



Direct Dark Matter searches with the DarkSide-20k experiment

Ioannis Manthos

University of Birmingham

on behalf of the DarkSide-20k Collaboration

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The hunt of Dark Matter

Indications of Dark Matter existence

- The rotation curve of galaxies and the movement of galaxies in clusters
- Gravitational lensing
- Formation of large- scale structures
- Inhomogeneities in the microwave background radiation



Observation of DM annihilation/decay products:

- antimatter
- gamma photons
- neutrinos



Production of DM particles in accelerators



See also K. Nikolopoulos talk



The Global Argon Dark Matter Collaboration

~500 collaborators, combining the expertise of 4 LAr experiments for direct DM searches



DarkSide-50



DEAP-3600



MiniCLEAN



ArDM THE A. B AND C OF GRAN SASSO Experiments at the Gran Sasso National Laboratory are housed in and around three

by 1,400 metres of rock.

where they are shielded from cosmic rays

huge halls carved deep inside the mountain, Laborator

Gran Sasso National Laboratory

- largest underground research centre
- covered by 1400 m of rock
- provides 3800 mwe shielding
- can be accessed by car, no mine elevators

Goal: DarkSide-20k

- will be installed in LNGS Hall-C
- construction: 2022 2024
- nominal duration of operation: 10 years



DarkSide-20k overview



Why Argon?

- \checkmark easy to purify, scalable
- \checkmark high ionization, good scintillator transparent to own scintillation
- \checkmark strong electron recoil discrimination via pulse shape

- Time Projection Chamber (TPC) filled with 49.7 t (active) of underground Ar (UAr) (20 t fiducial)
- Acrylic panels loaded with gadolinium (Gd-PMMA)
- Neutron veto buffer between TPC and Ti vessel, filled with 32 t (active) UAr
- Titanium Vessel contains UAr (99.2 t)
- Outer cosmic veto filled with 700 t atmospheric Ar (AAr) –shield for muons and their shower products

DarkSide-20k: Inner detector



- Octagonal TPC: inscribed diameter 350 cm
- Drift length: 348 cm
- Electron drift lifetime < 5 ms
- Drift field: 200 V/cm
- TPC anode/cathode: transparent pure acrylic coated with Clevios + TPB wavelength shifter (WLS).
- TPB WLS in all TPC inner surfaces
- TPC lateral walls: grooves with Clevios for field shaping (no copper ring)
- Reflector + PEN (WLS) on outer TPC wall and Ti vessel enclosing veto
- Light yield in TPC: >10 pe/keV_{ee} (S1), > 20 pe/e⁻ (S2)

Dual phase Time Projection Chamber

WIMP signal:

- Single nuclear recoil
- ROI: [30, 200] keVnr



Energy deposition in LAr produces scintillation photons and free electrons

2 excited Ar^{2*} states with different lifetimes:

singlet (\sim 6 ns) - triplet (\sim 1.6 μ s)

drift time

N

position

ER/NR events have different ionisation densities \rightarrow different fractions of singlet/triplet decays.

S1: primary scintillation in LAr (energy information and pulse shape discrimination)

S2: secondary scintillation from electroluminescence of electrons in gas pocket (energy information and position reconstruction)



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





Underground Argon

TPC and veto are filled with UAr in order to reduce Ar-39, produced in Atmospheric Argon by cosmogenic activation with activity \sim 1 Bq/kg.

Beta emitter with endpoint to 565 keV and half life of 269 years.



Underground Argon

URANIA: UAr extraction

- CO₂ well in Cortez, CO, USA
- Industrial scale extraction plant
- UAr extraction rate: 250-330 kg/day
- Purity 99.99%

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 : UAr measurement

- Located at LCS, Canfranc, Spain
- Double phase TPC with active volume of 1.4 kg of liquid UAr
- Ar-39 depletion factor sensitivity: U.L 90% CL. 6 × 10⁴ JINST 15, P02024 (2020)







Background: Nuclear recoil

Produced by neutrons, alphas:

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

Same recoil as WIMP!!! Nuclear Recoils $v/c \approx 10^{-3}$ Dense Energy Deposition n

Nuclear recoil reduction:

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

Neutron veto



- 40 cm thick space between the Ti vessel and Gd-PMMA (1% 99%)
- 8 walls made from 15 cm thick Gd-PMMA
- ESR reflector with PEN WLS foils on all the surfaces (174 m²)

Neutrons elastically scattering from argon nuclei are **indistinguishable** from **WIMPs**.



- Neutrons are moderated in the PMMA and captured by Gd
- Gd emits multiple γs with energy up to 8 MeV (light yield =2 p.e./keV)
- UAr scintillation light is shifted and detected in both TPC and Veto

suppression of the dangerous radiogenic neutrons background ≈0.1 n/200 t y from (a,n) reactions

Large area cryogenic SiPM light detectors

SPAD: Single photon avalanche diode

SPADs - **S**ingle **P**hoton **A**valanche **D**iodes: semiconductor devices based on a p-n junction reverse biased well above breakdown voltage (operating in Geiger mode).

PDU

(Photo Detection Unit)





4 PDMs are summed and read as a single channel (largest single SiPM unit ever!)

- Mass production of the raw wafers at LFoundry (Italy)
- TPC assembling facility NOA at LNGS
- Veto assembling facility in UK
- Testing facility in Italy, UK and Poland



- High **PDE** (~45%) >90% fill factor
- **Gain** ~ 10⁶
- SNR > 8
- Dark Count rate at 87 K < 5 cps/PDM
- Time resolution (sigma) ~10 ns
- Low power consumption < 100 μ W/mm²
- **Radiopure** ~2 mBq/PDM dominated by substrate and PCB

Performance in DarkSide PDU Test Facility



G. Testara, Lepton Photon 2021, Jan. 10-14, 2022

Veto photon detection module assembly in UK

Same structure, **ASICs** as amplifier 2500 veto PDMs to be produced by DarkSide-UK groups to instrument inner veto detector





waveform reconstruction & analysis tools developed

INFN/Torino ASIC design + INFN/Genova & INFN/LNGS PCB design + UK vTile production!

first UK vTile prototype tested in INFN/Genova shows results within specifications!

Pre-production period, full production starts early autumn 2022!

First UK-build veto PDU test planned this summer!



M. Walczak, APS April Meeting 2022

Veto PCB production at University of Birmingham



PCB Production in Rn-Controlled Environment (<5 Bq/m³)





ESSEMTEC SP-002 Manual Stencil printer Solder paste: CHIPQUIK SMDLTLFP250T4

Pick and Place machine – PCBs to come as 4x3 sheet

MECHATRONICA M60 pick

and place



New Reflow oven:

5 minutes at 150°C

1 minute at 200 °C

3 temperature probes

C.I.F FT05 advanced forced convection oven





ISO-7 clean room



Veto PCB production at University of Birmingham









Accumulating production statistics to define QA/QC acceptance criteria

Material Radiopurity

Very demanding background requirements (< 0.1 in 10 yr exposure) PSD alone is not sufficient

Assay all materials of the detector

- Counting facilities in four Underground laboratories involved (Boulby, LNGS, LSC, SNOLAB)
- 3 different techniques employed: ICPMS, HPGe, Po extraction for Upper, Middle and Lower ²³⁸U chain
- Hundreds of assays carried-out
- Platform to store and manage the results of the material assay campaign



Full characterization and calculation of the materials background

- Control of the cosmogenic activation of materials
- Control of the surface contamination
- Evaluation of the radioactive budget of the experiment including activation UG
- Evaluation of the systematic uncertainty from the material composition
- New MC tools for (α, n) calculations

DArkSide-20k is the first experiment with the (a,n) neutron background fully calculated with Geant4

Nucl. Instrum. Methods A 960, 163659 (2020)

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 WIMP sensitivity

The sensitivity of DS-20k to spin independent WIMPs for different lengths of runs, with the full exposure and with the fiducial cuts applied, compared to LZ and XENONnT.



The present projection - based on a 10 yr run, giving a fiducial volume exposure of 200 t yris 6.3 x 10^{-48} cm² for 90% C.L. exclusion and 2.1 x 10^{-47} for 5 σ discovery for 1 TeV/c² WIMP.

Summary

- The Global Argon Dark Matter Collaboration (GADMC) is a joint effort among all dark matter experiments with Ar target: ~500 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 centre 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!





