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DARKSIDE

Searches for Dark Matter Particles in the DARKSIDE Experiment

Grzegorz Zuzel

M. Smoluchowski Institute of Physics, Jagiellonian University in Kraków
on behalf of the DARKSIDE-20k Collaboration

Workshop at 1GeV scale: From mesons to axions, Faculty of Physics, Astronomy and Computer Science, Jag. Univ. in Krakow, 19-20.09.24

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Outline

- Introduction
- Background Issue
- DARKSIDE-20k and GADMC
- DS-20k Key Technologies
- Scientific Reach
- Summary

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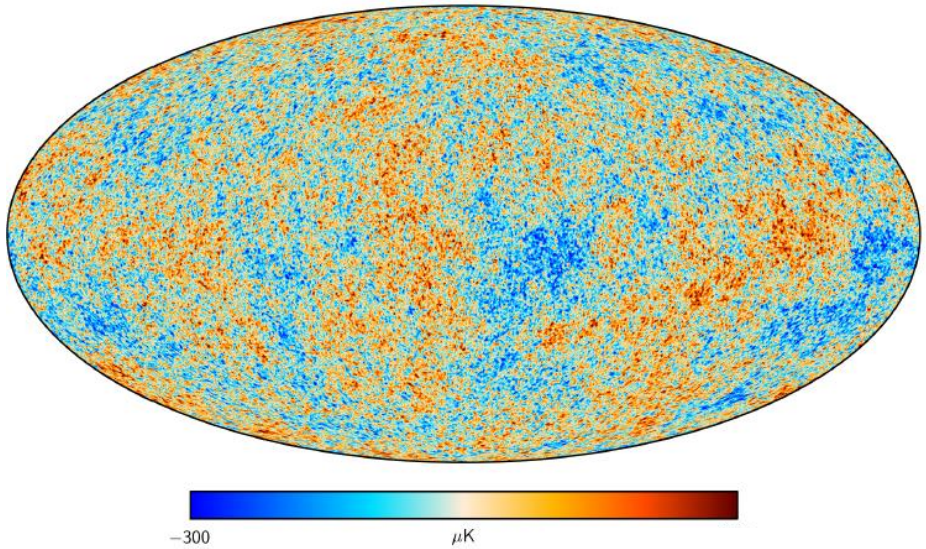
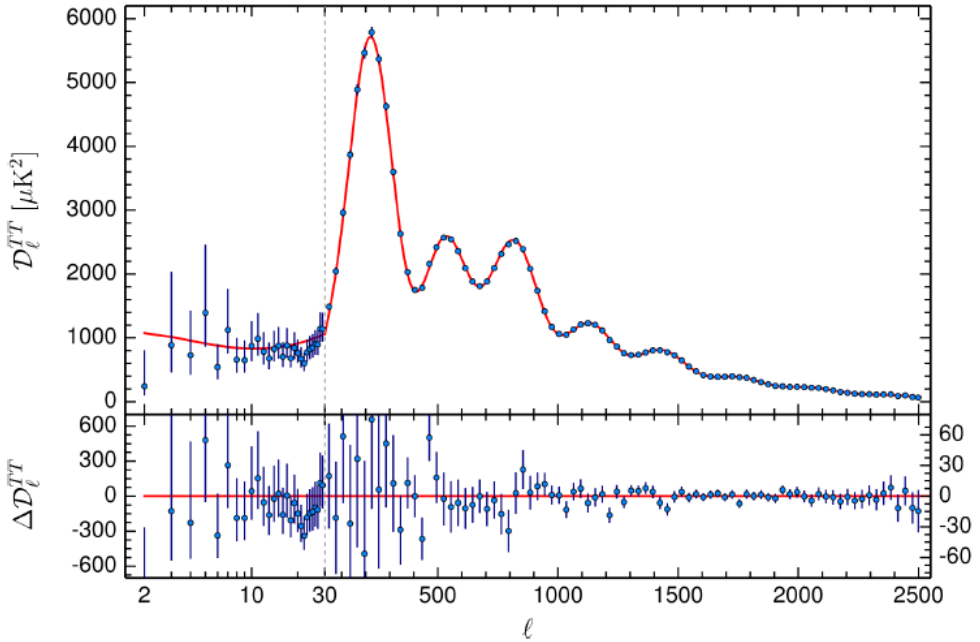
Dark Matter: Evidences



All-sky map of CMB temperature fluctuations produced by Planck

$T_R \sim 2.72$ K



Power spectrum of CMB temperature as measured by Planck

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Importance of the Project

Searches for direct interactions of dark matter (DM) particles (e.g. WIMPs – Weakly Interacting Massive Particles) and neutrino-less double beta ($0\nu\beta\beta$) decays are of unprecedented importance for modern particle physics, astrophysics and nuclear physics:

- Searches for new particles (WIMPs, Majorana neutrino)
- Tests of fundamental conservation laws (lepton number conservation)
- Determination of fundamental properties of particles (WIMPs / neutrinos: mass, interaction cross section, …)

Existence of WIMPs
Majorana Neutrino
Lepton number not conserved

Physics Beyond the Standard Model

Importance of the Project

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- Introduction
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Astroparticle Physics European Consortium

APPEC

The future of Astroparticle Physics in Europe

Presentation of the European Astroparticle Physics Strategy Mid-Term Update

07.12.2023, Brussels, Belgium

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Importance of the Project

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Importance of the Project

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Report from the
Particle Physics Project Prioritization Panel (P5)

Hitoshi Murayama & Karsten Heeger
on behalf of the P5 panel

HEPAP Meeting, December 7, 2023

U.S. DEPARTMENT OF ENERGY | Office of Science | National Science Foundation

Exploring the Quantum Universe

Recommendation 1

Not Rank-Ordered

In addition, we recommend continued support for the following ongoing experiments at the medium scale (project costs > $50M for DOE and > $4M for NSF), including completion of construction, operations, and research:

d. **NOvA**, **SBN**, **T2K**, and **IceCube** (*elucidate the mysteries of neutrinos*, section 3.1).
e. **DarkSide-20k**, **LZ**, **SuperCDMS**, and **XENONnT** (*determine the nature of dark matter*, section 4.1).
f. **DESI** (*understand what drives cosmic evolution*, section 4.2).
g. **Belle II**, **LHCb**, and **Mu2e** (*pursue quantum imprints of new phenomena*, section 5.2).

The agencies should work closely with each major project to carefully manage the costs and schedule to ensure that the US program has a broad and balanced portfolio.

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Background Issue

Signal expected in dark matter detectors is extremely weak:
~1 event/year/ton

- Reduction of background and lowering the energy detection threshold is absolutely crucial – these are the most challenging task in all DM projects
- **Background-free operation is a must for discovery**
- Background: everything what can mimic the signal: electronic noise, cosmic rays, environmental radioactivity, **residual radioactivity in the detector components**
- Detector components must be „free" of natural radioisotopes: **10^{10} lower activity concentrations compared to e.g. mineral water**
- **New instruments and techniques to verify radio-purities of material needed (JU strongly involved)**

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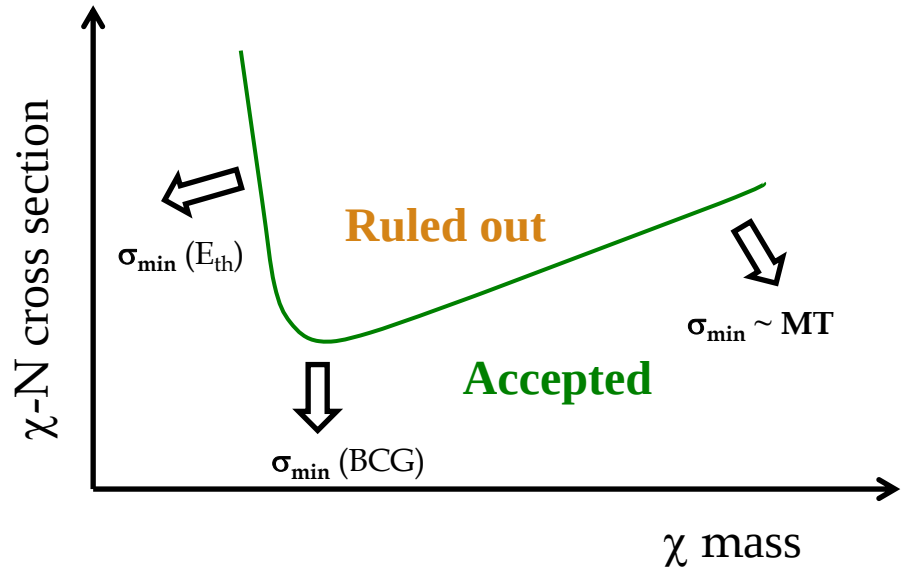
Expected Signal Rate

$$\frac{dR}{dE_R} = N_N \frac{\rho_0}{m_W} \int_{\sqrt{(m_N E_{th})/(2\mu^2)}}^{v_{max}} dv f(v) v \frac{d\sigma}{dE_R}$$

Detector physics: N_N, E_{th}

Particle/nuclear physics: $m_W, d\sigma/dE_R$

Astrophysics: $\rho_0, f(v)$



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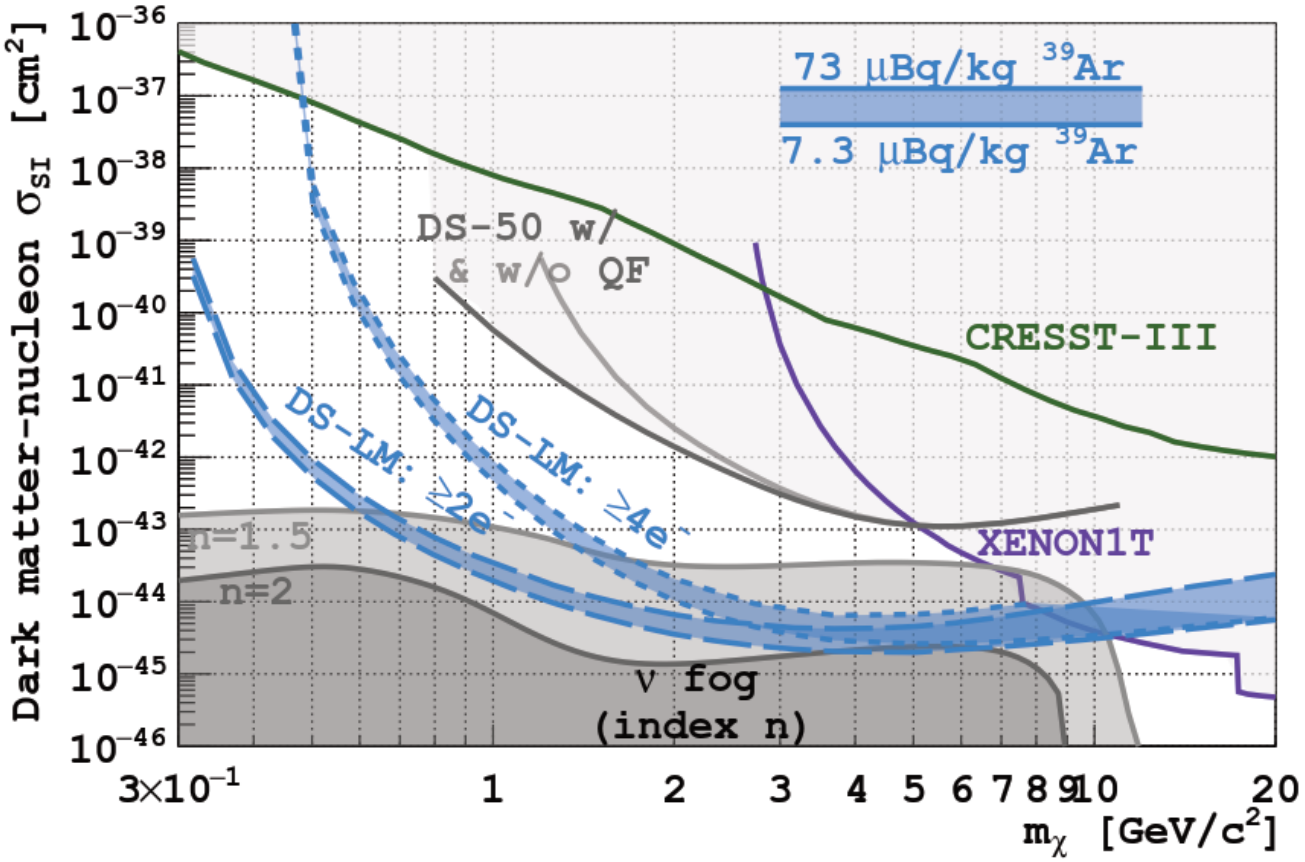
Background Issue

3σ significance evidence as a function of threshold and ^{39}Ar concentration in Ar



Phys. Rev. D 107, 112006 (2023)

- DARKSIDE-50 Collaboration, Phys. Rev. D 98 (2018) 102006
- GERDA Collaboration, Nature 544 (2017) 47

Two detectors with true background-free performance

WIMP Searches with Noble Gases

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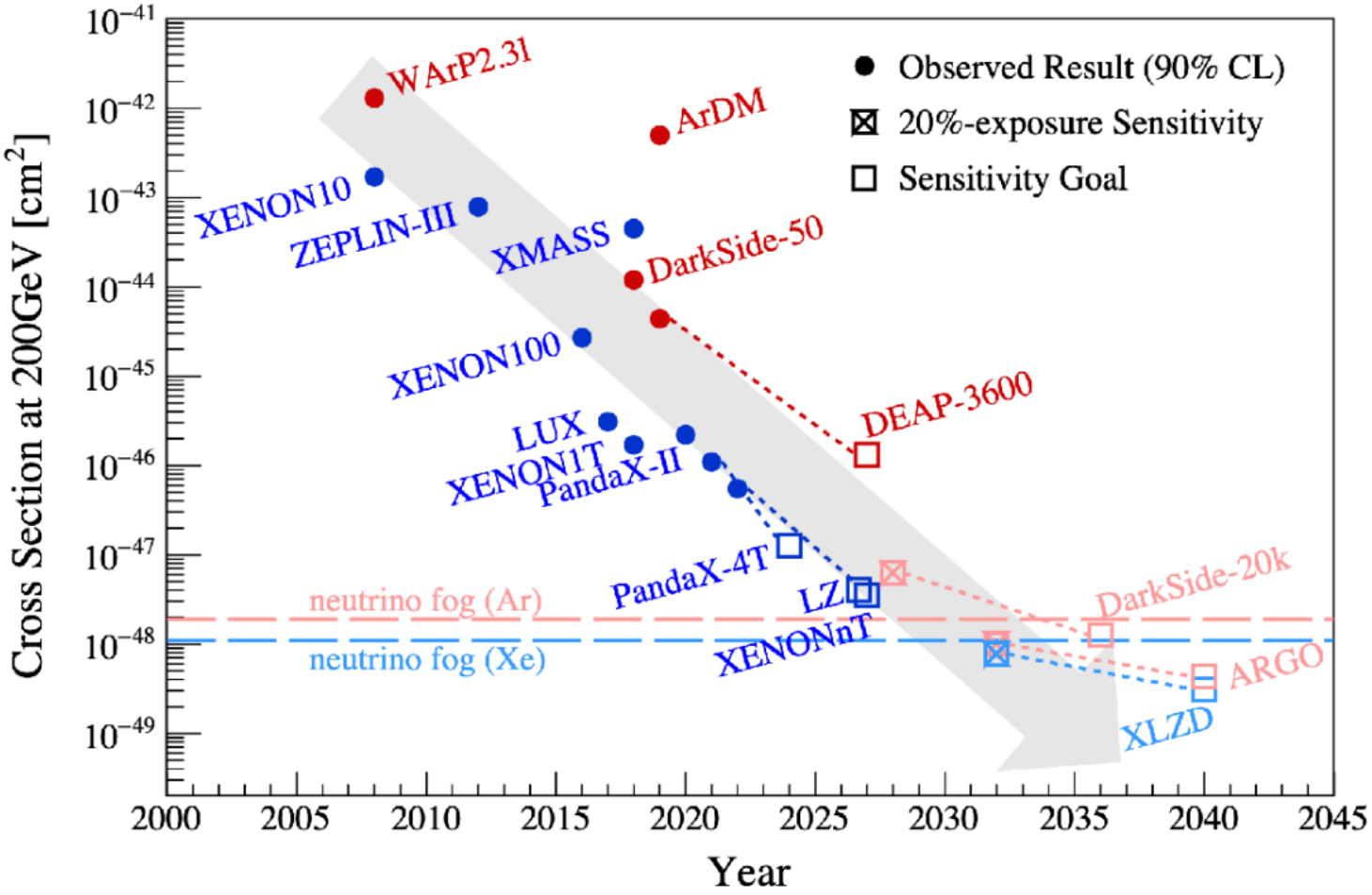

DARKSIDE: Dual Phase Ar TPC

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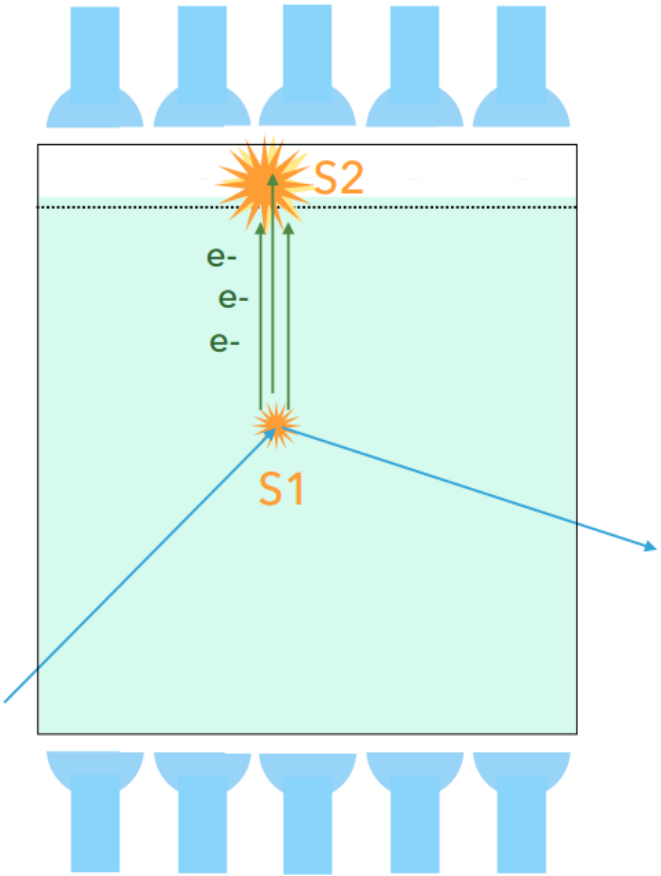

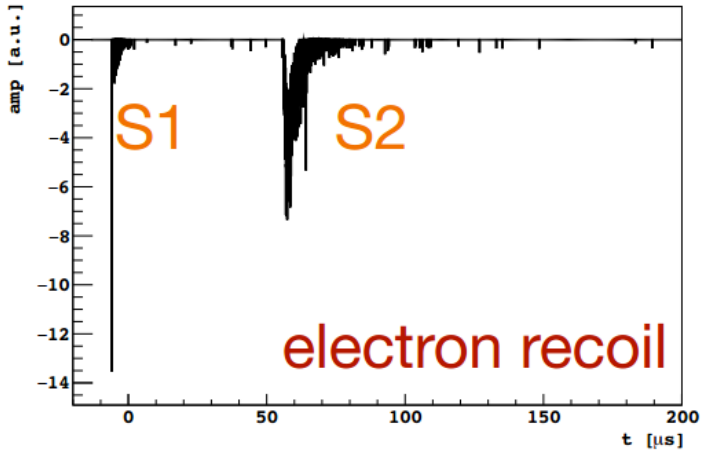

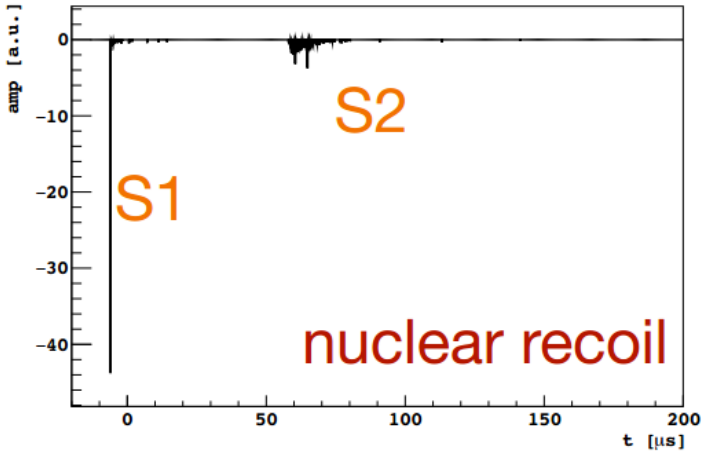

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Why Ar?

- Excellent scintillator

  LY: ~ few 10,000's of photons/MeV, λ = 128 nm

- Excellent pulse shape discrimination (PSD)

  > 10^8 reduction of e-recoil background events

- ^{39}Ar mitigated by using UAr

  Ar sourced from underground CO_2, depletion factor ~1400

- Relatively easy to purify form gaseous radioactive isotopes (^{222}Rn, ^{85}Kr, …)

  Low temperature adsorption

- Relatively cheap to procure in large quantities (~?00 tons)

  Once the production/purification hardware is set up

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DARKSIDE: Dual Phase Ar TPC

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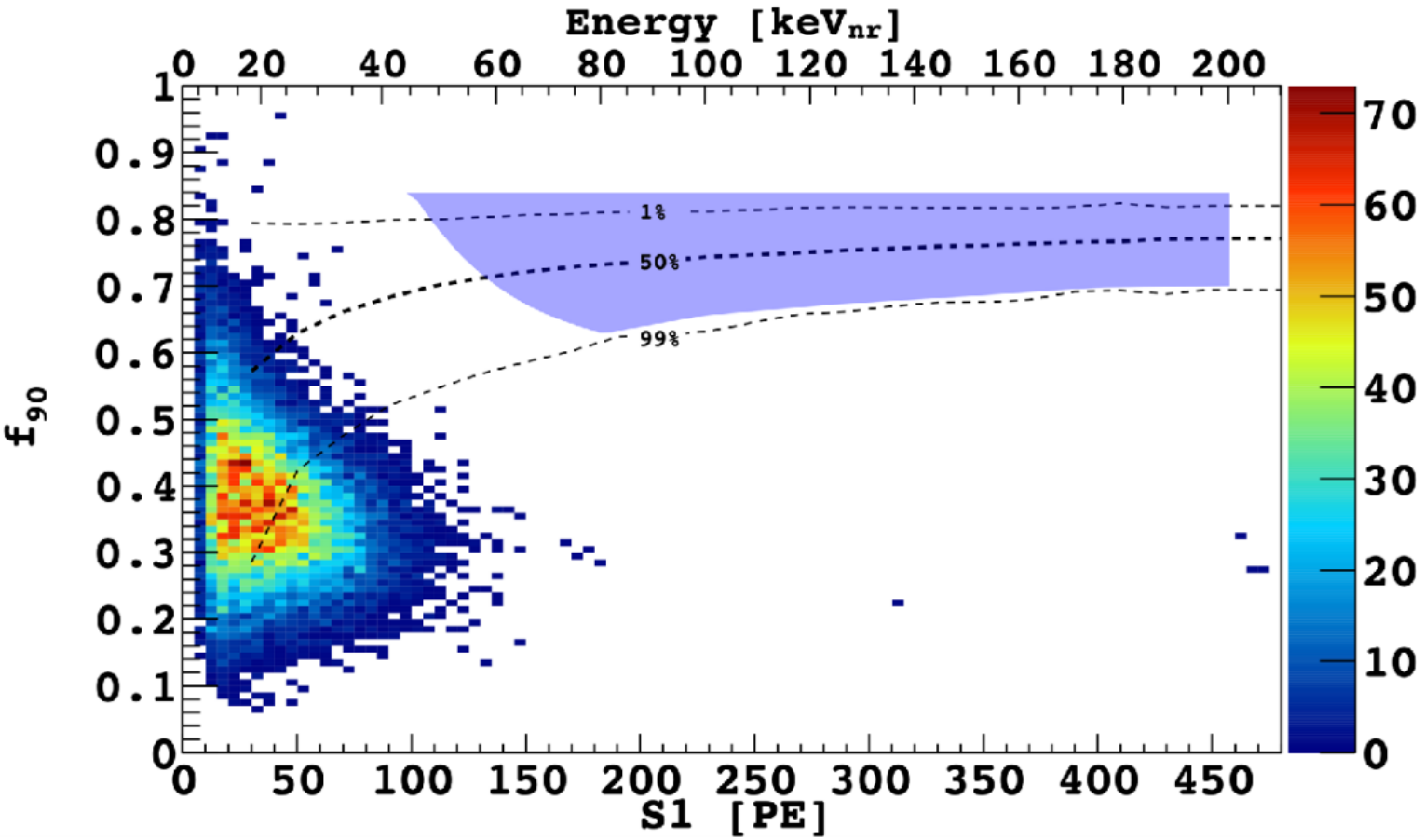
DARKSIDE-50: PSD with TPC event reconstruction



Phys. Rev. D 98, 102006 (2018)

Global Argon Dark Matter Collab.

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GADMC: 400 scientists to explore DM down to the neutrino fog

- Introduction
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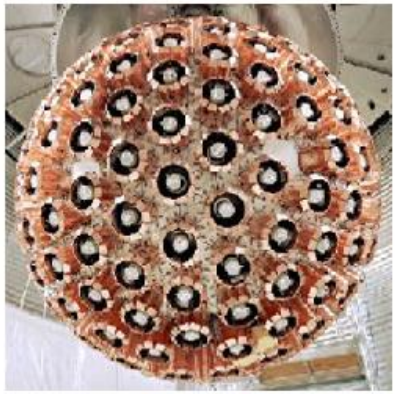
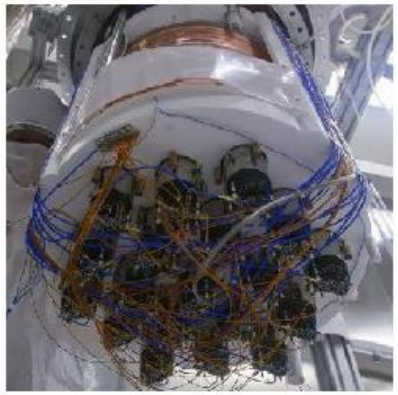
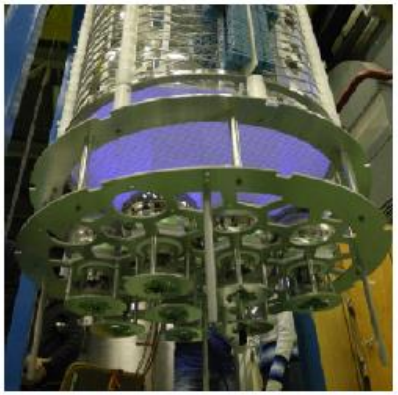


DEAP-3600

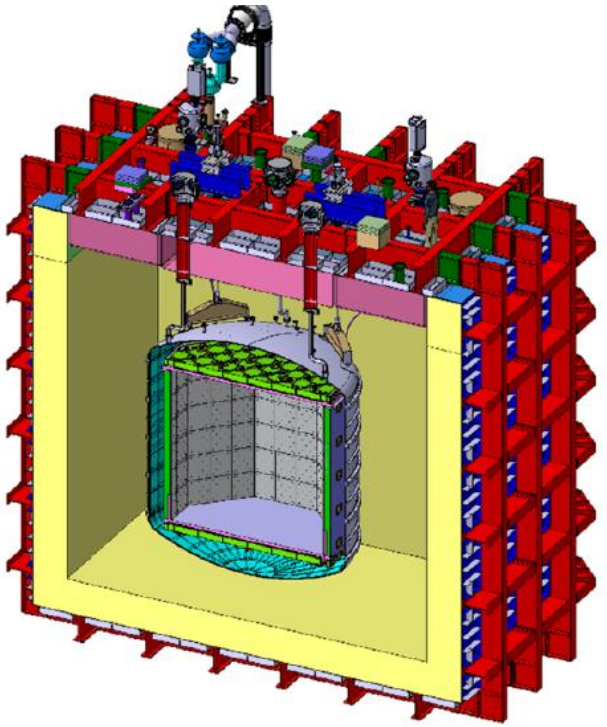
MiniCLEAN



DarkSide-50



ARDM



DarkSide-20k at LNGS

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DARKSIDE-20k at LNGS

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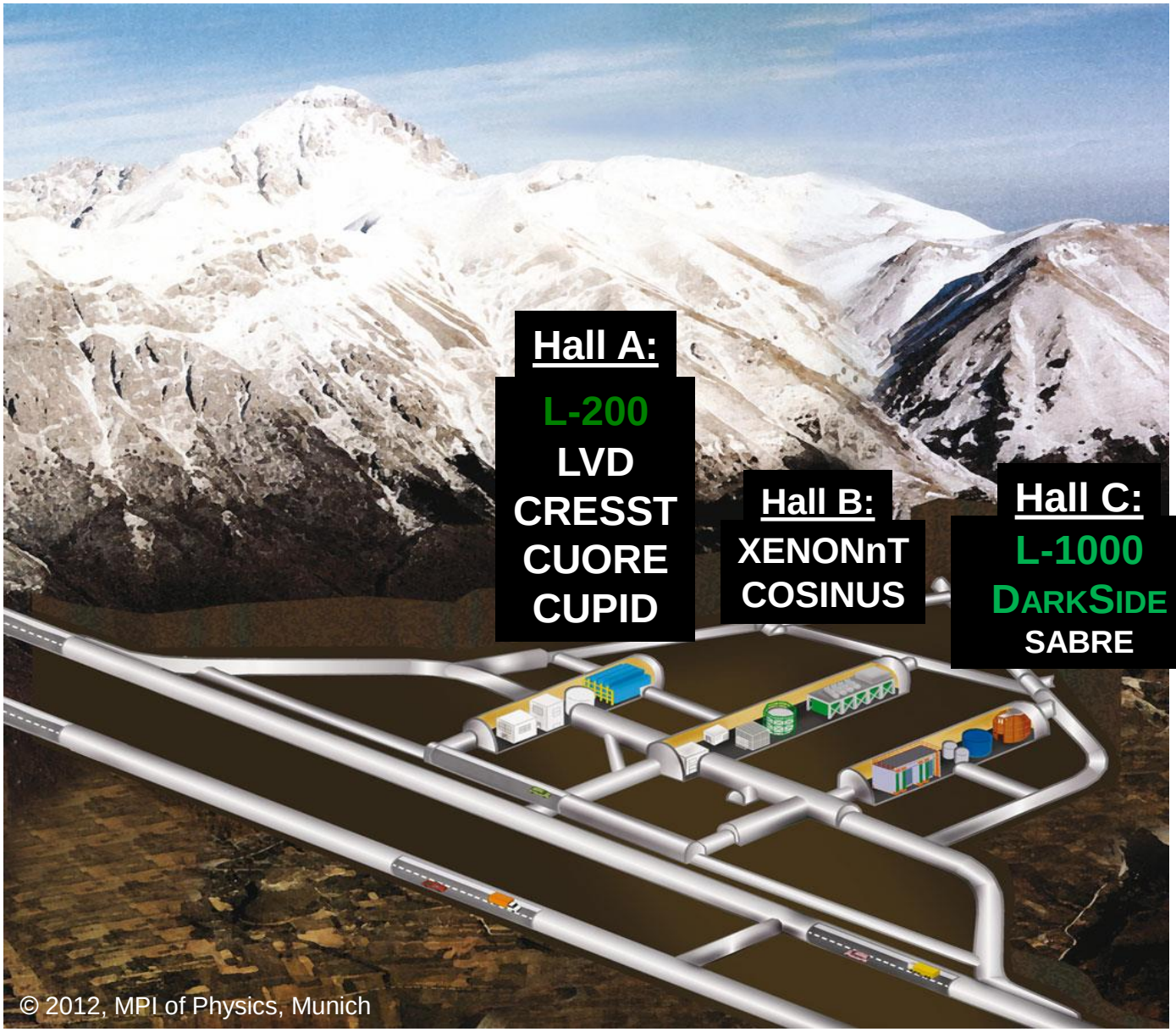

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DARKSIDE-20k Key Technologies

- Low-radioactivity argon extracted from underground (UAr)
  - ^{39}Ar decays
- SiPM-based cryogenic photosensors
  - radiogenic gammas and neutrons
- TPC constructed from ultra-pure acrylic
  - radiogenic gammas and radon progeny
- ProtoDUNE-like membrane cryostat filled with atmospheric argon (AAr)
  - cosmogenic neutrons, radiogenic backgrounds

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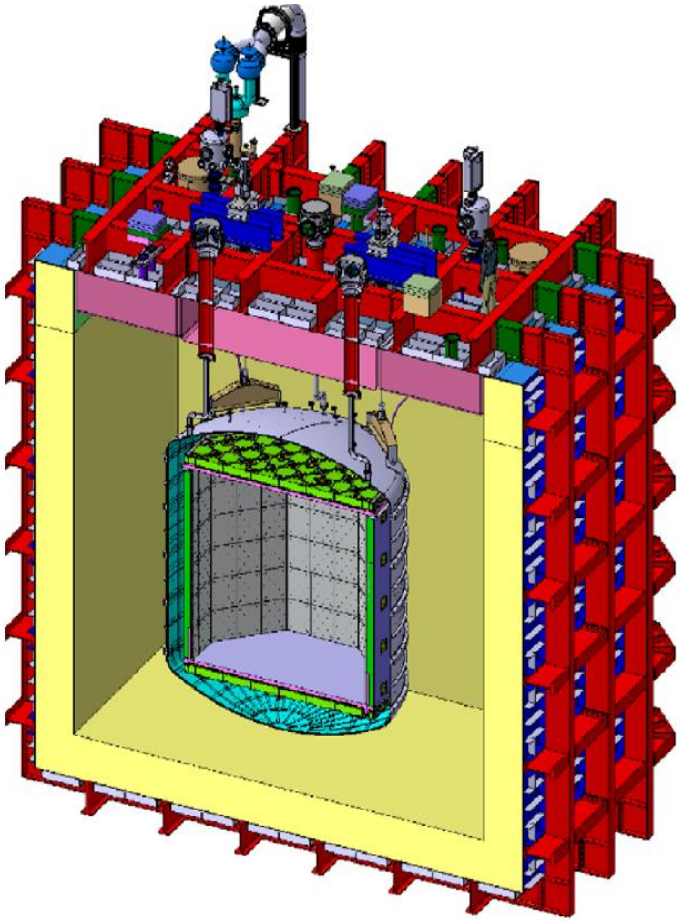
DARKSIDE-20k

DARKSIDE-20k detector in a nut shell



- 50 t of UAr active mass (20 t FV)
- Multiple channels for active background reduction, including PSD, fiducialization, and neutron veto
- Designed to have less than 0.2 n-induced nuclear recoil events and mis-identified electron recoils in ROI over 10 y (200 t×y) exposure.
- Expect to see ~3.2 coherent atmospheric neutrino scatters over 200 t×y exposure

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DARKSIDE Evolution

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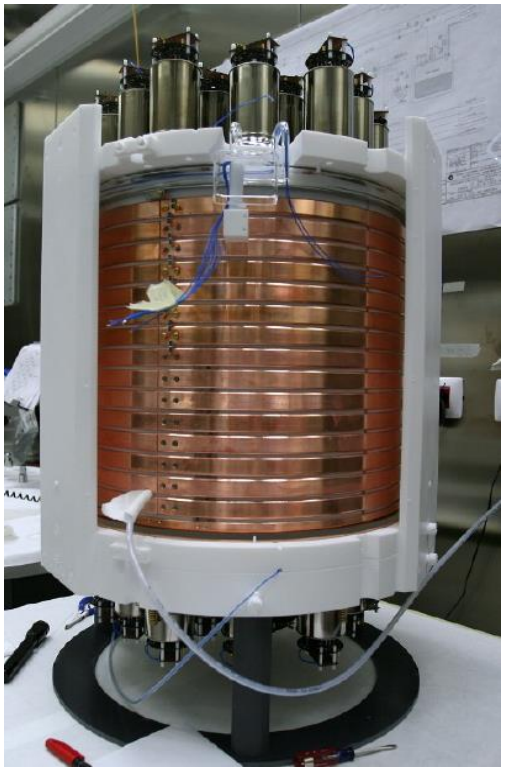
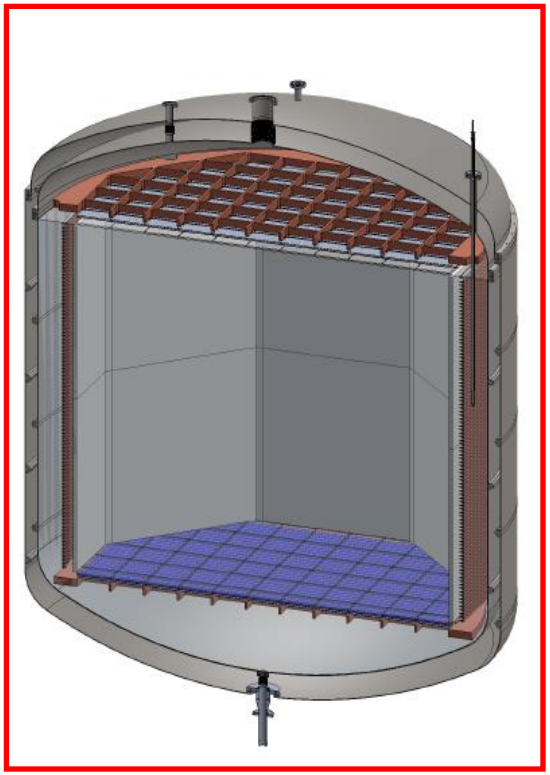
DS-10 prototype
(2011 - 2013)

DS-50 detector
(2015 - 2020)



DS-20k
(2027 –)



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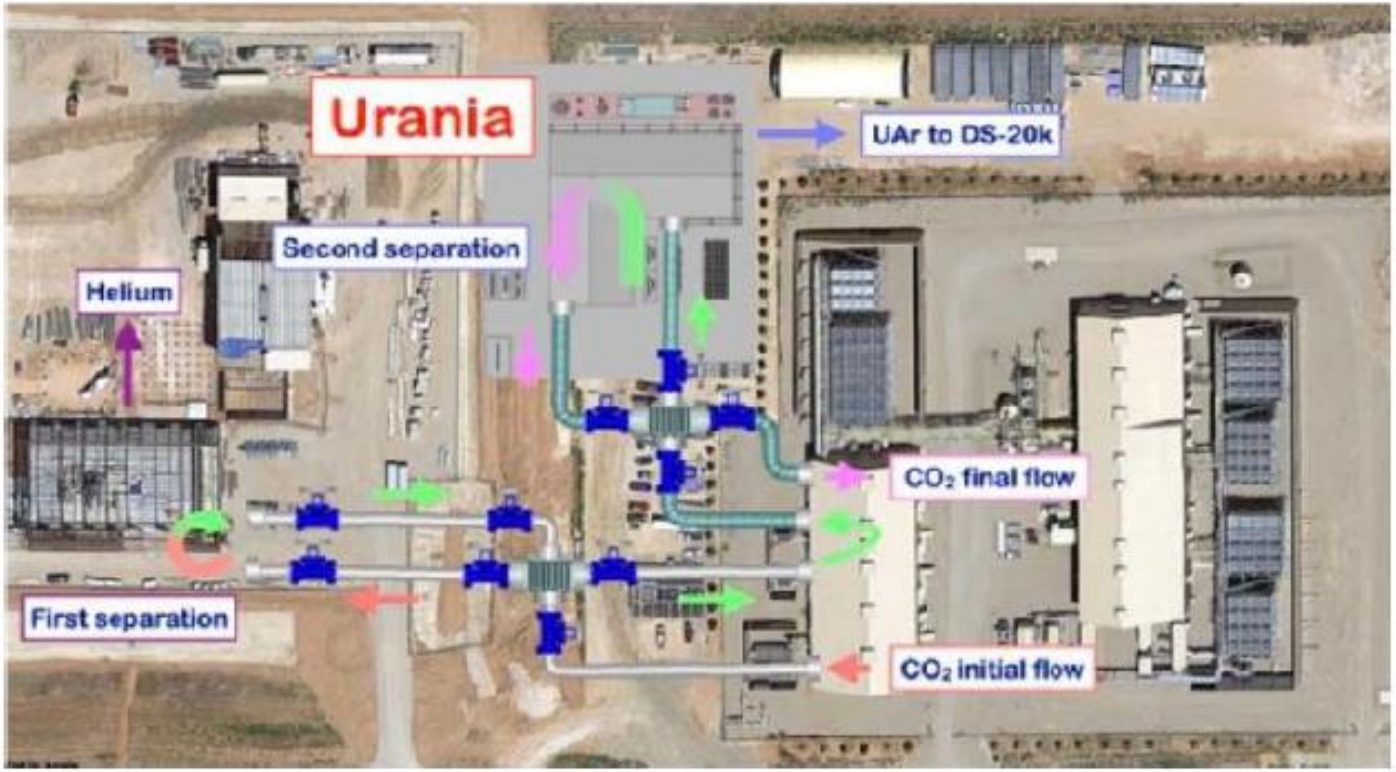
Underground Argon

UAr Production



URANIA, Colorado (US)

- Industrial scale extraction plant;
- Expected argon purity at outlet: 99.99%;
- UAr extraction rate: 250-330 kg/day

Underground Argon

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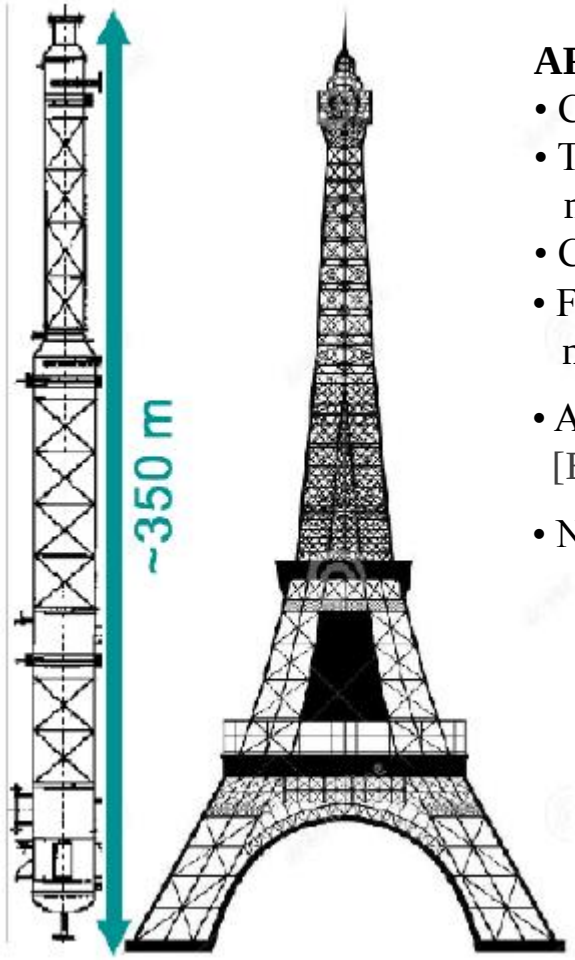
UAr Purification / Assay

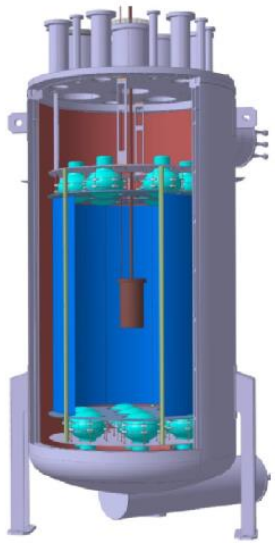


ARIA: UAr distillation plant

- Cryogenic distillation column in Sardinia (IT)
- Three sections: bottom reboiler, 28 central modules (12 m each), top condenser, ~350 m
- Chemical purification rate: 1 t/day
- First module operated according to specs with nitrogen in 2019 [Eur. Phys. J. C 81 (2021) 81]
- Ar run completed at the end of 2020 [Eur. Phys. J. C 83 (2023) 453]
- Now working on the full assembly

DArT : Measurement of the activity of the ^{39}Ar @LSC, Canfranc, Spain

- Single-phase inner detector for 1.42 kg of liquid UAr
- Will be installed inside ArDM detector, acting as an active veto.
- ^{39}Ar depletion factor sensitivity: U.L. 90% CL. 6×10^4 [2020 JINST 15 P02024]



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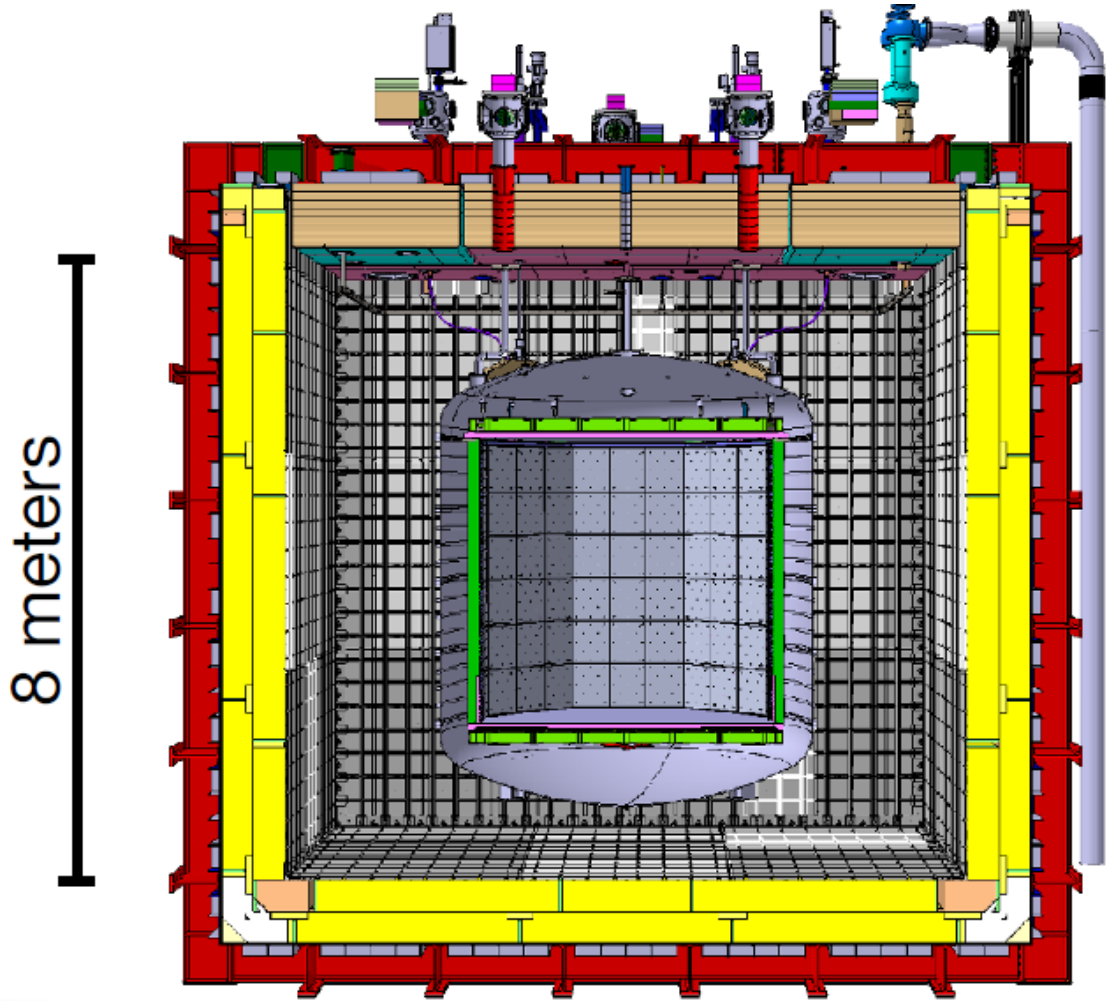
Membrane Cryostat

LNG technology: capacity of ~650 t, will hold AAr that will serve as muon veto, passive shield, and cryogenic buffer



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Membrane Cryostat at LNGS

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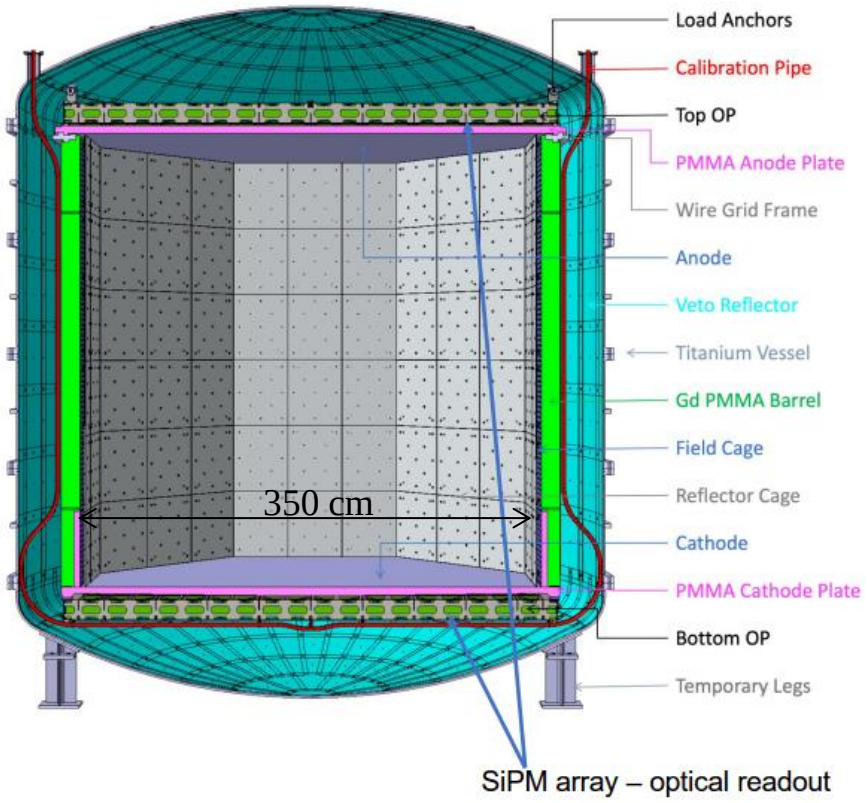
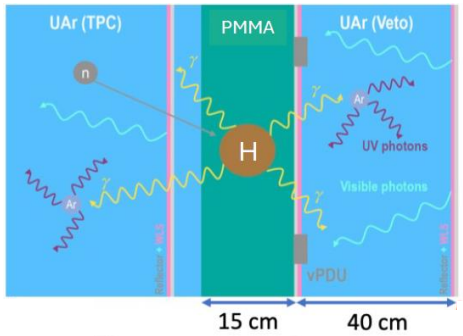
DARKSIDE-20k TPC



- Drift field: 200 V/cm
- Extraction field: ≥2,8 kV/cm
- Luminescence field: 4,2 kV
- Cathode voltage: -73,38 kV (min)
- Drift length: 348 cm
- Spatial res.: xy < 5 cm, z ~ 1 mm
- Gas pocket thickness: 7.0±0.5 mm
- LY (@null field) ~10 p.e./keVee
- S2 yield > 20 p.e./e-
- Acrylic as the main structure
- Electric field:
  - Conductive polymer (CleviosTM) coating as anode, cathode and field cage rings
  - SS wire grid
- 3M ESR used as reflector and TPB (coating) as wavelength shifter



- Acrylic (Hydrogen) + Argon
- Detection of 2.2 MeV gammas from neutron capture on H in TPC or Veto
  - 4π coverage: TPC walls, top and bottom endcaps
  - 40 cm thick UAr buffer + UAr in TPC
- Produced γ rays interact in UAr in both buffer and TPC
- 3M ESR used as reflector and PEN as wavelength shifter
- Scintillation lights detected by SiPMs in both buffer and TPC

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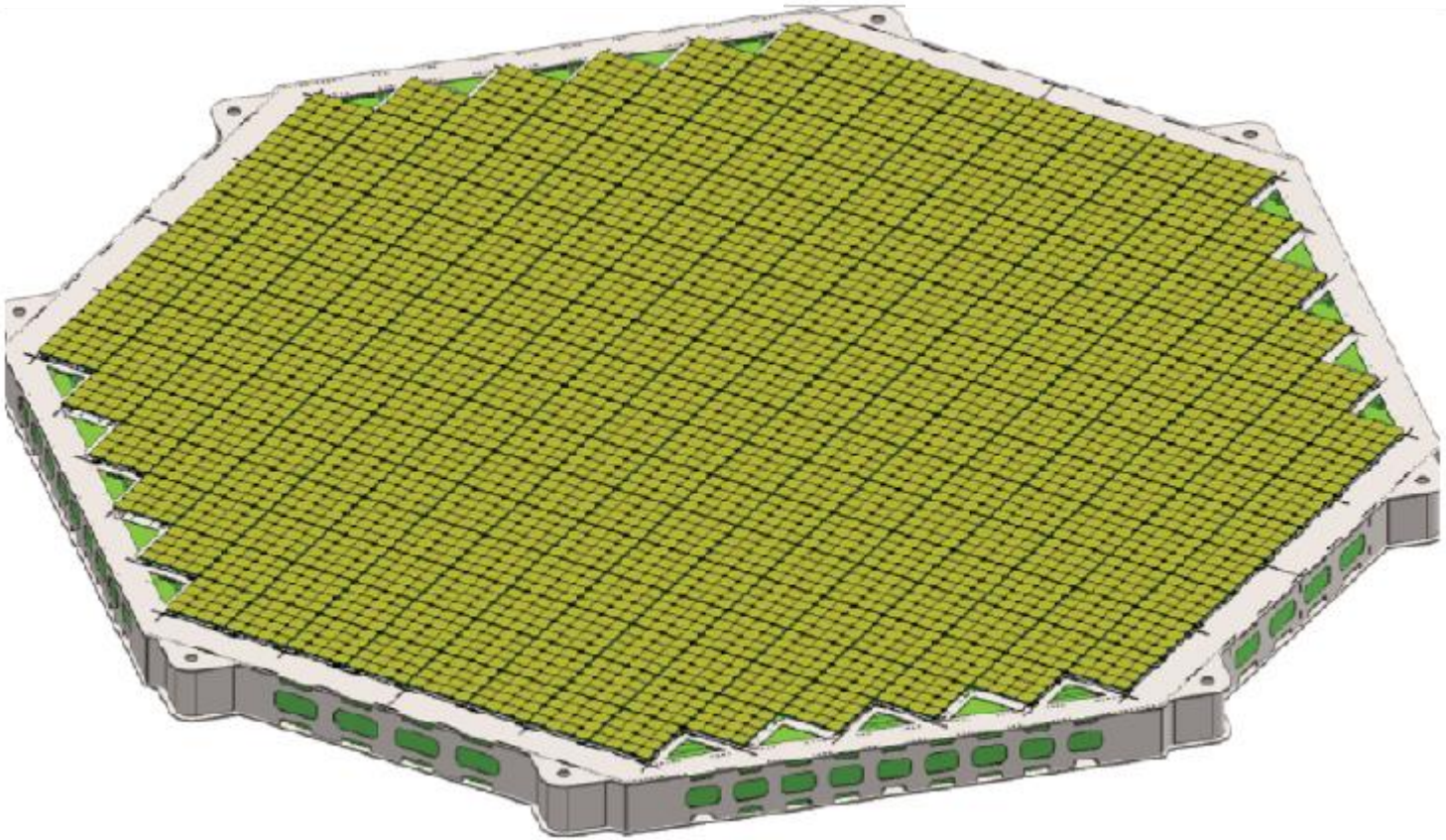
SiPM Based Photosesors

Low-radioactivity, high efficiency, low-cost, large-area photosensors using SiPMs developed in conjunction with FBK



DS-20k optical plane: 3.6 m diameter

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DS-20k Background Mitigation

GOAL: 0.2 ev. in ROI over 10 y (200 t×y) exposure

- **Electron recoils (ER)**
  - ^{39}Ar decays → underground argon and PSD
  - Radiogenic γ → material selection and PSD
- **Surface events**
  - Radon progeny → TPC surface handling and cleaning and fiducialization
- **Nuclear recoils (NR)**
  - Radiogenic neutrons, mainly from (α, n) → material selection and neutron veto
  - Cosmogenic neutrons from material activation due to residual muon flux → muon veto

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DS-20k Background Mitigation

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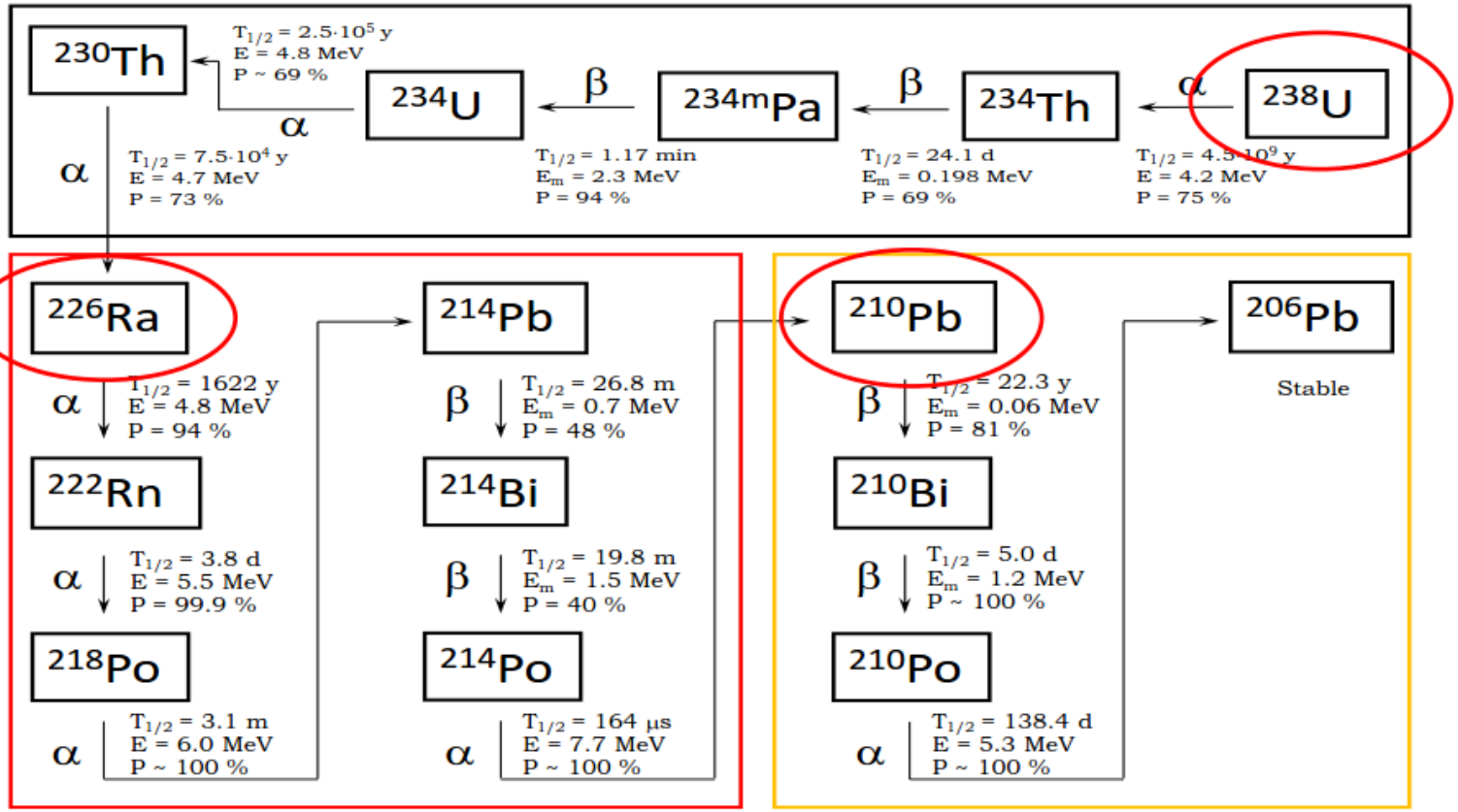
Confirmed disequilibrium in the ^{238}U chain, sub-chains need to be investigated separately



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DS-20k Background Mitigation

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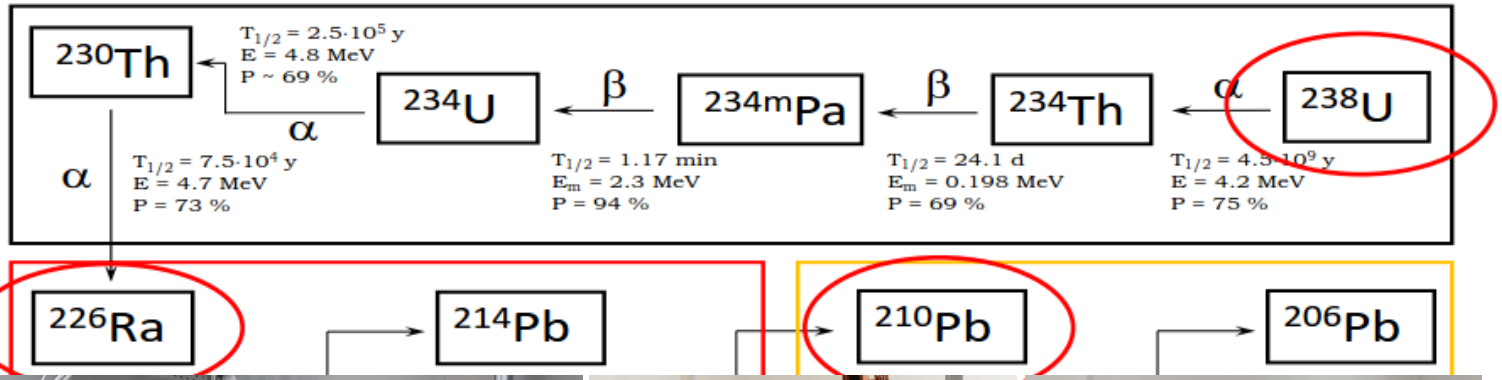

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DS-20k Projected Sensitivity

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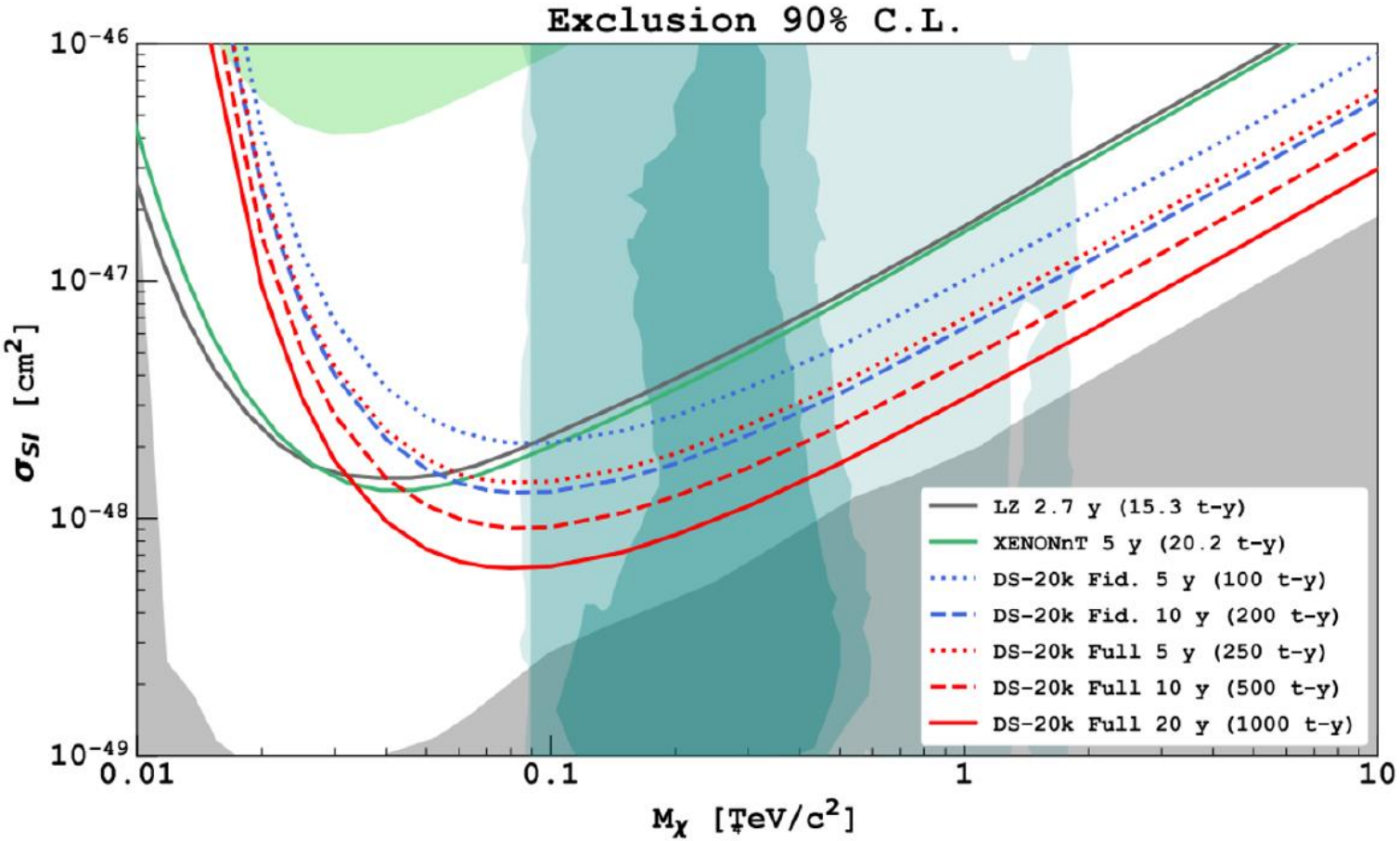

$M_\chi = 1$ TeV/c^2 $\rightarrow$ **$\sigma_{SI} \simeq 6.3 \times 10^{-48}$ cm^2**

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ARGO Projected Sensitivity

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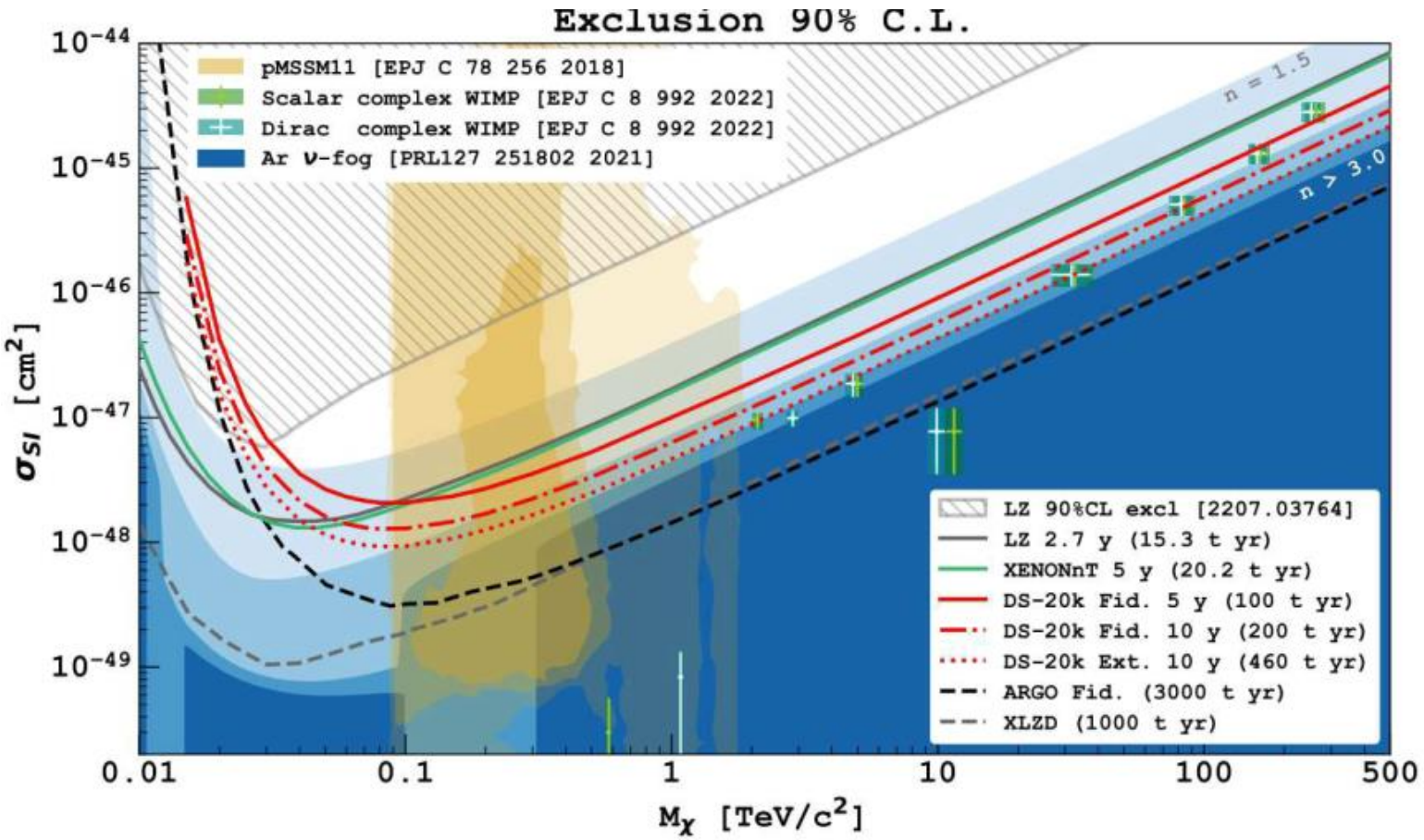

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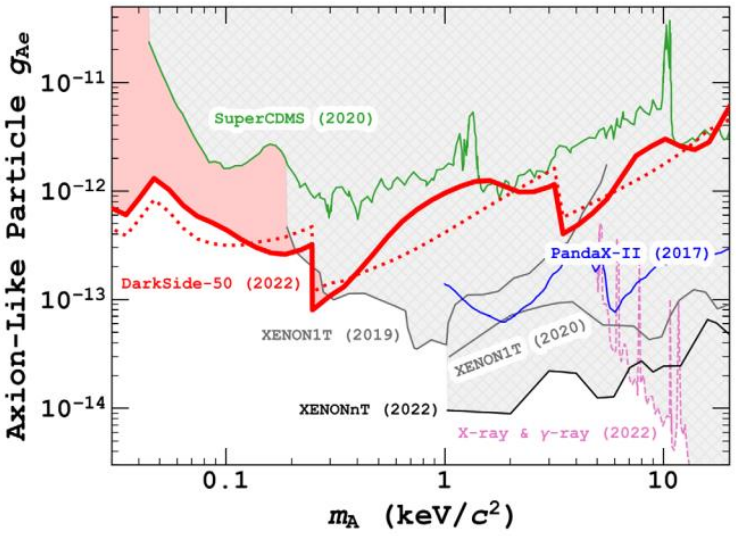
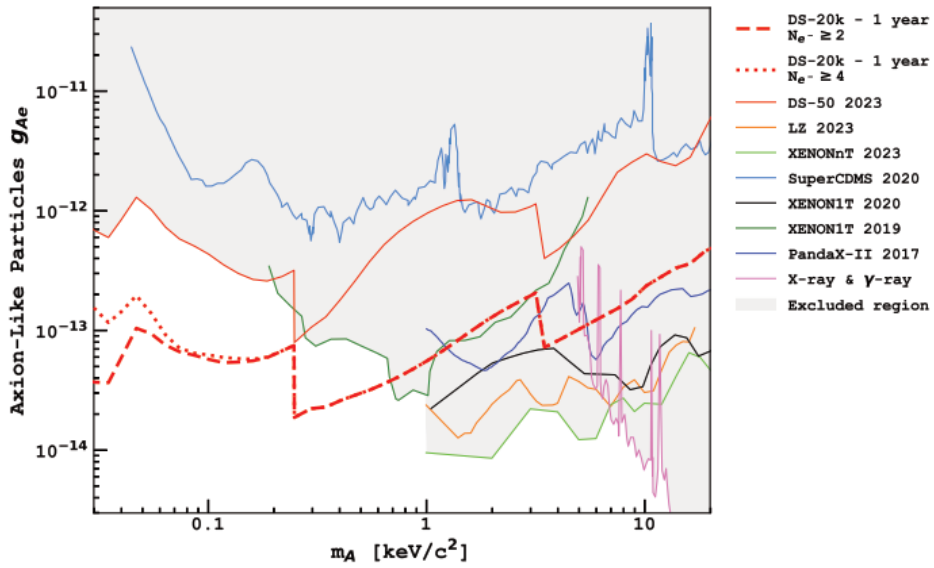
Sensitivity to Axions-like Particles



DARKSIDE-50 Result

PRL 130, 101002 (2023)



DARKSIDE-20k Predictions

arXiv:2407.05813v1 [hep-ex] 8 Jul 2024

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Summary

- DARKSIDE-20k is pushing the state-of-the-art knowledge in various technological areas
- DARKSIDE-20k is in position to lead the search for WIMPs above the LHC center of mass energy
- Achievement of background-free operation and low energy threshold is realistic and will allow to investigate also low DM masses
- DARKSIDE-20k construction is ongoing
- Data taking will start in 2027

DARKSIDE