DArTinArDM

A Dedicated Detector for ^{39}Ar Characterization in Underground Argon

Sara Tullio
on behalf of the DarkSide-20k collaboration

LOW RADIOACTIVITY TECHNIQUES 2026 WORKSHOP X

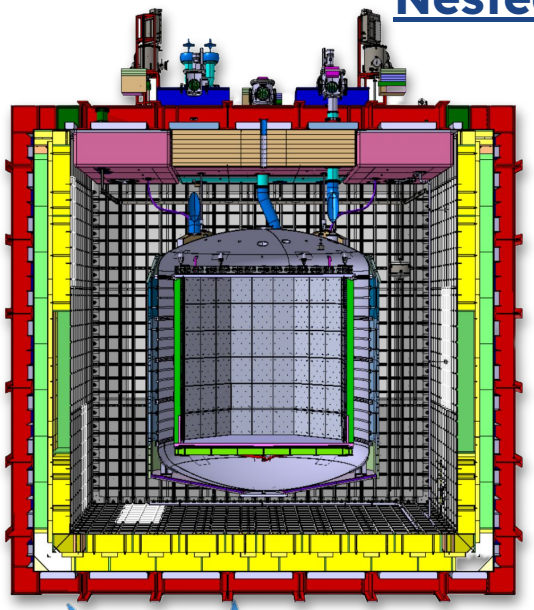
21st–24th September 2026
The Guildhall, York

The DarkSide-20k experiment

Under construction
@LNGS Hall C
3800 m w.e.

Next liquid argon TPC of the GADMC after DarkSide-50:

Rare events search
at **very low energy** → Scale up of the detector
Minimization of backgrounds



Nested detectors structure

Outer Veto

650 tonnes of AAr,
cosmogenic veto

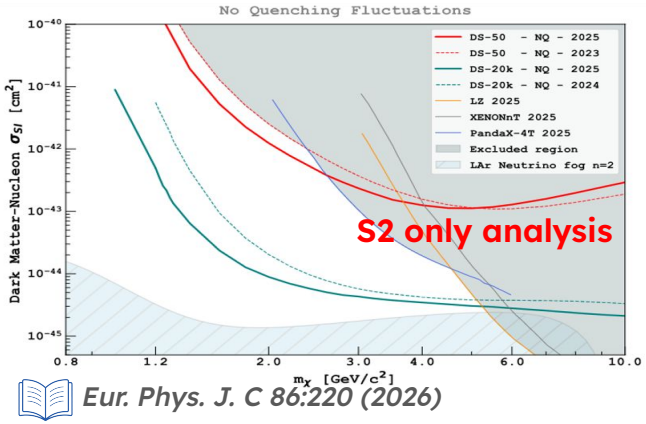
Inner Detector:

Inner Veto

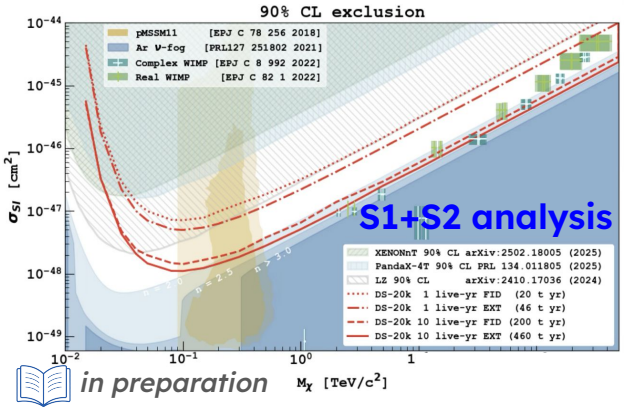
32 tonnes of UAr,
neutron veto

TPC

49.7 tonnes of UAr



Eur. Phys. J. C 86:220 (2026)



in preparation

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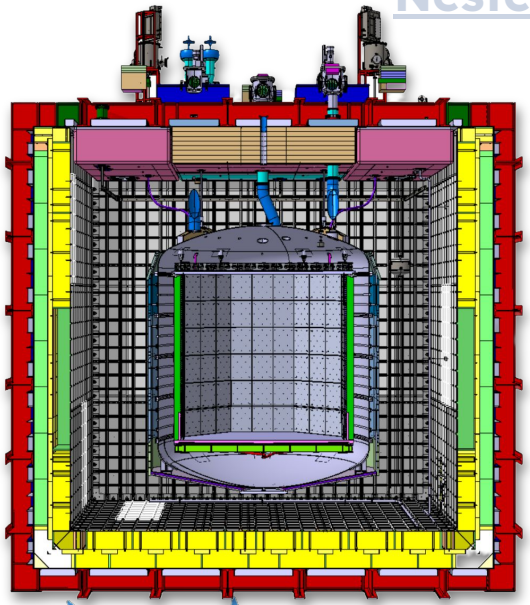

See DarkSide-20k overview poster for more details

cosmogenic veto

Inner Detector:

Inner Veto

32 tonnes of UAr,
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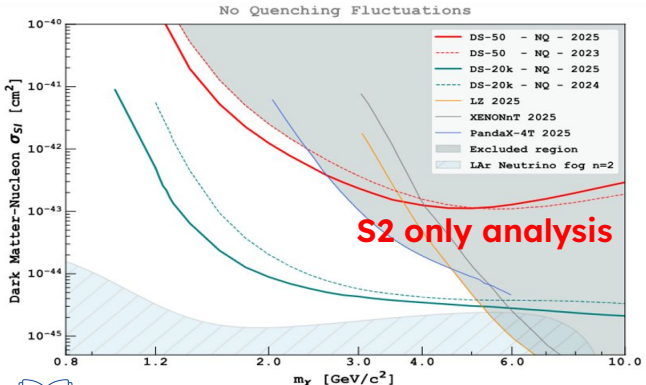

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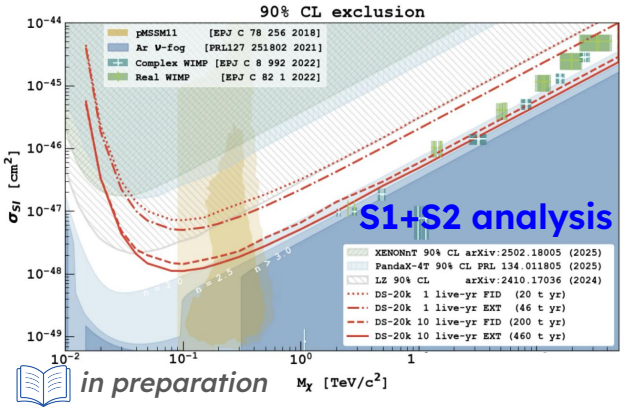
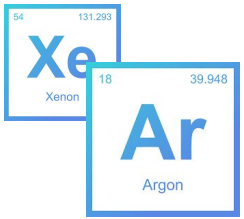


in preparation

Liquid Argon for direct Dark Matter searches

Some characteristics align perfectly with the TPC mechanism….

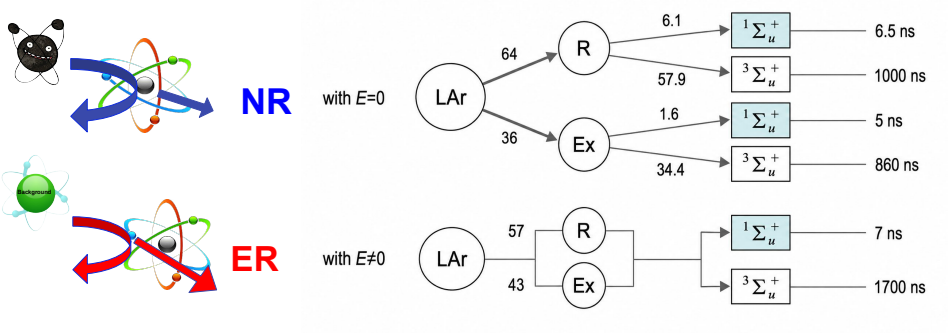


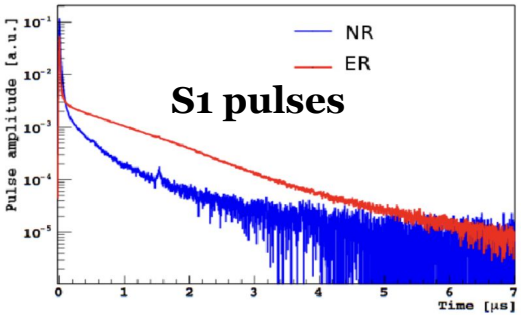
Shared with the other noble gases…

- Possibility of **large monolithic targets**
- Easy **radio-purification**
- Excellent **Ionization / scintillation properties**

Specific to Argon…

- **Abundance** in nature
- Identification of incident particles analyzing the shape of scintillation pulses (PSD)





High Pulse Shape Discrimination power (~ 10^9)

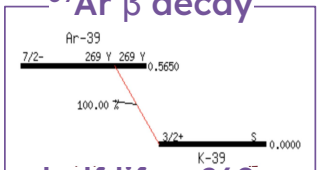
between **nuclear (NR)** and **electron recoil (ER)**

^{39}Ar β-decay background
The need of Underground Argon

Atmospheric Argon (AAr) → rich in ^{39}Ar

^{40}Ar+n→ 2n + ^{39}Ar

^{39}Ar β decay

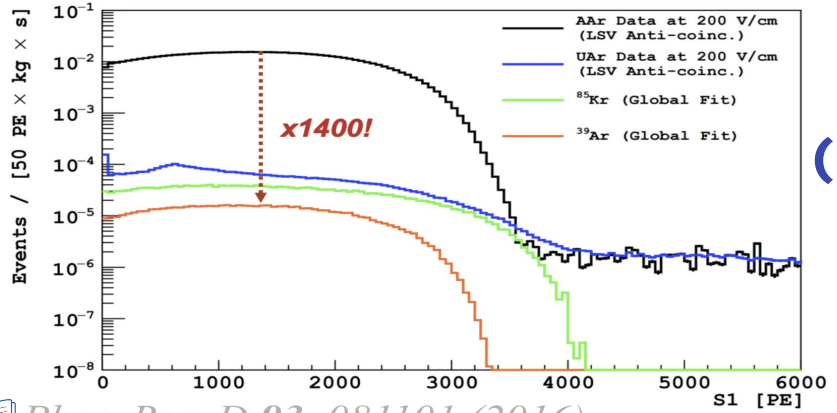


half life: ~269 y
activity: ~ 1Bq/kg

→ **100% dead time** in DS-20k
→ **limits S2-only analysis**
→ **lowers PSD reliability**

Underground Argon (UAr) → poor in ^{39}Ar

In DS-50 TPC:



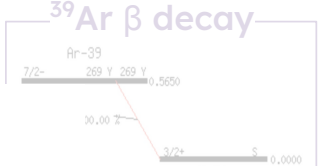
Phys. Rev. D **93**, 081101 (2016)

^{39}Ar activity
(1.4 ± 0.2) ·10³ times lower than in AAr

Upper limit!
The batch was probably affected by an air leak during extraction

^{39}Ar β-decay background
The need of Underground Argon

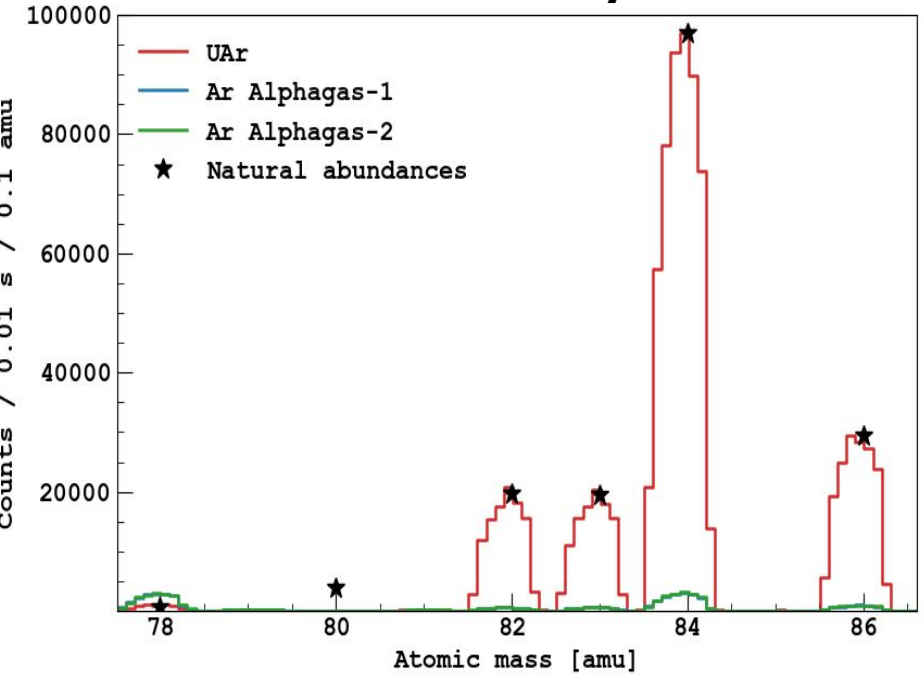
Atmospheric Argon → rich in ^{39}Ar



→ 100% dead time in DS-20k
→ limits S2-only analysis
→ lowers PSD reliability

vity: ~ 1Bq/kg

ICPMS analysis



^{85}Kr contamination confirmed

(Presence of different Kr isotopes at their natural abundances)

^{39}Ar activity

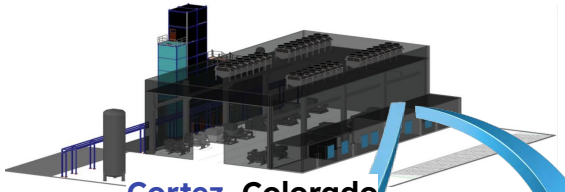
0.2) · 10^3 times lower than in AAr

Upper limit!

The batch was probably affected by an air leak during extraction

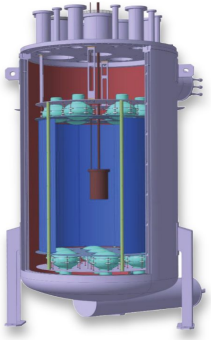
Underground Argon procurement chain

Urania facility
Industrial scale extraction plant

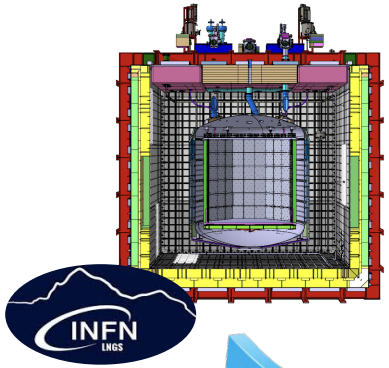


Cortez, **Colorado**

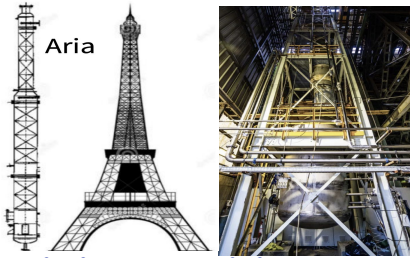
DarT in ArDM



UAr validation
Canfranc, **Spain**



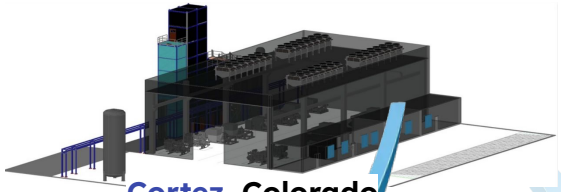
Aria facility
Purification via chemical separation



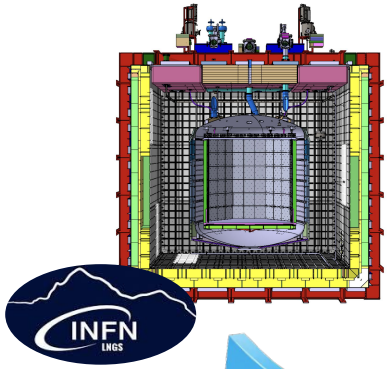
Nuraxi Figus, Sardinia, **Italy**

Underground Argon procurement chain

Urania facility
Industrial scale extraction plant



Cortez, Colorado



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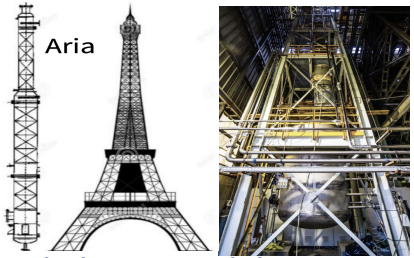

Nuraxi Figus, Sardinia, Italy

DarT in ArDM

UAr validation
Canfranc, Spain

See Celín Hidalgo's talk for more details

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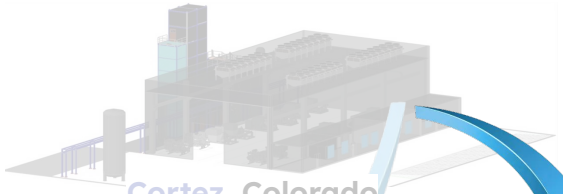

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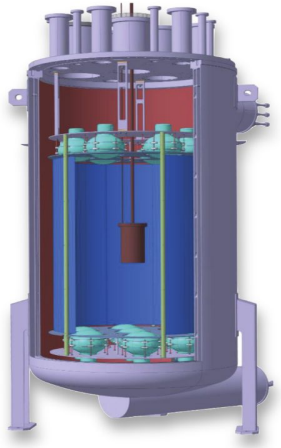

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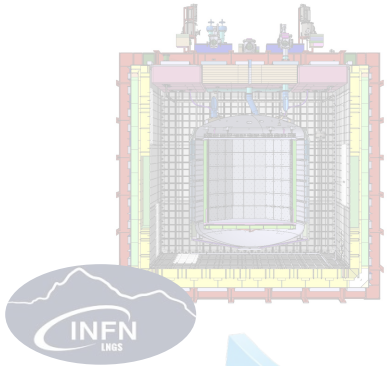

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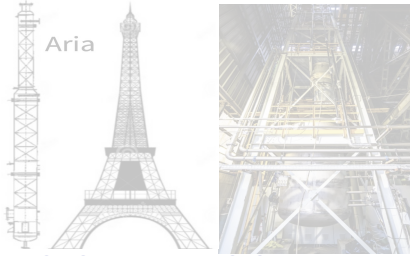


Nuraxi Figus, Sardinia, Italy

Focus of this talk

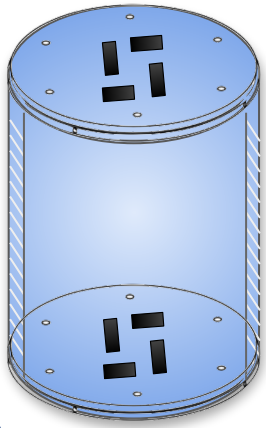
Why and What is DArTinArDM?

Canfranc Underground Lab
2400 m.w.e.

Expected ^{39}Ar concentration ~ 10^{-19} g/g: **beyond reach of ICP-MS**

Exploit the ArDM experiment (~ton-scale **dual-phase TPC**)
Turned into **single-phase detector** → **active veto for DArT**

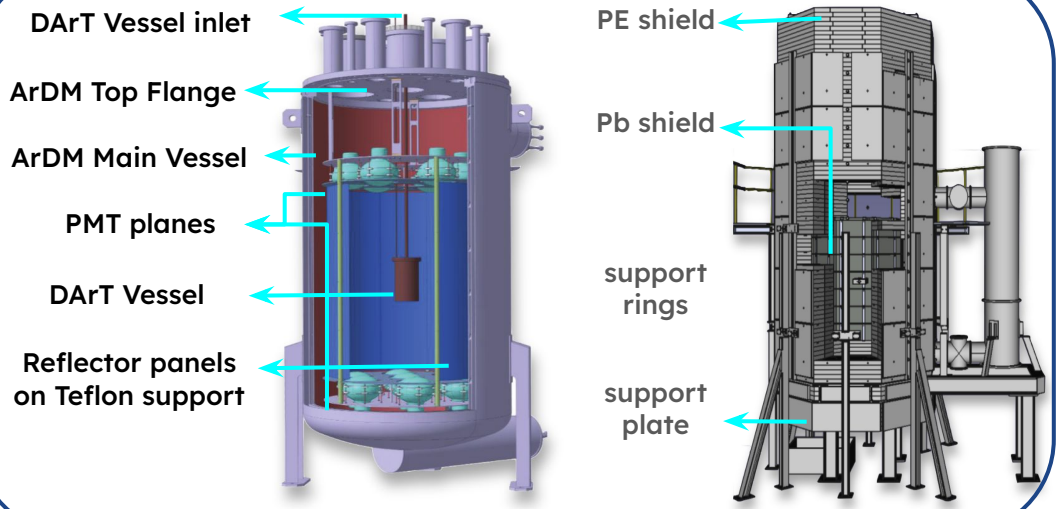
Depleted Argon Test detector



Single phase detector

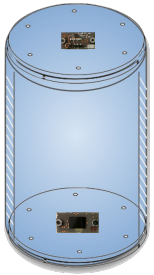
- Photosensors:
  8 × 1 cm² SiPMs
- 1.33 kg LAr active mass
- ESR reflectors
- TPB-coated acrylic

Argon Dark Matter active veto tank



DArT prototype – in test setup

Acrylic structure



2 SiPMs only

1.33kg LAr active mass

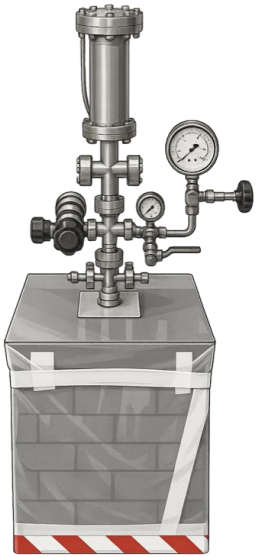
Copper vessel

Indium sealed

SSteel Cryostat

Filled with pressurized LN_2 (2.2 bar, 85 K)

Lead Shield



Flushed with Rn-free air

Goals of the setup

- Continuous performance over weeks
- Operational conditions for the DAQ and electronic
- **Measurement of the ^{39}Ar activity in atmospheric Ar**

+

Parallel operation with the main DArTinArDM detector,
enabling the order-0 quality check before the main detector filling.

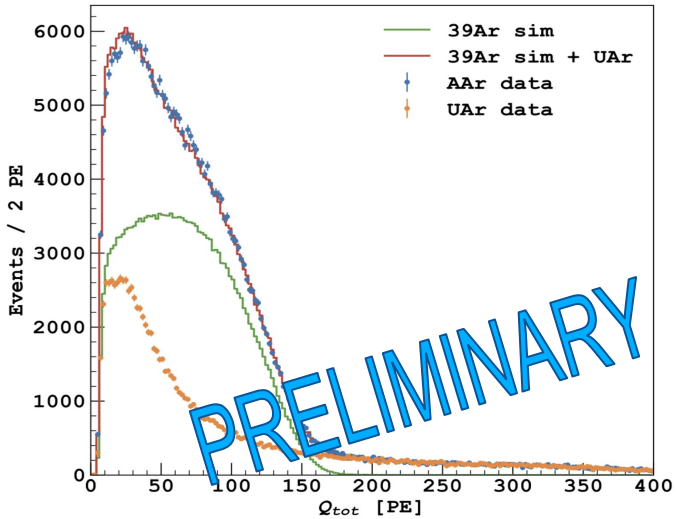
^{39}Ar activity in AAr

Paper under internal review

Integral method

$$A_{AAr} = \frac{N(AAr_{run}) - N(UAr_{run}) \cdot f_{AAr/UAr}}{\varepsilon_{AAr} \cdot t_{AAr}} + a_{UAr} \cdot M_{LAr}$$

$$a_{AAr} = A_{AAr} / M_{LAr}$$

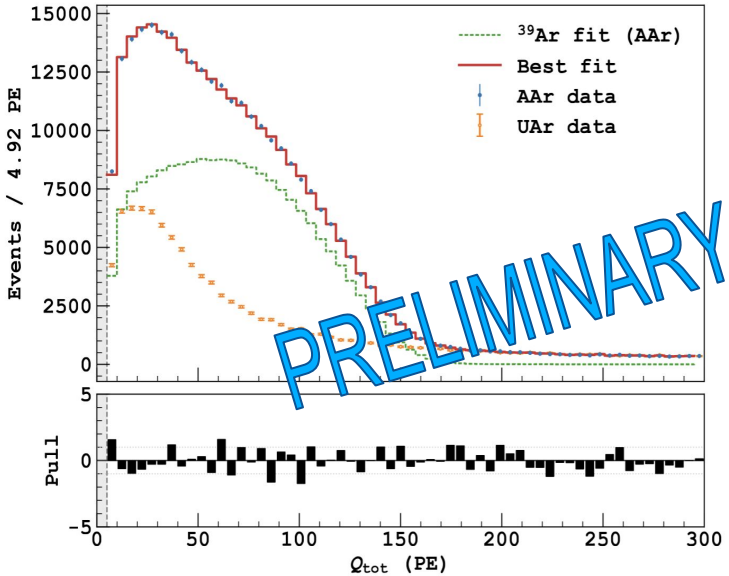


Binned Likelihood fit method

AAr data model ~ UAr + M_{LAr} a_{AAr} ^{39}Ar sim

Free parameters of the fit:

- S_f fine tuning energy scale parameter
- ^{39}Ar activity in AAr a_{AAr}



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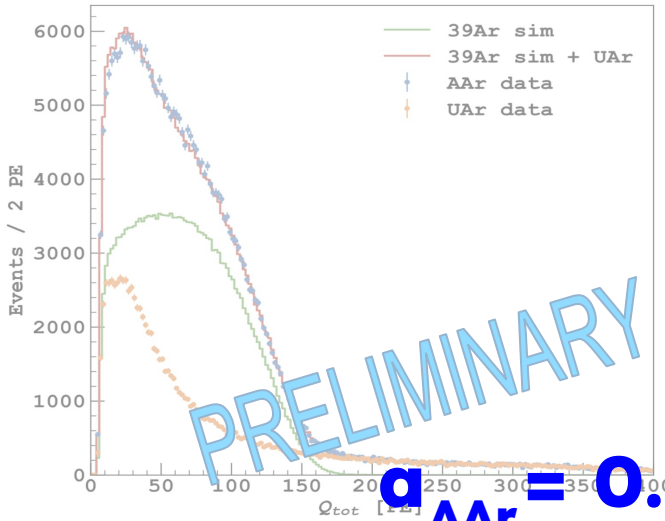
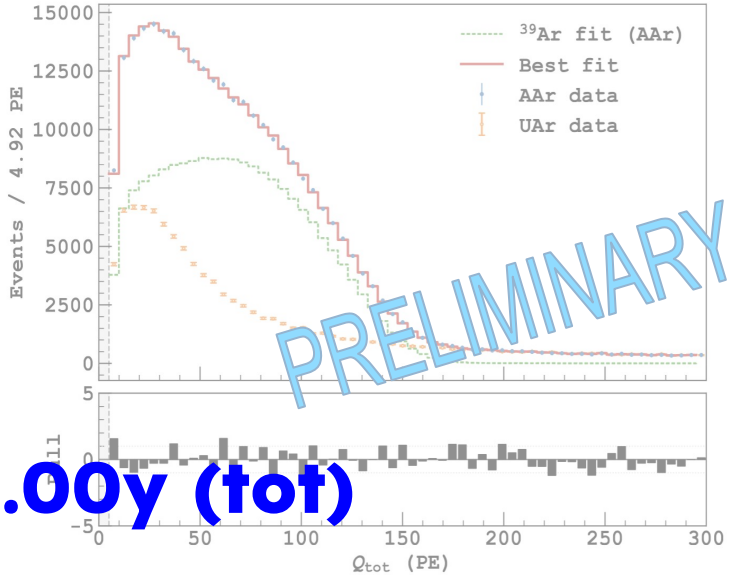




$a_{AAr} = 0.9xx \pm 0.00y$ (tot)

DArT in ArDM

DArT construction

ArDM refurbishment

Integration of DArT in ArDM




- Indium sealing, leak testing
- Filling of ArDM bath with LAAr
- Condensing Ar inside the DArT chamber

Urania & Aria UAr analysis

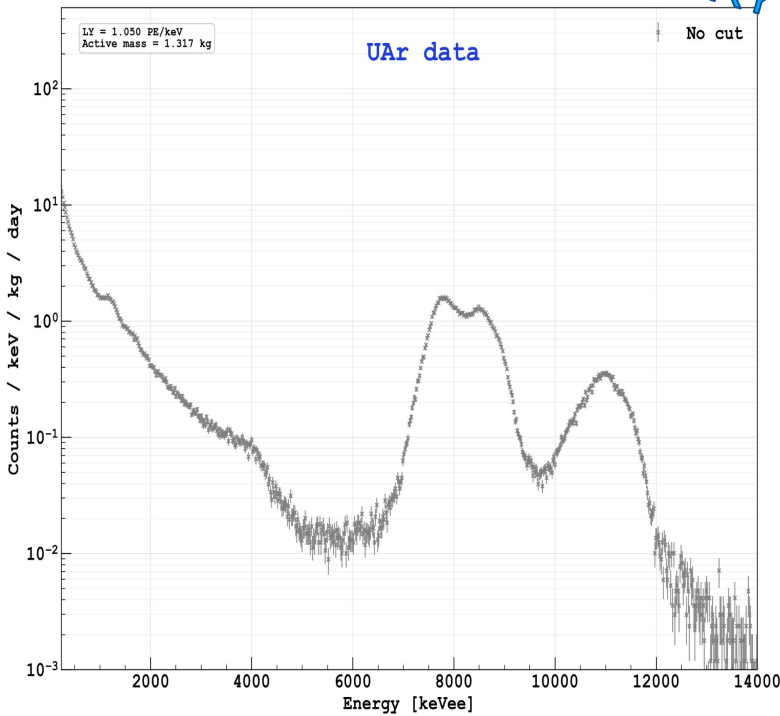
Commissioning data since January 2026

- Fine tuning of the reconstruction
- Definition of analysis workflow
- Argon purity monitor
- Background characterization
- Sensitivity projections

DArT analysis workflow

Raw charge spectrum in DArT detector

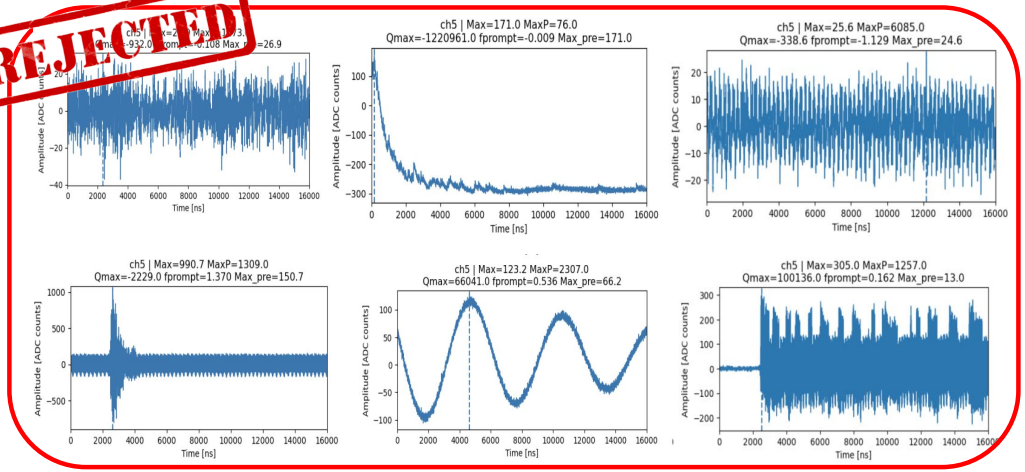
PRELIMINARY



DArT analysis workflow

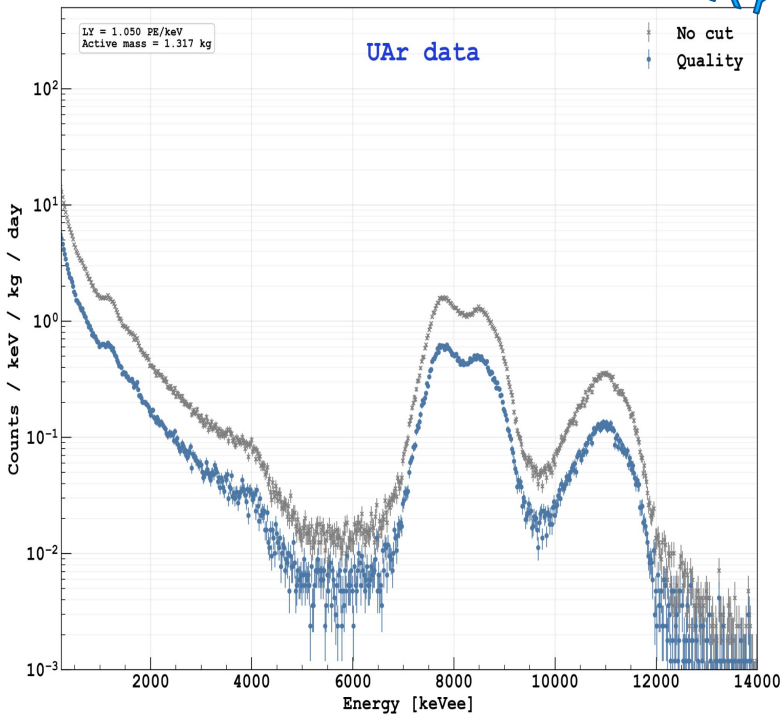
Raw charge spectrum in DArT detector

- **Quality cuts** - noise events rejection



- Software thrs
- |Max| > | x · Min|
- RMS < thrs
- MaxPre < thrs

PRELIMINARY

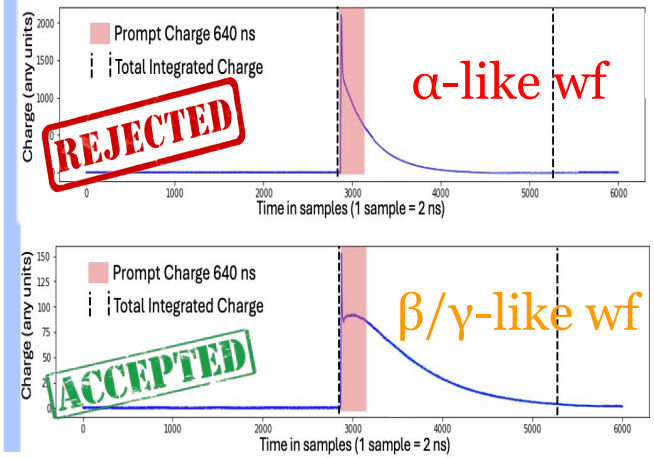


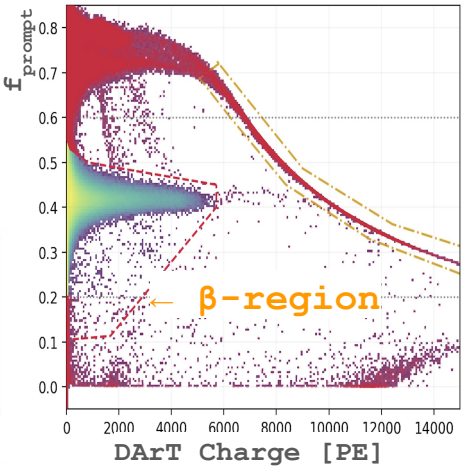
DArT analysis workflow

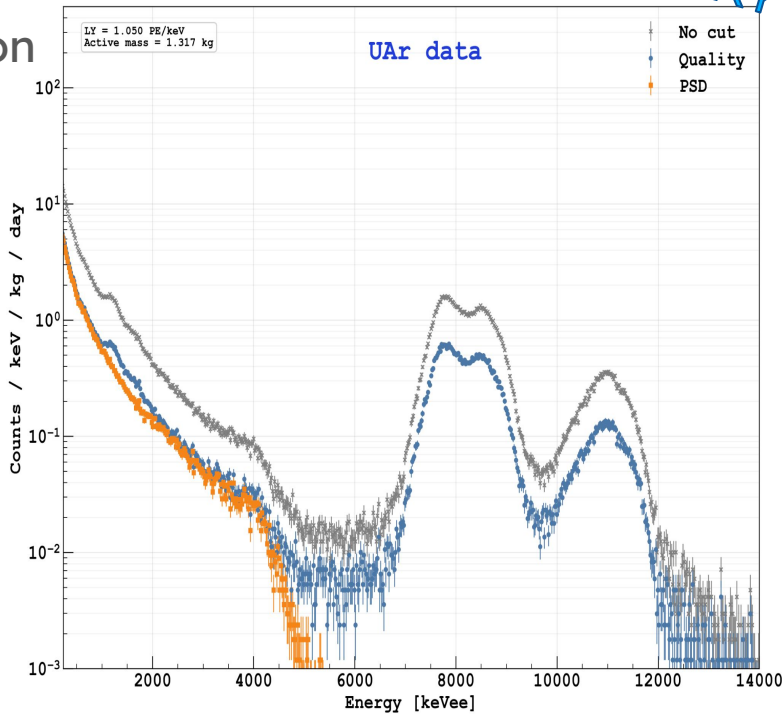
Raw charge spectrum in DArT detector

PRELIMINARY

- Quality cuts - noise events rejection
- **Pulse Shape Discrimination** - α particles rejection





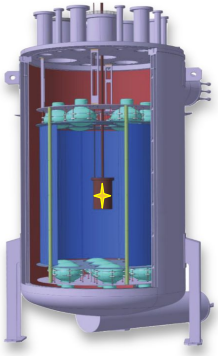


$$f_{prompt} = \frac{\text{Charge(640ns)}}{\text{Charge(full window)}}$$

DArT analysis workflow

Raw charge spectrum in DArT detector

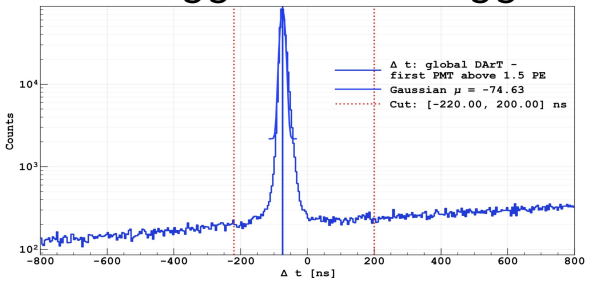
- **Quality cuts** - noise events rejection
- **Pulse Shape Discrimination** - α particles rejection
- **ArDM Veto cut** - internal / external γ rejection



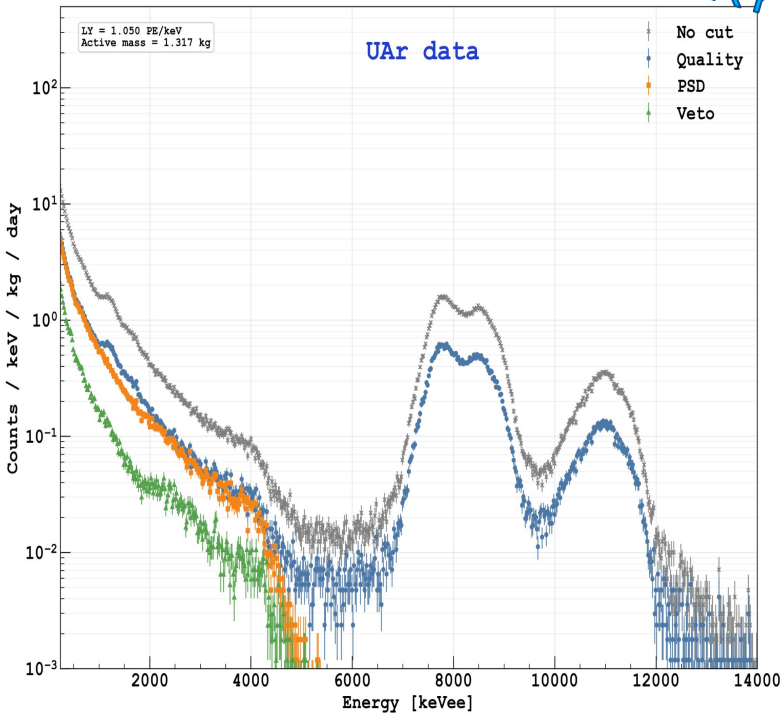
Veto condition:
Within the coincidence window
after a DArT energy deposit
≥3 ArDM PMTs detect ≥ 2 PE each

Veto tagging :
97% from outside (MC)
91% from BiPo (Data)

DArT trigger - ArDM trigger



PRELIMINARY



DArT analysis workflow

Raw charge spectrum in DArT detector

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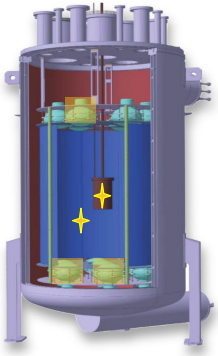
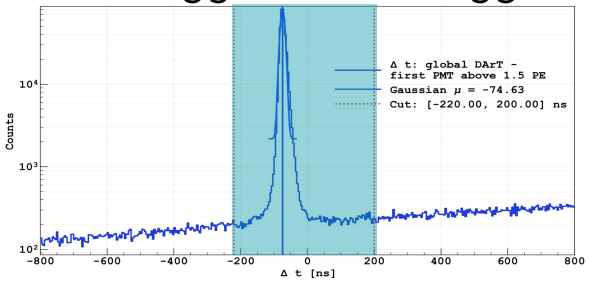
- **Pulse Shape Discrimination** - α particles rejection
- **ArDM Veto cut** - internal / external γ rejection



Veto condition:
Within the **coincidence window**
after a DArT energy deposit
≥3 ArDM PMTs detect ≥ 2 PE each

DArT trigger - ArDM trigger



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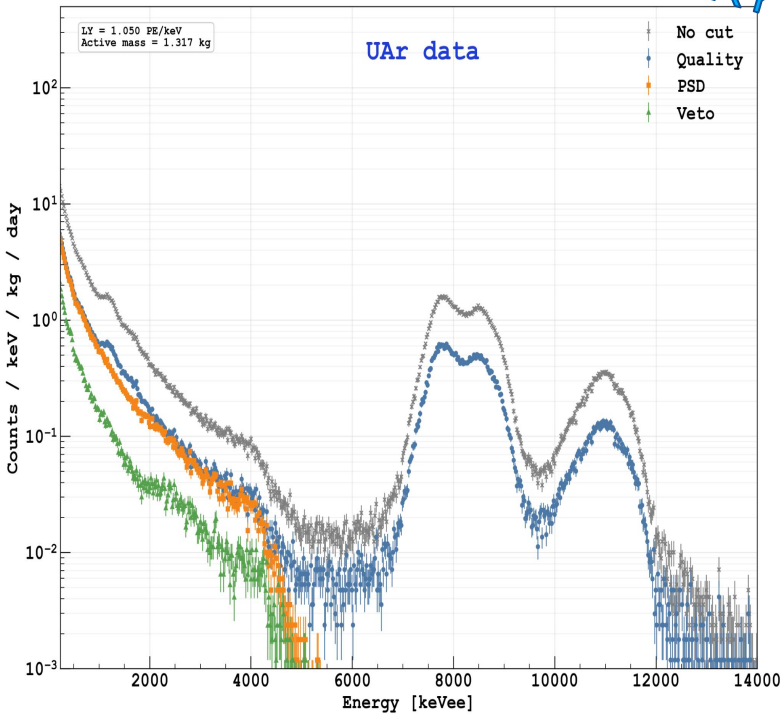

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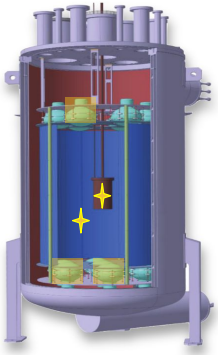
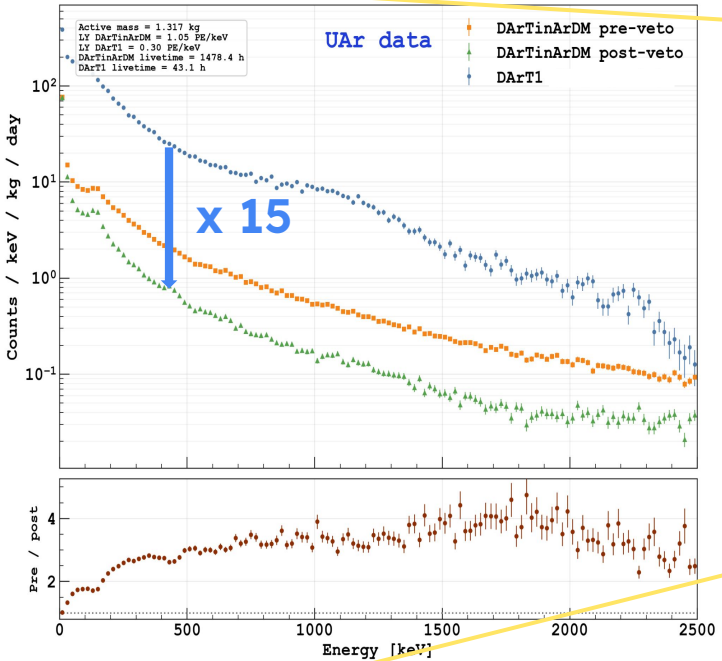
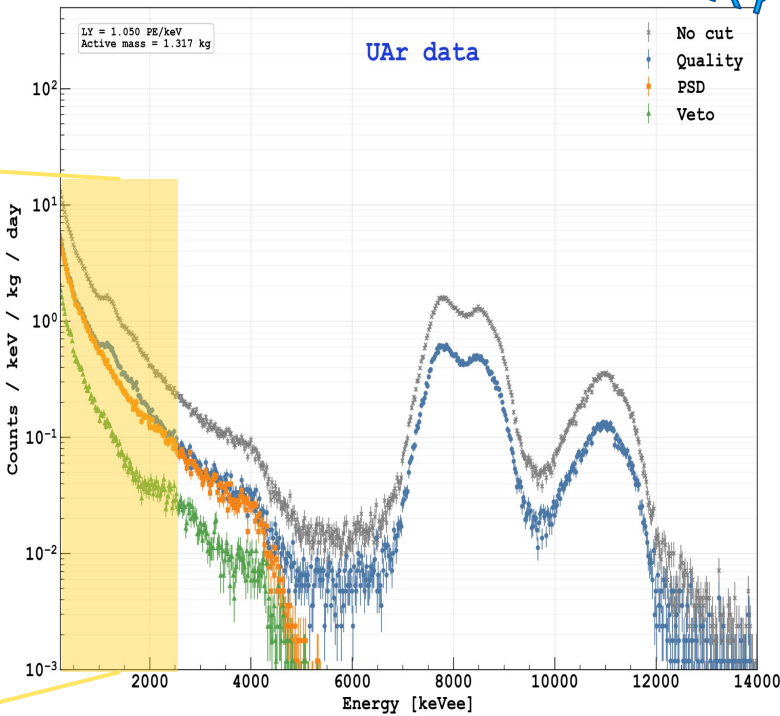




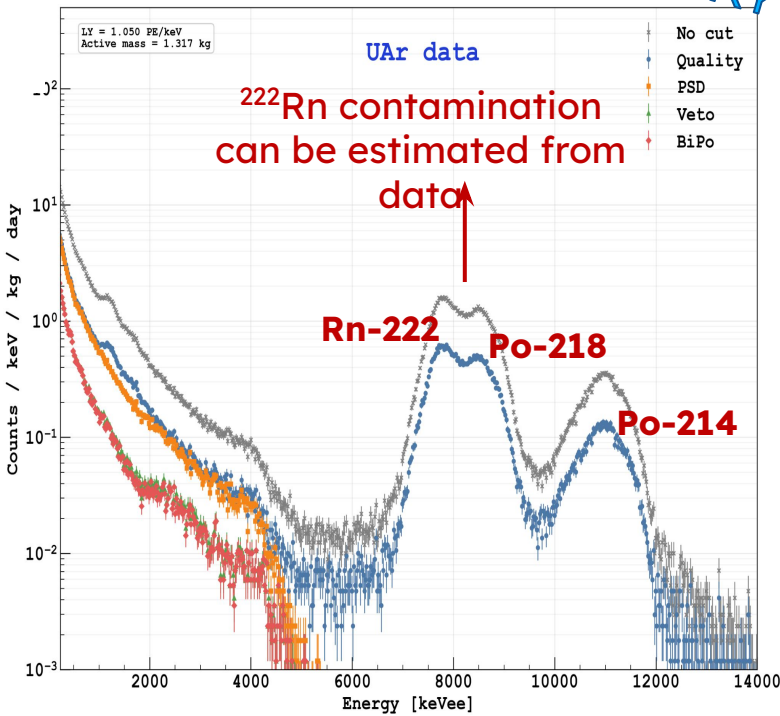


DArT analysis workflow

Raw charge spectrum in DArT detector

- **Quality cuts** - noise events rejection
- **Pulse Shape Discrimination** - α particles rejection
- **ArDM Veto cut** - internal / external γ rejection
- **BiPo cut** - ^{214}Bi rejection

PRELIMINARY



DArT analysis workflow

Raw charge spectrum in DArT detector

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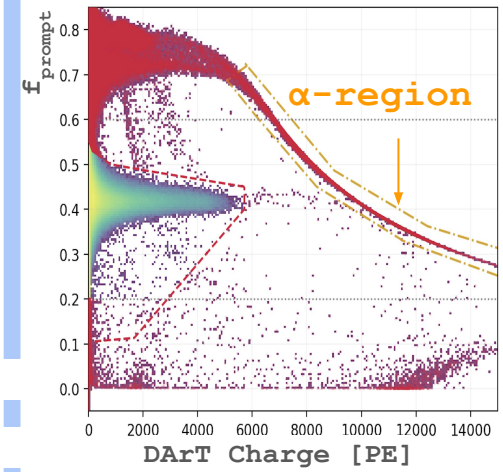
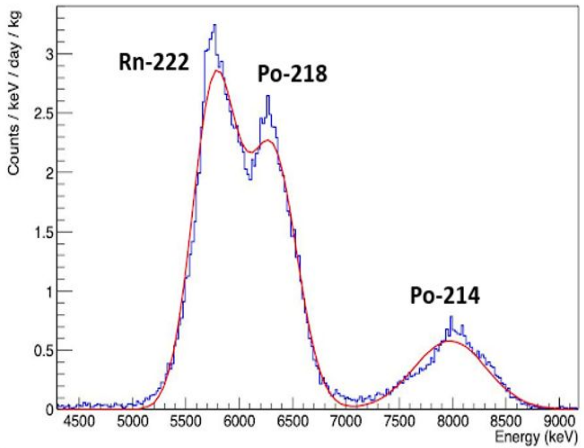
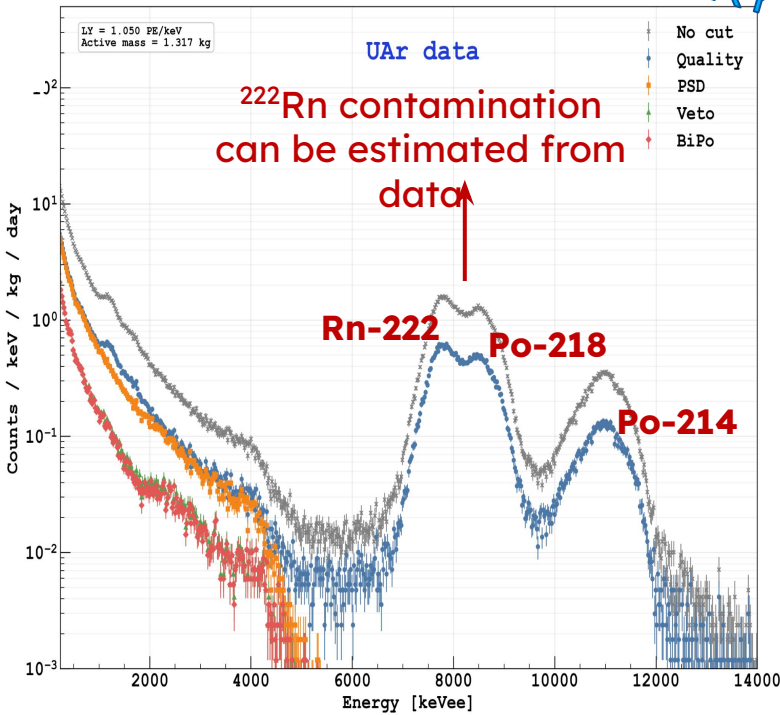




Fitted peaks	Rate (Hz)
^{222}Rn 26760 events / 397.06h	→ 0.018
^{218}Po 23698 events / 397.06h	→ 0.016
^{214}Po 9383 events / 397.06h	→ 0.006



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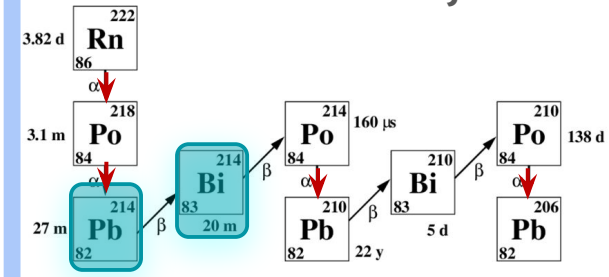
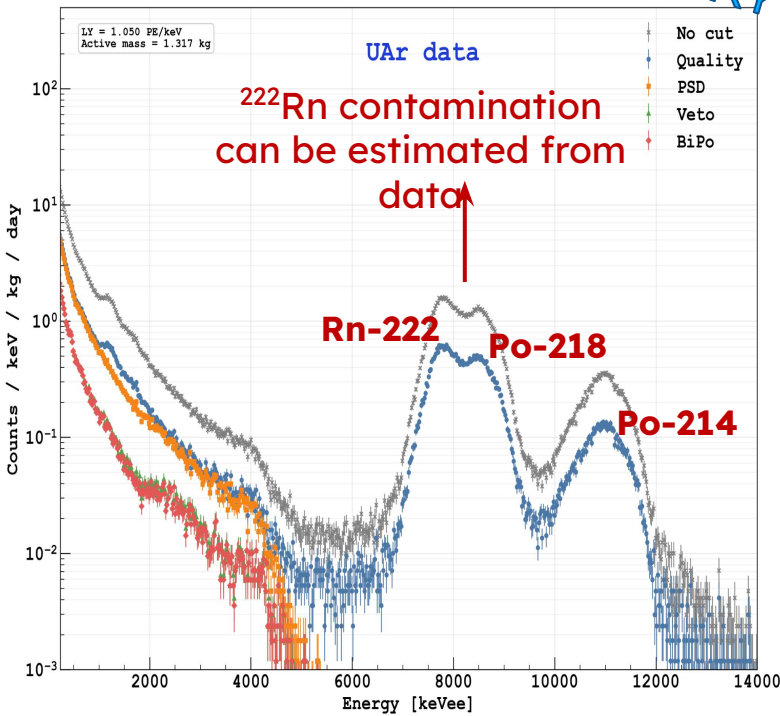


α_s → out of the ^{39}Ar ROI

β_s → of **^{214}Pb** and **^{214}Bi** in the ^{39}Ar ROI

PRELIMINARY



DArT analysis workflow

Raw charge spectrum in DArT detector

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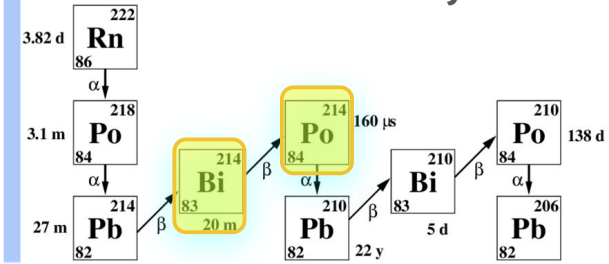
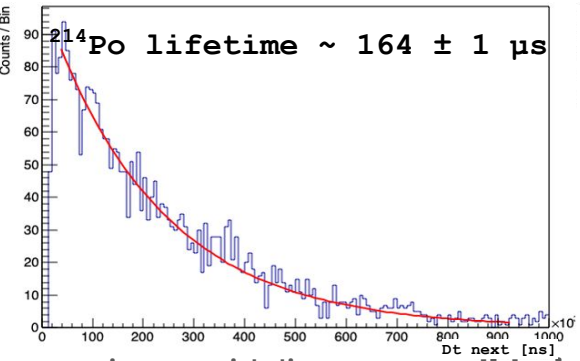
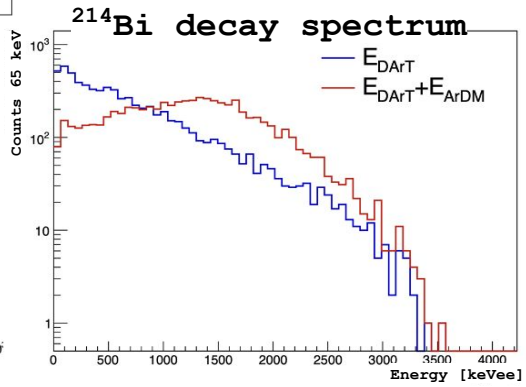


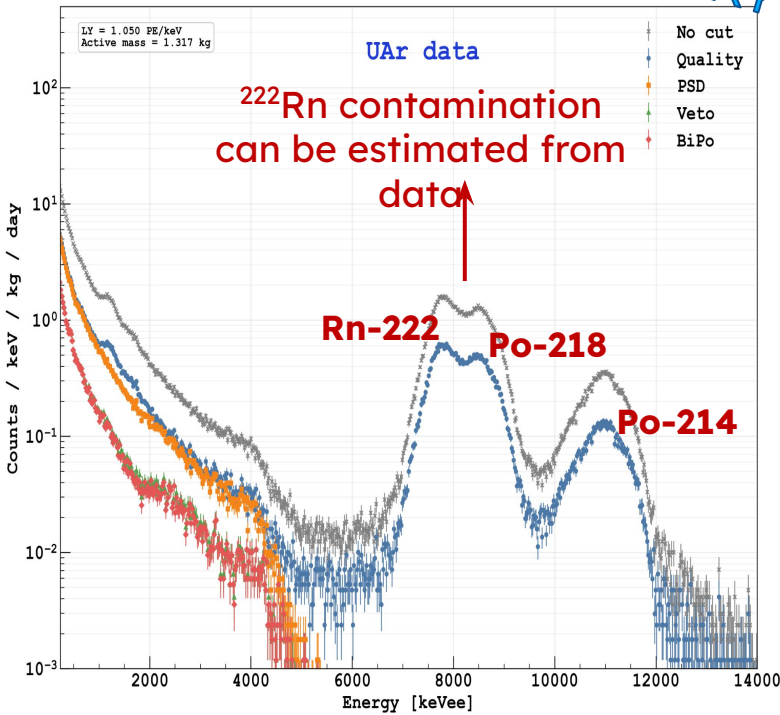
^{214}Bi signature:
β followed by an α in a time window coincidence.





consistent with literature, **validating** event timing and Rn-chain identification.

reconstructed by $E_{DArT}+E_{ArDM}$

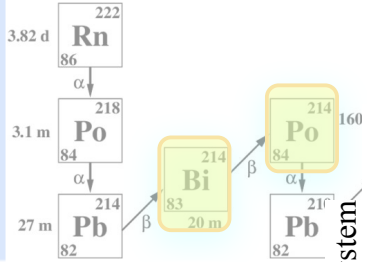


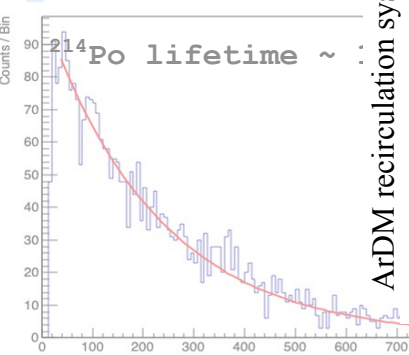
DArT analysis workflow

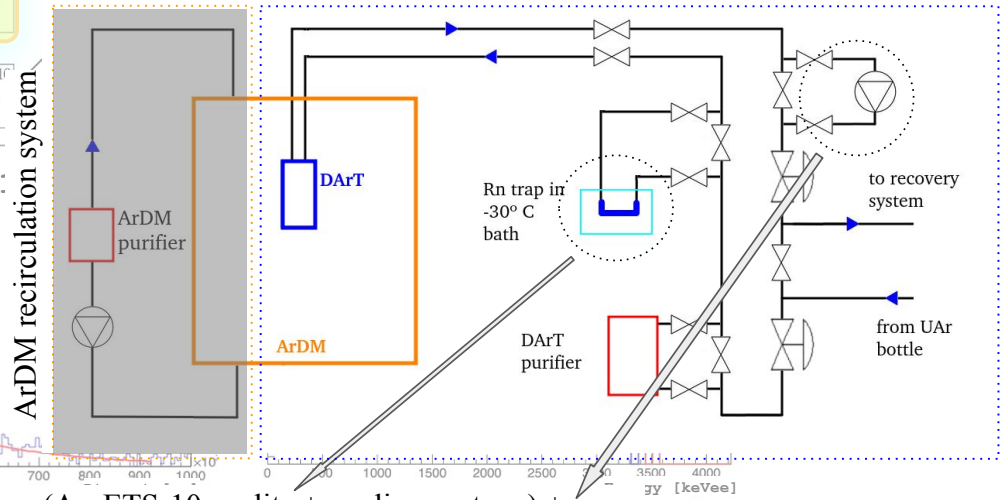
Raw charge spectrum in DArT detector

- Quality cuts - noise events rejection
- Pulse Shape Discrimination - α particles rejection
- ArDM Veto cut - internal / external γ rejection
- BiPo cut - ^{214}Bi rejection

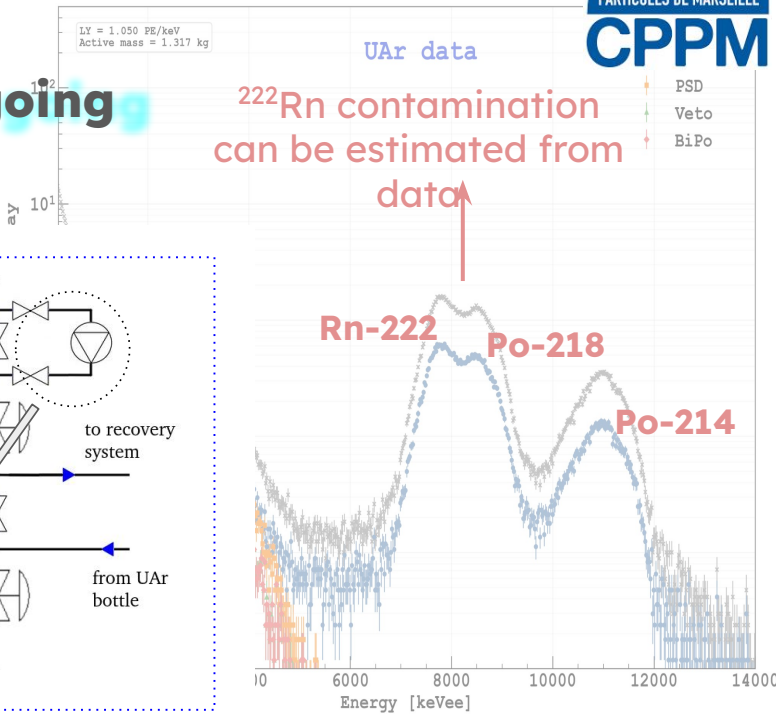
A Rn trapping system is going to be installed







(Ag-ETS-10 zeolite + cooling system) + pump



consistent with literatur… event timing and Rn-chain identification.

reconstructed by $E_{DArT}+E_{ArDM}$

DArT analysis workflow

Raw charge spectrum in DArT detector

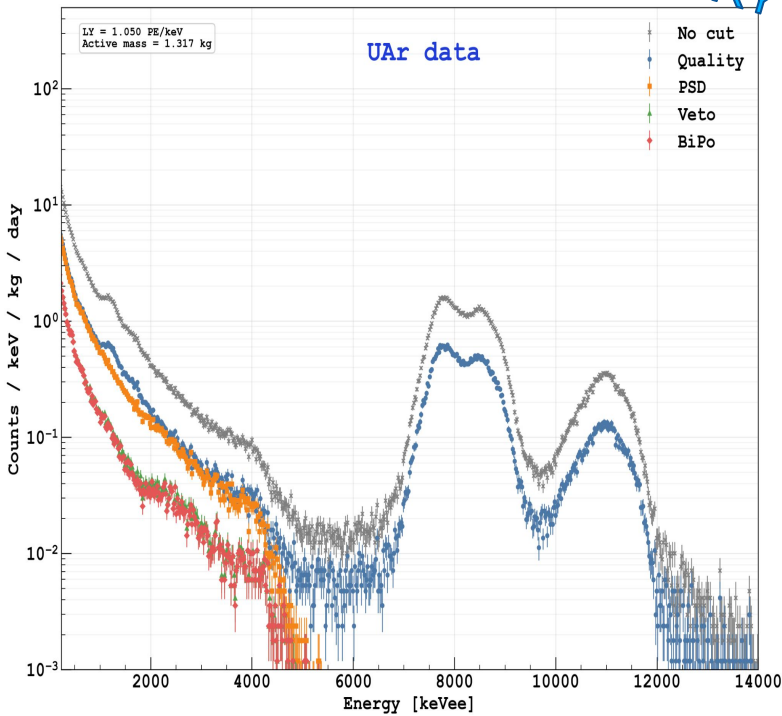
- **Quality cuts** - noise events rejection
- **Pulse Shape Discrimination** - α particles rejection
- **ArDM Veto cut** - internal / external γ rejection
- **BiPo cut** - ^{214}Bi rejection

Final charge spectrum

Rate after analysis cuts:

~ 40 mBq

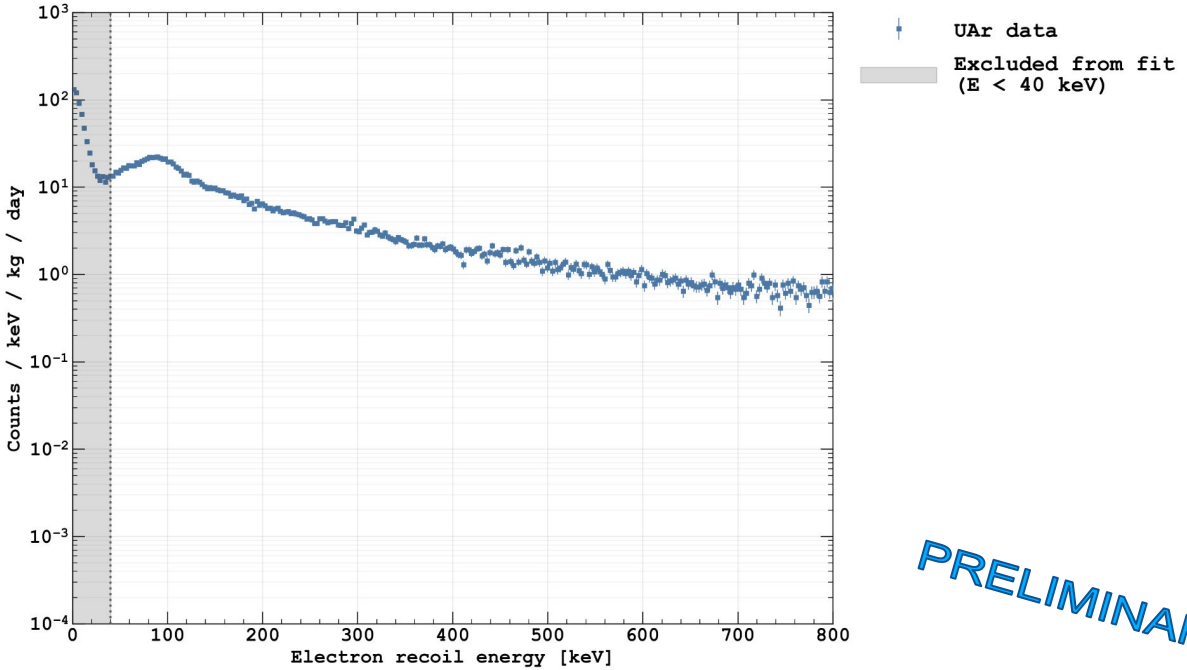
PRELIMINARY



Data driven sensitivity projections

From measured spectra to ^{39}Ar sensitivity

Binned profile-likelihood fit in the 40-600 keV window; Frequentist CLs evaluation in RooFit/RooStats



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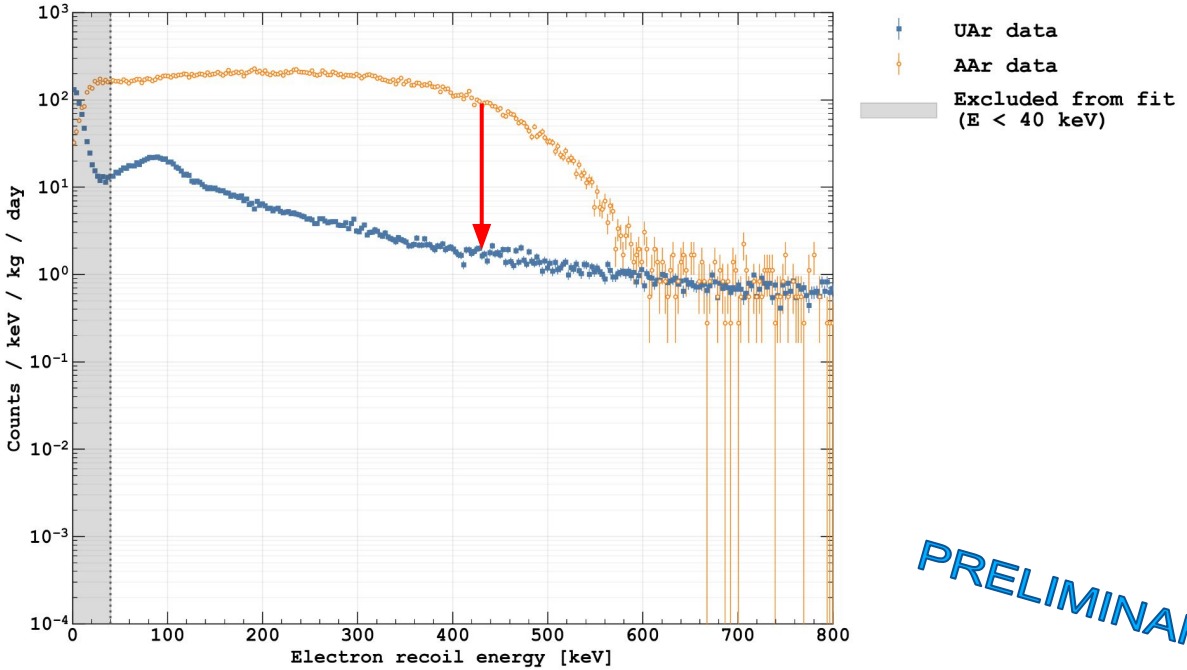
^{39}Ar signal template:
AAr - UAr



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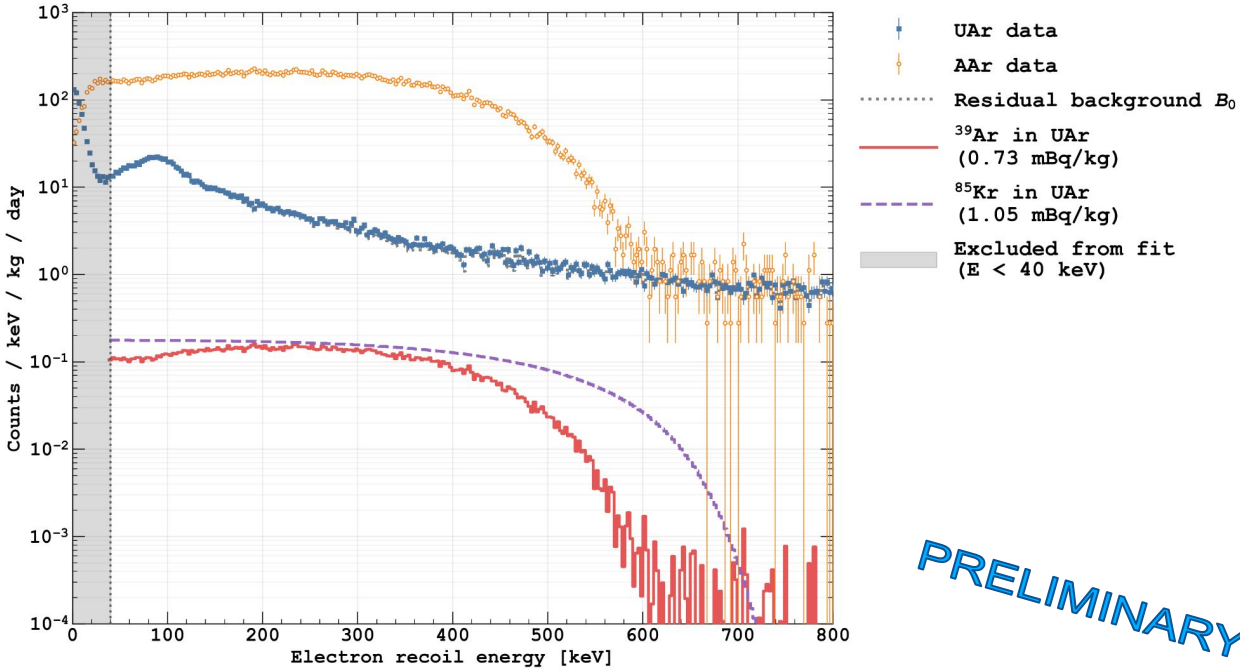
^{39}Ar signal template:
AAr - UAr

Background model:
UAr - ^{39}Ar - ^{85}Kr simulated

Reference activities:
(measured by DS-50 TPC)
UAr ^{39}Ar = 0.73 ± 0.11 mBq/kg
UAr ^{85}Kr = 1.05 ± 0.13 mBq/kg



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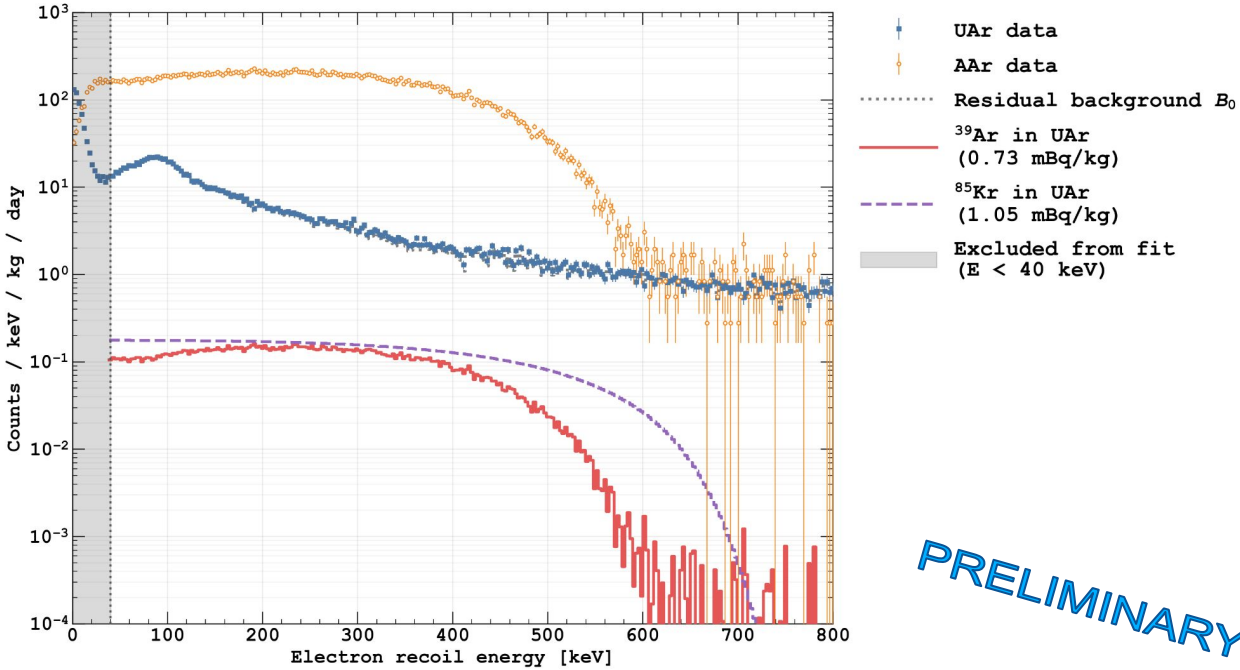
Toy-MC sensitivity

$$\lambda_i = B_{o,i} + \alpha_{Ar,UAr}\, {}^{39}Ar_{,i} + \alpha_{Kr,UAr}\, {}^{85}Kr_{,i} + \mu\, {}^{39}Ar_{,i}$$

Minimal **^{39}Ar activity** to which we are sensitive:



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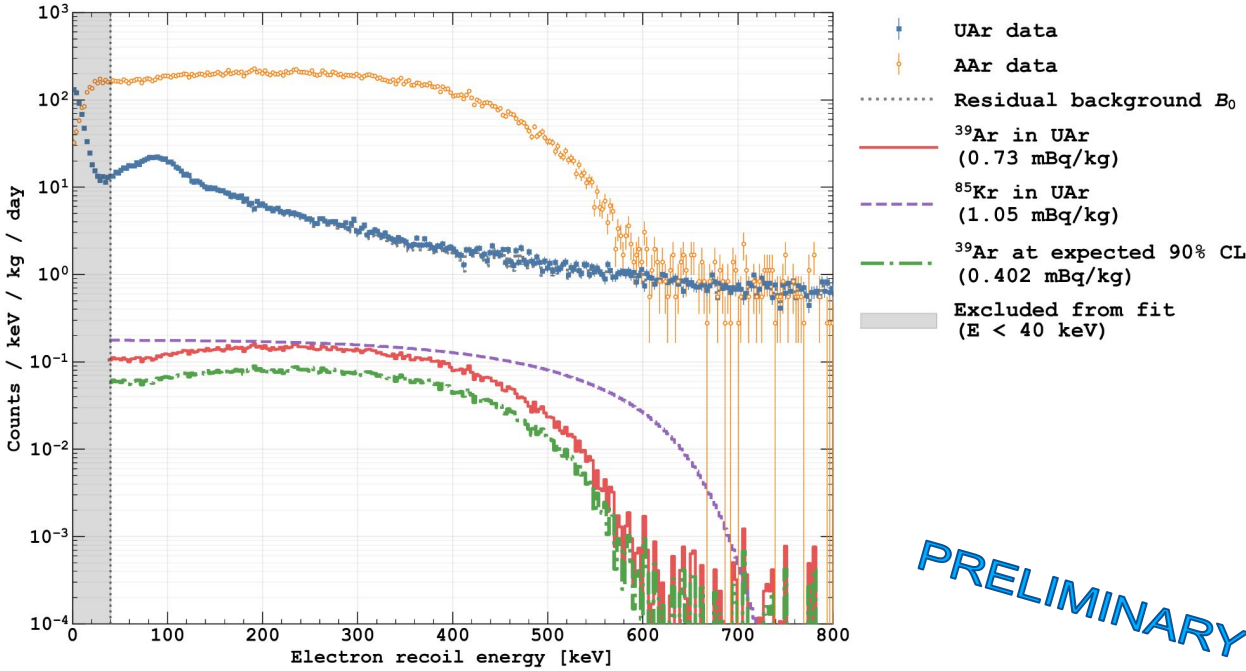
Minimal **^{39}Ar activity** to which we are sensitive:

1.3 months x kg exposure:
0.42mBq/kg at 90% C.L.



Conclusions & Outlook

The Need for UAr

Crucial to **suppress the ^{39}Ar background for DarkSide-20k** rare event searches.

DArTinArDM Fully Operational

DArT chamber successfully **integrated** into **ArDM active veto**;
DArT prototype running **parallel** for fast quality checks.

Stable Operations & Proven Sensitivity

Robust **workflow** (PSD, Veto, BiPo cuts)
Data-driven 39Ar sensitivity of **0.42 mBq/kg @ 90% C.L. achieved.**

Ongoing Efforts & Future Prospects

Finalizing **MC simulations** (G4DS framework) to characterize all **backgrounds sources.**
The setup is **ready to analyze UAr batches** for DS-20k, coming by the end of the year

UAr will play a pivotal role in future DM searches, 0 νββ, CEνNS, and beyond.
Stay tuned!

Thank you!

LOW RADIOACTIVITY TECHNIQUES 2026 WORKSHOP X

21st–24th September 2026
The Guildhall, York

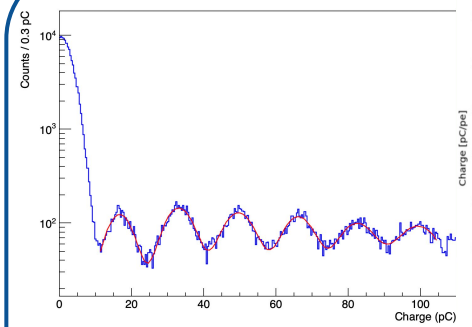
Backup

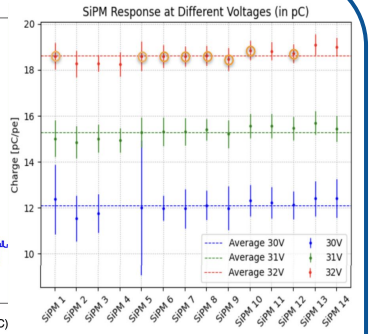
LOW RADIOACTIVITY TECHNIQUES 2026 WORKSHOP X

21st–24th September 2026
The Guildhall, York

DArT in ArDM - Depleted Argon Test construction

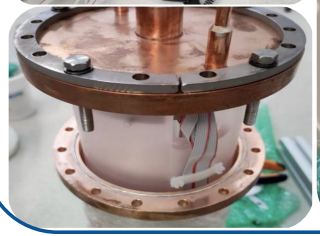
SiPMs characterization

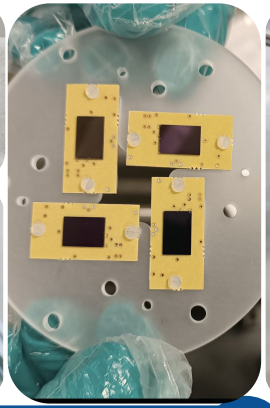




8 SiPMs showing similar gain were chosen

Assembly



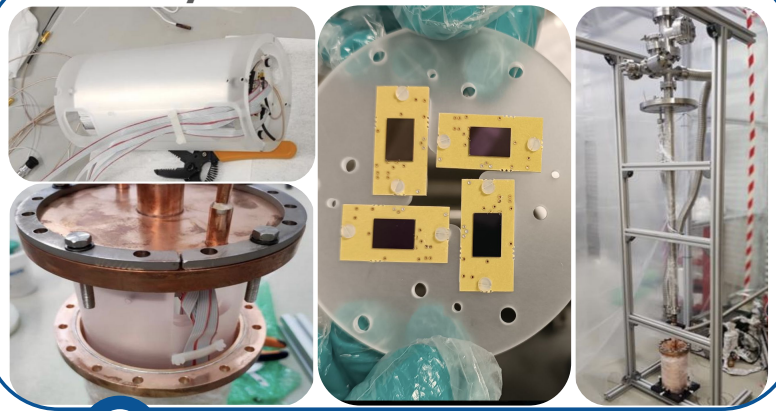


Cleaning of the pieces

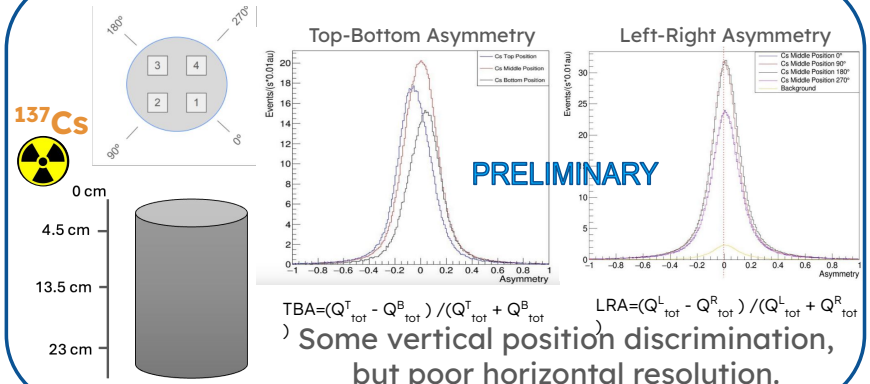
Isopropanol solution
Ultrasonic bath

DArT in ArDM - D epleted Ar gon T est construction

Assembly

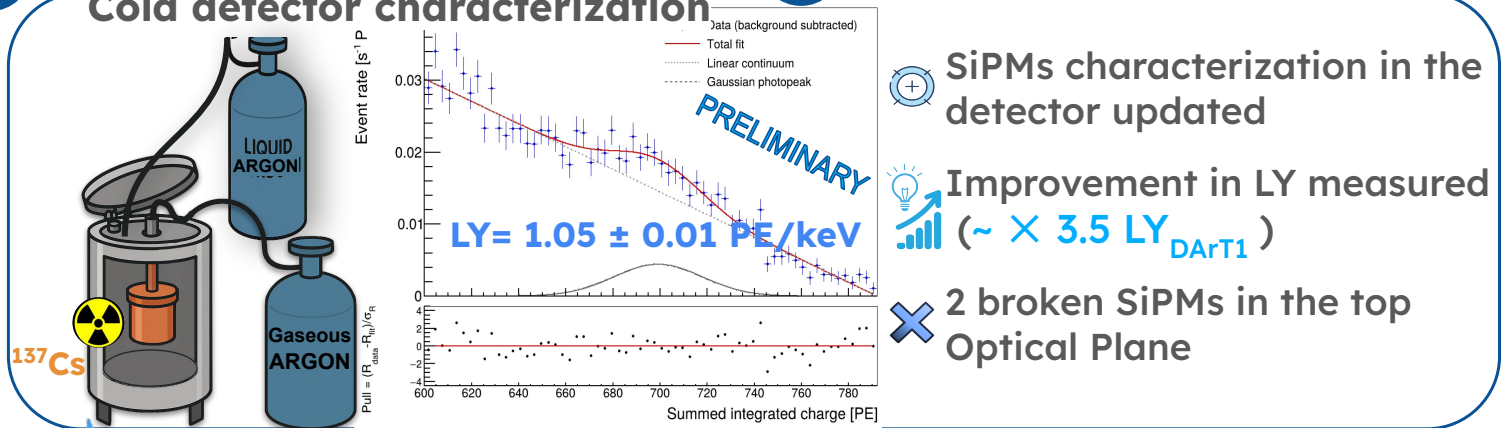


Position reconstruction



Some vertical position discrimination, but poor horizontal resolution.

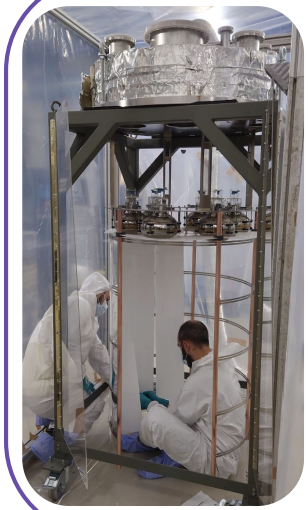
Cold detector characterization



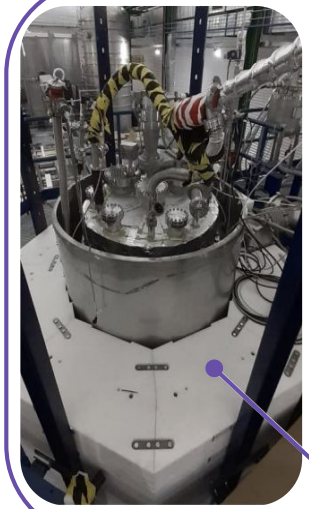
- SiPMs characterization in the detector updated
- Improvement in LY measured (~ × 3.5 LY_{DArT1})
- 2 broken SiPMs in the top Optical Plane

DArT in ArDM – Ar gon Dark Matter refurbishment

… from double to single phase



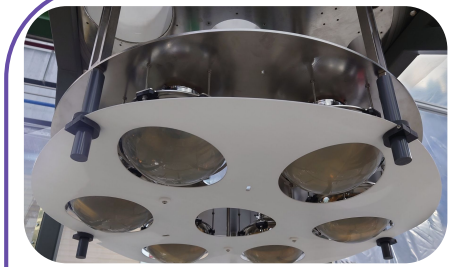
New field cage

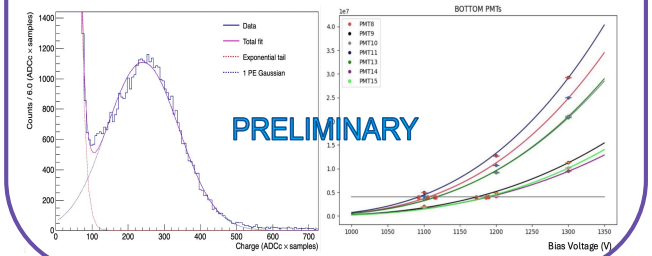


Pb shield

HDPE shield

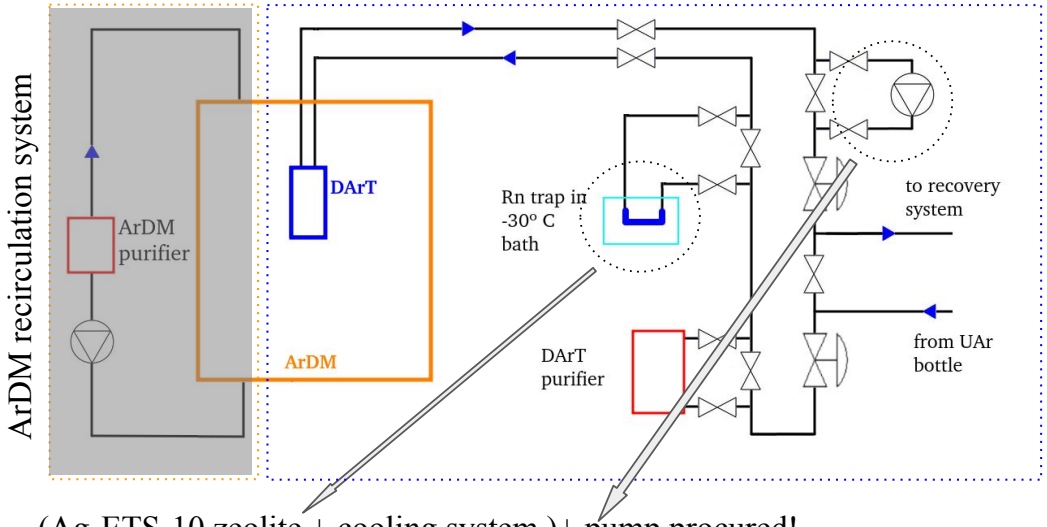
New Lead shield (~6t)



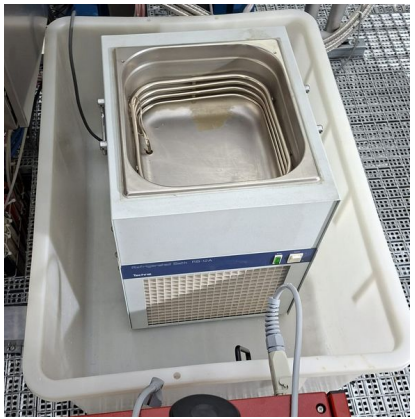


PMTs equalization

Rn trap installation



(Ag-ETS-10 zeolite + cooling system)+ pump procured!

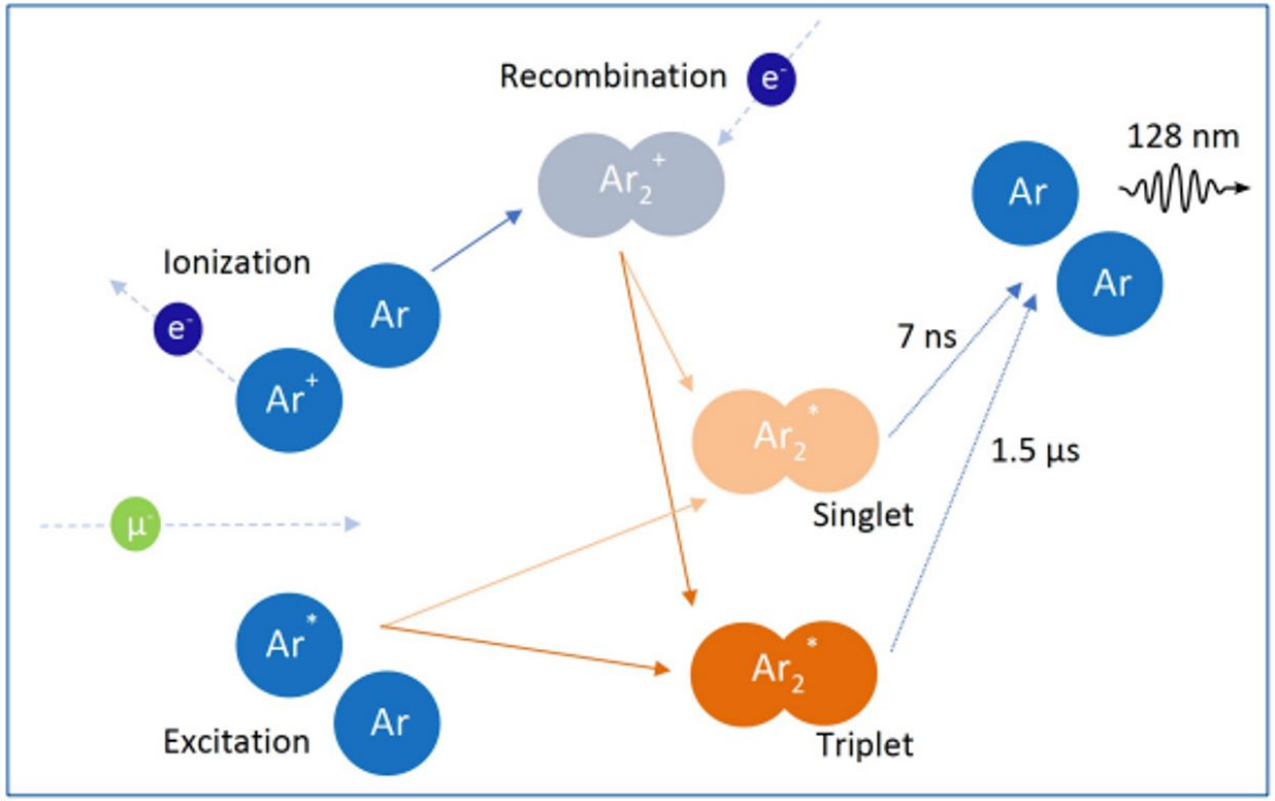


Cooling system

Pump

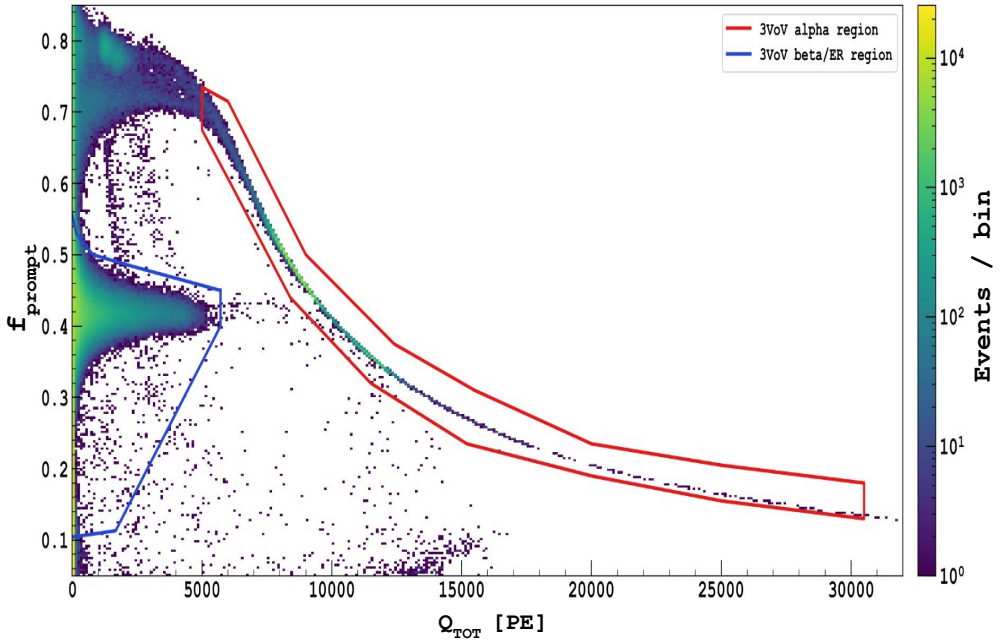
- UAr will pass through hot getter first and Rn trap later.
- Ag-ETS-10 zeolite trap operated in a -30ºC bath to enhance the Rn absorption.
- Rn is delayed in the trap while Ar flows through, which allows the Rn-222 to decay before reaching the detector.
- Given the current impedance of the filter + trap we can achieve ~ 1 slpm flow
- This reduces internal Rn-chain backgrounds, especially ^{214}Pb/^{214}Bi, relevant for the ^{39}Ar assay.

Ar Excitation and ionization process



DArT analysis workflow

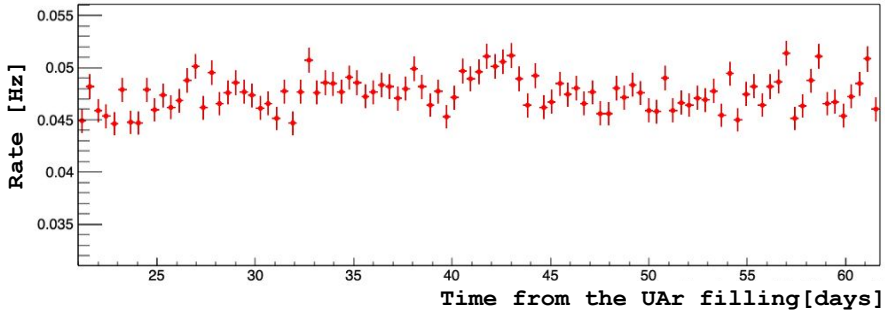
Rates variation



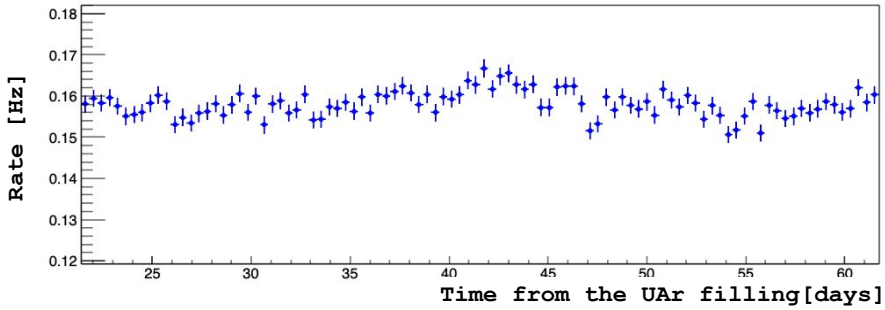
After noise rejection cuts
(Q_{TOT} > 40 pe)

Event rate stable over more than 60 days!

Alpha events rate



Beta events rate



UAr in other experiments: Legend-1000

- LEGEND-200: Initial phase deploying ~200 kg of enriched germanium detectors (^{76}Ge) in LAr @LNGS. Taking data with ~140 kg.
- LEGEND-1000: Planned to employ 1t of ^{76}Ge in UAr.

Intrinsic activity of ^{42}Ar in AAr

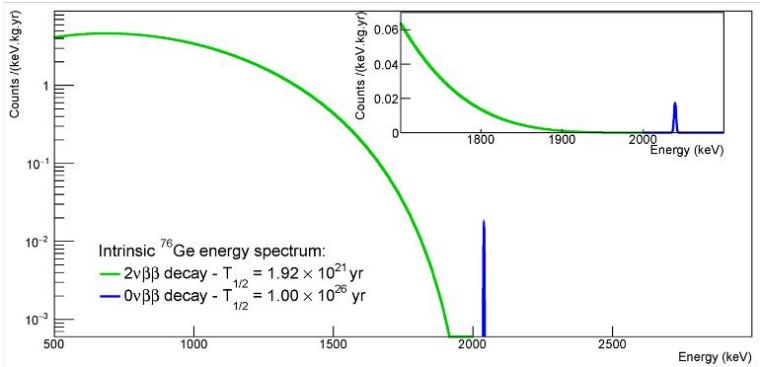
^{42}Ar

Cosmogenic: 40Ar(α, 2p)42Ar
β- decay to 42K with Qβ = 599 keV
t1/2 = 32.9 y
40.4 ± 5.9 μBq/kg
42K is a β- with a t1/2 = 12.4 h
β- decay to 42Ca with Qβ = 3.5 MeV

Same ROI of the $\beta\beta$ decay of ^{76}Ge: $Q_{\beta\beta}$ = 2.04 MeV

LEGEND-1000

LEGEND-200

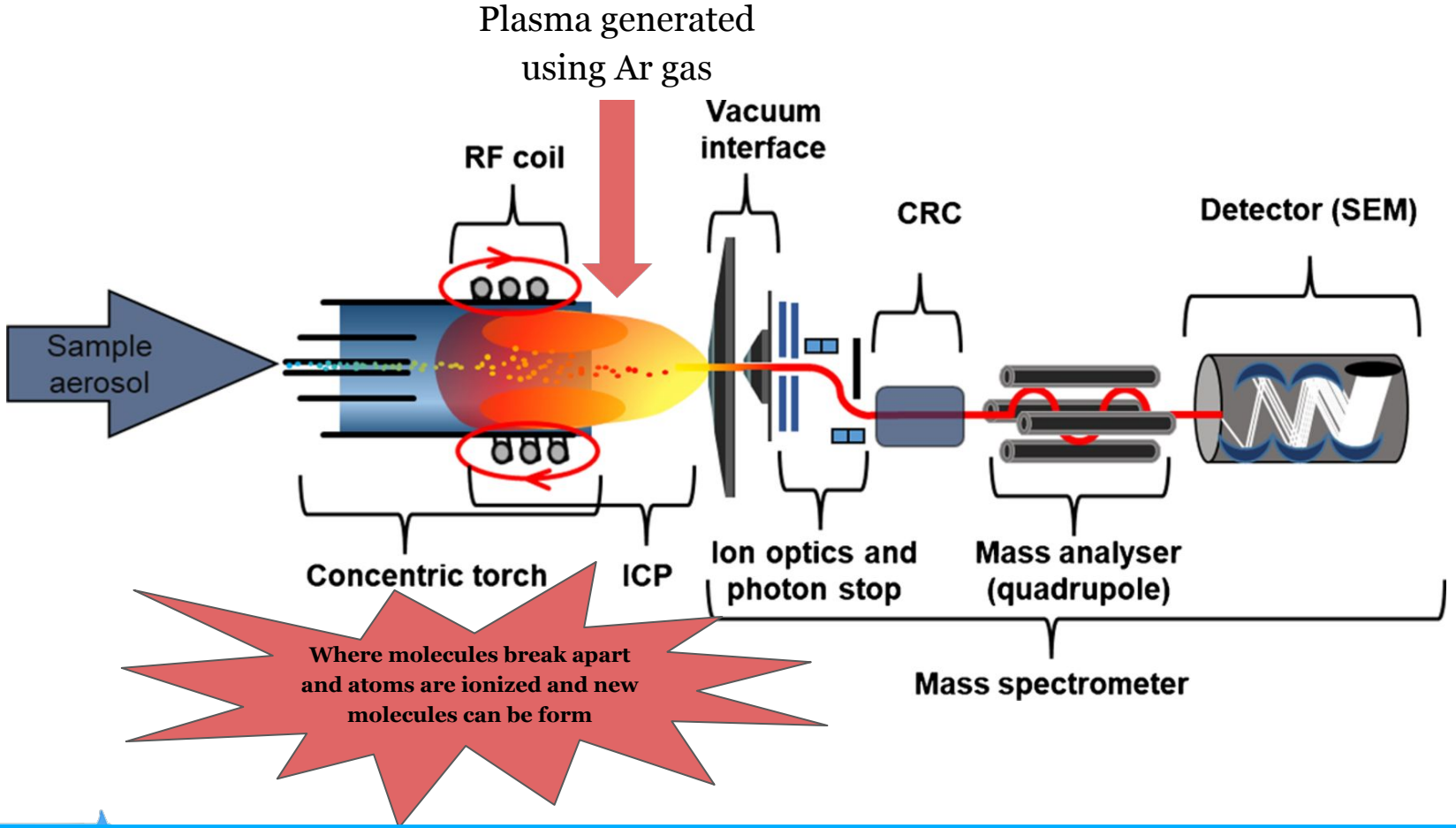


ICP-MS Analysis with the UAr of Ds-50

- There are some masses, corresponding to the most abundant elements in the gas and its interferences, that the ICP-MS doesn't measure → Forbidden Masses
- The ICP-MS has two different working modes:
  - Standard mode (STD).
  - With collision cell: to reduce the spurious signal given by polyatomic ions: collision with a non-reactive gas (He).

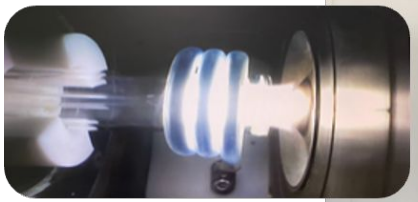
  This process is called kinetic energy discrimination (KED).
  In KED mode some masses forbidden in STD mode can be measured.

ICP-MS Scheme

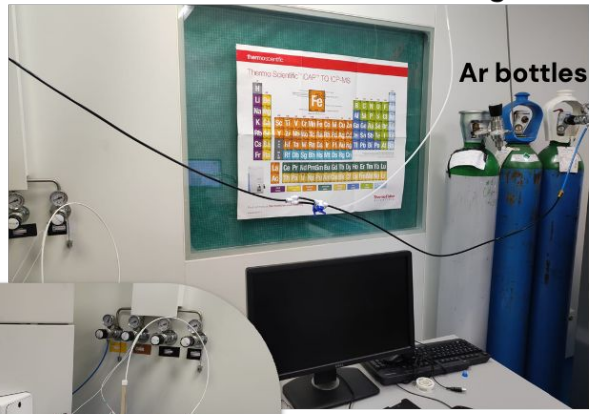


ICP-MS Setup

Plasma



Valves for bottle switching



Nebulizer

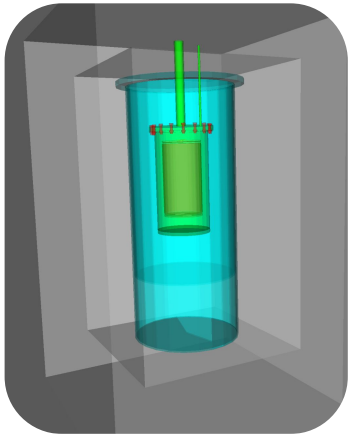
DArT1 in test setup - full simulation chain

Optical Simulation

Energy deposition

⬇️

Photon absorption



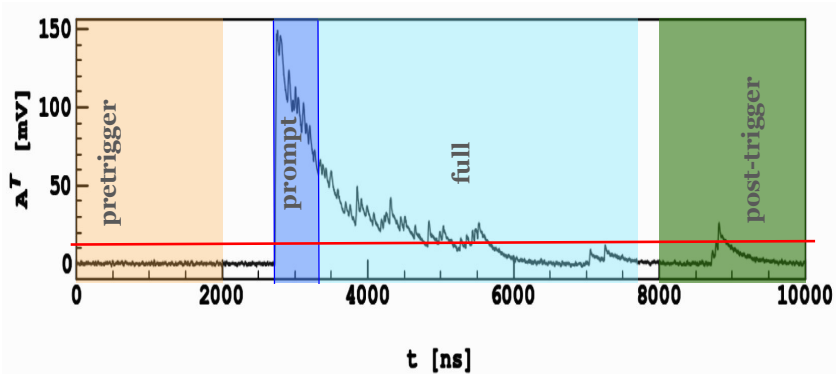
@g4ds package
Agnes et al 2017 JINST 12 P10015

Electronic simulation

Photon absorption

⬇️

Waveforms generation



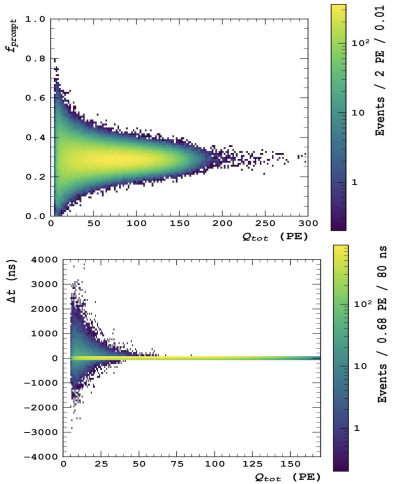
@ dslab

Reconstruction

Waveforms generation

⬇️

Physical observables

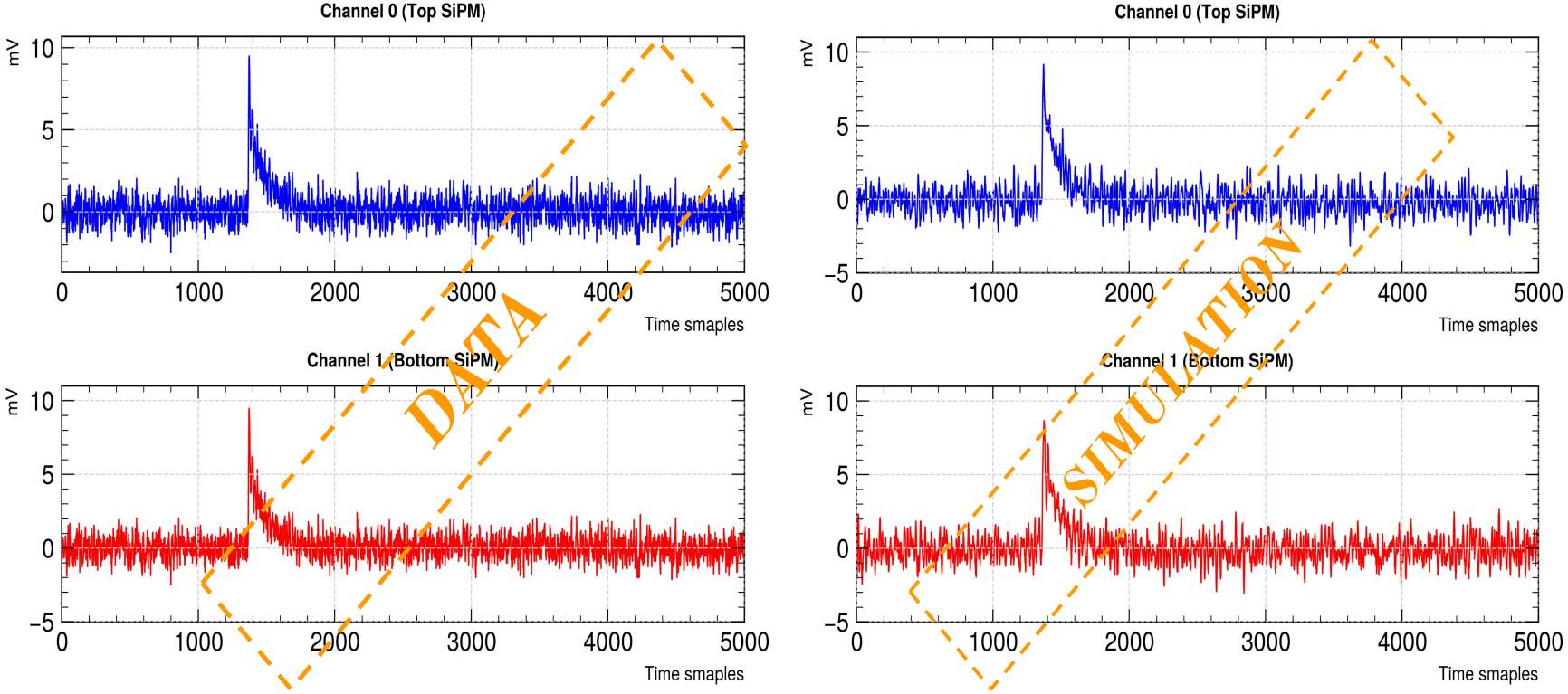


@ pyreco

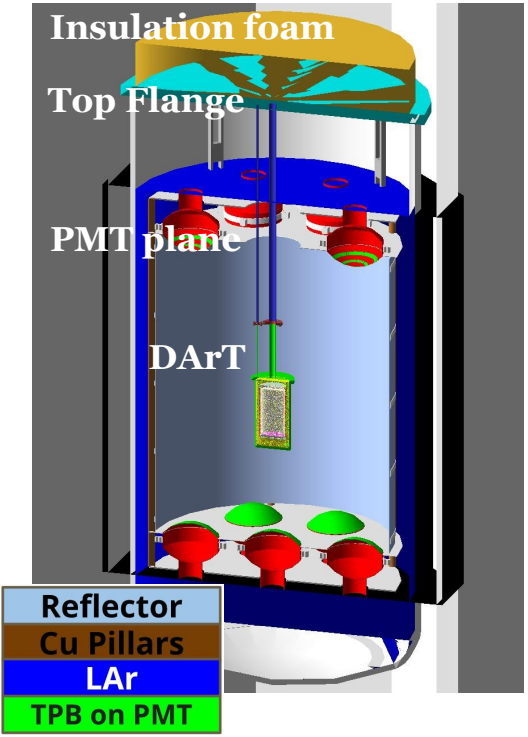
DArT1 in test setup - full simulation chain

Good agreement between data and simulations

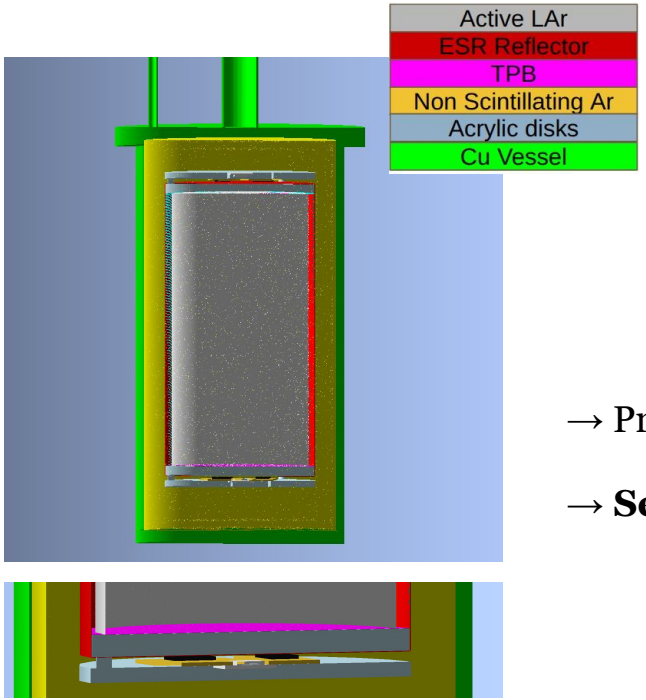
- Waveform level



DArT in ArDM simulation in G4DS11 - status



ArDM refurbished geometry
and materials are **implemented**.



DArT2 geometry implemented
Minor integrations of biasing, signal wires and metal pieces in the PCB are ongoing

Background simulations (external + material)

→ Precise **background estimation**

→ **Sensitivity update**