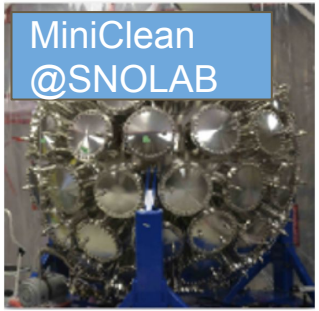
Status of the DarkSide-20k experiment

D.Santone, RHUL
DMUK, 5/5/2022

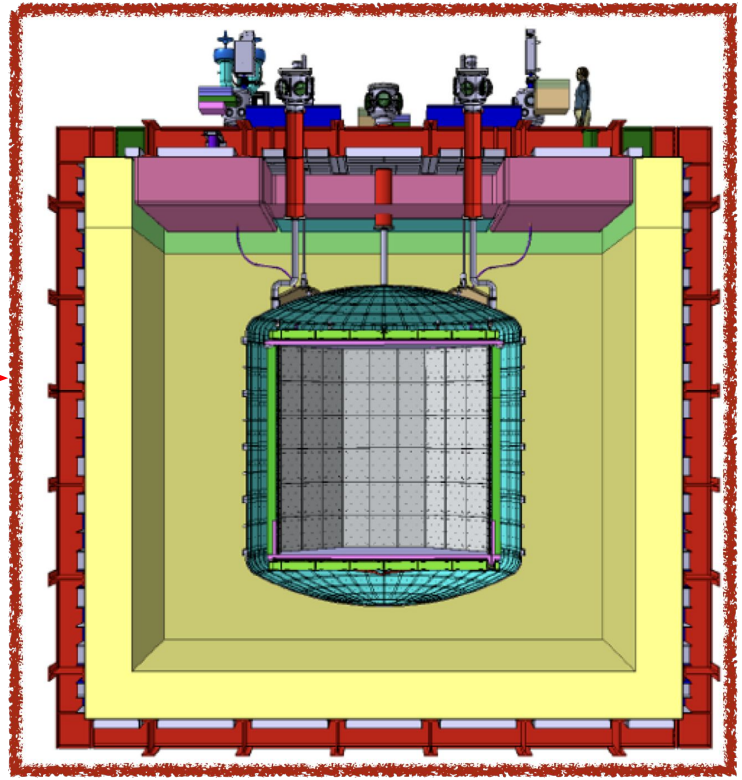
DARKSIDE-20K: Global Argon Dark Matter Collaboration



Darkside-20k

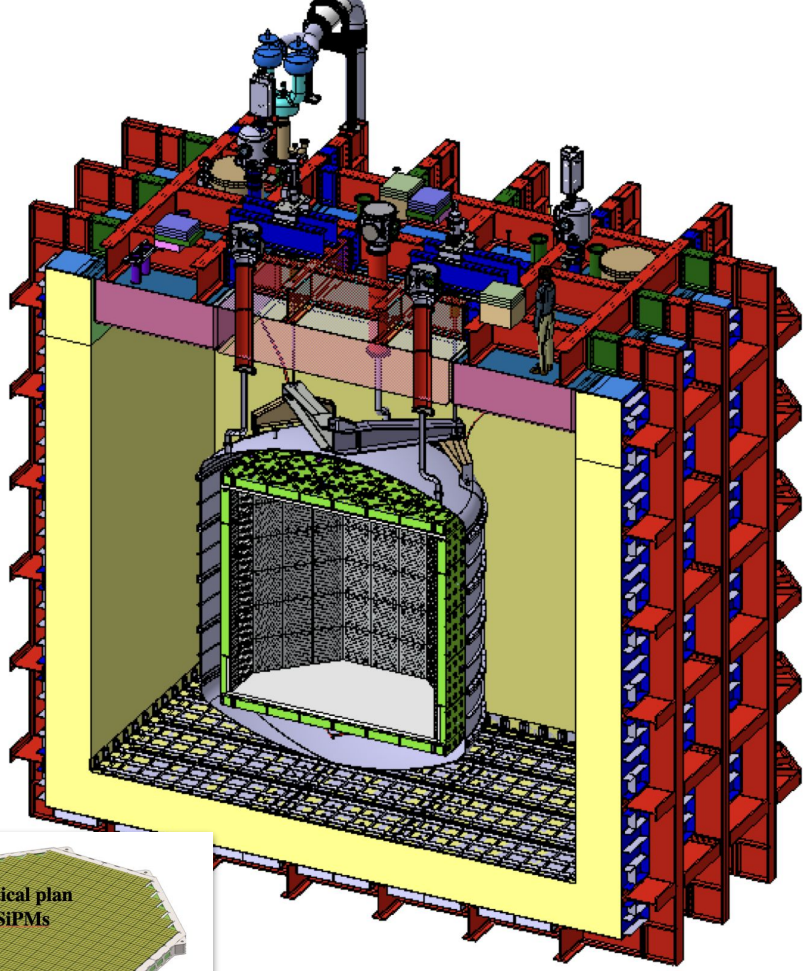
Construction at LNGS has started!

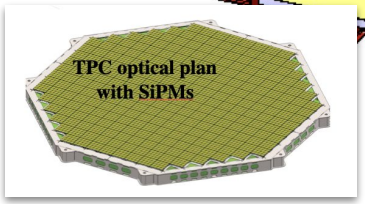
Data taking start in 2025
Nominal run time: 10 years



DARKSIDE-20K: Overview

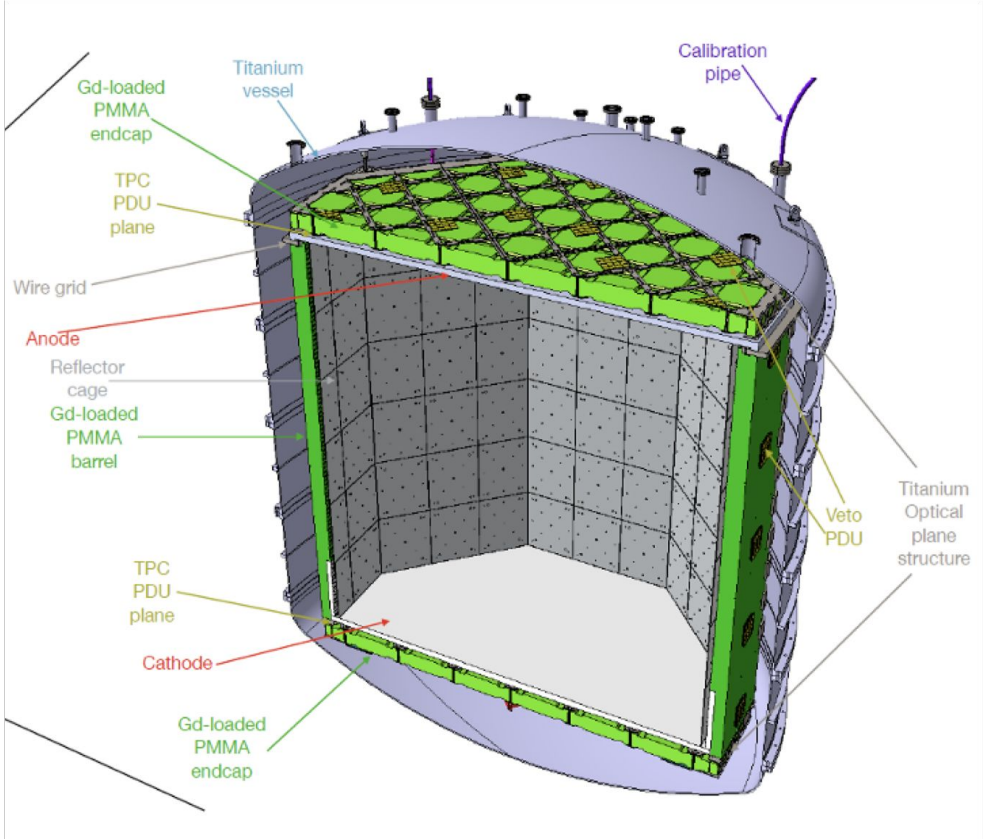
- Dual phase liquid Argon TPC: 50 tons of Underground Argon (UAr)
- Gadolinium loaded acrylic (Gd-PMMA) surrounding TPC wall for neutron capture
- Single phase Argon Veto detector: 35 tons of Underground Argon (UAr)
- Titanium vessel
- ProtoDUNE-like cryostat hosting 650 tons of Atmospheric Argon (AAr)
- TPC & veto equipped with 28 m^2 of Silicon Photomultiplier (SiPMs) readout





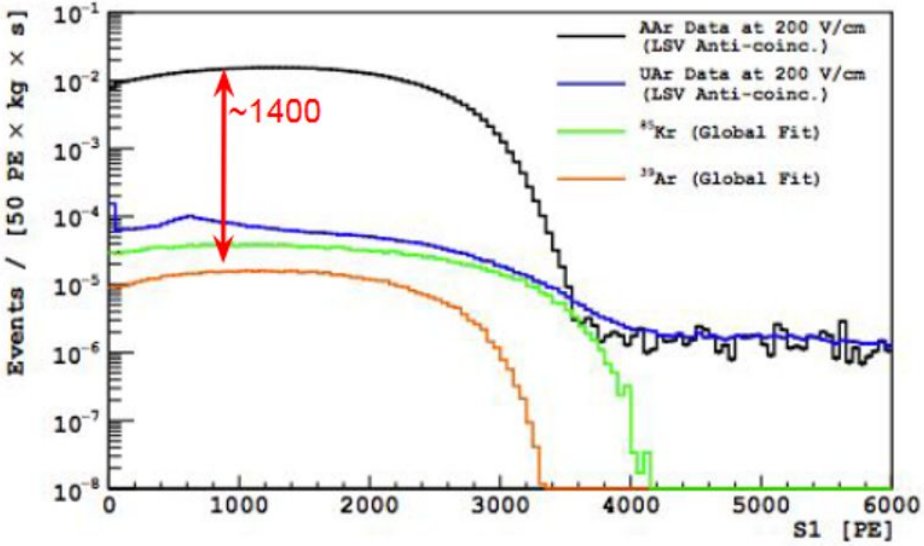
Inner Detector

- Octagonal TPC: 350 cm diameter
- Drift length: 348 cm
- Electron drift time > 5 ms
- Drift field: 2.8 kV/cm
- TPC anode/cathode: transparent pure acrylic coated with Clevios + TPB wavelength shifter (WLS)
- TPC lateral walls: grooves with Clevios for field shaping (no copper ring)
- Reflector + PEN (WLS) on TPC wall and Ti vessel enclosing veto
- Light yield in TPC: >10 phe/keV (S1), > 20 PE/e- (S2)



Underground Argon (UAr)

TPC and veto are filled with UAr in order to reduce Ar-39, which is produced in Atmospheric Argon by **cosmogenic activation** with activity ~ 1 Bq/kg. It is a beta emitter with **endpoint to 565 keV** and **half life of 269 years**.



DS-50 results: Phys. Rev. D 93, 081101(R) (2016)

39Ar deplaction factor: around 1400

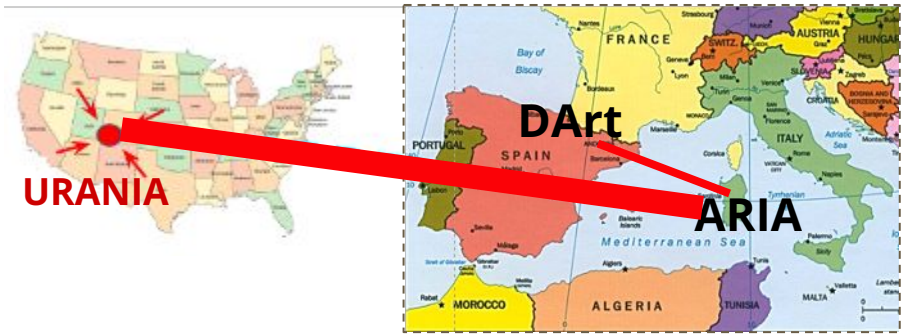
Total UAr:

- **TPC= 50 tons -> 36 Hz of Ar-39**
- **Veto = 35 tons -> 26 Hz of Ar-39**

Mitigated with pulse shape discrimination:

- Residual background is < 0.01 events / 200 tonne x year
- Dead time negligible

The path towards pure Ar: URANIA + ARIA + DArT



1. URANIA: UAr extraction

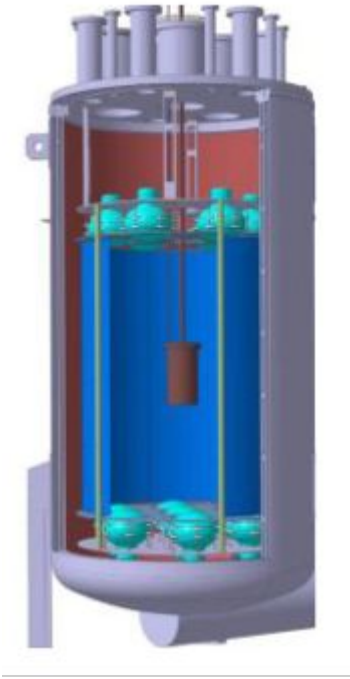
- CO_2 well in Cortez, CO, USA;
- Industrial scale extraction plant;
- UAr extraction rate: 250-330 kg/day;
- Purity 99.99%
- Plant ready to be shipped

2. ARIA: UAr purification

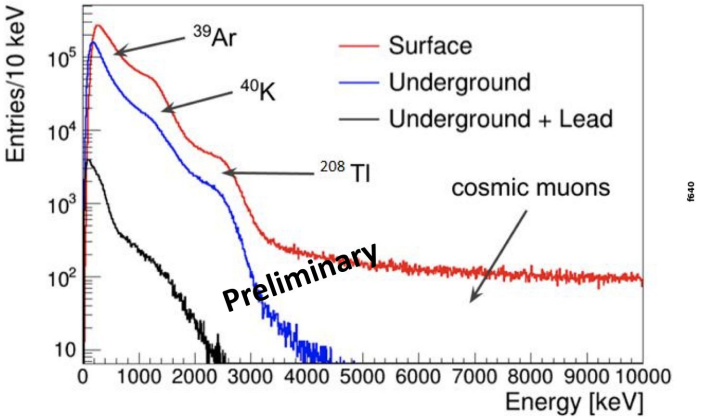
- Cryogenic distillation column in Sardinia (Italy)
- Chemical purification rate: 1 t/day
- Ar-39 separation power > 1000
- First module operated according to specs with Nitrogen in 2019
- Run completed with Ar at the end of 2020

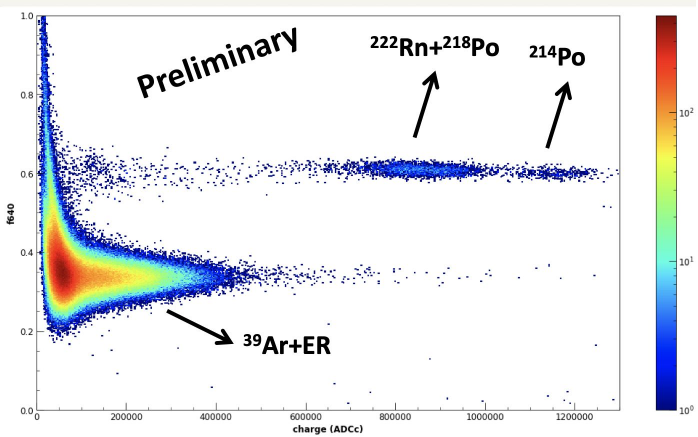
Eur.Phys.J.C 81 (2021) 4, 359

DArt

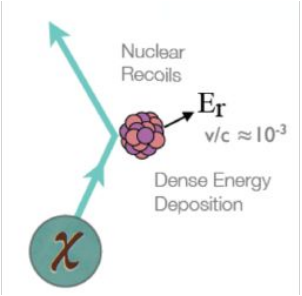


- Located at LCS, Canfranc
- Double phase TPC with active volume of 1.4 kg of liquid UAr
- Two 1 cm^2 SiPMs at the top & bottom
- External acrylic support
- Internal acrylic covered with TPB (WLS)
- Ar-39 depletion factor sensitivity: 6 x 10^4 90% C.L



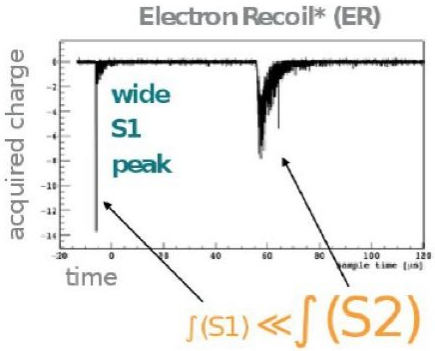


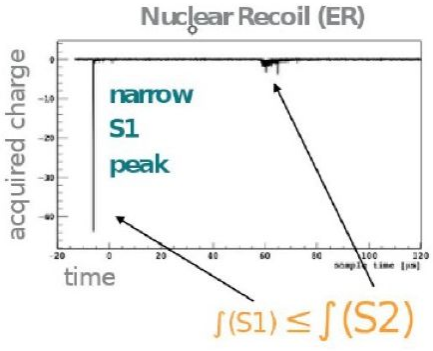
WIMP SEARCH: Signal

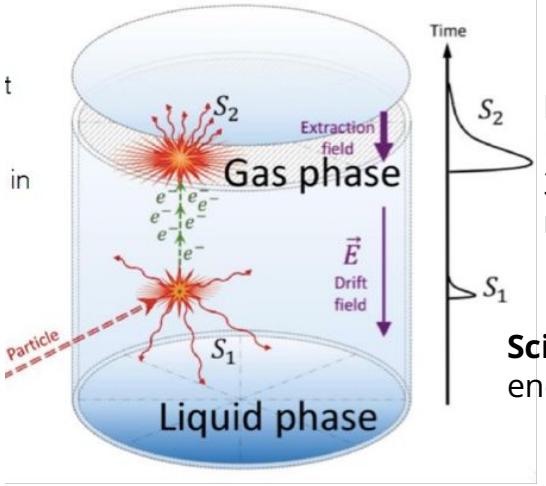


WIMP signal:

- Single nuclear recoil
- Recoil energy: 1-100 keV

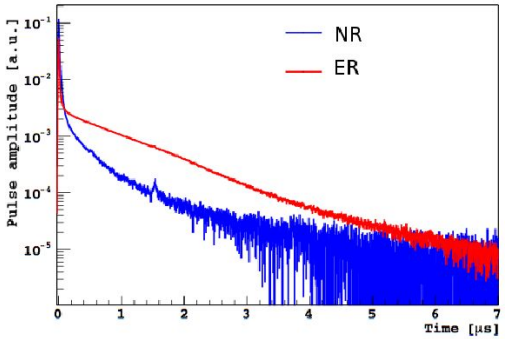






Ionization (S2):
Energy information & 3D position reconstruction

Scintillation light (S1):
energy information



S1 signal only in liquid Argon

Background: Electron recoil

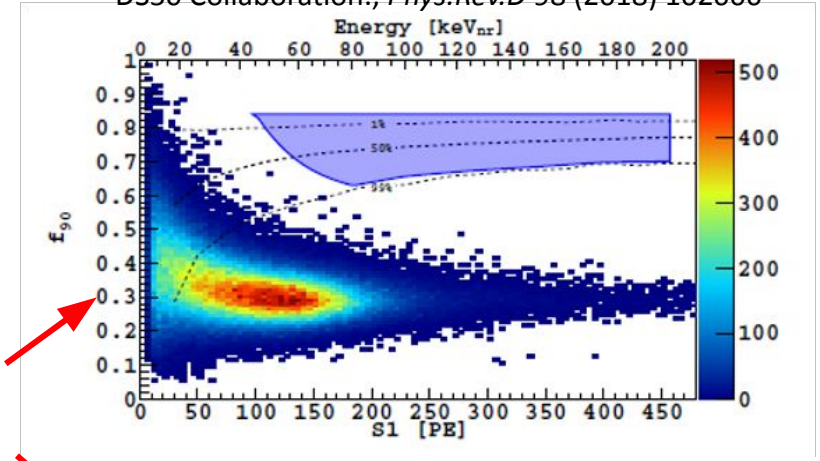
Produced by gamma, e-:

- U-238 & Th-232 decay chain: principally from Rn-222
- Ar-39 β-decay (reduced with UAr)
- Kr-85 β-decay
- Solar neutrino

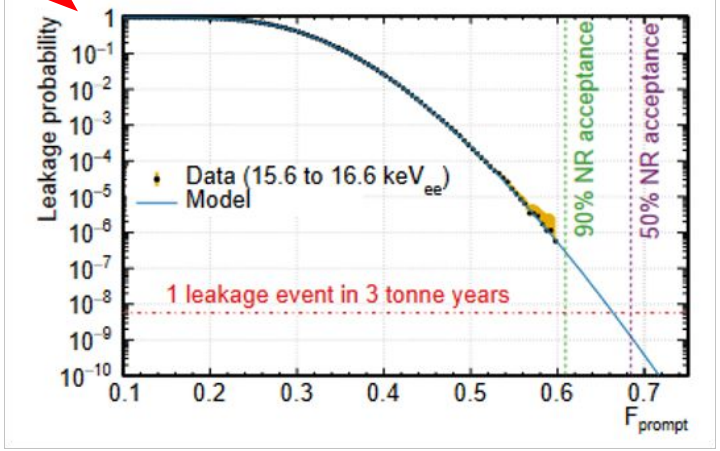
electronic recoils are rejected by Pulse shape discrimination, demonstrated by DS-50 & DEAP

Fprompt parameter:
PROMPT light
PROMPT + LATE light

DS50 Collaboration., *Phys.Rev.D* 98 (2018) 102006



DEAP Collaboration, *Phys.Rev.D* 100 (2019) 2, 022004

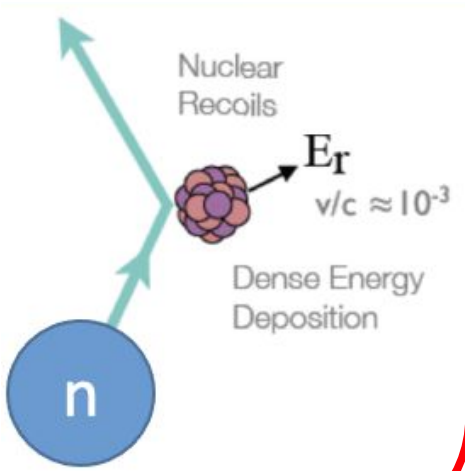


Background: Nuclear recoil

Produced by neutrons, alphas:

- Ur-238 and Th-232 contamination of detector material
- Cosmogenics interaction due cosmic ray
- (α,n) reaction in the detector material
- Spontaneous fission decay

Same recoil as WIMP



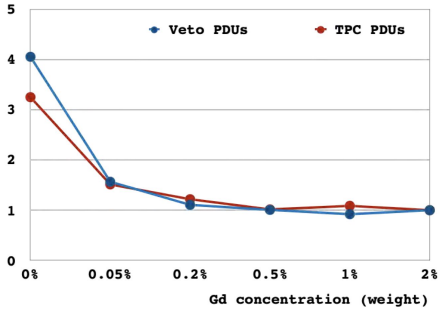
Nuclear recoil reduction:

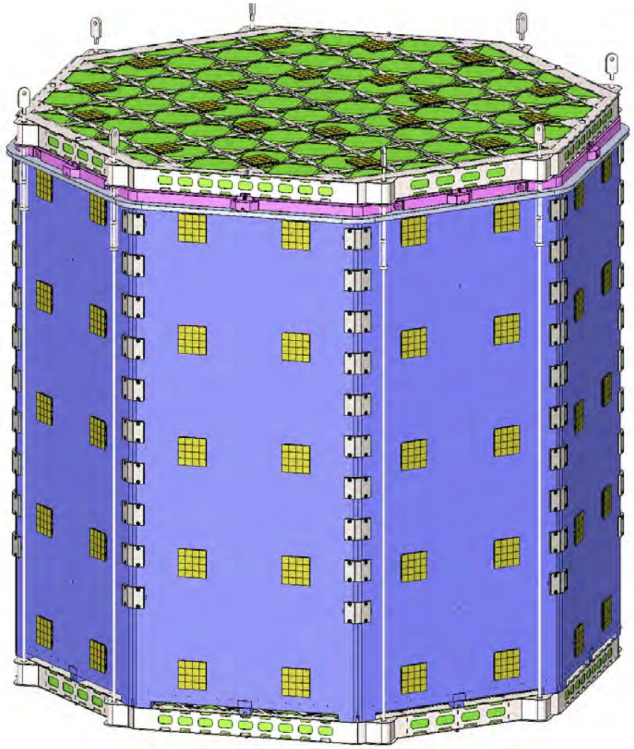
- Stringent material selection & radiopurity control
- Cut on multiple scatters event & r-z cuts-> fiducial volume = 20 tons
- **Neutron veto**

Neutron veto

Integrated TPC+veto system

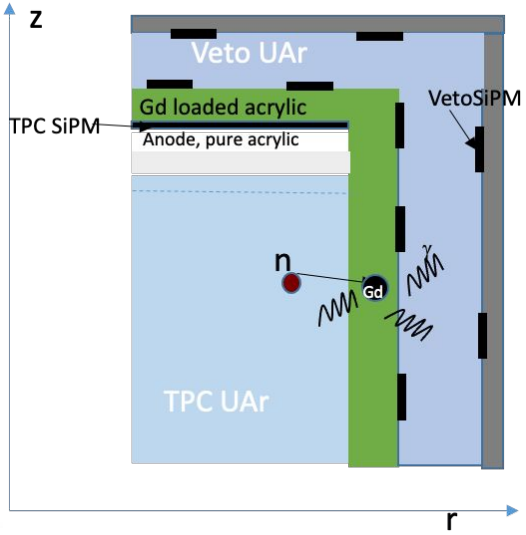
- TPC wall surrounding by Gd loaded PMMA for neutron capture
- Around TPC wall -> veto SIPMs for light detection
- Inside a Titanium vessel
- Reflector + PEN
- Veto SiPMs on TPC wall
- 1% fraction of Gd in PMMA





How does neutron capture?

- Neutron capture on Gd produce a high energy gamma cascade (8 MeV)
- Event with energy deposit of 50 keVee in the TPC **OR** 200 keVee in the veto tagged as neutron



Gd-PMMA: industrial production

Developed by DarkSide-20k

Sample produced in a industrial test @CLAX (Italy) -> homogeneity of 5% (ready for final production)

IGEPAL radiopurity problem -> high K-40 contamination

	U (ICPMS) [mBq/kg]	Th (ICPMS) [mBq/kg]	^{40}K (HP-Ge) [mBq/kg]
Igepal CO-520	<0.041	<0.12	$3.19*10^4$

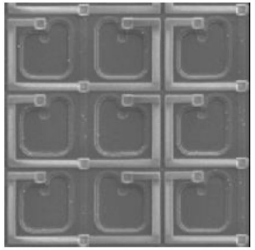
Purification & mass reduction to reduce gamma rate from K-40

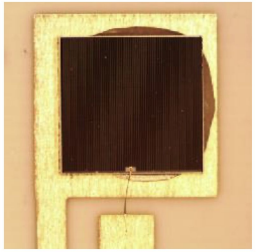
Contributor	Contributions to γ-background [Hz]			
	Igepal 0.1%$_w$ not purified		Igepal 0.1%$_w$ purified	
	TPC	Veto	TPC	Veto
Gd_2O_3	0.4	0.9	0.4	0.9
Igepal	10.2	19.6	0.3	0.5
PMMA	9.7	19.5	9.7	19.5
Total contribution from Gd-PMMA	20.3	40.2	10.1	20.5

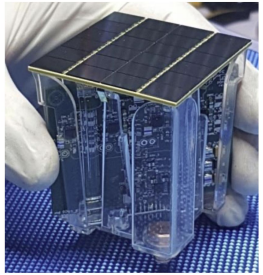
The γ bkg is safe!

Large area cryogenic SiPM light detectors

SPADs → SiPMs: 1mm^2 → PDM







SPADs - Single Photon Avalanche Diodes: semiconductor devices based on a p-n junction, reverse biased well above breakdown voltage (operating in Gieger mode).

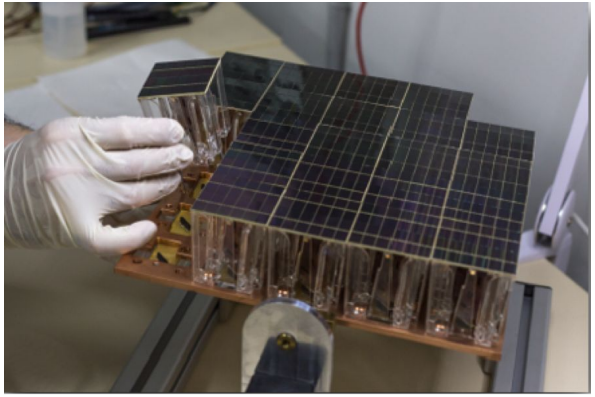
SiPMs - Silicon Photomultipliers: A single SiPM consists of ~94,900 SPADs. 24 SiPMs are grouped into tile (with an area of 25 cm2).

PDM - Photo Detector Module: The SiPM tile is combined with the front end board electronics to make a PDM. The signals from all SiPMs on the PDM are summed and read out as a single channel.

Quantity	Requirement
Breakdown voltage	26.8 +/- 0.2 V
SiPM response - recharge time	300 - 600 ns
Single Photoelectron (SPE) spectra	distinct PE
Gain	stable gain
Signal to noise ratio (SNR)	> 8
Dark count rate (DCR)	< 0.01 Hz/mm^2 (7 Vov) < 0.1 Hz/mm^2 (9 Vov)
Internal cross talk (CT) probability	< 33 % (7 Vov) < 50 % (9 Vov)
Afterpulsing (AP) probability	< 10 %

GROUPING SiPMs

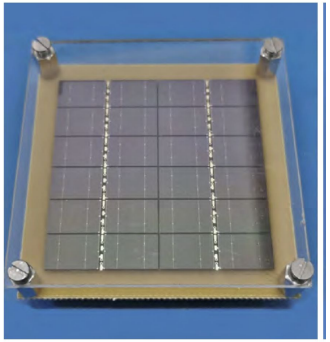
First Motherboard (MB)



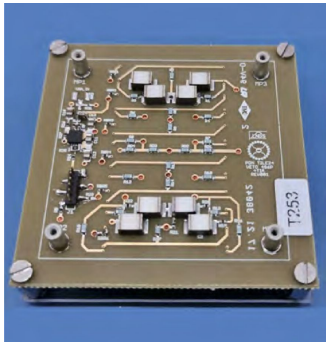
- The first prototype
- 25 Tiles
- Separate PCBs for various functions
- Thick structure (15 cm thick)
- Discrete elements amplifiers
- 25 outputs

Photo Detector Unit (PDU) now

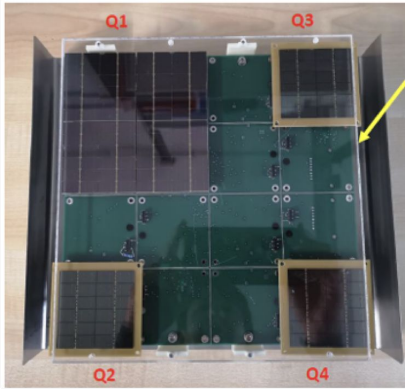
Side 1: 24 SiPMs



Side 2: Front-end electronics



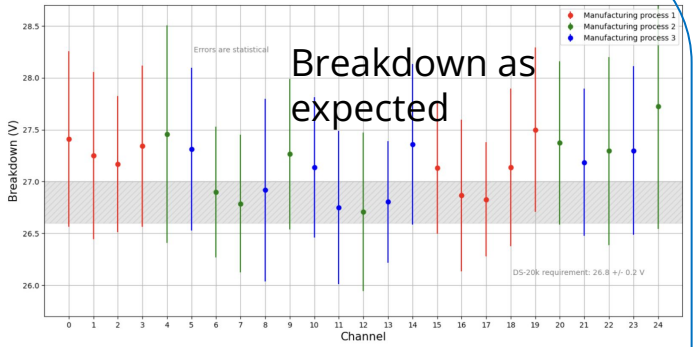
MB+: 16 tile+

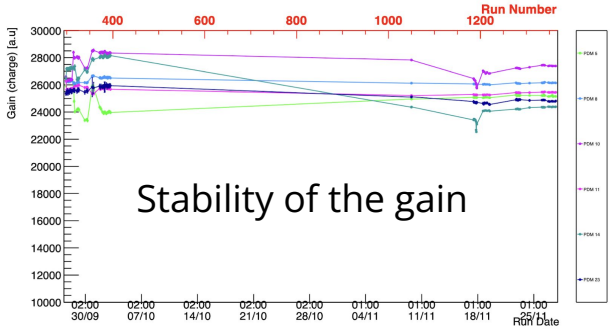


- 16 Tiles
- Single PCB for Tile & amplifier+
- 1 large PCB for control signals
- Thin structure
- Discrete elements (for TPC) and ASIC (for Veto) amplifier
- Sum of 4 amplified tile signals
- 4 outputs

Performance in DarkSide PDU Test Facility

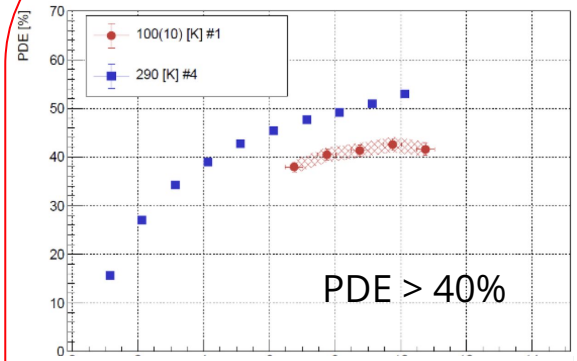
First MB

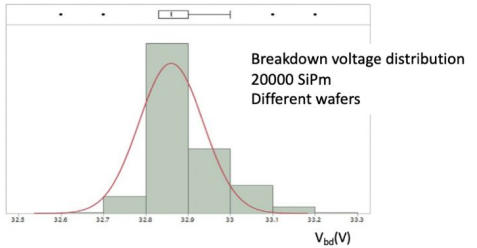


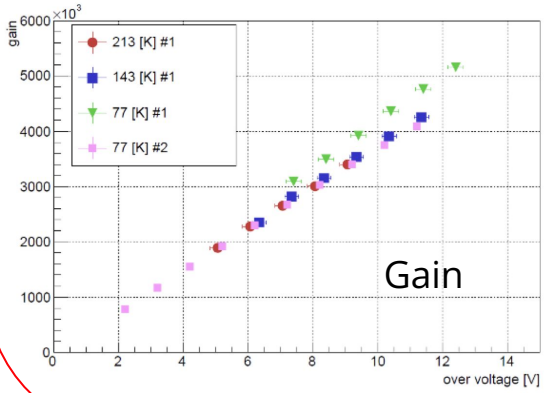


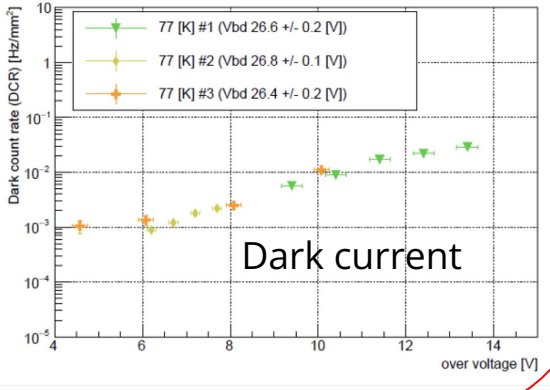
$$\mathrm{SNR} = \frac{\text{mean of 1PE peak}}{\text{mean of the baseline RMS}}$$ ~16

PDU: preliminary results







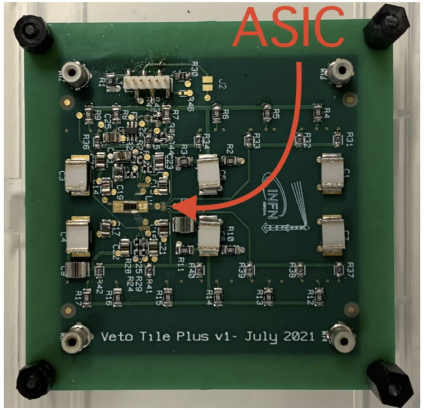


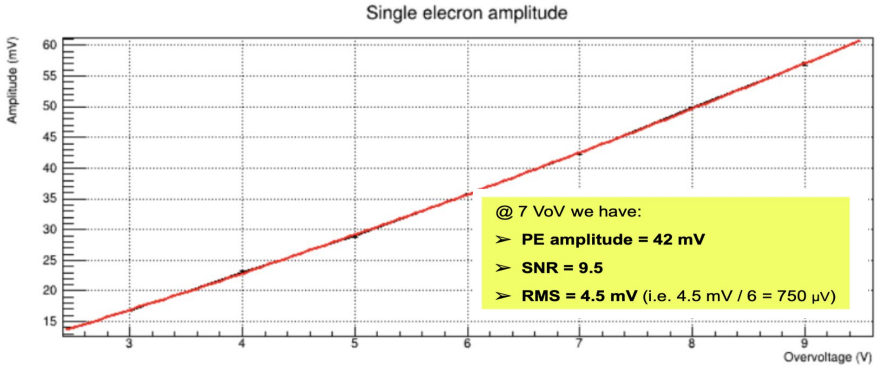
[See more at IOP'22 talk by Zoe Balmforth]

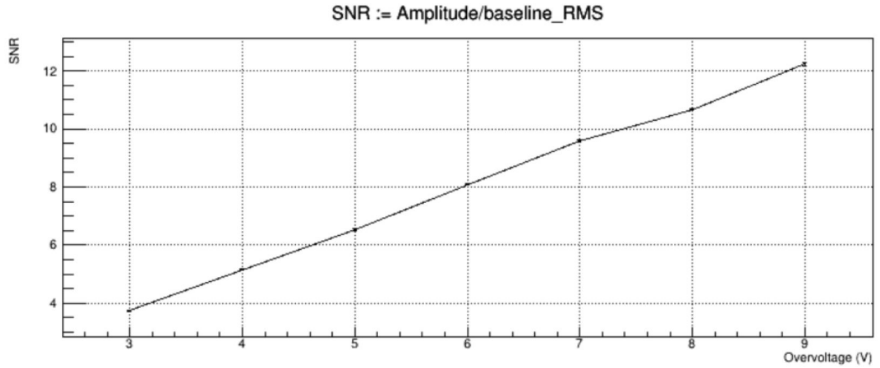
Veto Photon Detector Module

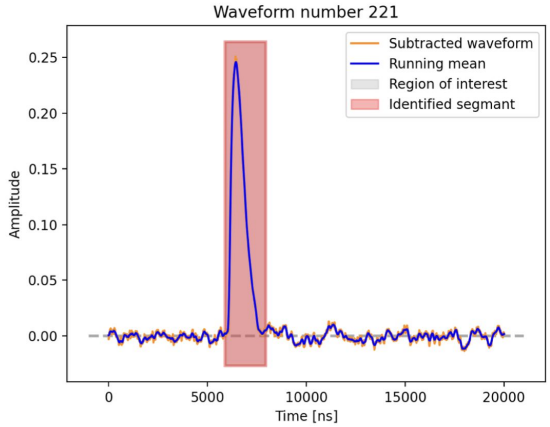
Same structure,
ASICS as amplifier,

2500 veto PDMs to be produced by **DarkSide-UK** groups to instrument Inner veto detector





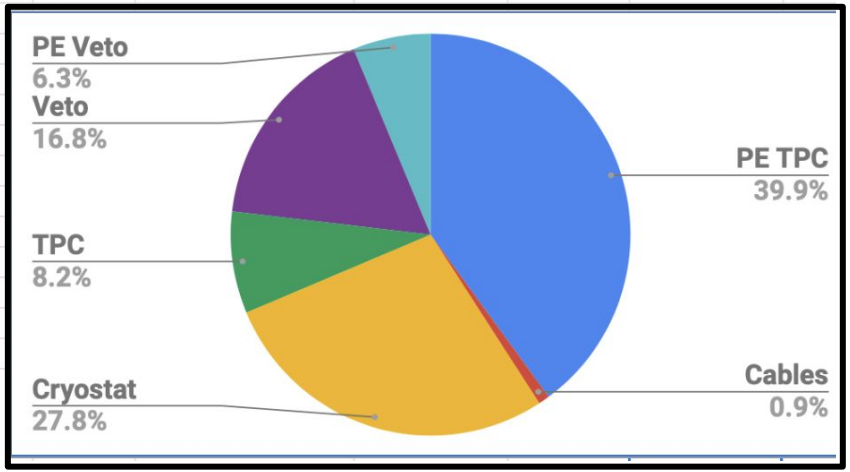


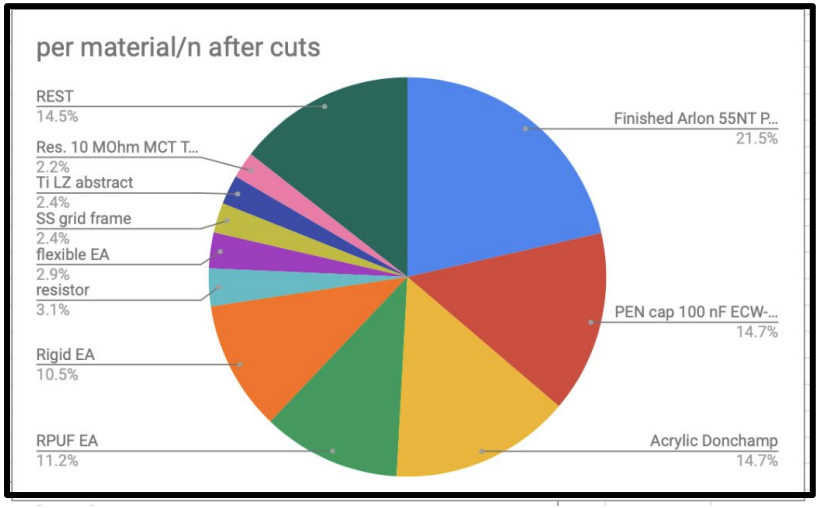


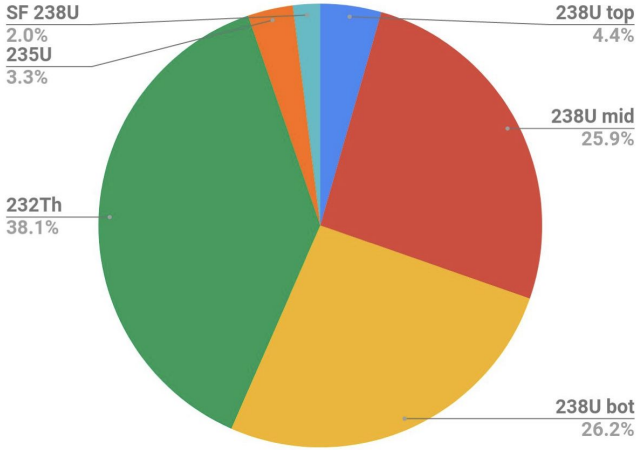
UK producing veto PDMs, and first veto PDU test planned this summer!

Background budget

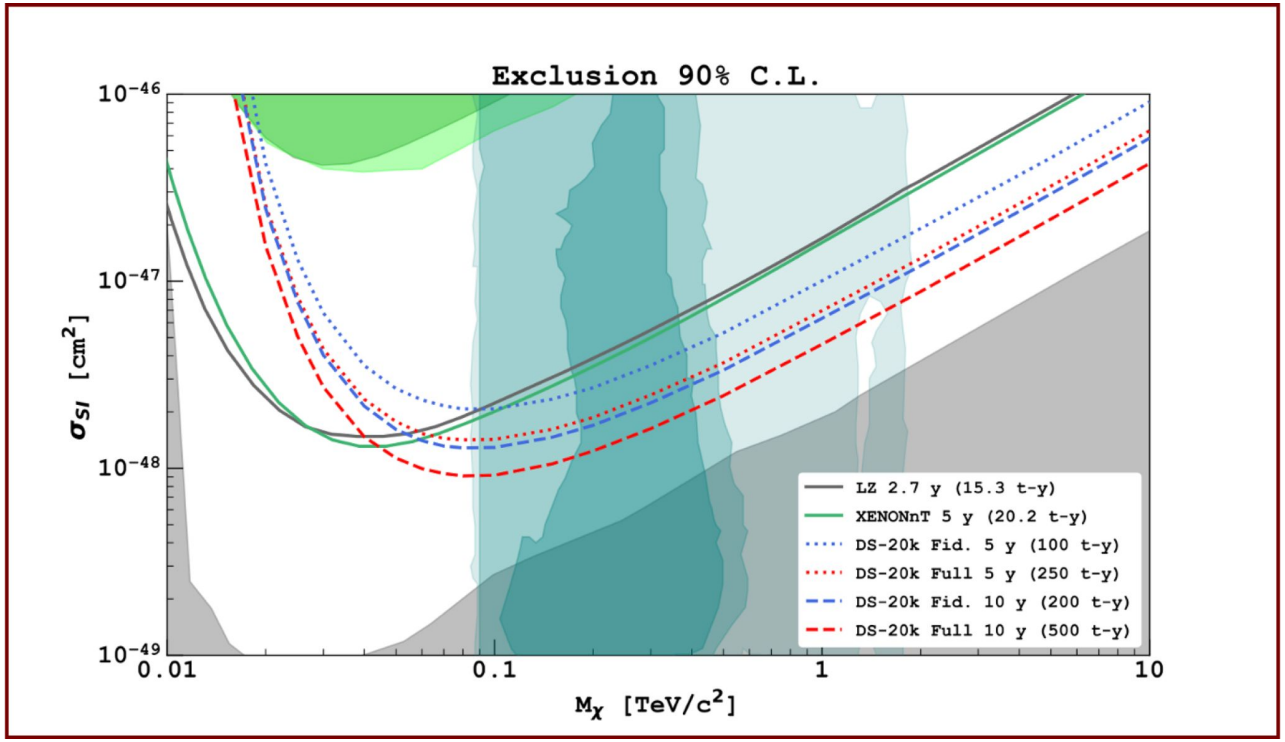
- PE & cryostat dominant contribution to background
- Based on ICP-MS, Ge assay and Po-210 radiochemical extraction measurements
- **0.1 events after all cuts in a full exposure of 200 ton x year**







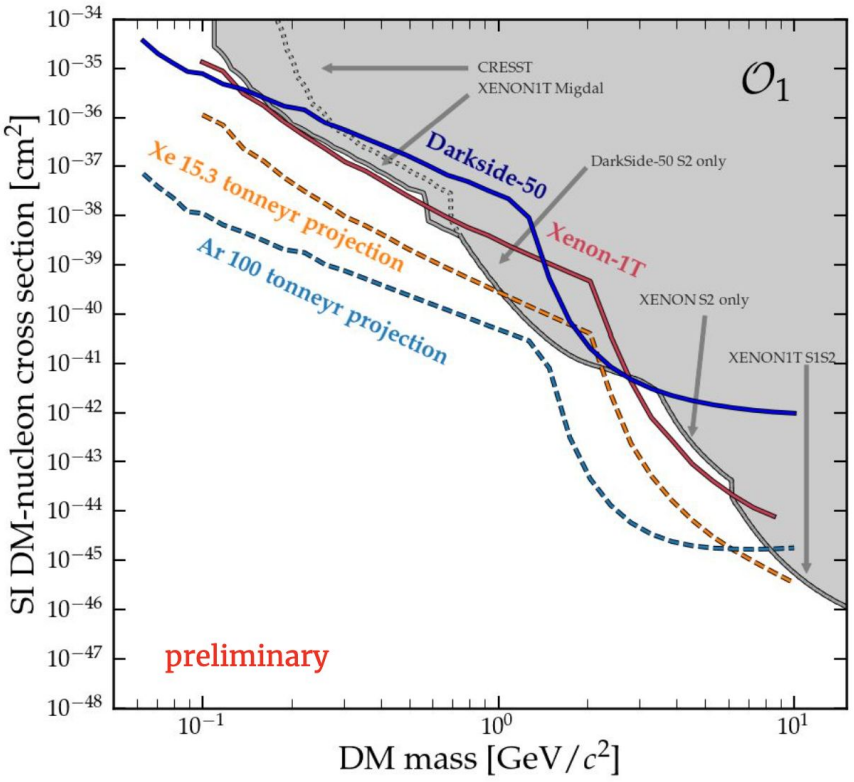
DarkSide-20K projected WIMP sensitivity

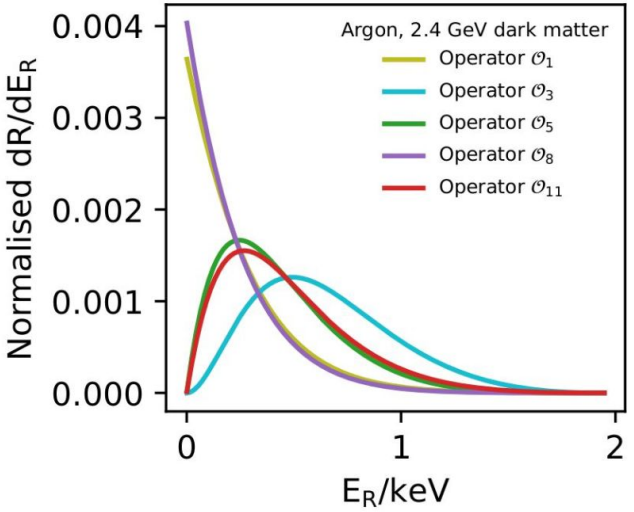


- 20 t Fiducial Mass analysis with 0.1 instrumental background events in 200 tonne-years
- 50 t Full Mass analysis uses background distributions in profile likelihood ratio

Turquoise filled contours are from pMSSM11 model, E. Bagnaschi et al., Eur. Phys. J. C 78, 87 (2018).

Sensitivity to light dark matter





- reinterpretation of published Ar and Xe results including Migdal effect (Ibe *et al.*), benchmarked against published results
- analysis of future prospects for light dark matter, for EFT operators beyond *O1*

See more at IOP'22 talk by Ellen Sandford

Summary and Outlook

- The **Global Argon Dark Matter Collaboration (GADMC)** is a joint effort among all dark matter experiments with Ar target: ~400 collaborators from ~100 institutions towards **DarkSide-20k**
- DarkSide-20k is pushing the **state-of-the-art** in several directions: SiPM technology, underground argon extraction & purification, Gd-PMMA, background assay campaign
- DarkSide-20k is **in position to lead** the search for WIMPs, with complimentary reach above the LHC center of mass energy
- **Fundamental role played by UK groups** in producing the SiPM readout modules for the veto detector, which is key to achieving the <0.1 instrumental backgrounds to the dark matter search! And **expanding the reach beyond heavy WIMPs…**