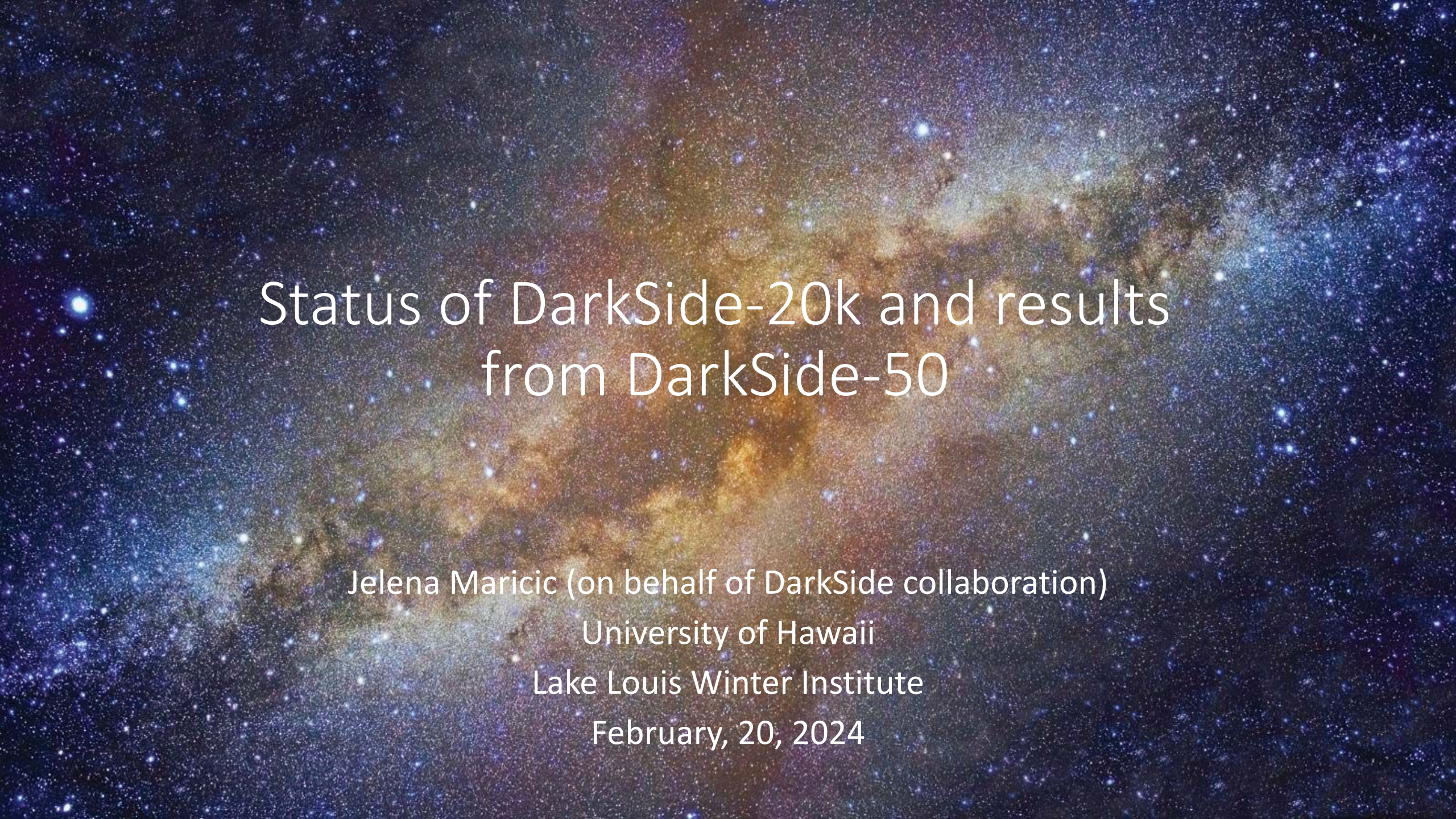
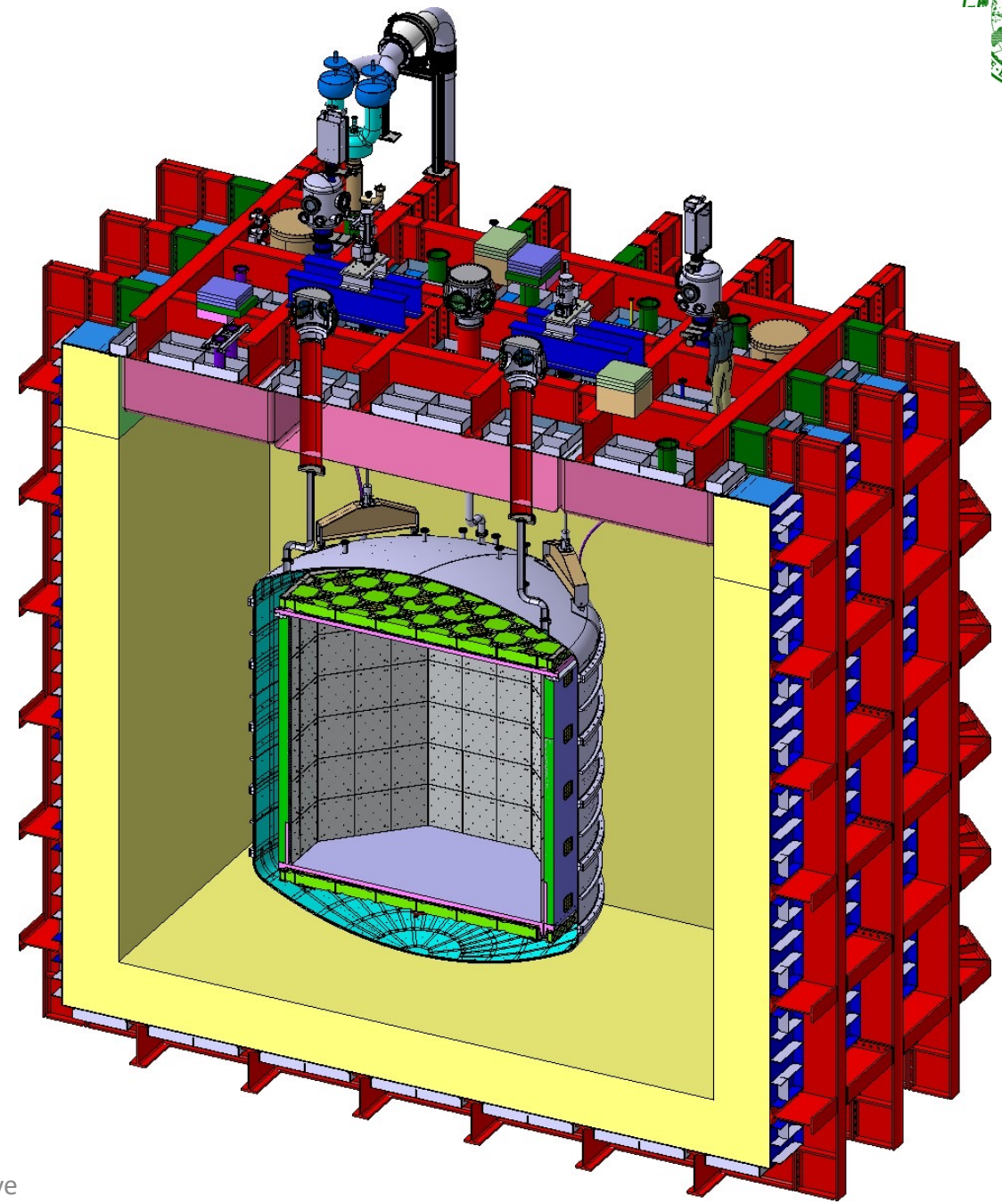


Status of DarkSide-20k and results from DarkSide-50

Jelena Maricic (on behalf of DarkSide collaboration)
University of Hawaii
Lake Louis Winter Institute
February, 20, 2024

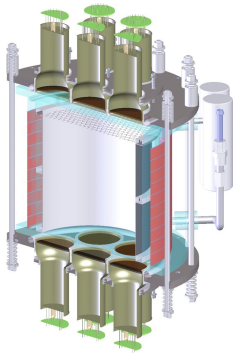
Outline

- Detection principle in dual phase Liquid Argon Time Projection Chamber (LAr TPC)
- DarkSide-20k detector design
- DarkSide-20k dark matter detection prospects
- Low mass search with DarkSide-50 and future prospects
- Summary



DarkSide Program: A multi-stage approach

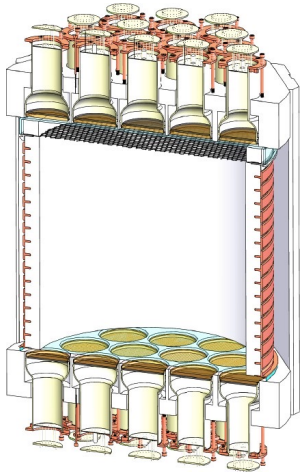
2012



DarkSide-10

- First prototype
- Helped to refine TPC design
- Demonstrated a light yield >9PE/keV$_{ee}$

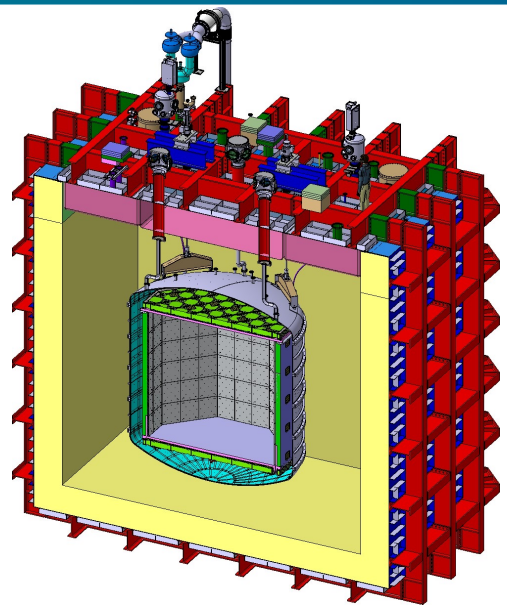
2013 - 2018



DarkSide-50

- Science detector
- Demonstrated the use of UAr
- First background-free results
- Best limits for low mass WIMP searches

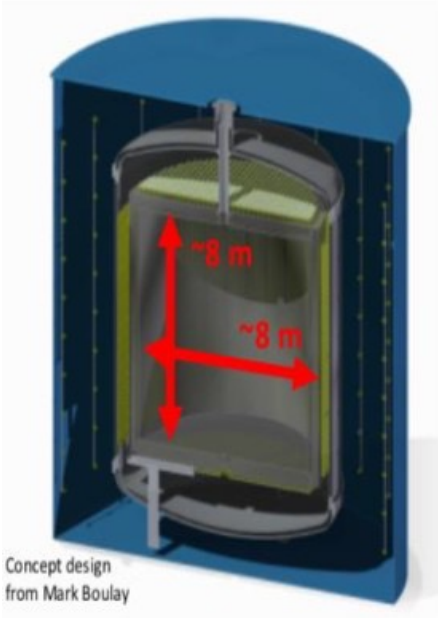
2026 - 2036



DarkSide-20k @LNGS

- Novel technologies
- First peek into the neutrino fog*
- Nominal exposure: 200 t y

2030s - …

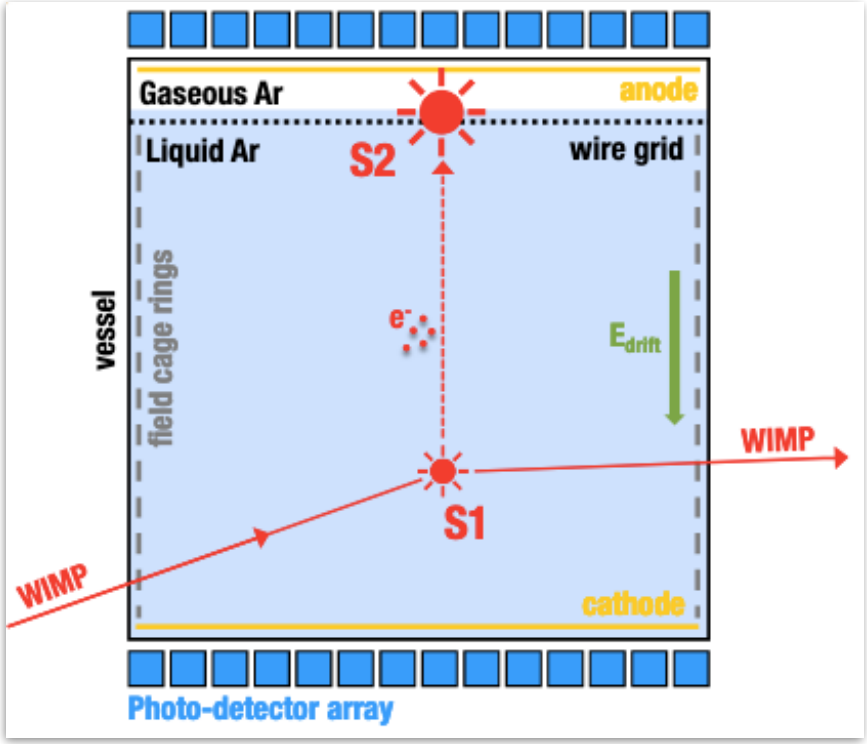


Argo (next talk)

- Ultimate LAr DM detector
- Push well into the neutrino fog
- Nominal exposure: 3000 t y

**Neutrino fog – irreducible background due to atmospheric and diffused supernovae neutrinos*

Dual-phase Time-projection Chamber (TPC)



- Pair of signals: S1 followed by S2
- S1– scintillation in Liquid Argon
- S2 – electroluminescence
  - Scintillation in gas phase proportional to extracted ionization charge

- Event vertex reconstruction in **3D**
- **Z**: charge drift, Δt(S2–S1), **time-projection**
- **XY**: reconstruction from top array pattern S2

Argon as a WIMP detection target

✓ Large signals (high photon yield and high charge yield)

✓ Easily scalable to ton-scale detectors + self-shielding

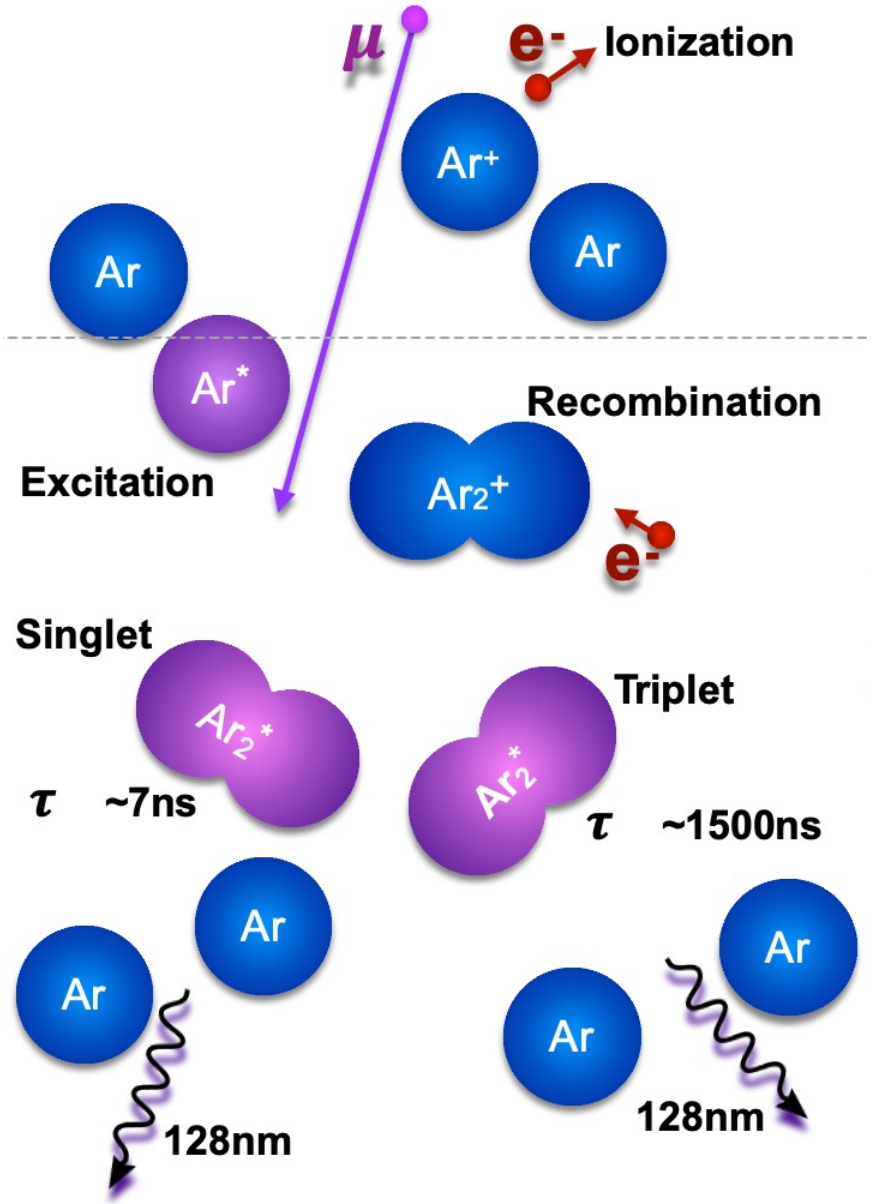
✓ Transparent to its own light

✓ Easy to purify for both electro-negative impurities and chemical impurities

✓ Argon source with low radioactivity (^{39}Ar) available

✓ A couple of electron recoil (ER) background rejection techniques (S2/S1, PSD)

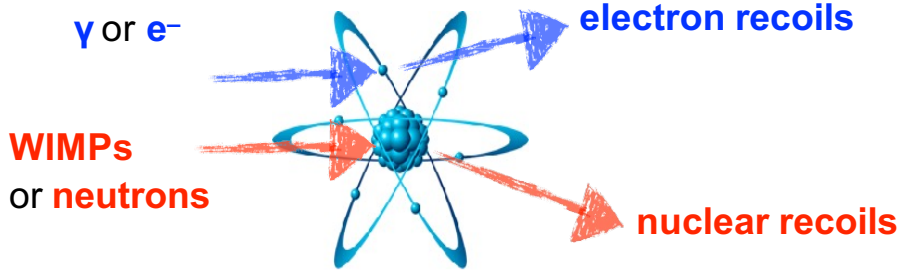
Pulse Shape Discriminations of ERs/NRs in LAr



- Excited argon atom combine with another argon atom to form excimers (excited dimers)
- They come in singlet (τ ~ 7ns) and triplet states (τ ~ 1500ns)
  - *Decay constant for triplet state much longer than for singlet*
- Scintillation light (λ = 128 nm) is a product of excimer decay
- NRs are characterized by much larger dE/dx than ERs

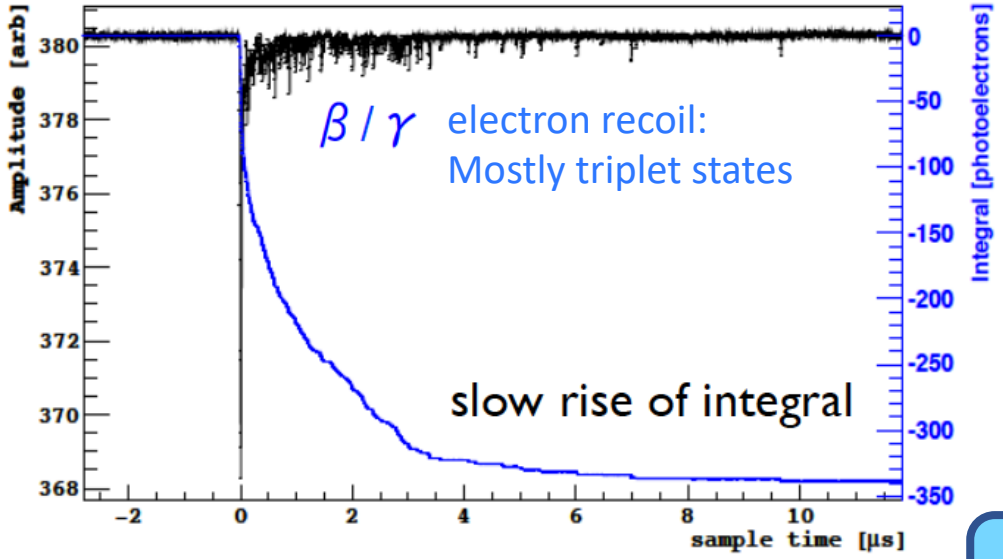
  →Scintillation light from the triplet states is severely suppressed in case of NRs compared to ERs
- Scintillation light time profile to distinguish:

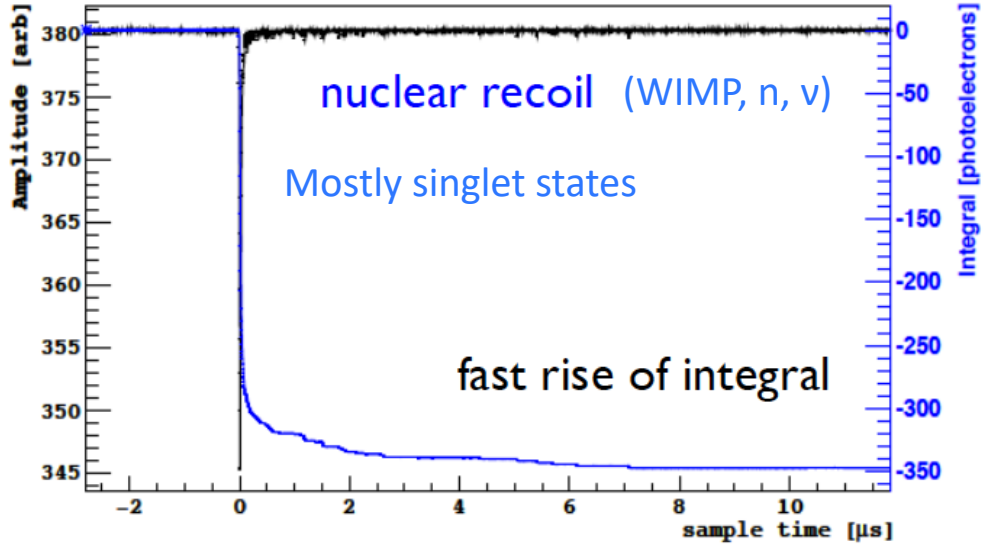
NRs (neutrons + WIMPs) from ERs (background)



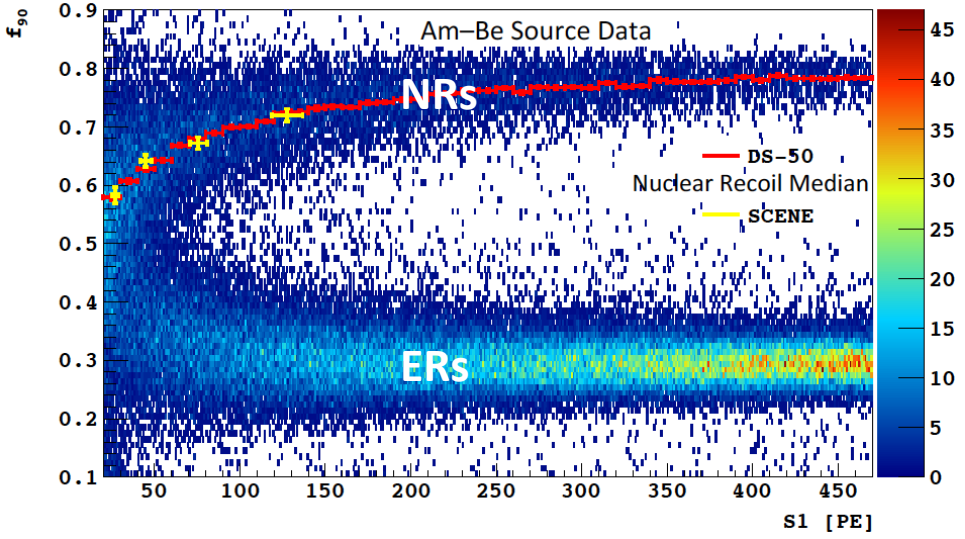
Electron Recoil (ER) Rejection in LAr: PSD

- Prompt light integral / total light integral clearly different for ERs and NRs





$$f_{prompt} = \frac{Prompt\ light}{Total\ light}$$



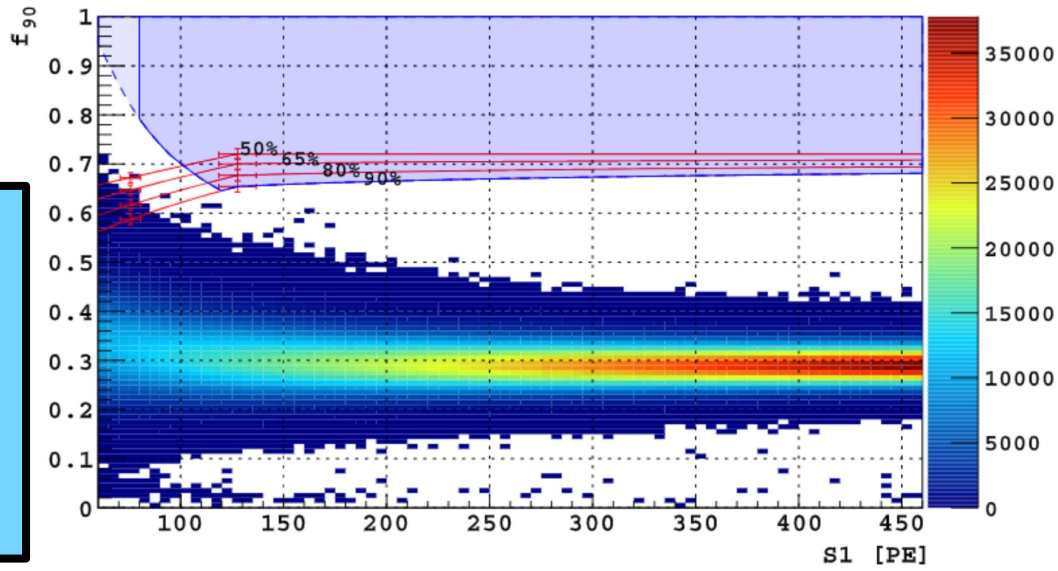
β , γ rejection

>1.5x10^7 in DS-50

10.1016/j.physletb.2015.03.012

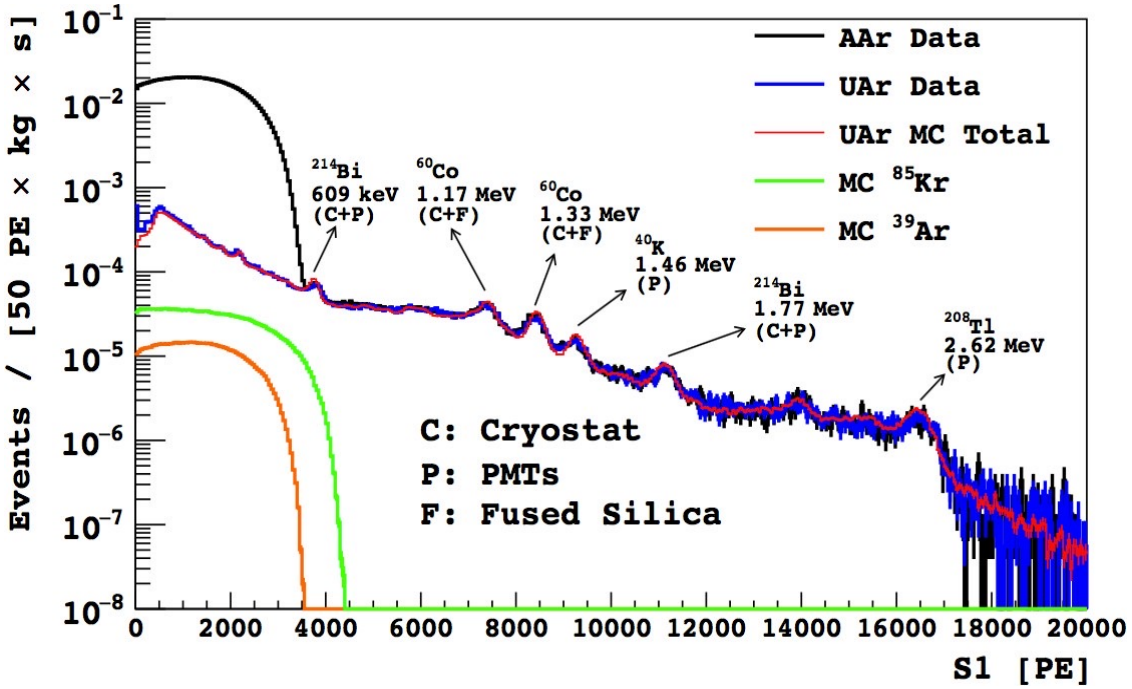
>1x10^8 (DEAP3600)

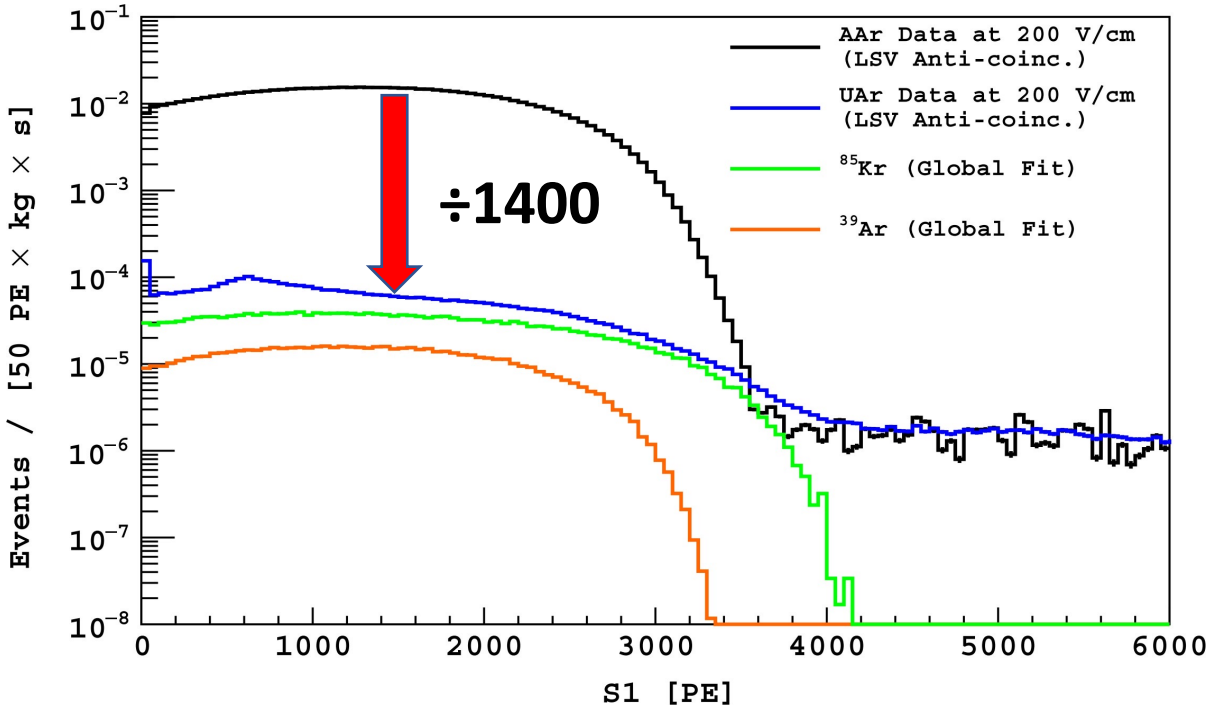
Eur. Phys. J. C 81,823 (2021)



DarkSide-50 *10.1016/j.physletb.2015.03.012*

^{39}Ar: Liquid Argon Intrinsic Background





- Radioactive, β-decay, $T_{1/2}$ = 269 years; 565 keV end point
- Cosmogenic: ^{40}Ar(n,2n)^{39}Ar in the atmosphere
- ~1 Bq/kg in atmospheric Ar – the main intrinsic background in Ar detectors

- ^{39}Ar activity sets DM detection threshold at low energies (PSD ineffective) due to pile-up
- **Argon from underground sources contain much less ^{39}Ar → 1400 suppression measured in DarkSide-50**
- Even higher suppression of ^{39}Ar possible.

Global Argon Dark Matter Collaboration (GADMC)

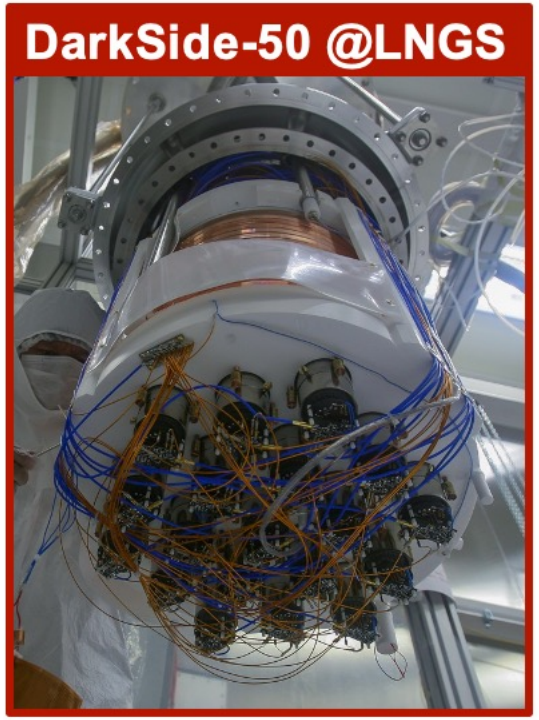
- Joint expertise of several argon dark matter experiments.
- Multi-national collaboration of >400 from
- >100 institutions, 14 countries, with a two-step program.

Intermediate goal:

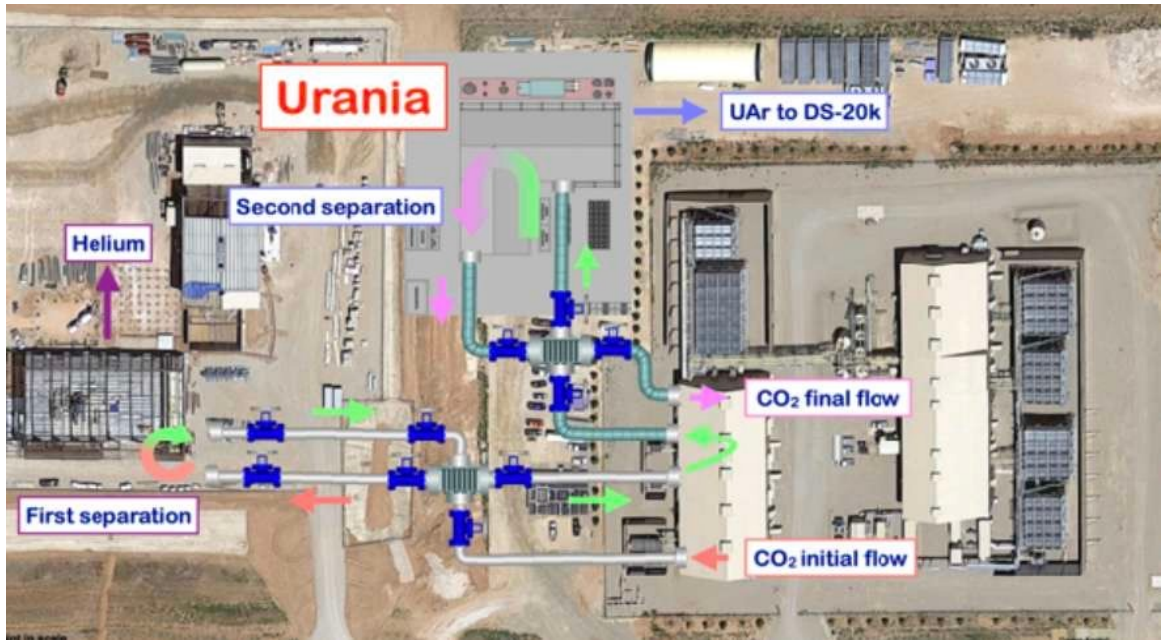
DS-20k, 200 ton yr exposure

Ultimate goal:

ARGO, 3000 ton yr exposure

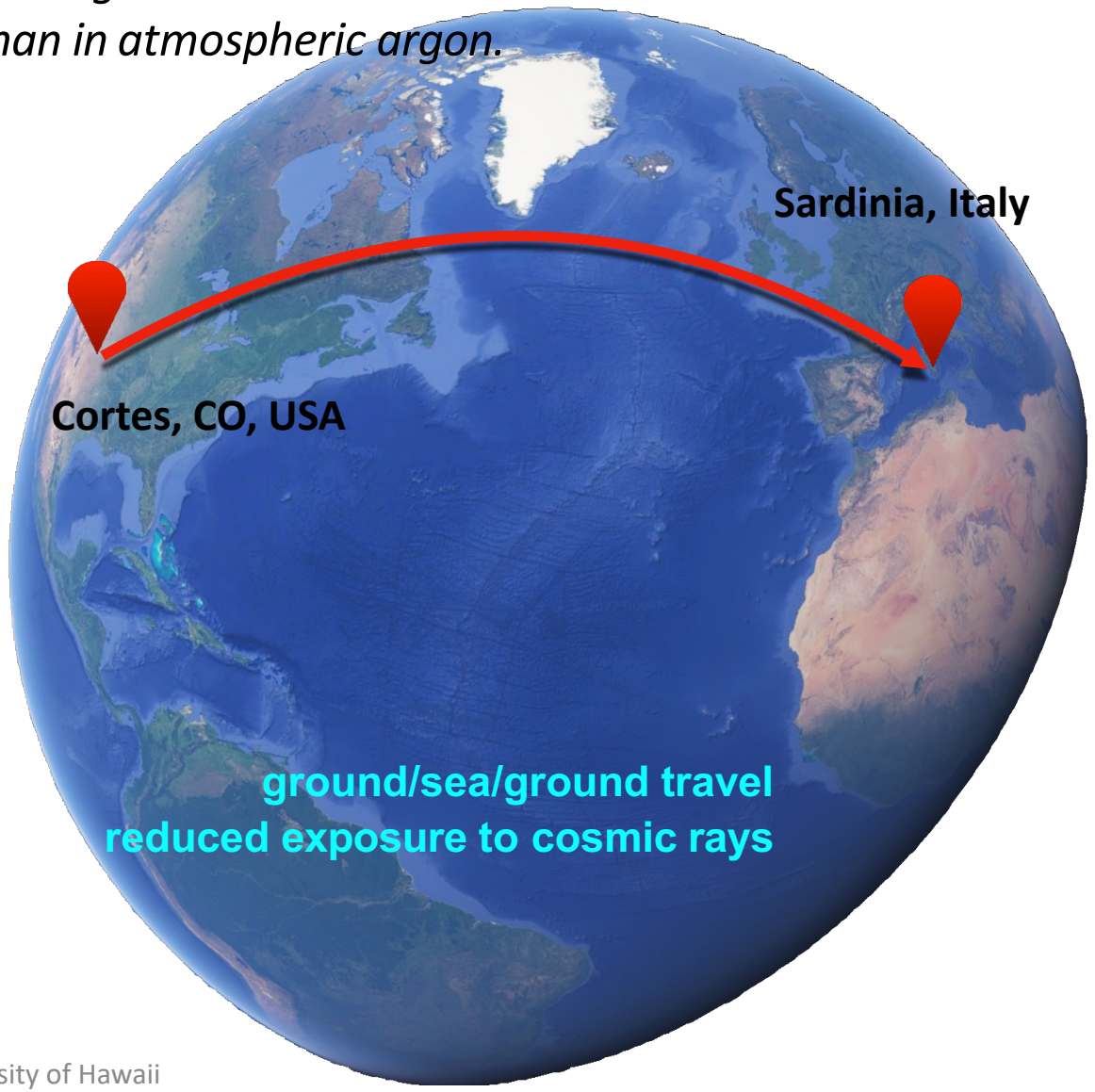


Journey of Underground Argon: Extraction



- CO_2 well in Cortez, CO, USA;
- 150 kg of UAr extracted for DarkSide-50 (140 gr/day)
- Industrial scale extraction plant- Urania project;
- Civil work ongoing;
- Expected argon purity at outlet: 99.99%;
- UAr extraction rate: 250 kg/day;
- Additional experiments interested in UAr from Urania: Argo, COHERENT, LEGEND1000

Underground well: ^{39}Ar concentration 1400 times lower than in atmospheric argon.

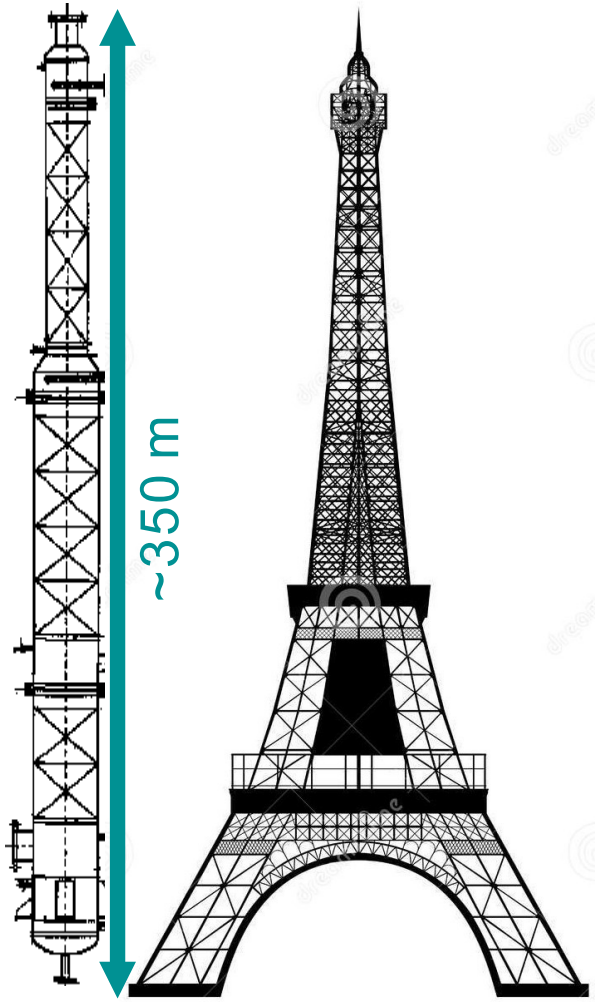


Journey of UAr: Purification

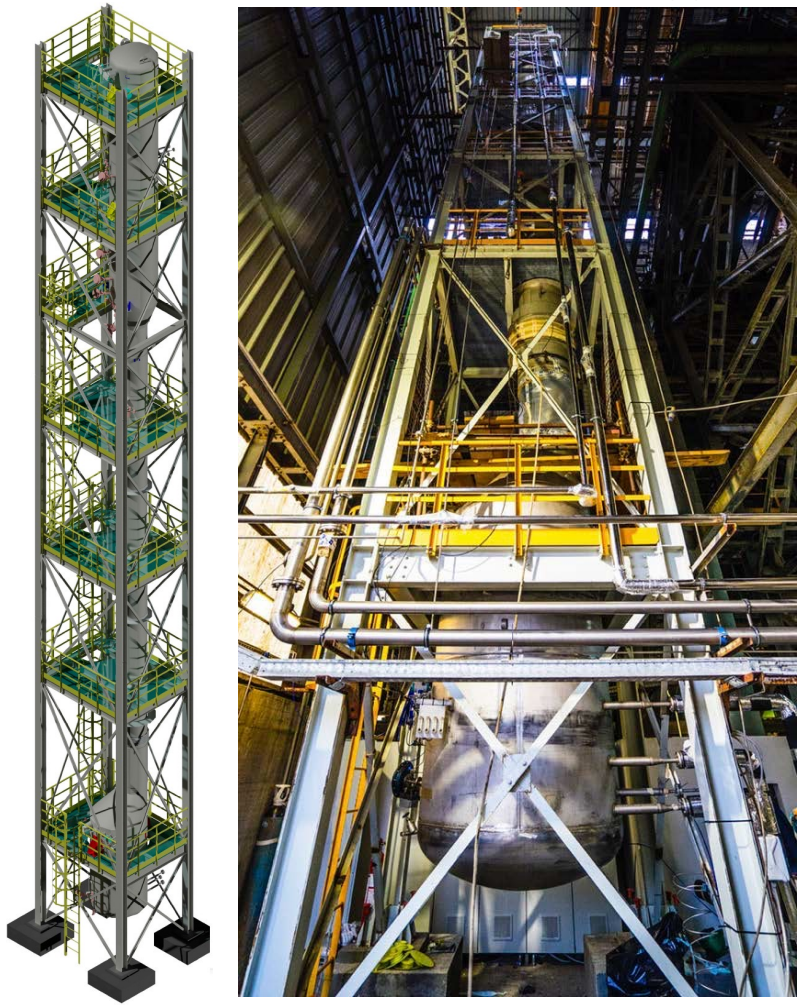
ARIA: UAr distillation plant for cryogenic isotopic destilation of ^{39}Ar

- Cryogenic distillation column in Sardinia (Italy).
- At least two more orders of magnitude reduction in nitrogen concentration (10^{-4} to 10^{-6}) by chemical purification
- Installed in the shaft of a coal mine
- Seruci-1: 350 m tall distillation column
- Seruci-0: 26 m tall already demonstrated ^{36}Ar - ^{40}Ar separation performances in a few days run
- Potential for isotope separation demonstrated on nitrogen in the Seruci-0: Eur.Phys.J.C 83 (2023) 5, 453

Sketch of ARIAwhen fully assembled

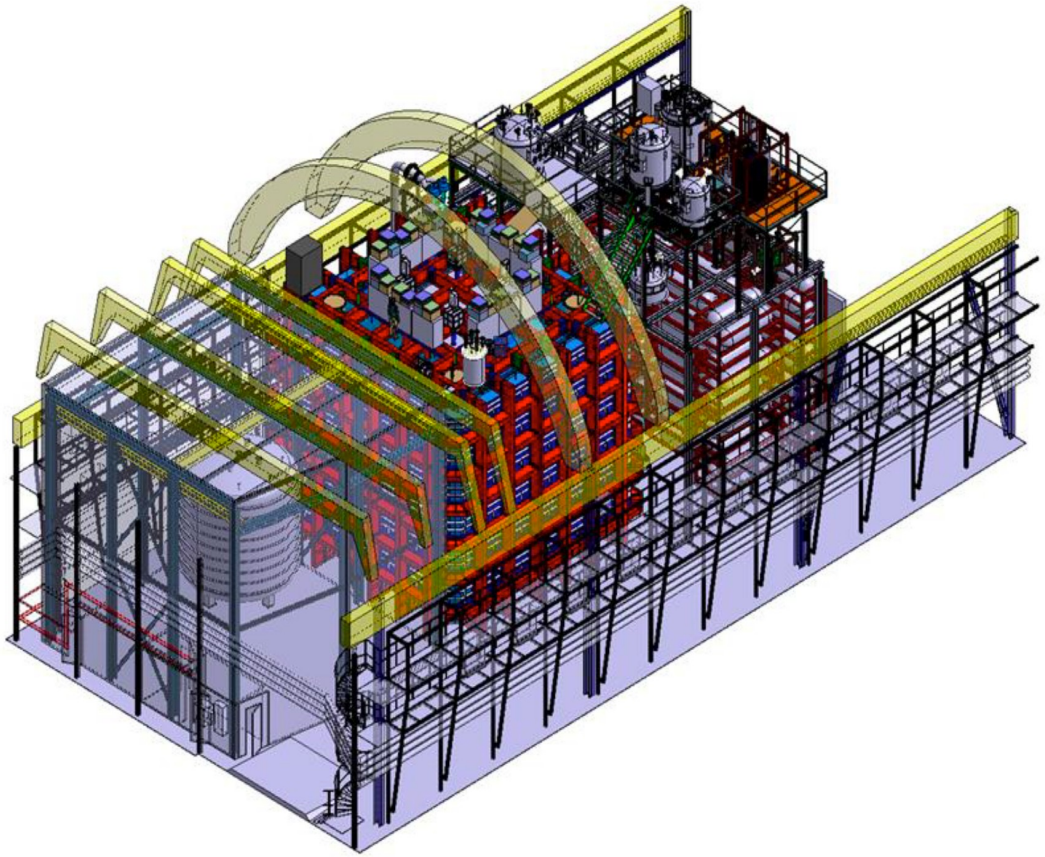


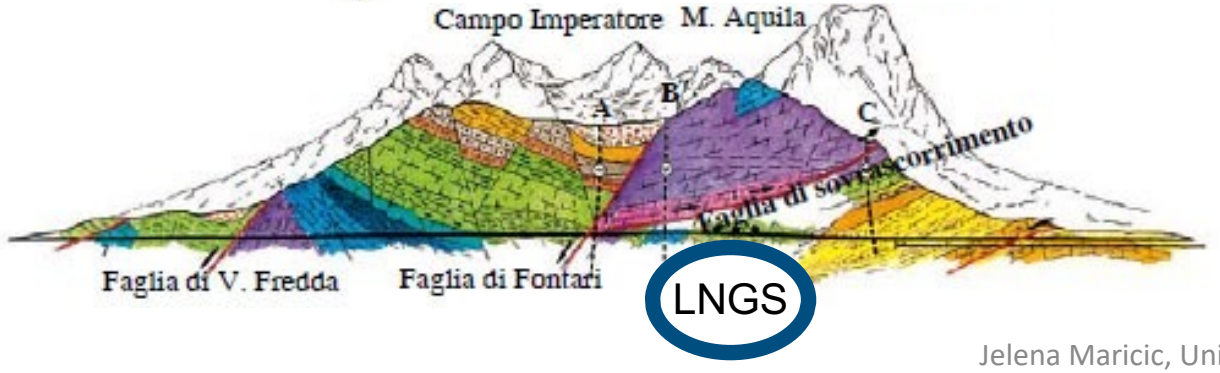
Drawing and picture of ARIA distillation column prototype



Eur.Phys.J.C 81 (2021) 4, 359

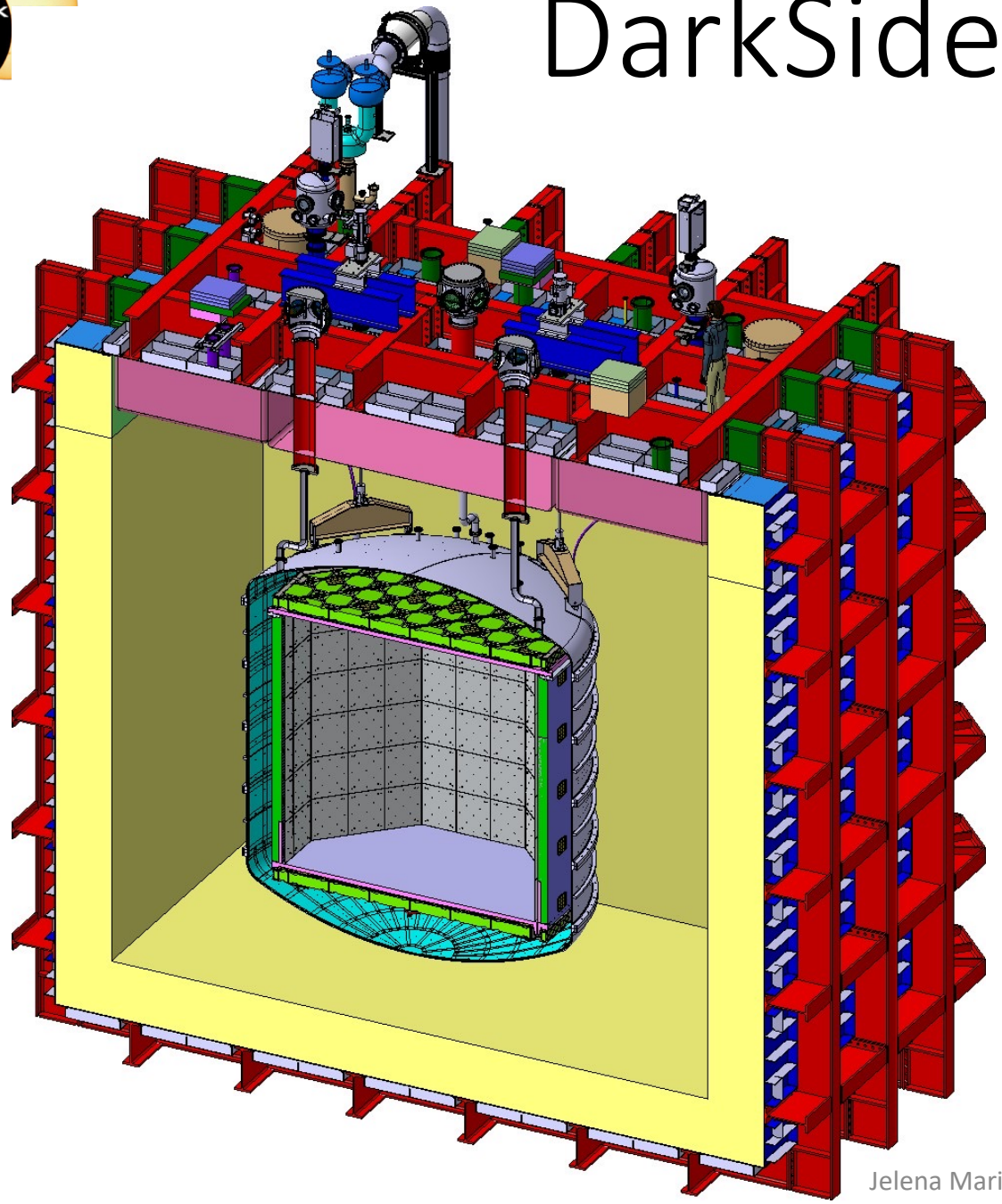
Host Laboratory for DarkSide-20k: LNGS





- Below ~1400m of rock (3400 m.w.e)
- Muon flux reduction factor ~10^6
- 3 main experimental halls (20x100x18 m^3)

DarkSide-20k Overview



Nested detectors structure:

ProtoDUNE-like cryostat (8x8x8m^3) - Muon veto

SS vessel separating AAr from underground UAr.

Gd-doped acrylic veto for neutrons

WIMP detector: dual-phase TPC hosting 50t of LAr

Fiducial mass: 20 tonnes

Silicon photomultiplier modules for light detection in the TPC and veto (~26 m^2)

Multiple detection channels for bkg supression:

Neutron after cuts: < 0.1 in 10 y

β and γ after cuts: < 0.1 in 10 y

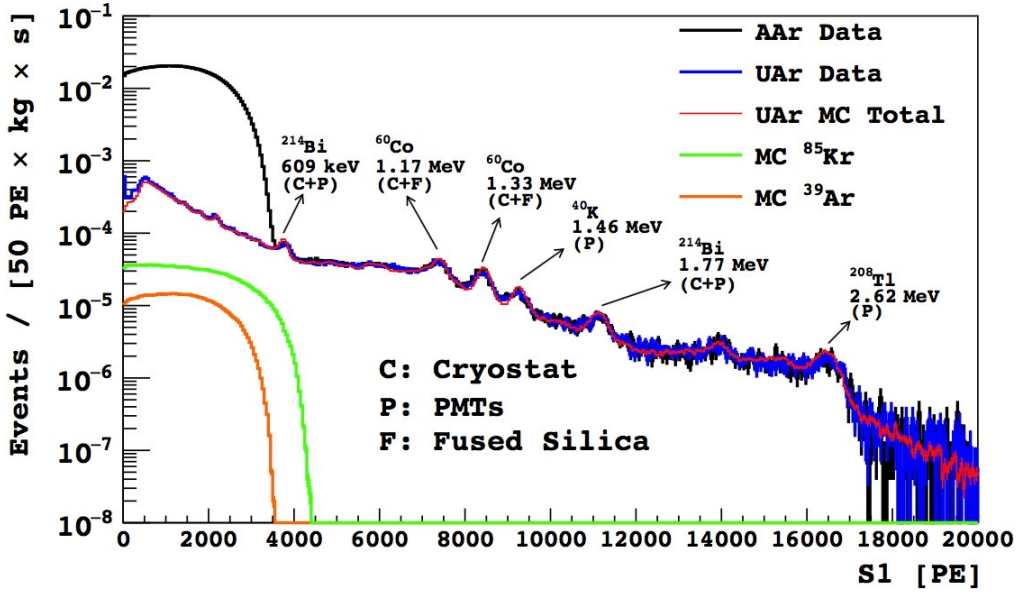
Position reconstruction resolution:

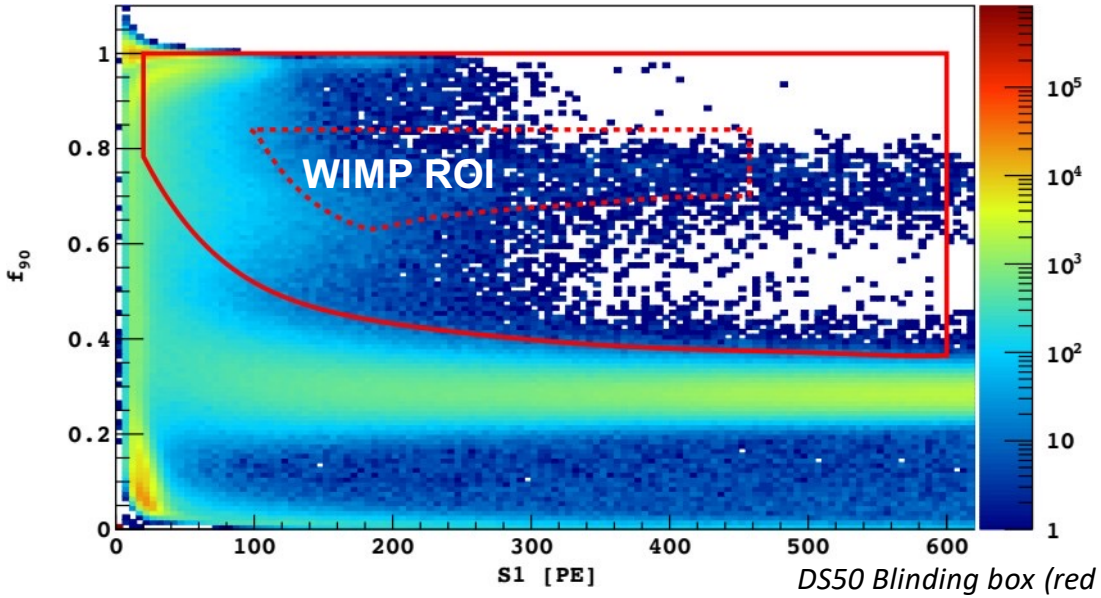
~ 1 cm in XY

~ 1 mm in Z

Backgrounds and Mitigation Strategies

Goal: <0.1 neutron in RoI (30~200 keV_{nr}) with 200 t-y exposure.





DS50 Blinding box (red outline) shown with 71-day data: PRD 93, 081101

Electron Recoils (ER)

^{39}Ar β decays → Use of UAr, PSD depleted Ar

γ decays from U,Th chains + non actinides (^{40}K, ^{60}Co, ^{137}Cs) → Material selection, PSD

Surface events

Radon progeny → Fiducialize, Surface cleaning, cryogenic Rn trap

Nuclear Recoils (NR)

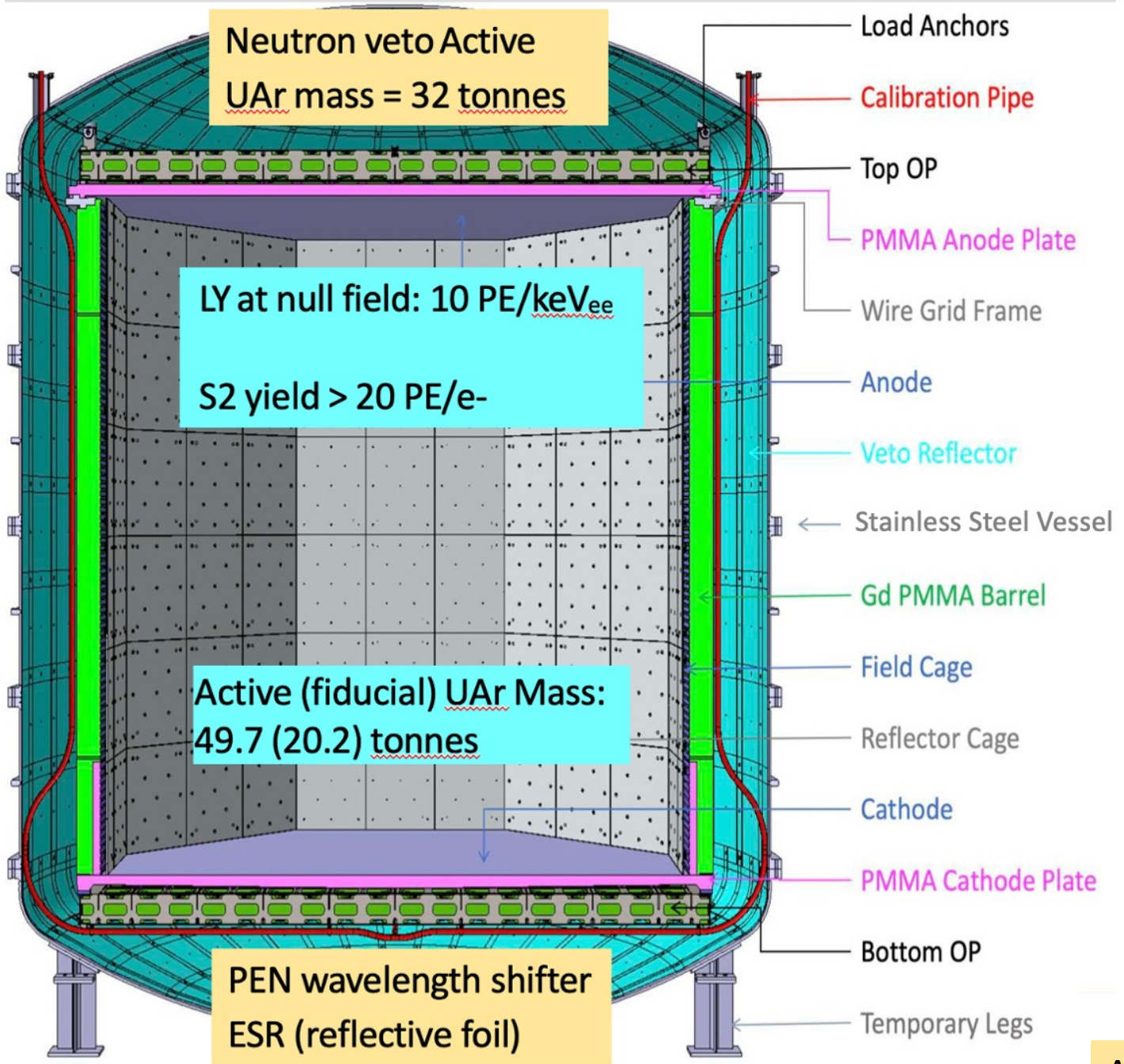
Radiogenic neutrons, mainly from (α,n) reactions.

→ Material selection, Neutron Veto

Cosmogenic neutrons, from materials activation due to residual muon flux → Muon Veto

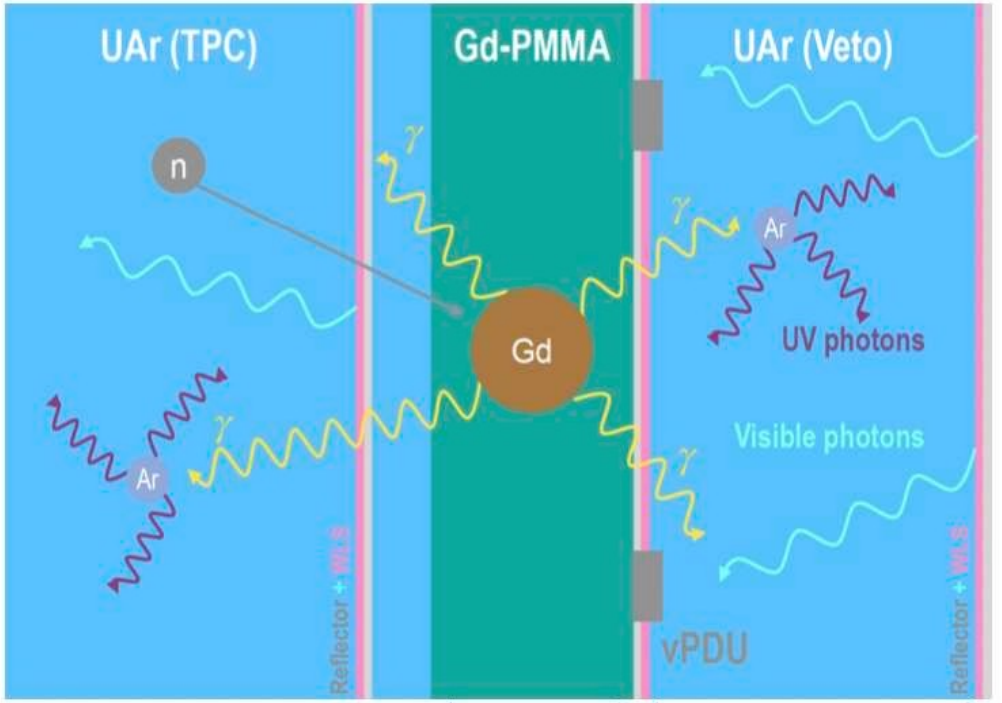
Atmospheric neutrinos → Irreducible

Inner Detector



Clevios™ coating serving as anode, cathode and field cage rings

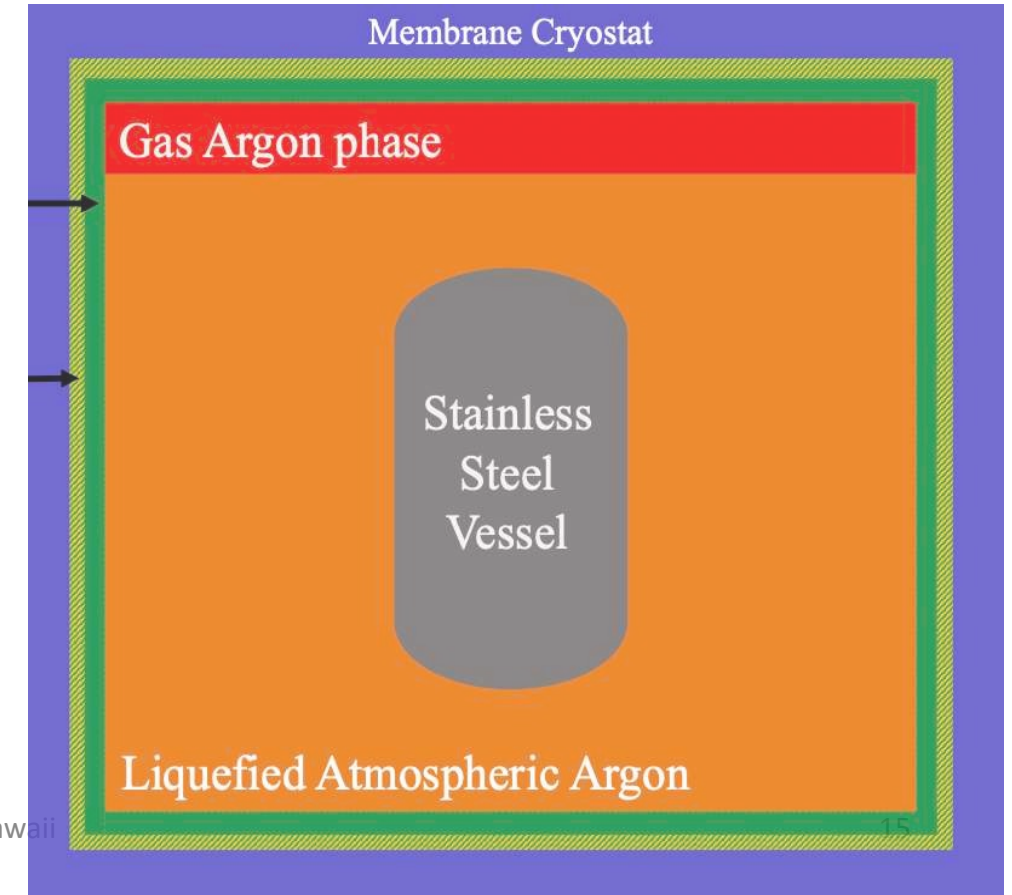
ESR (reflective foil)
+ TPB wavelength shifter



Active veto bkg tagging

Outer Detector

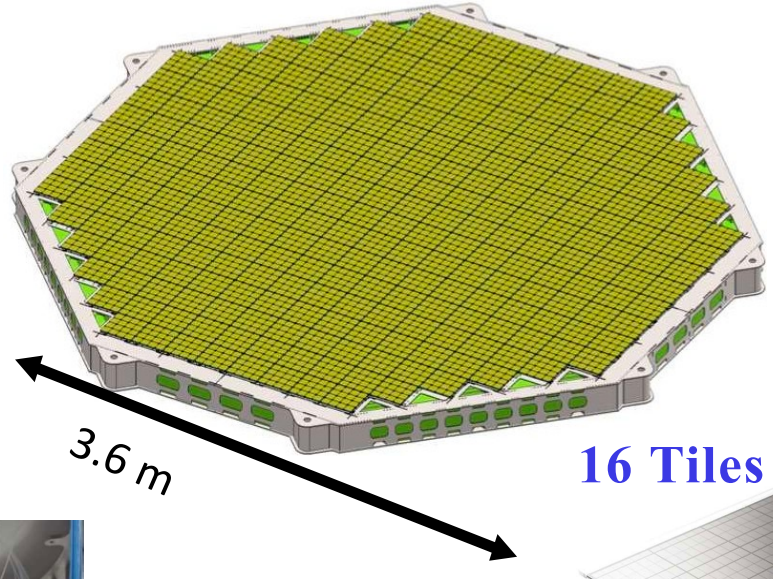
Low radioactivity membrane cryostat
Light Yield: 10 PE/MeV
For the WIMP search: cosmogenic < 0.016 events in 10 years exposure



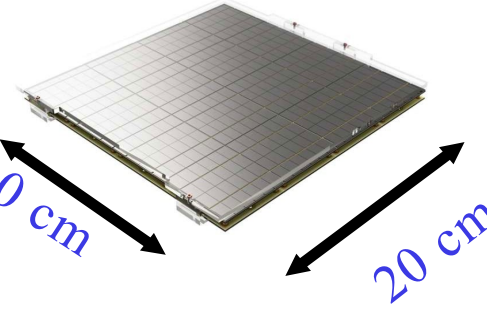
Photodetectors

- Cryogenic SiPMs developed with Fondazione Bruno Kessler (FBK):
  - PDE > 40% @ 77K;
  - DCR < 0.01 Hz/mm^2 @ 77K (7 VoV);
  - SNR > 8 (TPC);
- Need 26 m^2 for both TPC and veto!
- 680 PDUs!

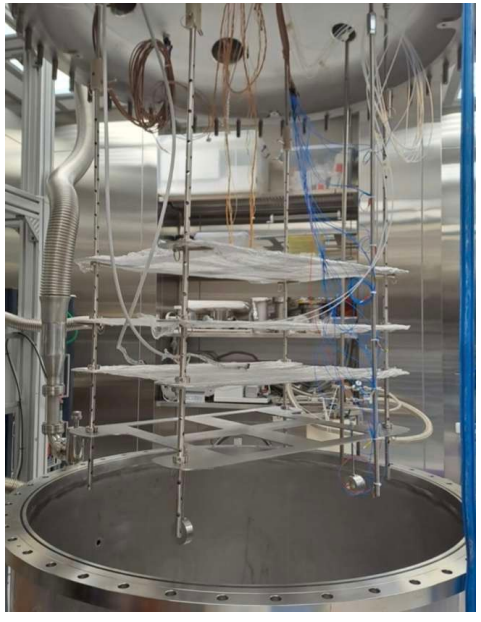
Optical Plane with 1056 channels



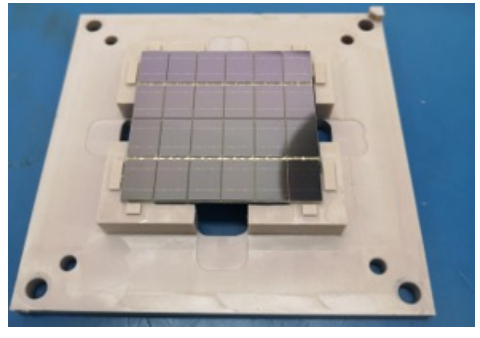
16 Tiles = 1 PDU



Nuova Officina at Assergi



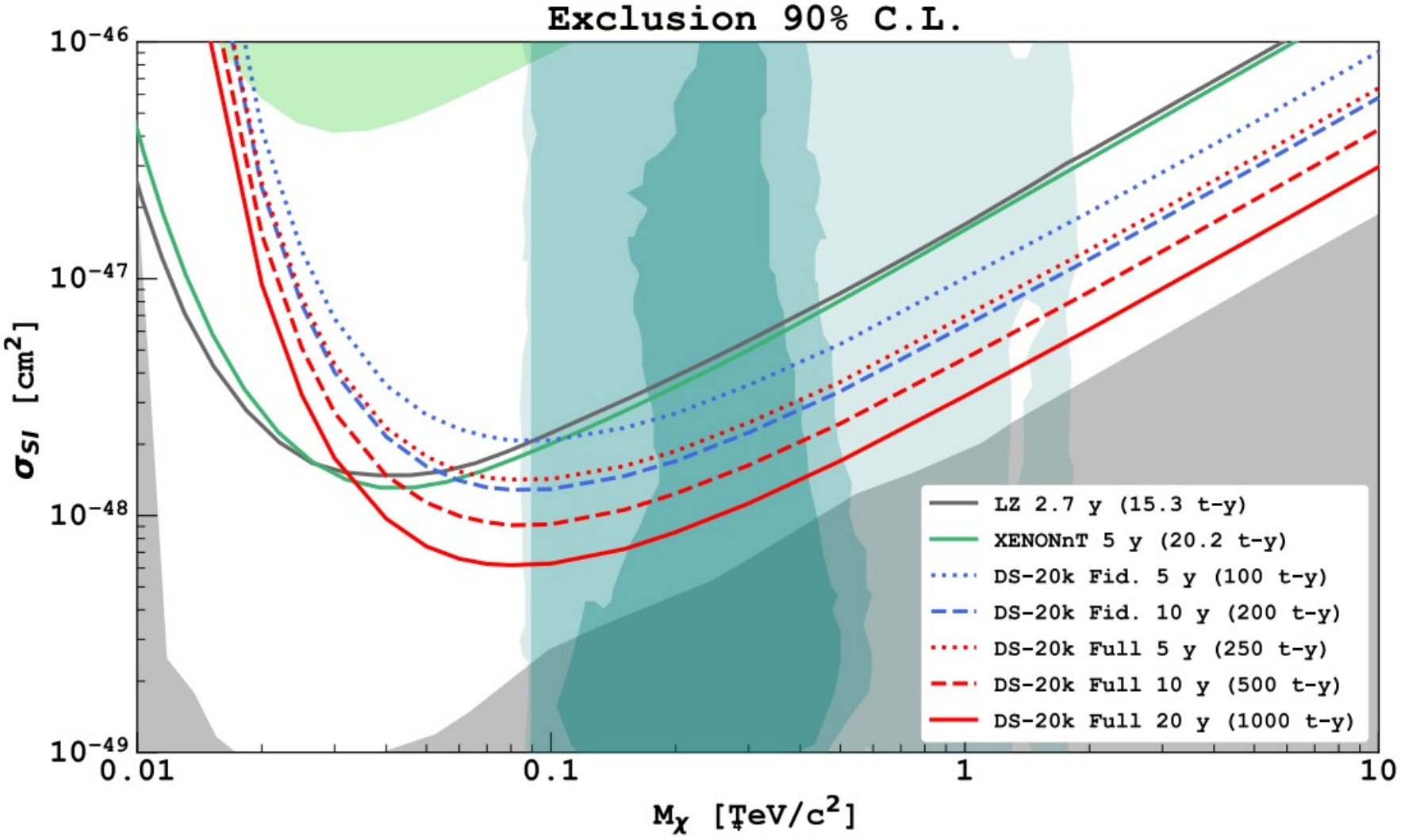
Test facility in Naples



Tile
5 cm x 5 cm
24 SiPMs

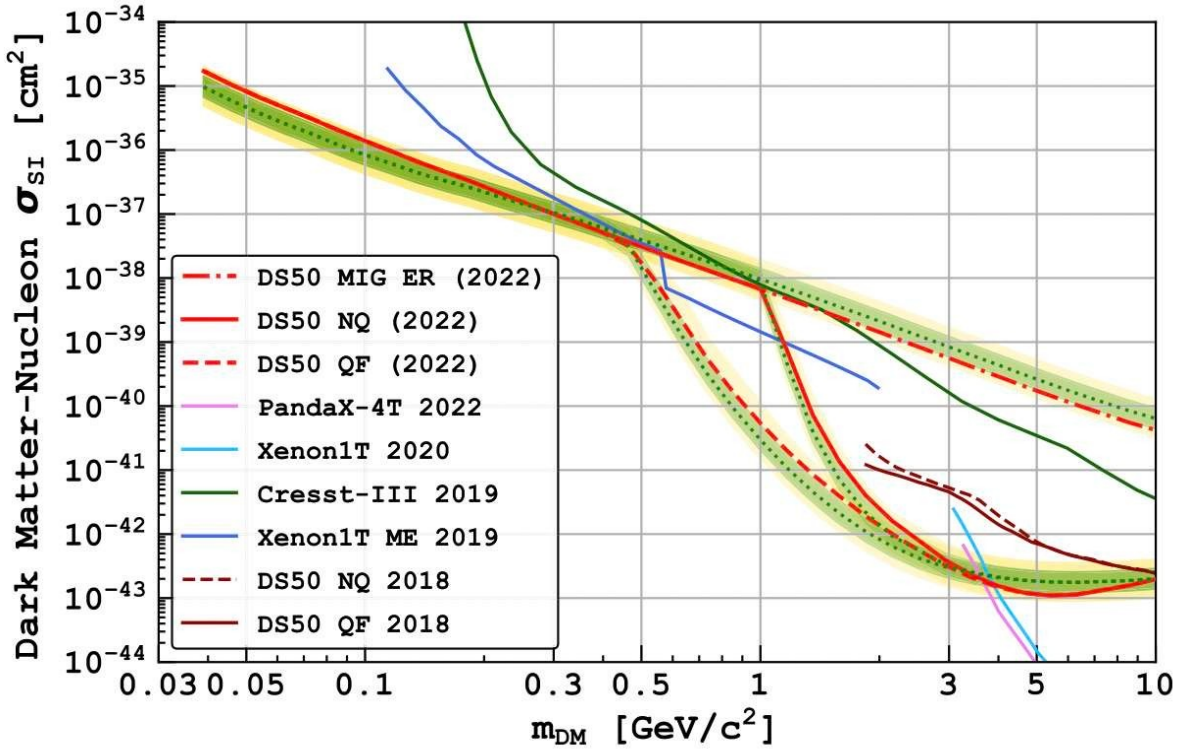
DarkSide-20k Physics Reach

- Sensitive to Spin Independent WIMPs
- Sensitivity: 6.3 × 10^{-48} cm^2 for a 1 TeV/c^2 WIMP (90% C.L.)
- (5σ) discovery: 2.1 × 10^{-47} cm^2 for a 1 TeV/c^2 WIMP
- Nominal exposure: (20×10) t yr
- Instrumental Background: 0.1 events in 200 t yr in RoI (30~200 keVnr)
- Expected neutrinos: 3.2 events in 200 t yr



Low-mass Dark Matter Search with DS-50

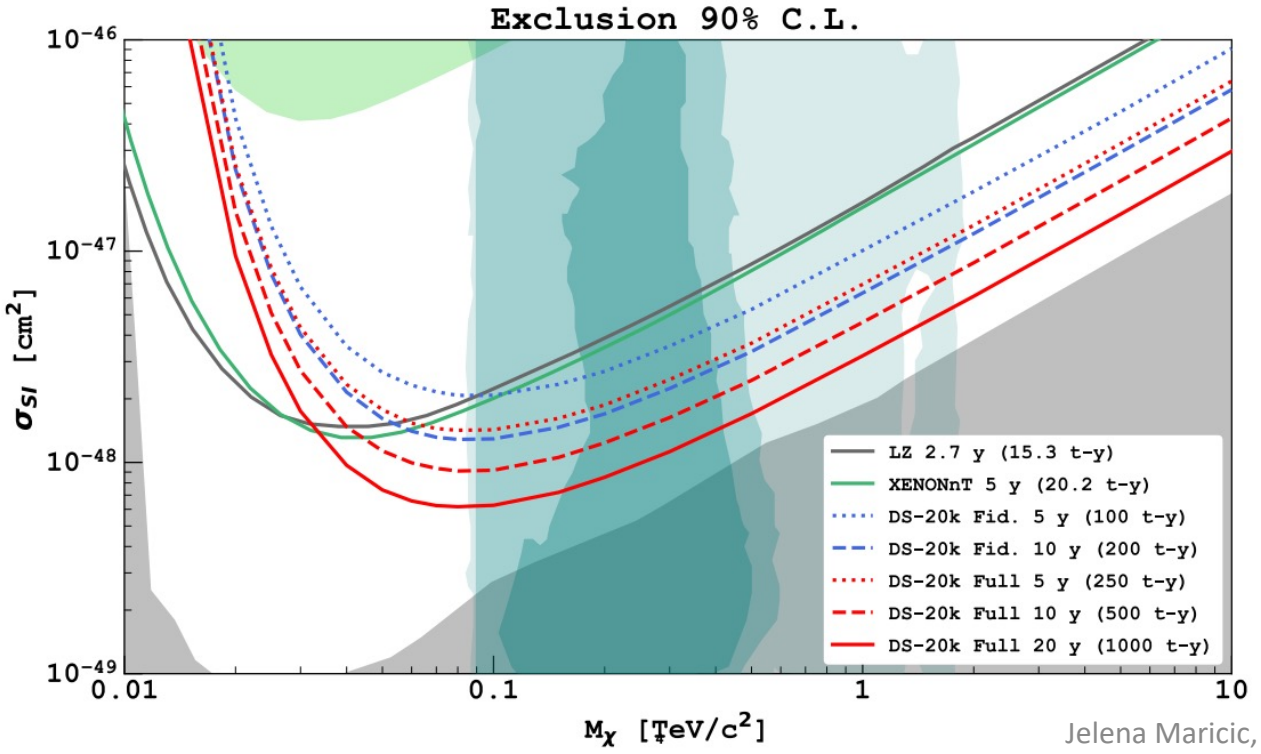
- High amplification (electroluminescence gain) of ~100 photons/e- enables low-mass DM search with S2 signal only
- Efficient electron detection capability down to 1e-
- Ionization electron extracted to gas-phase with ~100% efficiency
- S2-only signal; no PSD!
- Possible, thanks to high radiopurity of UAr target (low ER background)
- Contribution from spurious electrons (captured by impurities along their drift and reemitted with a delay) < $4e^-$

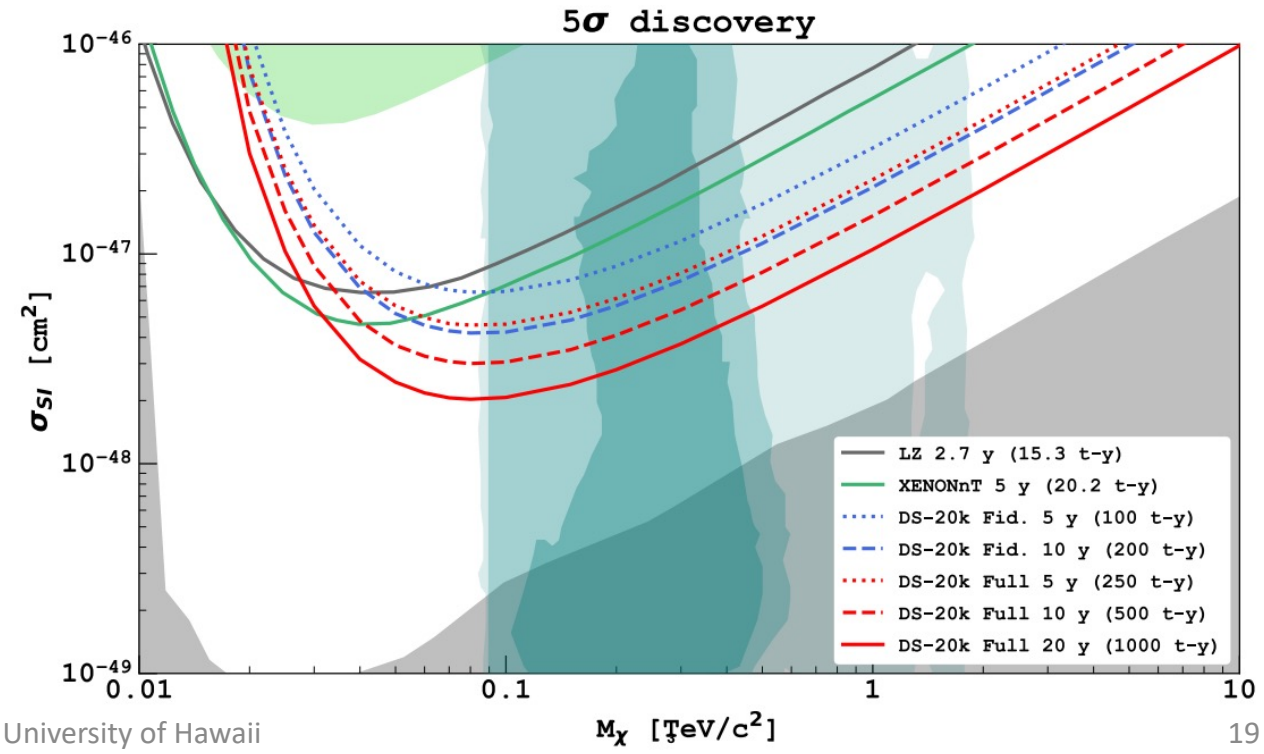


Physical Review Letters 130, 101001 (2023)

Summary

- ✓ Despite compelling astrophysical evidence, DM particle has not been directly detected yet
- ✓ DarkSide-20k builds upon vast experience of GADMC and successful, background-free DM search with DS-50
- ✓ DS-50 has the best limits on low-mass DM (1.2–3.6 GeV/c^2 WIMP);
- ✓ DS-20k background free run enabled by stringent material selection combined with unique TPC design, use of depleted Ar target, novel photon detectors, Gd-loaded acrylic veto, validated through calibration.
- ✓ DarkSide-20k will be the most sensitive DM detector for high-mass WIMP search with projected start in 2026.





Thank you!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