Sub-GeV DM searches in Semiconductor and Scintillator Targets

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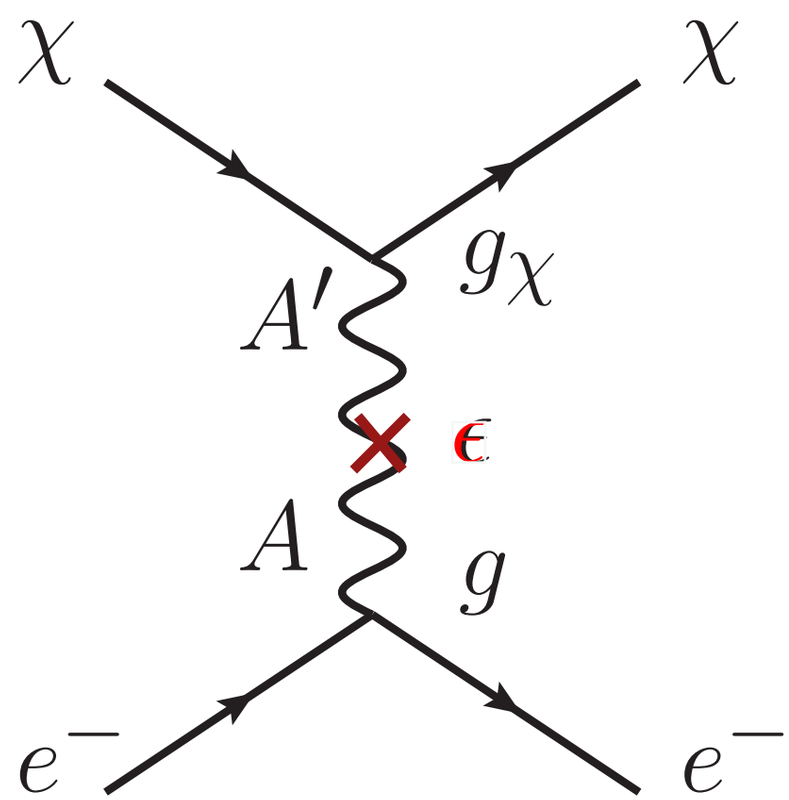
US Cosmic Visions: New Ideas in Dark Matter

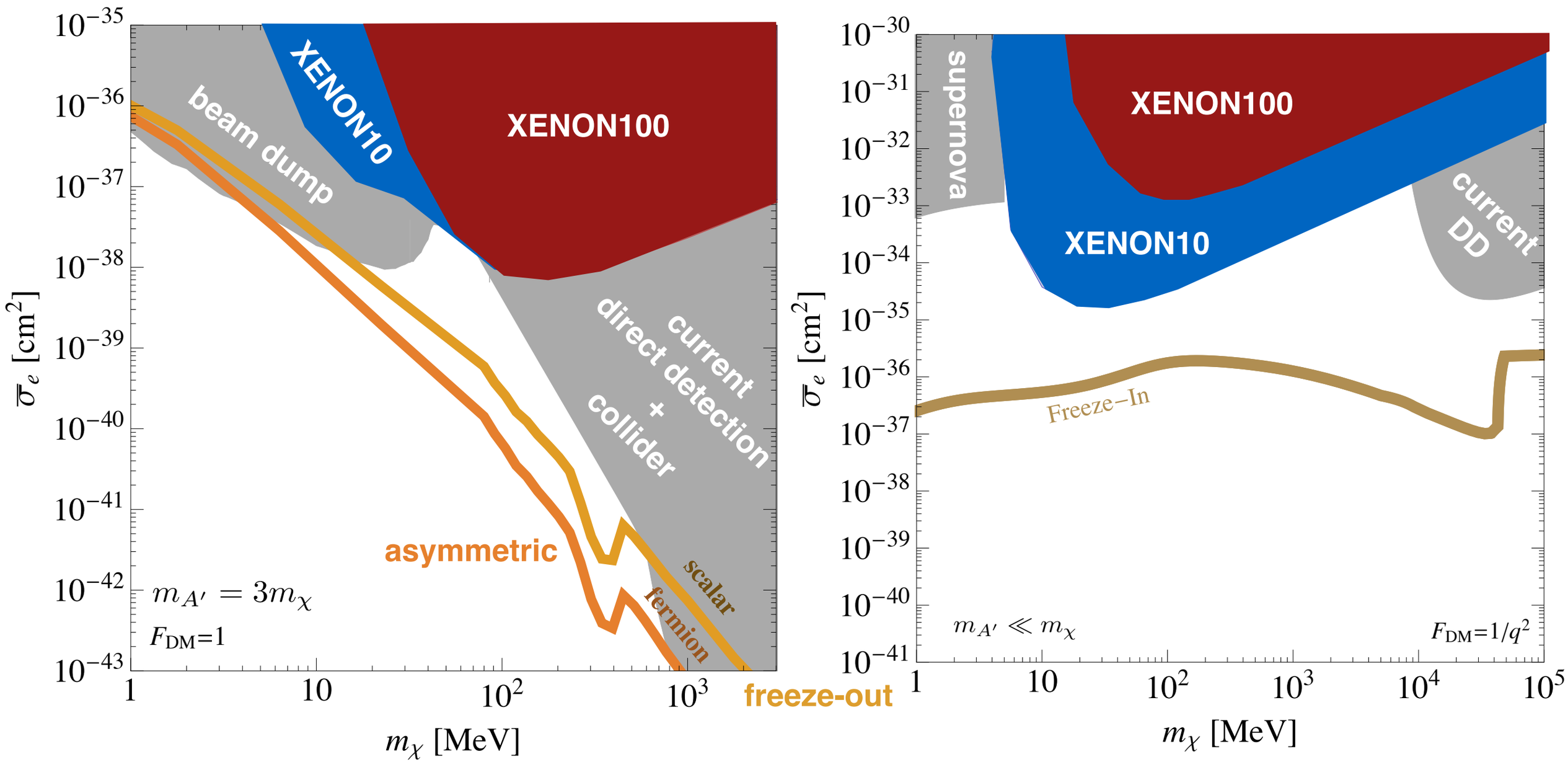
a model: dark photon

$$\mathcal{L} \supset -\frac{1}{4}F'^{\mu\nu}F'_{\mu\nu} - \frac{\epsilon}{2}F^{\mu\nu}F'_{\mu\nu} + \frac{1}{2}m_{A'}^2 A'^{\mu}A'_{\mu}$$



$$F_{DM}(q) = \frac{m_{A'}^2 + \alpha^2 m_e^2}{m_{A'}^2 + q^2} \simeq \begin{cases} 1\,, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 m_e^2}{q^2}\,, & m_{A'} \ll \alpha m_e \end{cases}$$

current status



Essig, Volansky, TTY [1703.00910]

ingredients for rate

material dependent

$$\frac{\mathrm{d}\langle\sigma v\rangle}{\mathrm{d}\ln E_R} = \frac{\overline{\sigma}_e}{8\mu_{\chi e}^2}\int q\ \mathrm{d}q\,\boxed{|f(k,q)|^2}\,|F_{DM}(q)|^2\eta(v_{min})$$

$$|f(k,q)|^2 = \left|\int d^3x\psi_f^*(\vec{x})\psi_i(\vec{x})e^{i\vec{q}\cdot\vec{x}}\right|^2$$

wave-function overlap between initial and final electron states

probability of going from state i to i'

ingredients for rate

solid state physics

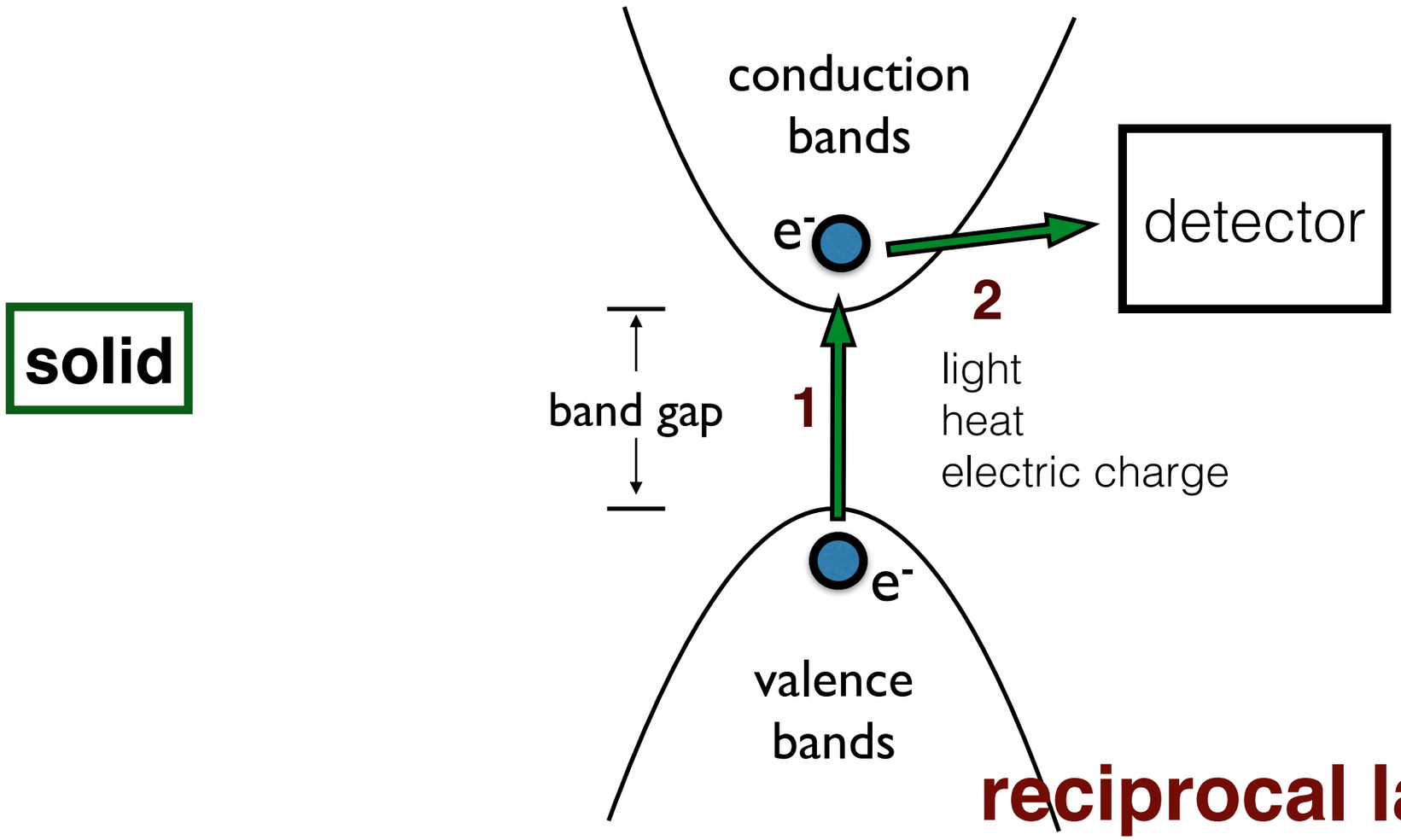
$$\frac{\mathrm{d}\langle\sigma v\rangle}{\mathrm{d}\ln E_R} = \frac{\overline{\sigma}_e}{8\mu_{\chi e}^2}\int q\ \mathrm{d}q\,|f(k,q)|^2|F_{DM}(q)|^2\eta(v_{min})$$

$$\Downarrow$$

$$\left|f_{i\to i'}(\vec{q},\vec{k})\right|^2 = \left|\sum_G \psi_{i'}^*(\vec{k}+\vec{G}+\vec{q})\psi_i(\vec{k}+\vec{G})\right|^2$$

contains directional dependence
***potentially powerful signal discrimination!**

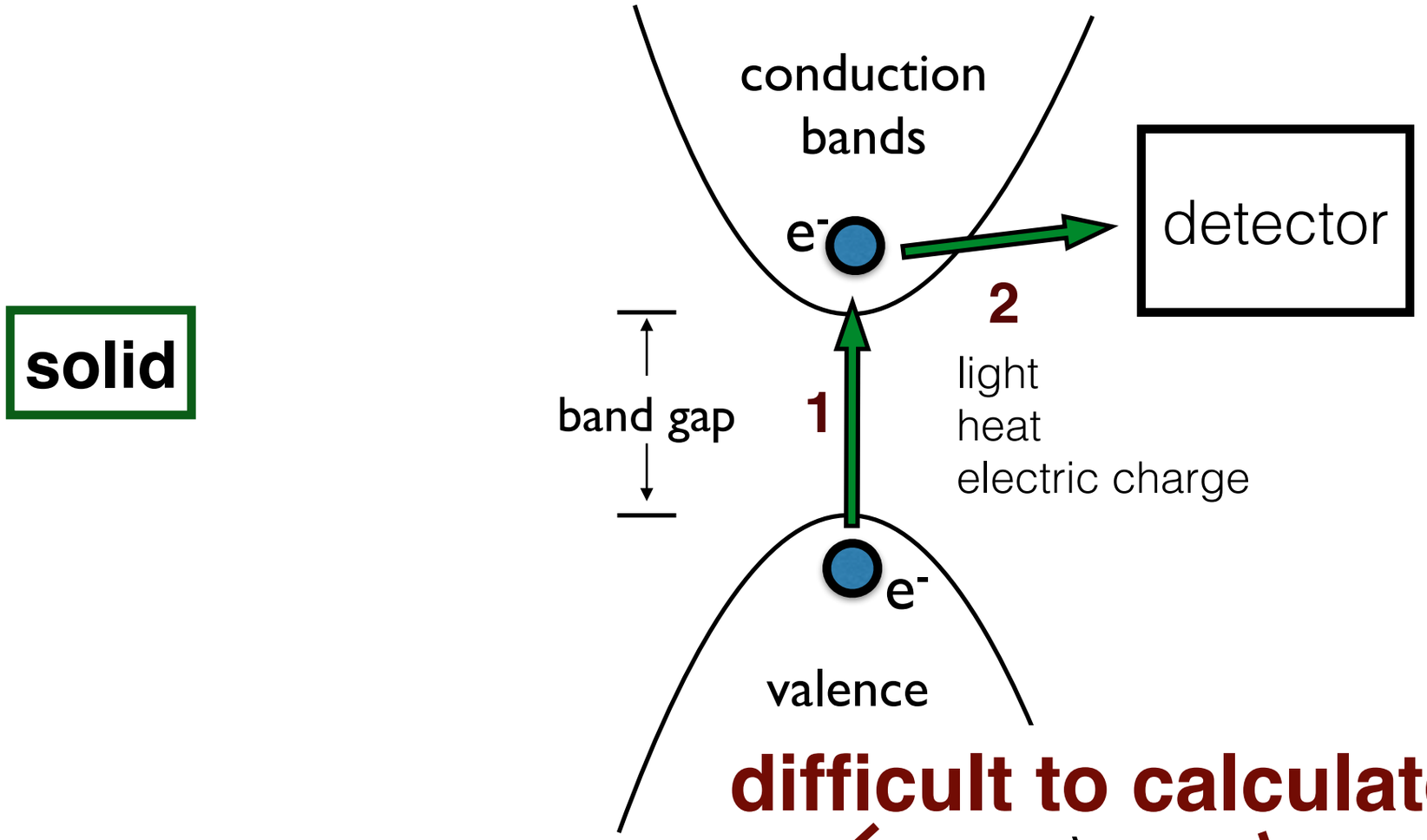
Essig, Mardon, Soto, Volansky, TTY (in preparation)



reciprocal lattice vector

$$\left| f_{i \to i'}(\vec{q}, \vec{k}) \right|^2 = \left| \sum_G \psi^*_{i'}(\vec{k} + \vec{G} + \vec{q}) \psi_i(\vec{k} + \vec{G}) \right|^2$$

electrons in a solid are part
of a complicated, many-body system



difficult to calculate these

$$\left| f_{i\to i'}(\vec{q},\vec{k}) \right|^2 = \left| \sum_G \psi^*_{i'}(\vec{k}+\vec{G}+\vec{q})\psi_i(\vec{k}+\vec{G}) \right|^2$$

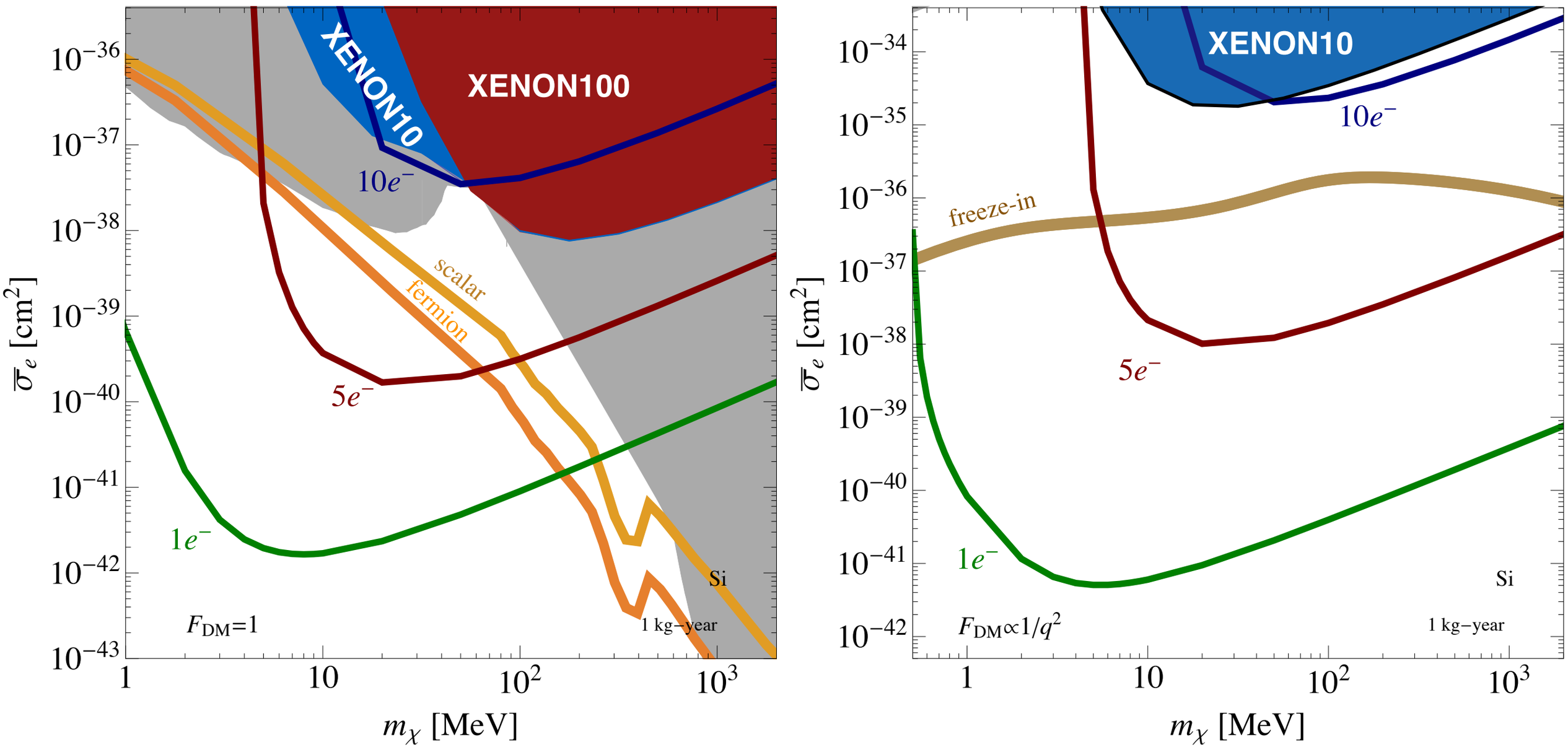
electrons in a solid are part
of a complicated, many-body system

http://www.quantum-espresso.org/

- **open source code that calculates electronic structure within density functional theory (DFT) using plane waves and pseudopotentials**
- **module QEdark calculates form factor:**

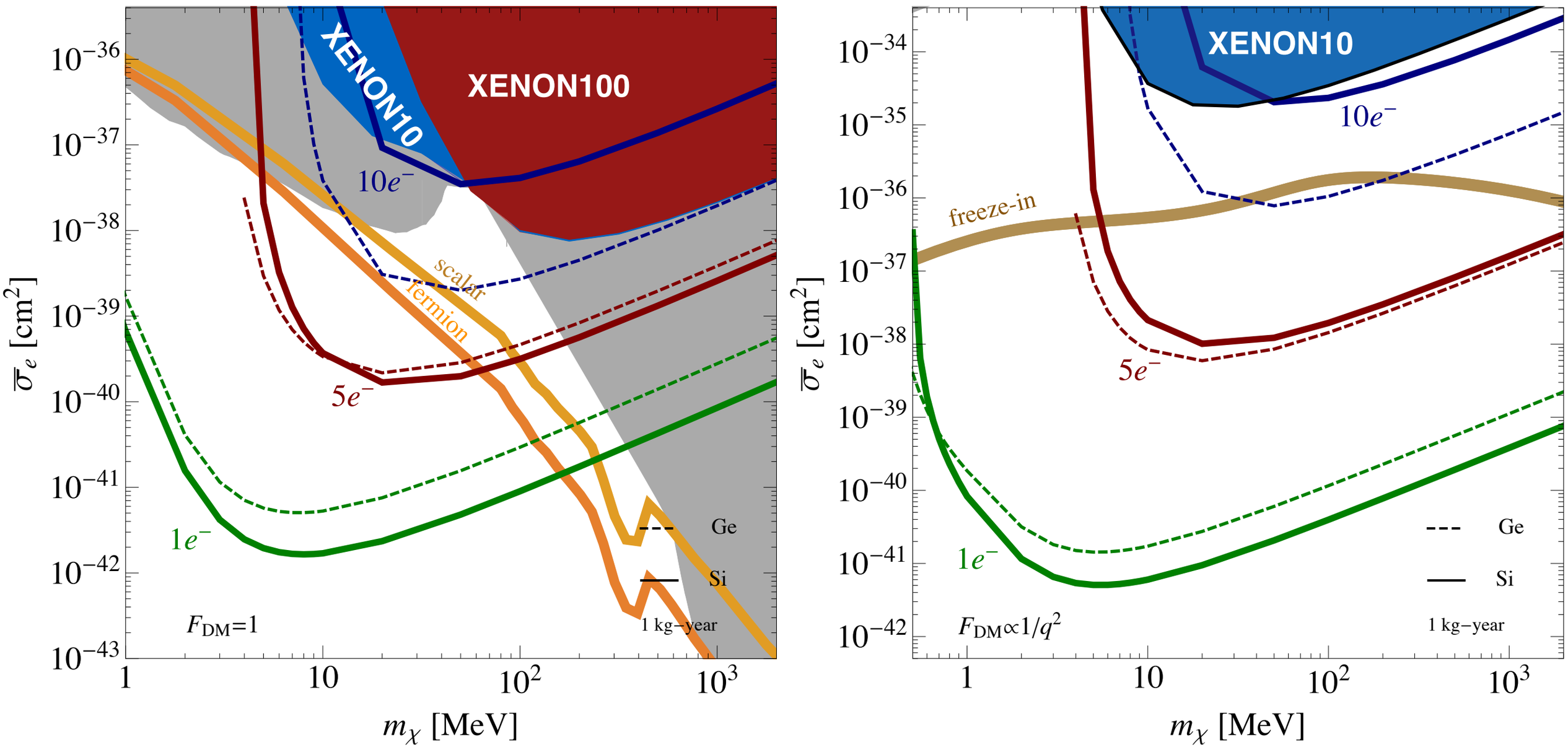
http://ddldm.physics.sunysb.edu/

silicon targets



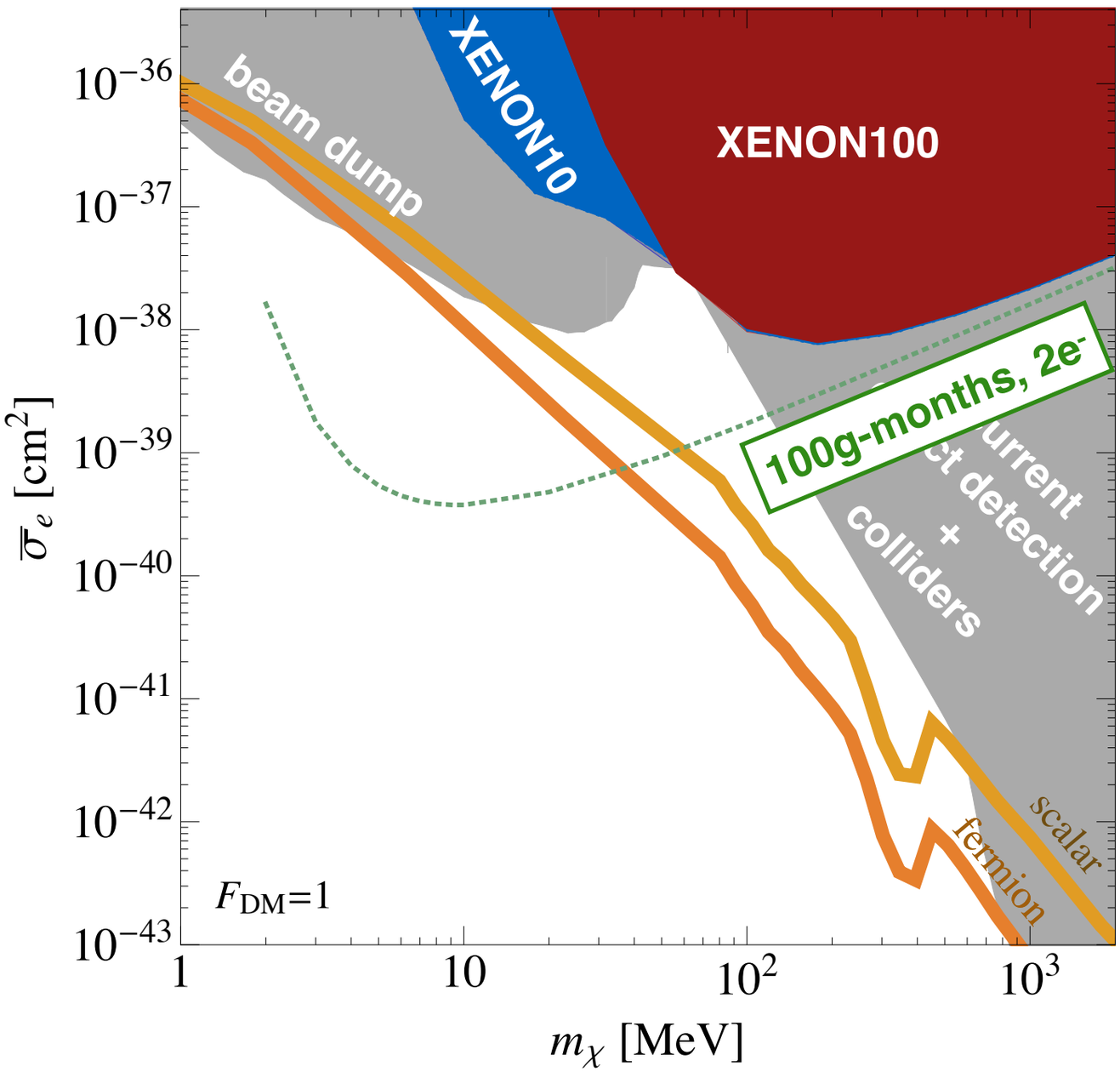
Essig, Fernandez-Serra, Mardon, Soto, TTY [1509.01598]

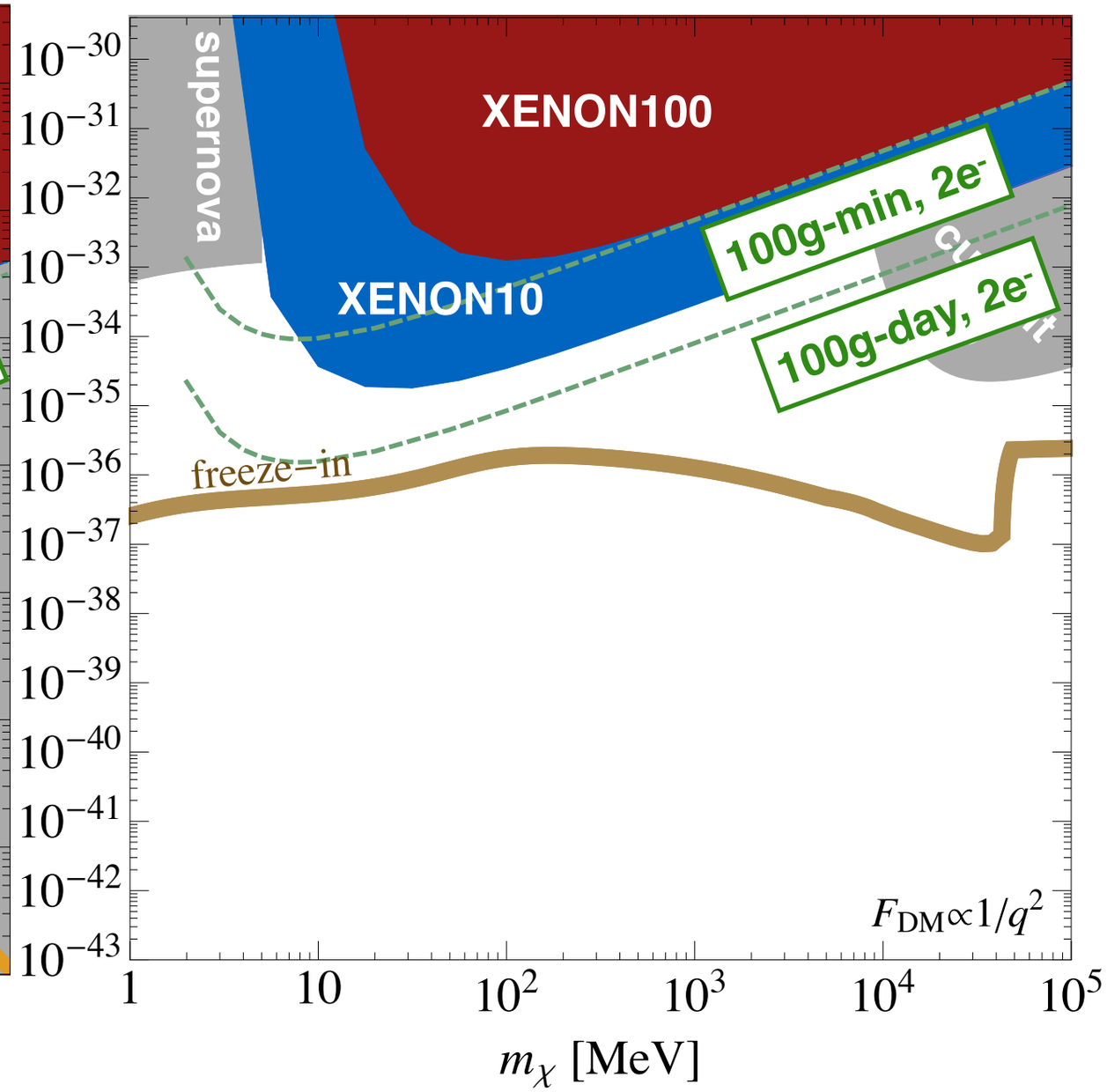
germanium targets



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

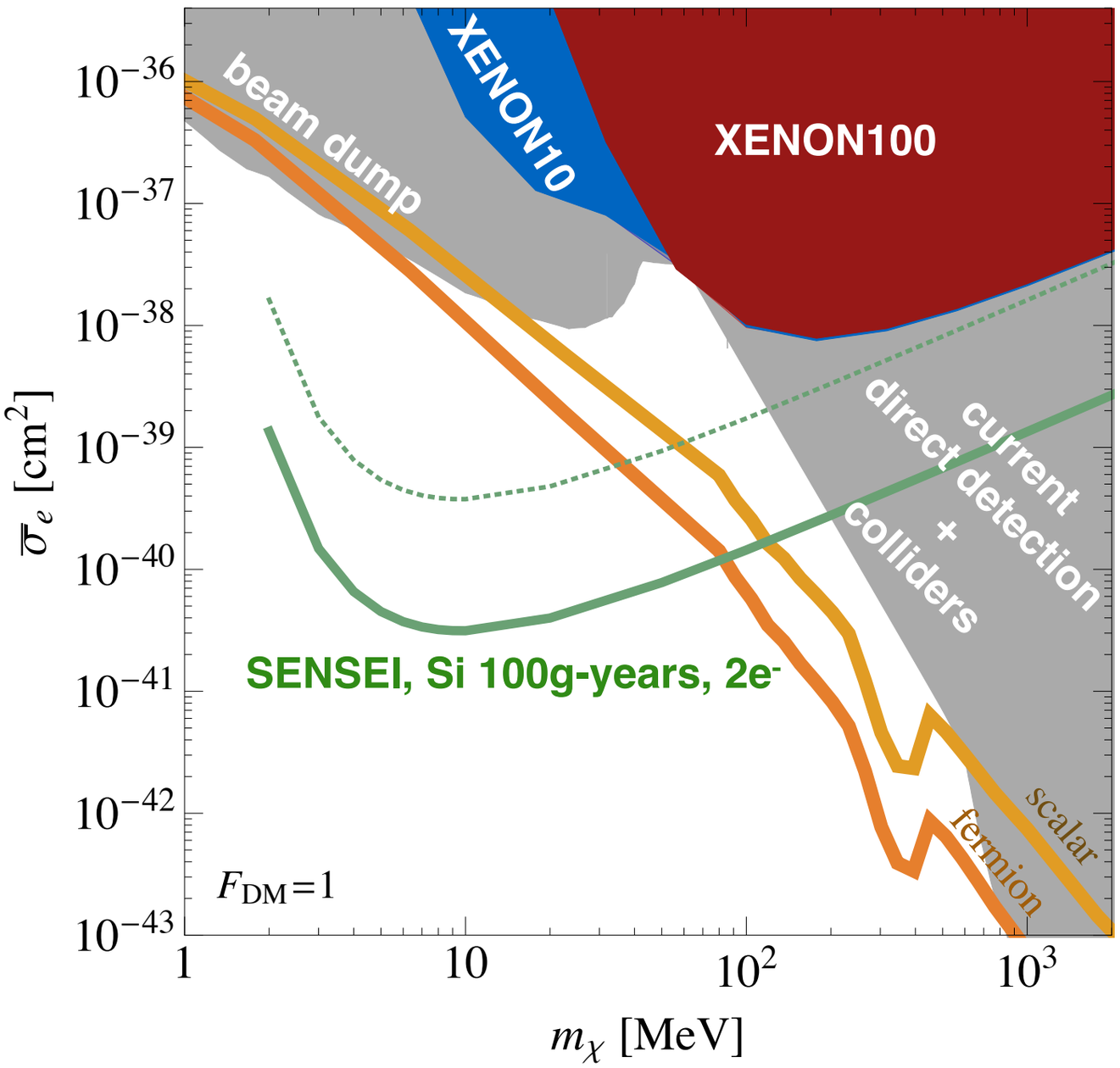
SENSEI projections

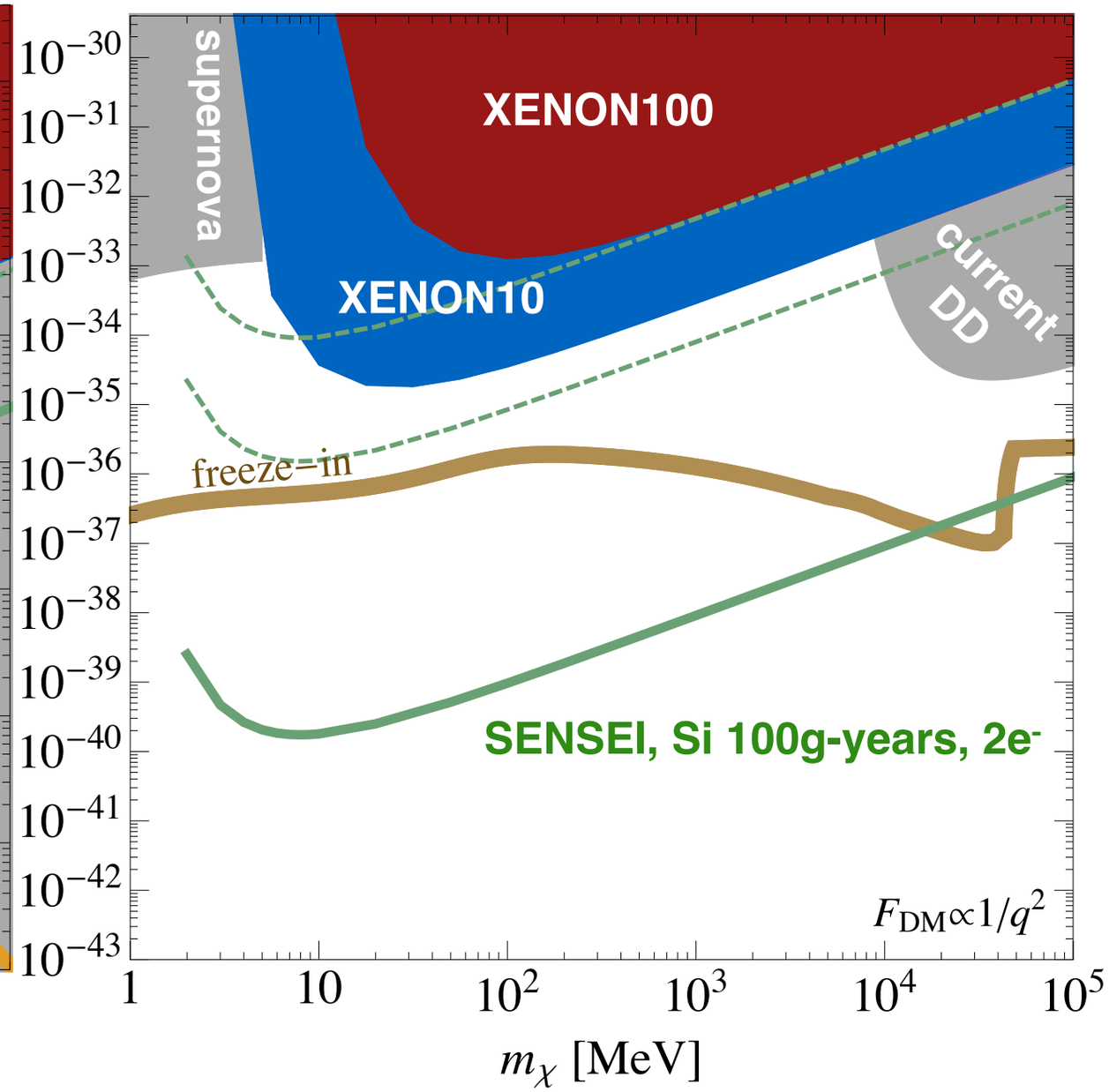




See talk by Javier Tiffenberg

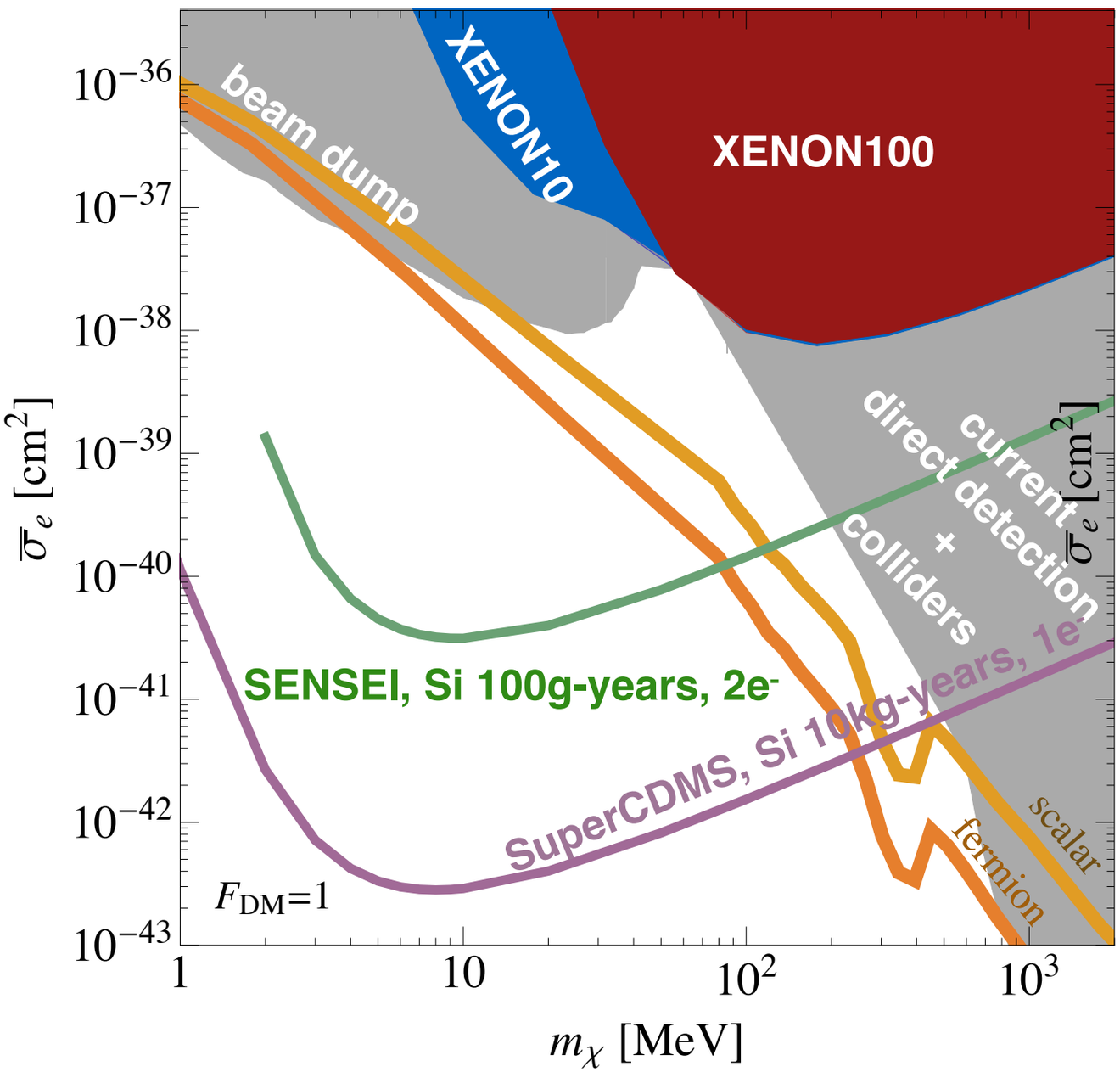
SENSEI projections

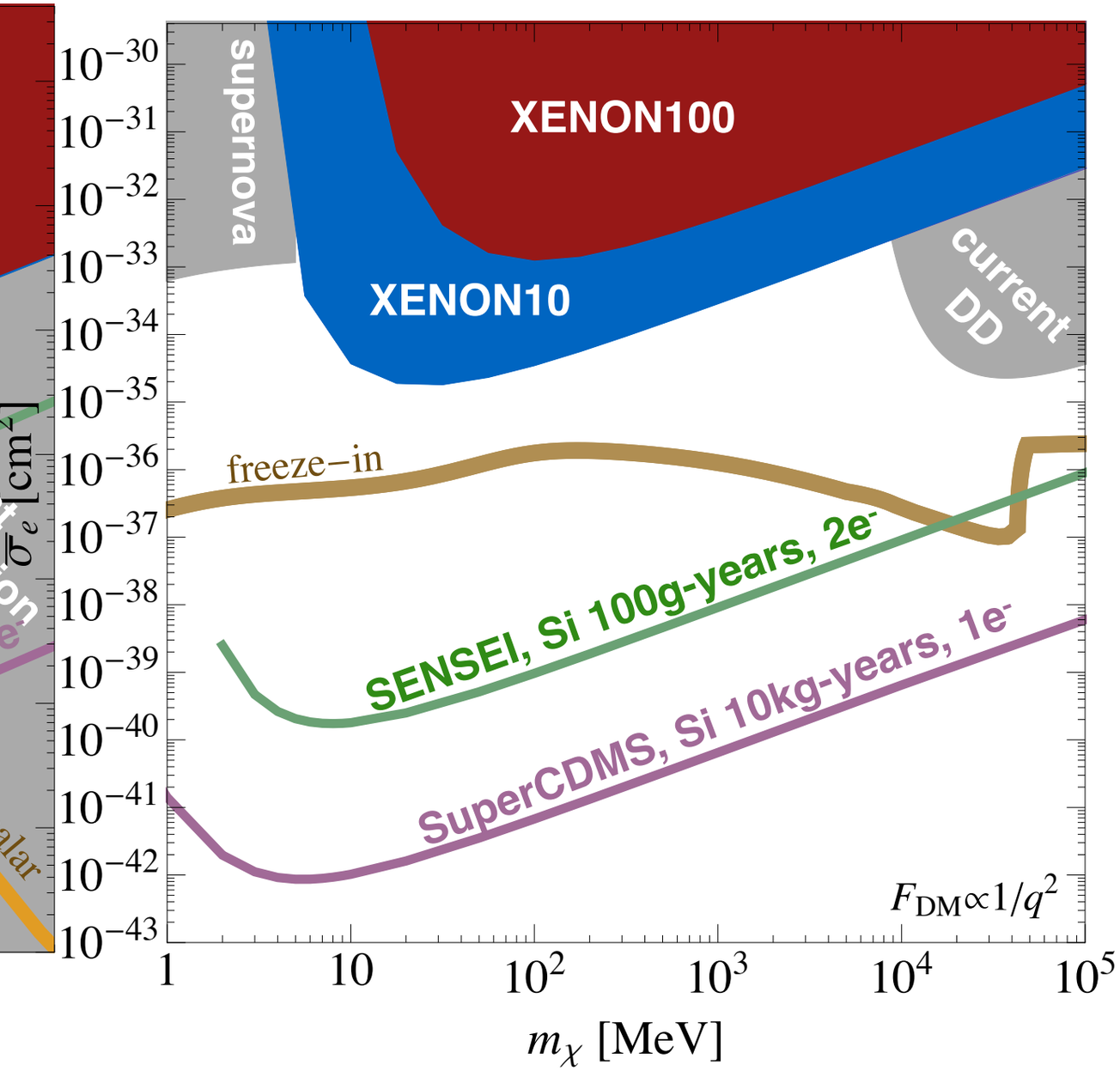




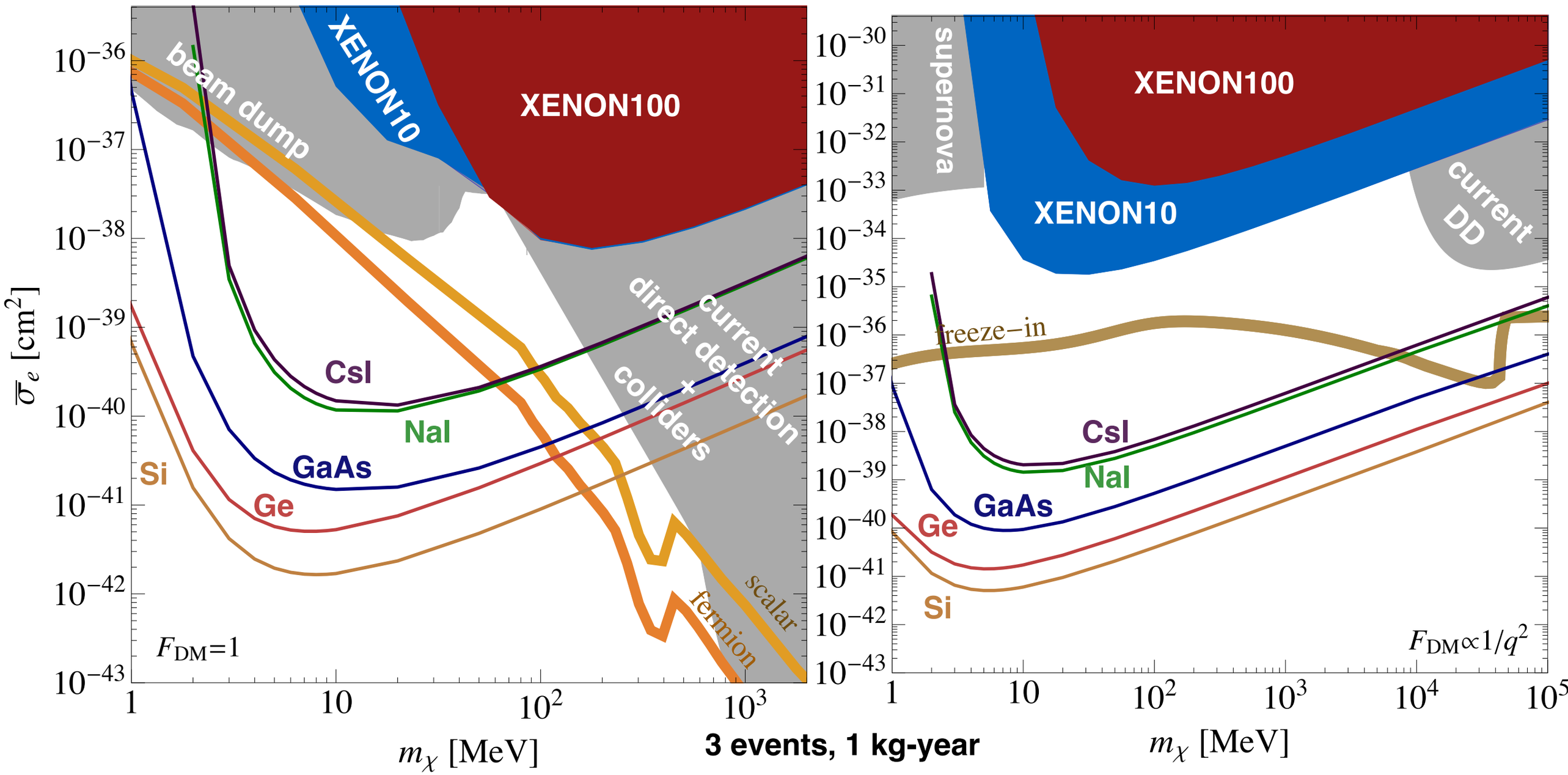
See talk by Javier Tiffenberg

SuperCDMS projections





scintillators

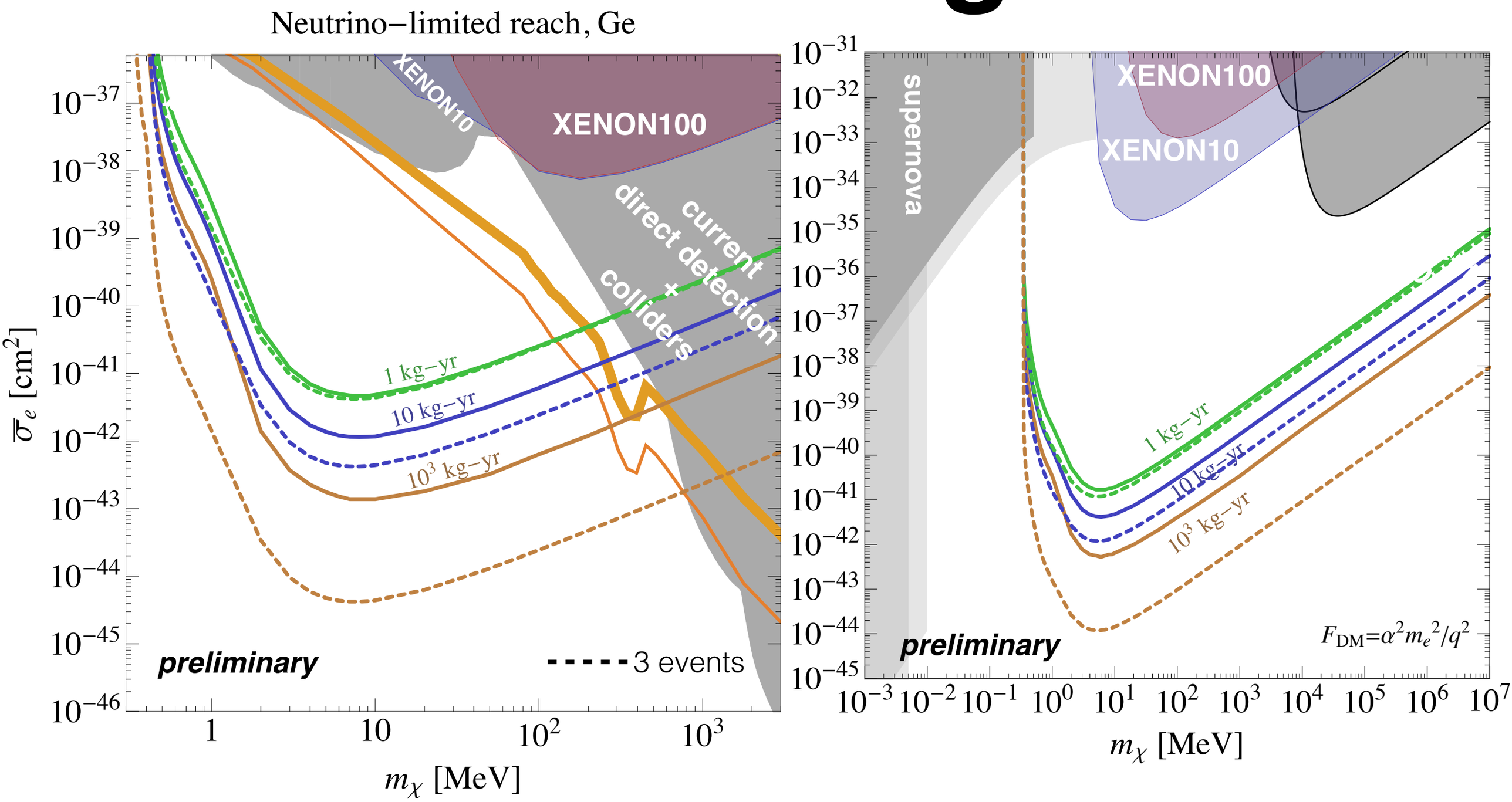


3 events, 1 kg-year

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

See talks by Jing Liu, Matt Pyle

neutrino background



Essig, Sholapurkar, TTY, *in preparation*

absorption

- **same experiments** can be used for down to ~eV DM

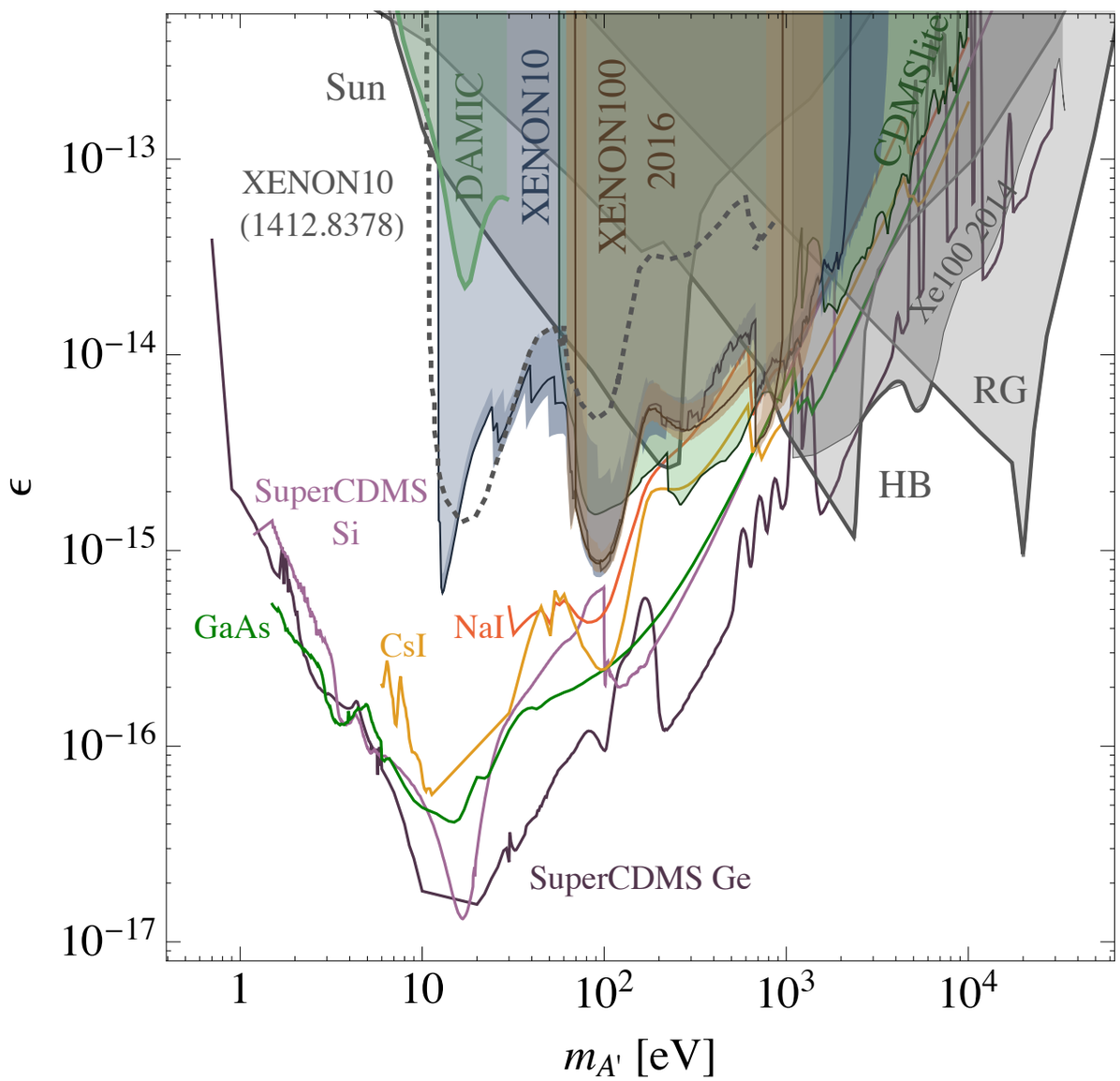
- consider absorption of DM instead of scattering

dark photon $$R \simeq \frac{\rho_{\rm DM}}{m_{A'}} \times \epsilon^2 \sigma_{\rm PE}(E = m_{A'})$$

axion $$R \simeq \frac{\rho_{\rm DM}}{m_{\rm DM}} \frac{3m_a^2}{4m_e^2} \frac{g_{aee}^2}{e^2} \sigma_{\rm PE}(E = m_a)$$

absorption

dark photon dark matter

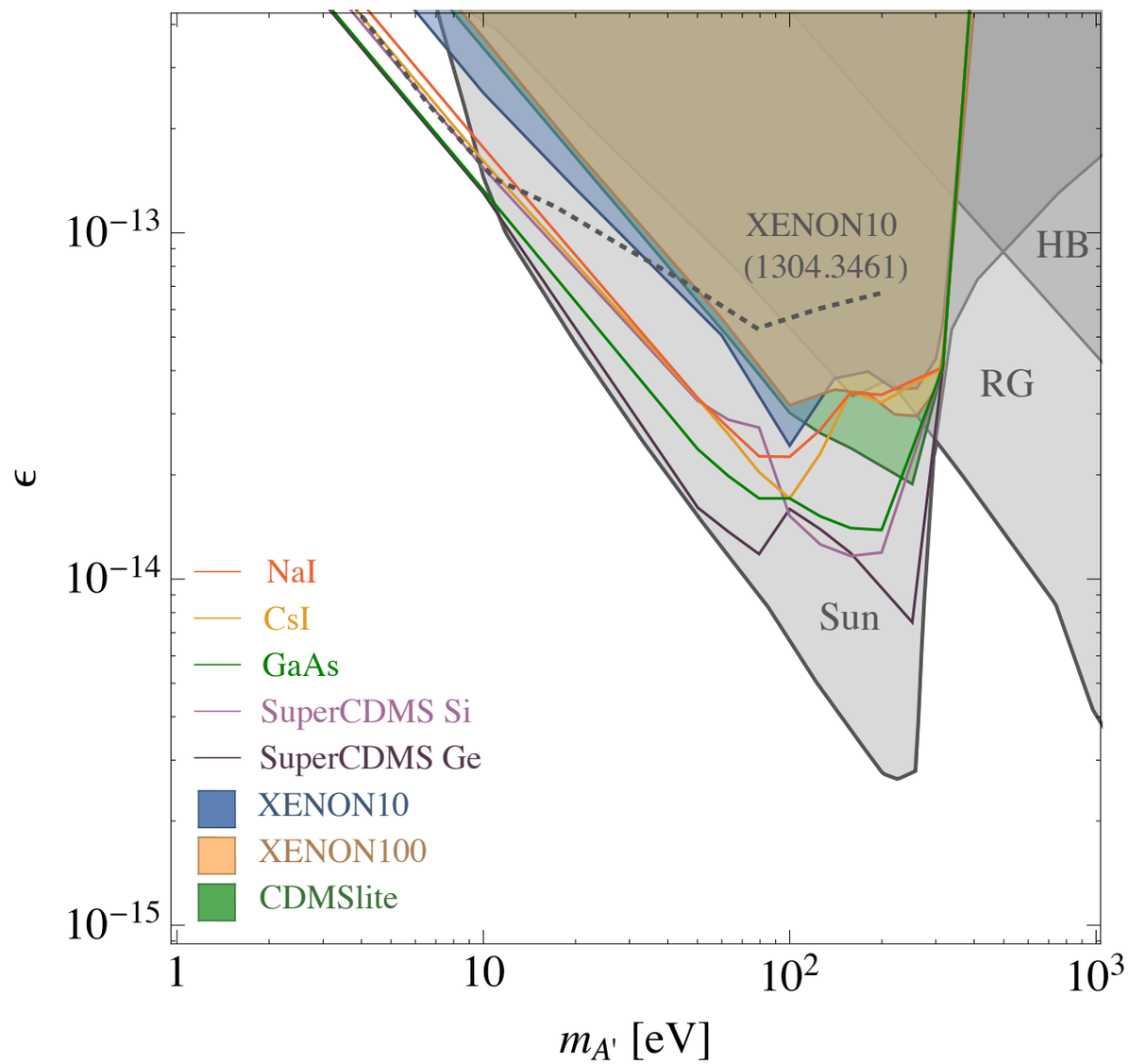


Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]

See also:
An, Pospelov, Pradler, Ritz [1401.8287]
An, Pospelov, Pradler [1309.6599]
Hochberg, Lin, Zurek [1604.06800,1608.01994]

absorption

solar dark photons



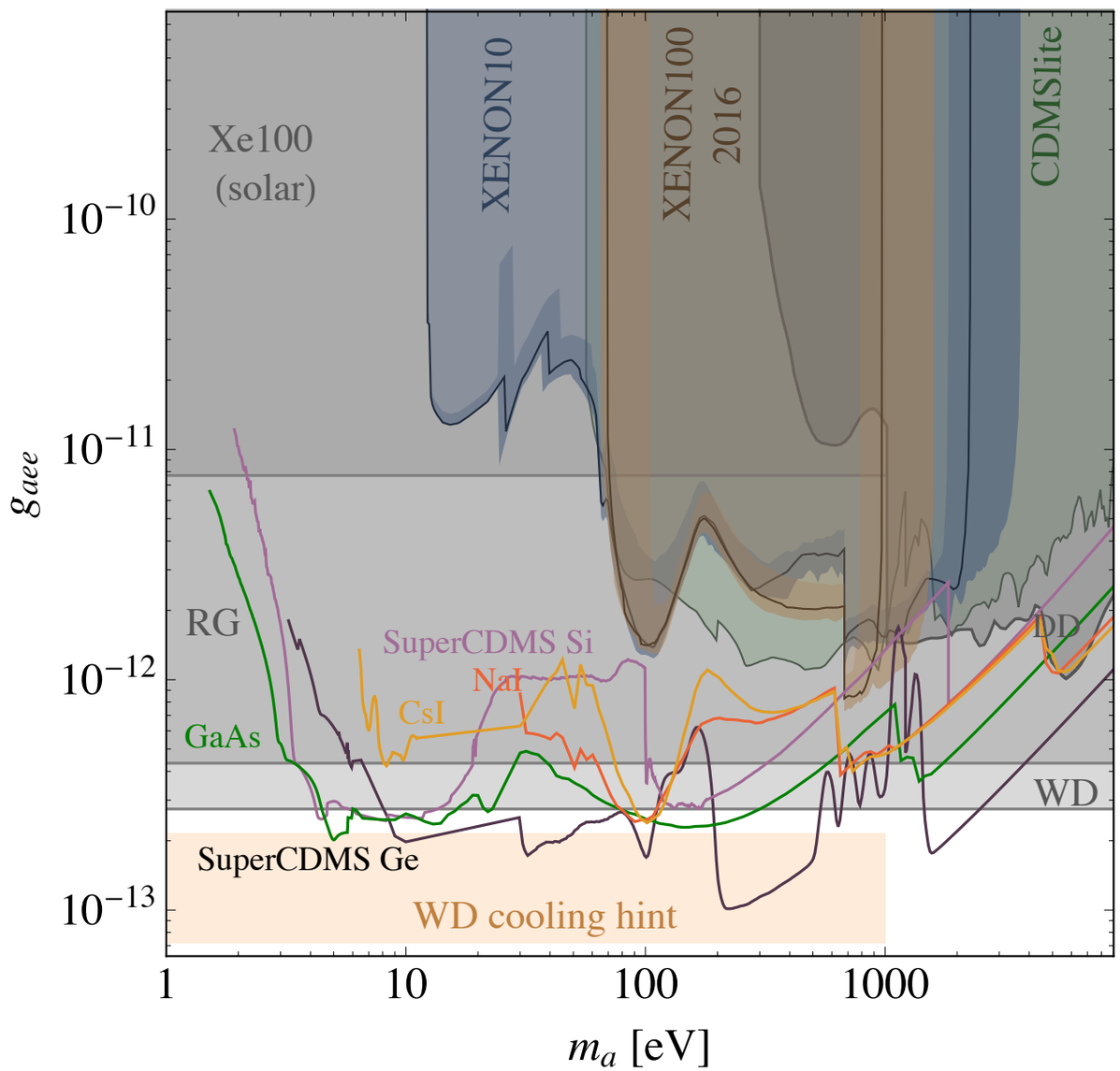
Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]

See also
An, Pospelov, Pradler [1304.3461]

absorption

See also Jaeckel, Raffelt, Redondo…

axions



Bloch, Essig, Tobioka, Volansky, TTY [1608.02123]