ArDM - The only Dual-Phase tonne-scale Liquid Argon Dark Matter Detector

SPS and ÖPG Joint Annual Meeting
September 2, 2021
Global Argon Dark Matter Collaboration (GADMC)

Multi-national collaboration of >500 people from >80 institutions with a two-step program
Joint expertise of several argon dark matter experiments

DarkSide-50  ArDM

A 50t depleted argon (DAr) Dual-phase TPC inside a 700t atmospheric argon (AAr) cryostat
⇒ Projected sensitivity of $1.2 \times 10^{-47}$ cm$^2$ at a WIMP mass of 1TeV/c$^2$
(with a 100 tonnyear exposure and a 20t fiducial mass)
Direct Dark Matter Detection (WIMPs)

Target Materials
- Xe, Ar, Ne, He
- Ge, Si, He
- C₃F₈, CF₃I
- Ge, Si, CaWO₄, NaI
- NaI, CsI
- CS₂, CF₄, CHF₃

Techniques
- Noble liquids
- Low-threshold
- Bubble chambers
- Cryogenic bolometers
- Scintillating crystals
- Directional detectors

Simple
PICASSO
COUPP
PICO

Heat

CRESST
COSINUS

Charge
Light

SuperCDMS
EDELWEISS

CoGeNT
CDEX
DAMIC
SENSEI
NEWS-G
DRIFT
MIMAC
DMTPC
NEWAGE

LUX/LZ
PandaX
XENON

ArDM
DarkSide

DAMA
DM-Ice
COSINE
SABRE
ANAIS
DEAP
XMASS
ArDM

Total volume: 1.5t of LAr
Active Dual-phase TPC target volume: 650kg of LAr
Located at: Laboratorio Subterráneo Canfranc (LSC), Spain
850m below the surface

Installation at LSC: 2012-2013
First Single-phase (SP) data-taking (Start of Run I): February 2015
Final Single-phase commissioning: July 2015
Upgrade to Dual-phase (DP): June 2016
First Dual-phase data-taking (Start of Run II): December 2017
Continuous upgrades and optimizations until late 2018
Dual-phase data-taking period: Summer 2019
Stopped operating in 2020
➡ new phase: DArT

Total raw data of Run I: 3.3 billion SP events
Total raw data of Run II: 3.5 billion DP events;
(thereof 334 million events with a neutron calibration source)
Two signals in LAr/GAr:

**S1** ➔ **Scintillation in the liquid**
(provides pulse-shape discrimination ➔ F90)

**S2** ➔ **Electroluminescence** (scintillation in the gaseous phase proportional to the extracted ionization charge; provides charge-to-light ratio ➔ S2/S1)

Event vertex reconstruction in **3D**

XY: S2 light pattern on top PMTs

Z: Time difference between S1 and S2 ➔ precise fiducialization
Background Discrimination

Two types of recoils
ER: Electrons and photons
NR: Neutrons and WIMPs

Two discrimination variables in Ar:
- F90 (pulse-shape)
- S2/S1 (charge-to-light ratio)

Region of interest for WIMPs/Neutrons
Background Discrimination

Two types of recoils
- ER: Electrons and photons
- NR: Neutrons and WIMPs

Two discrimination variables in Ar:
- F90 (pulse-shape)
- S2/S1 (charge-to-light ratio)

Region of interest for WIMPs/Neutrons
Pulse-Shape Discrimination (F90)

ER: Electrons and photons
NR: Neutrons and WIMPs

⇒ Only 1 in $\sim 10^5$ ER events is not rejected by pulse-shape discrimination alone (strongly energy dependent; here the RoI is F90 ≥0.6)

<table>
<thead>
<tr>
<th>S1 bin [p. e.]</th>
<th>ER Leakage into F90 ∈ [0.6, 1.0]</th>
<th>$N_{ER}$ Neutron Data</th>
<th>$N_{NR}$ DP Data</th>
<th>$^{252}$Cf NR events</th>
<th>$^{252}$Cf Activity [mBq]</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 to 80</td>
<td>1.34e-05 ± 2.03e-07</td>
<td>7684.8 ± 91.3</td>
<td>683.9 ± 21.2</td>
<td>7000.9 ± 93.7</td>
<td>55.51 ± 0.74</td>
</tr>
<tr>
<td>80 to 130</td>
<td>4.92e-09 ± 1.08e-10</td>
<td>3709.7 ± 61.2</td>
<td>217.3 ± 10.7</td>
<td>3492.4 ± 62.1</td>
<td>27.69 ± 0.49</td>
</tr>
<tr>
<td>130 to 180</td>
<td>2.88e-12 ± 8.06e-14</td>
<td>1478.5 ± 34.5</td>
<td>153.1 ± 8.9</td>
<td>1325.4 ± 35.6</td>
<td>10.51 ± 0.28</td>
</tr>
<tr>
<td>180 to 230</td>
<td>4.80e-15 ± 1.59e-16</td>
<td>1329.9 ± 36.5</td>
<td>124.6 ± 8.0</td>
<td>1205.3 ± 37.3</td>
<td>9.56 ± 0.30</td>
</tr>
<tr>
<td>Total:</td>
<td></td>
<td>14202.9 ± 120.8</td>
<td>1178.9 ± 26.6</td>
<td>13024.0 ± 123.7</td>
<td>103.26 ± 0.98</td>
</tr>
</tbody>
</table>
Two types of recoils
ER: Electrons and photons
NR: Neutrons and WIMPs

Discrimination via pulse shape (F90): $\sim 10^5$ (energy dependent)

Region of interest for WIMPs/Neutrons
Two types of recoils
ER: Electrons and photons
NR: Neutrons and WIMPs

Discrimination via pulse shape (F90): $\sim 10^5$ (energy dependent)

Region of interest for WIMPs/Neutrons
Background Discrimination

ArDM data with a neutron source allows the extraction of a new discriminator of ERs versus NRs

2D Gaussian fit of neutron-dominated data in the S2/S1 versus F90 plane

➡ New Neutron discriminator (the distance to the center of the 2D Gaussian in terms of its CDF)
   0: Very NR-like
   1: Very NR-unlike ⇔ ER-like

➡ additional ER rejection power (work in progress)
ArDM:
~30 live days
650kg active AAr target

DArT:
Radio-purity test of DAr inside the ArDM detector with ArDM working as a veto

DarkSide-20k:
20t active DAr target

Taken from: DarkSide-20k: A 20 Tonne Two-Phase LAr TPC for Direct Dark Matter Detection at LNGS; DOI: 10.1140/epjp/i2018-11973-4
DArT: $^{39}$Ar Depletion Factor Measurement Facility

Single-phase inner detector for 1.6 L of LAr inside 1t ArDM detector acting as an active veto for background radiation (at LSC)

→ Measure DAr-to-AAr $^{39}$Ar depletion factor (DF) of the order of 1000 with 10% precision in a one week run

Status: the PMTs have been tested in LN$_2$ at ETH Zürich and are currently being coated at LNGS; Integration of DArT into ArDM in the coming months

DF = 10, precision of 1%  
DF = 1400, precision of 7%
Global Argon Dark Matter Collaboration (GADMC)

Multi-national collaboration of >500 people from >80 institutions with a two-step program
Joint expertise of several argon dark matter experiments

DarkSide-50  ArDM

ARGO
~300t TPC
at Snowlab

DarkSide-20k

DEAP-3600  MiniCLEAN

A 50t depleted argon (DAr) Dual-phase TPC inside a 700t atmospheric argon (AAr) cryostat
➡ Projected sensitivity of $1.2 \times 10^{-47}$ cm$^2$ at a WIMP mass of 1TeV/c$^2$
(with a 100 tonnyear exposure and a 20t fiducial mass)
Questions?
Backup slides
DArT - Planned Schedule
Projected Sensitivity

DarkSide-20k goal:

increase exposure by 3-4 orders of magnitude

total number of background events in full exposure <0.1 (as in DarkSide-50)

Taken from: CERN Detector Seminar from May 28, 2021 by Alexander Kish;
The DarkSide-20k dual-phase argon TPC for particle dark matter detection
Indico: https://indico.cern.ch/event/1041835/