The Darkside-20k experiment at LNGS

RICAP 2024 - Roma International Conference on Astroparticle Physics

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Stefano Davini, INFN Genova - on behalf of the DarkSide Collaboration


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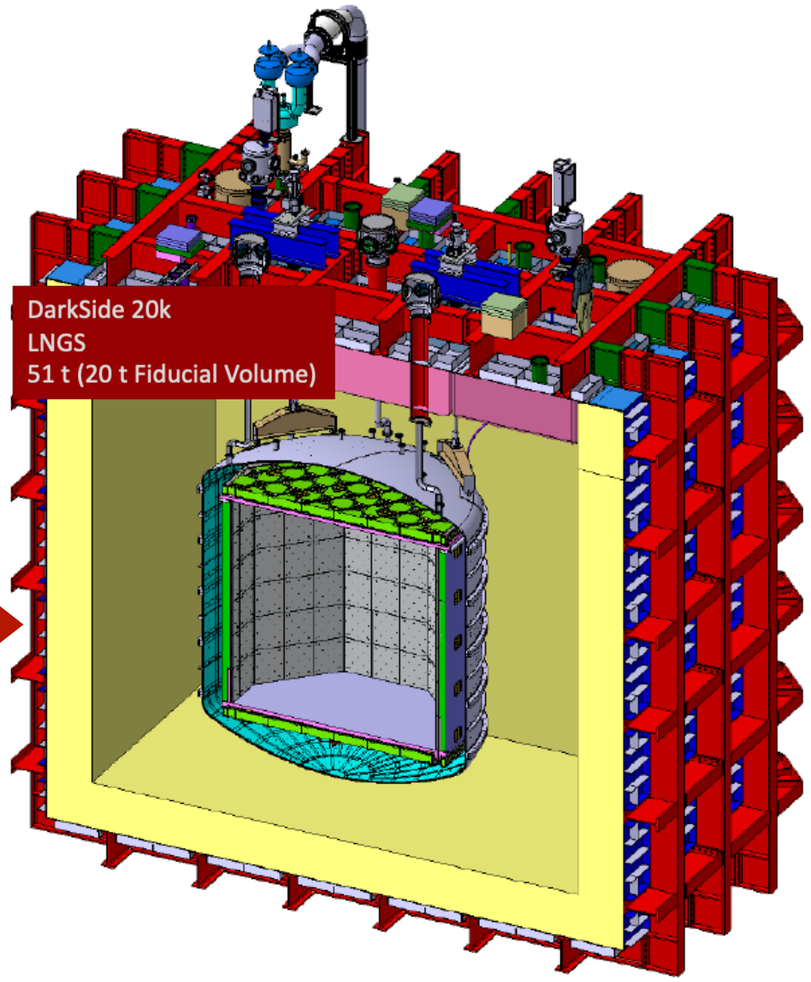
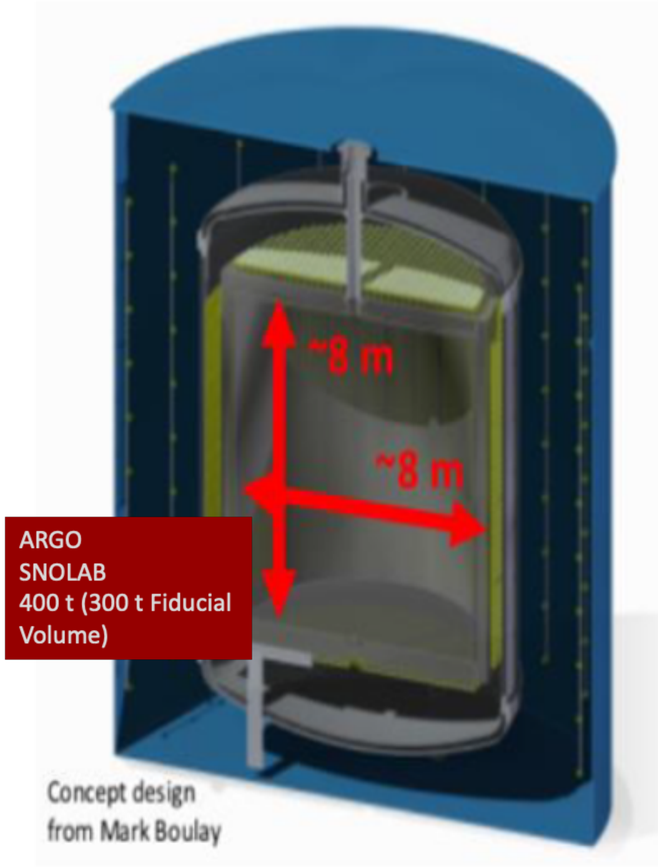
Direct search for WIMP in liquid Argon

The Global Argon Dark Matter Collaboration - GADMC



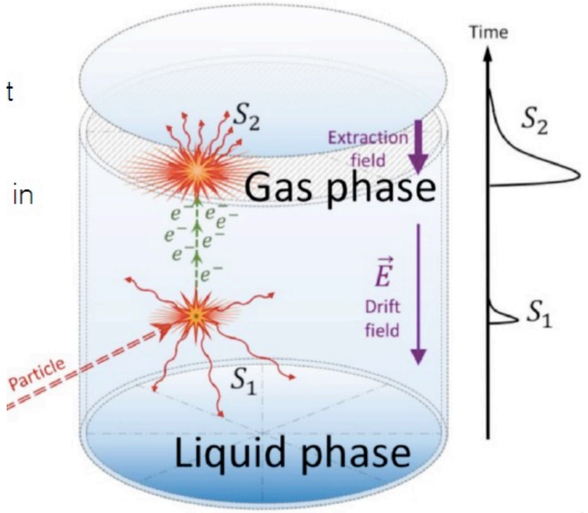
construction started in 2022
filling expected in 2027
nominal run time 10 years



Ar and Time Projection Chamber technology

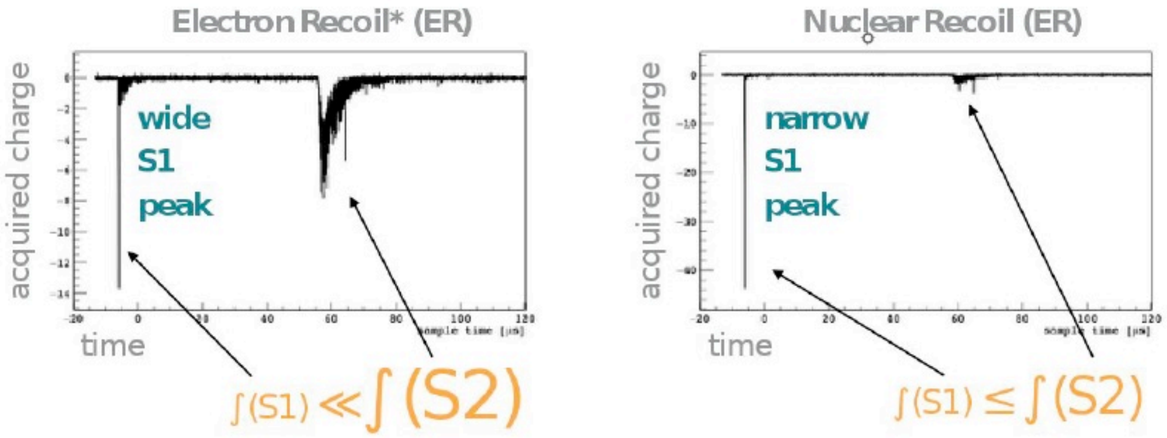
Scintillation (S1)
formation of excited Ar^{2*} and decay
short singlet state *6.7 ns*
long triplet state *1.6 μs*

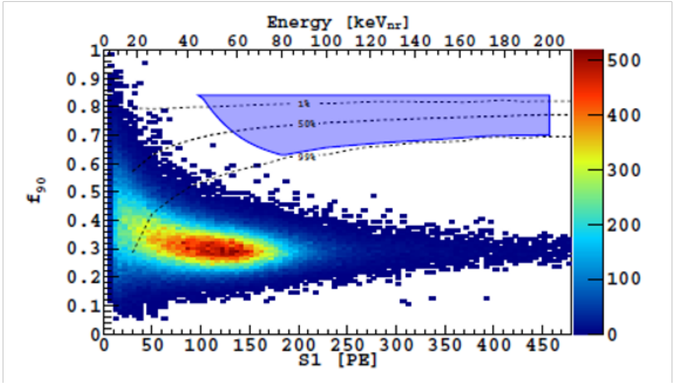
Electroluminescence (S2)
drift of e- in electric field
extraction in gas



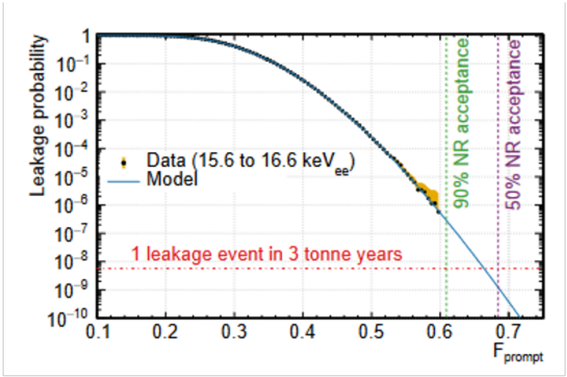
Dual Phase TPC: 3D space reconstruction

Nuclear recoil (NR) vs β-γ (ER) signal discrimination
Fraction of prompt and delayed light (f_{prompt}) + S2/S1 ratio



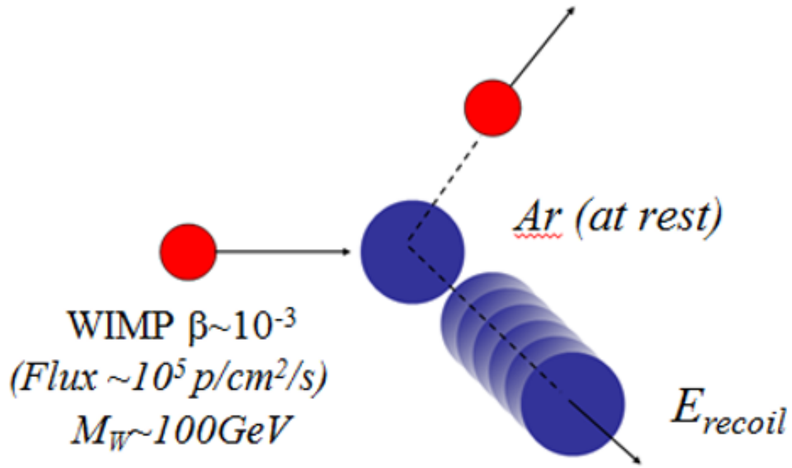


DS50 Coll, Phys Rev D 98 (2018) 102006



DEAP Coll, Euro Phys J C 81 (2021)

WIMP detection in Argon TPC



Large **Exposure** (Mass x Time)
~ 100 tons year

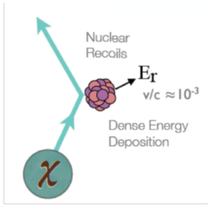
Low Energy **Threshold**
< 10 keV (S1+S2)
< 1 keV (S2 only)

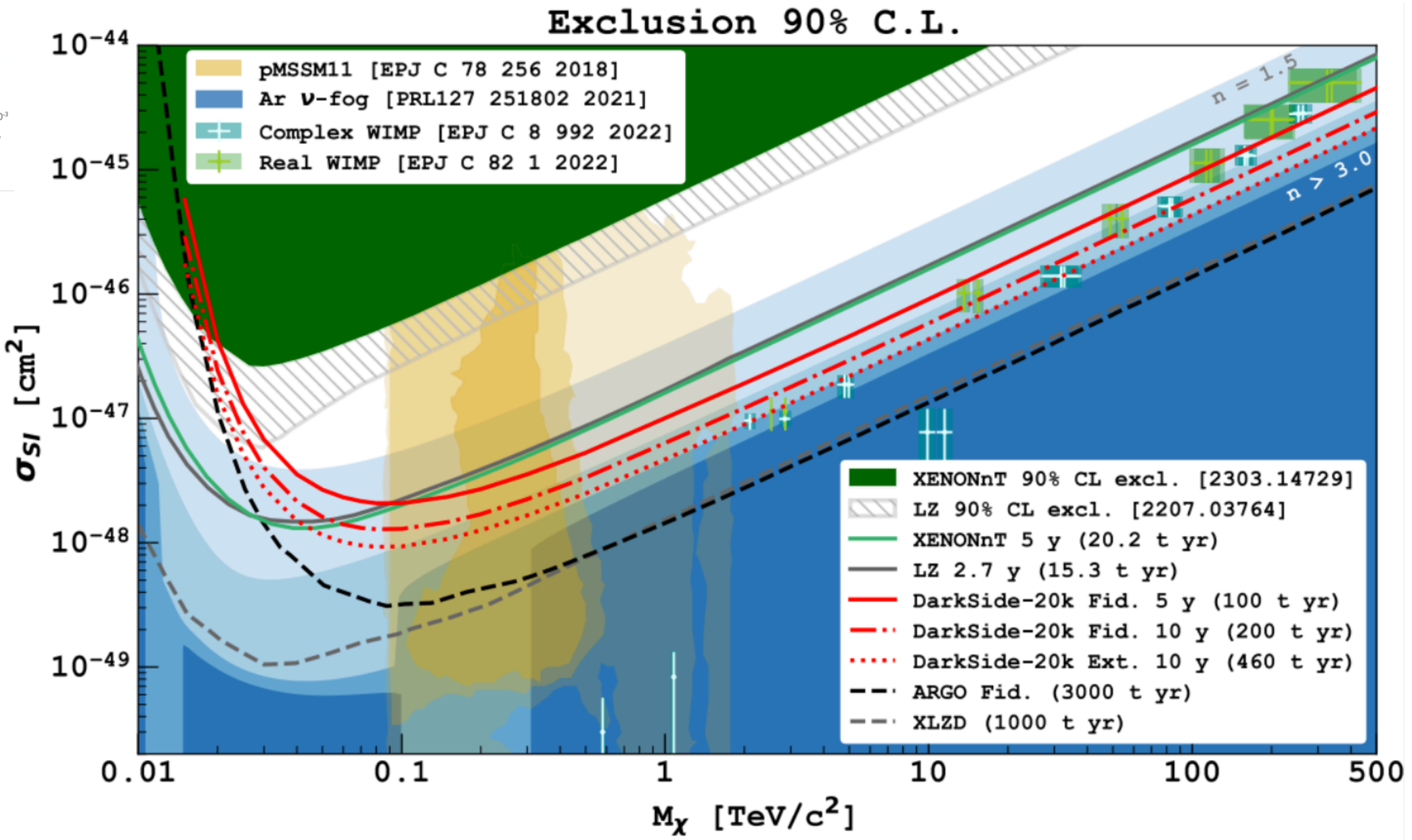
Low **Background** Rate
< 0.1 events in 100 tons year

Topology-based background discrimination
single-scatter vs multi-scatter (n, γ)

Pulse Shape based background discrimination
> 10^8

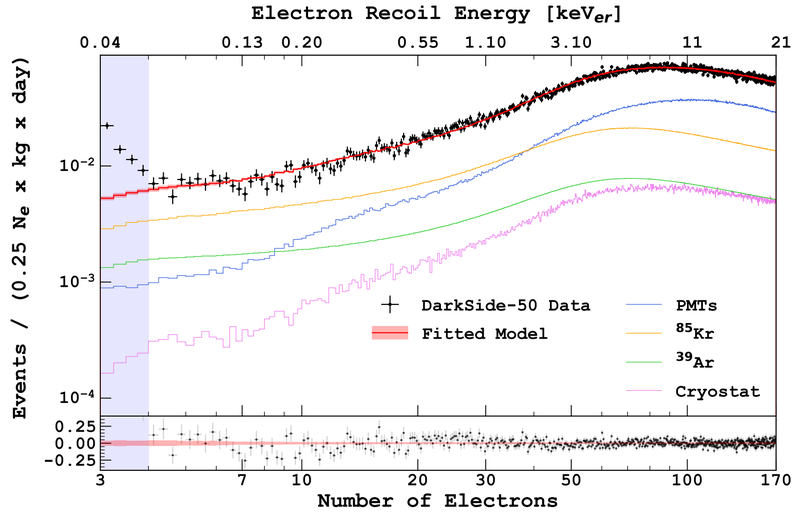
Expected WIMP sensitivity in DS-20k

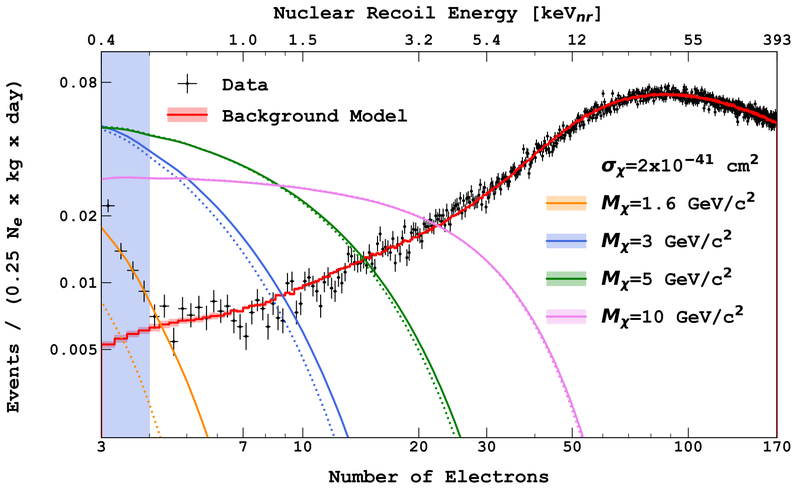




Low mass dark matter search

In DS50

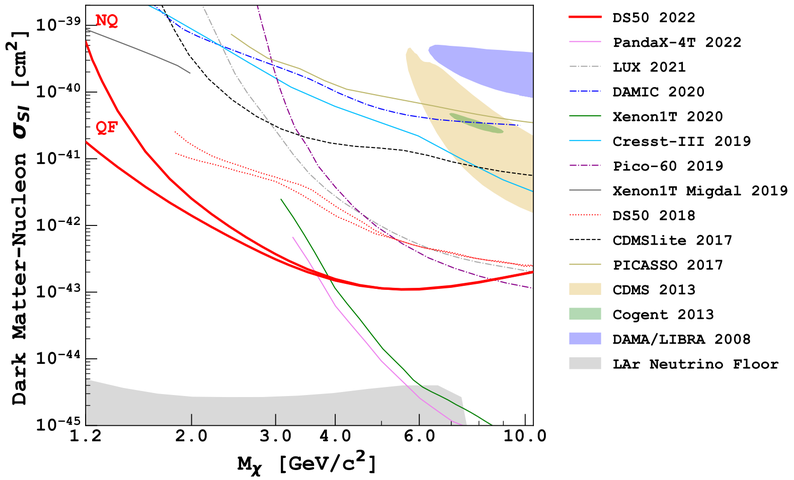


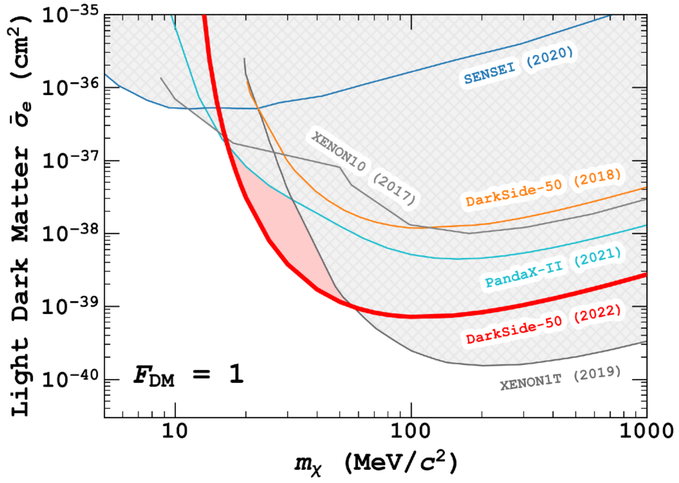


S2 only events to reach lower energy threshold

Sensitivity to **low mass dark matter** candidates

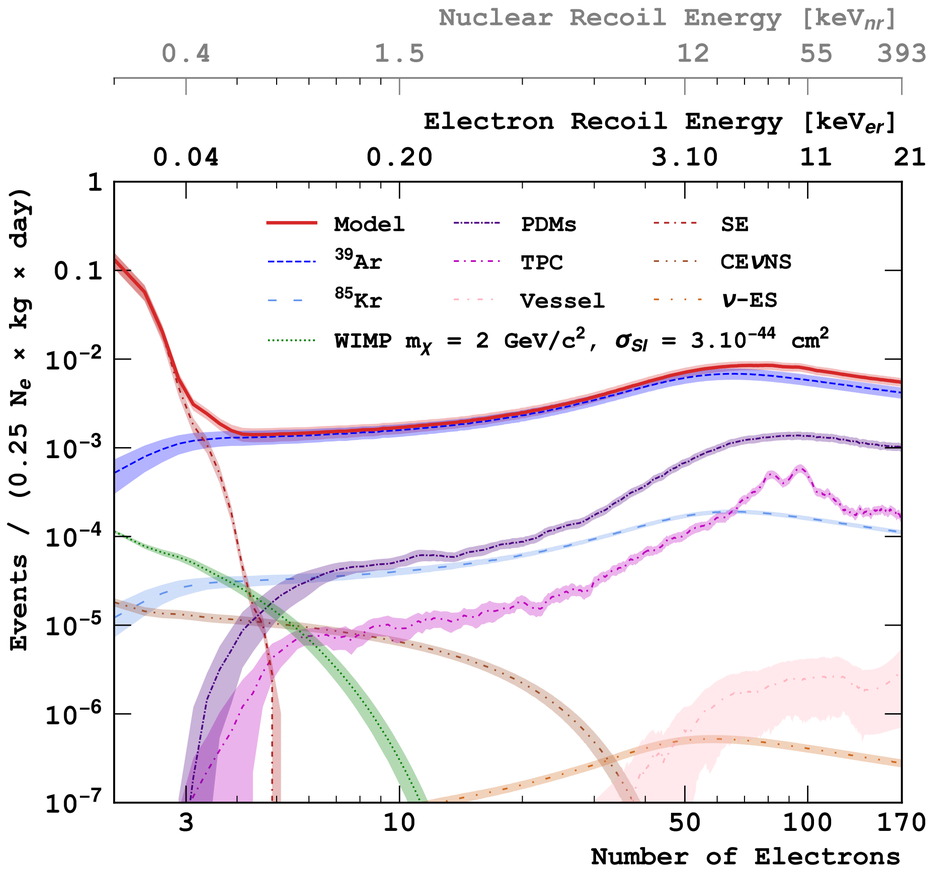
- **WIMP-nucleon** Phys. ReV. D 107 (2023) 063001
- **WIMP-electron** Phys. Rev. Lett. 130 (2023) 101002
- ***Migdal*** Phys. Rev. Lett. 130 (2023) 101001

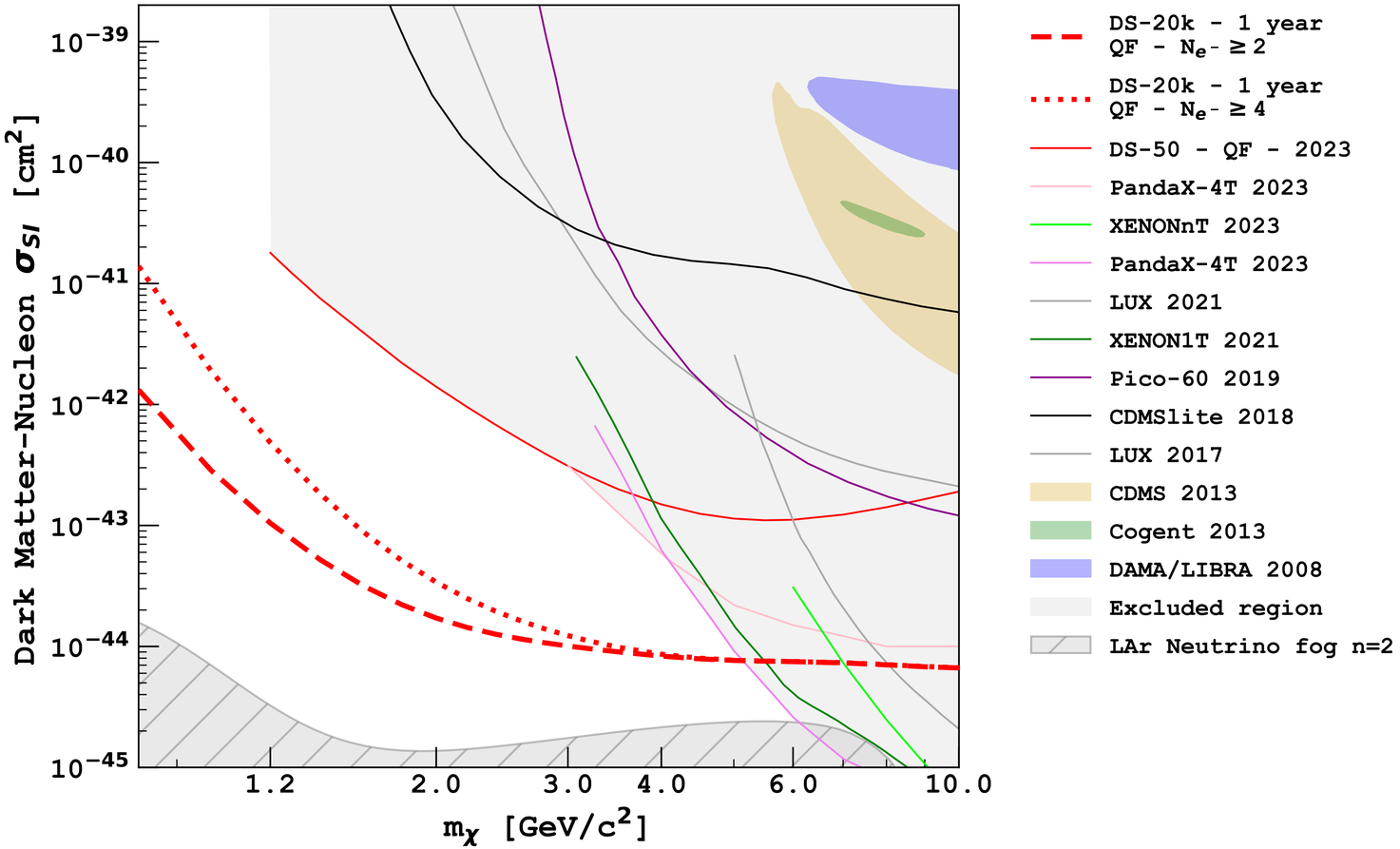




Low mass dark matter search

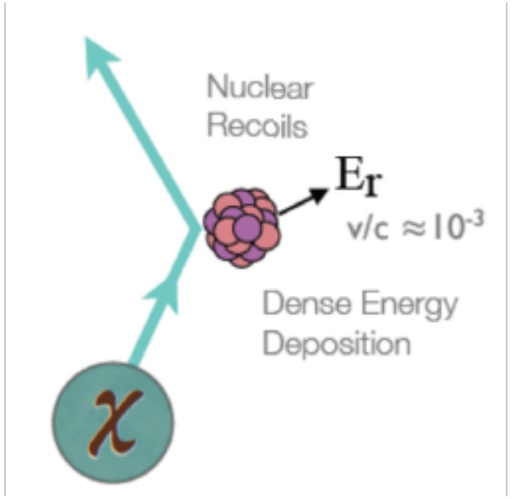
In DS-20k





arXiv:2407.05813

Signals and backgrounds



Signal

Nuclear Recoil up to 100 keV
Single scattering, known pulse shape
Up to a few events in the whole data taking

Background source	Mitigation strategy
^{39}Ar β decay	Use Ar from Underground source (UAr) + Pulse Shape Discimination (PSD)
γ from rocks and γ/β- from materials	Pulse Shape Discrimination (PSD) Selection of materials & procedures
Neutrons Radiogenic n (α,n) with a from material contaminants	Material screening. Definition of Fiducial Volume in the TPC and active VETO to reject neutron signal
Surface contamination due to Rn progeny	Surface cleaning Reduce the number of surfaces Installation in Rn abated air
Neutrino coherent scattering	irriducible

Radiopurity requirements

➢ Assay all materials of the detector

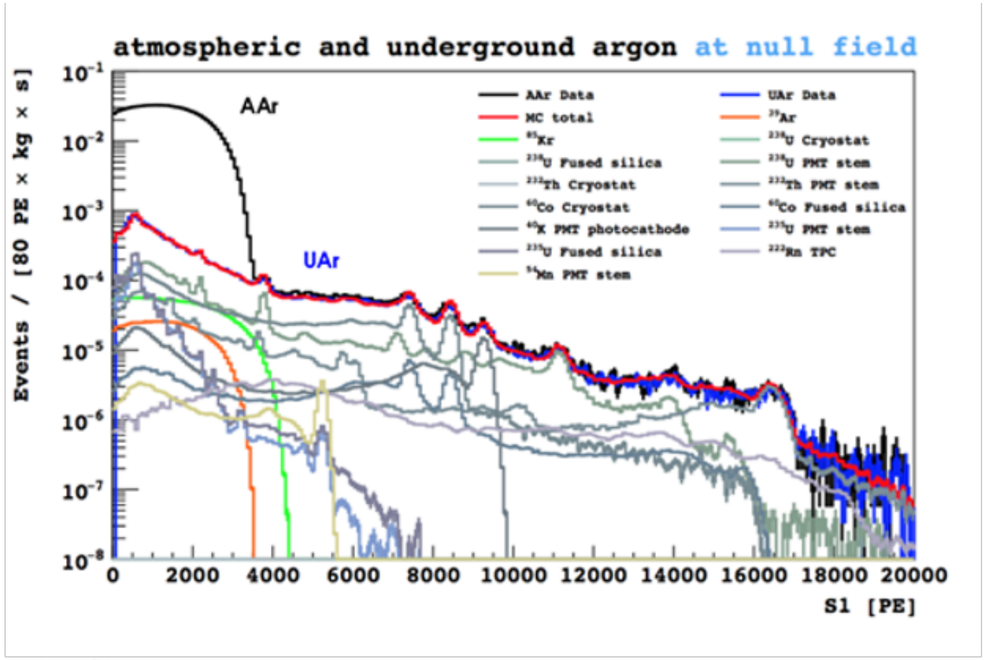
- Worldwide effort **Canada, Italy, France, Poland, Russia, Spain, UK, US…**
- Counting facilities in four Underground laboratories involved (Boulby, LNGS, LSC, SNOLAB)
- 3 different techniques employed: ICPMS, HPGe, Po extraction for Upper, Middle and Lower ^{238}U chain
- Hundreds of assays carried-out
- Platform to store and manage the results of the material assay campaign

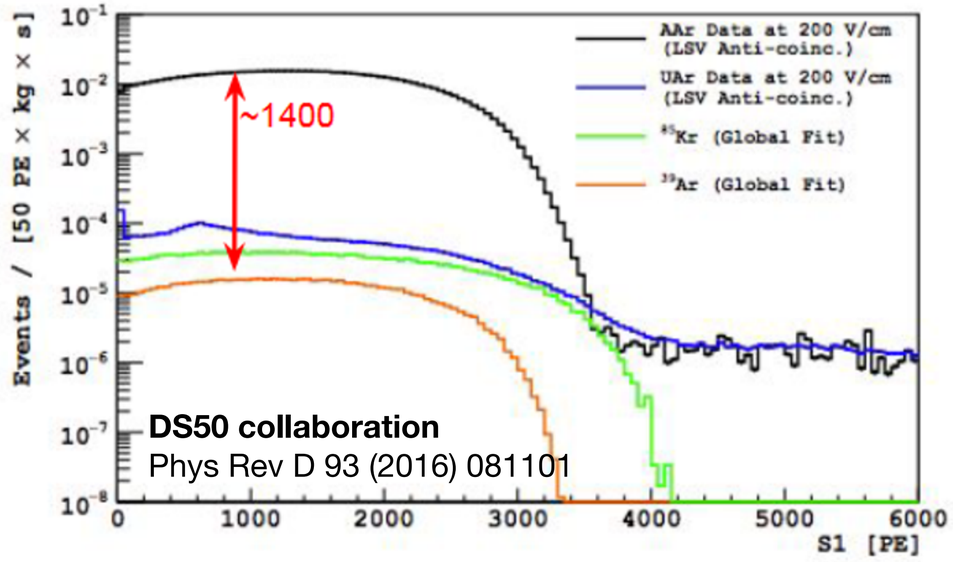
➢ Full characterization and calculation of the materials background

- Control of the cosmogenic activation of materials
- Control of the surface contamination
- Evaluation of the radioactive budget of the experiment including activation UG
- Evaluation of the systematic uncertainty from the material composition
- New MC tools for (α, n) calculations

Goal: <0.1 backgrounds in 10 year exposure

Radiopure Ar from underground sources





DS50 collaboration
Phys Rev D 93 (2016) 081101

^{39}Ar β decay (Q = 570 keV, half life 269 yr)

~ 1Bq/kg in **atmosphere** Ar

Origin from ^{40}Ar(n, 2n)^{39}Ar in atmosphere

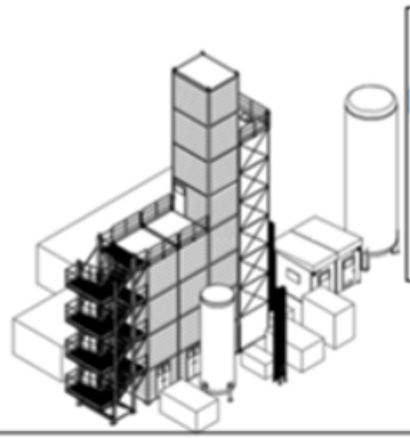
Extraction of Ar from **underground** sources, where such processes are suppressed

DS50 used 157kg of **UAr**

Depletion factor in ^{39}Ar : 1400 +/- 200

The procurement of UAr for DarkSide-20k

Characterisation: DArT
Measurement of the ^{39}Ar depletion factor



UAr transported via boat
for final purification at Aria

Production: Urania

- Commercial-scale plant to extract UAr
- Located in Southwestern Colorado
- UAr extracted from CO_2 well gas at the tonne scale

Purification: Aria

- 350 m tall cryogenic distillation column to purify UAr and isotopically separate argon and other elements
- Located in refurbished carbon mine shaft in Sardinia, Italy
- Will chemically purify the UAr for DS-20k to detector grade

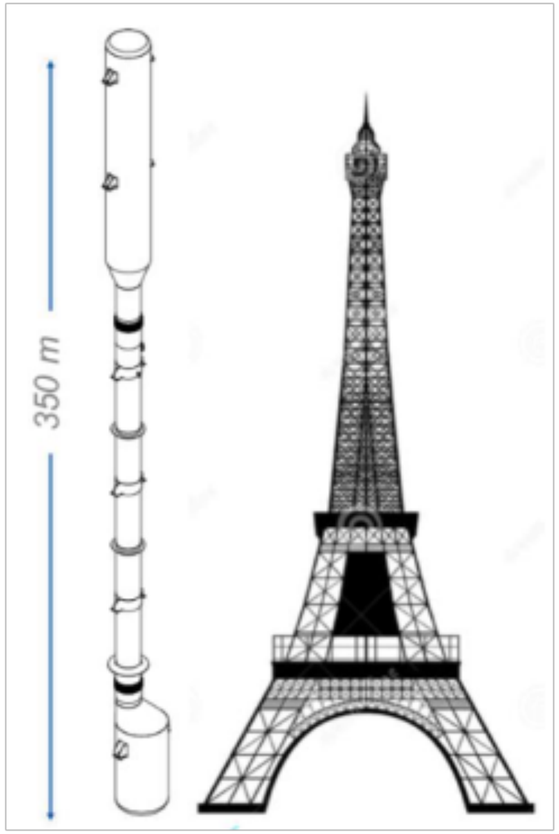
Underground Argon production

Enters Urania

- Company Kinder-Morgan extracts gas from subsoil, **DarkSide takes the argon** and returns the rest
- CO_2 well in Cortez, **Colorado**, USA
- **Industrial** scale extraction plant
- UAr **extraction** rate ~300 kg/day
- **Purity** 99.99%
- Plant assembly in progress

Underground Argon purification

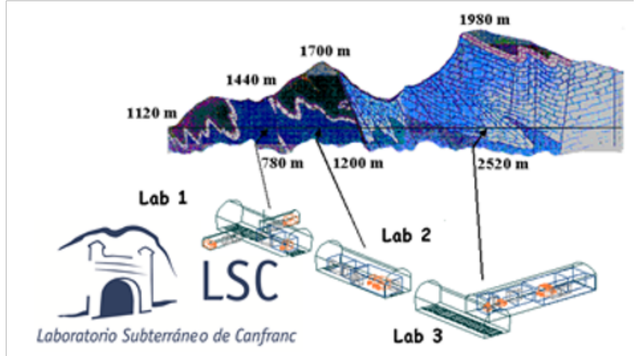
Enters Aria

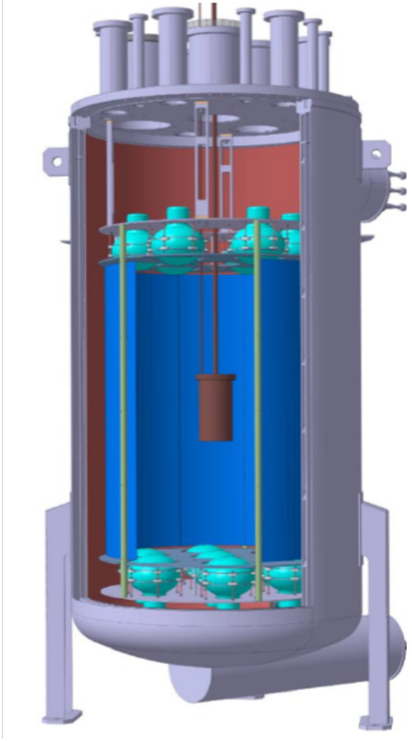


- Plant in **Sardinia**, Italy
- Cryogenic **distillation** column,
  350 m total height, 28 central modules
- Chemical production **rate** ~1ton/day
- First module **operated** according to specifics with nitrogen in 2019
  - *Eur. Phys. J C 81 (2021) 359*
- Runs completed with **Ar** at the end of 2020
  - *Eur. Phys. J C 83 (2023) 453*

Underground Argon characterization

Enters DArT in ArDM

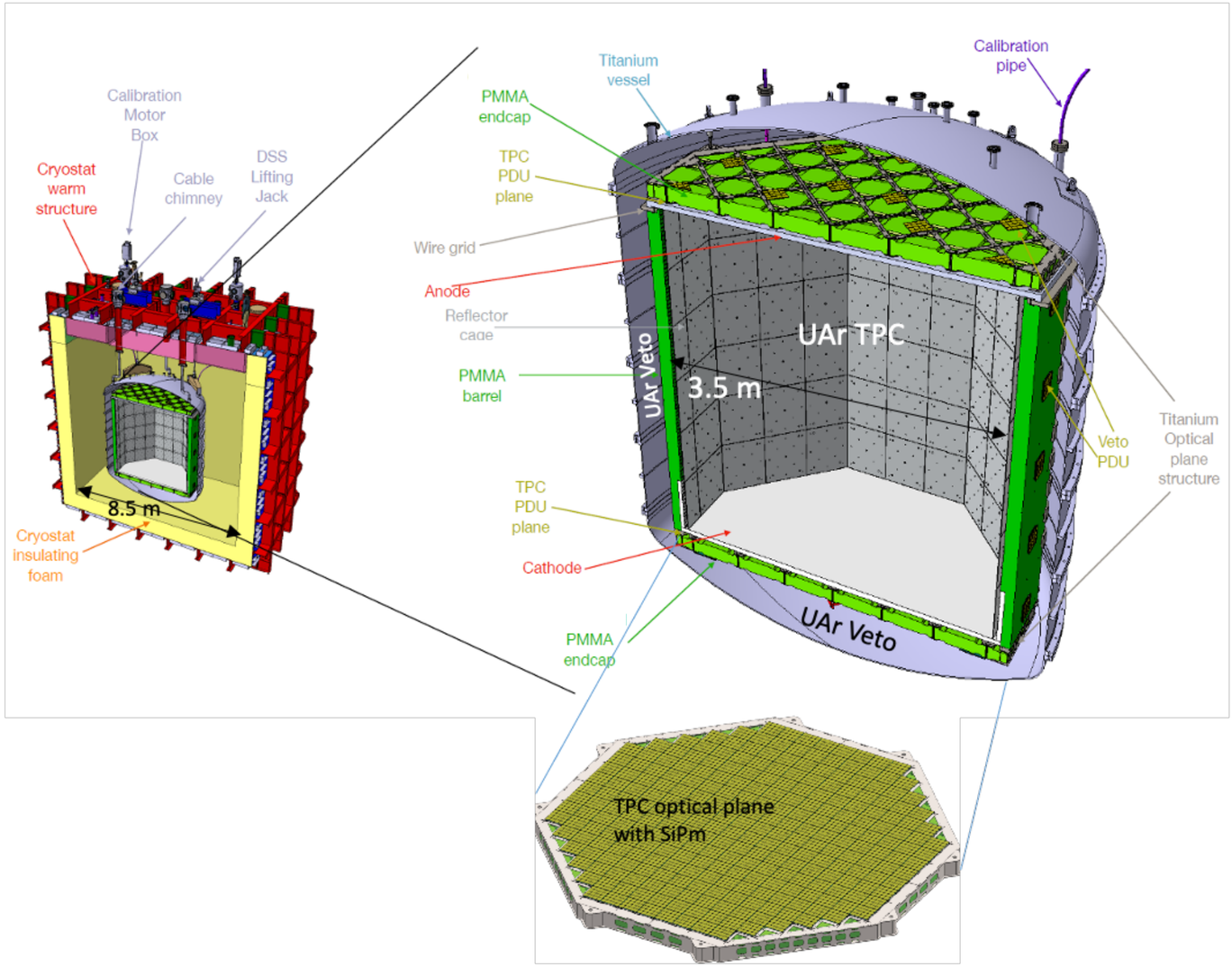




- DArT in **LSC**, Spain (~2500 mwe)
- Single phase **TPC** 1.4 kg **for UAr**, **inside** 2 ton total single phase TPC (ArDM)
- DArT 2 x 1cm^2 **SiPMs**, ArDM 2x12 cryogenic low background **PMTs**
- 50 cm passive neutron **shield** (Poly, 20 ton)
- ^{39}Ar depletion sensitivity 6x10^4 *JINST 15 (2020) P020024*

DarkSide-20k design

The inner TPC and its neutron Veto



Two phase LAr TPC

50 ton (20 ton FV) **UAr**

21 m^2 **cryogenic SiPMs**

Inner TPC surrounded by a single phase LAr **neutron Veto** detector

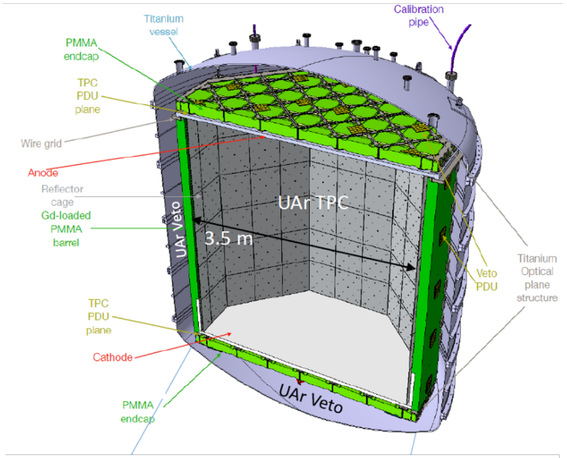
Integration of inner TPC + veto in a single object

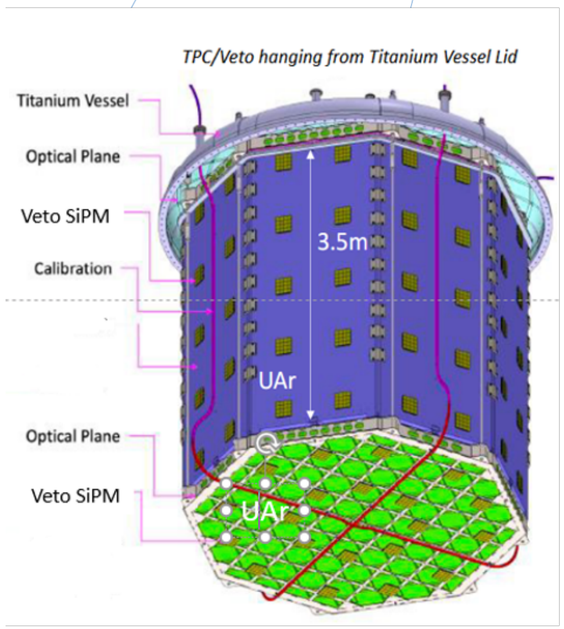
99 ton total UAr in a vessel

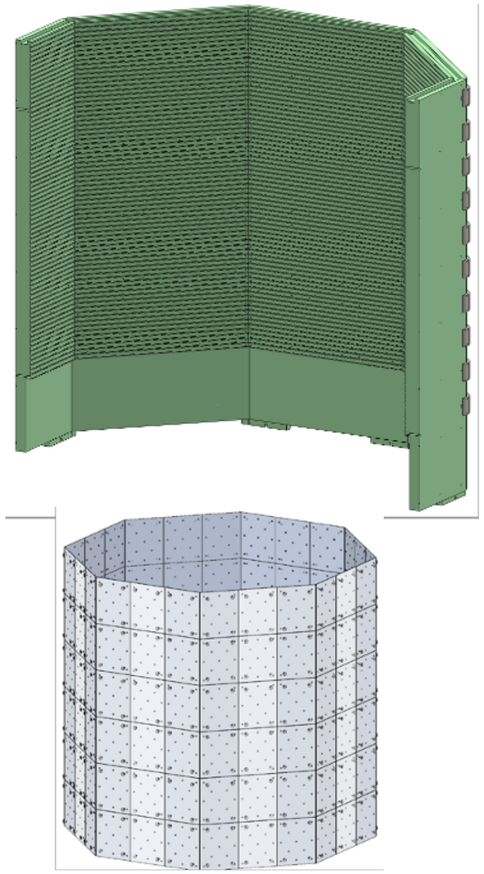
Within ~650 ton AAr membrane cryostat ProtoDUNE-like instrumented as muon veto

DarkSide-20k design

The inner TPC







Max **drift** length 348 cm

Electron drift **lifetime** > 5 ms

Gas pocket 5.0 +- 0.7 mm

Drift field 200 V/cm,
extraction field 2.8 kV/cm

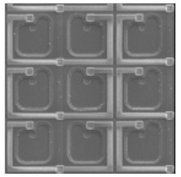
TPC **anode** and **cathode**
transparent pure **acrylic**
covered with **Clevios** (conduction)
and **TPB** (wavelength shifter)

Reflectors in the inner and outer walls

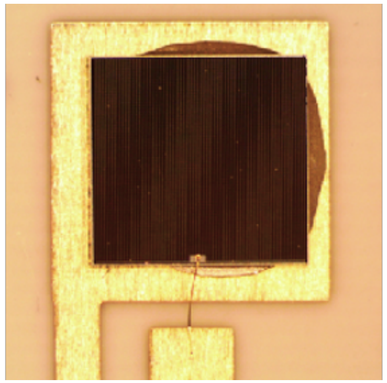
S1 ~10 pe/keV, **S2** > 20 pe/keV

DarkSide-20k Photosensors

Development of large area cryogenic radiopure SiPMs

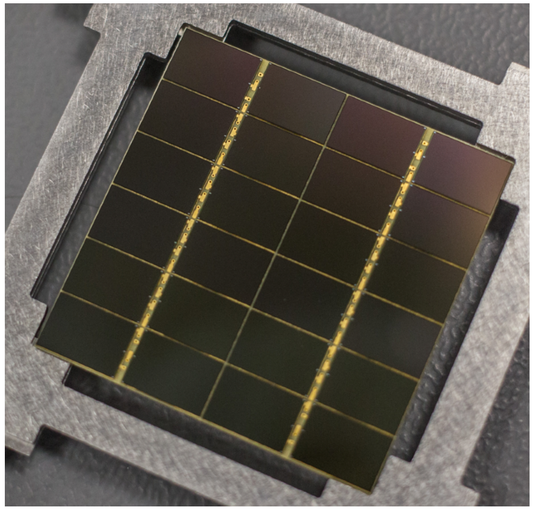


Single SPAD
~25 μm²



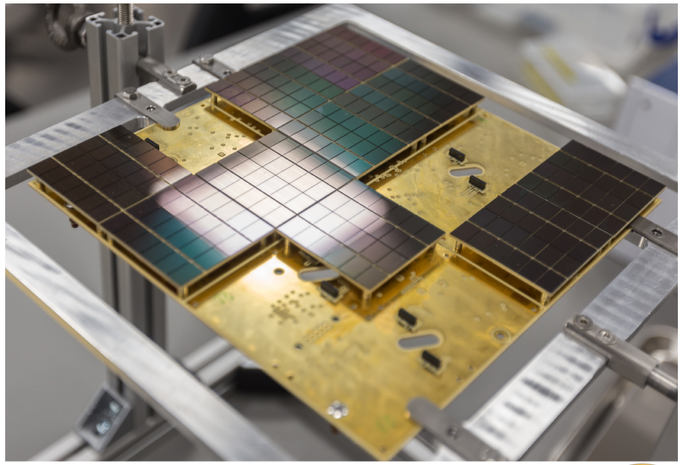
Single SiPM ~1 cm²

> 8000 PDMs (+2000 in the veto)
21 m² (inner TPC) + 5 m² (veto)
Mass production of the raw **wafers** at **LFoundry** (Italy)
Assembling facility **NOA** at **LNGS**
Other assembling facilities for veto in UK
Testing facility in **Napoli**



PhotoDetector module (Tile)
matrix of 24 SiPMs ~5x5 cm²

PhotoDetector Unit
matrix of 16 Tiles



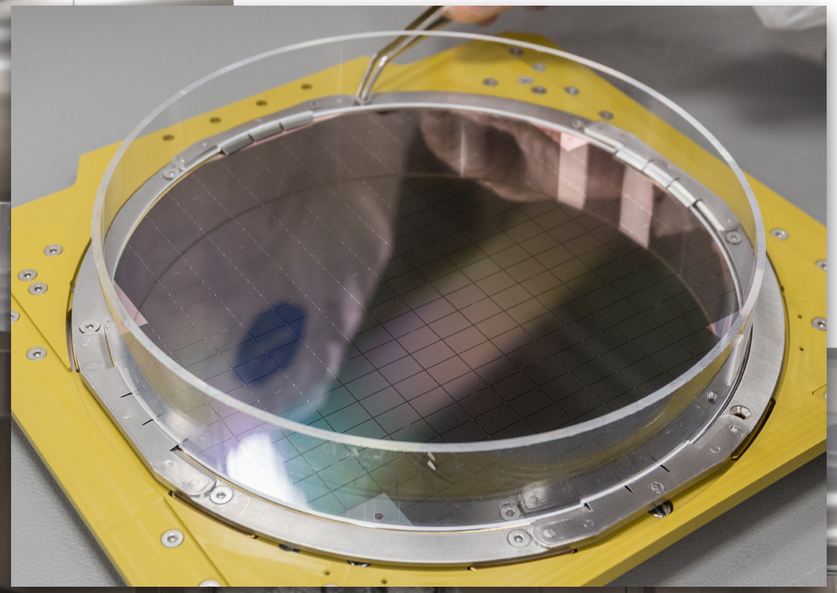
Radiopure ~2mBq/PDM dominated by substrate and PCB
High **PDE** (~45%) >90% fill factor
Gain ~ 10^6
Dark Count rate at 87 K < 5 cps/PDM
Time **resolution** ~10 ns
Low power consumption < 100 μW/mm²

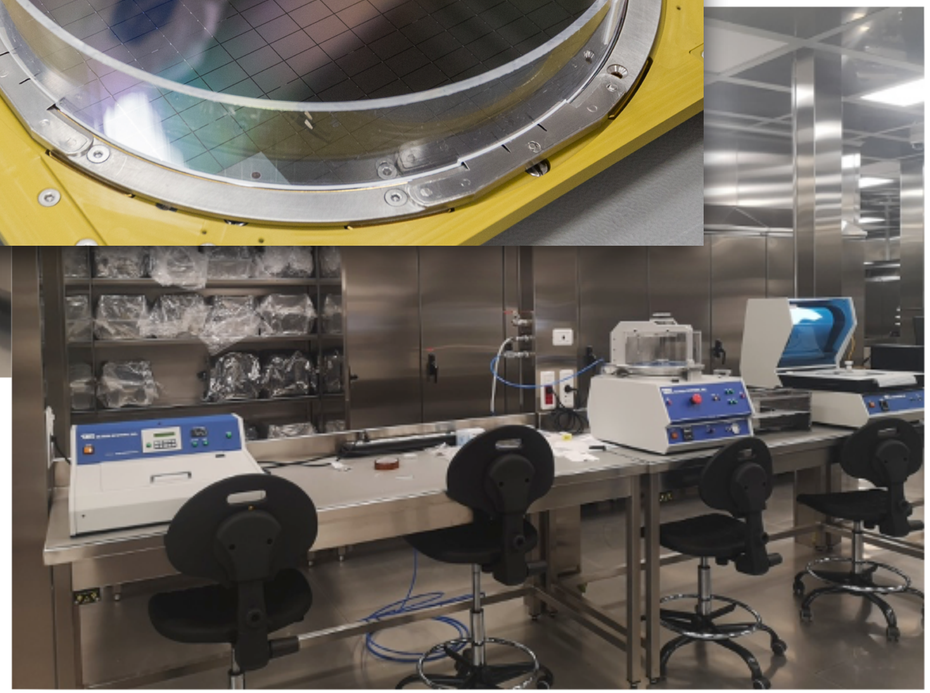
DarkSide-20k NOA Facility

Wafer level testing and handling

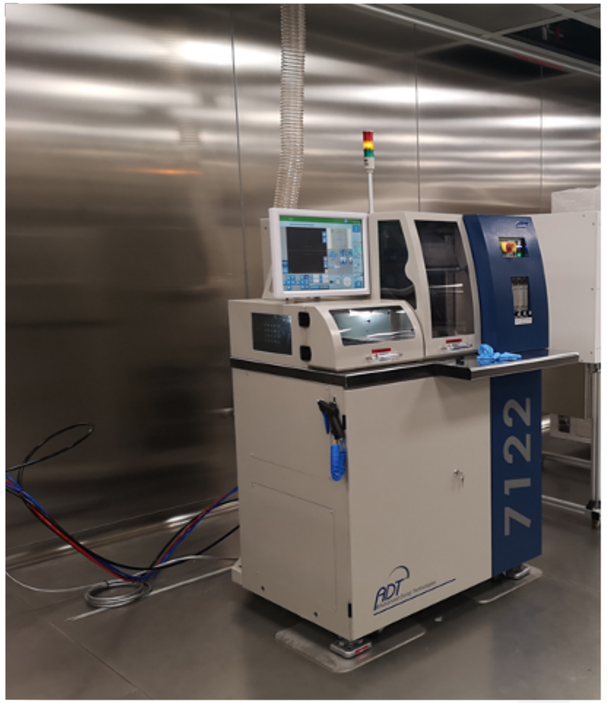
CryoProbe (FormFactor)
test single SiPMs in wafer

Wafer
with ~200 SiPMs





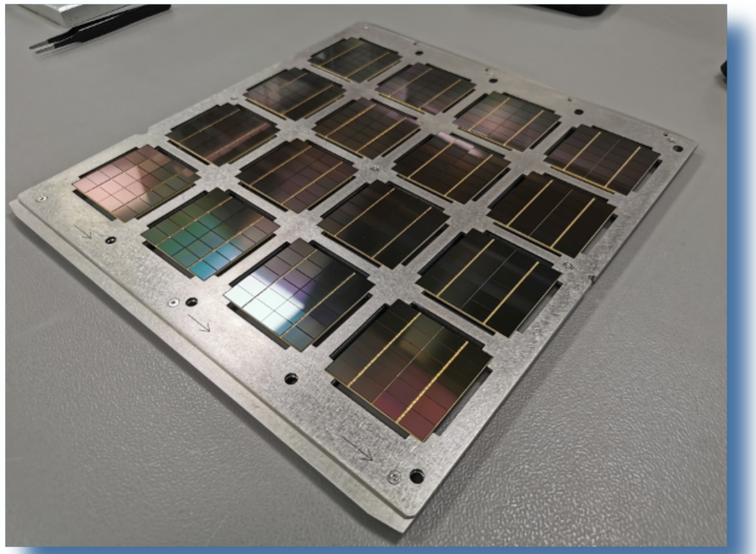
Handling and packaging tools
Frame Mounter, Die Expander, Dicer



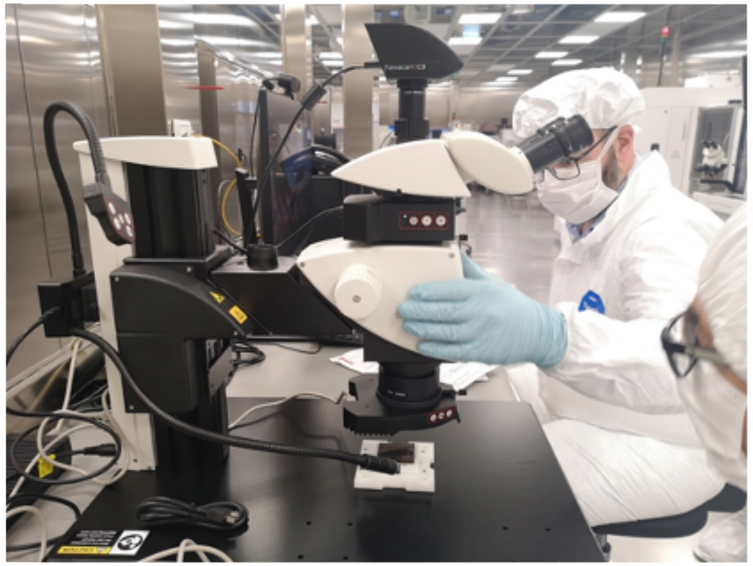
DarkSide-20k NOA Facility

Photosensor assembly

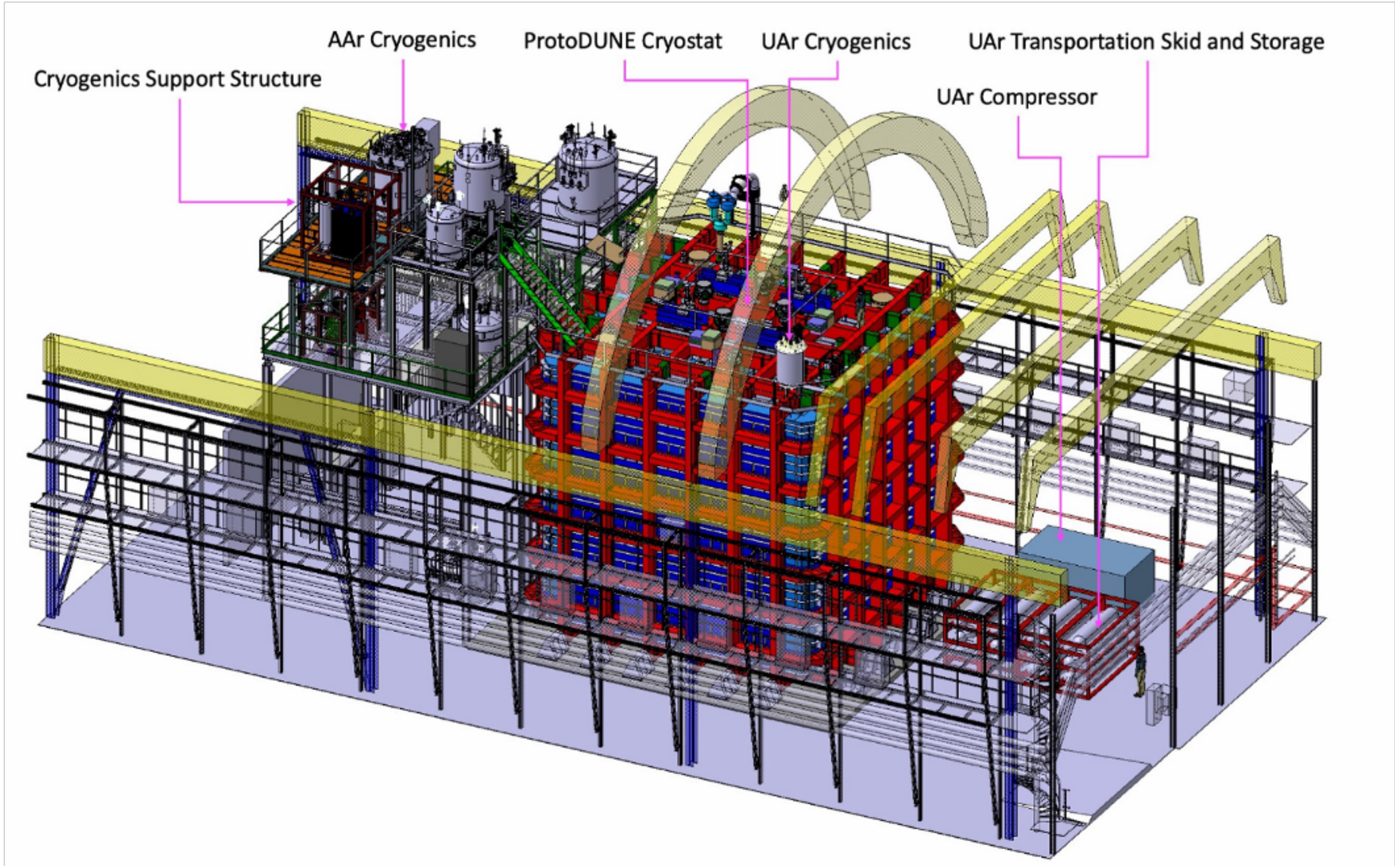
Flip Chip Bonder (Amicra)
Tiles of 24 SiPMs are assembled



Wire Bonder (Hesse)
Microscopes for Optical Inspection

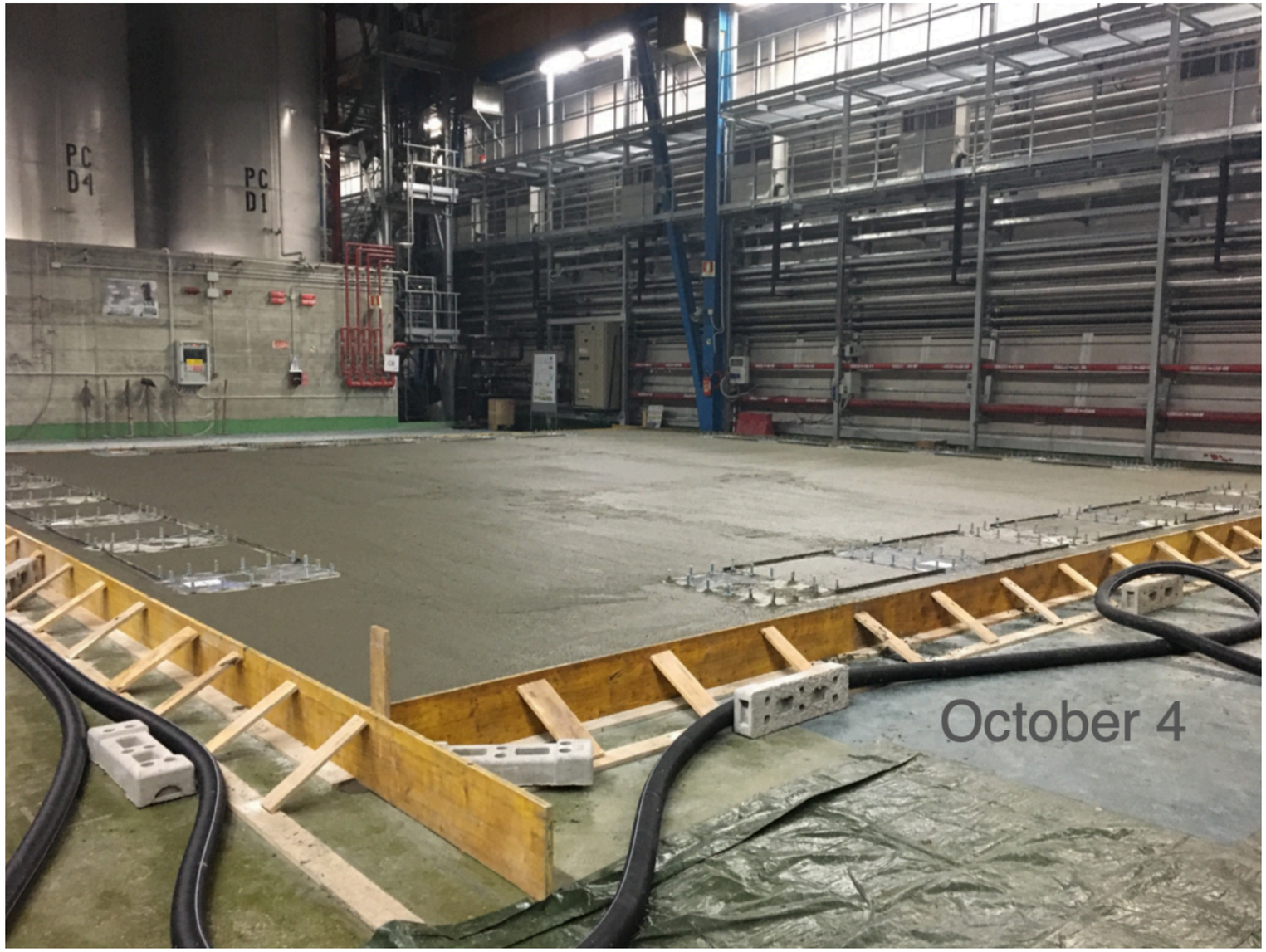


The DarkSide-20k facility at LNGS



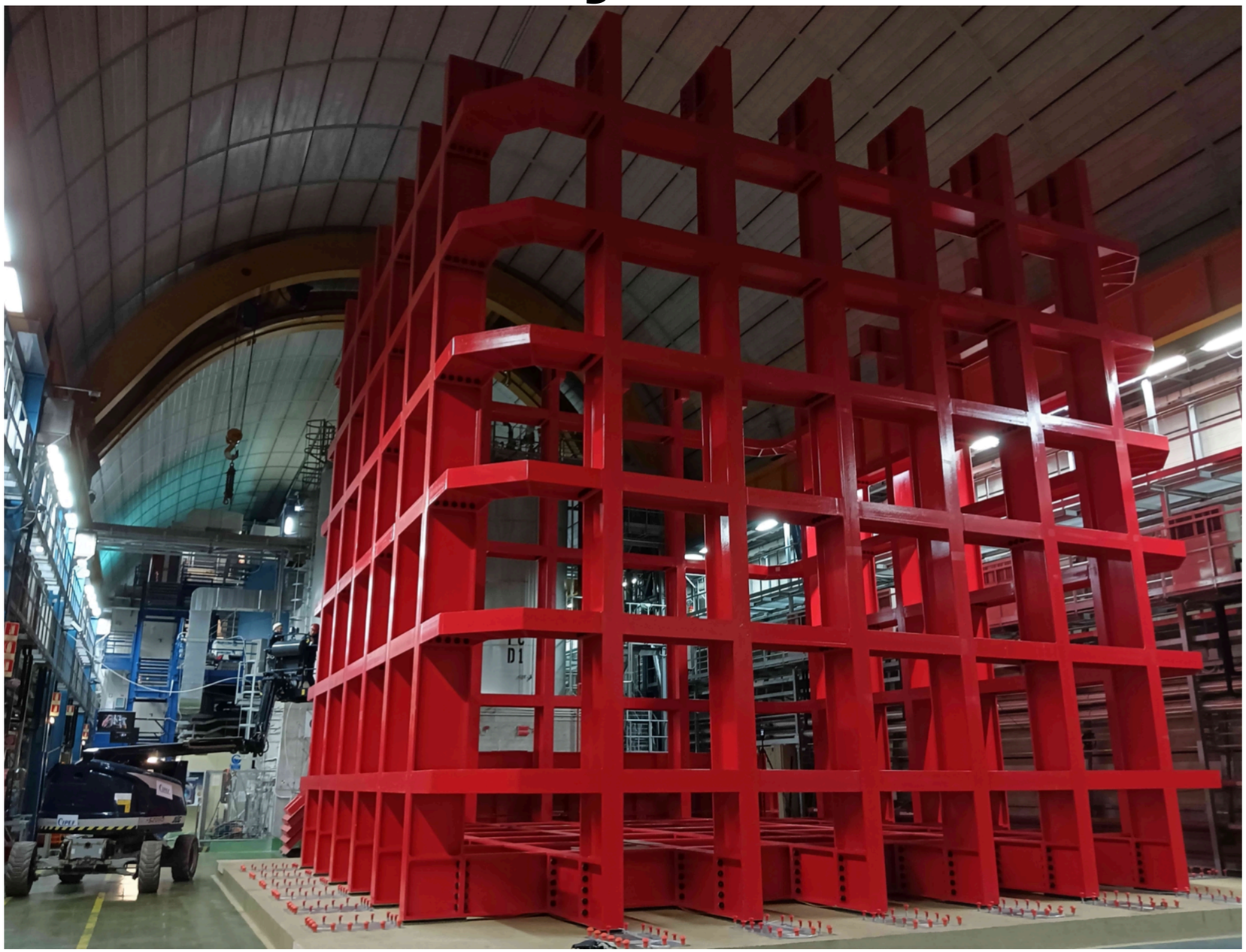
The DarkSide-20k facility at LNGS

October 2022



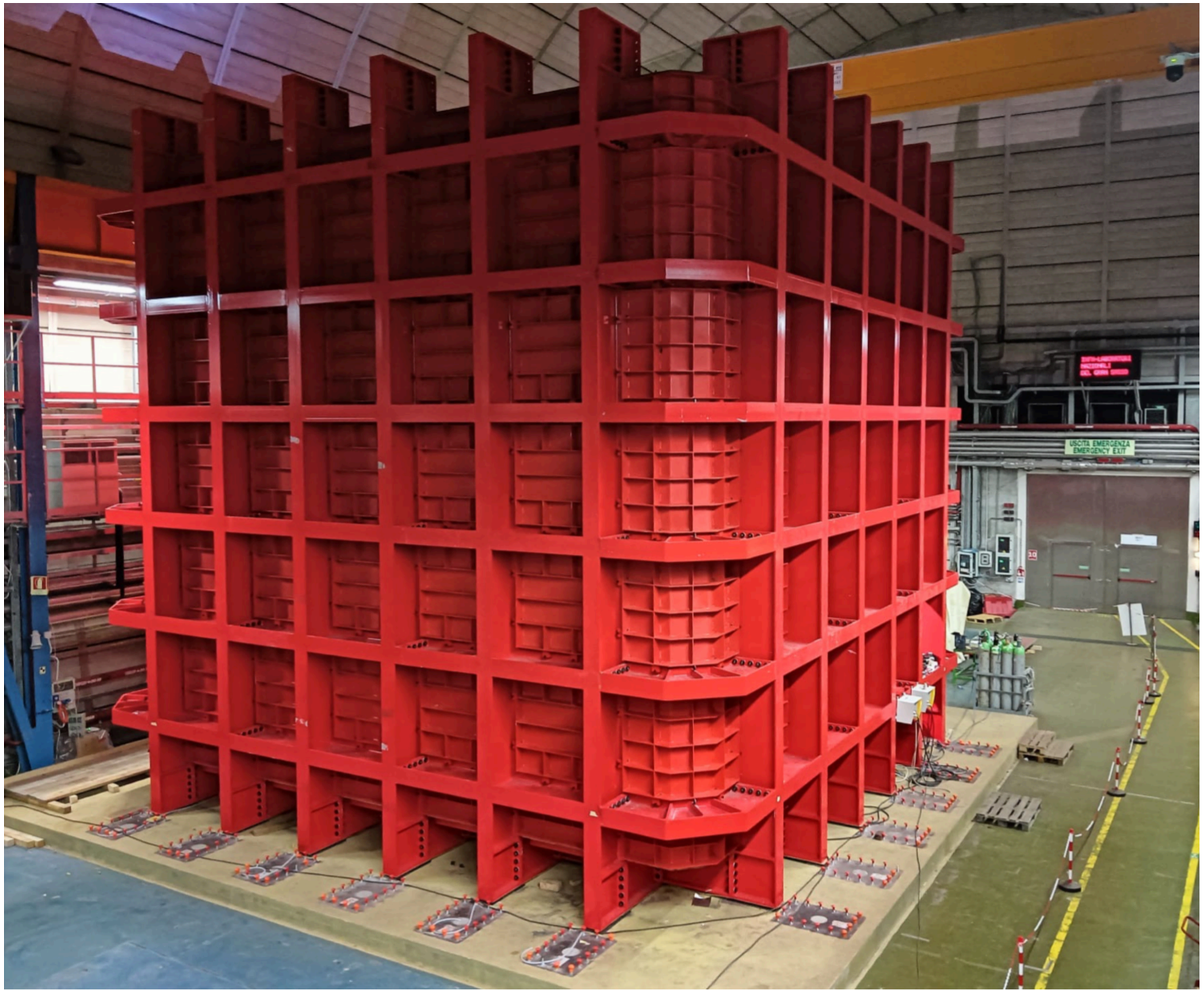
The DarkSide-20k facility at LNGS

June 2023



The DarkSide-20k facility at LNGS

August 2023



Outlook

- Argon has **outstanding background rejection** capabilities for WIMP dark matter direct searches
- Joint **global expertise** in the Global Argon Dark Matter Collaboration
- Technological **breakthrough** in photosensors, underground argon procurement, and distillation - R&D completed
- **DarkSide-20k construction started at LNGS!**
- Production of photosensors ongoing
- **Underground Argon** filling expected in 2027