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

Stanford University
SLAC NATIONAL ACCELERATOR LABORATORY
UCSB
Fermilab
University of Virginia

The Light Dark Matter eXperiment (LDMX)

University of Minnesota
Caltech
University of Michigan
Lunds universitet
Carnegie Mellon University

Light Dark Matter @ Accelerators 2025

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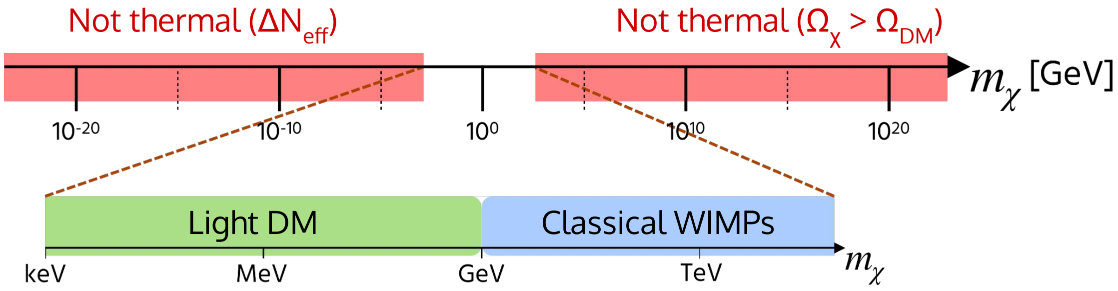
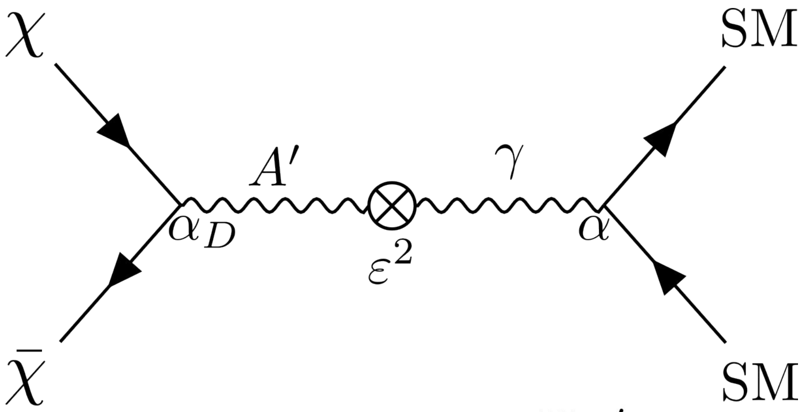
- DM as a **thermal relic** from the early universe is a predictive assumption.
  - **Narrows the large possible mass range of DM**.
  - Not sensitive to early-universe initial conditions.



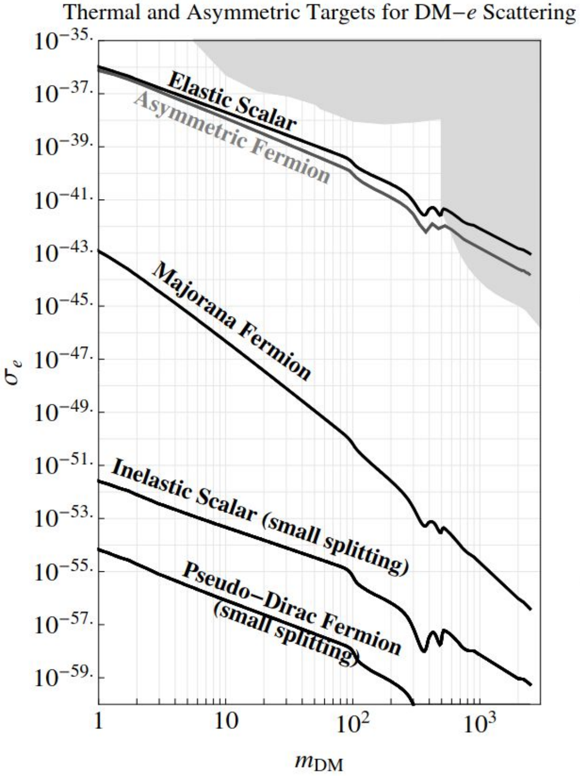
- **Assumption**: A light feebly-interacting mediator, between the SM and some dark sector, allows for **DM masses below the Lee-Weinberg bound**. Relatively unconstrained region so far!

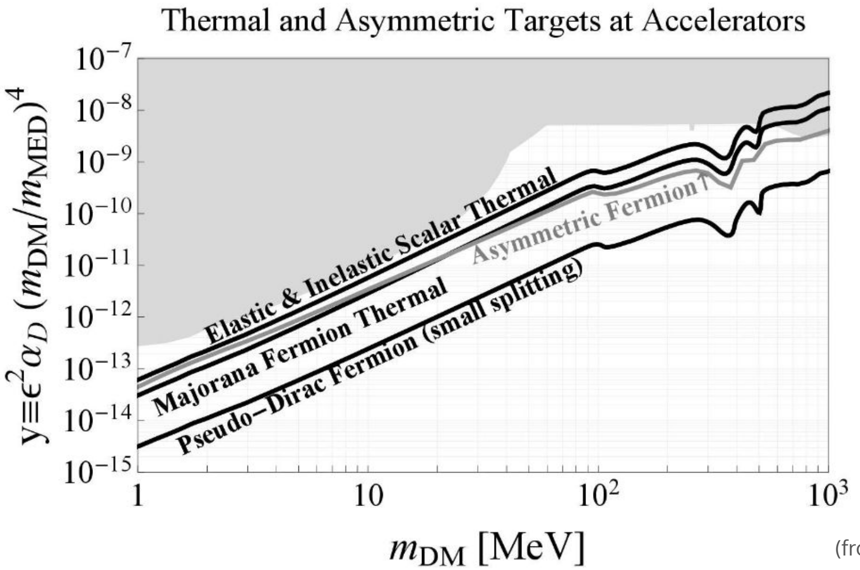
  Benchmark model: Massive **dark photon mediator**, kinetic mixing with the SM (hyper/EM)charge.

  Thermal targets, for a sub-GeV A′ mediator in reach at accelerators!



Kinetic mixing $\varepsilon F^{\mu\nu} F'_{\mu\nu}$

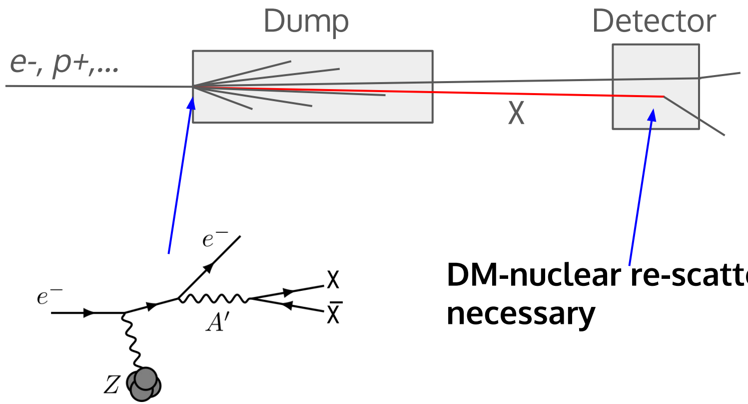




(from arXiv:1808.05219)

Compared to direct detection electron-recoil cross section, relativistic production at accelerators **has excellent sensitivity, regardless of the spin-structure** of DM particle.

Beam dump approach

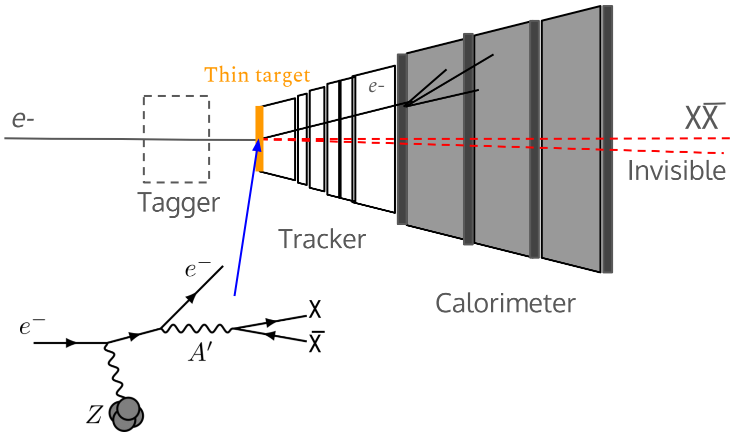


DM-nuclear re-scattering necessary

Requires:

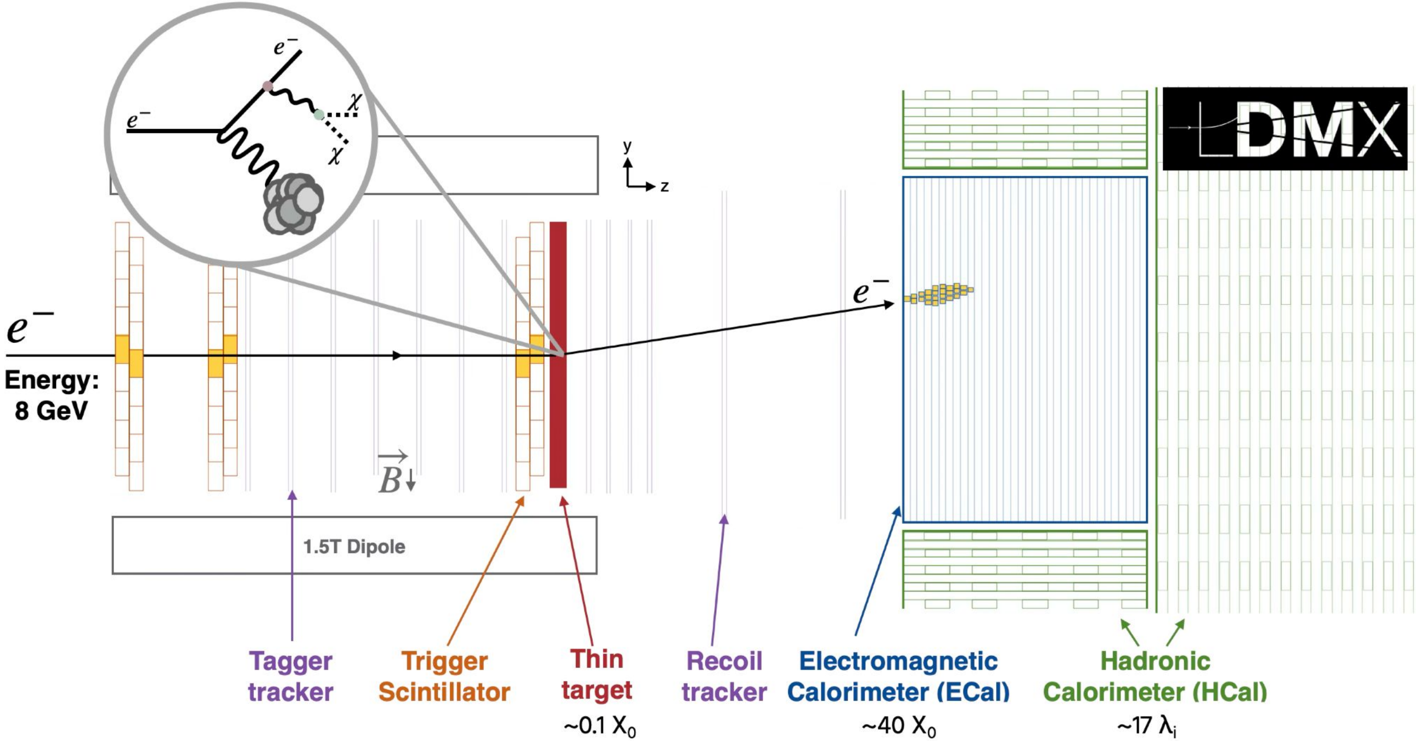
- Energetic and intense beam
- Massive detector

Missing momentum/energy approach



Requires:

- Low pile-up
- High repetition rate
- Fast and sensitive detectors



This missing momentum *and* missing energy signature drives the design of LDMX.

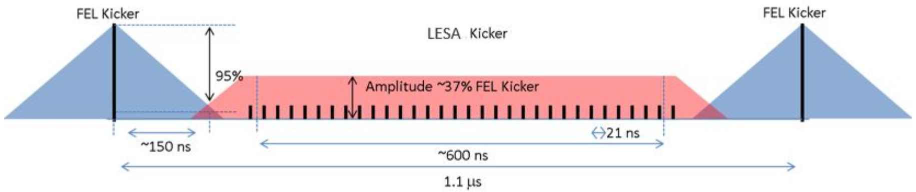
- The LCLS-II free-electron laser at SLAC delivers electrons for photon science with 1.1 µs between kicks. **Unfilled bunches** in ~600 ns window in-between.

- Concept: **populate in-between bunches with low current (60 pA) at 37.2 MHz** with a laser gun oscillator, and kick them out to End Station A.

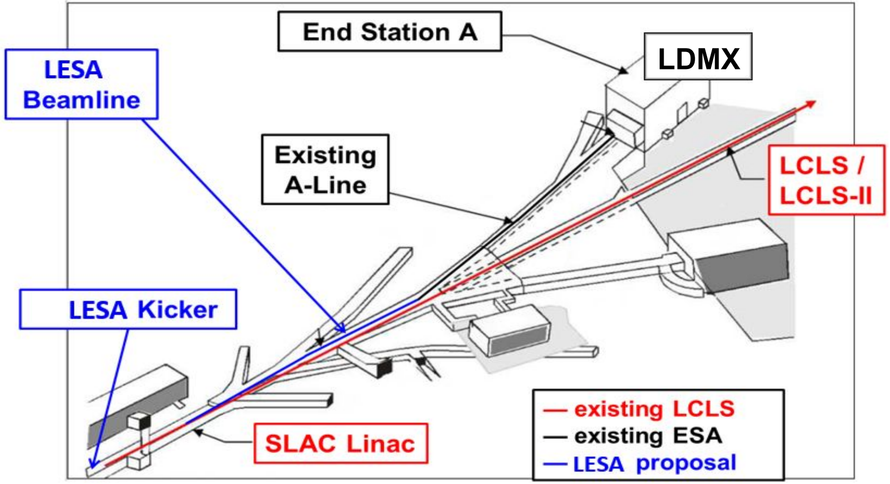
- **Linac to End Station A (LESA) is being constructed for this.**

- LCLS-II high energy upgrade imminent, from 4 to 8 GeV beam energy.

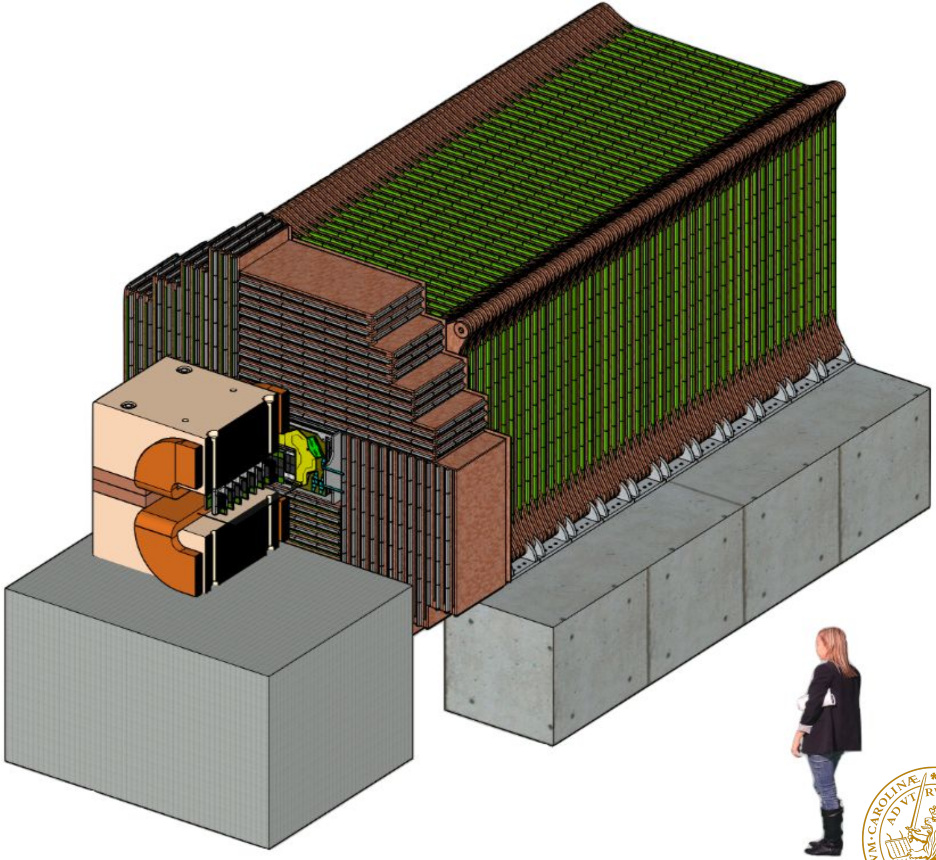
Currently, ongoing test beam and beam characterisation activities at the Sector 30 Transfer Line S30XL (right before LESA).



(from arXiv:2205.13215)



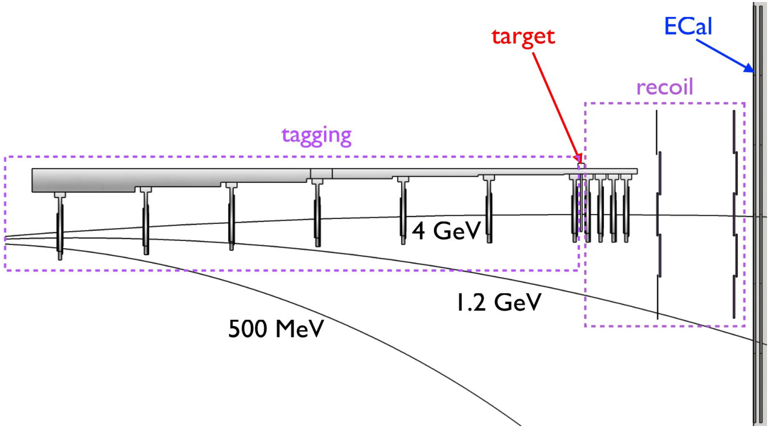
(modified from arXiv:2205.13215)

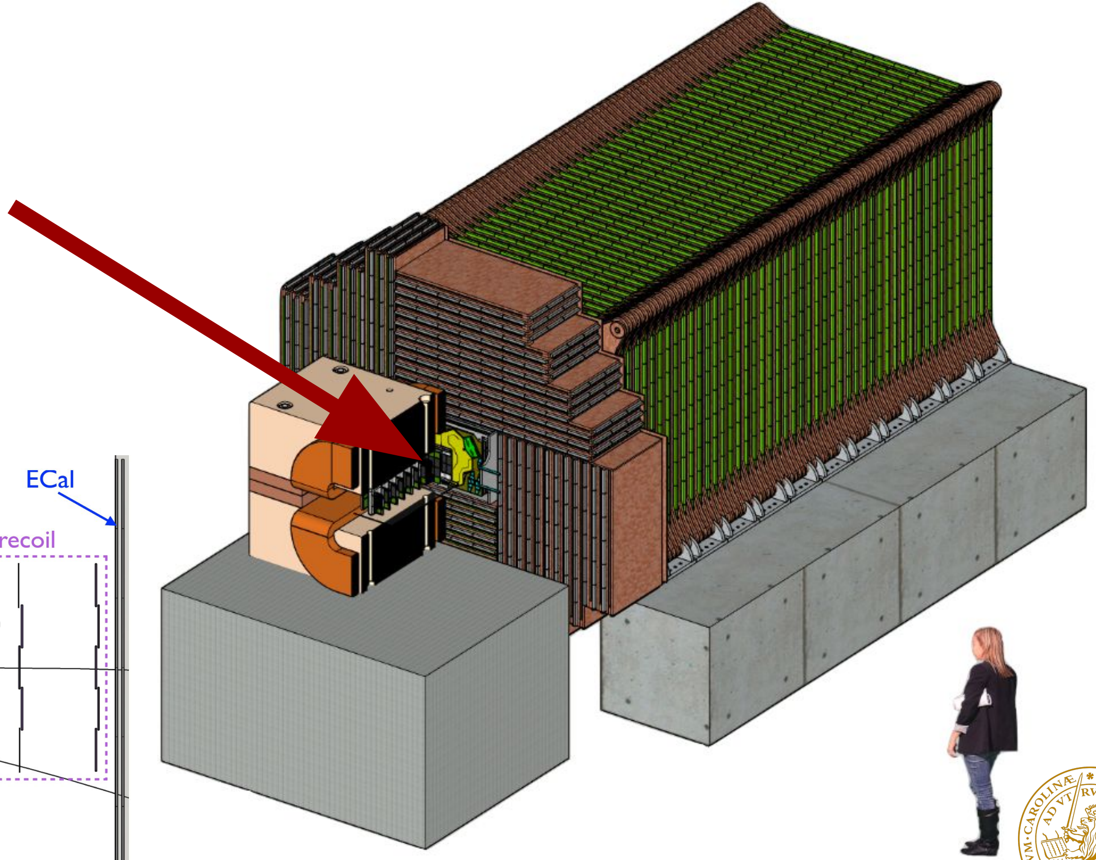


Tagging and recoil trackers around the target.

Electron p_T measurement made in fringe field of dipole magnet, with p_T resolution limited by multiple scattering in the thin target.

Track multiplicity is a background veto handle.



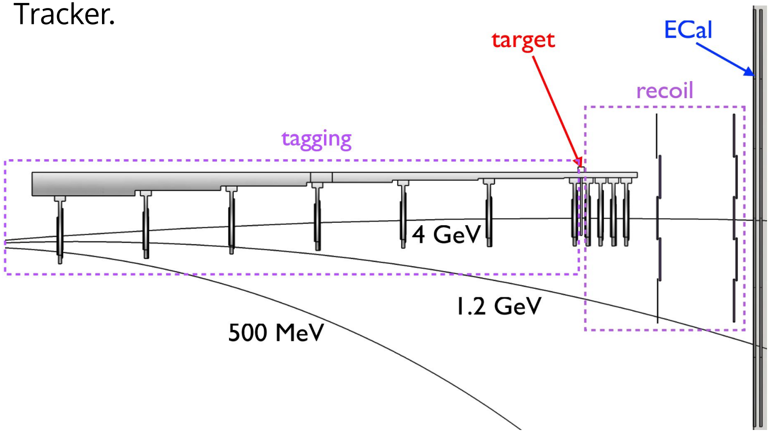


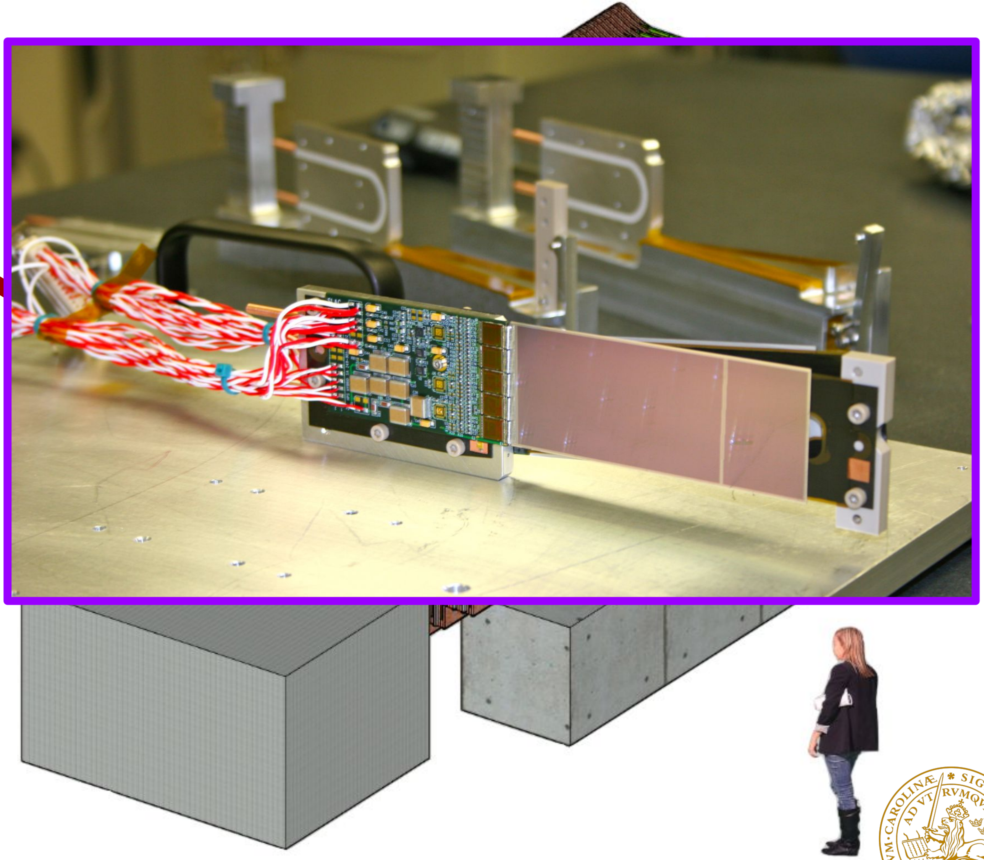
Tagging and recoil trackers around the target.

Electron p_T measurement made in fringe field of dipole magnet, with p_T resolution limited by multiple scattering in the thin target.

Track multiplicity is a background veto handle.

Reusing detector module and readout designs from the HPS experiment's Silicon Vertex Tracker.

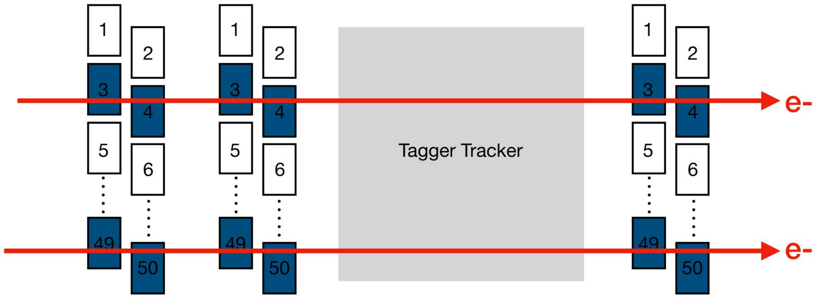


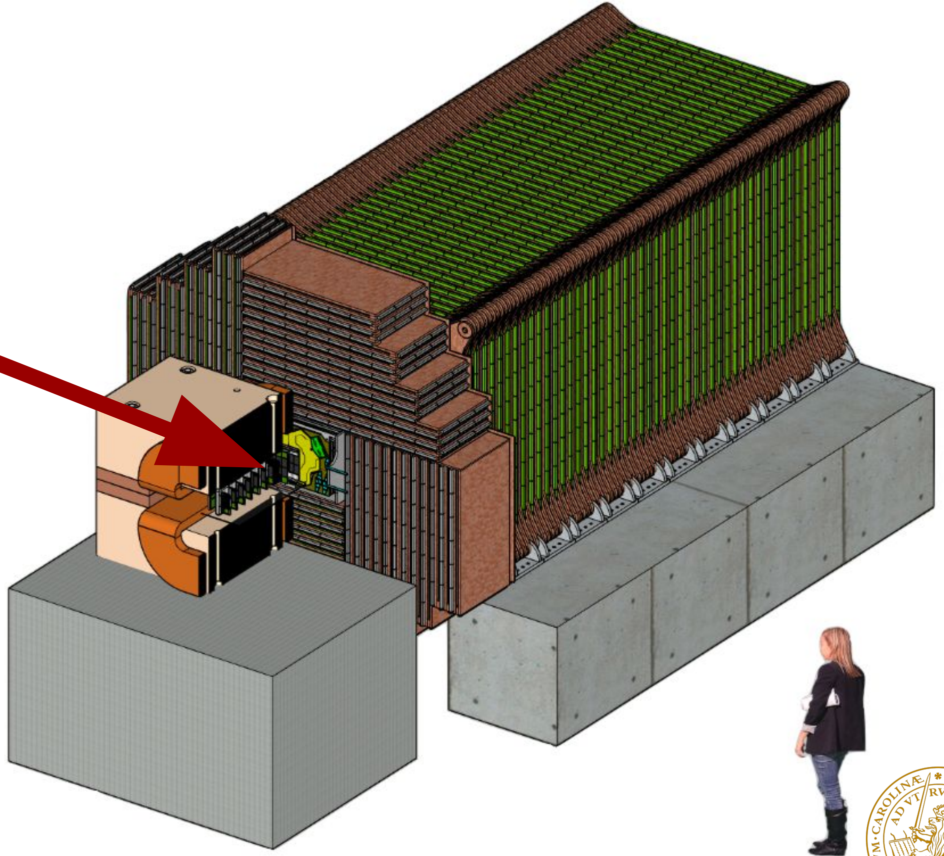


A trigger scintillator hodoscope performs fast electron counting, as input to the ECal's missing energy trigger.

Three arrays of segmented 2x3 mm^2 scintillator bars before and after the tagger tracker.

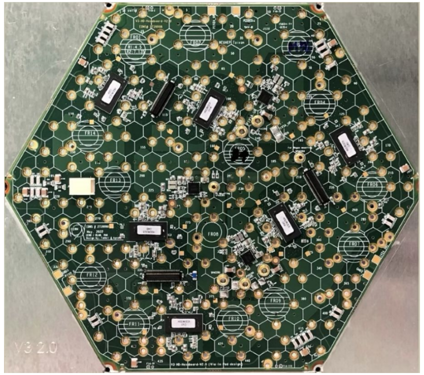
Instrumented with SiPMs and the QIE11 ASIC.

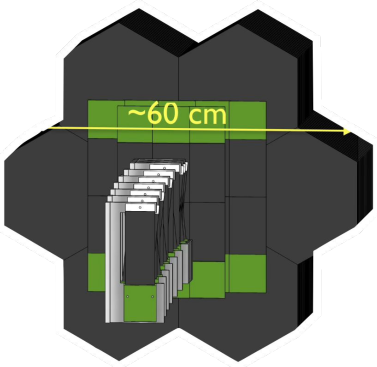


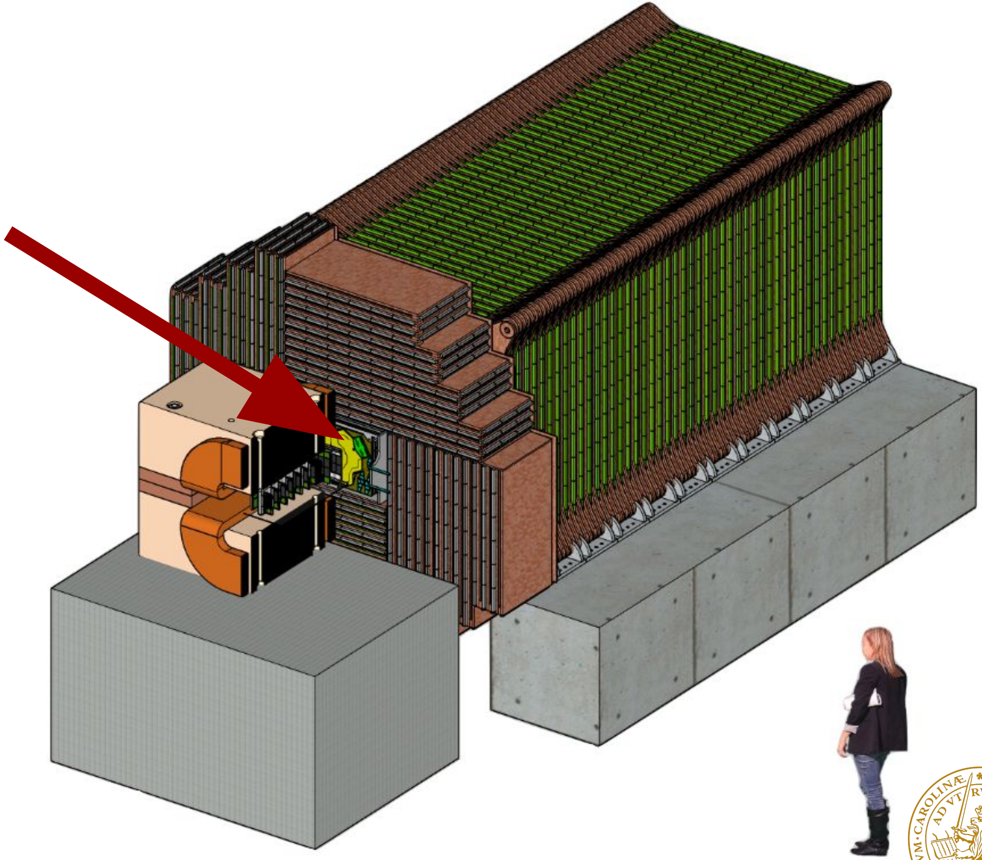


ECal: Si-W sampling calorimeter used to measure missing energy and it's high granularity allows for vetoing rare backgrounds and dealing with pile-up.

Miniature of CMS' Phase II Si-W High-Granularity Calorimeter, fast and radiation tolerant.



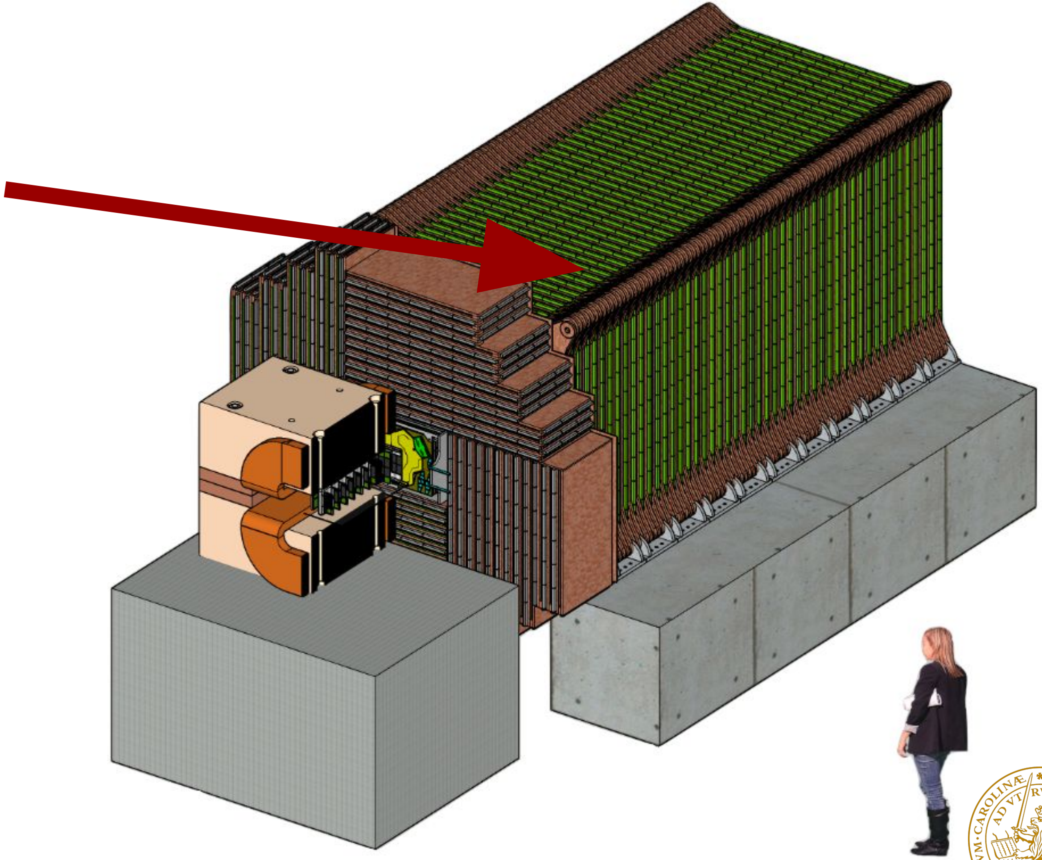




Neutral hadrons produced in photo-nuclear reactions may pass through the ECal undetected.

Solution: Surround ECal with sensitive neutron veto detector.

Hermetic steel-scintillator calorimeter, borrowing design from Mu2e's cosmic ray veto, using CMS' Phase II HGCROC ASIC for read-out.



LDMX

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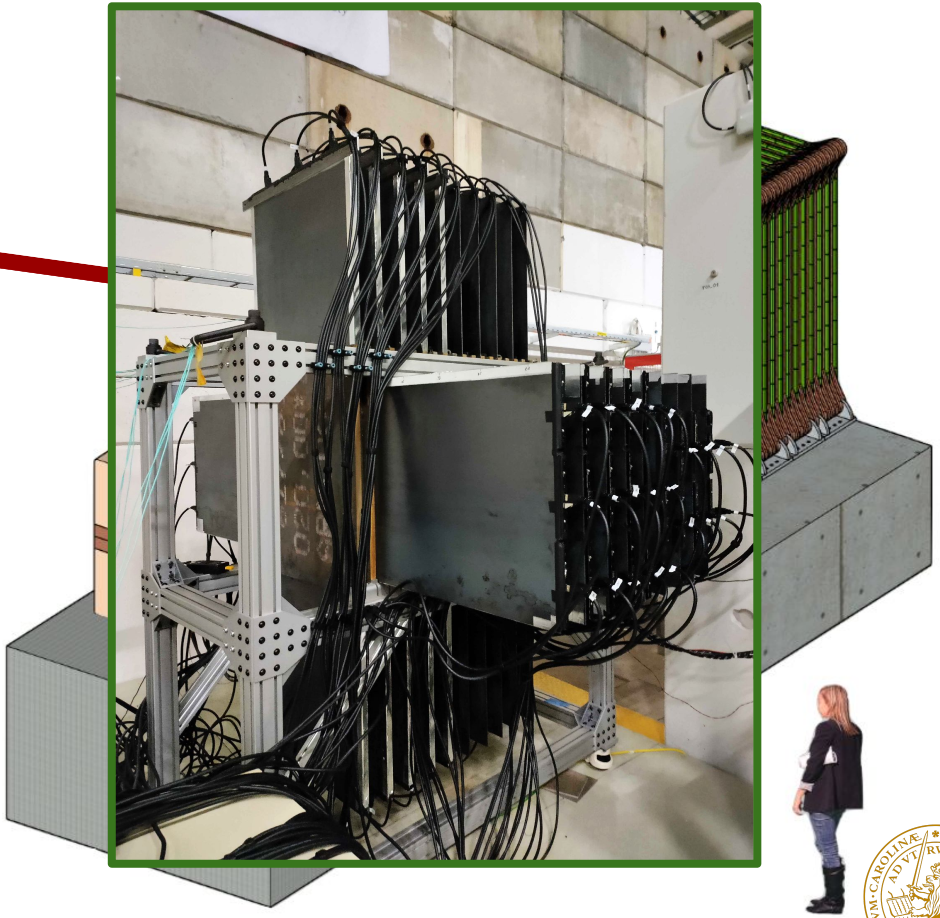
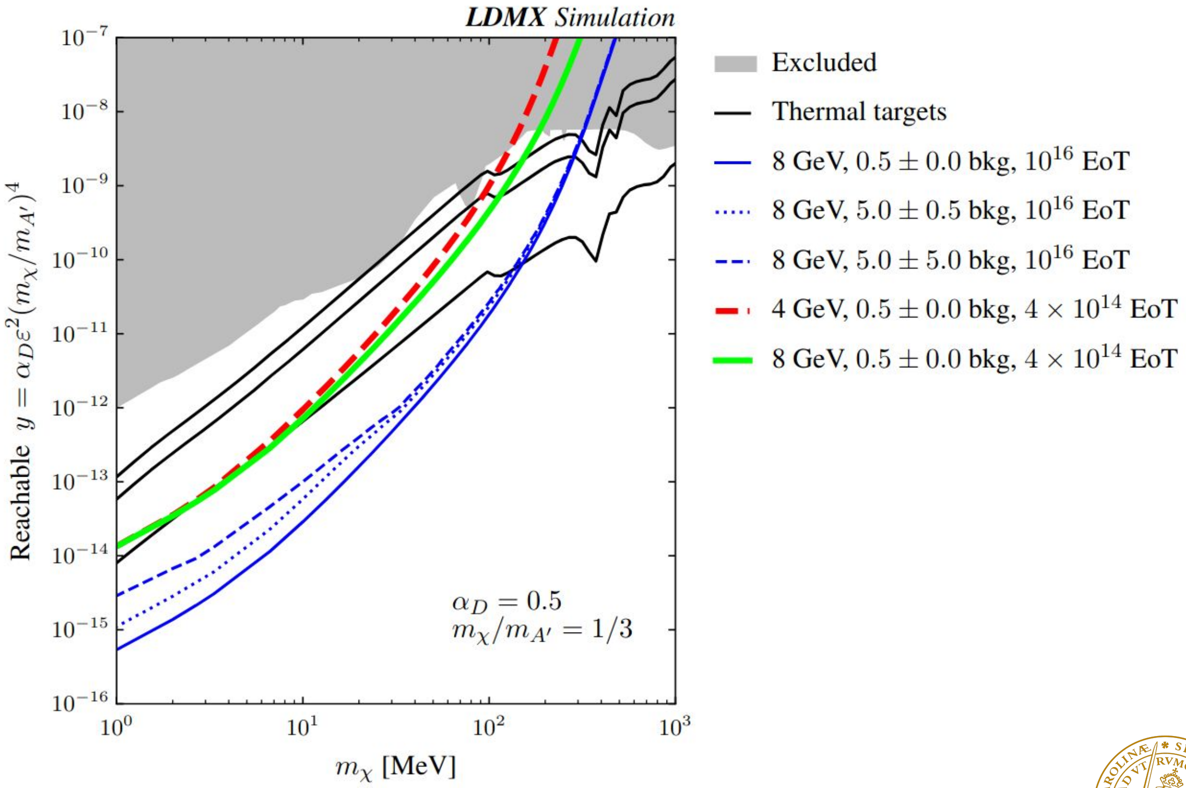


The complete 8 GeV run of LDMX expects 10^{16} electrons on target (EoT), in **blue. Unprecedented reach to the thermal targets with a missing momentum search!**

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



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

LDMX aims to be background-free, but the background has large variety.

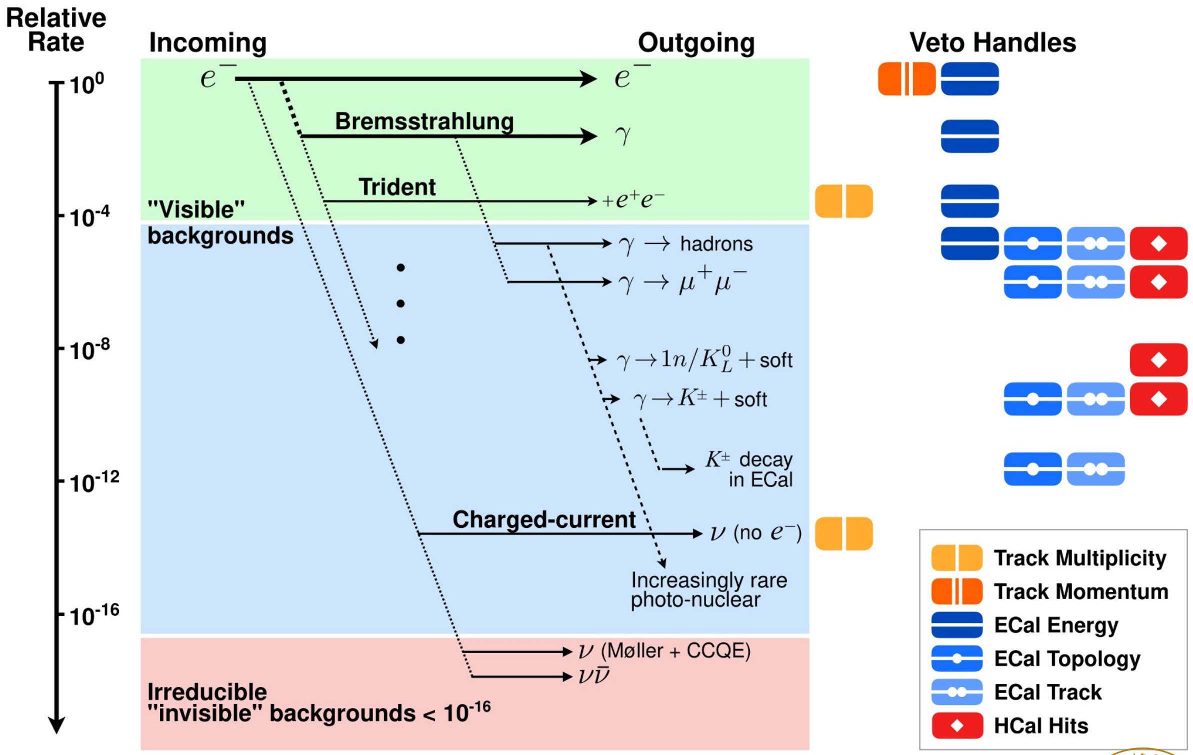
Bremsstrahlung from electrons scattering in the target can undergo:

- Muon-conversion
- Photo-nuclear reactions

inside either the target or ECal material.

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

No fundamentally irreducible backgrounds (e.g. neutrinos), that do not have veto handles in the experiment, at relevant rates.



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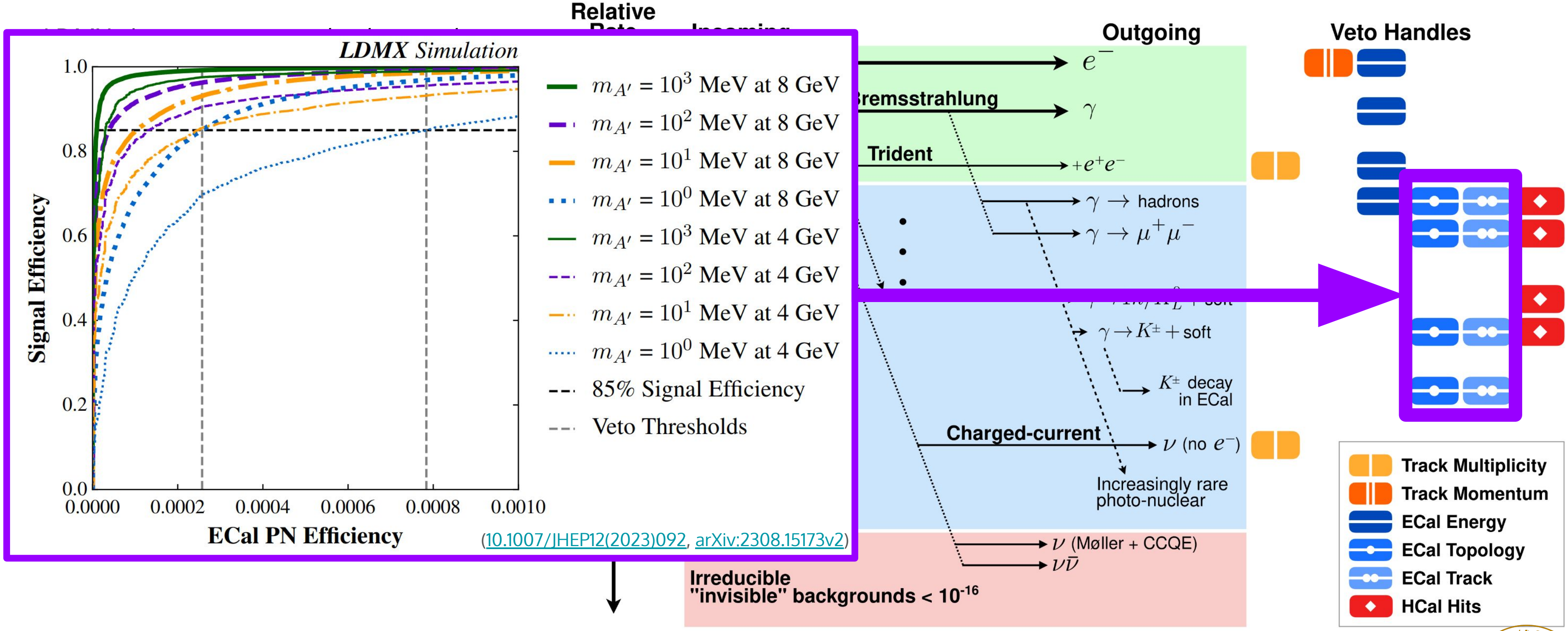

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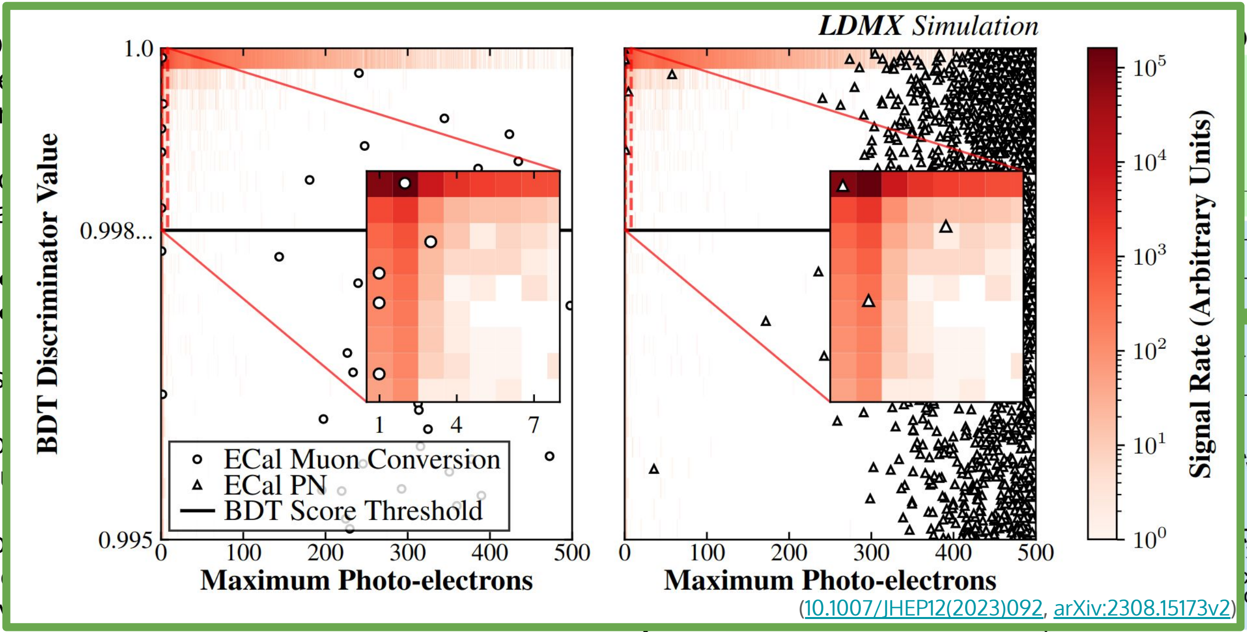

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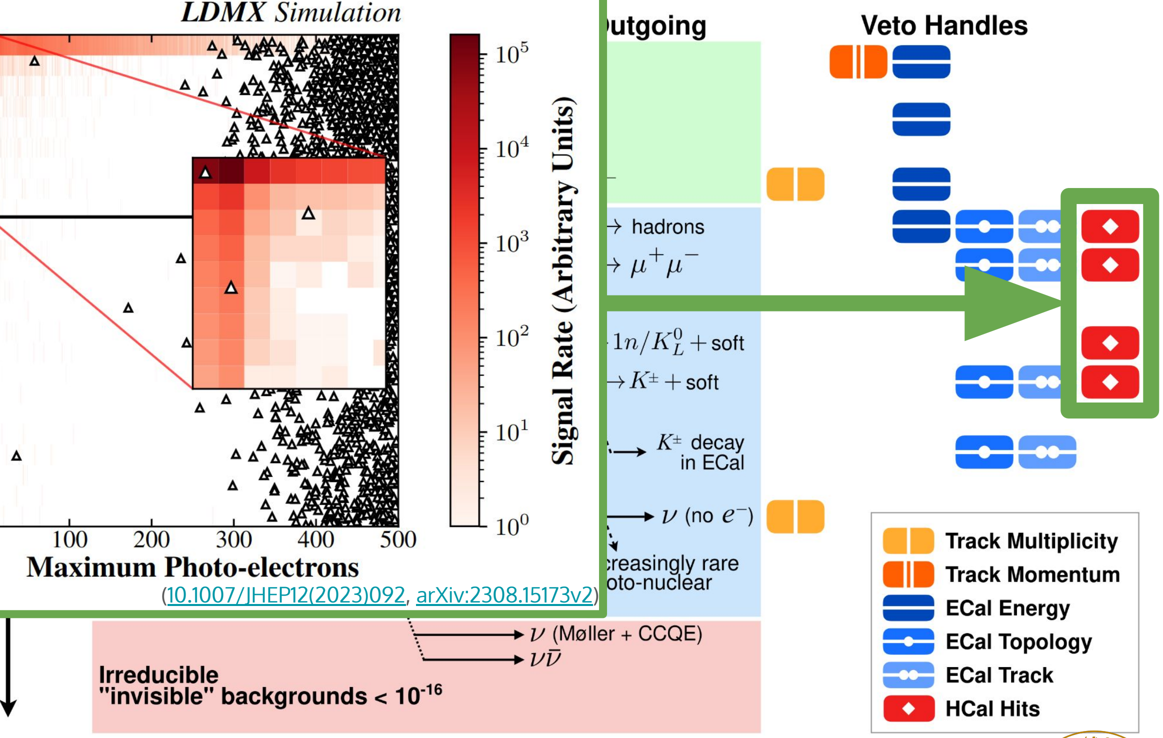


(10.1007/JHEP12(2023)092, arXiv:2308.15173v2)

So far: Geant4 simulation representative of 2×10^{14} electrons on target (EoT)*, at 4/8 GeV, without pile-up.

Missing momentum analysis 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

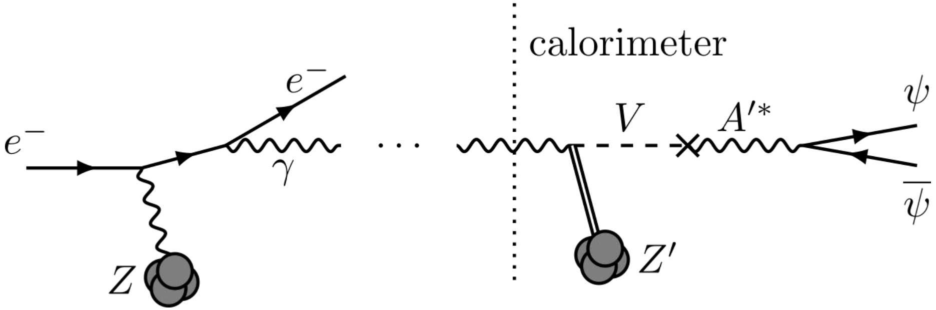
(10.1007/JHEP12(2023)092, arXiv:2308.15173v2)

Promising prospects for a background-free search in the missing momentum channel!

*By simulating specific background classes with careful cross-section biasing and event filtering.

Vector mesons, created through photo-production in the calorimeter, would mix with the A′.

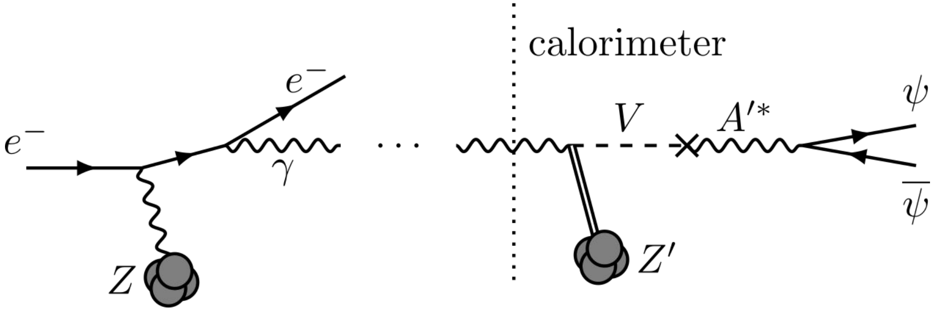
Additional production channel!

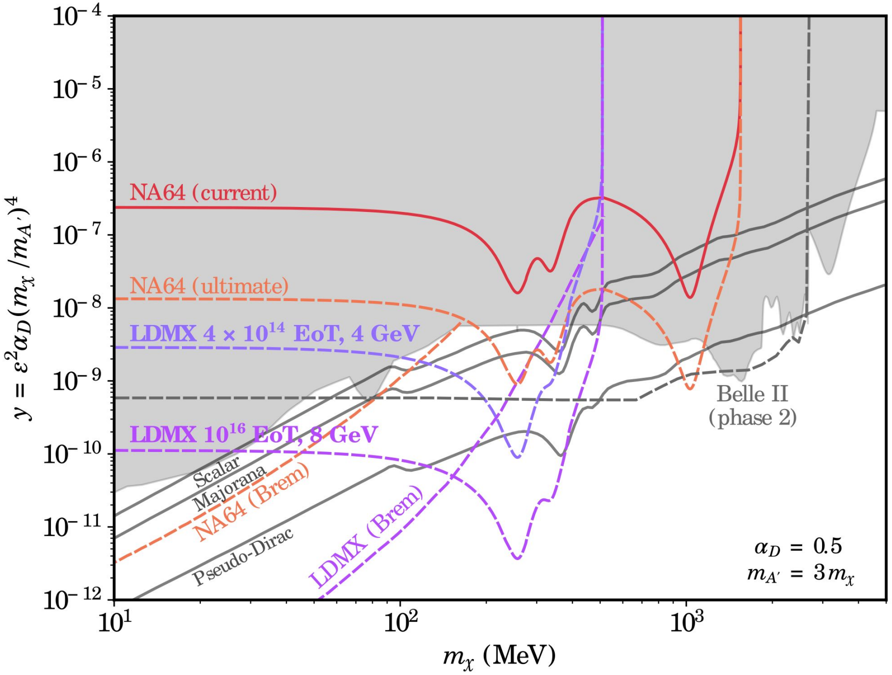


Vector mesons, created through photo-production in the calorimeter, would mix with the A′.

Additional production channel!

Provides reach beyond the missing momentum search at higher mediator masses.





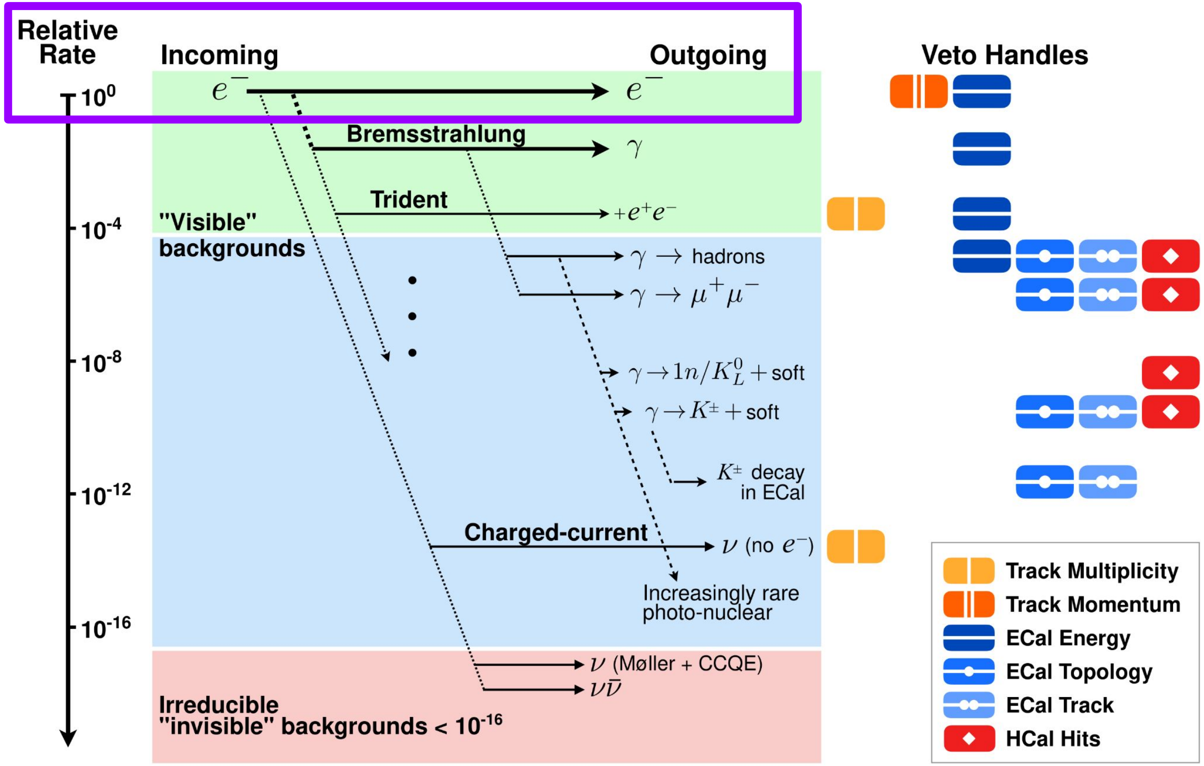
(both figures modified from 10.1103/PhysRevD.105.035036, arXiv:2112.02104v2)

Non-interacting beam electrons could produce an A′ as they hit the calorimeter, treating the ECal as an active target.

+ Sensitivity with low statistics
- Limited veto handles for rare backgrounds

MM search eventually more sensitive with statistics, but ECal-as-Target approach is suitable for an early LDMX result.

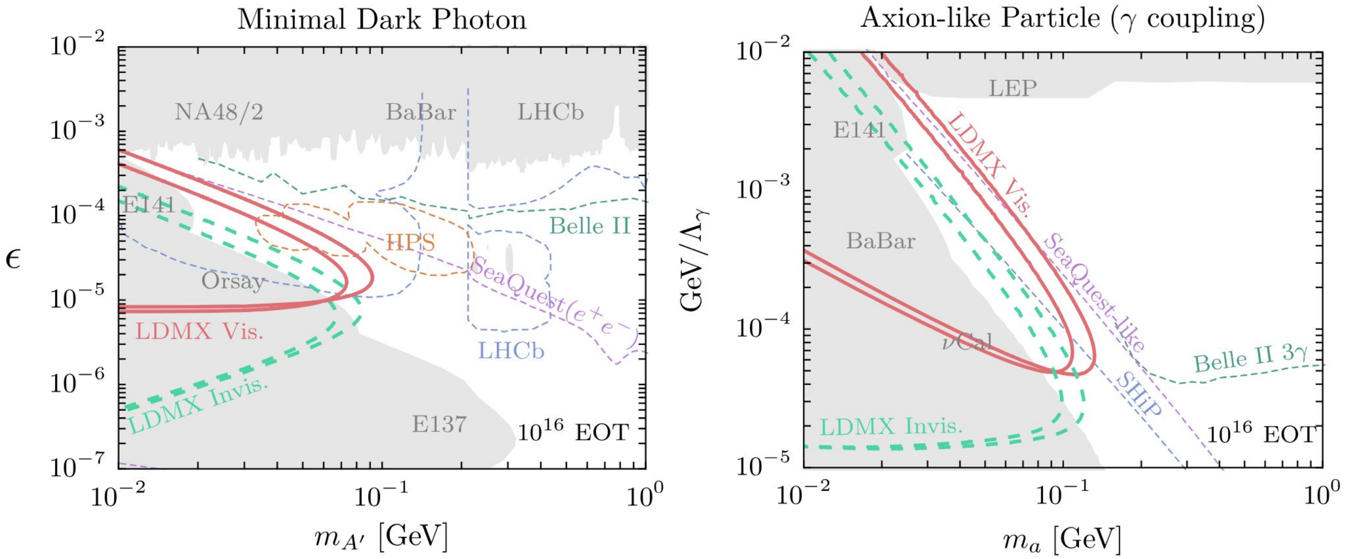
Paper on the way!



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

Long-lived particles could be produced in the target or ECal, and decay in the calorimeters downstream.

Ongoing simulation study about long-lived A's created in the target and decaying in the Hcal, **paper on the way**!

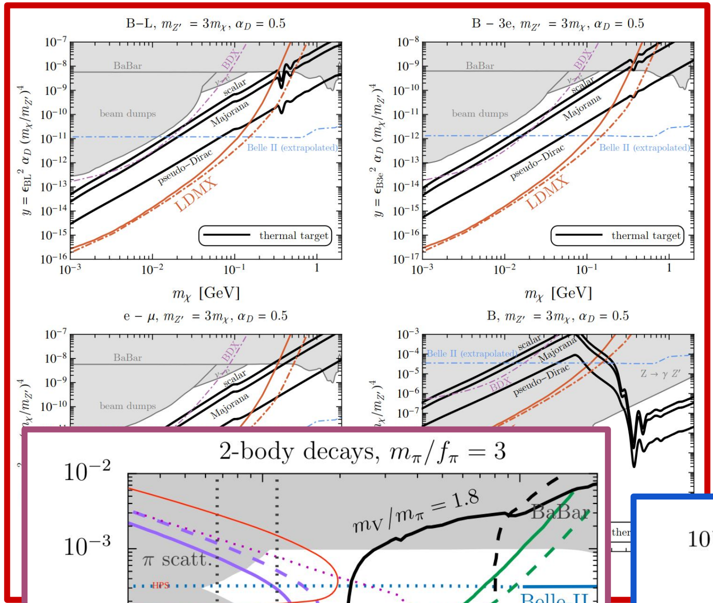


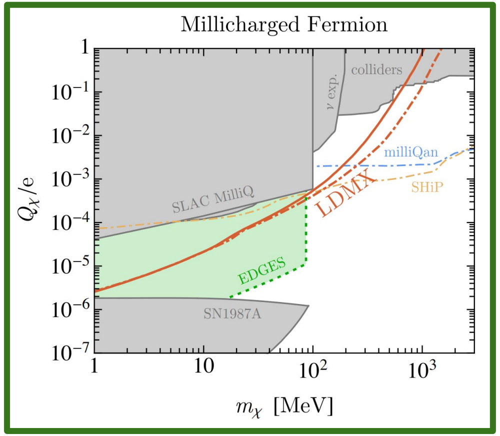
(Pheno plots from Phys. Rev. D 99, 075001, arXiv:1807.01730)

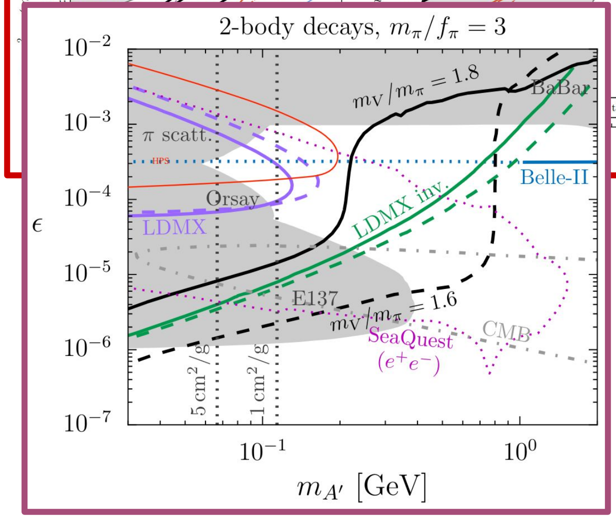
Snapshot: The Wide Physics Potential of LDMX

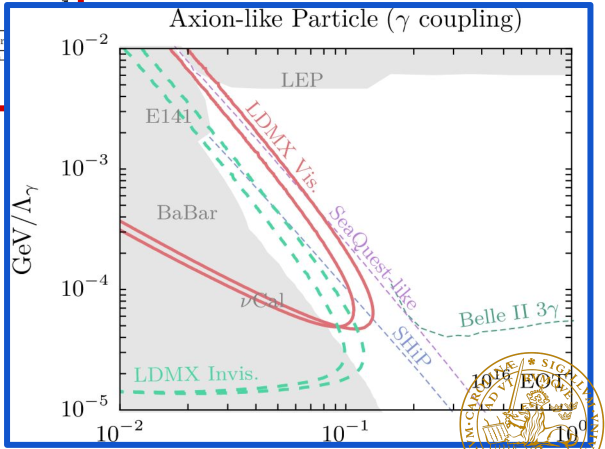
- **Other mediators**
- **Millicharged particles**
- inelastic DM (iDM)
- **SIMPs**
- Freeze-in DM
- Visible signatures (e.g. visibly decaying dark photons or **ALPs**)

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









Simulations (> $2{\times}10^{14}$ EoT) show **promising veto power in the missing momentum search.**

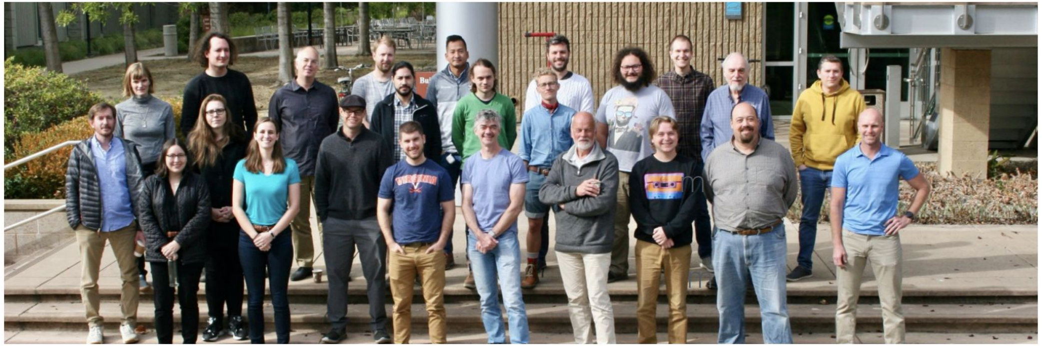
Ongoing simulation studies (among others):

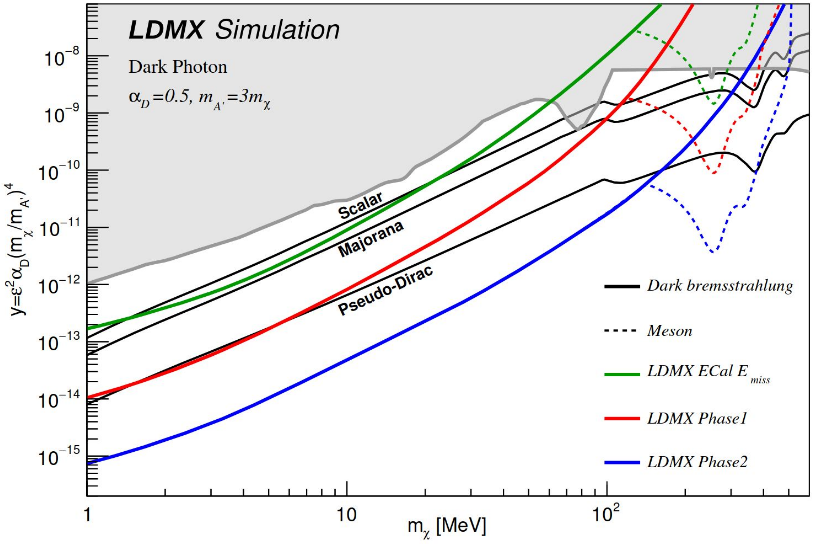
- Pile-up: Triggering and veto power
- Other signatures (visible decays, ECal as target)
- Comparing Geant4 with other particle transport simulations

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.

Currently we are working on a design report, and look forward to start construction of LDMX as soon as possible!





(from arXiv:2203.08192v2)