LDMX and a New Approach to Accelerator Dark Matter

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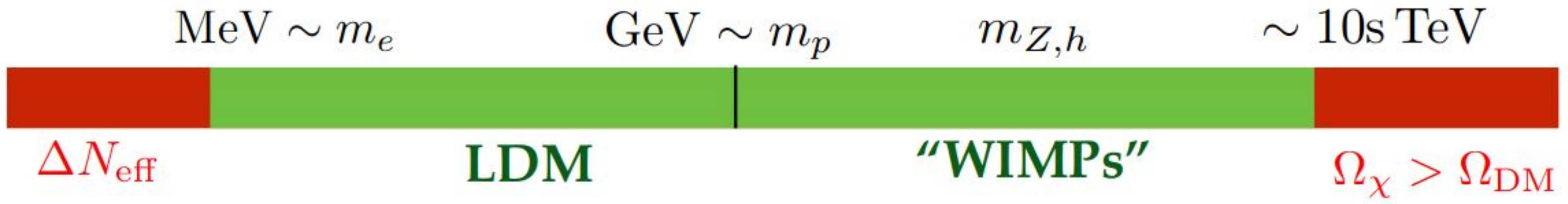
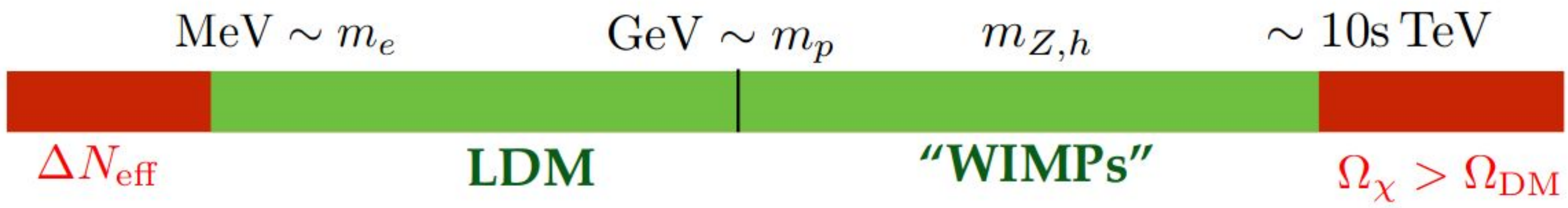
A Particle Physicists Look at Dark Matter

- For “standard” dark matter, mass is bounded to get correct observed properties
- Standard is well within theoretical framework of HEP and similar to SM
- Below: Mass power spectrum (10keV) and number of relativistic species(1MeV)
- Above: Annihilation rate wrong for relic abundance (10 TeV)
- WIMP’s are the long leading theory (light in a dark room)



Why is Standard Good?

- Build on experimental success of particle physics
- Minimal assumptions
- Minimal additional particle content (U(1) gauge interaction with 2 particles)
- Motivation of asymmetric dark matter (analogous to baryon asymmetry)



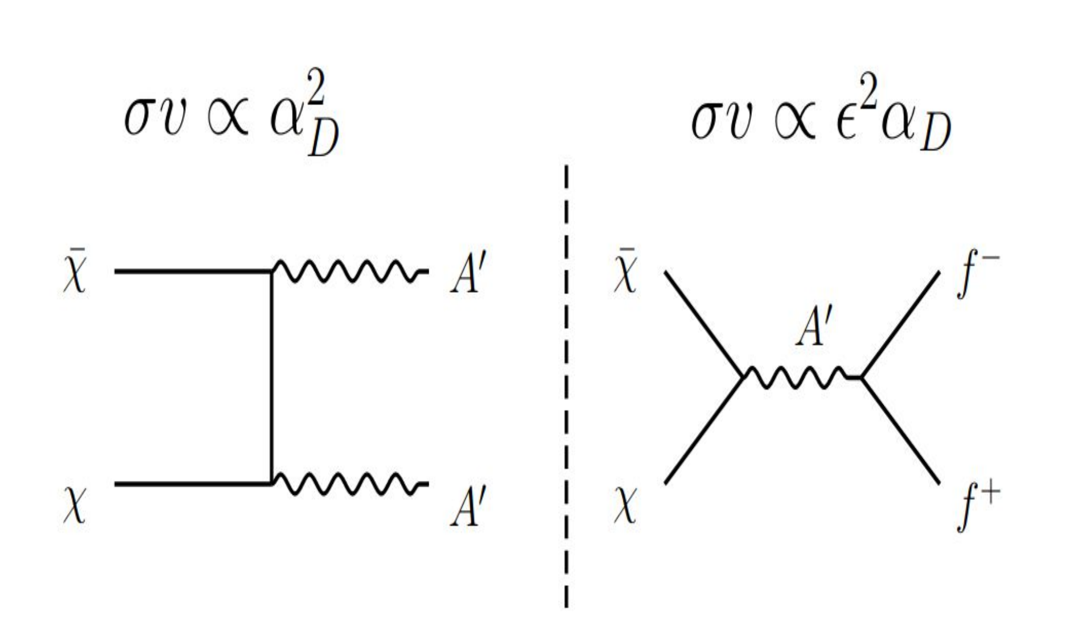
A Benchmark Model: Dark QED

$$\mathscr{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} + \frac{m^2_{A'}}{2}A'_{\mu}A'^{\mu} - A'_{\mu}(\epsilon e J^{\mu}_{\mathrm{EM}} + g_D J^{\mu}_{D}),$$

- After EWSB, with U(1) DM, there is kinetic mixing w/ DM and EM particles
- This can lead to radiation of dark photons from SM particles
- Many kinematic parameters, but the benchmark model here is for Mediator mass > 2 mass of dark charged particle
- Generally experiments can probe several dark current models

A Benchmark Model: Dark QED

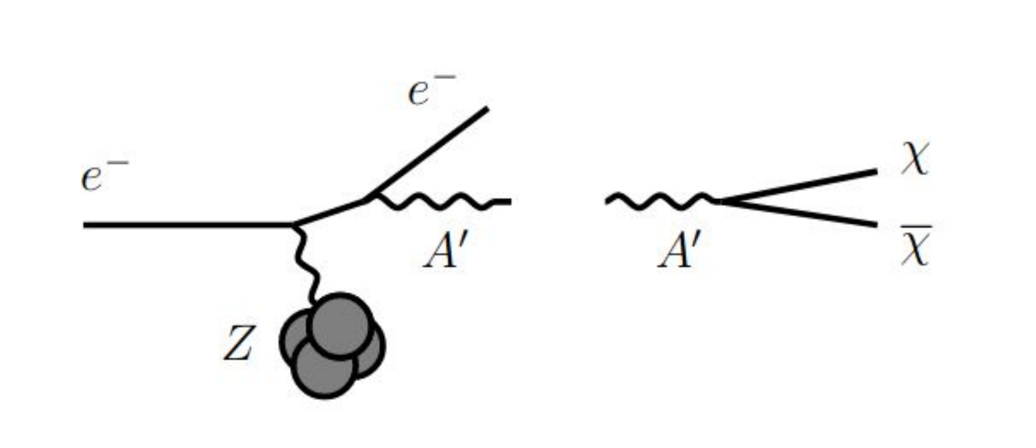
- For benchmark, focus on right
- For DA, xsec for correct relic density depends on kinetic mixing parameter
- For each chi mass, there is a minimum value of the coupling, giving an experimental target



Secluded Annihilation Direct Annihilation

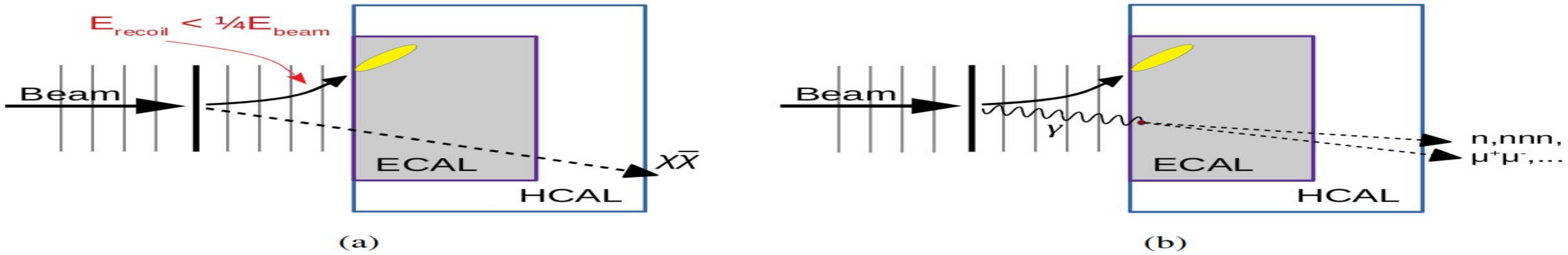
Light Dark Matter: Where Does It Come From, Where Does It Go?

- Analogous production to Bremsstrahlung
- Electrons on heavy target
- DM is heavy (relative to e) in this scenario
- DM carries away most of system's momentum
- Recoiling electron can be measured



So What Is Missing Momentum Method?

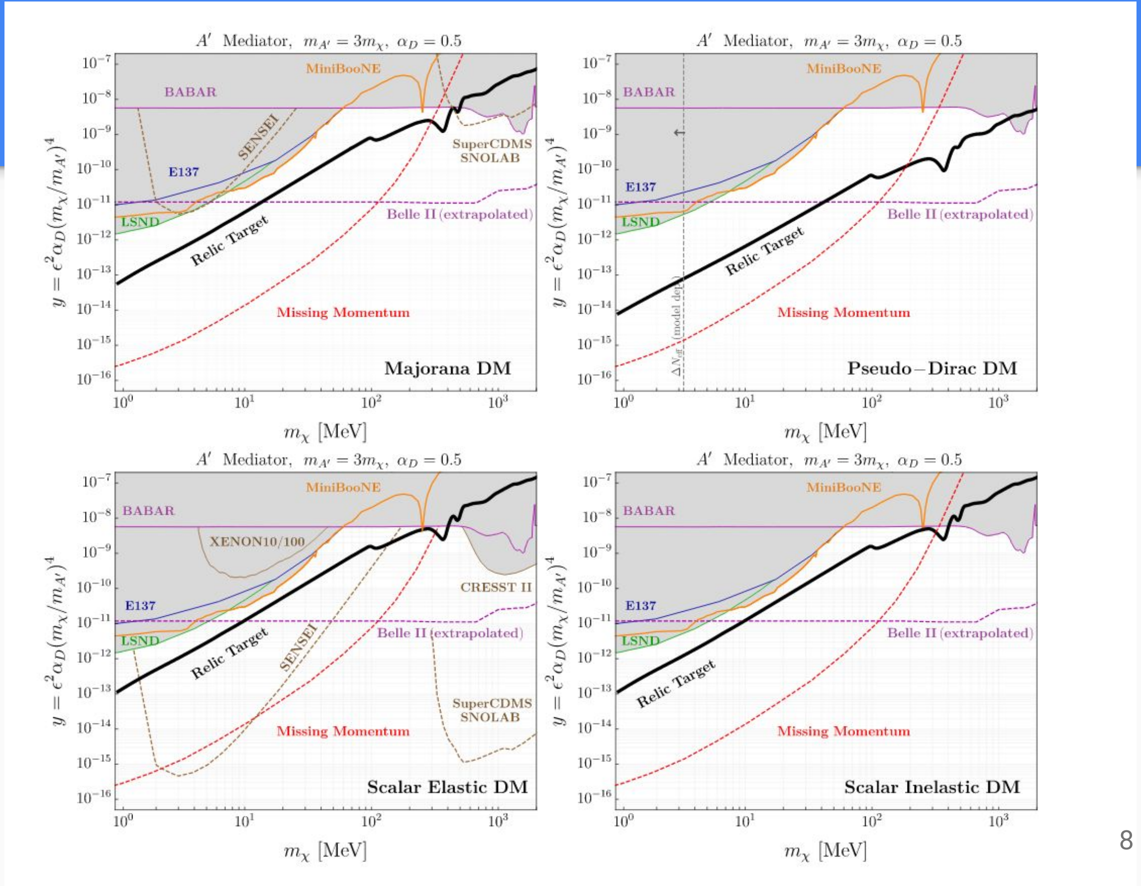
- Hierarchy of “Missing” precision experiments
  - Mass, ie reconstruct all particles in e+e- collisions
  - Momentum, ie measure initial and final 4 momentum of a particle interacting with DM
  - Energy, ie only reconstruct energy, without angular information
- Compromise generally between luminosity and signal purity
- LDMX settled on the Just Right experimental porridge: missing momentum



Possible Exclusion Scenarios

For 4 common DM current models, LDMX method can set good limits

Focus here is on LDMX approach of missing momentum

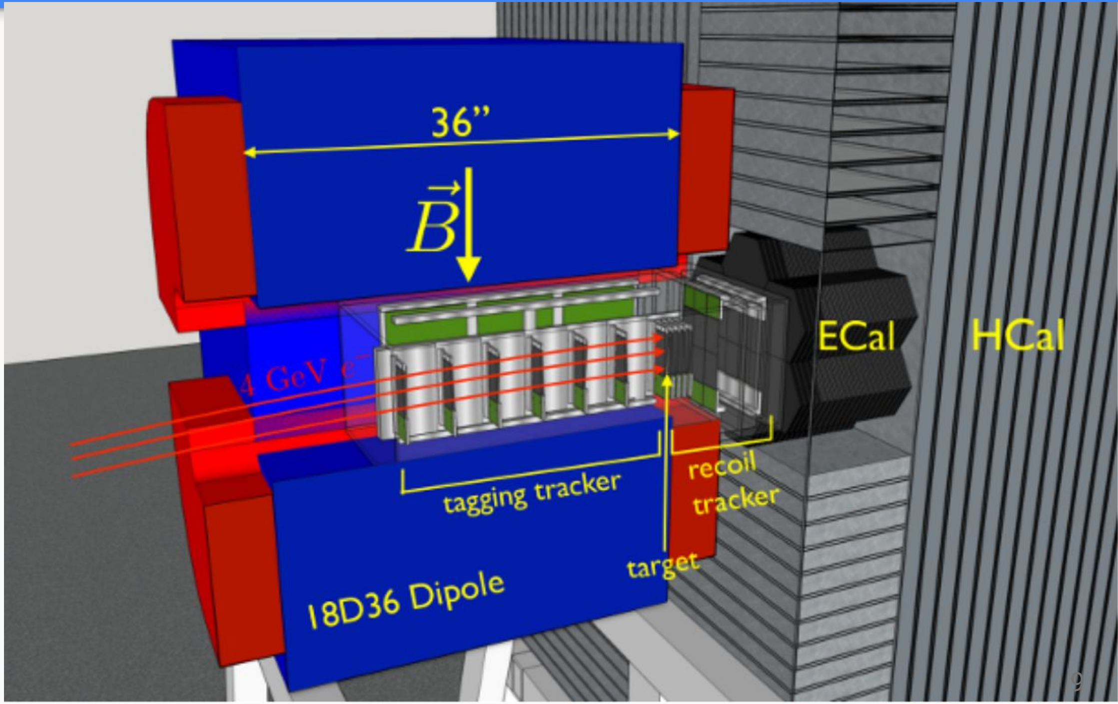


LDMX Design

LDMX utilizes 4 main detector components

- Upstream Tagger
- Downstream Tagger
- ECal
- HCal (veto)

O(1) e per bunch with 46 MHz rate



LDMX Cutaway

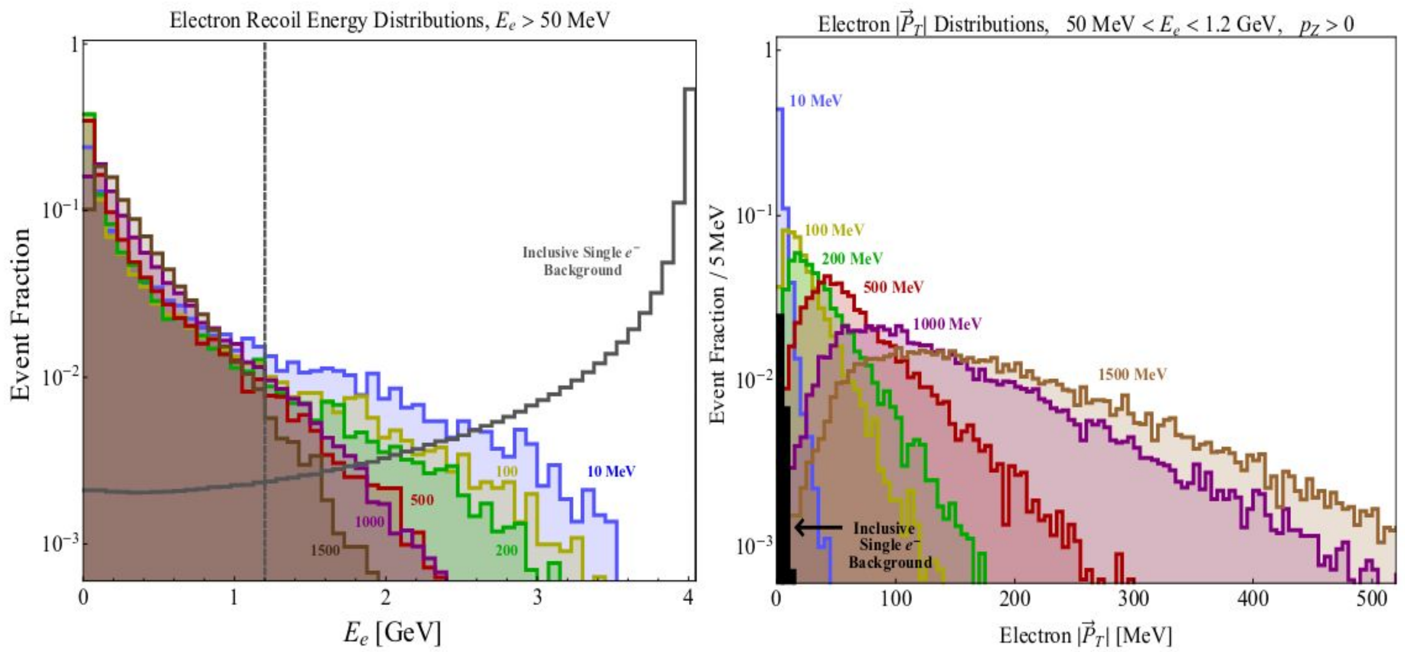
Tracking Detectors

- Two silicon microstrip detector subsystems
- Upstream tagging tracker
  - Tags incoming electrons to correctly characterize initial state
  - Upstream of target
  - Strong B field for higher resolution
- Downstream recoil tracker
  - Gets kinematics of recoiling electrons
  - After target
  - Weaker B field to capture soft, wide electrons that do not hit ECal

Calorimetry

- ECal
  - Energy determination which gives full four vector kinematics of scattered e in concert with recoil tracker
  - Sampling Cal designed after CMS forward HGC
- HCal
  - Veto system for neutral hadrons (neutrons) and MIP’s (muons) not seen in ECal
  - Scintillator based sampling calorimeter
  - Utilize technology from CMS or mu2e

What to Expect When You're Expecting Dark Matter: The Signal

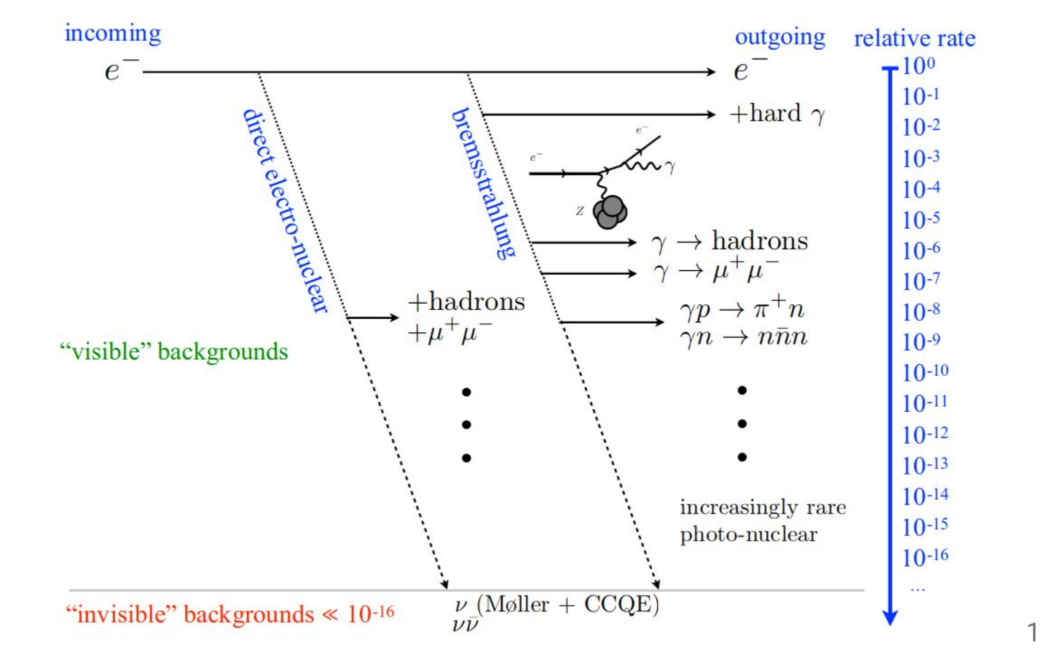


4 GeV Incident e-

Background Processes

Backgrounds factor into several different types

- Stray electrons
- Bremsstrahlung and nuclear interactions
- Neutrino processes



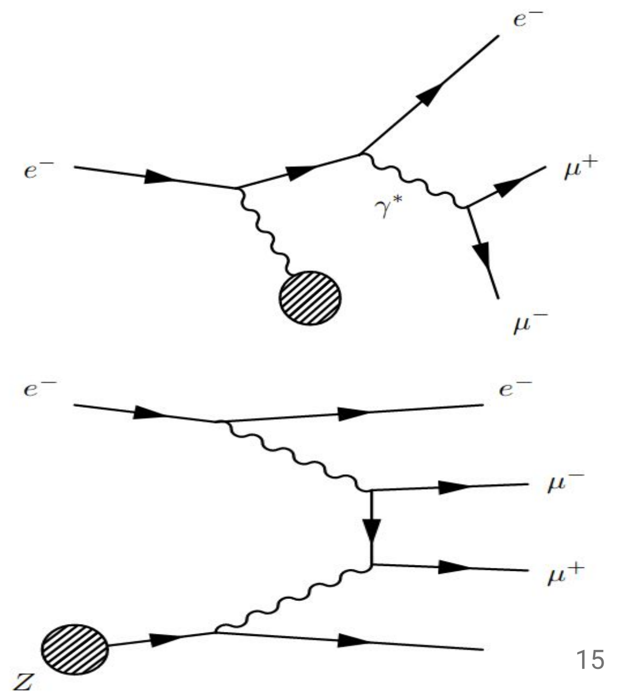
Stray Electron Backgrounds

Two main backgrounds

- Low energy incident electrons
  - Caused by beam impurities
  - Vetoed by incident detector
- Non Target Interacting Electron
  - Mainly an issue if combined with shower level effects that cause lowered energy in ECal

Bremsstrahlung and Nuclear Interactions

- Hard Brem
  - Need good photon reconstruction to measure distinct shower from e
  - e + photon should approximate beam energy
  - Rate order 10^-2 / incident electron
  - Hard enough brem is kinematically distinct from signal
- Nuclear/muon interaction
  - Either direct (electron-nuclear, muon production) or indirect (gamma goes to hadrons from brem)
  - Can lead to E mismeasurement
  - HCal used to veto (especially muons and neutrons

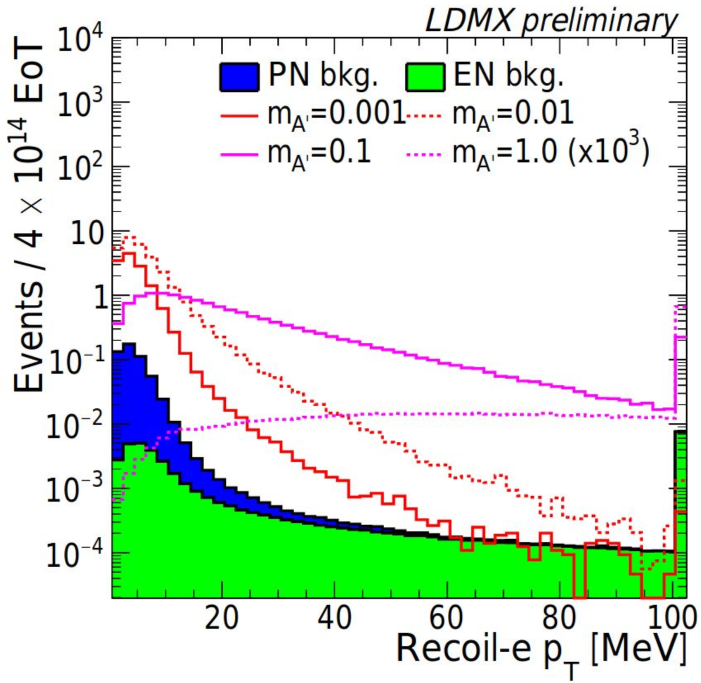


Neutrino Interactions

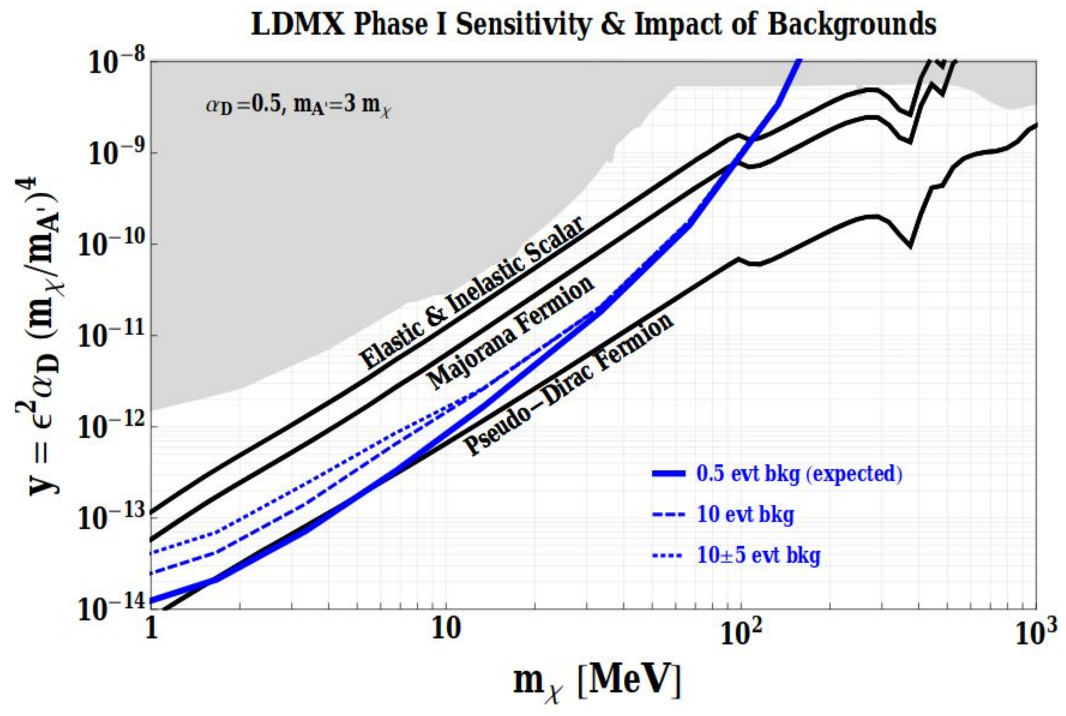
- CC neutrino interactions are NOT bkg (no FS e-)
- e+N→e+v+v+N : Leads to irreducible physics background
  - Rate really really small (10^-18 compared to hard brem) = 10^-5 events over LDMX phase I
  - More of a neutrino floor than current concern (analogous to WIMP neutrino floor)
- CC neutrino + other can fake signal
  - Initial e disappears, and new, low momentum e is produced and detected
  - Other similar topologies with neutrinos, but all v bkg are O(.01) evts over phase I

LDMX Planned Operation

- 4 GeV electron beam (conservative energy)
- 4 x 10^14 electrons on target as a benchmark run
- < 0.5 bkg events expected
- No need to cut on p_T unless additional backgrounds arise



So Where Does Phase I LDMX Get Us?



Expected Reach of Phase I LDMX

Summary

- Large regions of overall DM phase space unexplored
- Lots of room for improvement in simple, well motivated DM models
- LDMX's missing momentum approach is sensitive to sub GeV DM
- Use of existing technology for easier/cheaper design
- Low Backgrounds and distinct signal
- Complementary to existing efforts and good rejection of previously unexplored regions of phase space

Link to Arxiv

https://arxiv.org/pdf/1808.05219.pdf