



Production, Purification and Assay of Underground Argon for DarkSide-20k



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On behalf of the GADMC & DarkSide-20k Collaboration

International Conference of High
Energy Physics 2024 (ICHEP
2024), Prague, Czech Republic.



Overview:

- GADMC and DarkSide Program.
- DarkSide-20k and Sensitivity
- Need for UAr and Procurement Chain.
- Urania : The Extraction Plant
- Aria : The Purification Plant
- DArTinArDM : Assaying the UAr
- Conclusion and Forward

Other contributions from DarkSide.

Paolo Franchini's Poster on 18th about

'DarkSide-20k Veto SiPM Detectors: Construction and Characterisation'

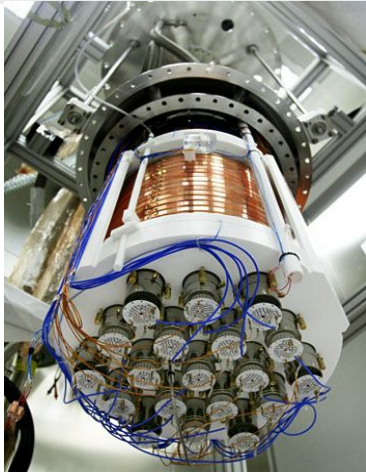
Daria Santone's Talk on 18th about

'Direct Dark Matter Search in the DarkSide-20k Experiment'

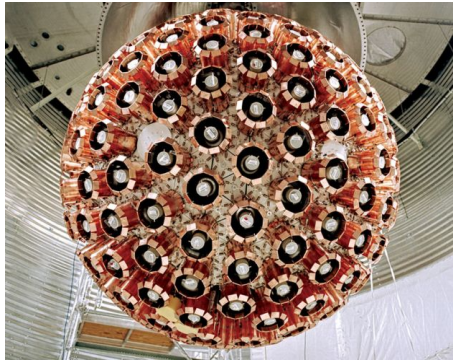
Yi Wang's Talk on 18th about

'Exploring Low-Mass Dark Matter with the DarkSide Detectors'

Global Argon Dark Matter Collaboration (GADMC):



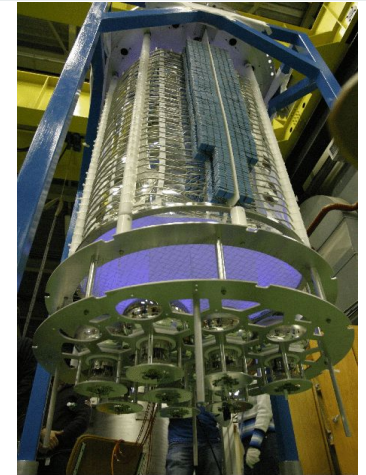
DS50 @ LNGS



DEAP 3600 @ SNOLAB



MiniCLEAN @ SNOLAB



ArDM @ Canfranc

GADMC:

We are ~ 100 institutions and > 400 collaborators from all the above experiments sharing knowledge and experience for the next step of direct DM search with LAr.

DarkSide-20k

ARGO

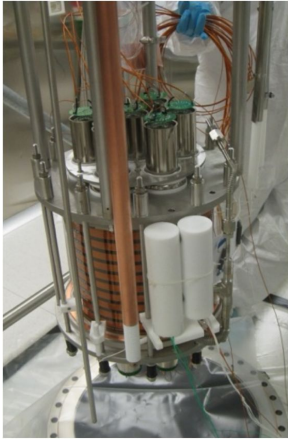
- ~ 20 t fiducial mass dual phase TPC
- ~ 50 t mass active + Neutron Veto
- ~ 700 t LAr External Muon Veto
- Under construction @ Hall C LNGS
- Commissioning foreseen in 2027.

- Future LAr DM detector ~ 203X and beyond
- 300 t fiducial volume
- Explore Heavy WIMPs to the neutrino floor

DarkSide Program



- Direct detection of WIMP dark matter signal in form of Nuclear Recoils (NRs).
- Based on a two-phase **argon** time projection chamber (TPC)
- Design philosophy based on having very low background levels that can be further reduced through active suppression, for **background-free** operation from both neutrons and β/γ 's



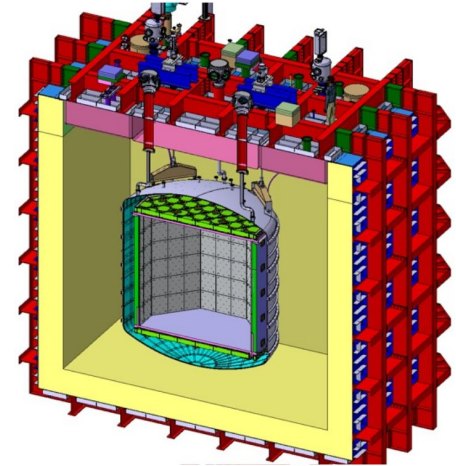
DarkSide-10

T. Alexander et al., *Astropart. Phys.* 49 (2013) 44
[arXiv:1204.6218]



DarkSide-50

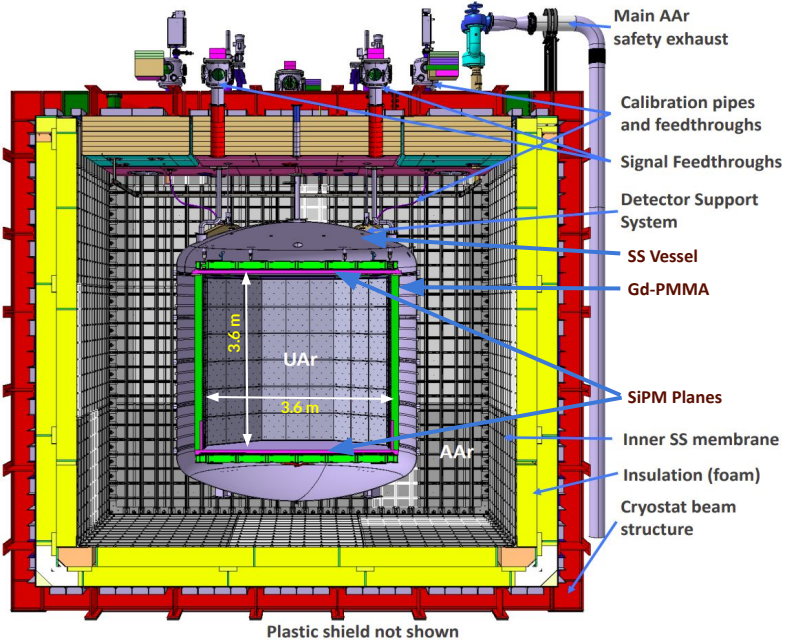
P. Agnes et al., *Phys. Rev. D* 93 (2016) 081101
[arXiv:1410.0653]



DarkSide-20k

C. E. Aalseth et al., *Eur. Phys. J. Plus* (2018) 133: 131
[arXiv:1707.08145]

DarkSide-20k Detector and Sensitivity:



Inner Detector:

- Octagonal shape dual phase argon TPC;
- Active UAr mass ~ 49.7 tonnes;
- Fiducial UAr mass ~ 20.2 tonnes;
- Inner Neutron veto \Rightarrow Active UAr mass ~32 tonnes.

Instrumental Background:

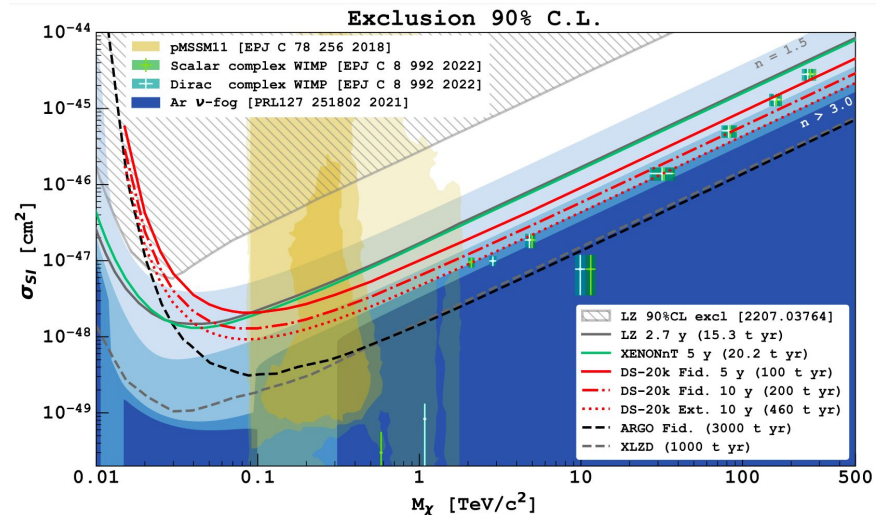
- 0.1 background events over 200 t-y in the ROI.
- Sensitivity to neutrino induced coherent scattering (CEvNS): 3.3 events

Exposure 200 t-y:

- 20 t fiducial volume with nominal 10 year run time
- 5 σ discovery: $2.1 \times 10^{-47} \text{ cm}^2 @ 1 \text{ TeV}/c^2$
- 90% C.L. exclusion: $6.3 \times 10^{-48} \text{ cm}^2 @ 1 \text{ TeV}/c^2$

Nested detectors structure:

- ProtoDUNE-like cryostat (12x12x12 m³ external)
- ~ 650 tonnes LAAr cryostat as muon veto.
- SS vessel separating AAr from underground UAr.
- Integrated neutron and γ veto (Gd-PMMA)
- ~5-10 cm plastic shielding around SS vessel, moderation of neutrons from cryostat insulation, LNGS Hall C (not in the drawing)



Underground Argon: A Necessity

The primary problem of atmospheric Argon is the isotope ^{39}Ar , forming the internal background.

$^{39}\text{Ar} \Rightarrow$ a beta emitter
 Primary Production \Rightarrow By spallation of cosmic rays on ^{40}Ar

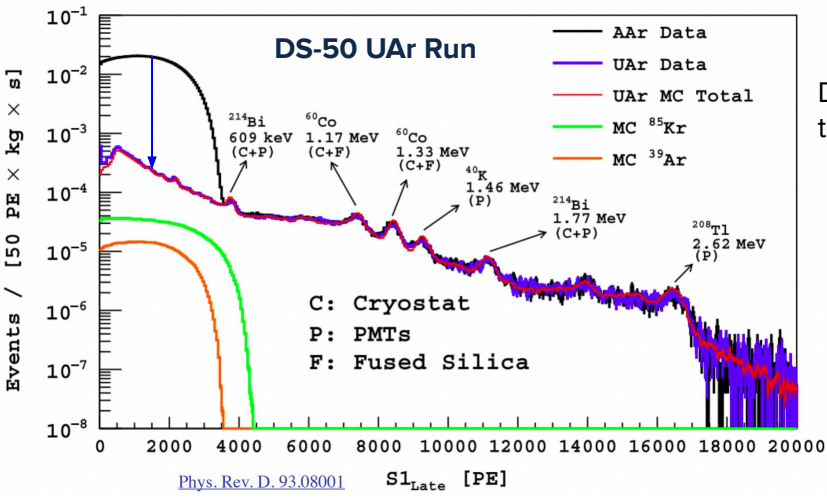
$Q_{\text{value}} = 565 \text{ keV}$
 Sp. Activity = 1 Bq/kg
 Half-life = 269 years

In a detector of ~ 50 tonnes
 Trigger rate $\Rightarrow 50 \text{ kHz}$

Argon stored underground is depleted in ^{39}Ar .
 Hence becomes our choice for target material.

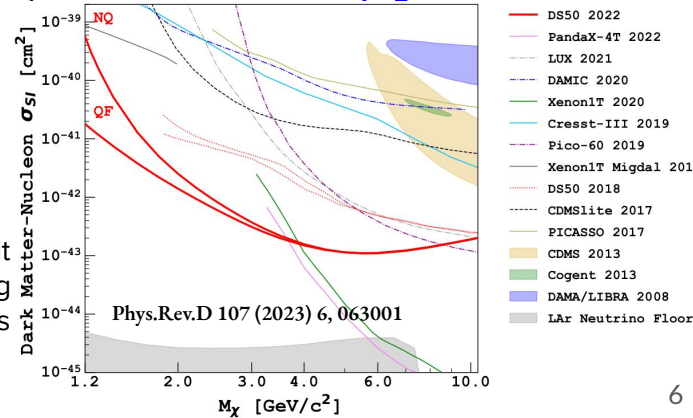
Expected electron type background rate in DS-20k $\sim 80 \text{ Hz}$

- High trigger rate leading to pile up problem of ERs
- Low performance of the PSD variable at lower energies
- Poses a major problem for S2 only analysis
- Leading background for low-mass searches with dual phase TPCs.



DarkSide-50 measured a depletion factor of 1400 in UAr with respect to AAU in terms of ^{39}Ar activity: ^{39}Ar activity in **UAr = $0.73 \pm 0.11 \text{ mBq/kg}$** .

DS-50 UAr S2-only result still holds the world leading limits for low mass SI-WIMPs $< 4 \text{ GeV}/c^2$



UAr Procurement Chain:

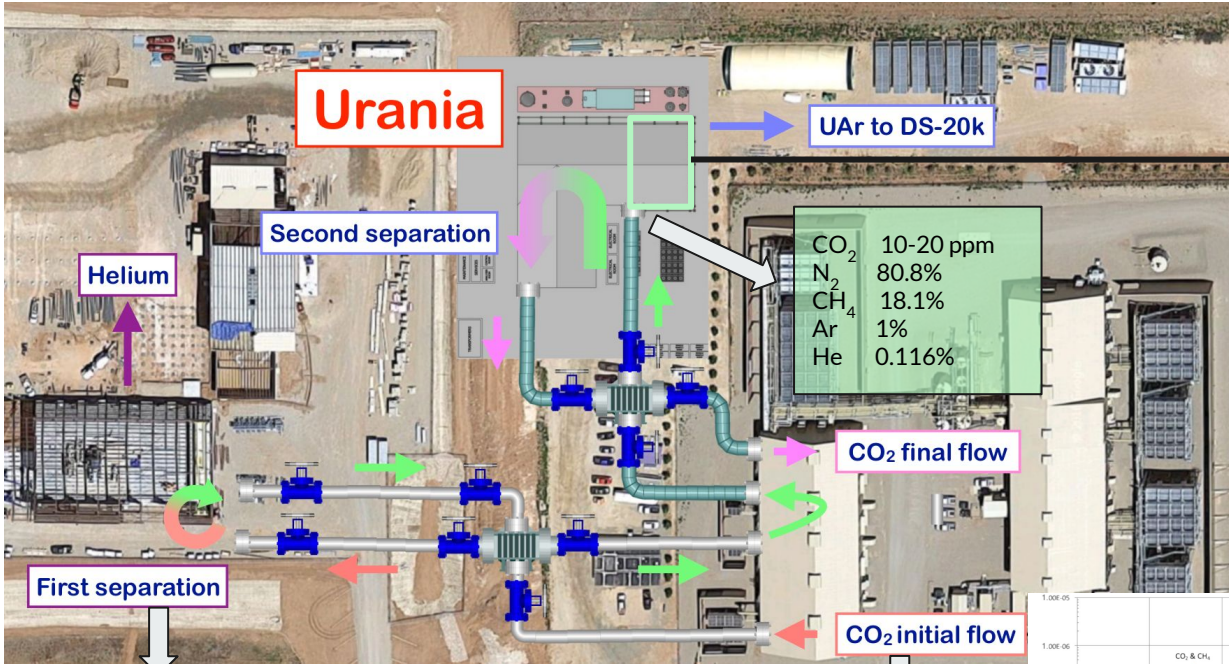


DarkSide-20k has a requirement of ~100 tonnes of UAr.



Urania Project

Located in Kinder Morgan Doe Canyon Facility, Urania will extract and purify the UAr from the CO₂ wells.

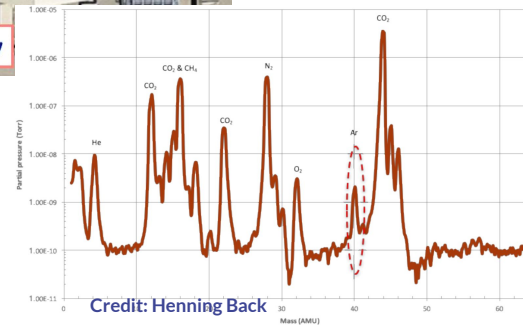


Recursive 2 stage Purification

1. Low pressure (~ 9 barg) cryogenic distillation to remove CH₄
2. Removal of N₂ and other lighter contaminants

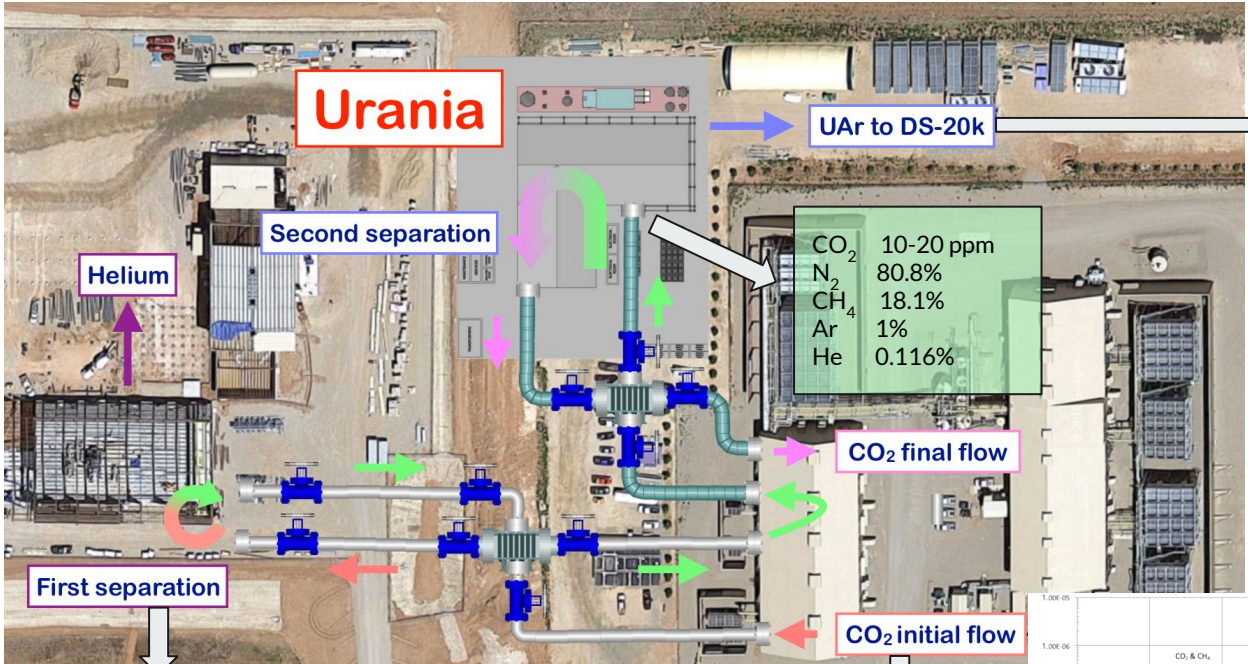
CO ₂	77.7%
N ₂	17.5%
CH ₄	4.5%
Ar	2200 ppm
He	250 ppm

CO ₂	95.5%
N ₂	3.5%
CH ₄	0.92%
Ar	400 ppm
He	50 ppm



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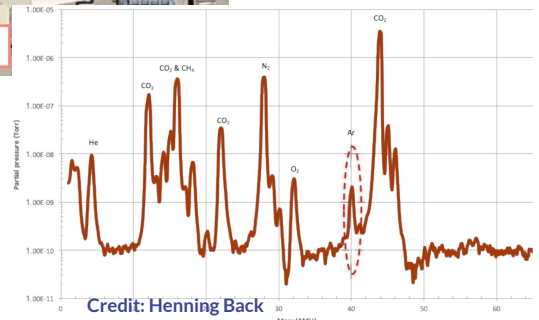
Output is 99.99% pure UArgon @ 250-330 kg/day.

Online monitoring system in place to know the gas composition after each stage.

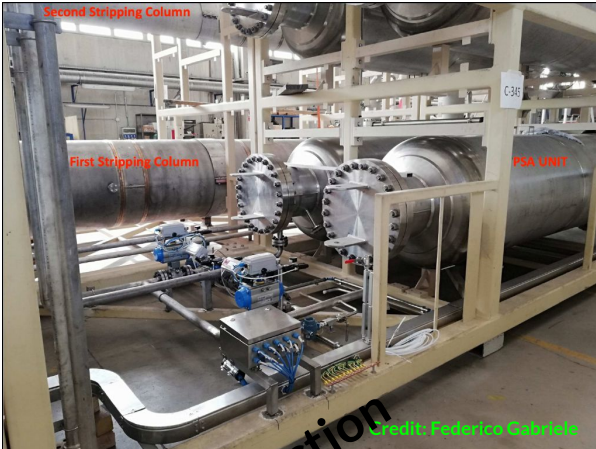
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Ar	400 ppm
He	50 ppm

CO ₂	10-20 ppm
N ₂	80.8%
CH ₄	18.1%
Ar	1%
He	0.116%



Urania Project



Current status of Urania: Site Preparation

Concrete base work has been finished. Site installation including various supporting systems is starting soon..



The shipping of UAr shall be done in liquid phase. Design of the containers are being finalized.

**Total of 8 containers
containing 15 tonnes each.**

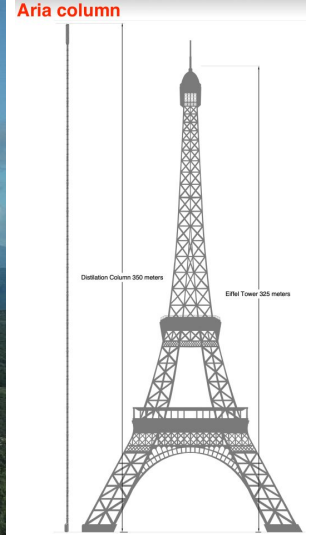


Aria Project: Cryogenic Distillation Plant

- Cryogenic distillation column (total height ~350 m)
 - 28 Central modules: 12 m each
 - 1 Condenser (top) module: 7 m
 - 1 Reboiler (bottom) module: 5 m
 - Outer Diameter of the column: 32.3 cm
 - Inner Diameter of the column: 31.8 cm
 - Outer Diameter of cold box: 71.2 cm
- Process is based on the difference in volatility
- Number of theoretical stages: ~2870
- Total column active height: ~ 287 m
- Chemical Purification rate: 1 t/d (or more)



Seruci-1 Site



Top module

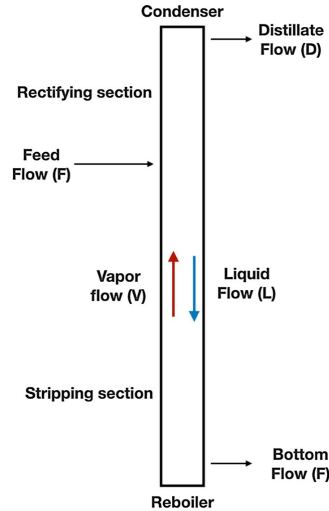


March, 2015

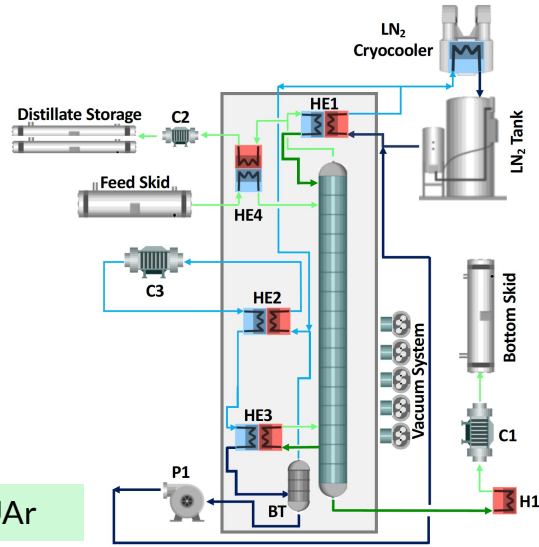
Aria Project: Conceptual and Structural Design



Working Principle

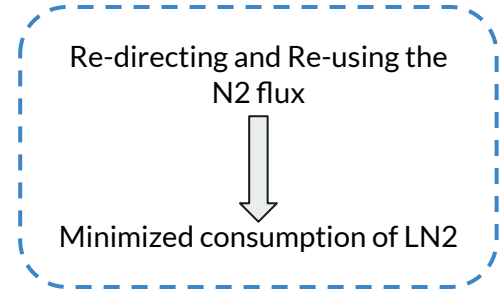


Purified UAr



Two independent cryogenic loops:

- a. argon loop
- b. refrigeration loop

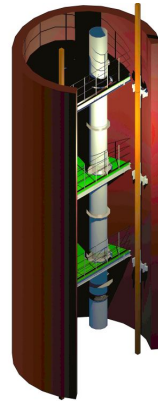


Two most important parameters of the distillation columns:

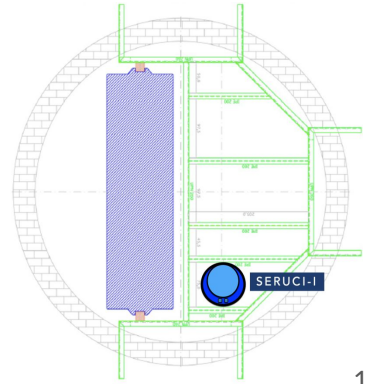
- a. Equivalent theoretical stages (N)
- b. Height equivalent to a theoretical plate (HETP)

Total column active height (L_a):

$$L_a = N \times HETP$$



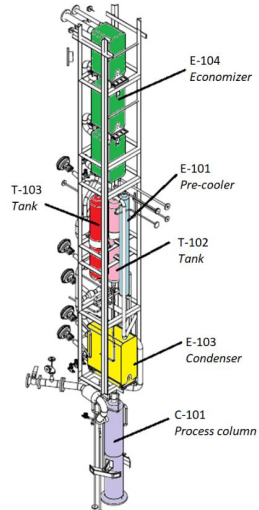
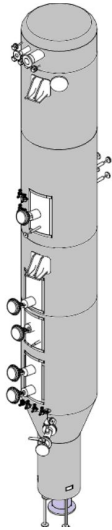
Ph. by Carbosulcis S.p.A



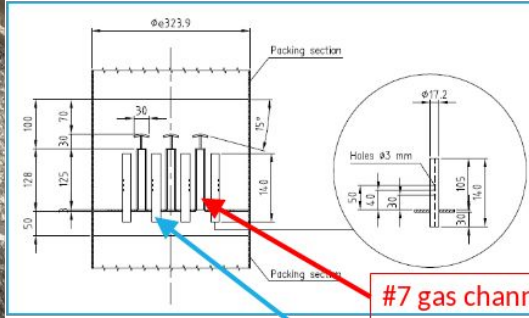
Aria Project: Conceptual and Structural Design



Top Module

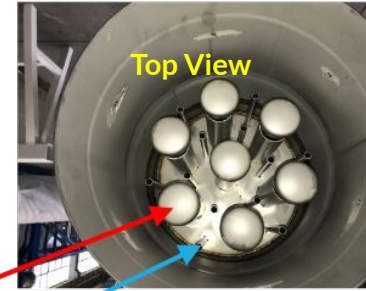


Credit: Arianna Steri

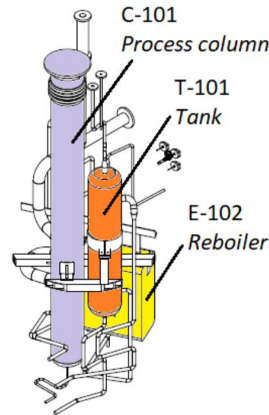
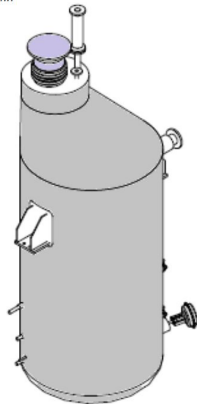


#7 gas channels

#12 liquid channels

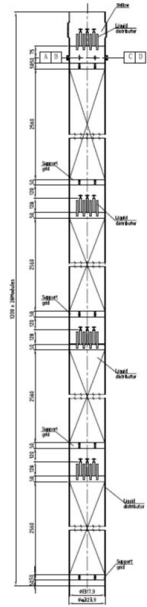
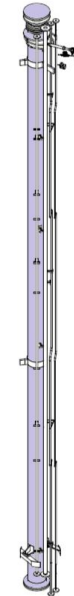


Bottom Module



The purpose of the packing is to support the liquid phase, for optimal thermodynamic contact between the rising vapor and the descending liquid.

Central Module

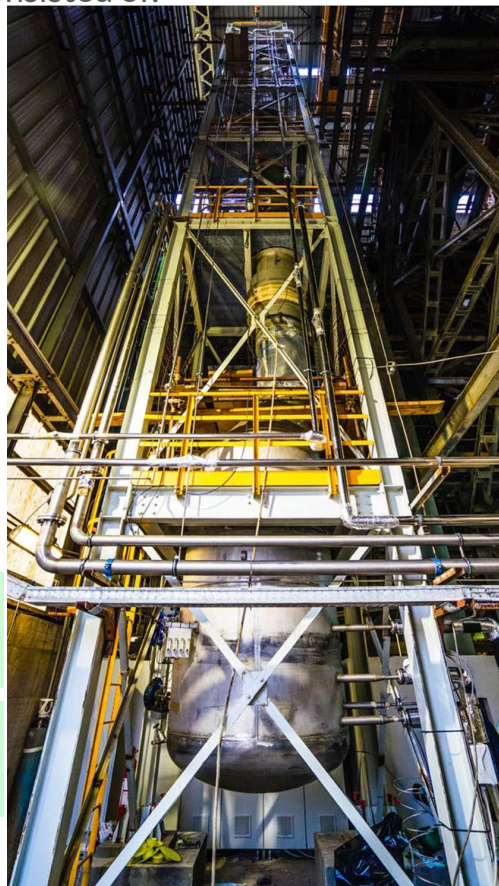


Aria Project: Prototype Seruci-0 Run and Results



A prototype plant called 'Seruci-0' was assembled to evaluate the performance of the plant. It consisted of:

- a. The top module
- b. 1 central module
- c. The bottom module

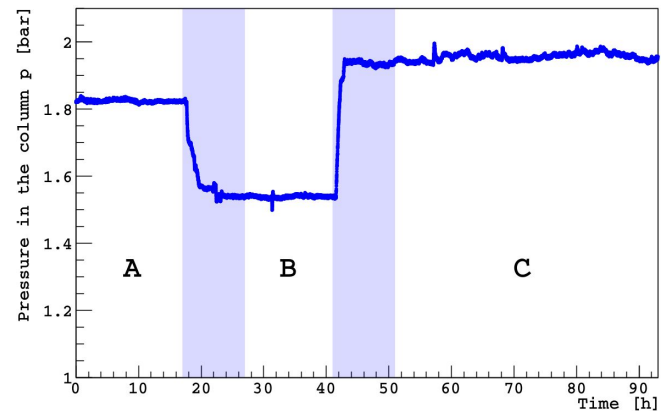
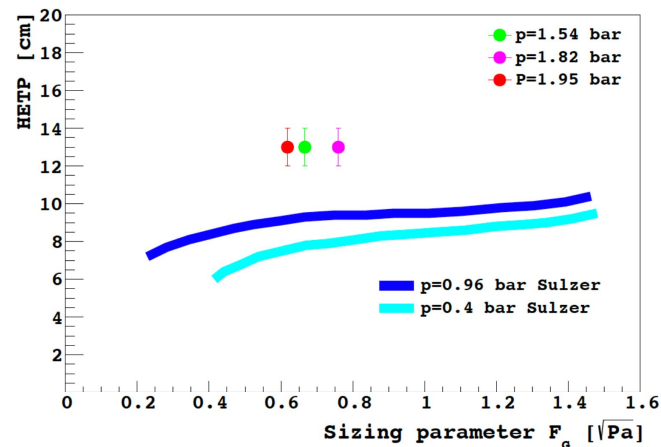


A dedicated sampling system coupled to a UGA was used to monitor the feed, distillate and output flow

First operation with nitrogen in 2019
(Eur. Phys. J. C (2021) 81:359)

Second operation with argon in 2021
(Eur. Phys. J. C (2023) 83:453)

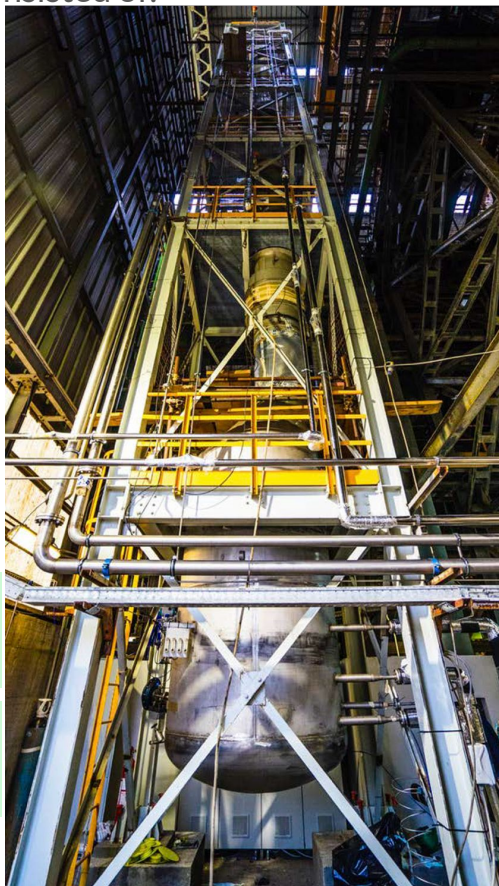
The Argon run was focused on performing an isotopic separation:



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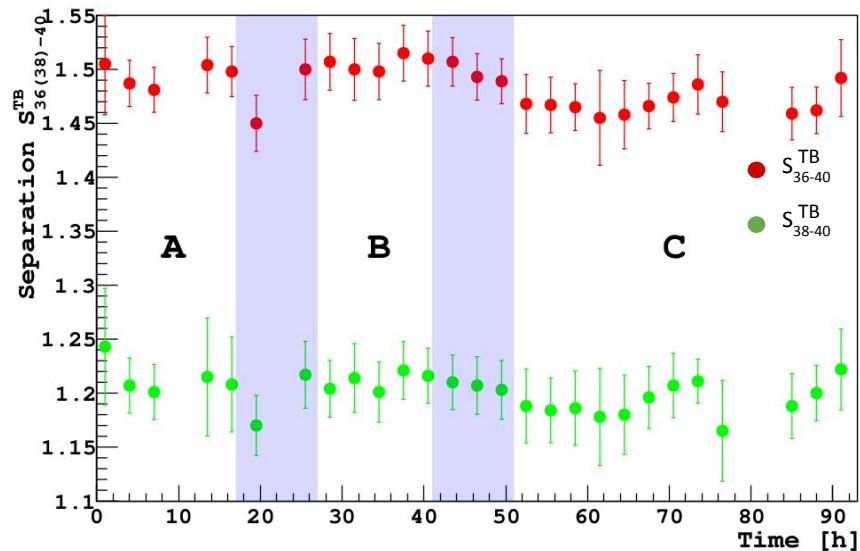


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(Eur. Phys. J. C (2023) 83:453)

The Argon run was focused on performing an isotopic separation:



Measured separation of Argon stable isotopes with time.

Current status of Aria:

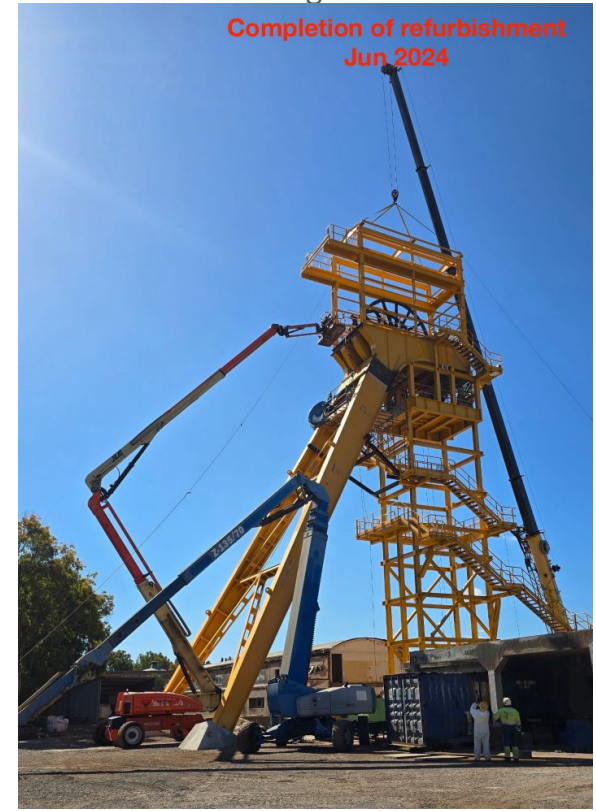
Installation of the support structure inside the shaft is ~ 25% completed. Resuming soon after a safety inspection..



Seruci-0 plans to run with $\text{Ar}+\text{O}_2$ and $\text{Ar}+\text{N}_2$ in trace mode to validate the plant performance for chemical distillation.



Refurbishment of the external mining castle is finished as of June, 2024



Lowering of the plant modules and installation starting end of Q1, 2025...

DArTinArDM Project



In order to assure the quality of UAr delivered, primarily regarding the content of ^{39}Ar , is essential for the operation of DS-20k.

DArT (Depleted Argon Target) refers to the small amount of Ar filled in a Cu vessel with an active mass of 1.35 kg.

- OFHC low radioactive vessel
- seen with eight 1 cm^2 radiopure SiPMs
- ESR reflectors
- Radiopure inner acrylic structure coated with TPB.

Need a dedicated setup to measure intrinsic activity of ^{39}Ar in UAr:

- concentration $\sim 10^{-19}\text{ g/g}$: beyond reach of ICP-MS
- pure beta emitter: no HPGe screening.

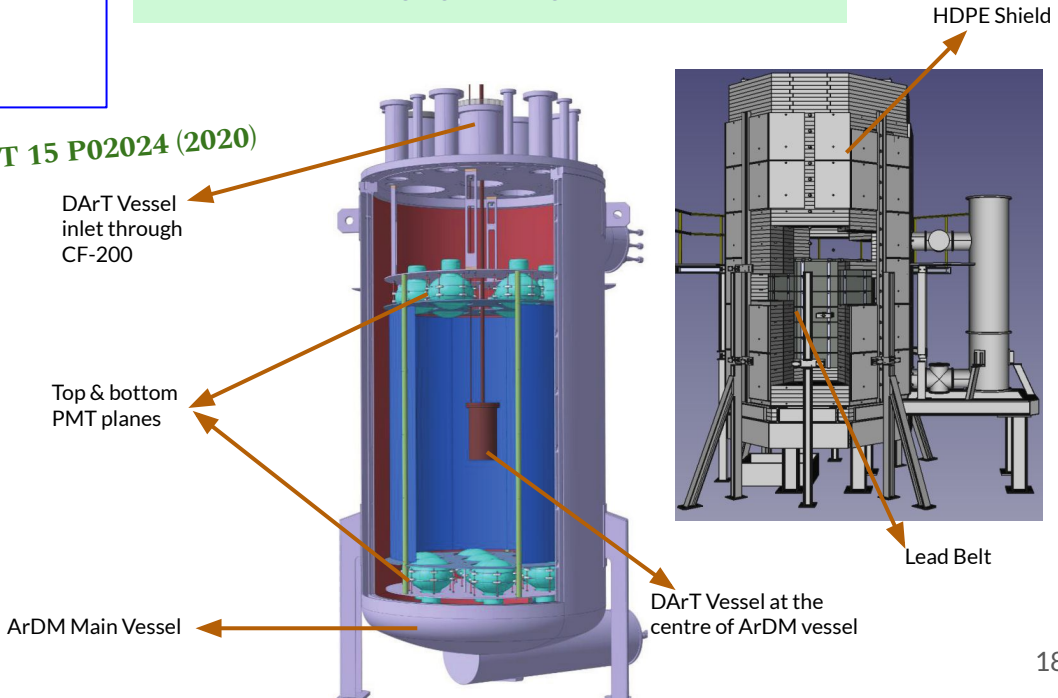
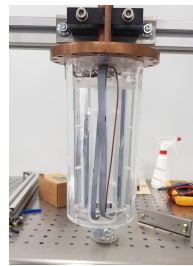
Need for dedicated low background setup.

Combination of passive shielding and active veto



Full description: JINST 15 P02024 (2020)

Projected Sensitivity:
< 1 mBq/kg with 10% statistical error in 1 week livetime

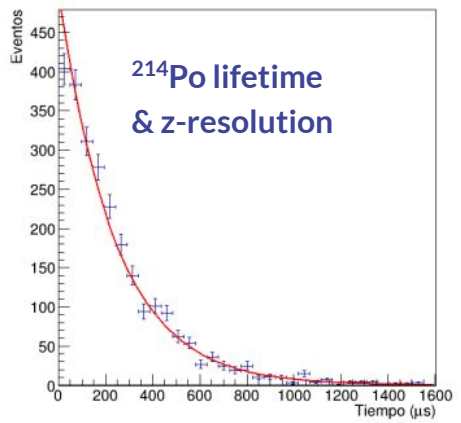
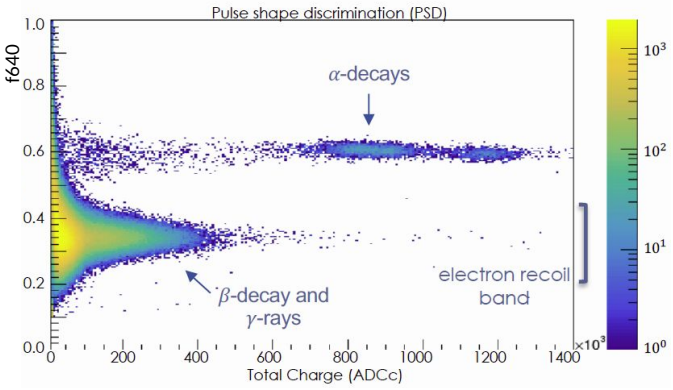
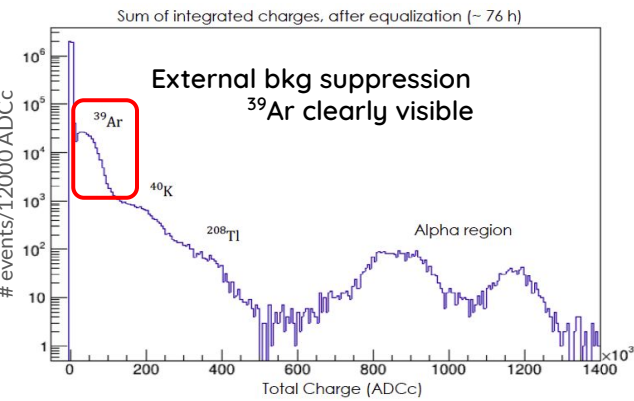
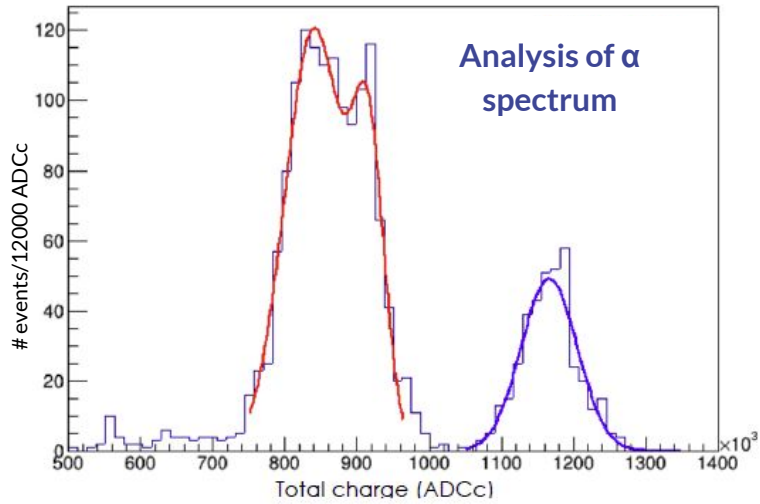


DArT in Test Setup

DArT has been running in a test setup Underground at LSC since 3 years.



Phase-1 of run was with first batch of SiPMs based on DS-20k photoelectronics design but tuned for DArT optical conditions.

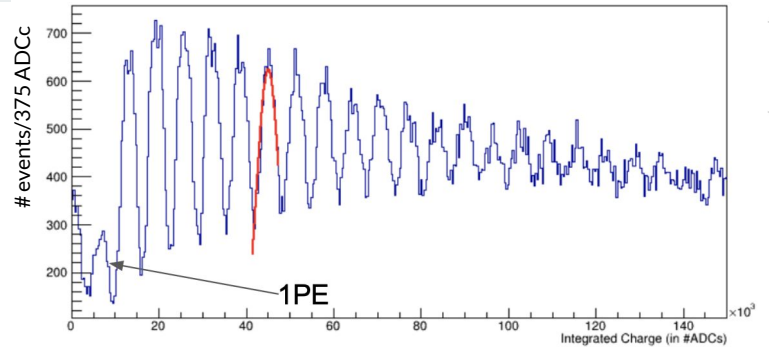


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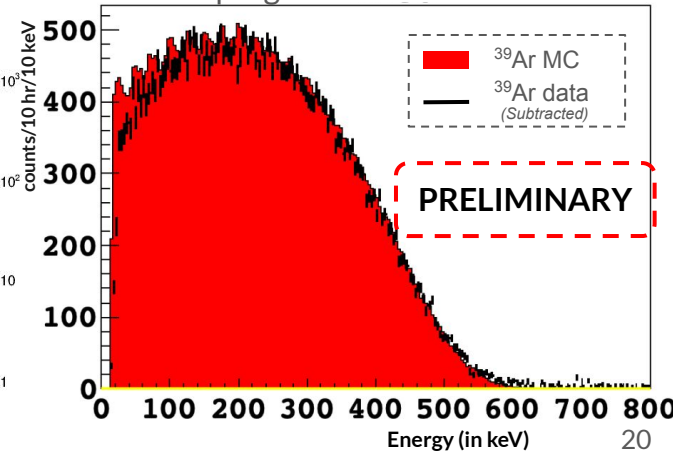
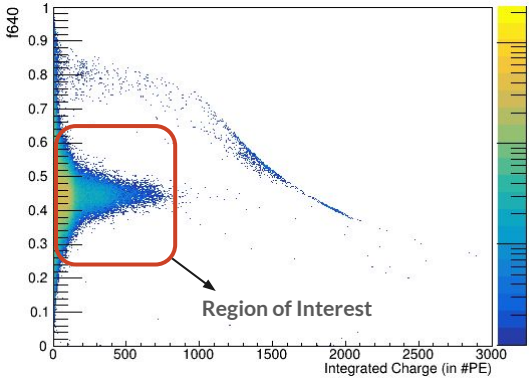
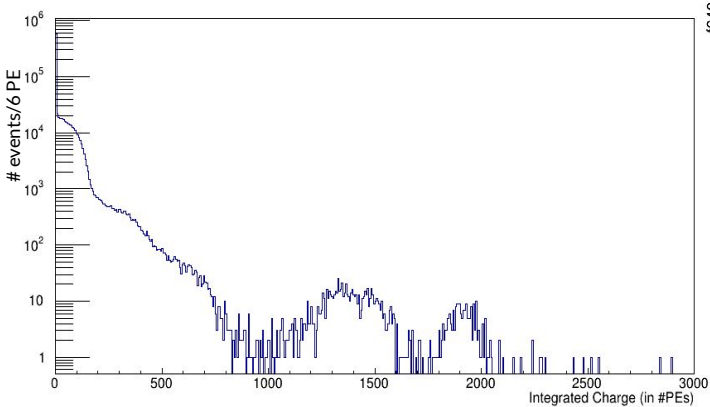


Phase-2 of run (till now) is with similar SiPMs but with improved performance in-terms of timing and response.

This setup was used to take data with AAr followed by UAr, in June.



Considering the UAr data as background only and analysis threshold of ~ 10 keV. A competitive measurement of ^{39}Ar specific activity in AAr is in progress.

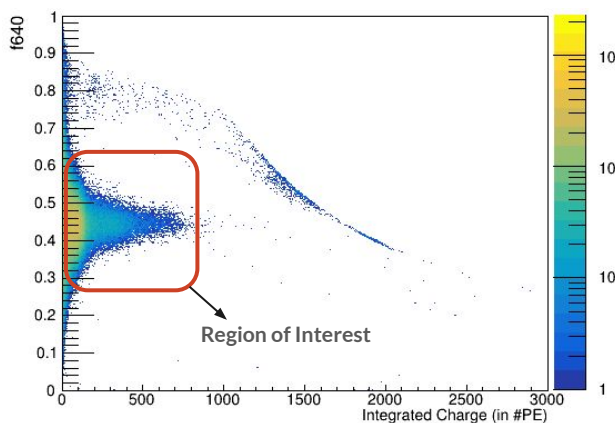
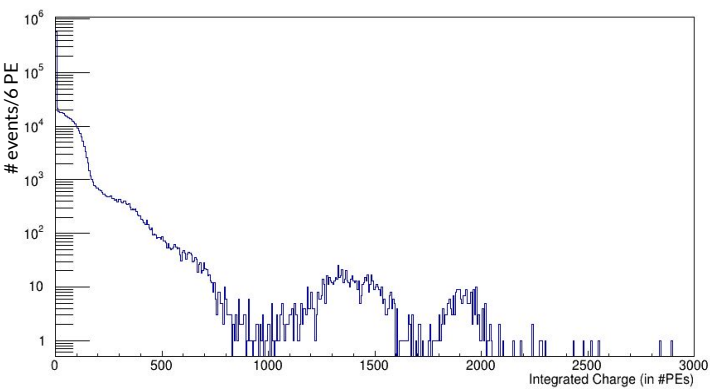
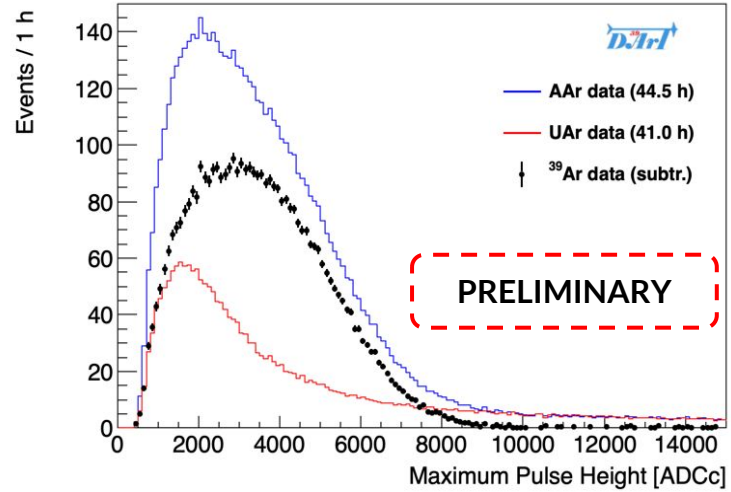


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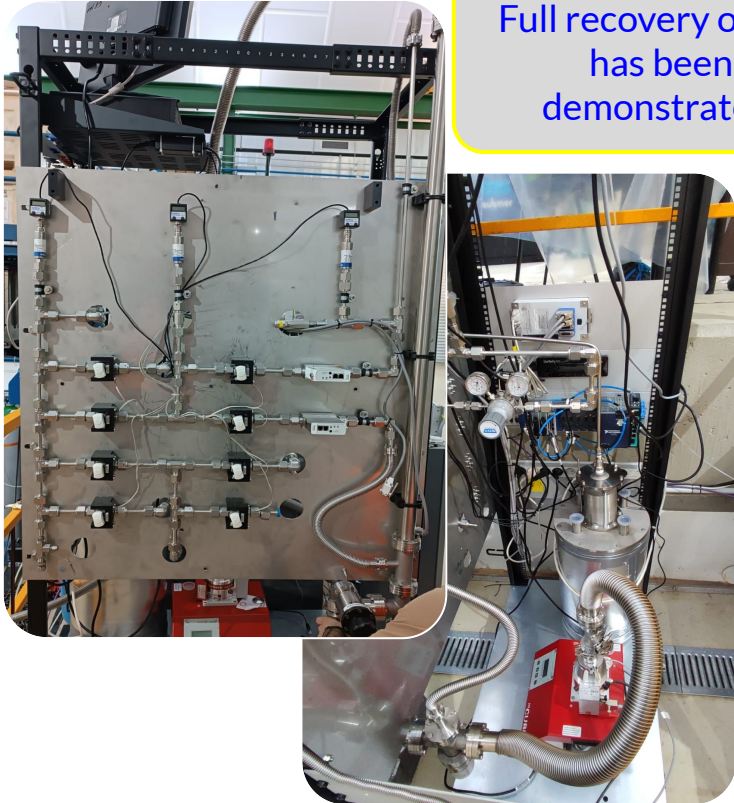
It has also been proved that unification of not-detector grade ^{39}Ar (like from Urania) is also possible using only prompt scintillation.

Current status of DArTinArDM:

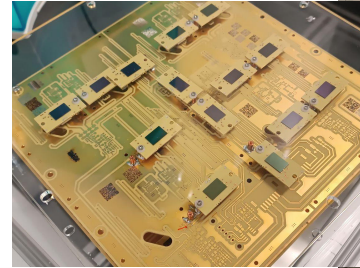


The designed gas system has been fully tested upto ~190 barg of pressure.

Full recovery of UAr has been demonstrated.



New batch of radiopure SiPMs received and characterized



ArDM is refurbished and all PMTs are fully functional.



Conclusion and Forward:



- Urania plant has been fabricated, leak tested and ready at Huston warehouse.
- The civil site is under preparation.
- The baseline for UAr transportation has been chosen to be done in liquid phase. Container design to be finalized.
- Aria prototype runs successful in proving the performance of the plant also extending to isotopic separation case.
- All required support structures (external and internal to the mine shaft) are in place.
- Final assembly of DArTinArDM is foreseen to start in September, 24.
- Full phase commissioning before the end of the year.

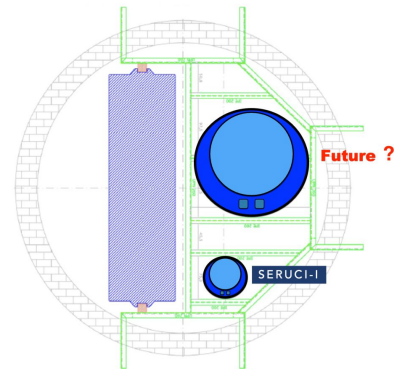
First batch of UAr from Urania to DArT may be in end-Q1, 2025

First batch of UAr from Urania to Aria expected in 2nd Half, 2025.

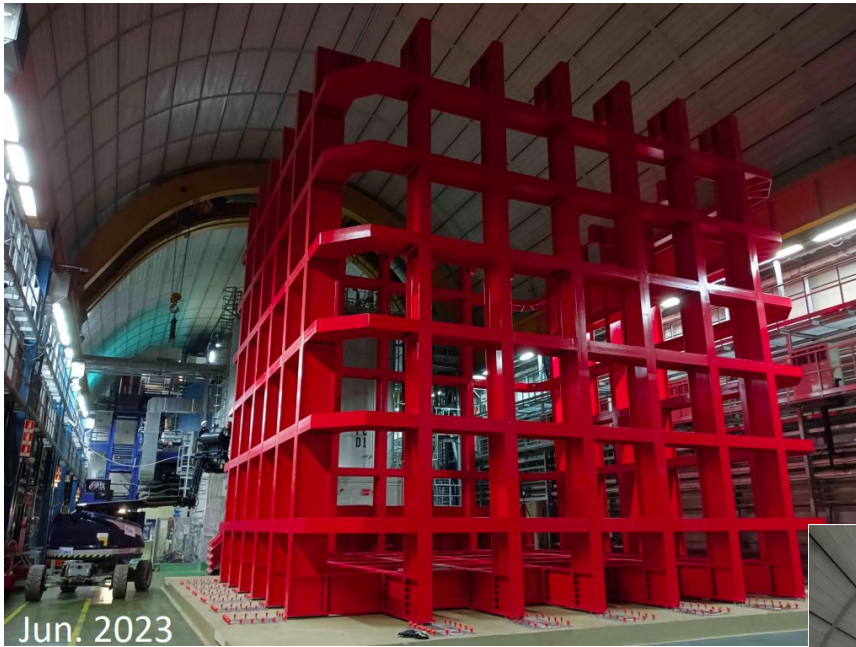
Interests from Global rare event search community:

- LEGEND-1000 (for $0\nu\beta\beta$ search) \Rightarrow 25 tonnes of UAr to be used in active veto volume. [\[MoU signed with GADMC\]](#)
 \rightarrow *Suppression of ^{42}Ar*
- COHERENT (for CEvNS) \Rightarrow 1 tonne for the active volume.
- ARGO (dark matter) \Rightarrow 400t [Next step of GADMC]
- DUNE MoO (Dark matter, SNv, $2\beta 0\nu$) \Rightarrow O(10,000) t

MoO Workshop 2022 (https://congresos.adeituv.es/dune_science/)



The voyage has begun....



Jun. 2023



June, 2024



Feb. 2024





Thank You for Your Attention

Backup

Process Flow Diagram of Urania:

