Light dark matter search with DarkSide-50

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GdR DUPhy - 19-21/10/2022

DarkSide-50

The Dual-Phase TPC

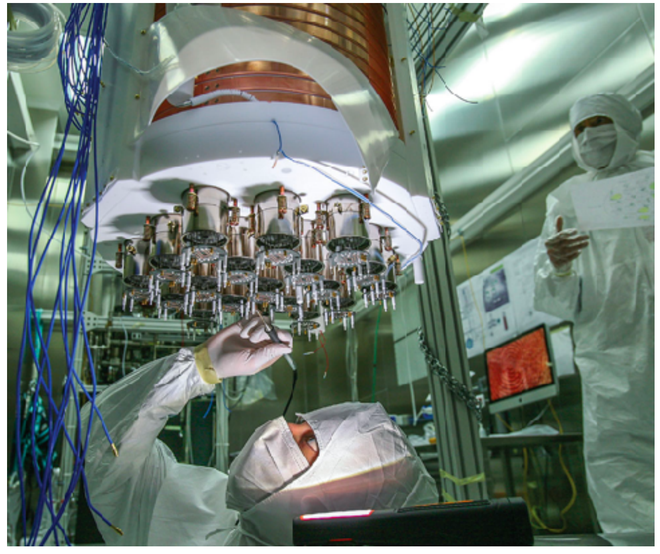
- 50 kg active mass of UAr
- 19 top + 19 bottom R11065 HQE 3” PMTs
- 36 cm height, 36 cm diameter
- Low field of 0.2 kV/cm drift

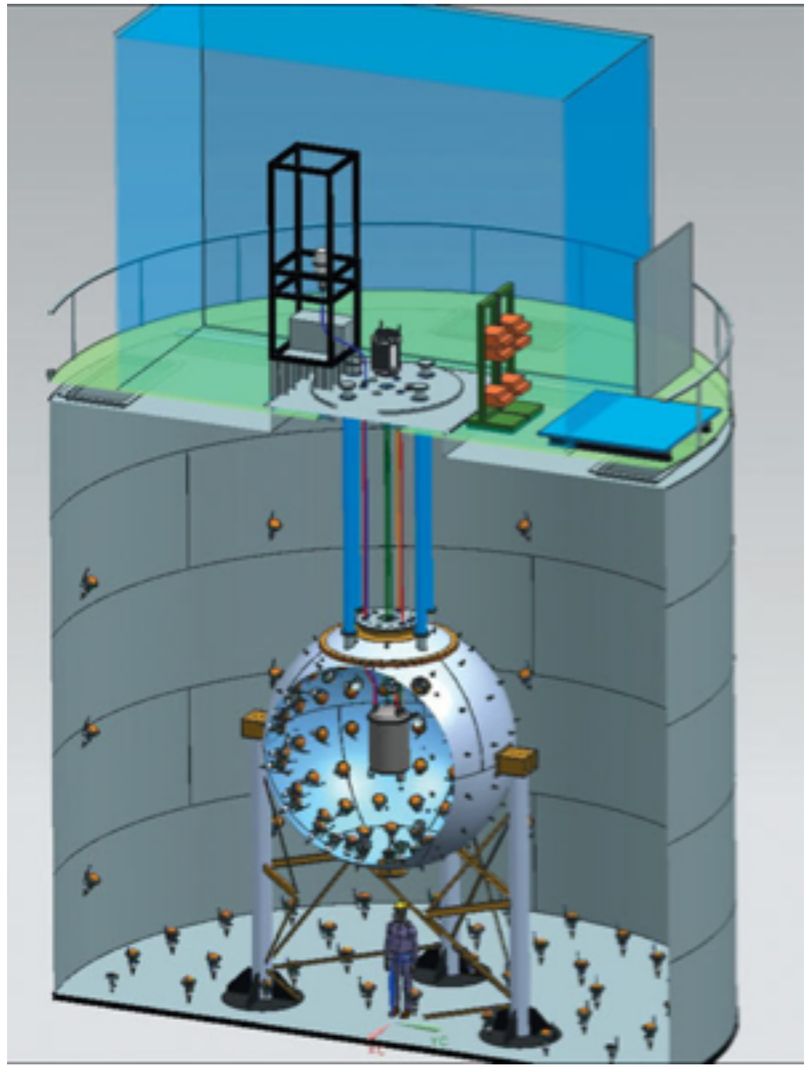
Liquid Scintillator Veto against neutrons

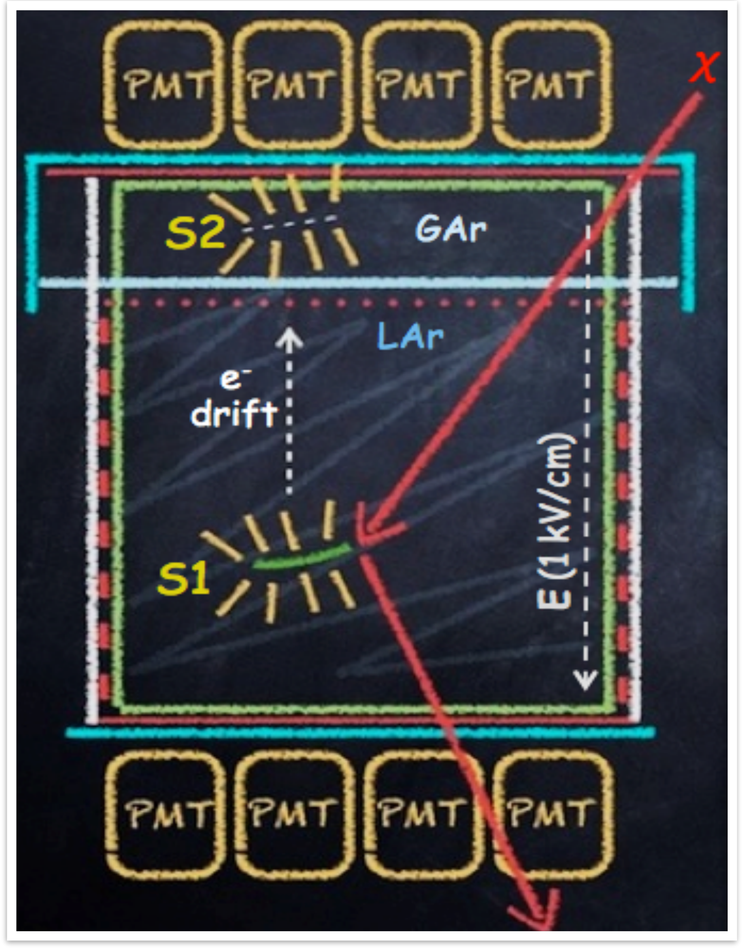
- 4 m diameter sphere
- Boron-loaded: 1:1 PC and TMB
- 110 8” PMTs
- LY ~ 500 pe/MeV

Cherenkov Water Detector

- 11 m diam. x 10 m
- 80 PMTs

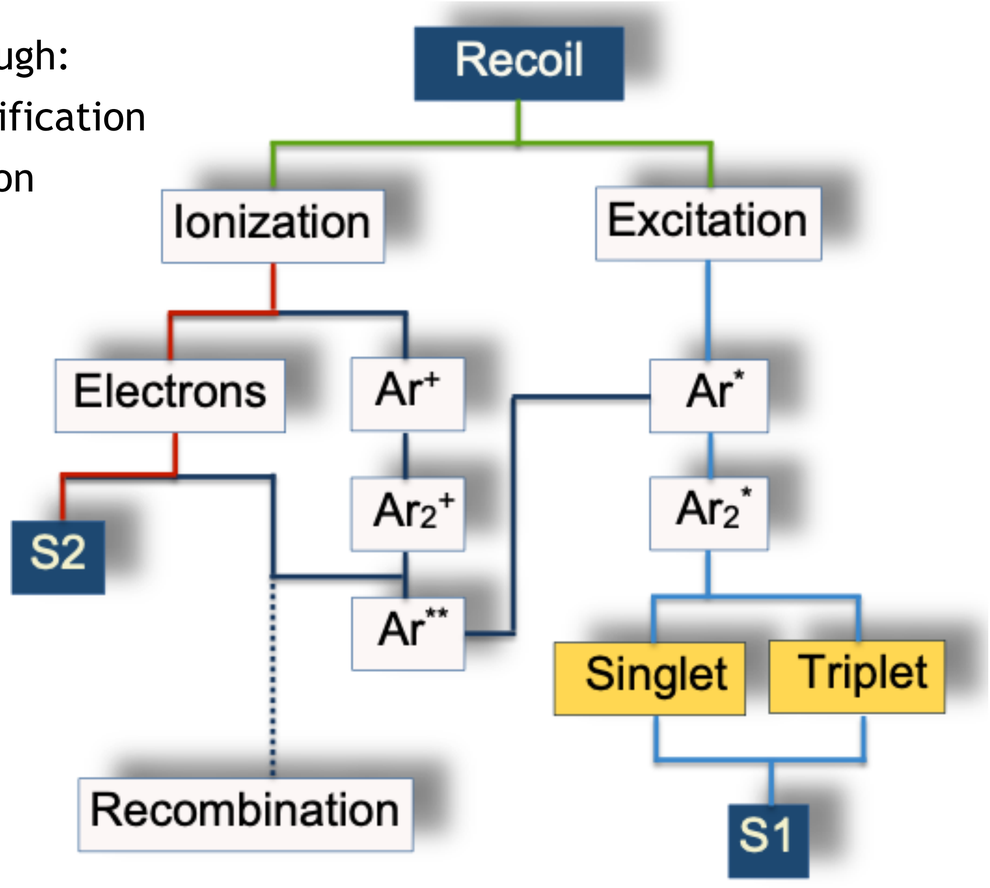






Particle discrimination through:

- Accurate 3D **position** identification
- **Multiple**-scattering rejection
- **S2/S1** ratio
- S1 **PSD** (if available)



The DS-50 high-mass search

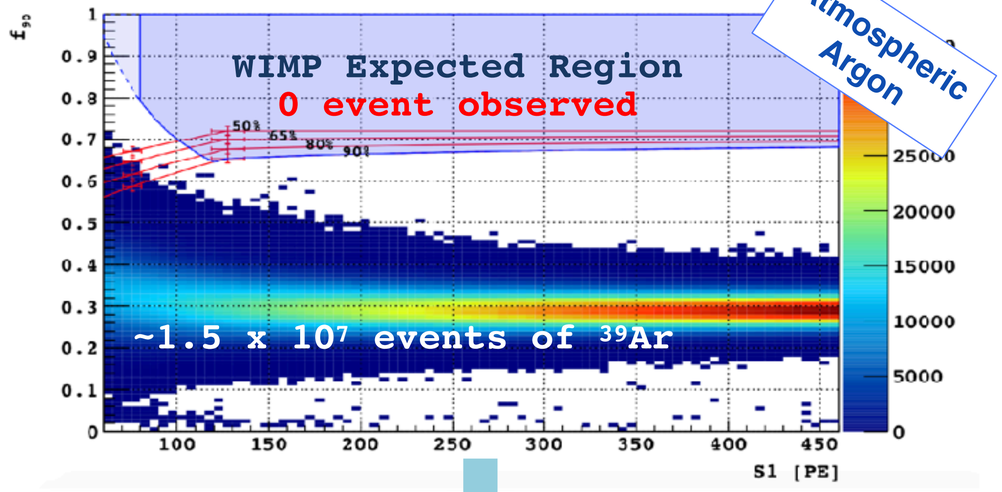
LAr scintillation times:

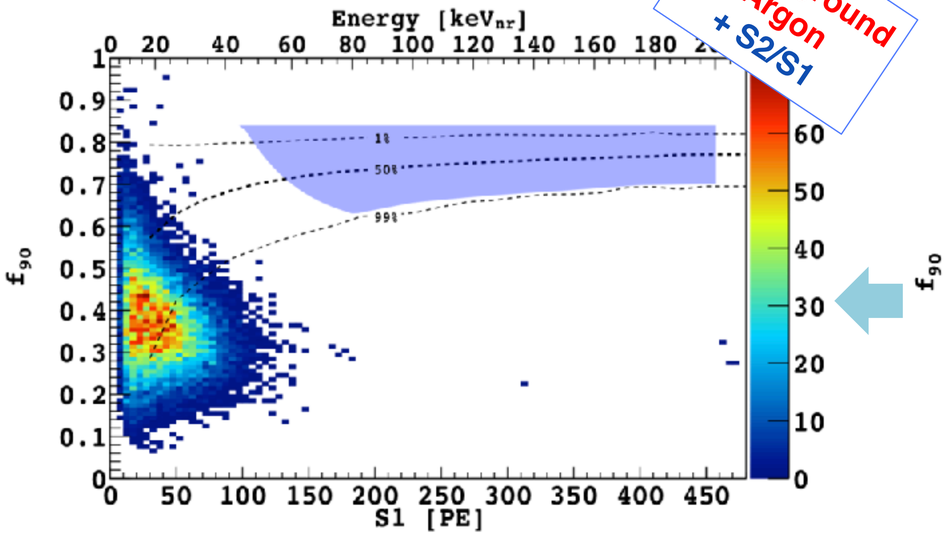
- singlet ~ 6 ns
- Triplet ~ 1600 ns

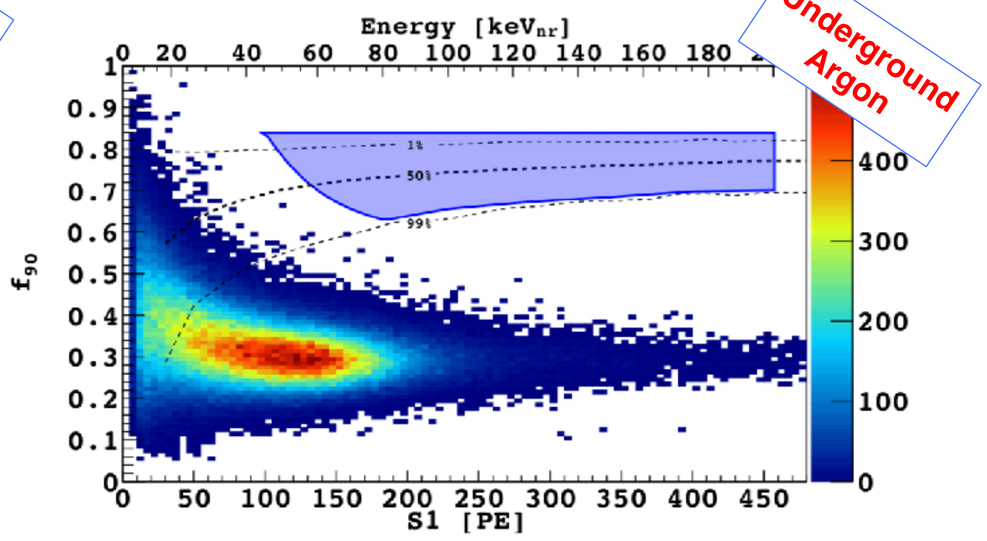
Singlet-to-triplet ratios:

- Nuclear recoils ~ 0.7
- Electron recoils ~ 0.3

Very distinctive (and unique) signatures to separate electron recoils from nuclear recoils





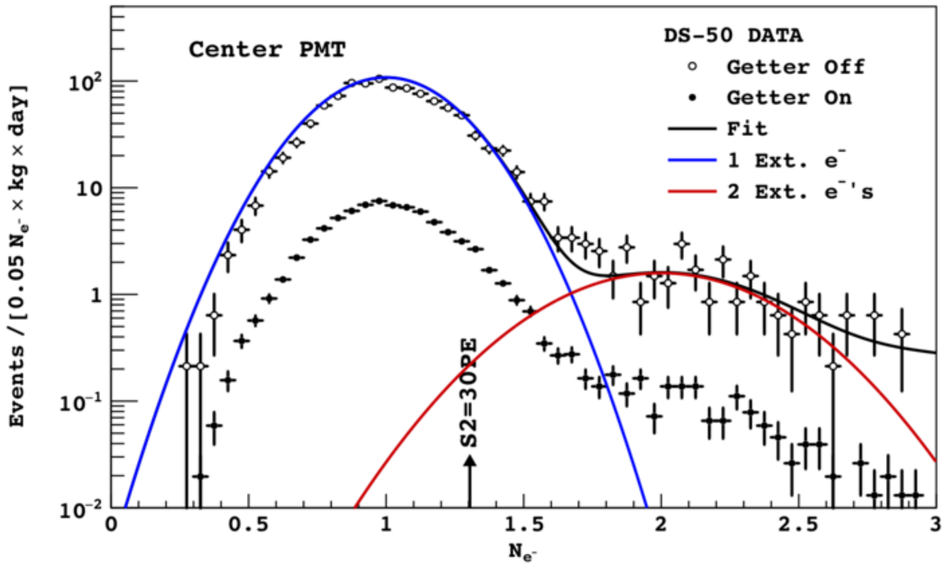


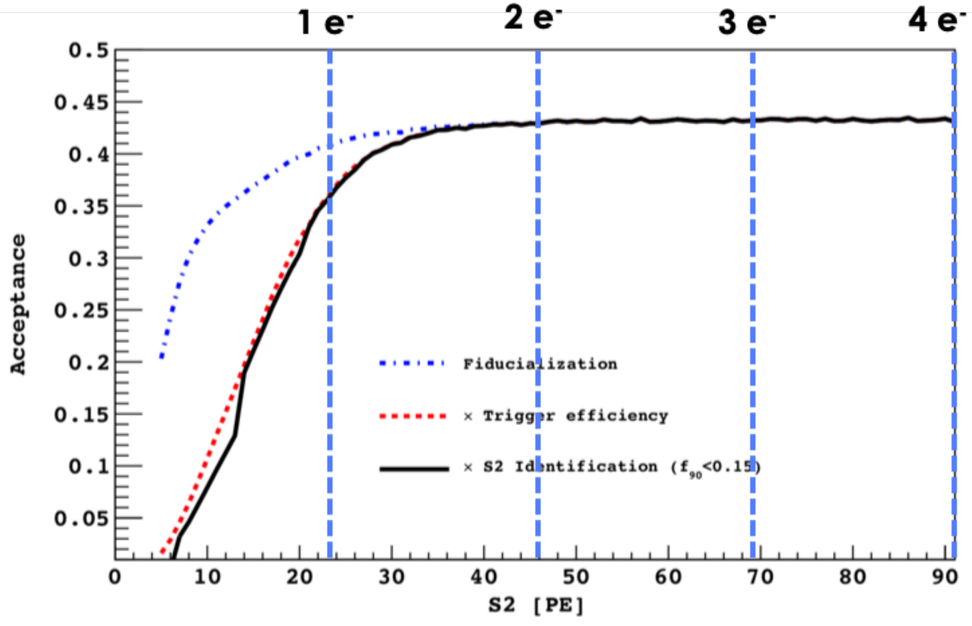
Background-free over more than 530 days!

Lowering the threshold

- **S1**
  - Detection efficiency (g1) ~ 16%

- **S2**
  - Efficiency to extract 1 e- in the gas pocket ~ 100%
  - Amplification factor (g2) = ~23 pe / e-





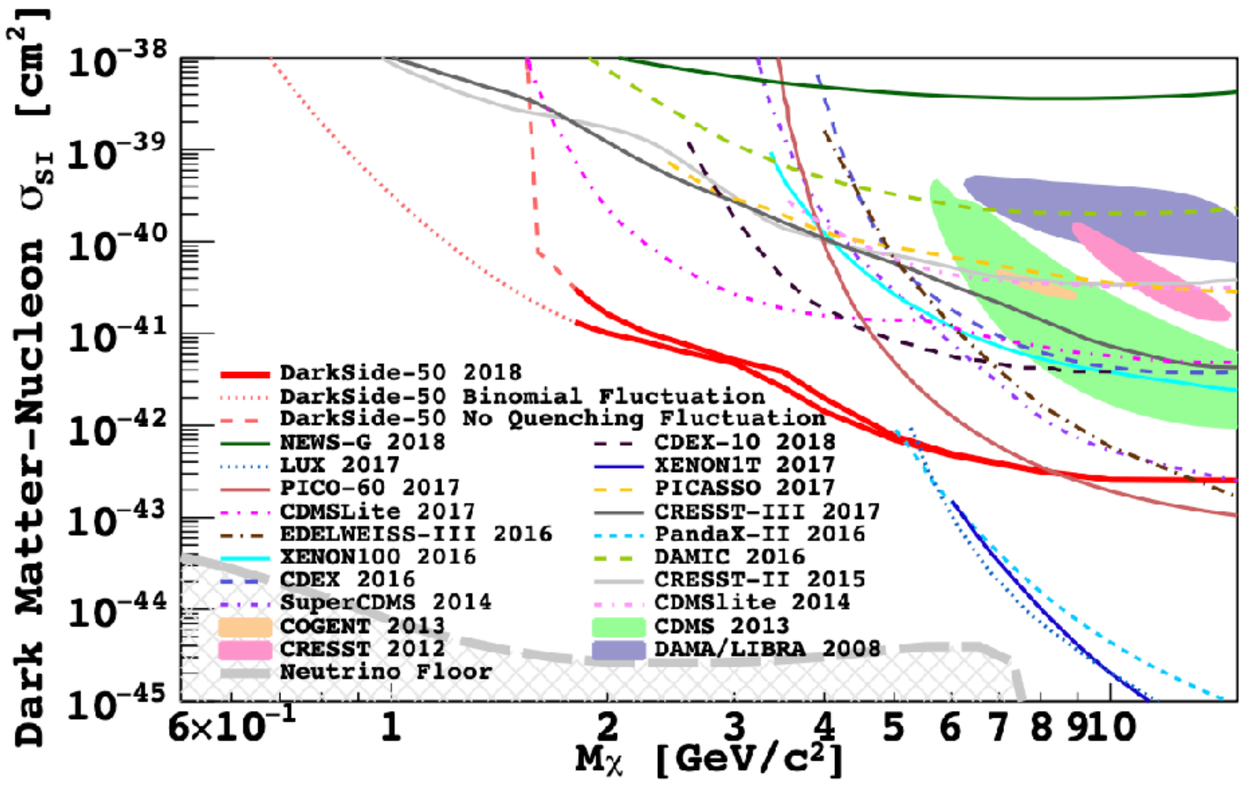
The DS-50 low-mass search in brief

- **2018** First results on light dark matter candidates with liquid argon using the ionization channel:
  - DarkSide-50, Phys. Rev. Lett. 121 (2018) 081307
  - DarkSide-50, Phys. Rev. Lett. 121, 111303 (2018)

- **2019** End of the DarkSide-50 data taking

- **2021** Measurement of the LAr ionization response down to the sub-keV with DarkSide-50
  - DarkSide-50, Phys.Rev.D 104 (2021) 8, 082005

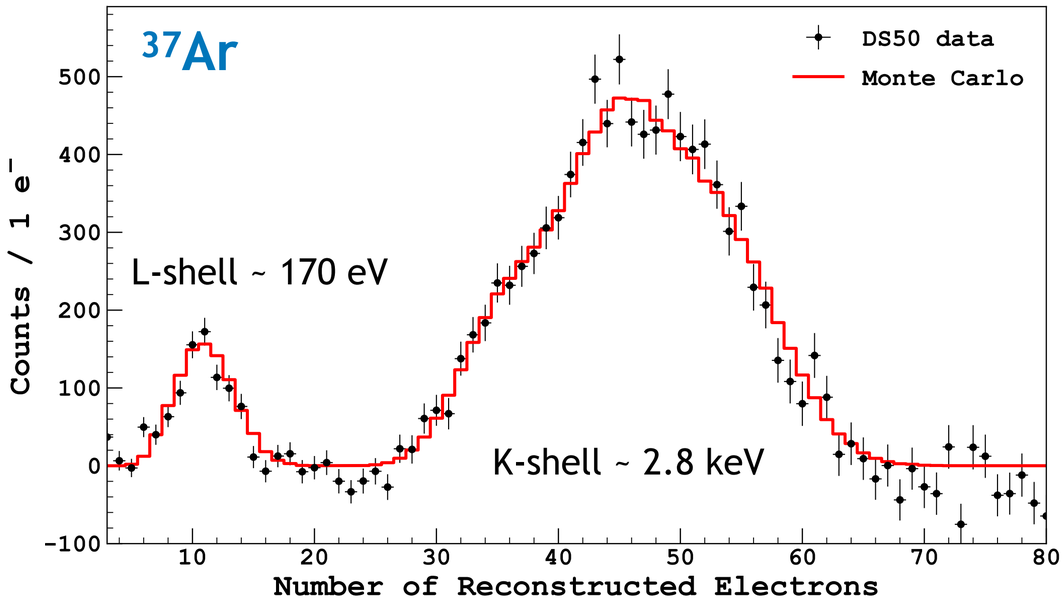
- **2022** Re-analysis of the DarkSide-50 dataset
  - DarkSide-50, arxiv:2207.11966 (2022)
  - DarkSide-50, arxiv:2207.11967 (2022)
  - DarkSide-50, arxiv:2207.11968 (2022)

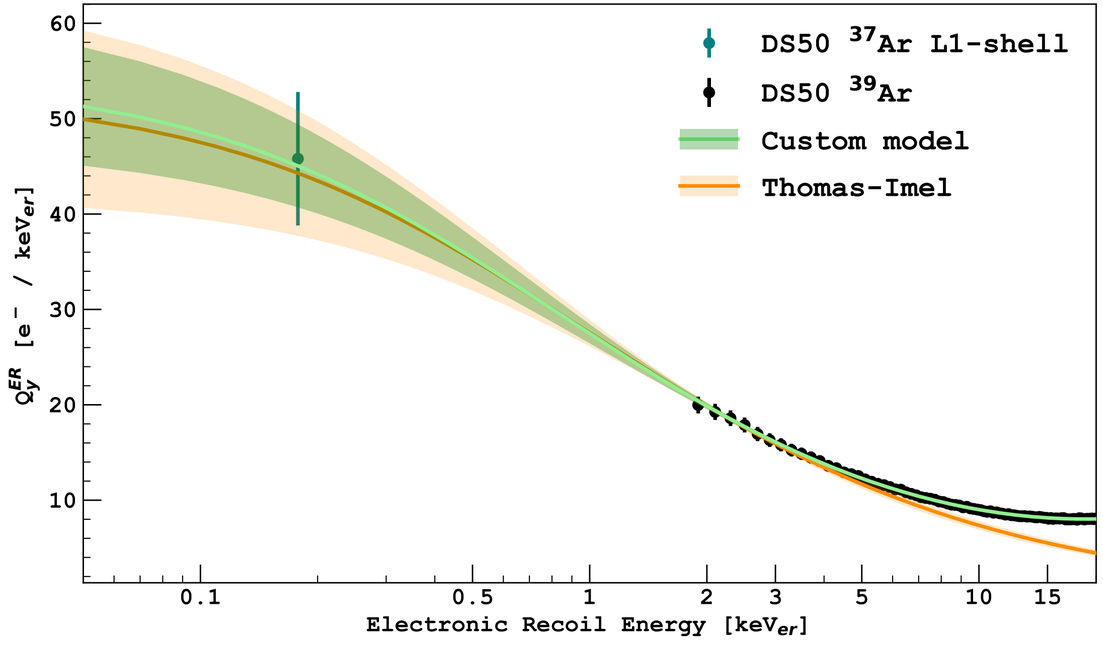


Low-energy ionization response: ER

Thomas-Imel + extended custom model

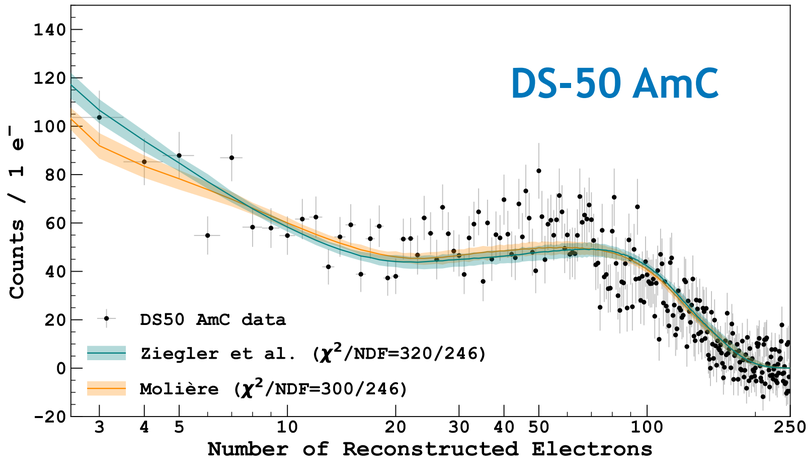
$$Q_y^{ER} = \left(\frac{1}{\gamma} + p_0 \left(E_{er}/\mathrm{keV}_{er} \right)^{p_1} \right) \frac{\ln(1+\gamma\,\rho\,E_{er})}{E_{er}}$$

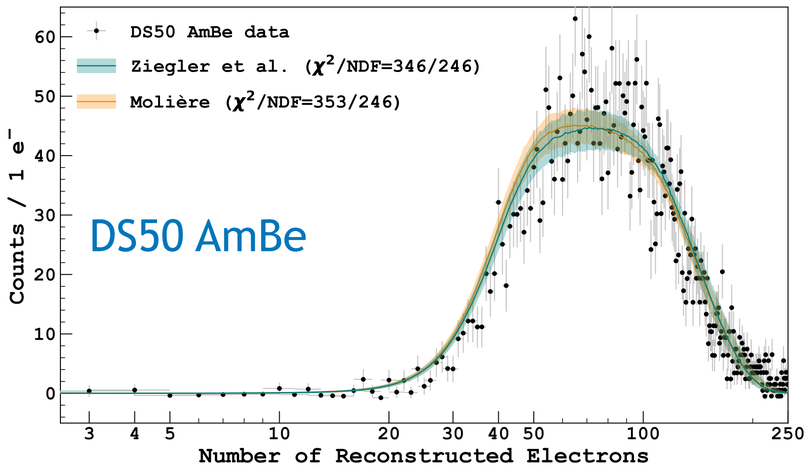


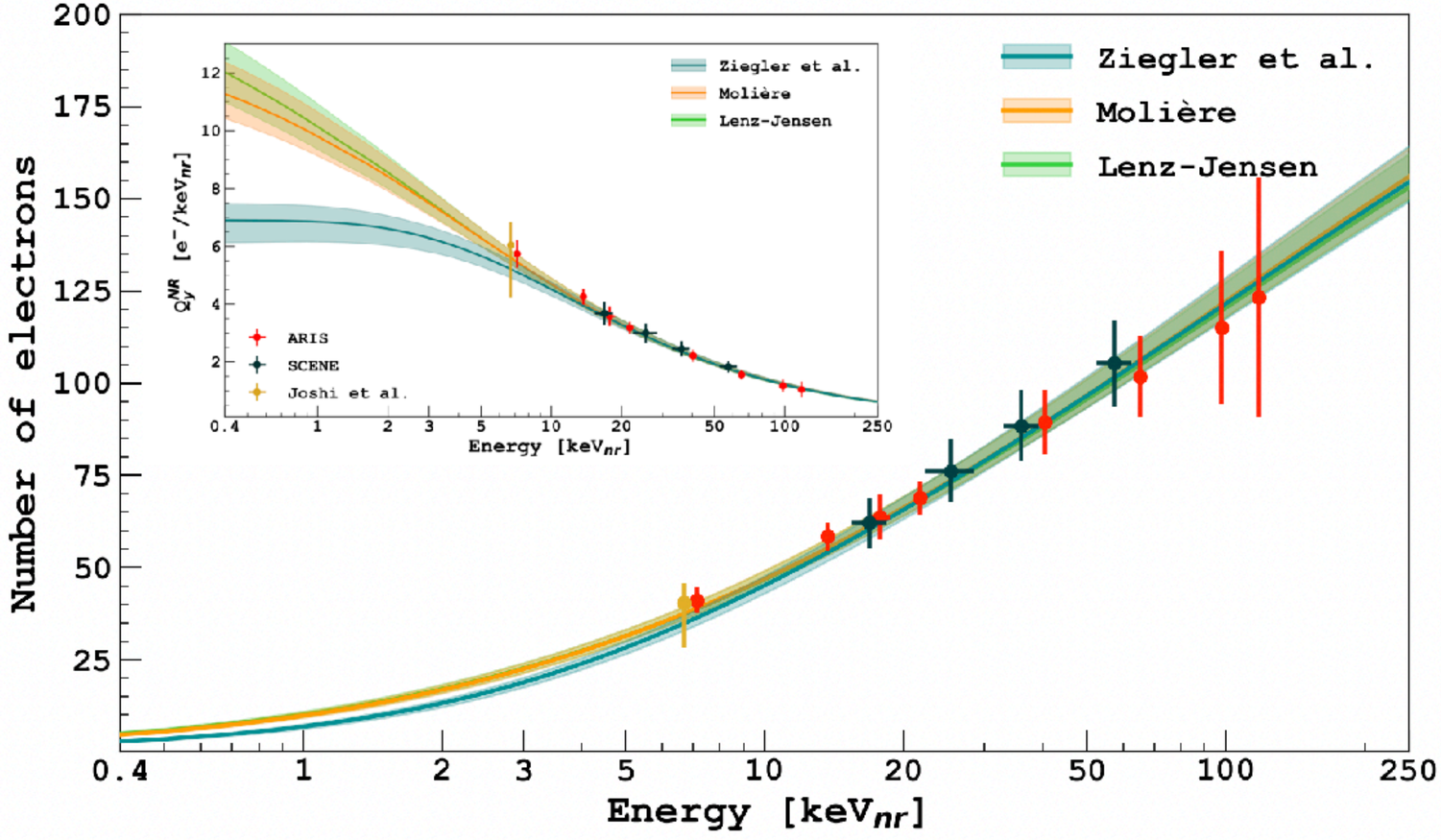


Low-energy ionization response: NR

Global fit to **DS-50 calibration data** with neutrons sources + **external datasets** (ARIS and SCENE)







Ziegler's screening function as baseline in the analysis

Dataset and data selection

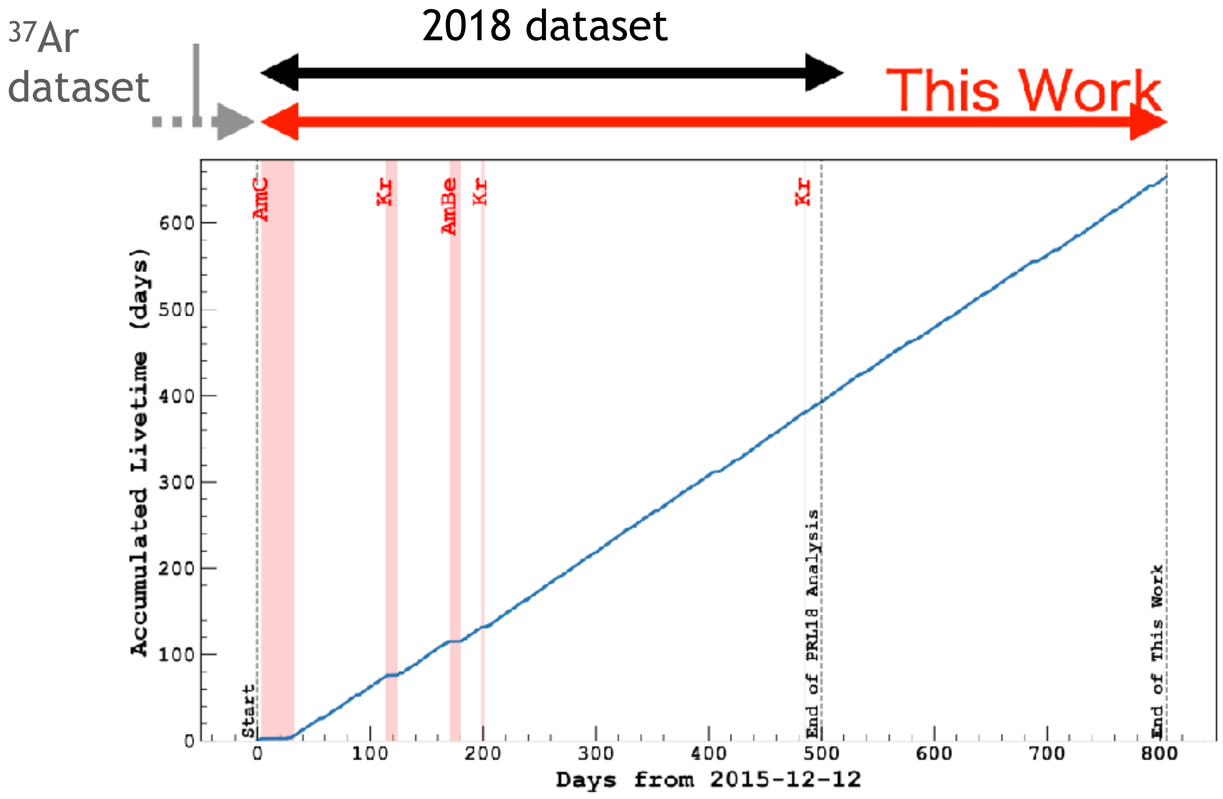
Exposure

- 650 live-days / 12 ton-day
- x 1.8 exposure used in 2018

Data Selection

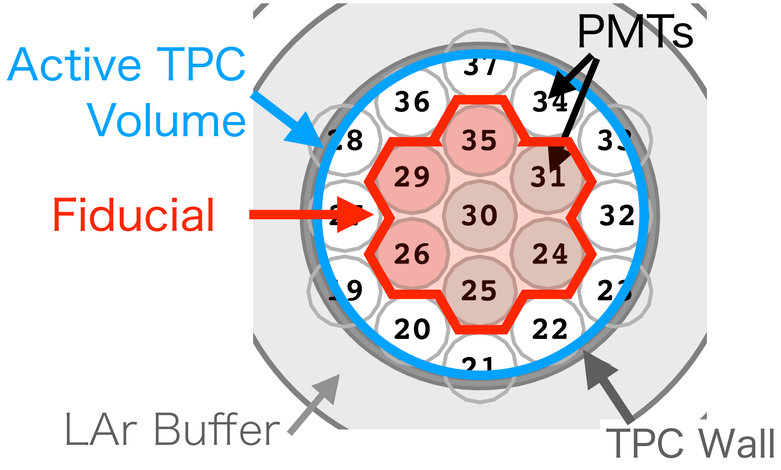
- Quality cuts
  - Pulse-shape: remove anomalous pulses due to the pile-up of multiple S2's or S1+S2
  - Acceptance: 95% at 4 Ne and 99% at >15 Ne

- Selection cuts
  - Fiducialization against external bg
  - S2/S1 against S2's from alphas on the walls
  - Time veto agains spurious (or "single") electrons



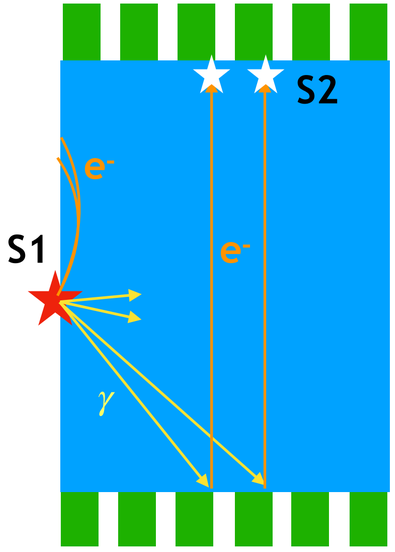
Data Selection

Fiducialization



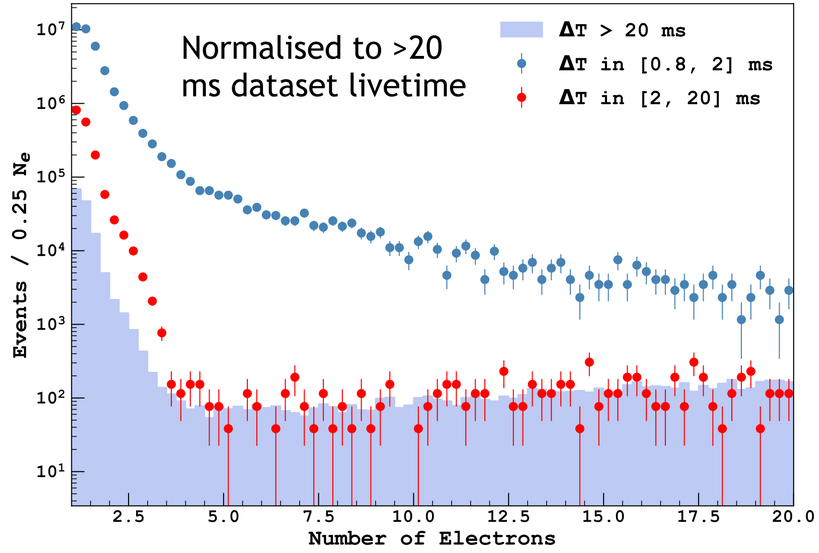
- Select events with max fraction of pes in one of the 7 central top PMTs
- Acceptance ~ 41%

Alpha-induced S2 pulses



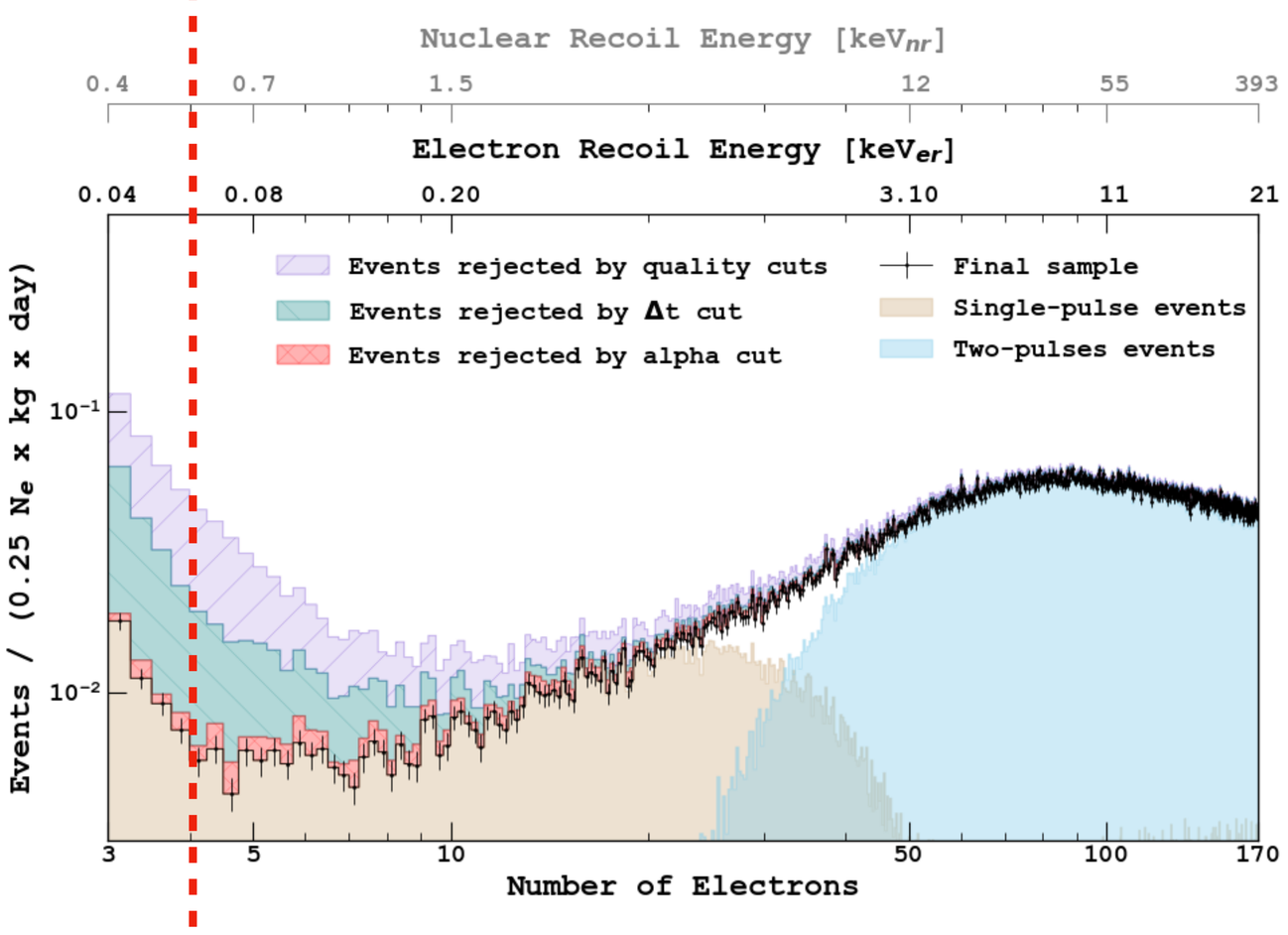
- Reject events with “anomalous” S2/S1
- Cut tuned on calibration data
- Acceptance ~ 99%

Spurious Electrons



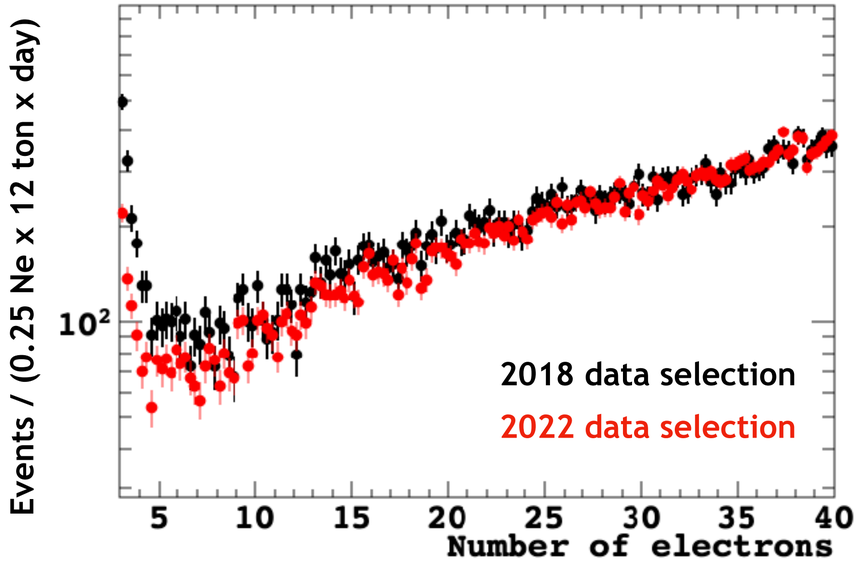
- Reject correlated events (if within 20 ms from the previous one)
- Acceptance ~ 97%

Data Selection



Analysis threshold

- Overall acceptance almost flat: 38.2% at 4 e^- and 40.2% at ≥15 e^-
- Low-Ne region more depleted than in 2018



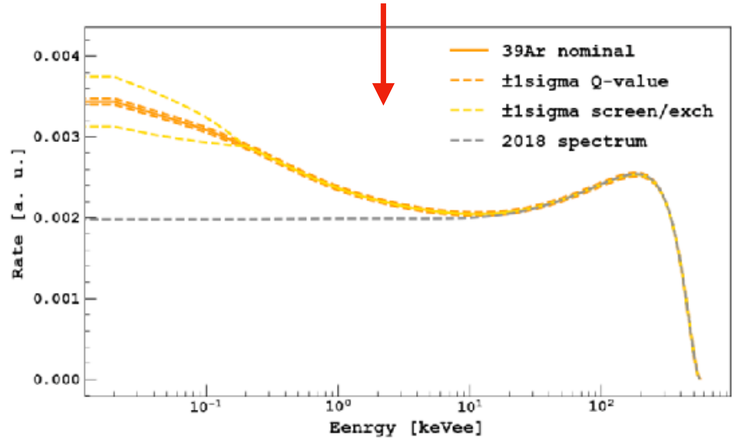
Background model: ^{39}Ar and ^{85}Kr

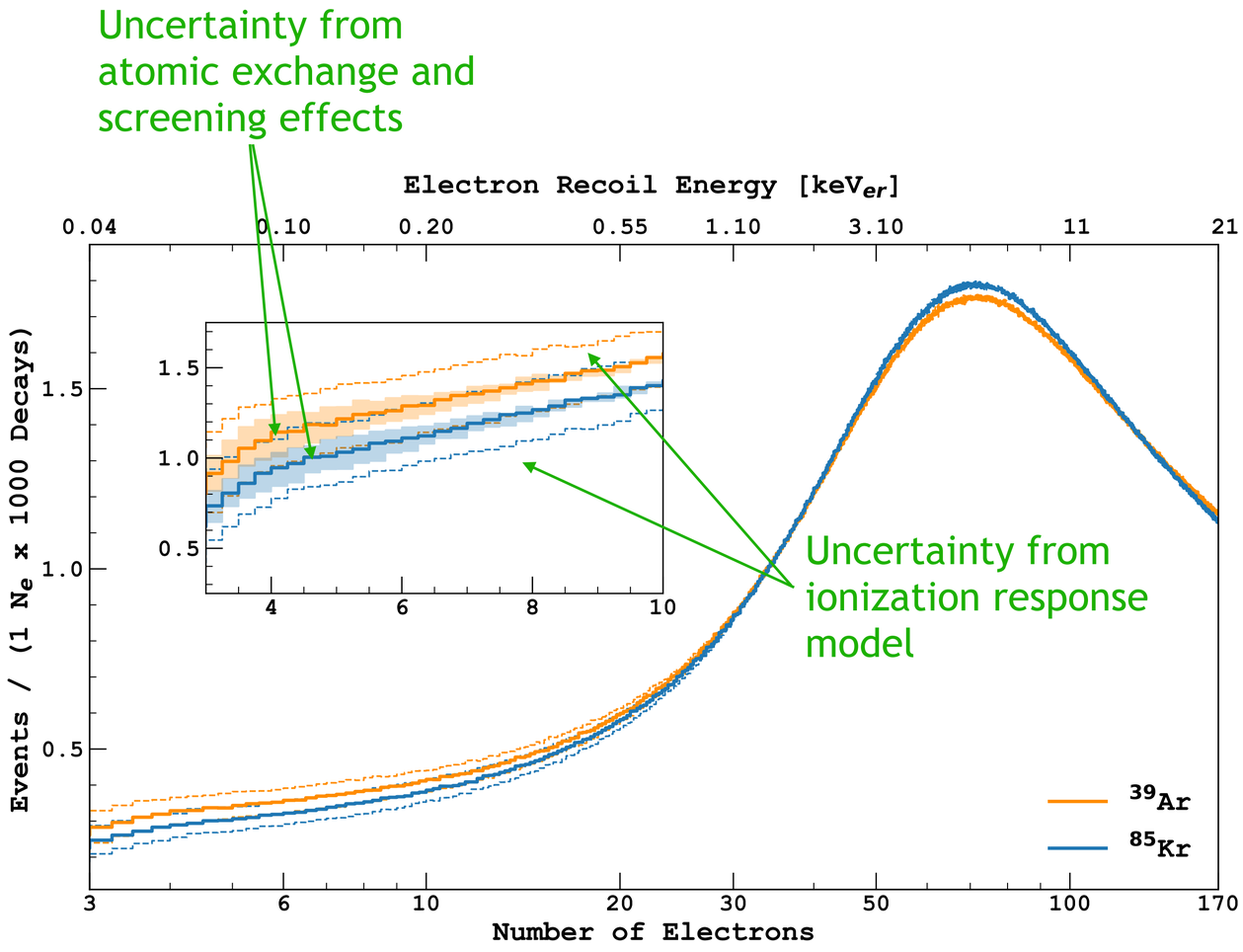
- Both ^{39}Ar and ^{85}Kr **uniformly distributed** in the LAr bulk

- ^{39}Ar activity: **0.7 ± 0.1 mBq/kg**
  - from high energy spectral fit

- ^{85}Kr activity: **1.8 ± 0.1 mBq/kg**
  - from high energy spectral fit
  - from fast coincidence through metastable state
  - from decay time fit

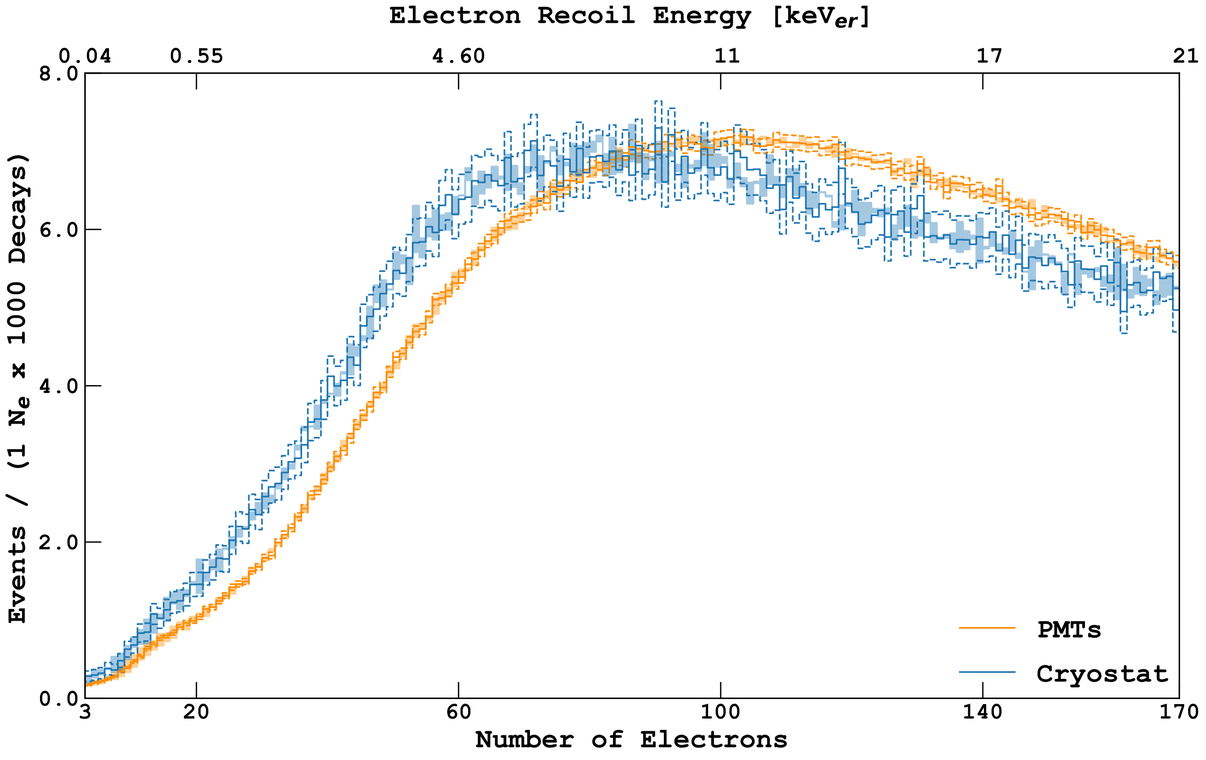
- Both unique first-forbidden beta decays: **additional atomic exchange and screening effects**

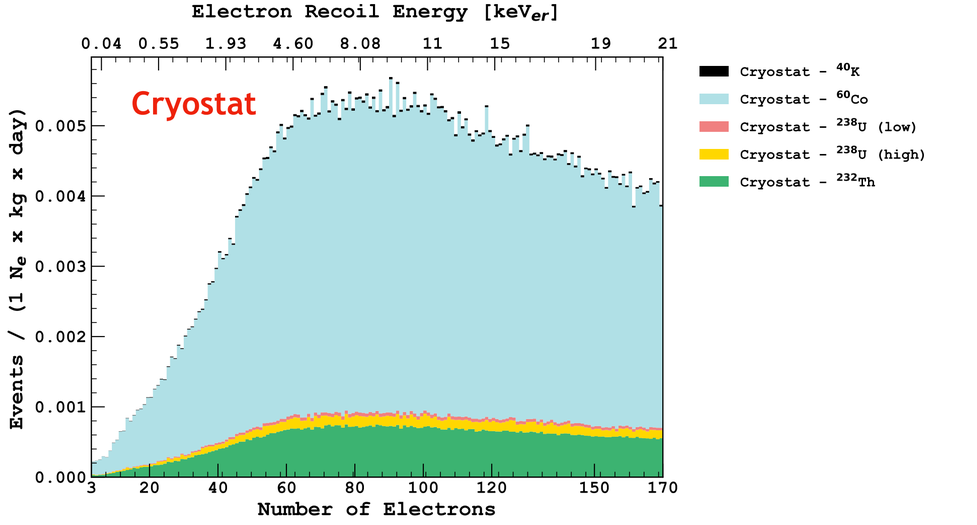


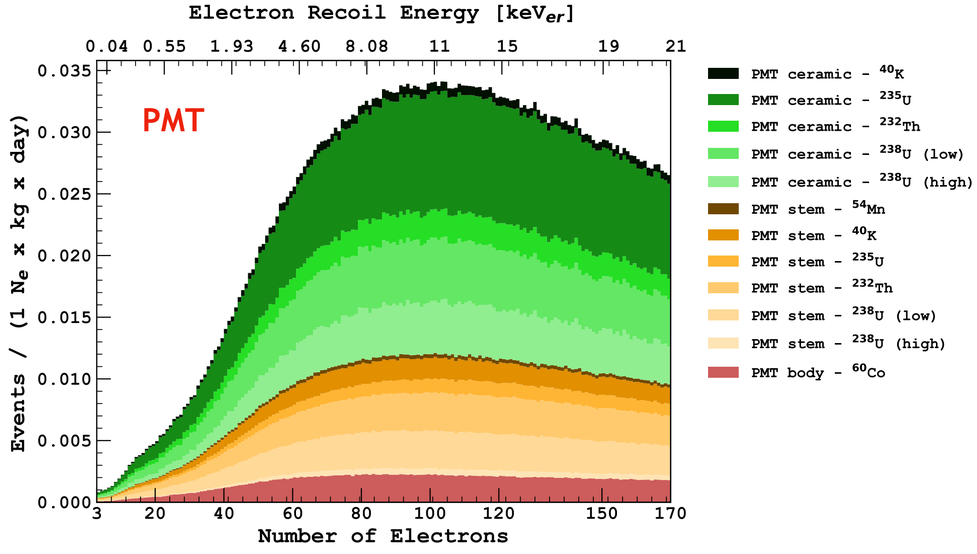


Background model: external

- New background model from material screening campaign
- In 2018 it was extrapolated from the fit of the high energy spectrum







Profile Likelihood and Systematics

$$\mathcal{L} = \prod_{i\,\epsilon\,\text{bins}} \mathcal{P}\left(n_i | m_i(\mu_s, \Theta)\right) \times \prod_{\theta_i\,\epsilon\,\Theta} \mathcal{G}(\theta_i^0 | \theta_i, \Delta\theta_i) \times \prod_{i\,\epsilon\,\text{bins}} \mathcal{G}\left(m_i^0 | m_i(\Theta), \delta m_i(\Theta)\right)$$

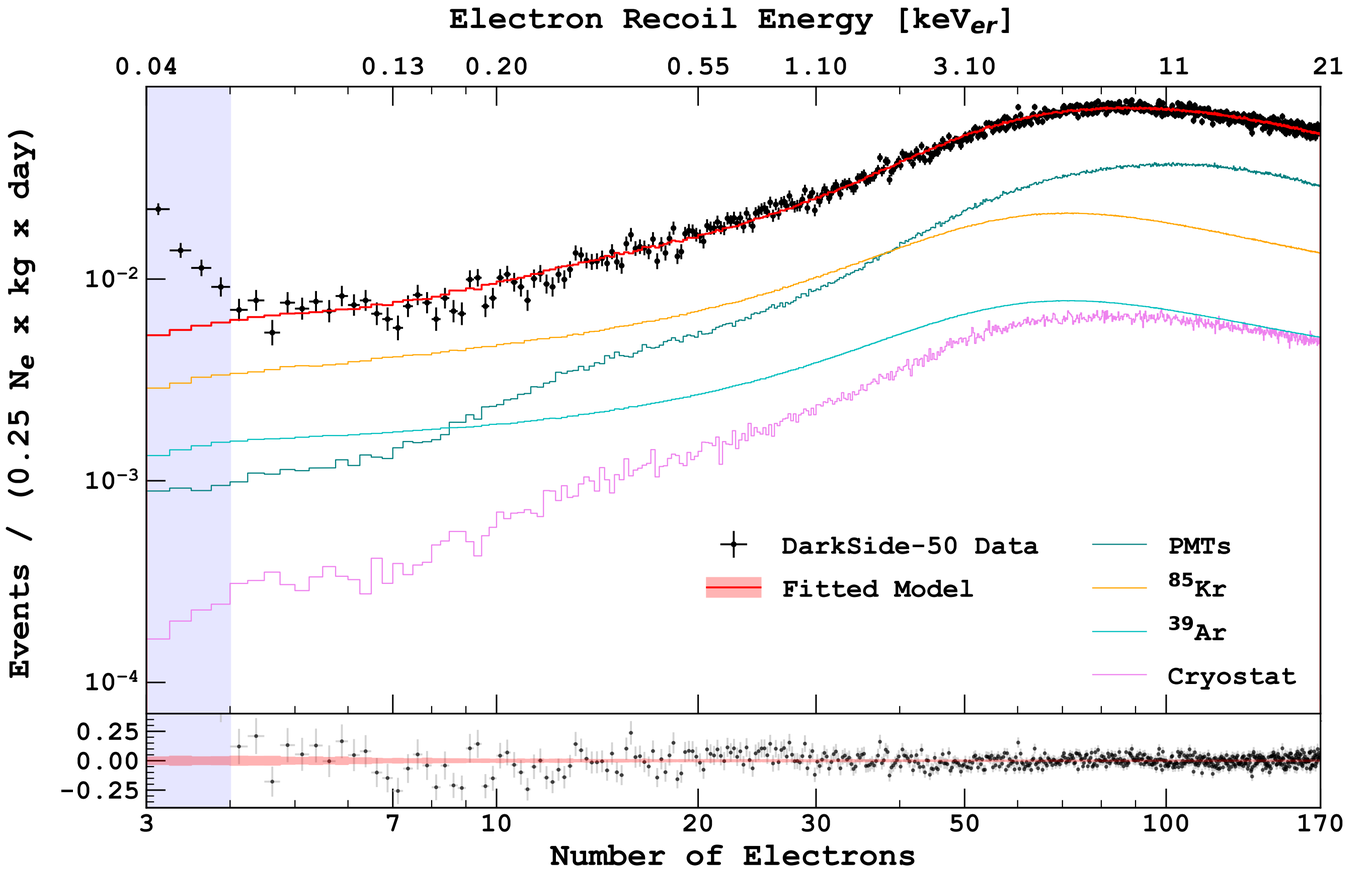
Poisson probability of observing n_i events in the i^{th}-bin with respect to the expected ones, $m_i(\mu_s,\Theta)$, with μ_s the signal strength

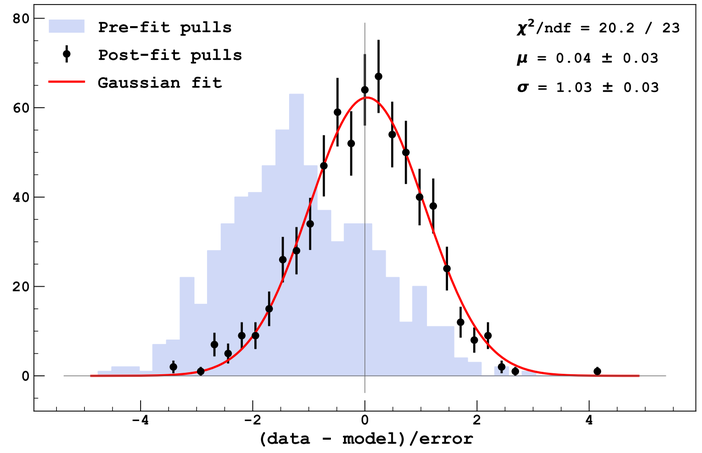
Gaussian penalties to account for the **nuisance parameters** (θ_0 and $\Delta\theta$ are the nominal central values and uncertainties)

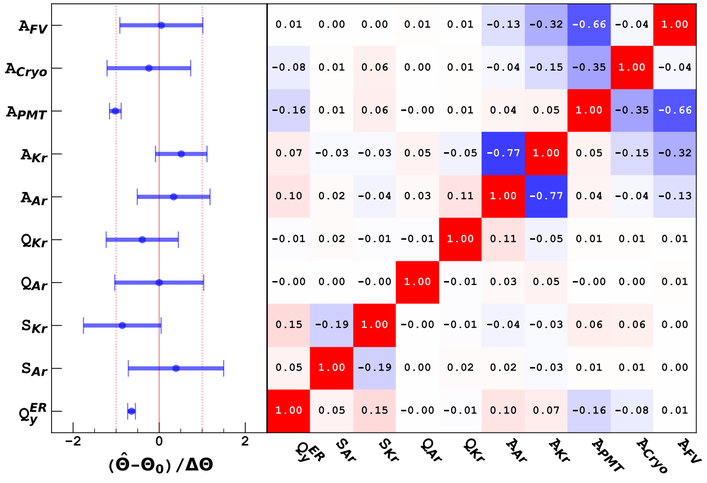
Statistical uncertainties of the **simulated** sample

	Name	Source	Affected components
Amplitude	A_{FV}	uncertainty on the fiducial volume	WIMP, ^{39}Ar, ^{85}Kr, PMTs, Cryostat
	A_{Ar}	14.0% uncertainty on ^{39}Ar activity	^{39}Ar
	A_{Kr}	4.7% uncertainty on ^{85}Kr activity	^{85}Kr
	A_{pmt}	11.5% uncertainty on activity from PMTs	PMT
	A_{cryo}	6.6% uncertainty on activity from the cryostat	Cryostat
Shape	Q_{Kr}	0.4% uncertainty on the ^{85}Kr-decay Q-value	^{85}Kr
	Q_{Ar}	1% uncertainty on the ^{39}Ar-decay Q-value	^{39}Ar
	S_{kr}	spectral shape uncertainty on atomic exchange and screening effects	^{85}Kr
	S_{Ar}	spectral shape uncertainty on atomic exchange and screening effects	^{39}Ar
	Q_y^{er}	spectral shape systematics from ER ionization response uncertainty	^{39}Ar, ^{85}Kr, PMTs, Cryostat
	Q_y^{nr}	spectral shape systematics from NR ionization response uncertainty	WIMP

Background-Only Fit

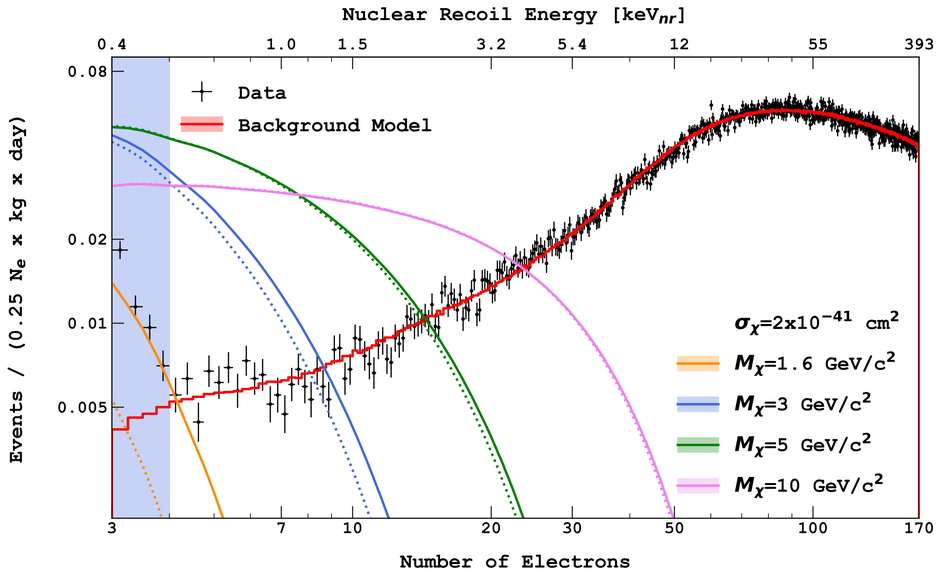


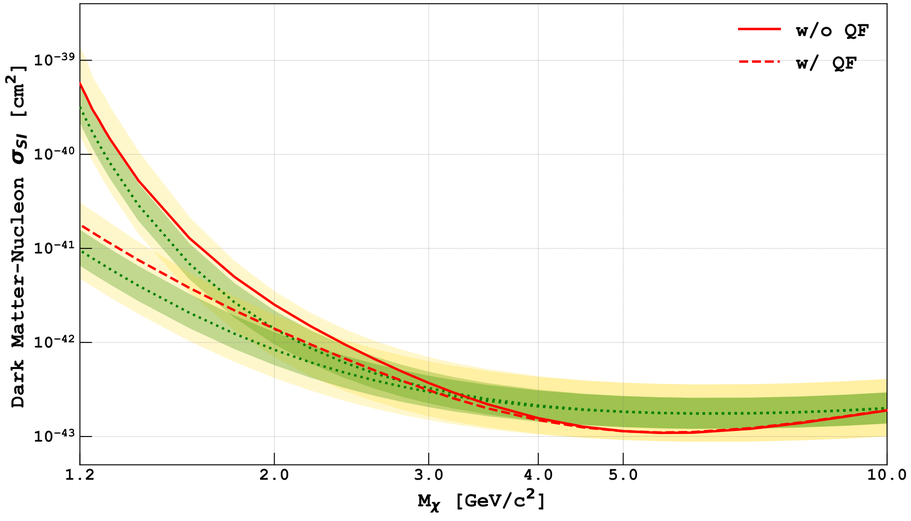




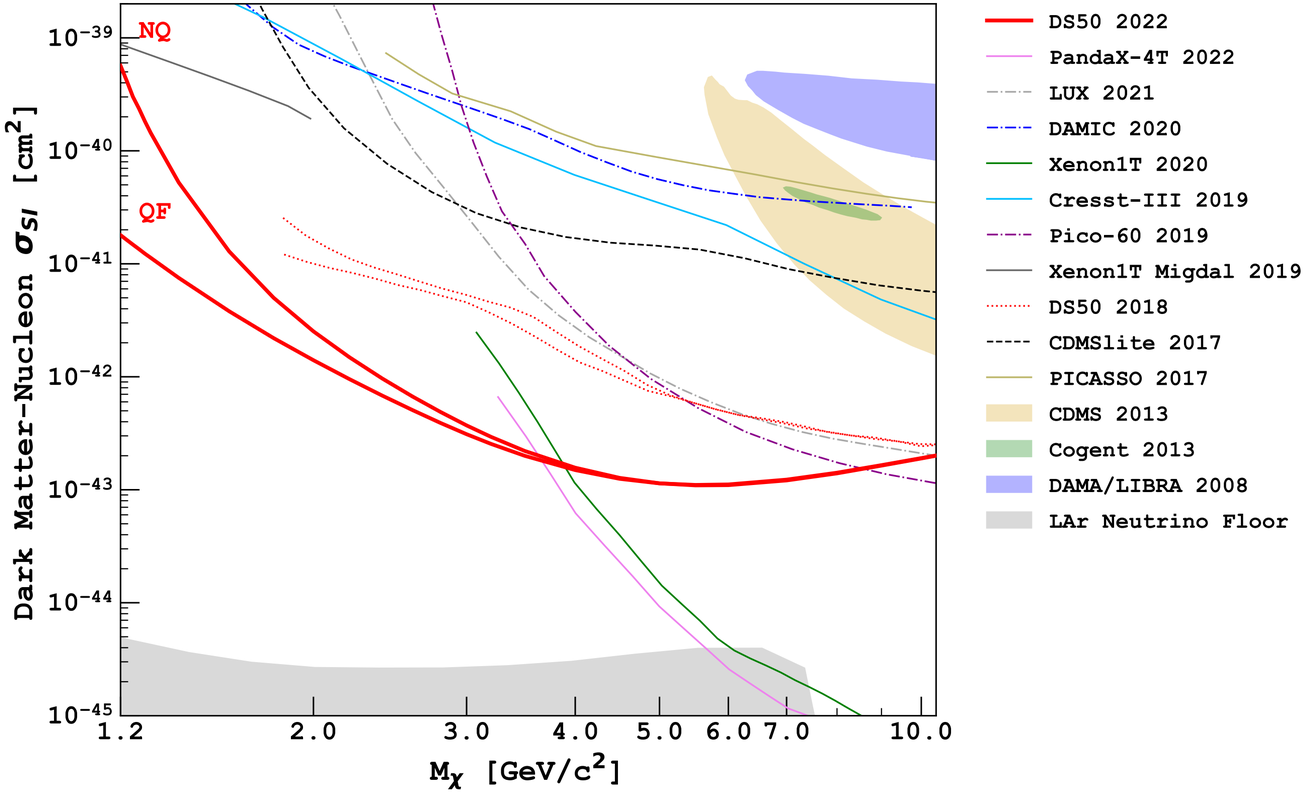
Tritium activity <1 μBq/kg (90% CL)

WIMP-nucleon interactions

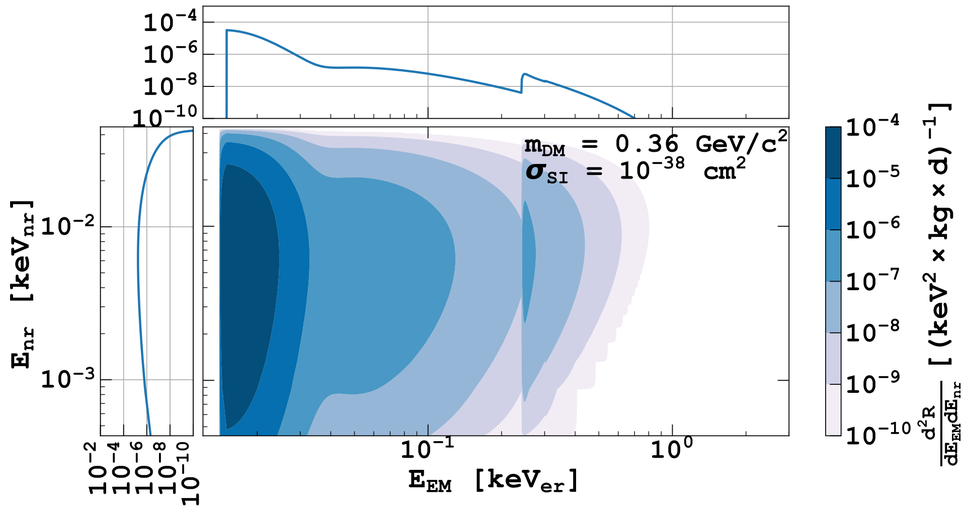


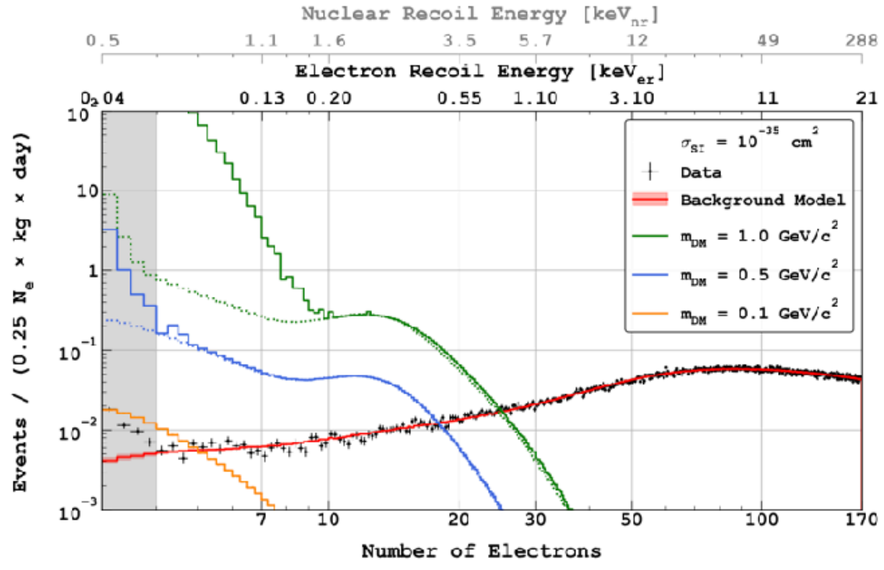


arxiv:2207.11966

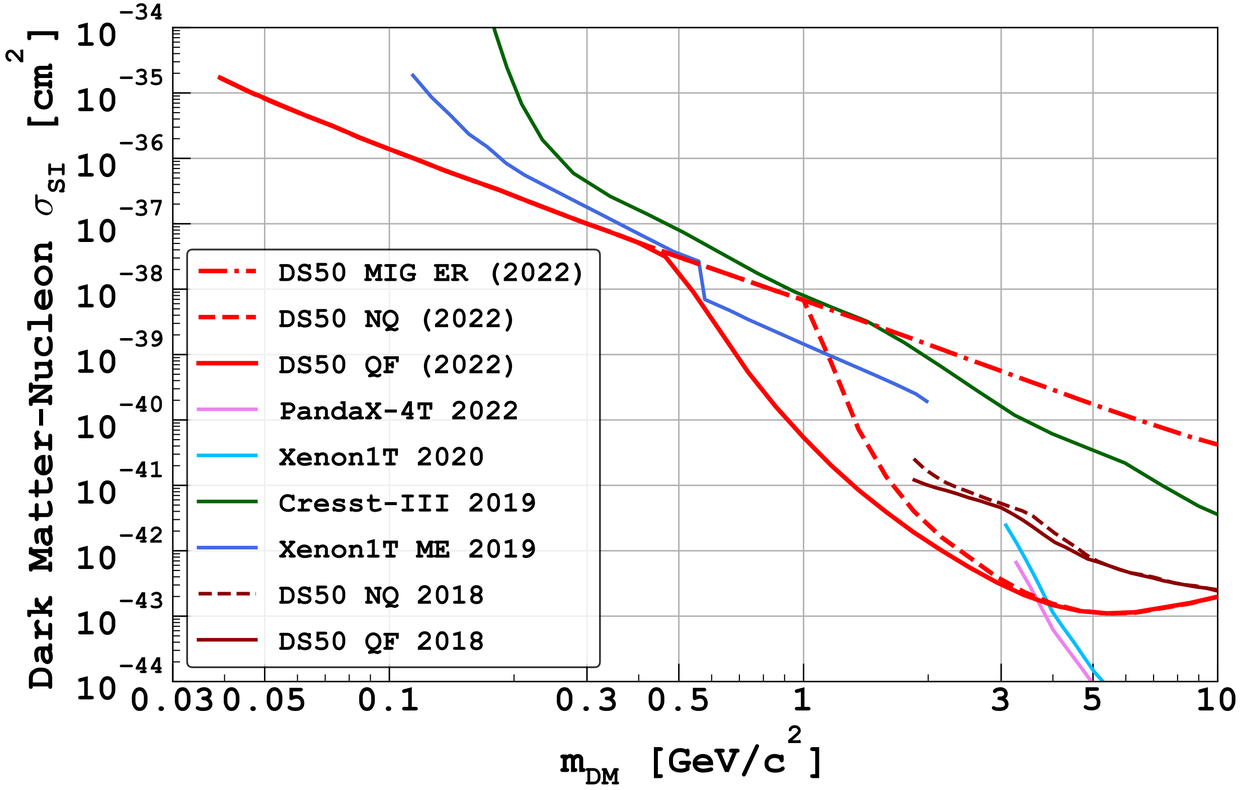


WIMP-nucleon interactions + Migdal effect



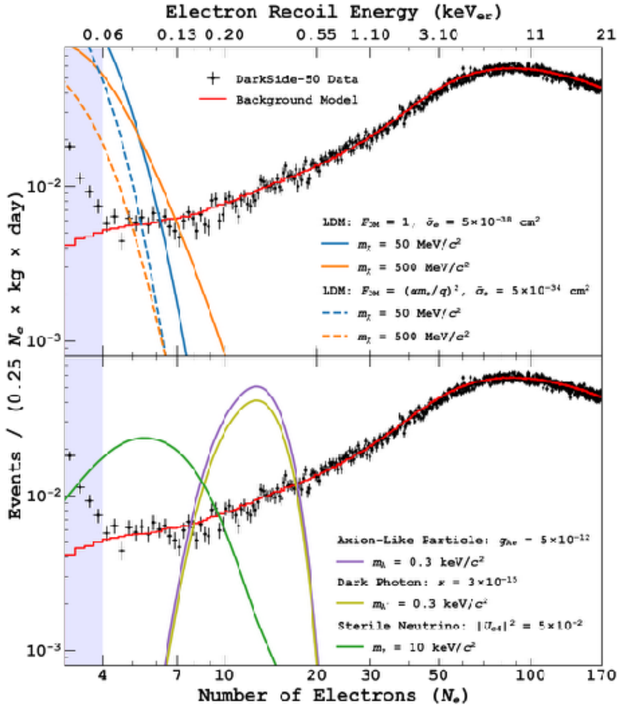


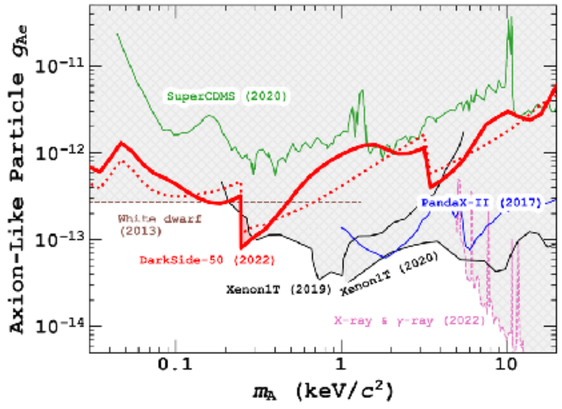
arxiv:2207.11967

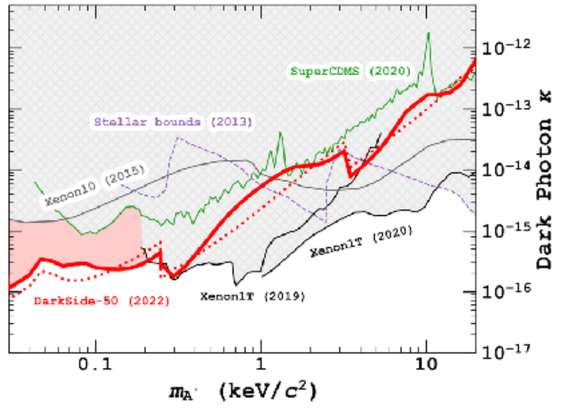


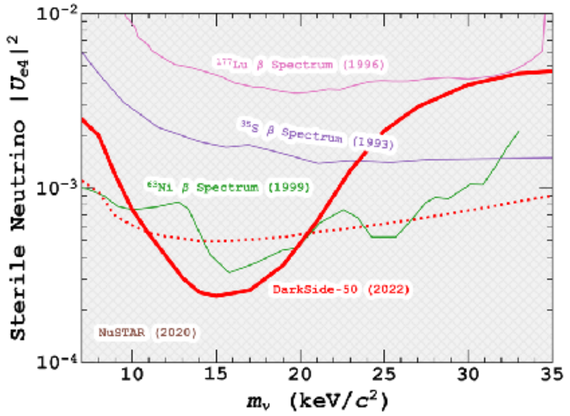
Leptophilic DM

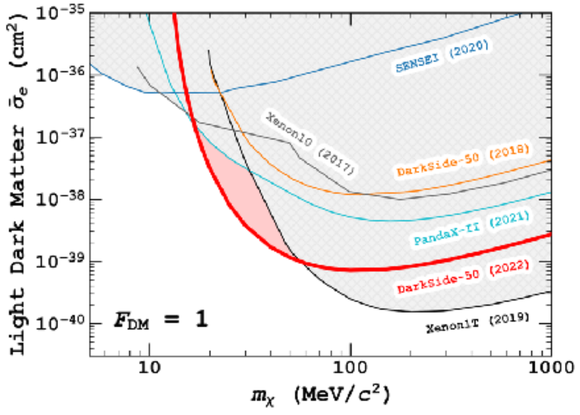
arxiv:2207.11968

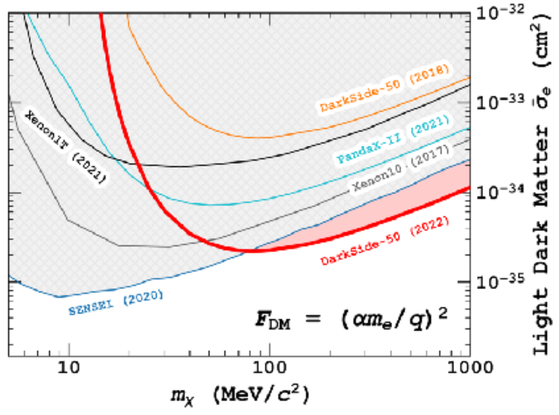






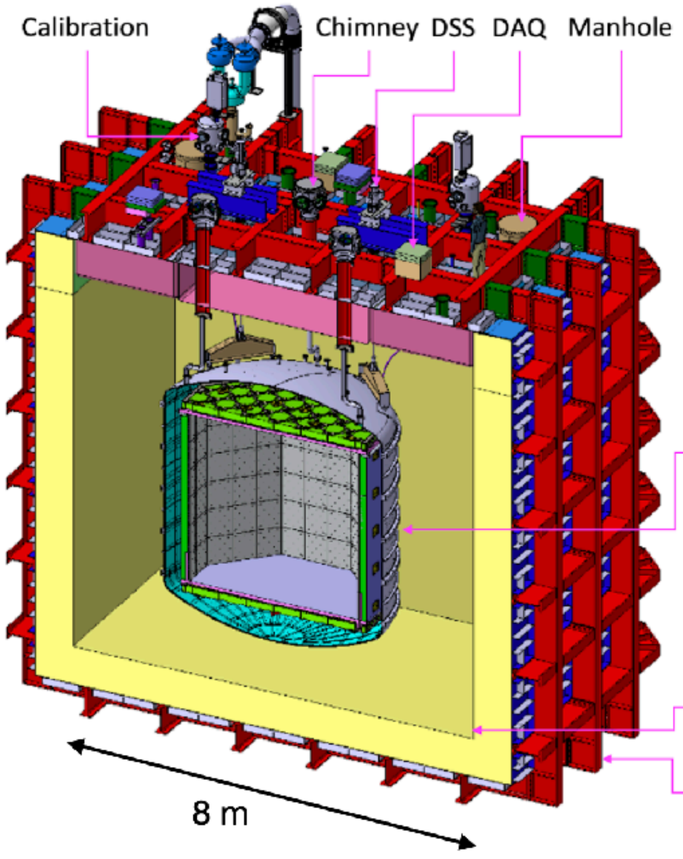


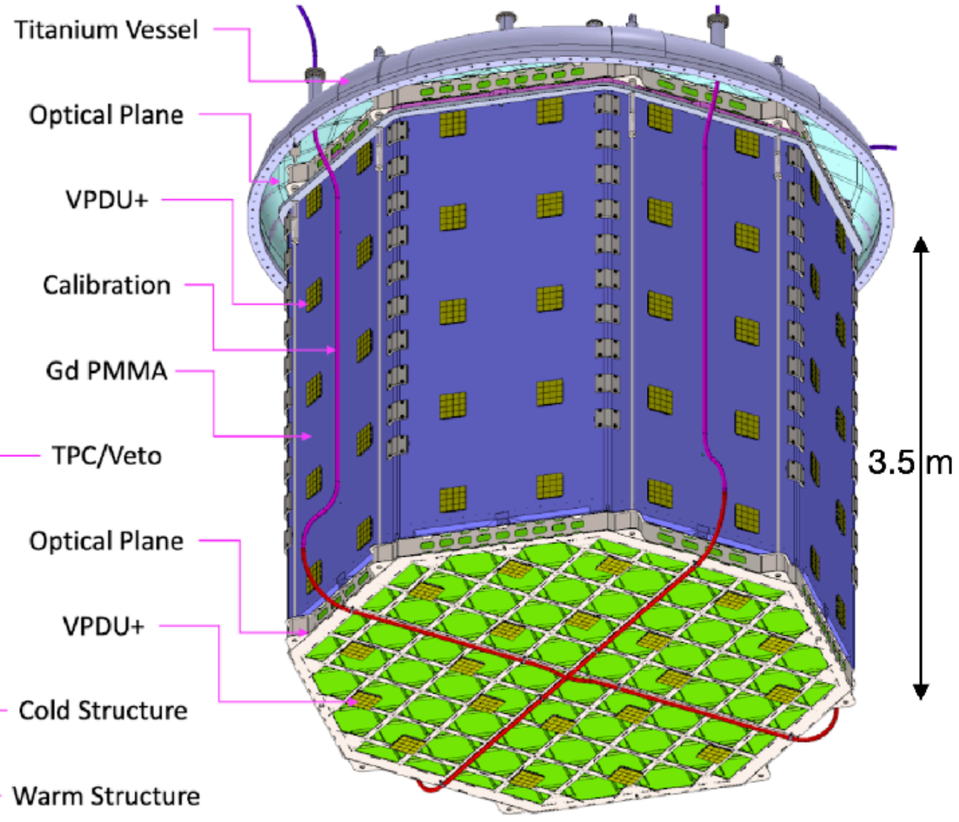


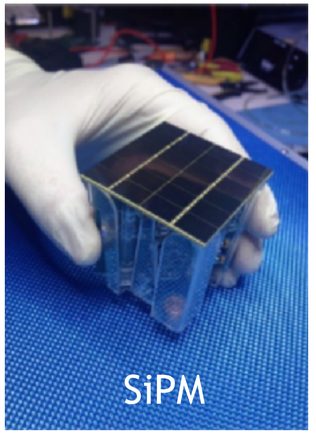


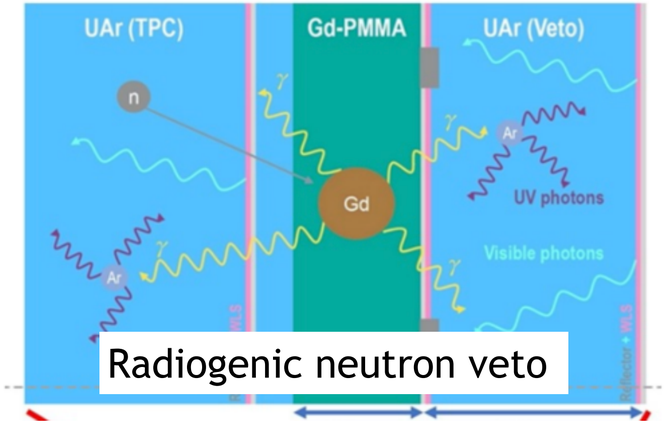
DarkSide-20k

50 ton LAr active volume, 20 ton fiducial: **half a day** to reach the same exposure of the DS50 low-mass analysis





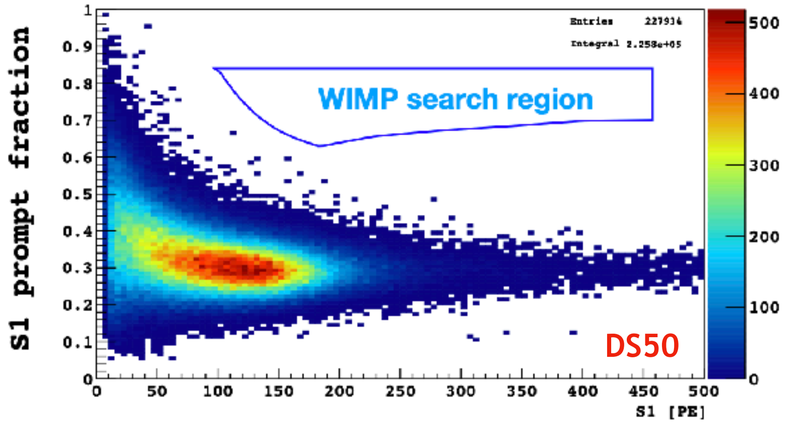




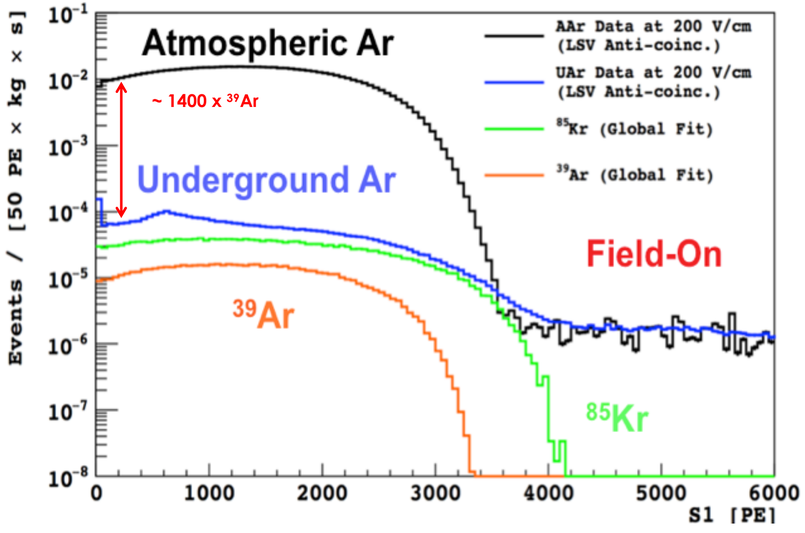
See Marie's talk about calibrations

50 ton LAr active volume, 20 ton fiducial: **half a day** to reach the same exposure of the DS50 low-mass analysis

Background suppression: Pulse Shape Discrimination rejects ERs with a power >10^8

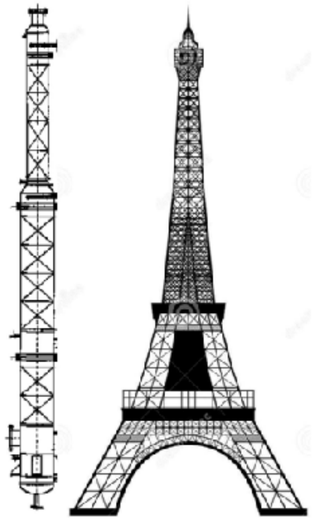


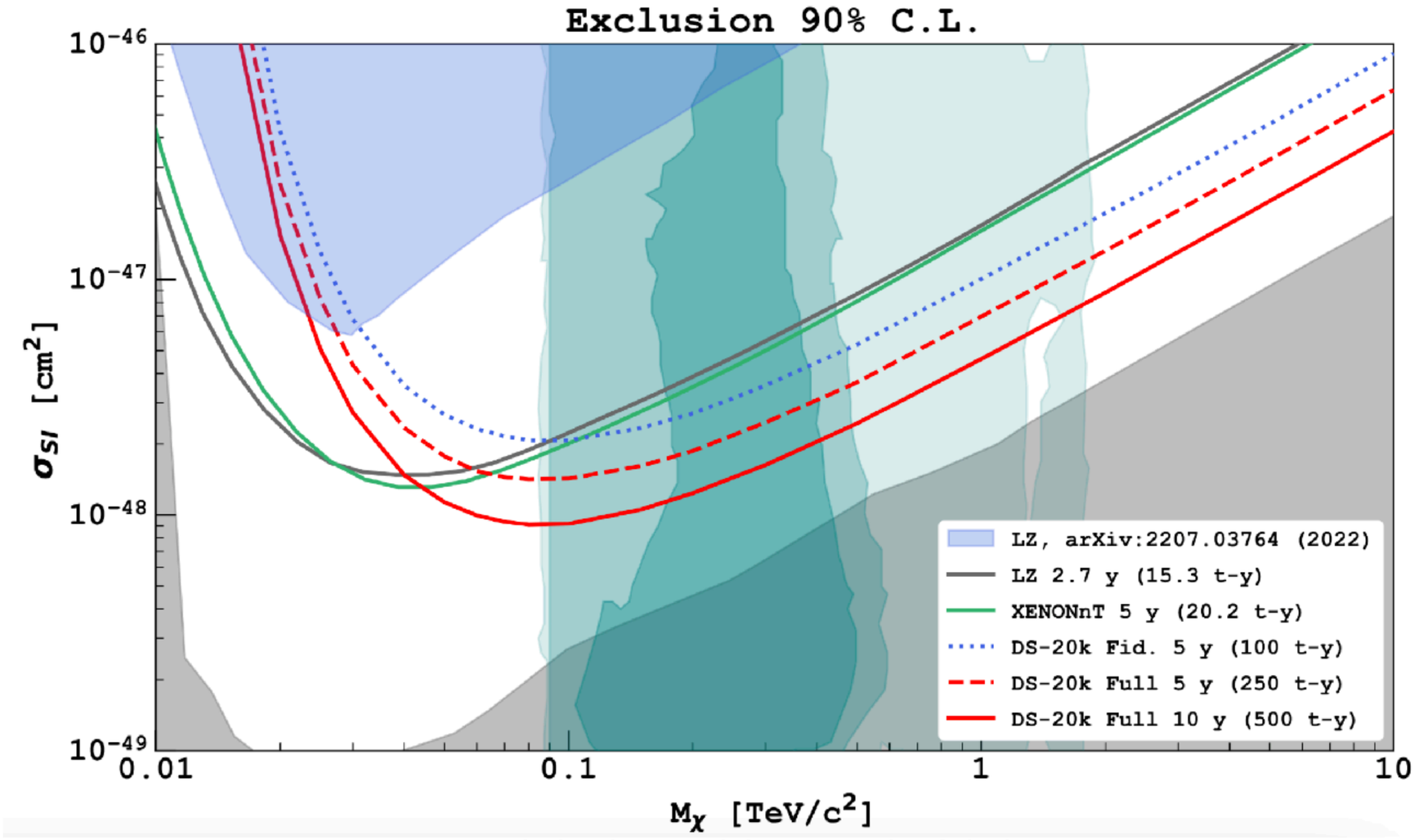
URANIA: LAr extracted from 2-km-depth CO_2 wells in Colorado



ARIA: cryogenic isotopic distillation plant

- in a mine shaft at CarboSulcis, S.p.A. in Nuraxi-Figus (SU), Italy
- 350m tall distillation column
- designed to reduce ^{39}Ar isotopic fraction in UAr by factor 10 per pass





nearly background-free search of dark matter

Conclusions

The DarkSide-50 low mass search saga….

- **Calibration of the liquid argon ionization response to low energy electronic and nuclear recoils with DarkSide-50**, DarkSide Collaboration, Phys.Rev.D 104 (2021) 8, 082005

- **Search for low-mass dark matter WIMPs with 12 ton-day exposure of DarkSide-50**, DarkSide Collaboration, arxiv:2207.11966 (2022)

- **Search for dark matter-nucleon interactions via Migdal effect with DarkSide-50**, DarkSide Collaboration, arxiv:2207.11967 (2022)

- **Search for dark matter particle interactions with electron final states with DarkSide-50**, DarkSide Collaboration, arxiv:2207.11968 (2022)

DarkSide-20k data taking expected in 2026