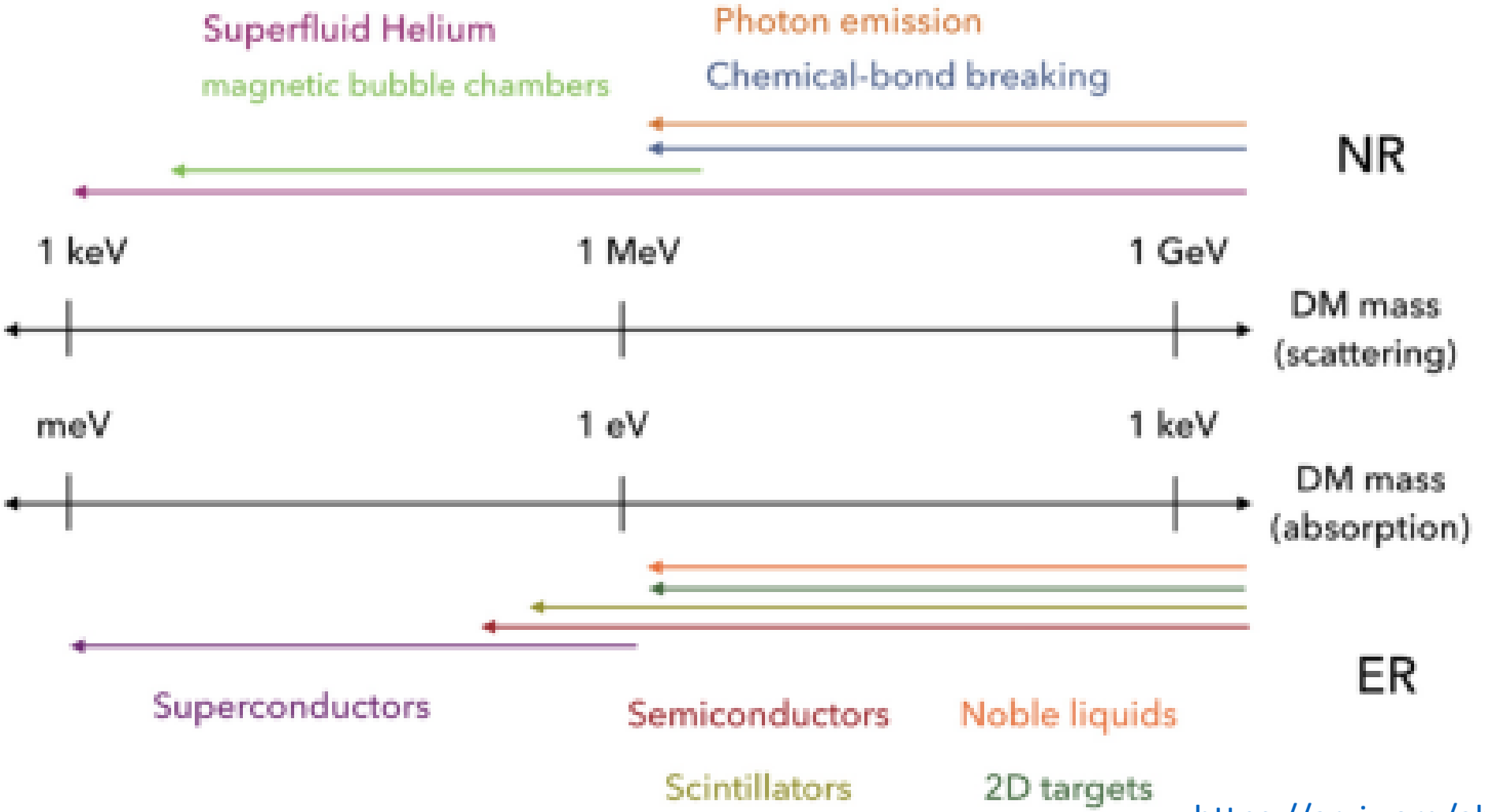
Direct Detection:
Recent Experimental Results & Near-Future Outlook

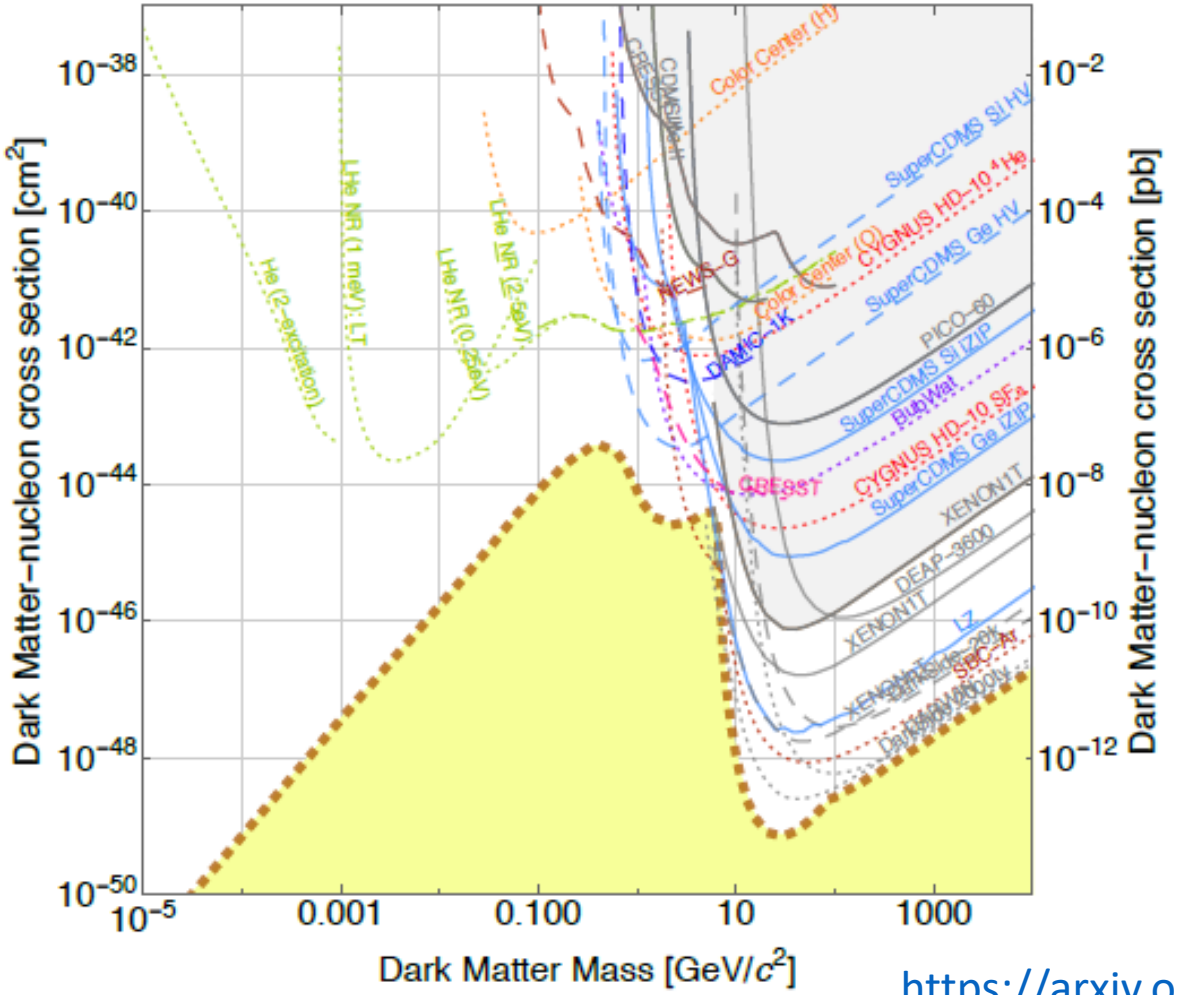
“Cosmic Visions” for Direct Detection



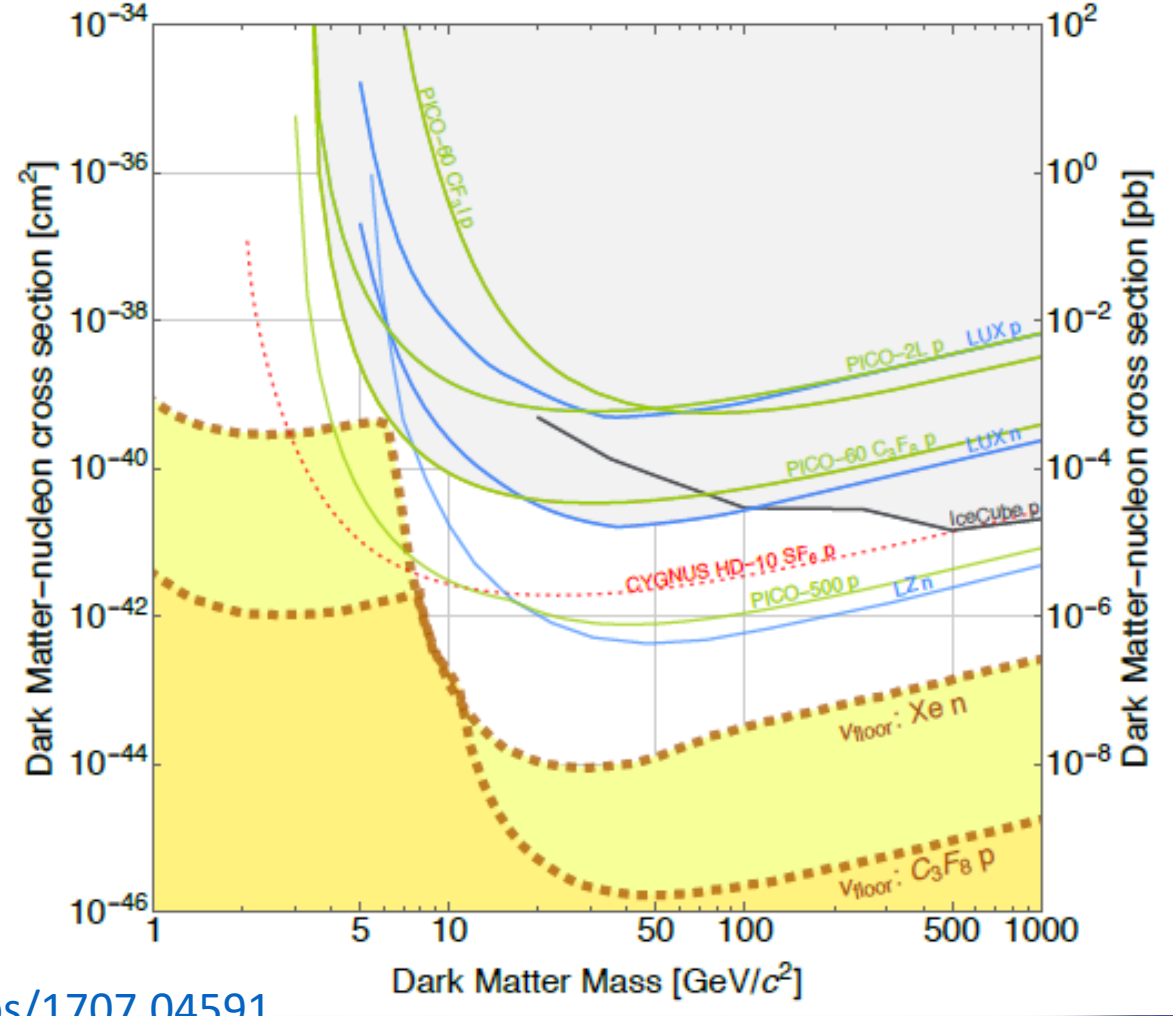
https://arxiv.org/abs/1707.04591

Nuclear Recoil Limits

Spin-Independent

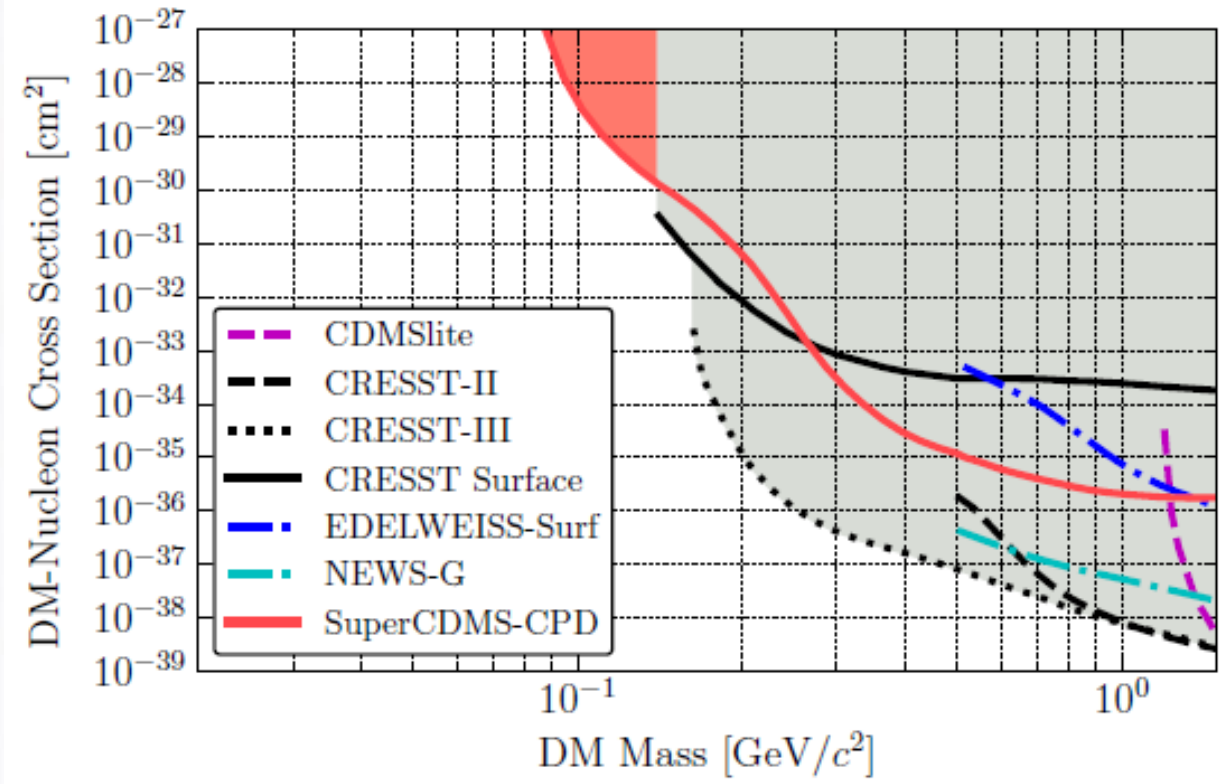


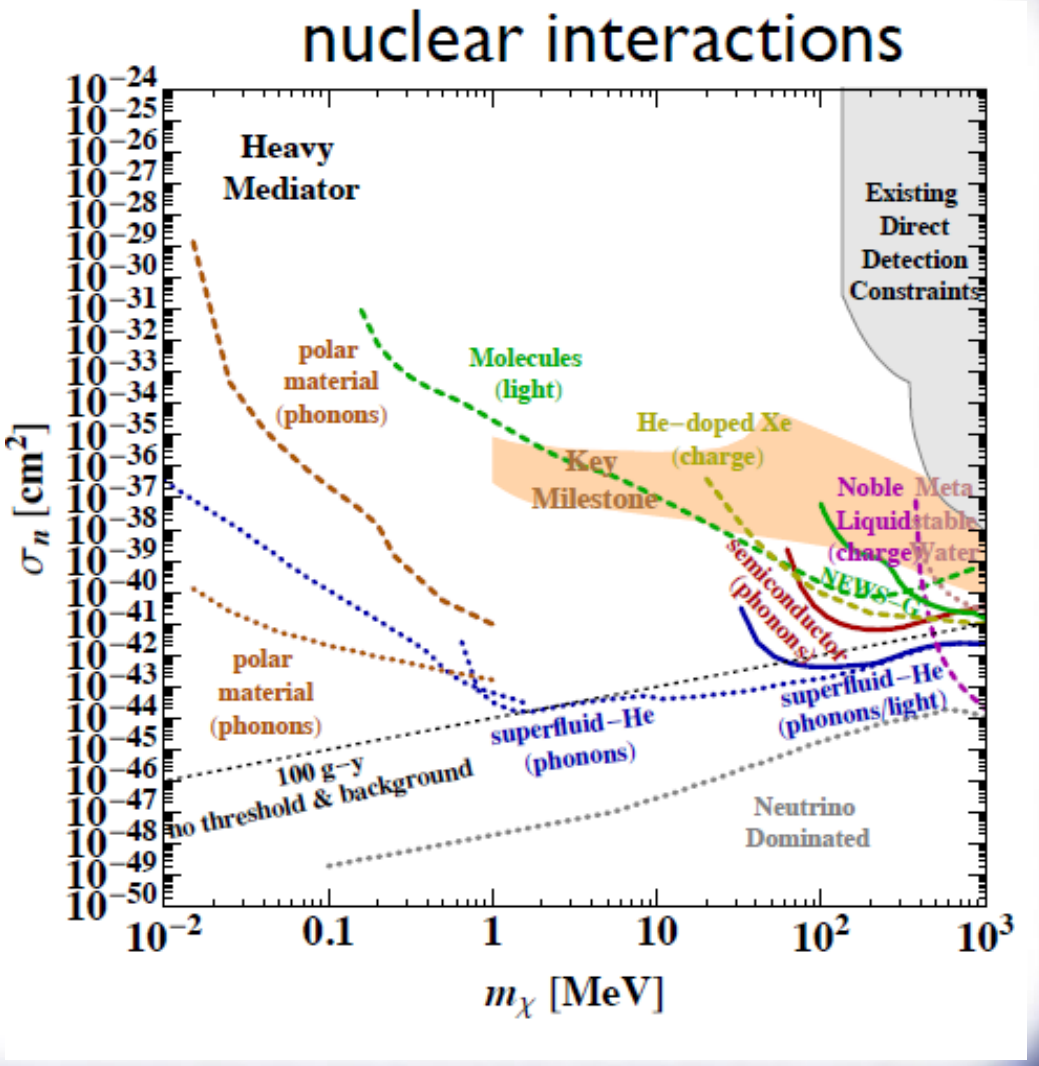
Spin-Dependent



https://arxiv.org/abs/1707.04591

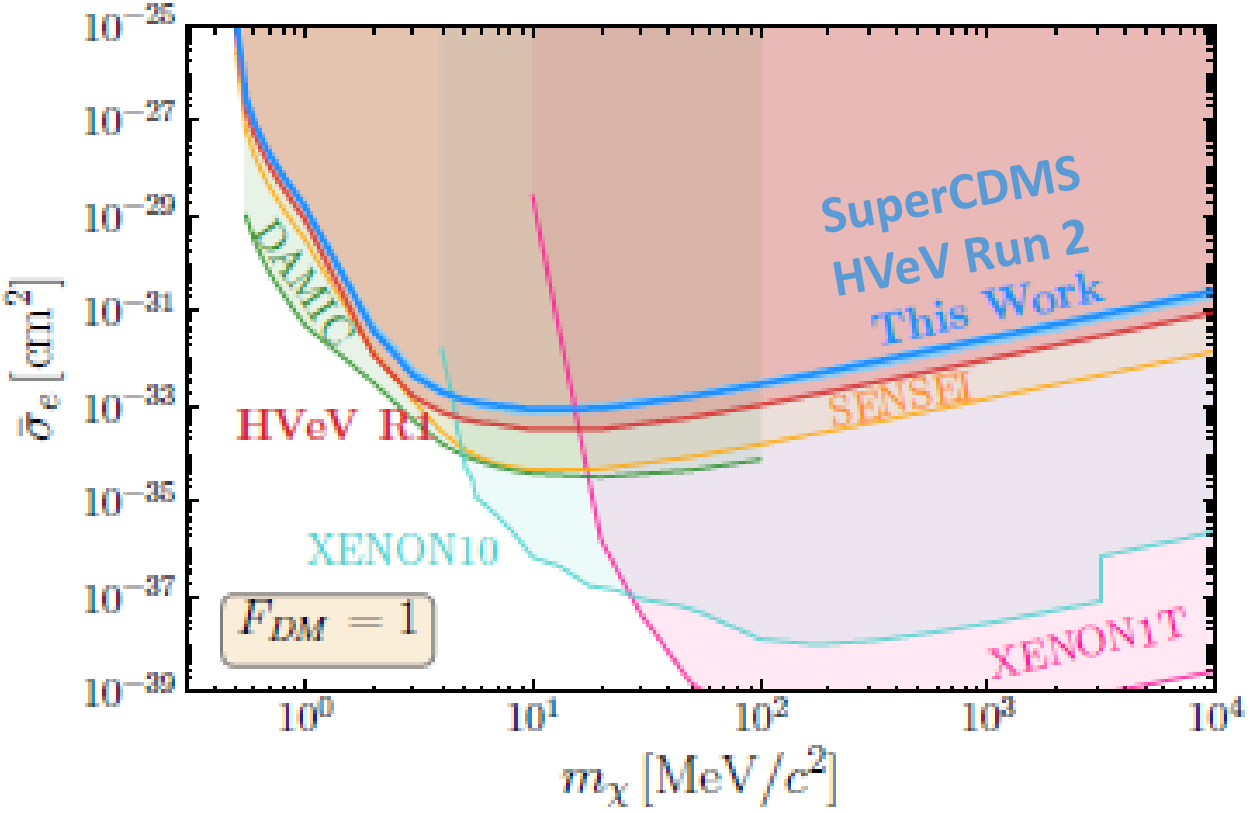
Low-Mass Nuclear Recoil Limits



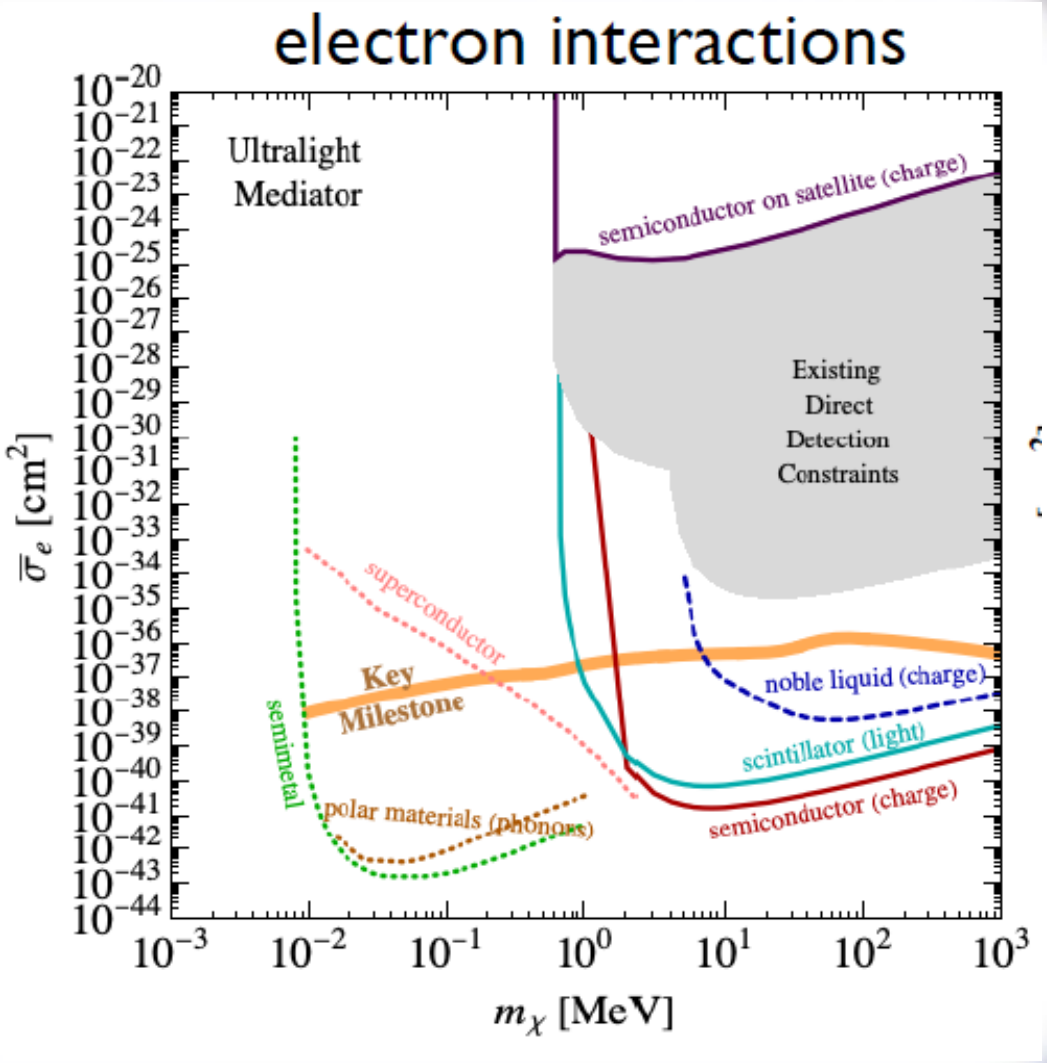


https://arxiv.org/abs/2007.14289

Electron Recoil Limits

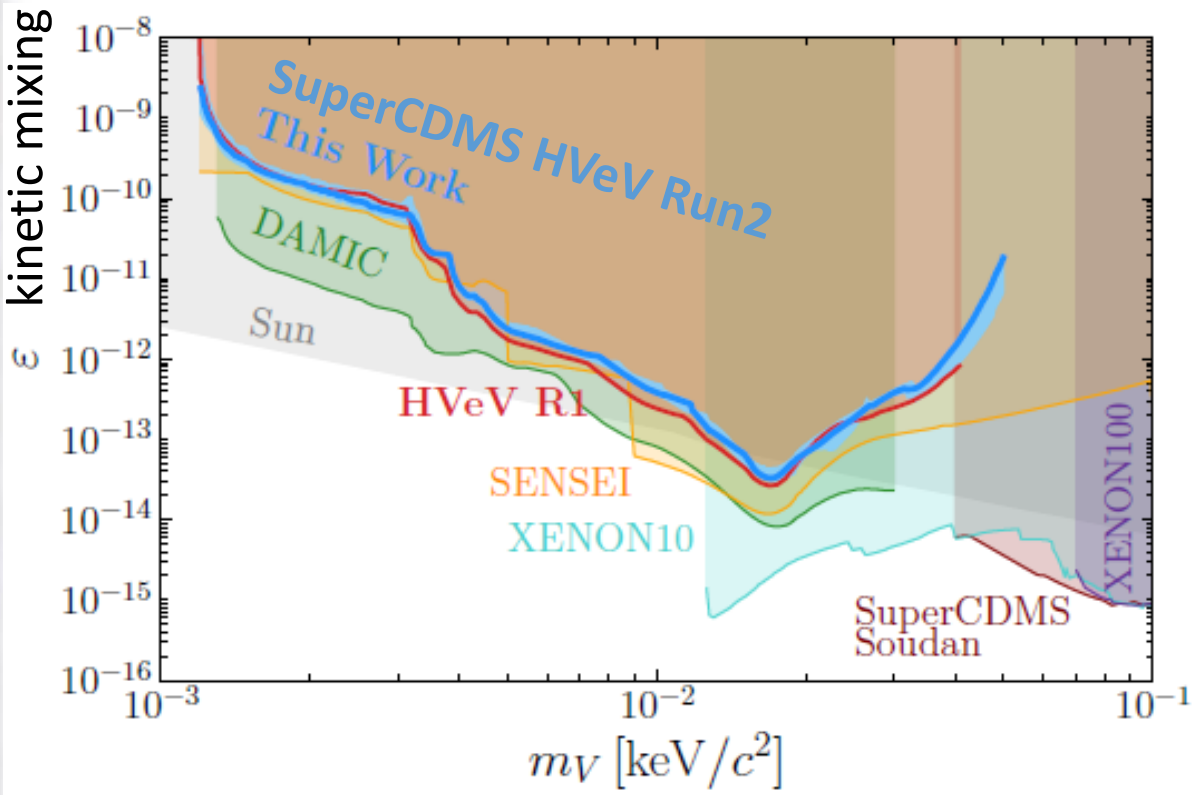


https://arxiv.org/abs/2005.14067

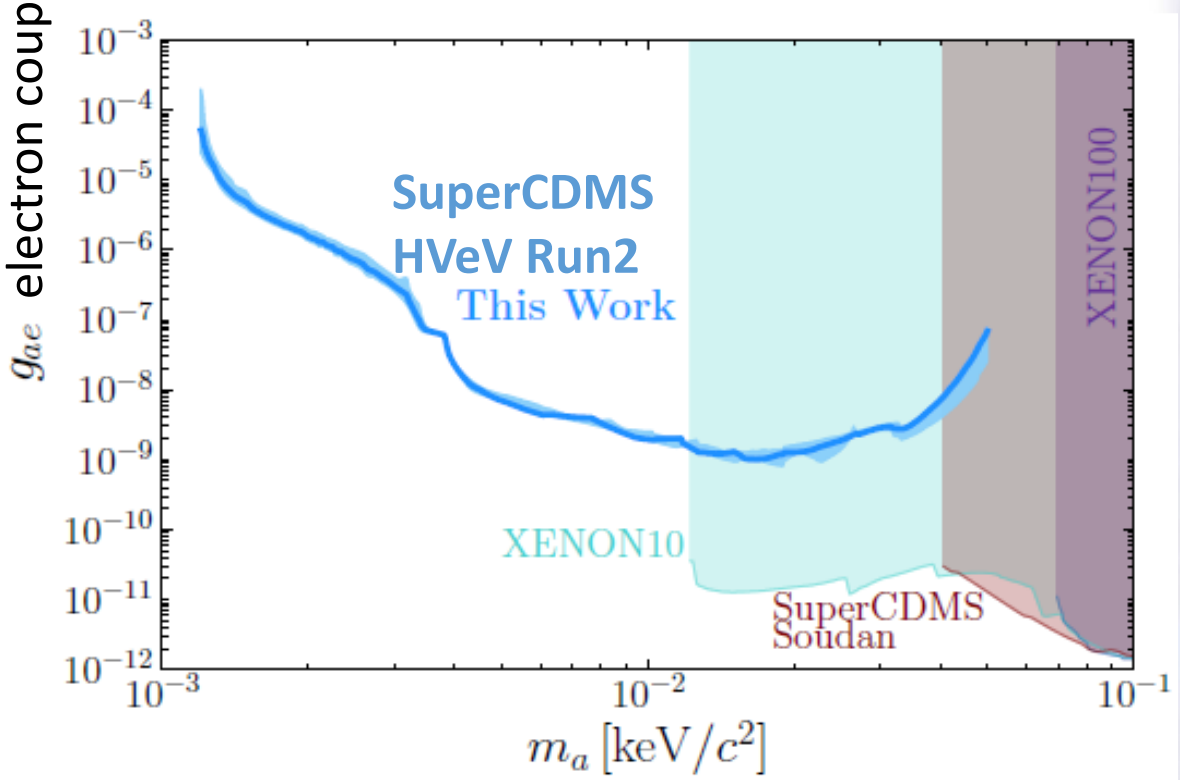


Dark Photon & Axion Limits

Dark Photons

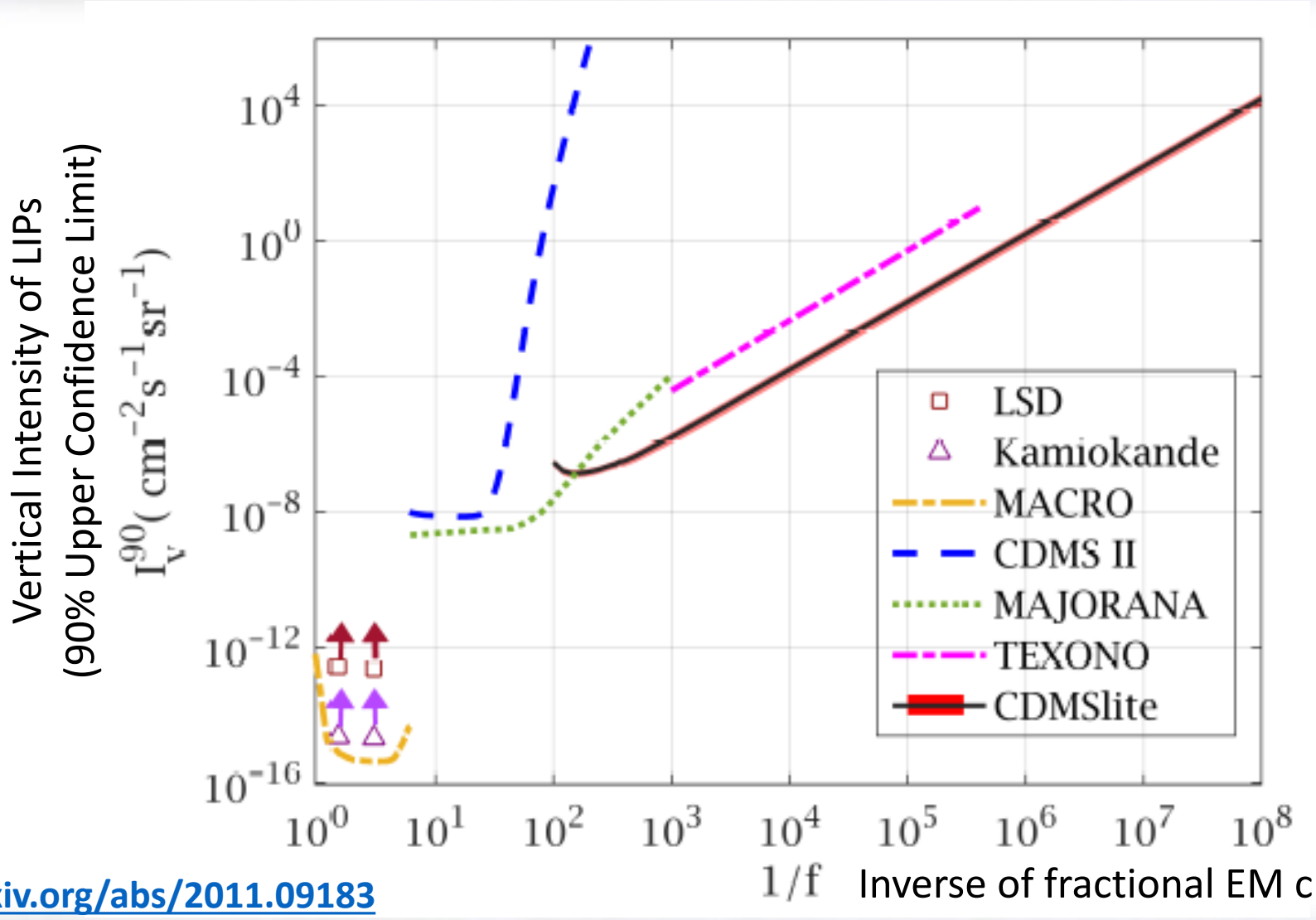


Axions



https://arxiv.org/abs/2005.14067

Lightly Ionizing Particle Limits

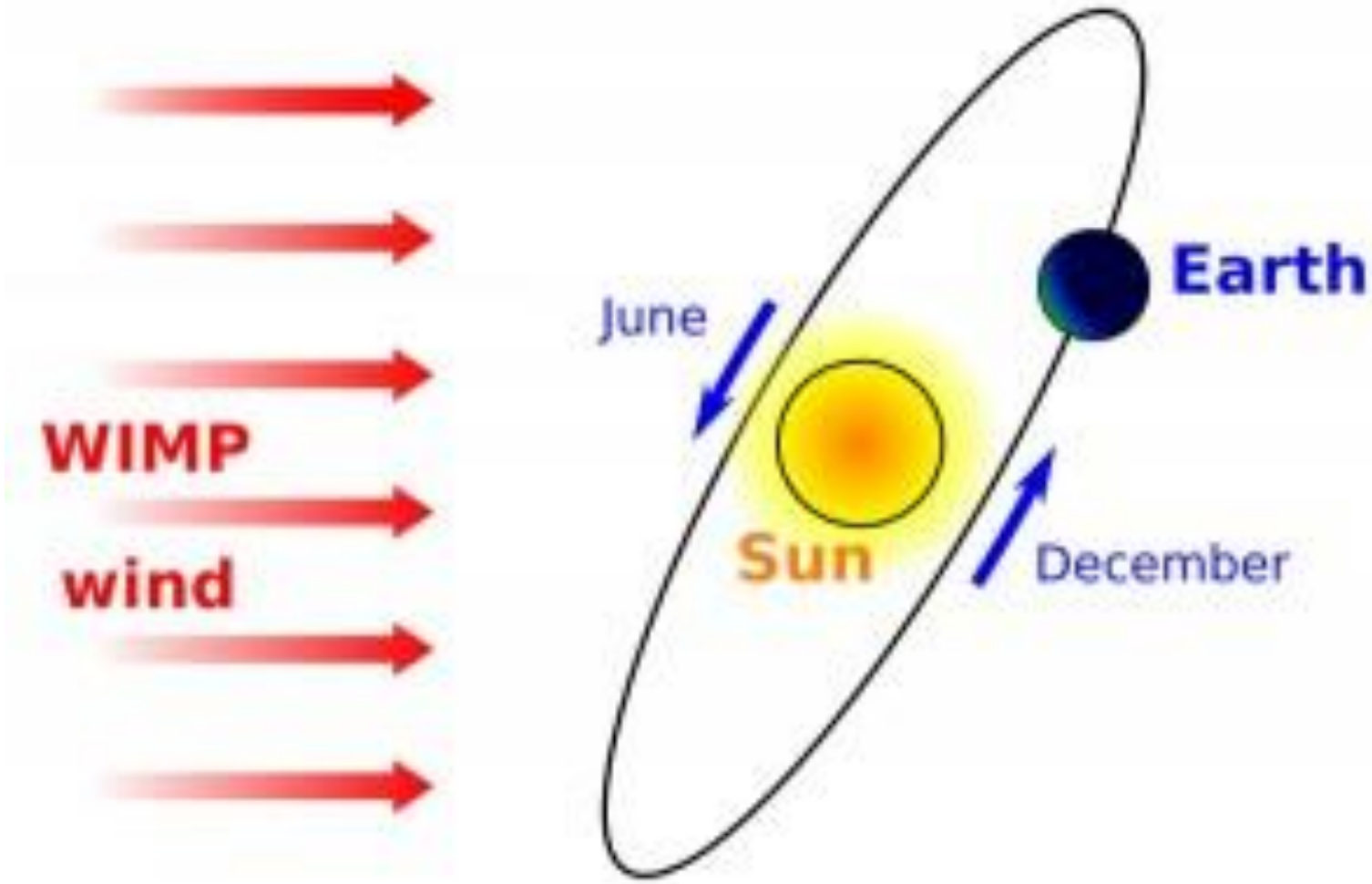


https://arxiv.org/abs/2011.09183

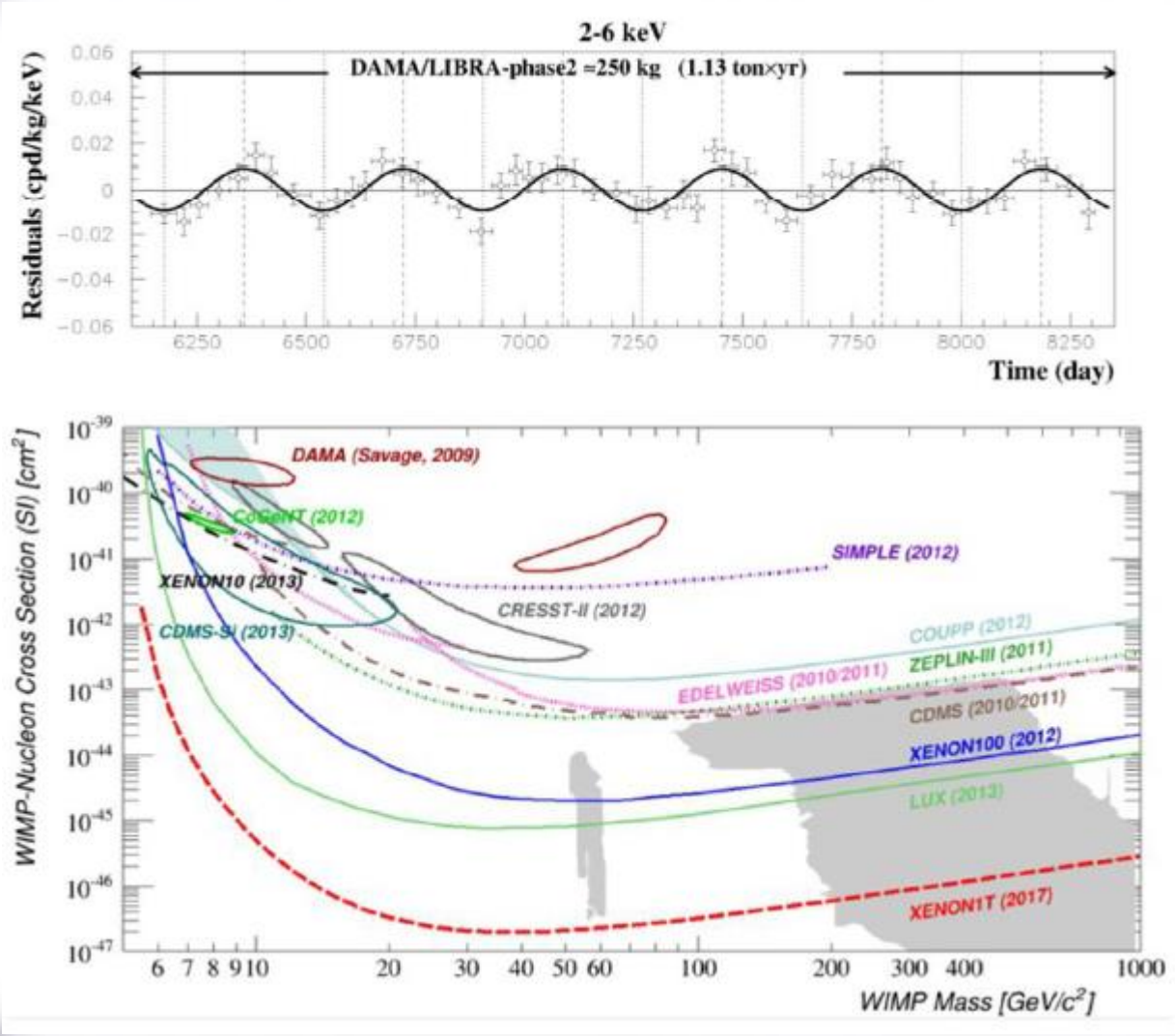
And Now For Something Confusing: DAMA

"Annual Modulation" analysis concept: the absolute number of events in the detector doesn't matter, only the relative number at different times of the year.

So, backgrounds that are constant in time don't matter … right?



And Now For Something Confusing: DAMA



DAMA/LIBRA sees 12-sigma "annual modulation" signal, incompatible with null-results from direct detection experiments that use background subtraction / modelling!

And Now For Something Confusing: DAMA

Is there corroborating evidence?

XENON excess: https://arxiv.org/abs/2006.09721

Or is the “DAMA signal” ruled-out?

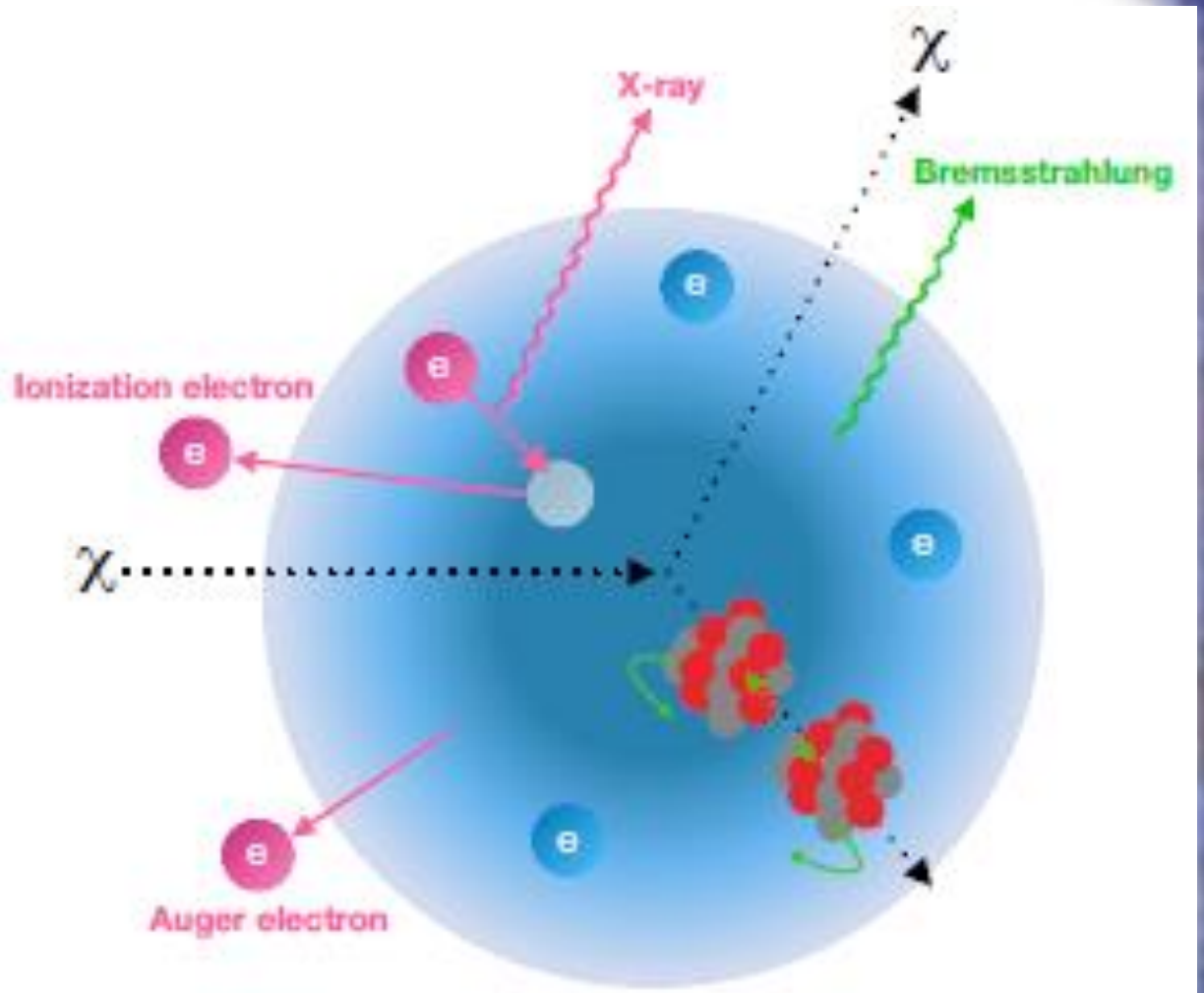
https://www.forbes.com/sites/startswithabang/2021/03/04/goodbye-damalibra-worlds-most-controversial-dark-matter-experiment-fails-replication-test/

COSINE: https://arxiv.org/abs/1906.01791

ANAIS: https://arxiv.org/abs/2103.01175

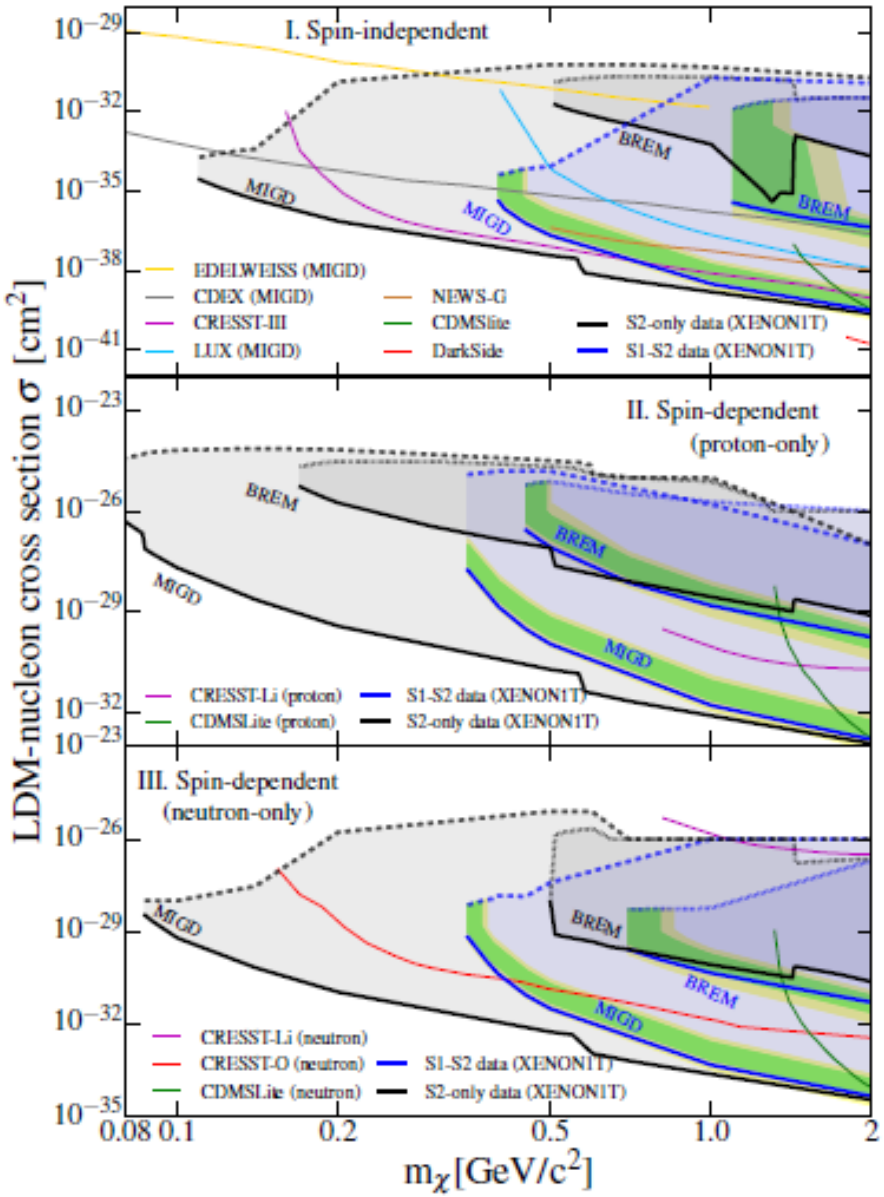
And Now For Something Confusing: Migdal Effect

- In nuclear elastic scattering, it has been hypothesized the electron clouds don't immediately follow the motion of the nucleus – they take time to catch up
- Resulting ionization & excitation of the atom is the "Migdal effect", which predicts secondary electronic recoils
- Looking for those recoils could lower energy threshold of DD experiments… right?
- There's a catch: Migdal Effect has never been directly, conclusively observed!



https://arxiv.org/abs/1907.12771

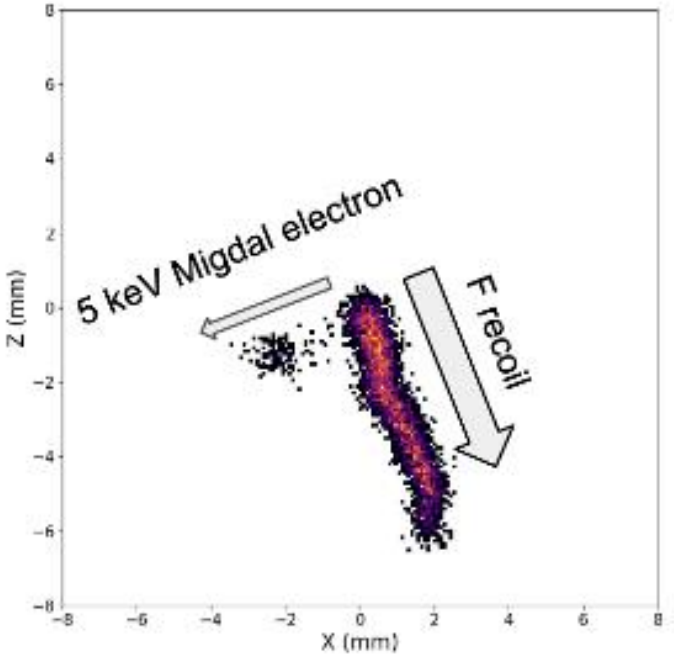
And Now For Something Confusing: Migdal Effect



MIGDAL

Migdal In Galactic Dark mAtter expLoration

https://www.ppd.stfc.ac.uk/Pages/MIGDAL-Experiment.aspx



XENON Collaboration
https://arxiv.org/abs/1907.12771

And Now For Something Fun: Tour of SNOLAB !

https://www.snolab.ca/facility/virtual-tour/

Collider & Fixed-Target Searches for Dark Sectors

Careful of the Portal

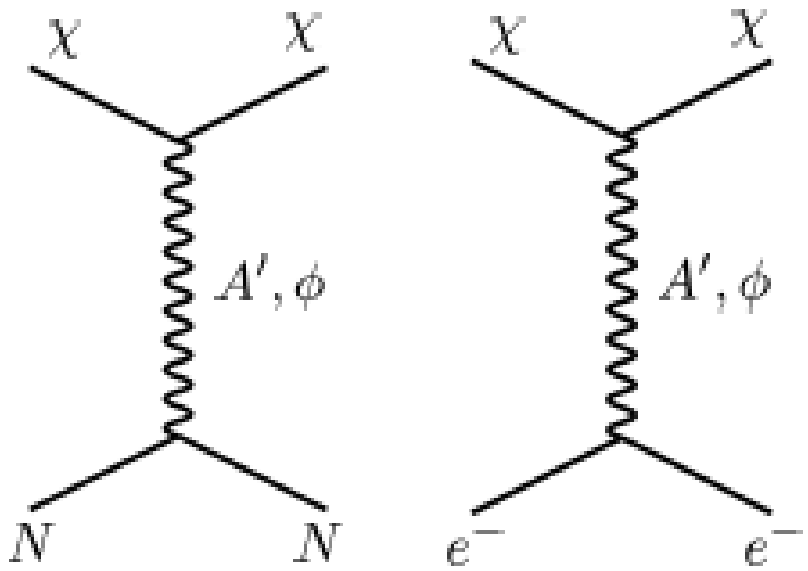
Careful of the Portal

In other words…
Treat the mediator differently at high energies than at low energies!

How to look for the mediator itself?

In scattering processes, can we "integrate out" the mediator?

- "Heavy" vs "light" mediator, "on-shell" vs "off-shell", "high" vs "low" momentum transfer

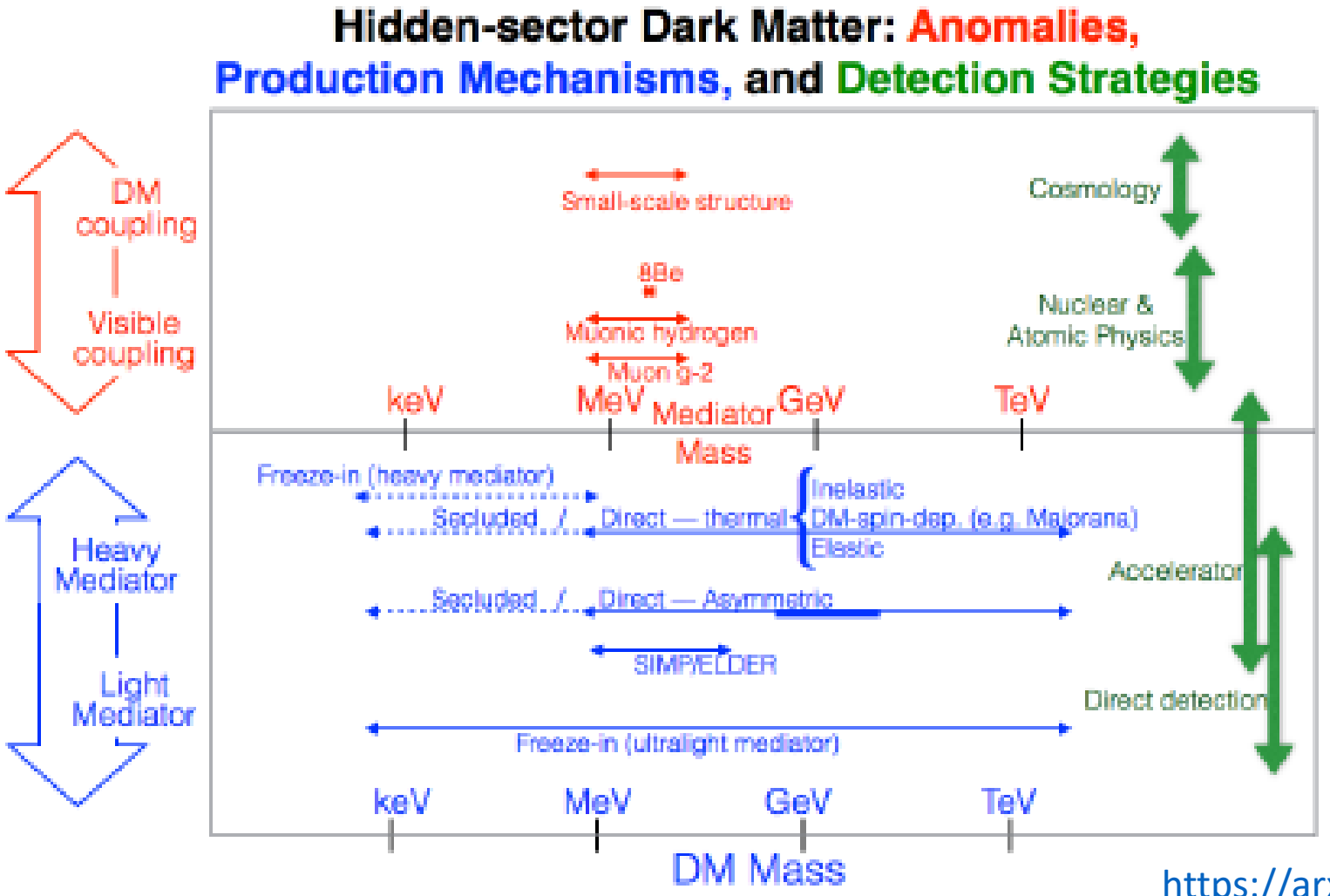


At high energies, parameterize limits in terms of y:

$$\sigma v \propto \epsilon^2 \alpha_D \frac{m_\chi^2}{m_{A'}^4} \equiv \frac{y}{m_\chi^2}$$

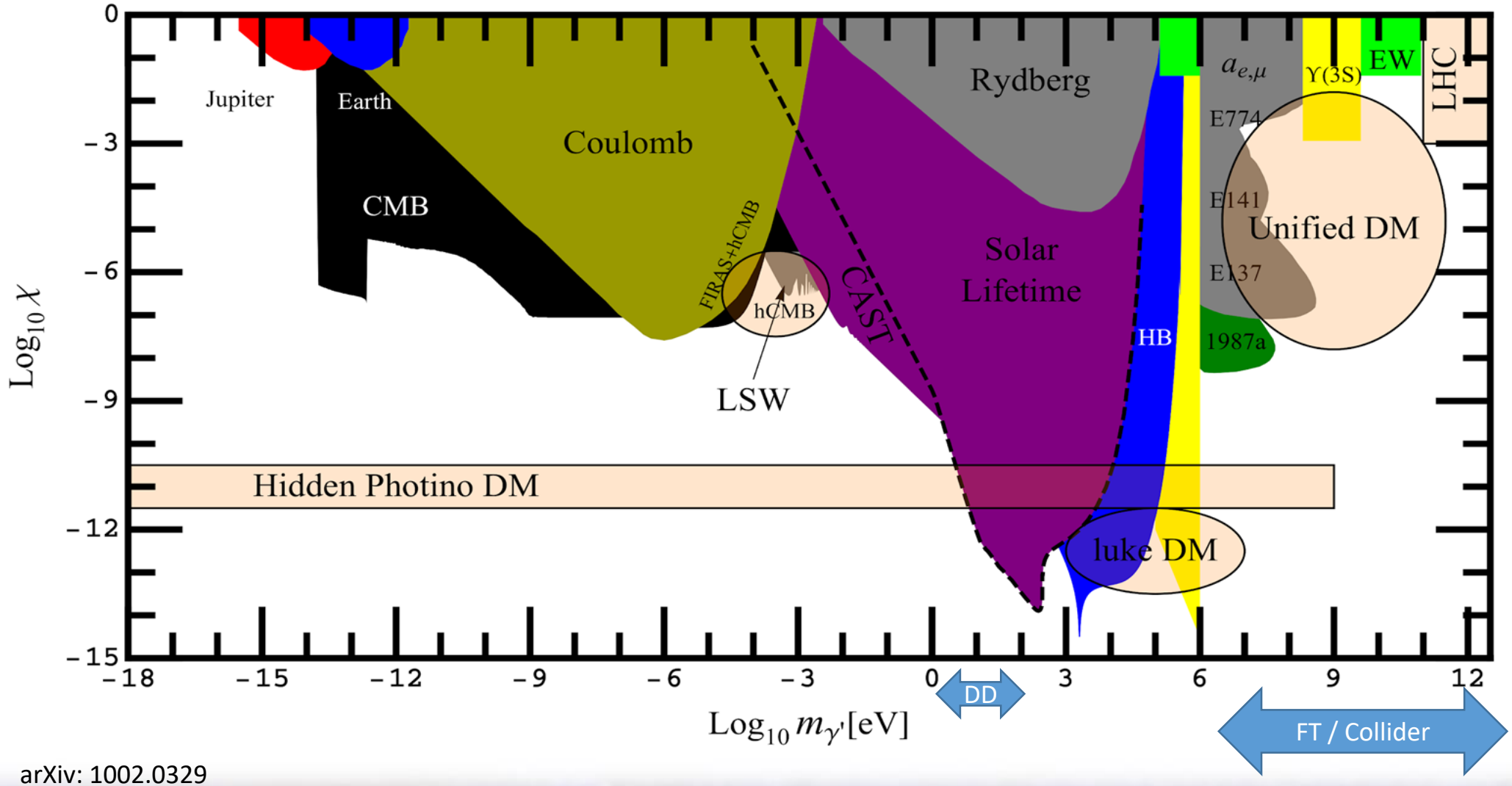
$$y \equiv \epsilon^2 \alpha_D \left(\frac{m_\chi}{m_{A'}}\right)^4$$

“Cosmic Visions” for Hidden Sectors



https://arxiv.org/abs/1707.04591

Dark Photon Search Landscape



arXiv: 1002.0329

Electron Scattering via Dark Photon

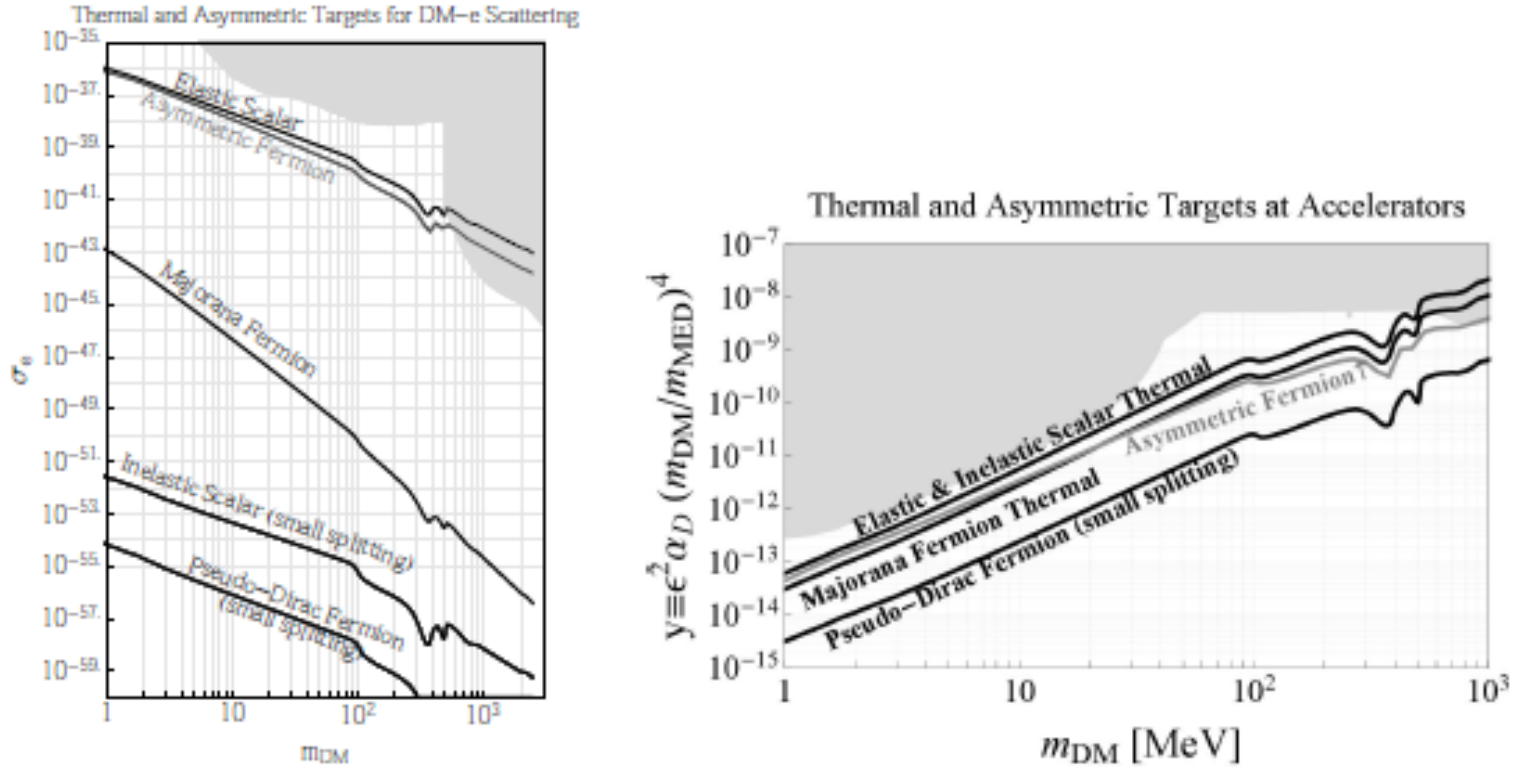
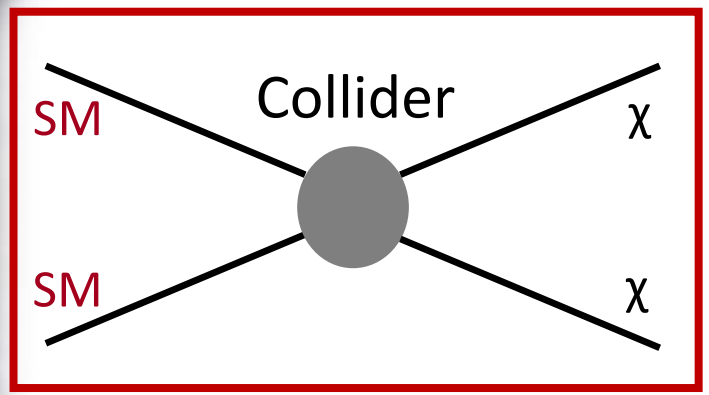


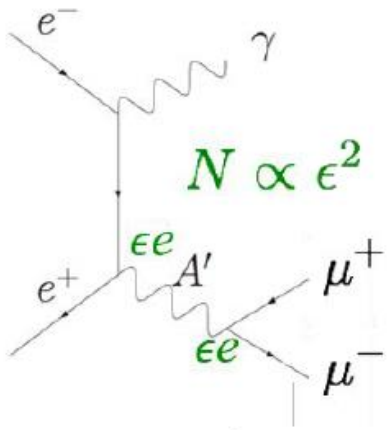
FIG. 17: Direct annihilation thermal freeze-out targets and asymmetric DM target for (left) non-relativistic e-DM scattering probed by direct-detection experiments and (right) relativistic accelerator-based probes. The thermal targets include scalar, Majorana, inelastic, and pseudo-dirac DM annihilating through the vector portal. Current constraints are displayed as shaded areas. Both panels assume $m_{\rm MED} = 3m_{\rm DM}$ and the dark fine structure constant $\alpha_D \equiv g_D^2/4\pi = 0.5$.

https://arxiv.org/abs/1707.04591

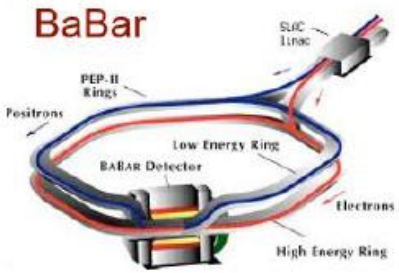
Collider Search Strategies



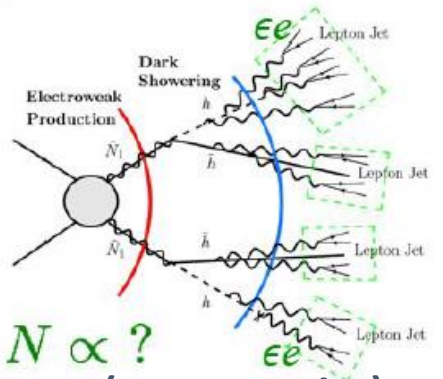
e^+e^- colliders



+ meson decays



pp collider

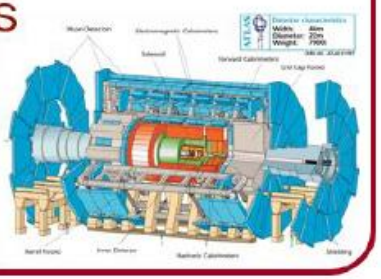


MET (e.g. monojet)

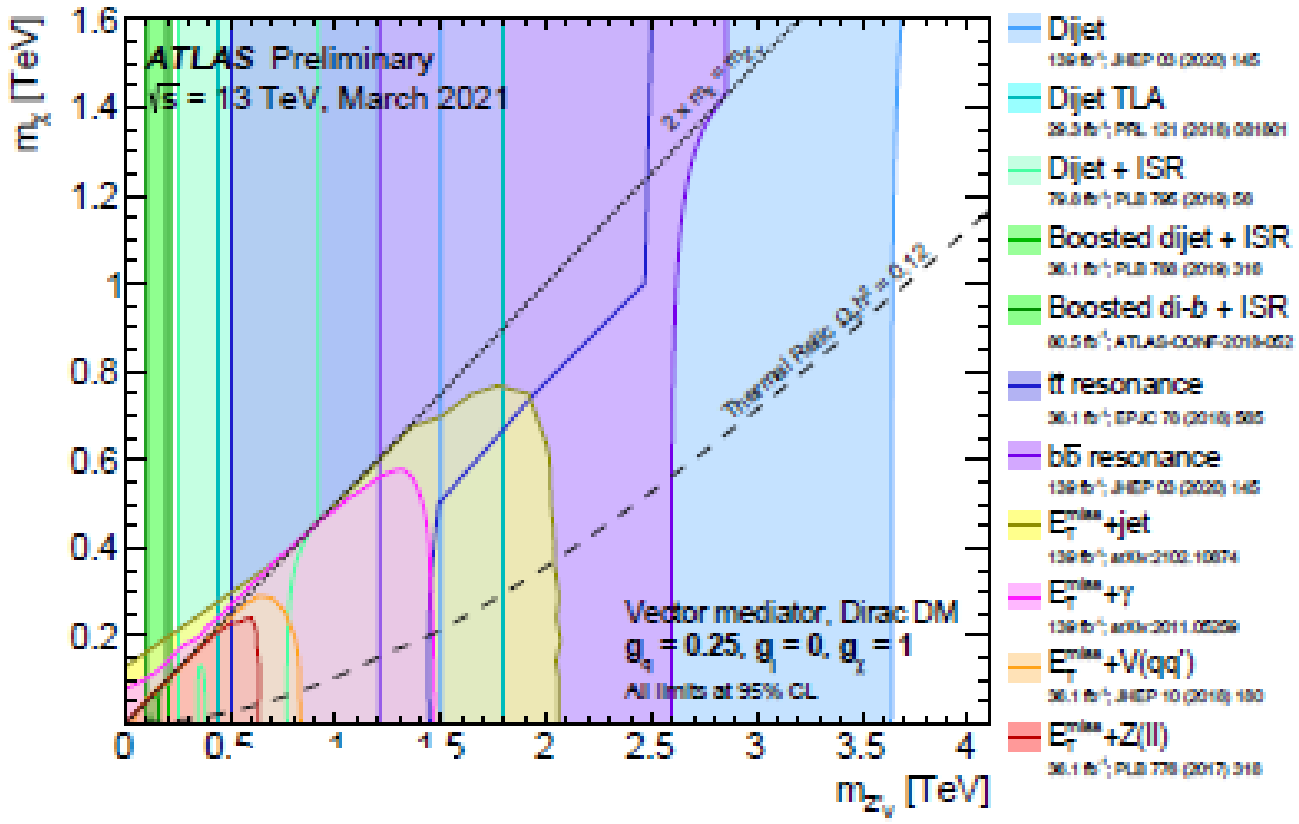
+ "lepton jets"

+ meson decays

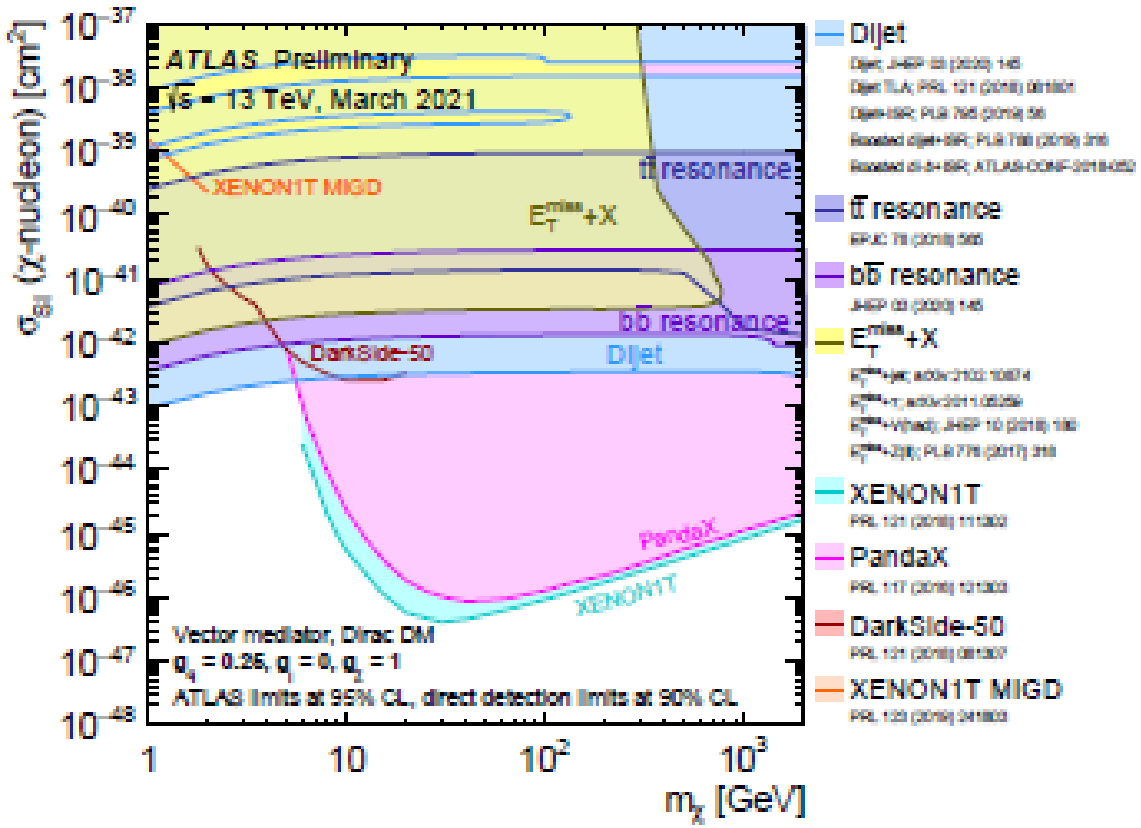
ATLAS
CMS
LHCb



Collider Search Strategies



(a)

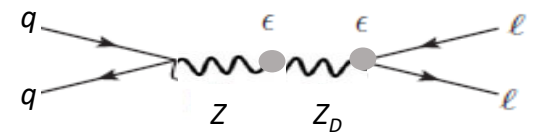


(b)

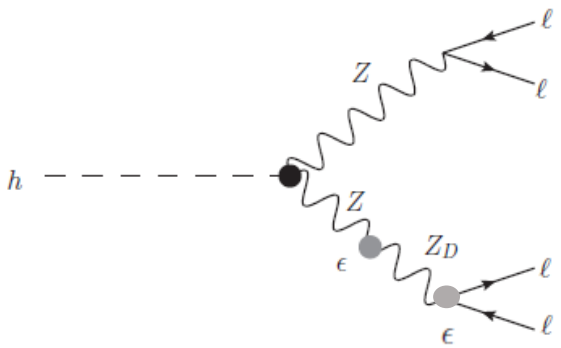
(a) Results on benchmark simplified DM model including a vector mediator and fermionic WIMPs. (b) Comparison of ATLAS results to direct-detection DM experiments in the case of a spin-independent interaction between WIMPs and nucleons. Figures from http://cds.cern.ch/record/2758386

Collider "Lepton-Jet" Search Strategies

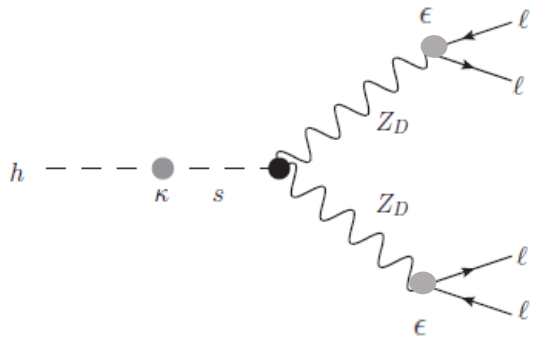
$pp \longrightarrow Z_D \longrightarrow l^+l^-$



$pp \longrightarrow h \longrightarrow Z\ Z_D \longrightarrow 2l^+\ 2l^-$



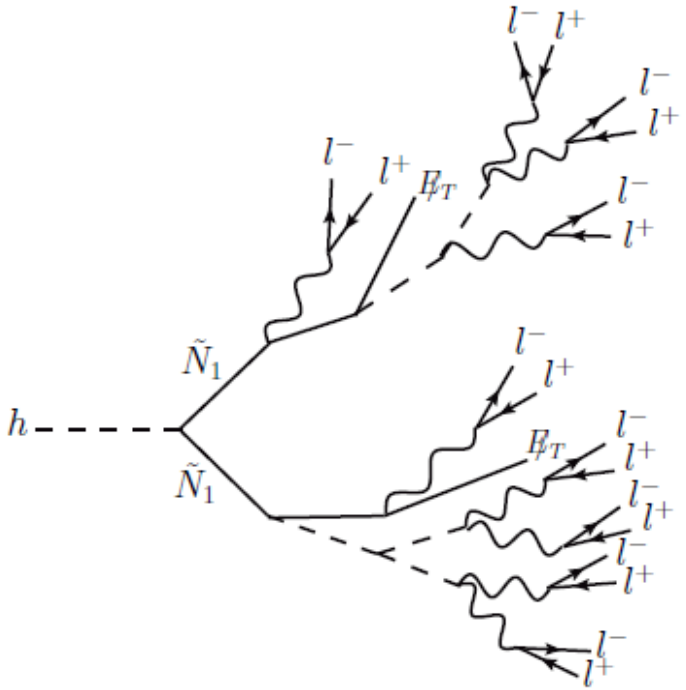
$pp \longrightarrow h \longrightarrow Z_D\ Z_D \longrightarrow 2l^+\ 2l^-$



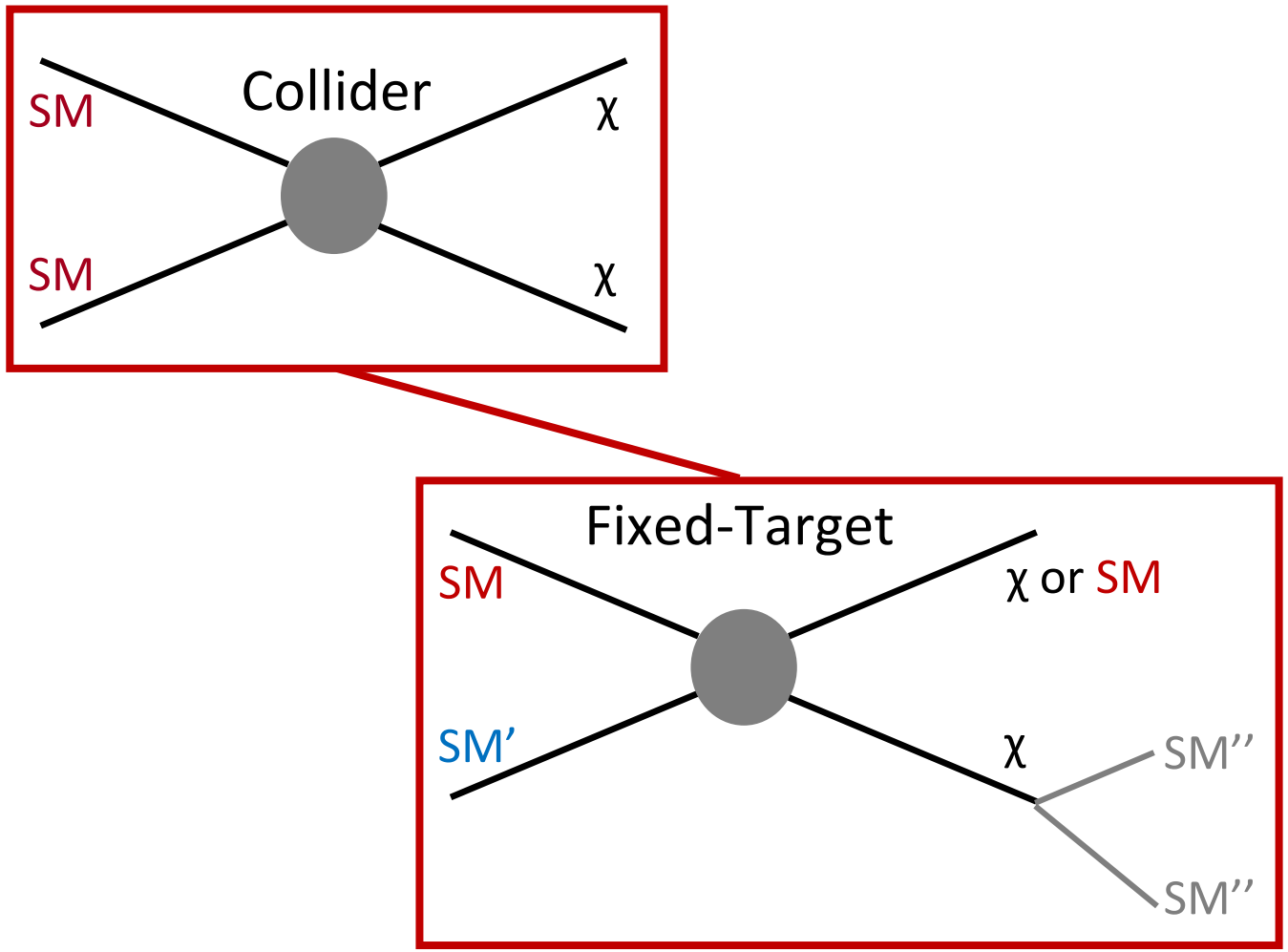
arXiv:1412.0018

Hidden Valley / SUSY

- Various combinations of dark vertices, decay chains

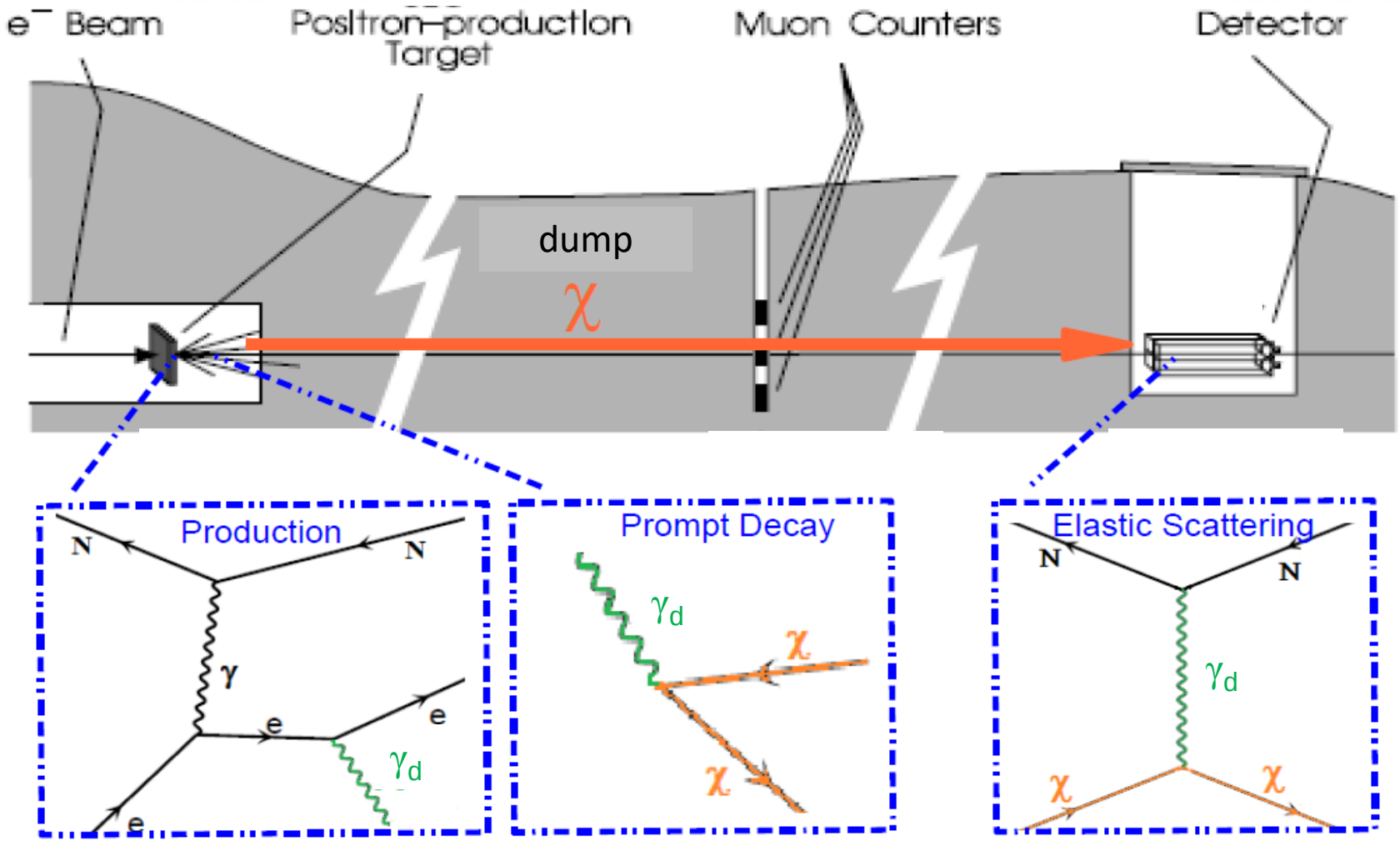


Fixed-Target Search Strategies



Dumps Aren't Just for Garbage…

Simplest beam dump



Phys. Rev. Lett. **111**, 221803 (2013)

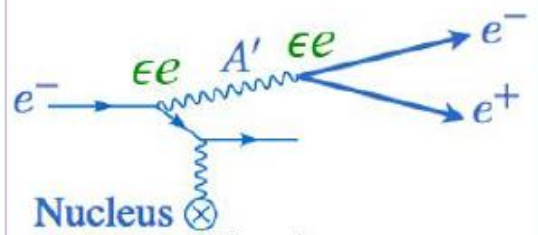
… They Can Get Complicated

More complex setups: target final-state dilepton signatures

(assuming dark photon is lowest-mass dark state)

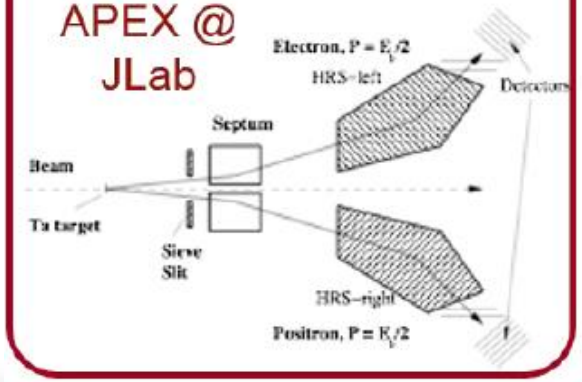
e^- fixed target

$N \propto \epsilon^2$



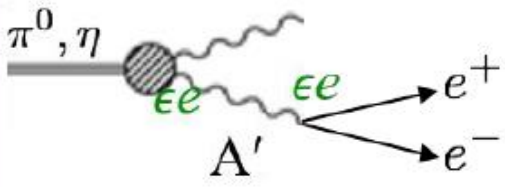
dark bremsstrahlung

APEX @ JLab

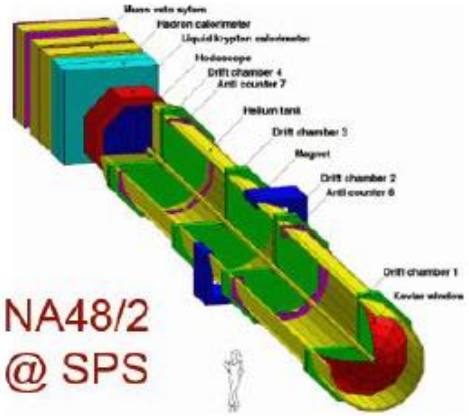


p fixed target

$N_\gamma \propto \epsilon^2$



meson decays



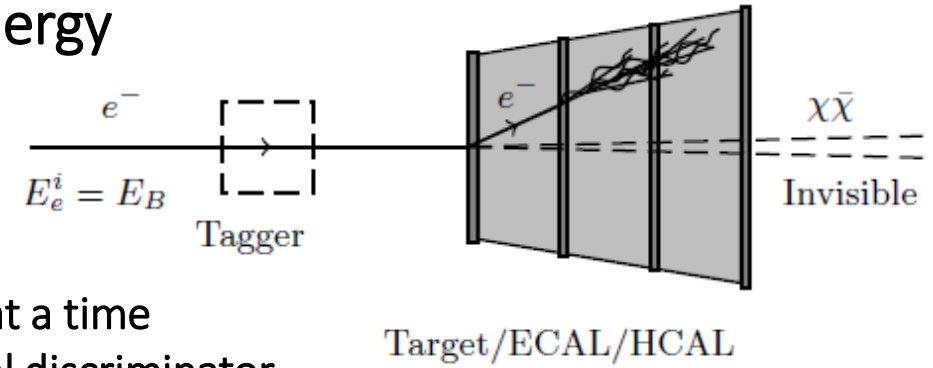
NA48/2 @ SPS

Uncloaking Invisibility

Even more sophisticated: also look for signatures of invisible decay products of dark photon

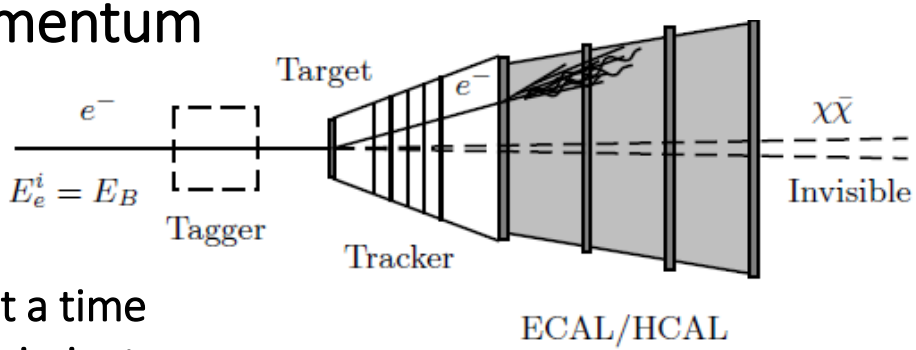
(assuming other dark sector particles are lower-mass than dark photon)

Missing Energy



One electron at a time
Only one signal discriminator
Insensitive to nature of interactions
Challenging backgrounds

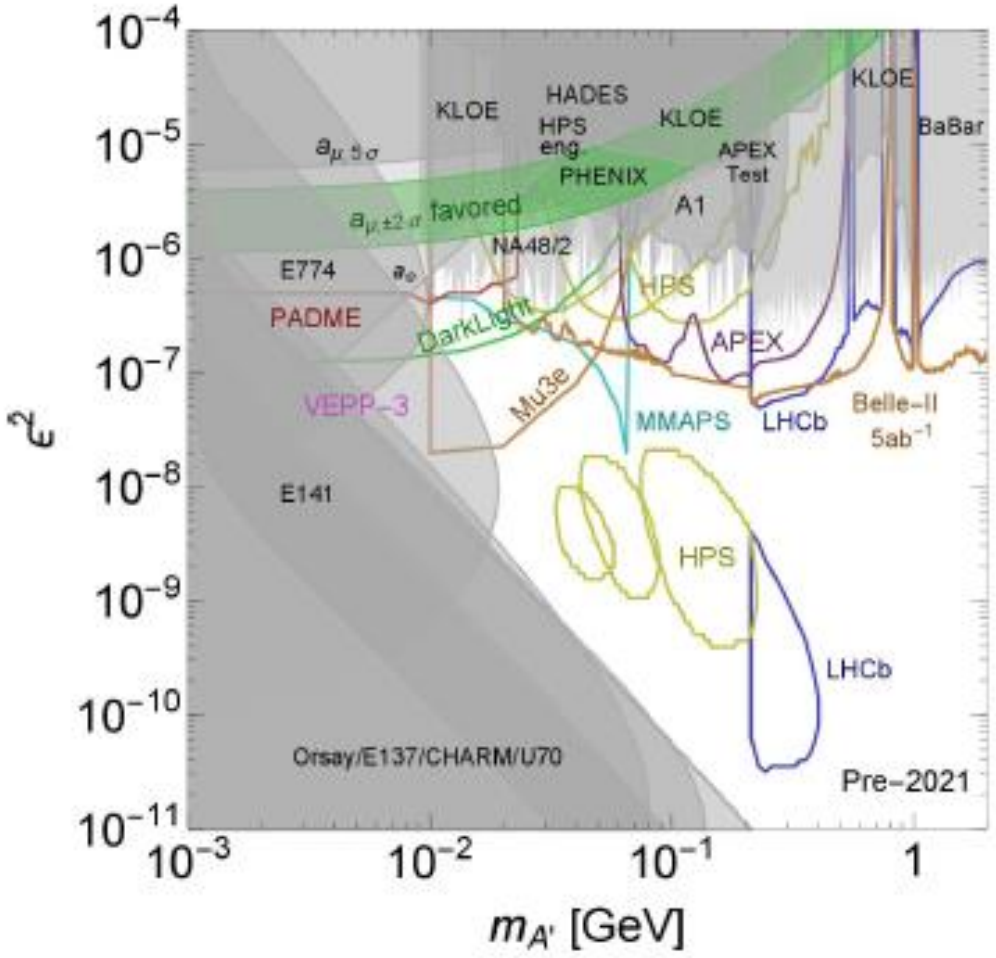
Missing Momentum

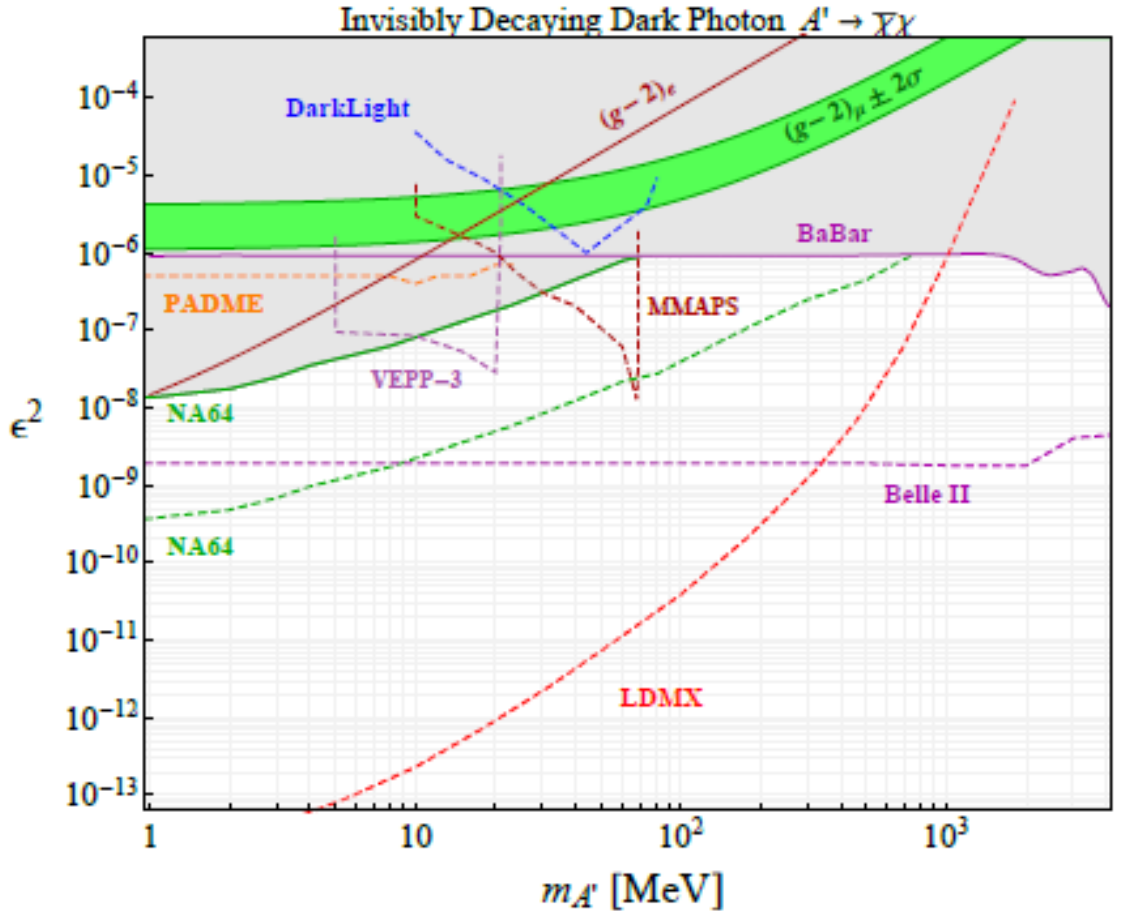


One electron at a time
Two signal discriminators
Sensitive to *A'* mass
"Zero-background"

Collider/Fixed-Target Limits on Dark Photons

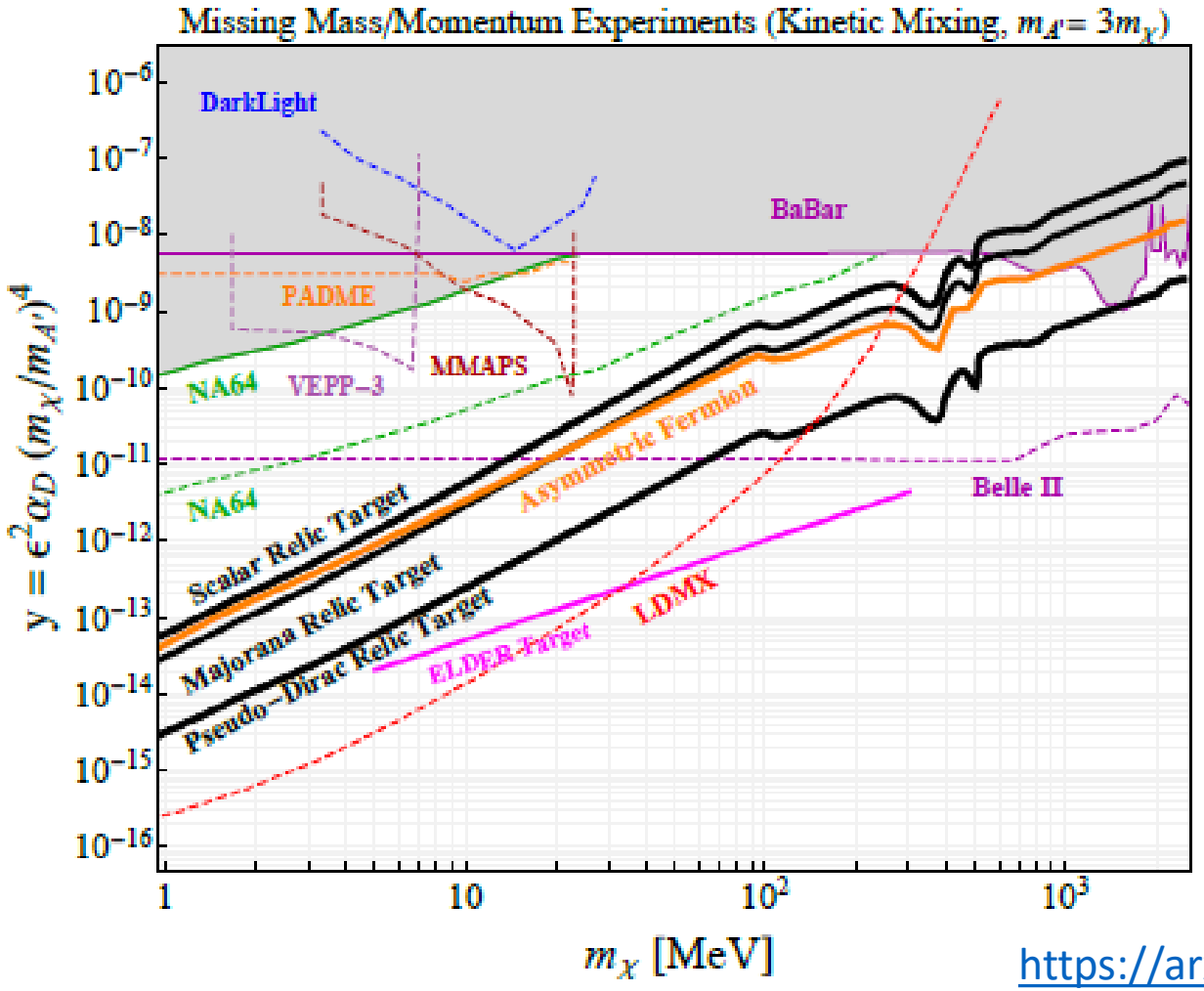
Visibly Decaying Dark Photon





https://arxiv.org/abs/1707.04591

Collider/Fixed-Target Limits on Dark Sectors



https://arxiv.org/abs/1707.04591