The DarkSide experiment

ON BEHALF OF THE DARKSIDE-20K COLLABORATION

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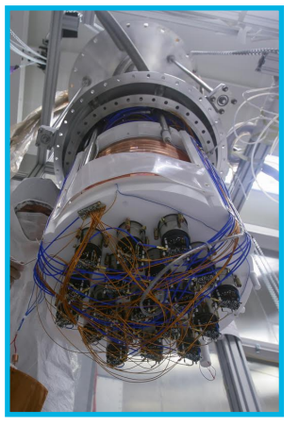
PATRAS WORKSHOP, MAINZ 11/08/2022

DarkSide as a part of Global Argon Dark Matter Collaboration

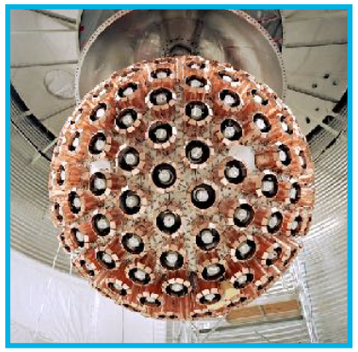
500 people, about 100 Institutions,

4 argon experiments: DarkSide-50 at LNGS; DEAP 3600 at Snolab; ArDM at Canfranc; Mini Clean at Snolab

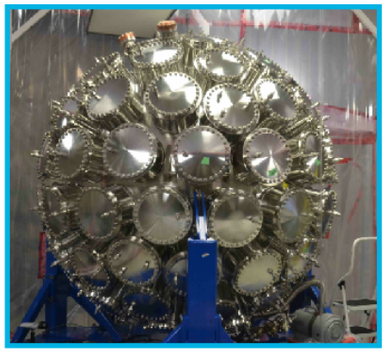
Joined expertise about low background liquid Argon based detectors



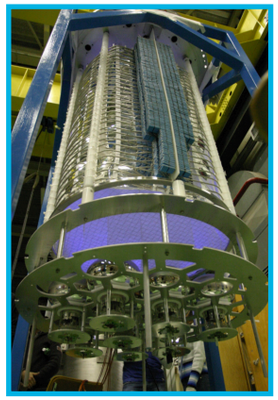
DarkSide-50



DEAP-3600



MiniCLEAN



ArDM

Multi step program towards WIMP dark matter detection:

Present goal: DarkSide 20k in LNGS, 50 tons of LAr (20 t FV)
(Prototypes, R&D towards Low Mass WIMP sensitivity)

Construction starts in 2022
Data taking from 2026, Nominal run time: 10 years

DarkSide-20k program and sensitivity

Direct detection of WIMP dark matter or to push the limit down to the neutrino floor.

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

Very low background levels and active suppression, **for the background-free operation from both neutrons and β/γ's.**

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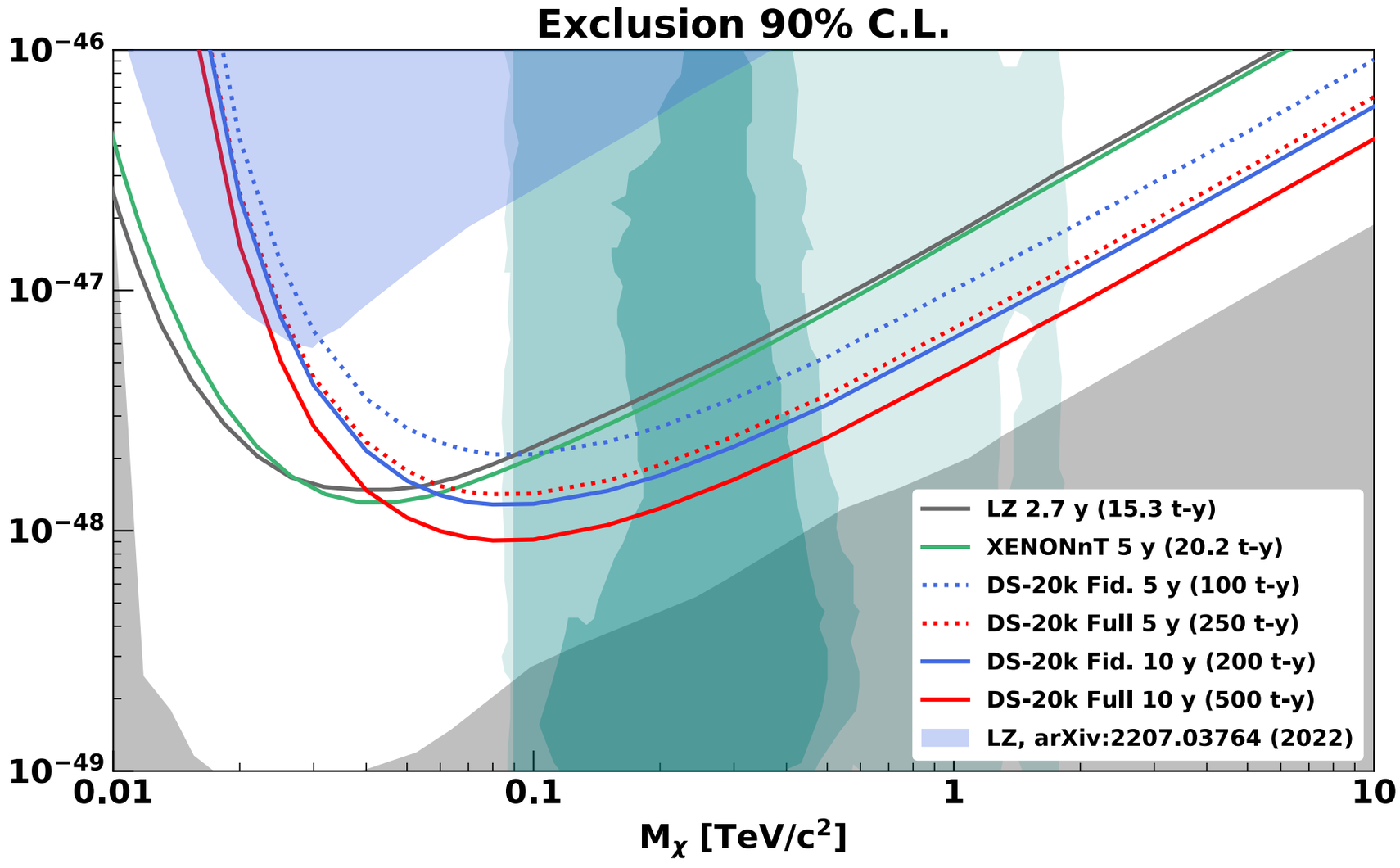
The sensitivity of DS-20k to WIMPs (spin independent cross section), for different lengths of runs, with the full exposure and with the fiducial cuts applied.

Comparison with Xenon based programs.



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

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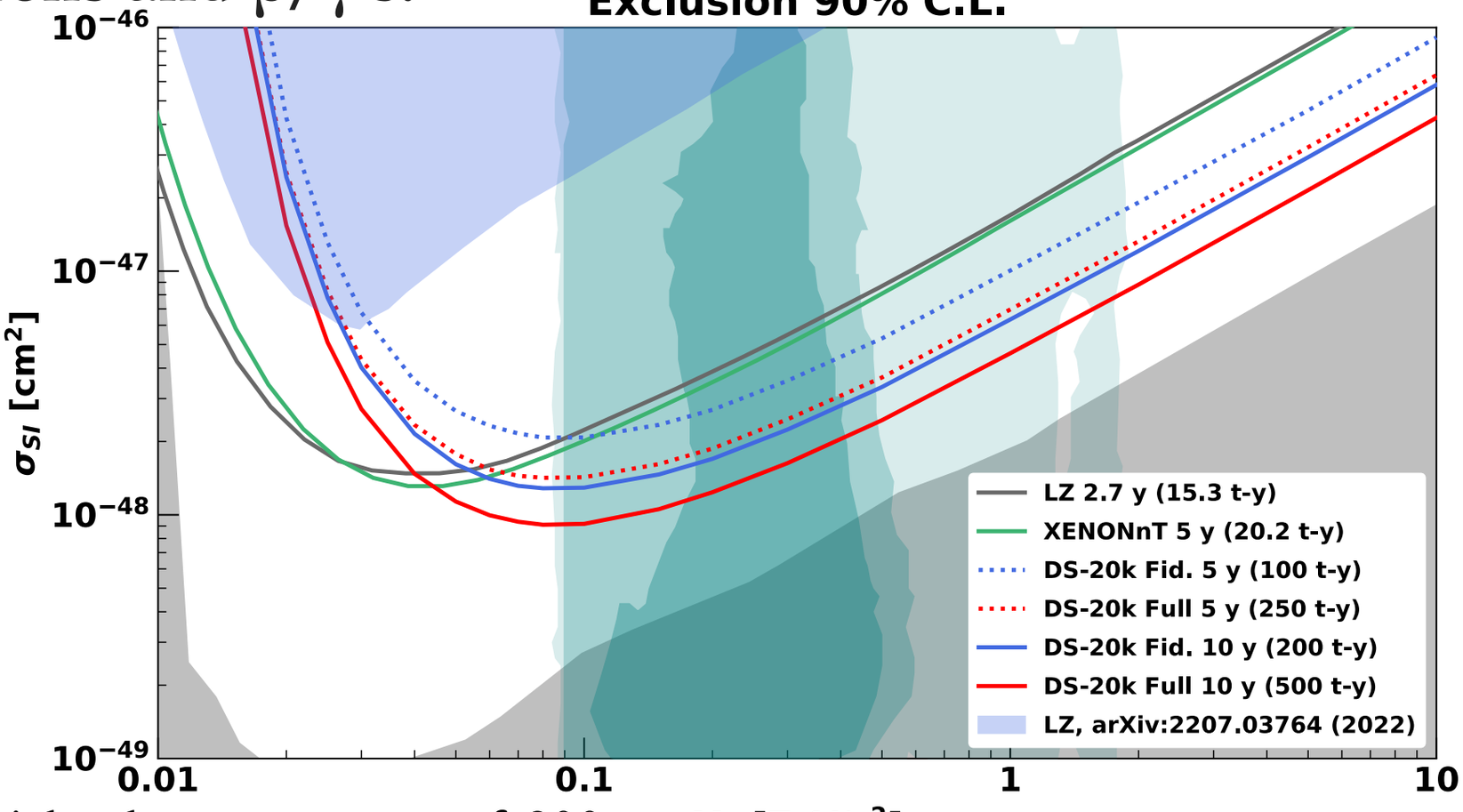


Sensitivity projection:
based on a 10 yr run, giving a fiducial volume exposure of 200t yr
is $\sigma = 6.3 \times 10^{-48}$ cm^2 for 1 TeV/c^2 WIMP for the 90% C.L. exclusion

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

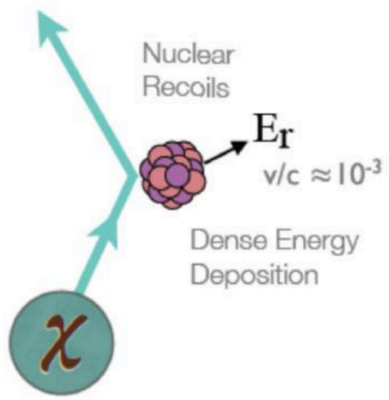
DarkSide - Liquid argon based program

Direct detection of WIMP dark matter or to push the limit down to the neutrino floor.

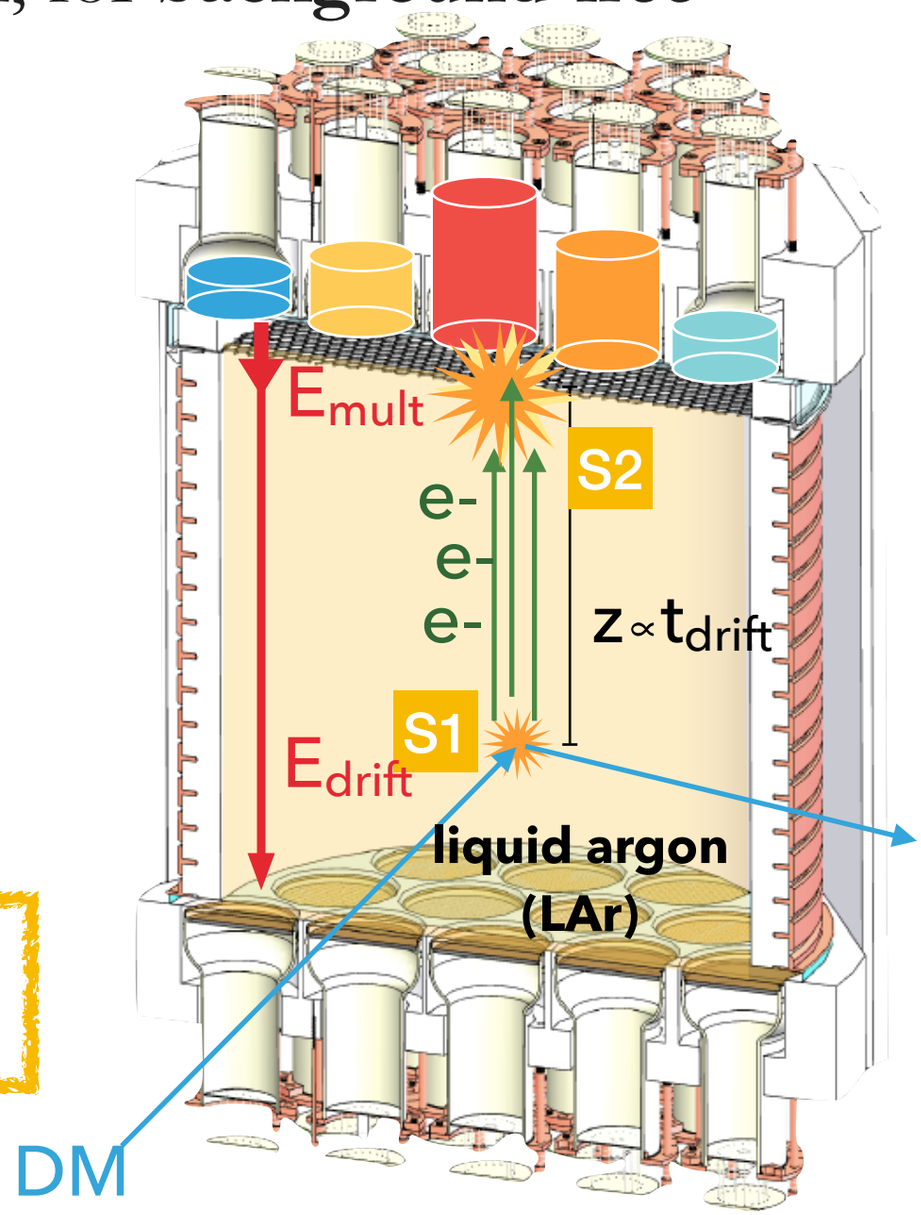
Based on a **two-phase argon** time projection chamber **TPC**

Very low background levels and **active suppression**, for **background-free** operation from both neutrons and β/γ's.

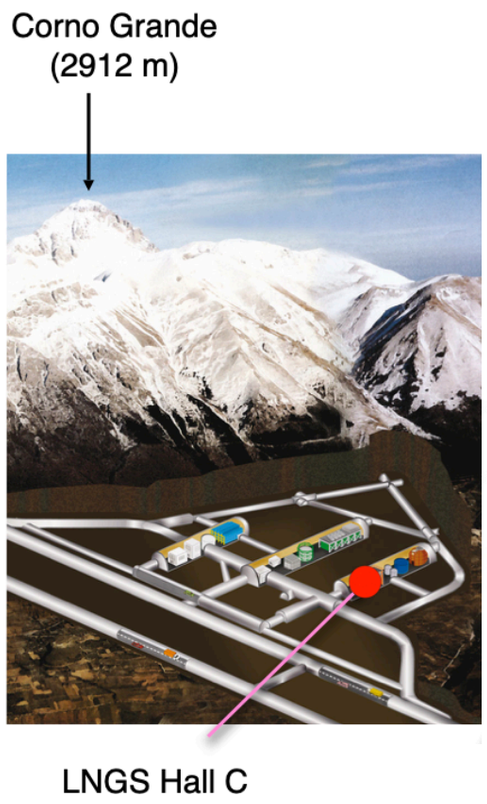
Ultimate background **Neutrino floor**:
coherent scattering neutrino - nucleus

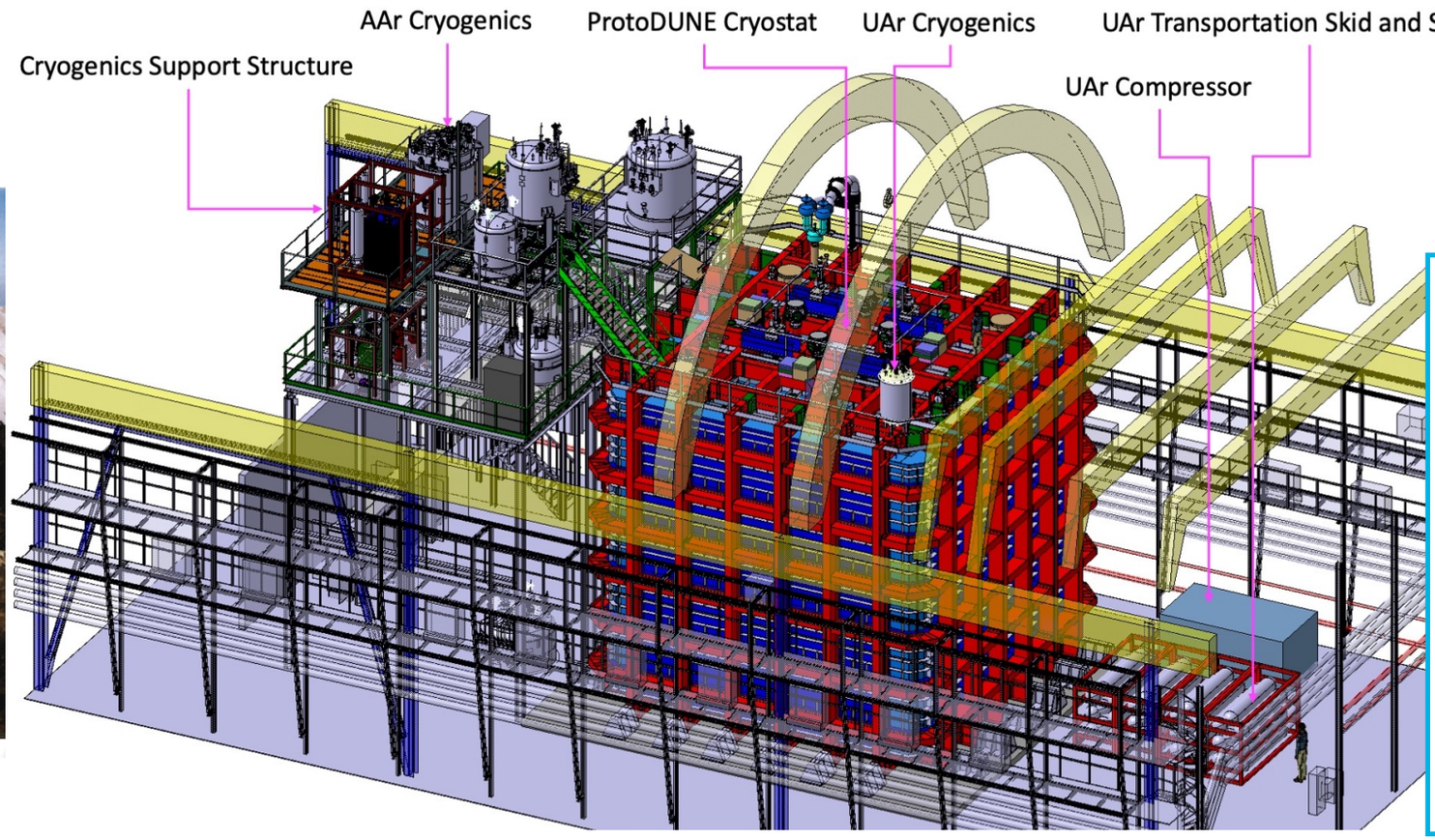


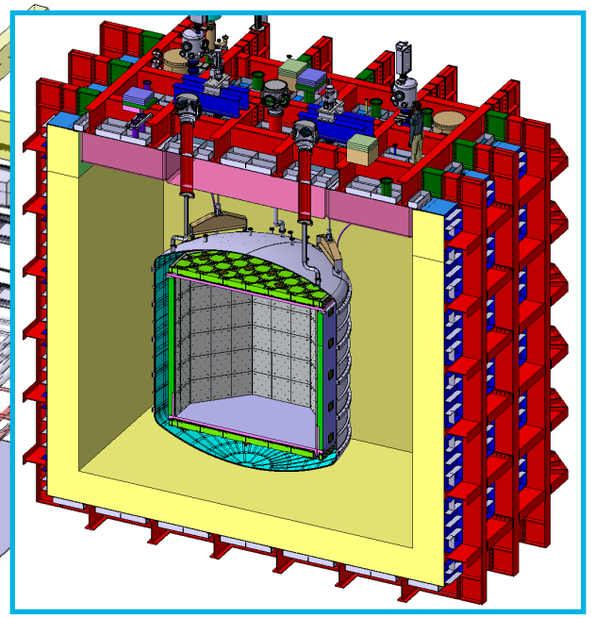
Searched signal **WIMP interaction**:
elastic scattering off a nuclei with recoil energy: 1 to 100 keV



DarkSide-20k detector







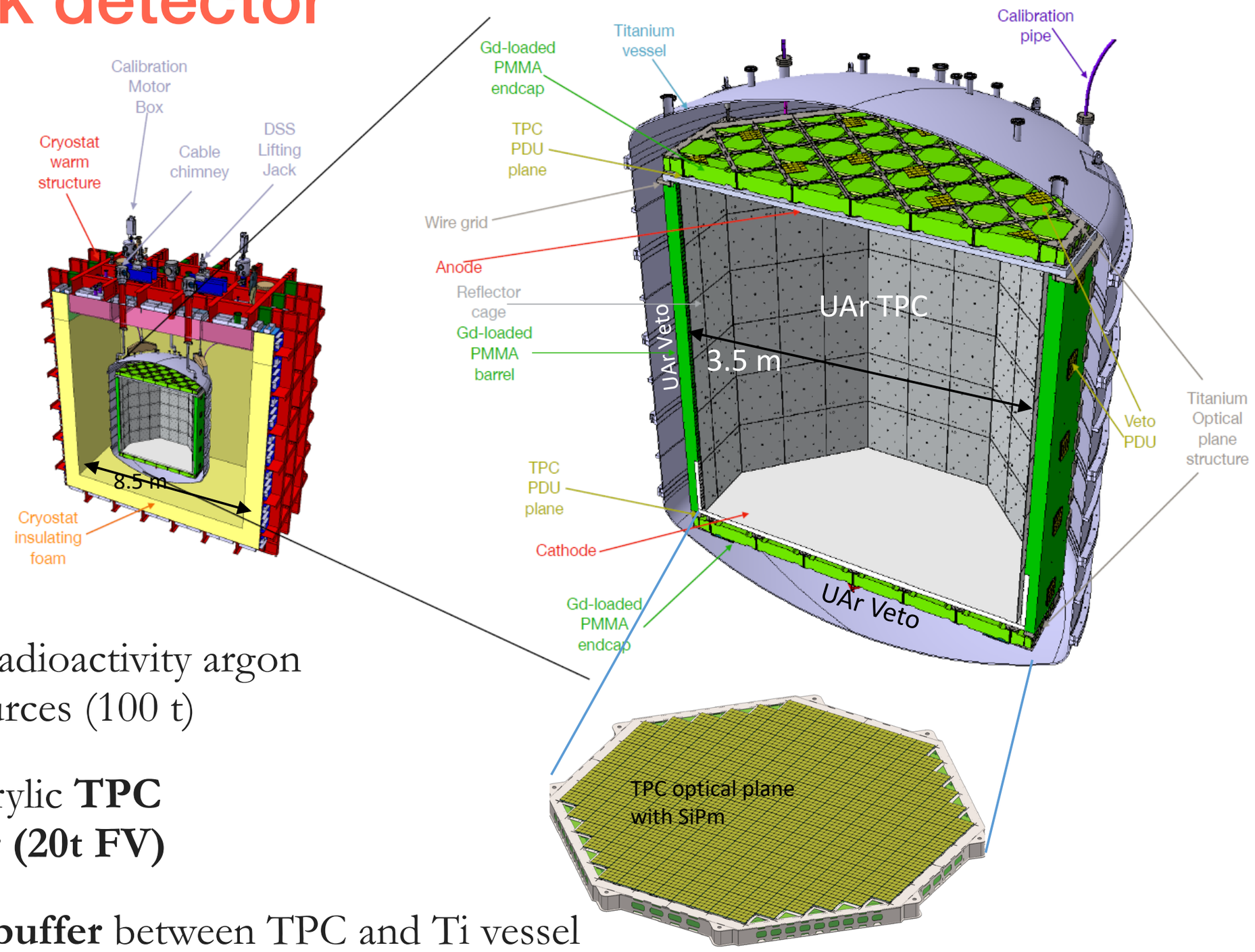
INFN-CERN agreement finalised

The installation will start later this year in the hall C at the Gran Sasso National Laboratory, in Italy.

Data taking with nominal run time: 10 years.

Nested structure of the detector with innovative technologies

DarkSide-20k detector



Titanium Vessel
containing liquid low radioactivity argon
from underground sources (100 t)

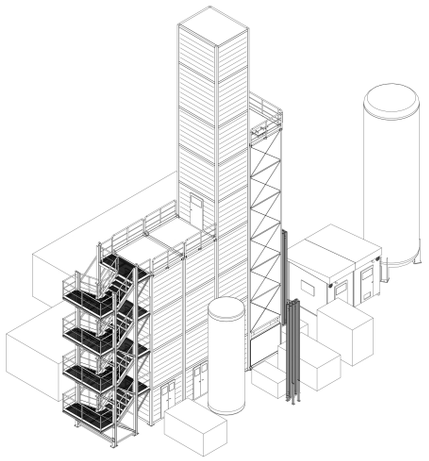
Gadolinium loaded acrylic **TPC**
filled with **50 t of UAr (20t FV)**

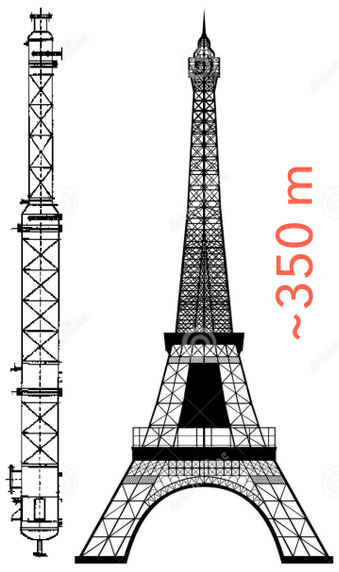
Neutron active veto buffer between TPC and Ti vessel

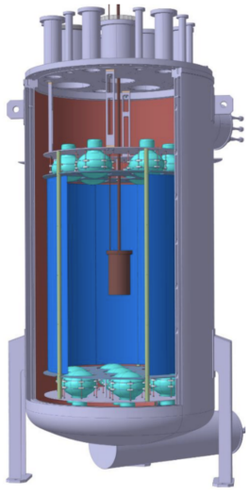
21 m^2 of **Cryogenic Silicon Photo-Multipliers** as light detectors

Membrane cryostat made in a ProtoDune-like technology

Underground argon Extraction & Isotope separation







Urania US (Extraction):

- Use of the argon extraction plant in Cortez, CO, to reach capacity of acquiring 330 kg/day of Underground Ar

Aria Italy (Isotope separation):

- 350 m tall column in the Seruci mine in Sardinia, Italy, for high-volume **chemical** and isotopic purification of Underground Argon. https://arxiv.org/abs/2101.08686

- Also isotope separation for medical scanners, for example, ^{17}O and ^{18}O.
  More details: *First module operated according to specs with Nitrogen in 2019*, Eur. Phys. J. C (2021) 81:359

DArT in ArDM Canfranc, Spain (Quality control)

- A "1.4-litre" single-phase low-background detector to measure the ^{39}Ar depletion factor of different underground argon batches (URANIA+ARIA).
  More details of DArT: JINST 15 P02024 (2020)

Large area, low noise, high speed SiPM based Photo sensor

Custom designed cryogenic SiPMs readout with the key features:

- Photon detection efficiency (PDE) ~45%
- Low dark-count rate < 20 cps
- Timing resolution ~ 10 ns

The 28m² for the TPC (2112 channels) + 480 channel for Veto detector.

Mass production of the raw wafer in LFoundry company and assembly in a dedicated facility at LNGS (Nuova Officina Assergi - NOA).

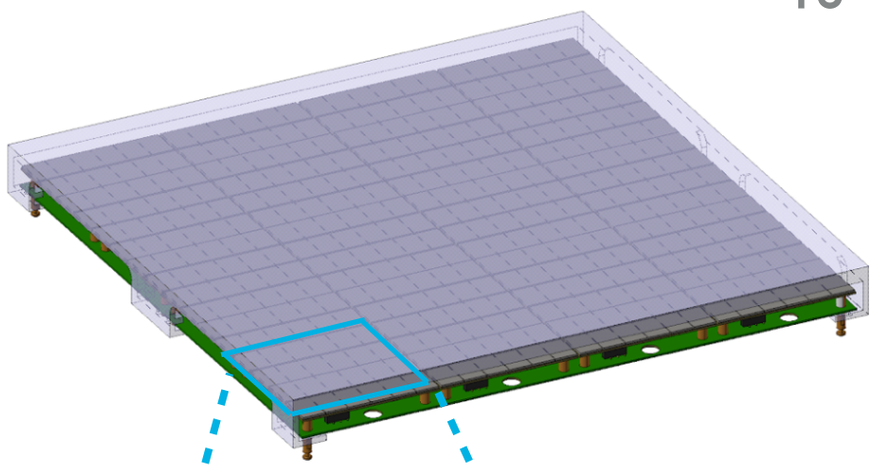


Photo Detector Unit (PDU) = matrix of 16 PDMs
20 x 20 cm²

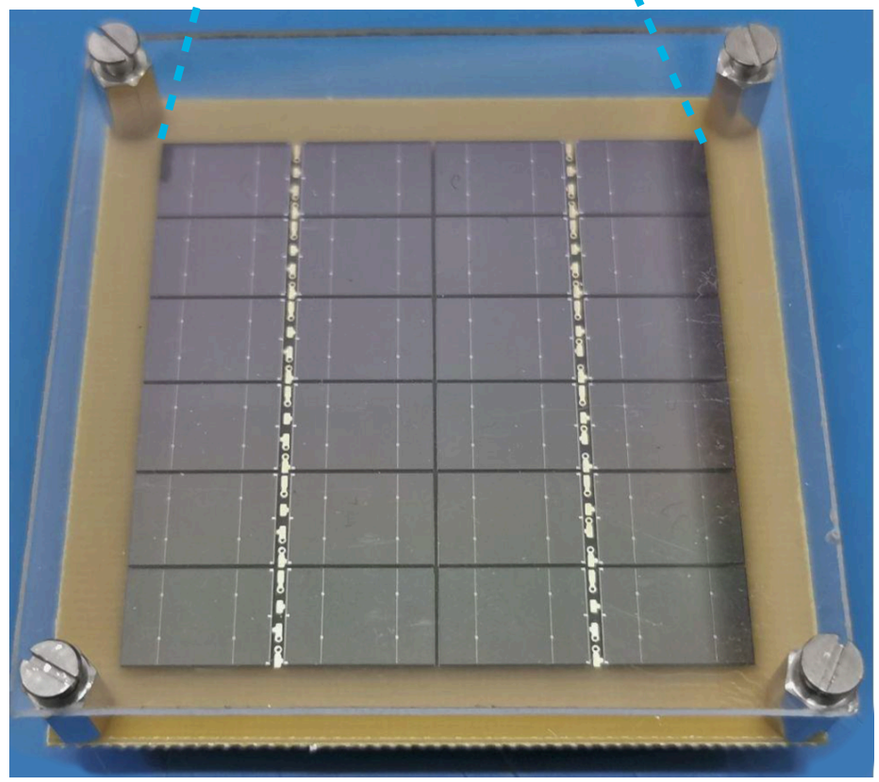


Photo Detector Module (PDM)
= matrix of 24 SiPMs, 5 x 5 cm²
4 PDMs are summed and read as a single channel
(largest single SiPM unit ever!)

Background mitigation strategies!

^{39}Ar (β decay) - use of Underground Argon

1400 times lower ^{39}Ar contamination than standard argon of atmospheric origin

Pulse Shape Discrimination (PSD) for β,γ rejection - a powerful tool possible to use in LAr TPC detector

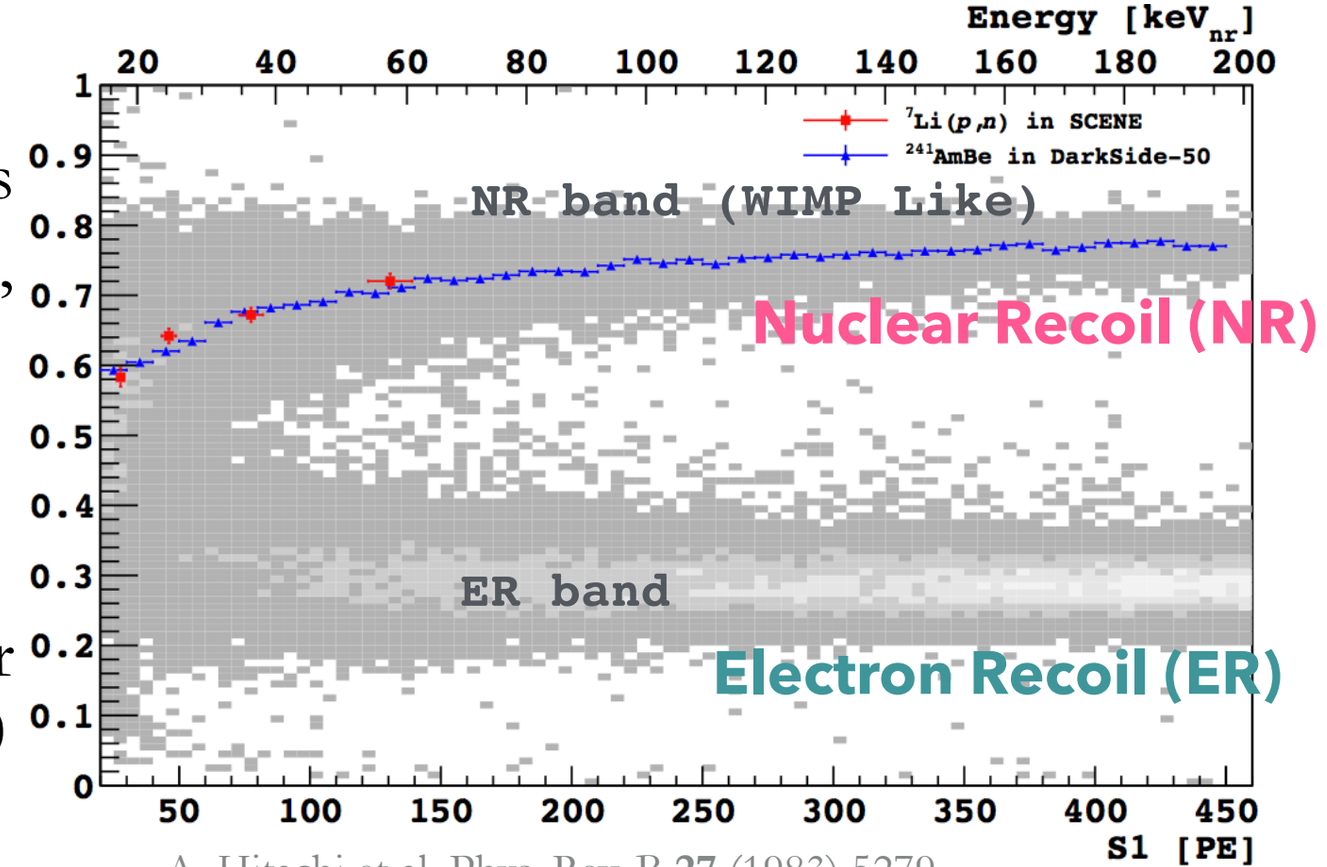
Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet and triplet excitation states, giving different pulse shape to be distinguished by.

Example:

the discrimination parameter **f90** defined as a ratio of detected light in the first 90 ns, compared to the total signal (S1).
Method optimised for DarkSide-50 data.

Plot:

use of AmBe calibration data (nuclear recoil) as WIMP-like signal by DarkSide-50



A. Hitachi et al. Phys. Rev. B **27** (1983) 5279

M. G. Boulay and A. Hime, Astropart. Phys. **25** (2006) 179

Background mitigation strategies!

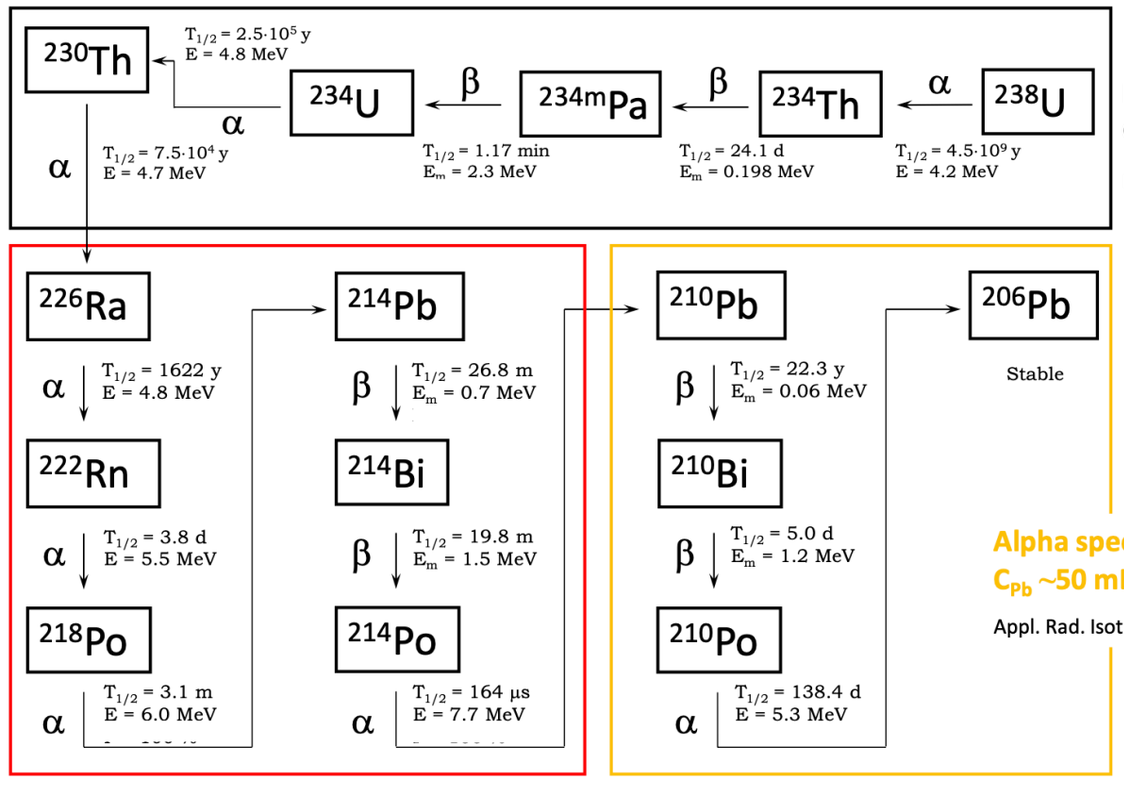
Neutron background - interaction in LAr undistinguishable from WIMP

- main source: **(α, n) reaction**, with the alpha particle coming from material contaminants

Mitigation: 1. **Material screening campaign** to reduce potential source of alphas.

- Big effort engaging laboratories around the world (Jagiellonian University, CIEMAT, SNO, Canfranc, LNGS, …) to measure radioactivity levels in **each (!) construction material.**

- Each uranium (^{238}U, ^{226}Ra, ^{210}Pb; ^{235}U) and thorium chain **is measured separately** using different methods, this allows to take into account **potential secular disequilibrium.**



ICP-MS:
$C_{U/Th}$ < 0.1 μBq/kg

NIM A 775 (2015) 93

HPGe:
C_{Ra} ~10 μBq/kg

Appl. Rad. Isot.
53 (2000) 191
Astrop. Phys.
18 (2002) 1

Alpha spectrometry
C_{Pb} ~50 mBq/kg

Appl. Rad. Isot. 126 (2017) 165

Potential disequilibrium in ^{238}U

Sample	^{238}U (ICP-MS)	^{226}Ra (HPGe)	^{210}Pb
Arlon 55NT (DARKSIDE Collaboration)	(1.95 ± 0.05) mBq/kg	(53 ± 5) mBq/kg	(128 ± 26) mBq/kg

from Tomasz Mróz, TAUP2021

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- Each uranium (^{238}U, ^{226}Ra, ^{210}Po; ^{235}U) and thorium chain **is measured separately** using different methods, this allows to take into account potential secular disequilibrium.

- Precise knowledge of the alpha flux allows to **simulate the (α, n) reactions** in DS-20k. (Geant4 based SaG4n software: http://win.ciemat.es/SaG4n/)

↓

Estimation of neutron background events during DS-20k operation.

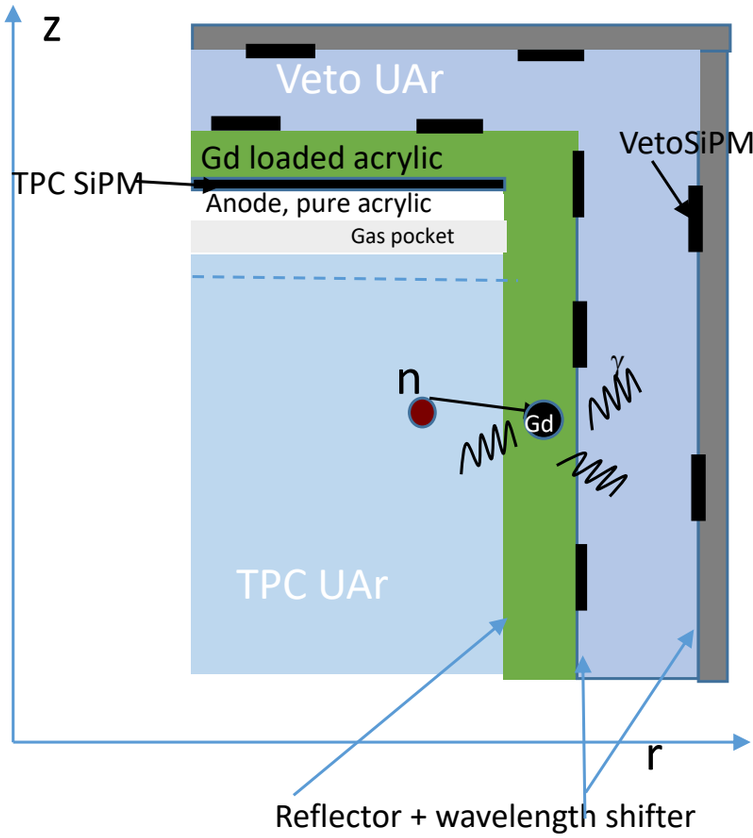
Background mitigation strategies!

Neutron background - interaction in LAr undistinguishable from WIMP

- main source: **(α, n) reaction**, with the alpha particle coming from material contaminants

Mitigation: 2. Definition of Fiducial Volume in the TPC + **active VETO** to reject n signal.

- Dedicated R&D towards innovative Gd-loaded plastic material:
  - optimised procedure: (Gd(MAA)3) gadolinium methacrylic acid to be dissolved in the liquid acrylic monomer, Goal 0.5-1% Gd concentration by weight.
- Surrounds completely the sensitive volume, TPC side panels + top and bottom caps, for an integrated TPC and Veto design
- Neutrons captured in Gd produce easy to detect 8 MeV gamma ray cascade in either the sensitive TPC volume or in the surrounding argon buffer
- Reduce dominant nuclear recoil (NR) background by a factor 10

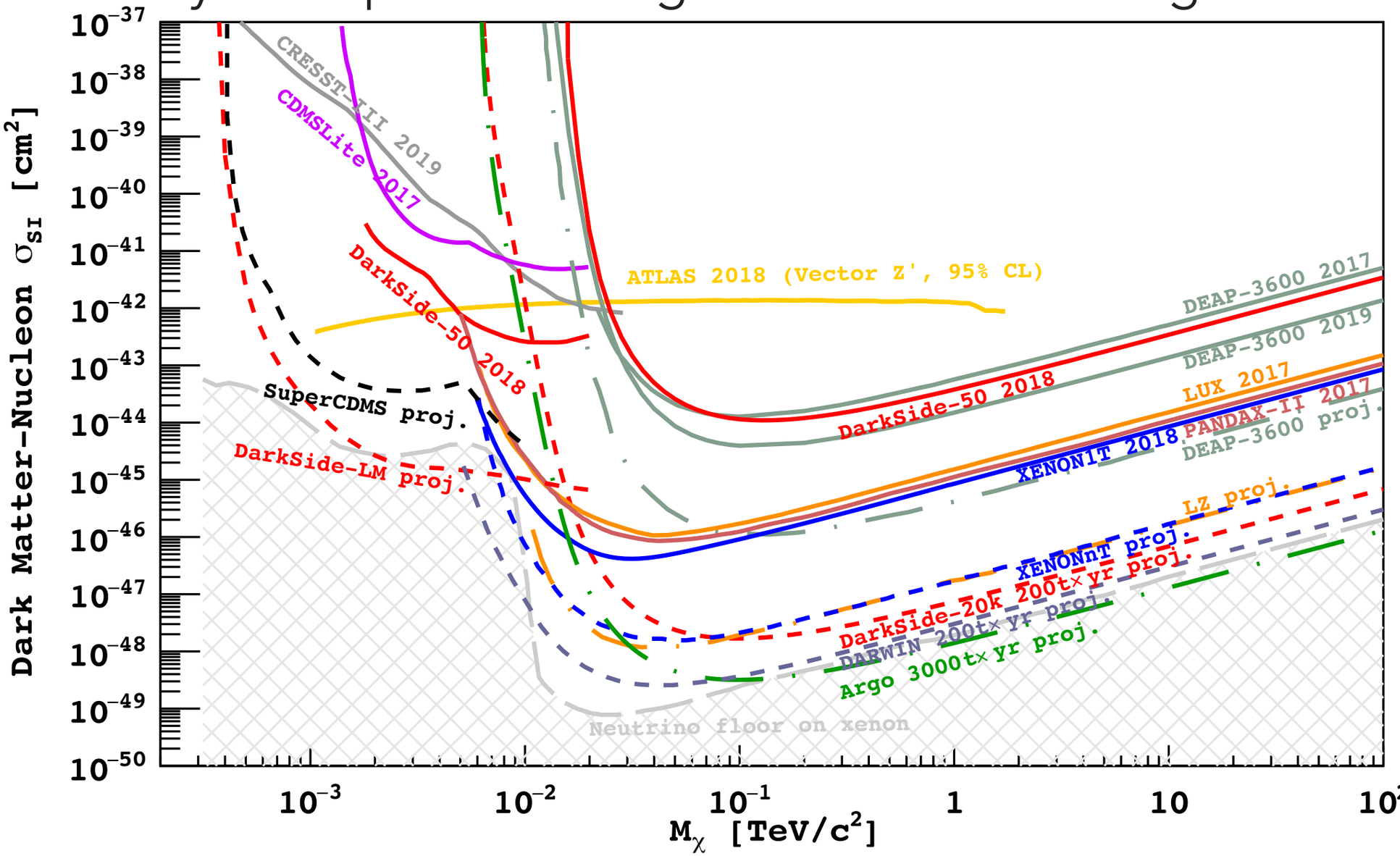


DS-20k - it is happening

- The R&D phase for the DS-20k detector is completed.
- Background reduction techniques are implemented (Background free operation!)
- Production of SiPMs already started
- Underground Ar procurement and characterisation project is ongoing (URANIA & ARIA & DArT)
- Construction of the DS-20k cryostat will start soon, Hall C is ready
- Data taking expected in 2026

Future - ARGO (in SNOLAB)

- A 300-tons fiducial mass detector filled with underground argon
- 3000 ton × year exposure to dig into the neutrino fog.



GADMC experiments cover the WIMP hypothesis from 1GeV/c² to several hundreds of TeV/c² masses in the search for spin-independent coupling.

Thank You !


Como
Milan
Verona
Venice
Padua
Trieste
Slovenia
Zagreb
Turin
Croatia
Genoa
Bologna
Bosnia and
Herzegovina
Zadar
Sarajevo
San Marino
Pisa
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