Light Dark Matter & Electron Beam Experiments

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"Dark Interactions" BNL Workshop

Outline

- **“Light” Dark Matter (LDM)**
- Context for Experimental Opportunities
- Beam dump dark matter experiment (BDX)

Bright and Dark Matter

We are not alone...

New type(s) of particle

Well-understood theory of **particles**, with interactions dictated by QM & Relativity

There is more to the Universe than the Standard Model matter

But where do we look?

Hunting Dark Matter

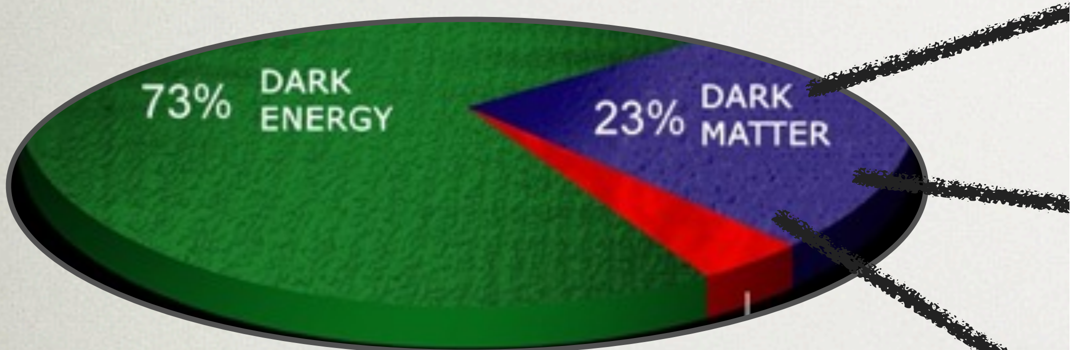
Is it simple, or complex?

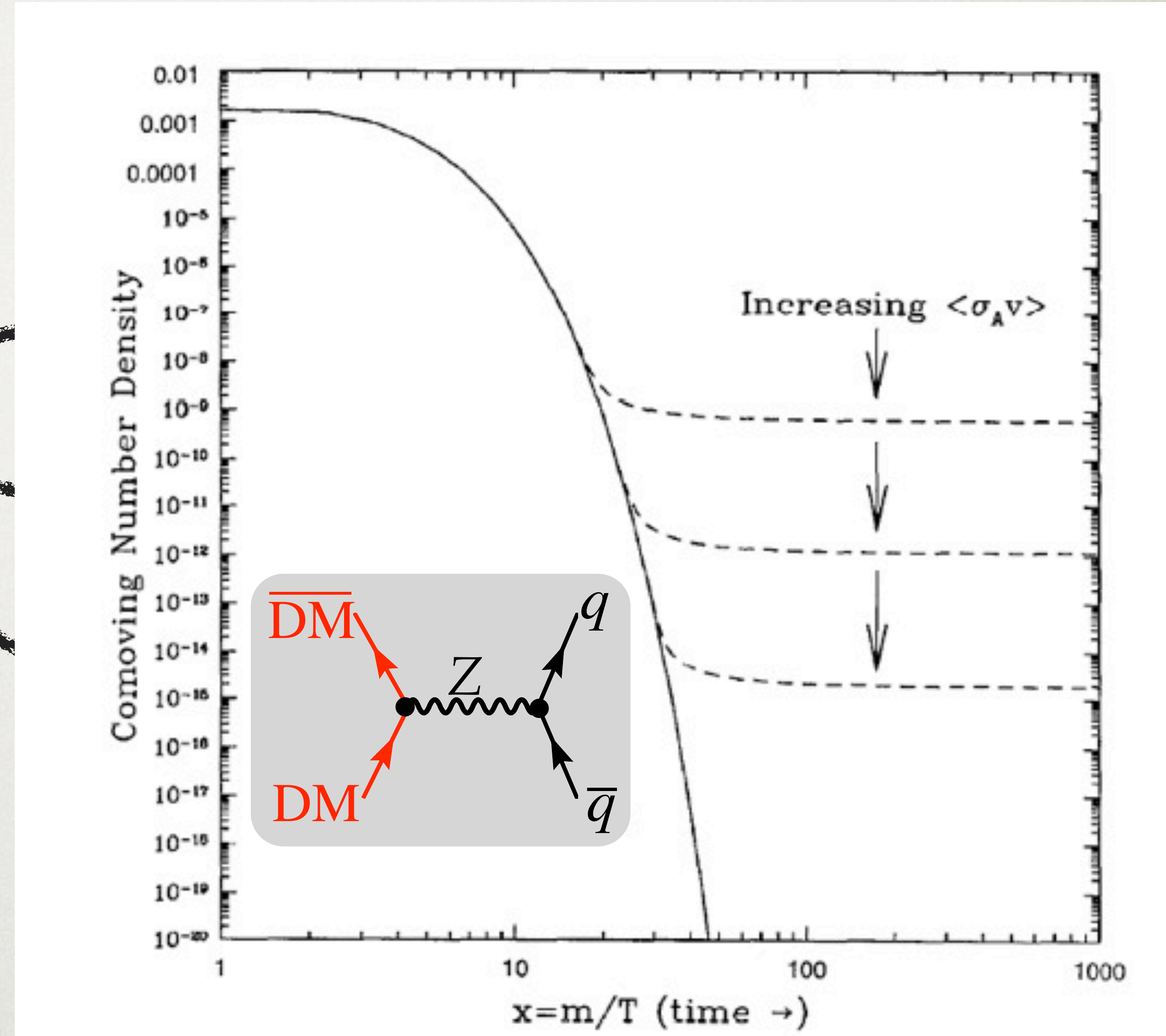
Is it just like us?
Or something really new?

Where did it come from?
What else can it teach us?

All evidence for dark matter is from gravitational effects –
we know very little about other interactions

Hunting Dark Matter

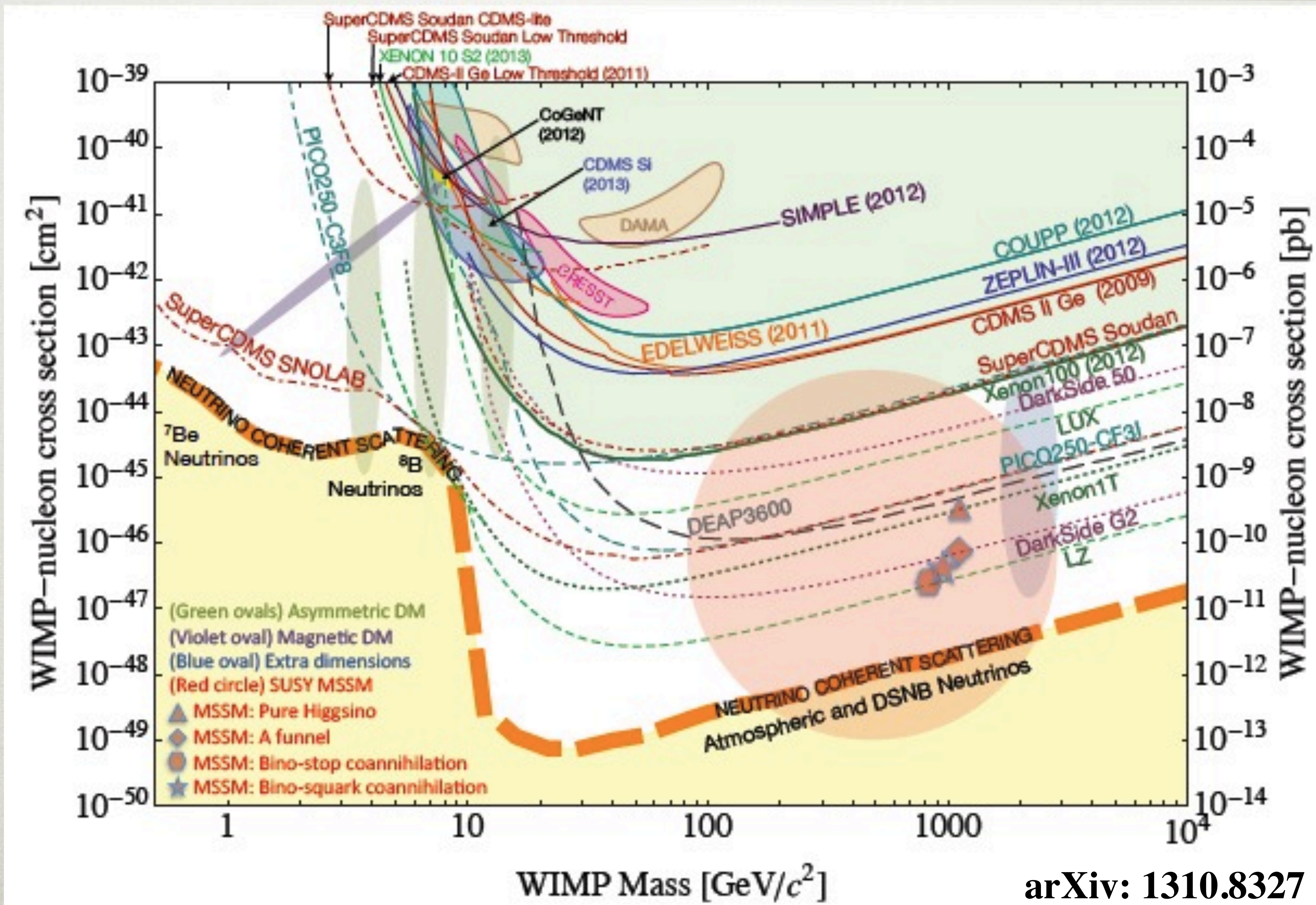




Thermal origin of dark matter suggests interactions with Standard Model matter

Direct Detection Program

Dark matter searches target the “weak-scale” paradigm



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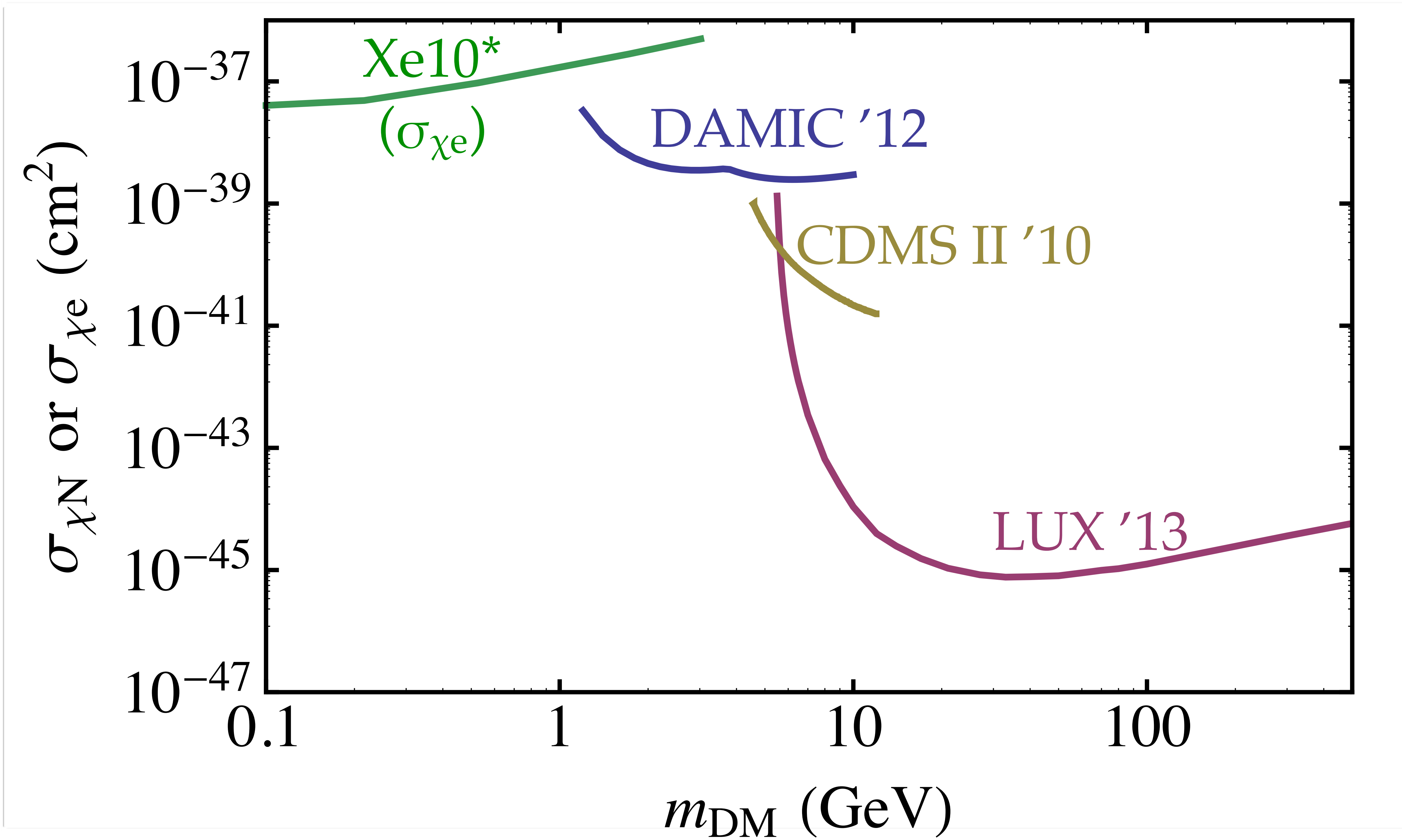
Towards Light DM

Direct detection results will test the possibility that dark matter interacts via weak-interaction mediators

Null results from LHC and direct detection challenging "standard" BSM paradigm for weak-scale physics
...maybe WIMP picture is too narrow...

General shift in thinking -- explore more broadly!

Explore More Broadly



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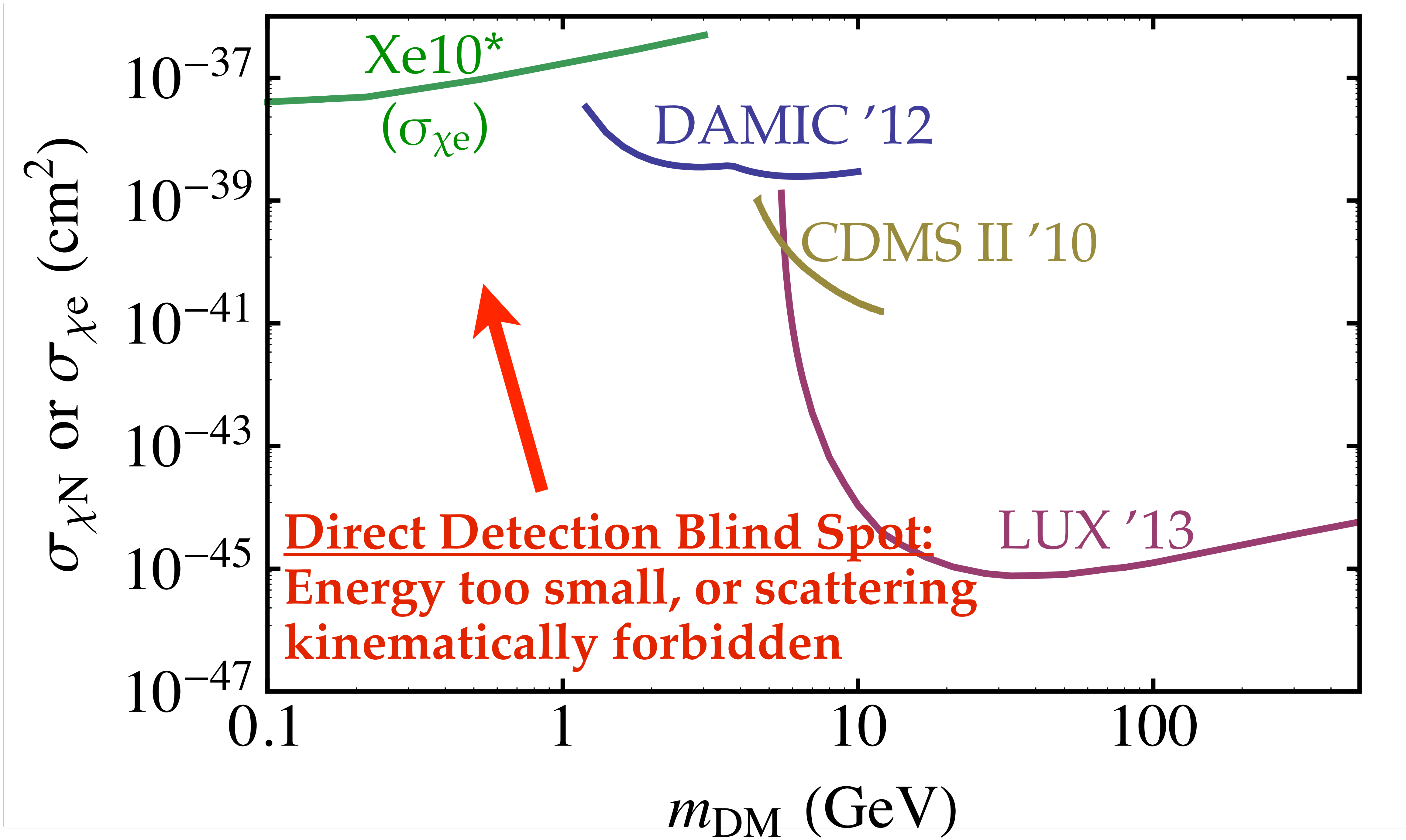
Explore More Broadly



Light Dark Matter

Relatively unexplored frontier!

Makes more sense in the context of hidden (or dark) sectors

Hidden Sector DM

New matter & forces?

$U(1)_D \times \ldots$

***dark forces** could be like strong (confined), weak (higgsed), or EM (long-range)*

$U(1)_Y \times SU(2)_W \times SU(3)_s$

EM weak strong

Dark matter could be part part of a hidden (or dark) sector: DM may carry gauge interactions with itself, but not be charged under Standard Model

Hidden Sector DM

New matter & forces?

$U(1)_D \times \ldots$

dark forces *could be like strong (confined), weak (higgsed), or EM (long-range)*

$U(1)_Y \times SU(2)_W \times SU(3)_s$

EM weak strong

Simple example scenario:

$$\mathcal{L}_D = \bar{\Psi}_D \gamma^\mu (\partial_\mu - i g_D A'_\mu) \Psi_D$$

dark matter fermion (or scalar) charged under a U(1)′

Hidden Sector DM

New matter & forces?

$U(1)_D \times \ldots$

***dark forces** could be like strong (confined), weak (higgsed), or EM (long-range)*

$U(1)_Y \times SU(2)_W \times SU(3)_s$

EM weak strong

But how can such dark sector dark matter interact with Standard Model?

Dark Sectors & The "Portals"

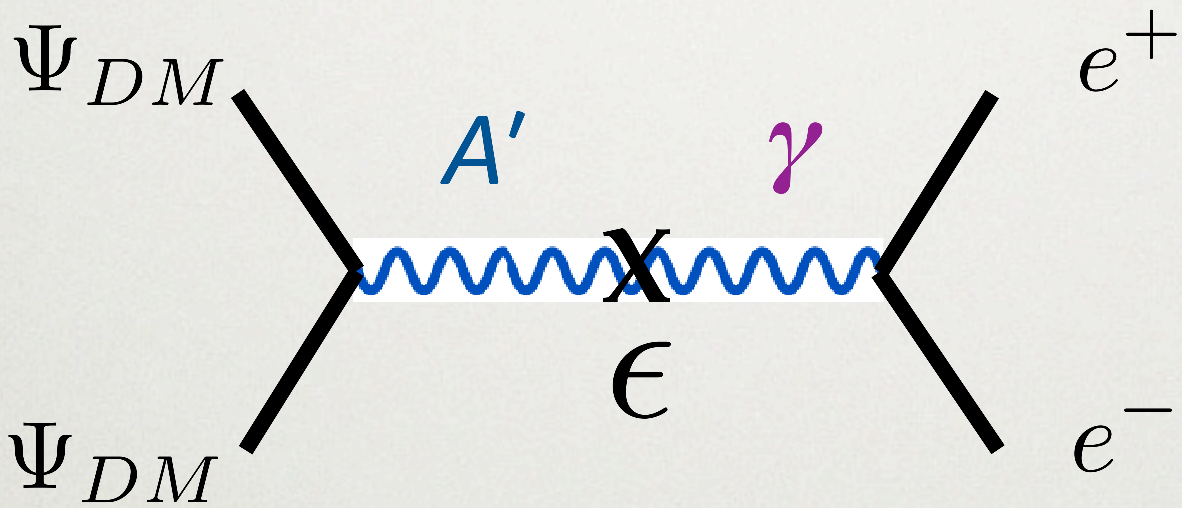
Small number of interactions allowed by Standard Model symmetries with dimensionless couplings

this means they can be sizeable irrespective of "where" they come from

Vector Portal	$\frac{1}{2}\epsilon_Y \, F^Y_{\mu\nu} F'^{\mu\nu}$	kinetic mixing?
Higgs Portal	$\epsilon_h \, \lvert h\rvert^2 \lvert\phi\rvert^2$	exotic rare Higgs decays?
Neutrino Portal	$\epsilon_\nu \, (hL)\psi$	not-so-sterile neutrinos?

Hidden Sector DM

Loop-level suppressed link between dark sector and Standard Model:



+ other modes

$$\sigma v \sim \frac{\alpha_D \alpha \epsilon^2}{m_{DM}^2}$$

LDM Intro Summary

LDM with thermal origin makes good sense in the context of dark sectors (weak coupling to SM with GeV-scale mass)

natural extension of the SM with sharply defined range of accessible phenomenology
[often motivated by discrepancies: g-2, cosmic rays...etc]

But what can be done to learn about LDM?

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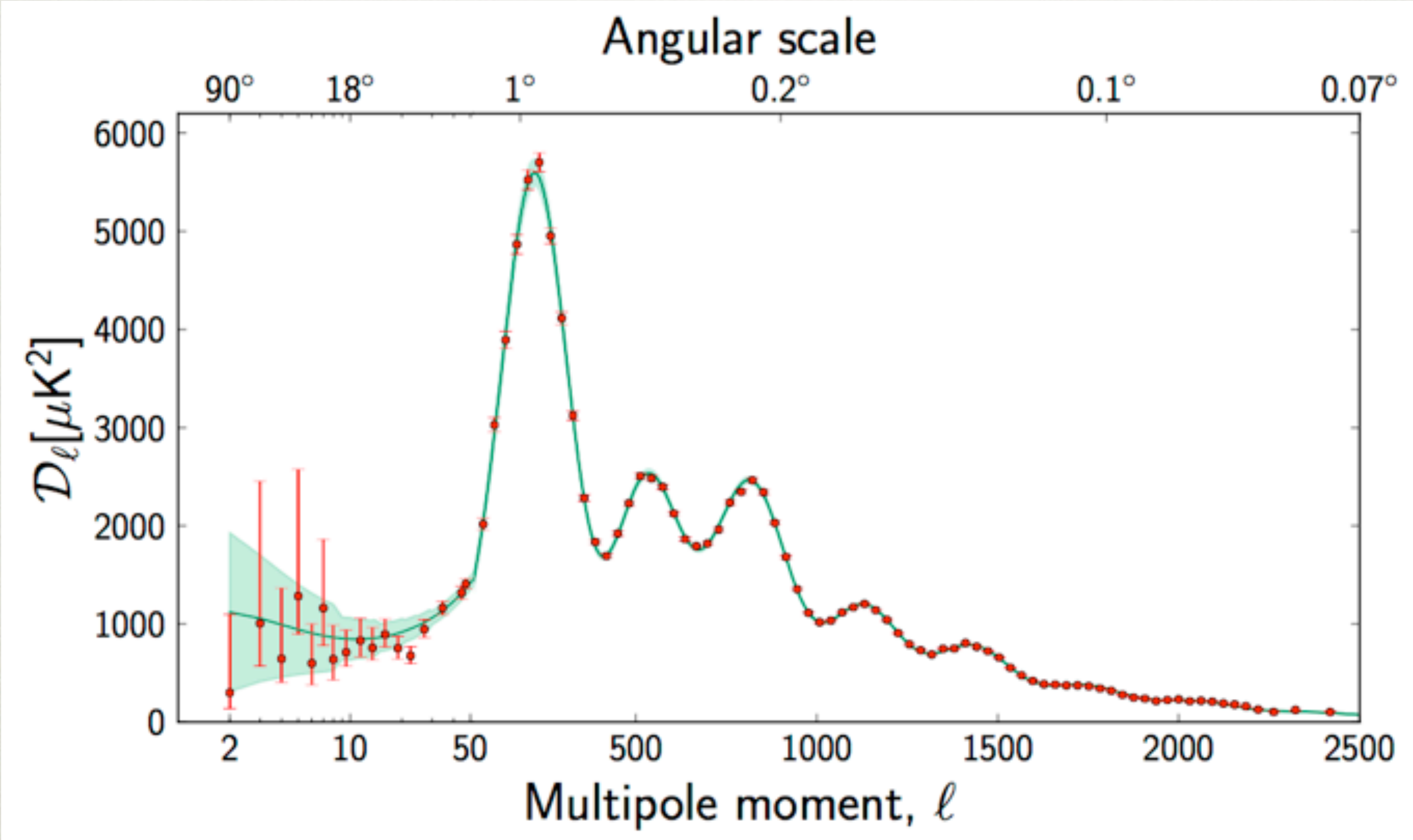
- **Context for Experimental Opportunities**
- Beam dump dark matter experiment (BDX)

LDM Cosmology



late time annihilation of dark matter into charged particles increases ionization of IGM near recombination: suppression of high-l CMB modes

LDM Cosmology

residual late-time annihilation important to consider for low mass dark matter

For O(1) annihilation to charged particles:

$$\sigma v \lesssim \left(\frac{m_{DM}}{10\ GeV}\right) \times 10^{-26} cm^3/s$$

[using Planck, ACT, SPT; see 1301.0819 for discussion]

LDM Cosmology

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$$\sigma v \lesssim \left(\frac{m_{DM}}{10\ GeV}\right) \times 10^{-26} cm^3/s$$

[using Planck, ACT, SPT; see 1301.0819 for discussion]

Is light dark matter ruled out?

LDM Cosmology

residual late-time annihilation important to consider for low mass dark matter

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$$\sigma v \lesssim \left(\frac{m_{DM}}{10\ GeV}\right) \times 10^{-26} cm^3/s$$

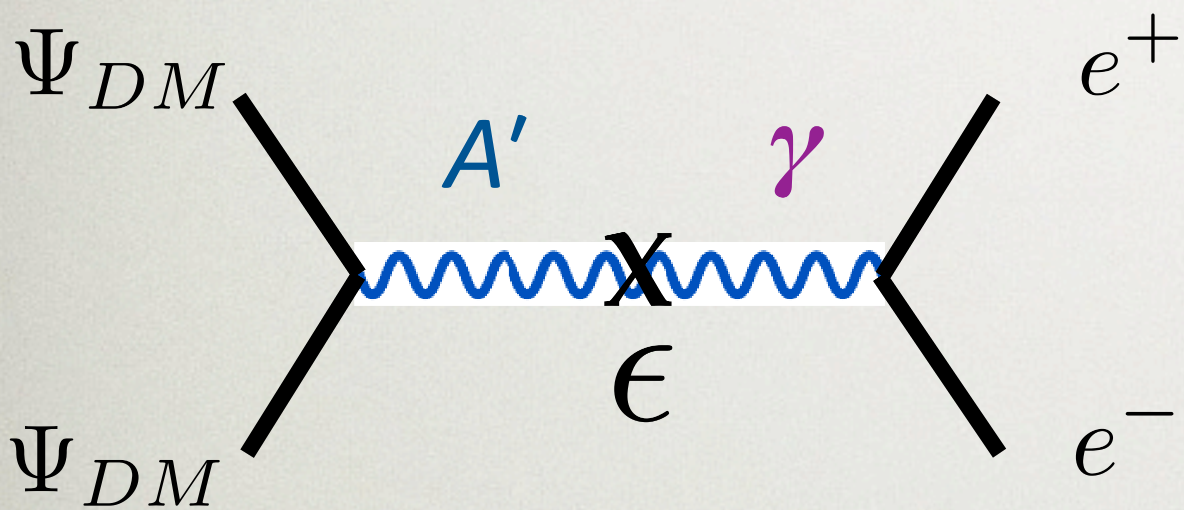
[using Planck, ACT, SPT; see 1301.0819 for discussion]

Is light dark matter ruled out? **No!**

LDM Cosmology

CMB constrains annihilation at recombination, long after LDM freezes out (for GeV-scale masses)

If DM is a **scalar** annihilating to SM particles:



+ other modes

Annihilation is p-wave suppressed:

$\sigma v \propto v^2$ → For MeV-GeV scale masses, perfectly **compatible with CMB**

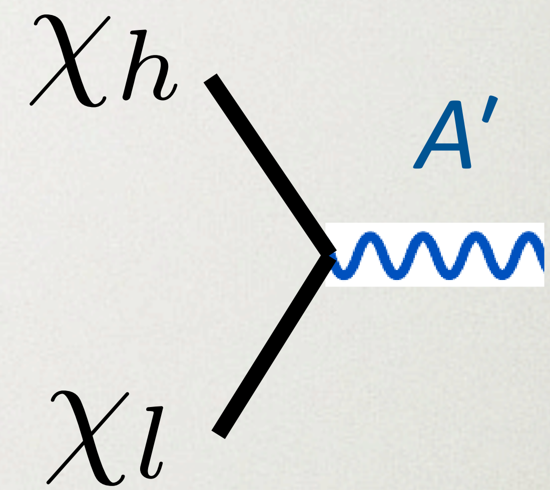
LDM Cosmology

LDM can come in Majorana fermion pairs
(i.e. “inelastic” DM)

χ_h
χ_l

small
mass
splitting

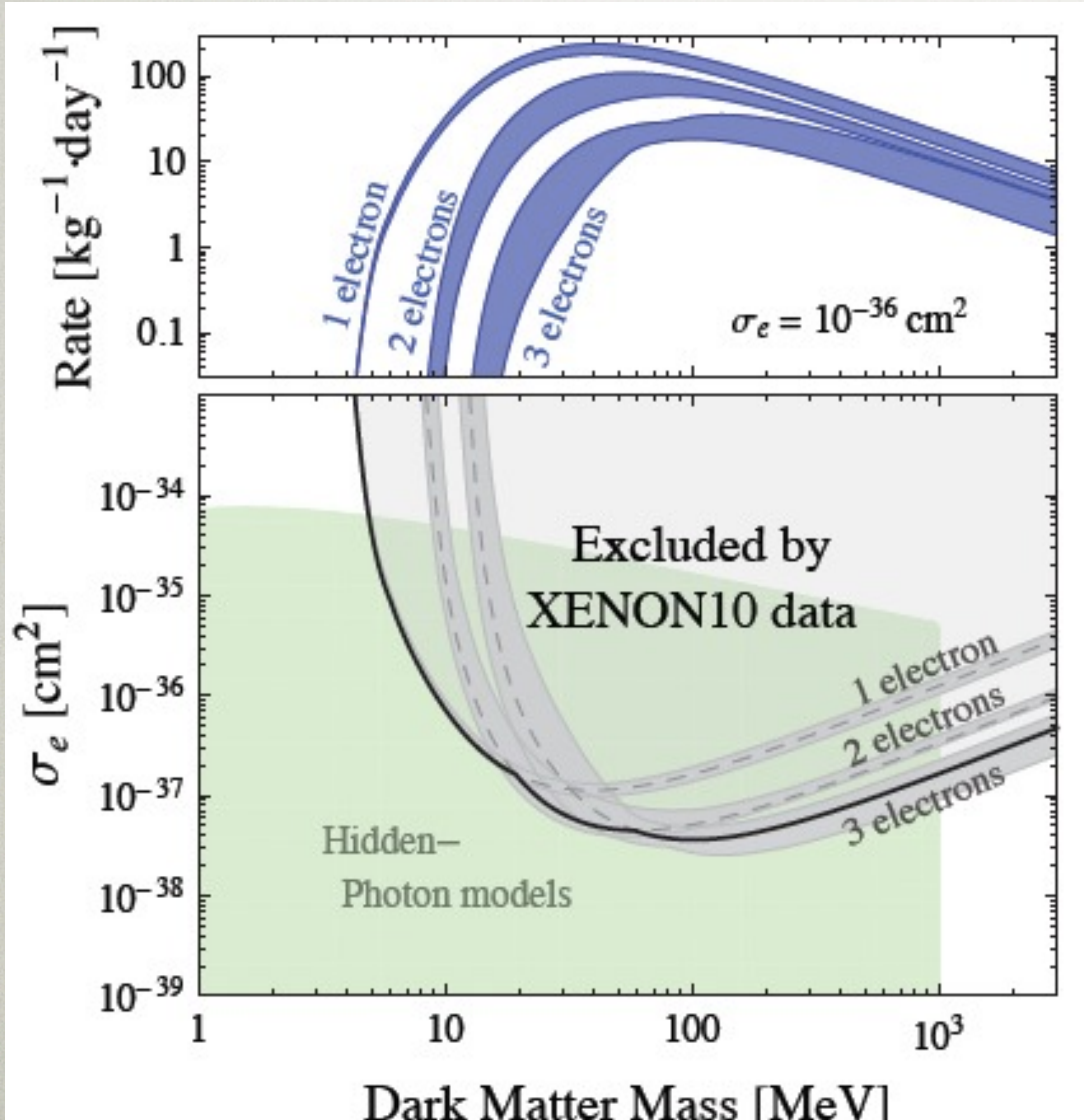
Annihilation
channel:



$\chi_l \chi_l$ annihilation channels are one-loop or three-body suppressed

χ_h is depleted by scattering before recombination,
hence negligible late time annihilation
CMB is fine

LDM Direct Detection



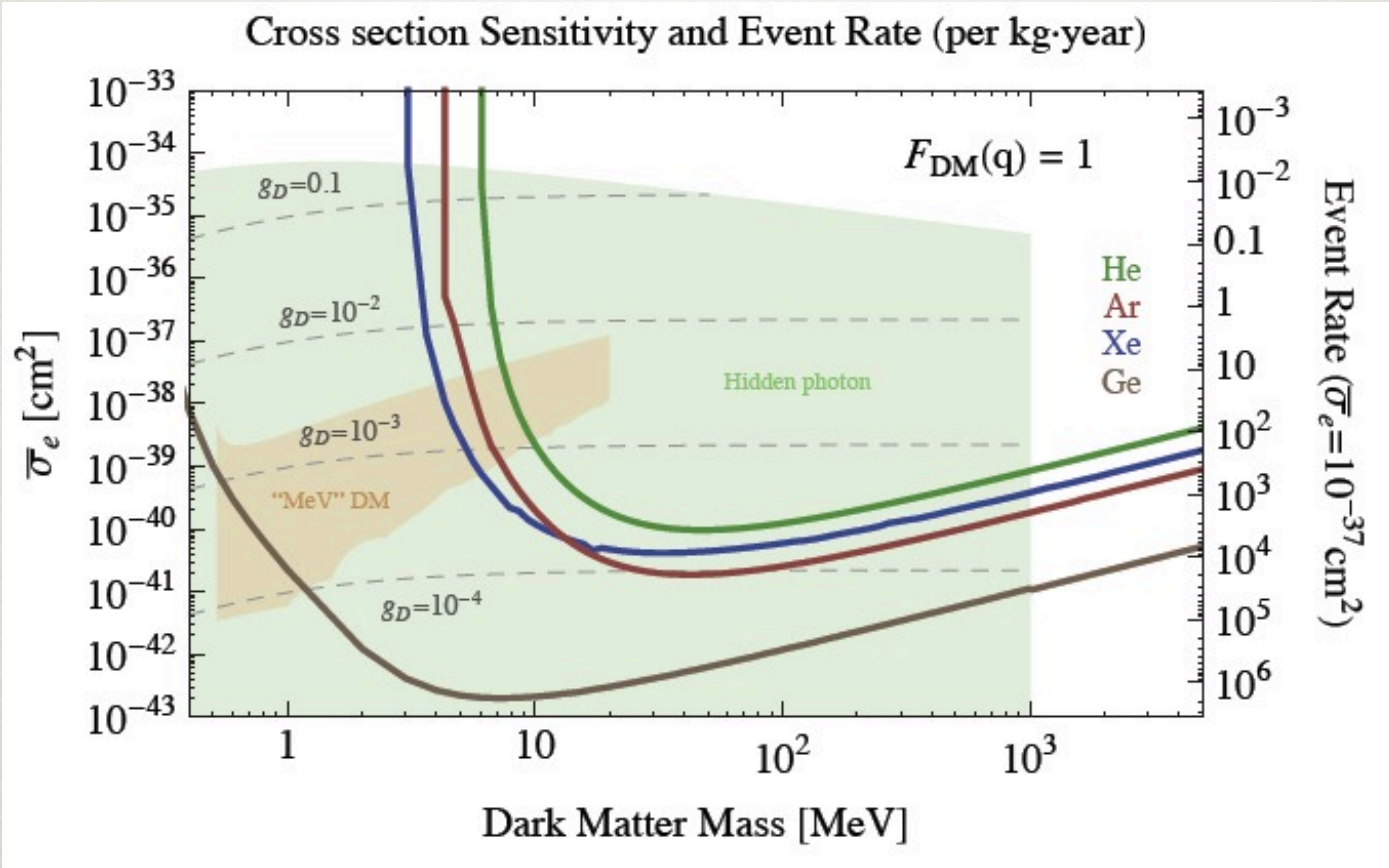
1206.2644

~10 eV threshold for DM-electron scattering to ionize electron(s)

LDM Direct Detection

Exposure limited prospects

1108.5383



Valuable to push sensitivity down!

Broad Experimental Effort Needed

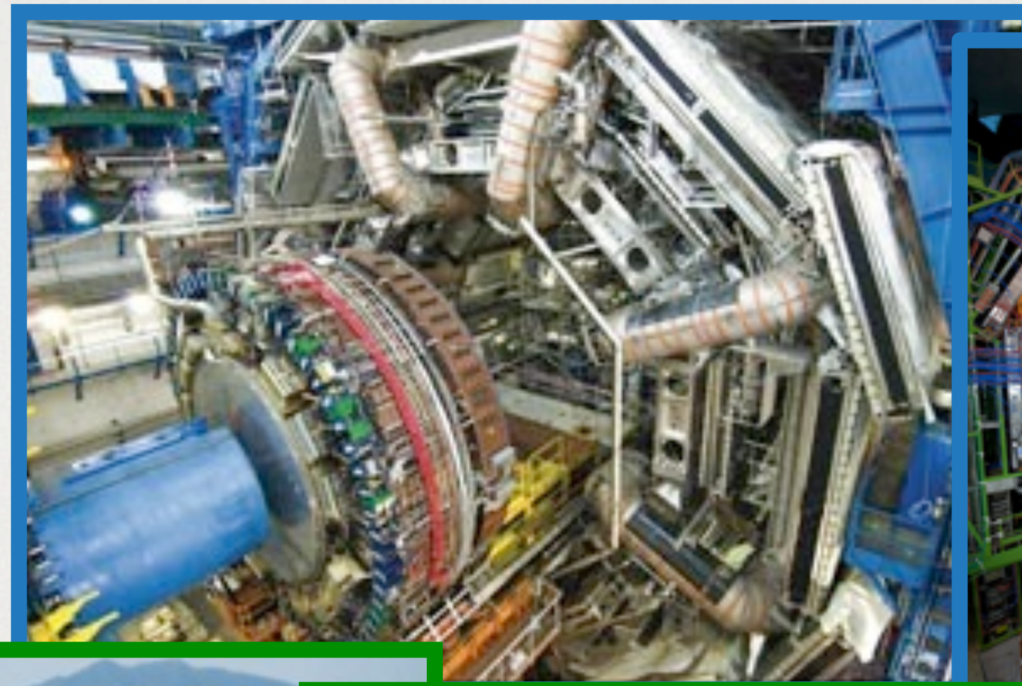
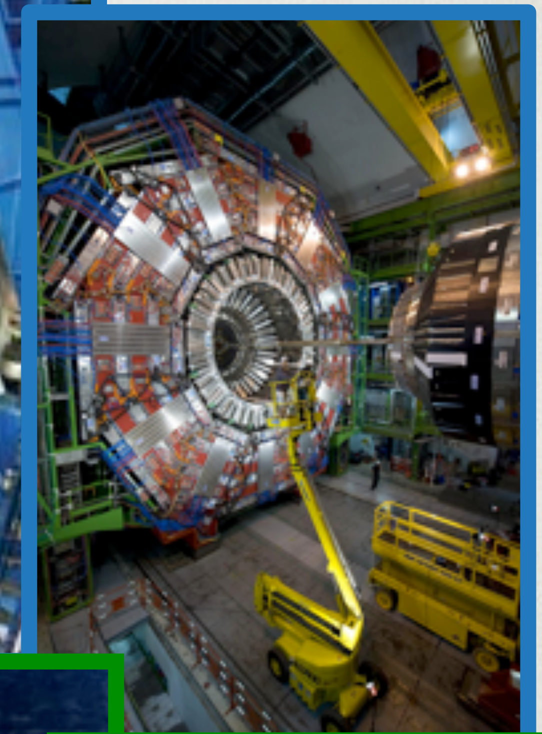
Pushing direct detection sensitivity is important

LDM with nonzero mass splittings (i.e. iDM) has highly suppressed direct detection rates

Important to have other robust techniques to produce and search for LDM and associated light mediators

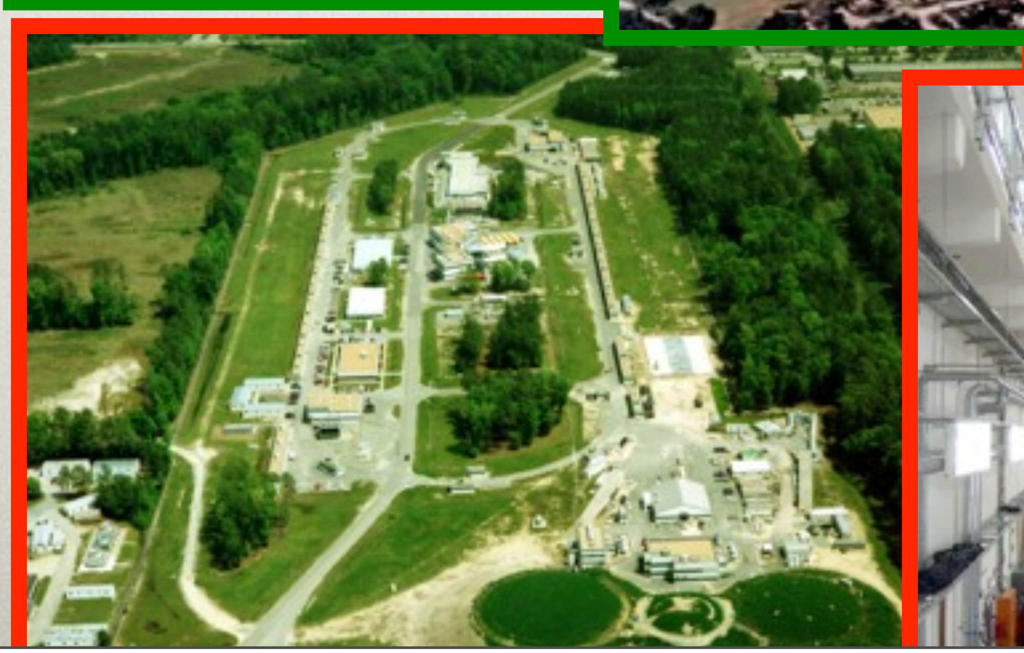
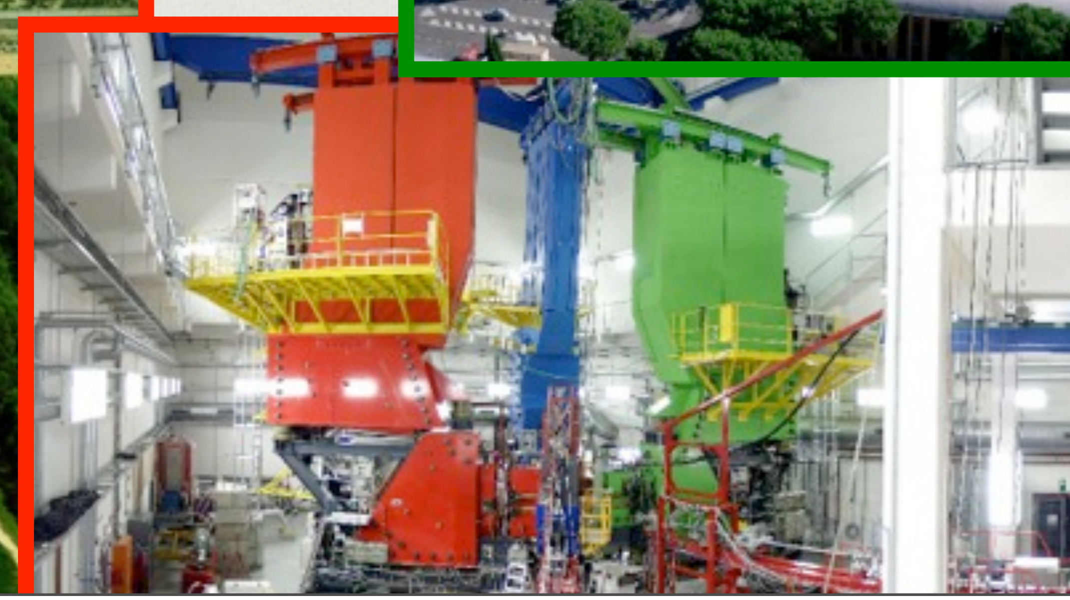
Explore broadly!

An Array of Exploration Opportunities!

High-energy colliders

High *intensity* colliders

Fixed Target

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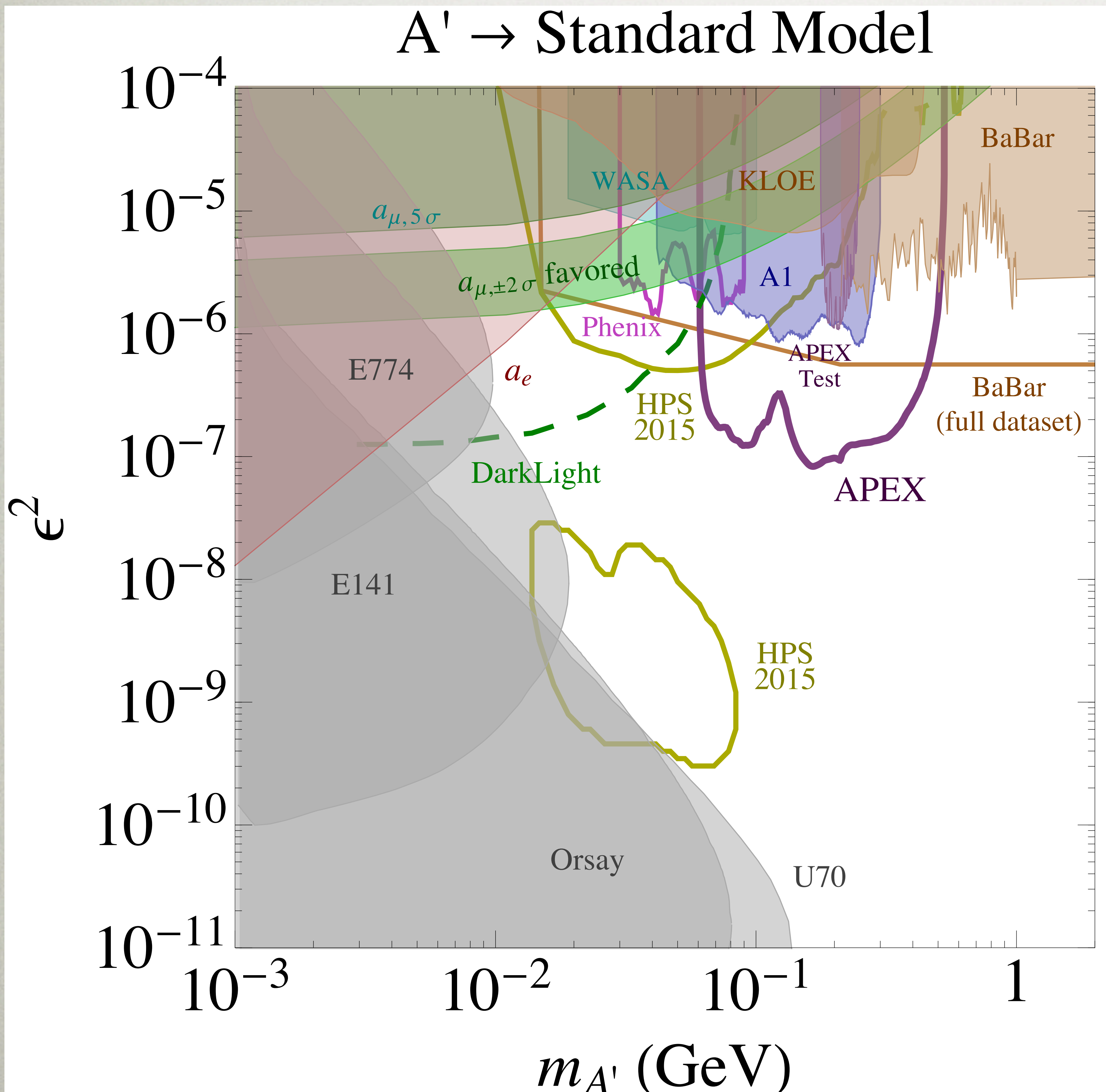
Direct Light Mediator Search (~2016 Prospects)

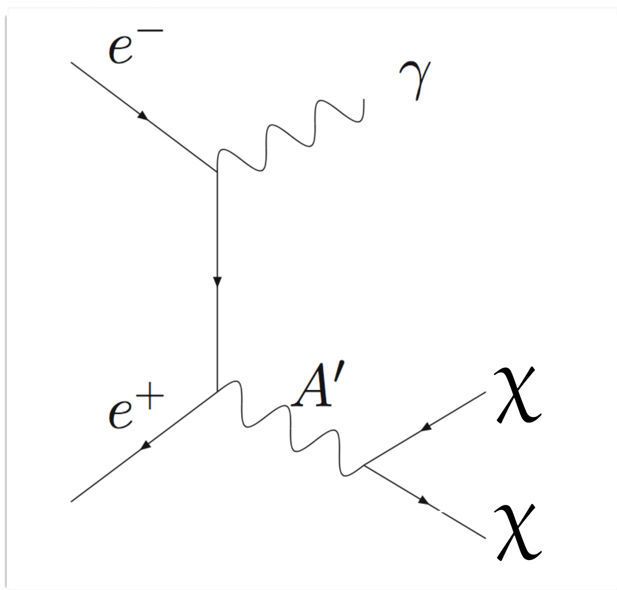


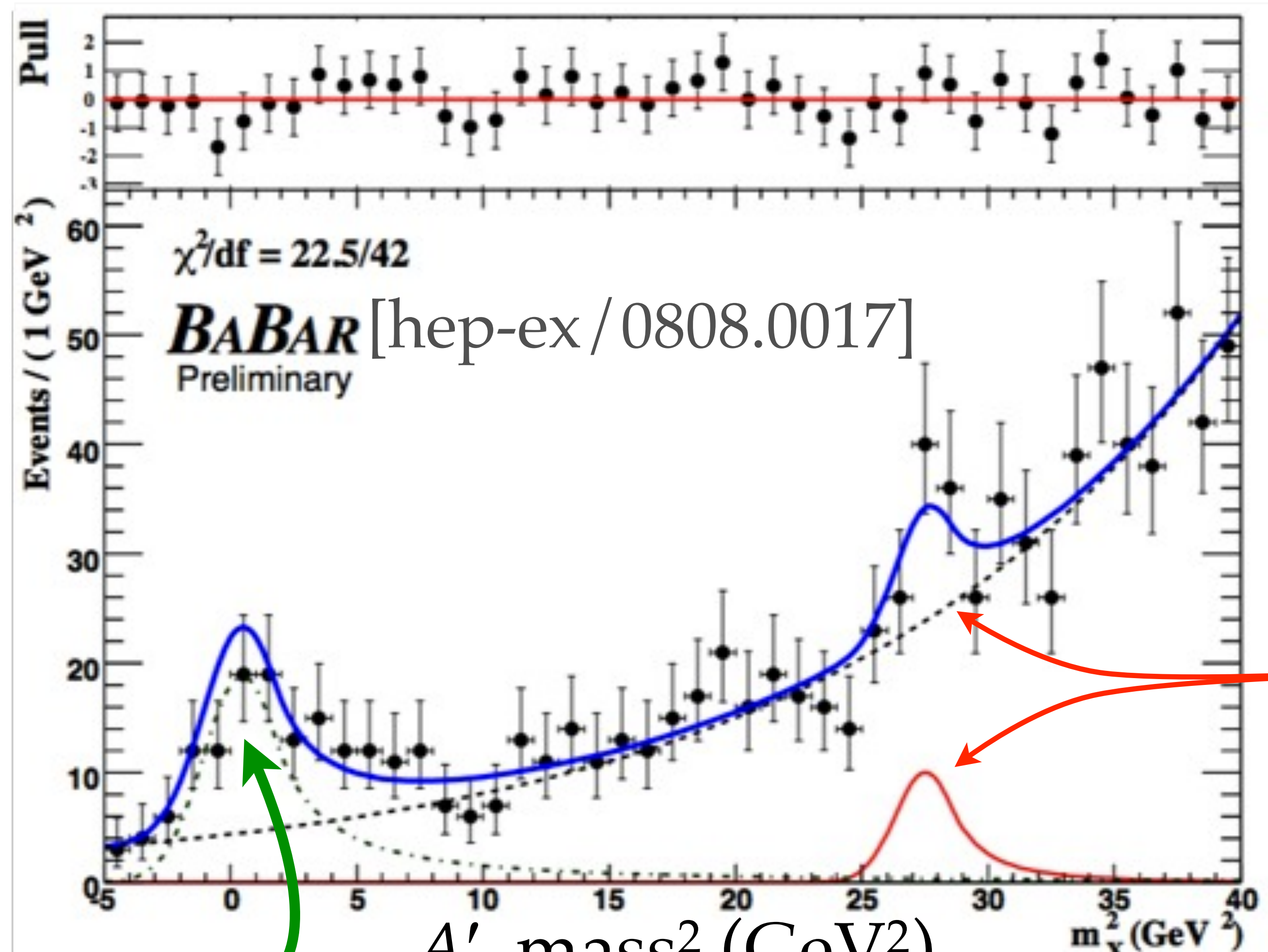
Qualitatively new and important territory will be explored in near future!

See: Snowmass 2013
http://www.snowmass2013.org/

A' Invisible Decays

$A' \rightarrow \chi\, \chi$ decay constrained by BaBar search

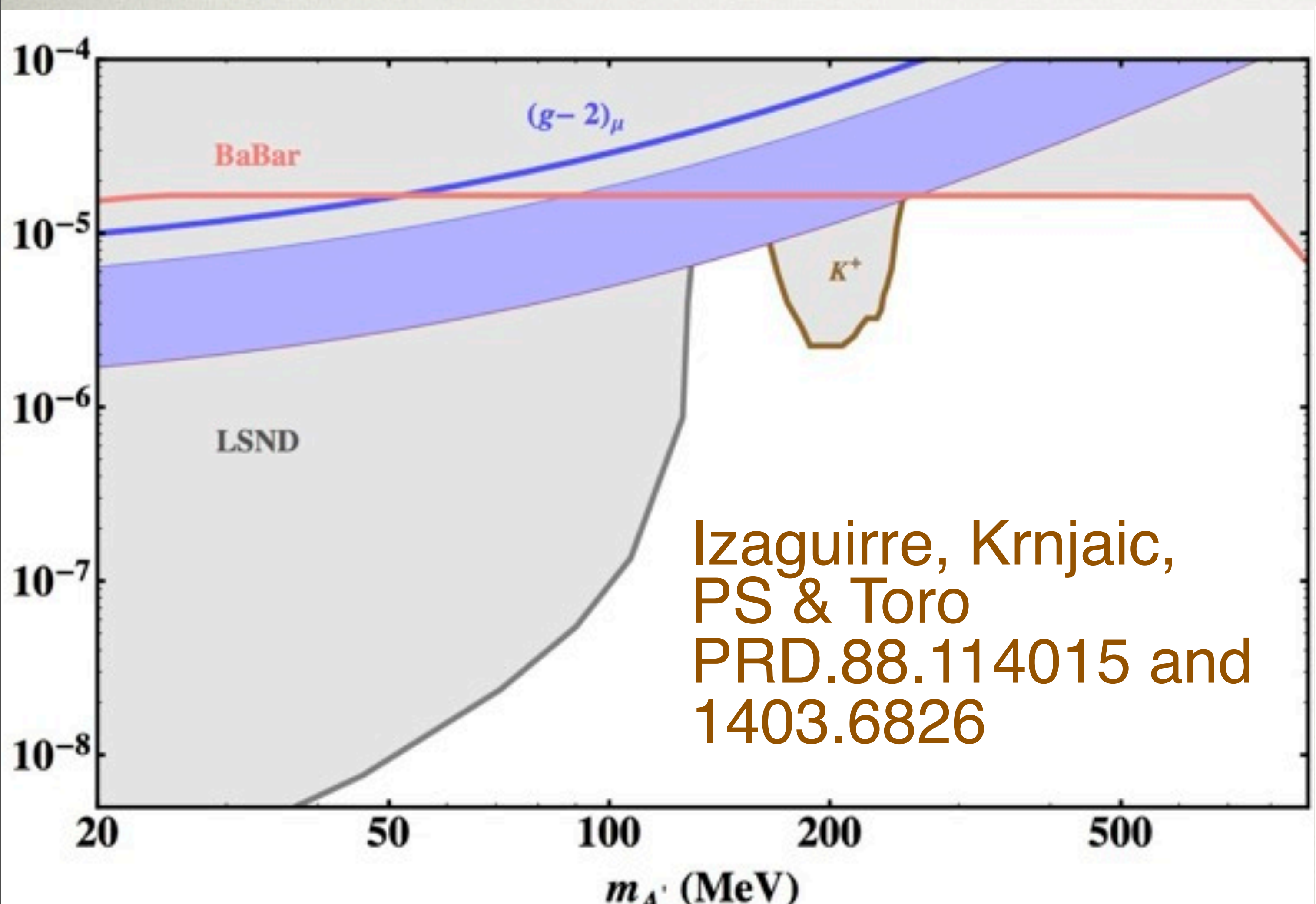


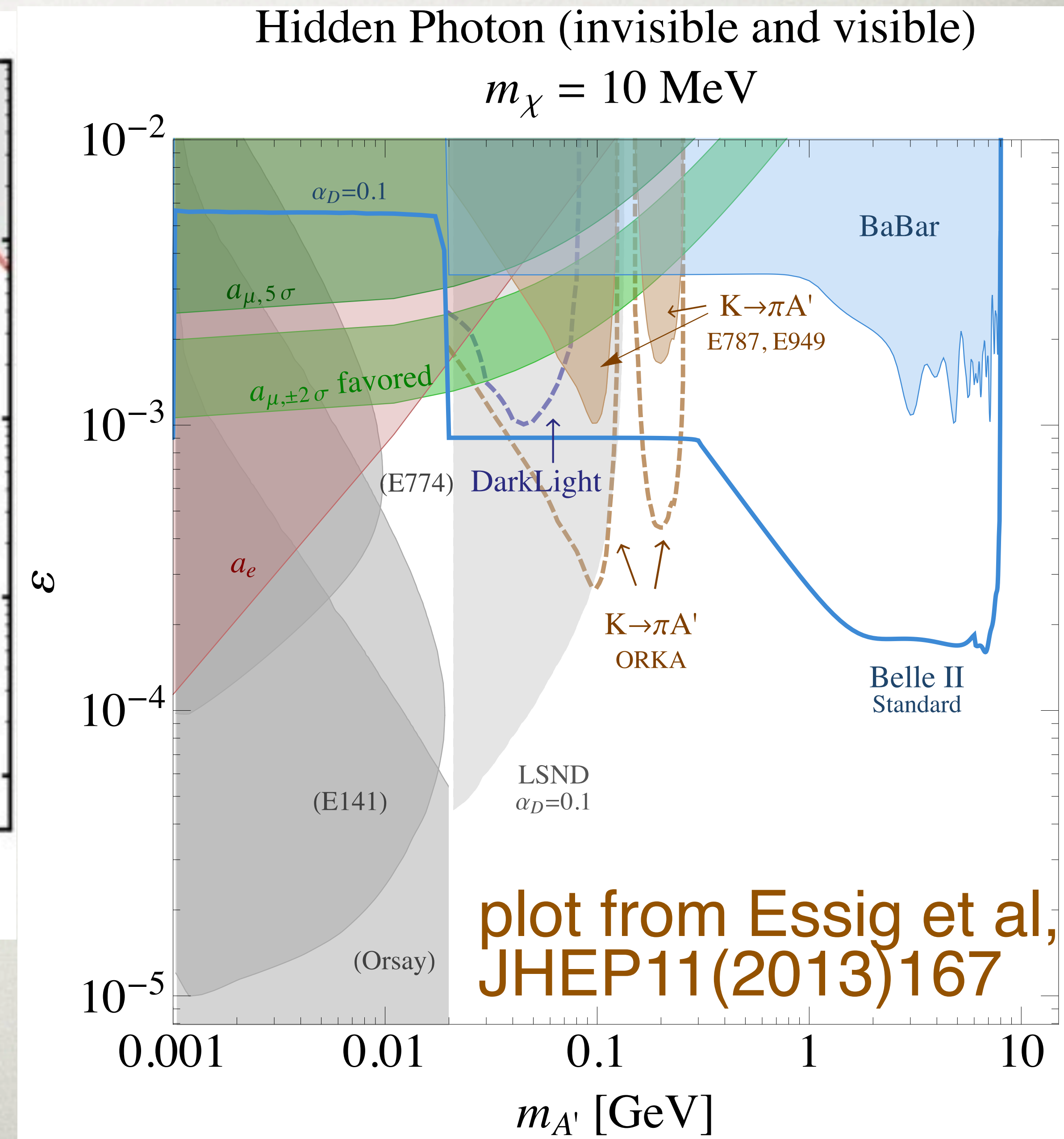


signal fit (not significant)

2γ background (signal-faking)

A' Invisible Decays





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Outline

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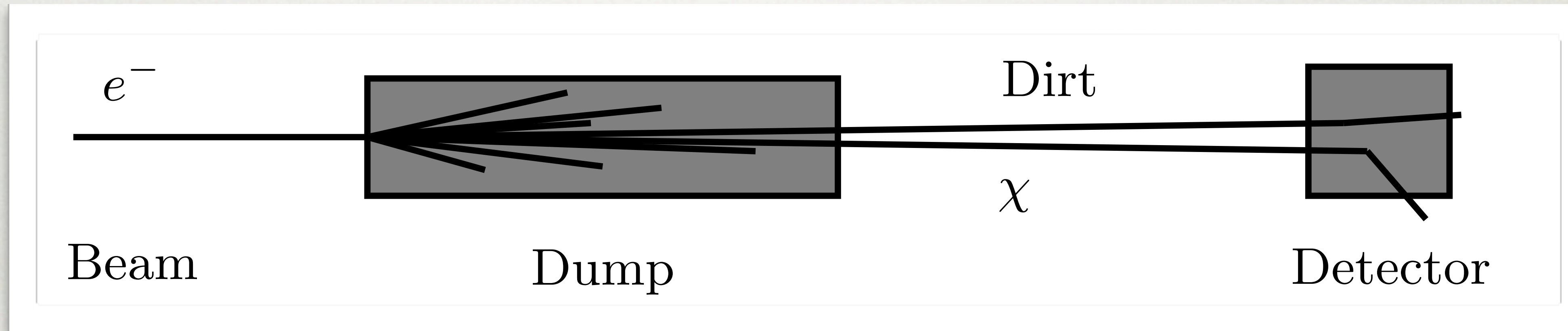
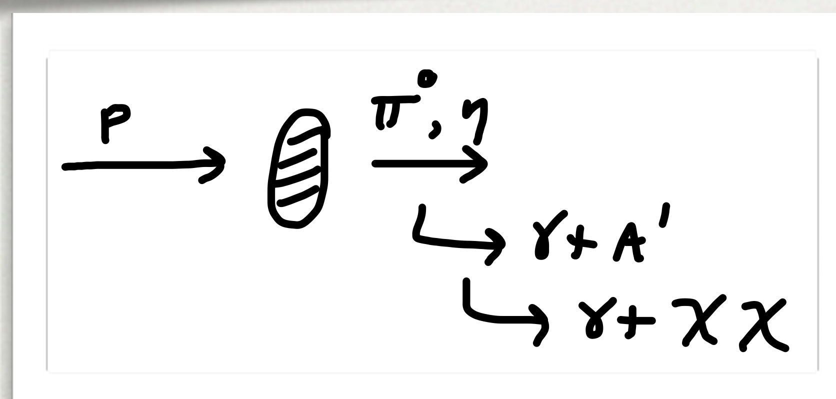
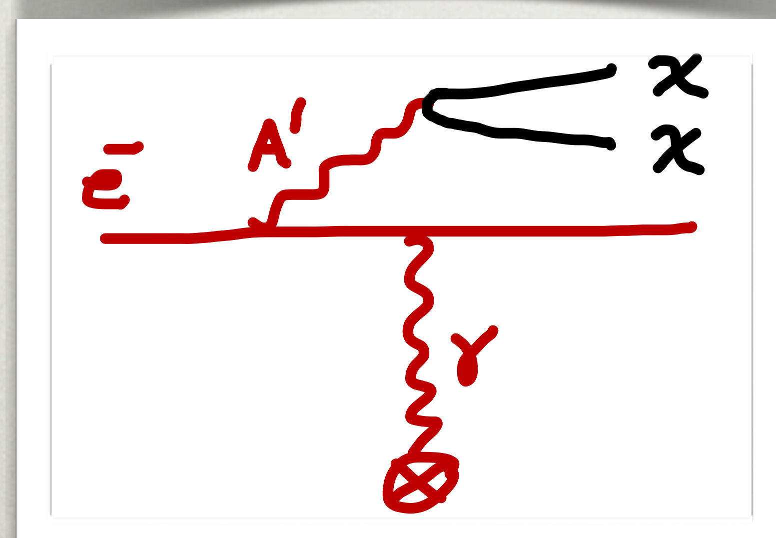
- **Beam dump dark matter experiment (BDX)**

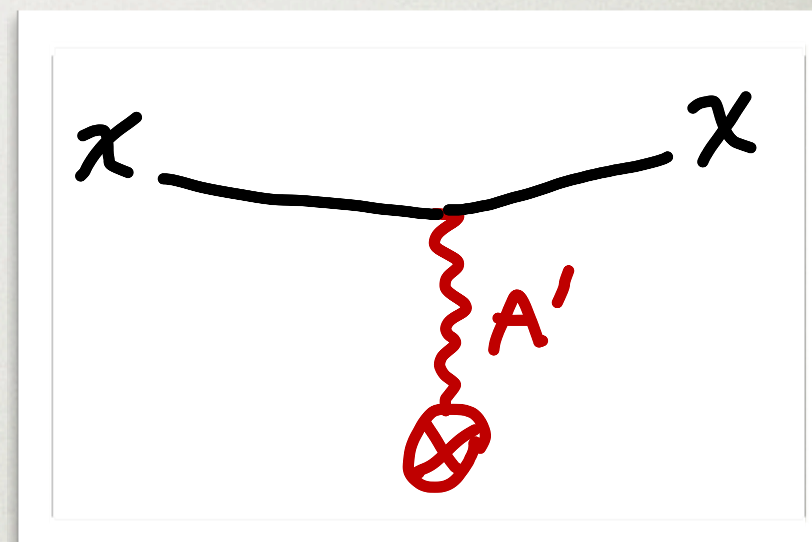
DM Production... and Detection



0906.5614, 1107.4580,1205.3499 Batell,DeNiverville, McKeen, Pospelov, Ritz





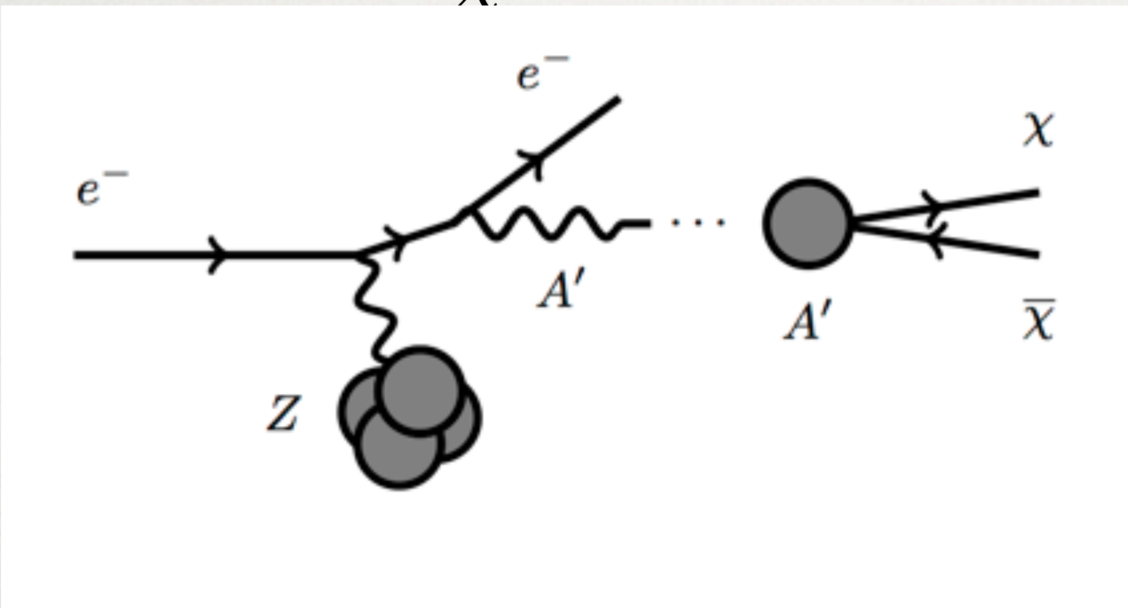


Izaguirre, Krnjaic, PS & Toro PRD.88.114015 and 1403.6826

nuclear dissociation; nucleon, nucleus, or electron recoil

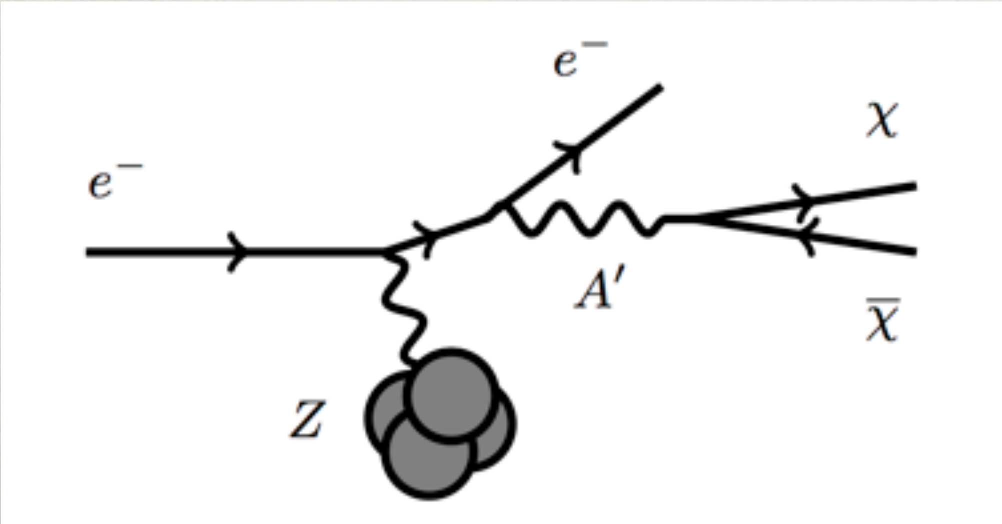
Electron Beam Production

$m_{A'} > 2m_\chi \implies$ on-shell A'-strahlung



$$\sigma \sim \frac{\epsilon^2}{m_{A'}^2}$$

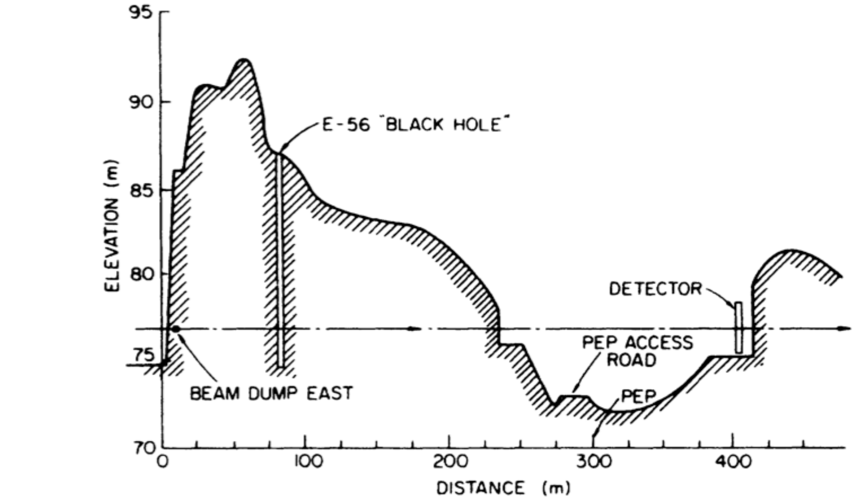
$m_{A'} < 2m_\chi \implies$ off-shell radiative

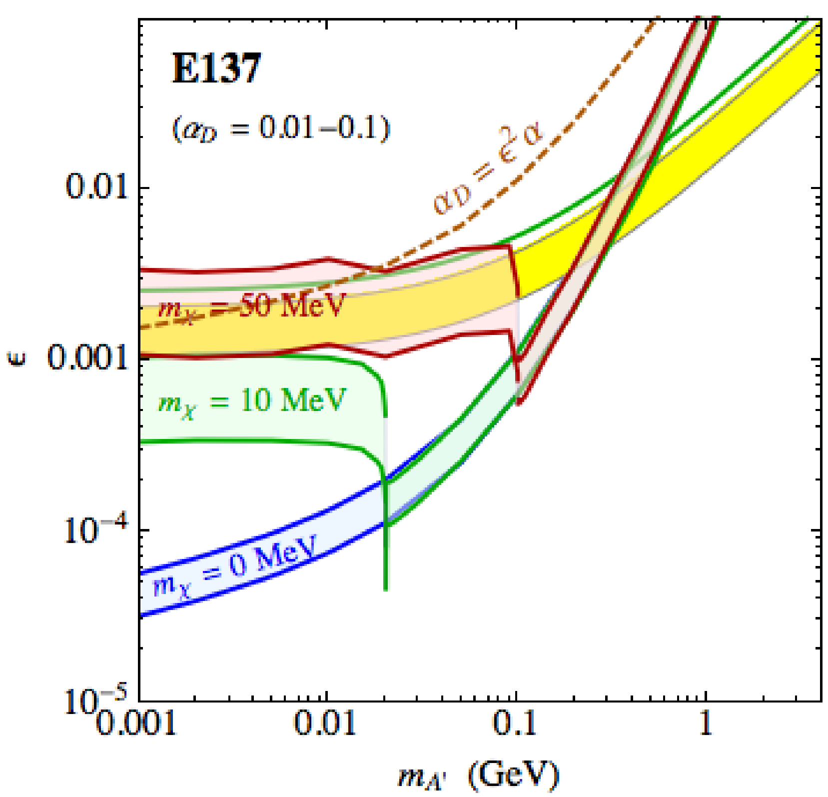


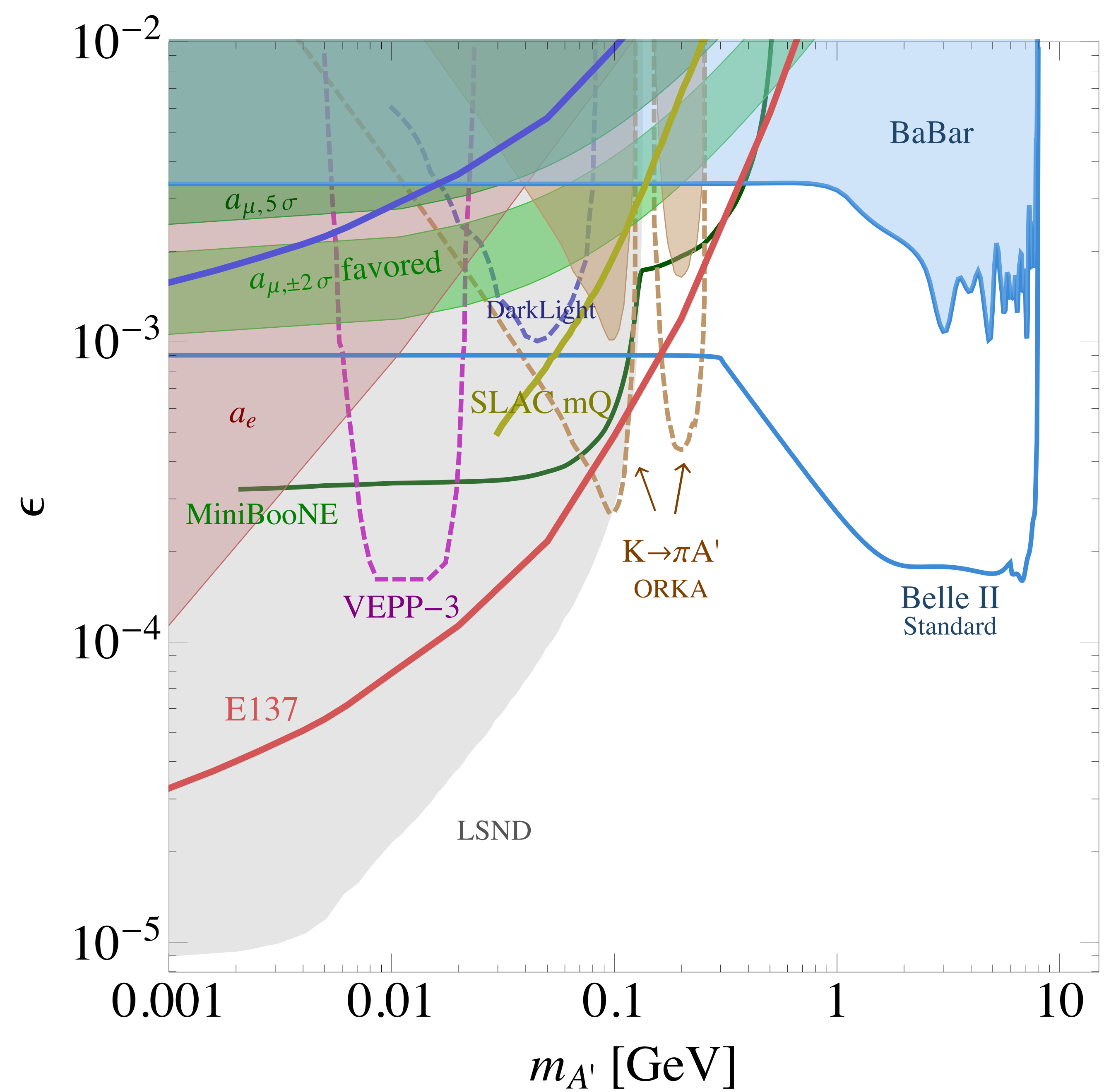
$$\sigma \sim \frac{\alpha_D \epsilon^2}{m_\chi^2}$$

Electron Beam Dumps in Action

E137 @ SLAC (1982)



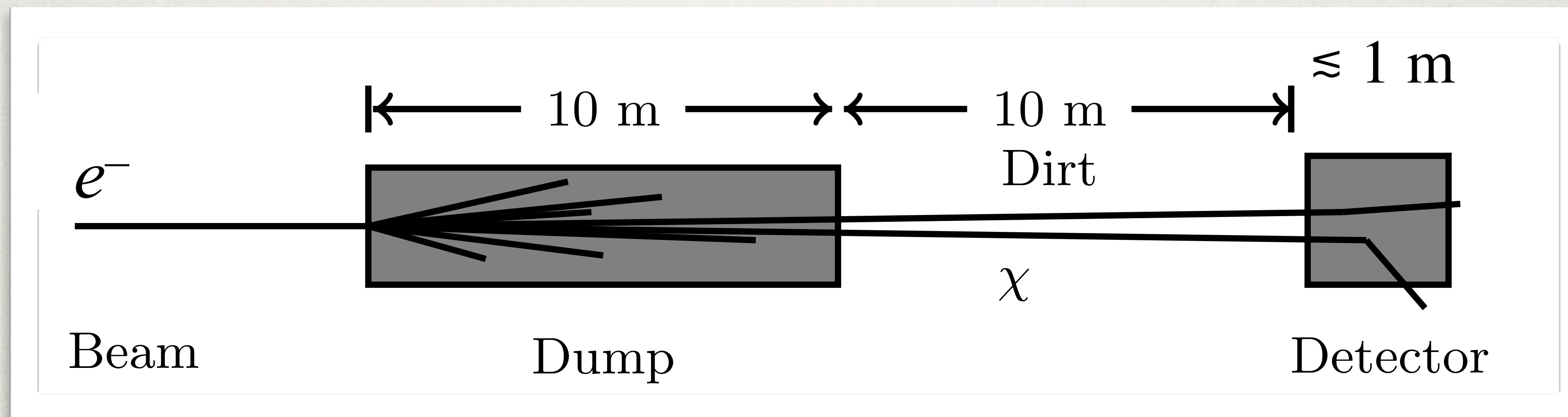




Plots from Ze'ev Surujon's talk @ FNAL, work to appear w/ Batell & Essig

Electron Beam Opportunity

For beam-related background rejection at 12 GeV:



Low beam bkg. & forward A′ production ⇒ small detector suffices!

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The BDX Experiment

V1.8
June 3, 2014

Letter of Intent to PAC 42

Dark matter search in a Beam-Dump eXperiment (BDX) at Jefferson Lab

The BDX Collaboration

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†Spokesperson

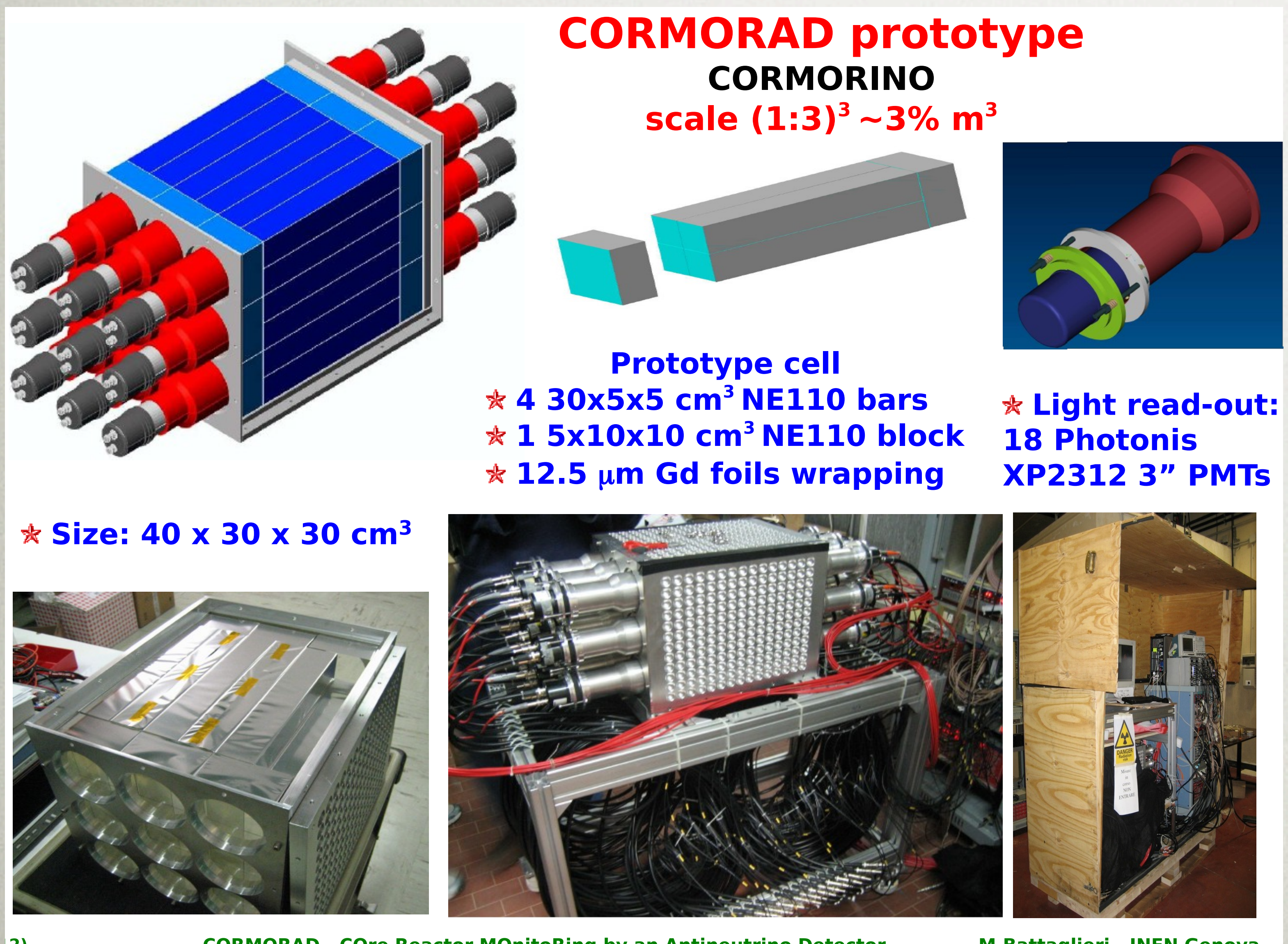
~80 person effort to launch a beam dump dark matter experiment at Jefferson Laboratory

LOI under review by JLab PAC 42
Work under way for full proposal and test run phase

Simple and Effective Concept

Plastic scintillator bars interlaced with lead

Narrow (~30cm) and long (~900cm) detector -- not a cube!
(large column density with good acceptance along beam line)

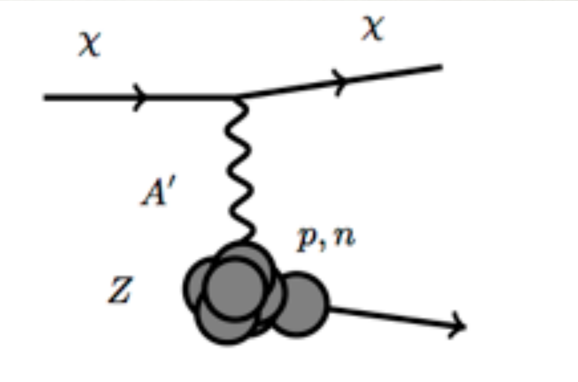


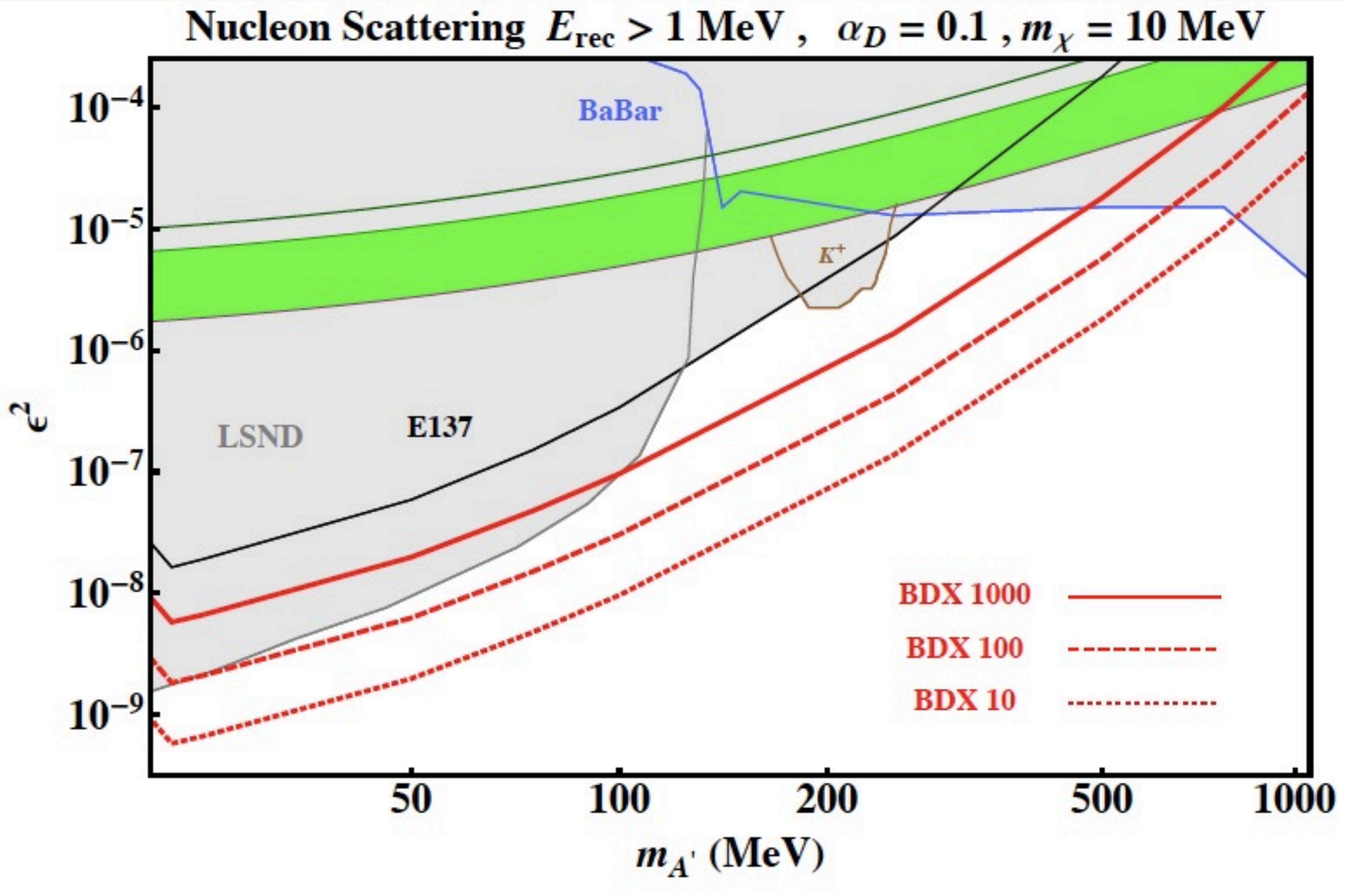
Detector approach
not finalized

New ideas are welcome!

BDX Sensitivity

Nucleon scattering channel





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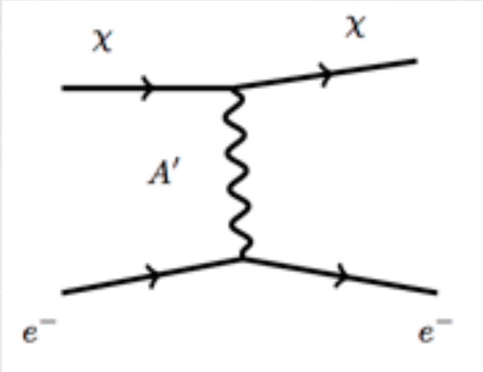
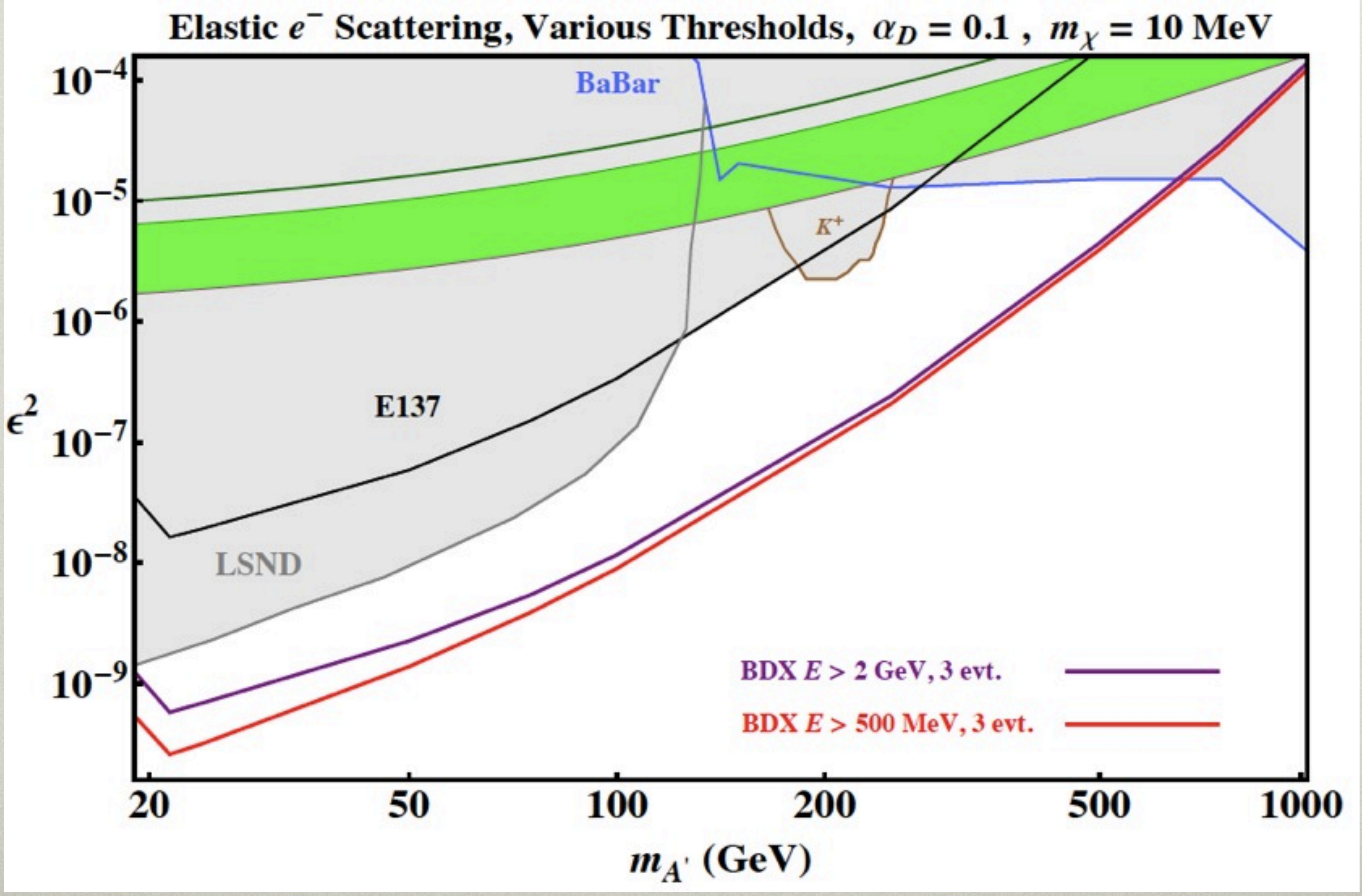
BDX Sensitivity

Electron scattering channel





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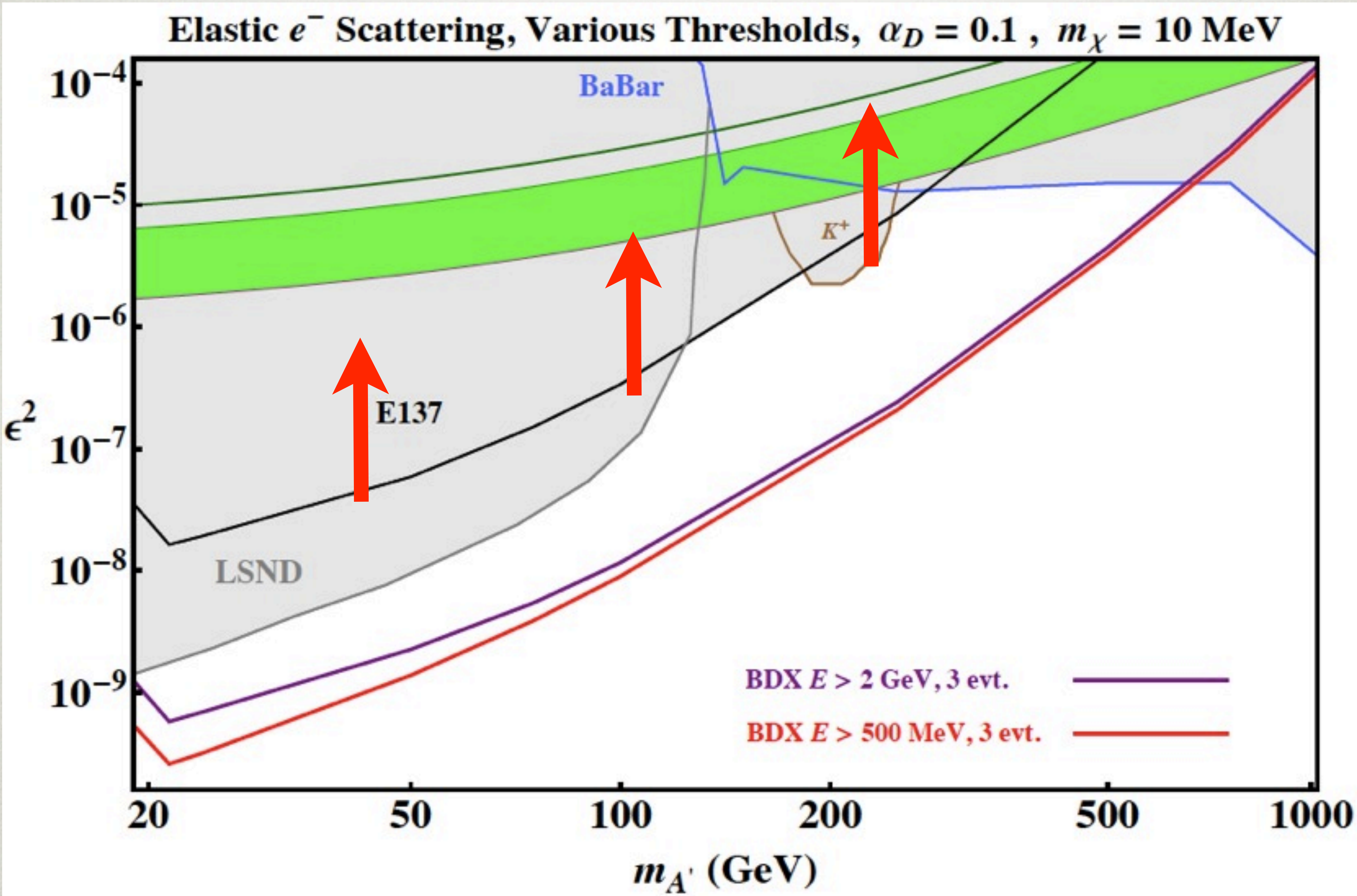
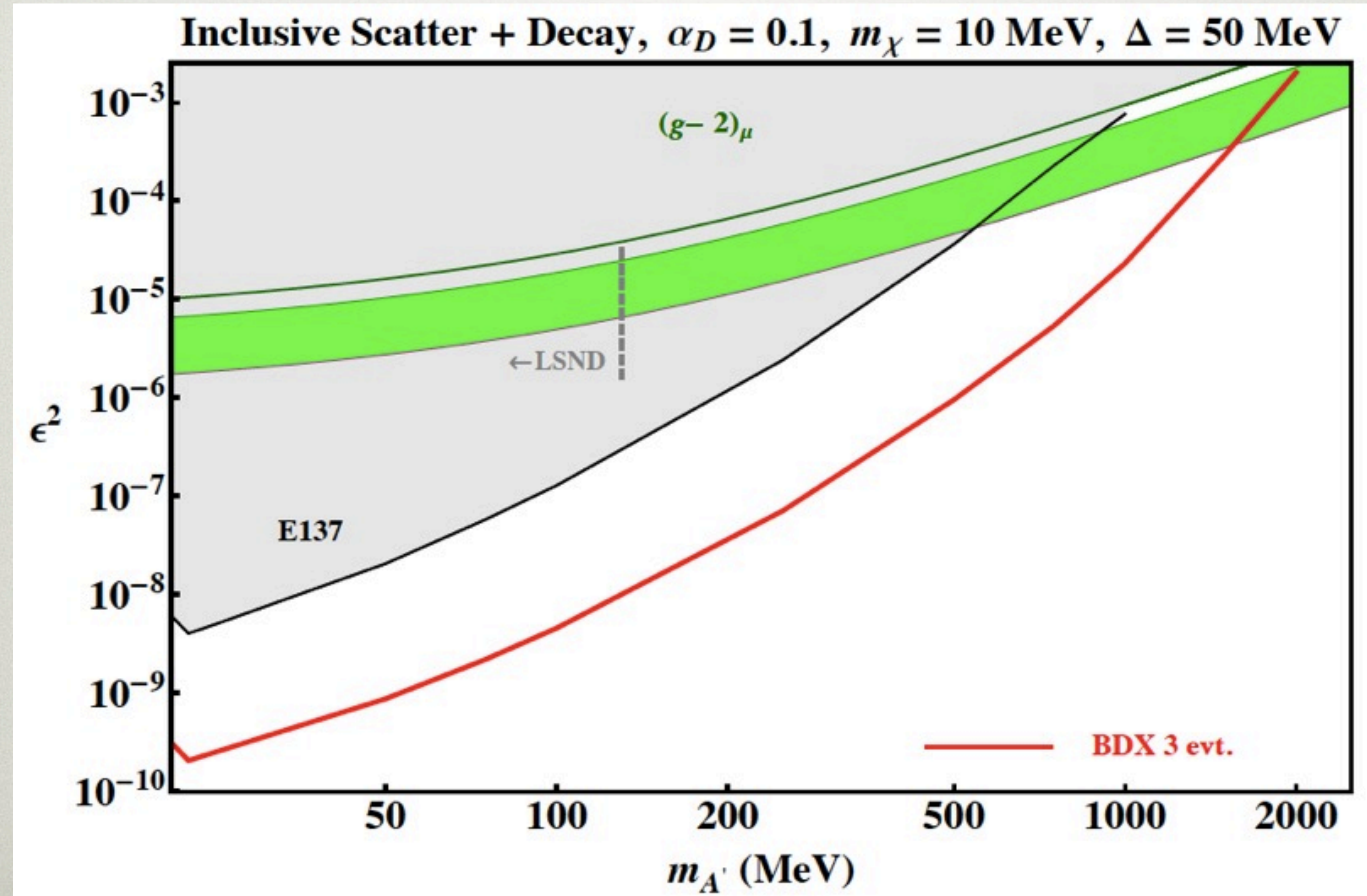
BDX Sensitivity



Sensitivity drops as α_D decreases → want more sensitivity to cover g-2 scenarios robustly!

BDX Sensitivity

Inelastic scattering channels...



Conclusions

- LDM with thermal origin makes good sense in the context of dark sectors
- Natural extension of the SM to consider
- Many opportunities for exploration – and discovery – abound!
  - New fixed-target experiments will powerfully explore light mediator parameter space
  - New and ongoing beam dump experiments exploring LDM production and detection with **orders of magnitude** enhanced sensitivity in multiple channels
  - *A′ invisible decays, including g-2 anomaly parameter space at small dark coupling will be thoroughly explored*
- Discovery or decisive test of simplest scenarios