UPDATES ON DARKSIDE

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on behalf of the DarkSide-20k Collaboration

NOW 2022, OSTUNI, 10 SEPTEMBER 2022

OVERVIEW

1. The physics case
2. Principles of direct dark matter detection
3. DarkSide status and perspectives

- The experimental program
- DarkSide-20k overview
- Detector design
- Argon target procurement

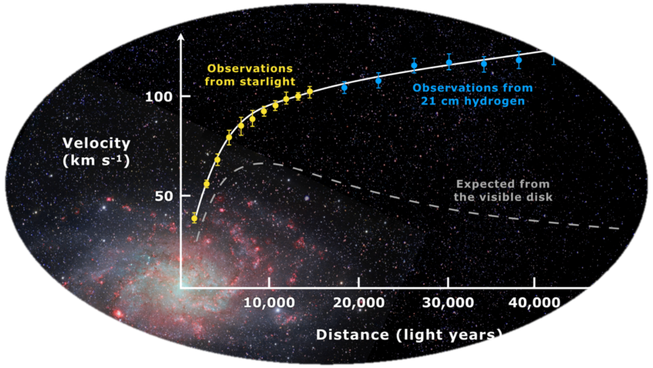
3. Available results and perspectives for the future

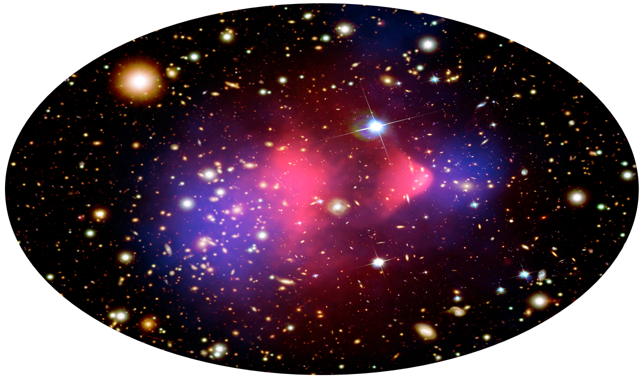
THE PHYSICS CASE

The evidence for the existence of Dark Matter (DM) is overwhelming, and it comes from a wide variety of astrophysical measurements, e.g.

Velocity dispersion of spiral galaxies

1970s: Ford and Rubin discovered that galaxies rotation are flat. The simplest explanation is that **galaxies contain far more mass** than can be explained by the bright stellar objects in the galactic disks.



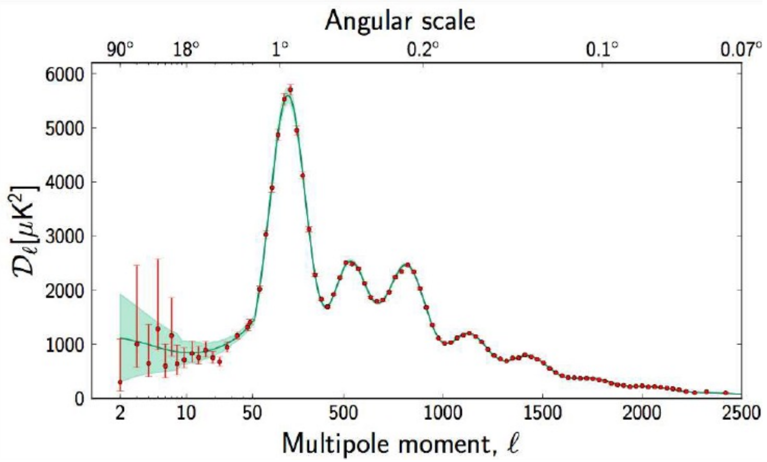


Bullet cluster and gravitational lensing

Lensing and optical observation of two galaxy clusters collision. The DM particles (blue) interacting only weakly could pass through each other more easily than the baryonic matter (pink).

Cosmic Microwave Background

CMB temperature anisotropy angular power spectrum seen by Planck, with the predictions for the best fit of the standard cosmological model parameters.



THE PHYSICS CASE

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Convincing evidences at different scales!

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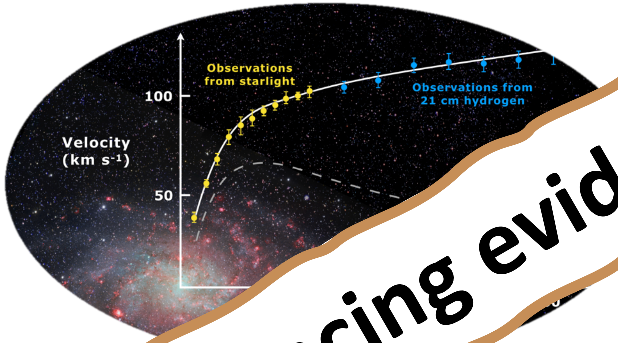

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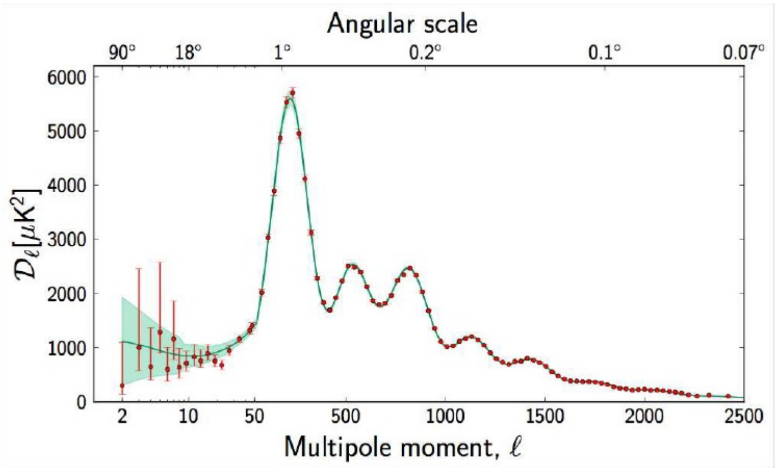
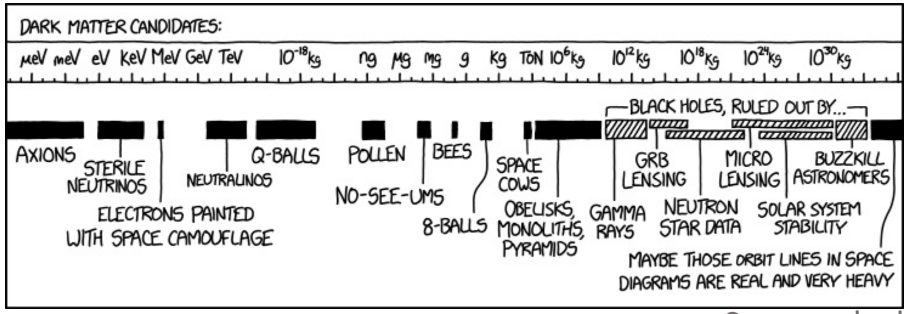
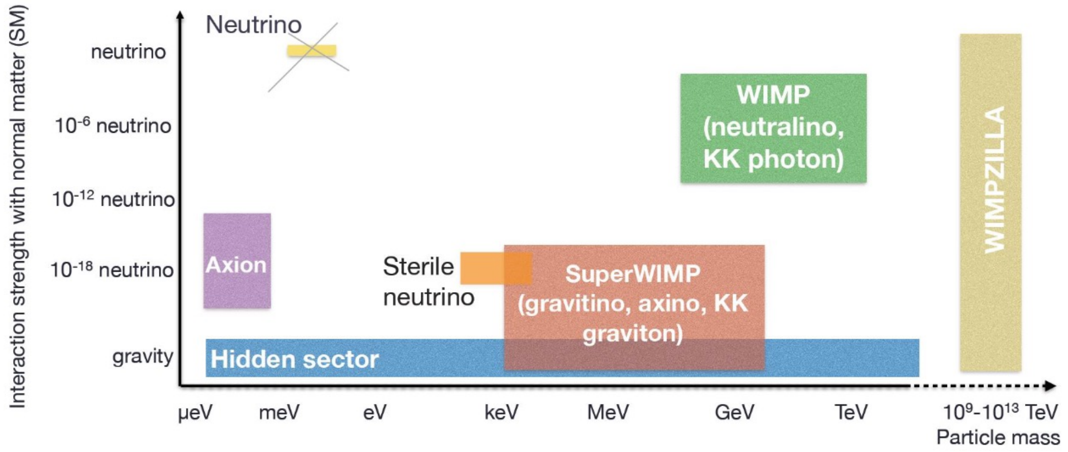


Detection of dark matter



Source:xkcd

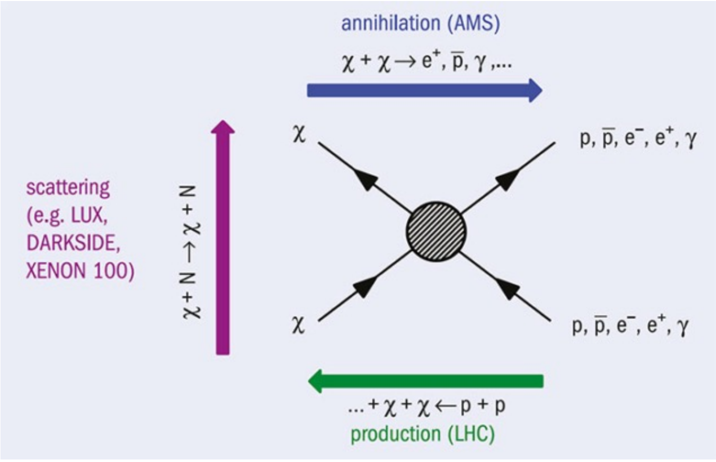


The most searched candidate are so-called Weakly Interacting Massive Particles (WIMP) that decoupled when non relativistic and are provided by many theories beyond the SM like SUSY

Direct detection

Detect DM as our Solar system passes through galactic halo. Nuclear recoils from elastic WIMP-nucleus scattering.

Depends upon local density and velocity-distribution.



Indirect detection

DM annihilation products. Final states include neutrinos, antiprotons, positrons and γ-rays.

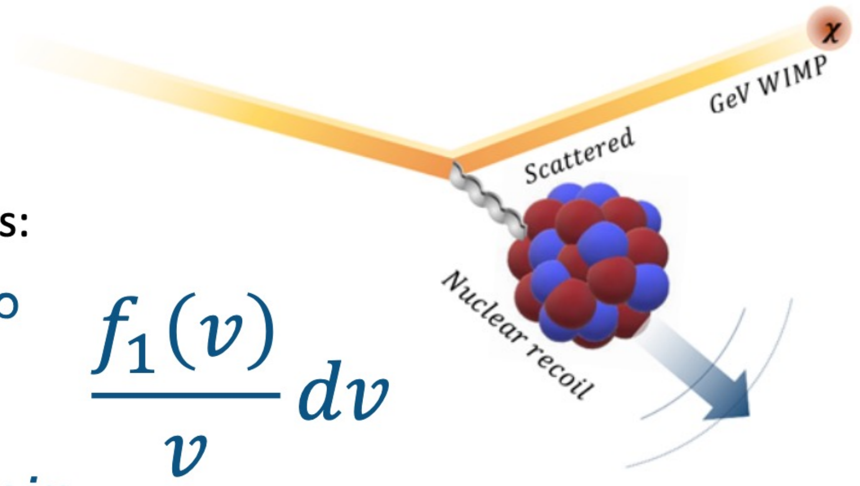
Astrophysical backgrounds are difficult to model.

Accelerator searches

DM particles pair produced in collisions. Missing ET, mono-'objects', etc...

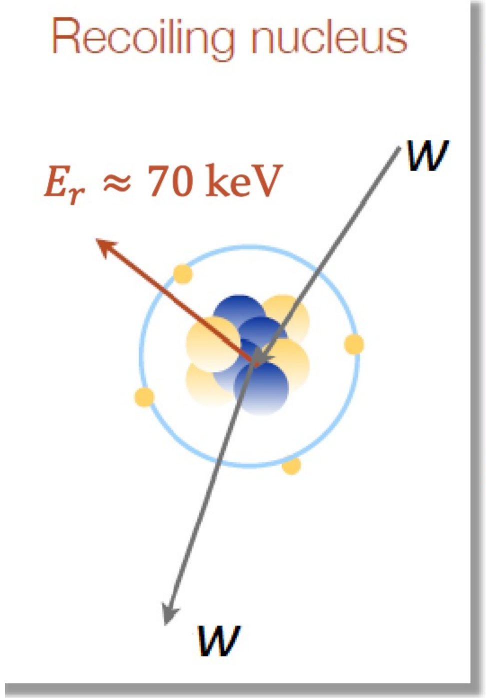
How to establish that the new particle is DM?

The WIMP spectrum



Standard **recoil spectrum**, i.e. differential event rate **per unit detector** mass:

$$\frac{dR}{dE_r} \propto \frac{\sigma_{SI}^{p}}{2\,\mu_{\chi p}^{2} M_\chi} \quad A^2|F(E_r)|^2 \quad \rho_0 \int_{v_{min}}^{\infty} \frac{f_1(v)}{v}\,dv$$



Physics

σ_{SI}^{p} → WIMP-nucleon cross section

M_χ → WIMP mass

$\mu_{\chi p}$ → WIMP-nucleon reduced mass

$\mu_{\chi N}$ → WIMP-nucleus reduced mass

Target material

A → atomic mass of target material

$F(E_r)$ → The finite size of the nucleus is implemented with a nuclear **Helm form Factor**

E_{th} → Energy threshold

Astrophysics (DM halo properties)

ρ_0 → local WIMP mass density

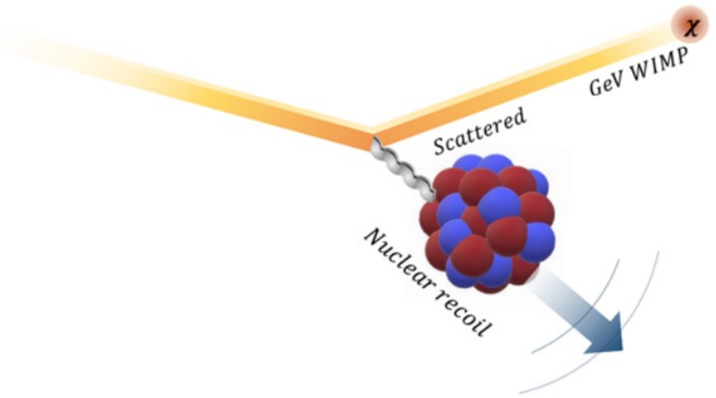
$f(v)$ → WIMP velocity distribution

v_{min} → minimum WIMP speed required to transfer an energy E_r to the nucleus of mass m_n in the detector.

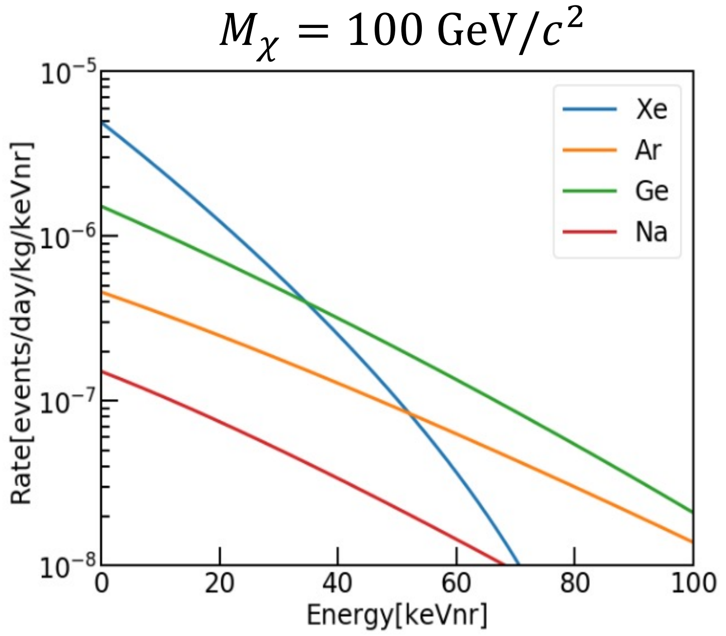
E_r → Recoiling nucleus energy

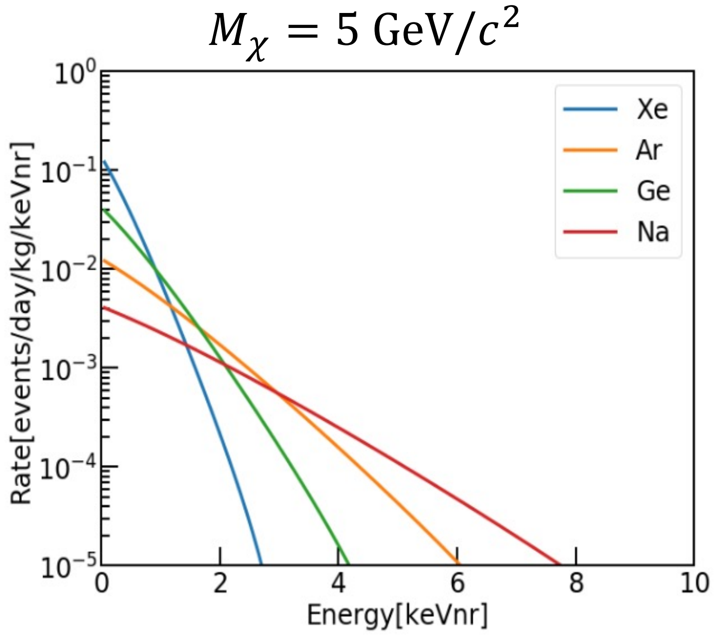
$$v_{min} = \sqrt{m_N E_r / (2\mu_{\chi N}^2)}$$

The WIMP spectrum



- Signal: **nuclear recoils** (NR)
- Rare events
- **Coherent** scattering enhancement (A^2)
- **High energy suppression** due to nuclear form factor (F^2)
- **Exponential rate** in observed energy
- Choice: target nucleus and detector mass



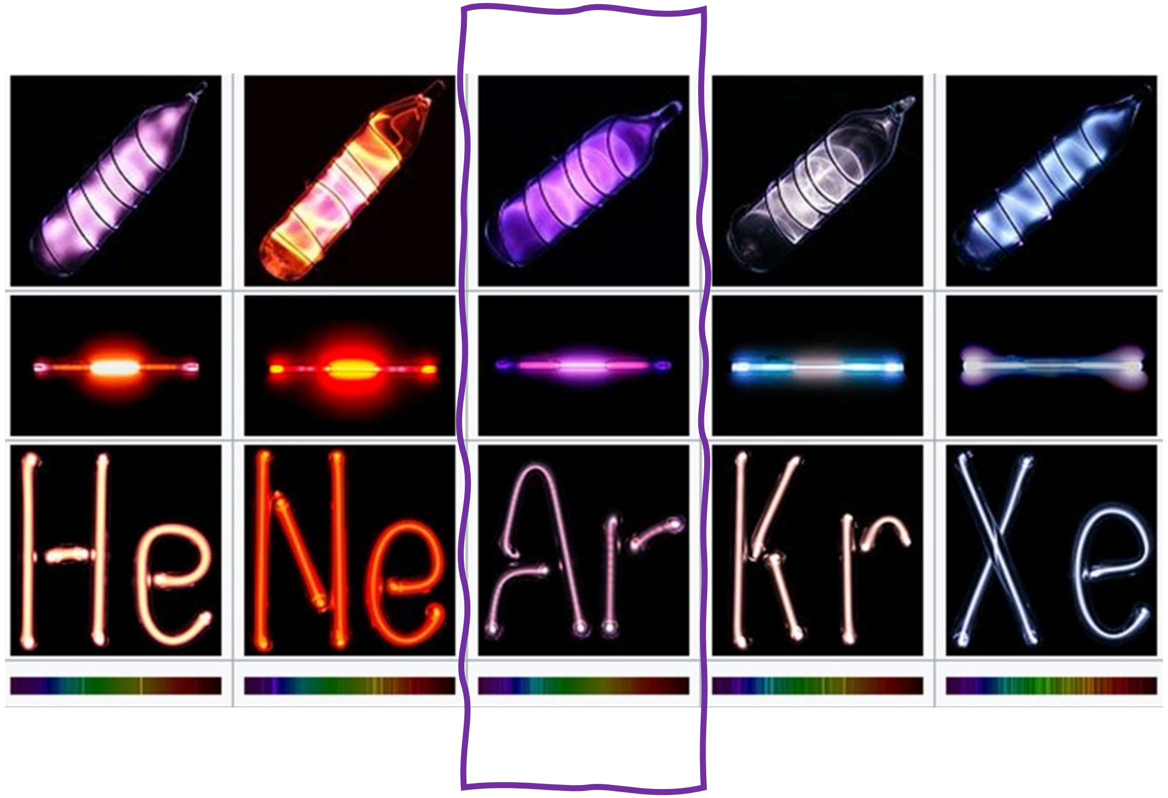


High M_χ
- Low number density
- High recoil energies
- High A target

Low M_χ
- High number density
- Low recoil energies
- High A target

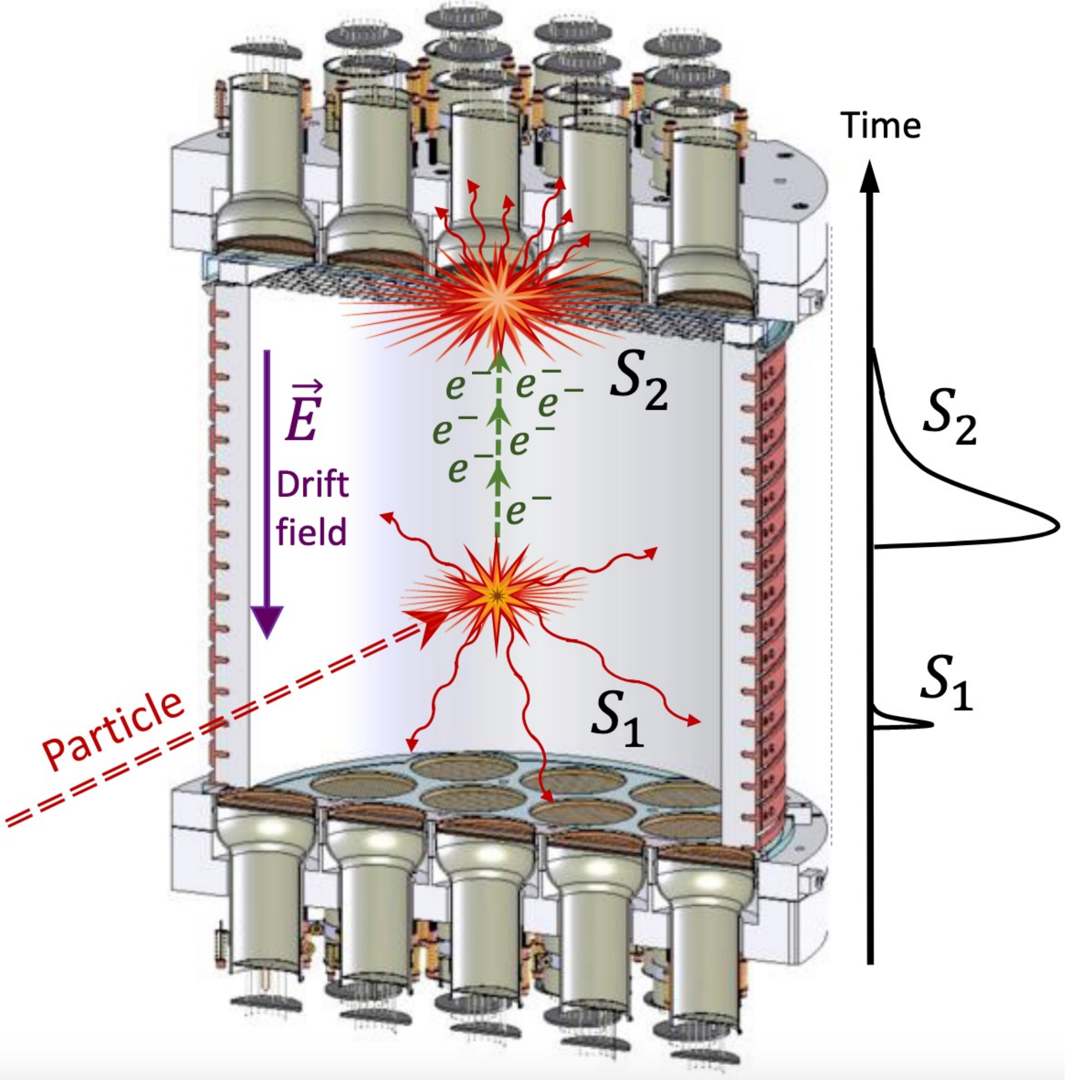
Direct searches with noble elements

- High density, inexpensive
  - Good scalability to large masses
- Low energy threshold (E O(10 keV))
- Easy to purify, also online
- Large ionization/scintillation yields
- Background suppression
  - Deep underground
  - Passive/active shielding
  - Low intrinsic radioactivity
  - ER background discrimination
- NR quenching at low energies



Complementarity of different elements: great value in case of an excess

Dual-phase TPC: working principle

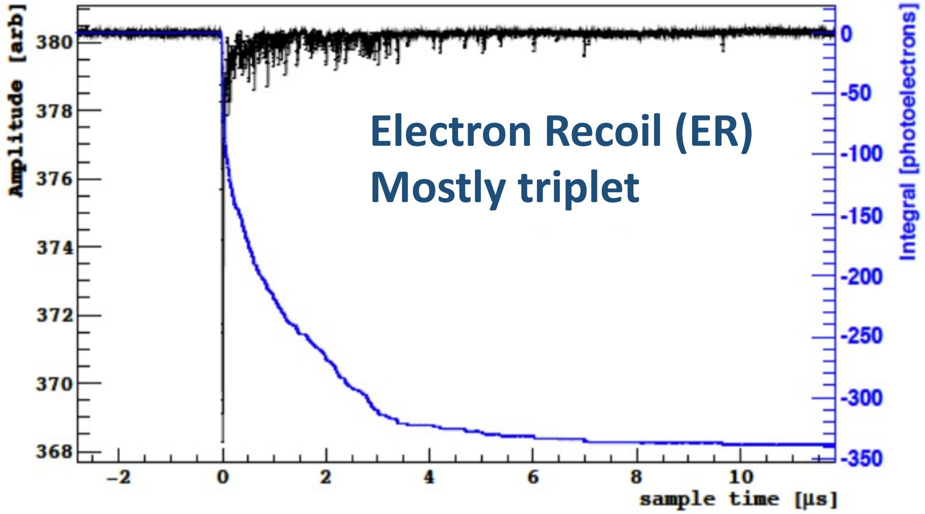


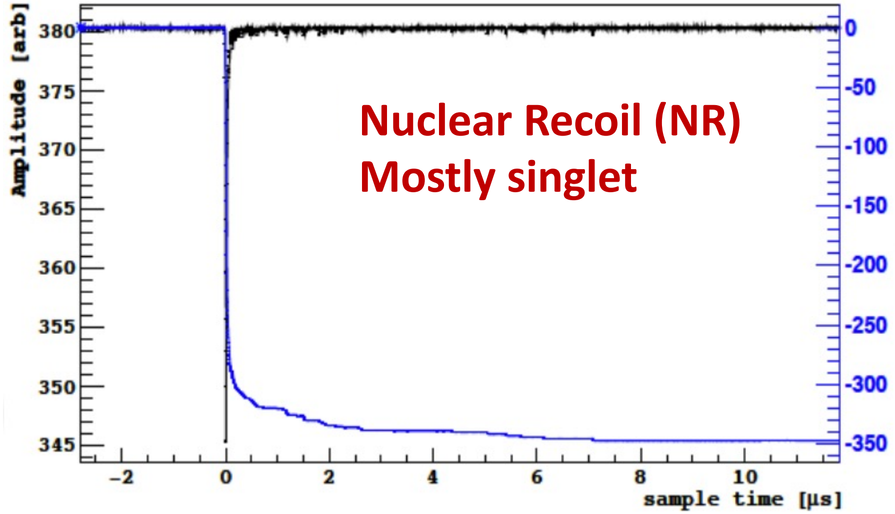
- Light collected by top and bottom cryogenic solid state photosensors

- **S1** = Primary scintillation in liquid Ar
- **S2** = Secondary scintillation in Ar gas pocket

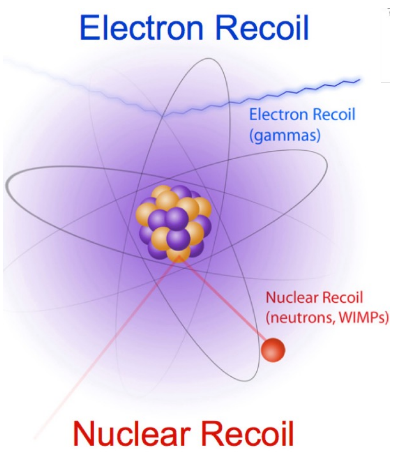
- Event 3D reconstruction:
  - S1 & S2 → full energy deposition
  - Drift time ($t_{S_2} - t_{S_1}$) → vertical (z) position
  - S2 Channel top light pattern → xy position

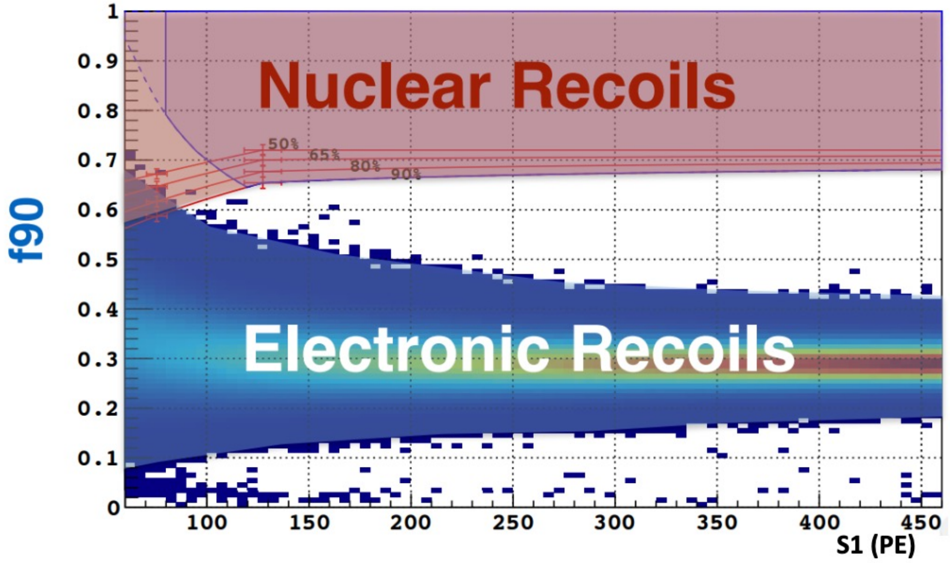
Pulse shape discrimination (PSD) in Ar





- ➢ Argon has a fast component with a **7 ns decay time (singlet)**, or a slower component with **1.6 µs (triplet) decay time** depending on the nature of incident particle.
- ➢ NR produces more $\tau_{singlet}$ and less $\tau_{triplet}$ states than ER.
- ✓ f_{90} = the fraction of S1 light collected in the first 90 ns.
- ✓ f_{90} rejection better than ~$1.5\text{x}10^7$ [10.1016/j.physletb.2015.03.012]

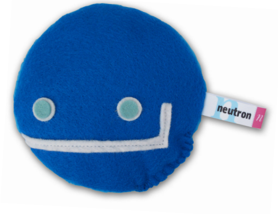




Thanks to PSD, electron recoil backgrounds can be identified and removed in WIMP searches!

Radiogenic and cosmogenic backgrounds

Neutrons



Radiogenic

- Natural radioactivity: (α,n) reactions
- Spontaneous fission
- Strict radiopurity reqs, material selection, neutron veto
- DS-50 pioneered neutron vetoes

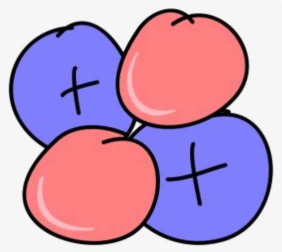
DarkSide Collaboration, "The veto system of the DarkSide-50 experiment". JINST, 11 (2016): P03016

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

Cosmogenic

- Muon-showers induced neutrons in lab
- β-delayed neutron emission
- Suppressed by going underground and using muon vetoes
- Large uncertainties in cosmogenic nuclear interactions

α-decays

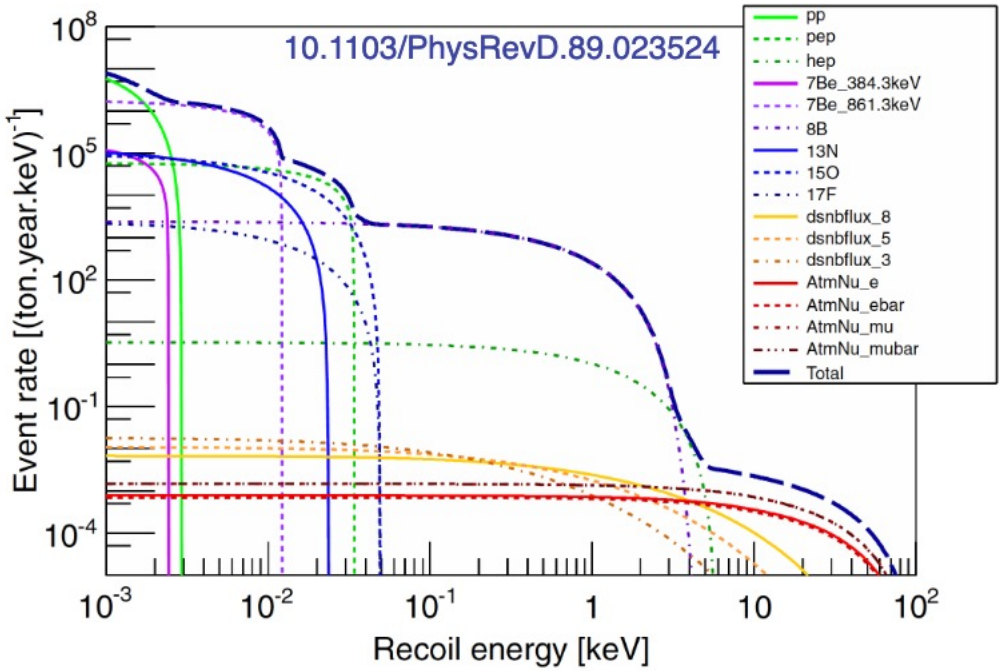


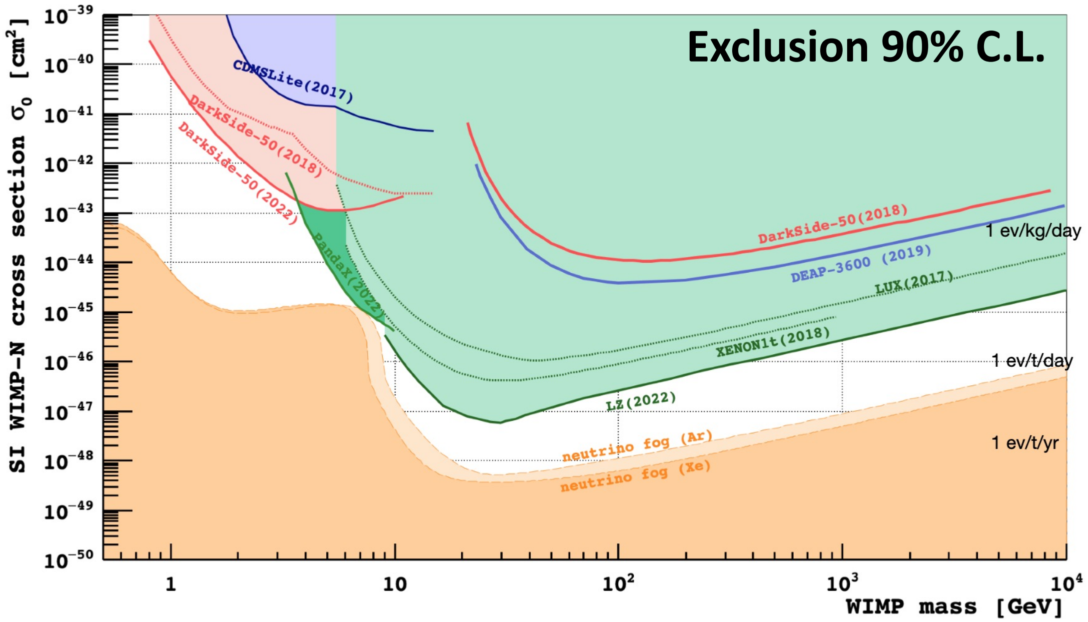
- Mostly from Rn+progeny, deposited on any surfaces exposed to air
- ^{210}Pb (in the **^{222}Rn** decay chain) has a 22 years half-life, β-decays to ^{210}Po
- ^{210}Po→source of 5.3 MeV α's & 100 keV recoiling ^{206}Pb nuclei
- May populate region of interest if α attenuates in detector walls or dust or if scintillation light is shadowed
- Control via Rn abatement, material selection, fiducialization & in situ removal from Ar
- Need low-energy heavy ion energy loss models

Neutrinos

- Coherent elastic neutrino-nucleus scattering (CEνNS) can produce nuclear recoils that mimic WIMPs
- Effective background subtraction requires decreasing systematics
- Precise measurements of CEνNS cross section & improved sub-GeV atmospheric ν models

- Solar ^{8}B at low energies
- Atmospheric ν at high energies





Neutrino floor/fog

Limit on experimental sensitivity for any detector!

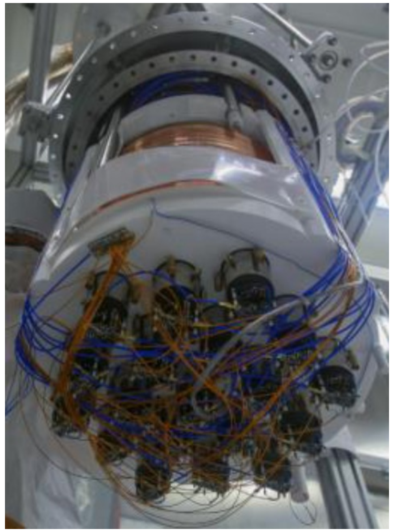
How to go beyond?

- Modulation
- Directionality
- Spectral information

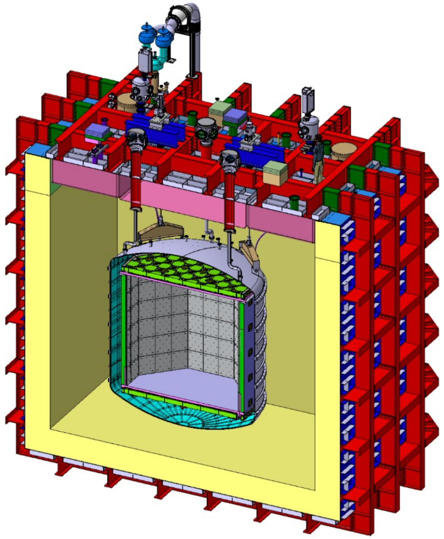
The DarkSide program

2012 | 2013-2021 | 2026-2036 | 2030-…

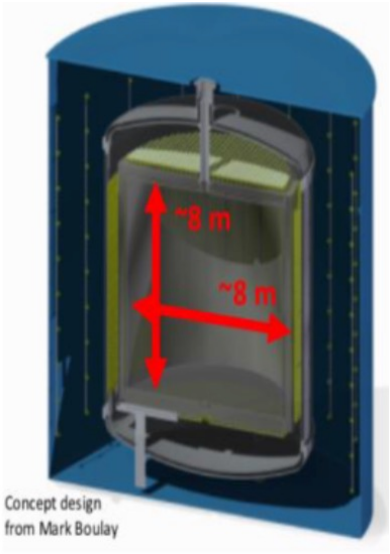
DarkSide-10
Technical prototype
No dark matter goal



DarkSide-50
Science detector. First bkg-free results with UAr. Best limits for low mass WIMP search.



DarkSide-20k @LNGS
Novel photosensor technology. First peek into the neutrino fog. Nominal exposure: 200 t y

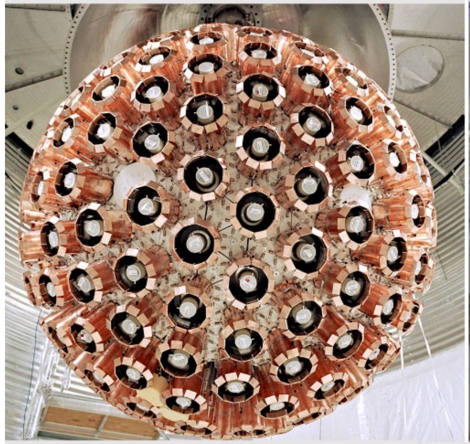


Argo @SNOLAB
Ultimate LAr DM detector. Push well into the neutrino fog. Nominal exposure: 3000 t y

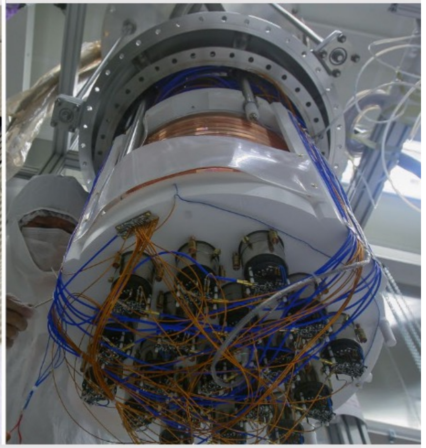
The Global Argon DM Collaboration GADMC

All joined together in 2017 to pursue future LAr-based dark matter detectors

DEAP-3600 @SNOLAB



DarkSide-50 @LNGS



ArDM @LSC

miniCLEAN @SNOLAB

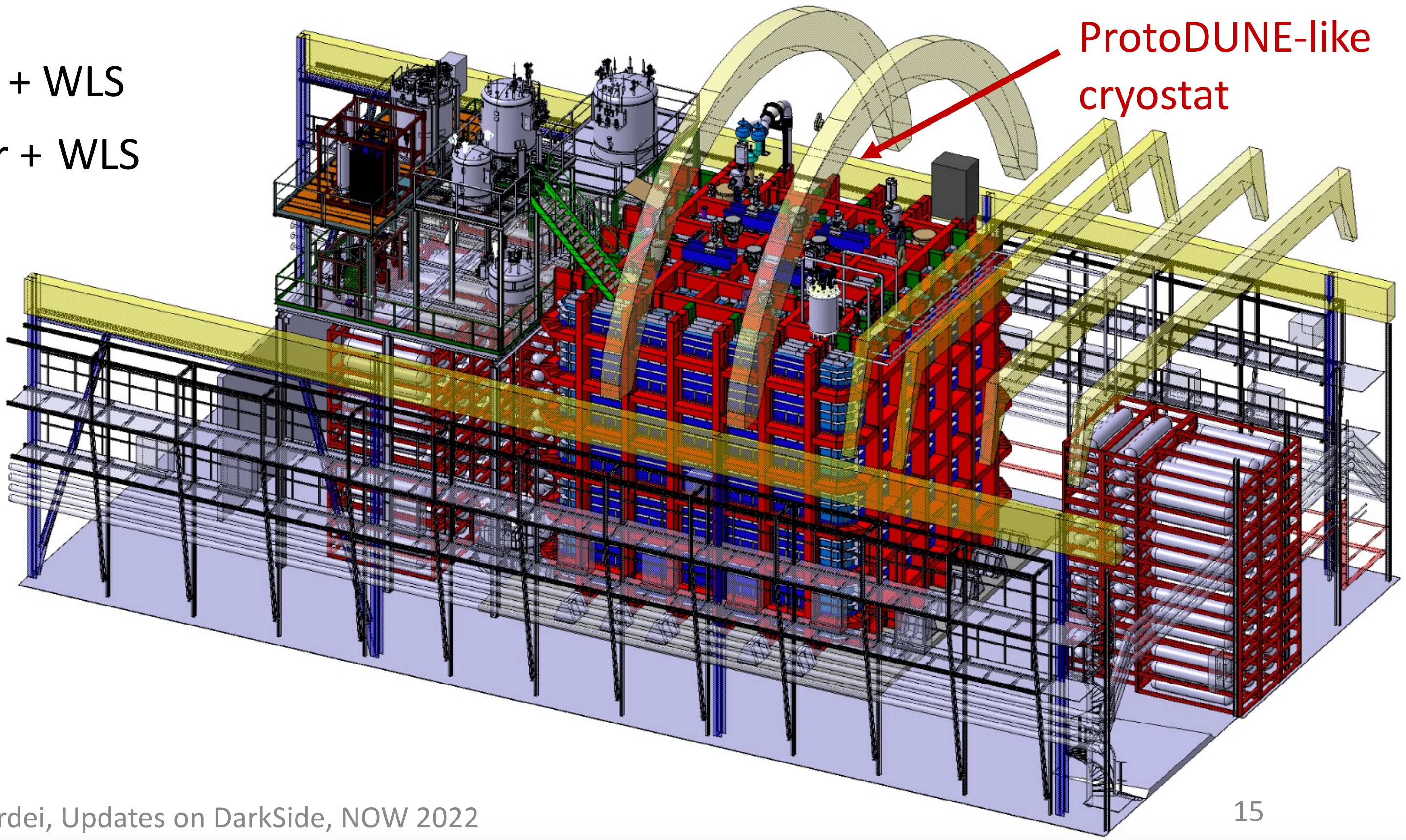
> 500 Collaborators, > 100 institutes distributed across 14 countries

DarkSide-20k overview

Nested detectors structure:

- ProtoDUNE-like cryostat ($8x8x8m^3$) - Muon veto
- Ti vessel separating AAr from underground Uar – n and γ veto
- WIMP detector: dual-phase TPC hosting 50t of LAr
- Fiducial mass: 20 tonnes
- TPC Vessel:
  - top and bottom: transparent pure acrylic + WLS
  - lateral walls: Gd-loaded acrylic + reflector + WLS
- TPC readout: ~$21m^2$ cryogenic SiPMs

- DarkSide-20k in Hall C @LNGS
- Below ~1400m of rock (3400 m.w.e)
- Muon flux reduction factor ~10^6



Position reconstruction resolution:

- ~ 1 cm in XY
- ~ 1 mm in Z

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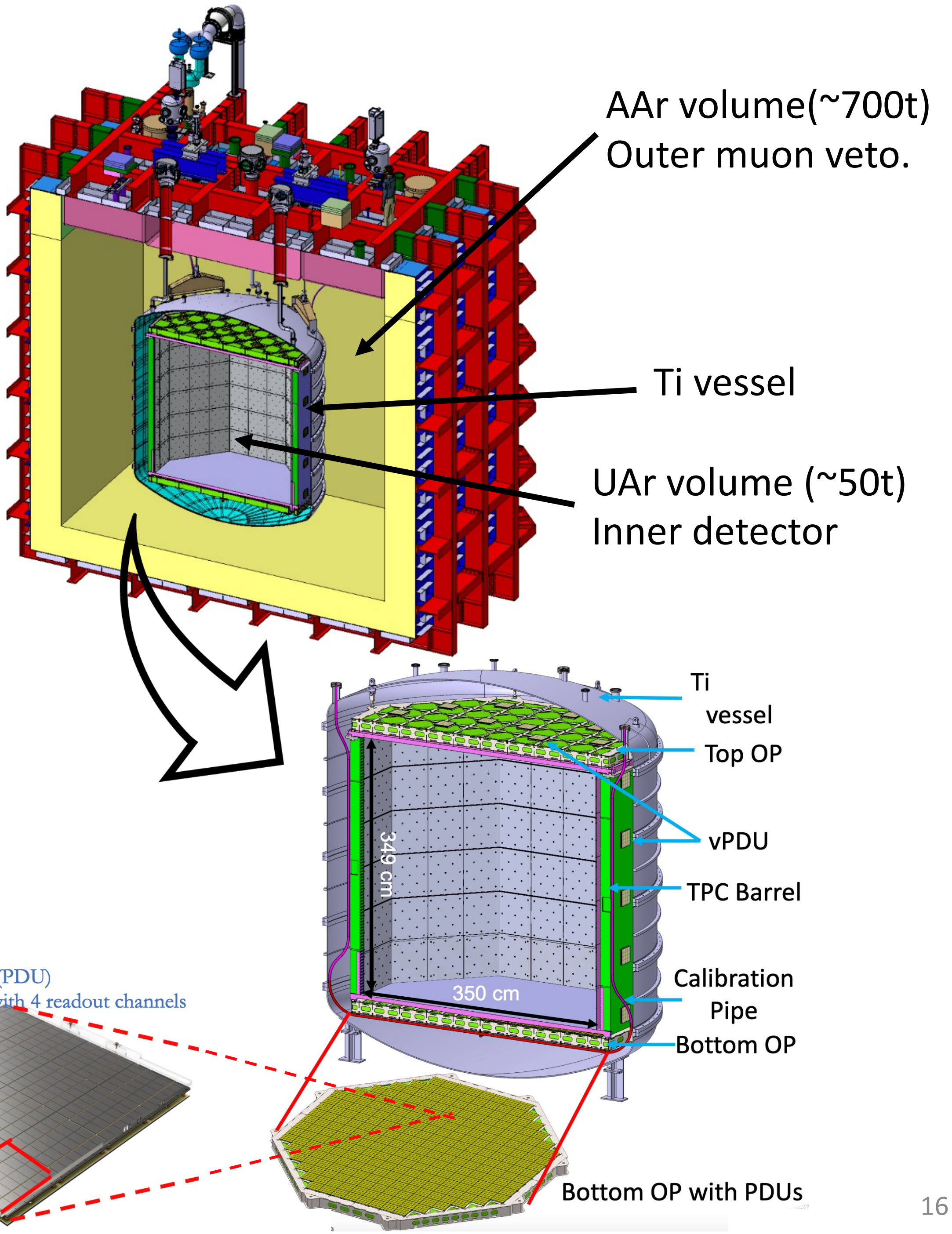
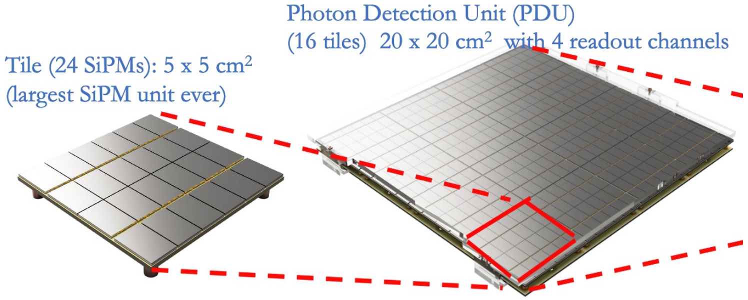
- TPC readout: ~21m^2 cryogenic SiPMs
- Veto
  - TPC surrounded by a single phase (S1 only) detector in UAr
  - TPC lateral walls + top&bottom planes in Gd-loaded acrylic
    - o to thermalize n (acrylic is rich in H)
    - o neutron capture releases high energy γ
  - Veto readout: 5 m^2 cryogenic SiPM

Position reconstruction resolution:

- ~ 1 cm in XY
- ~ 1 mm in Z





Underground argon and purification

Extraction

^{39}Ar radioactivity in atm Ar:

- β emitter with an endpoint of 565 keV

URANIA, Colorado (US)

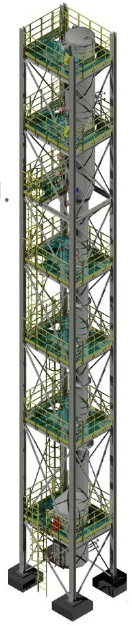
- Industrial scale extraction plant;
- Expected argon purity at outlet: 99.99%;
- UAr extraction rate: 250-330 kg/day and 120 t over two years

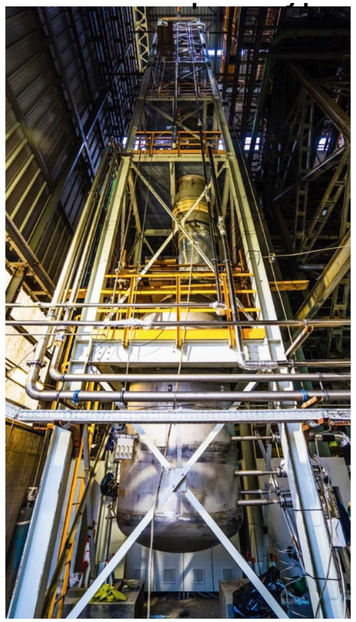
Purification

ARIA: UAr distillation plant

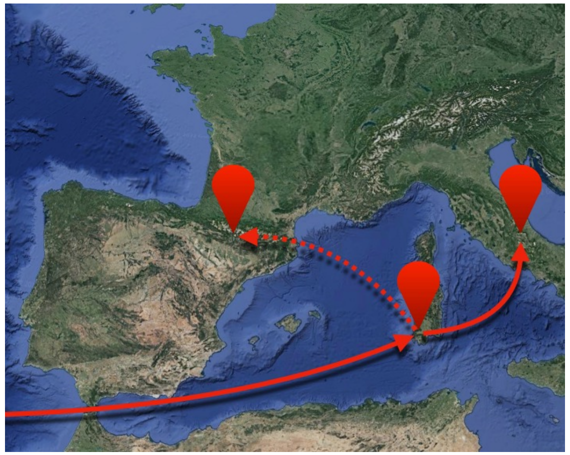
- Cryogenic distillation column in Sardinia (IT)
- Three sections: bottom reboiler, 28 central modules (12 m each), top condenser, ~350 m
- Chemical purification rate: 1 t/day

- First module operated according to specs with nitrogen in 2019 [Eur. Phys. J. C (2021) 81:359]
- Ar Run completed at the end of 2020: results to be published soon.
- Full assembly to start within 2022





Assaying and delivery

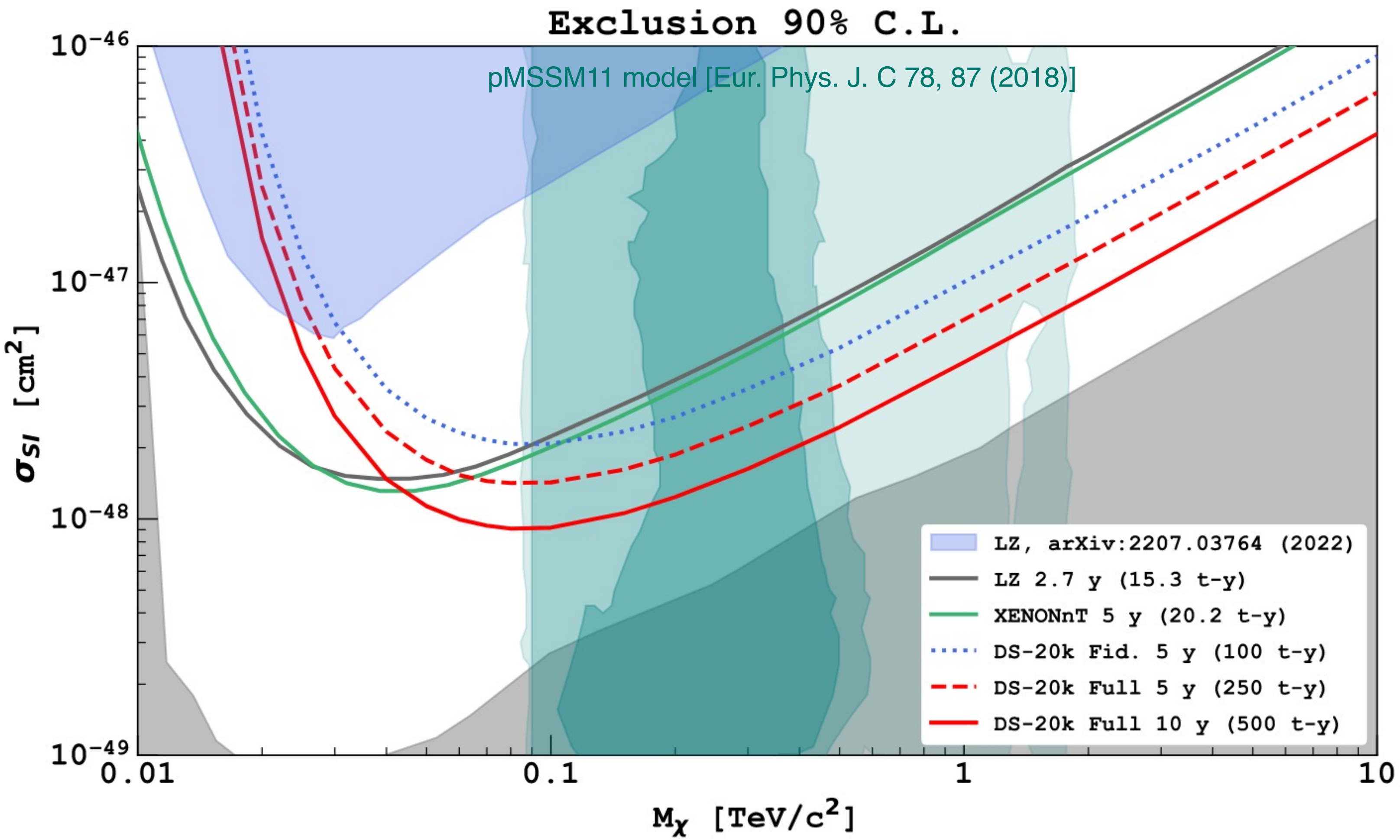


DArT : Measurement of the activity of the ^{39}Ar @LSC, Canfranc, Spain

- Single-phase inner detector for 1.42 kg of liquid UAr
- Will be installed inside ArDM detector, acting as an active veto.
- ^{39}Ar depletion factor sensitivity: U.L. 90% CL. 6×10^4 [2020 JINST 15 P02024]

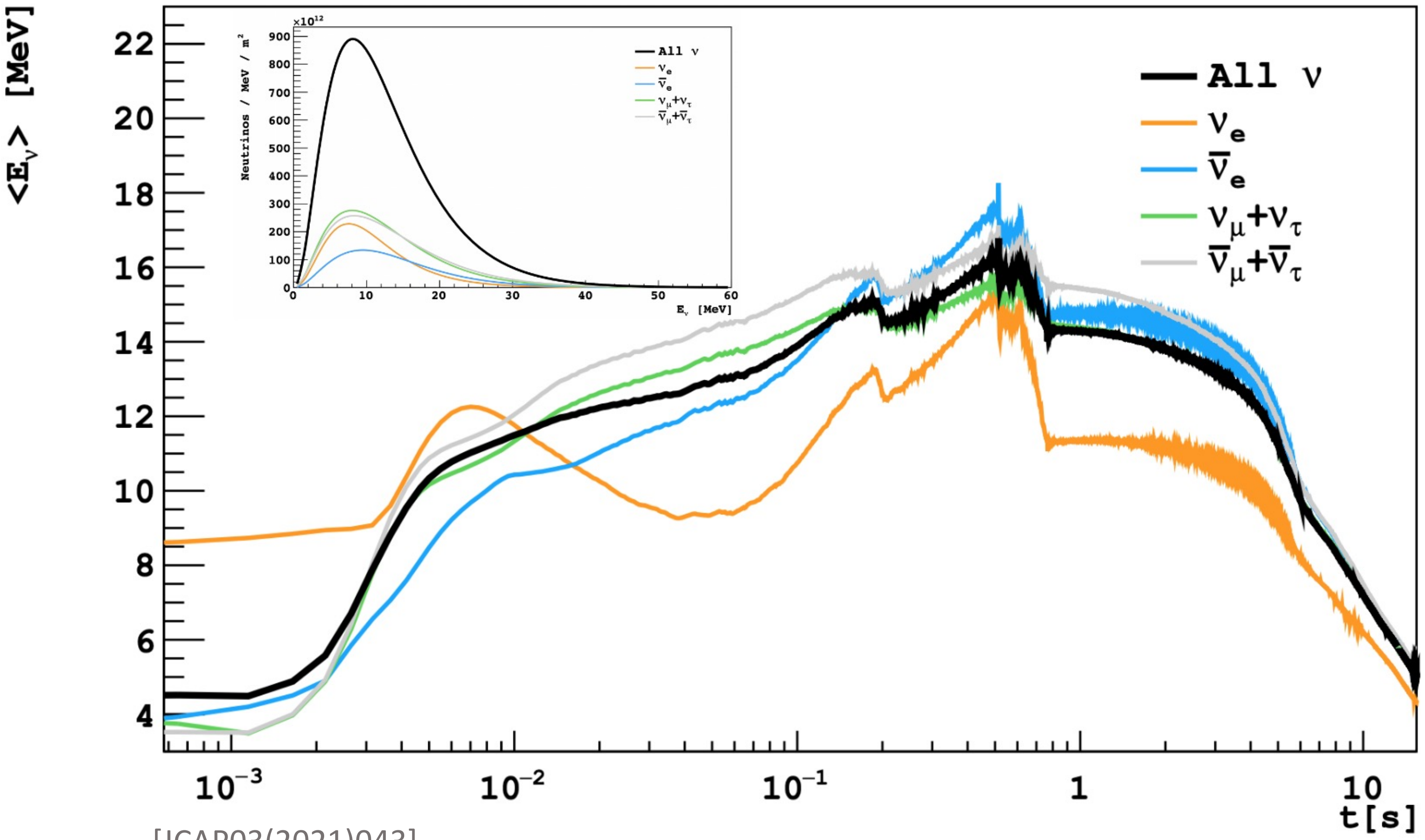
DarkSide-20k physics reach

- **Sensitivity**: 6.3×10^{-48} cm^2 for a 1 TeV/c^2 WIMP (90% C.L.)
- **Nominal exposure**: (20×10) t yr
- **Instrumental Background**: 0.1 events in 200 t yr
- **Expected neutrinos**: 3.2 events in 200 t yr



Core Collapse SN ν

Core-collapse supernovae (SN) are violent explosions of very massive stars at the end of their lives, triggered by the gravitational collapse of the stellar cores.



[JCAP03(2021)043]

- **99% of the total energy** of a core collapse SN (~10^{53} erg) is emitted through the **neutrino channel**.
  - **Ideal "messengers" for SNe**
- ~1% goes into the kinetic energy associated with the external layers of the progenitor that are ejected.
- 0.01% is radiated at UV, optical and near-infrared wavelengths.
- $\langle E_\nu \rangle$ is maximum in the accretion phase (15MeV) and drops to ~5MeV after ~10s.

SN ν in DS-20k & Argo

Sensitivity study on SN neutrino detection with GADMC LAr experiments, **DarkSide-20k** and **Argo**, exploiting Coherent elastic neutrino-nucleus scattering (CEνNS) .

[JCAP03(2021)043]

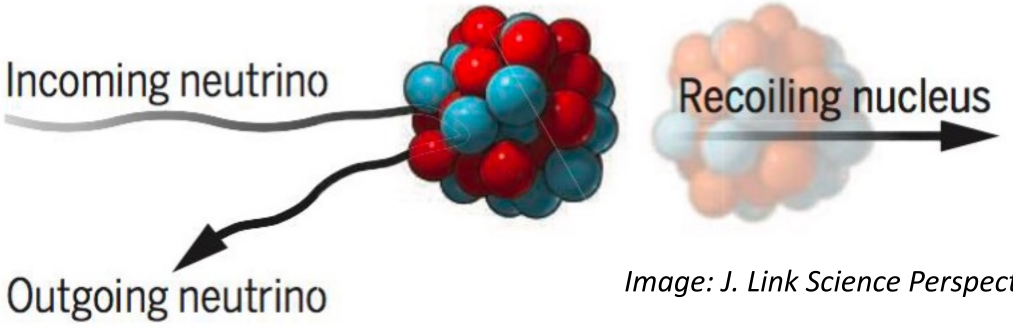
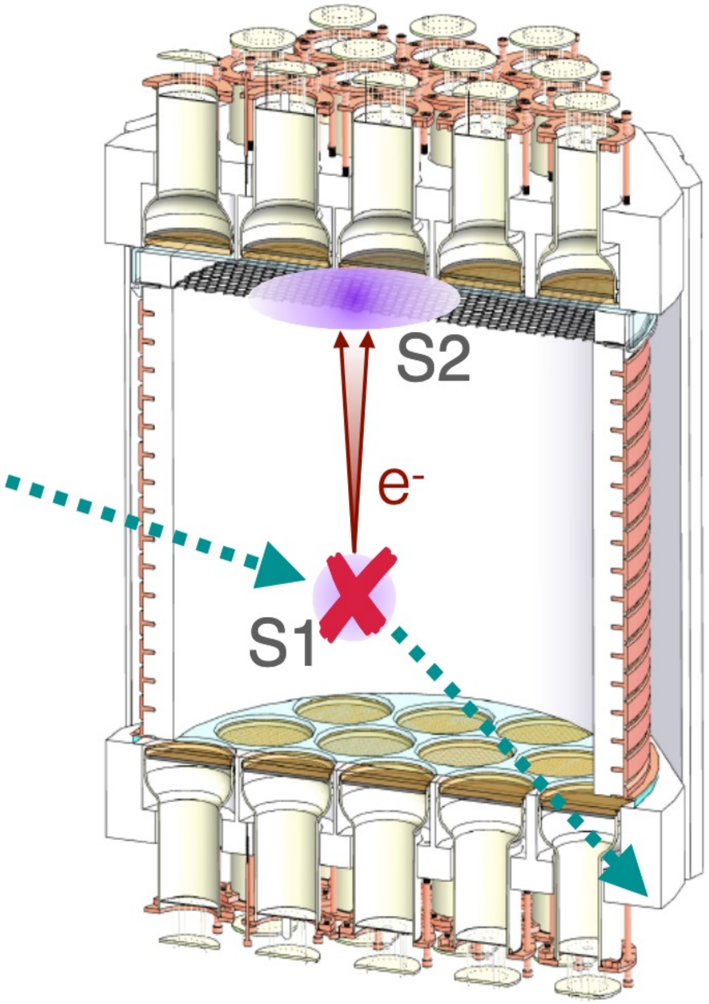


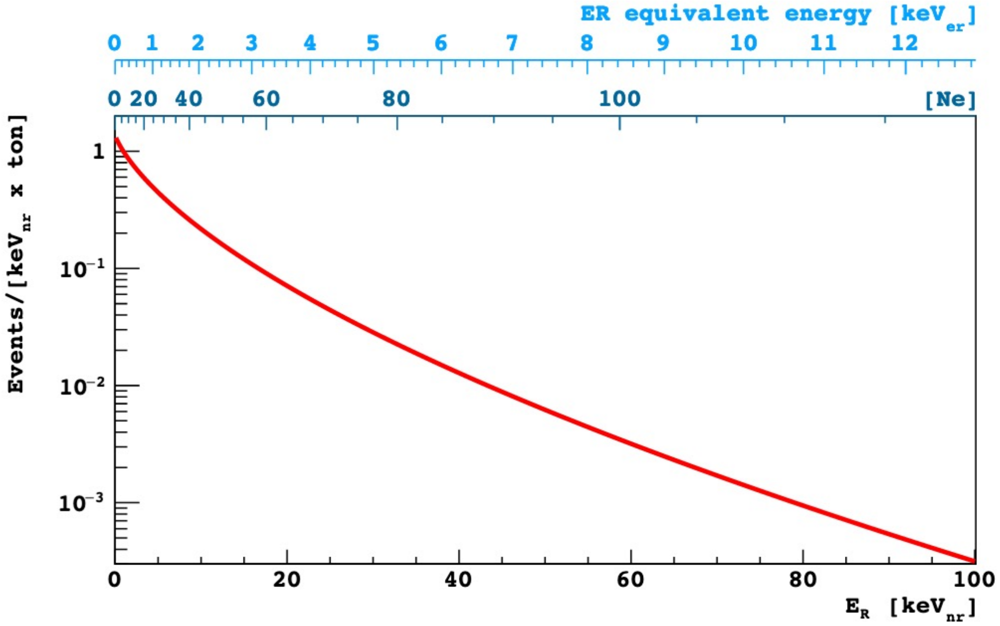
Image: J. Link Science Perspectives

- To date, the **only SN observed through ν is SN 1987A**: 25 events detected by Kamiokande-2, IMB and Baksan.
- Current and future giant detectors rely on the **electron antineutrino** detection via inverse beta decay (IBD) and are sensitive to **electron-neutrinos** via elastic scattering or electron neutrino charge current interaction
  - Water Cherenkov - **IBD** $\bar{\nu}_e + \mathrm{p} \to e^+ + n$: SuperK (32 kton) and HyperK (374 kton)
  - Liquid Scintillators – **IBD**: KamLAND (1 kton), LVD (1 kton) and JUNO (20 kton)
  - LAr: Charge Current (**CC**) $\bar{\nu}_e + {}^{40}\mathrm{Ar} \to e^- + {}^{40}\mathrm{K}^*$: DUNE (40 kton)

- Neutrino detection via CEνNS offers a unique and synergistic opportunity: **equally sensitive to all neutrino flavours and allows to measure the unoscillated SN neutrino flux**, plus large cross section!
  - • LAr: **CEvNS** $\nu_e + {}^{40}\mathrm{Ar} \to \nu_e + {}^{40}\mathrm{Ar}$: DarkSide-20k (47.1 tonnes) and Argo (362.7 tonnes)

CEνNS in DS-20k and Argo





- Nuclear recoil energy spectrum from SN neutrino interactions in LAr via CEνNS
- The window of observation is <100 keV$_{nr}$, with ~70% (~50%) of events with energy <10 keV$_{nr}$ (<5 keV$_{nr}$)

- Need to lower the energy thr ⇒ Look at S2 only events, S2 >> S1 (23ph/e- in DS50)

  → Successfully applied in PRL 121 (2018) 081307

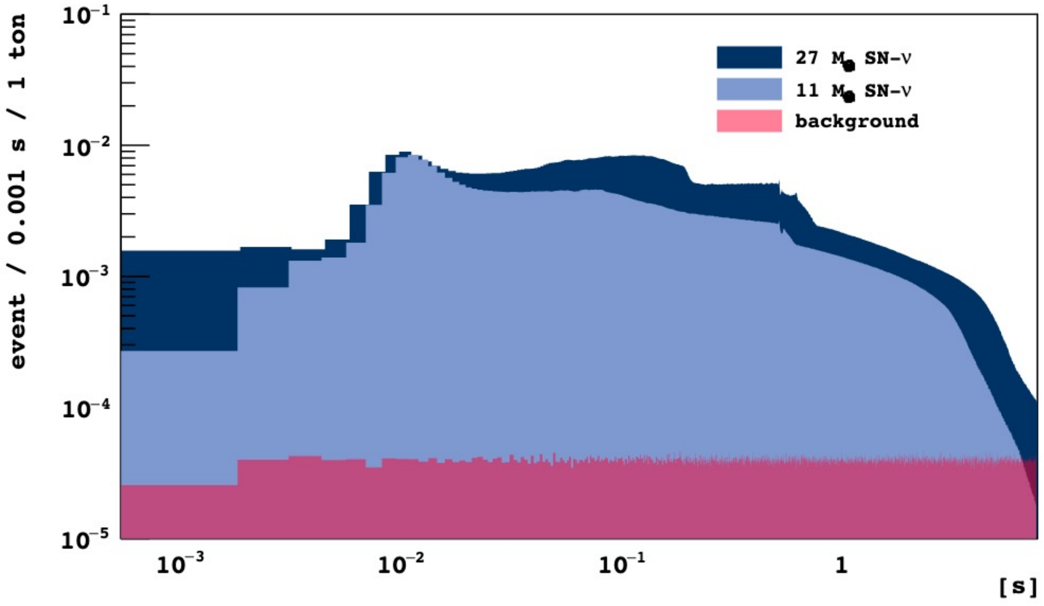
- **Pros:**
  - Low energy thr.: 0.46 keV$_{nr}$
  - 100% Trigger eff. > ~30PE
- **Cons: No S1**
  - No position reconstruction in z
  - No PSD ⇒ No ER rejection
  - Poor timing reconstr., limited to the TPC drift time

- **86% of SN CEνNS would be detected**

Sensitivity to SN ν

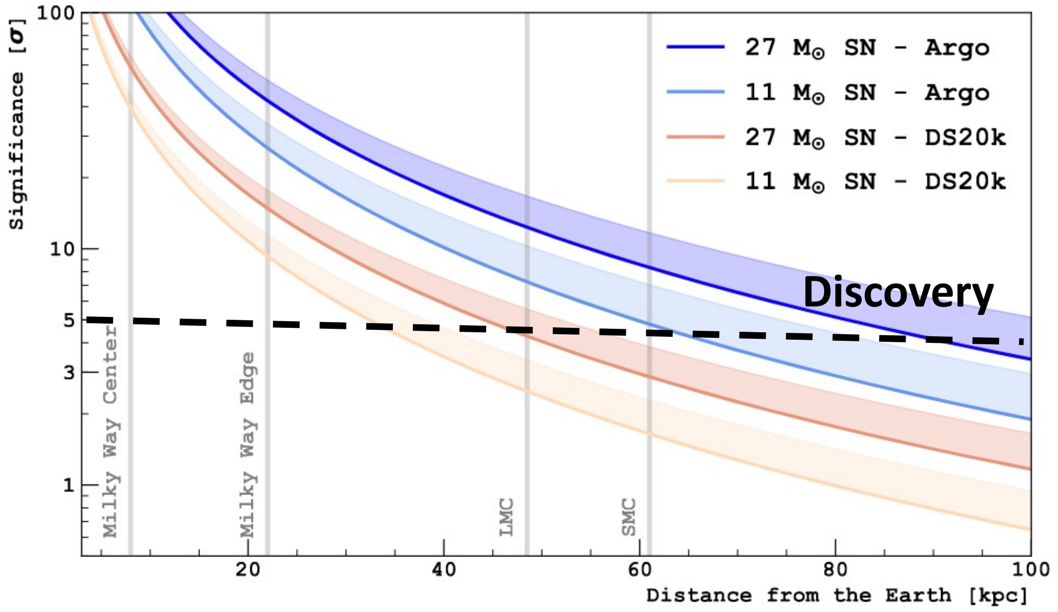
- Expected signal and background in 8s for a SN burst at a distance of 10kpc within the [3, 100] Ne⁻ energy window and in 8 s from the beginning of the burst

	DarkSide-20k	Argo
11-$M_\odot$ SN-νs	181.4	1396.6
27-$M_\odot$ SN-νs	336.5	2591.6
^{39}Ar	4.3	33.8
external background	1.8	8.8
single-electrons	0.7	5.1



[JCAP03(2021)043]

- Signal/Noise ratio SNR~10^2 during neutronization and accretion (1s). SNR~10 during cooling (>1s)
- Overall SNR~24 (45) for 11$M_\odot$ (27$M_\odot$)
- Sensitivity >5**σ** up to the Milky Way edge for DS-20k and the Small Magellanic Cloud for Argo.



[JCAP03(2021)043]

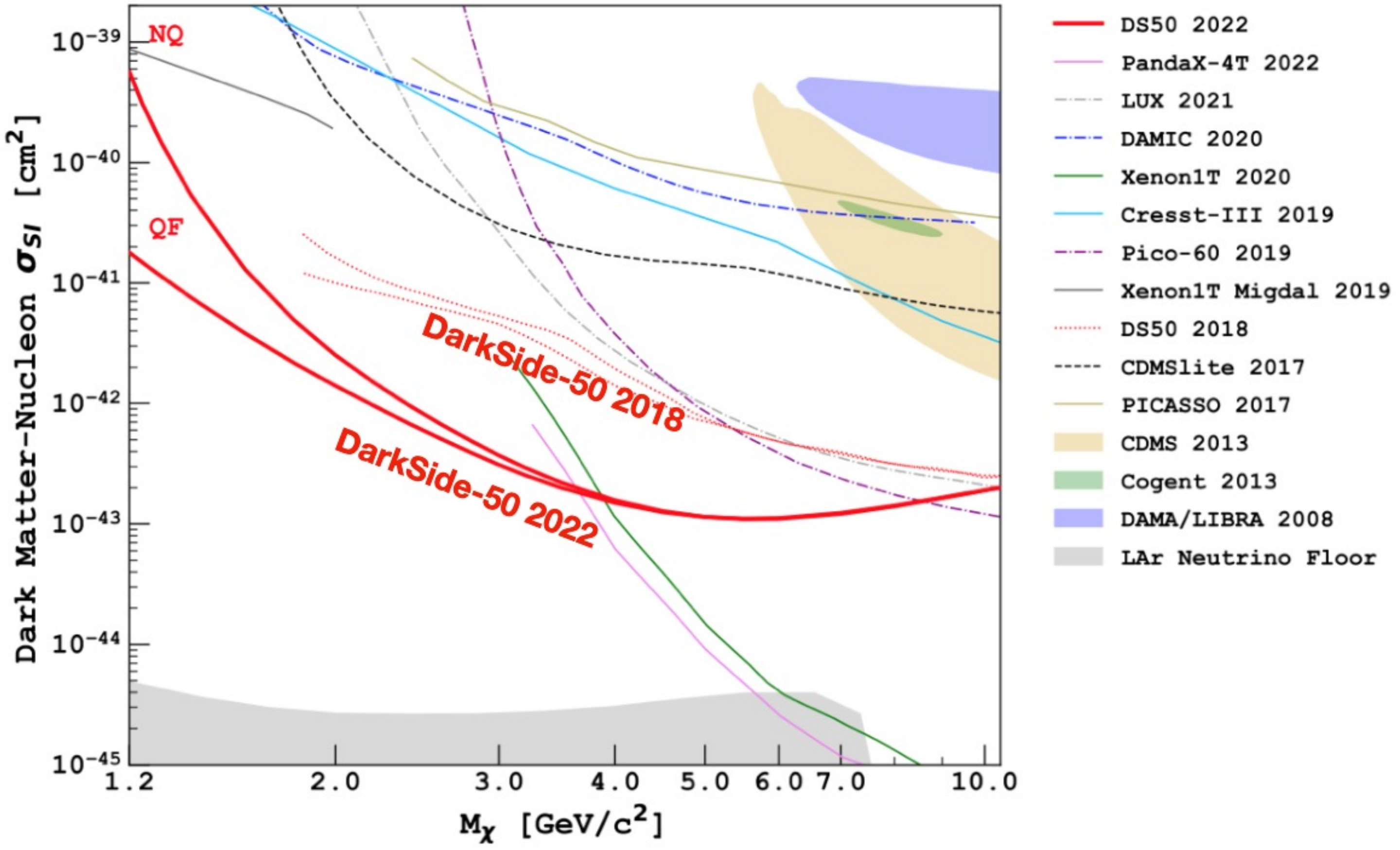
- **Interesting potentialities for both DS-20k and Argo!**

Sneak peek into recent DS-50 results

- **DarkSide-50 low mass**: ionization only spectrum
- Minimal fiducialization (only radial)
- No PSD
- No more bkg-free → Background model needed

- First analysis in 2018, recently updated!
- The new analyses benefits from
  - more accurate calibration of the detector response
  - improved background model
  - better determination of systematic unc.

- **WIMP-Nucleus** arXiv: 2207.11966 (2022)
- **Migdal effect** arXiv: 2207.11967 (2022)
- **WIMP-electron** arXiv: 2207.11968 (2022)



- **Factor 10 better than the previous DarkSide-50 limit!**

CONCLUSIONS

R&D phase for the DS-20k detector completed, construction is starting!

- Production of SiPMs started and PDU mass test facility is ready
- Underground Ar procurement and characterisation project is ongoing (URANIA & ARIA & DArT-ArDM)
- Underground Argon cryogenic system has been successfully tested at CERN and is being relocated at INFN-LNGS
- Construction of the DS-20k cryostat will start soon in Hall C
- Data taking expected in 2026

NOW
MMX
ν_e
ν_μ
$\nu_?$
ν_τ
Multi messenger
astrophysics
Oscillation parameters
future
ν masses, states and
interactions
Particle physics in
the cosmos
Oscillation parameters
present
ν
Neutrino Oscillation Workshop

BACKUP

Light DM-nucleus with DarkSide-50

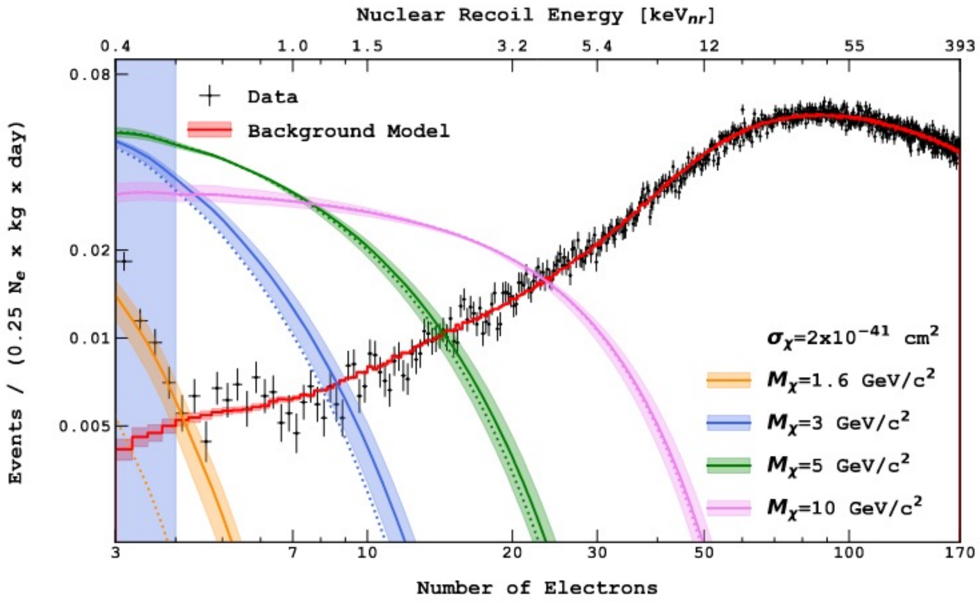


FIG. 10. Data and background model compared to expected WIMP spectra, assuming binomial quenching fluctuations (solid lines) and WIMP-nucleon scattering cross section equal to 2×10^{-41} cm^2. The systematic error associated with WIMP spectra is due to uncertainty on the NR ionization response. For reference, WIMP spectra assuming no quenching fluctuation (dashed lines) are also shown.

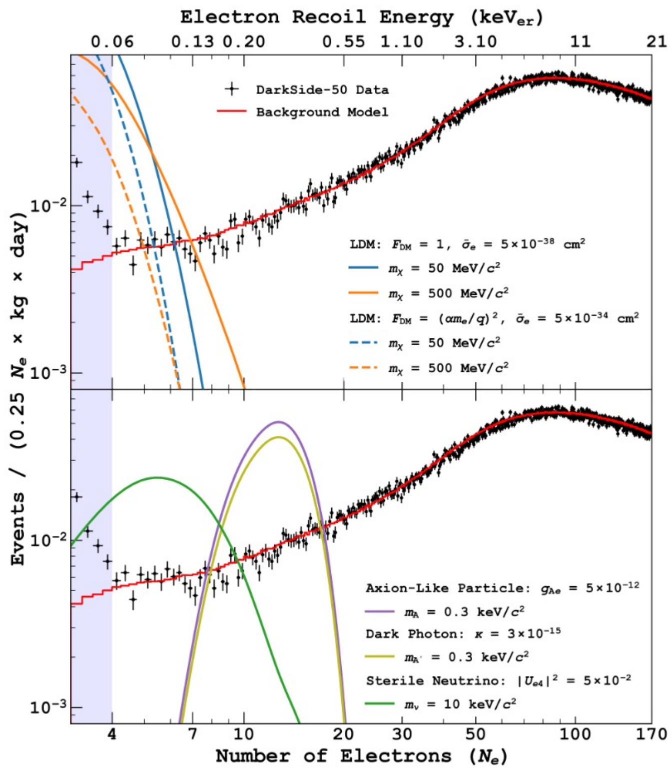
arXiv: 2207.11966 (2022)

DM-electron final states with DarkSide-50

We present a search for dark matter particles with sub-GeV/c^2 masses whose interactions have final state electrons using the DarkSide-50 experiment's $(12\,306 \pm 184)$ kg d low-radioactivity liquid argon exposure. By analyzing the ionization signals, we exclude new parameter space for the dark matter-electron cross section $\bar{\sigma}_e$, the axioelectric coupling constant g_{Ae}, and the dark photon kinetic mixing parameter κ. We also set the first dark matter direct-detection constraints on the mixing angle $|U_{e4}|^2$ for keV sterile neutrinos.

- Heavy DM can also scatter off electrons, but the energy of such interactions (ERs) is suppressed due to the small electron mass.
- 653.1 live-days of data collected with the DarkSide-50
- DM interactions in the form of
  - light DM-electron scattering with heavy or light mediator,
  - Pseudo-scalar DM (axion-like) and vector-boson DM (dark photons) through absorption by argon shell electrons,
  - sterile neutrino-electron scattering.

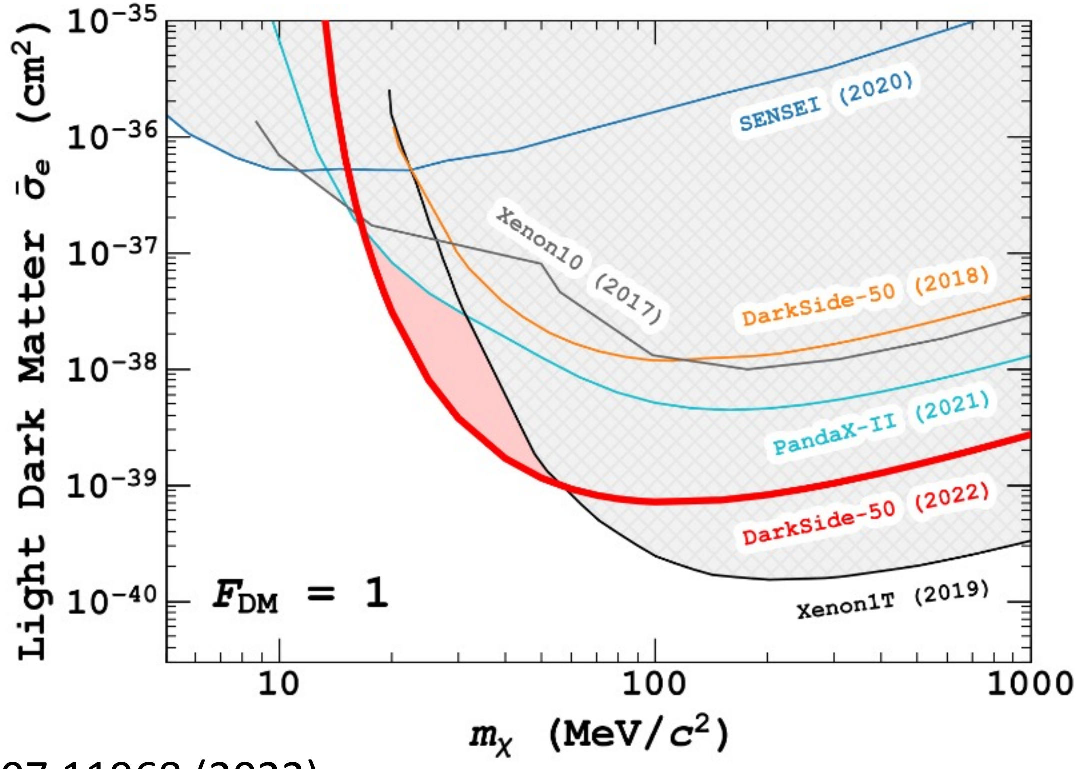
$$\nu_s + e \rightarrow \nu_e + e \text{ (and } \bar{\nu}_s + e \rightarrow \bar{\nu}_e + e)$$

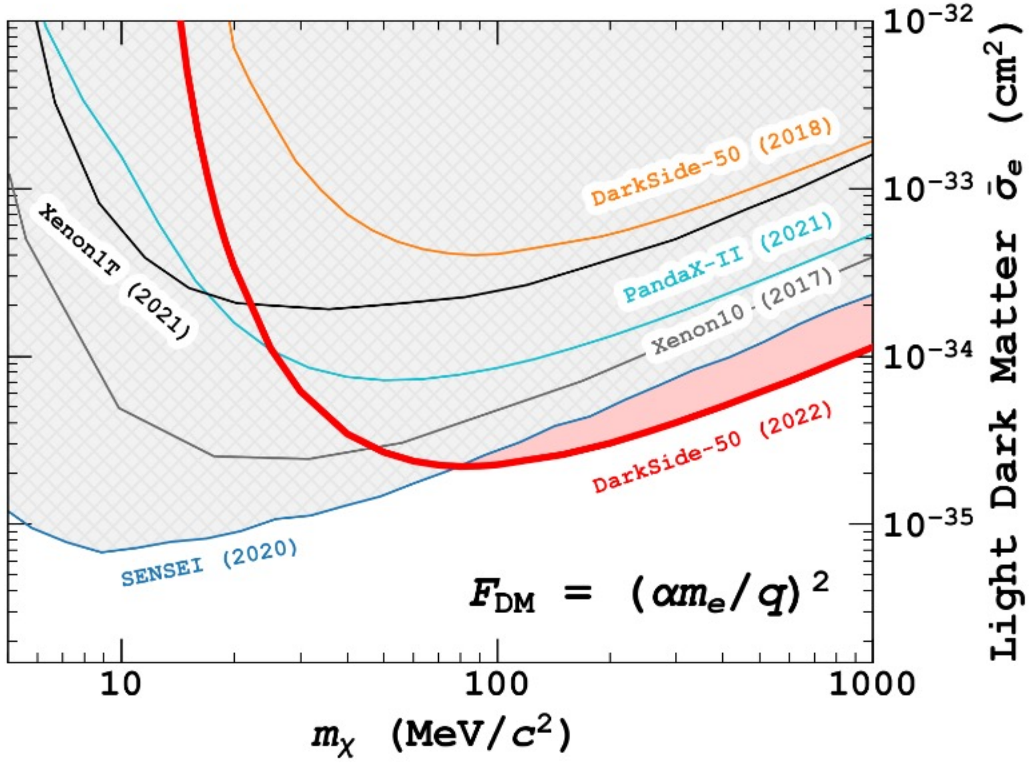


arXiv: 2207.11968 (2022)

DM-electron final states with DarkSide-50

- Best direct-detection limits on DM-electron scattering in the mass range of 16 MeV/c^2 to 56 MeV/c^2 for a heavy mediator and above 80 MeV/c^2 for a light mediator.
- Refined data selection criterion which suppresses correlated events between 4 e− and 7 e−.
- Additional sensitivity gain comes from improved data selection, a more accurate detector calibration, improved background modelling, and a larger data-set.

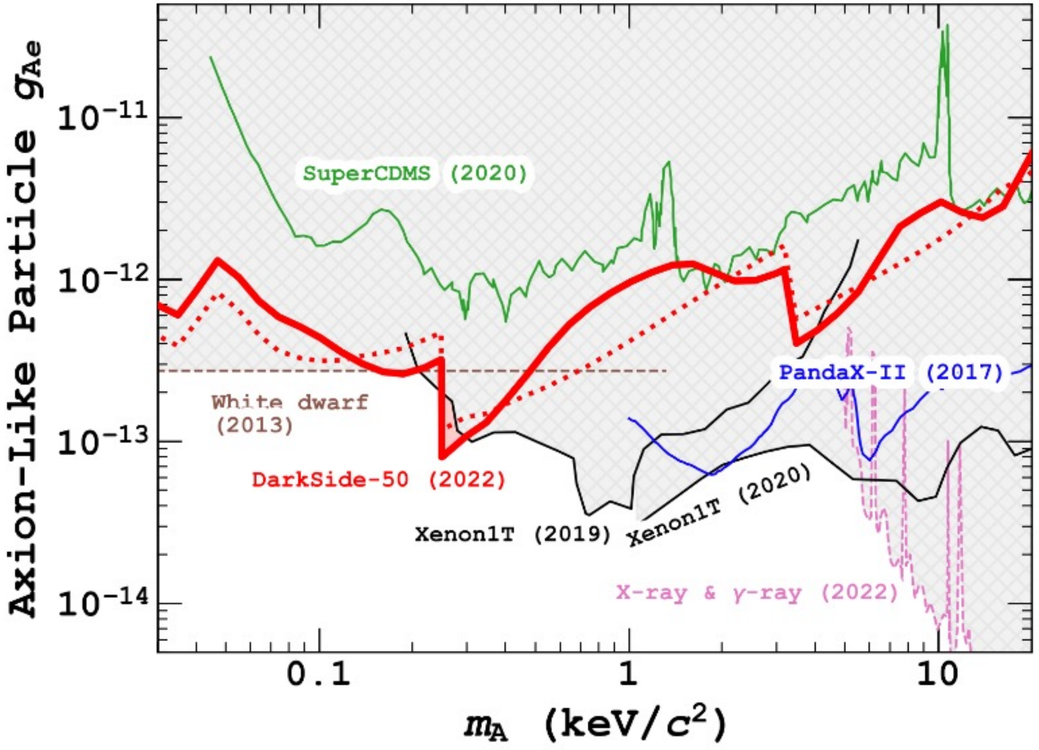


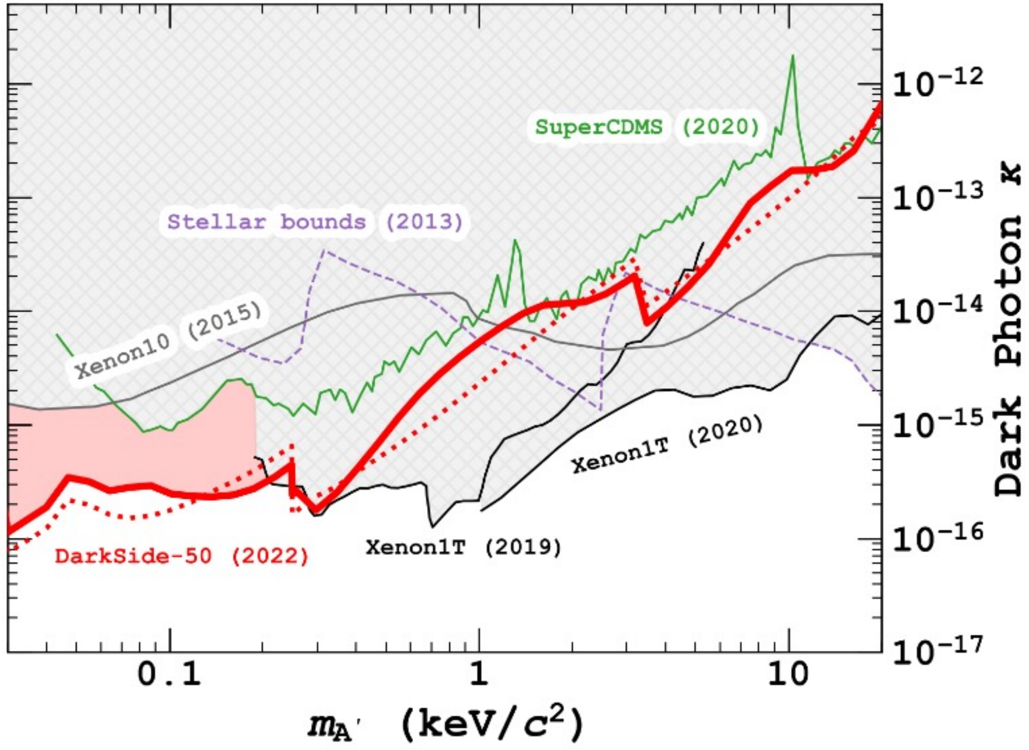


arXiv: 2207.11968 (2022)

DM-electron final states with DarkSide-50

- We have also placed the first constraints on galactic axion-like particles and dark photons with an argon target. Stronger direct-detection limits are placed on both gAe and κ for masses between 0.03 and 0.2 keV/c².

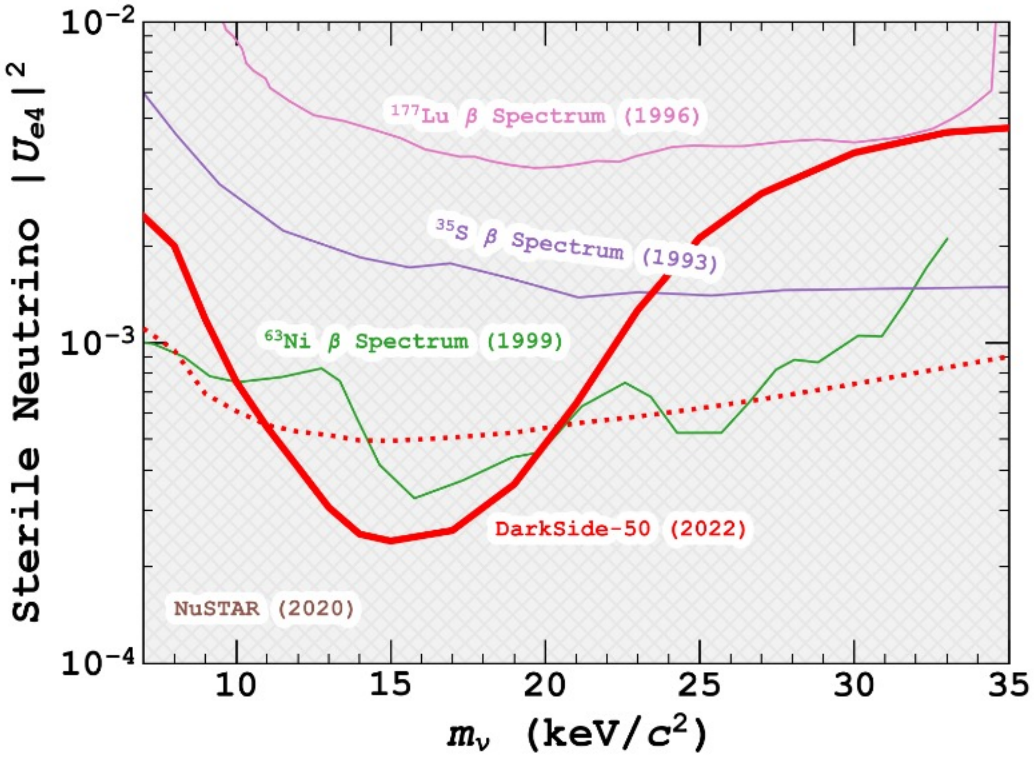




arXiv: 2207.11968 (2022)

DM-electron final states with DarkSide-50

- DS-50 is the first DM direct-detection experiment to set limits on the sterile neutrino mixing angle $|Ue4|^2$. Under the Standard Halo Model assumption, our results improve upon existing direct limits set by a high-precision measurement of the ^{63}Ni β spectrum [24]. However, these are well above the indirect detection limits set by the NuSTAR experiment



arXiv: 2207.11968 (2022)

DM-nucleon via Migdal effect with DS-50

Dark matter elastic scattering off nuclei can result in the excitation and ionization of the recoiling atom through the so-called Migdal effect. The energy deposition from the ionization electron adds to the energy deposited by the recoiling nuclear system and allows for the detection of interactions of sub-GeV/c^2 mass dark matter. We present new constraints for sub-GeV/c^2 dark matter using the dual-phase liquid argon time projection chamber of the DarkSide-50 experiment with an exposure of $(12\,306 \pm 184)$ kg d. The analysis is based on the ionization signal alone and significantly enhances the sensitivity of DarkSide-50, enabling sensitivity to dark matter with masses down to 40 MeV/c^2. Furthermore, it sets the most stringent upper limit on the spin independent dark matter nucleon cross section for masses below 3.6 GeV/c^2.

- Several mechanisms that explain the observed DM density point to light DM particles (LDM), with masses in the sub-GeV/c^2 range
- LDM is difficult to probe with direct detection experiments because the DM-induced nuclear recoil (NR) energy is generally below the detection threshold.

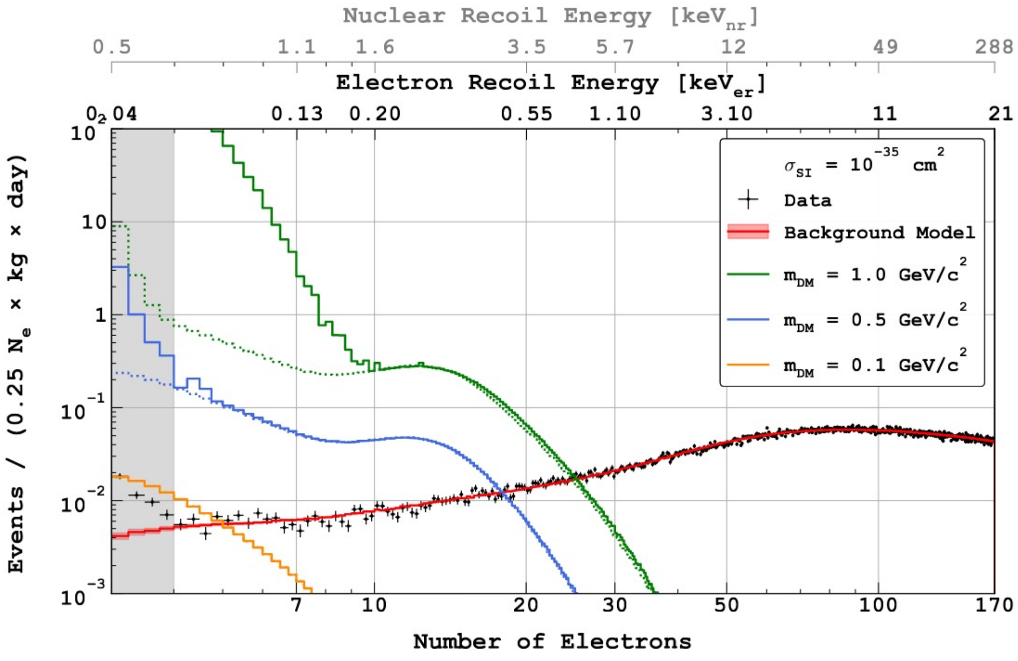
- Atomic effects modelled by Migdal predict emission of electrons associated with a fraction of nuclear recoils. This electron recoil (ER) component, in addition to the NR one, increases the probability of exceeding the detection threshold.
- The elastic scattering of a DM particle off an argon nucleus at rest induces an instantaneous momentum change of the nucleus with respect to the atomic electrons, resulting in the possible ionization or excitation of the atom: this is the ME!

- We consider only single-scatter events. Such events are identified by requiring a single valid S2 pulse.

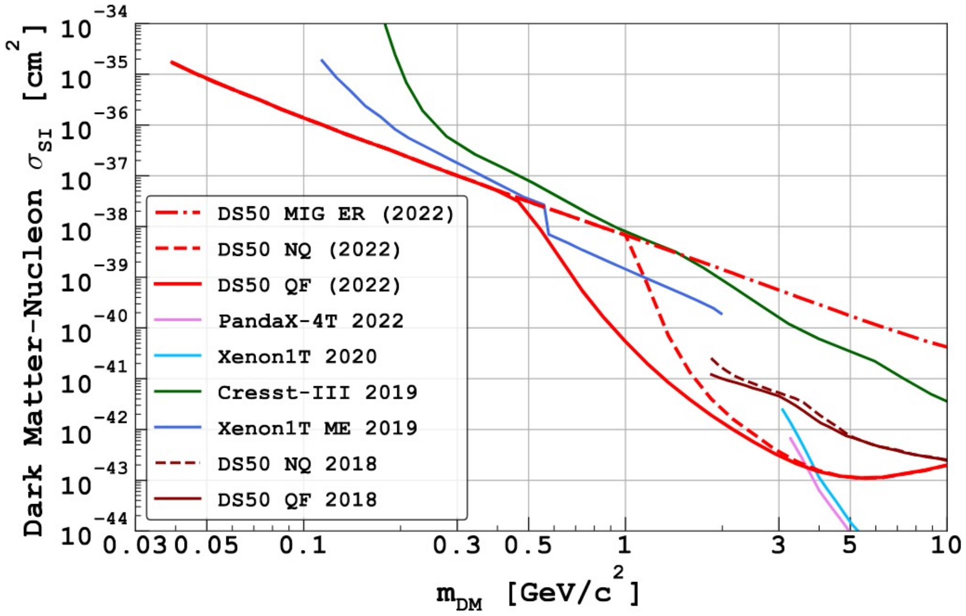
arXiv: 2207.11967 (2022)

DM-nucleon via Migdal effect with DS-50

- Given our uncertainties on how to model the size of the fluctuations of the ionization distribution of nuclear recoils, we consider two separate models.
- The first one (QF) allows for fluctuations in the ionization yield, recombination process and energy quenching modeled via binomial distributions. These fluctuations, for DM masses yielding events around or below the experimental threshold of Ne = 4, are significant given the small number of electrons.
- The second model (NQ) sets the fluctuations in energy quenching to zero.



World best limit on the SI DM-nucleon cross section for masses below 3.6 GeV/c^2 and down to 40 MeV/c^2



arXiv: 2207.11967 (2022)

Calibration campaigns of DS-50

- The DarkSide-50 Collaboration re-analyzed data from calibration campaigns with radioactive sources and measured, with high-accuracy, the LAr ionization response (Qy) to electron (ER) and nuclear (NR) recoils down to a few hundred electronvolts
- DarkSide-50 measurement of the ionization yield of electronic recoils down to ~180 eV_{er}, exploiting ^{37}Ar and ^{39}Ar decays, and extrapolated to a few ionization electrons with the Thomas-Imel box model.
- Moreover, a model-dependent determination of the ionization response to nuclear recoils down to ~500 eV*nr*, the lowest ever achieved in liquid argon, using in situ neutron calibration sources and external datasets from neutron beam experiments.

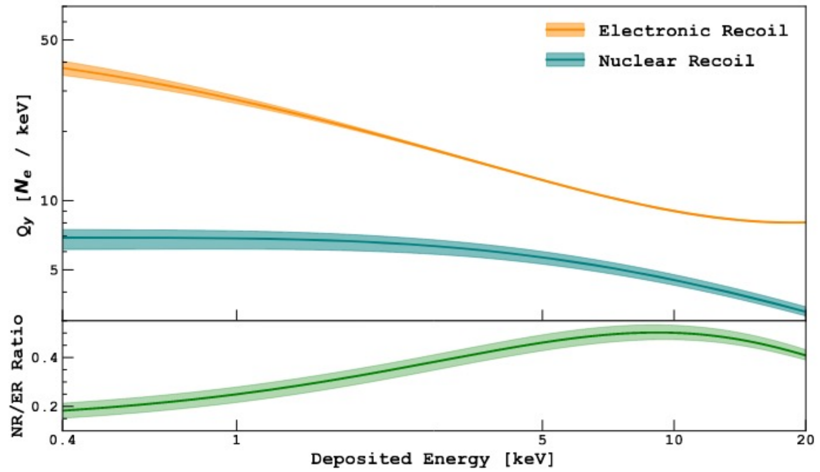
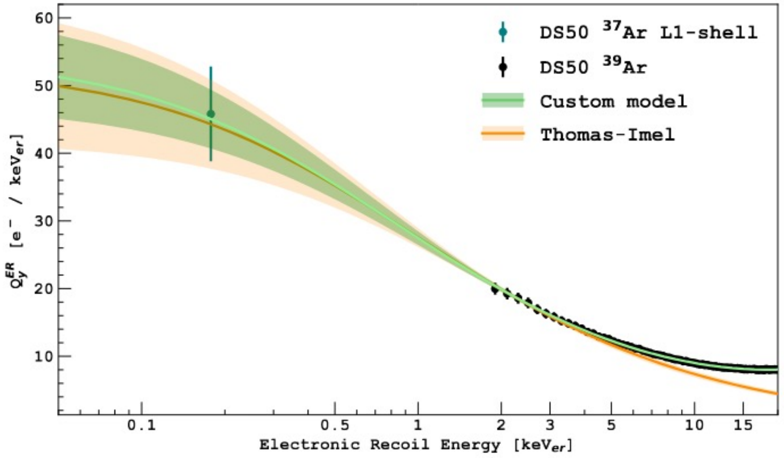


FIG. 1. LAr ionization response to nuclear (NR) and electronic (ER) recoils as a function of the deposited energy, as measured by DarkSide-50 [16].



Phys. Rev. D 104, 082005 (2021)

Calibration campaigns of DS-50

- The DarkSide-50 Collaboration re-analyzed data from calibration campaigns with radioactive sources and measured, with high-accuracy, the LAr ionization response (Qy) to electron (ER) and nuclear (NR) recoils down to a few hundred electronvolts
- DarkSide-50 measurement of the ionization yield of electronic recoils down to ∼180 eV$_{er}$, exploiting ^{37}Ar and ^{39}Ar decays, and extrapolated to a few ionization electrons with the Thomas-Imel box model.
- Moreover, a model-dependent determination of the ionization response to nuclear recoils down to ∼500 eV*nr*, the lowest ever achieved in liquid argon, using in situ neutron calibration sources and external datasets from neutron beam experiments.

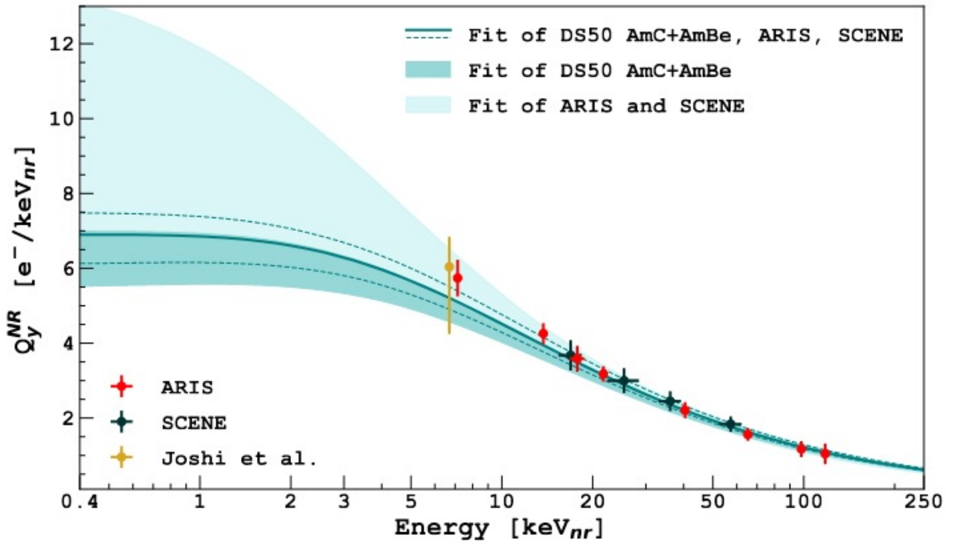


FIG. 8. Fit of the NR ionization yield at 200 V/cm from the combined fit of DarkSide-50 AmBe and AmC calibration data, together with datasets from SCENE [39] and ARIS measurements [35], the latter combined with the DarkSide-50 ionization-to-scintillation ratio. The measured Q_y^{NR} by Joshi *et al.* [40] at 6.7 keV$_{nr}$ is reported for comparison. The model bands correspond to 1 σ uncertainty.

Phys. Rev. D 104, 082005 (2021)

Background model for ERs in DS-50

- The event rate in the energy range of interest for light dark matter search is dominated by ^{39}Ar and ^{85}Kr decays, originated in the LAr bulk, and by γs and X-rays from radioactive isotopes in the detector components surrounding the active target.

- The rate of NRs from radiogenic and cosmogenic neutrons and from interactions of solar and atmospheric neutrinos, via coherent scattering off nucleus, is negligible with respect to the ER one, and therefore not considered in this analysis.

- ^{39}Ar and ^{85}Kr specific activities were estimated in the first 70 days DarkSide-50 dataset with underground argon at 0.73±0.11 mBq/kg and 2.05±0.13 mBq/kg

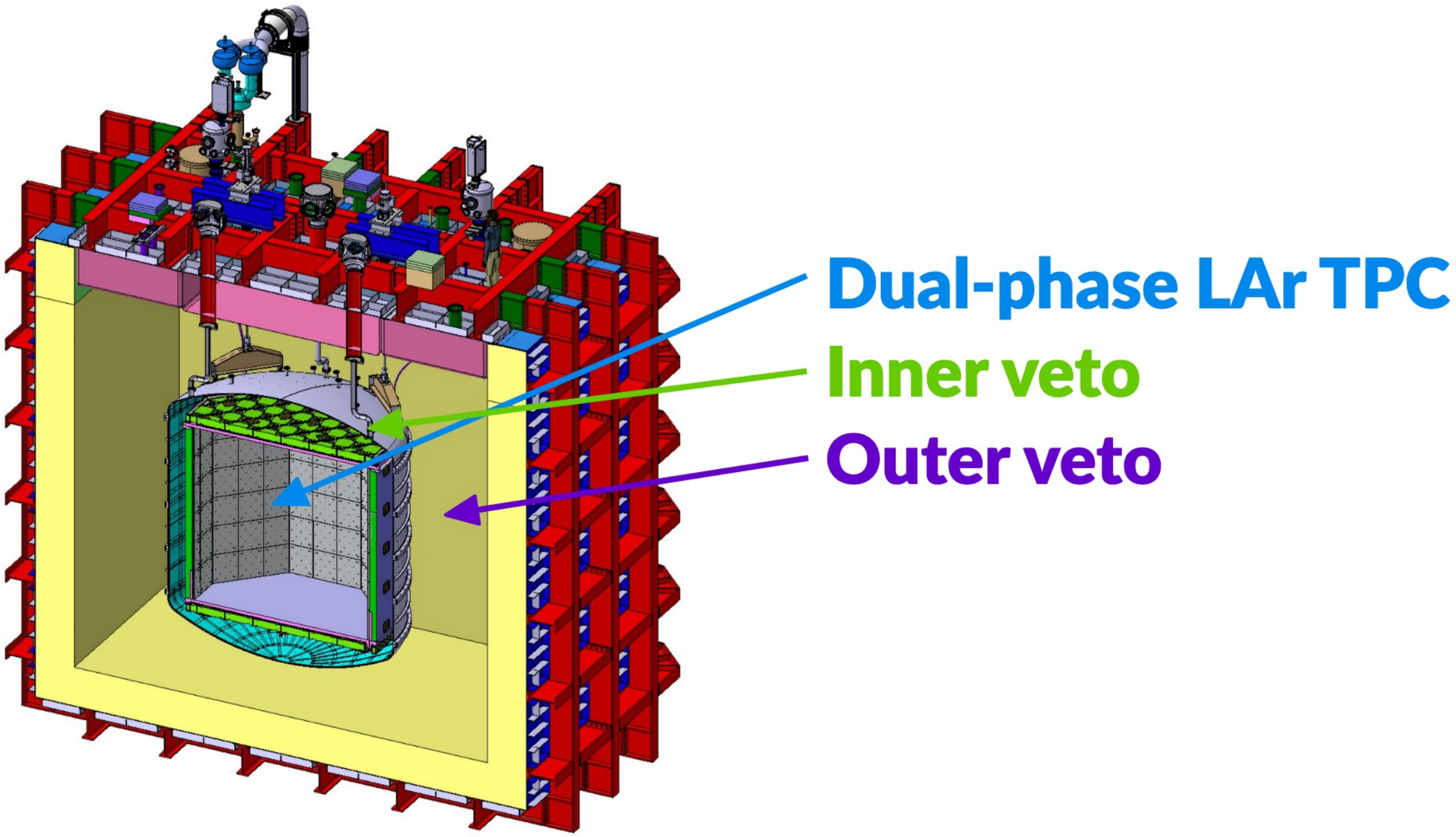
Location and source			Activity [Bq]	Single-scatter events in the RoI: Event rate [Hz]	Single-scatter events in the RoI: Total rate [Hz]
LAr		^{39}Ar	0.034 ± 0.005	$(8.4 \pm 1.2) \times 10^{-4}$	$(8.4 \pm 1.2) \times 10^{-4}$
LAr		^{85}Kr	0.084 ± 0.004	$(2.0 \pm 0.1) \times 10^{-3}$	$(2.0 \pm 0.1) \times 10^{-3}$
PMT	Stems	^{232}Th	0.16 ± 0.03	$(3.2 \pm 0.6) \times 10^{-4}$	$(3.5 \pm 0.4) \times 10^{-3}$
PMT	Stems	^{238}U up	1.06 ± 0.22	$(4.7 \pm 1) \times 10^{-5}$	
PMT	Stems	^{238}U low	0.34 ± 0.03	$(3.2 \pm 0.2) \times 10^{-4}$	
PMT	Stems	^{235}U	0.05 ± 0.01	$(1.2 \pm 0.2) \times 10^{-4}$	
PMT	Stems	^{40}K	2.39 ± 0.32	$(1.8 \pm 0.2) \times 10^{-4}$	
PMT	Stems	^{54}Mn	0.05 ± 0.02	$(3.5 \pm 0) \times 10^{-5}$	
PMT	Ceramic	^{232}Th	0.07 ± 0.01	$(2.4 \pm 0.4) \times 10^{-4}$	
PMT	Ceramic	^{238}U up	4.22 ± 0.88	$(4.1 \pm 0.8) \times 10^{-4}$	
PMT	Ceramic	^{238}U low	0.34 ± 0.03	$(5.3 \pm 0.4) \times 10^{-4}$	
PMT	Ceramic	^{235}U	0.21 ± 0.03	$(9.6 \pm 1.4) \times 10^{-4}$	
PMT	Ceramic	^{40}K	$(0.61 \pm 0.08$	$8.1) \pm 1.1 \times 10^{-5}$	
PMT	Body	^{60}Co	0.17 ± 0.02	$(2.5 \pm 0.3) \times 10^{-4}$	
Cryostat		^{232}Th	0.19 ± 0.04	$(8.0 \pm 1.7) \times 10^{-5}$	$(6.1 \pm 0.4) \times 10^{-4}$
Cryostat		^{238}U up	$1.30^{+0.2}_{-0.2}$	$(1.5 \pm 0.2) \times 10^{-5}$	
Cryostat		^{238}U low	$0.38^{+0.04}_{-0.19}$	$(5.4 \pm 0.6) \times 10^{-6}$	
Cryostat		^{235}U	$0.045^{+0.01}_{-0.02}$	$(9.7 \pm 1.5) \times 10^{-6}$	
Cryostat		^{60}Co	1.38 ± 0.1	$(4.9 \pm 0.4) \times 10^{-4}$	
Cryostat		^{40}K	$0.16^{+0.02}_{-0.05}$	$(3.5 \pm 0.4) \times 10^{-6}$	

TABLE I. Background activities and event rate in the RoI from the bulk, PMTs, and cryostat from material screening. The activity measurements are reported for chain progenitors only, while the event rates are quoted for full decay chains. The uncertainties are propagated from the screening measurements. An additional 10% systematic error is included in the PMT error, due to the uncertainty on the contamination partitioning between stems and body.

arXiv: 2207.11966 (2022)

DS-20k

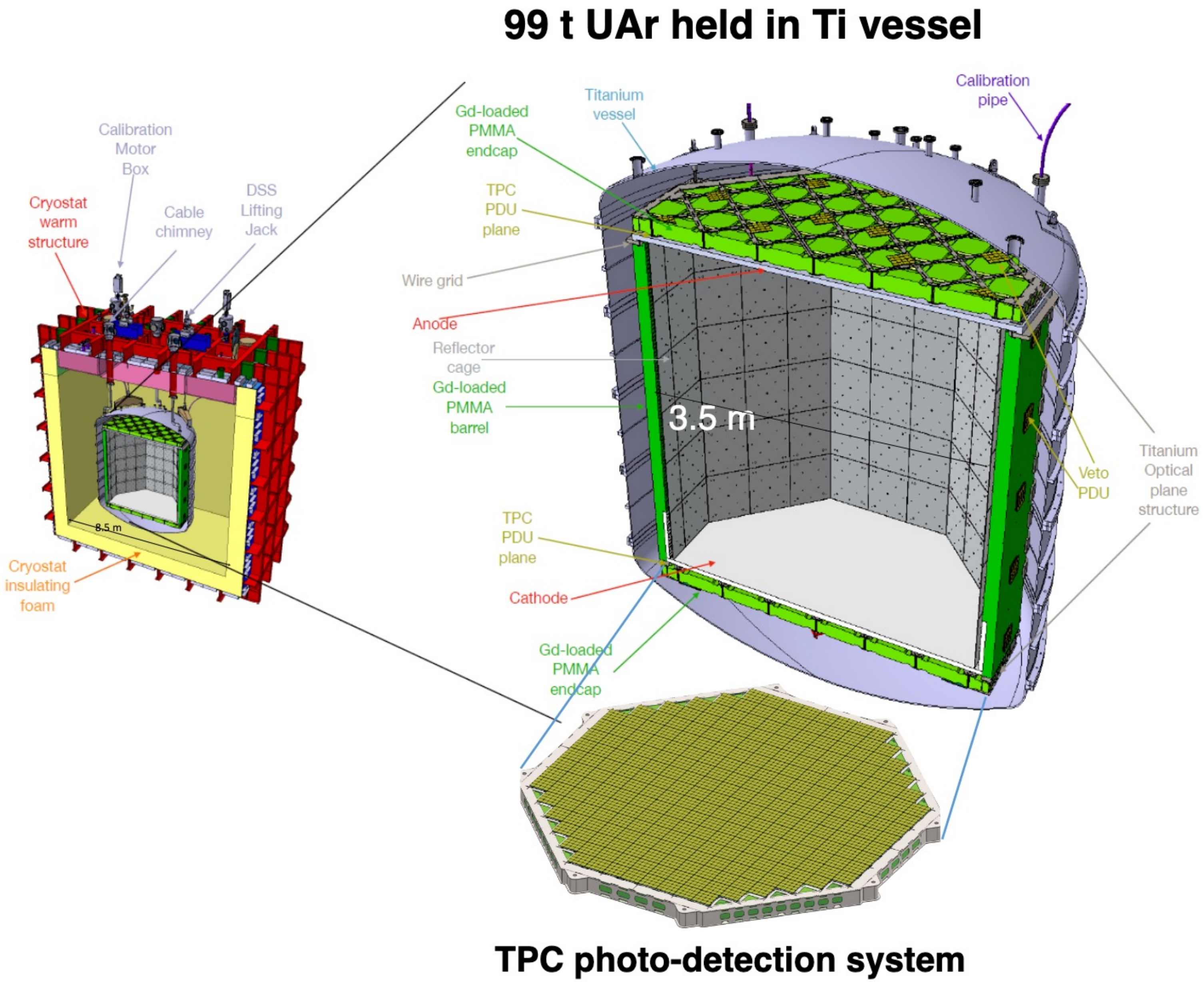
- ➢Three nested detectors
- ➢Integration of TPC and VETO in a single object



Inner detector

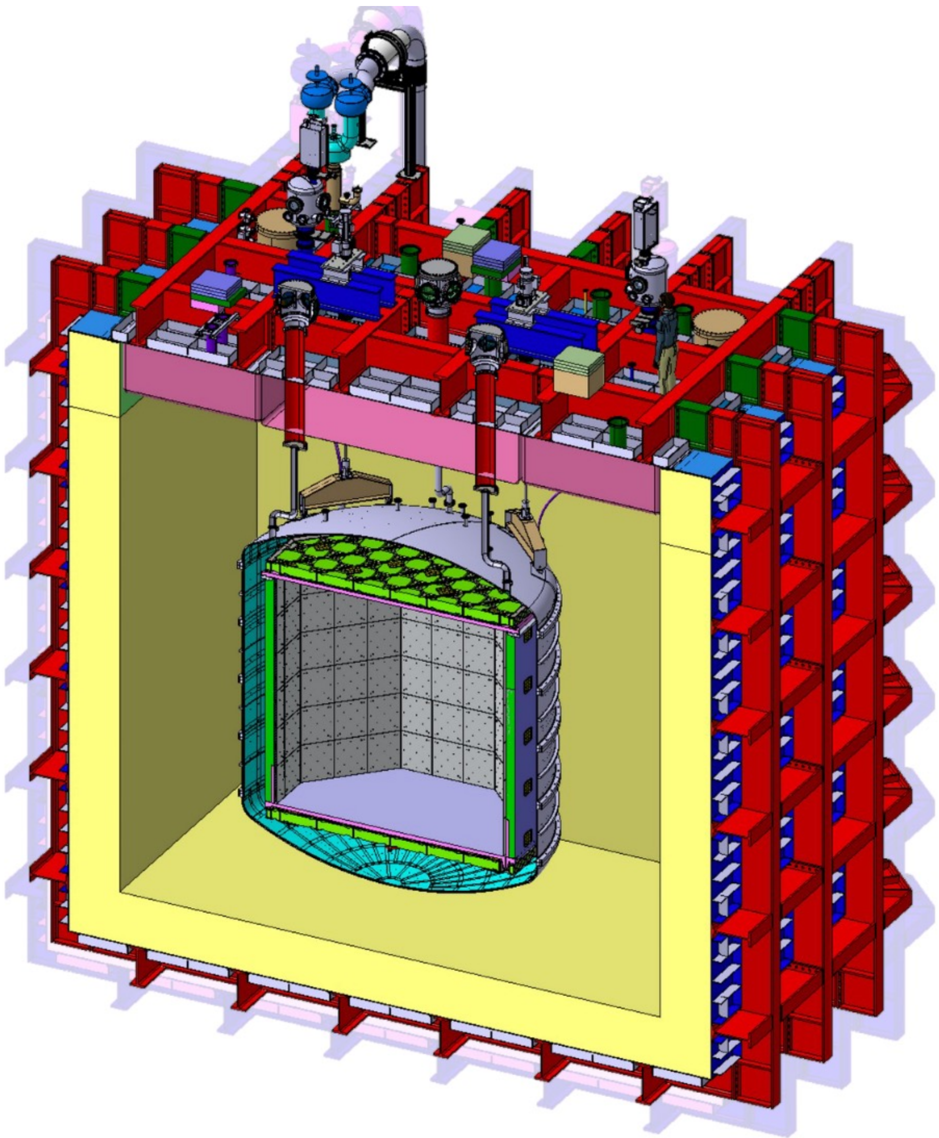
- TPC Vessel:
  Instrumentation: Contained in pure & Gd-doped (1 wt%) acrylic; field maintained by conductive Clevios coatings, ESR reflector + TPB wavelength shifter
- **TPC readout**: 21m^2 cryogenic SiPMs
- **Active mass**: 49.7 tonnes underground argon
- **Fiducial mass**: 20 tonnes underground argon

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



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



Inner veto

- **Instrumentation**: Contained in Ti 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.

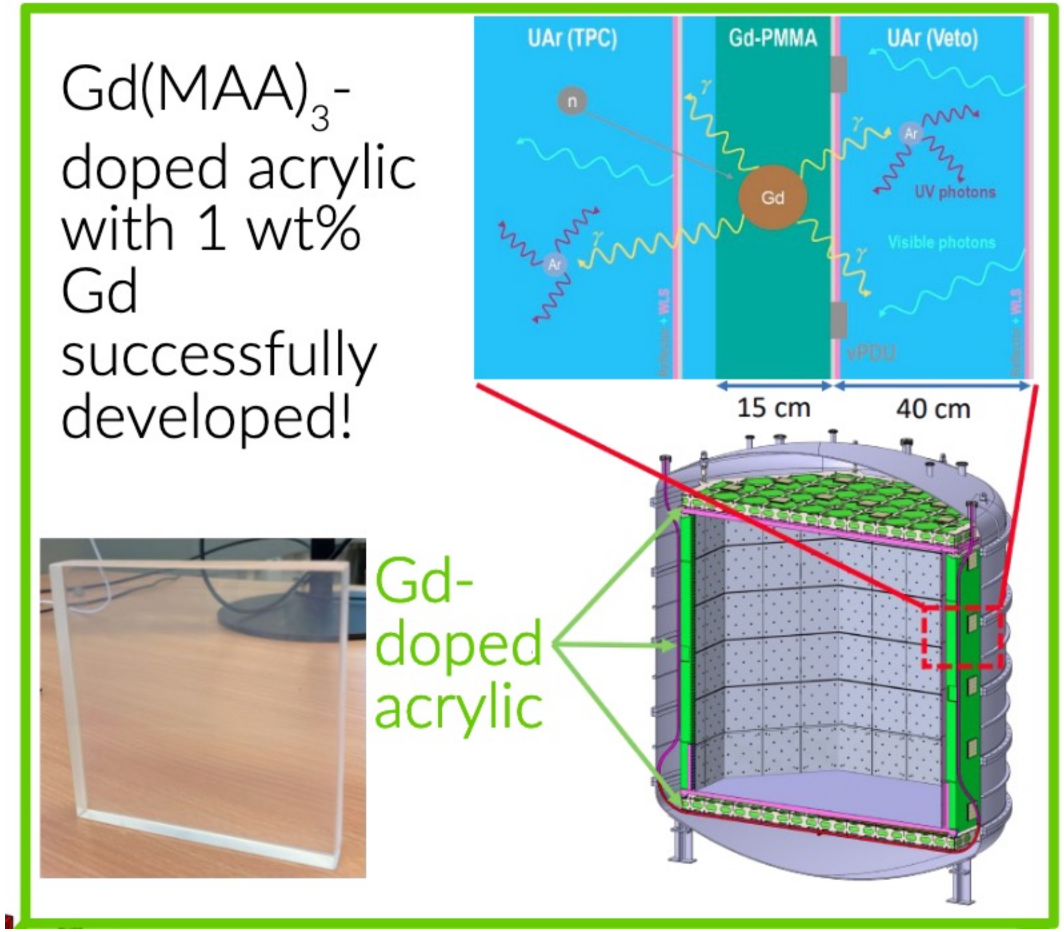
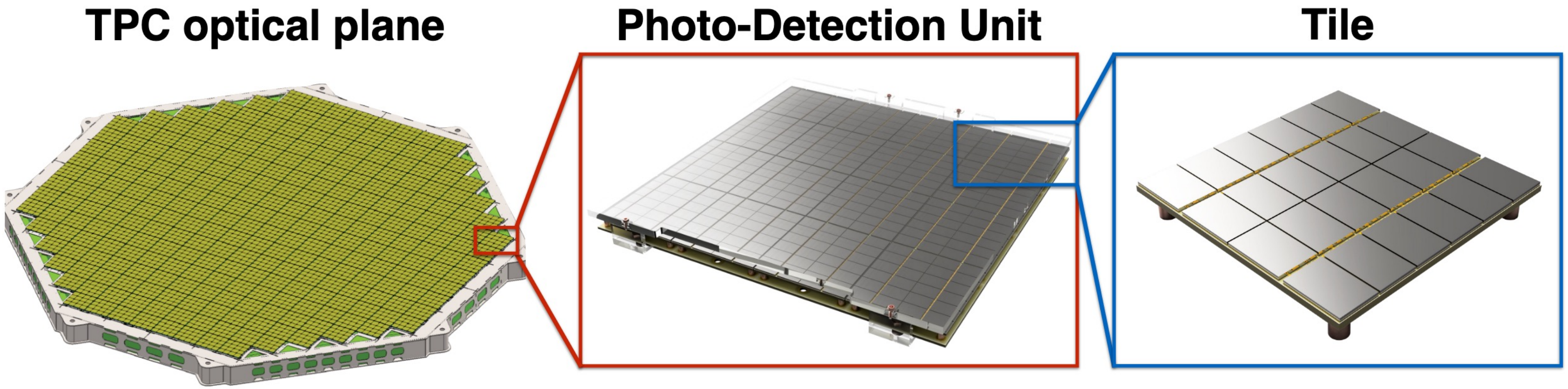


Photo-detection system

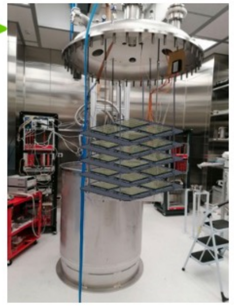


16 tiles arranged in 4 readout channels

TPC optical plane	Photo-Detection Unit	Tile
TPC planes area: ~21m^2	SiPM bias distribution	Photosensor
Organized in 525 PDUs	cryogenic pre-amplifiers bias	Array of 24 SiPMs
100% coverage of TPC top and bottom	Signal transmission	Signal pre-amplification
	Channels switch-on/off	

SiPM production at LFoundry (Italy)

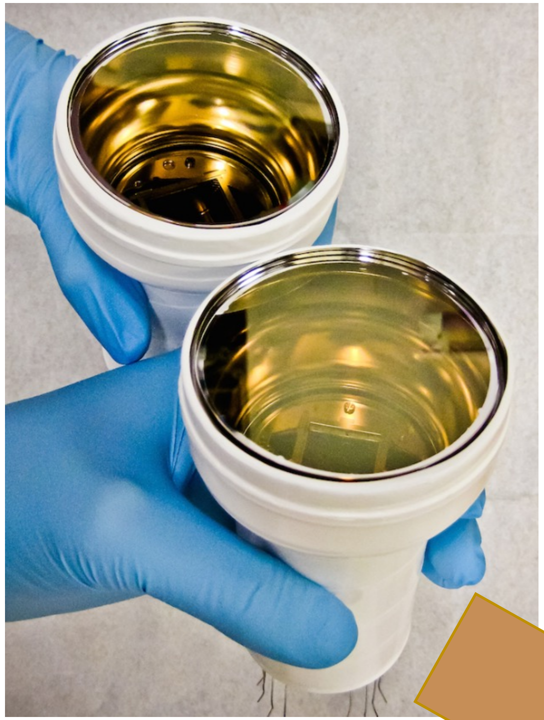
PDU packaging and assembly at Nuova Officina Assergi (NOA) at LNGS

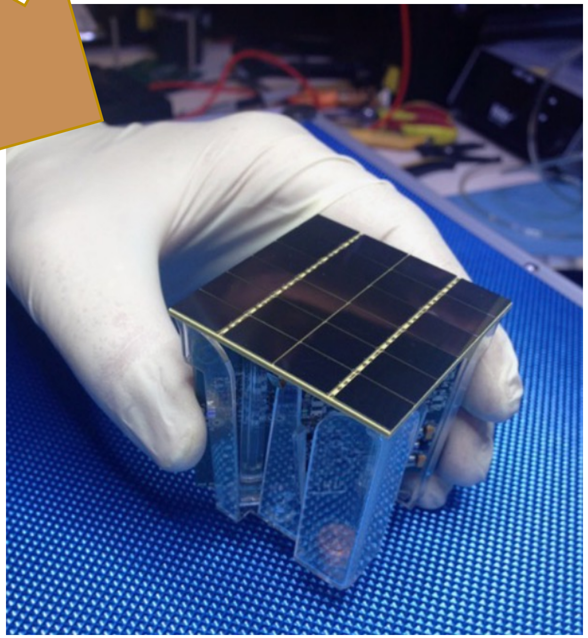


Testing at the Naples Test Facility

Why SiPMs?

- Lower radioactivity
- Higher Photon Detection Efficiency
- Higher active area
- Operated with low bias
- Lower cost





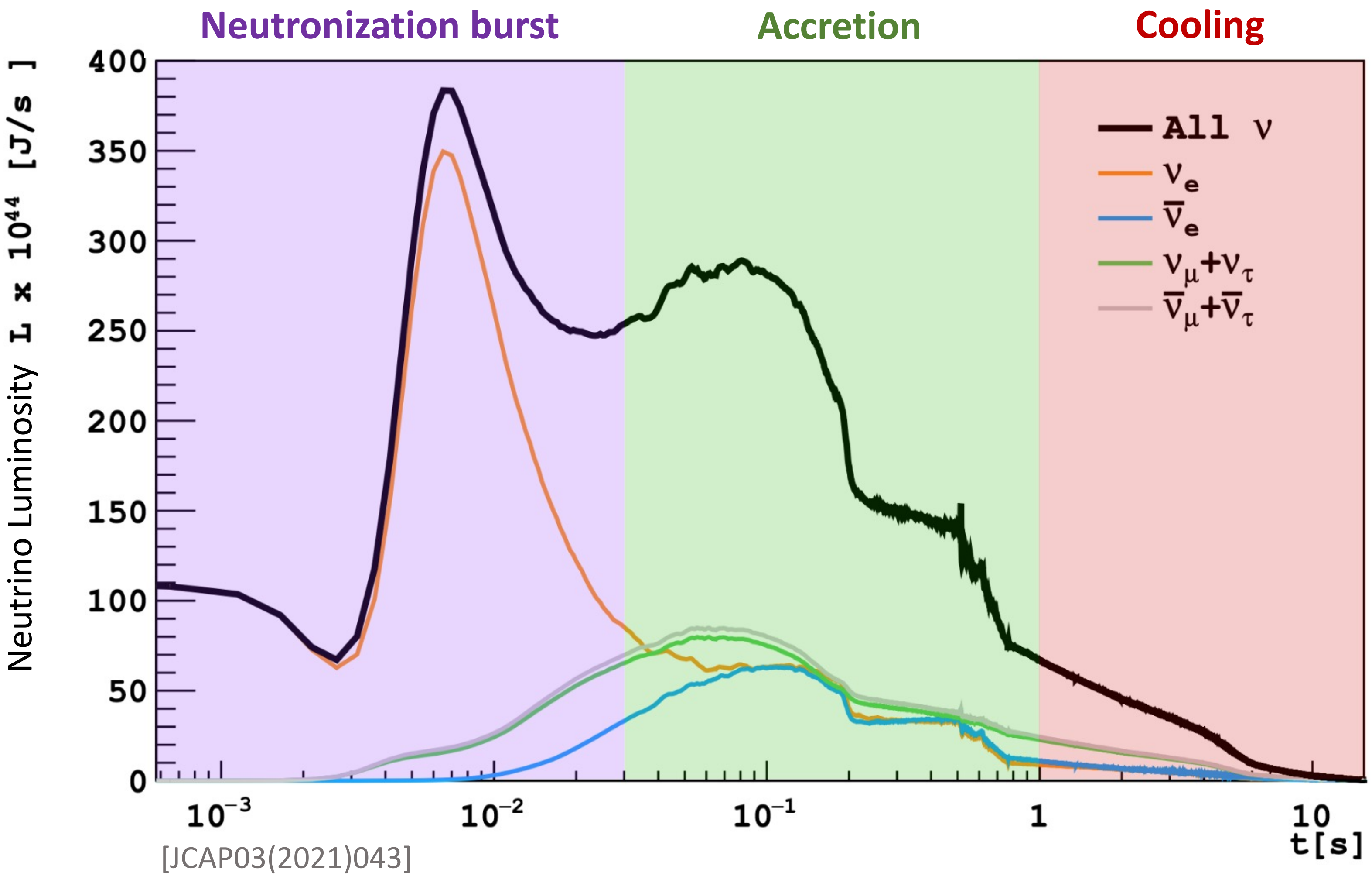
But...

- Higher dark rate and correlated noises (after-pulse, cross-talk)
- Small area (many channels)
- High output capacitance (high electronic noise, low bandwidth)

What can we learn from SN ν?

- Total energy of the explosion
- Observe a second collapse due to a nuclear matter phase transition
- Observe a black-hole formation during the first 10s
- Observe the shock stall and the duration of the accretion phase
- Observe Standing Accretion Shock Instability (SASI)
- Probe BSM physics from deviations of the neutrino spectra from SM physics
- Observe motion of shock through the mantle
- Determine the sphericity of the core collapse
- Determine the angular momentum of the Proto Neutron Star
- Determine neutrino mass ordering

Core Collapse SN ν

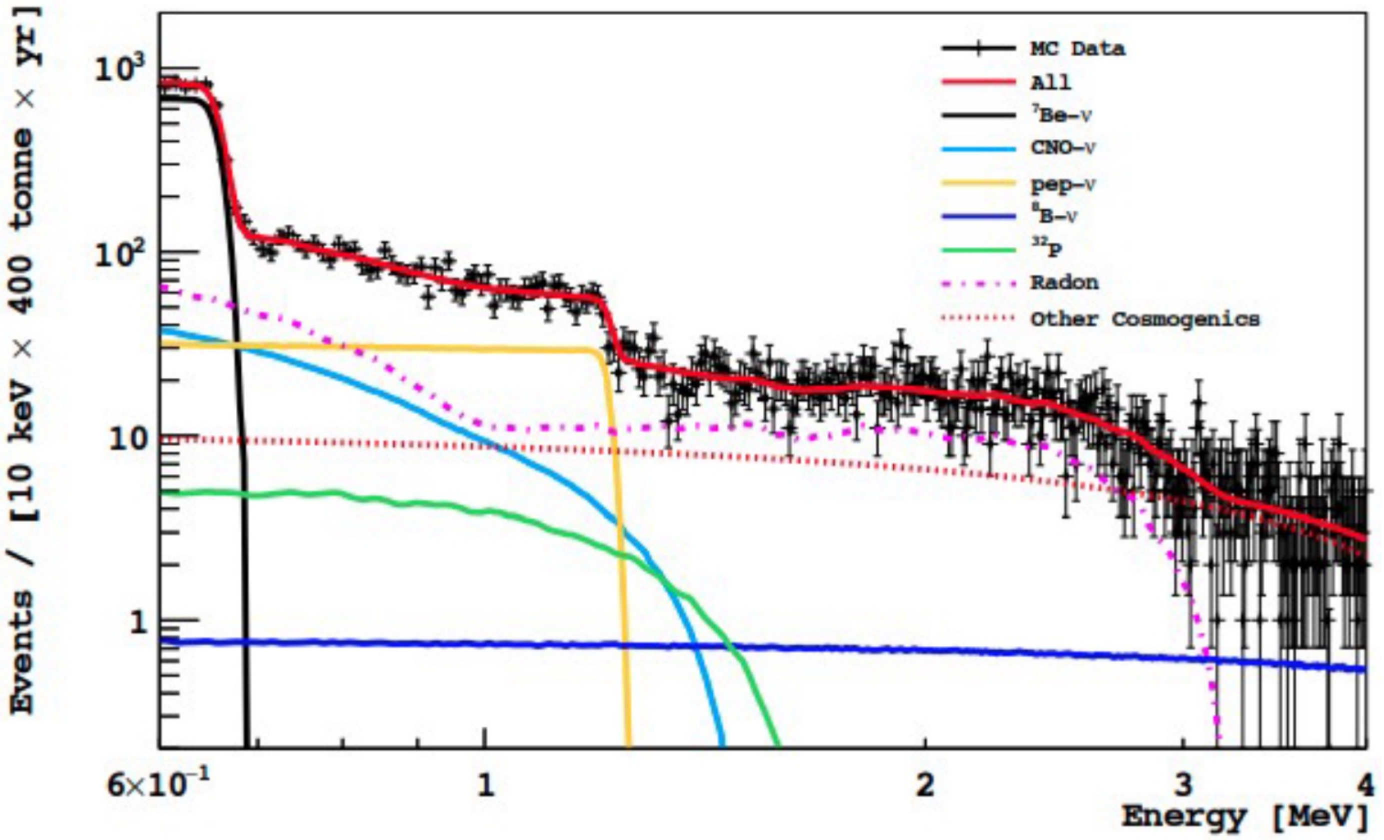


[JCAP03(2021)043]

- Hydrodynamical spherically symmetric simulations by Garching group. Two progenitors are simulated: $11M_\odot$ and $27\ M_\odot$ (here shown) at 10kpc.
- Core Collapse Supernova phases:
  1. **neutronization burst** (~30ms): neutronization burst dominated by neutrinos, not accessible via IBD.
  2. **accretion phase** (~0.02-1s),
  3. **cooling** (~1-10s).

What can we learn from SN ν?

- A low-background LAr detector with a 400 tonne year exposure can also:
- 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 $^{7}Be(p,\gamma)^{8}B$ 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

Dual-phase Ar TPC optimized for light DM

- **Dark matter lighter than 10 GeV/c²** encompasses a promising range of candidates.
- **DarkSide-LowMass**: optimized for a low-threshold electron-counting measurement
- Sensitivity to light Dm is explored for various energy thresholds and background rates.
- DarkSide-LowMass can achieve sensitivity to light DM down to the solar neutrino floor for GeV-scale masses and significant sensitivity down to 10 MeV/c² considering the Migdal effect or interactions with electrons

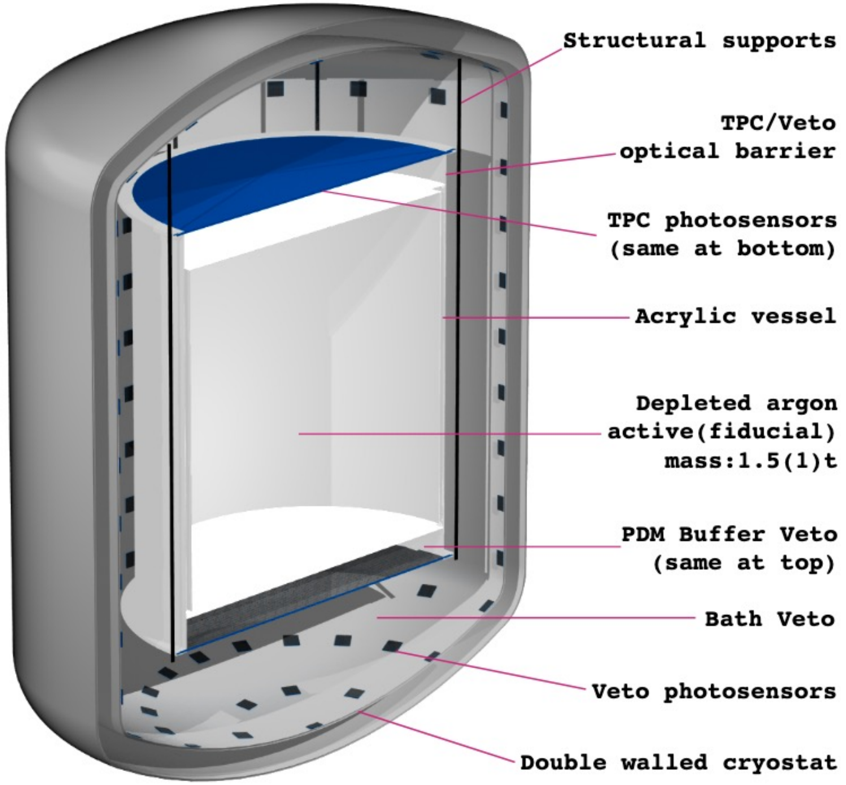


FIG. 1. Conceptual detector design: a 1.5 t dual-phase LAr TPC in an acrylic vessel, viewed by two photosensor arrays via 10 cm "buffer vetoes", in a UAr "bath veto" in a cryostat, immersed in a water tank (not shown).

NEW

arXiv: 2209.01177

Dual-phase Ar TPC optimized for light DM

NEW

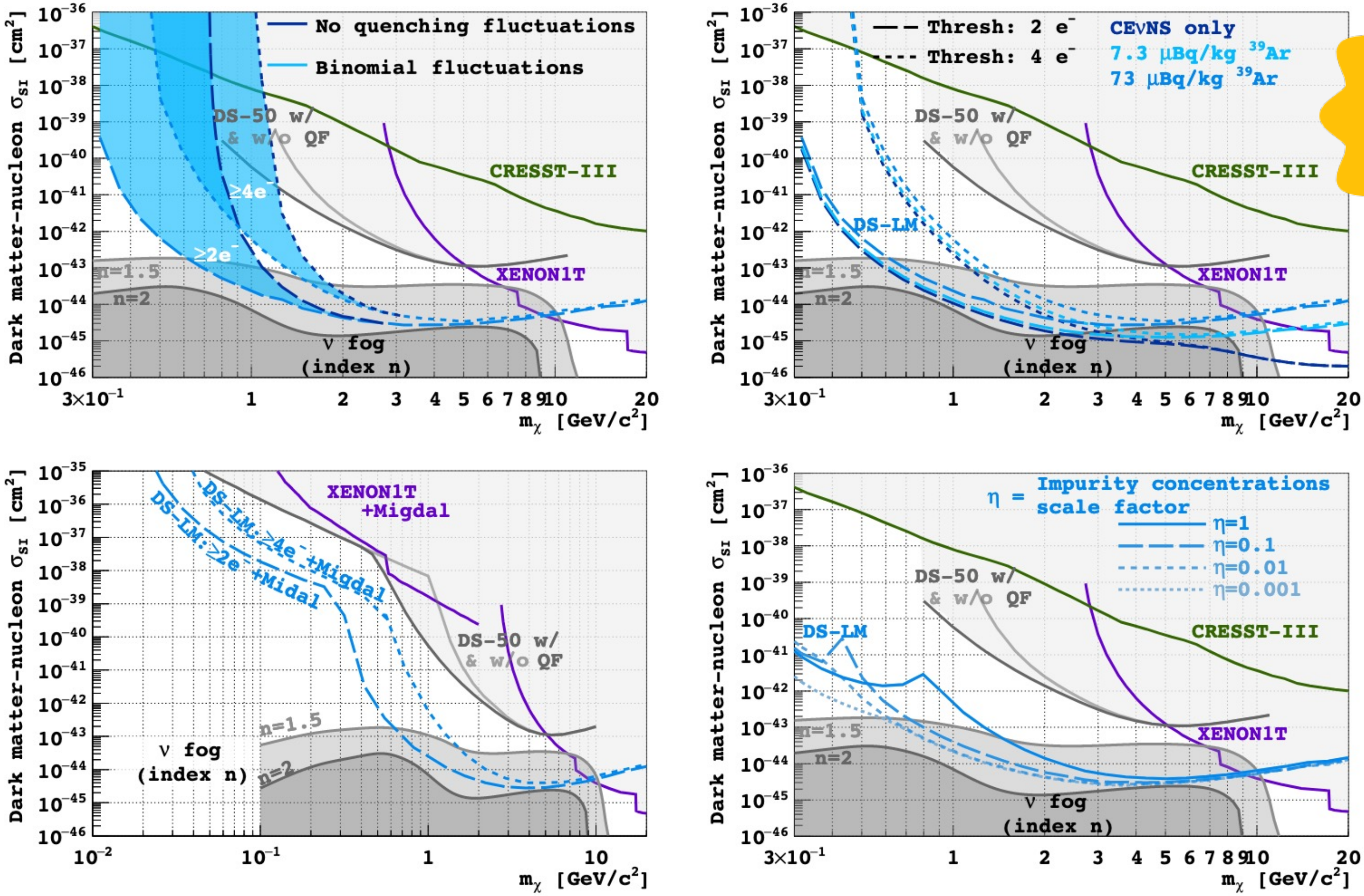


FIG. 9. Projected 90% C.L. upper limits on the spin-independent DM-nucleon scattering cross section for 1 t yr exposure: *(Top, left)* with and without binomial quenching fluctuations. *(Top, right)* with varying thresholds and background rates. *(Bottom, left)* including the Migdal effect. *(Bottom, right)* attempting to model and fit SE backgrounds (see Eq. (5)) at varying impurity concentrations relative to DarkSide-50, η. Unless otherwise stated, projections assume binomial quenching fluctuations and an ^{39}Ar activity of 73 µBq/kg. The neutrino fog in LAr with index n representing the resulting impediment to a 3σ DM observation is shown in shades of gray, calculated to m_χ=100 MeV/c^2 [13]. Current limits are shown from CRESST-III [84], DarkSide-50 [20, 21], and XENON1T [16, 85].

arXiv: 2209.01177