DarkSide-20k and the Liquid Argon Dark Matter Program

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The DarkSide Collaboration

AstroCeNT CAMK, Warsaw

Conference on Science at the Sanford Underground Research Facility, 11-13 May 2022

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Republic of Poland
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European Union European Regional Development Fund
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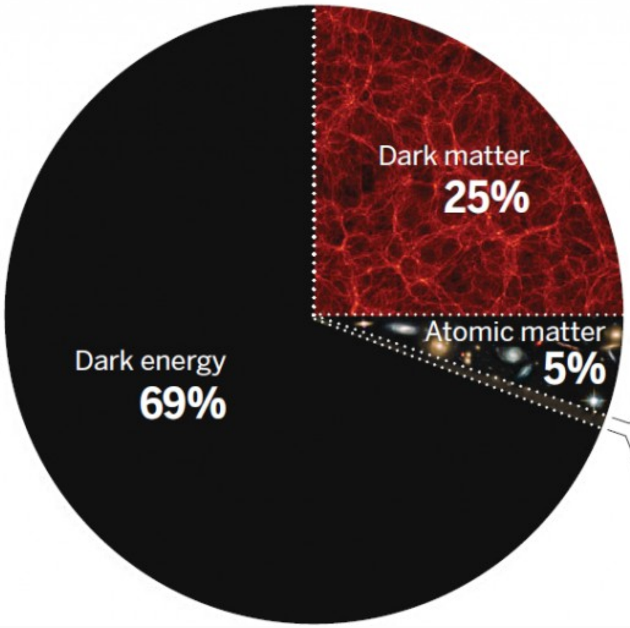
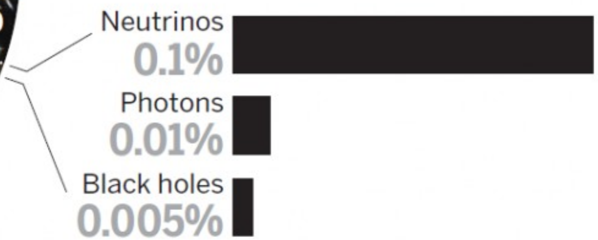
Dark Wave

Dark matter searches

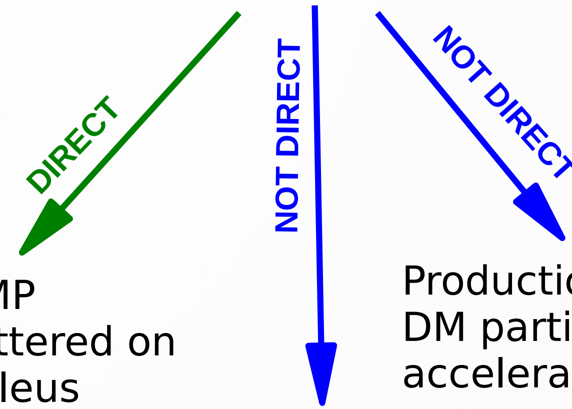


Dark matter :
1) baryonic e.g. MACHO: BH, neutron stars, brown dwars

2) non-baryonic
- hot: relativistic neutrinos
- cold: lower speed, **WIMP** 10 GeV- ~ TeV



Dark matter search

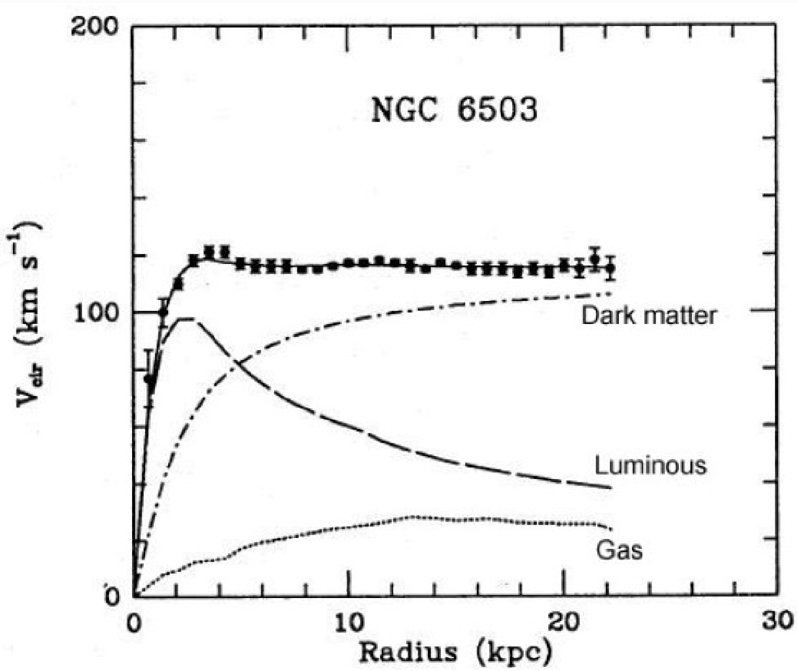


WIMP scattered on nucleus

Production of DM particles in accelerators

Observation of DM annihilation / decay products:
- antimatter
- gamma photons
- neutrinos

1. The rotation curve of galaxies and the movement of galaxies in clusters
2. Gravitational lensing
3. Formation of large-scale structures
4. Heterogeneities in the microwave background radiation



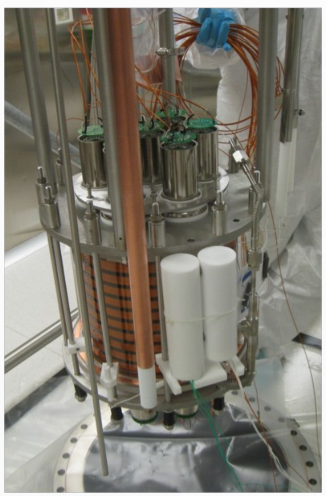
Begeman, Broeils, and Sanders, 1991

DarkSide program

Direct detection search for **WIMP** dark matter

Based on a **two-phase argon** time projection chamber (**TPC**)

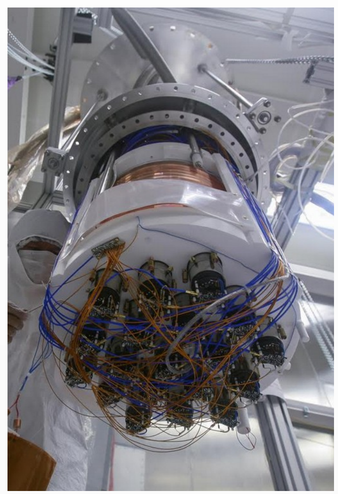
Design philosophy based on having very low background levels that can be further reduced through **active suppression**, for **background-free** operation from both neutrons and β/γ’s



2011-2013

DarkSide-10

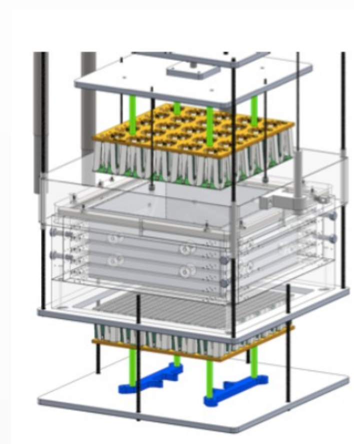
10 kg
Gran Sasso, IT
First prototype



2013-2020

DarkSide-50

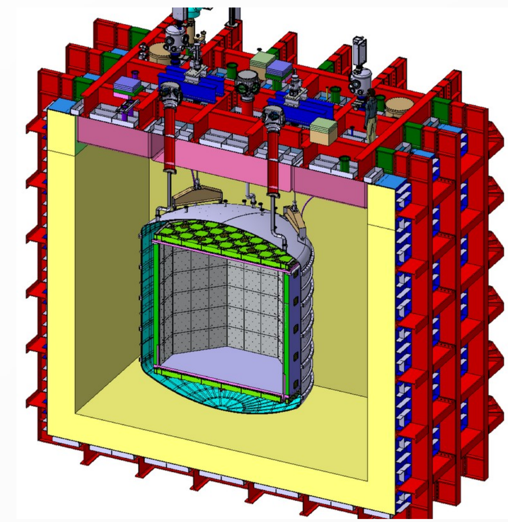
46 kg
Gran Sasso, IT
$3.78 \cdot 10^{-44}$ cm^{2} @ 1 TeV (1.4 yr exposure)



2019-2022

Proto0

10 kg
CERN, CH
test of new DS-20k technologies



2025-

DarkSide-20k

51 t
Gran Sasso, IT
$7.4 \cdot 10^{-48}$ cm^{2} @ 1 TeV (10 yr exposure)

Features of noble liquid detectors

- **Dense** and **easy to purify** (good scalability, advantage over gaseous and solid target)
- High **scintillation** & **ionization** (low energy threshold, not low enough to search < 1 GeV/c^2 DM)
- **Transparent** to own scintillation

For TPC:

- Amplification (electroluminescence gain) for ionization signal
- **Discrimination** electron/nuclear recoils **(ER/NR)** via **Pulse shape discrimination**

Liquid **Xenon**

- Denser & Radio pure
- Lower energy threshold
- ~~Higher sensitivity at low mass WIMP~~

Liquid **Argon**

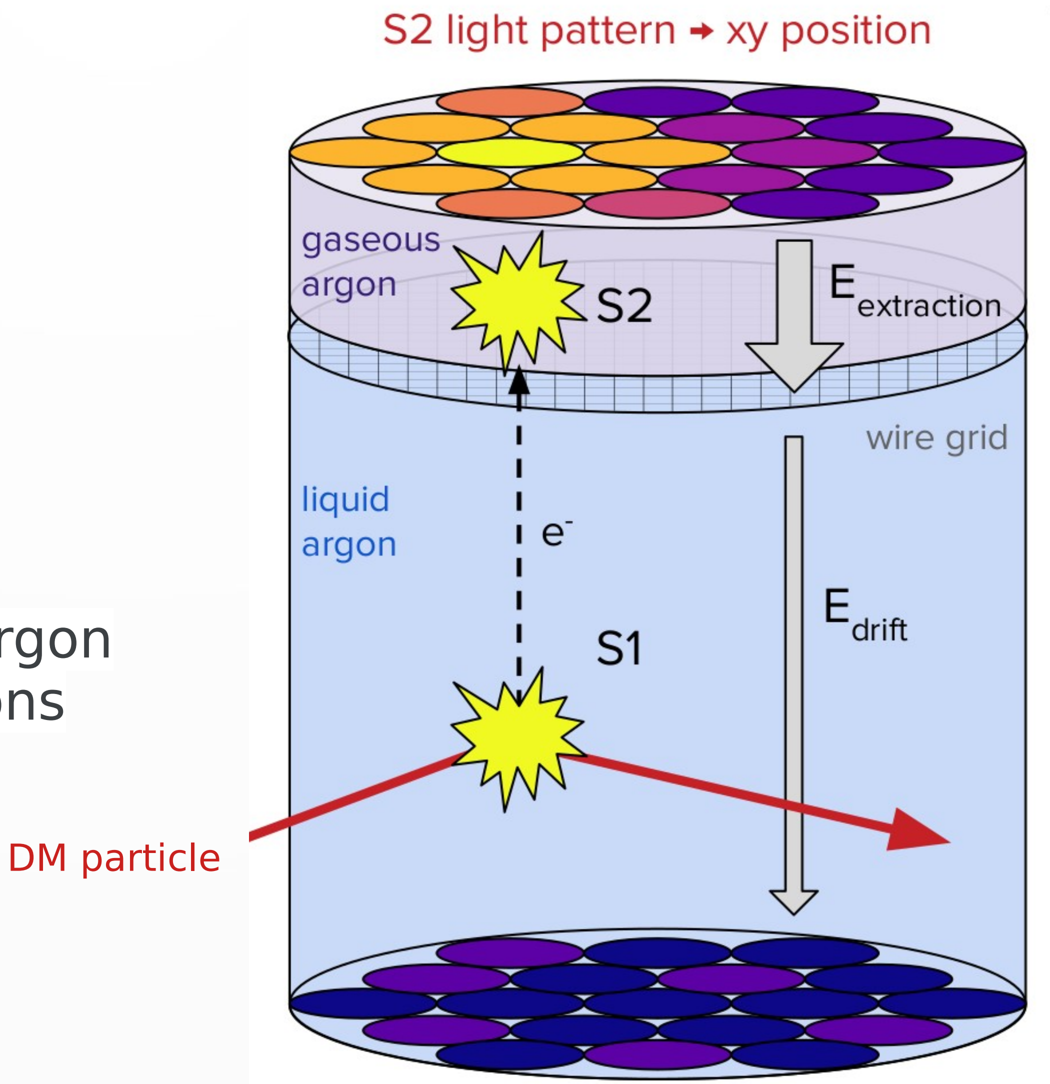
- lower temperature (Rn removal is easier)
- **Stronger ER discrimination** via pulse shape
- Intrinsic ER BG from ^{39}Ar
- Need wavelength shifter

The Time-Projection Chamber (TPC)

Based on DarkSide-50 TPC

S1: light produced in the liquid argon due to excitation and ionisation

S2: light produced in the gas argon pocket due to ionisation electrons drifted by an E field.



S2/S1 ratio and **Pulse Shape Discrimination (PSD)**

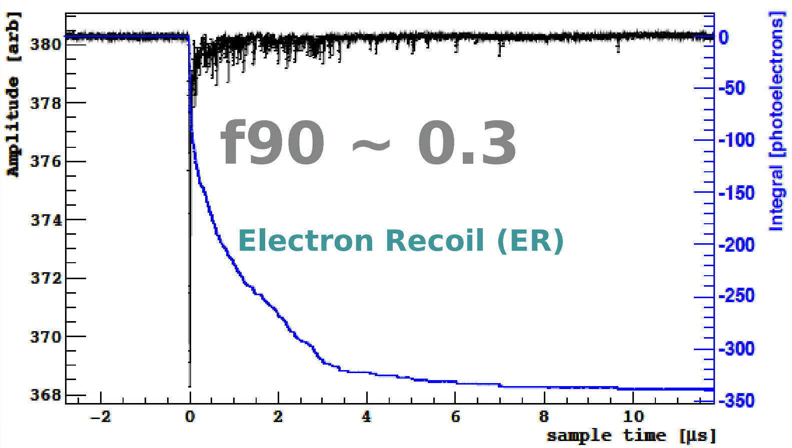
WIMPs will generate nuclear recoils (NRs)

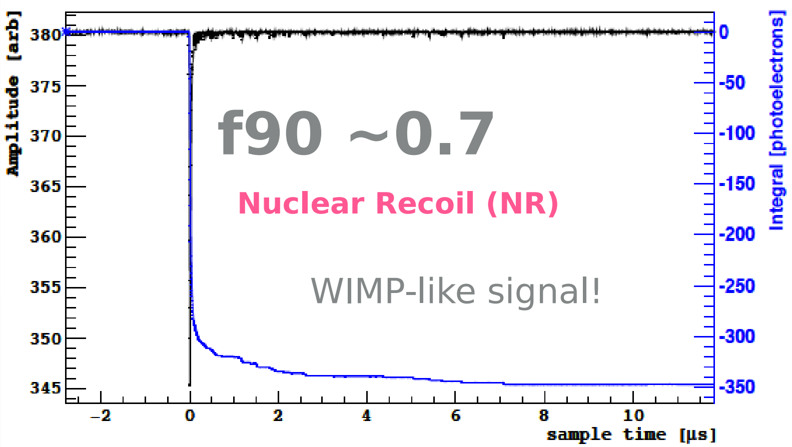
- Electron and nuclear recoils produce different excitation densities in the argon, leading to different **ratios of singlet and triplet excitation states**

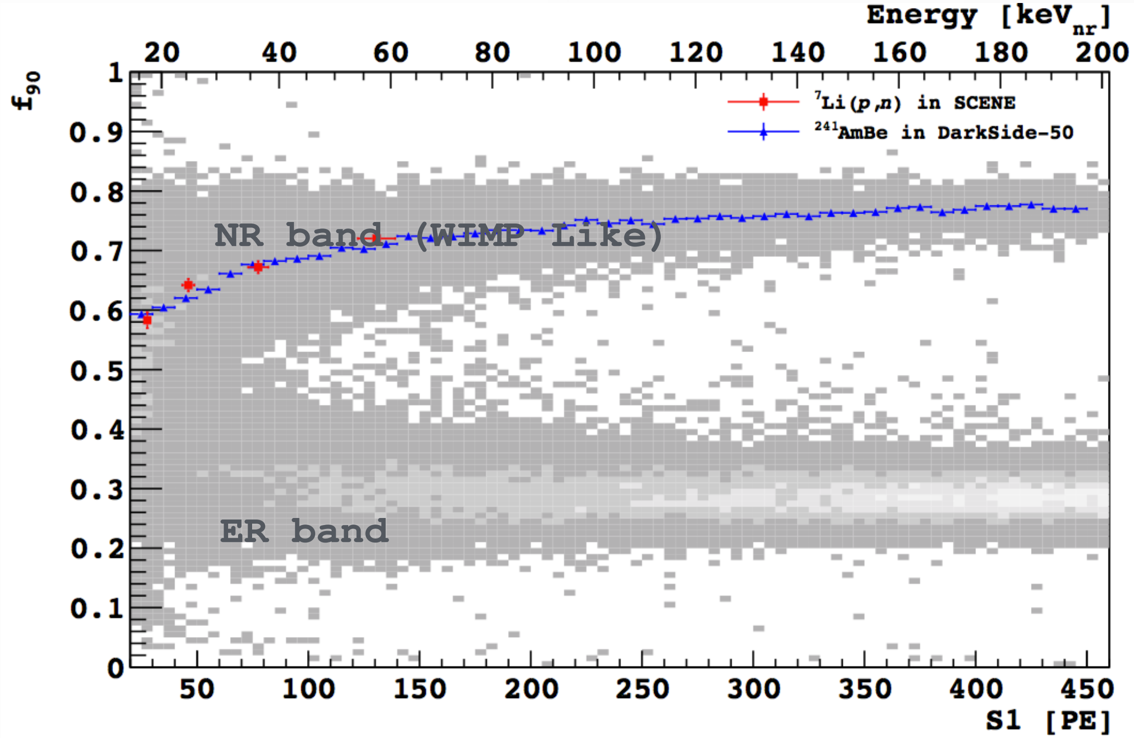
PSD parameter

F90: Ratio of detected light in the first 90 ns*, compared to the total signal

$$f90 = \frac{N_{prompt}}{N_{prompt} + N_{late}}$$







More for PSD: DEAP-3600, Eur. Phys. J. C 81, 823 (2021)

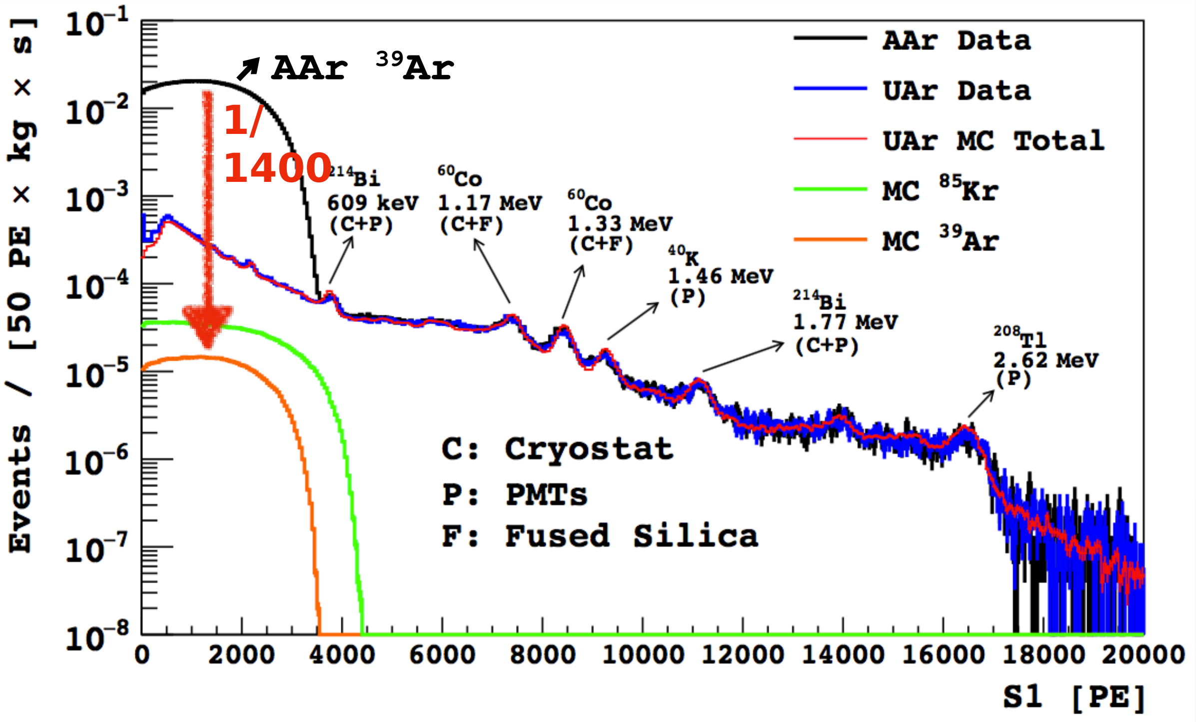
* the 90 ns is optimized value for DS50 and detector dependent parameter.

Underground Argon

- Intrinsic ^{39}Ar radioactivity in **atmospheric argon** is the primary background for argon-based detectors
- ^{39}Ar activity sets the dark matter detection threshold at low energies (where pulse shape discrimination is less effective)
- ^{39}Ar is a **cosmogenic isotope**, and the activity in argon from **underground sources** can be significantly lower compared to **atmospheric argon**

We deployed 157kg of underground argon in 2015.

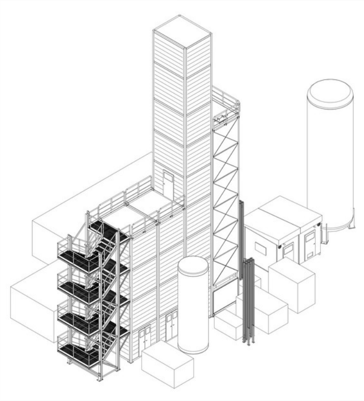
^{39}Ar reduction factor of ~1400!

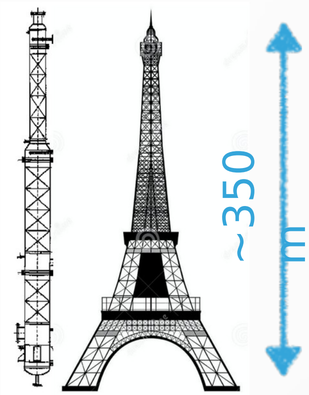


Extraction & isotope separation

- **Urania** (Extraction):
  - Takes place at argon extraction plant in Cortez, CO, to reach capacity of **330 kg/day** of Underground Argon
- **Aria** (Isotope separation):
  - 350 m tall column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon. **A factor 10 reduction of ^{39}Ar per pass is expected.**

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

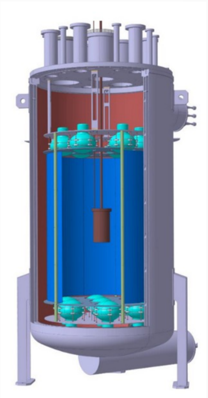




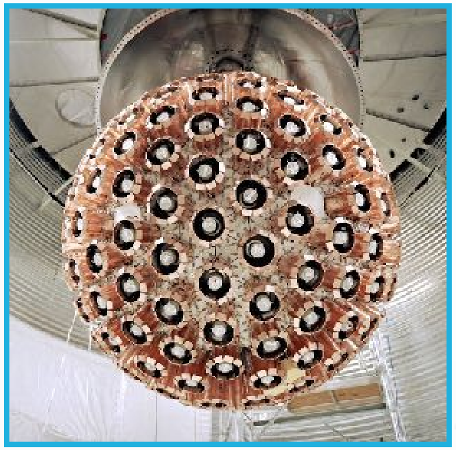
DArT:

- measurement of radiopurity of UAr in terms of Ar39 (batches from Urania and Aria)

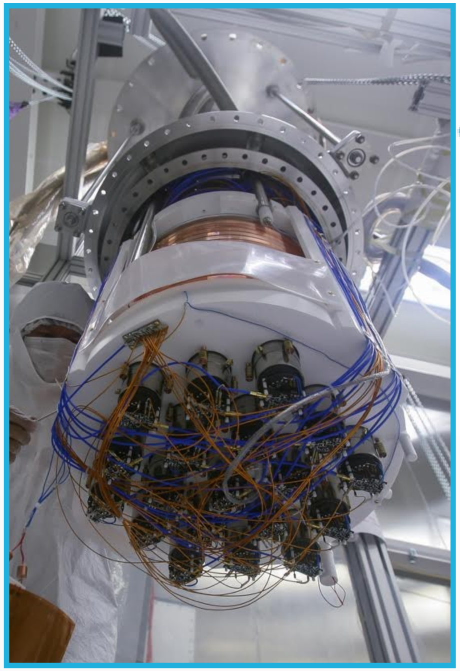
2020 JINST 15 P02024



Global Argon Dark Matter Collaboration (GADM)



DEAP-3600

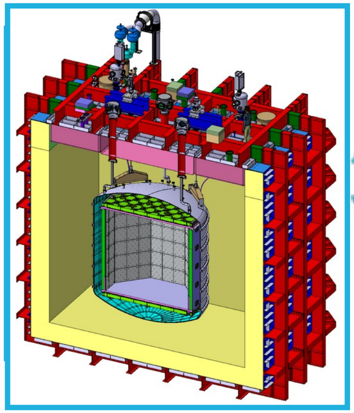


DarkSide-50

More than 400 scientists from past and present argon-based experiments in a single international argon collaboration: **GADMC**

A sequential, two-steps program:

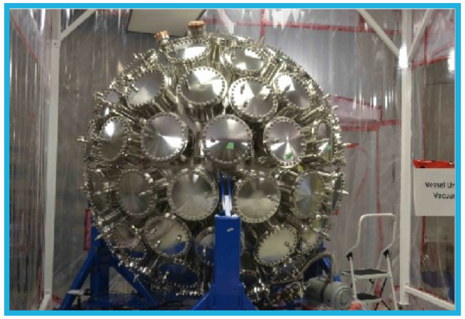
- DarkSide-20k (200 tonne yr fiducial)



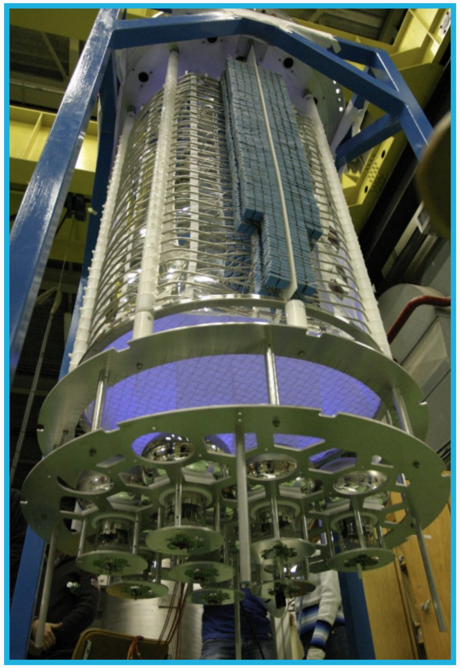
- Argo (3,000 tonne yr fiducial)

At SNOLAB
~203X

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



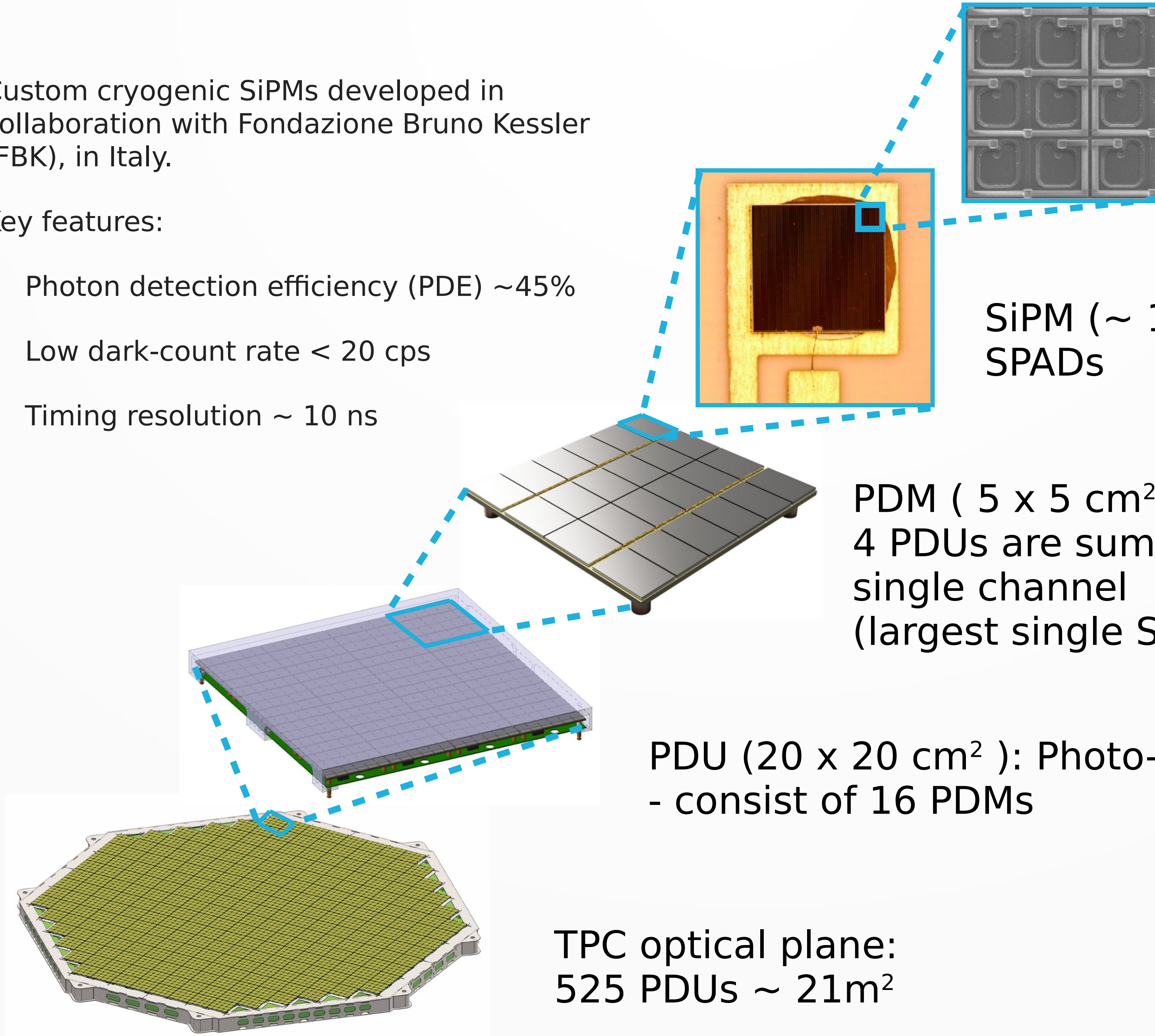
MiniCLEAN



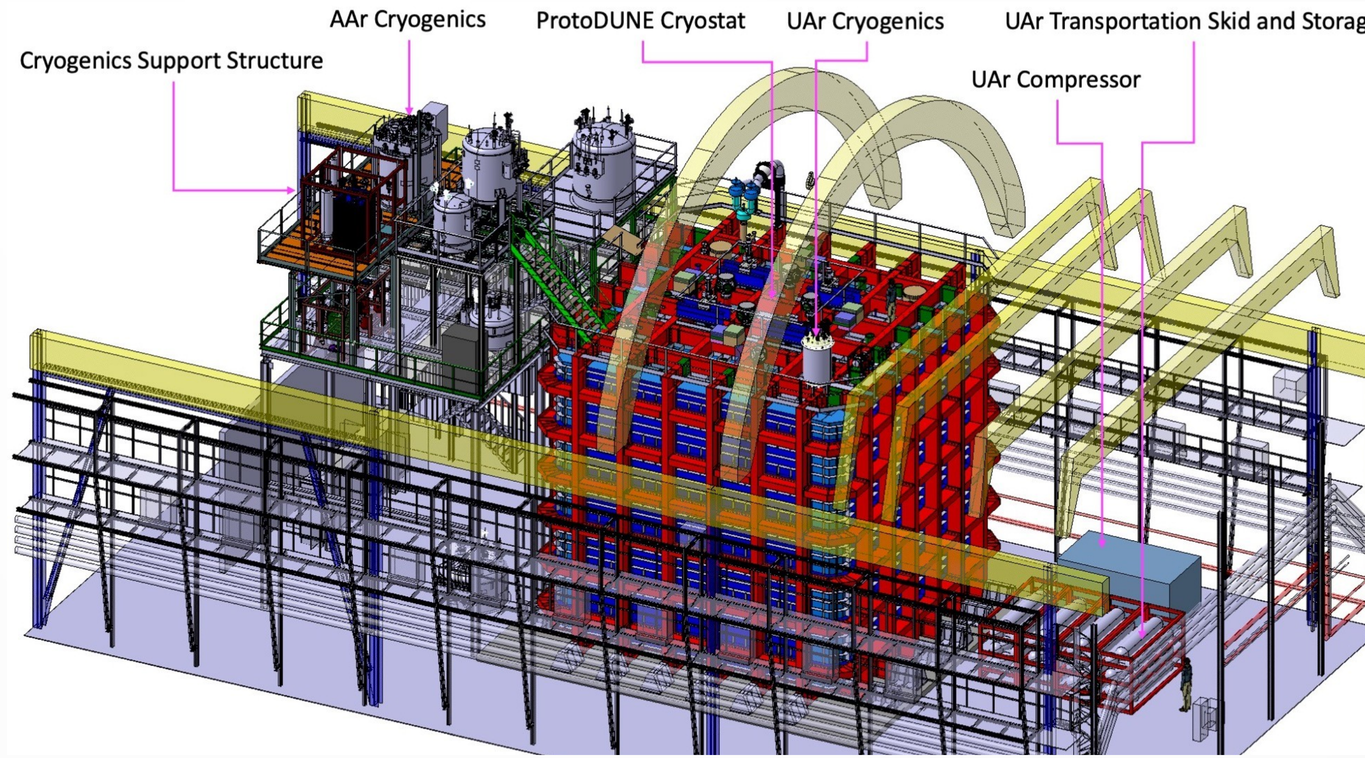
ArDM

DS-20k: Photo sensors

- Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.
- Key features:
  - Photon detection efficiency (PDE) ~45%
  - Low dark-count rate < 20 cps
  - Timing resolution ~ 10 ns

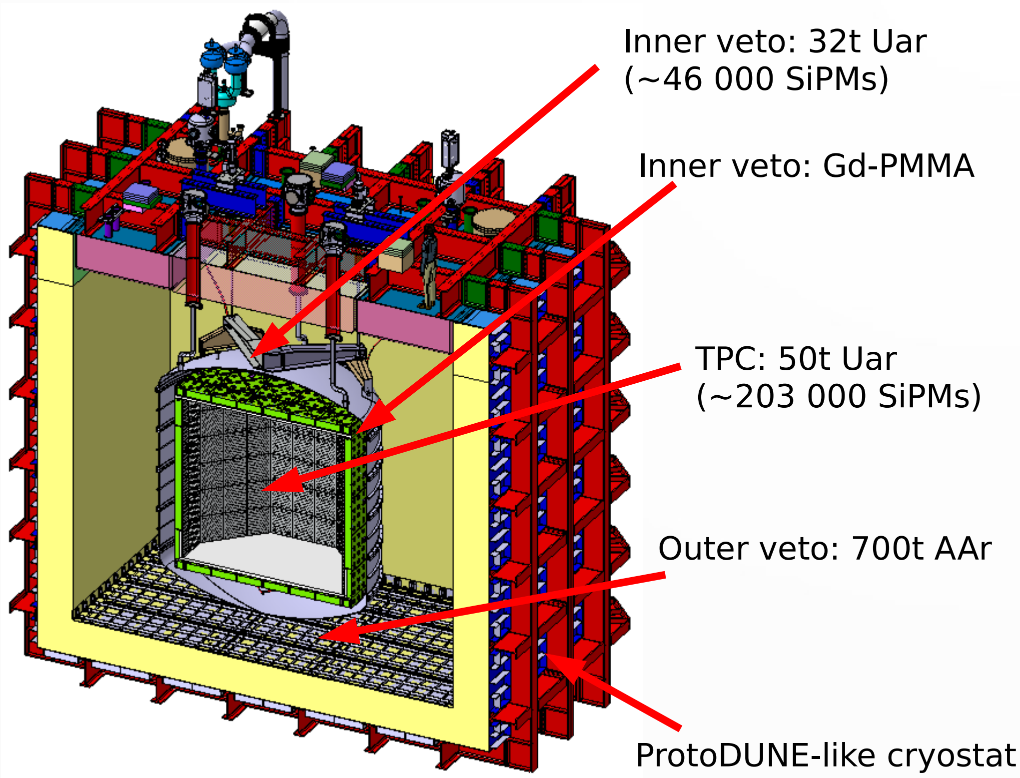


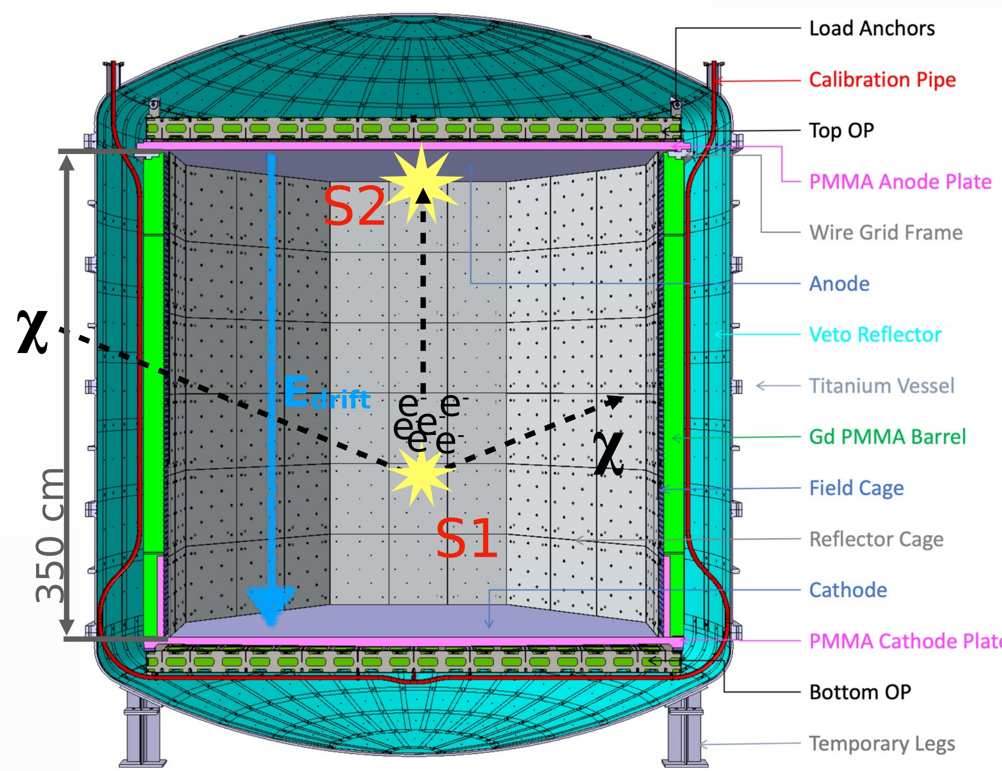
DarkSide-20k Detector



- Installed underground at the Gran Sasso National laboratories, in Italy (Hall-C)
- Covered with 1400m of rock (under the Gran Sasso mountain)
- 10 years of expected activity
- 21 m^2 instrumented with custom designed SiPM-based light detectors
- TPC filled with 50 t of UAr (20t fiducial)
- Target at 0.1 background event in 200 t yr exposure → world leading sensitivity

DarkSide-20k:Overview





Nested structure:

- Titanium Vessel contain liquid underground argon (100 t)
  - Gadolinium loaded TPC filled with 50 t of UAr
  - Neutron veto buffer between TPC and Ti vessel
- Membrane cryostat like the ProtoDune one

TPC:

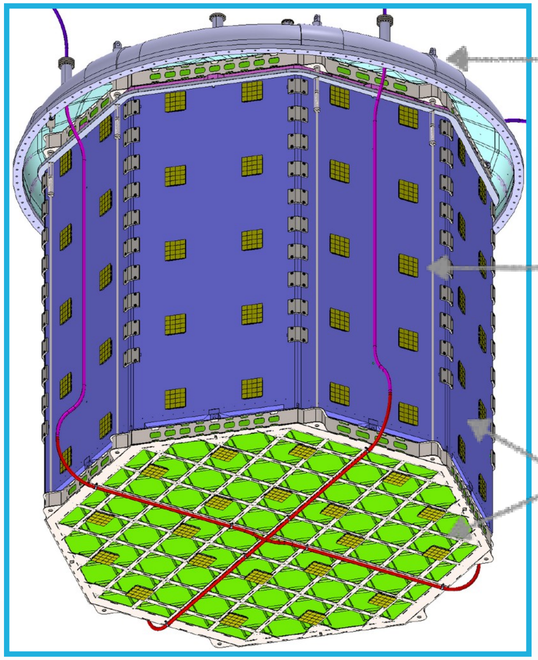
- Gd-doped acrylic, PMMA (polymethylmethacrylate), vessel to capture neutrons
- Octagonal shape
- Cathode and anode coated with new transparent conductor (Clevios) and wavelength shifter
- Sides covered with multilayer polymeric reflector evaporated with wavelength shifter (TPB)

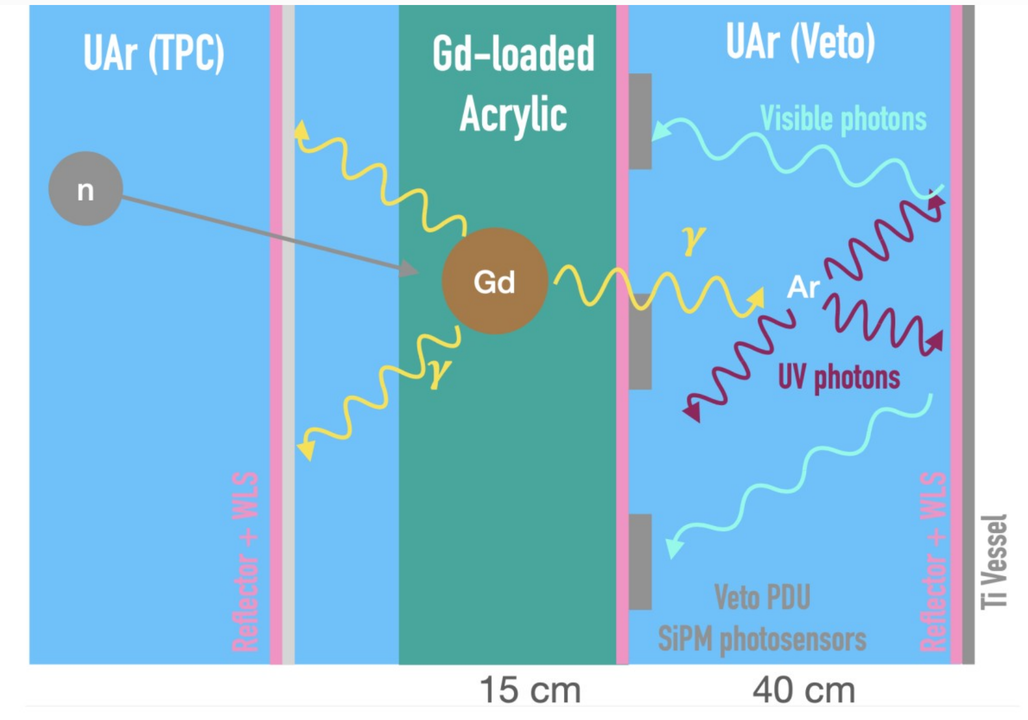
Veto detector

Neutrons elastically scattering from argon nuclei are indistinguishable from WIMPs signals. PSD is useless against neutron events.

Veto Structure

- 8 vertical panels of acrylic loaded with gadolinium (Gd-PMMA), form lateral walls of the TPC. Acrylic thickness: 15 cm.
- The UAr volume between the Ti vessel and Gd-PMMA serves as a veto volume with ~40 cm thickness.
- Reflector with WLS on all the surfaces



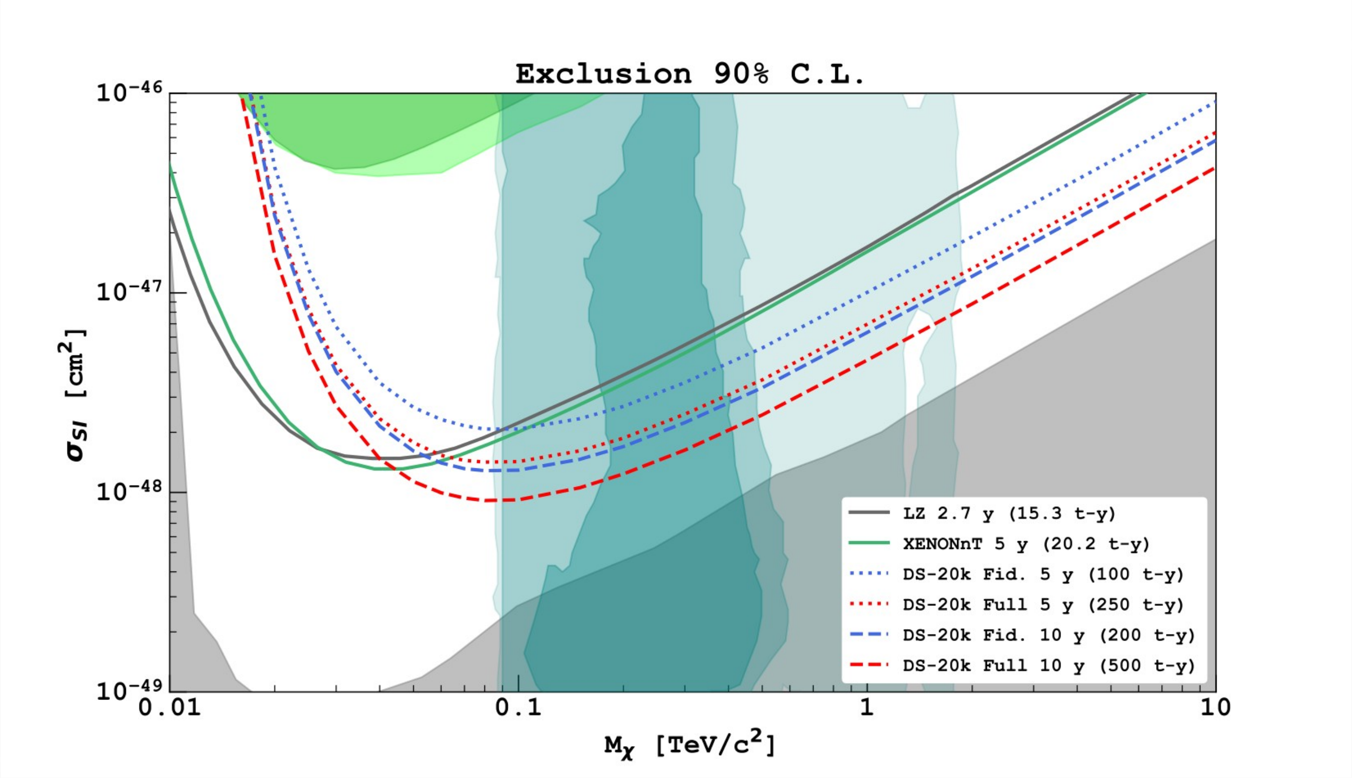


Veto Working Principle

1. Neutrons are moderated in the acrylic shell and then captured by gadolinium.
2. Gd emits multiple γ-rays with energy up to 8 MeV.
3. γ-rays interact in the liquid argon buffers.
4. LAr scintillation light is shifted and detected by ~3000 SiPM-based photosensors.

DS-20k: Expected sensitivity

The sensitivity of DS-20k to spin independent WIMPs for different lengths of runs, with the full exposure and with the fiducial cuts applied, compared to LZ and XENONnT.

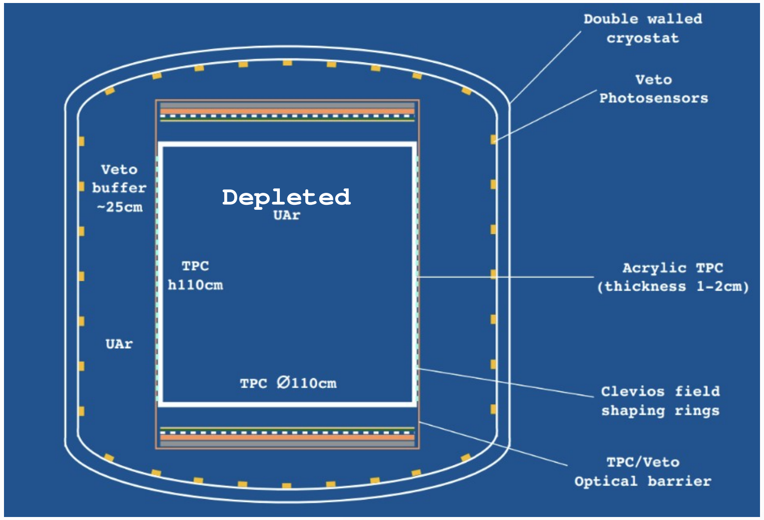


The present projection - based on a 10 yr run, giving a fiducial volume exposure of 200 t yr - is 6.3 x 10^{-48} cm^2 for 1 TeV/c^2 WIMP for the 90% C.L. exclusion.

Turquoise filled contours is from pMSSM11 model (E. Bagnaschi et al., Eur. Phys. J. C 78, 87 (2018).

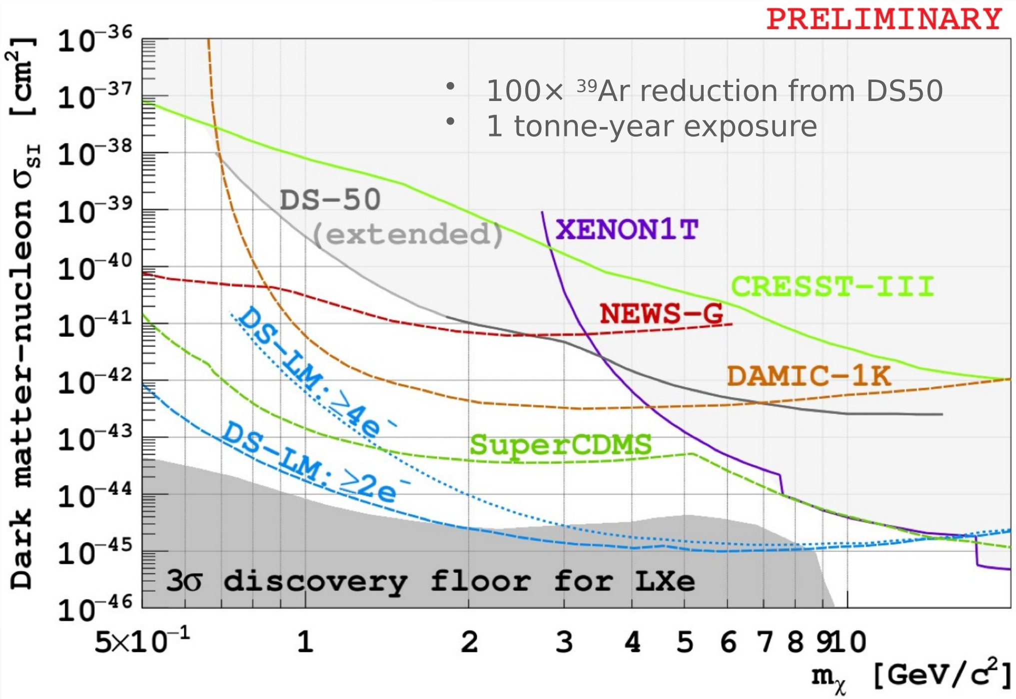
DarkSide-Low Mass: sensitivity

- **Scintillation signal** (S1): threshold at ~2 keV_{ee} / 6 keV_{nr} weak sensitivity to low mass WIMPs.
- **Ionization signal** (S2): threshold < 0.1 keV_{ee} / 0.4 keV_{nr}
- **Use ionization (S2) only**



Sensitive to low mass WIMPs!!

- Amplified in the gas region
- Sensitive to a single extracted electron
- The electron yield for nuclear recoils increases at low energy



Ar has lighter mass than Xe. So, more efficient momentum transfer from low mass DM.

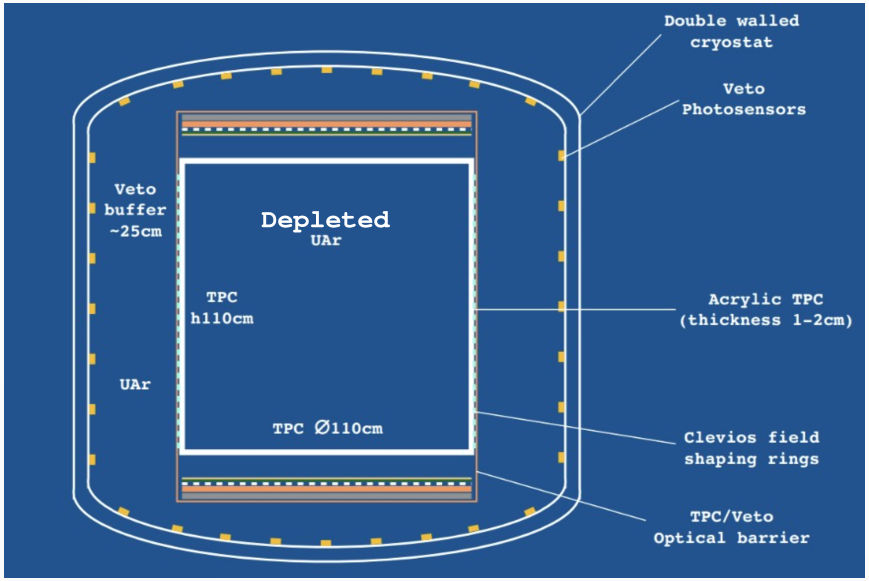
Summary

- TPC with underground Ar has excellent properties suited to high and low mass WIMP searches.
- Projects for scaling up of UAr extraction (URANIA) and purification (ARIA) are well developed.
- ^{39}Ar depletion factor will be confirmed batch by batch in DArT.
- We are close to finalization of the photosensor array design and starting large scale production.
- The TPC and Veto designs are well developed.
- Aim at the better sensitivity than the current generation of WIMP search experiments.

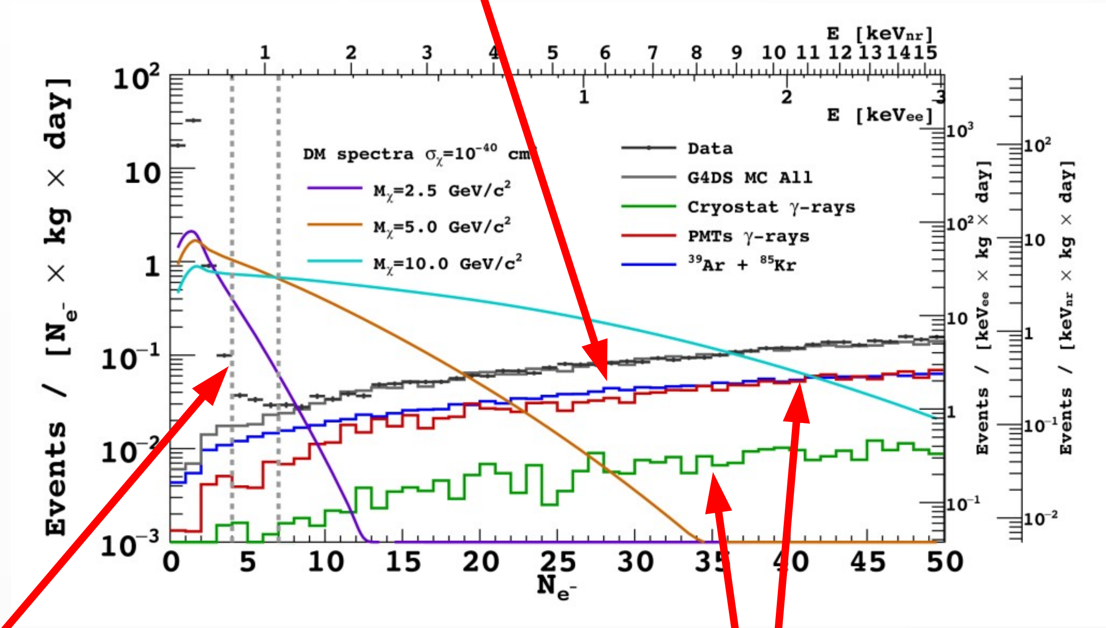
Thank you!

DarkSide-LowMass: concept & backgrounds

- TPC LAr mass: 1.5t (1t fiducial)
- TPC height/diameter: 111 cm
- TPC PDM number: 864
- Sensitivitity: < 10 GeV/c² WIMP mass



Beta-decay:
- ^{39}Ar
- ^{85}Kr in LAr



Spurious electron events (1-4 Ne),
Impurities in argon interacting with drifting electrons from ionization (under investigation)

Main dominant backgrounds from PMT/Cryostat gamma-rays

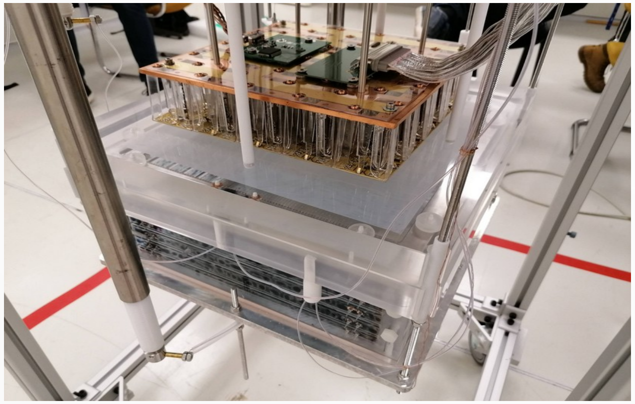
Low gamma materials
2-fold veto

DS-50 data: P. Agnes et al., Phys. Rev. Lett. 121, 081307 (2018)

Prototypes

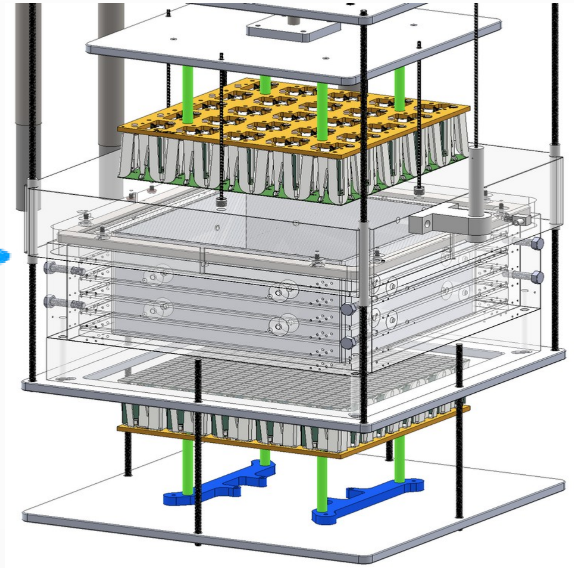
- Two Photo Detector Units (PDUs) were already tested in LN_2 at LNGS & CERN.
- **Proto-0** *(spring 2022).* **One PDU** mounted on the Proto-0 TPC **in Naples** for the integration test, the S2 study and the adjustable Gas Pocket tests. From ITO to Clevios polymer.

October 2019



Proto-0 at CERN

Spring 2022



Proto-0 at Naples