(https://lcls.slac.stanford.edu/lcls-ii)

The Light Dark Matter eXperiment at 8 GeV

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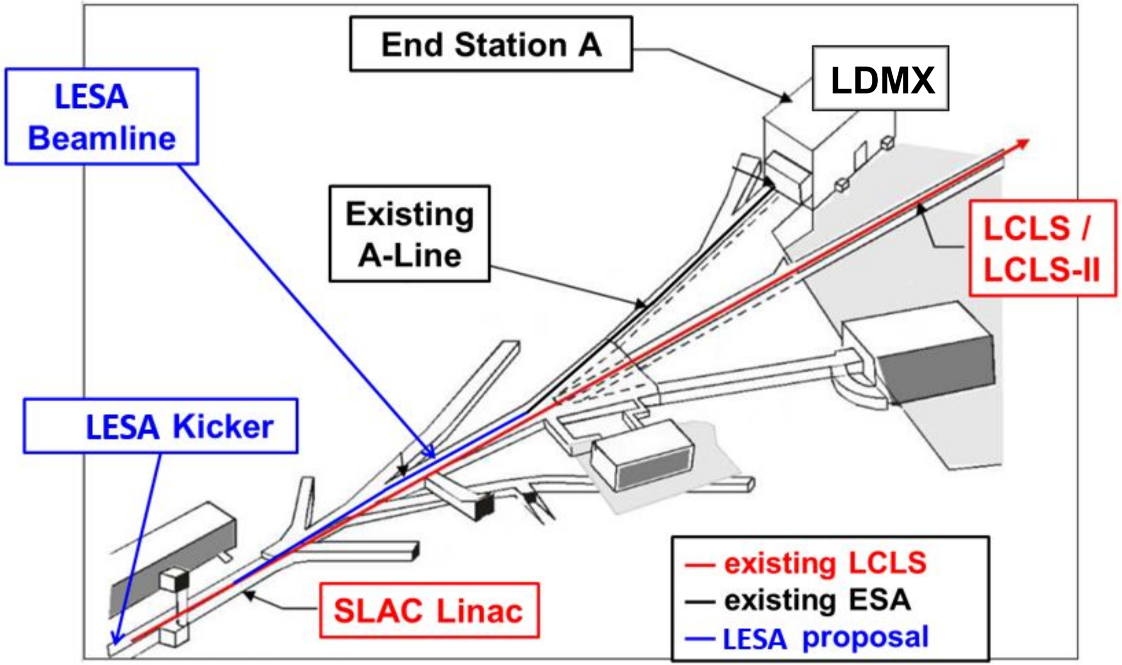
LDMX is a proposed fixed-target experiment, sensitive to missing momentum and missing energy, to search for light DM (and more!).

LDMX wants an electron beam with:

- Low current
- High repetition rate

We can kick out electrons *between* the bunches delivered for photon physics, at SLAC's LCLS-II accelerator! For this, the Linac to End Station A (LESA) is being constructed.

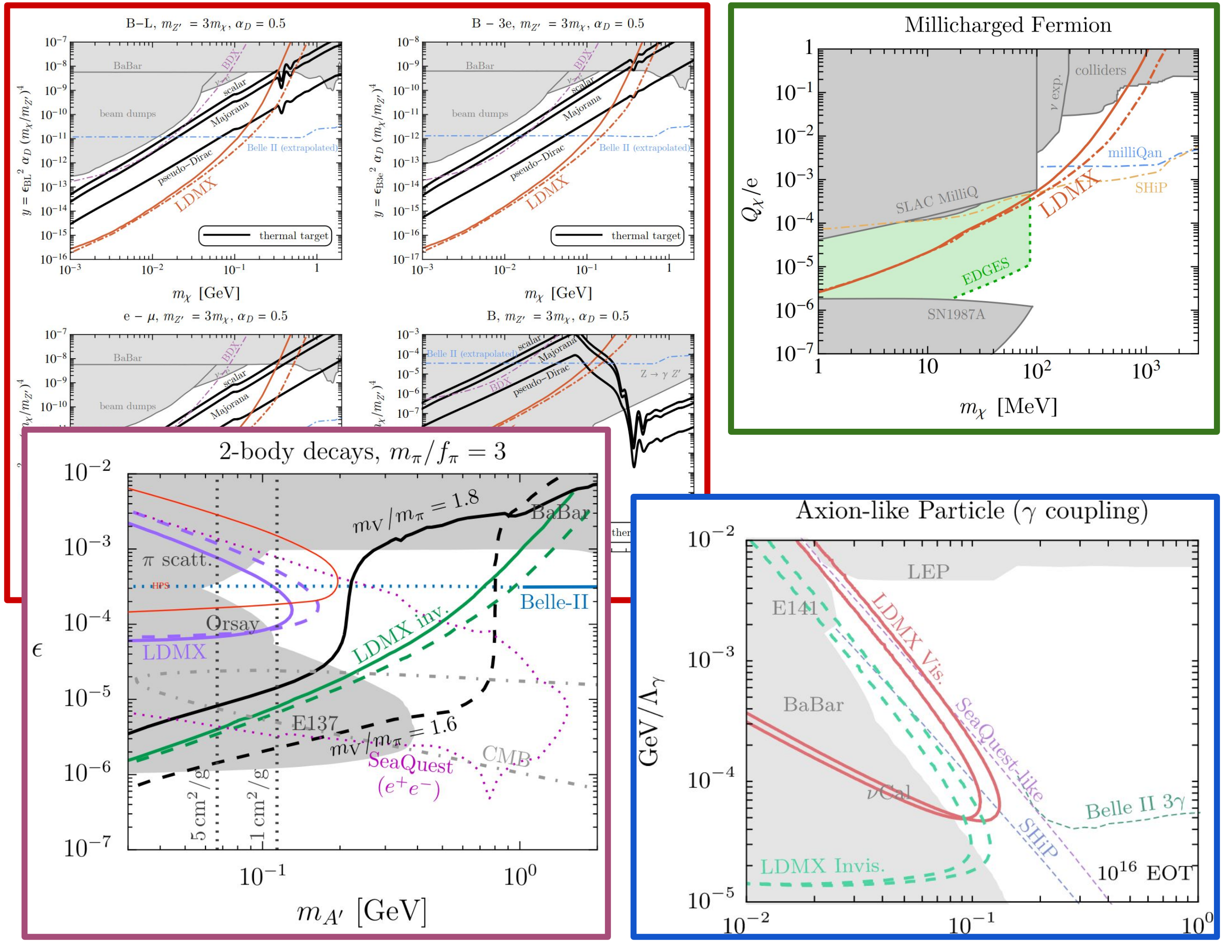
LCLS-II currently delivers 4 GeV electrons, but an accelerator upgrade to 8 GeV is imminent.



(modified from arXiv:2205.13215)

Snapshot: The Wide Physics Potential of LDMX

- **Other mediators**
- **Millicharged particles**
- inelastic DM (iDM)
- **SIMPs**
- Freeze-in DM
- Visible signatures (e.g. visibly decaying dark photons or **ALPs**)



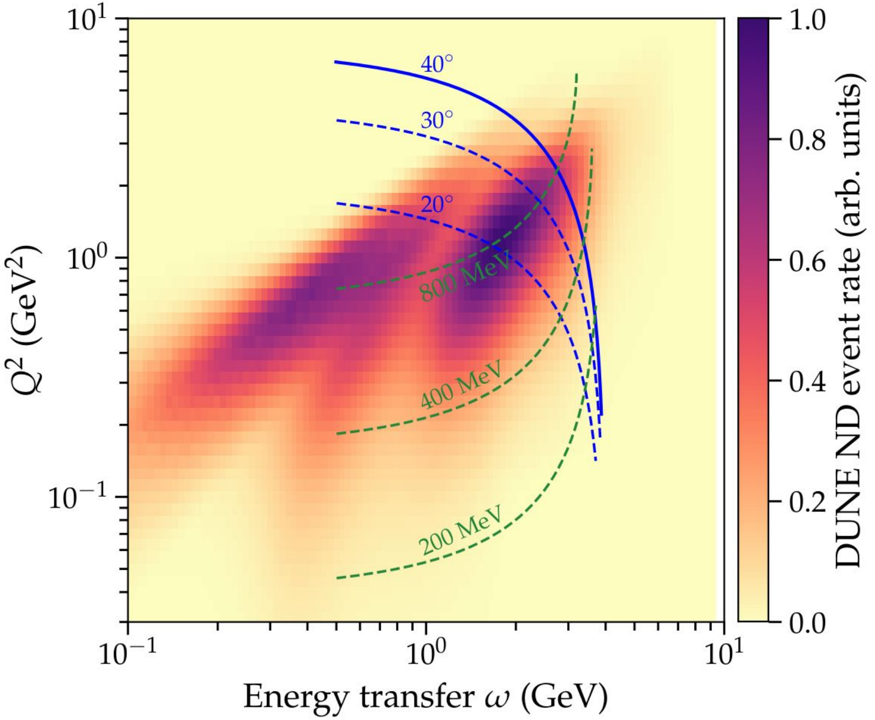
Dark Matter, Millicharges, Axion and Scalar Particles, Gauge Bosons, and Other New Physics with LDMX: Phys. Rev. D 99, 075001 (arXiv:1807.01730)

Snapshot: The Wide
Phy
LDM

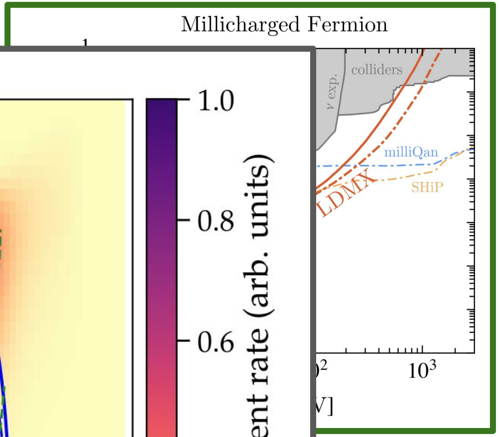
Electro-nuclear Measurements

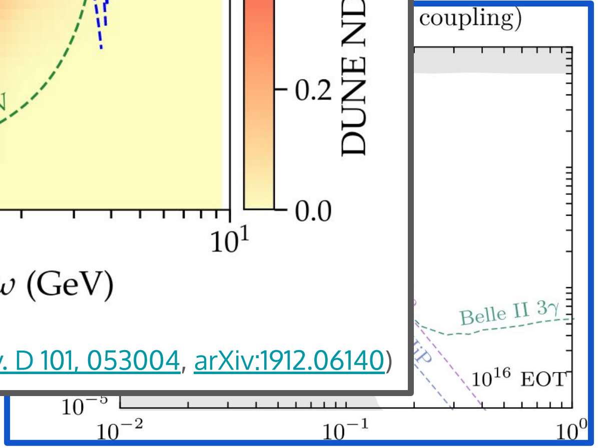
Not only searches for “new” physics at LDMX, but also standard model measurements.

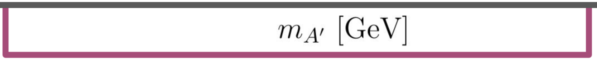
LDMX can make electron-nucleon cross-section measurements, which are important for the neutrino program!



(Phys. Rev. D 101, 053004, arXiv:1912.06140)

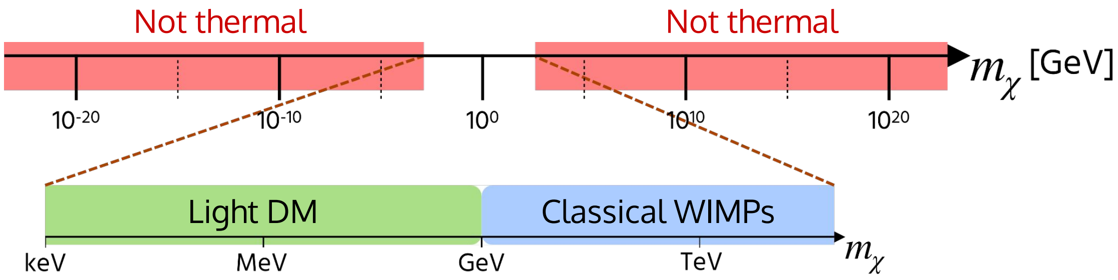




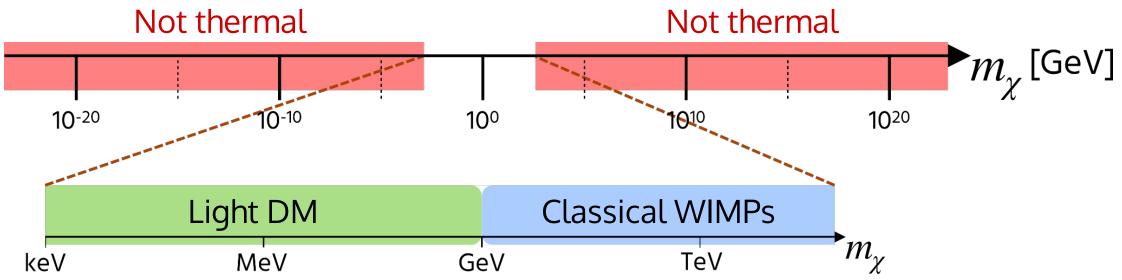


Dark M
Scalar
Other
Phys. R
(arXiv:1

- Viewing DM as a **thermal relic** from the early universe is a predictive assumption, which **narrows the large possible mass range of DM**.

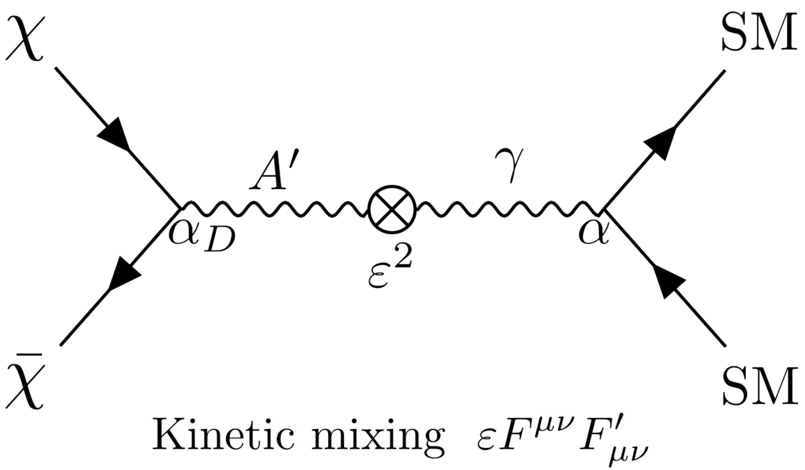


- Viewing DM as a **thermal relic** from the early universe is a predictive assumption, which **narrows the large possible mass range of DM**.



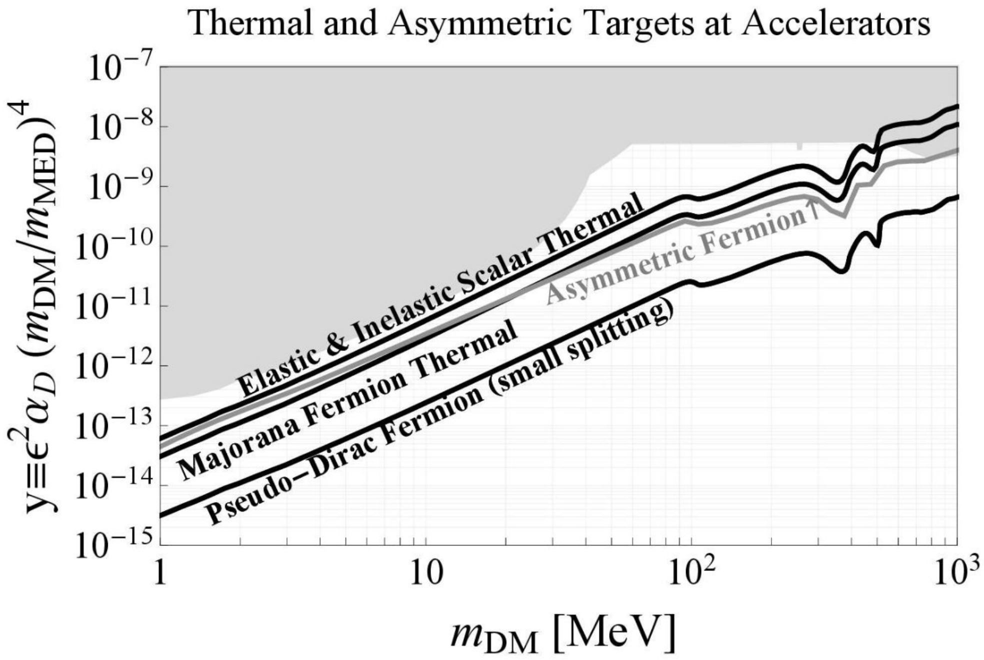
- **Assumption**: A light feebly-interacting mediator between the SM and some dark sector. These light mediators allows for **DM masses below the Lee-Weinberg bound** on the classical WIMP range. Relatively unconstrained region so far!

  Benchmark model: Massive **dark photon mediator**, mixes with the SM (hyper/EM)charge.

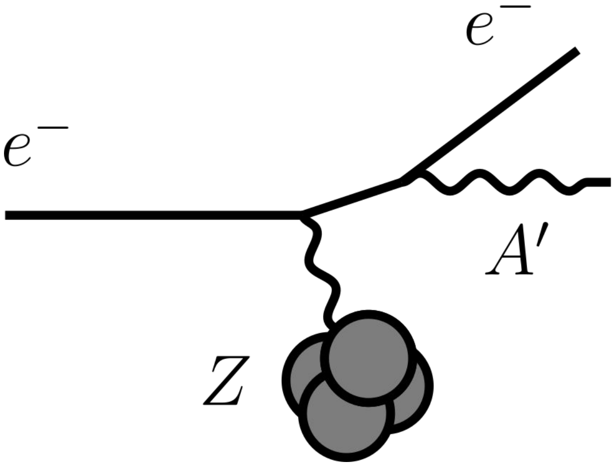


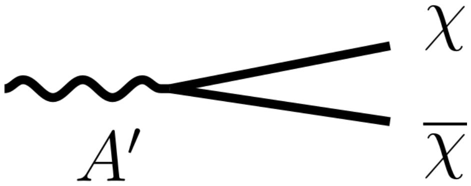
Thermal targets, for an A′ mediator, in reach at accelerators!

Relativistic production at accelerators is **not very sensitive to the spin-structure** of the DM particle.



(LDMX initial design study: arXiv:1808.05219)



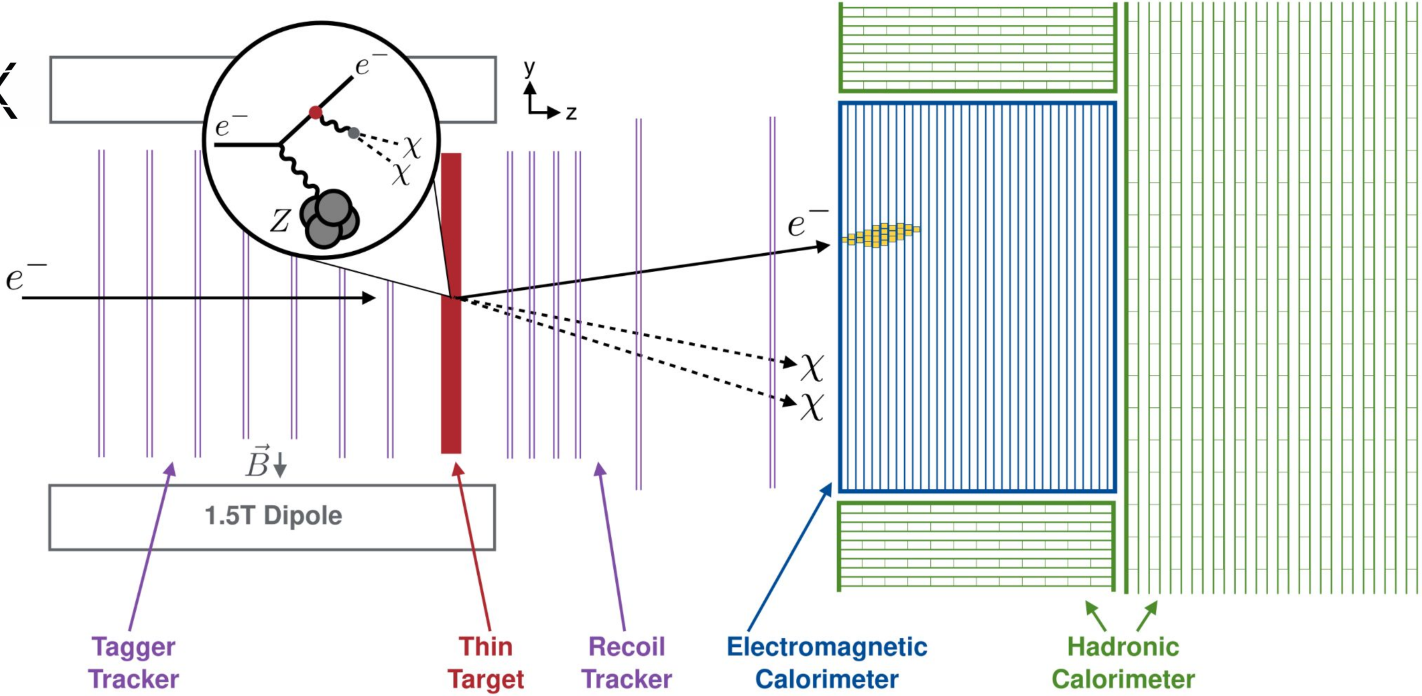


Electrons scattering on heavy tungsten nuclei

- ‘Dark’ bremsstrahlung production channel

Targeting parameter space where the *A′* decays to DM.

Not considering decays back into SM particles.
(Separate studies for *visible* signatures underway!)

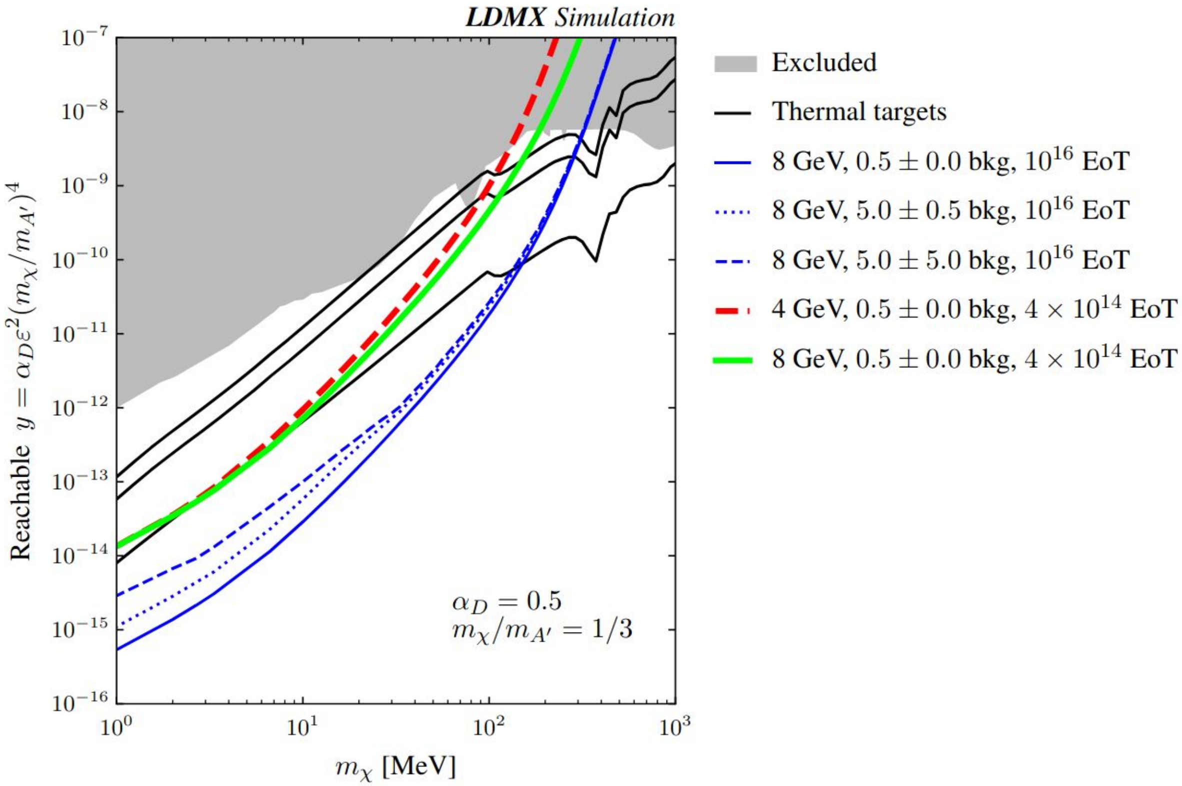


Missing momentum *and* missing energy

The complete 8 GeV run of LDMX expects 10^{16} electrons on target (EoT), in **blue.** Unprecedented reach to the thermal targets!

But, the reach is highly dependent on low background and controlled background uncertainties.

2×10^{14} EoT simulation study at 8 GeV: 10.1007/JHEP12(2023)092 (arXiv 2308.15173v2)



(10.1007/JHEP12(2023)092, arXiv:2308.15173v2)

LDMX aims to veto every background event, but the background has large variety.

(Normal) Bremsstrahlung from electrons scattering in the target can undergo:

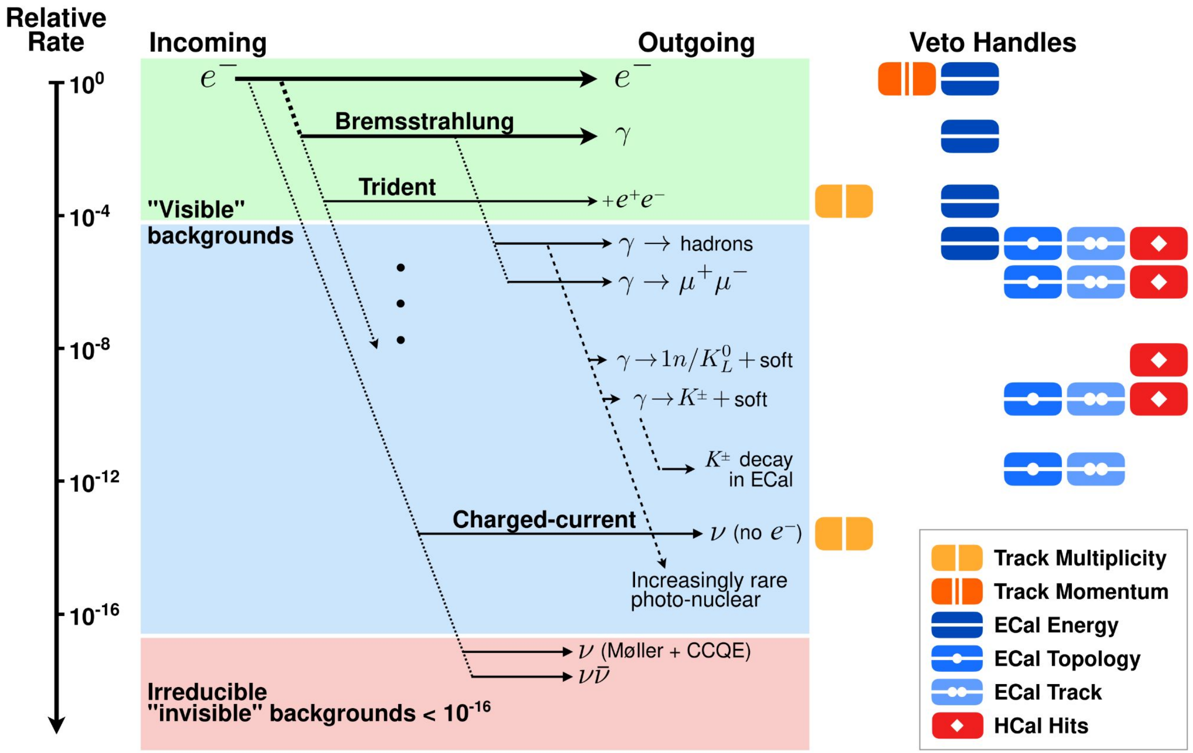
- Muon-conversion
- Photo-nuclear reactions

inside either the target or ECal material.

Notably, photo-production of single neutrons and kaons is challenging.

No fundamentally irreducible backgrounds, that do not have veto handles in the experiment, at relevant rates.

Sub-detectors borrow technology from other existing experiments.



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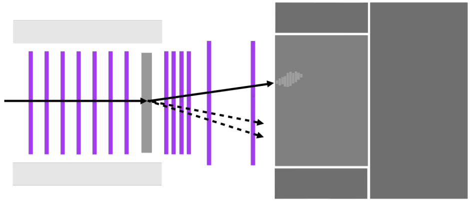
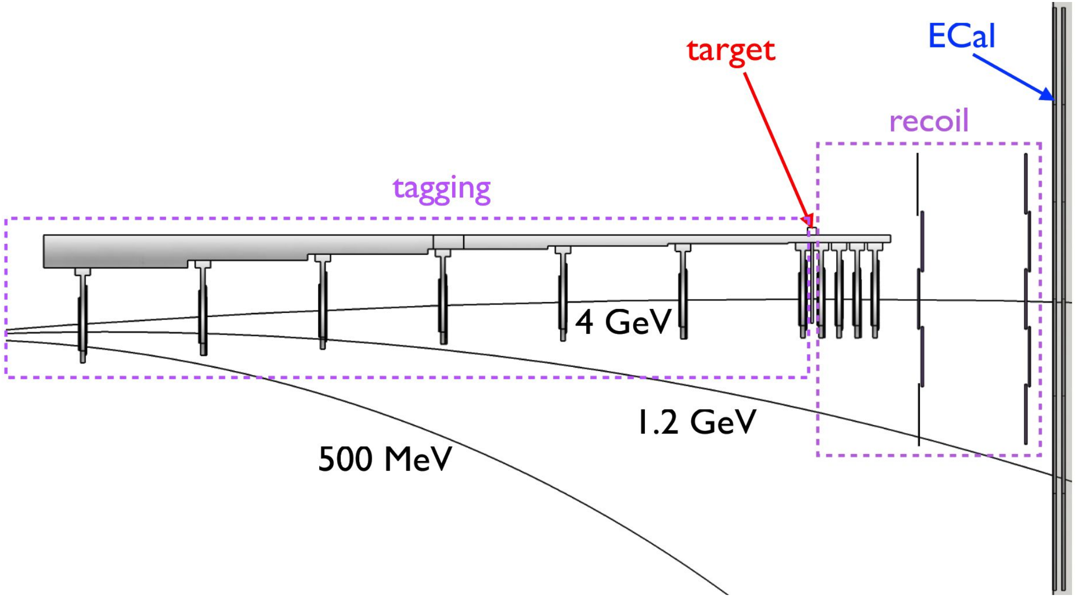
Tagger and Recoil Trackers



Measures the missing momentum of the recoil electron.

For background reactions in the target, the track multiplicity in the recoil tracker may be used as a veto.



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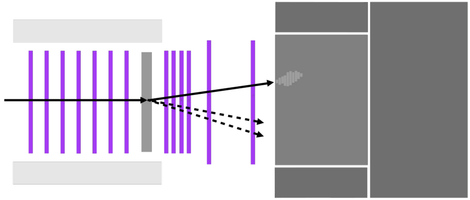

Tagger and Recoil Trackers

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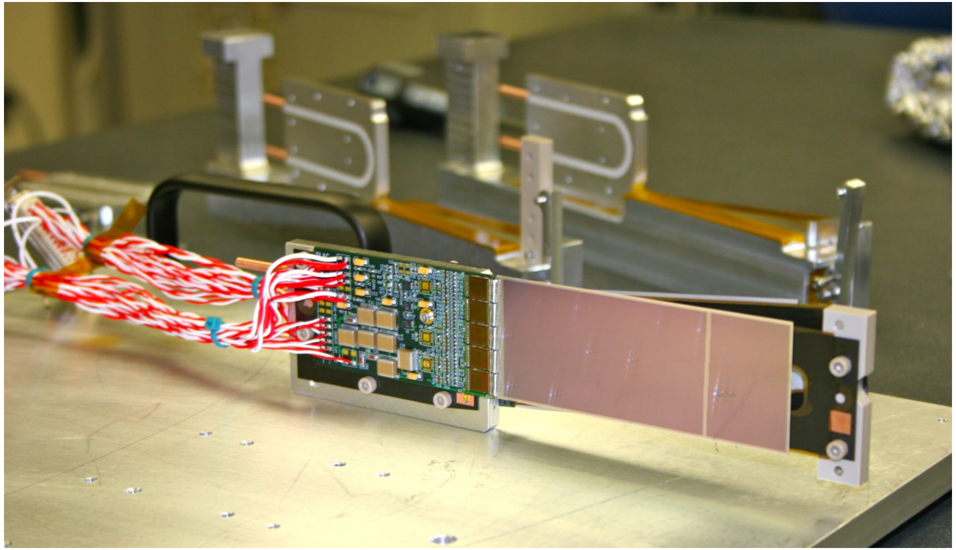
Sensors from the HPS experiment's Silicon Vertex Tracker.

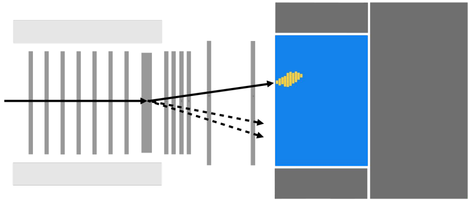


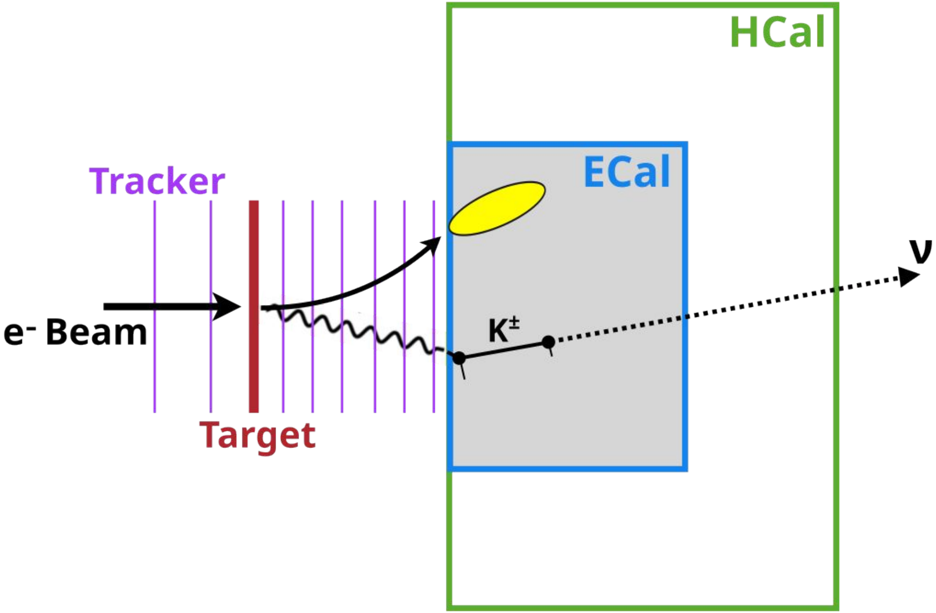
Silicon module from the HPS experiment (from https://pos.sissa.it/167/032/pdf)

Photo-nuclear Backgrounds

Missing energy in the ECal is a trigger condition.

But, photo-nuclear final-states may appear with missing energy.





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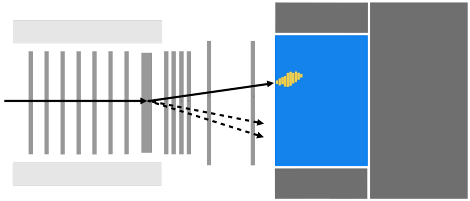

Missing energy in the ECal is a trigger condition.

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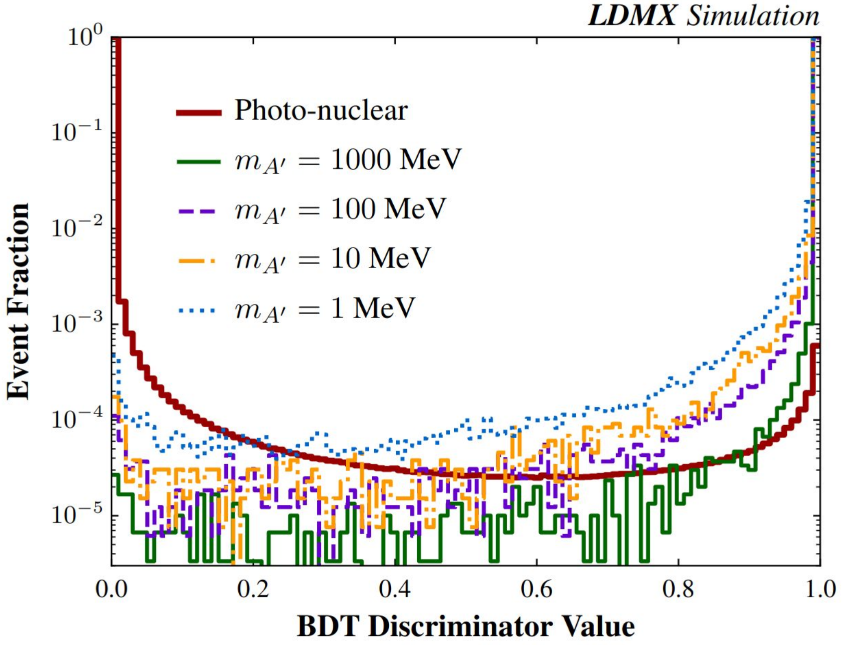
Solution: train BDT/neural-net on features in the granular ECal, to see activity in the region the bremsstrahlung photon should hit.



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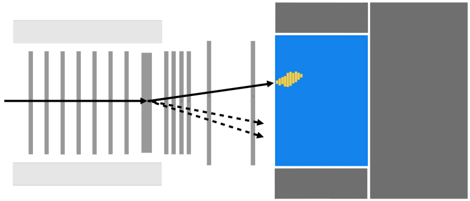

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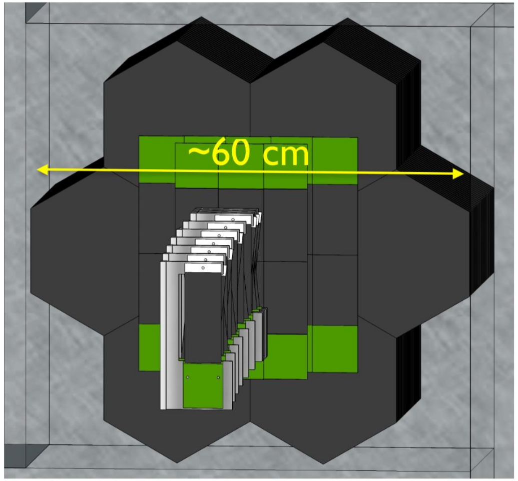
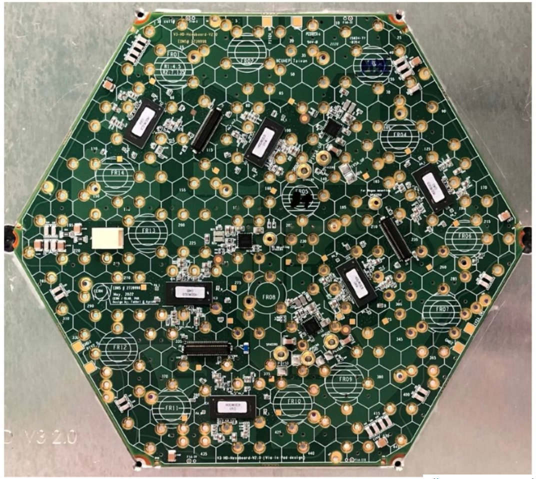
Based on CMS' Si-W High-Granularity Calorimeter.





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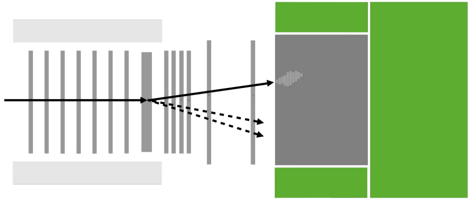
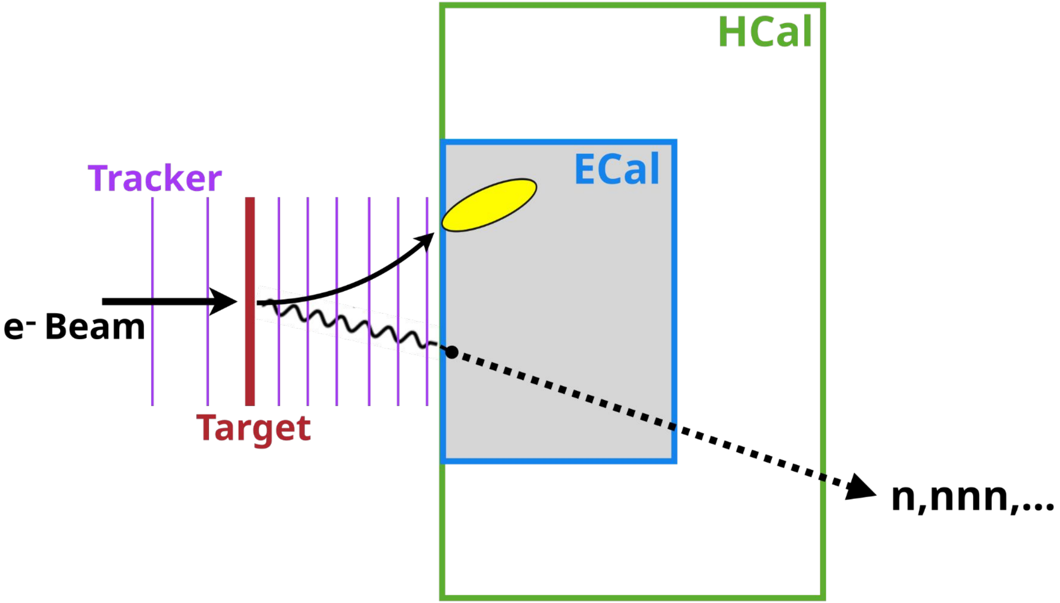
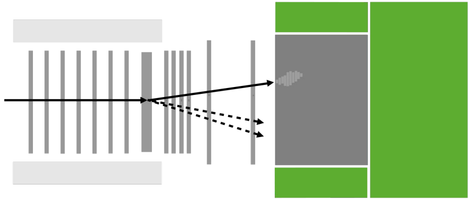


Neutral Hadrons

Neutrons produced in photo-nuclear reactions may pass through the ECal undetected.

Instead, they should be caught by the surrounding **hadronic calorimeter**.





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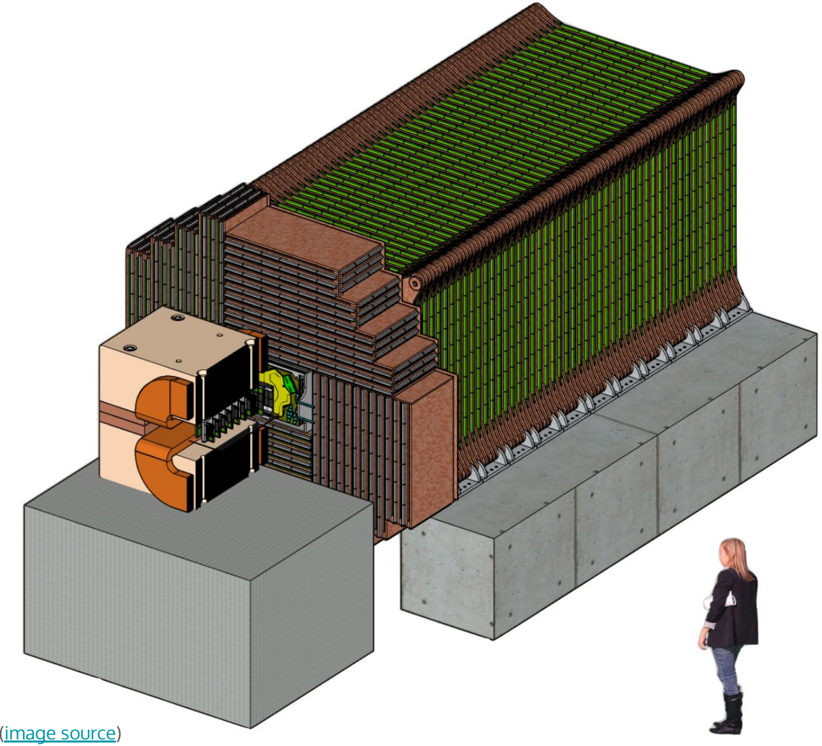
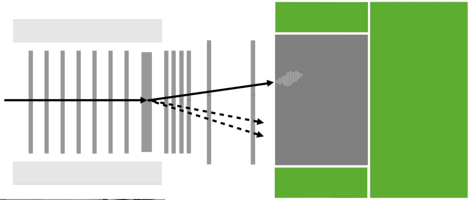
Steel-scintillator calorimeter, borrowing design from the Mu2e experiment's cosmic ray veto, and using CMS' HGCROC for read-out.

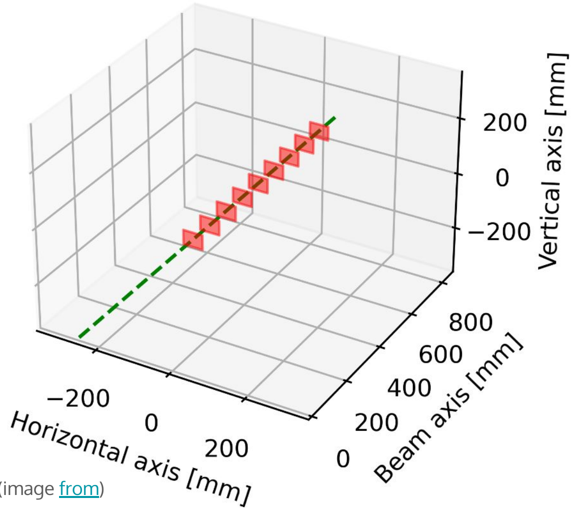


(image source)

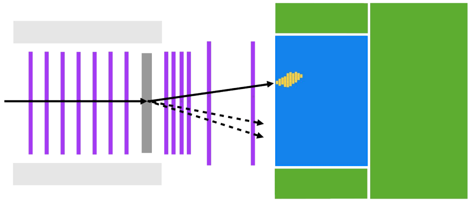


HCal Prototype

Prototype slice was tested at CERN's East Area in 2022, now waiting to be tested at SLAC.



(image from)



Simulation representative of $2{\times}10^{14}$ electrons on target (EoT), at 8 GeV, without pile-up.

Cut flow:

1. *Missing energy* (online/offline) and *missing momentum* (offline)
2. ECal energy deposits must only resemble a single electron shower
3. No activity in the HCal
4. Tracking in ECal to remove the rarest photo-nuclear backgrounds

	Photo-nuclear		**Muon conversion**	
	Target-area	**ECal**	**Target-area**	**ECal**
EoT Equivalent	2.00×10^{14}	2.00×10^{14}	2.00×10^{14}	2.00×10^{14}
Trigger (front ECal energy < 3160 MeV)	7.57×10^{7}	4.43×10^{8}	2.37×10^{7}	8.12×10^{7}
Total ECal energy < 3160 MeV	2.73×10^{7}	7.27×10^{7}	1.76×10^{7}	6.06×10^{7}
Single track with p < 2400 MeV/c	3.03×10^{6}	6.64×10^{7}	5.32×10^{4}	5.69×10^{7}
ECal BDT (85% eff. $m_{A'} = 1$ MeV)	1.50×10^{5}	1.04×10^{5}	< 1	< 1
HCal max PE < 8	< 1	2.02	< 1	< 1
ECal MIP tracks = 0	< 1	< 1	< 1	< 1

(10.1007/JHEP12(2023)092, arXiv:2308.15173v2)

No background remaining!

Zero-background veto has been established for a (pile-up free) sample of 2×10^{14} electrons on target.

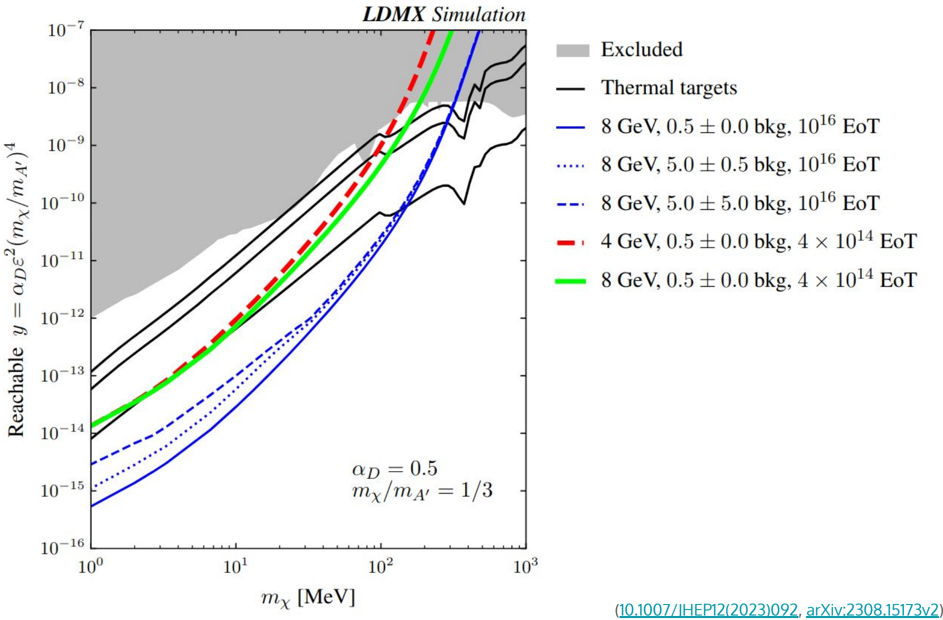
LDMX has promising reach for this common benchmark light dark matter model!

What's next for LDMX?

The construction of the beamline to LDMX is planned to complete in 2025, and already this year we aim to perform beam characterisation with some LDMX sub-systems.

Test beams of the HCal and trigger-scintillator detectors were performed in 2022, and more are planned at SLAC next year with additional sub-systems tested, placed at LDMX's final position.

Currently we are working on a design report, and ultimately plan to start construction of LDMX in late 2026/2027.



(10.1007/JHEP12(2023)092, arXiv:2308.15173v2)

Summer Reading

LDMX initial design study: arXiv:1808.05219

4 GeV Veto Study: 10.1007/JHEP04(2020)003, arXiv:1912.05535

8 GeV Veto Study: 10.1007/JHEP12(2023)092, arXiv:2308.15173v2

Lepton-Nucleus Cross Section Measurements for DUNE with the LDMX Detector:
10.1103/PhysRevD.101.053004, arXiv:1912.06140

Testing GeV-Scale Dark Matter with Fixed-Target Missing Momentum Experiments:
10.1103/PhysRevD.91.094026, arXiv:1411.1404

Accelerating the Discovery of Light Dark Matter: 10.1103/PhysRevLett.115.251301, arXiv:1505.00011

Dark Matter, Millicharges, Axion and Scalar Particles, Gauge Bosons, and Other New Physics with LDMX:
10.1103/PhysRevD.99.075001, arXiv:1807.01730

Thanks!

Crafoord foundation

U.S. DEPARTMENT OF ENERGY

Office of Science

Vetenskapsrådet

Knut and Alice Wallenberg Foundation

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LDMX

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UNIVERSITY OF MINNESOTA

Carnegie Mellon University

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Fermilab

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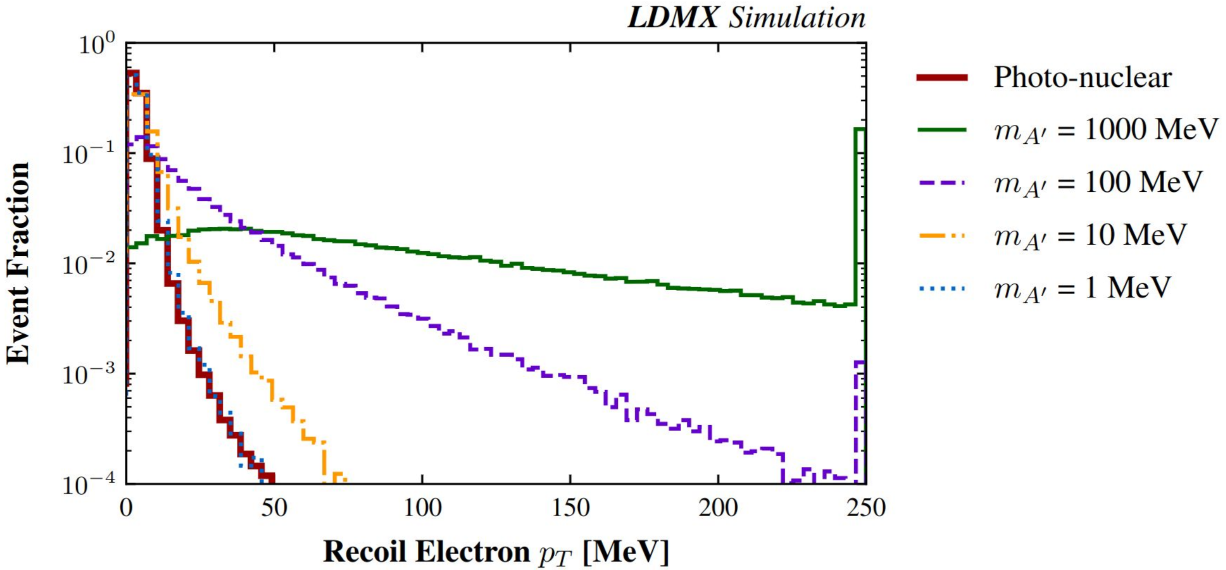
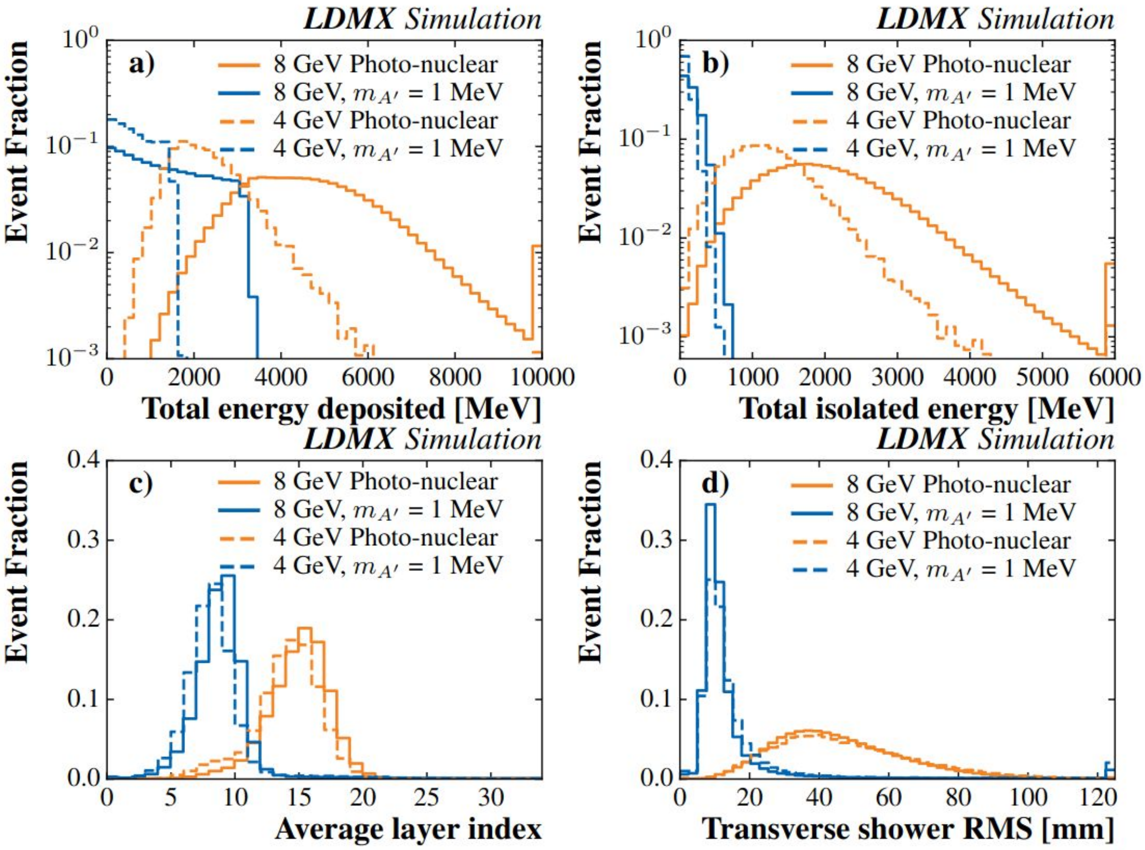
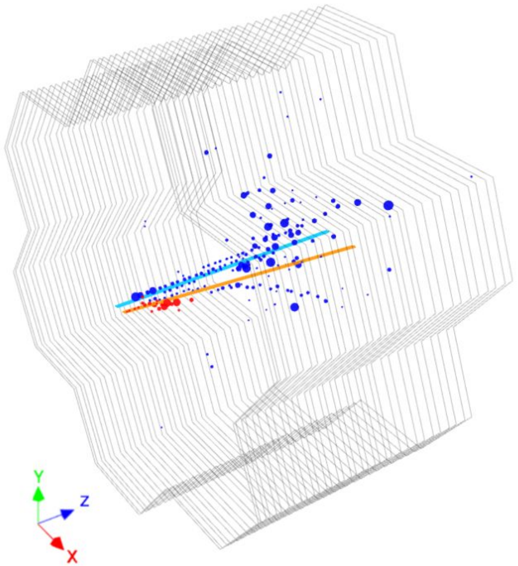
UCSB

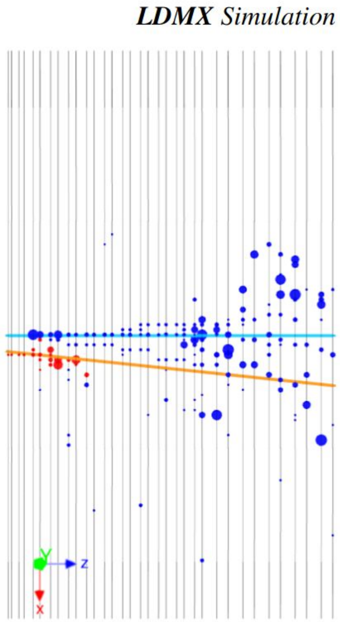
Bonus Slides

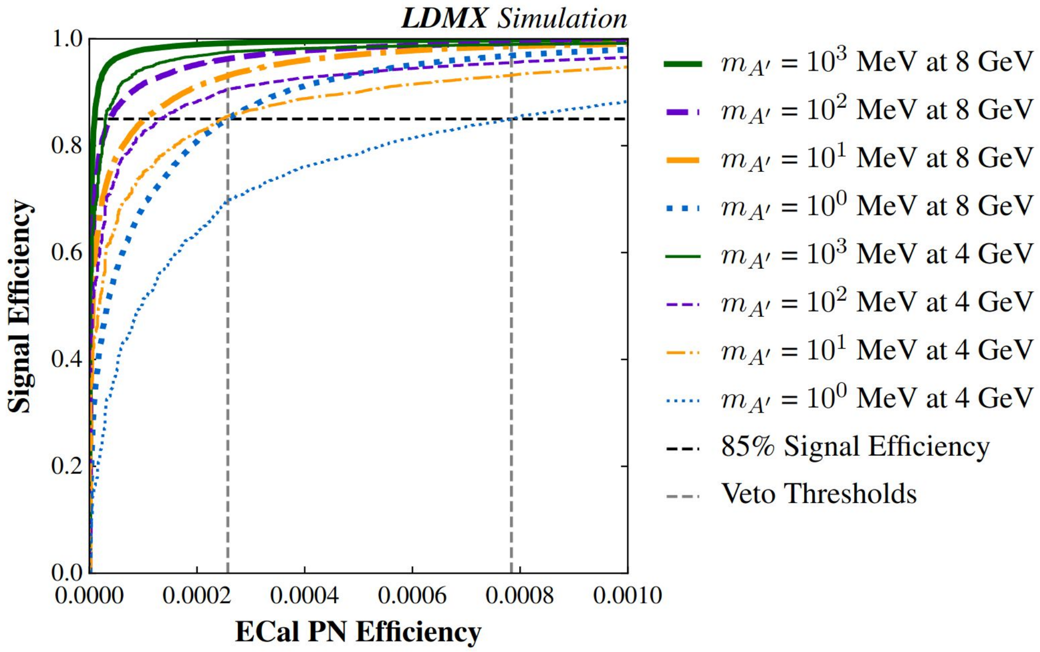


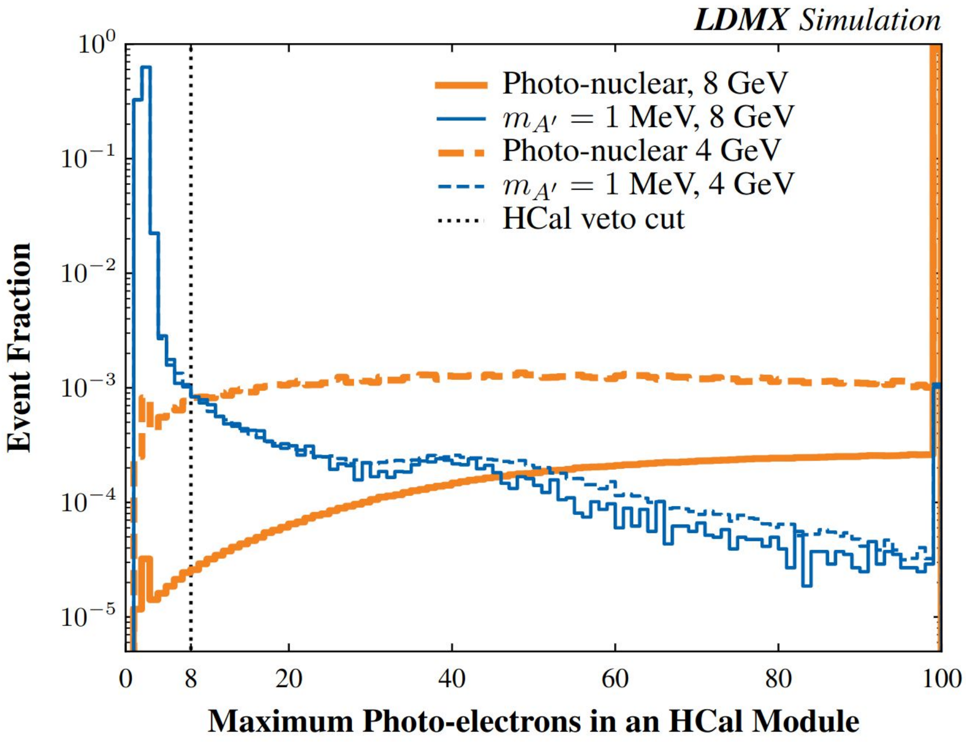
LDMX Simulation
Event Fraction
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
0
50
100
150
200
250
Recoil Electron p_T [MeV]
Photo-nuclear
$m_{A'}$ = 1000 MeV
$m_{A'}$ = 100 MeV
$m_{A'}$ = 10 MeV
$m_{A'}$ = 1 MeV

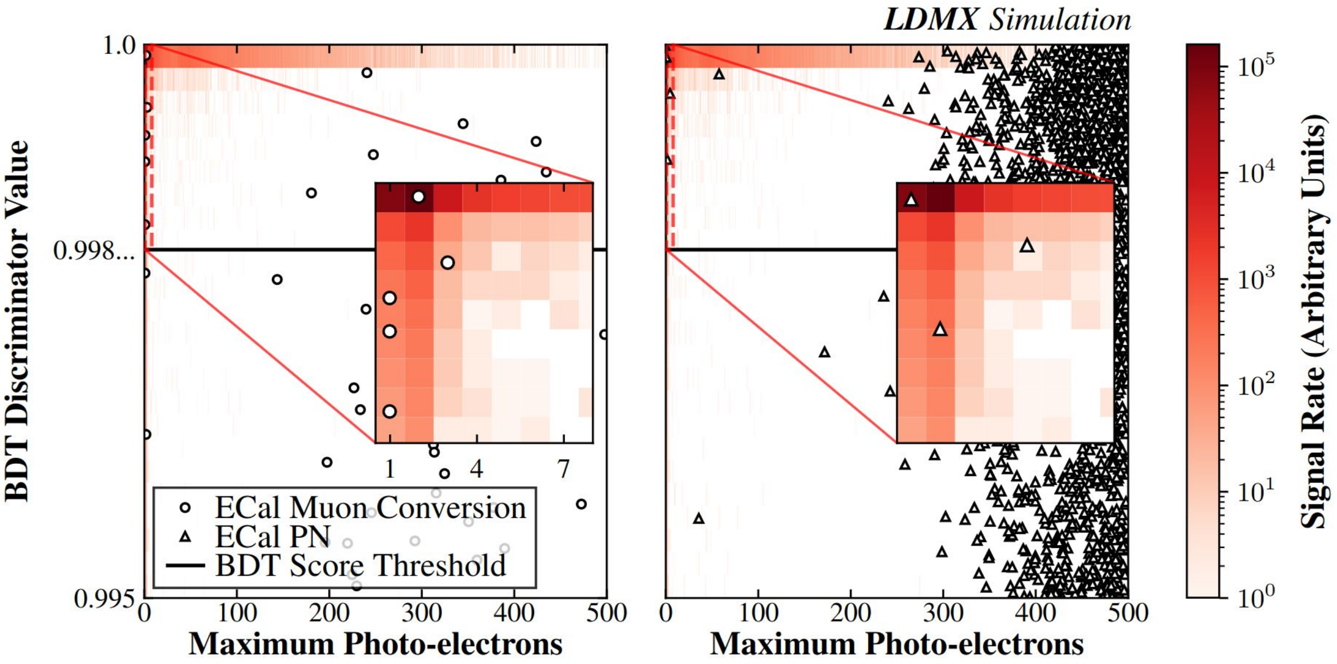

LDMX Simulation
a)
8 GeV Photo-nuclear
8 GeV, $m_{A'}$ = 1 MeV
4 GeV Photo-nuclear
4 GeV, $m_{A'}$ = 1 MeV
Event Fraction
Total energy deposited [MeV]
LDMX Simulation
b)
8 GeV Photo-nuclear
8 GeV, $m_{A'}$ = 1 MeV
4 GeV Photo-nuclear
4 GeV, $m_{A'}$ = 1 MeV
Event Fraction
Total isolated energy [MeV]
LDMX Simulation
c)
8 GeV Photo-nuclear
8 GeV, $m_{A'}$ = 1 MeV
4 GeV Photo-nuclear
4 GeV, $m_{A'}$ = 1 MeV
Event Fraction
Average layer index
LDMX Simulation
d)
8 GeV Photo-nuclear
8 GeV, $m_{A'}$ = 1 MeV
4 GeV Photo-nuclear
4 GeV, $m_{A'}$ = 1 MeV
Event Fraction
Transverse shower RMS [mm]

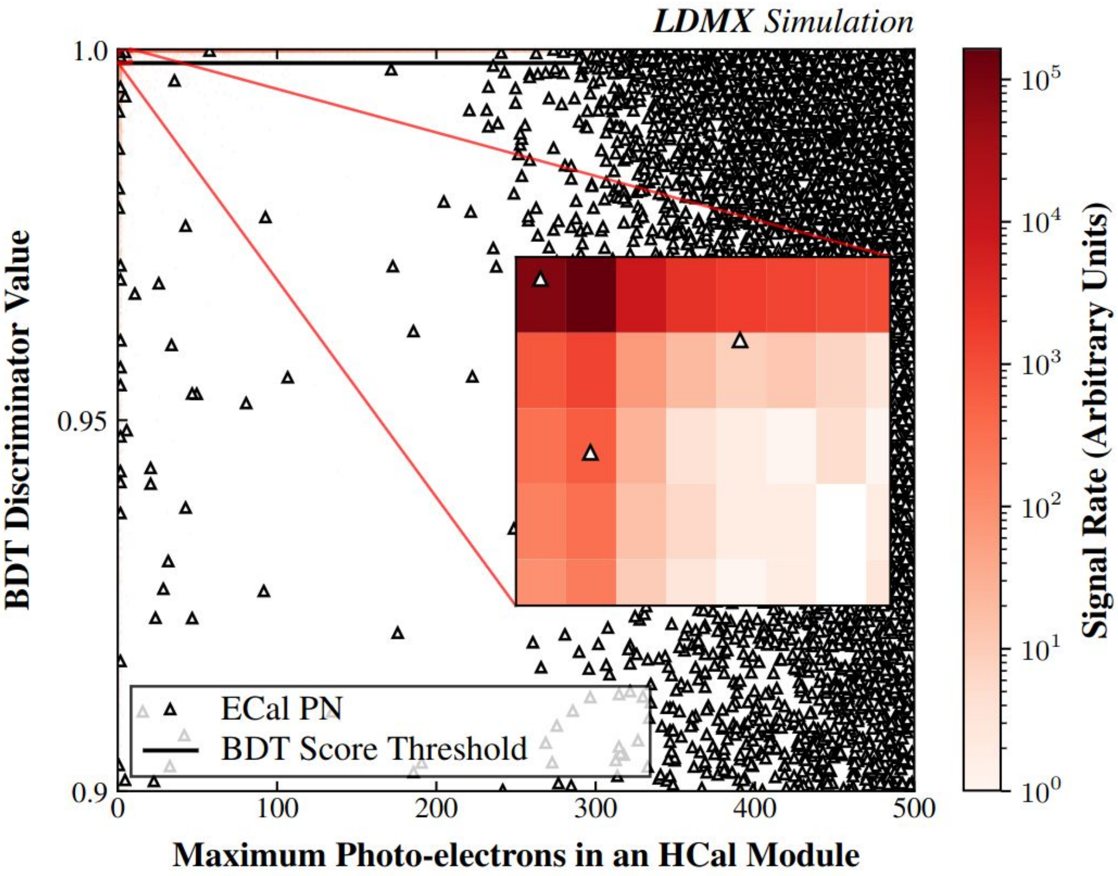

Y
Z
X

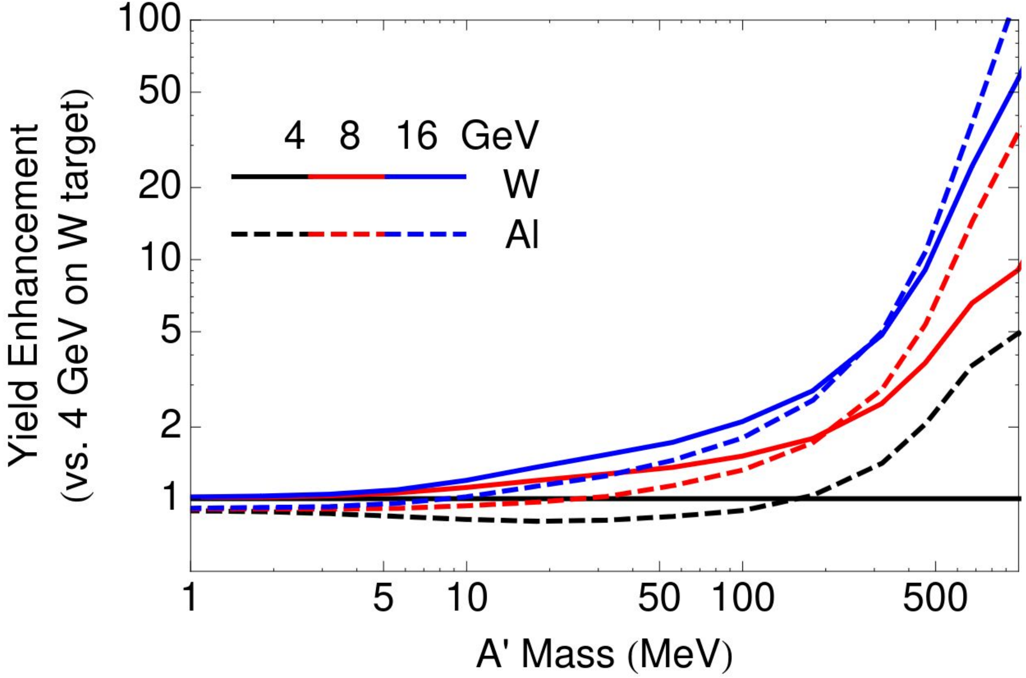

LDMX Simulation
Y
Z
X

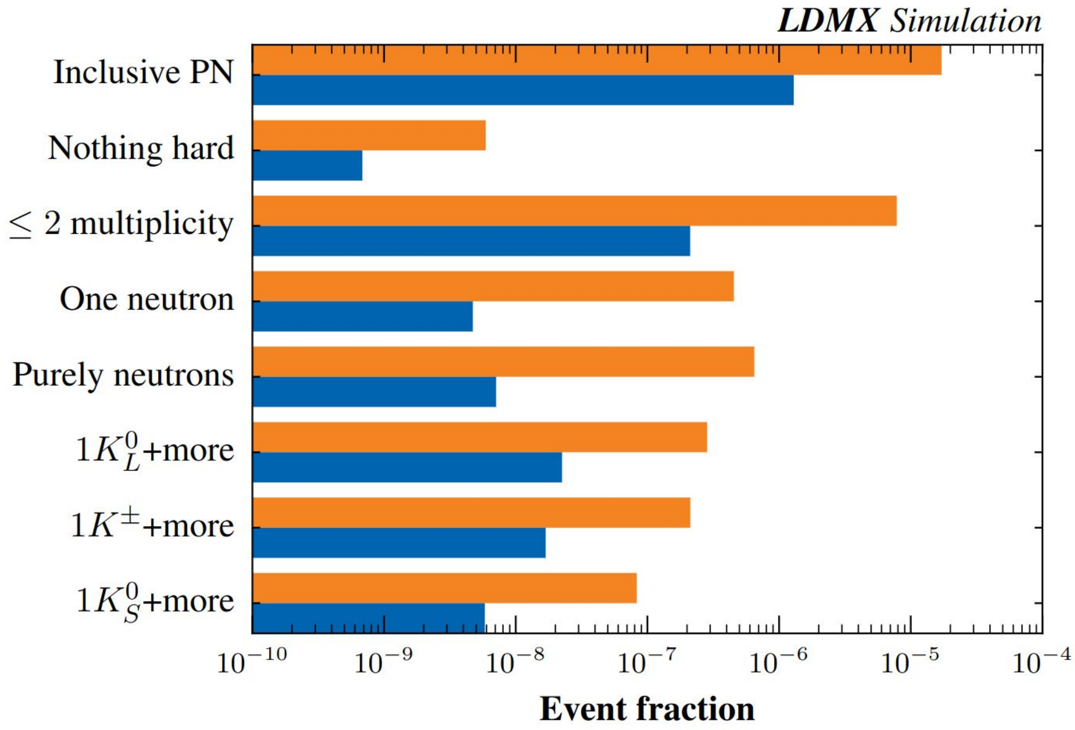

LDMX Simulation
Signal Efficiency
ECal PN Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.0000
0.0002
0.0004
0.0006
0.0008
0.0010
$m_{A'}$ = 10^3 MeV at 8 GeV
$m_{A'}$ = 10^2 MeV at 8 GeV
$m_{A'}$ = 10^1 MeV at 8 GeV
$m_{A'}$ = 10^0 MeV at 8 GeV
$m_{A'}$ = 10^3 MeV at 4 GeV
$m_{A'}$ = 10^2 MeV at 4 GeV
$m_{A'}$ = 10^1 MeV at 4 GeV
$m_{A'}$ = 10^0 MeV at 4 GeV
85% Signal Efficiency
Veto Thresholds

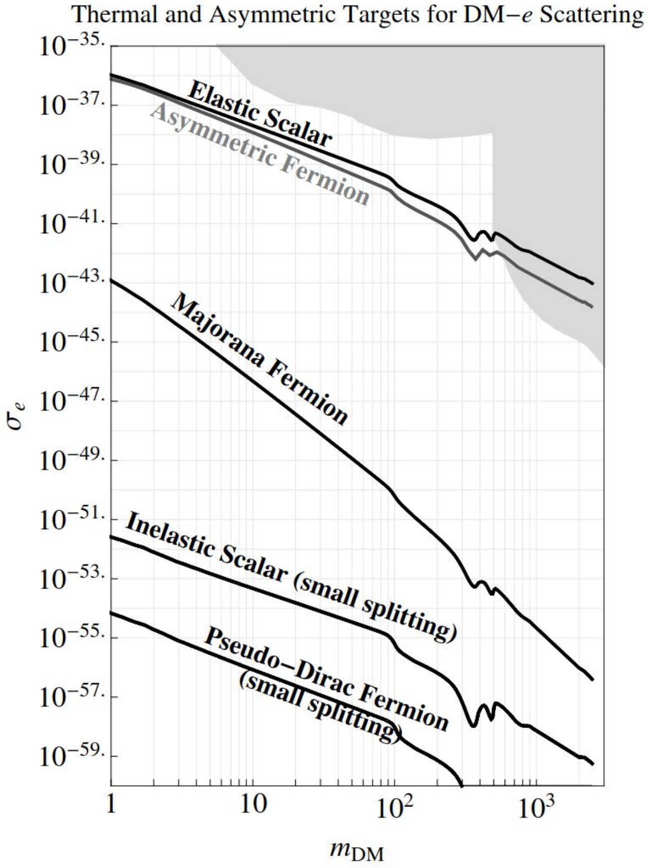

LDMX Simulation
Photo-nuclear, 8 GeV
$m_{A'} = 1$ MeV, 8 GeV
Photo-nuclear 4 GeV
$m_{A'} = 1$ MeV, 4 GeV
HCal veto cut
Event Fraction
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0
8
20
40
60
80
100
Maximum Photo-electrons in an HCal Module


LDMX Simulation
1.0
0.998...
0.995
BDT Discriminator Value
0
100
200
300
400
500
Maximum Photo-electrons
1
4
7
ECal Muon Conversion
ECal PN
BDT Score Threshold
Signal Rate (Arbitrary Units)
10^5
10^4
10^3
10^2
10^1
10^0


LDMX Simulation
BDT Discriminator Value
1.0
0.95
0.9
0
100
200
300
400
500
Maximum Photo-electrons in an HCal Module
ECal PN
BDT Score Threshold
Signal Rate (Arbitrary Units)
10^5
10^4
10^3
10^2
10^1
10^0


Yield Enhancement
(vs. 4 GeV on W target)
100
50
20
10
5
2
1
4 8 16 GeV
W
Al
1
5
10
50
100
500
A' Mass (MeV)


LDMX Simulation
Inclusive PN
Nothing hard
≤ 2 multiplicity
One neutron
Purely neutrons
$1K_L^0$+more
$1K^{\pm}$+more
$1K_S^0$+more
4 GeV
8 GeV
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
10^{-4}
Event fraction


Thermal and Asymmetric Targets for DM−e Scattering
Elastic Scalar
Asymmetric Fermion
Majorana Fermion
Inelastic Scalar (small splitting)
Pseudo−Dirac Fermion
(small splitting)
σ_e
m_{DM}
$10^{-35.}$
$10^{-37.}$
$10^{-39.}$
$10^{-41.}$
$10^{-43.}$
$10^{-45.}$
$10^{-47.}$
$10^{-49.}$
$10^{-51.}$
$10^{-53.}$
$10^{-55.}$
$10^{-57.}$
$10^{-59.}$
1
10
10^2
10^3

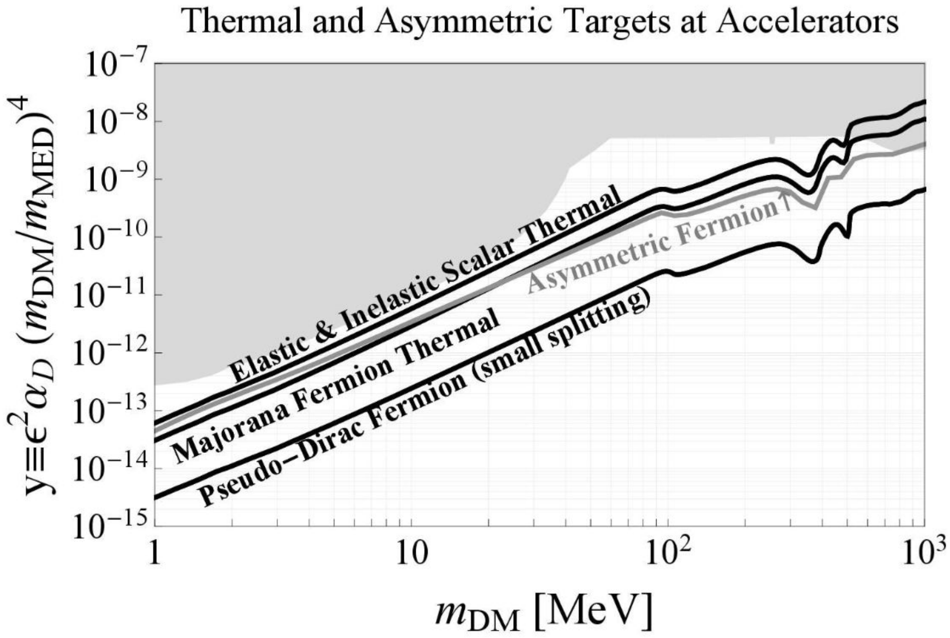

Thermal and Asymmetric Targets at Accelerators
Elastic & Inelastic Scalar Thermal
Asymmetric Fermion↑
Majorana Fermion Thermal
Pseudo−Dirac Fermion (small splitting)
$y \equiv \epsilon^2 \alpha_D (m_{DM}/m_{MED})^4$
m_{DM} [MeV]
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
1
10
10^2
10^3

	Photo-nuclear		Muon conversion	
	Target-area	**ECal**	**Target-area**	**ECal**
EoT Equivalent	8.99×10^{14}	1.98×10^{14}	9.45×10^{15}	2.40×10^{15}
Trigger (front ECal energy < 3160 MeV)	3.40×10^{8}	4.39×10^{8}	1.12×10^{9}	9.73×10^{8}
Total ECal energy < 3160 MeV	1.23×10^{8}	7.19×10^{7}	8.29×10^{8}	7.27×10^{8}
Single track with p < 2400 MeV/c	1.36×10^{7}	6.57×10^{7}	2.51×10^{6}	6.82×10^{8}
ECal BDT (85% eff. $m_{A'} = 1$ MeV)	6.76×10^{5}	1.03×10^{5}	2.0	5.0
HCal max PE < 8	0	2.0	0	3.0
ECal MIP tracks = 0	0	0	0	0