

Status and prospects of the DarkSide project

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on behalf of the GADMC Collaboration

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Outline

- Principle of LAr TPC
- GADMC Collaboration
- DarkSide-50 recent results
- DarkSide-20k overview
- Summary

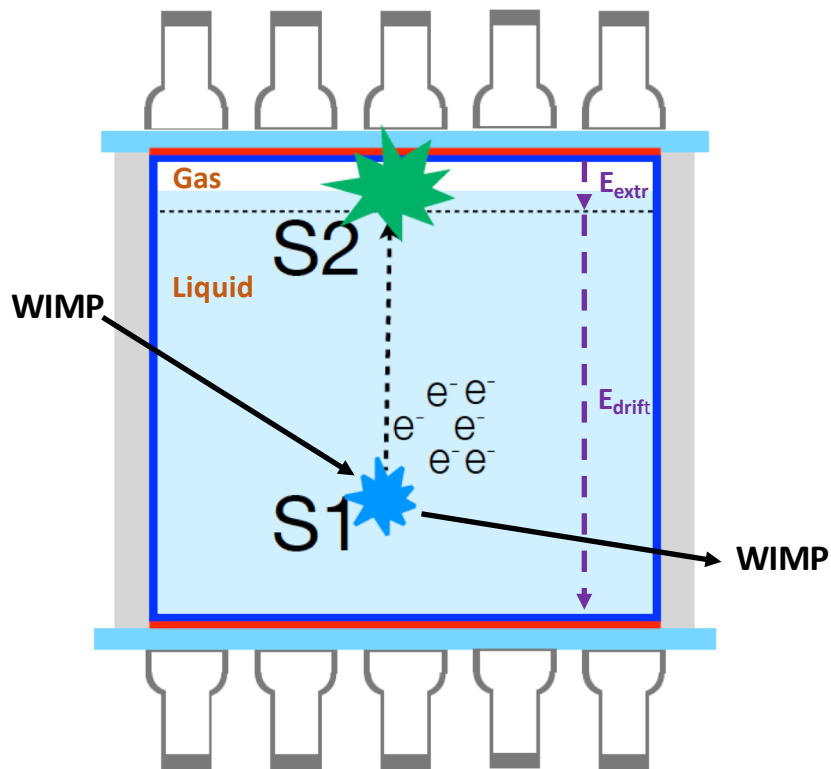
Liquid Argon as Target

- Relatively dense (1.4 kg/L)
- Easy to liquefy and purify (>5 ms electron lifetime)
- Good electron transport property
 - High electron mobility (~ 1 mm/us at practical drift field)
 - Low electron diffusion ($D_L \sim 4$ cm²/s, $D_T \sim 13$ cm²/s)
- High scintillation yield
 - ~ 40 k photons/MeV
 - Transparent to its own scintillation light (128 nm)
- Pulse Shape Discrimination (PSD)
 - Fast component: 7 ns
 - Slow component: 1.6 us
 - ER rejection power: $\sim 10^8$
- Main challenge
 - ^{39}Ar radioactive isotope, cosmogenic product, β decay emitter ($Q = 565$ keV), half life 269 y
- Solution: underground Ar

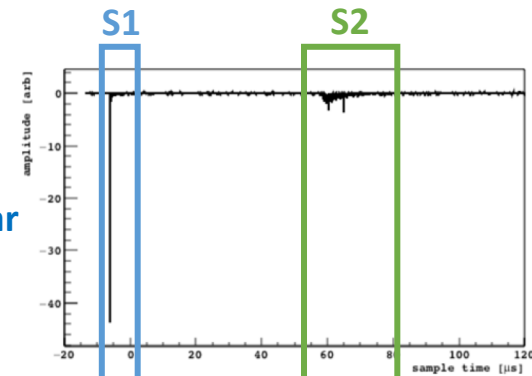
Dual-phase Liquid Argon TPC

- ✓ Particle identification
- ✓ 3D position reconstruction
- ✓ Scalability

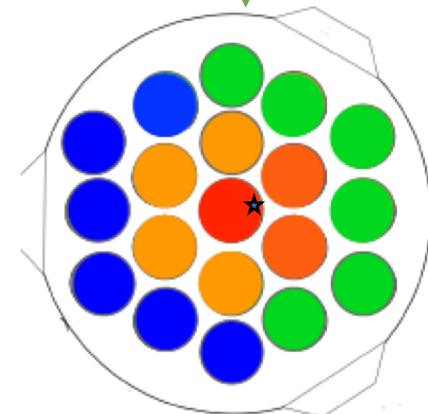
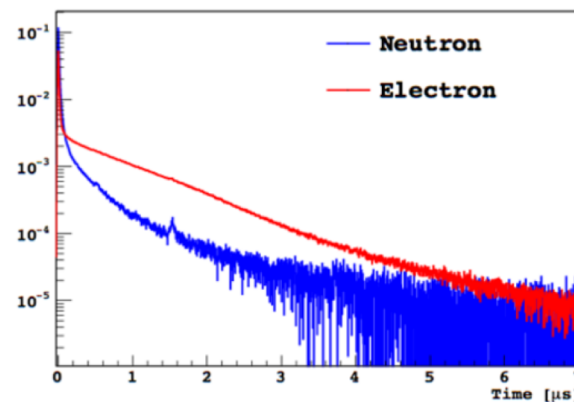
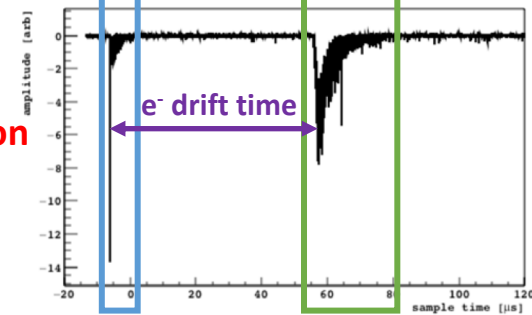
Light + Charge



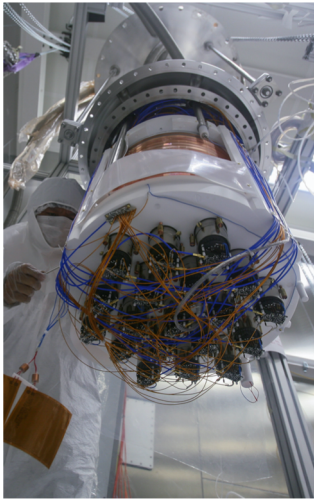
Nuclear recoil



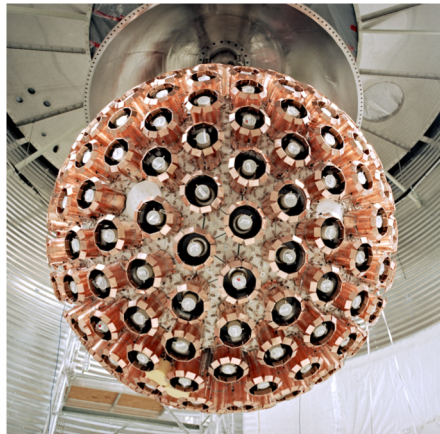
Electron recoil



Global Argon Dark Matter Collaboration

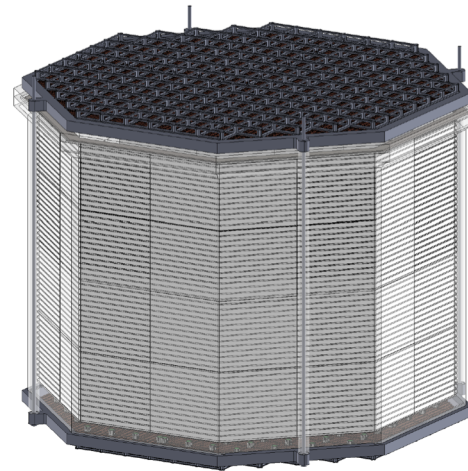
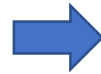


DarkSide-50
(running)
Dual phase
46 kg



DEAP-3600
(running)
Single phase
3.3 tonnes

miniCLEAN
ArDM



DarkSide-20k
Dual phase, 50 tonnes
2022-



~300 tonnes

ARGO
2030's

Letter of Commitment from underground labs :

- Laboratori Nazionali del Gran Sasso (LNGS)
- SNOLAB
- Laboratorio Subterraneo de Canfranc (LSC)

DarkSide-20k is now a CERN recognized
experiment: RE37

DarkSide-50 Recent Results

- High-Mass Analysis

Physical Review D 98 (10), 102006 (2018)

- Low-Mass Analysis

Physical Review Letters 121 (8), 081307 (2018)

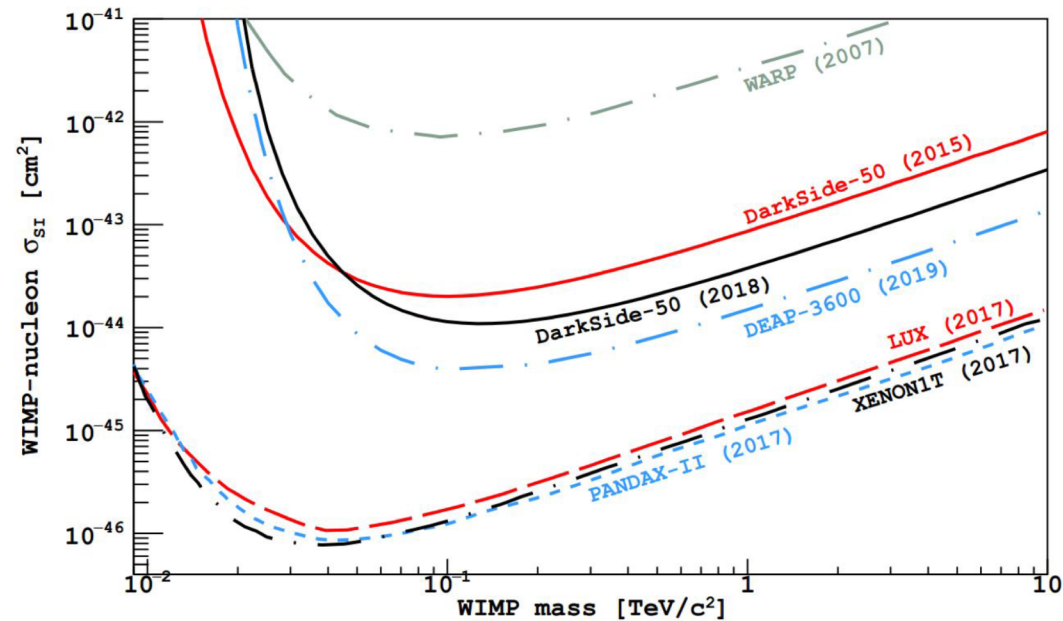
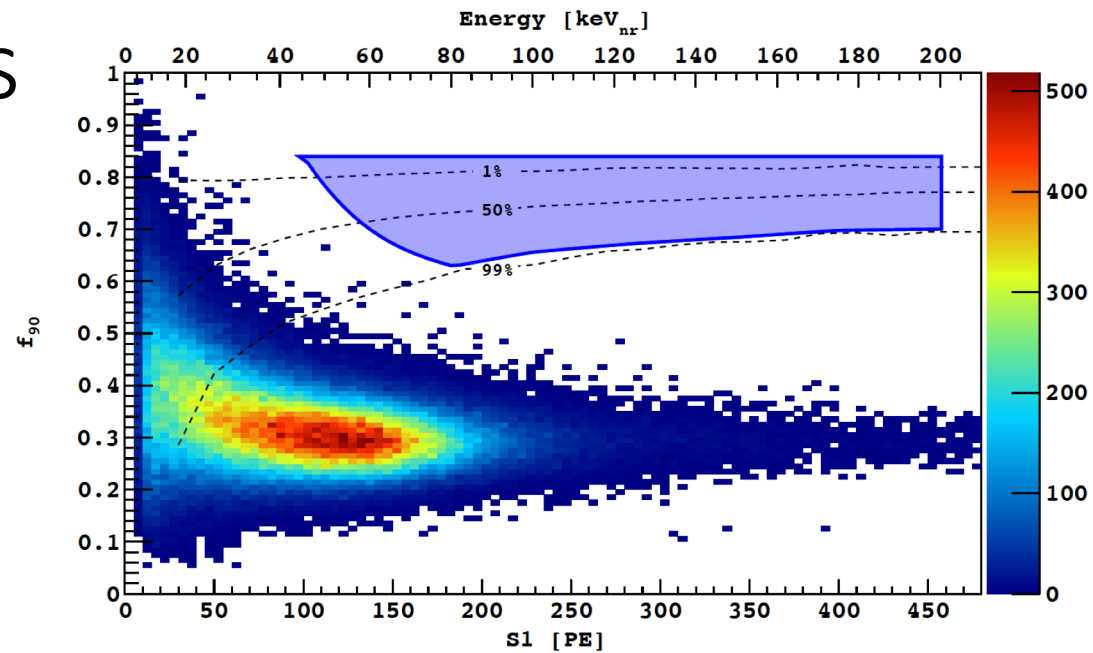
- Sub-GeV Dark-Matter-Electron Scattering

Physical Review Letters 121 (11), 111303 (2018)

High-Mass Analysis

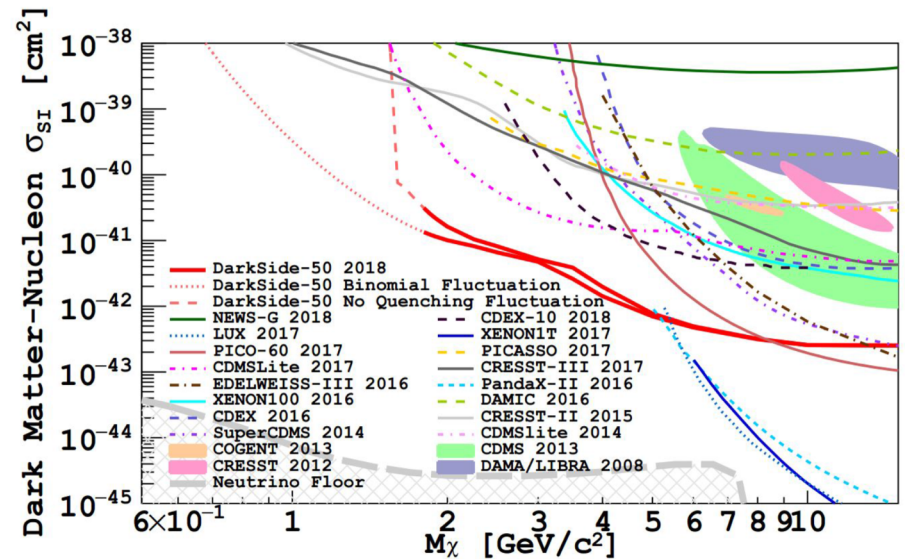
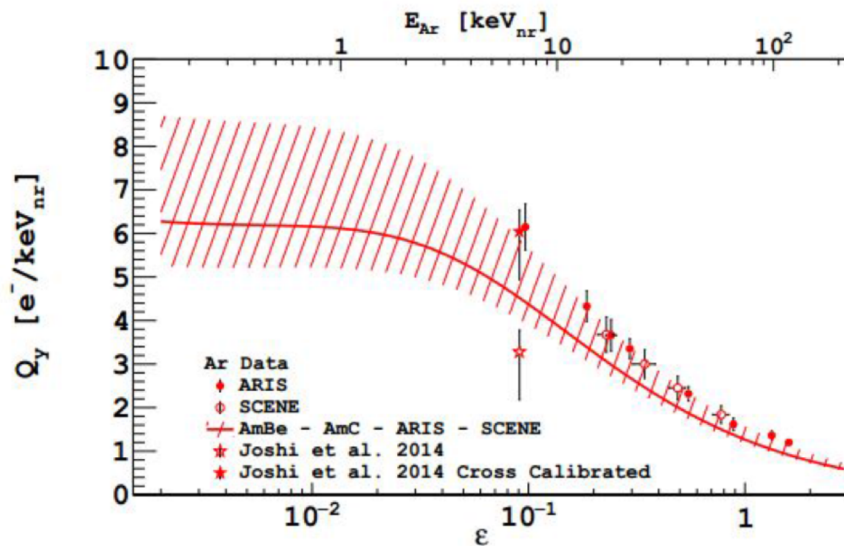
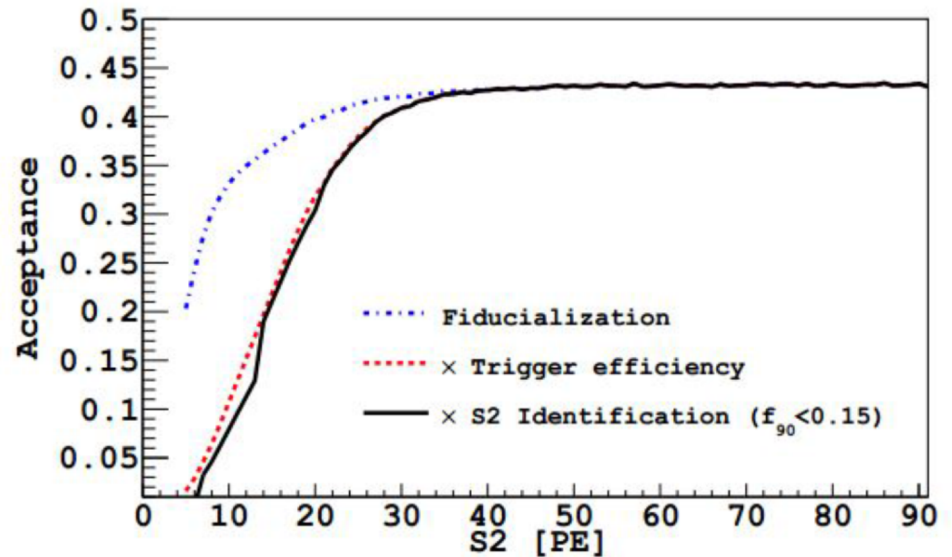
A blind analysis of 532 live-days (16.6 T d) exposure with low-radioactivity underground argon

Background	Estimated # surviving all cuts
Cosmogenic neutrons	$< 3 \times 10^{-4}$
Radiogenic neutrons	$< 5 \times 10^{-3}$
Surface α	1×10^{-3}
Cherenkov + scintillation	0.08
Total	0.09 ± 0.04



Low-Mass Analysis (S2-only)

- Detection threshold down to 1 electron of S2 (N_{e-})
- S2-only energy scale of nuclear recoil is calibrated by AmBe and AmC sources

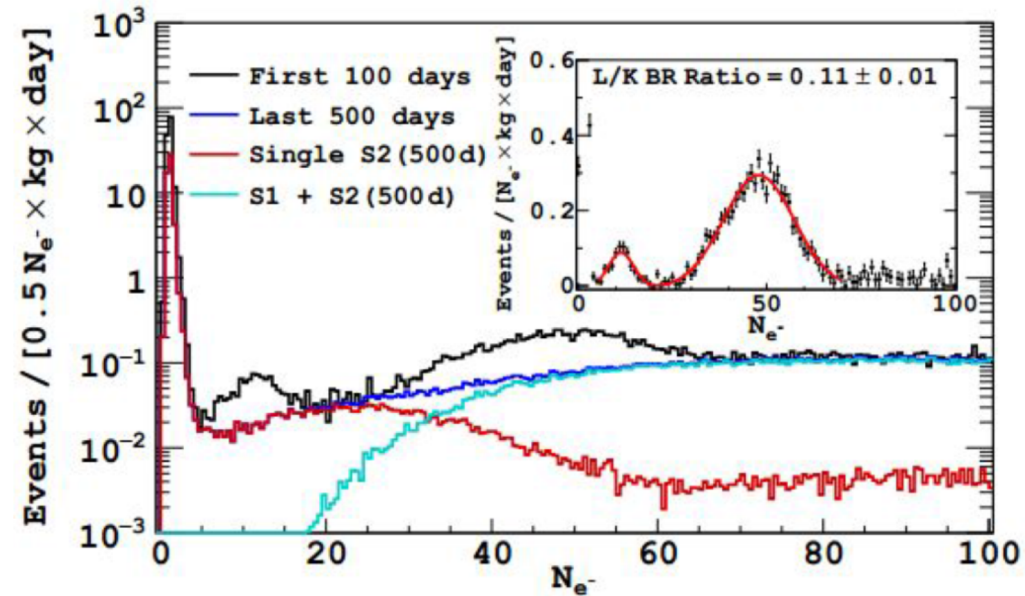


Sub-GeV Dark-Matter-Electron Scattering

Dark matter form factor depends on the mass of mediator ($m_{A'}$)

$$F_{\text{DM}}(q) = \frac{m_{A'}^2 + \alpha^2 m_e^2}{m_{A'}^2 + q^2} \simeq \begin{cases} 1, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 m_e^2}{q^2}, & m_{A'} \ll \alpha m_e \end{cases}$$

Electron recoil energy scale is calibrated from ^{37}Ar decay from the first 100-day data

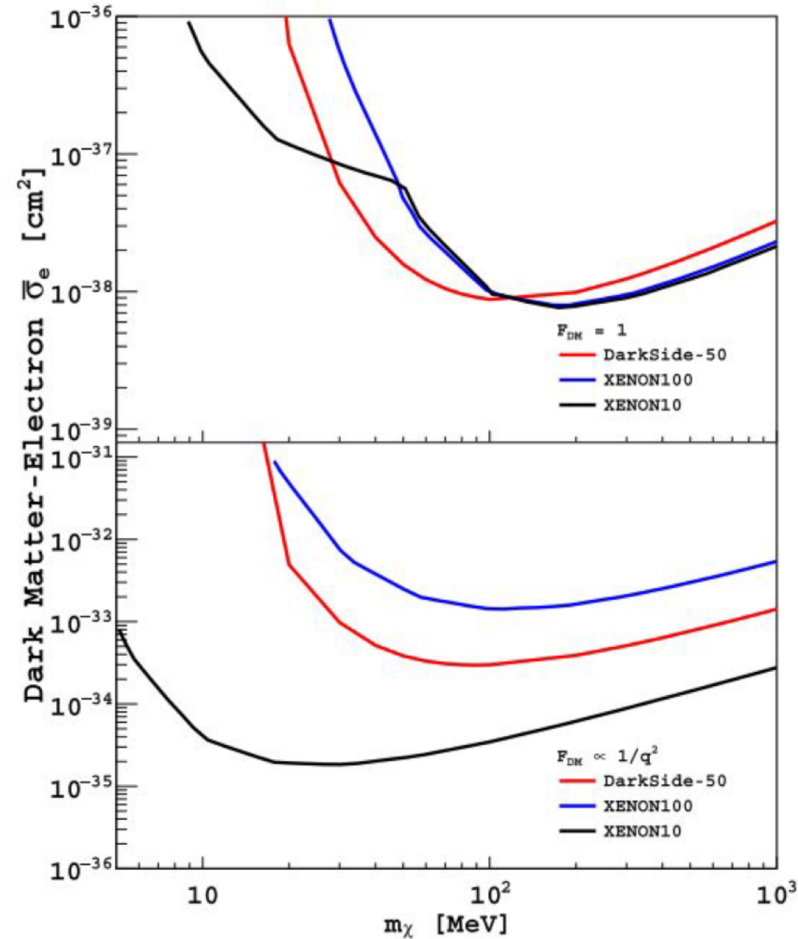
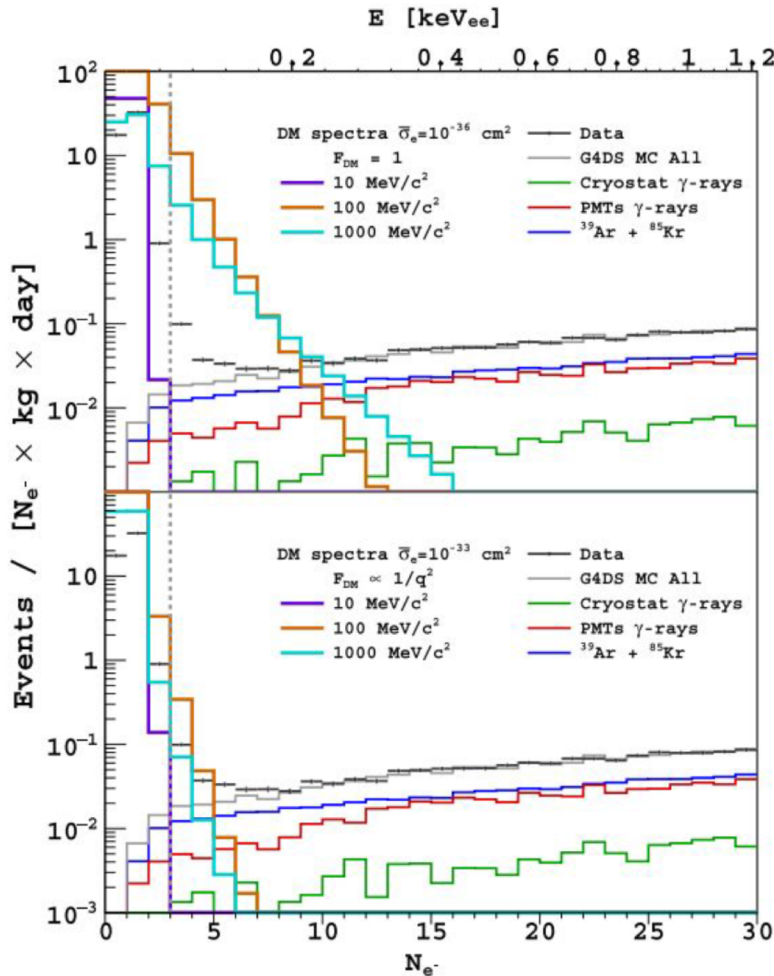


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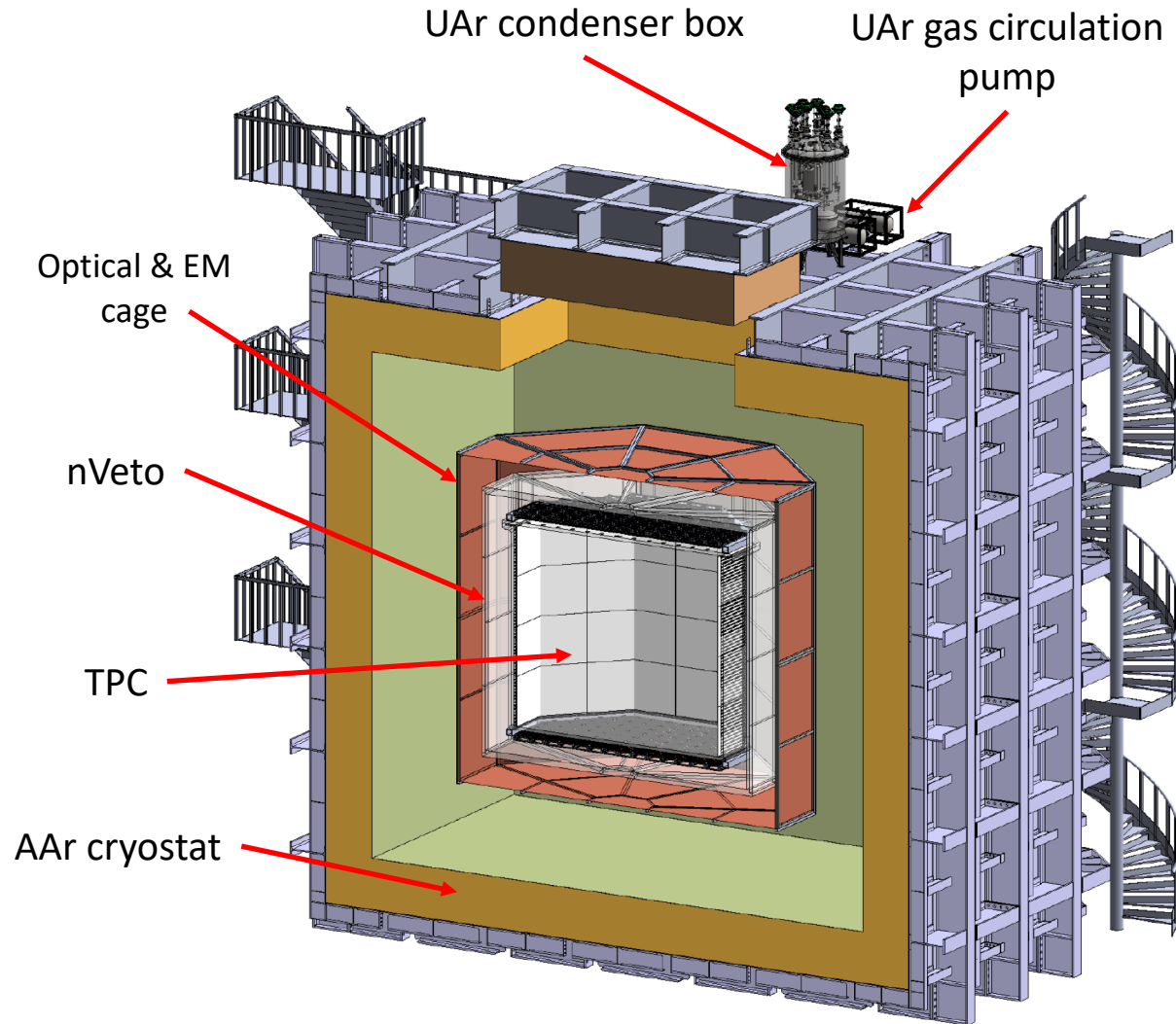
$F_{\text{DM}} = 1$

$F_{\text{DM}} \propto 1/q^2$



DarkSide-20k Design

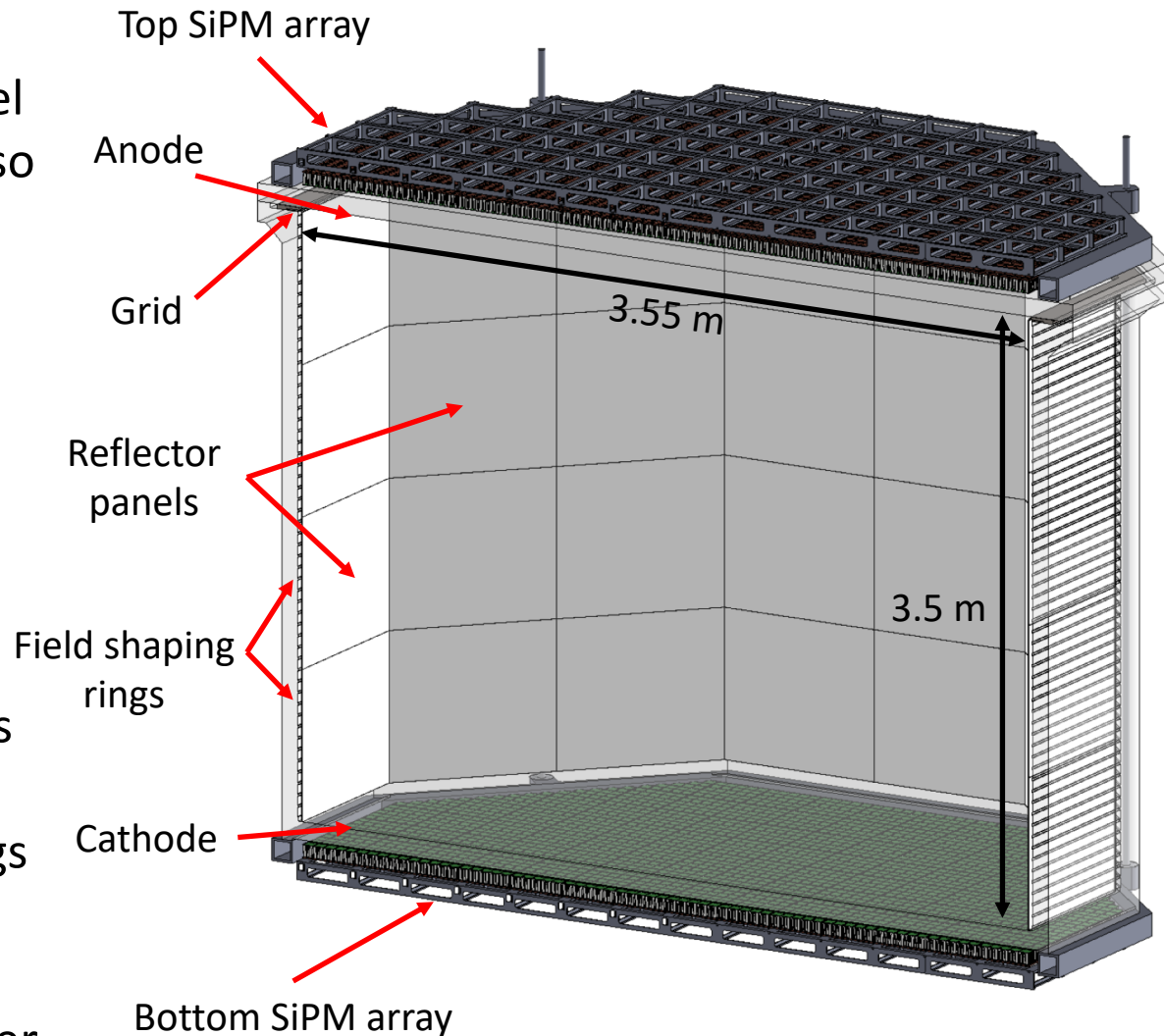
- Sealed acrylic TPC containing 50 tonnes of Underground Argon (UAr)
- ProtoDUNE-like cryostat containing ~ 700 tonnes of Atmospheric Argon (AAr)
- Gd-doped acrylic panels as neutron veto
- SiPMs as photosensors: 8280 channels for TPC; ~ 3000 channels for Veto



(Supporting structure not shown)

Sealed Acrylic TPC

- Sealed (bonded) acrylic vessel itself serving as part of TPC, so to minimize inactive volume and make full use of UAr
- No extra UAr vessel needed, reduce background
- SiPM arrays and associated cables moved out of TPC, much less outgassing
- Clevios (transparent conductive polymer) coatings as anode, cathode, bottom ground and field shaping rings
- ESR foil as reflectors
- All internal surface coated with TPB as wavelength shifter



SiPM Photosensors

- Customized SiPM for LAr, combined effort of DarkSide and FBK
- Compact and high coverage
- High S/N (>8)
- High PDE ($\sim 50\%$)
- SiPM Mass production by LFoundry
- Packaging of PDM and FEB in NOA, L'Aquila
- Full production chain largely funded by Regione Abruzzo, Italy

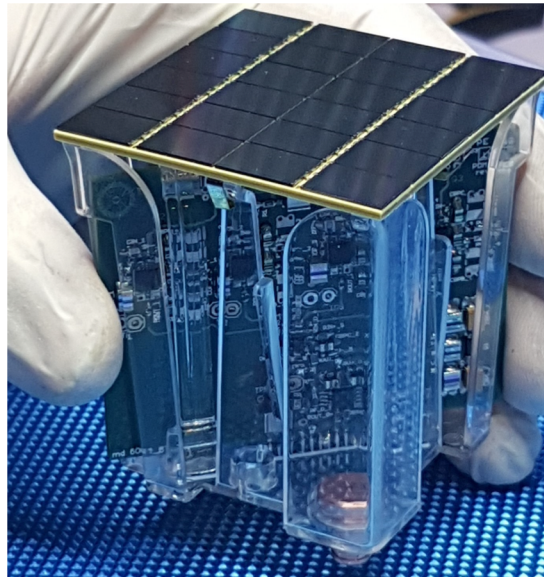
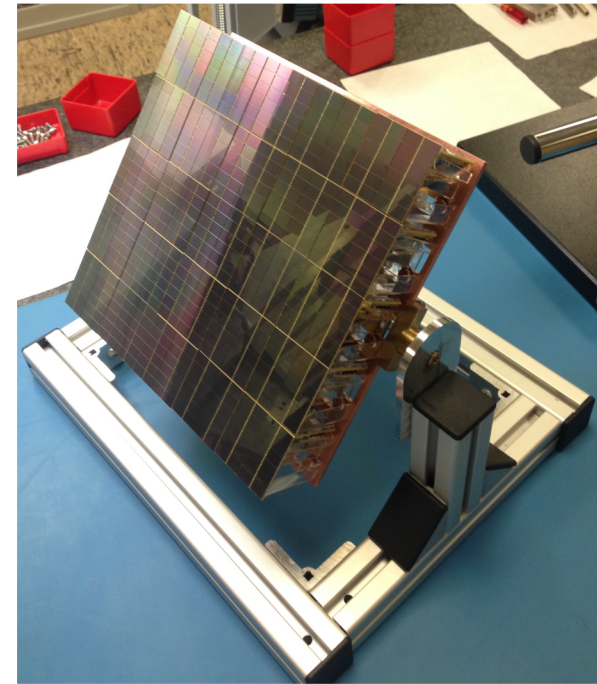


Photo-Detector Module (PDM)
5 cm x 5 cm



Motherboard,
containing 25 PDMs

Underground Argon

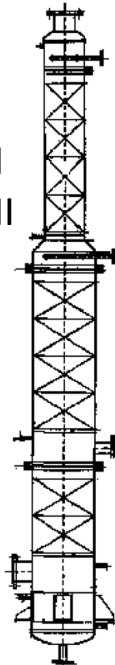
Urania

- Procurement of at least 60 tonnes of UAr from the same source as for DS-50 (Colorado, USA)
- Extraction of 250 kg/day, with 99.9% purity
- UAr then transported to Sardinia, Italy for final chemical purification by Aria



Seruci-0

Seruci-I
Seruci-II

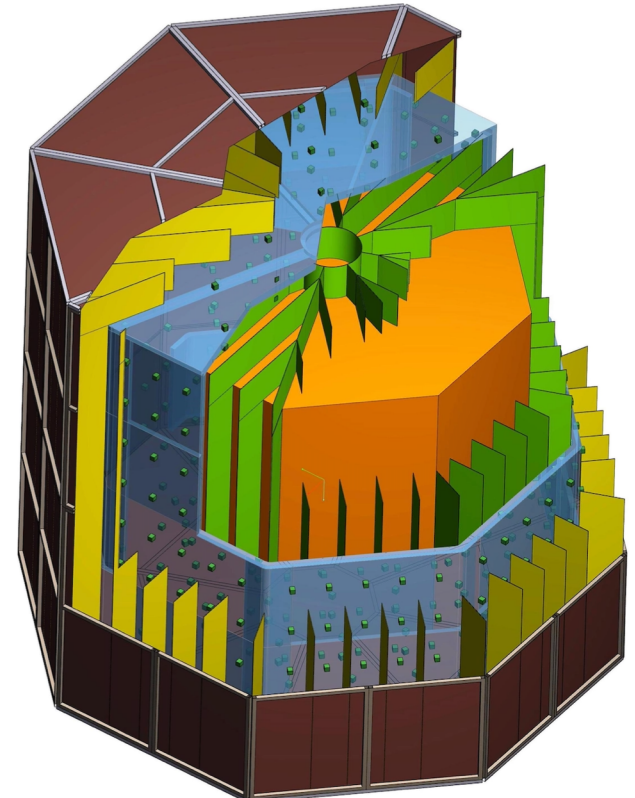
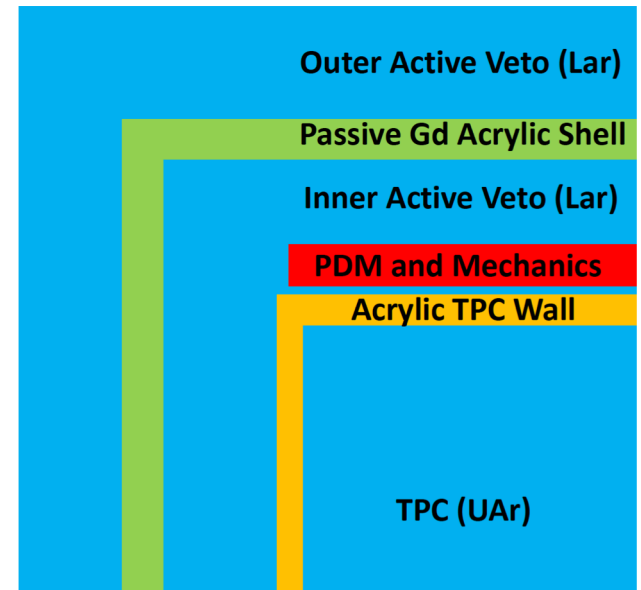


Aria

- 350-m tall cryogenic distillation column in Seruci, Sardinia, Italy
- Final chemical purification of the UAr
- Process ~1 tonne/day with 10^3 reduction of all chemical impurities
- Isotopically separate ^{39}Ar from ^{40}Ar

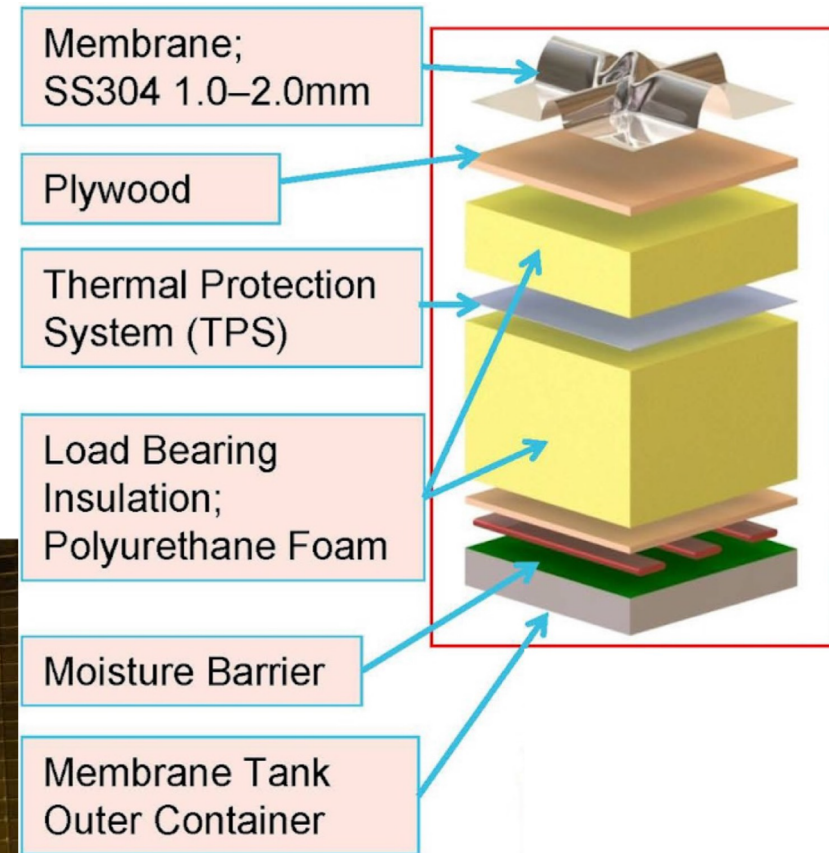
Neutron Veto

- 4- π coverage to TPC
- 10-cm thick passive Gd-loaded acrylic shell to moderate and capture neutrons
- 40-cm thick inner and outer active liquid AAr volumes to detect gammas emitted from neutron captured by Gd
- Same SiPM as TPC, but different FEB
- Faraday cage to optically and electrically isolate Veto and TPC
- Vertical segmentations to reduce pile-up rate of ^{39}Ar event from AAr
- ESR foil as reflector
- All internal surface of each sector coated with TPB as wavelength shifter



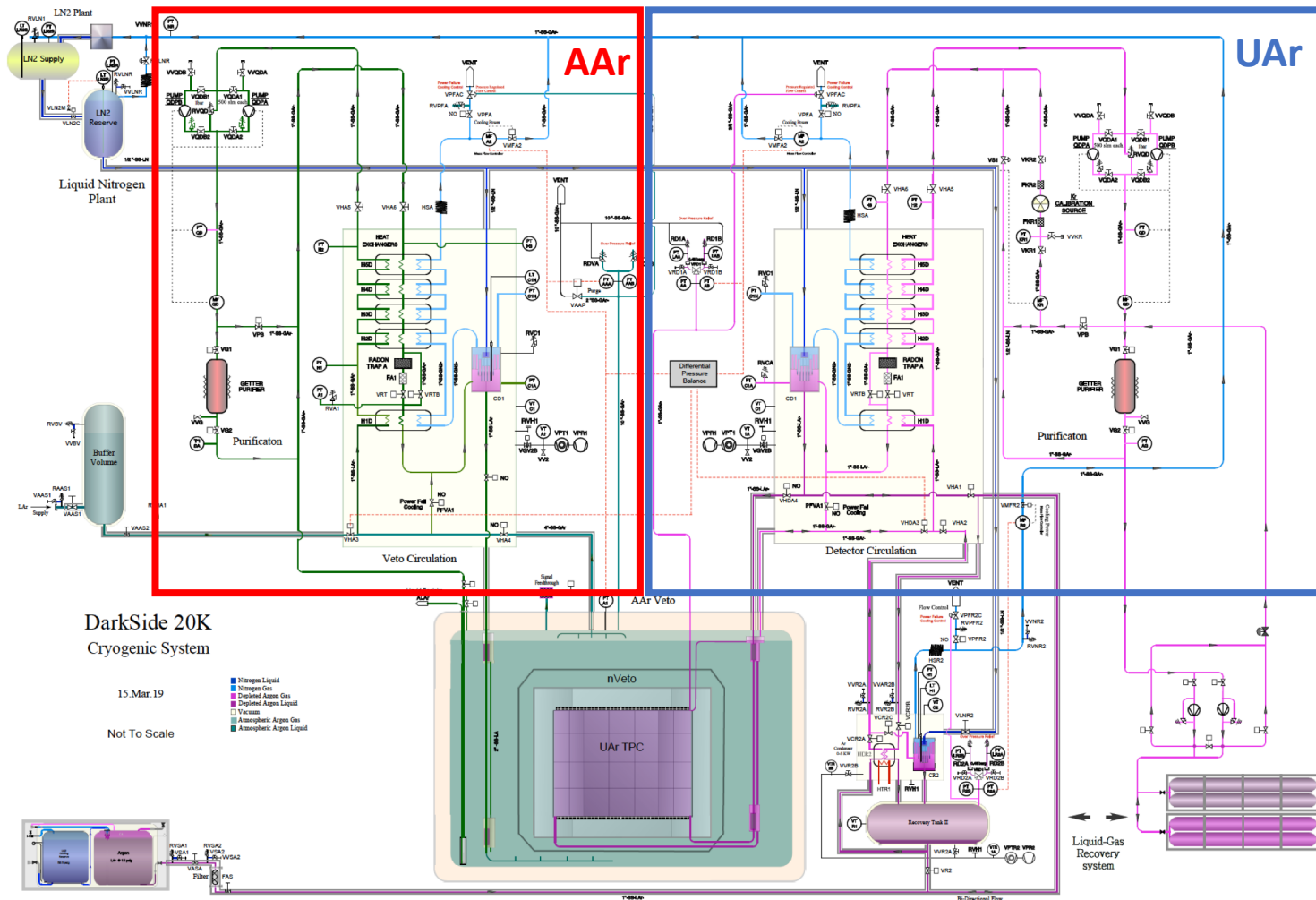
A_{Ar} cryostat

- Membrane + passive thermal insulation
- Matured technique adopted from the Liquefied Natural Gas carriers and vessels
- Experience from construction of ProtoDUNE cryostat
- Access and support of TPC and Veto from top roof
- Penetrations on top roof determined by the requirements of all sub-systems

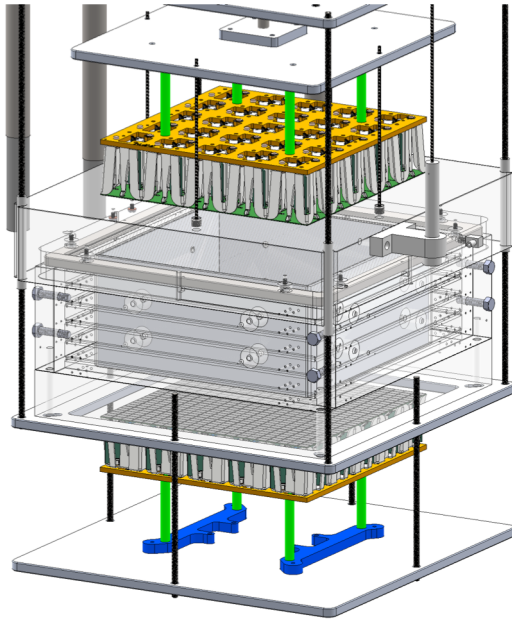


Cryogenics and gas handling

- UAr cryogenics and gas handling system is derived from the success of DS-50: electron lifetime >5ms, TPC pressure stability ± 0.023 psi
- Total required cooling power: 500 W, gas phase argon circulation and purification speed: 1000 slpm
- AAr cryogenics and gas handling system utilizes the experience of both ProtoDUNE and DS-50



DarkSide Prototypes

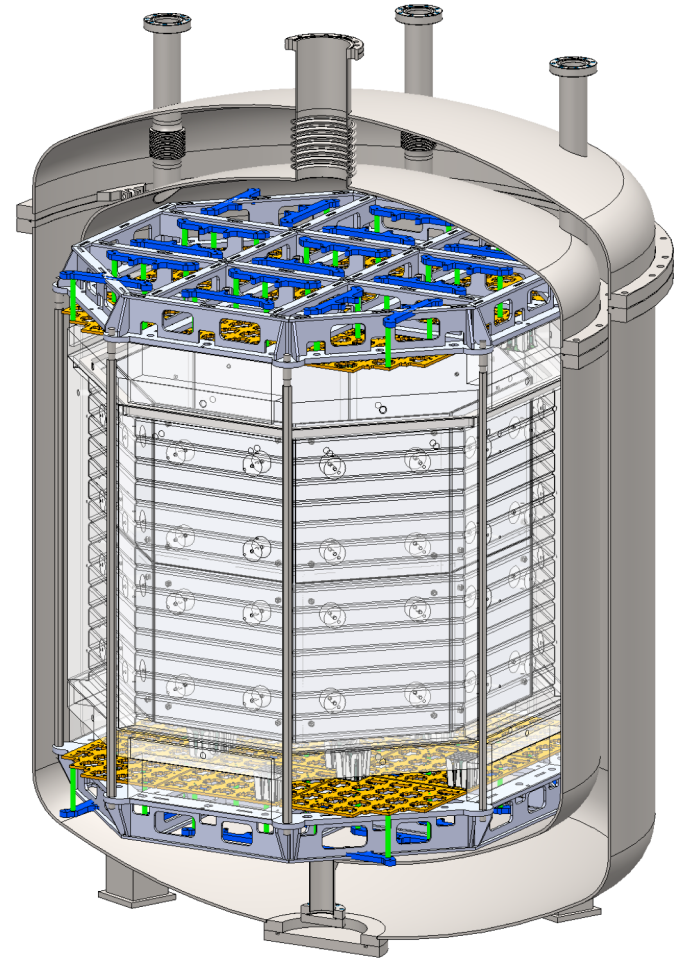


Proto-0
Under construction @CERN

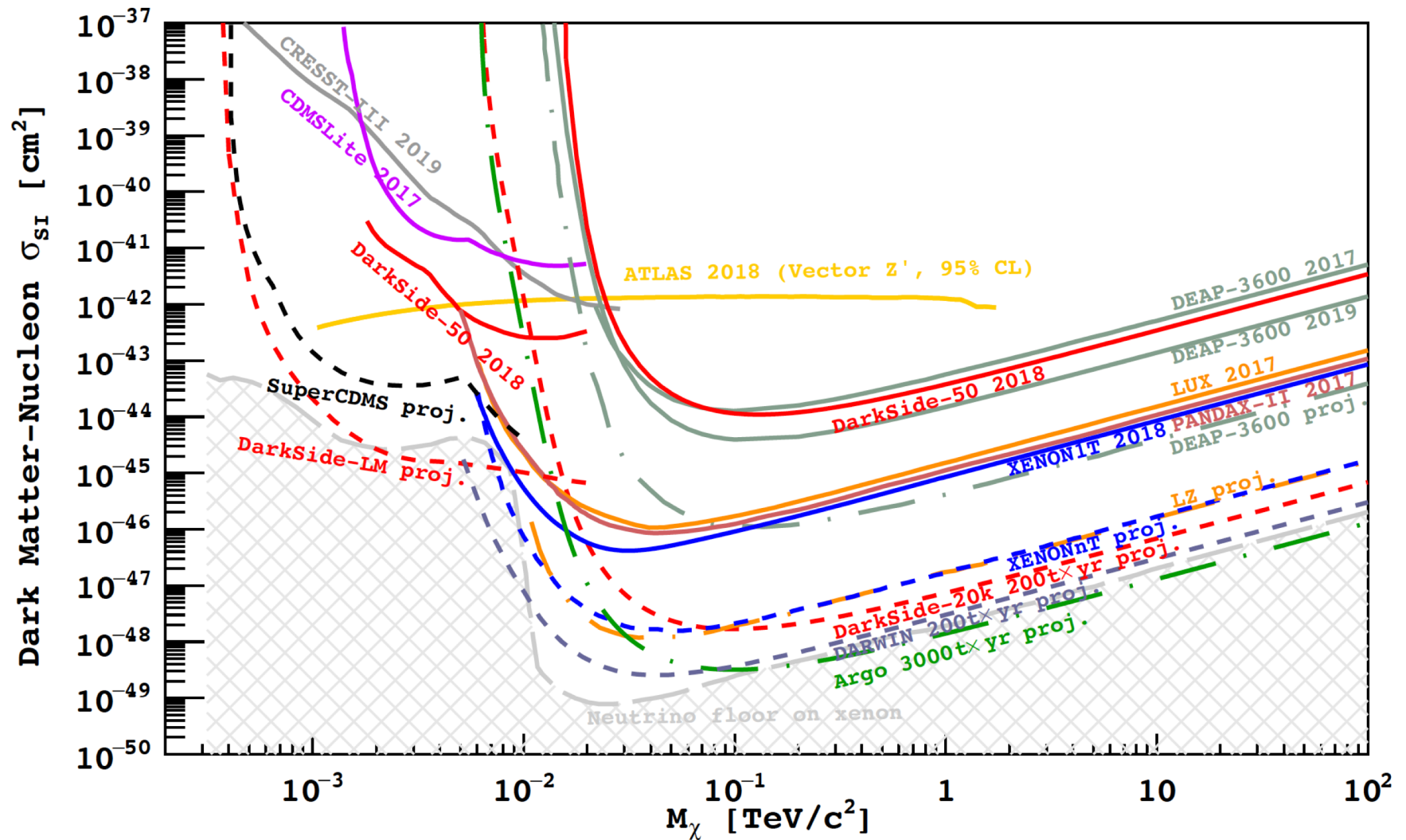
Test bench for:

- SiPM integrated test
- DAQ scheme
- Clevios coating
- ESR as reflectors
- Acrylic bonding
- S2 study
-

Proto-1ton: scaled down version
of DS-20k, test bench for all DS-20k's features
Will be assembled @CERN in Q2 2020



Projected Sensitivity



Summary

- Global Argon Dark Matter Collaboration has been established to unite the efforts towards an ultimate LAr dark matter detector
- DarkSide-50 results have proven the competitiveness of LAr technology in low-mass WIMP region as well
- DarkSide-20k is developing essential technologies on several fronts, aiming to start data taking in 2022
- LAr technology is very promising to lead the path towards the neutrino floor in both high- and low-mass WIMP regions