Material Assay Campaign of the DarkSide-20k experiment

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on behalf of the DarkSide-20k Collaboration

8th ICRM-LLRMT
Assergi (Italia), May 3rd 2022
Outline

- DarkSide-20k
- Radiopurity constraints for WIMP searches with LAr
- The assay campaign:
  - tools & organization
  - Results so far
- The Underground Argon program
- Conclusions and outlook
The Global Argon Dark Matter Collaboration towards DarkSide-20k

Joint effort of all former DM experiments using Liquid Ar targets:

- > 400 scientists
- > 100 institutions

50 tons (20 fiducial) * 10 y program

Ultimate step: **ARGO** (300 t)

**The goal:** explore heavy dark matter to the neutrino floor and beyond with extremely low instrumental background

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Argon dual-phase Time Projection Chambers

- Liquefied target + electroluminescence in gas
- **Low threshold** (7.5 keV$_{ee}$). Down to 0.1 keV$_{ee}$ for S2-only.
- **Multiton** detectors (50 t in DarkSide-20k).
- Large distance between target and unavoidable radioactive components. **Self-shielding**.
- **Underground argon** to minimize intrinsic $^{39}$Ar activity.
- Multiple detection channels for **background suppression** due to **Pulse Shape Discrimination**.

![ER-like event](image1)

![NR-like event](image2)

$\frac{S_2}{S_1}$ $> \frac{S_2}{S_1}$

Due to an enhancement of the recombination process

V. Pesudo - XIII CPAN Days - Mar 21st 2022
DarkSide-20k in numbers

- Nested detector with
  - ProtoDUNE-like cryostat: $8 \times 8 \times 8$ m$^3$ hosting $650$ t of atm Ar
  - Ti vessel+structure hosting $99$ t underground Ar.
  - UAr + Gd-loaded acrylic Veto for neutrons and $\gamma$ (Marini’s talk).
  - Central Dual-phase Ar TPC:
    - $50$ t UAr ($20$ t fiducial)
    - $348$ cm drift L
    - $350$ cm side to side
    - Cathode @ $-73.4$ kV.

- Multiple detection channels for background supression in Region Of Interest (ROI).
  - neutrons after cuts $< 0.1$ in $10$ y
  - Zero Background from $\beta$ and $\gamma$

- Position reconstruction resolution
  - $< 5$ cm in XY
  - $\sim 1$ mm in Z

- $21$ m$^2$ of SiPM + $5$ m$^2$ in veto.
  - Coverage in TPC Optical plane $> 90\%$

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Radiopurity needs for WIMP searches with liquid Ar

- Most α backgrounds very local in the surfaces and of much higher energy than expected WIMP recoils: **Not in ROI**.
- Degraded α (in suspended dust) could mimic a WIMP-like signal.
- Degraded surface α in coincidence with a β or γ could mimic a WIMP-like signal.
- Moreover, low-E α-decays can induce X(α,xn)Y reactions in the detector materials.
- 4-9 MeV α emitted in the naturally occurring $^{232}$Th and $^{238}$U series, present everywhere to some extent.
- A neutron recoil is indistinguishable from the expected WIMP recoil.
- β and γ do not contribute as background for the search by themselves, but contribute to pile up and the overall rate.
  - S1-S2 coincidences after long drift times (up to 5 ms) require very **small trigger rate**.
- **Cosmogenic muons** (Vallivilayil’s talk) can produce high energy neutrons and showers of unstable particles, with a variety of lifetimes.
  - Deep underground + monitor history of exposure

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Radiopurity needs for WIMP searches with liquid Ar

- **Radiopurity control** over every component that goes into the detector.
  - Down to the resistor level
- Knowledge on the **chemical composition** of the components in order to calculate the n yield via $X(\alpha,xn)Y$.
  - DarkSide is the first experiment with the $(\alpha,n)$ neutron background 
    **fully calculated with Geant4**: SaG4n (http://win.ciemat.es/SaG4n/)
    Exploiting experimental data (JENDL)
    Biasing techniques + geometries


- **Complete simulations**, especially critical for $\gamma$ and neutron transport (large mean free path).
Radiopurity needs for WIMP searches with liquid Ar

- Control on the **surface exposure to air**:
  - $^{222}$Rn decay daughters attach to surfaces and have long half-lives ($^{210}$Pb 22 y).

- **Hundreds of assays** performed combining
  - Inductively Coupled Plasma Mass Spectrometry,
  - HP Germanium screening,
  - surface screening
  - Po radiochemical extraction

- Monitor the **history of exposure of materials to cosmogenic radiation**.

- **Worldwide effort involving**
  - **underground facilities**: LSC (Sp), Gran Sasso (It), Boulby (UK), SNOLAB (Ca)
  - other: Temple (US), CIEMAT (Sp), Mendeleev U. (Ru), U. Jagiellonian (Pl), Aix-Marseille U. (Fr).
DS-Materials working group organization

DS-Materials

Assay Campaign
- Assay results
- Elemental analysis
- Database

(α,n) neutron budget and γ-rate
- R.A. Budget
- (α,n) neutron / Fission-
- γ-rate

Other backgrounds from the materials
- Neutrons from the rock
- Cosmogenics AG/UG
- Rn diffusion and plate-out

QA/QC
- Surface contamination
- Surface cleaning protocols
- Material Storage/Transportation/Handling
Web-interfaced Database of assay results

Online database that centralizes the full assay process

- New material or component? Assay request!
- Sample allocation depending on available mass and needs
- Information on sample/assay status
- Storage and organization of results

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The tools and organization

DS-20k materials DB structure

Assay request from Working Group
- assay request
- material samples (detailed information)
- additional information (procedures, comments)
- document cloud

Sample evaluation and dispatch
- assigned institutional queues
- screening methods (general characteristics)
- assay status history

Screening
- assay results (numerical results)
- assay reports (written documentation)
- contacts (people and institutions involved)
- document cloud

Evaluation
- RA budget update
- decision on material application

Feedback to the Working Group

R.A. budget spreadsheet
(storing the results of the accepted samples, materials compositions, weights ...etc)

(α,n) neutron background

γ event rate (VETO+TPC)
The decision making

- Effort going on for more than 5 years. Now entering the critical phase of final sample purchase, validation and storage
The techniques

- **ICPMS**: sensitive to concentrations ($^{238}\text{U}$ and $^{232}\text{Th}$ only)
- **HPGe**: Sensitive to gamma emitters through all the decay chains and other nuclides ($^{40}\text{K}$, $^{60}\text{Co}$, $^{137}\text{Cs}$...). Need larger amounts, longer times and geometry dependent
- **Po radiochemical extraction**: alpha spectroscopy after redox chemical extraction and deposition in silver disk.

![Diagram of the techniques]

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ICPMS

SYSTEMATIC BREAKING OF SECULAR EQUILIBRIUM IN 238U CHAIN

(NOT SIGNIFICANT IN 232Th CHAIN)
neutron budget in pies

- PhotoElectronics and cryostat dominate.
- Top 10 contributors represent 85% of the budget.
- $^{210}$Po contributes up to 26% of the neutron production (1 alpha in 10 + 6).
- 0.1 neutron background events after cuts in 10 y.
The Underground Argon program

Critical for the success of the GADMC program.

Urania & Aria under construction

DArT taking data at LSC without ArDM veto. ArDM fully refurbished by the end of June.
Conclusions and outlook

- **Global Argon Dark Matter Collaboration (GADMC)** is a joint effort of ~400 collaborators from ~100 institutions working towards WIMP detection with a dual phase Ar TPC.

- DarkSide-20k has developed deep understanding of gamma background (for rates and pile up) and particularly neutron background. **Pushing the state-of-the-art in background suppression.**

- Very robust infrastructure for sample assay and information, including assays with 3 or more techniques.

- Relevant **contributions for the low background community**: new procedures for neutron yield estimates, standardization of assays (beyond HPGe and ICPMS), book keeping and storing results...

- **Fundamental role played by underground facilities** (LSC, LNGS, Boulby and SNOLAB) and other facilities (Temple, CIEMAT, Mendeleev U., U. Jagiellonian, Aix-Marseille U.) to fully characterize the radioactivity with no secular equilibrium assumption.
Thank you! Grazie!
Overall Status of the project

- Site preparation to host cryostat
- Starting tenders for procurements
- Off-site testing performance of:
  - photoelectronics (Naples)
  - cryogenics (CERN)
- Building URANIA
- Building Aria
- Refurbishing ArDM to host DArT
- Fine-tuning at the technical drawing and integration level.
- Ongoing final review of TDR by INFN before installation.
The challenges: large area cryogenic radiopure SiPMs

- Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.
- Photon detection efficiency ~45%
- Low dark-count rate < 20 cps
- Timing resolution ~ 10 ns
- 2112 channels TPC + 480 channels Veto.
- Mass production of the raw wafer in LFoudnry company.
- PDM + PDU assembly in a dedicated facility at LNGS (NOA).
Scientific goals of DarkSide-20k

- $6.3 \times 10^{-48}$ cm$^2$ for 1 TeV/c$^2$ WIMP (90% C.L.)
- $2.1 \times 10^{-47}$ cm$^2$ (5σ) discovery
- Nominal exposure: (20×10) t yr
- Instrumental background: 0.1 events
LOW MASS SENSITIVITY

- **Scintillation signal** (S1): threshold at \(~ 2 \text{ keV}_{ee} / 6 \text{ keV}_{nr}\) weak sensitivity to low mass WIMPs.

- **Ionization signal** (S2): threshold < 0.1 keV$_{ee}$ / 0.4 keV$_{nr}$ **Sensitive to low mass WIMPs!!**

- Use Ionization (S2) Only.
  
  - Amplified in the gas region (~23 PE/e- or more)
  
  - Sensitive to a single extracted electron
  
  - The electron yield for nuclear recoils increases at low energy

- Ar has lighter mass than Xe. So, more efficient momentum transfer from low mass DM.

- Need 100 times lower $^{39}$Ar contamination, lower radioactivity from detector, lower impurities in active volume.
Scientific goals of DarkSide-20k

- Perform WIMP searches in unexplored regions of the parameter space using the most background suppressed experiment to date. **Best sensitivity for the heavy-side of the space parameter.**
- **Pave the way** for ARGO, which will measure down to the neutrino floor.

Physics program beyond WIMPs

- Exotic DM searches
- Solar axions
- SuperNova neutrinos
- Unprecedented
  - study of Ar properties
  - **Radiopurity control and mitigation**
  - SiPM development
- Low mass search (DS-LowMass)
- + Many more
**Background estimates in DarkSide-20k**

<table>
<thead>
<tr>
<th>Background type</th>
<th>Bg events in ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>(α,n) neutrons from U and Th</td>
<td>9.5 × 10⁻²</td>
</tr>
<tr>
<td>Fission neutrons from U-238</td>
<td>&lt;2.3 × 10⁻³</td>
</tr>
<tr>
<td>Neutrons from Rn-222 diffusion and surface plate-out</td>
<td>&lt;1.4 × 10⁻²</td>
</tr>
<tr>
<td>Cosmogenic neutrons</td>
<td>&lt;6.0 × 10⁻¹</td>
</tr>
<tr>
<td>Neutrons from the lab rock</td>
<td>1.5 × 10⁻²</td>
</tr>
<tr>
<td>Random surface α decay + S2 coincidence</td>
<td>&lt;5.0 × 10⁻²</td>
</tr>
<tr>
<td>Correlated ER + Cherenkov</td>
<td>&lt;1.8 × 10⁻²</td>
</tr>
<tr>
<td>Uncorrelated ER + Cherenkov</td>
<td>&lt;3.0 × 10⁻²</td>
</tr>
<tr>
<td>ER</td>
<td>&lt;1.0 × 10⁻¹</td>
</tr>
</tbody>
</table>

Current estimates of trigger rate:

- 94 Hz in TPC
- 138 Hz in veto