The DarkSide experiment for direct dark matter search with liquid argon

Alexander Kish
University of Hawaii

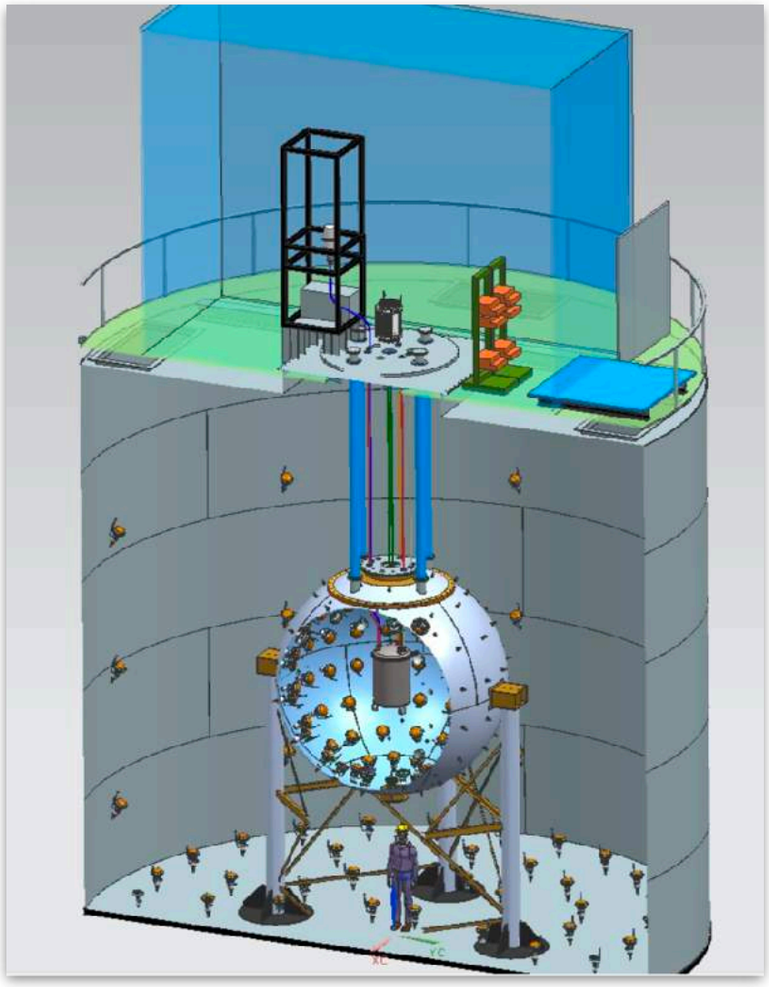
on behalf of the DarkSide collaboration

3rd South American Dark Matter Workshop, December 3, 2020

Outline

- DarkSide-50 (DS-50) dual-phase argon TPC and its latest physics results
- Status of the DarkSide-20k (DS-20k) experiment and associated R&D
- Global Argon Dark Matter Collaboration (GADMC) and ARGO
- Coherent neutrino-nucleus scattering (CEνNS) and sensitivity of the future large argon TPCs to core-collapse supernova neutrinos

The DarkSide-50 Experiment

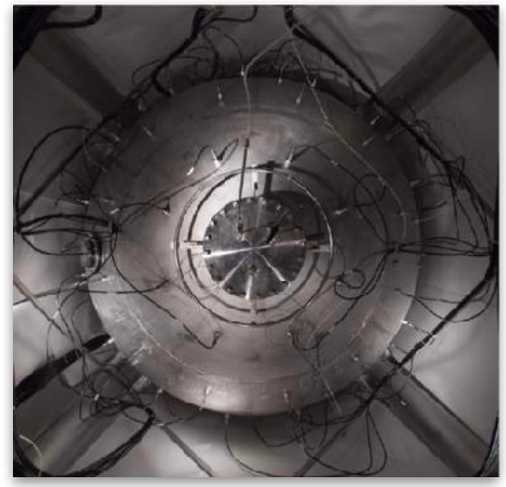


Water Cherenkov detector

- stainless steel cylinder (D 11m, H 10m)
- 1kT of ultra-pure H_20
- 80 PMTs (8”)

→ passive shield for external radiation

→ active veto for muons



Liquid scintillator detector

- stainless steel sphere (D 4m)
- 30t of ^{10}B-loaded liquid scintillator
- 110 PMTs (8”)

→ active gamma and neutron veto

Inner argon TPC

- PTFE cylinder with 46kg LAr target
- 38 Hamamatsu PMTs (3”, R11065)
- TPB-coated inner surfaces
- fused silica diving bell with 1cm gas pocket
- transparent silica cathode and anode coated by ITO (indium tin oxide)

DarkSide-50 TPC

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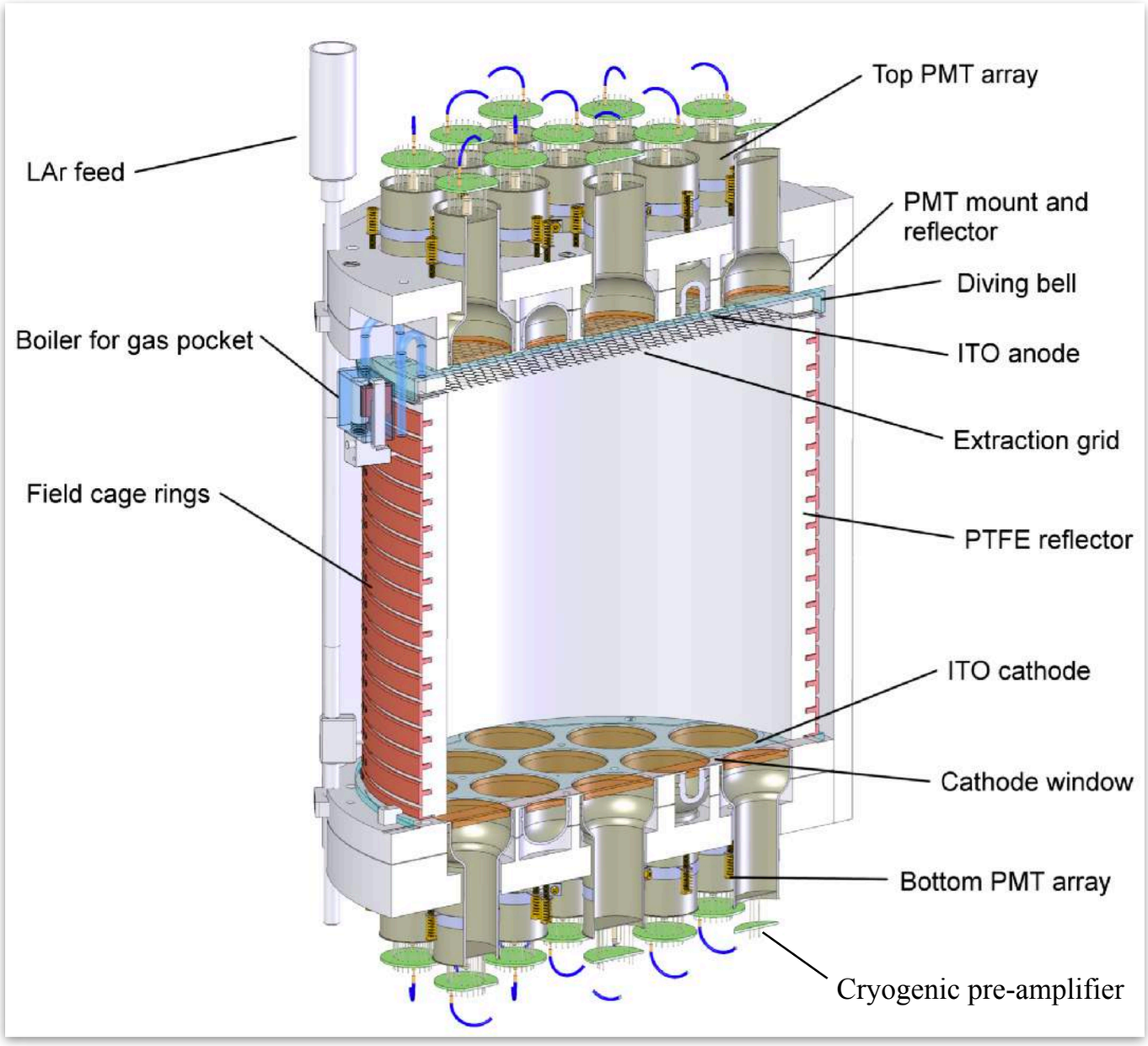


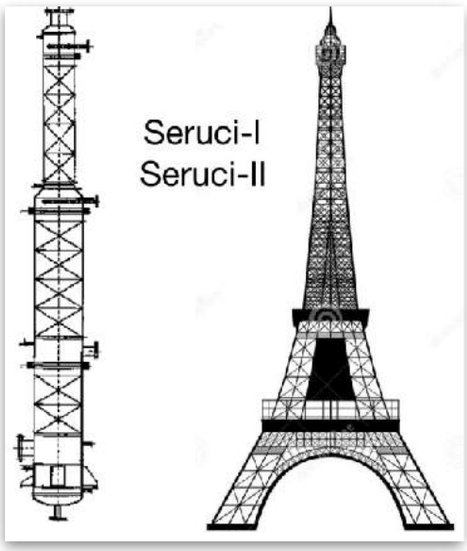
Underground Argon

Production
URANIA – Colorado, USA

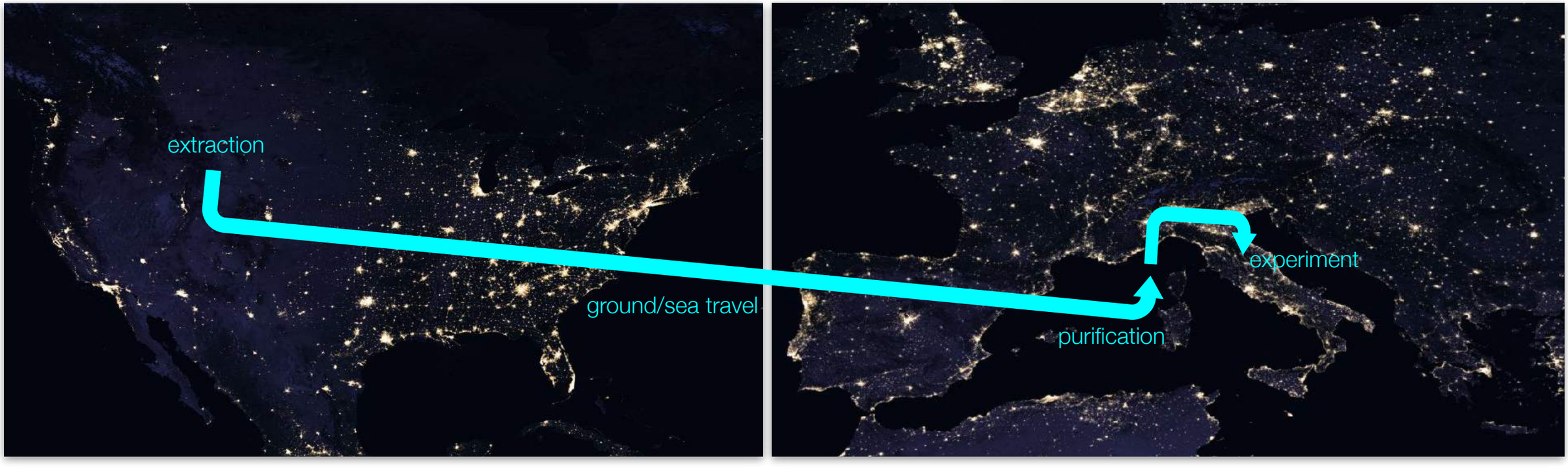
- Underground argon extraction (purity 99.9%, 250 kg/day)

Purification
ARIA – Sardinia, Italy

- Distillation with a 350m tall column (~tonne/day)
- Isotopic separation of ^{40}Ar and ^{39}Ar



- Factor 1000 reduction of chemical impurities



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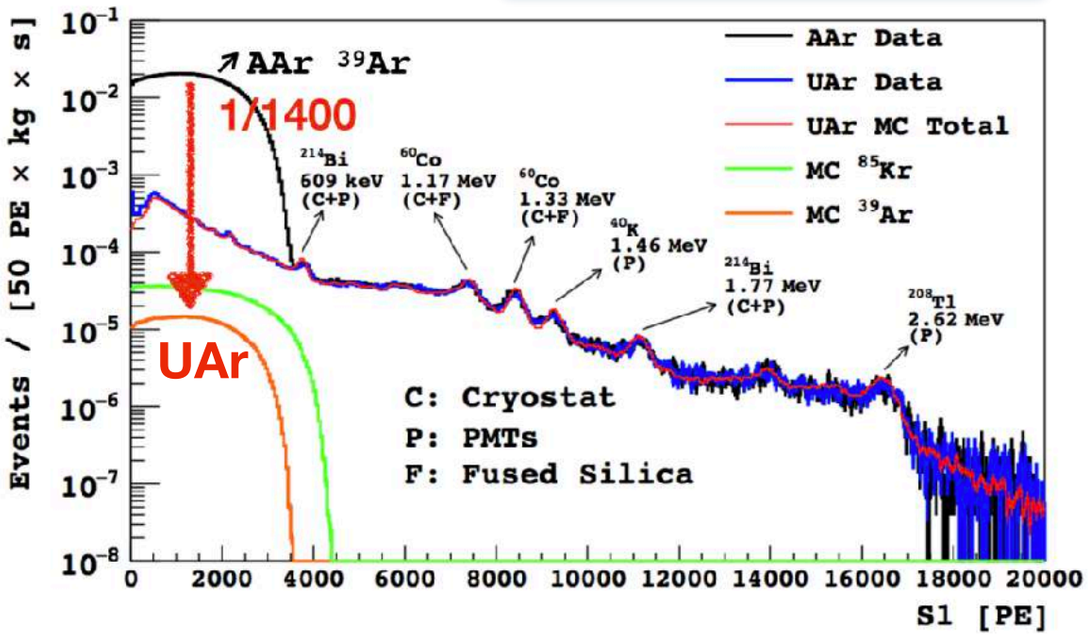
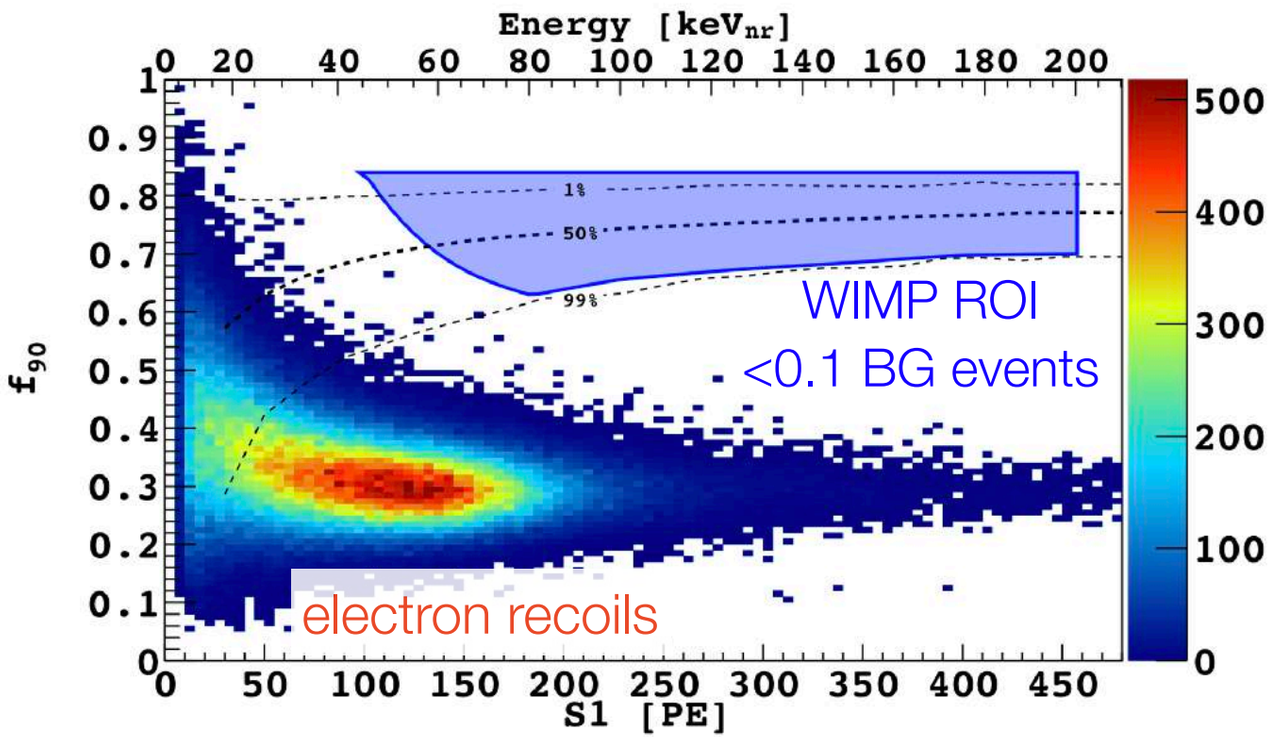
DarkSide-50 WIMP search

PRD 93, 081101 (2016)

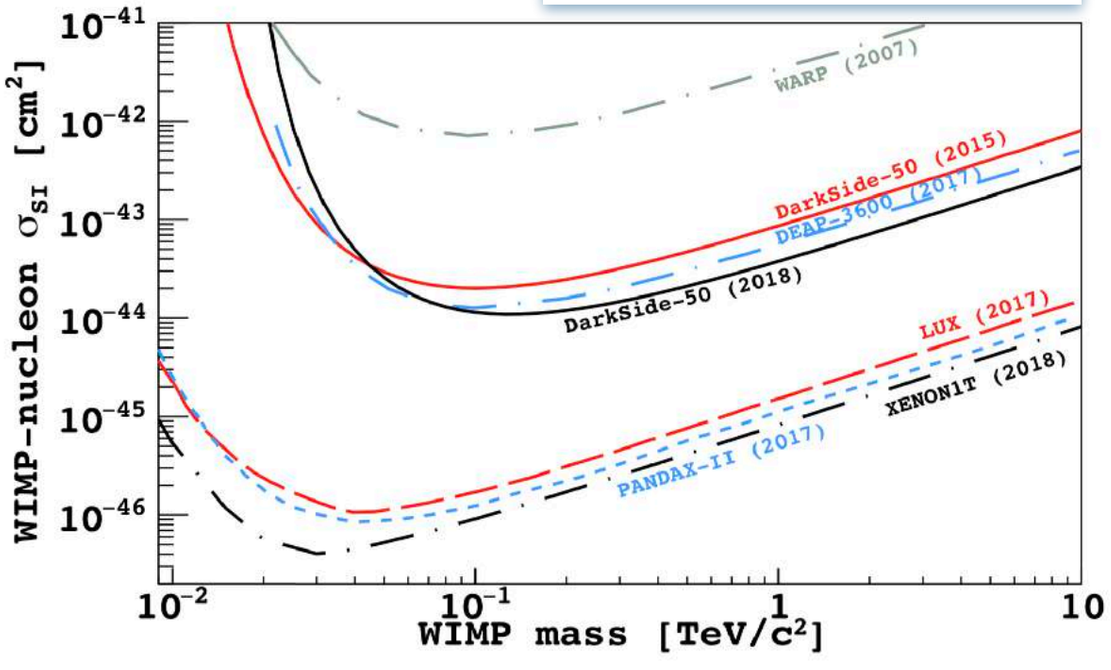
PRD 95, 069901 (2017)

- Underground argon (UAr): activity ~0.7 mBq/kg
- Light yield 8 PE/keV
- Exposure: 532 live days × 31.3kg = 16660 kg days
- Pulse-shape EM BG discrimination
- WIMP-nucleon SI $\sigma = 1.14 \times 10^{-44}$ cm^2 @100 GeV/c^2





PRD 98, 102006 (2018)



Low-mass WIMP searches with DarkSide-50

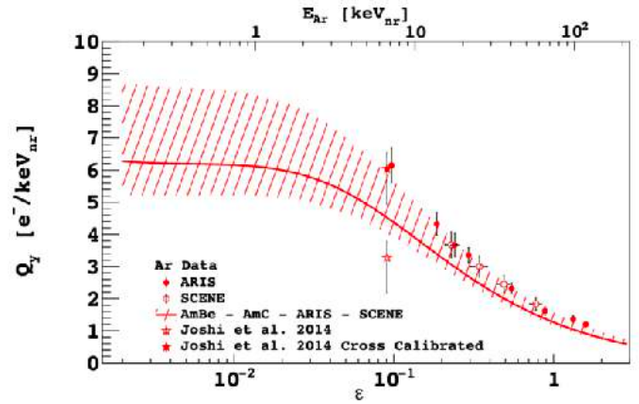
PRL 121, 081307 (2018)

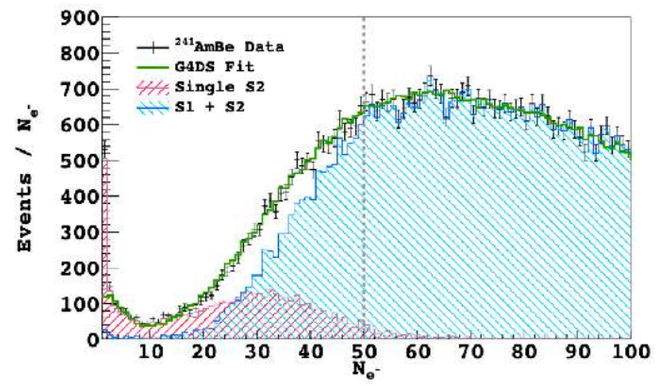
Low-mass WIMP search with ionization signal (S2)

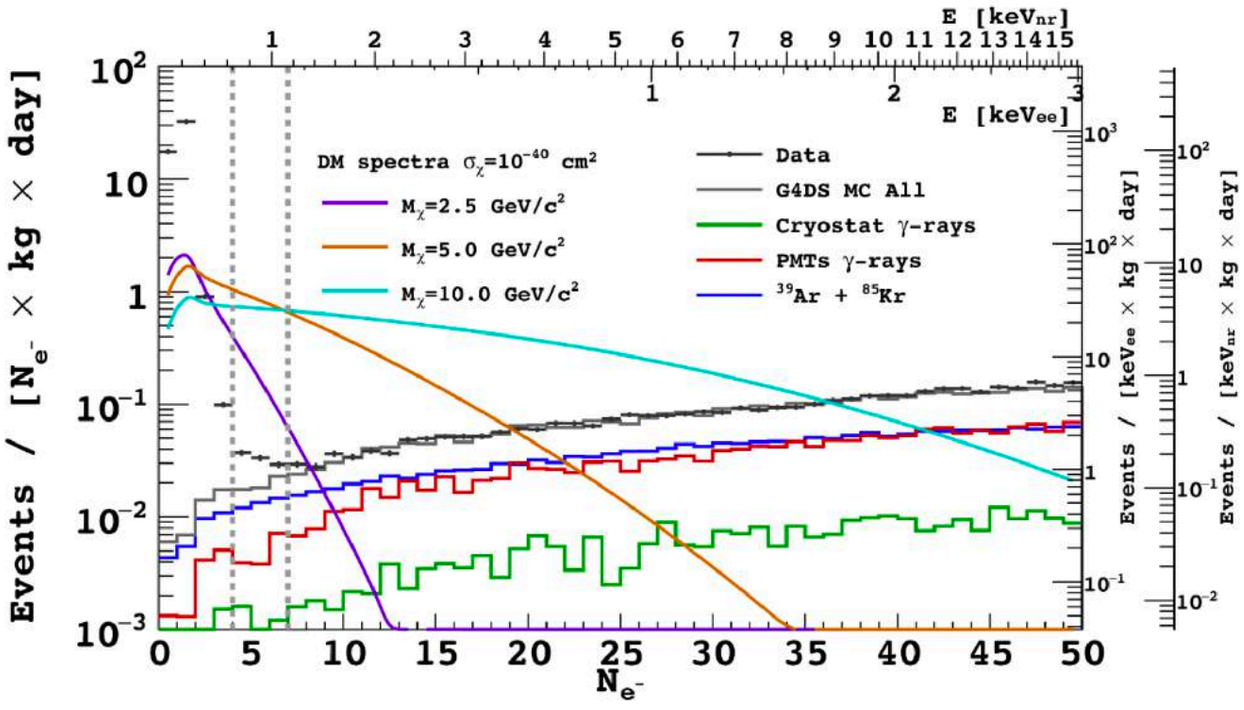
- search for very low energy nuclear recoil signals (WIMP mass range <20 GeV/c^2)
- low-radioactivity target with 6786 kg×days exposure

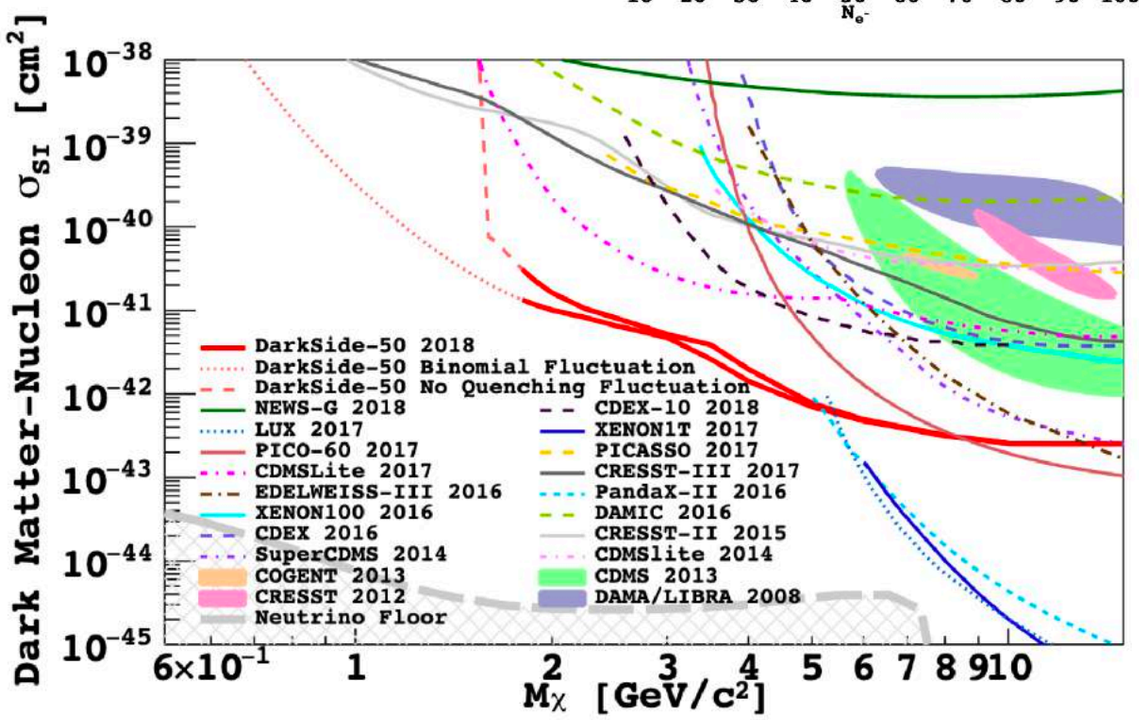
- full signal acceptance 0.1 keV_{ee}, analysis threshold 0.6 keV_{nr}
- measured event rate at 0.5 keV_{ee} is 1.5 events/kg/day

- best DM exclusion limit for 1.8–6 GeV/c^2 WIMP







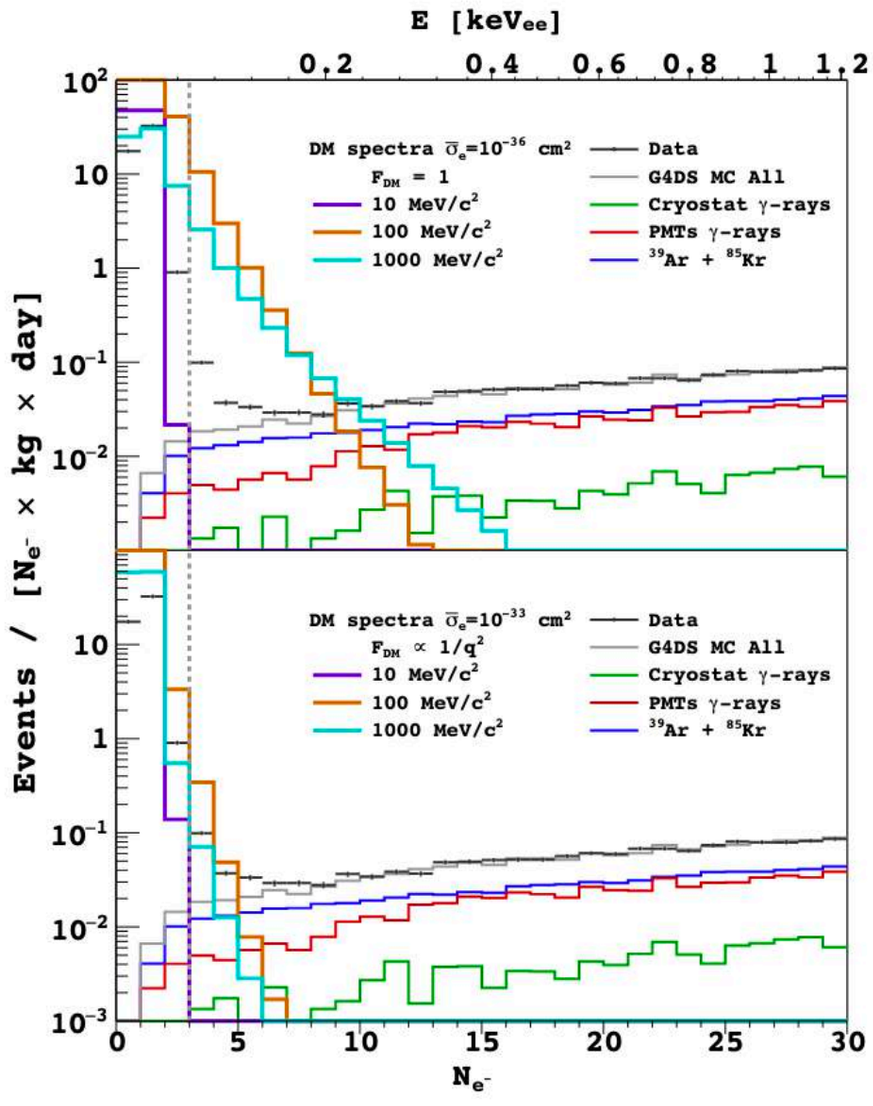


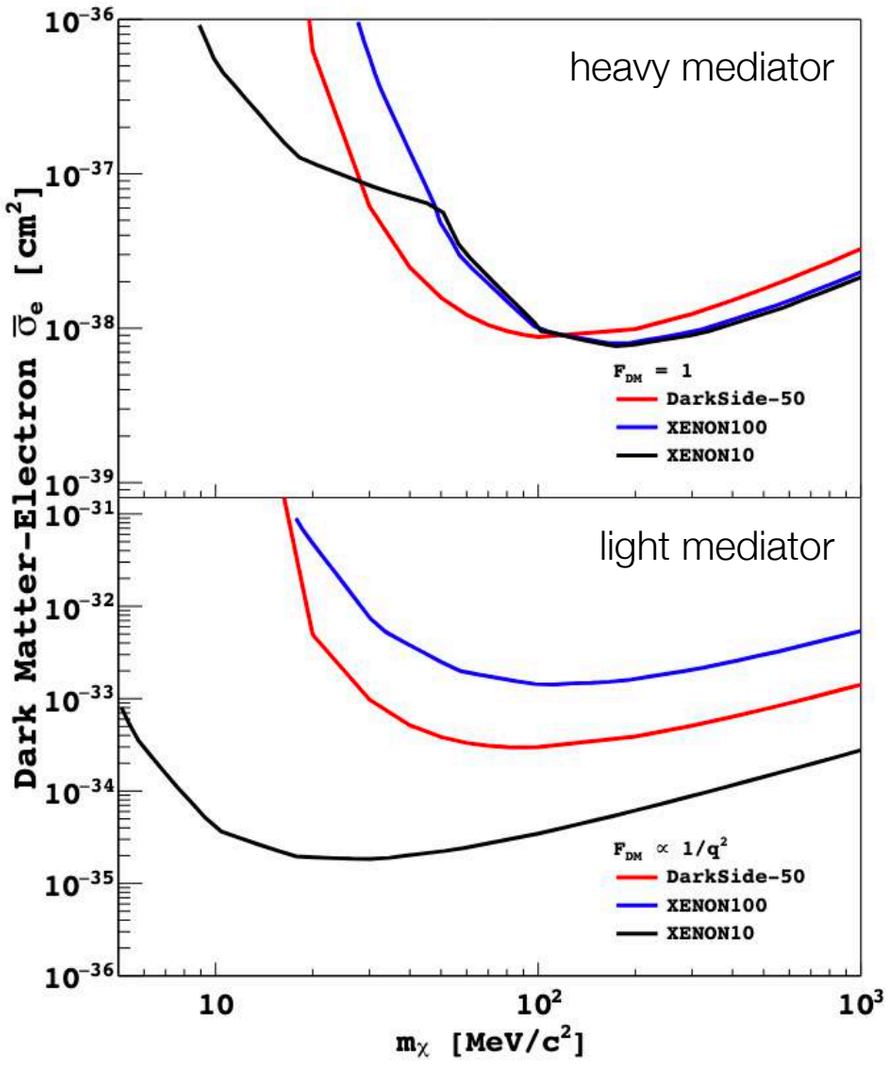
Low-mass Dark Matter Searches with DarkSide-50

PRL 121, 111303 (2018)

Dark matter – electron scattering

- search for light dark matter: interaction through a vector mediator with couplings weaker than weak scale
- analysis threshold 3 extracted electrons (~0.05 keV_{ee})
- improvement upon existing limits for momentum-independent scattering of DM particles with mass 30-100 MeV/c^2





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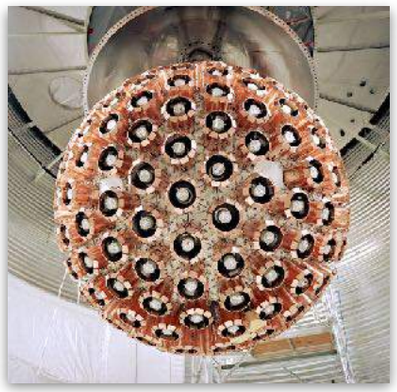
Global Argon Dark Matter Collaboration (GADMC)

- Joint expertise of several argon dark matter experiments

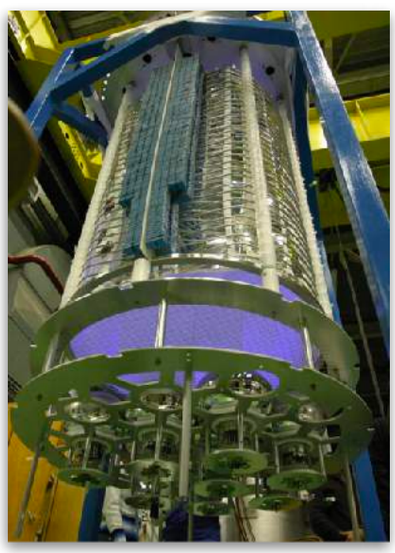
> 500 researchers from 83 institutions
two-step program

DarkSide-50

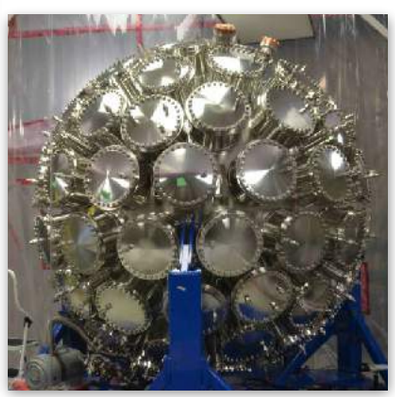
DEAP-3600



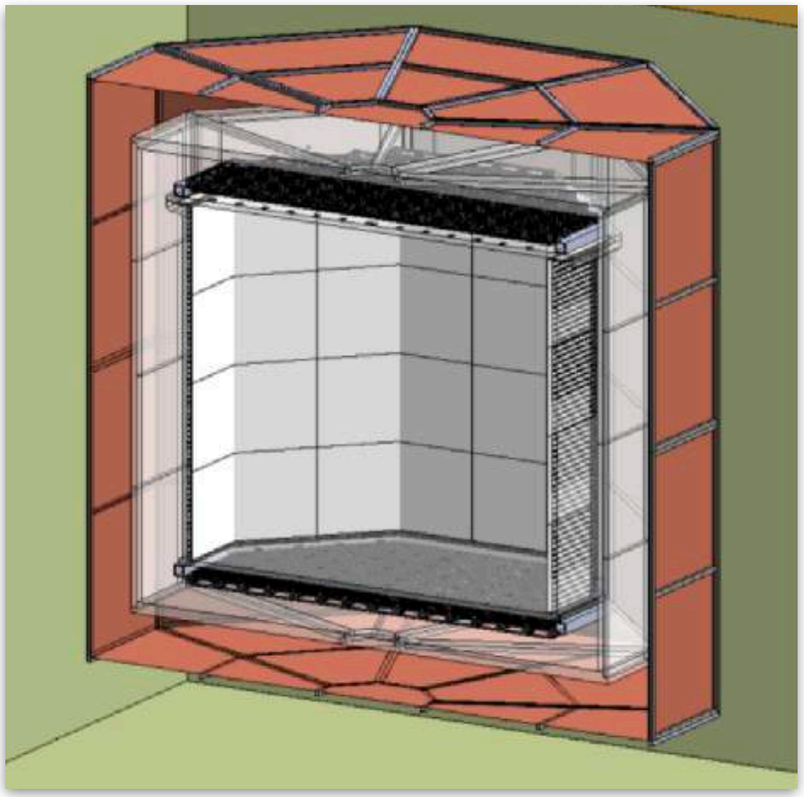
ArDM



MiniCLEAN



DarkSide-20k
(DS-20k)
from 2022 @ LNGS



ARGO

~300t TPC
@ SNOLAB
(from 2029)

50t underground LAr dual-phase TPC, 700t atmospheric LAr veto
→ sensitivity 1.2×10^{-47} cm^2 at WIMP mass of 1TeV/c^2
(with 100 tonne year exposure with a 20t fiducial mass)

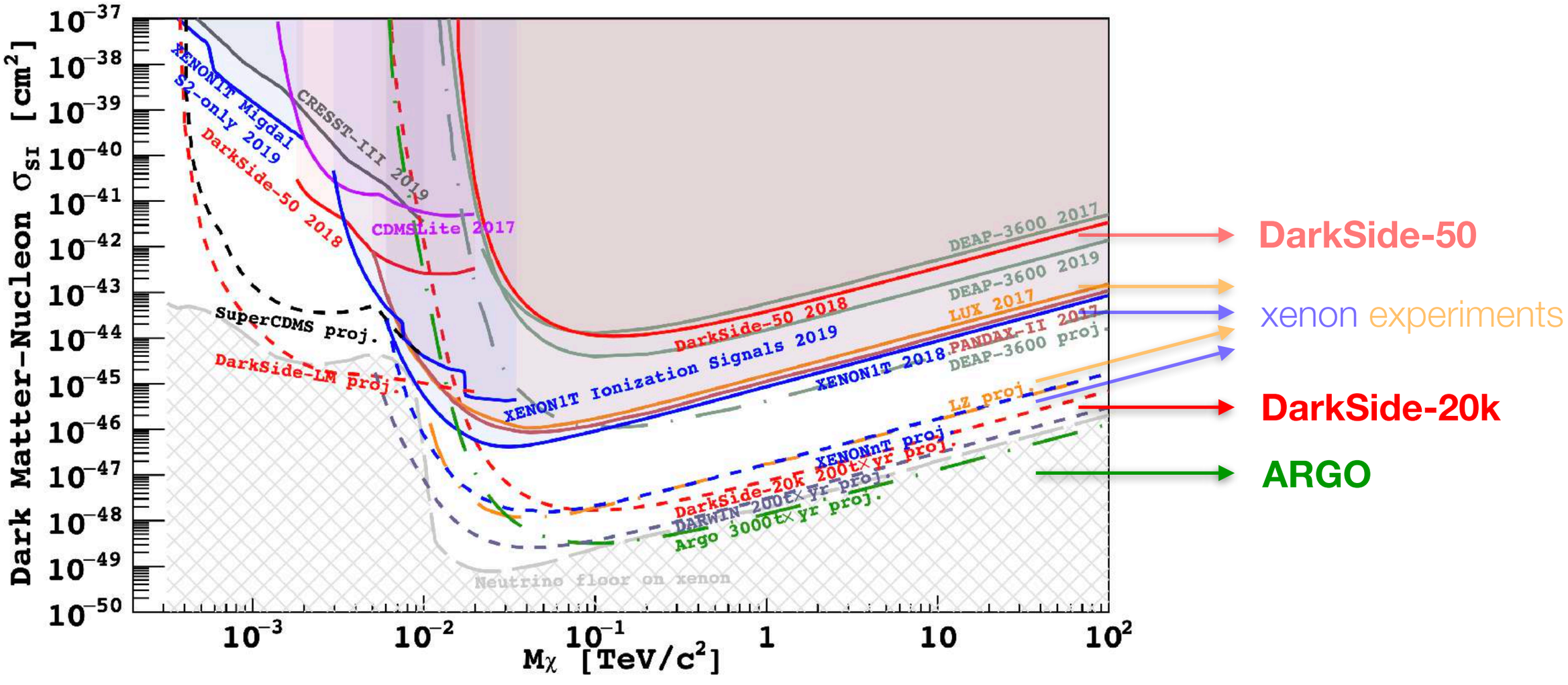
Projected Sensitivity

DarkSide-20k goals:

- increase exposure by 3-4 orders of magnitude
- the same total number of background events in full exposure (<0.1)

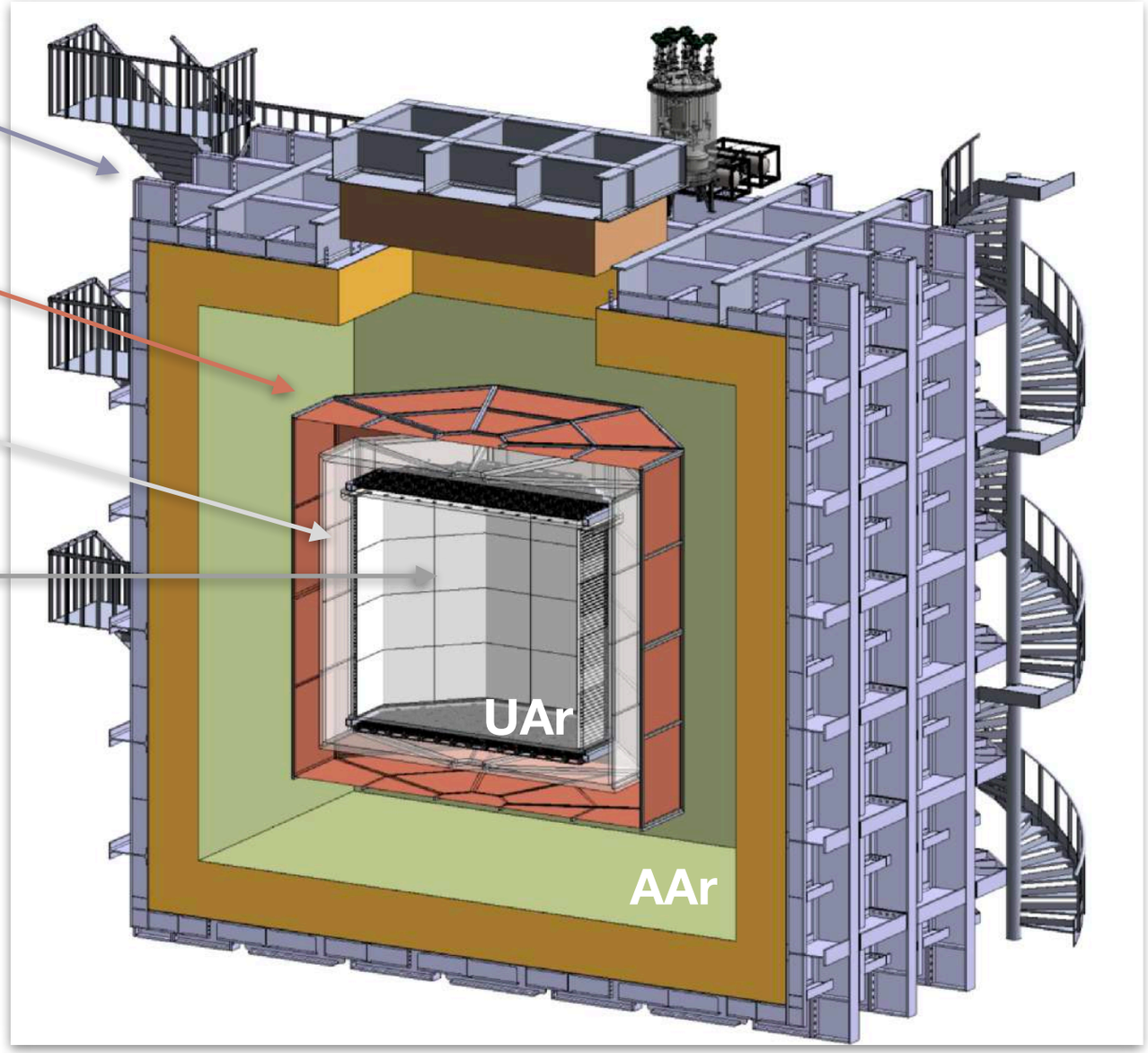
Requirements:

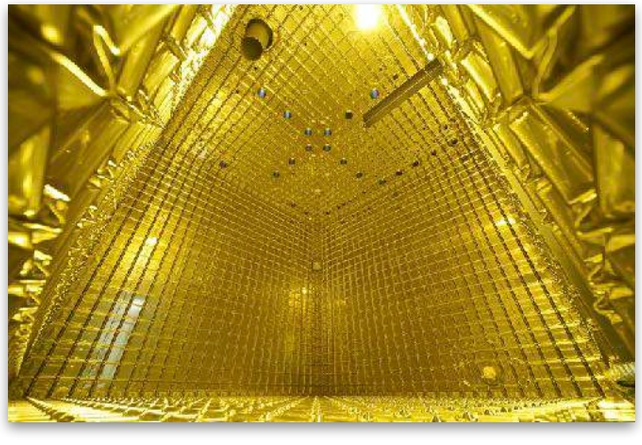
- lower contamination in all components
- efficient shielding and neutron veto
- photosensors optimised to work in liquid argon at 87K

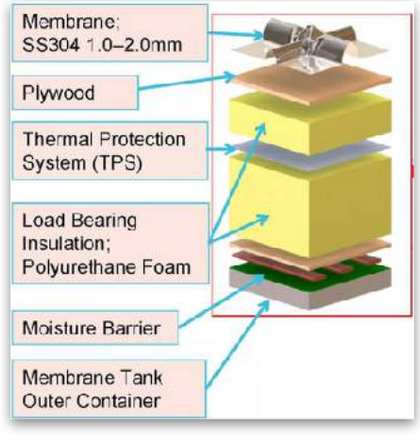


The DarkSide-20k Dark Matter Experiment

- ProtoDUNE-like membrane cryostat
- Optical and EM barrier (copper shell)
- Shielding and neutron veto with atmospheric argon and Gd-doped acrylic panels
- Octagonal sealed acrylic TPC with underground argon
- Separate cryogenic systems for atmospheric and underground argon volumes
- Silicon photomultiplier modules for light detection in the TPC and veto (~30m^2)

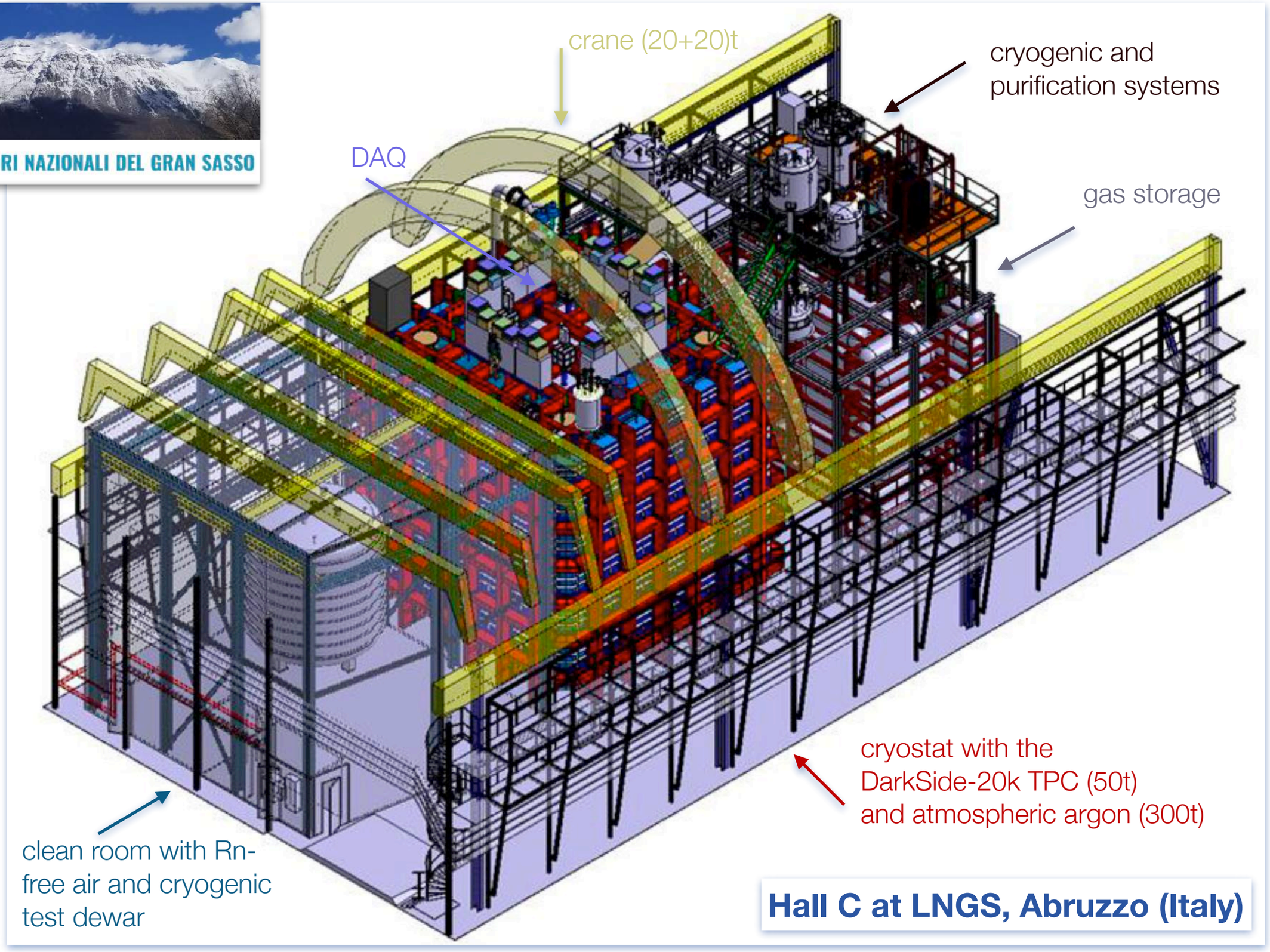






The DarkSide-20k Dark Matter Experiment

INFN LABORATORI NAZIONALI DEL GRAN SASSO

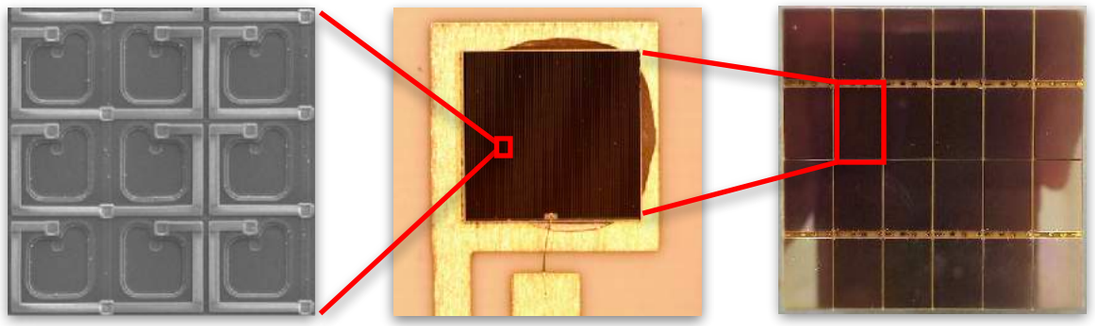


Hall C at LNGS, Abruzzo (Italy)

Photo Electronics for DarkSide-20k

- NUV-HD-Cryo

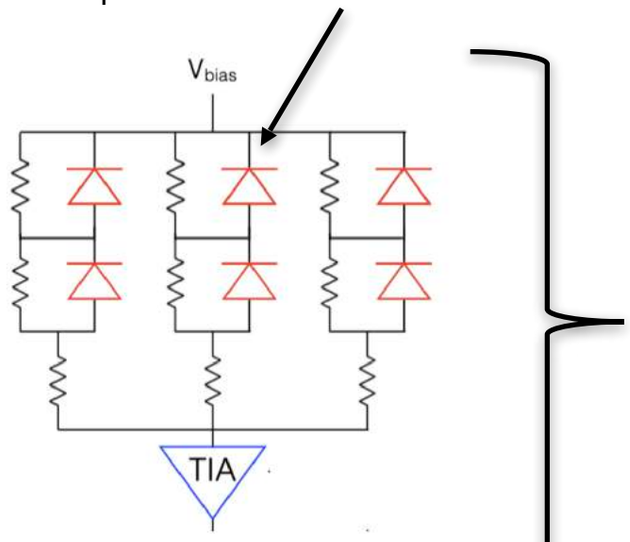
- Combined effort of the DarkSide members and Fondazione Bruno Kessler (FBK), Trento (Italy)



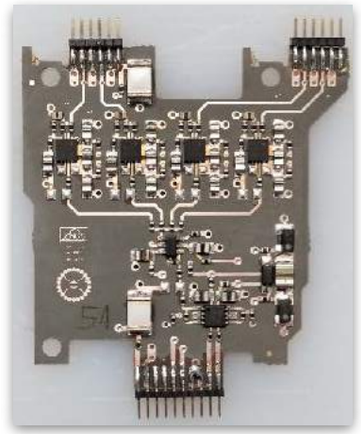
Individual SPADs
25-30 μm²

Single SiPM
~1 cm²

Single tile
(24 SiPMs, ~22 cm²)



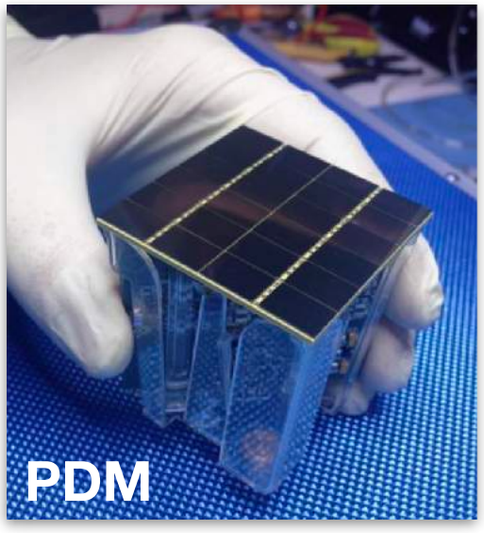
x4 then summed



Front End Board

PDM: PhotoDetection Module
- SiPM tile + front-board electronics in acrylic cage
- one summed readout channel

PDU: PhotoDetection Unit
- 25 PDMs with mechanical support structure
- base mechanical unit for DS-20k
- contains routing structure for power and signal readout



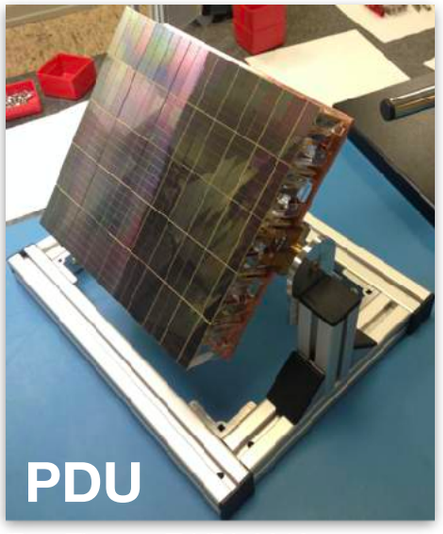


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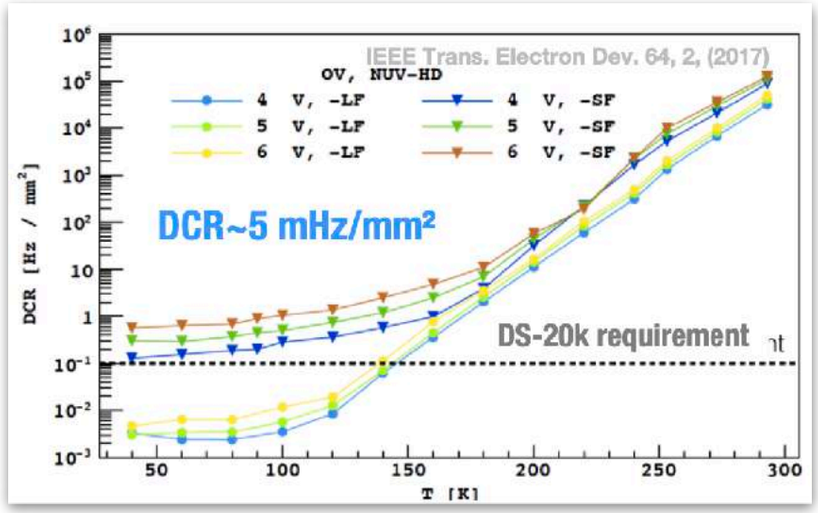
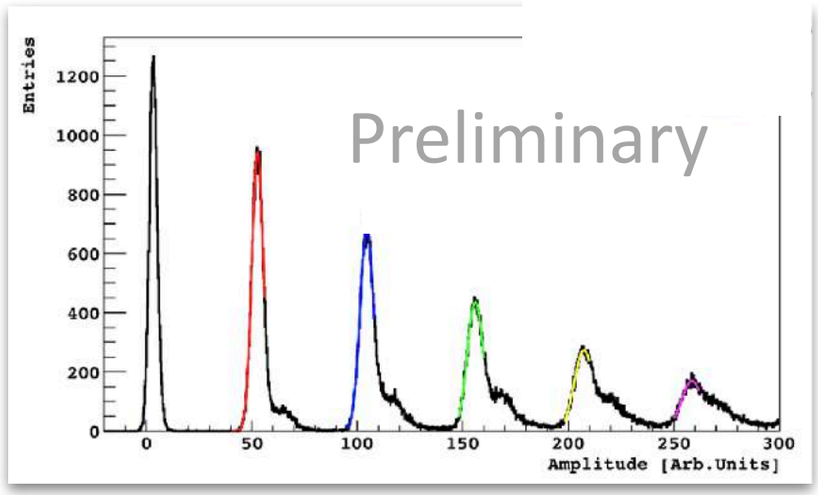
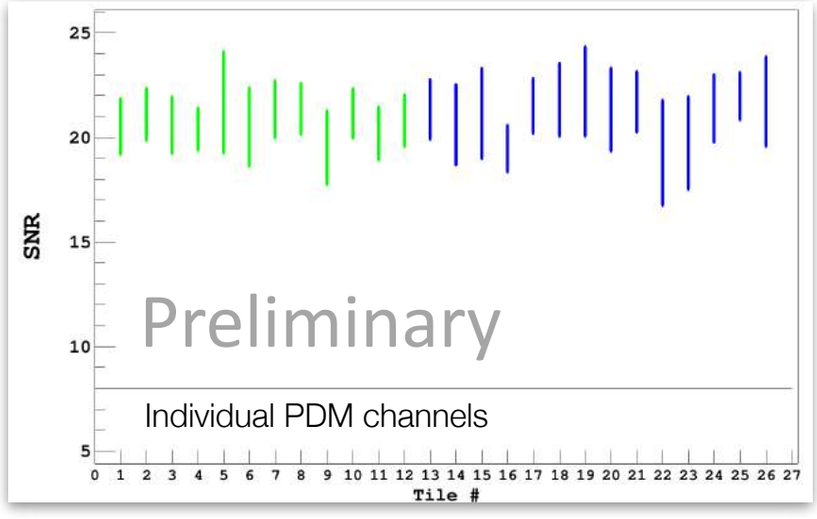
Photo Detection Module Performance

- Optimized for LAr temperature (~90K)
- Fill factor 90%
- Photodetection efficiency (PDE) ~50%
- Low dark-count rate <0.1 Hz/mm^2
- Timing resolution <10 ns
- Excellent single photoelectron resolution
- High signal-to-noise ratio
- Power consumption <100 μW/mm^2







IEEE Transactions on Electron Devices 64/2 (2017)

Cryogenic Characterization of FBK HD Near-UV Sensitive SiPMs

Fabio Acerbi, Stefano Davini, Alessandro Ferri, Cristiano Galbiati, Graham Giovanetti, Alberto Gola, George Korga, Andrea Mandarano, Marco Marcante, Giovanni Paternoster, Claudio Piemonte, Alessandro Razeto, Veronica Regazzoni, Davide Sablone, Claudio Savarese, Gaetano Zappalá, and Nicola Zorzi

IEEE Transactions on Nuclear Science 65/1 (2018)

Development of a novel single-channel, 24 cm^2, SiPM-based, cryogenic photodetector

Marco D'Incecco, Cristiano Galbiati, Graham K. Giovanetti, George Korga, Xinran Li, Andrea Mandarano, Alessandro Razeto, Davide Sablone, and Claudio Savarese

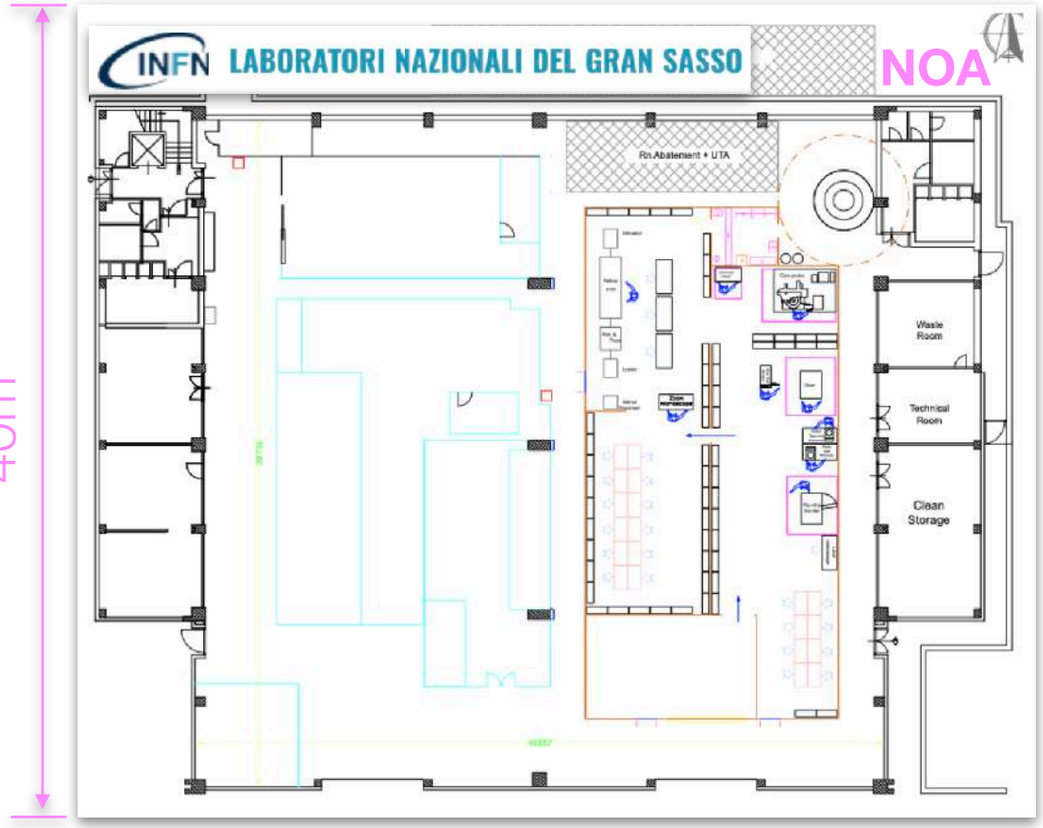
IEEE Transactions on Nuclear Science 65/4 (2018)

Development of a very low-noise cryogenic pre-amplifier for large-area SiPM devices

Marco D'Incecco, Cristiano Galbiati, Graham K. Giovanetti, George Korga, Xinran Li, Andrea Mandarano, Alessandro Razeto, Davide Sablone, and Claudio Savarese

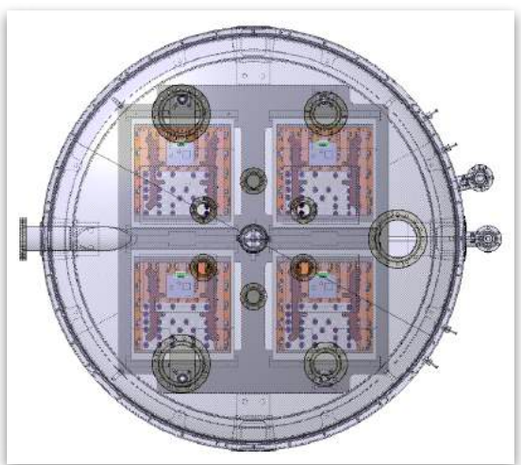
SiPM PDM Production – NOA Facility at LNGS

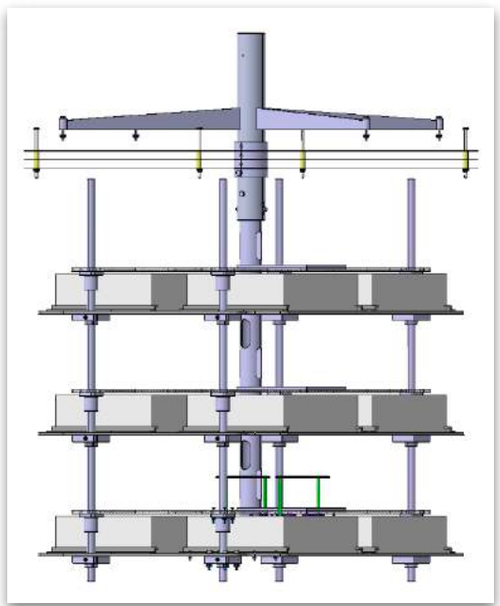
- Development and technology transfer from FBK (Trento, IT) to LFoundry (Avezzano, IT) for production of raw SiPM wafers



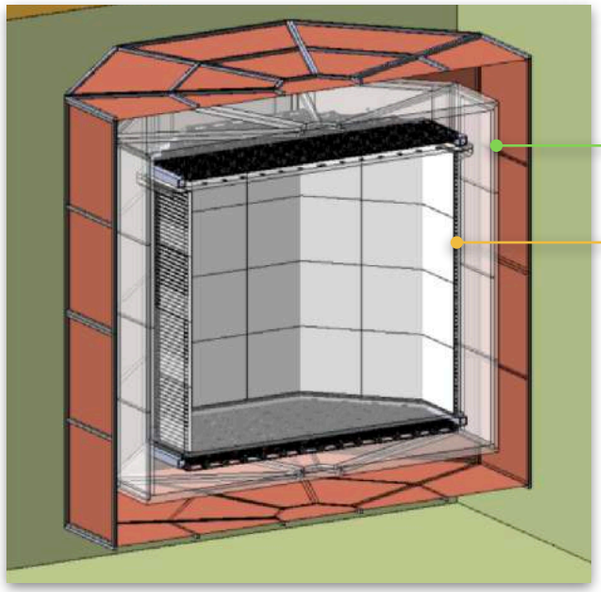
- **Production facility** for SiPM based photo electronics at LNGS
- Equipment procurement in progress
- DarkSide-20k production is the 1st task

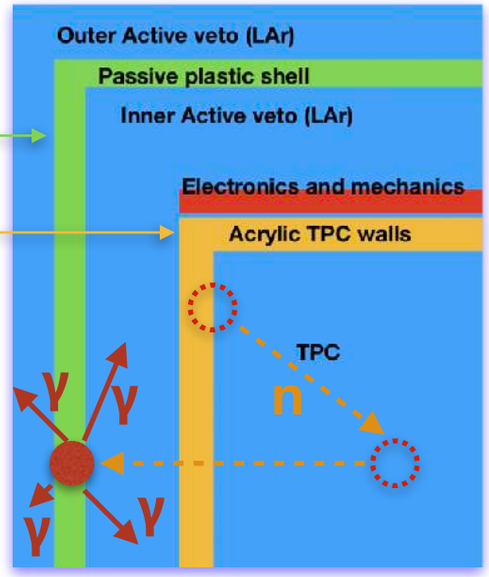
- PDM **Test facility** in Naples

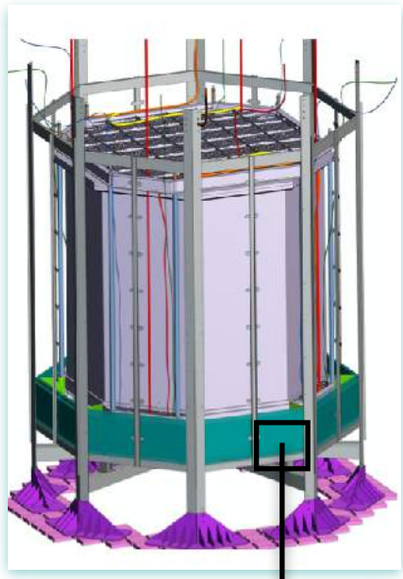




Neutron Veto







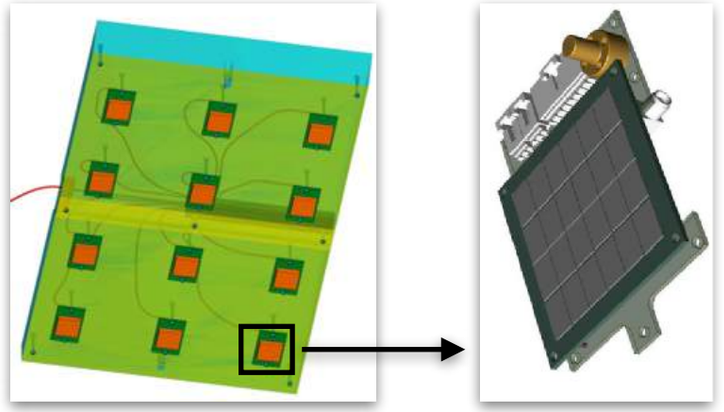
- 300t of atmospheric argon in two 40cm thick buffers surrounding the TPC

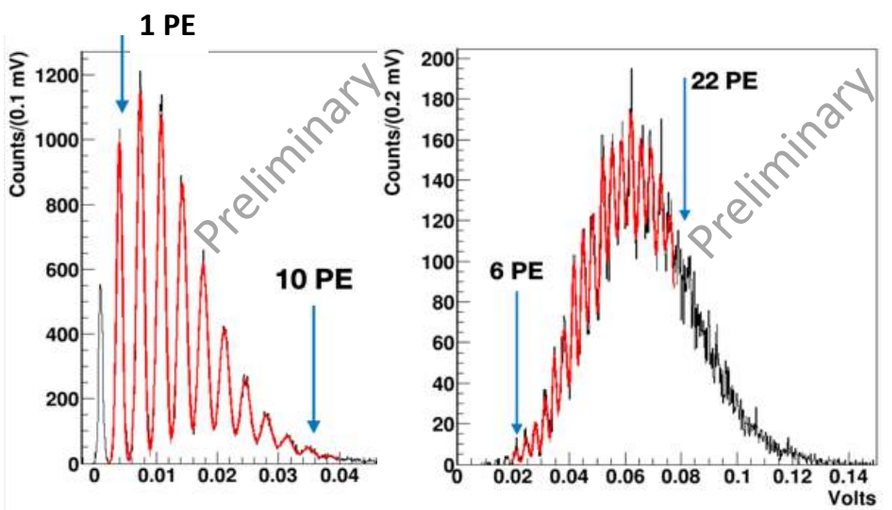
- 10cm thick Gd-doped acrylic panels between the LAr buffers for neutron moderation and capture

- ~3000 photodetection units with analog CMOS front-end read-out (MeV signals → higher dynamic range than TPC requirement)

- ESR reflector foils with PEN wavelength shifter

- Primary work and R&D at Genoa and Turin, Italy and AstroCent, Poland





The DArT Detector

Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon

C.E. Aalseth[a], S. Abdelhakim[b], F. Acerbi[c,d], P. Agnes[e], R. Ajaj[f], I.F.M. Albuquerque[g], T. Alexander[a], A. Alici[h,i], A.K. Alton[j], P. Amaudruz[k] + Show full author list

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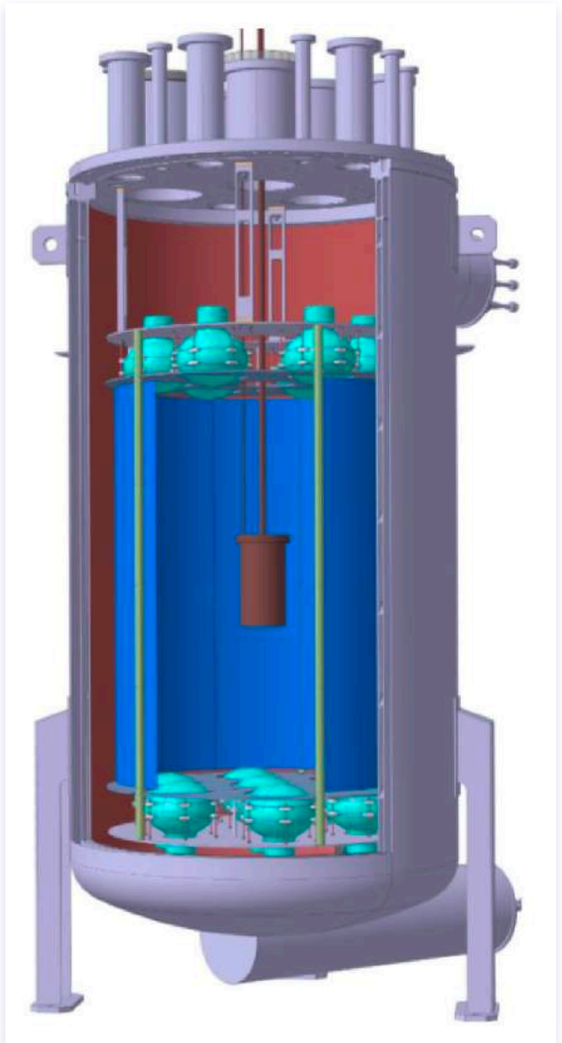
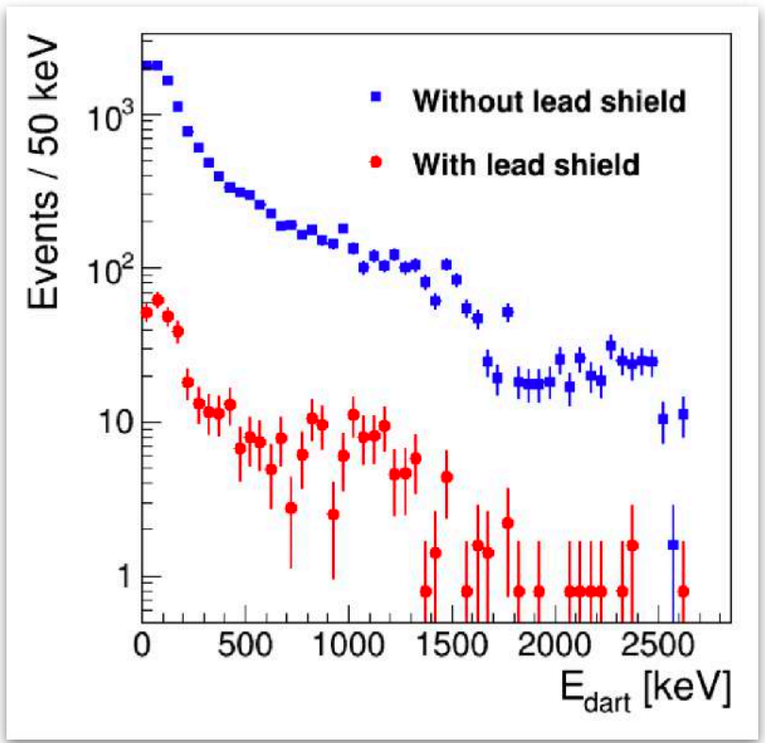
Journal of Instrumentation, Volume 15, February 2020

• The DArT in ArDM experiment at Canfranc underground laboratory (LSC) will be able to measure UAr-to-AAr ^{39}Ar depletion factor of the order of 1000 with 10% precision in one week of running

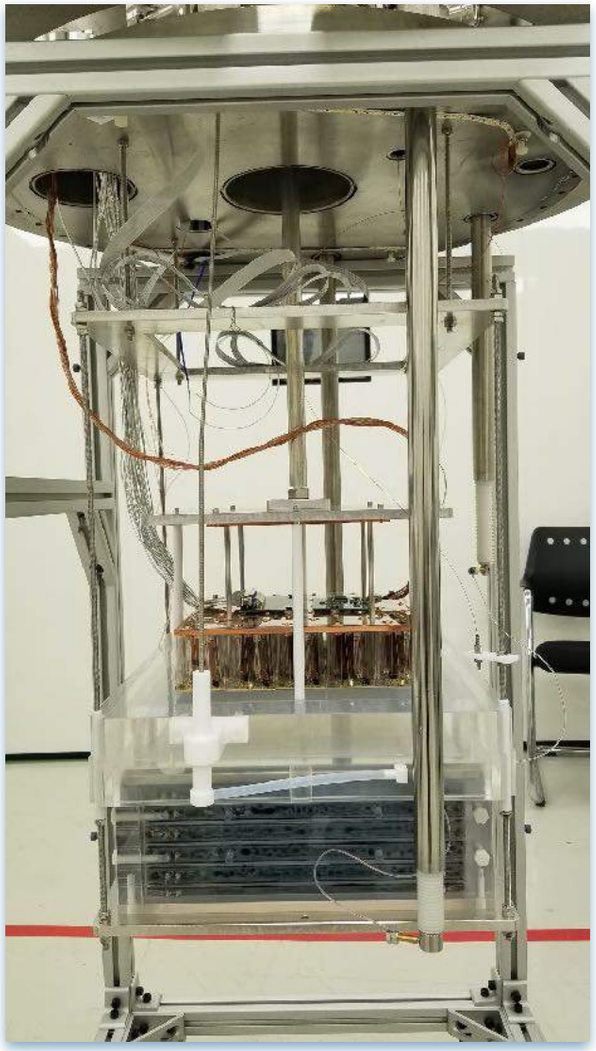


• Single-phase inner detector for 1.6 liters of LAr inside 1tonne ArDM detector acting as an active veto for background radiation



Prototyping Program

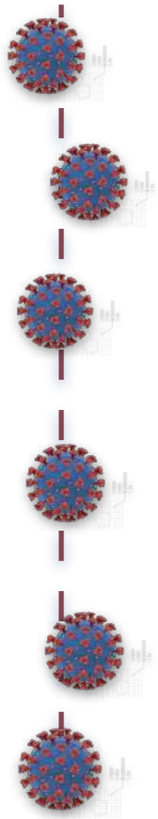
- **DS Proto-0**
- Active volume ~10kg
- Confirmation of conductive polymer for the field cage and anode
- Gas pocket thickness optimization: matching the PDM dynamic range and S2 signal optimisation
- DAQ, signal processing, and analysis path development



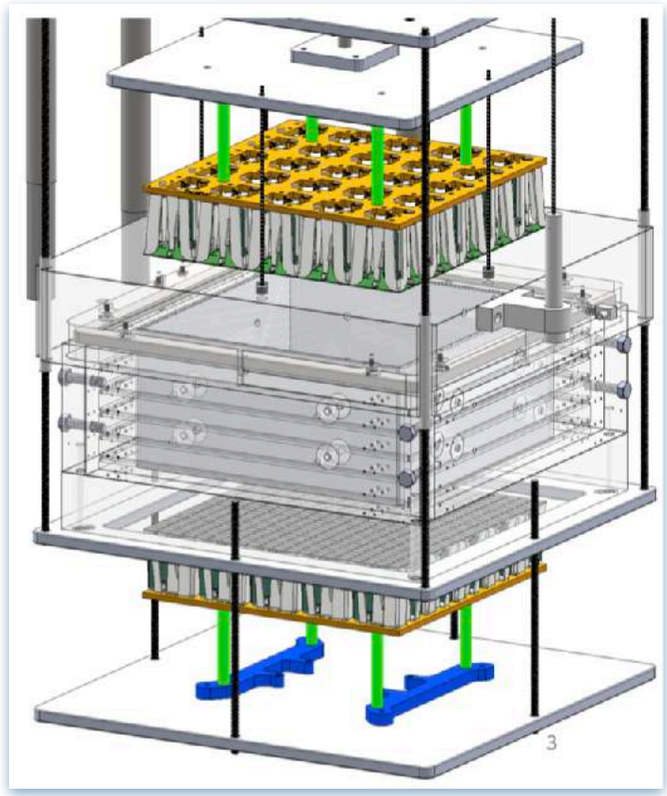
Phase-I
(2019)

- one photodetection unit with 25 modules

COVID
(2020)



Phase-II
(2021)

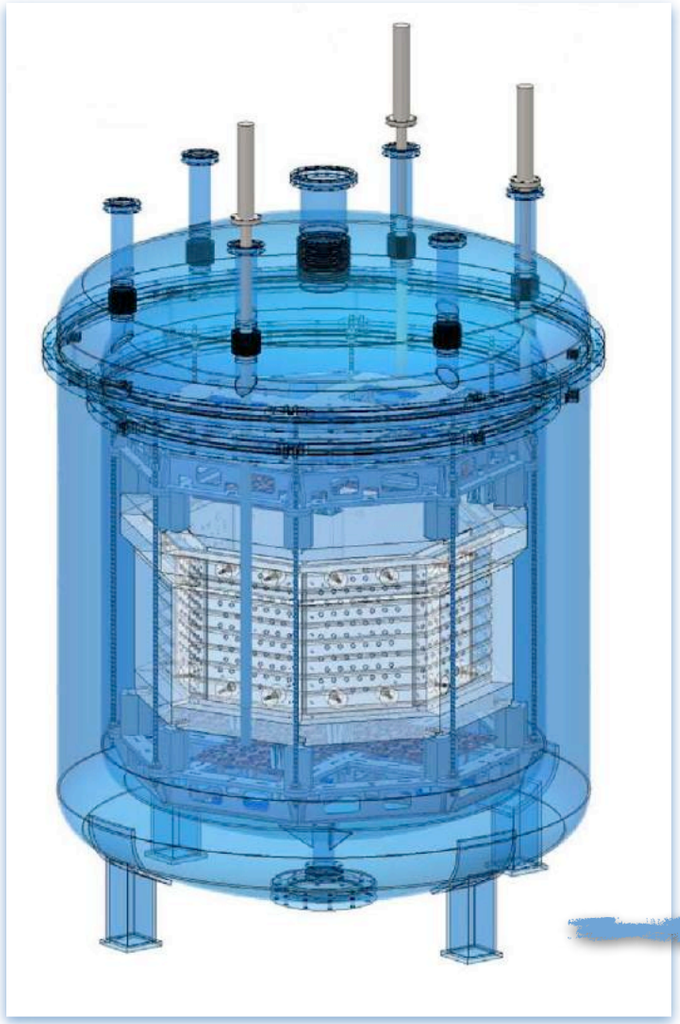


- two PDUs top and bottom
- S1 and S2 studies @ Naples

Prototyping Program

DS Proto-1

- Scaled down version of DS-20k TPC
- Active volume ~350 kg
- 250 photodetection channels
- Acrylic vessel is being prepared in Canada
- Photoelectronics production and tests in Italy
- Test all developed technologies and procedures for DS-20k



<u>DS-20k TPC underground argon cryogenic system</u>

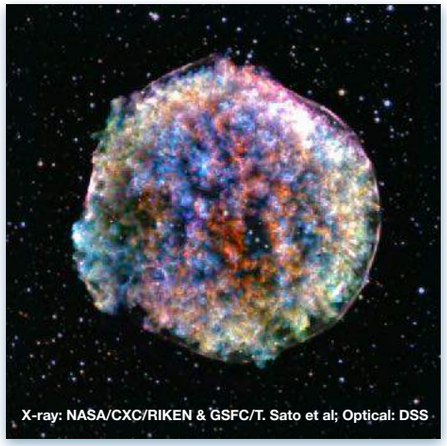
- LN_2-based, 6kW cooling power, 1000 l/min
- tests at CERN CryoLab starting January 2021

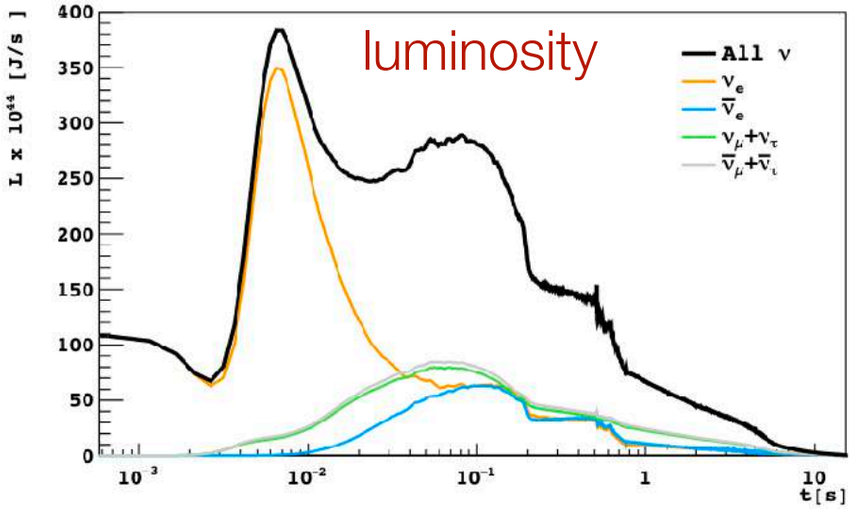
Sensitivity to Supernova Neutrinos

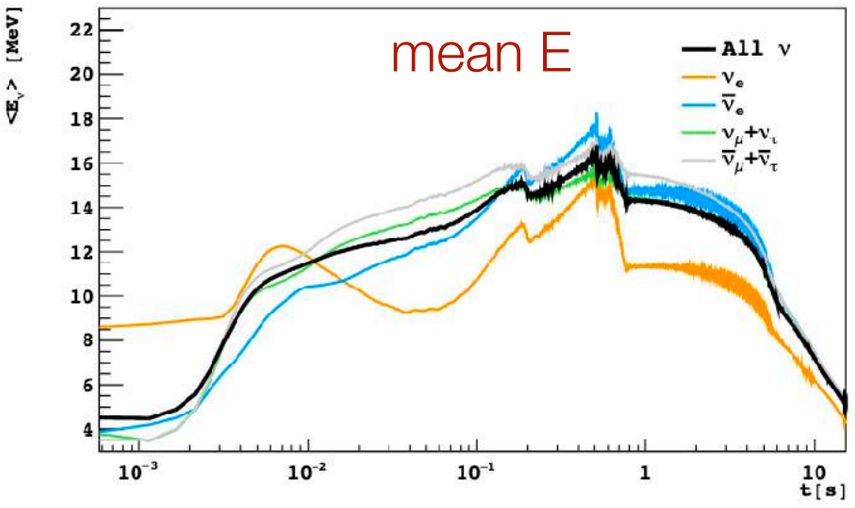
PREPARED FOR SUBMISSION TO JCAP

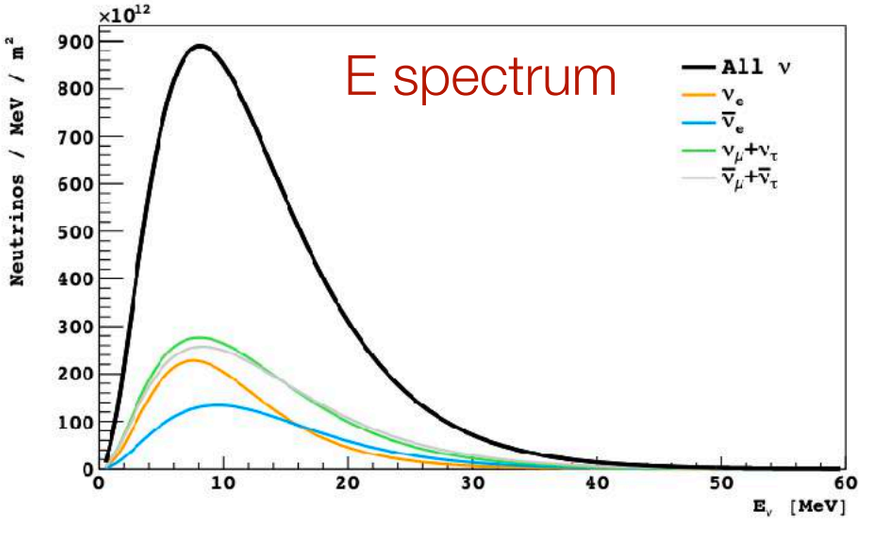
arXiv:2011.07819

Sensitivity of future liquid argon dark matter search experiments to core-collapse supernova neutrinos









・Core-collapse supernovae – explosions of massive stars triggered by the gravitational collapse of the stellar cores

・Characteristic emitted energy ~10^{64} eV (gravitational binding energy of a 1.4M⊙ core collapsing into a neutron star):

0.01% – UV, optical and near-IR radiation

~1% – kinetic energy of external layers ejected at ~103 km/s

99% – **neutrinos**

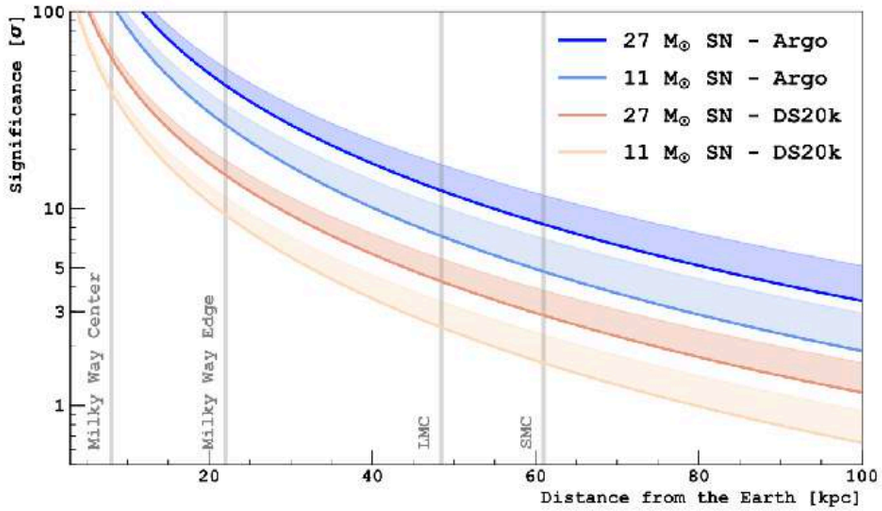
→ ideal for studying final stages of stellar evolution

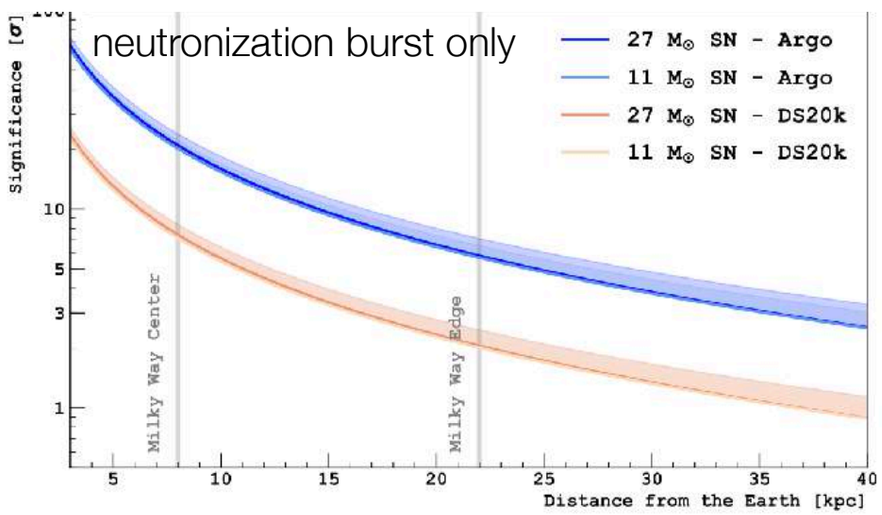
→ constraints on the neutrino mass and ordering

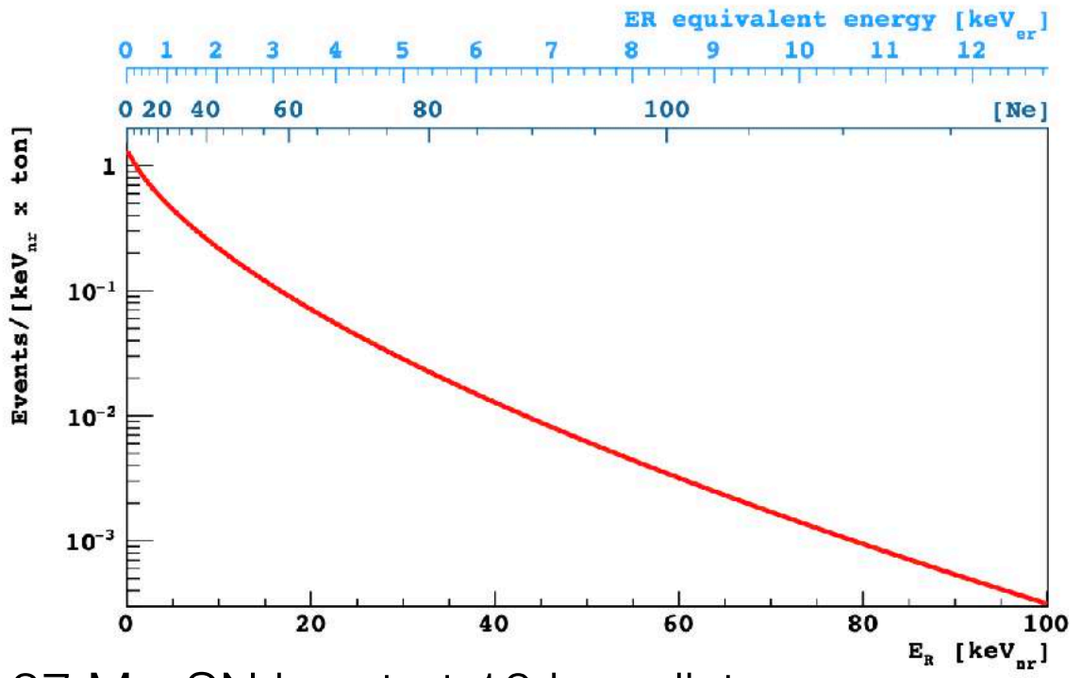
Sensitivity to Supernova Neutrinos

- Energy threshold ~0.5 keV_{nr} by ionization signal
- CEνNS interaction
- 11 $M_\odot$ projenitor star

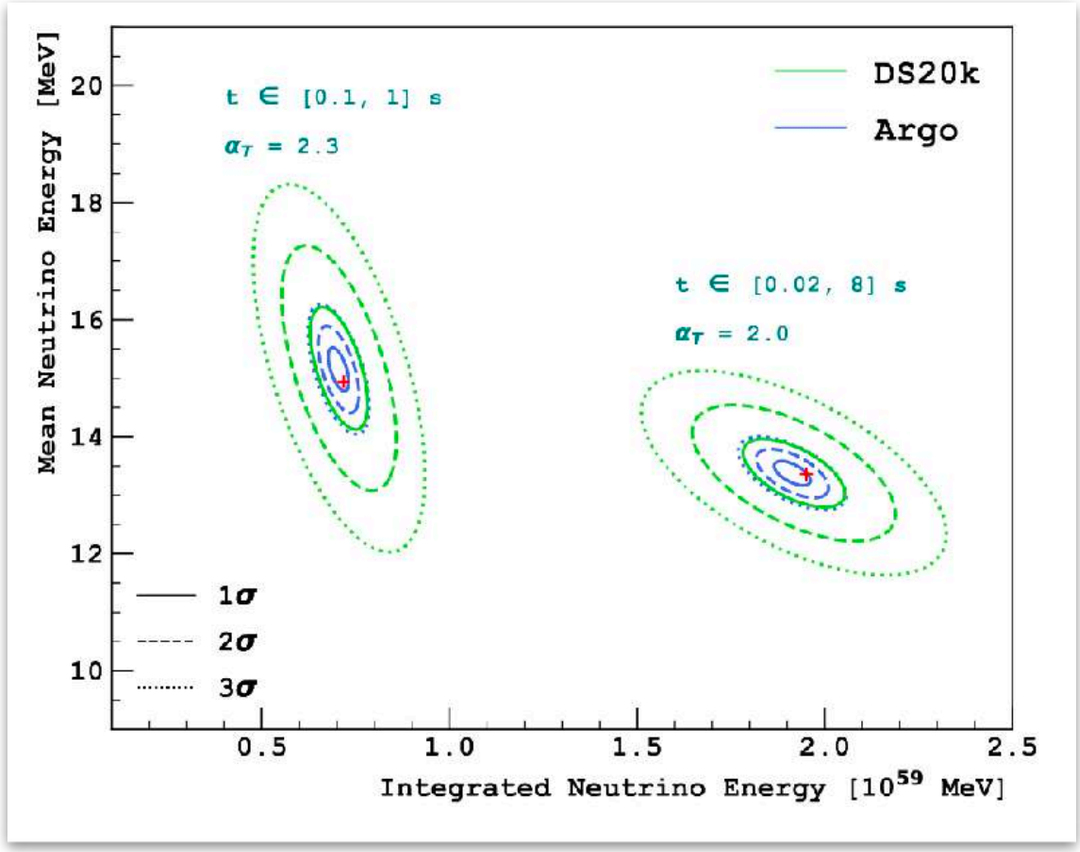
→ DarkSide-20k and ARGO have the potential to discover supernova bursts through our galaxy and up to small Magellanic Cloud







- 27 $M_\odot$ SN burst at 10 kpc distance



Summary

Dual-phase argon TPCs
are a proven and competitive technology for WIMP searches
demonstrated by the DarkSide-50 experiment with underground argon

- background-free at high mass
- low mass: best sensitivity for 1.8–5.5 GeV/c^2 WIMP

The Global Argon Dark Matter Collaboration (GADMC) with joint global expertise
is rapidly proceeding with the DarkSide-20k as the next step
key technologies:

- large-scale production of novel SiPM-based cryogenic photosensors
- extraction and purification of large quantities of low-radioactivity underground argon
- TPC technologies: acrylic vessels, conductive polymers, wavelength-shifters, reflectors
- active neutron veto with atmospheric argon and Gd-doped plastic

Vibrant and consistent research program projected for the future
several LOIs submitted to SNOWMASS 2021

- ”Applications for Underground Argon”
- ”Searching for Dark Matter with Liquid Argon”
- ”Instrumentation and R&D for the Global Argon Dark Matter Collaboration (GADMC)”
- ”The Neutrino Physics Program of the GADMC”