DARKSIDE-20K AND THE FUTURE LIQUID ARGON DARK MATTER PROGRAM

MASAYUKI WADA

AstroCeNT, Warsaw

19/10/2021

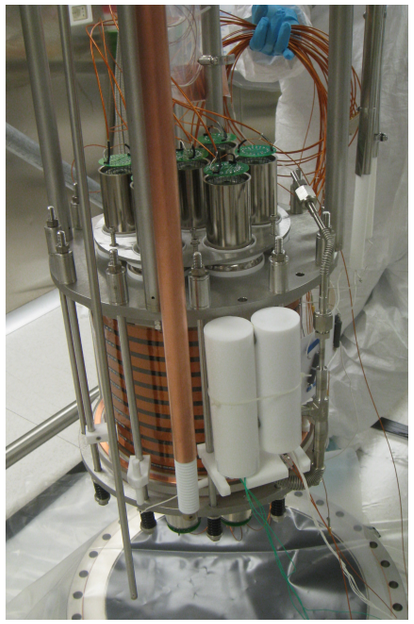
32ND RENCONTRES DE BLOIS

Dark Wave
European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund

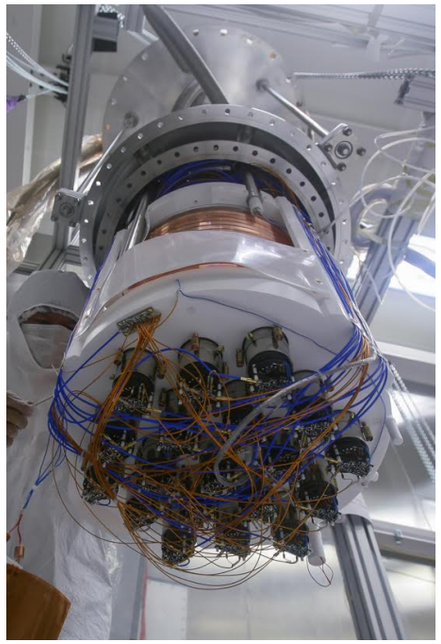
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 962480

DARKSIDE PROGRAM

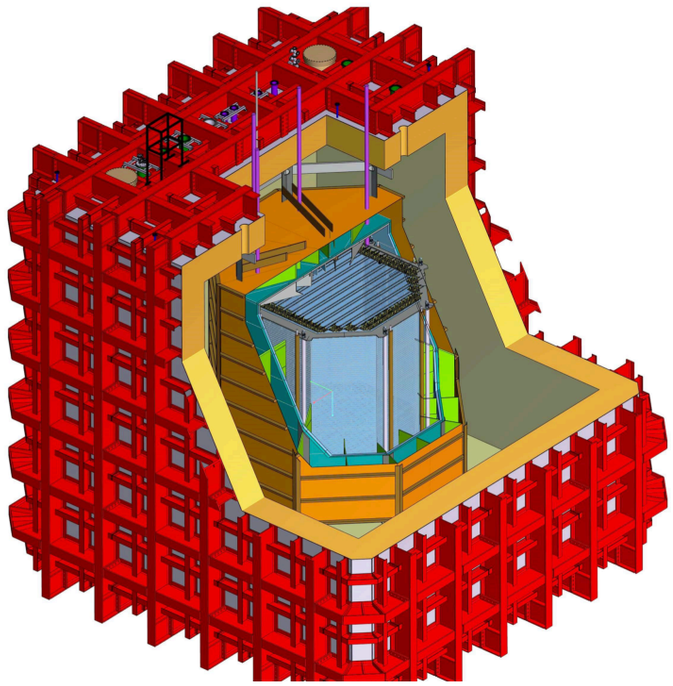
- **Direct detection** search for **WIMP** dark matter
- Based on a **two-phase argon** time projection chamber (**TPC**)
- Design philosophy based on having very low background levels that can be further reduced through **active suppression**, for **background-free** operation from both neutrons and β/γ's



DarkSide-10



DarkSide-50

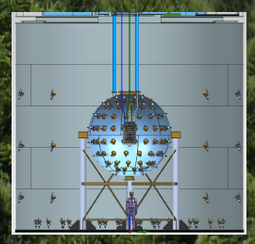


DarkSide-20k

and **DarkSide-LowMass**
for low-mass dark matter searches

Gran Sasso

3800 m w. e.



Deep underground location at LNGS, Italy.

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

- High electron **mobility** and **low diffusion**
- Amplification (electroluminescence gain) for ionization signal
- **Discrimination** electron/nuclear recoils **(ER/NR)** via **ionization/scintillation ratio**

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

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

- High electron **mobility** and **low diffusion**
- Amplification (electroluminescence gain) for ionization signal
- **Discrimination** electron/nuclear recoils **(ER/NR)** via **ionization/scintillation ratio**

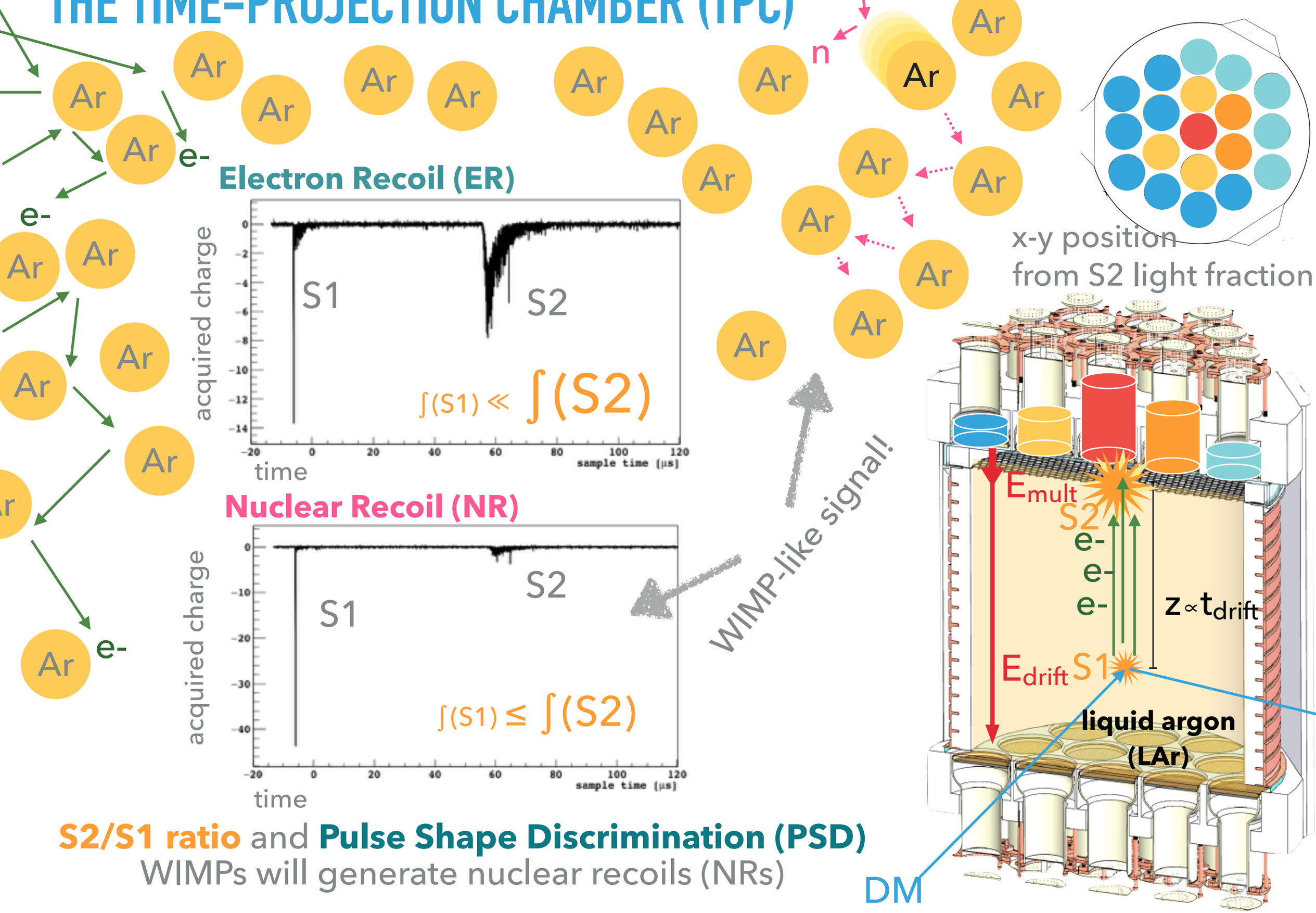
Liquid **Xenon**

- 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)



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

WIMPs will generate nuclear recoils (NRs)

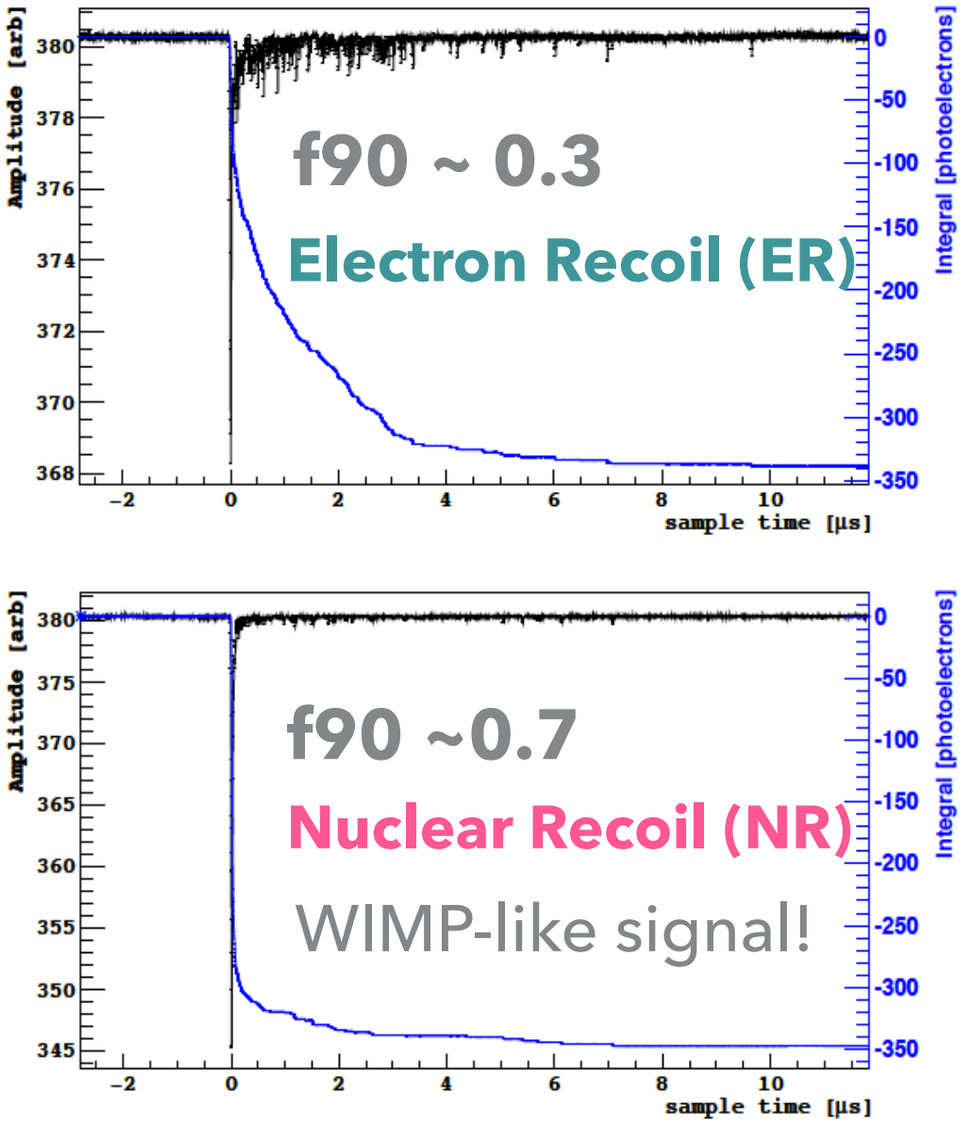
PULSE SHAPE DISCRIMINATION

β & γ Rejection

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

τ singlet ~ 7 ns

τ triplet ~ 1500 ns



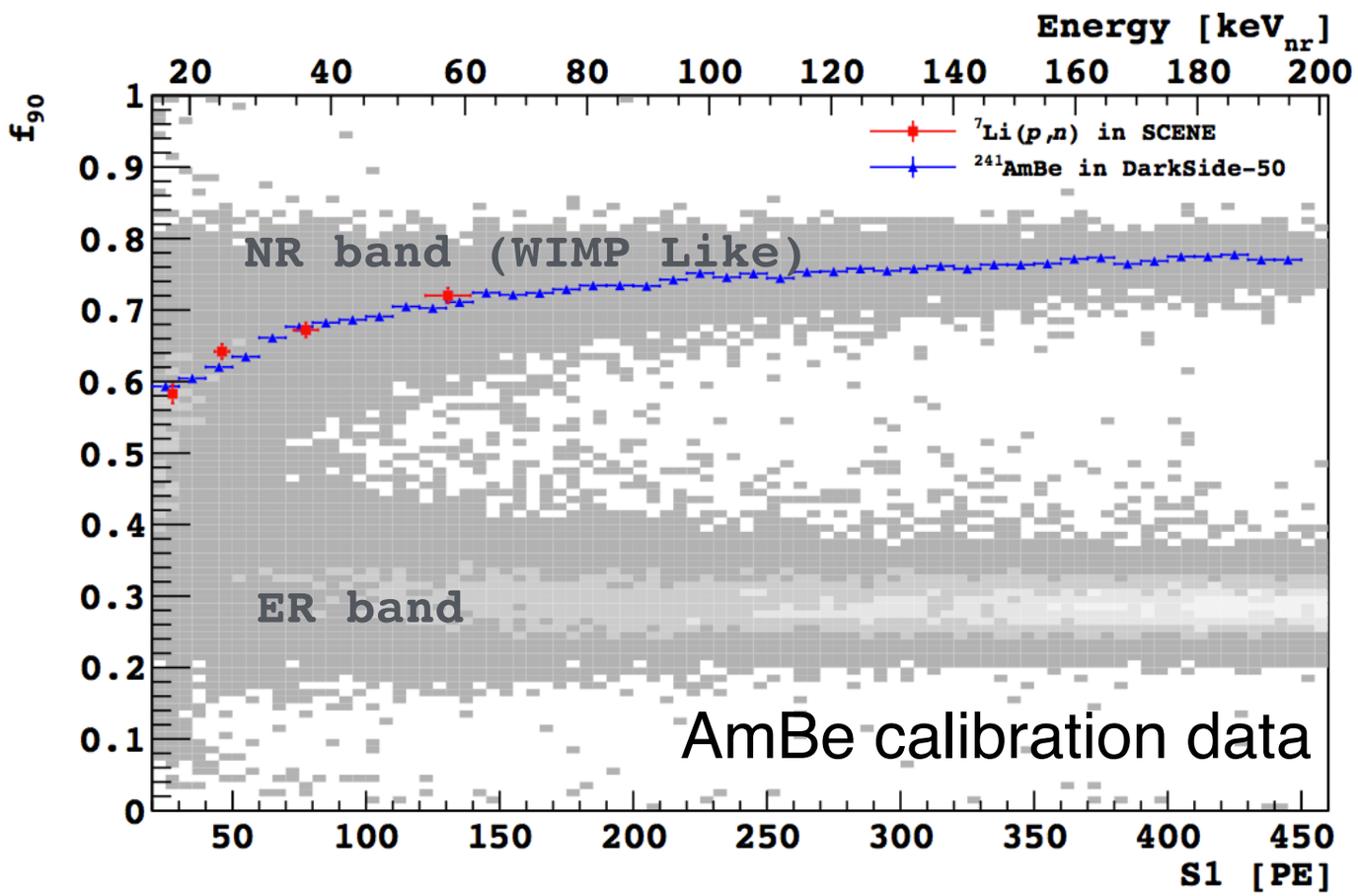
PSD parameter

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

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

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

~ Fraction of singlet states



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

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

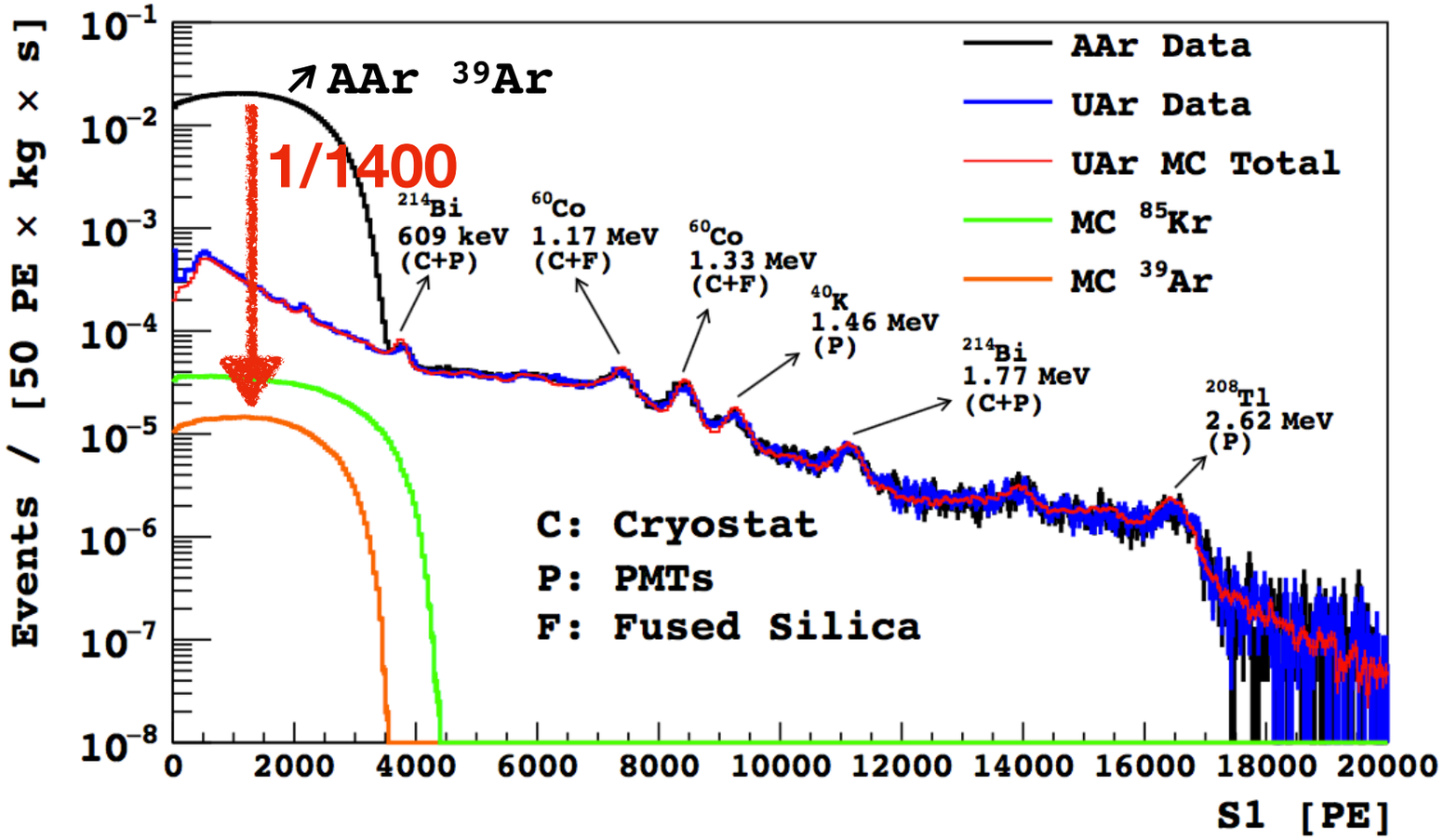
UNDERGROUND Ar

β & γ Rejection

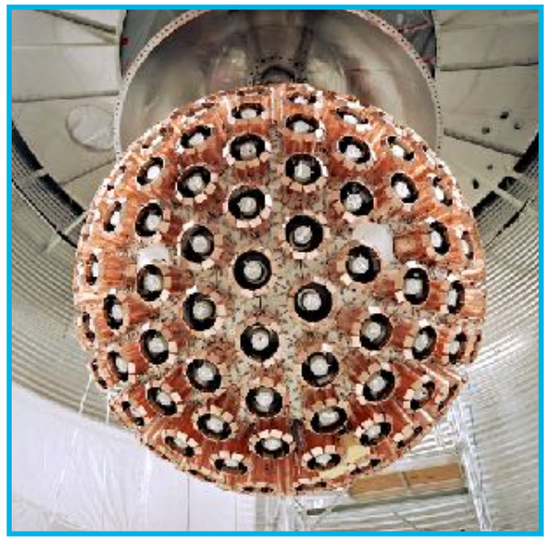
- Intrinsic ^{39}Ar radioactivity in **atmospheric argon** is the primary background for argon-based detectors
- ^{39}Ar activity sets the dark matter detection threshold at low energies (where pulse shape discrimination is less effective)
- ^{39}Ar is a **cosmogenic isotope**, and the activity in argon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



GLOBAL ARGON DARK MATTER COLLABORATION

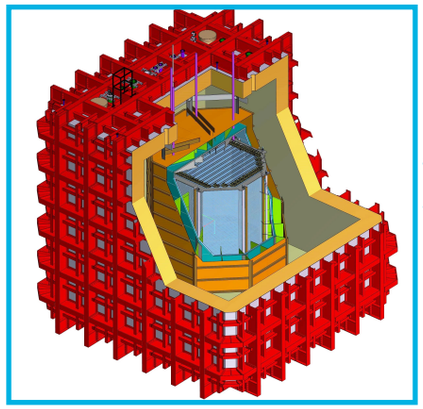


DEAP-3600

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

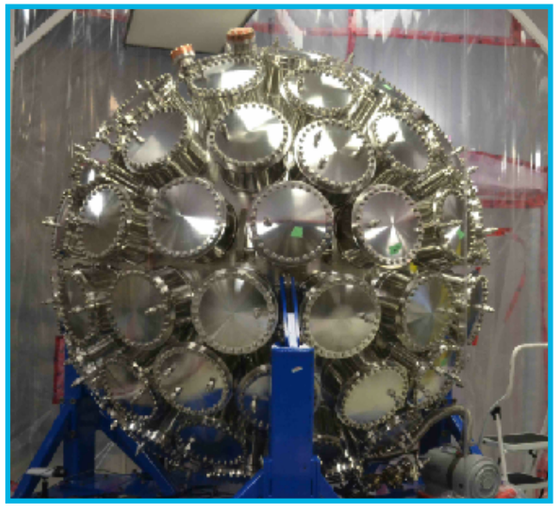
A sequential, two-steps program:

- DarkSide-20k (200 tonne yr fiducial)

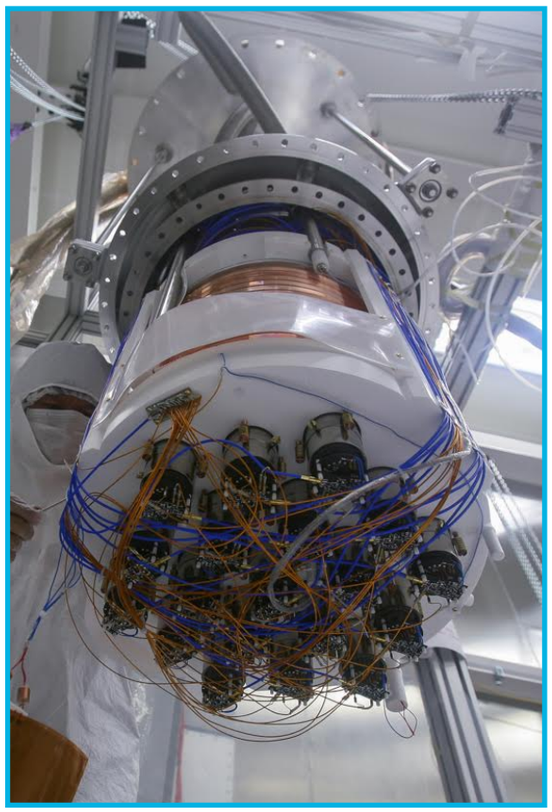


- Argo (3,000 tonne yr fiducial)

At SNOLAB
~203X

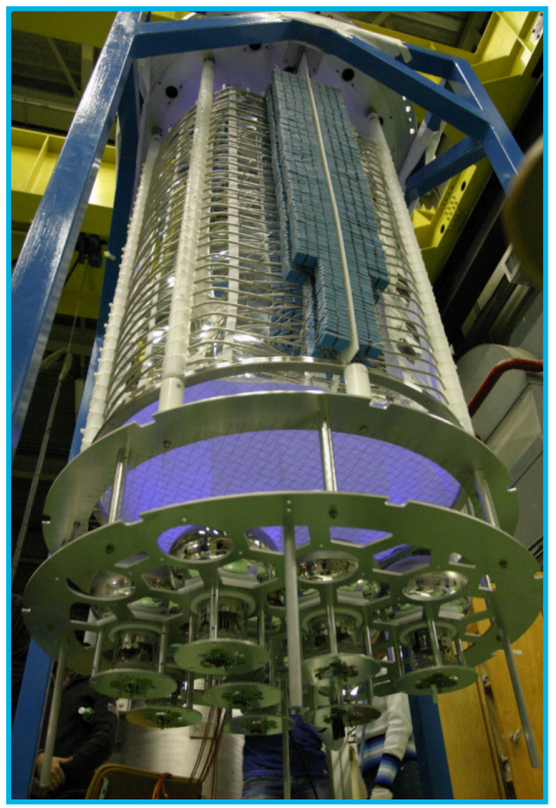


MiniCLEAN



DarkSide-50

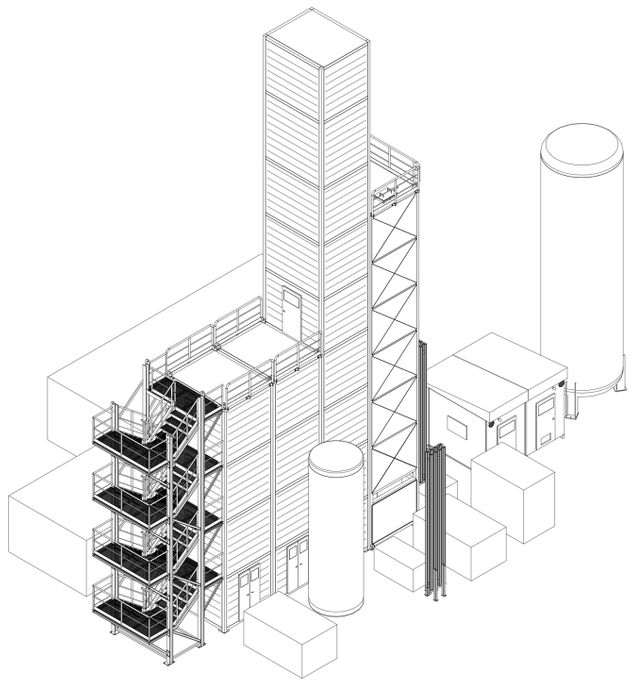
The goal: explore heavy dark matter to the neutrino floor and beyond with extremely low instrumental background



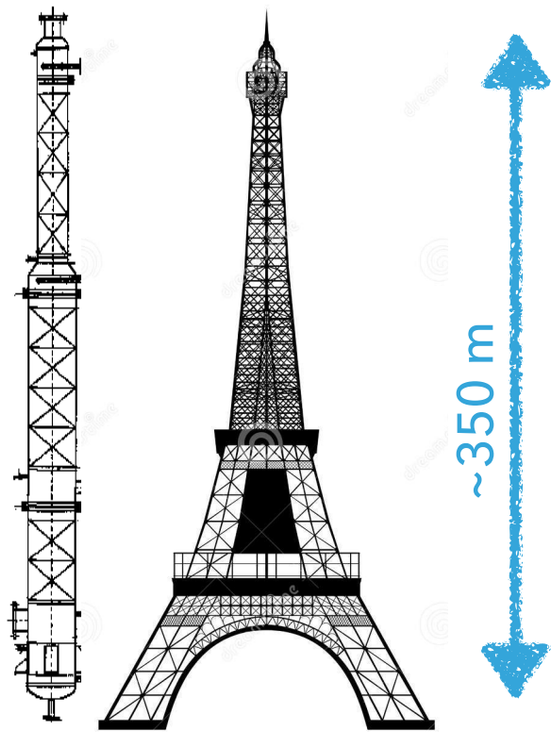
ArDM

EXTRACTION & ISOTOPE SEPARATION

- **Urania** (Extraction):
  - Expansion of the argon extraction plant in Cortez, CO, to reach capacity of **330 kg/day** of Underground Argon



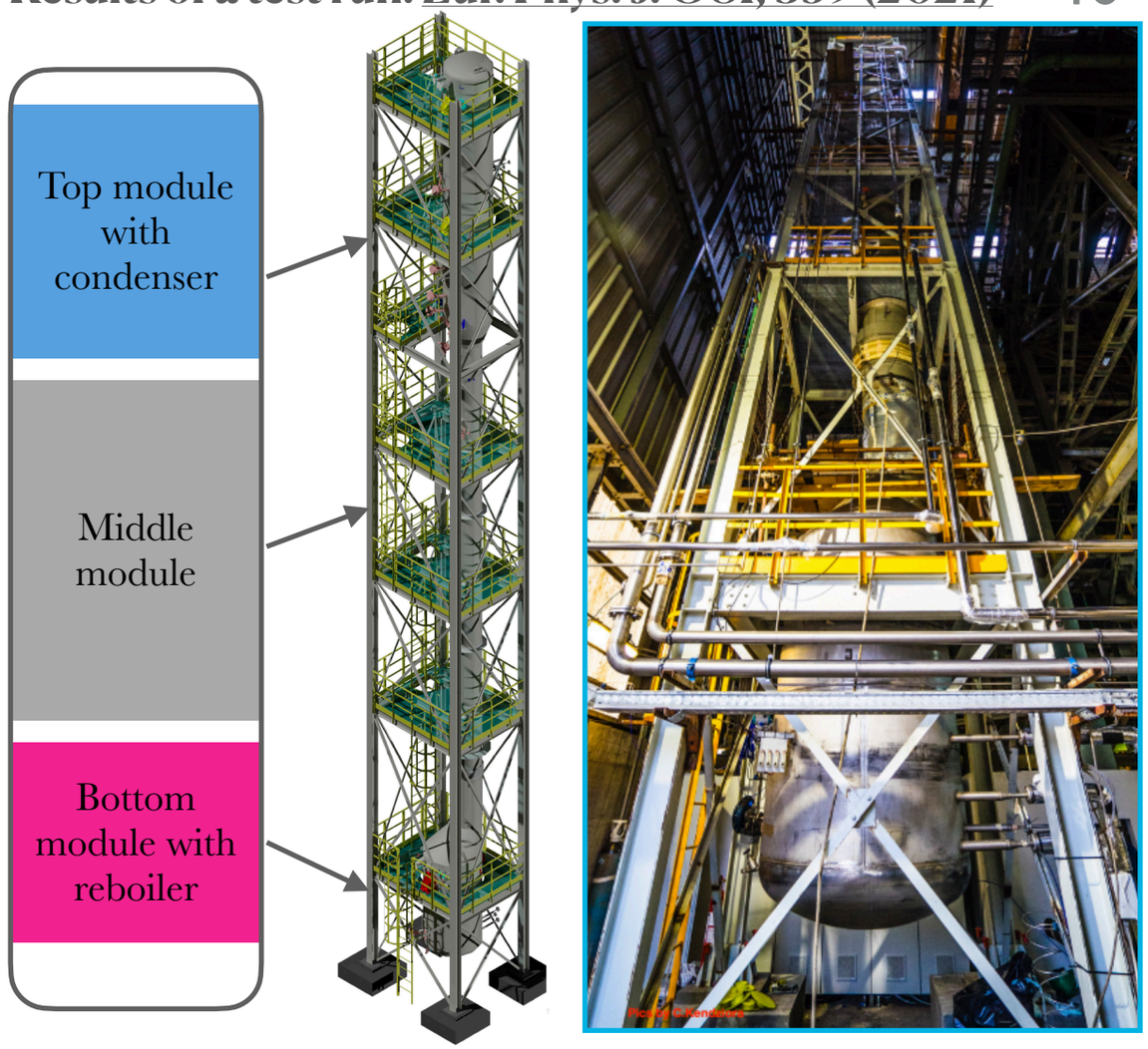
- **Aria** (Isotope separation):
  - Very tall column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon. **A factor 10 reduction of ^{39}Ar** per pass is expected.
  - Other isotope separation for medical scanners, for example, ^{17}O and ^{18}O.



ARIA UPDATE

- The demonstrator column (26 m) that consists of three modules was **successfully tested** in July-Oct. 2019 with LN_2.
- The results are in agreement with the expectations and validate the concept and design of the plant.
- **April 2021**: Successful **test installation** of the first module (of 24 central ones) in the shaft at Seruci mine.
- **Assembly** of the final column in the well - 2022.

Results of a test run: Eur. Phys. J. C 81, 359 (2021)

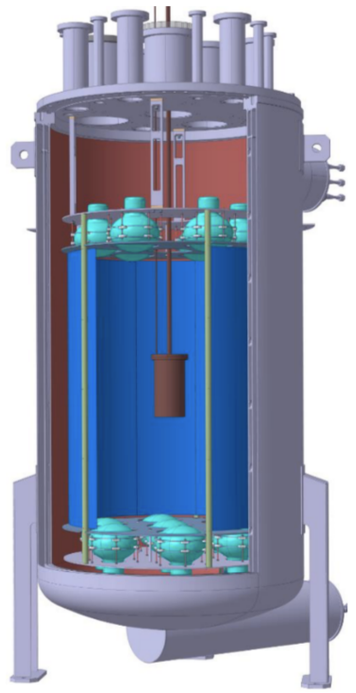


Prototype ARIA column ~26 m

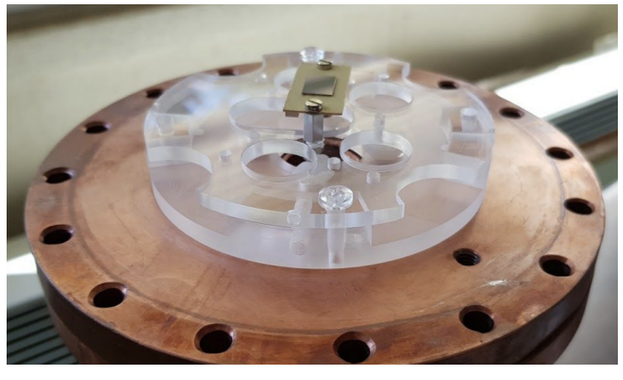
Test installation of the module

ARGON RADIO-PURITY MEASUREMENT

- **DArT:** a single phase low-background detector to measure the ^{39}Ar depletion factor of different underground argon batches (URANIA+ARIA).
- Cylinder made of 99.99% OFHC Cu, 1.42 kg of LUAr. PMMA support structure with TPB coating. Two 1 cm^2 SiPMs.
- To be installed inside the ArDM apparatus (Canfranc Laboratory, Spain) filled with LAr (850 kg AAr) used as active veto.
- Sensitivity to the depletion factor of 1000 with 10% precision in one week run.



DArT in ArDM



DArT SiPM

DArT was installed at LSC in April 2021 and the following installation in ArDM is foreseen in the beginning of 2022.

More details of DArT: JINST 15 P02024 (2020)

PHOTO SENSOR

- 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
- The 28m^2 for the TPC (8280 channels) + 3000 channel for Veto detector. Mass production of the raw wafer in LFoundry company and assembly in a dedicated facility at LNGS (NOA).

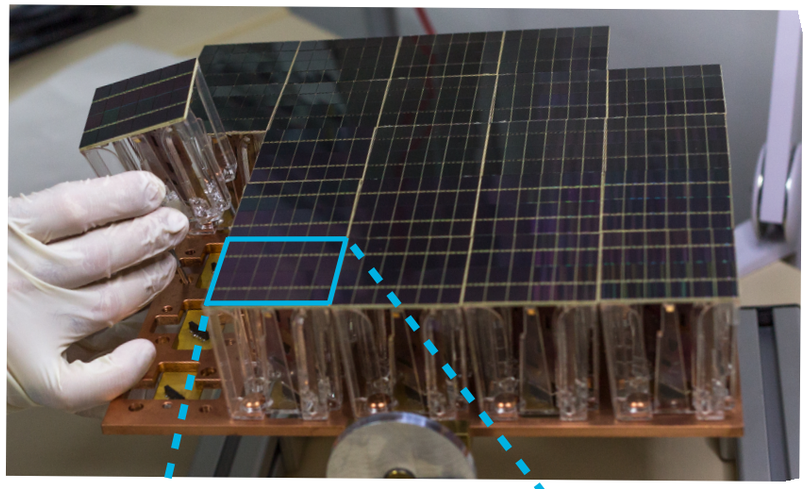


Photo Detector Unit (PDU) = matrix of 25 PDMs
25 x 25 cm^2

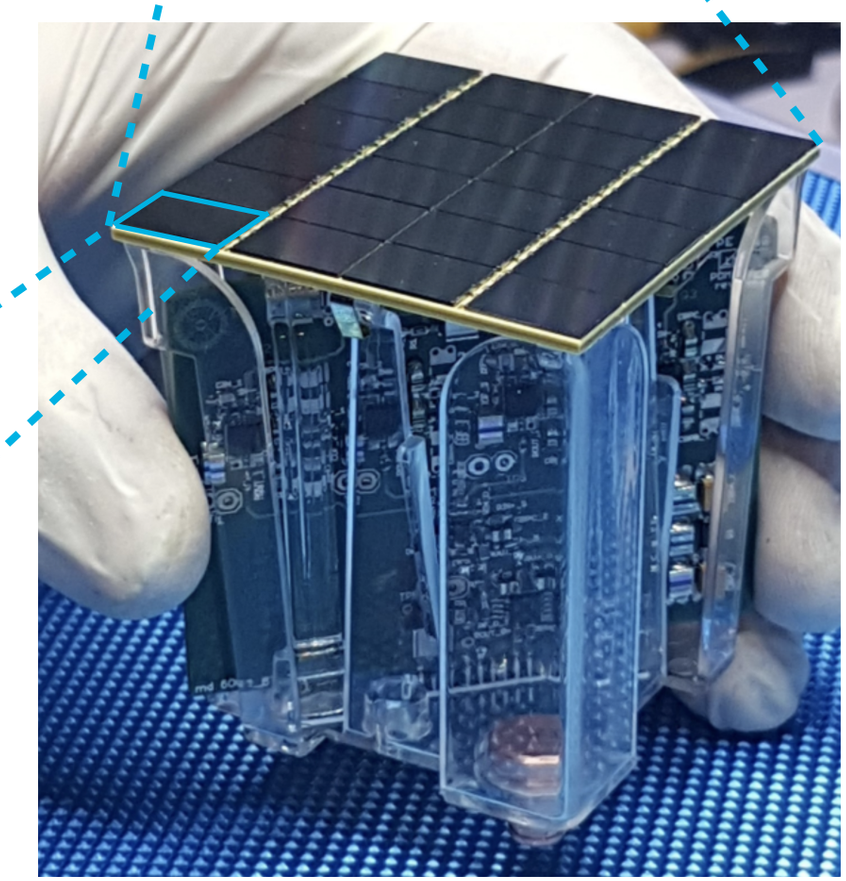
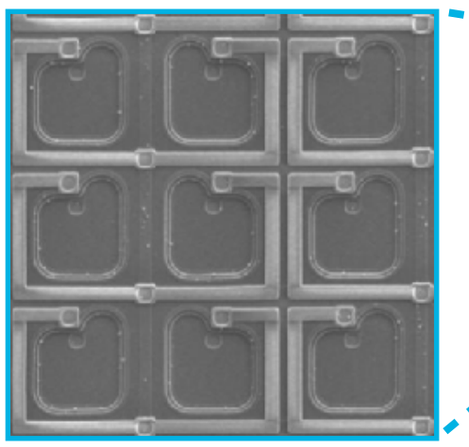
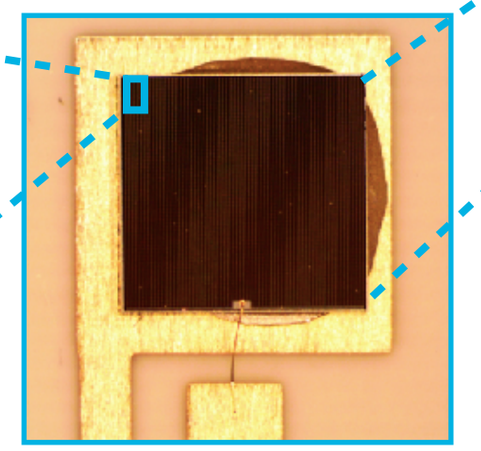


Photo Detector Module (PDM)
= matrix of 24 SiPMs, 5 x 5 cm^2
Read as a single channel
(largest single SiPM unit ever!)



Single SPADs

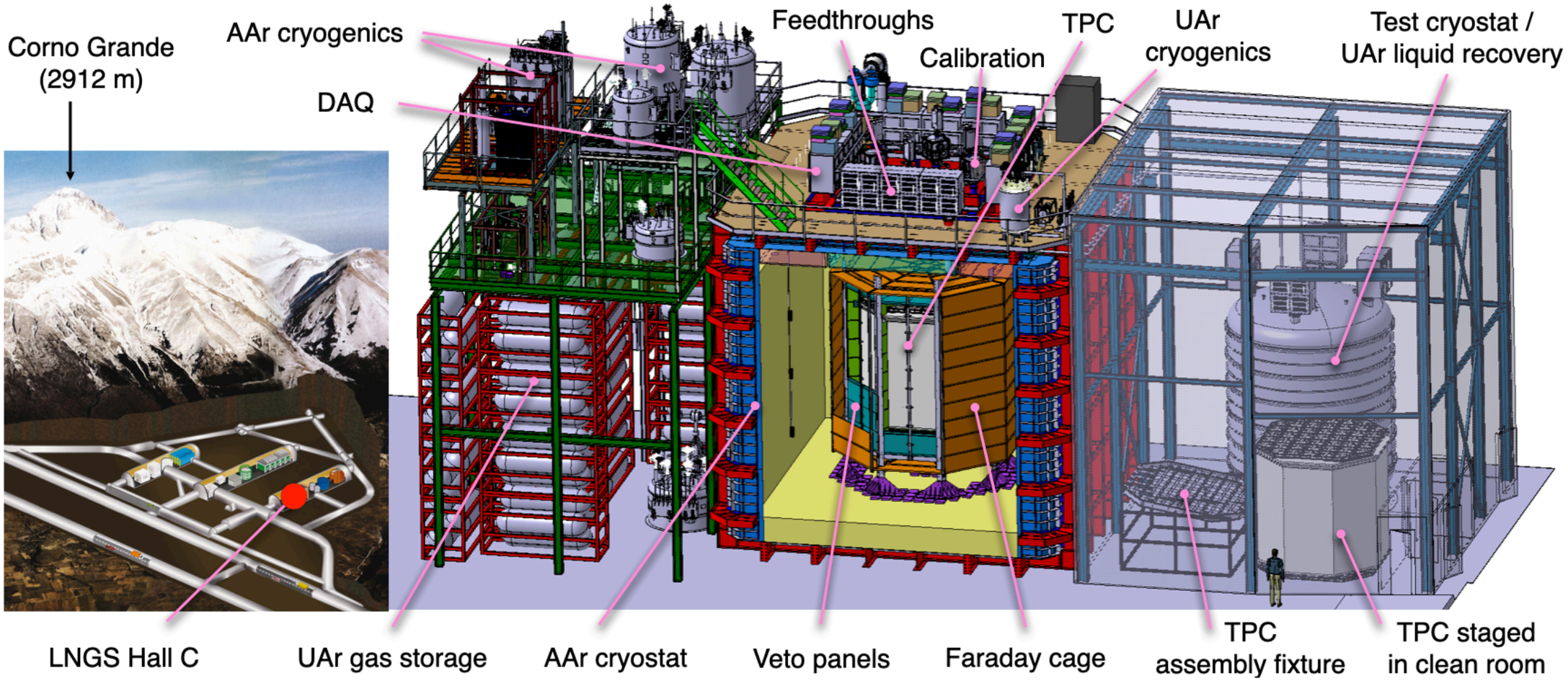
~25-30 μm^2



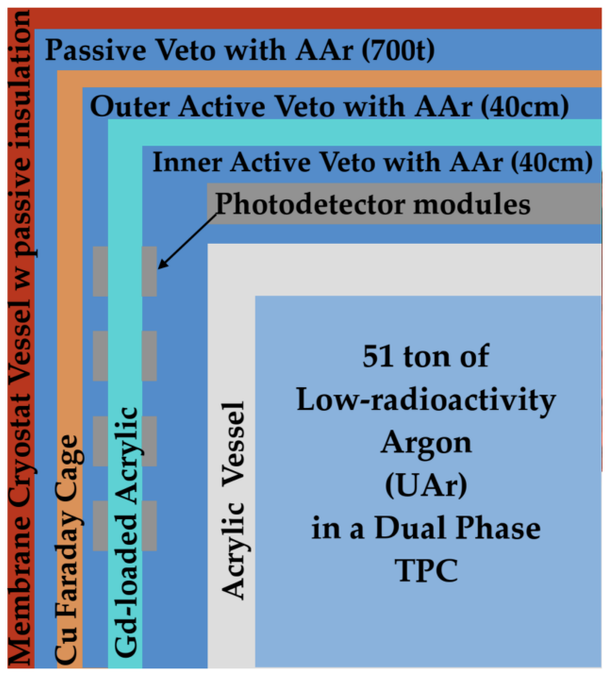
Single SiPM

~1 cm^2

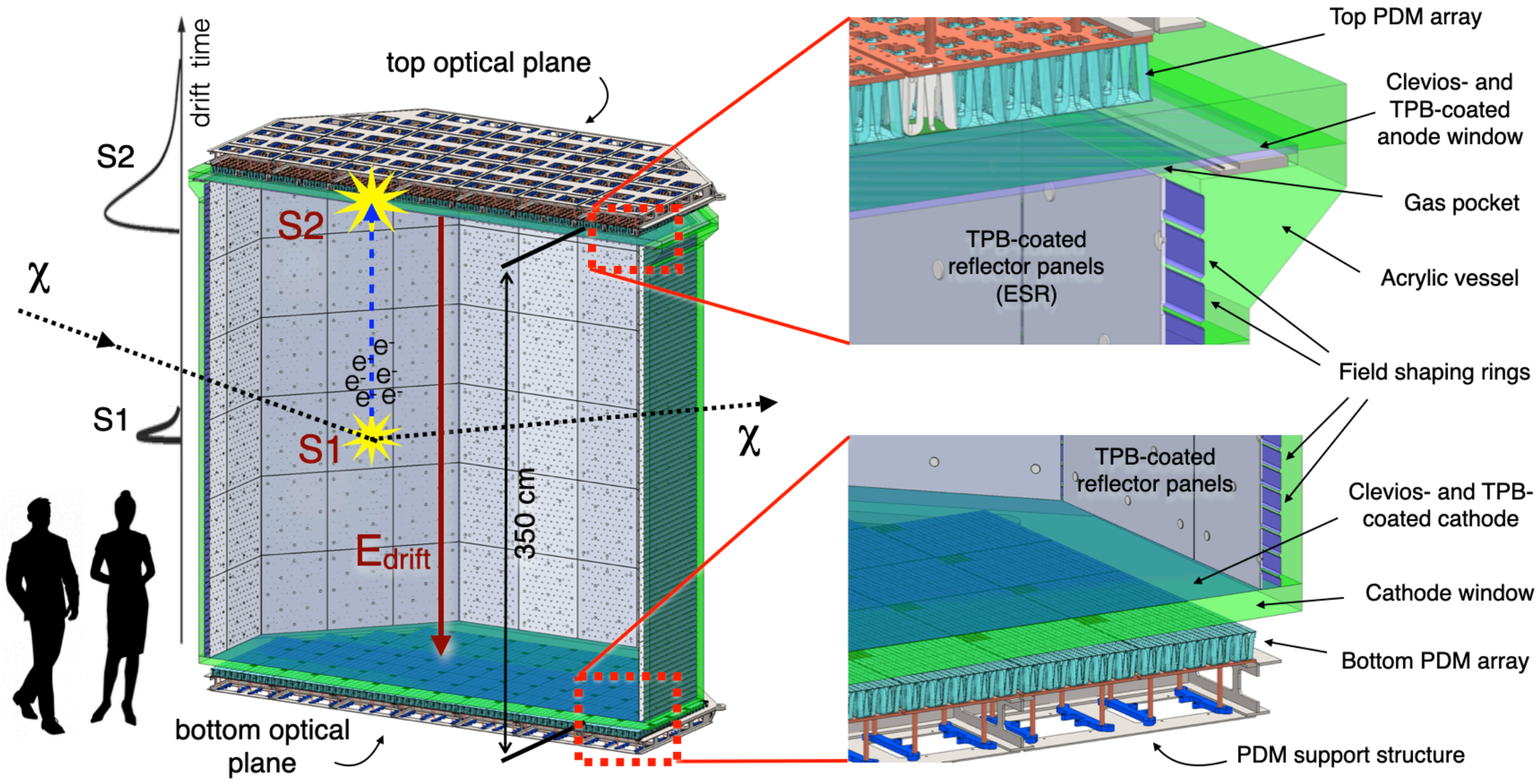
DARKSIDE-20K DETECTOR



- DarkSide-20k will be installed underground at the Gran Sasso National laboratories, in Italy.
- The detector has a nested structure:
  - Sealed acrylic TPC filled with 50 t of UAr
  - Neutron veto
    - Two liquid atmospheric argon buffers
    - Gadolinium loaded acrylic shell between the buffers
- Membrane cryostat like the ProtoDune one



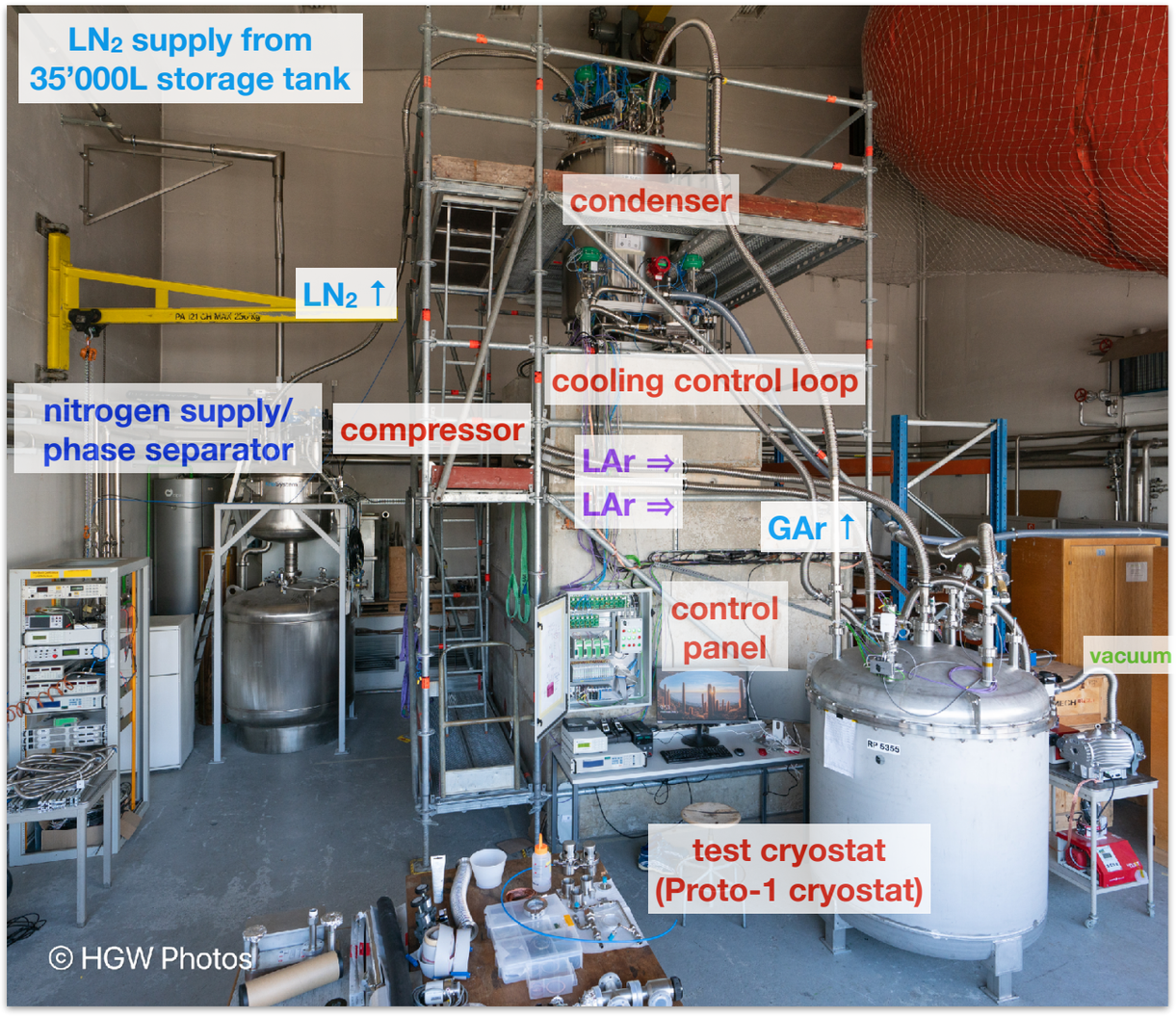
TIME PROJECTION CHAMBER



- Ultra pure acrylic vessel, sealed with the bonding technique
- Octagonal shape
- Cathode and anode coated with new transparent conductor (Clevios) and wavelength shifter
- Grooves with Clevios for field cage (No copper rings)
- Wire grid for extraction and electroluminescence fields
- Sides covered with multilayer polymeric reflector evaporated with wavelength shifter (TPB)
- SiPMs planes external to anode and cathode

CRYOGENIC SYSTEM FOR TPC

- Integrated test of the UAr cryogenics is ongoing at CERN.
- Up to 10 kW (latent heat + heat exchanging) adjustable condenser box.
- 1000 SLM circulation speed with two homemade pumps in parallel.
- The first test was taken in July 2021.
- More tests are planned later this year.



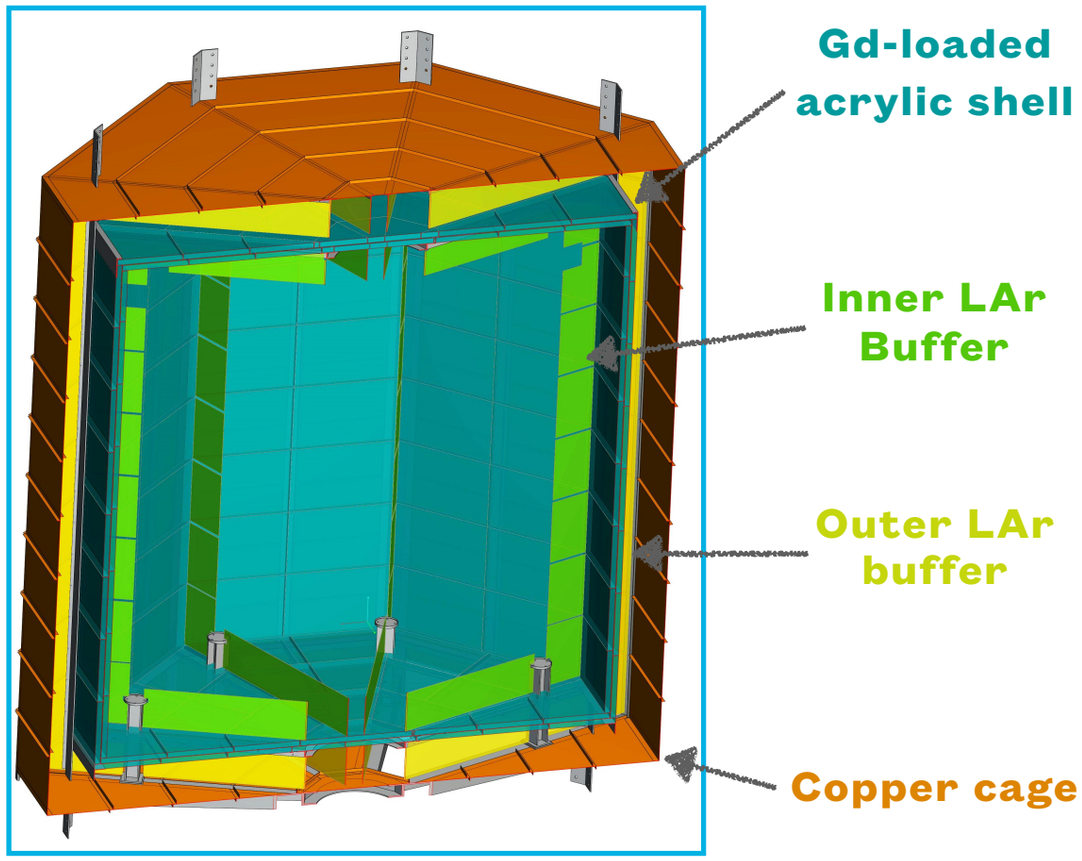
TPC Cryogenic system (test installation) at CERN

VETO DETECTOR

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

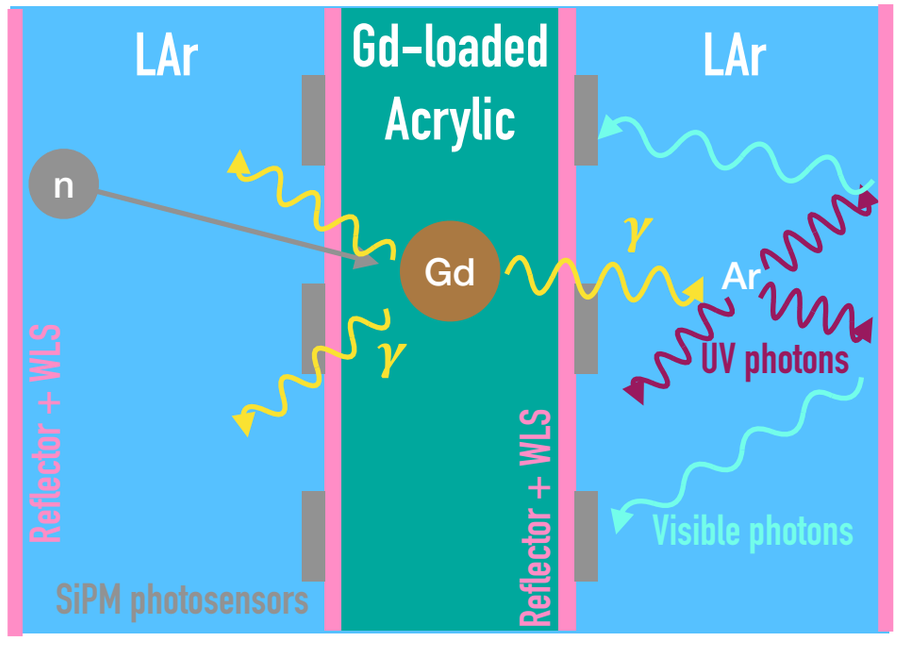
Veto Structure

- 424 panels of acrylic loaded with gadolinium, form a shell around the TPC. Total acrylic thickness: 10 cm.
- The shell is sandwiched between two atmospheric liquid argon buffers, each ~ 40 cm thick. Both buffers are divided in 8 sectors
- Reflector with WLS on all the surfaces



Veto Working Principle

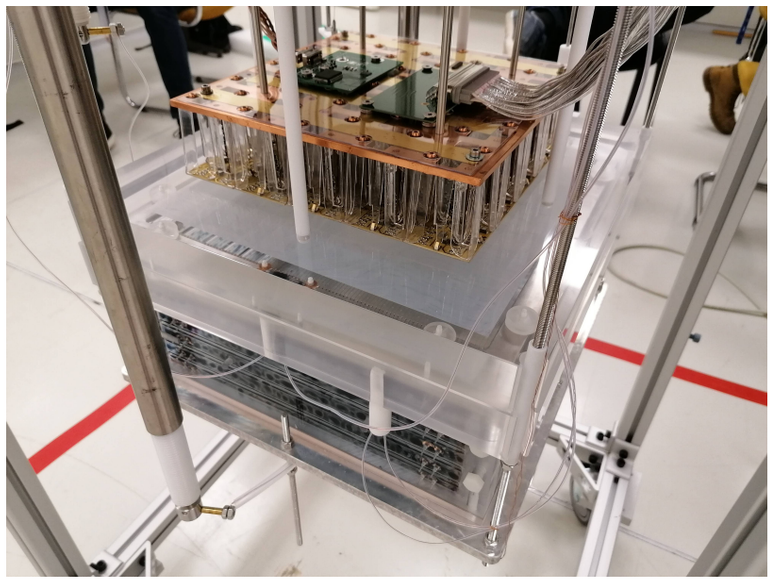
1. Neutrons are moderated in the acrylic shell and then captured by gadolinium.
2. Gd emits multiple γ-rays with energy up to 8 MeV.
3. γ-rays interact in the liquid argon buffers.
4. LAr scintillation light is shifted and detected by ~3000 SiPM-based photosensors.



PROTOTYPES

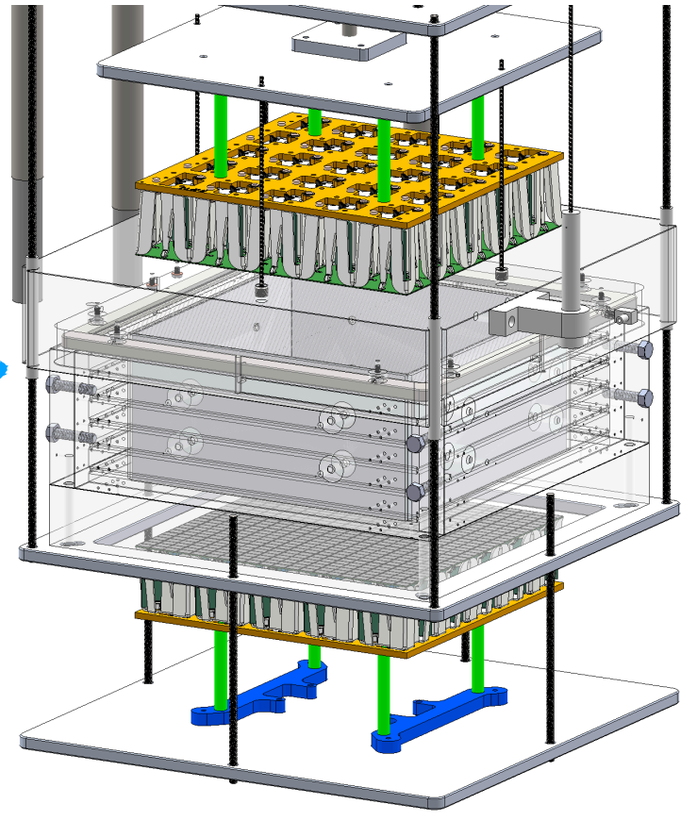
- Two Photo Detector Units (PDUs) were already tested in LN_2 at LNGS & CERN.
- **Proto-0** *(spring 2022)*. **Two PDUs** mounted on the Proto-0 TPC **in Naples** for the integration test, the S2 study and the adjustable Gas Pocket tests. From ITO to Clevios polymer.
- **Proto-1t** *(from summer 2022)*. Tests of the scaled version of DS-20k, PDUs and octagonal acrylic vessel, **at CERN**.

October 2019



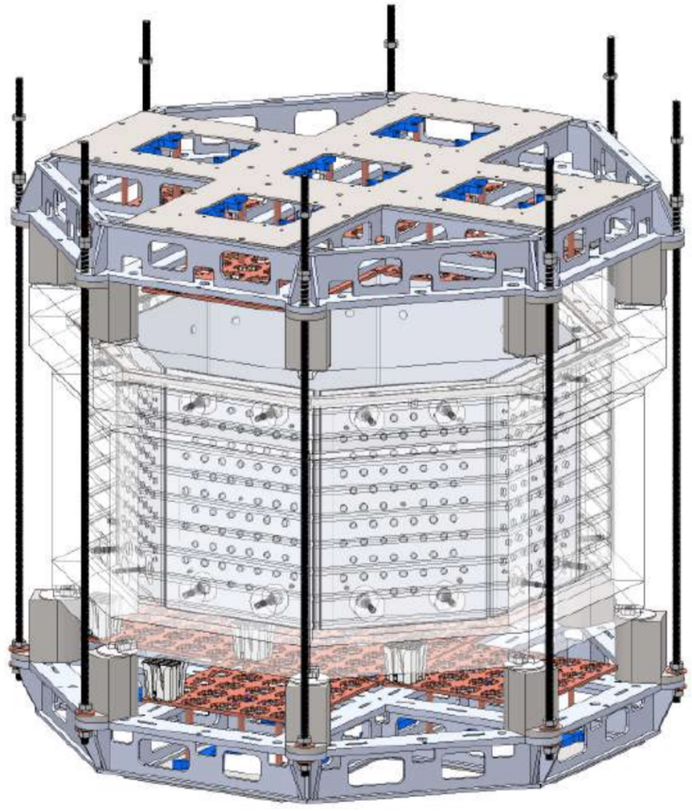
Proto-0 at CERN

Spring 2022



Proto-0 at Naples

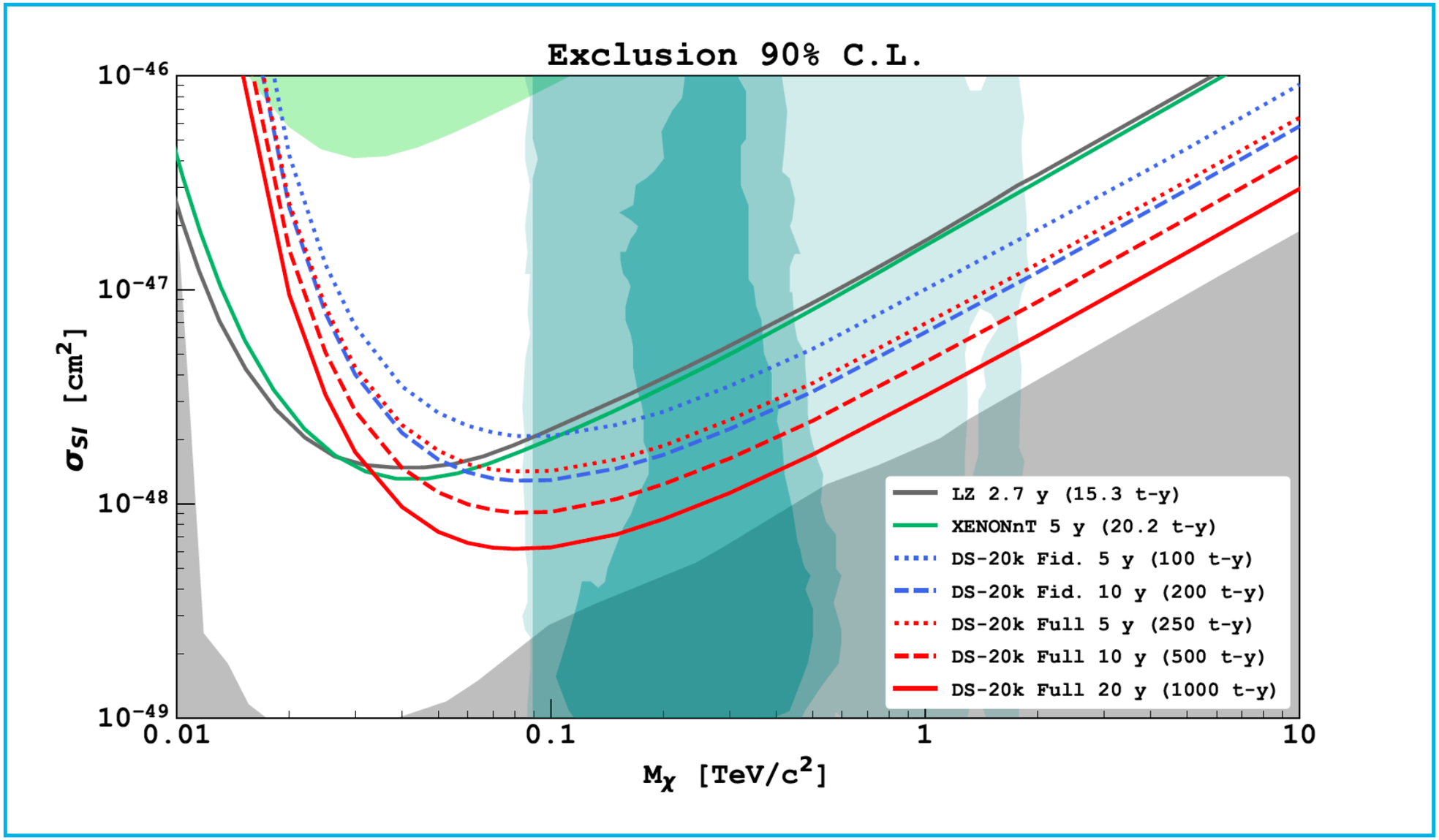
from Summer 2022



Proto-1T at CERN

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 full volume exposure of 500 t yr - is 4.6 x 10^{-48} cm^2 for 1 TeV/c^2 WIMP for the 90% C.L. exclusion.

SUMMARY

- Underground Ar has excellent properties suited to WIMP search.
- 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 cryogenic system is tested at CERN.
- The TPC and Veto designs are well developed.
- Aim at the better sensitivity than the current generation of WIMP search experiments.

Dark Wave
European Funds Smart Growth
Republic of Poland
FNP Foundation for Polish Science
European Union European Regional Development Fund

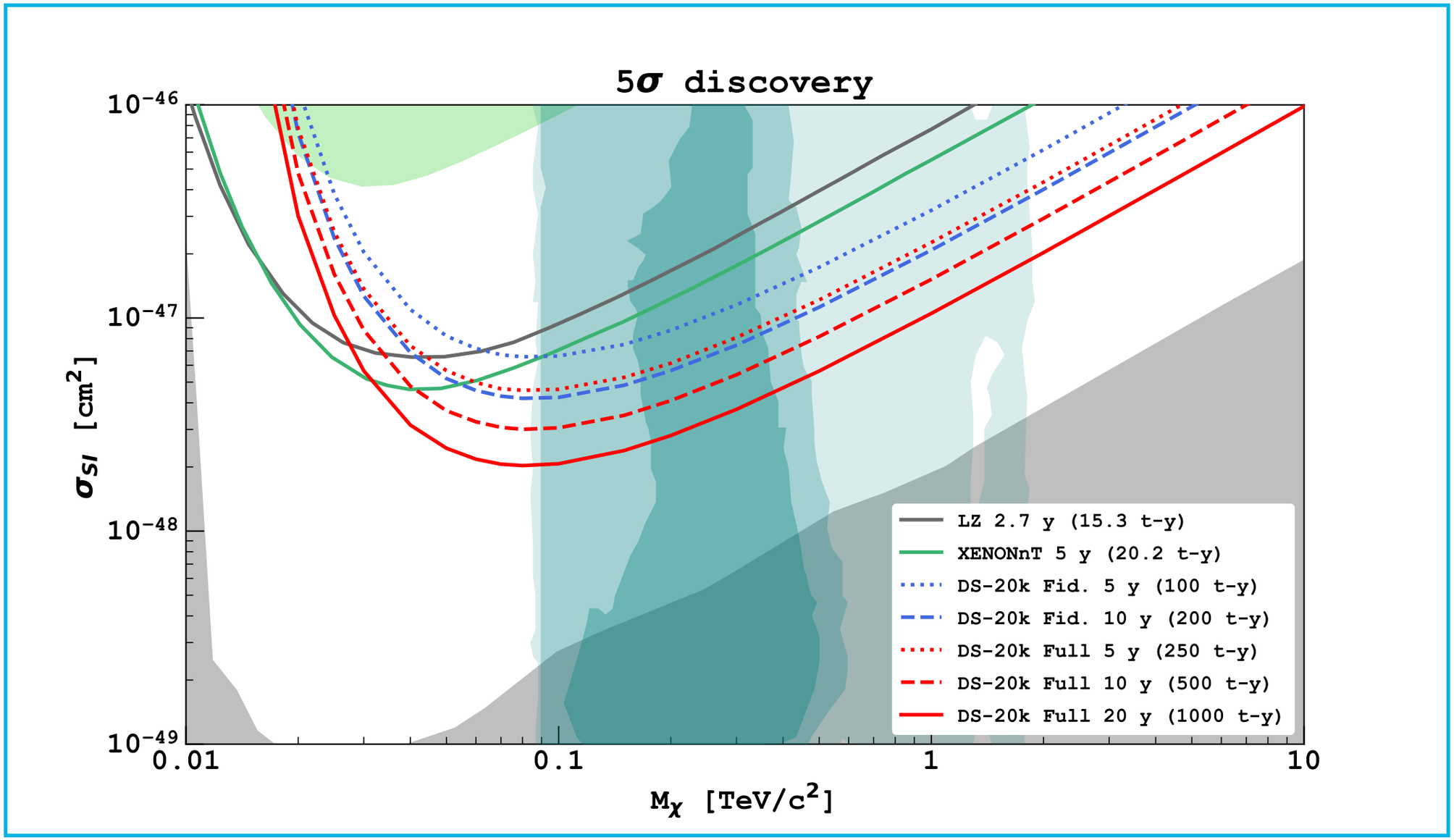
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 962480

Thank you!


AstroCeNT
Budker Institute of Nuclear Physics
BROOKHAVEN NATIONAL LABORATORY
CENTRO FERMI
MUSEO STORICO DELLA FISICA E CENTRO STUDI E RICERCHE ENRICO FERMI
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CPPM
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich
FONDAZIONE BRUNO KESSLER
Fermilab
FORT LEWIS COLLEGE
ESTABLISHED 1911
Instituto de Física
Universidade de São Paulo
INFN
IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY
INSTM
POLITECNICO MILANO 1863
NATIONAL RESEARCH CENTER "KURCHATOV INSTITUTE"
LPNHE
PARIS
Politechnika Łódzka
Novosibirsk State University
*THE REAL SCIENCE
Pacific Northwest NATIONAL LABORATORY
SAPIENZA
UNIVERSITÀ DI ROMA
ROMA TRE
UNIVERSITÀ DEGLI STUDI
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE
UNIVERSITY OF SUSSEX
TIFPA
Trento Institute for Fundamental Physics and Applications
TRIUMF
THE UNIVERSITY OF CHICAGO
UMASS
UNIVERSITÉ DE SHERBROOKE
WARWICK
THE UNIVERSITY OF WARWICK
araid
FUNDACIÓN ARAGONESA PARA LA INVESTIGACIÓN Y EL DESARROLLO

EXPECTED SENSITIVITY

- The 5σ significance 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 full volume exposure of 500 t yr - is 1.5 x 10^{-47} cm^2 for 1 TeV/c^2 WIMP for the 5σ discovery.

ReD EXPERIMENT

Work on going...

LAr TPC

Design by UCLA

Cryogenic System

Neutrons Detectors

Scattering Chamber

n beam

^{7}Li Beam

REcoil Directionality