DarkSide-20k and the future
Liquid Argon Dark Matter program

Giuliana Fiorillo
Università degli Studi di Napoli “Federico II” & INFN Napoli
The case for DarkSide-20k

- WIMPs are still excellent candidates for particle dark matter
- WIMP masses: 0.01 - 10 TeV and cross sections: $10^{-40} - 10^{-50}$ cm$^2$
- Several 100 ton yr exposures needed for a discovery program
  ➡ staged program to reach fully scalable detector design and operation at the multi-ton scale
The DarkSide program at LNGS

A scalable technology for direct WIMP search:
2-phase low background Argon TPC

DarkSide-10: technical prototype, no DM goal
Sensitivity: $10^{-44} \text{ cm}^2$

DarkSide-50
Sensitivity: $10^{-47} \text{ cm}^2$

DarkSide-20k

Timeline:
- 2011
- 2012
- 2013
- 2014
- 2015
- 2016
- 2017
- 2018
- 2019
- 2020
- 2021
- 2022
WIMP mass [TeV/c^2]

WIMP-nucleon σ_{SI} [cm^2]

- DarkSide-50 (2015)
- DarkSide-50 (2018)
- DEAP-3600 (2017)
- DEAP-3600 (proj.)
- Future 300-tonne GADMC detector (3kt yr proj.)
- Future 300-tonne GADMC detector (1kt yr proj.)
- LUX (2017)
- LZ (proj.)
- PANDAX-II (2017)
- XENON1T (2017)
- XENON1T (proj.)
- XENONnT (proj.)
- WARP (2007)
- DarkSide-50 (2015)
- DarkSide-20k (200 t yr proj.)

Neutrino floor
DarkSide design: how to defeat background

- **Identification:**
  - ER/NR discrimination using PSD
  - ER/NR discrimination via S2/S1
  - 3D reconstruction of interactions (rejects $\gamma$ and surface bkgds)

- **Passive suppression:**
  - Isotopically depleted Argon
  - Low radioactive materials
  - Low radioactive light-detectors

- **Active shielding:**
  - Neutron Veto (Liquid Scintillator)
  - Muon Veto (Water Cherenkov Detector)
DarkSide-50

✓ ER/NR Discrimination
- PSD vs S1 for 1422 kg d atmospheric argon (AAr) exposure
- $1.5 \times 10^7$ ER events from $^{39}\text{Ar}$ activity in AAr and Zero NR events

✓ Suppression: AAr Vs UAr
- Underground argon (UAr): 150 kg successfully extracted from a CO$_2$ well in Colorado
- $^{39}\text{Ar}$ depletion factor >1400

see talk by P. Meyers
Scaling up towards the neutrino floor: next stage world Argon program

LAr high discrimination power + depleted argon allow for the several hundreds ton yr background-free exposures needed to reach the neutrino floor

DS50-1: discrimination $1.5 \times 10^7$ at LY=7 PE/keV at 200 V/cm [PLB 743, 456 (2015)]


see talk by S. Westerdale

DarkSide
• DEAP-3600
• miniCLEAN
• ArDM

DarkSide-20k $\rightarrow$ multi 100 ton

> 350 researchers from $\sim$ 80 Institutes

Global Argon Dark Matter Collaboration (GADMC)
DarkSide future program

DarkSide-20k
a 20-tonnes fiducial argon detector
100 tonne×year background-free search for dark matter

GADMC detector
a 300-tonnes depleted argon detector
1,000 tonne×year background-free search for dark matter
DarkSide-20k

Conceptual approach: ultra-low background levels and the ability to measure backgrounds in situ

Baseline design:

- 30 ton total, 20 ton fiducial, underground argon
- 14m² SiPM sensors (low radioactivity, increased LY)
- inside high efficiency neutron shield/veto

100 ton yr background-free exposure
Two key technologies enabling DarkSide-20k and future LAr program

- **Cryogenic SiPMs**
  - **DarkSide-20k @ Abruzzo** large area, cryogenic silicon photomultiplier optical modules assembly and test facility (Nuova Officina Assergi - NOA)

- **Liquid argon target depleted in the radioactive $^{39}$Ar**
  - **URANIA** extraction of large quantities of underground argon
  - **ARIA** Isotopic separation via cryogenic distillation
URANIA

- Procurement of 50 tonnes of UAr from same Colorado source as for DS-50
- Extraction of 100 kg/day, with 99.9% purity
- UAr transported to Sardinia for final chemical purification at Aria

ARIA

- Big cryogenic distillation column in Seruci, Sardinia
- Final chemical purification of the UAr
- Can process $O(1 \text{ tonne/day})$ with $10^3$ reduction of all chemical impurities
- Ultimate goal is to isotopically separate $^{39}\text{Ar}$ from $^{40}\text{Ar}$

see talk by A. Renshaw
Nuova Officina Assergi

- SiPM cryotest
- Tile & FEB packaging
- Photon Detector Modules and Motherboards (25 PDM) assembly

see talk by A. Razeto
DarkSide-20k PSD

Projected LY: 10PE/keV

f_{200}: fraction of S1 light in 200ns

arXiv:1707.08145
NR acceptance region defined by requiring < 0.005 ER events/(5-PE bin) (< 0.1 events in the WIMP search region),

The resulting equivalent ER reduction factor is > 3 \times 10^9, more than sufficient to maintain background-free operation for more than 200 t yr.
DarkSide-20k backgrounds

<table>
<thead>
<tr>
<th>Background</th>
<th>Events in ROI [100 t yr$^{-1}$]</th>
<th>Background [100 t yr$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal $\beta/\gamma$'s</td>
<td>$1.8 \times 10^8$</td>
<td>0.06</td>
</tr>
<tr>
<td>Internal NRs</td>
<td>negligible</td>
<td>negligible</td>
</tr>
<tr>
<td>$e^- - \nu_{pp}$ scatters</td>
<td>$2.0 \times 10^4$</td>
<td>negligible</td>
</tr>
<tr>
<td>External $\beta/\gamma$'s</td>
<td>$10^7$</td>
<td>$&lt;0.05$</td>
</tr>
<tr>
<td>External NRs</td>
<td>$&lt;81$</td>
<td>$&lt;0.15$</td>
</tr>
<tr>
<td>Cosmogenic $\beta/\gamma$'s</td>
<td>$3 \times 10^5$</td>
<td>$\ll 0.01$</td>
</tr>
<tr>
<td>Cosmogenic NRs</td>
<td>–</td>
<td>$&lt;0.1$</td>
</tr>
<tr>
<td>$\nu$-Induced NR</td>
<td>1.6</td>
<td>–</td>
</tr>
</tbody>
</table>

- TPC inside a SS cryostat, inside a liquid scintillator active neutron veto, inside a 15m diameter 16m tall water tank, as active muon veto
  - assuming the same level of radioactivity as in DS50, ER background dominated by $^{39}$Ar
  - $(\alpha,n)$ reactions in PTFE reflector and cryostat largest sources of neutrons

arXiv:1707.08145

14
A LAr shield for DarkSide-20k

- AAr in ProtoDune style large cryostat to provide shielding and active VETO
- allows to eliminate Liquid Scintillator Veto and Water tank
  ➡ Significantly simplify the overall system complexity and operation
  ➡ Fully scalable design for future larger size detector (300 ton)
CERN Neutrino Platform:

- Two almost identical cryostats built for NP02 and NP04 experiments
- About 8x8x8 m$^3$ inner volume, 750 t of LAr in each one
- Cryostat technology and expertise taken from LNG industry
- Construction time: 55 weeks (NP04), 37 weeks (NP02)
- Thought since the beginning to be installable underground
DarkSide-20k inner detector

- AAr shield provides the opportunity to remove the largest contribution to neutron background, the SS cryostat:
  - CU vessel with the shape of the TPC (octagonal prism) providing also a possible path to increase the active Argon size
- TPC reflector realised from a sandwich of acrylic+3M foil removes the second big contributor to neutron background (PTFE)
- Residual neutron background from sub-leading contribution from substrates, electronic components, optical fibers, copper parts and acrylic
DarkSide-20k nVeto conceptual design

• Several options are being considered for a cryogenic veto inside the LAr shield:
  • hydrogenated materials for efficient thermalisation
  • possible addition of further material with high capture cross section

→ no showstoppers for meeting the goal of 0.1 neturon/100 t yr identified so far, considering also the reduced neutron background of the new design
DarkSide-20k sensitivity

WIMP mass [TeV/c²]

WIMP–nucleon $\sigma_{SI}$ [cm²]

DarkSide-20k (100 t yr proj.)
DarkSide-20k (200 t yr proj.)
Future 300-tonne GADMC Detector (1kt yr proj.)
DEAP-3600 (proj.)
LUX (2017)
LZ (proj.)
PANDAX-II (2017)
XENON1T (2017)
XENON1T (proj.)
XENONnT (proj.)
WARP (2007)
DarkSide-50 (2015)
DEAP-3600 (2017)
DarkSide-50 (2018)

Neutrino floor
Conclusions

● DarkSide-20k set to start in 2021, with a projected sensitivity of $1 \times 10^{-47}$ cm$^2$ for a 1 TeV/c$^2$ dark matter particle mass and an exposure of 100 tonne$\times$yr

● Global Argon Dark Matter Collaboration aiming at 1,000 tonne$\times$year search for dark matter

● Two key enabling technologies:
  ▸ Upgrade of production of depleted argon to many tonnes (URANIA & ARIA)
  ▸ Cryogenic photosensors based on SiPM arrays with area of 15 m$^2$ (NOA)
DarkSide-20k @ LNGS Hall C

THANK YOU
1ton prototype TPC
Triangular Mother Board (TRB)

15 PDMs each

Square Mother Board (SQB)

25 PDMs each