Finding Dark Matter in the Lab

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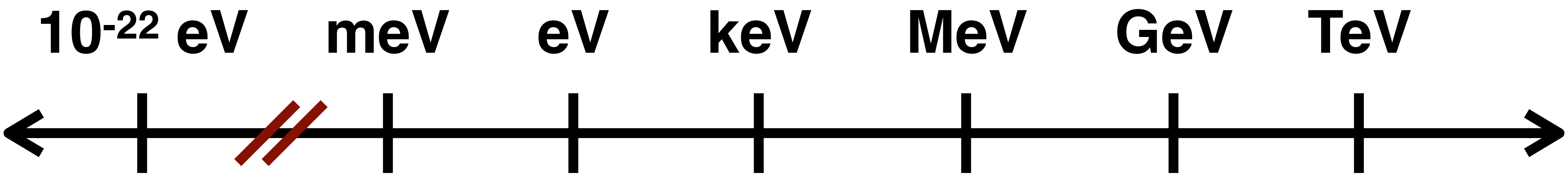
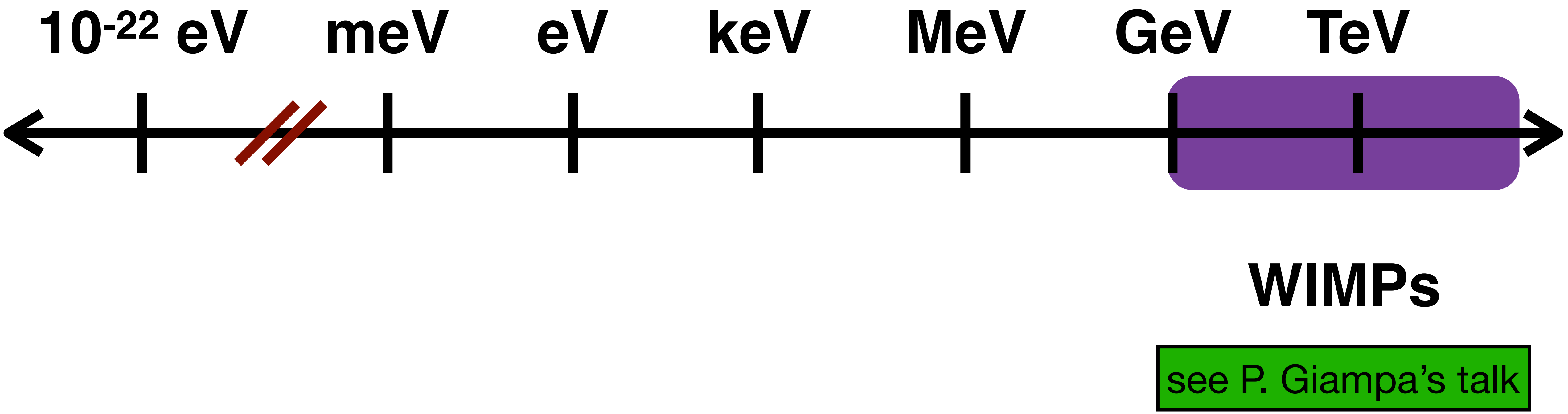
(University of Oregon)

TRIUMF Science Week — August 20, 2020

dark matter candidates



dark matter candidates



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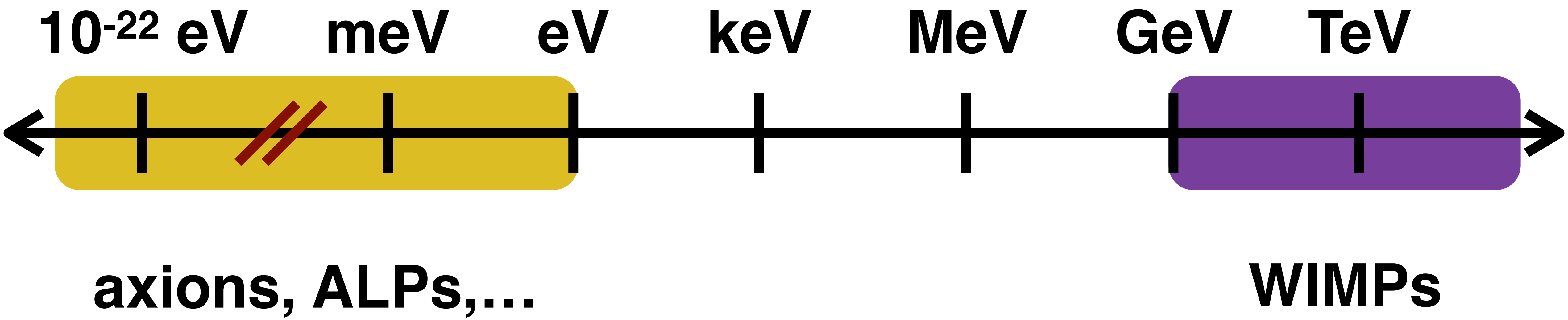
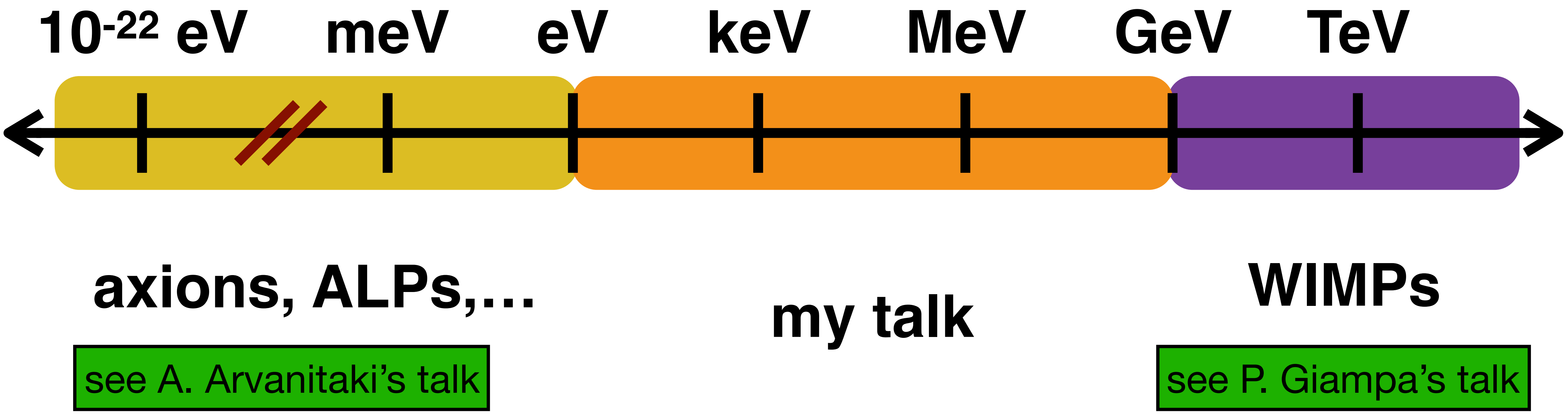


see A. Arvanitaki's talk

see P. Giampa's talk

dark matter candidates



Ways to find DM in the lab

- **produce** DM at accelerators or colliders
- **detect** galactic DM with underground detectors
  - look for scattering of DM with target material
  - look for absorption of DM within target material

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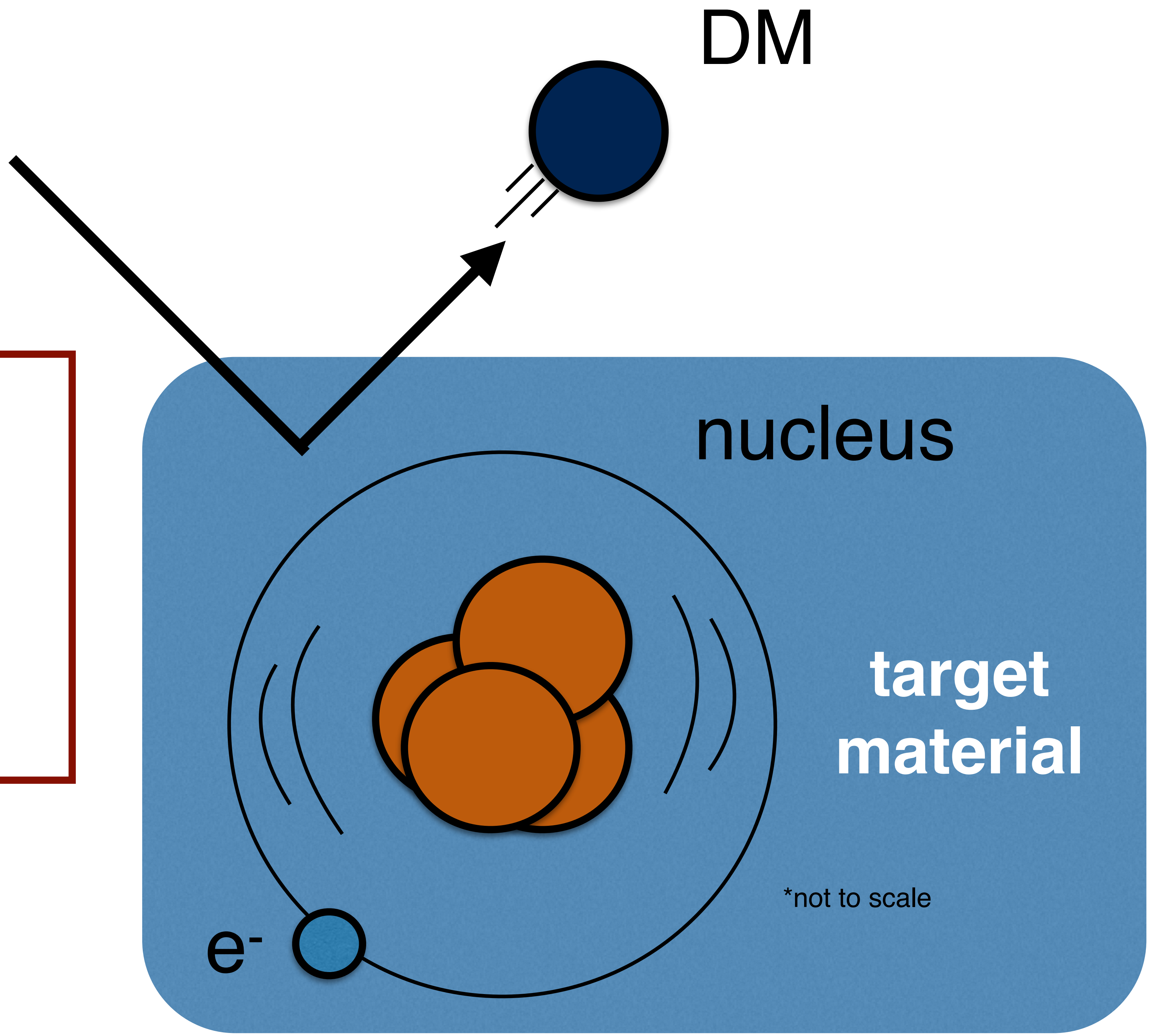
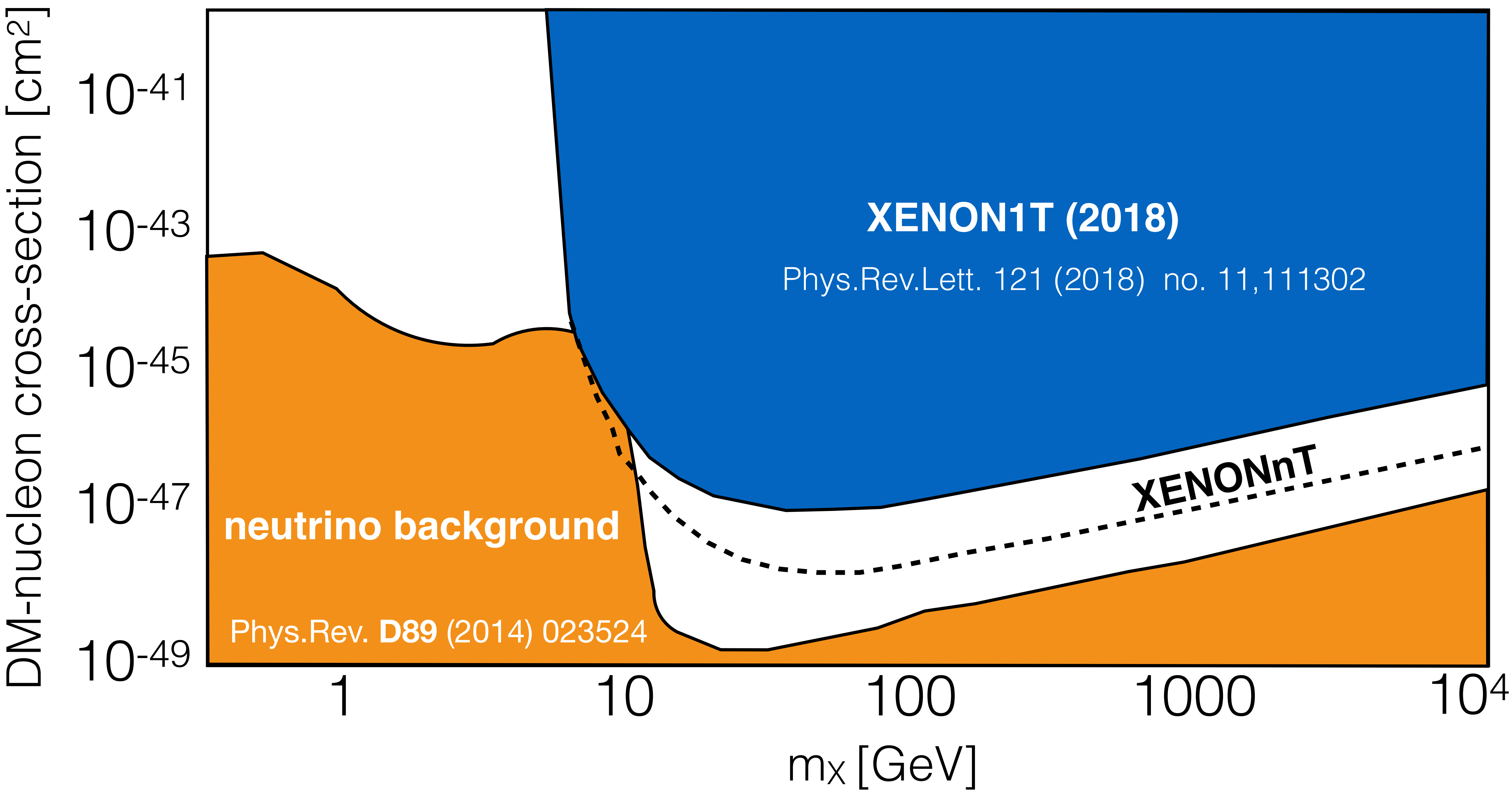
I will focus on this

DM direct detection

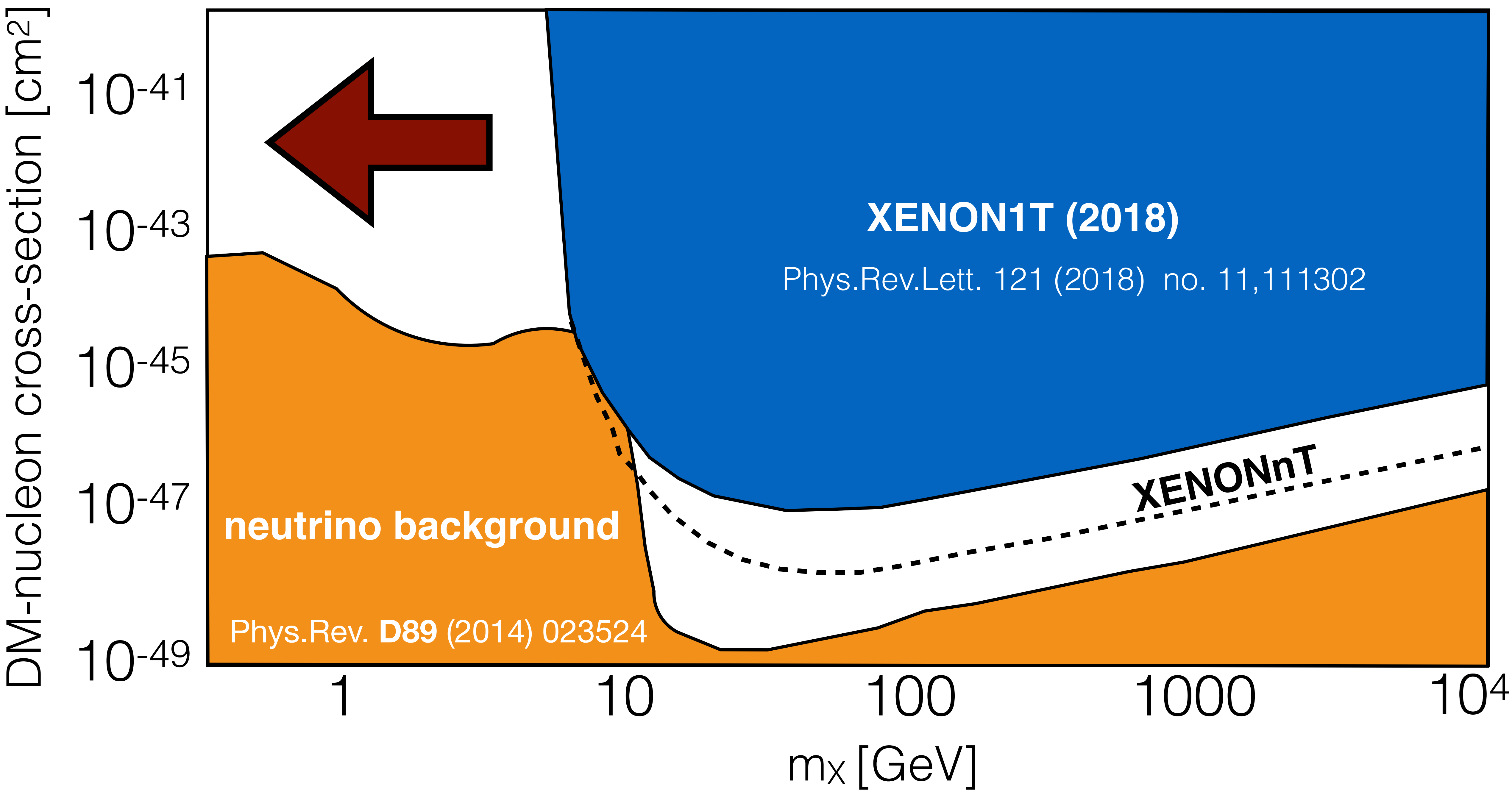
signal:
phonons,
scintillation
photons,
ionization
electrons



direct detection



direct detection



sub-GeV DM direct detection

- **Dark matter-electron scattering** in noble liquids, semiconductors, and organic molecules
- **Dark matter-nuclear scattering** through the Migdal scattering and bremsstrahlung
- **Absorption** of light dark matter, including axion-like particles and dark photons.
- **Dark matter scattering off collective modes** in molecules and in crystals (including phonons, plasmons and magnons)

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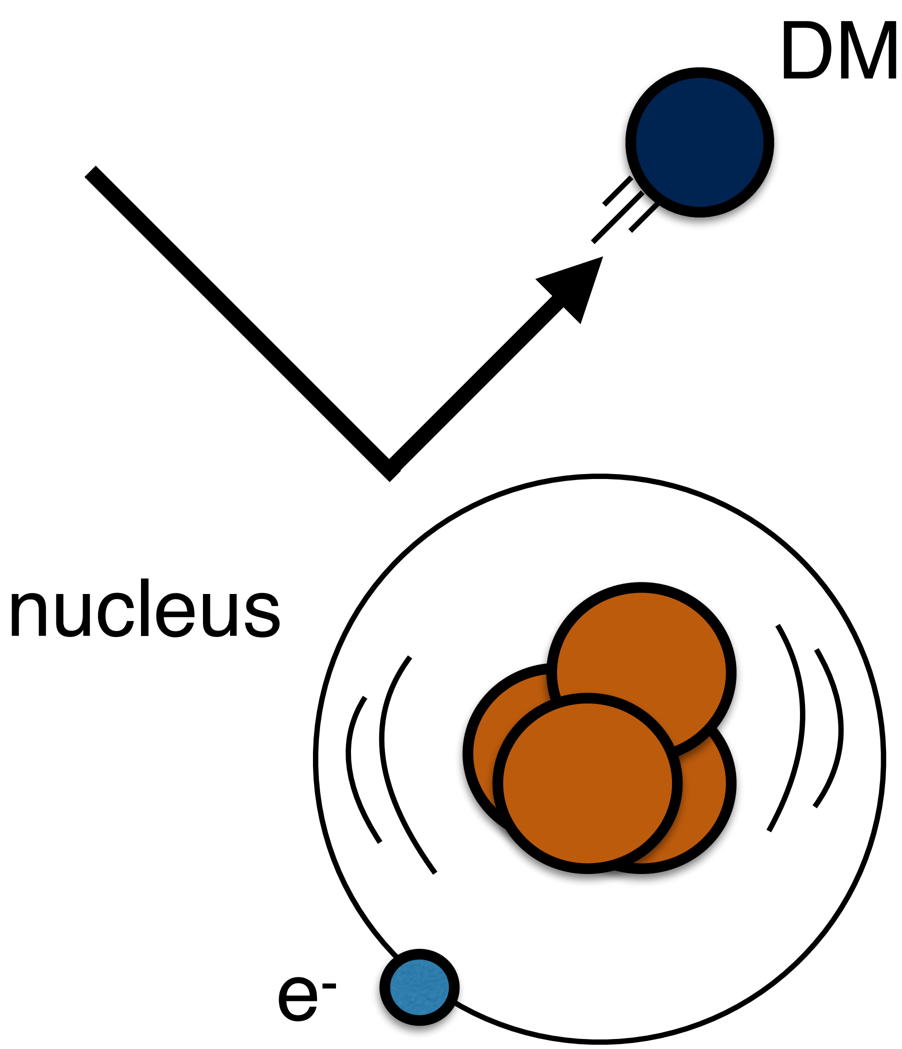
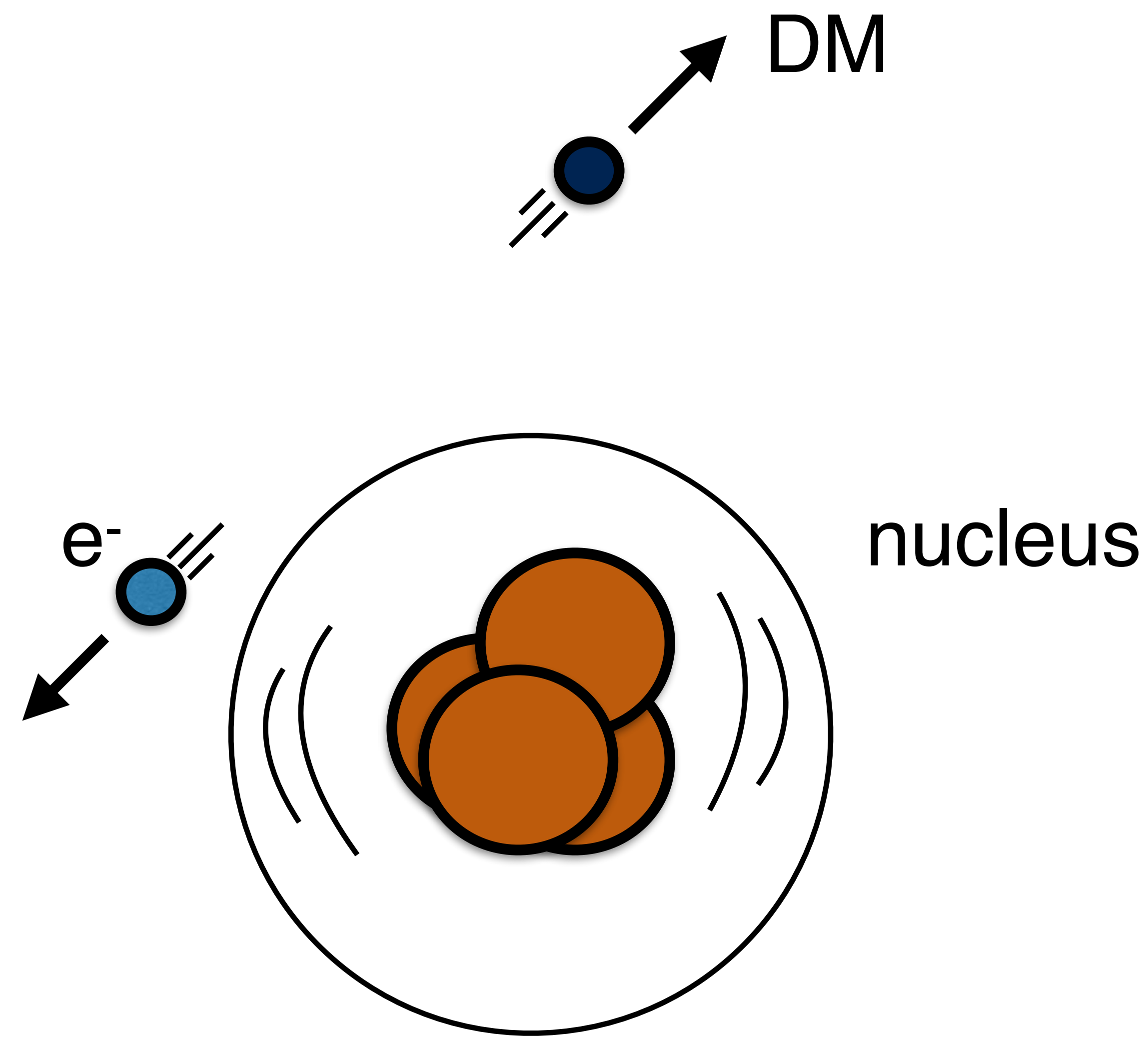


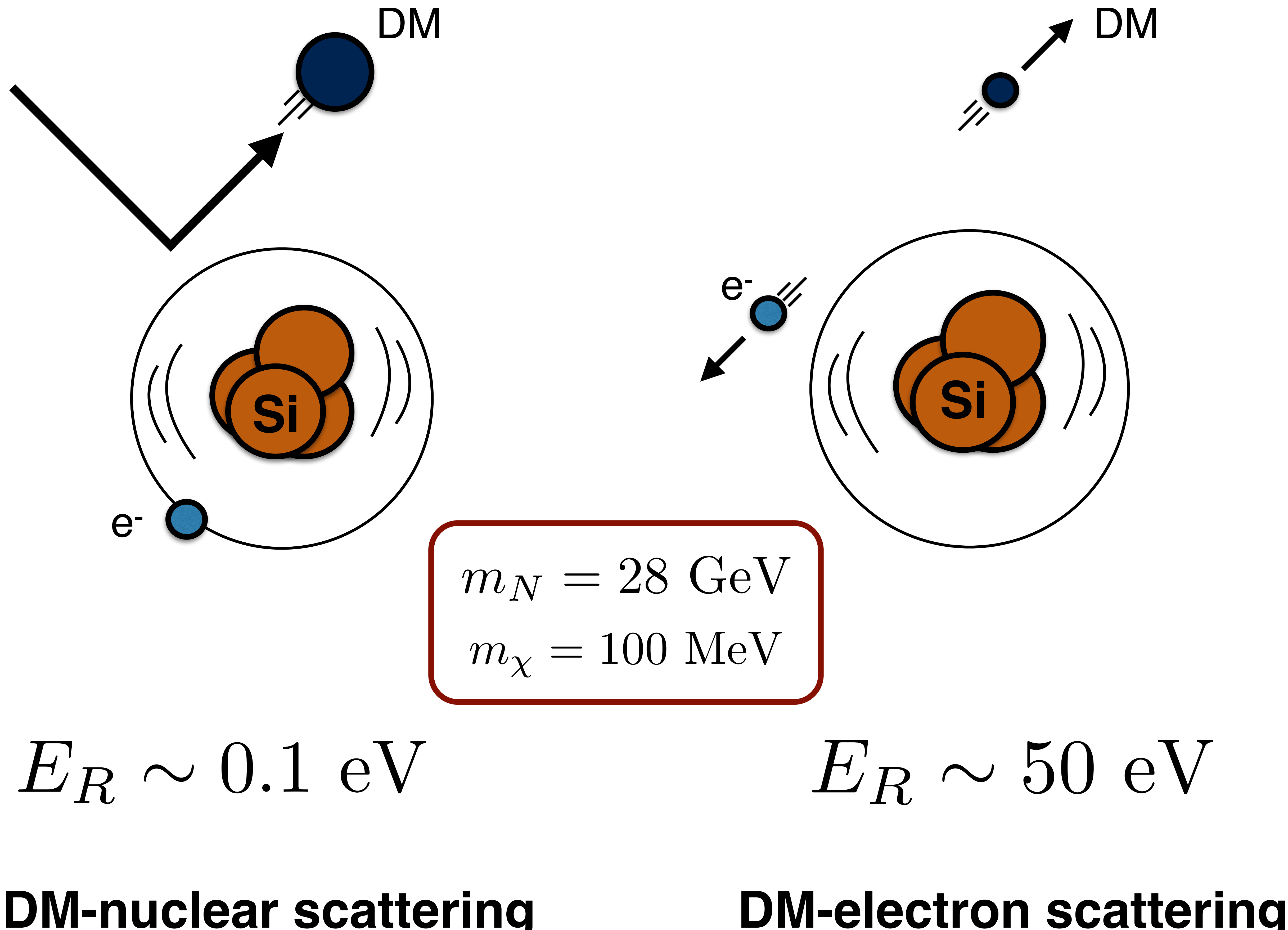
$$E_R = \frac{q^2}{2m_N}$$
$$\simeq 50 \text{ keV} \left(\frac{m_\chi}{100 \text{ GeV}}\right)^2 \left(\frac{100 \text{ GeV}}{m_N}\right)$$

DM-nuclear scattering

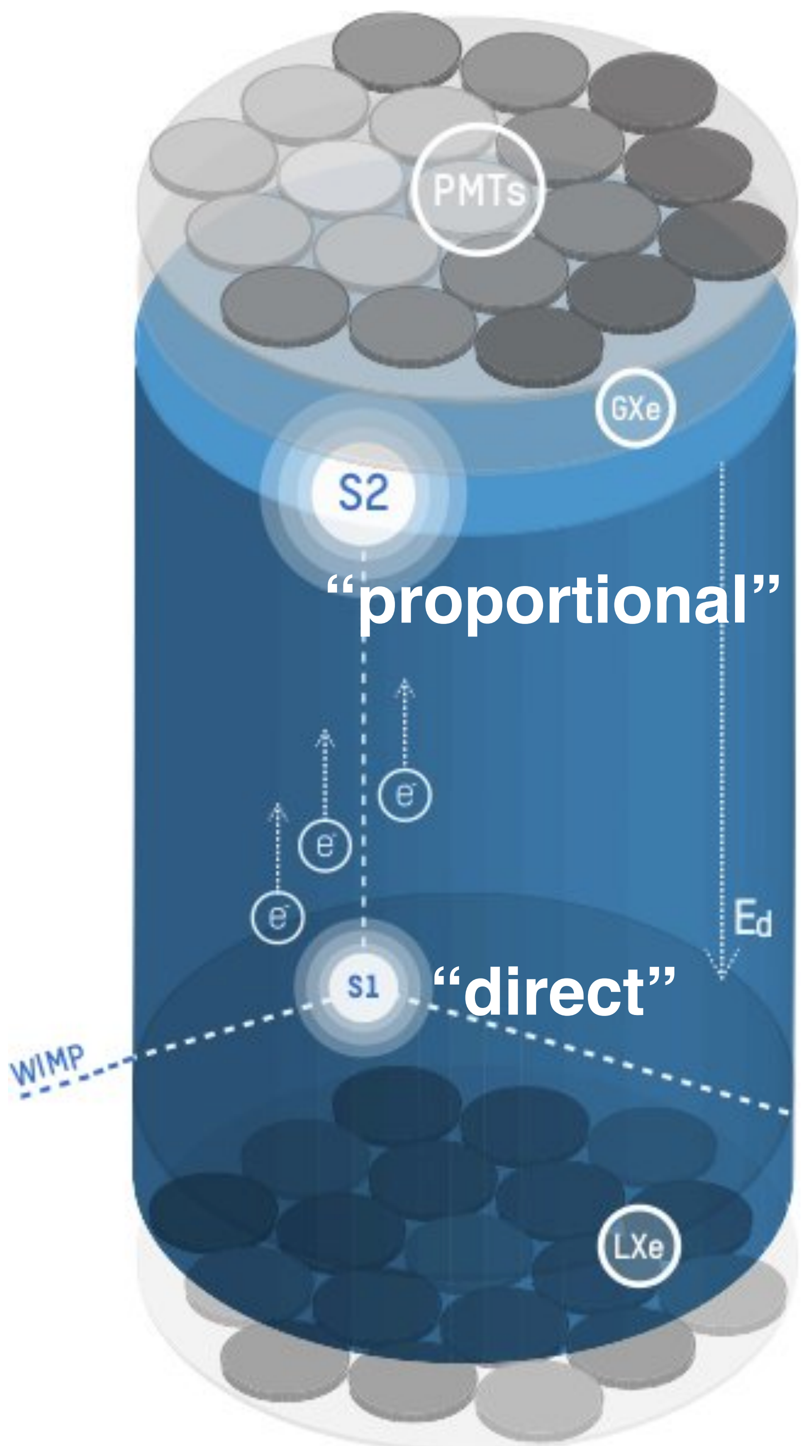


$$E_R = \vec{q}\cdot\vec{v} - \frac{q^2}{2\mu_{\chi N}}$$
$$\sim \frac{1}{2}\text{eV} \times \left(\frac{m_\chi}{\text{MeV}}\right)$$

DM-electron scattering


DM
e-
Si
DM
e-
Si
$m_N = 28$ GeV
$m_\chi = 100$ MeV
$E_R \sim 0.1$ eV
$E_R \sim 50$ eV
DM-nuclear scattering
DM-electron scattering

Liquid Xenon/Argon



https://commons.wikimedia.org/wiki/File:2phaseTPC_b.jpg

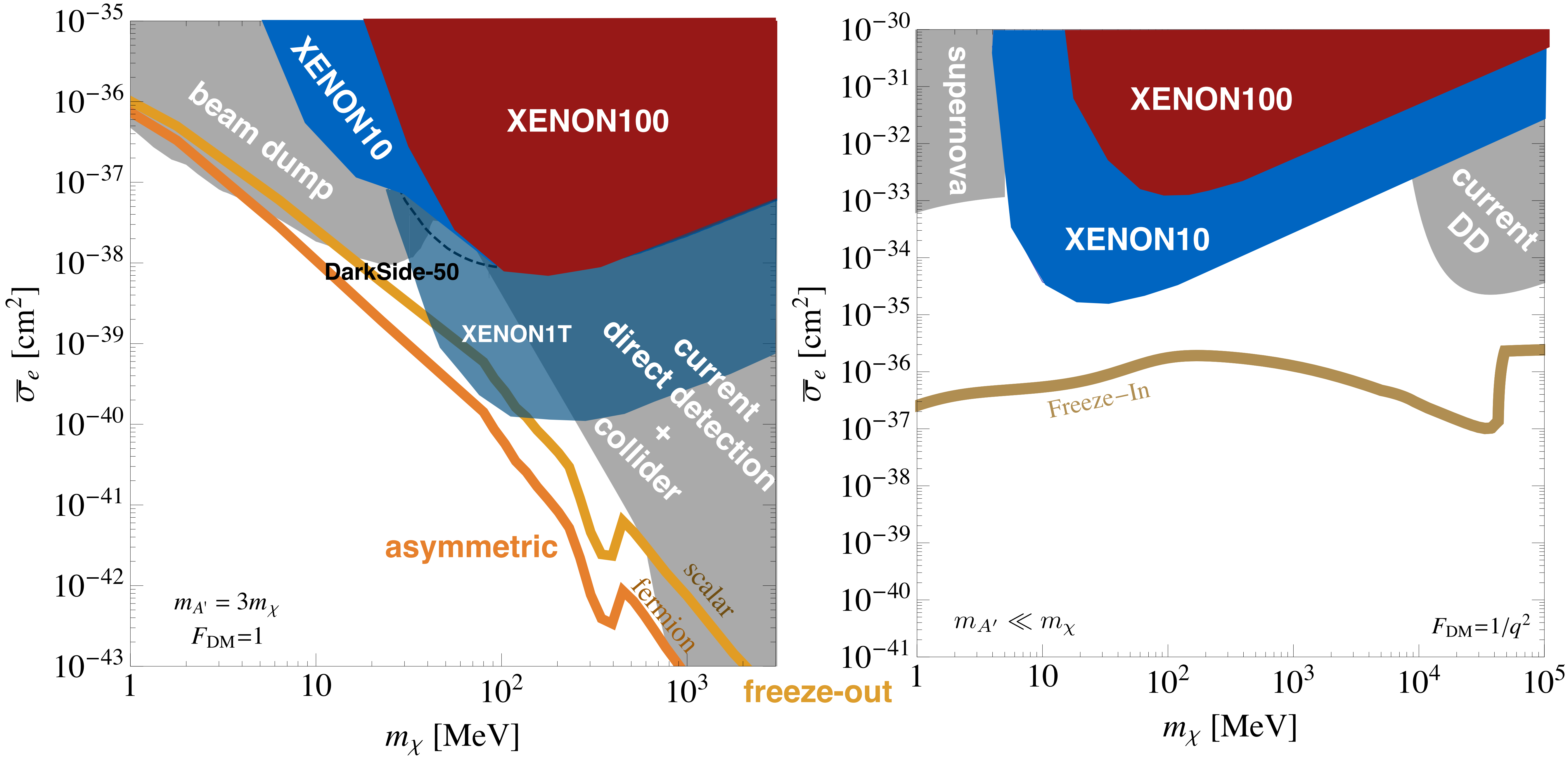
i.e. XENON10, XENON100, XENON1T, LUX, DarkSide…

DM-electron scattering
=
S2 only signal

sensitive to ~10 eV energy depositions

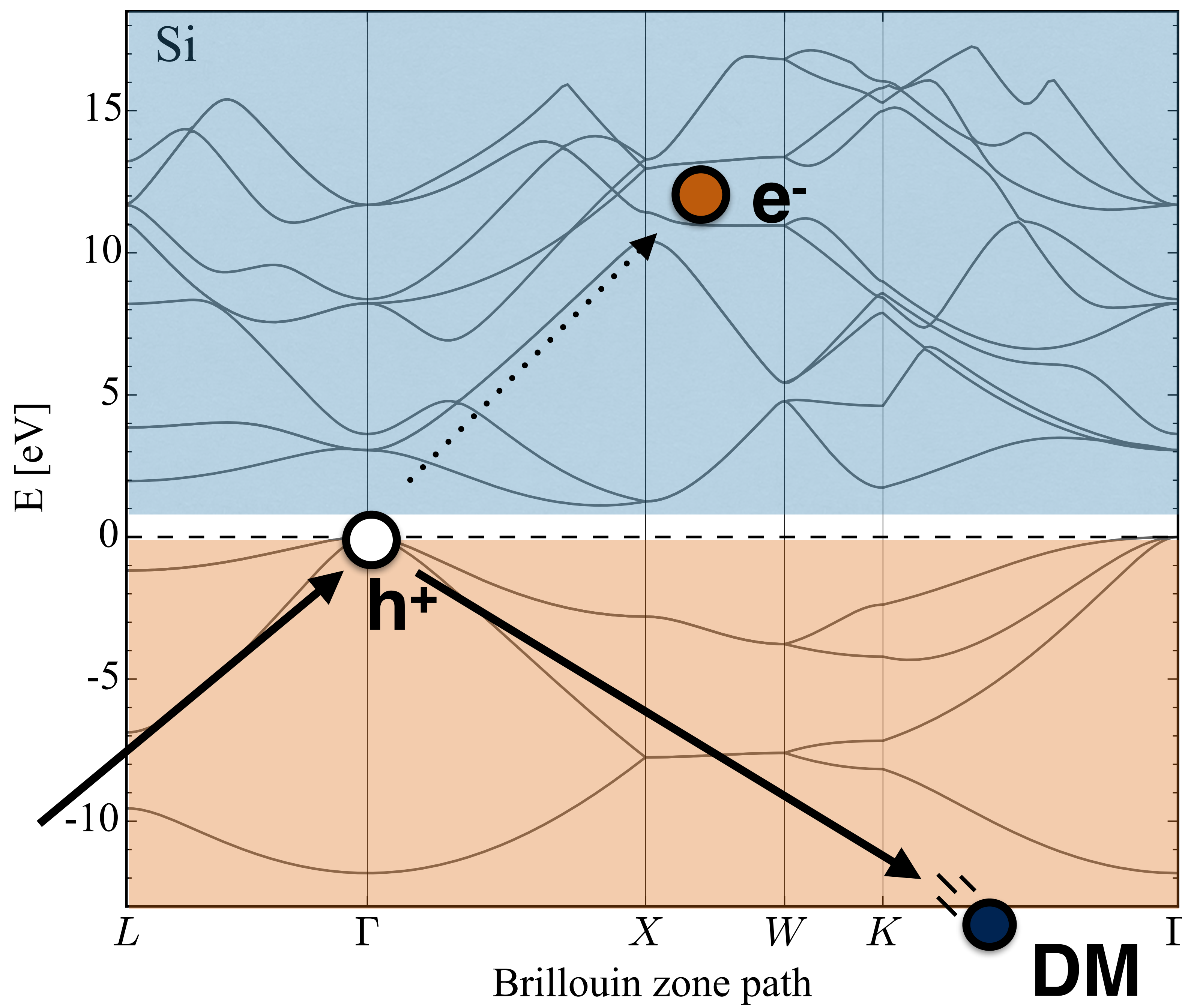
measures **P**hoto**E**lectrons

dark photon



Essig, Volansky, TTY [1703.00910], DarkSide Collaboration [1802.06998], XENON1T [1907.11485]

semiconductor targets



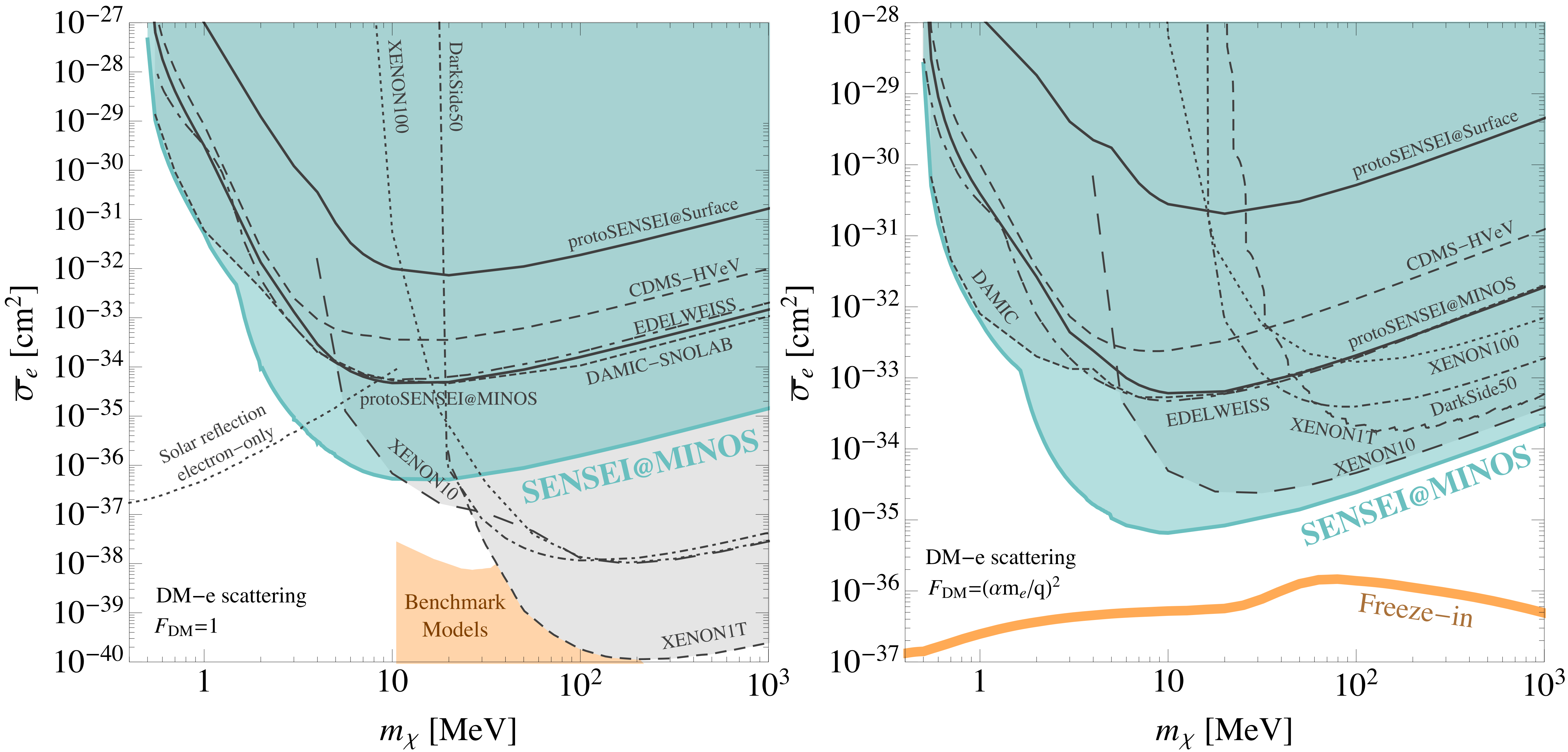
detect the electron(s)

sensitive to ~eV energy depositions

i.e. silicon, germanium

Essig, Mardon, Volansky [1108.5383]
Graham, Kaplan, Rajendran, Walters [1203.2531]
Lee, Lisanti, Mishra-Sharma, Safdi [1508.07361]
Essig, Fernandez-Serra, Mardon, Soto, Volansky, TTY [1509.01598]

DM-electron scattering



SENSEI collaboration [arXiv:2004.11378], *submitted to PRL*

sub-GeV DM direct detection

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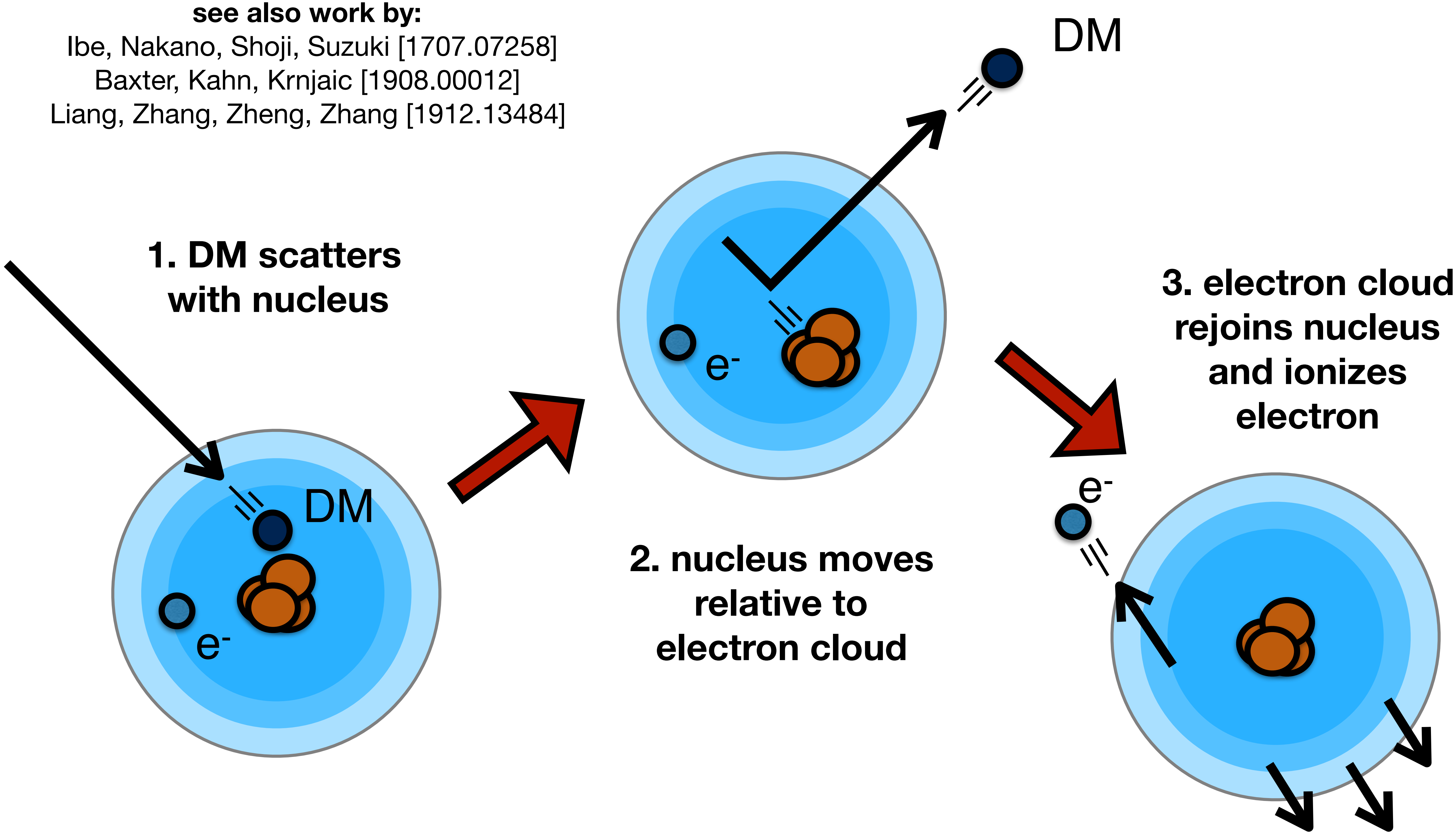
"Migdal" scattering

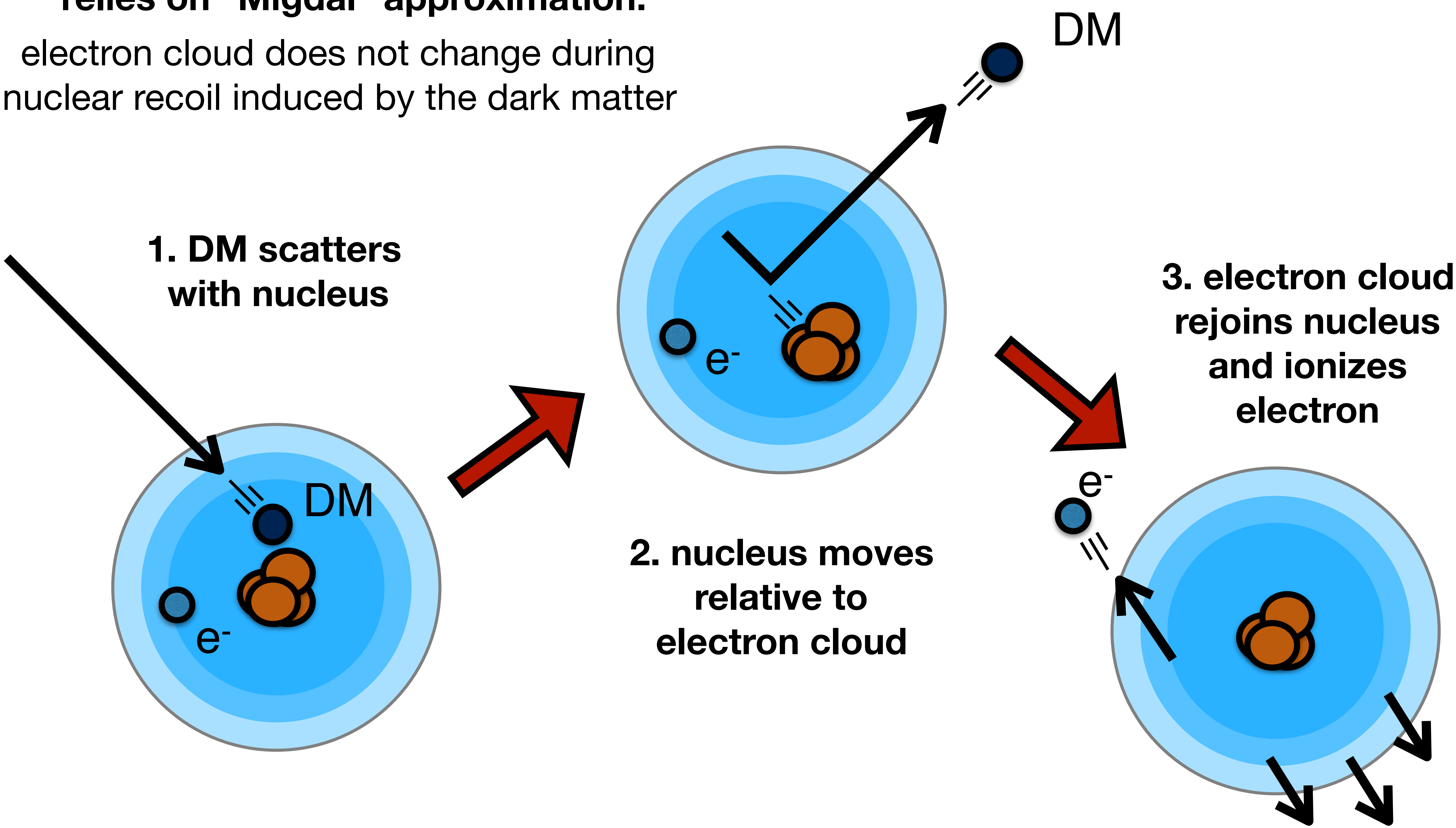
see also work by:
Ibe, Nakano, Shoji, Suzuki [1707.07258]
Baxter, Kahn, Krnjaic [1908.00012]
Liang, Zhang, Zheng, Zhang [1912.13484]



“Migdal” scattering

***relies on “Migdal” approximation:**

electron cloud does not change during nuclear recoil induced by the dark matter



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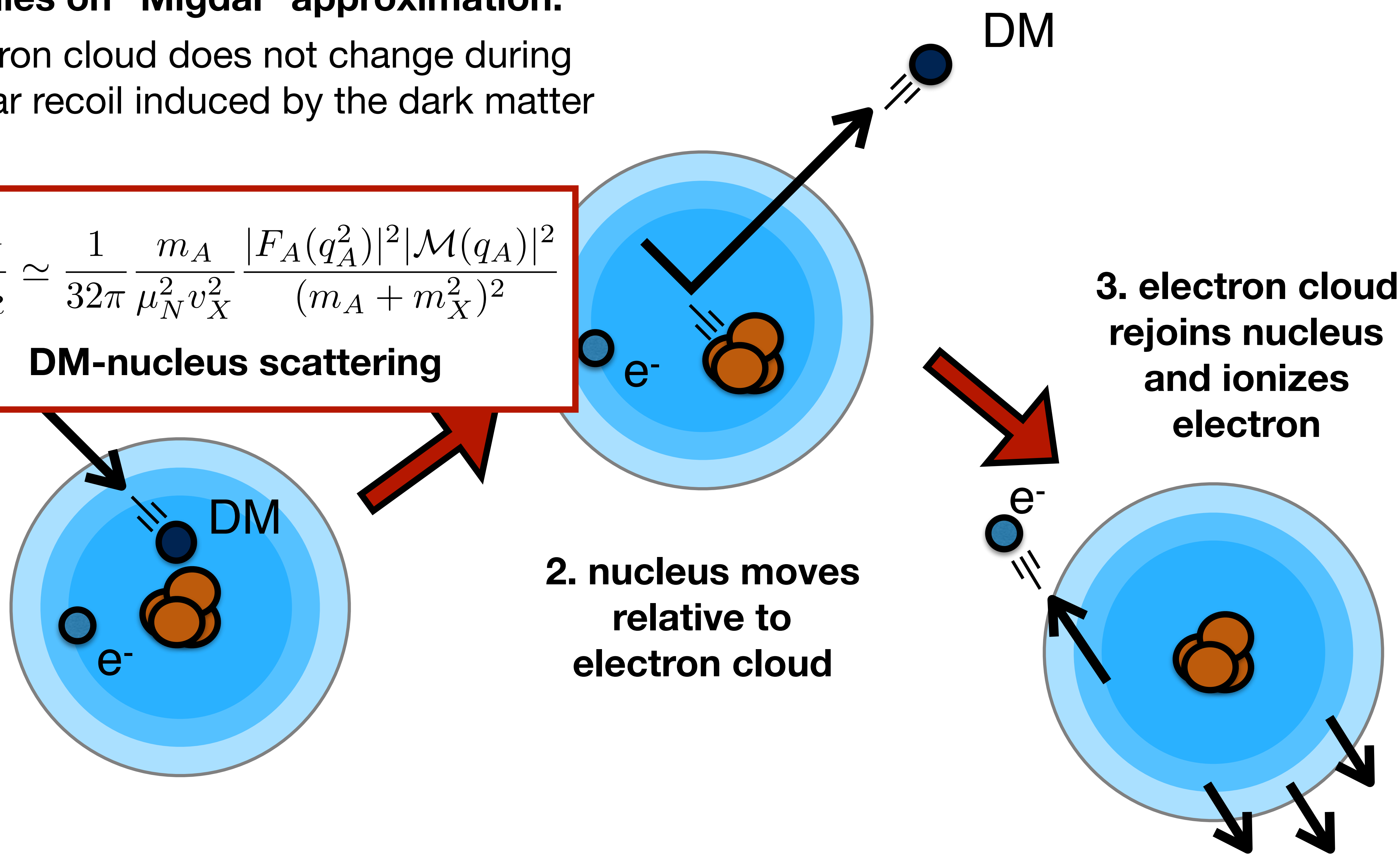
$$\frac{d\sigma_N}{dE_R} \simeq \frac{1}{32\pi} \frac{m_A}{\mu_N^2 v_X^2} \frac{|F_A(q_A^2)|^2 |\mathcal{M}(q_A)|^2}{(m_A + m_X^2)^2}$$

DM-nucleus scattering



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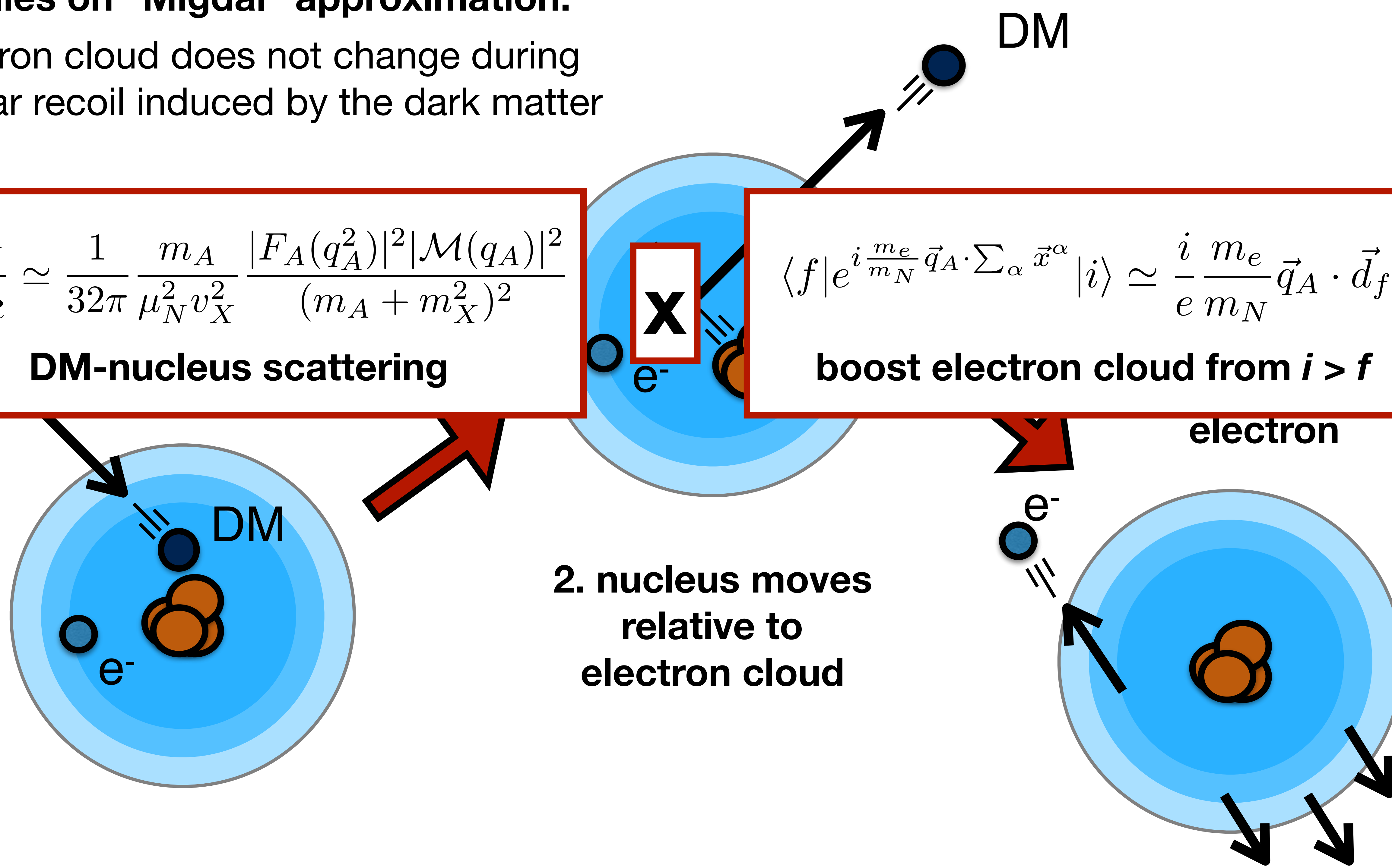
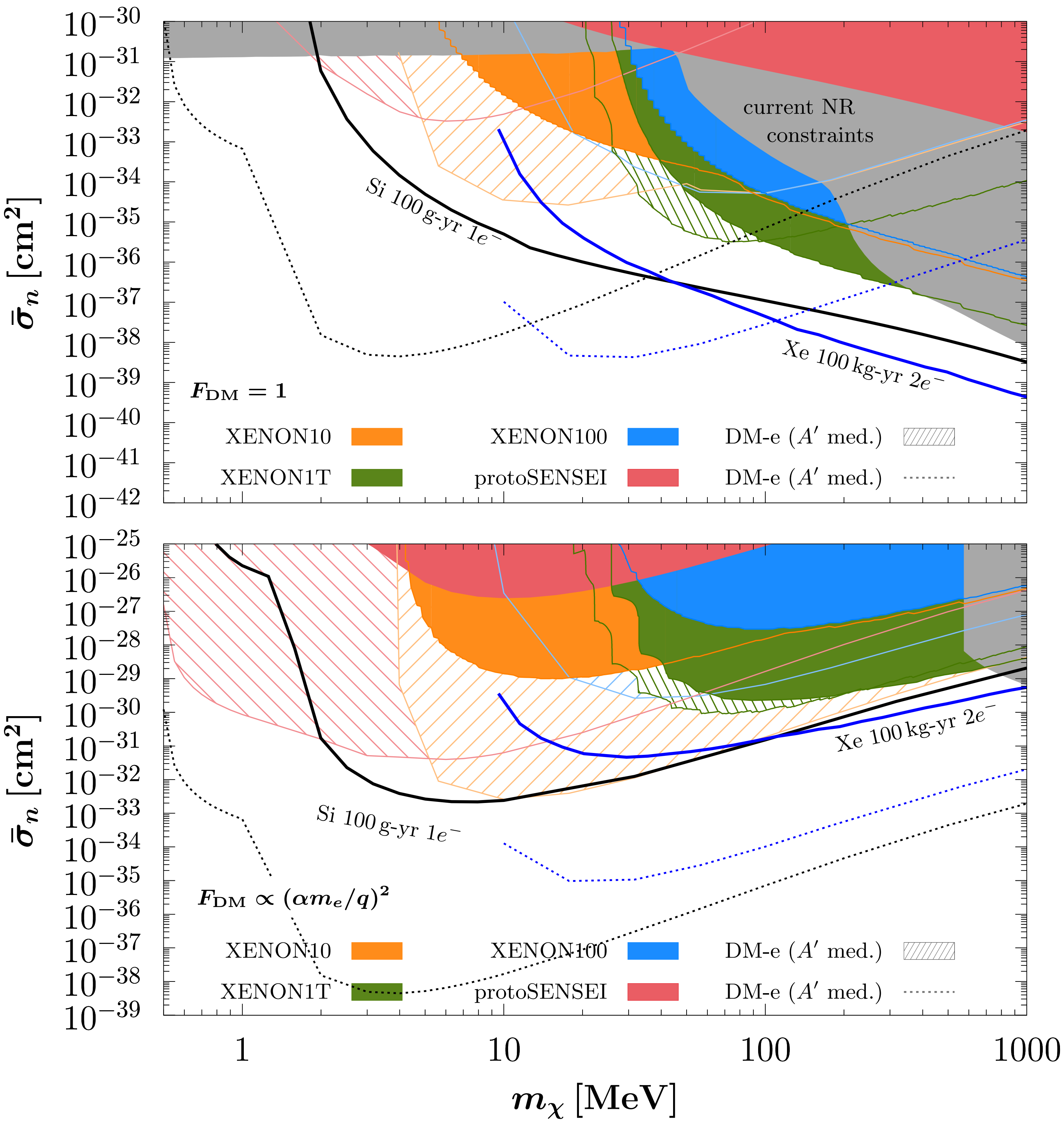
DM-nucleus scattering

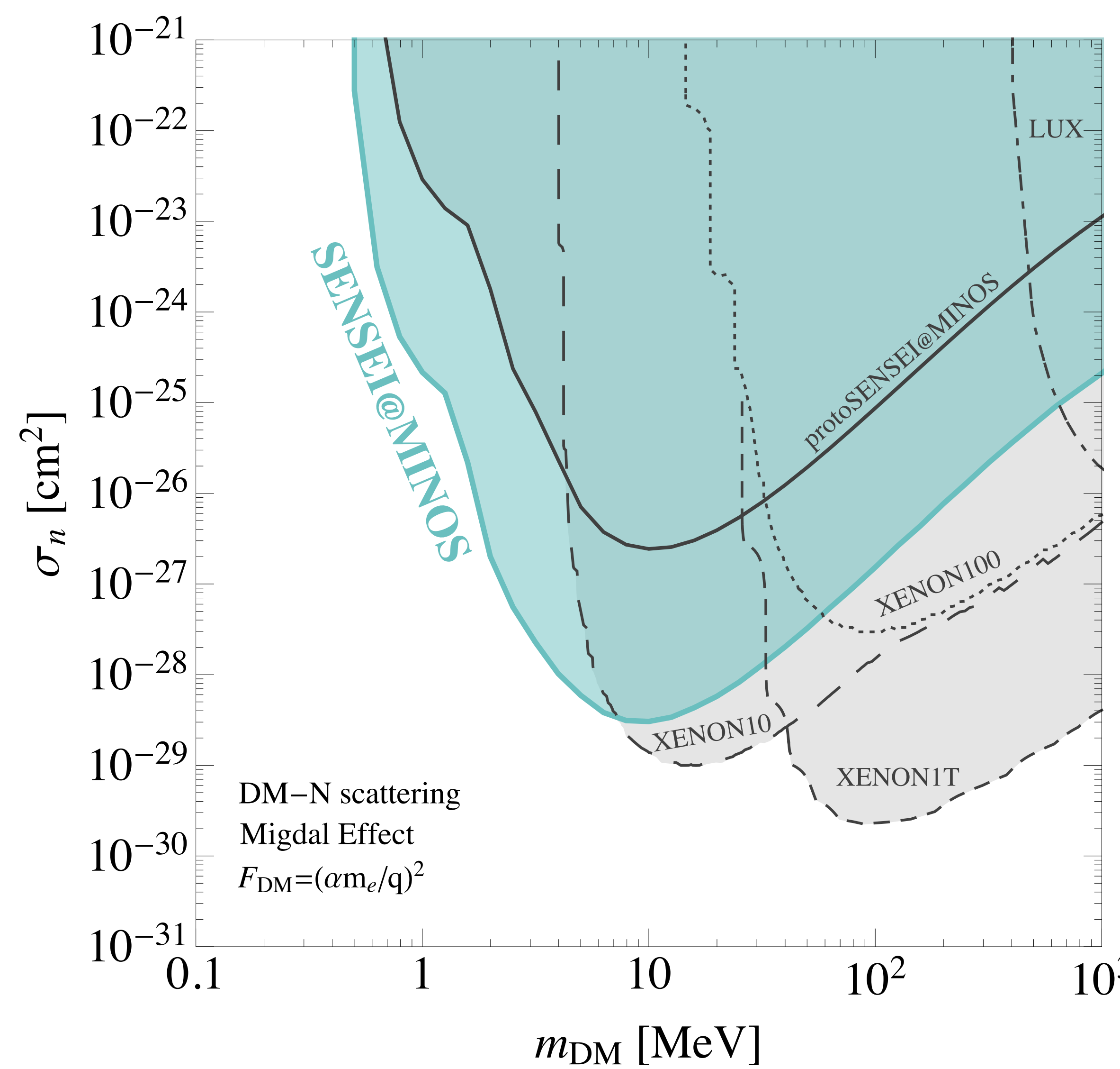
$$\langle f | e^{i \frac{m_e}{m_N} \vec{q}_A \cdot \sum_\alpha \vec{x}^\alpha} | i \rangle \simeq \frac{i}{e} \frac{m_e}{m_N} \vec{q}_A \cdot \vec{d}_{fi}$$

boost electron cloud from *i* > *f*



“Migdal” scattering





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Essig, Pradler, Sholapurkar, TTY *Phys.Rev.Lett.* 124 (2020) 2, 021801 [arXiv:1908.10881]

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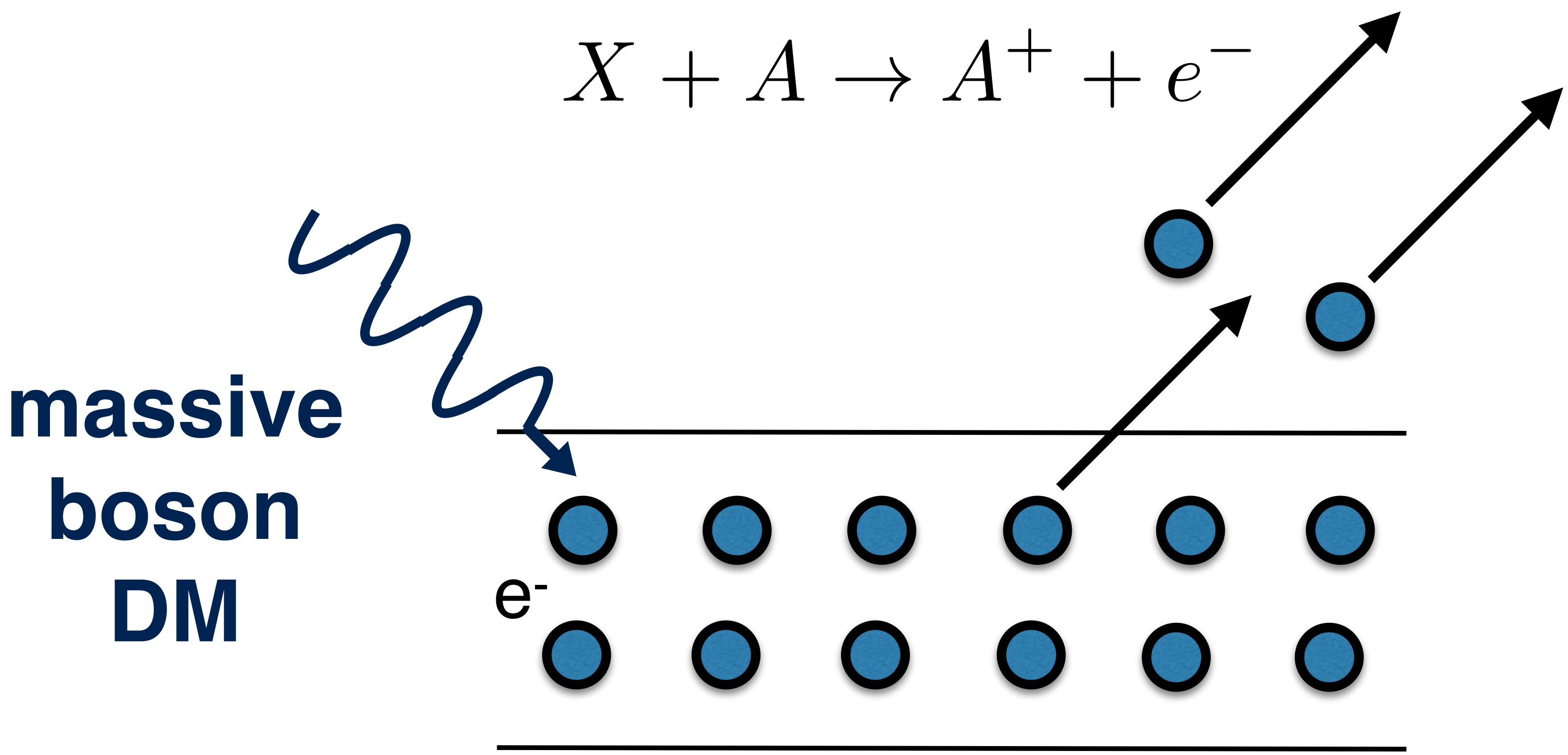
see talk by M. Baryakhtar for other examples

- **Dark matter scattering off collective modes** in molecules and in crystals (including phonons, plasmons and magnons)

photoelectric effect

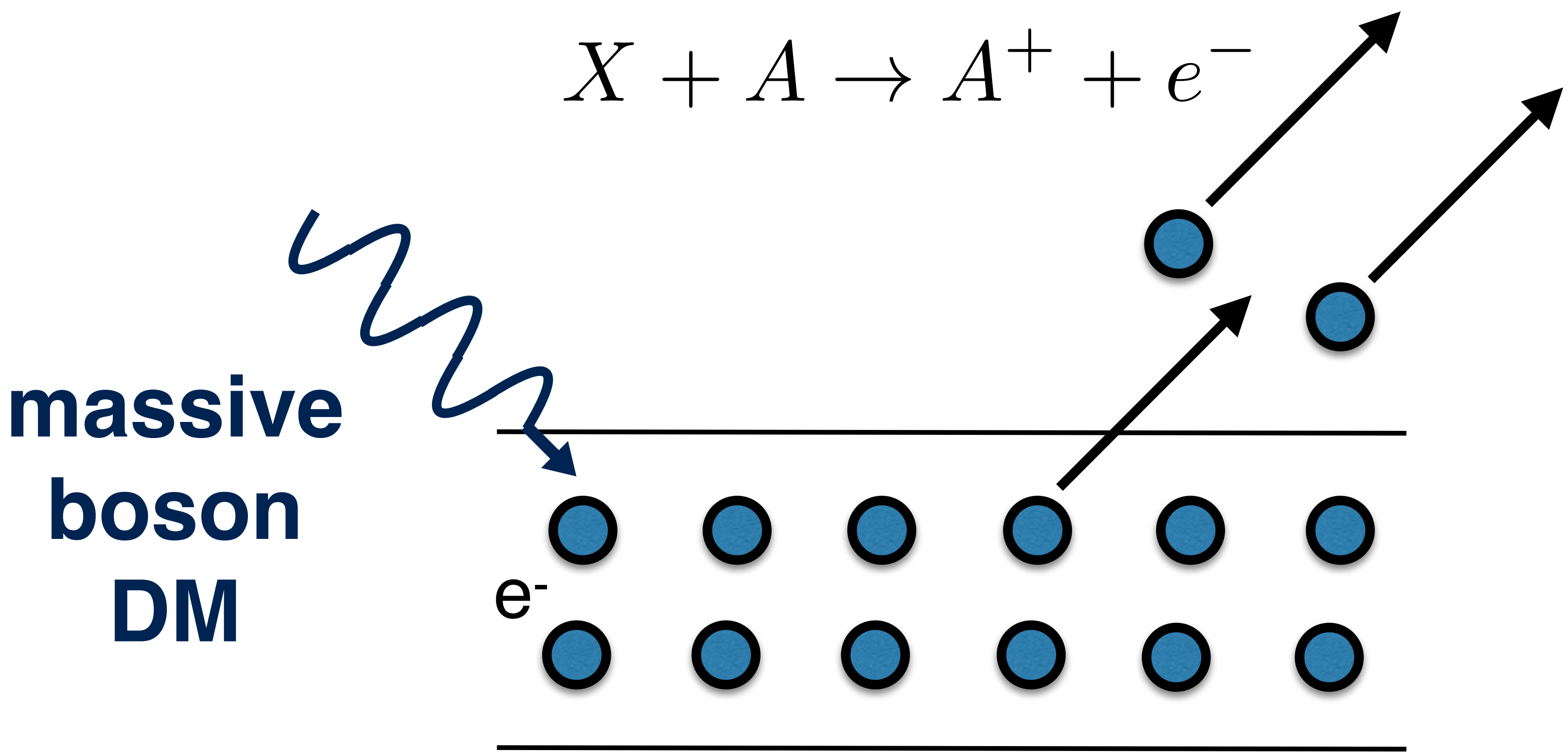
$$X + A \to A^{+} + e^{-}$$



absorb all of the energy
the incoming dark matter

photoelectric effect

$$X + A \to A^{+} + e^{-}$$



photon

$$|\vec{q}| = \omega$$

bosonic dark matter

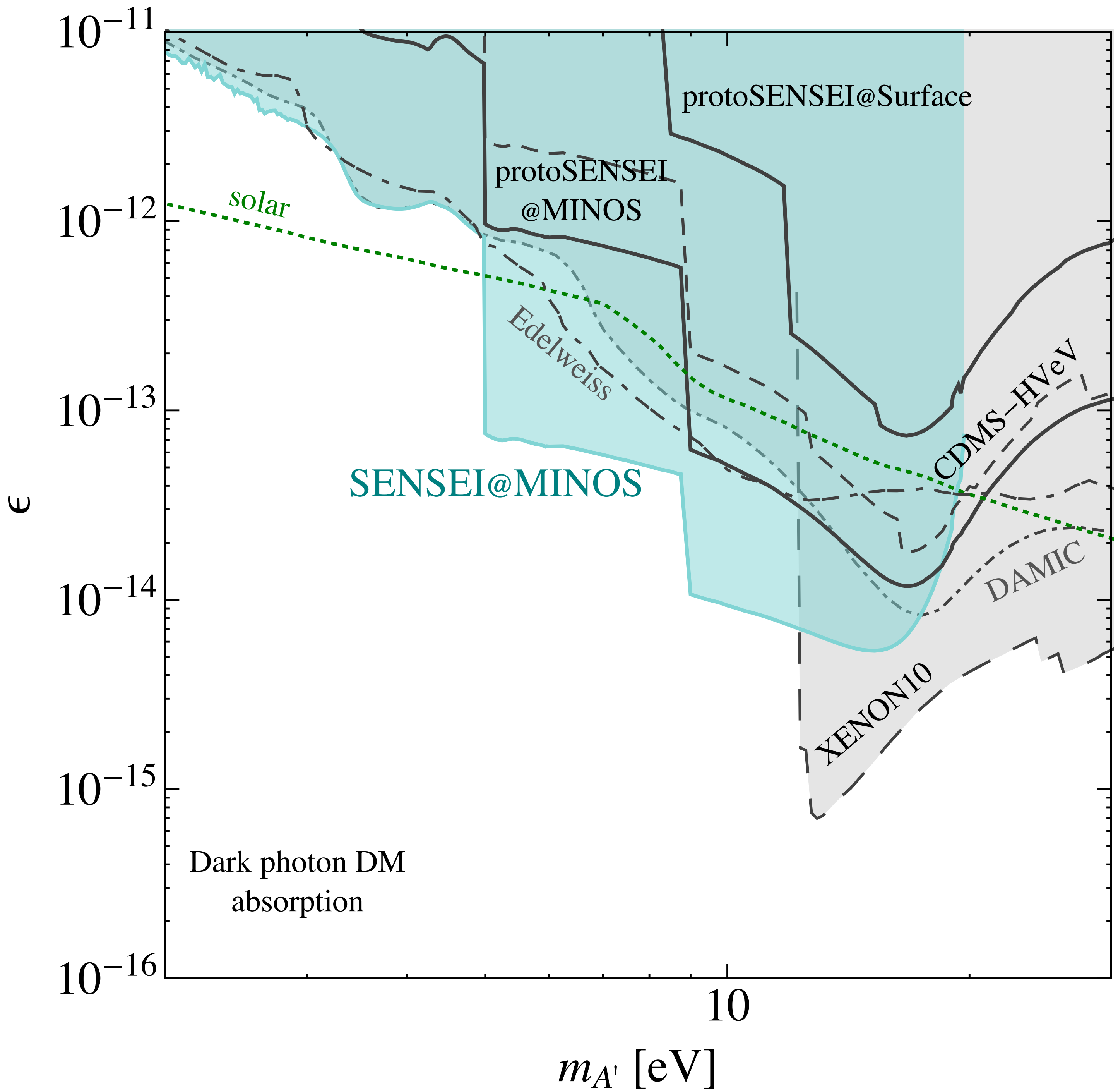
$$|\vec{q}| = m_X v_{\rm DM} \sim 10^{-3}\omega$$

$$< \quad |\vec{q}_e|$$

can relate massive boson absorption to photon absorption

$$\sigma_{DM}(\omega) \propto \sigma_{\rm PE}(\omega)$$

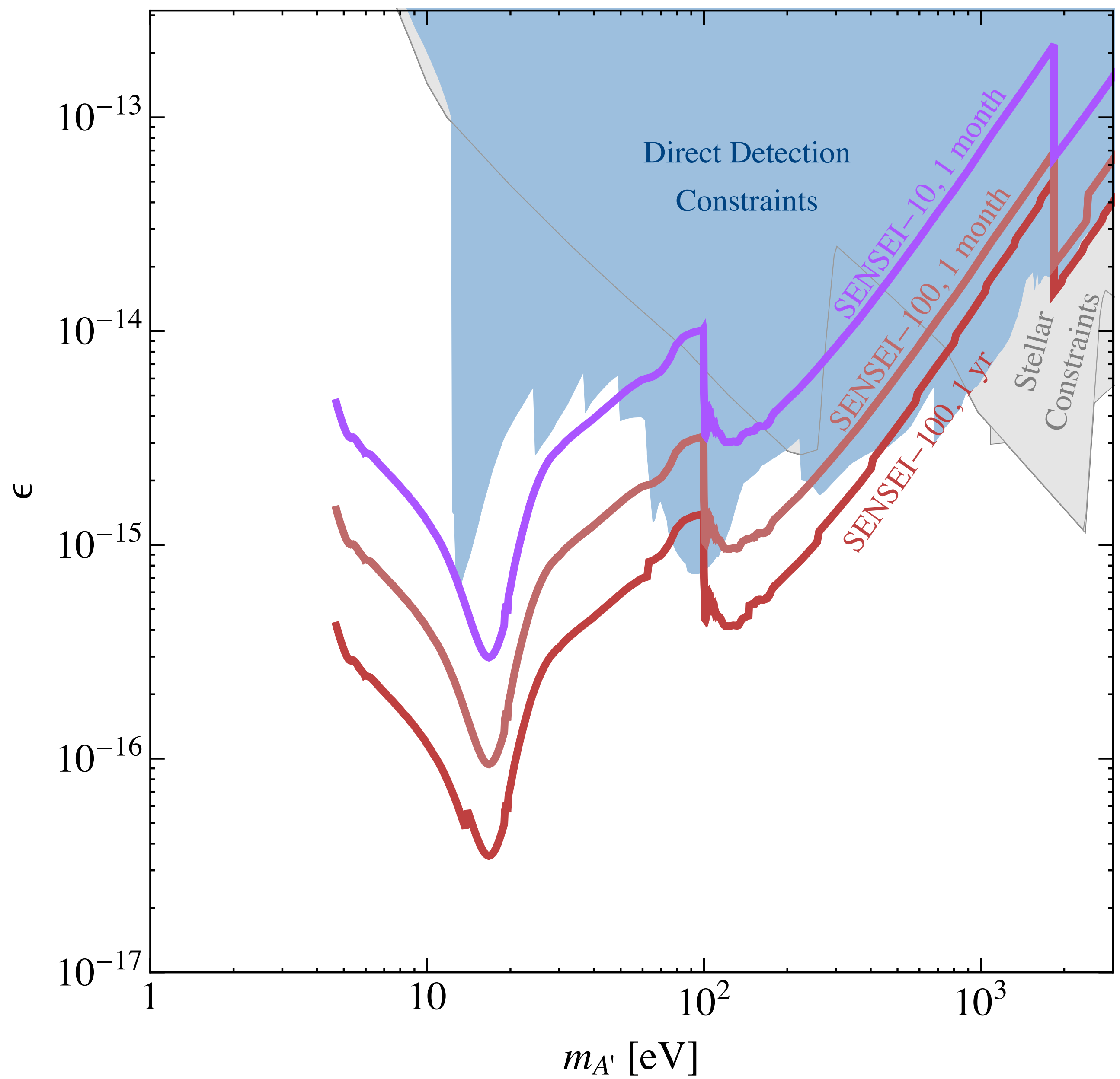
Dark Photon DM

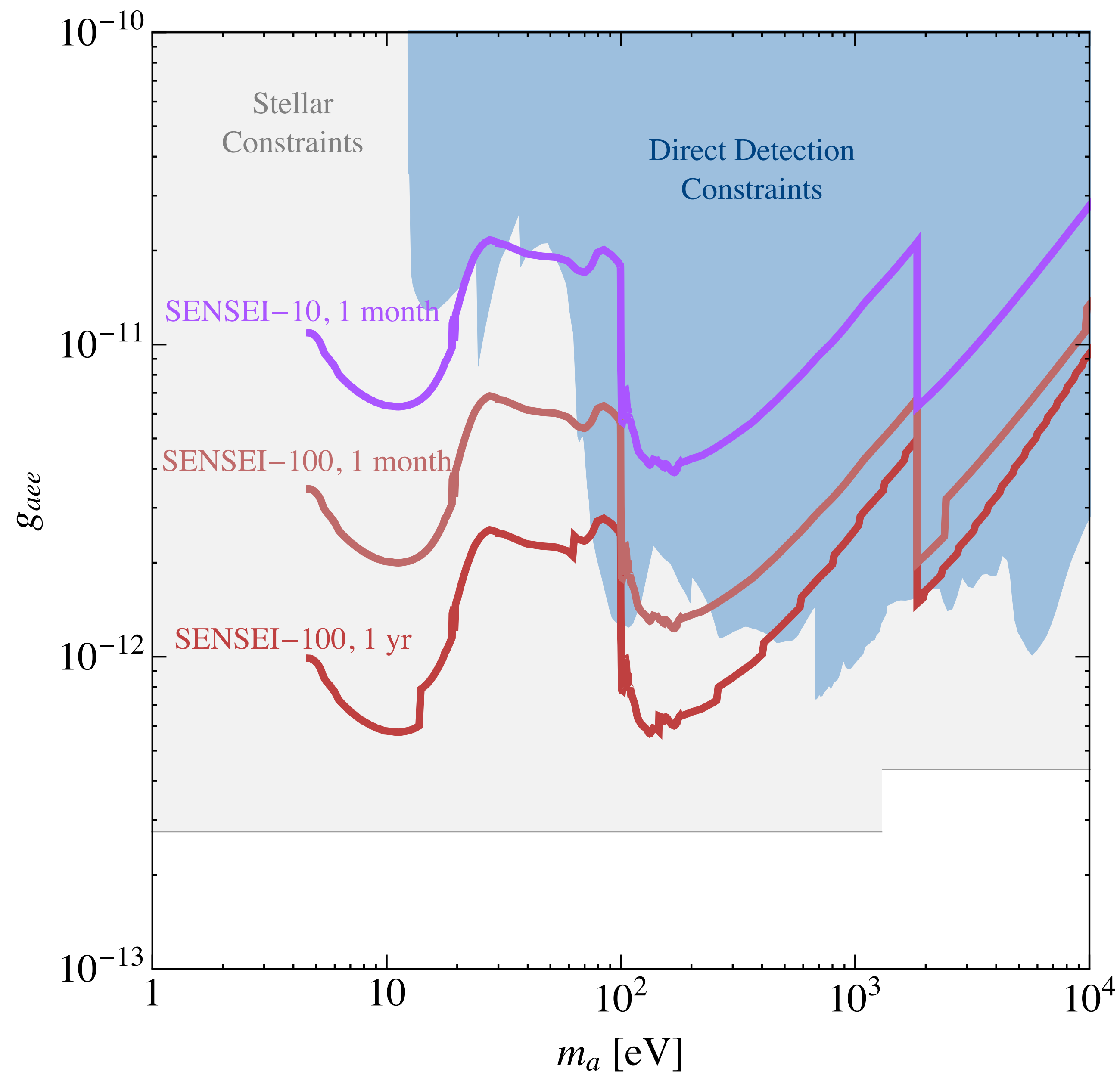


SENSEI collaboration [arXiv:2004.11378], ***submitted to PRL***

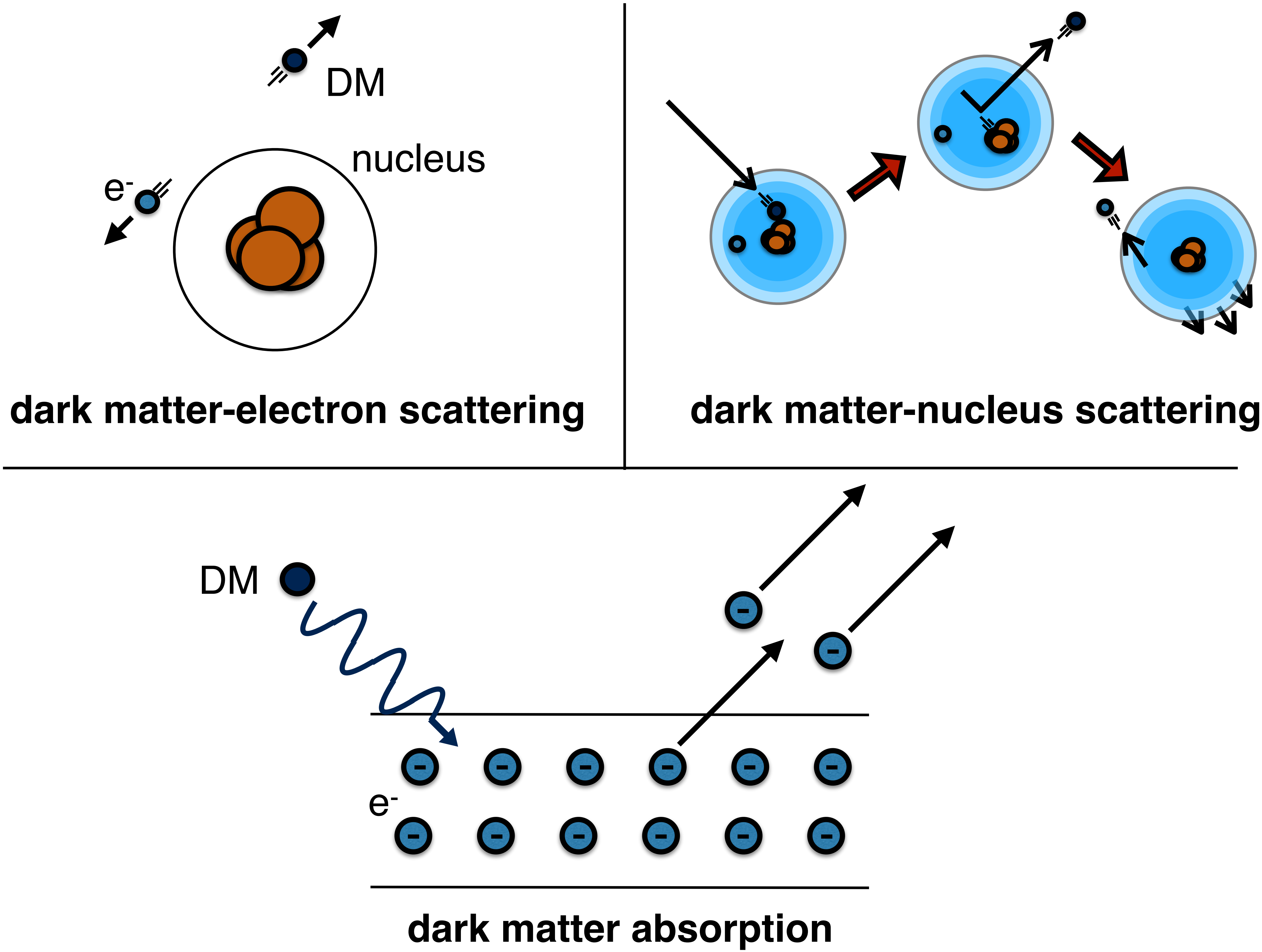
physics potential

bosonic absorption





based on: Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]


DM
nucleus
e-
dark matter-electron scattering
dark matter-nucleus scattering
DM
e-
dark matter absorption

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see talk by M. Pyle

collective modes

- phonons: collective excitation of atoms in a crystal
  - acoustic: “in-phase”
  - optical: “out-of-phase”
- magnons: collective excitation of electron spin
  - sensitive to spin-dependent interactions (DM-coupling to electron spin)
- sensitivity to ~keV DM masses
- may require new materials — area of active research
- there are also plasmons (collective excitation of electrons)…

see work by e.g. A. Caputo, A. Esposito, E. Geoffray, Y. Kahn, S. Knapen, G. Krnjaic, S. Griffin, T. Lin, T. Melia, A. Mitridate, A. D. Polosa, S. Rajendran, S. Sun,T. Trickle, Z. Zhang, K. Zurek, …

dark matter candidates