Search for low mass WIMP dark matter with DarkSide

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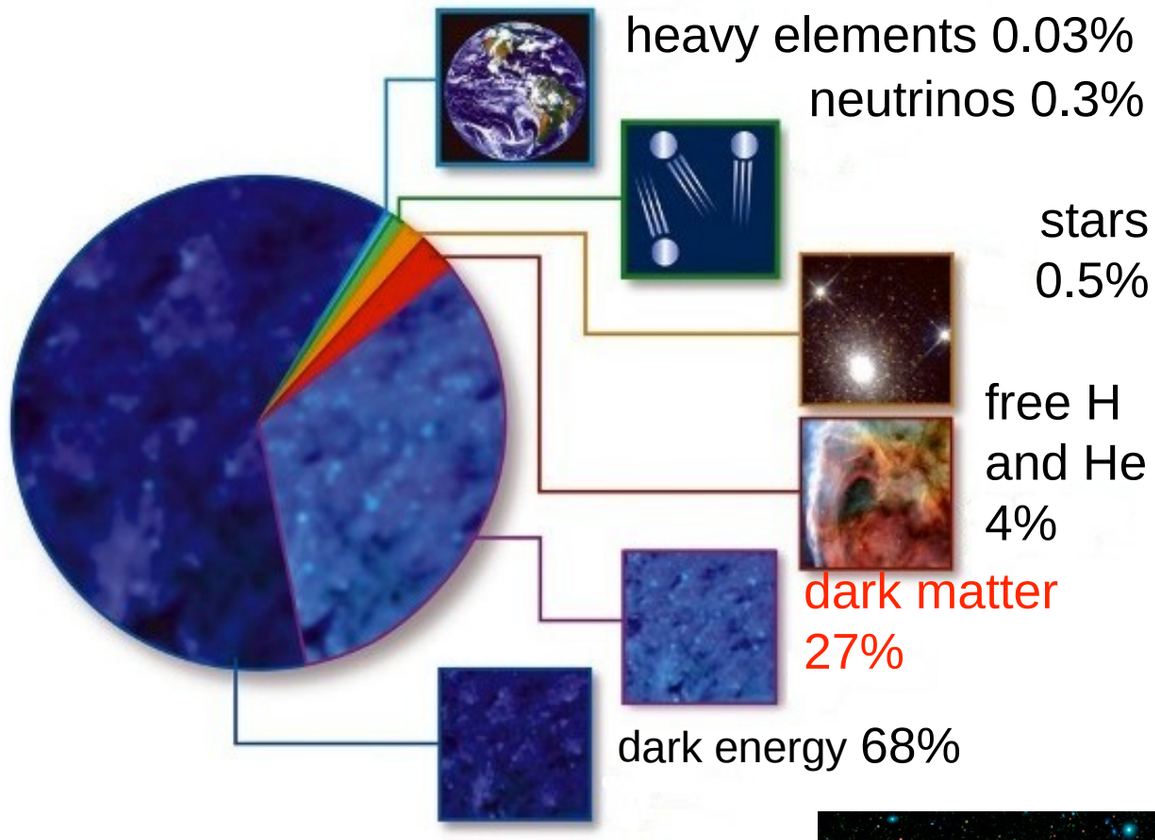
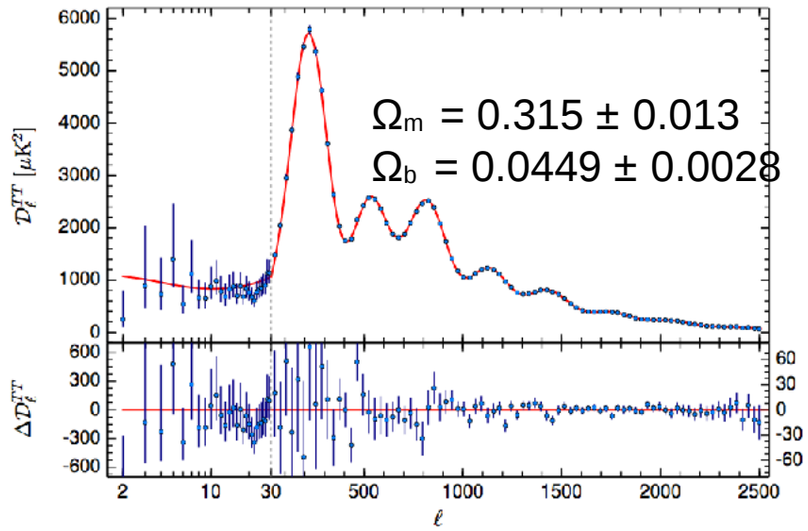
(NRC "Kurchatov Institute" & NRNU MEPHI)
on behalf of DarkSide collaboration

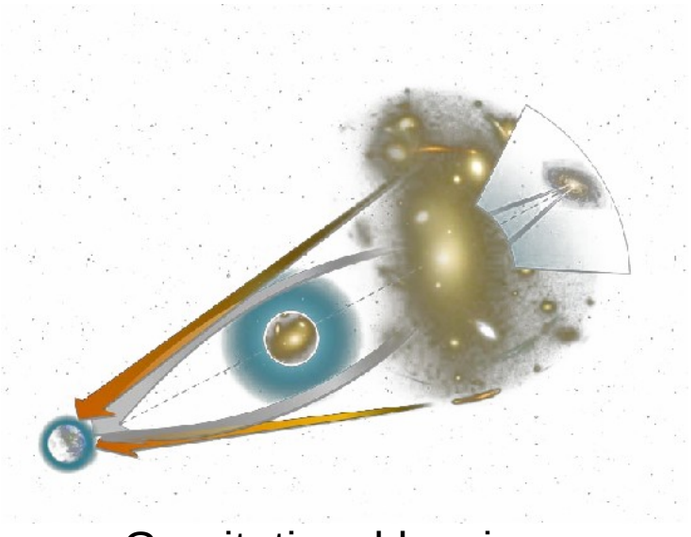
ICPPA–2022, 1 December, 2022, Moscow, Russia

Dark Matter from Astrophysical Observations

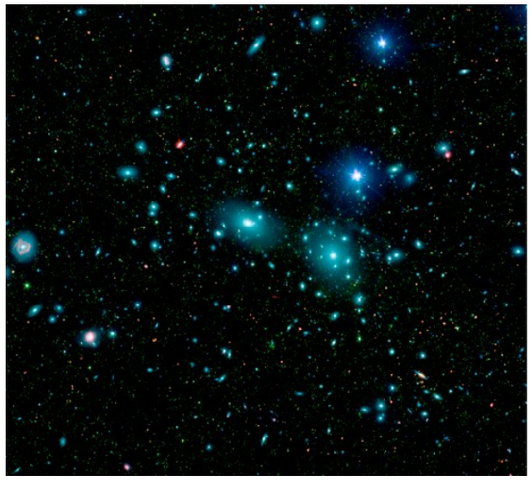




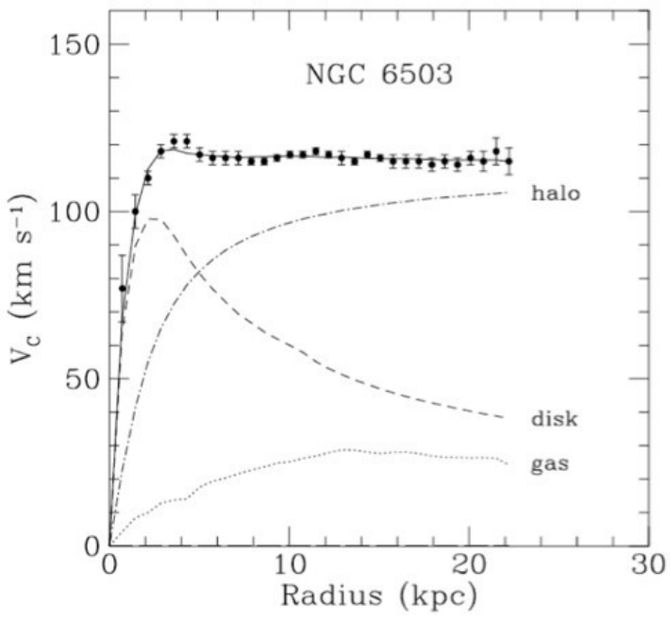
Temperature spectrum of Cosmic Microwave Background



Gravitational lensing



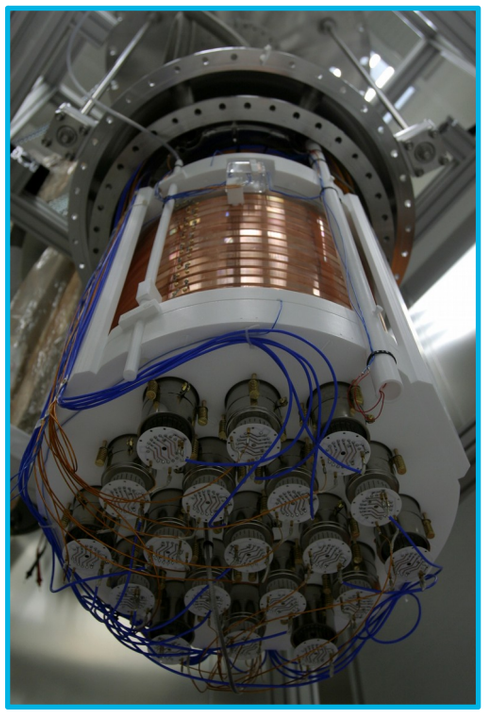
Redshift / velocity dispersion measurements in galaxy clusters



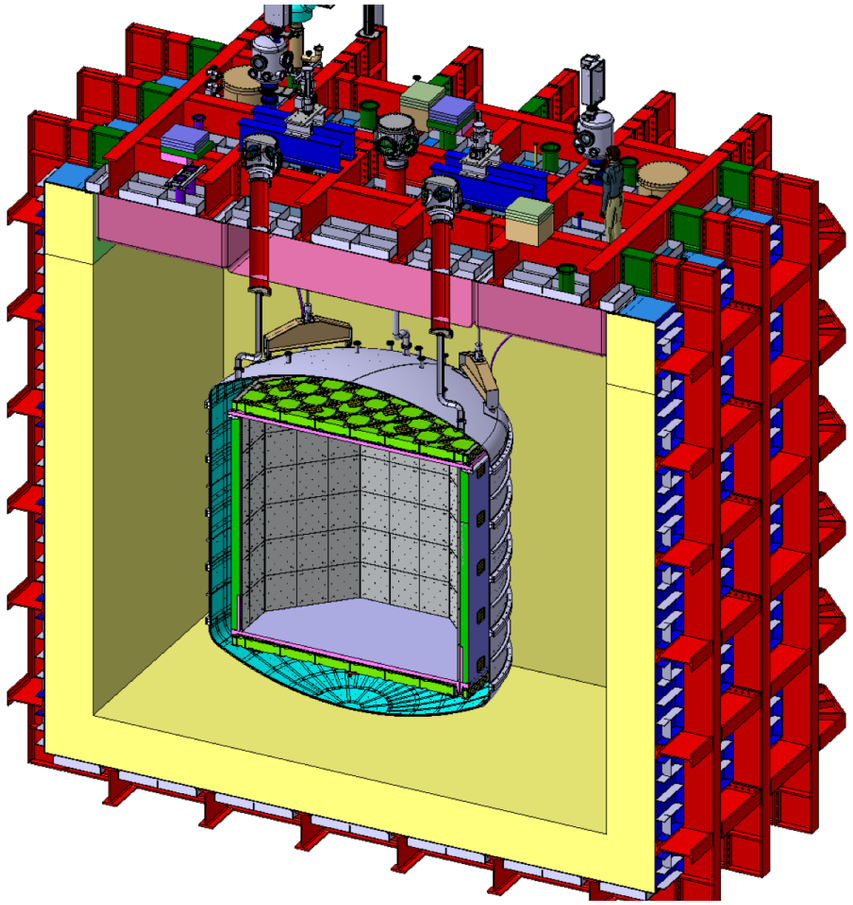
Rotation curves of stars and gas in galaxies

Direct WIMP Dark Matter Search with Argon, DarkSide Program

DarkSide-10
2010–2012
10 kg-scale prototype

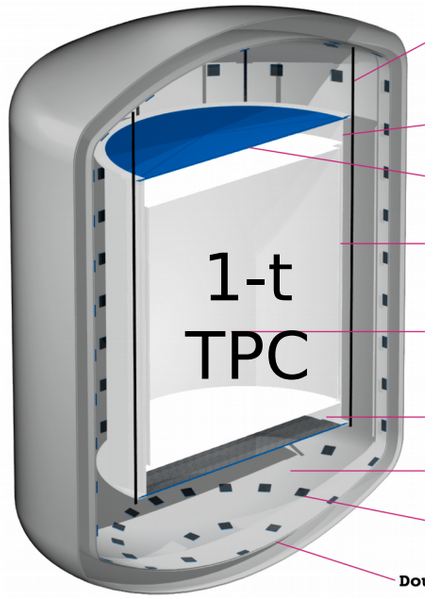


Darkside-50
2013–2019
46 kg active mass

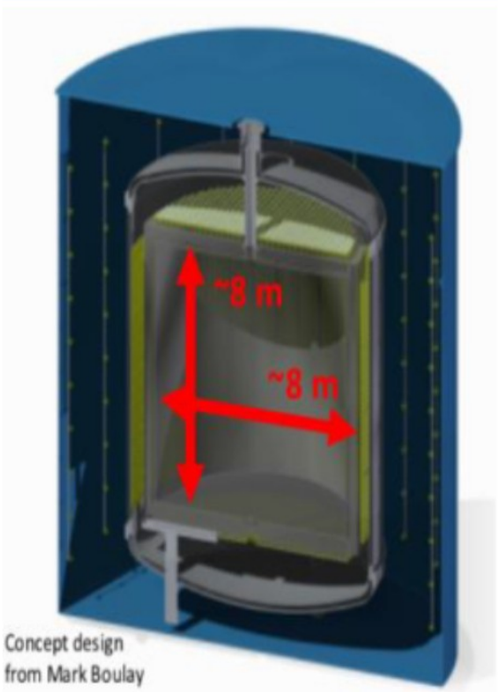


DarkSide-20k 2026 -
20 tonne fiducial mass
Approaching ‘ν-floor’

The goal: explore dark matter to the neutrino floor and beyond with extremely low instrumental background



DS-LowMass

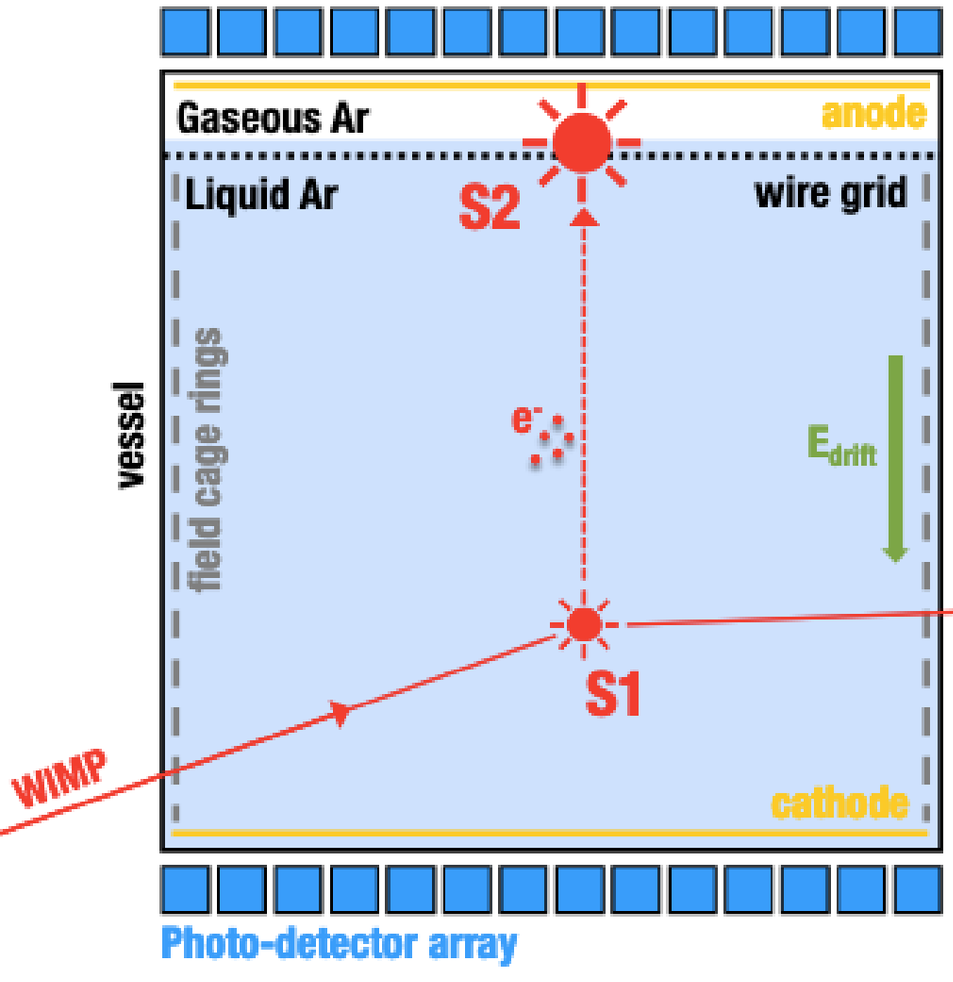


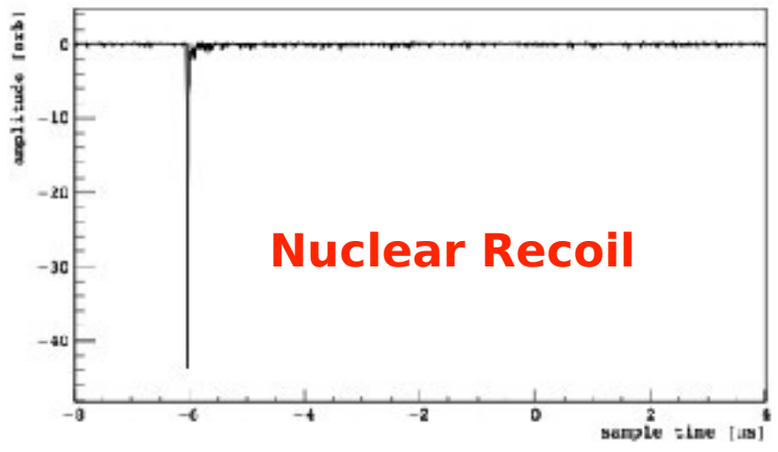
ARGO ~2030
3k tonne-year

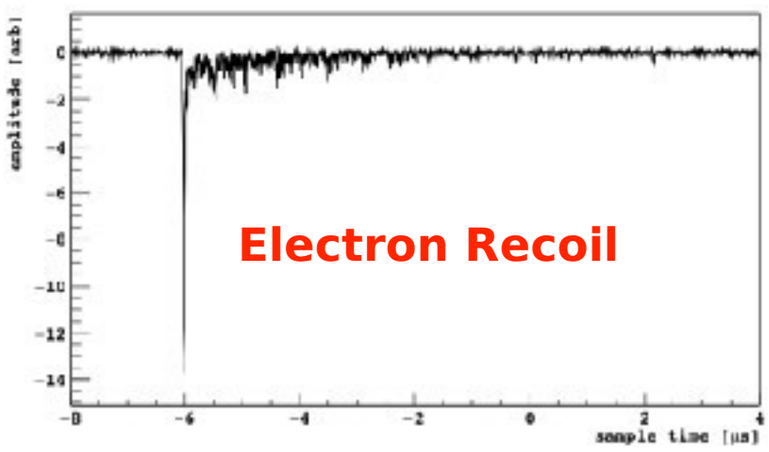
Direct Dark Matter Detection

One of the well-known candidates for dark matter - WIMP, Weakly Interacting Massive Particle, M ~ [GeV -TeV], e.g. from supersymmetry: neutralino, lightest superpartner with R-parity conservation

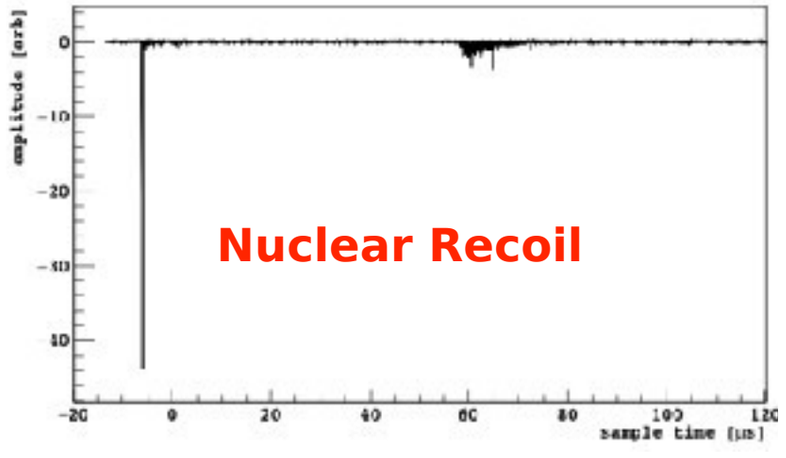
Dual-phase time-projection chamber (TPC)

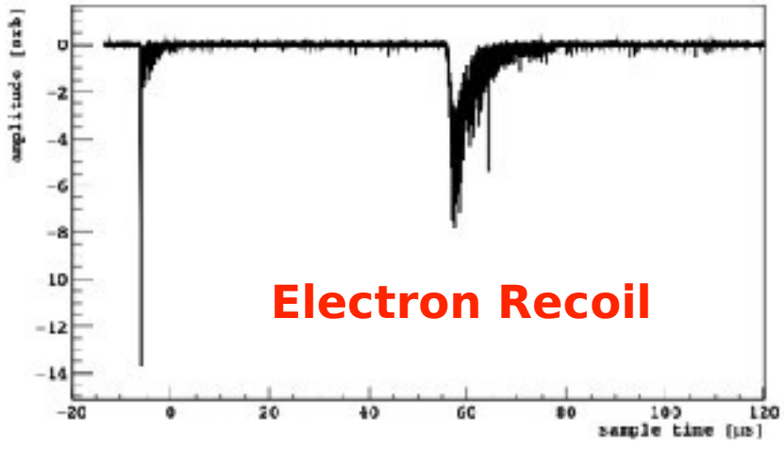






- X-Y position is determined by the top PMTs (*SiPM*) array with S2.





- Z position from drift time.

Low Radioactivity Underground Argon

Urania plant

UAr extraction plant in Colorado

^{39}Ar reduction: at least 1400

Extraction: 250 kg/day at 99.99% purity

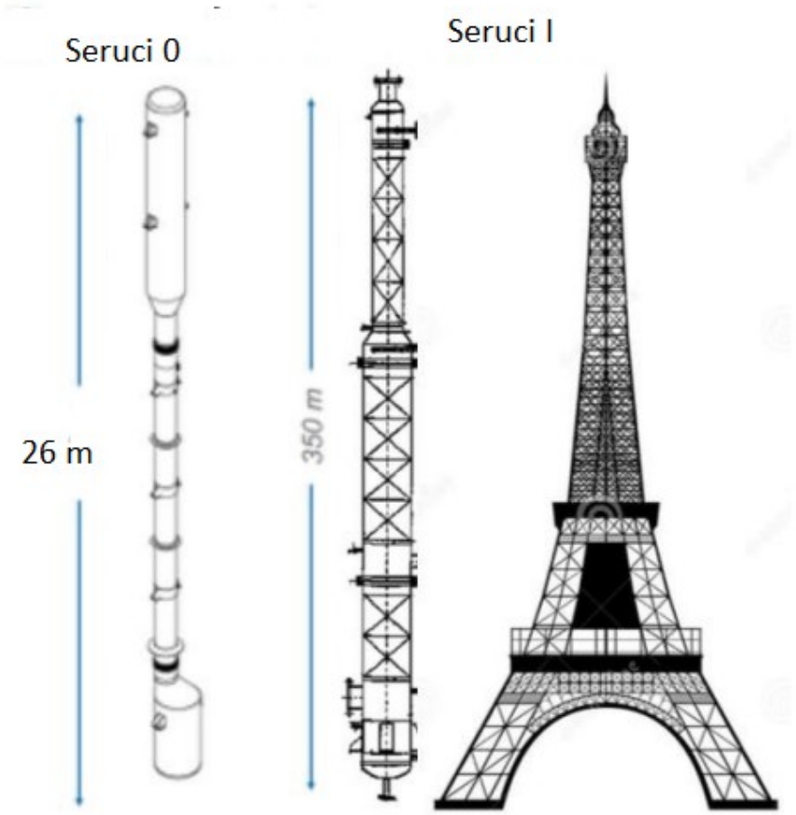
Aria plant

UAr purification in Sardinia

350 m-tall cryogenic distillation column

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

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



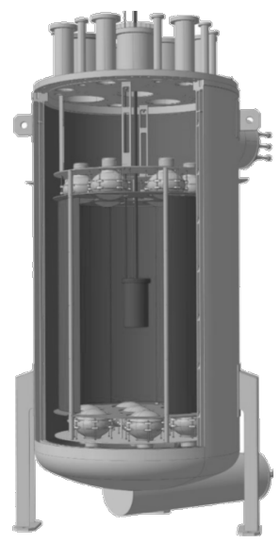
DarkSide Collaboration. “Separating 39Ar from 40Ar by cryogenic distillation with Aria for dark matter searches”. Eur.Phys.J.C 81 (2021) 4, 359

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

DArT detector

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

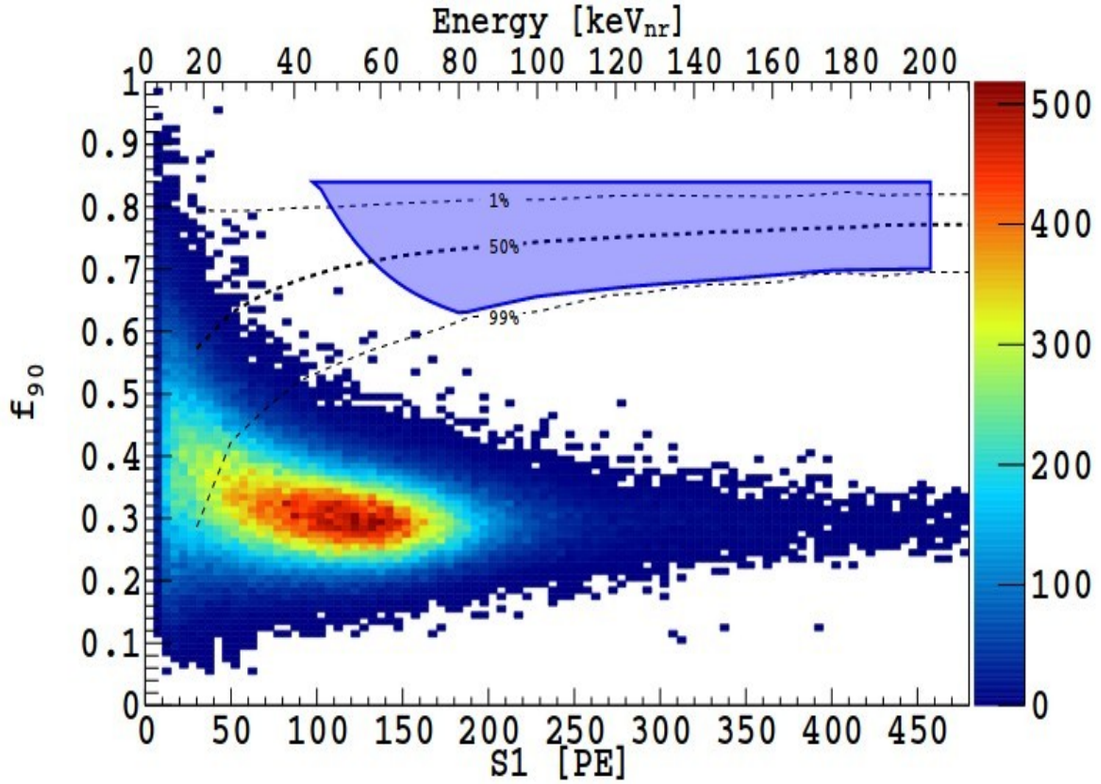
Sensitivity: depletion factor U.L. of 6×10^4 at 90% C.L. in 1 week of counting time



Two types of analyses for WIMP search

S1+S2

Search for 2 signals from nuclear recoil
WIMP mass range > 20 GeV/c^2
Pulse Shape Discrimination
Background free analysis (< 0.1 events)
Energy diapason 45-200 keV_{nr}

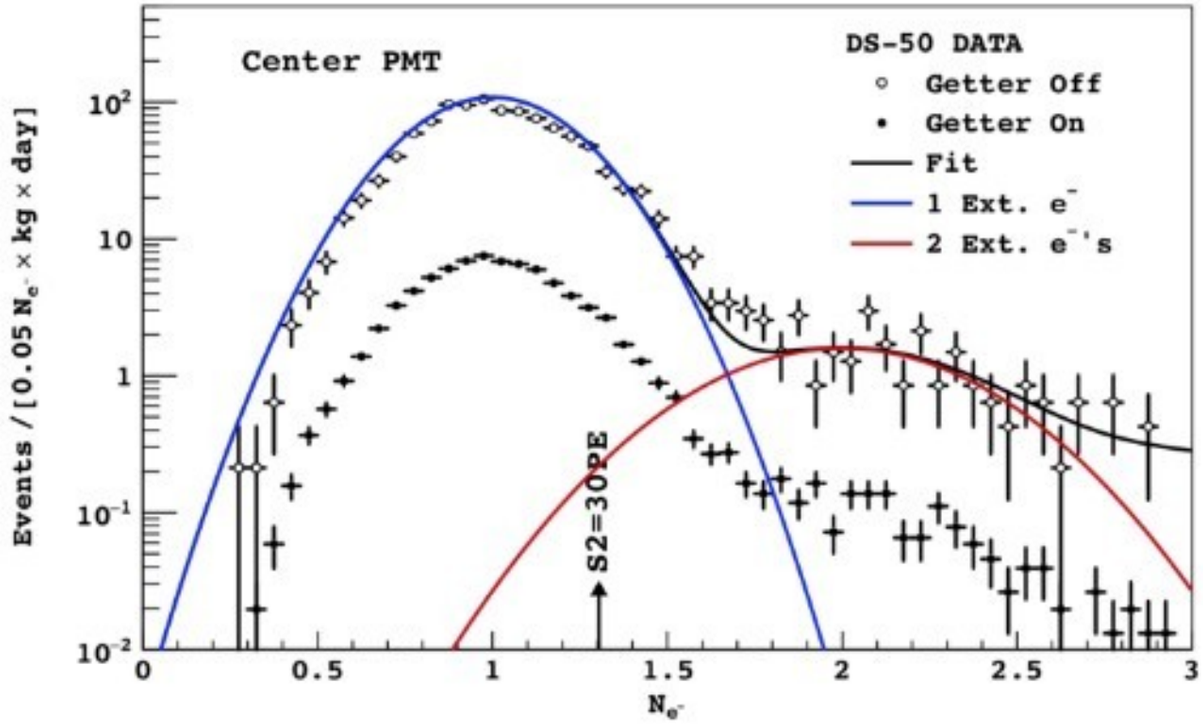


Phys.Rev. D 98, (2018) 10, 102006

S2-only

Search for low energy nuclear recoil signals WIMP mass range 1.8-20 GeV/c^2
Full signal acceptance at 0.1 keV_{ee} Energy threshold 0.6 keV_{nr}

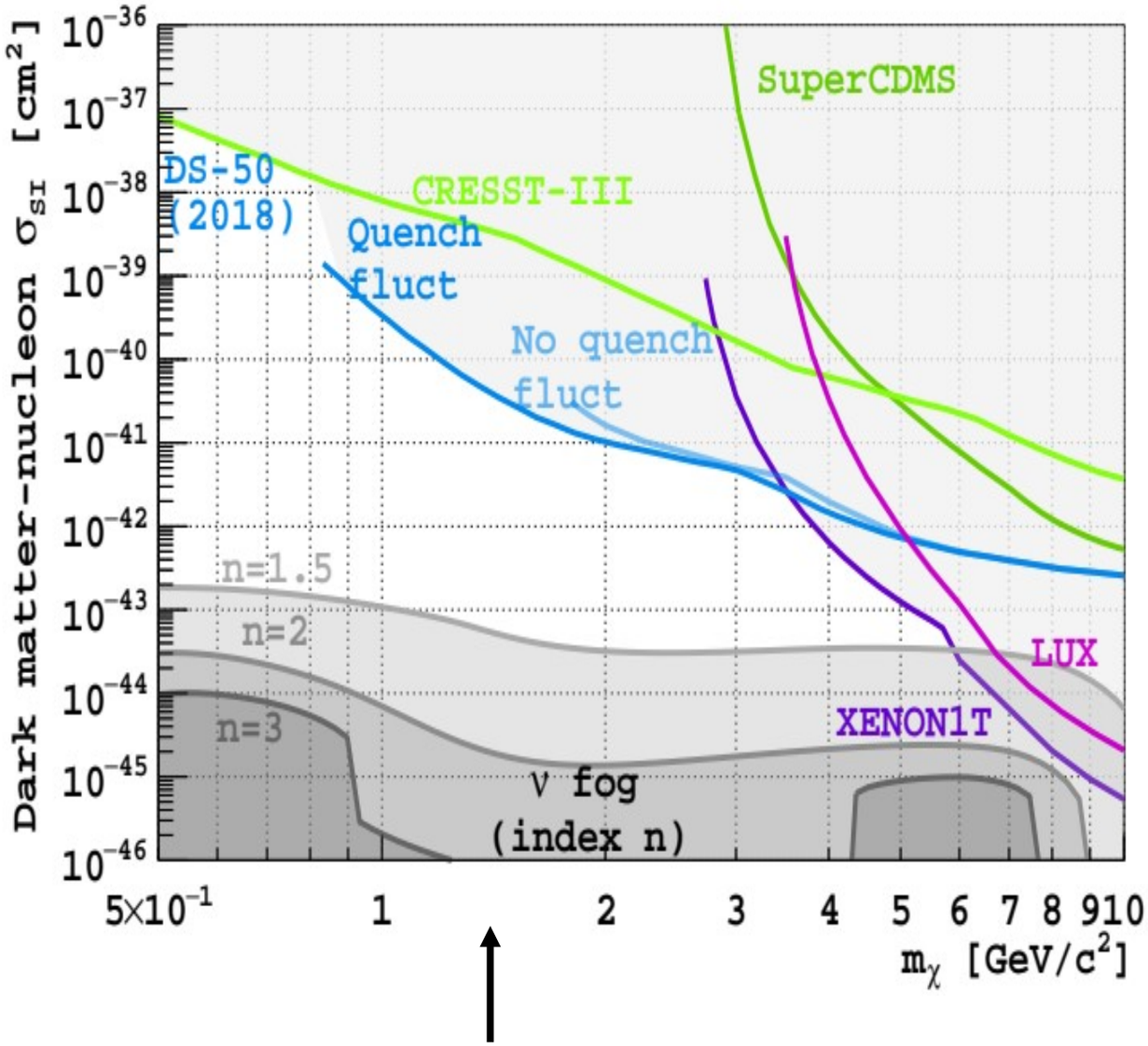
Best DM exclusion limit for 1.8–6 GeV/c^2 WIMP

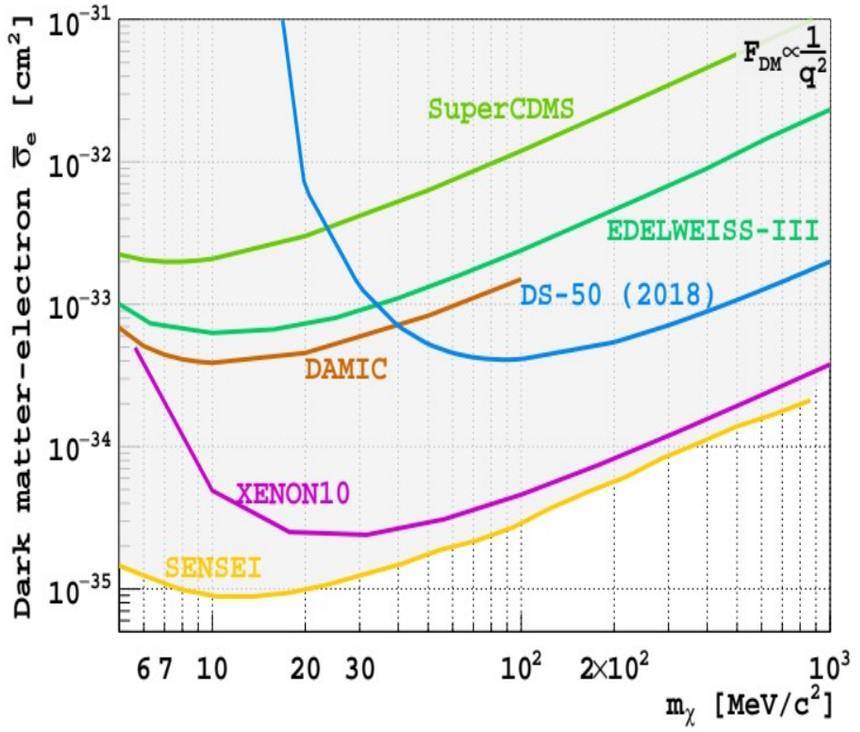


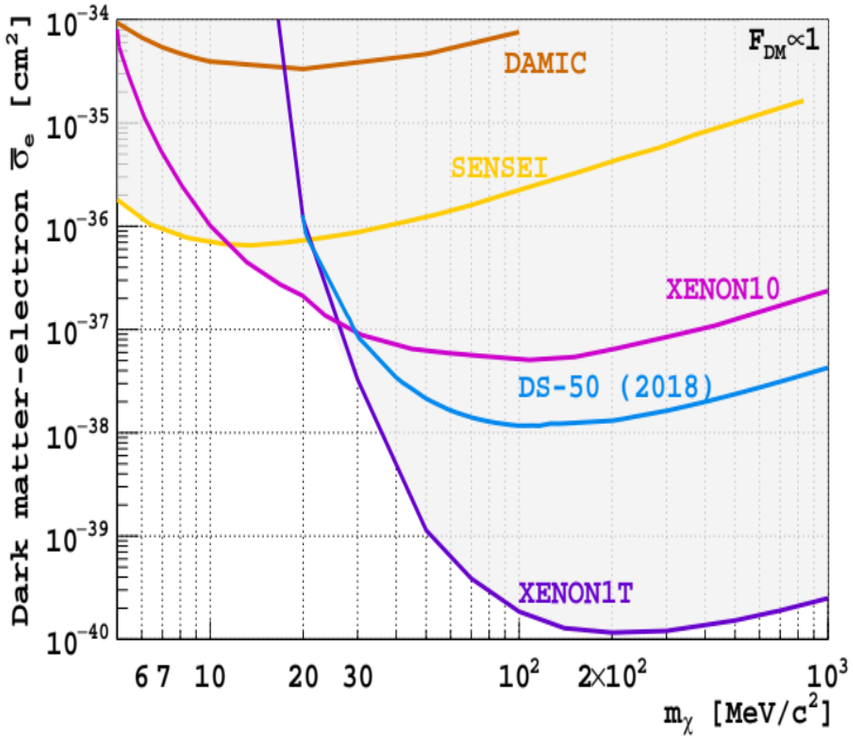
Single-electron background

Phys.Rev.Lett. 121 (2018) 8, 081307

Light WIMP search in DS-50







DarkSide Collaboration. "Low-Mass Dark Matter Search with the DarkSide-50 Experiment"
Phys. Rev. Lett. 121 081307 (2018)

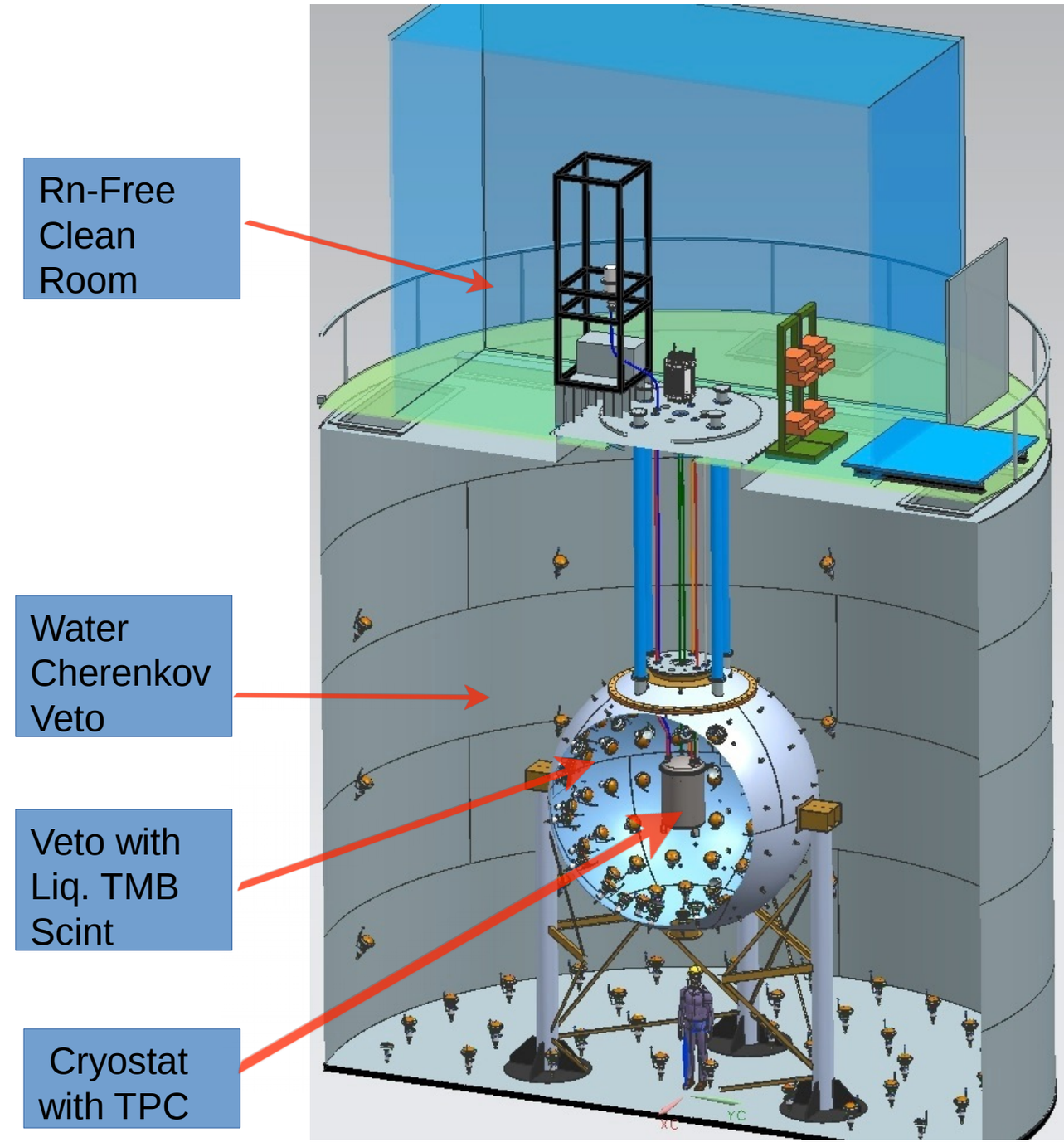
DarkSide Collaboration. "Constraints on Sub-GeV Dark-Matter-Electron Scattering from the DarkSide-50 Experiment".
Phys. Rev. Lett. 121 111303 (2018)

Renewed analyses for light WIMP search in DS-50

- *Underground Argon campaign*
- *First 9 months of data is not used to wait for the ^{37}Ar (cosmogenic) to decay*
- *Extended exposure 650 live-days of data (12 ton-day) ~x 1.8 exposure than previous analysis*
- *Improved data selection. Detector was quite stable for the whole period of 26 months*

  $\delta T = \pm 0.02$ K, $\delta P < \pm 0.005$ psi,

  $\delta(S1) \sim 0.4\%$, $\delta(S2) < 1\%$, $\tau e > 10$ ms (more than x20 of the full drift time)
- *New LAr response calibration*
- *New background modeling, including atomic effects of β-decays*

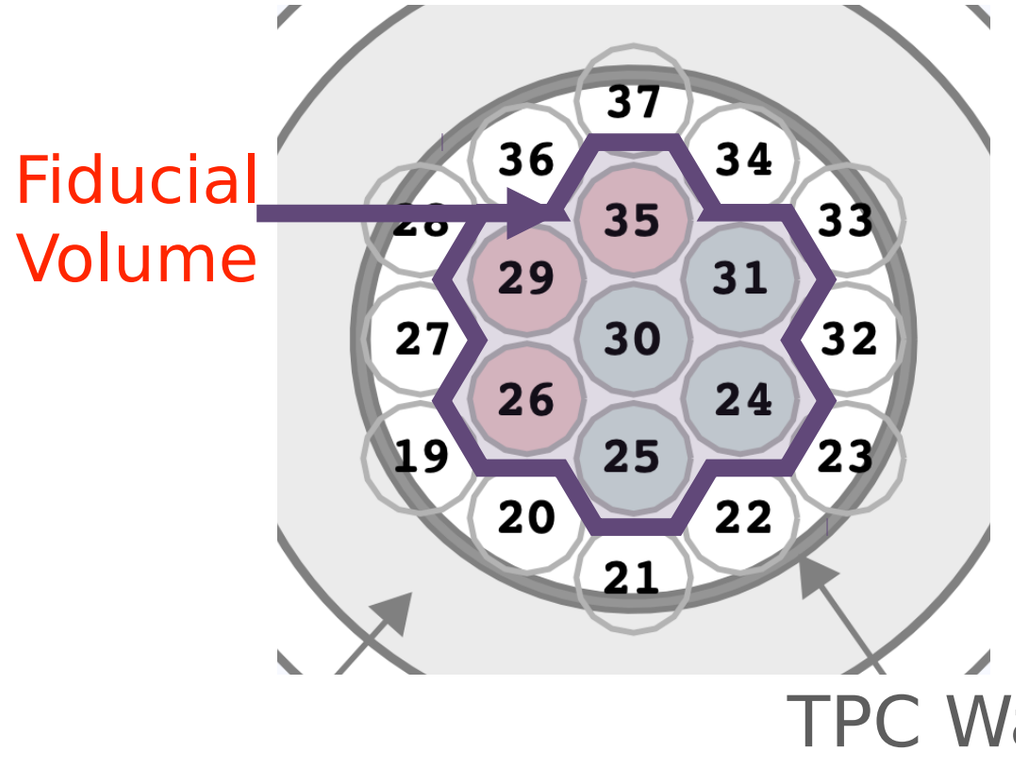


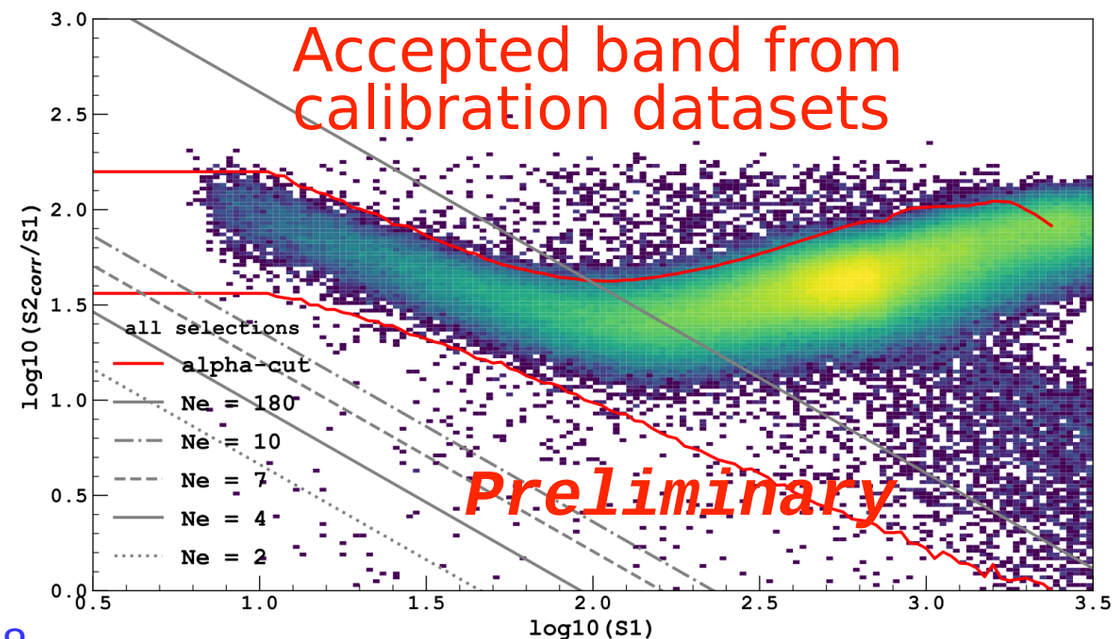
Renewed Analyses for Light WIMP Search in DS-50 Data Selection

Fiducialization - events in the volume under 7 inner PMTs are selected to shield radiation from materials

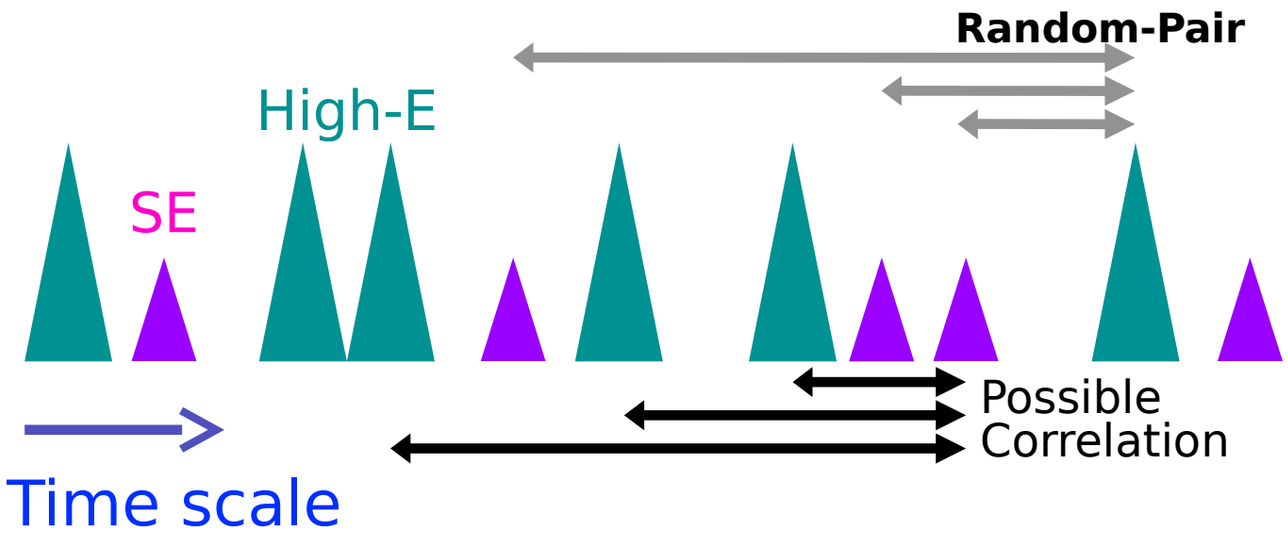
Pileup pulses - pulse rise time and width are used to remove multiple low-S2 pulses misidentified as one pulse

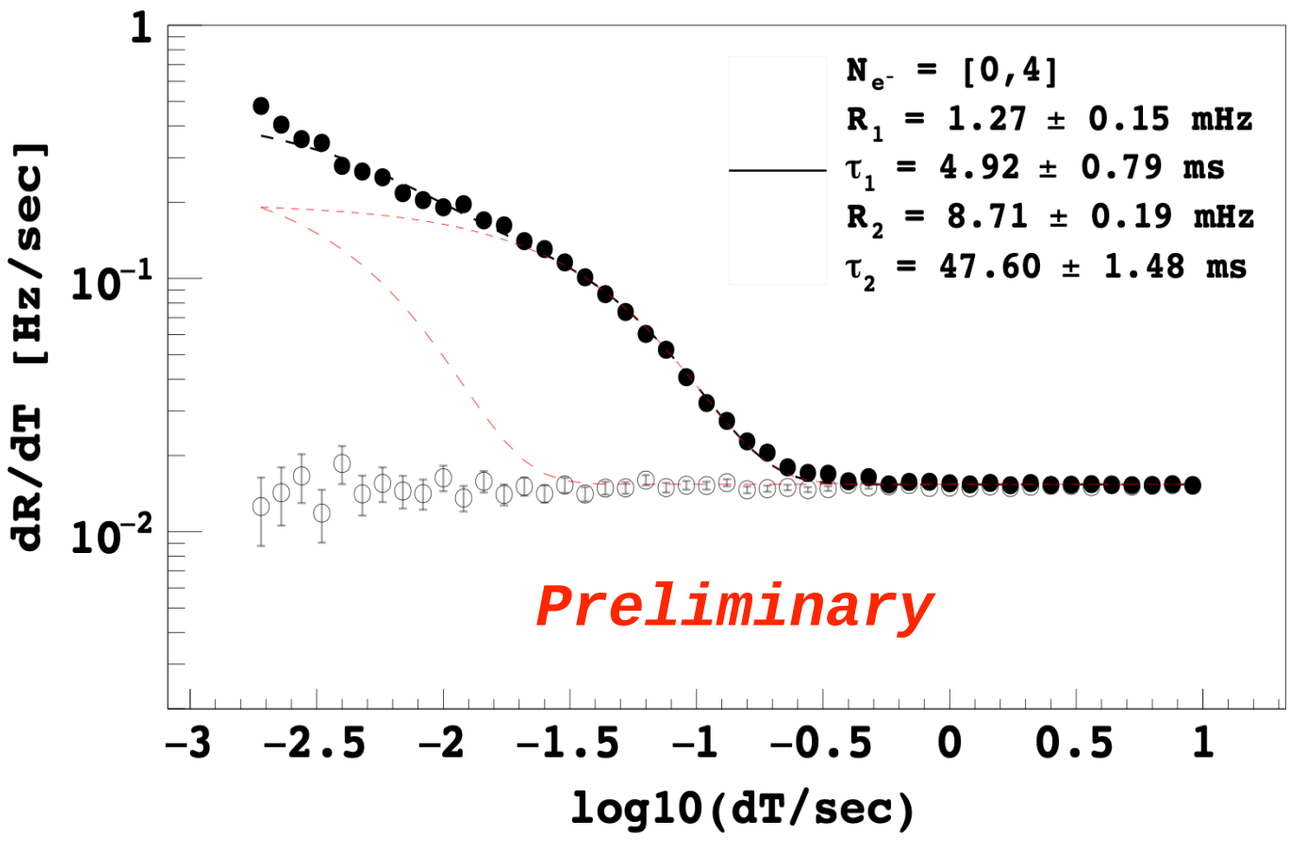
Surface-α veto -S2/S1 band from calibration datasets used to reject surface-α induced event





Data Selection – Spurious Electron Veto





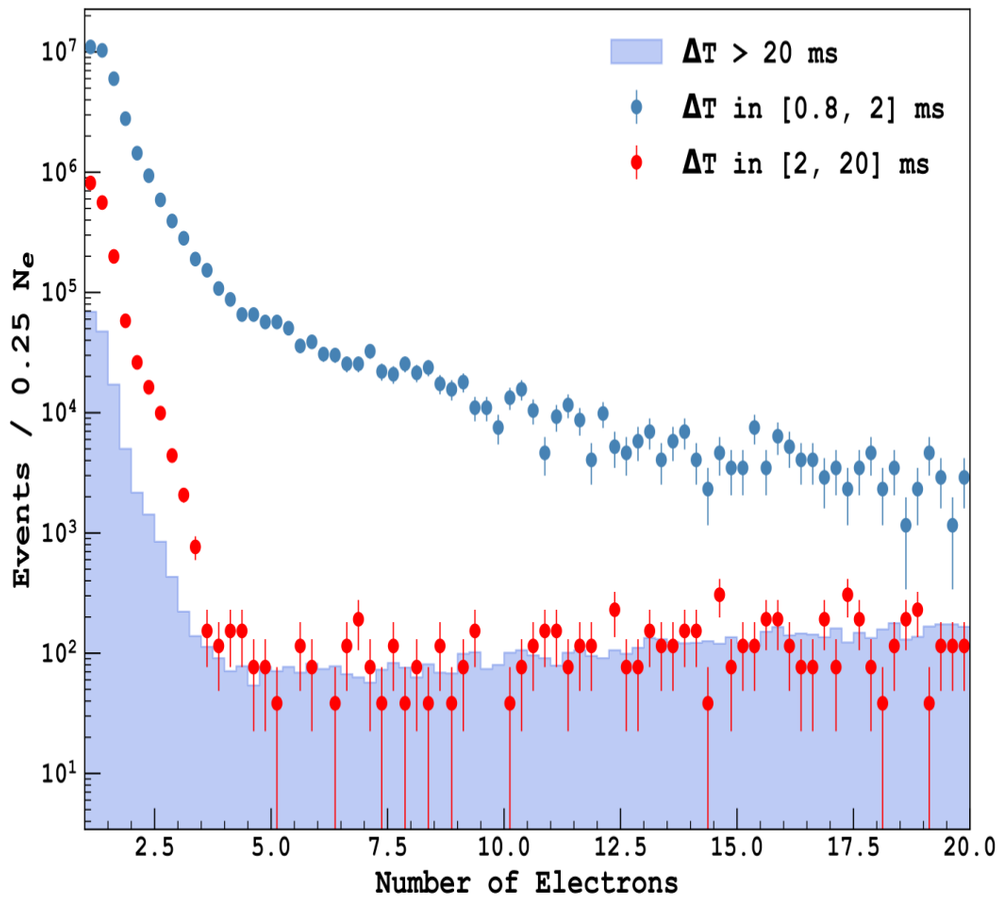
See also Astropart.Phys. 140 102704 (2022)

DS-50 observes the SE rate exponentially decaying with ~5 ms and ~50 ms time-constants

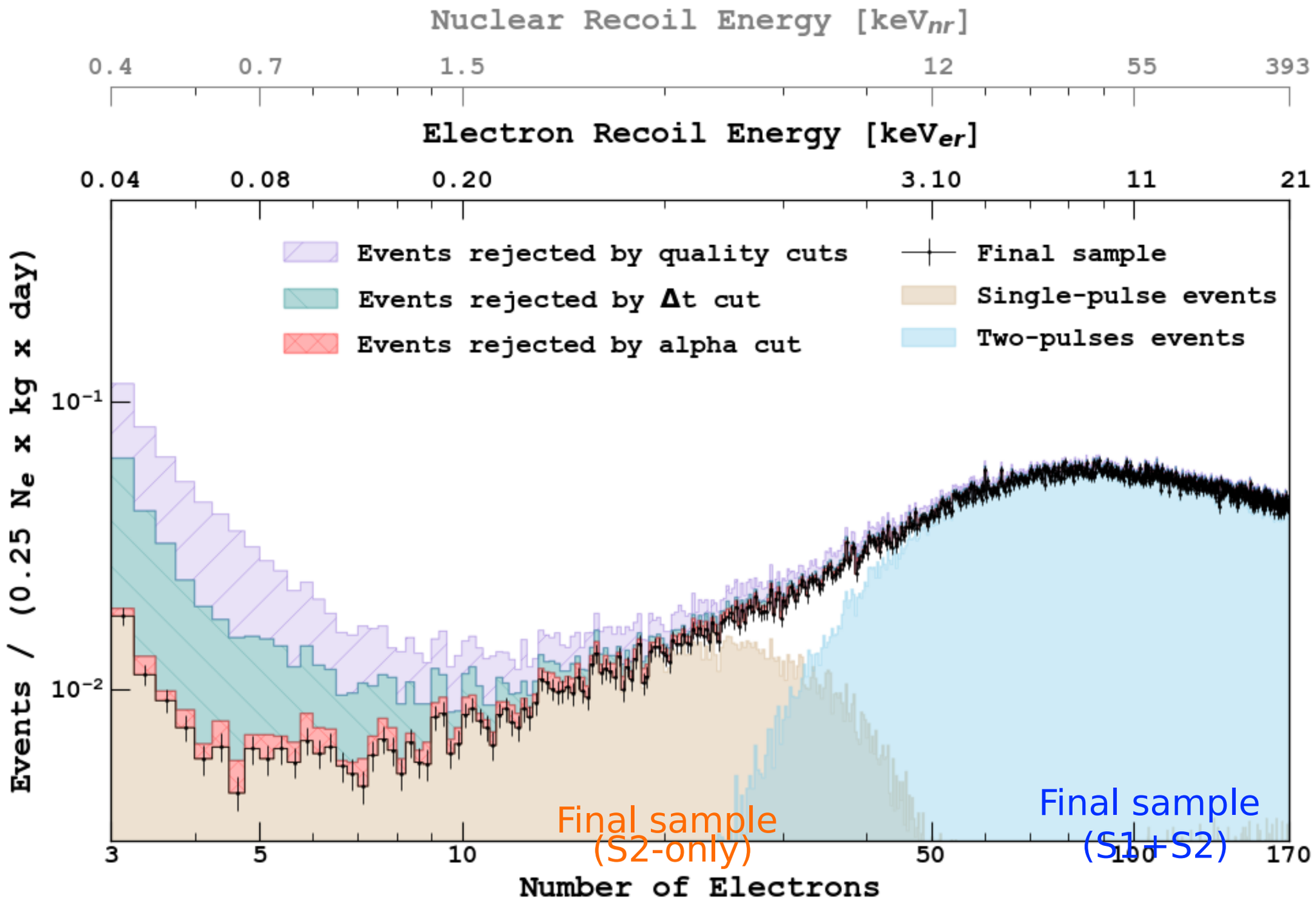
A few delayed electrons signal is found after normal event :

"Spurious Electron (SE)".

20 ms veto is applied for all events to maximize S/B ratio



Data Sample



Signal efficiency is >95% for the region of interest (N_e = [4, 170])

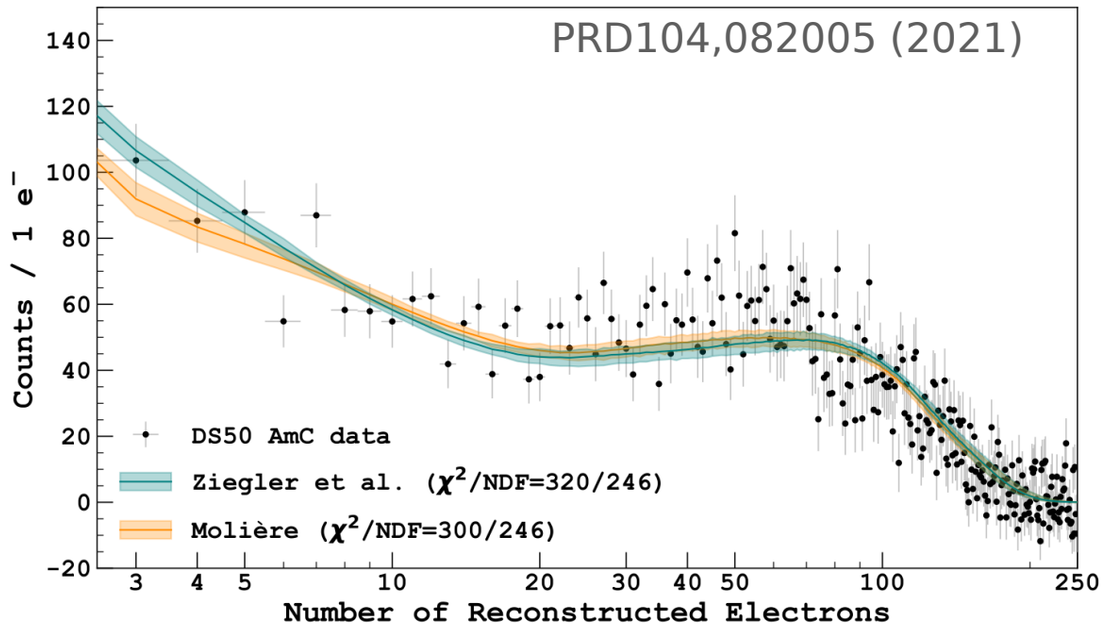
Liquid Argon Response Calibration

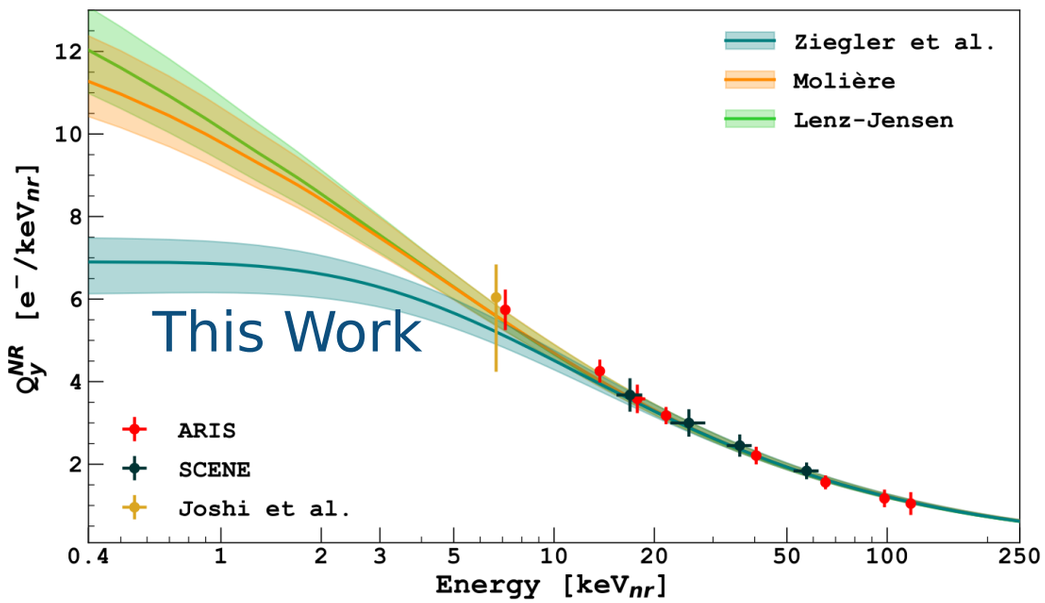
Response to nuclear recoils

The model is based on Ar & e- recombination process and energy losses due to nuclear stopping power

Parameters are tuned using DS-50 neutron calibration data (AmC and AmBe neutron sources) and external datasets from SCENE and ARIS experiments

The most “conservative” prediction among several theoretical models used





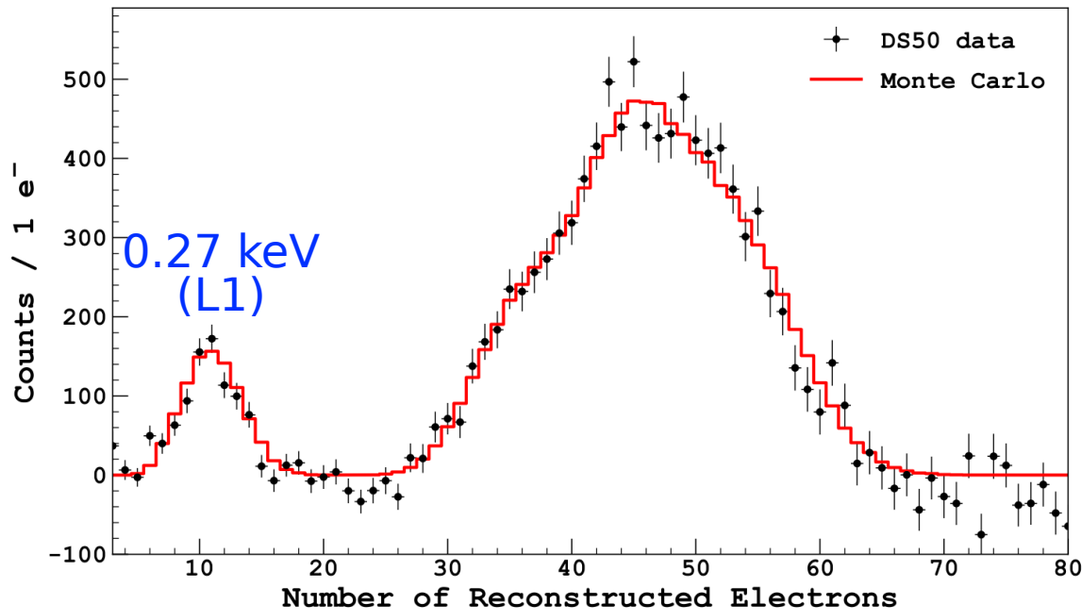
Liquid Argon Response Calibration

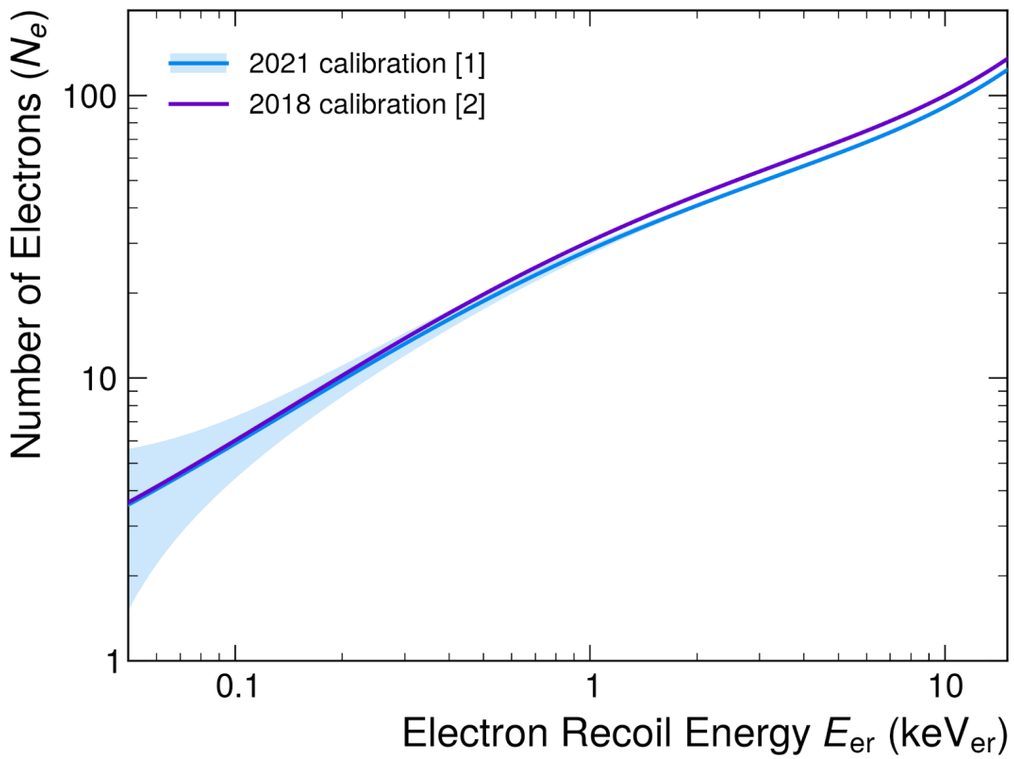
Response to electrons

Parameters are tuned for ^{37}Ar (L1-shell) peak from the UAr campaign and ^{39}Ar sample from AAr campaign

Compared to the previous analysis, ^{83m}Kr and ^{37}Ar (K-shell) peaks are removed from the calibration to avoid distortion from their complex decay schemes

This allows for energy Region of Interst to be extended up to 170 e- (21 keV)



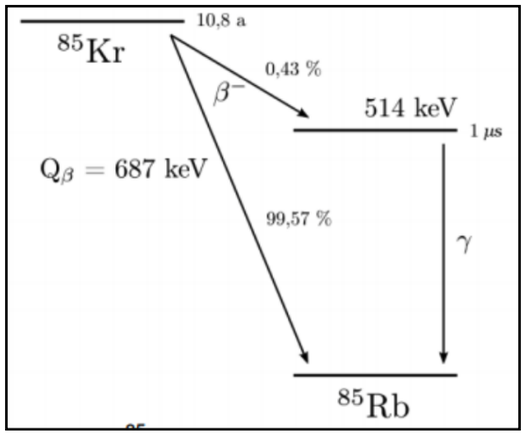


Detector Background

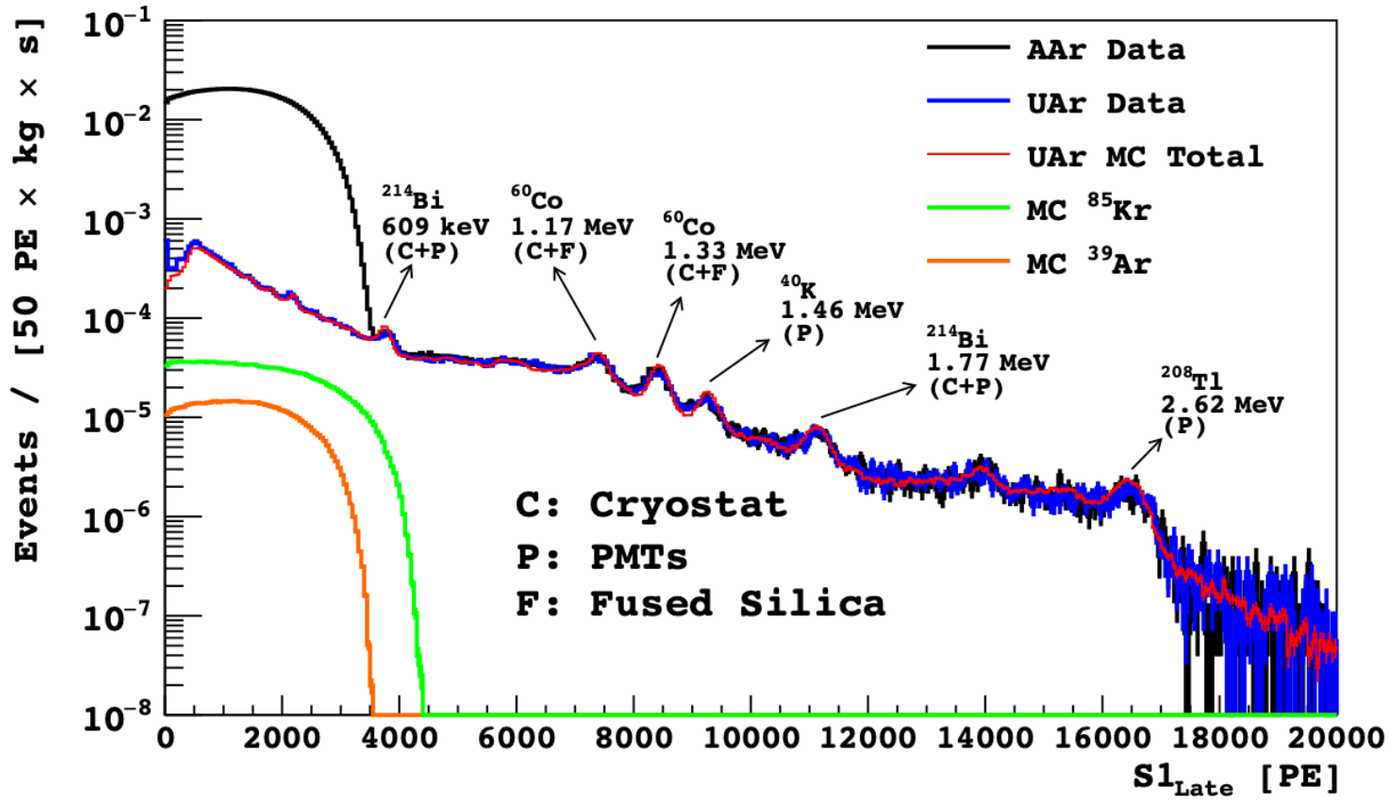
The activities are constrained by fitting higher energy spectrum, cross-checked by β+γ fast coincidence events

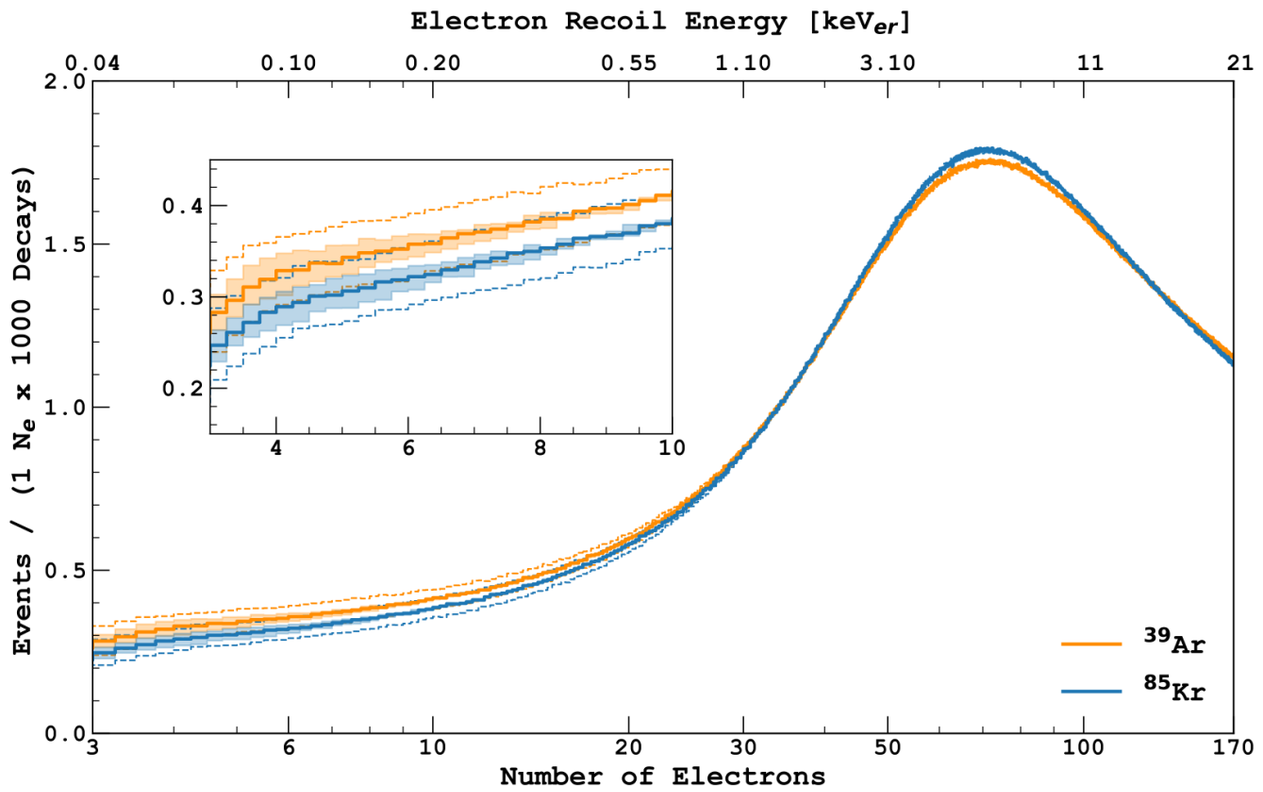
^{39}Ar : 0.7 ± 0.1 mBq/kg

^{85}Kr : 1.8 ± 0.1 mBq/kg



The spectrum shape is accounted for recent calculations of atomic exchange and screening effects with associated uncertainties





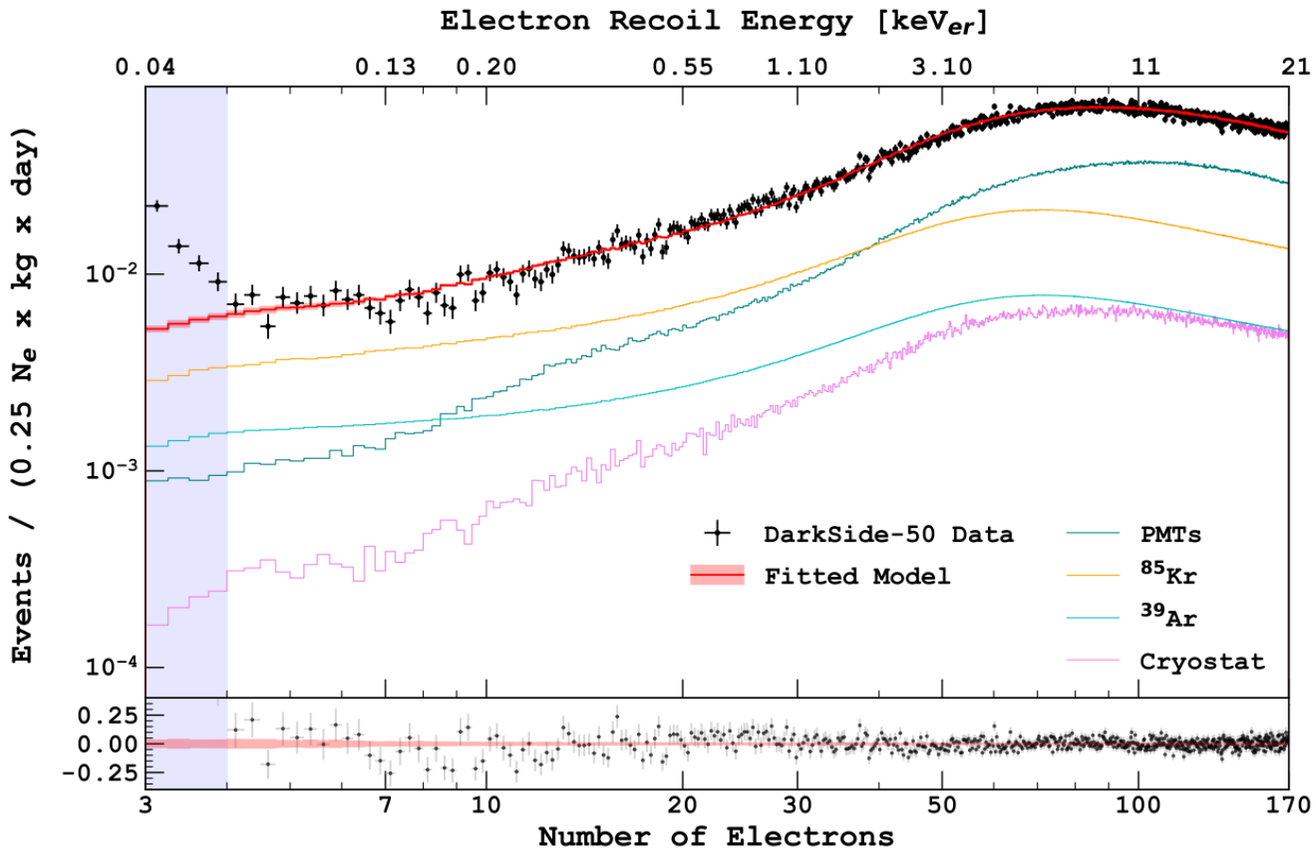
Background Only Fit

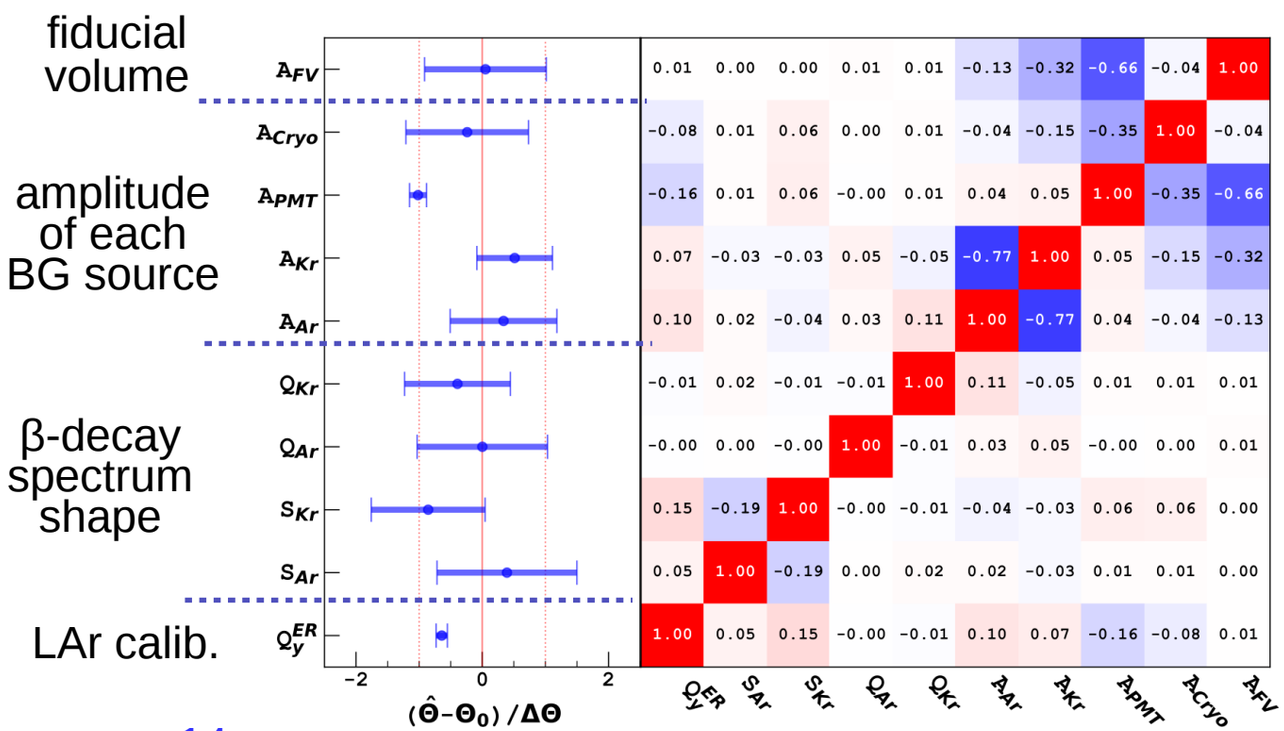
Observed data is consistent to the background model prediction within the systematic uncertainties.

Background model and uncertainty (red line and shaded area) from the data fit in the [4, 170] N_e range, and the individual contributions from the internal (^{39}Ar and ^{85}Kr) and external components (cryostat and PMTs).

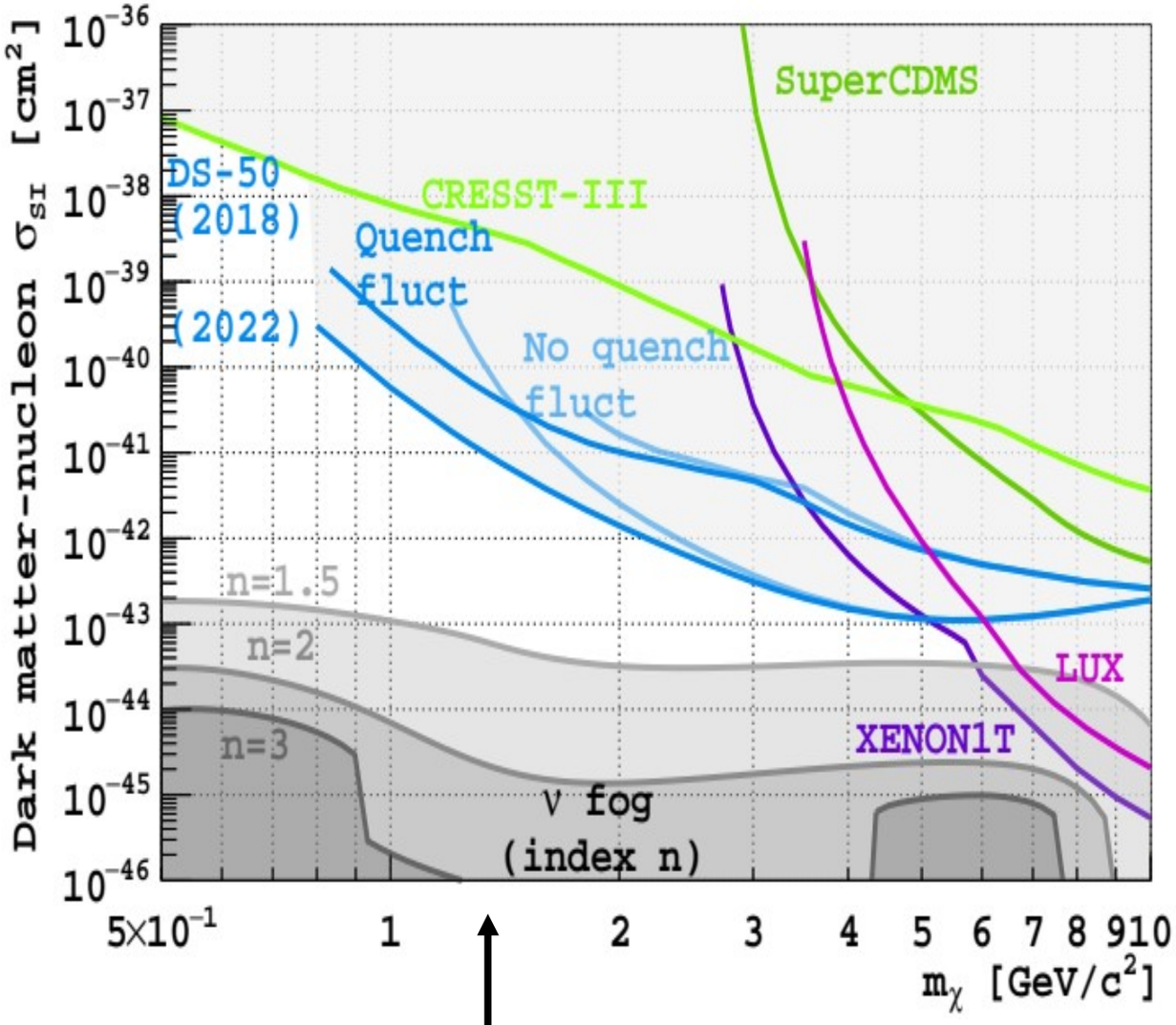
An excess of events with respect to the background model is observed below 4 N_e.

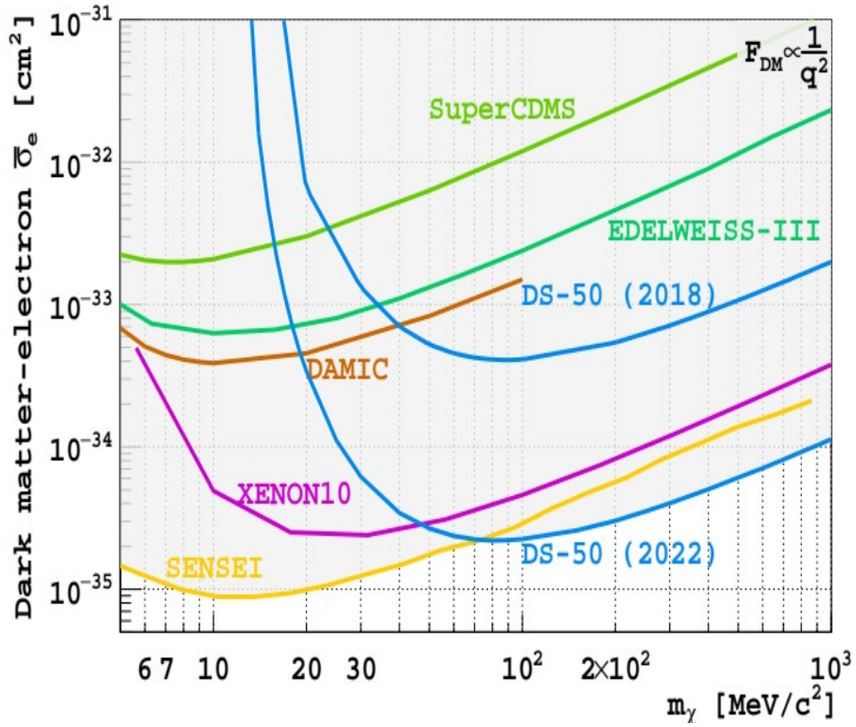
All nuisance parameters fall within 1σ, without any strong correlation

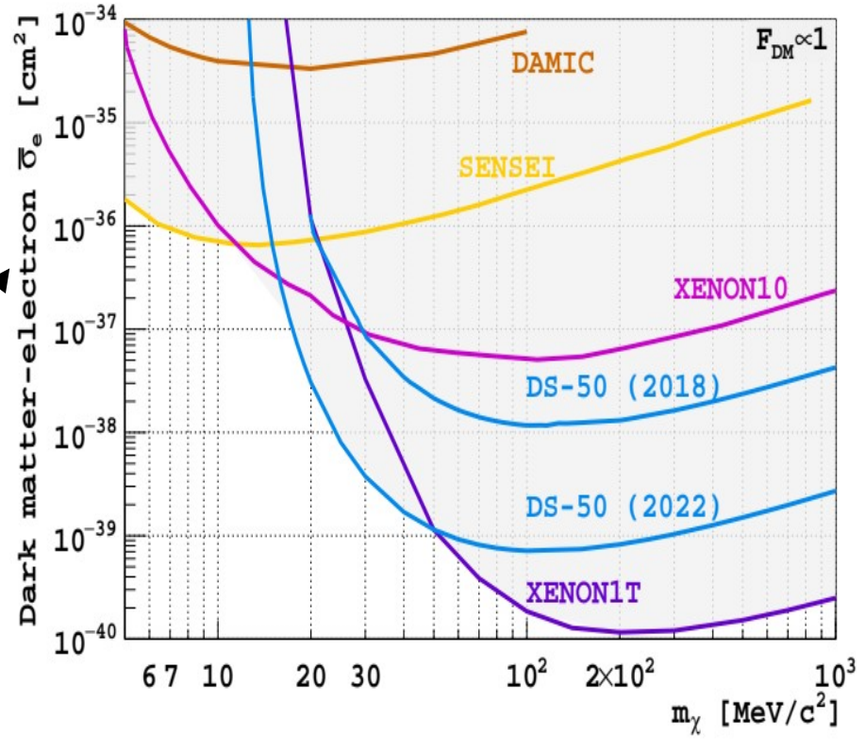




Light WIMP New Exclusion Limits in DS-50







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

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

The most stringent limit at
$M_\chi = [1.2, 3.6]$ GeV/c^2

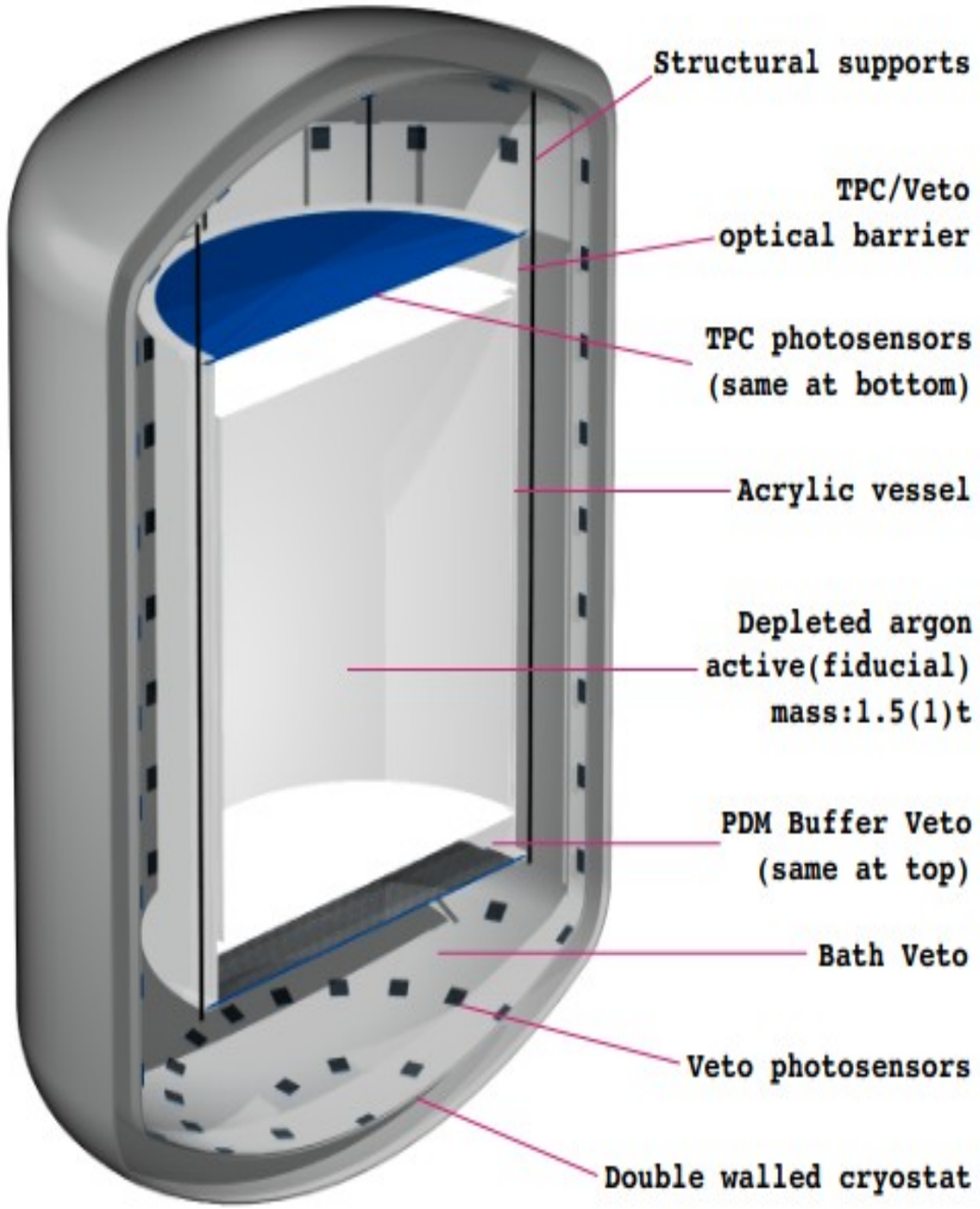
DarkSide-LowMass Detector for Light WIMP Search

Materials r/a purity studied in DarkSide-20k and DEAP-3600

Dominant γ sources (cryostat & photoelectronics) deparated from TPC by active vetoes

SiPM photosensors developed for DS-20k
Much lower γ activity than PMTs

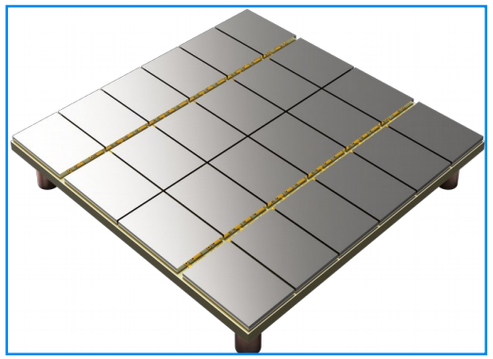
Underground argon low in ^{39}Ar and further depleted, using DS-20k's Urania & Aria plants



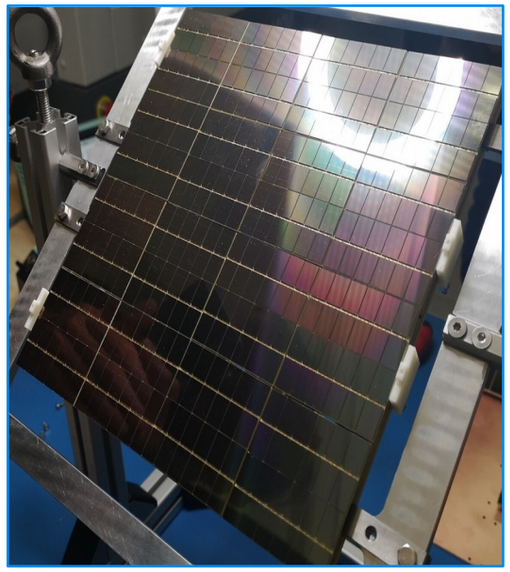
Low-background SiPMs developed for DarkSide-20k

Developed with Fondazione Bruno Kessler (FBK)
Photodetection efficiency: > 40% at 77K
Dark count rate: <0.01 Hz/mm2 at 77 K (7 VoV)

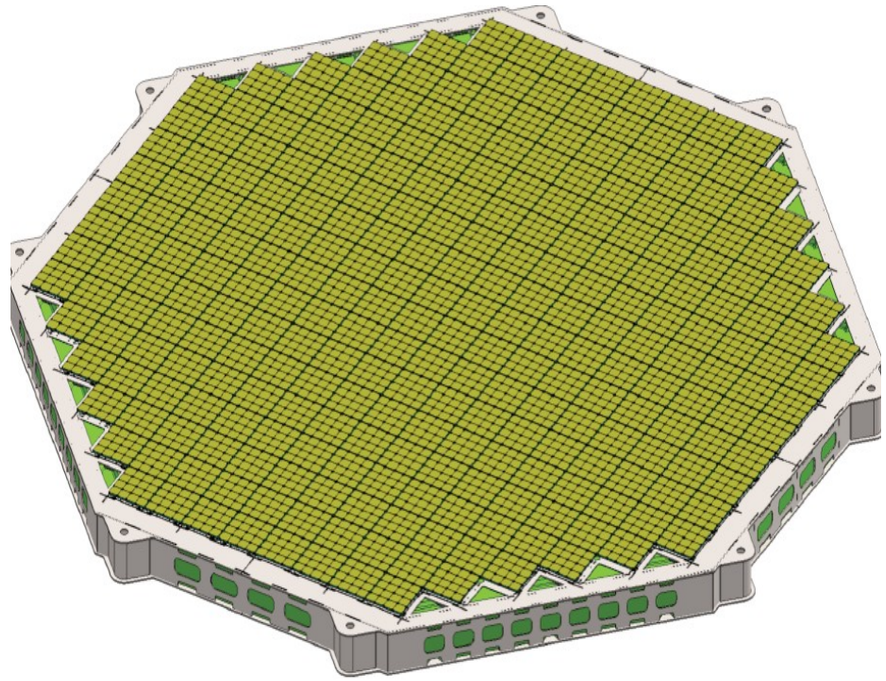
SiPMs
[8×12 mm^2]



Tile (24 SiPMs)
[5×5 cm2]



PhotoDetection Unit (PDU)
(16 tiles, arranged into 4 channels)
[20×20 cm2]

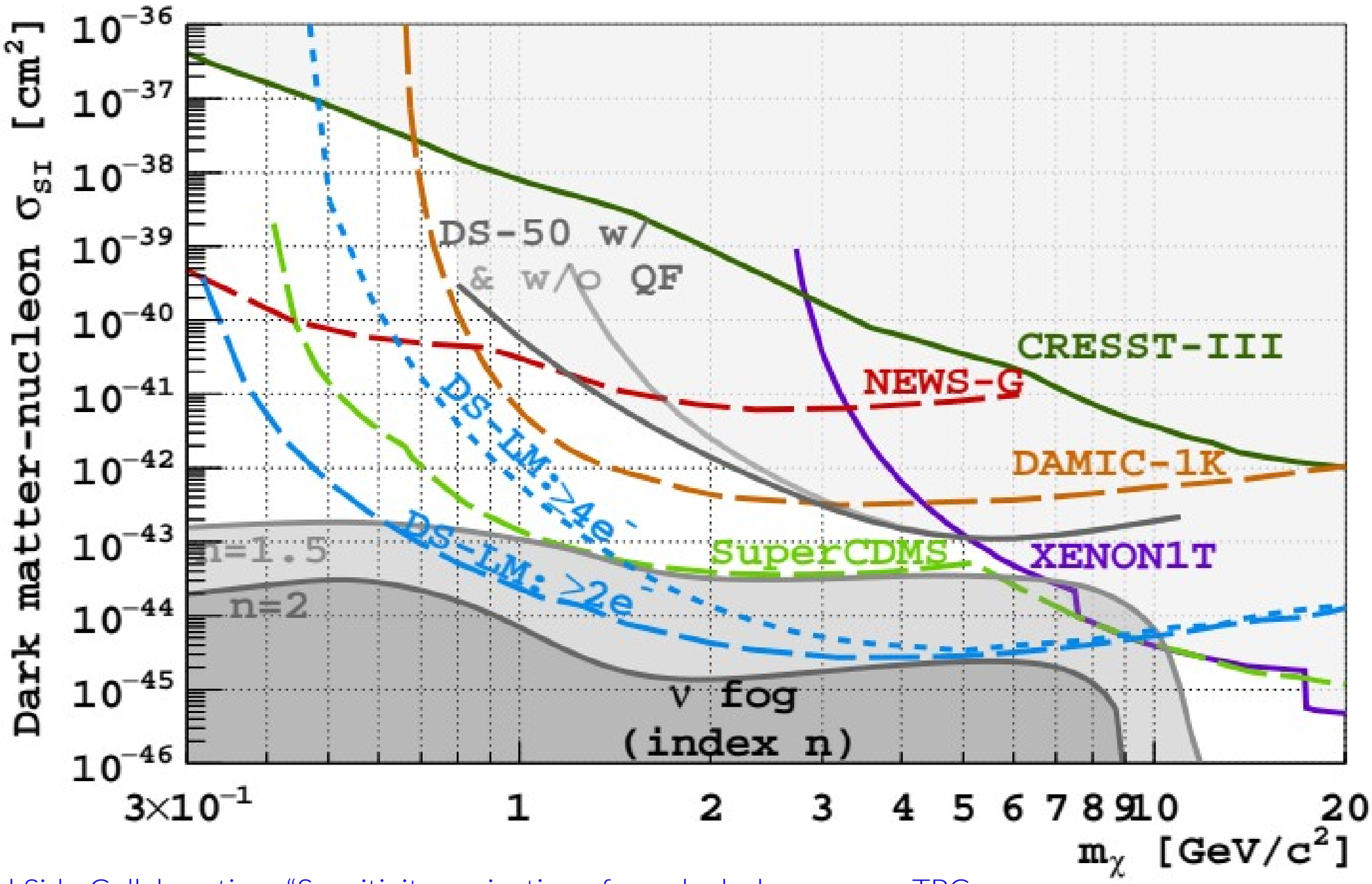


Optical Plane
(264 PDUs)

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

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

Projected and current 90% CL upper limits on spin-independent DM-nucleon scattering for Darkside-LowMass



DarkSide Collaboration. "Sensitivity projections for a dual-phase argon TPC optimized for light dark matter searches through the ionization channel" (2022), arXiv:2209.01177

Conclusion

- Search for low mass WIMPs was carried out for the extended dataset from 2-years of DarkSide-50 experiment with low-radioactivity Underground Argon target.

- Liquid Argon Time Projection Chamber achieved high accuracies in measuring the extremely low energy depositions in liquid argon targets.

- The new analysis benefits from efficient data selection based on better understanding of the detector, more accurate calibration of the detector response, improved background model.

- The most stringent exclusion limit achieved on spin-independent DM-nucleon scattering for low-mass WIMPs at $M\chi = [1.2, 3.6]$ GeV/c^2. arXiv:2207.11966-11968

- New experiment DarkSide-LowMass has been designed for low-mass WIMP search down to the “solar-neutrino fog”. arXiv:2209.01177

- DarkSide-20k, DarkSide-LowMass, and ARGO experiments will explore WIMP down to the “solar-neutrino fog”. DS-20k data taking will start from 2026.

Thank you for your attention