Light Dark Matter Search with Liquid Argon

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FEATURES OF NOBLE LIQUID DETECTORS

- **Dense** and easy to purify (good scalability, advantage over solid targets)
- High **scintillation** & **ionization** (low energy threshold, not low enough to search < 1 GeV/c² DM)
- **Transparent** to own scintillation

For TPC

- High electron **mobility** and **low diffusion**
- Amplification for ionization signal
- **Discrimination** electron/nuclear recoils (ER/NR) via ionization/scintillation ratio

Liquid **Xenon**

- Denser & Radio pure
- Lower energy threshold
- Higher sensitivity at low mass WIMP

Liquid **Argon**

- lower temperature (Rn purification is easier)
- **Stronger ER discrimination**
- Intrinsic ER BG from ³⁹Ar
- Need wavelength shifter
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COMPARISON WITH XENON100

- **DS-50** has lower BG at the lowest Ne bins.
- **Ar** sees more events with given WIMP mass and cross section.

<table>
<thead>
<tr>
<th>XENON100</th>
<th>DarkSide-50</th>
</tr>
</thead>
<tbody>
<tr>
<td>BG [evt/keVnr/kg/d]</td>
<td>0.5 (\text{in } [0.7, 1.7] \text{ keVnr})</td>
</tr>
<tr>
<td>BG [evt/keVnr/kg/d]</td>
<td>0.07 (\text{in } [3.4, 9.1] \text{ keVnr})</td>
</tr>
<tr>
<td>Analysis threshold</td>
<td>0.7 keVnr</td>
</tr>
</tbody>
</table>

**FIG. 3.** Energy distribution of the events remaining in the data set after all data selection cuts. As an example, the expected spectrum for a WIMP of 6 GeV/c\(^2\) and a spin-independent WIMP-nucleon scattering cross section of \(1.5 \times 10^{-41}\) cm\(^2\) is also shown. The corresponding nuclear recoil energy scale is indicated on the top axis. The charge yield model assumed

**FIG. 4.** Energy distribution of the events remaining in the data set after all data selection cuts. As an example, the expected spectrum for a WIMP of 6 GeV/c\(^2\) and a spin-independent WIMP-nucleon scattering cross section of \(1.5 \times 10^{-41}\) cm\(^2\) is also shown. The corresponding nuclear recoil energy scale is indicated on the top axis. The charge yield model assumed

**TABLE I.** Acceptances of the different data selections and 

- **Single S2 and 10 ms cut** 95% 49041
- **Radial cut (starting events)** 100% 254901

**WIMP spectra in Xe and Ar**
S2/S1 ratio and Pulse Shape Discrimination (PSD)
WIMPs will generate nuclear recoils (NRs)
DARKSIDE-50

THE TIME-PROJECTION CHAMBER (TPC)

Electron Recoil (ER)

Nuclear Recoil (NR)

S2/S1 ratio and Pulse Shape Discrimination (PSD)

WIMP-like signal!

DM
The events in Ne<4 are delayed electrons related to impurities.

The origin of the excess at low Ne events (4<Ne<10) is unknown and under investigation.
DARKSIDE LOW MASS

CRITERIA FOR FUTURE LAr TPC

- Low activity of $^{39}$Ar
- Low impurity
  - good electron lifetime
  - low rate of the single electron events
- Ultra-pure photo-sensor
- Pure (or no) cryostat
**Urania (Underground Argon):**

- Expansion of the argon extraction plant in Cortez, CO, to reach capacity of **100 kg/day** of Underground Argon

**Aria (UAr Purification):**

- Very tall column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon. A factor 10 reduction of \(^{39}\text{Ar}\) per pass is expected.
Exposure: 1 tonne year

$^{39}$Ar: 1µBq/kg (currently ~1mBq/kg in DS-50) with $^{39}$Ar depletion in Aria plant

SiPM: 50 times lower contribution than currently achieved in DS-20k (cleaner and reduced electronics)

Acrylic: 5 mm thickness with the activities achieved by JUNO collaboration.

No cryostat

Analysis threshold: 2 Ne (~0.4 keVnr)

No systematic uncertainties are included
ASSUMPTIONS

- No BGs except the internal $^{39}$Ar BG, external gamma BGs from the detector components, and coherent neutrino BGs (the neutrino electron scattering is an order smaller and ignored).

- Low Ne events will be suppressed via deep fiducialization, pulse shape, and reduced activity in the active volume.
Ultra-light DM ($m_\chi \ll 1$ GeV) scatter off electrons

DM signals are also ER.

The same measured spectrum as the WIMP search can be used.

Two extreme cases of Dark Matter form-factor are considered

- $F_{DM} = 1$ heavy mediator
- $F_{DM} \propto 1/q^2$ light mediator

The dashed lines are with assumptions of 1 uBq/kg for $^{39}$Ar, 1 uBq/PDM, Cu cryostat, 80,000 kg day, and 2e-threshold.
NR IONIZATION YIELDS

AmBe neutron source

- MC + Ionization model [1] fit to NR data from AmBe and AmC.
- Need calibration points at low recoil energies

AmC neutron source