Status of dark matter searches with liquid argon detectors

Shawn Westerdale [UC Riverside]
(for the Global Argon Dark Matter Collaboration)

Conference on the Intersection of Particle and Nuclear Physics
Lake Buena Vista, Florida – August 2022

UCR PHYSICS & ASTRONOMY

DEAP 3600

DARKSIDE

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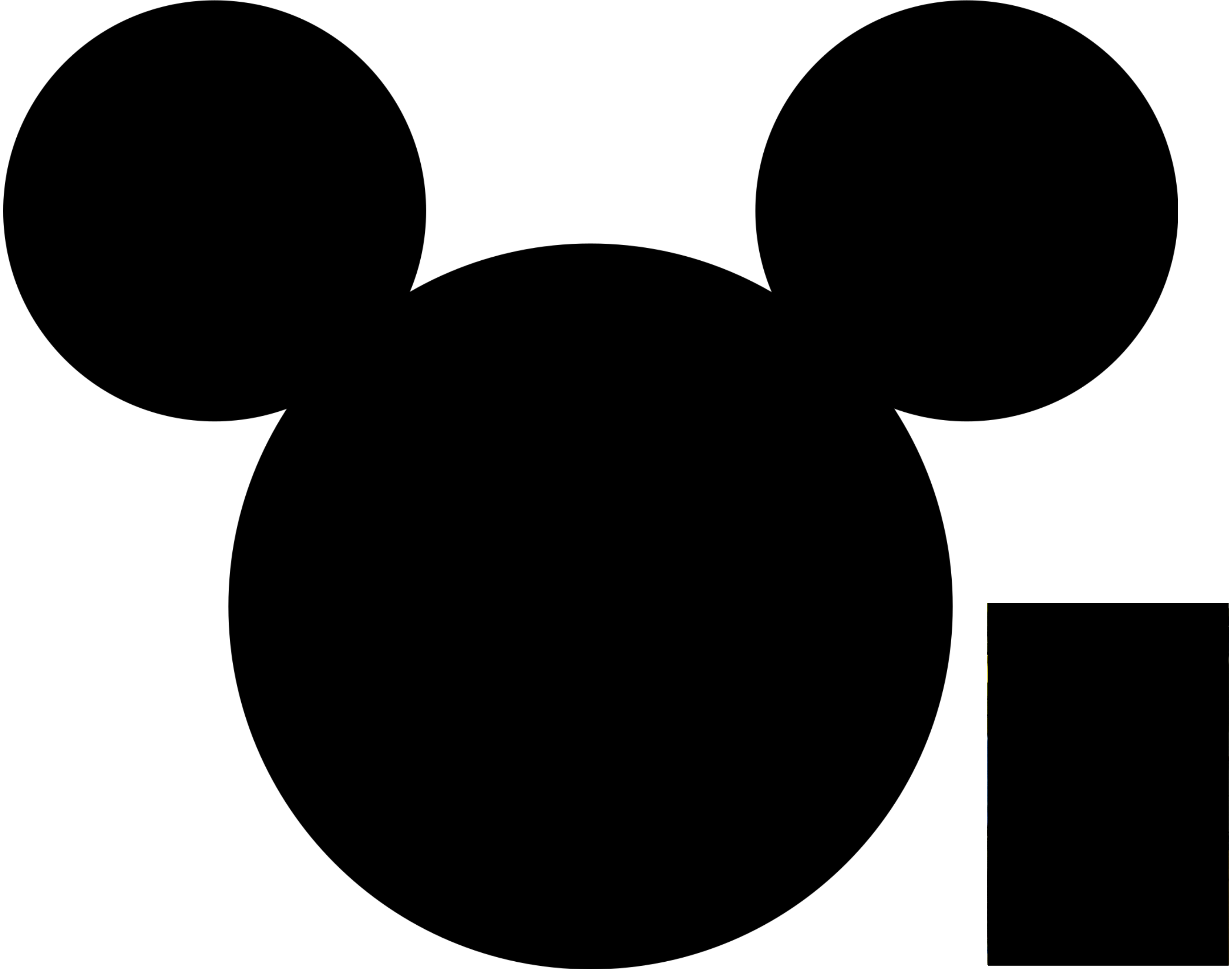
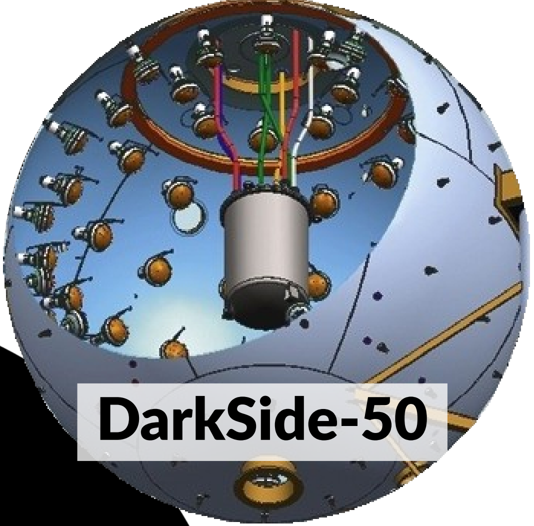
Where we are

(any resemblence to things other than dark matter detectors is purely incidental)





Where we are

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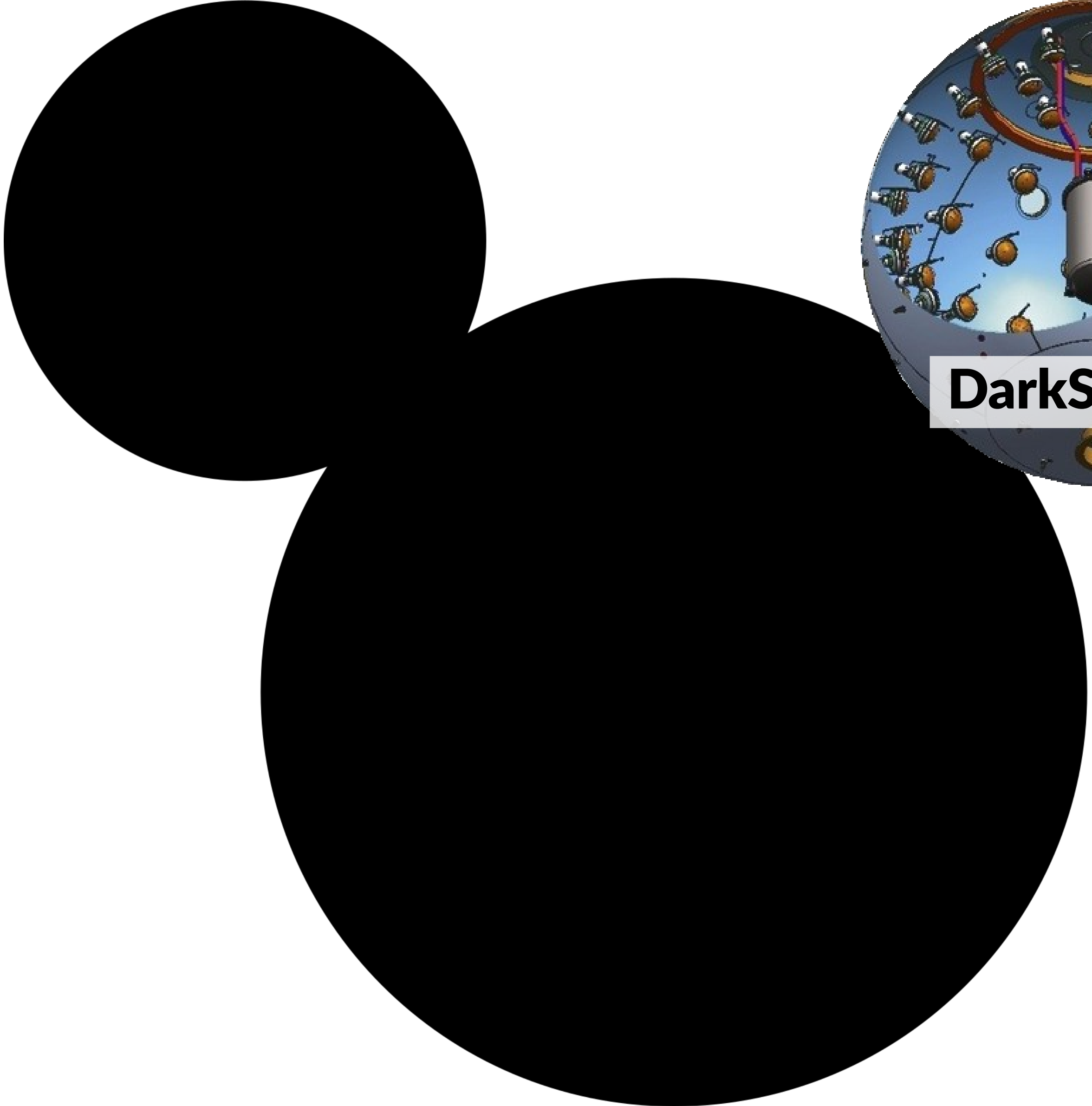
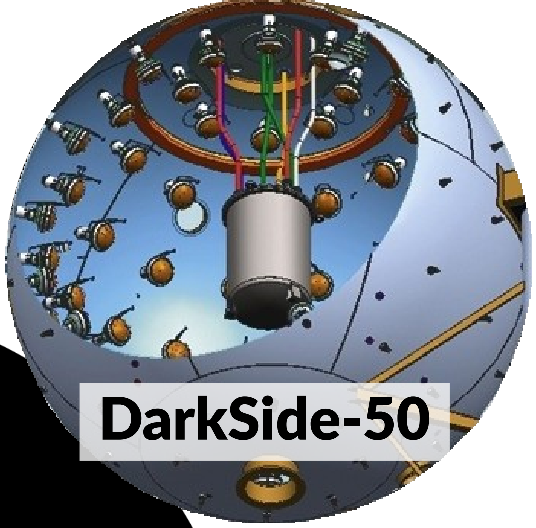
★ **DarkSide-50:**

- LAr mass: 46 kg
- LNGS (Italy)

Dual-phase TPC (ionization+scintillation)





Where we are

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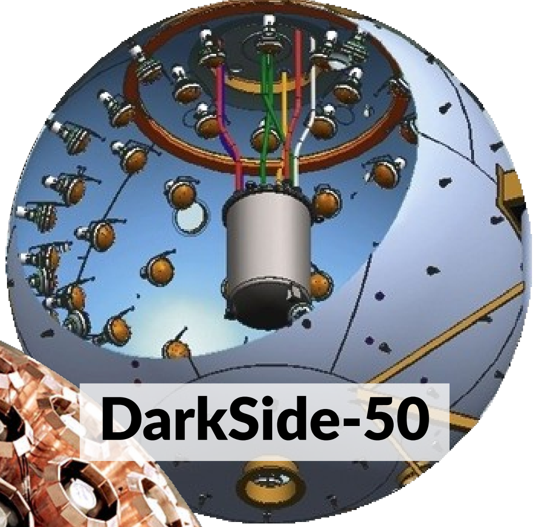
★ **DarkSide-50:**
- LAr mass: 46 kg
- LNGS (Italy)

ArDM:
- LAr mass: 850 kg
- Canfranc (Spain)

Dual-phase TPC (ionization+scintillation)



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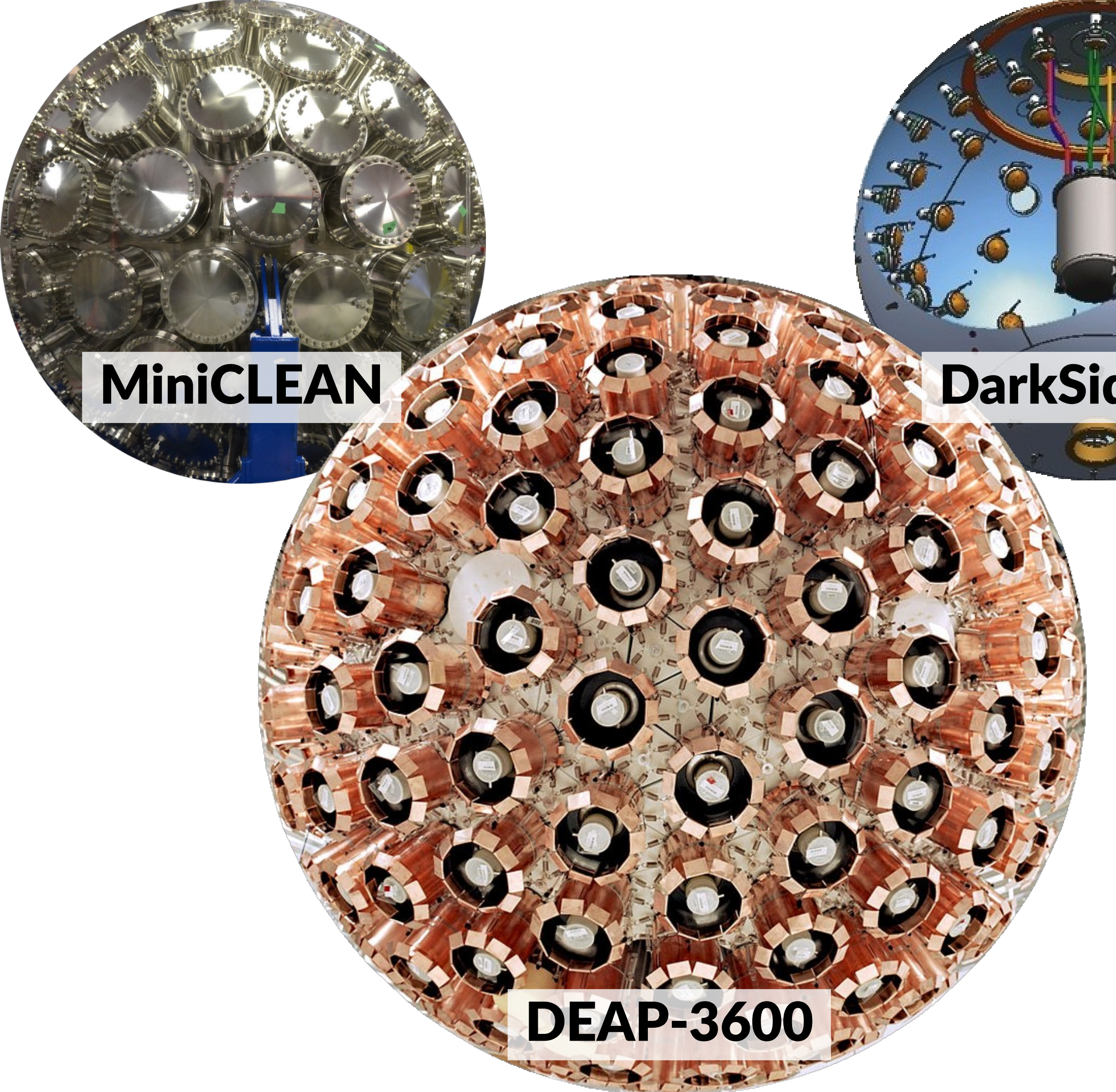
Dual-phase TPC (ionization+scintillation)

★ **DEAP-3600:**
- LAr mass: 3300 kg
- SNOLAB (Canada)

Single-phase scintillation counter



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ArDM:
- LAr mass: 850 kg
- Canfranc (Spain)

Dual-phase TPC (ionization+scintillation)

★ **DEAP-3600:**
- LAr mass: 3300 kg
- SNOLAB (Canada)

MiniCLEAN:
- LAr mass: 500 kg
- SNOLAB (Canada)

Single-phase scintillation counter

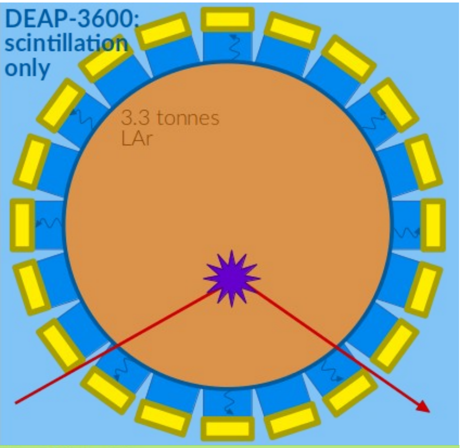
Where we are

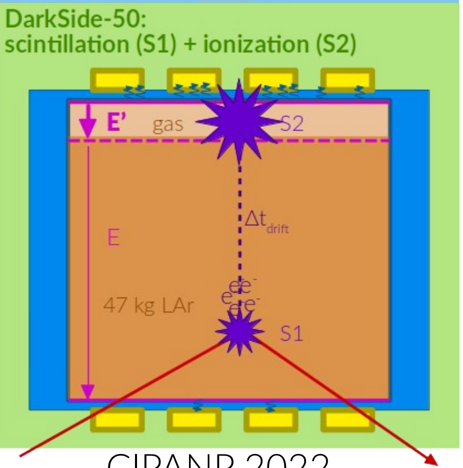
(any resemblence to things other than dark matter detectors is purely incidental)

2017

All joined together to form the Global Argon Dark Matter Collaboration (GADMC) to pursue future LAr-based dark matter detectors

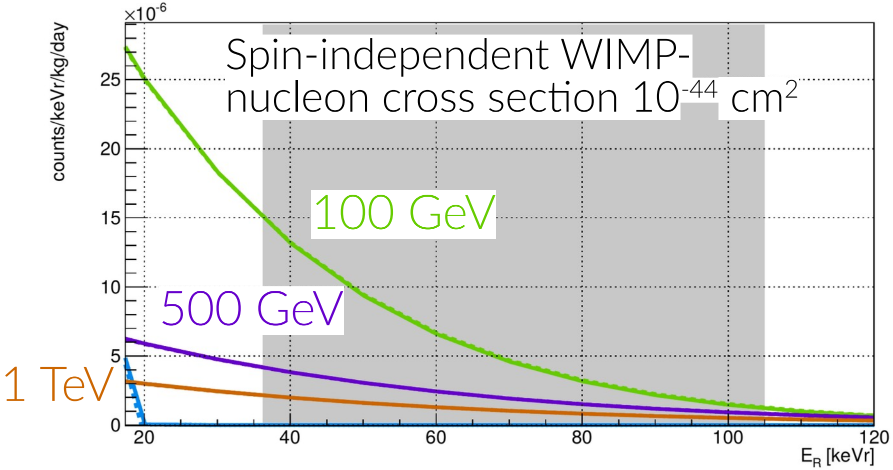
Signal we are looking for





For the primary WIMP search
(m_χ ~ 10 GeV/c^2 to 100 TeV/c^2)

- Nuclear recoil ~30–200 keV
- Single scatter
  - In TPC, each scatter → S2
- Uniformly distributed in LAr



Other searches (partial list)

Light DM w/ nuclear coupling w/ & w/o Migdal effect *(m_χ~10MeV to 10GeV)*

Light DM w/ electronic coupling *(m_χ~10 MeV to 1 GeV)*

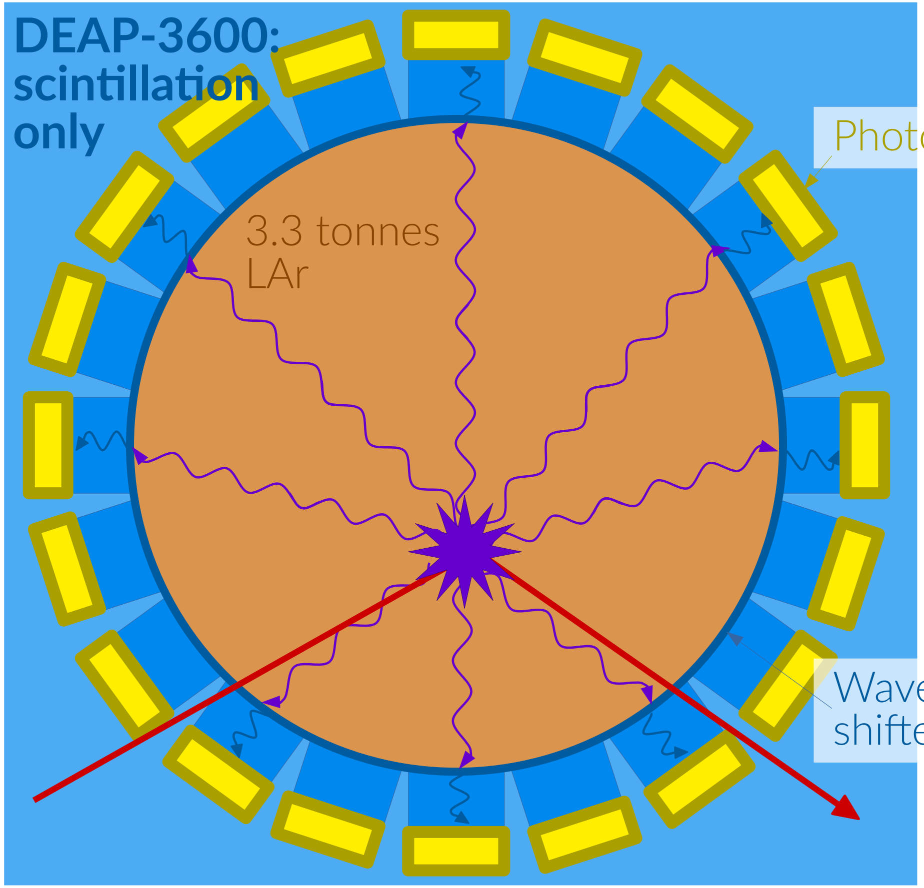
Axion-like particles dark photons via absorption peaks *(m_χ~20 eV to 10 keV)*

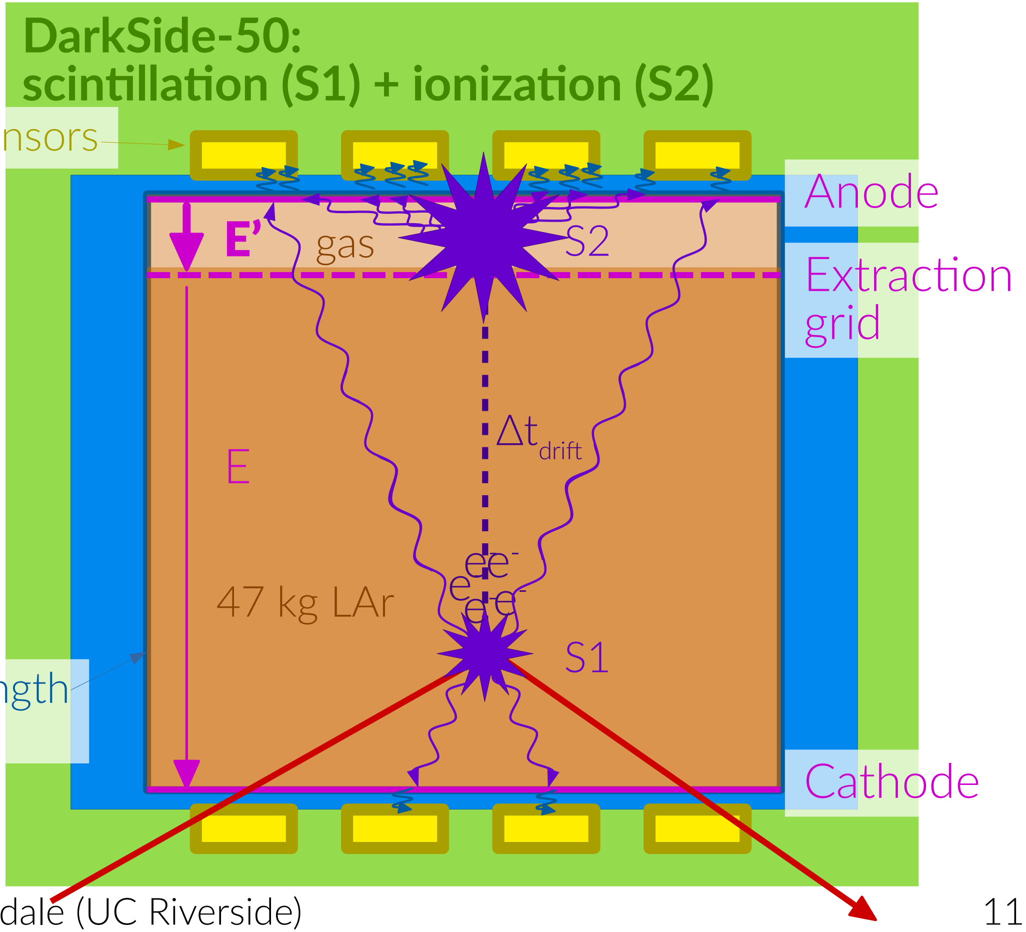
- O(10 eV) to O(1 keV) signals in TPC's S2-only channel

Ultra-heavy DM with high cross sections *(m_χ~10^5 GeV to M_{Planck})*

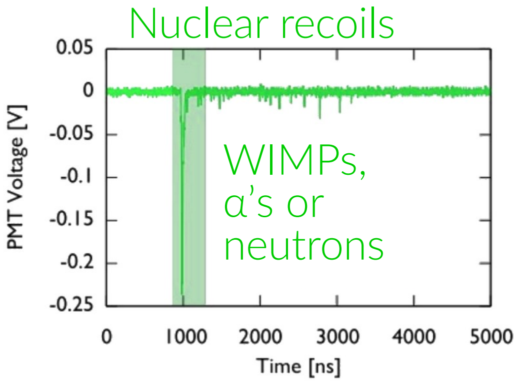
- Many co-linear ~40 keV nuclear recoils, but rarely enter detector

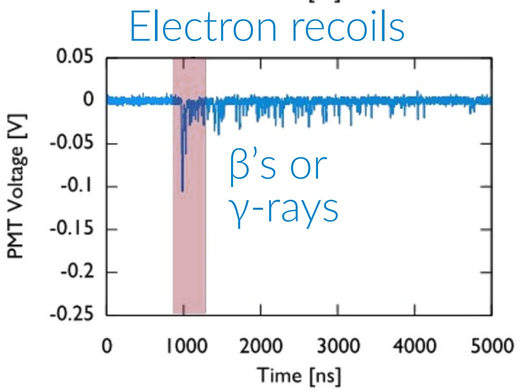
Two different detector types





S1 pulse shape discriminates between electronic and nuclear recoils





LAr scintillation time profile: $S(t) \sim A_s\exp(-t/\tau_s) + A_t\exp(-t/\tau_t)$

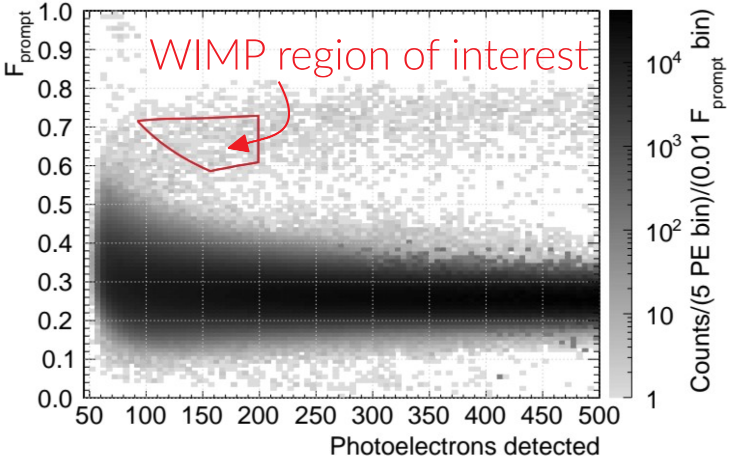
$\tau_s \sim 8$ ns $\quad \tau_t = 1.4 \pm 0.1$ µs

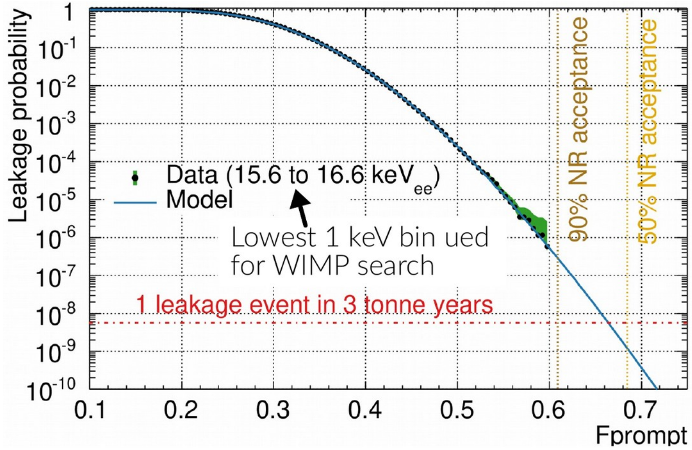
For nuclear recoils : $A_s \sim 0.7$, $A_t \sim 0.3$

For electronic recoils: $A_s \sim 0.25$, $A_t \sim 0.75$

F_{prompt} = Fraction of light in prompt window

DEAP: AmBe neutron calibration data

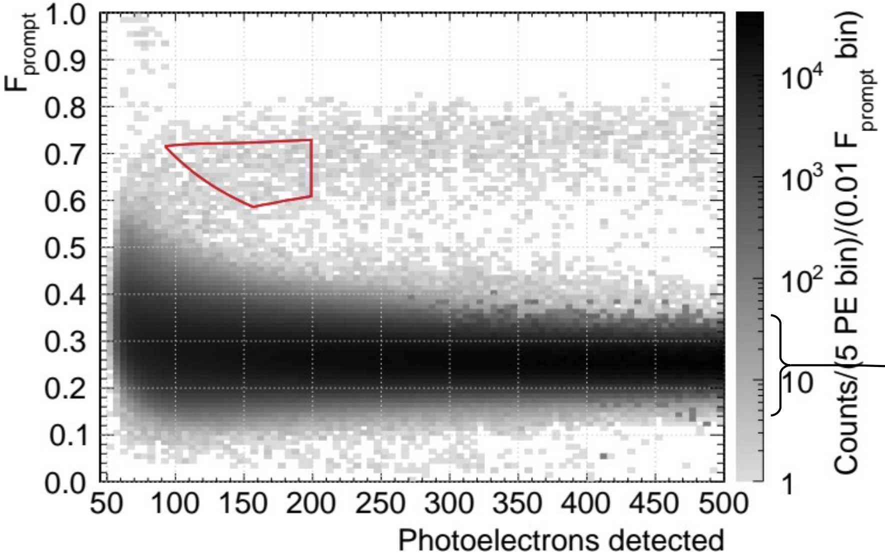


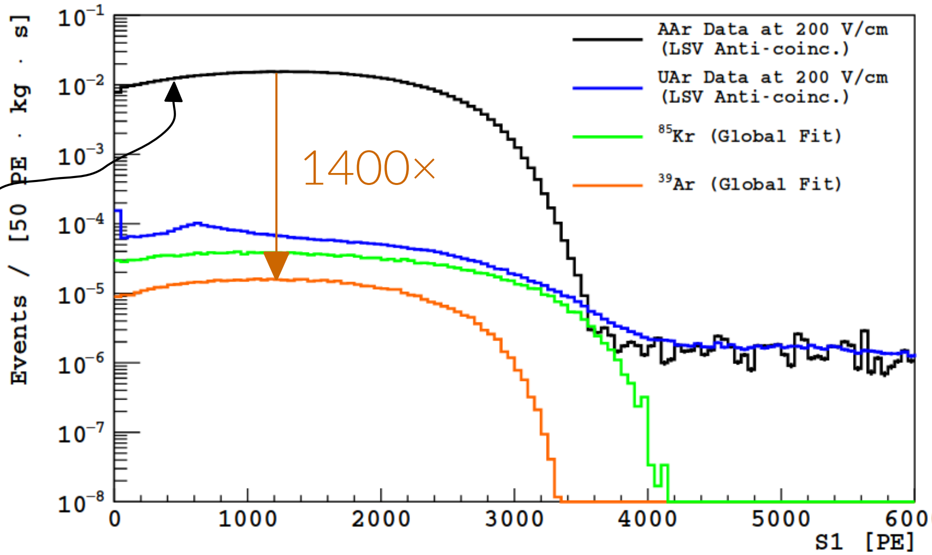


DEAP Collaboration, "The liquid-argon scintillation pulseshape in DEAP-3600". Eur. Phys. J. C 80, 303 (2020)

DEAP Collaboration, "Pulse-shape discrimination against low-energy ^{39}Ar β-decays in liquid argon with 4.5 tonne-years of DEAP-3600 data". Eur. Phys. J. C 81, 823 (2021)

DarkSide-50 pioneered use of underground Ar to reduce ^{39}Ar





^{39}Ar β-decays with 565 keV endpoint, $t_{1/2}$~269 yrs
Present in atmospheric Ar at 0.95±0.05 Bq/kg

ArDM Collaboration, "Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC". J.CAP12(2018)011

Backgrounds efficiently removed by PSD
In large TPCs, may induce overwhelming dead time
Dominant background in S2-only analyses w/o PSD

DarkSide-50 found that Ar extracted from underground (UAr) has at least 1400× less ^{39}Ar than atmospheric Ar

DarkSide Collaboration, "Backgrounds and pulse shape discrimination in the ArDM liquid argon TPC". J.CAP12(2018)011

Enables several-tonne scale LAr TPCs and sub-keV threshold S2-only analyses

Thanks to PSD, WIMP search is primarily sensitive to nuclear recoil backgrounds

Neutrons

Radiogenic

(α,n) reactions
Spontaneous fission

Strict radiopurity reqs (^{232}Th, ^{238,235}U)

DS-50 pioneered neutron vetoes

DarkSide Collaboration, "The veto system of the DarkSide-50 experiment". JINST, 11 (2016): P03016

Large uncertainty in (α,n) & (α,nγ) cross sections

Cosmogenic

Muon showers in lab
β-delayed neutron emission

Suppressed by going underground and using muon vetoes

Large uncertainties in cosmogenic nuclear interactions

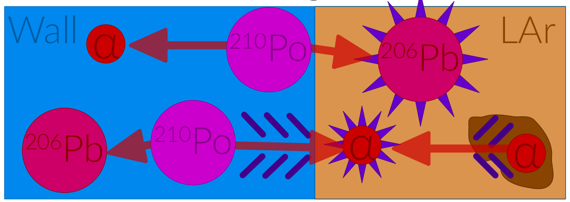
α-decays

Mostly from Rn+progeny, deposited on any surfaces exposed to air

^{210}Pb (in the ^{222}Rn decay chain) has a 22 year half-life, β-decays to ^{210}Po

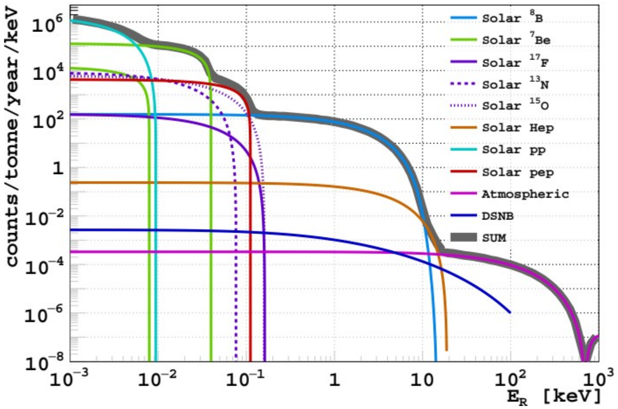
^{210}Po→source of 5.3 MeV α's & 100 keV recoiling ^{206}Pb nuclei

May populate region of interest if α attenuates in detectors walls or dust or if scintillation light is shadowed



Control via Rn abatement, material selection, & *in situ* removal from Ar
Need low-energy heavy ion energy loss models

Neutrinos

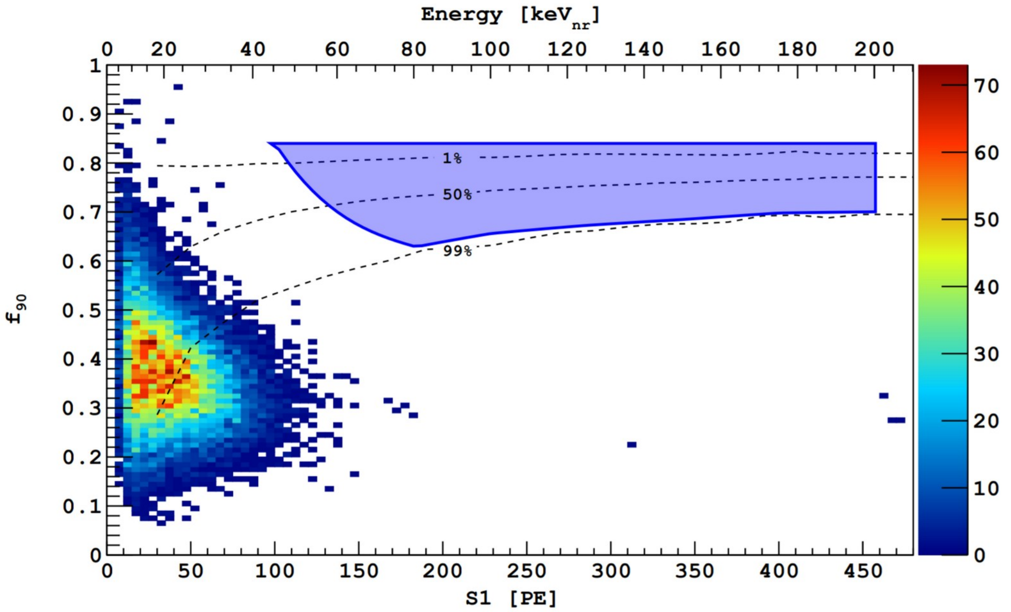


Coherent elastic neutrino-nucleus scattering can produce nuclear recoils that mimic WIMPs

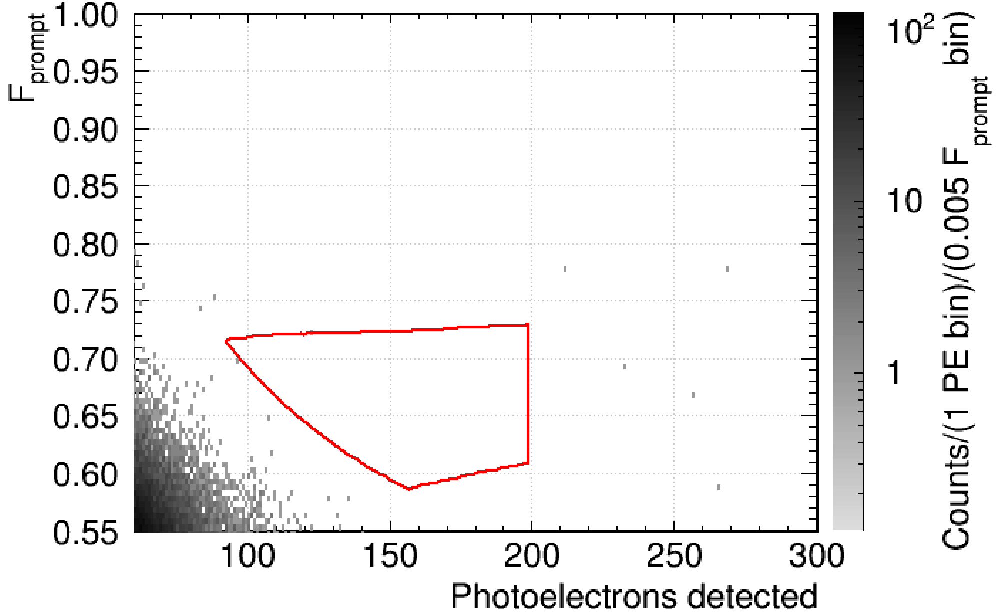
Effective background subtraction requires decreasing systematics

Precise measurements of CEvNS cross section & improved sub-GeV atmospheric ν models

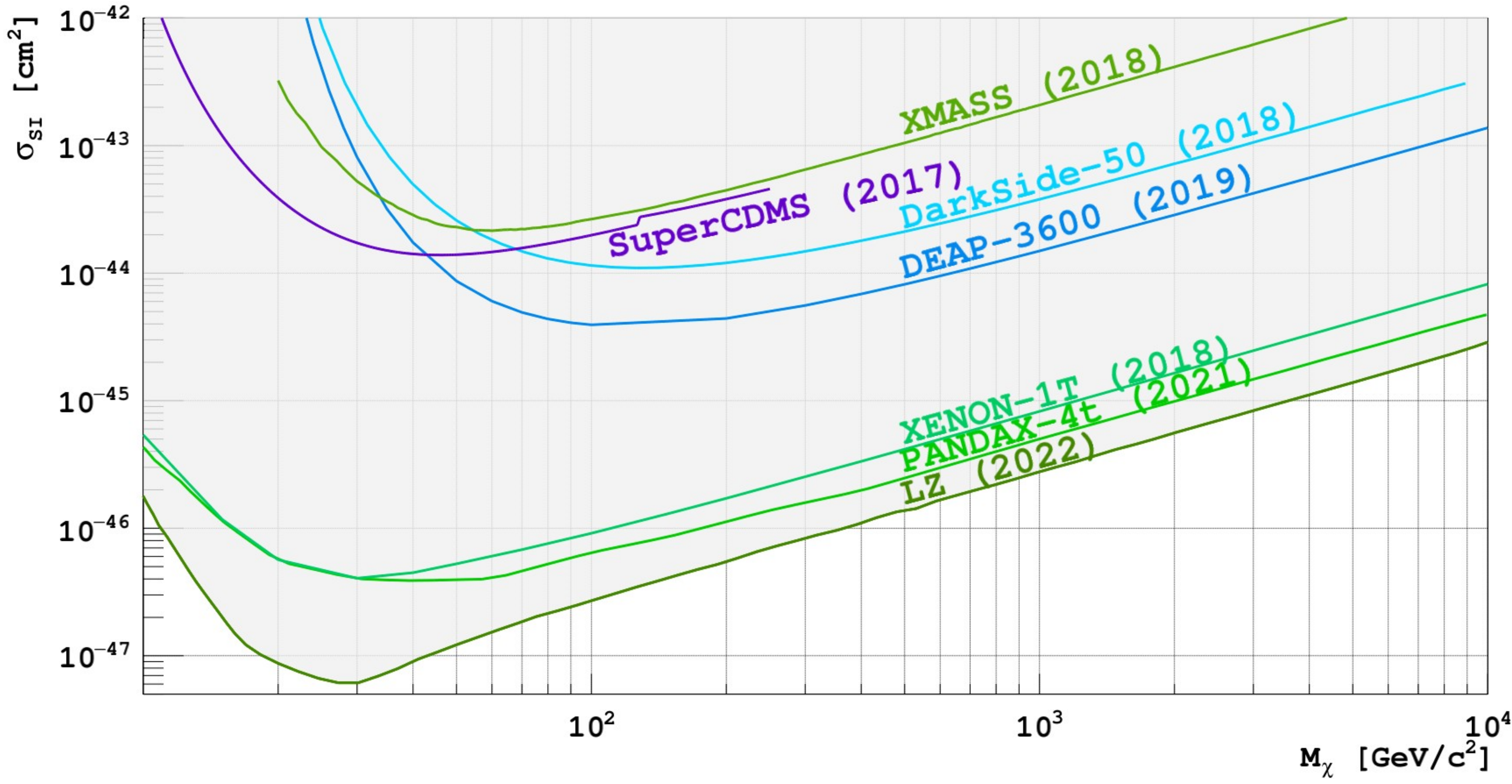
Neither experiment has seen any WIMP-like events in region of interest



DarkSide Collaboration. "DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon". Phys. Rev. D 98, 102006 (2018)

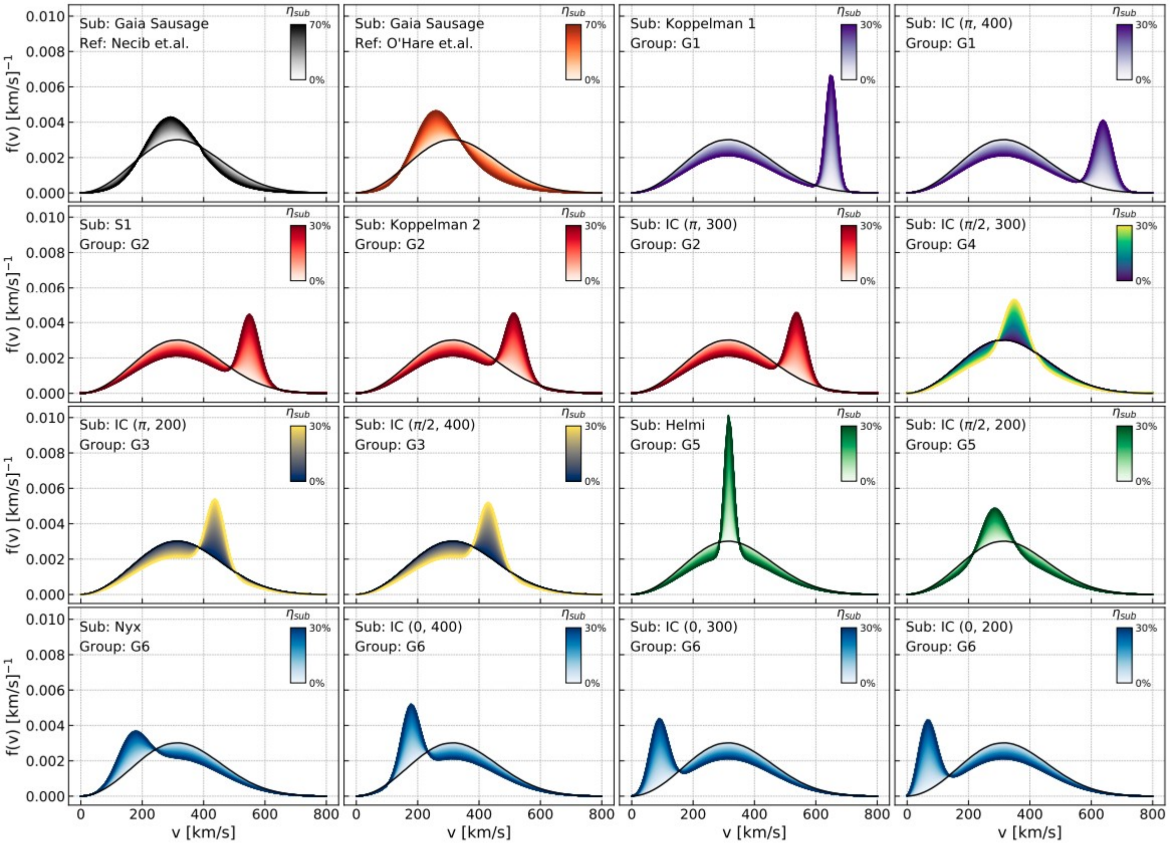


DEAP Collaboration. "Search for dark matter with a 231-day exposure of liquid argon using DEAP-3600 at SNOLAB". Phys. Rev. D 100, 022004 (2019)



σ_{SI} [cm^2]
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
XMASS (2018)
SuperCDMS (2017)
DarkSide-50 (2018)
DEAP-3600 (2019)
XENON-1T (2018)
PANDAX-4t (2021)
LZ (2022)
10^2
10^3
10^4
M_χ [GeV/c^2]

How do astrophysical uncertainties impact direct detection limits?



Re-casting DEAP-3600 null results as constraints on 5 coupling constants defined in a non-relativistic effective field theory O_1, O_3, O_5, O_8, and O_{11}.

Consider 16 variations on the local DM speed distribution in the Standard Halo Model, using observed stellar debris flows and streams as traces for potential substructures in the DM halo

$$\mathcal{O}_1 = 1_\chi 1_N$$

$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$$

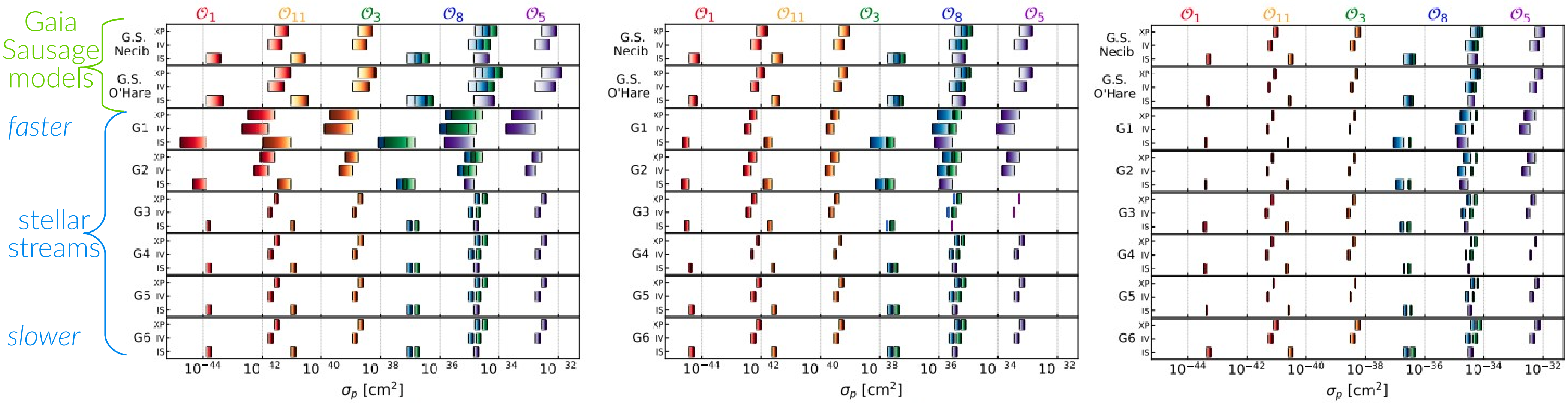
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}_\perp\right)$$

$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}_\perp$$

$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$

DEAP Collaboration. "Constraints on dark matter-nucleon effective couplings in the presence of kinematically distinct halo substructures using the DEAP-3600 detector". Phys. Rev. D 102, 082001 (2020)

Different impacts for operators; degeneracies are introduced that will require multiple targets to break



(a) m_χ=40 GeV/c^2 (b) m_χ=100 GeV/c^2 (c) m_χ=3 TeV/c^2

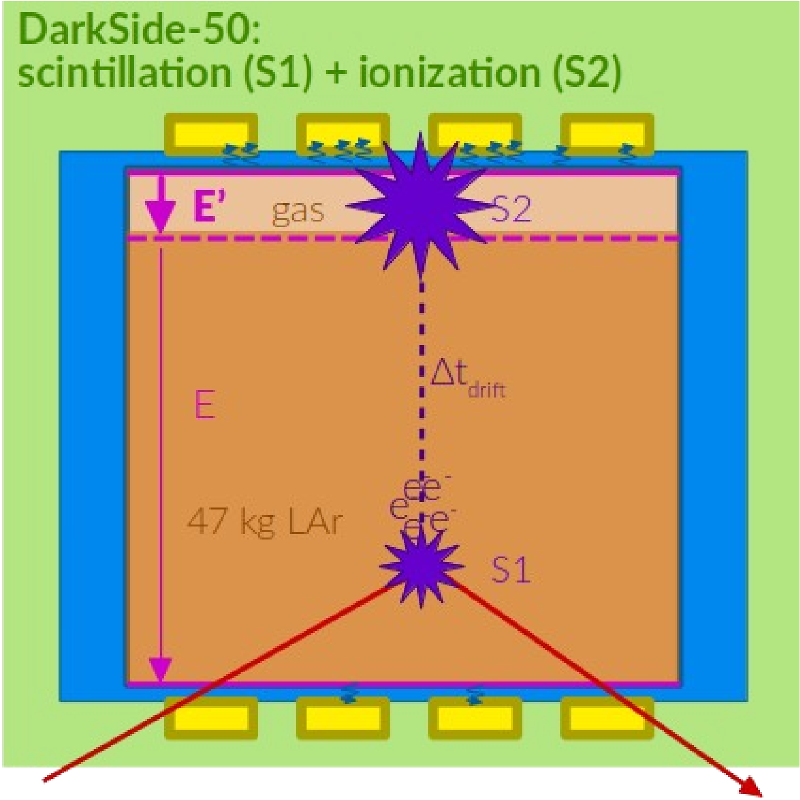
$\mathcal{O}_1 = 1_\chi 1_N$ $\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$ $\mathcal{O}_3 = i\vec{S}_N \cdot (\frac{q}{m_N} \times \vec{v}_\perp)$ $\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}_\perp$ $\mathcal{O}_5 = i\vec{S}_\chi \cdot (\frac{\vec{q}}{m_N} \times \vec{v}_\perp)$

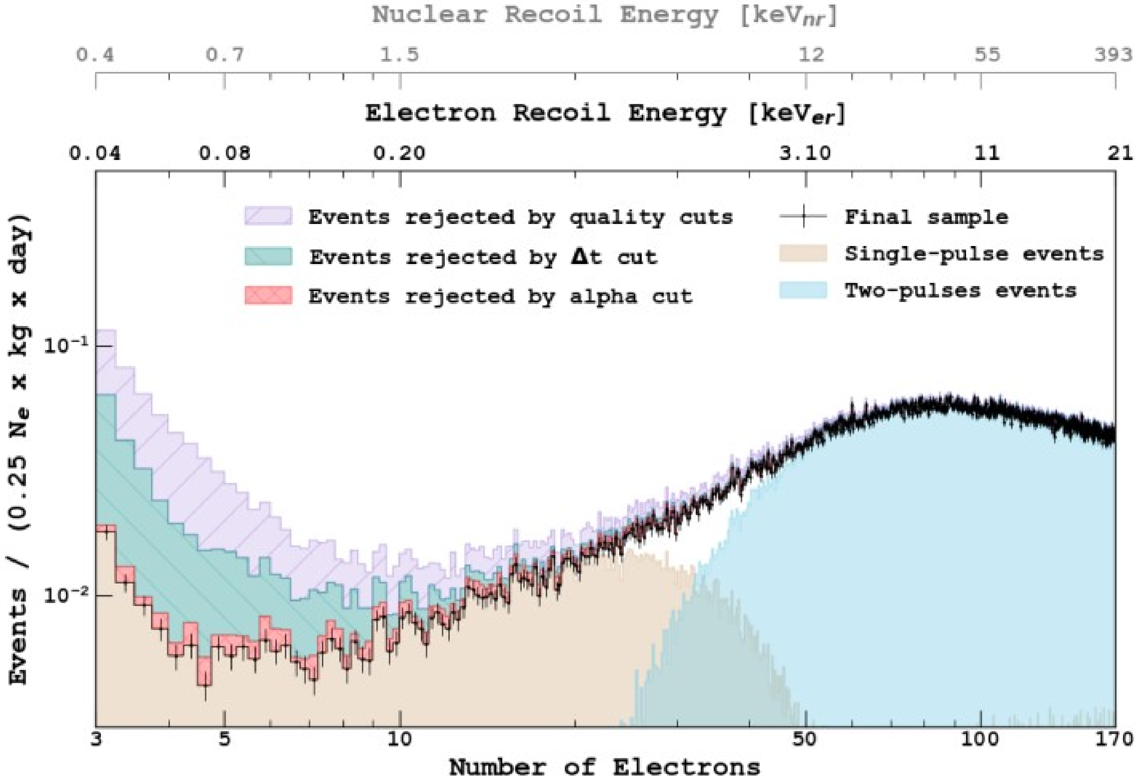
Lighter masses: signals are near threshold; changing speed distribution has a large impact

Heavier masses: effects drop away for some operators, but persist for those w/ $v_\perp$ dependence

DEAP Collaboration. "Constraints on dark matter-nucleon effective couplings in the presence of kinematically distinct halo substructures using the DEAP-3600 detector". Phys. Rev. D 102, 082001 (2020)

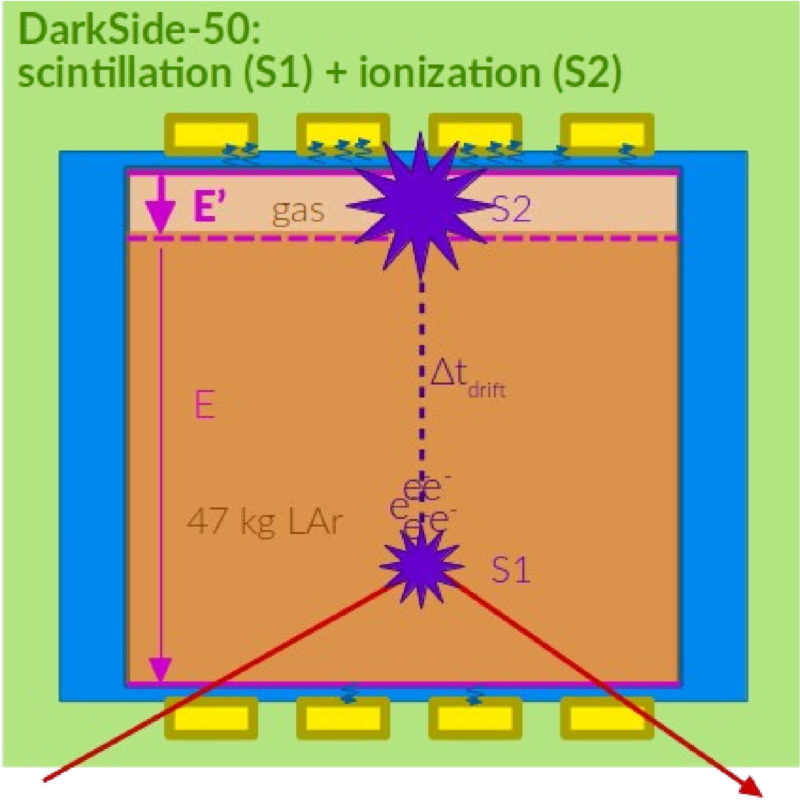
DS-50 light DM search: Gas pocket amplification enables S2-only searches sub-keV thresholds

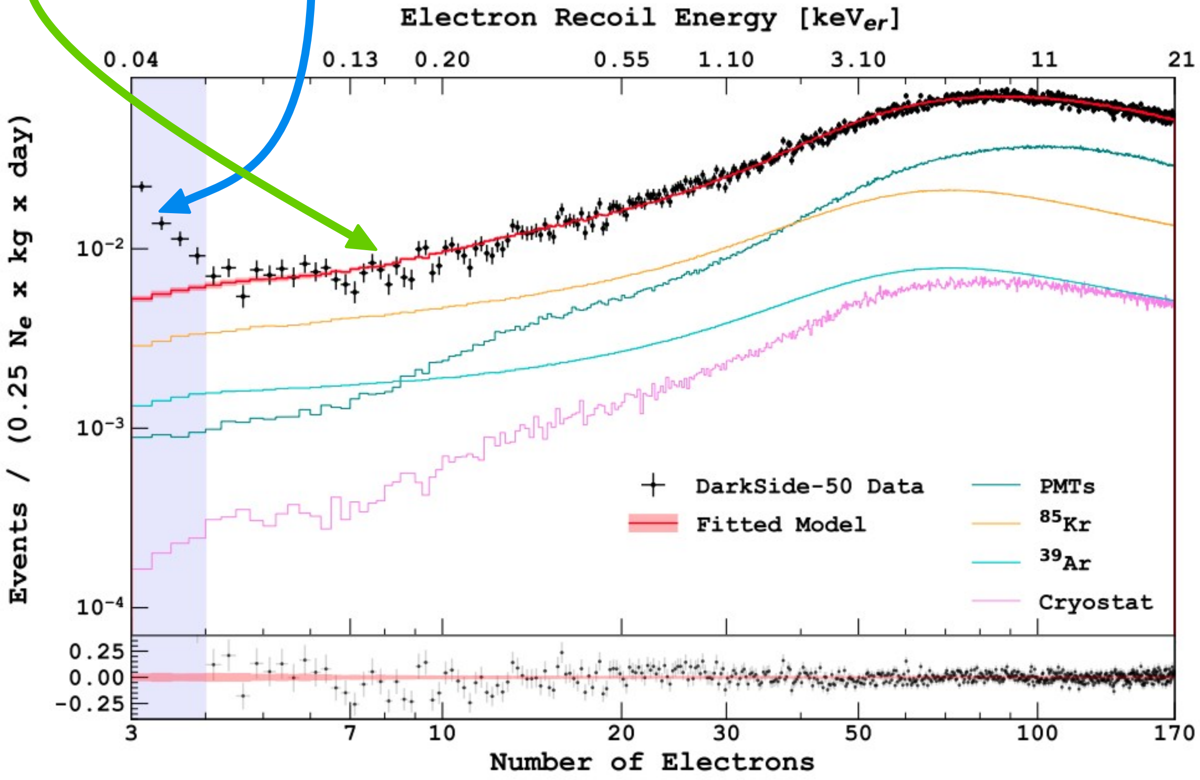




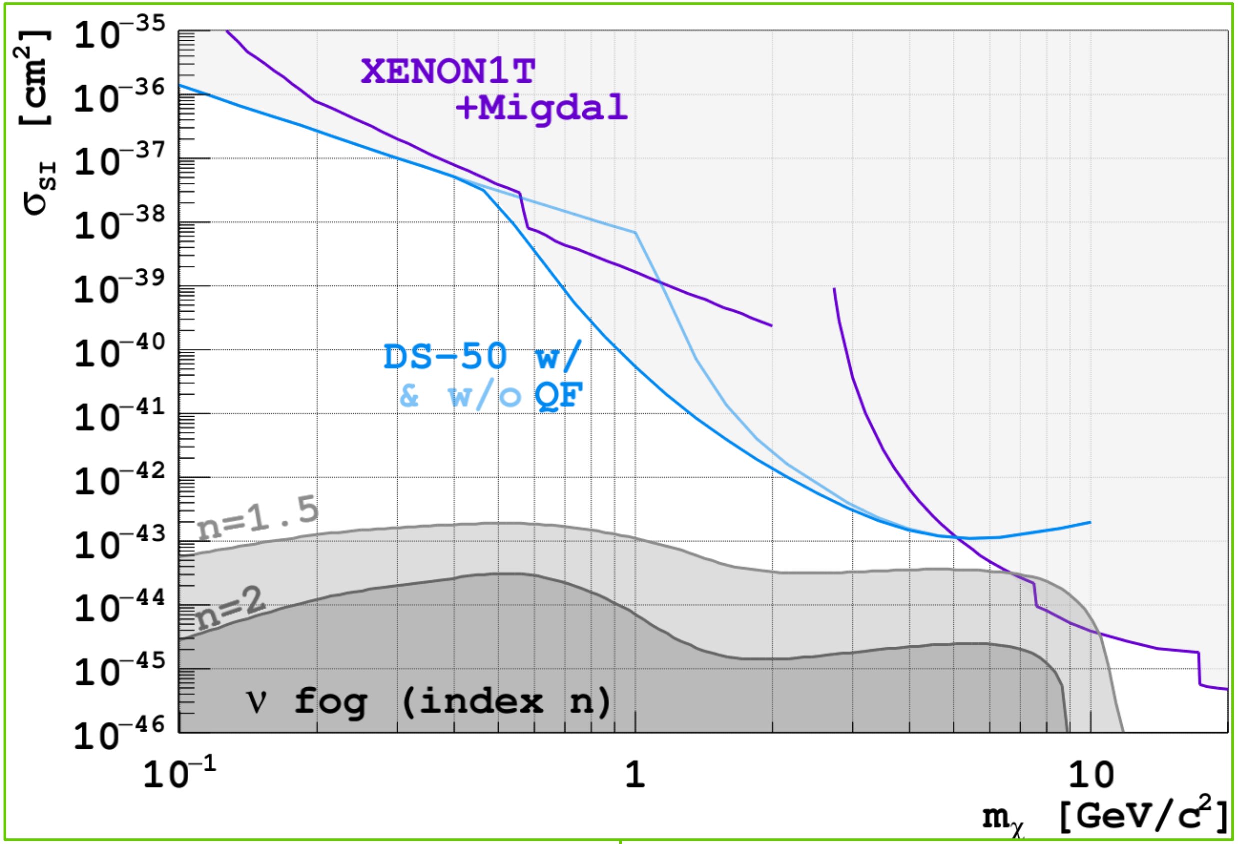
DarkSide Collaboration. "Search for low-mass dark matter WIMPs with 12 ton-day exposure of DarkSide-50". arXiv:2207.11966 (2022)

DS-50 light DM search: Loss of S1 and PSD causes electronic recoil & spurious e^- bkgds to arise



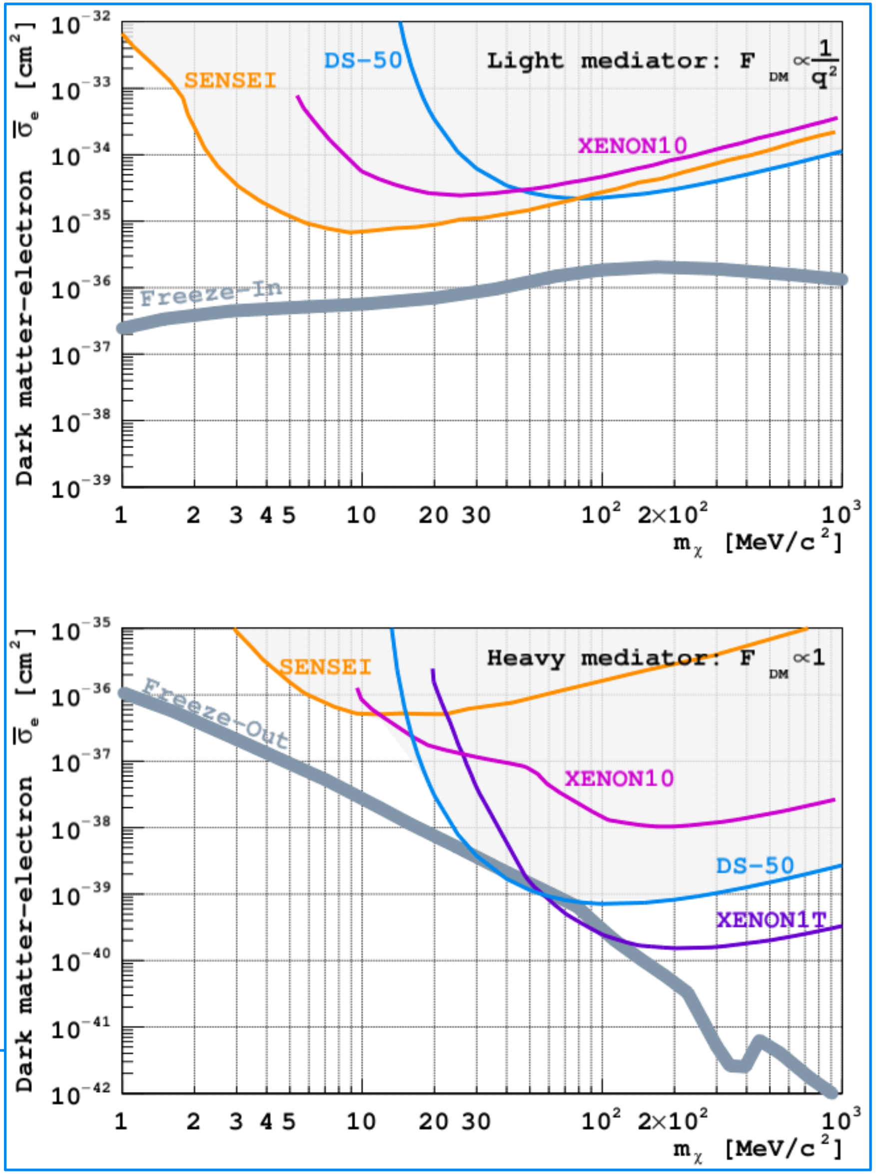


DarkSide Collaboration. "Search for low-mass dark matter WIMPs with 12 ton-day exposure of DarkSide-50". arXiv:2207.11966 (2022)

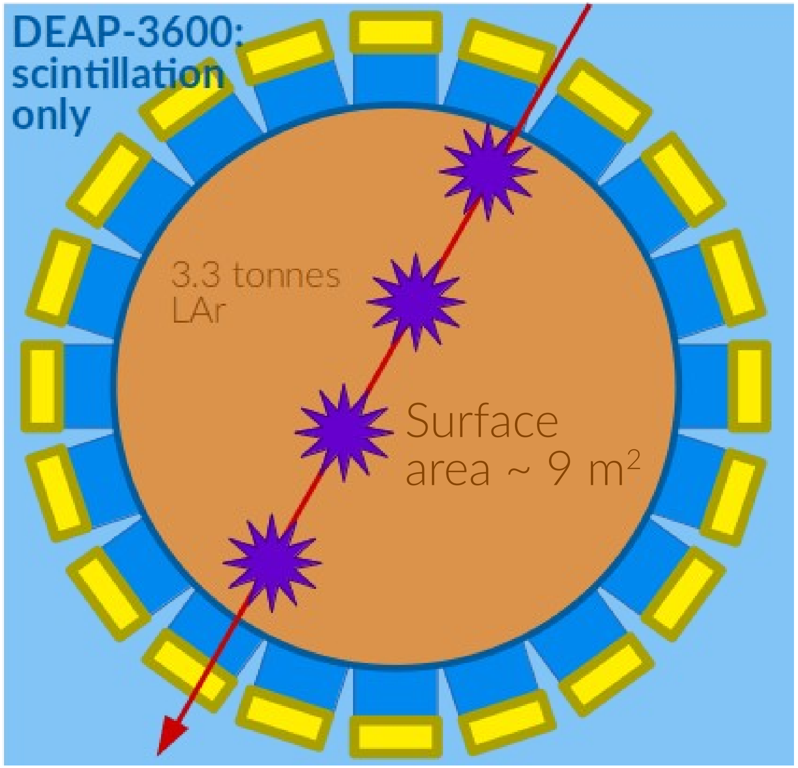


DarkSide Collaboration. “Search for dark matter-nucleon interactions via Migdal effect with DarkSide-50”. arXiv:2207.11967 (2022)

DarkSide Collaboration. “Search for dark matter particle interactions with electron final states with DarkSide-50”. arXiv:2207.11968 (2022)



DEAP-3600 ultraheavy DM search: Use dedicated analyses in large detectors



At very high masses, single-scatter searches lose sensitivity due to **low DM number density**

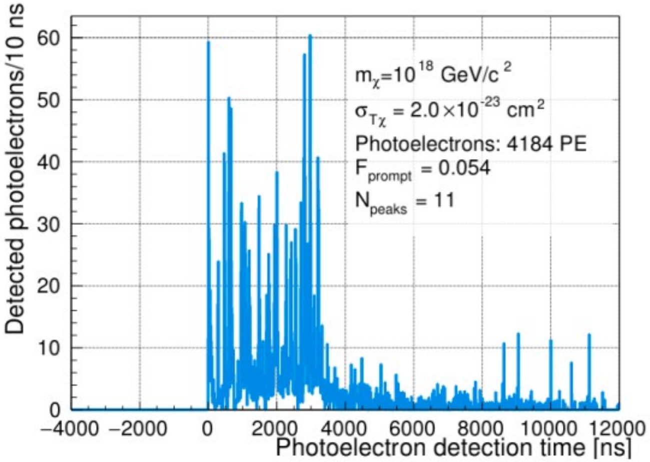
- If DM never enters the detector, it cannot be detected, no matter how high the cross section
- Sensitivity at high masses scales like detector **surface area** – need large area to catch sparse DM

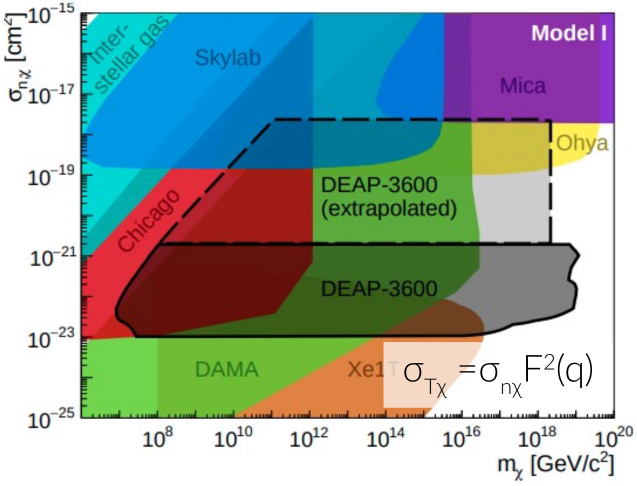
At high masses, experimentally allowed cross sections go high enough for DM that **scatters multiple times**

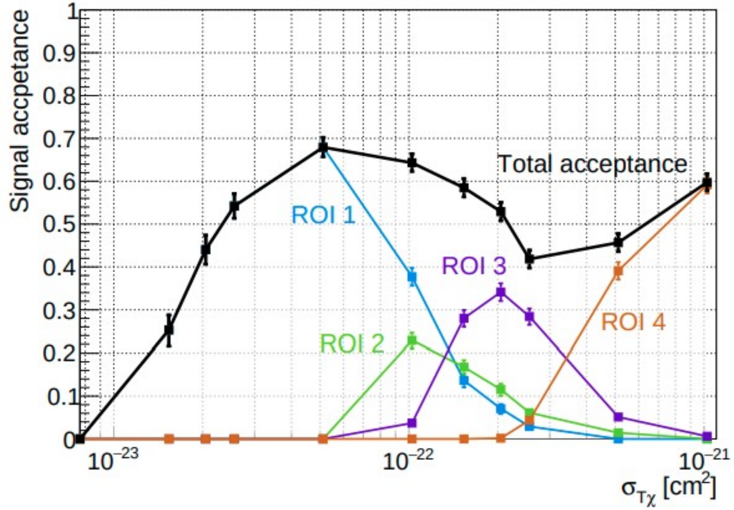
- These signals would be **rejected by typical single-scatter searches** and are therefore unconstrained
- Must account for **attenuation in lab overburden**

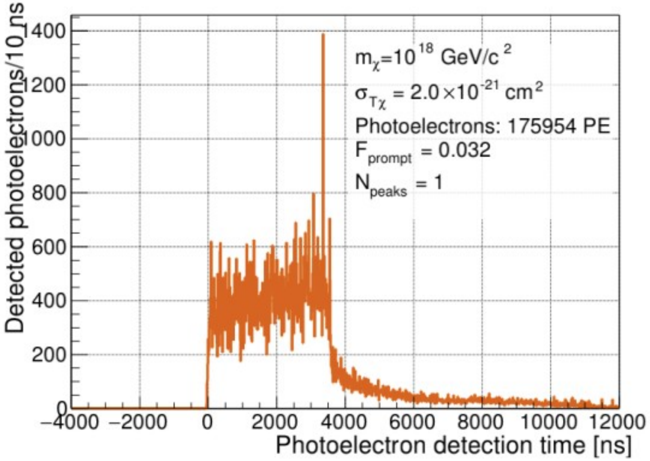
DM w/ masses up to M_{Planck} motivated by **cosmological models**; may be produced by gravitational mechanisms, inflaton decay, phase transitions, and other mechanisms

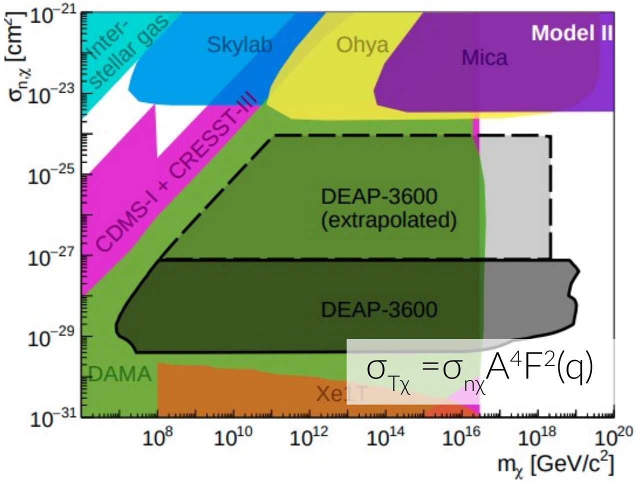
D. Carney *et al.* "Snowmass2021 Cosmic Frontier White Paper: Ultraheavy particle dark matter". arXiv:2203.06508 (2022)











Multi-scatter DM signatures identified by peak-finder & F_{prompt}

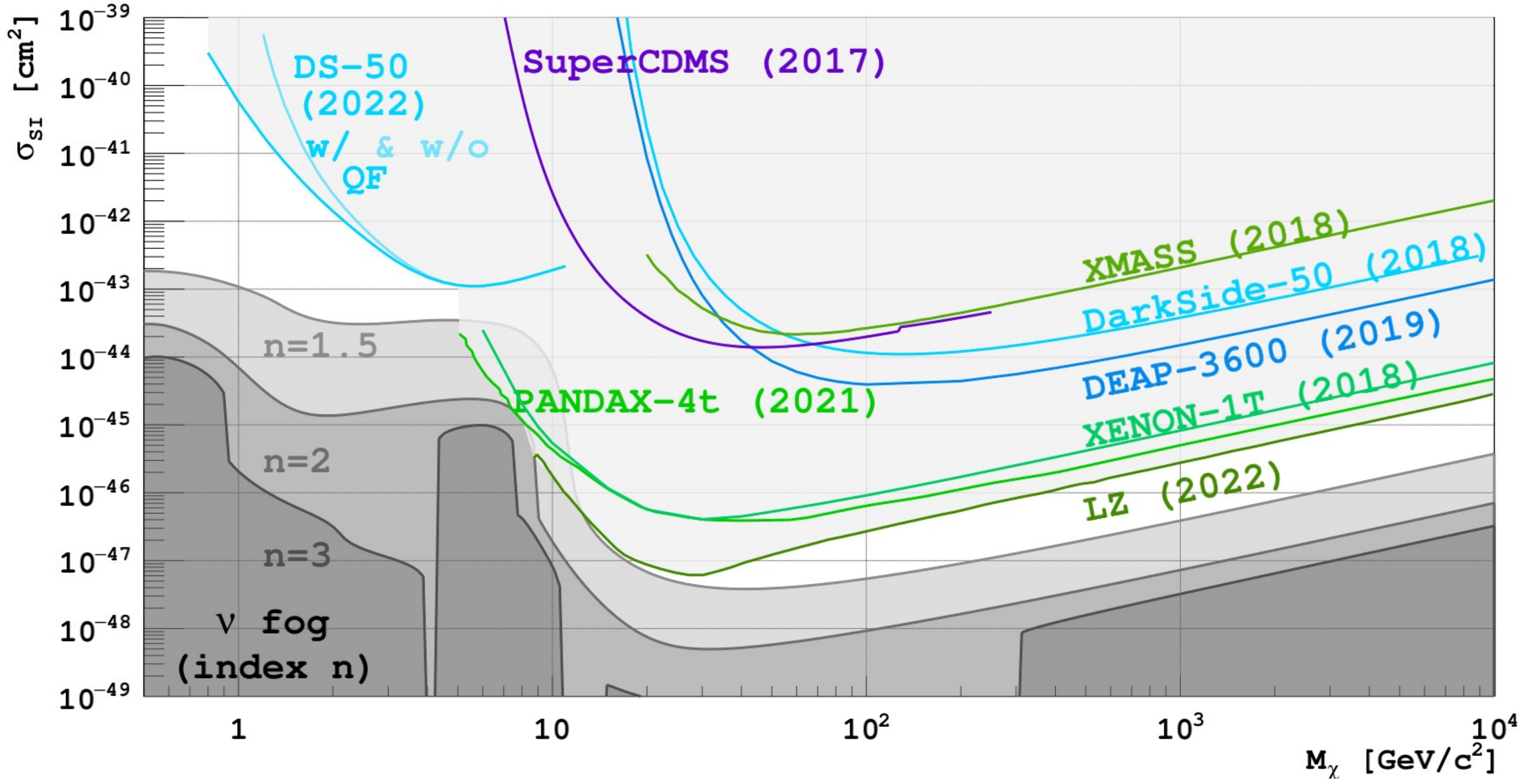
Four ROIs defined to let cuts evolve with signal shape at high σ; <<1 bkgd

Acceptance from sim. w/ overburden attenuation & detector response

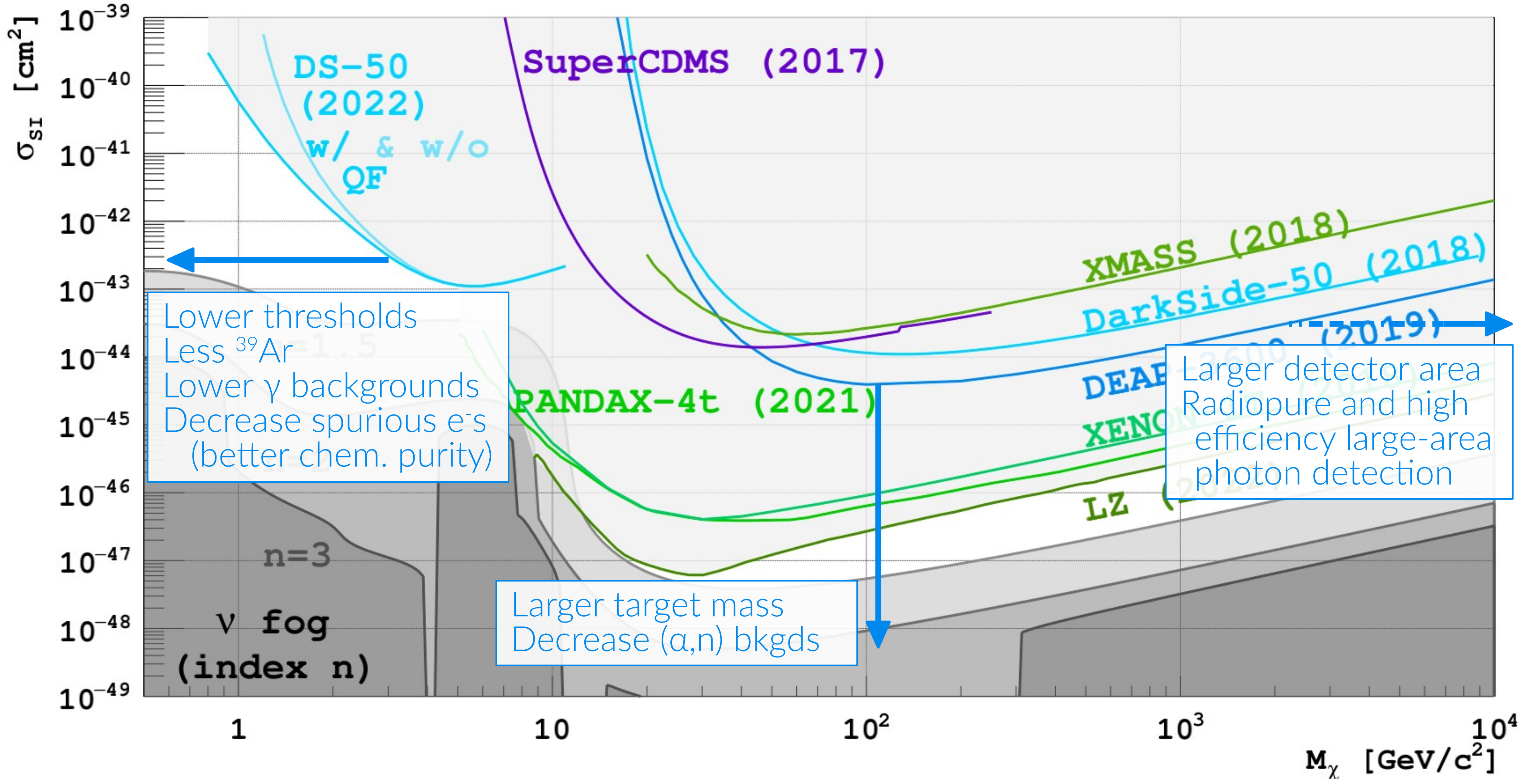
For σ too high to simulate, use conservative lower bound: *extrapolated* region

DEAP Collaboration. "First direct detection constraints on Planck-scale mass dark matter with multiple-scatter signatures using the DEAP-3600 detector". Phys. Rev. Lett. 128, 011801 (2022)

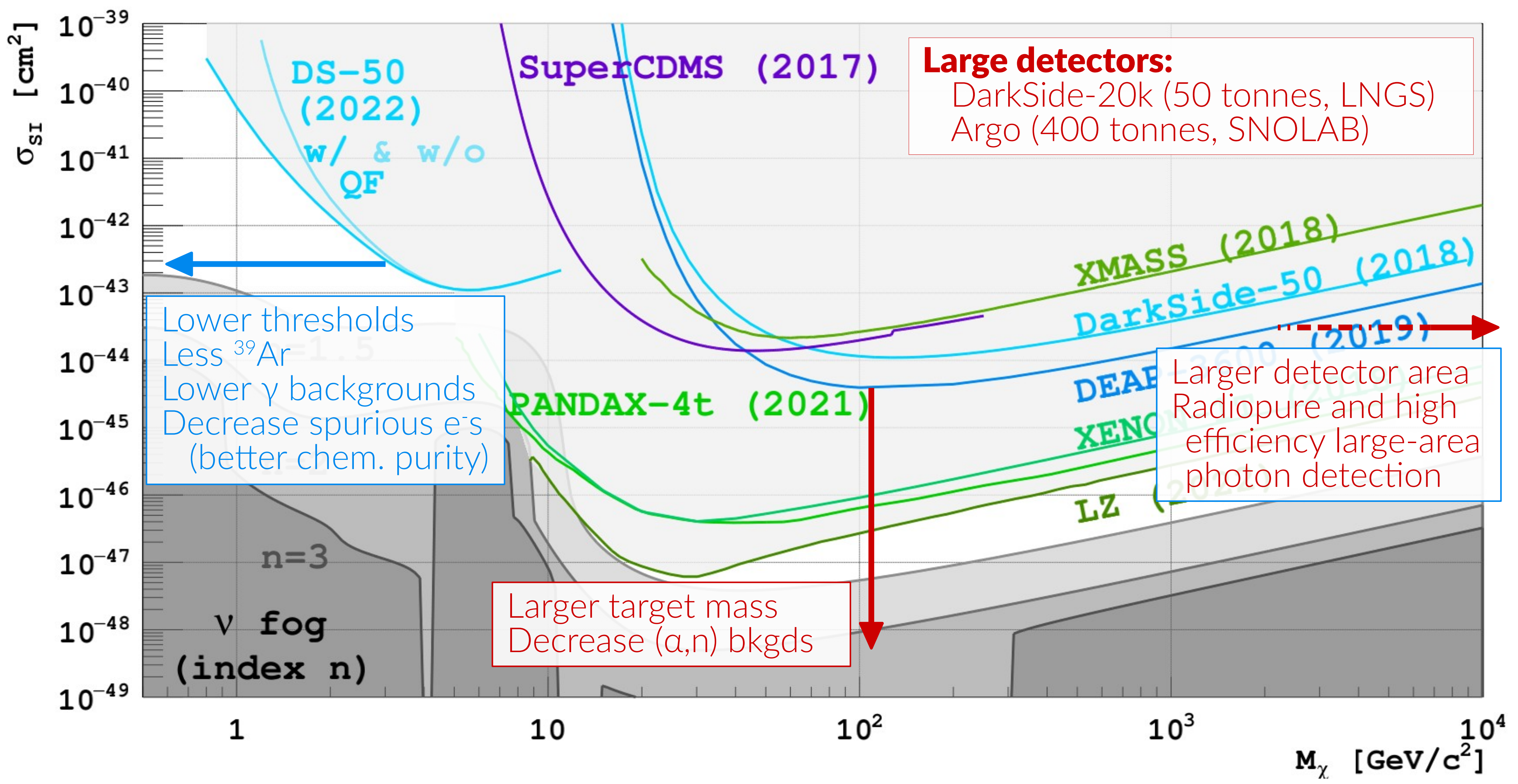

TOMORROWLAND



σ_{SI} [cm^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
DS-50 (2022) w/ & w/o QF
SuperCDMS (2017)
XMASS (2018)
DarkSide-50 (2018)
DEAP-3600 (2019)
XENON-1T (2018)
LZ (2022)
PANDAX-4t (2021)
n=1.5
n=2
n=3
ν fog (index n)
1
10
10^2
10^3
10^4
M_χ [GeV/c^2]



σSI [cm2]
10−39
10−40
10−41
10−42
10−43
10−44
10−45
10−46
10−47
10−48
10−49
DS−50
(2022)
w/ & w/o
QF
SuperCDMS (2017)
XMASS (2018)
DarkSide-50 (2018)
(2019)
DEAP
XENON
LZ
PANDAX-4t (2021)
n=3
ν fog
(index n)
1
10
10²
10³
10⁴
Mχ [GeV/c²]
Lower thresholds
Less 39Ar
Lower γ backgrounds
Decrease spurious e-s
(better chem. purity)
Larger target mass
Decrease (α,n) bkgds
Larger detector area
Radiopure and high
efficiency large-area
photon detection



Large detectors:
DarkSide-20k (50 tonnes, LNGS)
Argo (400 tonnes, SNOLAB)
Lower thresholds
Less 39Ar
Lower γ backgrounds
Decrease spurious e-s
(better chem. purity)
Larger target mass
Decrease (α,n) bkgds
Larger detector area
Radiopure and high
efficiency large-area
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DS-50
(2022)
w/ & w/o
QF
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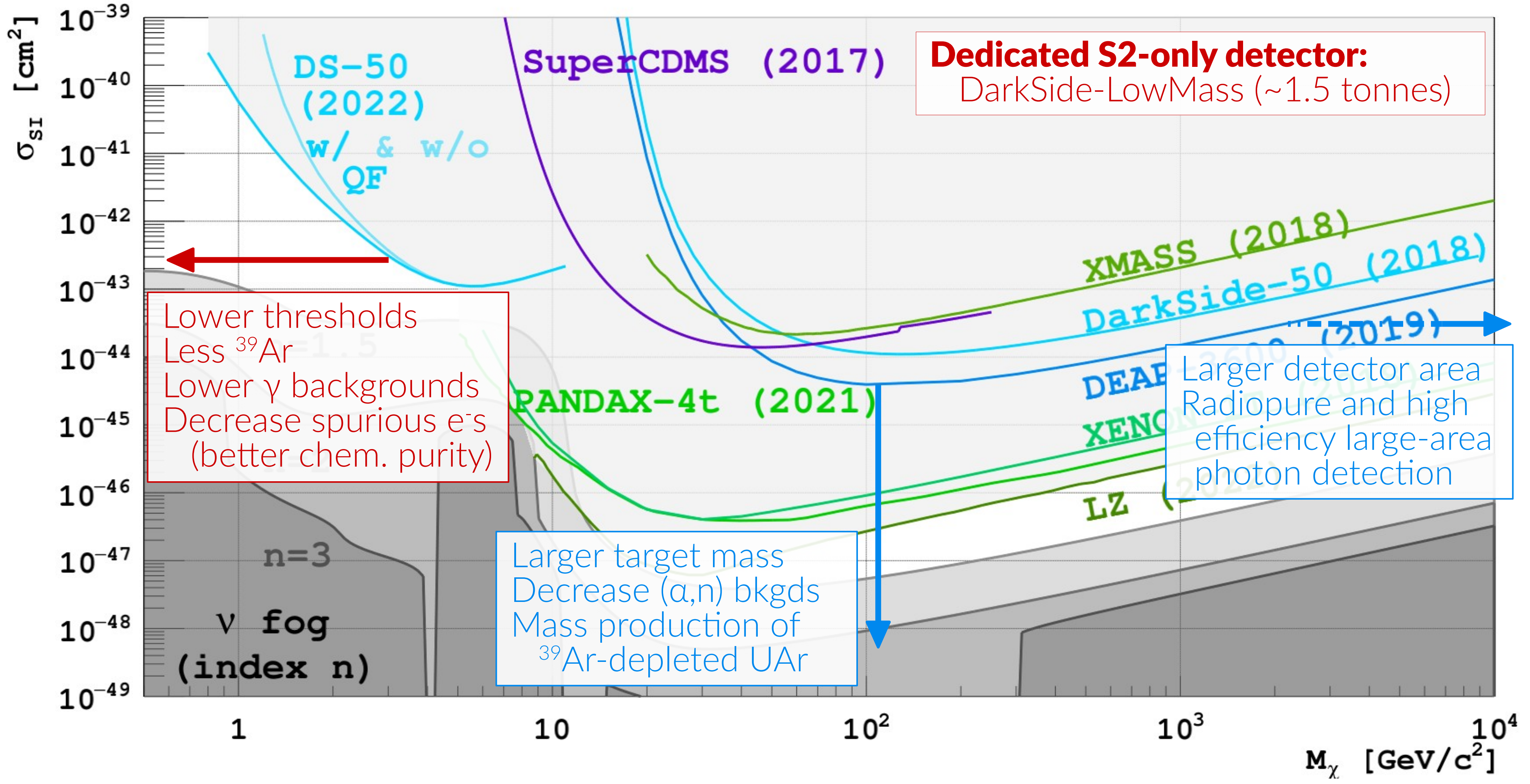
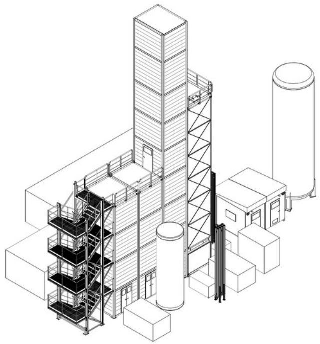
DarkSide-50 (2018)
DEAP-3600 (2019)
PANDAX-4t (2021)
XENON
LZ
n=3
ν fog
(index n)
σSI [cm2]
Mχ [GeV/c2]



Dedicated S2-only detector:
DarkSide-LowMass (~1.5 tonnes)
DS-50 (2022) w/ & w/o QF
SuperCDMS (2017)
XMASS (2018)
DarkSide-50 (2018)
DEAP-3600 (2019)
PANDAX-4t (2021)
XENON
LZ
Lower thresholds
Less ^{39}Ar
Lower γ backgrounds
Decrease spurious e⁻s
(better chem. purity)
Larger detector area
Radiopure and high efficiency large-area photon detection
Larger target mass
Decrease (α,n) bkgds
Mass production of ^{39}Ar-depleted UAr
n=3
ν fog (index n)
σ_{SI} [cm^2]
M_χ [GeV/c^2]

UAr: Low radioactivity argon

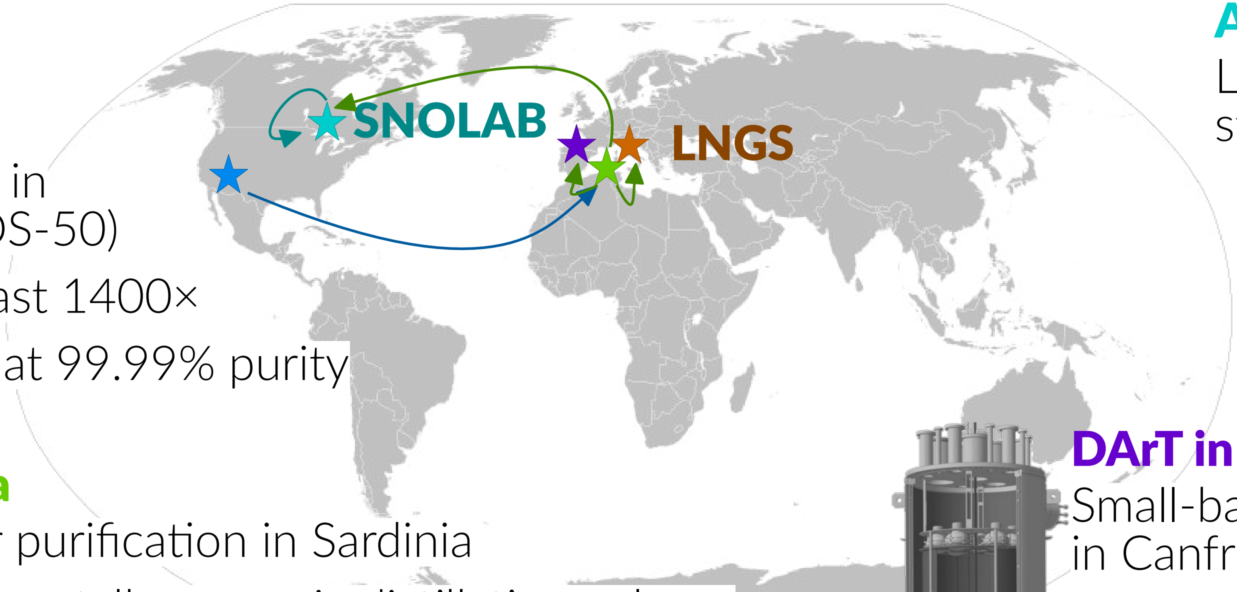


Urania

UAr extraction plant in Colorado (same as DS-50)

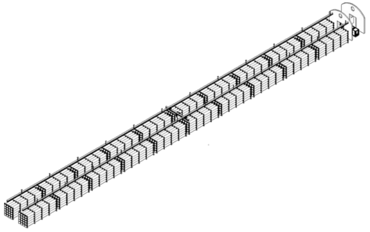
^{39}Ar reduction: at least 1400×

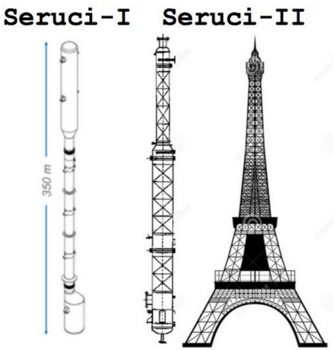
Extract: 250 kg/day at 99.99% purity



ARGUS

Long-term UAr storage at SNOLAB





Aria

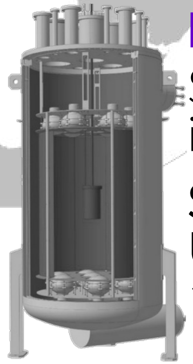
UAr purification in Sardinia

350 m-tall cryogenic distillation column

Chem. purification: 10^3× reduction at O(1 tonne/day)

^{39}Ar depletion: 10× reduction at O(10 kg/day)

DarkSide Collaboration. "Separating ^{39}Ar from ^{40}Ar by cryogenic distillation with Aria for dark matter searches". Eur.Phys.J.C 81 (2021) 4, 359

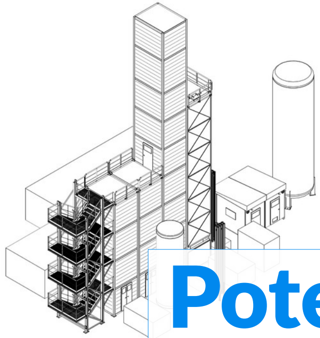


DArT in ArDM

Small-batch ^{39}Ar assay facility in Canfranc Lab, Spain

Sensitivity: depletion factor U.L. of 6×10^4 at 90% C.L. in 1 week of counting time

DarkSide Collaboration. "Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon". JINST 15 P02024 (2020)



UAr: Low radioactivity argon

Potential uses in neutrino experiments via ^{39}Ar and ^{42}Ar depletion

Reminder:

$^{39}Ar \rightarrow {}^{39}K + \beta^-$ (Q_β = 565 keV, $T_{1/2}$ = 269 yrs)

$^{42}Ar \rightarrow {}^{42}K + \beta^-$ (Q_β = 599 keV, $T_{1/2}$ = 32.9 yrs)

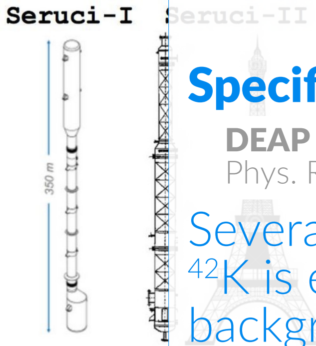
$^{42}K \rightarrow {}^{42}Ca + \beta^- + \gamma$ (Q_β = 3.5 MeV, $T_{1/2}$ = 12.4 hrs, 0.02% BR for E_γ = 2.4 MeV)

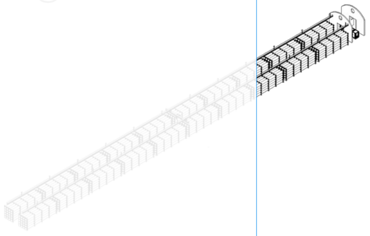
Specific activity of $^{42}Ar/^{42}K$: 40.4±5.9 µBq/kg of atmospheric argon

DEAP Collaboration. "Electromagnetic Backgrounds and Potassium-42 Activity in the DEAP-3600 Dark Matter Detector". Phys. Rev. D 100, 072009 (2019)

Several orders of magnitude reduction are expected in underground argon

^{42}K is expected to be a significant background in LEGEND-100, a DUNE-like low-background module, and other neutrino experiments.





DarkSide Collaboration. "Separating ^{39}Ar from ^{40}Ar by cryogenic distillation with Aria for dark matter searches". Eur.Phys.J.C 81 (2021) 4, 359

DarkSide Collaboration. "Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon". JINST 15 P02024 (2020)

SiPMs: Low-radioactivity, high efficiency Si photomultiplier development

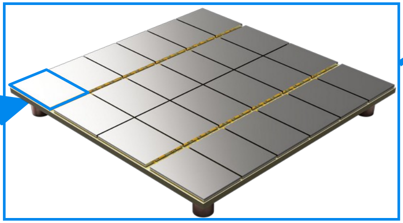
Developed with Fondazione Bruno Kessler (FBK)

DarkSide Collaboration. "Cryogenic Characterization of FBK RGB-HD SiPMs". JINST 12 P09030 (2017)

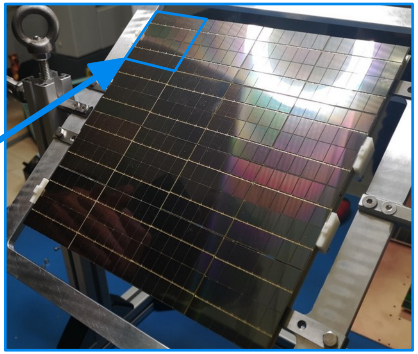
- Photodetection efficiency: > 40% at 77K
- Dark count rate: <0.01 Hz/mm^2 at 77 K (7 VoV)
- SNR: >8 (TPC)

SPAD

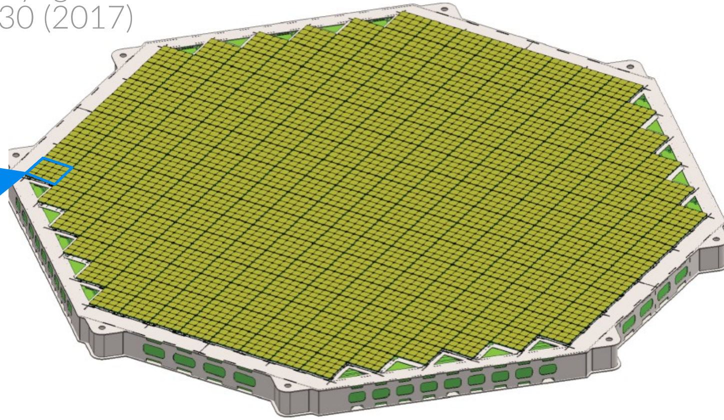
SiPMs [8×12 mm^2]



Tile (24 SiPMs) [5×5 cm^2]



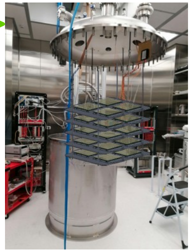
PhotoDetection Unit (PDU) (16 tiles, arranged into 4 channels) [20×20 cm^2]



Optical Plane (264 PDUs)

SiPM production at LFoundry (Italy)

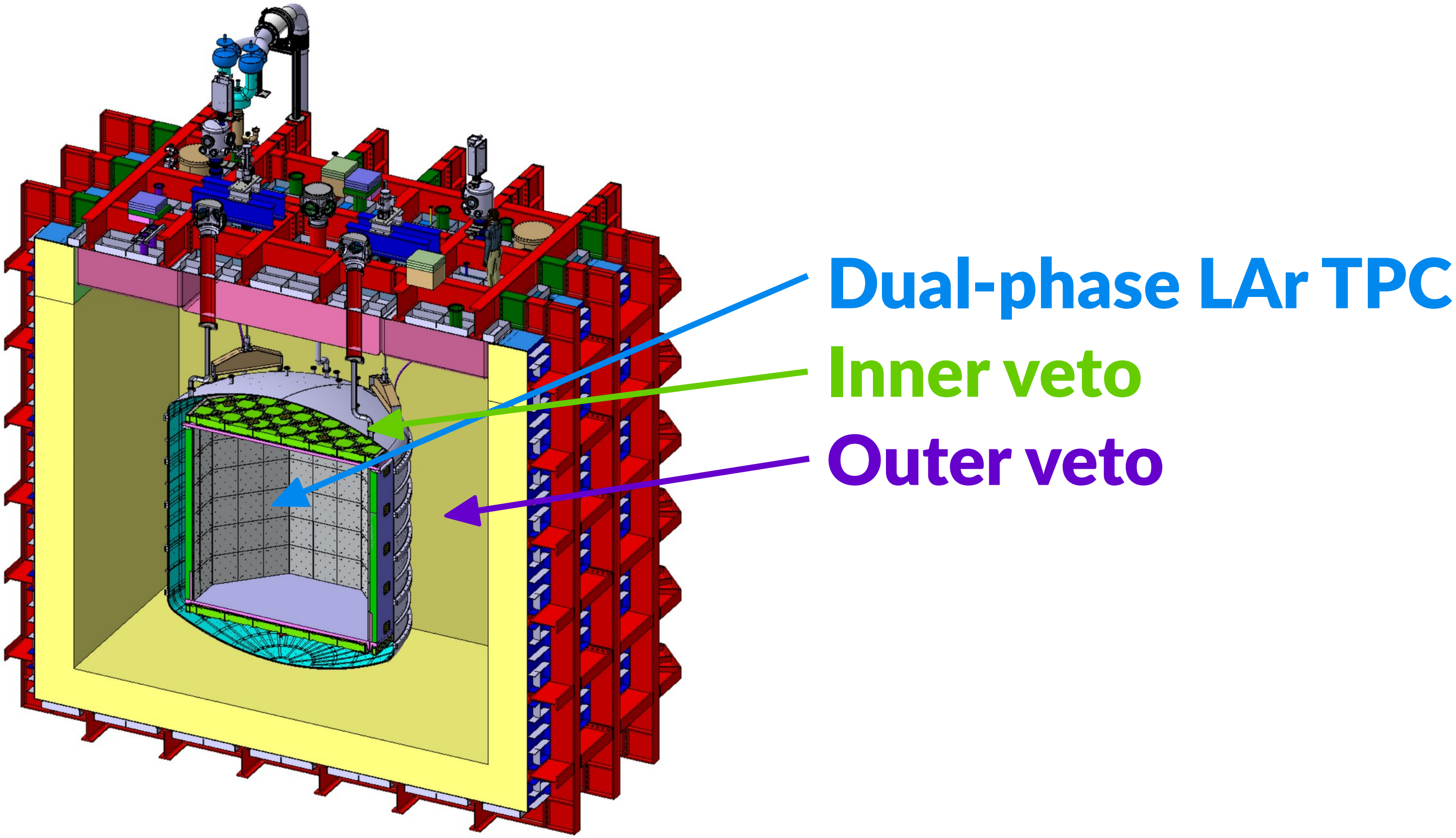
PDU packaging and assembly at Nuova Officina Assergi (NOA) at LNGS



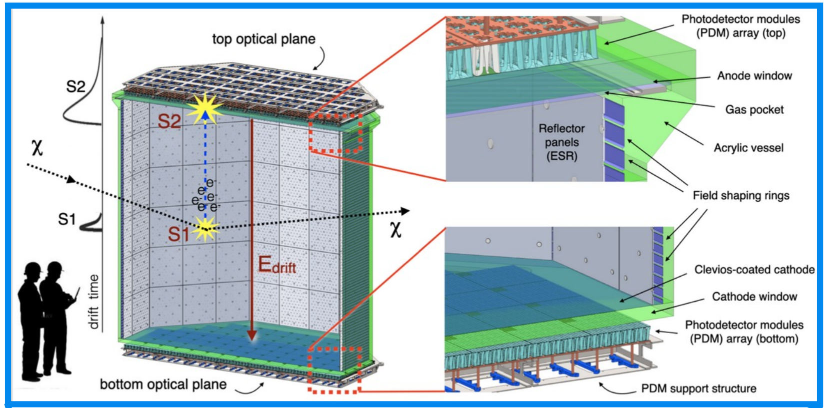
Testing at the Naples Test Facility

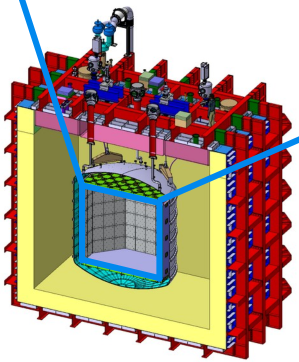
A. Gola *et al.* "NUV-Sensitive Silicon Photomultiplier Technologies Developed at Fondazione Bruno Kessler". Sensors19(2), 308 (2019)

DarkSide-20k: Three nested detectors



DarkSide-20k: Three nested detectors





Dual-phase LAr TPC

Instrumentation: Contained in pure & Gd-doped (1 wt%) acrylic; field maintained by conductive Clevios coatings, ESR reflector + TPB wavelength shifter; viewed by PDUs

Active mass: 49.7 tonnes underground argon

Fiducial mass: 20 tonnes underground argon

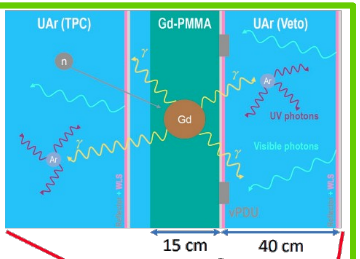
Goal: Detect dark matter! Expect 3 background events from atmospheric neutrinos, and <<1 from other sources

Inner veto

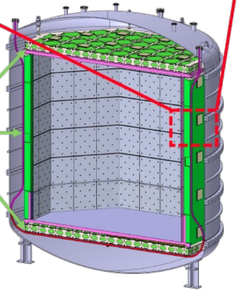
Outer veto

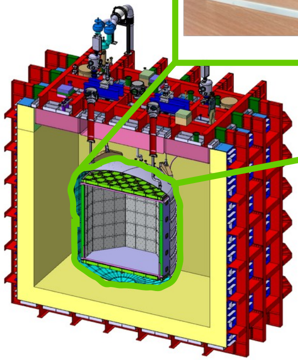
DarkSide-20k: Three nested detectors

Gd(MAA)$_3$-doped acrylic with 1 wt% Gd successfully developed!



Gd-doped acrylic





Dual-phase LAr TPC

Inner veto

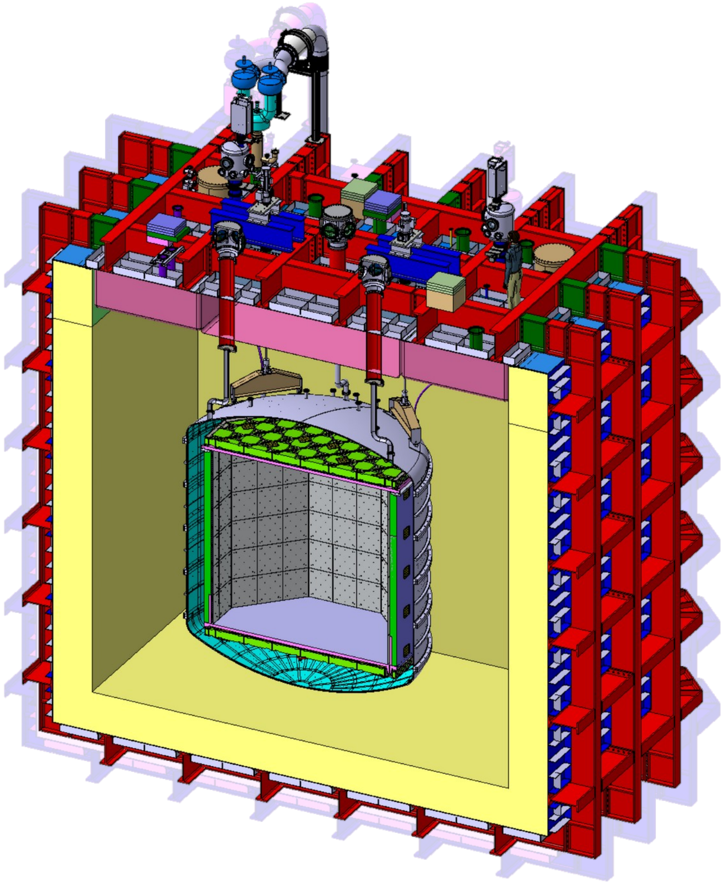
Instrumentation: Contained in stainless steel vessel, viewed by PDU arrays

Active mass: 32 tonnes of underground argon

Goal: Veto (α,n) & spontaneous fission neutrons from ^{235,238}U and ^{232}Th in detector materials by detecting (n,γ) in Gd-doped acrylic surrounding TPC. Aim to veto 85-90% of WIMP-like neutron events.

Outer veto

DarkSide-20k: Three nested detectors



Dual-phase LAr TPC

Inner veto

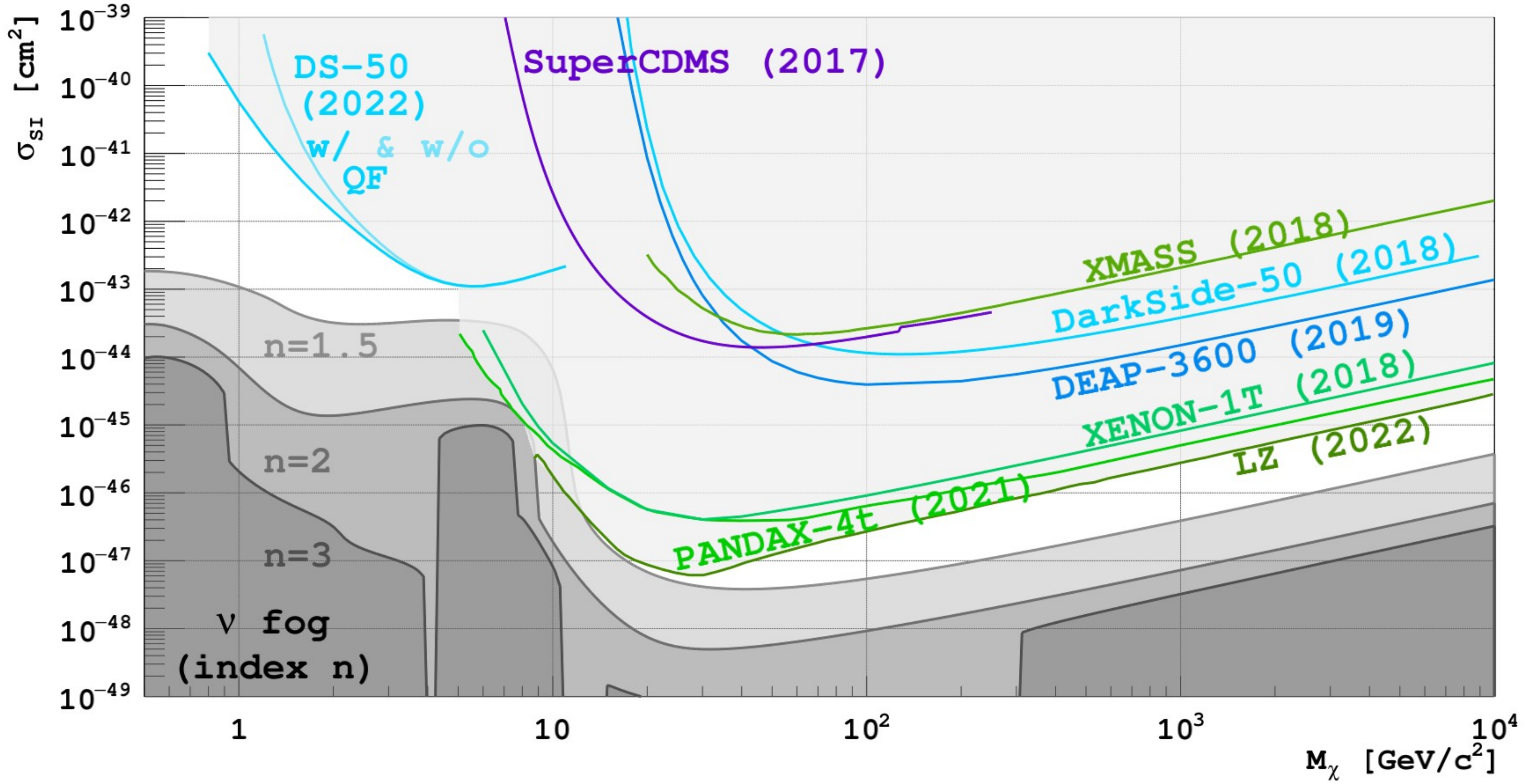
Outer veto

Instrumentation: ProtoDUNE-like cryostat; PDU arrays hanging from top, lined with wavelength-shifting and reflective foils

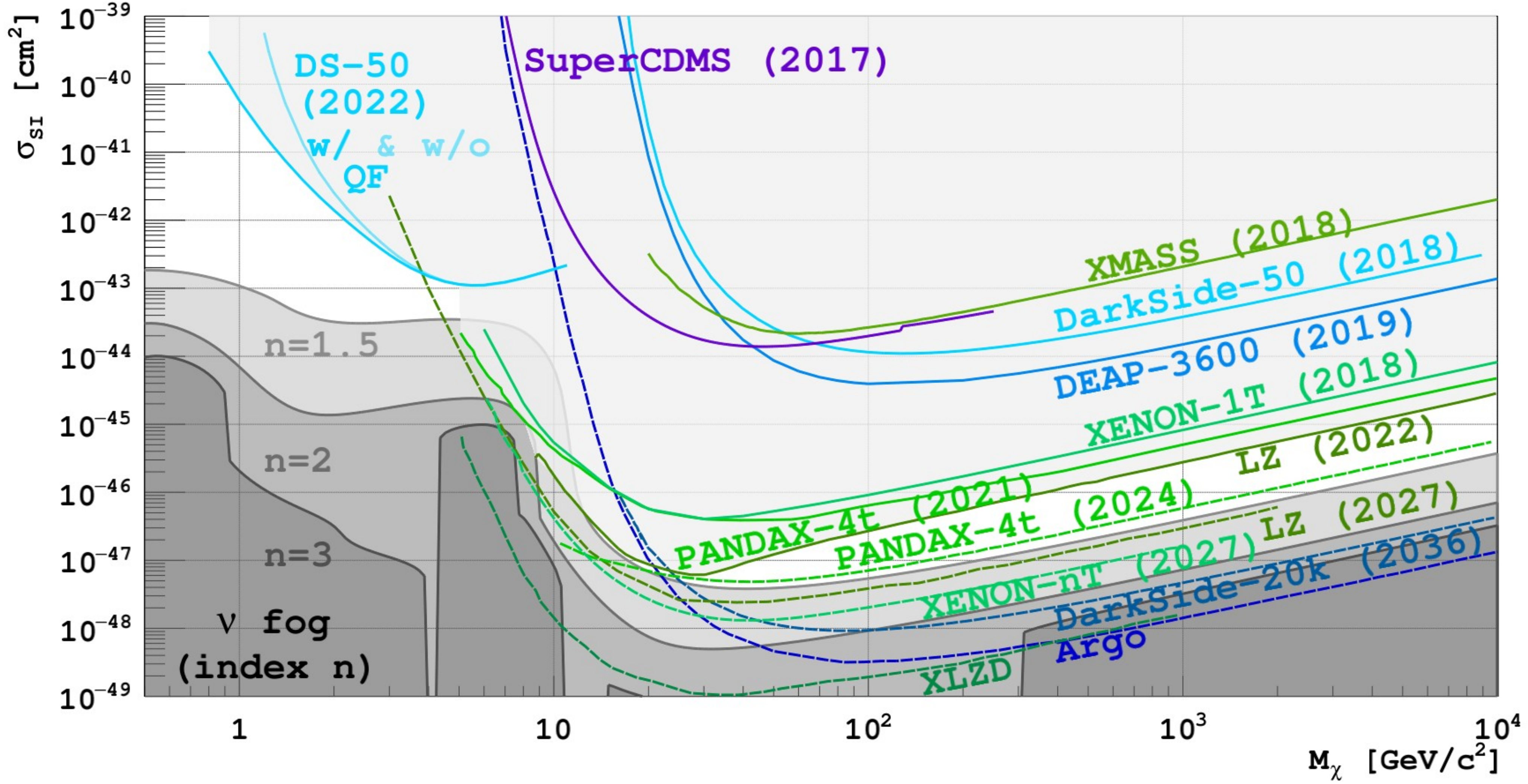
Active mass: ~650 tonnes of atmospheric argon

Goal: Veto neutrons from cosmogenic muon showers, based on signal from muon+shower products

Beginning construction at LNGS

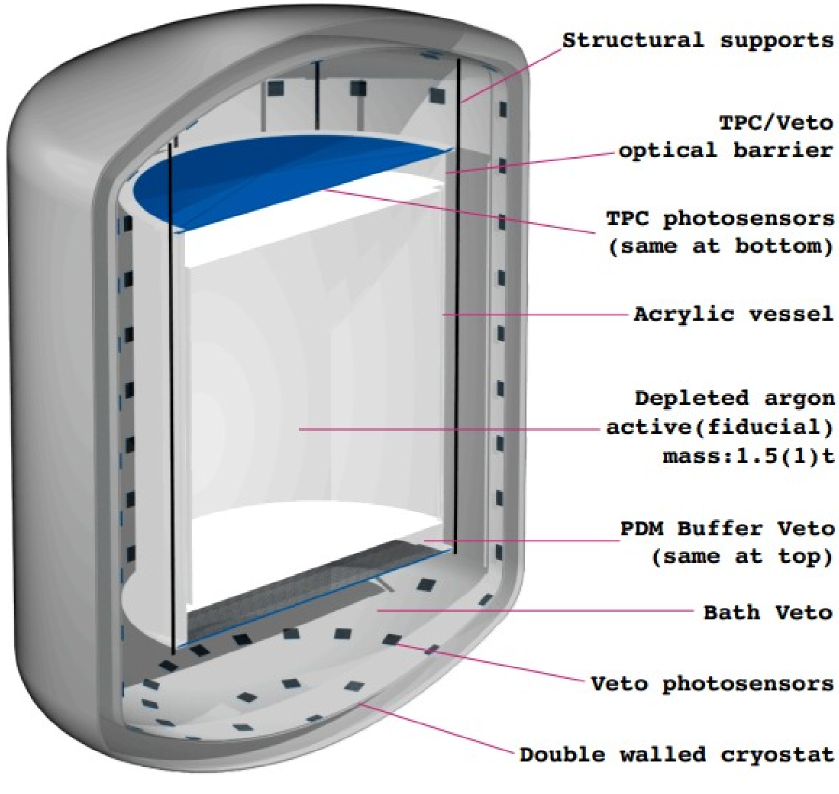


σ_{SI} [cm^2]
10^{-39}
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
10^{-49}
1
10
10^2
10^3
10^4
M_χ [GeV/c^2]
DS-50 (2022) w/ & w/o QF
SuperCDMS (2017)
XMASS (2018)
DarkSide-50 (2018)
DEAP-3600 (2019)
XENON-1T (2018)
LZ (2022)
PANDAX-4t (2021)
n=1.5
n=2
n=3
ν fog (index n)



σ_{SI} [cm^2]
M_χ [GeV/c^2]
DS-50 (2022) w/ & w/o QF
SuperCDMS (2017)
XMASS (2018)
DarkSide-50 (2018)
DEAP-3600 (2019)
XENON-1T (2018)
LZ (2022)
PANDAX-4t (2021)
PANDAX-4t (2024)
LZ (2027)
XENON-nT (2027)
DarkSide-20k (2036)
Argo
XLZD
n=1.5
n=2
n=3
ν fog (index n)

DarkSide-LowMass: Optimized for S2-only analyses



Cryostat immersed in water tank (not shown)

Active (fiducial) mass: 1.5 (1) tonnes underground argon

Better 1e$^-$ resolution: Stronger electroluminescence field and more uniform extraction grid using tense wire grid

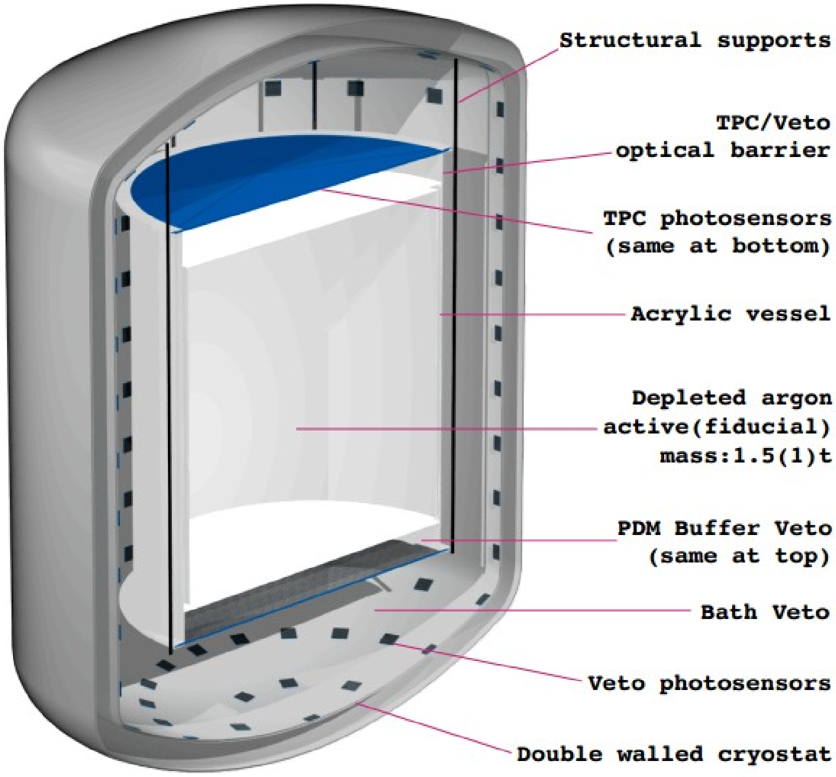
Additional ^{39}Ar depletion: 10–100× relative to DS-50 w/ Urania improvements and isotopic purification in Aria

Decreased γ activity: Low-radioactivity SiPMs and stainless steel from DS-20k, ultrapure acrylic from DEAP

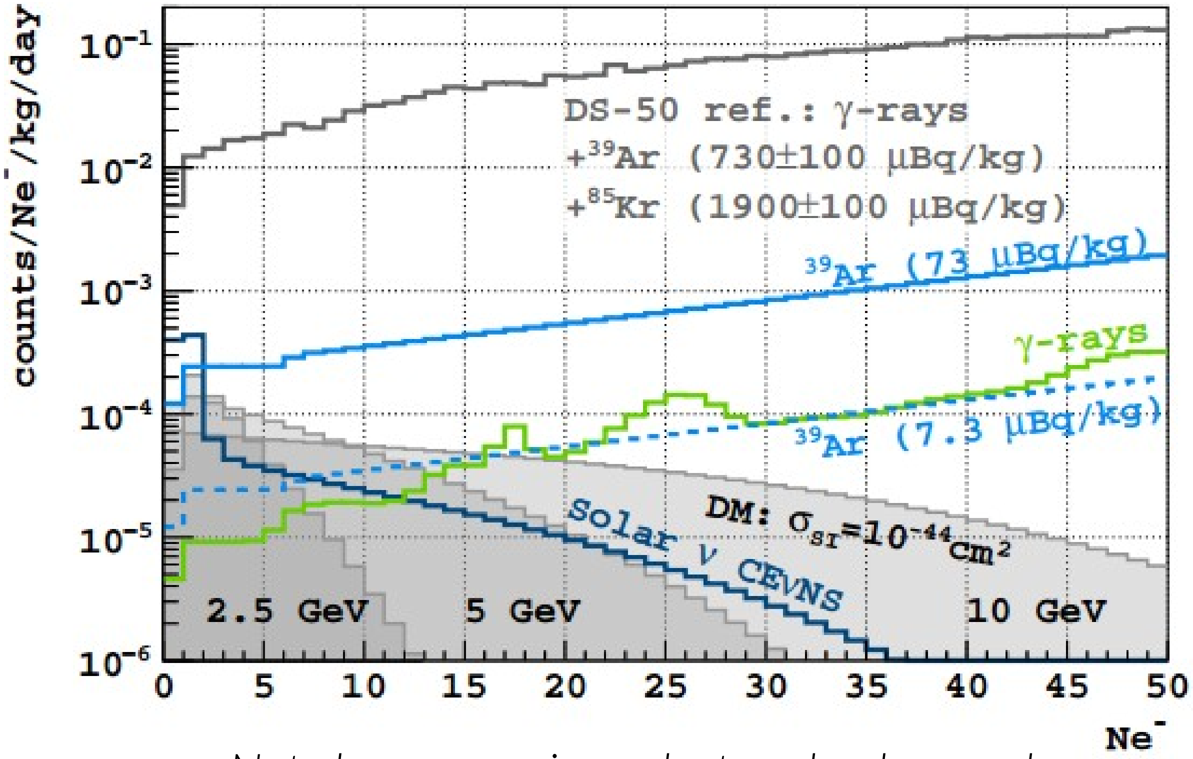
Two-fold γ veto: Additional 10× suppression of γ backgrounds with PDM buffer veto and bath veto, which tag γ's coming from the two dominant sources (photoelectronics and cryostat) *en route* to TPC

Lower spurious e$^-$ background rate: Through improved argon purity, and targeted removal of most important impurities, pending ongoing R&D

DarkSide-LowMass: Optimized for S2-only analyses

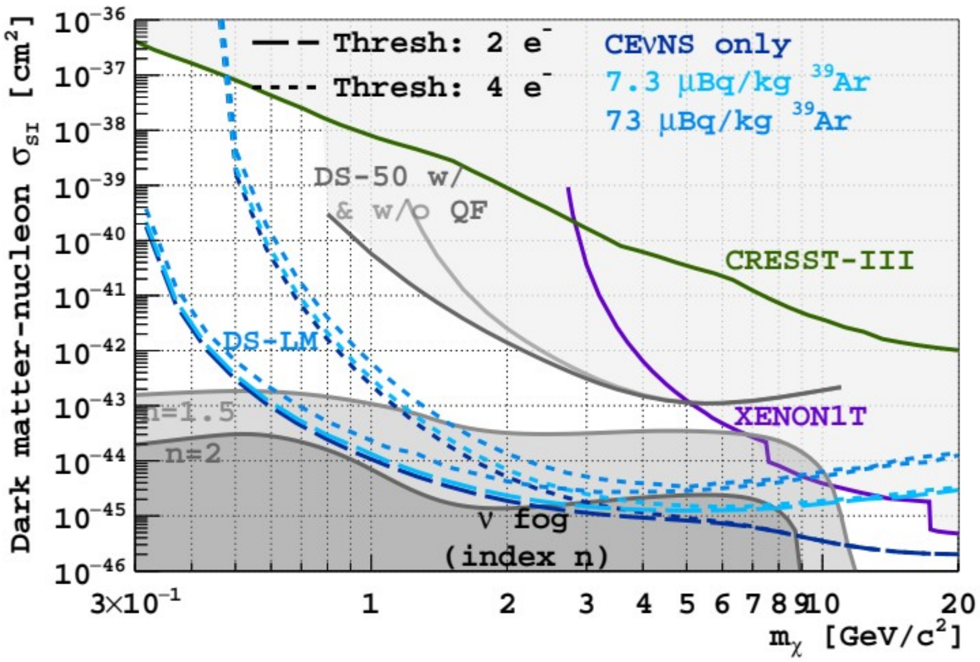


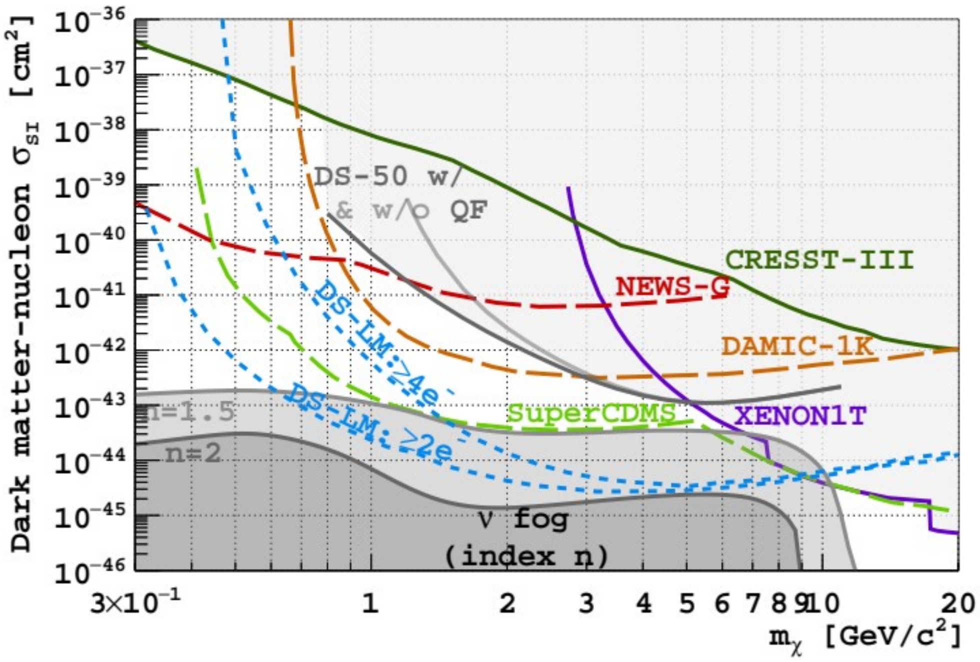
Cryostat immersed in water tank (not shown)

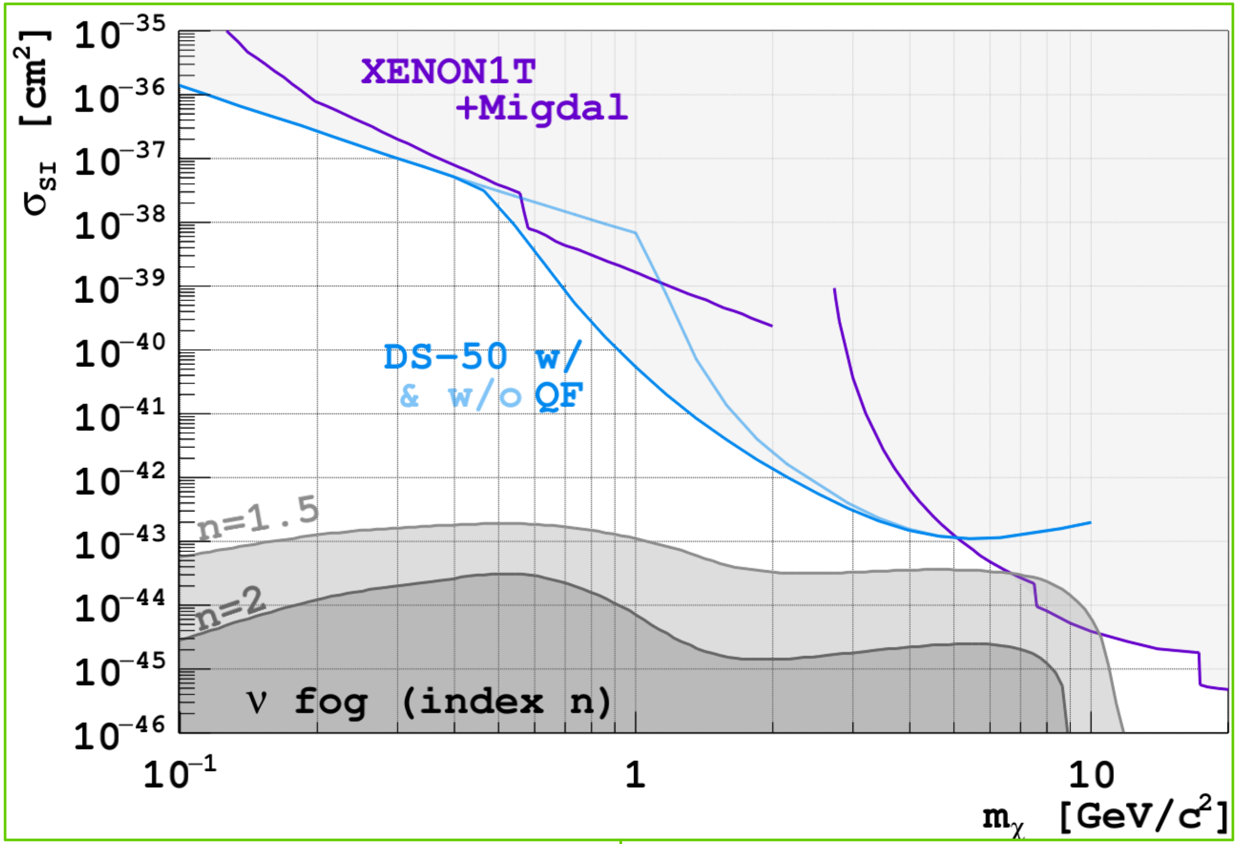


Not shown: spurious electron backgrounds

DarkSide-LowMass: Sensitivity to the ν fog in 1 tonne year exposure

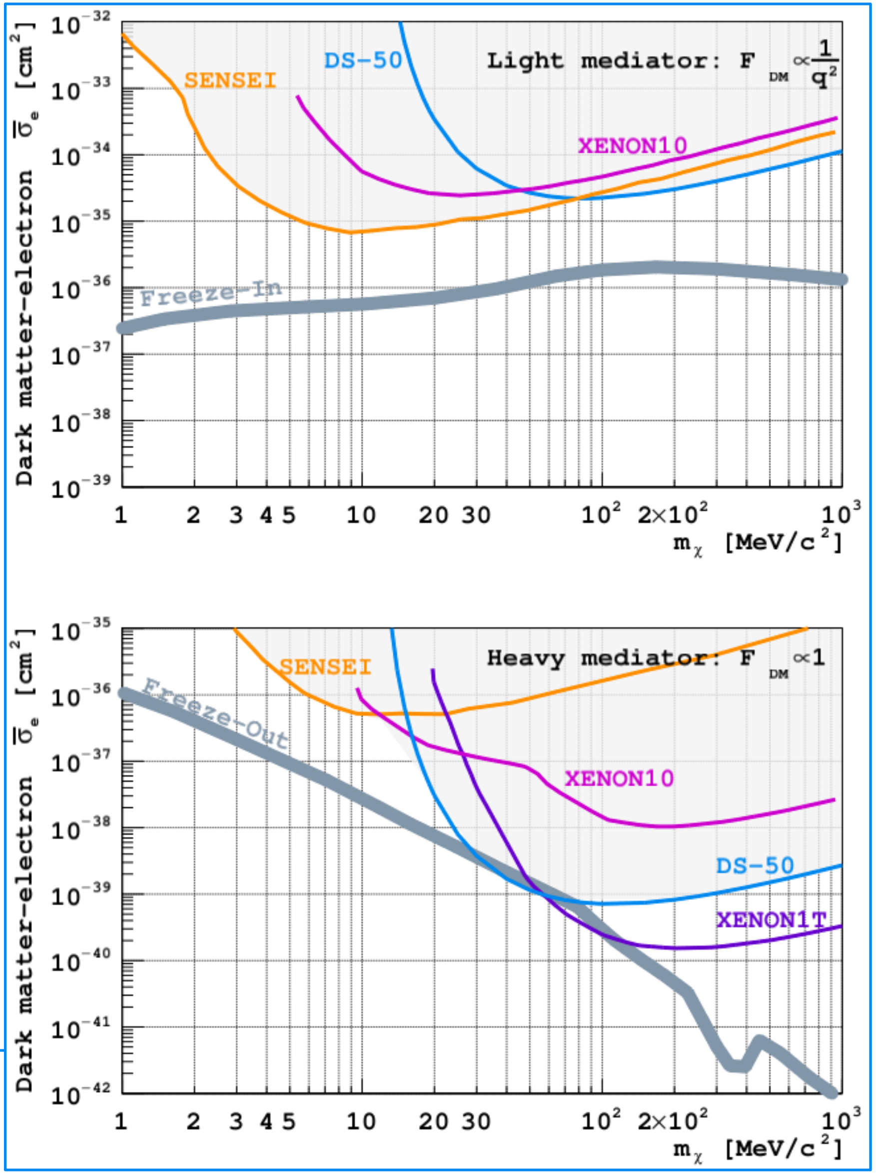


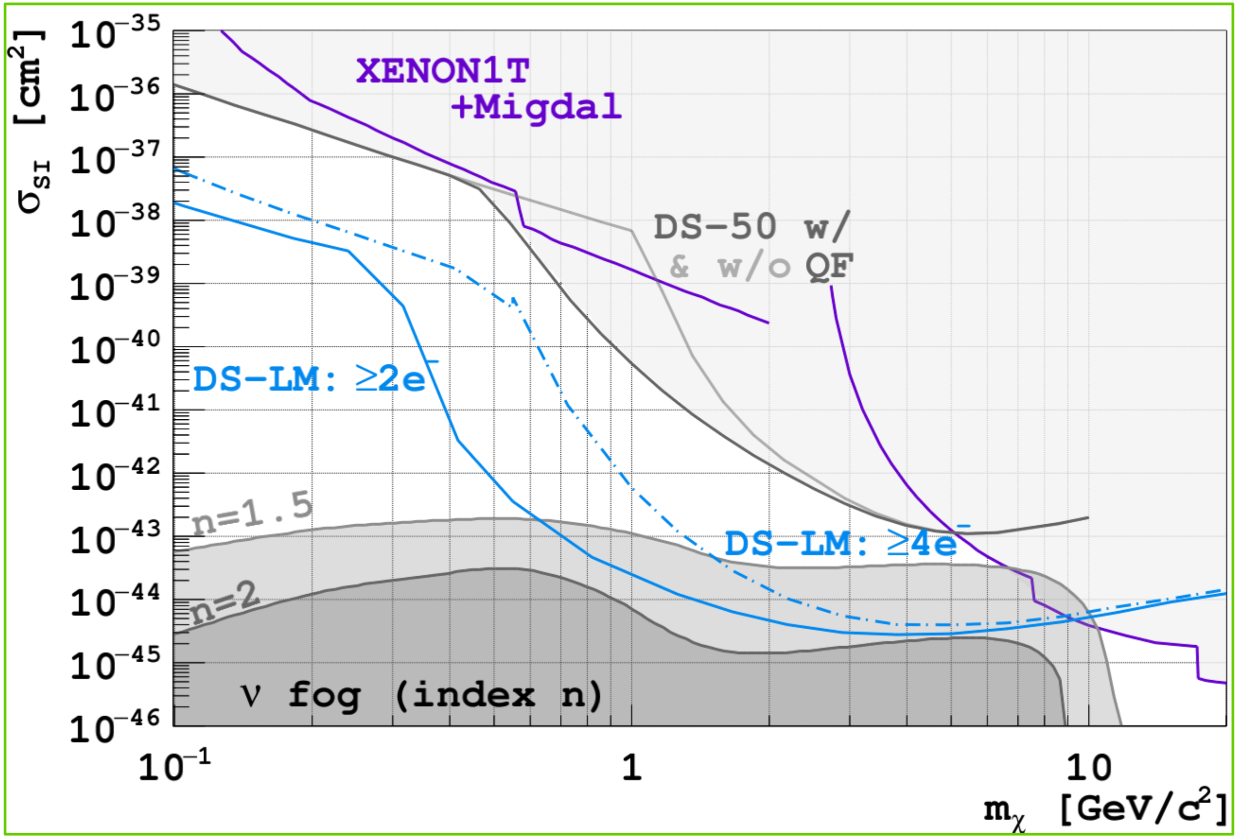


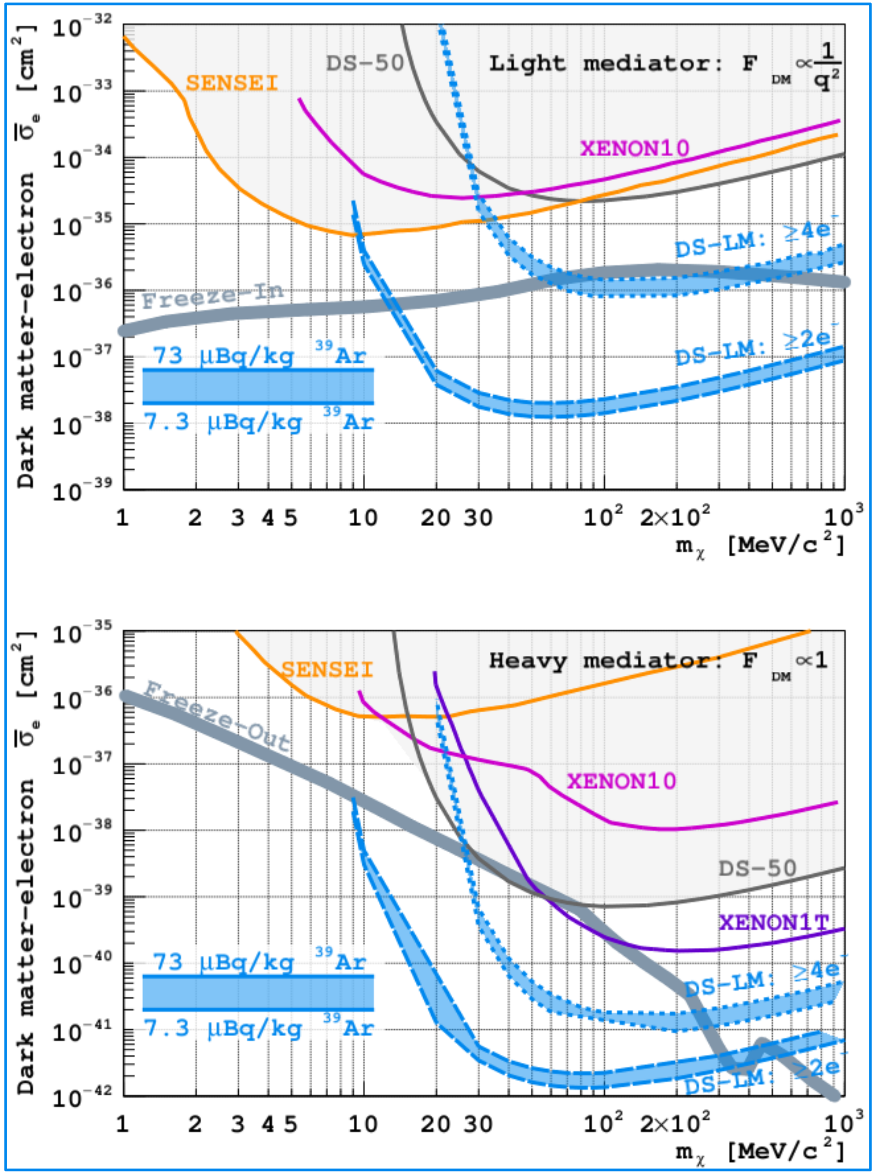


DarkSide Collaboration. "Search for dark matter-nucleon interactions via Migdal effect with DarkSide-50". arXiv:2207.11967 (2022)

DarkSide Collaboration. "Search for dark matter particle interactions with electron final states with DarkSide-50". arXiv:2207.11968 (2022)



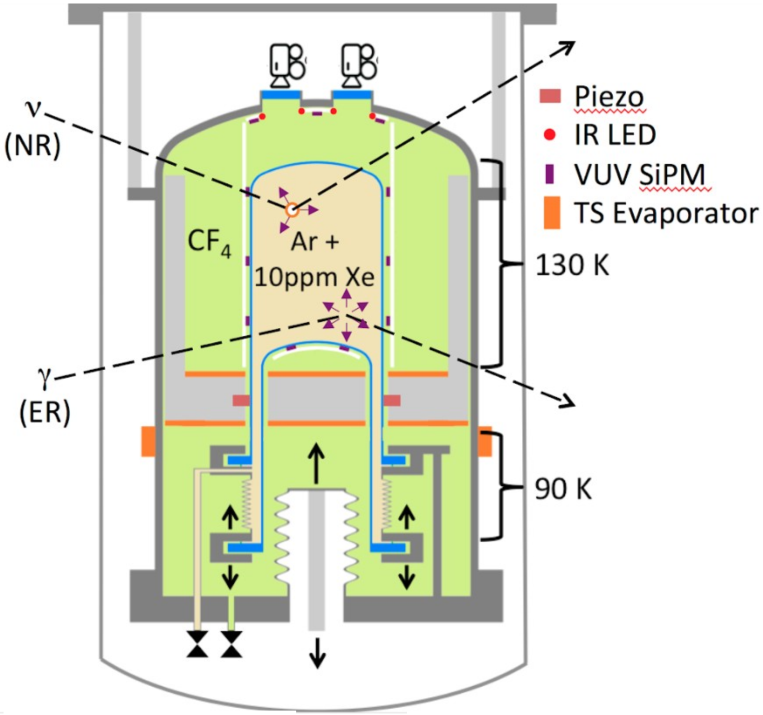




Nuclear couplings: Sensitivity to GeV-scale candidates down into the neutrino fog

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

Other LAr DM detectors: SBC



Scintillating Bubble Chamber

Instrumentation: Xe-doped LAr bubble chamber, viewed by VUV-sensitive SiPMs

Principle: Recoiling nuclei lose ~80% of their energy to heat (invisible to a TPC), which nucleate in superheated LAr

ER discrimination: Recoiling e^-'s lose little energy to heat; β's & γ's won't nucleate!

NR Veto: Light DM nuclear recoils won't scintillate; α's & neutrons may → veto

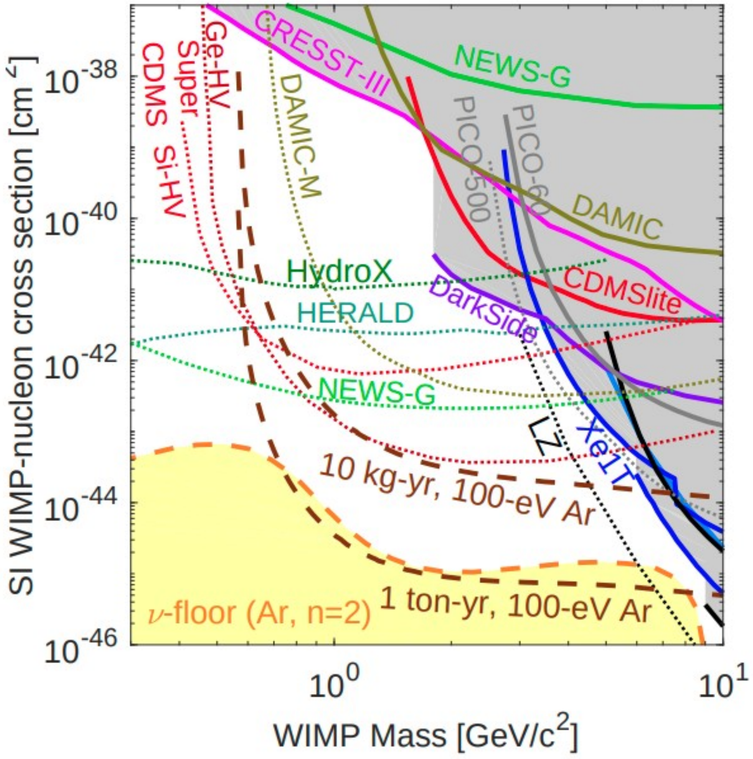
Threshold: Sub-keV (nuclear recoils) possible w/o electronic recoils nucleating

Target: 1 bkgd/10 kg/year, at SNOLAB

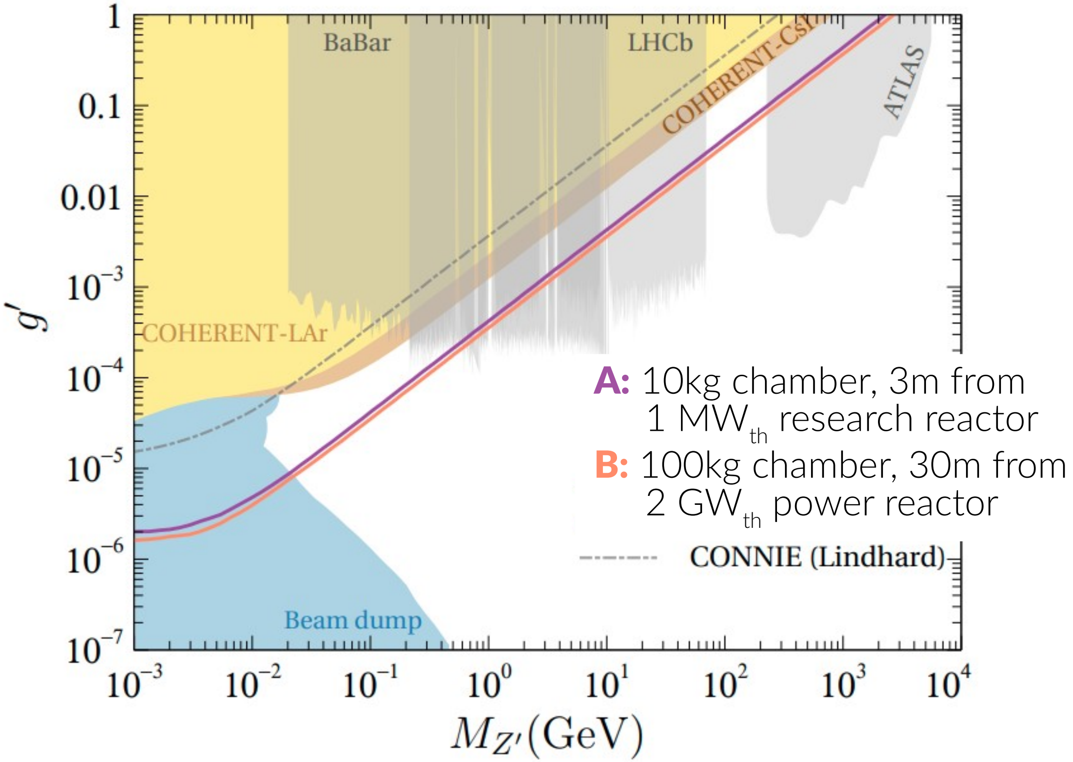
SBC Collaboration. "Snowmass 2021 Scintillating Bubble Chambers: Liquid-noble Bubble Chambers for Dark Matter and CEvNS Detection". arXiv:2207.12400 (2022)

Other LAr DM detectors: SBC

Direct detection search at SNOLAB

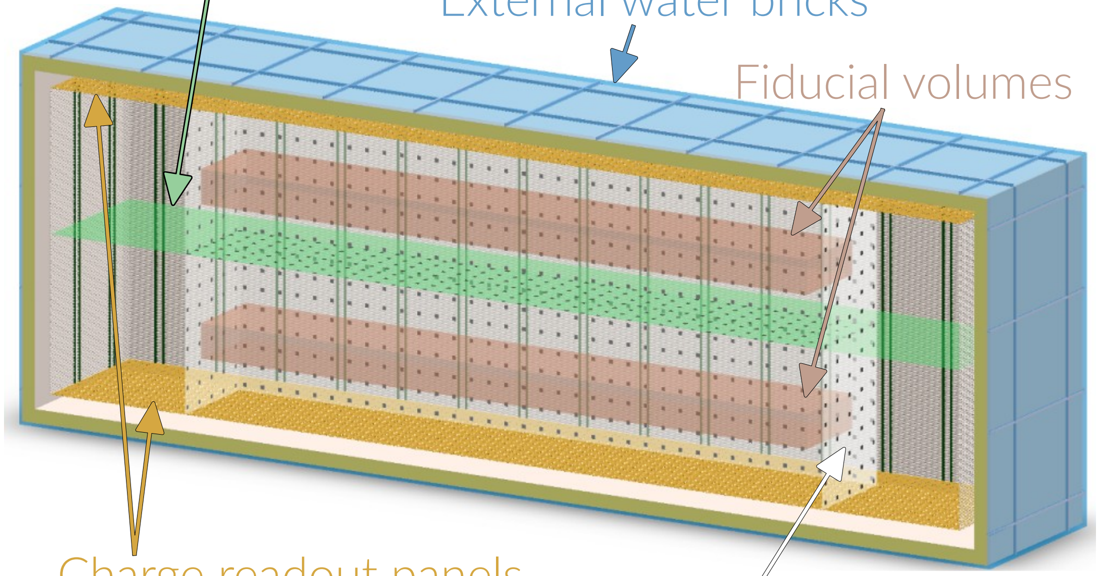


Measuring CEvNS from reactor neutrinos



SBC Collaboration. "Snowmass 2021 Scintillating Bubble Chambers: Liquid-noble Bubble Chambers for Dark Matter and CEvNS Detection". arXiv:2207.12400 (2022)

Other LAr DM detectors: Low-background DUNE-like far detector



Low-background module

Module not endorsed by the DUNE collaboration

Instrumentation: Vertical drift with 2kT fiducial mass of UAr, viewed by SiPMs

Principle: UAr, shielding, and strong fiducialization enable low backgrounds

ER discrimination: Pulse-shape discrimination and UAr to remove β's & γ's

NR mitigation: Low-background materials, fiducialization, and multi-scatter cuts to remove neutron backgrounds

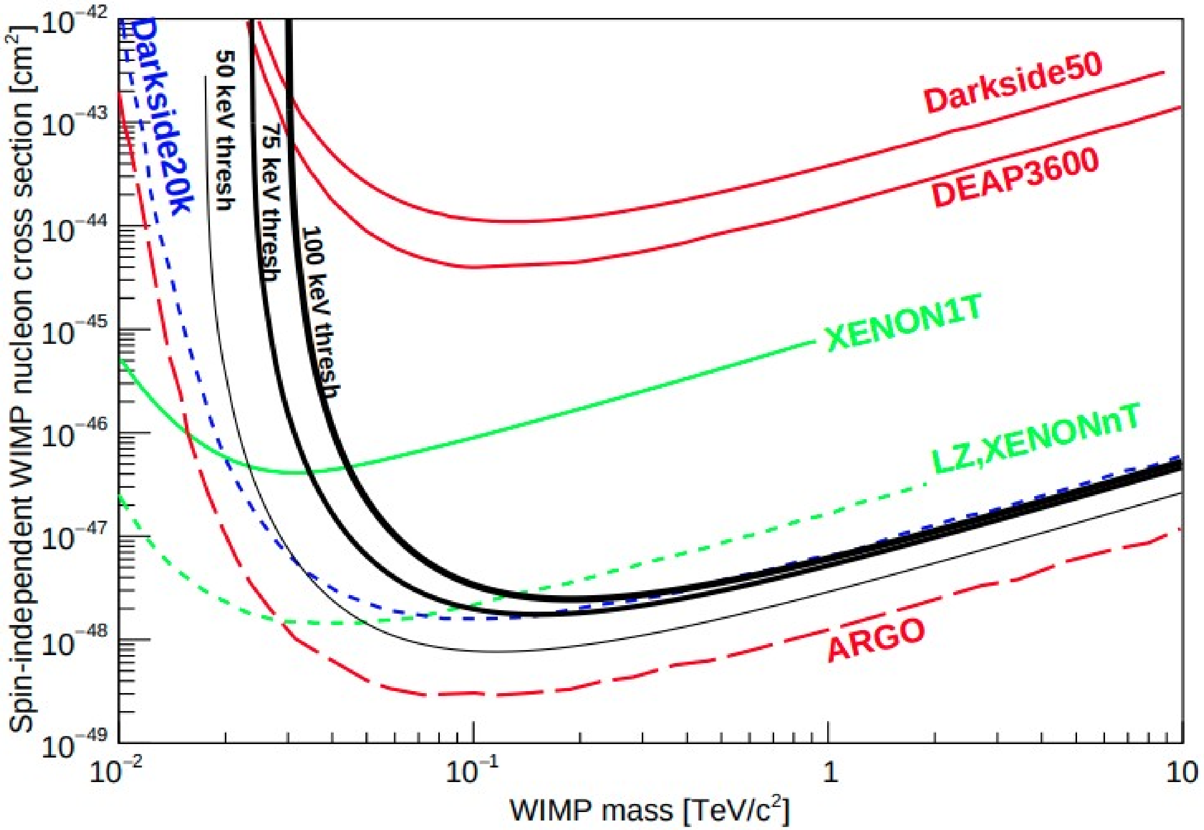
Threshold: $\lesssim$100 keV with UAr

Target: 10–30 bkgd/(3 ktonne year)

E. Church *et al.* "Dark matter detection capabilities of a large multipurpose Liquid Argon Time Projection Chamber". JINST 15 P09026 (2020)

A. Avasthi *et al.* "Low Background kTon-Scale Liquid Argon Time Projection Chambers". arXiv:2203.08821 (2022)

Other LAr DM detectors: Low-background DUNE-like far detector



Proposed for the DUNE "Module of Opportunity" fourth far detector

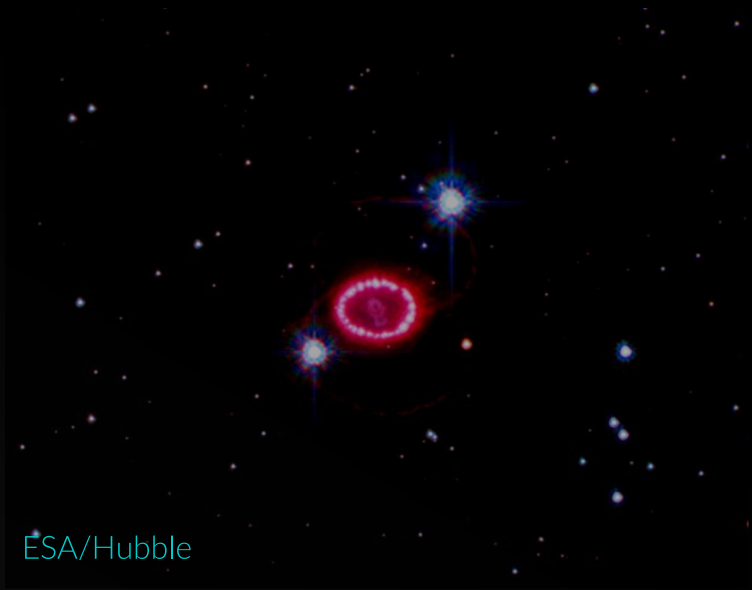
Broad physics reach beyond DM search:

- **Supernova neutrinos** via CEνNS and CC, fully sensitive to SNe from the Magellanic cloud
- **Solar neutrino physics**, incl. precise Δm^2_{21} & CNO ν flux measurements, constrain ν Non-Standard Interactions
- **0νββ search** if loaded with Xe

E. Church *et al.* "Dark matter detection capabilities of a large multipurpose Liquid Argon Time Projection Chamber". JINST 15 P09026 (2020)

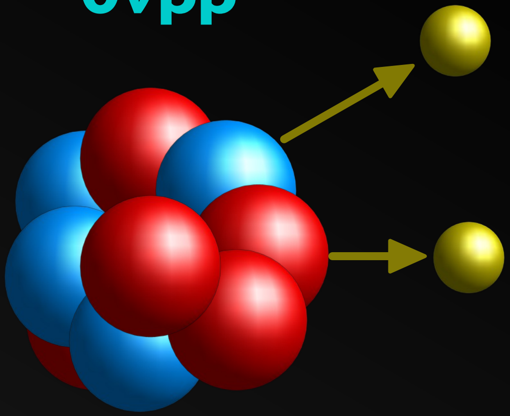
A. Avasthi *et al.* "Low Background kTon-Scale Liquid Argon Time Projection Chambers". arXiv:2203.08821 (2022)

Supernova neutrinos



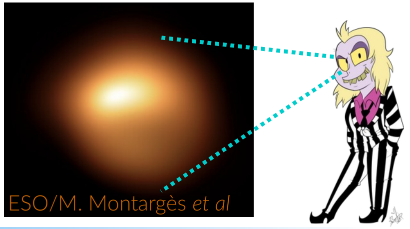
Solar neutrinos

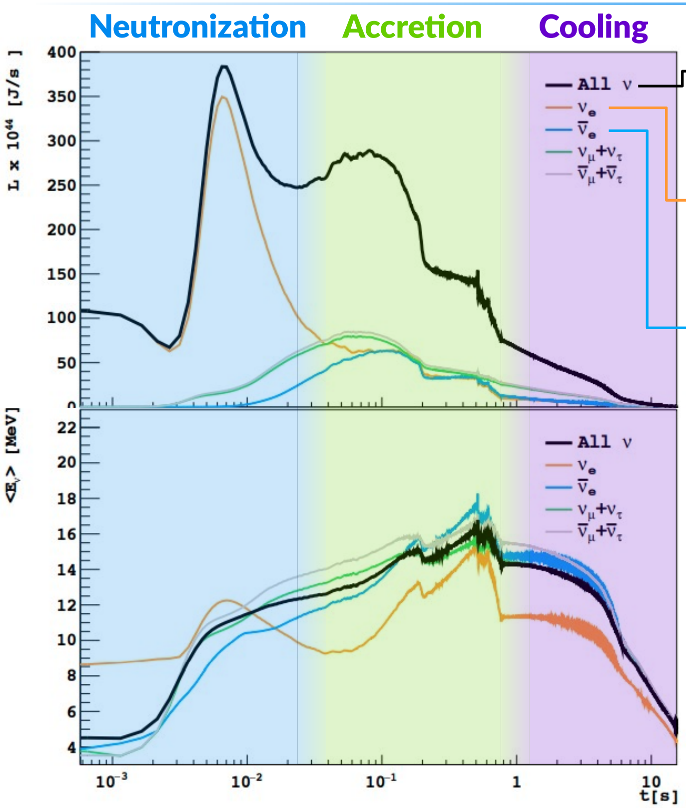
0νββ



Reactor neutrinos

Supernova neutrino detection

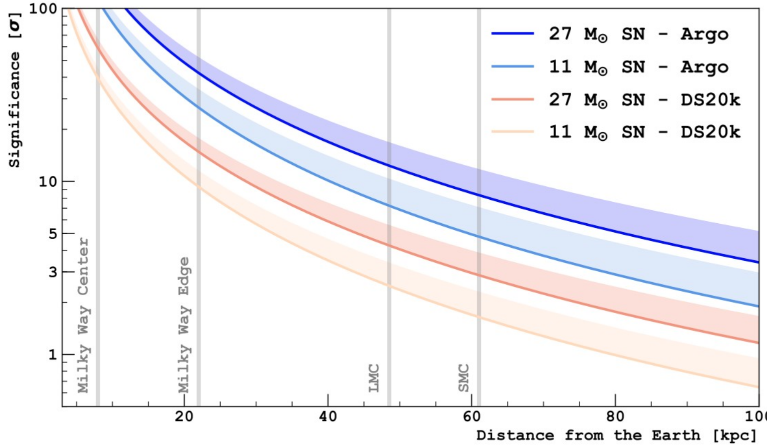




All Ar+ν→Ar+ν (*e.g.* in Argo)

ν_e $^{40}Ar+\nu_e \rightarrow {}^{40}K+e^-$ (*e.g.* in DUNE)

$\bar{\nu}_e$ $p+\bar{\nu}_e \rightarrow n+e^+$ (*e.g.* in IceCube)



DarkSide Collaboration. "Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos". JCAP03(2021)043

CEvNS is flavor-universal: Complements flavor-dependent channels

Coherent σ enhancement: Detectable by O(10–100 tonne) detectors

Test: Type Ia explosion mechanisms, failed supernova progenitor models

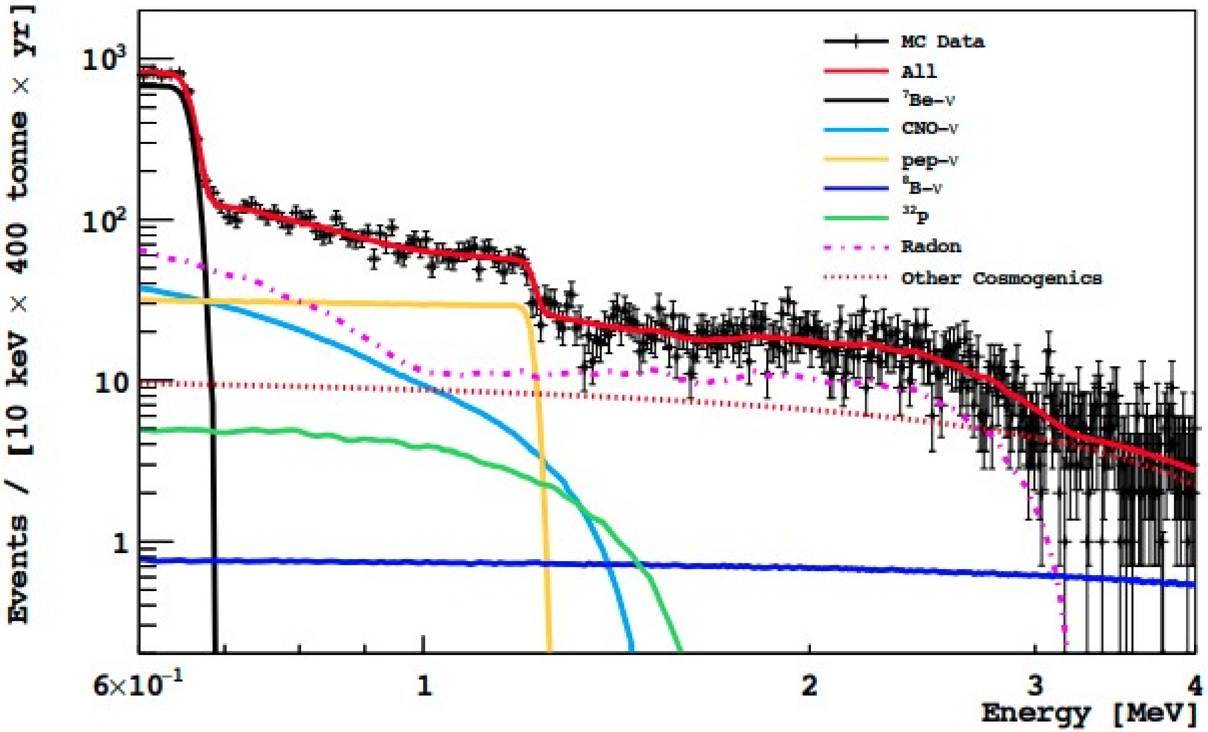
Observe: All 3 phases + Standing Accretion Shock Instability (SASI)

Measure: Explosion energy, collapse sphericity, PNS angular momentum

Probe ν: mass ordering, non-standard interactions, self-interactions

N. Raj. "Neutrinos from Type Ia and Failed Core-Collapse Supernovae at Dark Matter Detectors". Phys. Rev. Lett. 124, 141802 (2020)

Solar neutrinos

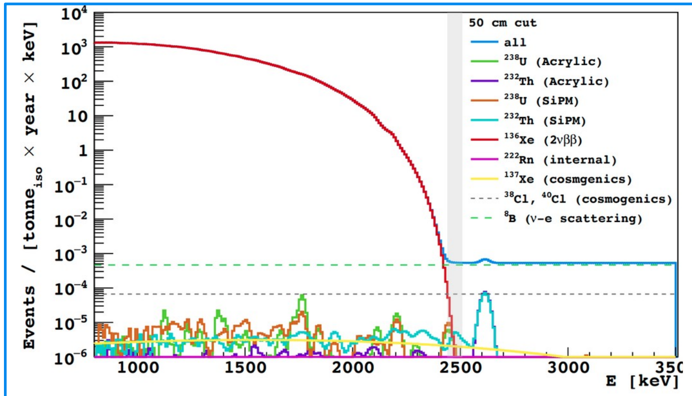


A low-background LAr detector with a 400 tonne year exposure can…

- Measure ^{7}Be, *pep*, and CNO neutrinos to improved precision
- Distinguish between the high- and low-metallicity solar models
- Improve our understanding of the sun's composition
- Measure the S17 $^7Be(p,\gamma)^8B$ nuclear cross section used in the Standard Solar Model

D. Franco *et al*. "Solar neutrino detection in a large volume double-phase liquid argon experiment". JCAP08(2016)017

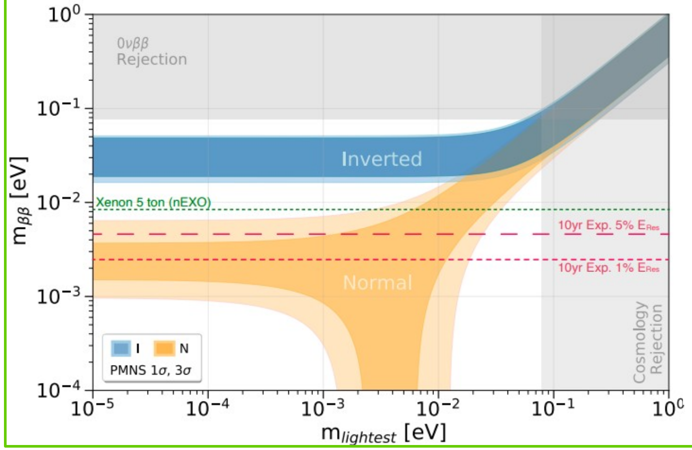
0νββ



DarkNoon

250tonne UAr, with 20mol% Xe, enriched in ^{136}Xe to 90%

M. Bossa. "Low-mass dark matter and neutrino-less double beta decay searches with the darkside technology". PhD thesis. Gran Sasso Science Inst. (2019)



Xe-doped, low-background DUNE-like module

17ktonne UAr, with ~2mol% Xe, enriched in ^{136}Xe to 90%

A. Mastbaum *et al.* "Xenon-Doped Liquid Argon TPCs as a Neutrinoless Double Beta Decay Platform". arXiv:2203.14700 (2022)

Why load Xe in LAr?

Fiducialization: low-cost & scalability enable large masses; fiducial cuts remove bkgds

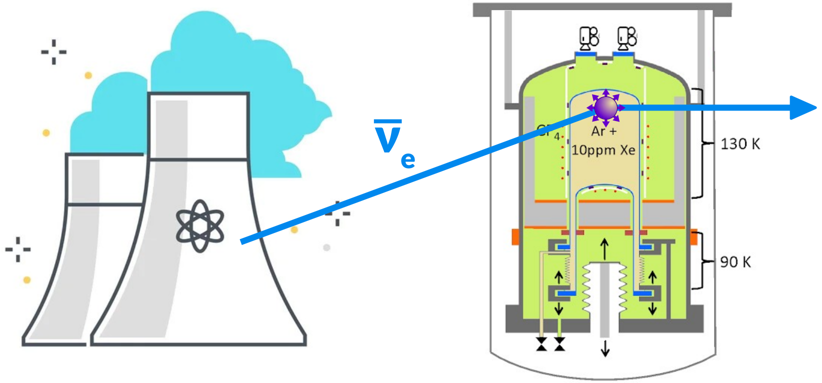
Improved optics: more transparent to scintillation→ better position reconstruction

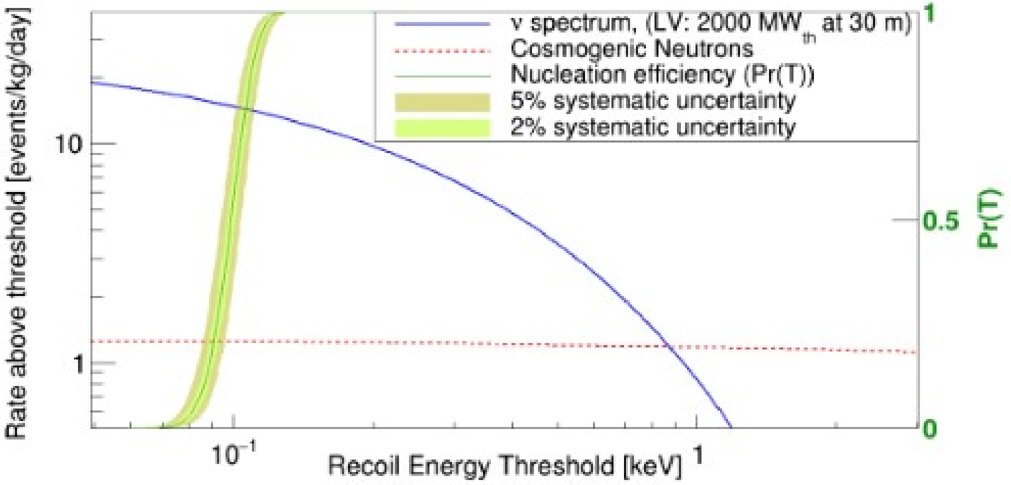
Possible 1e$^-$ cuts via Cherenkov

Lower internal backgrounds: enabled by excellent radio & chem. purity of LAr (esp. for Rn)

Precise resolution: Percent-level energy resolution achievable

Reactor neutrinos





A low-threshold LAr detector at a nuclear reactor can measure CEvNS to…

- Measure the weak mixing angle at low energy
- Perform competitive searches for new light gauge boson mediators and non-standard neutrino interactions
- Constrain the neutrino's magnetic moment
- Measure neutron density distribution in ^{40}Ar
- Search for eV-scale sterile neutrinos

SBC Collaboration. "Physics reach of a low threshold scintillating argon bubble chamber in coherent elastic neutrino-nucleus scattering reactor experiments". Phys. Rev. D 103, 091301 (2021)

M. Cadeddu *et al*. "Average CsI neutron density distribution from COHERENT data". Phys. Rev. Lett. 120, 072501 (2018)

Thank you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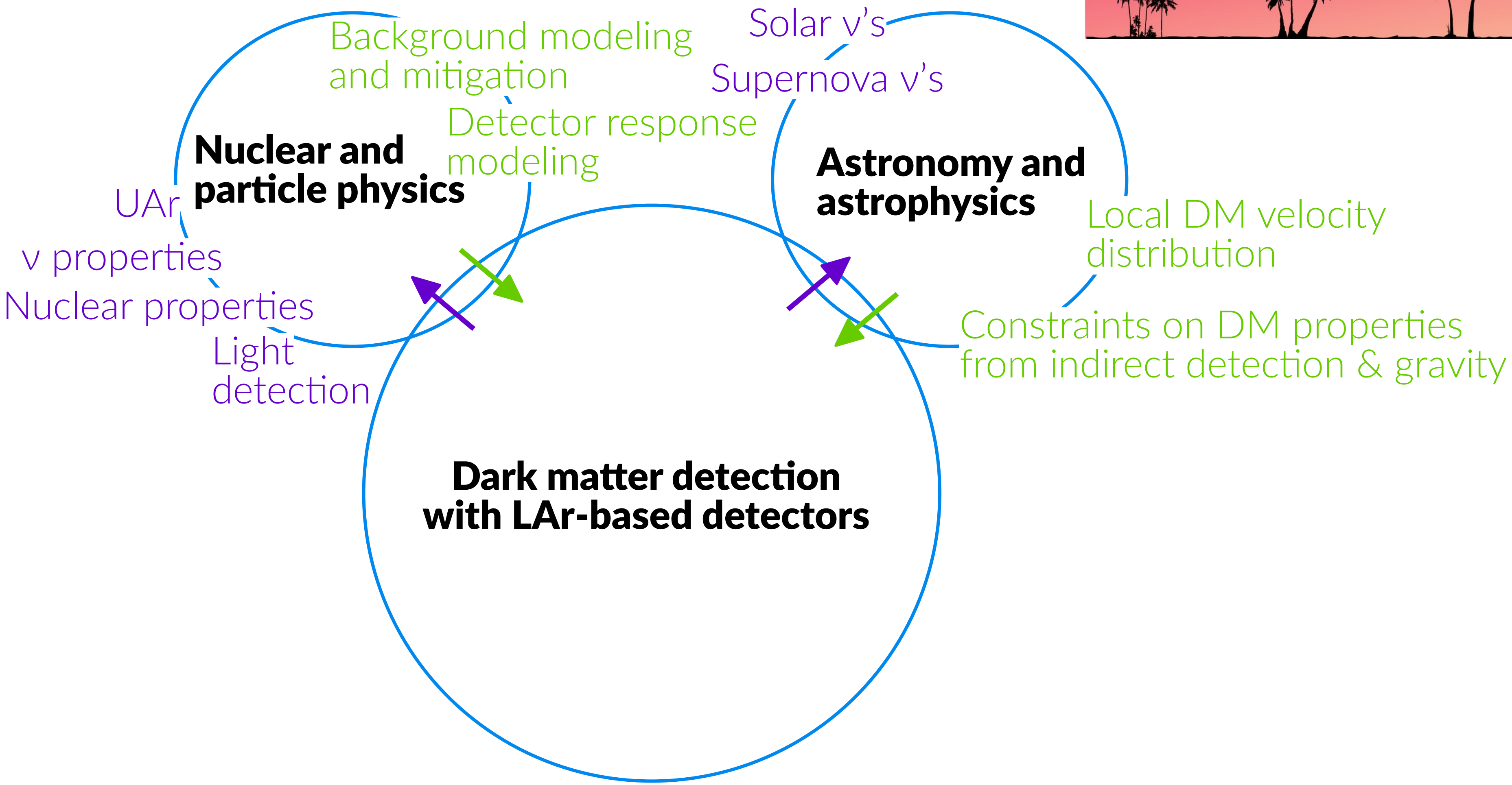
Background modeling
and mitigation
Solar ν's
Supernova ν's
Detector response
modeling
Nuclear and
particle physics
Astronomy and
astrophysics
UAr
ν properties
Nuclear properties
Light
detection
Local DM velocity
distribution
Constraints on DM properties
from indirect detection & gravity
Dark matter detection
with LAr-based detectors