Low Radioactivity Argon for Dark Matter searches



Roberto Santorelli CIEMAT – Madrid

(on behalf of the DarkSide Collaboration)





MINISTERIO DE CIENCIA E INNOVACIÓN







TIPP 2023 – CTICC Cape Town, 06/Sep/2023

Outline

- LAr for Dark Matter direct searches
- Ar-39 in atmospheric Ar
- Radiopure UG-Ar: extraction and purification
- DArT experiment @ LSC
- Prospects of the UG-Ar for rare event searches
- Conclusions

LAr: A Dream technology for DM search



coupling spin-dependent / spin-independent



- Large Exposure (Mass × Time) : ~100s tonne×year
- Low Energy Threshold : ~10 keV
- Event topology : alpha, muon..
- Discrimination between Signal and Bkg: $> 10^8$
 - Bkg Rate after cuts NR-like event
- : <0.1 evt in the exposure



DarkSide-20k @ LNGS

DS-20k UG @ LNGS





- ≈650 t Ar in a membrane cryostat (VETO)
- 50 t (20 t FV) Ar target
- 21 m² cryogenic SiPMs
- >10 phe/keV in the TPC (S1)
- top/bottom planes Gd loaded (1%) acrylic (nthermalization/capture)





➢ 200 t·y: 6.3×10⁻⁴⁸cm² (90% C.L., 1 TeV/c²)

< 0.1 bkg in 200×20 t·y exposure</p>
~Background free

Roberto Santorelli - TIPP 2023

Frontiers

- Large mass (tens to hundreds of tons) and long drift (some meters scale)
- Very low thresholds (~keV)
- New sensors
- Extreme radiopurity

³⁹Ar in Atmospheric Argon (AAr)

- β -emitter with 565 keV endpoint, $T_{1/2}=269$ y (cosmogenic)
- Pure beta emitter, no accompanying gamma radiation
- $\sim 17 \text{ mBq/m}^3$ in atmosphere
- Present in AAr due to the production process (isotopic abundance ~ $8 \times 10^{-16} \text{ g}(^{39}\text{Ar})/\text{g}(^{\text{Nat}}\text{Ar})$)



 1.01 ± 0.02 (stat) ± 0.08 (syst) Bq/kg of ^{Nat}Ar

Pileup problems in multi-ton TPCs!!!

Radiopure target: Underground Argon (UAr)

- Argon from underground gas reservoirs \rightarrow shielded from cosmic rays
- Production from natural radioactivity reactions (e.g. (α, n) -induced on ³⁹K) suppressed if the gas is from the mantle (ppb level of U and Th)



 1400 ± 200^{39} Ar depletion factor in UAr with respect to AAr *Phys. Rev. D* **93**, 081101 (2016)

International effort underway to procure radiopure argon extracted from underground reservoirs

Extraction – Purification – Measurement



Roberto Santorelli - TIPP 2023

Extraction

URANIA project: <u>Production</u> ready for construction in Cortez mine, Colorado. First procurement of 60 ton from the CO₂ wells ~250 kg/d, 99.99% purity (120t +25th per 0vbb)





Purification to the detector grade

ARIA project: Ar chemical <u>purification</u> by cryogenic distillation (1t/day)



- 350 m height, 31.8 cm inner cryogenic distillation column (Sardinia, Italy)
- The tallest ever built of this type
- Designed to reduce the isotopic abundance of Ar-39 in UAr by another factor of 10 per pass
- Production rate with ARIA in chemical purification mode (DarkSide-20k): ~1ton/day
- Production rate with ARIA in isotopic separation mode: several kg d⁻¹
- Medical applications (isotope supply)

ARIA

- SERUCI-0: short version of the Aria column using only the reboiler, the condenser, and one central module
- SERUCI-1: 28 middle modules

- Top module (Condenser) 7m
- Middle modules -12m
- Bottom module (boiler) 5m



Successful nitrogen distillation run of the SERUCI-0 prototype installed outside the Carbosulcis coal mine



Isotopic ratio ${}^{36}Ar/{}^{40}Ar$ as a function of time.

Eur.Phys.J.C 83 (2023) 4, 435





UAr radiopurity measurement @LSC:ArDM







ArDM detector:

- 850 kg active volume (≈ 2 t total)
- Cryogenic low rad. PMT arrays (R5912 2×12)
- 50 cm passive neutron shield (Poly, 20 ton)
- Data taken 2014-2018



- OFHC copper vessel with two top pipes.
- Two 1 cm² SiPMs at top and bottom with the electronics integrated.
- External acrylic support structure. Cylinder + two SiPM supports.
- Internal acrylic cylinder and two disks covered with TPB (200 μ g/cm²).
- Reflector around SiPMs and between acrylic cylinders.
- Act.volume of 1.4 kg: 620 evt/week for UAr (0.73 mBq/kg).











- Signal: β decays of ³⁹Ar (ROI \in [0,600] keV) with < 10 keV deposited in the veto (minimal veto threshold)
- **Background:** untagged γ particles mainly from the radioactive decays in the detector materials (+ external)

Background source	Evts/week ROI	Untagged Evts/week ROI
ArDM Cryostat	3164.4	218.3
ArDM PMTs	1053.0	42.8
ArDM supp. structure	28.5	0.6
Lead Belt	150.5	16.2
DArT vessel	16.6	5.4
Arlon SiPM	40.9	23.5
Acrylic	9.1	4.1
External without Pb	117623.0	10020.5
Total without Pb	122098.9	10301.7
External with Pb	2596.2	155.7
Total with lead	7209.9	465.5



Signal 620 evt/week (D.F. 1400) \rightarrow S/B > 1 for UAr



	 DART events untagged ³⁹Ar Spectrum Simulated data 	"Design and constru ultra-low radioactive JINST 1	ction of a new detector to measure e-isotope contamination of argon" 15 (2020) 02, P02024.
	Monte Carlo	Depletion factor with respect to AAr	Statistical uncertainty [%]
40- 1	VIO	10	0.4
20		100	1.3
		1400	6.7 DS-50
~0 2000 4000	6000 8000 10000 12000 14000 E _{dart} [PE]	14000	41.1

- Installation in ArDM by the end of 2023
- Commissioning of DArT in ArDM in 2024
- Detector fully operative from early 2025
- In the long term, DArT will measure on a regular basis the UAr batches received from URANIA/ARIA before their use in DarkSide-20k

ArDM preparation



- 13 new cryogenic PMTs (R5912) for the veto
- New reflector cage with TPB on the reflector panels
- New 6 t inner Pb shield



Commissioning in a test setup







- Independent from ArDM
- Control on the filling level
 performed by Arduino Mega
 acting on two (In & Out)
 cryogenic valves.
- Automatic filling system
- Filling triggered by level meter.
- Online monitoring with a webcam on a raspberry.
- Remote actuation possible via ssh for emergencies.
- Several weeks of data taking in stable conditions

AAr data in the test setup



Measured t_{1/2} (²¹⁴Po) = 158.3 ± 6.1 (stat) µs

AAr data in the test setup



UAr Transportation

- We are considering liquid containers: final choice of specific container still to be made.
- The activity of ³⁹Ar induced during extraction, purification and transport on surface, in baseline conditions, is evaluated to be <5% of the UAr activity measured in DarkSide-50 (*Astropart.Phys.* 152 (2023) 102878), and thus considered acceptable.
- Other products in the UAr such as ³⁷Ar and ³H are shown not to be relevant due to short half-life and assumed purification methods.

UAr for rare events searches

➤ ~ 100 t produced for DarkSide-20k (starting Q4 of 2024)

- We recently signed with the LEGEND Collaboration an agreement for the provision of 25 t of UAr for the LEGEND1000 argon veto, after the DarkSide-20k production (Ar-42 background mitigation).
- > A lot of interest from other experiments
 - COHERENT 1 t (CEvNS)
 - ARGO ~300t (dark matter)
 - DUNE O(10,000) t



Conceptual studies : 3 kt x 10 yr

Conclusions

- The small Ar-39 contamination does not make feasible to use atmospheric argon in the next generation of Dark Matter search experiments
- ~1400 depletion demonstrated in UAr: UAr will be key to the physics programs of the future DM direct search with argon
- International effort underway to procure radiopure argon extracted from underground reservoirs with three different projects: URANIA, ARIA and DArT
- ➢ First 2 y production for DS-20k by the end of 2024
- ➤ A lot of interest from the rare event search community



Extraction – Purification – Measurement



DarkSide-20k @ LNGS



- 50 t (20 t FV) low-radioactivity Ar (UAr)
- 21 m² cryogenic SiPMs
- 5 m² cryogenic SiPMs in the Veto
- 99 t UAr in total in a Ti vessel
- TPC lateral walls + additional top/bottom planes in Gd loaded (1%) acrylic (n- thermalization/capture)

- ≈650 t AAr in a membrane cryostat, proto-DUNE like
- 2 independent cryogenics purification loops



- >10 phe/keV in the TPC (S1)
- $>20 \text{ PE/e}^{-}$ (S2)
- 2 phe/keV in the Veto
- \sim cm (xy) and \sim mm (z) pos. res.



Commissioning in a test setup





- Setting the operating conditions of the system
- Long terms stability
- Characterization of the DAQ
- Study of the SiPM optimal operating conditions
- Data transfer / processing / storage
- Test of the reconstruction/analysis tools •
- Tuning of the MC
- First study of the internal backgrounds



Channel 0

Triplet lifetime ~1230 ns

