

LSC



UGAP Conference, Tohoku University

LRT@LSC

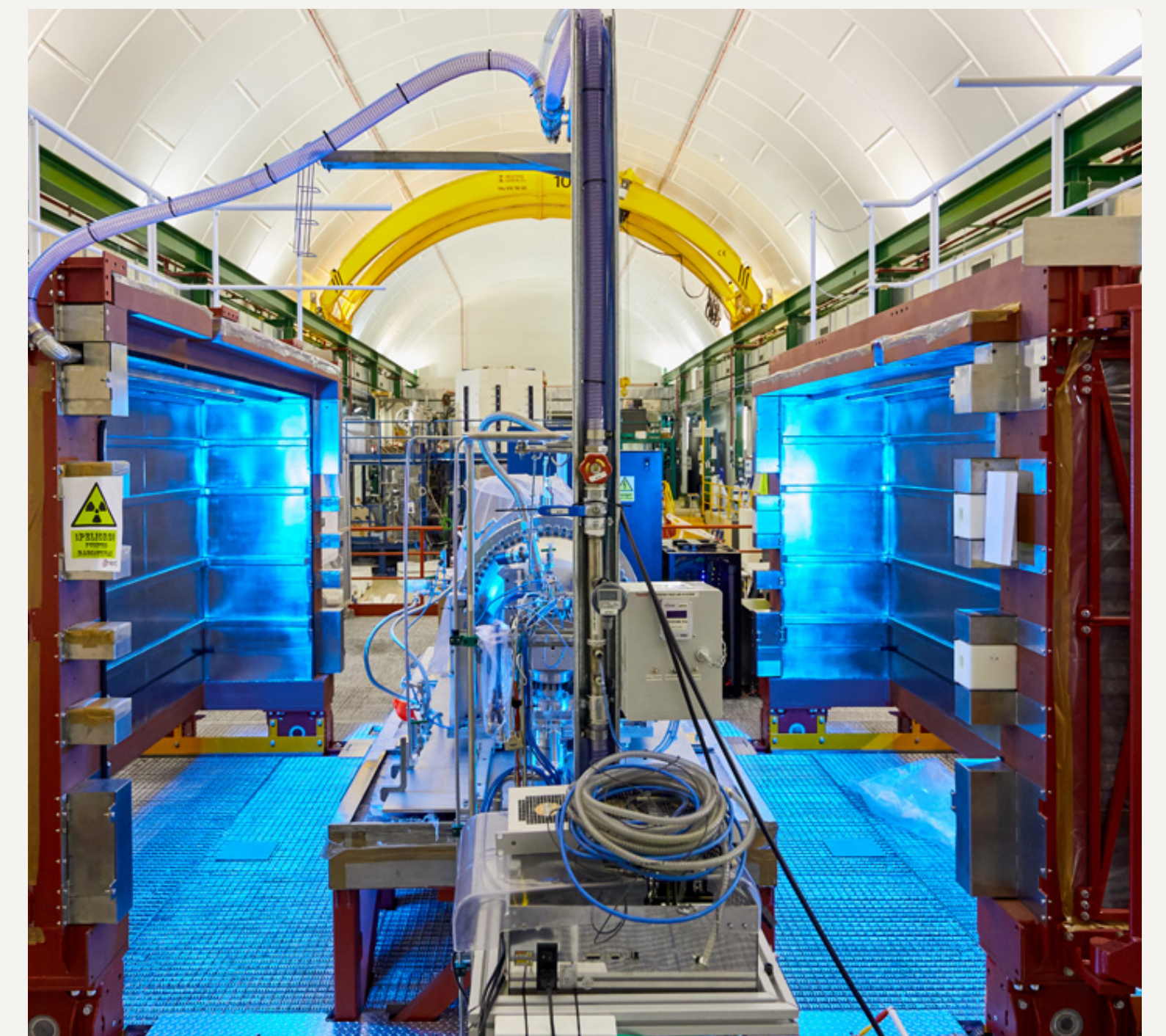
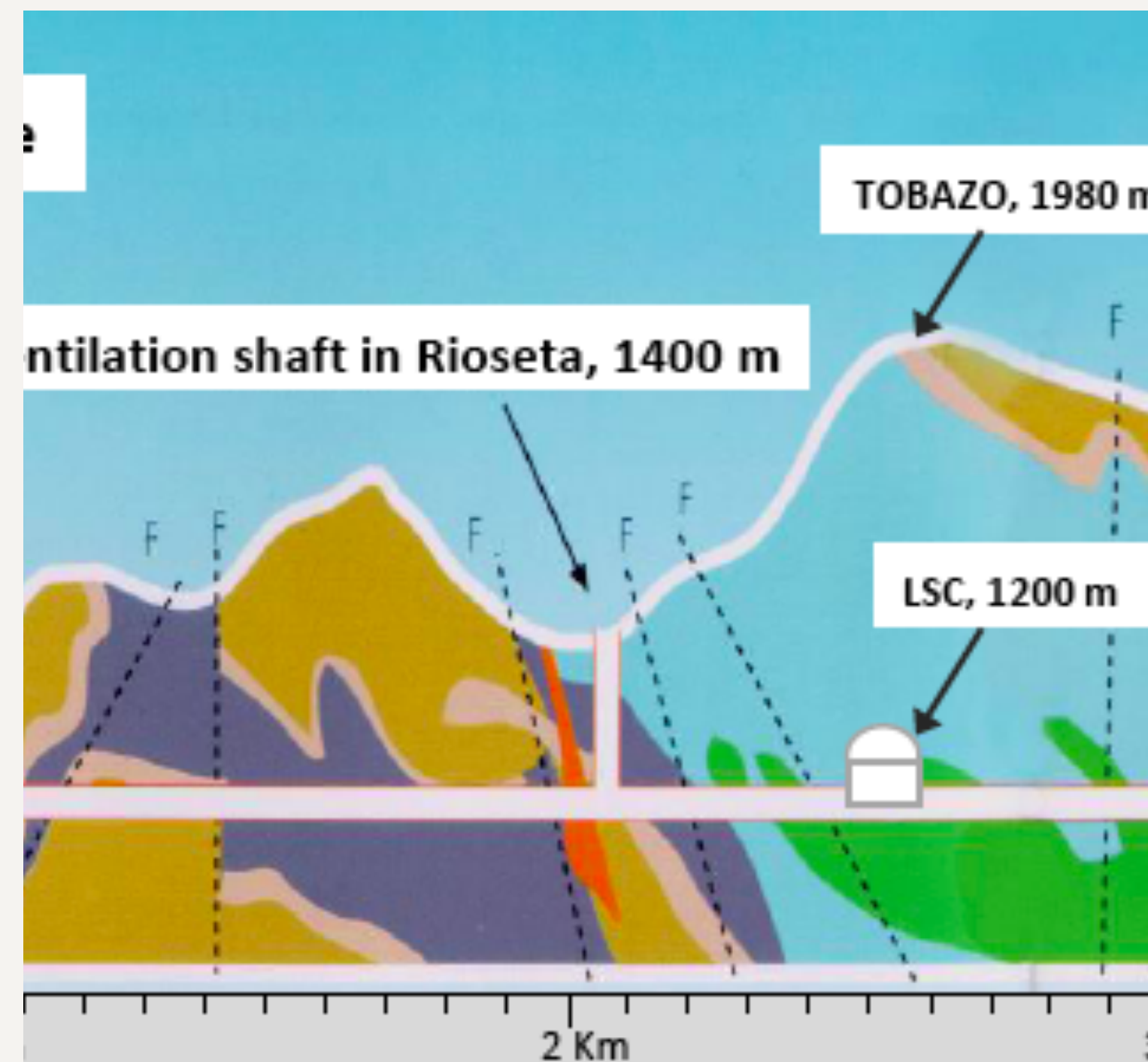
Canfranc Underground Lab

Located in Spanish-French Pyrenees border. Two-way access tunnels: abandoned train tunnel and operative road tunnel.

First experiments (IGEX, ...) since 1986. Modern lab, 1600 m², operative since 2010. 260 scientists from 50 institutions.

800 meters (v) of rock - muon flux is $5 \times 10^{-7} \text{ cm}^{-2} \text{ s}^{-1}$; neutron flux ($E < 10 \text{ MeV}$) is $3.5 \times 10^{-6} \text{ cm}^{-2} \text{ s}^{-1}$; gamma flux is $2 \text{ cm}^{-2} \text{ s}^{-1}$

Radon abatement system: 220 m³/h radon-reduced air at 1 mBq/m³



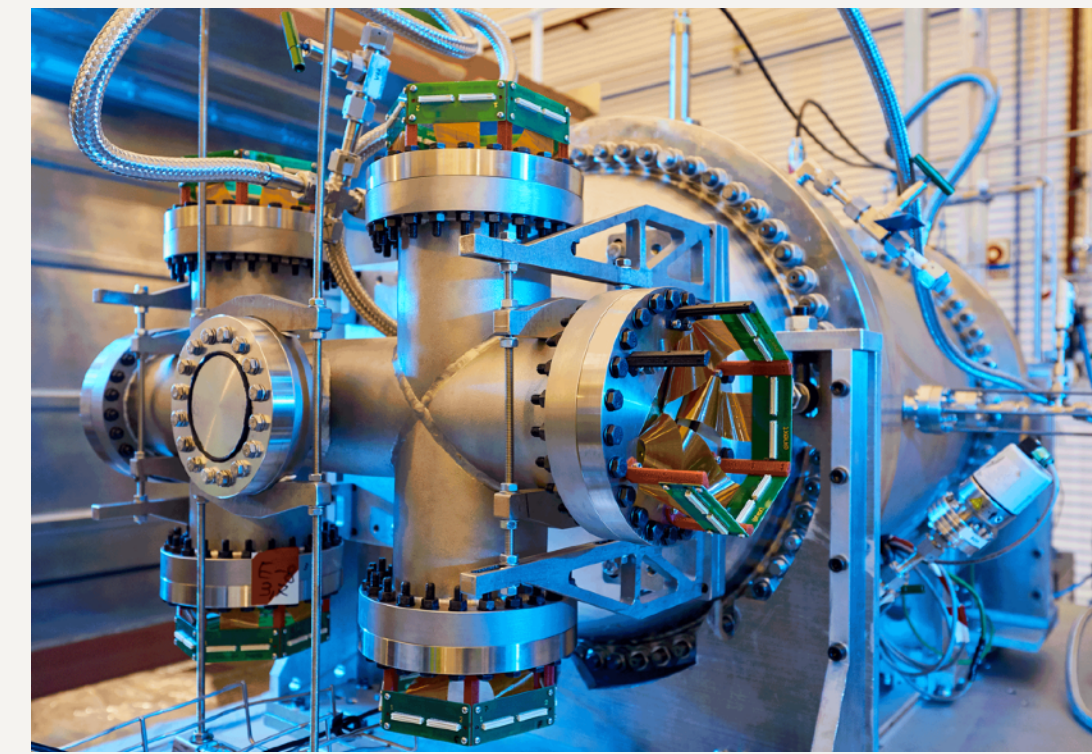
Experiments running/completed at LSC



ANAIS Experiment



DArT in ArDM



NEXT-W Experiment



CROSS demonstrator

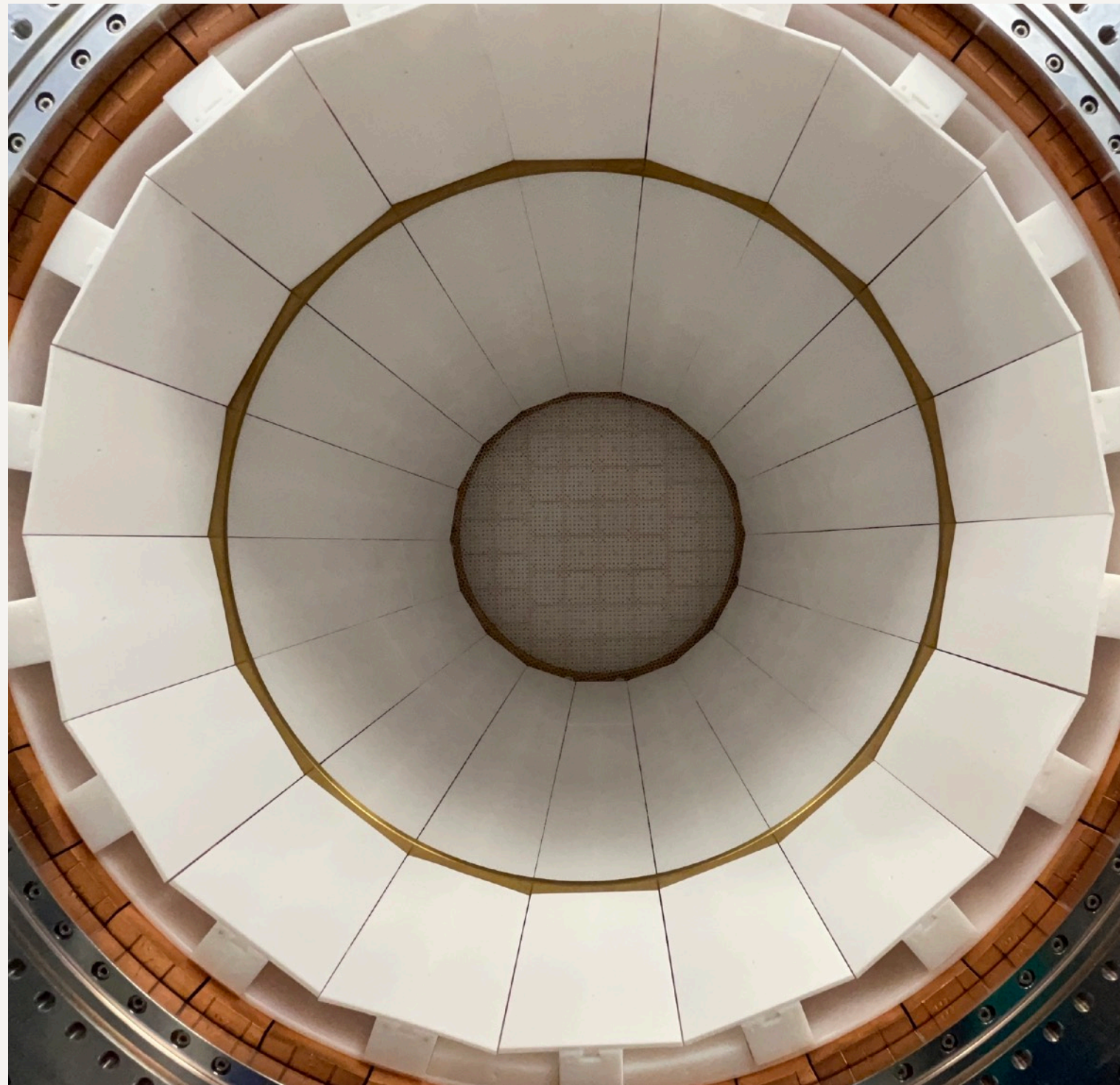
ANAIS experiment: Modulation excluded at 3 sigma. Started **last (7th) year** of data taking **to reach 5 sigma** exclusion.

DArT in ArDM: Measurement of ^{39}Ar activation in UAr from Colorado drilling site (^{40}Ar). In operation until 2026.

NEXT-White experiment: Finished in 2021. ^{136}Xe Gas electroluminescent TPC at 10 bar (3.5 kg). Best Xenon energy resolution (0.9% FWHM, at 2.6 MeV). Electron track reconstruction improves double beta events (27 factor rejection with 57% efficiency). Neutrinoless double beta decay $T_{1/2} > 10^{24}$ yr [KamLAND-zen limit is 2.3×10^{26}] at 90%CL.

CROSS demonstrator: Low background dilution refrigerator studying surface beta events in TeO_2 and $\text{Li}_2^{100}\text{MoO}_4$ crystals.

2023 Highlights on experiments @LSC



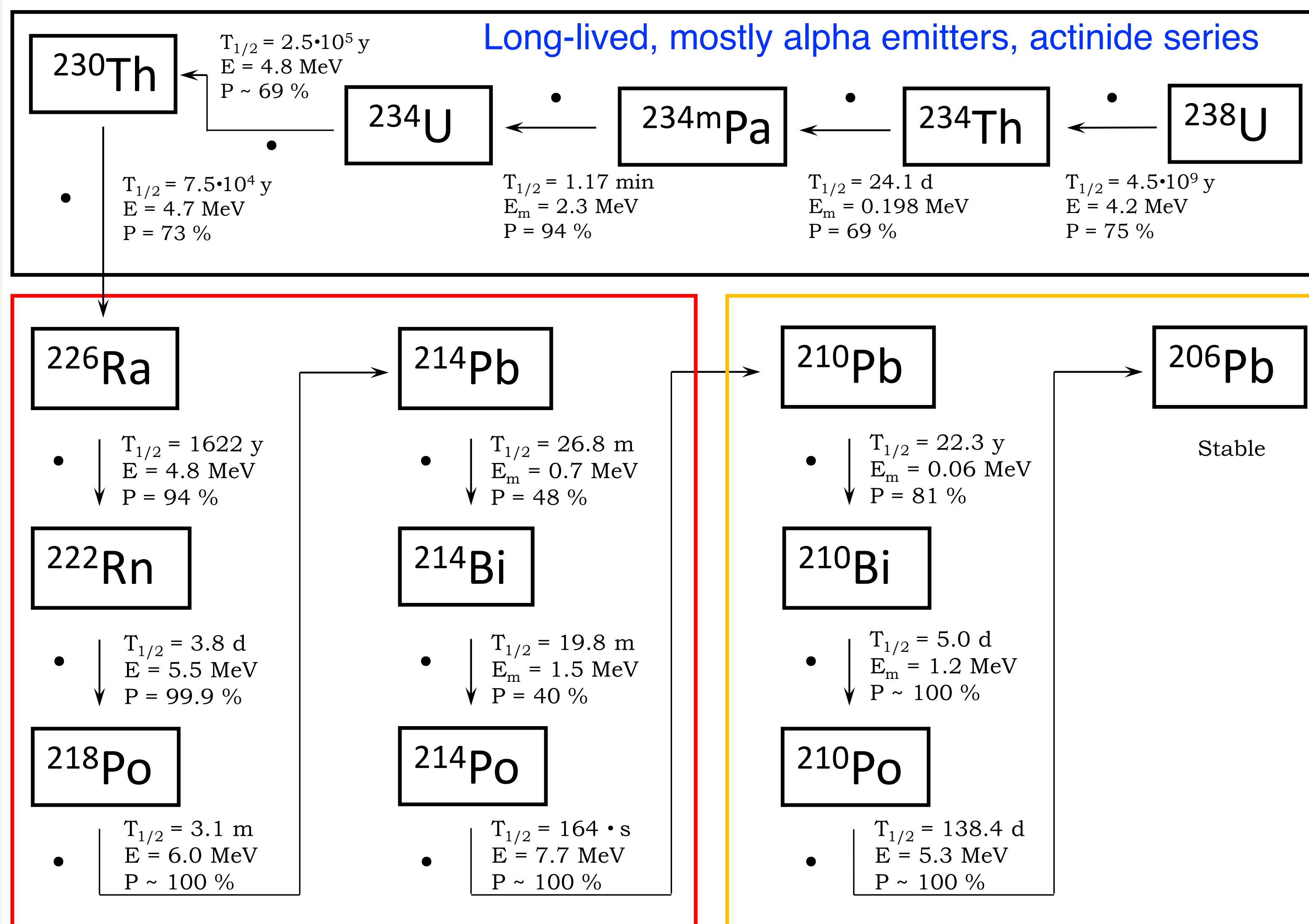
NEXT-100 experiment: Detector installation **completed in 2023**. **NEXT-HD experiment first steps** (see JJ's talk).

GeRysy: **New** lowest background world **record** in **HPGe** gamma screening with **$\mu\text{Bq/kg}$ sensitivity** (led by **G. Zuzel**). Well-type suited for small samples from NEXT-100, Dark Side, LEGEND-200 components. Completing calibration run.

New ICPMS-QQQ placed in Class ISO5 clean room underground: **2 (20) ppq** sensitivity in ^{238}U (^{232}Th). ppb ^{40}K . Copper and steel (NEXT-100 and DAMIC), EFCu (DAMIC), NaI crystals (SABRE), Mo samples (RMD).



LRT on COPPER



Ra, Rn and its short-lived progeny

Rn long-lived progeny

MOTIVATION

Screening of the construction materials for the next generation experiments like NEXT, LEGEND, DarkSide, DAMIC, ...

Develop onsite methods to obtain large amounts of radio-pure copper (NEXT-HD).

Secular equilibrium may not hold, rather a rule than an exception, and ICP-MS may not be sufficient to estimate background.

Each sub-chain assayed separately.

Ultra-sensitive spectrometers to assay ^{226}Ra
 Very limited screening capabilities worldwide at the level of $10 \mu\text{Bq/kg}$ or ppt U-equivalent.



LOW BACKGROUND MEASUREMENTS LSC SERVICE IN 2019

Name	V [cm ³]	M [kg]	FWHM @ 1332 keV [keV]	Integral (40-2700) keV [cts/kg/day]	Tl-208 583.19 keV [cts/kg/day]	Bi-214 609.3 keV [cts/kg/day]	Co-60 1332.5 keV [cts/kg/day]	K-40 1460.8 keV [cts/kg/day]
GeOroel	420	2.26	2.20	141.76	0.68	0.43	0.04	0.07
Asterix	387	2.06	1.93	173.11	0.41	0.74	0.33	0.62
GeAnayet	410	2.22	2.01	569.17	4.46	1.22	0.15	0.72
GeLatuca	410	2.22	1.84	472.80	4.40	1.29	0.23	0.83
GeTobazo	410	2.22	1.99	499.04	4.10	1.03	0.22	0.73
GeAspe	409	2.22	2.06	707.24	4.64	1.06	0.23	0.66

Sensitivity range, assuming secular equilibrium and 10% efficiency:

$^{238}\text{U} \sim 10 - 100$ ppt

$^{232}\text{Th} \sim 50 - 330$ ppt

$^{40}\text{K} \sim 10 - 100$ ppb

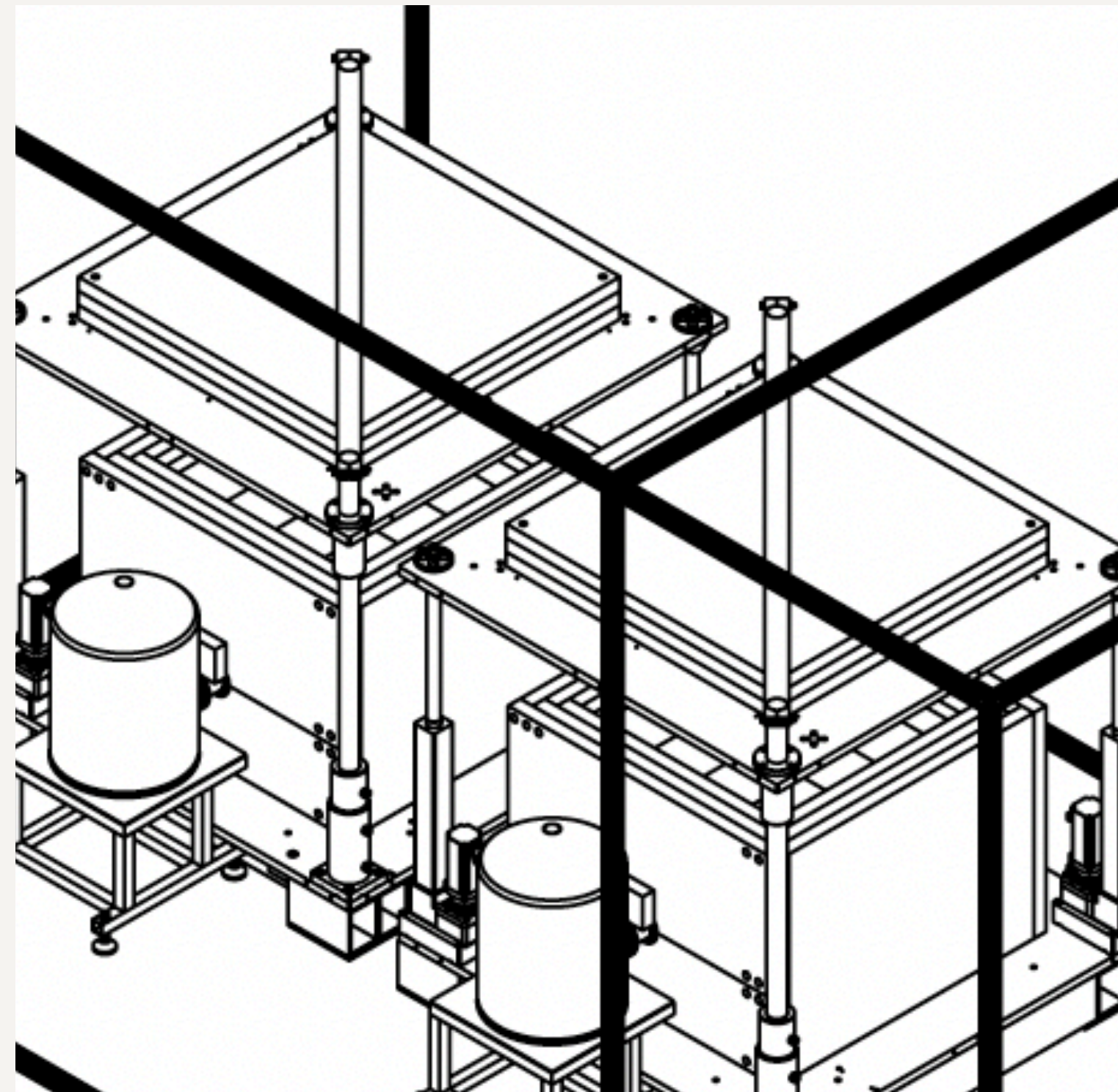
HPGe contribution to $\text{Gd}_2(\text{SO}_4)_3$ screening
for SK-Gd (part of EGADS)

Best sensitivity in LSC HPGe detectors was $100 \mu\text{Bq/kg}$ or 10 ppt U-equivalent (world most-sensitive $10 \mu\text{Bq/kg}$ GeMPI-1)

IMPROVING LRT: MAKING OF THE THREE GLORIES

Hall C refurbished as a noise reduced radon free clean room to host three new HPGe, structure with bottom/top plates and lifters/steeper motors, 520 lead bricks (59 of 1-3 Bq/kg, 207 of 4-5 Bq/kg), 40 Cu pieces and 20 PE (5% B) plates.

UHPGe detector delivered in June 2020: GeRysy installation completed in early 2023 (UJ-LSC coll, led by G. Zuzel). Rysy is a mountain in the crest of the High Tatras, lying on the border of Poland and Slovakia. Rysy has three summits.





Two tons of ultra-pure copper were casted for fabrication of the detector cryostat and the most internal layer of the shield. Freshly pulled 400-cm³ HPGe crystal (~2.1 kg, ~100 % rel. efficiency) with SAGe-well geometry (well capacity is 19.7 cm³). Radio-purity of the copper validated by ICPMS, HPGe and ²¹⁰Pb chemical separation: high purity and strong disequilibrium. 2cm removed from all surfaces of forged copper, and remaining cut in smaller pieces: dedicated pieces sent to Canberra.

Low ²¹⁰Pb lead bricks were selected by the detection of low-background beta spectrometry of ²¹⁰Bi. For the production of soldering material, low activity tin (30 mBq/kg) was selected to be melted with archaeological lead in the proportion 60:40.

Isotope	Activity concentration [mBq kg ⁻¹]	Comments
²³⁸ U	< 0.012	< 1 ppt U. 90 % C.L. (ICP-MS)
²³⁴ Th	< 4.2	Upper ²³⁸ U sub-chain, 90 % C.L. (HPGe)
^{234m} Pa	< 0.45	Upper ²³⁸ U sub-chain, 90 % C.L. (HPGe)
²²⁶ Ra	(29 ± 8) · 10 ⁻³	(HPGe)
²¹⁰ Pb	14 ± 2	(²¹⁰ Po extraction)
²³² Th	< 0.004	< 1 ppt Th. 90 % C.L. (ICP-MS)
²²⁸ Ra	< 0.027	90 % C.L. (HPGe)
²²⁸ Th	< 0.041	90 % C.L. (HPGe)
²³⁵ U	< 0.069	90 % C.L. (HPGe)
⁴⁰ K	< 0.14	90 % C.L. (HPGe)
⁶⁰ Co	(14 ± 4) · 10 ⁻³	(HPGe)



[Production and characterization of ultra-pure materials for low background applications](#), Frontiers in Physics (2024), G. Zuzel, T. Mroz, M. Wojcik, J. Perez, S. Stoch, F. Ferella, M. Laubenstein, C. Pena-Garay



LOW RADIOACTIVITY TECHNIQUES

Detector holder, soldering material, gas adsorber, ... selected in cooperation with the manufacturer of the detector.

GeRysy I is the **New** lowest background **world record** in HPGe for screening (collaboration UJ-LSC, led by G. Zuzel).

GeRysy II and III construction already started: bottom/top plate and lifters/steeper motors installed in Hall C at LSC.

GeRysy II and III construction in progress should benefit from GeRysy. Further improvements in HPGe components.

Detector	M_{act} [kg]	V_{cham} [L]	Lab	2023 results Counting rates [cts/yr/kg] in various energy regions / peaks [keV]						
				40 - 2700	609	662	583	1332	1461	2614
GeRysy	2.27	15	LSC	64 ± 1	74 ± 19	< 27	27 ± 17	< 37	60 ± 16	26 ± 9
GeMPI	2.21	15	LNGS	66 ± 1	< 30	57 ± 27	< 21	35 ± 8	86 ± 12	18 ± 5
GATOR	2.20	15	LNGS	$103 \pm 1^*$	99 ± 33	50 ± 17	--	83 ± 17	83 ± 17	33 ± 16
GeOroel	2.31	10 ?	LSC	142	190	--	182	91	66	--

First calibration run, completed in the first semester of 2023, showed very low background detector (still hot).



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New calibration run, first semester of 2024, shows the **lowest background world record** HPGe screening detector .

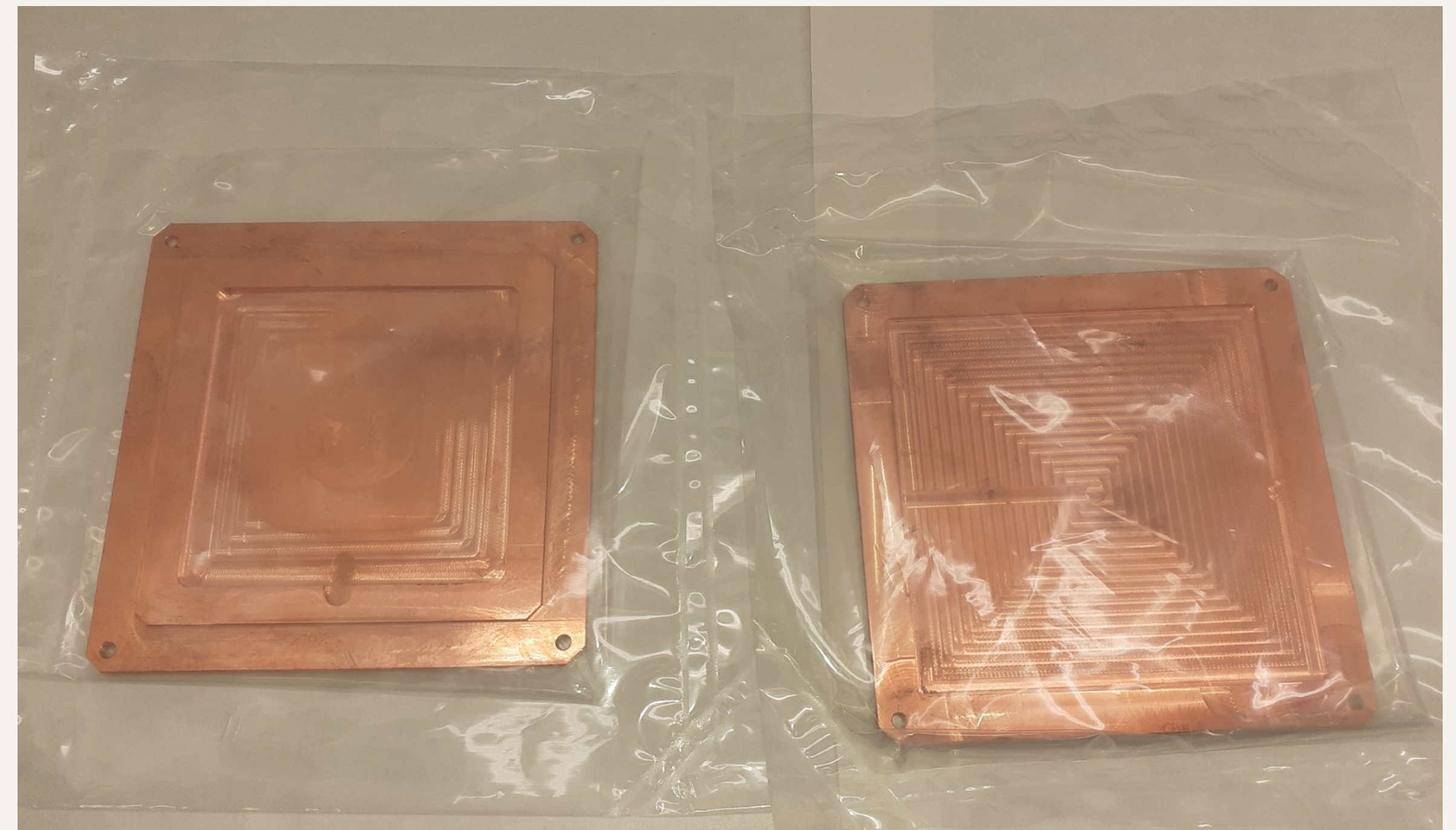
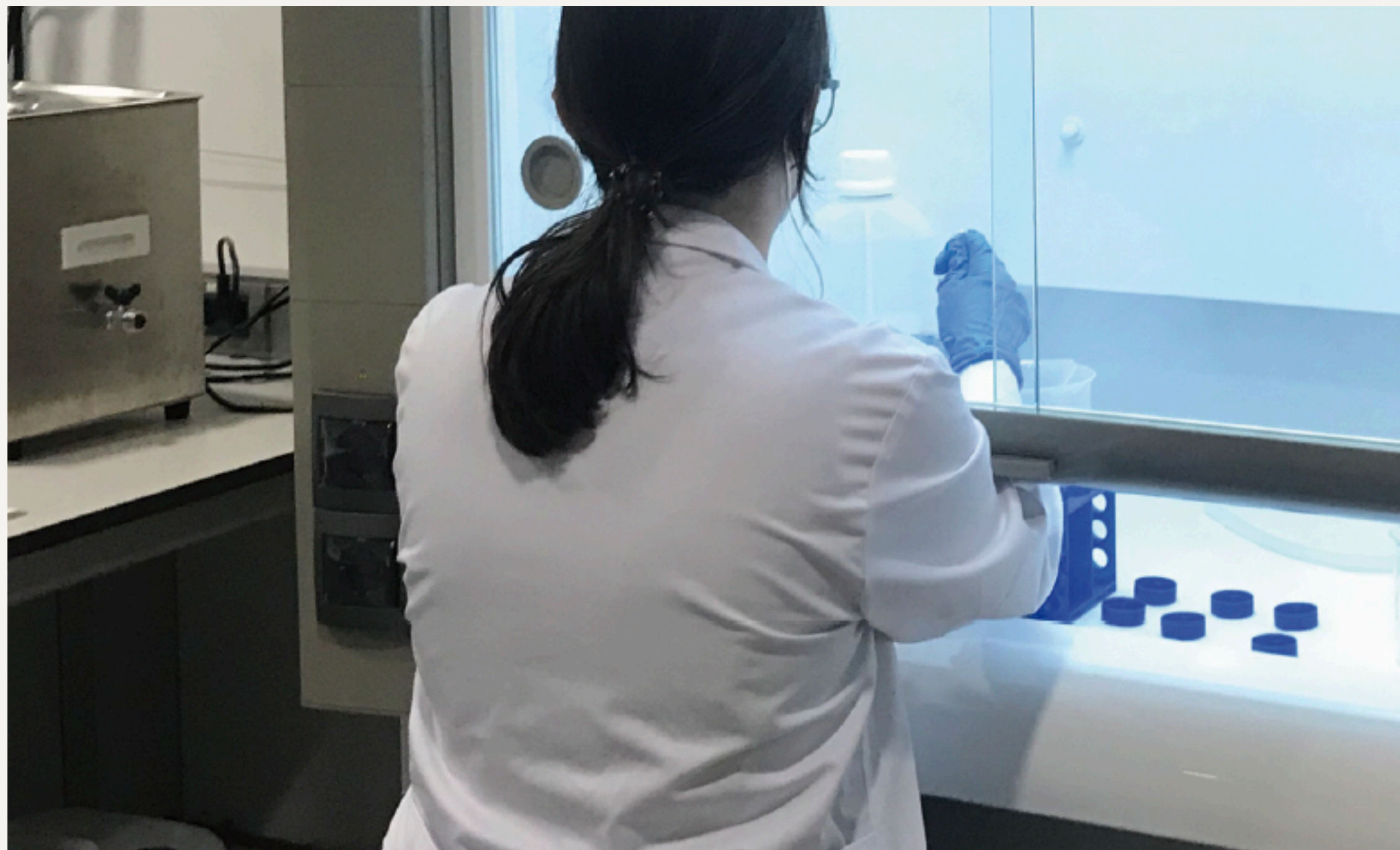
IMPROVING ON BEST COMMERCIAL COPPER

Monitor at $O(1)$ ppq sensitivity in U, requires refined chemistry separation and very clean conditions and chemicals.

New ICPMS-QQQ with automatic sampling in clean room underground matches PNNL high standards (ppq sensitivity in U)

Improved EFCu production: production of copper lids, cryostat components for DAMIC experiment.

Production of $O(100)$ kg copper batches for additive printing (collaboration with LNGS): Multi-purpose EFCu powder





OTHER LRT PROGRAMS

- ^{39}Ar $Q=565\text{keV}$ and $T_{1/2}=269\text{y}$; 8×10^{-16} in AAr; 1Bq/Kg ; 0.7mBq/kg in UAr
 - Produced by muon capture on ^{39}K and (α, n) -induced (n, p) reactions on ^{39}K
- ^{42}Ar $Q=599\text{keV}$ and $T_{1/2}=32.9\text{y}$ (relevant for $0\nu 2\beta$ decay searches (LEGEND) due to the β 's of the daughter isotope ^{42}K , $Q=3\text{MeV}$ and $T_{1/2}=12\text{h}$); 7×10^{-21} in AAr, $68\mu\text{Bq/Kg}$
- A lot of interest in the UAr by several experiments:
- Now expression of interest by:
 - LEGEND1000 25 tonnes ($2\beta 0\nu$)
 - COHERENT 1 tonne (CEvENS)
 - DUNE module 3 or 4 $O(10,000)$ tonnes (dark matter, SNv, $2\beta 0\nu$); see Valencia MoO workshop
 - Darkside-LowMass 1 tonne further depleted



Urania

DArT

DS-20k

Aria

UAr

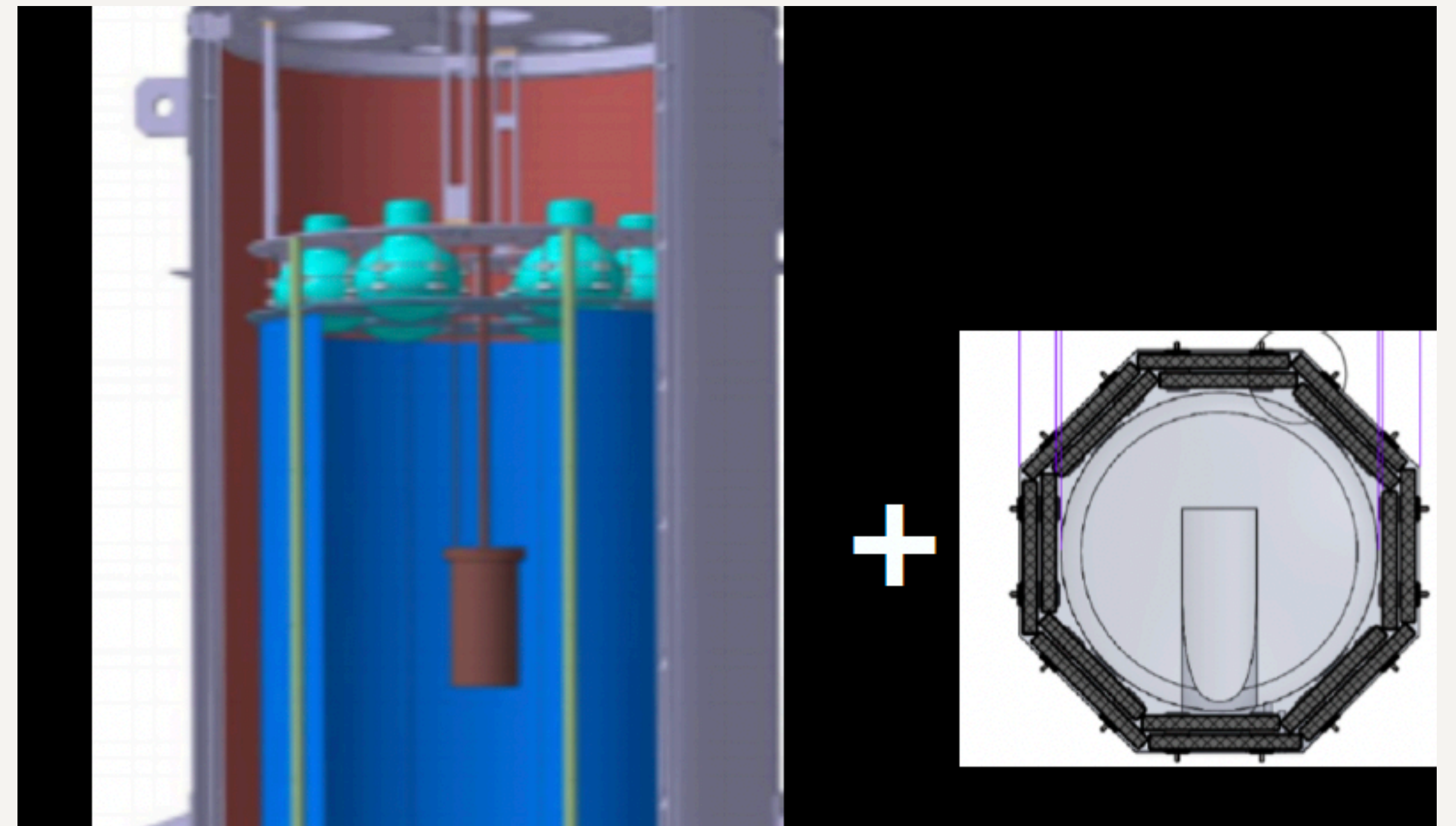
HIGH SENSITIVITY ^{39}Ar MEASUREMENT REQUIREMENTS

Expected sensitivity to be observed on ^{39}Ar : DF 60,000 (to be compared to 1,400 for UAr measured by DarkSide-50)

Status: ArDM equipped with double phase setup and 1-ton argon recovery vessel. Lead belt and PE in place

New TPC ready in ArDM vessel. 1 liter cryostat to host UAr ready. Agreement DS-LSC. Start sampling in fall.

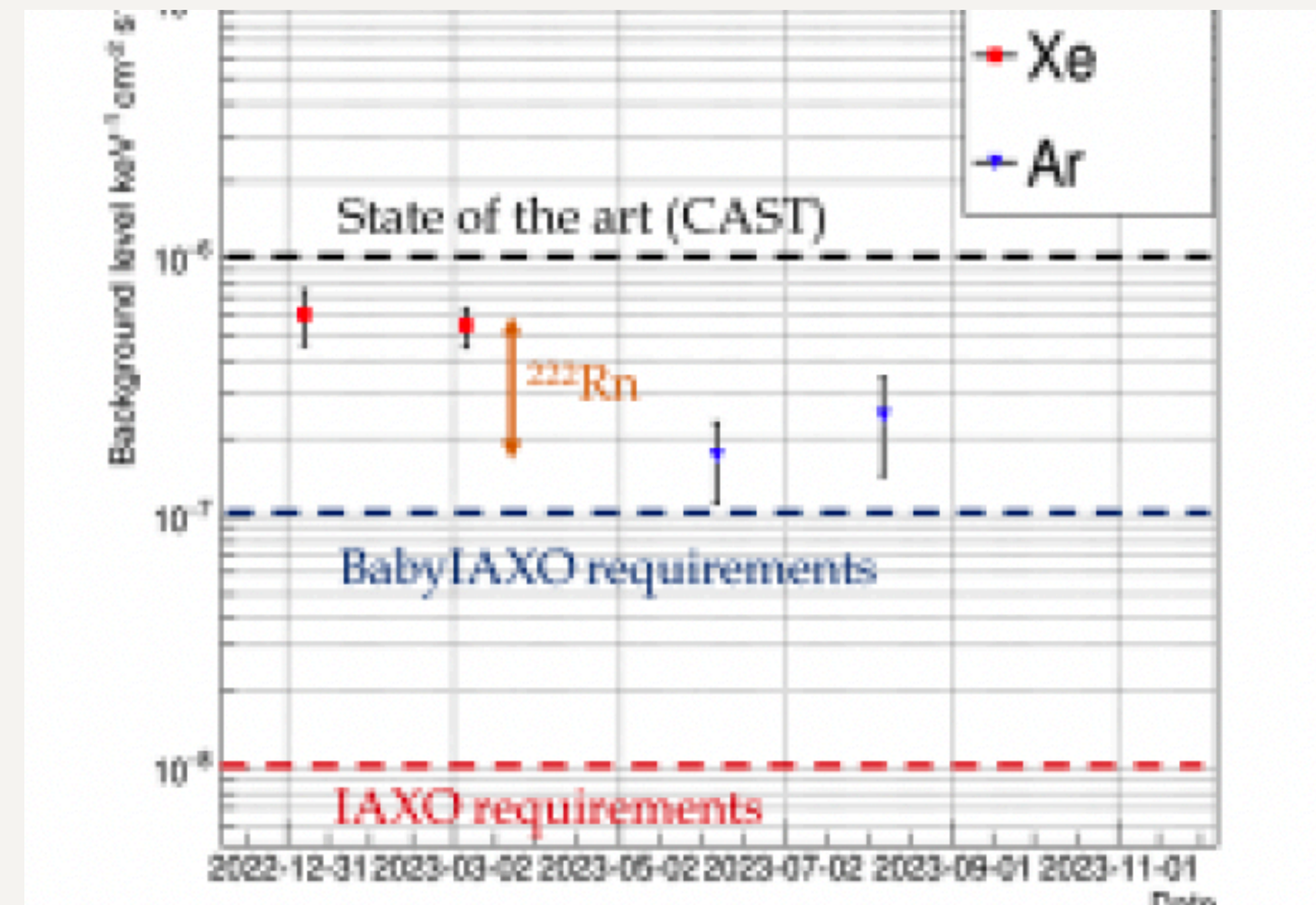
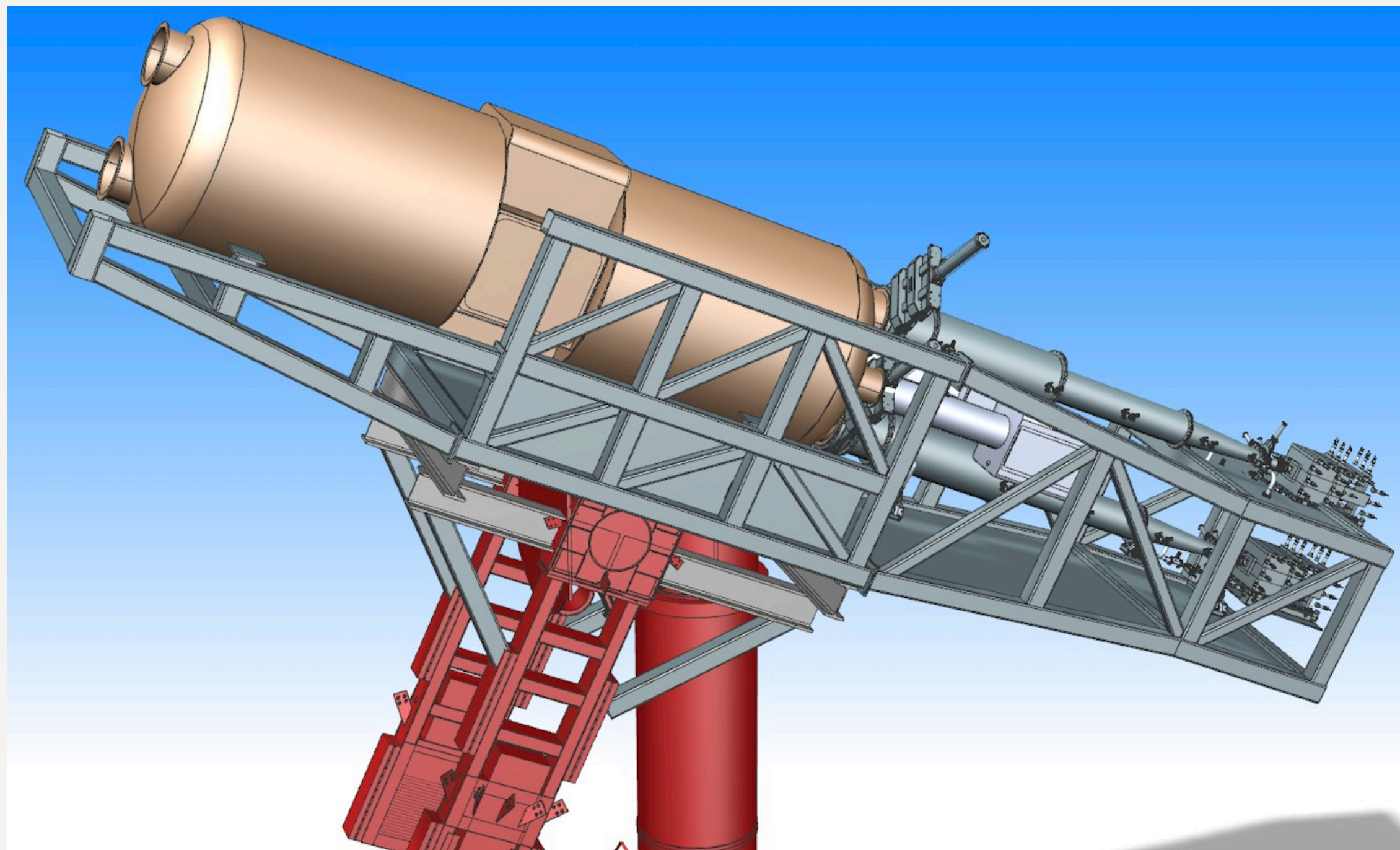
2-yrs operation to monitor UAr production in several batches (small production for LEGEND and COHERENT in discussion)



BabyIAXO-D1 - Screening of materials for solar axion searches

X-ray background characterization of materials for future Baby IAXO experiment at DESY.

IAXO-D1 Micromegas prototype (SDD also tested) at LSC since October 2022. Xenon-Neon-isobutane mixture first, replaced by Argon-isobutane in open loop -> $1.7 \cdot 10^{-7}$ counts/keV/cm²/s (lowest background ever) - baseline technology



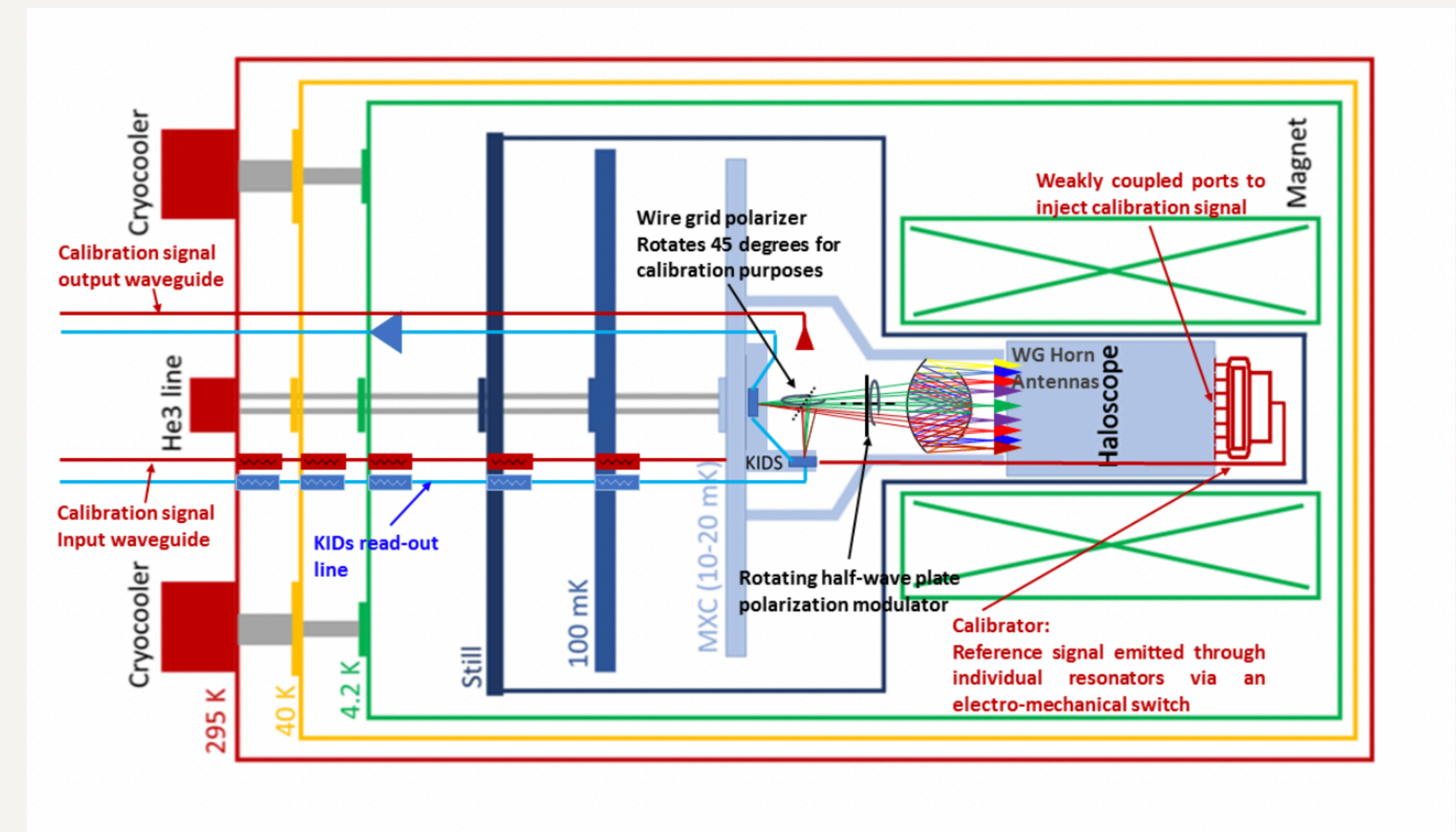
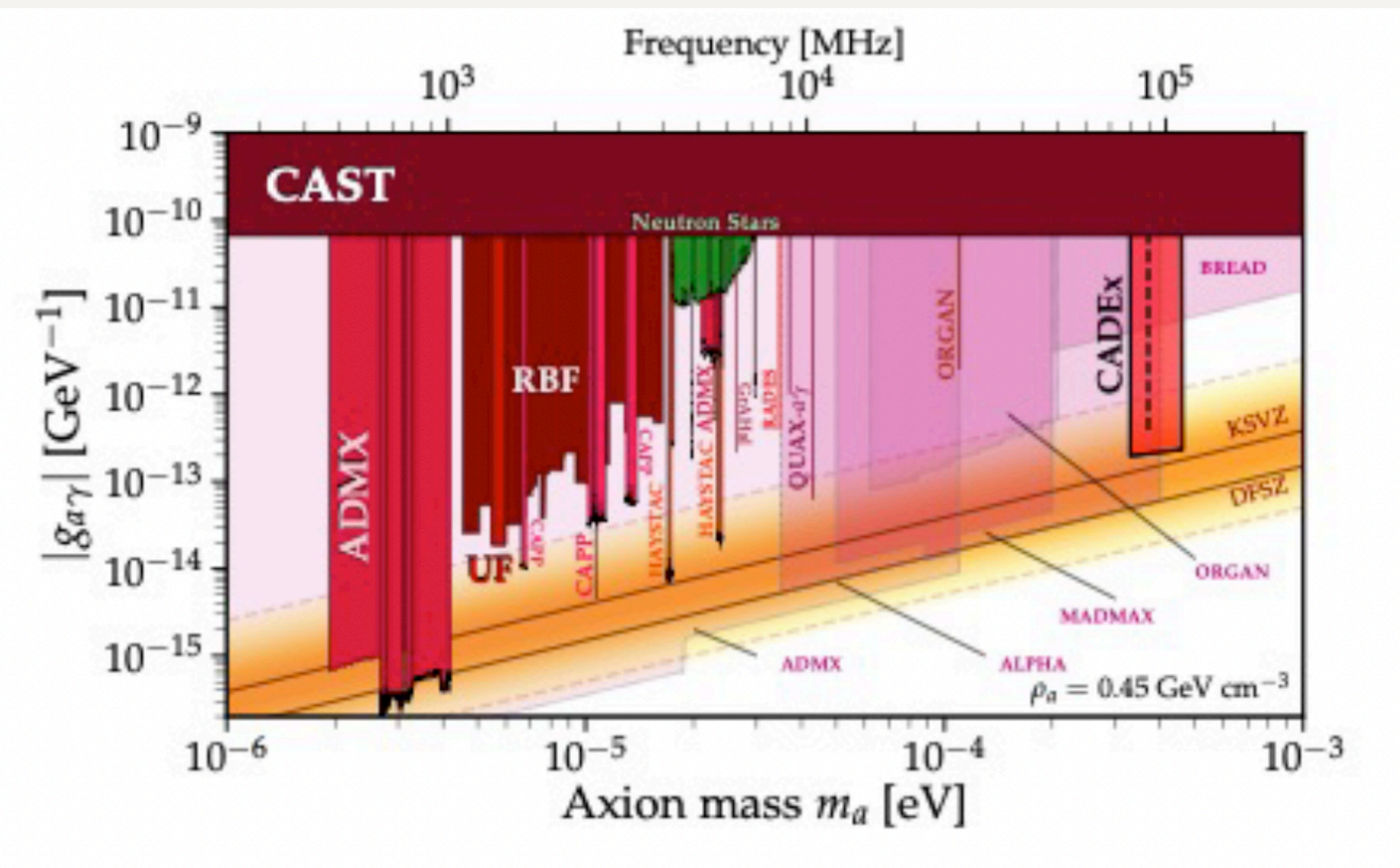
HIGH SENSITIVITY MEASUREMENT REQUIREMENTS

CaDEX experiment (JCAP 2023) - 90 [86-110] GHz search for DM axions in a 10 mK dilution fridge (10^{-19} W/ $\sqrt{\text{Hz}}$ sensitivity)

Haloscope - Rectangular cavities designed, including critical coupling ($a \cdot 10a \cdot 50a$, $a=5/3$ mm) - WR10 waveguides

Quasi-optical guiding by reflection at several mirrors: 16 horn antenna apertures

LEDKIDs have been designed: free space impedance at W-band, absorption for two orthogonal polarizations $Q=60000$



Laboratorio Subterráneo Canfranc



Improving LRT

