New physics results from Darkside-50

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Direct detection: Nuclear Elastic Scattering

Xenon/Argon are complementary.

\[ R \propto N \frac{\rho_x}{m_\chi} \sigma_{xN} \langle v \rangle \]

Astrophysics

Detector

Particle physics

\[ M_W = 2.5 / 50.0 \text{ GeV} \quad \sigma_{SI} = 1 \times 10^{-44} \text{ cm}^2 \]

Rate above threshold, per ton/day

Xenon Argon

\[ E_{\text{recoil}}^{nr} \quad [\text{keV}] \]
Direct detection limits

20 GeV-1 TeV searches: first thought models constrained. The neutrino floor is the target of next generation detectors.

1 GeV-10 GeV searches: weakly constrained (only a small set of dedicated experiments like DAMIC, CDMSLite).
DarkSide Collaboration

Italy, USA, Russia, Spain, France, China, Brasil, Poland
A new collaboration has been formed with groups from DS-50, ArDM and DEAP-3600 to construct DS-Proto, DS-20K and Argo.

- DS-50 → 50 kg
- DS-Proto → ~1 ton
- DS-20K → ~20 ton
- Argo → ~200 ton
Goals and design

**Goal:** WIMP search down to the neutrino floor with almost no background

**Design:**
- **Double Phase Time Projection Chamber:** XYZ fiducialization and Single/Multiple Scatter identification.
- **Argon target:** discrimination through pulse shape and ionization to scintillation ratio.
- **Underground argon naturally depleted in $^{39}\text{Ar}$** (~1400 compared to Atmospheric Argon)
- **Outer detectors:** shielding and veto neutrons
Time Projection Chamber

**DS-50** 46.4 kg total mass
S1 → Scintillation signal (~10 μs pulse with two components)
  - Fraction of light within 90 ns: ER/NR discrimination
S2 → Ionization signal (~10 μs pulse, shape due to secondary scintillation)
  - Drift time: Z position
  - Fraction of light in each PMT: XY position
  - S2/S1: ER/NR discrimination

Maximum drift time 375 μs
PSD discrimination: the strength of the Argon target

Electron Recoil

Nuclear Recoil

S1 = 80-85 PE

S1 = 180-185 PE

Atmospheric Argon Data.
f90 ER calibration
Decreasing rejection power due to photo-statistics

**WIMP search region:**
- Intersection of desired ER leakage line (~1 event in 70 days in this example) with neutron recoil acceptance line.
- Effective threshold: ~30 keV$_{ne}$

The f90 ER leakage into the NR band is of the order of 1 in $10^7$

70 day Underground Argon run
The outer detectors

Water Cherenkov Detector (WCD)
80 PMTs (8")
1000 tonnes

Liquid Scintillator Veto (LSV)
110 PMTs (8")
30 tonnes, 3 m diameter

TPC+Cryostat

Shielding and anticoincidence,
Radiogenic and Cosmogenic neutrons,
Gammas and Cosmic Rays.

LSV uses Boron Loaded Scintillator (PC+TMB+PPO), neutron rejection efficiency 99.64%.

$^{14}$C purification was required to detect $\alpha$ from neutron capture (short range particle)
Blind analysis

- blind enlarged box containing WIMP search region in the a F90 vs S1 parameter space (at event reconstruction level)
- model BG events: calibration data and MC tuning
- Refine cuts based on leakage BG events (≤ 0.1 event total)
- Test BG models on outer strip of blind box
  - Unblind WIMP region
Backgrounds

<table>
<thead>
<tr>
<th>Background</th>
<th>Events surviving all cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Type 1</td>
<td>&lt;0.0007</td>
</tr>
<tr>
<td>Surface Type 2</td>
<td>0.00092 ± 0.00004</td>
</tr>
<tr>
<td>Radiogenic neutrons</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Cosmogenic neutrons</td>
<td>&lt;0.00035</td>
</tr>
<tr>
<td>Electron recoil</td>
<td>0.08±0.04</td>
</tr>
<tr>
<td>Total</td>
<td>0.09 ± 0.04</td>
</tr>
</tbody>
</table>
Alpha background abatement:
Mainly fiducialization and energy range

Surface alphas whose energy is not fully contained in the TPC are the most dangerous. But a loose fiducial cut is very effective against them.

The wall effect and TPB scintillation are also signatures of surface background.

~2.5 mBq/m² $^{210}$Po surface activity
~2.1 μBq/kg $^{222}$Rn bulk activity
Neutron background abatement:
LSV cuts: 99.64% rejection efficiency

Monitoring neutron rate:
LSV Prompt Tag + f90(S1)

Given LSV efficiencies measured with AmBe/AmC sources.

Delayed LSV signal (neutron captures): 99.58%

\[ \sigma = 3837 \text{ barn on } ^{10}\text{B} \text{ (20% natural abundance)} \]

\[ ^{10}\text{B} + n \rightarrow \begin{cases} \text{ } ^{7}\text{Li} \ (1015 \text{ keV}) + \alpha \ (1775 \text{ keV}) & (6.4\%) \\ \text{ } ^{7}\text{Li}^* + \alpha \ (1471 \text{ keV}) , ^{7}\text{Li}^* \rightarrow ^{7}\text{Li} \ (839 \text{ keV}) + \gamma \ (478 \text{ keV}) & (93.6\%) \end{cases} \]

\[ ^{1}\text{H} + n \rightarrow ^{2}\text{H} + \gamma \ (2223 \text{ keV}) \quad I_p/I_p(\text{max}) = 100\% \quad \sigma = 0.33\text{b} \]

\[ ^{13}\text{C} + \gamma \ (3090 \text{ keV}) \quad I_p/I_p(\text{max}) = 100\% \]

\[ ^{12}\text{C} + n \rightarrow \begin{cases} \text{ } ^{13}\text{C} + \gamma \ (4945 \text{ keV}) & I_p/I_p(\text{max}) = 67\% \quad \sigma = 0.0034\text{b} \\ ^{13}\text{C} + \gamma \ (1860 \text{ keV}) & I_p/I_p(\text{max}) = 57\% \end{cases} \]

Prompt LSV signal (neutron thermalization): 99.27%

- *Phase-I* Nov. 2013 – June 2014: 50% mass fraction of PC, 50% TMB, 2.5 g/L PPO
- *Phase-II* Feb. 2015 – present: 95% mass fraction of PC, 5% TMB, 1.4 g/L PPO
Beta and gamma background

Prediction and refinement of the assayed activities.

<table>
<thead>
<tr>
<th>Source</th>
<th>PMTs fitted [Bq]</th>
<th>Assayed [Bq]</th>
<th>Cryostat [Bq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{232}\text{Th}$</td>
<td>0.277±0.005</td>
<td>0.23±0.04</td>
<td>0.19±0.04</td>
</tr>
<tr>
<td>$^{40}\text{K}$</td>
<td>2.74±0.06</td>
<td>3.0±0.4</td>
<td>0.16±0.02</td>
</tr>
<tr>
<td>$^{60}\text{Co}$</td>
<td>0.15±0.02</td>
<td>0.17±0.02</td>
<td>1.4±0.1</td>
</tr>
<tr>
<td>$^{238}\text{U}_{\text{low}}$</td>
<td>0.84±0.03</td>
<td>0.69±0.05</td>
<td>0.378±0.04</td>
</tr>
<tr>
<td>$^{238}\text{U}_{\text{up}}$</td>
<td>4.2±0.6</td>
<td>5.3±1.1</td>
<td>1.3±0.2</td>
</tr>
<tr>
<td>$^{235}\text{U}$</td>
<td>0.19±0.02</td>
<td>0.27±0.4</td>
<td>0.045±0.007</td>
</tr>
</tbody>
</table>

Liquid Argon Activity [mBq/kg]

| $^{85}\text{Kr}$ | 1.9 ± 0.1 | $^{39}\text{Ar}$ | 0.7±0.1 |

$^{39}\text{Ar}$ Atmospheric 1 Bq/kg
Underground 0.7 mBq/kg

PMT gamma background dominates the budget.
Given the ER leakage into NR band, this background should not be a problem, **BUT**

**Cherenkov mixed events spoils it**

**Fused silica Cherenkov** effectively removed thanks to unusual high light fraction in a single PMT

**Teflon Cherenkov** is the dominant background
To reach <0.1 background of Teflon Cherenkov it was required:
- New S1(f90) WIMP search region.
- XYZ fiducialization.

A cut in S2/S1 ratio was also applied
Cross section limits

The reflector design in the next generation experiments has been redefined to inhibit Cherenkov production.

"DarkSide50 532 day Dark Matter Search with Low Radioactivity Argon"
ArXiv:1802.07198
**DS-50 results for 2-10 GeV WIMPs**

- Argon/Xenon are sensitive to 1-10 GeV WIMPs if nuclear recoil detection threshold is $\leq 1 \text{ keV}_{ne}$.
- No ER/NR discrimination (Limits based on spectral shape).
- Sensitivity depends on overall background level.

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**Scintillation signal threshold too high. Ionization signal needs to be used.**

For Argon, $1 \text{ keV}_{ne} \rightarrow 5-9$ electrons

arXiv: 1802.06994

Accepted for publication in PRL
1 electron $\rightarrow$ 23 PE (at the center of the TPC)

DS-50 is fully efficient for $N_e > 2$

Only events in TPC core are used (less background, a better single electron resolution)

For $N_e < 3$ background is mostly due to impurities.
The Ne spectrum

The first 100 days of the UAr run have $^{37}\text{Ar}$, very useful to calibrate the ER ionization yield at energies as low as 270 eV.
The expected $N_e$ spectrum for WIMPs
The corresponding cross section limits

DS-50 has excellent sensitivity in the 2-10 GeV mass range.

Not possible without **Underground Argon** (1400 lower $^{39}$Ar content than Atmospheric)

Very good prospects for DS-Proto and DS-20K.
DS-20K

- New collaboration: DS-50, ArDM and DEAP-3600.
- Radio pure SiPMs
- Underground Argon procurement and purification (ARIA+URANIA)
- Data taking from 2022.
- Cherenkov BG abatement: 3M foil instead of PTFE.
- Neutron BG abatement: Cyogenic Veto system
- ~50 ton UAr
- <0.1 evt/100 ton yr
- Scalability for 300 ton.
Expected sensitivity