DarkSide-50: status of the detector and results

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DarkSide-50 Collaboration

- USA
  - Augustana University
  - Black Hills State University
  - University of Chicago
  - University of Hawaii
  - University of Houston
  - University of Massachusetts
  - Princeton University
  - Temple University
  - UC Davis
  - UCLA
  - Virginia Tech
  - FNAL, LANL, LLNL, PNNL, SLAC

- Italy
  - INFN LNGS
  - Gran Sasso Science Institute
  - INFN and Universita degli Studi
    - Cagliari, Genova, L’Aquila, Milano, Napoli, Perugia and Roma 3

- Russia
  - Joint Institute for Nuclear Research, Dubna
  - SINP, Lomonosov Moscow SU
  - NRC Kurchatov Institute
  - St. Petersburg NPI

- France
  - APC Universite Paris 7 Diderot
  - LPNHE Paris
  - Universite de Strasbourg

- Brazil - Campinas
- China - IHEP
- Poland - Jagiellonian University
- Ukraine - Institute for Nuclear Research
DarkSide: experiment concept

- Direct detection search for WIMP dark matter.
- Based on a two-phase argon time projection chamber (TPC)
- Ultra low background
  - Deep underground at LNGS
  - Low-background materials, including Ar target
- Powerful background rejection
  - Pulse Shape Discrimination (PSD)
  - Ionization/Scintillation ratio (S2/S1)
  - Surface rejection using 3D position reconstruction
- Active neutron and muon vetoes
  - In situ background measurement
Photodetectors
(19, 3" PMT, Top and Bottom)

Ar Gas

Wavelength Shifter + Reflector

Ar Liquid

Cold Amplifiers
(gain 24 allowing PMTs to operate at lower gain ~3x10^5)

Anode

E_{gas} \sim 5\text{ kV/cm}

E_{liq} \sim 3\text{ kV/cm}

Grid

E_{drift} \sim 0.2\text{ kV/cm}

Field Cage Rings

Cathode

35.6 \text{ cm}
Nuclear Recoil excites and ionizes the liquid argon ⇒ scintillation light (S1)

e^− are drifted and then extracted into the gas region ⇒ electroluminescence (S2)

- Time between the S1 and S2 (Drift Time) gives z-position.
- Fraction of S2 in each PMT allows x-y position reconstruction.
Backgrounds

Electron Recoils

39Ar $\rightarrow$ 39K
$\sim 10^5$ evt/kg/day
($\sim 10^4$ evt/kg/day in WIMP energy range)

γ
$\sim 10^2$ evt/kg/day

Nuclear Recoils

μ
(~5 evt/day in TPC)
(~370 evt/day in WT)

Radiogenic n
$\sim 6 \times 10^{-4}$ evt/kg/day

α
γ
$\sim 10$ evt/m²/day

$M_\chi = 100$ GeV, $\sigma = 10^{-45}$ cm² $\rightarrow$ WIMP Rate $\sim 10^{-4}$ ev/kg/day
Electron Recoil Discrimination

Pulse Shape Discrimination

- Based on the primary scintillation signal in the liquid phase (S1)
- Electron and nuclear recoils produce different excitation densities in the argon, leading to different ratios of singlet (∼6ns) and triplet (∼1500ns) excitation states

**PSD parameter**

- F90: Ratio of detected light in the first 90 ns, compared to the total signal
- F90~Fraction of singlet states
First run with AtmAr

Data taking with AtmAr started November 2013

- There are $1.5 \times 10^7$ events dominated by $^{39}$Ar.
- 0 events in WIMP search region
- $f_{90} (+z$ fiducialization $+$ single scatters) suppress ER background exceptionally
39 Ar Reduction

Atmospheric Ar

How is it produced?

- $^{40}$Ar produced underground through decay of $^{40}$K
- $^{39}$Ar is *cosmogenic* produced by $^{40}$Ar(n,2n) interactions in the atm.

Production of UAr

1. Extraction at Colorado (CO2 Well)
2. Purification at Fermilab
3. Shipped to LNGS
39 Ar Reduction

DS-50 filled with UAr in March 2015

- Fitted 85Kr activity in UAr: 2.05 ± 0.13 mBq/kg
- Fitted 39Ar activity in UAr: 0.73 ± 0.11 mBq/kg
- 39Ar activity in AAr: 1000 mBq/kg

39 Ar reduction factor: 1400!!!
$^{85}$Kr delayed coincidences

$^{85}$Kr: 0.4% BR to $^{85m}$Rb ($T_{1/2} = 1\mu$s, 514 keV $\gamma$)

Signature: two S1s ($\beta+\gamma$) in delayed coincidence

Rates
This method: $1.92 \pm 0.05 \frac{\text{mBq}}{\text{kg}}$
Spectral fit: $2.05 \pm 0.13 \frac{\text{mBq}}{\text{kg}}$
Good Agreement!!!
Neutron Rejection

**Water Tank**
- 11 m diameter x 10 m high
- 80 PMTs
- Active muon veto
  - tag cosmogenic neutrons
- Passive neutron and $\gamma$ shielding

**Liquid Scintillator Veto**
- 4 m diameter sphere
- Boron-loaded: PC + TMB
- 110 8” PMTs
- Active neutron veto
  - tag neutrons in TPC
  - in situ measurement of neutron BG
- Passive neutron and $\gamma$ shielding
Neutron Rejection

Neutron calibration

- Goal - observe neutron captures on $^{10}$B
- **93.6%**: $^{10}$B + n $\Rightarrow$ $^7$Li$^*$ + $\alpha$
  $^7$Li$^*$ $\Rightarrow$ $^7$Li + $\gamma$ (478 keV)
- **6.4%**: $^{10}$B + n $\Rightarrow$ $^7$Li (1015 keV) + $\alpha$ (1775 keV)
  $\alpha$ (1775 keV) equivalent to 50–60 keVee

Both channels detected
Signals above LSV detection threshold

>99.1% efficiency to veto neutrons from neutron capture signals alone (AmBe + simulation)
DM search with UAr began immediately after turning on fields.

~1.5 Hz trigger rate, predominantly ER events
Nuclear recoil acceptance

- Cuts: select single scatters (single S1 + single S2) with no signal in veto.
- Efficiencies evaluated using UAr data + AmBe data + MC
- Dominant acceptance loss: accidental coincidences in veto

![Graph showing NR acceptance vs. S1 [PE] and Energy [keV_{nr}]](image-url)
Dark Matter search with UAr

- 70.9 live-days
- 36.9 kg fiducial volume

- Expect <0.15 ER leakage events

No events in the WIMP search region.
Dark Matter search with UAr

DarkSide-50: best Argon limit, second target above 100GeV/c^2
The future...

- DarkSide-20k: 30 tonne (20 tonne fiducial) detector
- ARGO: 300 tonne (200 tonne fiducial) detector

Challenges

- Further depletion of $^{39}$Ar: UAr (Urania Project) & Depleted Argon (Aria Project)
- Further reduction in surface contamination: SiPM & ultra-clean Titanium

See poster by Ed Hungerford: The DarkSide 20k Experiment
Running with AtmAr acquired $1.5 \times 10^7$ $^{39}$Ar events with 0 in WIMP search region.
  - Exceptional ER background suppression

Concentration of $^{39}$Ar in UAr is 1400 times lower than in AAr.

DarkSide-50 has the strongest WIMP limit among Ar target experiments.

Currently in stable WIMP search mode.
  - Already acquired $> 4$ times more data previously published and first blinded WIMP search analysis coming soon!

Future Liquid Argon TPC are planned to reach eventually the neutrino floor.
BACK UP SLIDES
- $^{39}\text{Ar}$ (565 keV$_{ee}$ endpoint) present in AAr
- $^{83\text{m}}\text{Kr}$ gas deployed into detector (41.5 keV$_{ee}$)

Fits to $^{39}\text{Ar}$ and $^{83\text{m}}\text{Kr}$ spectrum indicate

LIGHT YIELD: $7.9 \pm 0.4$ PE/keV$_{ee}$ at zero field and $7.0 \pm 0.3$ PE/keV$_{ee}$ at 200 V/cm
Nuclear recoil calibration

SCENE
Scintillation Efficiency of Nuclear Recoils in Noble Elements

Pulsed monoenergetic proton beam

\[ ^7\text{Li}(p, n)^7\text{Be} \]
produces monoenergetic low energy neutrons

2.3 MeV protons generate \(-0.5\) MeV neutrons

Scintillator cells at fixed angles with respect to the beam detect outgoing neutrons

Angle \(\theta\) determines energy of the elastic nuclear recoil in argon
SCENE: nuclear recoil calibration $L_{\text{eff}}$
Nuclear recoil calibration $f_{90}$ bands
Electron Recoil Discrimination: $S_2/S_1$
Further Depletion of $^{39}\text{Ar}$

- Urania (Underground Argon)
- Expansion of the argon extraction plant in Cortez, CO
- Extract UAr at 100kg/day

- Aria (UAr Purification)
- Very tall (350m) cryogenic dist. column in the Seruci mine in Sardinia, Italy
- Chemical and isotopic purification of Underground Argon
- Factor 10 reduction *per pass*