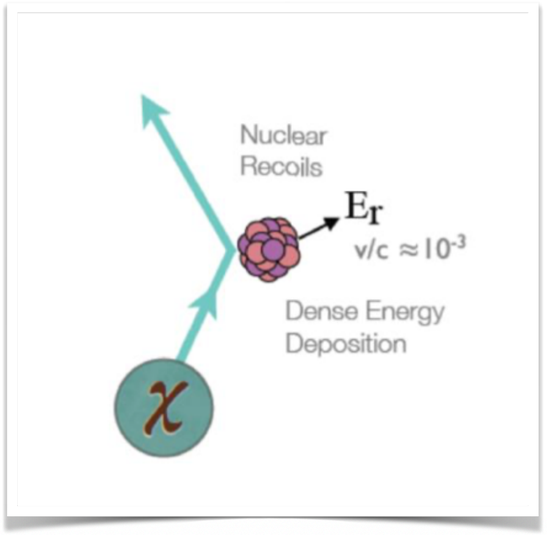
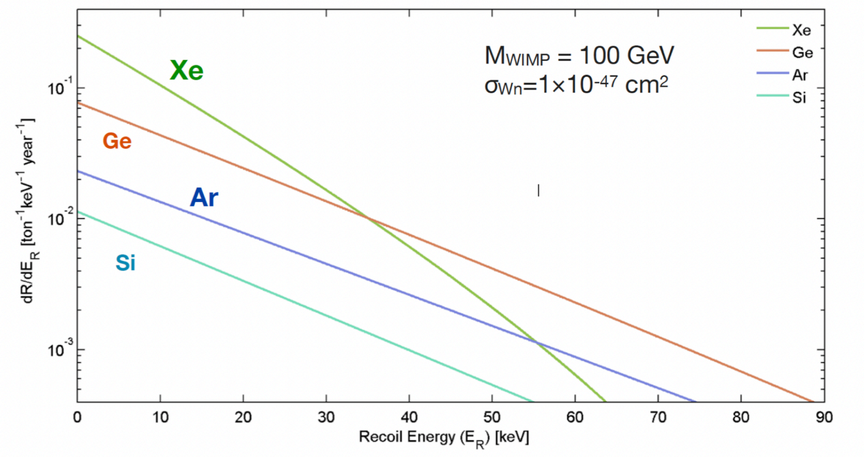
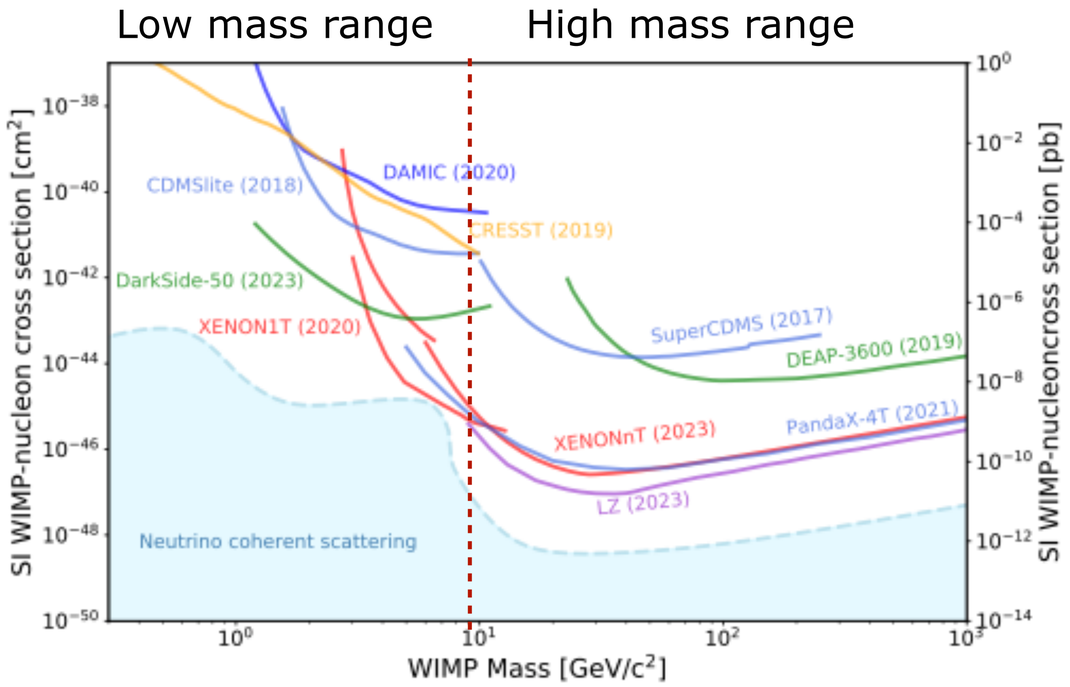
DARK MATTER DETECTION IN DARKSIDE-20k ERA: The challenge of radiopurity and low background

Daria Santone, University of Oxford
On Behalf of DarkSide-20k Collaboration
TevPA Conference, Valencia, 3/11/2025

WIMP DIRECT DETECTION







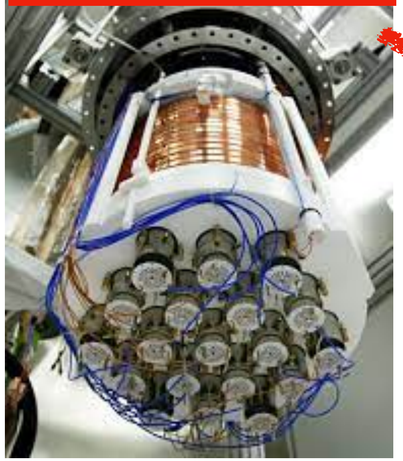
to reach lower cross section sensitivity, need bigger target mass and **better background suppression**

https://pdg.lbl.gov/2024/reviews/rpp2024-rev-dark-matter.pdf

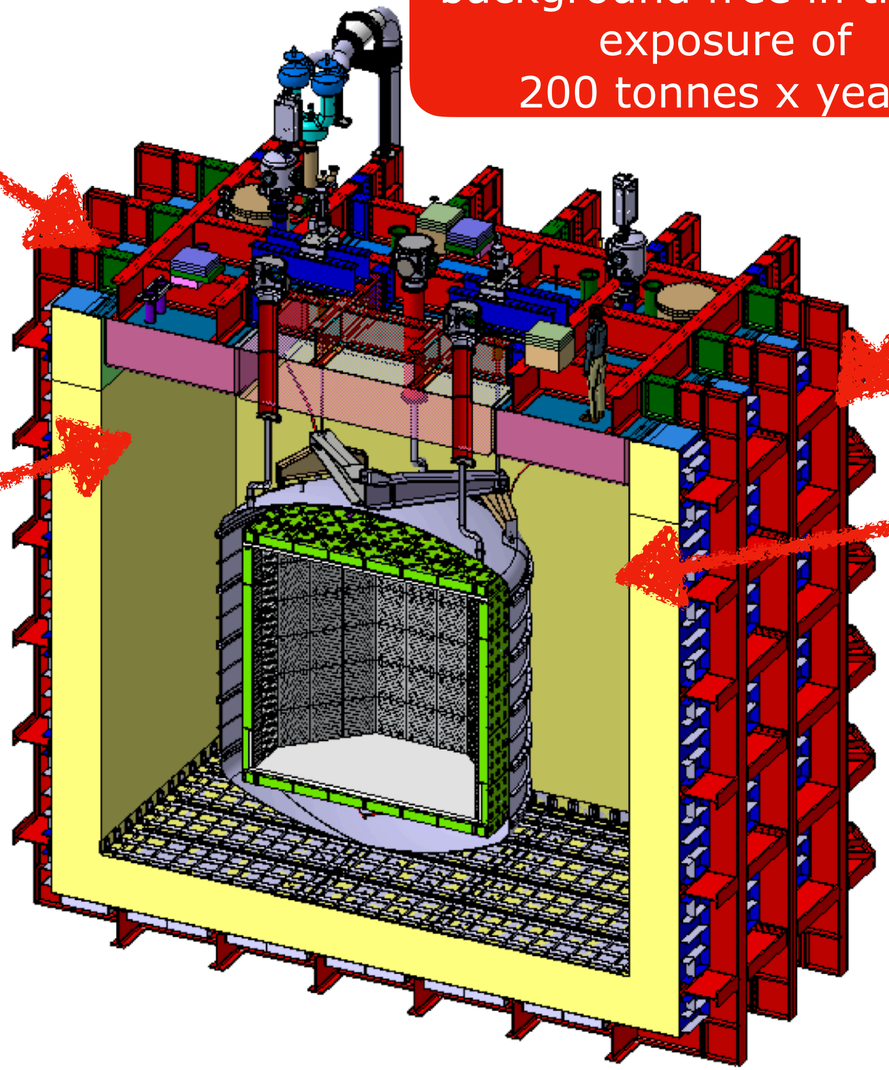
DARKSIDE-20k

DarkSide-20k aims to operate in instrumental background free in the full exposure of 200 tonnes x years

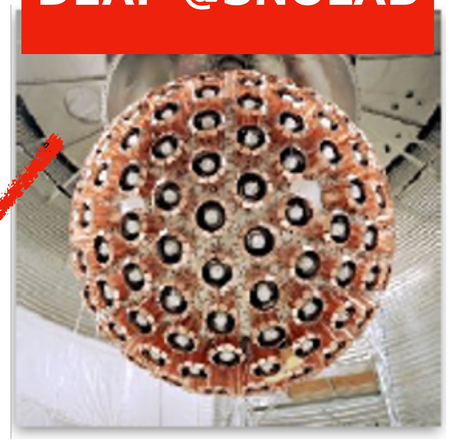
DS-50 @LNGS



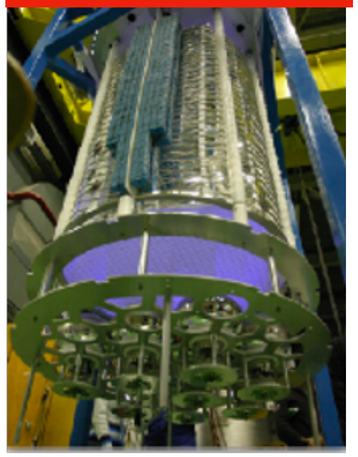
Miniclean @SNOLAB



DEAP @SNOLAB

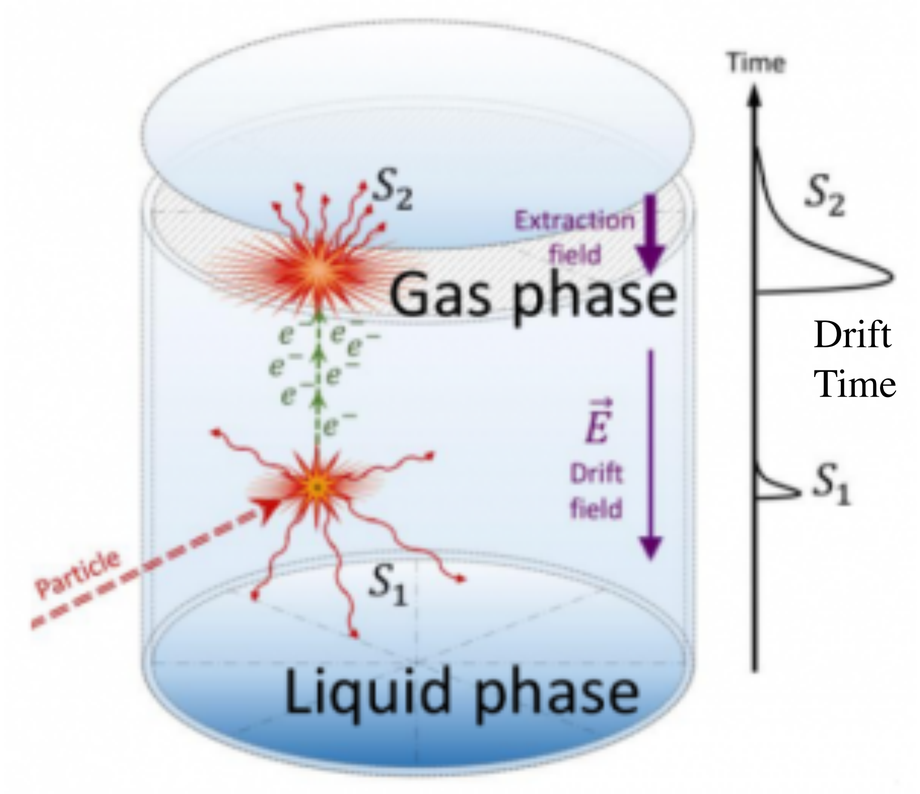


ArDM @CANFRANC

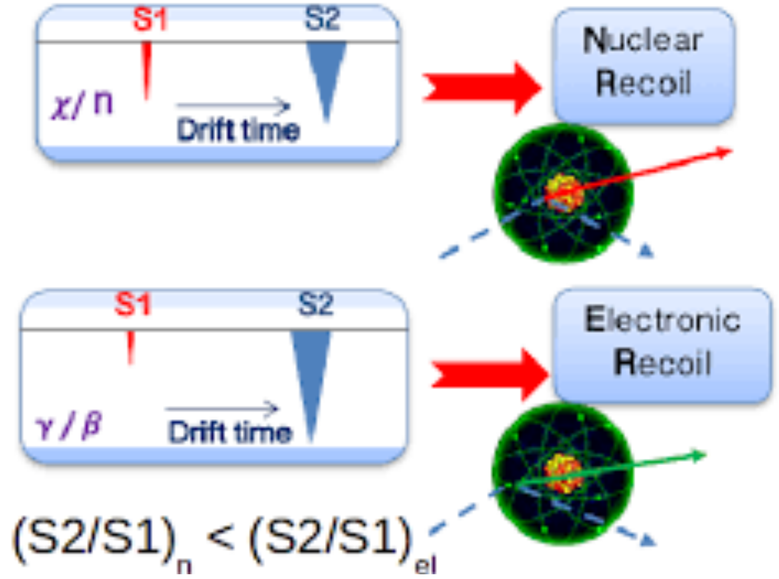


DARK MATTER SEARCH IN DARKSIDE

Dual phase Time projector Chamber (TPC)



- Signal: S1 (primary scintillation) + S2 (charge signal)
- S2 light pattern gives x-y position
- Drift time give z position
- S1-S2 relative size give particle information
- S2-only analysis → sensitivity to very low energies: ≈180 eV (electron recoil)

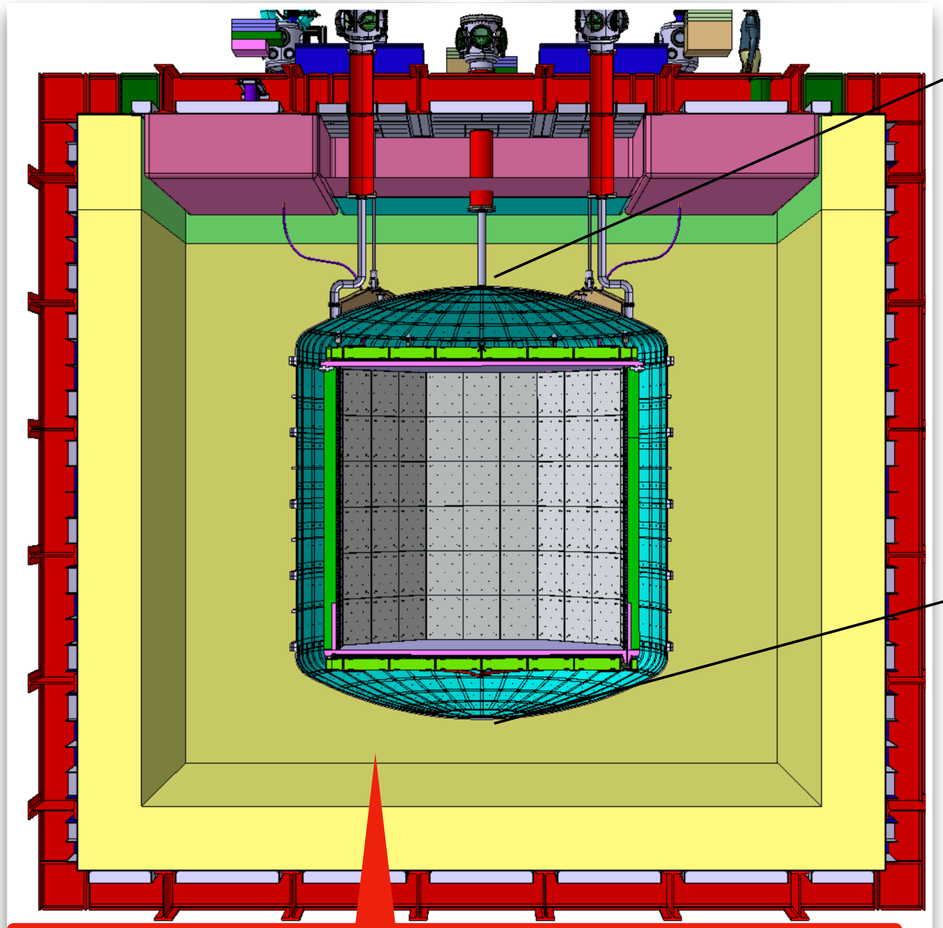


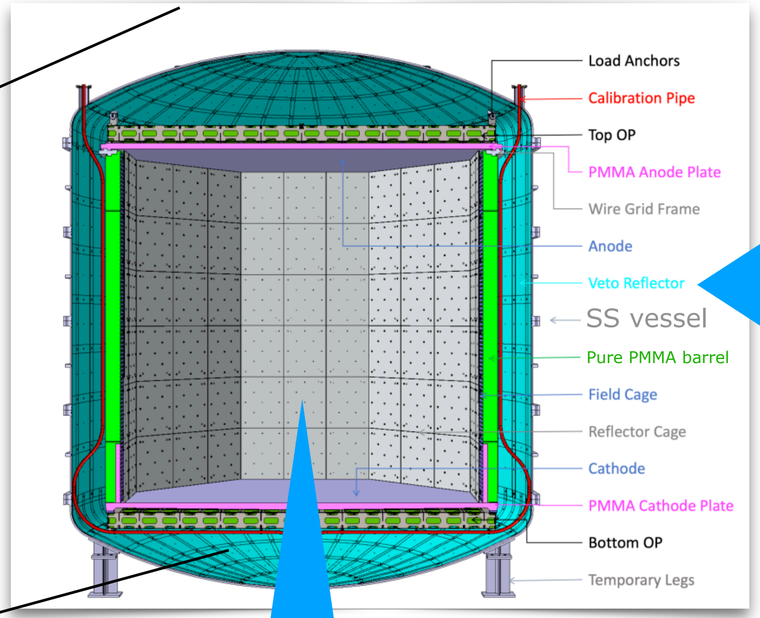
See talk:
"DarkSide-20k TPC Mockup: A Step Towards the Realization of DS-20k"
By Clea Sunny

DarkSide Target material: liquid Ar from underground (UAr)

DARKSIDE-20k: overview

Inner detector





Neutron veto:

- 15 cm of Pure PMMA as neutron veto around TPC
- Immersed in 35 tonnes of UAr
- Equipped with large array of SiPM for 5 m^2 coverage
- Light yield: 2 pe/keV
- Enclosed in a SS vessel
- HDPE neutron shield around SS vessel

Dual Phase TPC:

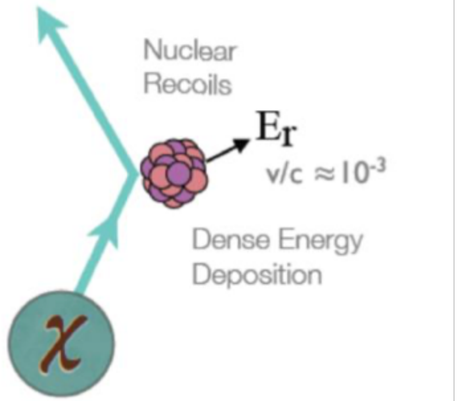
- Filled with 50 ton of Underground Argon (UAr)
- Equipped with two optical plate -> large array of SiPM for 21 m^2 coverage
- Light yield:
  - S1 (scintillation signal): 10 pe/keV
  - S2 (charge signal): 20 pe/e-

Outer veto filled with 650 tonnes of atmospheric argon as cosmogenic veto

See talk:
"The DarkSide-20k project updates and perspectives"
By Sandro De Cecco

WIMP SIGNAL & BACKGROUNDs

WIMP SIGNAL

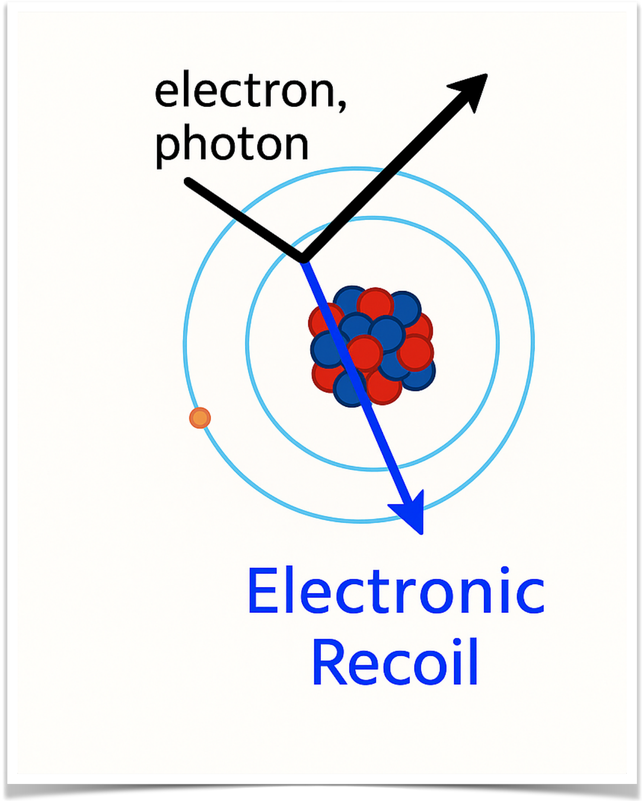


- Single nuclear recoil
- Energy recoil between 1 and 100 keV

BACKGROUND

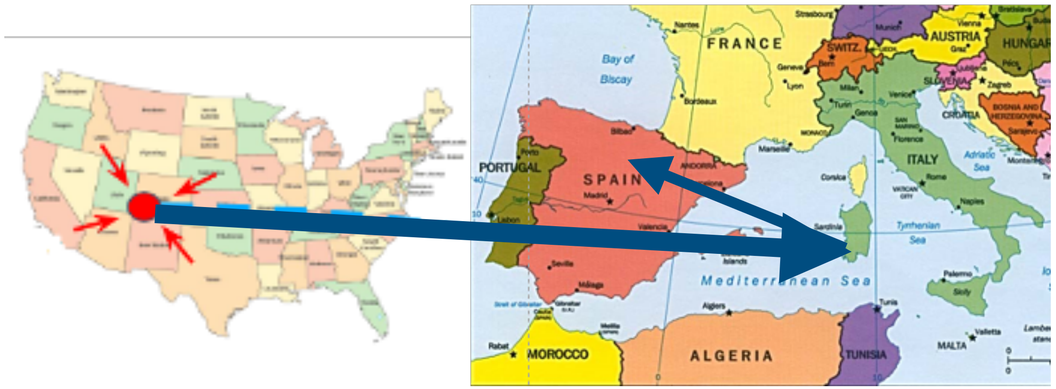
Background source	Mitigation strategy
^{39}Ar β decay	Use Underground Argon + pulse shape discrimination
γ from rock and γ,e from material	Pulse shape discrimination Selection material
Radiogenic neutron **(α,n) reaction in detector material**	Material screening & selection Definition of Fiducial volume in the TPC **Veto to reject neutron signal**
Surface contamination due Rn progeny	Surface cleaning Reduce the number of surfaces Installation of Rn abated system
Muon induced background	Cosmogenic veto
Neutrino coherent scatter	Irreducible

Electron recoil suppression



See talk: "*The Underground Argon program of the Global Argon Dark Matter Collaboration* " by **Daniel Díaz Mairena**

THE PATH TOWARDS PURE UAr: Urania->Aria->DArT



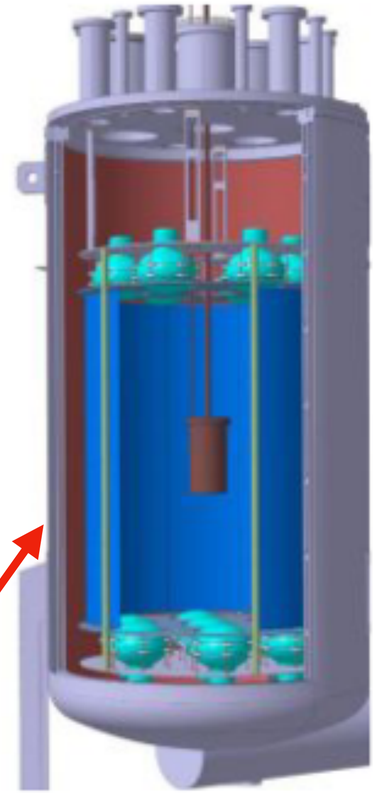
1. Urania: UAr extraction

- UAr extraction plant in Cortex, Colorado, USA
- UAr extraction rate up to 330kg/day with a 99.99% purity

2. ARIA: UAr purification

- Cryogenic distillation column in Sardinia (Italy)
- First module operated according to specs with nitrogen in 2019
- Chemical purification rate: 1 t/day

Eur.Phys.J.C 81 (2021) 4, 359

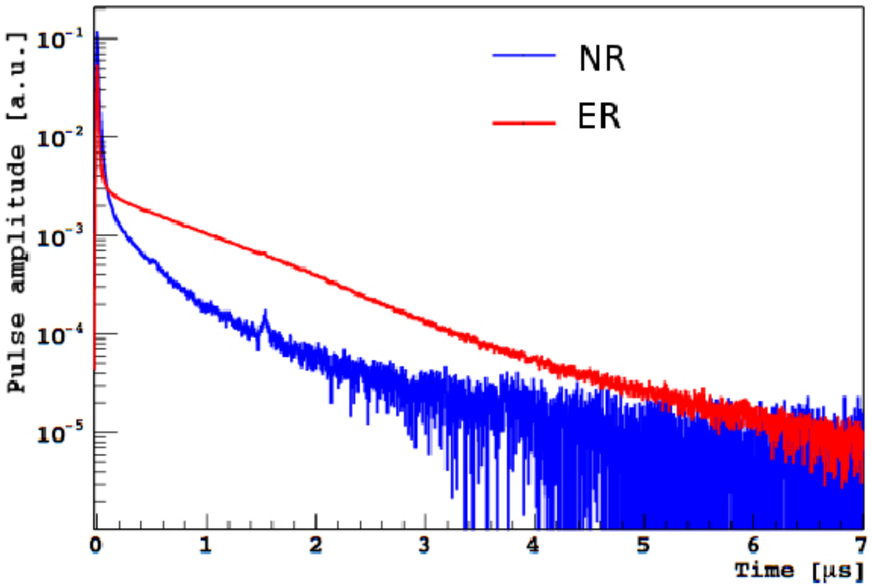


3. DART

- Double phase TPC with active volume of 1.4 kg of liquid UAr located at Canfranc, Spain
- Ar-39 depletion factor sensitivity: 6 x 10^4 90% C.L

ELECTRON RECOIL

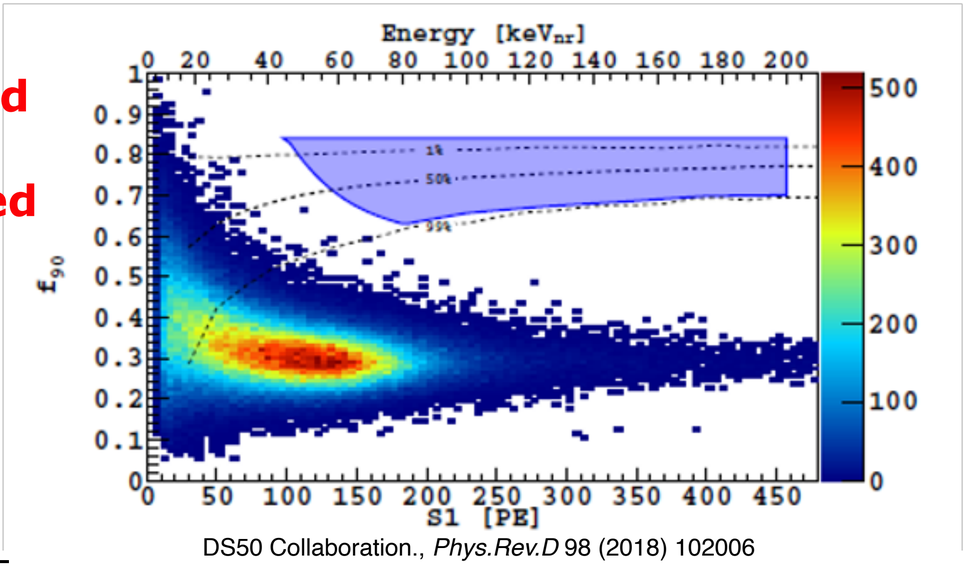
S1 pulse shape in LAr



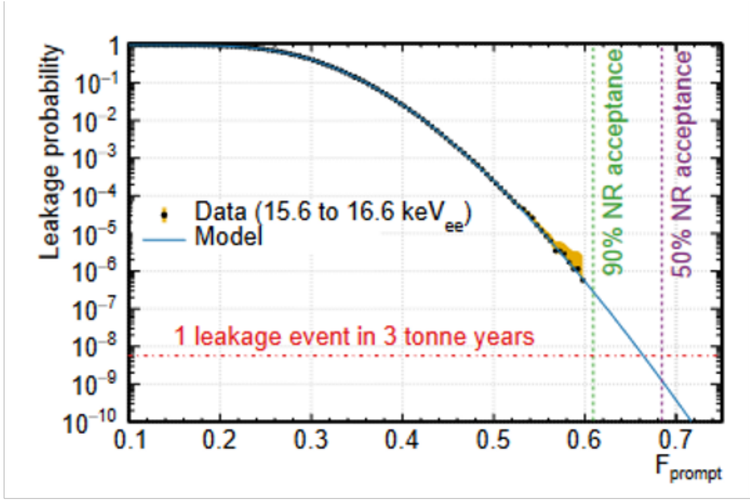
electronic recoils are rejected by Pulse shape discrimination, demonstrated by DS-50 & DEAP

Pulse shape parameter

$$PSD = \frac{PROMPT\ LIGHT}{PROMPT + LATE\ LIGHT}$$



DS50 Collaboration., *Phys.Rev.D* 98 (2018) 102006

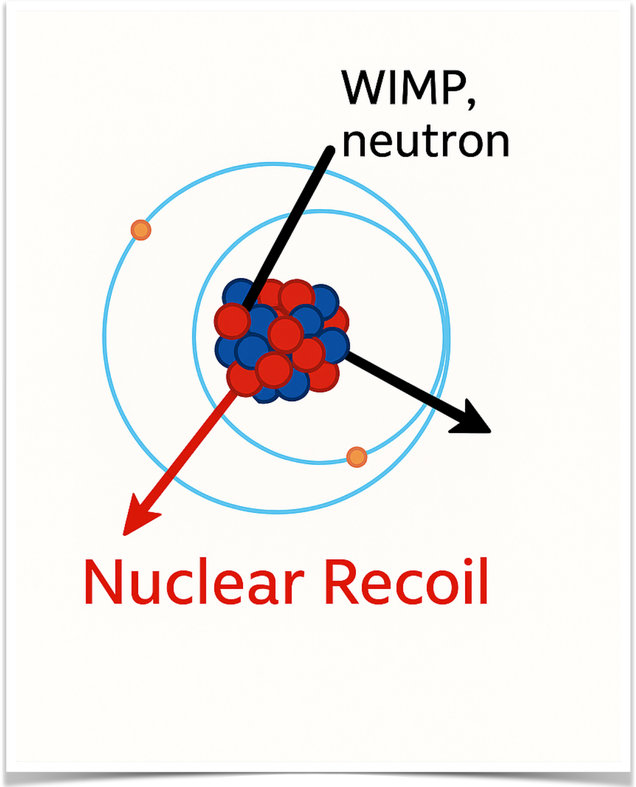


DEAP Collaboration, *Phys.Rev.D* 100 (2019) 2, 022004

Ar-39 depletion factor in UAr: around 1400
- **TPC= 50 tons -> 36 Hz of Ar-39**
- **Veto = 35 tons -> 26 Hz of Ar-39**

Mitigated with pulse shape discrimination:
- residual background is < 0.01 events / 200 tonne x year
- dead time is negligible

Material selection and neutron veto



ASSAY CAMPAIGN

Neutron sources:

- ^{238}U and ^{232}Th contaminations of the detector material
  - (α,n) reaction in the detector material
  - Spontaneous fission decays
- cosmic ray induced neutron production

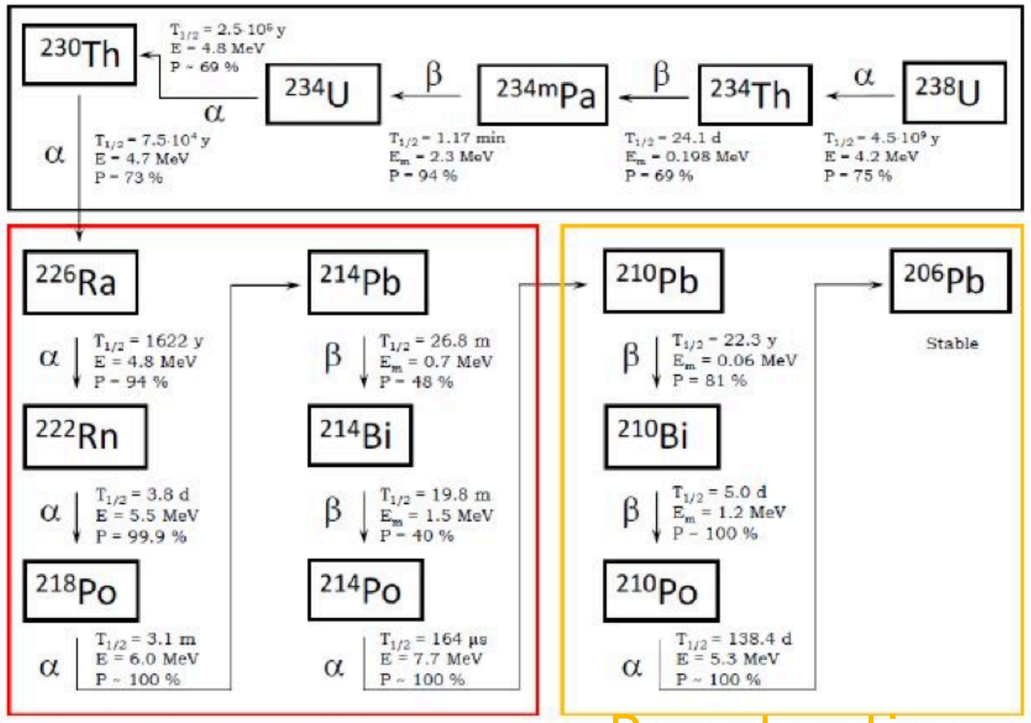
Secular breaking equilibrium in U chain fondamental for neutron budget estimation:

- *Baseline: factor 20 breaking when no direct measurements are available*
- *25% of neutron coming from ^{210}Po given this breaking*

Control over every component that goes into the detector thanks to:

- Three different assay techniques
- Chemical composition of all material for neutron yield estimation
- Surface contamination and exposure control

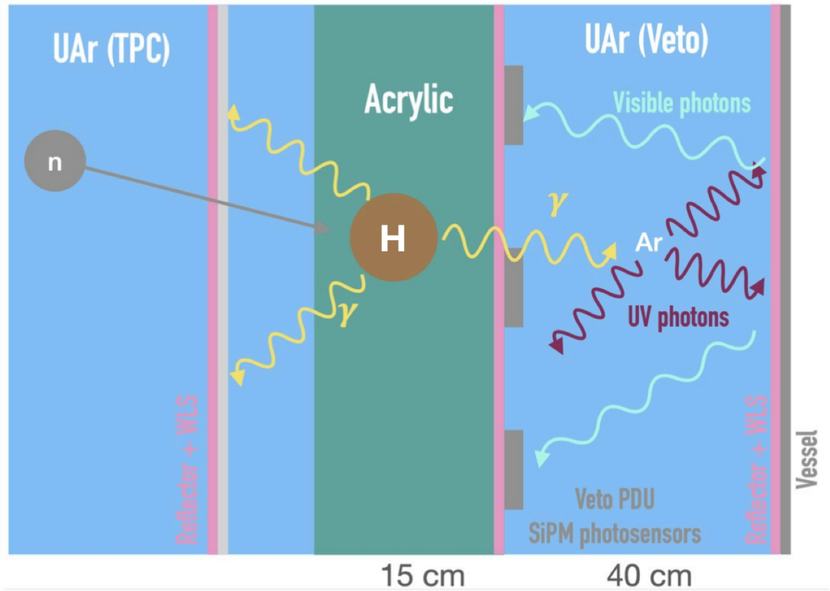
ICPMS



HPGE

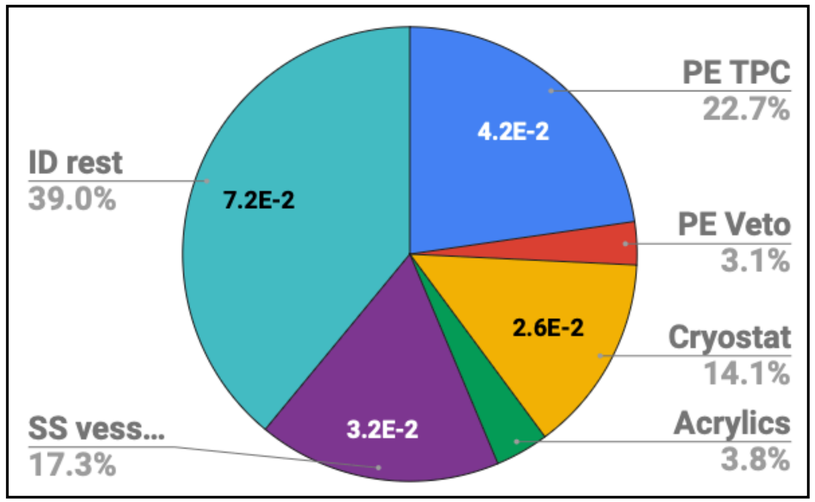
Po extraction

NEUTRON DETECTION



- 15 cm pure PMMA surrounding the TPC as neutron moderator
- Detection mostly on Hydrogen and Argon
- Detecting gamma rate produced on Hydrogen (2.1 MeV) and on Argon (6 MeV)
- Detection on veto argon buffer or on TPC

- **Neutron identification**:
  - Single NR
  - Energy in ER: 30< E_{NR}<200 keV_{NR}
  - R-z position cuts—> FV = 20 tons
  - Energy deposit in ER in the TPC > **50 keV OR** energy deposit in UAr veto > **200 keV**
  - TPC-veto window of 800 μs



<0.21 neutron WIMP like event in 200 tonnes x years

Radiopurity control

Radio-purity control is essential to minimize background; the photodetector case has been reported, and similar efforts are ongoing for other components to reduce exposure time and surface contamination

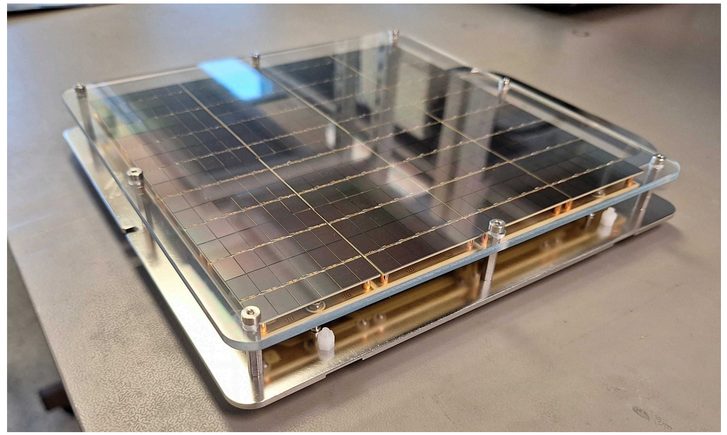
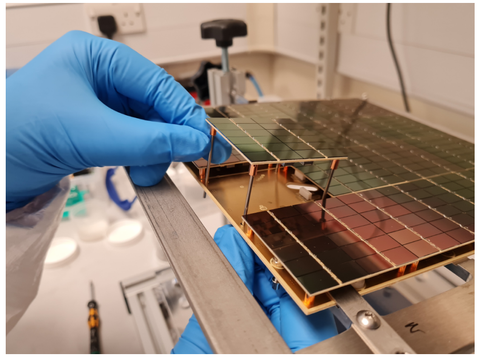


Photo Detection Unit
See talk:
"DarkSide-20k 26 m² SiPM Detectors: Production and Characterisation"
By Paolo Franchini

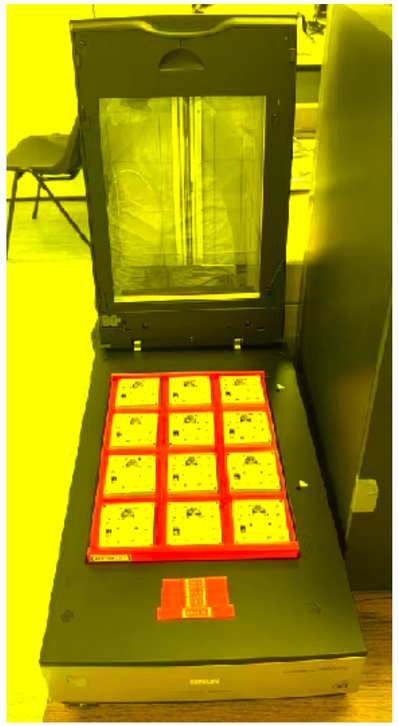
ASSEMBLY AND CHARACTERIZATION

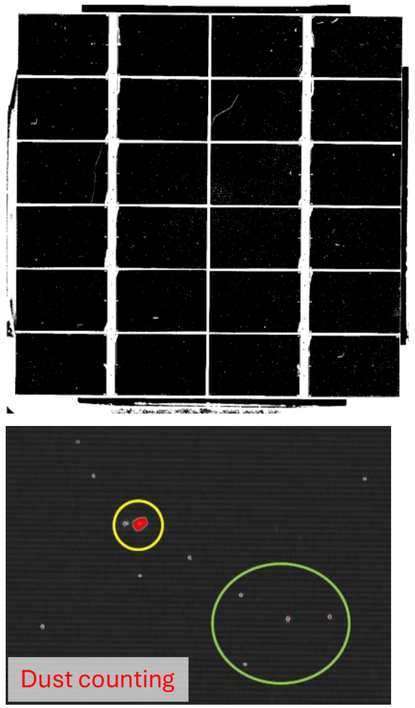
Radon level
Below
5Bq/m³

All steps from production to characterization performed in IS05-IS07 clean room



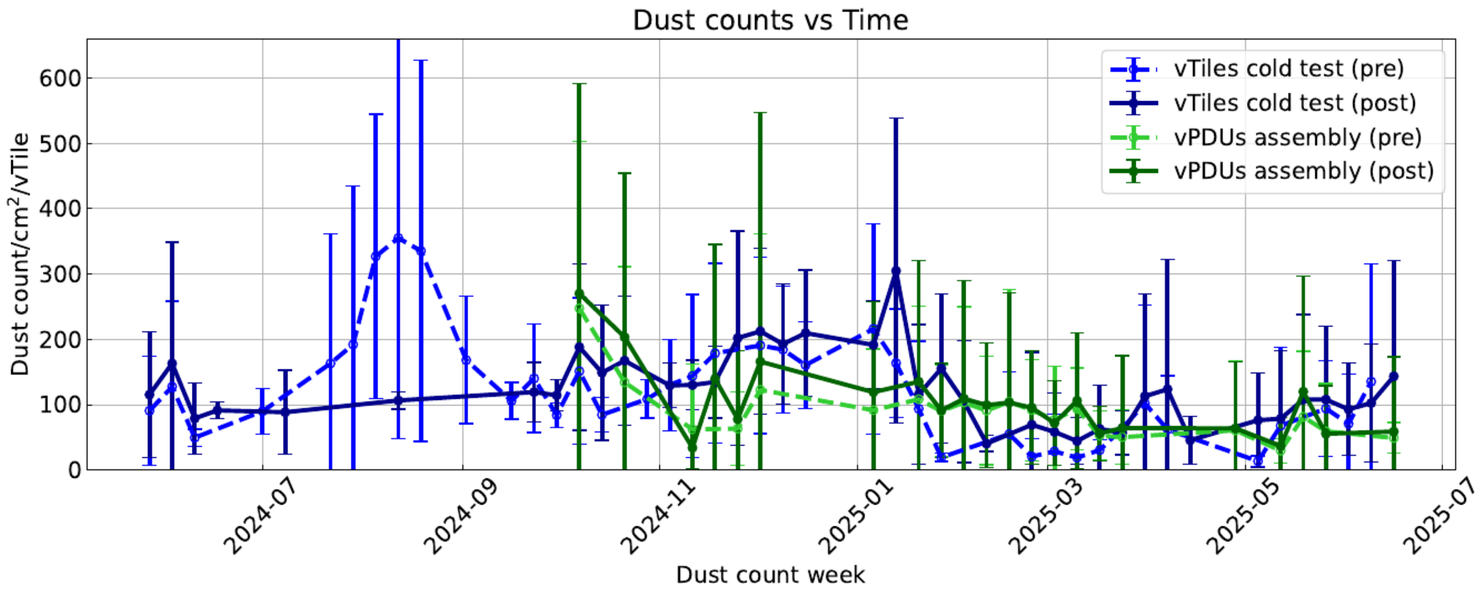
DUST MEASUREMENT





Counting of dust particle/area
in each step of production

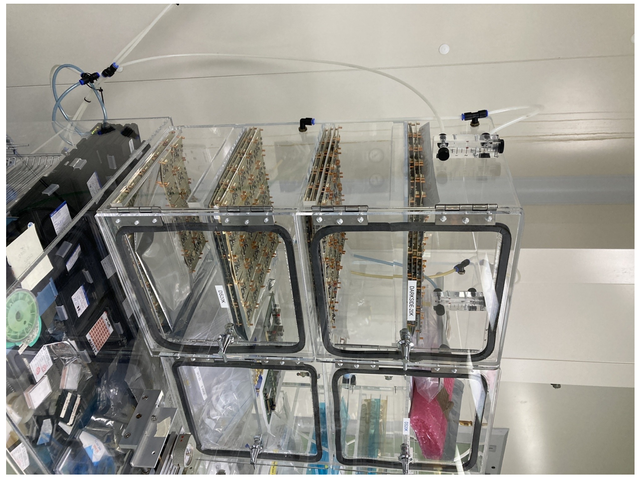
Monitoring of dust



Requirement: <500 ng/cm^2

STORAGE AND EXPOSURE

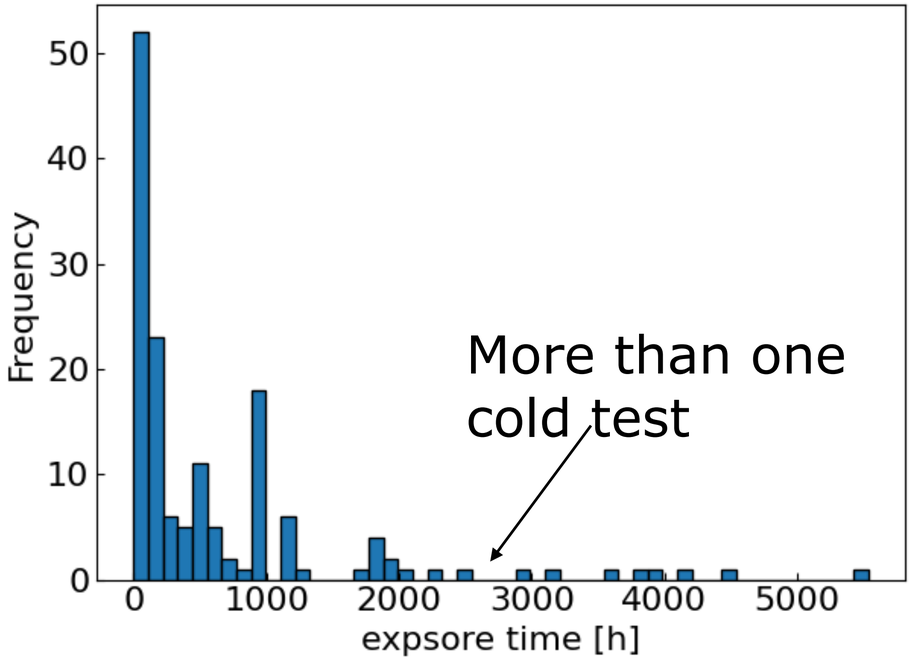
PCB storage
nitrogen-flushed containers



Radon barrier bags

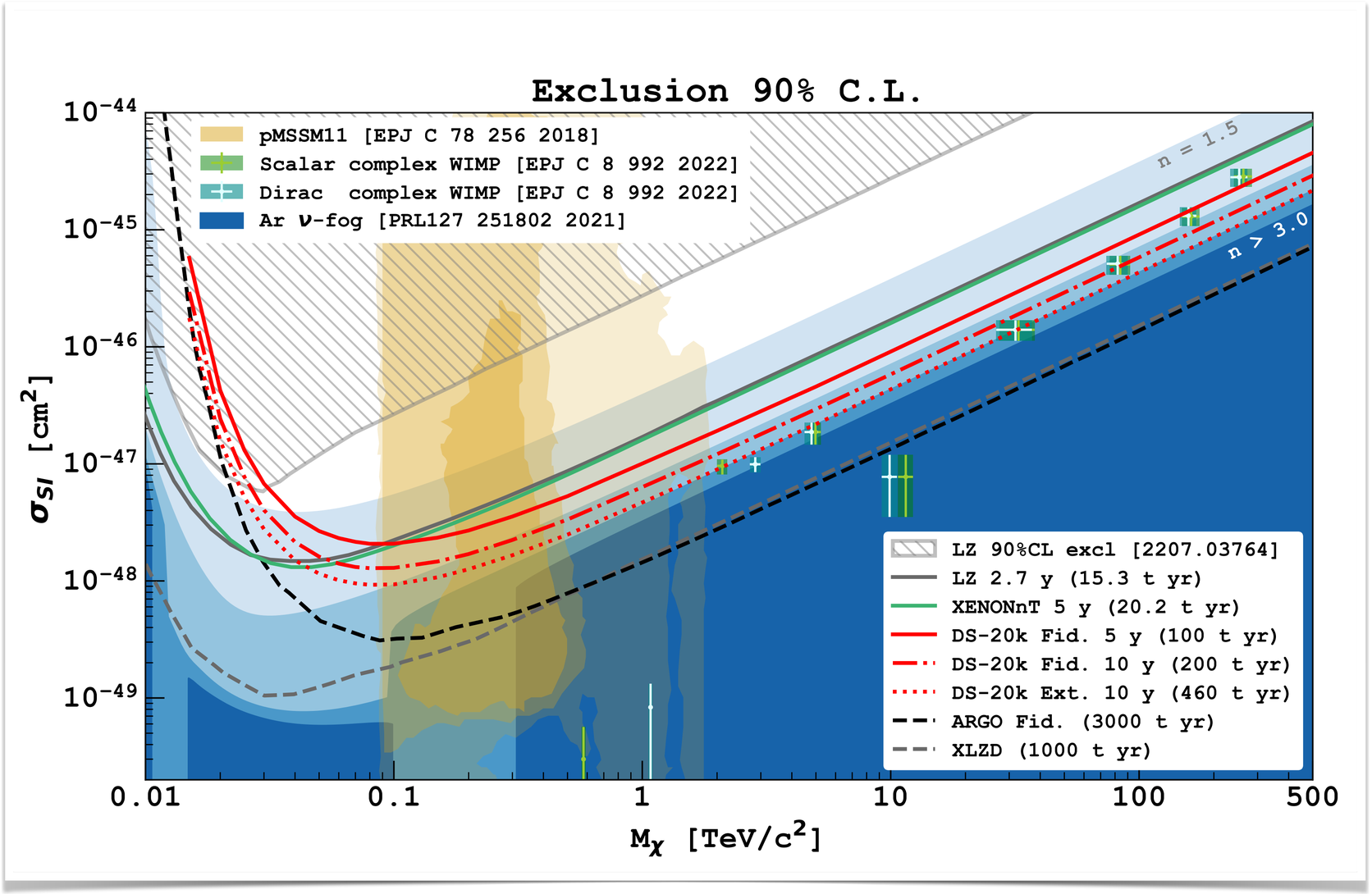
PDU storage in
nitrogen-purged conditions

Tracking timing of exposure, i.e
assembly and cold charatherization



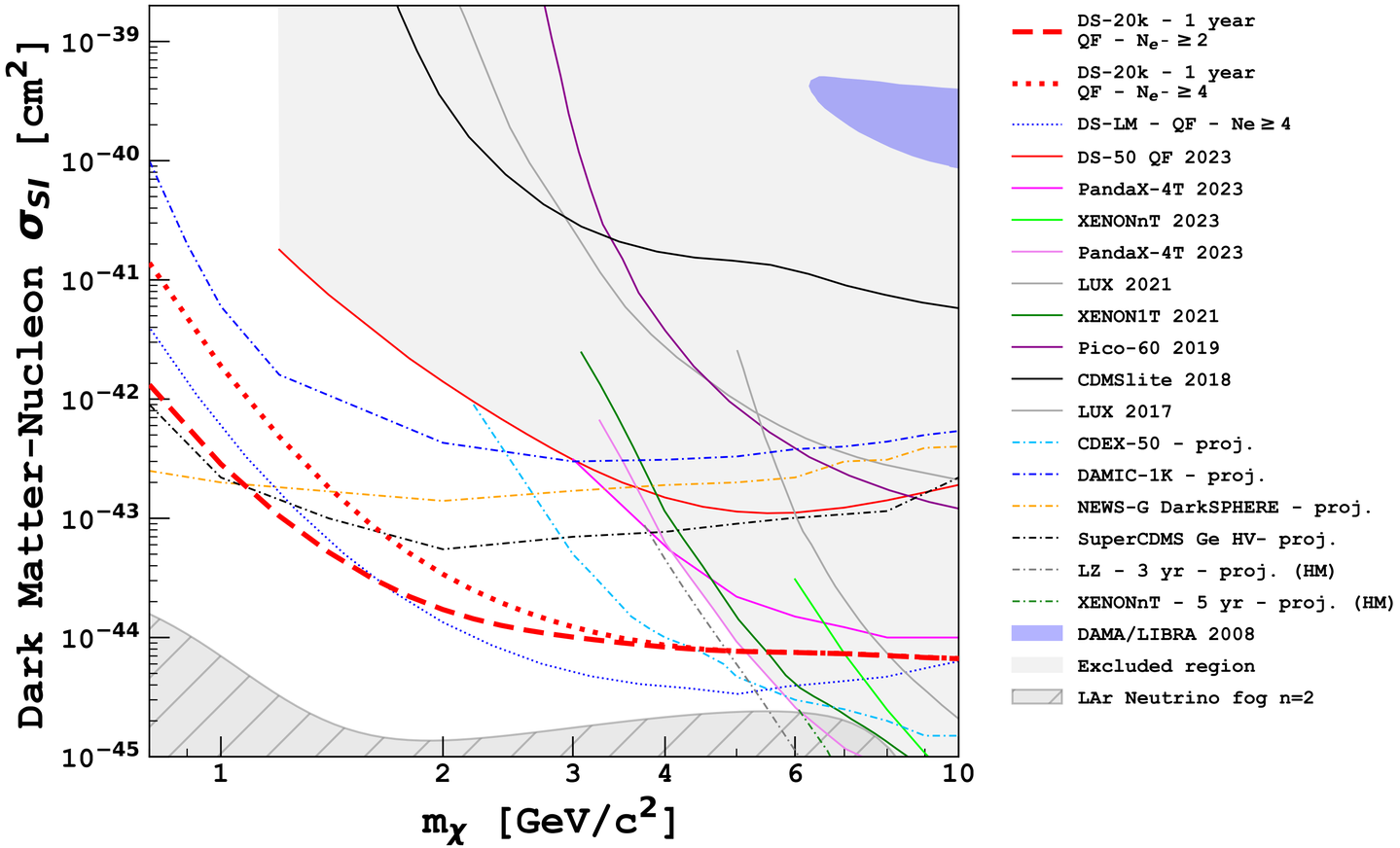
DARKSIDE-20k SCIENCE GOAL

HIGH MASS DARK MATTER SENSITIVITY



- Sensitivity to high mass WIMP-nucleon scatter cross section of 7.4 x 10^{-48} cm^2 for a 1 TeV/c^2 WIMP for a total exposure of 200 tons x years
- Total background events after all cuts: < 0.21 neutron wimp like events in a total exposure of 200 tons x years

LOW MASS SEARCH



- Using only charge signal
- Detailed background from DS-50 data
- First assessment of DS-20k sensitivity to low mass dark matter particle
- Sensitivity below 5 GeV/c^2

Nature Commun Phys 7, 422 (2024)

CONCLUSIONS

- **DarkSide-20k is pushing the state-of-the-art in several directions**: SiPM technology, underground argon extraction & purification, background assay campaign
- **DarkSide-20k stands among the leading direct detection experiments for WIMPs**, with sensitivity complementary to collider and indirect searches
- **Fundamental to its performance are rigorous material selection, precise background modeling, and strict radiopurity control to achieve unprecedented background suppression.** In particular, secular equilibrium breaking along the U chain is crucial for accurate neutron background estimates, with over 25% of neutrons arising from ^{210}Po due to this disequilibrium.
- **Fundamental role played by neutron veto detector** which is key to achieving free instrumental backgrounds to the dark matter search! And expanding the reach beyond heavy WIMPs…