The search for dark matter in Darkside **TeVPa 2023 - TeV Particle Astronomy** Napoli, Italy, September 13, 2023 Stefano Davini, INFN Genova - on behalf of the DarkSide Collaboration





Ar and Time Projection Chamber technology

Scintillation (S1)

formation of excited Ar^{2*} and decay short singlet state 6.7 ns long triplet state 1600 ns

Electroluminescence (S2)

drift of e- in electric field extraction in gas



Dual Phase TPC: 3D space reconstruction



WIMP detection in Argon TPC



- Large **Exposure** (Mass x Time) ~ 100 tons year
- Low Energy **Threshold** < 10 keV
- Low **Background** Rate < 0.1 events in 100 tons year
- **Topology**-based background discrimination: single-scatter vs multi-scatter (n, γ)
- **Pulse Shape** based bkg discrimination > 10⁸



Direct search for WIMP in liquid Argon The Global Argon Dark Matter Collaboration - GADMC











nominal run time 10 years

Expected WIMP sensitivity in DS-20k



DS-50 low mass dark matter search



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- S2 only events to reach lower energy threshold
- Sensitivity to low mass dark matter candidates
 - Phys. Rev. Lett. 130 (2023) 101001
 - Phys. Rev. Lett. 130 (2023) 101002
- see E. Pantic talk

- Phys. ReV. D 107 (2023) 063001
- Calibration of low energy nuclear recoils with ReD at LNS Catania *Eur. Phys. J.* C 81 (2021) 1014

see I. Albuquerque talk



Radiopure Ar from underground sources



- ³⁹Ar β decay (Q = 570 keV, half life 269 yr)
- ~ 1Bq/kg in atmosphere Ar
- Origin from ⁴⁰Ar(n, 2n)³⁹Ar in atmosphere
- Extraction of Ar from **underground** sources, where such processes are suppressed
- DS50 used 157kg of UAr
- **Depletion factor** in ³⁹Ar : 1400 +/- 200

The procurement of UAr for DarkSide-20k



Underground Argon production Enters Urania



- Company Kinder-Morgan extracts gas from subsoil, DarkSide takes the argon and returns the rest
- CO₂ well in Cortez, Colorado, USA
- Industrial scale extraction plant
- UAr extraction rate ~300 kg/day
- **Purity** 99.99%
- Plant assembly in progress



Underground Argon purification Enters Aria



- Plant in Sardinia, Italy
- Cryogenic distillation column, 350 m total height, 28 central modules
- Chemical production rate ~1ton/day
- First module operated according to specifics with nitrogen in 2019
 - Eur. Phys. J C 81 (2021) 359
- Runs completed with **Ar** in end of 2020
 - Eur. Phys. J C 83 (2023) 453



Underground Argon characterization Enters DArT in ArDM



- DArT in **LSC**, Spain (~2500 mwe)
- Single phase **TPC** 1.4 kg for UAr, inside 2 ton total single phase TPC (ArDM)
- DArT 2 x 1cm² SiPMs, ArDM 2x12 cryogenic low background **PMTs**
- 50 cm passive neutron **shield** (Poly, 20 ton)
- ³⁹Ar depletion sensitivity 6x10⁴ *JINST* 15 (2020) P020024



Radiopurity requirements

Assay all materials of the detector

- Worldwide effort Canada, Italy, France, Poland, Russia, Spain, UK, US...
- 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

Goal: <0.1 backgrounds in 10 year exposure

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

DS-20k signals and backgrounds



Signal

Nuclear Recoil up to 100 keV Single scattering, known pulse shape

Background source
³⁹ Arβdecay
γ from rocks and γ , β - from mat
Neutrons Radiogenic n (α ,n) with a from matrix
Surface contamination due to F
Neutrino coherent scattering

Up to a few events in the whole data taking

	Mitigation strategy
	Use Ar from Underground source (UAr) + Pulse Shape Discimination (PSD)
erials	Pulse Shape Discrimination (PSD) Selection of materials & procedures
aterial contaminants	Material screening. Definition of Fiducial Volume in the TPC + active VETO to reject n
Rn progeny	Surface cleaning Reduce the number of surfaces Installation in Rn abated air
	irriducible



DarkSide-20k design The inner TPC and its neutron Veto



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Two phase LAr TPC 50 ton (20 ton FV) **UAr** 21 m² cryogenic SiPMs Inner TPC surrounded by a single phase LAr neutron Veto detector **Integration** of inner TPC + veto in a single object

99 ton total UAr in a vessel

Within ~650 ton AAr membrane cryostat ProtoDUNE-like instrumented as muon veto



DarkSide-20k design The inner TPC



TPC/Veto hanging from Titanium Vessel Lid







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Max drift length 348 cm

- Electron drift **lifetime** > 5 ms
- Gas pocket 5.0 +- 0.7 mm

Drift field 200 V/cm, extraction field 2.8 kV/cm

TPC **anode** and **cathode** transparent pure **acrylic** covered with **Clevios** (conduction) and **TPB** (wavelength shifter)

Reflectors in the inner and outer walls

S1 ~10 pe/keV, **S2** > 20 pe/keV

DarkSide-20k design The neutron veto



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Single neutron recoil **indistinguishable** from WIMP-Ar recoil ...

... but the neutron will ultimately **thermalise** and being **absorbed** by a nucleus

Identify neutron events with **coincidences** in the veto

Gd loaded PMMA (a new material)

DarkSide-20k Photosensors Development of large area cryogenic radiopure SiPMs



Single SPAD ~25 μm²





Single SiPM ~1 cm²

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

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> 8000 PDMs (+2000 in the veto)
21 m² (inner TPC) + 5 m² (veto)
Mass production of the raw wafers at LFoundry (Italy)
Assembling facility NOA at LNGS
Other assembling facility for veto in UK
Testing facility in Napoli



Photodetector module (Tile) matrix of 24 SiPMs ~5x5 cm² **Photodetector Unit** matrix of 16 Tiles



DarkSide-20k NOA Facility Wafer level testing and handling



DarkSide-20k NOA Facility Photosensor assembly

Flip Chip Bonder (Amicra)

Tiles of 24 SiPMs are assembled

Wire Bonder (Hesse) **Microscopes for Optical Inspection**

The DarkSide-20k facility at LNGS

The DarkSide-20k facility at LNGS October 2022

The DarkSide-20k facility at LNGS January 2023

The DarkSide-20k facility at LNGS June 2023

The DarkSide-20k facility at LNGS August 2023

Outlook

- direct searches
- Joint global expertise in the Global Argon Dark Matter Collaboration
- Technological breakthrough in photosensors, underground argon procurement, and distillation - R&D completed
- Construction started at LNGS!!
- Production of photosensors in 2024
- **UAr** filling expected in 2026
- We'll spot WIPMs if they're out there!

Argon has outstanding background rejection capabilities for WIMP dark matter

