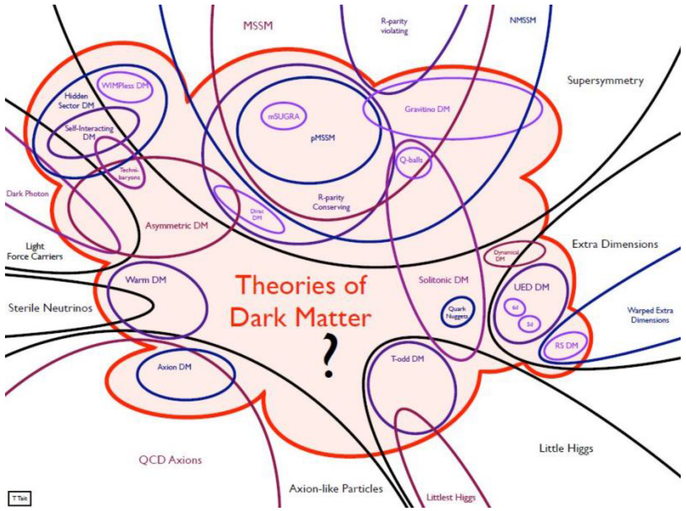
THE DARKSIDE-20k EXPERIMENT AND THE FUTURE LIQUID ARGON DARK MATTER PROGRAM

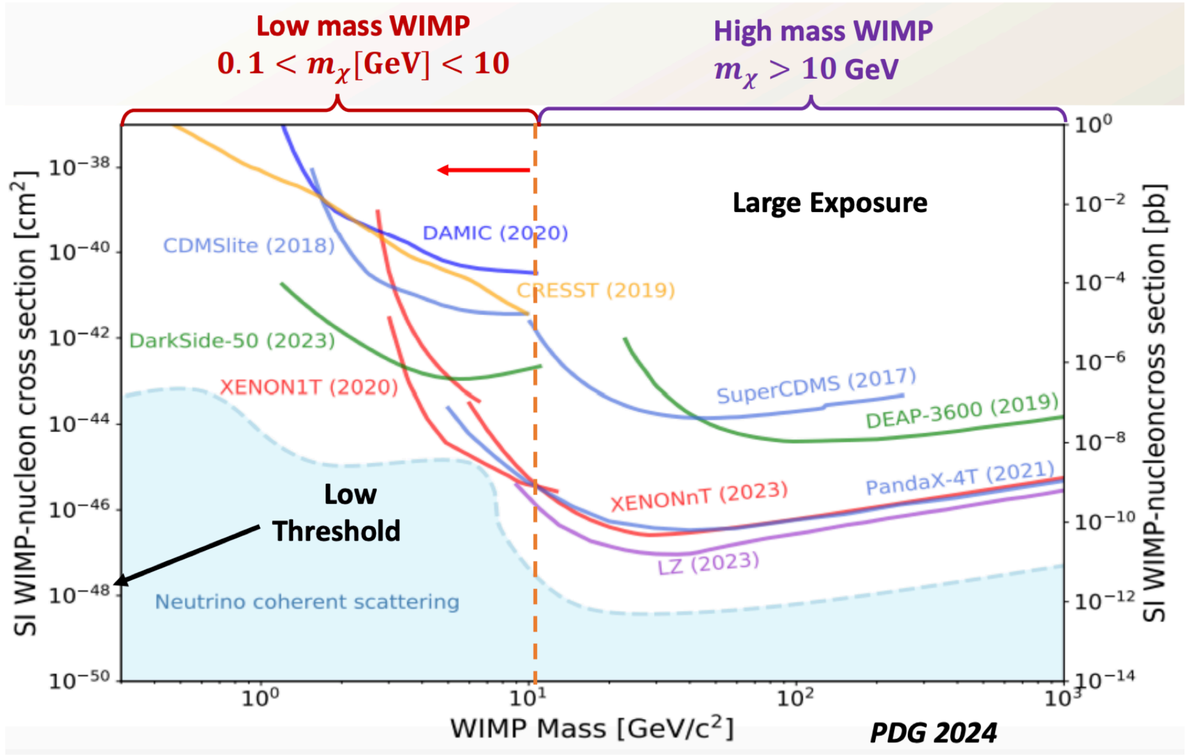
Daria Santone, University of Oxford
On behalf of DarkSide-20k collaboration
Blois 2024, 23/10/2024

DARK MATTER CANDIDATES



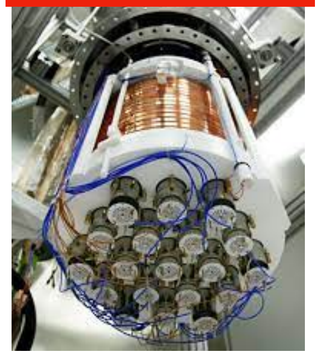
WIMP “Miracle"

- Weak scale interaction lead to correct density in the universe
- Mass scale: MeV - 100 TeV
- Motivated by many theories

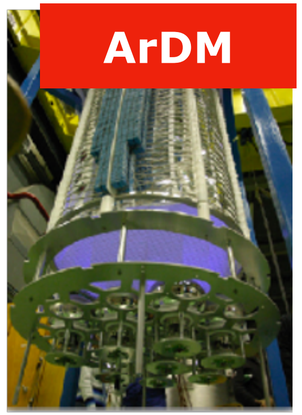


GLOBAL ARGON DARK MATTER PROGRAM

DS-50

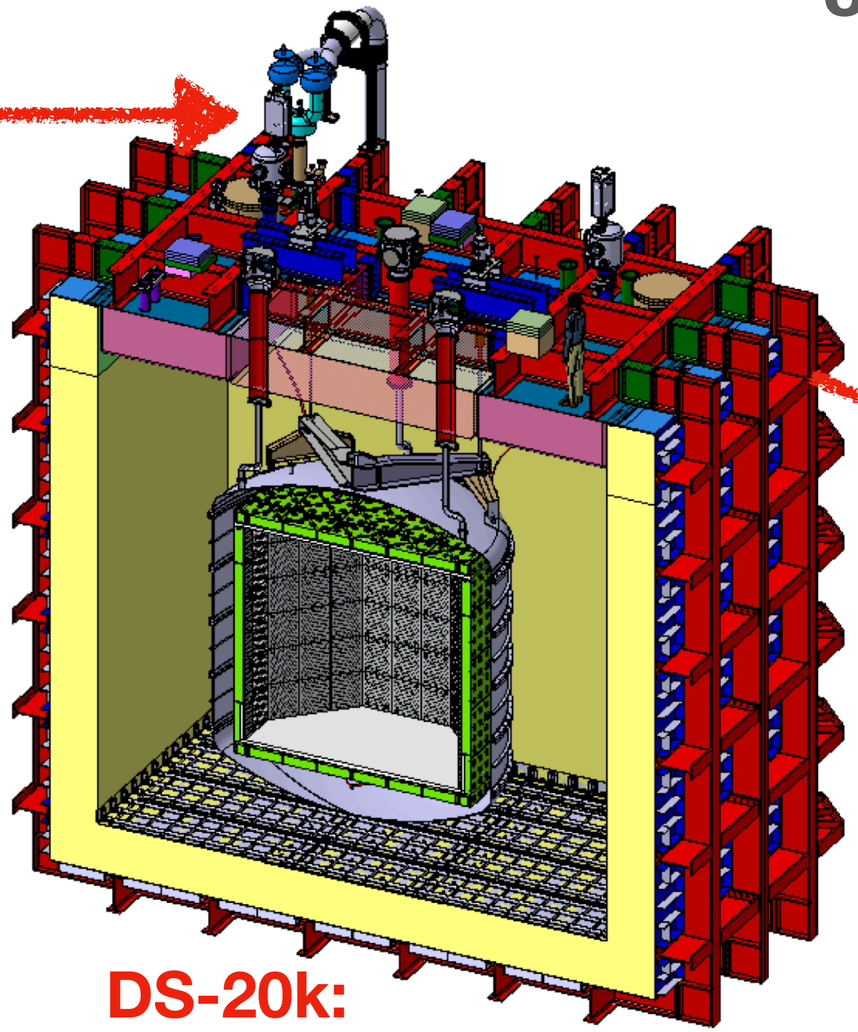


ArDM



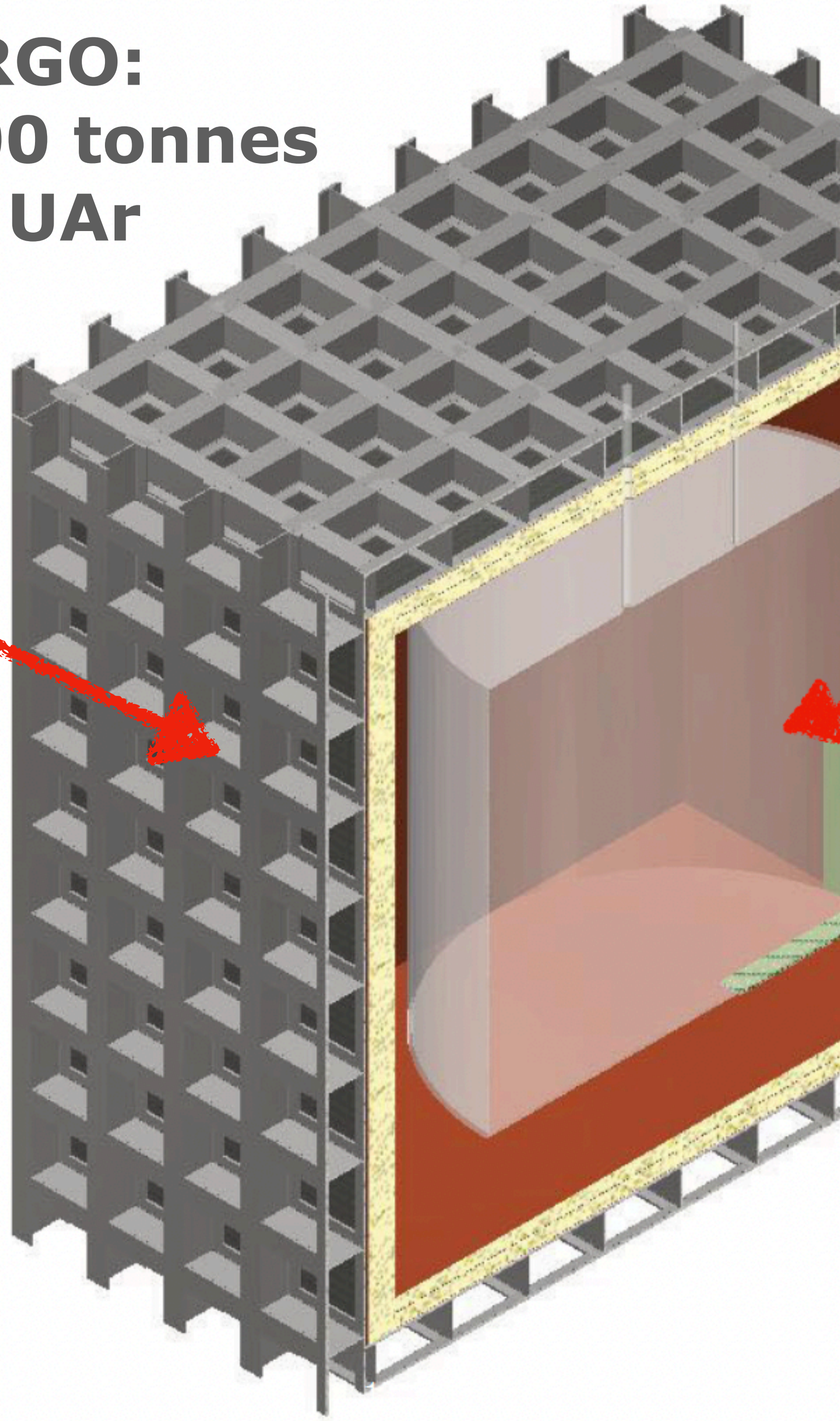
DEAP

Miniclean



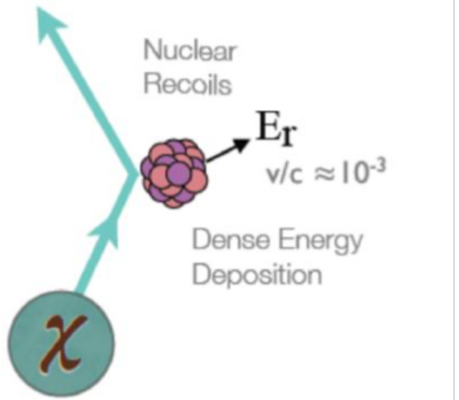
DS-20k:
50 tonnes of UAr
(20 tonnes FV)

ARGO:
600 tonnes
of UAr



WIMP SIGNAL & BACKGROUNDs

WIMP SIGNAL



- Single nuclear recoil
- Energy recoil between 1 and 100 keV

BACKGROUND

Background source	Mitigation strategy
^{39}Ar β decay	Use Underground Argon + pulse shape discrimination
γ from rock and γ,e from material	Pulse shape discrimination Selection material
Radiogenic neutron **(α,n) reaction in detector material**	Material screening & selection Definition of Fiducial volume in the TPC **Veto to reject neutron signal**
Surface contamination due Rn progeny	Surface cleaning Reduce the number of surfaces Installation of Rn abated system
Muon induced background	Cosmogenic veto
Neutrino coherent scatter	Irreducible

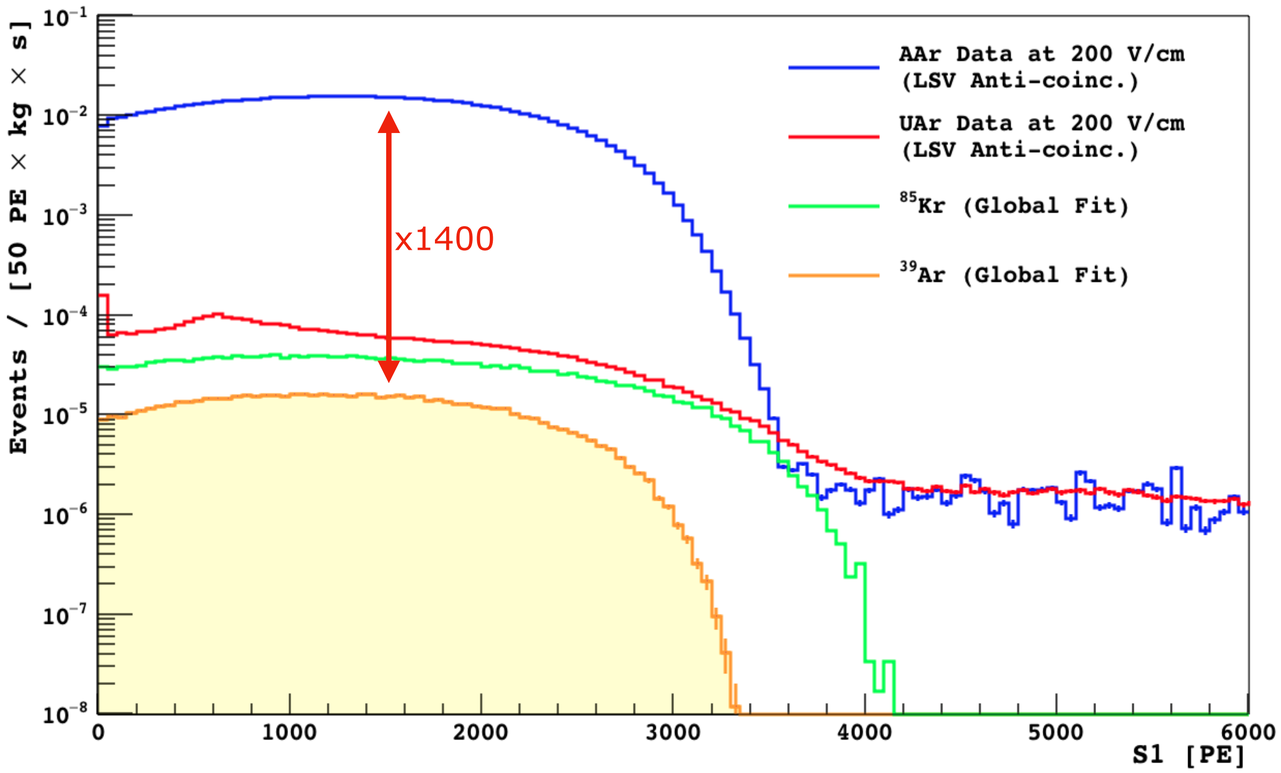
WIMP SEARCH IN DS-50

50 kg of Underground Argon (UAr)
Data taking: 2013 - 2018, total exposure of 0.03 tons x years
Low mass search using charge signal only

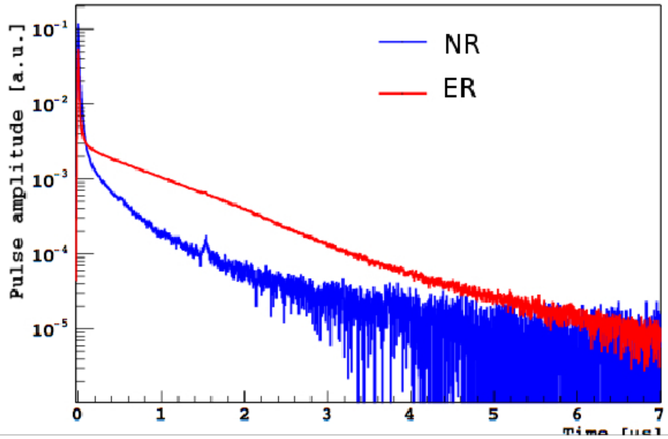
BACKGROUND REJECTION

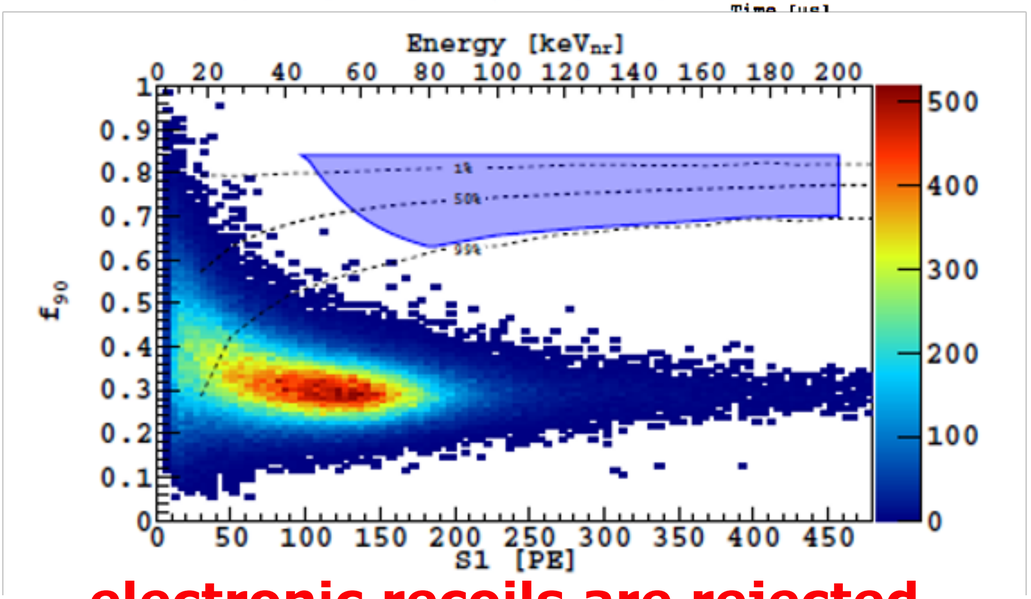
TPC filled with UAr in order to reduce Ar-39, which is produced in Atmospheric Argon by **cosmogenic activation** with activity ~ 1 Bq/kg.It is a beta emitter with **endpoint to 565 keV** and **half life of 269 years**.

Phys. Rev. D 93, 081101(R) (2016)



Scintillation (S1) pulse shape in LAr



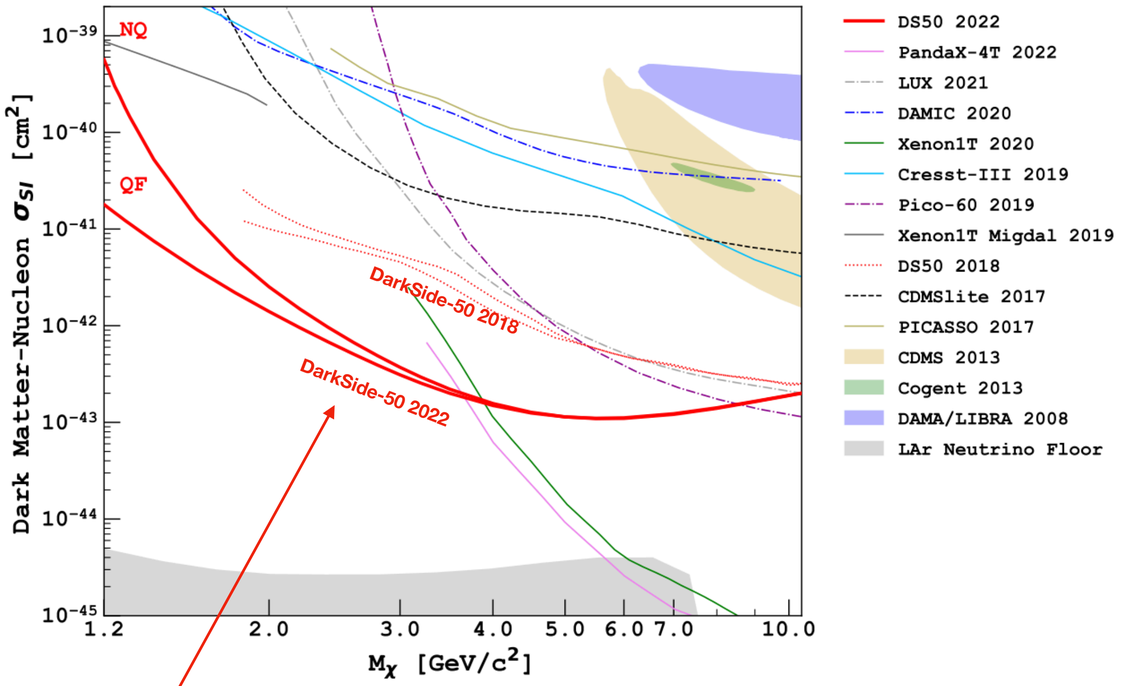


electronic recoils are rejected by Pulse shape discrimination

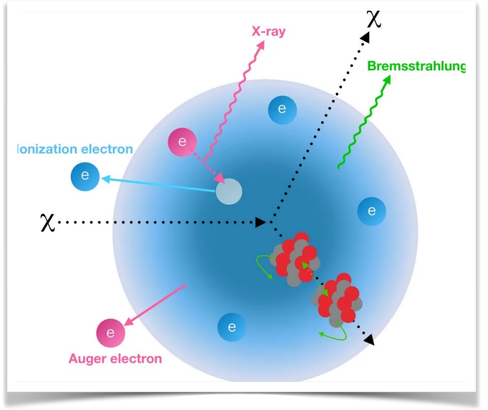
LOW MASS RESULTS

Re-analyse the full DS50 dataset
with a more detailed calibration model

Phys.Rev.D 107 (2023) 6, 063001

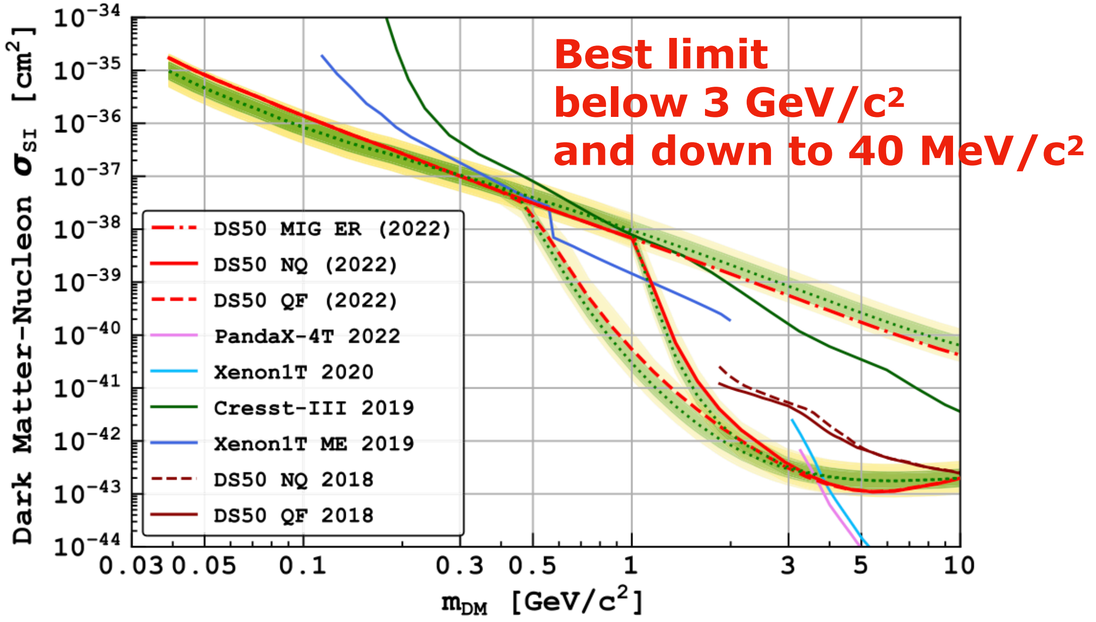


Best limit in the region between 1.2 and 3.6 GeV/c²



Reinterpretation of published Ar and Xe resulting including Migdal effects benchmarked again published results

Phys. Rev. Lett. 130, 101001



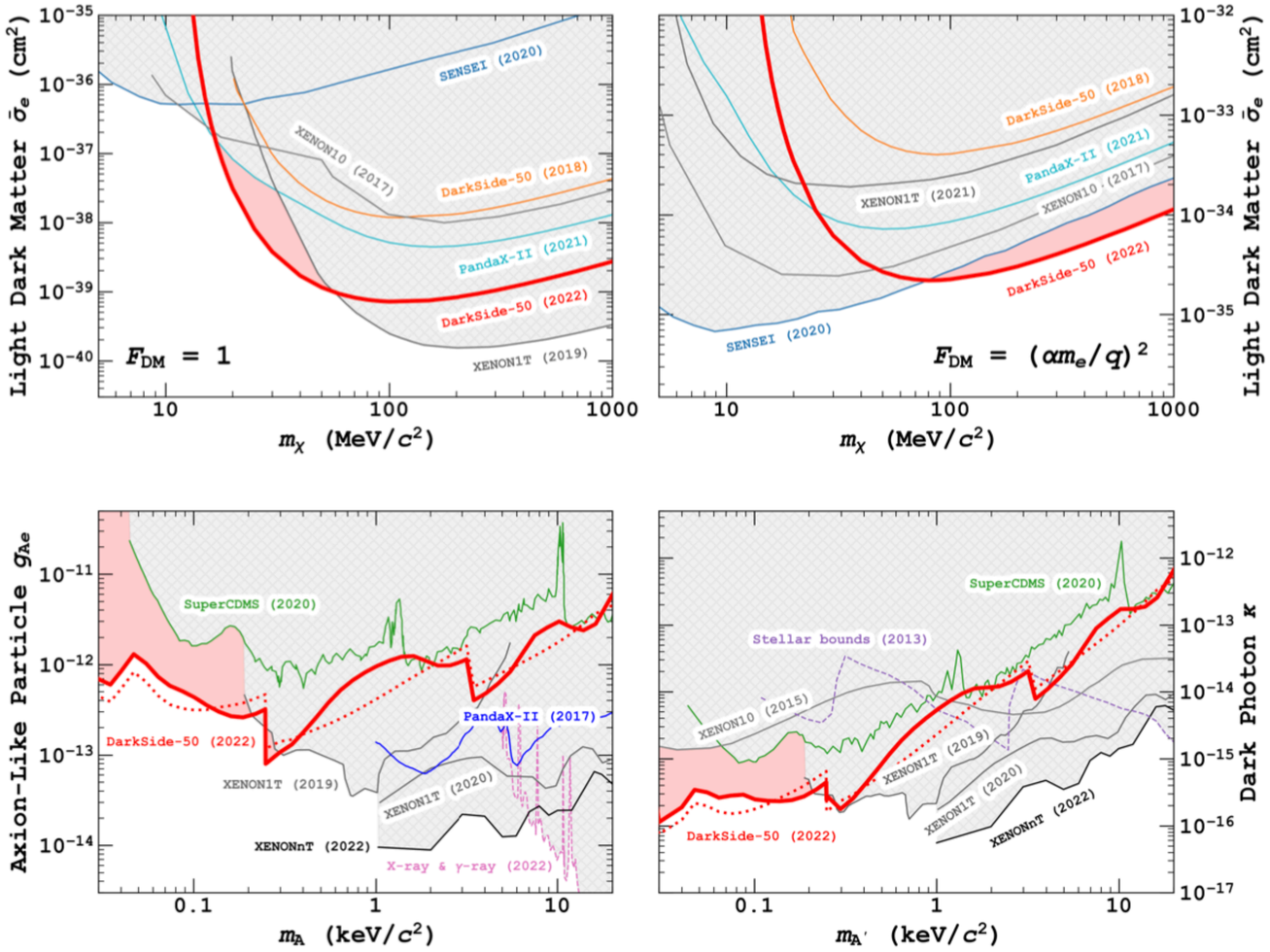
DM-e- SCATTERING RESULTS

Phys. Rev. Lett. 130, 101002 (2023)

- Exclusion limits at 90% C.L. on DM particle

  interactions with electron final states
- Limits on dark matter-electron scattering in the [16, 56] MeV/c^2 mass range for a heavy mediator and

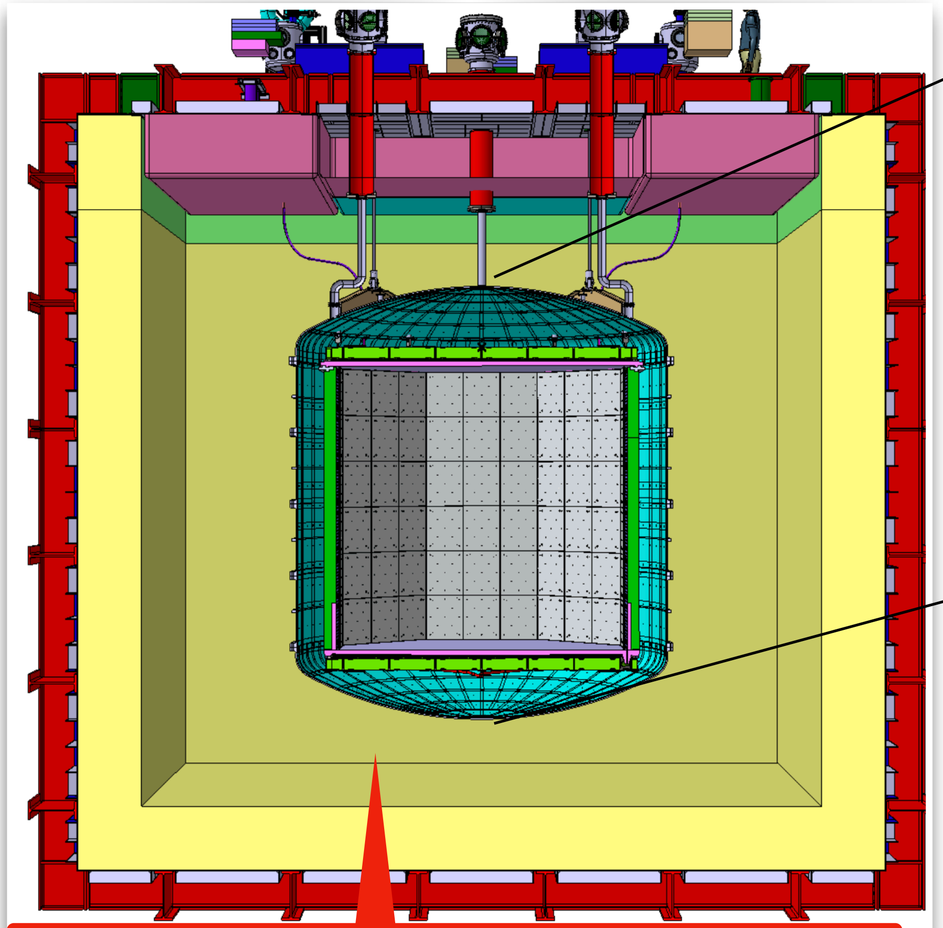
  above 80 MeV/c^2 for a light mediator

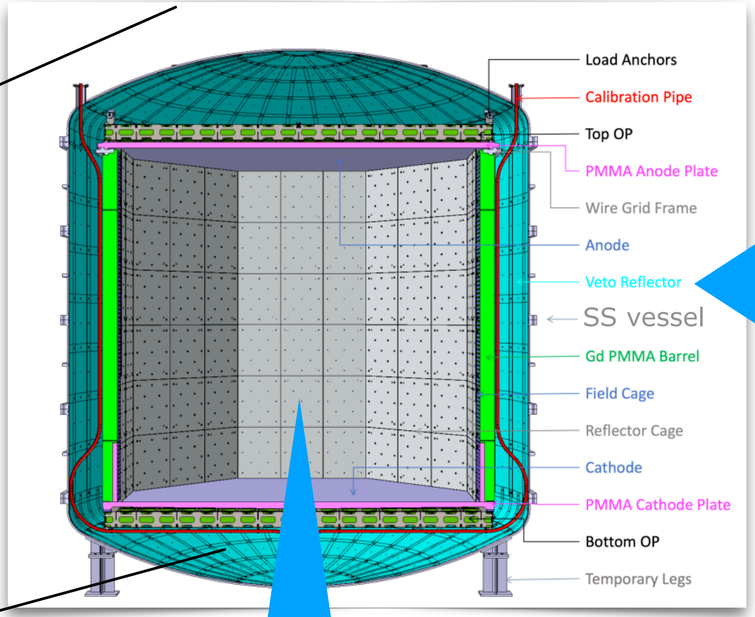


WIMP SEARCH IN DS-20k

DARKSIDE-20k: overview

Inner detector





Neutron veto:

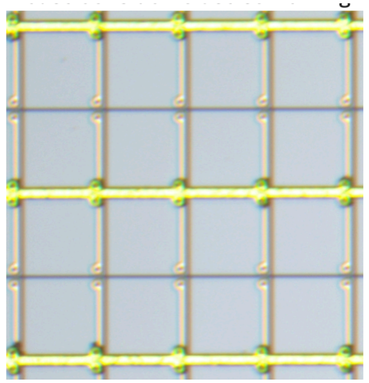
- (Gd)PMMA as neutron veto
- Immersed in 35 tonnes of UAr
- Equipped with large array of SiPM for 5 m^2 coverage
- Light yield: 2 pe/keV
- Enclosed in a SS vessel
- HDPE neutron shield around SS vessel

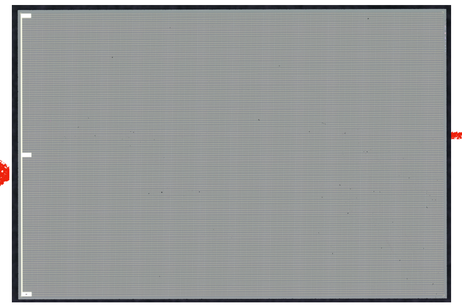
Dual Phase TPC:

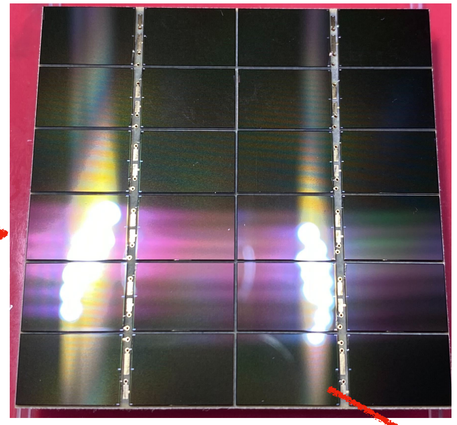
- Filled with 50 ton of Underground Argon (UAr)
- Equipped with two optical plate -> large array of SiPM for 21 m^2 coverage
- Light yield:
  - S1 (scintillation signal): 10 pe/keV
  - S2 (charge signal): 20 pe/e-

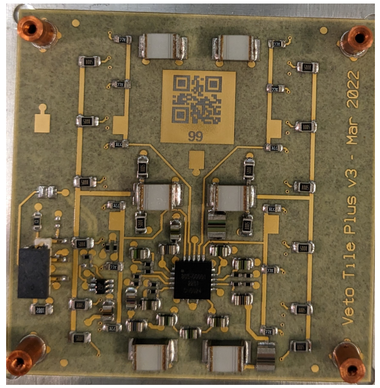
Outer veto filled with 650 tonnes of atmospheric argon as cosmogenic veto

READOUT: LARGE SiPM ARRAY









TILE:

- Side 1: 5 x 5 cm² array of 24 SiPMs covering ~24 cm², the signals of all SiPMs are summed
- Side 2: front-end electronics for signal amplifier -> ASIC for veto and discrete element for TPC

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

SiPMs - Silicon PhotoMultiplier: a single SiPM consists of around 94,900 SPADs. Area: 8 x 12 mm²

518 PDUs in the TPC
120 PDUs in the neutron veto
30 PDUs in the outer veto

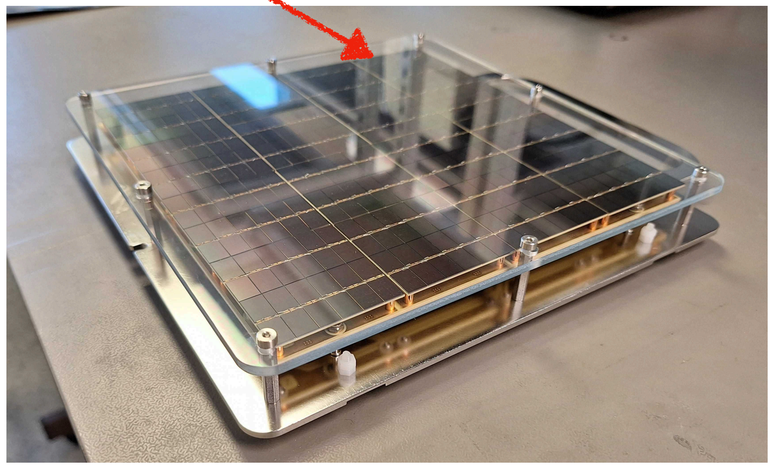
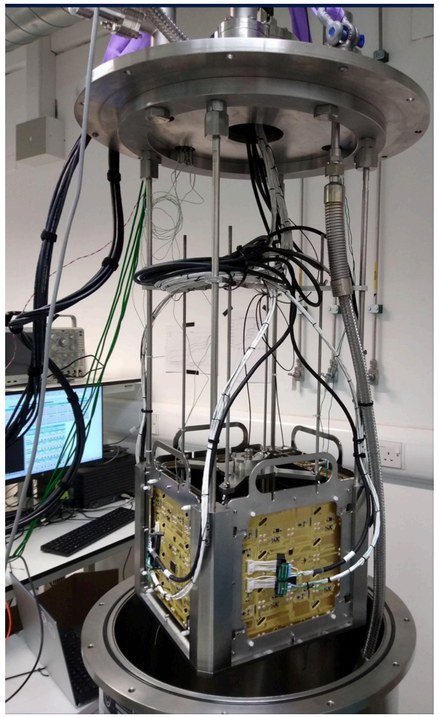


Photo Detection Unit (PDU)

- 16 tiles are assembled together in a **PDU**: **20 x 20 cm²**
- 1 large PCB to individually enable/disable and bias each single tile and to sum the signals from a quadrant
- 4 tiles are summed together, i.e. 4 tiles correspond to 1 DAQ channel
- **4 outputs: 1/4 DAQ channels -> 1/4 cables-> lower radioactivity**

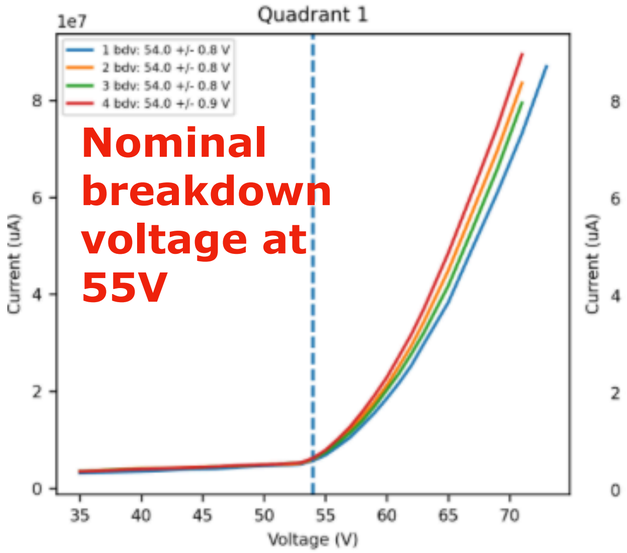
READOUT: LARGE SiPM ARRAY(2)

Laser calibration in liquid nitrogen of TPC-veto PDU determines whether a PDU has a single PE performance good enough to be integrated into the detector. Tests are performed across Italian, UK, and Poland institutions



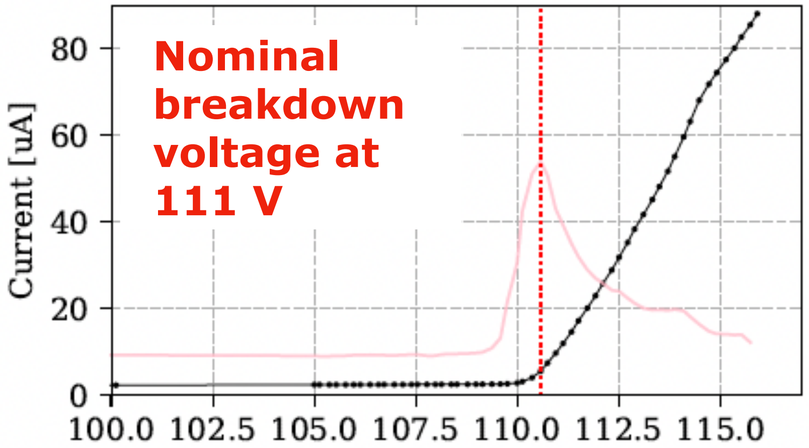
Edinburgh test stand

Veto PDU

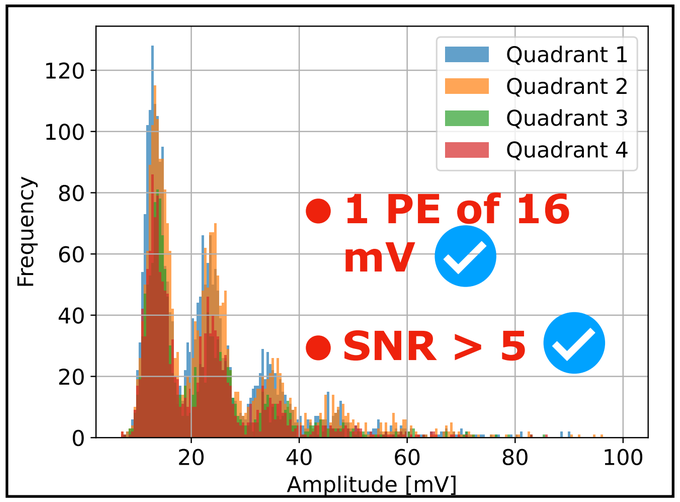


Both TPC and veto PDU meets requiremer

TPC PDU

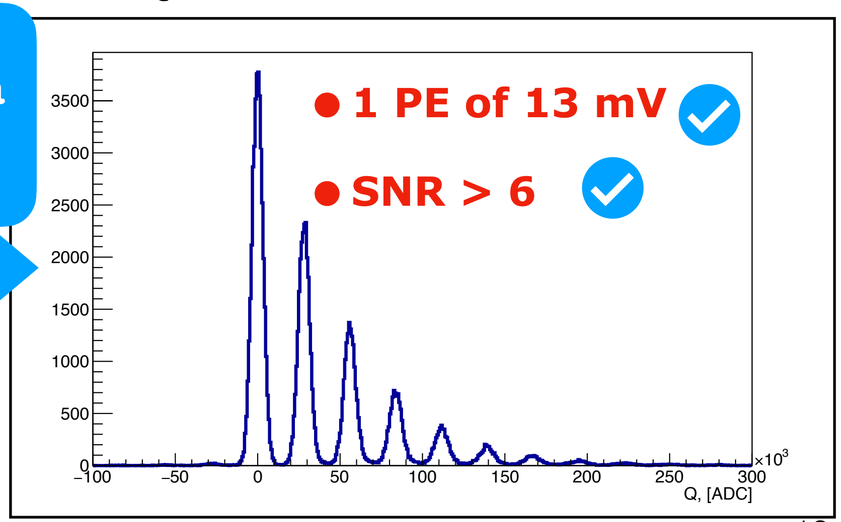


Quadrant PE distribution

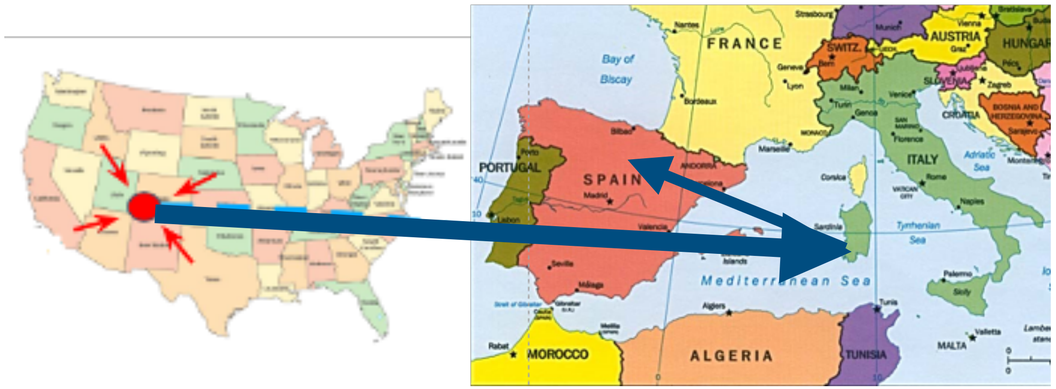


Readout area 10x10 cm²

Quadrant PE distribution



THE PATH TOWARDS PURE UAr: Urania->Aria->DArT



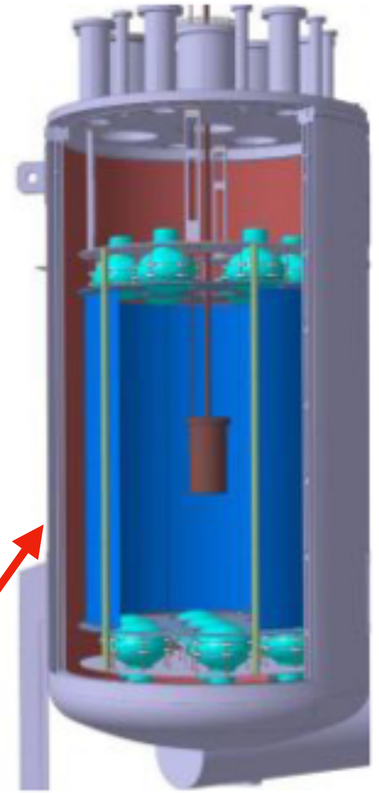
1. Urania: UAr extraction

- UAr extraction plant in Cortex, Colorado, USA
- UAr extraction rate up to 330kg/day with a 99.99% purity

2. ARIA: UAr purification

- Cryogenic distillation column in Sardinia (Italy)
- First module operated according to specs with nitrogen in 2019
- Chemical purification rate: 1 t/day

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



3. DART

- Double phase TPC with active volume of 1.4 kg of liquid UAr located at Canfranc, Spain
- Ar-39 depletion factor sensitivity: 6 x 10^4 90% C.L

NEUTRON BACKGROUND

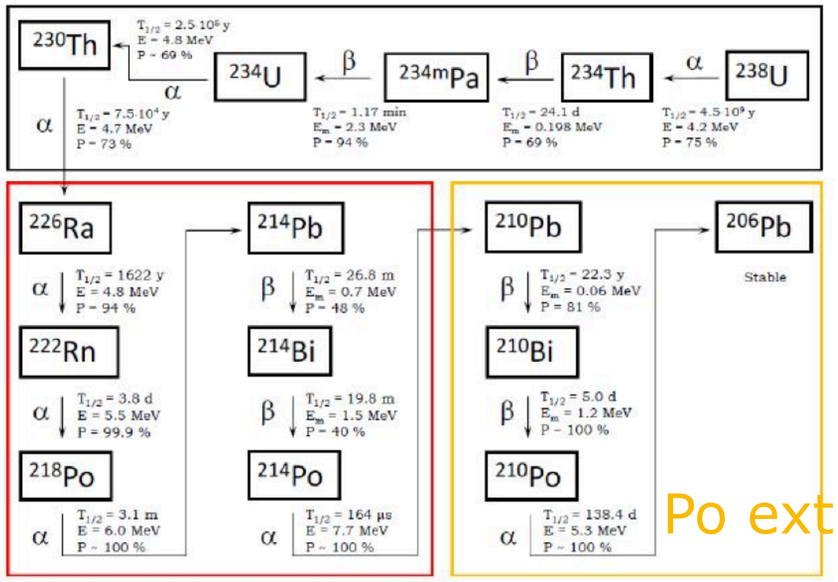
Neutron sources:

- ^{238}U and ^{232}Th contaminations of the detector material
  - (α,n) reaction in the detector material
  - Spontaneous fission decays
- cosmic ray induced neutron production

Radio-assay campaign to control
Every components goes into the detector

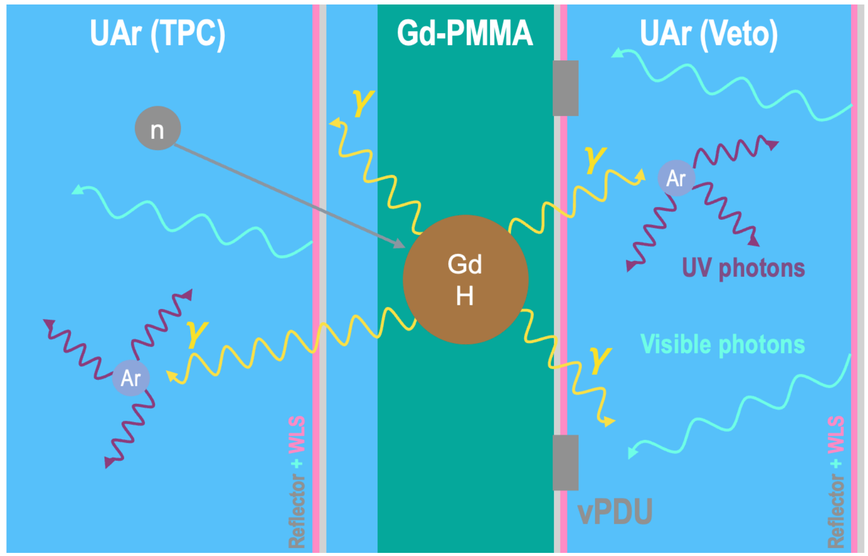
ICPMS

HPGE



Po extraction

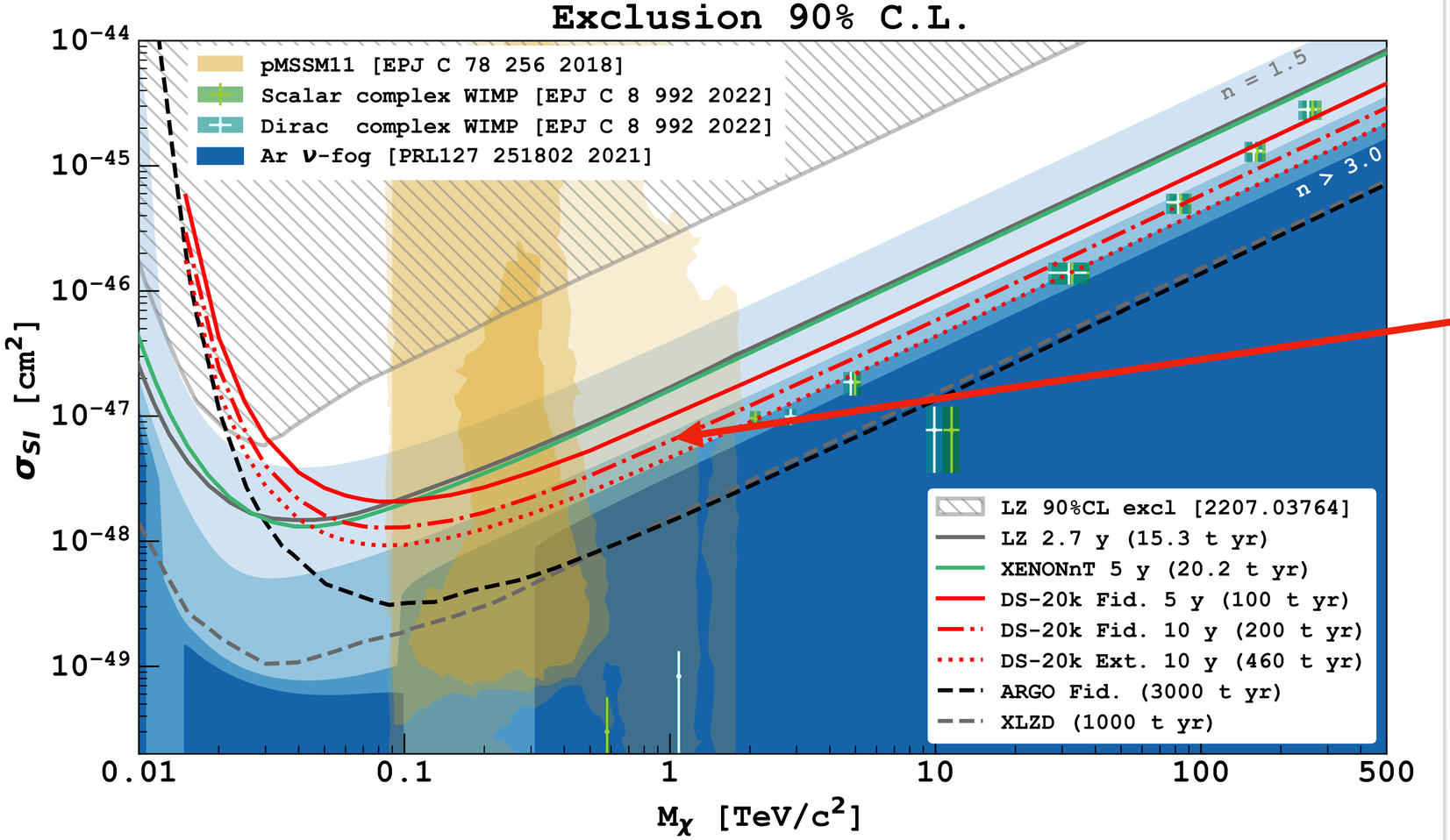
Neutron detection



- 15 cm of PMMA surrounding the TPC as neutron moderator
- detection of 2.1 MeV gammas from neutron capture on H (53%) in TPC or veto
- *R&D on Gd-PMMA development: detection of 8 MeV gamma produced in neutron capture on Gd (64%)*

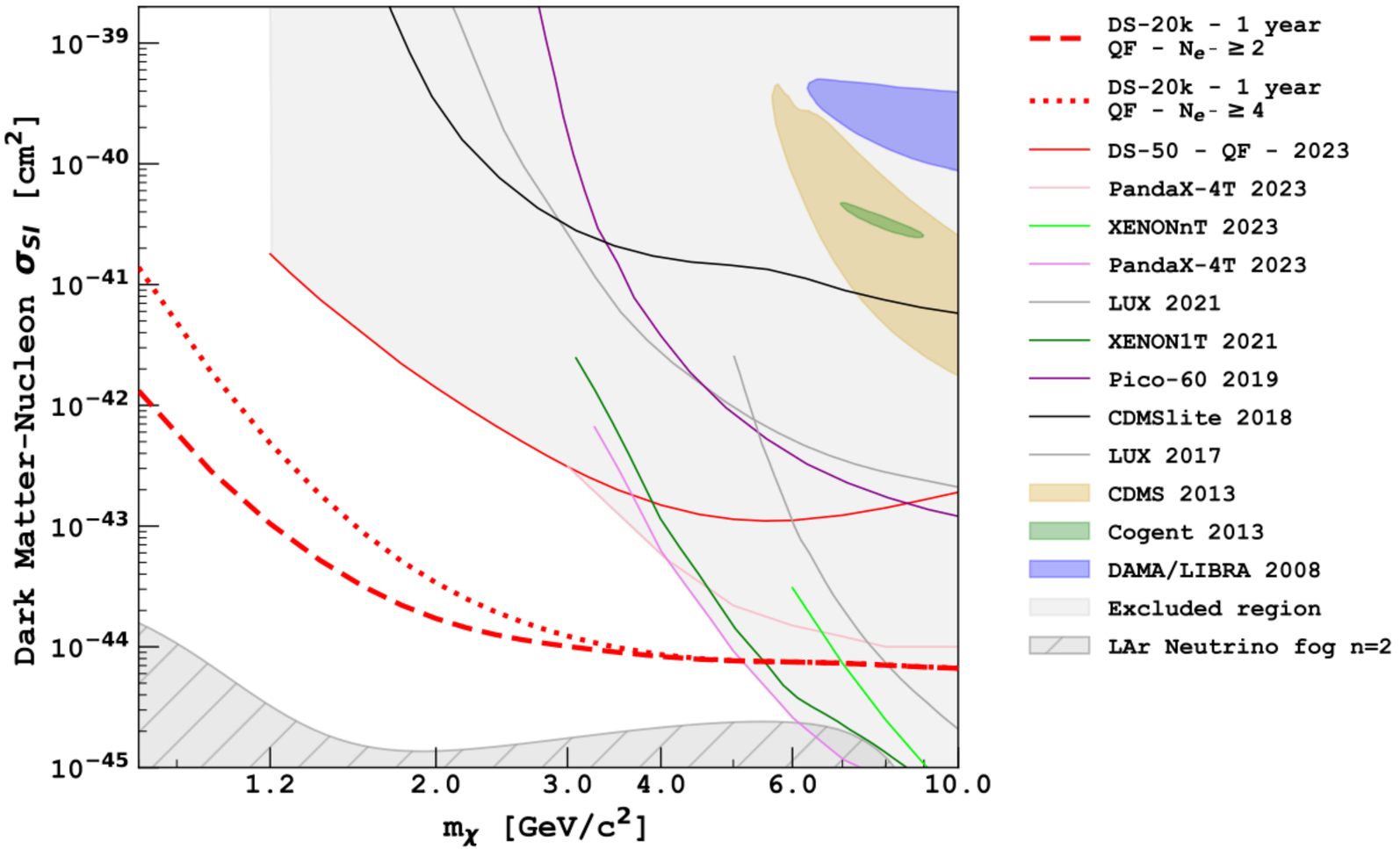
background goal: <0.1 neutron Wimp event in 200 tonne x years

HIGH MASS DARK MATTER SENSITIVITY



Sensitivity to high mass WIMP-nucleon scatter cross section of 7.4 x 10^{-48} cm^2 for a 1 TeV/c^2 WIMP for a total exposure of 200 tons x years

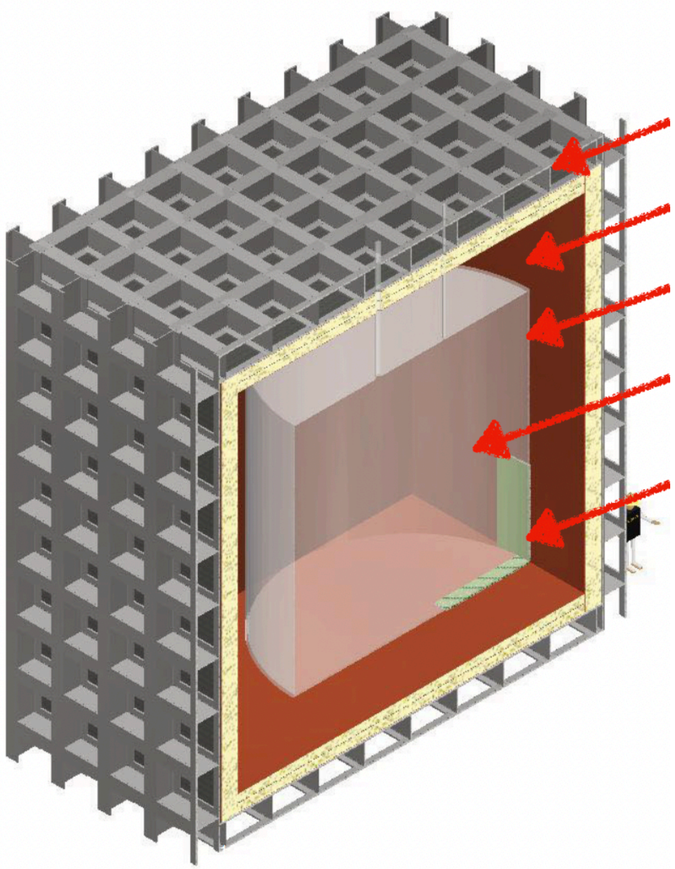
LOW MASS SEARCH



- Using only charge signal
- Detailed background from DS-50 data
- First assessment of DS-20k sensitivity to low mass dark matter particle
- Sensitivity below 5 GeV/c^2

https://arxiv.org/pdf/2407.05813, sent to Nature

WHAT NEXT?



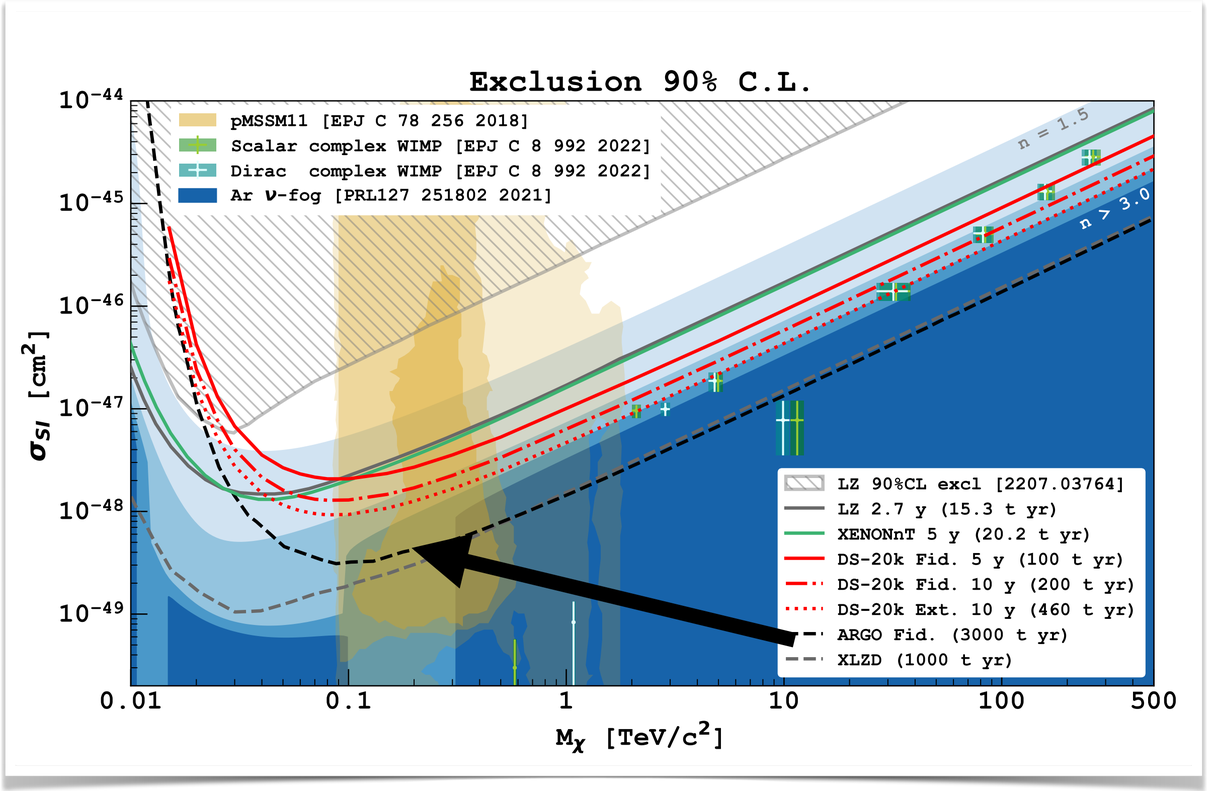
Outer cryostat

Liquid argon buffer

Ultrapure acrylic vessel

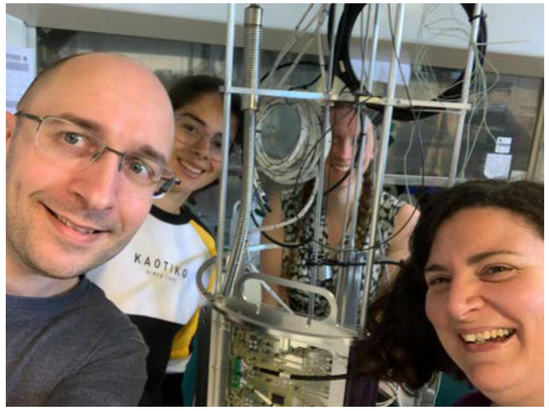
600 tonnes low-radioactivity Argon

250m^2 SiPMs covering



CONCLUSIONS

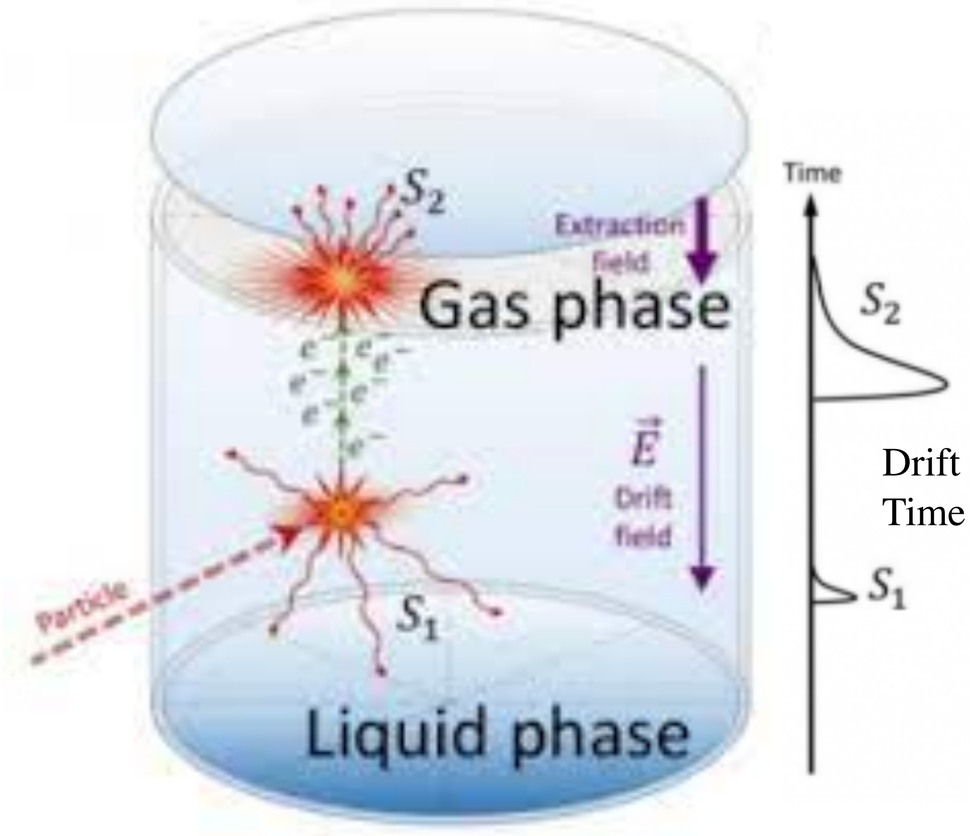
- **DarkSide-20k is pushing the state-of-the-art in several directions**: SiPM technology, underground argon extraction & purification, background assay campaign
- **DarkSide-20k is in position to lead the search for WIMPs**, with complimentary reach above the LHC center of mass energy
- **Fundamental role played by neutron veto detector** which is key to achieving the <0.1 instrumental backgrounds to the dark matter search! And expanding the reach beyond heavy WIMPs…
- **Darkside-20k construction has started, data taking will start in 2027**



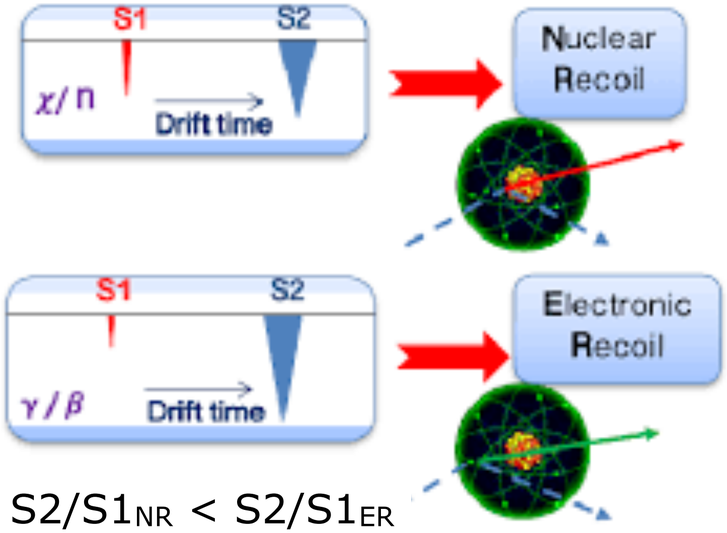
BACKUP

DARK MATTER SEARCH IN DARKSIDE

Dual phase Time projector Chamber (TPC)



- Signal: S1 (primary scintillation) + S2 (charge signal)
- S2 light pattern gives x-y position
- Drift time give z position
- S1-S2 relative size give particle information



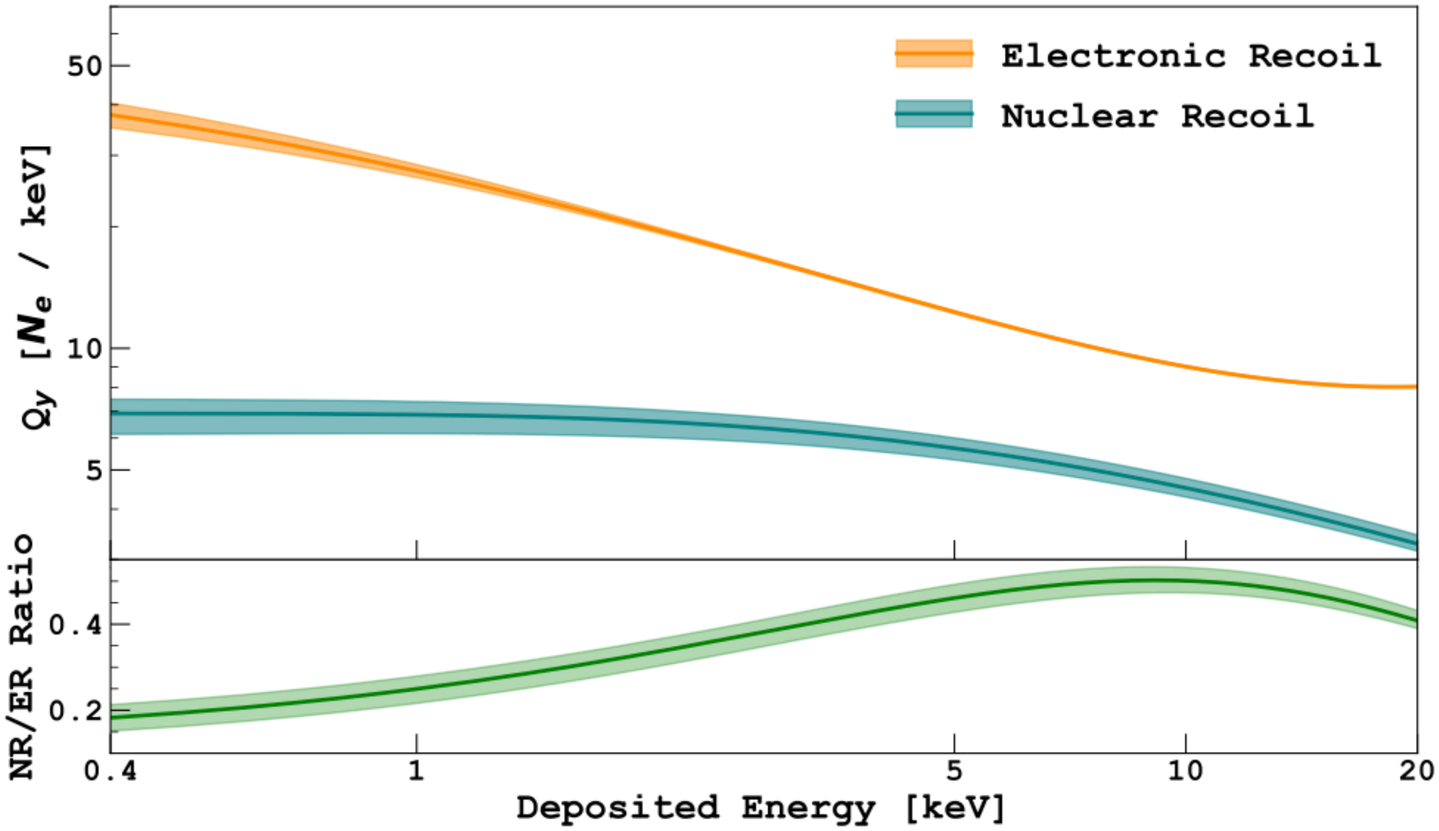
$S2/S1_{NR} < S2/S1_{ER}$

DarkSide Target material: liquid Ar from underground (UAr)

WIMP NUCLEON INTERACTION

Re-analyse the full DS50 dataset with a more detailed calibration model

Phys. Rev. Lett. 130, 101001



- Electron recoil modelling using ^{37}Ar, ^{39}Ar decay naturally in the early LAr dataset, focus on ionisation signal below 180 eV_{er}
- Nuclear recoil from in-situ neutron calibration (AmC), energy down to 500 eV_{nr}

DARKSIDE SIPM REQUIREMENTS

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 %