New Ideas for sub-GeV Dark Matter Direct Detection

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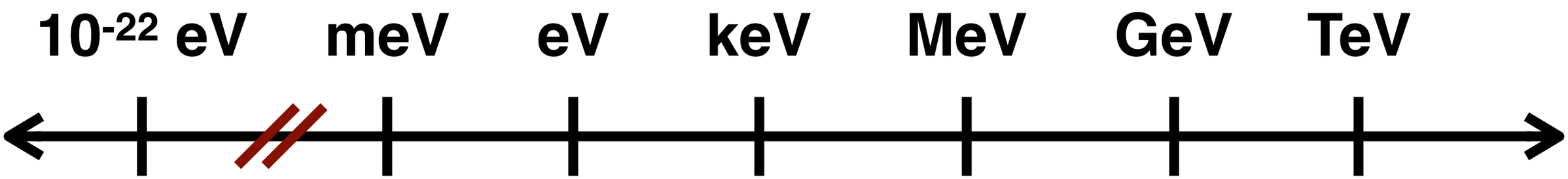
(CERN & University of Oregon)

PLANCK 2018 -- Bonn

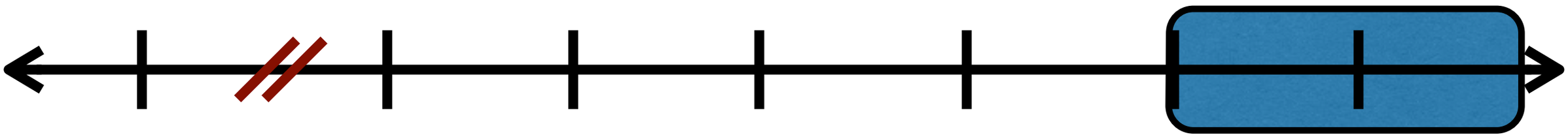
May 25, 2018

dark matter candidates



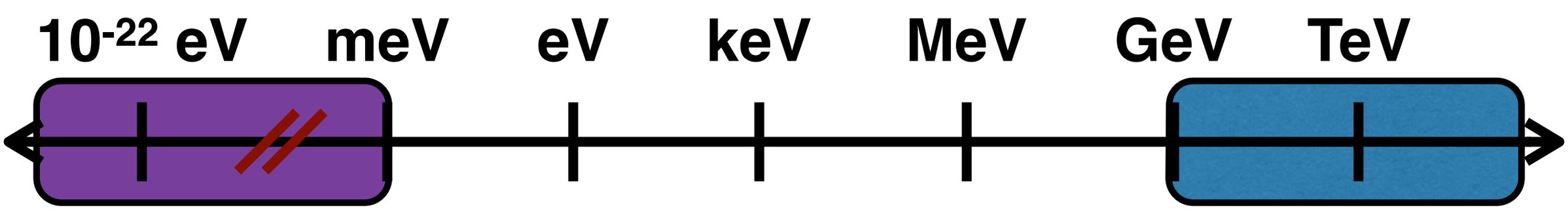
dark matter candidates

10^{-22} eV meV eV keV MeV GeV TeV



“WIMP”

dark matter candidates



“axions/ALPs”

“WIMP”

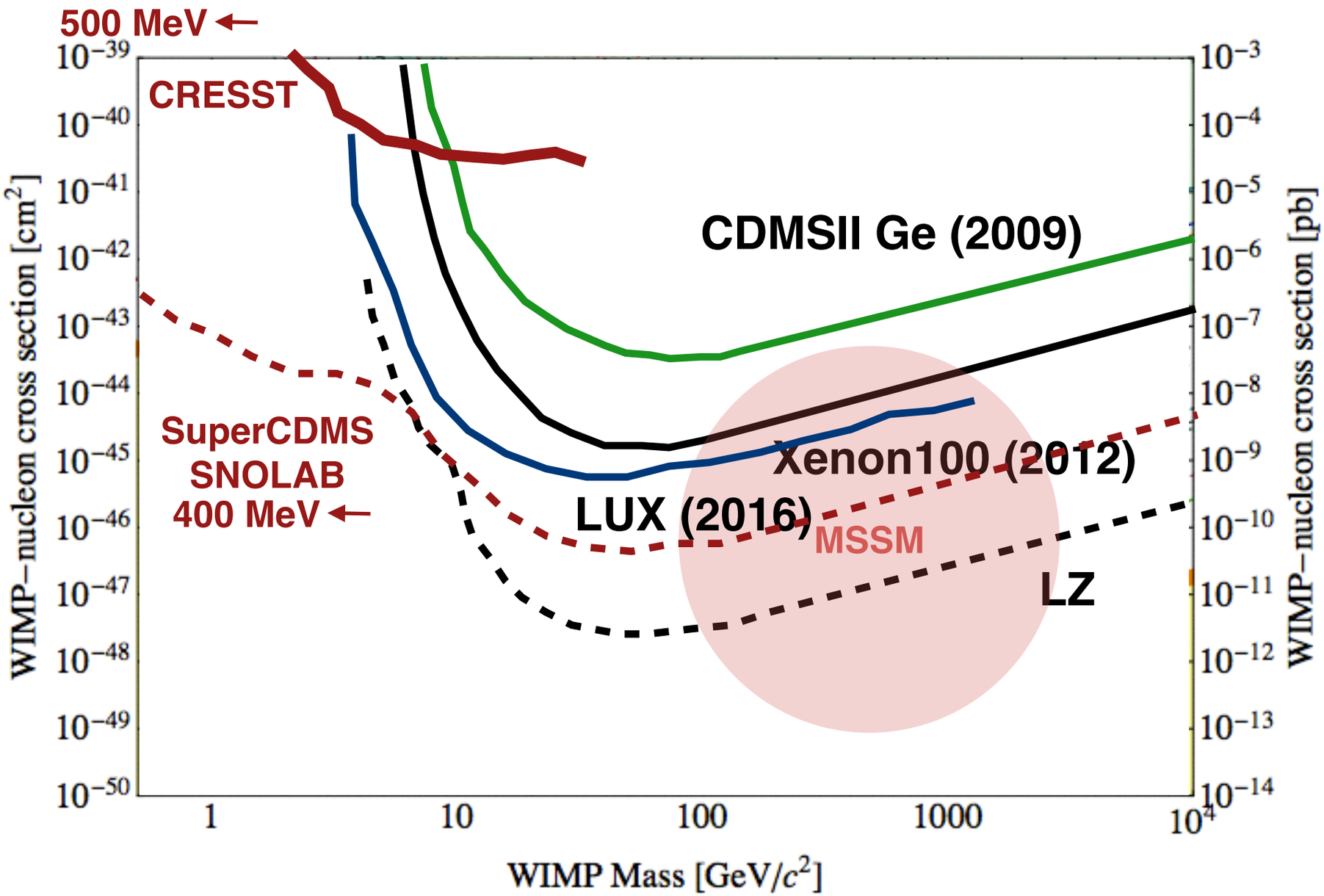
challenges for meV-GeV DM direct detection

fundamental challenge:

need enough **energy transfer**
from DM-target interaction
to create a detectable **signal**

depends on process
and
detector setup

DM-nucleon elastic scattering



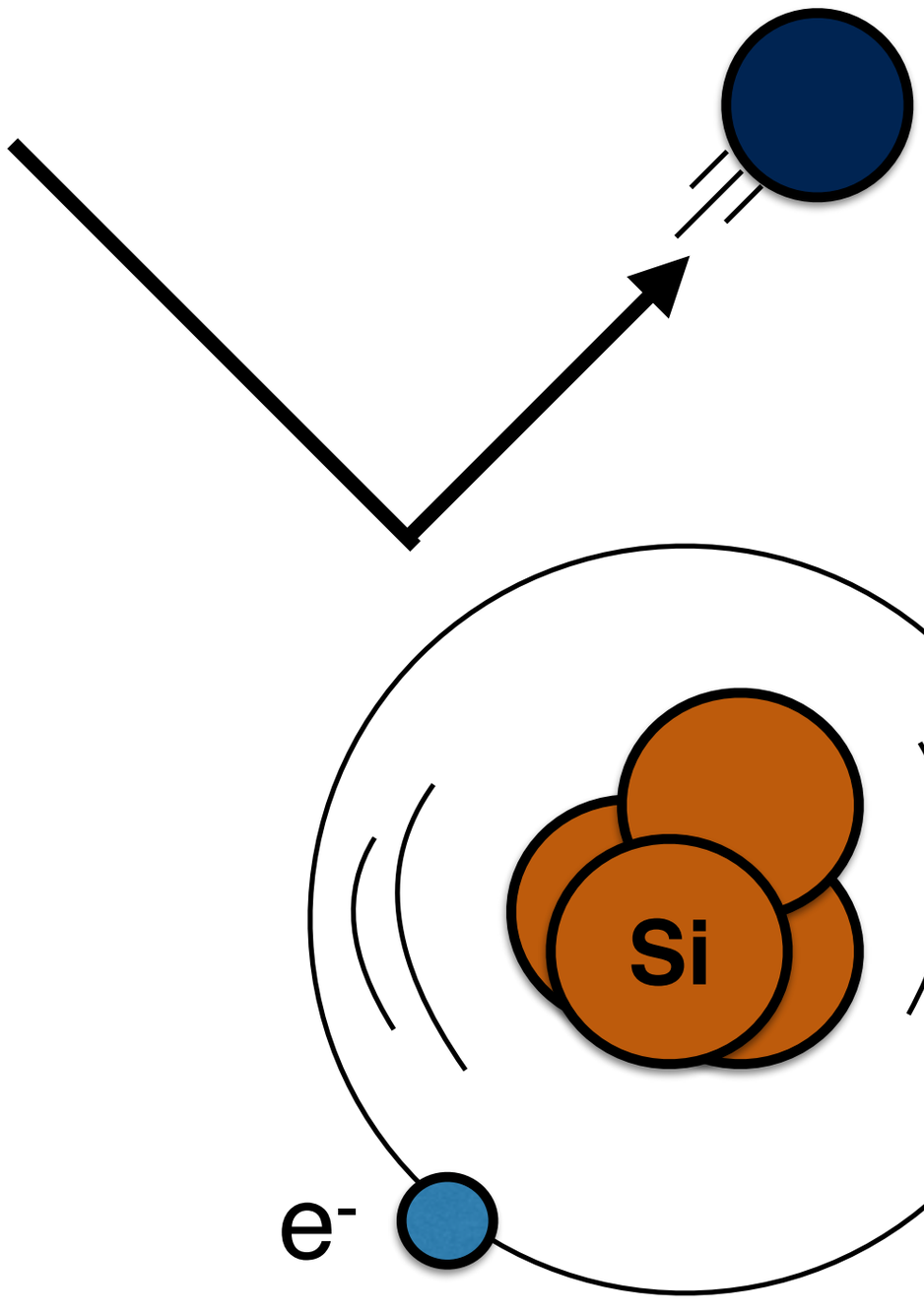
$$E_R = \frac{q^2}{2m_N}$$

momentum transfer

DM

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

nucleus mass



*not to scale

$$m_N = 28 \text{ GeV}$$

$$m_\chi = 100 \text{ GeV}$$

$$E_R \sim 100 \text{ keV}$$

available for detection

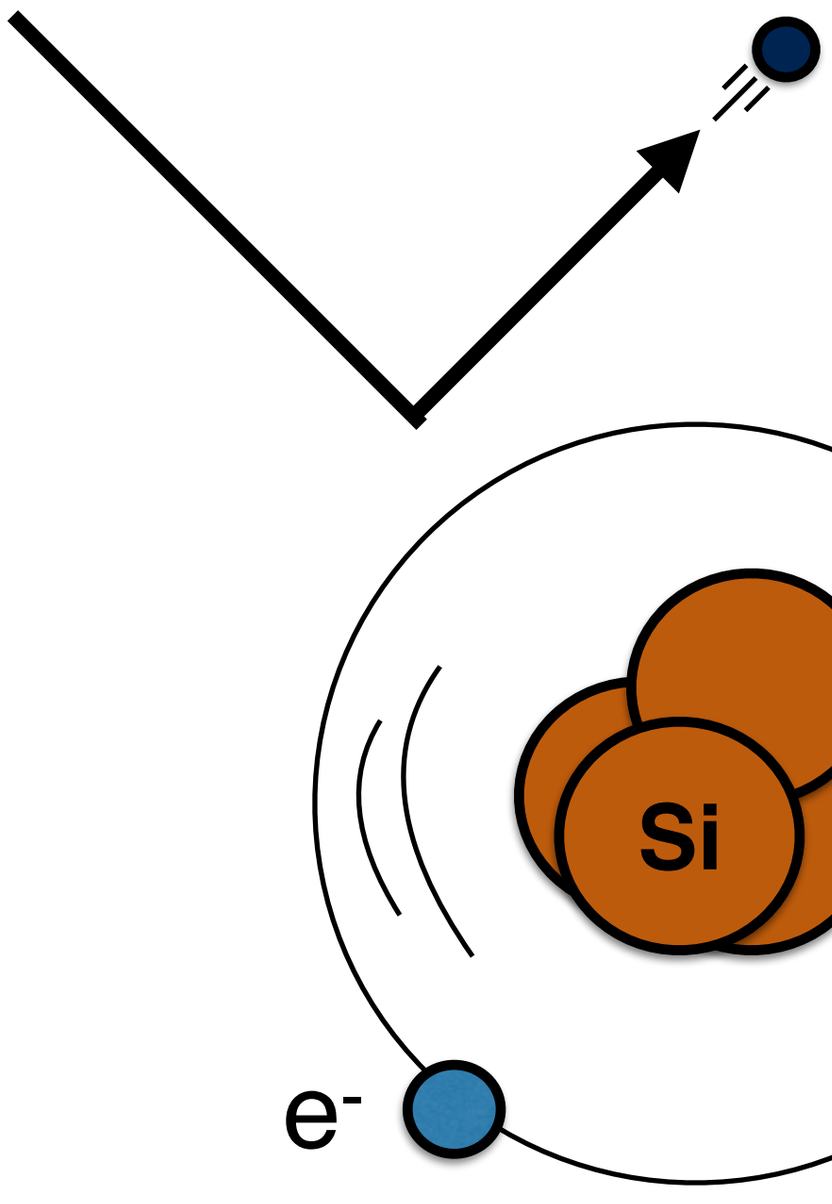
$$E_R = \frac{q^2}{2m_N}$$

momentum transfer

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

nucleus mass

DM



*not to scale

$m_N = 28\ \text{GeV}$

$m_\chi = 100\ \text{MeV}$

$E_R \sim 0.1\ \text{eV}$

available for detection

detecting sub-GeV DM in 2 easy steps

1. increase amount of detectable energy
2. decrease energy threshold or increase sensitivity

detecting sub-GeV DM in 2 easy steps

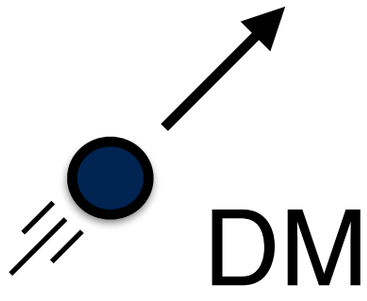
1. increase amount of detectable energy

consider different physical processes

2. decrease energy threshold or increase sensitivity

consider a variety of materials

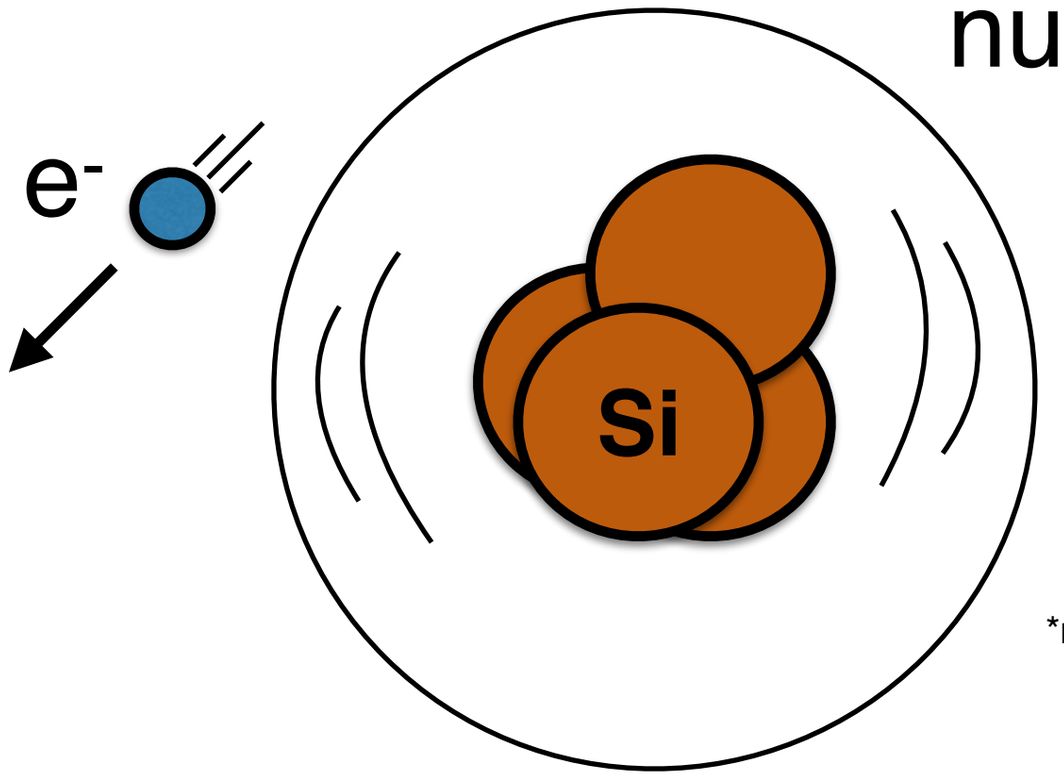
DM-electron scattering



$$E_R = \vec{q} \cdot \vec{v} - \frac{q^2}{2\mu_{\chi N}}$$

$$\sim \frac{1}{2}\mathrm{eV} \times \left(\frac{m_\chi}{\mathrm{MeV}}\right)$$

$$m_N = 28\ \mathrm{GeV}$$



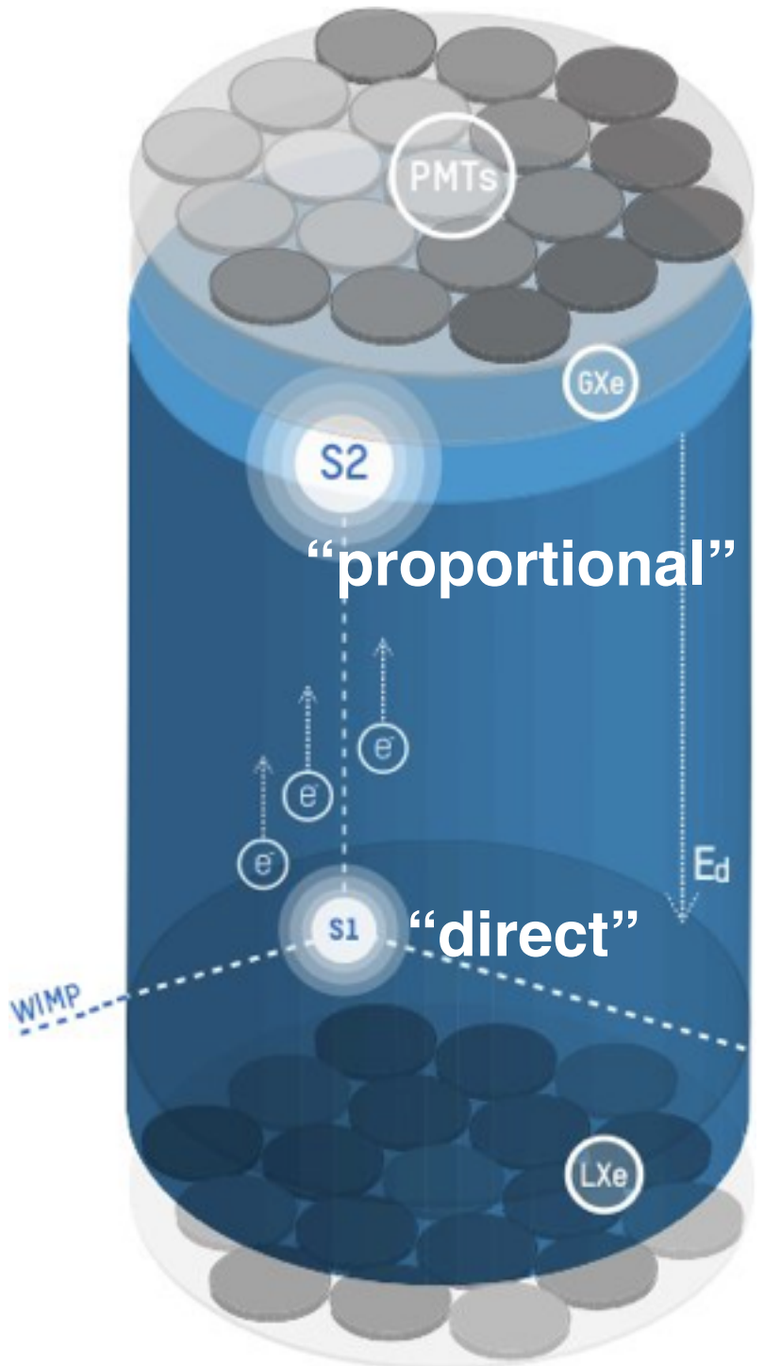
*not to scale

$$m_\chi = 100\ \mathrm{MeV}$$

$$E_R \sim 50\ \mathrm{eV}$$

available for detection

Liquid Xenon



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

i.e. XENON10, XENON100, XENON1T, LUX, UA(1)'

DM-electron scattering

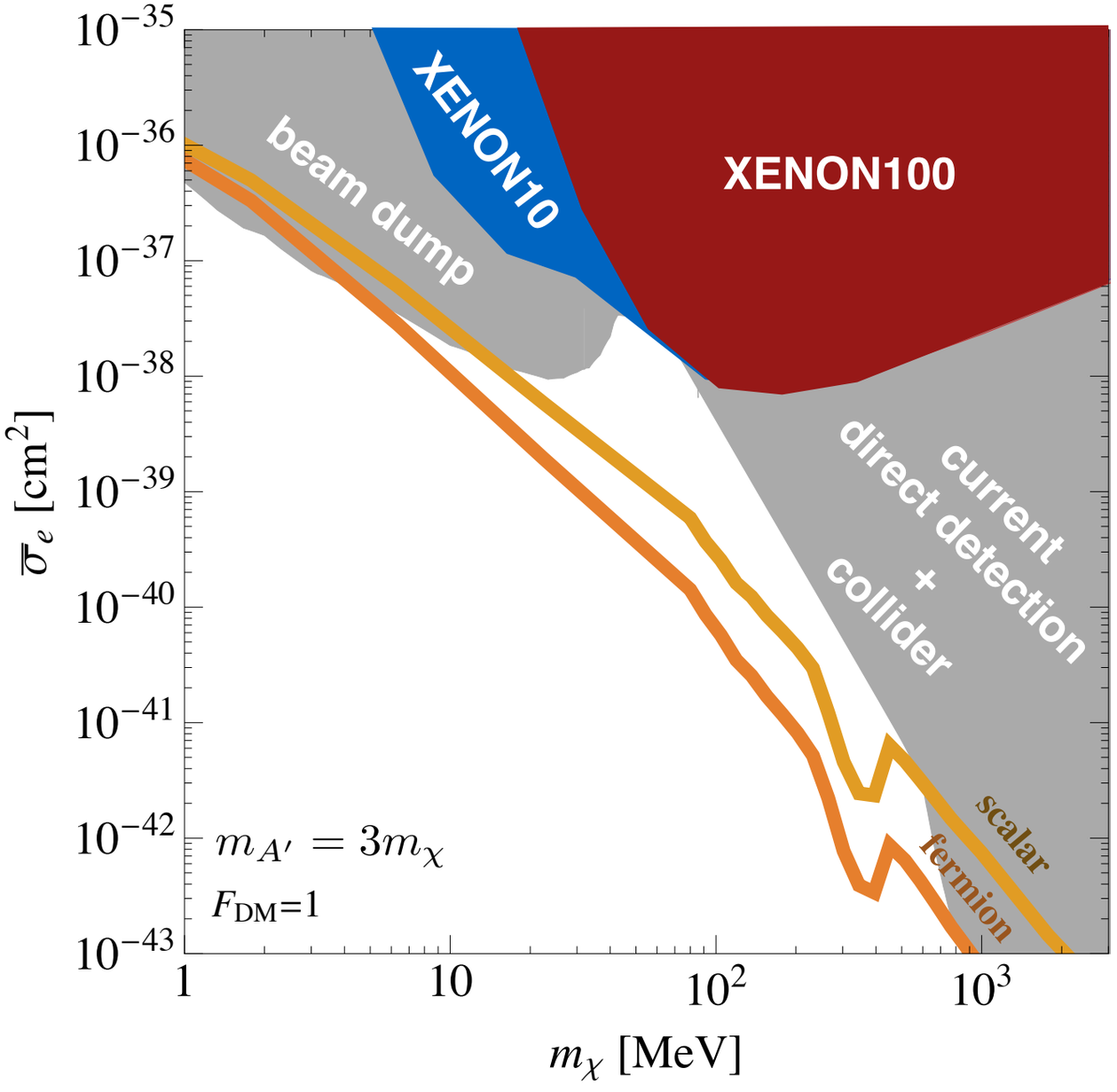
=

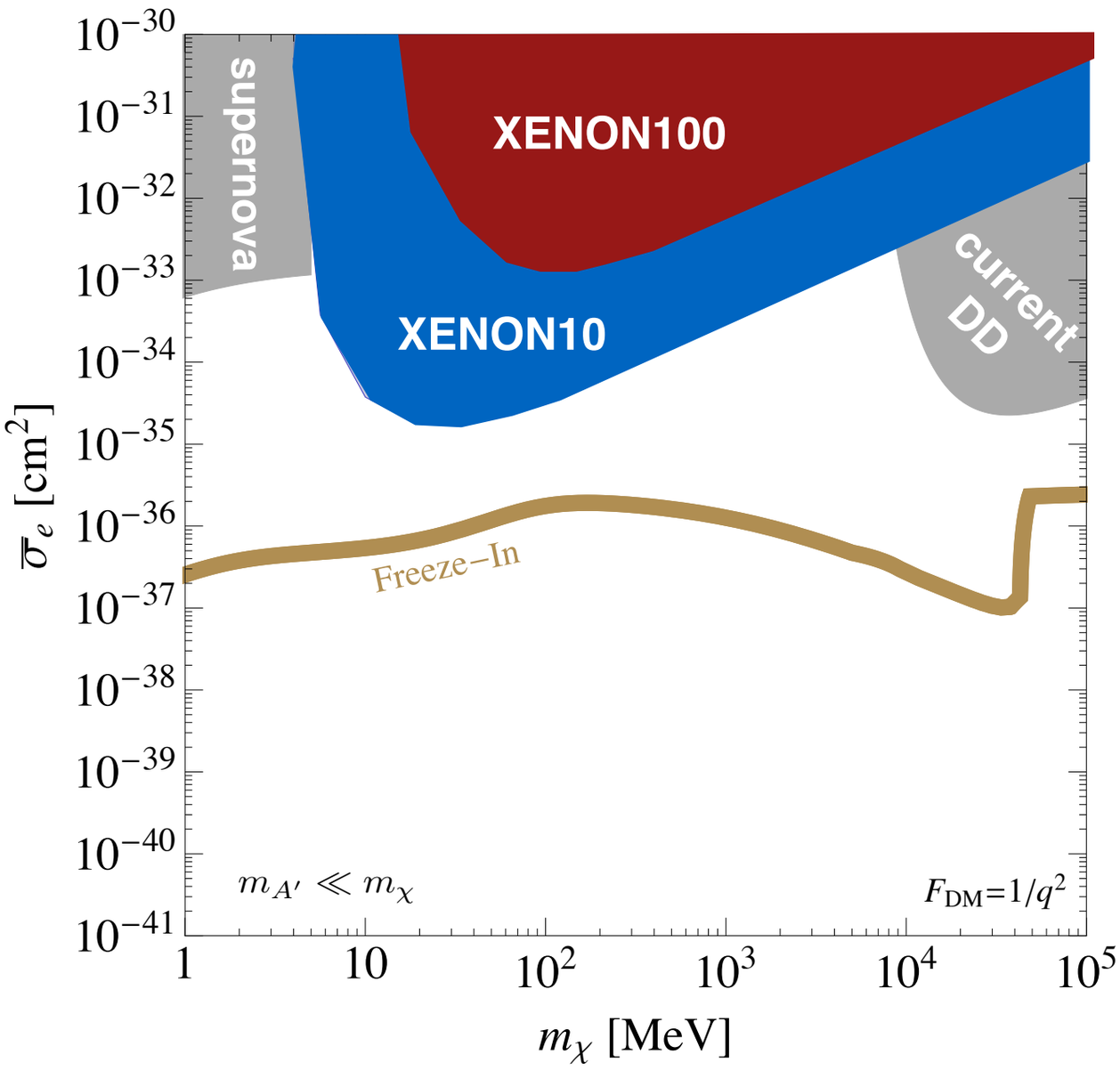
S2 only signal

sensitive to ~10 eV energy depositions

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

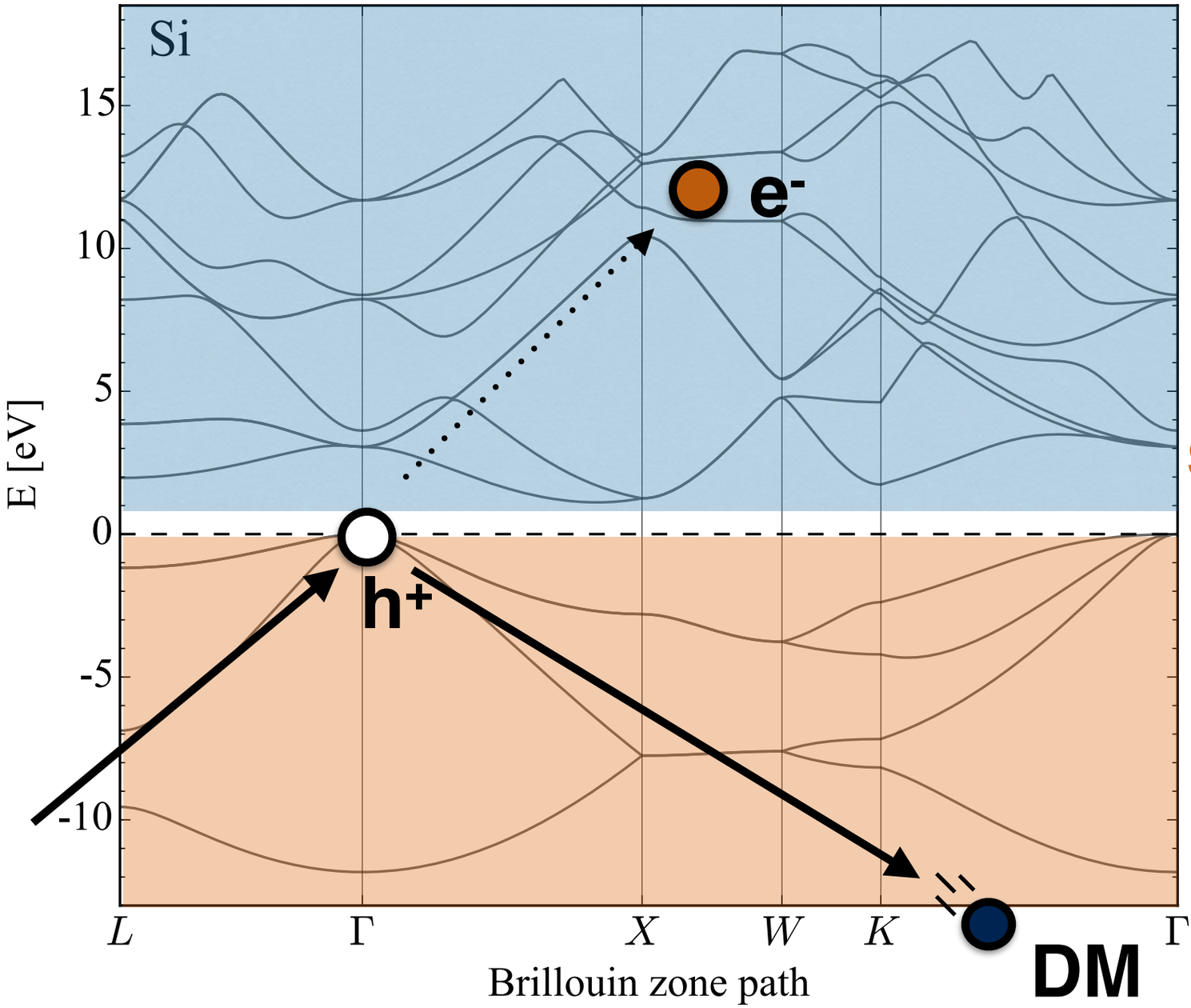
DM-electron scattering





Essig, Volansky, TTY [1703.00910]

semiconductor targets



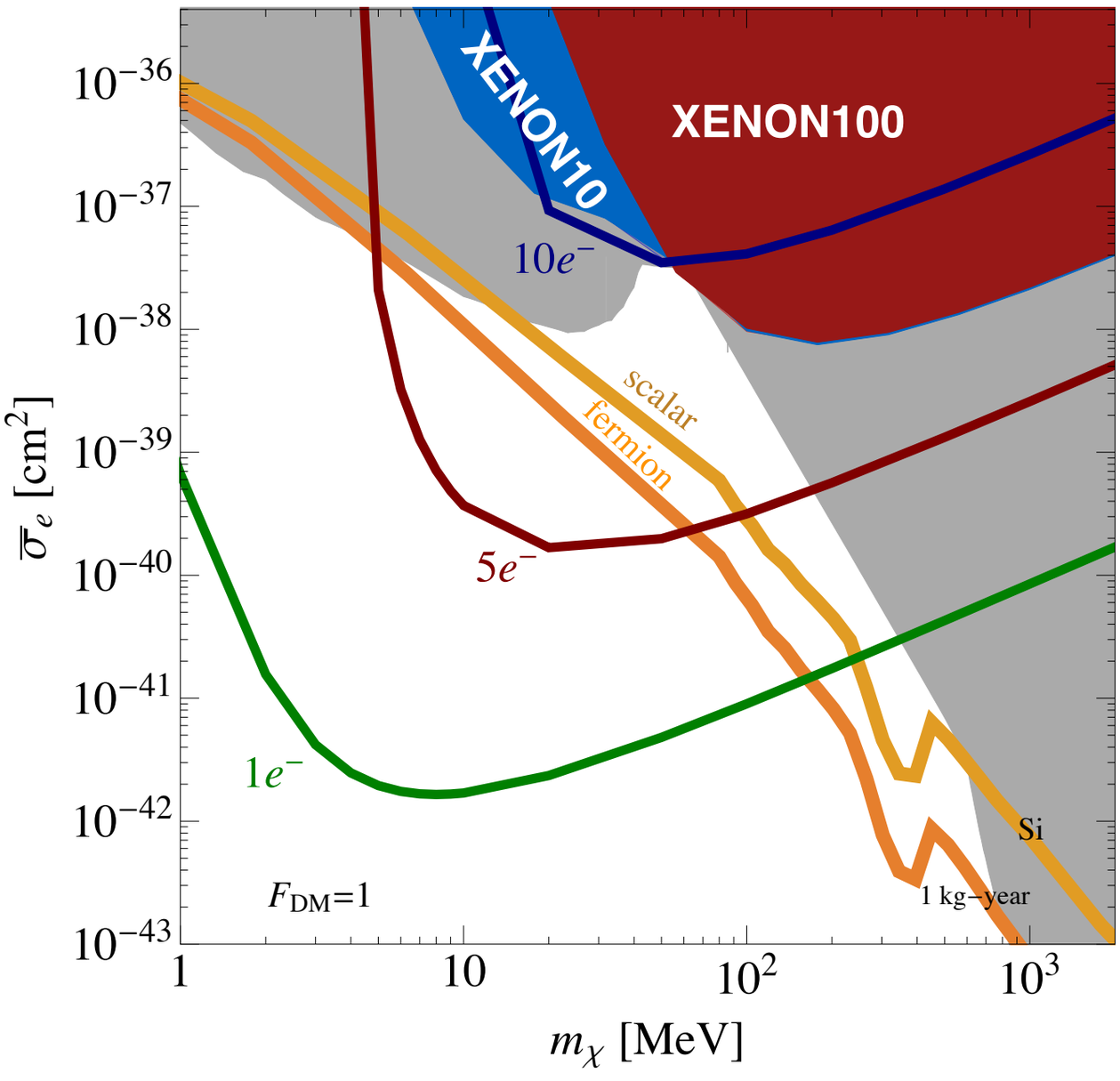
detect the electron(s)

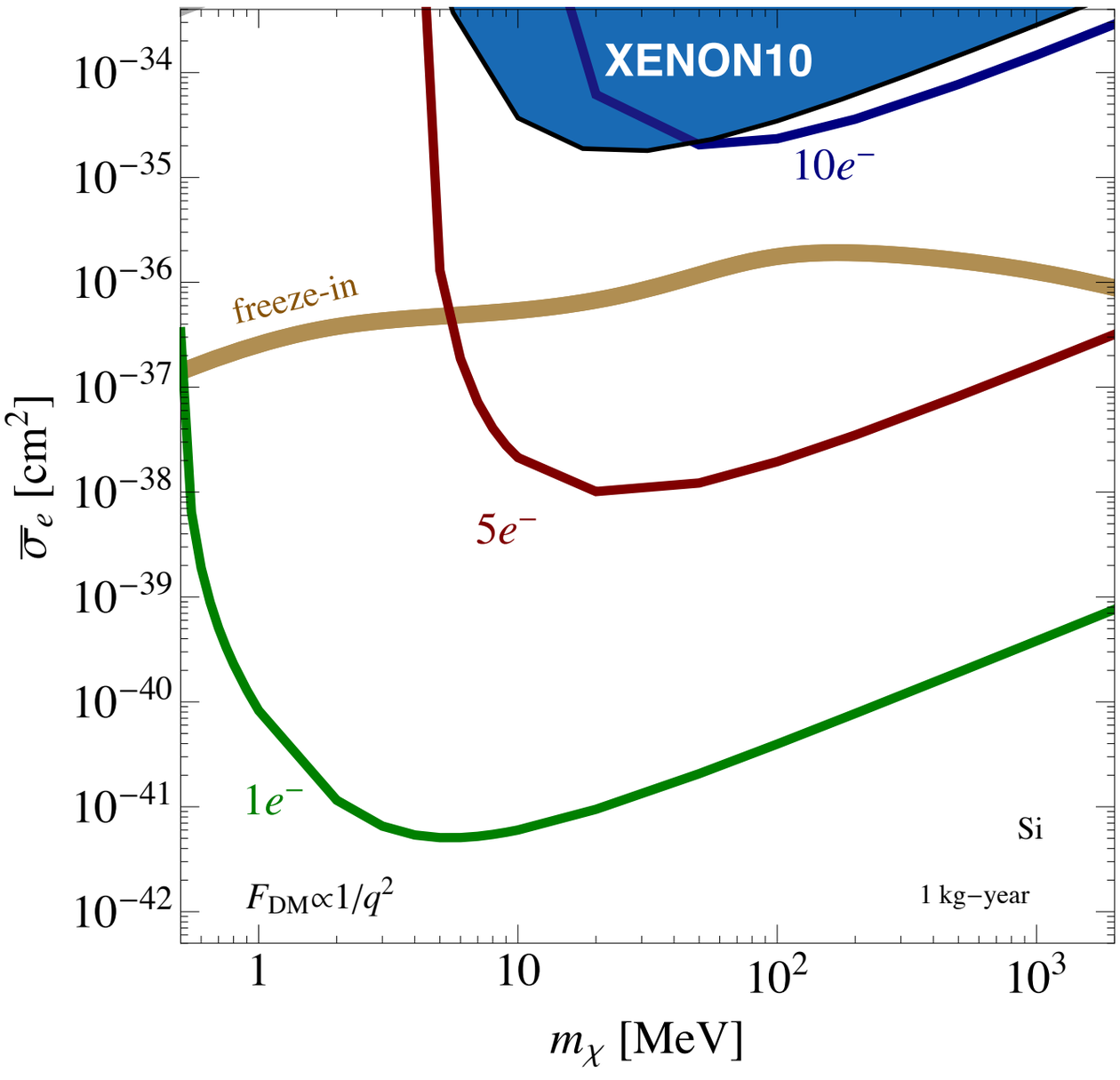
sensitive to ~eV energy depositions

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]

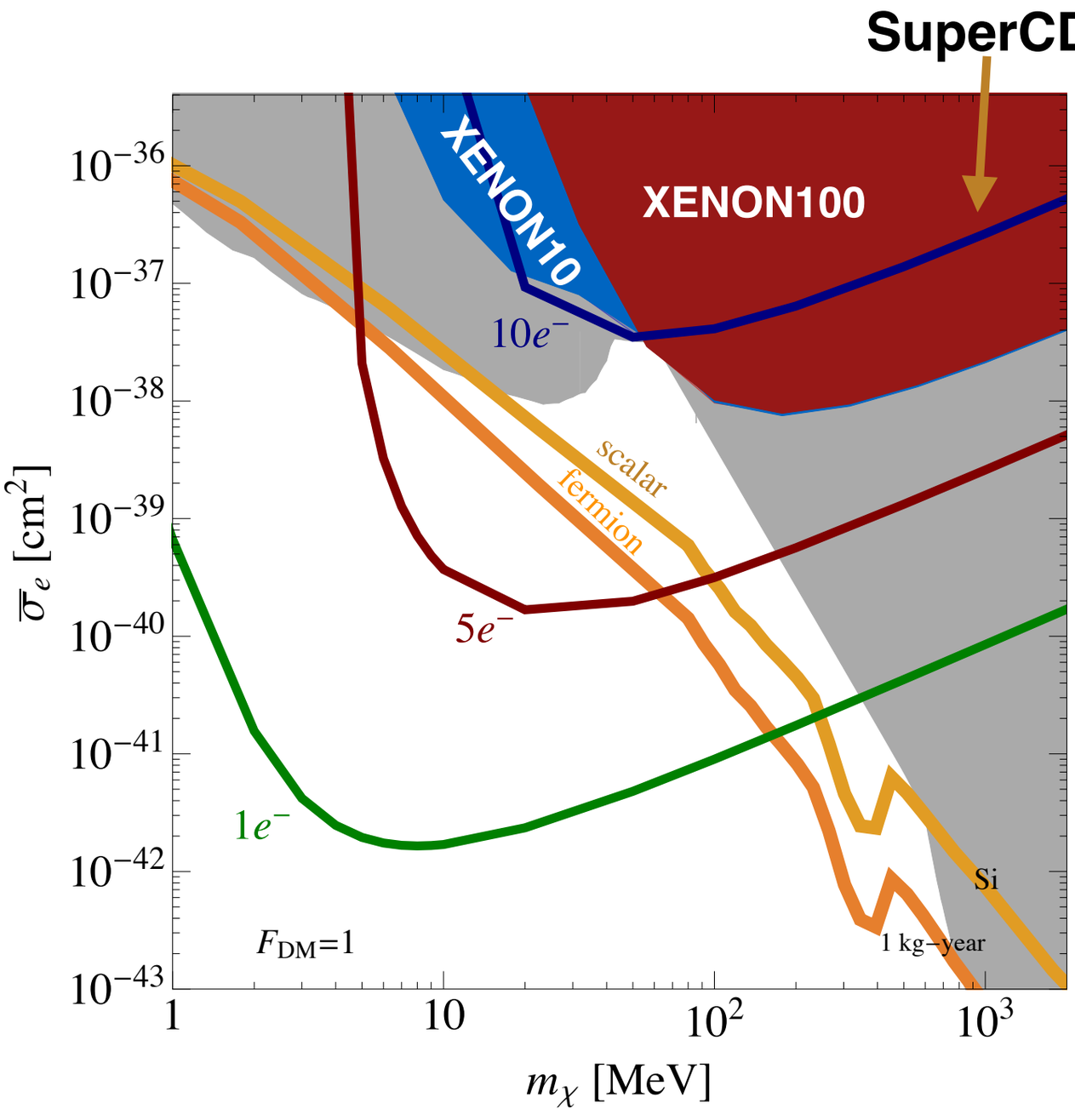
threshold dependence

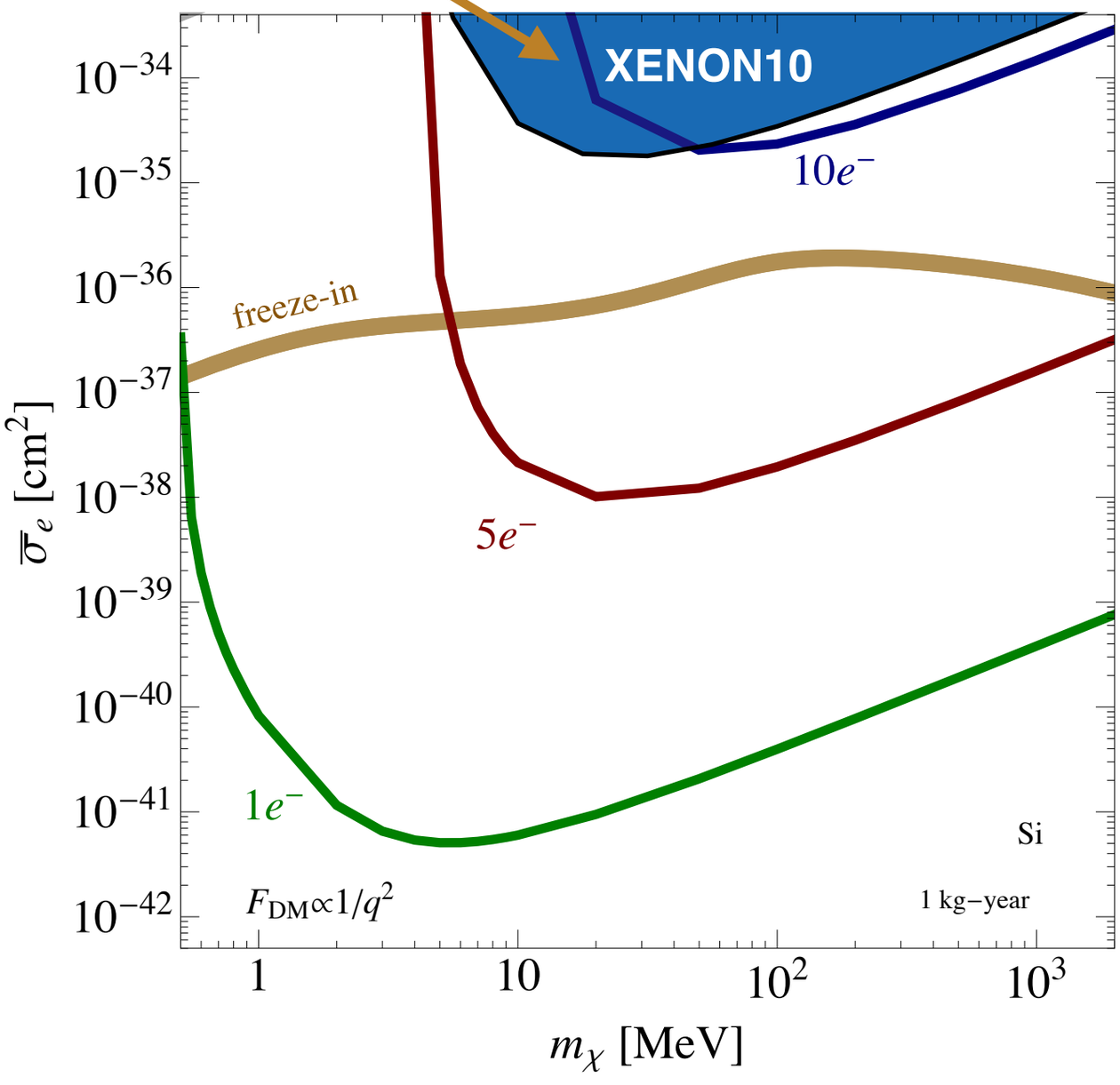




Essig, Fernandez-Serra, Mardon, Soto, TTY [1509.01598]

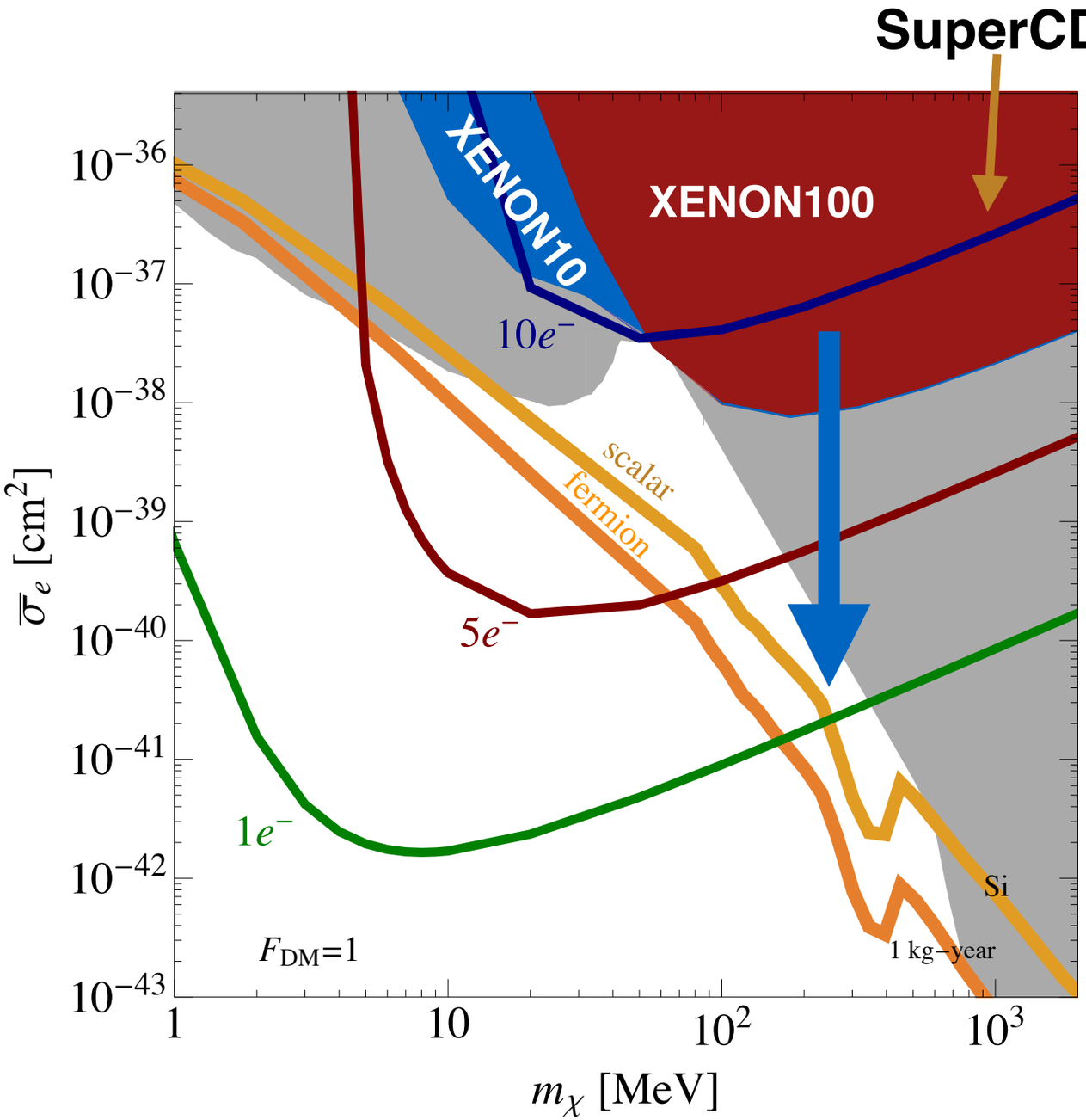
threshold dependence

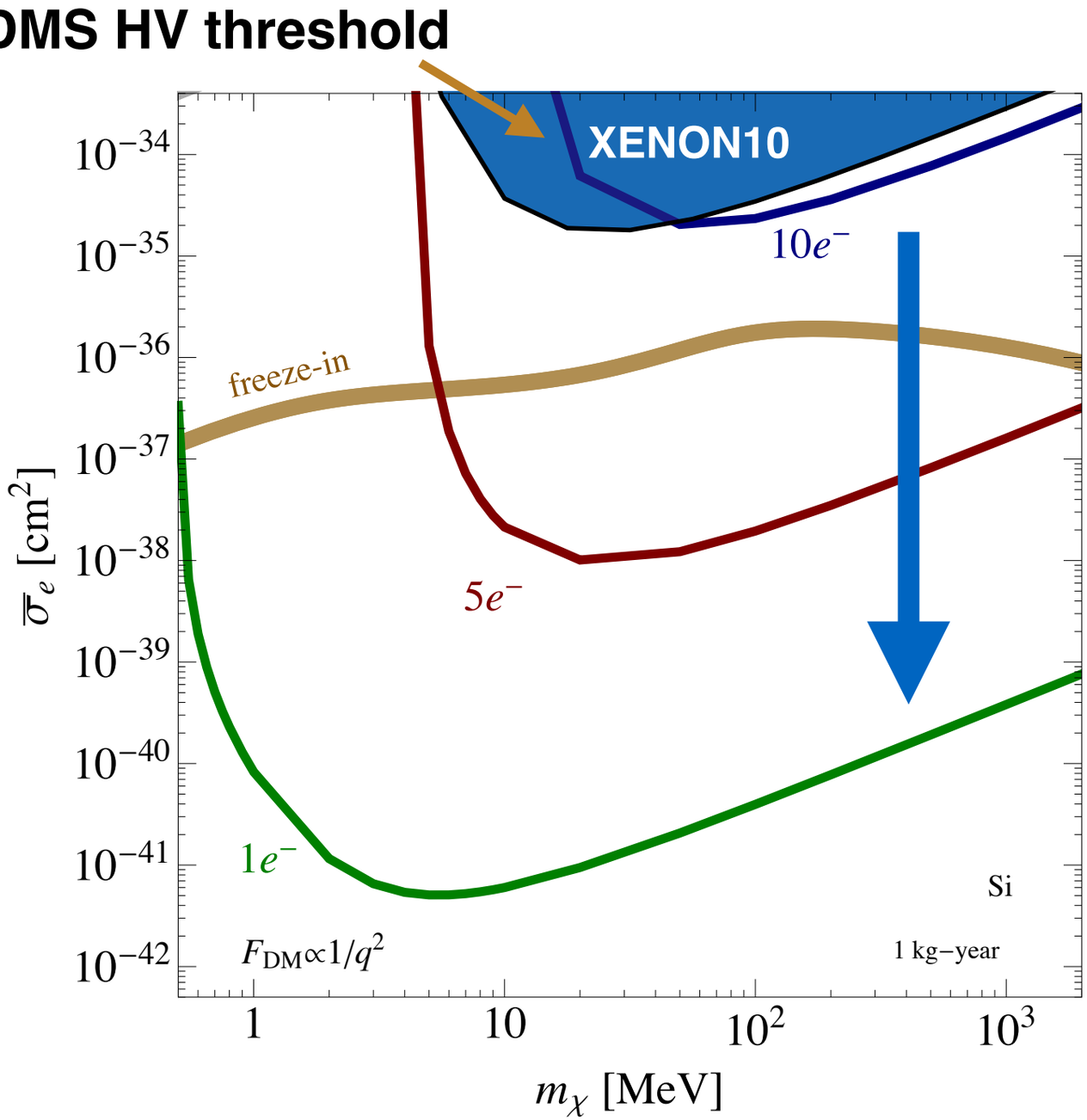




Essig, Fernandez-Serra, Mardon, Soto, TTY [1509.01598]

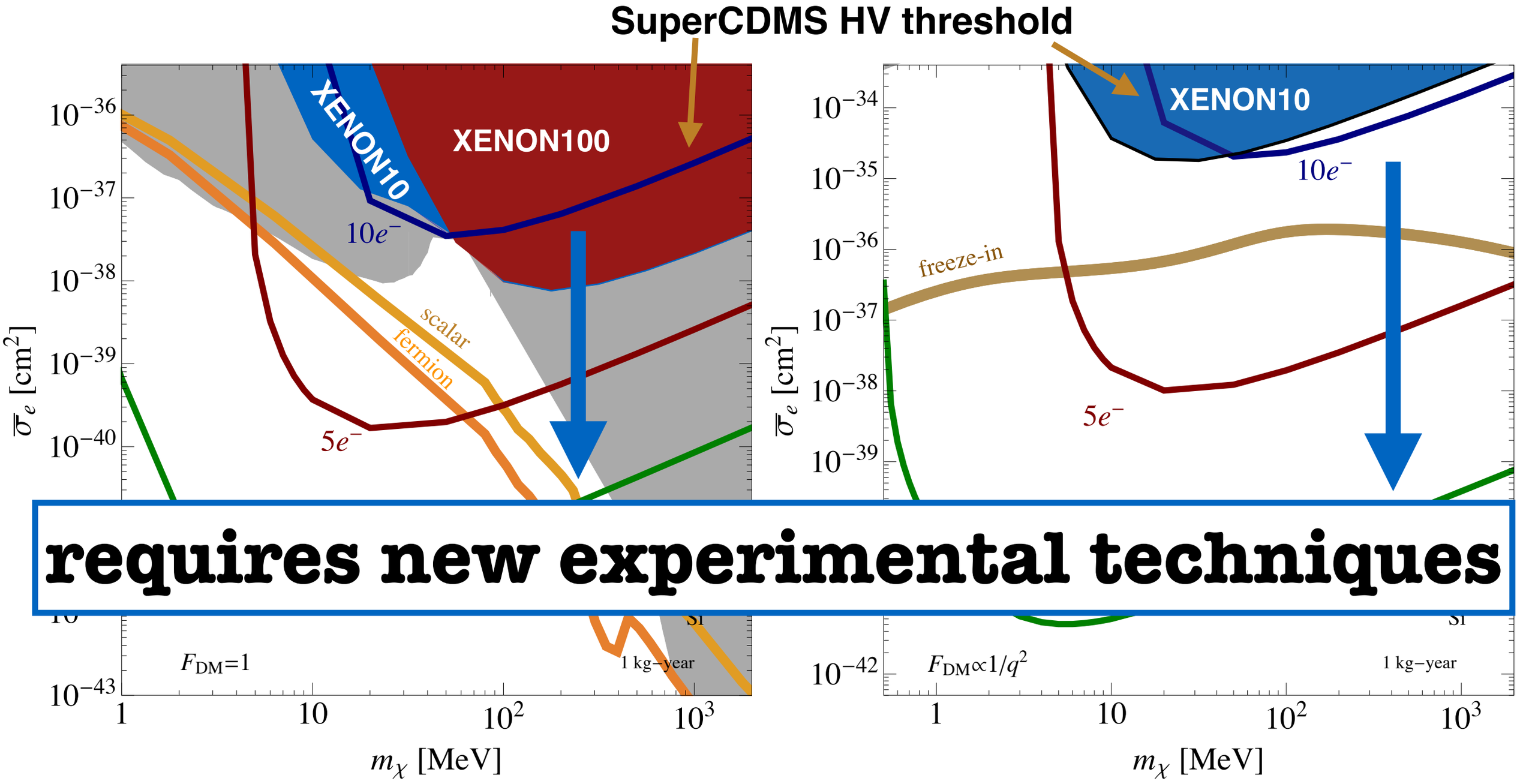
threshold dependence





Essig, Fernandez-Serra, Mardon, Soto, TTY [1509.01598]

threshold dependence



requires new experimental techniques

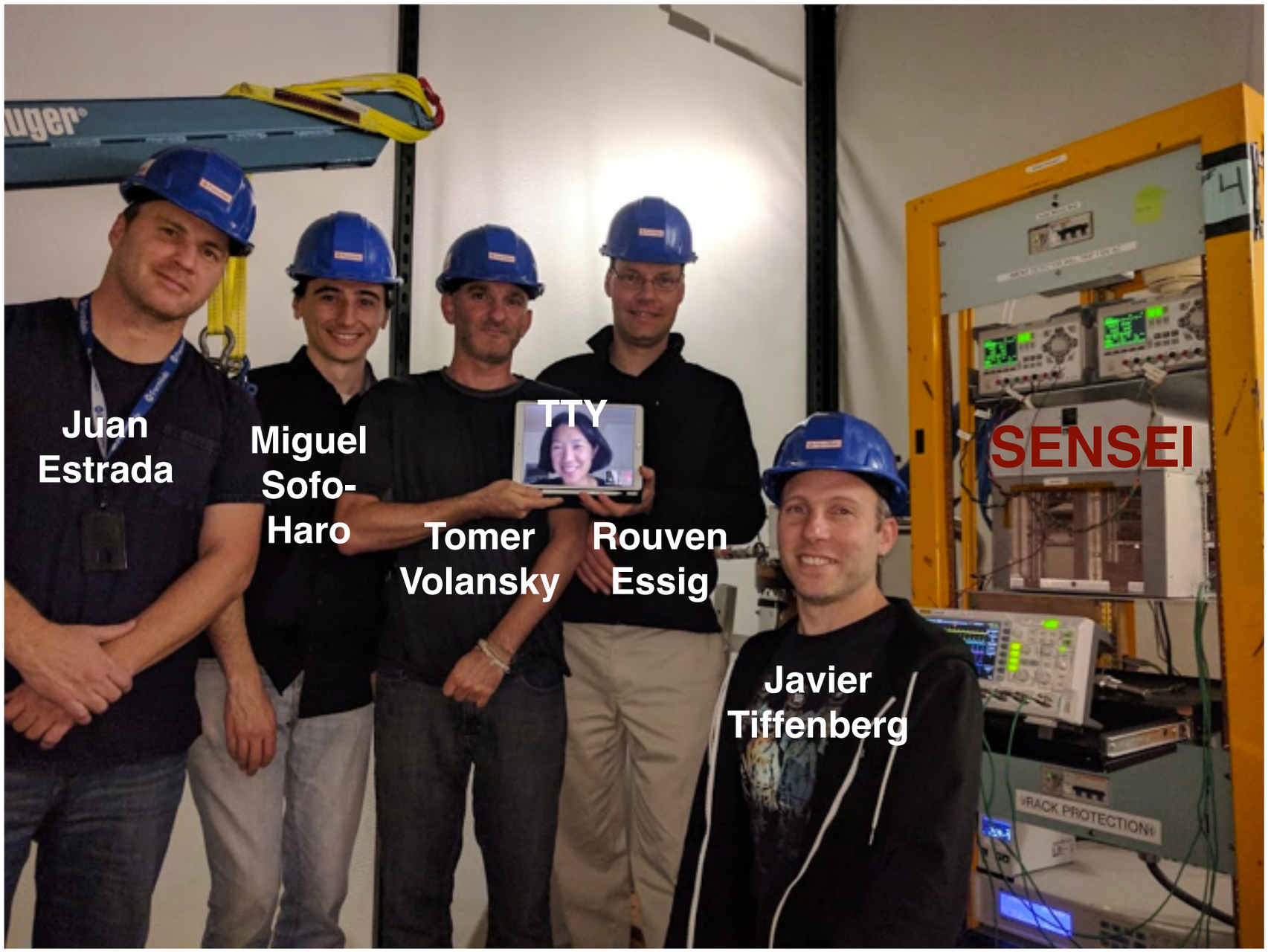
Essig, Fernandez-Serra, Mardon, Soto, TTY [1509.01598]

Fermilab

SENSEI

HEISING-SIMONS FOUNDATION

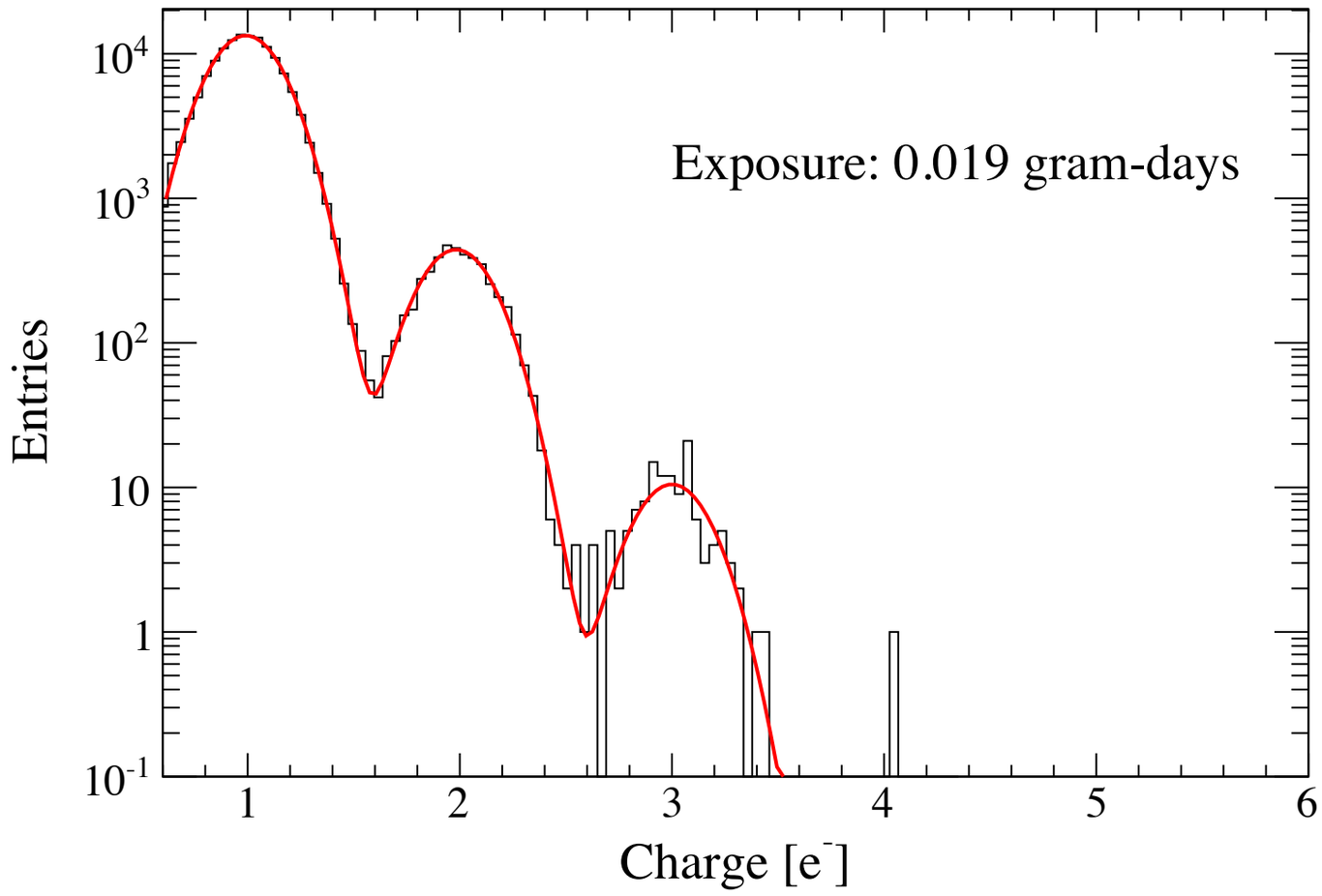
Sub-**E**lectron-**N**oise **S**kipper CCD **E**xperimental **I**nstrument



+ Guillermo Fernandez Moroni
+ Michael Crisler
+ Alex Drlica-Wagner

first results!

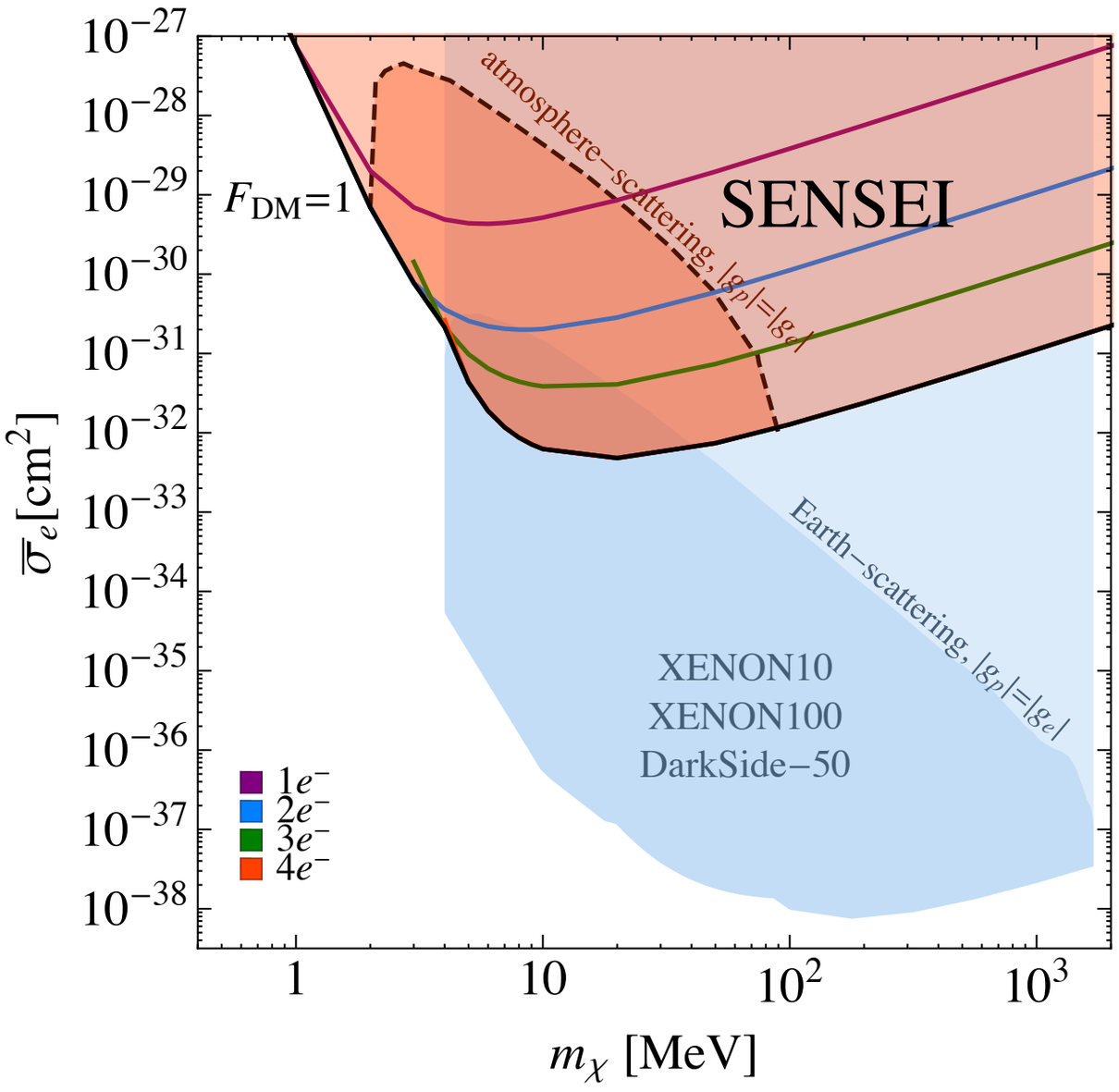
~0.02 g-days of commissioning data from a surface run

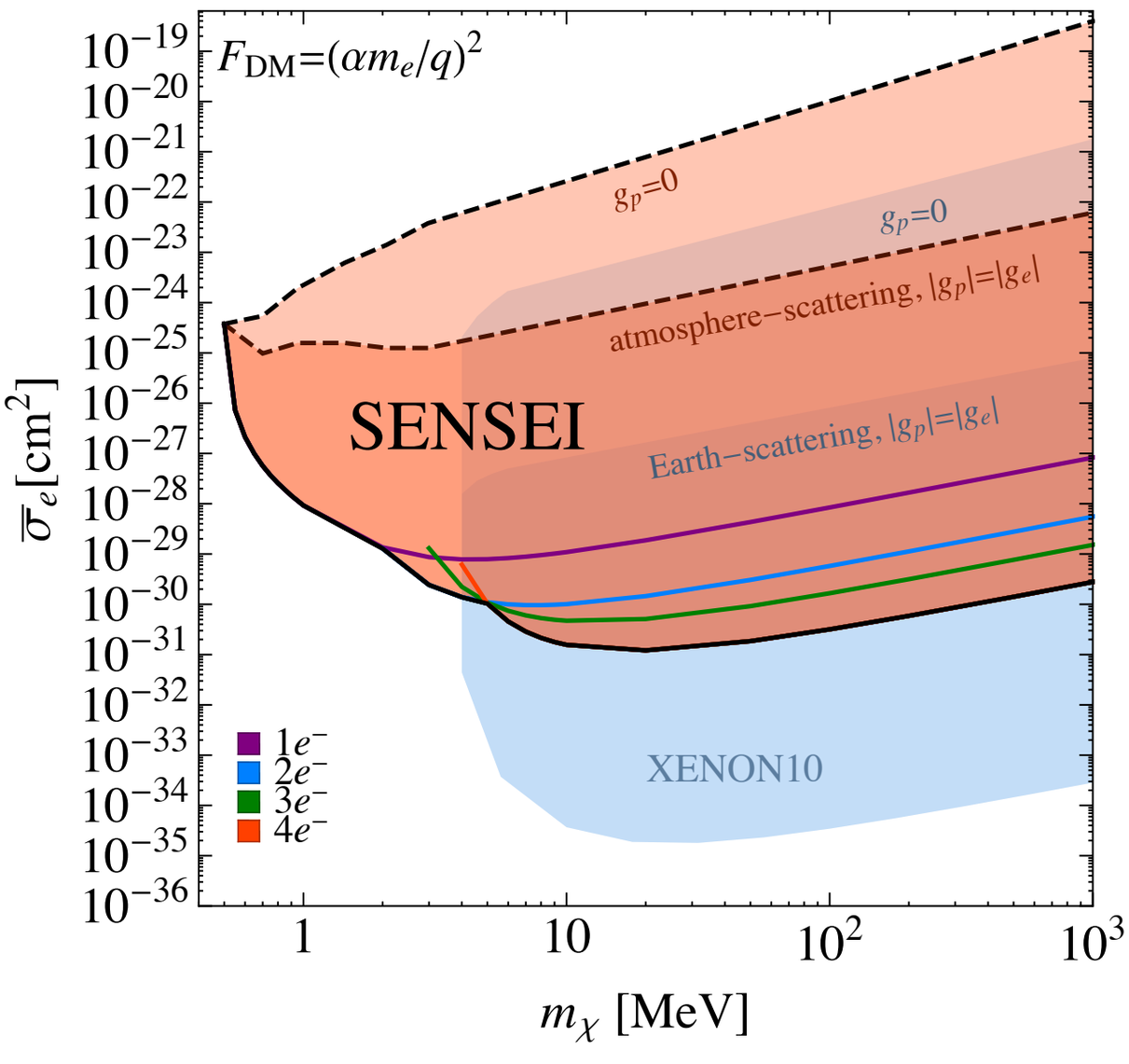


SENSEI Collaboration [1804.00088]

first results!

~0.02 g-days of commissioning data from a surface run





SENSEI Collaboration [1804.00088]

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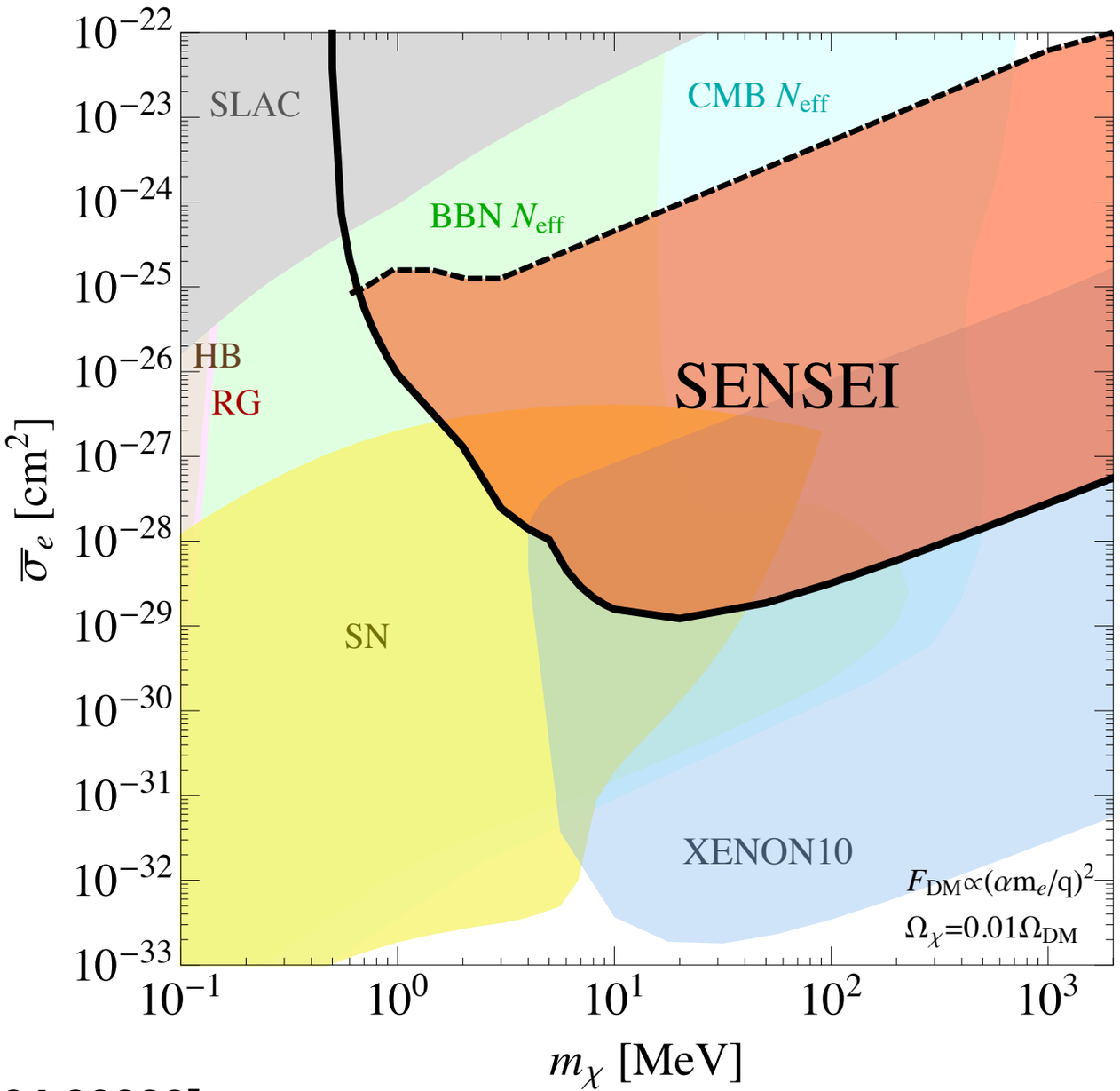
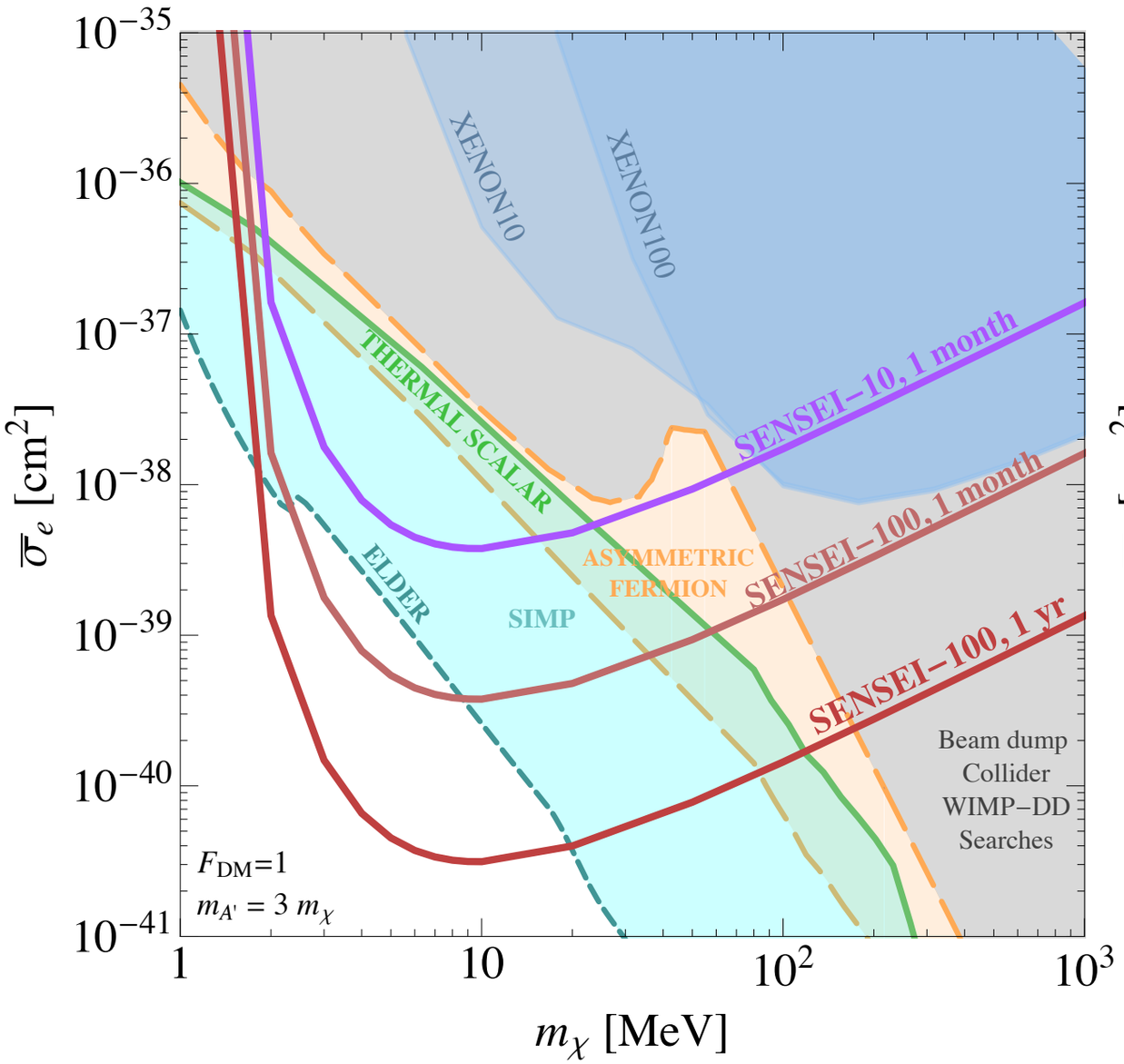
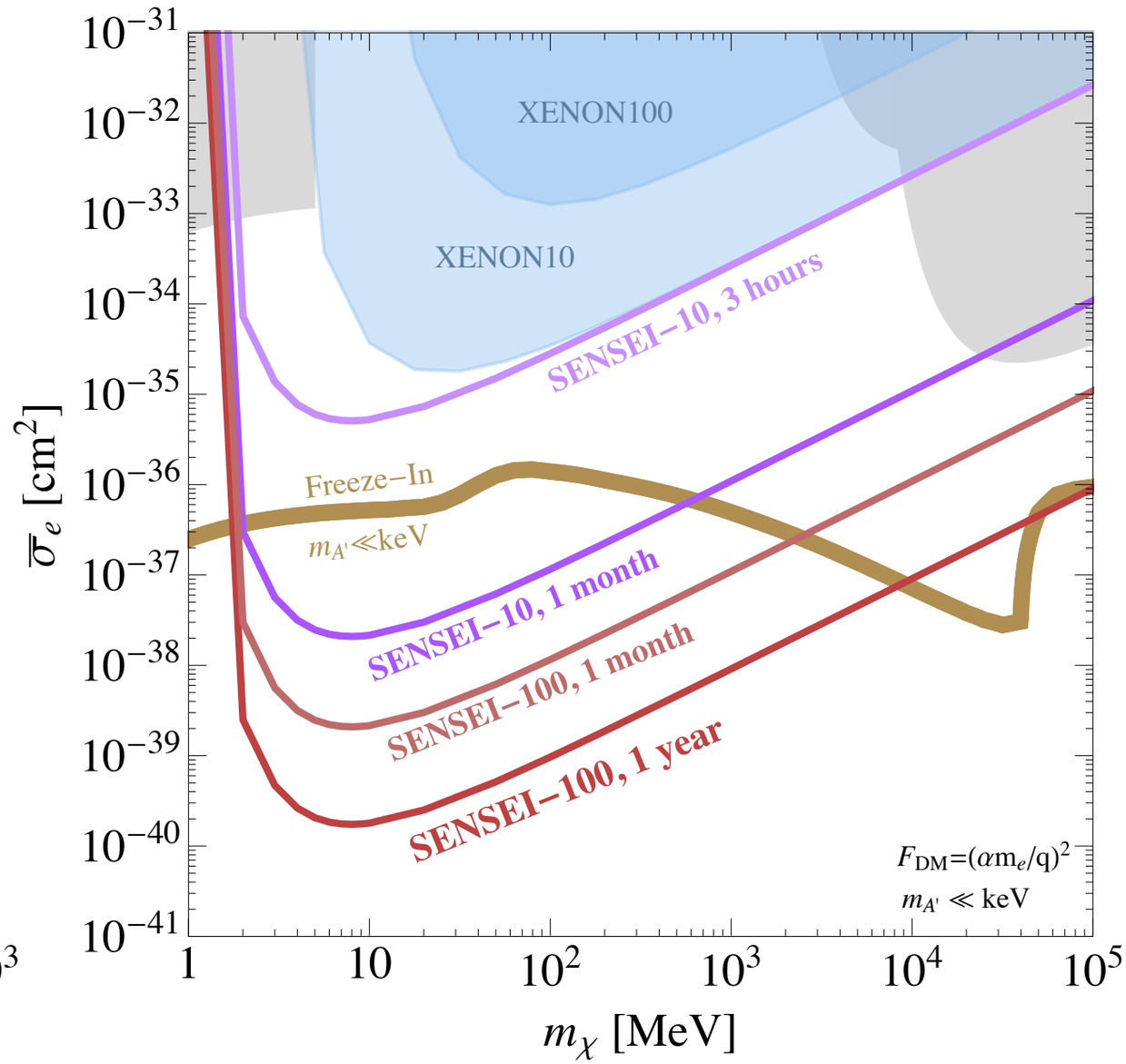


SENSEI Collaboration [1804.00088]

physics potential

electron scattering



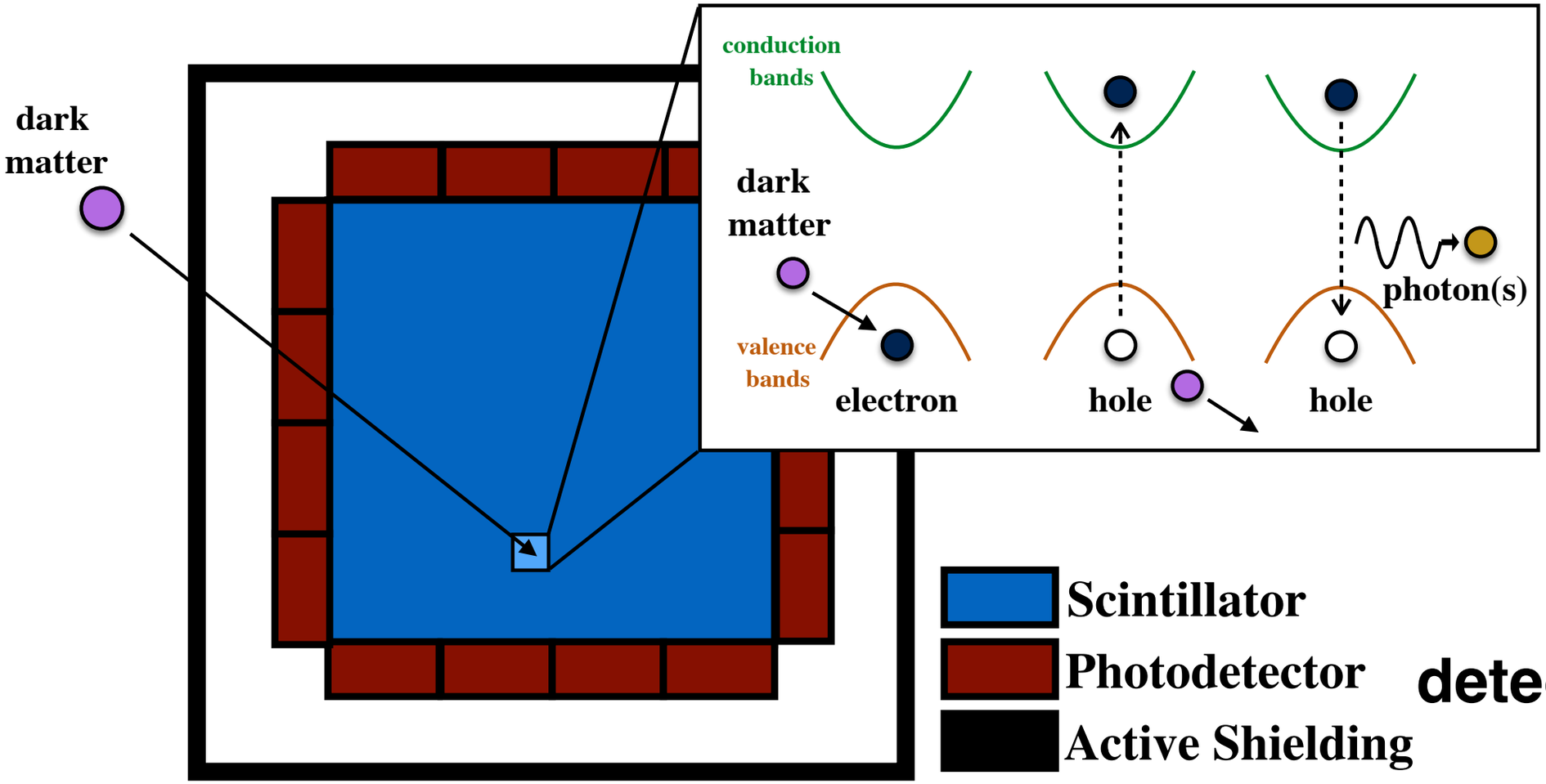


based on:

SENSEI: A Novel Search for Light Dark Matter, *to appear*

Essig, Volansky, TTY [1703.00910], Essig, Fernandez-Serra, Mardon, Soto, Volansky, TTY [1509.01598]

scintillators



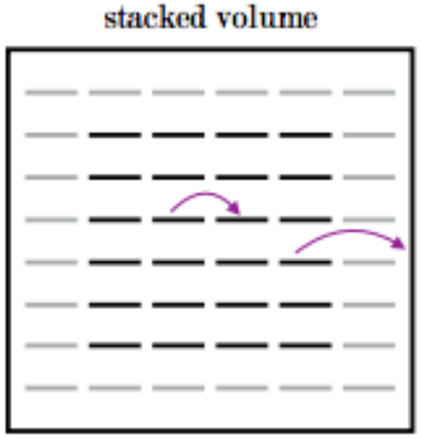
detect the photon(s)

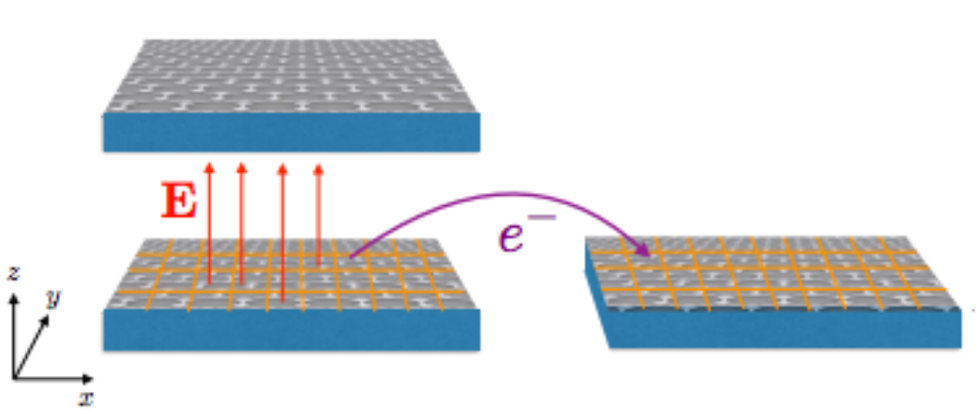
sensitive to ~eV energy depositions

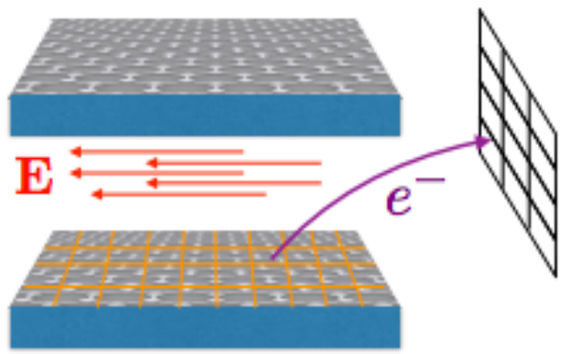
Derenzo, Essig, Massari, Soto, TTY [1607.01009]

i.e. GaAs, NaI, CsI

graphene and carbon nanotubes





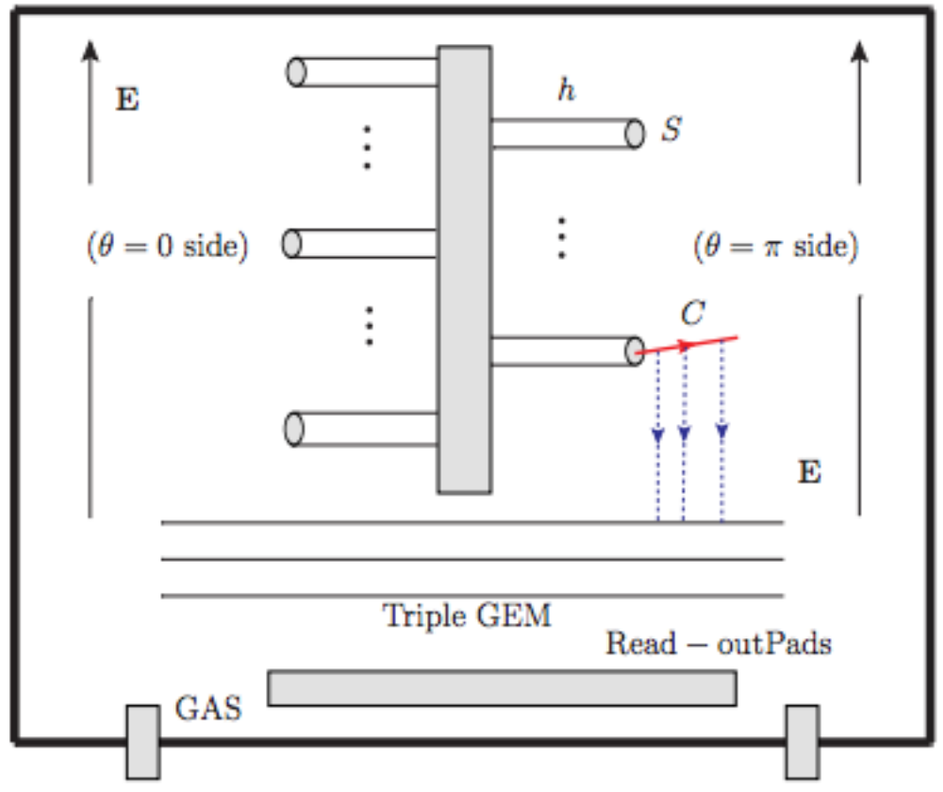


$$\Phi \simeq 4.3 \text{ eV}$$

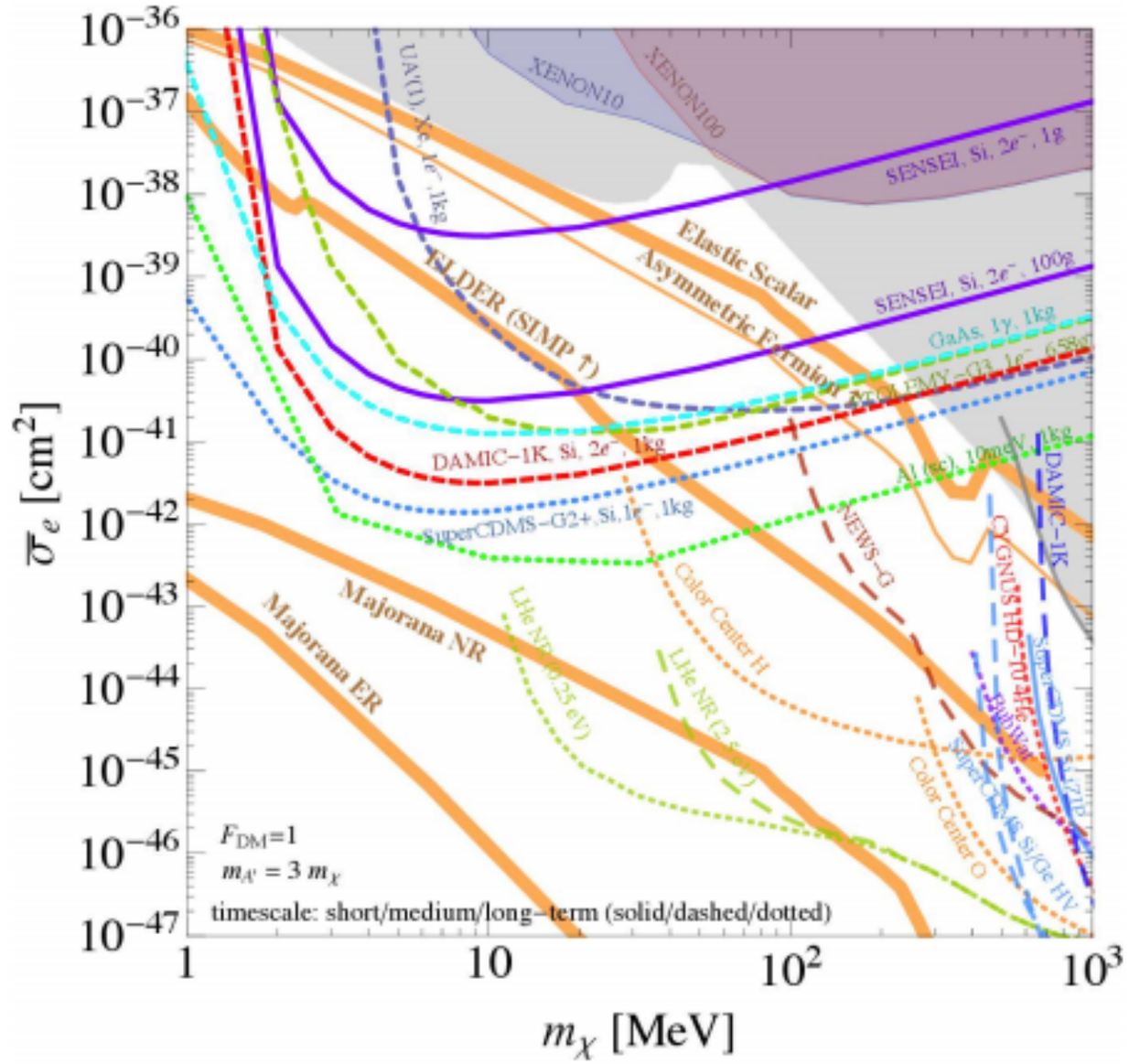
work function = minimum energy to eject an electron

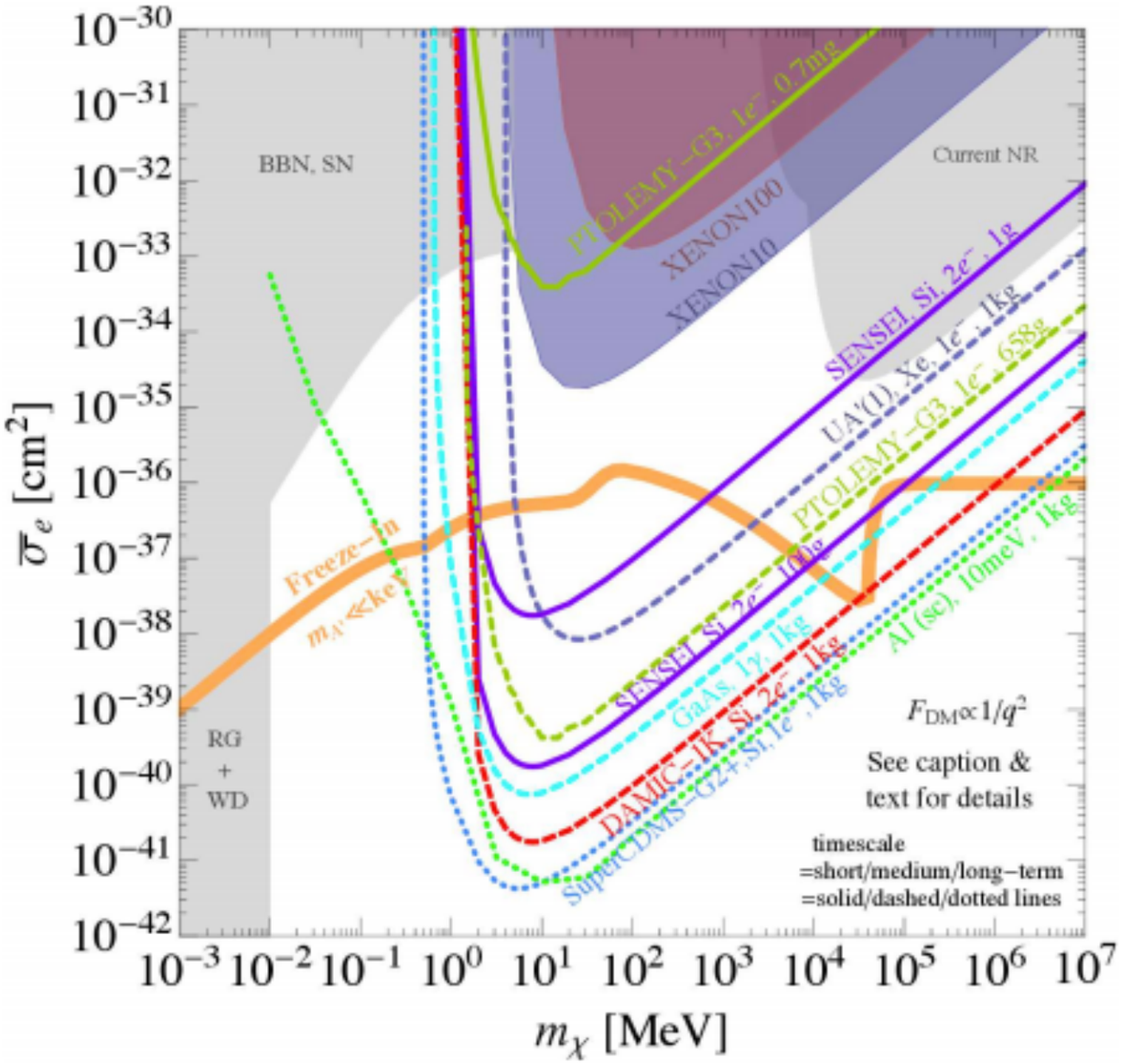
has directional sensitivity!

Hochberg, Kahn, Lisanti, Tully, Zurek [1606.08849]
Capparelli, Cavoto, Mazzilli, Polosa [1412.8213]
Cavoto, Luchetta, Polosa [1706.02487]



MeV-GeV DM-e scattering

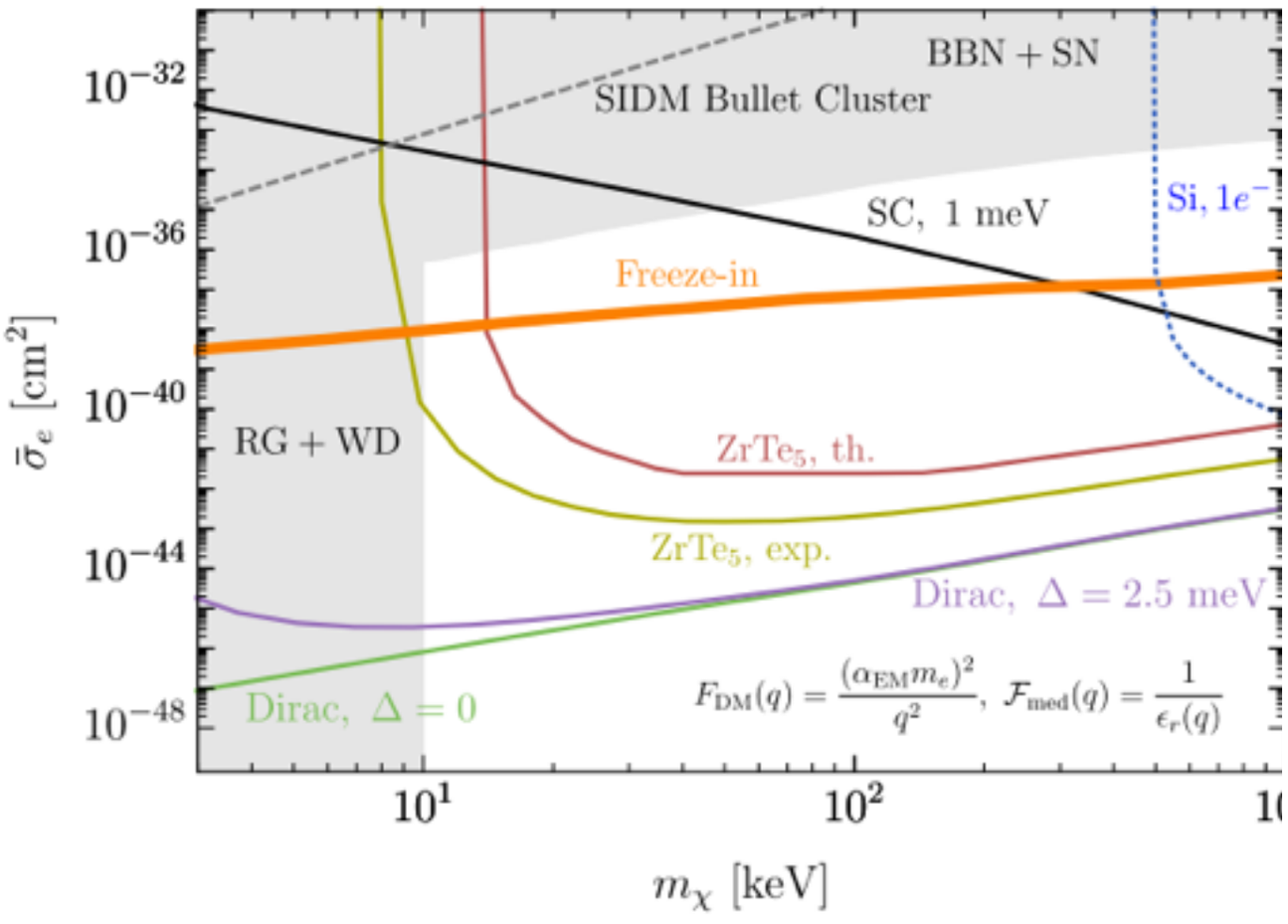




US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report [1707.04591]

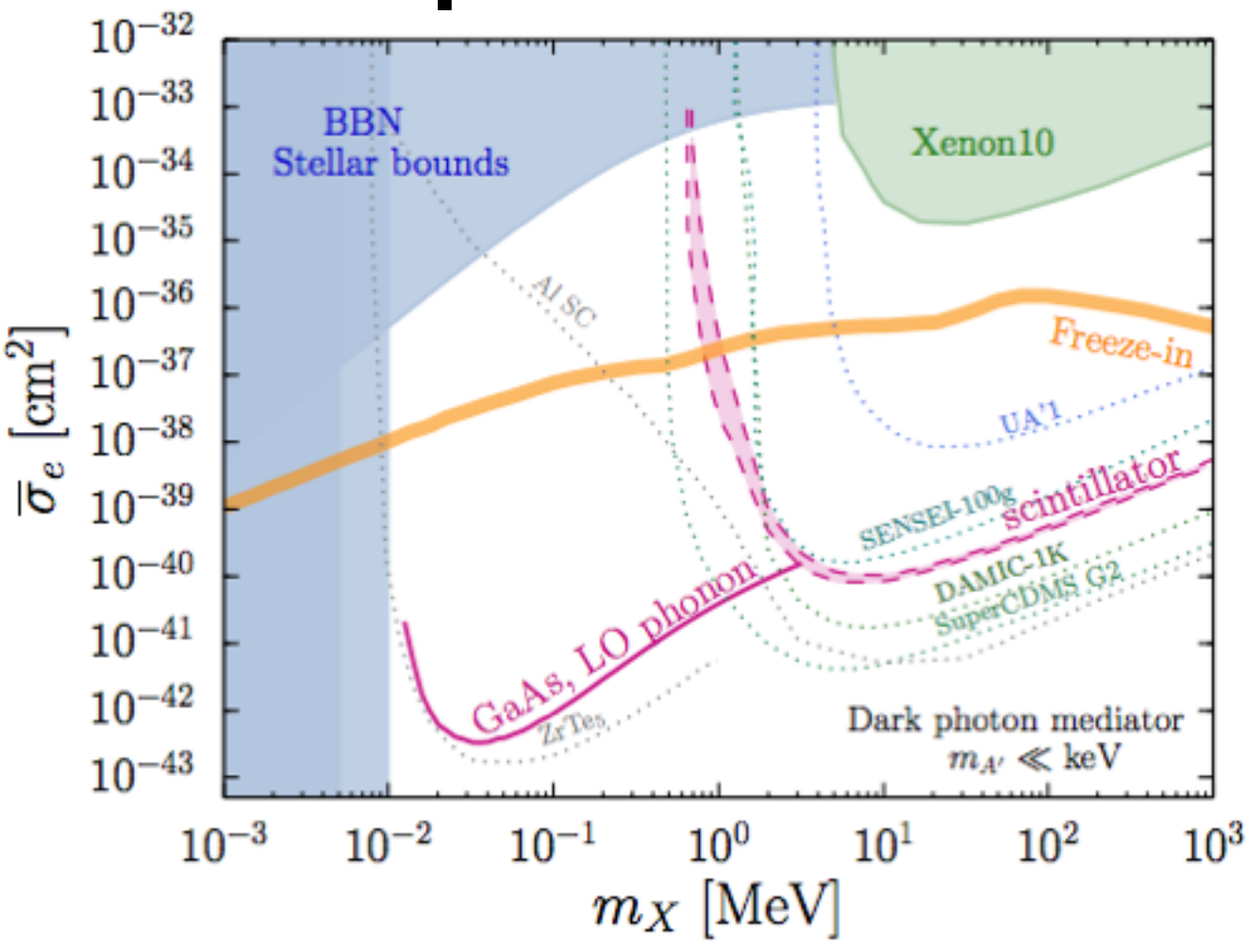
sub-MeV DM scattering

Dirac Metals



Hochberg, Kahn, Lisanti, Zurek, Grushin, Ilan, Griffin, Liu, Weber, Neaton [1708.08929]

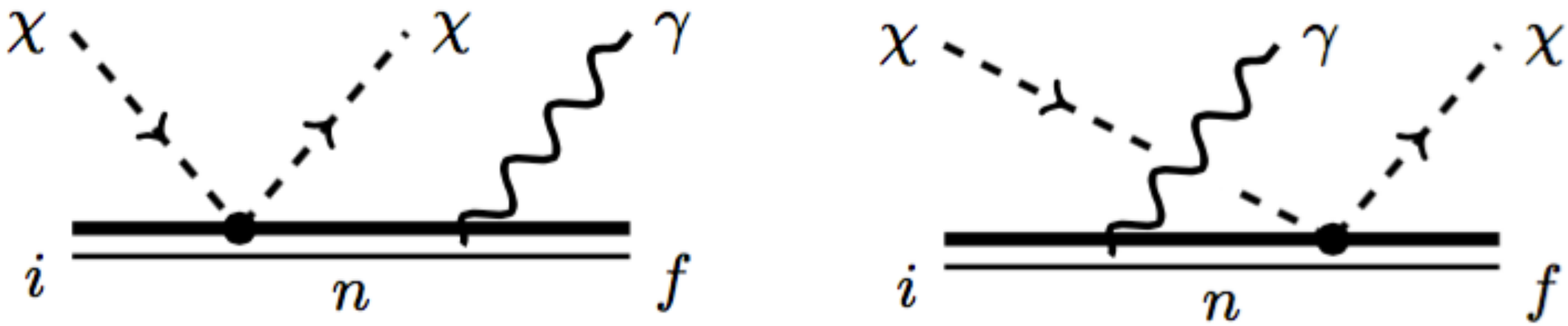
Optical Phonons, superconductors



Knapen, Lin, Pyle, Zurek [1712.06598]

see Kathryn Zurek's talk

DM-nucleon scattering + photon



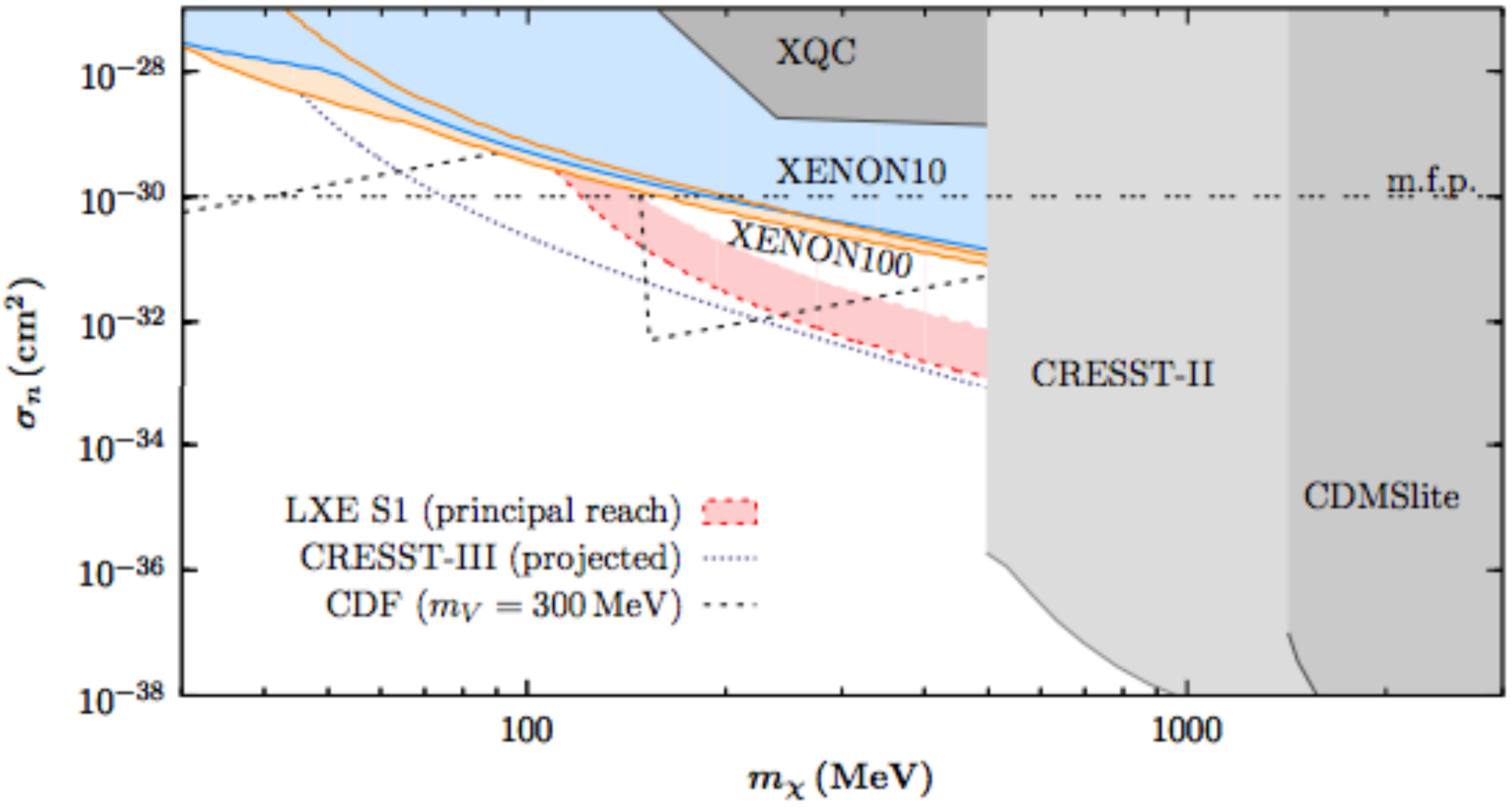
$$d\sigma = |V_{fi}|^2 \frac{\omega^2 d\omega d\Omega_K}{(2\pi)^3} \times d\sigma_{\rm el}$$

dipole transition element

Kouvaris, Pradler [1607.01789]
McCabe [1702.04730]

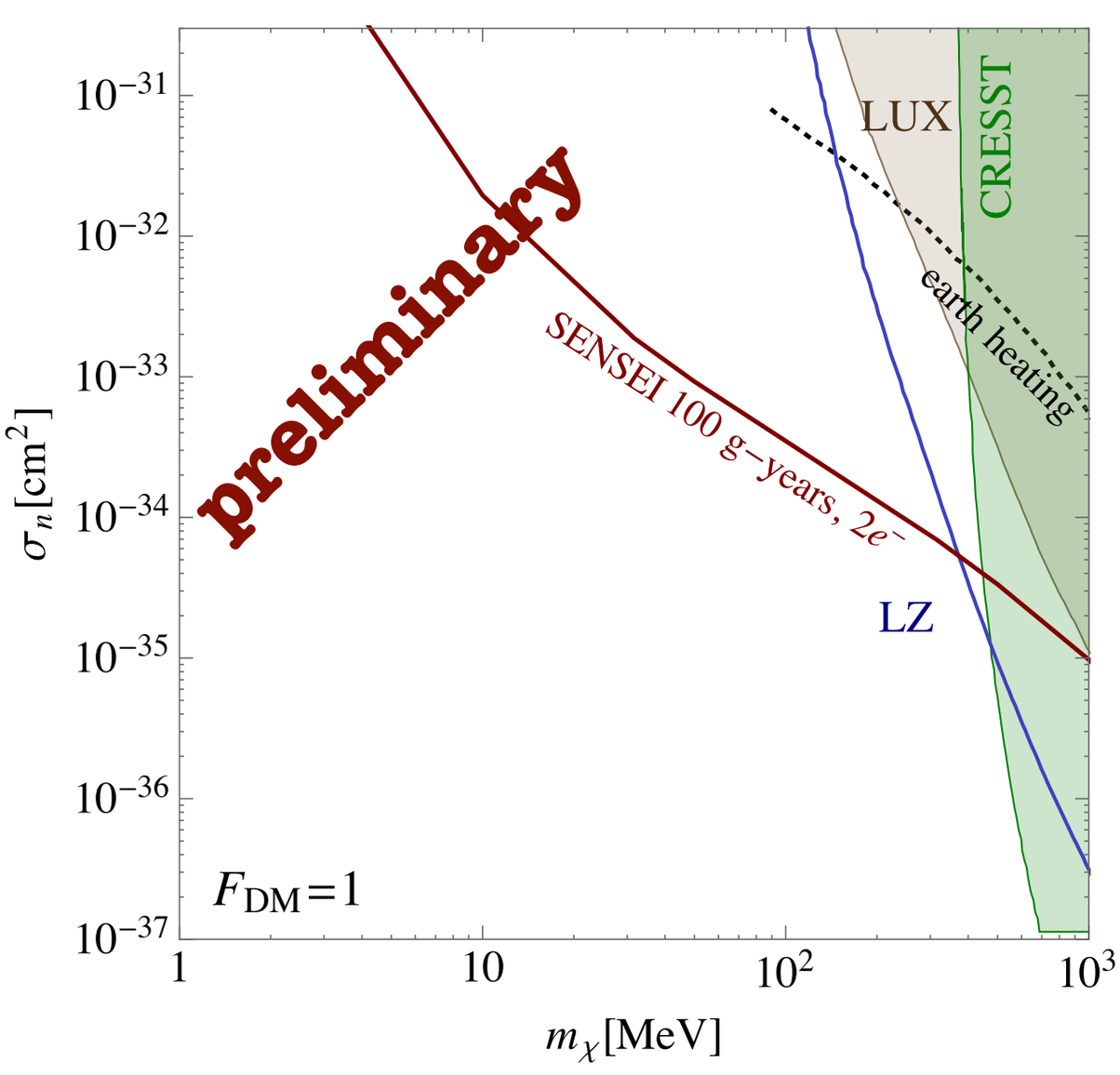
see also Josef Pradler's talk

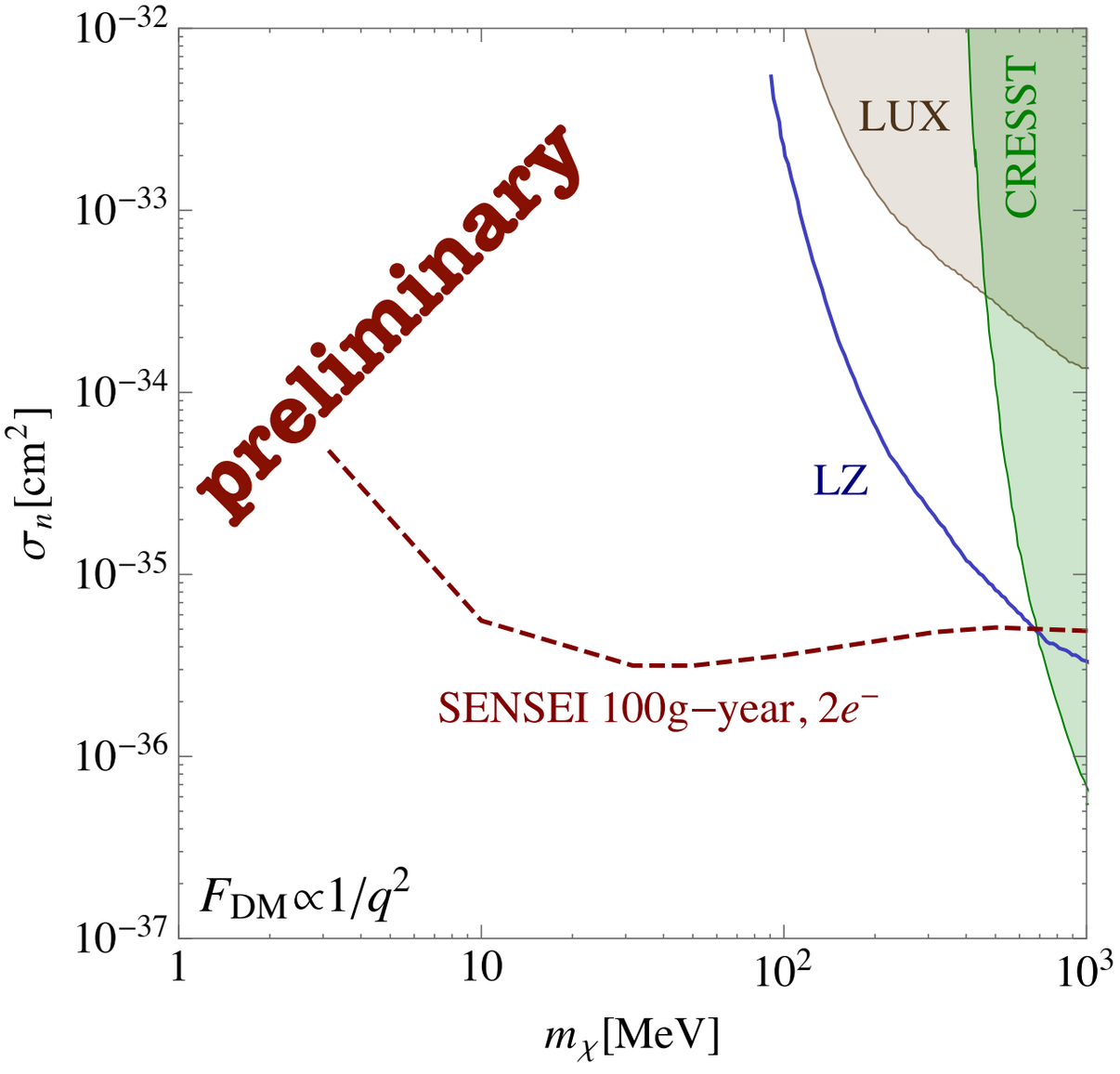
DM-nucleon scattering + photon



Kouvaris, Pradler [1607.01789]

photon emission

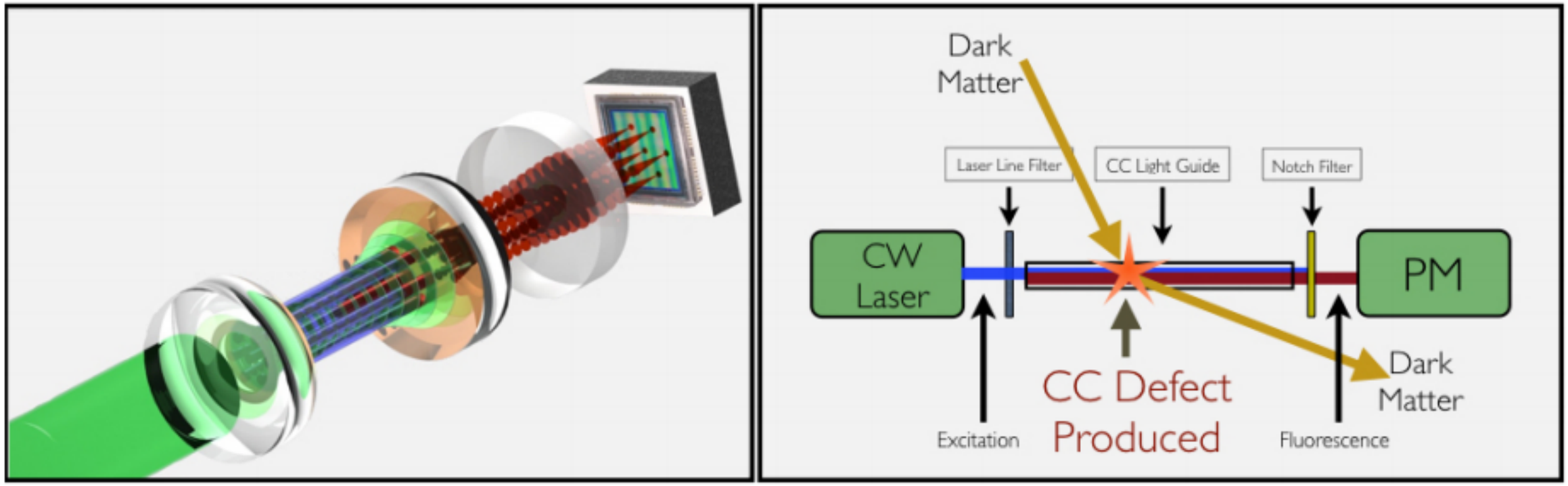




SENSEI: A Novel Search for Light Dark Matter, *to appear*

DM interaction triggers a physical or chemical change in target material

color centers

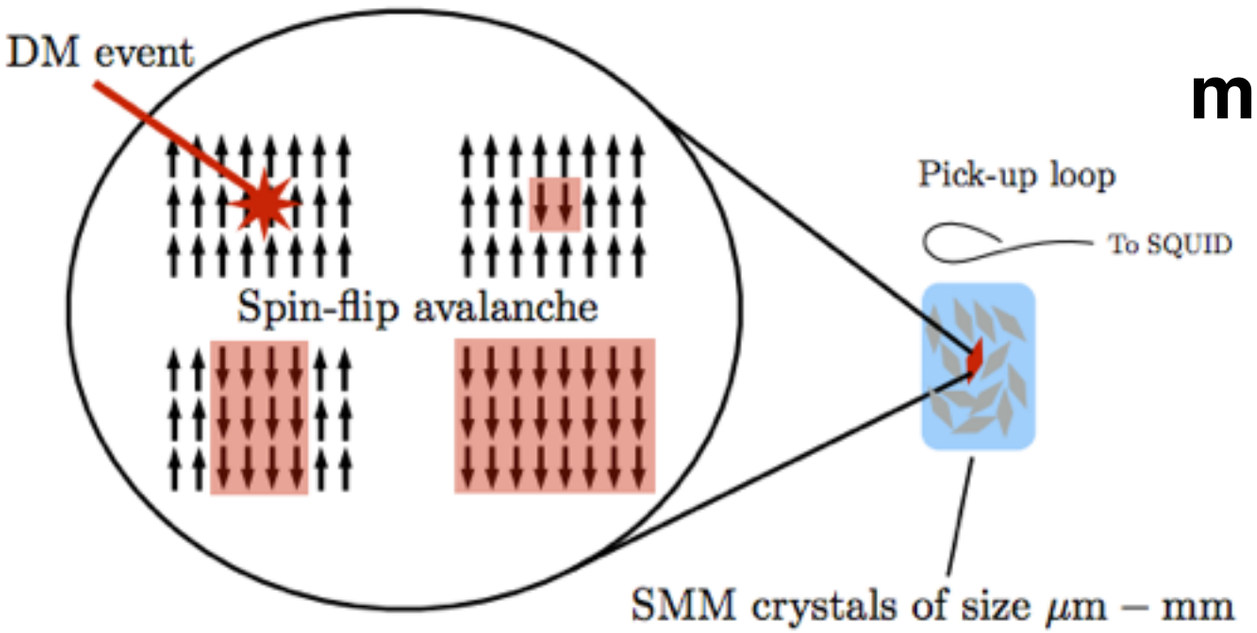


DM interaction creates a long-lived defect in the crystal

sensitive to ~10 eV energy depositions

Budnik, Chesnovsky, Slone, Volansky [1705.03016]

magnetic bubbles



single molecule magnets (SMM) = molecular crystals with molecules that act like tiny, non-interacting magnets

relies on the coherence of interaction event to create a measurable signal

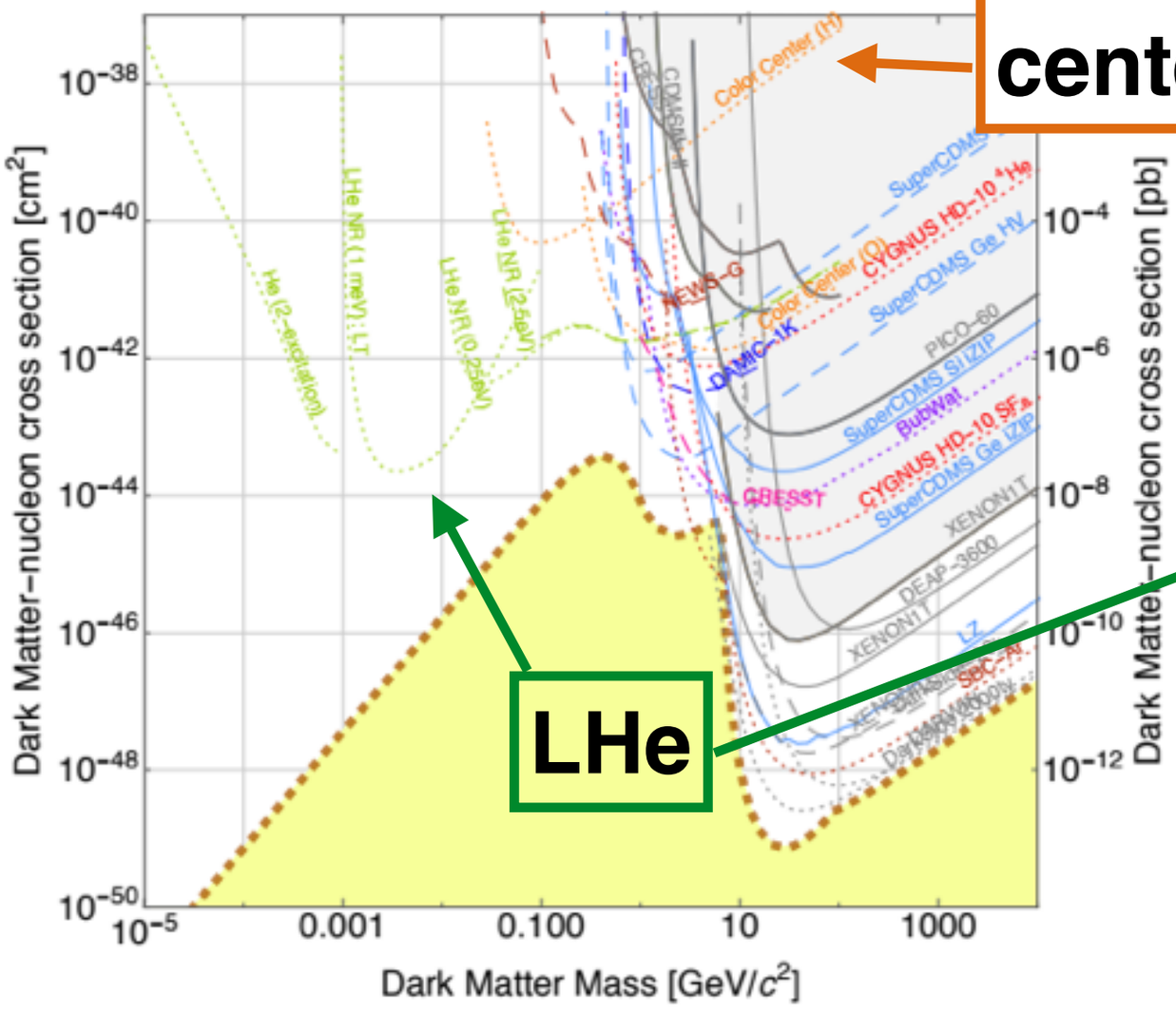
sensitive to 10^{-3} eV-10 eV energy depositions

Bunting, Gratta, Melia, Rajendran [1701.06566]

DM-nucleon interactions

color centers

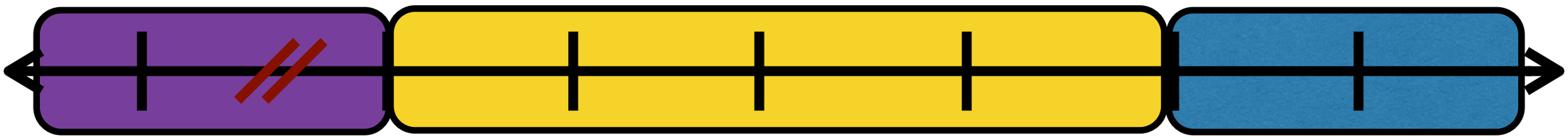
LHe



US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report [1707.04591]

dark matter candidates

10^{-22} eV meV eV keV MeV GeV TeV



“axions/ALPs” “WIMP”

dark matter candidates