UCR PHYSICS & ASTRONOMY

Overview of dark matter direct detection experiments, including background and radiopurity challenges

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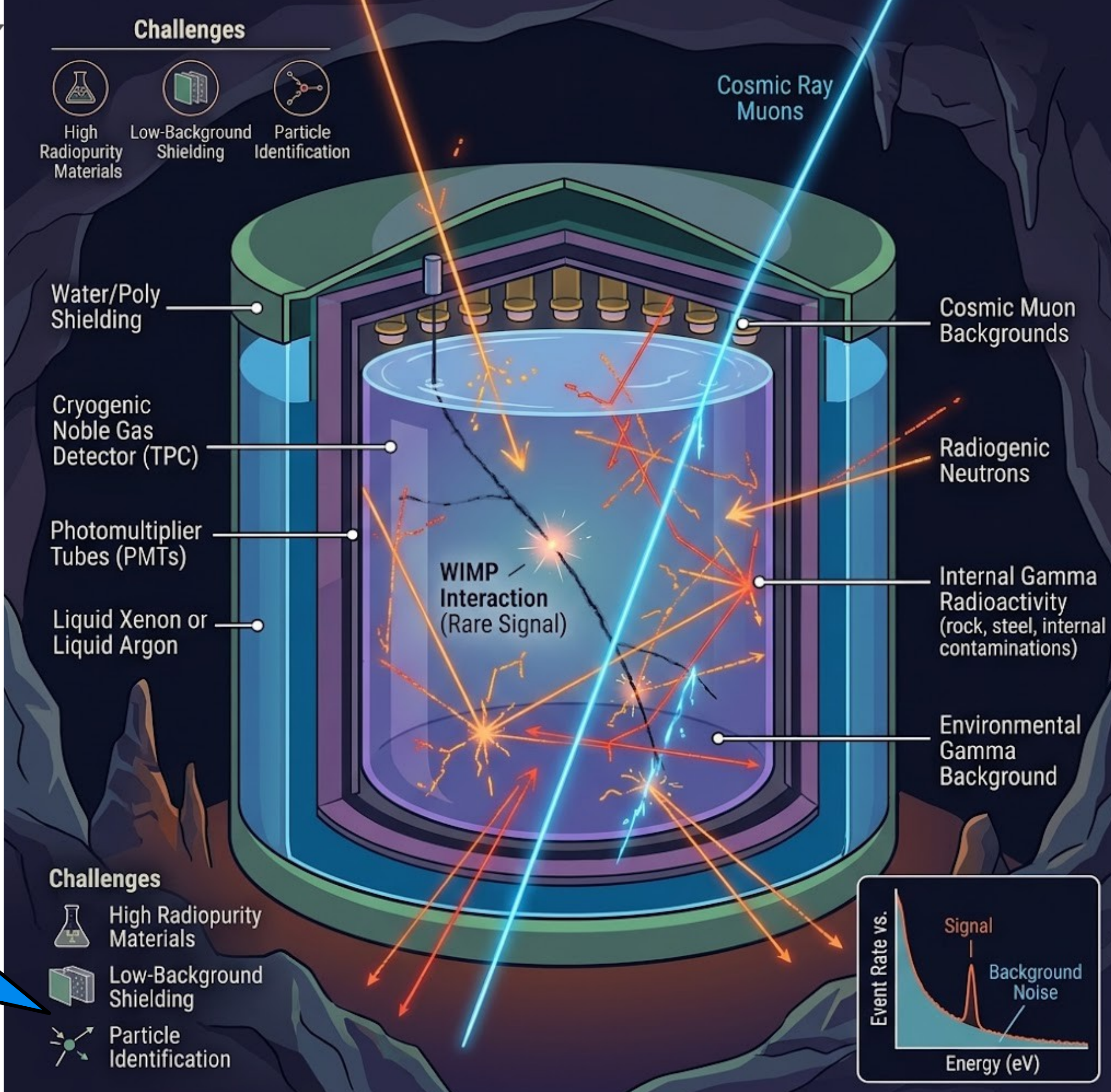
Low Radioactivity Techniques

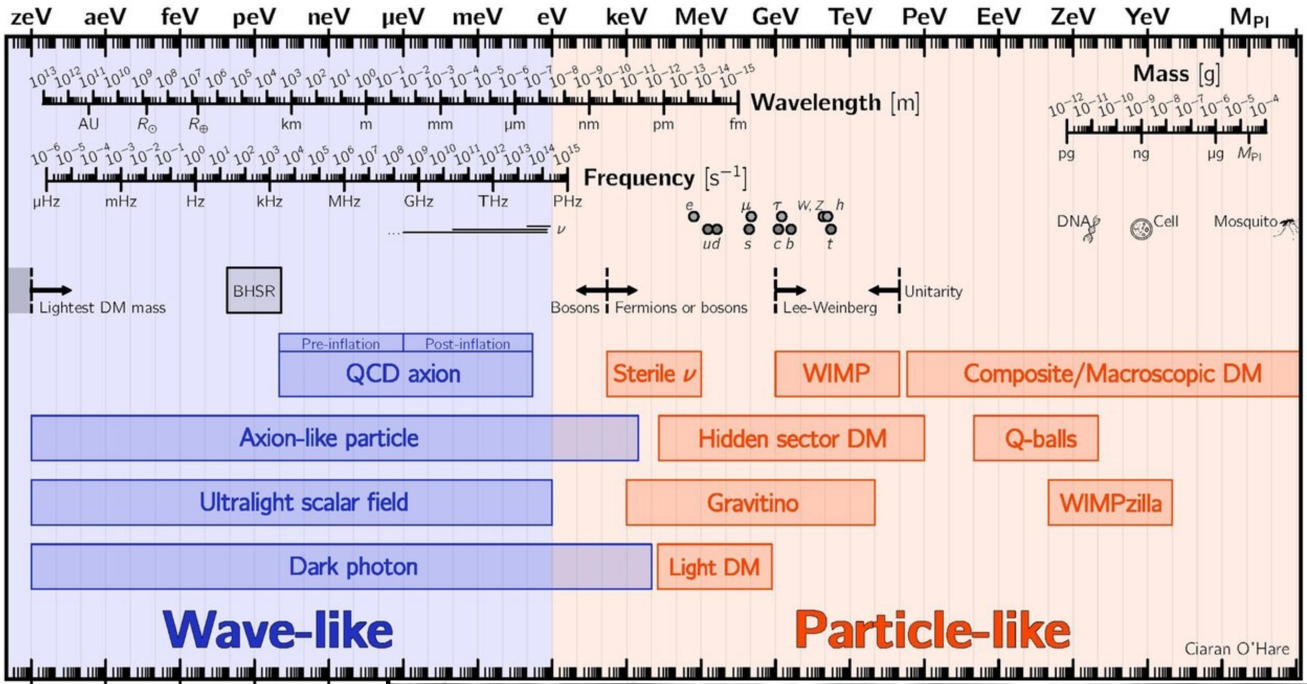
York, UK

22 September, 2026

CE CI Center for Experimental Cosmology & Instrumentation

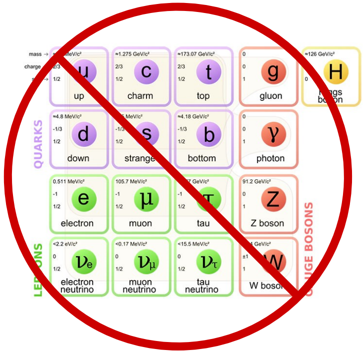
Gemini, illustrate this title

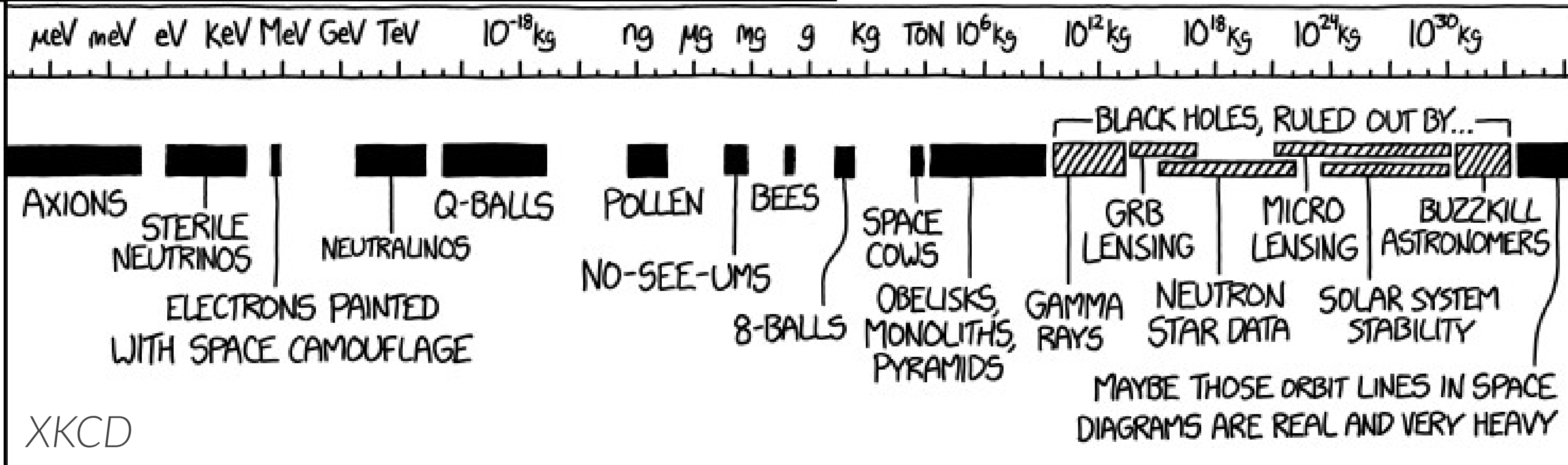


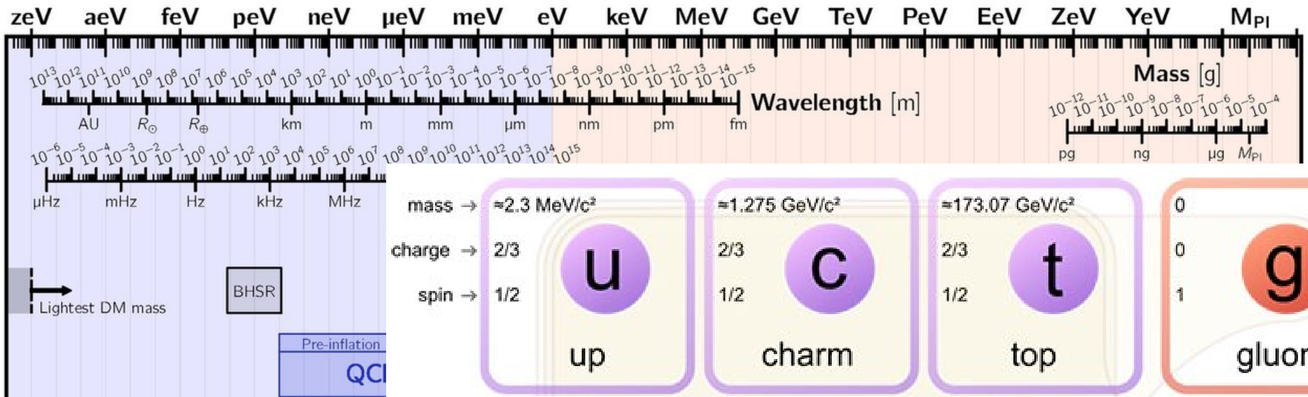


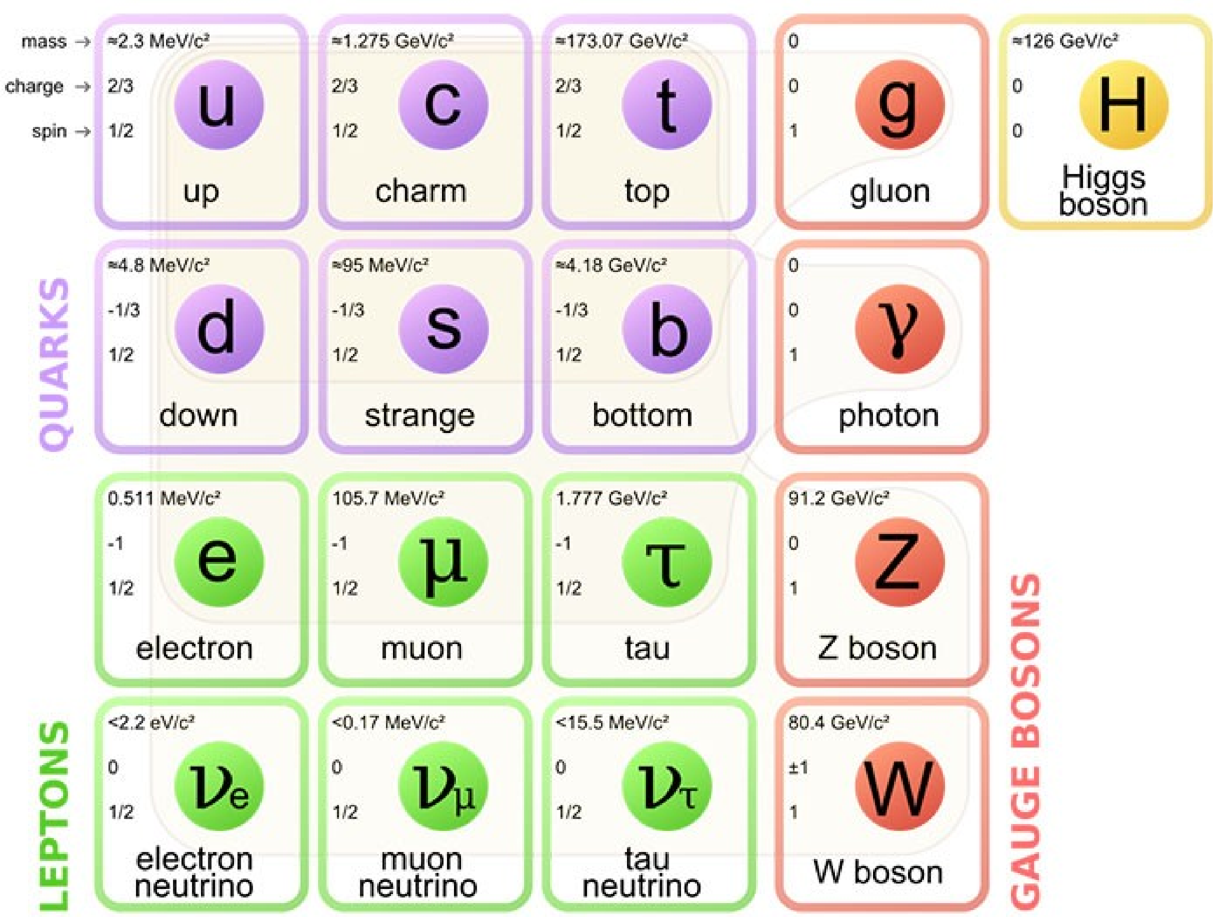
We will discuss

- Different experiments
- Signals we can search for
- Background challenges for these signals



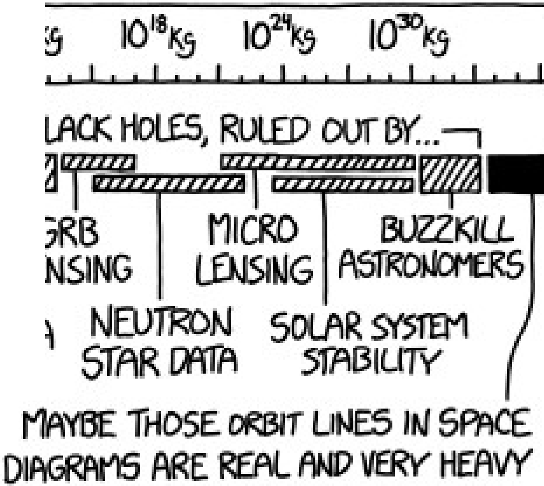






ll discuss

- t experiments
- we can search for
- und challenges
- e signals



XKCD

Dark matter experiments

1. **Scintillation counters:** DEAP-3600 See Chris Jillings talk

See Ewan Fraser talk, Tea Hall poster

1+2. **LAr/LXe TPCs S1+S2:** DarkSide, XENON, LZ, PandaX, XLZD, Argo

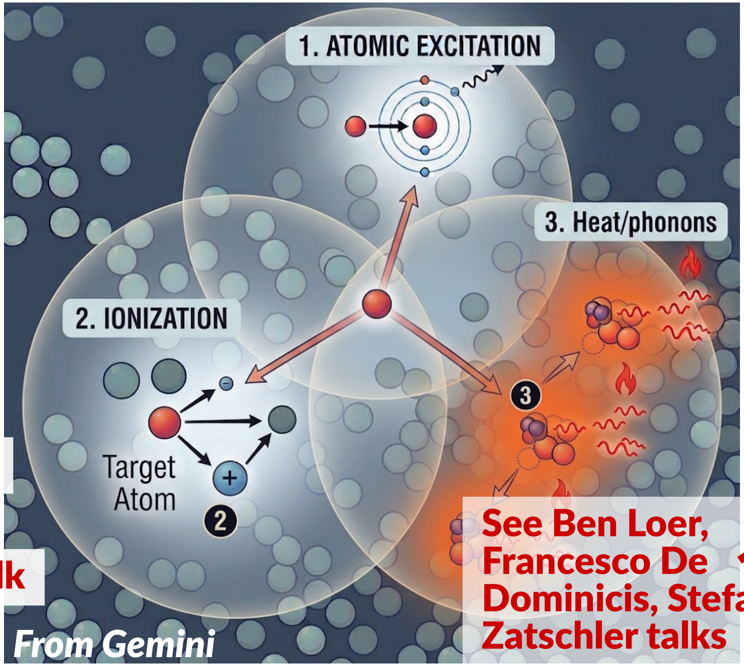
See Celin Hidalgo talk, Sarah Tullio & Michela Lai posters

See Ferdos Dastgiri talk and Bram Miles poster

2. **LAr/LXe TPCs S2-only:** DarkSide-LowMass, DarkSide-20k, XENONnT, LZ, PandaX See Yue Meng talk

Gas ionization chambers: NEWS-G See Marie-Cécil Piro talk

CCDs: DAMIC-M, SENSEI



See Ben Loer, Francesco De Dominicis, Stefan Zatschler talks

1+2. **Scintillating Bubble chambers:** SBC

See Mayank Tripathi talk and Rajan Anderson Dornan poster

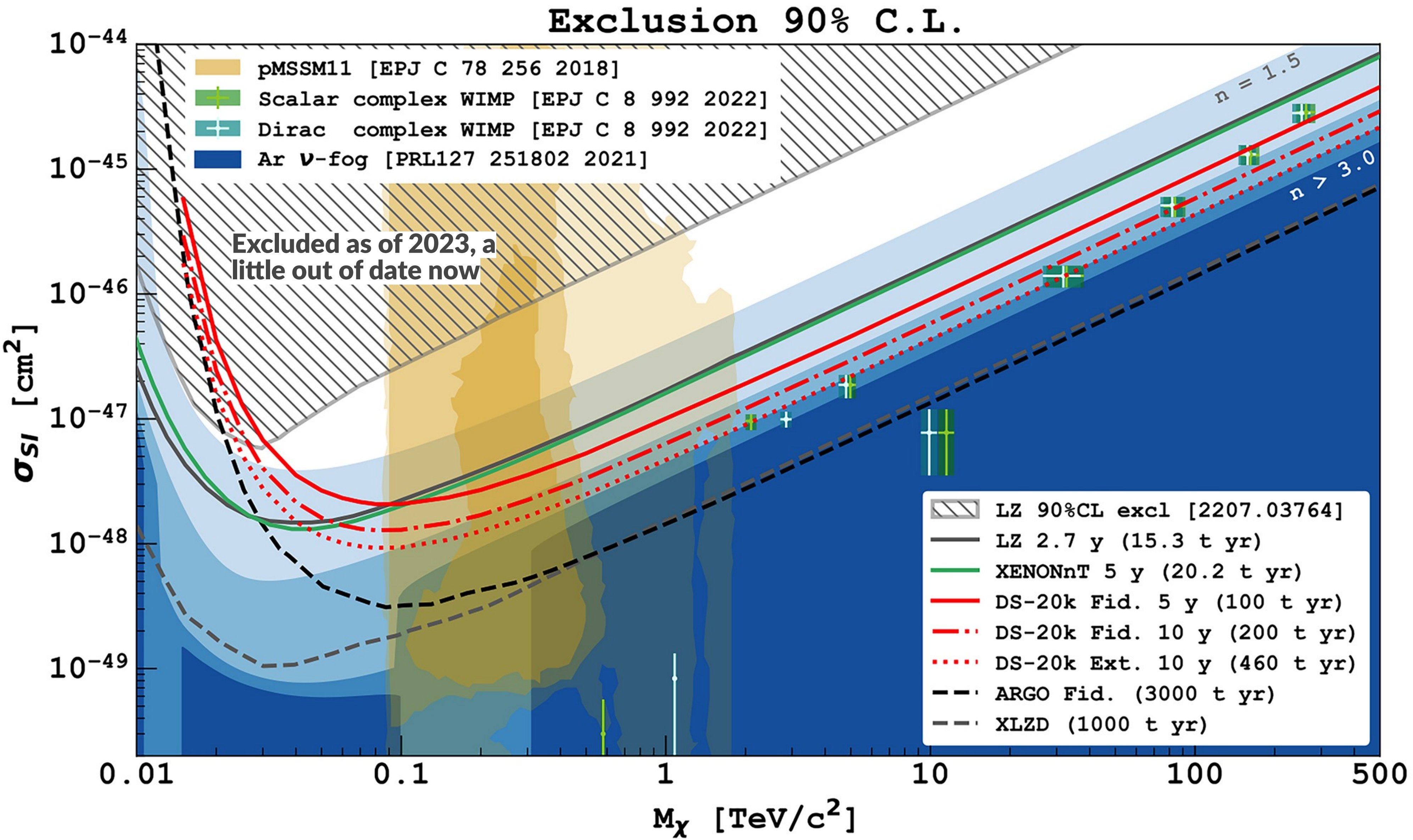
3. **Bubble chambers:** PICO

Phonon detectors: TESSERACT, phonon-only searches in SuperCDMS and CRESST…

See Ziqing Hong talk and Nevena Cail poster

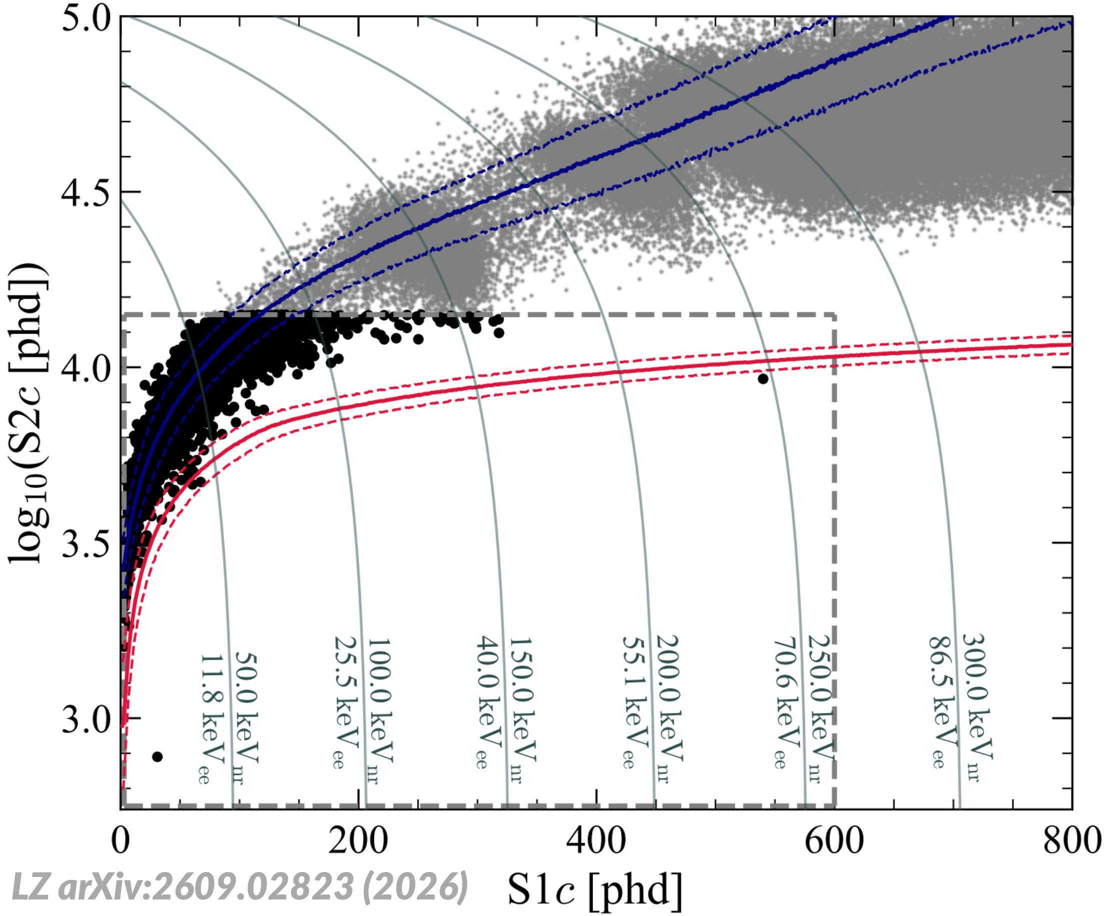
2+3. **Phonon+Charge detectors:** SuperCDMS, CRESST…

See Samir Banik poster

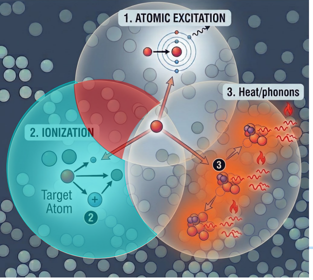


Exclusion 90% C.L.
pMSSM11 [EPJ C 78 256 2018]
Scalar complex WIMP [EPJ C 8 992 2022]
Dirac complex WIMP [EPJ C 8 992 2022]
Ar ν-fog [PRL127 251802 2021]
Excluded as of 2023, a little out of date now
n = 1.5
n > 3.0
LZ 90%CL excl [2207.03764]
LZ 2.7 y (15.3 t yr)
XENONnT 5 y (20.2 t yr)
DS-20k Fid. 5 y (100 t yr)
DS-20k Fid. 10 y (200 t yr)
DS-20k Ext. 10 y (460 t yr)
ARGO Fid. (3000 t yr)
XLZD (1000 t yr)
σ_{SI} [cm^2]
M_χ [TeV/c^2]
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
0.01
0.1
1
10
100
500

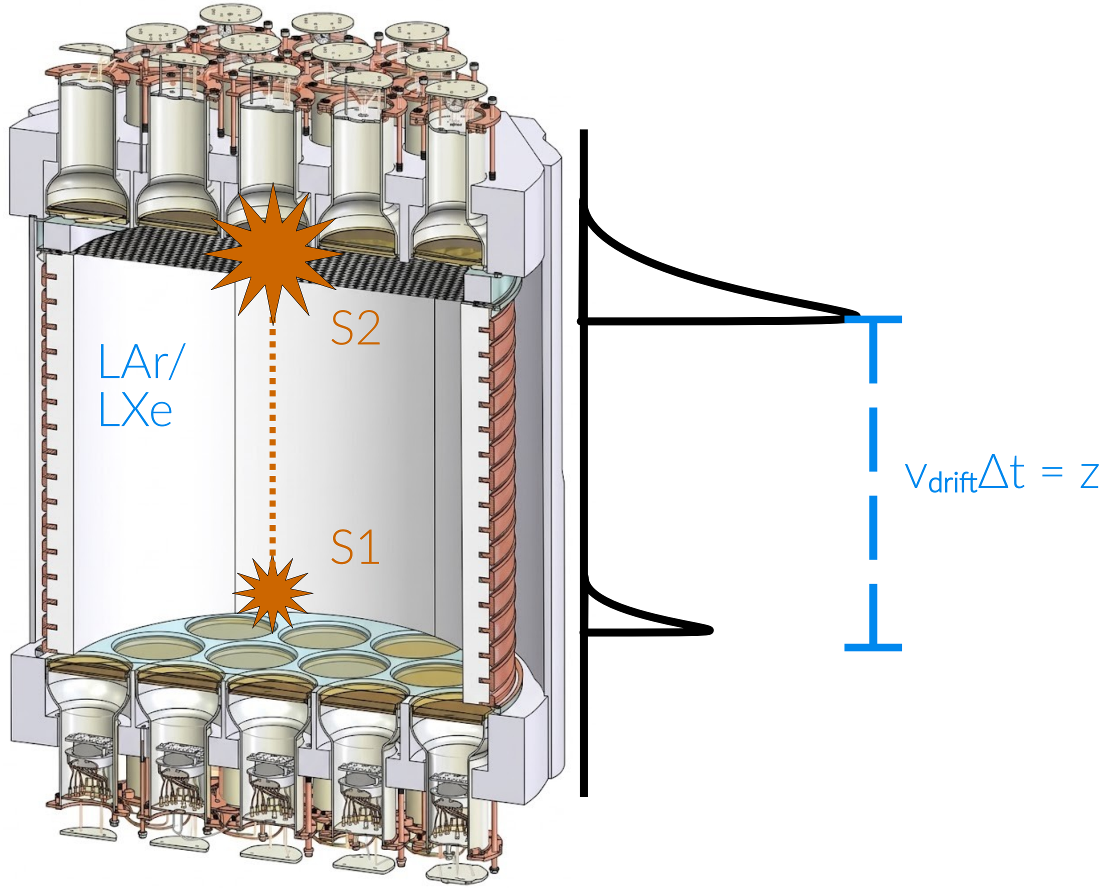
The LZ event: DM or background?



LZ arXiv:2609.02823 (2026)



Noble liquid TPCs



Scalability to large target masses

Excellent transparency to light & electrons

Highly purifiable

Strong event reco and bkgd rejection

Energy: S1, S2 $\propto$Edep

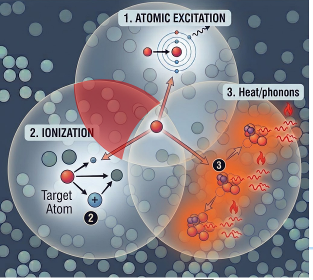
Fiducialization: t_{S2}-t_{S1}→z, S2 PE dist.→x,y

ER/NR discrimination: S2/S1, PSD (in LAr)

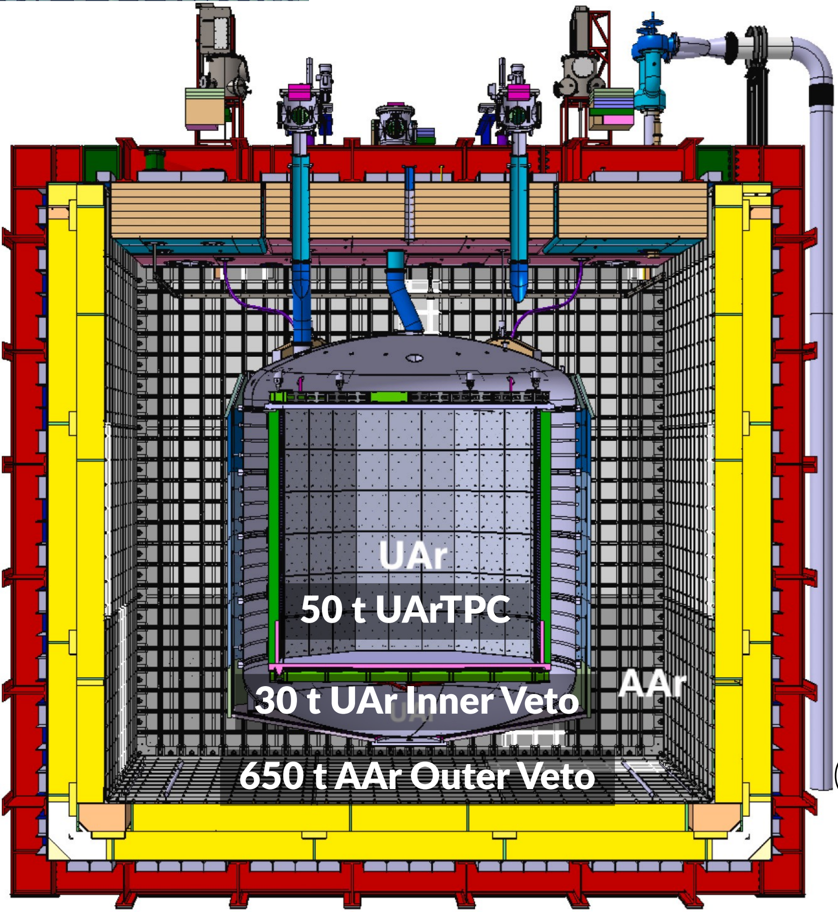
Sensitive DM searches

S1 + S2 analyses for heavy WIMP searches

S2-only analyses for light DM searches



DarkSide/GADMC TPCs

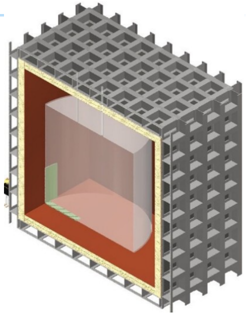


DarkSide-50

50 kg LArTPC
Pioneered UAr, use of neutron vetoes (30 tonne borated LS)

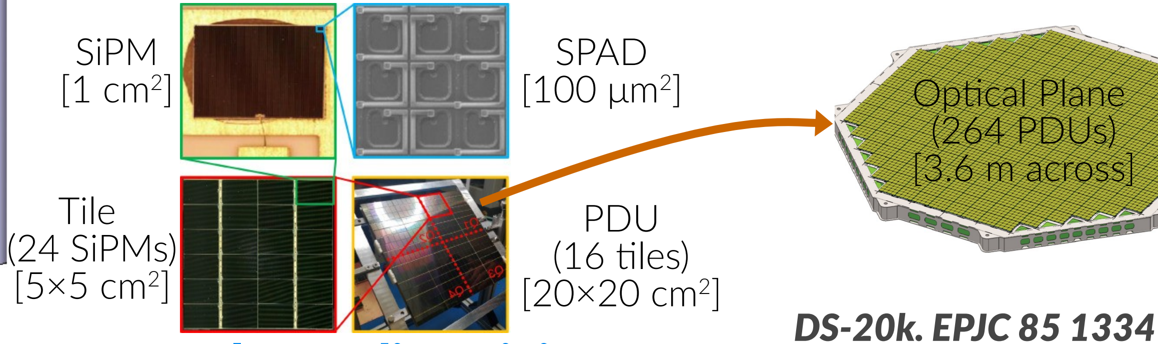
DarkSide-20k

50 t UArTPC + IV + OV
Novel PDU fab.: full swing
Mockup, Proto-0 successful
TPC construction ongoing



Argo

400 t UAr
Targeting WIMP search to ν floor

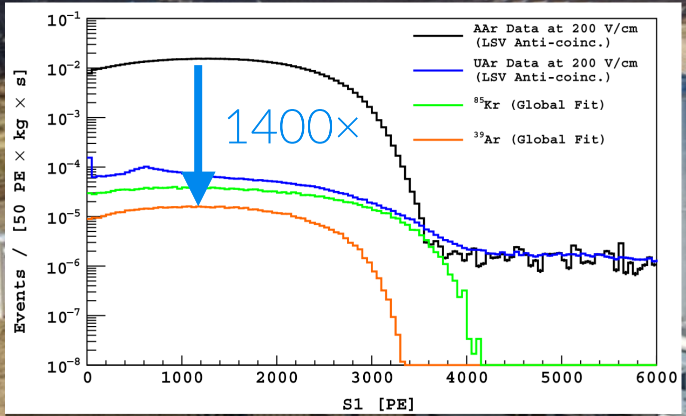


Very low radioactivity!

DS-20k. EPJC 85 1334 (2025)
DS-20k. EPJC 85 534 (2025)

Urania

Cortez, CO, USA
250 – 330 kg/day UAr extraction
Capacity: 120 t over 2 years
UAr purity: 99.99%
Ready for commissioning



DS-50 Phys. Rev. D 93, 081101 (2016)

Aria

Sardinia, Italy
350 m-tall distillation column
1 t/d, 99.999% purification
At 10 kg/d, reduce ^{39}Ar 10×
Serucci-0 (24m) successful

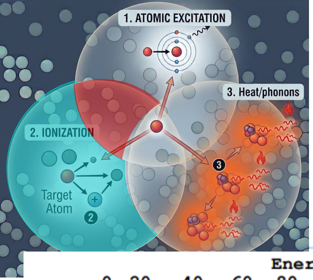
DS-20k. EPJC 83 453 (2023)

DArT-in-ArDM

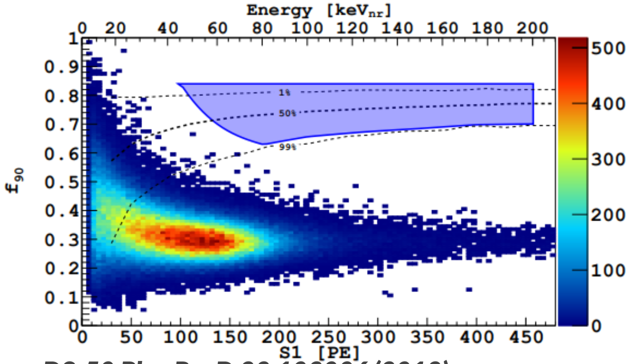
Canfranc Underground Lab, Spain
Measur ^{39}Ar activity in small batch
Operational and running

DS-20k JINST 15 P02024 (2020)

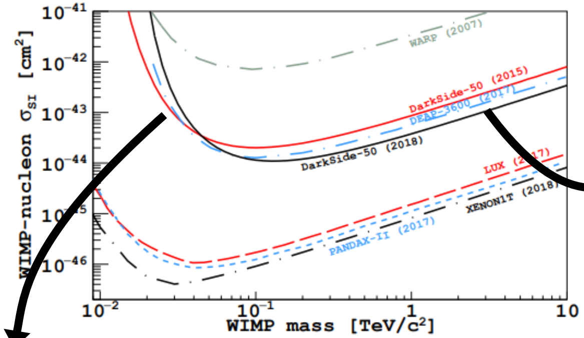
See talks by Celín Hidalgo, Sarah Tullio



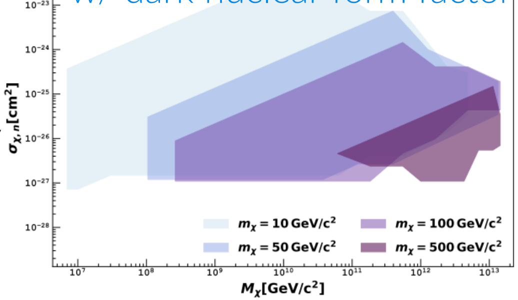
DarkSide-50 results



DS-50 PhysRevD.98.102006 (2018)

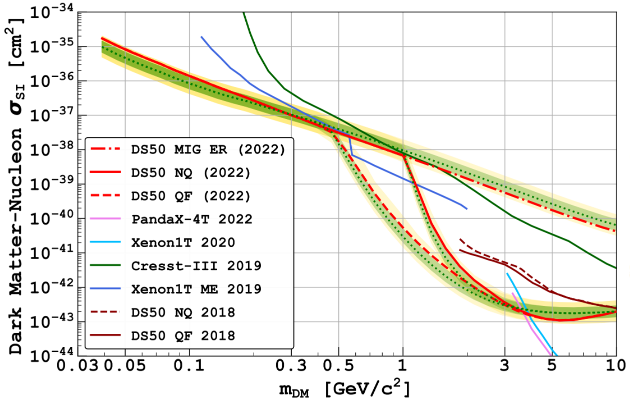


UHDM exclusion regions
w/ dark nuclear form factor



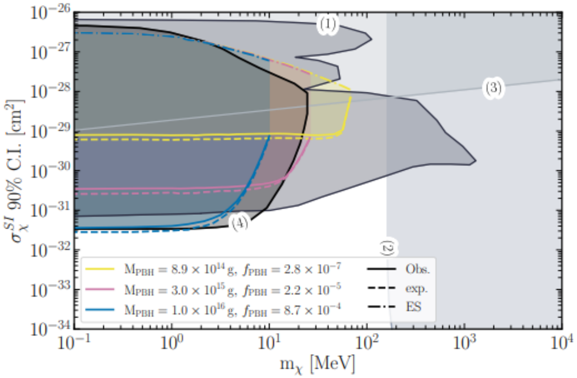
DS-50 Phys. Rev. D 114, 052001 (2026)

LDM-nucelus scattering + Migdal



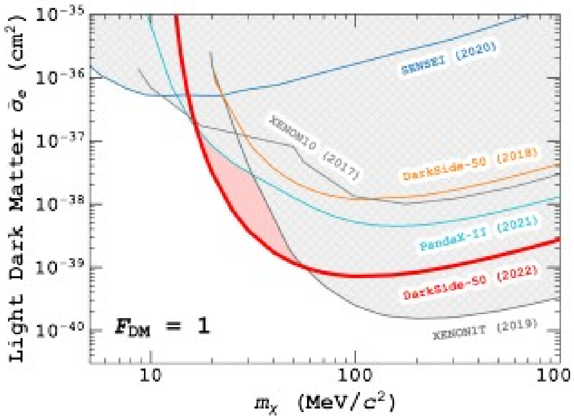
DS-50 Phys. Rev. D 107, 063001 (2023) +
Phys. Rev. Lett. 130, 101001 (2023)

Fermionic DM exclusion
regions from PBH evaporation



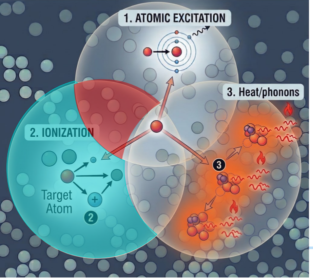
DS-50 Phys. Rev. D 112, 123058 (2025)

LDM-e$^-$ scattering

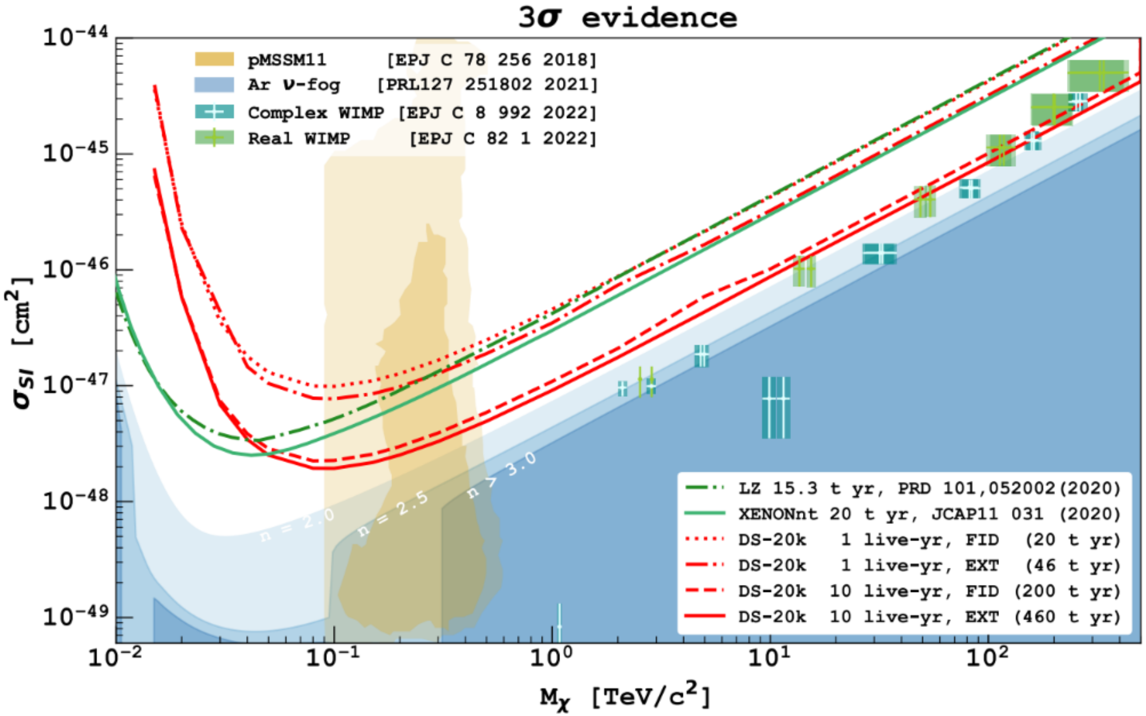


DS-50 Phys. Rev. Lett. 130, 101002 (2023)

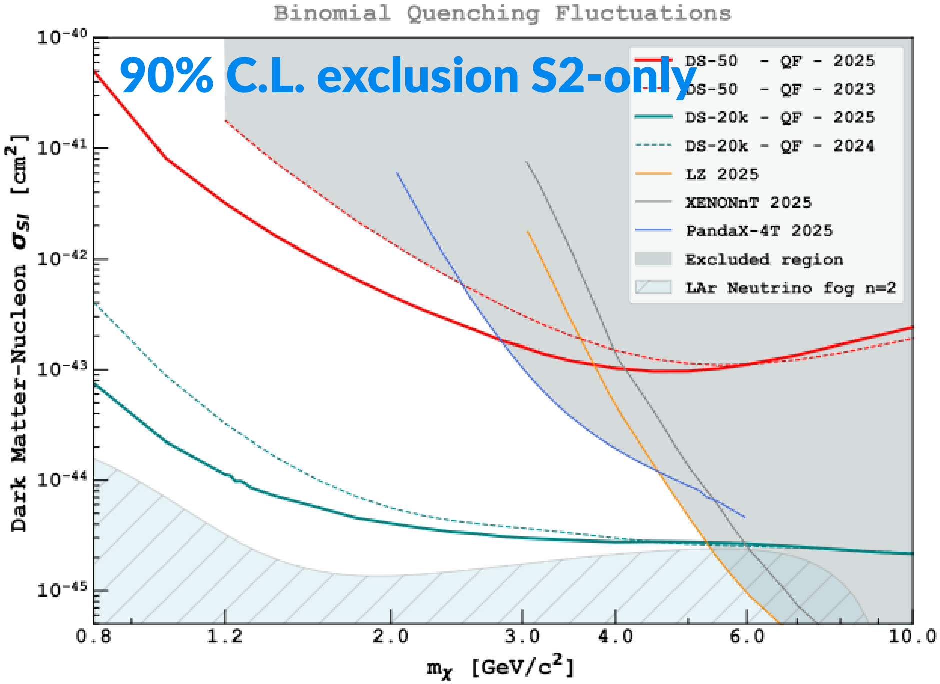
and others



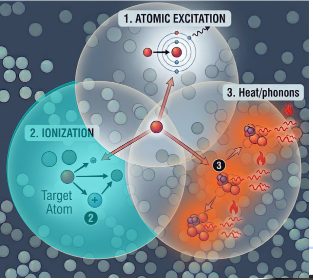
DarkSide-20k projections



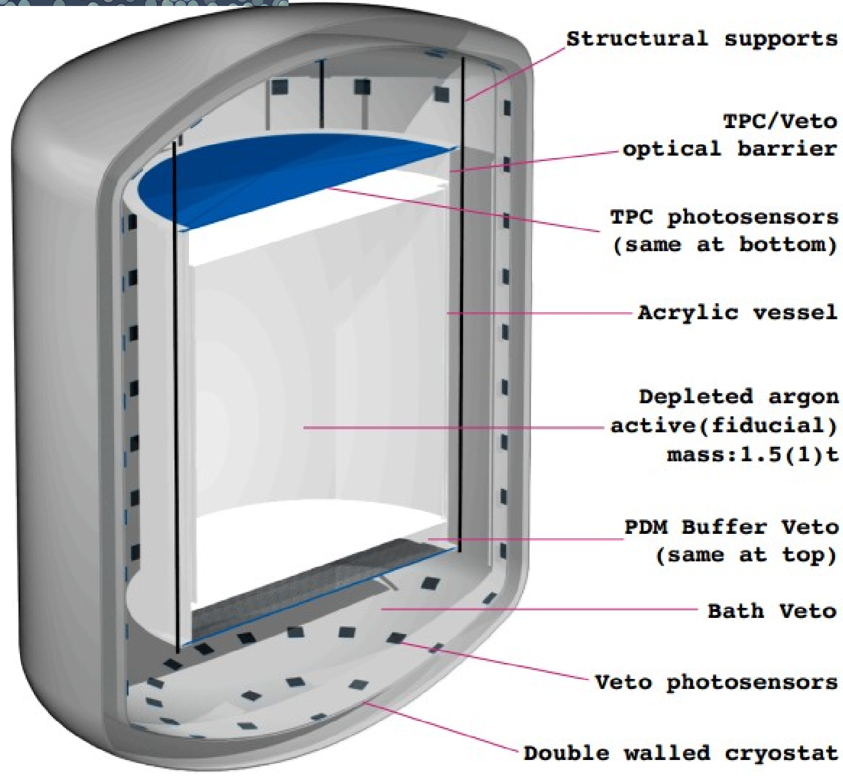
EPJC 133 131 (2018)

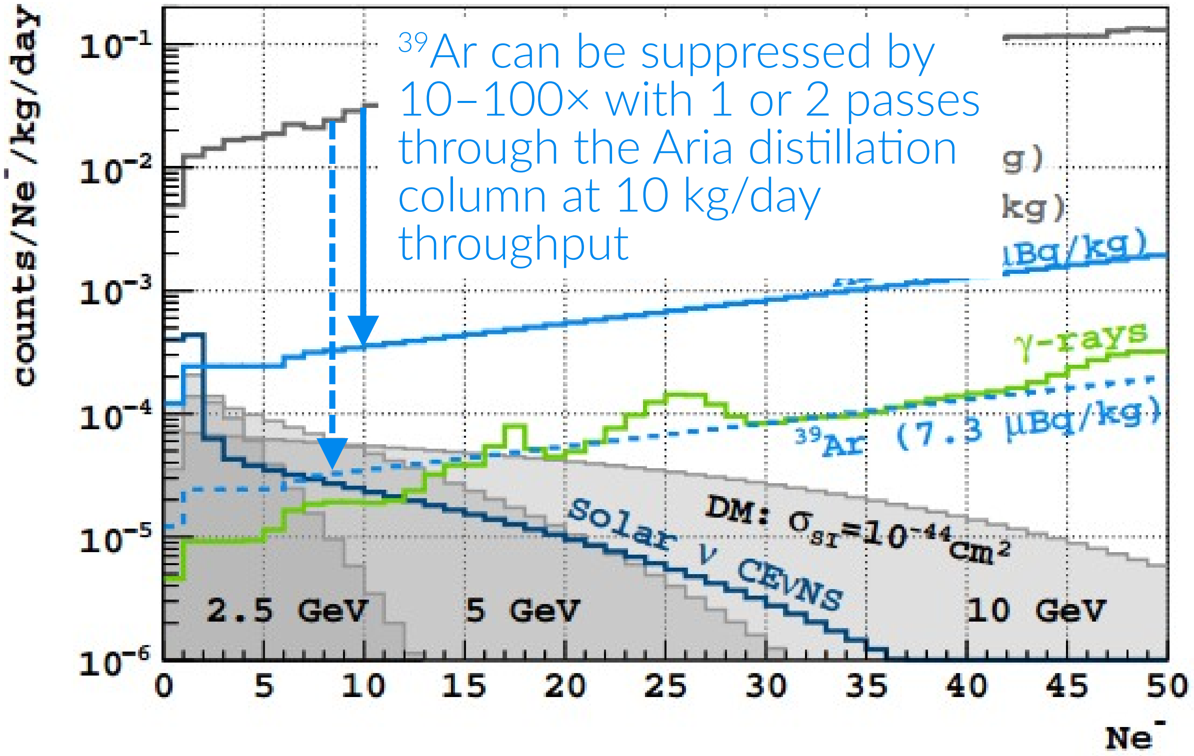


DS-20k Phys. Rev. D 113 123045 (2026)



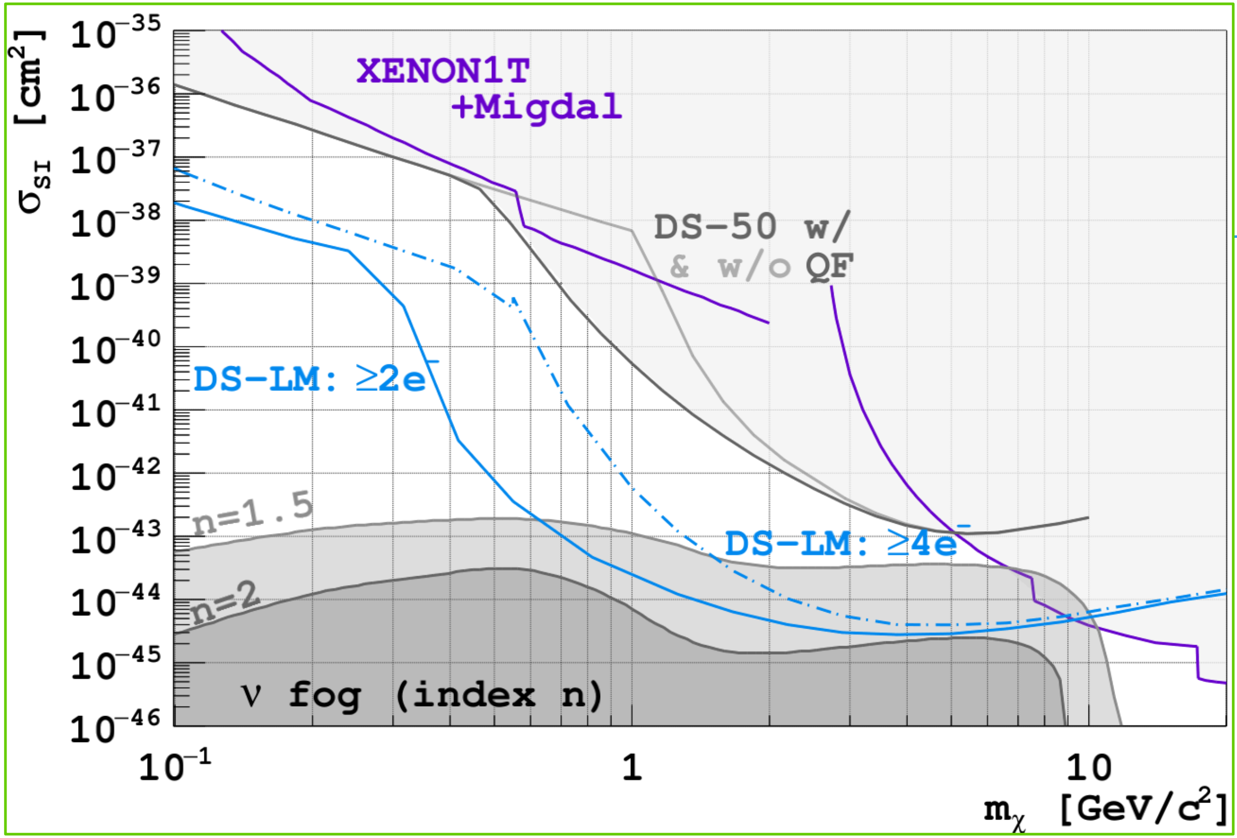
DarkSide-LowMass





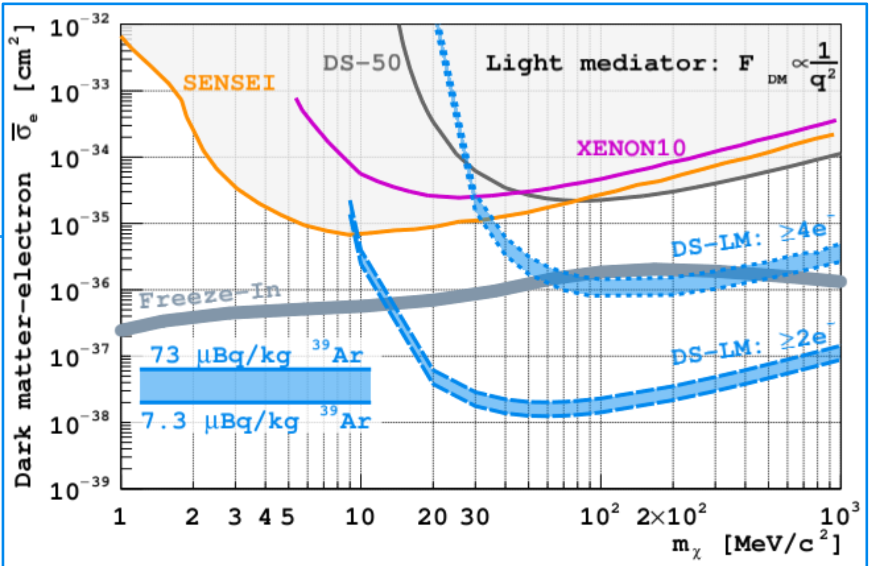
Cryostat immersed in water tank (not shown)

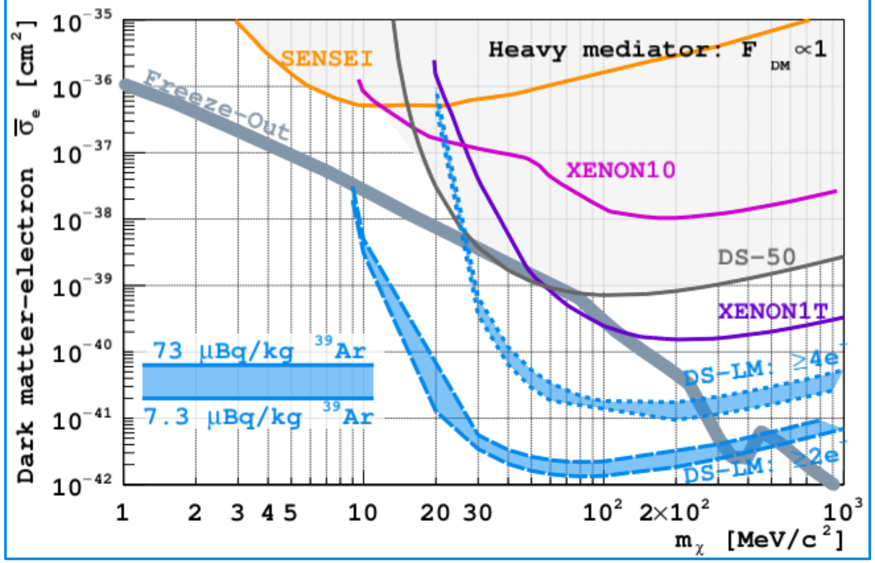
Global Argon Dark Matter Collaboration *Phys. Rev. D 107, 112006 (2023)*



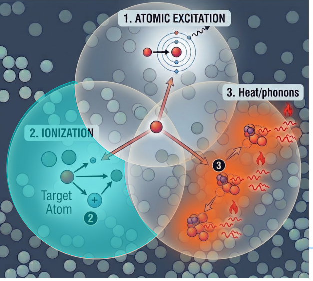
Nuclear couplings: Sensitivity to GeV-scale candidates down into the neutrino fog

Electronic couplings: Sensitivity to sub-GeV candidates covering cross sections that explain the relic abundance in freeze-in and freeze-out production mechanisms





Global Argon Dark Matter Collaboration *Phys. Rev. D 107, 112006 (2023)*



Lower thresholds by doping?

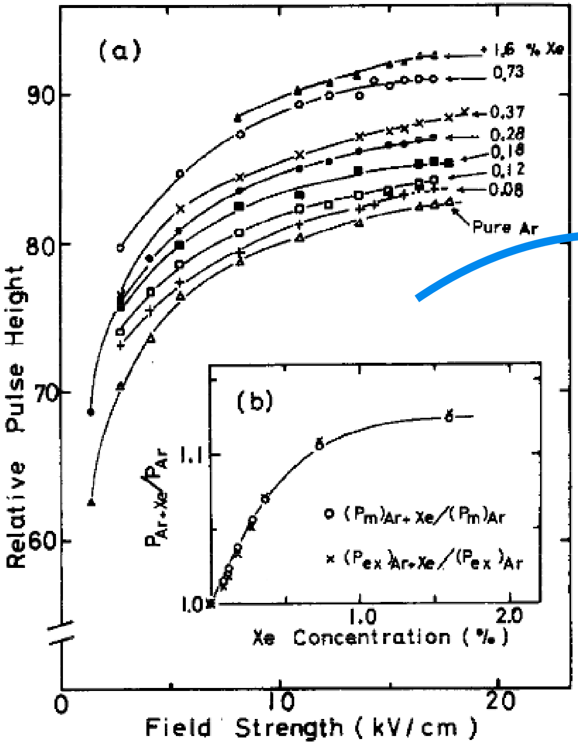


Fig. 1. a) Saturation curves of the pulse height produced by ^{207}Bi conversion electron for the different concentration of Xe. b) Relative ionization yields as a function of doped-Xe concentration.

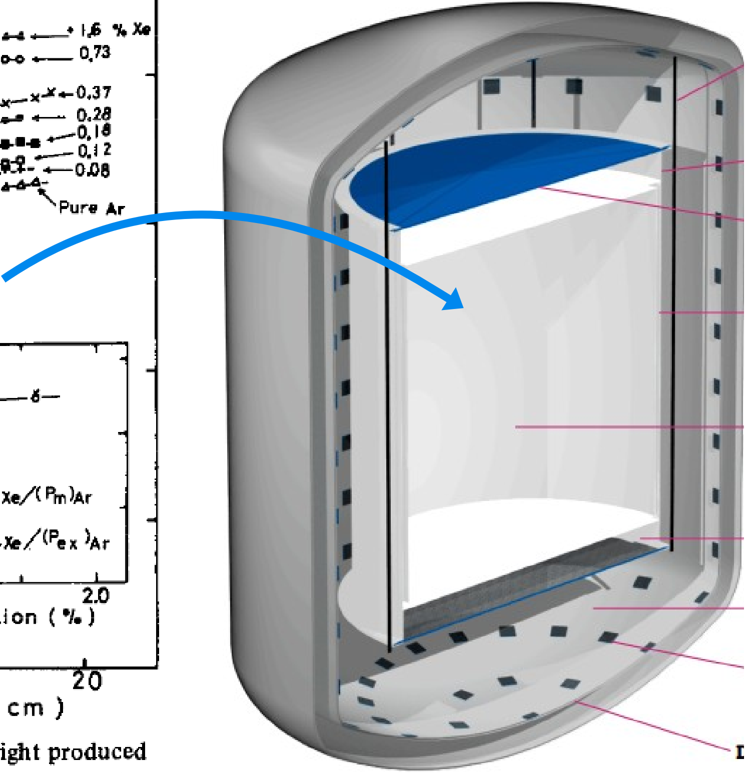


Photo-sensitive dopants:

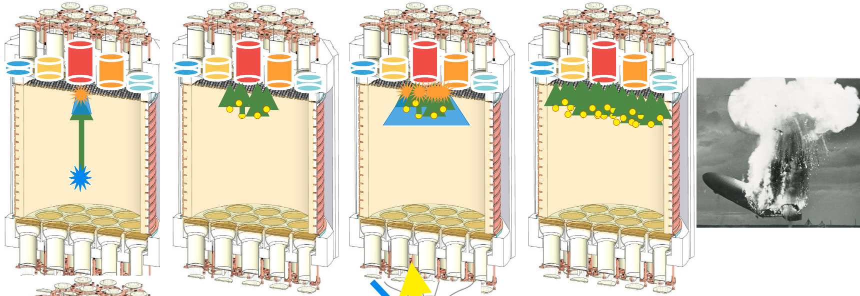
Low ionization energy → High e$^-$ yield

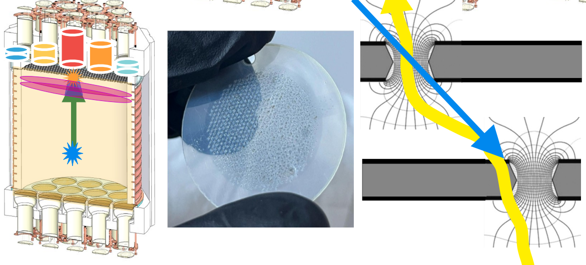
Convert S1 to S2 → More e$^-$

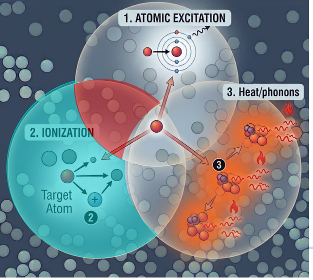
At high concentrations: ^{1}H as target

Ongoing R&D!

Also studied for HydroX in LXe

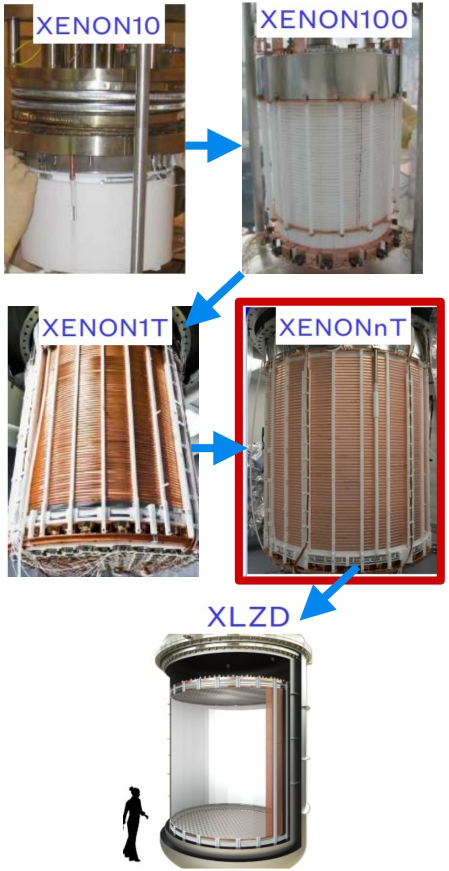






XENONnT

Credit: *Shengchao Li, "Recent Dark Matter Search Results from XENONnT"Closing in on thermal relics*
Masatoshi Kobayashi, "The XENONnT experiment and its latest results", TeVPA 2026



Ongoing upgrades of XENONnT

8.5 t LXe total

Upgrades will fix cathode electrodes → expecting 10× better ER/NR discrimination

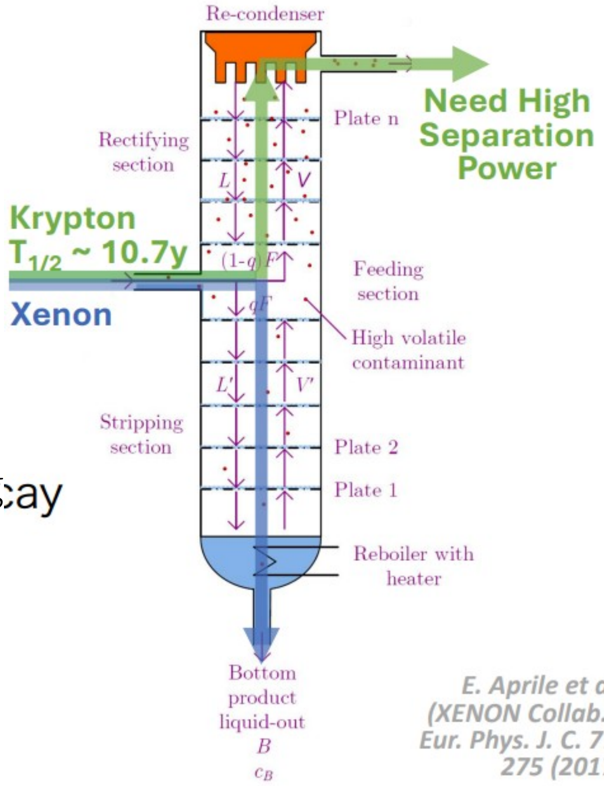
Target purification

Inline distillation column

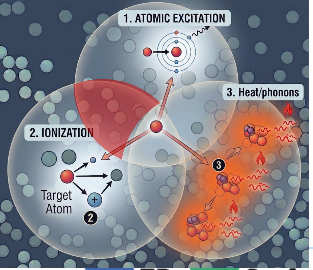
Lowers ^{85}Kr to 48 ppq→9 nBq/kg

^{222}Rn abundance ~1 µBq/kg

XENONnT. EPJC 84 8, 784 (2024)

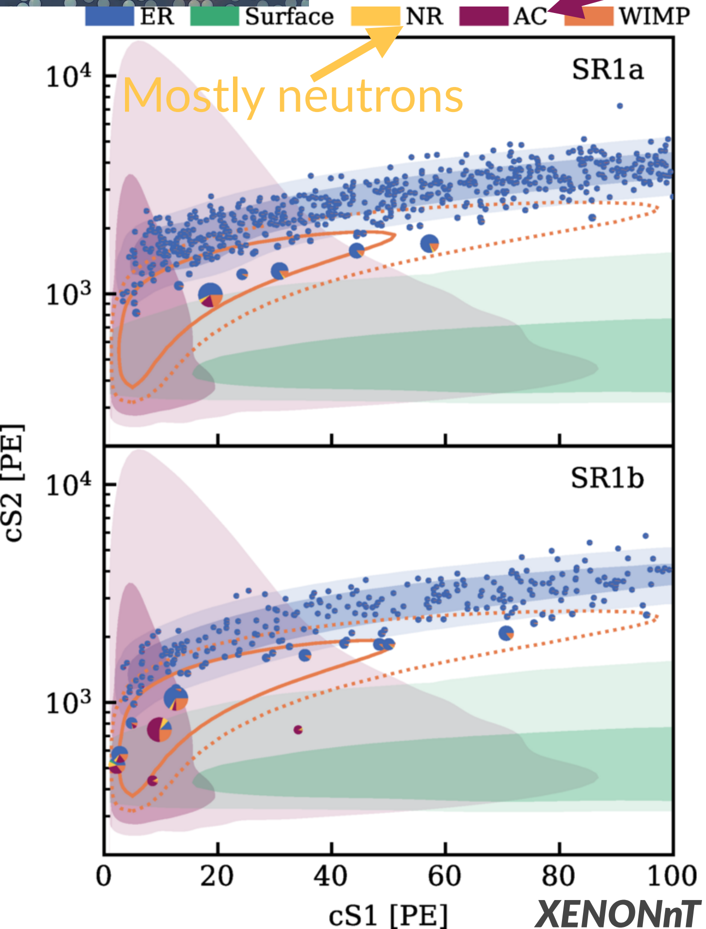


E. Aprile et al. (XENON Collab.), Eur. Phys. J. C. 77, 275 (2017)



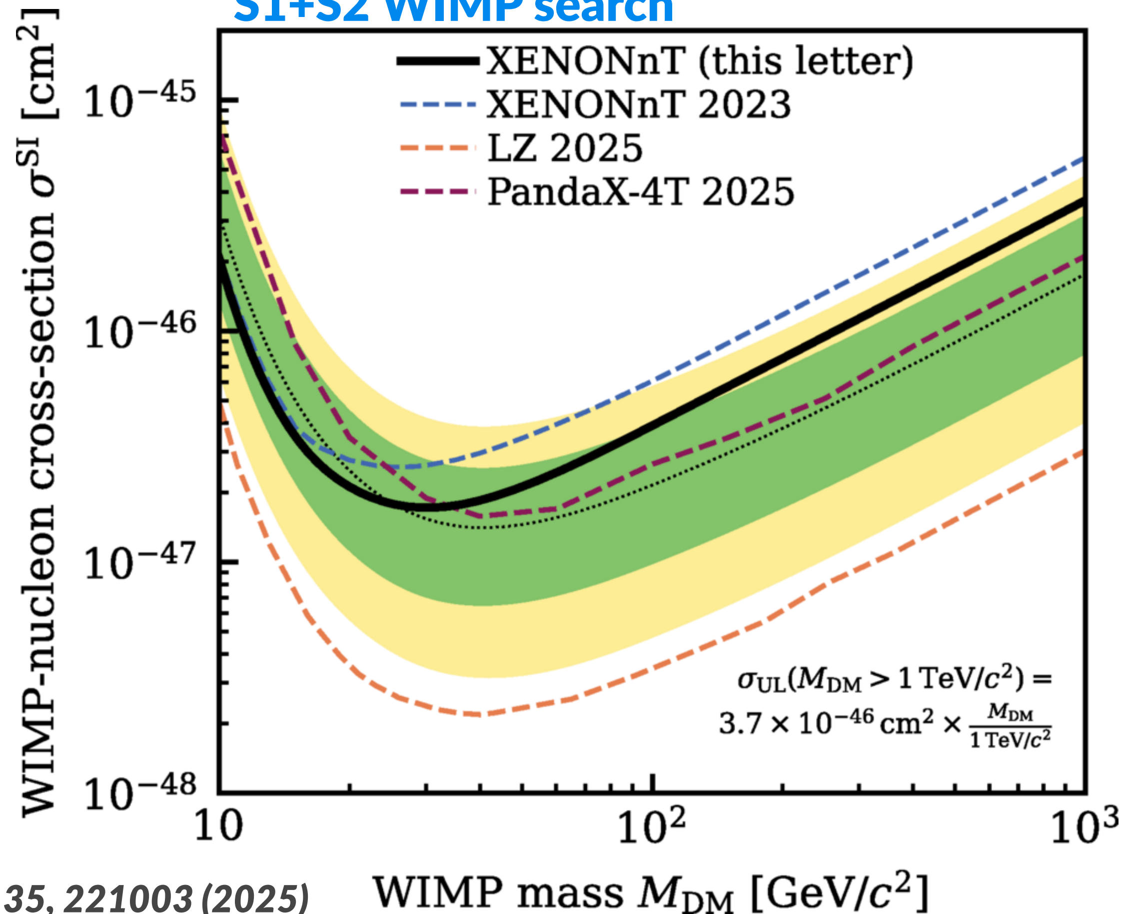
XENONnT WIMP search

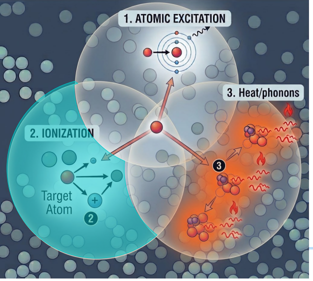
Mismatched S1/S2 (Acc. Coinc.)



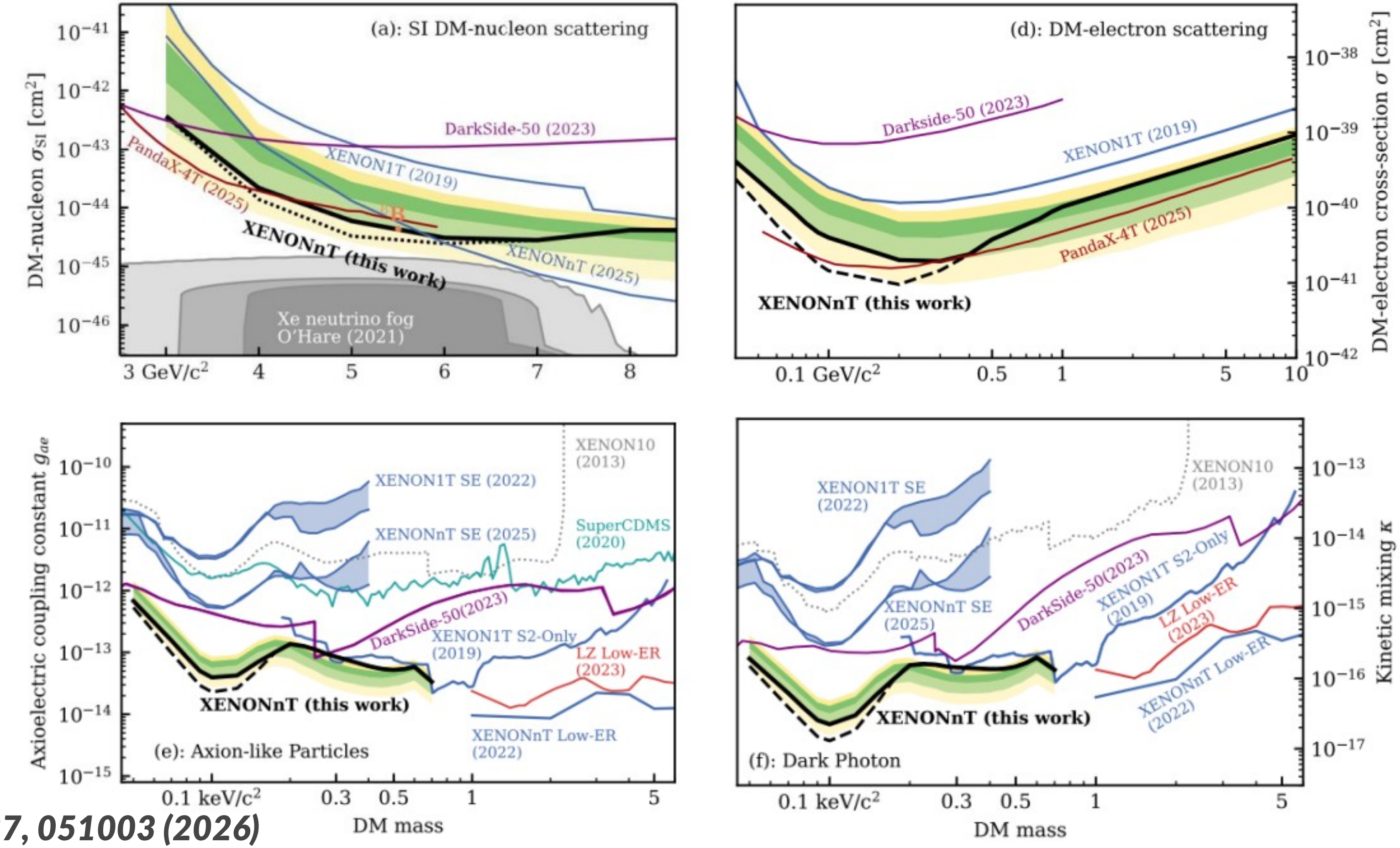
XENONnT PRL 135, 221003 (2025)

S1+S2 WIMP search

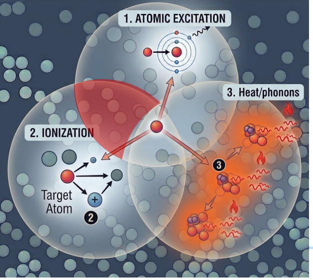




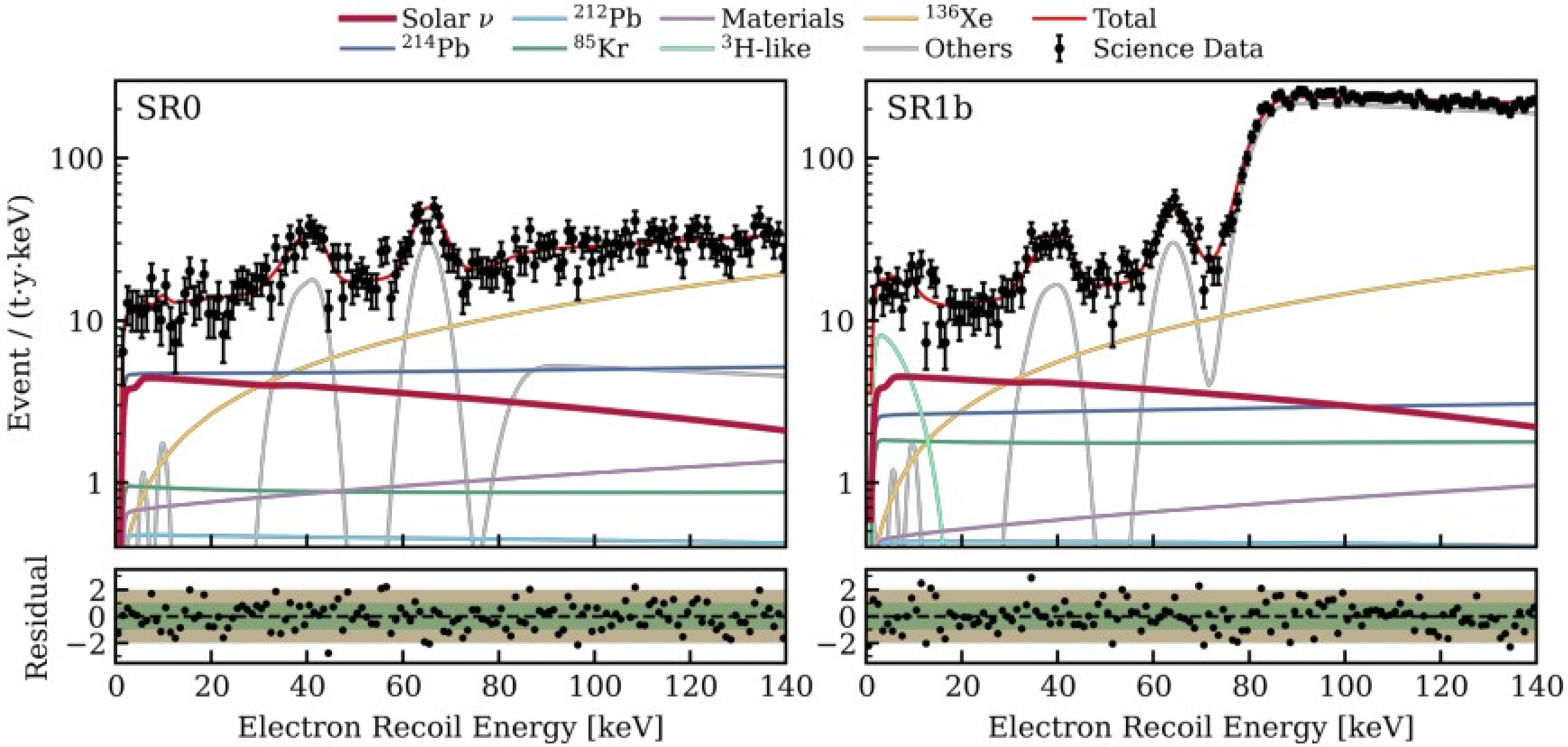
XENONnT S2-only search



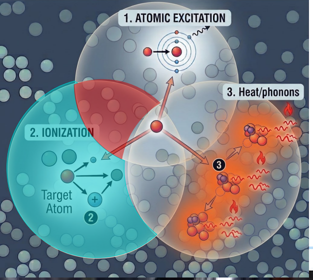
XENONnT PRL 137, 051003 (2026)



XENONnT pp ν-e⁻ scattering

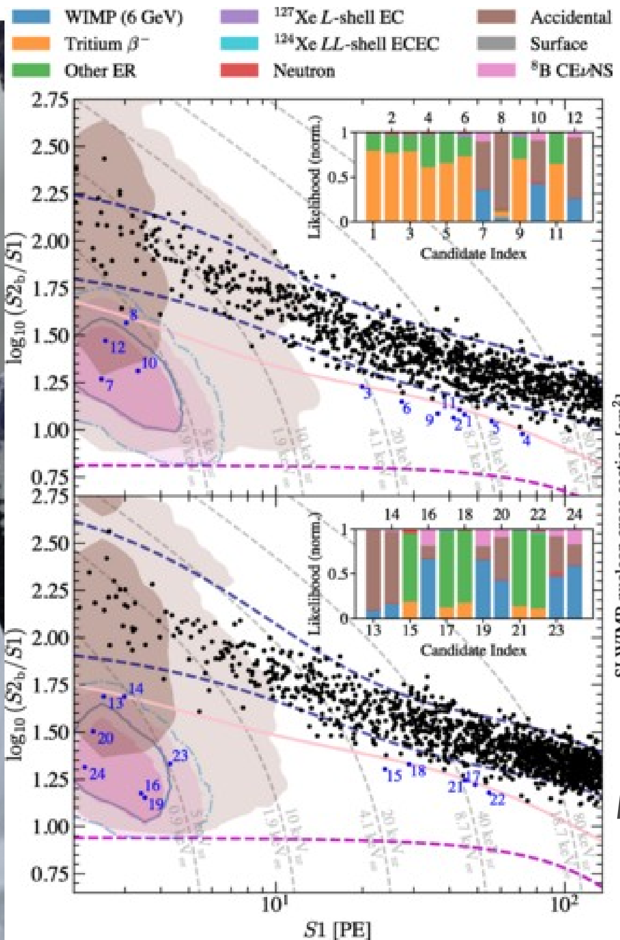


XENONnT arXiv:2608.29450



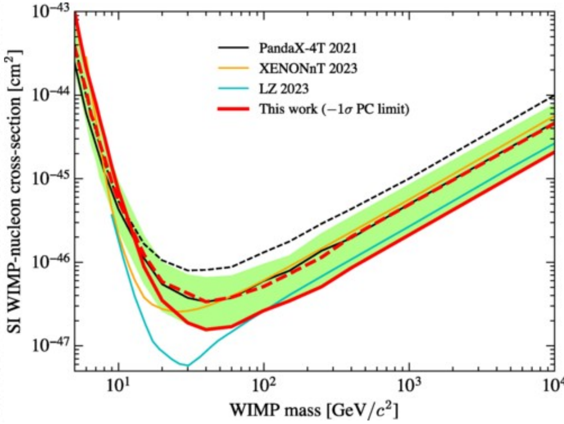
PandaX-4T

See Yue Meng's talk!

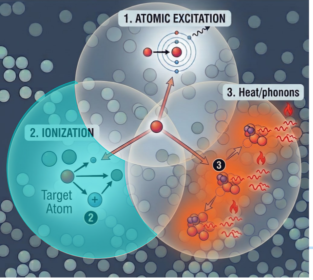


Full program complete: ~700 live days

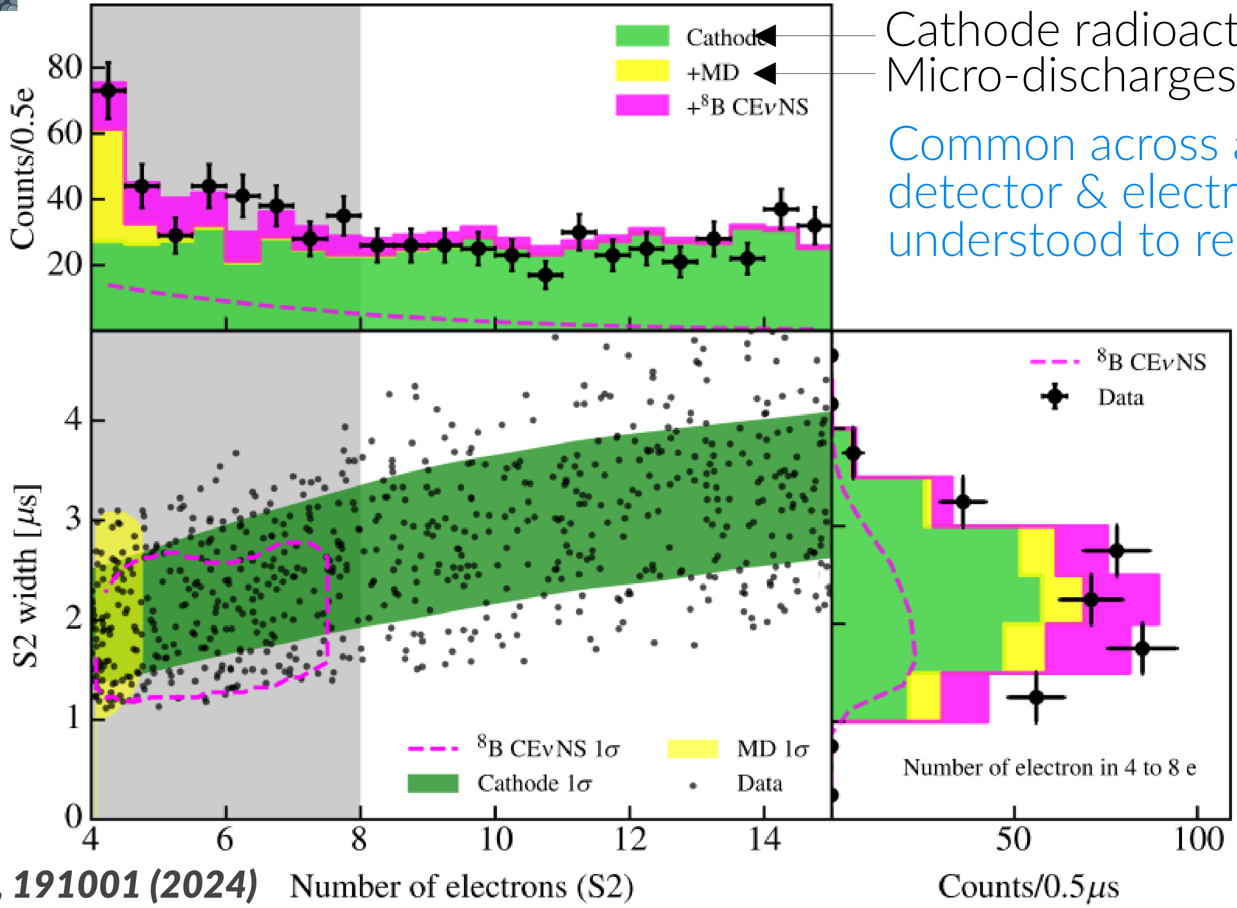
PandaX-20T funded, preparing for installation in 2027



PandaX PRL 134 011805 (2025)



PandaX-4T 2.6σ "indication" of ^{8}B CEvNS in S2-only

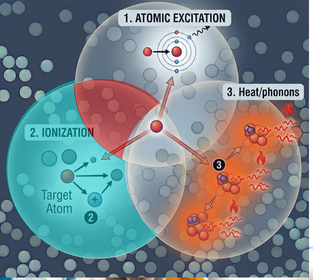


Cathode radioactivity

Micro-discharges

Common across all TPCs: low-energy detector & electrostatic effects must be understood to reach >3σ!

PandaX PRL 133, 191001 (2024)

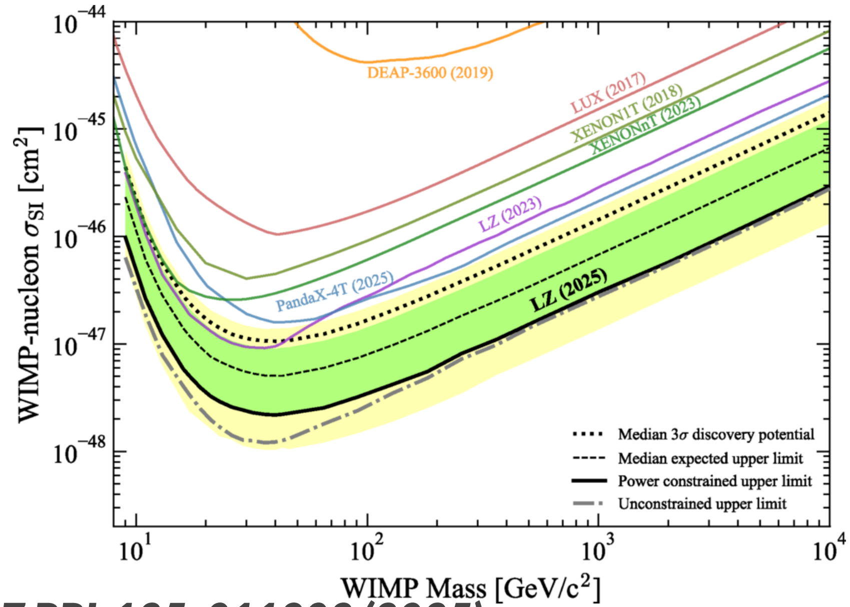


LUX-ZEPLIN (LZ)

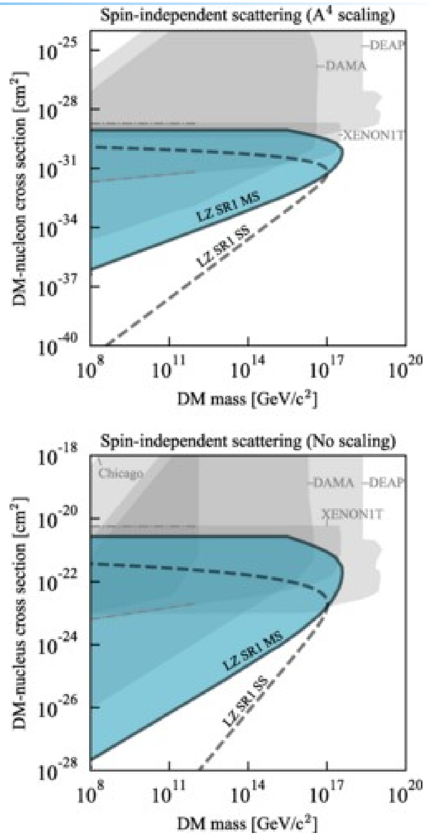
Exposure: 7 t active mass, since 2021

Veto system: Xe skin (γ-rays) + GdLS neutron veto + water muon veto

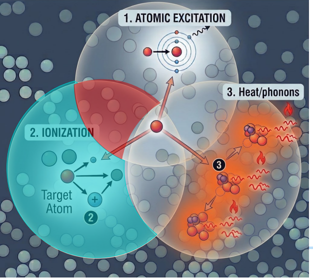
Primarily designed for WIMP searches; sensitive to a wide range of phenomena



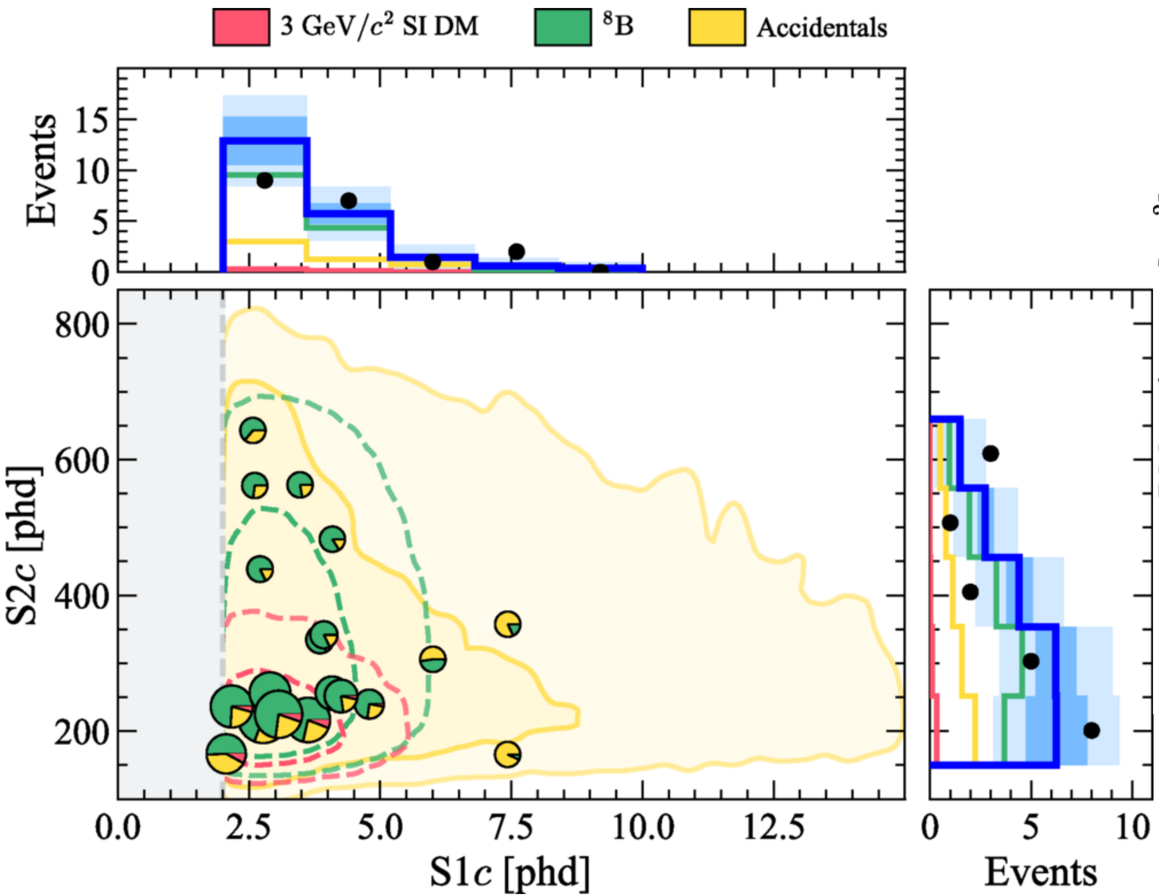
LZ PRL 135, 011802 (2025)

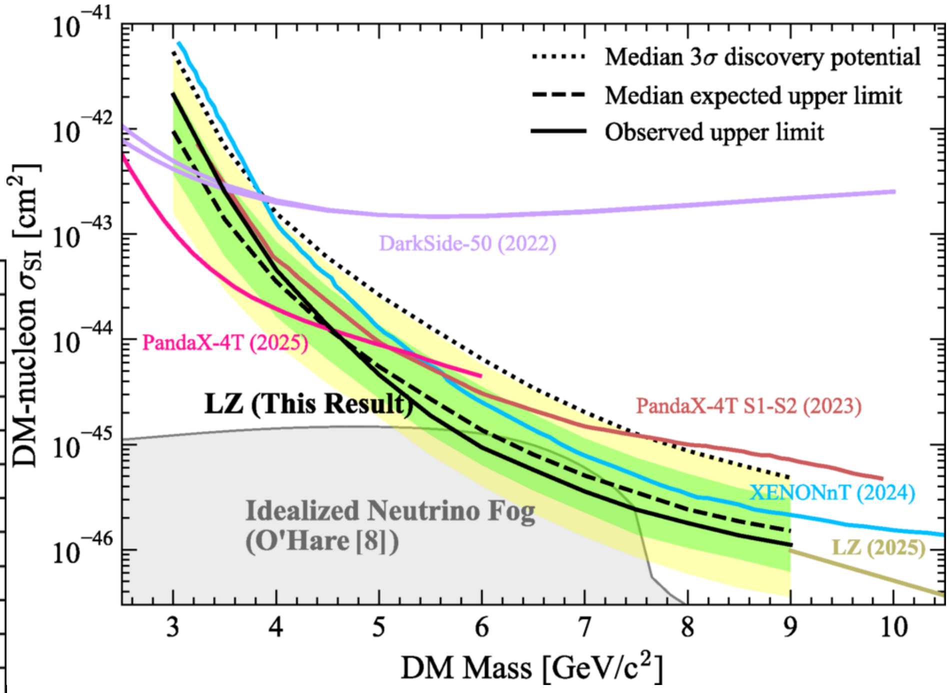


LZ PRD 109, 112010 (2024)



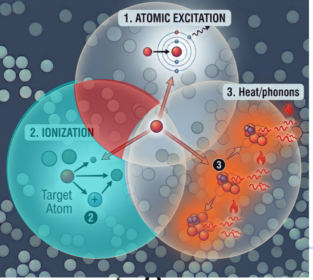
LZ measurement of ^{8}B CEvNS 4.5σ and light DM search



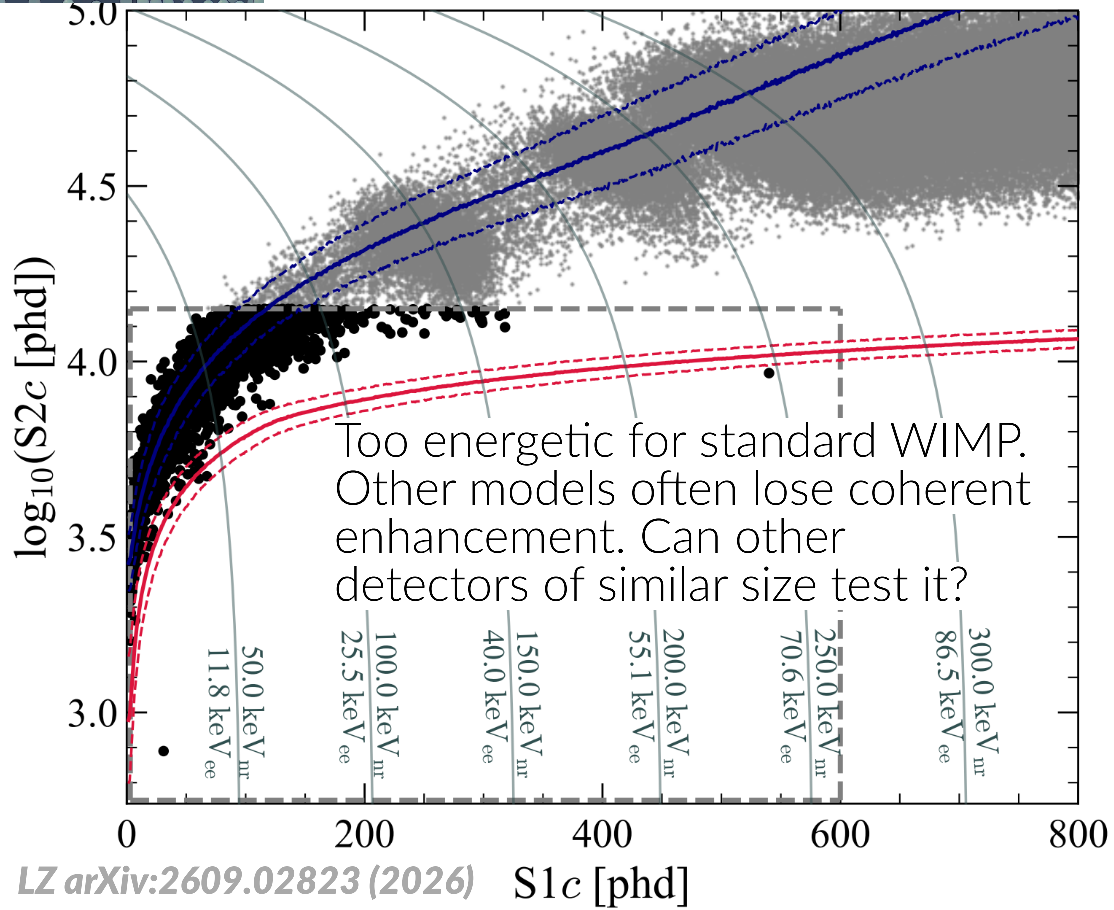


LZ PRL 137, 091806 (2026)

When is he going to mention the recent result??



The LZ event (2.6σ)

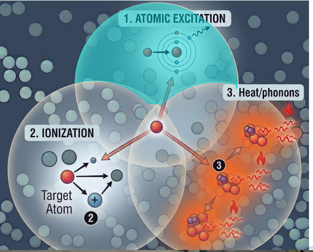


Too energetic for standard WIMP. Other models often lose coherent enhancement. Can other detectors of similar size test it?

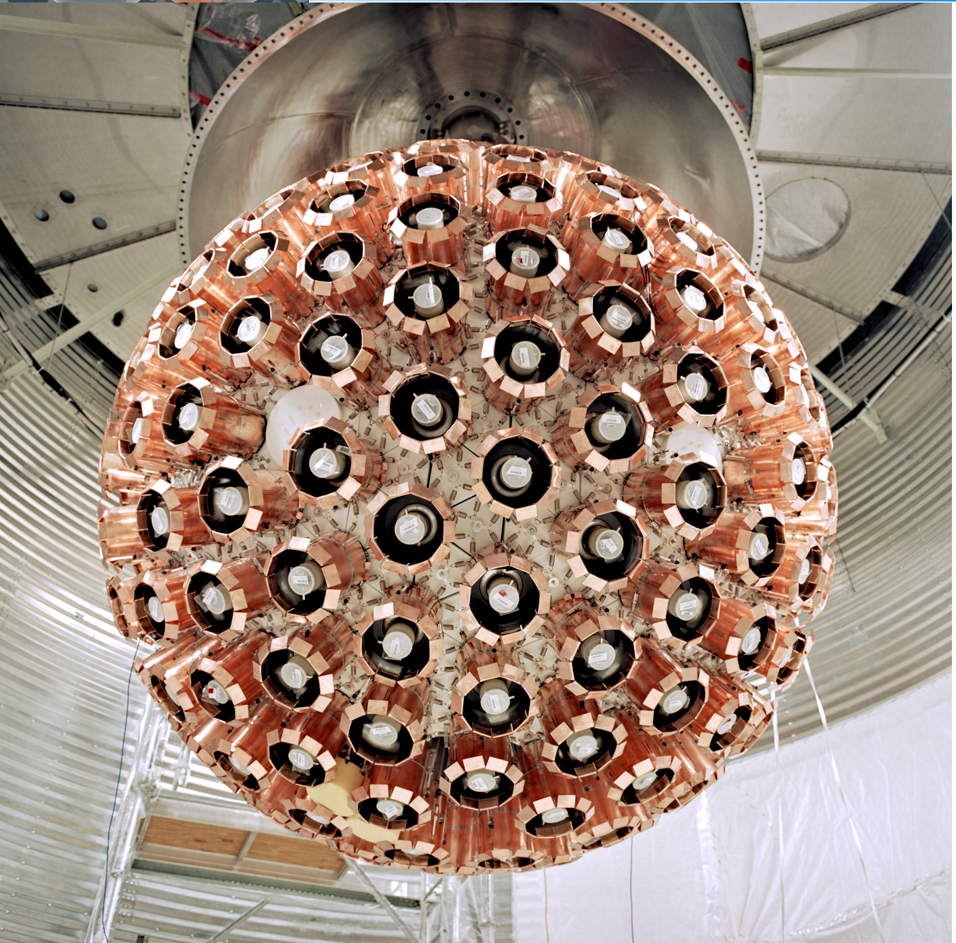
LZ arXiv:2609.02823 (2026)

NR event, 2.6σ tension with background model in 2.8 t-yr exposure, including:

Source	Expected Events	Fit Result
Internal β decays	1341 ± 160	1340 ± 43
ν ER	140.6 ± 8.4	140.3 ± 8.4
^{136}Xe	110.0 ± 16.5	114.2 ± 16.1
CH_3T & ^{14}C	55.3 ± 3.1	55.2 ± 3.1
^{124}Xe	21.0 ± 6.3	22.6 ± 5.0
^{83m}Kr	17.1 ± 5.1	$17.0^{+3.5}_{-3.3}$
^{125}I	8.9 ± 2.7	9.8 ± 2.3
Detector ERs	8.5 ± 3.4	$9.4^{+1.7}_{-1.6}$
Accidental coincs.	2.7 ± 0.6	2.6 ± 0.6
^{127}Xe + ^{125}Xe	1.5 ± 0.3	1.2 ± 0.3
Atmospheric ν	$(1.1 \pm 0.2) \times 10^{-1}$	$(1.1 \pm 0.2) \times 10^{-1}$
^{8}B+*hep* ν	$(5.7 \pm 0.6) \times 10^{-2}$	$(5.7 \pm 0.6) \times 10^{-2}$
MSSI	$(4.9 \pm 4.9) \times 10^{-3}$	$(4.6^{+4.8}_{-4.6}) \times 10^{-3}$
Detector NRs	–	$[0, 0.118]$
1000 GeV/c^2 WIMP	–	$1.0^{+1.4}_{-0.7}$
Total counts	–	1713 ± 39
Observed counts	–	1710



DEAP-3600



Exposure: 3.3 t LAr, 7.1 t-yr (total), 2.7 t-yr (fid)

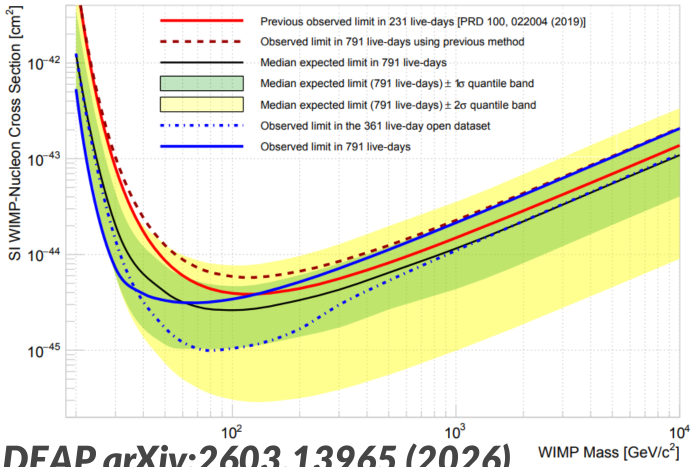
Shielding: 50 cm-thick acrylic + filler blocks

Status: Paused in 2020 for upgrades. Now testing

WIMP search: 231 live-day bkgd free (2017)
790 live-day, bkgd limited (2026)

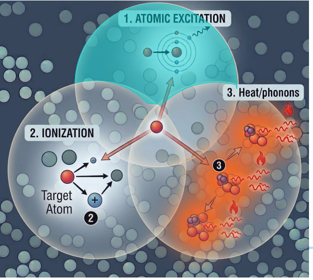
Low Rn: 0.153±0.005 μBq/kg ^{222}Rn
4.3±1.0 nBq/kg ^{220}Rn

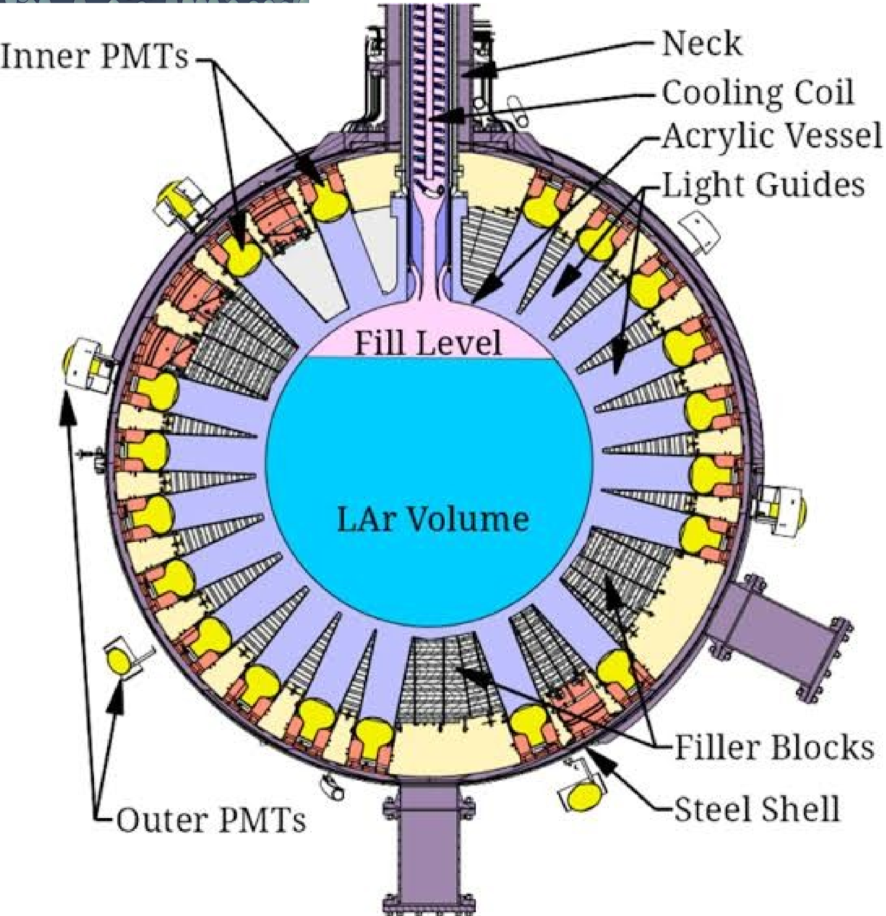
See Chris Jilling's talk



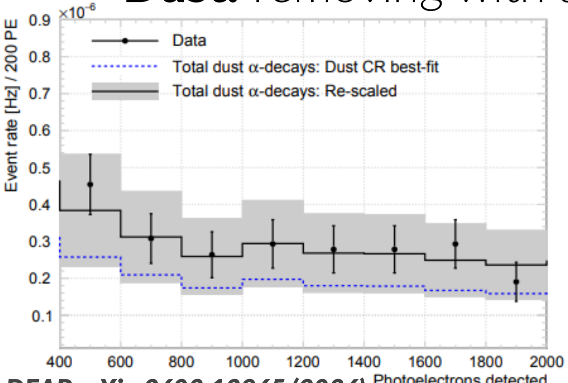
DEAP arXiv:2603.13965 (2026)

DEAP-3600's main backgrounds and upgrades to solve them

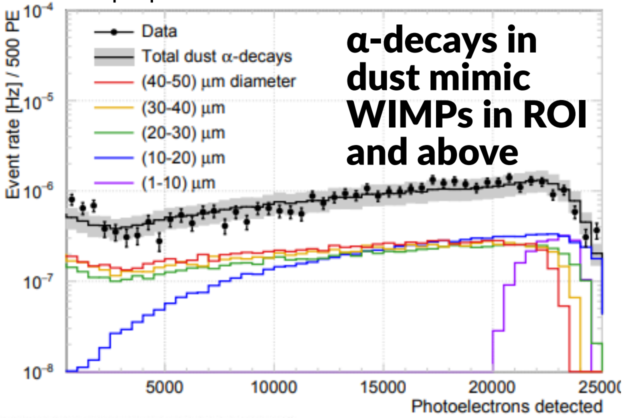




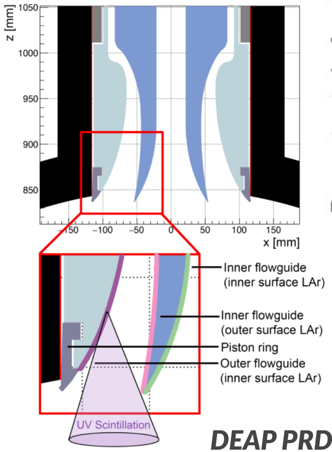
Dust: removing with a LAr pipe + filtration

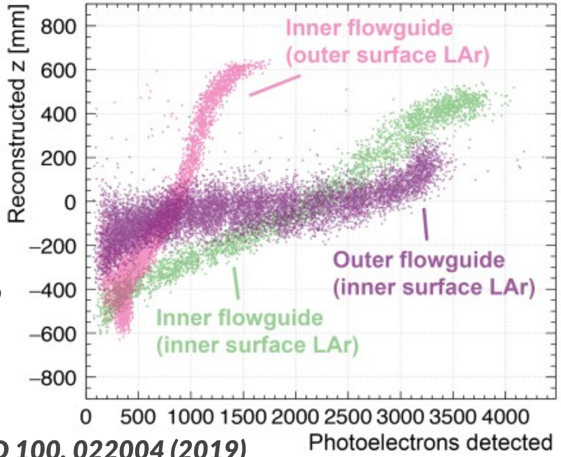


DEAP arXiv:2603.13965 (2026)



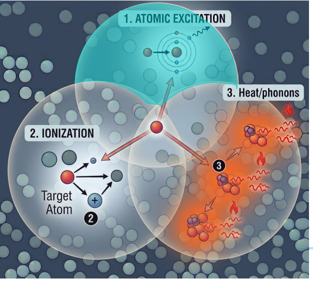
α-decays in dust mimic WIMPs in ROI and above



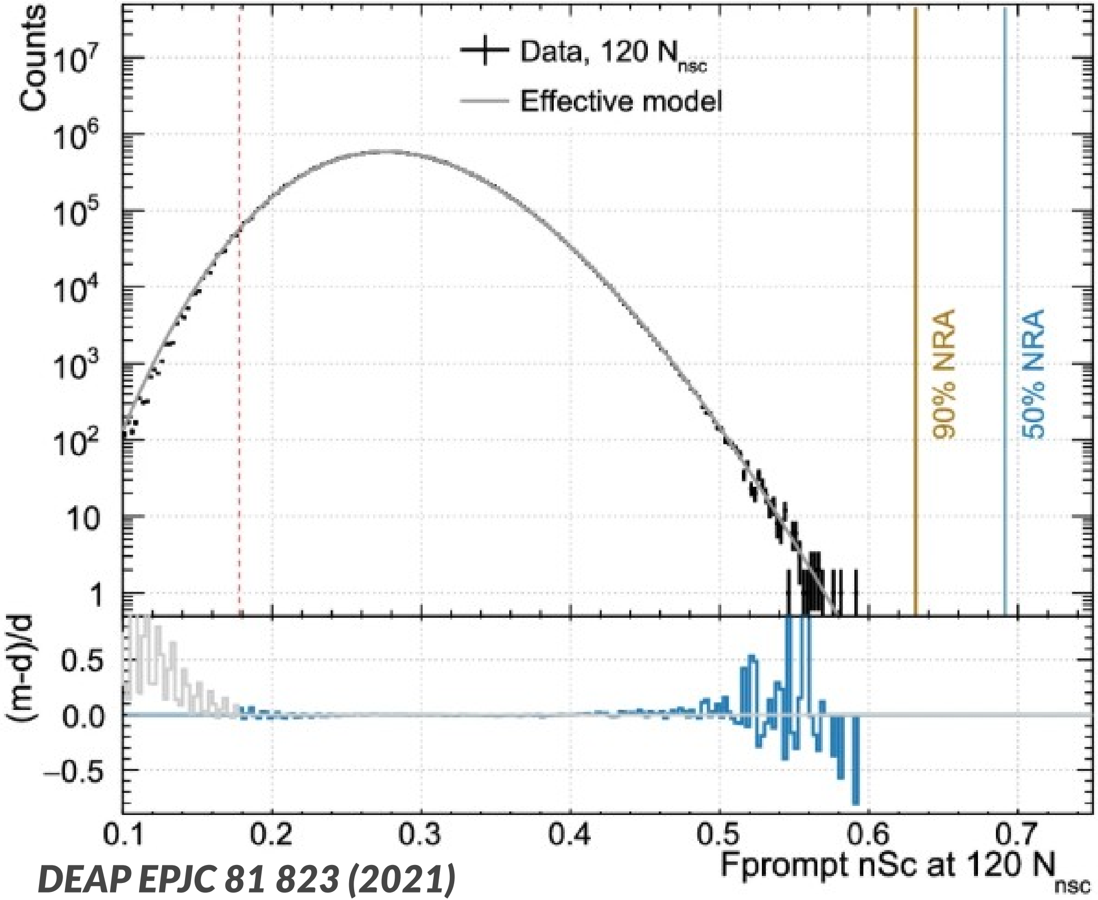


DEAP PRD 100, 022004 (2019)

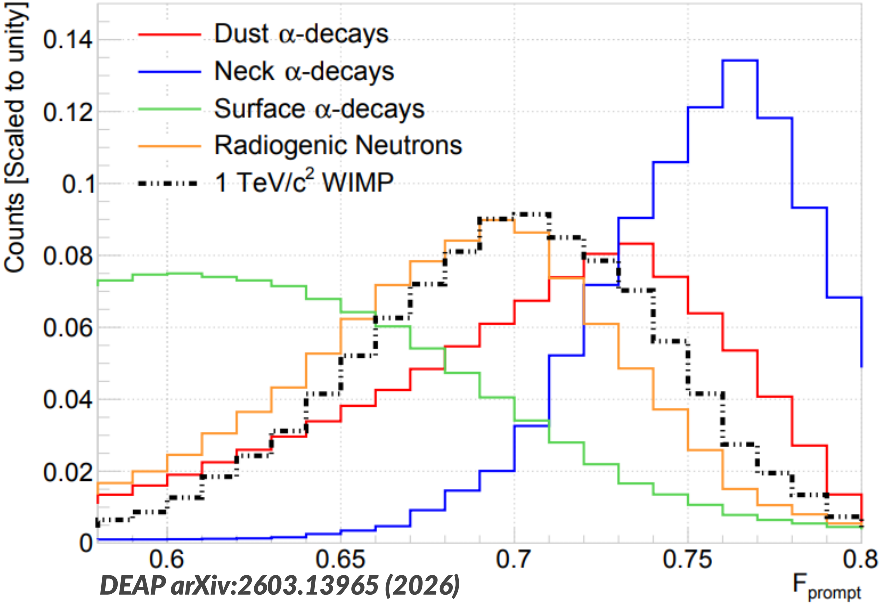
Shadowed α's adding slow Pyrene scintillator coating to neck flow guides → veto



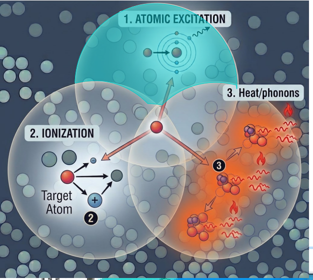
DEAP: PSD 10^8-10^{10} ER rejection, less helpful against dust



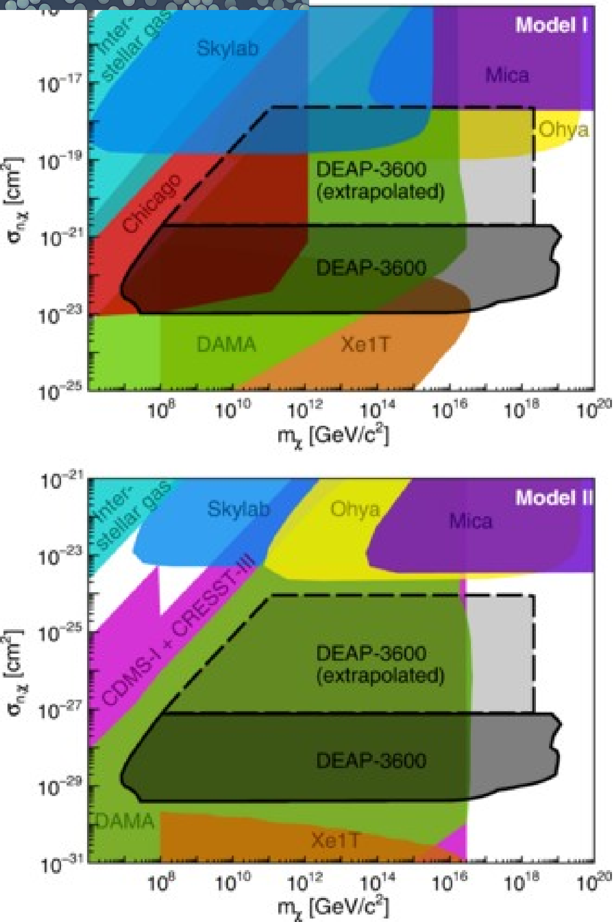
DEAP EPJC 81 823 (2021)



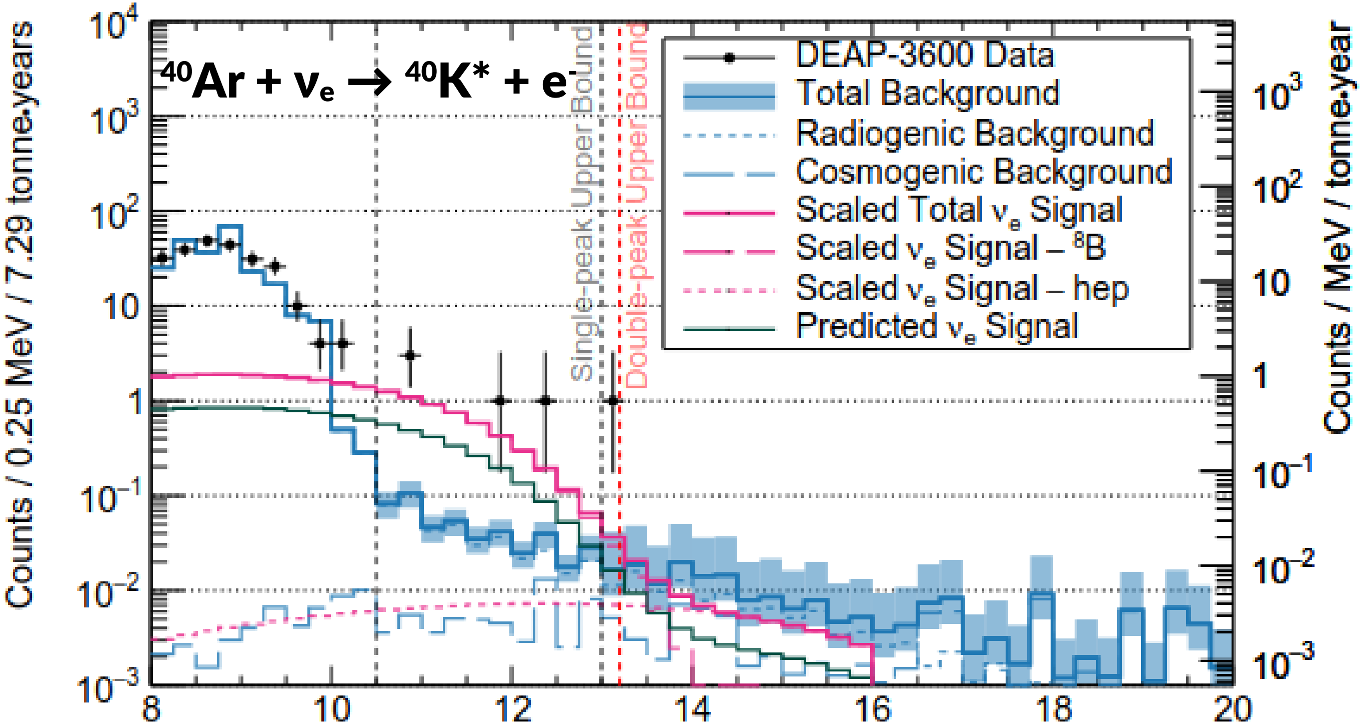
DEAP arXiv:2603.13965 (2026)



DEAP Ultra-heavy DM and ^{8}B ν_e absorption (4σ) measurement

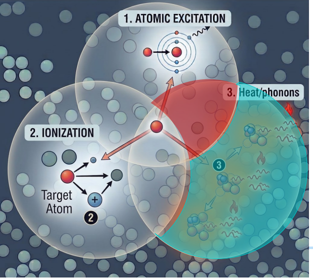


DEAP PRL 128, 011801 (2022)



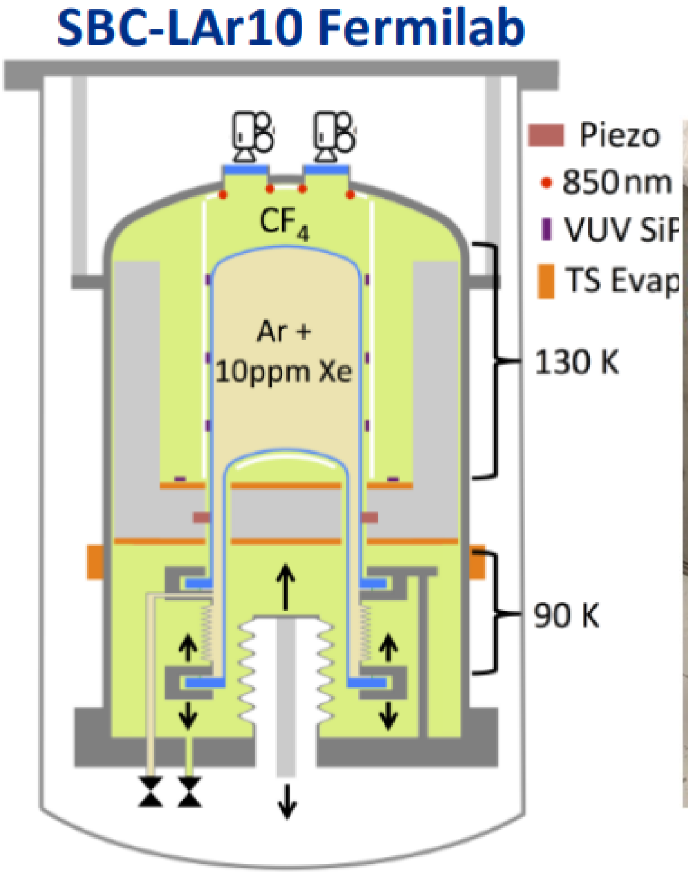
DEAP arXiv:2605.12769

Dominant backgrounds: (n,γ) and cosmogenics where muon misses LAr



Scintillating Bubble Chamber

***Credit:** Gray Putnam's SBC-LAr10 presnetation at APS DNP Meeting 20 July 2026*



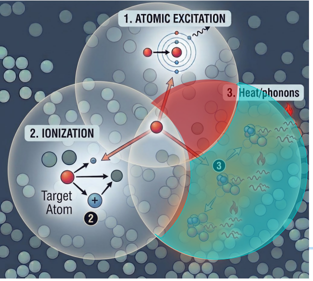
Principle: Low-energy nuclear recoils will nucleate bubbles, ERs will not. Energetic backgrounds scintillate → veto

First images at FNAL MINOS

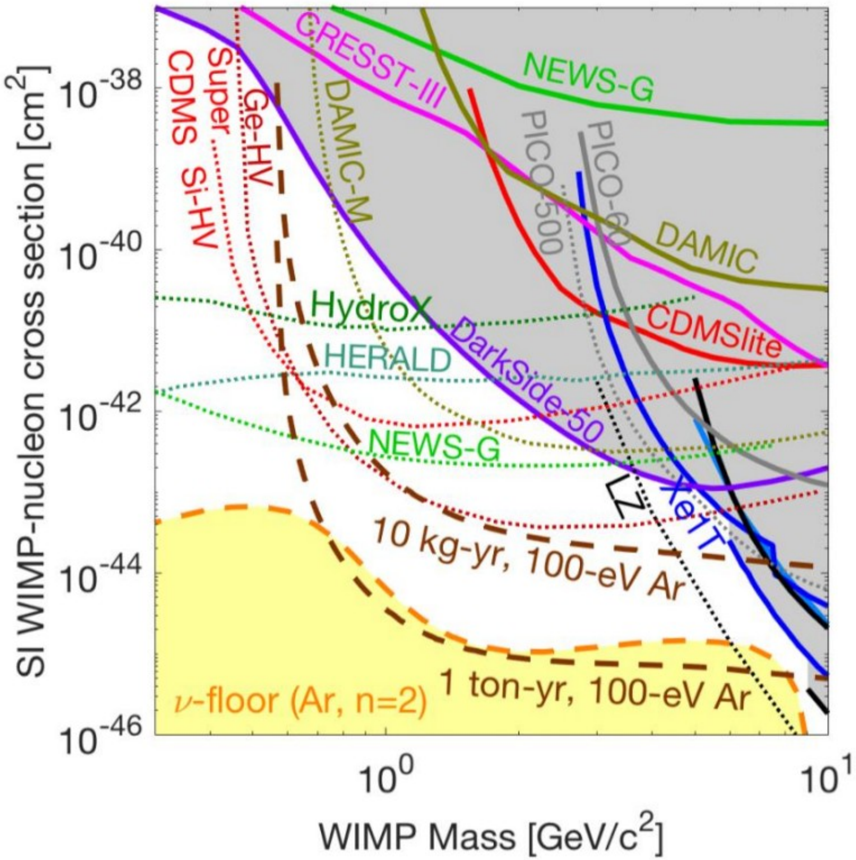
Potential background from γ-ray Thomson scattering

Stable operations at FNAL, low-energy calibration into 2027

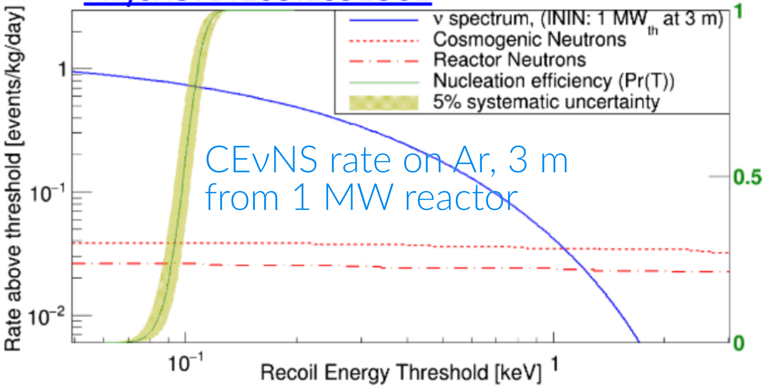
Near-identical SBC-LAr10 to be installed at SNOLAB this Fall!

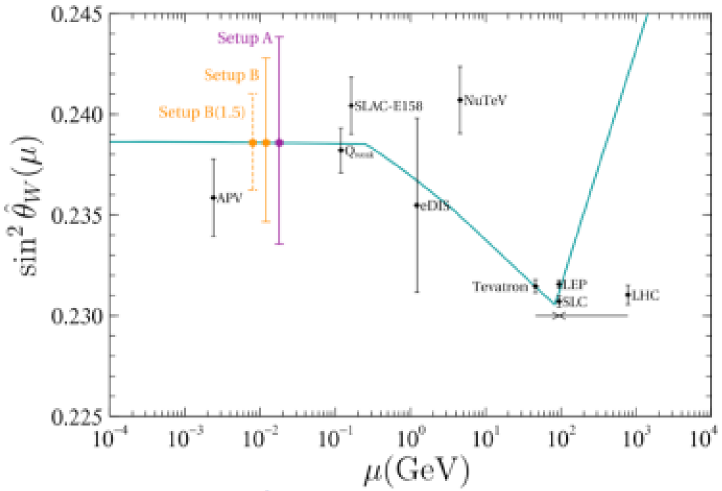


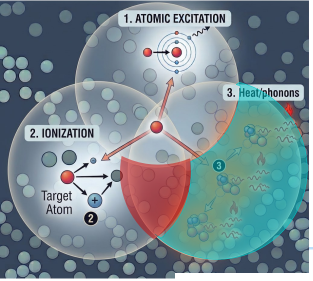
SBC sensitivity to WIMPs and reactor CEvNS



PhysRevD.103.L091301

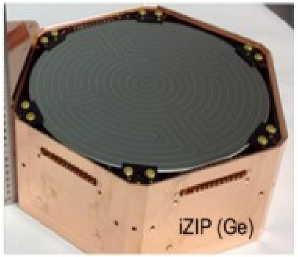






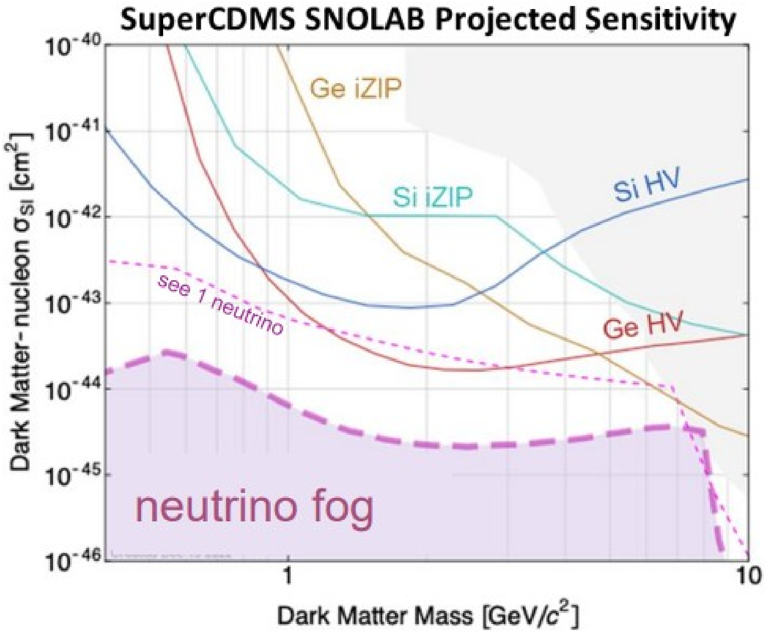
SuperCDMS

Credit: *Miriam Diamond's talk at SNOLAB Future Projects Workshop, May 2026*



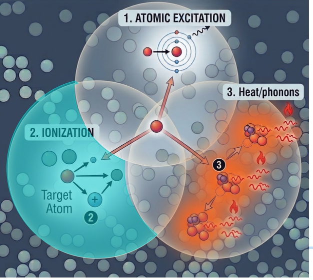
	Germanium	Silicon
HV	Low energy thresholds	
	Larger exposure No ^{32}Si radioactive background	Sensitive to lowest DM masses
iZIP	Nuclear Recoil Discrimination Sensitive to ^{8}B ν-scatter	
	Probe Ge backgrounds	Probe Si backgrounds

Low-energy backgrounds must content with Low-Energy Excess!



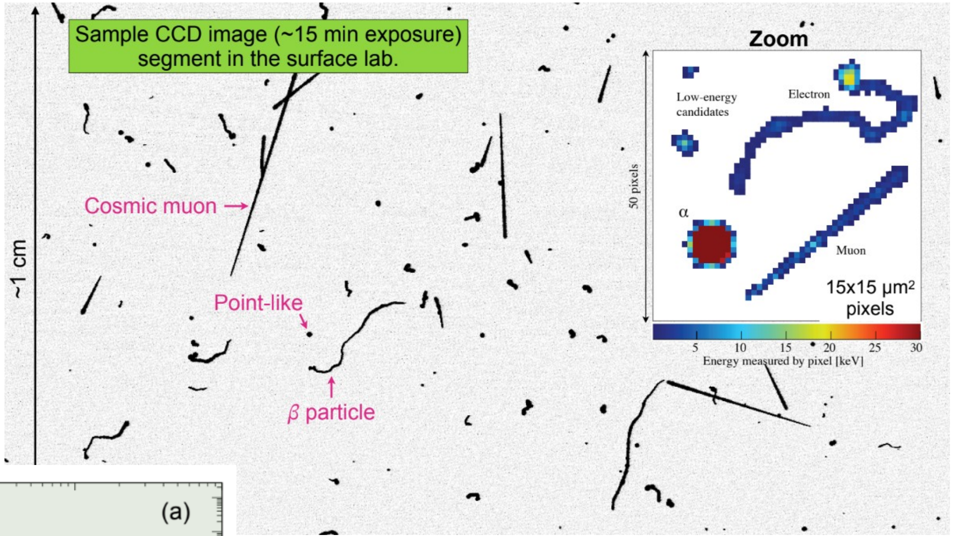
Science run started August 7
...stay tuned for results!

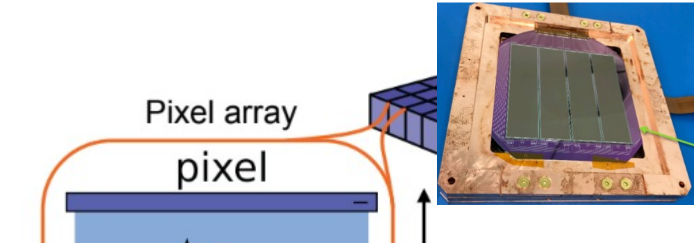
See Ziqing Hong's talk and Nevena Cail's poster

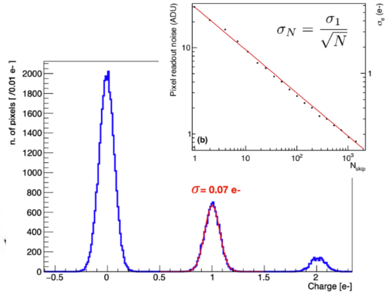


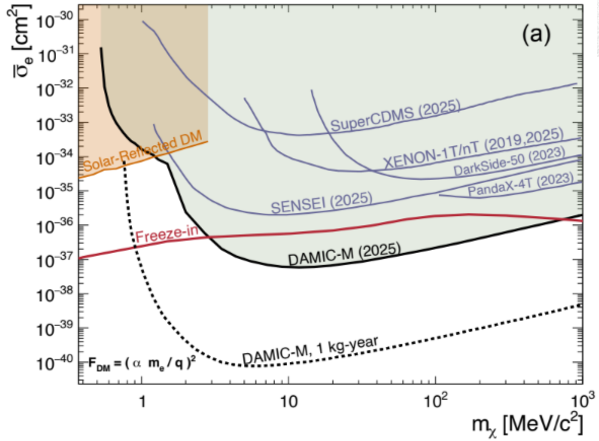
DAMIC-M and Sensei CCDs

Credit: *Alvaro Chavarria's talk at UC Riverside CECI Workshop On Detector Science (2026 CWODS)*
Yikai Wu's talk at APS DPF meetiing, July 2026









Excellent resolution with SkipperCCDs down to ~1 eV Si bandgap

DAMIC-M at Modane: Prototype data in 2025, leading limits

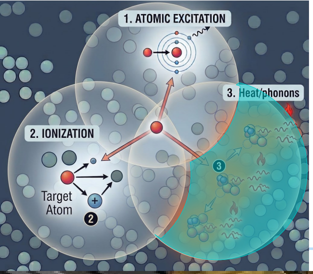
Full detector payload under construction at LSM, online late 2026

26 CCD modules (~360 g active mass) tested underground

SENSEI at SNOLAB: Currently running with ~40 g Si

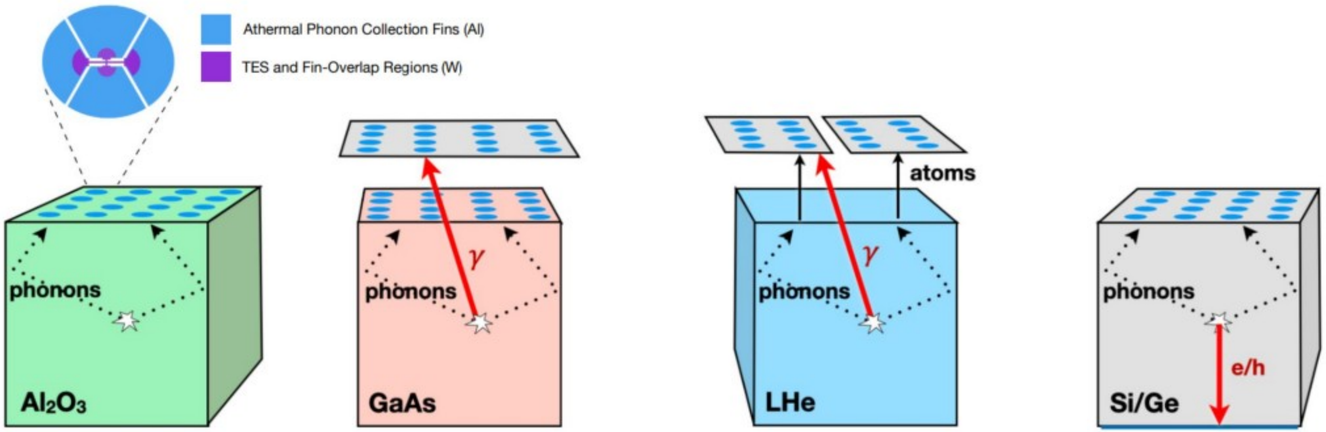
Lowest 1e$^-$ rate measured at $(1.4\pm0.1)\times10^{-5}$ e$^-$/pixel/day

Results soon!



TESSERACT

Credit: *Bjoern Penning's talk at ICHEP 2026*



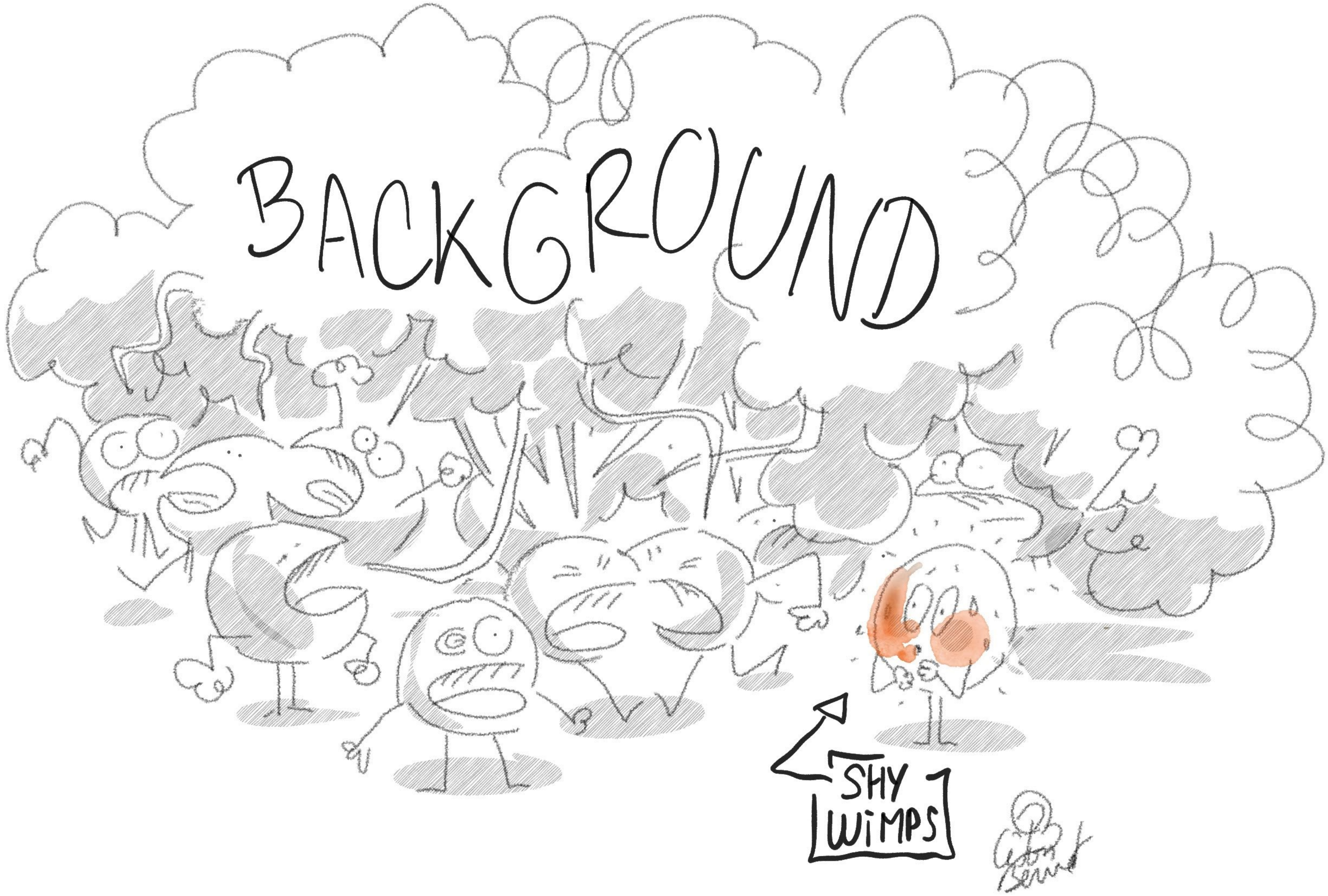
$$\sigma_E \propto V_{\text{det}}^{1/2} T_c^3$$

Achieved recently T_c ~15-20 mK
→ ~100 meV threshold achievable on 1 cm^3 crystals

2025: Completed DOE Gateway Review summer
2028: Assembly at Modane
2029: Physics

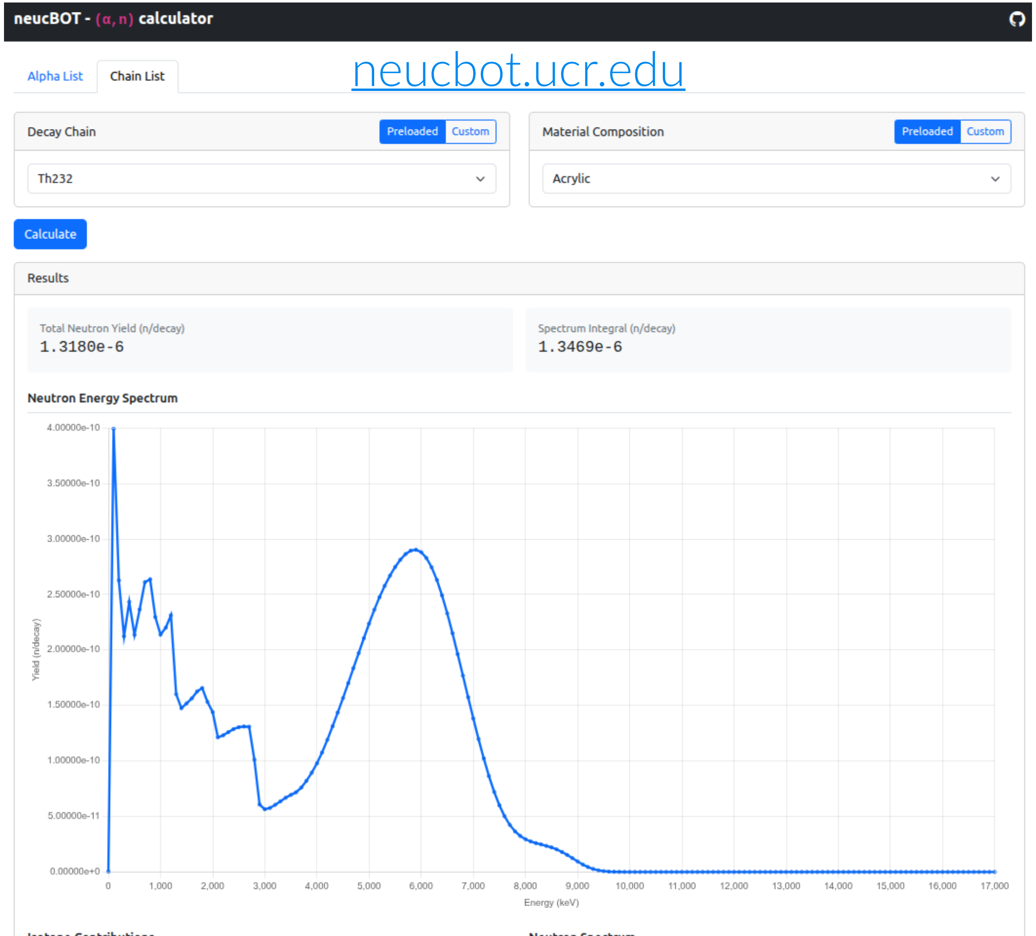
Mitigate low-energy excess with multi-channel coincidence

Swap out multiple targets


BACKGROUND
SHY
WIMPS

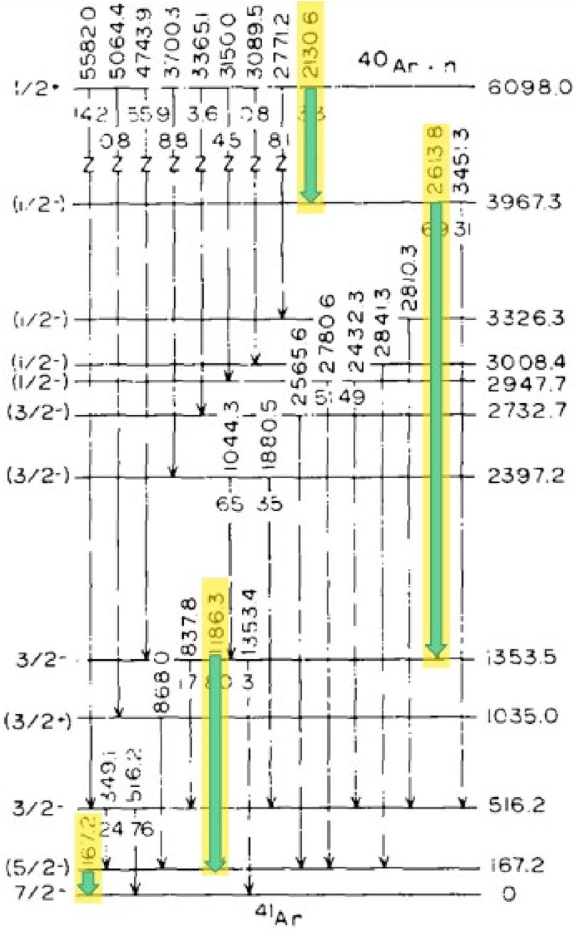
Neutron backgrounds

- Neutrons are a nuisance
  - WIMP-like NRs
  - (n,γ) backgrounds ~10 MeV
- Several options to calculate them
  - SOURCES4 (Fortran)
    - M. Parvu et al. Appl. Rad. Isotopes 225, 112035 (2025)
  - SaG4N (C++, Geant4 integration)
    - E Mendoza et al. NIM A 960, 163659 (2020)
  - NeuCBOT (Python, web interface)
    - S Westerdale, PD Meyers. NIM A 875, 57-64 (2017)
    - MB Gromov et al. Phys At Nucl 86, 181-187 (2023)
    - Recent additions of JENDL and EXFOR integration, α-energy loss / neutron energy correlation (on GitHub, adding to web interface soon)
    - Currently adding γ-ray/final nuclear state correlations
- Nuclear data needed to calculate (α,n) yields and γ-ray correlations are often lacking!
  D Cano-Ott et al. J Phys G 53 023001



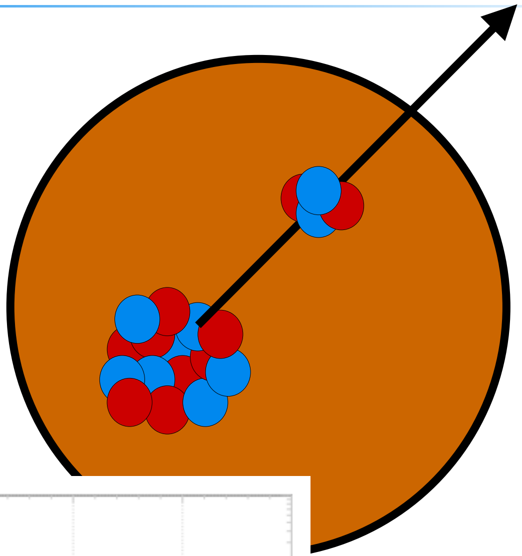
(n,γ) calculations

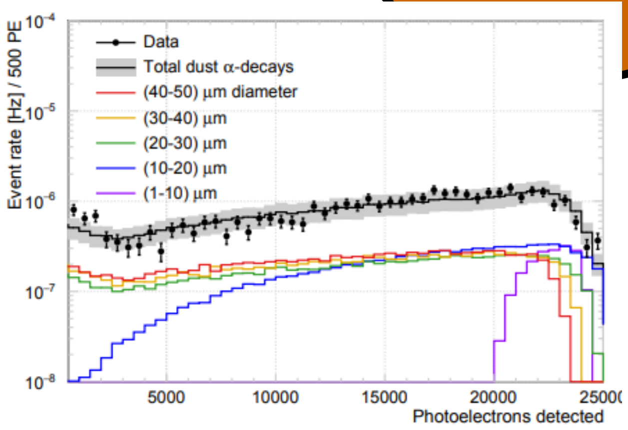
- Important for neutron veto signals and MeV physics (e.g. ν_e CC, $0\nu\beta\beta$)
- Default Geant4 G4NDL and G4PhotonEvaporation models do not reproduce known peaks and correlations well
- Many unknowns in nuclear structure data make perfect simulations impossible!
- Two new options:
  - G4RiversideCASCADE: Walks through nuclear level structures built from ENSDF/other databases, using PhotonEvaporation to fill in gaps, includes X-rays and Auger e^-
    - L Weimer et al. NIM A 1093, 171940 (2027)
    - GitHub: main branch G4-10, see G4-11 branch
    - Working on integration with future G4 release
  - NuDex: Combines ENSDF and RIPL-3 for statistical nuclear model + ENSDF cascade simulation
    - E Mendoza EPJ Web of Conferences 239, 17006 (2020)
    - Added to recent versions of G4-11



Dust backgrounds

- Emerging as a potentially important background as noble liquid detectors scale to large sizes
- α-particles attenuate in dust, fall in WIMP ROI
- Elaborate measures taking to avoid dust ingress, but many potential sources
  - Ambient dust from lab air (largely organic, sometimes metallic)
  - Dust from gas/cryogen bottles …
- Developing methods to quantify (e.g. tracking dust exposure with witness samples during assembly)
- How does dust impact S2? E field distortions? e⁻ shadowing? Depends on dust composition?
- Spatial distribution of dust can be very complicated!
- With high rates, can model *in situ*, but hard if dust levels are low enough!

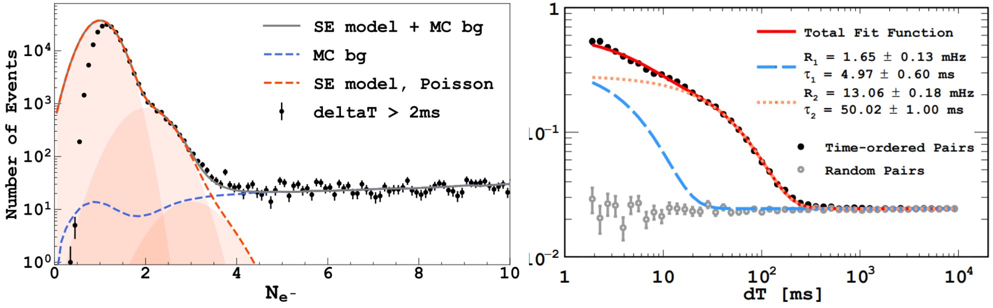




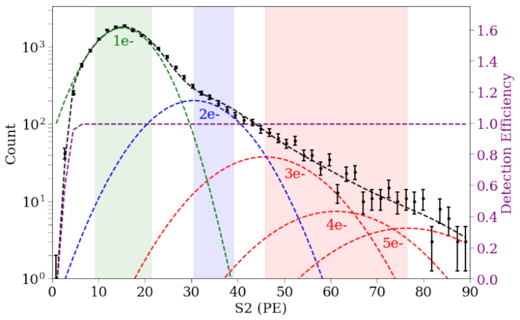
DEAP arXiv:2603.13965 (2026)

Spurious Electron Backgrounds

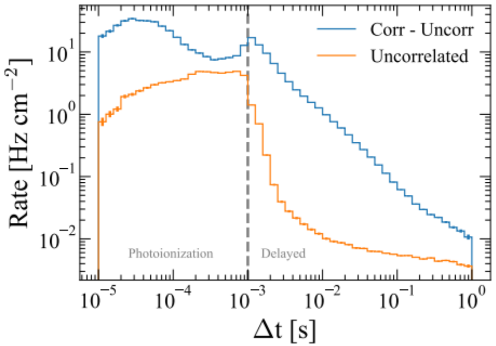
- Few-electron isolated S2 pulses, typically following large “normal” S2s
- Poorly understood
- Time correlations
  - LAr: Double exponential
  - LXe: Power law
- Directly proportional to previous S2 size and t_{drift}
- Leading theory: e^- delayed by impurities
- Still many unknowns! Ongoing topic of R&D and *in situ* detector studies



DS-50 EPJC (2026, in press)



A Kopec et al JINST 16 P07014 (2021)

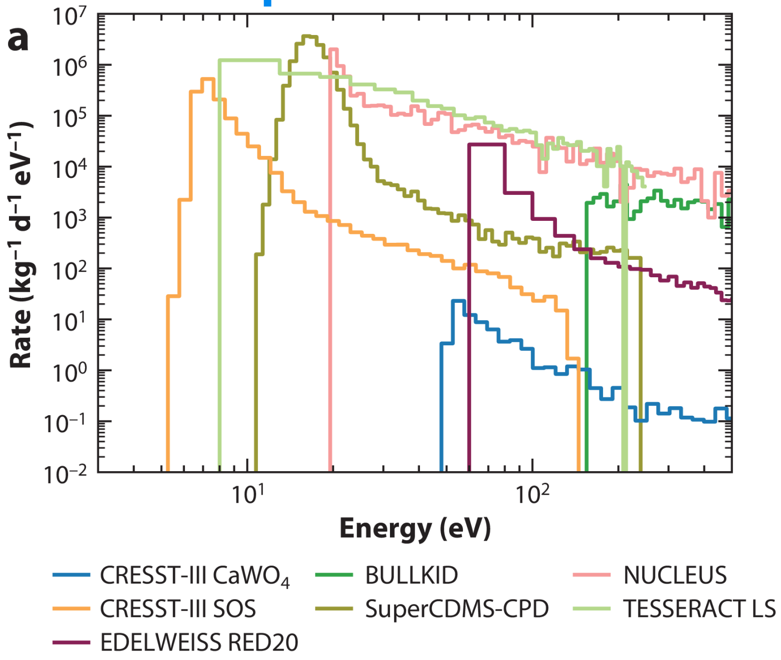


LZ PRD 113, 072018 (2026)

Low Energy Excess

- Solid state cryogenic detectors' lowest energies limited by large, excess event rate
- Well-document, poorly understood
- Thermal effects at ultra-cold temperatures, mechanical vibrations, atomic dislocations, and other candidate mechanisms are a topic of active R&D
- Annual EXCESS workshops

LEE in phonon detectors



D Baxter et al. ARNPS 75, 301 (2025)

Summary and Outlook

- Significant progress narrowing down dark matter parameter space for a wide range of signal types
- Rapid progress being made with several different, complementary detector technologies
- As we move forward, we are discovering and tackling new background sources
- Next few years will be exciting to watch!

END