The Light Dark Matter eXperiment, LDMX

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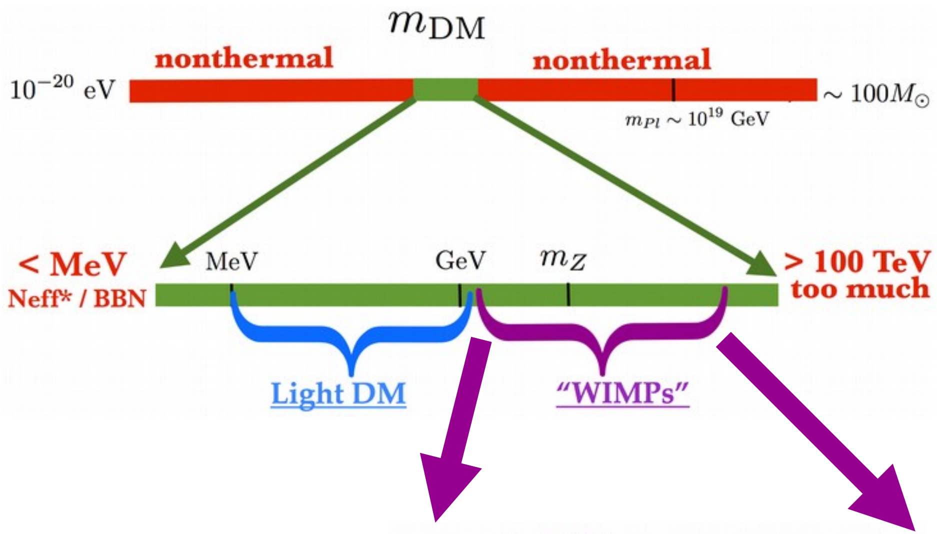
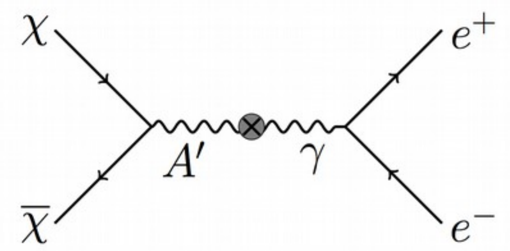
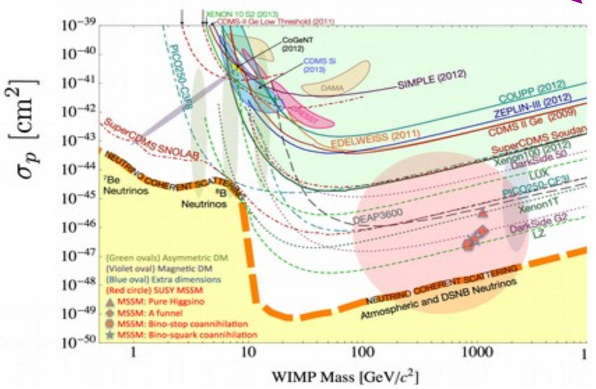
Thermal dark matter below ~1 GeV

- The existence of dark matter is well-established by cosmological and astrophysics observations
- The freeze-out hypothesis has been a key motivating concept in the search for dark matter
  - Dark matter particle mass is a ~free parameter, but lighter masses require weaker couplings to the visible SM
  - “WIMP miracle” matches weak mass and coupling scales → simple forms excluded by direct and collider searches
- Light dark matter naturally implies a new force carrier mediating the “weaker-than-weak” connection between the SM and DM sectors

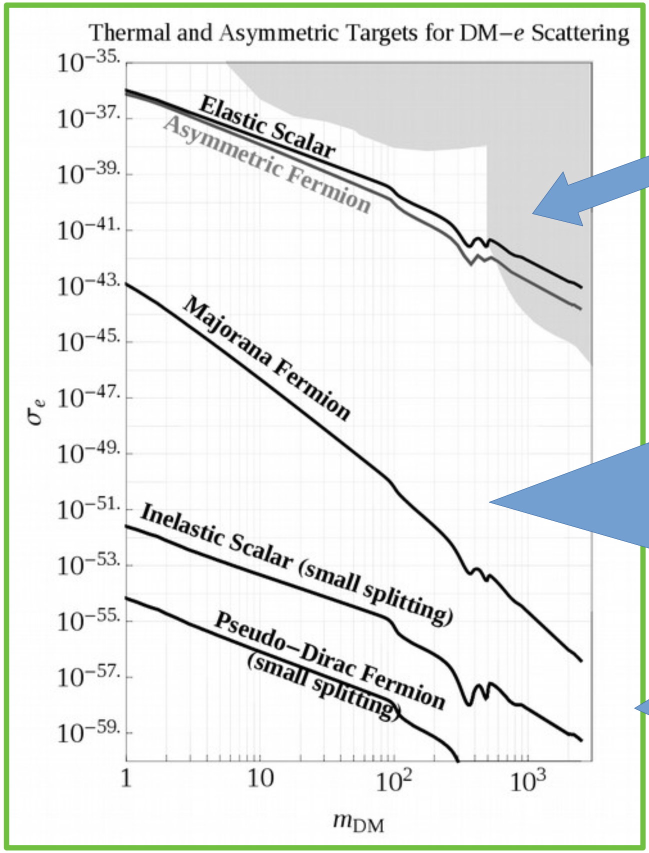


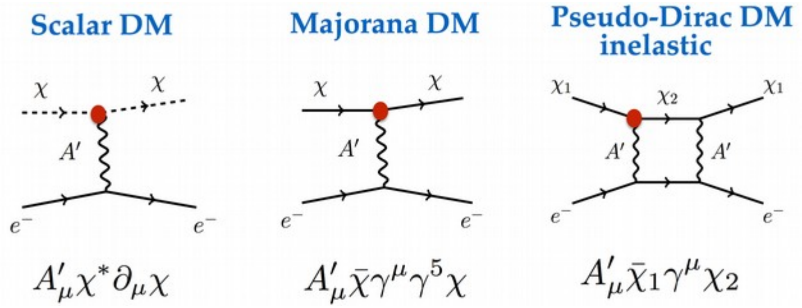


$$\epsilon F'_{\mu\nu} F^{\mu\nu}$$



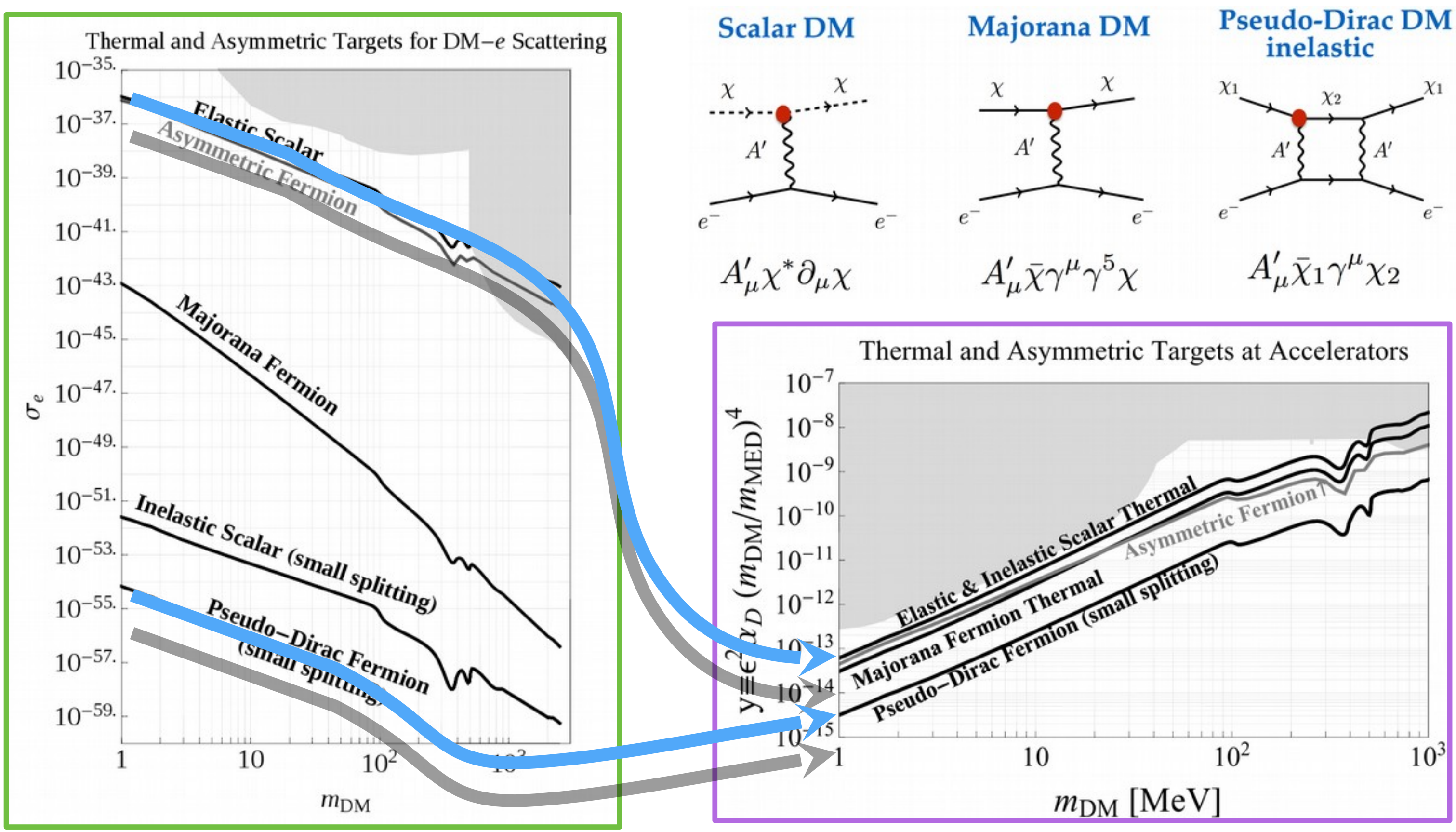
Relativistic advantages





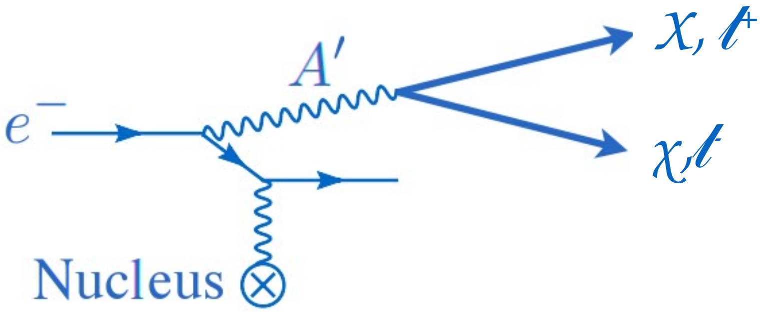
- **Direct-detection requires experimental observation of non-relativistic dark matter**
  - Sensitive to the details of the coupling, which can result in very large scattering rate suppression

Relativistic advantages

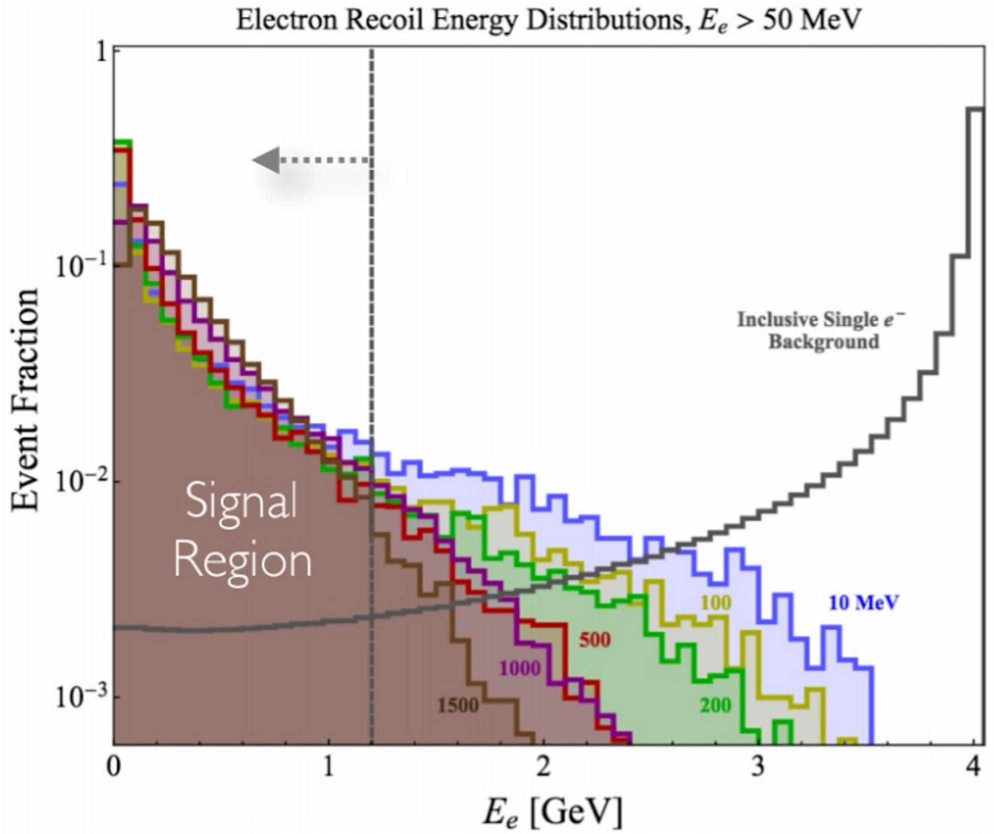


- **Direct-detection requires experimental observation of non-relativistic dark matter**
  - Sensitive to the details of the coupling, which can result in very large scattering rate suppression
- **Accelerator-based production of dark matter moves the production to the relativistic regime, where the thermal target for freeze-in naturally collapses to a narrow band**

Electron fixed-target kinematics

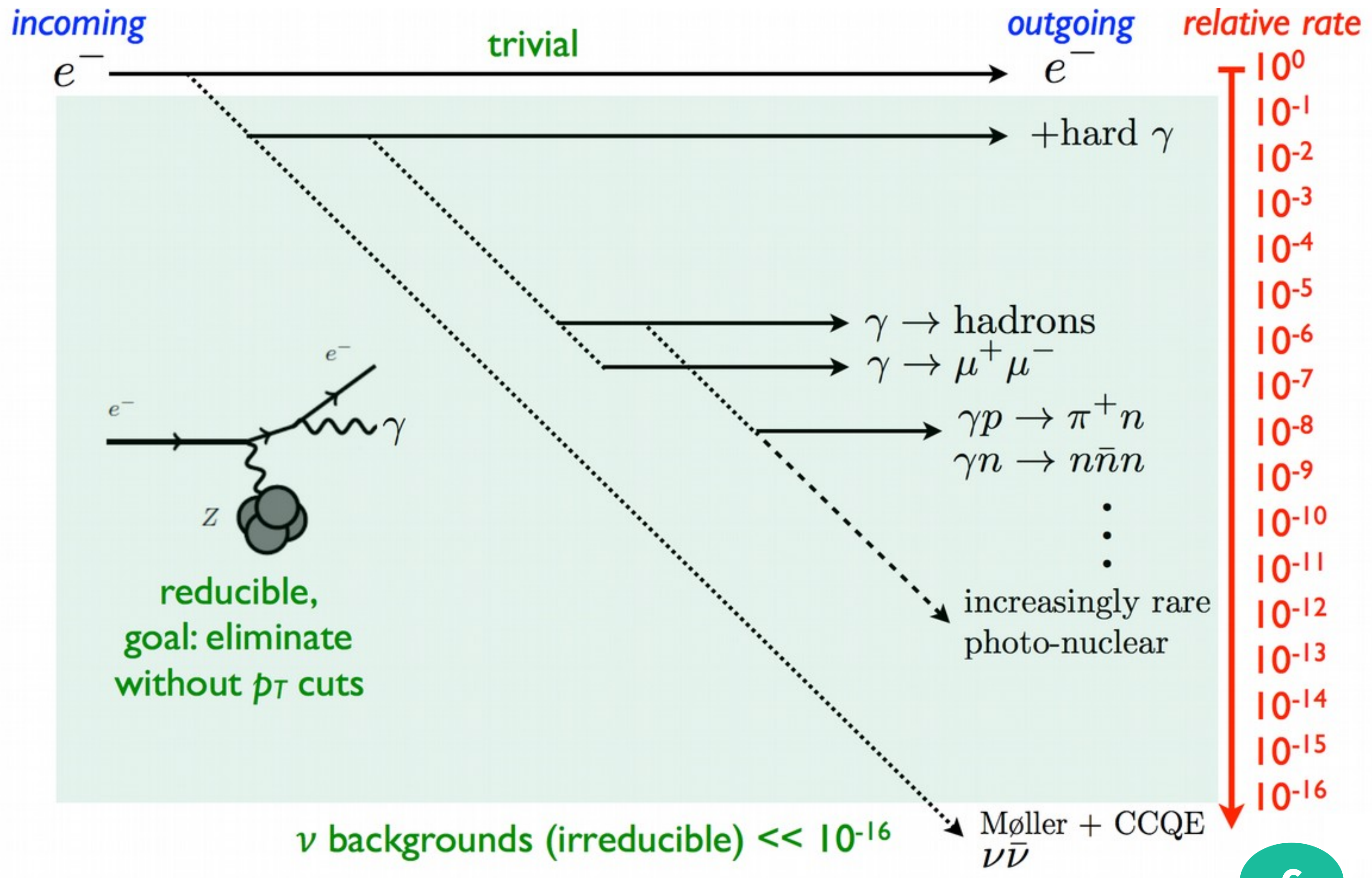


- For $m_{A'} >$ ~$2m_e$, A' carries most of the momentum after the interaction
- Signal signature is a single low-momentum electron → large missing momentum/energy
- Recoil electron receives a transverse momentum kick ~ $\sqrt{m_{A'}}$

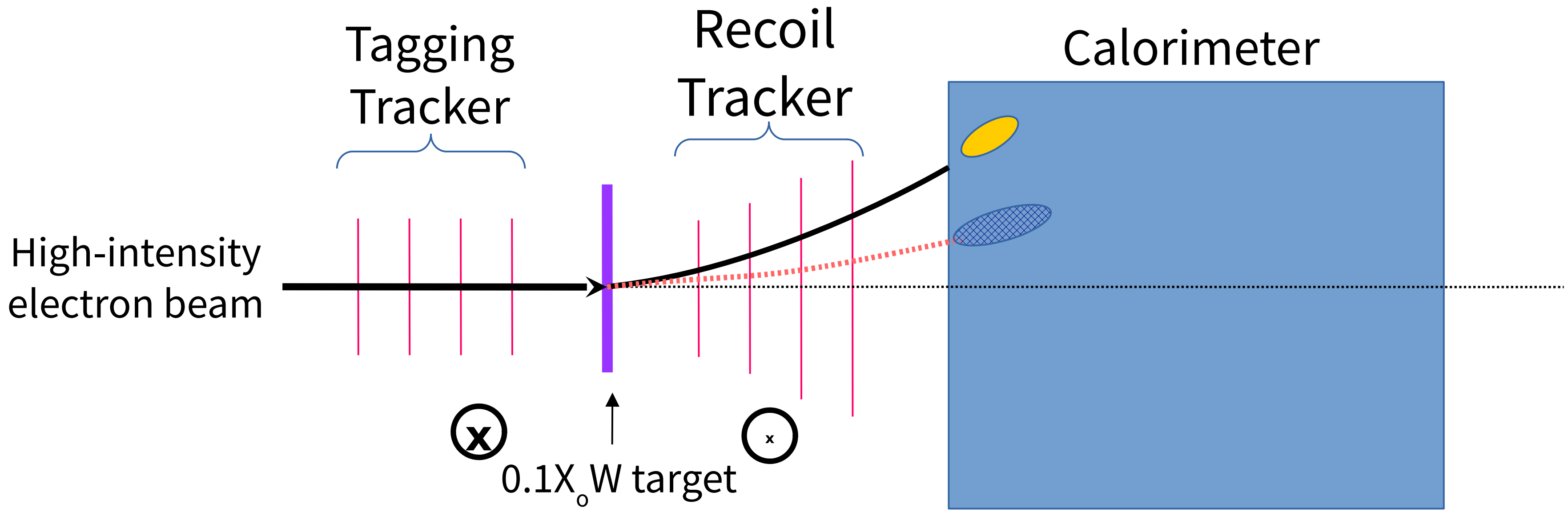


Heirarchy of backgrounds

- **Dominant backgrounds initiated by standard-model brehmstrahhlung**
  - Observation of photon showers is critical
- **Irreducible backgrounds are at a very low level for these beam energies**
  - More challenging for higher beam energies (> 20 GeV)



Detector concept



Beam which enables O(10^{16}) electrons to be individually identified & reconstructed

low-current, high repetition rate beam (10^{16}/year is ~ 1e^- / 3 ns)

possibilities include DASEL @ SLAC (4/8 GeV) or CEBAF @ JLAB (< 11 GeV)

Detector technology with fast readout and high radiation tolerance

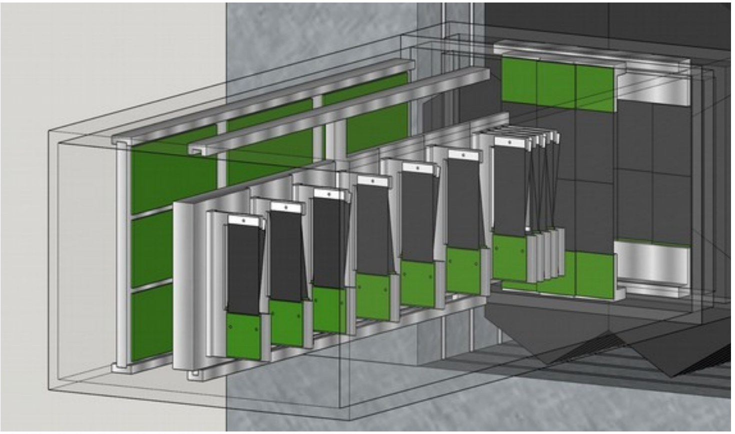
high momentum resolution, low mass tagger/recoil tracker

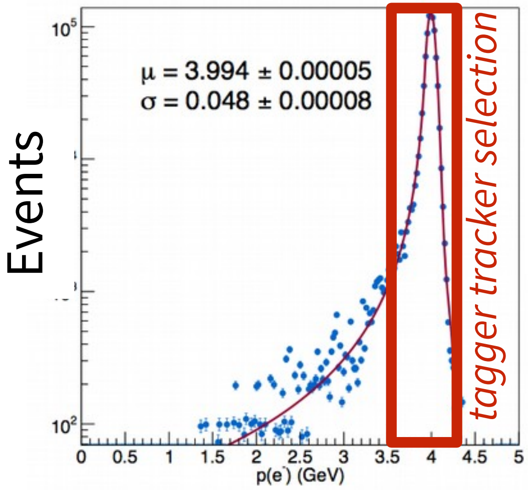
high energy resolution EM calorimeters (ECal)

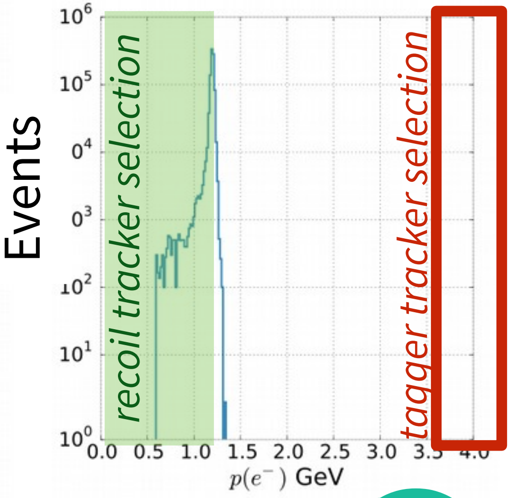
Design study: arXiv:1808.05219

Tracker based on HPS

- **Silicon strip spectrometers:**
  - Single 1.5T dipole magnet with 2 field regions
  - tagger tracker: located in magnet bore
    - measure incoming momentum
    - efficiently identify off-energy beam components
  - recoil tracker: located in fringe field
    - measure outgoing momentum
    - good recoil momentum resolution

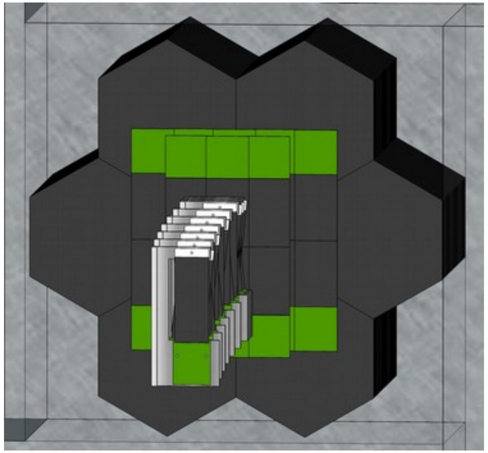


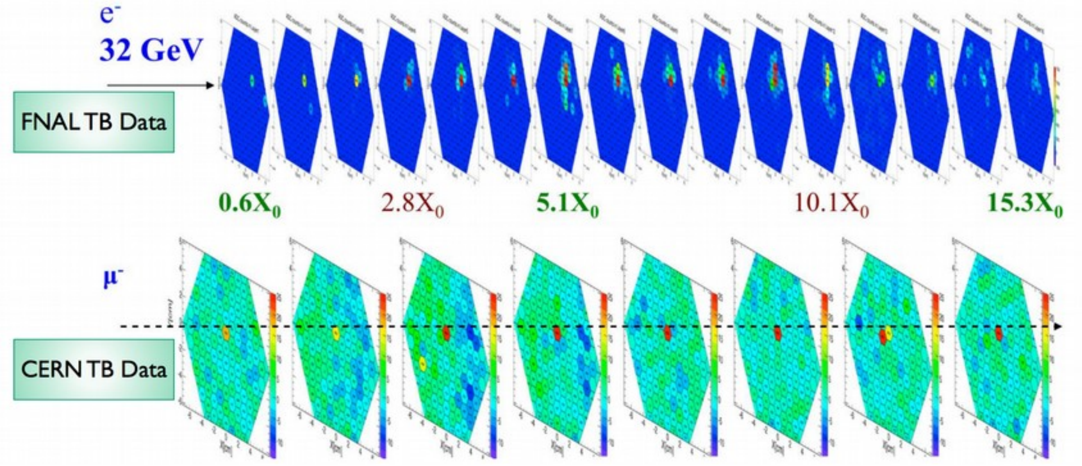


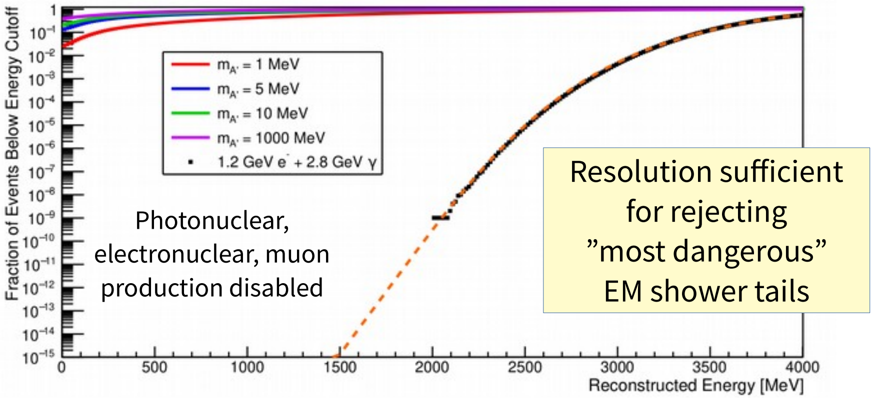


High-rate/high-radiation ECAL from HL-LHC

- **40 X_0 tungsten-silicon imaging calorimeter**
  - fast shaping and readout, radiation tolerant
  - MIP sensitivity (S/N=10-15), precision shower timing (50 ps)
- **High granularity: can exploit both transverse & longitudinal shower shapes to reject PN events and handle multiple incoming electrons in a single integration period**
- **Leverages technology developments for CMS HL-LHC endcap calorimeter**

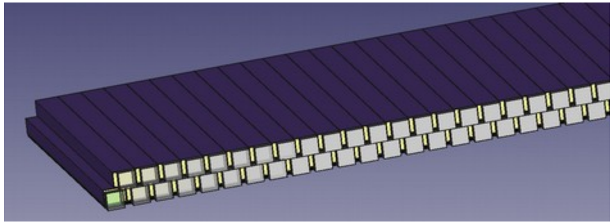


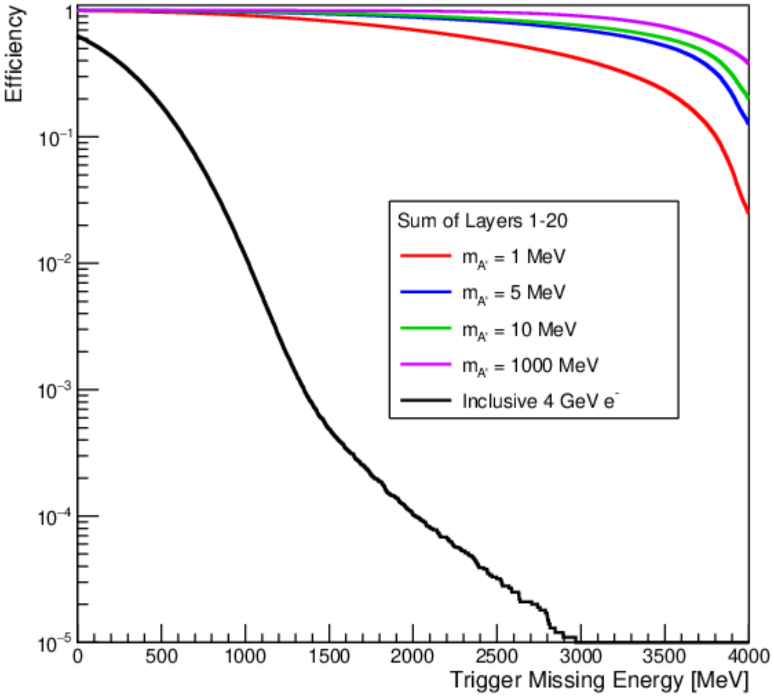




Missing energy trigger

- **Missing energy trigger based on energy observed in the ECAL compared with amount expected for given number of incoming beam electrons**
  - Incoming electron number determined using an array of scintillator strips read out with SiPMs
  - Trigger threshold optimization depends on mean occupancy of the accelerator bunches

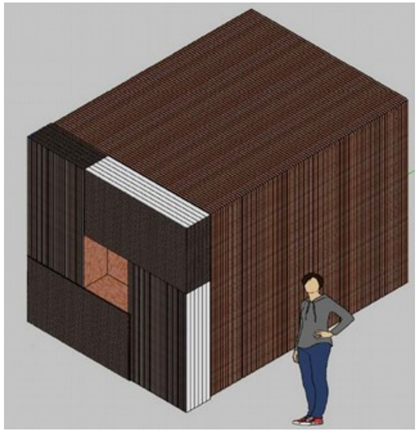


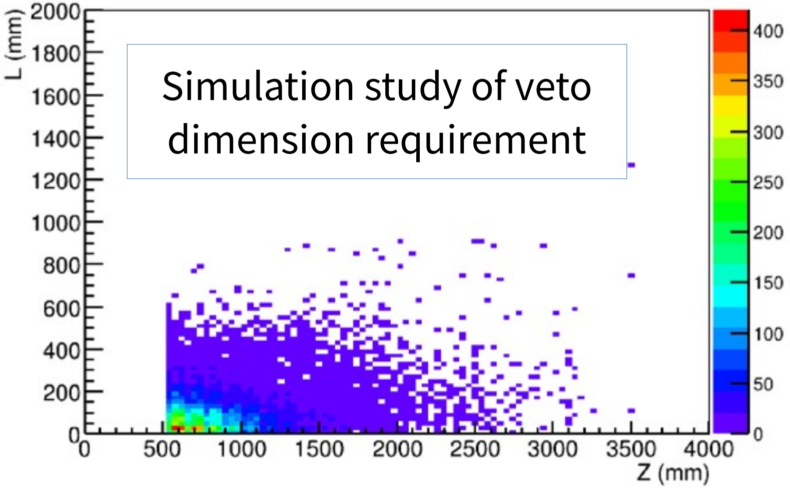


n_{beam}	Fraction of Bunches (Signal)	Trigger Scintillator Efficiency	Missing Energy Threshold [GeV]	Calorimeter Trigger Efficiency	Rate [Hz]	Signal Inefficiency
1	36.8% (36.8%)	100%	2.50	99.2%	588	0.3%
2	18.4% (36.8%)	97.4%	2.35	98.0%	1937	1.7%
3	6.1% (18.4%)	92.4%	2.70	91.6%	1238	2.8%
4	1.5% (6.1%)	84.3%	3.20	77.2%	268	1.6%
Total					4000	8.8%

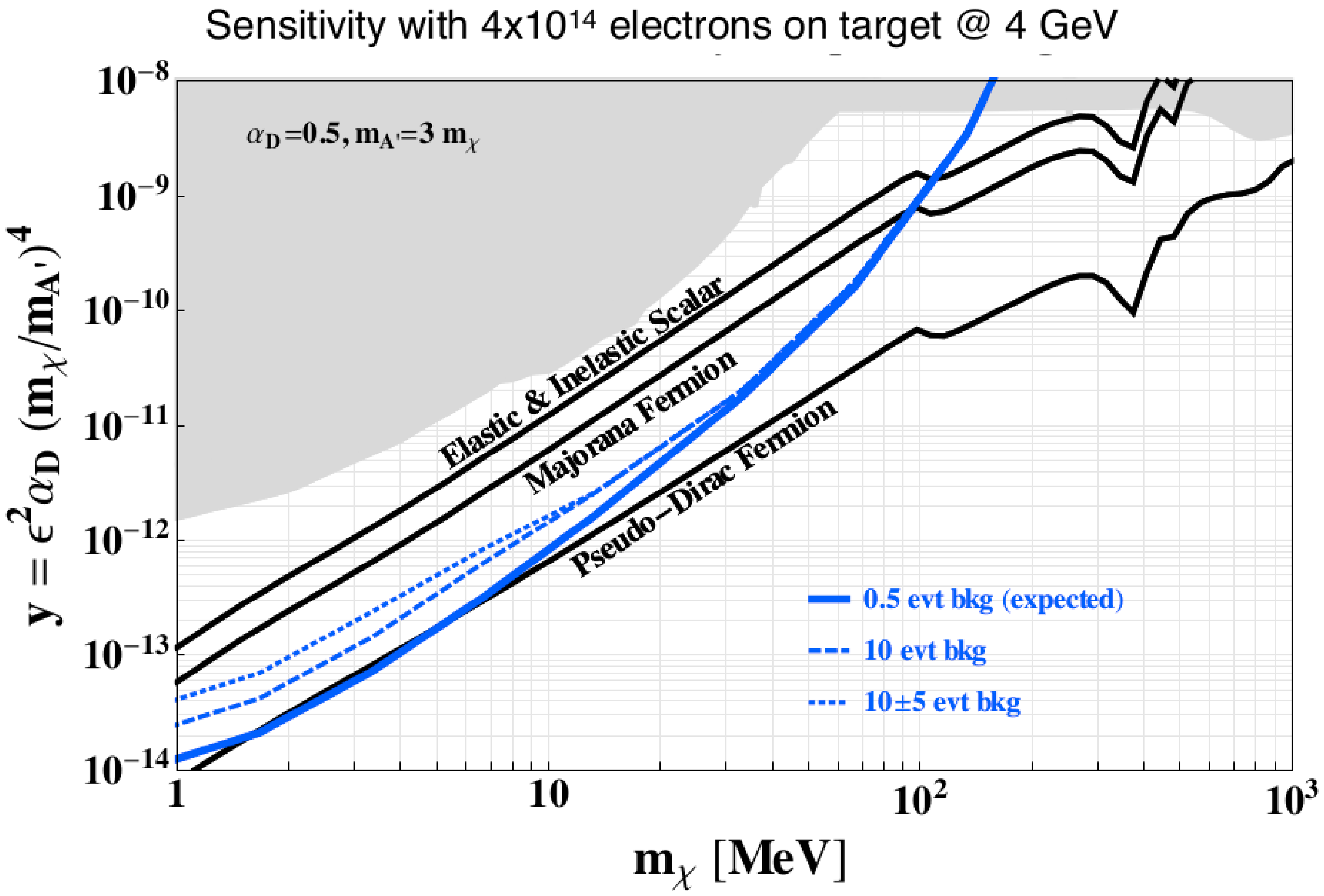
Hadron calorimeter

- Key goal is to identify neutrons produced in photonuclear interactions
- Design concept is a steel-absorber calorimeter with plastic scintillator active material and WLS/SiPM readout
- HCAL will surround ECAL and also provide significant forward depth (in nuc) for a highly-efficient neutron veto
  - Veto becomes easier with an 8 GeV electron beam



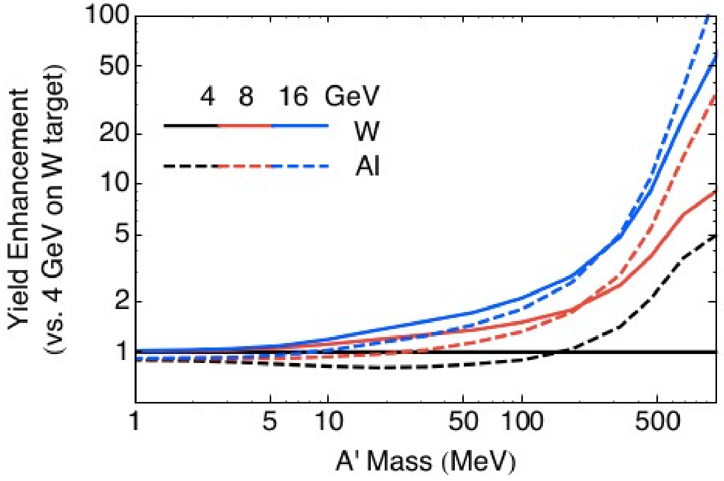


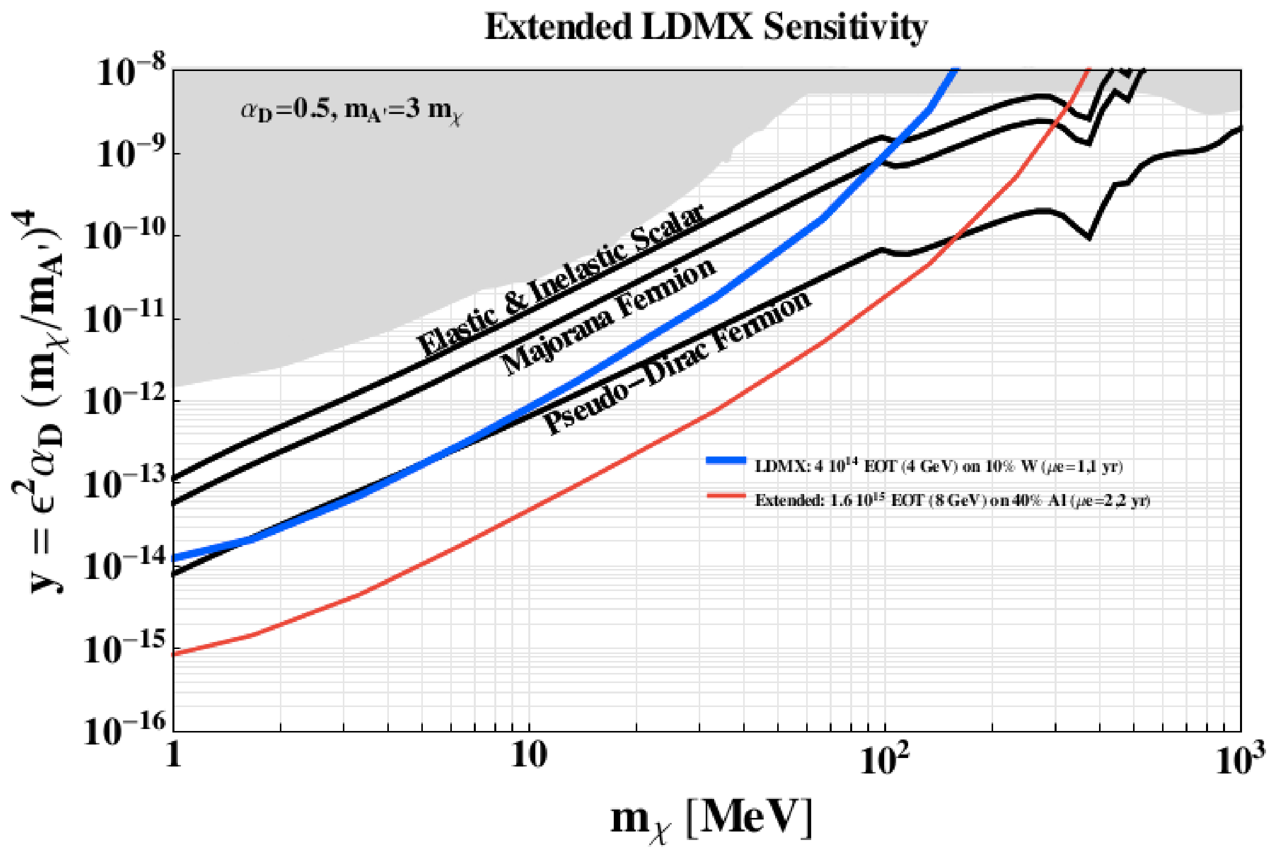
LDMX Sensitivity with 4x10^{14} EOT



- Performance for a first phase using a 4 GeV beam (e.g. existing LCLS2 line)
- Detailed analysis including model variations in arXiv:1808.05219

Full LDMX Sensitivity





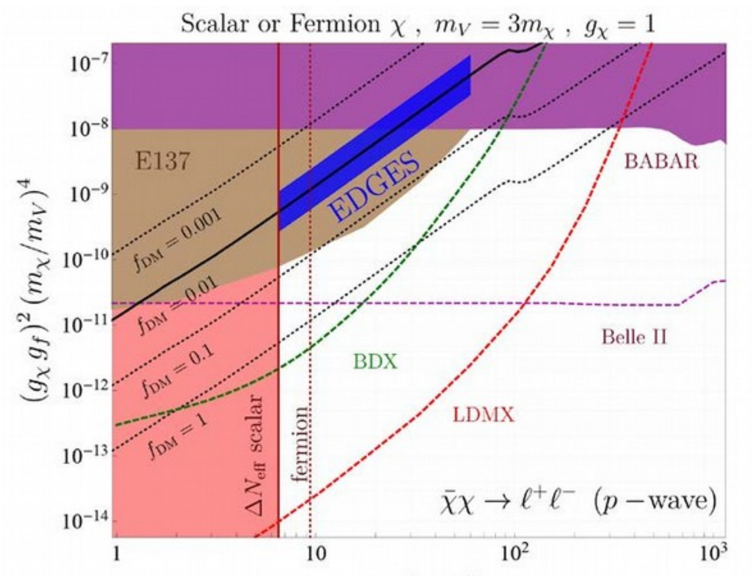
- **Strategies which extend the initial reach**
  - Higher beam energy (4 GeV → 8 GeV)
  - Thicker target provides benefits at higher A' masses
  - Higher statistics (1.6 x 10^{15} EOT)
- **Unprecedented sensitivity surpassing all existing and projected constraints by orders of magnitude for DM masses below a few hundred MeV.**

Prospects and Summary

- The thermal-relic hypothesis is one of the most compelling DM scenarios, and the broad vicinity of the "normal matter" scale is a good place to be looking – logical extension of WIMP
- Accelerator based experiments are the unique probe of relativistic dark matter physics, with broad and distinctive sensitivity to light dark matter scenarios -- and could reveal much of the underlying dark sector physics together with direct detection experiments
- LDMX would offer unprecedented sensitivity to light DM, surpassing all existing and projected constraints by orders of magnitude for DM masses below a few hundred MeV.
- More generally, the experiment will be able to explore a broad array of sub-GeV physics, and could also perform photonuclear & electronuclear measurements useful for planned neutrino experiments.
- Design is advanced and the presented physics potential is all accessible within the next decade!

Other physics accessible with LDMX

- Missing energy DM searches – use calorimeter as a target, complementary backgrounds
- Millicharged particles



Krnjaic, Berlin, Hooper, McDermott, 1803.02804

- Facility for electron-nuclear and photon-nuclear measurements important for future neutrino experiments