible signatures has been presented, which further expands LDMX's sensitivity
- Photonuclear backgrounds for A′ decays in the ECal can be rejected on the order of $10^5$ while maintaining a high signal efficiency
- Continuing work:
  - Further drive down photonuclear background levels
  - Explore other background sources – $\gamma \rightarrow \mu^+\mu^-$, $\gamma \rightarrow e^+e^-$, target PN
  - A′ decays in the HCal


# 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

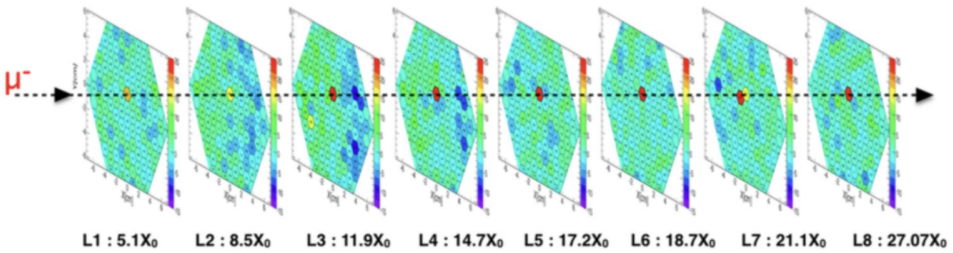
UNIVERSITY of VIRGINIA

# Backup

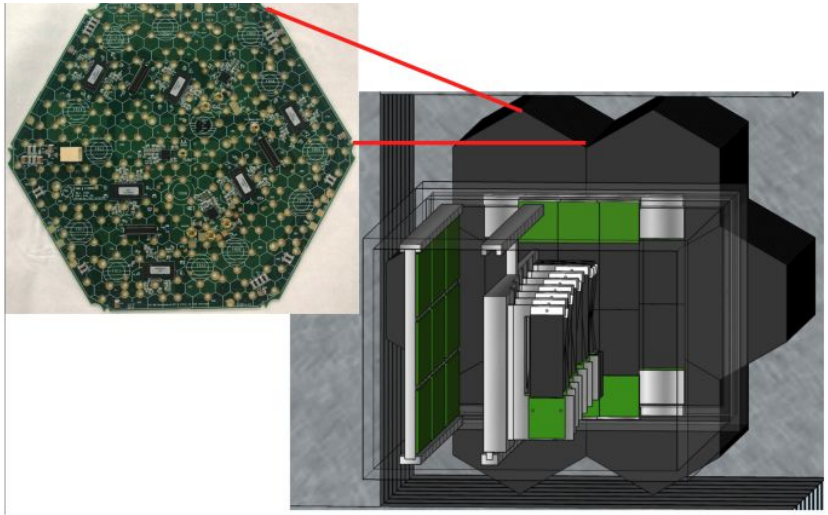
# Backup: LDMX Electromagnetic Calorimeter

40 $X_0$ Si-W sampling calorimeter based on CMS HGCal upgrade

- Dense, radiation hard, and has full shower containment
- Fast triggering
- Capable of MIP tracking
- High granularity, so both transverse and longitudinal shower shapes can be used to reject backgrounds

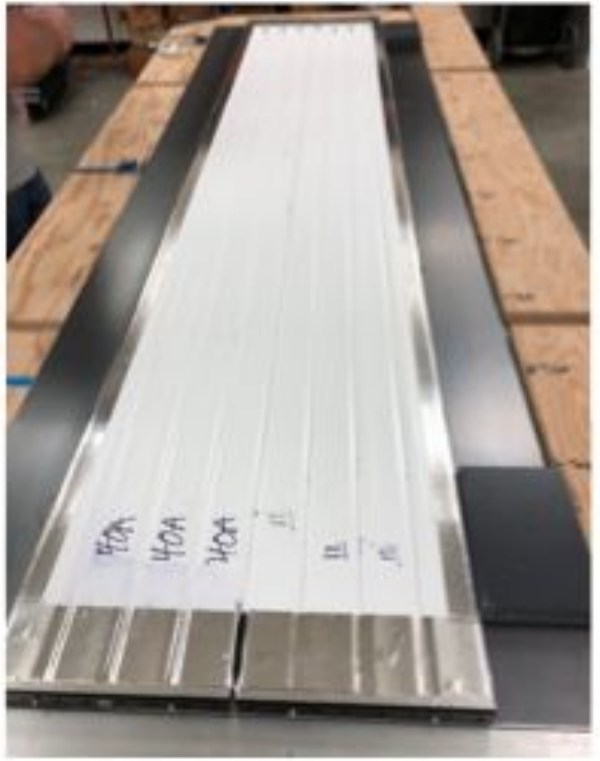



A. Martelli on behalf of CMS. arXiv: 1708.08234

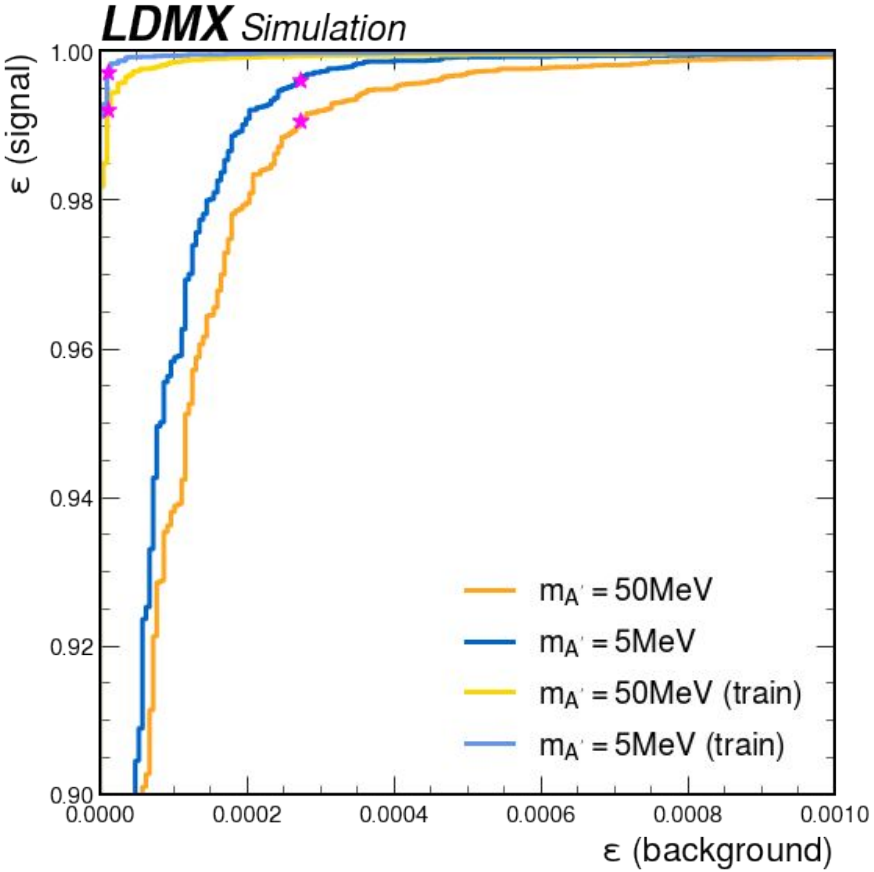


# Backup: LDMX Hadronic Calorimeter

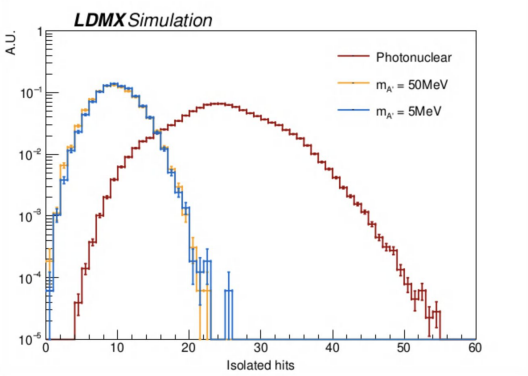
- Layered steel and scintillator calorimeter based on design of Mu2e Cosmic Ray Veto
  - Scintillators have embedded wavelength shifting fibers read out by SiPMs
- Highly efficient and optimized veto for photonuclear processes that produce neutral hadrons

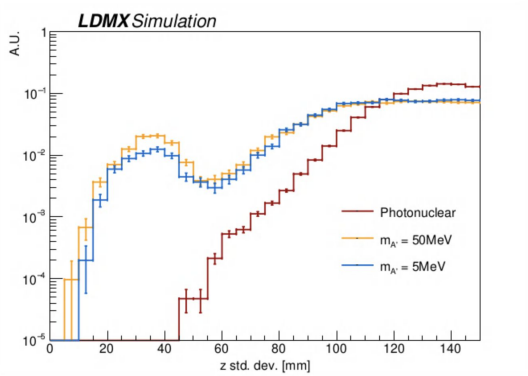


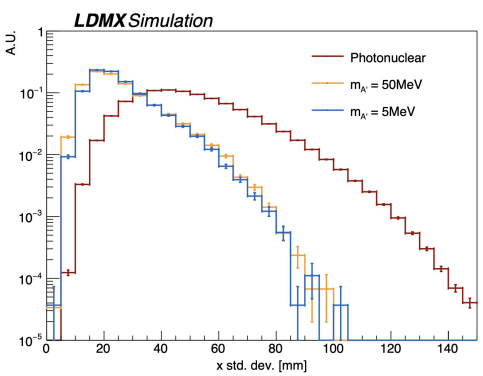
# Backup: Training vs testing

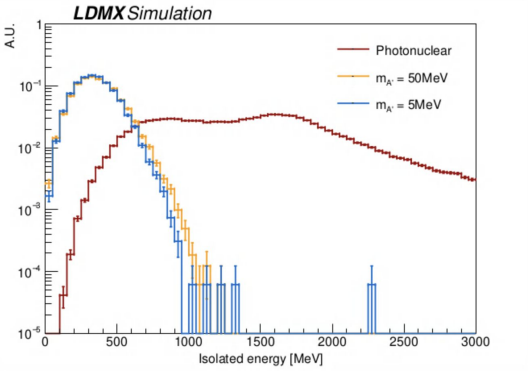


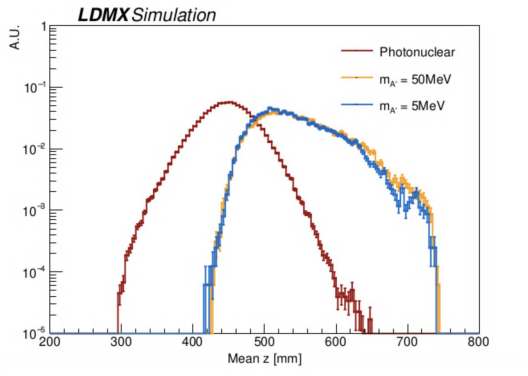
# Backup: Distribution of BDT input features (1/3)

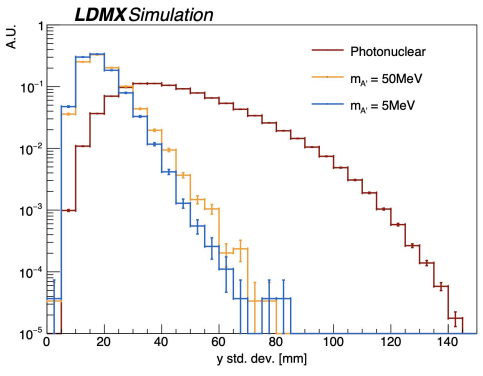


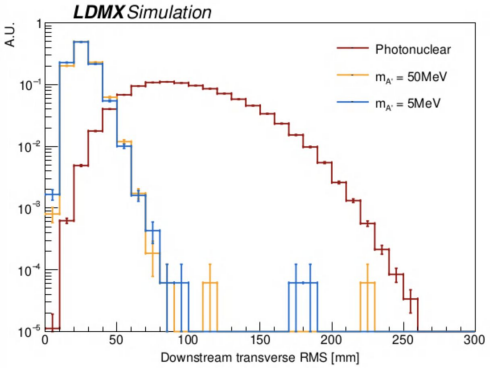



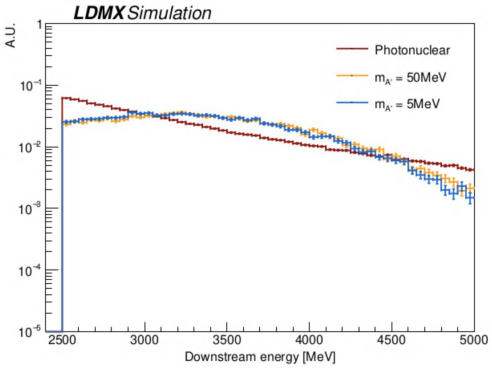



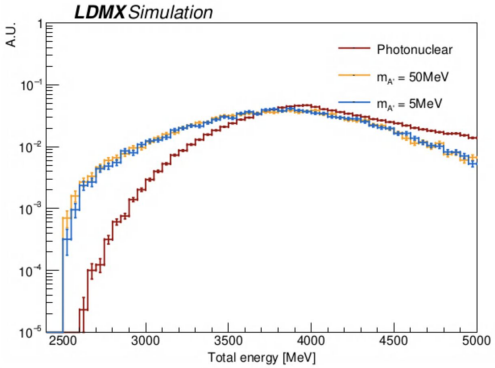



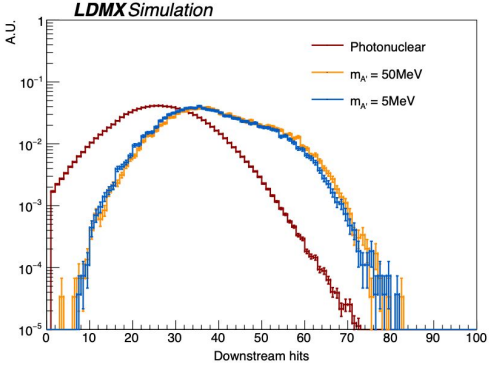



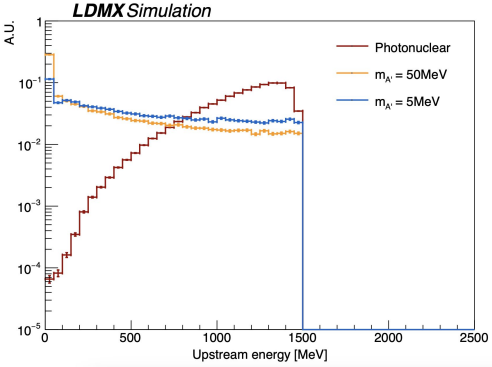
# Backup: Distribution of BDT input features (2/3)

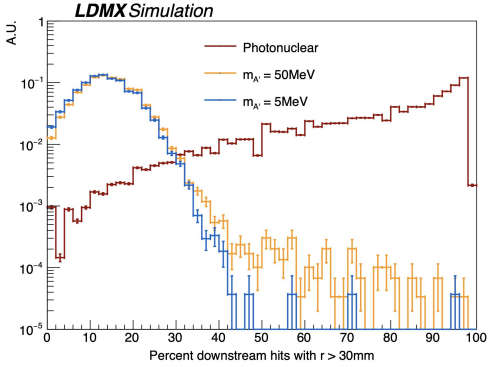


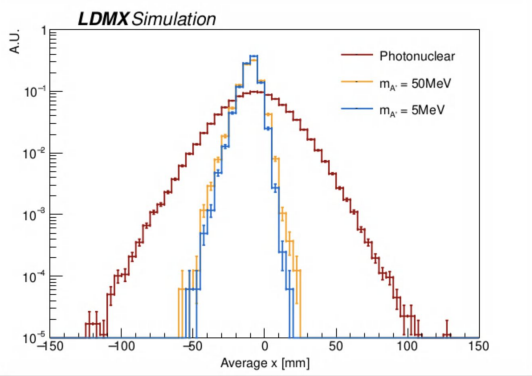



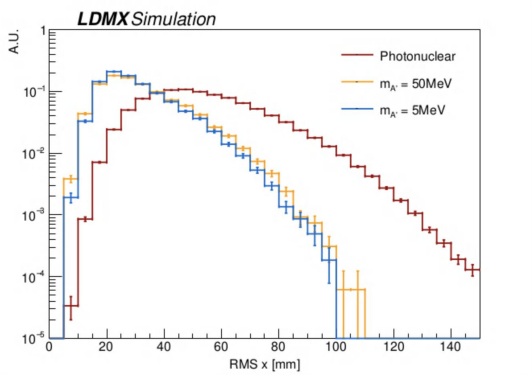



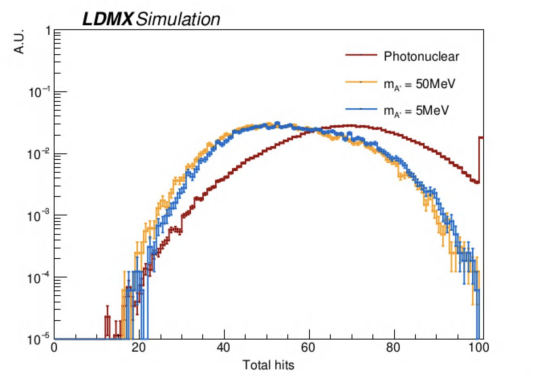



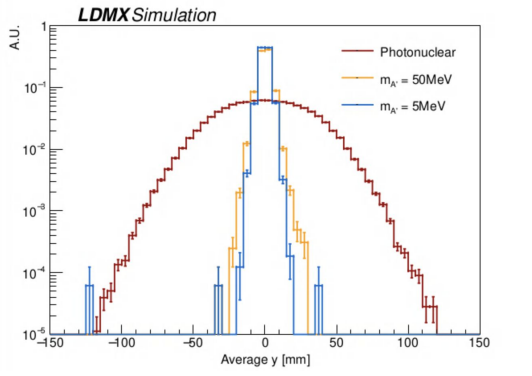



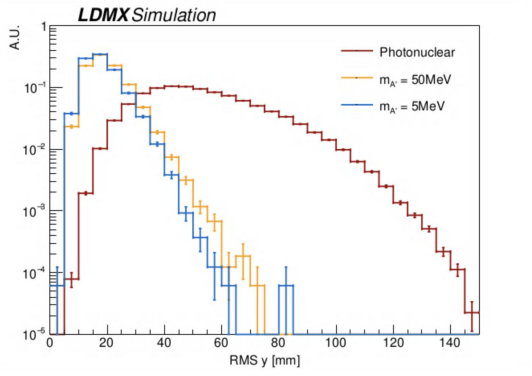
# Backup: Distribution of BDT input features (3/3)

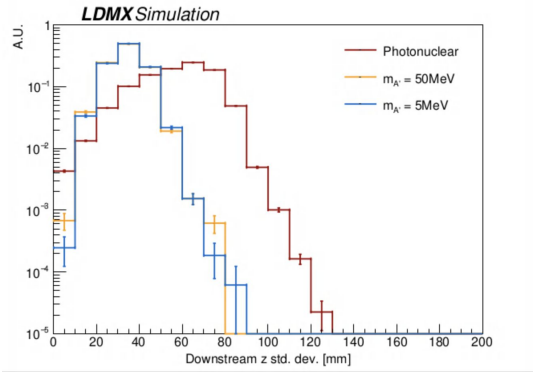


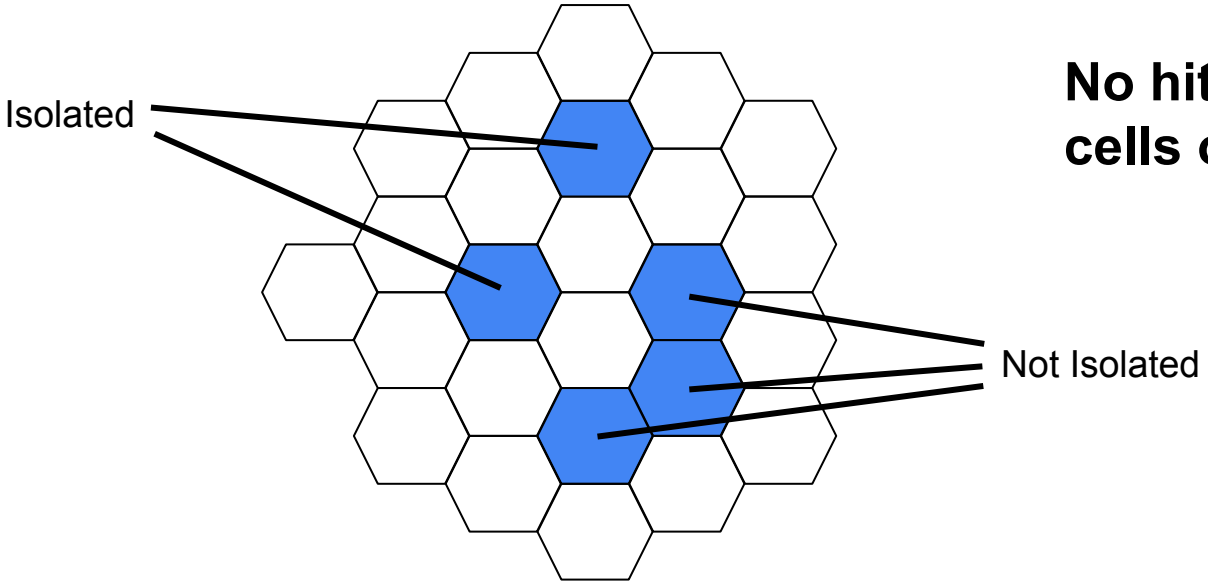



# Backup: What is an isolated hit?




**No hits in neighboring cells of the same layer**

# Backup: Sensitivity

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

- All systems handling veto: expect < 1 background event for 4 x $10^{14}$ EOT with 4 GeV beam energy
- Even with 20x expected background events, LDMX would provide competitive sensitivity
  - We still want to optimize our sensitivity