The DarkSide Program

Direct dark matter search with depleted argon

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What is DarkSide?

- A graded program of increasingly larger and more sensitive dark matter detectors.
- Each detector is a two-phase Ar time projection chamber (TPC).
- Employs Ar with low content of radioactive $^{39}\text{Ar}$, for increased sensitivity.
What is dark matter?

*Dark*: no electromagnetic interactions

Evidence of dark matter comes from rotational velocity profiles of galaxies and gravitational lensing

\[-v(r) \sim \sqrt{M(r)/r}\] expected but not observed

One possible candidate: Weakly Interacting Massive Particles (WIMPs)
Direct dark matter detection

- Most experiments look for WIMPs
- Dark matter particles are expected to pass through the earth, occasionally colliding with a nucleus along their way
- Placing a target, aim to detect the nuclear recoil produced by such a collision
WIMPs and Neutrons scatter from the Atomic Nucleus

Photons and Electrons scatter from the Atomic Electrons
Direct Dark Matter searches: current status

- WIMP dark matter well motivated by cosmological arguments, CMB, astrophysical observations, particle physics models (e.g. supersymmetry)
- Very high discovery potential
- Conflicting results from different experiments (DAMA, CoGeNT, XENON)
- Large leap in sensitivity is possible thanks to liquefied noble gases
- Significant developments in detector technology
How it works

Passive Shielding (Water)

Active Shielding: (Neutron Veto)

TPC

Diagrams by Emily Lebsack
How it works

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How it works

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High Uniform Electric Field (Drift Field)

Higher Electric Field (Extraction Field)
How it works

Diagram by Emily Lebsack

1. **Particle approaches and interacts with argon atom.**

2. **Reaction also causes ionization of argon atoms,**
   **producing free electrons.**

3. **Primary scintillation light** (s1) is released and is collected by PMTs.
How it works

Electrons are drifted upward by electric field.

Diagrams by Emily Lebsack
Electrons are extracted into gaseous argon, where the argon gas produces photons by electroluminescence. These photons are detected by the PMTs (s2).

Diagrams by Emily Lebsack
**Key features**

**LOW BACKGROUND:** key requirement of all direct-detection experiments

*Depleted Ar:* underground gas sources are less exposed to cosmic rays, and hence have low content of $^{39}$Ar (cosmogenically created in the atmosphere).

*Active neutron veto:* boron-loaded liquid scintillator surrounds the active detector, enabling the detection and veto of neutrons passing through the TPC.

*QUPIDs:* QUartz Photon-Intensifying Detectors. New photodetectors with low radioactive background and high quantum efficiency.
Depleted Ar

Distillation column running at FNAL. Will separate argon from underground gas.
Current status

- DarkSide-10 completed two technical runs in Princeton
- DarkSide-50 currently being designed, will begin construction in June
- Distillation column is extracting argon with low 39Ar content at FNAL
- QuPIDs being developed by Hamamatsu and UCLA
Backgrounds in DS-50

- Cosmogenic backgrounds reduced by water tank
- Radiogenic neutron-induced backgrounds reduced by active veto
- $\beta/\gamma$-induced background reduced by depleted Ar and discrimination techniques
Active Neutron Veto

- B-loaded scintillator tank outside cryostat
- High capture cross-section of $^{10}\text{B}$ reduces capture time, allowing little external shielding and use of conventional PMTs for veto
- Veto efficiencies found from simulations:
  - $\gamma$’s: 50%
  - Radiogenic neutrons: 99.5%
  - Cosmogenic neutrons: 95%
  - (only for neutrons produced outside the liquid scintillator volume)
Cosmogenic neutrons

Cosmogenic μ’s traverse the lab rock and impinge on the detector

Neutrons produced by (μ,n) reactions on lab rock and detector components

Simulate neutrons, not entire μ showers. Conservative, because we ignore veto-able secondary showers

Soon, will simulate μ showers in Fluka, then carry particles through detector in Geant4
Electron recoil background

- γ-INDEUCED:
  γ's emitted by radioactive nuclei produce electron recoils

- $^{39}$Ar-INDEUCED:
  $^{39}$Ar in liquid Ar undergoes β decays (Q=565keV)

Natural Ar: $\sim$200 cts/(kg keV_{ee} d)
### Backgrounds in DS-50

<table>
<thead>
<tr>
<th>Detector Element</th>
<th>Electron Recoil Backgrounds</th>
<th>Radiogenic Neutron Recoil Backgrounds</th>
<th>Cosmogenic Neutron Recoil Backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw</td>
<td>After Cuts</td>
<td>Raw</td>
</tr>
<tr>
<td>$^{39}\text{Ar}$</td>
<td>$&lt;1.7 \times 10^7$</td>
<td>$&lt;0.0050$</td>
<td>--</td>
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<tr>
<td>Fused Silica</td>
<td>$1.8 \times 10^5$</td>
<td>$5.5 \times 10^{-5}$</td>
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<td>PTFE</td>
<td>150</td>
<td>$4.6 \times 10^{-8}$</td>
<td>0.020</td>
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<tr>
<td>Copper</td>
<td>1100</td>
<td>$3.2 \times 10^{-7}$</td>
<td>0.0020</td>
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<tr>
<td>QUPIDs</td>
<td>$3.5 \times 10^4$</td>
<td>$1.1 \times 10^{-5}$</td>
<td>0.26</td>
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<tr>
<td>R11065 PMTs</td>
<td>$1.2 \times 10^6$</td>
<td>$3.6 \times 10^{-4}$</td>
<td>16.2</td>
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<tr>
<td>Titanium</td>
<td>$1.2 \times 10^5$</td>
<td>$3.6 \times 10^{-5}$</td>
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<tr>
<td>Veto Scintillator</td>
<td>35</td>
<td>$1.1 \times 10^{-8}$</td>
<td>0.025</td>
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<tr>
<td>Veto PMTs</td>
<td>$1.2 \times 10^6$</td>
<td>$3.7 \times 10^{-4}$</td>
<td>0.019</td>
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<tr>
<td>Veto tank</td>
<td>$8.5 \times 10^4$</td>
<td>$2.6 \times 10^{-5}$</td>
<td>$5.6 \times 10^{-5}$</td>
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<tr>
<td>Water</td>
<td>3100</td>
<td>$9.2 \times 10^{-7}$</td>
<td>$5.6 \times 10^{-4}$</td>
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<td>CTF tank</td>
<td>4200</td>
<td>$1.2 \times 10^{-6}$</td>
<td>$2.9 \times 10^{-3}$</td>
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<td>LNGS Rock</td>
<td>460</td>
<td>$1.4 \times 10^{-7}$</td>
<td>0.051</td>
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<tr>
<td><strong>Total</strong></td>
<td>--</td>
<td>0.0055 [0.0059]</td>
<td>--</td>
</tr>
</tbody>
</table>

Unit: cts/(0.1 ton y); window: 10-100 keV$_r$; depletion factor: >25; square brackets: PMTs
Summary

Distillation column will begin purification of large quantities of depleted argon

DarkSide-50 inner detector: end of 2011

DarkSide-50 + neutron veto in operation at LNGS: mid-2012

Ton-scale detector DS-1k: ~2014
Collaborators

Princeton University
FermiLab (FNAL)
Temple University
Augustana College
Black Hills State University
UCLA
UMass – Amherst
University of Arkansas
University of Houston
University of Notre Dame
Universita degli Studi Napoli
Universita degli Studi Milano
Universita degli Studi Genova
Universita degli Studi Perugia
INFN-Gran Sasso
IHEP Beijing
JINR Dubna
RRC Kurchatov Institute Moscow
St. Petersburg Nuclear Physics Institute
More information

- 2009 & 2010 DarkSide proposals.
- Soon our website...