

Measurement of underground Argon radiopurity for dark matter direct searches

Ludovico Luzzi
(CIEMAT)

on behalf of the DarkSide-20k collaboration

TAUP 2023, Vienna
28 of August – 1 of September 2023



Underground Argon in Dark Matter Direct Detection



Why argon?

- 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**
- Large multi-ton detectors and affordable



Main limitation

Intrinsic activity of ^{39}Ar in atmospheric argon
(neutrons from cosmic rays: $^{40}\text{Ar}(n, 2n)^{39}\text{Ar}$):

- β decay with $Q_\beta = 565$ keV
- $t_{1/2} = 269$ y
- ~ 1 Bq/kg
- Pure beta emitter

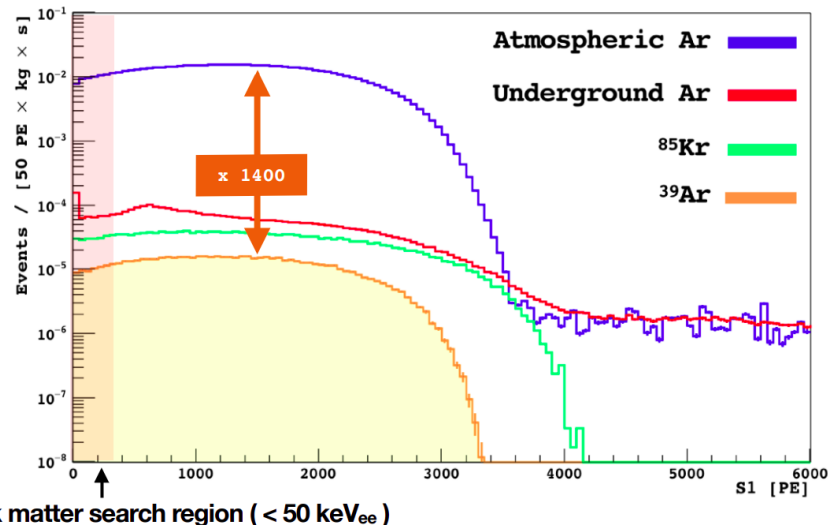
**Underground argon (UAr),
with significant reduction
of ^{39}Ar**

Low Radioactivity UAr for DarkSide-20k

- DarkSide-50 measured a ^{39}Ar depletion factor of 1400 in UAr with respect to AAr, corresponding to a ^{39}Ar activity of 0.96 mBq/kg
- This measurement was probably affected by an air leak in the UAr extraction chain of DarkSide-50
- A full new UAr extraction plan has been designed and is being constructed for DarkSide-20k
- An higher depletion factor can be expected in the UAr of DarkSide-20k

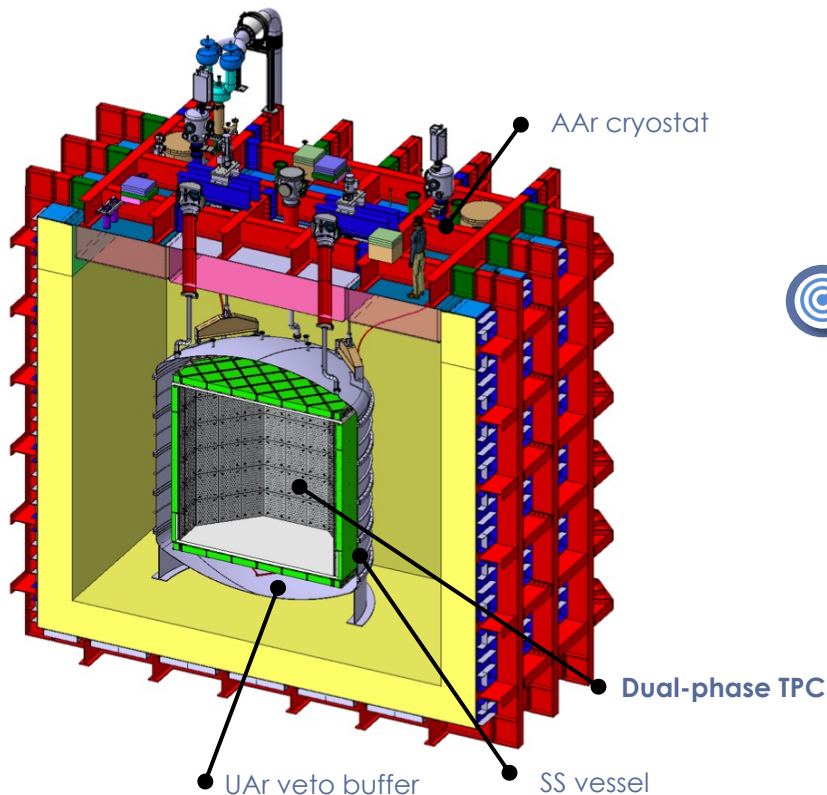
🎯 We want to **quantify the UAr radiopurity for DS-20k**

🎯 We need to **verify quality of every batch** before introducing it in DarkSide-20k



Latest Results from the DarkSide-50 experiment at LNGS, Paolo Agnes, University of Houston, ICHEP 2020

DarkSide-20k detector @ LNGS

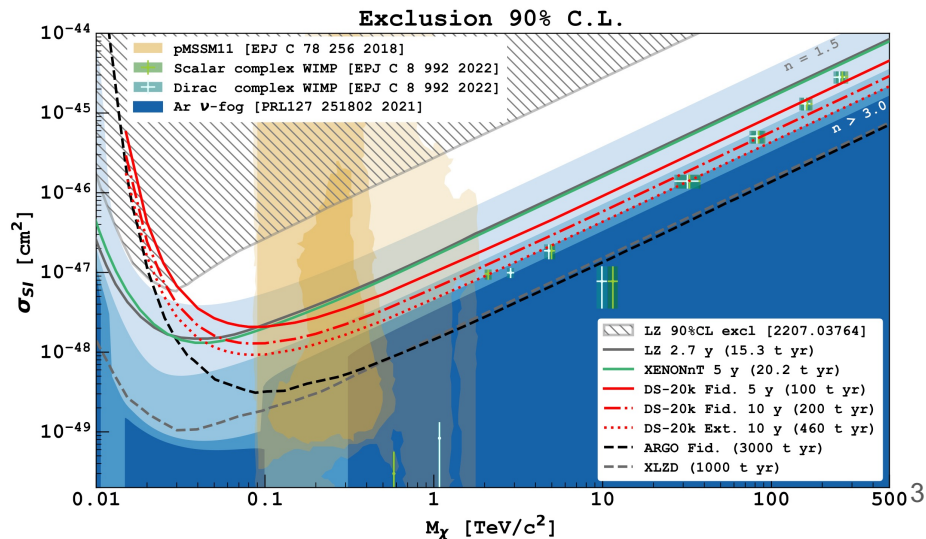


- ▶ A 20-tonnes fiducial (50 tonnes total) argon detector filled with UAr
- ▶ TPC acrylic vessel surrounded by UAr + Gd-loaded acrylic shell as a neutron veto
- ▶ 21 m² of **Cryogenic SiPMs**



•• **Goal** <0.1 background events in ROI (20-200 keV) with 200 t-y exposure

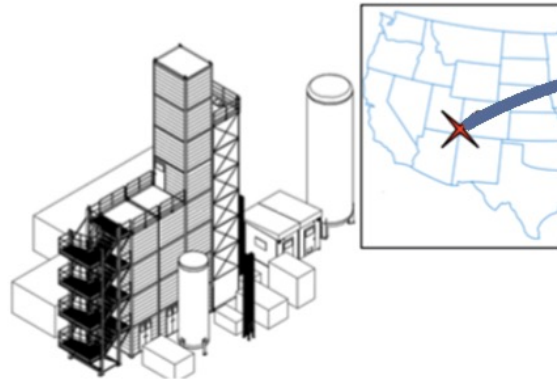
Eur. Phys. J. Plus **133**, 131 (2018)



Low Radioactivity UAr for DarkSide-20k



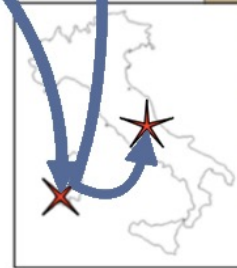
Characterisation: DArT in ArDM at Canfranc Underground Laboratory (LSC)
Measurement of the ^{39}Ar depletion factor



Production: Urania (Colorado, USA)



UAr transported via boat
for final purification at Aria



Purification: Aria (Sardinia, Italy)



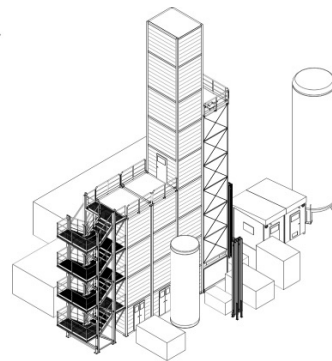
Low Radioactivity UAr for DarkSide-20k

For more details see Walter Bonivento's presentation:
The DarkSide-20k argon procurement chain

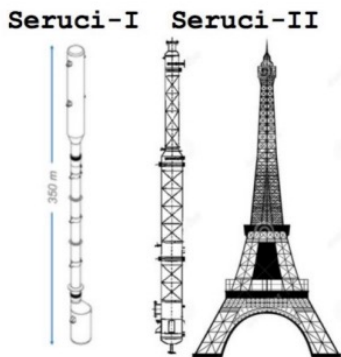


•• Urania

- Procurement of 50 tonnes of UAr from CO₂ well in Colorado, USA
- Extraction of 330 kg/day, with 99.9% purity
- UAr transported to Sardinia for final chemical purification at Aria



Aria ••



Big cryogenic distillation column in Seruci, Sardinia ◀

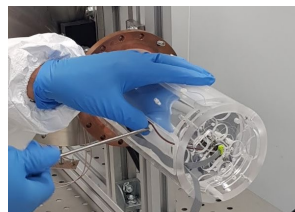
Final chemical purification of the UAr ◀

Can process O(1 tonne/day) with 10³ reduction of all chemical impurities ◀

Ultimate goal is to isotopically separate ³⁹Ar from ⁴⁰Ar (at the rate of 10 kg/day in Seruci II) ◀

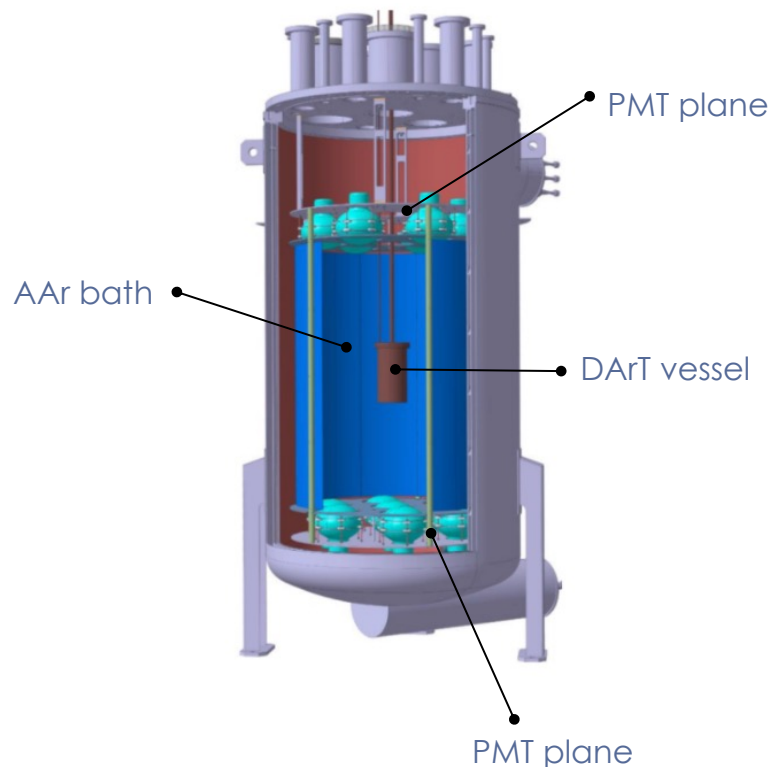
DArT in ArDM

- DArT is a low-background detector designed to measure the ^{39}Ar depletion factor of different UAr batches (URANIA + ARIA)
- Vessel filled with 1.35 kg of liquefied UAr:
 - ▶ Readout by two 1 cm² SiPMs (up to 8) from DS-20k
 - ▶ Mylar reflector to enhance light collection
 - ▶ TPB-coated inner acrylic vessel
- Located at LSC (1400 m.w.e.) 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 gamma and neutron background



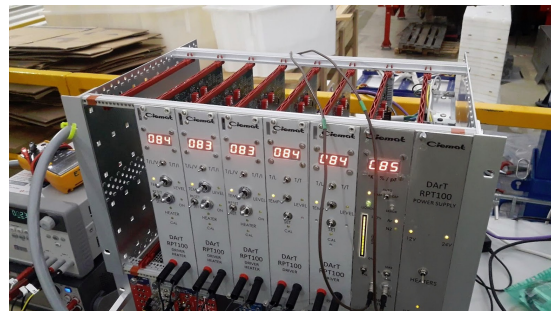
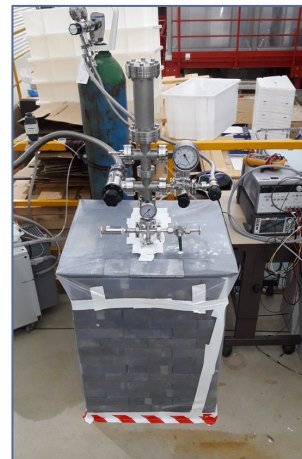
DArT in ArDM

- **Signal events** are electrons from the β decay of ^{39}Ar , depositing all the energy in DArT and leaving no signal in the veto. ROI $\in [0,600]$ keV
- **Background events** are γ particles from radioactive decays in the detector materials and in the hall surrounding the detector
- Background events that leave signal in DArT ROI and more than 10 keV in ArDM are **rejected**
- If less than 10 keV is deposited in ArDM they will go **untagged** and contribute to the background



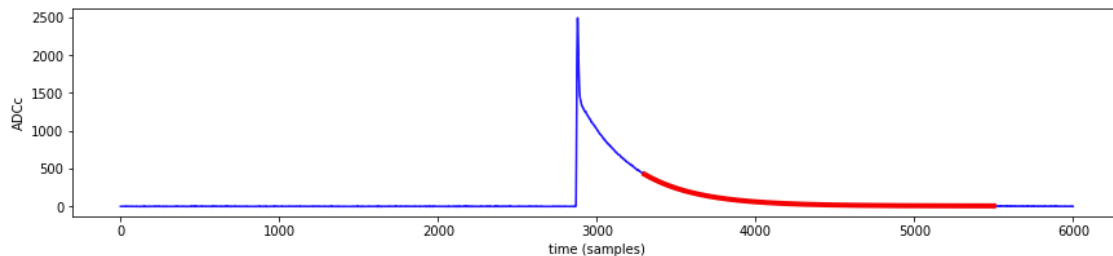
DArT in Test Setup: Operations (Atmospheric Argon)

- Specific setup for tests:
 - ▶ cryostat with pressurized LN₂ @ 85 K. **No veto**
 - ▶ Installation in an ad-hoc Pb-castle flushed with Rn-free air
- It has allowed for:
 - ▶ Evaluation of continuous performance of the detector over weeks
 - ▶ Characterization of the photoelectronics and light collection efficiency
 - ▶ Determination of feasible operational conditions of the DAQ and electronics
 - ▶ Setting protocols for operating the inner detector
 - ▶ Preliminary measurement of ³⁹Ar intrinsic activity (analysis ongoing)



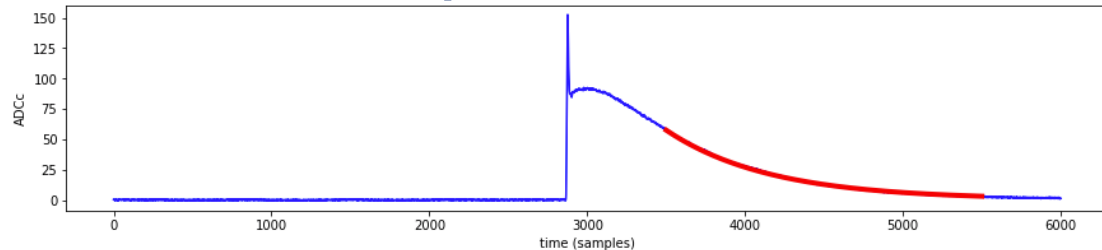
Particle Identification in DArT

α decay



Triplet lifetime ~ 1230 ns

β decay

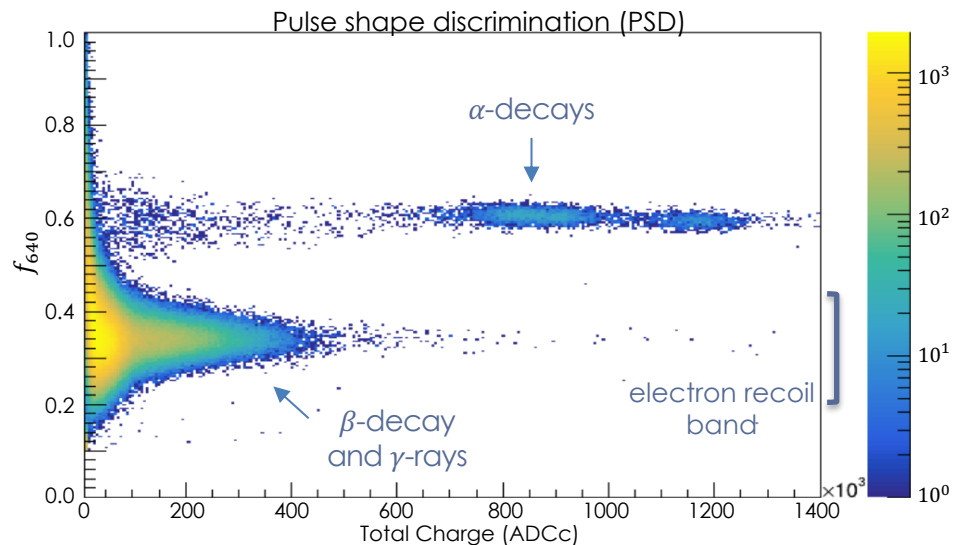


Slower SiPM response

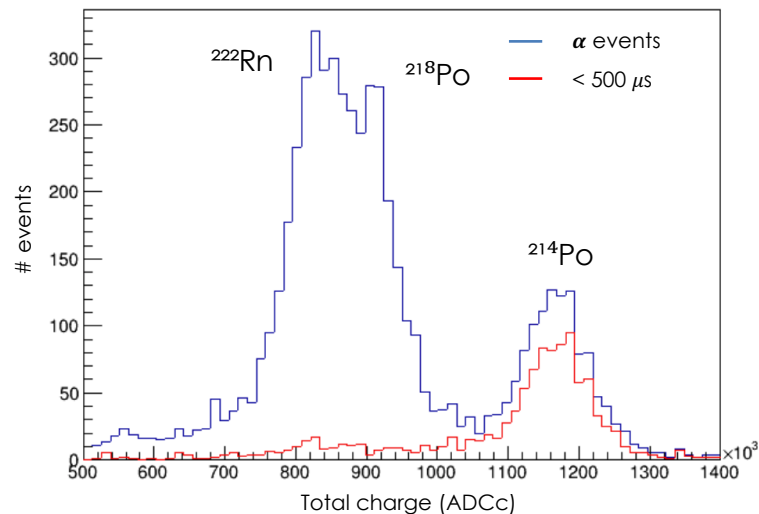


efficient PSD using f_{prompt} (640 ns)

Characterization of Events in Lar



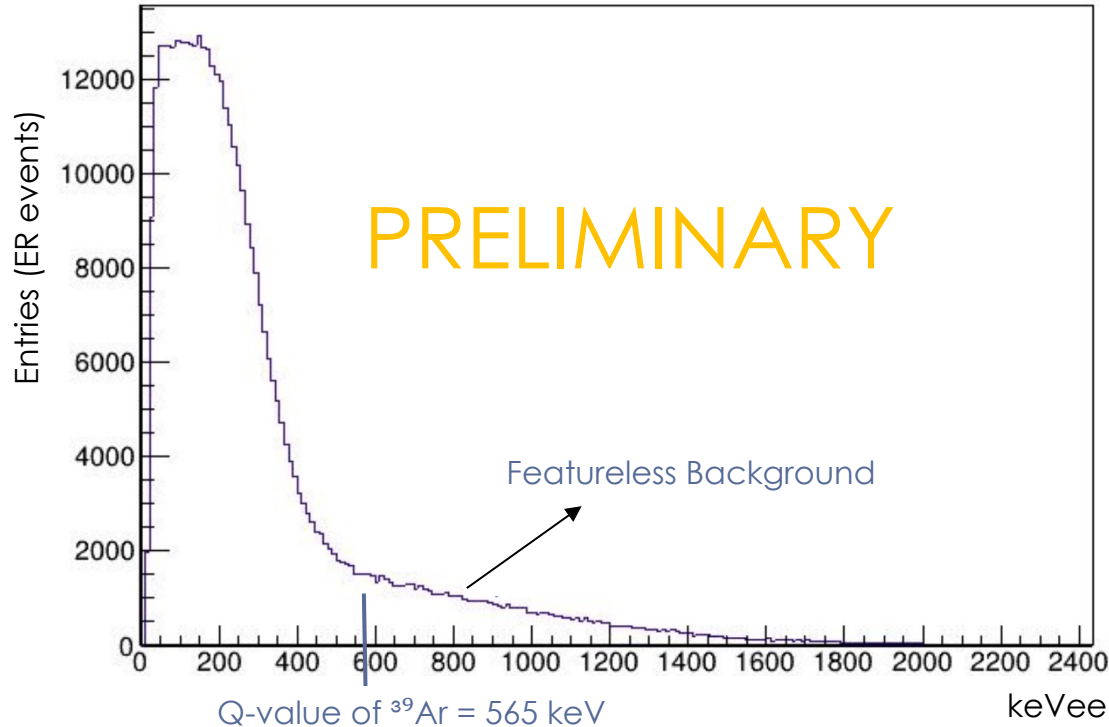
Alphas identified with PSD + BiPo coincidence



Measured $t_{1/2} (^{214}\text{Po}) = 158.3 \pm 6.1 \text{ (stat)} \mu\text{s}$

Compatible with the value measured with more precise experiments of $164.3 \mu\text{s}$

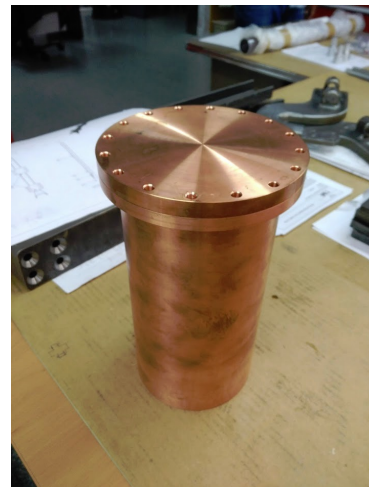
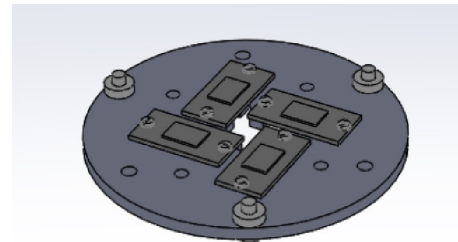
^{39}Ar Activity of Atmospheric Argon (DArT in Test Setup)



- ^{39}Ar spectrum is visible underground with Pb-shield
- Assuming a featureless linear background and a threshold of 33 keV, the ^{39}Ar rate is ~ 1 cps
- Uncertainty is dominated by systematics, under evaluation

DArT 2.0

- A new version of DArT (DArT 2.0) has been designed
- We plan to operate DArT and DArT 2.0 as twin experiments:
 - ▶ DArT will keep operating in test cryostat and will give information about the operation and problems of DArT 2.0
 - ▶ DArT 2.0 will operate in ArDM to study the underground argon
- DArT 2.0 will have 8 SiPMs instead of two ▶ better the light yield
- The new DArT 2.0 vessel is ready
- New radiopure acrylic structure is under construction in Canada

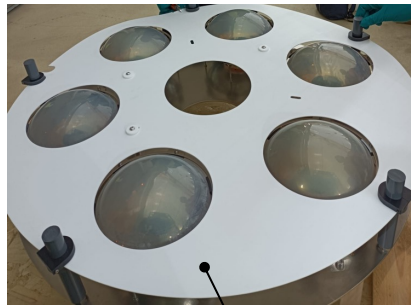


ArDM: Hardware Upgrade

- The refurbishment of ArDM is on-going at LSC
 - ▶ lead belt attached to the polyethylene shield
 - ▶ PMT plans mounted
 - ▶ Reflectors installed inside to enhance the light yield



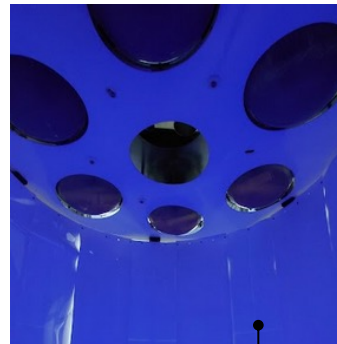
PE Shield Pb Belt



PMT Plan with reflector coated by TPB



Top Flange

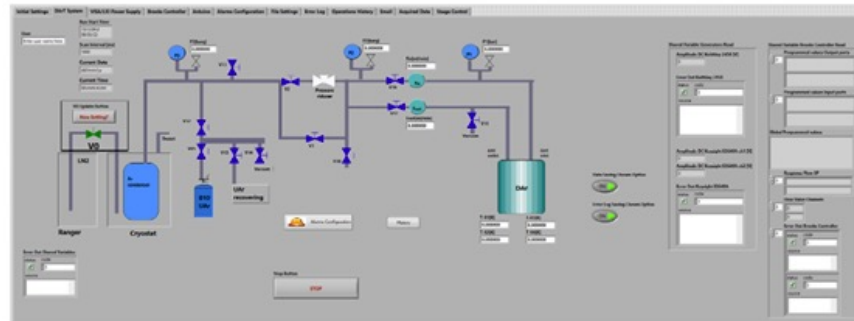


Reflector Coated by TPB

ArDM: Software Upgrade

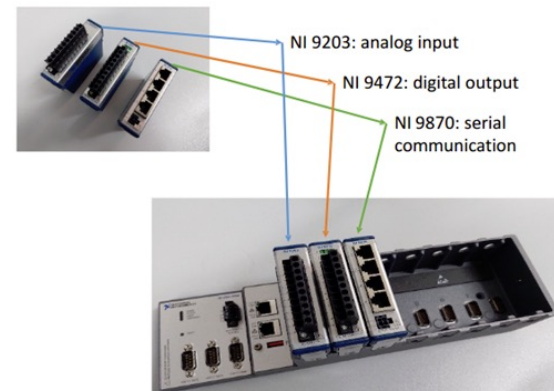
- We are working on implementing the **software** part:

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



- DAiT in ArDM **slow control**:

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



Conclusions

- ▶ Underground argon will be key to the physics programmes of DarkSide-20k and ARGO
- ▶ DArT will measure the concentration of ^{39}Ar in UAr for depletion factors exceeding 10 times that reported by DarkSide-50 (1400)
- ▶ 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 on way to start ArDM and DArT will be installed soon inside of it
- ▶ In the long term, DArT will measure on a regular basis the UAr batches received from URANIA/ARIA before their use in DarkSide-20k
- ▶ Commissioning of DArT in ArDM in 2024
- ▶ DArT in ArDM will be fully operative from early 2025

