

DarkSide Program

Masato Kimura (AstroCeNT, Warsaw)
on behalf of DarkSide Collaboration

22 June 2022 | New Perspectives | Fermilab

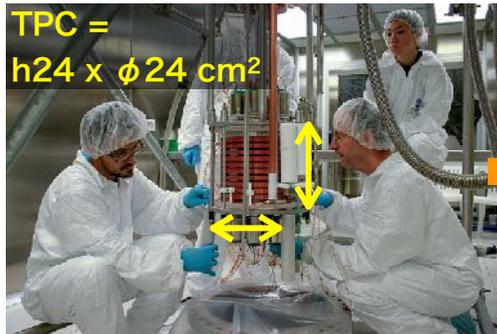
FERMILAB-SLIDES-22-084-V

DarkSide

-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

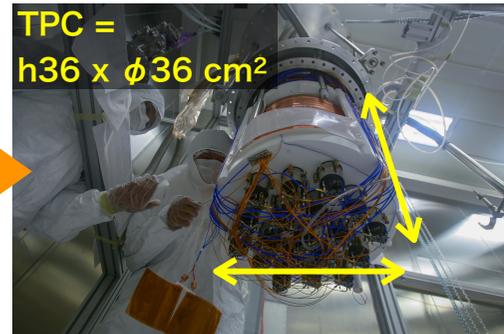


2010–2012

10 kg-scale prototype

Proofing detector performance

DS-50

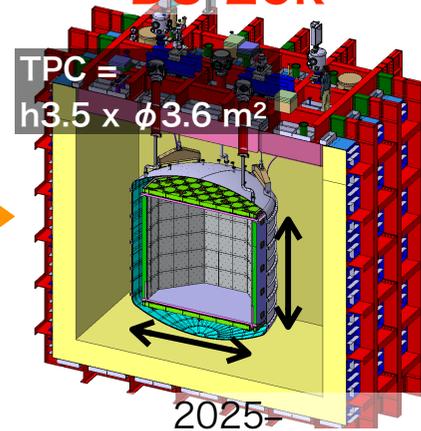


2013–2018

46 kg active mass

Yielding many physics results
(PRD98,102006, PRL121,081307,..)

DS-20k

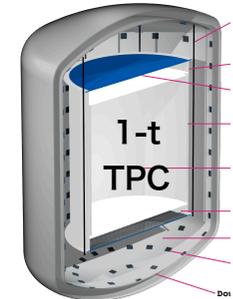


20 tonne fiducial mass
with many new technologies
Approaching ' ν -floor'

ARGO

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

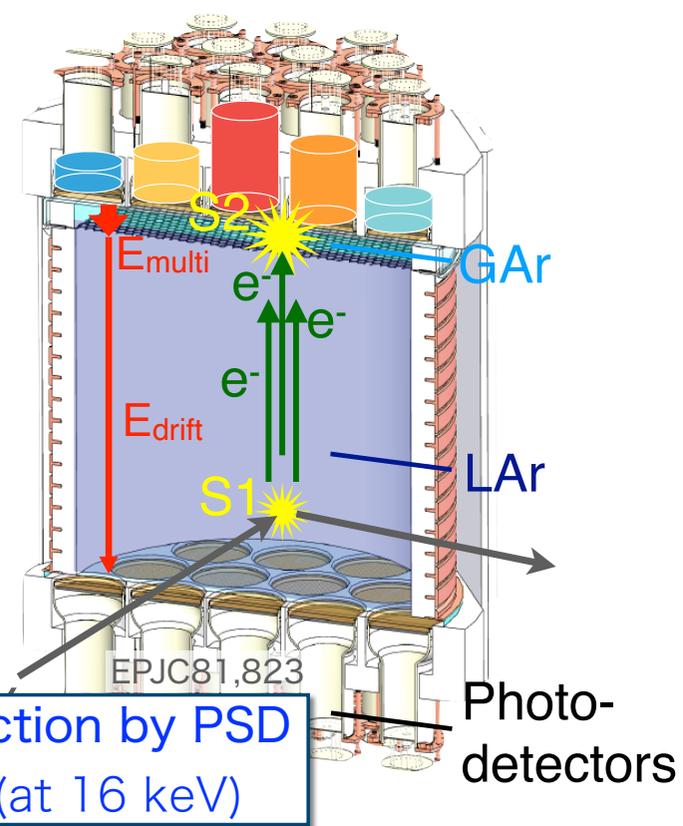
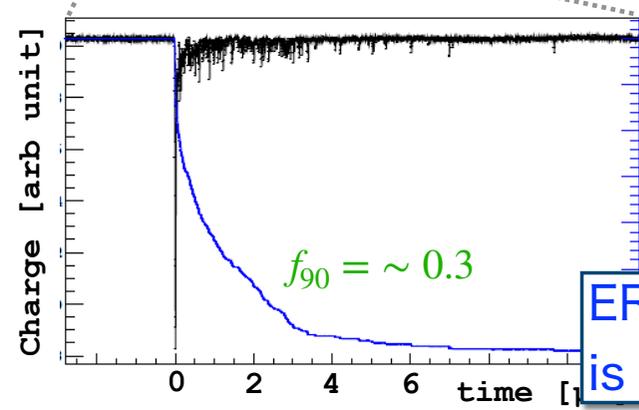
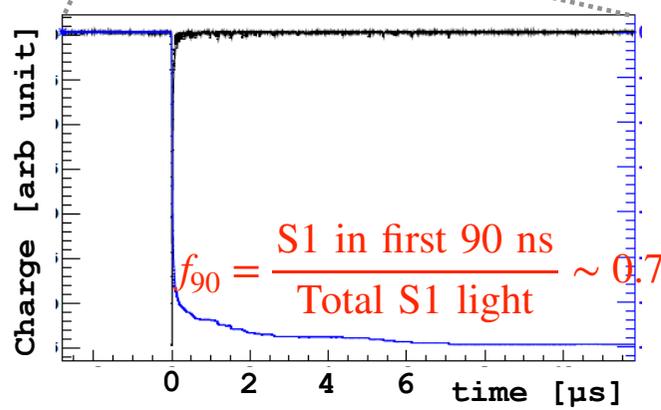
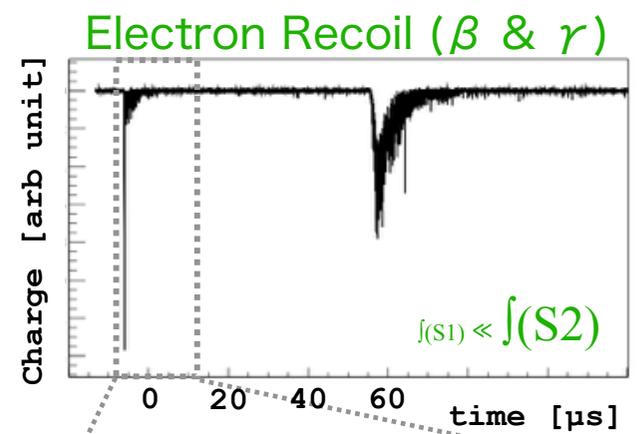
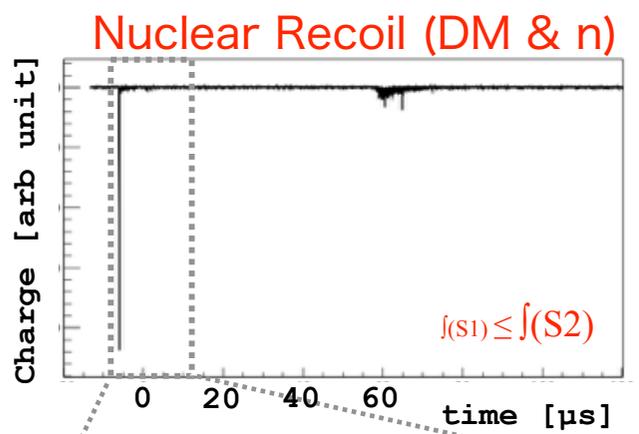
DS-LowMass



Reaching ' ν -floor'

Particle Identification

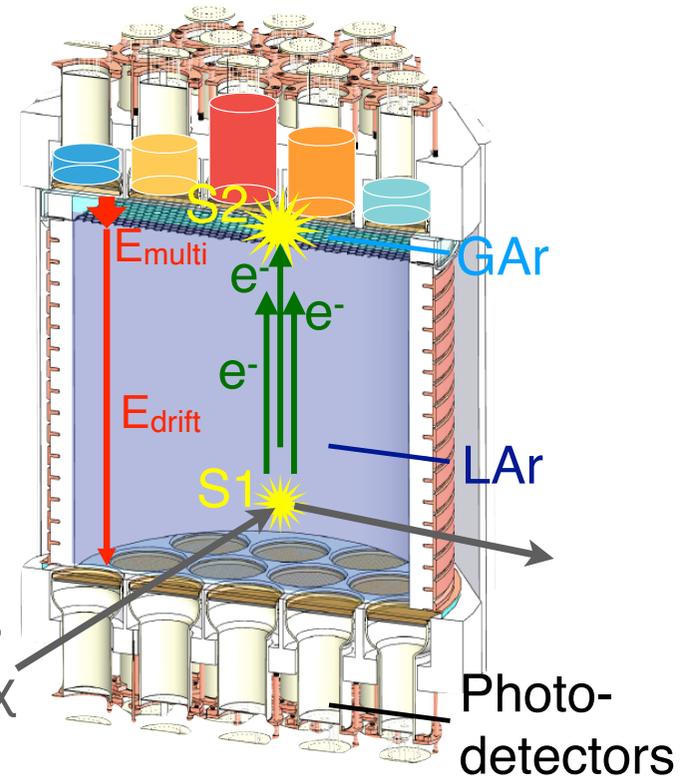
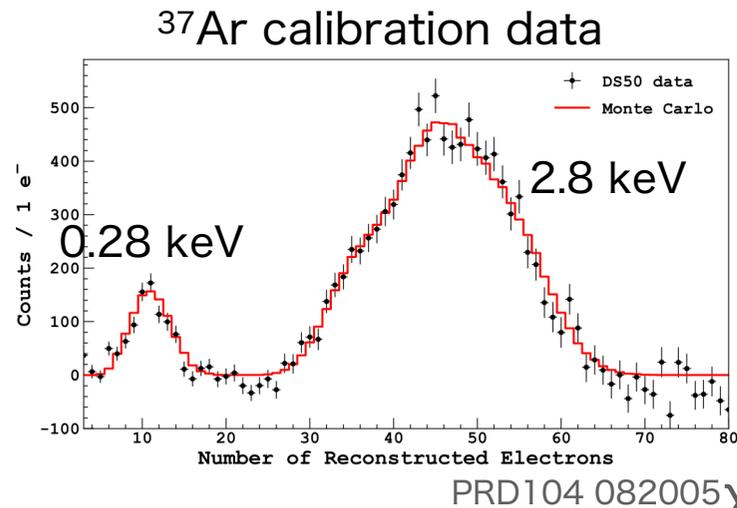
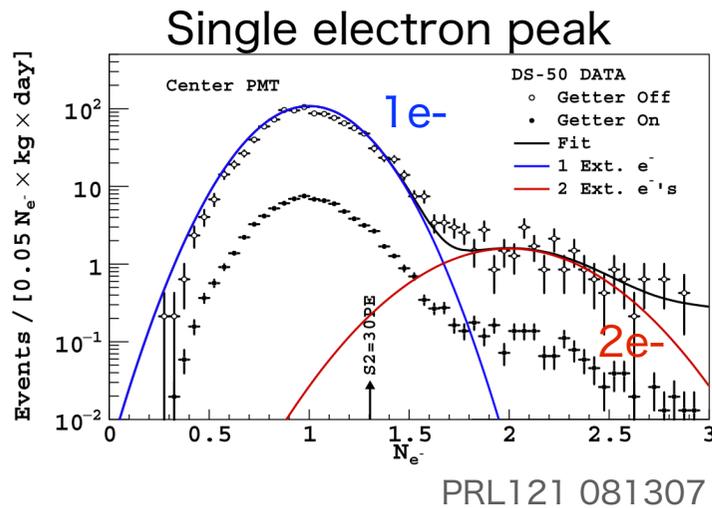
- o S1 pulse-shape (PSD) and S2/S1 ratio give powerful ER/NR discrimination
 - Difference of dE/dx leads the different population of Ar excited status



ER rejection by PSD
is $> 10^8$ (at 16 keV)

Single-Electron Sensitivity

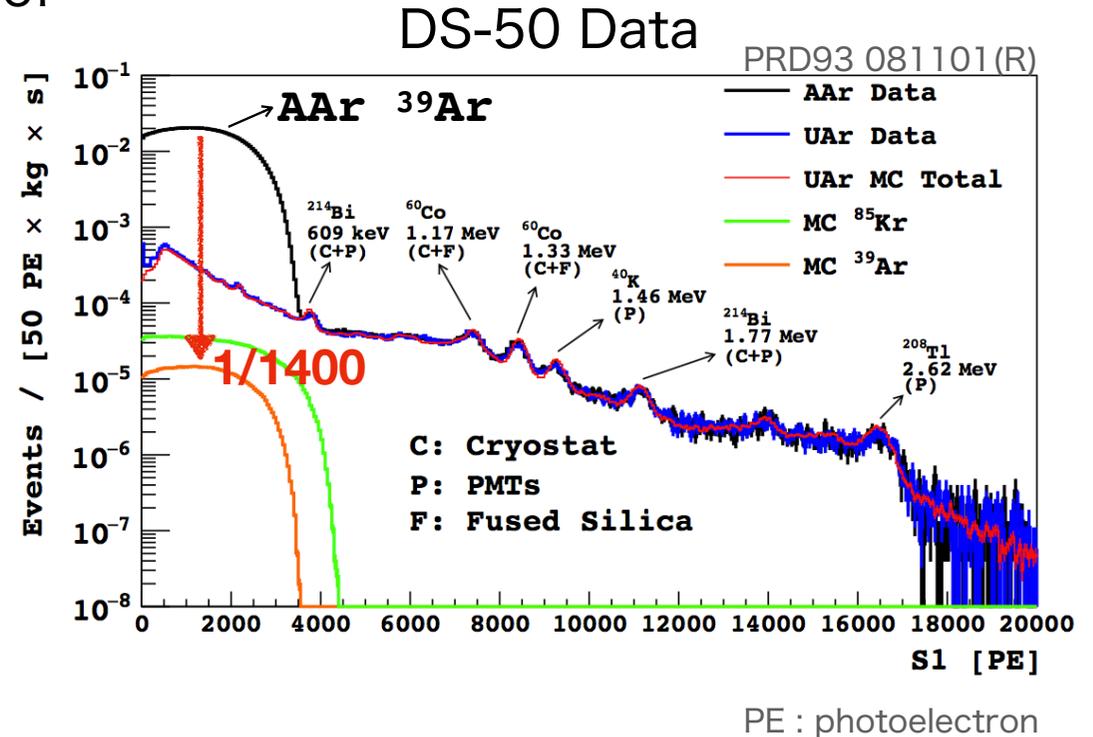
- Efficient electron detection down to $1e^-$
 - Ionization electron extracted to gas-phase with $\sim 100\%$ efficiency
 - High amplification (electroluminescence gain) of typically ~ 100 photons/ e^-



Sensitive to very low-energy deposition

Underground Argon (UAr)

- Atmospheric argon contains ~ 1 Bq/kg of ^{39}Ar , a cosmogenic β -decay isotope
 - $t_{1/2} = 269\text{-years}$, $Q = 565$ 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



UAr for Future Experiments

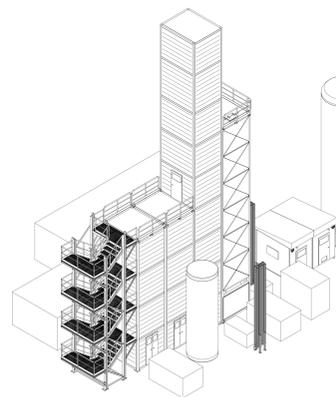
7

- Extraction, Purification, and Measurement facilities are under construction to deploy further ^{39}Ar -suppressed argon



Urania

Colorado, US



Expansion of the argon extraction plant (**330 kg/day**).

Designed to prevent from any air contamination

Aria

Sardinia, Italy

EPJC81 359



A 350-m tall column in the Seruci mine for chemical and isotopic purification

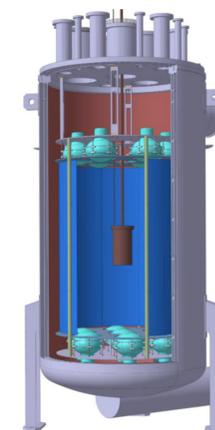
Factor 10 reduction of ^{39}Ar per pass* (depleted-UAr)

*not feasible for DS-20k

DArT

Canfranc-lab, Spain

JINST15 P02024



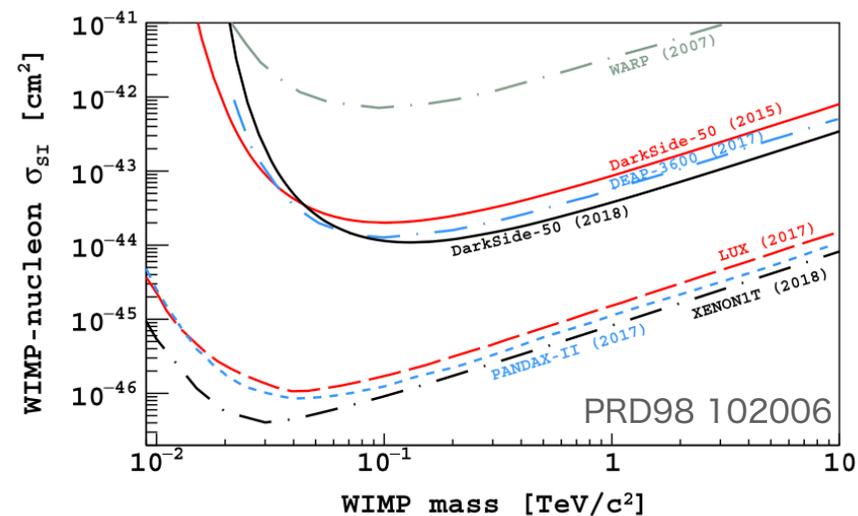
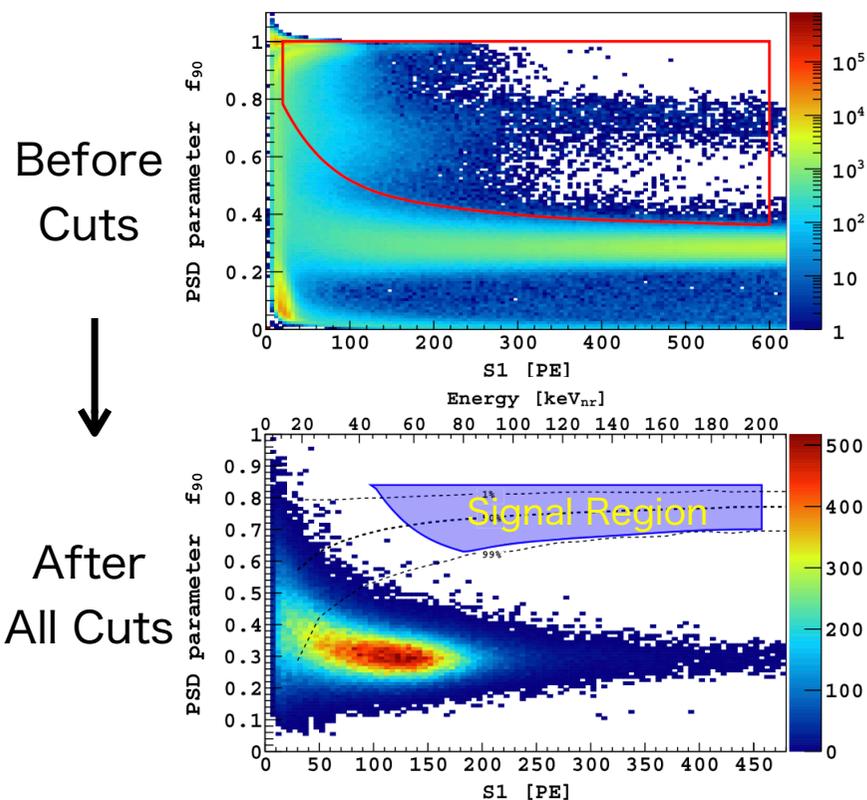
Low-background LAr scintillation detector to measure ^{39}Ar depletion factor

Sensitivity to the depletion factor of 1000 with 10% precision in one week

Results from DS-50

Background-Free WIMP Search

- Signal region is defined as to be **<0.1 background event** for the full exposure of **16,660 kg-days** (blind analysis)
 - UAr, PSD, and veto-detectors surrounding the TPC made it possible



No event is observed in signal region

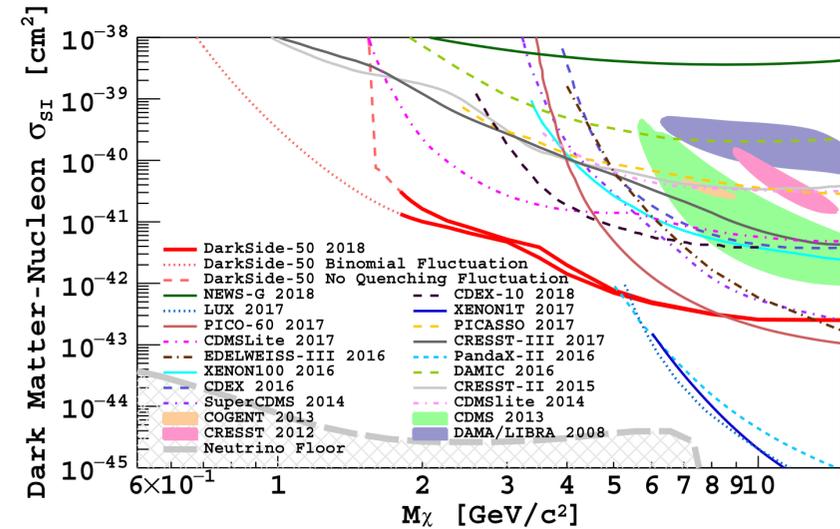
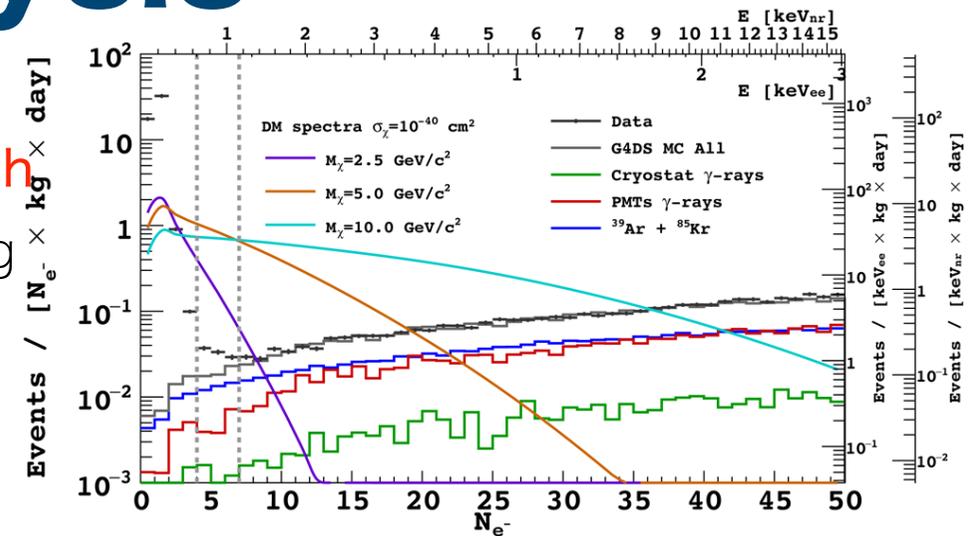
Need much more detector exposure

→ DS-20k will achieve **x3000 (200 tonne-year)**
of **Background-Free exposure!**

“S2-Only” Analysis

PRL121 081307

- Extremely low background level in low-Ne region allows **<10 GeV/c² WIMP search**
 - S1 is missing**; WIMP is searched by fitting energy spectrum together with the background model
- Stringent exclusion limit** is set on a few GeV/c² region
 - Sensitivity is limited by background level -> DS-20k and DS-LM will overcome
 - Energy threshold is limited by **unknown event below 4e-**;
 - Need understanding of the detector (-> Next slide to be continued)



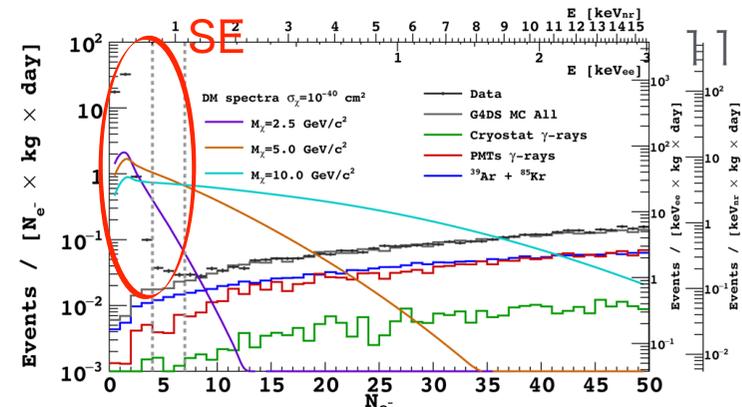
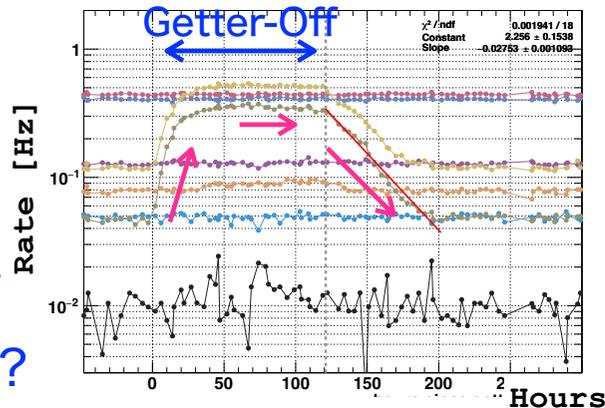
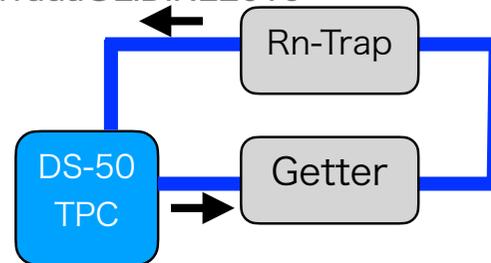
Spurious Electron

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

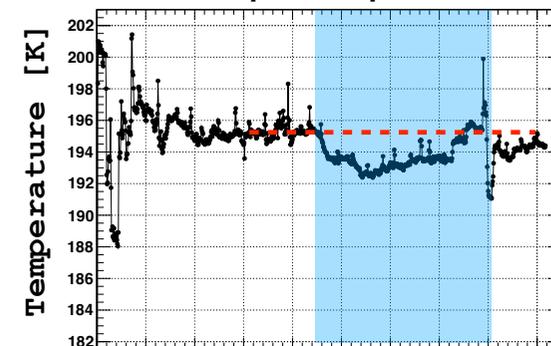
Correlation with detector operation

- 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?**

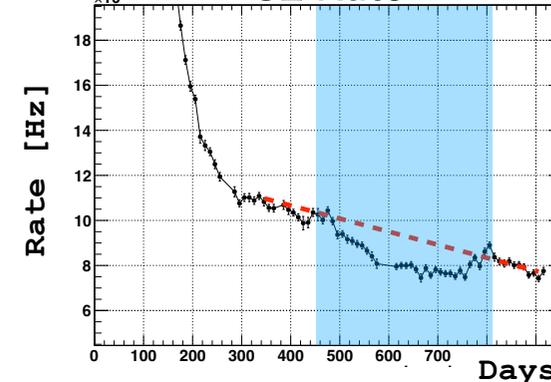
M.Wada@LIDINE2019



Rn-Trap Temperature



SE Rate



Spurious Electron

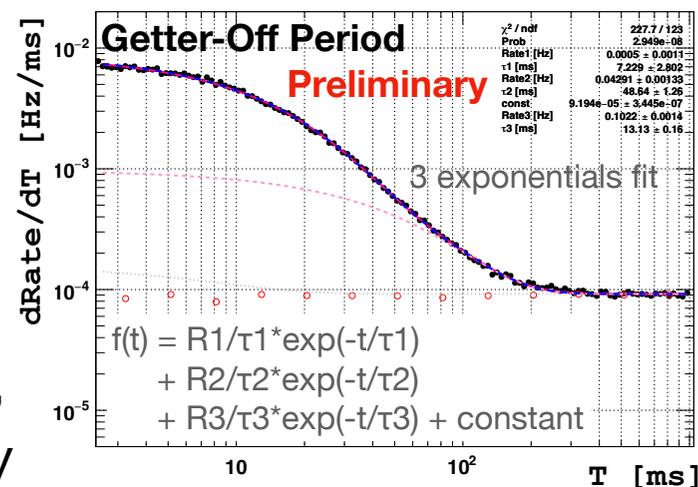
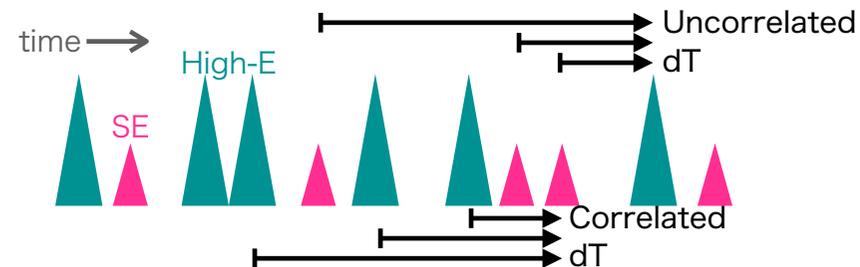
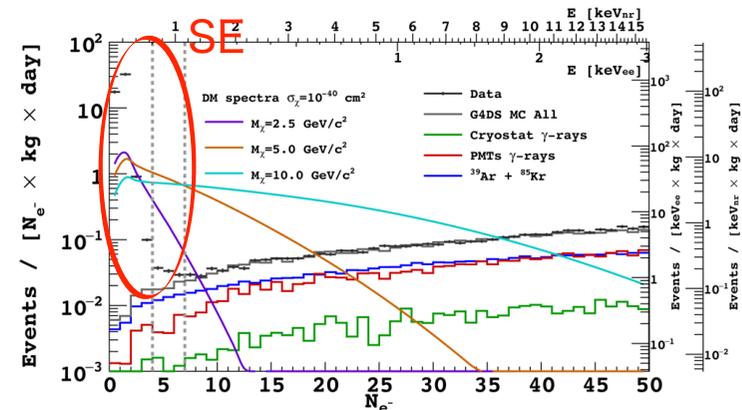
Some “hint” about the origin of low-Ne event
(so-called spurious electron, SE) from DS-50 data

Time-correlation with its ‘parent’

M.Wada@LIDINE2019

- Time-evolution of SE rate after high-energy event is measured
- There is **O(5–500ms) time correlation** between SE and high-energy events
- Several time-constant components exist
- Ionization electron occasionally trapped by several kind of impurities and then released?

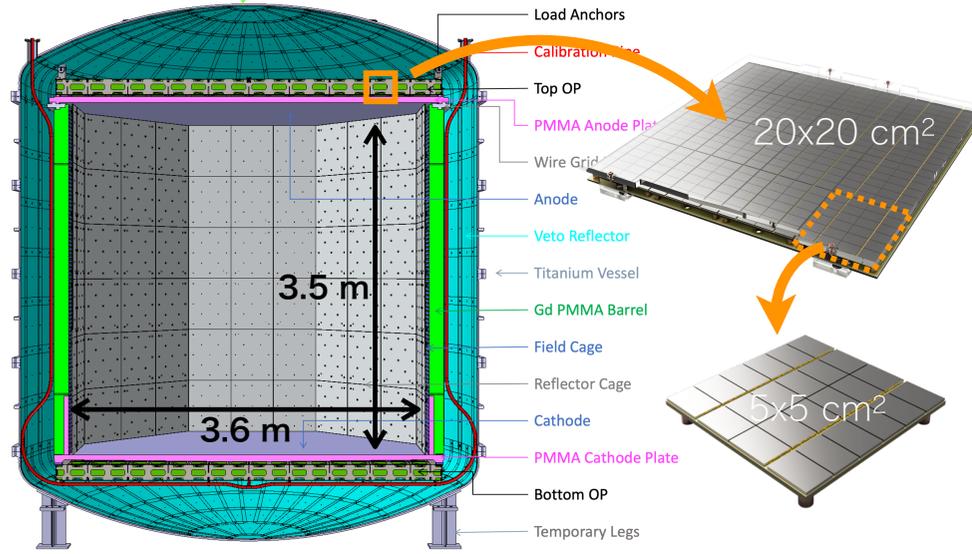
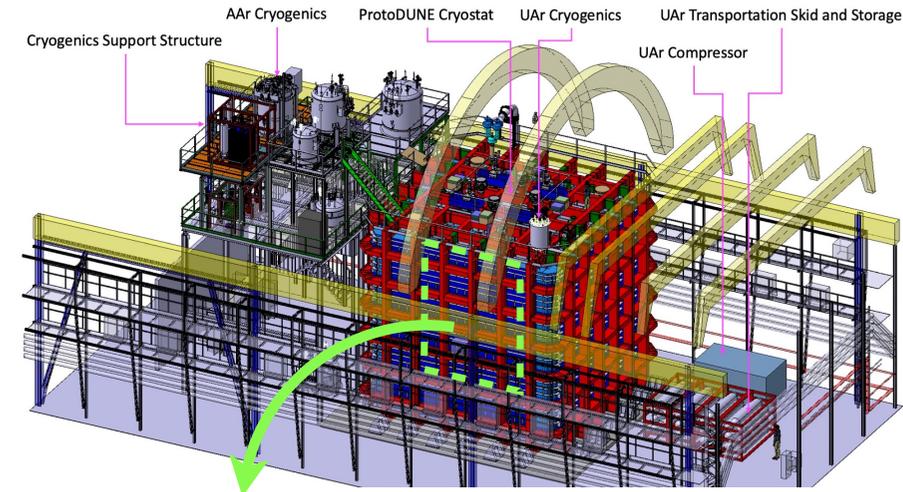
Dedicated measurement will confirm hypotheses, so that the S2-only analysis gets higher sensitivity



Future Experiments

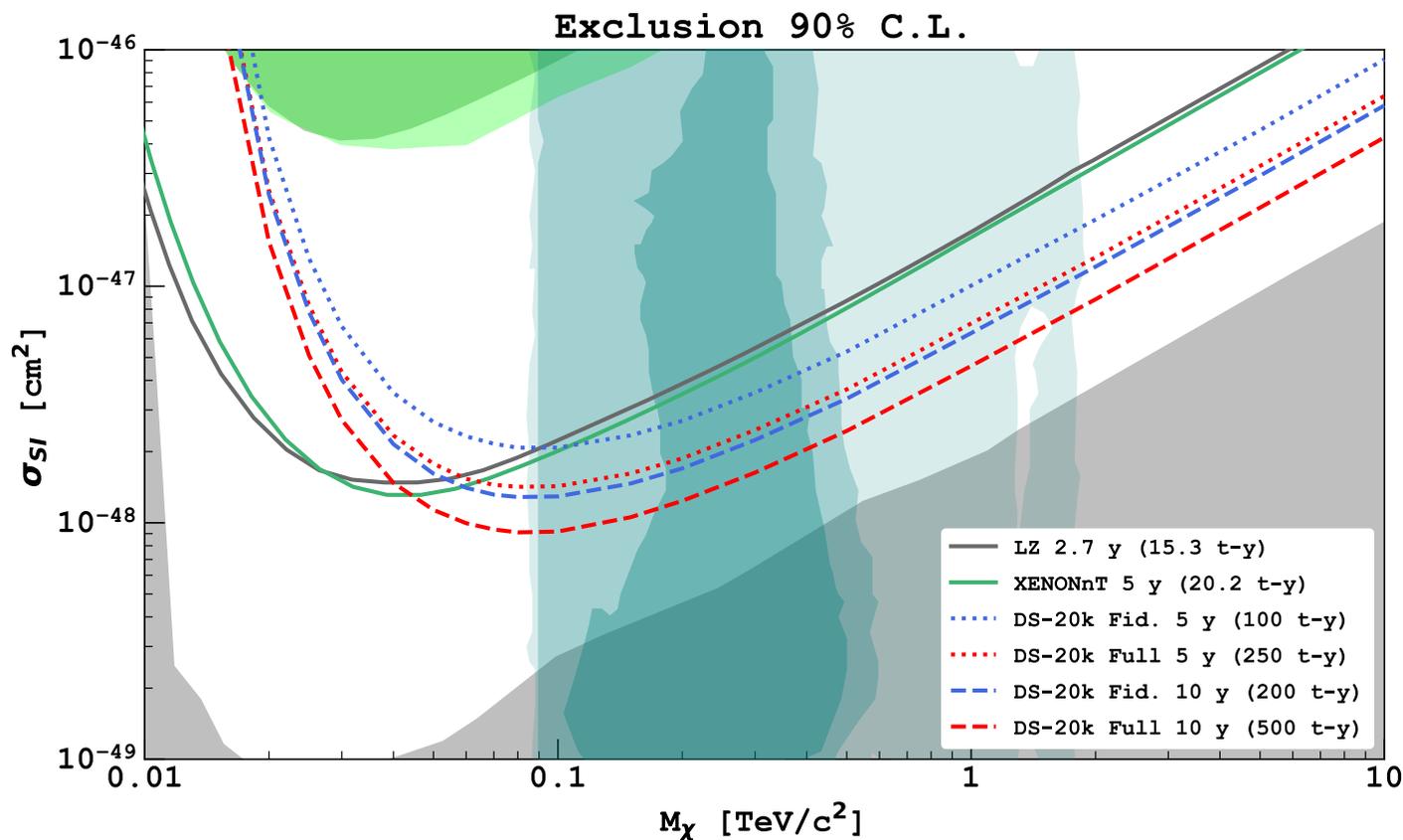
DarkSide-20k

20 t (50 t) fiducial (active) mass 14
Ar-TPC with many new technologies



- **ProtoDUNE-like cryostat** filled with 700 t of atmospheric argon
- UAr-maintaining cryogenic system with an unique heat exchanger/condenser design
- **Radiopure titanium vessel** holding total 100 t of UAr and TPC
- **Gd-doped acrylic panels** consisting TPC, working as neutron background veto
- Octagonal TPC with new transparent conductor
- **Custom cryogenic SiPMs detection plane** covering 21 m²

DarkSide-20k Sensitivity



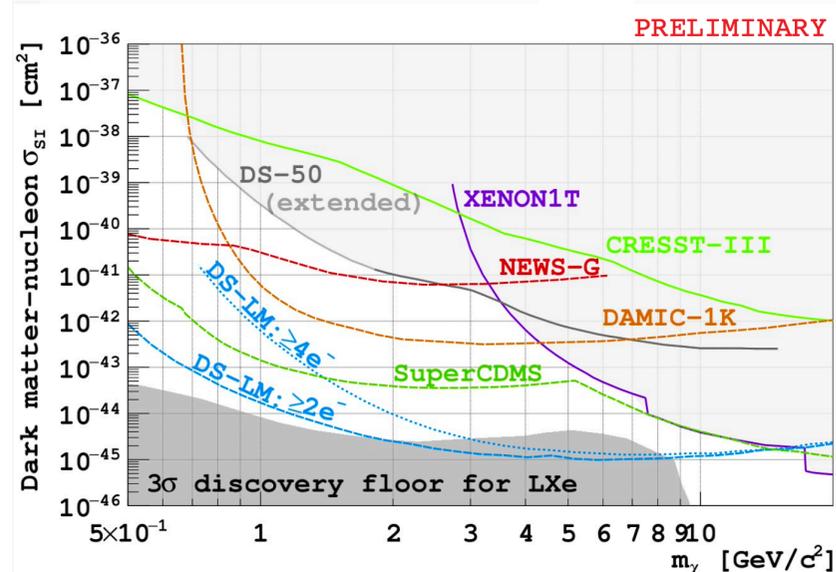
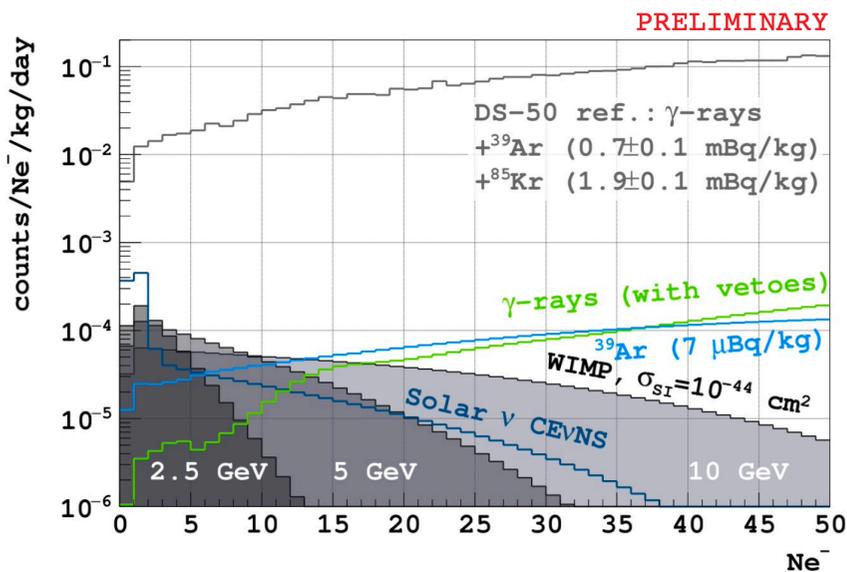
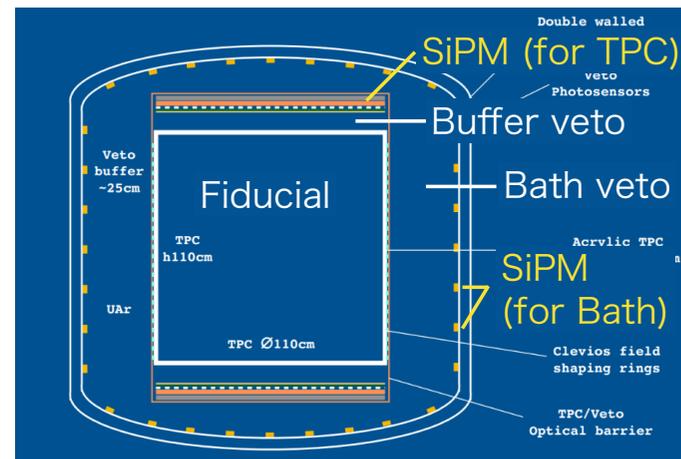
Turquoise filled contours are from pMSSM11 model (EPJC78, 87)

10 years of operation approaches ' ν -floor' with the **background-free** condition for $0.1 \text{ TeV}/c^2$

Work in progress for S2-only analysis sensitivity

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/c² with 1 year exposure



Summary



- **DarkSide-50** has shown strong potential of Ar-TPC for direct dark matter search;
 - 17k kg-days exposure of **background-free WIMP search** thanks to UAr and PSD
 - **low-mass (1 GeV/c²) WIMP search** using only S2 signal with an energy threshold down to 1 keV
 - It also gives lessons for future experiments, such as **SE background** preventing lower energy threshold
 - **DarkSide-20k** is under construction, will be the most sensitive LAr detector ever built with new technologies
 - **DarkSide-LM** is under consideration to go down to ν -floor around 1 GeV/c² region with S2-only technique
- High sensitivity of **DarkSide** for wide mass region gives good chance to **discover DM**

Backup