

Direct searches with Argon and study on cosmogenic activation above ground for the DarkSide-20k project



- Liquid Argon detectors
- DarkSide-20k
- Cosmogenic activation
 - Methodology
 - Steel and Copper
 - Titanium
 - Argon



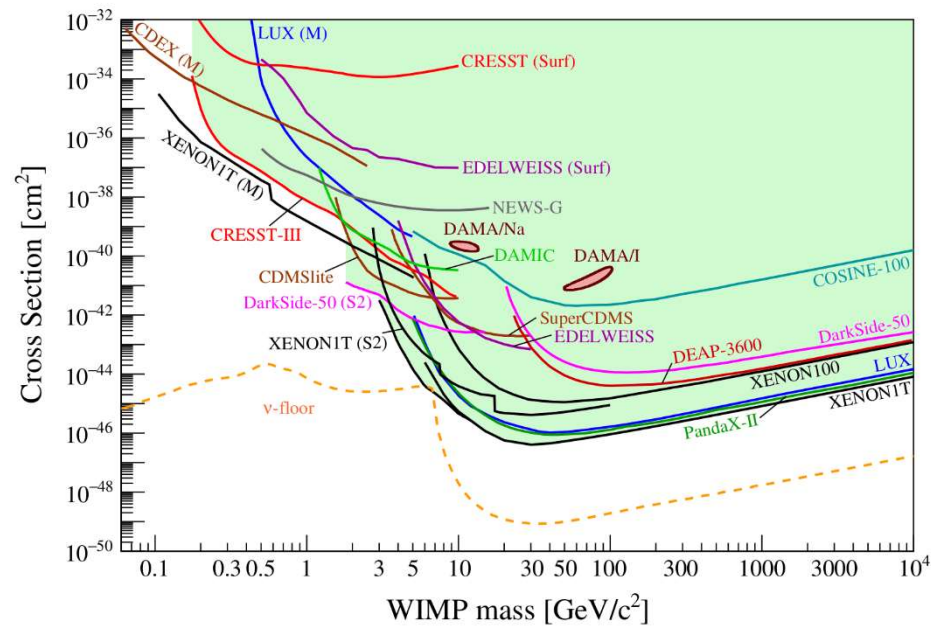
Susana Cebrián scebrian@unizar.es
on behalf of the DarkSide-20k collaboration
23rd May 2022



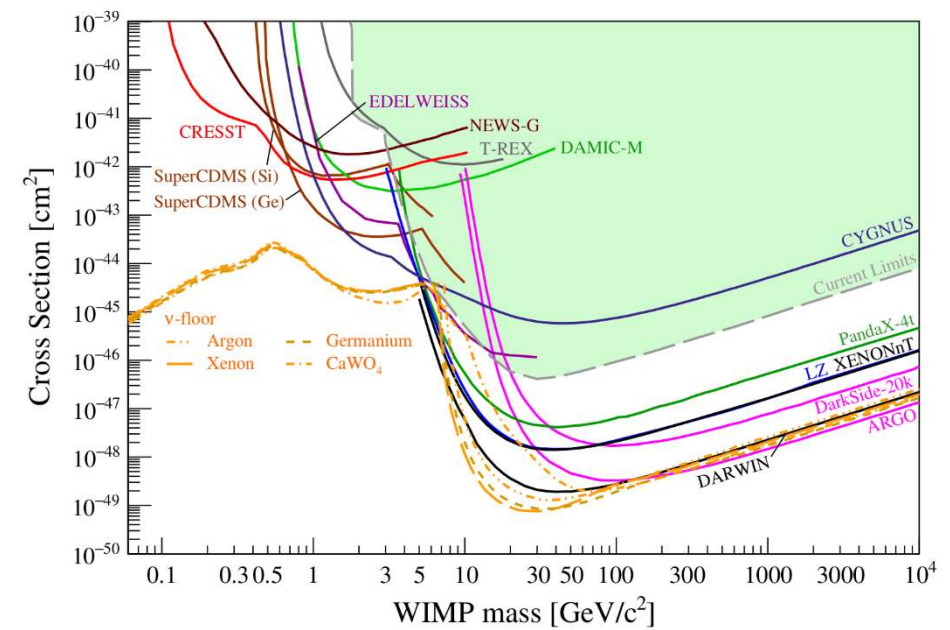
Direct detection

DM-nucleon Spin-Independent scattering

Results



Prospects



J. Billiard et al, APPEC Committee Report, Rep. Prog. Phys. 85 (2022) 056201

Liquid Ar detectors

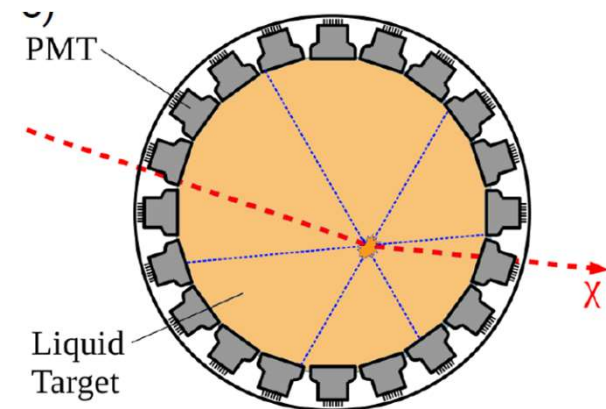
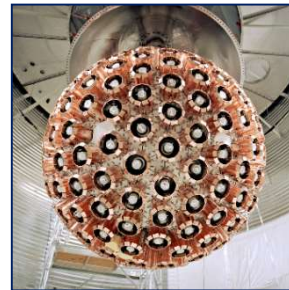
Noble gases (Xe, Ar) scintillate and can be ionized
 Liquid state: massive and compact DM targets

Ar: + different scintillation pulse shape for **ER** and **NR** → very efficient PSD
 -- presence of ^{39}Ar activity → use of underground Ar (UAr) mandatory

- **Single-phase liquid Ar:** measuring only scintillation

DEAP-3600: at SNOLAB (Canada)
 First multi-ton detector in operation
 ER leakage probability of $4 \cdot 10^{-9}$

R. Ajaj et al, Phys. Rev. D 100 (2019) 022004
 P. Adhikari et al, Phys. Rev. D 102, 082001 (2020)
 P. Adhikari et al, Phys. Rev. Lett. 128, 011801 (2022)

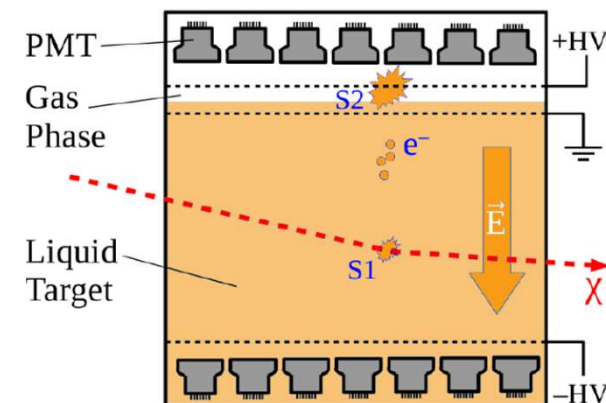


M. Schumann, J. Phys. G46 (2019)103003

- **Dual-phase liquid Ar:** TPC measuring **S1** primary scintillation + **S2** secondary scintillation from drifted e^-

DarkSide-50: at Gran Sasso (Italy)
 Leading sensitivity at 1.8–3.5 GeV,
 searches for low mass DM with S2 only,
 feasibility of using UAr shown

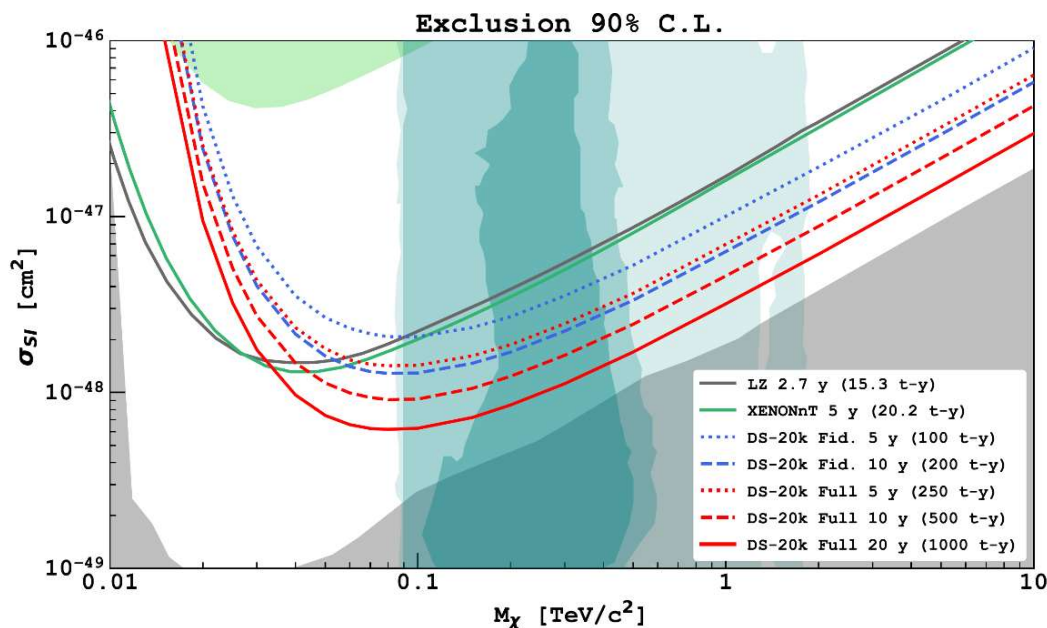
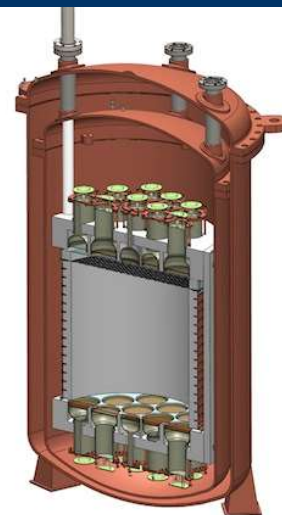
P. Agnes et al, Phys. Rev. D 98 (2018) 102006
 P. Agnes et al, Phys. Rev. Lett. 121 (2018) 081307
 P. Agnes et al, Phys. Rev. Lett. 121 (2018) 101303



Liquid Ar detectors: GADMC

Global Argon Dark Matter Collaboration (GADMC):

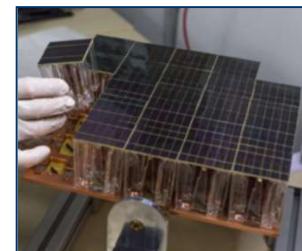
joining ArDM, DarkSide-50, DEAP-3600, and MiniCLEAN to operate LAr TPCs reaching the scale of **multi-ton** detectors to push the sensitivity for WIMP detection down to the neutrino fog



- **DarkSide-20k**: 20 t (fiducial) at Gran Sasso, starting in 2025
- **DarkSide-LowMass**: 1 t (fiducial), S2 only to lower threshold → more ultrapure Ar needed
- **ARGO**: 360 t, at SNOLAB, end of the decade

Program:

- Development of custom-designed **SiPMs**
- Design of **active vetos** to reject backgrounds
- Procurement of large amounts of radiopure **underground Ar (UAr)**

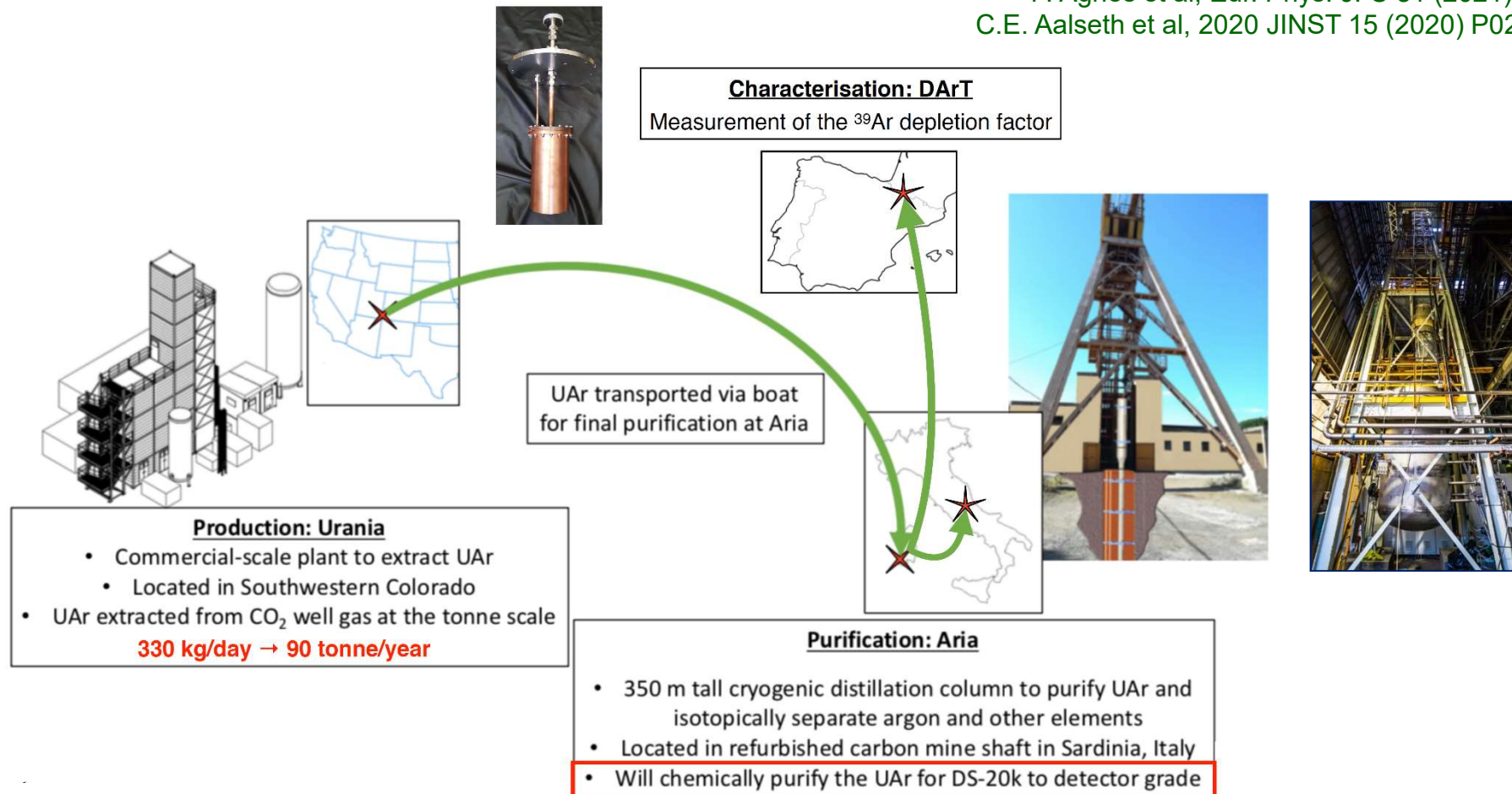


Liquid Ar detectors: GADMC

Procurement of low-radioactivity UAr

- **Urania:** extraction from CO₂ wells in Colorado (as DarkSide-50)
- **Aria:** purification in a cryogenic distillation column in Sardinia
- **DArT:** quantification of ³⁹Ar in a chamber in the ArDM detector in Canfranc

P. Agnes et al, Eur. Phys. J. C 81 (2021) 359
C.E. Aalseth et al, 2020 JINST 15 (2020) P02024

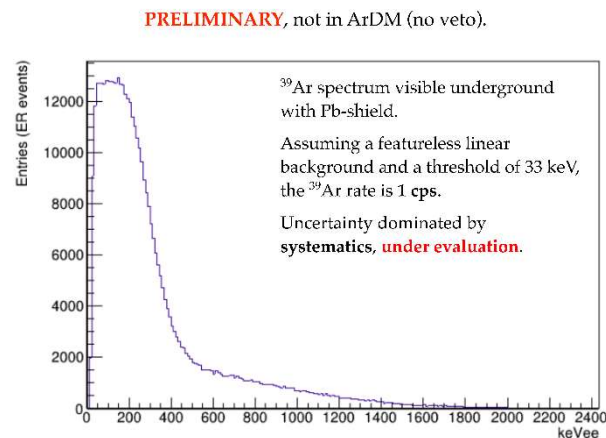


Liquid Ar detectors: DArT

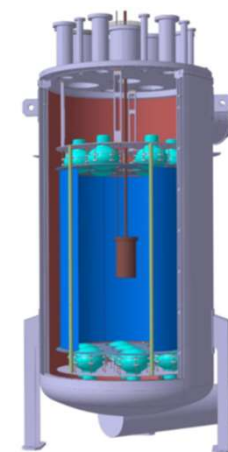
Goal: to measure depletion factors of ^{39}Ar > 1000 with statistical accuracy better than 10% in one week of counting time (each batch of DarkSide-20k must be tested)

C.E. Aalseth et al, 2020 JINST 15 (2020) P02024

- **Design, assembly and test at CIEMAT**
- Small target filled with 1.35 kg of liquefied UAr
- Seen by two 1 cm² SiPMs
- PMMA support structure with TPB coating, OFHC Cu cylinder



- **First operation at Canfranc**
- Pressurized LN₂ bath at 85 K
- Pb shielding

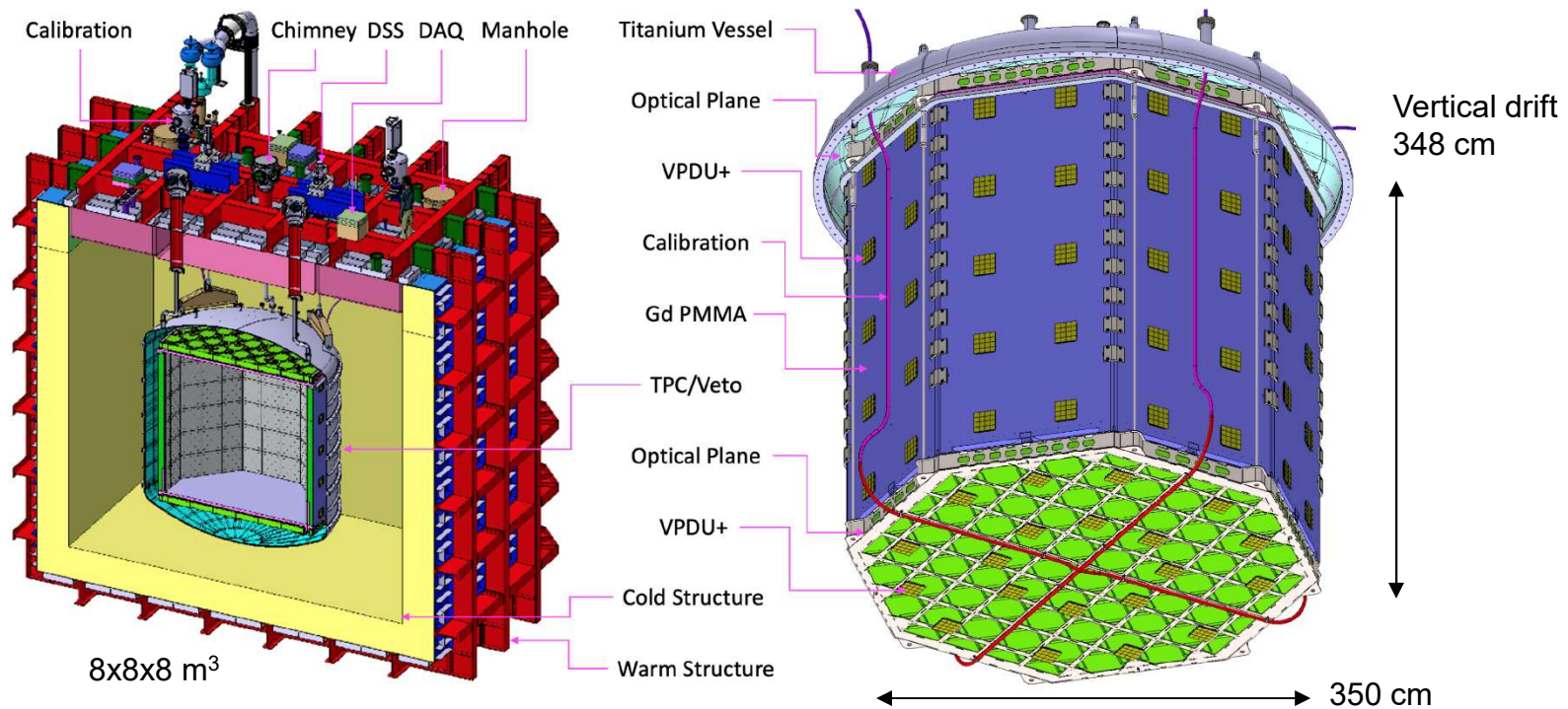


- **Being placed inside ArDM detector** in single phase
- ~1 t Atmospheric Ar buffer used as shield and veto, with 13 PMTS
- New Pb-shield hanging from existing polyethylene shield
- Operation starting at end 2022, beginning 2023

DarkSide-20k: design

Dual-phase TPC read by **SiPMs** (21 m^2) with 3D space reconstruction capability
Filled and surrounded by **UAr**: 99.2 t required, 51.1 t inside TPC, **20.2 t** fiducial mass

- **TPC**: Gd-PMMA vessel to moderate and capture neutrons
- **Inner veto**: Titanium vessel
- **Outer veto**: 700 t of Atmospheric Argon, ProtoDUNE-like membrane cryostat

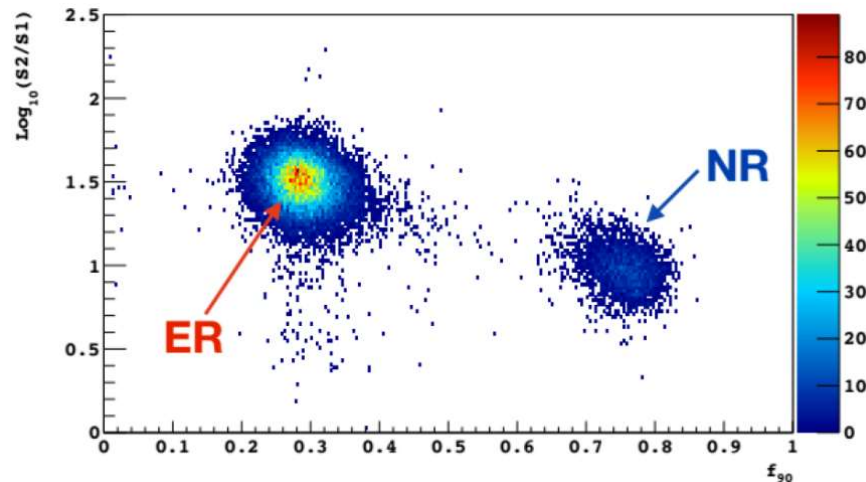


All the components carefully selected requiring ultra-low radioactivity

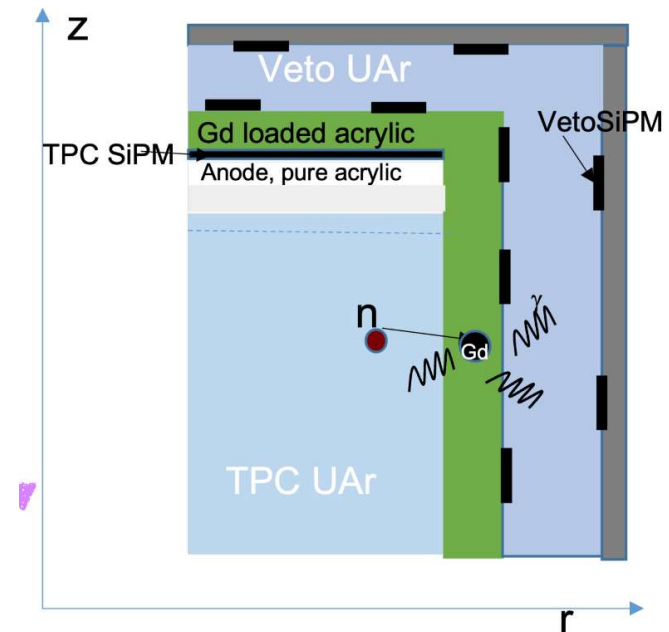
DarkSide-20k: background

Goal: <0.1 events over a 200 t·y exposure

- ✓ Very **efficient discrimination** between ER and NR, thanks to PSD and S1/S2
- ✓ **Veto capabilities** for muons and neutrons



f90: fraction of light in first 90 ns



- ➔ Radiogenic **neutrons** by (α ,n) reactions or fission, producing indistinguishable NRs by single scattering, are the main background source
- But **beta/gamma** background from **primordial or cosmogenic radioactivity** must be analyzed too due to acceptance losses for ER+NR pile-up in TPC or accidental coincidences in TPC and Veto

Cosmogenic activation: methodology

Goal: to determine if **activity induced by exposure to cosmic rays** during fabrication, transport and storage of components could be an issue in order to identify limits on the surface residency time and assess the necessity of taking some steps:

- Storing materials underground
- Avoiding flights
- Using shields against cosmic rays

Studies for **copper, stainless steel, titanium** and **argon**

1. To know the **production rates** R of relevant isotopes in the targets, from
 - Scarce experimental data from irradiation/controlled exposure experiments
 - Calculations from **production cross sections** and **cosmic ray spectrum**:

$$R = N_t \int \sigma(E)\phi(E)dE$$

N_t = number of target nuclei

ϕ = flux of cosmic rays

σ = production cross section

E = particle energy

2. To estimate the **induced activity** A knowing the exposure history to cosmic rays

$$A = R[1 - \exp(-\lambda t_{exp})] \exp(-\lambda t_{cool})$$

t_{exp} = exposure time

t_{cool} = cooling time underground

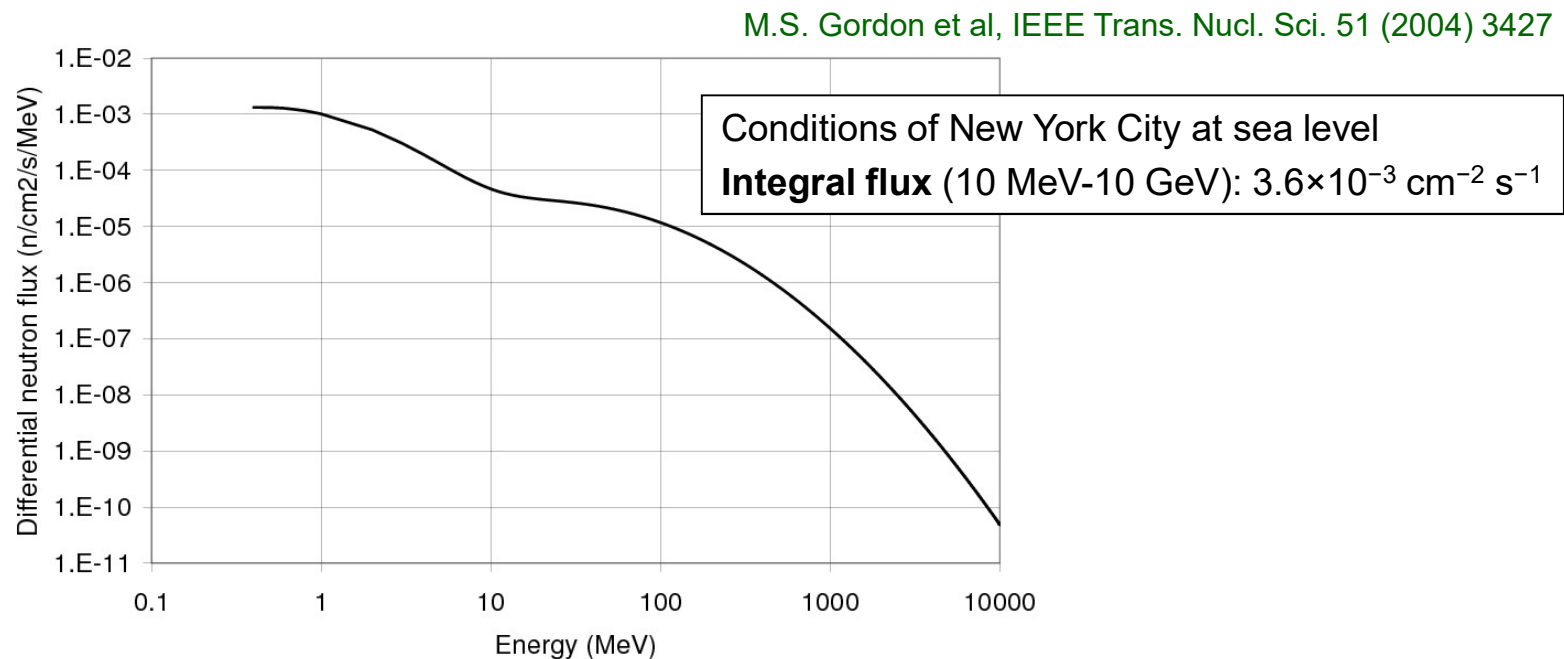
3. To compute the **background rate** generated by Monte Carlo simulation: G4DS

Cosmogenic activation: methodology

- **Flux of cosmic rays**

At the Earth's surface nuclide production is dominated by **neutrons** because of the absorption of charged particles in the atmosphere

A parametrization based on a set of measurements of cosmic neutrons on the ground across the US considered



As it depends on altitude and geomagnetic rigidity, **correction factors** must be applied to the parametrization

Cosmogenic activation: methodology

- **Production cross sections**

Select the best description of the excitation function $\sigma(E)$ by nucleons from

- **Experimental data**: from beam experiments

 - EXFOR** database: typically few data for neutrons

- **Semiempirical formulae** (Silberberg&Tsao equations): targets $A \geq 3$, products $A \geq 6$ and $E > 100$ MeV

 - COSMO, YIELDX, ACTIVIA** codes

- **Monte Carlo simulation**: standard packages (Geant4, FLUKA, ...), libraries

 - TENDL** (TALYS-based Evaluated Nuclear Data Library):

 - Using the TALYS code
 - For **neutrons and protons up to 200 MeV**

 - HEAD-2009** (High Energy Activation Data) library: only for $Z \geq 12$.

 - Using a selection of models and codes (CEM, CASCADE/INPE, MCNP, ...) dictated by an extensive comparison with EXFOR data.
 - For **protons from 150 MeV to 1 GeV**

 - JENDL** (Japanese Evaluated Nuclear Data Library) :

 - Using GNASH code
 - For **neutrons and protons up to 200 MeV, from 20 MeV to 3 GeV** in High Energy File

Copper and steel

- Abundant information on **production rates R** from different codes and measured saturation activities in samples exposed for long-time to cosmic rays

S. Cebrián, Universe 6 (2020) 162

- Activity A** evaluated for extreme cases from measured rates R:

$t_{\text{exp}}=1$ month, $t_{\text{exp}}=1$ year, $t_{\text{exp}}=10$ year (sea level)

$t_{\text{cool}}=0$

Copper

Copper	mass (kg)
HV, LV cables for signal transmission	113.4
Cathode HV cables	4.24
TPC field cage	0.17
PDMs electronic components	756.9
Total	875

Measured rates on 125 kg at Gran Sasso after 270 d

Activities <1 Bq, even for 10 y

Isotope	$T_{1/2}$ (d)	Decay mode Main γ emissions (keV), I (%)	R ($\text{kg}^{-1}\text{d}^{-1}$)	A (1 m) (Bq)	A (1 y) (Bq)	A (10 y) (Bq)
^{46}Sc	83.79	889.3 (99.98%); 1120.5 (99.98%)	2.18 ± 0.74	0.005 ± 0.002	0.021 ± 0.007	0.022 ± 0.007
^{54}Mn	312.19	834.8 (99.98%)	8.85 ± 0.86	0.006 ± 0.001	0.050 ± 0.005	0.090 ± 0.009
^{59}Fe	44.49	1099.3 (56.5%); 1291.6 (43.2%)	18.7 ± 4.9	0.071 ± 0.019	0.189 ± 0.049	0.189 ± 0.050
^{56}Co	77.24	846.8 (100%); 1238.3 (67.6%)	9.5 ± 1.2	0.023 ± 0.003	0.093 ± 0.012	0.096 ± 0.012
^{57}Co	271.82	122.1 (85.6%)	74 ± 17	0.055 ± 0.013	0.454 ± 0.104	0.749 ± 0.172
^{58}Co	70.85	810.8 (99%)	67.9 ± 3.7	0.175 ± 0.010	0.668 ± 0.036	0.687 ± 0.037
^{60}Co	1923.95	1173.2 (99.97%); 1332.5 (99.99%)	86.4 ± 7.8	0.009 ± 0.001	0.108 ± 0.010	0.640 ± 0.058

Copper and steel

- Abundant information on **production rates R** from different codes and measured saturation activities in samples exposed for long-time to cosmic rays

S. Cebrián, Universe 6 (2020) 162

- Activity A** evaluated for extreme cases from measured rates R:

$t_{\text{exp}}=1$ month, $t_{\text{exp}}=1$ year, $t_{\text{exp}}=10$ year (sea level)

$t_{\text{cool}}=0$

Stainless steel

Stainless steel	mass (kg)
AAr cryostat	6,600
Beams and shell	218,000
TPC wire frames and grids	703
Barrel brackets	352
Total	225,655

Activities at ~100 Bq,
just for 1 y

Isotope	$T_{1/2}$ (d)	Decay mode Main γ emissions (keV), I (%)	R ($\text{kg}^{-1}\text{d}^{-1}$)	A (1 m) (Bq)	A (1 y) (Bq)	A (10 y) (Bq)
^7Be	53.22	477.6 (10.5%)	389 ± 60	329 ± 51	1007 ± 155	1016 ± 157
^{46}Sc	83.79	889.3 (99.98%); 1120.5 (99.98%)	19.0 ± 3.5	10.9 ± 2.0	47.2 ± 8.7	49.6 ± 9.1
^{54}Mn	312.19	834.8 (99.98%)	233 ± 26	39.2 ± 4.4	338 ± 38	608 ± 68
^{56}Co	77.24	846.8 (100%); 1238.3 (67.6%)	20.7 ± 3.5	12.8 ± 2.2	52.0 ± 8.8	54.1 ± 9.1
^{58}Co	70.85	810.8 (99%)	51.8 ± 7.8	34.4 ± 5.2	131 ± 20	135 ± 20
^{60}Co	1923.95	1173.2 (99.97%); 1332.5 (99.99%)	6.27	0.18	2.0	12

Measured rates at Gran Sasso after 314 d,
except for ^{60}Co from Geant4

Titanium

- **Production rates R** previously evaluated by **GEANT4** and **ACTIVIA**.

C. Zhang et al., *Astropart. Phys.* 2016, 84, 62

Isotope, Half life	n(<4 MeV)	n(>4 MeV) (kg ⁻¹ d ⁻¹)	Muon	Proton	Total (kg ⁻¹ d ⁻¹)	ACTIVIA1/2 (kg ⁻¹ d ⁻¹)
²² ₁₁ Na, 2.6 yr	0.00	0.20	0.00	0.08	0.28	0.93/0.79
²⁶ ₁₃ Al, 7.2 × 10 ⁵ yr	0.00	0.41	0.02	0.10	0.52	1.02/1.02
³² ₁₄ Si, 150 yr	0.00	1.51	0.00	0.14	1.65	0.87/1.21
⁴⁰ ₁₉ K, 1.3 × 10 ⁹ yr	0.00	20.98	0.12	0.97	22.06	27.46/60.98
⁴⁷ ₂₀ Ca, 4.5 d	0.00	10.13	0.01	0.09	10.23	0.31/0.72
⁴⁶ ₂₁ Sc, 83.8 d	0.31	270.42	0.43	4.32	275.49	107.80/270.07
⁴⁴ ₂₁ Sc, 3.3 d	1.83	385.35	0.54	6.39	394.12	48.78/116.38
⁴⁴ ₂₂ Ti, 63 yr	0.00	95.94	0.46	3.68	100.08	4.84/12.03
⁵⁰ ₂₃ V, 1.4 × 10 ⁷ yr	0.00	0.32	0.01	0.07	0.39	4.40/14.13
⁵¹ ₂₄ Cr, 27.7 d	0.00	0.02	0.00	0.00	0.02	0/0

Except for ⁴⁶Sc, significant yields are either:

- Very short-lived
- Very long-lived, requiring huge exposures (⁴⁰K, ⁵⁰V)
- Produce non-dangerous emissions; pure or almost pure β (³H, ³³P, ³⁵S, ³⁹Ar; ⁴⁵Ca); low energy <80 keV γ rays (⁴⁴Ti, ⁴⁹V)



New estimate of production rate of ⁴⁶Sc

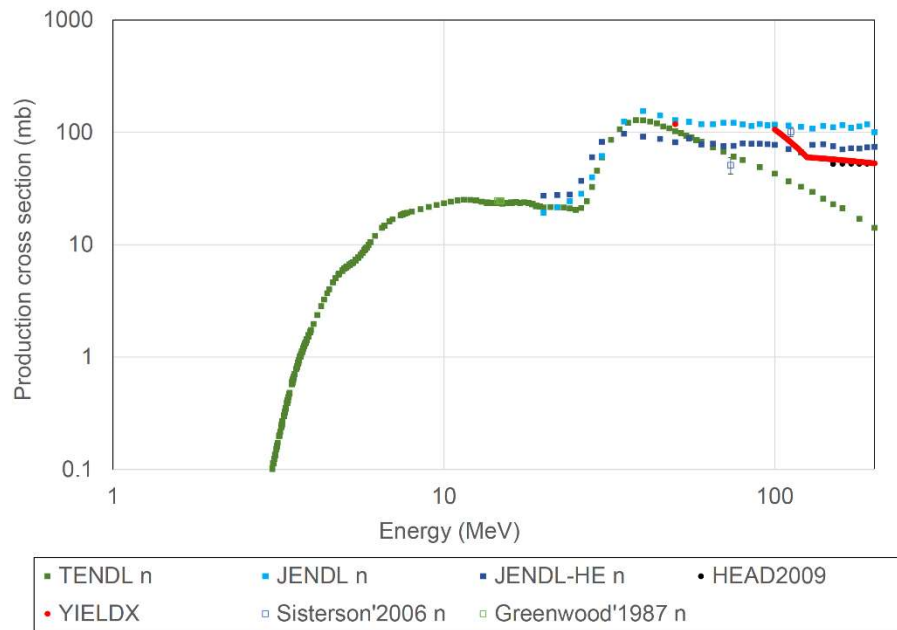
β⁻ decay, T_{1/2}=83.787 d

Main γ emissions: 889.3, 1120.5 keV
(100% probability)

Titanium: ^{46}Sc

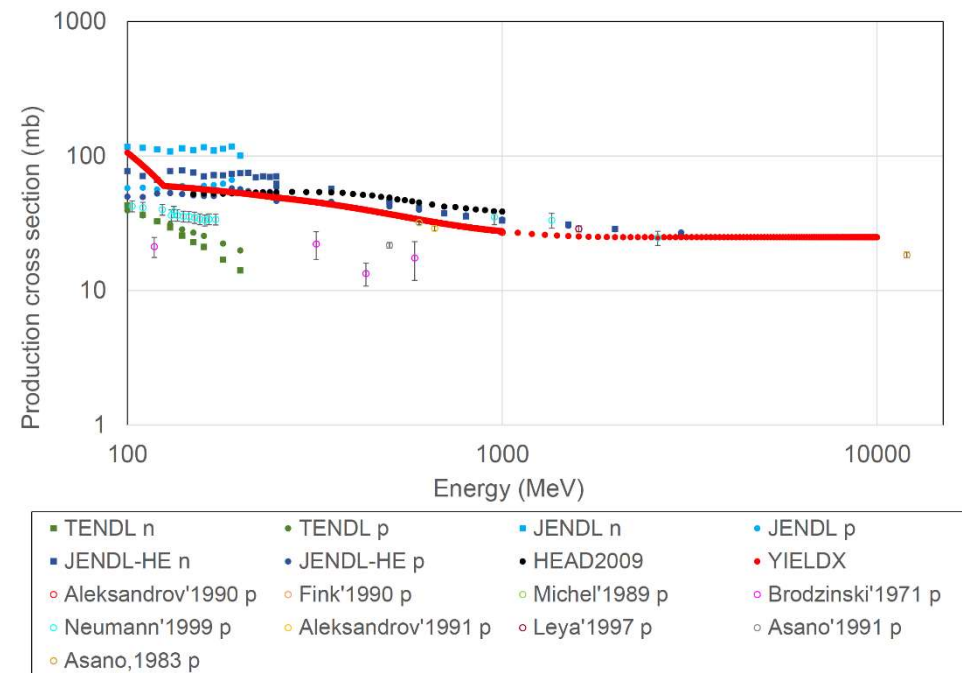
- Production cross sections**

Selected description from different excitation functions $\sigma(E)$ by nucleons.



<100 MeV:

- Good agreement for the only two n measurements



>100 MeV:

- Good agreement between calculations and data (except for old series)

Titanium: ^{46}Sc

- Production rate R** contributions in $\text{kg}^{-1} \text{d}^{-1}$

$$R = N_t \int \sigma(E)\phi(E)dE$$

	TENDL-2019 (n)	JENDL-4.0 (n)	YIELDX	HEAD-2009	JENDL-HE (n)
<20 MeV	16.0				
20-200 MeV	146.6	270.8			187.7
200-1000 MeV			37.9	44.8	49.5
1-10 GeV			2.4		2.6

To sum contributions in the whole energy region, calculations giving the lowest and highest rates in each region considered to get mean value and uncertainty

Code	R ($\text{kg}^{-1}\text{d}^{-1}$)
COSMO	289.4
ACTIVIA	270.16
Geant4	275.5
Estimated rate in this work	(271±68)

- Activity** assuming saturation

$(3.14 \pm 0.79) \text{ mBq/kg}$

At the order of measured activity in different types of Ti screened by LUX, XENON1T

Titanium	mass (kg)
Optical plane structure	928
TPC rods	52
Vessel	8,230
Support structure for inner veto	300
Total	9,510

Overall activity of 30 Bq of ^{46}Sc expected

Argon

- **Relevant cosmogenic products**

^{39}Ar : β^- emitter with $Q=565$ keV, $T_{1/2}=\mathbf{269}$ y mainly produced by $^{40}\text{Ar}(n,2n)^{39}\text{Ar}$

Measured activity in

- **Atmospheric Ar**: ~ 1 Bq/kg (WARP, ArDM, DEAP)
- **Underground Ar**: (0.73 ± 0.11) mBq/kg (DarkSide-50)

^{37}Ar : EC decay, $E_{e,K\text{ shell}}=2.8$ keV, $T_{1/2}=\mathbf{35.02}$ d mainly produced by $^{40}\text{Ar}(n,4n)^{37}\text{Ar}$

Observed in DarkSide-50

^{42}Ar : β^- emitter, $Q=599$ keV, $T_{1/2}=\mathbf{32.9}$ y producing **^{42}K** (β^- emitter, $Q=3525$ keV, $T_{1/2}=12.36$ h) \rightarrow potential background for neutrinoless double beta decay

In Atm Ar: DBA: 92^{+22}_{-46} $\mu\text{Bq/kg}$, GERDA: 50-100 $\mu\text{Bq/kg}$, DEAP $(40.4\pm 0.5.9)$ $\mu\text{Bq/kg}$

Production mechanisms: two-step neutron capture and $^{40}\text{Ar}(\alpha,2p)^{42}\text{Ar}$

Not observed in UAr of DarkSide-50

^3H : β^- emitter with $Q=18.6$ keV, $T_{1/2}=\mathbf{12.3}$ y

- Quantified yields in **Ge** detectors (EDELWEISS, CDMSlite) and observed hints in **NaI(Tl)** crystals (ANAIS, COSINE)
- Purification systems for LAr should remove all non-noble radionuclides, as also assumed in **LXe**, but tritium proposed as a possible explanation for the XENON1T excess

Argon

- **Production rates R** (sea level): available information
 - First measurement for ^{39}Ar and ^{37}Ar in an **irradiation experiment** at Los Alamos (LANSCE) with a neutron beam, quantifying products with a proportional counter at PNNL + calculations at sea level from alternate mechanisms

R. Saldanha et al, Phys. Rev. C 100 (2019) 024608

Reaction	Estimated ^{39}Ar production rate [atoms/(kg _{Ar} day)]	Fraction of total AAr (%)
$^{40}\text{Ar} (n, 2n)^{39}\text{Ar} + ^{40}\text{Ar}(n, d)^{39}\text{Cl}$	759 ± 128	72.3
$^{40}\text{Ar} (\mu, n)^{39}\text{Cl}$	172 ± 26	16.4
$^{40}\text{Ar} (\gamma, n)^{39}\text{Ar}$	89 ± 19	8.5
$^{40}\text{Ar} (\gamma, p)^{39}\text{Cl}$	23.8 ± 8.7	2.3
$^{40}\text{Ar} (p, 2p)^{39}\text{Cl}$	<0.1	<0.01
$^{40}\text{Ar} (p, pn)^{39}\text{Ar}$	3.6 ± 2.2	0.3
$^{38}\text{Ar}(n, \gamma)^{39}\text{Ar}$	$\ll 0.1$ (UAr) 1.1 ± 0.3 (AAr)	- 0.1
Total	1048 ± 133	100

Reaction	Estimated ^{37}Ar production rate [atoms/(kg _{Ar} day)]
$^{40}\text{Ar} (n, 4n)^{37}\text{Ar}$	51.0 ± 7.4
$^{40}\text{Ar} (\gamma, 3n)^{37}\text{Ar}$	3.5 ± 0.7
$^{40}\text{Ar} (p, p3n)^{37}\text{Ar}$	1.3 ± 0.4
$^{36}\text{Ar}(n, \gamma)^{37}\text{Ar}$	0.9 ± 0.3 (UAr) 36 ± 11 (AAr)
$^{38}\text{Ar}(n, 2n)^{37}\text{Ar} + ^{38}\text{Ar}(\gamma, n)^{37}\text{Ar} + ^{38}\text{Ar}(p, pn)^{37}\text{Ar}$	<0.05 (UAr) 0.43 ± 0.05 (AAr)
Total	56.7 ± 7.5 (UAr) 92 ± 13 (AAr)

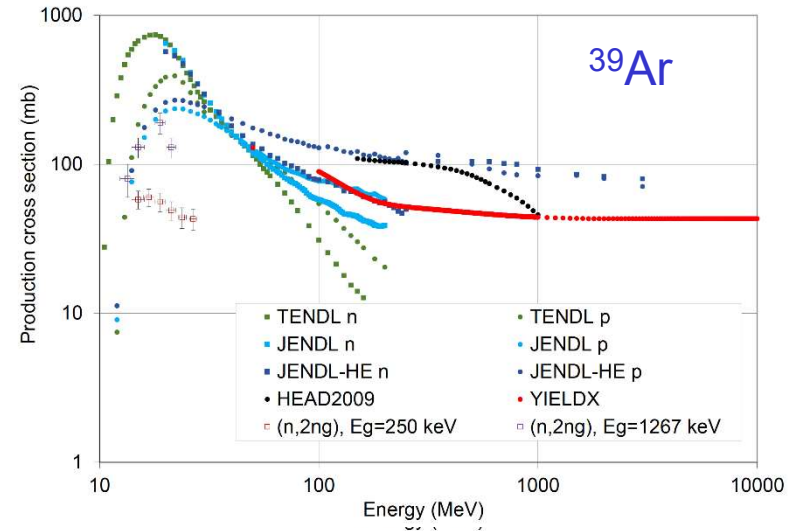
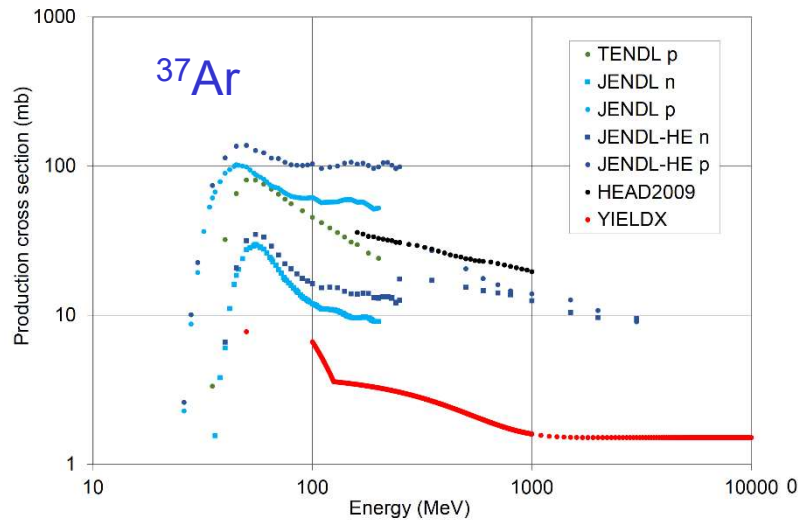
- Rates for ^{37}Ar , ^{39}Ar and ^{42}Ar from neutrons, protons and muons recently estimated by **GEANT4** simulation too

C. Zhang, D.M. Mei arXiv:2202.06403

Argon

- Production rates R (sea level): new calculations

$$R = N_t \int \sigma(E)\phi(E)dE$$



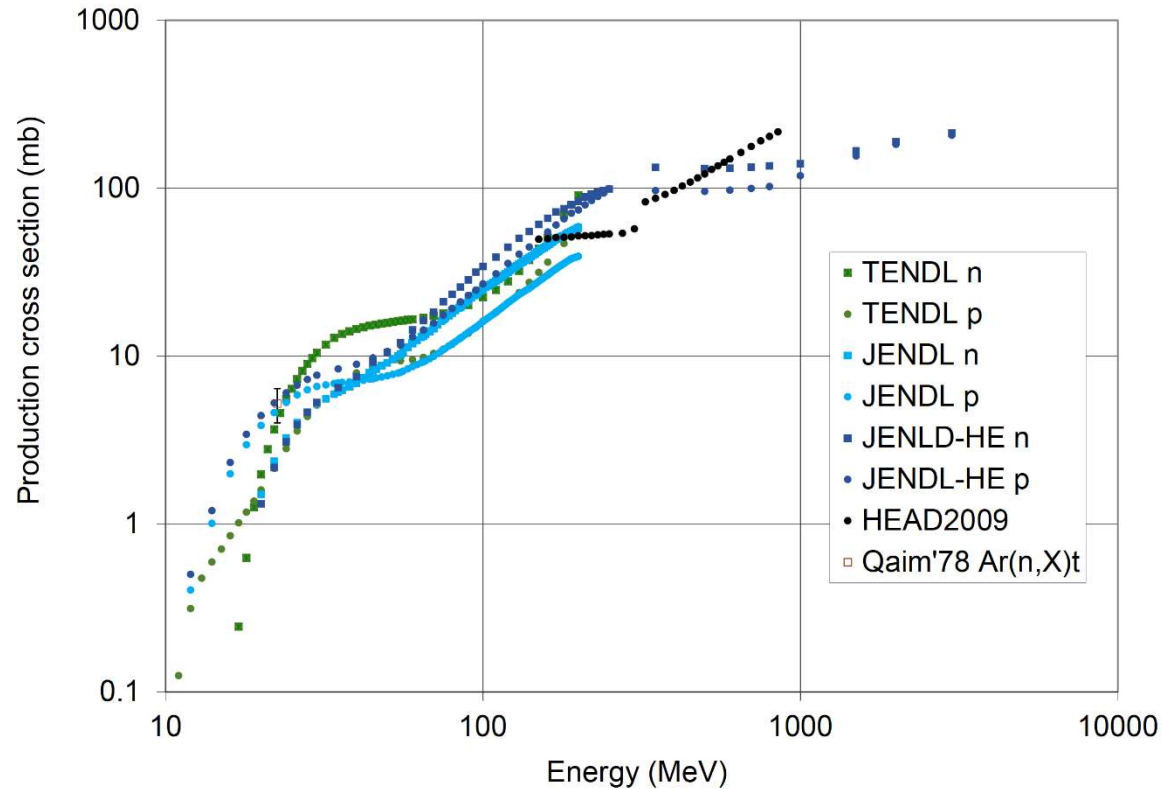
^{37}Ar			^{39}Ar		
This work	Cut (MeV)	R ($\text{kg}^{-1} \text{d}^{-1}$)	This work	Cut (MeV)	R ($\text{kg}^{-1} \text{d}^{-1}$)
LE+HE			LE+HE		
TENDL(p)+HEAD2009	150	153.6	TENDL+HEAD2009	150	726.4
TENDL(p)+YIELDX	100	93.5	TENDL+YIELDX	100	697.1
TENDL(p)+YIELDX	200	122.7	TENDL+YIELDX	200	646.0
JENDL-HE(n)	30	63.9	TENDL+JENDL-HE(n)	20	804.3
Estimated rate in this work		109±45	Estimated rate in this work		725±79
Measurement [78]		51.0±7.4			759±128
ACTIVIA [78]		17.9±2.2			200±25
MENDL-2P [78]		155±19			188±24
TALYS [78]		76.8±9.6			753±94
INCL++ (ABLA07) [78]		79.3±9.9			832±104
Geant4 [29]		176	TENDL-2015 [78]		726±91
					858

^{39}Ar : fully compatible with measured value and several calculations

^{37}Ar : larger discrepancies

Argon

- **Production rates R** (sea level): new calculations for ${}^3\text{H}$



Same approach but including more data

J. Amaré et al, *Astropart. Phys.*97 (2018) 96

	R ($\text{kg}^{-1} \text{d}^{-1}$)
Estimated rate in this work	168 ± 53
TENDL+HEAD2009 [73]	146 ± 31
TALYS [10]	44.4
Geant4 [26]	84.9
ACTIVIA [26]	82.9

Argon

- **Activity A** from measured production rates for ^{37}Ar , ^{39}Ar and estimated rate for ^3H for realistic exposure conditions

$$A = R[1 - \exp(-\lambda t_{exp})] \exp(-\lambda t_{cool})$$

Fix tentative **exposure times** and **places (altitude)** for shipping:

URANIA → ARIA → LNGS

Planned to produce **120 t**, shipped in high pressure gas cylinder (2 t per skid)

1. **Extraction and storage of UAr at Urania:** 3 skids filled before transportation, exposures of 8, 16, 24 days
2. **Trip from Urania to a shipping port (Houston):** 7 days
3. **Trip overseas to Europe:** 60 days at sea + 7 days from Cagliari to Aria

Steps 1-3 repeated 20 times, 16 months

4. **Processing and storage of UAr at Aria:** 2 runs with 60 t each taking 60 days, if stored underground
5. **Trip from Aria to LNGS:** 10 days, 10 trips with 12 t each

Total time: from Urania to Aria 614 days + 100 days from Aria to LNGS

Argon

- Activity A in $\text{kg}^{-1} \text{d}^{-1}$ for ^{37}Ar , ^{39}Ar and ^3H

^{39}Ar	Neutrons	Muons	Protons	Gamma rays	Total
R [78]	759 ± 128	172 ± 26	3.6 ± 2.2	112.8 ± 20.9	
Urania	0.551 ± 0.093	0.0483 ± 0.0073	0.0035 ± 0.0022	0.0127 ± 0.0024	0.616 ± 0.093
US	0.139 ± 0.024	0.0148 ± 0.0022	0.0009 ± 0.0005	0.0056 ± 0.0010	0.161 ± 0.024
Overseas	0.359 ± 0.061	0.081 ± 0.012	0.0017 ± 0.0010	0.053 ± 0.010	0.495 ± 0.063
Aria	0.321 ± 0.054	0.073 ± 0.011	0.0015 ± 0.0009	0.048 ± 0.0088	0.444 ± 0.056
Italy	0.0536 ± 0.0090	0.0121 ± 0.0018	0.0003 ± 0.0002	0.0080 ± 0.0015	0.0739 ± 0.0093
Sum	1.42 ± 0.13	0.229 ± 0.018	0.0079 ± 0.0026	0.127 ± 0.014	1.79 ± 0.13
Final	1.42 ± 0.13	0.229 ± 0.018	0.0078 ± 0.0026	0.127 ± 0.014	1.79 ± 0.13
(%)	79.6	12.8	0.4	7.1	

^{37}Ar	Neutrons	Thermal neutrons	Protons	Gamma rays	Total
R [78]	51 ± 7.4	0.9 ± 0.3	1.3 ± 0.4	3.5 ± 0.7	
Urania	87 ± 13	2.99 ± 0.92	0.93 ± 0.19	0.239 ± 0.080	91 ± 13
US	24.5 ± 3.6	0.81 ± 0.25	0.453 ± 0.091	0.116 ± 0.039	25.9 ± 3.6
Overseas	37.5 ± 5.4	0.95 ± 0.29	2.57 ± 0.51	0.66 ± 0.22	41.7 ± 5.5
Aria	35.5 ± 5.1	0.90 ± 0.28	2.43 ± 0.49	0.63 ± 0.21	39.4 ± 5.2
Italy	9.2 ± 1.3	0.234 ± 0.072	0.63 ± 0.13	0.162 ± 0.054	10.2 ± 1.3
Final	8.03 ± 0.74	0.209 ± 0.040	0.524 ± 0.070	0.135 ± 0.030	8.90 ± 0.75
(%)	90.3	2.3	5.9	1.5	

Exposure at Urania produces largest contribution

"Final" presents the sum from all exposure steps including properly decays.

Neutrons give most of the yield

If no purification applied

^3H	Neutrons
R	168 ± 53
Urania	2.66 ± 0.84
US	0.67 ± 0.21
Overseas	1.73 ± 0.54
Aria	1.55 ± 0.49
Italy	0.259 ± 0.082
Sum	6.9 ± 1.1
Final	6.5 ± 1.1

Argon

- **Activity A** in mBq/kg when all UAr is in Gran Sasso

^{39}Ar	0.0207 ± 0.0015
^{37}Ar	0.1030 ± 0.0086
^3H (no purification)	0.076 ± 0.012
^3H (purification at Aria)	0.00297 ± 0.00094

A residual level of 2.8% of quantified activity of ^{39}Ar in DarkSide-50 is confirmed

^{37}Ar will decay fast

Purification reduces activity of ^3H by a factor 25

- **Counting rate** in DarkSide-20k

G4DS simulation of gamma emissions from the full set of detector components to estimate rates in the TPC (50 t) and in the Veto (32 t) from measured activities


	TPC rate (Hz)	Veto rate (Hz)
Gamma	52	135
Beta	36	26
Total	88	161

γ : including ^{46}Sc in Ti giving 0.4 and 25 Hz, negligible ^{54}Mn in steel
 β : measured ^{39}Ar activity in DarkSide-50

^{39}Ar :	1.0	0.66
^{37}Ar :	5.1	3.3
^3H :	0.15	0.09

From estimated cosmogenic activation in UAr

Summary

- Liquid Ar TPCs in development by **GADMC** have excellent properties to explore both high and low mass WIMPs
 - Great effort underway to guarantee the required **UAr**: extraction at **Urania**, purification at **Aria** and precise ^{39}Ar quantification in **DArT in ArDM** at Canfranc
 - **DarkSide-20k** starting in 2025 at Gran Sasso: intense work on TPC and Veto design, photosensors and **control of backgrounds**
 - **Cosmogenic activation** in LAr and other massive components has been studied as a source of β/γ **background** to assess the contribution to counting rates and decide about exposure restrictions
 - For **copper, stainless steel** and **titanium**, activity of relevant products has been evaluated for conservative exposure times finding no significant contribution
 - Calculations for ^{46}Sc in **Ti**: $R = (271 \pm 68) \text{ kg}^{-1}\text{d}^{-1}$, $A = (3.14 \pm 0.79) \text{ mBq/kg}$
 - For **UAr**, activation assuming conditions as realistic as possible, has been computed for ^{39}Ar , ^{37}Ar and ^3H from measured production rates and a new estimate for tritium $R = (168 \pm 53) \text{ kg}^{-1}\text{d}^{-1}$
 - ^{39}Ar : $A=(20.7\pm 1.5) \mu\text{Bq/kg}$, 2.8% of measured DarkSide-50 activity
 - ^{37}Ar and ^3H : not problematic thanks to short half-life and purification
-  No showstoppers to achieve the scientific goals identified from either radiogenic or cosmogenic origin