Exploring sub-GeV Dark Matter with LDMX

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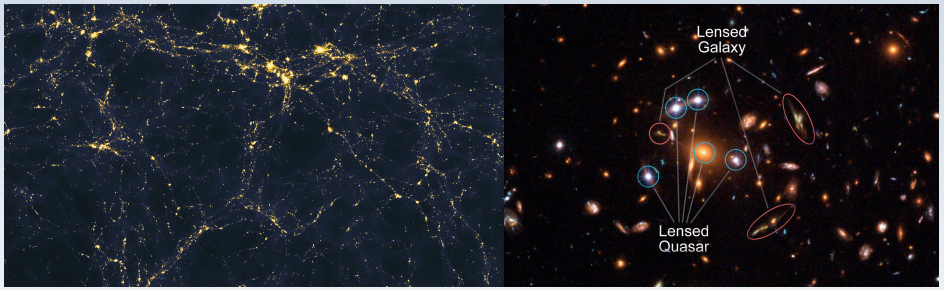
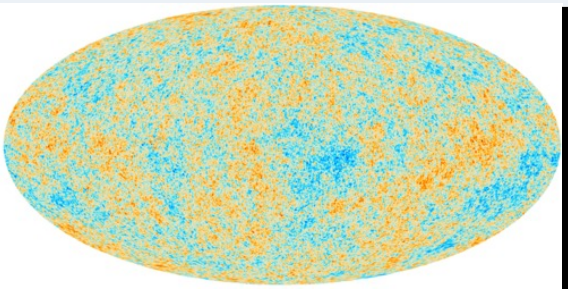
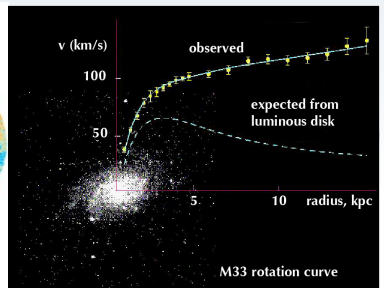
Partikeldagarna, October 17 2018

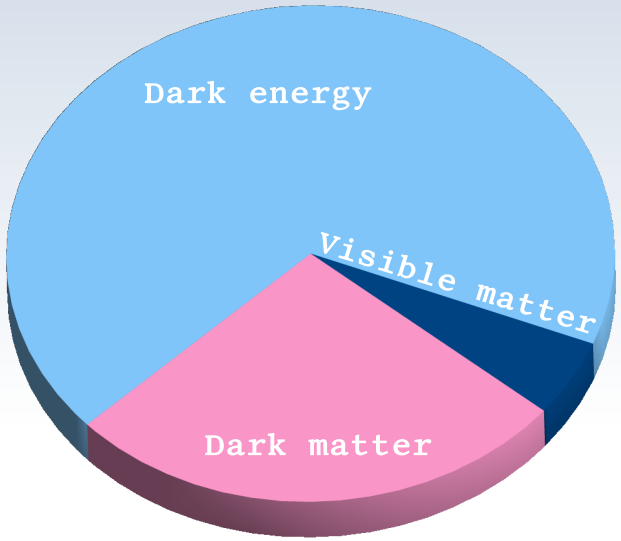
Dark Matter

What do we know?









- gravitational interactions
- no hints about DM mass

What are reasonable assumptions when looking for it?

- particle nature
- non-gravitational interactions with particles charged under SM
  - $\rightarrow$ thermal equlibrium if annihilation rate $>$ Hubble expansion rate
    $\rightarrow$ freeze-out gives relic abundance

DM mass and the WIMP miracle

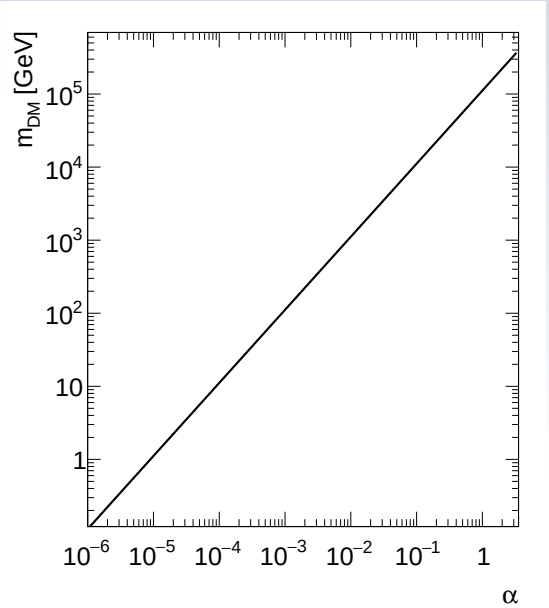
The abundance and rate condition provide a minimum interaction strength $\rightarrow$ experimental sensitivity target.

Mass dependent!

- the already known weak interaction strength and relic abundance gives $m_{DM} \sim$ EW scale

No WIMP observations so far (direct detection, LHC, ...)

- too simplistic?



Toy illustration using Jay Wacker's back-of-the-envelope calculation here:

Freeze-out: rate $\Gamma = H$ at $T = T_{freeze-out} \sim m_{DM}$

use $\Gamma = n\sigma v, H = T^2/M_{Pl}$

Lift assumption of the weak interaction: the mass constraint falls!

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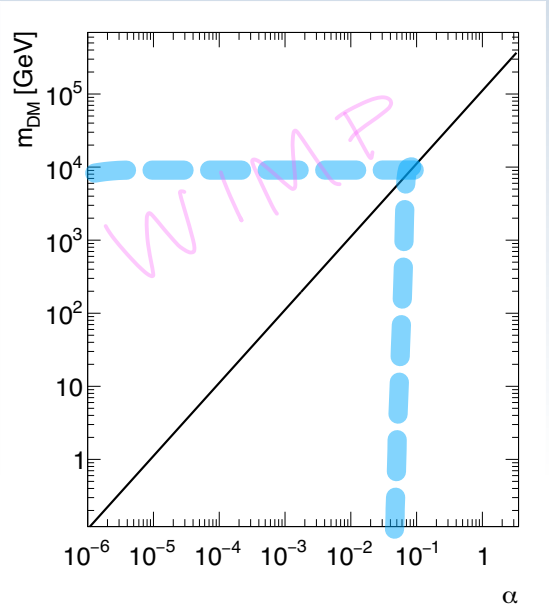

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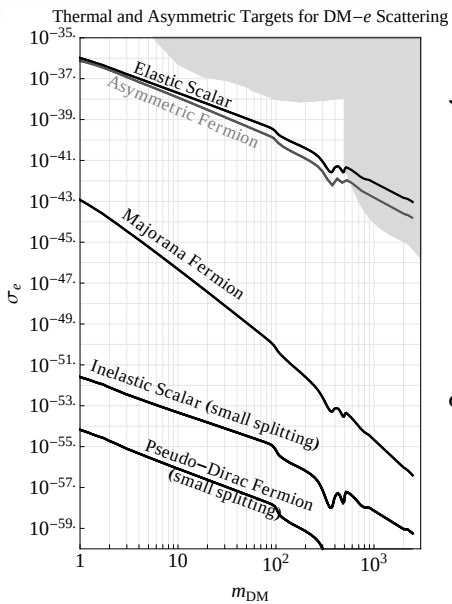
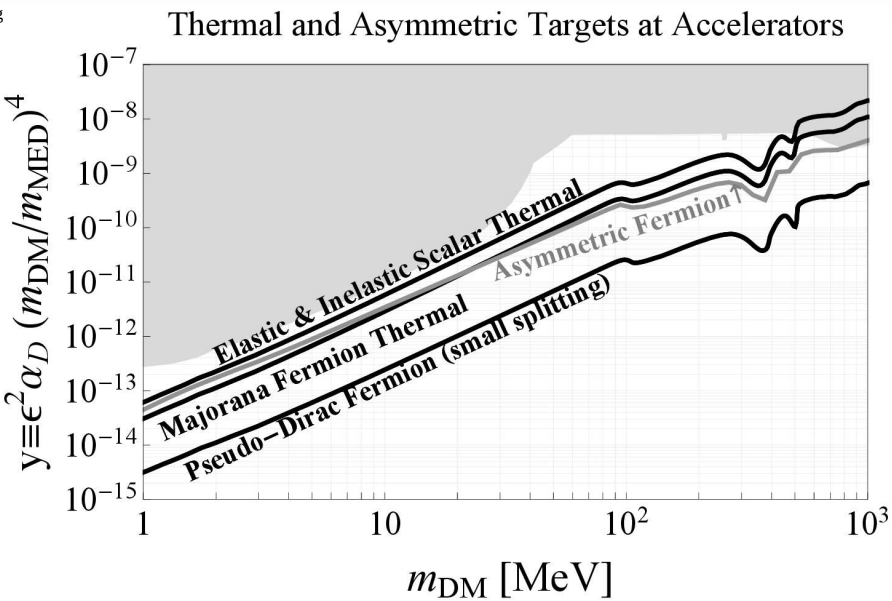
Sub-GeV Dark Matter

The thermal DM model motivates experimental sensitivity in the MeV-GeV regime[1]– but nobody limits us to detecting the stable DM around us...

Accelerator-based mediator detection: complementary to direct detection

- relativistic particles $\rightarrow$ overcomes velocity suppression
- sensitivity to many types of DM particles



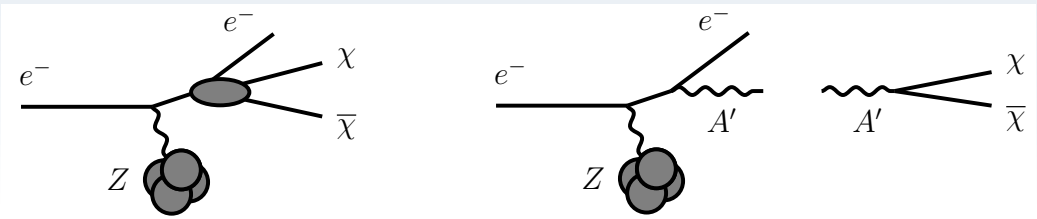


[1] highlighted regime in 2017 US DM community report

Experimental approach

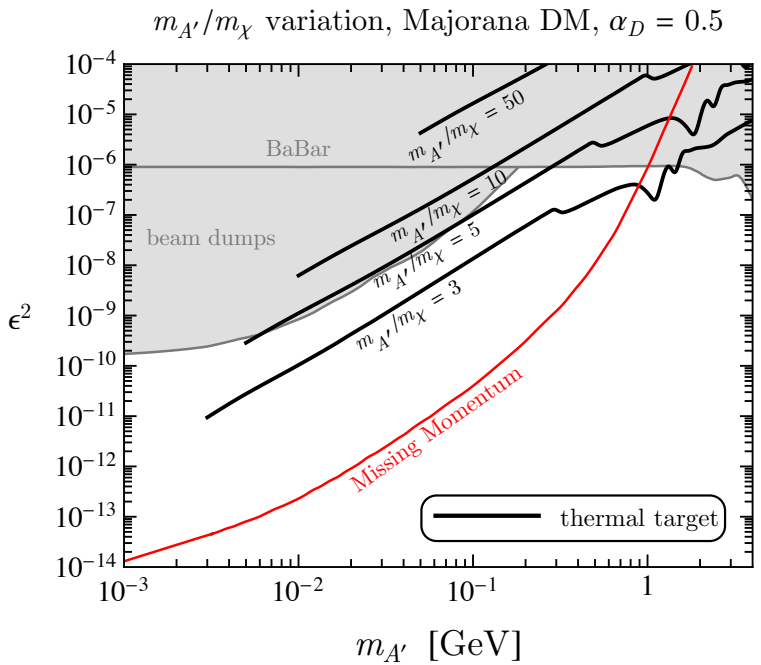
Possibly simplest conceivable model: $U(1)_D$ gauge field in the dark sector $\rightarrow$ massive "dark photon" mediator A'

Sensitivity to dark QED through kinetic mixing ε to photons
$\Rightarrow$ "dark bremsstrahlung" in electric fields



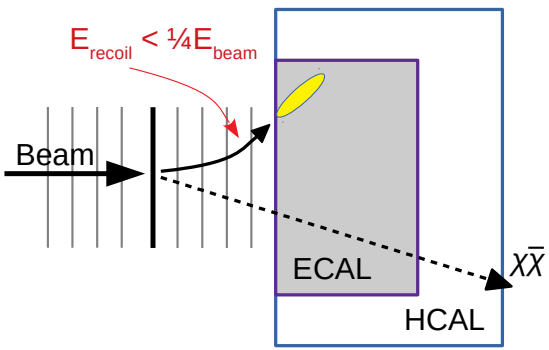
Identifyable with:

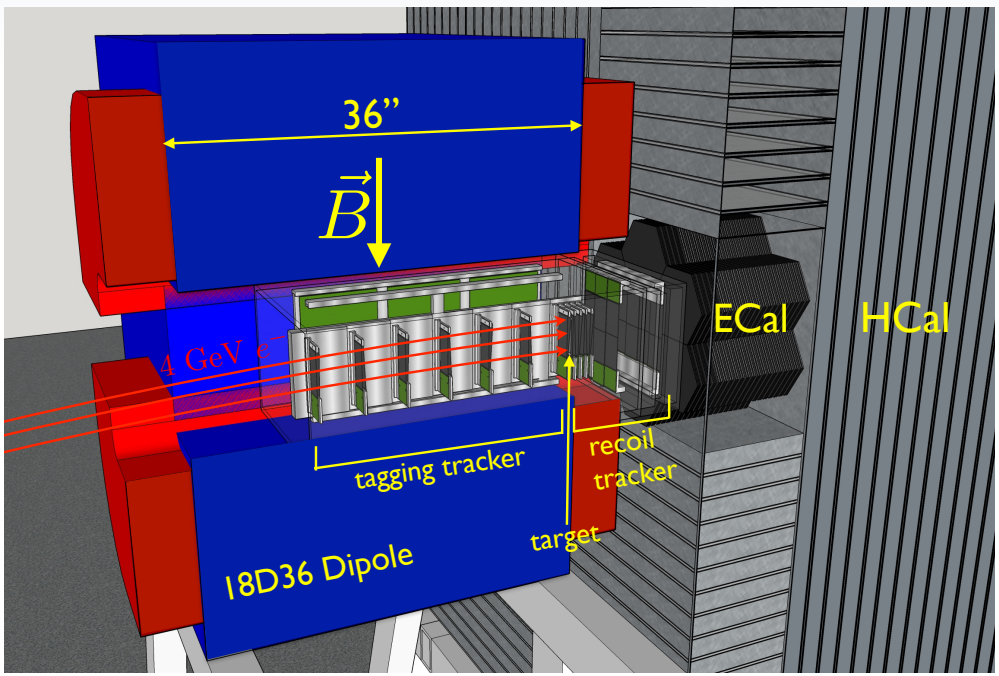
- missing momentum and energy from radiation of a massive particle
- while rejecting QED bremsstrahlung events.



LDMX design

- 4 GeV beam with 1 electron per bunch
- 20ns bunch spacing
- in total 10^{14} electrons on target (EoT)
- thin W target (0.1 radiation lengths (X_0))
- tracker in B-field





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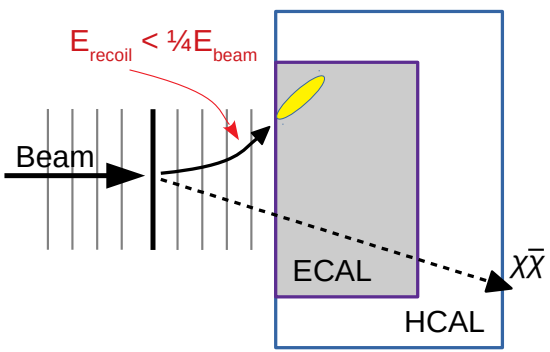

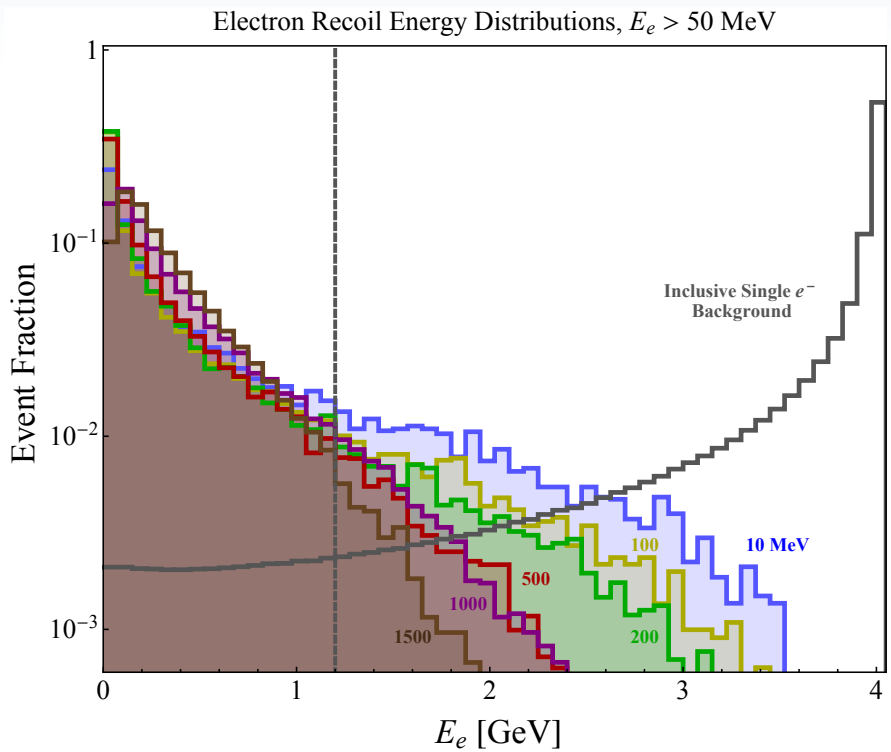

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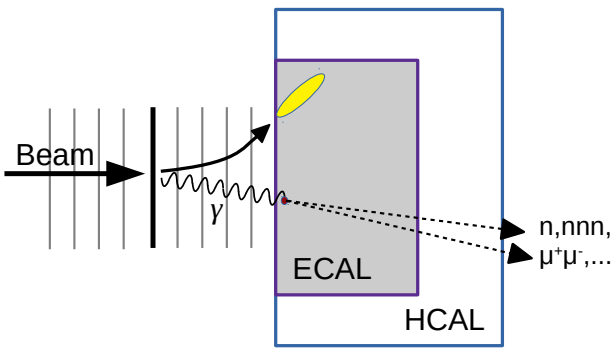

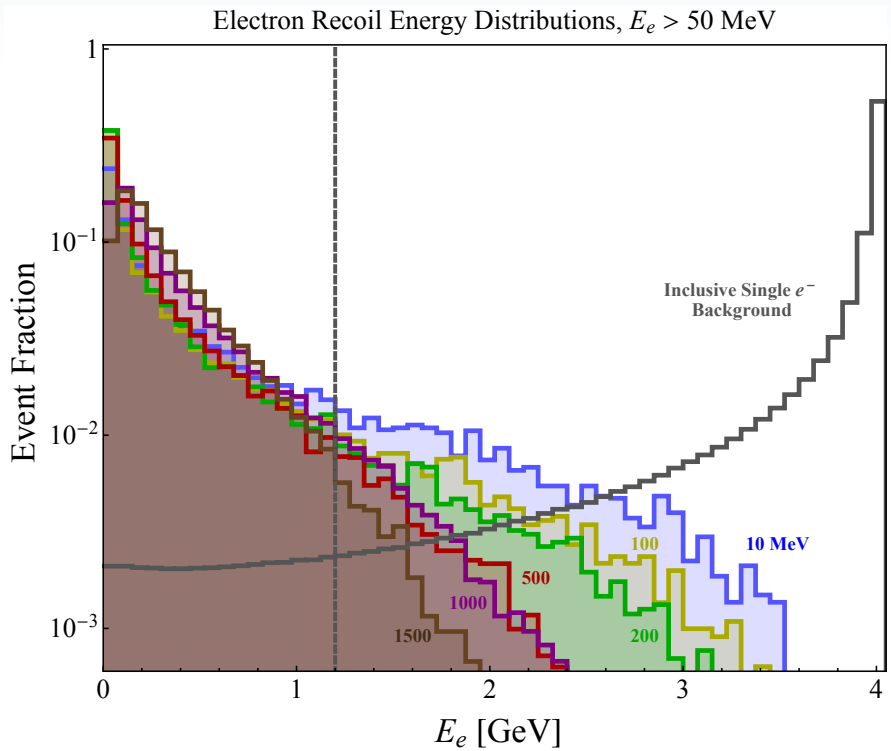

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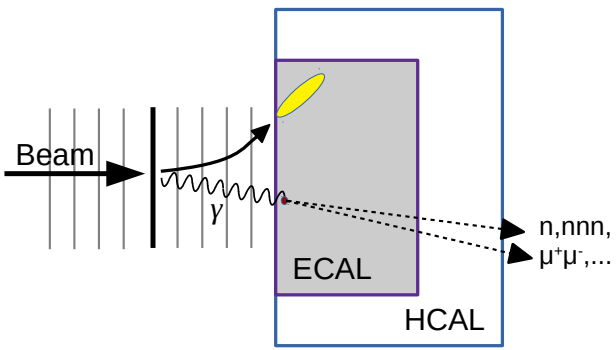

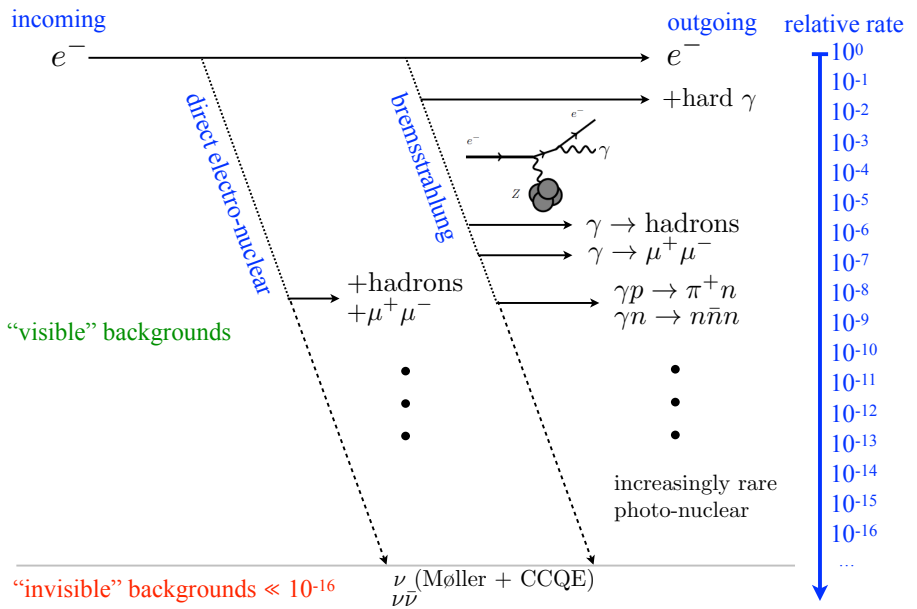

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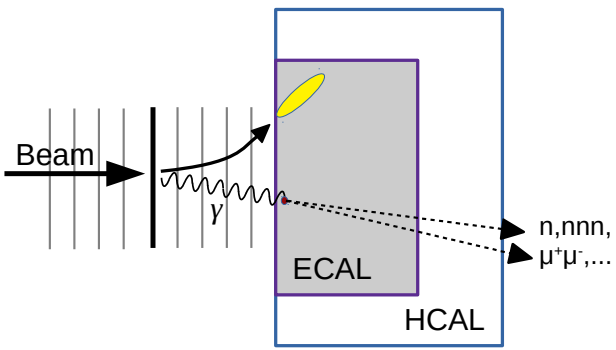
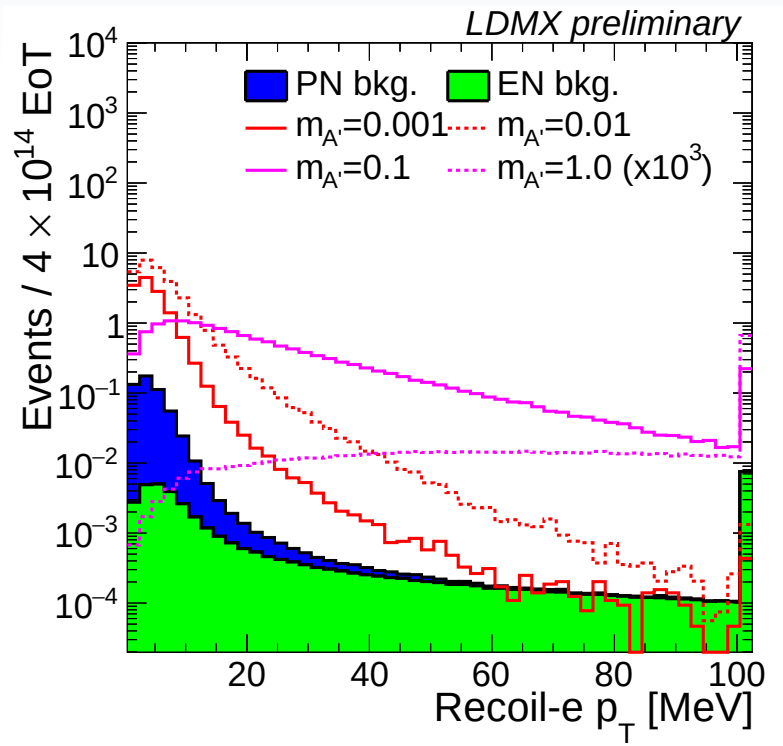




Calorimetry

Electromagnetic sampling calorimeter (ECal)

- Fast, radiation hard, highly granular and deep
  - based on CMS upgrade design (forward Si-W calorimeter)
- Can do MIP tracking (muon rejection)
- Lund University is contributing readout PCB design

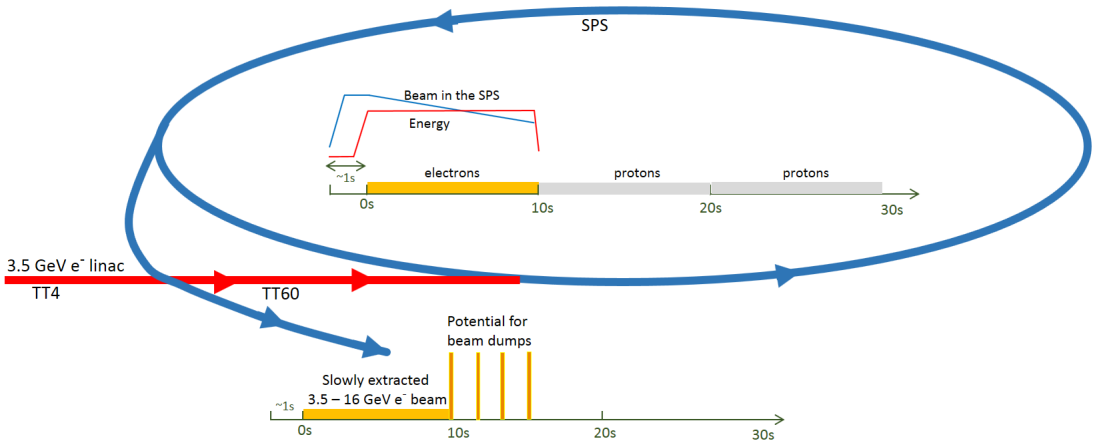
Hadronic sampling calorimeter (HCal)

- Hermetic, granular and fast enough for trigger
  - veto photo-nuclear reactions like $\gamma n \rightarrow nn\bar{n}$
- Plastic scintillator and steel absorber
- Simple veto on N_{cells} above threshold for sensitivity to A' signal
  - displaced vertices in more complicated reality?
- Lund University group focusing on construction and triggering

Plan

White paper in August. Making use of existing technologies, construction start by 2020, data taking foreseen in 2022.

- SLAC: first phase with 4 GeV beam, Phase 2 upgrade to 8 GeV,
- or possibly 16 GeV beam at CERN (as early as 2022):
  - restore electron beam capabilities in SPS (Expression of Interest)
  - electron injector linac based on CLIC technology, fits in existing unused tunnel
  - 12s cycle fits in supercycle of 30-40s for normal proton operation
  - Lund initiative
  - evolving surprisingly quickly; we will know more in half a year



Dark Sector Physics with a Primary Electron Beam Facility at CERN

Torsten Åkesson,[1] Fabio Bossi,[2] Antonio Boveia,[3] Markus Brugger,[4] Lene Bryngemark,[1] Philip N. Burrows,[5,4] Massimo Carpinelli,[6,7] Nuria Catalan,[4] Riccardo Catena,[8] Augusto Ceccucci,[4] James Chappell,[9] Owen Colegrove,[10] Giulia Collura,[10] Jan Conrad,[11] Karel Cornelis,[4] Roberto Corsini,[4] Hans Danielsson,[4] Steffen Doebert,[4] Caterina Doglioni,[1] E. C. Dukes,[12] Yann Dutheil,[4] Valentina Dutta,[10] Bertrand Echenard,[13] Lyn Evans,[4] Matthew A. Fraser,[4] Alexander Friedland,[14] Jonathan Gall,[4] Jake S. Gessner,[4] Brennan Goddard,[4] Norman Graf,[14] R. C. Group,[12] Alexej Grudiev,[4] Edda Gschwendtner,[4] Vincent Hedberg,[1] Joshua Hiltbrand,[15] David Hitlin,[13] Joseph Incandela,[10] Lars Jensen,[4] Robert Johnson,[16] Rhodri Jones,[4] Venelin Kozhuharov,[17] Gordan Krnjaic,[18] Mike Lamont,[4] Andrea Latina,[4] Thibaut Lefevre,[4] Emanuele Leonora,[19] Fabio Longhitano,[19] Else Lytken,[1] Jeremiah Mans,[15] Takashi Maruyama,[14] Jeremy McCormick,[14] Gerard Mcmonagle,[4] Eric Montesinos,[4] Omar Moreno,[14] Patric Muggli,[4] Geoffrey Mullier,[1] Timothy Nelson,[14] Gavin Niendorf,[10] John A. Osborne,[4] Yannis Papaphilippou,[4] Reese Petersen,[15] Ruth Pöttgen,[1] Javier Prieto,[4] Mauro Raggi,[20] Nunzio Randazzo,[19] Alexander Read,[21] Carlo Rossi,[4] Daniel Schulte,[4] Philip Schuster,[14,22] Valeria Sipala,[6,7] Steinar Stapnes,[4] Igor Syratchev,[4] Natalia Toro,[14,22] Nhan Tran,[18] Domenico D'Urso,[6,7] Paolo Valente,[23] Andrew Whitbeck,[18] and Walter Wuensch[4]

[1]*Lund University, Department of Physics, Box 118, 221 00 Lund, Sweden*
[2]*INFN Laboratori Nazionali di Frascati, Italy*
[3]*The Ohio State University, Department of Physics and Center for Cosmology and Astroparticle Physics, 191 W. Woodruff Ave., Columbus, Ohio 43210, USA*

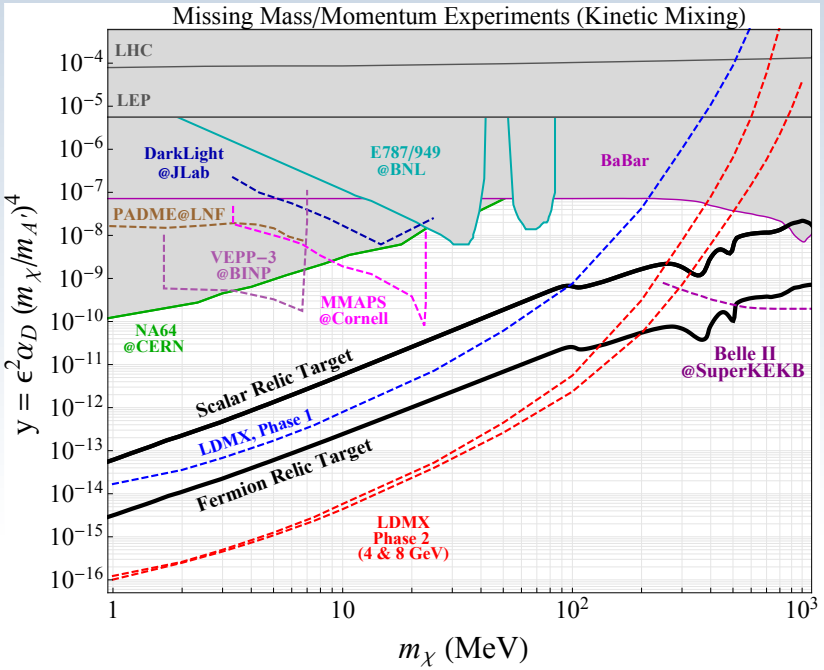
Phase 2 implications

- $10^{14} \rightarrow 10^{16}$ electrons on target

$\Rightarrow$ $n_e = O(10)$ electrons per bunch

- W $\rightarrow$ Al target with $0.4X_0$

Phase 1 Phase 2



$\Rightarrow$ higher xsec for photo- and electro-nuclear interactions
  - but more collimated at 16 GeV beam energy

$\Rightarrow$ need to be able to reject background from overlaid electrons in HCal while retaining signal sensitivity

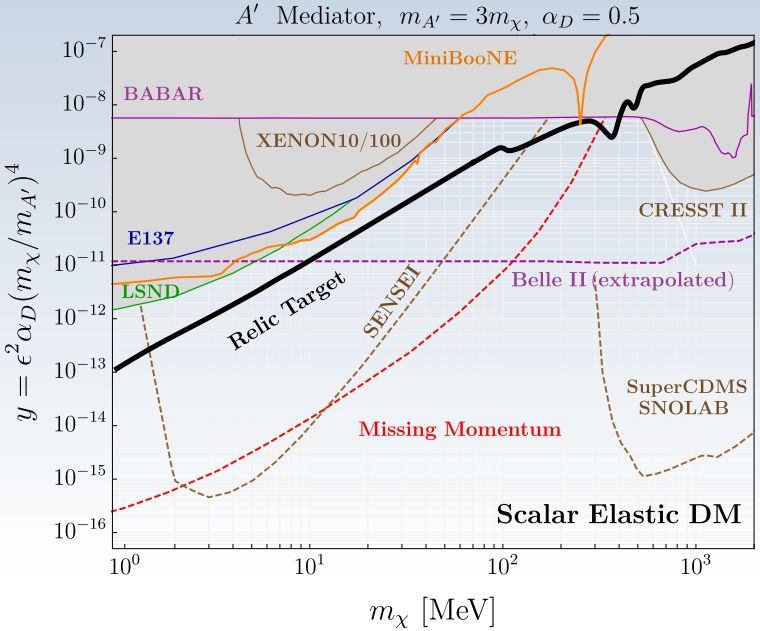
This, and enhanced sensitivity to more "exotic" DM models, motivates Lund University focus on HCal and Phase-2 triggering.

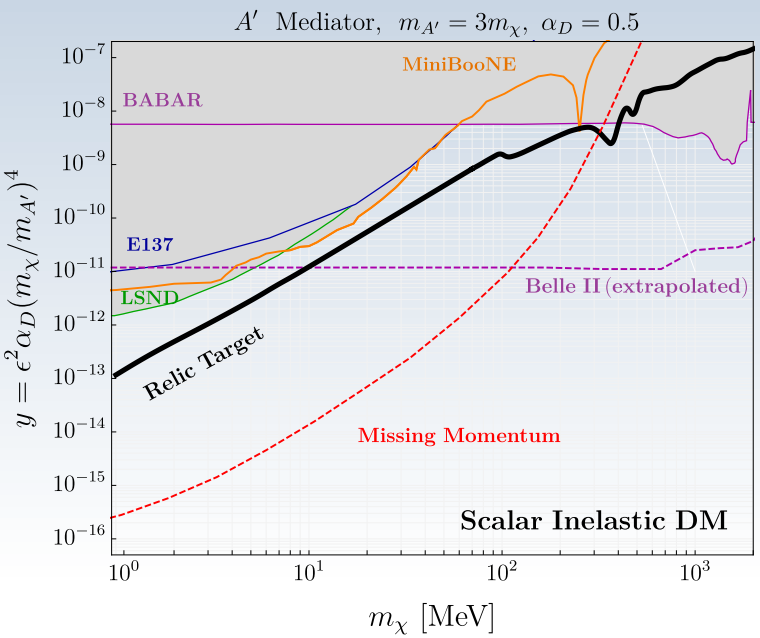
Conclusions

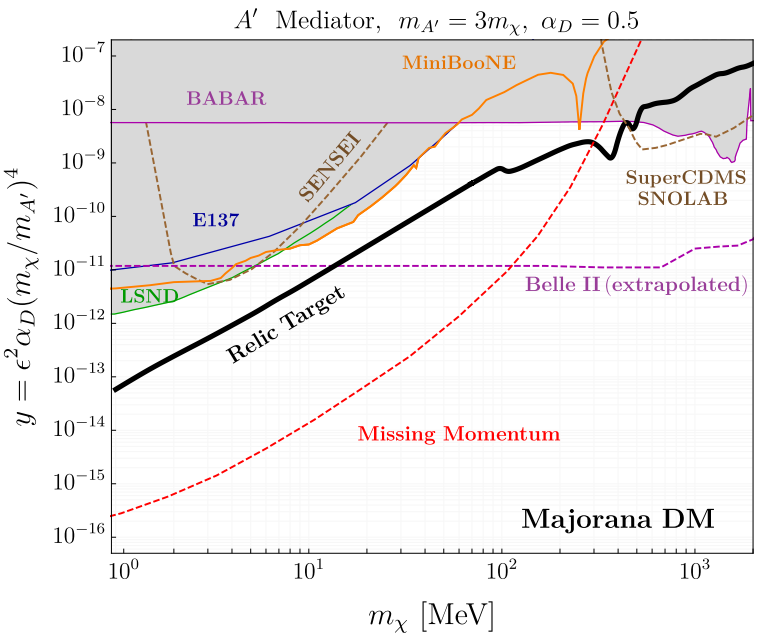
- The sub-GeV mass regime for DM is well motivated and insufficently explored
- LDMX is being designed to achieve unprecedented sensitivity in this regime
  - data-taking in early 2020's
- A wide range of DM and other BSM models can be probed
  - conclusive results on viable thermal targets within reach
  - rich physics landscape explored in this paper on extended physics potential
- The Lund University group is contributing to this effort in the areas of calorimetry and triggering, and is the driving force behind the CERN scenario.

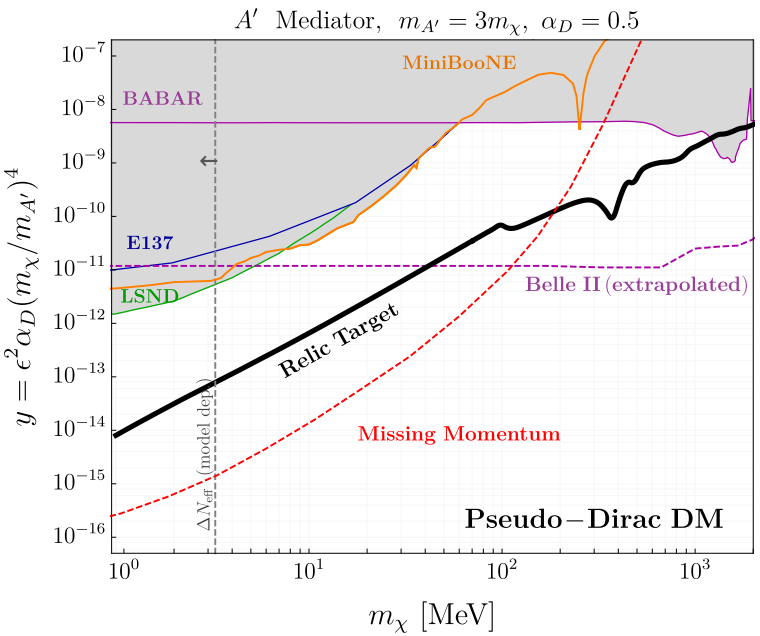
Backup

Comparison to other existing/upcoming searches

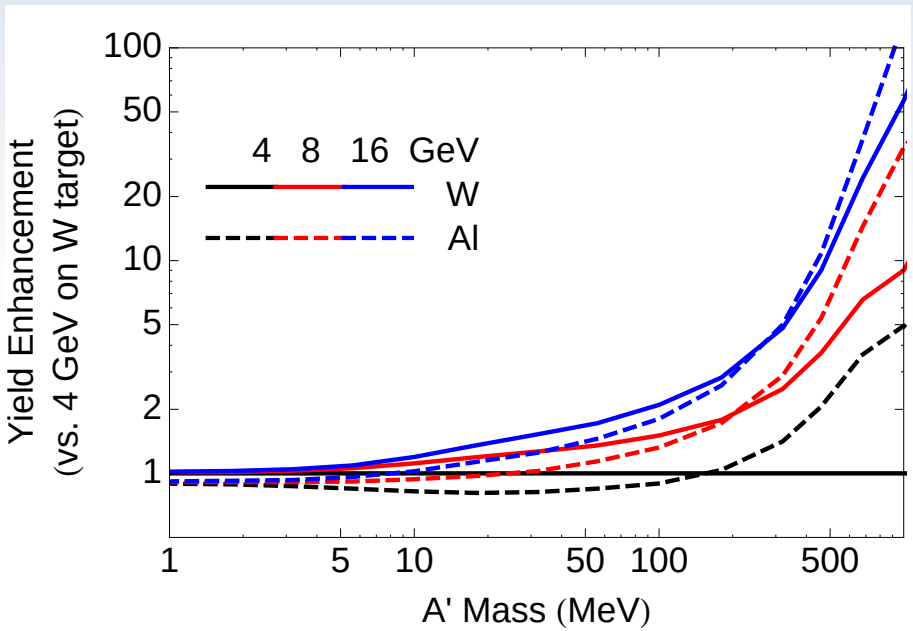




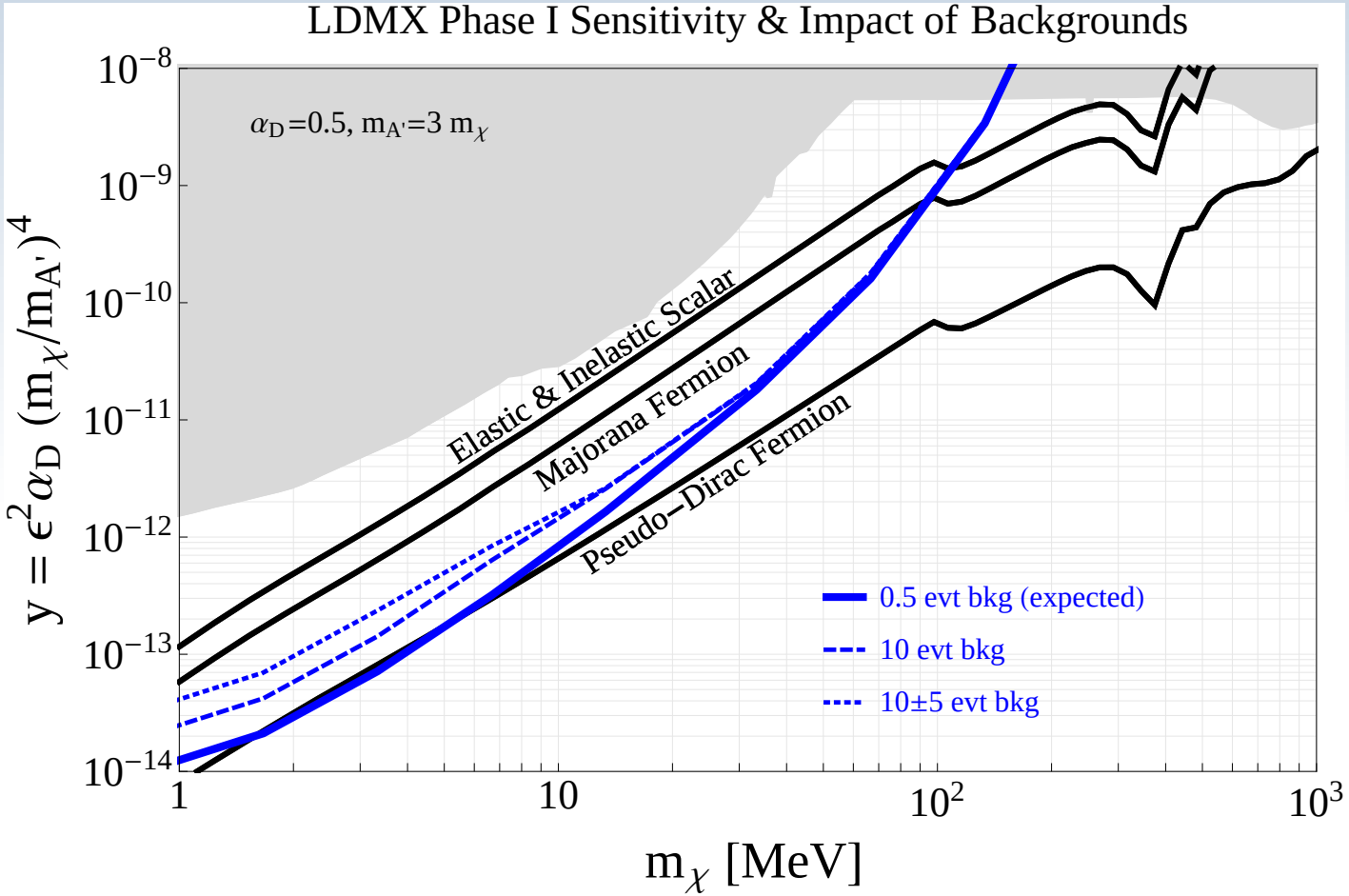




Signal yield at different beam energy/target

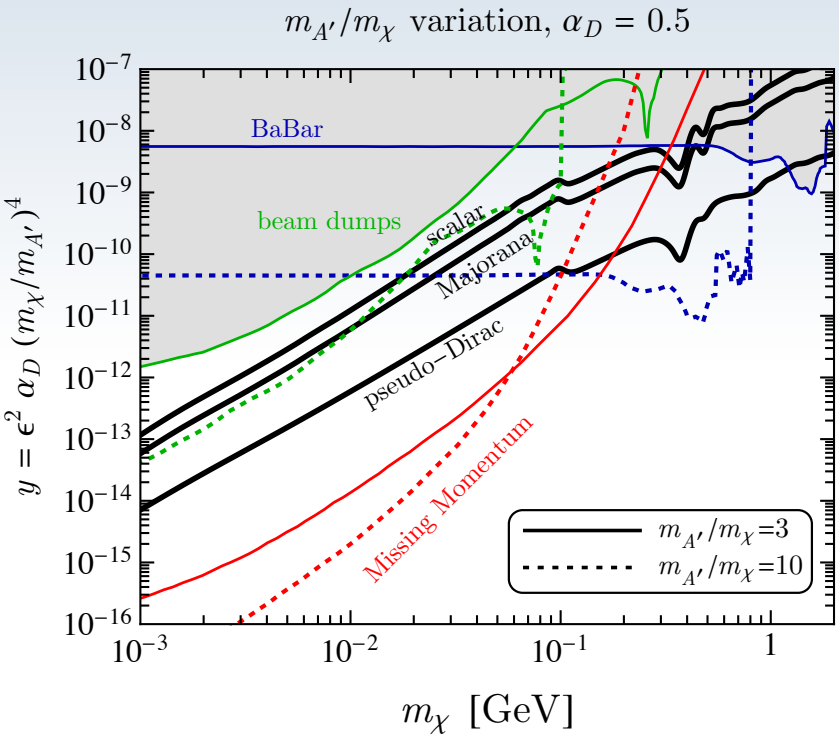


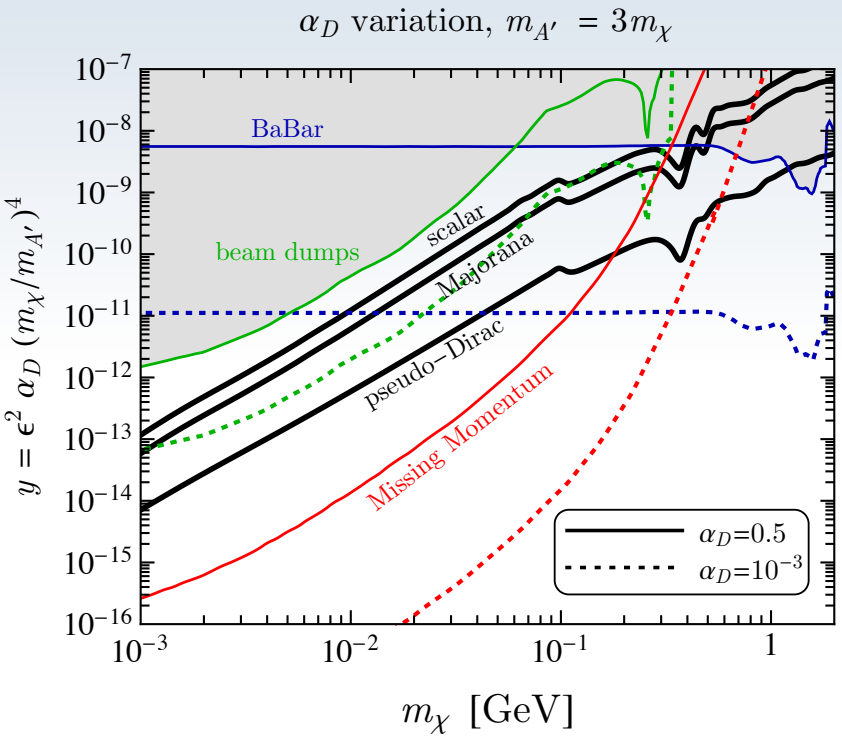
Reach with background uncertainty



Including the possibility of larger backgrounds than expected

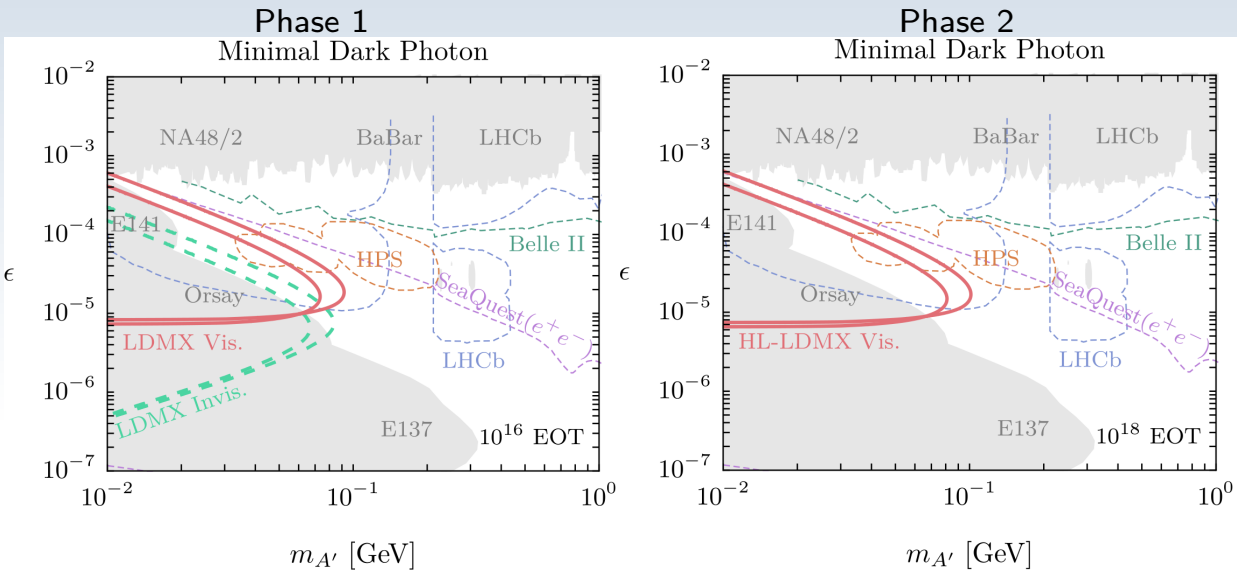
Parameter variations



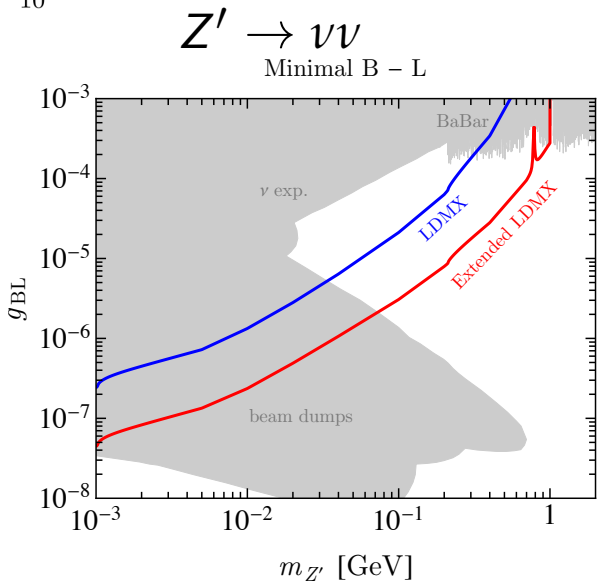


LDMX sensitivity to other physics scenarios

Paper on extended physics potential for more about axions, ADM, ...



Visibly decaying DM. Displaced vertices..?



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  - $\sim$ 30 layers of 7 hexagonal modules
  - 40 radiation lengths
- Can do MIP tracking (muon rejection)

Hadronic sampling calorimeter (HCal)

- Hermetic, granular and fast enough for trigger
  - veto photo-nuclear reactions like $\gamma n \to nn\bar{n}$
  - range of neutron energies
- Plastic scintillator and steel absorber
  - alternating bars in x, y of $1.5 \times 5 \times 300$ cm
- Simple veto on N_{cells} above threshold for sensitivity to A' signal
  - displaced vertices in more complicated reality?