Material Assay Campaign of the DarkSide-20k experiment

Vicente Pesudo
(CIEMAT / Lab. Sub. Canfranc)
on behalf of the DarkSide-20k Collaboration

8th ICRM-LLRMT
Assergi (Italia), May 3rd 2022

Outline

- DarkSide-20k
- Radiopurity constraints for WIMP searches with LAr
- The assay campaign:
  - tools & organization
  - Results so far
- The Underground Argon program
- Conclusions and outlook

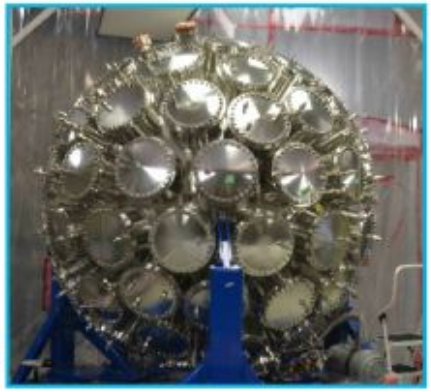
The Global Argon Dark Matter Collaboration towards DarkSide-20k

DEAP-3600

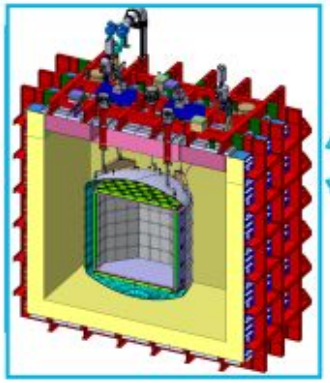
Joint effort of **all** former DM experiments using Liquid Ar targets:

- > 400 scientists
- > 100 institutions

50 tons (20 fiducial) * 10 y program



MiniCLEAN



DarkSide-50

Ultimate step: **ARGO** (300 t)

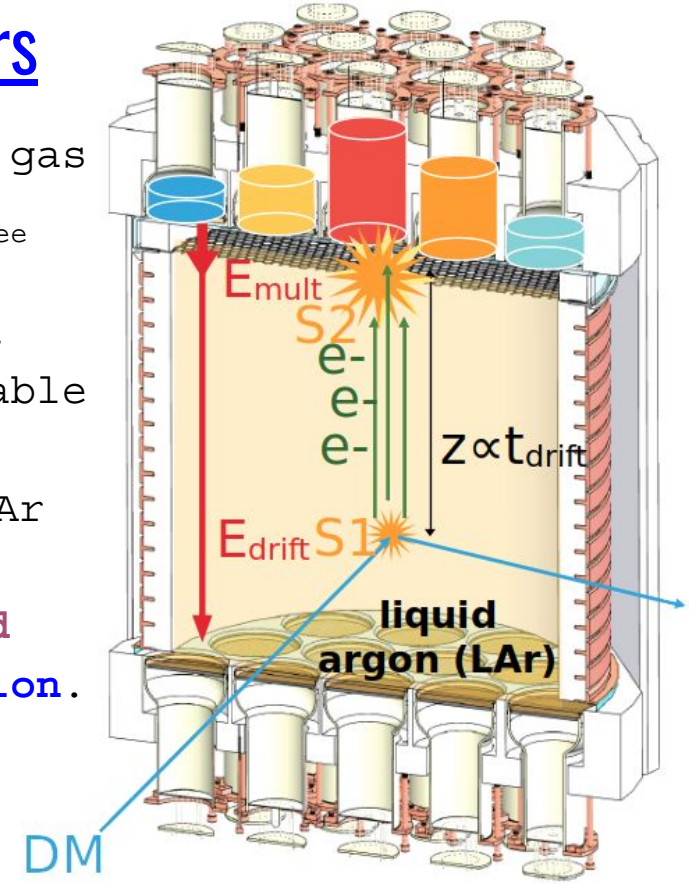
At SNOLAB
~203X

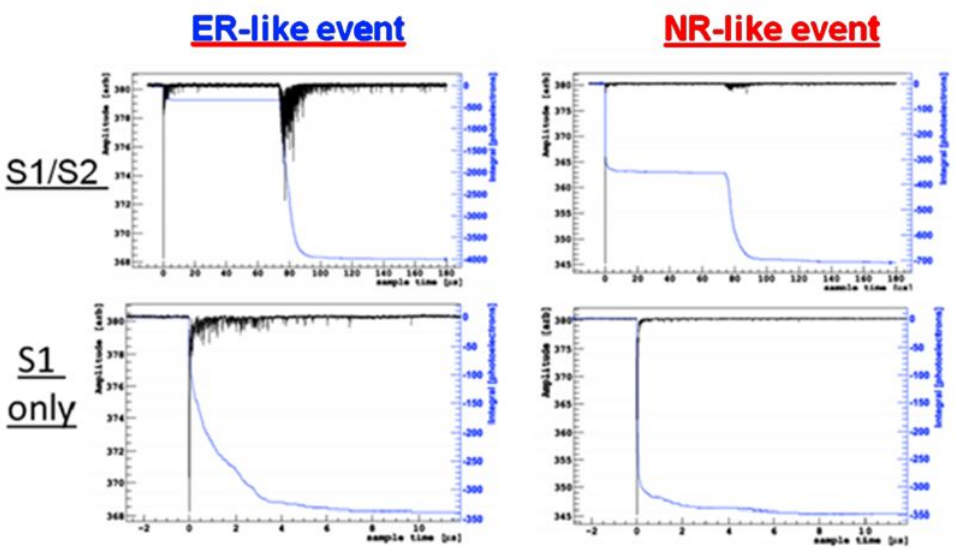
ArDM

The goal: explore heavy dark matter to the neutrino floor and beyond with extremely low instrumental background

Argon dual-phase Time Projection Chambers

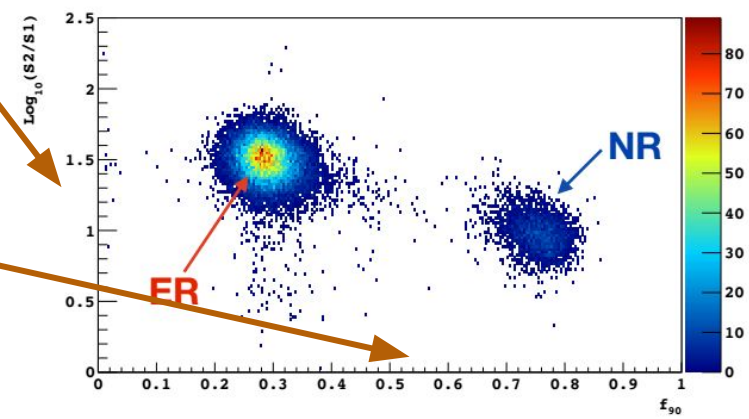
- Liquefied target + electroluminescence in gas
- **Low threshold** (7.5 keV_{ee}). Down to 0.1 keV_{ee} for S2-only.
- **Multiton** detectors (50 t in DarkSide-20k).
- Large distance between target and unavoidable radioactive components. **Self-shielding.**
- **Underground argon** to minimize intrinsic ^{39}Ar activity.
- Multiple detection channels for **background supression** due to **Pulse Shape Discrimination**.





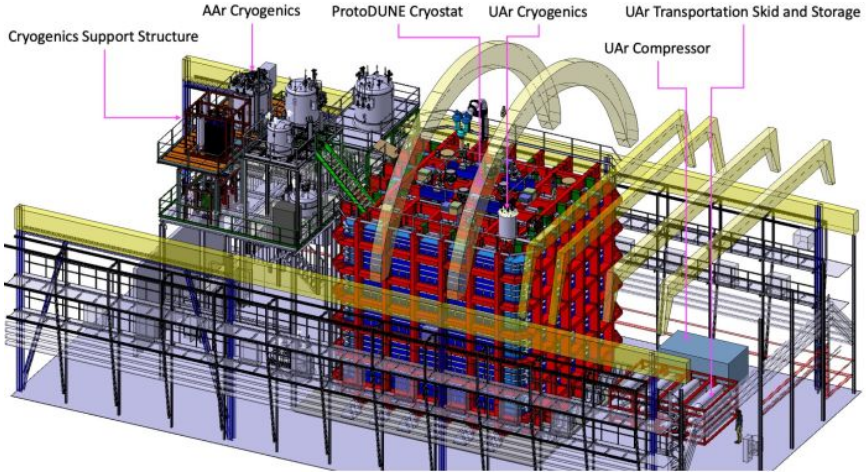
$$\left.\frac{S_2}{S_1}\right|_{ER} > \left.\frac{S_2}{S_1}\right|_{NR}$$

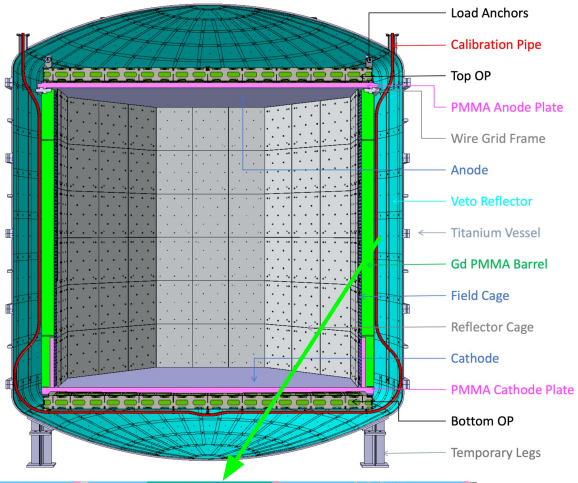
Due to an enhancement of the recombination process

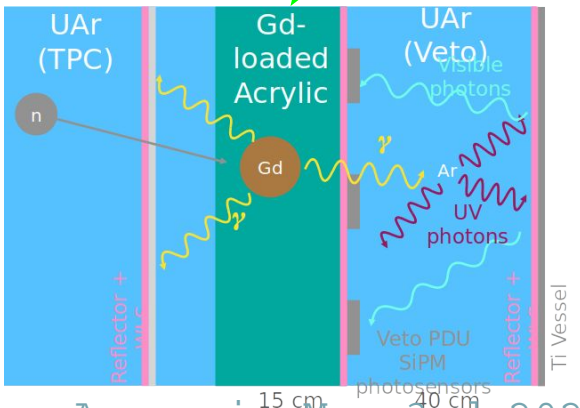


DarkSide-20k in numbers

- Nested detector with
  - ProtoDUNE-like cryostat: 8 x 8 x 8 m^3 hosting **650 t** of atm Ar
  - Ti vessel+structure hosting **99 t underground Ar**.
  - UAr + Gd-loaded acrylic Veto for neutrons and γ (Marini's talk).
  - Central **Dual-phase Ar TPC:**
    - 50 t UAr (**20 t fiducial)**
    - 348 cm drift L
    - 350 cm side to side
    - Cathode @ **-73.4 kV**.
- Multiple detection channels for background supression in Region Of Interest (ROI).
  - **neutrons** after cuts **< 0.1 in 10 y**
  - **Zero Background from β and γ**
- Position reconstruction **resolution**
  - < 5 **cm** in XY
  - ~ 1 **mm** in Z
- **21 m^2** of SiPM + **5 m^2** in veto.
  - Coverage in TPC Optical plane > 90%







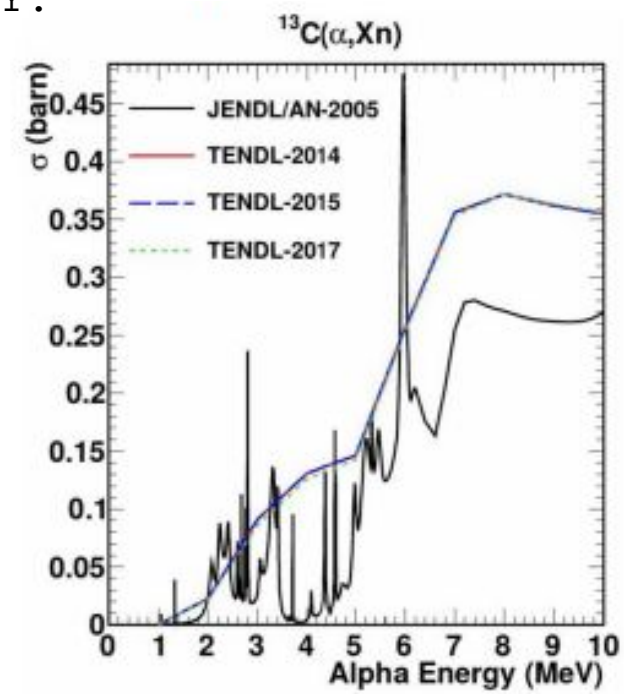
Radiopurity needs for WIMP searches with liquid Ar

- Most **α backgrounds** very local in the surfaces and of much higher energy than expected WIMP recoils: **Not in ROI**.
- **Degraded α** (in suspended dust) could mimic a WIMP-like signal.
- **Degraded surface α** in coincidence with a β or γ could mimic a WIMP-like signal.
- Moreover, low-E α-decays can induce X**(α,xn)**Y reactions in the detector materials.
- 4-9 MeV α emitted in the naturally occurring **^{232}Th and ^{238}U** series, **present everywhere** to some extent.
- A **neutron recoil is indistinguishable** from the expected WIMP recoil.
- β and γ do not contribute as background for the search by themselves, but contribute to pile up and the overall rate.
  - S1-S2 coincidences after long drift times (up to 5 ms) require very **small trigger rate.**
- **Cosmogenic muons** (Vallivilayil's talk) can produce high energy neutrons and showers of unstable particles, with a variety of lifetimes
  - Deep underground + monitor history of exposure

Radiopurity needs for WIMP searches with liquid Ar

- **Radiopurity control** over **every component** that goes into the detector.
  - Down to the resistor level
- Knowledge on the **chemical composition** of the components in order to calculate the n yield via X(α,xn)Y.
  - DarkSide is the first experiment with the (α,n) neutron background **fully calculated with Geant4**:
    SaG4n (http://win.ciemat.es/SaG4n/)
    Exploiting experimental data (JENDL)
    Biasing techniques + geometries

    Nucl. Instrum. Methods A 960, 163659 (2020)

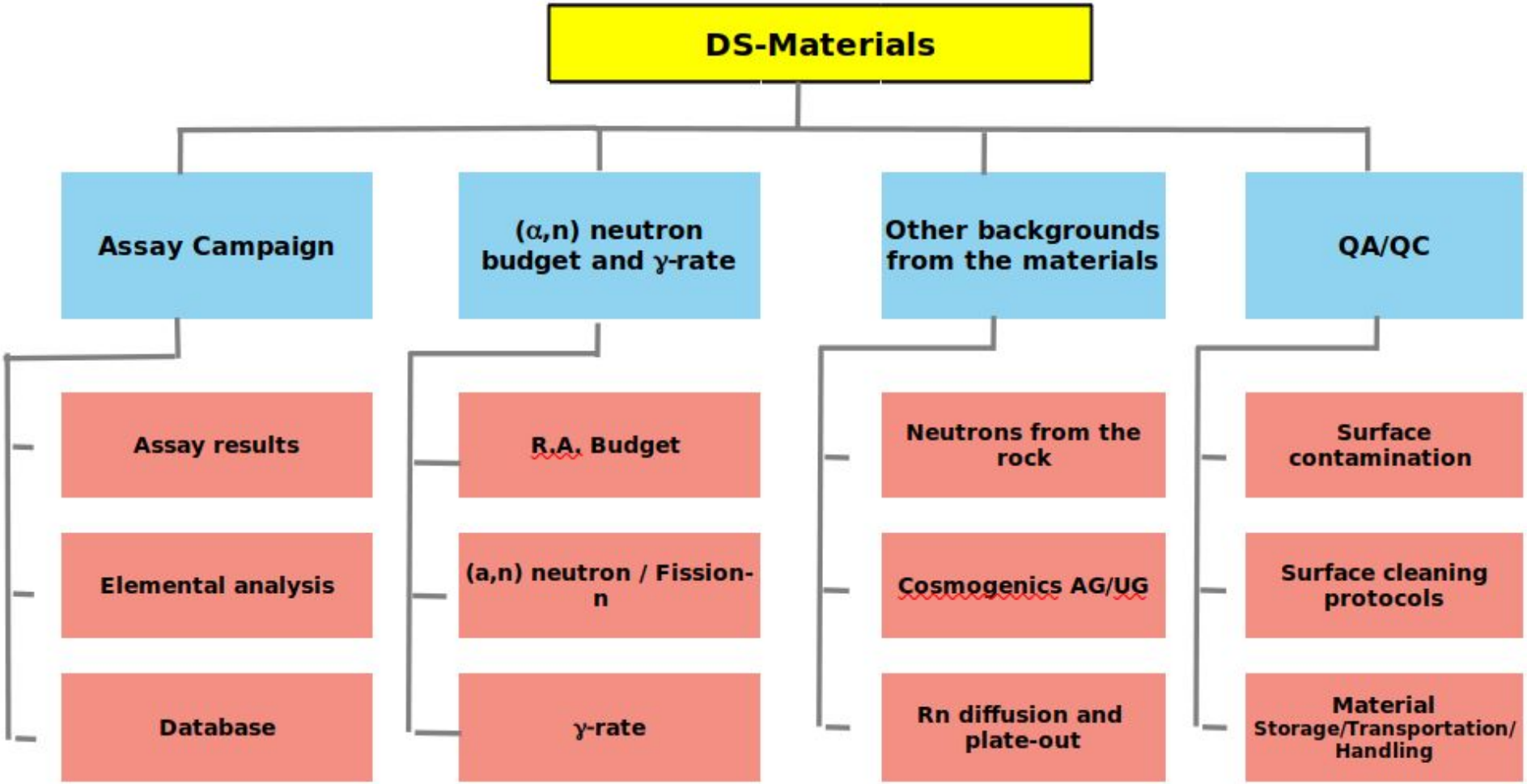


- **Complete simulations**, especially critical for γ and neutron transport (large mean free path).

Radiopurity needs for WIMP searches with liquid Ar

- Control on the **surface exposure to air**:
  - ^{222}Rn decay daughters attach to surfaces and have long half-lives (^{210}Pb 22 y).
- **Hundreds of assays** performed combining
  - Inductively Coupled Plasma Mass Spectrometry,
  - HP Germanium screening,
  - surface screening
  - Po radiochemical extraction
- Monitor the **history of exposure of materials to cosmogenic radiation.**
- **Worldwide effort involving**
  - **underground facilities**: LSC (Sp), Gran Sasso (It) Boulby (UK), SNOLAB (Ca)
  - other: Temple (US), CIEMAT (Sp), Mendeleev U. (Ru), U. Jagiellonian (Pl), Aix-Marseille U. (Fr).

DS-Materials working group organization



Web-interfaced Database of assay results

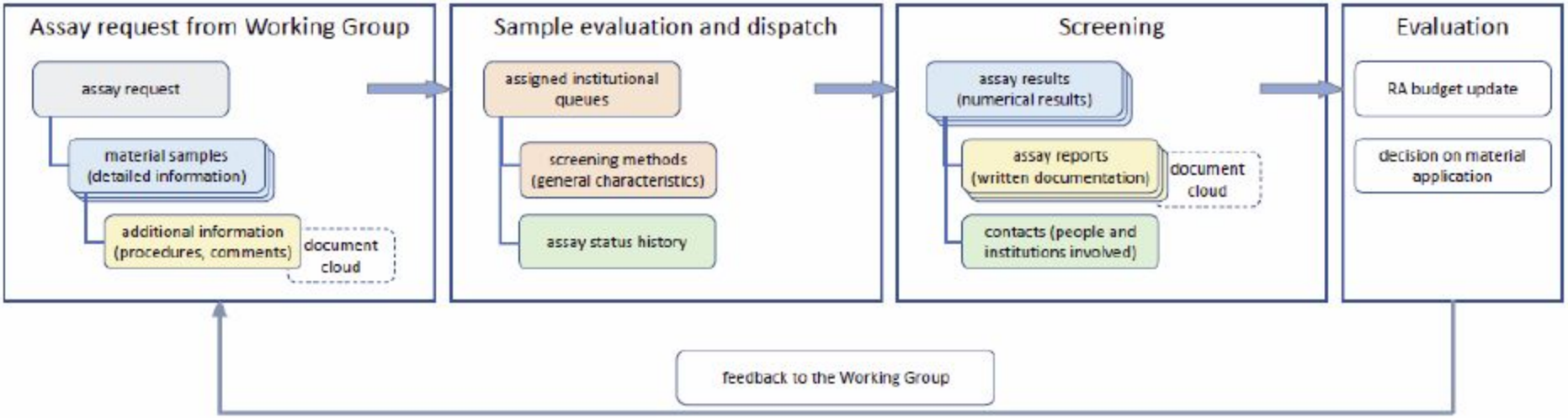
ID	Report	Name	Reference	Method	Sample	Date	^{227}Ac	^{228}Ac	^{210}Po	^{210}Po, gross alpha activity	^{226}Ra	^{228}Ra	^{220}Rn	^{222}Rn	^{46}Sc	Th	^{228}Th	^{232}Th	^{234}Th	^{44}Ti
				SNOLAB),																
2124	289	Gadolinium sulfate 301 Decision pending	DarkSide-20k	HPGe GeOroel (Iulian Catalin 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 %)				

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

The tools and organization

DS-20k materials DB structure



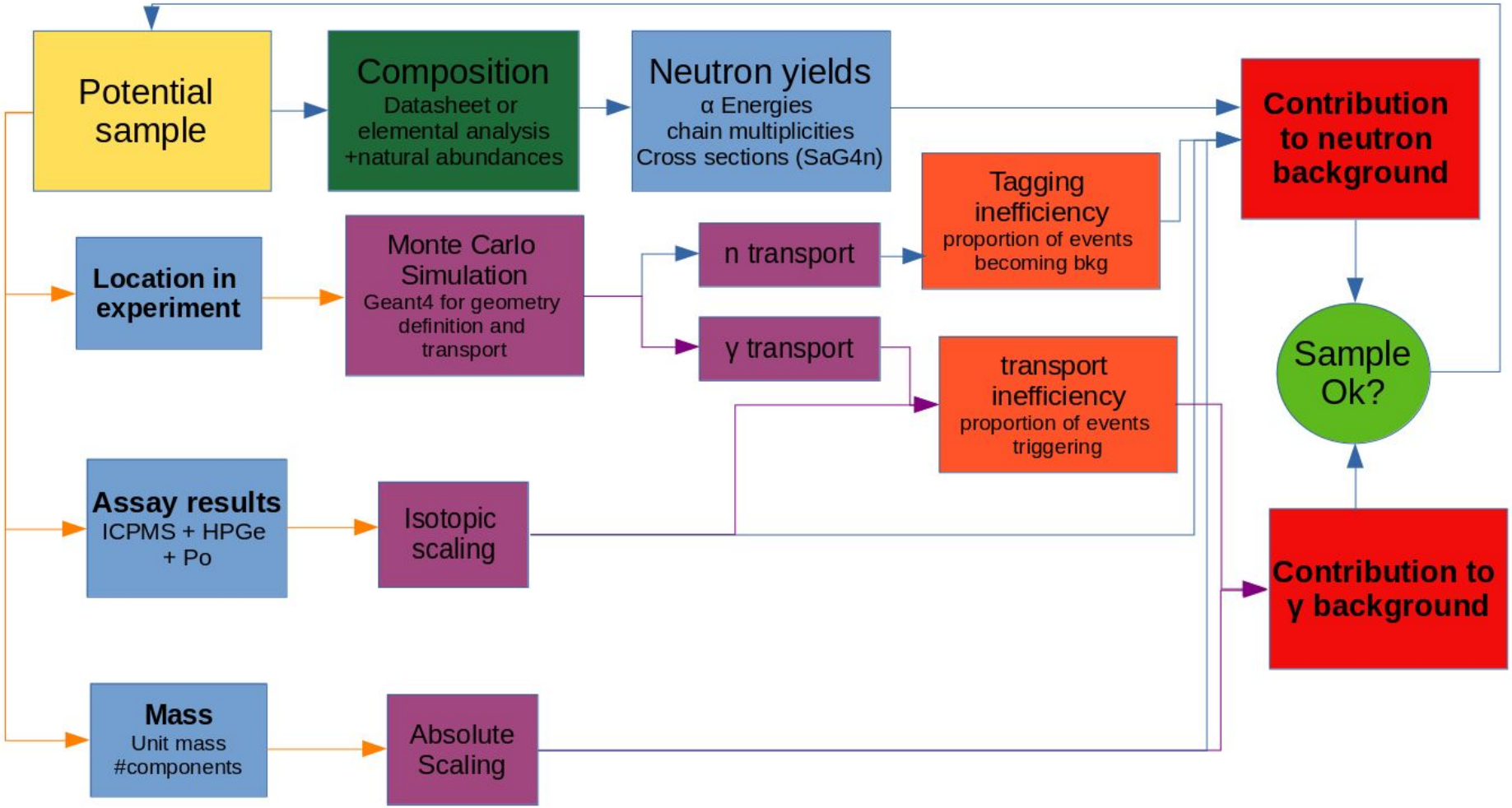
R.A. budget spreadsheet

(storing the results of the accepted samples, materials compositions, weights ...etc)

(α,n) neutron background

γ event rate (VETO+TPC)

The decision making

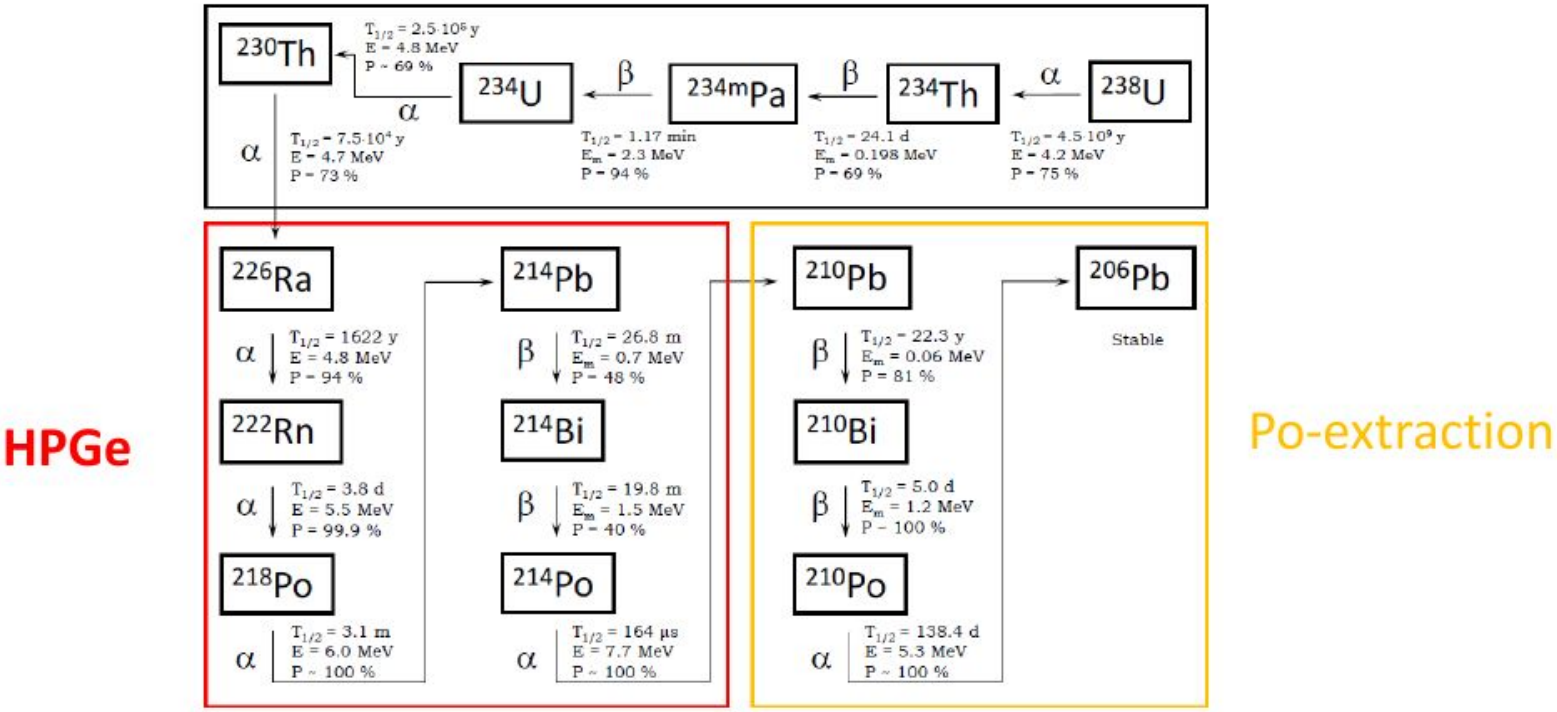


- Effort going on for more than 5 years. Now entering the critical phase of final sample purchase, validation and storage

The techniques

- ICPMS: sensitive to concentrations (^{238}U and ^{232}Th only)
- HPGe: Sensitive to gamma emitters through all the decay chains and other nuclides(^{40}K, ^{60}Co, ^{137}Cs…). Need larger amounts, longer times and geometry dependent
- Po radiochemical extraction: alpha spectroscopy after redox chemical extraction and deposition in silver disk.

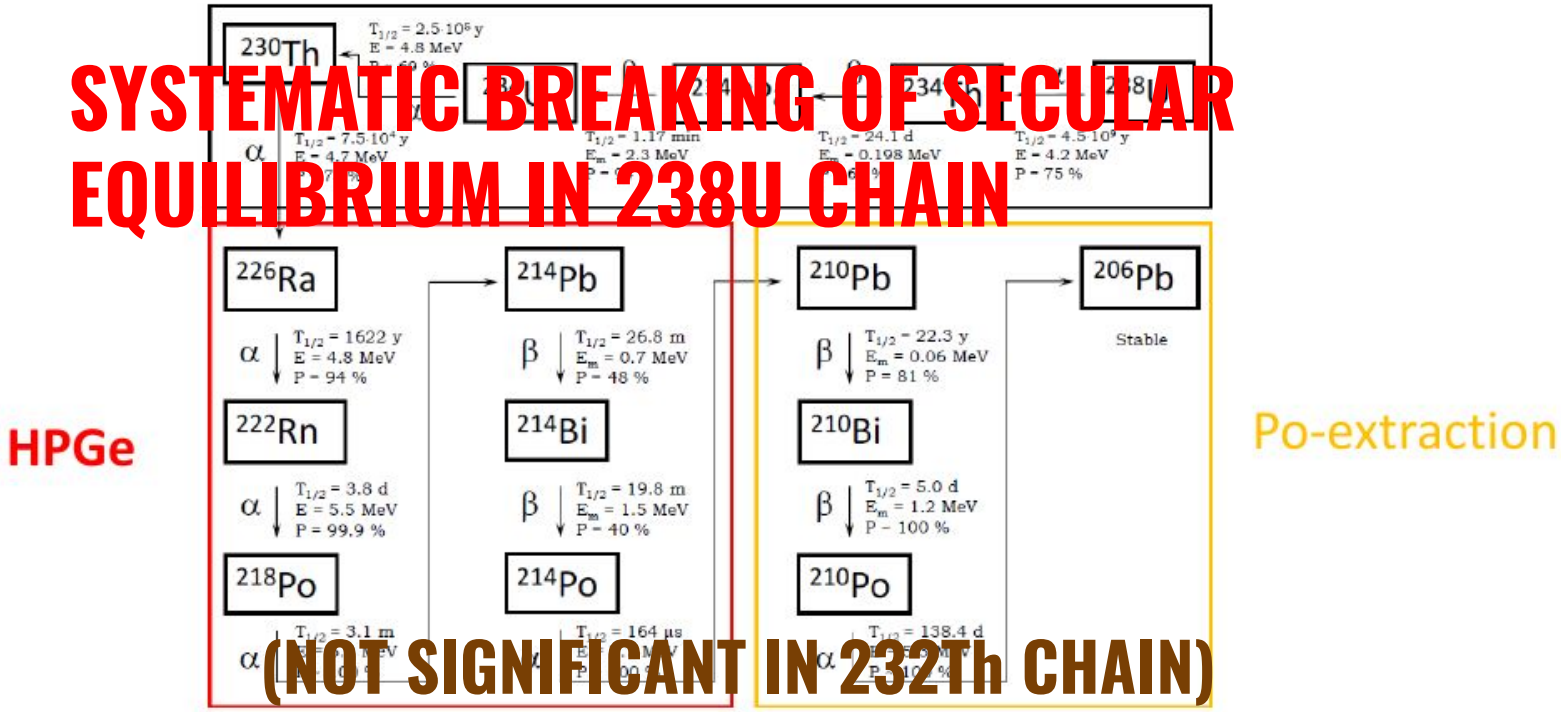
ICPMS



The techniques

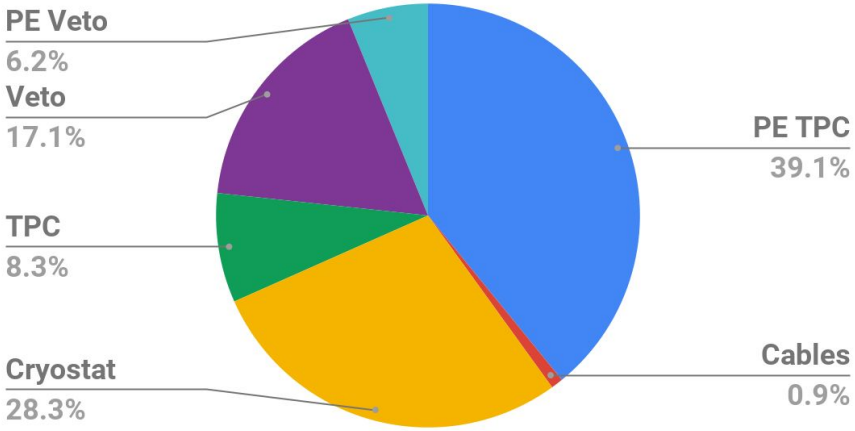
- ICPMS: sensitive to concentrations (^{238}U and ^{232}Th only)
- HPGe: Sensitive to gamma emitters through all the decay chains and other nuclides(^{40}K, ^{60}Co, ^{137}Cs…). Need larger amounts, longer times and geometry dependent
- Po radiochemical extraction: alpha spectroscopy after redox chemical extraction and deposition in silver disk.

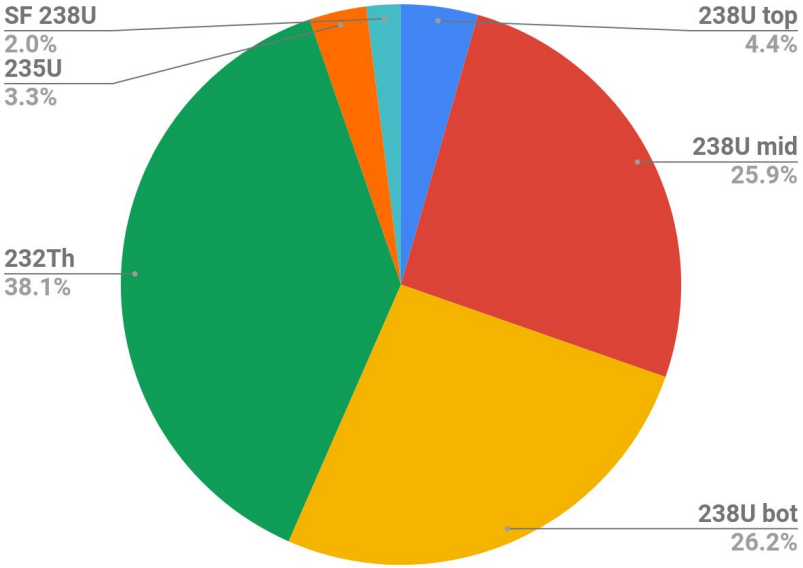
ICPMS

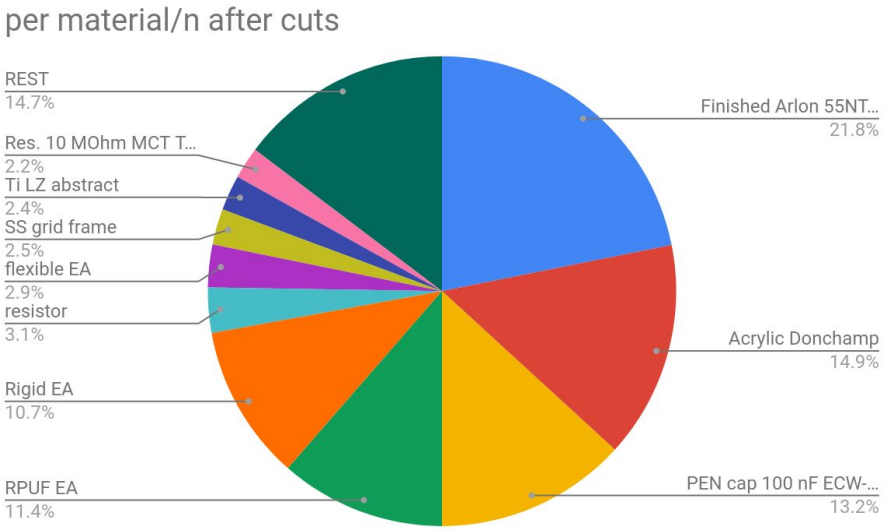


neutron budget in pies

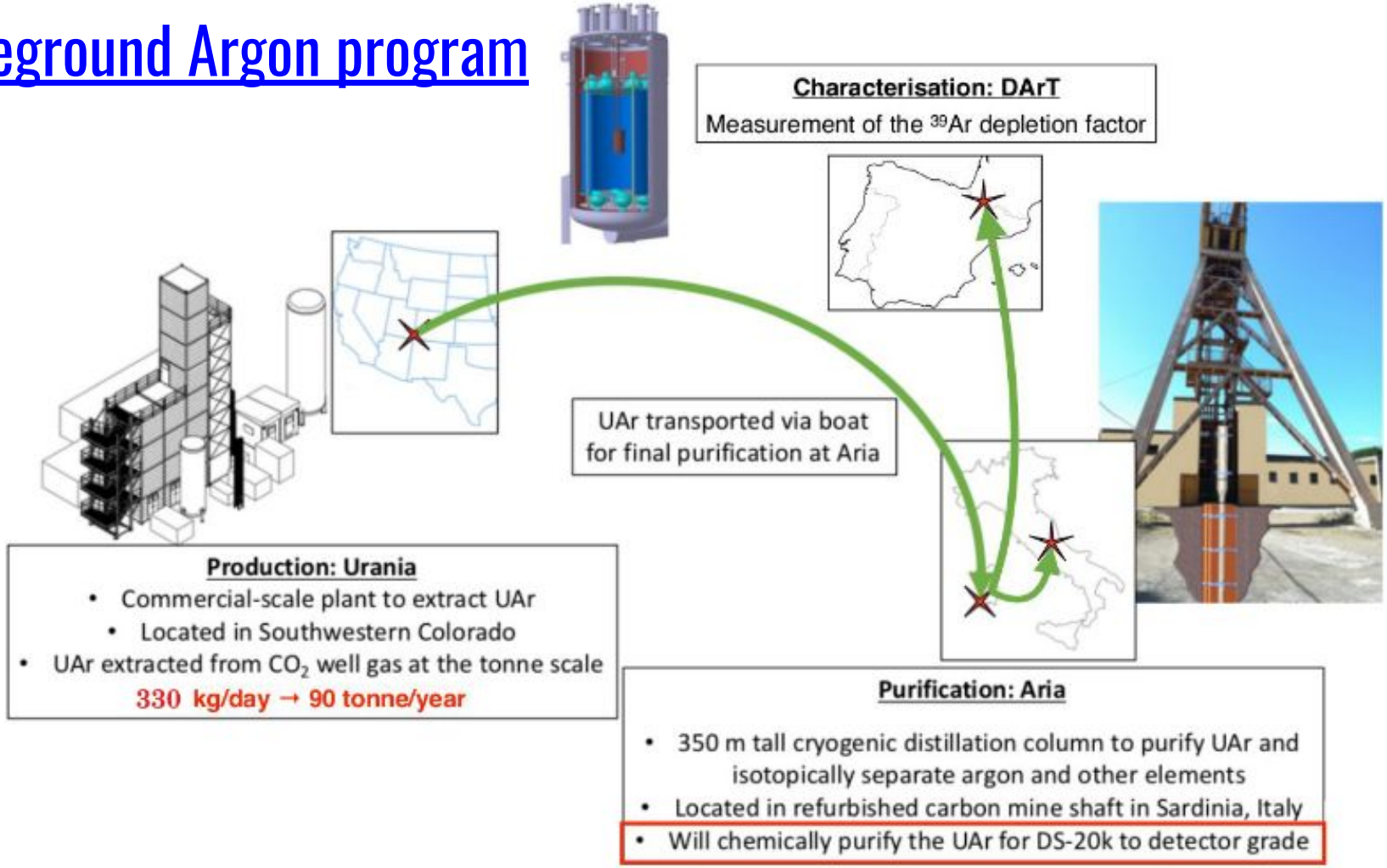
- PhotoElectronics and cryostat dominate.
- Top 10 contributors represent 85% of the budget
- ^{210}Po contributes up to 26% of the neutron production (1 alpha in 10 + 6)
- 0.1 neutron background events after cuts in 10 y.







The Undeground Argon program



Critical for the success of the GADMC program.

Urania & Aria under construction

DArT taking data at LSC without ArDM veto. ArDM fully refurbished by the end of June.

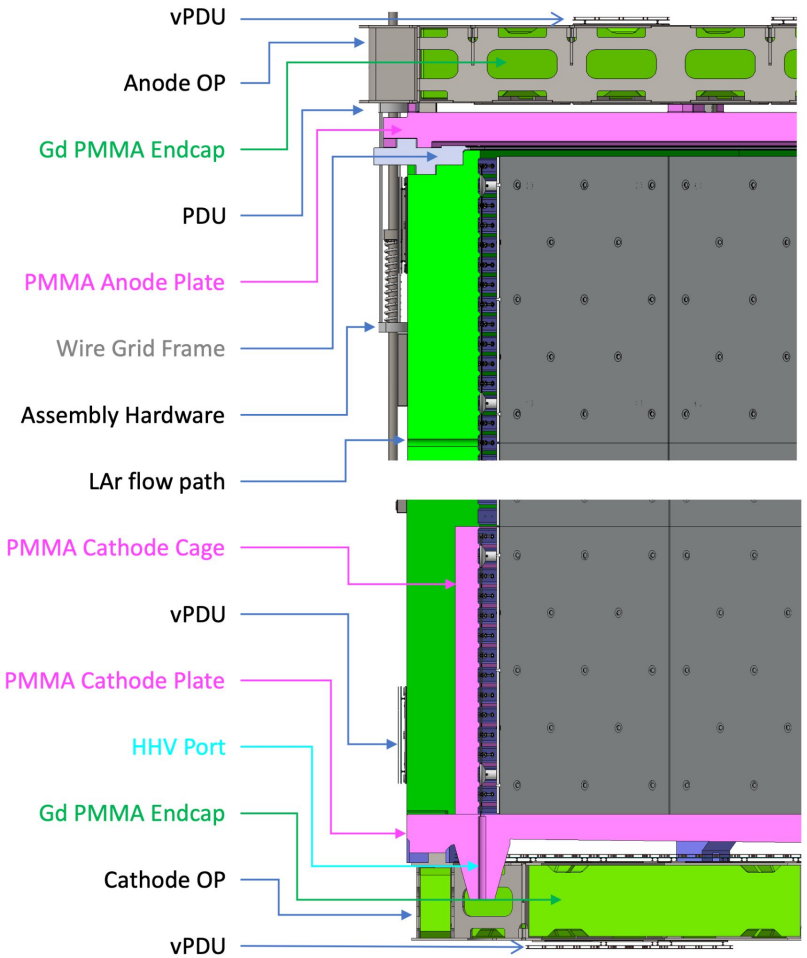
Conclusions and outlook

- **Global Argon Dark Matter Collaboration (GADMC)** is a joint effort of ~400 collaborators from ~100 institutions working towards WIMP detection with a dual phase Ar TPC.
- DarkSide-20k has developed deep understanding of gamma background (for rates and pile up) and particularly neutron background. **Pushing the state-of-the-art** in **background suppression**.
- Very robust infrastructure for sample assay and information, including assays with 3 or more techniques.
- Relevant **contributions for the low background community**: new procedures for neutron yield estimates, standardization of assays (beyond HPGe and ICPMS), book keeping and storing results…
- **Fundamental role played by underground facilities** (LSC, LNGS, Boulby and SNOLAB) and other facilities (Temple, CIEMAT, Mendeleev U., U. Jagiellonian, Aix-Marseille U.) to fully characterize the radioactivity with no secular equilibrium assumption.

Thank you! Grazie!

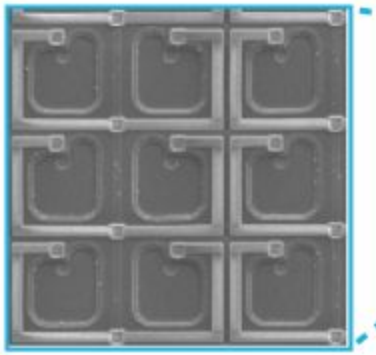
Overall Status of the project

- Site preparation to host cryostat
- Starting tenders for procurements
- Off-site testing performance of:
  - photoelectronics (Naples)
  - cryogenics (CERN)
- Building URANIA
- Building Aria
- Refurbishing ArDM to host DArT
- Fine-tuning at the technical drawing and integration level.
- Ongoing final review of TDR by INFN before installation.

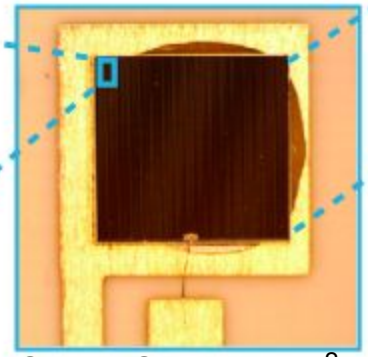


The challenges: large area cryogenic radiopure SiPMs

- Custom cryogenic SiPMs developed in collaboration with Fondazione Bruno Kessler (FBK), in Italy.
- Photon detection efficiency **~45%**
- Low dark-count rate **< 20 cps**
- Timing resolution **~ 10 ns**
- **2112** channels TPC **+ 480 channels** Veto.
- Mass production of the raw wafer in LFoundry company.
- **PDM + PDU assembly** in a dedicated facility at LNGS (NOA).

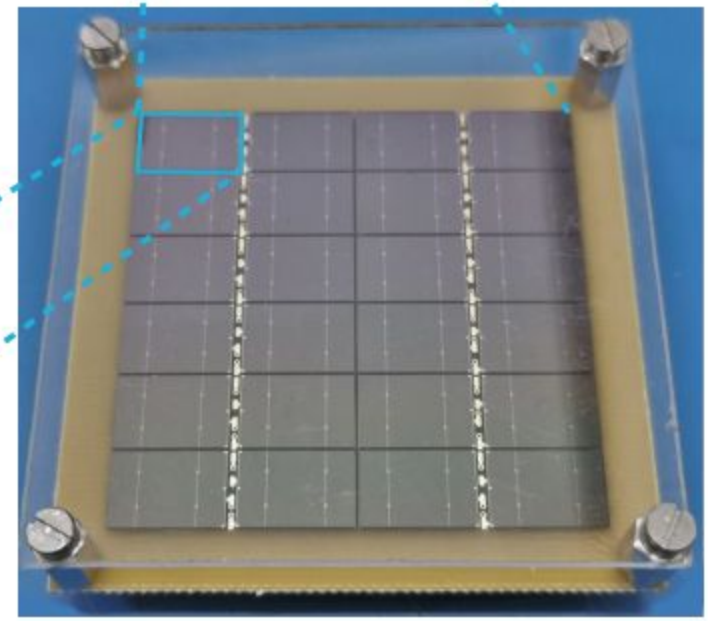


Single SPAD 25-30 μm^2



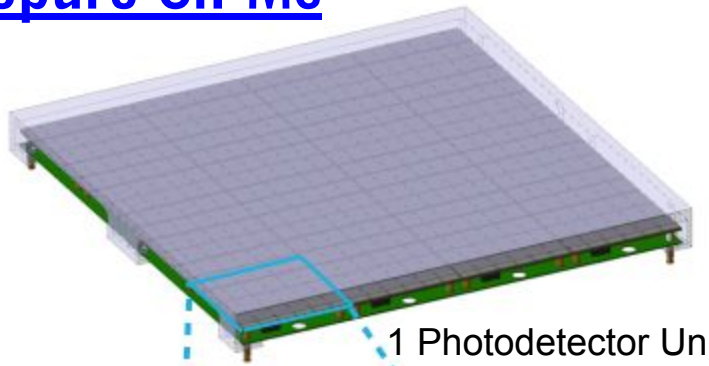
Single SiPM 1 mm^2

x 24



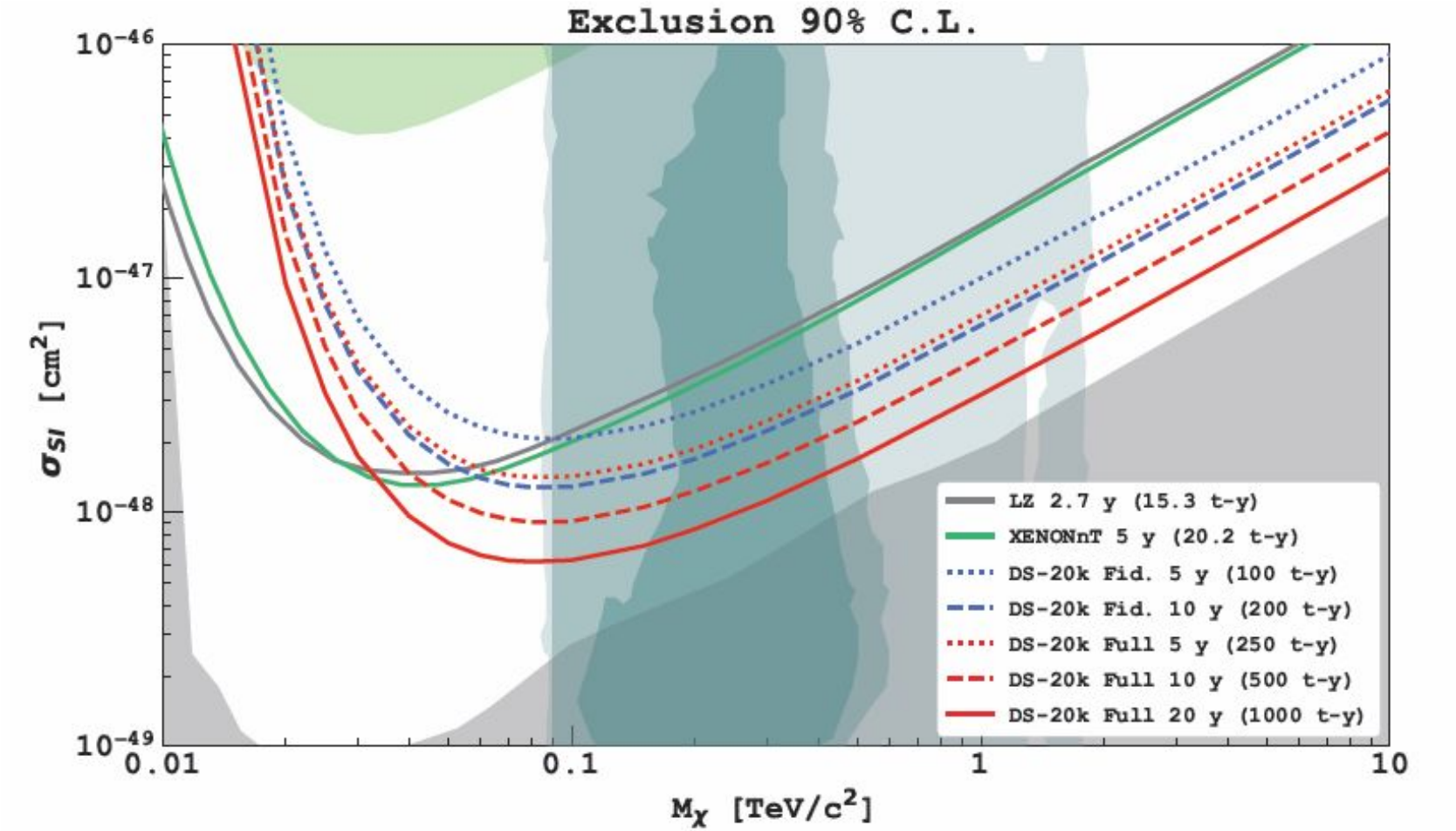
1 Photodetector module (PDM)

x 16



1 Photodetector Unit (PDU)

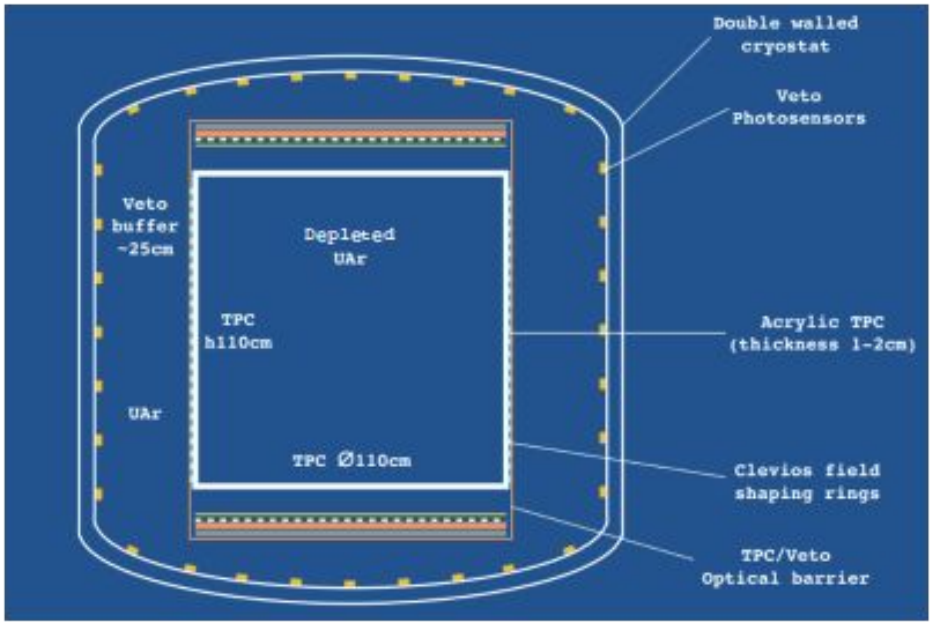
Scientific goals of DarkSide-20k

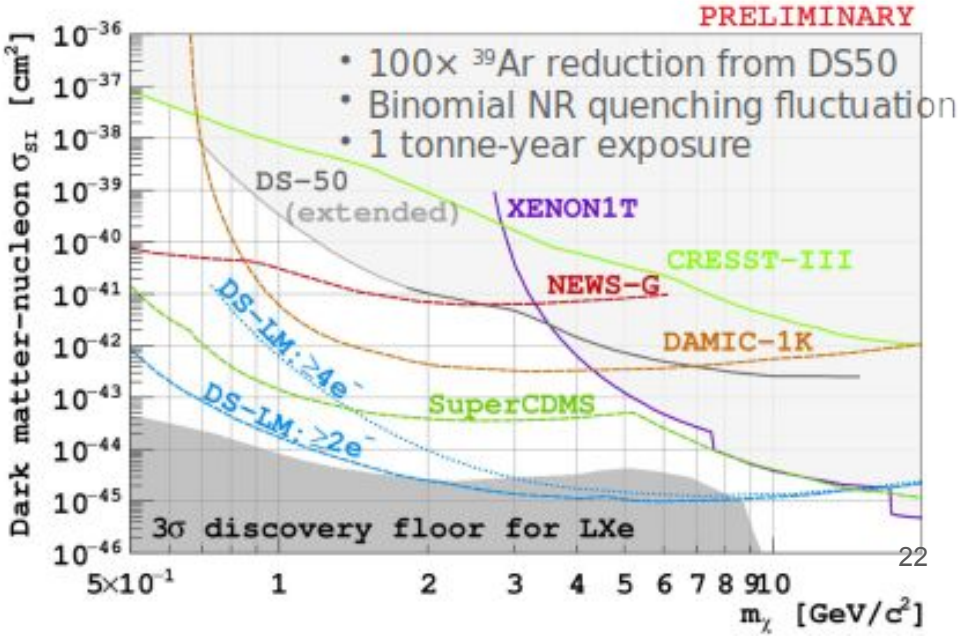


- 6.3×10^{-48} cm^2 for 1 TeV/c2 WIMP (90% C.L.)
- 2.1×10^{-47} cm^2 (5σ) discovery
- nominal exposure: (20×10) t yr
- Instrumental background: 0.1 events

LOW MASS SENSITIVITY

- **Scintillation signal** (S1): threshold at ~2 keV_{ee} / 6 keV_{nr} weak sensitivity to low mass WIMPs.
- **Ionization signal** (S2): threshold < 0.1 keV_{ee} / 0.4 keV_{nr} **Sensitive to low mass WIMPs!!**
- Use Ionization (S2) Only.
  - Amplified in the gas region (~23 PE/e^- or more)
  - Sensitive to a single extracted electron
  - The electron yield for nuclear recoils increases at low energy
- Ar has lighter mass than Xe. So, more efficient momentum transfer from low mass DM.
- Need 100 times lower ^{39}Ar contamination, lower radioactivity from detector, lower impurities in active volume.



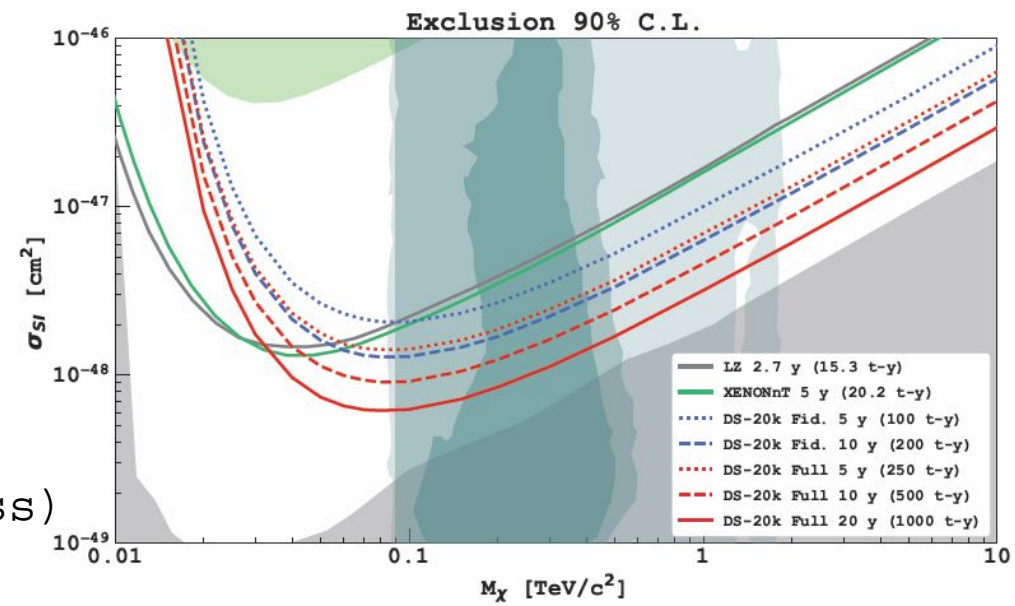


Scientific goals of DarkSide-20k

- Perform WIMP searches in unexplored regions of the parameter space using the most background suppressed experiment to date. **Best sensitivity for the heavy-side of the space parameter.**
- **Pave the way** for ARGO, which will measure down to the neutrino floor.

Physics program beyond WIMPs

- Exotic DM searches
- Solar axions
- SuperNova neutrinos
- Unprecedented
  - study of Ar properties
  - **Radiopurity control and mitigation**
  - SiPM development
- Low mass search (DS-LowMass)
- + Many more



Background estimates in DarkSide-20k

Background type	Bg events in ROI $[200\,\mathrm{t\,yr}]^{-1}$
(α,n) neutrons from U and Th	9.5×10^{-2}
Fission neutrons from U-238	$<2.3 \times 10^{-3}$
Neutrons from Rn-222 diffusion and surface plate-out	$<1.4 \times 10^{-2}$
Cosmogenic neutrons	$<6.0 \times 10^{-1}$
Neutrons from the lab rock	1.5×10^{-2}
Random surface α decay + S2 coincidence	$<5.0 \times 10^{-2}$
Correlated ER + Cherenkov	$<1.8 \times 10^{-2}$
Uncorrelated ER + Cherenkov	$<3.0 \times 10^{-2}$
ER	$<1.0 \times 10^{-1}$

Current estimates of trigger rate:

- 94 Hz in TPC
- 138 Hz in veto