

Underground argon for rare event searches: DarkSide-20k and beyond

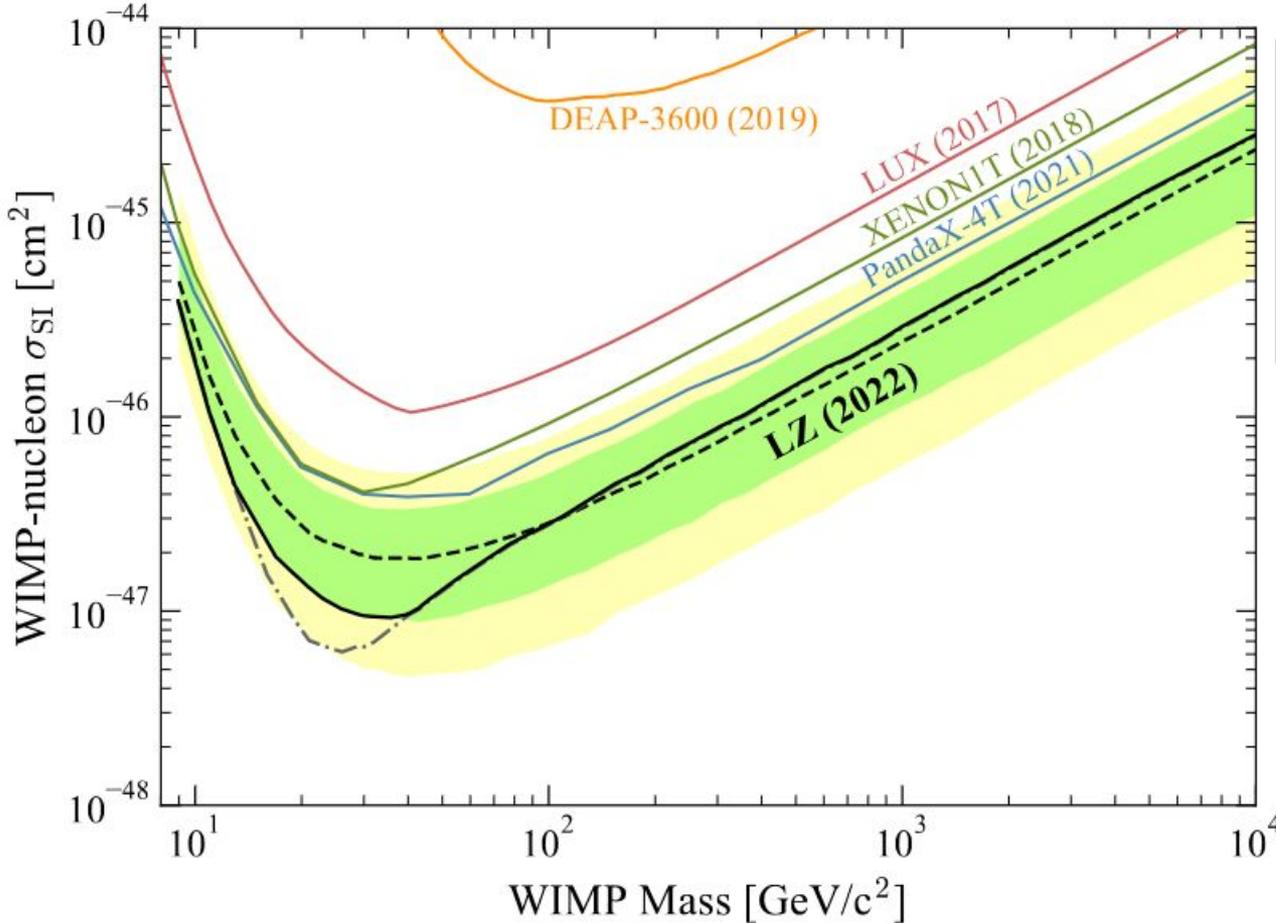


Vicente Pesudo
(CIEMAT / LSC)
for the DS-20k collaboration

Santander, 2 de Octubre 2023

L International Meeting on Fundamental Physics and XV
CPAN days

Status of “canonic” WIMP searches



Field currently lead by dual-phase time projection chambers with Xe target

LZ Phys. Rev. Lett. 131, 041002 (2023)

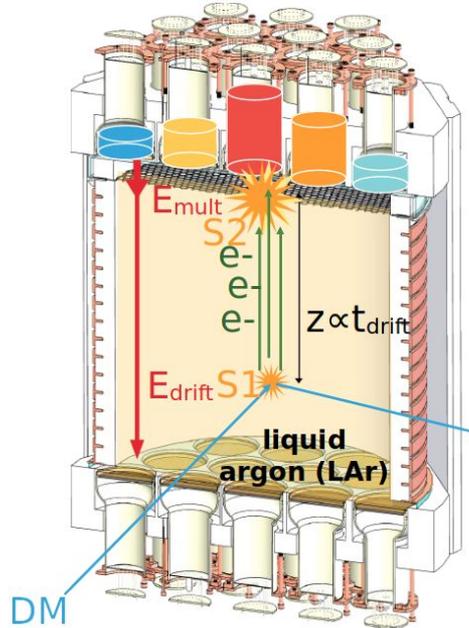
Dual-phase TPCs

Massive targets

Scintillation detected promptly (S1)

Uniform E field to measure ionization: prevents recombination + drifting e⁻ to anode

**At low Energies, S1 and S2 almost featureless:
Unambiguous identification of S1-S2 necessary**



e⁻ extracted to gas phase in stronger field to induce electroluminescence (S2)

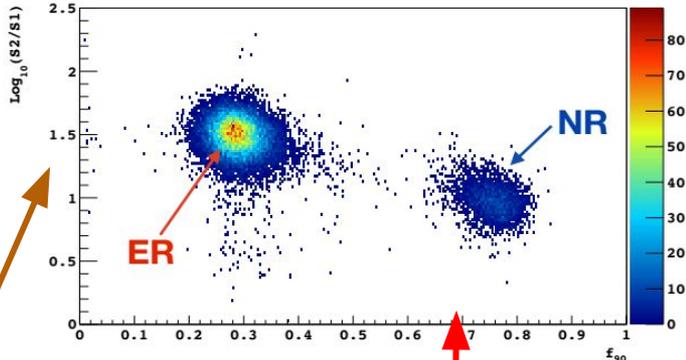
light pattern in detection plane provides XY information

Time difference between S1 and S2 provides Z info
(mm resolution)

S2/S1 provides particle discrimination

Ar, what's the point?

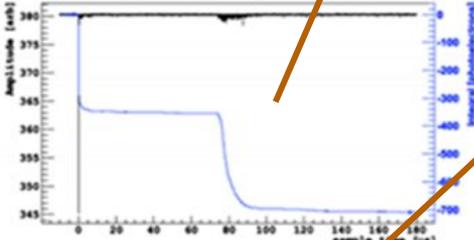
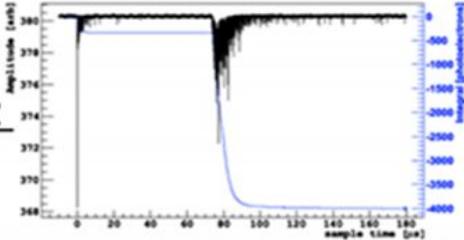
Additional discrimination variable: Pulse shape discrimination



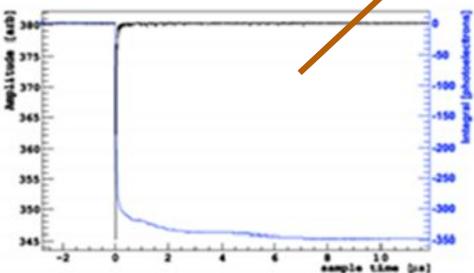
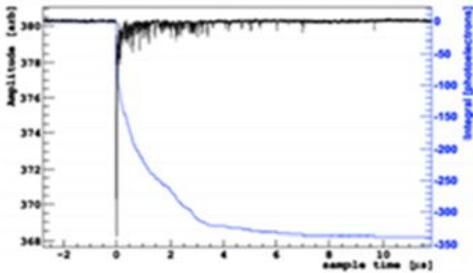
ER-like event

NR-like event

S1/S2



S1 only



Zero background mode

Ar, what's the problem?

The main limitation of **atmospheric Ar** for low-E low-background searches is its **intrinsic ^{39}Ar activity**:

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

^{39}Ar is produced mainly via spallation of cosmic rays on ^{40}Ar :

Ar stored deep underground for long periods (underground Ar, **UAr**) has not undergone cosmic activation, hence has **reduced ^{39}Ar content**.

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Fundamental to scale up:

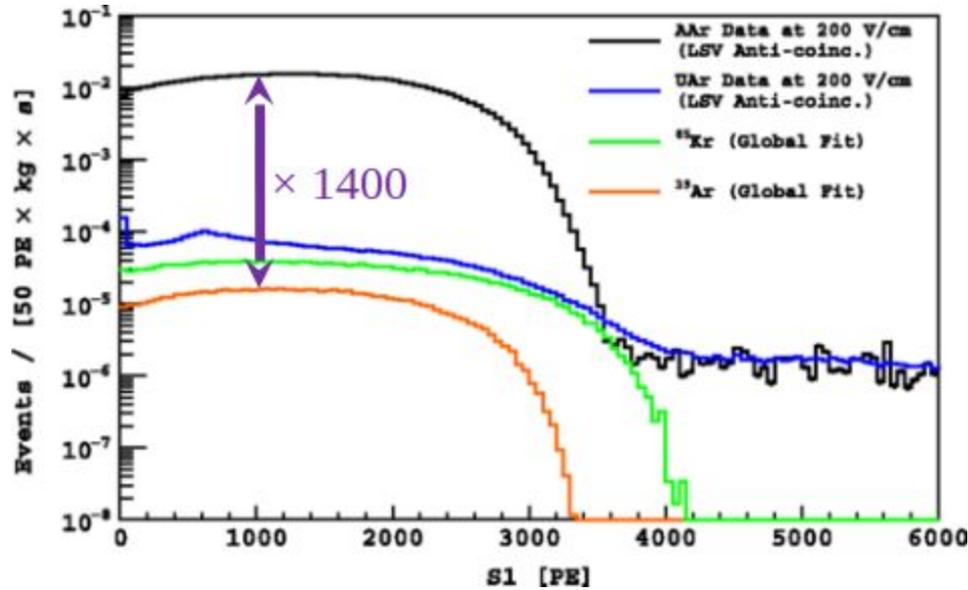
50 tonne  ~ 50 kHz

**ms drift & S1-S2 identification
not feasible**

^{39}Ar is produced mainly via spallation of cosmic rays on ^{40}Ar :

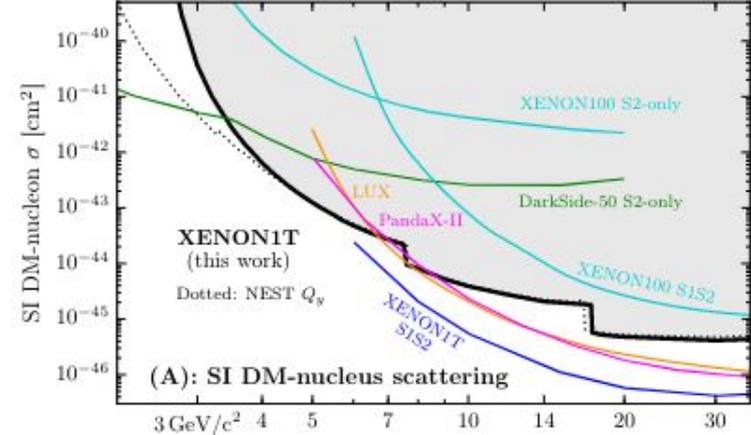
Ar stored deep underground for long periods (underground Ar, **UAr**) has not undergone cosmic activation, hence has **reduced ^{39}Ar content**.

Underground Ar in DarkSide-50



DarkSide-50 showed a depletion factor of 1400 in UAr with respect to atmospheric Ar activity:
 $A(\text{UAr}) = 0.73 \pm 0.11 \text{ mBq/kg}$.

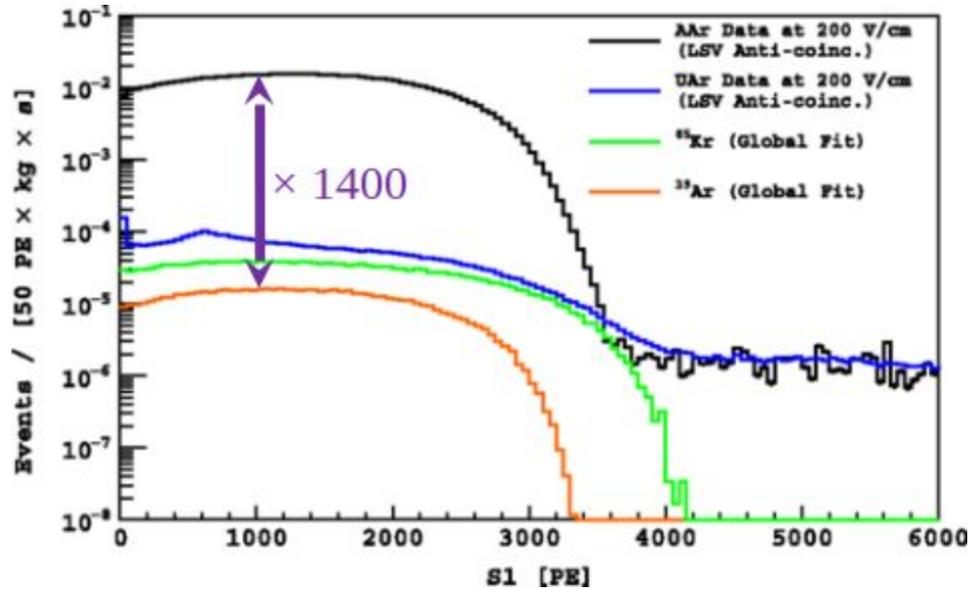
Phys. Rev. Lett. 123, 251801
arXiv:1907.11485



Still world-leading for some region of the **low mass WIMPs** parameter space with S2-only analysis.

Solid alternative to bolometers in view of the recurrent excess found so far

Underground Ar in DarkSide-50



DarkSide-50 showed a depletion factor of 1400 in UAr with respect to atmospheric Ar activity:
 $A(\text{UAr}) = 0.73 \pm 0.11 \text{ mBq/kg}$.

Extraction and purification of UAr is a proven technology

Presence of ⁸⁵Kr evidences **exposure to air** at some point...
Increasing ³⁹Ar activity.

Verification of UAr compliance is needed for each batch

UAr intrinsic activity should be lower than in DarkSide-50

DarkSide-20k

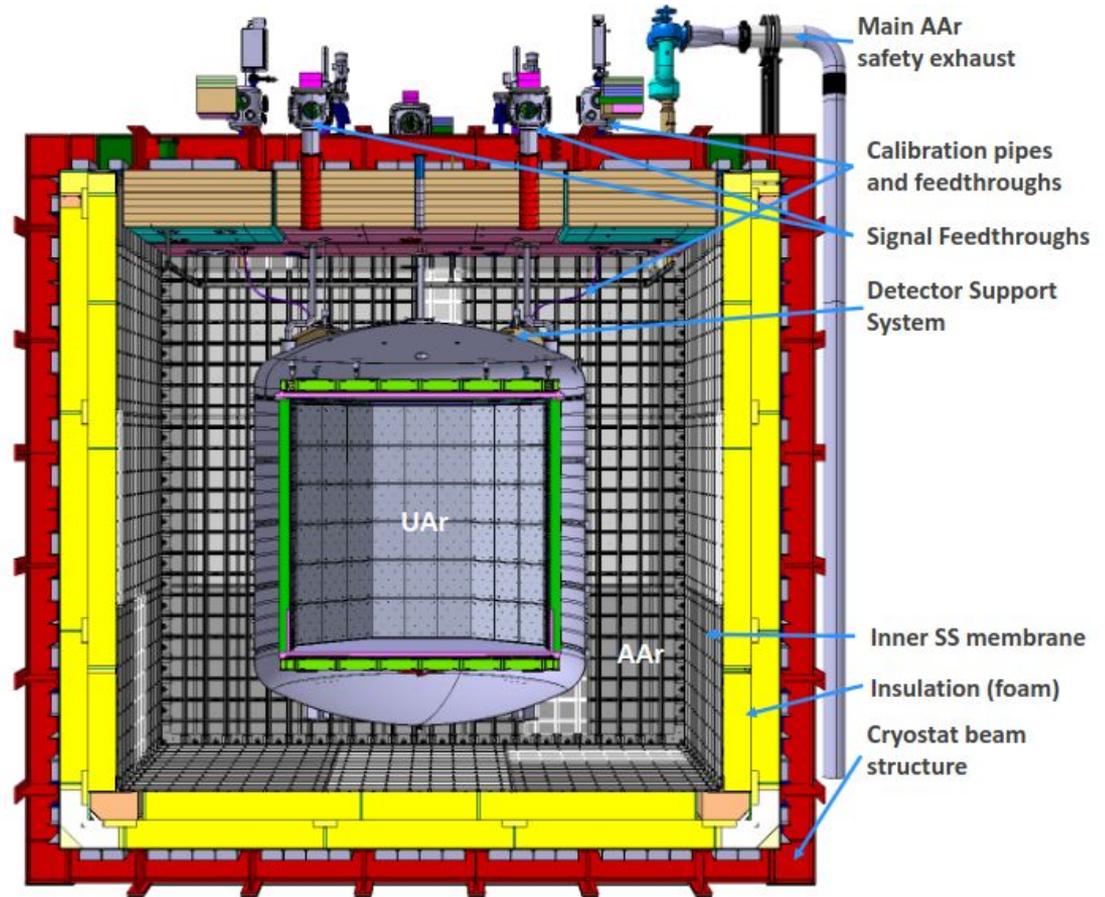
90 tonnes of UAr

50 TPC (20 fiducial) + 40 Veto

650 tonnes of AAr as buffer and muon veto

ProtoDune-like cryostat

21 m² of cryogenic & high QE & radiopure SiPM + electronics



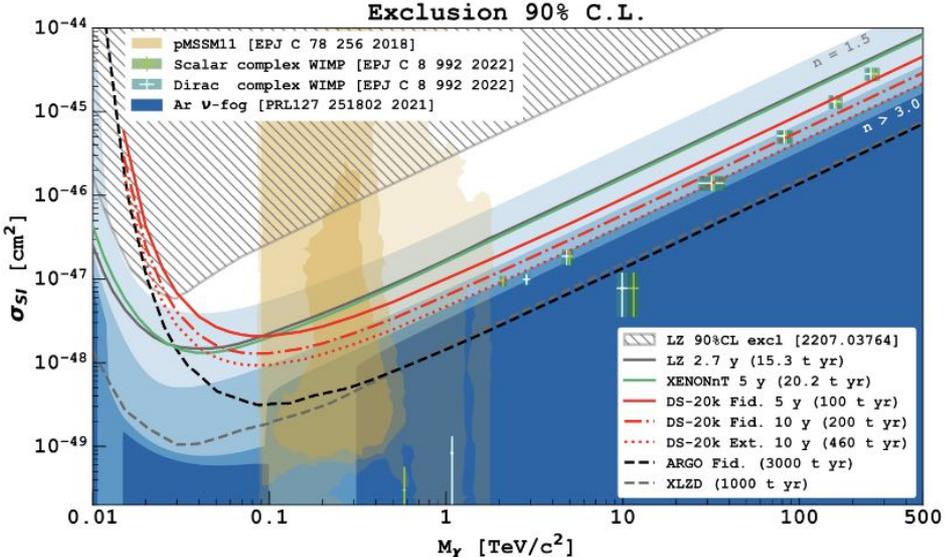
First detector of the Global Argon Dark Matter Collaboration

DarkSide-20k

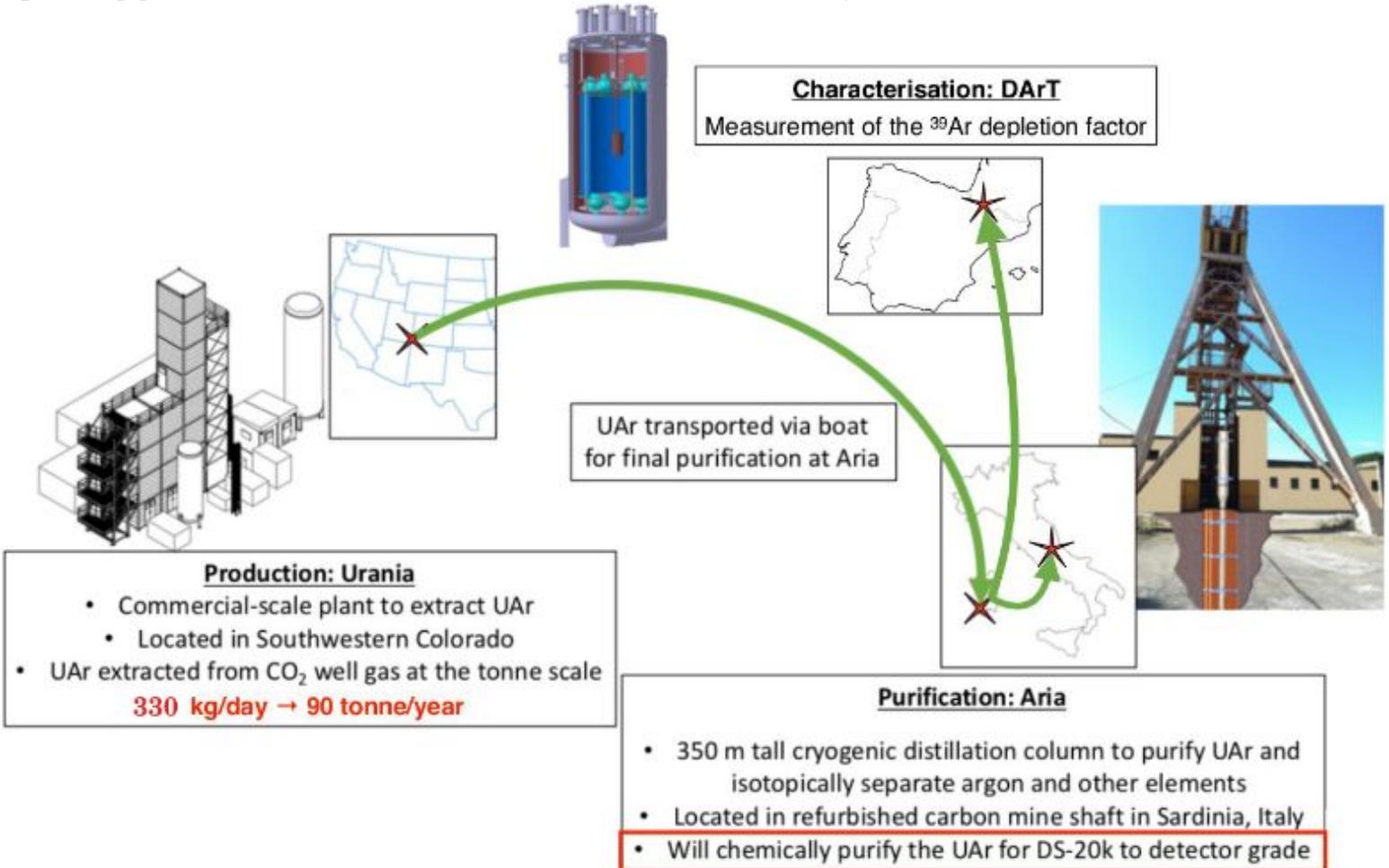
Already under construction in Hall C of LNGS!!



With the goal of leading the search for WIMPs



UAr program of DarkSide: Urania, Aria and DArT

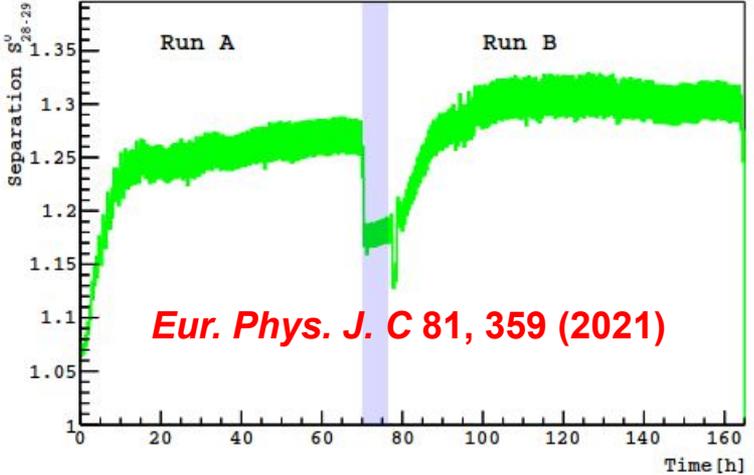
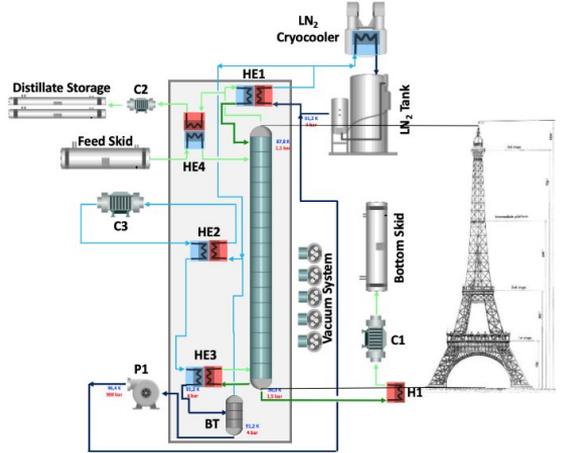


Aria

Aria will be the facility devoted to the cryogenic distillation of Ar: 99.999% purity.

Seruci-0 (26 m instead of 350 m) also proved isotopic distillation of LN₂ and Ar isotopes:

Separation factor top-bottom of 1.3 for ¹⁵N-¹⁴N / ¹⁴N-¹⁴N molecules.



DArT in ArDM

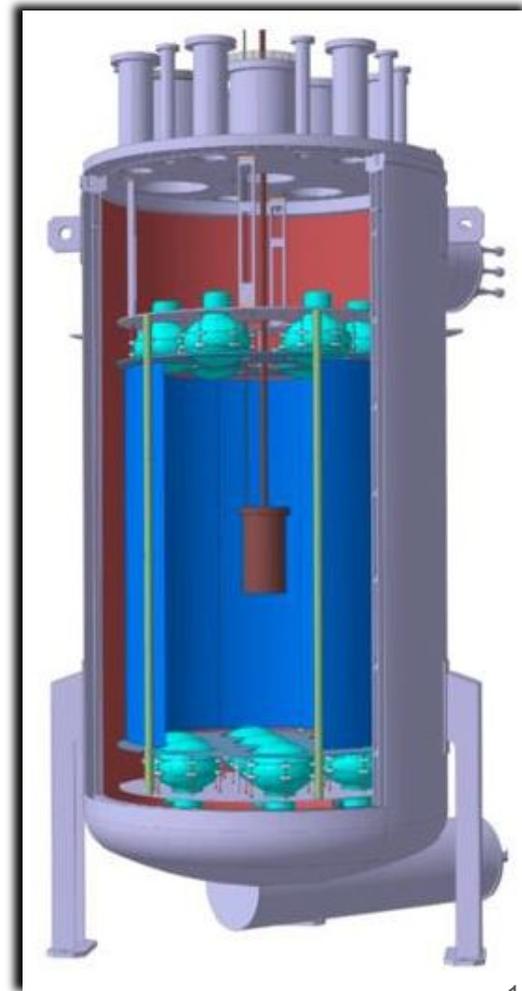
Full description: JINST 15 P02024 (2020)

Setup to measure intrinsic activity of ^{39}Ar in UAr:

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

ArDM acting as active veto with atmospheric Ar

Characterization of
1.4 kg of UAr per batch
from both Urania and
Aria



Setup to measure intrinsic activity of ^{20}Ar in UAr

+ concentration

+ pure beta em

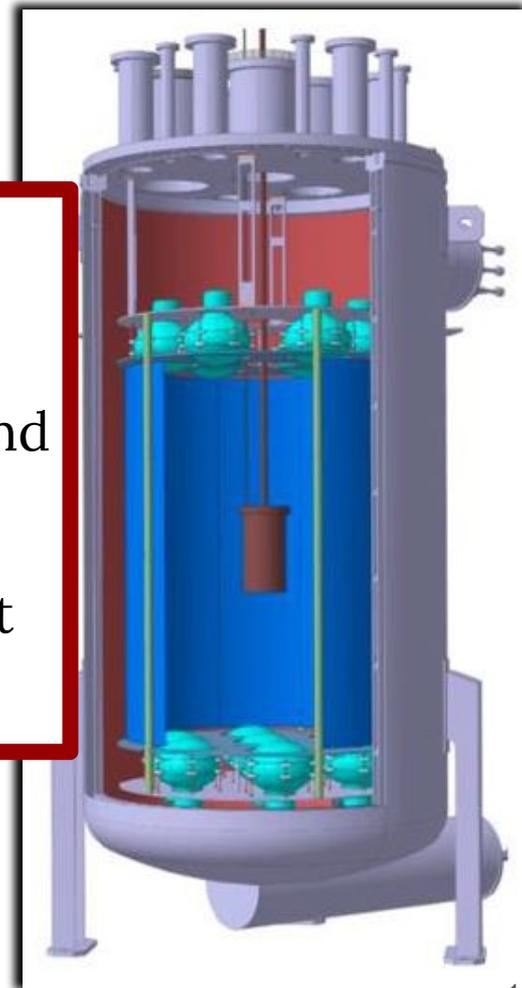
ArDM already refurbished.

DArT prototype fully characterized:
awaiting production of final SiPMs and
acrylic supports.

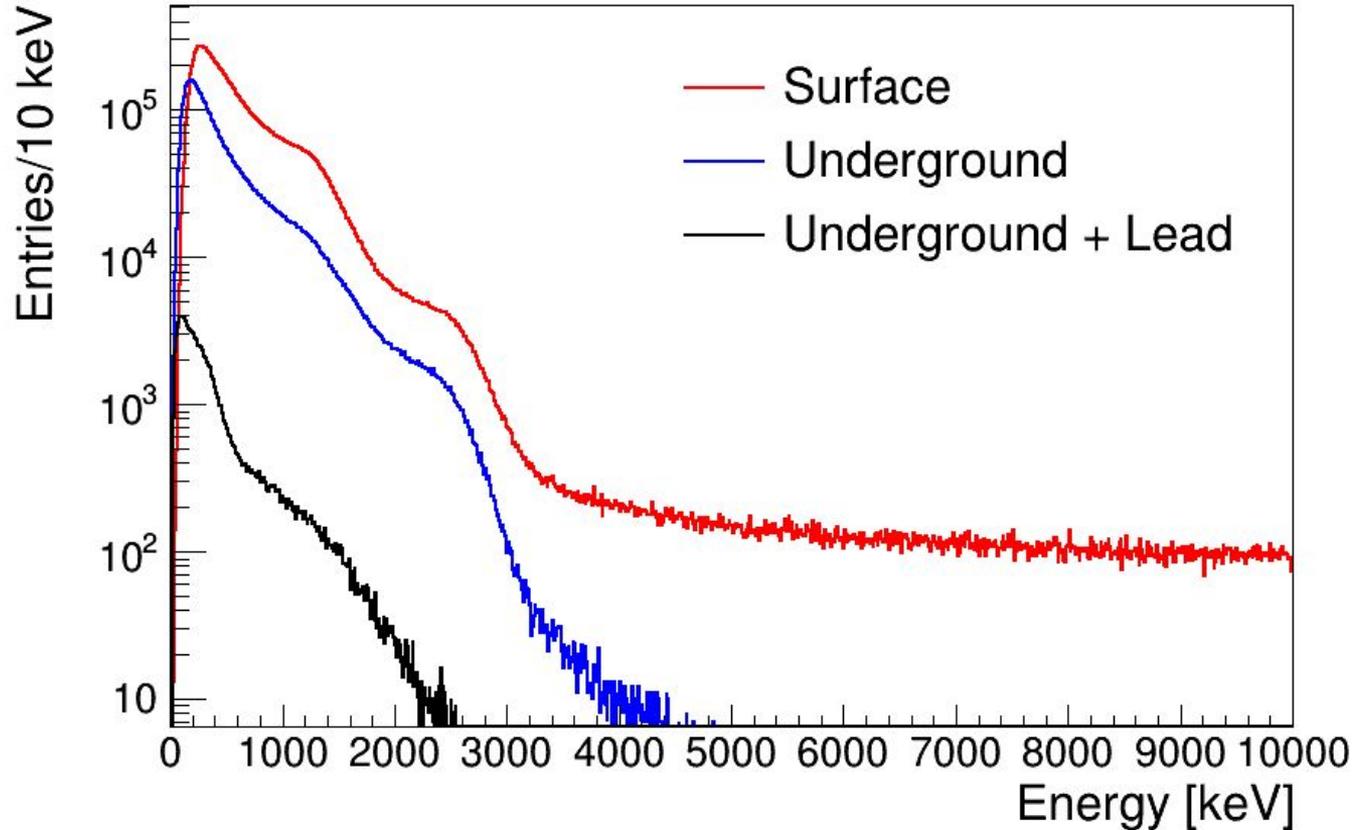
Imminent: competitive measurement
of ^{39}Ar activity in atmospheric Ar.

Characterization

1.4 kg of UAr per batch
from both Urania and
Aria



Characterization data (atmospheric Ar)



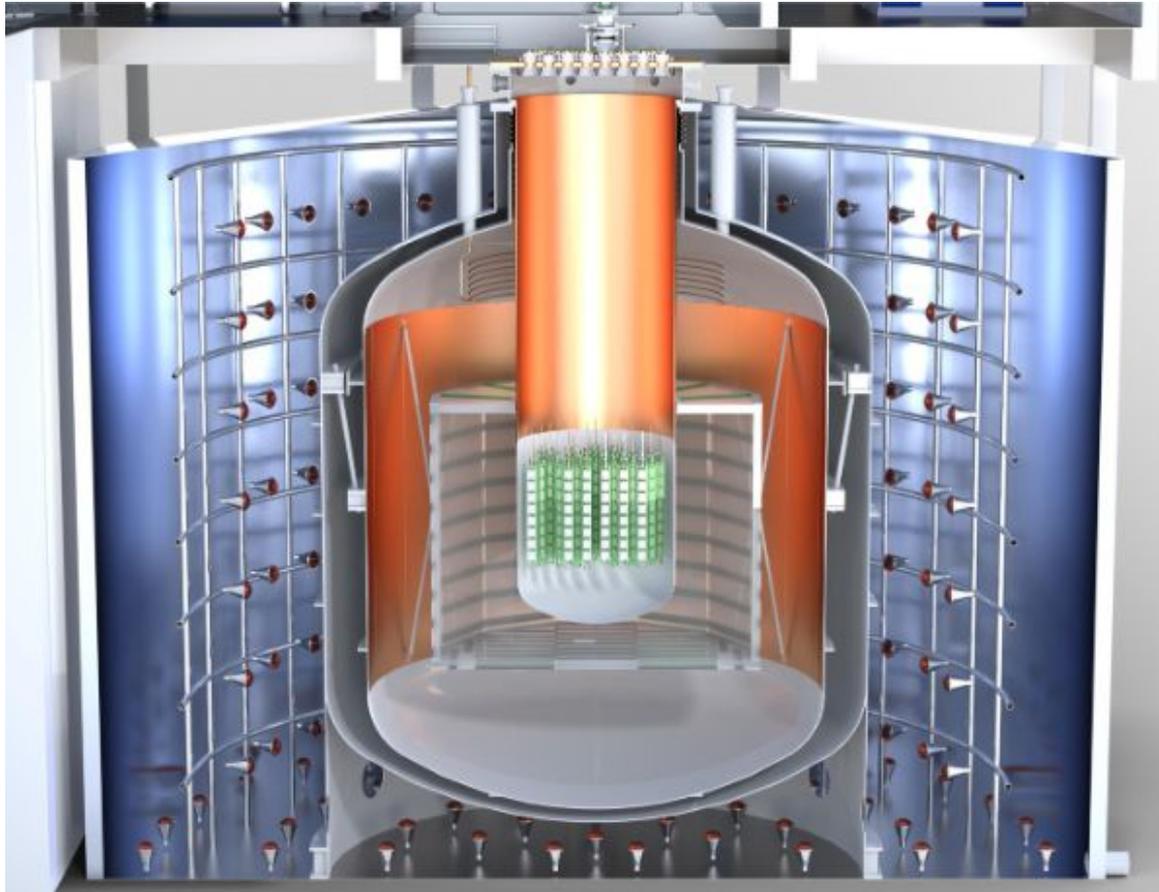
Normalized in live time.

REMINDER:

Not in ArDM,

No veto.

Beyond DarkSide-20k I: LEGEND-1000



Will search for neutrinoless double beta decay in ^{76}Ge ($Q_{\beta\beta} = 2039 \text{ keV}$)

Expected sensitivity $> 10^{28} \text{ y}$

Ar veto proven successful by GERDA and LEGEND-200, but ^{42}Ar (33 y) \rightarrow ^{42}K (12 h & $Q_{\beta} = 3525 \text{ keV}$) main bkg.

Shorter lifetime + also produced cosmogenically:

Further suppressed than ^{39}Ar !

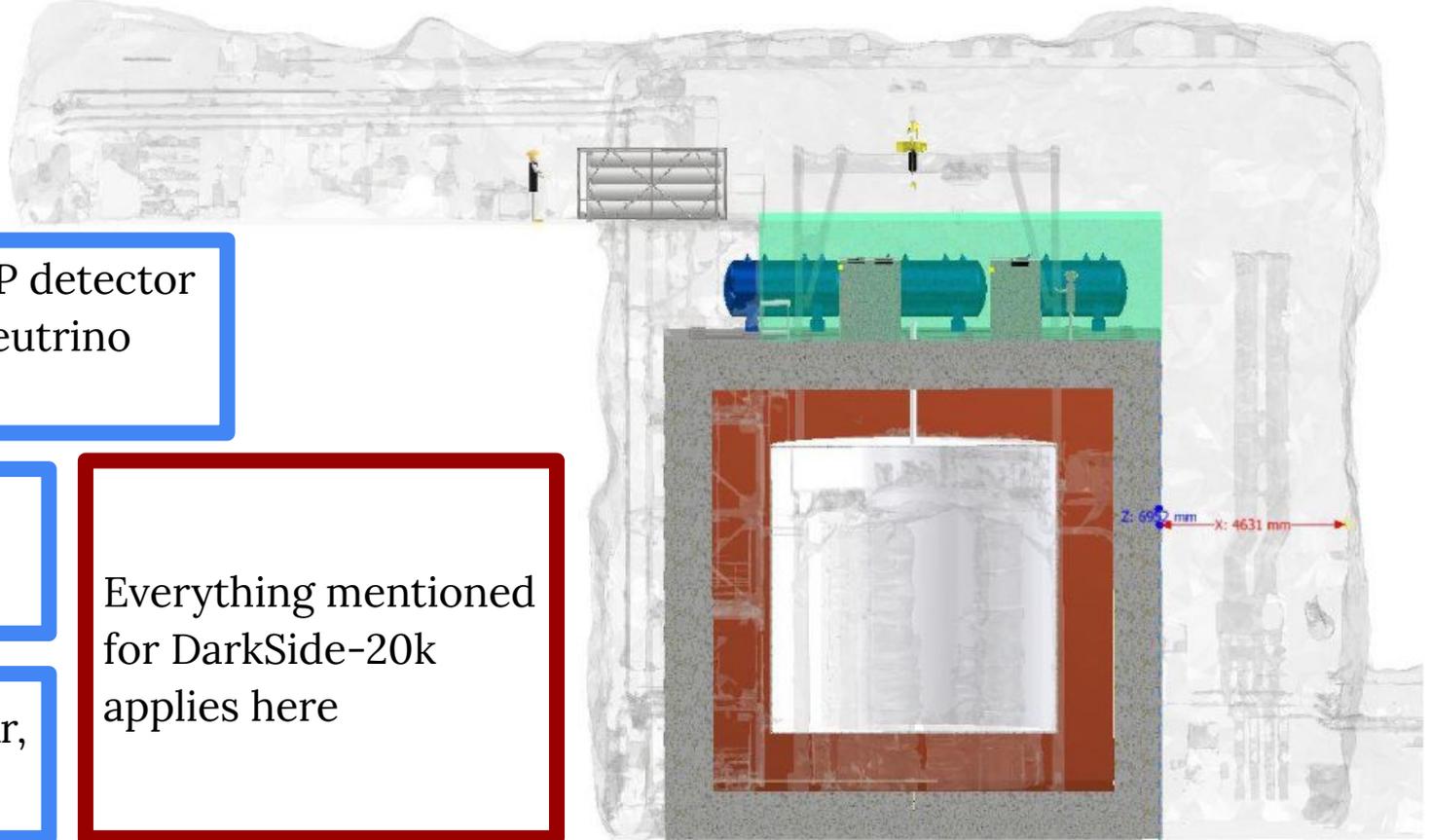
Beyond DarkSide-20k II: ARGO

Ultimate Ar WIMP detector
to reach to the neutrino
floor

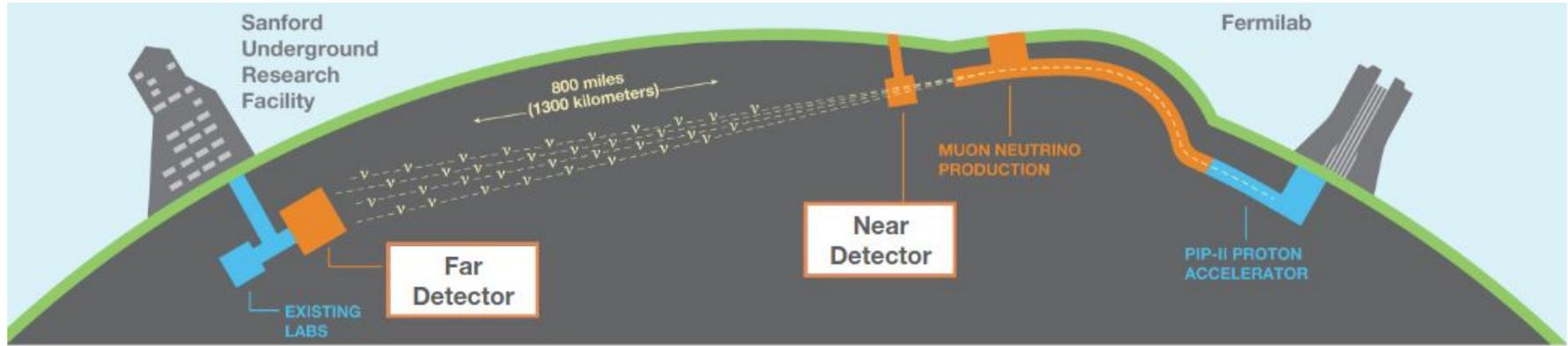
7 m in diameter x
7 m high

400 tonnes of UAr,
200 fiducial

Everything mentioned
for DarkSide-20k
applies here



Beyond DarkSide-20k III:



DUNE, for the module of opportunity
O (10 ktonne)

DarkSide Low-mass
O (1 onne)

COHERENT, for measurement of
CEvNS O (1 tonne)

Other low-background applications
and vetos

Conclusions

- **Argon** has pulse shape discrimination capabilities that place it as an **outstanding target for rare event searches**.
- The presence of ^{39}Ar in atmospheric Ar **is a show stopper** for the coming generations of experiments.
- The DarkSide collaboration is in a steady path to **procure 110 tonnes of purified underground argon** for DarkSide-20k.
- The production will go on to procure UAr for, at least, Legend and ARGO.
- **Spain has a high-visibility role in this endeavour**, hosting a key facility for the success of the program at the Lab. Sub. Canfranc and with leading roles by Universidad de Zaragoza and CIEMAT.

BACKUP

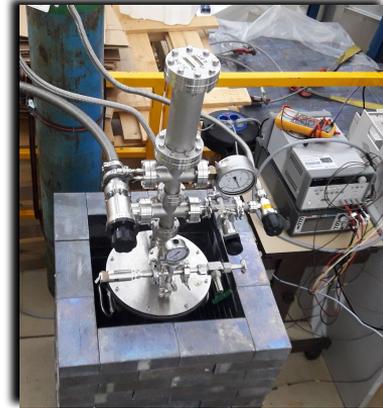
Performance of inner detector (atmospheric Ar)

Specific setup for tests in surface (CIEMAT) and underground (LSC)

- Substitution of atmospheric Ar bath by pressurized LN2 @ 85 K. **No veto**
- Installation in an ad-hoc Pb-castle flashed with Rn-free air (underground only).

It has allowed for:

- **evaluation of continuous performance** of the detector in runs of three weeks (expected measurement time per batch of UAr).
- **Characterization** of the **photoelectronics** and light collection efficiency.
- **Determination** of feasible **operation conditions** of the DAQ and electronics.
- **Setting protocols** for operating the inner detector
- **Preliminary measurements** of ^{39}Ar intrinsic activity in a small detector (analysis ongoing).



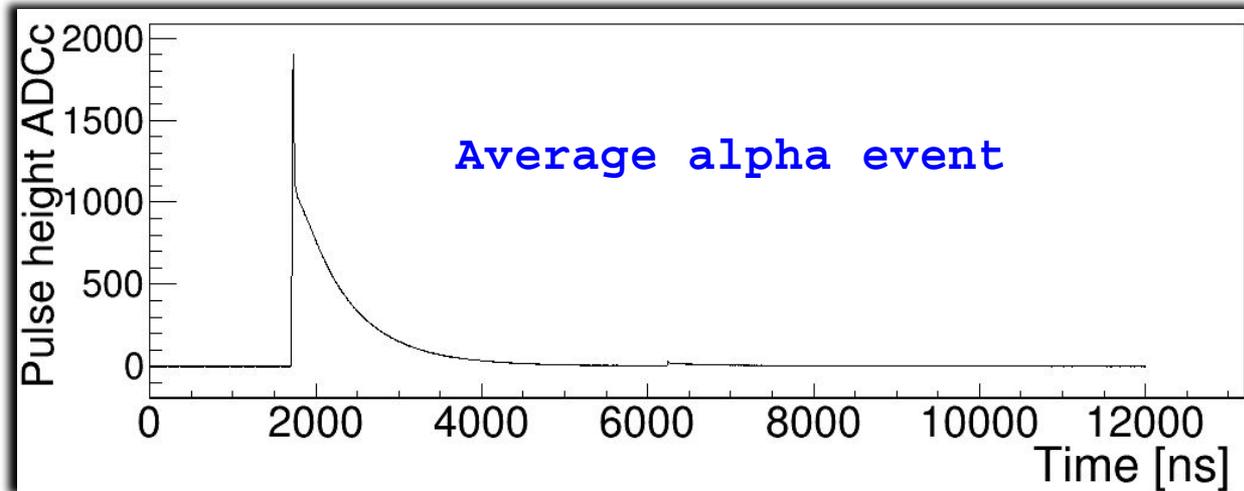
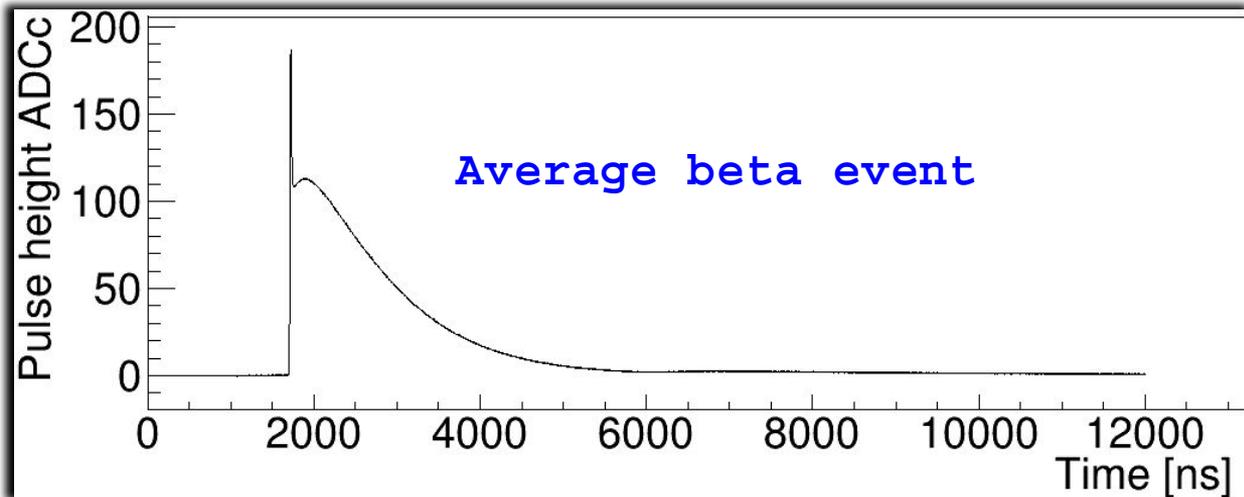
LAr + SiPMs

One of the first tests of the performance of **SiPMs in LAr**

Measured **triplet** lifetime:
1230 ns

Clear PSD even with slower SiPM response

f90  f640

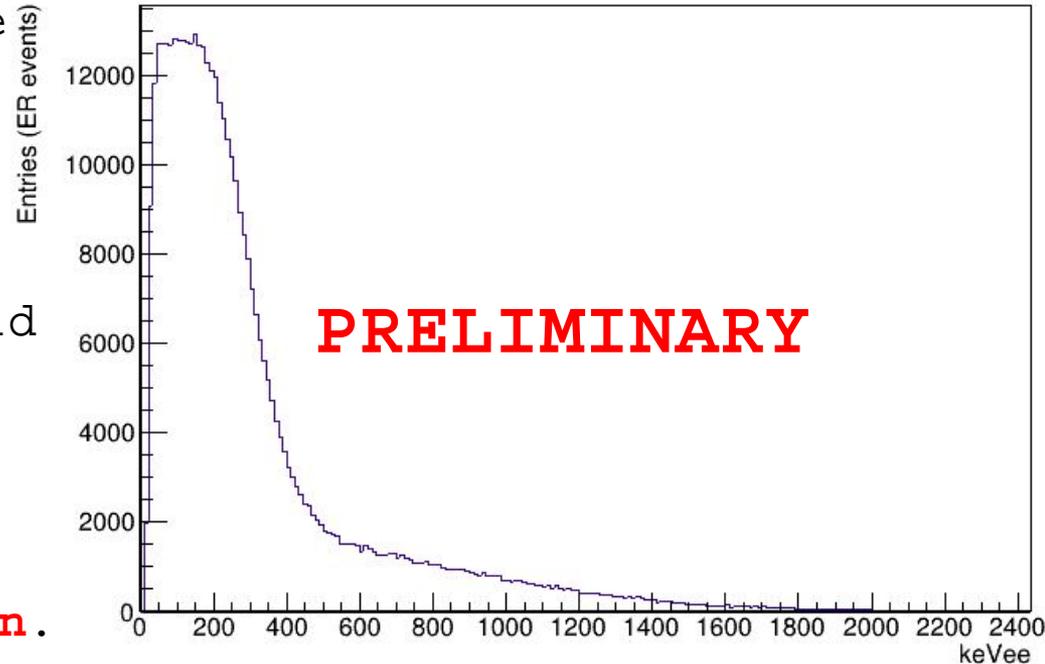


^{39}Ar activity of atmospheric Ar with no veto

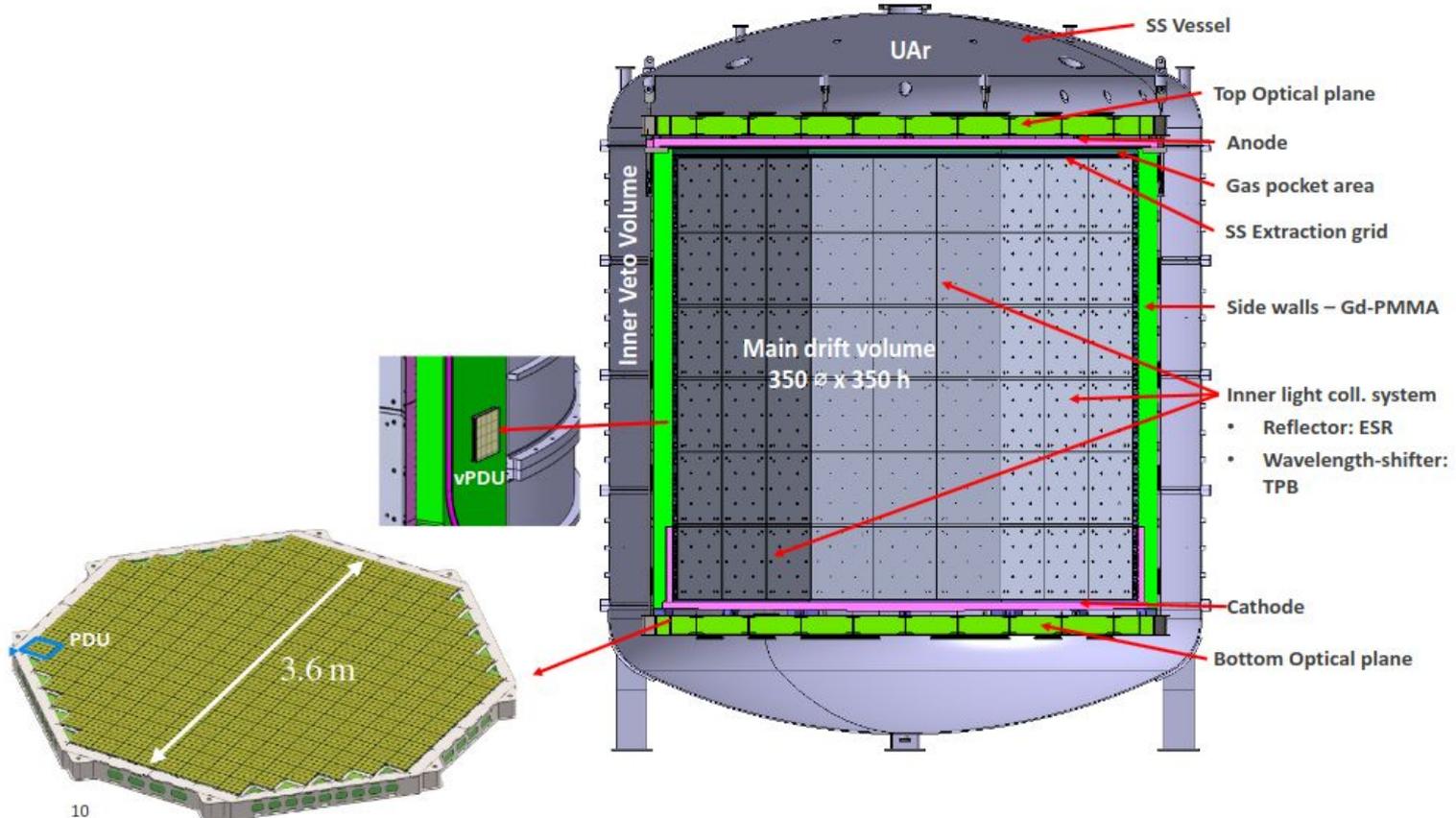
Clear pattern of ^{39}Ar visible underground with Pb-shield.

Subtracting a featureless linear background below the ^{39}Ar spectrum, and a threshold at 33 keV, we measure **1.0 cps.**

Uncertainty lead by **systematics, under evaluation.**



DarkSide-20k

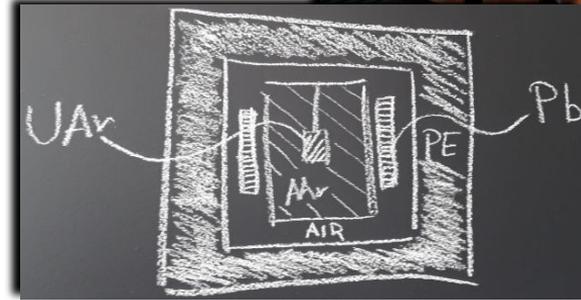


DArT in ArDM

Full description: JINST 15 P02024 (2020)

Small target filled with 1.35 kg of liquefied UAr:

- Seen by eight 1 cm² SiPMs
- Mylar reflector to enhance light collection
- TPB-coated inner acrylic vessel



Will be placed inside ArDM detector in single phase:

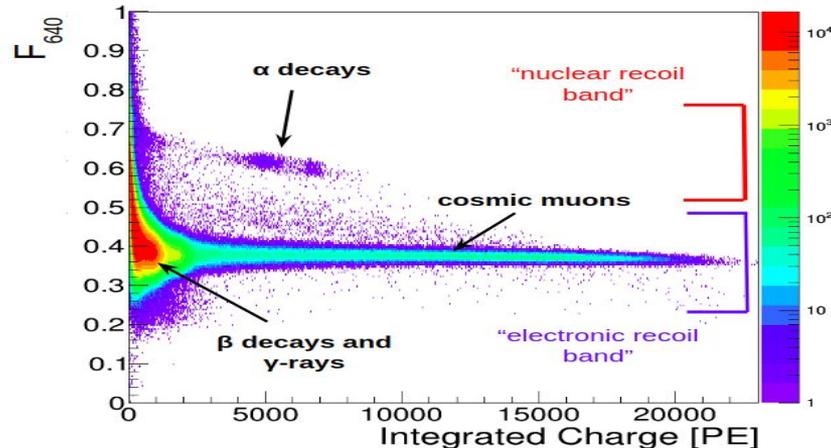
- 13 PMTs will see a ~1 tonne AAr buffer used as shield and veto
- New Pb-shield hanging from existing Polyethylene shield.

Based at Canfranc Underground Lab (Spain)

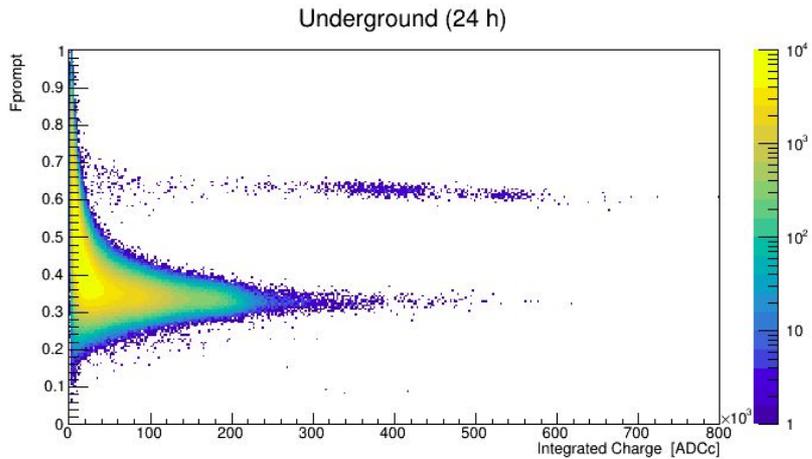
- Under 1400 m.w.e
- Procuring the Pb for the shield



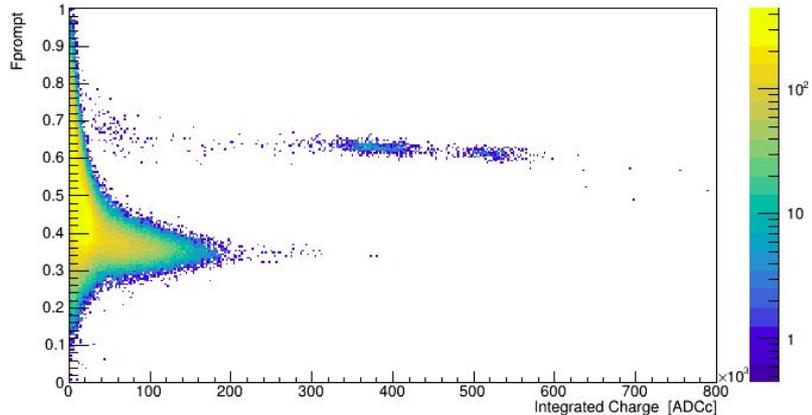
Reducing external backgrounds



Underground + Lead (24 h)



Underground (24 h)



Underground + Lead + Rn-free Air flow (24 h)

