DarkSide-50/-20k experiments – recent results and prospects

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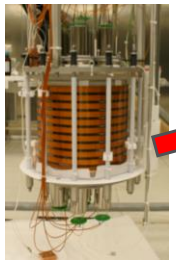
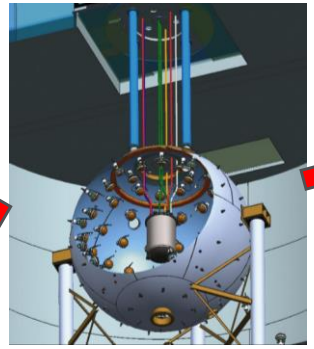
DarkSide program

Located 1400m underground lab. at LNGS, Italy ⟶

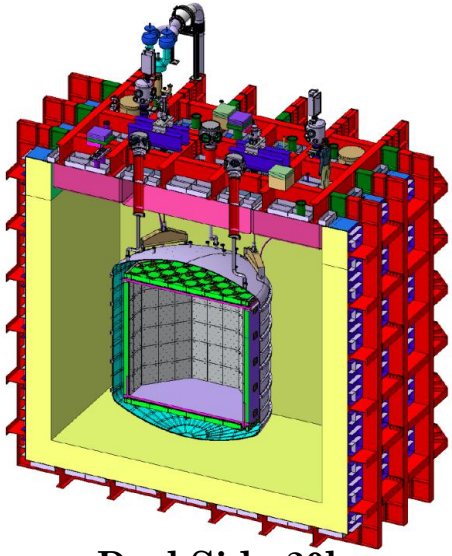
LAr dual phase direct detection experiments designed to detect WIMP scattering interactions from the dark matter halo



DarkSide-10
2012



DarkSide-50
0.03 tyr exposure
2013-2018



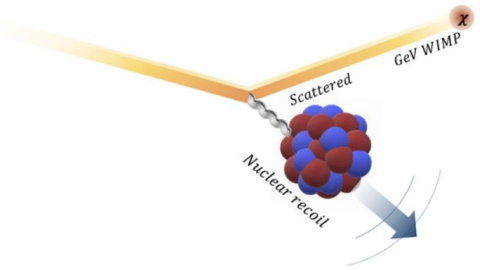
DarkSide-20k
200 tyr exposure
2026 +

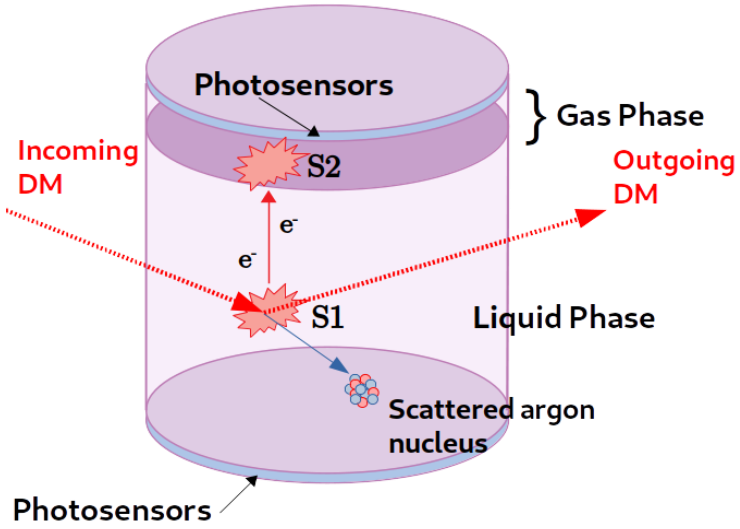
ARGO
3000 tyr exposure
2030s +
High mass focus

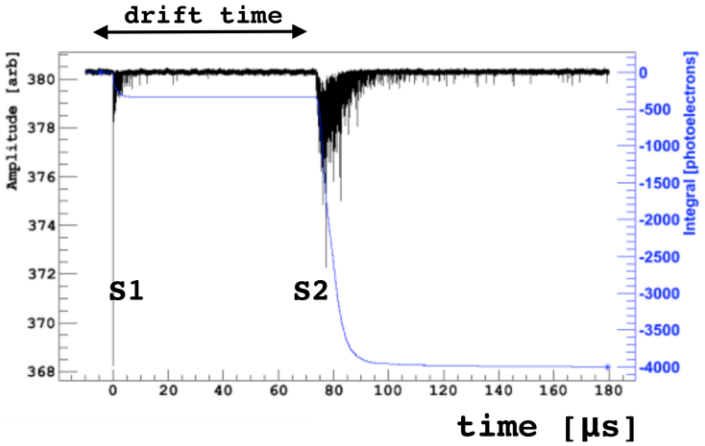
DarkSide-LowMass
Proposed 1 tyr exposure
Low mass (sub GeV)

Multiple collaborations joined together in 2017 to form the Global Argon DM Collaboration (GADMC) for future LAr-based dark matter detectors

LAr TPC principles

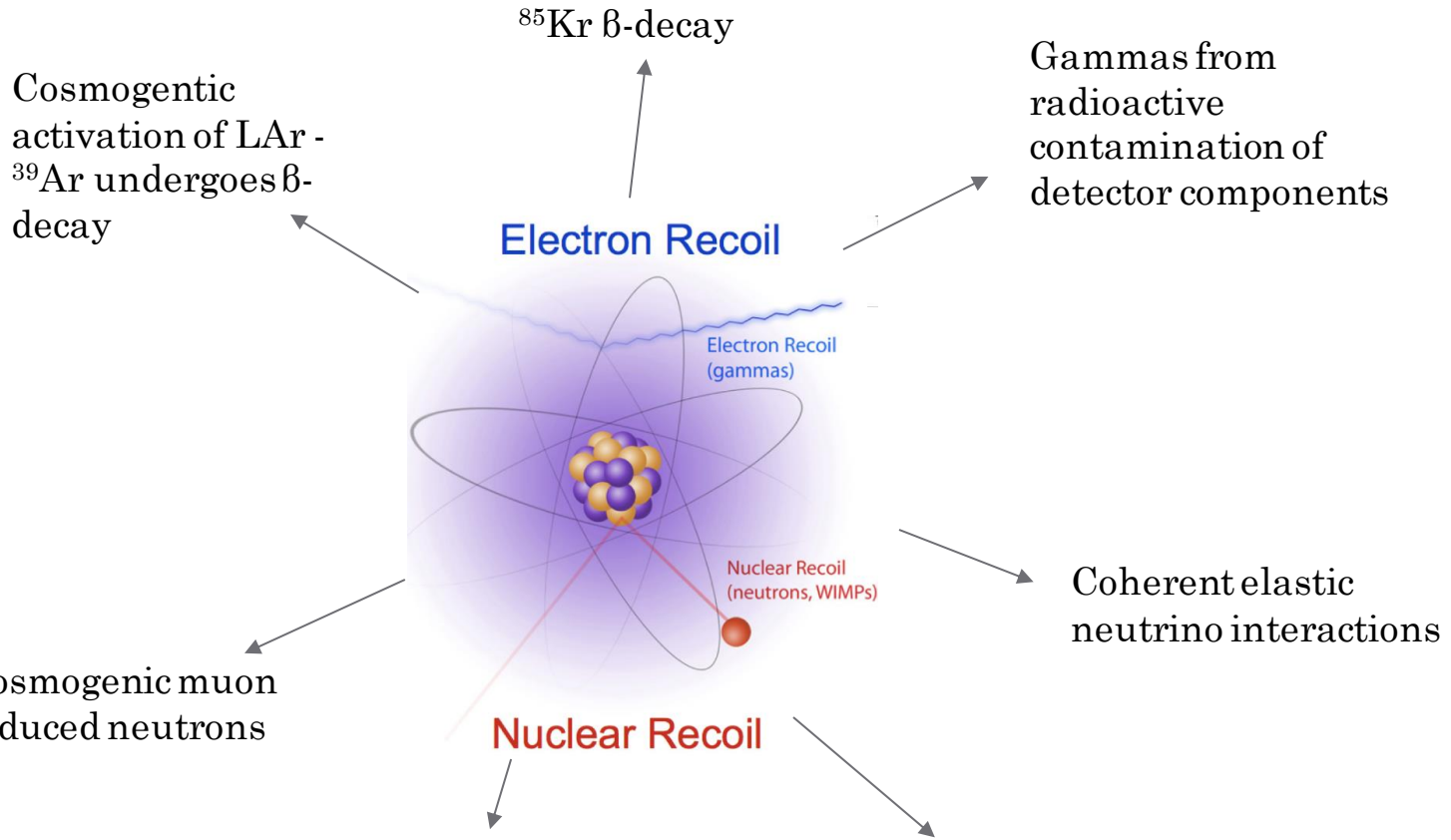






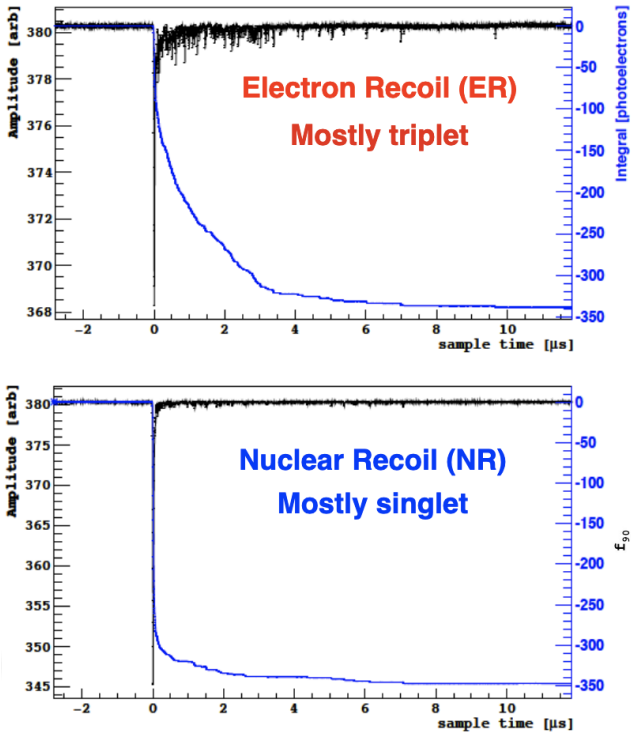
- DM-nucleus interaction creates initial **scintillation pulse (S1)** in LAr
- Electric field drifts ionisation electrons up to top of TPC
- Electrons are accelerated across gas phase to produce secondary **ionisation pulse (S2)**
- These are seen by photosensors on top and bottom of the TPC
- Use the S1-S2 time difference to measure Z position of event, and the S2 light distribution to determine XY position: 3D reconstruction

Important backgrounds for DarkSide



DarkSide-20k aim: <0.1 background events in the total 200tyr exposure

Pulse shape discrimination



f_{prompt} = prompt light/total light

f_{90} : fraction of S1 light pulse collected in the first 90ns

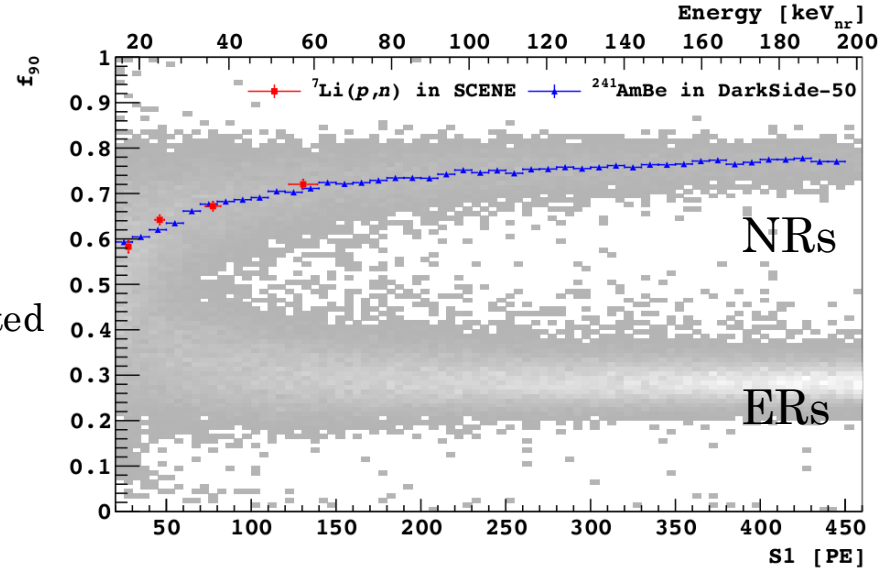
- f_{90} (NR) ~ 0.7
- f_{90} (ER) ~ 0.3

Argon dimers decay with two different decay constants:

tau_{fast} ~ 6 ns and tau_{slow} ~ 1600ns

Electron recoil and nuclear recoil events excite a different fraction of singlet and triplet state decays.

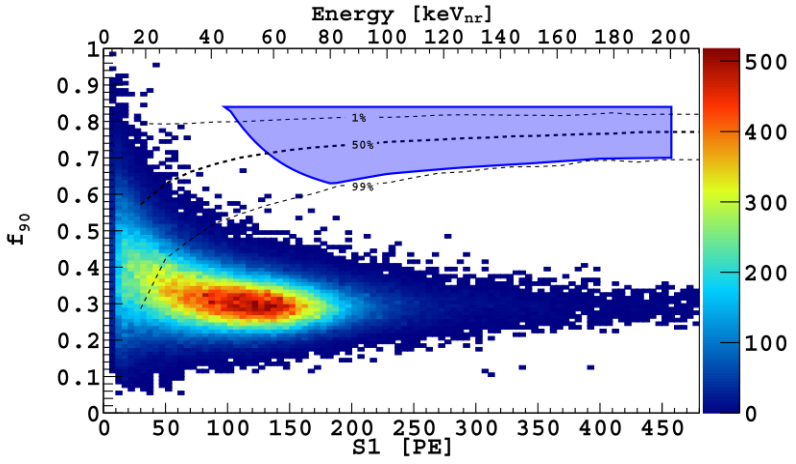
This can be utilised to discriminate between WIMP NR events and ER backgrounds.

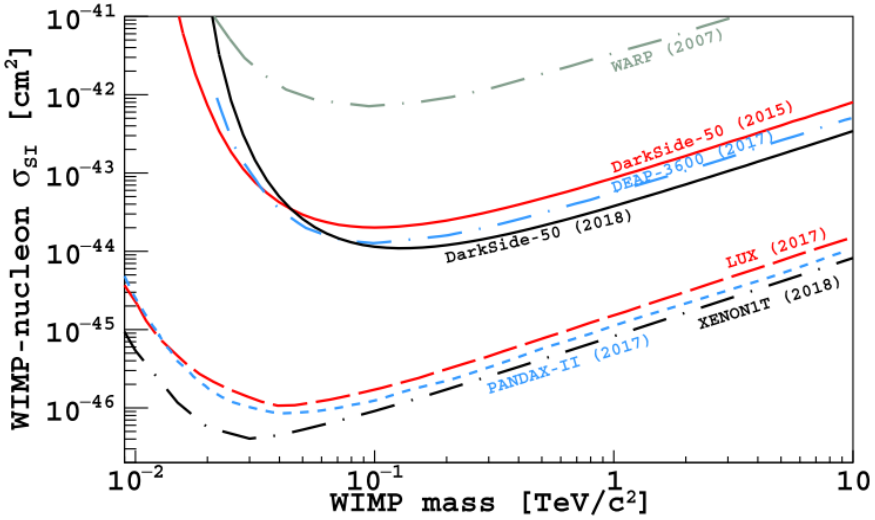


arXiv:1802.07198

DarkSide-50 high mass results

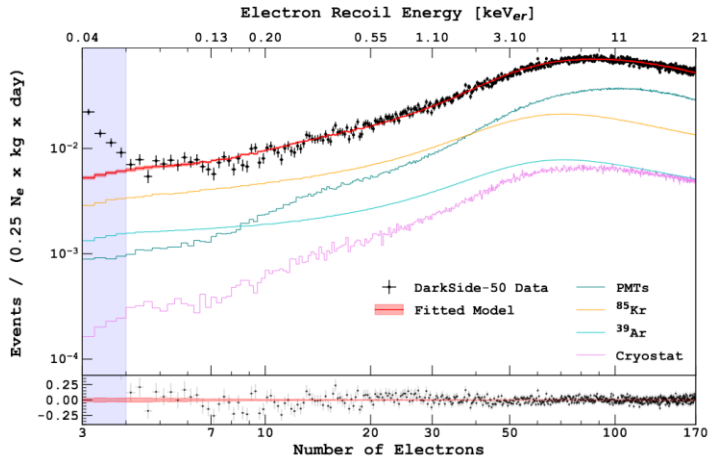
- Total exposure: 166,600 kg days, using 532 days of data
- Demonstrated **1400x reduction** in ^{39}Ar backgrounds using underground argon vs atmospheric
- Reject ER background events using PSD to a level of one in 1.5×10^7
- This allowed the blind DM search to be **background free**





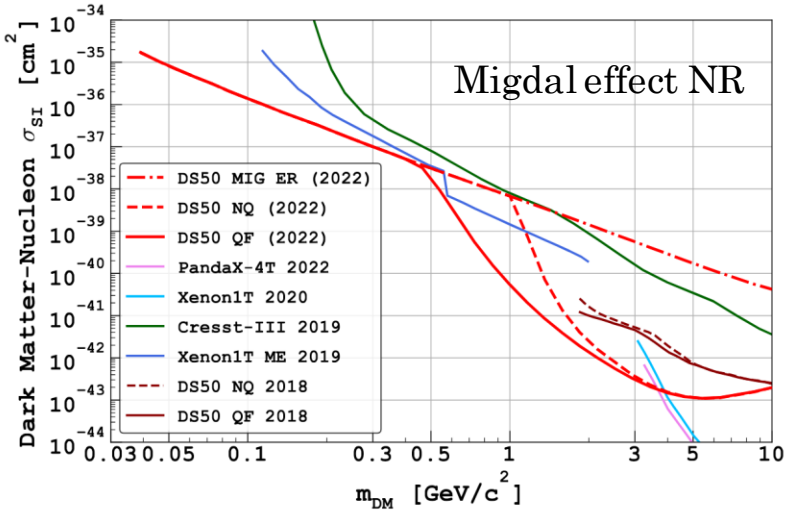
arXiv:2207.11966
arXiv:2207.11967
arXiv:2207.11968

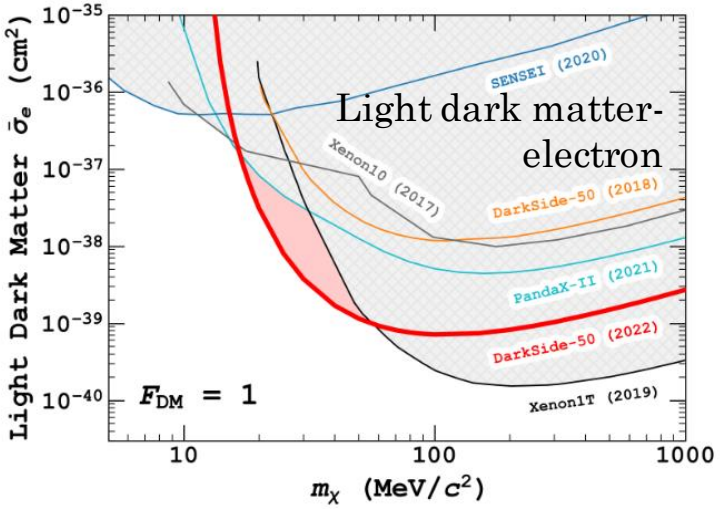
DarkSide-50 low mass results



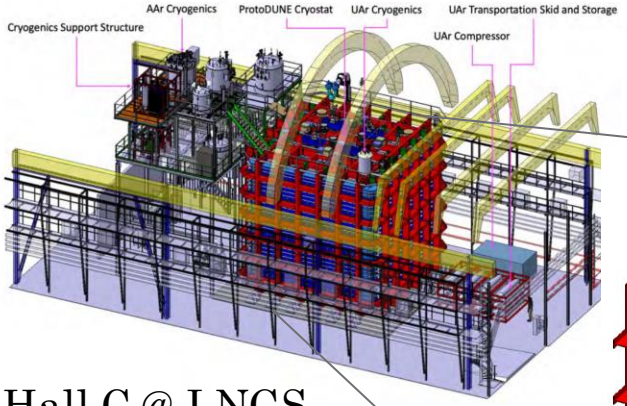
S2 only background spectra

- Using only the S2 signal we can access much lower energy events
- Analysis threshold : 4e- (0.6keVnr)
- Migdal effect: additional ER energy from electron cloud can push NR events above detector threshold
- Migdal analysis gives sensitivity down to 0.04 GeV - most stringent limit in this mass region (below ~3 GeV)
- Also placed exclusion limits on a range of models with electron final states

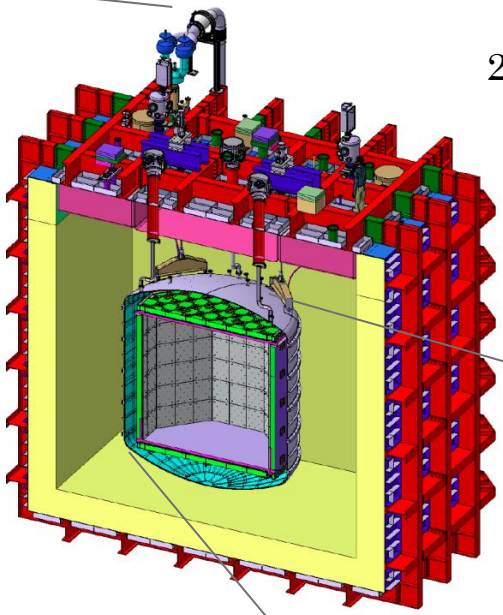


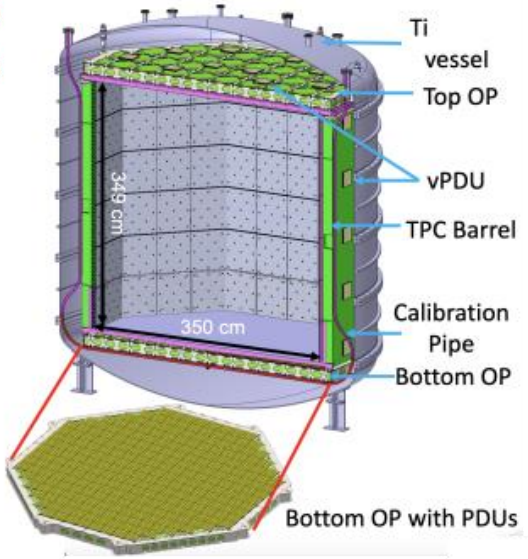


DarkSide-20k design



Hall C @ LNGS





Nested design:

1. ProtoDUNE-like cryostat (8m tall) holds 600t AAr bath: **muon veto**

2. Stainless steel vessel holds 12t UAr: **neutron veto**

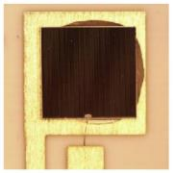
3. Inner TPC contains 50t UAr

Inner TPC:

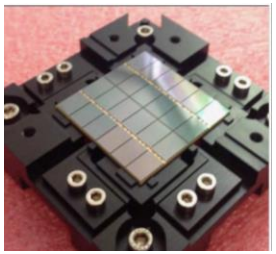
- Octagonal TPC with inner diameter 350cm
- Instrumented with SiPM sensors on top and bottom optical plane: 21m^2 coverage
- Drift field: 2.8kV/cm
- Walls coated with Reflector + PEN (WLS)

DarkSide-20k SiPM sensors

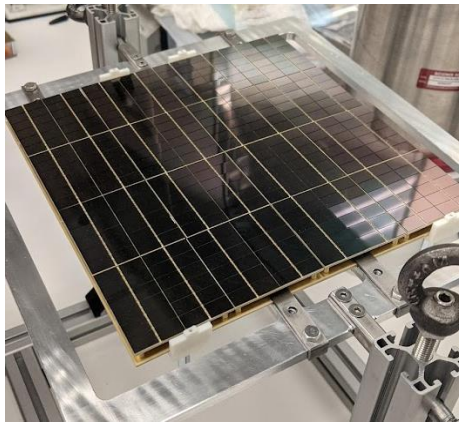
SiPM
(1mm^2)

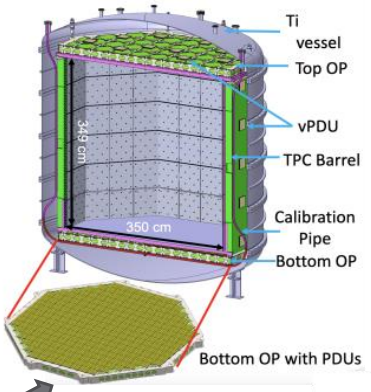


PDM tile
(5x5cm)



Photodetector unit (PDU)
Array of 16 tiles assembled on MB
(20x20cm)





528 PDUs form the optical planes of the TPC, covering 21m^2

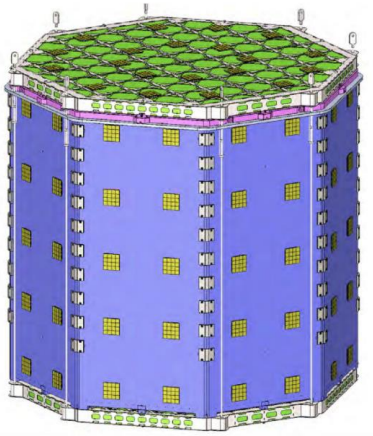
Why SiPMs?:
Higher photon detection efficiency, lower radioactivity, lower cost, operated with lower bias

Challenges:
- Small area - need to produce **large area arrays** of SiPM sensors
- High electronic noise
- Higher dark rate and correlated noise

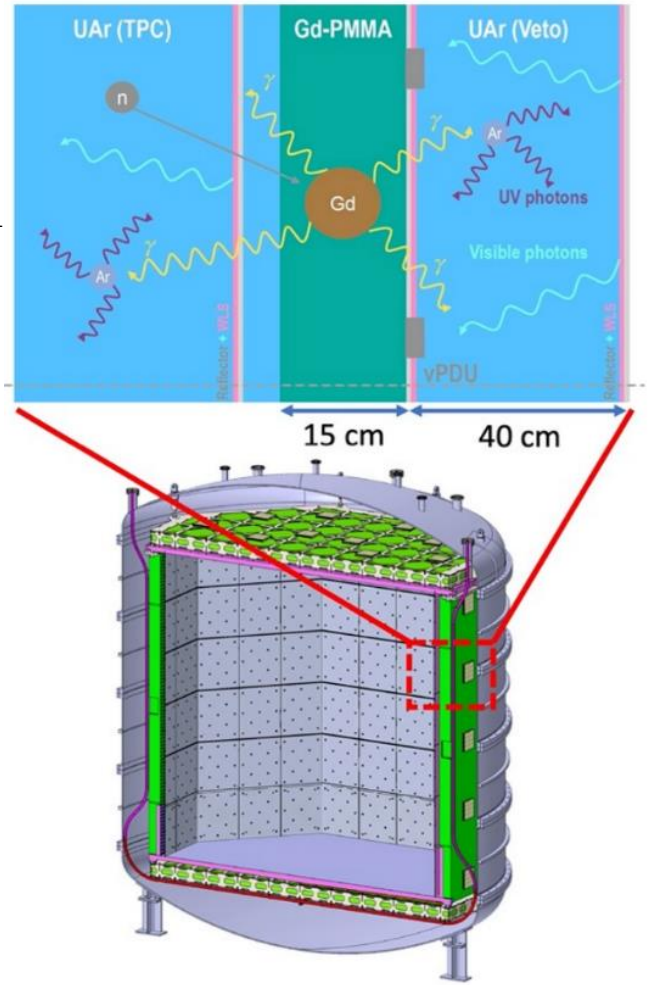
Result:
DarkSide have successfully developed state of the art large-area PDU sensors which meet and exceed the performance requirements of the detector, including having single photon resolution.

DS20k Background reduction: NRs

- Reduce radiogenic neutron backgrounds by tagging them in the veto volume (between TPC and stainless steel vessel)
- Neutron veto : UAr volume instrumented with 5m^2 of vPDUs (single phase)



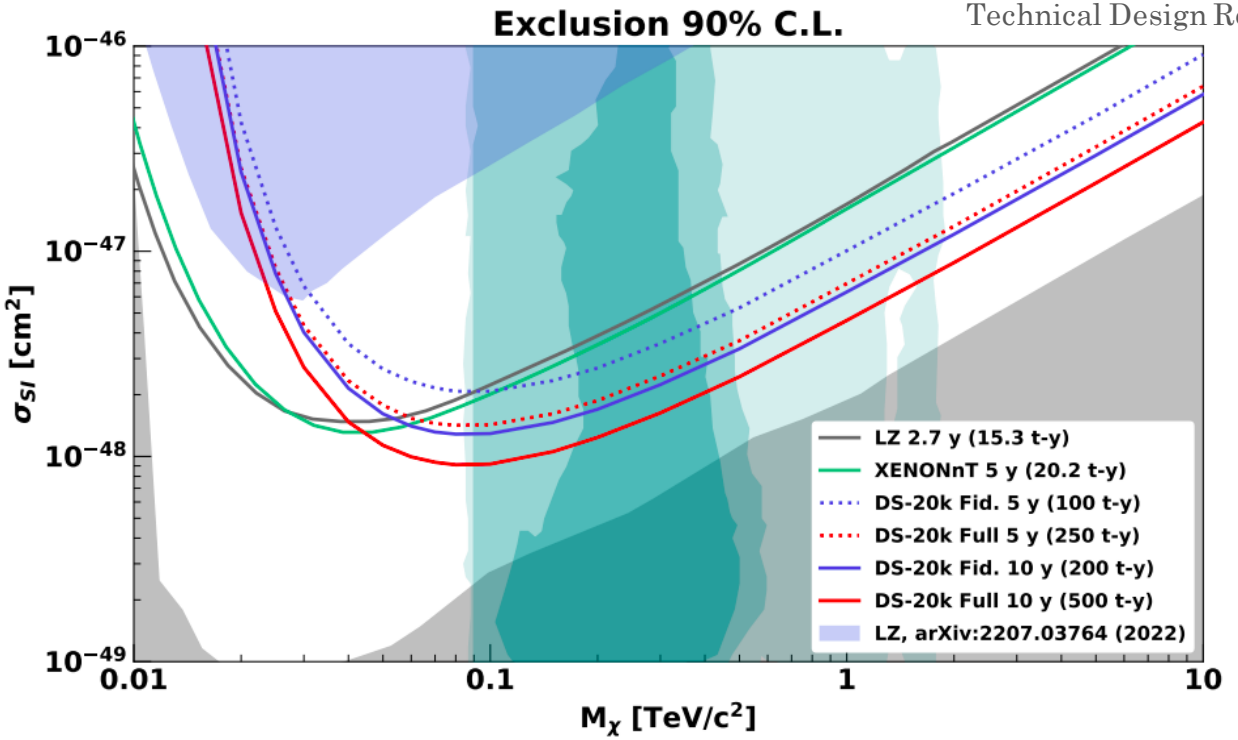
Veto PDUs mounted on TPC walls facing outwards into veto volume



Gd-loaded acrylic layer (10cm thick) between the TPC and veto is used to capture neutrons and release high energy gammas (shower up to 8 MeV)

DarkSide-20k sensitivity

Curves from DarkSide-20k Technical Design Report



- DarkSide-20k expected to be the most sensitive dark matter search in the next decade
- Projected sensitivity based on background free search (using fiducial volume), and using the full active volume, compared to xenon-based detectors
- Neutrino backgrounds become important: 3.2 events in 200 tyr
- DS20k will additionally be able to carry out S2 only searches to reach much lower masses than shown here (as seen from DarkSide-50)

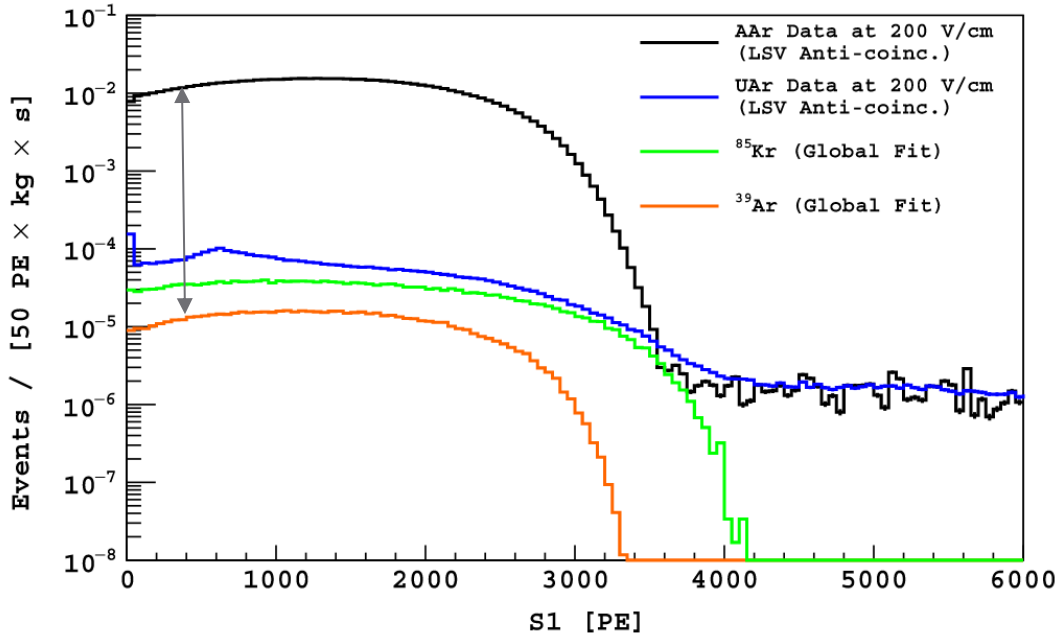
Conclusions

- DarkSide-50 was able to carry out a background free DM search, setting an upper limit on the dak matter cross-section of 1e-44cm^2 at 100GeV
- DarkSide-50 can set world-leading exclusion limits in mass region down to 0.04 GeV using S2 only analysis and the Migdal effect
- DarkSide-20k R&D complete, and construction phase is starting, including SiPM production, construction of cryostat, UAr production
- Data taking is expected from 2026
- Expected sensitivity at 100 GeV: ~1e-48 cm^2, approaching the neutrino floor.
- We have highlighted some of the design aspects which contribute to DarkSide-20k sensitivity, including the muon and neutron veto system, SiPM photosensors, underground argon

Backup slides

Underground argon

Phys. Rev. D 93, 081101 (2016)



39Ar is produced by cosmic rays in the atmosphere -> beta-decay

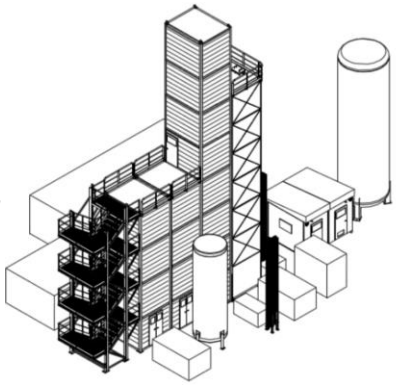
- Activity in atmospheric argon: ~1 Bq/kg
- Activity in underground argon: 0.73 ± 0.10 mBq/kg

DarkSide-50 demonstrated 1400x reduction in 39Ar backgrounds using underground argon

Underground argon for DS20k

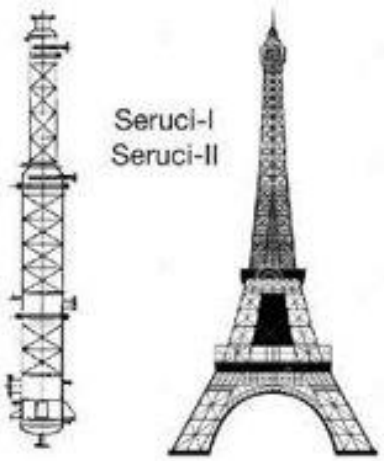
1. Extraction of argon: Urania

- Underground argon is extracted from industrial CO2 wells in Colorado, USA
- Extraction plant ready to ship
- Extract 330 kg/day
- Purity is 99.99%



2. Purification of argon: Aria

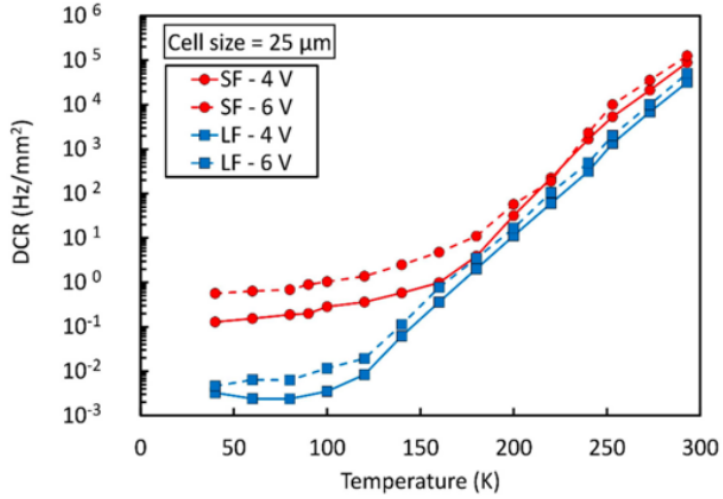
- Argon is transported from Colorado to Sardinia, Italy
- At the coal mine, a distillation column purifies the argon at a rate of 1t/day
- Reduction of 39Ar by a factor of 10
- Chemical and isotopic purification

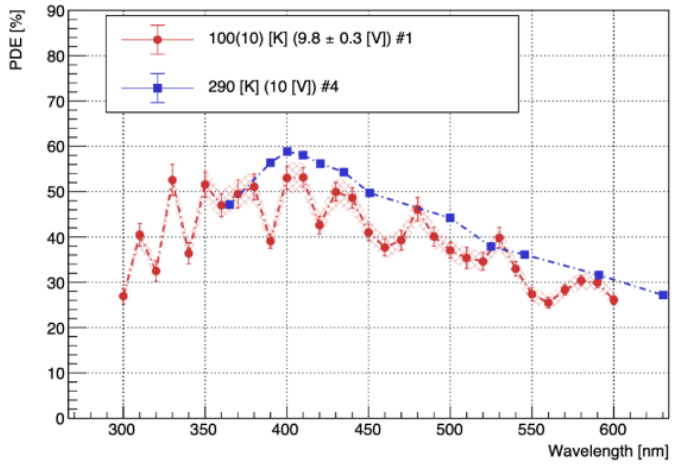


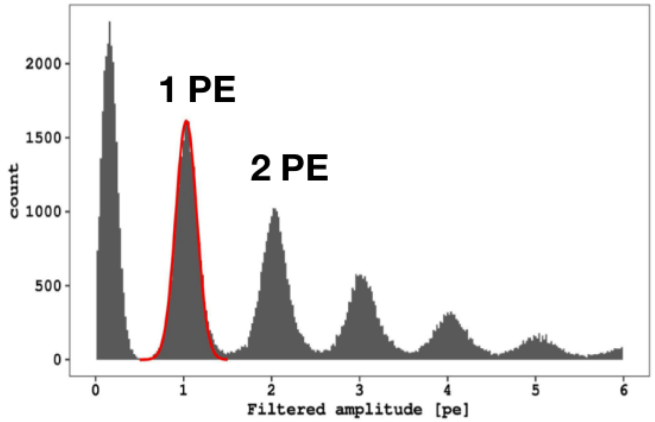
3. Qualification: DArT

- Single phase LAr detector which can measure the depletion of 39Ar in Canfranc, Spain
- 1.42 kg of UAr, installed inside the ArDM detector

SiPM sensor testing

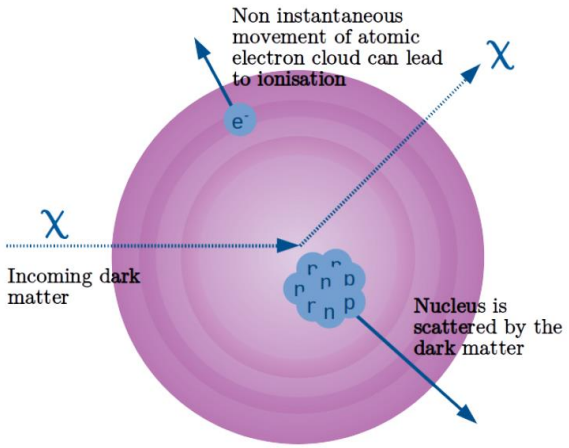






parameter	spec required	spec achieved
PDE @ 420 nm	> 40%	> 42%
DCR (87 K)	250 Hz / tile	~ 20 Hz / tile
correlated noise probabilities (afterpulses, cross talk)	< 50% + 50%	<10% + 35%
SiPM gain	> 1E6	> 1E6
SNR after ARMA filter	> 8	> 15
time resolution	~ 10 ns	~15 ns

Migdal effect



Differential rate:

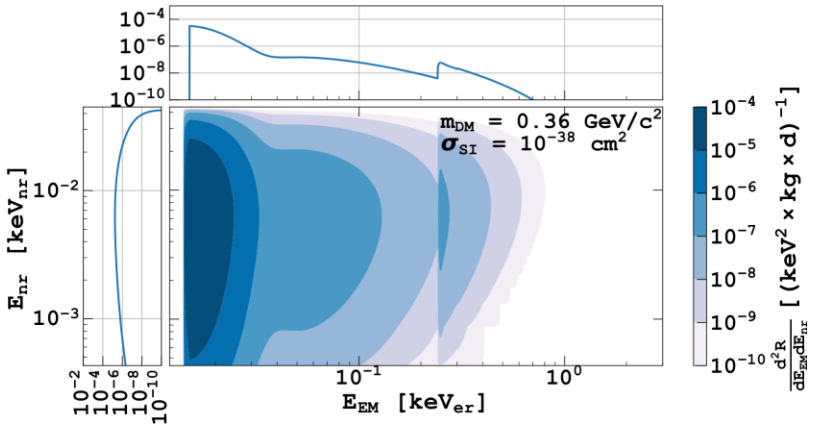
$$\frac{dR}{dE_R\, dE_{EM}\, dv_{DM}} \simeq \frac{dR_0}{dE_R\, dv_{DM}} \times \frac{1}{2\pi} \sum_{n,\ell} \frac{d}{dE_e} p^c_{q_e}(n\ell \to (E_{EM} - E_{n\ell}))$$

Nuclear recoil differential rate from the EFT framework

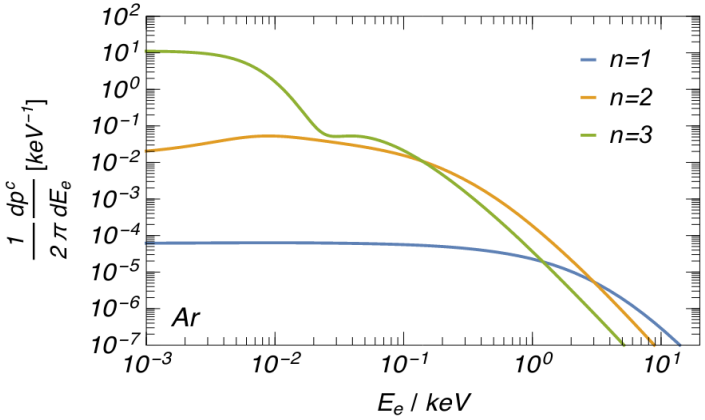
Sum over different energy levels

Ionisation probability

Total electromagnetic energy: $E_{EM} = E_{\mathrm{er}} + E_{n\ell}$

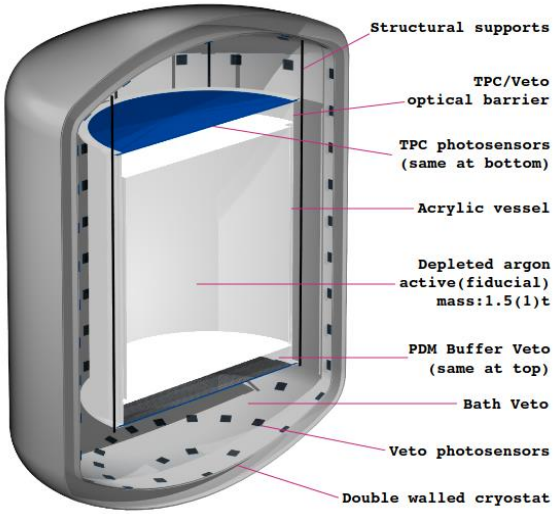


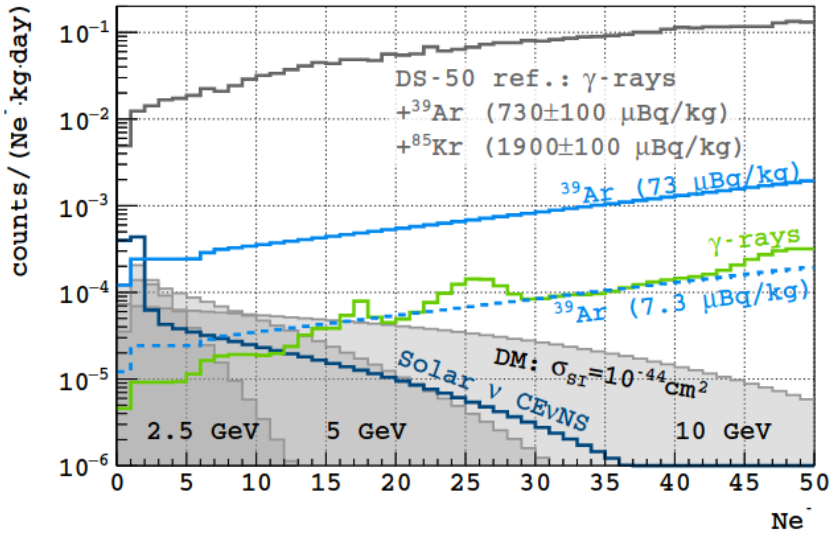
Ionisation probabilities from Ibe et al (arXiv:1707.07258) :



arXiv:2209.01177

DarkSide-LowMass





- Proposed small (1 tonne scale) S2-only dedicated detector
- Additional depletion of UAr to reduce 39Ar background
- R&D to reduce spurious electron backgrounds
- Expected to reach neutrino floor within 1 year of running
- Aim to use a 2e- threshold

arXiv:2209.01177

DarkSide-LowMass