

# WG 1:

## New avenues in direct detection

Conveners:

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Thank you to all WG participants for excellent contributions!

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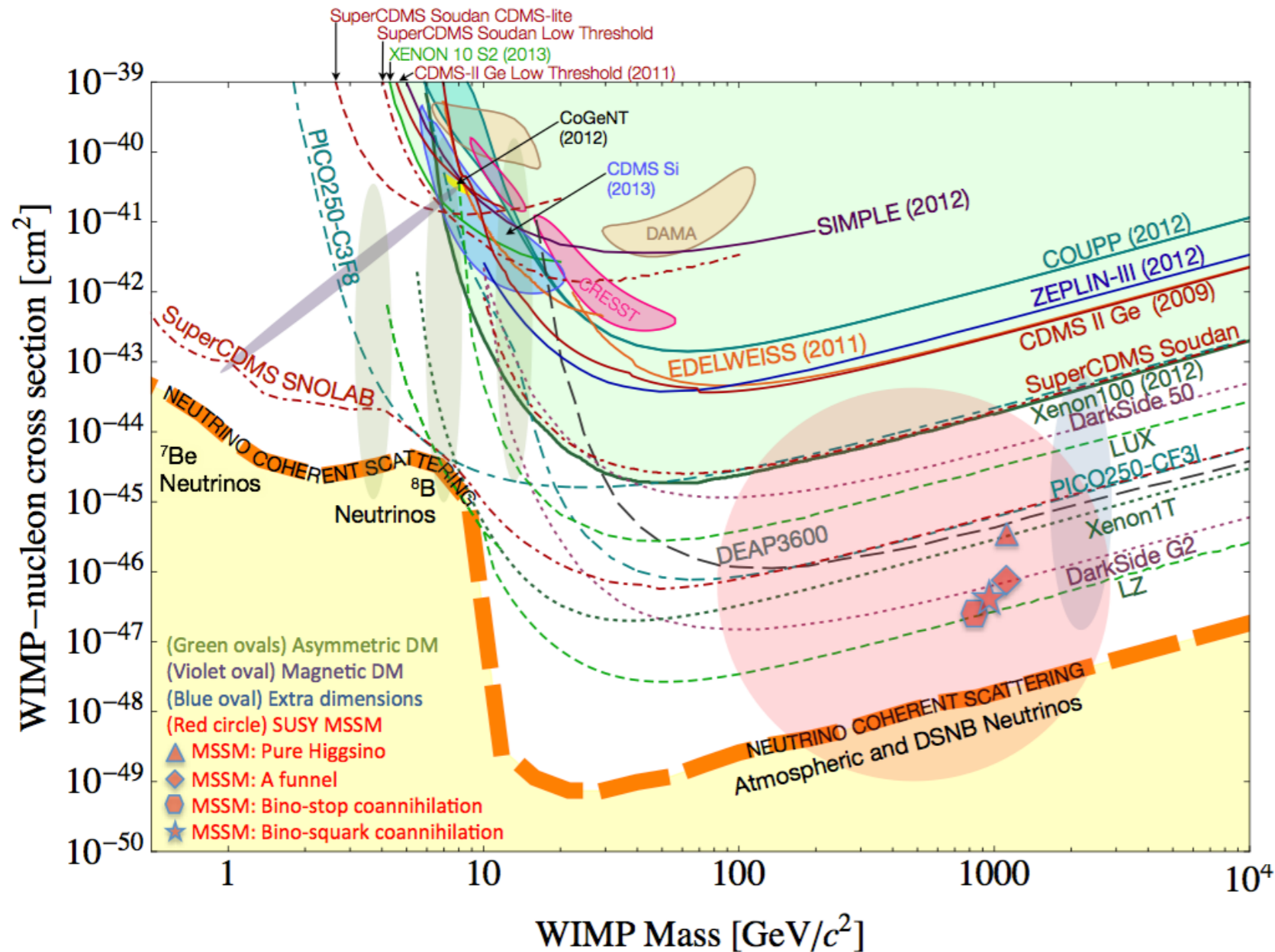
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- Several small projects < few \$million can probe orders of magnitude of new parameter space for WIMPs and sub-GeV DM to  $O(\text{MeV})$  masses, with project start-dates of FY19
- R&D funding in parallel allows projects to push < MeV & to lower cross-sections in a few-year time-scale

# Direct Detection Landscape



1310.8327

G2 WIMP  
experiments

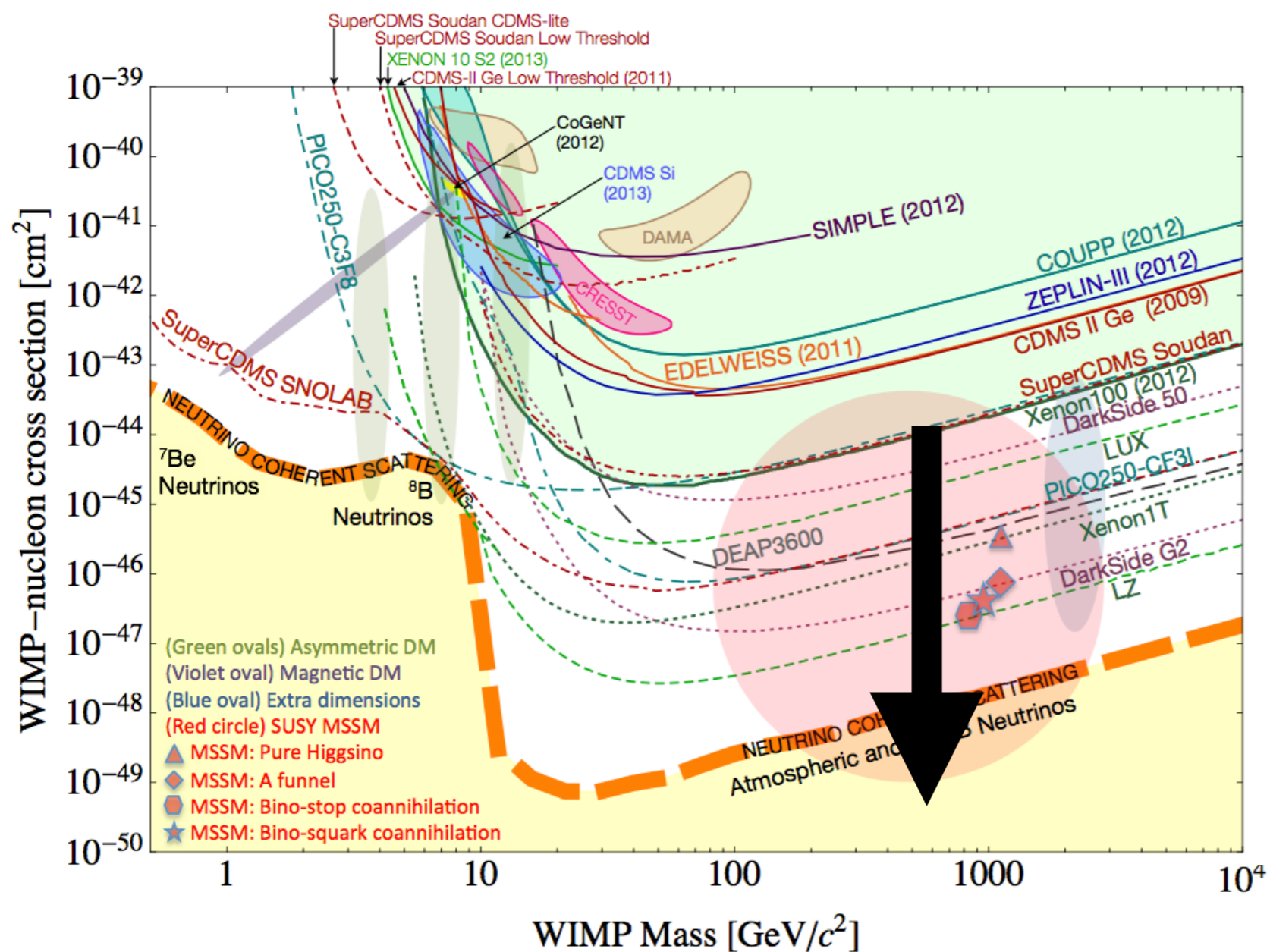
- LZ
- SuperCDMS

(won't consider potential successors, which have different time & budget scales)

The WIMP program is active, important, and exciting!



# Beyond G2: go very big



push to & beyond  
 $\nu$  “floor” for large  
 masses

## Motivation:

- WIMPs
- $\nu$  astrophysics

## Requires:

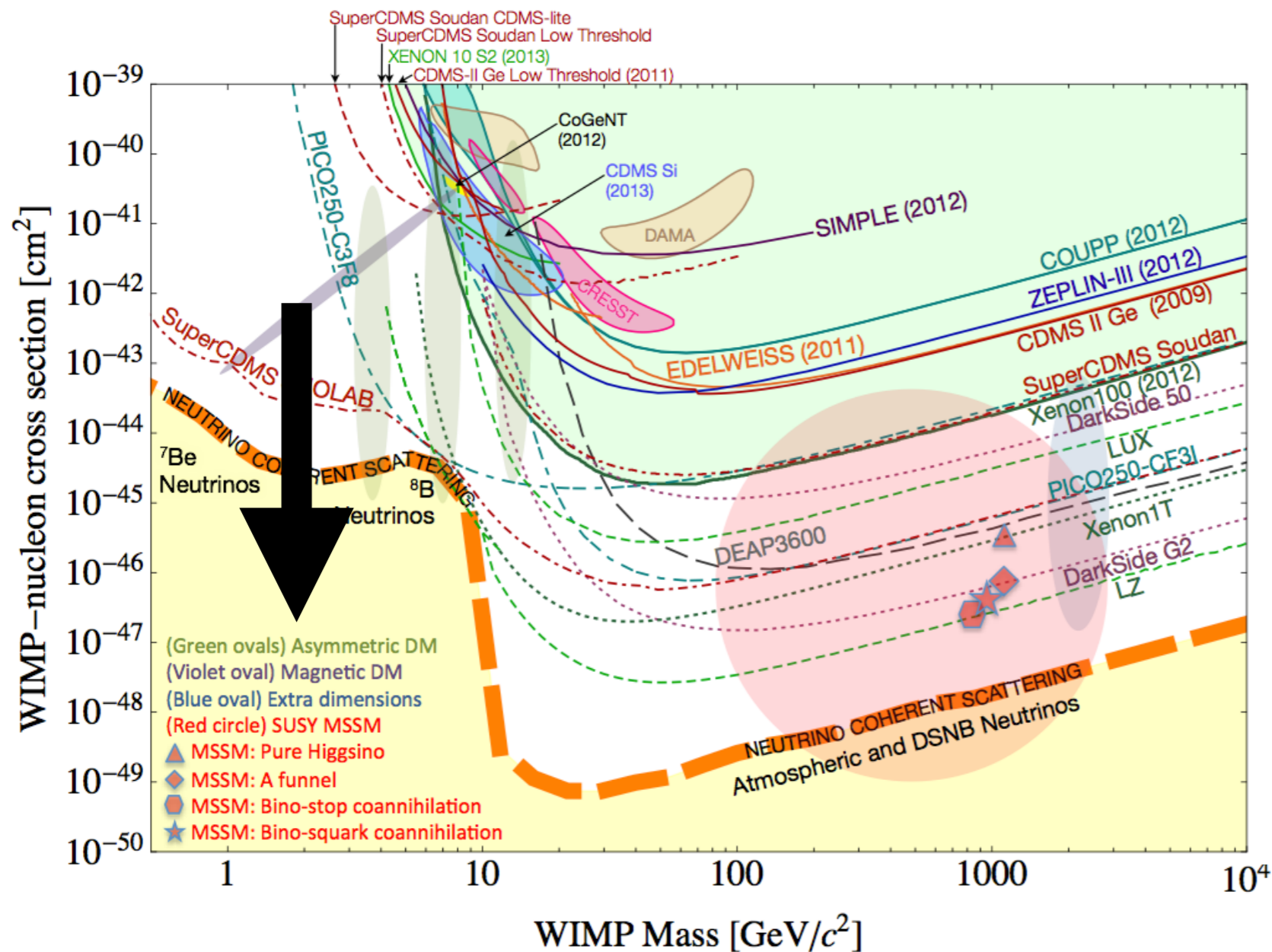
- very large targets (LXe, LAr)
- directionality to go beyond  $\nu$  floor (NEWSdm) A. Di Crescenzo
- further R&D to scale

1310.8327

>\$10 million

# Beyond G2: go big, lower threshold

push to & beyond  
 $\nu$  "floor" at 0.3 to  
 few GeV



## Motivation:

- WIMPs
- Asymmetric DM
- $\nu$  astrophysics

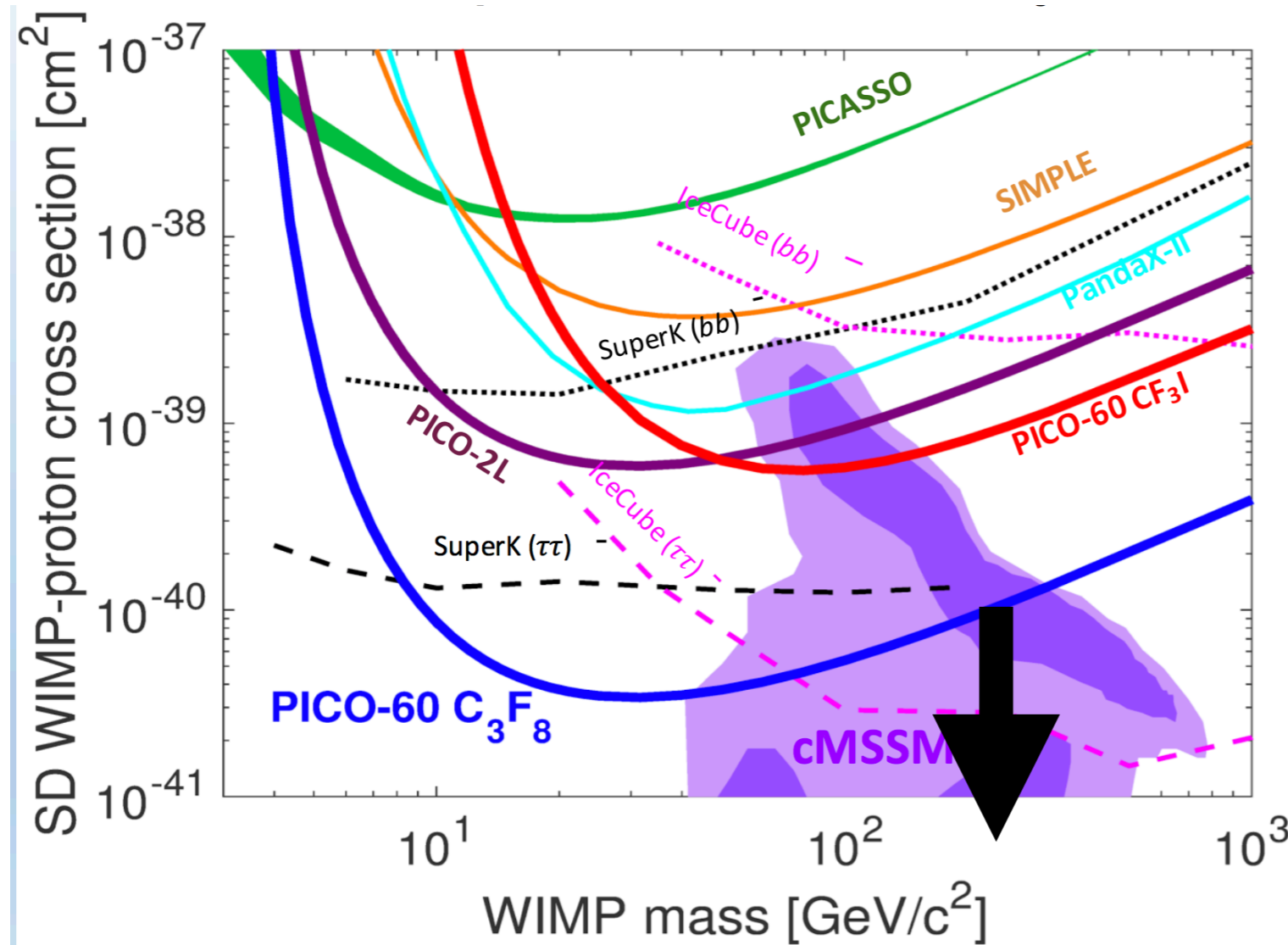
## Requires:

- large targets
- directionality or annual modulation to go beyond  $\nu$  floor

1310.8327

<\$10 million

# Beyond G2: Spin-dependent, WIMP



probe SD (proton) well below current constraints (LZ will do SD (neutron))

Motivation:

- WIMPs

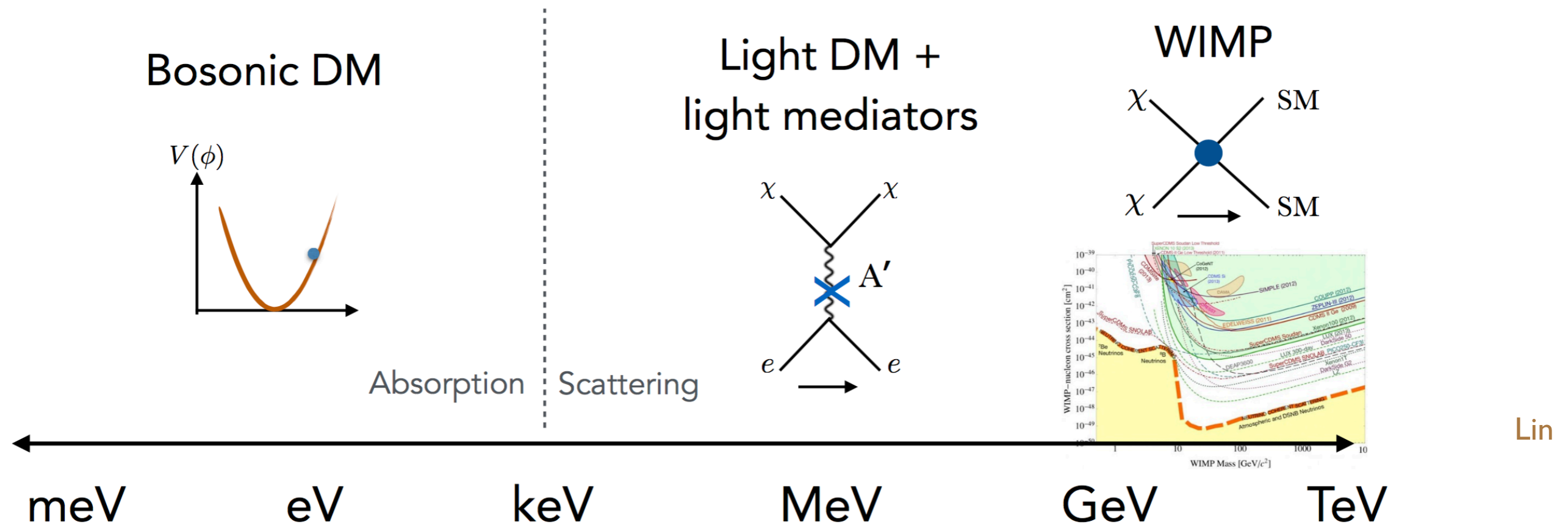
Requires:

- larger targets w/ SD sensitivity (e.g. fluorine)

see talk by Sonnenschein

~few \$million

# Beyond G2: go to (much) lower masses



## Motivation:

- Various Dark-sector models  
(thermal, asymmetric, freeze-in, SIMP, ELDER...)

## Requires:

- low thresholds
- control of radioactive backgrounds
- control of dark counts & instrumental backgrounds

~\$0.5–3 million

# Science Targets and Experiments beyond G2

## O(GeV) WIMPs

- DAMIC
- NEWS-G
- CYGNUS
- Scintillating bubble chambers

## Spin-dependent (proton)

- PICO

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## sub-GeV DM: ER

- SENSEI
- xenon charge-only
- graphene (PTOLEMY G3)
- Doped Ge w/ internal amplification
- Scintillators (GaAs, NaI)
- Superconductors

## sub-GeV DM: NR

- Superfluid He w/ TES
- Superfluid He field ionization
- Color centers

(not exhaustive list)

# Creating a table...

<b>Experiment</b>	<b>target material</b>	<b>readout</b>	<b>science</b>	<b>budget</b>	<b>timescale</b>

EXP	target material	readout	science	budget	timescale
scintillating bubble chambers	Xe, Ar, C <sub>6</sub> F <sub>6</sub> , H <sub>2</sub> O	light heat (bubble)	GeV WIMPS	\$200K	10 kg Xenon 2 yr program to test with coherent scattering CENNS
CYGNUS HD-10	SF <sub>6</sub> 4He	charge cloud tomography, directional sensitivity	GeV WIMPS	R&D \$250k 1 m <sup>3</sup> ~ \$450k 10 m <sup>3</sup> ~ \$3M	R&D 1 yr 1 m <sup>3</sup> : 2yr 10 m <sup>3</sup> : 2yr
DAMIC	Si	charge	GeV WIMPS	\$3M	start 2019-2020 the construction R&D going now
news-G	H, He	charge	GeV WIMPS		installing 140 cm sphere at SNOLAB in 2018
liquid xenon TPC	Xe	charge only	sub-GeV DM - ER	\$3M	1 yr design 1 yr deploy 10kg @surf 1 yr commission and run
SENSEI	Si	charge	sub-GeV DM - ER	\$1.2M	2 yrs to build the 100g experiment starting (could start now)
Doped germanium with internal amplification	Ge semiconductor	charge 0.1 eV (nuclear)	sub-GeV DM - ER	R&D 600k 10 kg → 1.5M 100kg → 10M	R&D +3yr
2d graphere Ptolomey-G3	graphene cube	charge(G-FET) (300 B channel count @ 1 kHz	sub-GeV DM - ER	\$200k needed for wafer fab for demonstrator (1e4 cm <sup>2</sup> )	1 yr fab 1 yr data ready for the "generation 1"
single photon detector with TES readout	GaAs(Si)	light	sub-GeV DM - ER	R&D 200k project 600k	R&D 1eV thr the project would on on SuperCDMS 2020
NaI/ScI cooled crystals	NaI/ScI	light	sub-GeV DM - ER	R&D - \$250k projecy \$100k	R&D - 3 yr project 2020 w/TES
superconducting AL cube	Al superconductor	TES meV energy resolution.	sub-GeV DM - ER		+10 yr science program
LHe detector	He	phonon	sub-GeV DM - NR	3M	2018 R&D 2020 final design 2022 start data taking
field ionization helium	He	phonon	sub-GeV DM - NR	R&D \$725k	R&D 3 years
color centers	crystals (example: CaF)	light	sub-GeV DM - NR		R&D going on now
bubble chambers PICO	wide range of target nuclei. This is what makes then unique.	heat (bubbles)	spin dependent	lowest cost per ton of any target mass pico-500 - ~\$3M	just finished pico-60 pico40L in Fy17 (funded) pico 500 coming
emulsions (news-dm)	high position resolutions nuclear emulsions (silver bromide crystals + I C O N H S)	imaging with optical microscopes, and validation of candidates with X-ray microscope	beat neutrino floor	—	R&D phase complete. Technical test to confirm negligible background running now.

# Future: O(GeV) WIMPs (beyond G2)

## DAMIC

- Si CCD
- ~1 kg
- detect  $e^-$

P. Privitera

## NEWS-G

- Gas spheres (Ne, He, H)
- ~30 kg
- Charge amplification

G. Gerbier

## CYGNUS

- Directional gas TPC ( $SF_6/He$ )
- probe below  $\nu$  floor

S. Vahsen

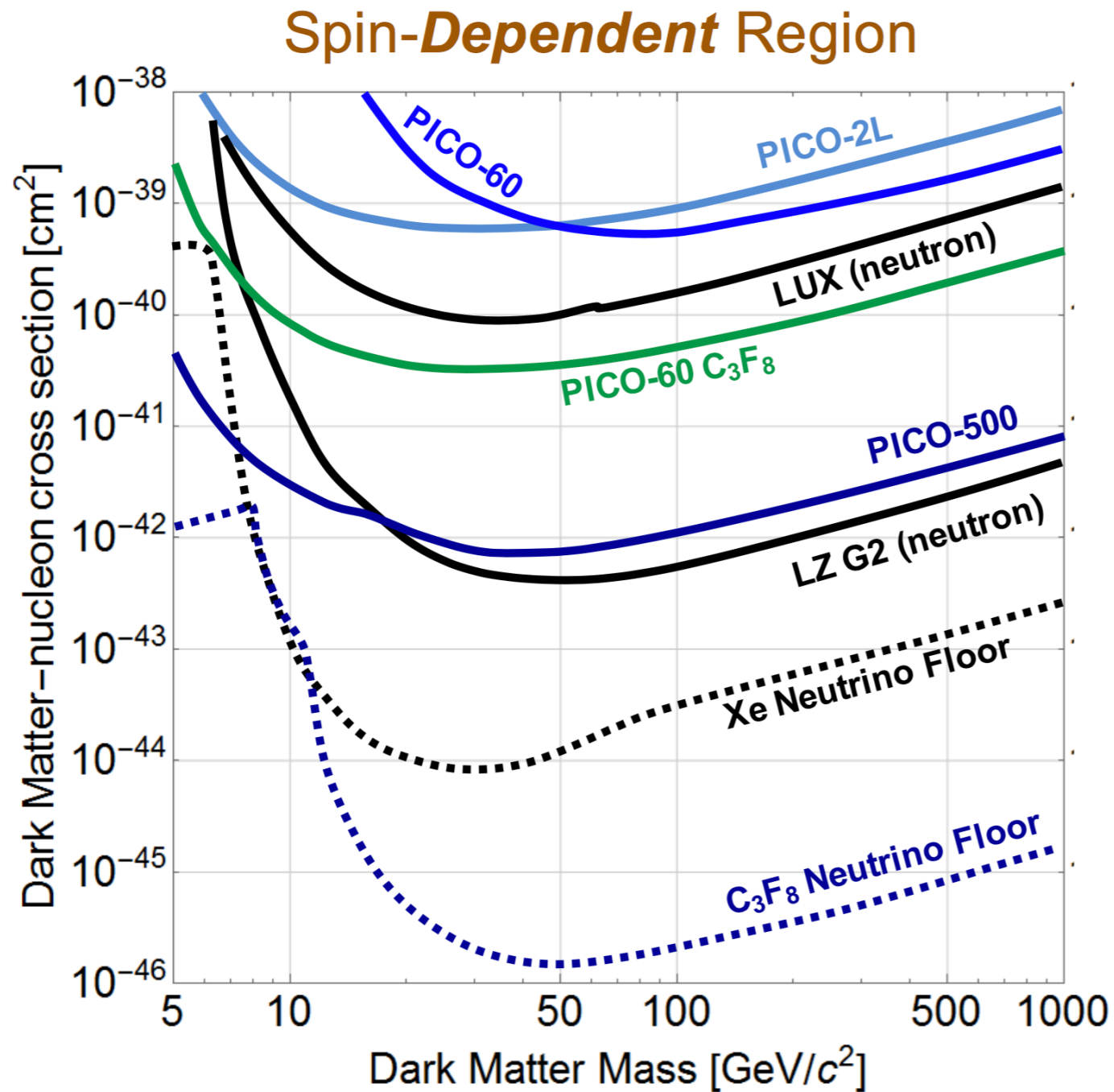
## Scintillating bubble chambers

- LXe, LAr, water, ...
- enhanced background rejection

E. Dahl, M. Szydagis

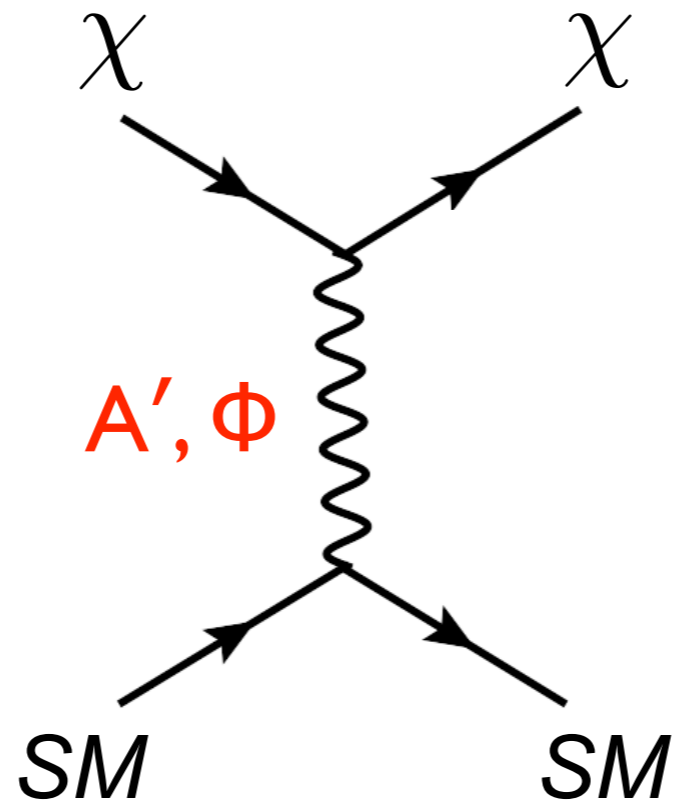


# Future: Spin-dependent



PICO  
 $\text{C}_3\text{F}_8$  bubble chamber  
500 kg  
~\$3 million

# Future: sub-GeV DM



# sub-GeV DM

Distinguish two types of interactions, e.g.

$\sigma_e$  VS  $m_{\text{DM}}$

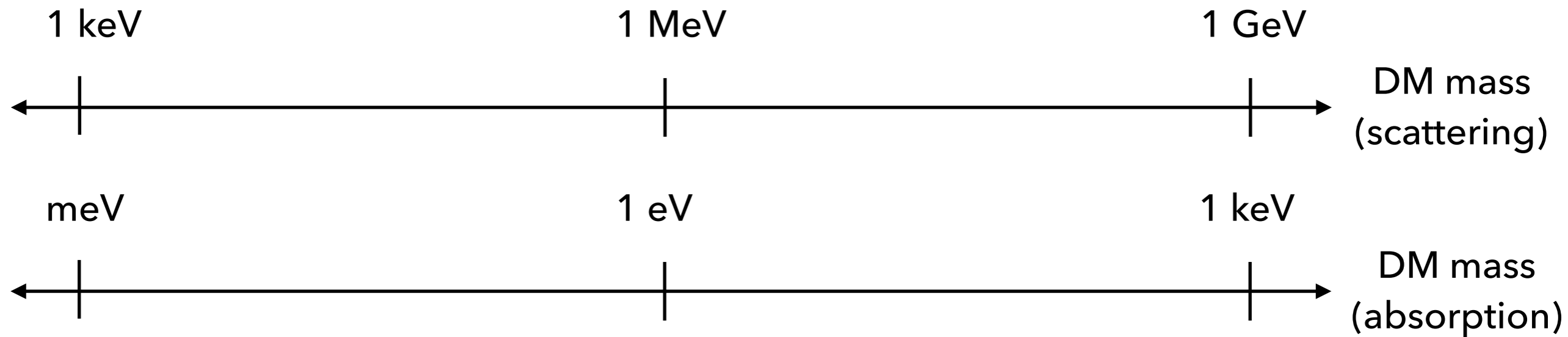
- dark photon mediator
- vector, coupling  
predominantly to leptons

$\sigma_N$  VS  $m_{\text{DM}}$

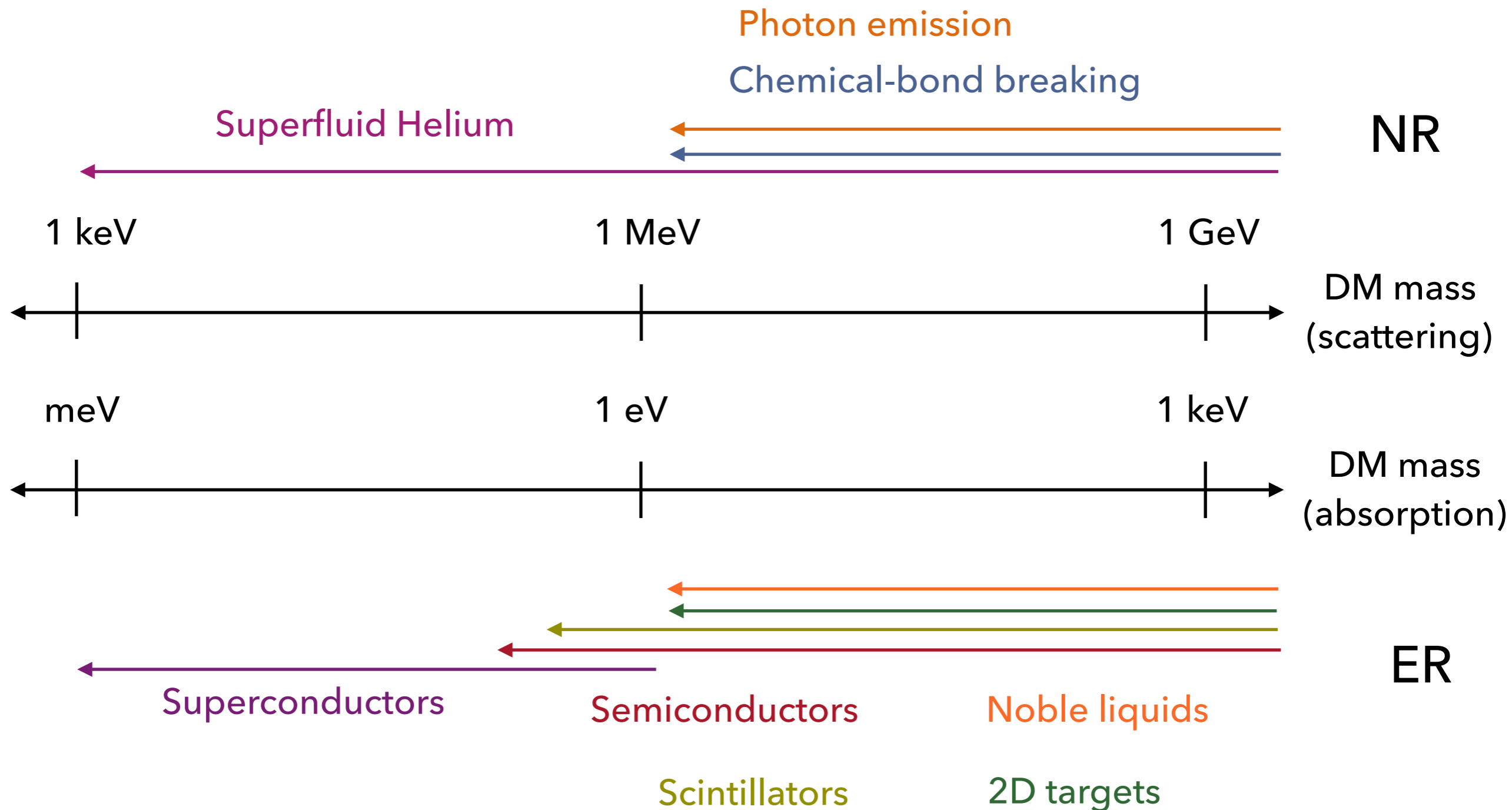
- dark photon mediator
- vector, coupling  
predominantly to quarks
- scalar

Important to test interactions separately

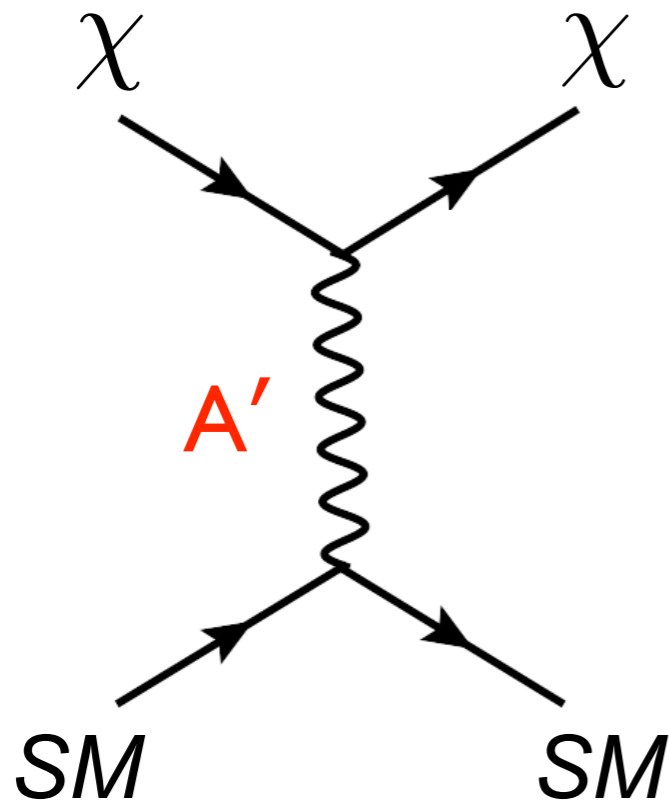
# Explosion of new ideas over last few years



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# DM scattering cross section behavior



- “heavy”  $A'$  ( $\sim m_{\text{DM}}$ )

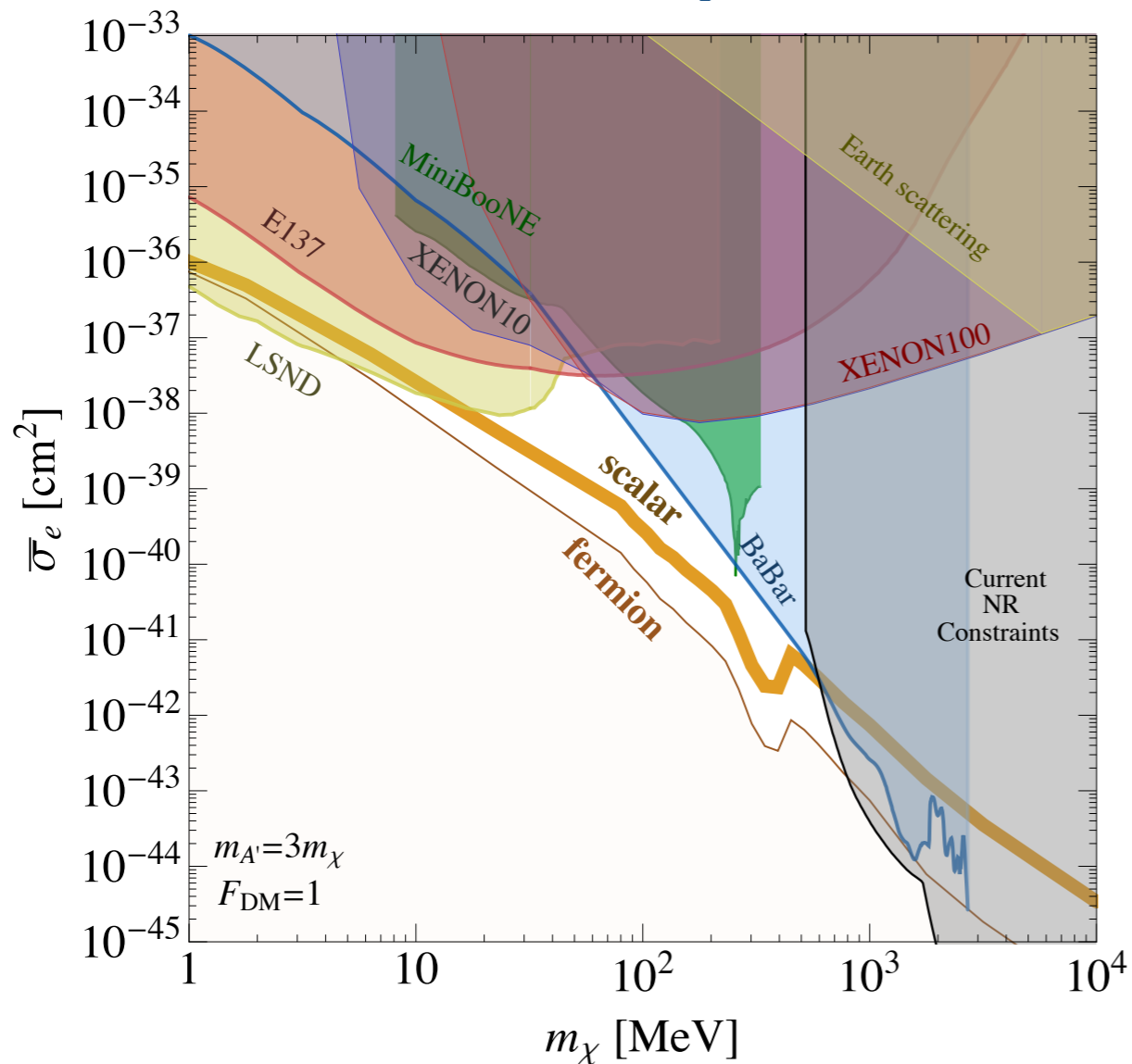
$$\bar{\sigma}_e \propto \frac{\epsilon^2 \alpha_D}{m_{A'}^4} \mu_{\chi e}^2$$

- ultra-light  $A'$  ( $\ll \text{keV}$ )

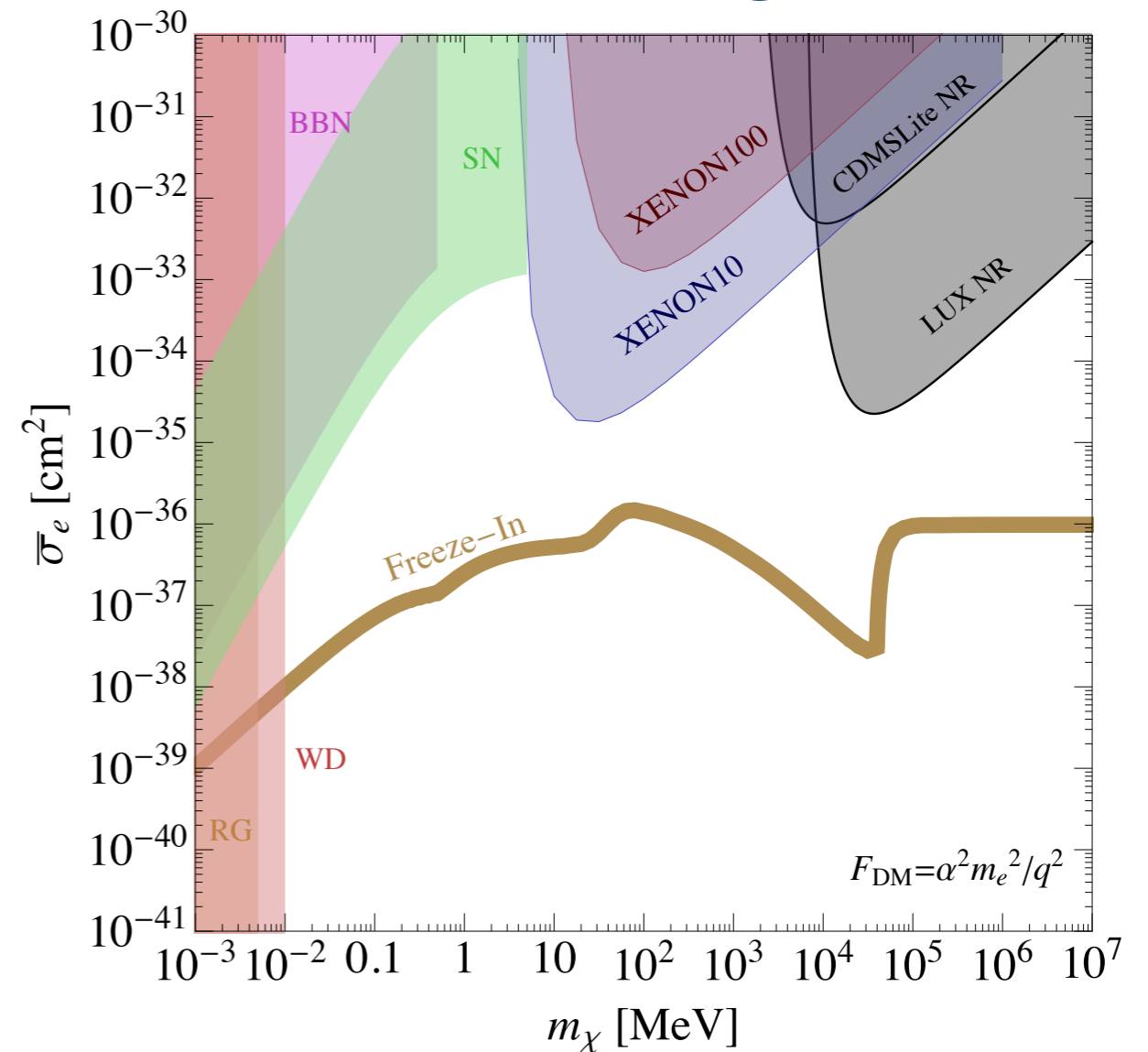
$$\sigma \propto \frac{16\pi \mu_{\chi e}^2 \alpha \alpha_D \epsilon^2}{q^4}$$

# Benchmarks: dark-photon mediators

“Heavy”



Ultralight

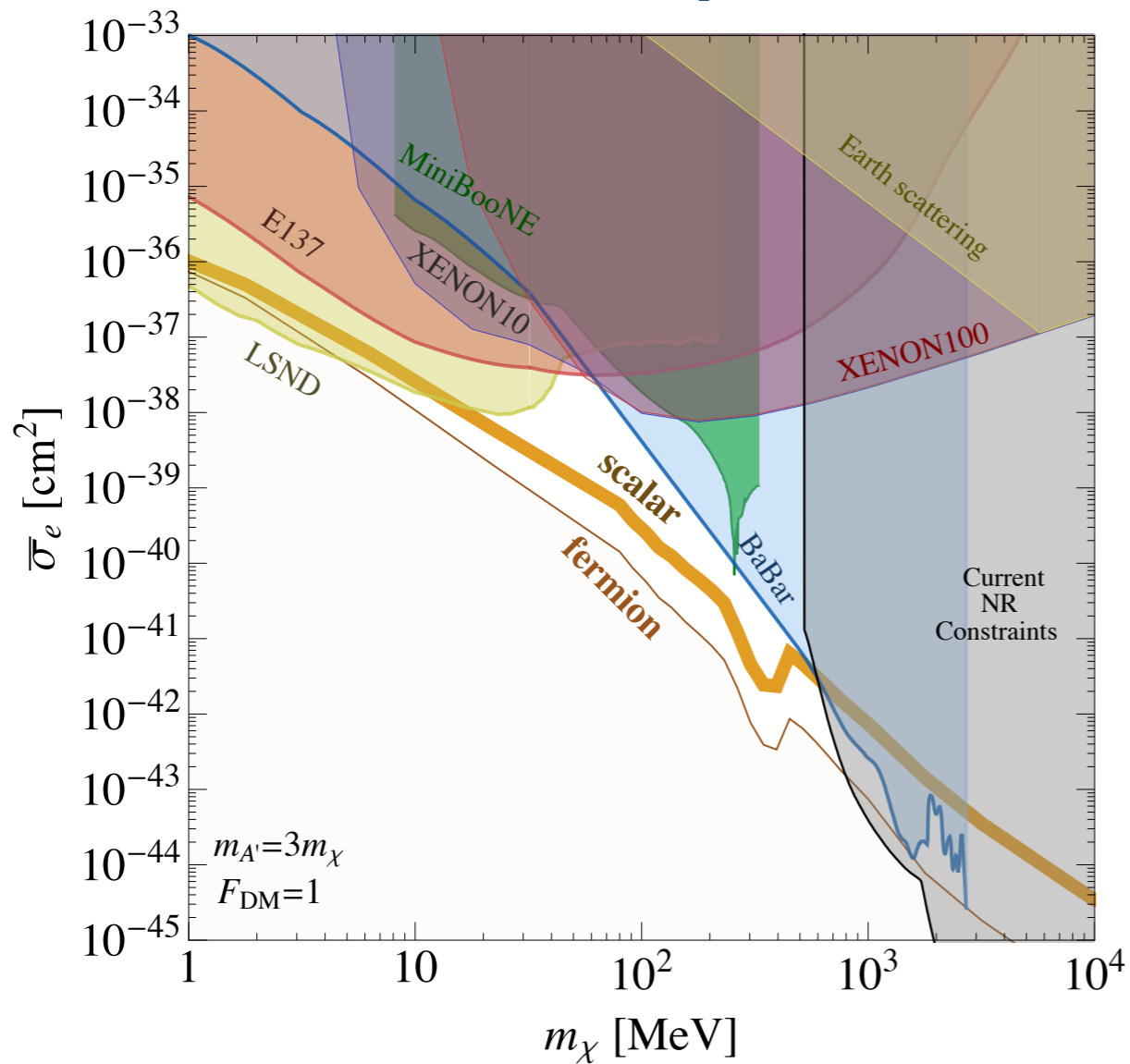


exciting complementarity  
with collider & beam-dump  
probes (for elastic scattering)

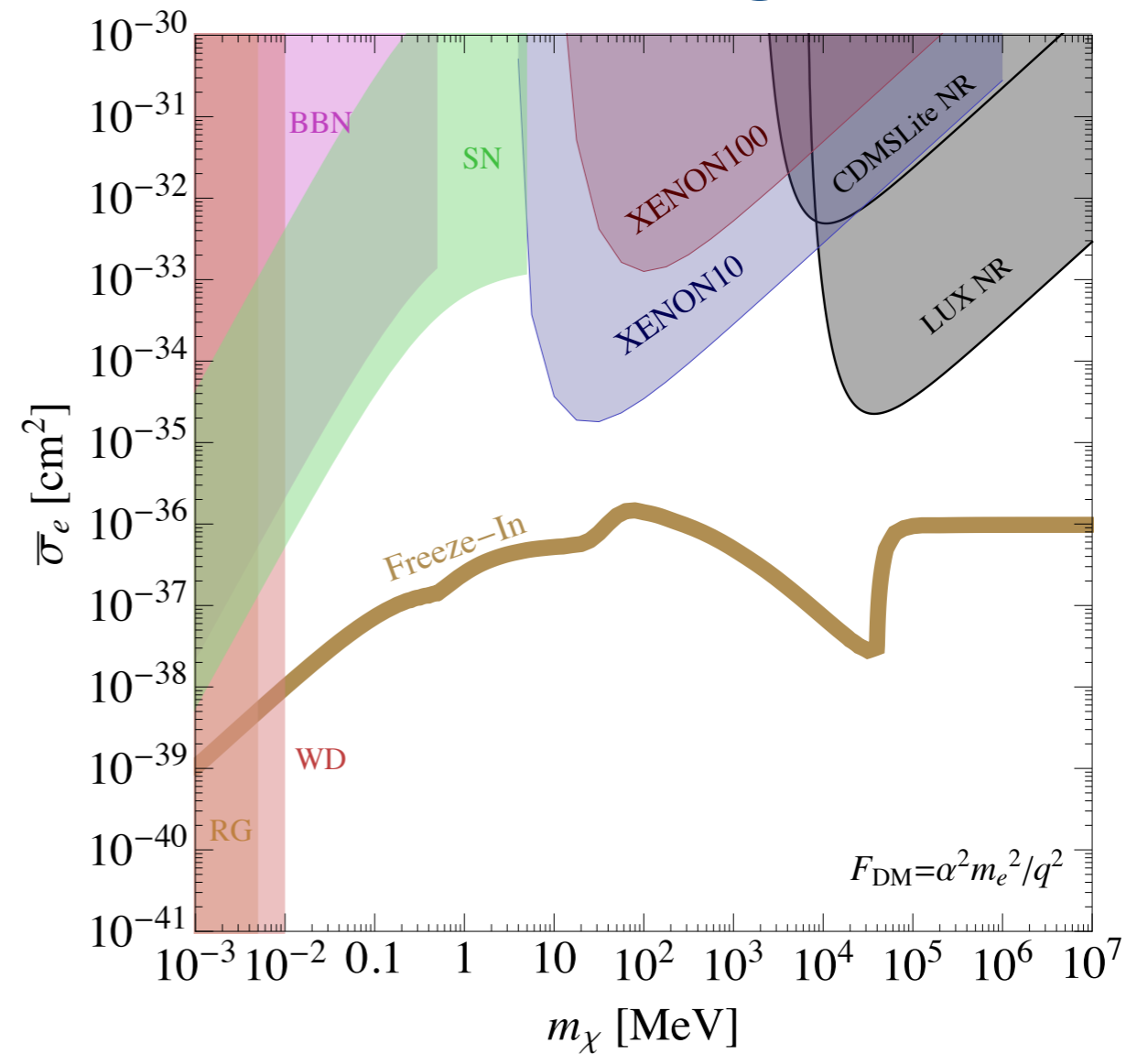
ultralight mediator scenario  
is uniquely probed by  
Direct Detection

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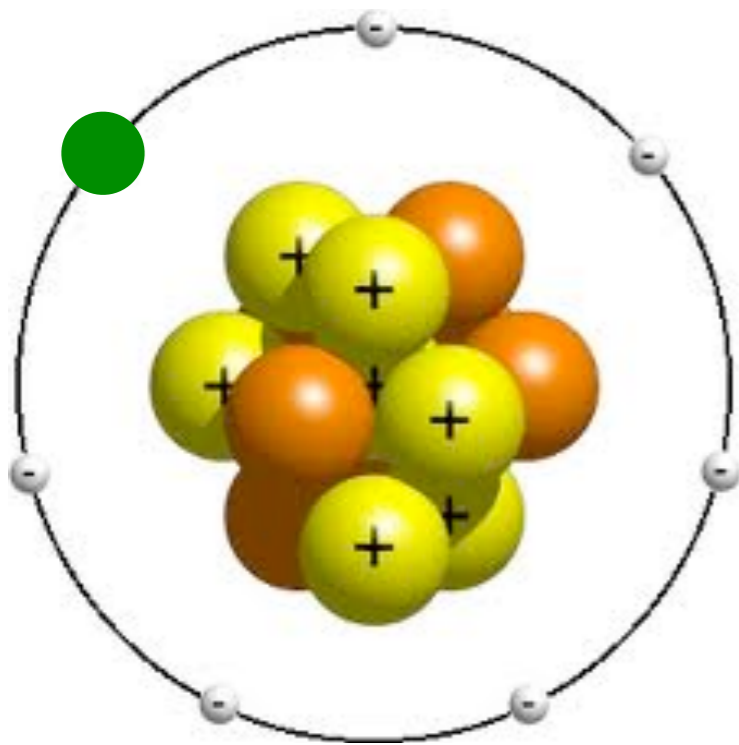
Ultralight



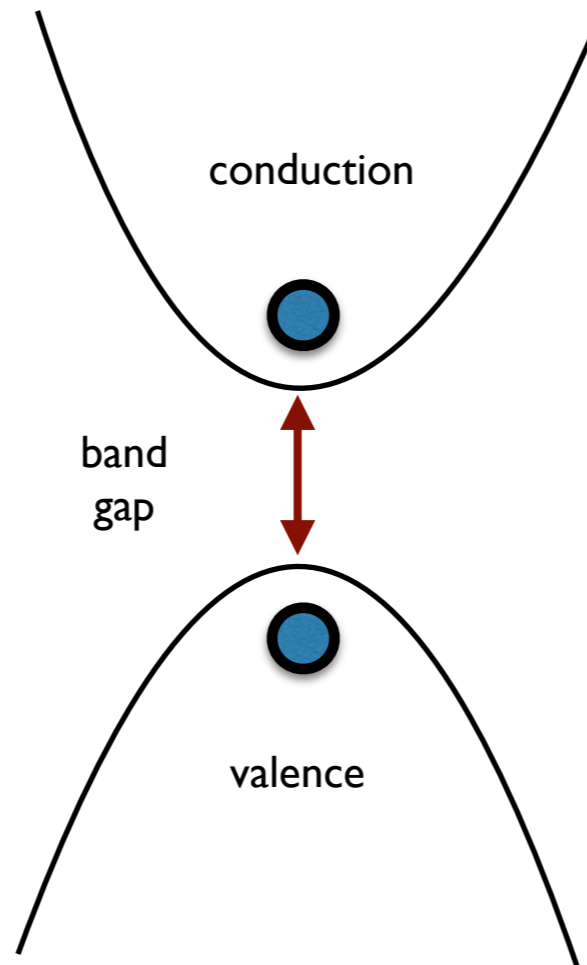
*important also to go well beyond these benchmarks!*



# Can probe w/ e.g. electron recoils



noble liquids



semiconductors,  
scintillators

too tired to find  
picture here

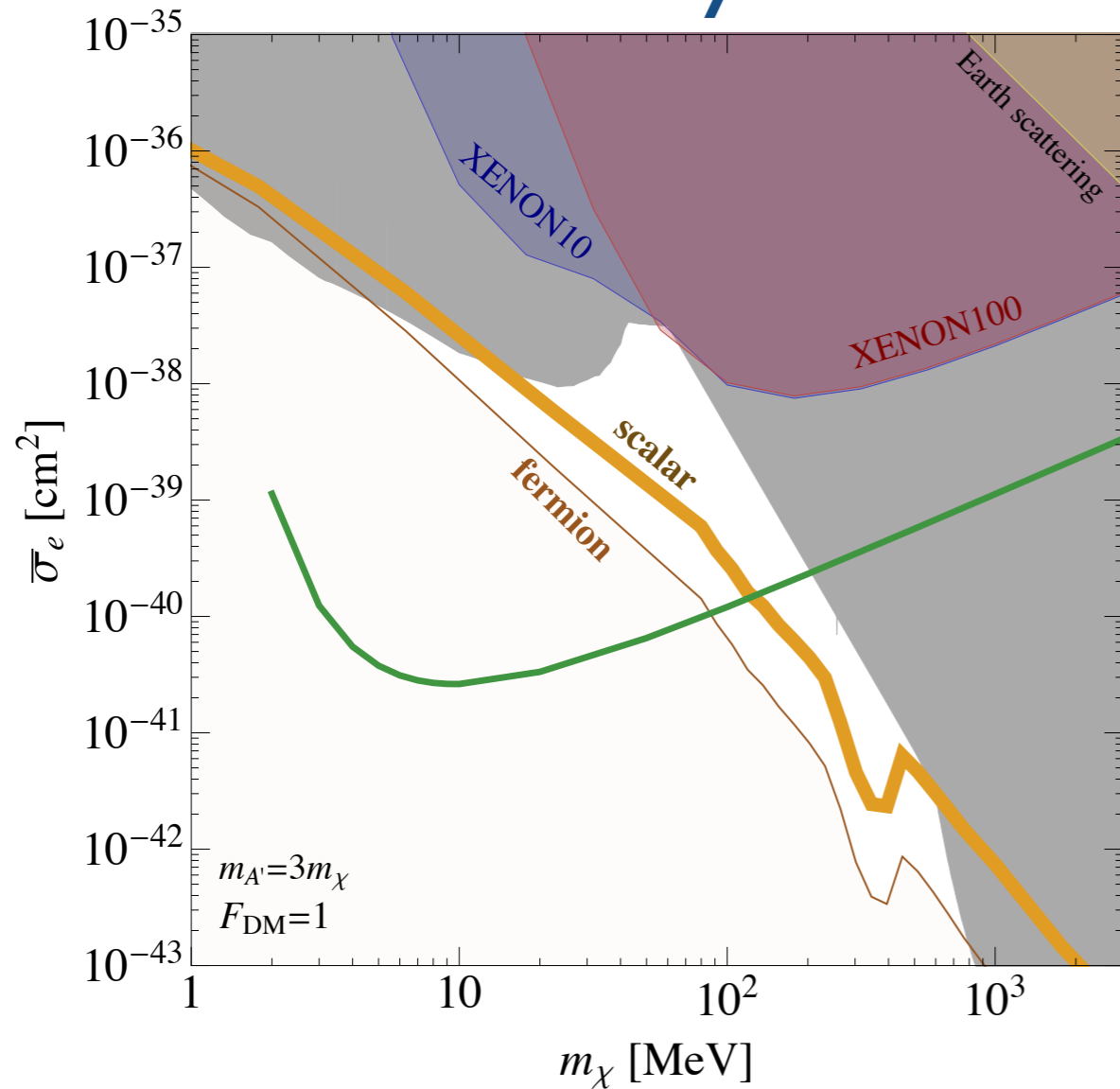
superconductors

# Backgrounds

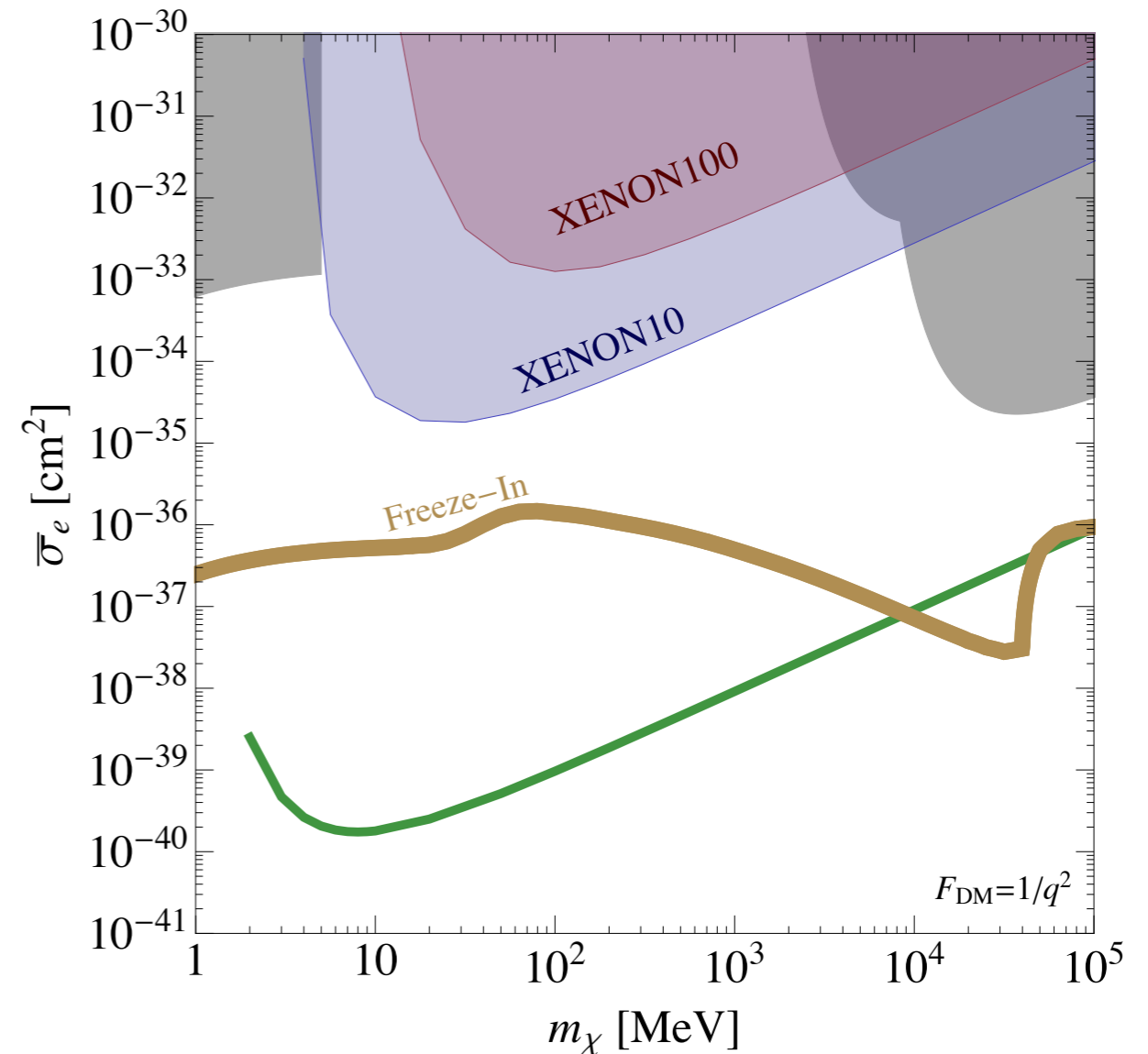
- Solar neutrino background is small
- Radiogenic backgrounds to few-eV electron recoil events likely  $< 1$  event/kg/year/eV  
(based on projections for measured values at  $O(50$  eV))
- For sub-GeV searches, critical backgrounds are:
  - dark counts
  - EM interference
  - vibrations

# Example Projections: dark photon mediator

“Heavy”



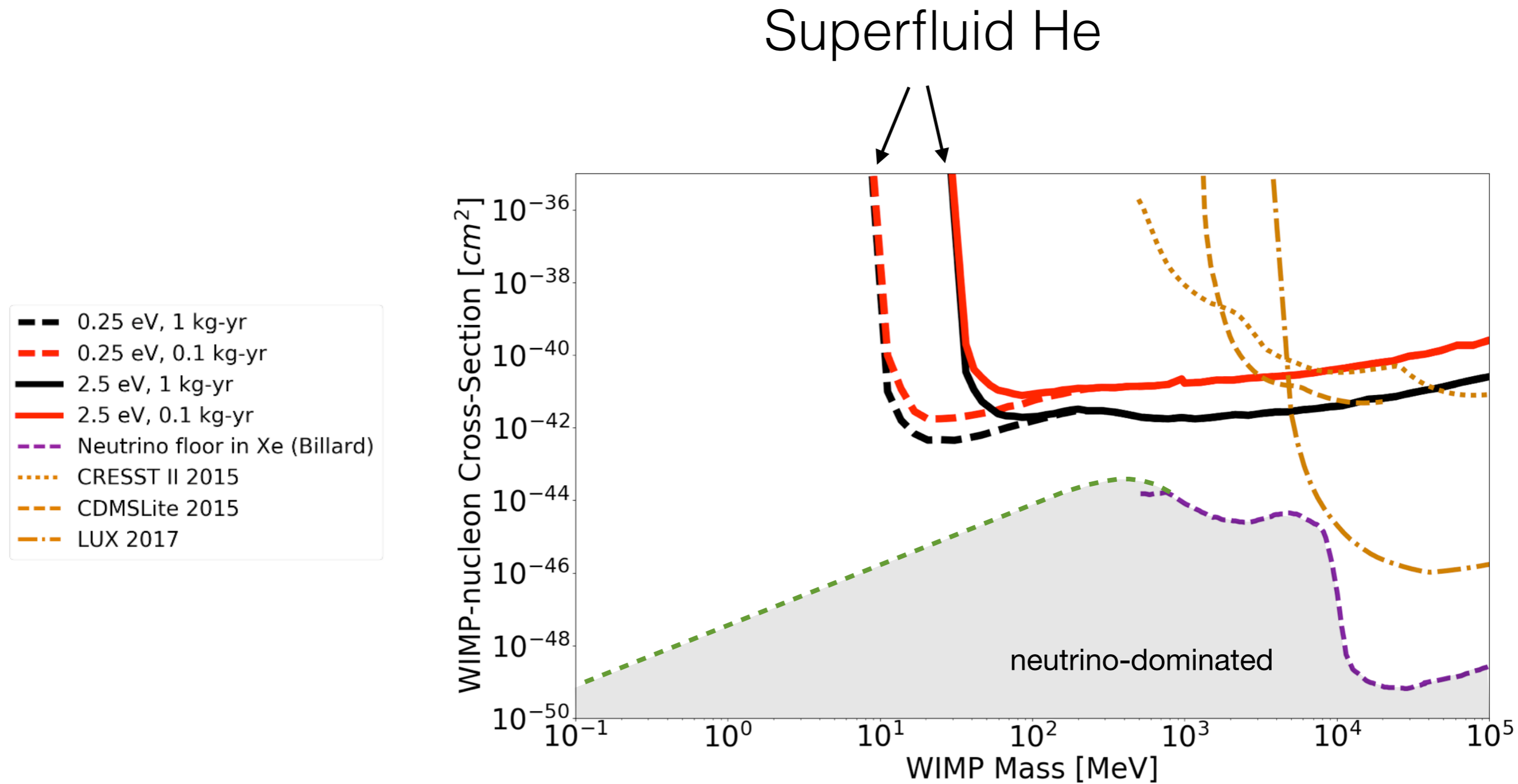
Ultralight



Si, 2e<sup>-</sup> threshold, 100 gr-year

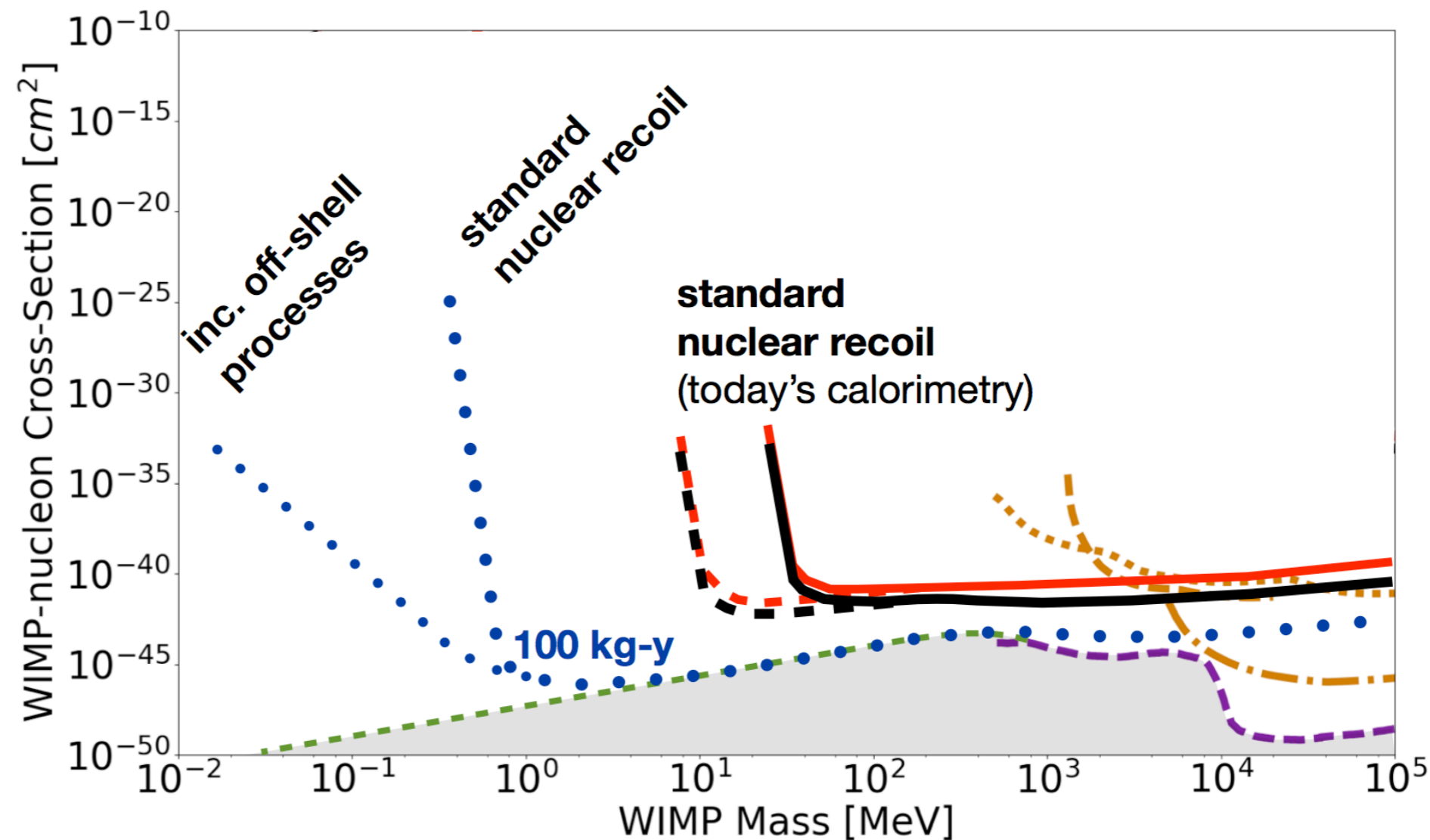
potential projects ready for FY19 (or earlier)

# Example Projections: NR



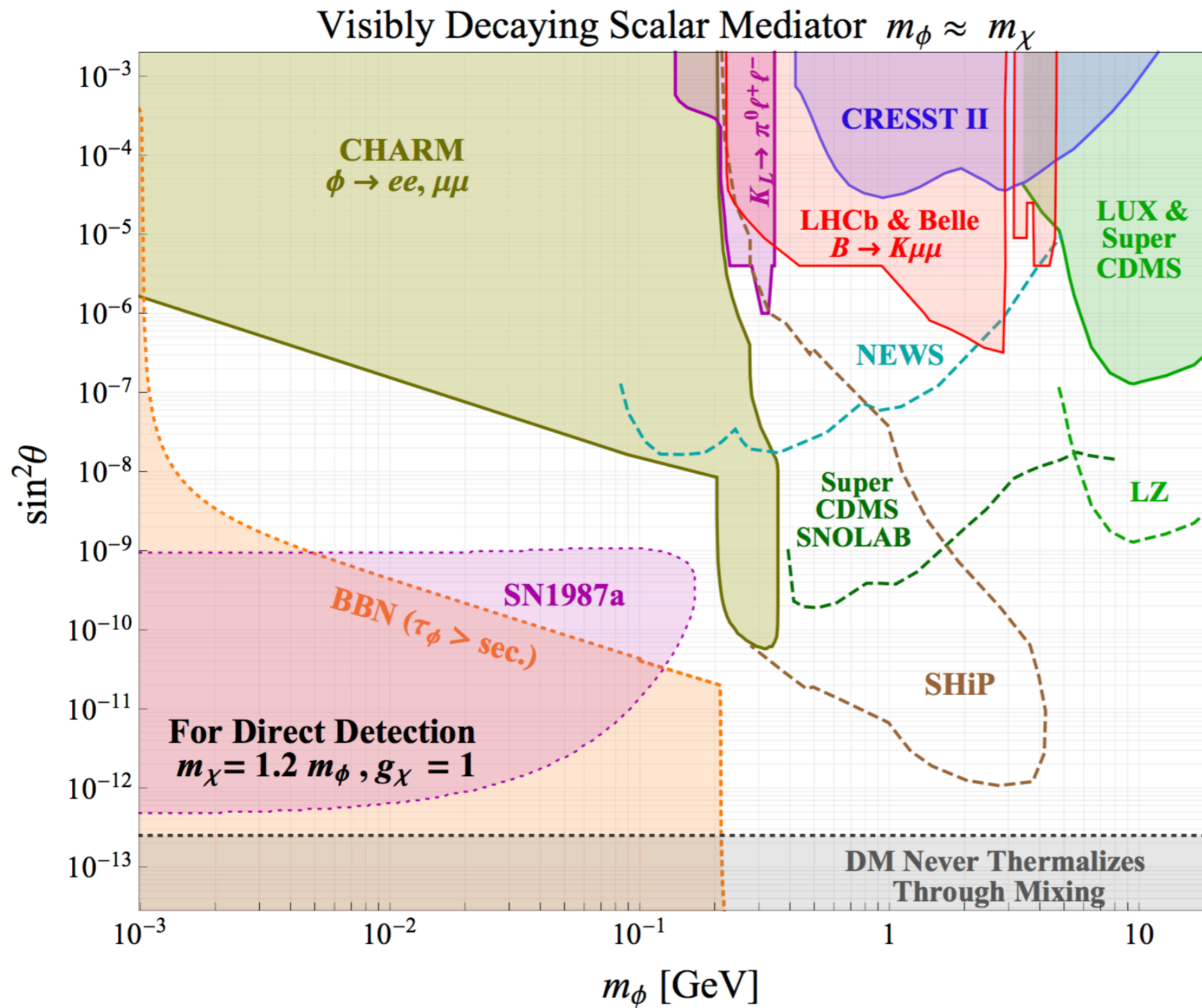
# Example Projections: NR

Superfluid He  
w/ ultra-low threshold



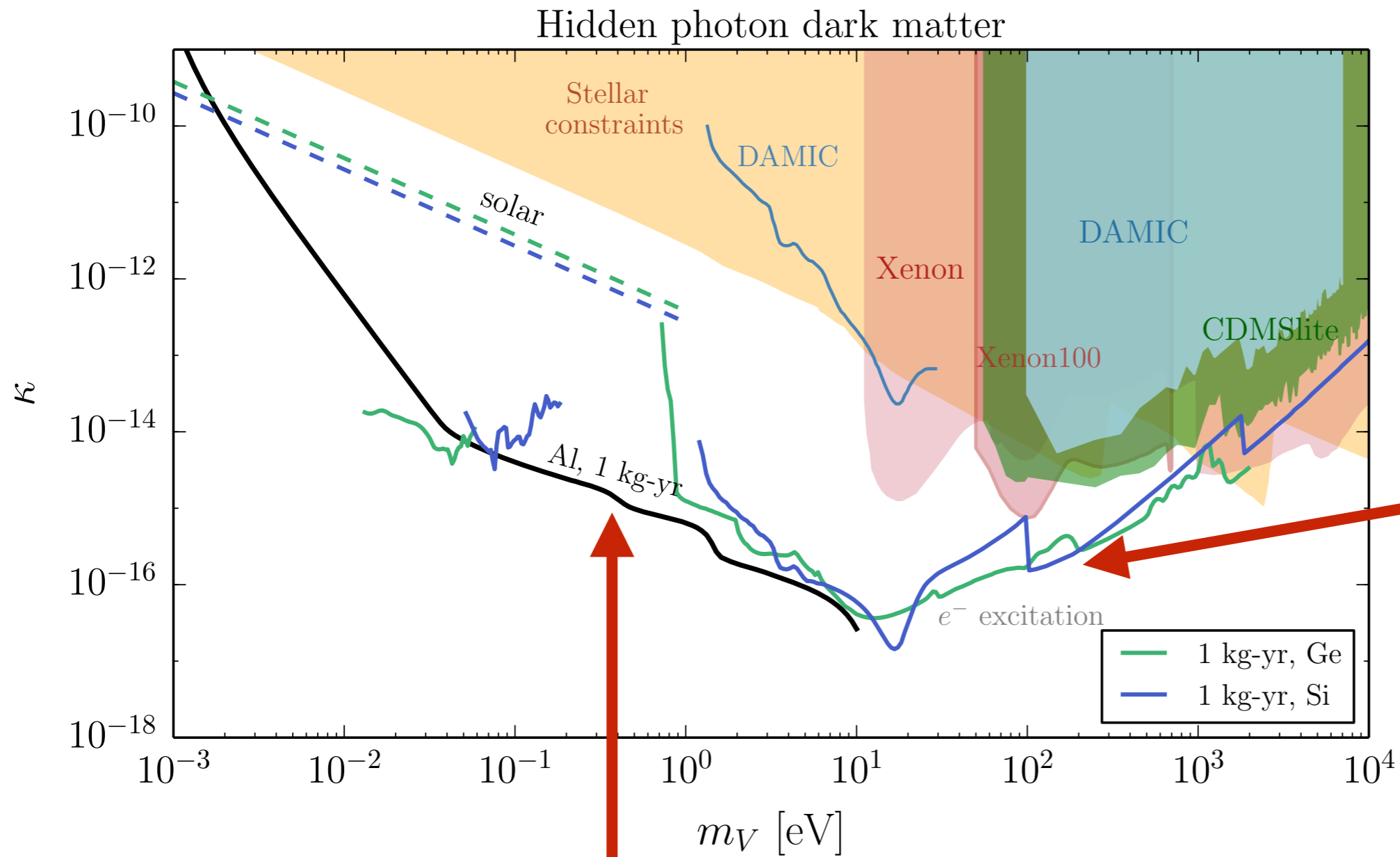
- 0.25 eV, 1 kg-yr
- 0.25 eV, 0.1 kg-yr
- 2.5 eV, 1 kg-yr
- 2.5 eV, 0.1 kg-yr
- Neutrino floor in Xe (Billard)
- CRESST II 2015
- CDMSLite 2015
- LUX 2017

# Scalar mediator



only some  
projections  
shown

# Absorption



Si or Ge  
detector  
potential  
projects ready  
for FY19

superconductor  
long-term R&D

# Facilities exist for calibration, testing, & science!

- **TUNL: calibration of low-energy nuclear recoils**  
Triangle Universities Nuclear Laboratory
- **NEXUS: prototyping and testing facility**  
Northwestern Experimental Underground Site at Fermilab
- **CUTE: testing and science facility**  
Cryogenic Underground Test Facility
- **SuperCDMS SNOLAB**  
space for a new experiment



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