The DarkSide program at LNGS: update and outlook

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DarkSide

Direct search for WIMP dark matter

using a Liquid Argon Time Projection Chamber

at Laboratori Nazionali del Gran Sasso
Plan of Talk

• Updates on DS-50 (15’)
  • Calibrations, Underground Argon Run
• DS-20k, ARGO (5’)
  • Urania, Aria
The DarkSide-50 detectors at LNGS
The DarkSide-50 LAr-TPC

Target

filled with Underground Argon

active mass 46 kg       total mass 153 kg
The DarkSide-50 borated Liquid Scintillator Veto

Anti-coincidence detector for neutrons

\[ {}^{10}\text{B} + \text{n} \rightarrow {}^{7}\text{Li} + \alpha \ (1775 \text{ keV}) \quad 6.4\% \]

\[ {}^{10}\text{B} + \text{n} \rightarrow {}^{7}\text{Li}^* + \alpha, \quad {}^{7}\text{Li}^* \rightarrow {}^{7}\text{Li} + \gamma \ (478 \text{ keV}) \quad 93.6\% \]
The DarkSide-50 Water Cherenkov Detector

Anti-coincidence detector for muons
Two phase LAr-TPC

S1 - scintillation
light yield ($\beta$) - 7.0 PE/keV
light yield (n) - 2.0 PE/keV

S2 - ionization
Drift field - 200 V/cm
Extraction field - 2.8 kV/cm

19 PMTs on top
19 PMTs on bottom
Pulse Shape Discrimination

electron - nuclear recoil discrimination

PSD parameter $f_{90}$: fraction of S1 in the first 90 ns
DarkSide-50 First result
Atmospheric Argon run
(2014)
Third best dark matter limit at high masses

- Neutrino Limit
- DS-50 (2014)
- WARP (2007)
- PandaX-I (2014)
- CDMS (2010)
- XENON-100 (2012)
- LUX (2013)

\[ \sigma \left[ \text{cm}^2 \right] \]

\[ \begin{align*}
\sigma & \geq 10^{-40} \\
\sigma & \geq 10^{-41} \\
\sigma & \geq 10^{-42} \\
\sigma & \geq 10^{-43} \\
\sigma & \geq 10^{-44} \\
\sigma & \geq 10^{-45} \\
\sigma & \geq 10^{-46} \\
\sigma & \geq 10^{-47}
\end{align*} \]

\[ M_\chi \left[ \text{GeV/c}^2 \right] \]

PLB 743 (2015) 456
Atmospheric Argon run

Background free
PSD electron background discrimination $> 15 \times 10^6$
Major activities in DarkSide-50 (late 2014 and 2015)
Reconstitution of the **Liquid Scintillator**

**Calibration** Measurements with Radioactive Sources

Running of LAr-TPC with low-\(^{39}\)Ar **UAr**

Full detector system functioning in low background mode **appropriate for extended dark matter search**
DarkSide-50
Calibration Campaigns

Gamma sources: $^{57}\text{Co}$, $^{133}\text{Ba}$, $^{137}\text{Cs}$

Neutron sources: $^{241}\text{AmBe}$

Detector response at different drift fields

Understanding TPC and LSV, tuning of Monte Carlo
Agreement between DS-50 and extrapolated SCENE acceptance curves
CALIS - CALibration Insertion System
$^7\text{Li}(p,n)$ in SCENE

$^{241}\text{AmBe}$ in DarkSide-50
Energy spectrum of neutron captures in LSV

\( ^{10}\text{B} + n \rightarrow ^{7}\text{Li}^* + ^{4}\text{He} \)

\( ^{7}\text{Li}^* \rightarrow ^{7}\text{Li} + \gamma \)
Developed x-y reconstruction algorithms
Check in data using $^{214}$BiPo coincidences
Understanding S2

Measured radial dependence of S2
Evaluated x-y correction map using $^{83m}$Kr data
Anti-correlation between S1 and S2 (recombination)
Energy variable (linear combination) with slightly improved resolution

\[ E = a \text{S1} + b \text{S2} \]

83mKr

5.7% resolution

S1[PE]

6.3% resolution

S2 [PE]

- position corrected

Counts

5.941 \times 10^6 \pm 1.258 \times 10^9

Mean

0.0 \pm 41.8

Sigma

0.012 \pm 2.406

Mean

0.0 \pm 290.7

Sigma

0.10 \pm 18.38

Energy variable (linear combination) with slightly improved resolution
Underground Argon
Extraction in Colorado

Purification at FNAL

Shipping to LNGS
LAr-TPC operations with UAr

\textbf{AAr} draining (Mar 18 - 22, 2015)

\textbf{UA}r filling (Mar 25 - Apr 1, 2015)

Re-commissioning of the detector: \textsuperscript{39}Ar, light yield…
atmospheric and underground argon at null field
atmospheric and underground argon at 200 V/cm

< 1/300
< 1/1000

$^{39}$Ar in UAr < 1 mBq/kg

$^{85}$Kr in UAr ~ 2 mBq/kg
$^{85}\text{Kr}$ in UAr with coincident $\gamma$ search

Check spectral evidence using rare $^{85m}\text{Rb}$ branch with coincident $\gamma$

Agreement between coincidence search ($33.1 \pm 0.9$ cpd of $^{85}\text{Kr}$ in $^{85m}\text{Rb}$) and expected from spectral fit ($34.9 \pm 1.0$ cpd of $^{85}\text{Kr}$ in $^{85m}\text{Rb}$)
Dark matter search with UAr

started on April 8, 2015
Dark matter search with UAr

Non-blind analysis on first 70 days of UAr

TPC cuts as close as possible to AAr search

LSV efficiency increased (see S. Westerdale’s presentation)

Will be public in few weeks
DarkSide 20k and Argo
LHC @14 TeV

Dark Side 20k

ARGO

WARP (2007)
CDMS (2009)
PandaX-I (2014)
DS-50 (2014)
XENON-100 (2012)
LUX (2013)

Neutrino Limit
1 event from neutrino-induced nuclear recoil
Future DarkSide detectors

**DS-20k**
30 tonne (20 tonne fiducial) detector

**ARGO**
300 tonne (200 tonne fiducial) detector
DarkSide 20k LAr-TPC

15 m² of SiPM’s

*reduced radioactivity*
*improved photon detection yield*

Low-radioactivity titanium cryostat from Russia
Further depletion of $^{39}\text{Ar}$
Urania

Replacement of the Ar extraction plant in Colorado

Reach capacity of 100 kg/day of UAr

MIUR/INFN funds from Progetto Premiale 2013
Aria

350 m tall distillation column in the Seruci mine in Sardinia, Italy

Chemical and isotopic purification of Underground Argon

Exploits finite vapor pressure difference between $^{39}\text{Ar}/^{40}\text{Ar}$

*Protocollo di Intesa between INFN and Regione Sardegna*
DarkSide-20k and ARGO
DarkSide status and outlook

- **DS-50** running in background free mode
- **Underground Ar**gon, $^{39}$Ar isotopic depletion $< 1/1000$
- **Dark matter search** with UAr, results are imminent
- **DS-20k** and **Argo** ambitious programs
The End
Backup
The DarkSide-50 LAr-TPC
$^7\text{Li}(p, n)^7\text{Be}$ reaction produces low energy monoenergetic neutrons. TOF measurement between target, LAr and organic scintillators allows clean identification of elastic neutron interactions of known energy.
Liquid Scintillator Veto reconstitution

Removing high-$^{14}$C TMB (June, 2014)

Add radiopure TMB at 5% concentration (Jan 2015)

$^{14}$C activity decreased from 150 kBq to 0.3 kBq

More efficiency neutron veto cuts than in AAr campaign
LSV energy spectrum

- **Original TMB (50% concentration)**
- **Replacement TMB (5% concentration)**
Calibration with $^{83m}$Kr
Understanding S2

Before x-y correction

After x-y correction
DATA–MC comparison: $^{57}$Co source next to the cryostat
Presented
atmospheric and underground argon at null field

Events / (80 PE x kg x s)

- AAr Data
- UAr Data
atmospheric and underground argon at 200 V/cm

< $1/300$
<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sigma$ [cm$^2$] @1 TeV/c$^2$</th>
<th>$\sigma$ [cm$^2$] @10 TeV/c$^2$</th>
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<tbody>
<tr>
<td>LUX</td>
<td>$1.1 \times 10^{-44}$</td>
<td>$1.2 \times 10^{-43}$</td>
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<tr>
<td>[10k kg×day Xe]</td>
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<tr>
<td>XENON</td>
<td>$1.9 \times 10^{-44}$</td>
<td>$1.9 \times 10^{-43}$</td>
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<td>[7.6k kg×day Xe]</td>
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<tr>
<td>DS-50</td>
<td>$2.3 \times 10^{-43}$</td>
<td>$2.1 \times 10^{-42}$</td>
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<tr>
<td>[1.4k kg×day Ar]</td>
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<tr>
<td>ArDM</td>
<td>$8 \times 10^{-45}$</td>
<td>$7 \times 10^{-44}$</td>
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<td>[1.5 tonne×yr Ar]</td>
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<tr>
<td>DEAP-3600</td>
<td>$5 \times 10^{-46}$</td>
<td>$5 \times 10^{-45}$</td>
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<td>[3.0 tonne×yr Ar]</td>
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<td>XENON-1ton</td>
<td>$3 \times 10^{-46}$</td>
<td>$3 \times 10^{-45}$</td>
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<td>[2.7 tonne×yr Xe]</td>
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<tr>
<td>LZ</td>
<td>$5 \times 10^{-47}$</td>
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<td>[15 tonne×yr Xe]</td>
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<td>DS-20k</td>
<td>$9 \times 10^{-48}$</td>
<td>$9 \times 10^{-47}$</td>
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<tr>
<td>[100 tonne×yr]</td>
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<td>1 Neutrino Event</td>
<td>$2 \times 10^{-48}$</td>
<td>$2 \times 10^{-47}$</td>
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<td>[400 tonne×yr Ar or 300 tonne×yr Xe]</td>
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<tr>
<td>ARGO</td>
<td>$9 \times 10^{-49}$</td>
<td>$9 \times 10^{-48}$</td>
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<tr>
<td>[1,000 tonne×yr]</td>
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