Monitoring ^{39}Ar Background for DarkSide-20k with DArTinArDM

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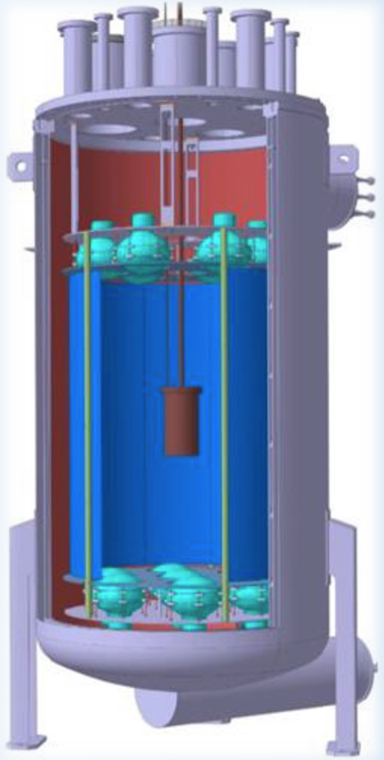
On behalf of the DarkSide-20k Collaboration

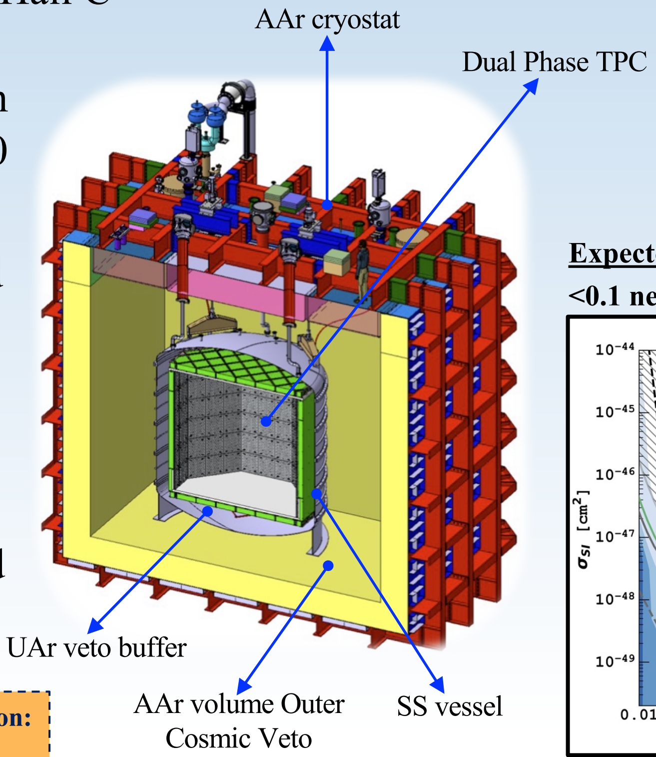


DArTinArDM is a high precision experiment at Canfranc Underground Laboratory **(LSC)** to measure the concentration of ^{39}**Ar** in underground argon samples **(UAr)** for **DarkSide-20k**.

DarkSide-20k

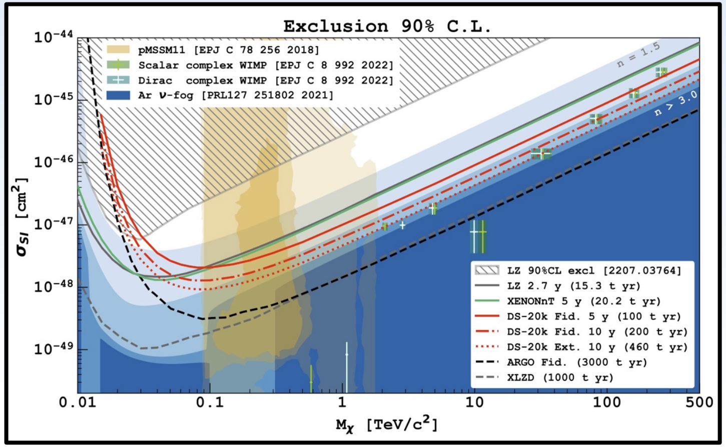
- **DarkSide-20k** is the next project of the **GADMC** after DarkSide-50
- Under construction at **LNGS** Hall C

- A **20-tonne** fiducial argon detector filled with **UAr** (50 tonnes total volume)
- **TPC** acrylic vessel surrounded by UAr + Gd-loaded acrylic shell as a neutron veto.
  A. Caminata's talk
- 21 m^2 of **Cryogenic SiPMs**
- The inner detector is immersed in the AAr bath (~700 tonnes)



For more details see Andrea Zani's presentation:
The DarkSide 20k Experiment

Expected Background:
<0.1 neutrons in ROI (20-200 keV) with 200 t-y exposure



Eur. Phys. J. Plus 133, 131 (2018)

Argon in Dark Matter Direct Detection

An ideal target?

- Negligible self-absorption of photons ⇨ **Efficient collection of scintillation light**
- Attachment probability for electrons almost null ⇨ **Excellent ionization detector**
- Pulse Shape Discrimination (PSD) of scintillation ⇨ **Excellent background rejection**
- Quite abundant in atmosphere (~ 1%) ⇨ **Large multi-ton detectors are affordable**

^{39}Ar

Intrinsic activity of ^{39}Ar in atmospheric argon (AAr) → In multi-ton TPCs for rare event search the high trigger rate results in pile up problems

Cosmogenic: $^{40}Ar(n,2n)^{39}Ar$

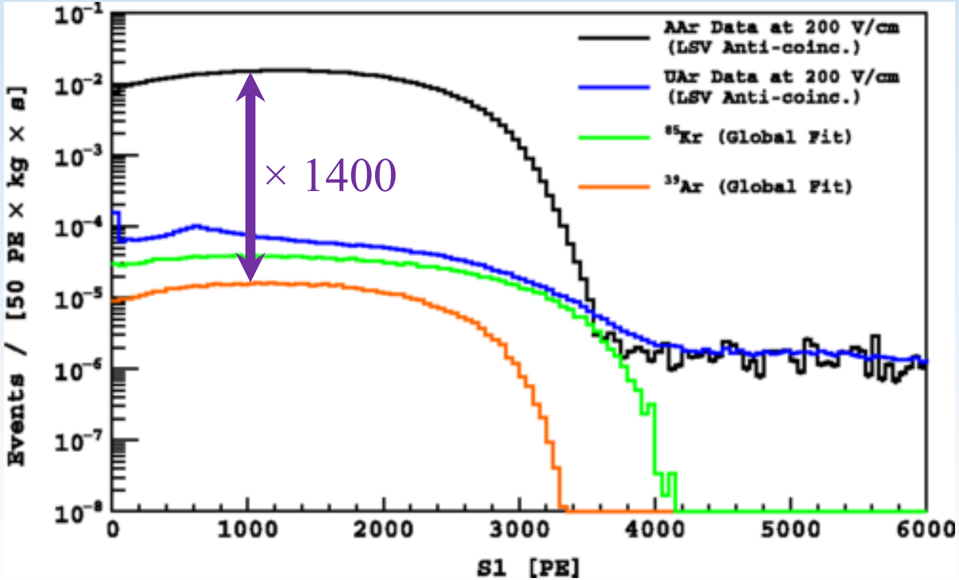
- β^- decay with $\mathbf{Q_\beta = 565 \pm 5}$ **keV** *IAEA NDS*
- **Pure β** emitter
- $t_{1/2} = 269$ y
- Activity = 0.964 ± 0.001 Bq/kg
  DEAP Eur. Phys. J. C 83, 642 (2023)

Use of underground argon (**UAr**), with significant reduction of **^{39}Ar**

UAr for DarkSide-20k

DarkSide-50 measured a **^{39}Ar depletion factor of 1400** in UAr with respect to AAr, i.e. a ^{39}Ar activity of **0.73 ± 0.11 mBq/kg**:

This UAr batch was probably affected by an air leak during extraction: **Upper limit**



Phys. Rev. D ***93****, 081101 (2016)*

A full new UAr extraction plan for DarkSide-20k

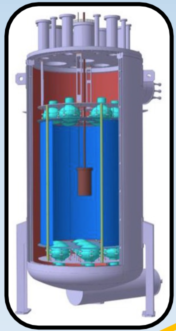
A higher depletion factor can be expected in the UAr of DarkSide-20k

We will measure the ^{39}Ar levels of every batch for Darkside-20k

Extraction-Purification-Measurement

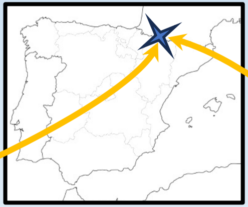
For more details see Valentina Cocco's presentation:

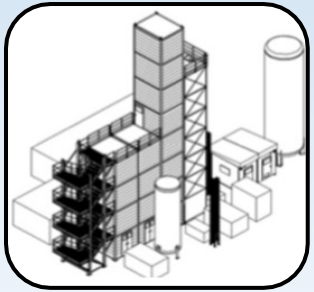
The DarkSide-20k argon procurement chain

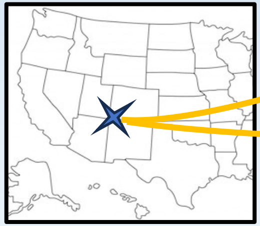


Characterisation: DArT in ArDM at LSC (Aragon, Spain)

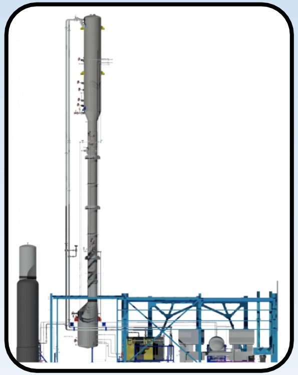
- Measurement of the ^{39}Ar depletion factor







UAr transported via boat for final purification at Sardinia



Production: Urania (Colorado, USA)

- Procurement of 50 tonnes of UAr from CO_2 well
- Extraction of 330 kg/day, with 99.9% purity

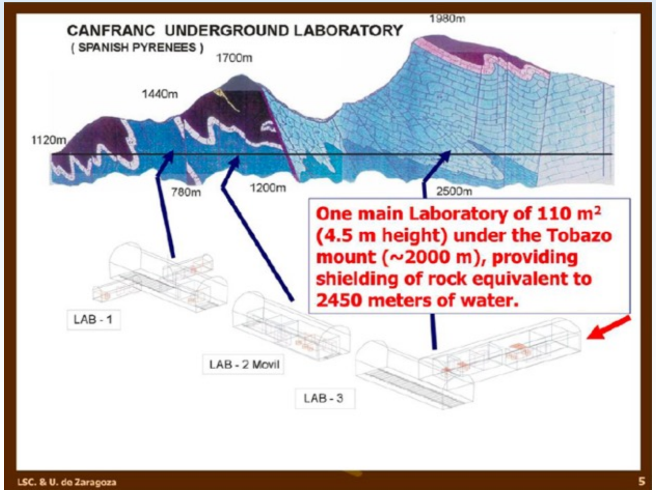
Purification: Aria (Sardinia, Italy)

- 350 m tall cryogenic distillation column to purify UAr and isotopically separate argon and other elements
- Can process 1 tonne/day with 10^3 reduction of all chemical impurities

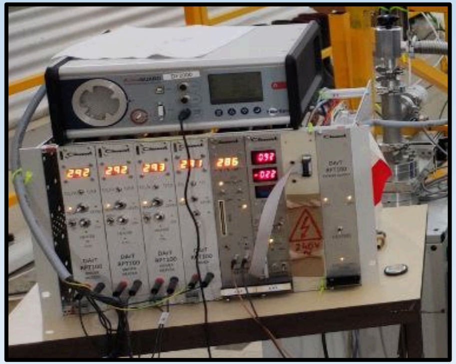
DArT at LSC

- DArT is a **low-background detector** designed to measure the **^{39}Ar depletion factor** of different UAr batches (URANIA + ARIA):
  - Copper vessel with an active volume of 1.35 kg of liquefied Ar
    620 evt/week for UAr (0.73 mBq/kg)
  - Inner acrylic structure coated with TPB
  - Mylar reflector to enhance light collection
  - Readout by 1 cm^2 SiPMs from DS-20k
    2 SiPM test setup and 8 in DArT in ArDM
- Located at LSC under mount Tobazo (~850 m rock)

Full description: 2020 JINST 15 P02024

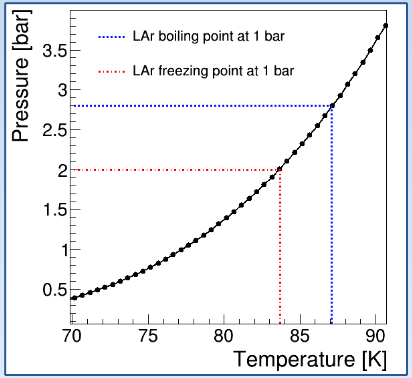


DArT in Test Setup



DArT test setup:

- Cryostat with **pressurized LN_2** at 85 K
- **No veto**
- **Lead shield** flushed with Rn-free air

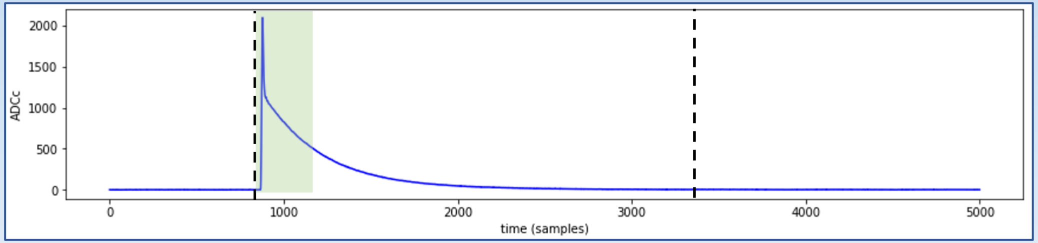


The test set up allowed us to:

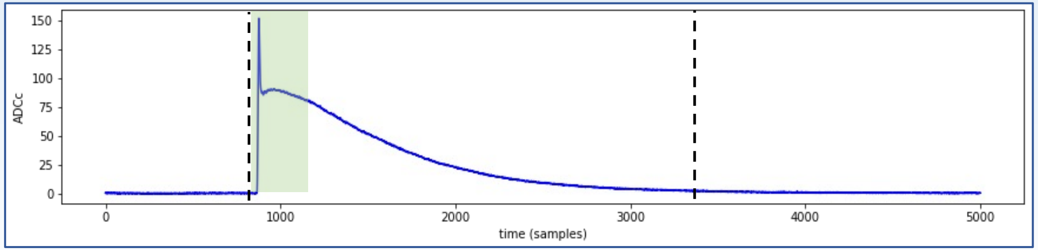
- **Evaluate of the detector's continuous performance** over weeks
- **Establish** the viable **operational conditions** for the DAQ and electronics
- **Characterize** of **photoelectronics** and light collection efficiency
- **Set protocols** for operating the inner detector
- **Make a preliminary measurement of ^{39}Ar** activity in atmospheric Ar

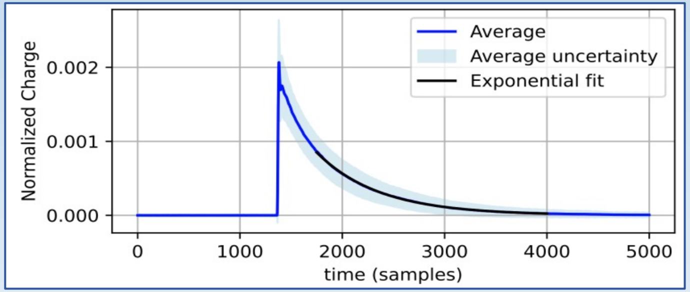
Particle Identification in DArT

α decay



β decay





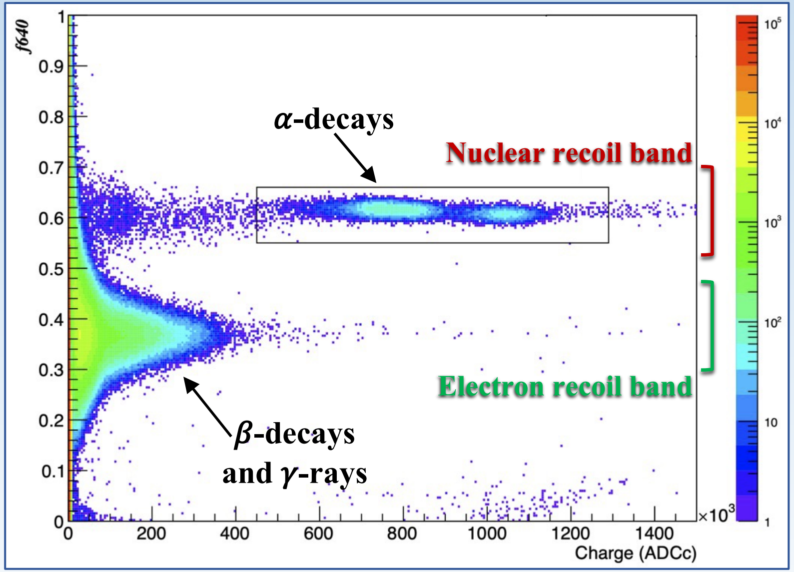
Triplet Lifetime ~1.4 μs

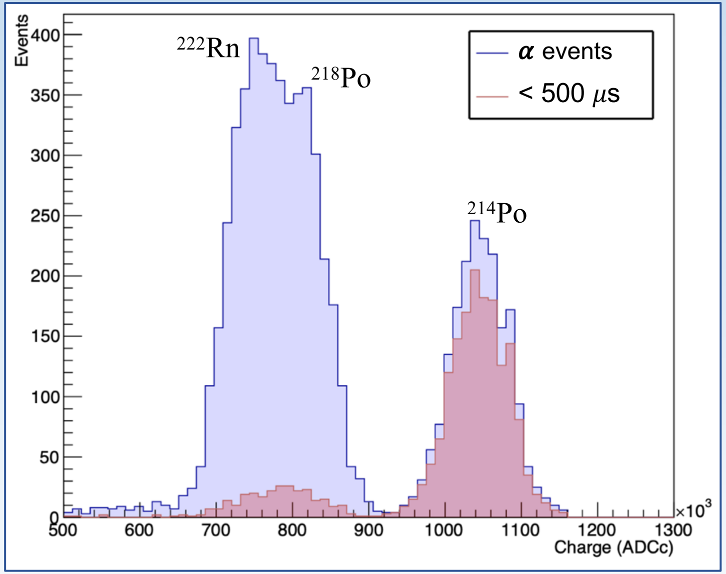
Pulse shape discrimination
using f_{prompt} :

$$\frac{Int.\ Charge_{\ first\ 640\ ns}}{Integrated\ Charge}$$

Characterization of events in LAr

Pulse shape discrimination (PSD)





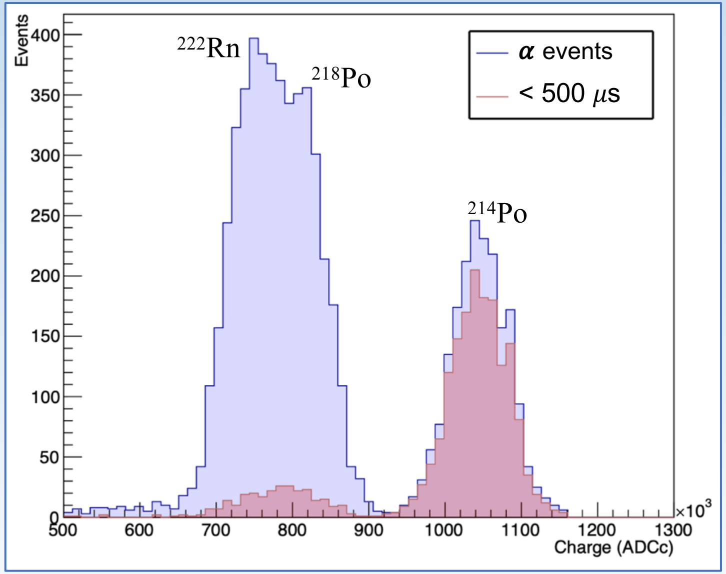
PSD + BiPo coincidence →

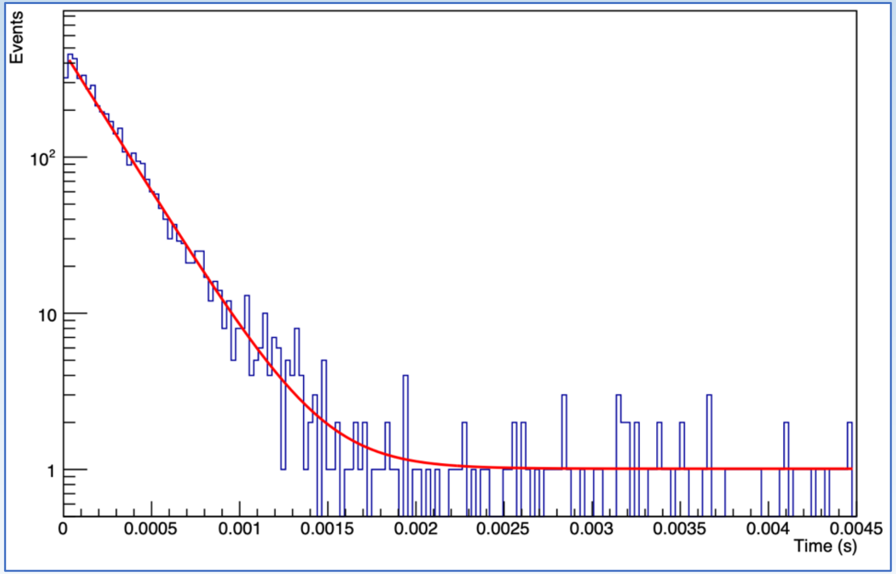
Measured $t_{1/2}(^{214}\text{Po}) = 166.6 \pm 2.6\ (\text{stat})\ \mu s$

Compatible with the value measured with more precise experiments: $t_{1/2}(^{214}\text{Po}) = 163.47 \pm 0.03\ \mu s$

IAEA Nuclear Data Section

Characterization of events in LAr





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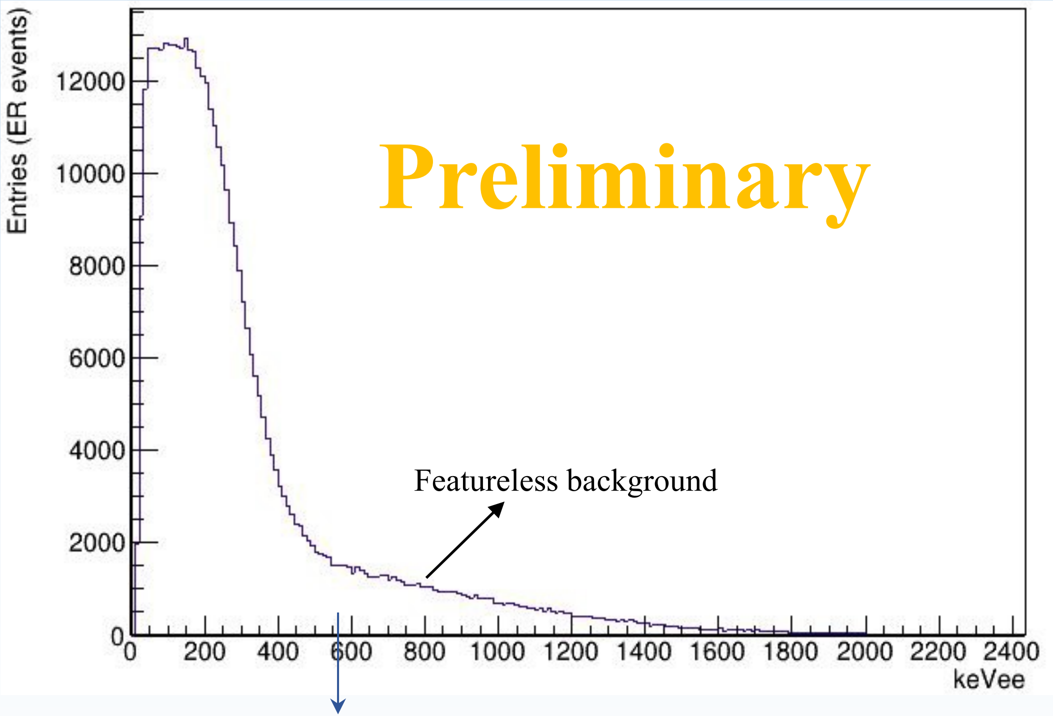
IAEA Nuclear Data Section

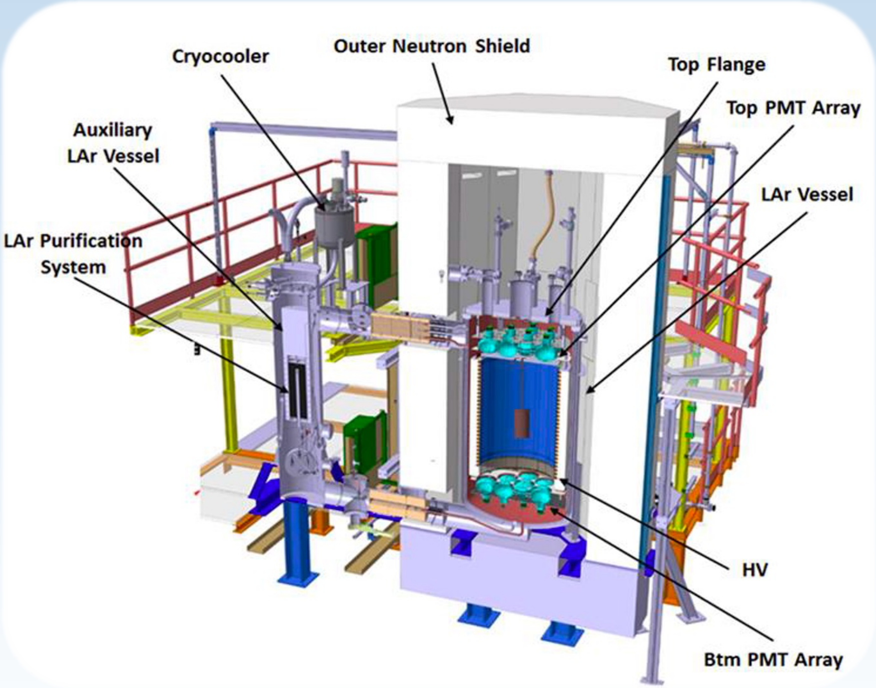
Activity of ^{39}Ar in Atmospheric Argon



Q-value of ^{39}Ar = 565 keV

- A clear pattern of the **^{39}Ar spectrum** is visible underground in the Pb-shield
- Assuming a featureless linear background and a threshold of 33 keV, the **^{39}Ar rate is ~1 cps**
- The uncertainty is dominated by **systematics**, and this is currently under evaluation

DArT in ArDM



DArT has been designed to be installed inside ArDM single-phase:

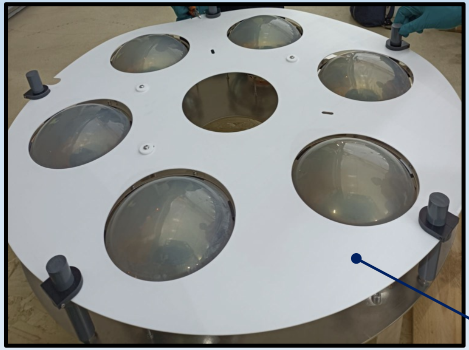
- 13 PMTs will see ~1 tonne AAr buffer used as shield and veto
- Pb + HDPE passive shield to minimize external background

Signal: Electrons from the β decay of ^{39}Ar, depositing all the energy in DArT and leaving no signal in the veto (minimal veto threshold of 10 keV). ROI $\in$ [0,600] keV.

Background: γ particles from radioactive decays in the detector materials and in the hall surrounding the detector that leave a signal in DArT.

Full description: 2020 JINST 15 P02024

Hardware Upgrade of ArDM

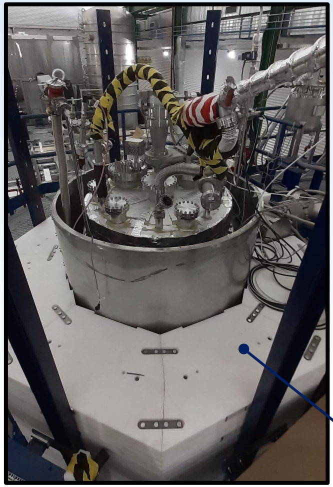


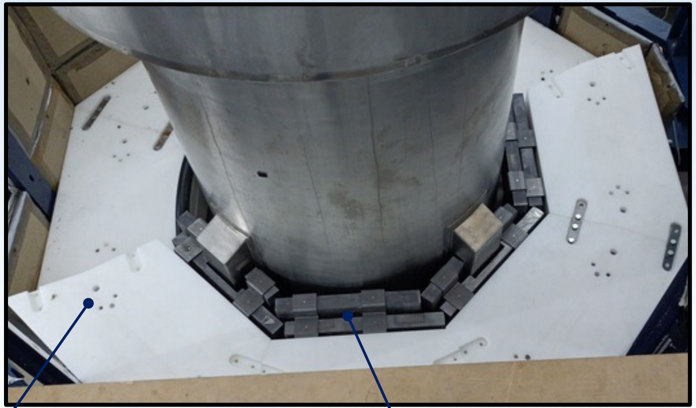
The refurbishment of ArDM has been completed:

- 6 tonnes of lead belt attached to the polyethylene shield
- PMT planes mounted
- Reflectors installed inside

ArDM is ready to host DArT

PMT Plan with reflector coated by TPB





PE Shield

Pb Belt

Reflector Coated with TPB

DArT 2.0

DArT 2.0 has been designed to operate inside ArDM

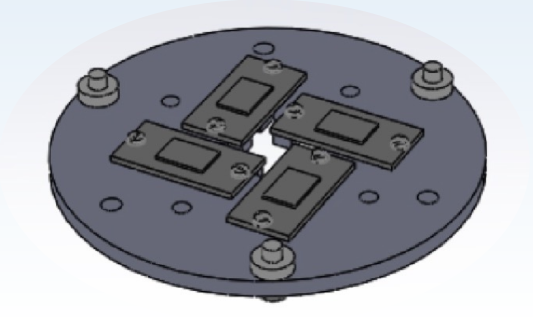
We plan to operate DArT and DArT 2.0 in parallel:

- DArT will keep operating in test cryostat and will be used as auxiliary set up and test bench for DArT 2.0
- DArT 2.0 will operate in ArDM to study the underground argon

DArT 2.0 will have 8 SiPMs instead of 2 to increase the light yield

New radiopure acrylic structure is under construction in Canada

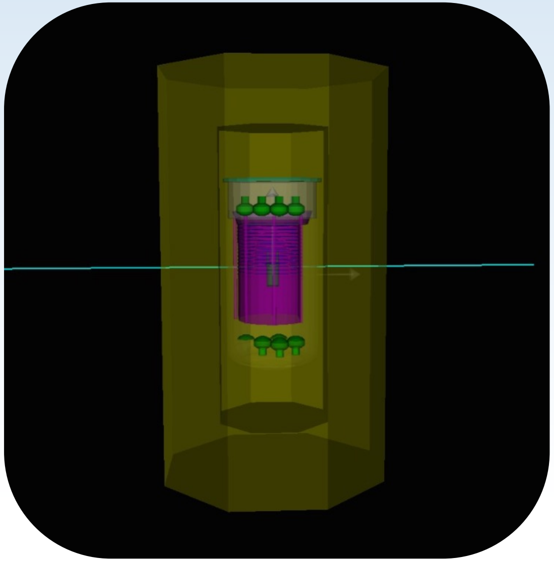
The new DArT vessel is ready

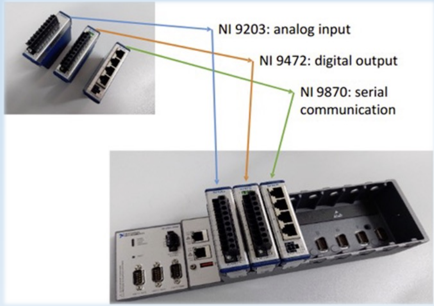


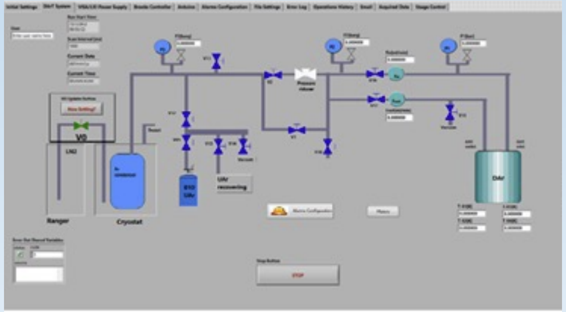
Software Upgrade of ArDM

Continuous progress on the software prompt:

- Data handling/storage
- Development of reconstruction/analysis tools
- Tuning of the MC







DArT in ArDM slow control, independent of ArDM's:

- Developed at U. Cagliari based on NI compactRIO-9068 hardware
- Gas system developed by INFN-Cagliari and CIEMAT. First tests onsite on-going

Conclusions

- Atmospheric argon is unsuitable for the next generation of rare events searches due to its intrinsic ^{39}Ar activity.
- Underground argon will be key to physics programs for future underground detectors such as DarkSide-20k, ARGO, Legend and DUNE.
- We have validated the performance of DArT and we are in position to perform competitive measurements of ^{39}Ar activity in atmospheric Ar.
- We are about to start up ArDM and will soon install DArT 2.0 inside it.
- In the long term, DArT will measure the UAr batches received from URANIA and ARIA before their use in DarkSide-20k.
- The first UAr samples are expected for 2025 and we will be ready well in advance. The commissioning of DArT in ArDM is planned for early 2024.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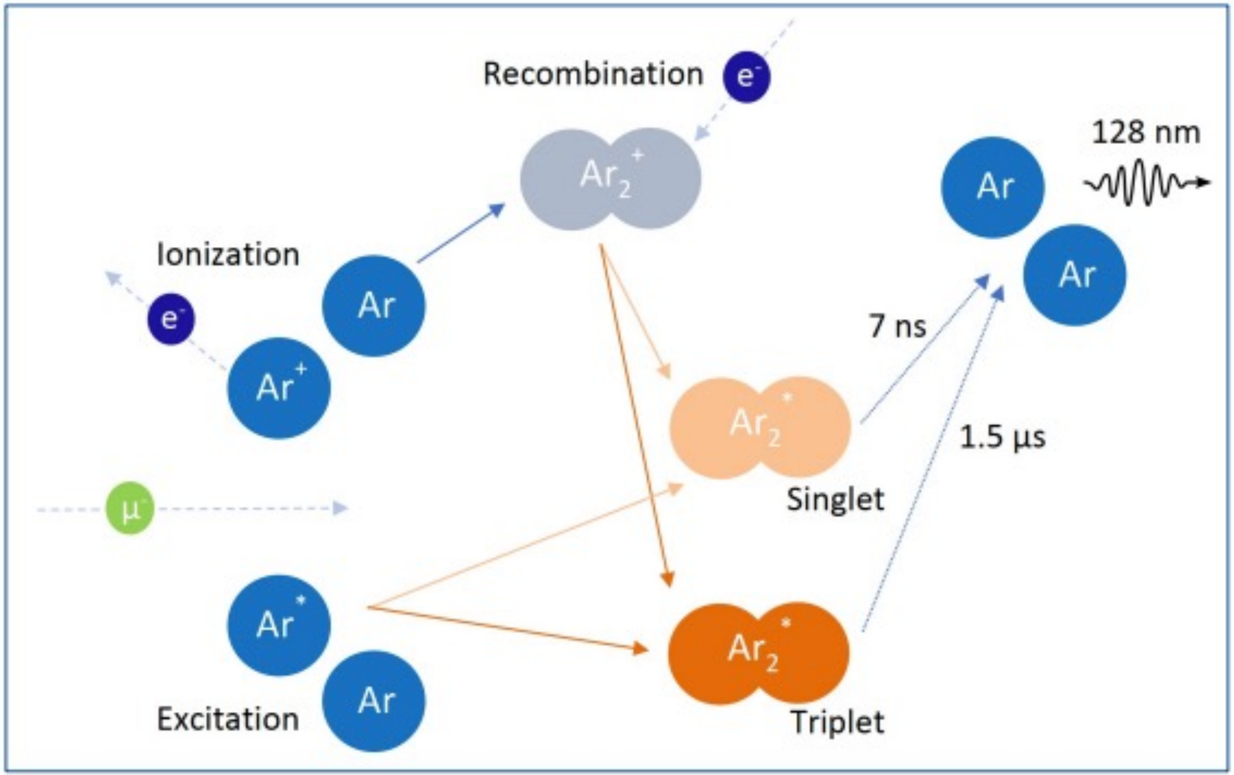
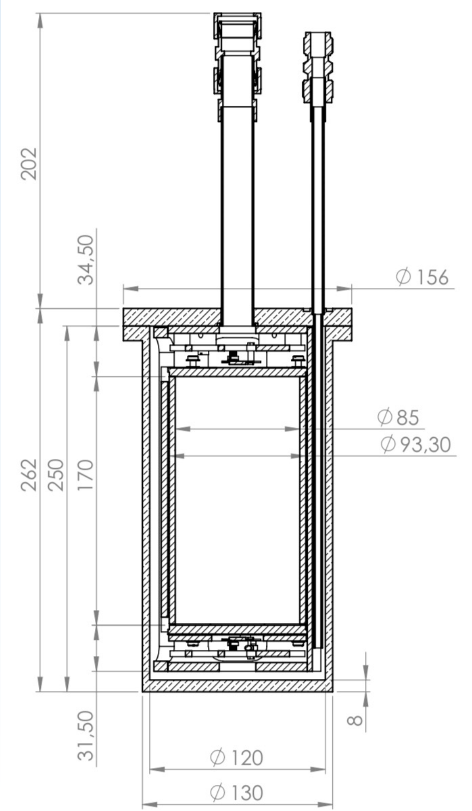
Back up

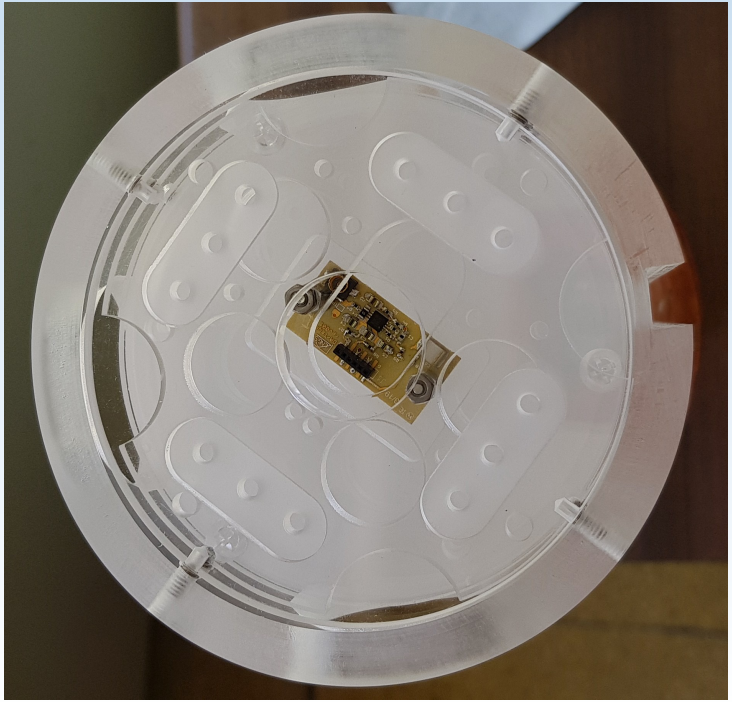
Ar Excitation and ionization process



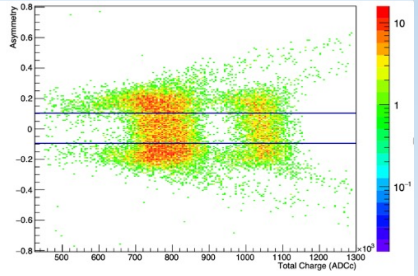
Andrea Zani's presentation: *The DarkSide 20k Experiment*

DArT





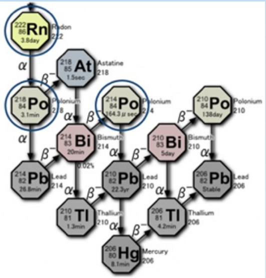
Alpha peaks identification

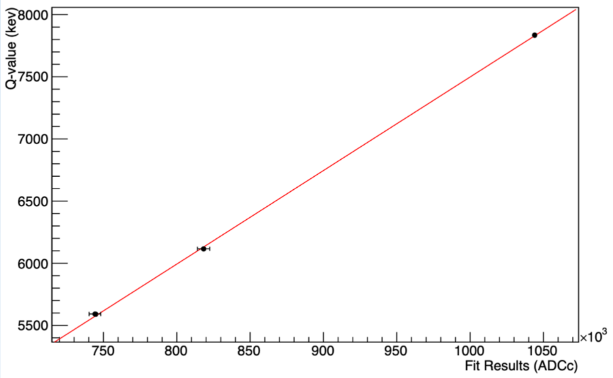


$^{222}Rn\ (Q - value = 5590{,}30\ keV)$

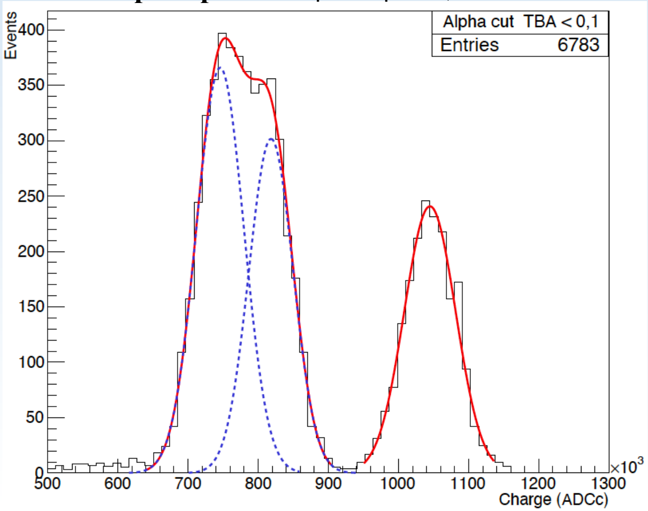
$^{218}Po\ (Q - value = 6114{,}68\ keV)$

$^{214}Po\ (Q - value = 7833{,}46\ keV)$





Alpha spectrum $|TBA| < 0,1$:



$$f_1(x) = p_1 e^{-\frac{1}{2}\left(\frac{x-\mu_1}{\sigma_1}\right)^2} + p_2 e^{-\frac{1}{2}\left(\frac{x-\mu_2}{\sigma_2}\right)^2}$$

$$f_2(x) = p_3 e^{-\frac{1}{2}\left(\frac{x-\mu_3}{\sigma_3}\right)^2}$$

	Constantes del ajuste
p_1	$(9{,}763 \pm 0{,}643) \cdot 10^1$
μ_1	$(7{,}434 \pm 0{,}045) \cdot 10^5$
σ_1	$(3{,}175 \pm 0{,}213) \cdot 10^4$
p_2	$(8{,}649 \pm 0{,}674) \cdot 10^1$
μ_2	$(8{,}165 \pm 0{,}048) \cdot 10^5$
σ_2	$(3{,}001 \pm 0{,}238) \cdot 10^4$
p_3	$(6{,}625 \pm 0{,}286) \cdot 10^2$
μ_3	$(1{,}045 \pm 0{,}001) \cdot 10^6$
σ_3	$(3{,}453 \pm 0{,}095) \cdot 10^4$

$$E(x) = mx + n$$

$$m = (7,458 \pm 0,068) \cdot 10^{-3}\ keV/_{ADCc}$$

$$n = (37,27 \pm 59,60) keV$$

$$E_{^{222}Rn} = (5581{,}55 \pm 84{,}63) keV$$

$$E_{^{218}Po} = (6126{,}73 \pm 88{,}57) keV$$

$$E_{^{214}Po} = (7830{,}88 \pm 92{,}66) keV$$