Material Assay Campaign for the DarkSide-20k experiment

Roberto Santorelli

on behalf of the DarkSide-20k collaboration

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
cfp CIEMAT física de partículas
DARKSIDE
39 D.ArT

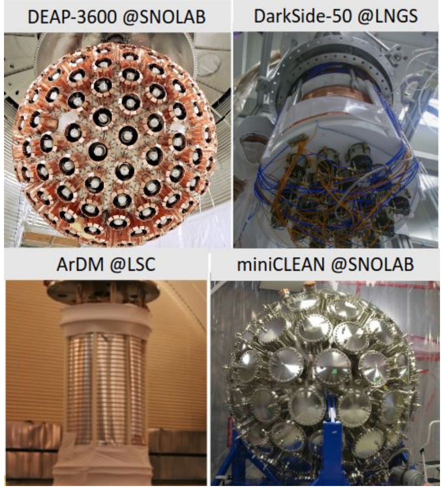
Outline

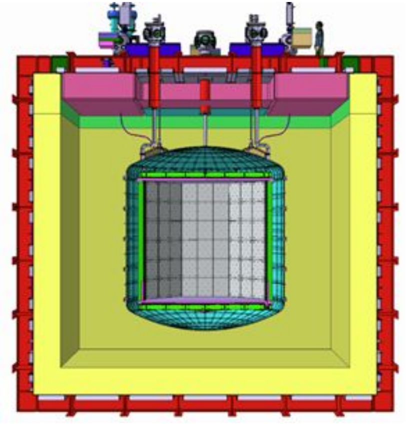
- DarkSide-20k
- Radiopurity requirements for WIMP searches with LAr
- The assay campaign:
  - Tools & organization
  - Results so far
- Conclusions and outlook

The Global Argon Dark Matter Collaboration

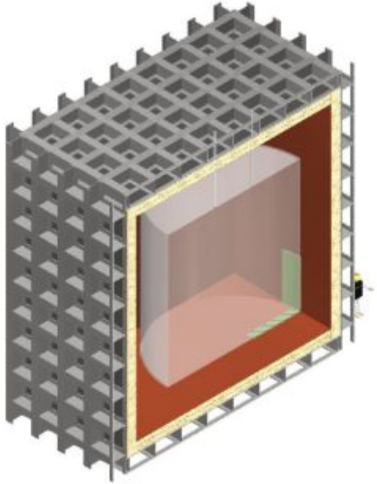
Joint effort of **all** former DM experiments using Liquid Ar targets: Combined expertise from four LAr experiments to explore dark matter to the neutrino floor and beyond

- > 500 scientists
- > 100 institutions
- 14 counties



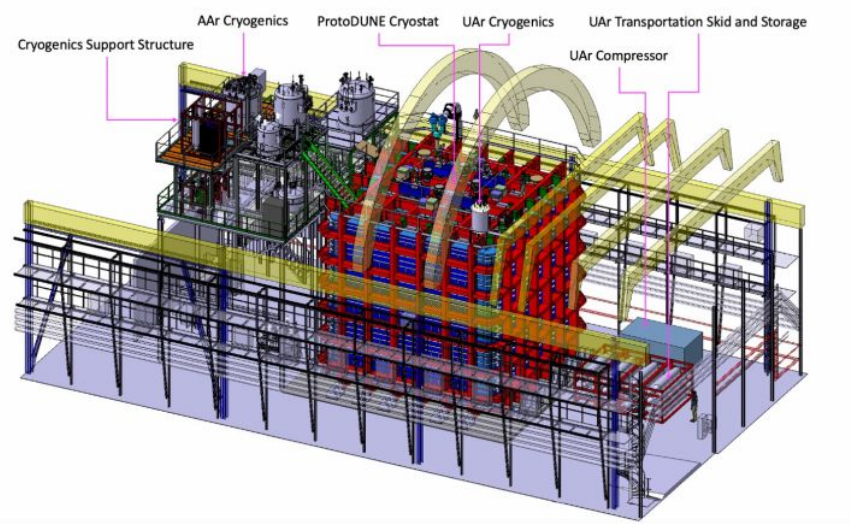


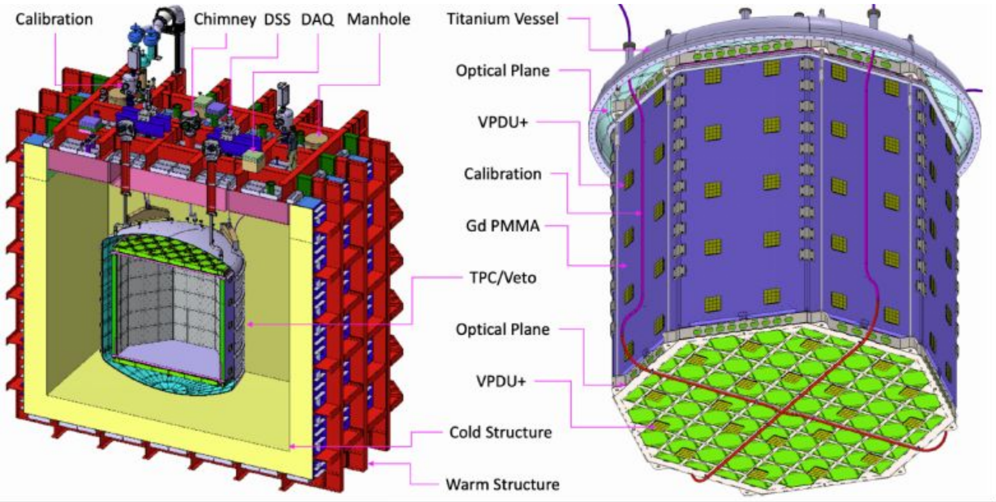
DS-20k: 200 t·y
20 t fd. (50 t active)
[ops 2027-]



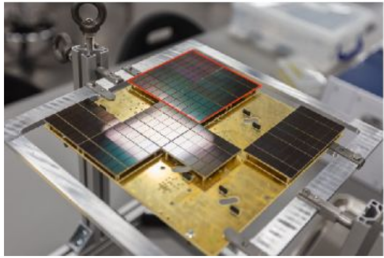
ARGO: ~ 3000 t·y
300 t fd. (400 t active)
[early 2030's]

The DarkSide-20k experiment

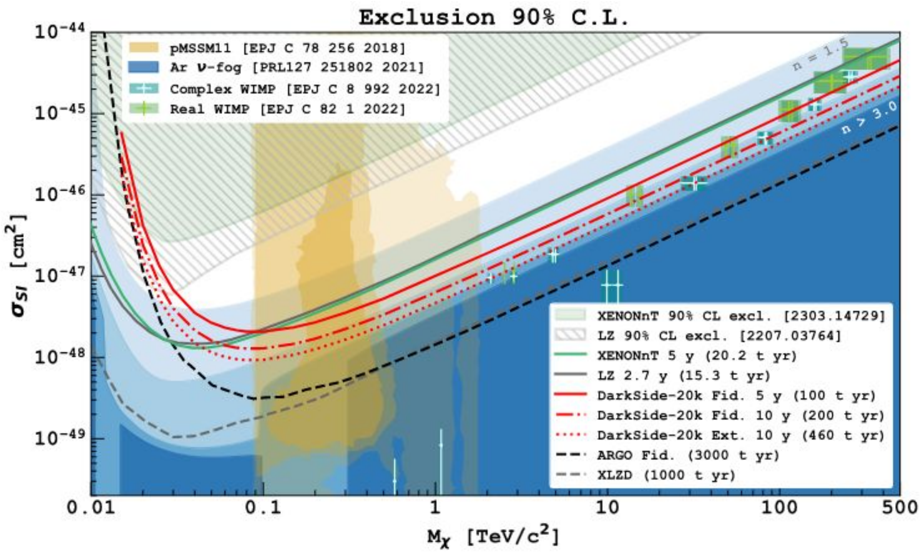




- Nested detector with
  - ProtoDUNE-like cryostat: 8 x 8 x 8 m^3 hosting **650 t** of atm Ar
  - SS vessel+structure hosting **99 t underground Ar**.
  - UAr + acrylic Veto for neutrons and γ.
  - Central **Dual-phase Ar TPC:**
    - 50 t UAr (**20 t fiducial)**
    - 348 cm drift
    - Cathode @ **-73.4 kV**
- **21 m^2** of SiPM + **5 m^2** in veto.
  - Coverage in TPC Optical plane > 90%

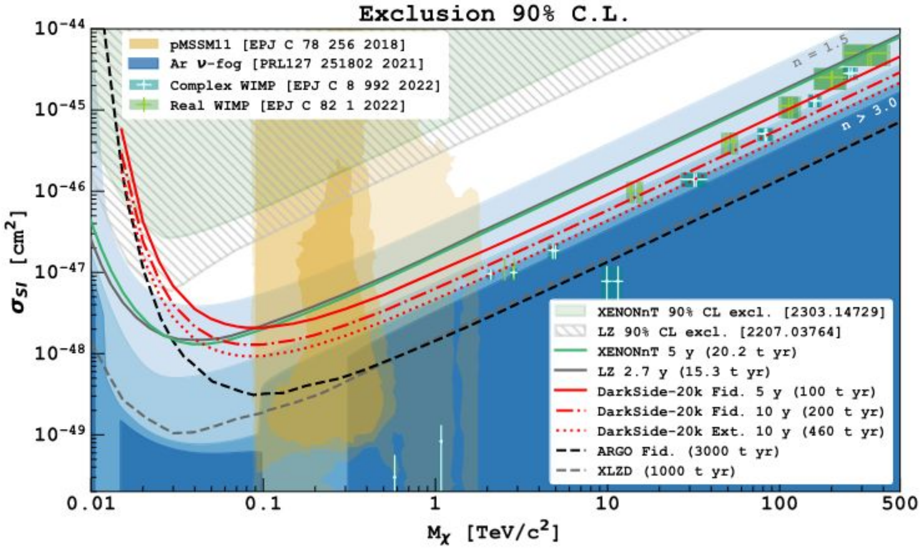


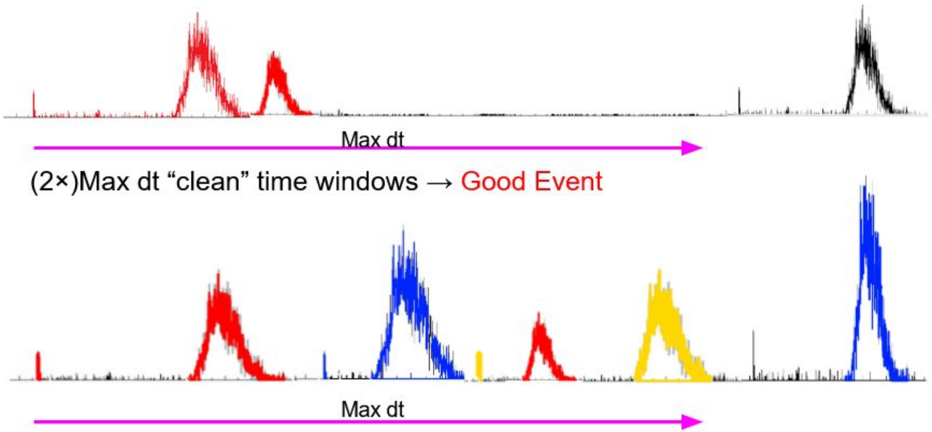
Radiopurity requirements for WIMP searches with liquid Ar



- neutrons after cuts < 0.1 in 10 y
- < 0.05 from β and γ

Radiopurity requirements for WIMP searches with liquid Ar

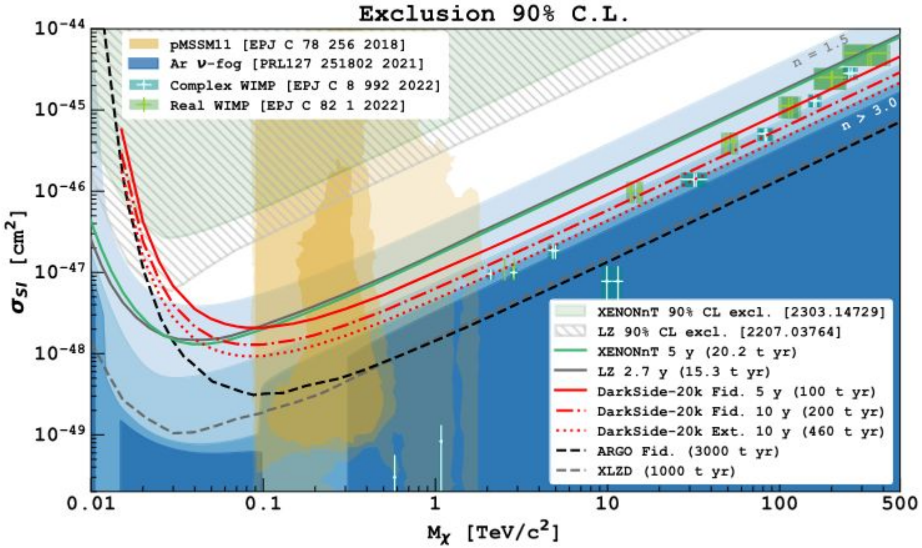


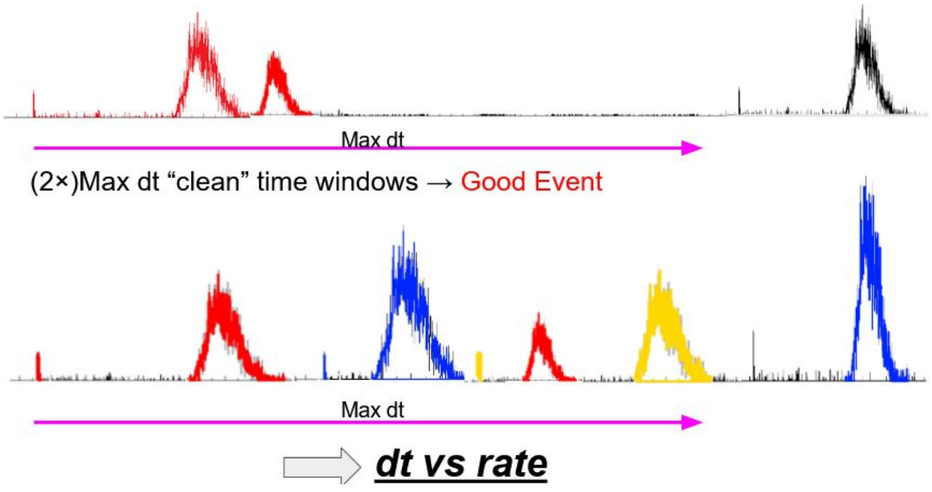


dt vs rate

- neutrons after cuts < 0.1 in 10 y
- < 0.05 from β and γ

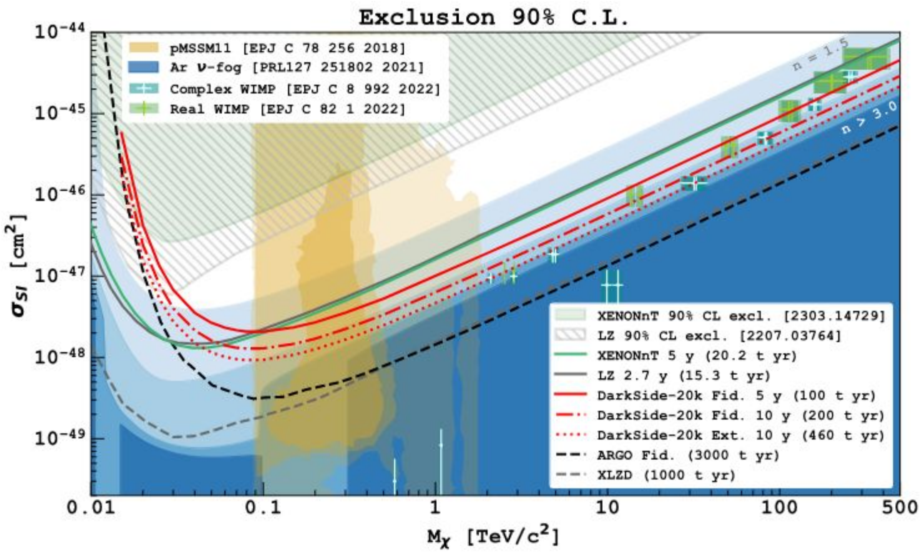
Radiopurity requirements for WIMP searches with liquid Ar

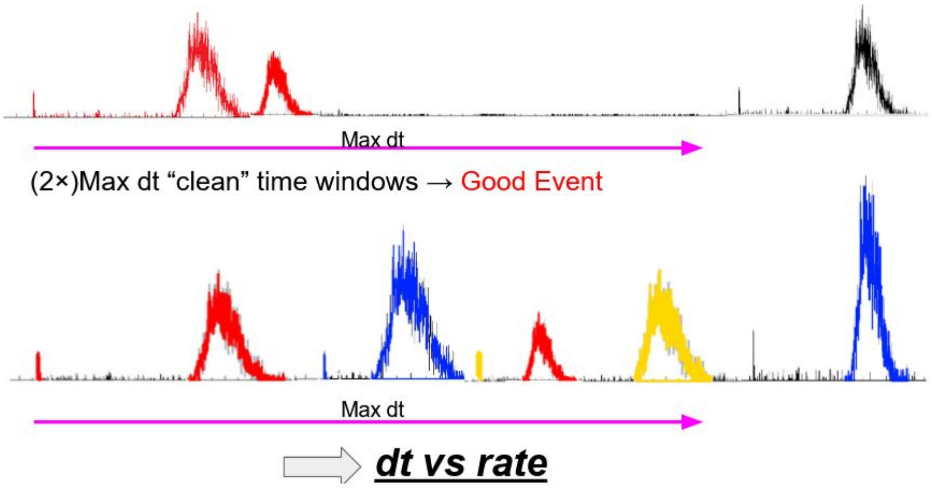




- **GOAL: Complete control over every component that goes into the detector (Down to the resistor level)**
- **To investigate the secular equilibrium of the U-Th decay chains**
- **Knowledge on the chemical composition of the components in order to calculate the n-yield via X(α,xn)Y**

Radiopurity requirements for WIMP searches with liquid Ar

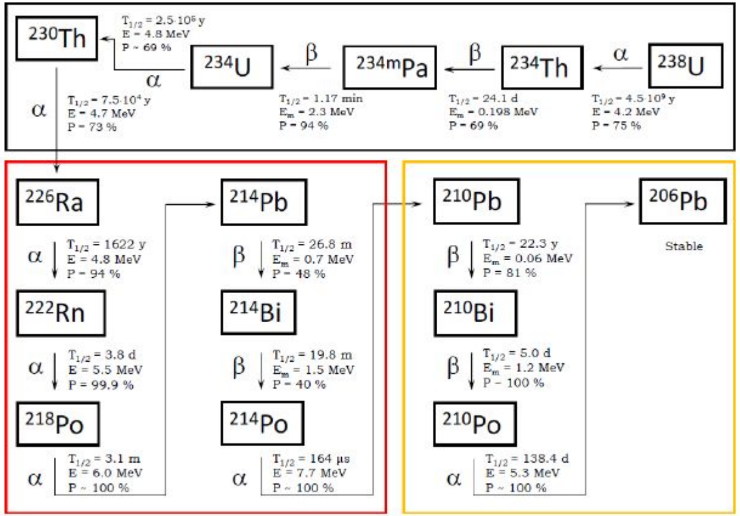




- GOAL: Complete control over every component that goes into the detector (Down to the resistor level)
- To investigate the secular equilibrium of the U-Th decay chains
- Knowledge on the chemical composition of the components in order to calculate the n-yield via X(α,xn)Y
- Full Monte Carlo simulations for the (α,xn) calculation with the detailed detector geometry
- Control on the surface exposure to air for the ^{210}Pb/^{210}Po surface contamination, Cosmogenics…
- Handling, transportation, recontamination QA/QC…

Equilibrium in the U-238 chain

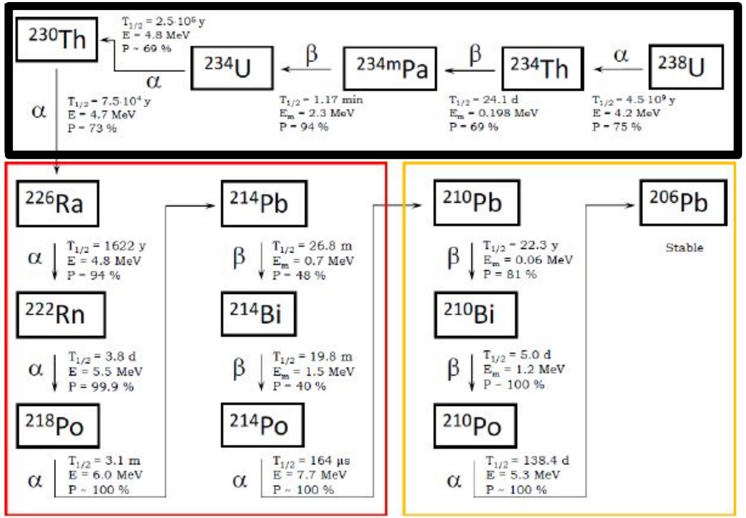
BREAKING OF THE SECULAR EQUILIBRIUM AT ^{226}Ra



SECOND BREAKING OF THE EQUILIBRIUM IN ^{210}Pb

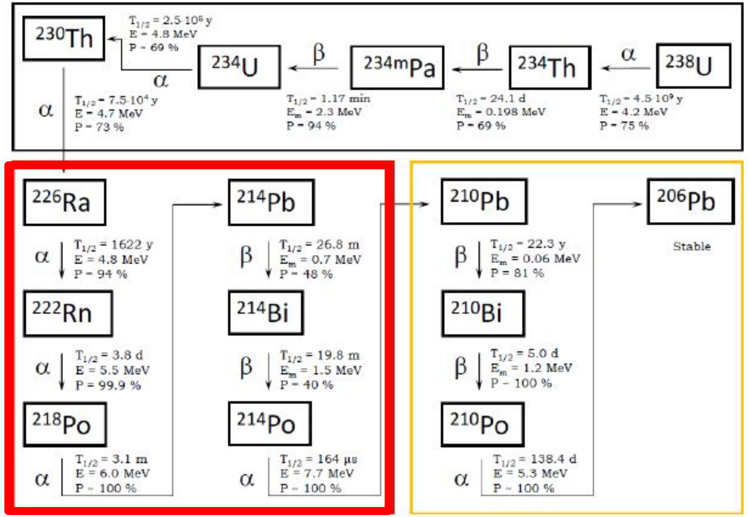
Equilibrium in the U-238 chain

ICPMS

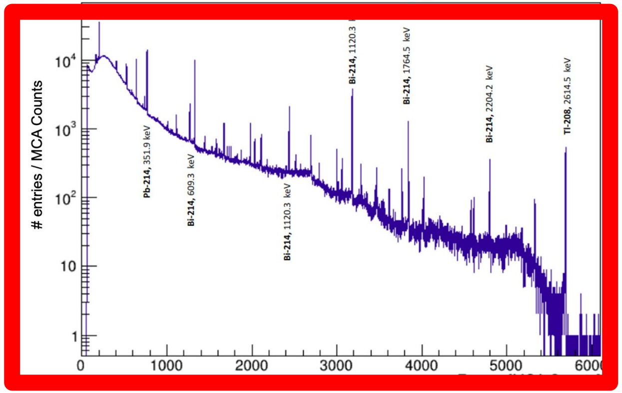


- Very little mass needed
- Relatively fast
- Digestion
- Destructive
- Only U-238 (Th-232)

Equilibrium in the U-238 chain

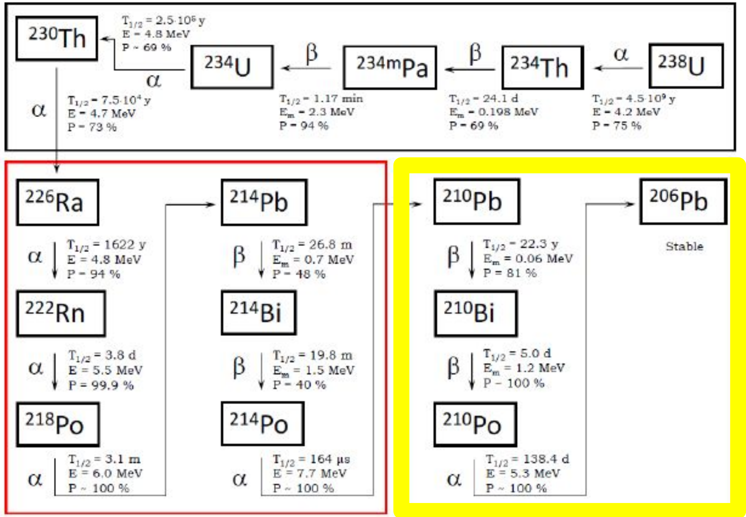


HPGe

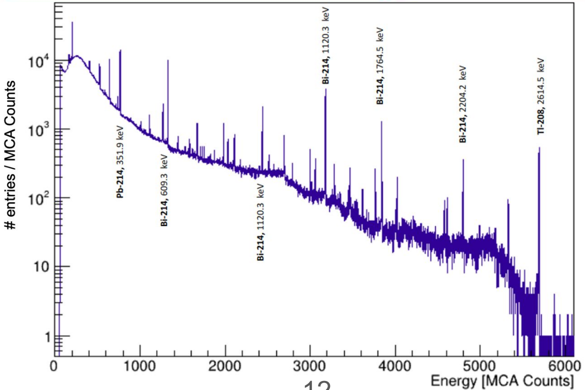


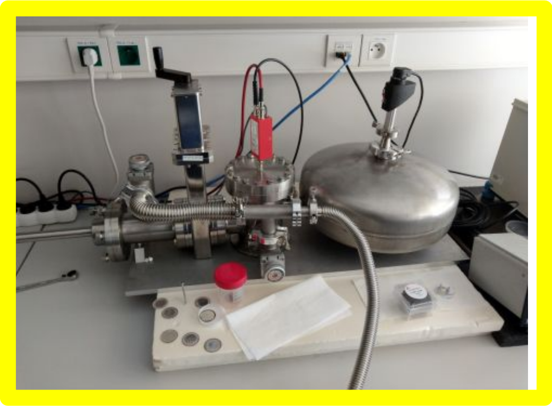
- Larger mass needed
- Slow
- Non-destructive
- Gamma activity (^{40}K+...)

Equilibrium in the U-238 chain



Radiochemical





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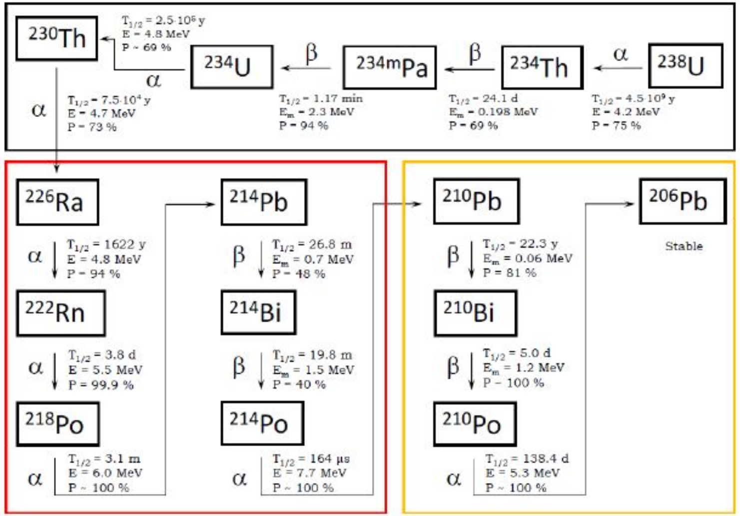
Equilibrium in the U-238 chain

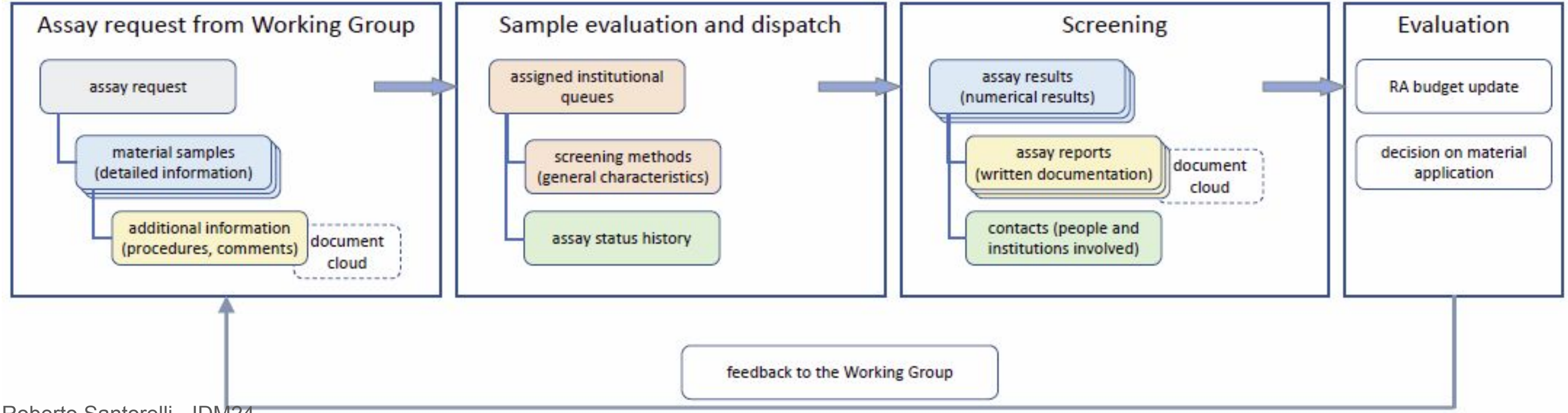


- XIA surface (and not so *surface*) screening
- Monitor the history of exposure of materials to **cosmogenic radiation**.
- **Worldwide effort involving**
    - underground facilities: LSC (Sp), Gran Sasso (It), Boulby (UK), SNOLAB (Ca)
    - + CIEMAT (Sp), Jagiellonian Univ. (Pl), Aix-Marseille U. (Fr), Mendeleev U. (Ru), Temple (US)...

DarkSide materials DB structure

Online database that centralizes the full assay process

- New material or component? Assay request!
- Sample allocation depending on available mass and needs
- Information on sample/assay status
- Storage and organization of results.



DarkSide materials Web interface

Online database that centralizes the full assay process

- New material or component? Assay request!
- Sample allocation depending on available mass and needs
- Information on sample/assay status
- Storage and organization of results.

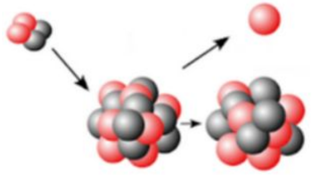
DB: Web-interface

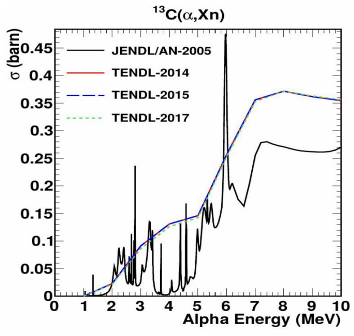
ID	Report	Name	Reference	Method	Sample	Date	^{227}Ac	^{228}Ac	^{210}Po	^{210}Po, gross alpha activity	^{226}Ra	^{228}Ra	^{220}Rn	^{222}Rn	^{46}Sc	Th	^{228}Th	^{232}Th	^{234}Th	^{44}Ti
				SNOLAB),																
2124	289	Gadolinium sulfate 301 Decision pending	DarkSide-20k	HPGe GeOroel (Iulian Catalin Bandac, *LSC CANFRANC*),	complete	2019-08-27		387±24 [mBq/kg] (1 sigma)			9.4±1.4 [mBq/kg] (1 sigma)						274±14 [mBq/kg] (1 sigma)			
2121	288	OPA838 284 More assays needed	PDM module	Polonium-210 chemical extraction (Grzegorz Zuzel, *IF UJ*),	complete	2019-08-27			5.64±0.69 [Bq/kg] (1 sigma)											
2112	286	Harwin clips (clamp) 272 Satisfactory	PDM module	HPGe GeMPI (Matthias Laubenstein, *LNGS, INFN*),	complete	2019-08-13					30±9 [mBq/kg] (1 sigma)	<36 [mBq/kg] (2 sigma)					<27 [mBq/kg] (2 sigma)		<0.95 [Bq/kg] (2 sigma)	
2105	286	OPA838 284 More assays needed	PDM module	HPGe GeMPI (Matthias Laubenstein, *LNGS, INFN*),	complete	2019-08-13					77±8 [mBq/kg] (1 sigma)	25±10 [mBq/kg] (1 sigma)					19±6 [mBq/kg] (1 sigma)		<0.95 [Bq/kg] (2 sigma)	
2119	287	Silver loaded epoxy EJ2189 294 Decision pending	PDM module	HR-ICP-MS (Stefano Nisi, *LNGS, INFN*),	complete	2019-08-13										850±300 [ppt] (30 %)				

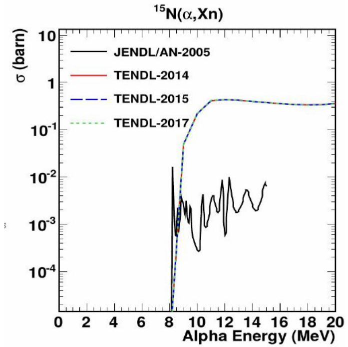
Neutron yield calculation

$$Y_i(E_\alpha) = \frac{\eta_i}{\eta} \int_0^{E_\alpha} \frac{\sigma^i_{(\alpha,Xn)}(E)}{\varepsilon(E)} dE$$

E_α is the initial energy of the α particle;
η_i is the number density of nuclide i;
η is the number density of the material;
$\sigma^i(\alpha,Xn)(E)$ is the neutron production x-sec for the nuclide i
$\varepsilon(E) = -\frac{dE}{dx}$ is the stopping power of the material







DarkSide is the first experiment with the (α,n) neutron background fully calculated with Geant4

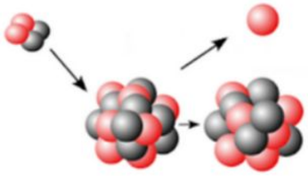
SaG4n: Simple and versatile tool provided to the community SaG4n (http://win.ciemat.es/SaG4n/)

"*Neutron production induced by α-decay with Geant4*", Nucl. Instrum. Methods A 960, 163659 (2020)

- Exploiting evaluated libraries (JENDL)
- Detailed geometries (actual geometry and border effects)
- Neutron transport, precise tracking
- Biasing techniques

(α,n) white paper

2405.07952



Multidisciplinar WG on (α,n) neutron yield studies

alphan@ciemat.es

Members of several DM experiments + Neutrino + Nuclear + IAEA:

- DarkSide-20k
- XENON
- LZ
- CRESST …

White paper on (α, n) neutron yield calculations

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(Dated: Tuesday 28th May, 2024- 00:28, Version: F1.0)

Understanding the radiogenic neutron production rate through the (α, n) reaction is essential in many fields of physics like dark matter searches, neutrino studies, nuclear astrophysics and medical physics. This white paper provides a review of the current landscape of (α, n) yields, neutron spectra and correlated γ-rays calculations, and describes the existing tools and the available cross sections. The uncertainties that contribute to (α, n) yield calculations are also discussed with plans for a program to improve the accuracy of these estimates. Novel ideas to measure (α, n) cross sections for a variety of materials of interest are presented. The goal of this study is to reduce the uncertainty in the expected sensitivity of next-generation physics experiments in the keV–MeV regime.

CONTENTS

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Understanding the radiogenic neutron production rate through the (α, n) reaction is essential in many fields of physics like dark matter searches, neutrino studies, nuclear astrophysics and medical physics. This white paper provides a review of the current landscape of (α, n) yields, neutron spectra and correlated γ-rays calculations, and describes the existing tools and the available cross sections. The uncertainties that contribute to (α, n) yield calculations are also discussed with plans for a program to improve the accuracy of these estimates. Novel ideas to measure (α, n) cross sections for a variety of materials of interest are presented. The goal of this study is to reduce the uncertainty in the expected sensitivity of next-generation physics experiments in the keV–MeV regime.

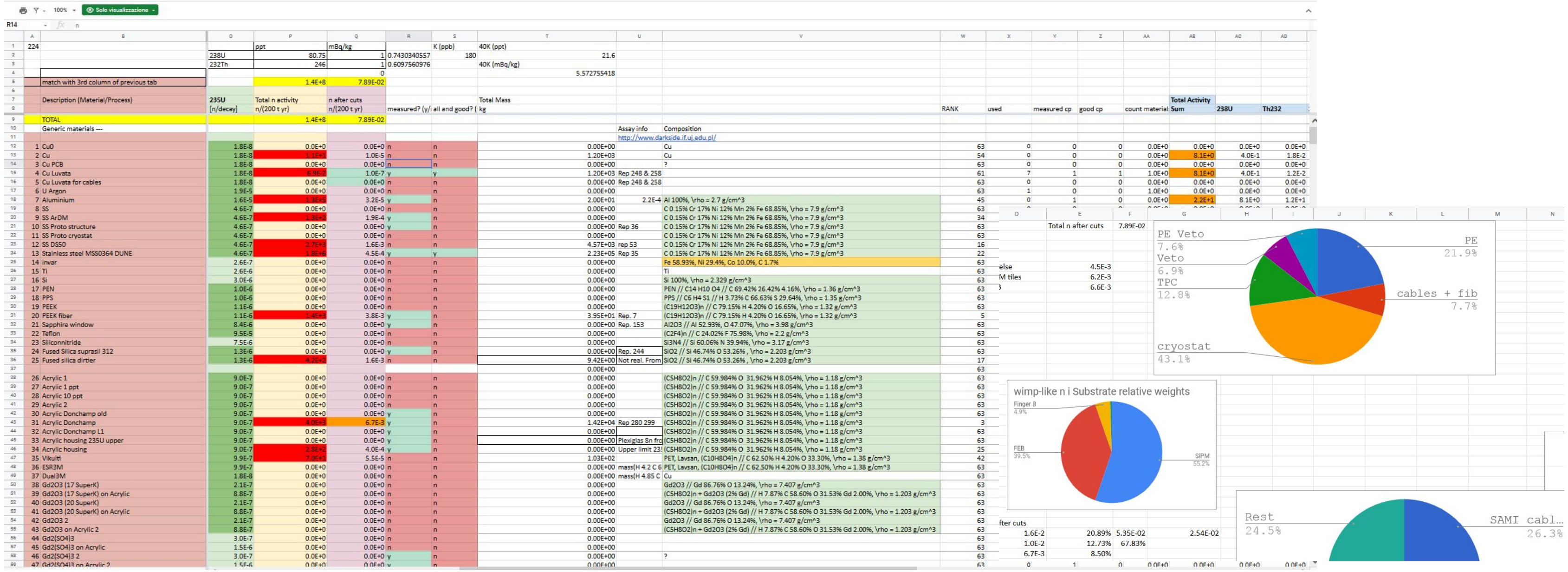
Background budget spreadsheet

R.A. budget spreadsheet

Storing the results of the samples, materials composition, contribution to the bkg …

(α,n) neutron background

γ event rate(VETO+TPC)



Operation protocols

Protocols that account for all steps in the manipulation of every component that makes it into the detector:

- Storage upon arrival
- Storage during any intermediate step
- Every time that things need to be unbagged and rebagged
- Manufacturing
- Assembly
- Cleaning
- Testing
- Final storing
- Final assembly

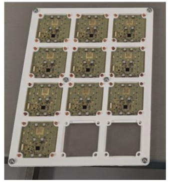
Operation protocols

Written procedures for each step, including radio-purity control

Storage of wafers

#	Step	Details
1	Receipt of wafers	• Wafer shipments arrive at Liverpool containing wafers for both STFC and Liverpool. Typically half the quantity received will be forwarded to STFC in the original NOA packaging. Half will be retained at Liverpool. • Upon receipt of wafers they (all wafers, including ones forwarded to STFC) are tagged in the database as being located at Liverpool using ds20k_veto_location_gui . • For the wafers retained, these are typically vacuum-bagged in batches of 5 in Reber food bags. These are then transferred to the cleanroom and moved to nitrogen storage for picking later.

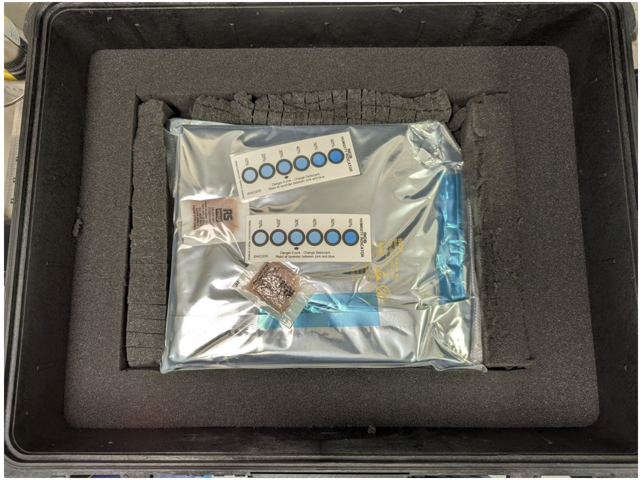
PCB shipping

10	Preparing for shipping	 3D printed 4x3 shipping fixture for PCBAs.	1. Place PCBs into a 3D printed PLA shipping fixture. Shipping fixtures are ultrasonically cleaned in ethanol every time they are used. 2. Secure lid of shipping fixture using m4 bolts and nuts. 3. Place the fixture into an ESD bag. 4. Vacuum seal the bag. 5. Place the vacuum sealed bag into another ESD bag and seal the outer bag at atmospheric pressure. In this way the inner bag is surrounded by low Rn cleanroom air to avoid contamination in the case of vacuum loss. *	• Shipping fixture secure and stal • Vacuum holds bag.

vPDU testing, Initial steps

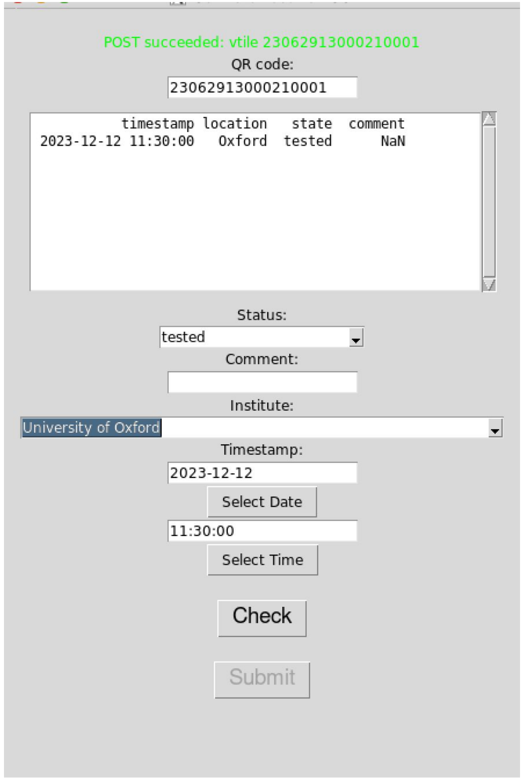
No.	Step	Description	Remarks
1	vPDU received	Move the vPDU in the clean room, Remove the vPDU from PeliCase in the clean room lobby	
2.	Environment check	Particle counter measurement before un-bagged the vDPU	ISO7: 352,000 particles per cubic meter or less ≥0.5 μm sized particles, 83,200 particles per cubic meter or less ≥1 μm sized particles, and 2,930 particles per cubic meter or less ≥5 μm sized particles
3.	Un-bagged vDPU for testing	Remove vPDU from the bags and update the status on the database	

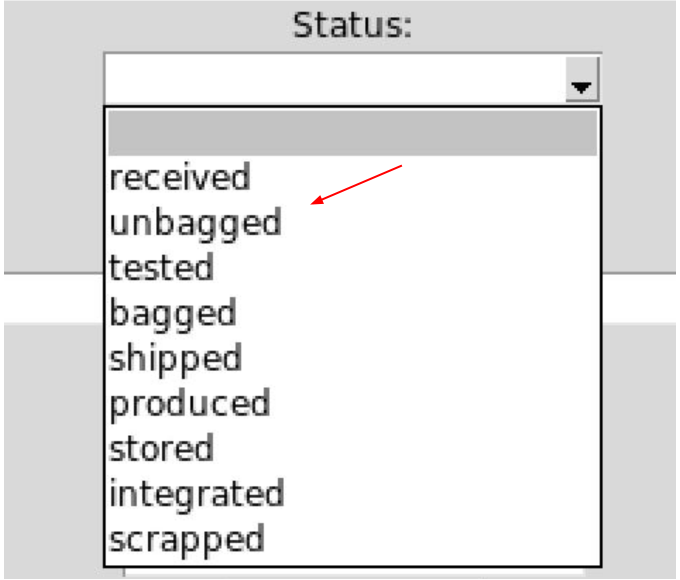
Operation protocols



- ESD bag
- Reber bag for radon protection
- Desiccant and humidity control inside Reber bags
- Second Reber bag for radon protection
- Protective cases

Exposure and tracking Database





Save the timing when the status is changed on DB

Every relevant action on a vPDU is registered in a DB with an identifying code and a time stamp.

Each facility has an appointed person responsible for the interaction with the Materials WG.

vTile populated vs sum of the components

	Summing components [mBq]	vTile fully assembled after testing [mBq]
U-up	1.3	1.1
U-mid	0.8	0.8
U-low	31.7	58.6
Th-232	0.7	0.34
U-235	0.1	0.05
K40	7.8	4.7

Passive (PCB, Resistors, Capacitors) and active el. components.
Copper pillars, connectors, soldering paste…

"Populated" tile radioactivity in very good agreement with the sum of the components

Relatively small difference in ^{210}Pb under study (not a show stopper)

Other relevant topics

- Cleaning protocols
- Control on the surface exposure to air:

  - ^{222}Rn decay daughters on surfaces (^{210}Pb 22 y)

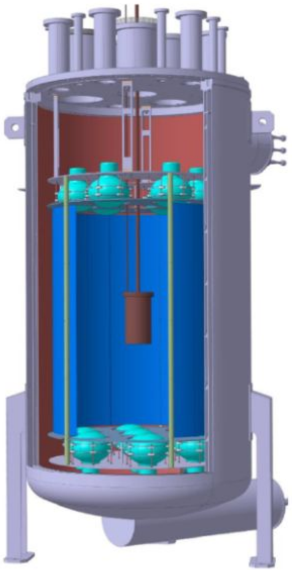
- Monitor the history of exposure of materials to cosmogenic radiation

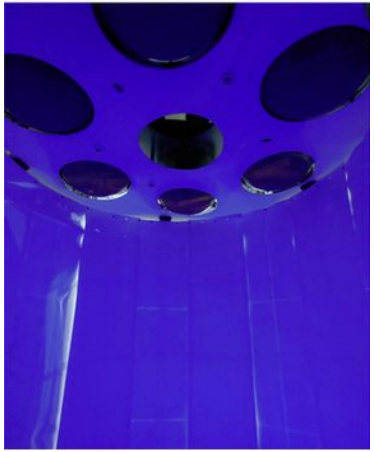
  - "Study of cosmogenic activation above ground for the DarkSide-20k experiment"
    Astropart.Phys. 152 (2023) 102878

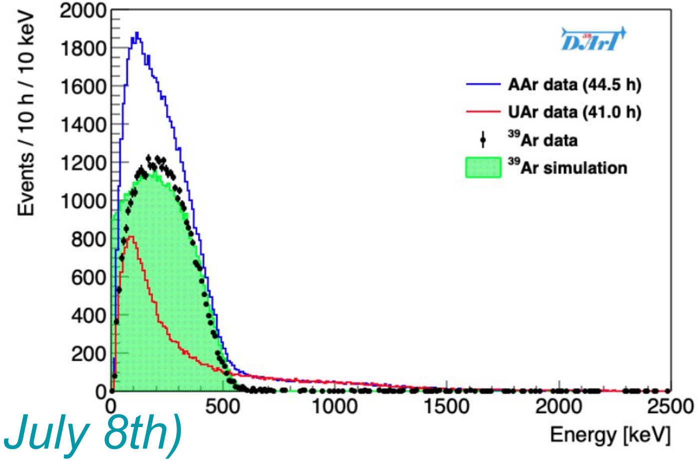
- Evaluation of the systematic uncertainty from the material composition and cross-sections
- Knowledge on the chemical composition of the components in order to calculate the n yield via X(α,xn)Y with Geant4
- MANY (Measurement of Alpha Neutron Yields) collaboration

  -> (α,n) cross-section measurement with a thick target and α beam

UAr assay @ LSC







Talk by V. Pesudo (Monday, July 8th)

Conclusions and outlook:

- DarkSide-20k has developed a very detailed material assay campaign for the full control / mitigation of the backgrounds
- Three assays per sample for the full control of the U-238 decay chain
- New tools for neutron yield calculation
- Control of cosmogenics, Rn, surface exposure..
- Cleaning and surface protocols

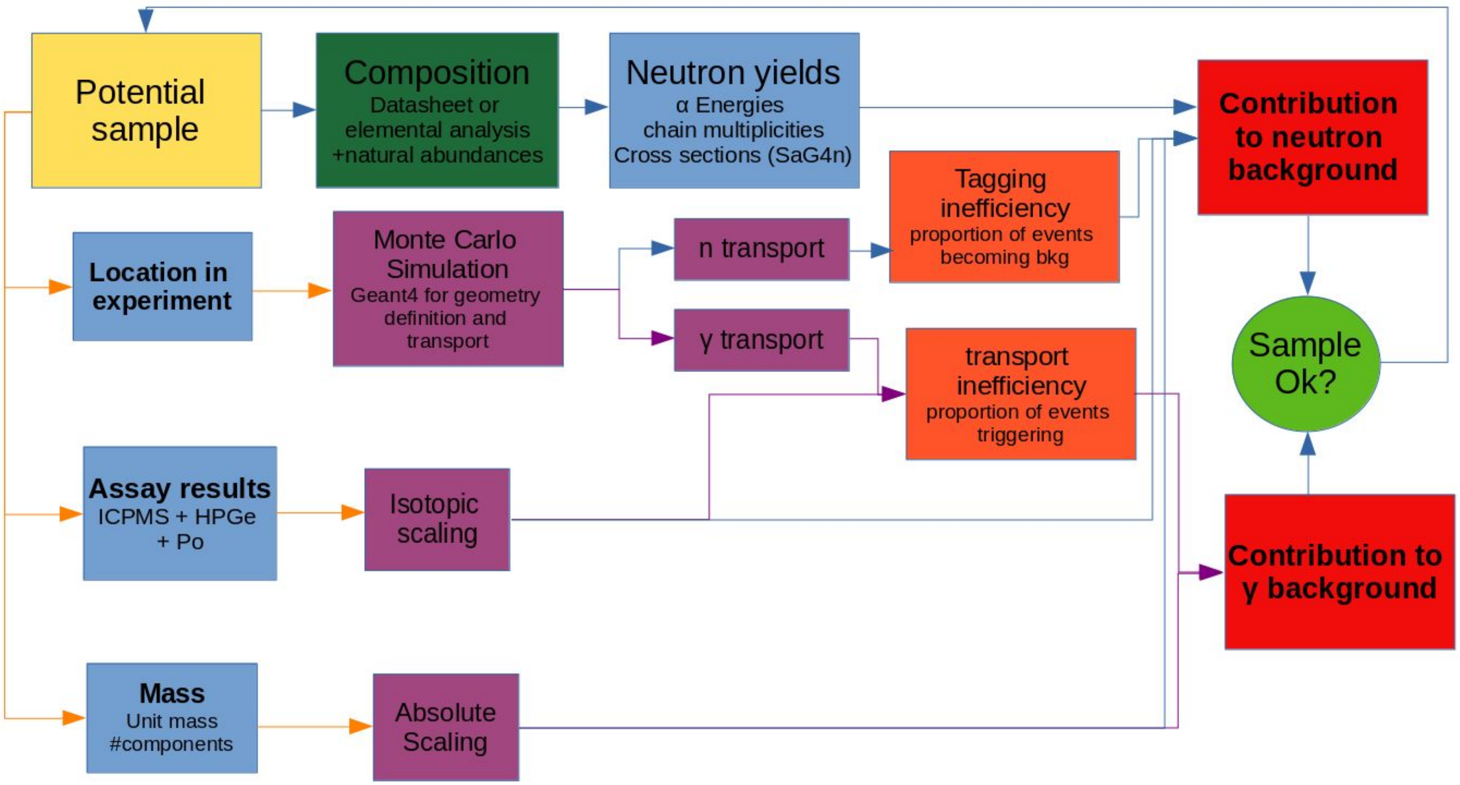
  ….
- Pushing the state-of-the-art in many fronts in this field

Thank you!

Credits to: Chiara Chiarelli (L’Aquila, Italy)

Backup

The decision making process



Th-232 equilibrium