Search for low mass WIMP dark matter with DarkSide-50

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on behalf of DarkSide-50 Collaboration

21 September 2022 | LIDINE at Warsaw

European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480
Dark Wave

The DarkSide Program

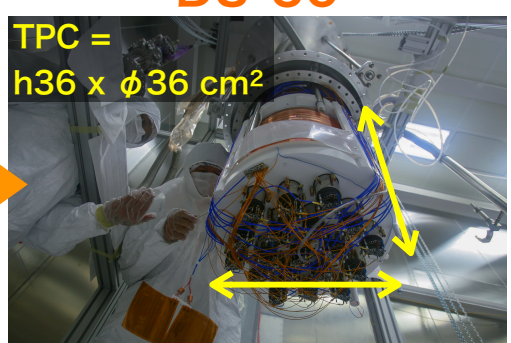
-Direct WIMP Dark Matter Search with Argon-

- Looking for **dark matter in our galaxy scattering from argon atom**
- Based on **dual-phase argon time-projection-chamber (TPC)** (liquid and gas)
- Locating at LNGS, a **deep underground laboratory**, in Italy

DS-10

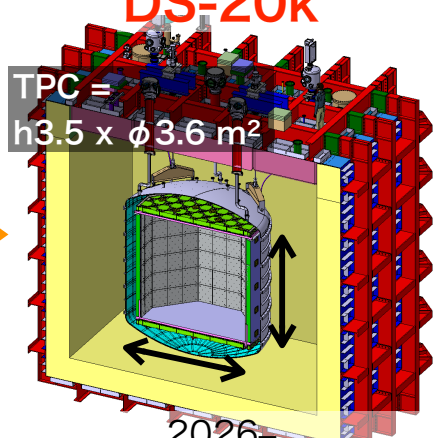
2010–2012
10 kg-scale prototype
Proofing detector performance

DS-50



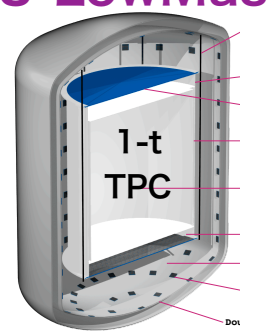
2013–2019
46 kg active mass
Yielding many physics results
(PRD98,102006, PRL121,081307,..)

DS-20k



2026-
20 tonne fiducial mass
with many new technologies
Approaching 'ν-floor'

DS-LowMass

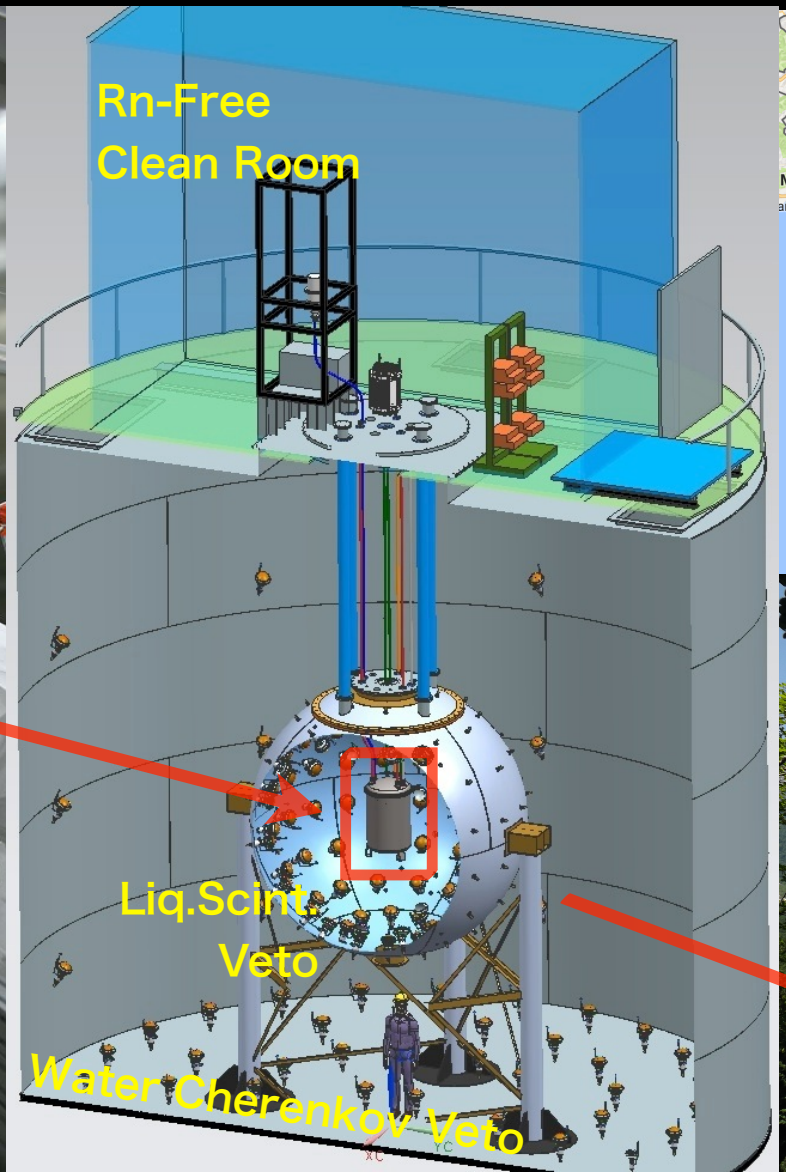


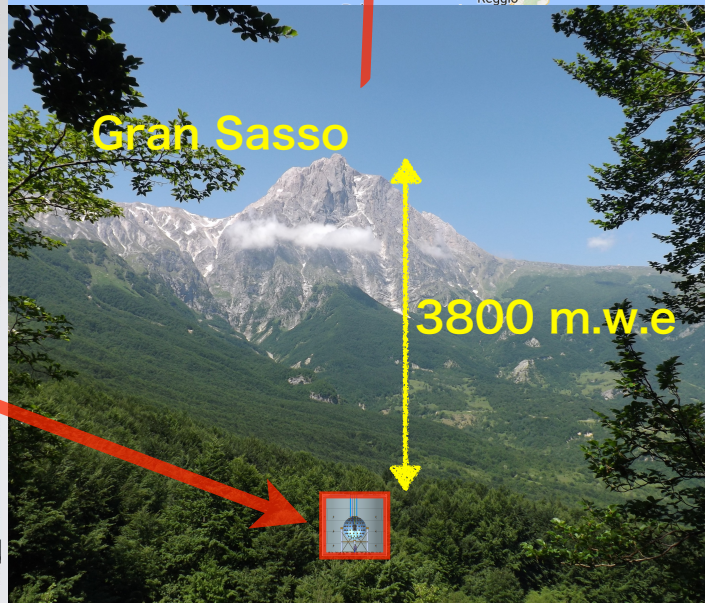
ARGO

At SNOLAB ~203X
3k tonne-year
Ultimate detector

Reaching 'ν-floor'

DarkSide-50 Detector

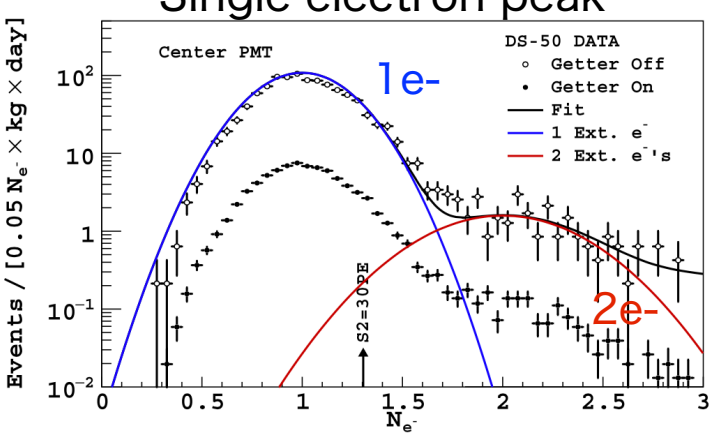




Dual-Phase Argon TPC

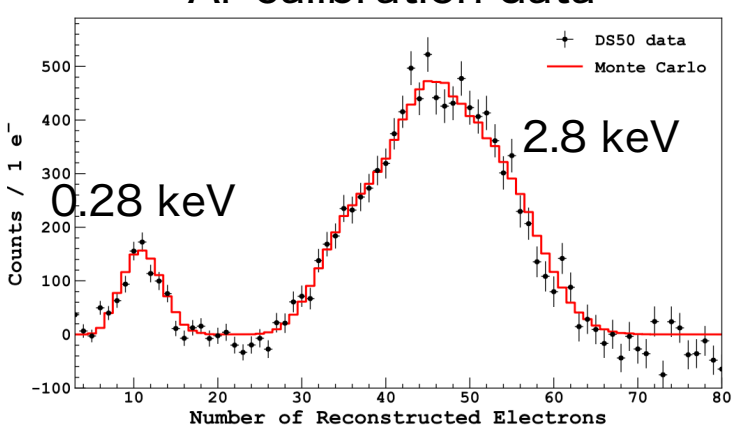
- **Efficient electron detection capability** down to 1e- via the secondary electroluminescence signal (S2)
  - Ionization electron extracted to gas-phase with **~100% efficiency**
  - High amplification of S2 photon **(23 PE/e- in DS-50)**

Single electron peak

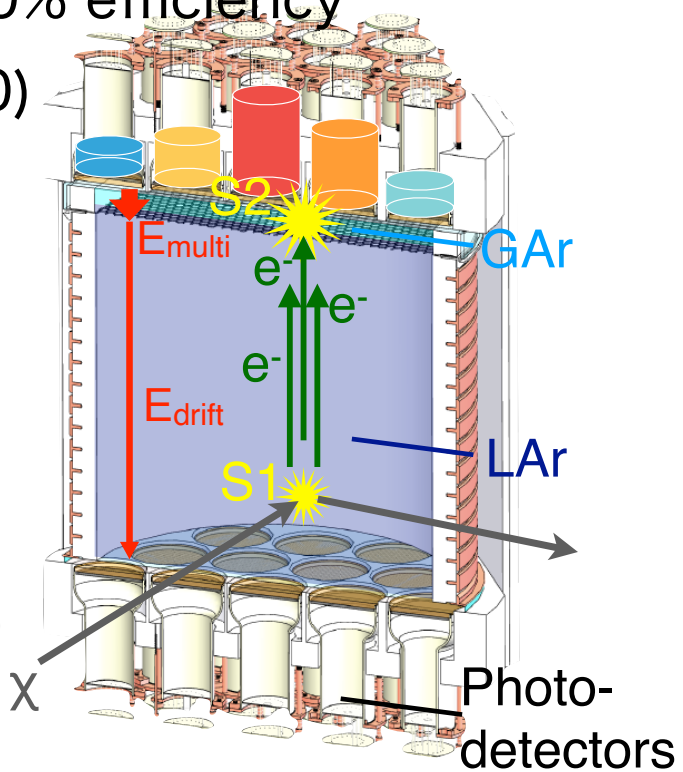


PRL121 081307

^{37}Ar calibration data



PRD104 082005

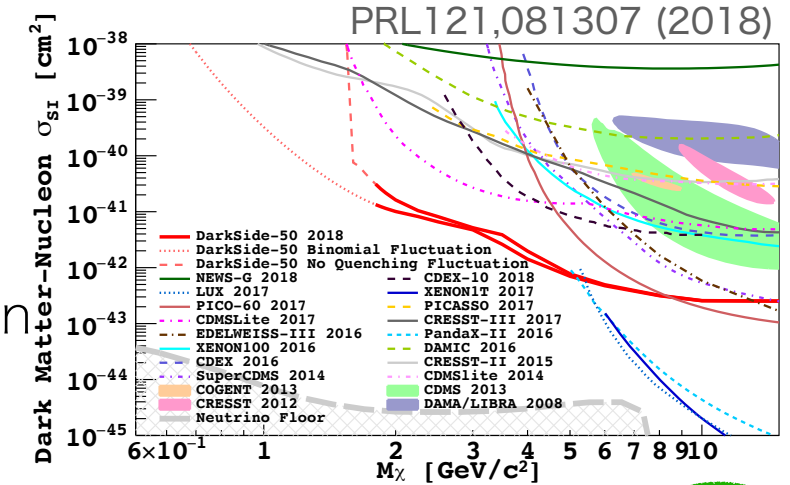


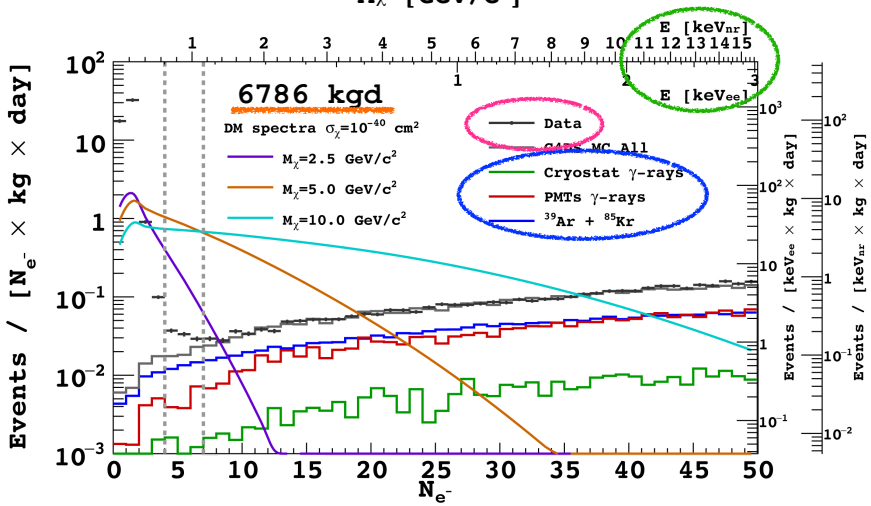
Sensitive to very low-energy deposition

DS-50 Low-Mass WIMP Search

- DS-50 published the first stringent exclusion limit on GeV/c^2 region in 2018 using 350 live-days dataset (6.8 tonne-days)
- A new analysis has been conducted benefitting from many updates, such as
  - Extended exposure,
  - Improved data selection criteria,
  - More accurate detector calibration,
  - Better background modeling

PRL121,081307 (2018)

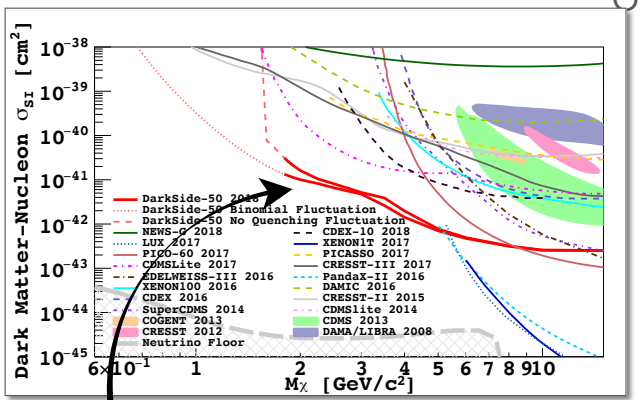


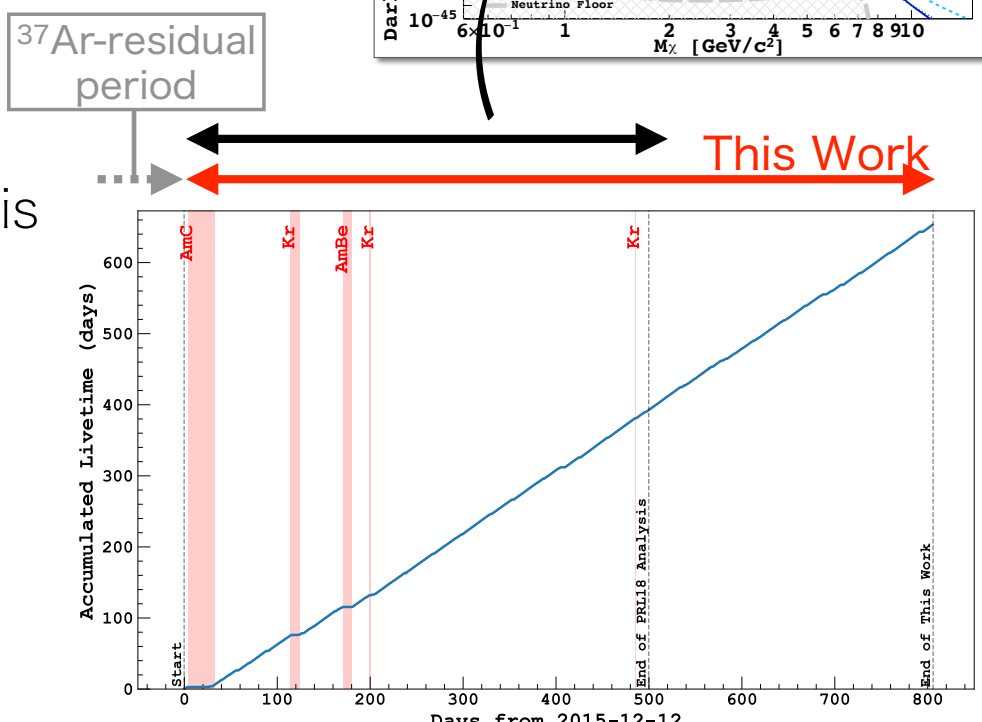


New result from the updated analysis is presented here

Dataset

- DarkSide-50 **Underground Argon** campaign
  - First 9 months of data is not used to wait for the ^{37}Ar (cosmogenic) to decay
  - 650 live-days of data (12 ton-day); ~x1.8 exposure than previous analysis
- No significant break without several calibration campaigns;
- **Detector was quite stable for the whole period of 26 months**
  - δ T = ±0.02 K, δ P < ±0.005 psi,
  - δ (S1) ~0.4%, δ (S2) <1%, τ_e >10 ms (more than x20 of the full drift time)





Data Selection

Fiducialization

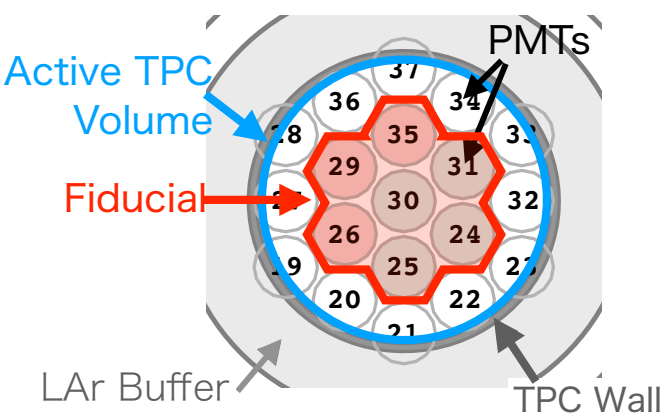
- Events **beneath 7 innermost PMTs** are selected to shield radiation from materials (Same as the 2018 analysis)
- Uncertainty due to thermal contraction (~1%) is included

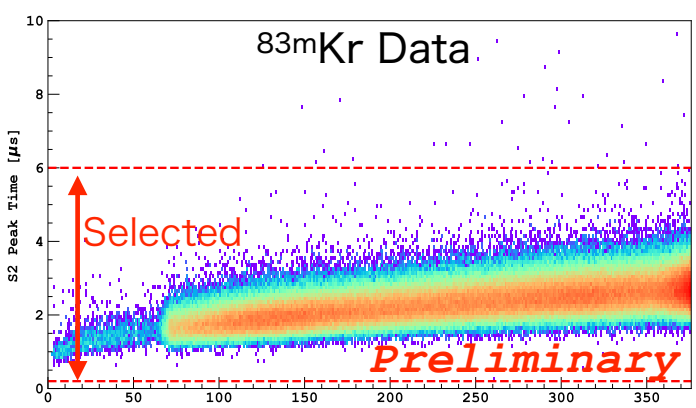
Pileup pulses

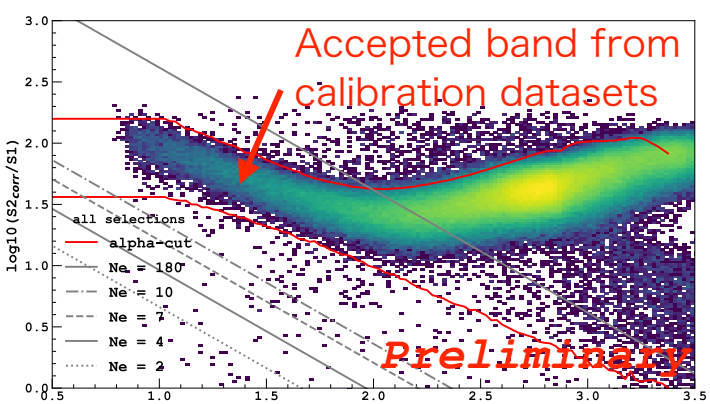
- **Pulse's rise-time** and **width** are used to remove multiple low-S2 pulses misidentified as one pulse
- Efficiency is assessed as >95% at 4e-

Surface-α veto

- **S2/S1** band cut is imposed to reject α-decay event on surface mimicking low-Ne signal
- They have large S1 associated with small S2 induced by photoelectric effect

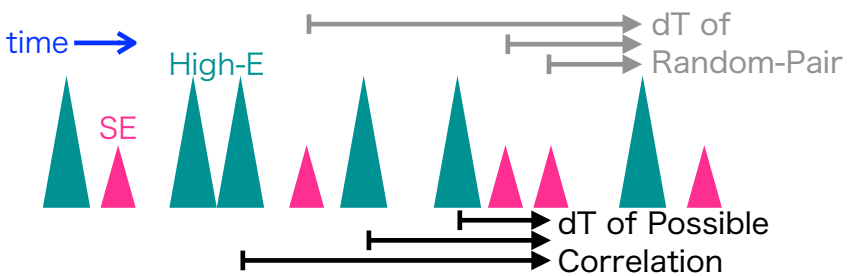


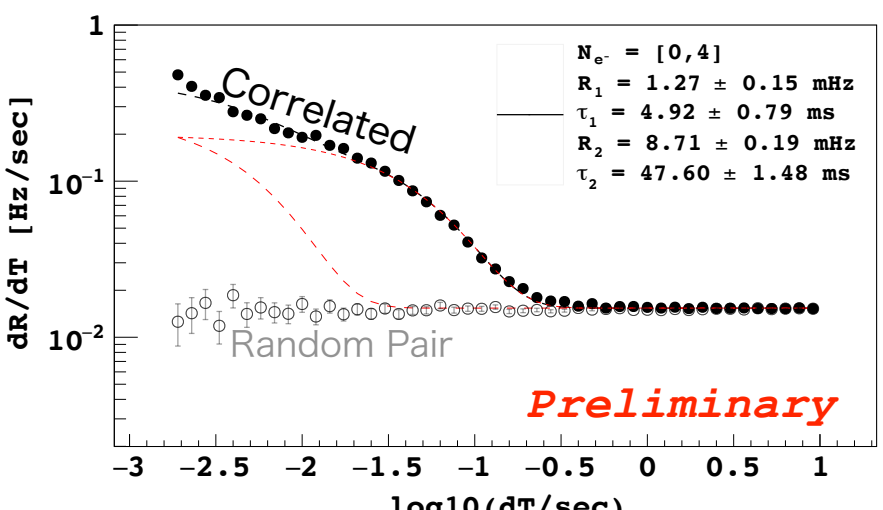




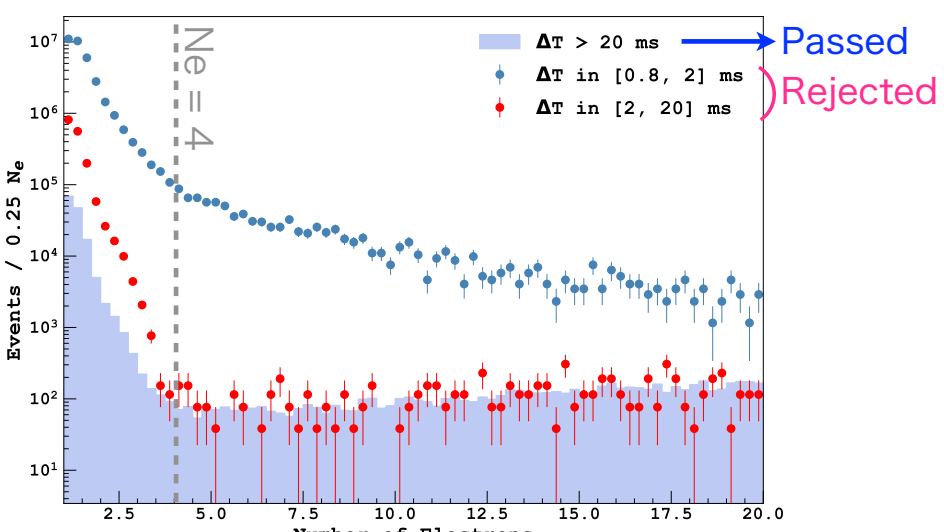
Data Selection

Spurious Electron Veto





- A few delayed electrons signal is found after normal event : "Spurious Electron (SE)".
- DS-50 observes the SE rate **exponentially decaying** with **~5 ms** and **~50 ms** time-constants
- Based on our best knowledge, 20 ms veto is applied for all events to maximize S/B ratio



* See also: Astropart.Phys. 140 102704 (2022)

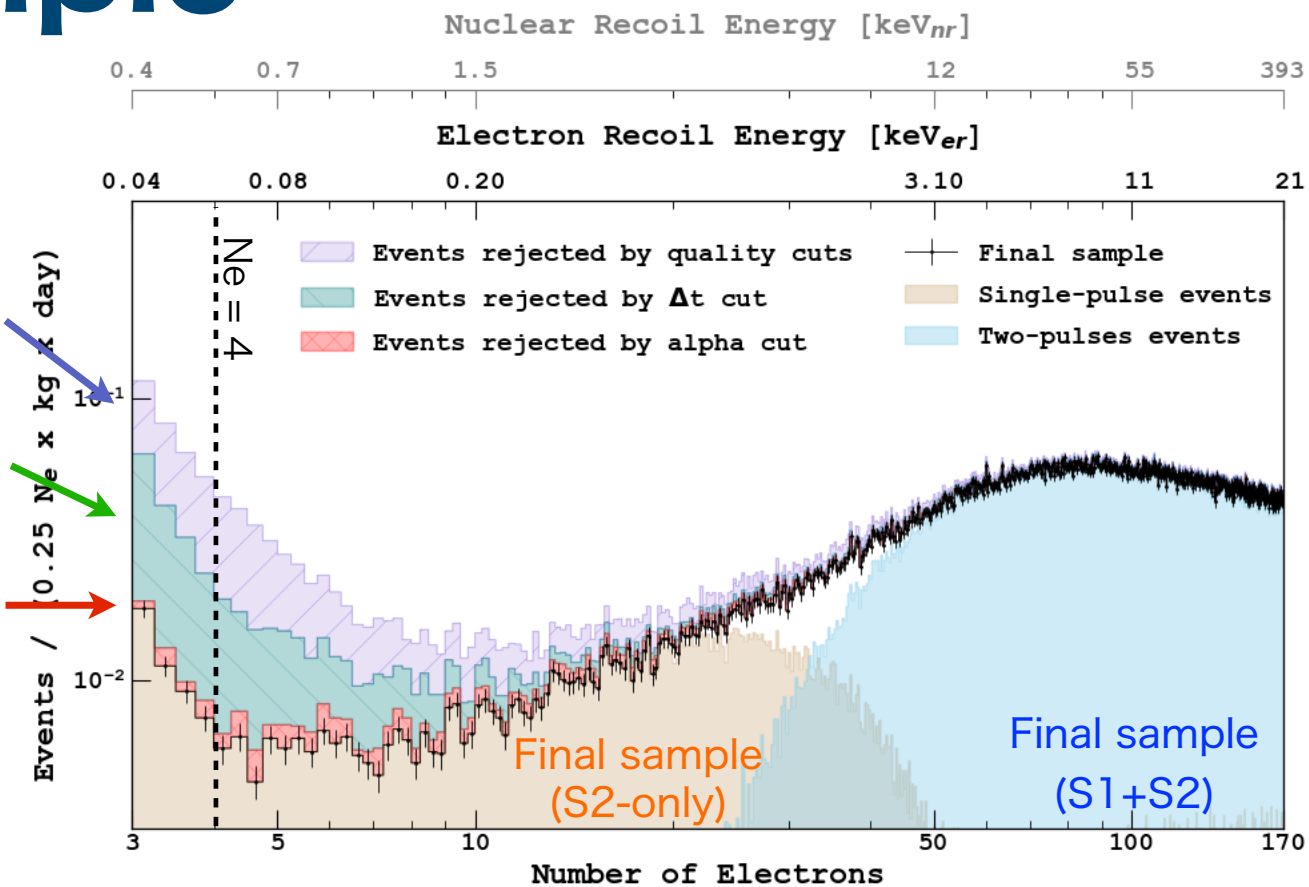
** Another SE-dedicated paper is in preparation

Data Sample

Multiple-pulses &
Pileup events

SE events &
Incorrectly triggered events

Surface-α events



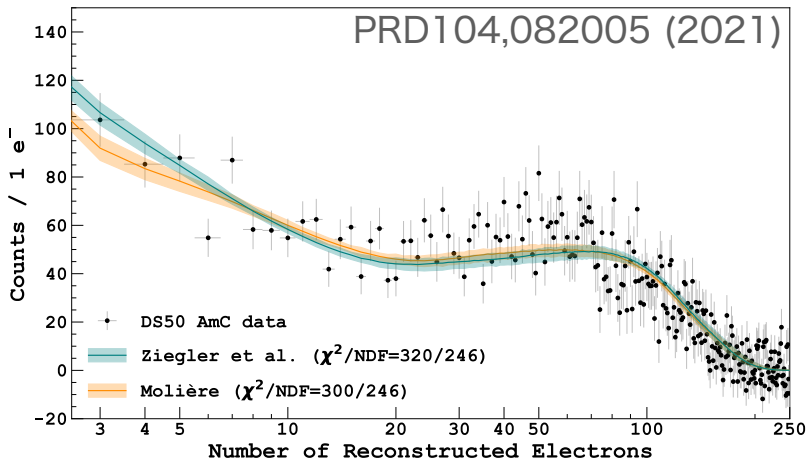
Signal efficiency is >95% for the region of interest (Ne = [4, 170])

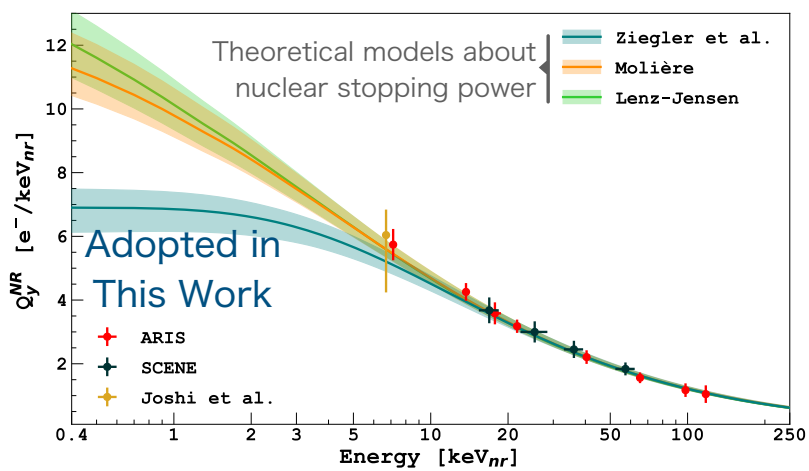
LAr Response Calibration

Ionization yield models tuned for new dedicated measurements

NR Response

- The model is based on Ar+-e- recombination process and energy loss due to nuclear stopping power
- Parameters are tuned using **DS-50 neutron calibration data** (AmC and AmBe) and external datasets from SCENE and ARIS experiments
- We use the most "conservative" prediction among several theoretical predictions





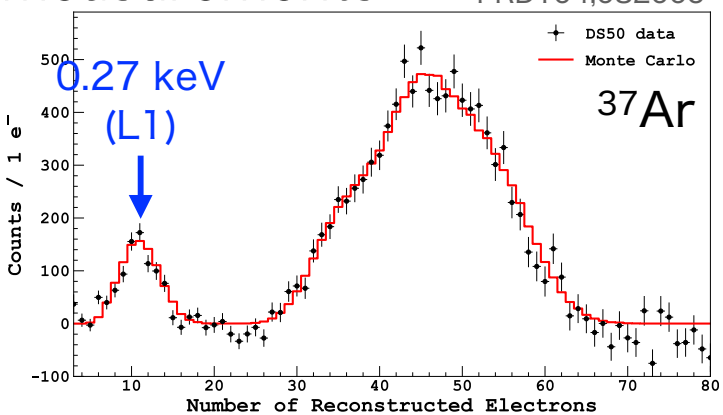
LAr Response Calibration

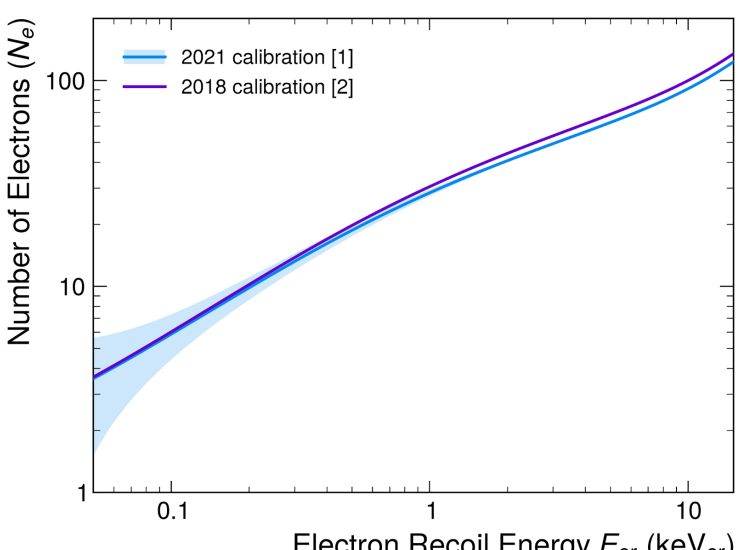
Ionization yield models tuned for new dedicated measurements

PRD104,082005

ER Response

- 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 RoI to be extended up to 170 e- (21 keV)**



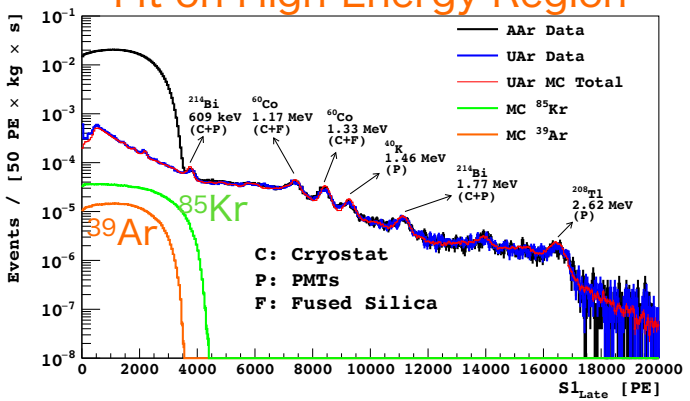


Background -^{39}Ar & ^{85}Kr-

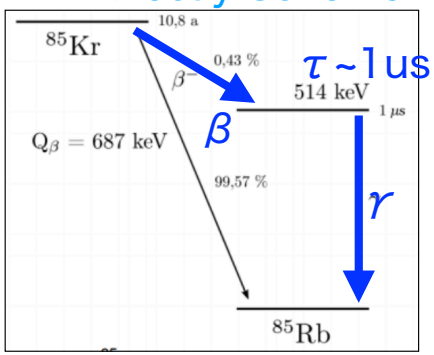
- The activities are constrained by fitting higher energy spectrum, cross-checked by $\beta+\gamma$ fast coincidence events
  - ^{85}Kr : 1.8 ± 0.1 mBq/kg
  - ^{39}Ar : 0.7 ± 0.1 mBq/kg
- The spectrum shape is accounted for recent calculations of **atomic exchange** and **screening effects** with associated uncertainties

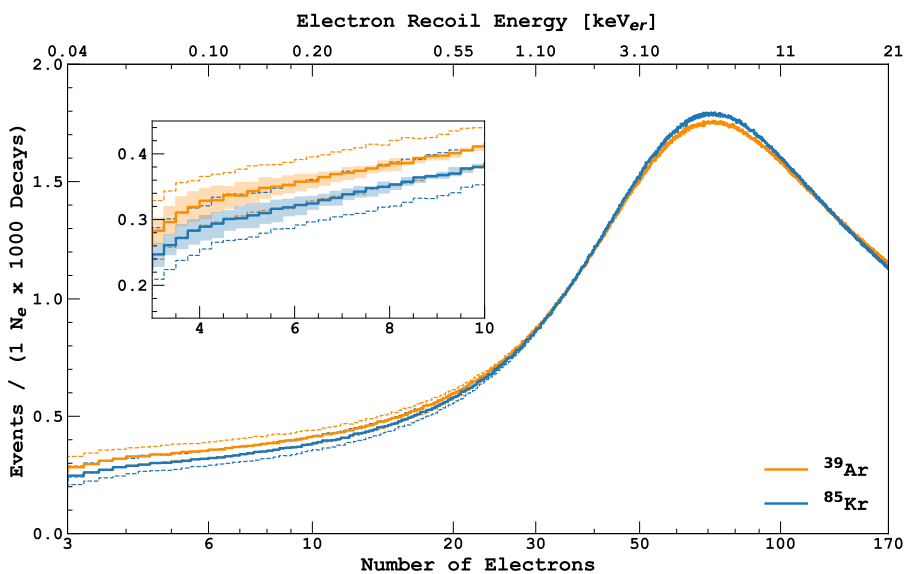
* See detail: PRA90,012501 & PRC102,065501

Fit on High-Energy Region



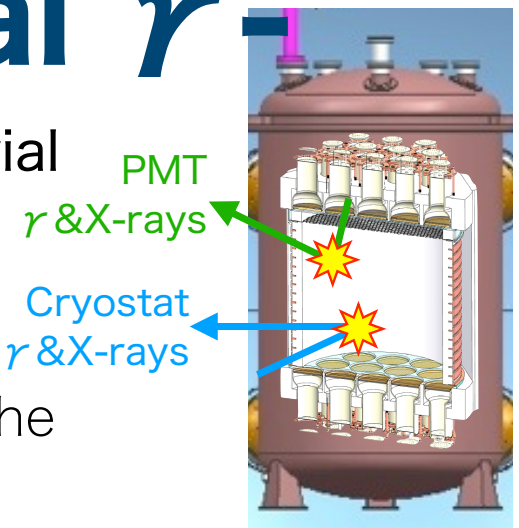
^{85}Kr Decay Scheme

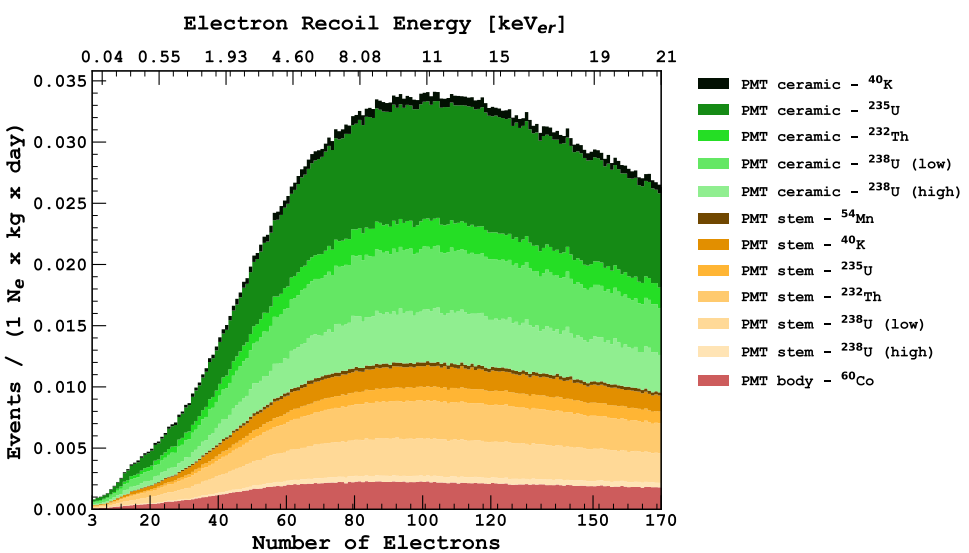


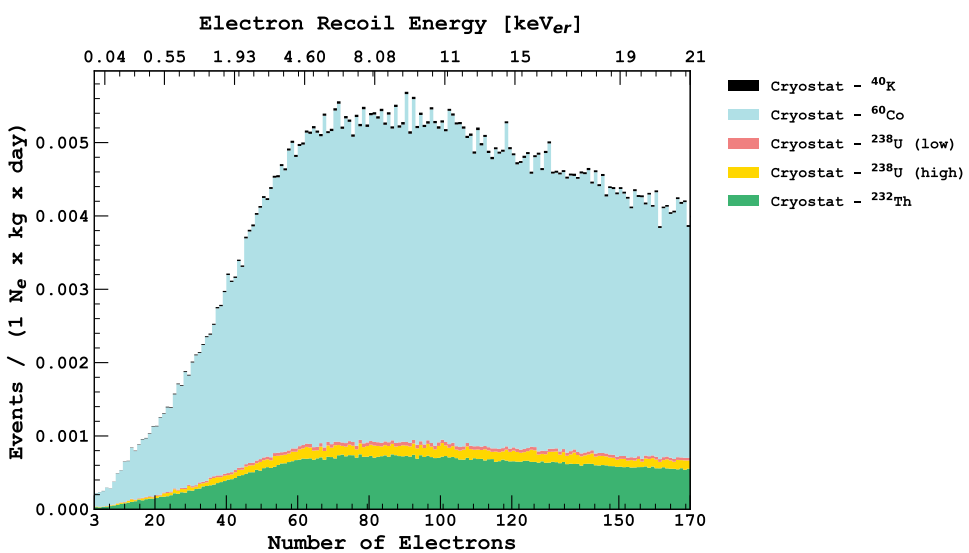


Background -External γ -

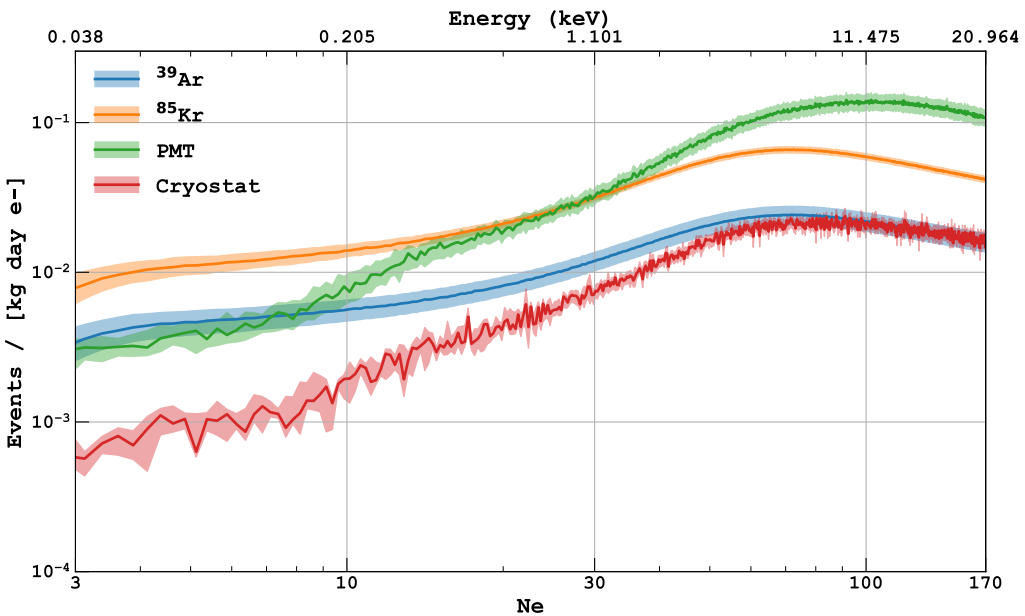
- **Extensive simulation** has been conducted with **material radioassay measurements**
  - Each of these activities is constrained within ~10%
  - The extended energy RoI allows to further constrain the activities a posteriori

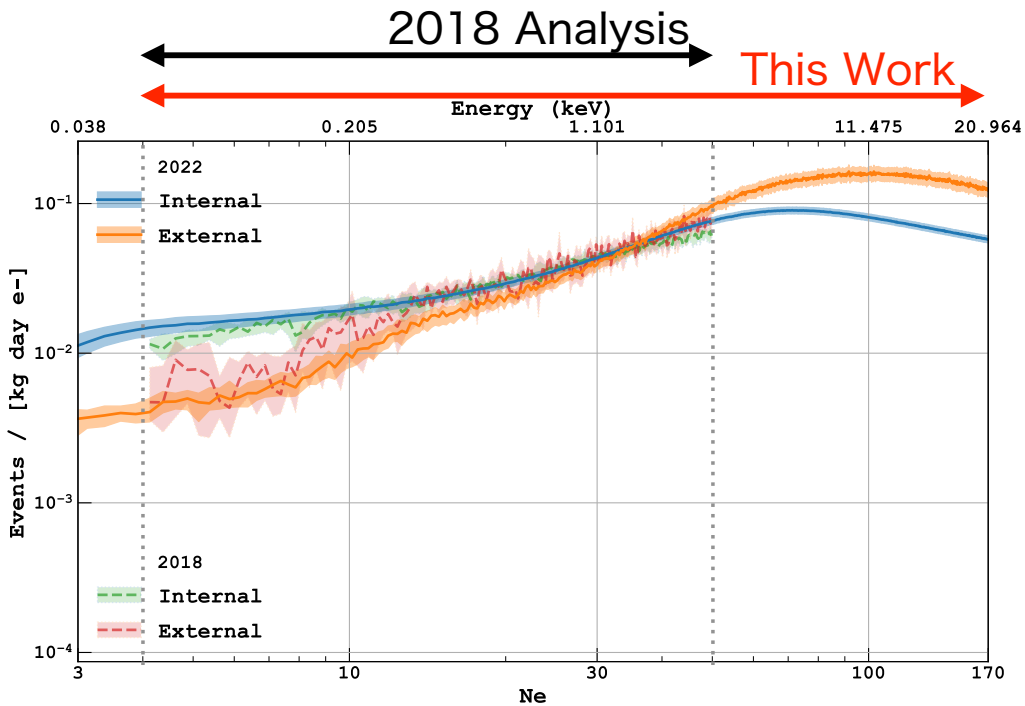






Background Summary

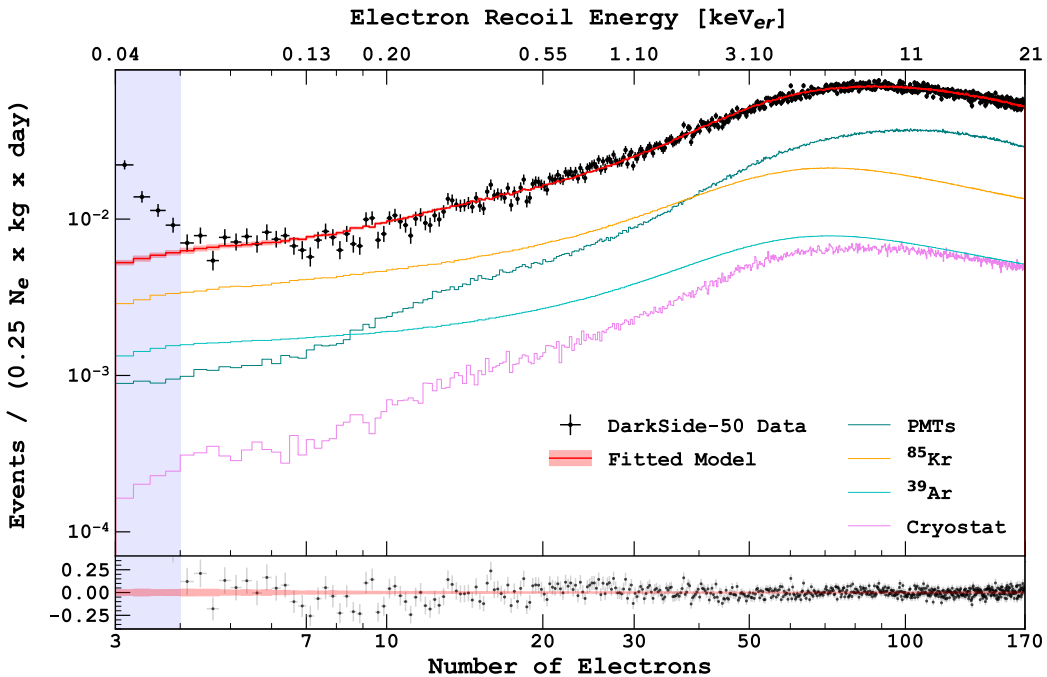


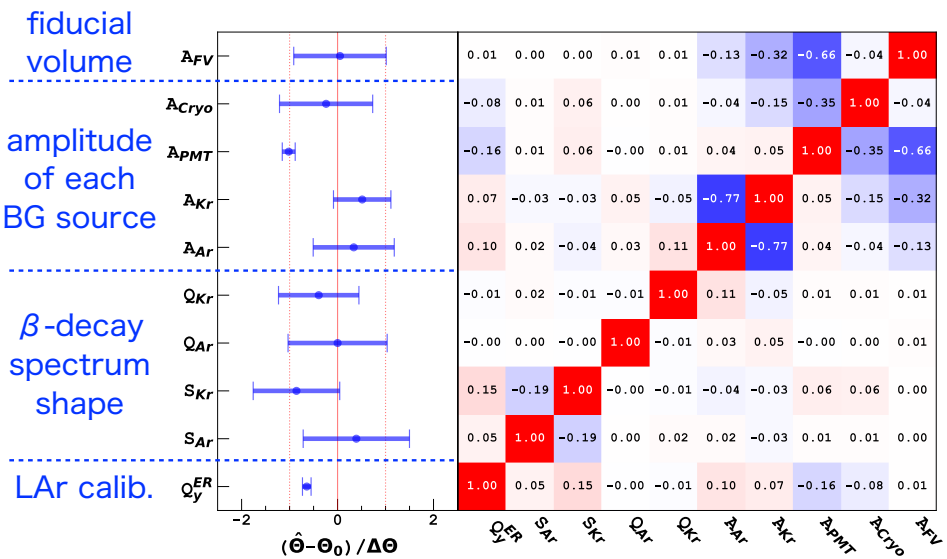


Compared to the previous analysis,

- **Each background component is well constrained** a priori
- The energy RoI is extended **up to 170 e- (21 keV)** thanks to new LAr calibration

Result : Background-Only Fit



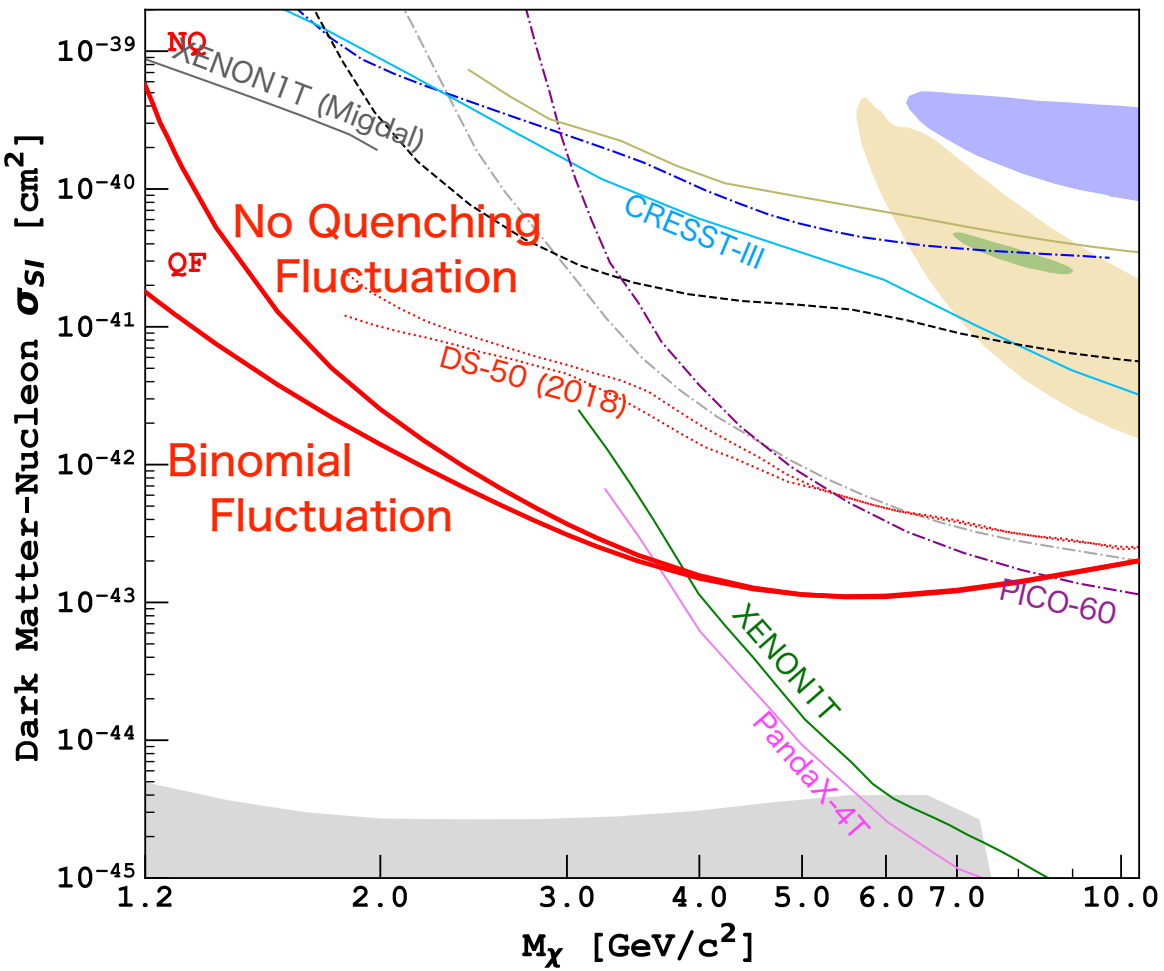


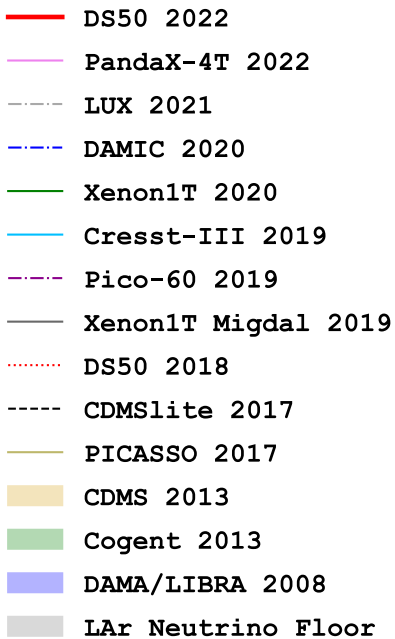
Observed data is consistent to the background model prediction within the systematic uncertainties

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

WIMP Exclusion Result

arXiv:2207.11966





The most stringent limit at

M_χ = [1.2, 3.6] GeV/c^2

Conclusion

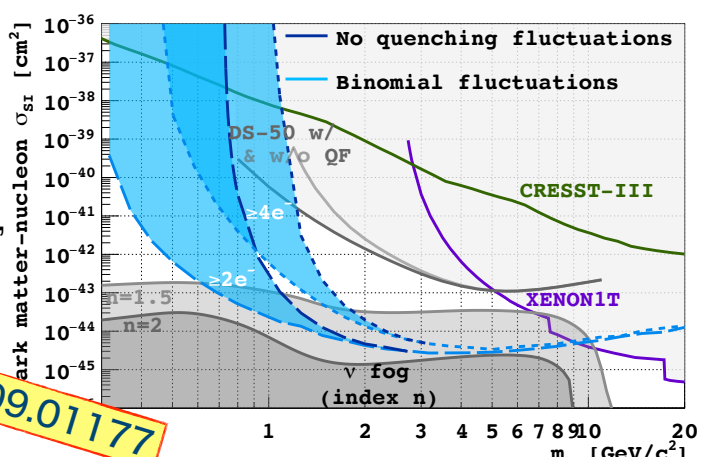
- New result for low mass WIMP search is presented from the extended dataset from 2-yr of DarkSide-50 UAr campaign
- Compared to the previous result, the new analysis benefits from..
  - efficient data selection based on better understanding of the detector,
  - more accurate calibration of the detector response,
  - improved background model
- Unfortunately we do not observe WIMP signature, setting the most stringent exclusion limit at M_χ = [1.2, 3.6] GeV/c^2

arXiv:2207.11966-11968

Future Prospect

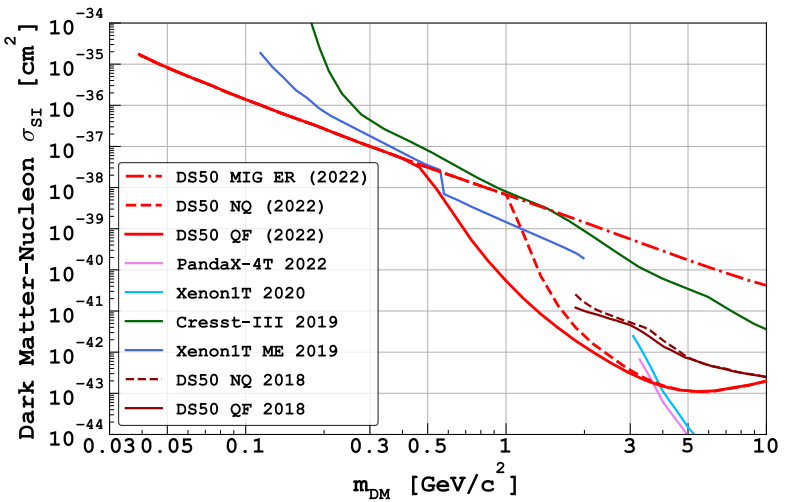
- DarkSide-20k, DarkSide-LowMass, and ARGO will explore low mass WIMP down to the "solar-neutrino fog"
  - DS-20k data taking will start from 2026
  - Sensitivity projection of DS-LM has recently posted

arXiv:2209.01177



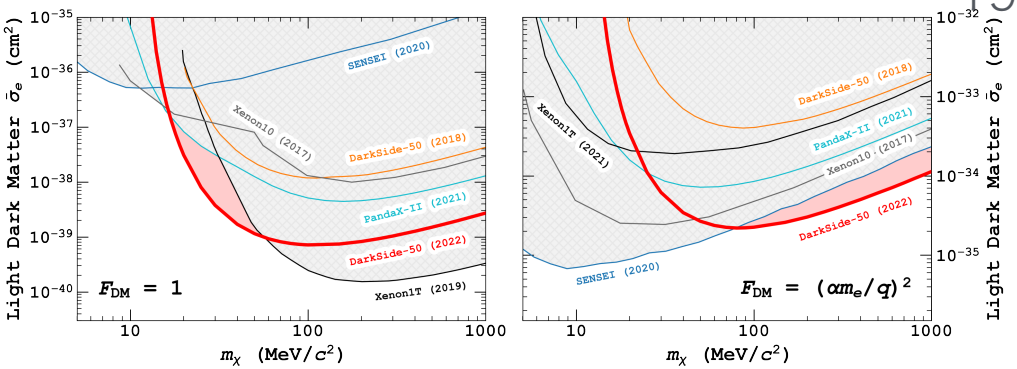
Backup

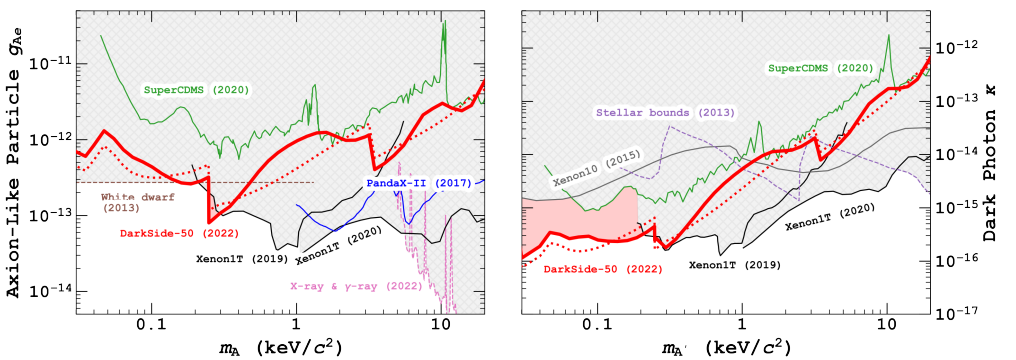
WIMP with Migdal Effect

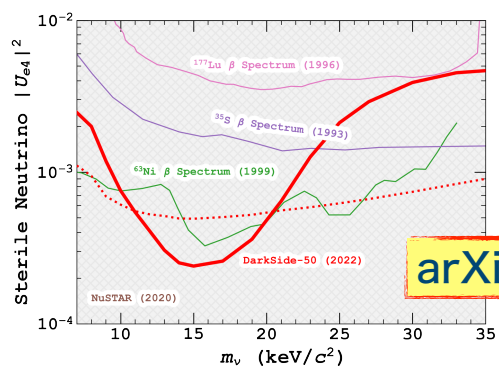


arXiv:2207.11967

Electron Coupling Channel

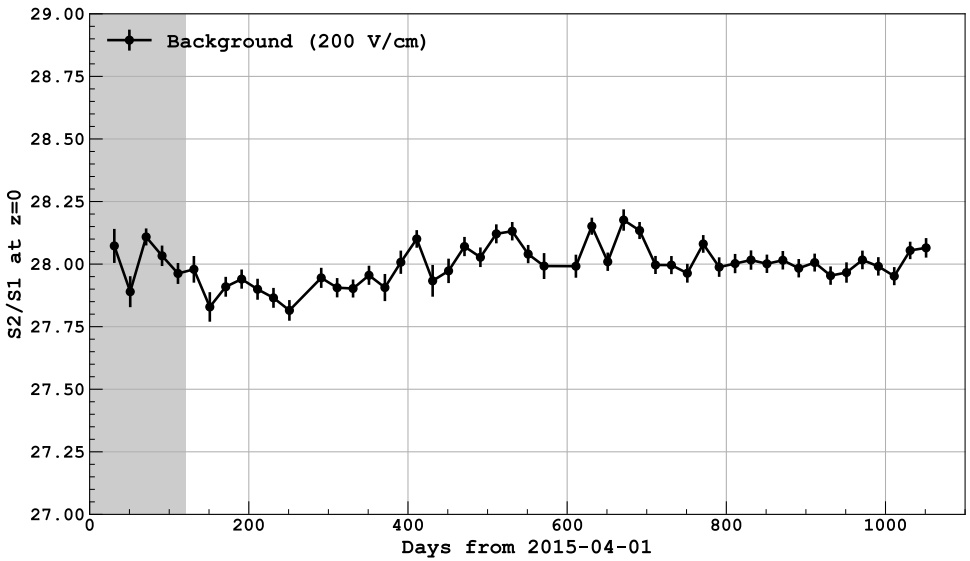




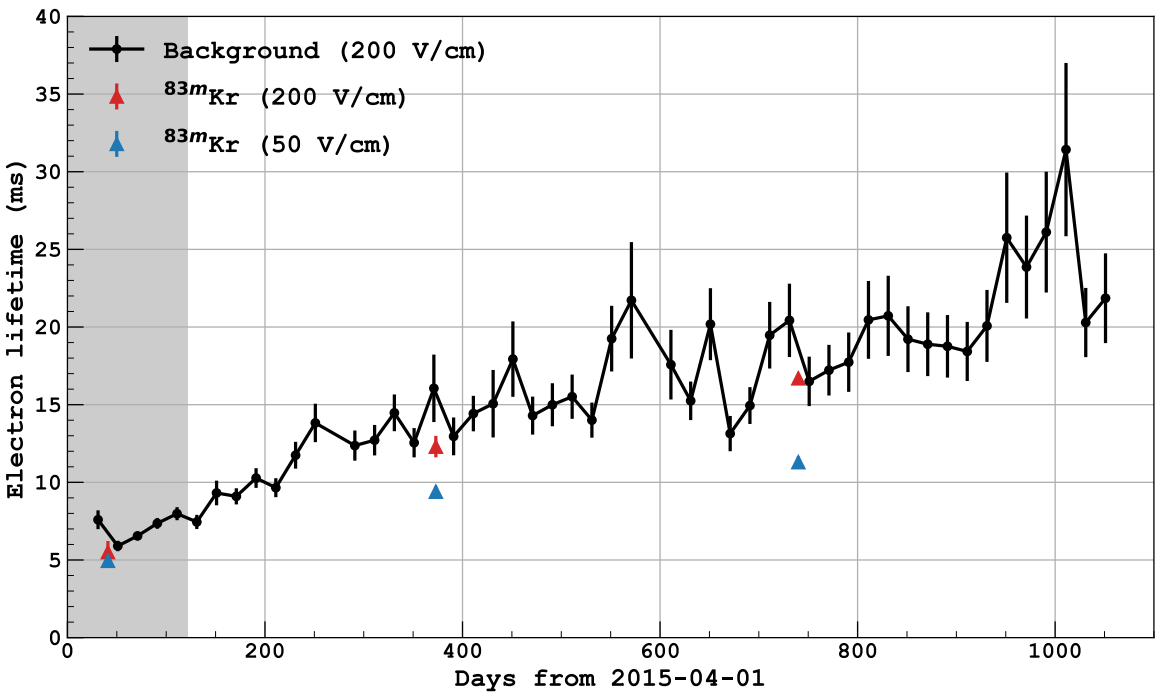


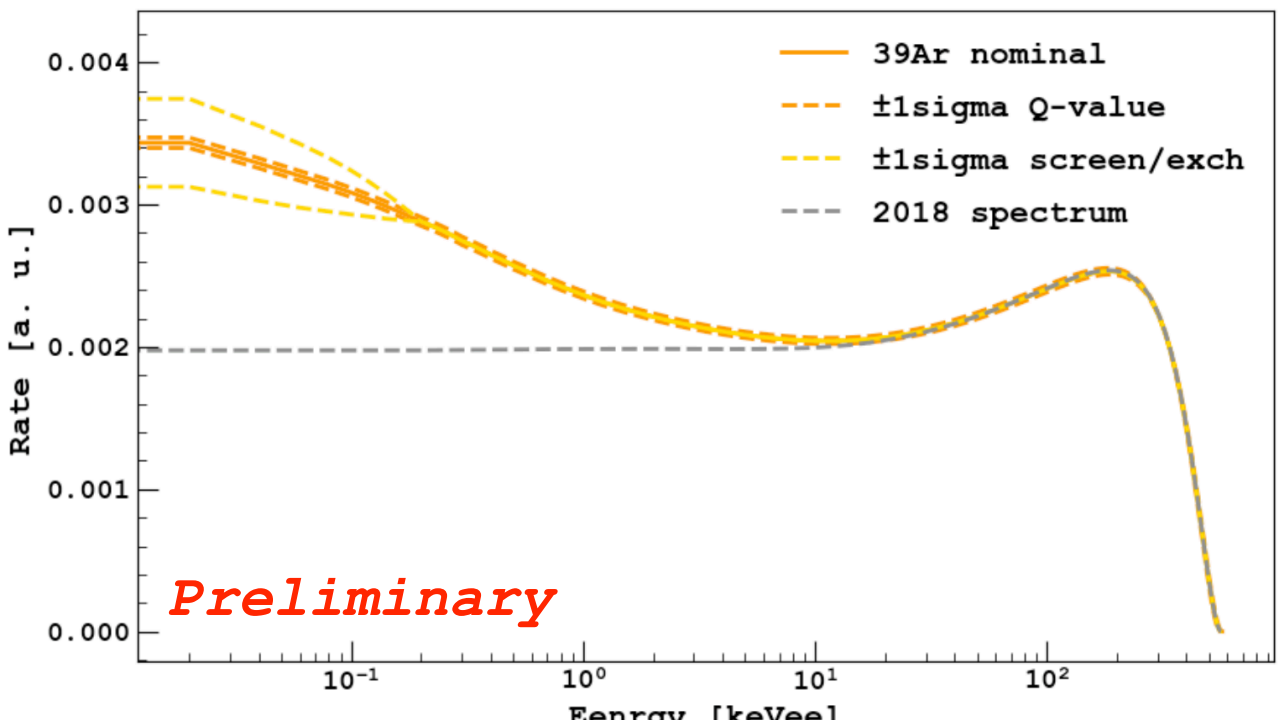
arXiv:2207.11968

Temporal Evaluation



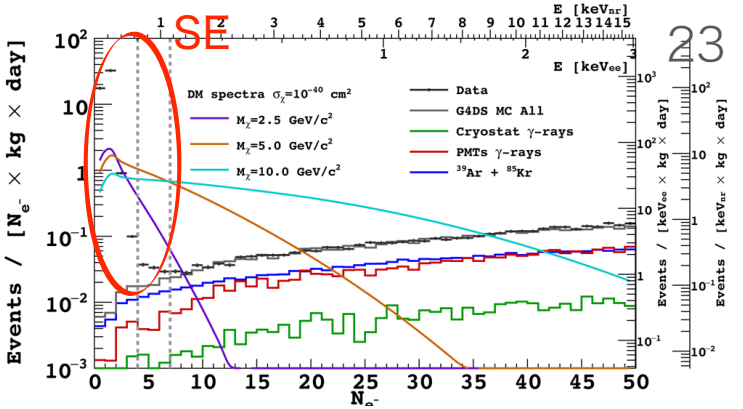
Electron Lifetime




39Ar nominal
±1sigma Q-value
±1sigma screen/exch
2018 spectrum
Preliminary
Rate [a. u.]
0.004
0.003
0.002
0.001
0.000
10^{-1}
10^{0}
10^{1}
10^{2}
Eenrgy [keVee]

Spurious Electron

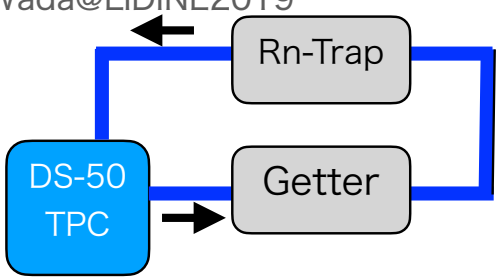
Some "hint" about the origin of low-Ne event (so-called spurious electron, SE) from DS-50 data

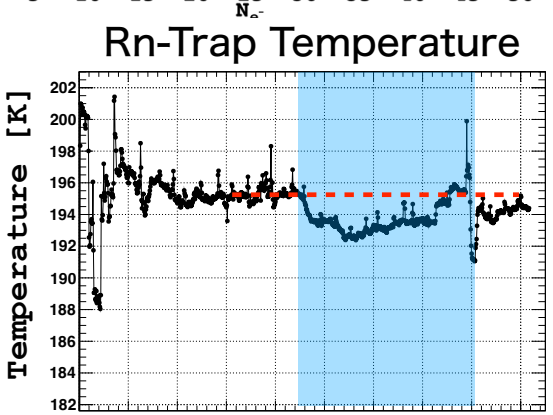


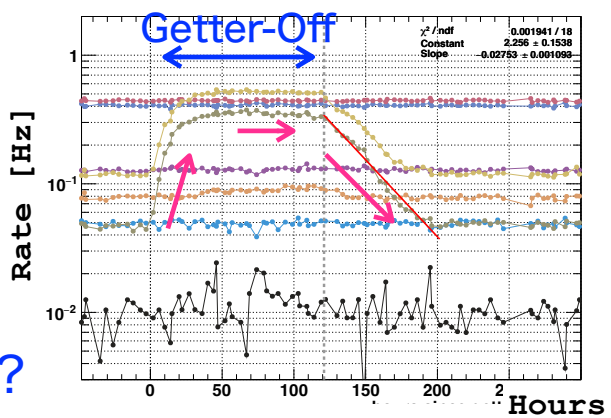
Correlation with detector operation

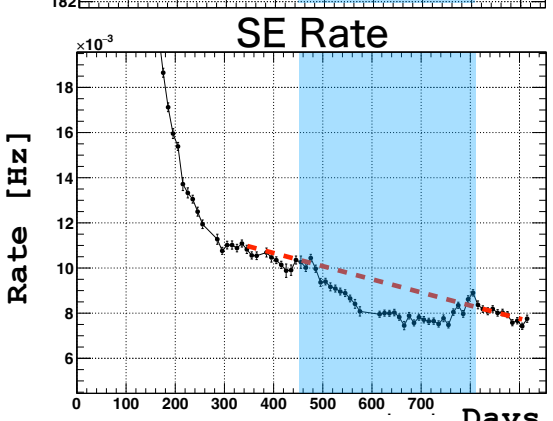
- Argon is continuously purified during the operation
- The SE rate increases during **getter-off period**
- The SE rate looks to have a correlation with **Rn-Trap temperature**
- (At least some of) the origin of SE could be impurity in argon?

M.Wada@LIDINE2019



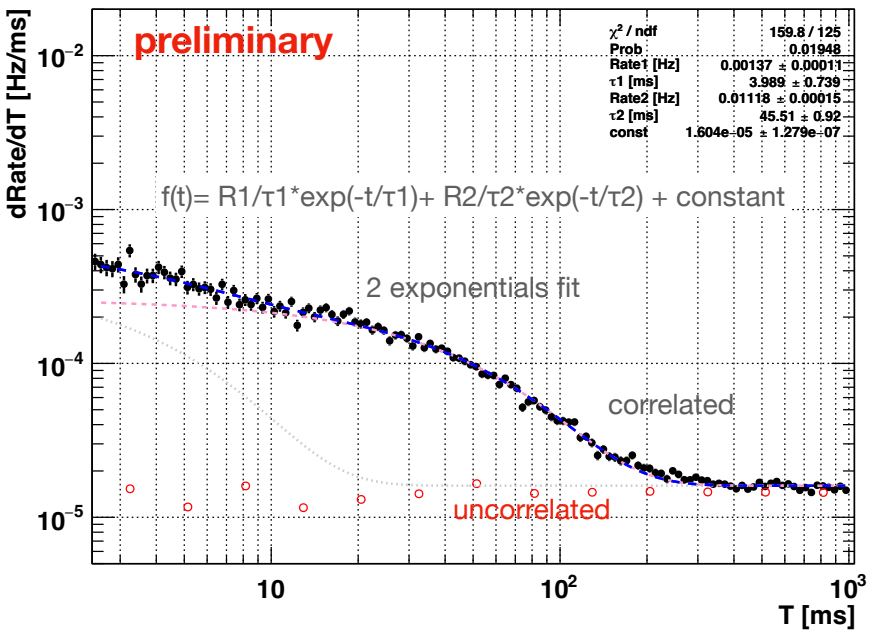




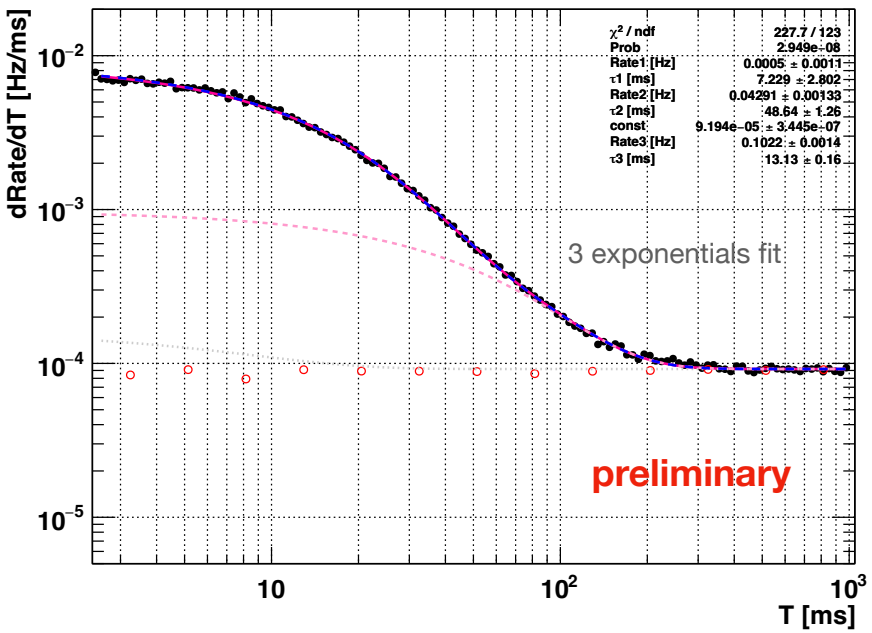


SE Time Correlations

Normal runs (300-320 days)



Getter off data



- At least two exponentials are necessary. Not power law unlike in Xenon based TPC.

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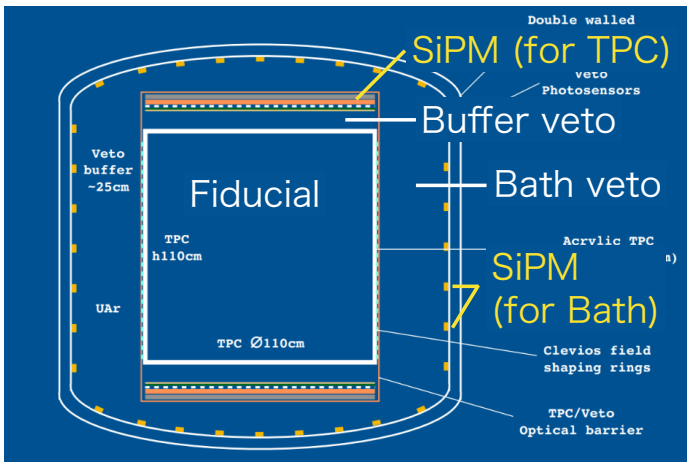
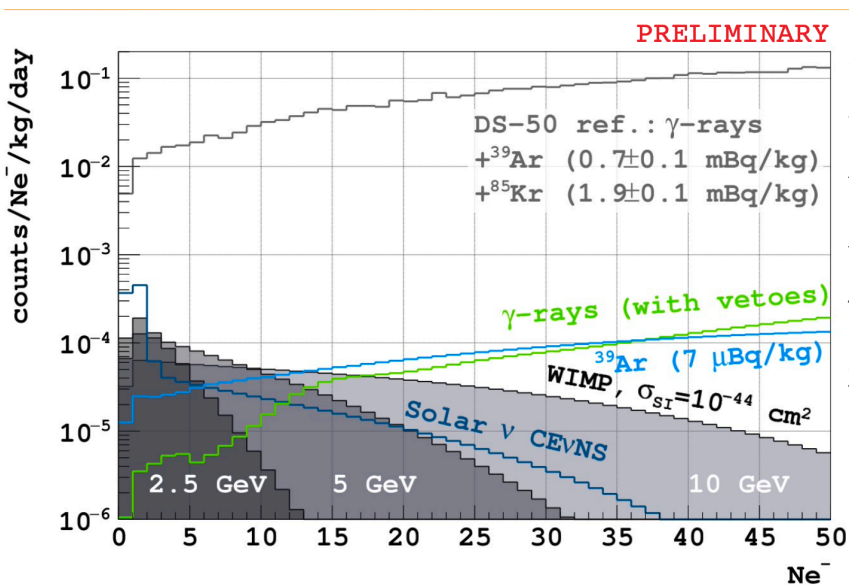
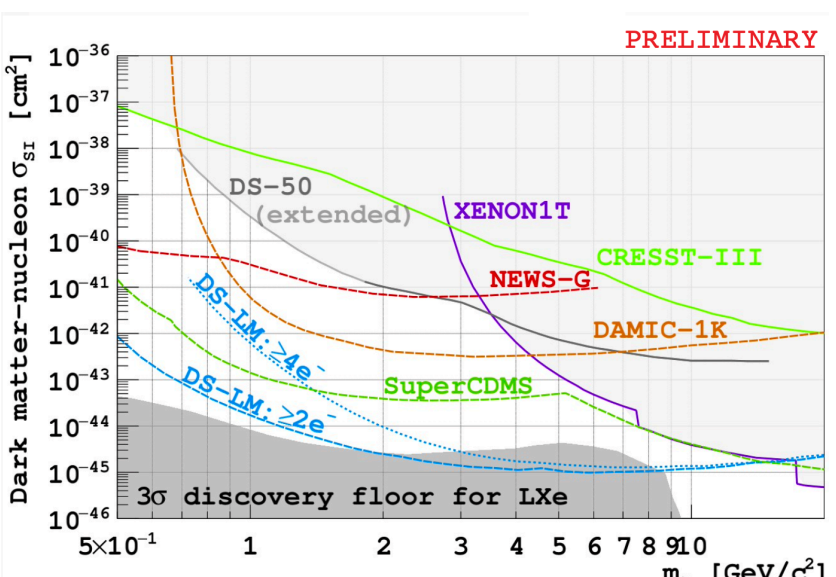
- **In getter off data, an additional time constant of 13 ms appeared** and three exponentials are used.

DarkSide-LowMass

- S2-only dedicated detector
  - Smaller and lower ER-background rate by depleted-UAr, low-γ materials, and veto-buffers
- Expected to reach ν-floor above 1 GeV/c^2 with 1 year exposure



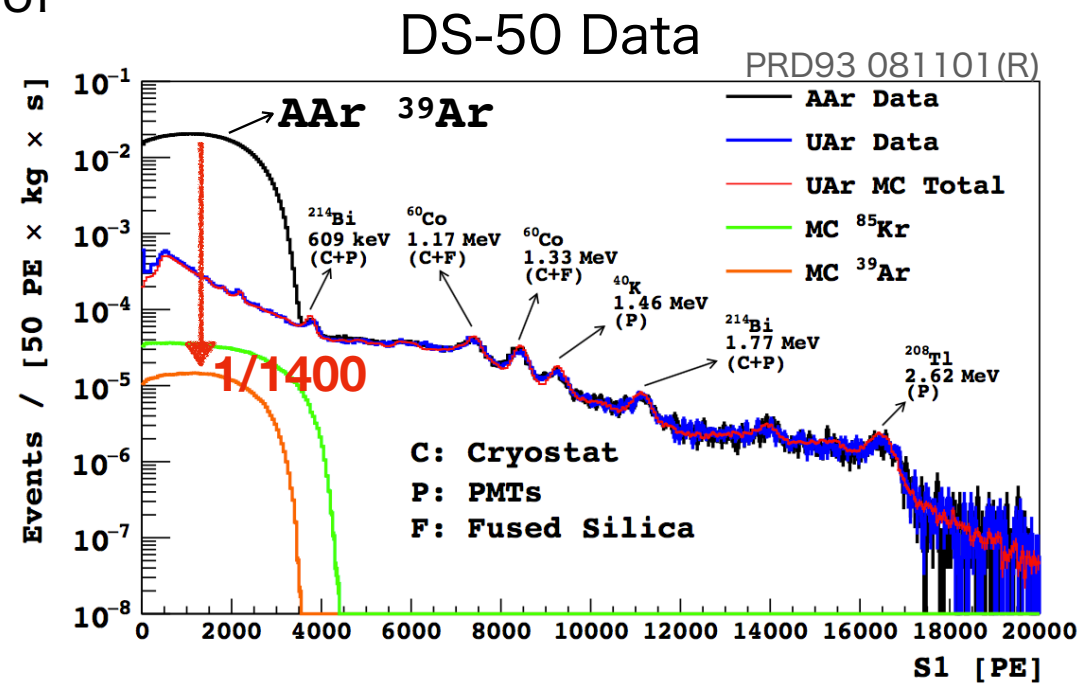




Underground Argon (UAr)

- Atmospheric argon contains ~1 Bq/kg of ^{39}Ar, a **cosmogenic β-decay isotope**
  - $t_{1/2}$ = 269-years, Q = 565 keV
  - Preventing from setting lower energy threshold where particle identification is less effective
  - Preventing from event pileup within a time window covering both S1 and S2

- DS-50 used argon from underground source for the first time, showing **significantly lower ^{39}Ar concentration**



PE : photoelectron