A Global Liquid Argon Dark Matter Search Program

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On behalf of the Global Argon Dark Matter Collaboration (GADMC)
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Why Liquid Argon (LAr)

• Efficient Scintillator
  • 40 photons/keV\textsubscript{ee} @ 128 nm
  • Transparent to own scintillation light

• High ionization yield
  • W \sim 10-20 eV with a high electron mobility
  • Further background discrimination with S2/S1 (factor of \sim 10^2)

• Powerful PSD in the scintillation signal
  • Separate ER background from the WIMP induced NR signal
  • Rejection factor of >10^9

• Simple cryogenic and gas handling with inline filter
  • Easily purified to achieve long electron drift lengths
Background Mitigation Strategy

- Deep underground sites to shield cosmic rays

- Screening and selection of detector materials

- Two-phase Ar TPC: 3D-TPC fiducialization; S1 PSD, S2/S1 cut

- Active liquid scintillator neutron veto

- Underground argon (UAr) with reduced $^{39}$Ar
S1 Signal

e,γ

χ,n
S1 Signal

Field shaping rings keep uniform 200 V/cm drift field

Ionization: e^+

Scintillation: S1

S1: 6ns & 1.6μs
S2 Signal

Extraction Field = $\sim 3$ kV/cm

Ionization: $e^-$

Scintillation: $S1$

Electro-luminescence: $S2$
Pulse Shape Discrimination with S1

Singlet and triplet fraction difference gives >10^9 rejection between NR and ER

\[ f(t) = \left[ \frac{q}{\tau_F} e^{-t/\tau_F} + \frac{1-q}{\tau_S} e^{-t/\tau_S} \right] \]

\[ \tau_F = 6\,\text{ns} \]
\[ \tau_S = 1.6\,\mu\text{s} \]
\[ q = F90 = \begin{cases} 
0.3ER \\
0.7NR 
\end{cases} \]
2-Phase TPC

The drift time gives the z-position with mm precision.

Top Array PMT light fractions for S2 give x,y location.
Underground Argon (UAr)

- $^{40}\text{Ar}(n,2n)^{39}\text{Ar}$ occurs in the atmosphere
- Argon that has remained underground can therefore have extremely low levels of $^{39}\text{Ar}$

- DS-50 UAr fill measured the $^{39}\text{Ar}$ reduction factor: $>10^3$!!
16,660 kg day UAr exposure
UAr Ionization Signal Analysis

Single electron detection very efficient
Summary of Darkside-50

- AAr 2013-2015, UAr since 04/2015
  - Cryogenics system very stable
  - TPC HV system stable for years

- LY @ null field ~8 pe/keV_{ee}

- 1,422 kg-days AAr + 19,276 kg-days UAr
  - No remaining background in WIMP search region!!!

- Ionization signal analysis give leading result for low-mass WIMPS
The GADMC Program

- DarkSide-50 (running)
- DEAP-3600 (running)
- miniCLEAN
- ArDM

- DS-20k (50 tonnes) ~2022

- Argo (300-400 tonnes) ~2027
Darkside-20k: A United Front

- Brings together all existing LAr dark collaborations
  - DarkSide-50
  - DEAP-3600
  - ArDM
  - miniCLEAN

- 50 tonnes sealed PMMA
- UAr target
- Silicon photomultipliers
- AAr-based Veto in ProtoDUNE style membrane cryostat
AAr Cryostat

Identical size and shape as ProtoDUNE

Side TCO replaced by “top-cap” deployment
Sealed PMMA Acrylic Vessel

- Containment of UAr from AAr, no nearby cryostat
- Clevios+TPB coated diving-bell anode window
- SiPM planes moved outside of active volume
- Reflector from low-mass ESR foils and PMMA
- Field-rings machine-grooved and Clevios coated
- HV delivery via feedthrough and cold-cable
- Clevios+TPB coated cathode window
- Builds on experience gained from DEAP-3600
UAr: Urania

The Urania project will procure 50 tonnes of UAr from the same Colorado source as for DS-50.

Will extract 250 kg/day, with 99.9% purity → 90 tonnes/yr.

UAr will be transported to Sardinia for final chemical purification at Aria.
UAr: Aria

Final chemical purification of the UAr

Processing of O(1 tonne/day) with $10^3$ reduction of all chemical impurities

Ultimate goal is to isotopically separate $^{39}\text{Ar}$ from $^{40}\text{Ar}$
Cryogenics

- Membrane cryostat + AAr cryogenics

- UAr cryogenics, circulation speed up to 1000 stdL/min in gas phase (by DarkSide-built circulation pump)
Large Area SiPMs

- Compact $\rightarrow$ increase coverage
- $>50\%$ PDE @ 420 nm
- $0.1 \text{ Hz/mm}^2$ DCR
- SiPM tiles $\rightarrow$ PDMs
- $>22 \text{ m}^2$ of SiPMs total

Photo-Detector Module (PDM)
LAr+Gd-Doped PMMA Veto

TPC optically isolated from AAr volumes

Passive shell of Gd-doped PMMA (n moderation/capture)

Inner/outer layers of active AAr for n capture gamma detection

Optically/electrically isolated from outside AAr by copper vessel

Segmented approach to reduce overall rate from $^{39}\text{Ar}$ in AAr
The integration between the protoDUNE like membrane cryostat and the DarkSide-20k TPC is being designed by both protoDUNE engineers and GADMC engineers.

Overall integration at LNGS Hall C, TPC will be tested in a test vessel before installing into the membrane cryostat.

DarkSide-20k is now a CERN recognized experiment (RE37).
DS-Protos at CERN

Integrated acrylic TPC for S2 study
With SiPMs as photosensors
Under construction @CERN

Key techniques:
SiPM integrated test
Conductive polymer (Clevios)
ESR as reflectors
Acrylic bonding

Proto_1ton: scaled down version of DS-20k, sealed acrylic TPC
Will be assembled @CERN in Q2 2020
DS-LowMass

- Potential to reuse DS-Proto (~1 tonne) TPC @ LNGS
- 350 kg active volume
- Active Neutron Veto
- Low mass sensitivity has been demonstrated by DS-50 (S2 only analysis)
Ultimate WIMP Sensitivity

Dark Matter-Nucleon $\sigma_{SI}$ [cm$^2$]

$M_\chi$ [TeV/c$^2$]

CRESST-III 2017
CDMSlite 2017
ATLAS 2018 (Vector Z', 95% CL)
DarkSide-50 2018
DEAP-3600 2017
LUX 2017
DEAP-3600 proj.
DARWIN 200
Argo 3000t x yr proj.
Neutrino floor on xenon
DarkSide-LM proj.
SuperCDMS Ge HV proj.
XENONnT proj.
XENON1T 2018, PANDAX-II, 2017
PANDAX-II 2017
LZ proj.
LUX 2017
Neutrino Detection in DS-20k

- DS-20k will be sensitive to coherent elastic neutrino nucleus scattering (CEvNS)

- Neutral current interaction $\rightarrow$ Flavor blind measurement that is not affected by oscillations
Supernova Neutrinos in DS-20k

11 $M_{\text{Sun}}$ at 10 kpc

Full-burst detection $\sigma$ (200-300 events)

Total flux/Ave. $E$ measured within 10%

Neutronization burst detection $\sigma$ (10 events)
Thank You!
Backups
Projected Sensitivities
Projected Sensitivities
Neutrino Cross Section in LAr

K. Scholberg 2012
SN Flux Time-evolution

Neutronization Burst \( \sim 50 \) ms

Accretion Phase \( \sim 750 \) ms

Cooling Phase \( \sim 10 \) s
SN Neutrinos in Argo

Argo Measurements of Neutrino Average Energy & Total Energy Emited

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<tbody>
<tr>
<td>Entries</td>
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<tr>
<td>Mean y</td>
</tr>
<tr>
<td>Std Dev x</td>
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<tr>
<td>Std Dev y</td>
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measured-Neutrino-Average-Energy / true-Neutrino-Average-Energy

measured-Total-Energy / true-Total-Energy
The Darkside-50 Detector

- Rn-free clean room
  (10-15 mBq/m³ in 110 m³)

- Water Cherenkov muon veto:
  1 kton H₂O

- Boron-loaded liquid scintillator
  ~30 ton (50% TMB + 50% PC)

- Two-Phase LAr TPC
  50 kg active volume
Darkside-50 TPC

- **PTFE Cylinder**
  - h=36 cm, d=36 cm, 46 kg (44 kg fiducial), inner surface is coated with TPB

- **38 3” Hamamatsu PMTs:**
  - R11065: 19(top) + 19(bottom)
  - Cold amplifier (low PMT HV)

- **Cathode and anode windows:**
  - Fused silica w/ ITO transparent layers (15 nm) & TPB

- **Field shaping copper rings:**
  - Uniform electric field: \( E_{\text{drift}} = 220 \text{ V/cm} \) \( E_{\text{gas}} = 2.8 \text{kV/cm} \)

- **Fused silica diving bell**
  - Gas pocket holding for S2 signal
Veto Detectors

• Water Cherenkov Veto
  • Muon flux reduced by $10^6$ (>99% efficient)
  • 80 PMTs, 11 m diameter x 10 m high
  • Detect the Cerenkov light produced by the muons and other showering particles
  • Provides passive gamma and neutron shielding

• Liquid Scintillator Veto
  • 4 m boron-loaded liquid scintillator (PC:TMB)
  • 110 8” PMTs
  • Efficiently detect escaping neutrons and veto any associated nuclear recoil backgrounds
    • >99% efficiency for neutrons
  • Provide in situ measurement of the neutron background rate
Calibration System

\[
\begin{align*}
S_1 \text{ [PE]} & \quad 50 \quad 100 \quad 150 \quad 200 \quad 250 \quad 300 \quad 350 \quad 400 \quad 450 \\
90 \quad f & \quad 0.1 \quad 0.2 \quad 0.3 \quad 0.4 \quad 0.5 \quad 0.6 \quad 0.7 \quad 0.8 \quad 0.9 \quad 1
\end{align*}
\]

\( \text{AmBe in DarkSide-50} \)

\( \text{Energy [keV]} \)
Backgrounds

- Internal radioactivity
- Gamma Rays
- Cosmic muons
- Radiogenic neutrons
- Fast neutrons

\[ \alpha, \beta, \mu, n, p, \gamma \]