Low Radioactivity Argon for Dark Matter and Rare Event Searches

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DarkSide-50

• located at Gran Sasso National Laboratory (LNGS)

• dual-phase Liquid Argon TPC
  ▪ contained within liquid scintillator veto (LSV)
  ▪ the LSV is contained within a Water Cherenkov detector

• TPC filled with 50kg of Argon
  ▪ first filled with atmospheric argon (data taking began in 2013) → P. Agnes et al. (DarkSide Collaboration) Phys Lett B. 743, 456, 2015.
  ▪ 2nd fill with argon sourced from underground (taking data with UAr since 2015) → P. Agnes et al. (DarkSide Collaboration). Phys. Rev. D 93, 081101(R), 2016. and P. Agnes et al. (DarkSide Collaboration) Phys Rev D 98, 102006, 2018.

for more information on DarkSide-50 see
P.Agnes talk: Latest Result from DarkSide-50 Experiment at LNGS (Wednesday, July 29)
DarkSide-50 Underground Argon

in the atmosphere: $^{39}\text{Ar}$ activity of 1 Bq/kg

DS-50 measured $^{39}\text{Ar}$ specific activity of $0.73 \pm 0.10$ mBq/kg

residual $^{39}\text{Ar}$ likely from air infiltration during extraction

(P. Agnes, et al. (DarkSide collaboration) Phys. Rev. D 93, 081101(R) (2016))
Experiments Requiring Low-Radioactivity Argon
("The Low-Radioactivity Underground Argon Workshop: A workshop synopsis" arXiv:1901.10108 (2019))

• DarkSide-20k and ARGO
  ▪ WIMP Dark Matter search
  ▪ Argon is primary WIMP target
  ▪ Argon related background: $^{39}$Ar decay
  ▪ Masses required:
    ✓ DarkSide-20k – 50 tons
    ✓ ARGO – 300-500 tons

• COHERENT
  ▪ Coherent elastic $\nu$-nucleus scattering
  ▪ Argon is primary neutrino target
  ▪ Argon related background: $^{39}$Ar
  ▪ Masses required:
    ✓ SNS/COHERENT – 1 ton
    ✓ CAPTAIN-MILLS – 10 tons

• LEGEND
  ▪ Neutrinoless double beta decay
  ▪ Argon shield surrounding HPGe detectors
  ▪ Argon related background: $^{42}$K decay ($^{42}$Ar daughter)
  ▪ Mass required:
    ✓ 6(10 tons)

• DUNE
  ▪ Low-energy neutrino program
  ▪ Argon is primary neutrino target
  ▪ Ar related backgrounds: $^{42}$Ar, $^{39}$Ar, and $^{42}$K
  ▪ Mass potentially needed:
    ✓ 17 ktons/module

slide from Henning Back at LRT 2019
DarkSide-20k

• the next generation in the DarkSide program

• will be located at Gran Sasso National Laboratory (LNGS)

• dual-phase Liquid Argon TPC

• will require 50ton of Underground Argon

for more information on DarkSide-20k see
L. Rignanese talk: DarkSide-20k and the Direct Dark Matter Search with Liquid Argon (Tuesday, July 28)
\[^{39}\text{Ar}}\text{ Production}\]

- in the atmosphere: \(^{39}\text{Ar}\) produced from cosmic ray interactions primarily from \(^{40}\text{Ar}\)

- \(^{39}\text{Ar}\) activity in atmosphere: 1Bq/kg – represents large background for Dark Matter Experiments

- underground \(^{39}\text{Ar}\) produced from neutron interactions with \(^{39}\text{K}\)

| Reaction                  | Estimated \(^{39}\text{Ar}\) Production rate [atoms/kg/day] | Fraction of total AAr [%] |
|---------------------------|-------------------------------------------------------------|---------------------------|
| \(^{40}\text{Ar}(n, 2n)^{39}\text{Ar} + \) \(^{40}\text{Ar}(n, \alpha)^{39}\text{Cl}\) | \(759 \pm 122\)                                              | 72.3                      |
| \(^{40}\text{Ar}(\gamma, n)^{39}\text{Cl}\) | \(172 \pm 19\)                                              | 16.4                      |
| \(^{40}\text{Ar}(\gamma, n)^{39}\text{Ar}\) | \(89 \pm 19\)                                               | 8.5                       |
| \(^{40}\text{Ar}(\gamma, p)^{39}\text{Cl}\) | \(23.8 \pm 8.7\)                                            | 2.3                       |
| \(^{40}\text{Ar}(p, 2p)^{39}\text{Cl}\) | <0.1                                                       | <0.01                     |
| \(^{40}\text{Ar}(p, p^n)^{39}\text{Ar}\) | \(3.6 \pm 2.2\)                                             | 0.3                       |
| \(^{38}\text{Ar}(n, \gamma)^{39}\text{Ar}\) | \(<0.1 (\text{UAr})\)                                       | -                         |
| Total                     | \(1048 \pm 126\)                                           | 100                       |

\[(O. \ Šrámek, et al., Geochimica et Cosmochimica Acta 196 (2017) 370)\]

Saldanha et al. *Cosmogenic production of 39Ar and 37Ar in argon*. United States. doi:10.1103/PhysRevC.100.024608.
Where to find Underground Argon?

- 2009: location found for argon low in $^{39}$Ar
- Southwest Colorado CO$_2$ wells
- 400ppm Argon in CO$_2$
- this site is currently the only known/proven source for argon low in $^{39}$Ar (Where else can low-$^{39}$Ar in argon be found?)

- for DS-50
  - UAr extracted at a plant in Colorado
  - shipped to Fermi National Accelerator Laboratory in Illinois, USA for purification
  - UAr production averaged 140g/day

but DS-20k and any future/planned argon experiments will need much more UAr and at a faster rate...

(S.M.V. Gilfillan, Geochim. et Cosmochim. Acta 72 (2008) 1174–1198)
From the wells to the detector

Step 1:
Extract argon from CO₂ wells with designated plant, **Urania**

Step 2:
Ship UAr to Sardinia, Italy for chemical purification, **Aria**

Step 3:
Ship purified UAr to **LNGS** for insertion into DS-20k

Quality Assurance:
small portion of UAr sent to **DArT** for ³⁹Ar measurement
*(What is the ingrowth of ³⁹Ar during flight?)*
Urania

- will be located next to the previous location in Colorado, USA
- will extract UAr from same source as DS-50
- extraction and chemical purification plant to be built by Polaris
- capable of extracting UAr at rate of 300 kg/day with 99.99% purity

Brianne R. Hackett, ICHEP, July 2020
Future Urania Location

photo courtesy of Henning Back
• cryogenic isotopic distillation plant
• being installed in a mine shaft at CarboSulcis, S.p.A. in Nuraxi-Figus (SU), Italy
• 350m tall distillation column
• designed to reduce $^{39}\text{Ar}$ isotopic fraction in UAr by factor 10 per pass
• production rate of several kg/day

paper forthcoming
Aria – for DS-20k

- UAr from Urania will arrive at Aria with 99.99% purity
- at the time scale needed for DS-20k, Aria will provide chemical purification
- will use for chemical purification at rate of 1000 kg/day
- argon recovery will be close to 100%

Marino Simeone, LRUUA workshop, 2018
DArT

- located at Canfranc Underground Laboratory, Spain
- housed within the 1 tonne ArDM experiment
- single-phase LAr detector with active volume ~1L
- setup capable of measuring UAr to AAr $^{39}$Ar depletion factors of the order of 1000 with 10% precision
- will be able to measure the $^{39}$Ar content not only for DS-20k, but for future argon experiments as well

C.E.Aalseth et al. “Design and construction of a new detector to measure ultra-low radioactive-isotope contamination in argon.” Journal of Instrumentation, Volume 15, February 2020.
Thank you