DarkSide-20k and the Future Liquid Argon Dark Matter Program

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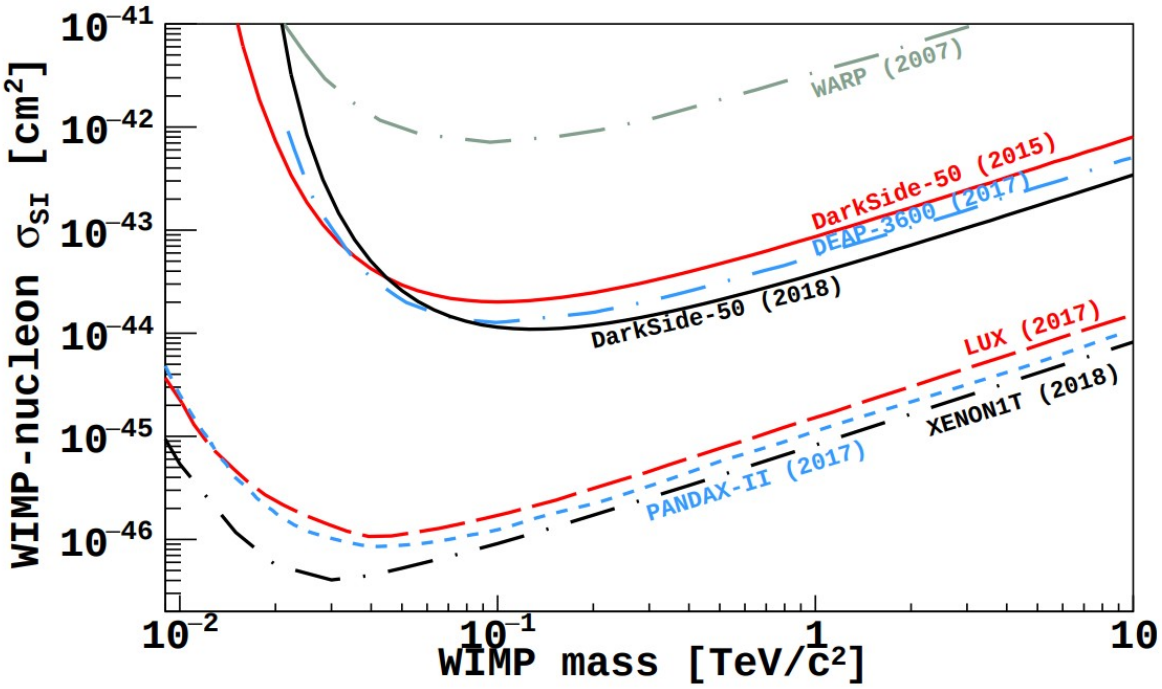
on behalf of the DarkSide Collaboration

25/05/2022

Motivation

Explore direct detection for WIMP Dark Matter down to the neutrino floor

→ Build on existing DarkSide-50 technology
- Low instrumental background
- Dual phase argon time projection chamber



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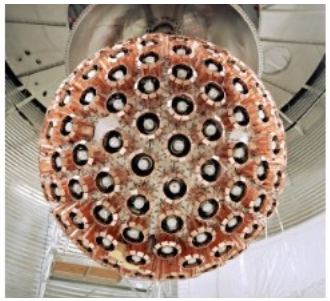
Noble liquid detectors assets:
- Efficient background discrimination
- Massive target
- High scintillation yield

Liquid argon detectors assets:
- Massive
- Radiopure
- High scintillation yield
- High ionization yield
- Low electron mobility
- Argon mass << Xenon mass
- Higher recoil energy (transferred momentum) wrt Xe at low energy

→ Upgrade to a **20 t detector** to **gain exposure** and hence **improve sensitivity** to dark matter

The Global Argon Dark Matter Collaboration

Four Argon-based Experiments gathered in GADMC



DEAP-3600

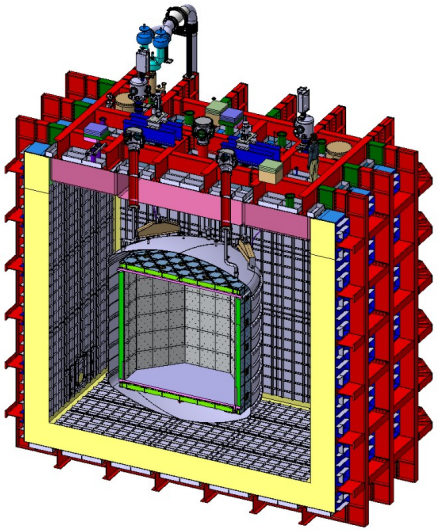
ArDM

DarkSide-50

MiniClean

~ 500 people
100 institutions

DarkSide-20k



Projects:
- DS-Lowmass
- Argo (300 t)

DarkSide Experiment

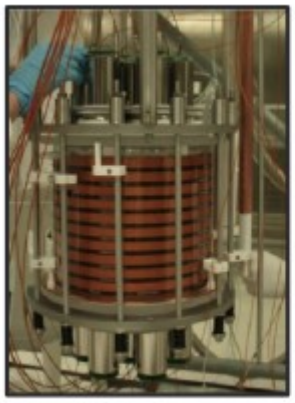
Direct Detection of Dark Matter using Liquid Argon

→ Argon dual-phase Time-Projection Chamber (TPC)

→ Direct detection by nuclear or electronic scattering

→ Background free at high WIMPs masses (Pulse Shape Discrimination)

→ Modeled background for low DM masses studies (< 10 GeV/c2)

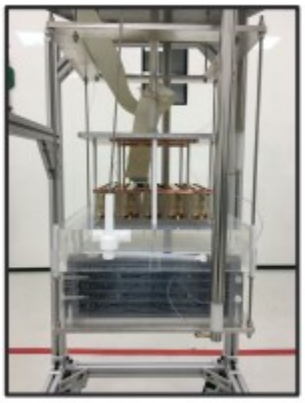


DS-10

2011 - 2013

DS-50

2013 - 2020

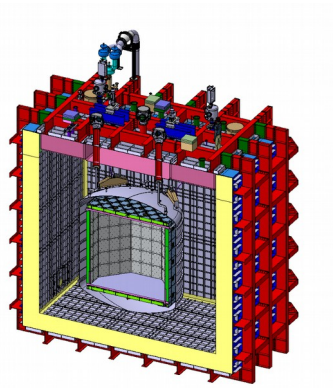


DS-Proto0

2019 - 2022

DS-Proto1T

2022 - ...



DS-20k

2025 - ...

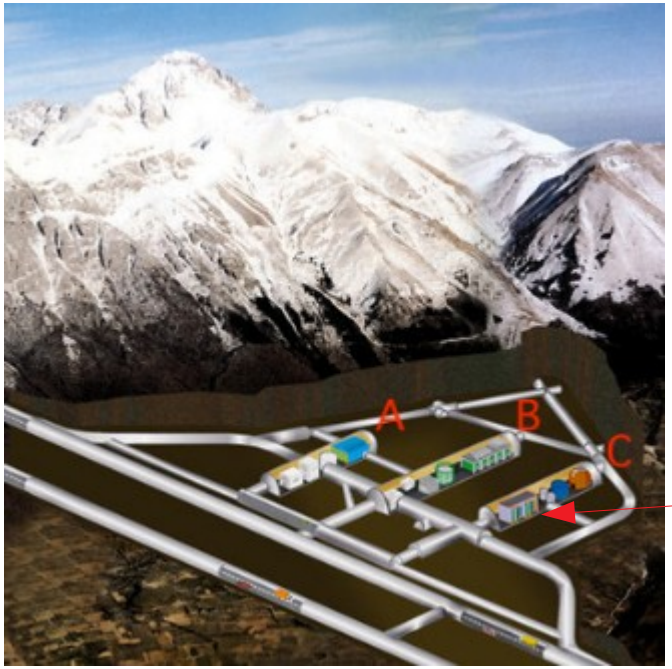
Argo

...

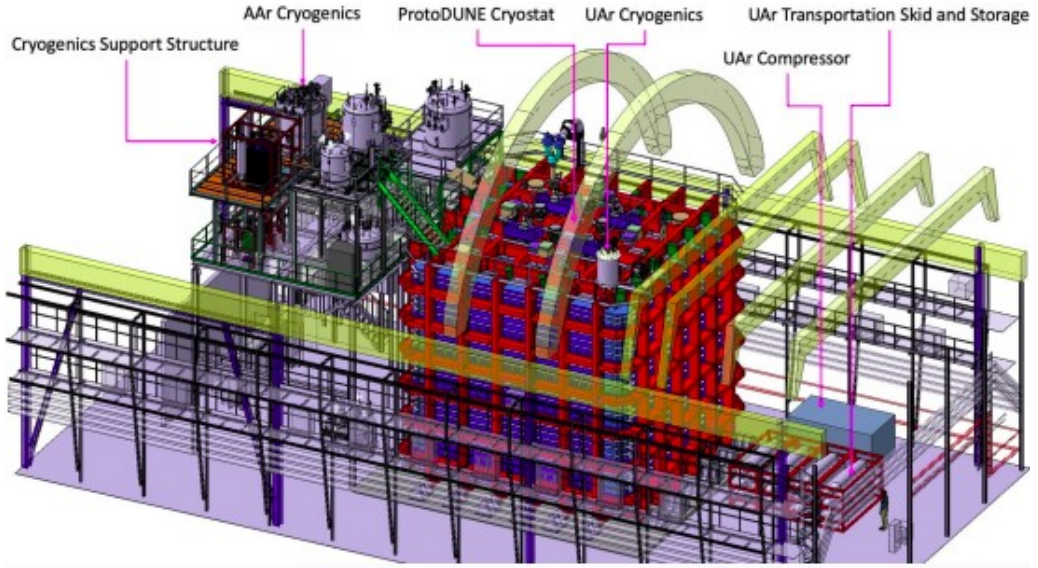
Laboratori Nazionali del Gran Sasso (LNGS)

Underground Research Facility

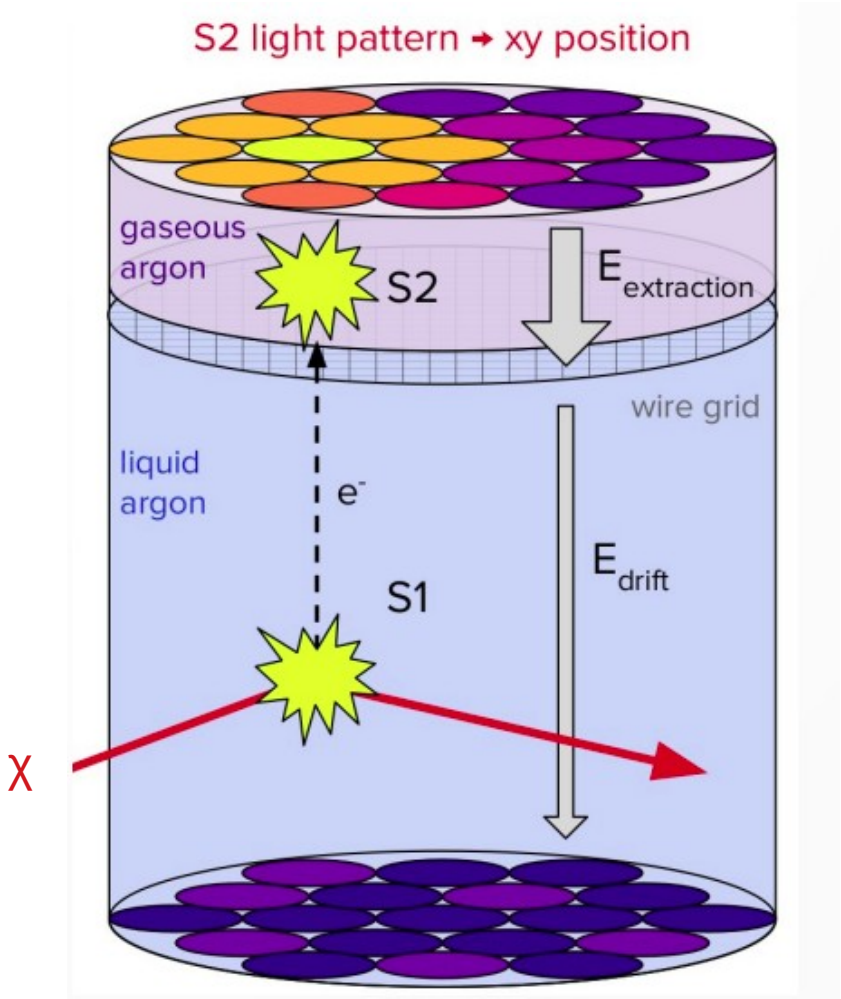
→ 1400 m of rock above the facility



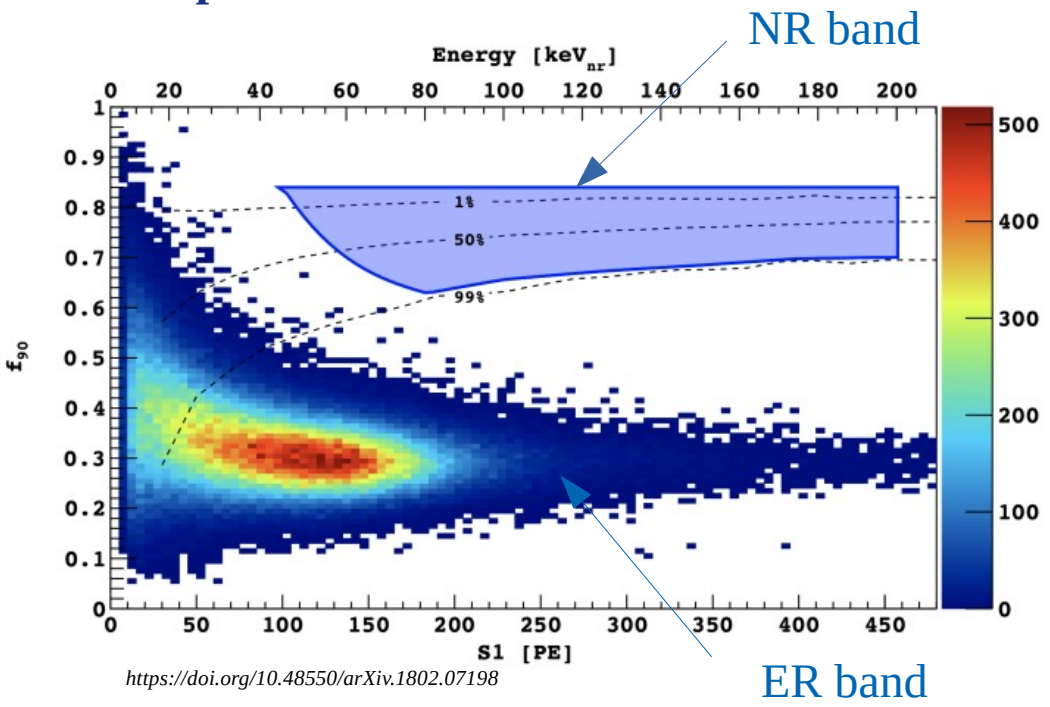
DarkSide-20k will be in Hall-C



Time Projection Chamber



Pulse Shape Discrimination



https://doi.org/10.48550/arXiv.1802.07198

- Discrimination between electron recoils (ER) and nuclear recoils (NR)

- β, γ rejection background

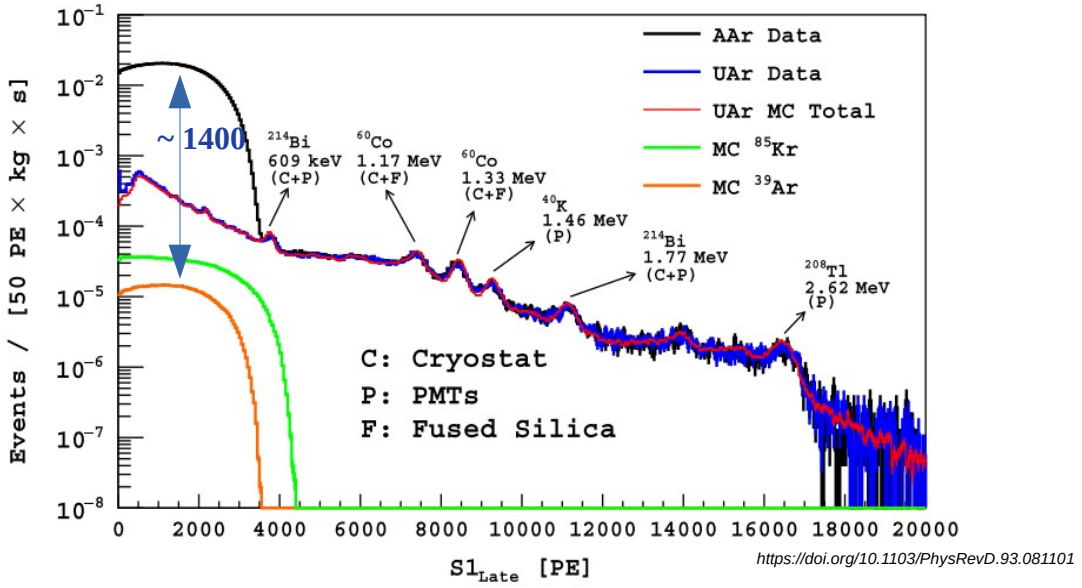
- Based f90: the ratio of scintillation light in the first 90 ns compared to the total
  - → ER ~ 0.3
  - → NR ~ 0.7

Underground Argon (UAr)

- 39Ar radioactivity in **atmospheric** argon:
  - → β-emitter with an endpoint of 565 keV
  - → activity ~ 1Bq/kg

- 39Ar **cosmogenic** isotope
  - → Lower 39Ar production rate in UAr

Using **UAr** allows to have a **reduction factor of background ~1400**.



https://doi.org/10.1103/PhysRevD.93.081101

Thanks to UAr + PSD:
We expect **< 0.1 events/(200t year)** of residual background due to electron recoils

UAr: Urania / Aria /DArT

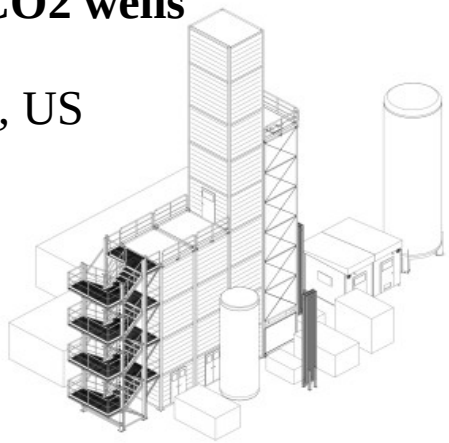
Urania

Extraction of UAr from CO2 wells

- Plant in Cortez, Colorado, US

- Can extract 330 kg/day

- Purity 99.99%



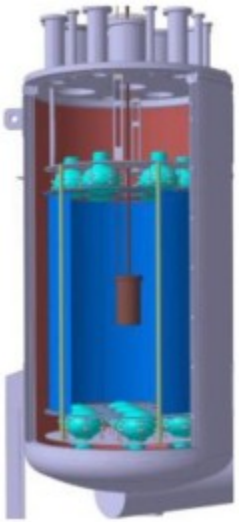
DArT

Measures 39Ar depletion factor

- At LSC, Canfranc, Spain

- Radiopure single phase LAr inner detector (1.42 kg LAr)

-Veto: Inside ArDM detector (1t LAr)



Aria

Perform chemical and isotopic purification of UAr

- At Seruci mine in Sardinia, Italy

- Distillation Column, rate 1t/day
- A 39Ar reduction factor 10 expected per pass

- Medical applications (oxygen isotope separation for instance)

- Assembly of the final column will be finish this year

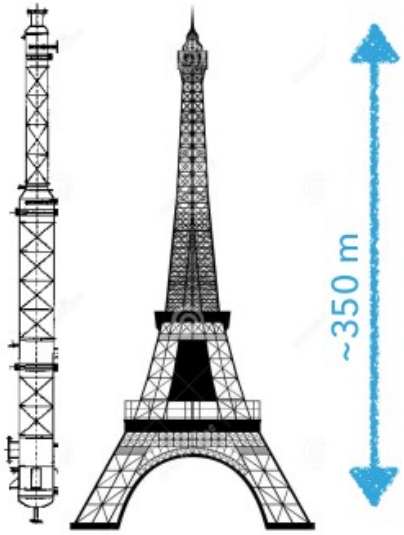


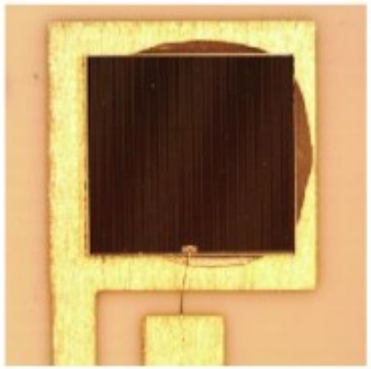
Photo Detection

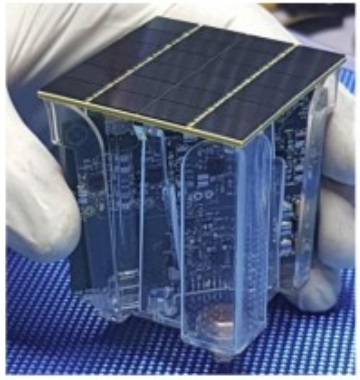
Single-Photon Avalanche Diode (SPAD) – 25-30 µm²

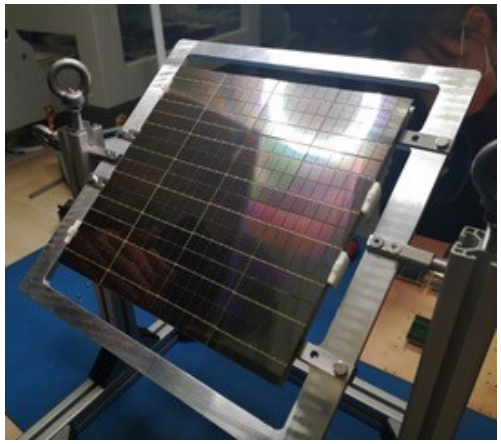
Silicon Photomultipliers (SiPM) – 7.9 x 11.7 mm²
Composed by SPADs

Photo Detector Module (PDM) – 5 x 5 cm²
Composed by 24 SiPMs

Photo Detection Unit (PDU) – 20x20 cm²
composed by 4x4 PDMs







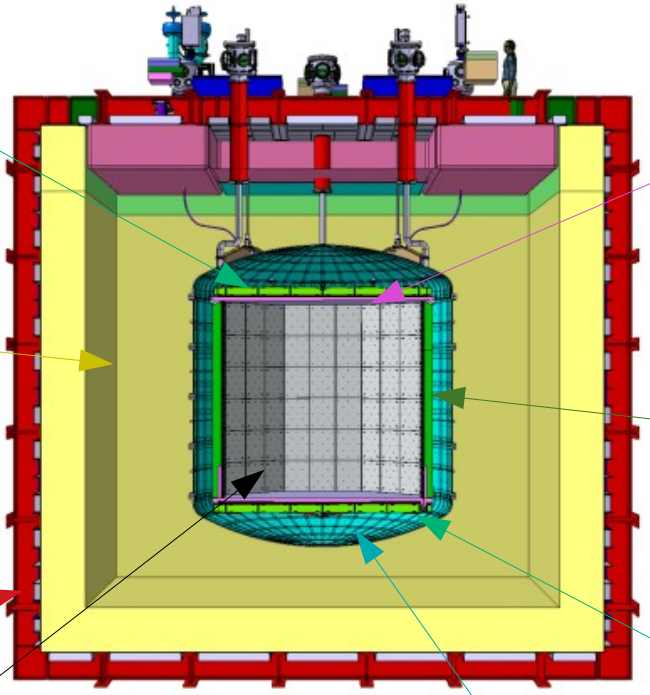
SiPMs

- Developed with the Fondazione Bruno Kessler
  - → 8448 tiles for the TPC
  - → 1920 tiles for the Veto

- Key features:
  - → Low dark count rate < 20 cps
  - → Timing resolution ~ 10 ns
  - → Photon detection efficiency ~ 45 %
  - → Radiopure ~ 2mBq/PDM

DarkSide-20k: Design

Nested structure detector



Top Optical Plane

Acrylic panels loaded with gadolinium

Outer veto: ~700t of AAr

TPC acrylic vessel

Membrane cryostat

Bottom Optical Plane

TPC with 50t of UAr
Fiducial mass of 20t

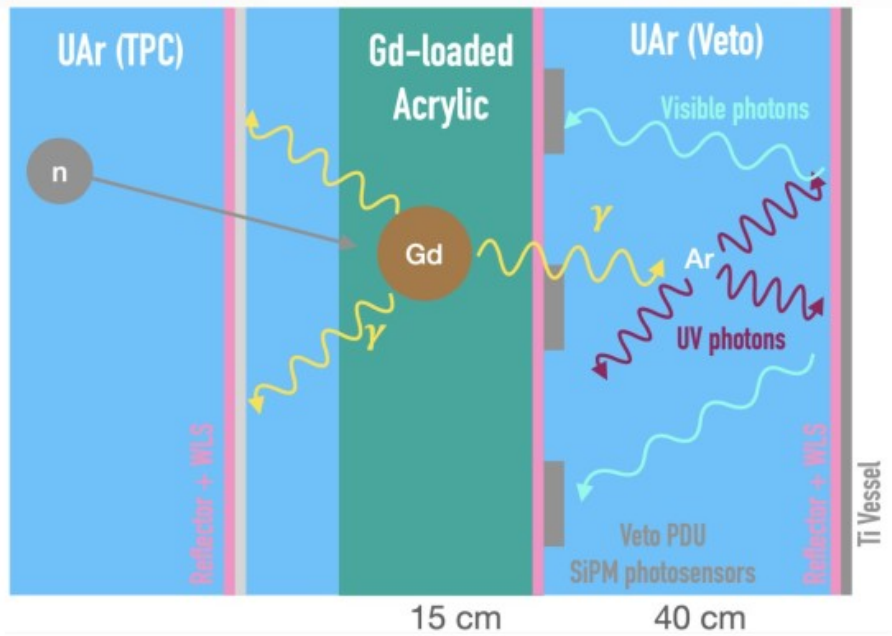
Inner veto:
Titanium vessel filled with 32t of UAr

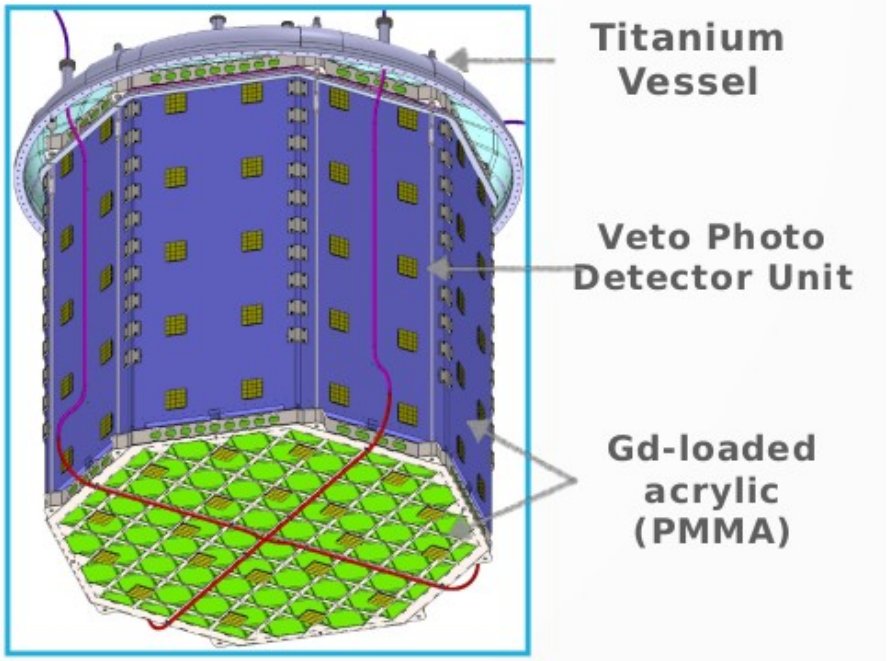
21 m² of SIPMs in the TPC
5 m² cryogenic SiPMs in the Veto

DarkSide-20k: Inner Veto

Neutron Veto Principle

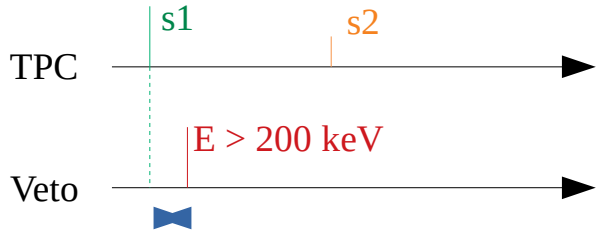
→ Neutrons are captured by the Gd-loaded Acrylic
→ Gd emits γ rays up to 8 MeV
→ They interact with UAr
→ The scintillation light is shifted using TPB
→ And then detected by SiPMs





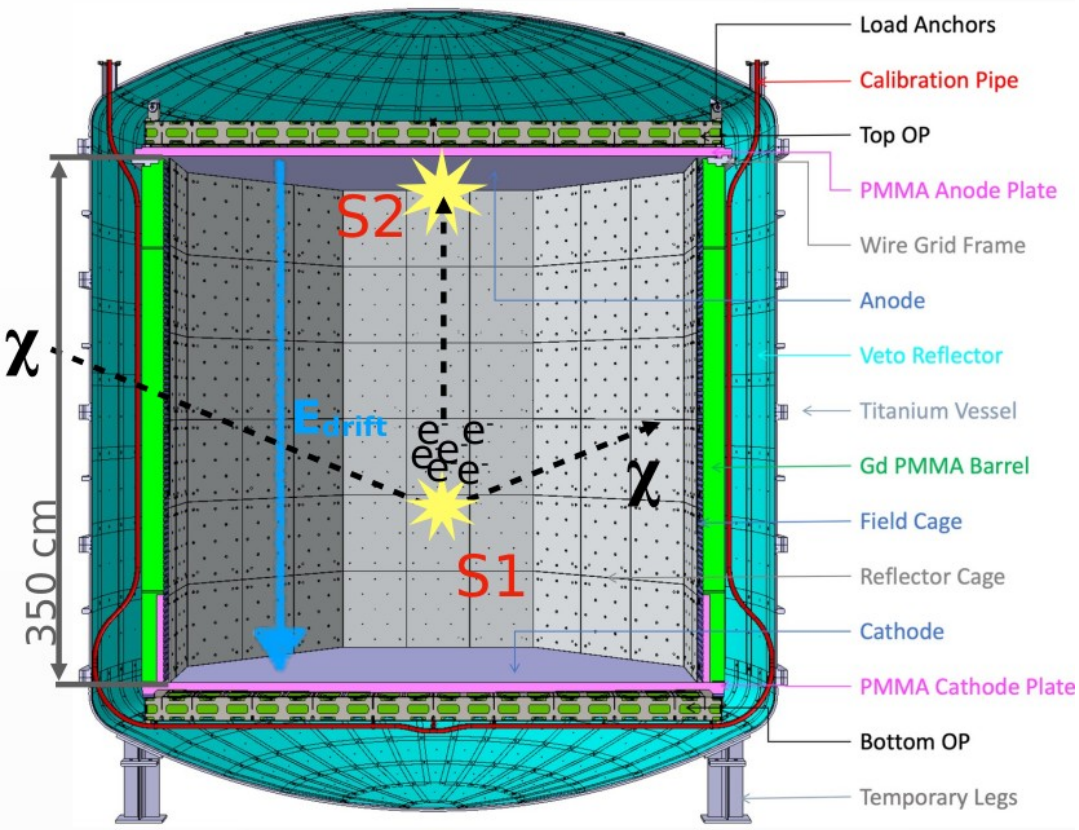
Veto Condition

→ Measured energy of the scintillation light in the veto > 200 keV and within a 800 μs time coincidence with an s1 in the TPC



DarkSide-20k: TPC

Design inside the Titanium Vessel:



Features:

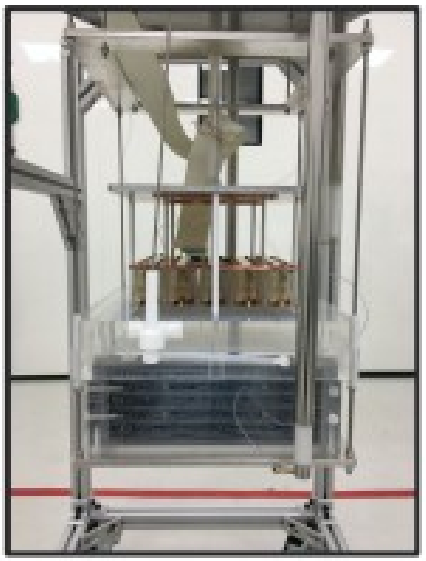
Maximum drift length: 348 cm
Octagonal inscribed circle diameter: 350 cm
Gas pocket width: 7.0±0.5 mm
S1 Light Yield: 10 pe/keV
S2 Yield: > 20pe/e-

Drift field: 200 V/cm
Extraction field: 2.8kV/cm
Luminescence field: 4.2kV/cm

XY resolution: < 5cm
Z resolution: 1 mm

UAr mass in TPC: 51.1t
Vertical fiducial cut: 70 cm
Radial fiducial cut: 30 cm
Fiducial UAr mass: 20.2t

Prototypes



DS-Proto0

→ At CERN (2019 - 2020) and then at Naples (2022)

Goal:

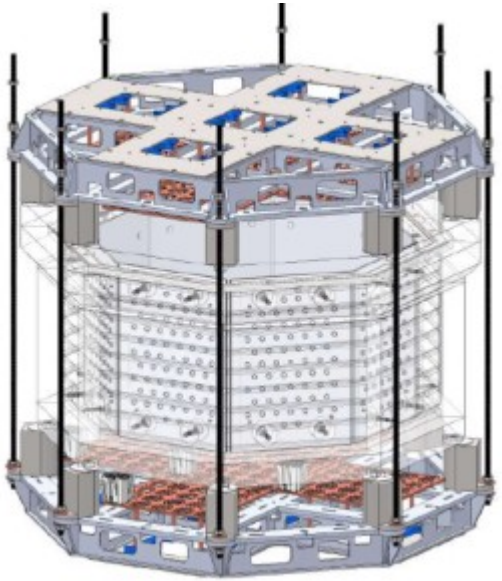
→ First test of a full motherboard with SiPMs
→ Test of the formation of the gas pocket
→ Development of the offline calibration and reconstruction software

DS-Proto1T

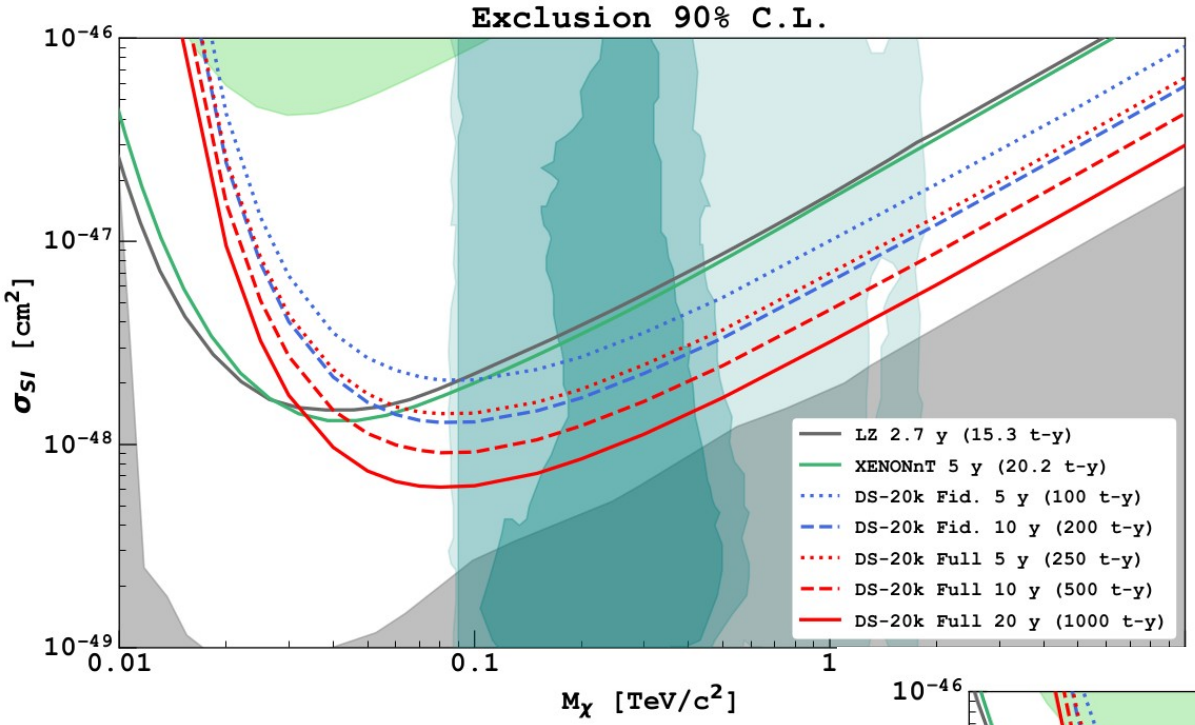
→ At CERN, started in 2022

Goal:

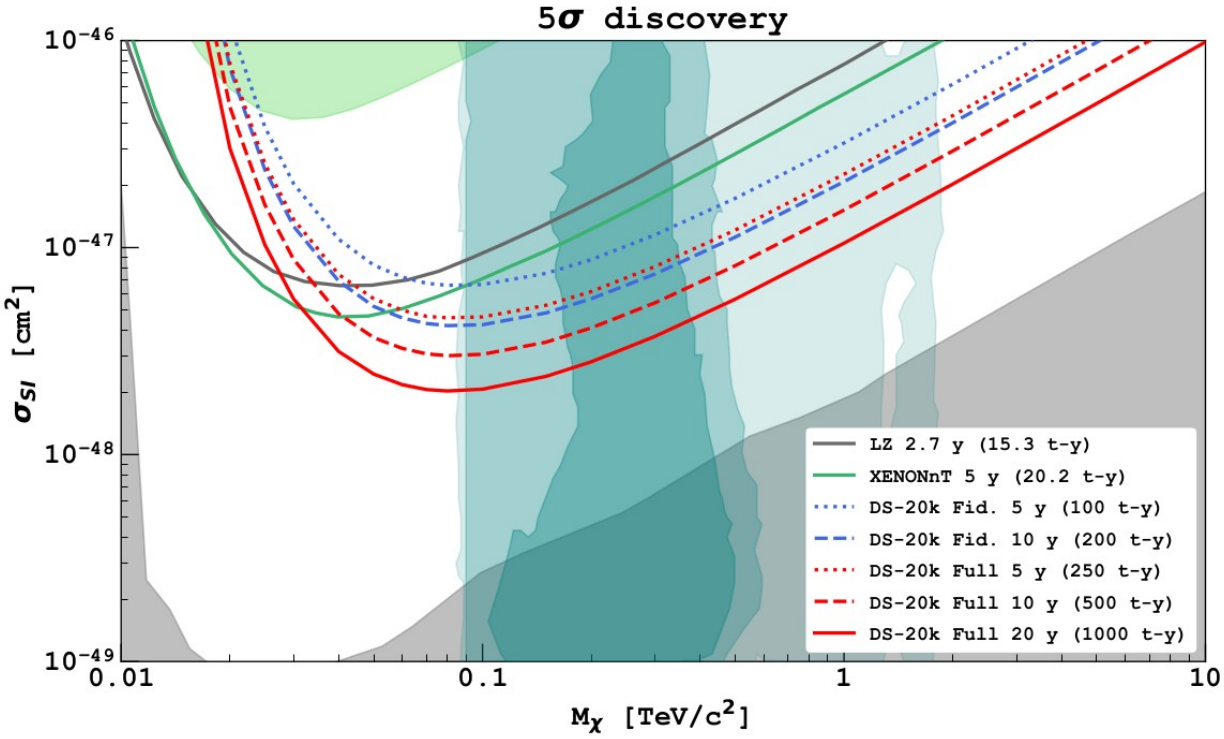
→ Test of a down-scaled version of DarkSide-20k
→ Test of PDUs and of the octagonal acrylic vessel



DarkSide-20k: Sensitivity



Sensitivity to spin independent WIMPs

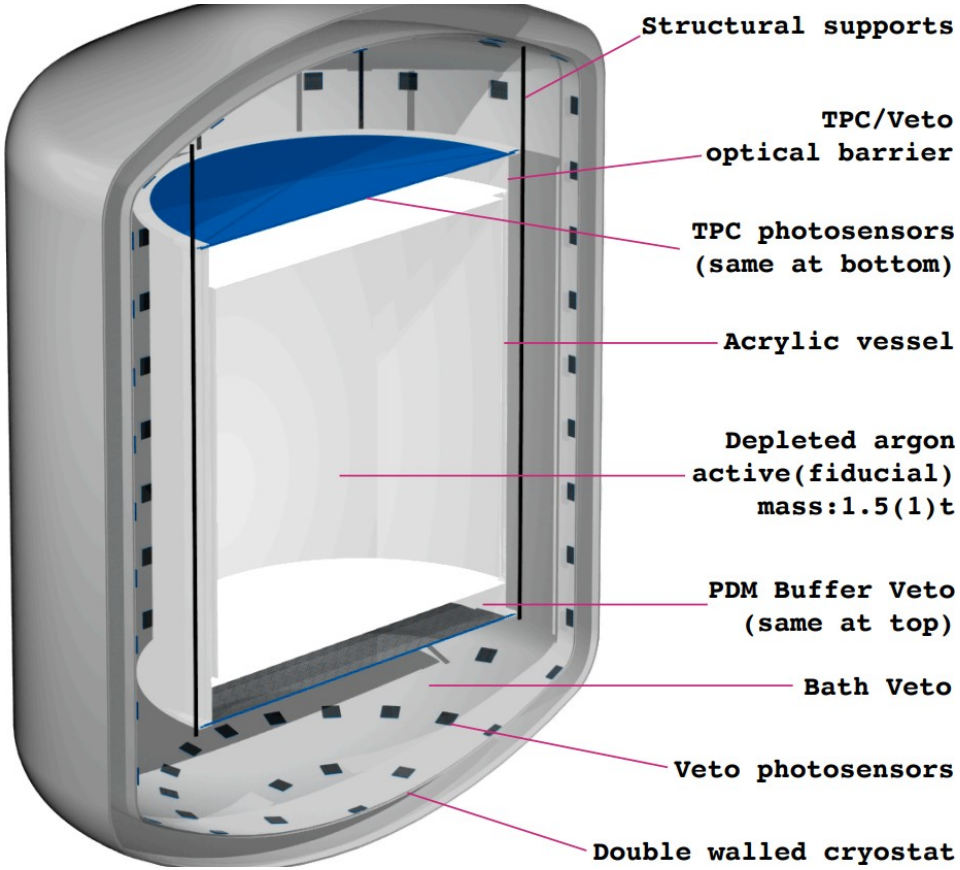


Side Project: DarkSide-Lowmass

Design

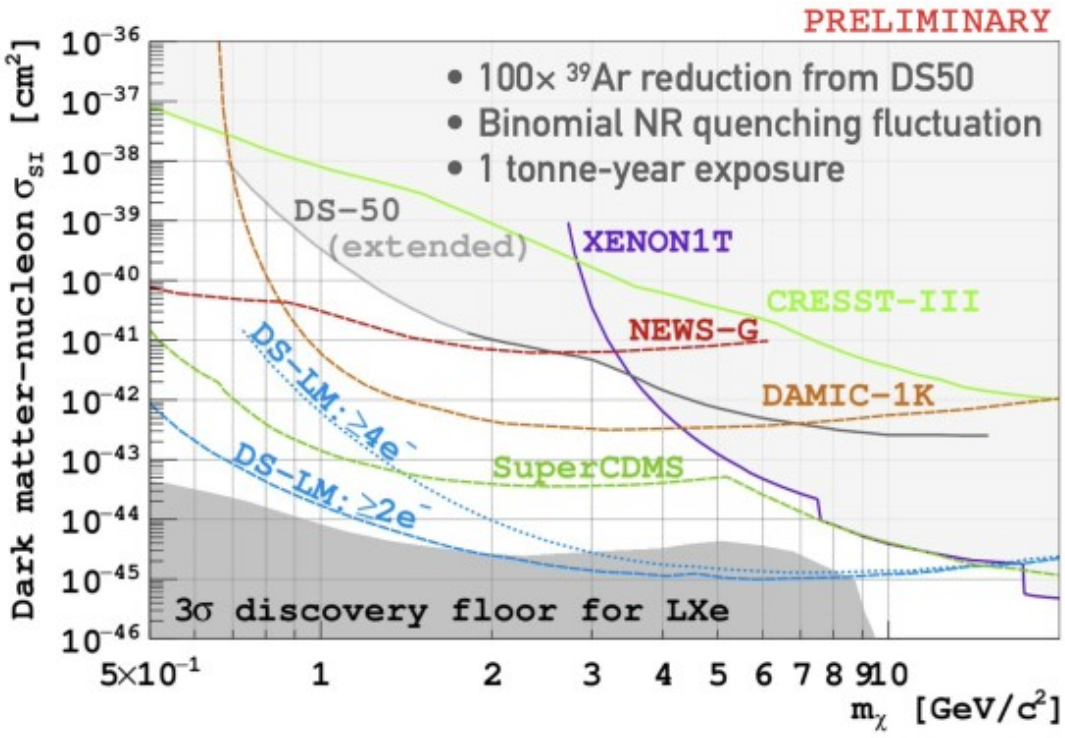
→ Dual-Phase TPC
→ Cylinder or octagonal shape
→ 864 PDMs

Aim: Gaining sensitivity to **light dark matter** candidates



Based on the **s2 only signal** as for DarkSide-50 low mass analysis

Discovery sensitivity



→ Sensitive **up to** the **neutrino floor**

Summary

→ **UAr** allows to perform efficient WIMP searches both a low and high masses

→ A dedicated process **Urania/Aria/DArT** is under development to scale up UAr production

→ A new detector aiming at reaching a better sensitivity to dark matter :

DarkSide-20k

→ A large collaboration (GADMC) with **expertise** on argon detectors

→ **Technological developments**, for instance for photo-sensors

→ Construction of DarkSide-20k started in **2022** and the data taking will start in **2025**

Thank you for your attention!