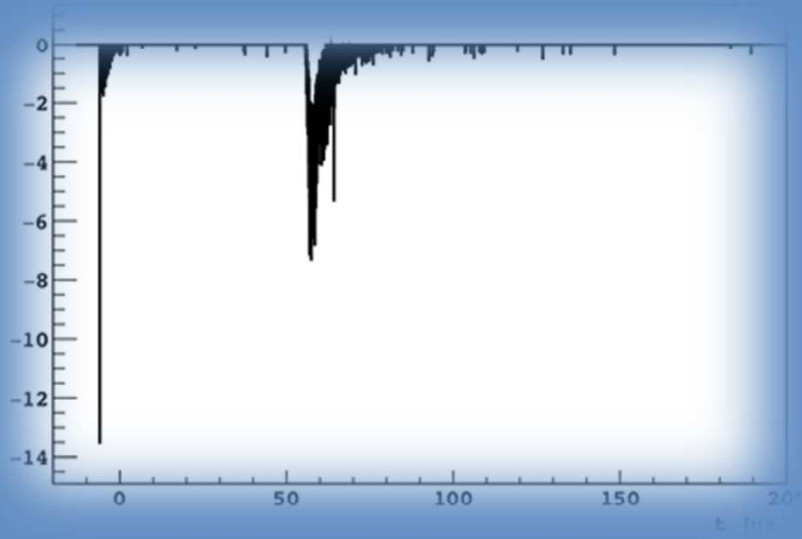
Low radioactivity Argon for the DarkSide-20k experiment



Roberto Santorelli

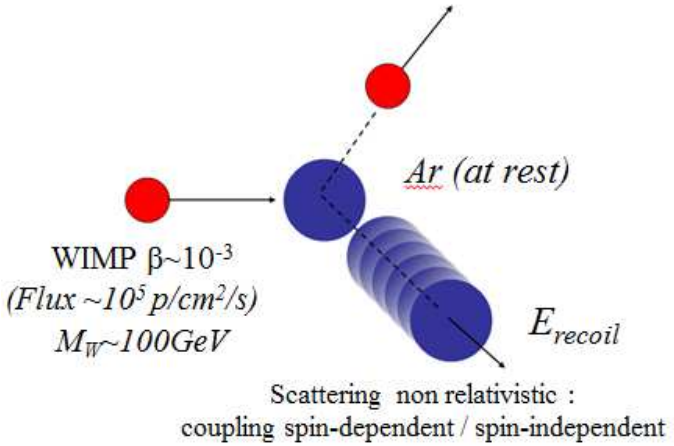
CIEMAT – Madrid

TIPP 2021– Virtual conference 25/May/2021

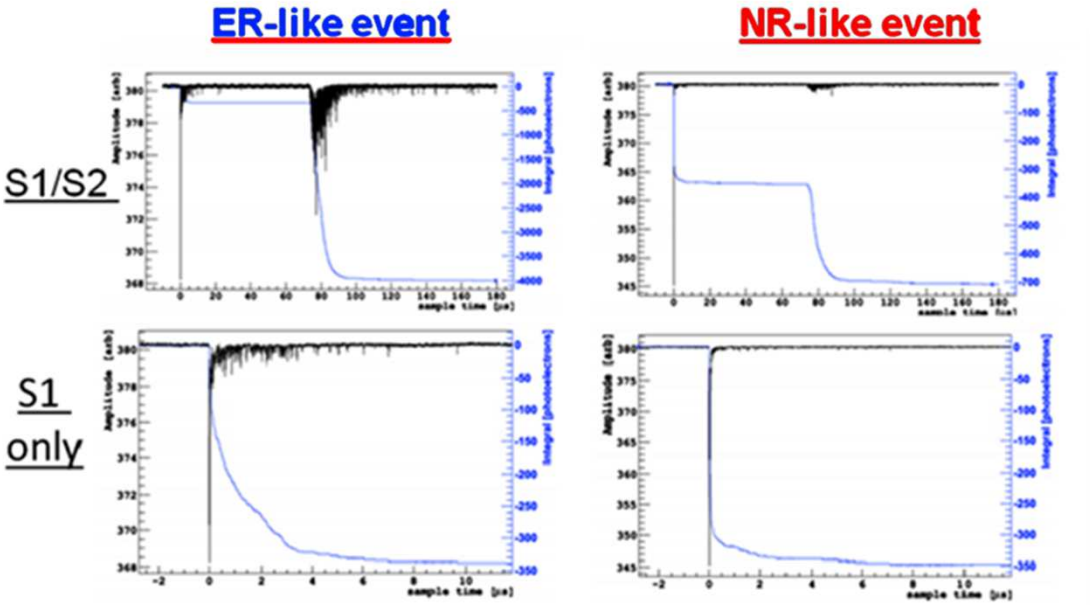
Outline

- LAr for Dark Matter direct searches, recent achievements and the Global Argon Dark Matter Community
- Ar-39 in atmospheric Ar and radiopure underground Ar
- DArT experiment @ LSC
- Prospects and conclusions

LAr: Dream technology

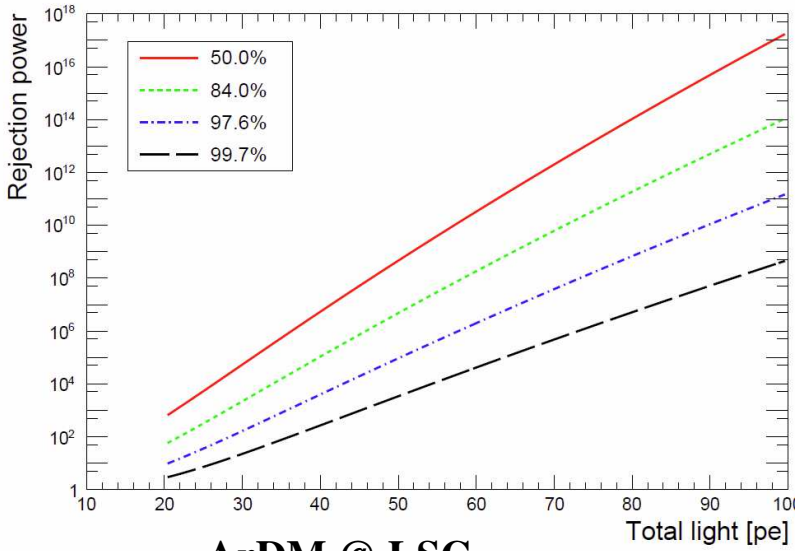


- Large Exposure (Mass × Time) : ~100s tonne×year
- Low Energy Threshold : ~10 keV
- Event topology : alpha, muon..
- Low Background Rate : <0.1 evt in the exposure
- Discrimination between Signal and Bkg: > 10^8



$$\left.\frac{S_2}{S_1}\right|_{ER} > \left.\frac{S_2}{S_1}\right|_{NR}$$

Due to an enhancement of the recombination process

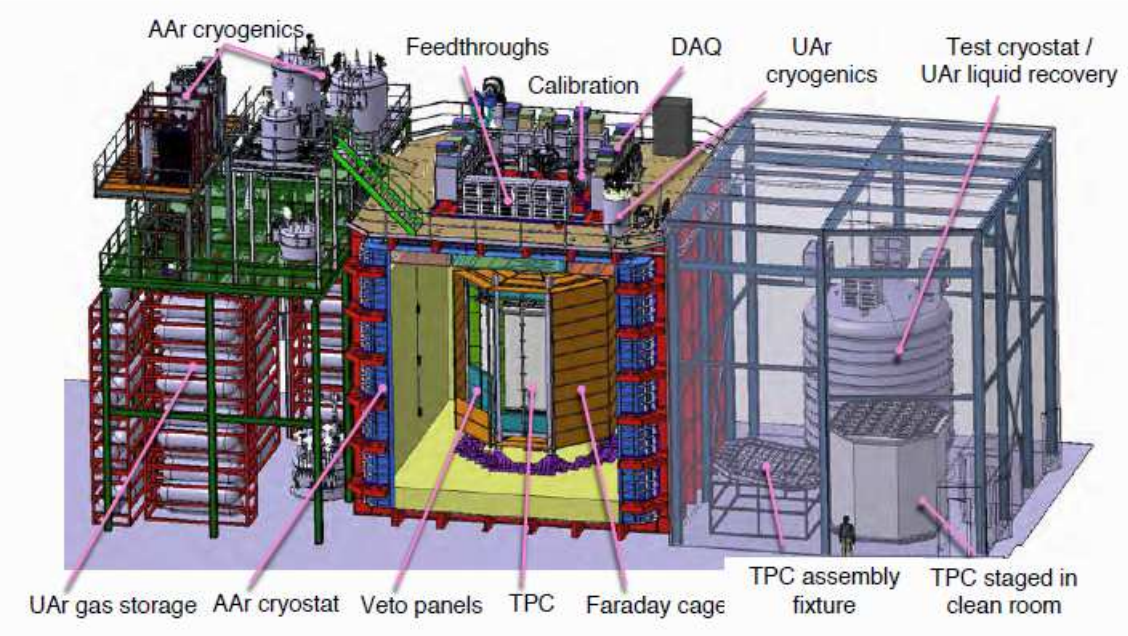


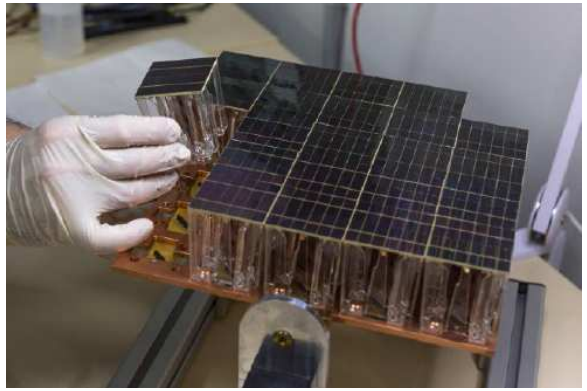
ArDM @ LSC
JCAP 12 (2018) 011

Towards 200 t·yr: GADMC

- There is a remarkable and unique opportunity of having large exposures (~200 t·yr) in background free mode with an argon TPC
- The dual-phase LAr-TPC is able to exceed the current experimental limits, reaching the neutrino floor
- ***GADMC***: New collaboration with groups from DS-50, ArDM, DEAP-3600 and MiniCLEAN.

DS-20k @ LNGS





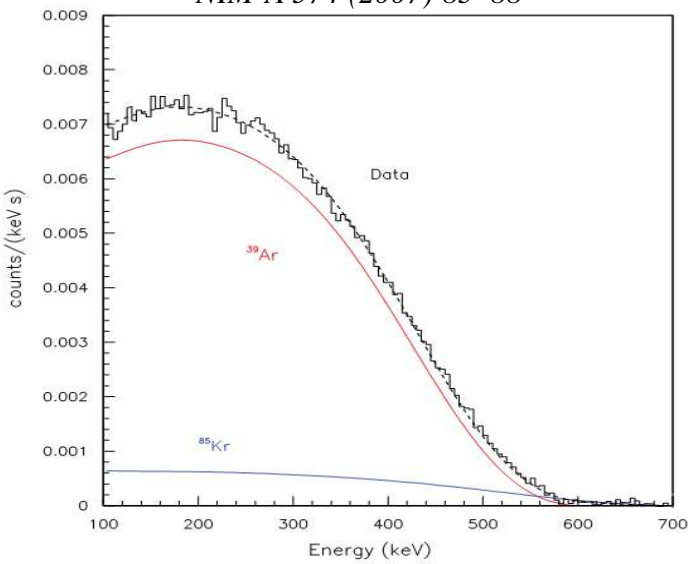
- Large mass
- New sensors
- ***Extreme radiopurity***

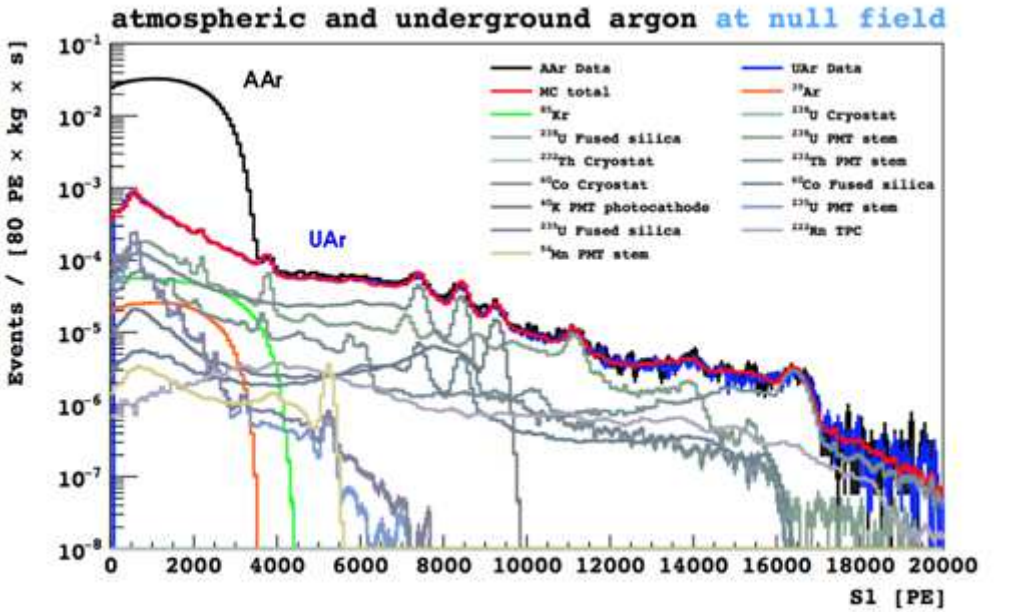
More in Emilija Pantic's talk (later today)

^{39}Ar in AAr

- β-emitter with 565 keV endpoint (cosmogenic, ~17 mBq/m^3 in atmosphere)
- $T_{1/2}$=269 y
- Pure beta emitter, no accompanying gamma radiation
- Present in relatively abundant quantities in AAr due to the production process

"Measurement of the specific activity of Ar-39 in natural Argon"
NIM-A 574 (2007) 83–88





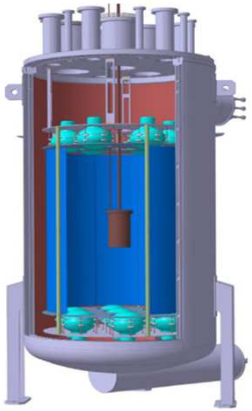
1.01 ± 0.02(stat) ± 0.08(syst) Bq/kg of ^{nat}Ar
(isotopic abundance ~ 8×10^{-16} in mass)

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

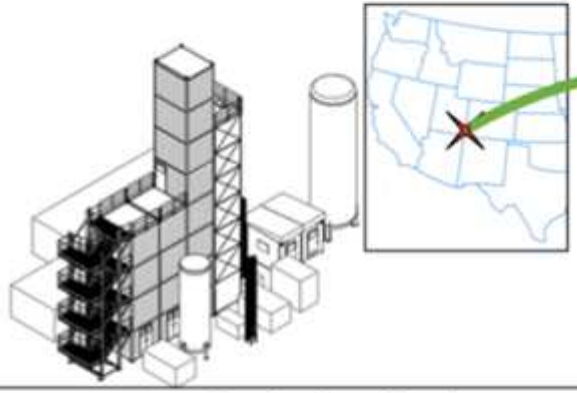
Pileup problems in multi-ton TPCs!!!

Extraction – Purification – Measurement

International effort underway to procure radiopure argon extracted from underground reservoirs



Characterisation: DArT
Measurement of the ^{39}Ar depletion factor



UAr transported via boat for final purification at Aria

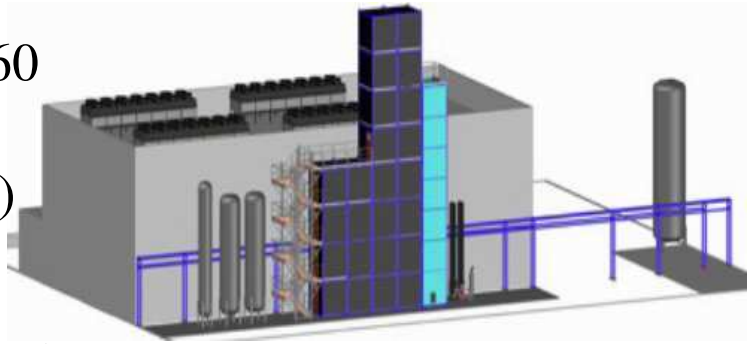
Production: Urania
- Commercial-scale plant to extract UAr
- Located in Southwestern Colorado
- UAr extracted from CO_2 well gas at the tonne scale

100 tonne/year

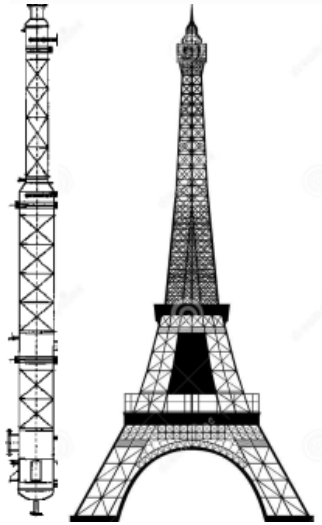
Purification: Aria
- 350 m tall cryogenic distillation column to purify UAr and isotopically separate argon and other elements
- Located in refurbished carbon mine shaft in Sardinia, Italy
- Will chemically purify the UAr for DS-20k to detector grade

Extraction and purification

- **URANIA** project: Procurement of more than 60 tonnes of UAr extracted from the CO_2 wells in Cortez mine, Colorado (~330 kg/d, 99.99% purity)



- **ARIA** project: Ar chemical purification and isotopic separation by cryogenic distillation



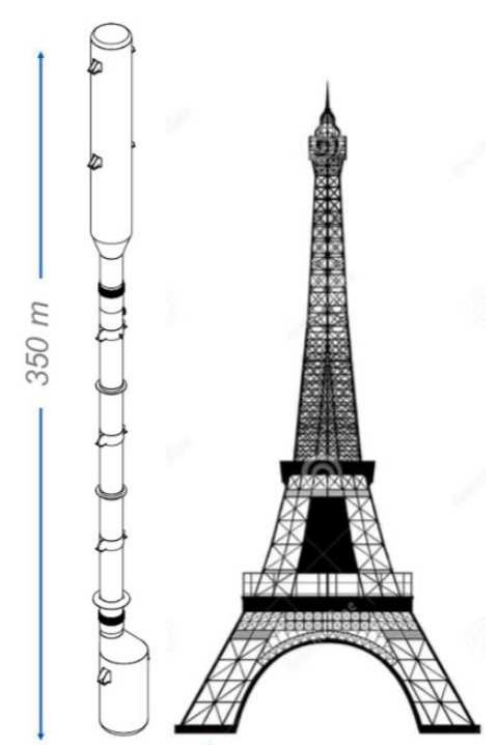
- 350 m height, 31.8 cm inner cryogenic distillation column (Sardinia, Italy)
- The tallest ever built of this type
- Designed to reduce the isotopic abundance of Ar-39 in UAr by another factor of 10 per pass
- Production rate with ARIA in chemical purification mode (DarkSide-20k): ~1ton/day
- Production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

- Medical applications (isotope supply)

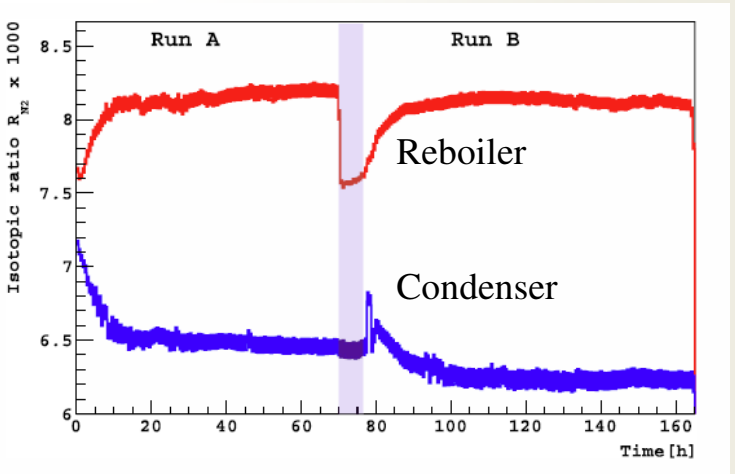
ARIA

- 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

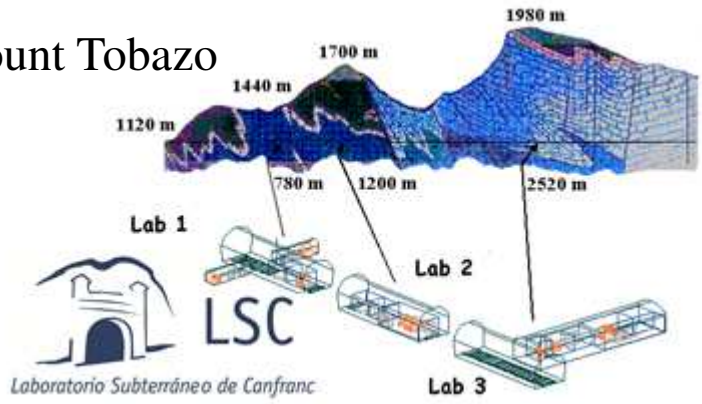


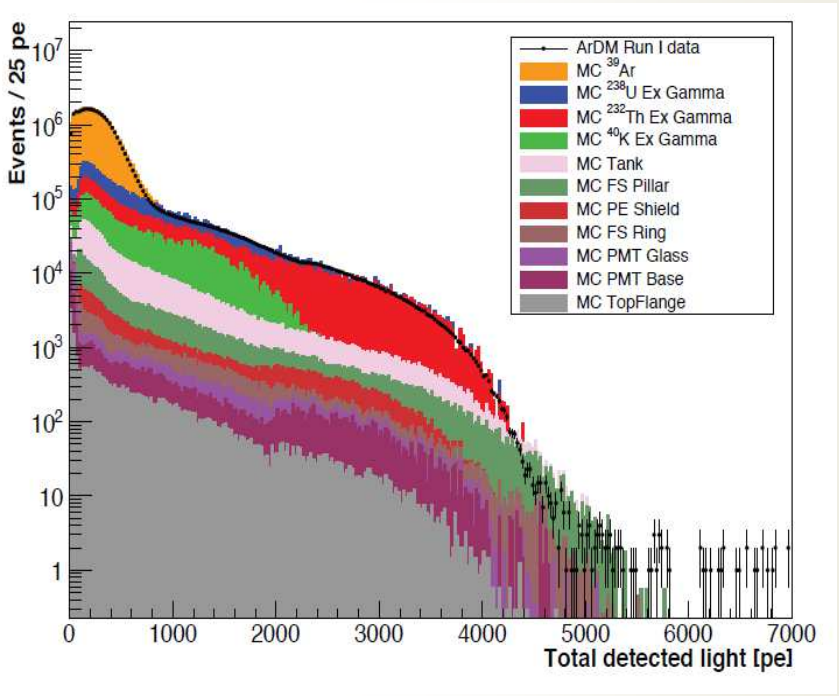
Eur.Phys.J.C 81 (2021) 4, 359

UAr radiopurity measurement: DArT in ArDM @LSC

ArDM
- Double-phase EL-TPC
- 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

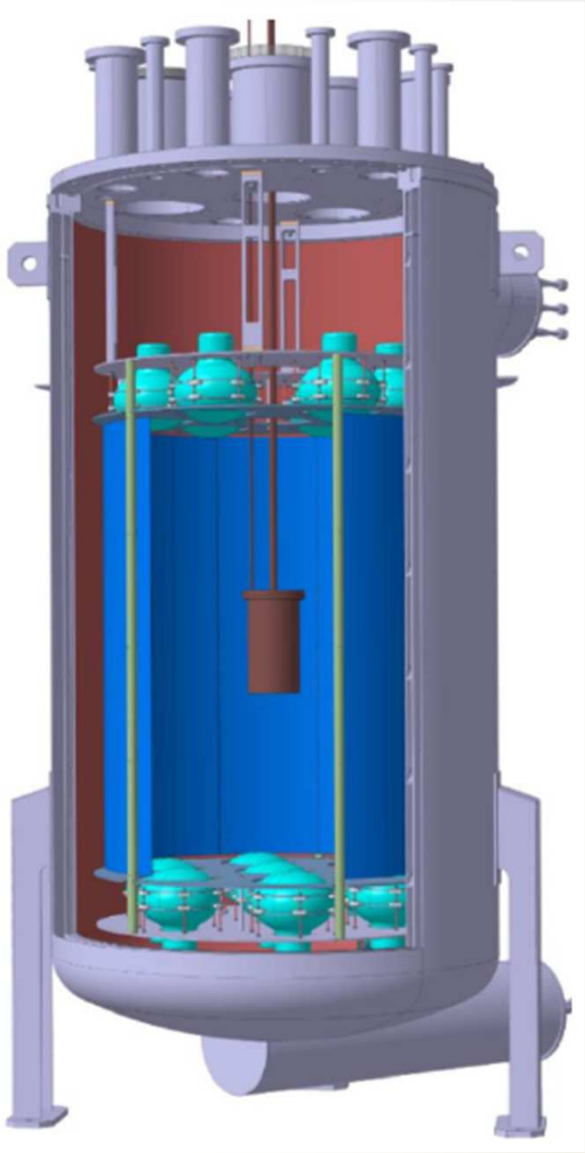
Main Lab under mount Tobazo
- ~850 m rock
- ~2500 mwe
- 1400 m^2





Ar-39: the dominant background (0.95±0.05 Bq/kg)
JCAP 2017.03 (2017)

UAr radiopurity measurement: DArT in ArDM @LSC



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- 850 kg active volume (≈2 t total)
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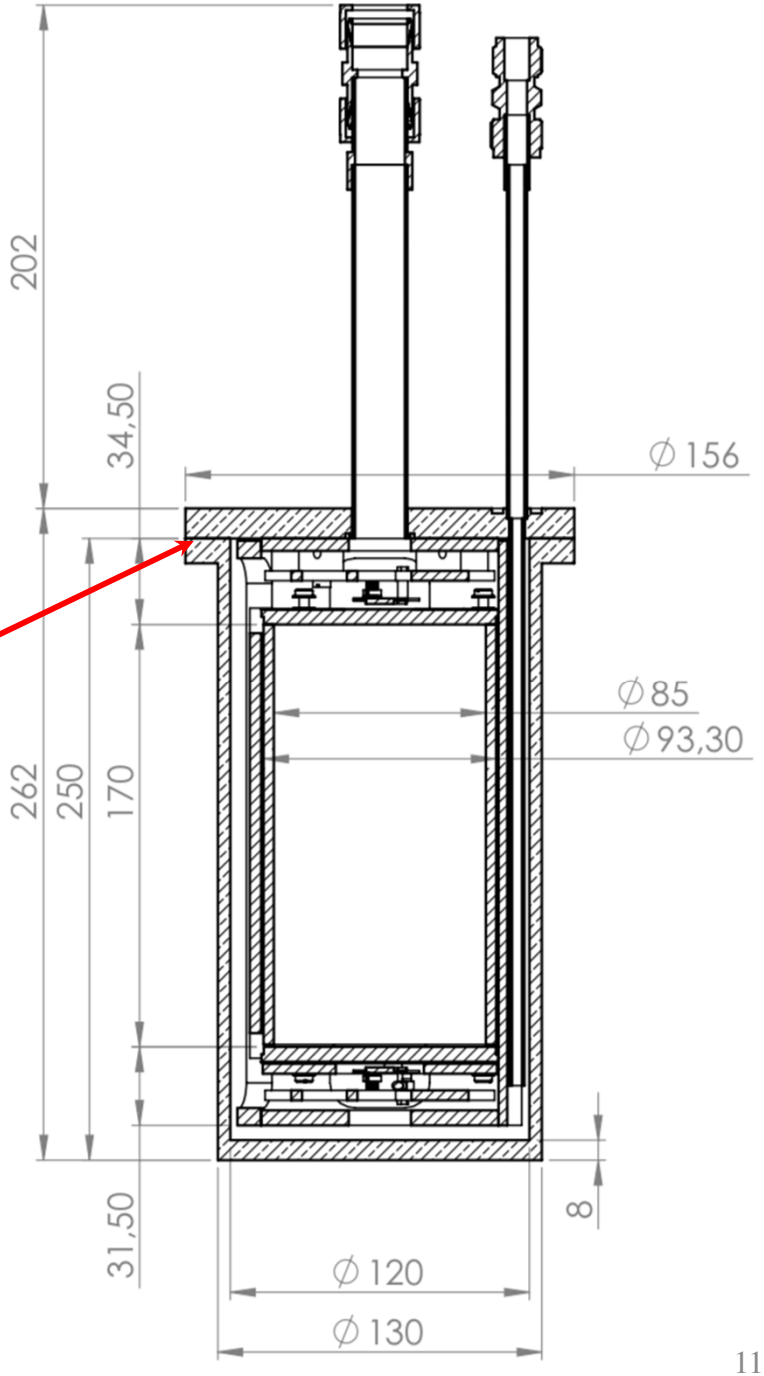
DArT design

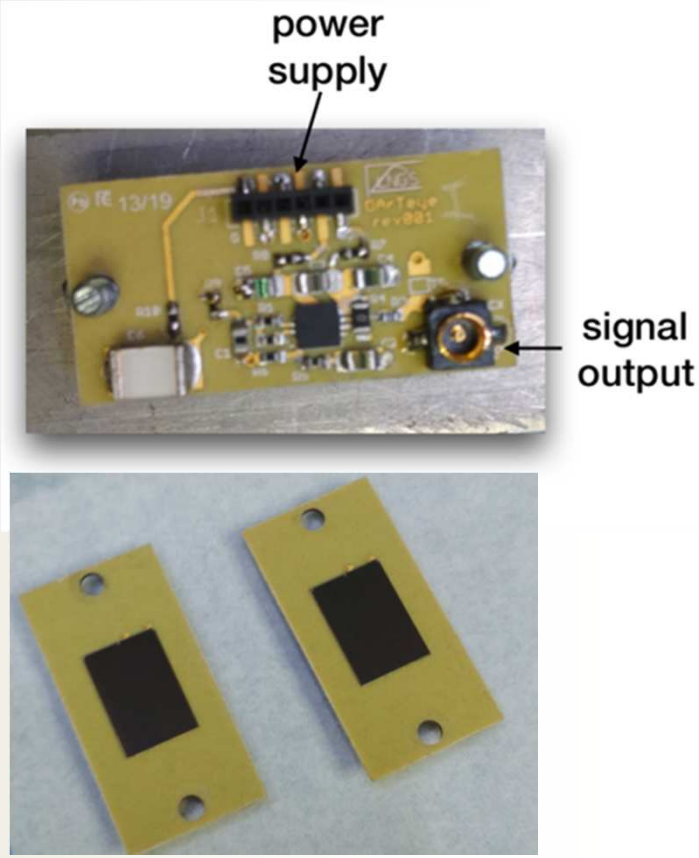
- OFHC copper vessel with two top pipes. Total weight → 7 kg and volume → 3 L.

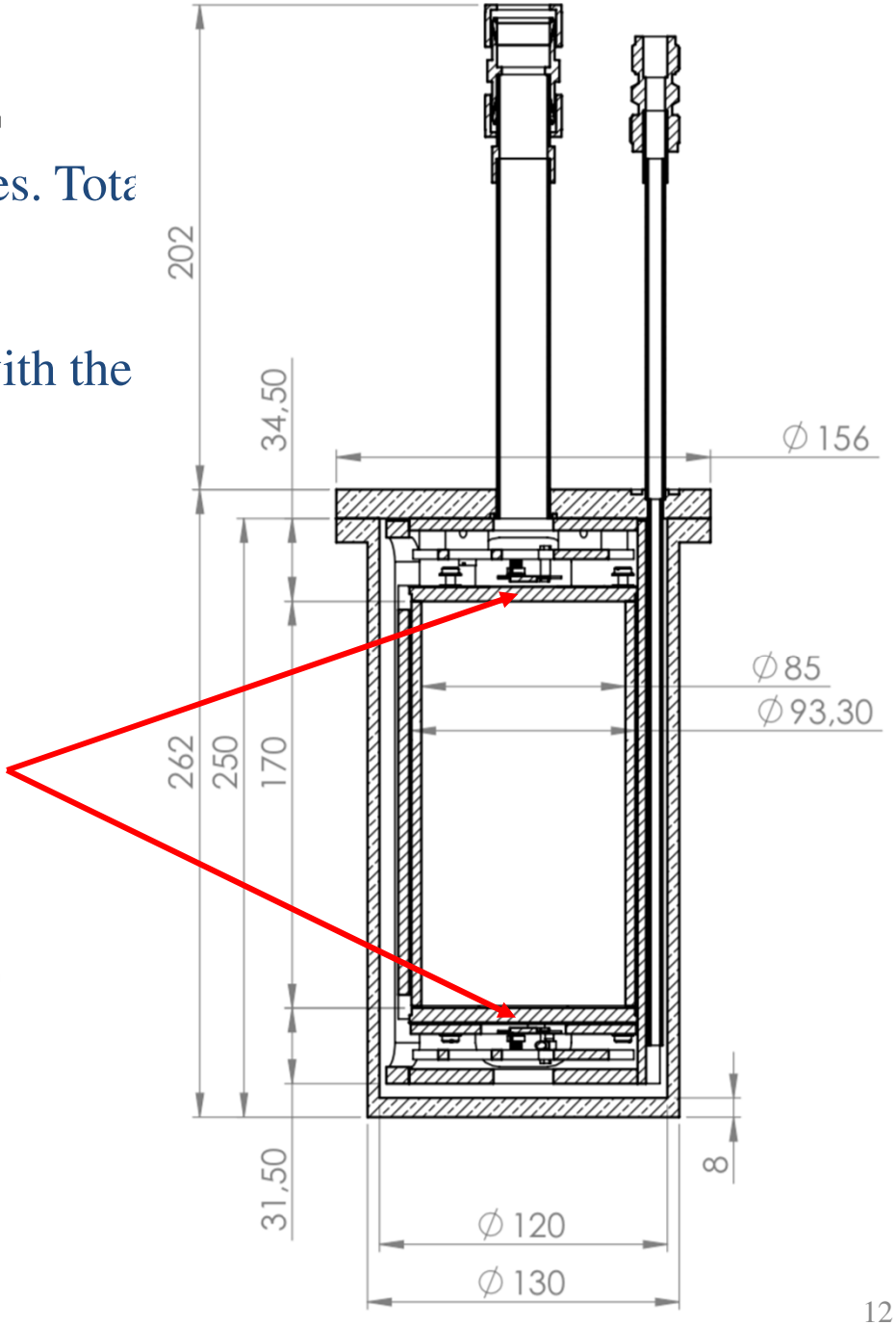


DArT design

- OFHC copper vessel with two top pipes. Tota weight → 7 kg and volume → 3 L.

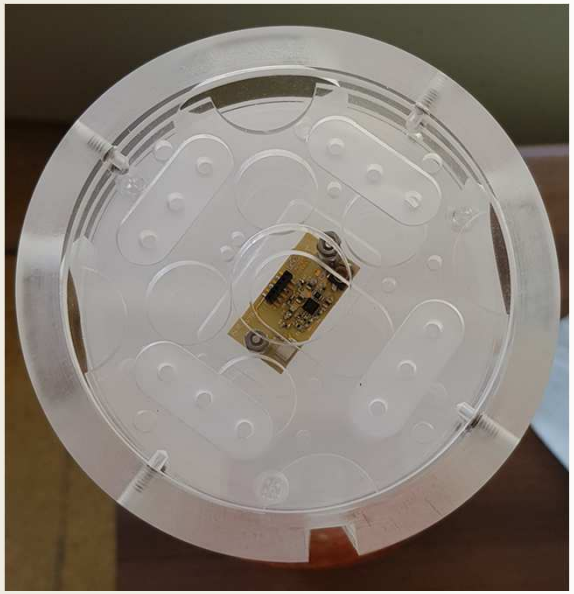
- Two 1 cm^2 SiPMs at top and bottom with the electronics integrated.

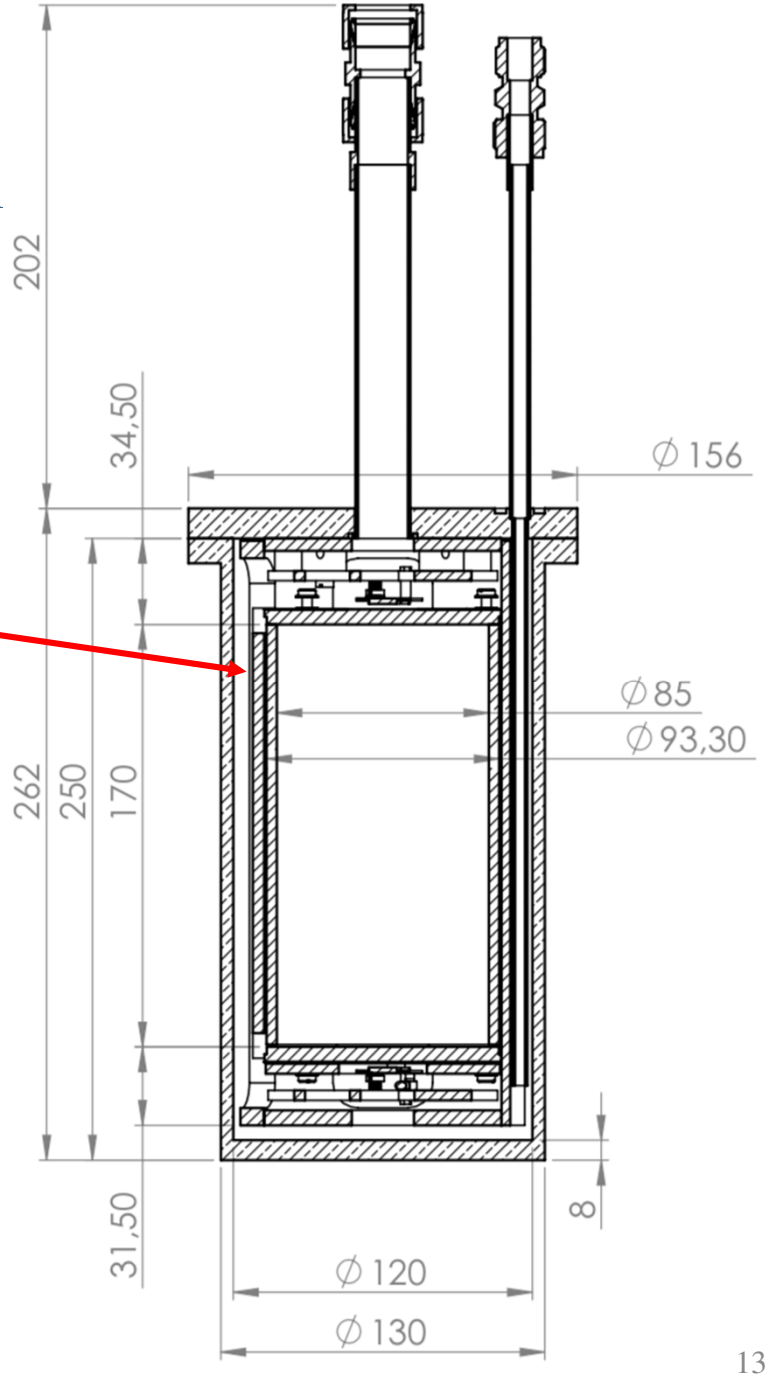




DArT design

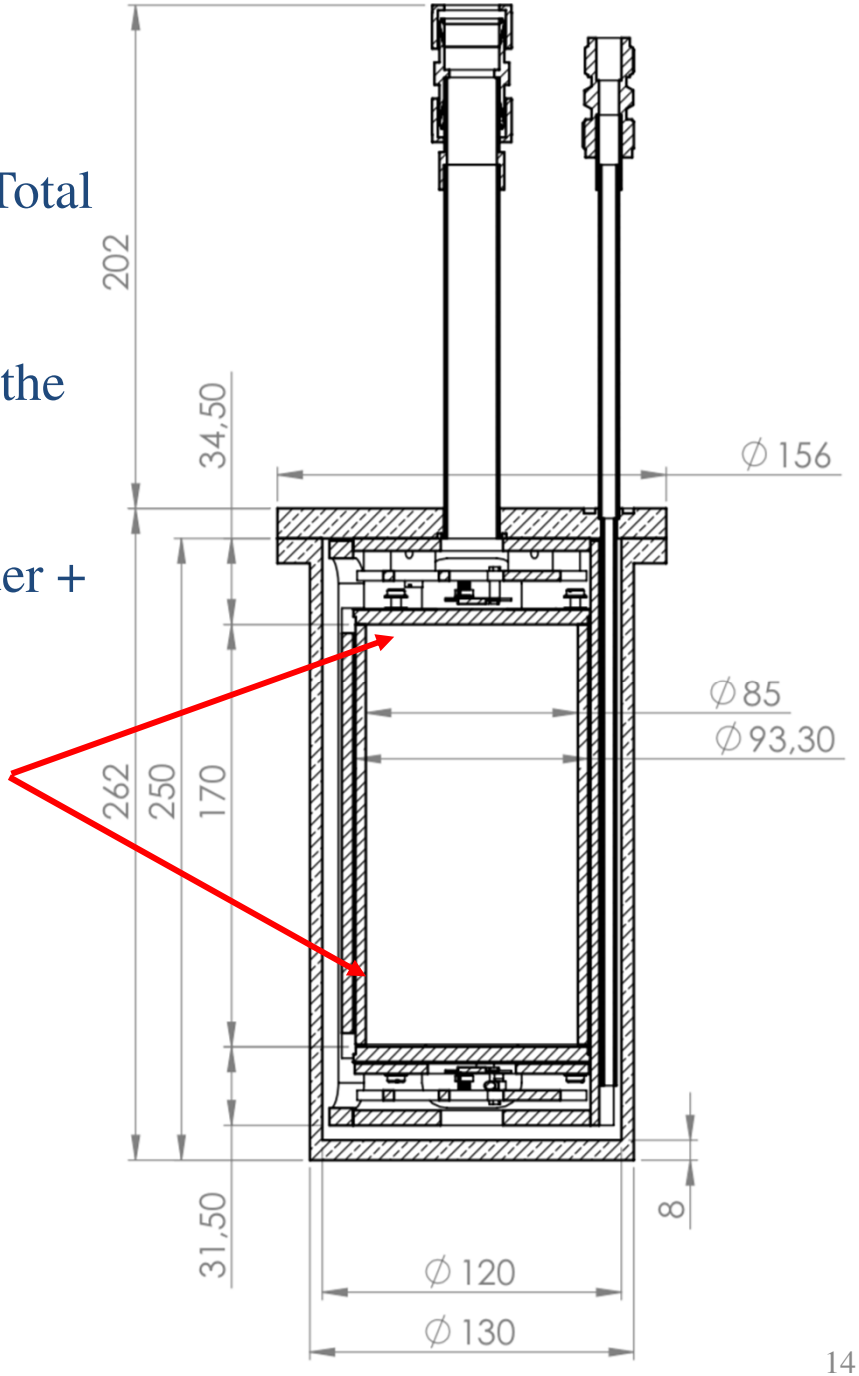
- OFHC copper vessel with two top pipes. Total weight → 7 kg and volume → 3 L.
- Two 1 cm^2 SiPMs at top and bottom with the electronics integrated.
- External acrylic support structure Cylinder + two SiPM supports.





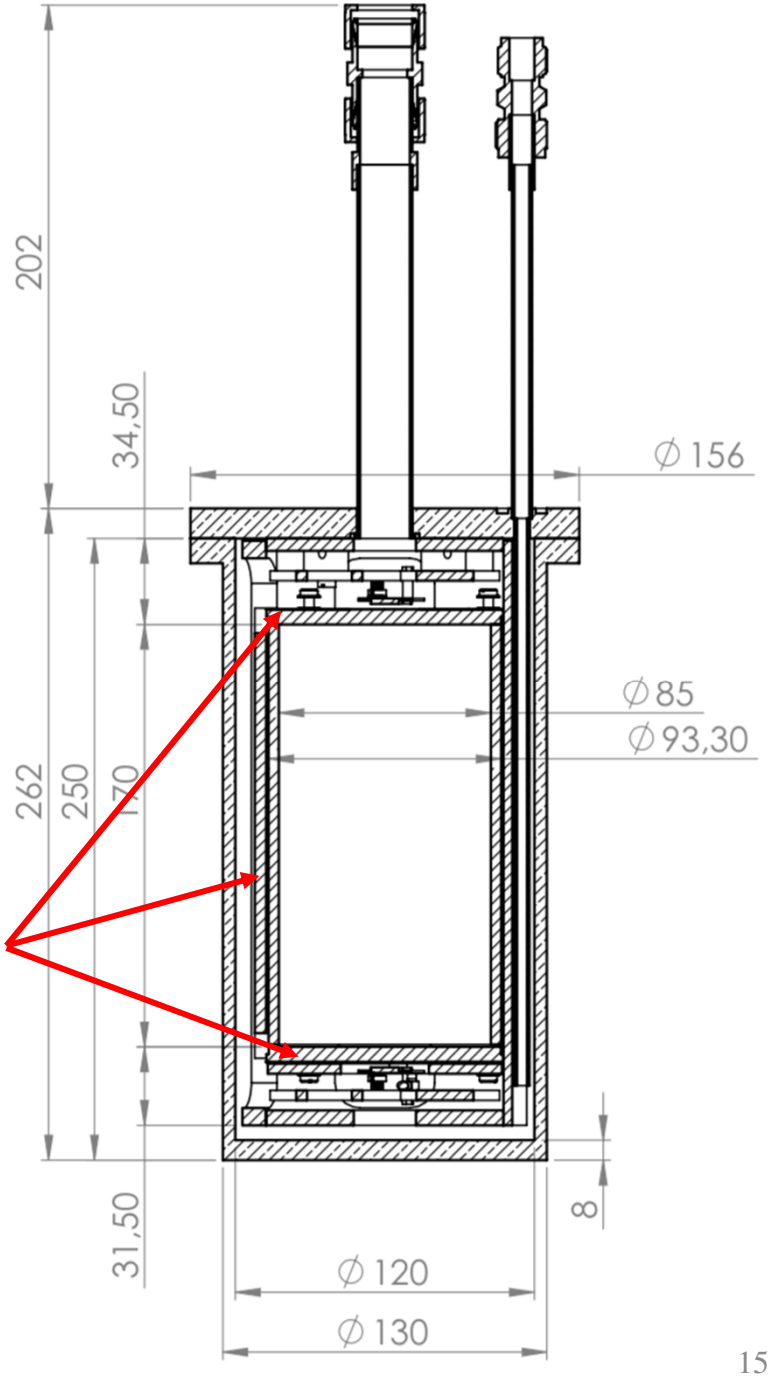
DArT design

- OFHC copper vessel with two top pipes. Total weight → 7 kg and volume → 3 L.
- Two 1 cm^2 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 µg/cm^2).



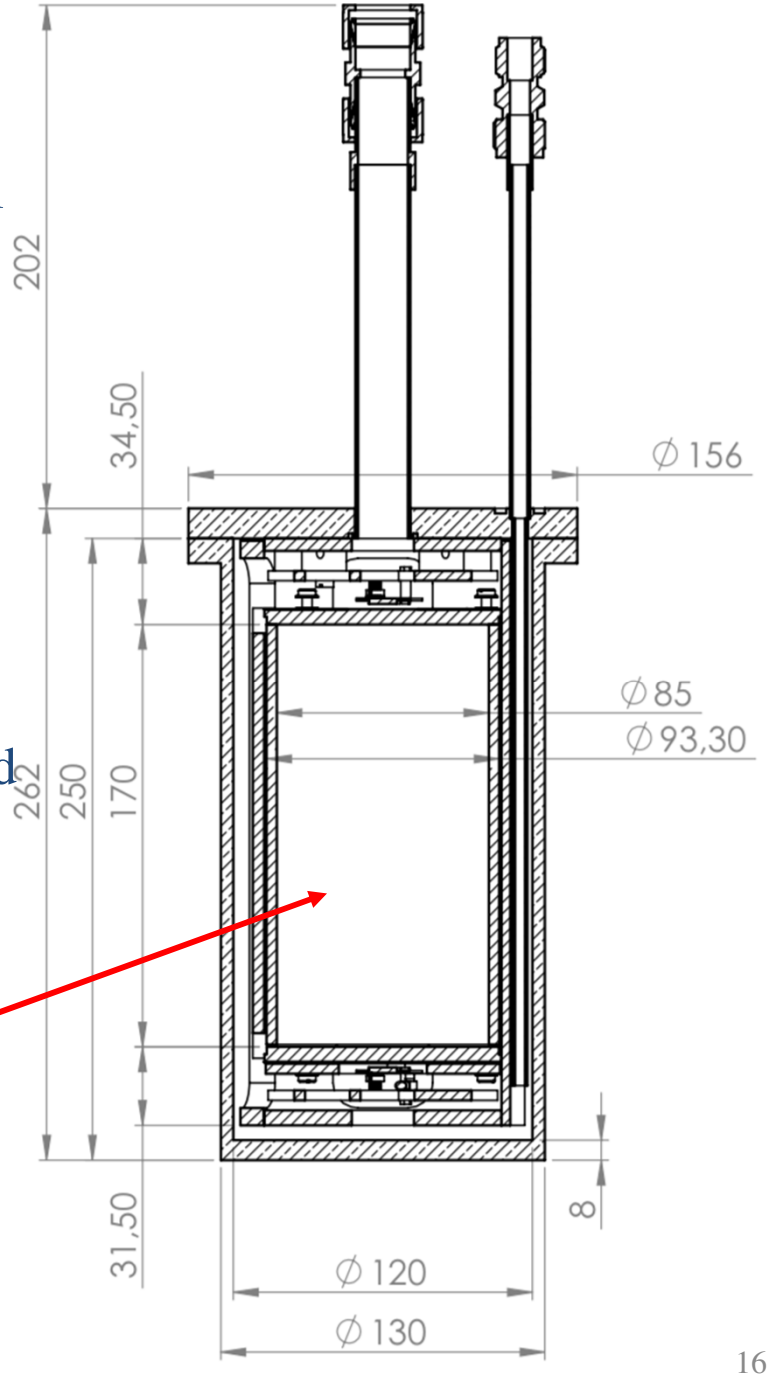
DArT design

- Reflector around SiPMs and between acrylic cylinders.

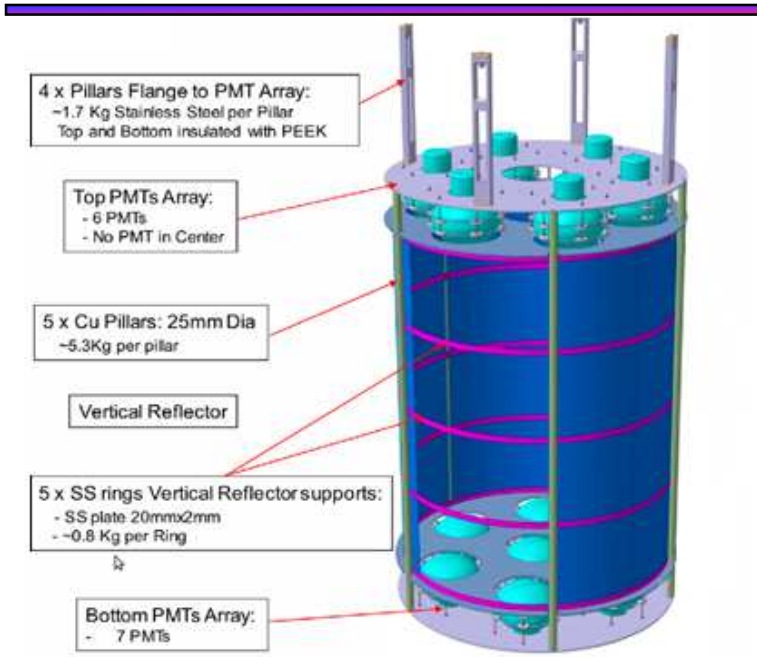


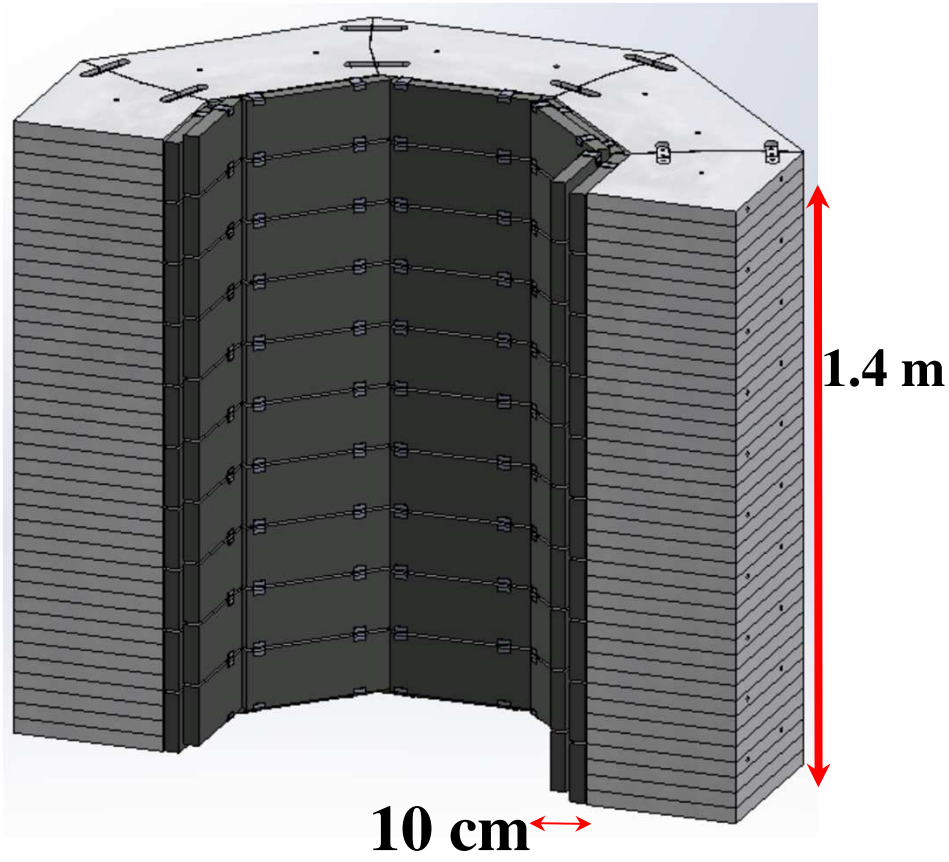
DArT design

- OFHC copper vessel with two top pipes. Total weight → 7 kg and volume → 3 L.
- Two 1 cm^2 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 $\mu g/cm^2$).
- Reflector around SiPMs and between acrylic cylinders.
- Active volume of 1.4 kg.
  620 evt/week for UAr (0.73 mBq/kg).



Active veto and passive shield

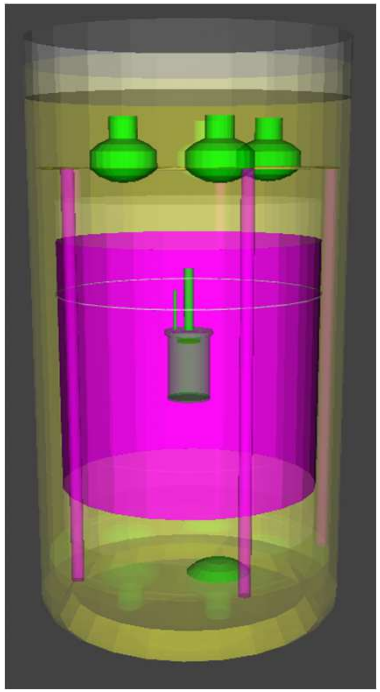




- External polyethylene shielding (20 t)
- Inner Pb shielding (6.5 t)

Background model

Untagged: E_{ArDM} < 10 keV (veto)
ROI: 1 < E_{DArT} < 600 keV



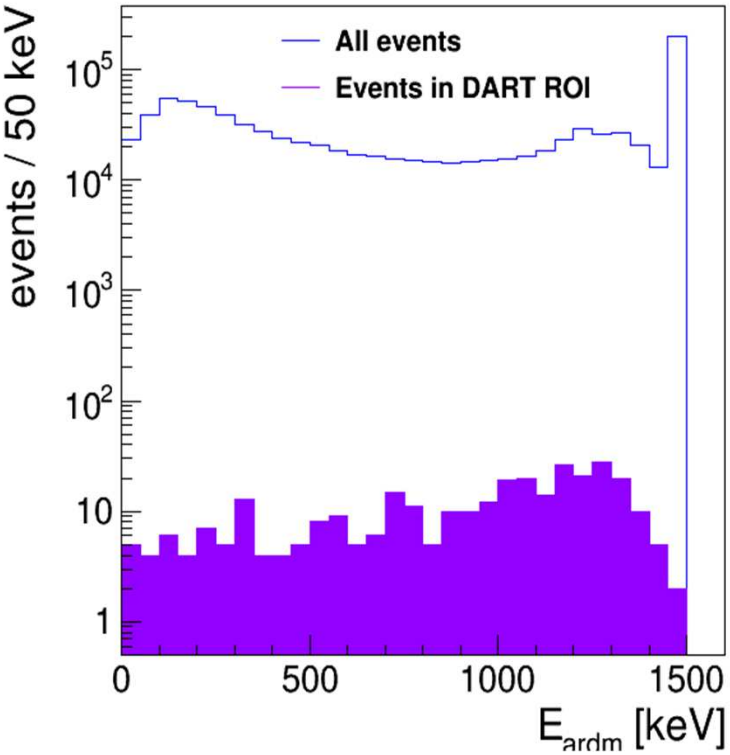
Background source	Evts/week ROI	Untagged Evts/week ROI
ArDM Cryostat	3164.4	218.3
ArDM PMTs	1053.0	42.8
ArDM supp. structure	28.5	0.6
Lead Belt	150.5	16.2
DArT vessel	16.6	5.4
Arlon SiPM	40.9	23.5
Acrylic	9.1	4.1
External without Pb	117623.0	10020.5
Total without Pb	122098.9	10301.7
External with Pb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

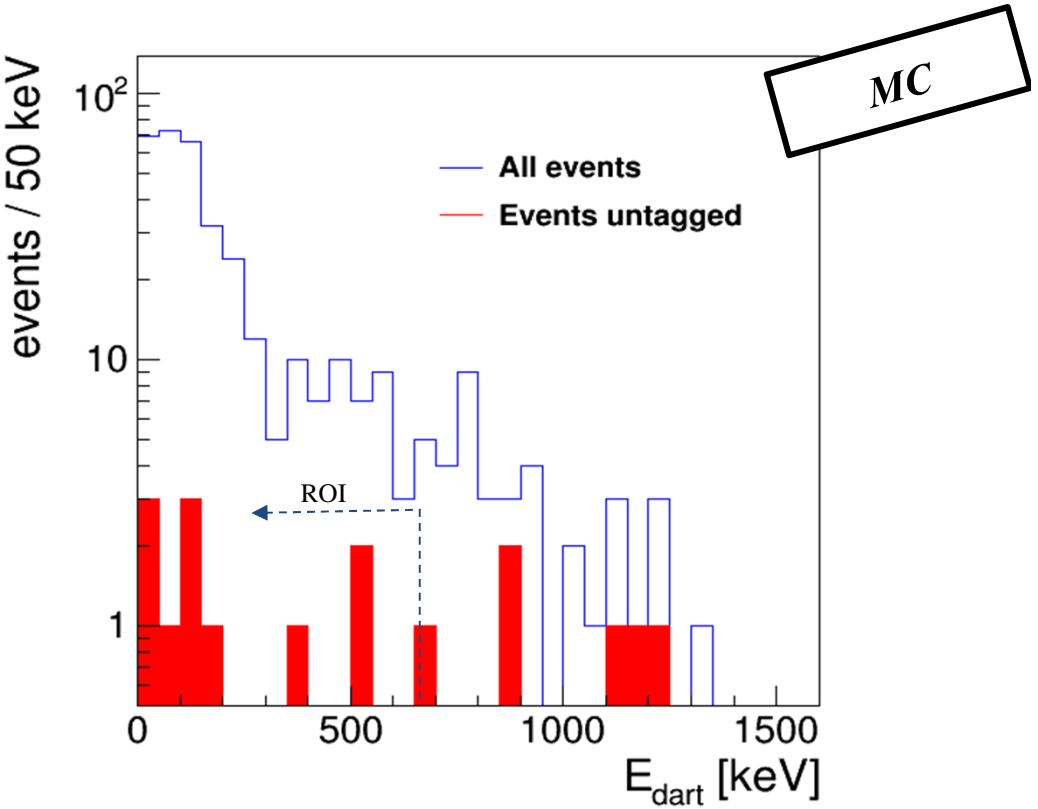
Signal expected 620 evt/week → S/B > 1 for UAr

Signal and background in DArT

ROI: $1 < E_{dart} < 600$ keV **Untagged evts: $E_{ardm} < 10$ keV (veto)**

Cryostat ^{40}K: events in **ArDM 909200**, events in **DART ROI 324**, **Untagged 11**





- Expected number of ^{39}Ar events in 1 week:
  - ~4×10^8 in ArDM (610 Hz from AAr)
  - ~620 in DArT (1 ℓ) - UAr, 0.73 mBq/kg (from DS-50)
  - ~85 in DArT (1 ℓ) - UAr, 0.10 mBq/kg (depletion factor 10^4)

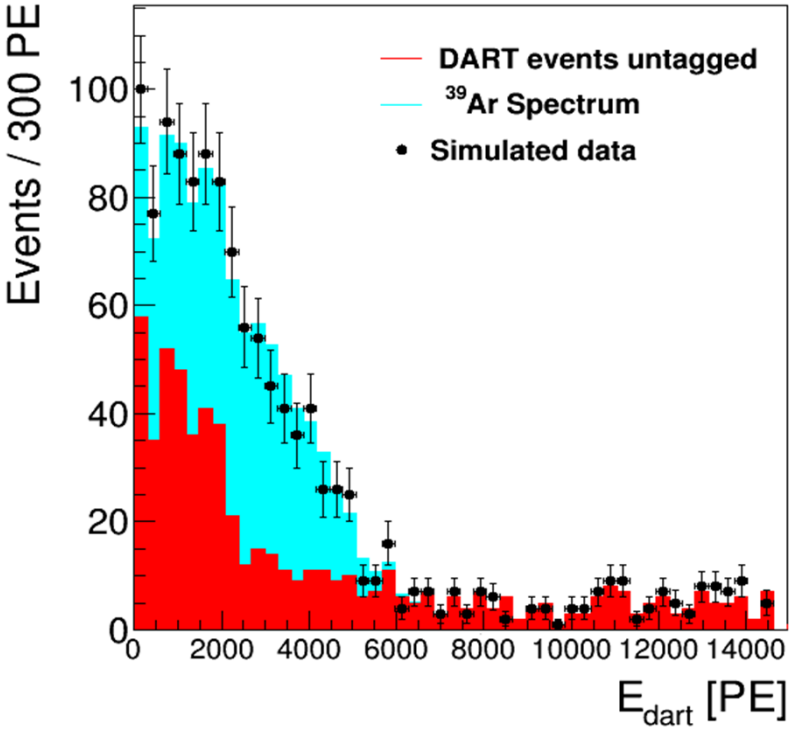
Sensitivity in DArT

Sensitivity from a fit:

$$d = n_S S + n_B B$$

d = simulated data
S = signal
B = background

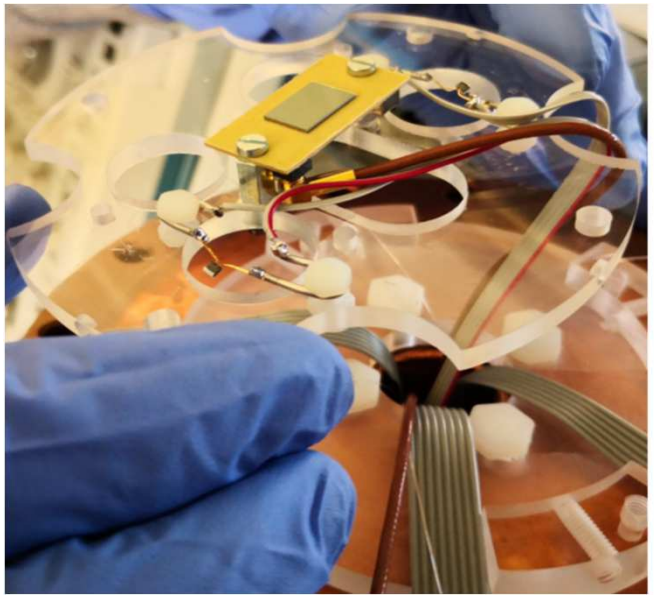
"Design and construction of a new detector to measure ultra-low radioactive-isotope contamination of argon"
JINST 15 (2020) 02, P02024.

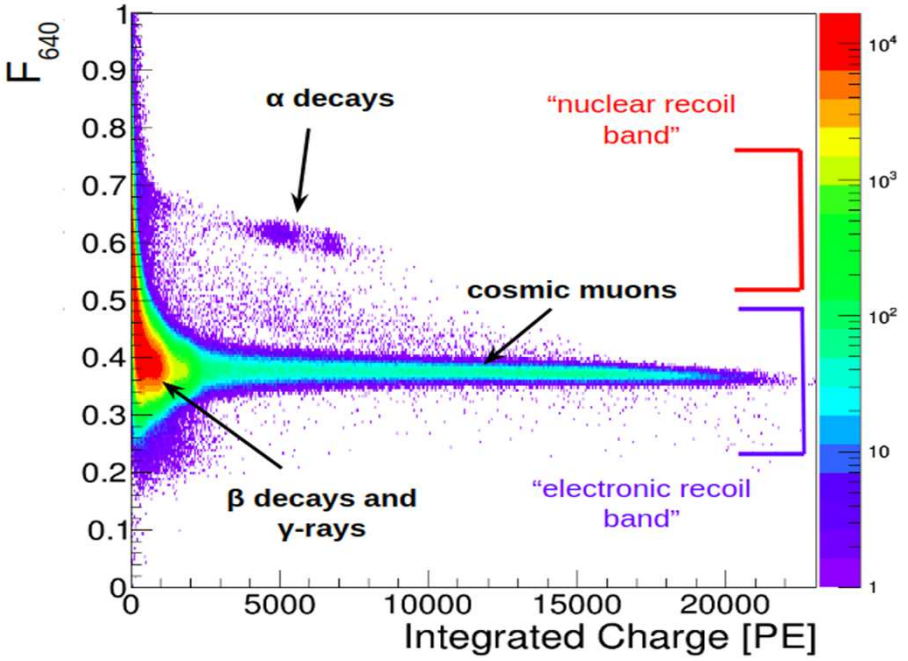


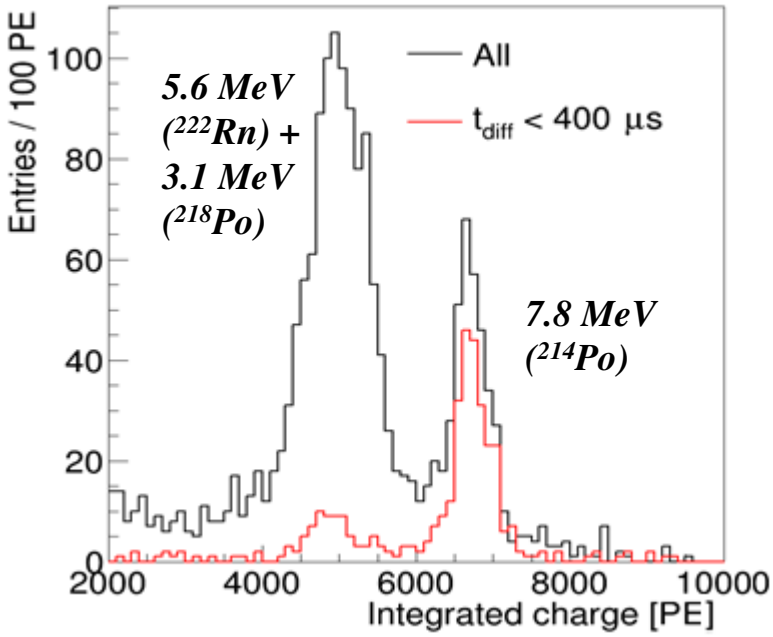
Depletion factor with respect to AAr	Statistical uncertainty without lead [%]	Statistical uncertainty with lead [%]
10	0.5	0.4
100	2.5	1.3
DS-50 1400	20.3	6.7
14000	/	41.1

DArT assembly and tests on surface at CIEMAT

- Gas argon condensed from bottle using pressurized liquid nitrogen.
- Data taken for several days continously. Argon purity stable over time.







DArT underground @ LSC

- DArT installed at LSC in April 2021. Data acquisition underground ongoing with AAr in the test cryostat
- Installation in ArDM foreseen in 2021

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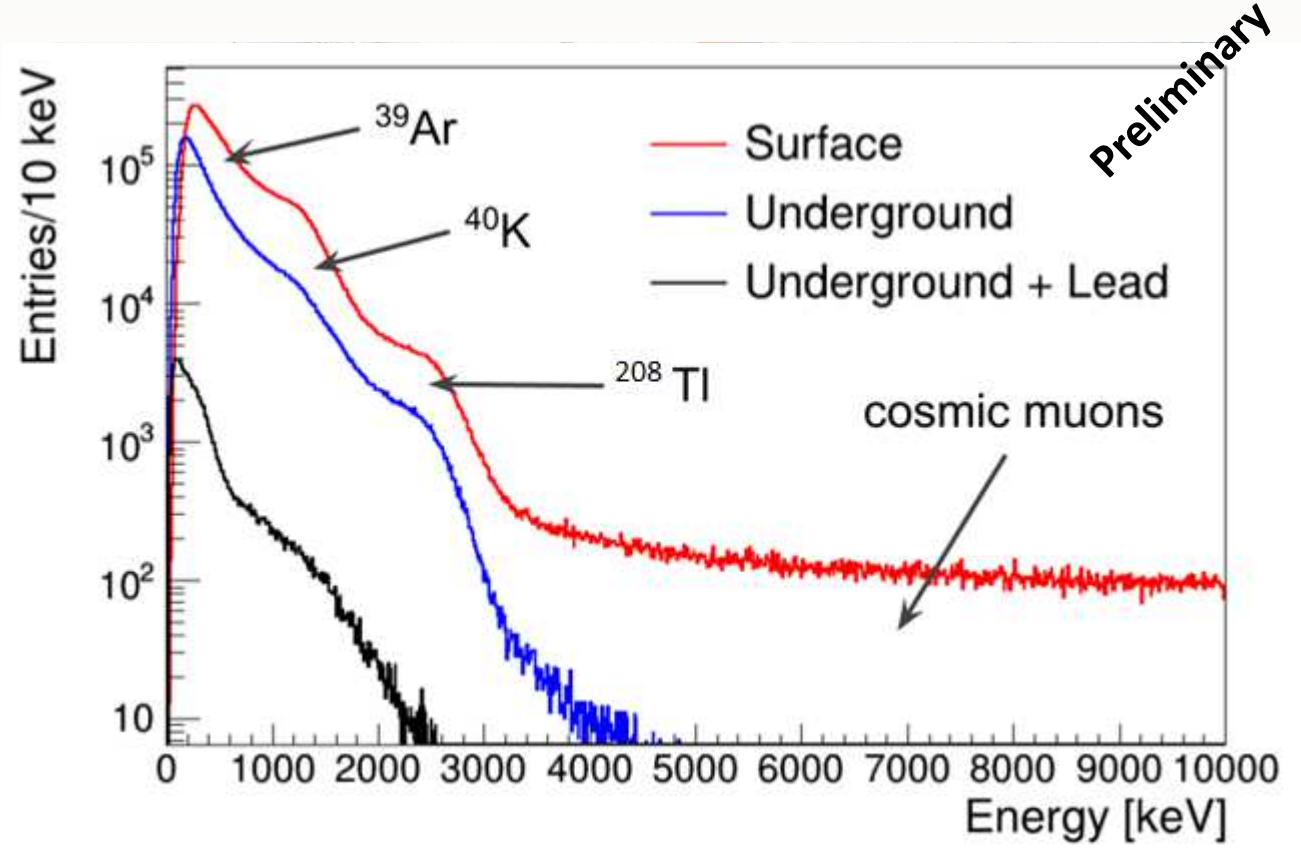

Conclusions

- Argon: outstanding ER background rejection in direct dark matter search experiments
- The small Ar-39 contamination does not make feasible to use atmospheric argon in the next generation of Dark Matter DD-experiments
- International effort underway to procure radiopure argon extracted from underground reservoirs
- DArT in ArDM: radiopurity measurement of underground argon in operations @ LSC