Universiteit van Amsterdam

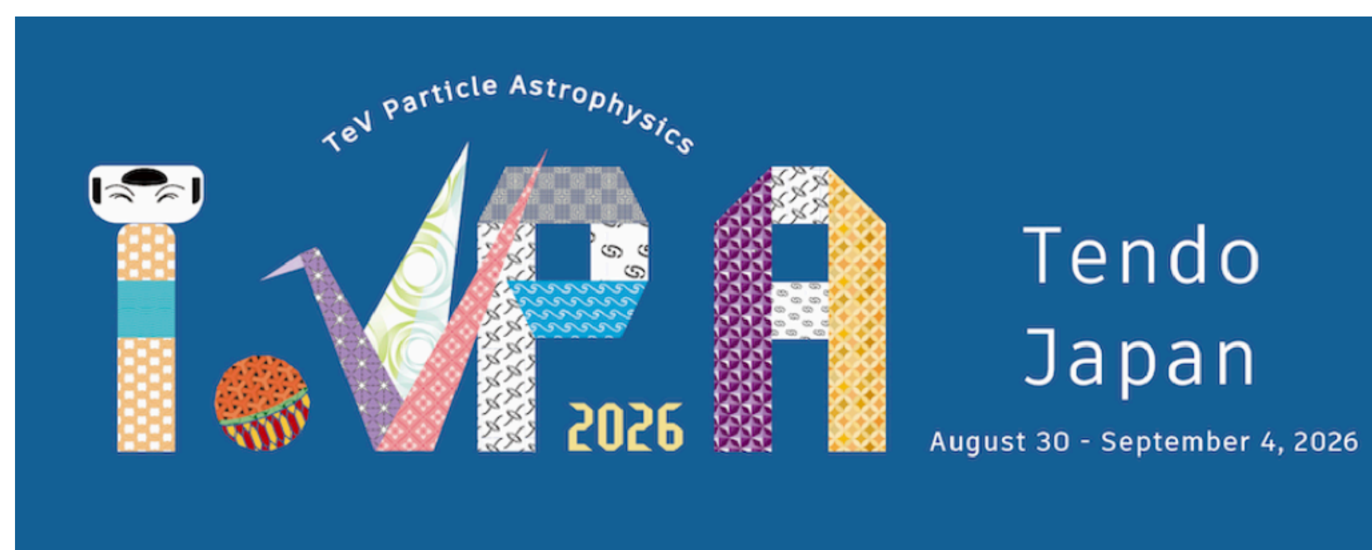
Nikhef

Direct dark matter detection - onward into the neutrino fog

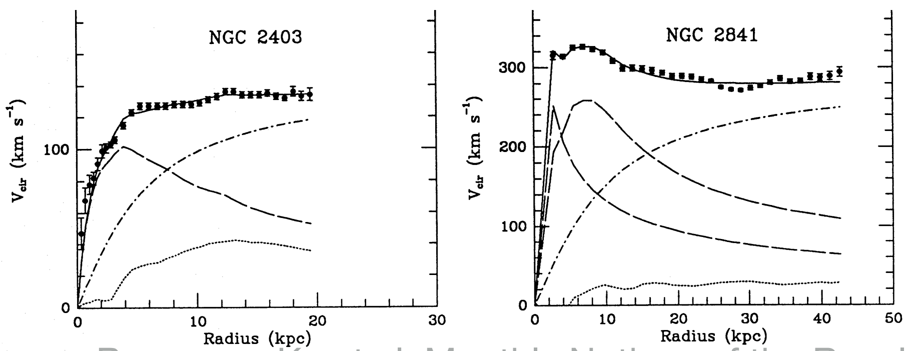
Tina Pollmann

TeVPA 2026

Tendo, Japan

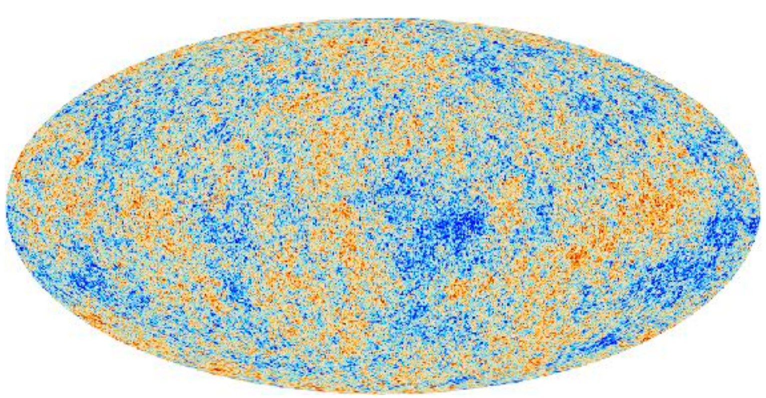


Evidence for missing matter in the universe, and in particular a missing particle, has been found at all astronomical scales.



Begeman, K., et al. Monthly Notices of the Royal Astronomical Society 249, 523–537 (1991).

NASA/CXC/CfA/M.Markevitch et al.; NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.; NASA/STScI; Magellan/U.Arizona/D.Clowe et al



© ESA and the Planck Collaboration

Galactic rotation curves

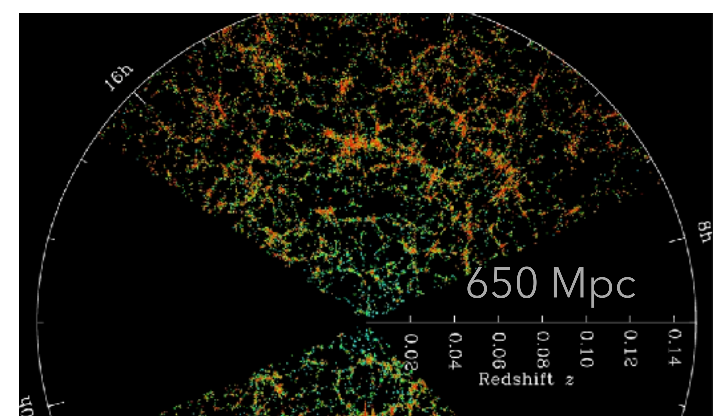
Velocity of galaxies in clusters

Lensing/microlensing

Structure formation in the universe

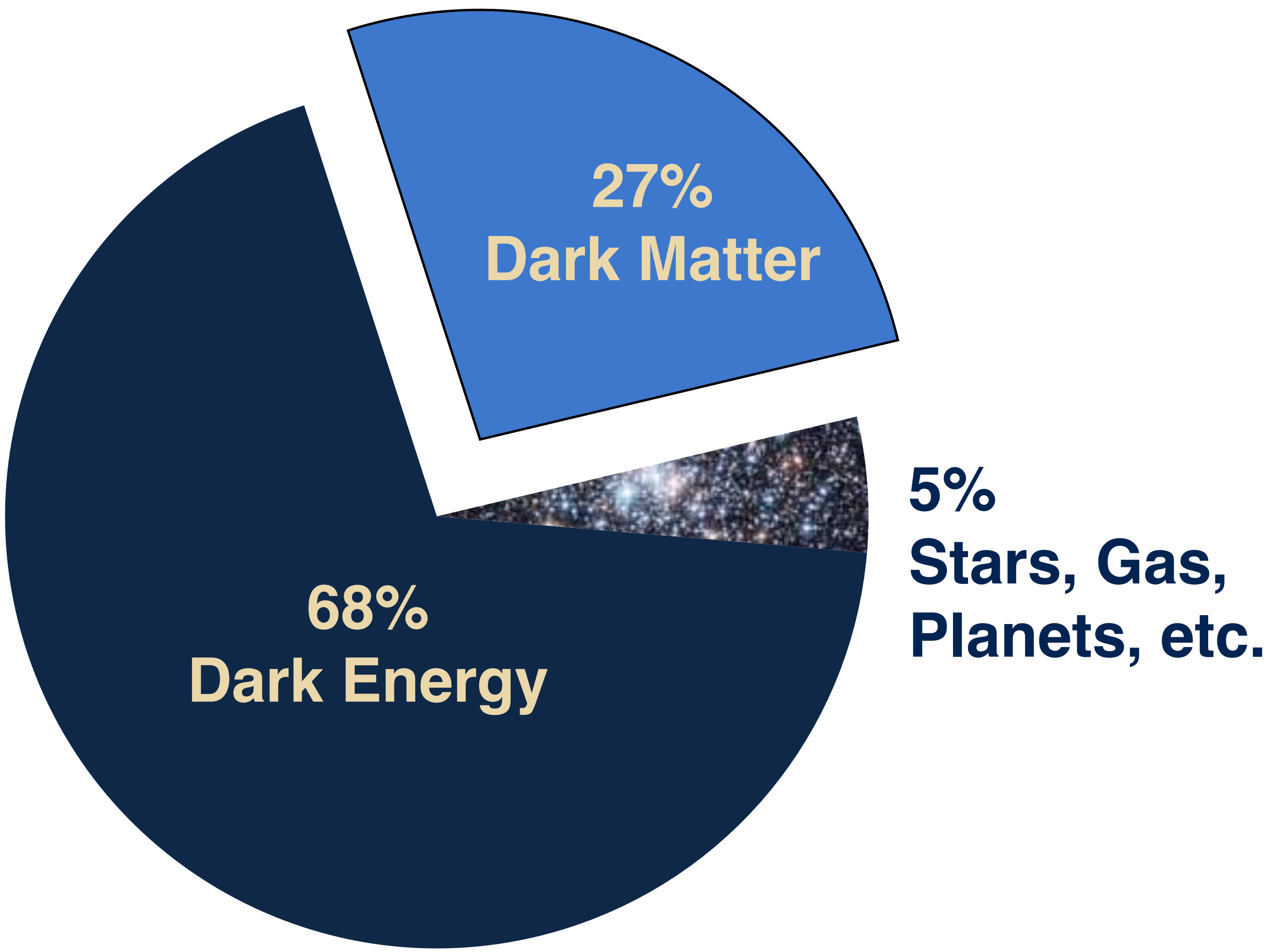
Cosmic microwave background

Hubble telescope image archive

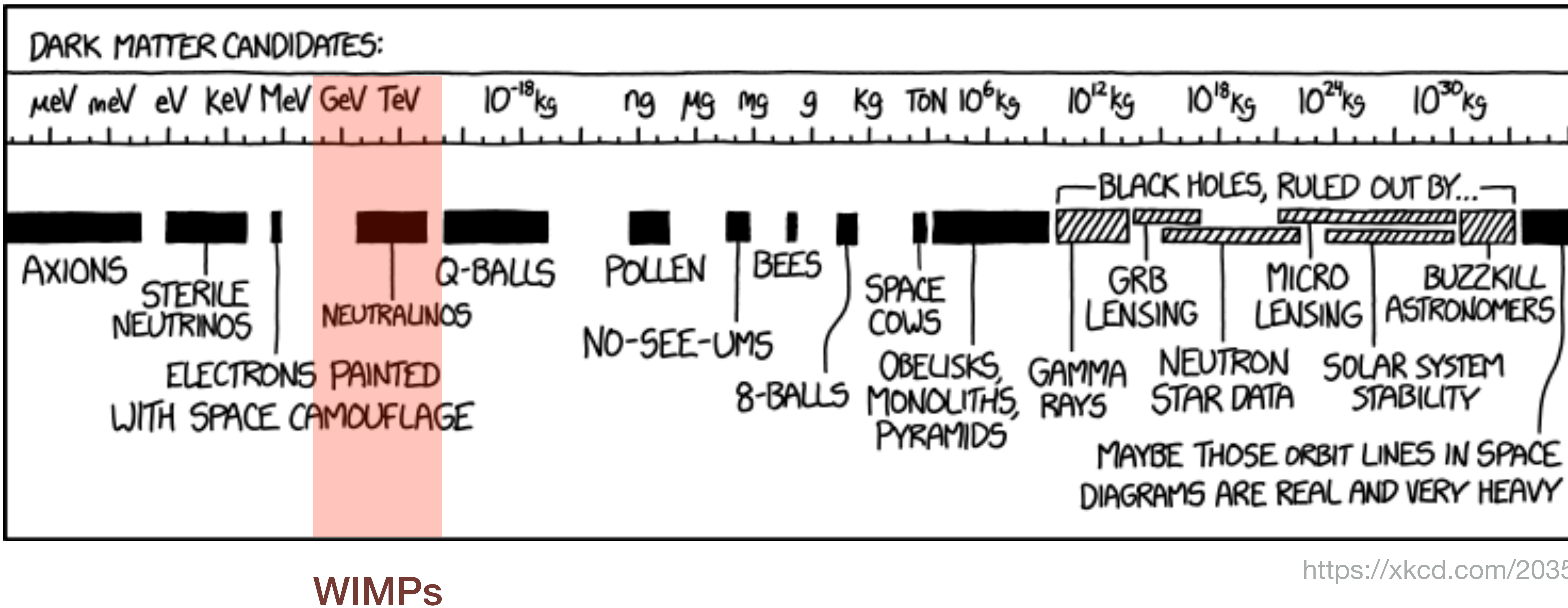


Sloan Digital Sky Survey

The standard model of cosmology puts the composition of the universe at 27% Dark Matter.

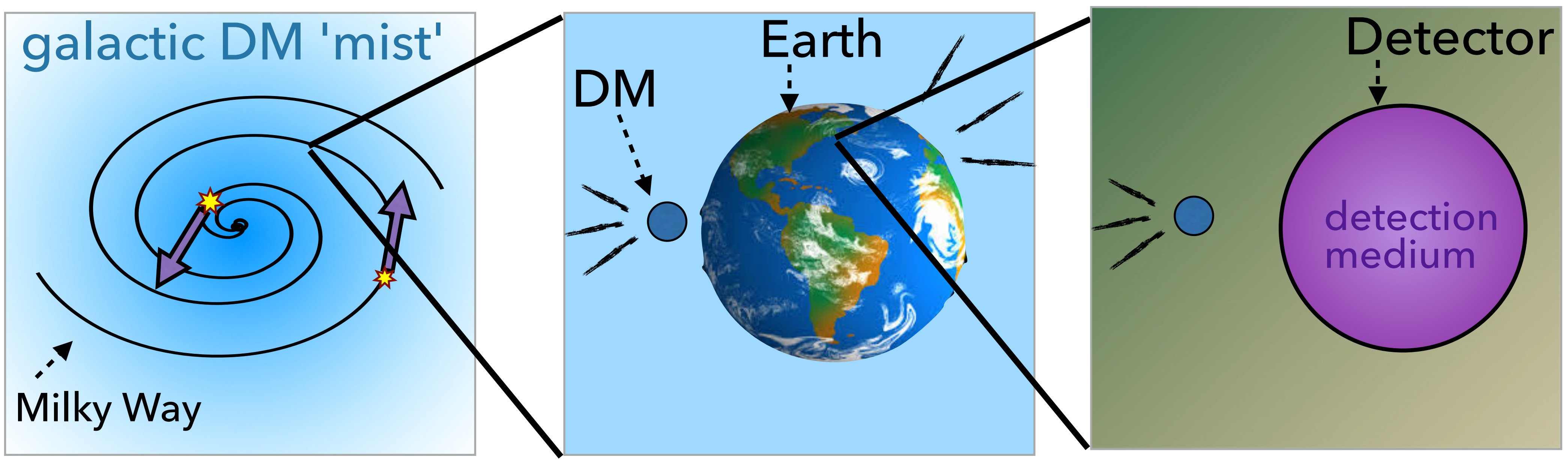


Weakly interacting massive particles (WIMPs) are (still) a well-motivated particle-dark matter candidate

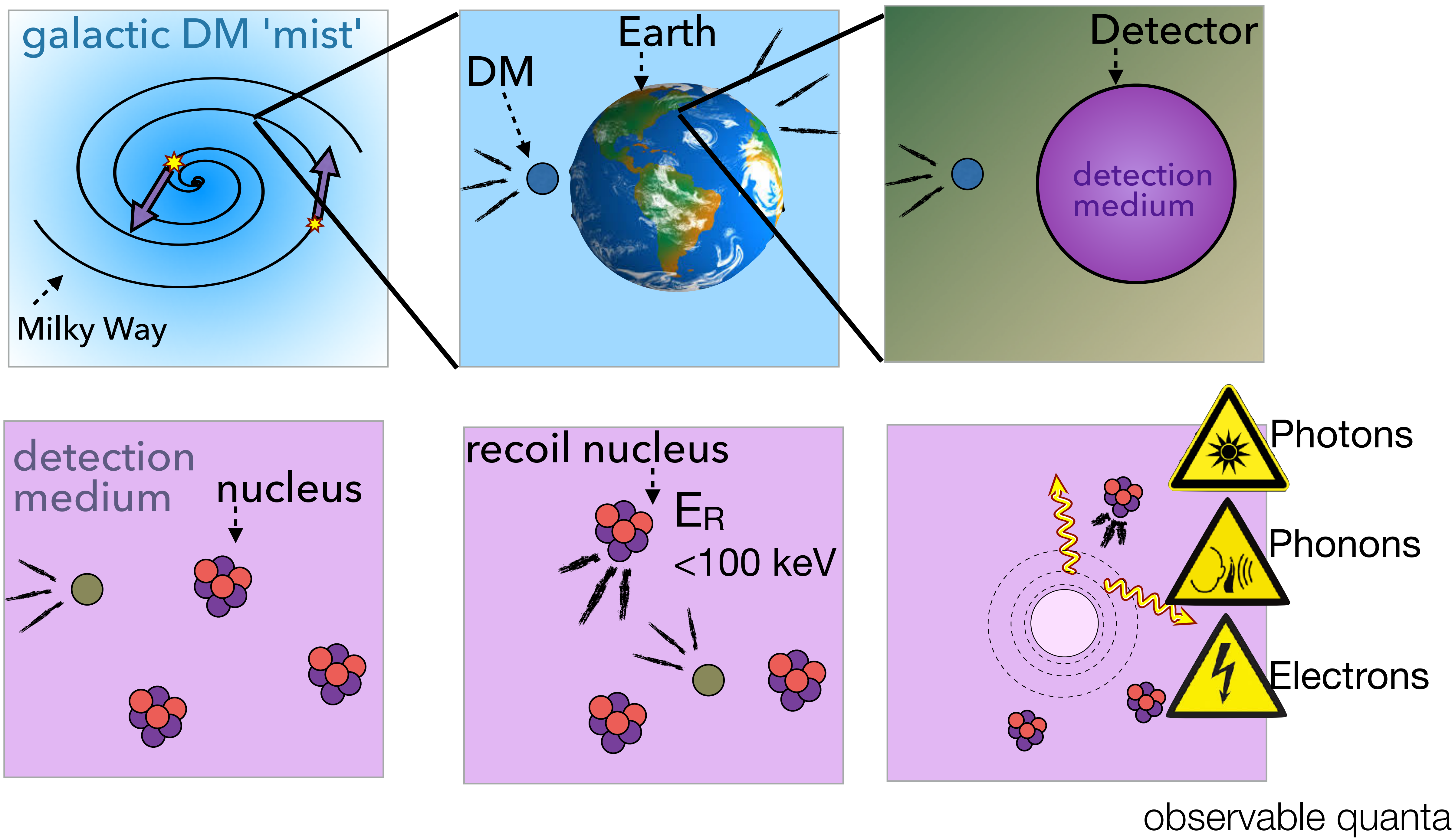


https://xkcd.com/2035/

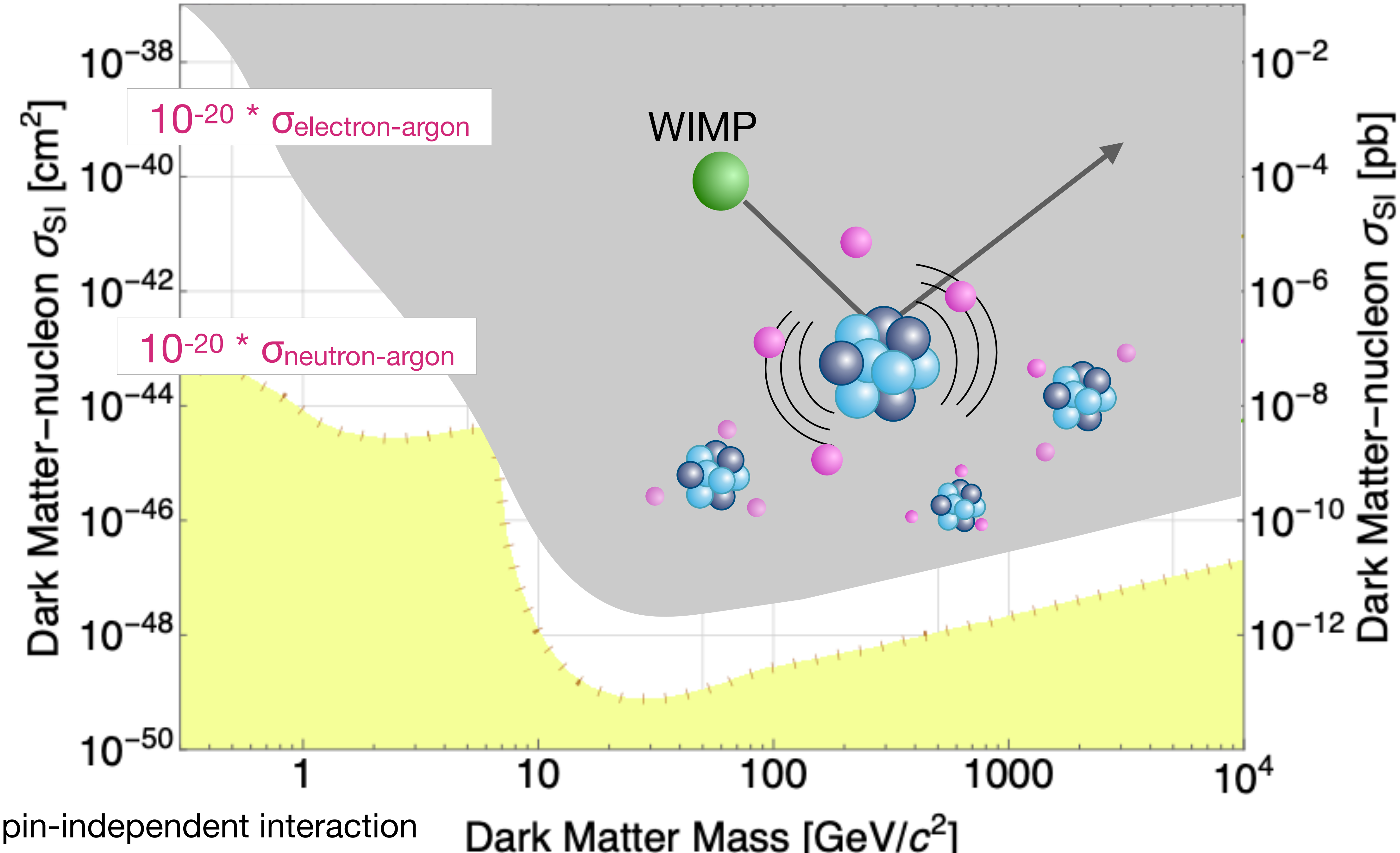
Direct detection: coherent elastic scattering between galactic DM (WIMP) and SM particles (atomic nuclei) in our detector.



Direct detection: coherent elastic scattering between galactic DM (WIMP) and SM particles (atomic nuclei) in our detector.

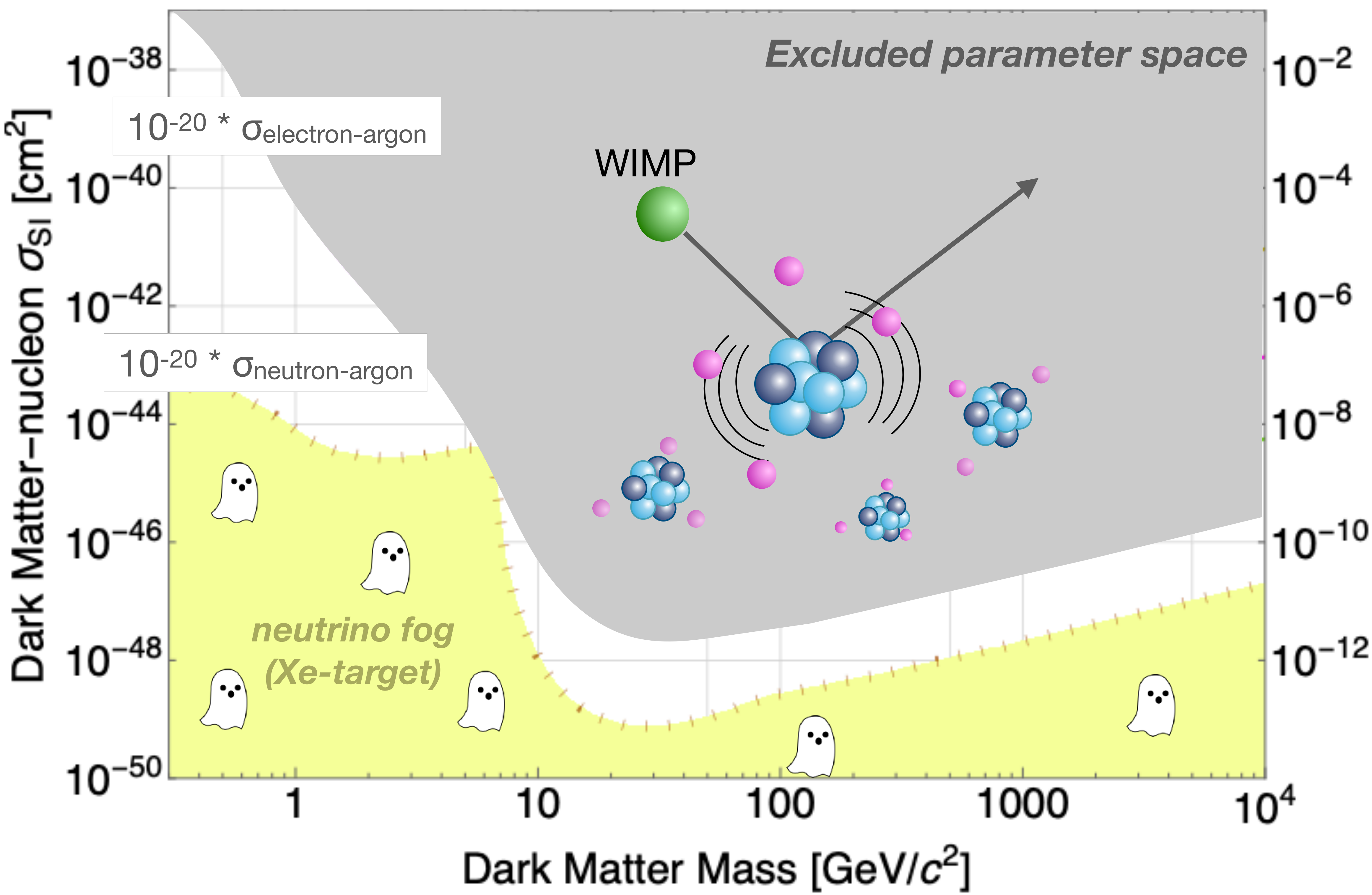


Direct detection of WIMP dark matter - the playing field

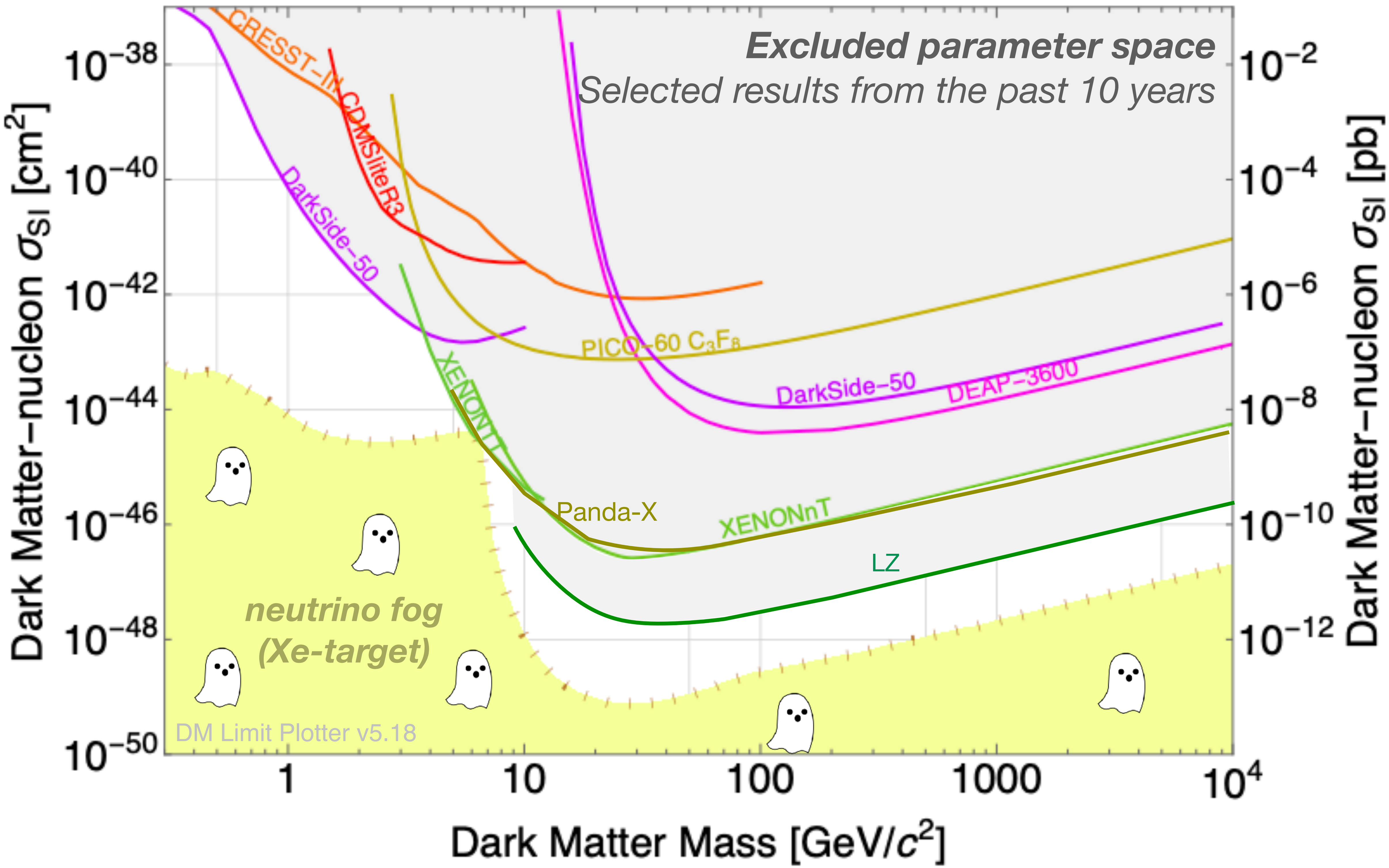


$\sigma_{\chi\text{-N, SI}}$ = spin-independent interaction cross section, scaled to a single nucleon; interpretation in other interaction models out of scope here

Direct detection of WIMP dark matter - the playing field



Direct detection of WIMP dark matter - null-results so far



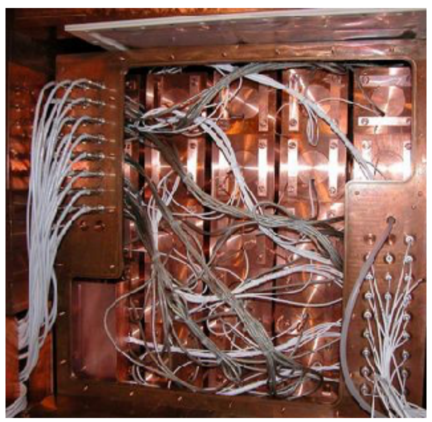
https://arxiv.org/pdf/2603.13965 (DEAP)
https://arxiv.org/pdf/2601.11296 (XENON LM)
https://arxiv.org/pdf/2502.18005 (XENON HM)
https://arxiv.org/pdf/2107.13438 (PandaX)
https://arxiv.org/pdf/2207.11967 (DarkSide)

https://arxiv.org/pdf/1904.00498 (CRESST)
https://arxiv.org/pdf/1902.04031 (PICO)
https://arxiv.org/pdf/1808.09098 (CDMS)
https://arxiv.org/pdf/2410.17036 (LZ)

Technologies for direct detection: crystals and bubble chambers for low mass search ($\mathcal{O}$(eV) thresholds, small target mass) *

crystals

DAMA/LIBRA (NaI(Tl))

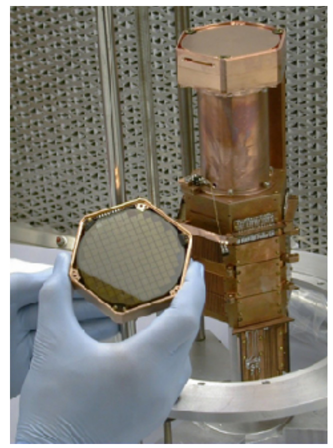


25 x 9.7kg

CRESST II (CaWO4)

8 x 300g

CDMS II (Si)

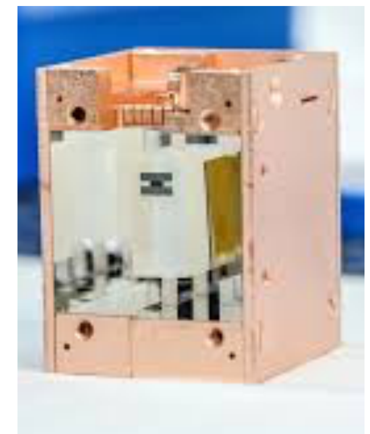


19 x 239g

CoGeNT (Ge)

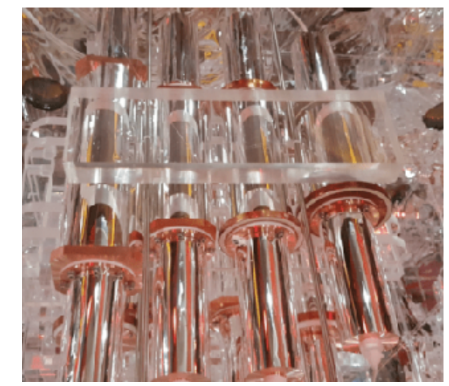
440 g

CRESST III (CaWO4)



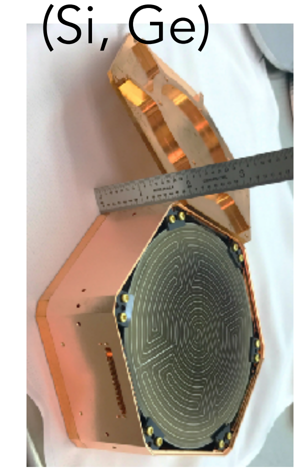
10 x 25g

COSINE (NaI)



8 * 12.5kg

SuperCDMS @SNOLAB (Si, Ge)



24 * 1.2kg

2003

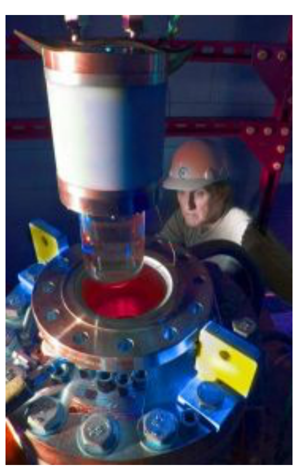
bubble-chambers and proportional counters

2026

PICASSO (C4F10)

32x 4.5 l (80 g)

COUPP 4 kg (CF_3I)



4 kg

PICO 2l (C3F8)

2 L

PICO 60 (C3F8)

60 L

NEWS-G (Ne+CH4 (0.7 %))

283 g

SBC (LAr+Xe (ppm))

10 kg

*) Non-exhaustive selection of experiments

Technologies for direct detection: liquid noble gas targets for high mass search ($\mathcal{O}$(keV) thresholds, large target mass) *

Argon

2007

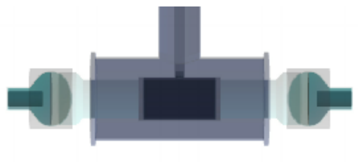
WArP

1.8 kg

microCLEAN

4 kg

DEAP-1



7.6 kg
(6.1 kg)

DarkSide-50

46.4 kg
(36.9 kg)

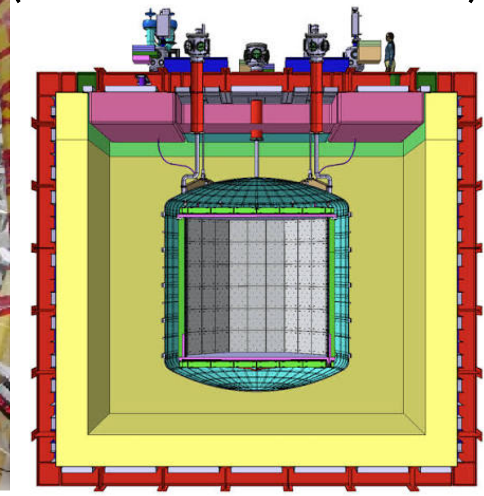
ArDM

1900 kg
(1000 kg)

DEAP-3600

3400 kg
(1000 kg)

DarkSide-20k
(under construction)

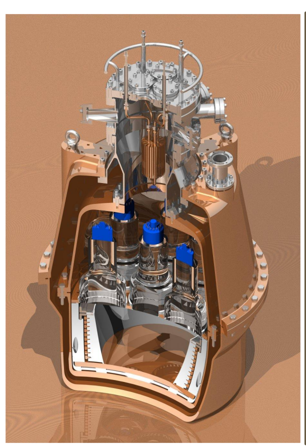


50 tonnes

2026

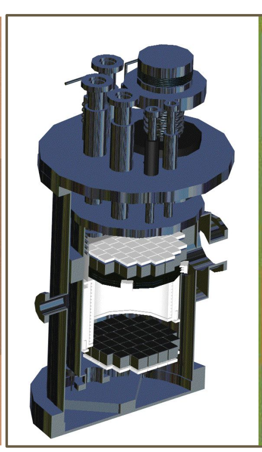
Xenon

ZEPLIN-II



31 kg
(7.2 kg)

XENON10

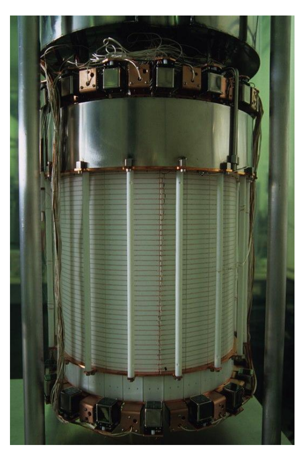


15 kg
(5 kg)

ZEPLIN-III

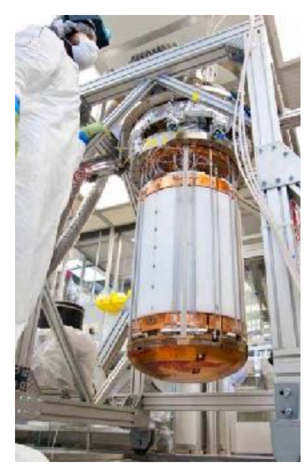
12 kg
(7 kg)

XENON100



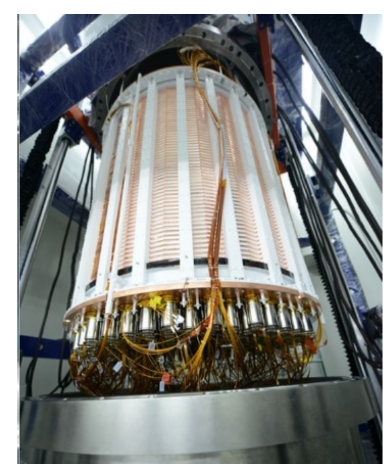
62 kg
(34 kg)

LUX/PandaX-II/XENON1T



250-2000 kg

PandaX-4t

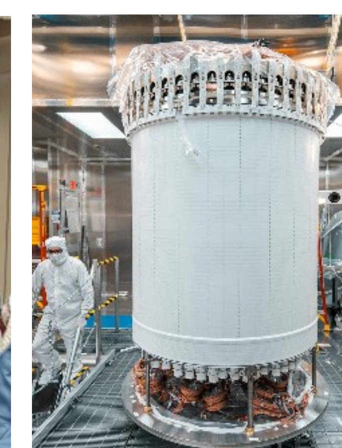


4 tonnes

XENONnT

6 tonnes

LZ



7 tonnes

T. Pollmann, TeVPA 2026

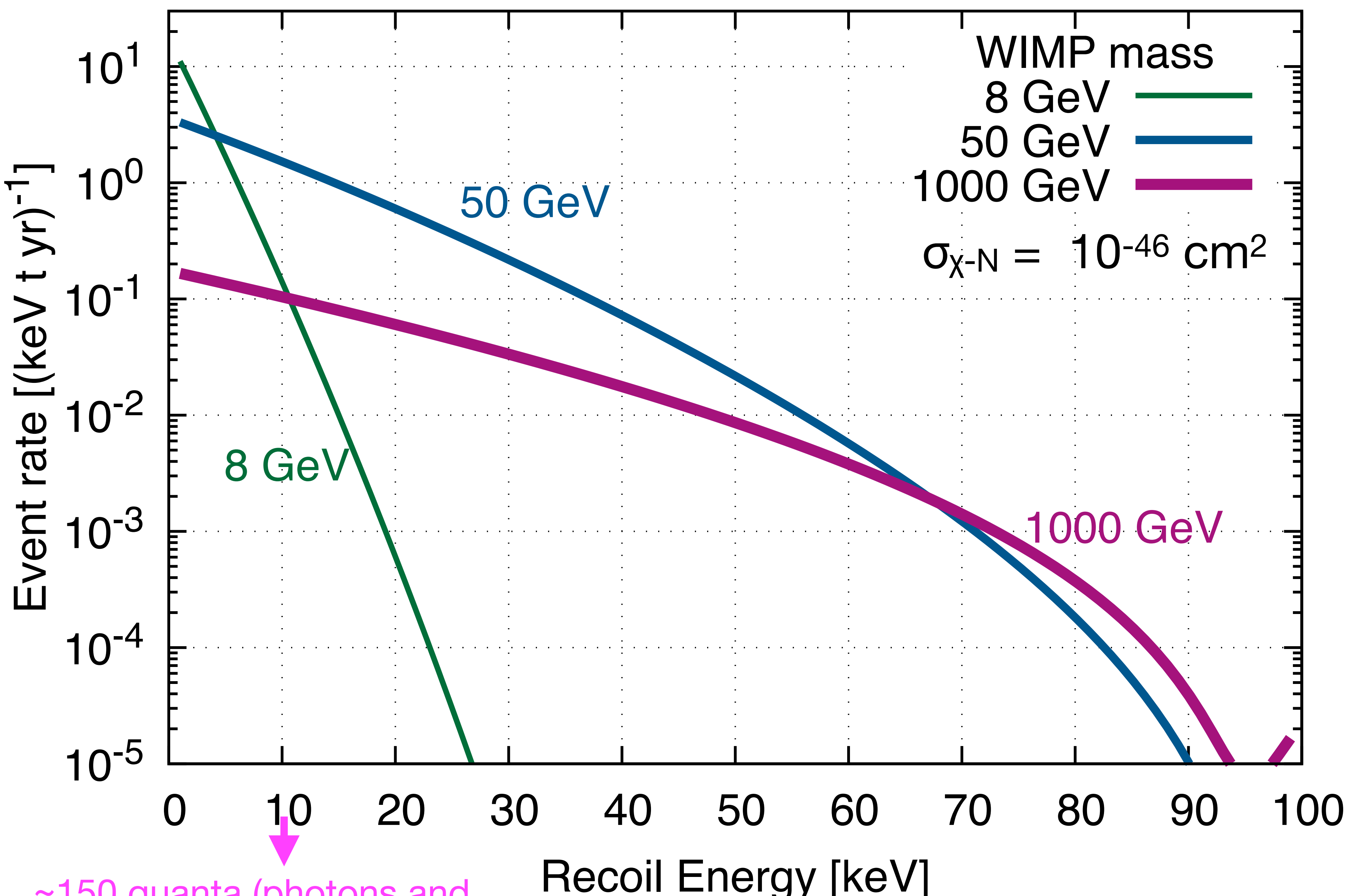
*) Non-exhaustive selection of experiments

Xenon detectors from slides by: Chamkaur Ghag UCL 5 June 2019

The challenges of direct detection: Low energy and small signal rates.

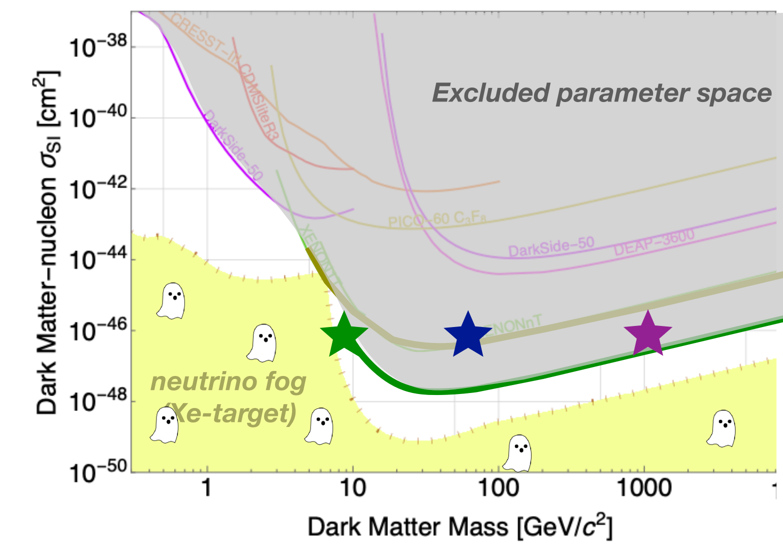
Differential 'WIMP' dark matter recoil spectrum.

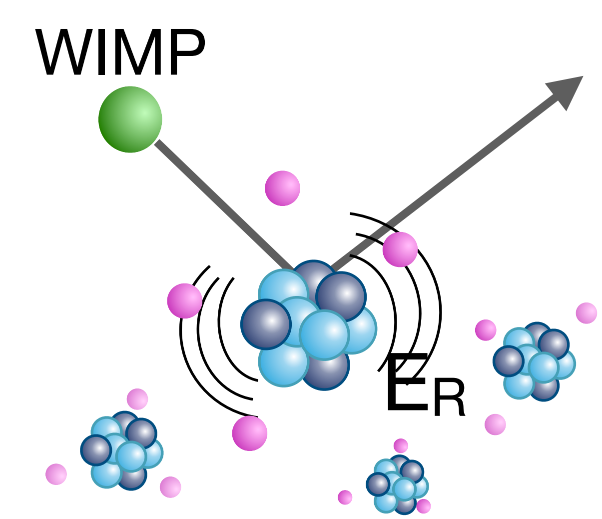
On xenon, standard assumptions*



~150 quanta (photons and electrons) produced in liquid Xe

~120 quanta in liquid Ar

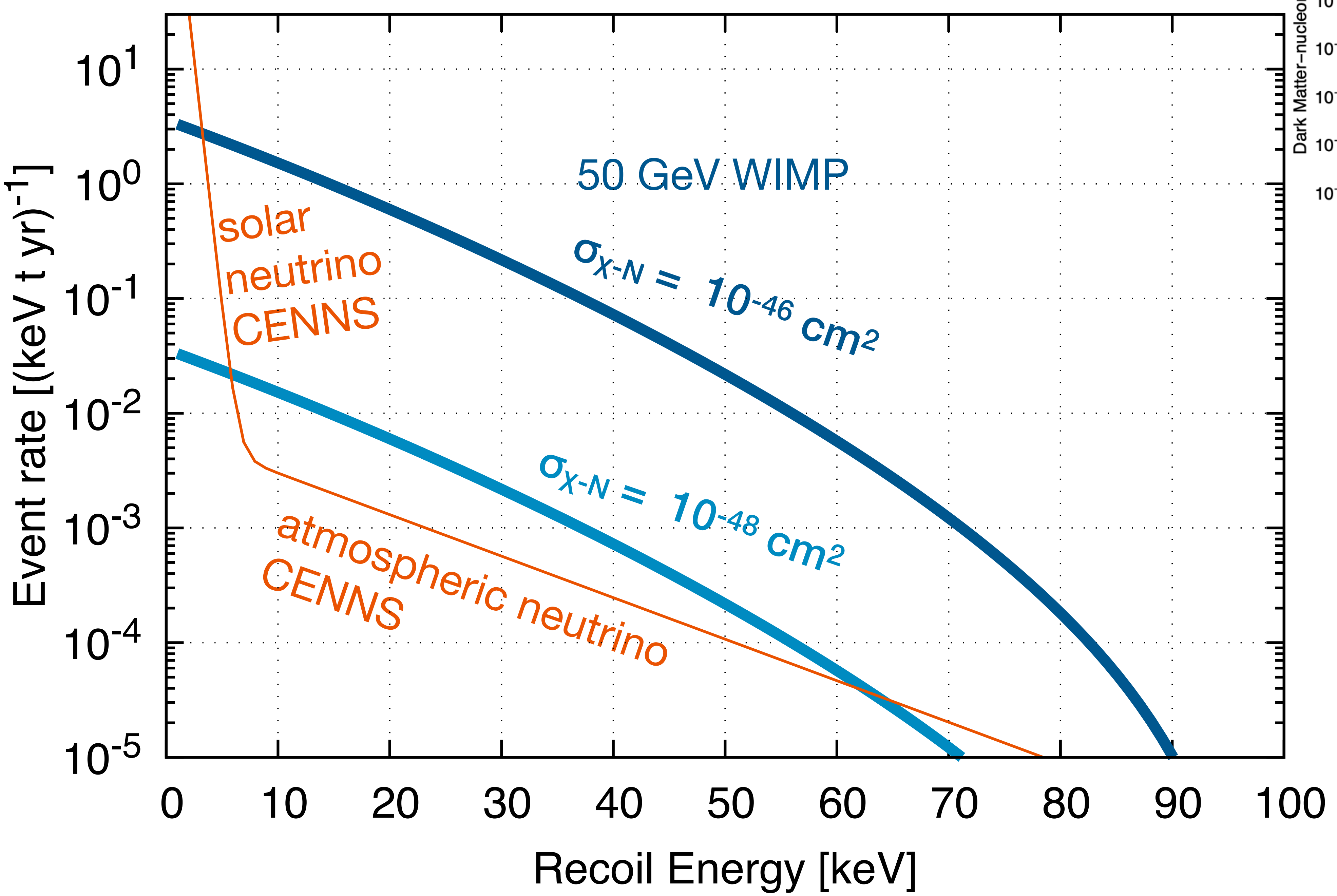


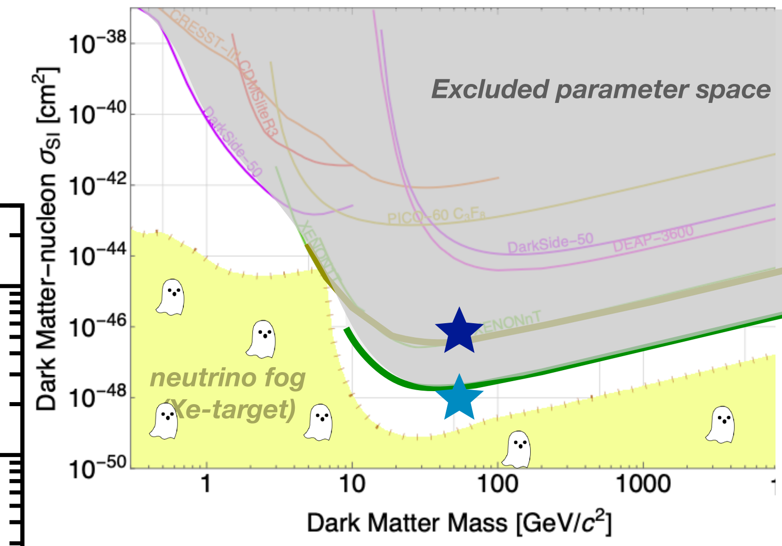


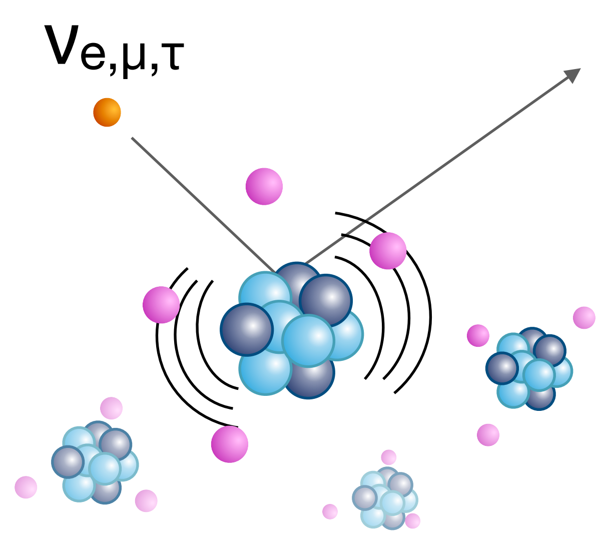
* Lewin, J, and P Smith. *Astroparticle Physics* 6 (1996): 87–112.

Challenge and opportunity: Irreducible background from coherent elastic neutrino-nucleus scattering

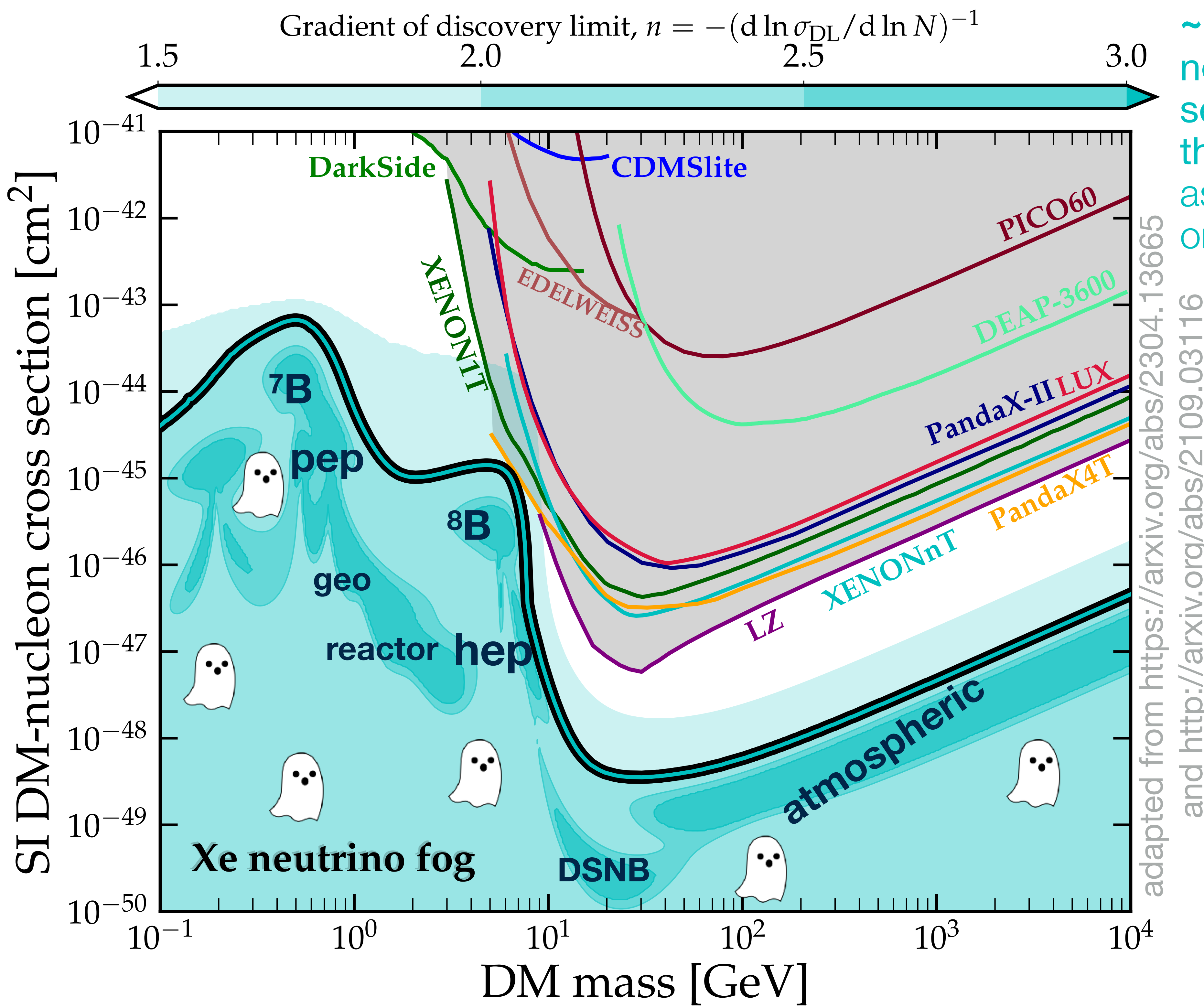
As we go to lower interaction cross sections, WIMP spectra of certain masses resemble neutrino CENNS spectra.





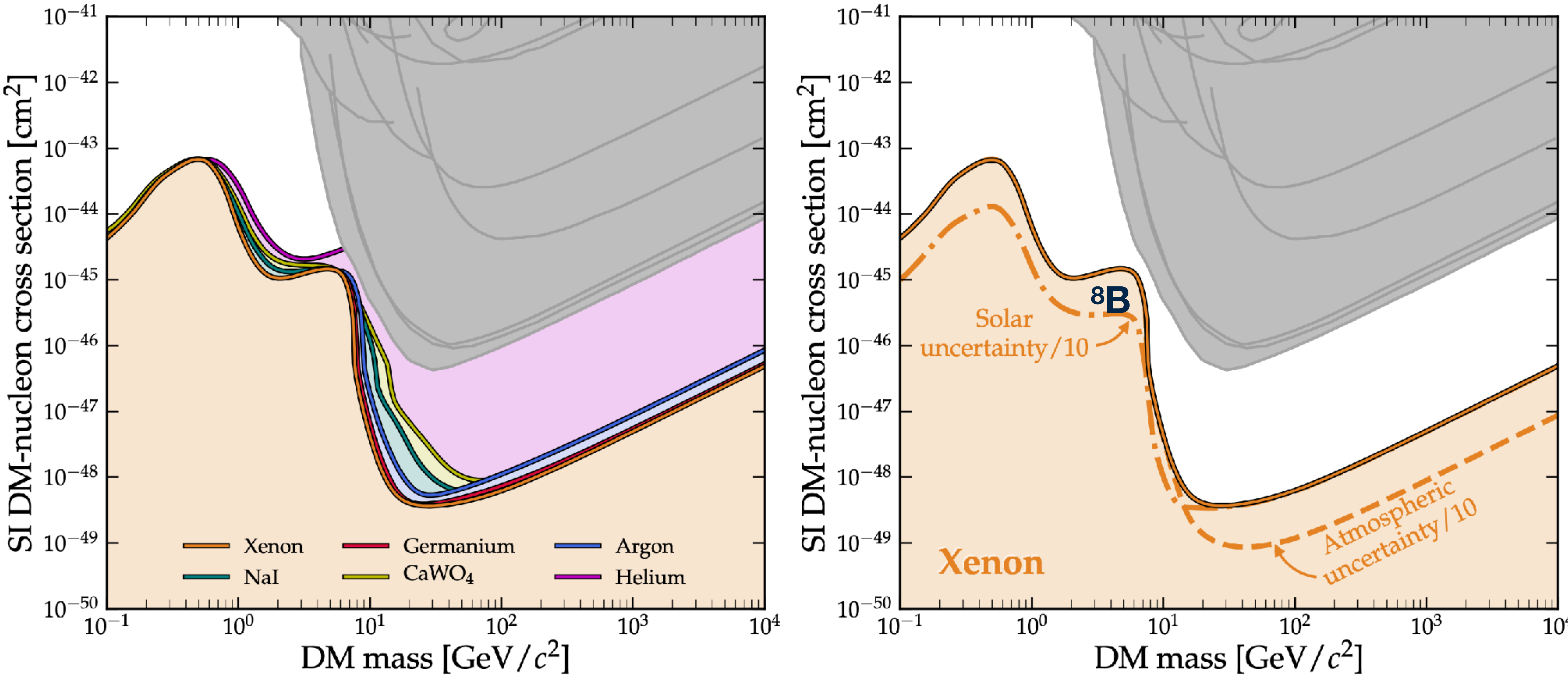


Background from cosmic neutrinos will impact the sensitivity to Dark Matter.



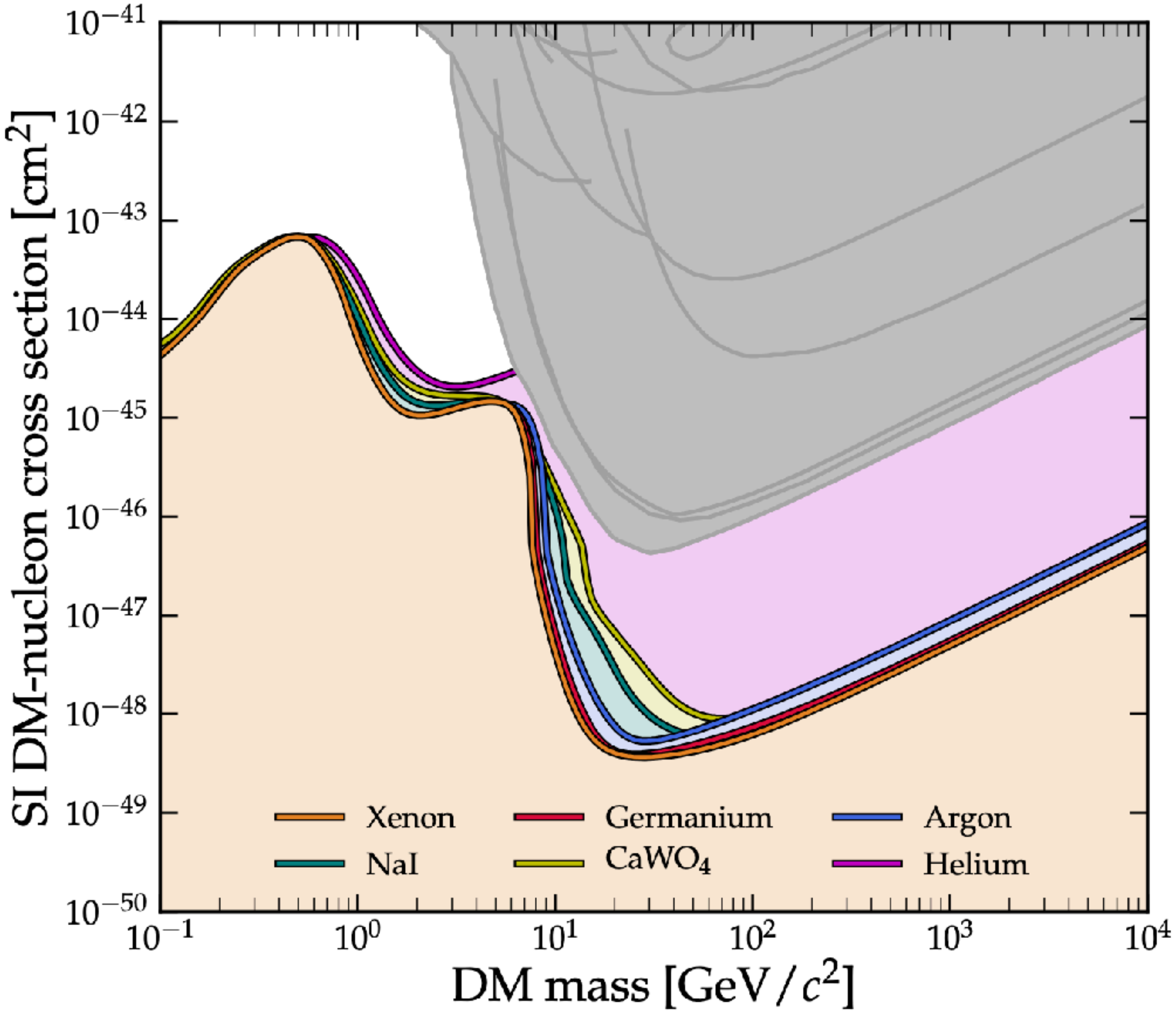
~ how much more exposure is needed to get the same sensitivity you'd have without this background (under a given assumption for the uncertainty on the neutrino fluxes)

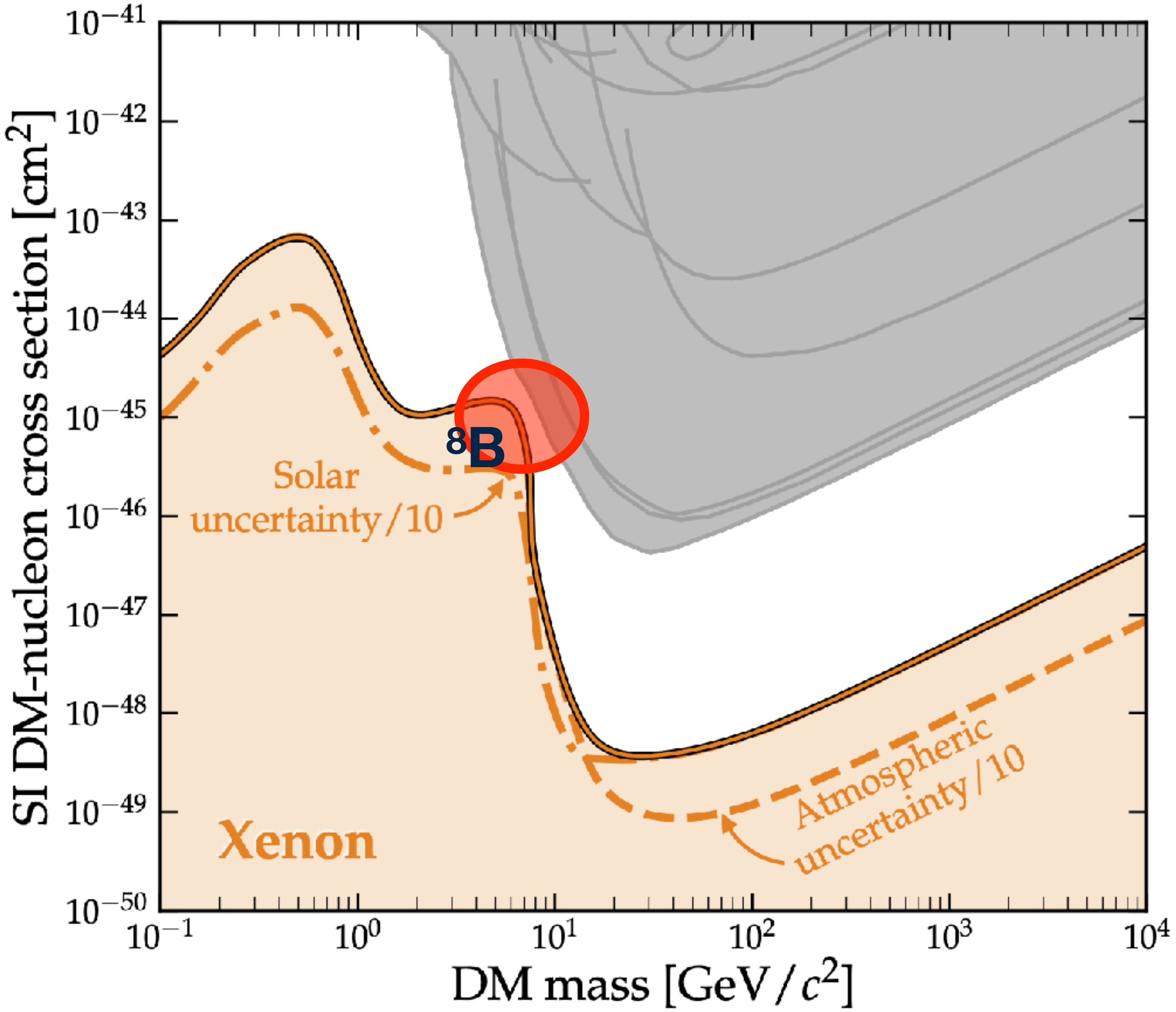
The shape of the neutrino fog looks different for different target materials, and lowers as neutrino flux uncertainties get better constrained.



http://arxiv.org/abs/2109.03116

The shape of the neutrino fog looks different for different target materials, and lowers as neutrino flux uncertainties get better constrained.

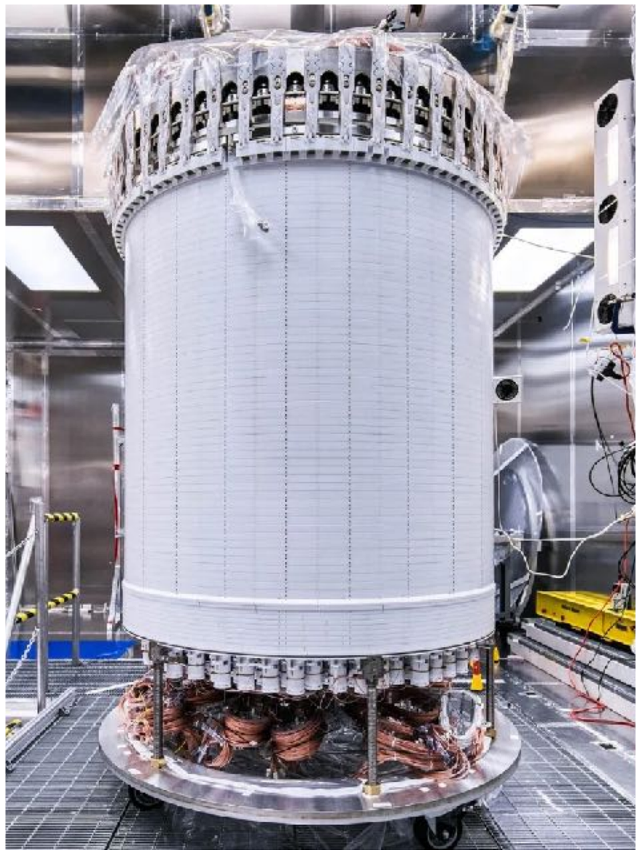




http://arxiv.org/abs/2109.03116

Current (high-mass WIMP) detectors recently have had their first encounters with the neutrino fog

LZ (USA)



liquid xenon 7 tonne

4.5σ for B8 CEvNS
(arXiv:2512.08065, 2025)

XENONnT (Italy)

5.9 tonne

2.73σ for B8 CEvNS
(arXiv:2408.02877, 2024)

3.3σ for B8 CEvNS
(arXiv:2604.06002, 2026)

PandaX-4t (China)

3.7 tonne

2.64σ for B8 CEvNS
(arXiv:2407.10892, 2024)

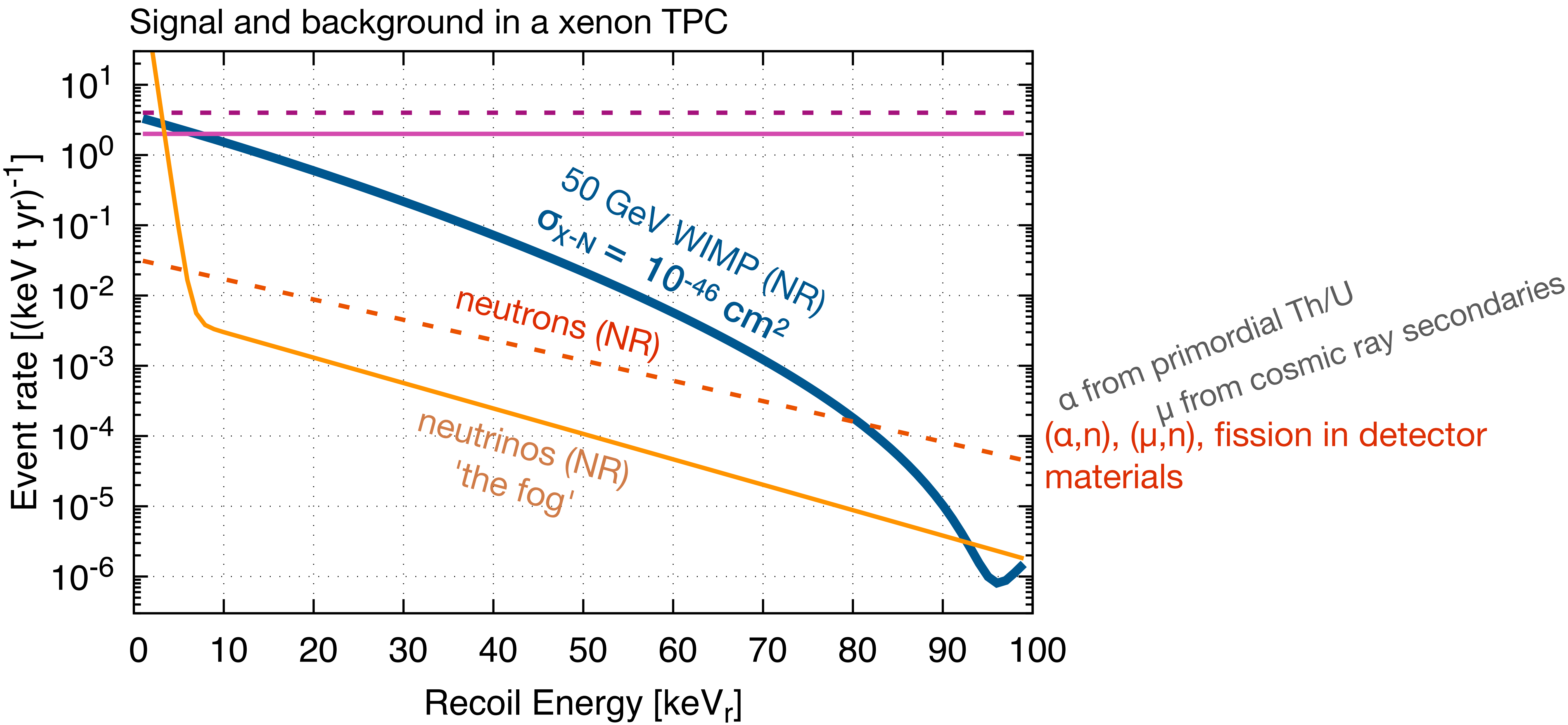
2.2σ for pp, ν-e
(arXiv:2607.02405, 2026)

DEAP-3600 (Canada)

liquid argon: 3.3 tonne

4.0σ for B8 ν_e+Ar40
charged-current absorption
(arXiv:2605.12769, 2026)

Huge advances over the years to bring 'reducible' backgrounds to a sufficiently low level.

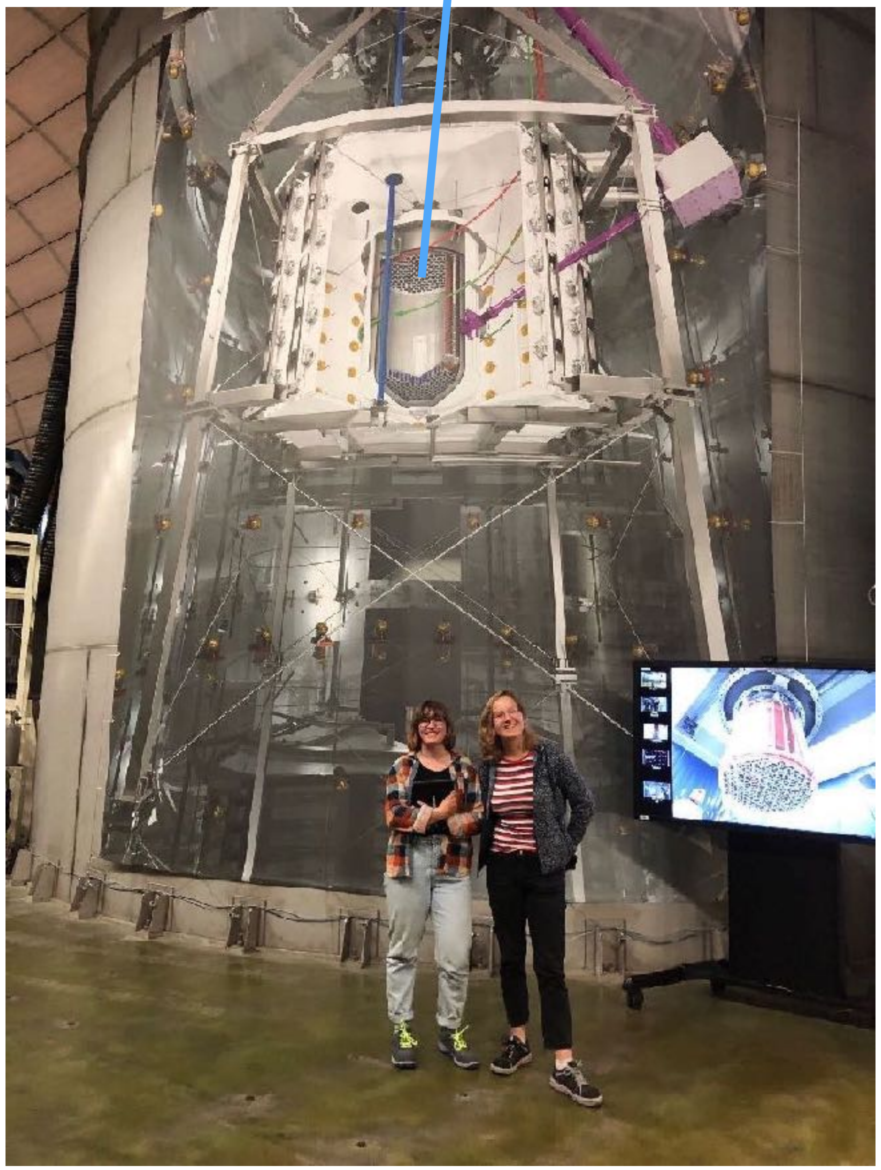


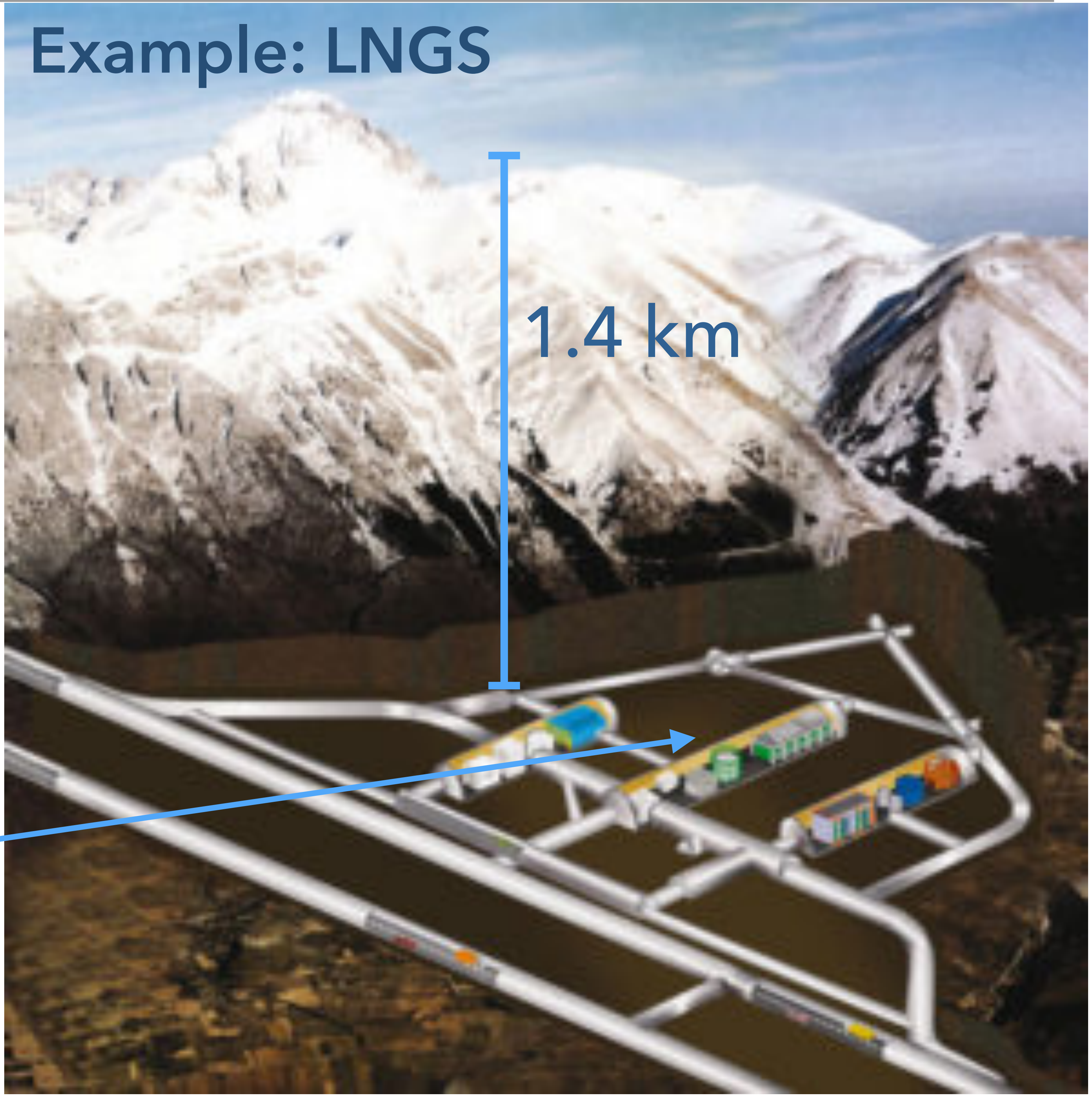
Background rates approximate expectation for XENONnT, only fiducial volume cut

based on: arXiv:2007.08796 and arXiv:1802.06039

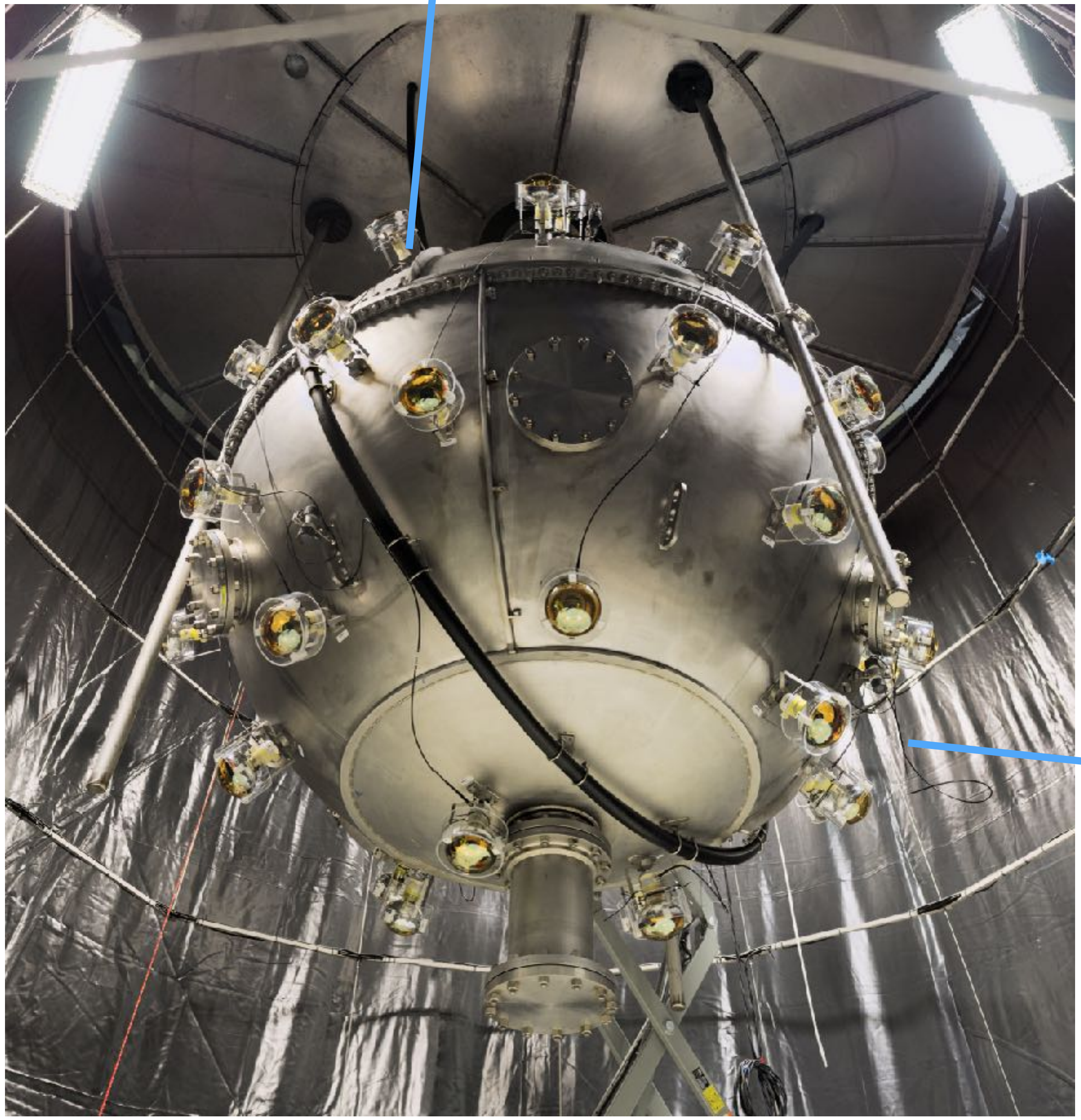
Shielding against cosmic rays includes going to deep underground laboratories and placing detectors in several layers of additional active and passive shielding.

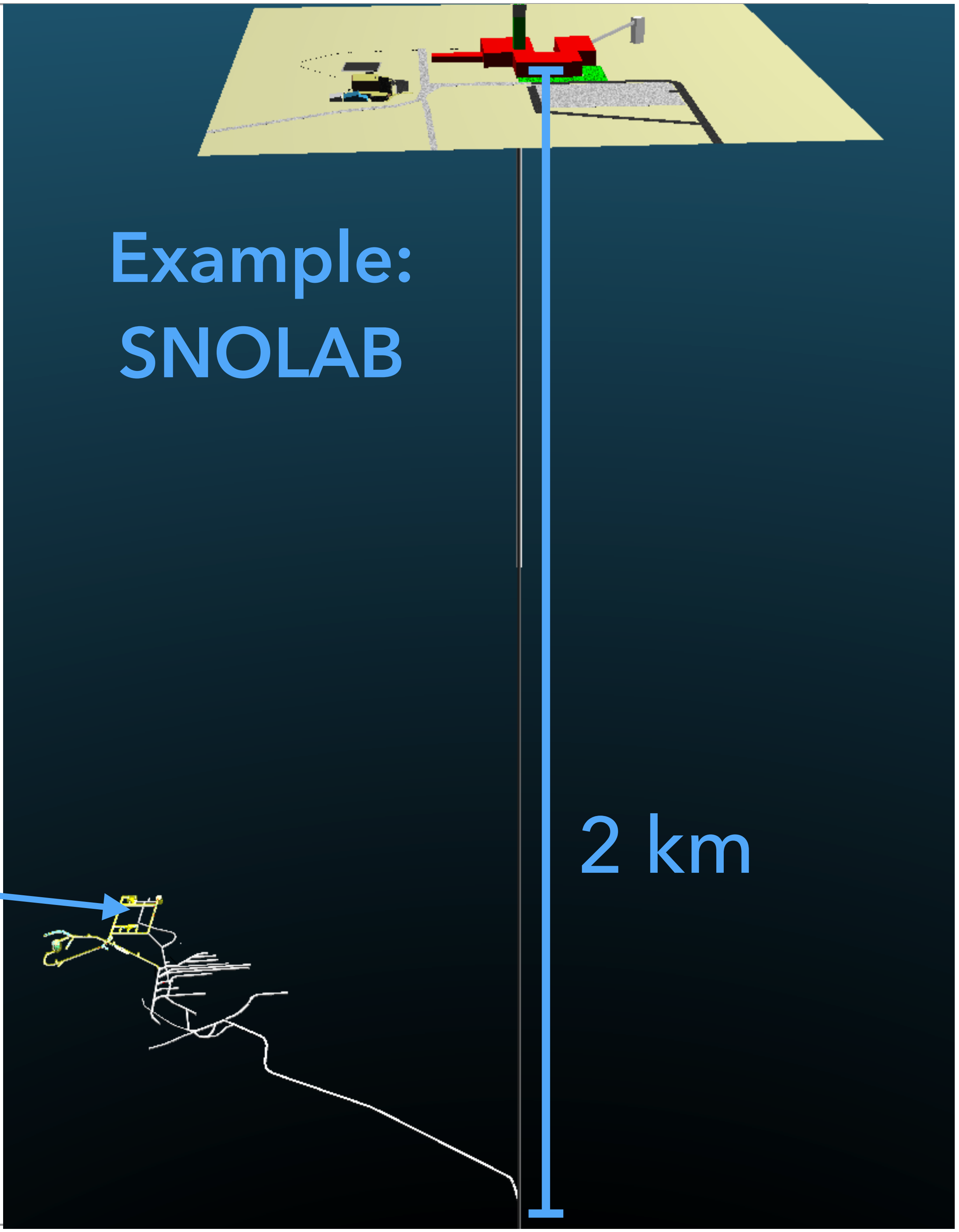
XENONnT detector





Shielding against cosmic rays includes going to deep underground laboratories and placing detectors in several layers of additional active and passive shielding.

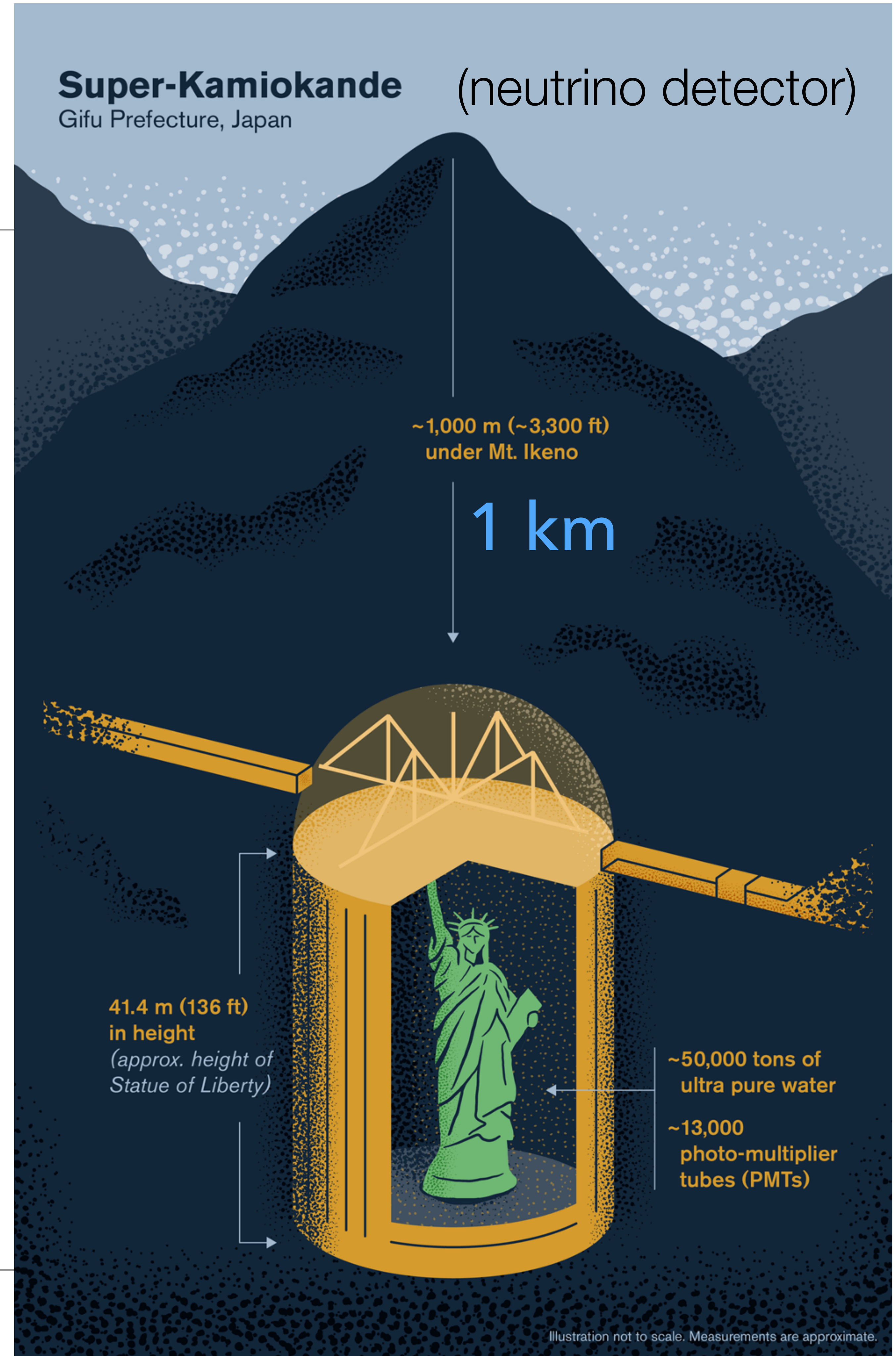




Shielding against cosmic rays includes going to deep underground laboratories and placing detectors in several layers of additional active and passive shielding.

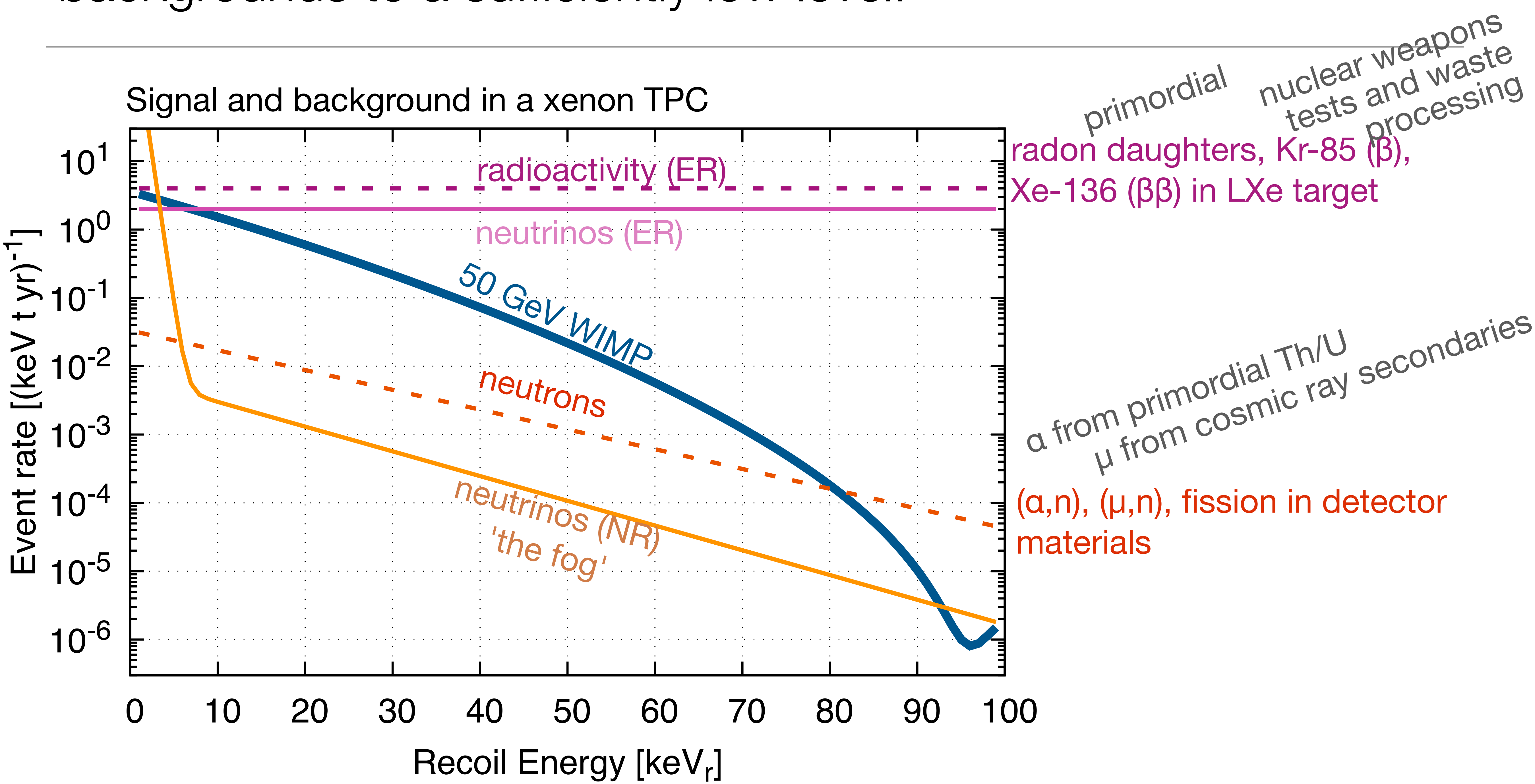
Example:
Kamioka Observatory

XMASS (completed)
NEWAGE



https://www.symmetrymagazine.org/article/a-new-view-into-the-history-of-the-universe

Huge advances over the years to bring 'reducible' backgrounds to a sufficiently low level.

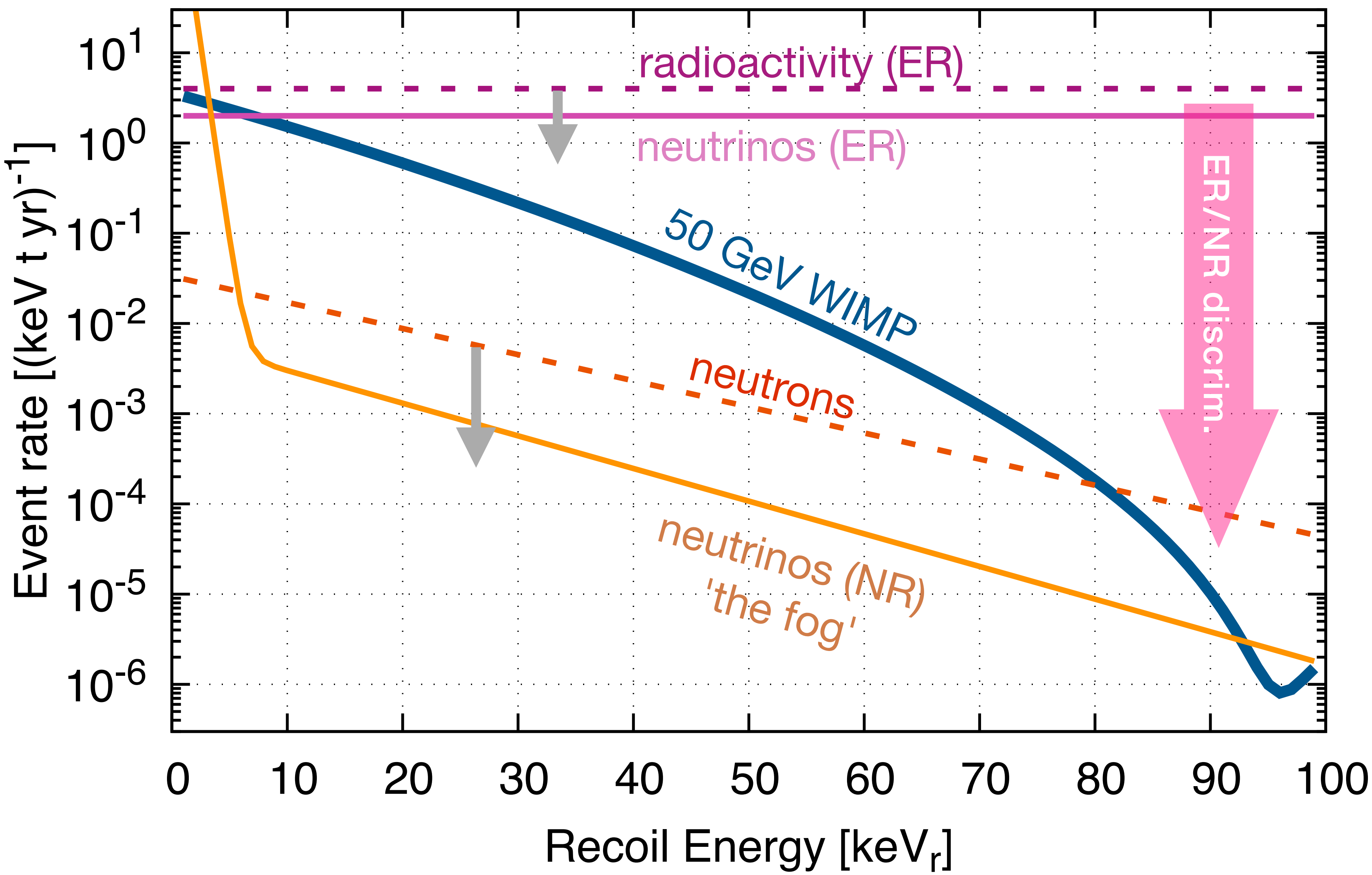


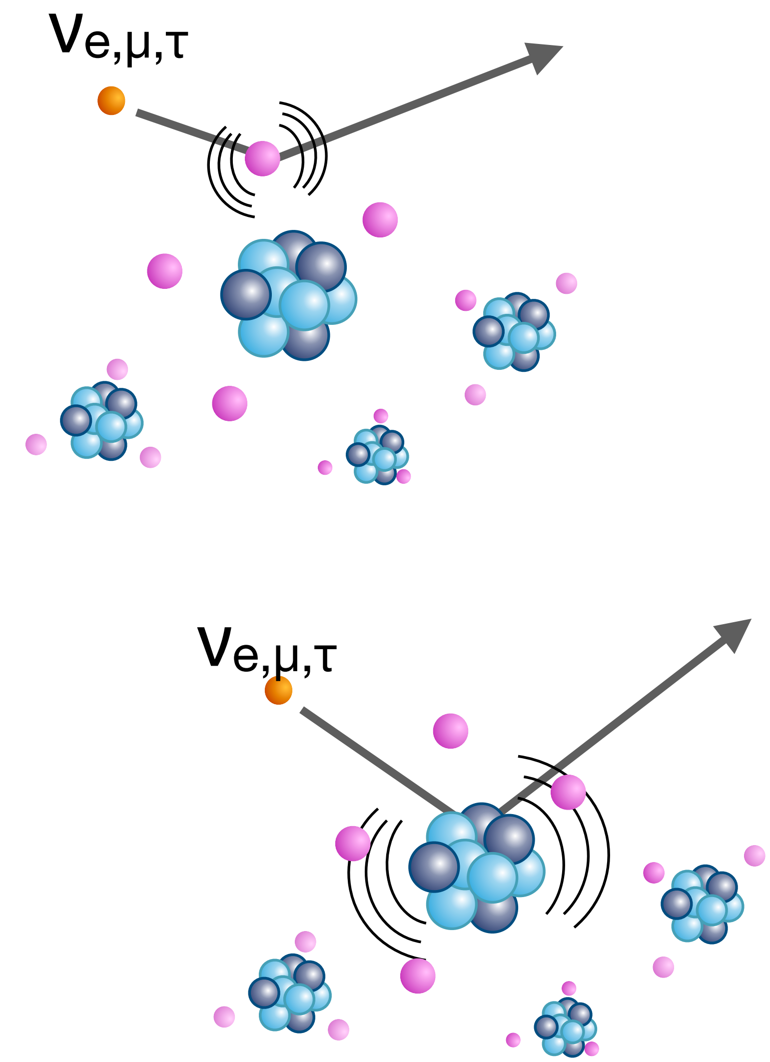
Background rates approximate expectation for XENONnT, only fiducial volume cut

based on: arXiv:2007.08796 and arXiv:1802.06039

To increase sensitivity down to the neutrino fog, detectors have to become even **bigger**, and **quieter**

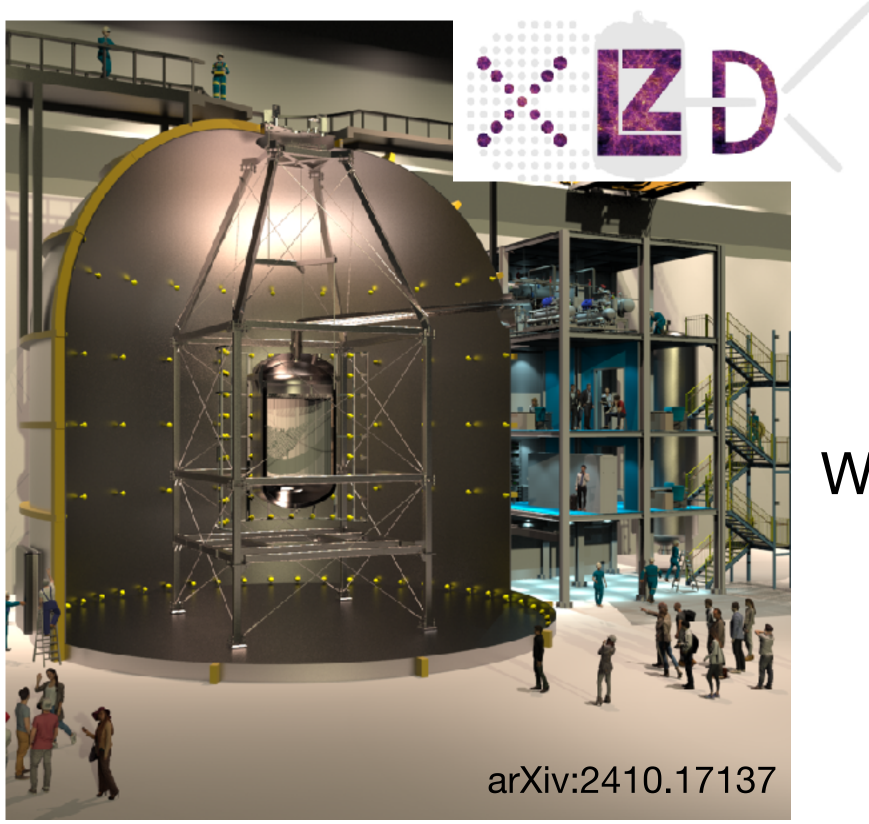
Signal and background in a xenon TPC





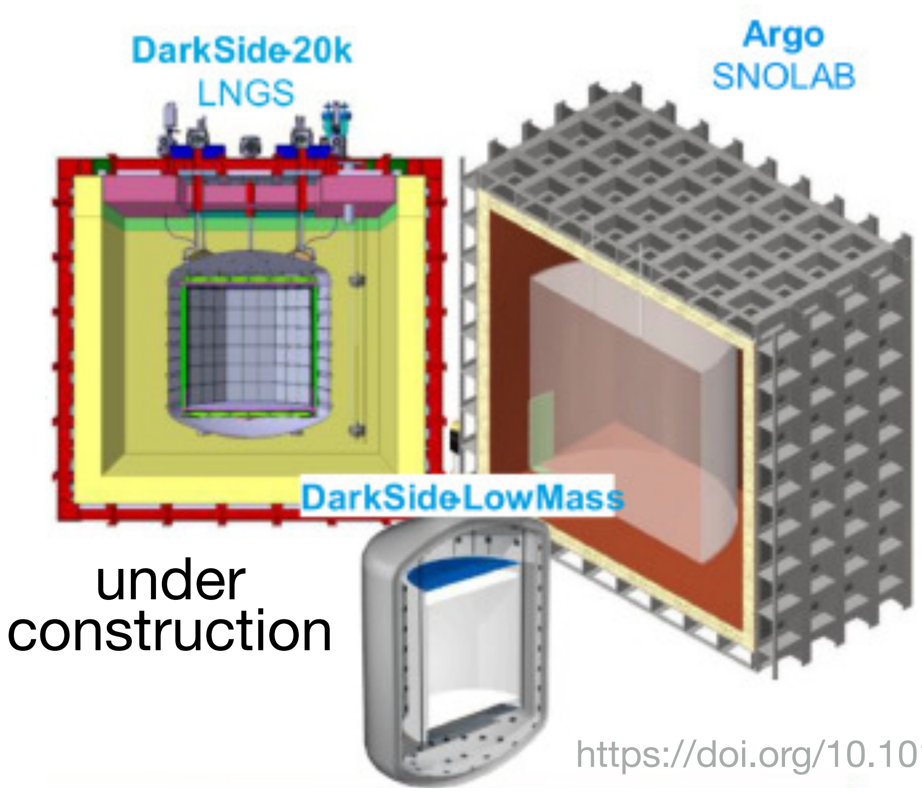
- Improved detector material radiopurity
- Improved shielding
- Improved analysis

Decades of R&D have put us in a position to reach into the neutrino fog with the next generation of detectors.



Xenon

XLZD
XENON + LZ + DARWIN
60 t LXe TPC
Working towards CDR



https://doi.org/10.1016/j.nuclphysb.2024.116436

Argon

GADMC
Global Argon Dark Matter Collaboration

300 t LAr TPC
Concept

crystals bubble-chambers and proportional counters

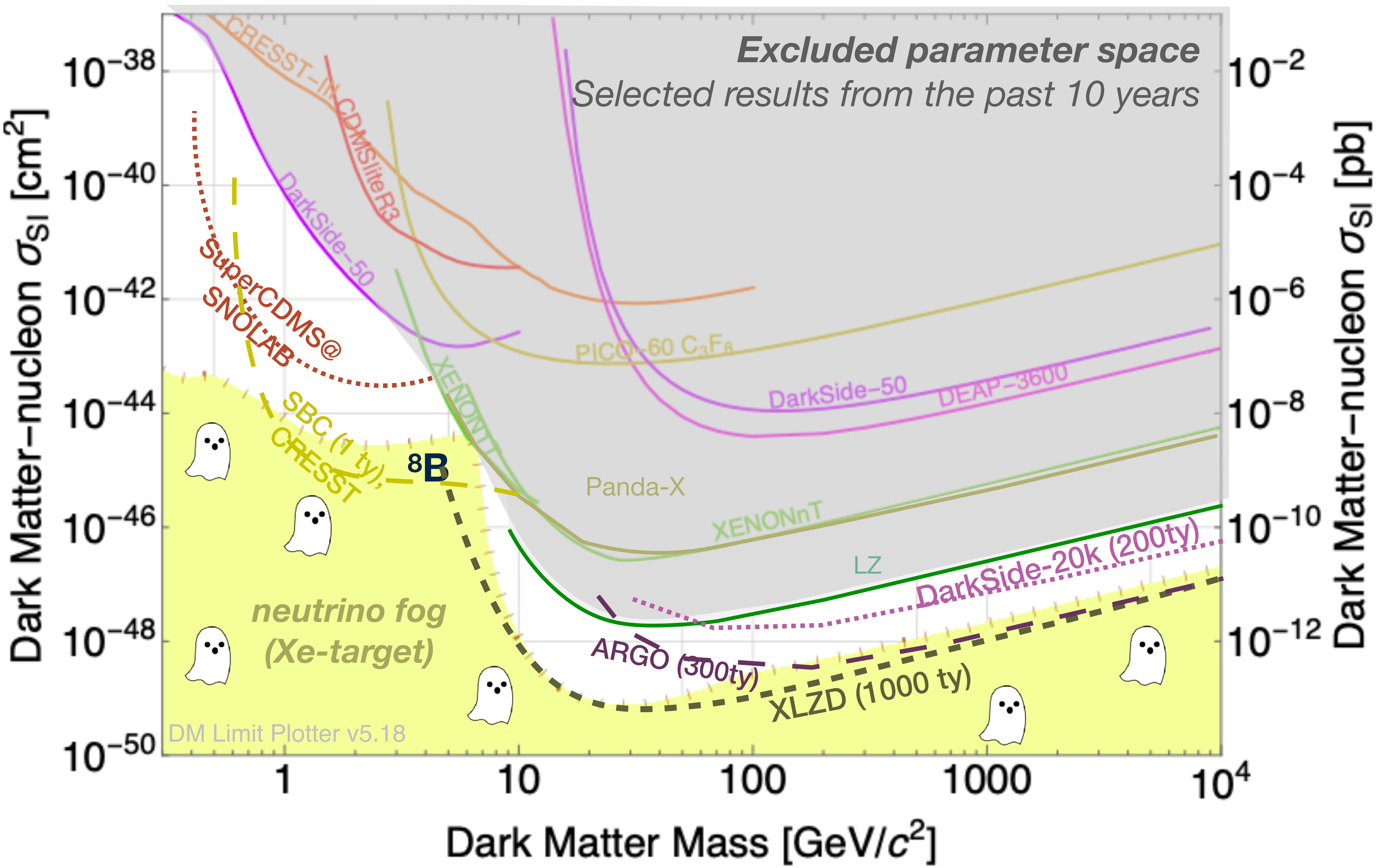
SBC,
https://doi.org/10.3390/universe9080346
CRESST upgrade,
https://arxiv.org/pdf/2505.01183
Super CDMS upgrade,
https://arxiv.org/pdf/2203.08463
News-G/DarkSPHERE
https://arxiv.org/abs/2301.05183

blue sky R&D

to further penetrate the neutrino fog through directional sensitivity

NEWAGE, MIMAC, DRIFT, CYGNO/CYGNUS, ...

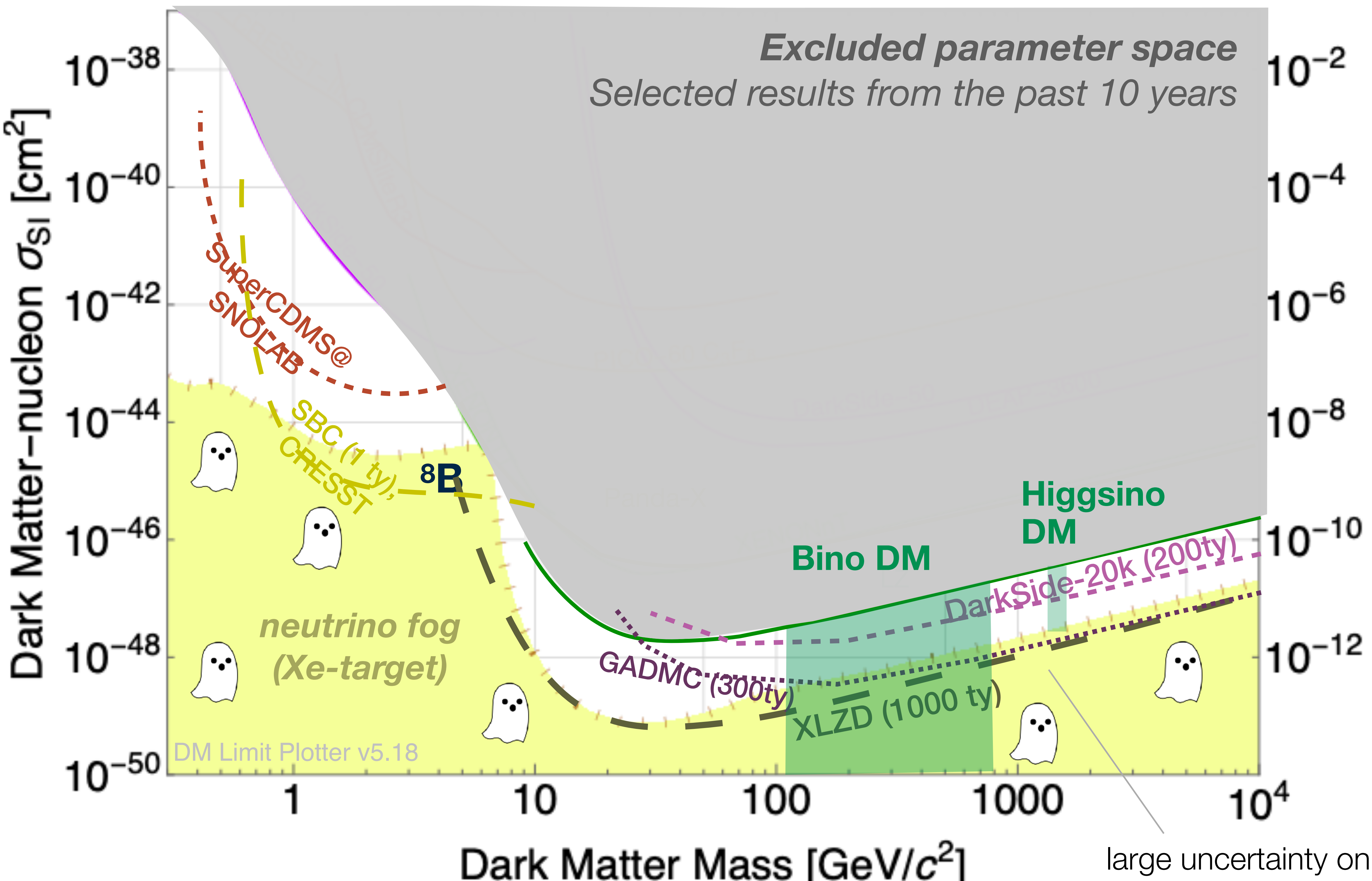
Onward into the fog



https://doi.org/10.3390/universe9080346 (SBC)
https://arxiv.org/abs/1610.00006 (SuperCDMS)
http://arxiv.org/abs/2410.17137 (XLZD)
https://arxiv.org/abs/1707.08145 (DarkSide)

https://arxiv.org/abs/2505.01183 (CRESST)
(Several more planned experiments/upgrades not shown for space reasons)

Many DM candidates could still hide in the gap, even some from the constrained minimal supersymmetric model (standard WIMP).

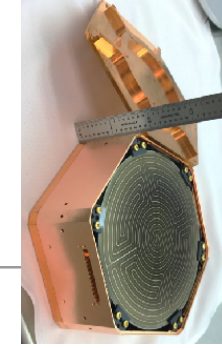


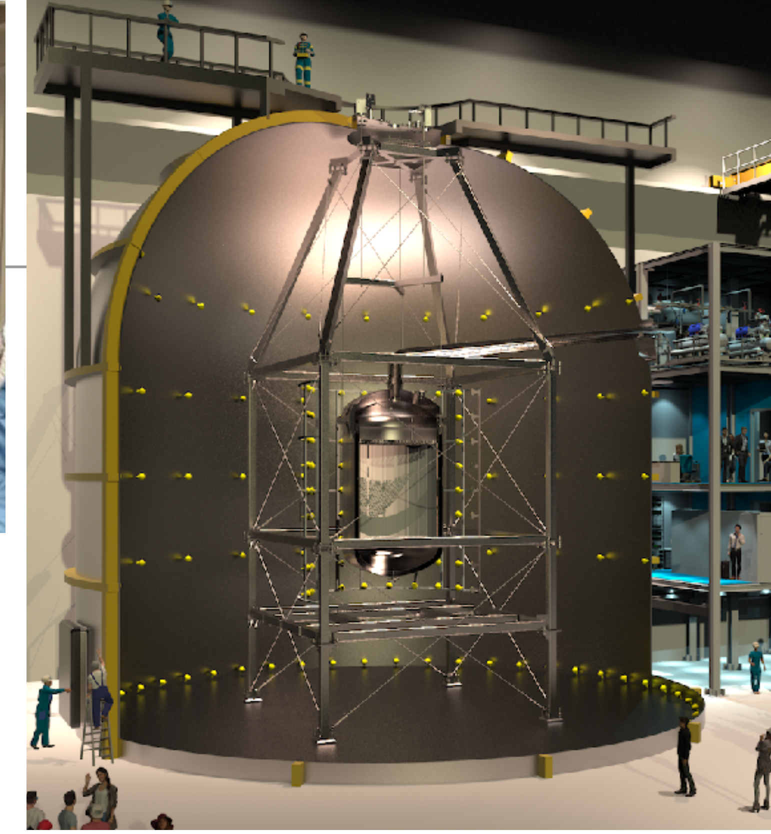
large uncertainty on atm. neutrino flux raises the fog here

https://doi.org/10.3390/universe9080346 (SBC)
https://arxiv.org/abs/1610.00006 (SuperCDMS)
http://arxiv.org/abs/2410.17137 (XLZD)
https://arxiv.org/abs/1707.08145 (DarkSide)

(Several more planned experiments/upgrades not shown for space reasons)

Summary





- Particle Dark Matter would solve model discrepancies in both cosmology and particle physics in an elegant way. WIMPs continue to be a good DM candidate.
- Direct detection is sensitive to the DM component of our galaxy (if the particle is in the right mass range)
- Several running WIMP detectors have not found WIMP Dark Matter, nor other types of Dark Matter (several 'non-standard' searches), but have first evidence of solar neutrinos, opening up many new physics channels.
- Future detectors being designed now will be multi-purpose observatories for astrophysical neutrinos, while continuing to look for DM particle candidates