



Status and Prospects of DarkSide-20k & DArTinArDM

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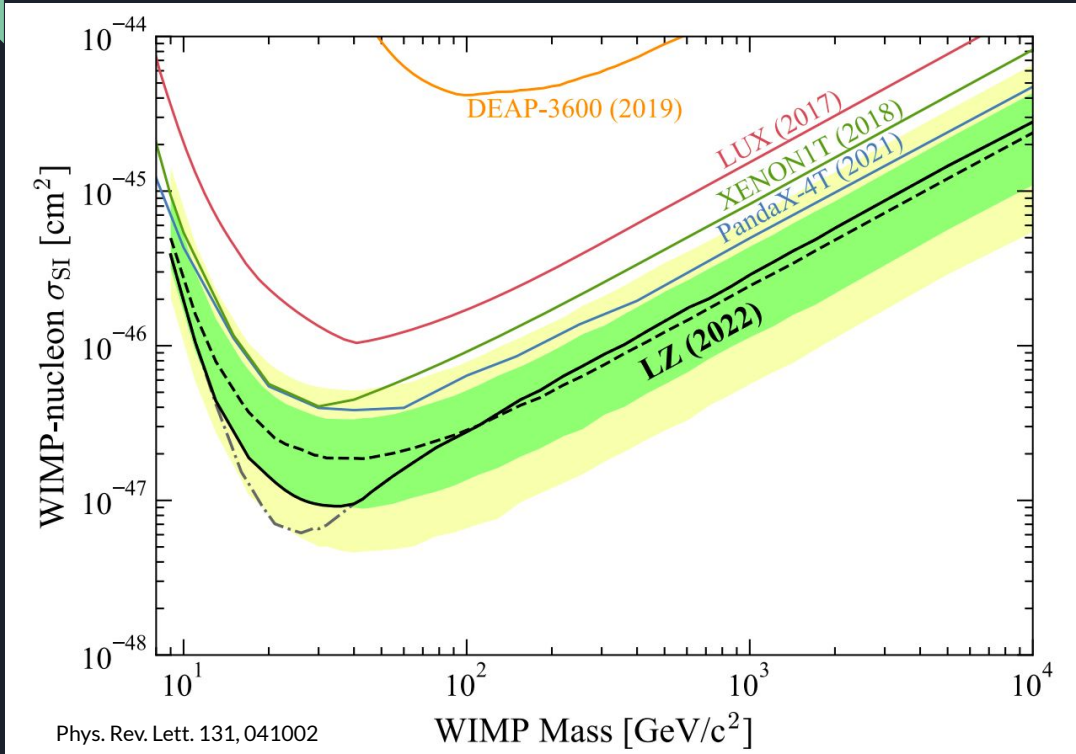
On behalf of the GDMC & DarkSide-20k Collaboration

20th MultiDark workshop
Gandía, Spain.
(25-27 October 2023)



≡ Status of Direct Detection of “Heavy” WIMPs :

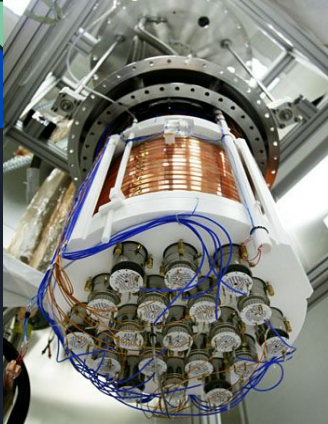
A global effort is being put to search for the direct signature of canonical/heavy Weakly Interacting Massive Particles (WIMPs) as dark matter candidates.



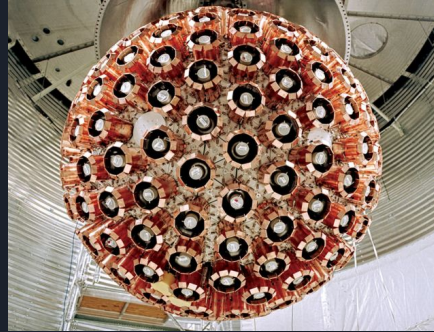
The expected signature would be in form of nuclear recoil (NR), over the background due to spin-independent interaction of WIMPs with target nucleus.

The field is currently led by Xe target dual phase TPCs.

Global Argon Dark Matter Collaboration (GADMC):



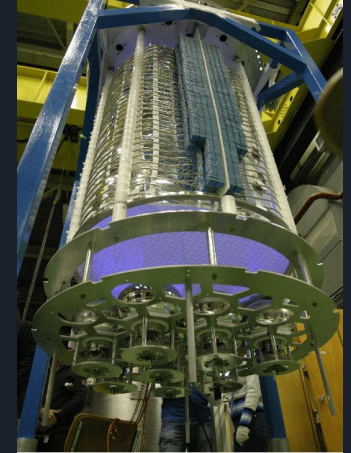
DS50 @ LNGS



DEAP 3600 @ SNOLAB



MiniCLEAN @ SNOLAB



ArDM @ Canfranc

GADMC:

We are ~ 100 institutions and ~ 500 collaborators from all the above experiments sharing knowledge and experience for the next step of direct DM search with LAr.

DarkSide-20k

ARGO

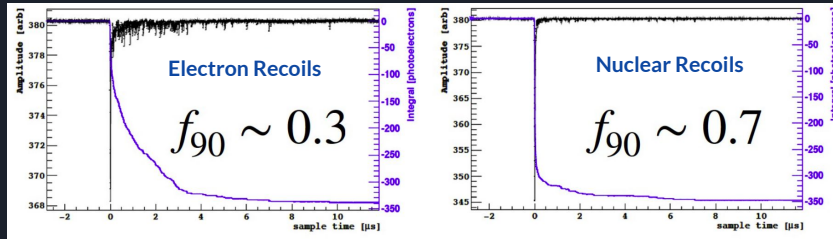
- ~ 20 t fiducial mass dual phase TPC.
- ~ 32 t fiducial mass active Neutron Veto.
- ~ 700 t External Muon Veto.
- Under construction @ Hall C LNGS.
- Commissioning foreseen in 2026.

- Future LAr DM detector – 2030 and beyond
- 300 t fiducial volume

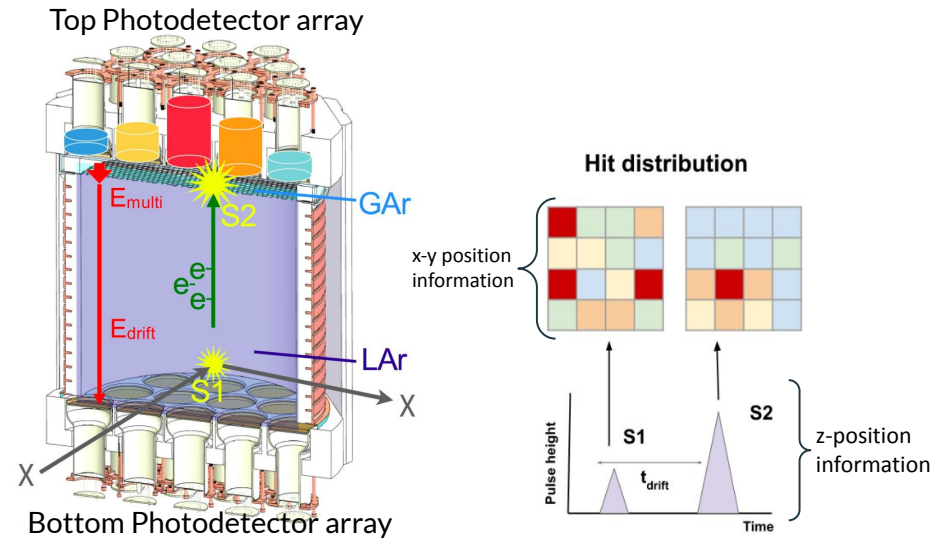
Liquid Argon and Dual-Phase TPC

Advantages of Ar as a detection medium:

- Quite abundant in atmosphere (~ 1%) : cost efficient
- High scintillation and ionization yield : very detailed particle information
- Very high pulse shape discrimination (PSD) : can distinguish nuclear recoils (NR) events separately from electron recoils (ER) events ~ 1 NR in 10^8 ERs
- Ar has a light nucleus : can enable us to lower the detection threshold to sub-keV range without losing efficiency



DEAP 3600 Pulshape: Eur. Phys. J. C 80, 303 (2020)
DEAP 3600 PSD: Eur. Phys. J. C 81, 823 (2021)



- Two separated light signals:
 - Prompt scintillation (S1) followed by a
 - Proportional scintillation (S2) due to electroluminescence
- 3D position reconstruction is possible by combining the hit distribution and drift-time.
- Efficient electron extraction (~100%)

Turning Towards Underground Argon:

The main problem of atmospheric Argon is the isotope ^{39}Ar , forming the intrinsic background.

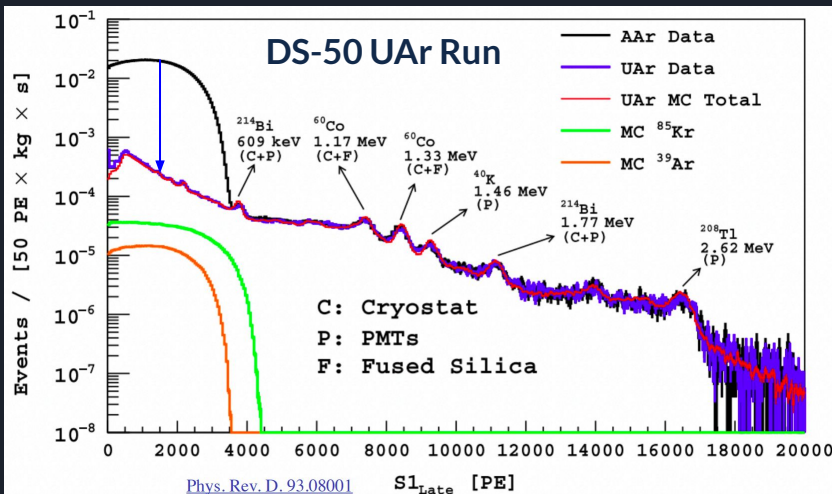
$^{39}\text{Ar} \Rightarrow$ a beta emitter
Primary Production \Rightarrow By spallation of cosmic rays on ^{40}Ar

$Q_{\text{value}} = 565 \text{ keV}$
Activity = 1 Bq/kg
Half-life = 269 years

In a detector of ~ 50 tonnes
Trigger rate $\Rightarrow 50 \text{ kHz}$

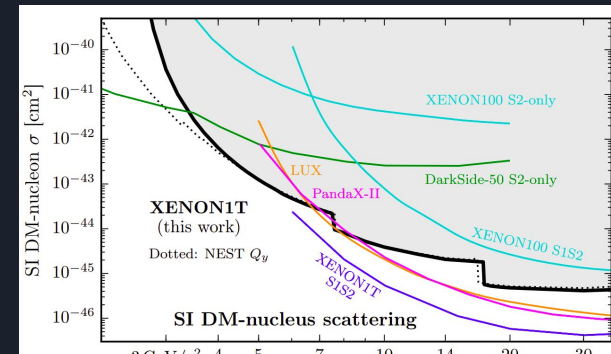
Argon stored underground is depleted in ^{39}Ar .
Hence becomes our choice for target material.

- High trigger rate leading to pile up problem of ERs
- Low performance of the PSD variable at lower energies
- Poses a major problem for S2 only analysis



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

DS-50, S2-only result still holds the world leading limits for low mass SI-WIMPs $< 4 \text{ GeV}/c^2$



Journey of Underground Argon for DarkSide-20k



Extraction at Urania

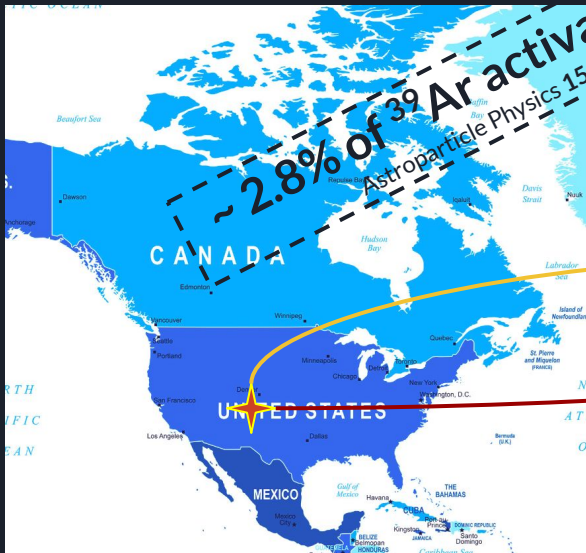
- From CO₂ wells Doe Canyon, Colorado, USA
- Industrial scale plant, 250 kg/day
- Purity 99.99%, initial CO₂, CH₄, N₂ and ⁸⁵Kr



Purification at Aria

- Located in the Carbosulcis coal mine, Sardinia, Italy.
- Aria is a cryogenic distillation column of 350 m high
- Primary role would be to perform chemical purification of UAr
- Has the ability to perform isotopic separation
- Output ~ 1 tonne/day

Journey of Underground Argon for DarkSide-20k



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Final Assay at
DARtinArDM
@ LSC, Canfranc

ARIA : Cryogenic Isotopic Distillation Plant

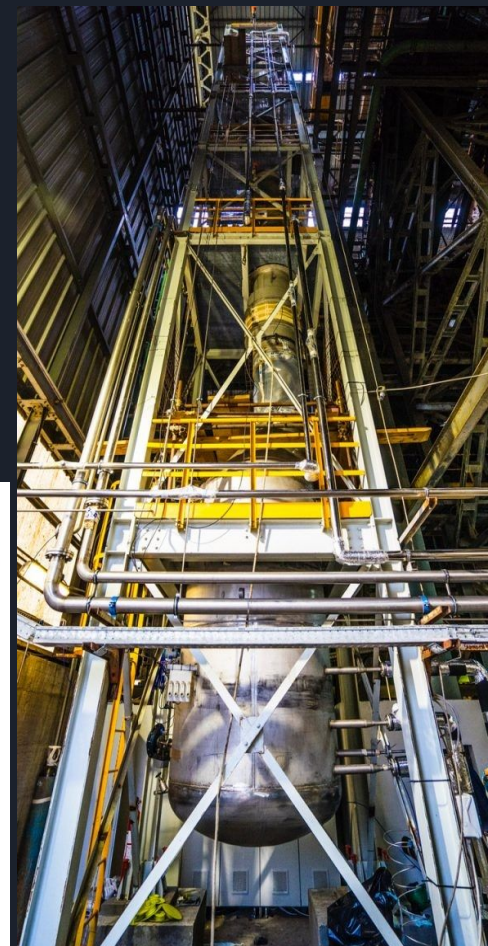
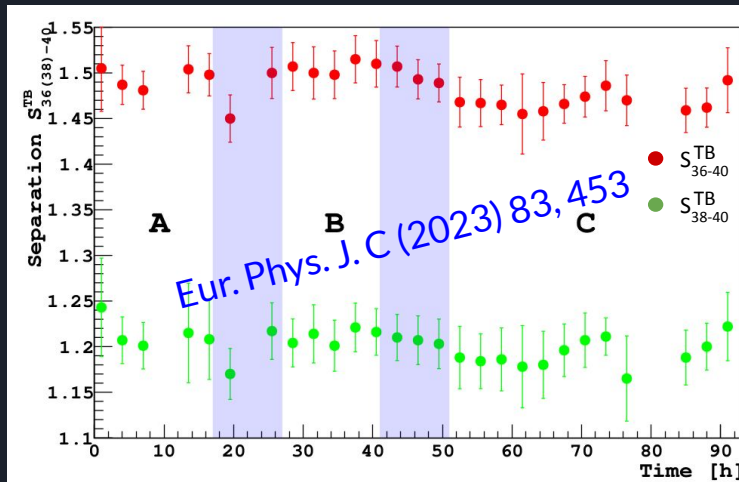
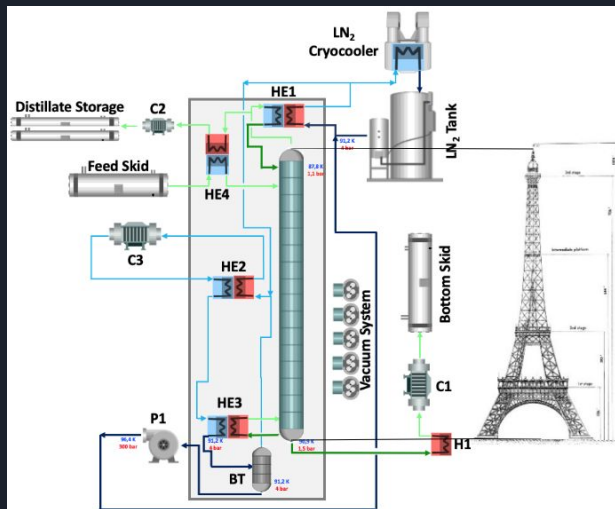
Aria will be the facility devoted to the cryogenic distillation of Ar.

Seruci-0 (26 m instead of 350 m) already proved isotopic distillation of N_2 (in 2019 - 20).

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

In 2021, the same column processed Ar.

S_{i-j}^{TB} = main parameter for measuring the isotopic separation



Need for Characterization of UAr

As demonstrated by DarkSide-50, the UAr can have a depletion factor of ~ 1400 , w.r.t AAr activity (0.73 mBq/kg ^{39}Ar specific activity).

But, this is just an upper limit, as presence of ^{85}Kr is indicative of air contamination.

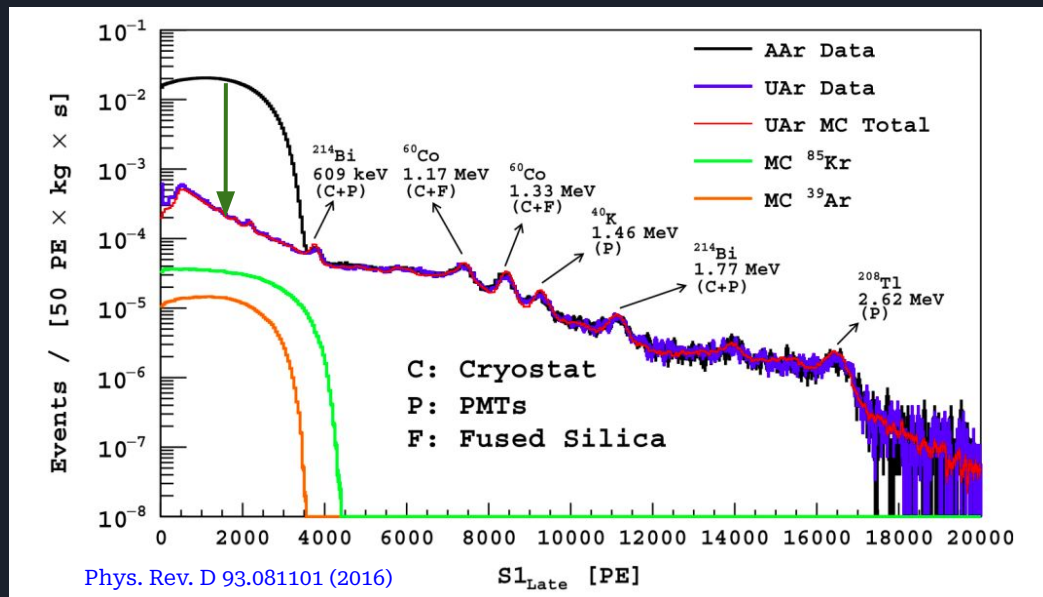
To avoid this in future, systems in place for air monitoring during future UAr production (at Urania)



Final verification of ^{39}Ar level and chemical purity level are still required



This requires continuous operation.



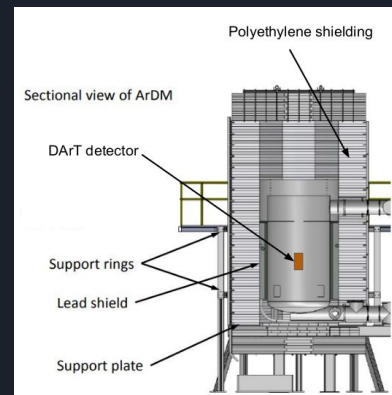
Assaying the UAr: DArTinArDM

Full description: JINST 15 P02024 (2020)

Need a dedicated setup to measure intrinsic activity of ^{39}Ar in UAr:

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

Need for dedicated low background setup.



DArT (Depleted Argon Target) refers to the small amount of Ar filled in a Cu vessel with an active mass of 1.35 kg.

- seen with two 1 cm^2 SiPMs
- Mylar reflectors
- inner acrylic structure coated with TPB.

Projected Sensitivity:
1 mBq/kg with 10% statistical error in 1 week livetime



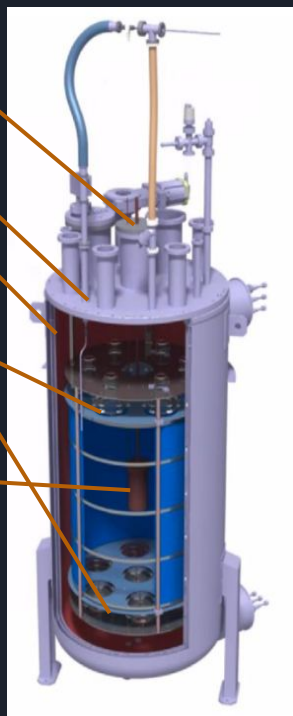
DArT Vessel inlet through CF-200

ArDM Top Flange Modified

ArDM Main Vessel

Top & bottom PMT planes

DArT Vessel placed at halfway between the PMT planes



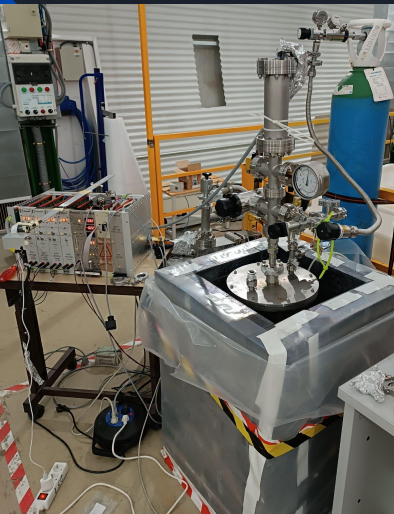
The previous ArDM main vessel will be used as a active veto and shield.

- ~ 1 tonne of AAr.
- seen with 13 PMTs
- Pb + Polyethylene shield

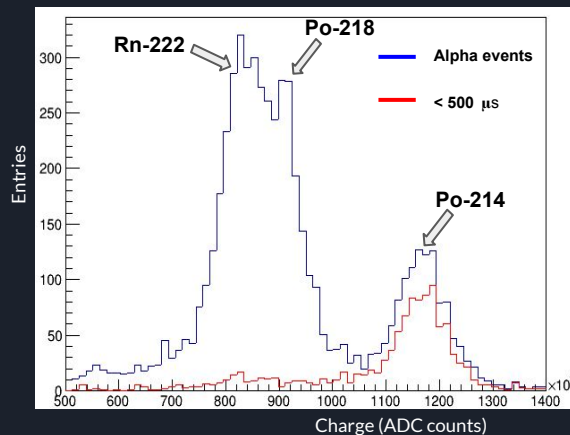
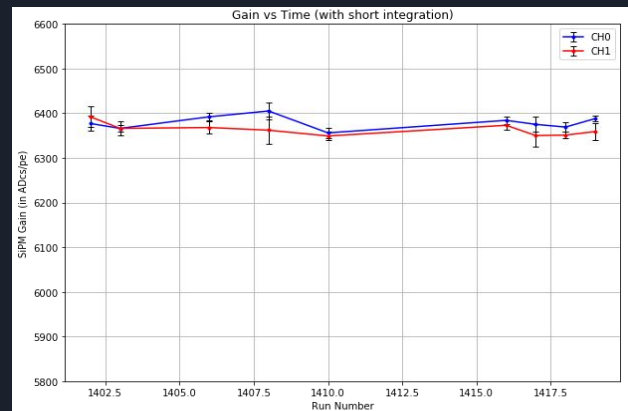
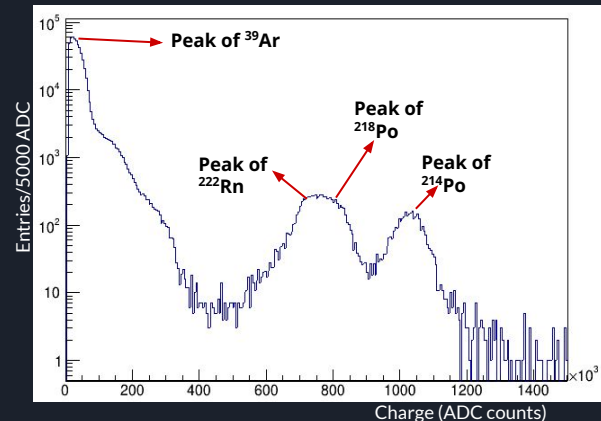


Based at Hall A of Canfranc Underground Lab (Spain) under 2400 m.w.e

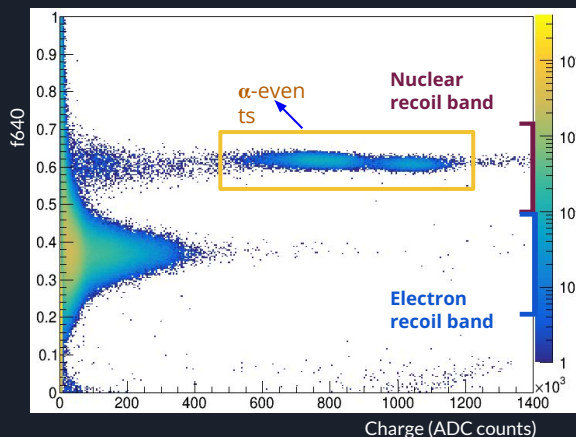
DART is Live in a Test Setup



- Need to ensure the robustness and tightness of the design
- Testing the SiPMs in conditions very similar to the full operational conditions
- Understanding the potential of the detector
- The setup consists of:
 - ◆ External Lead Shield
 - ◆ SS-Cryostat acting as temperature bath with pressurized LN₂ (**No veto**)
 - ◆ The DART Vessel (filled with AAr)
- Pb shield is flushed with Rn-free air

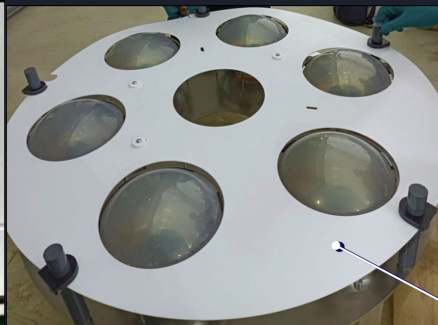


The half life of the events marked in red is calculated to be = $158.25 \pm 6.1 \mu$ s
 Compatible with $t_{1/2}({}^{214}\text{Po}) = 164.3 \mu$ s



The optical model of the detector is under development.

Refurbishment of ArDM & DArT 2.0



TPB coated reflectors



TPB coated reflectors

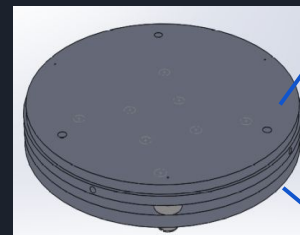


New DArT vessel is ready

Acrylic is under procurement from Canadian colleagues

A few changes in design have been brought.

The top & bottom acrylic structures are modified to a unified structure.



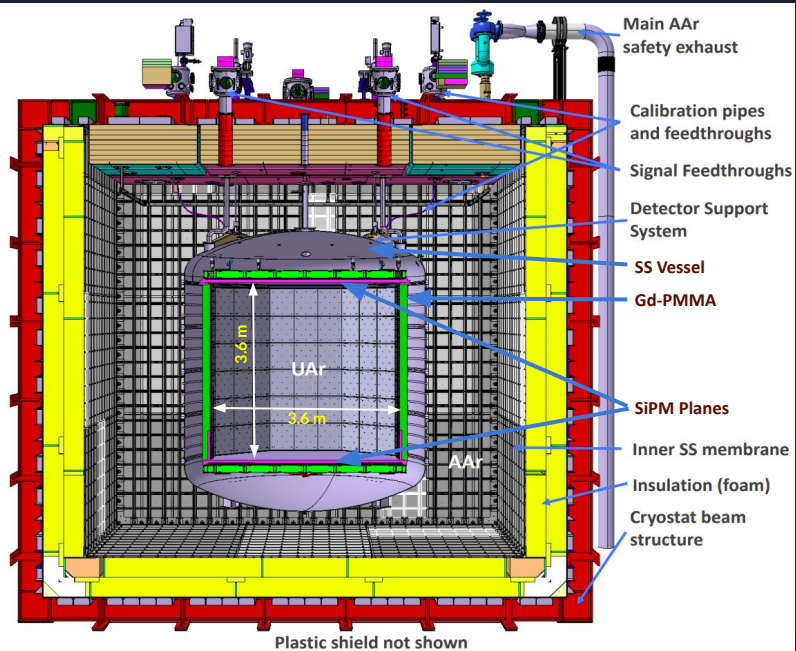
Internal cap coated with TPB

Reflector with 4 windows

External cap with 4 SiPMs

No. of SiPMs increased from 2 to 8.

DarkSide-20k Detector, Background and Sensitivity:



Nested detectors structure:

- ProtoDUNE-like cryostat (12x12x12 m³ external)
- Muon veto 32 vPDUs
- SS vessel separating AAr from underground UAr.
- Integrated neutron and γ veto
- ~5-10 cm plastic shielding around SS vessel, moderation of neutrons from cryostat insulation, LNGS Hall C (not in the drawing)

Inner Detector:

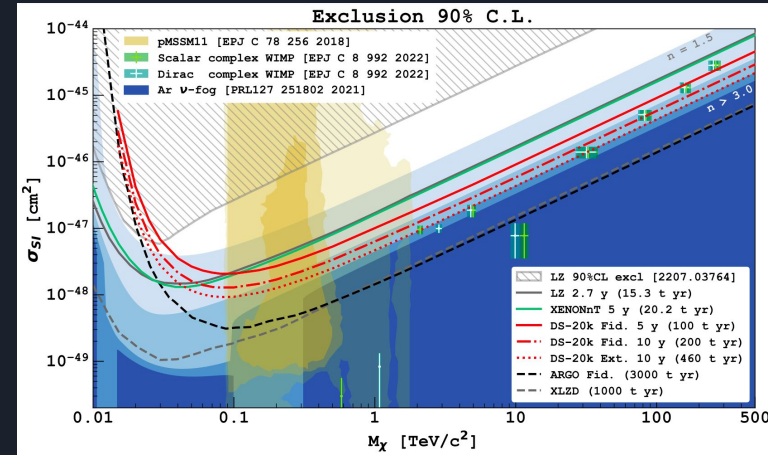
- Octagonal shape dual phase argon TPC;
- Active UAr mass ~ 49.7 tonnes;
- Fiducial UAr mass ~ 20.2 tonnes;
- Inner Neutron veto \Rightarrow Active UAr mass ~32 tonnes.

Instrumental Background:

- 0.1 background events over 200 t-y in the ROI (30-200 keVnr).
- Sensitivity to neutrino induced coherent scattering (CEvNS): 3.2 events

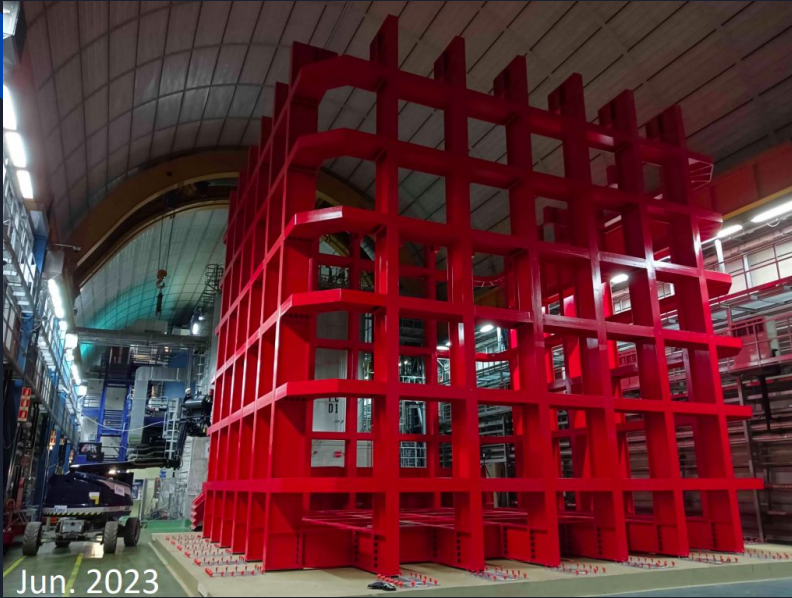
Exposure 200 t-y:

- 20 t fiducial volume with nominal 10 year run time
- 5 σ discovery: $2.1 \times 10^{-47} \text{ cm}^2 @ 1 \text{ TeV}/c^2$
- 90% C.L. exclusion: $6.3 \times 10^{-48} \text{ cm}^2 @ 1 \text{ TeV}/c^2$

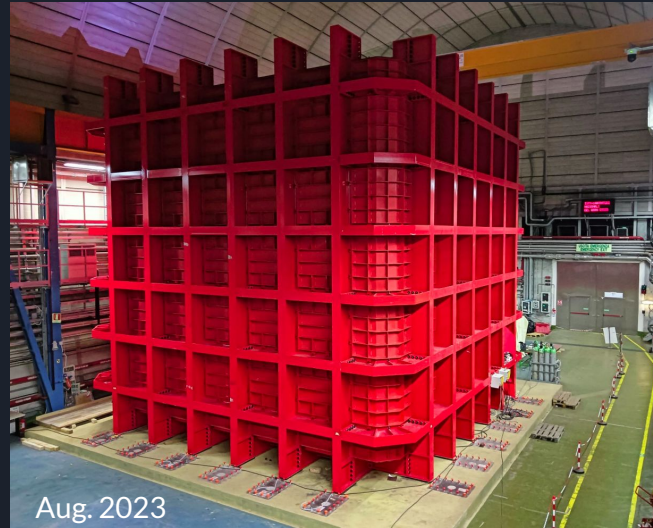




Construction Begins...



Jun. 2023



Aug. 2023



Aug. 2023



Forward...

- DarkSide-20k is the next leading experiment in the LAr DM detection community in both size and sensitivity to high mass SI WIMPs.
- This year has marked beginning of construction of the detector, starting from the cryostat.
- Production and characterization of PDUs are ongoing
- Next months would mark the starting of construction of Urania extraction plant in Colorado.
- Mockup for the DS-20k detector is planned in December, 2023 @Hall C, LNGS.
- With ArDM refurbished, we are ready to install DArT in the ArDM tank.
- Final Acrylic structure for DArT is under procurement from Canada.
- 6 kg of UAr, used in DS-50, arrived LSC in August, first spectrometric measurements ongoing.
- Soon DArT in test setup will be filled by UAr for a data taking.

Collaboration Meeting @ June,2023



Thank You for Your Attention



Backup Slides

DArT Test Setup



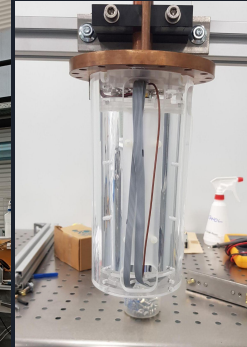
The Test setup



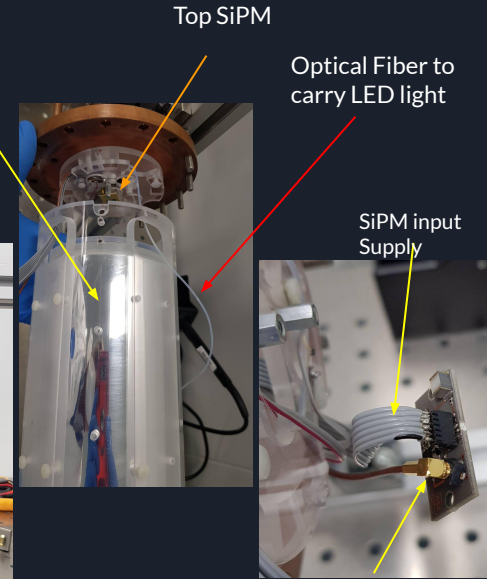
Cryostat



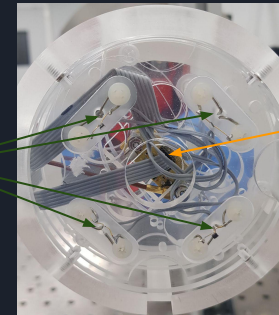
DArT Vessel



Acrylic Structure



RPT-100s

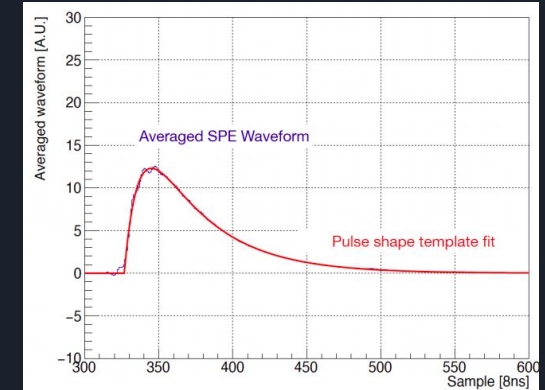
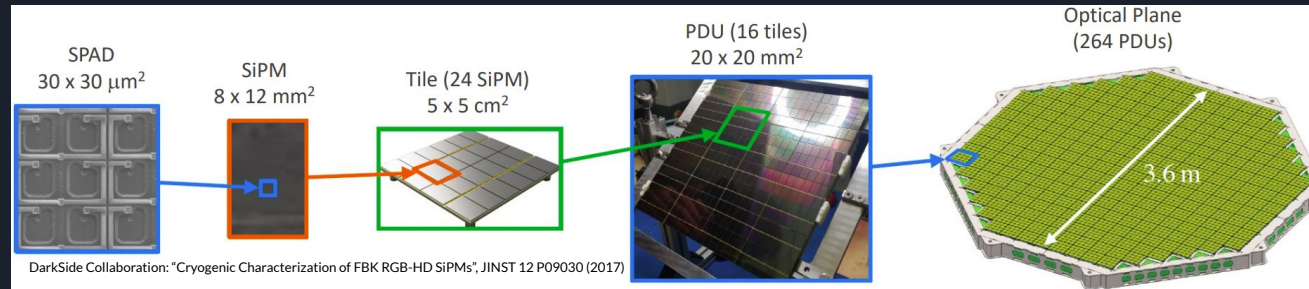


Bottom SiPM

Photodetectors and DAQ:

DS-20k will use SiPMs as the face of readout photo-electronics

- Developed with Fondazione Bruno Kessler (FBK)
- Lower radioactivity
- Higher photon-detection efficiency
- Higher active area ("fill factor")
- Lower bias voltage
- Photon detection efficiency (PDE) > 40% at 77K
- Dark count rate (DCR) < 0.01 Hz/mm² at 77K (7 Volts overVoltage)
- Signal-to-Noise ratio (SNR) > 8 (TPC PDU)



$$V(t) = (e^{-(T-t)/\tau_1} - e^{-(T-t)/\tau_2})$$
$$\tau_1 = 330 \text{ ns} \ \& \ \tau_2 = 77 \text{ ns}$$

DAQ Concept:

- Detectors are readout without global (hardware) trigger - **Trigger-less**
 - Each channel generates a data flow independent from the others
- Digitized waveform are processed in real time - **FPGA+CPU processing**
- Flexible selection of events from full state of the detectors - **Time Slice**
- Additional requirement: On-the-fly **data reduction** before writing to disk

DAQ Relevant Parameters:

- 2112 readout channels TPC
- 480 readout channels Veto (inner)
- 128 readout channels Veto (outer)
- Expected event rate: 88 interactions/s in the TPC active volume