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Underground Laboratory Challenges

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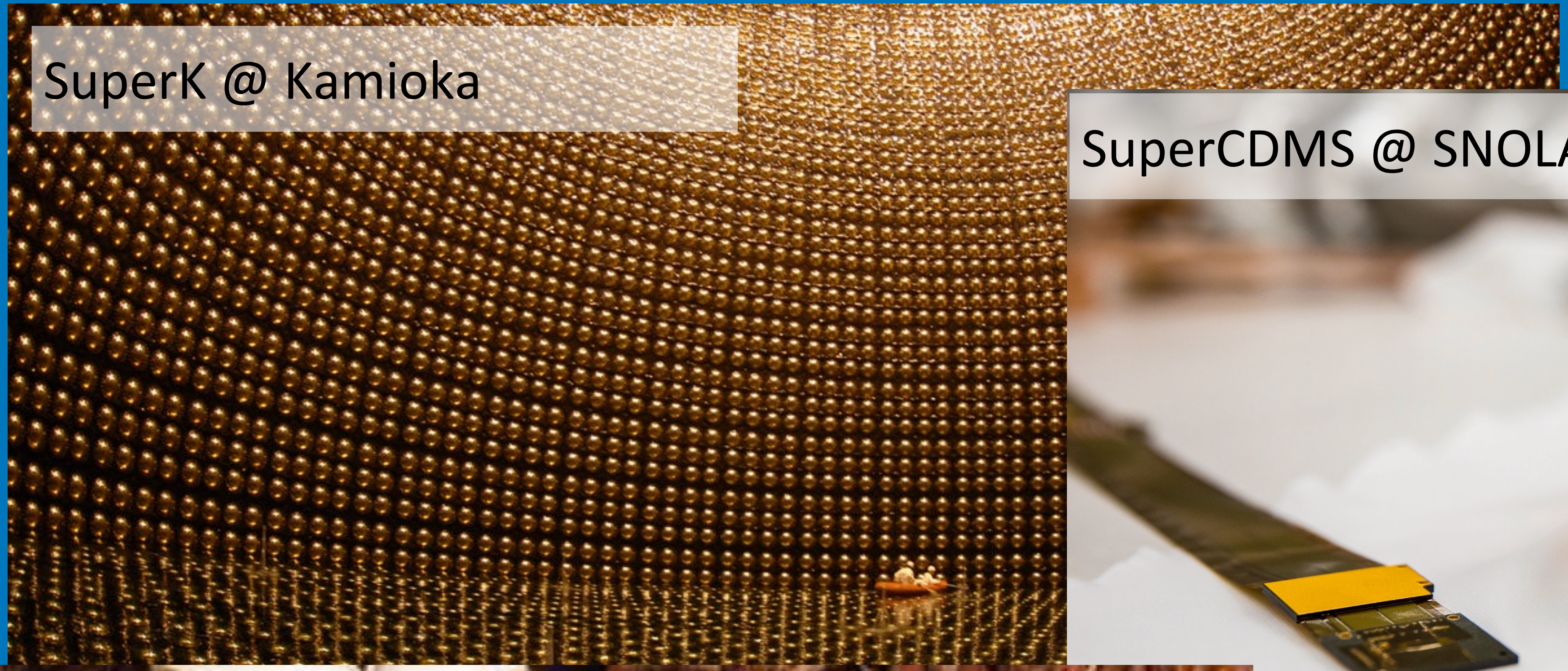
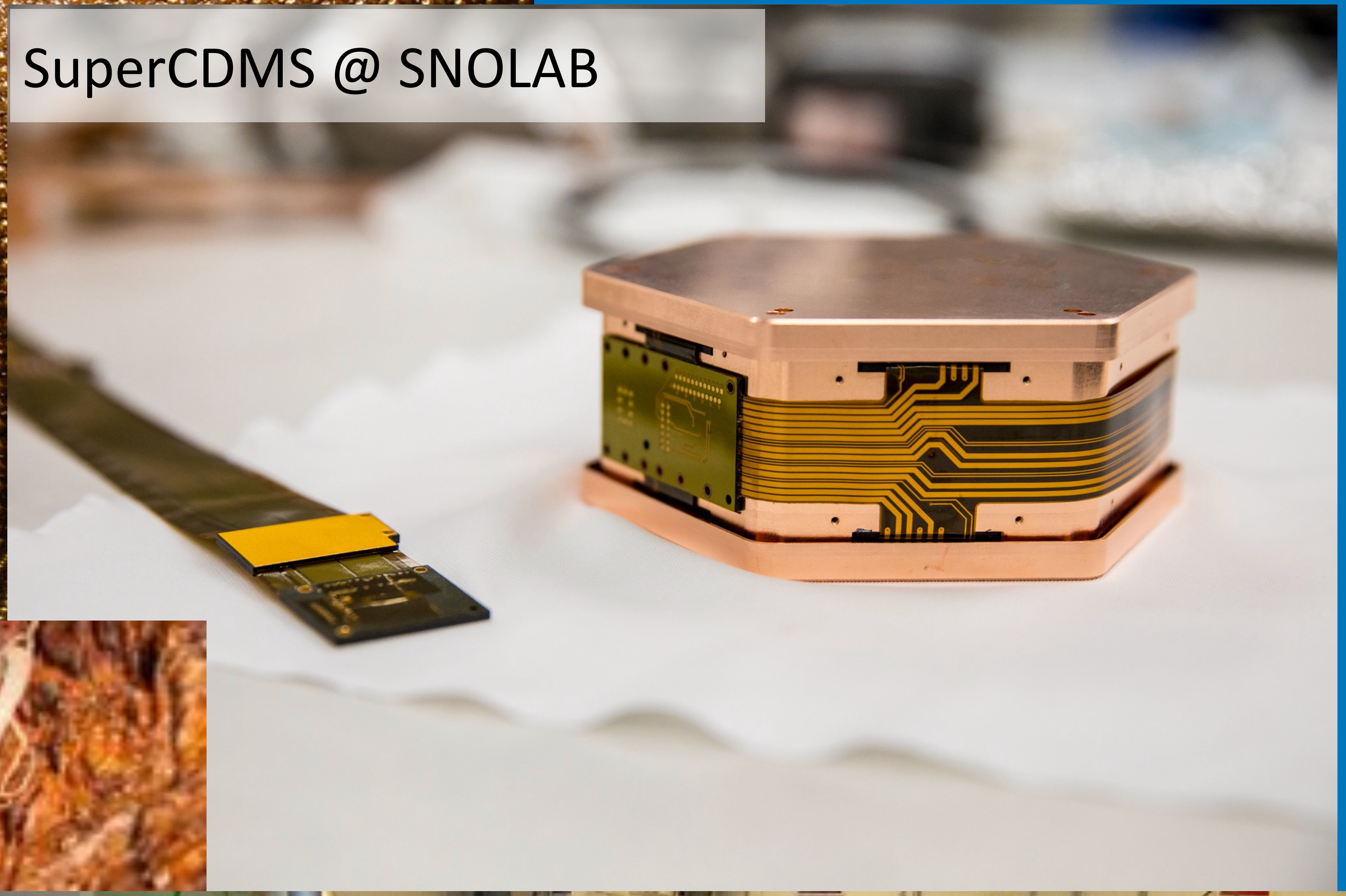
SNOLAB

World Class Science @ Underground Laboratories

- Neutrino Physics
- Dark Matter
- Double Beta Decay
- Nuclear Astrophysics
- Quantum Technology
- Rare Processes
- Geophysics
- Gravitational Waves
- General Relativity
- Biology and Astrobiology
- Nuclear Security
- Energy Storage
- ….


SuperK @ Kamioka


SuperCDMS @ SNOLAB


Water Sampling @ SURF

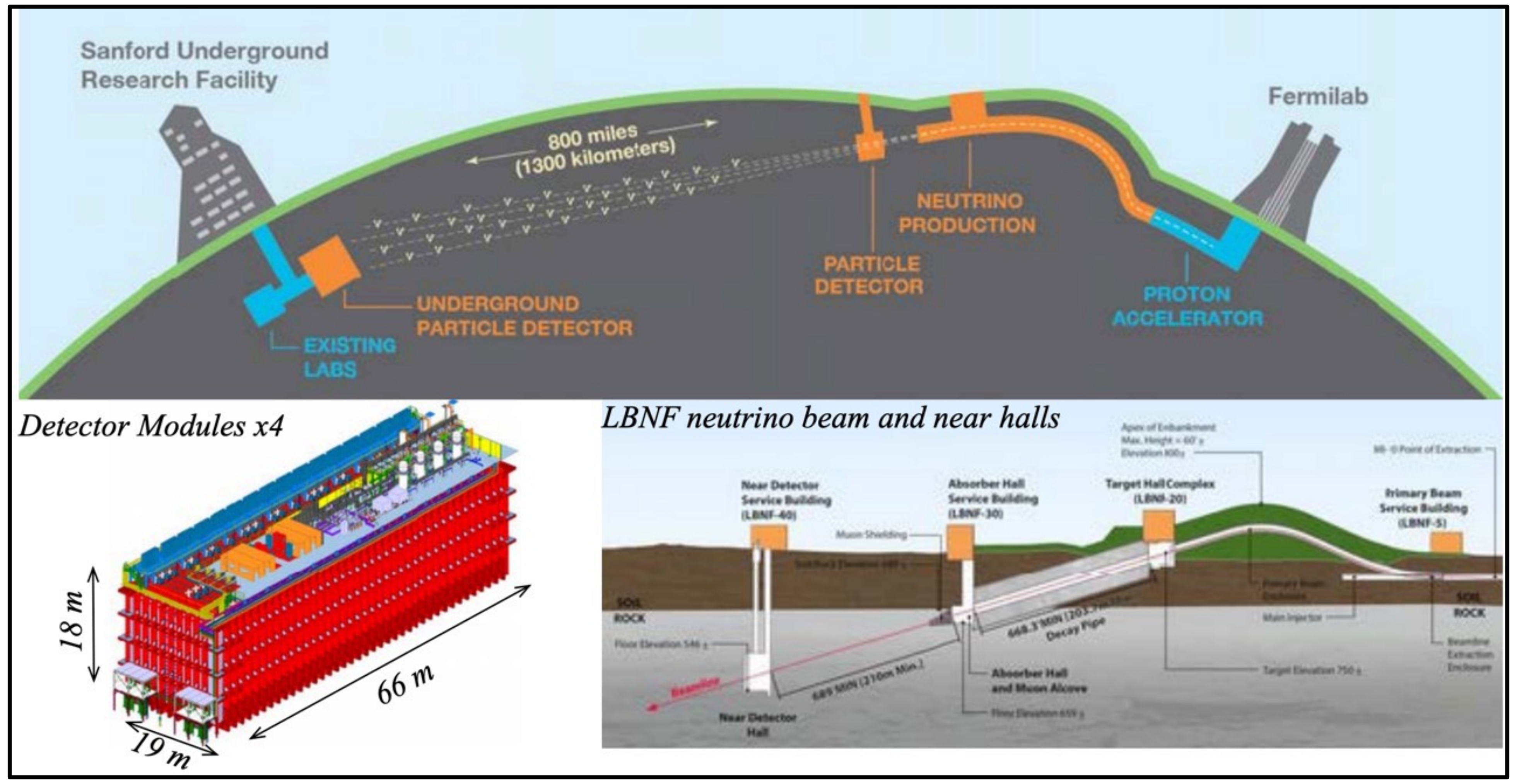

LUNA @ LNGS

Underground Laboratories Around the World

Science that Sets the Stage

Long Baseline Neutrino Facility / DUNE

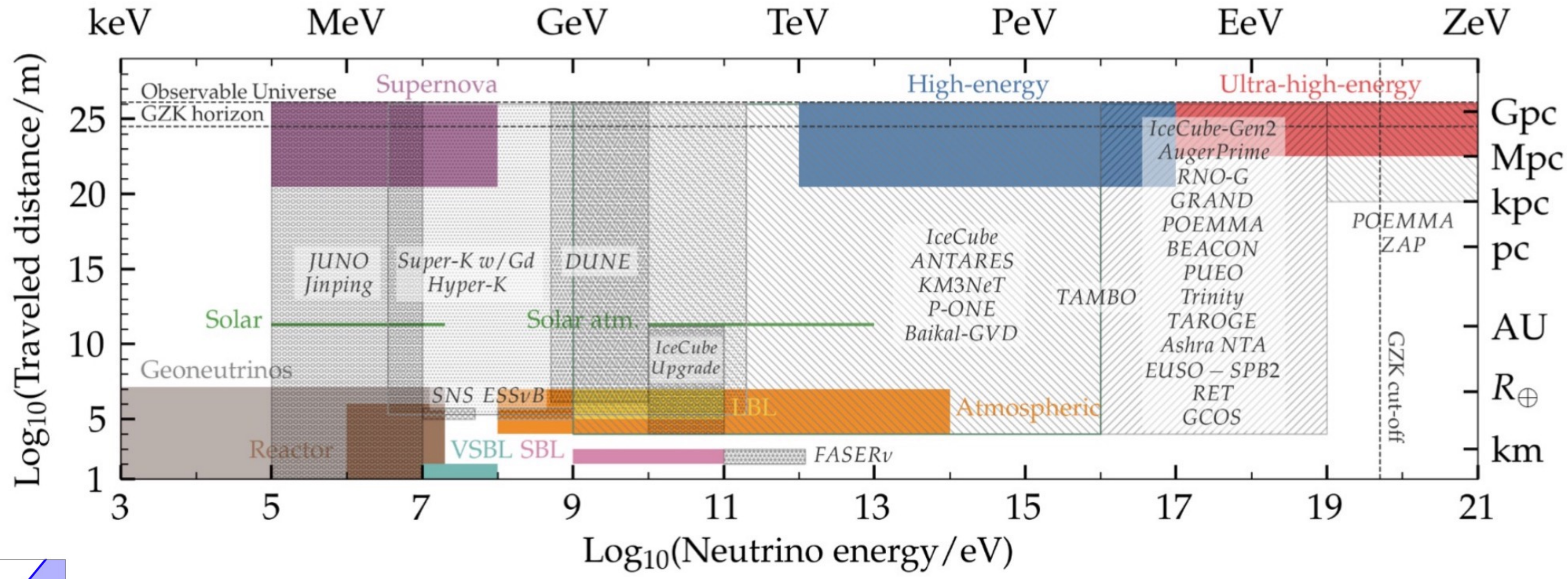
- Requires world-class underground infrastructure
- LBNF enables US science priorities in accelerator-based neutrino experiments
- R&D for the DUNE module of opportunity may require unique underground infrastructure



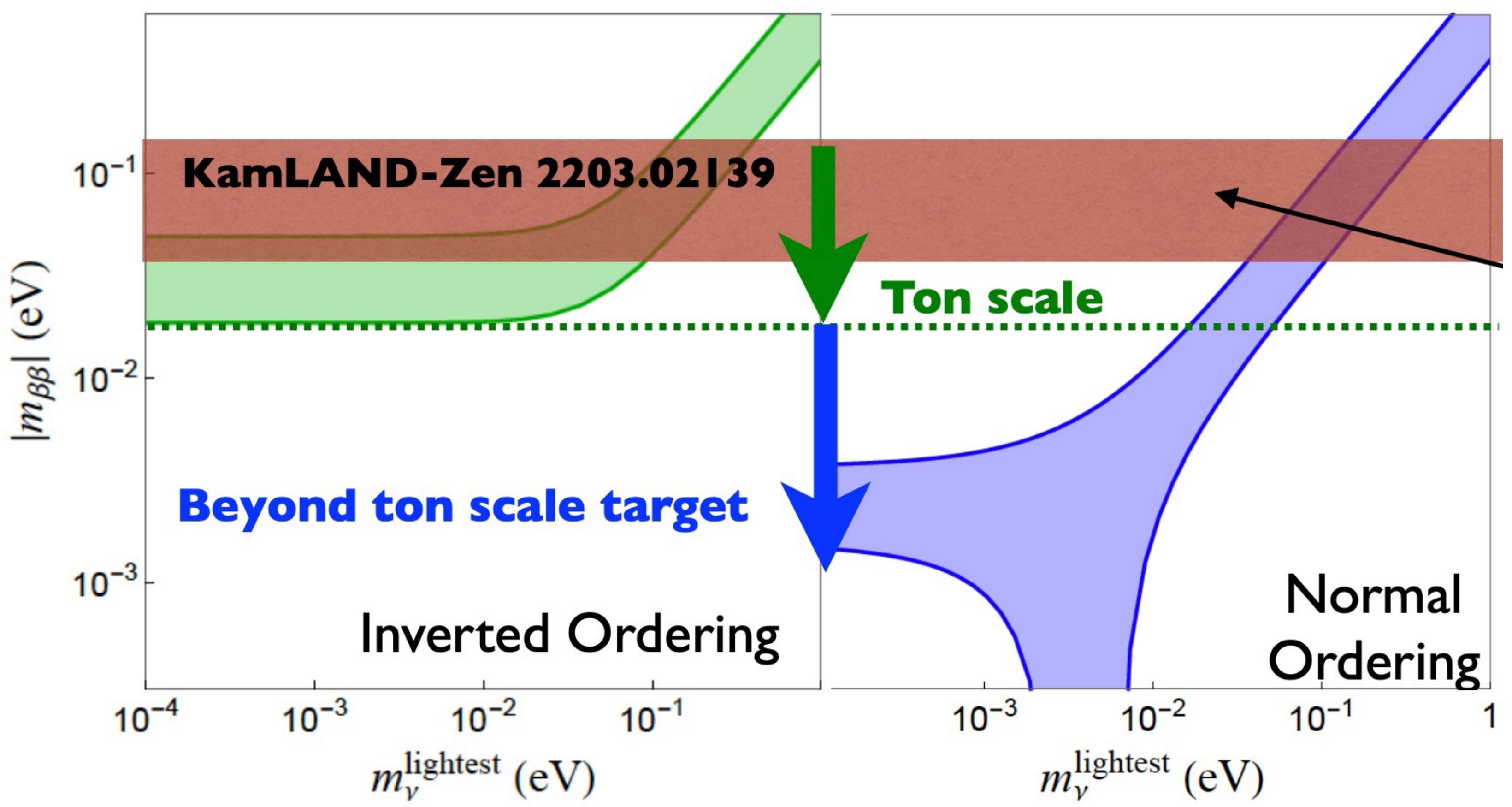
Excavation of caverns for DUNE is complete!

Neutrino Rare Processes and 0νββ Decay

Experiments studying natural sources of neutrinos and reactors require underground space and infrastructure



K. Scholberg et al, Snowmass 2022



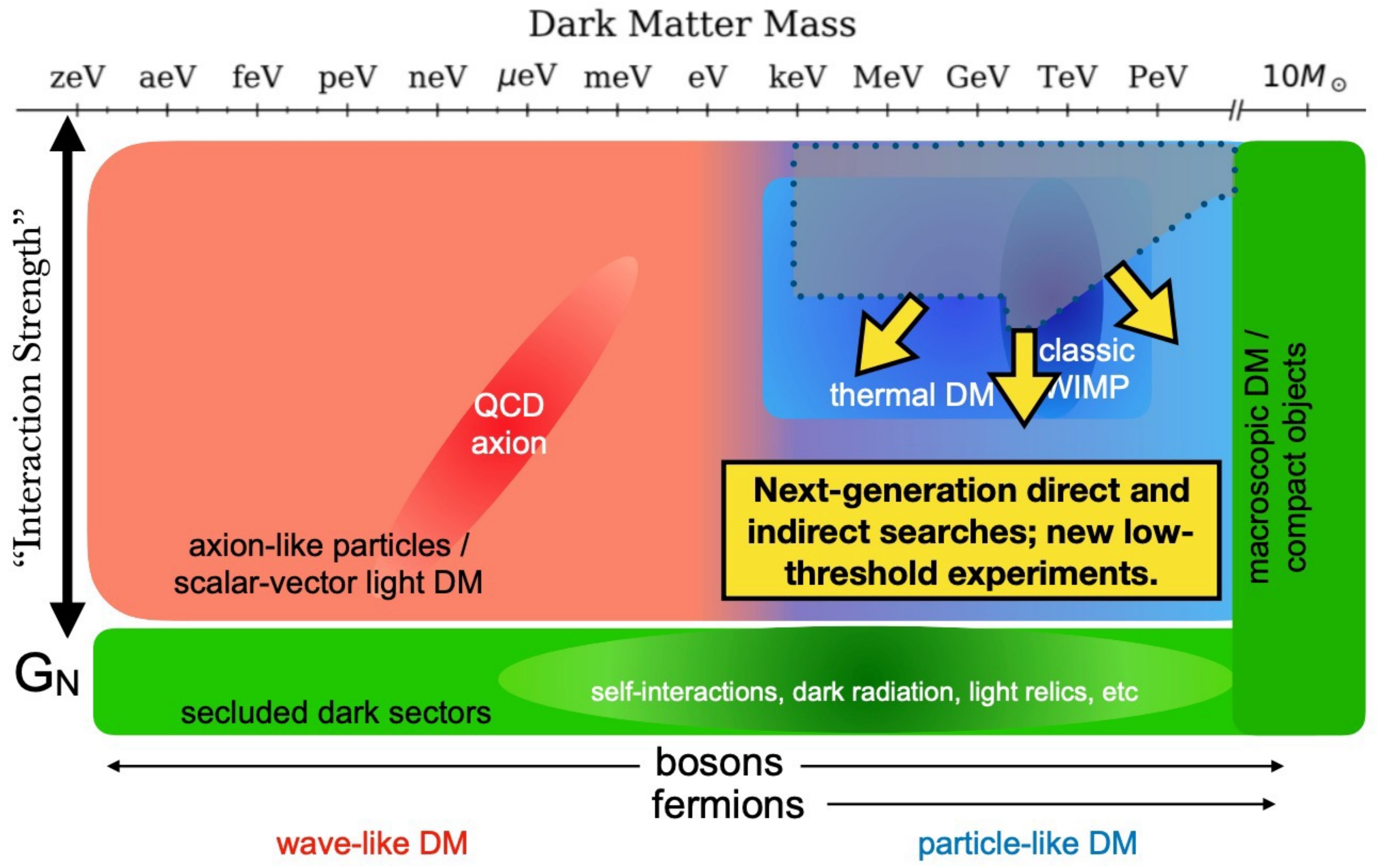
V. Cirigliano et al, Snowmass 2022

Large, deep space and infrastructure are required for next generation 0νββ decay experiments.

Depth requirements will be more stringent for beyond tonne-scale 0νββ decay experiments.

Dark Matter Searches

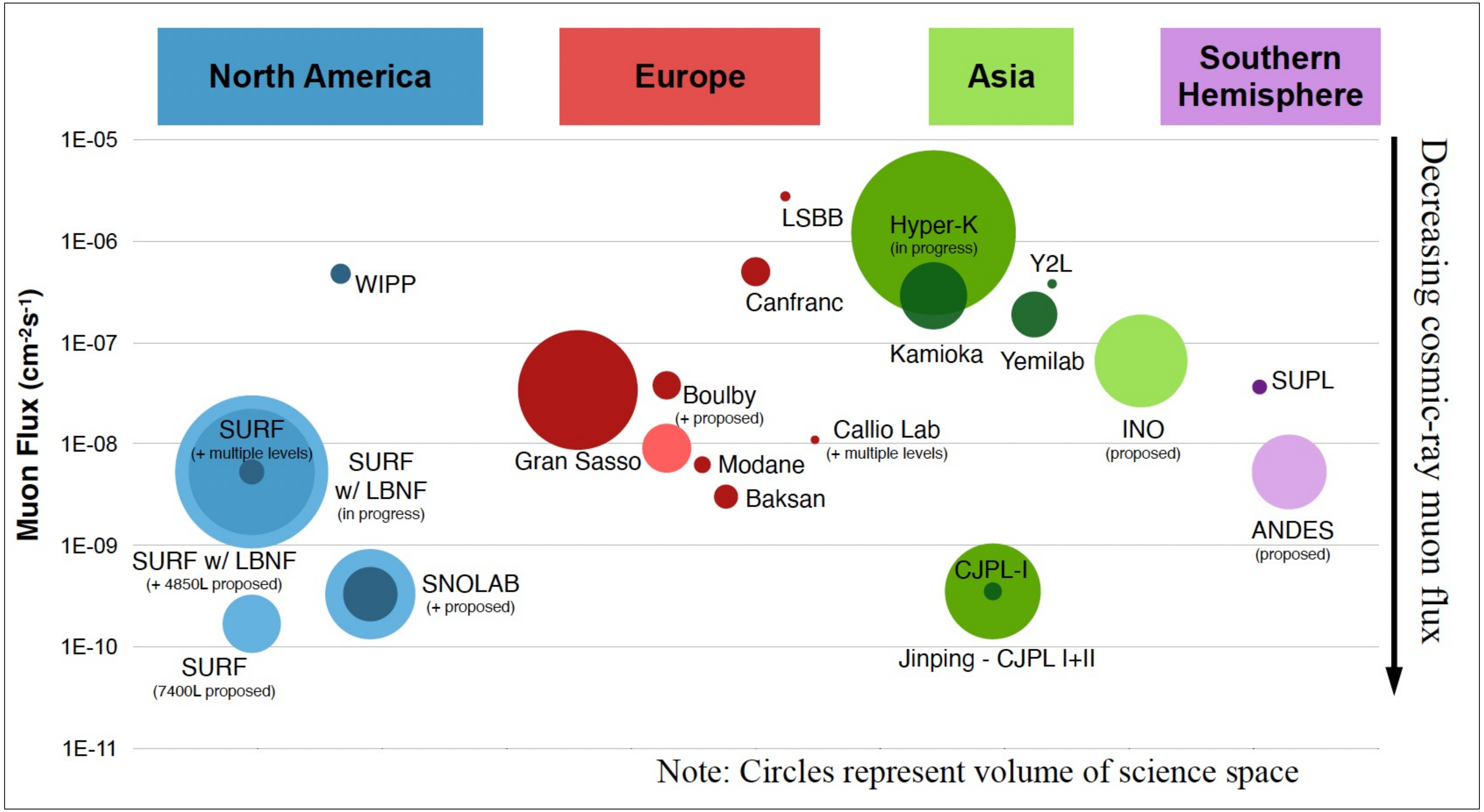
- Next generation dark matter searches at high mass will require large facilities and have even more stringent background requirements
- Next generation low threshold dark matter searches will require facilities for small to medium size projects
- R&D for next generation devices and projects will involve unique underground infrastructure



A. Chou, Snowmass 2022

Space Needs and Constraints

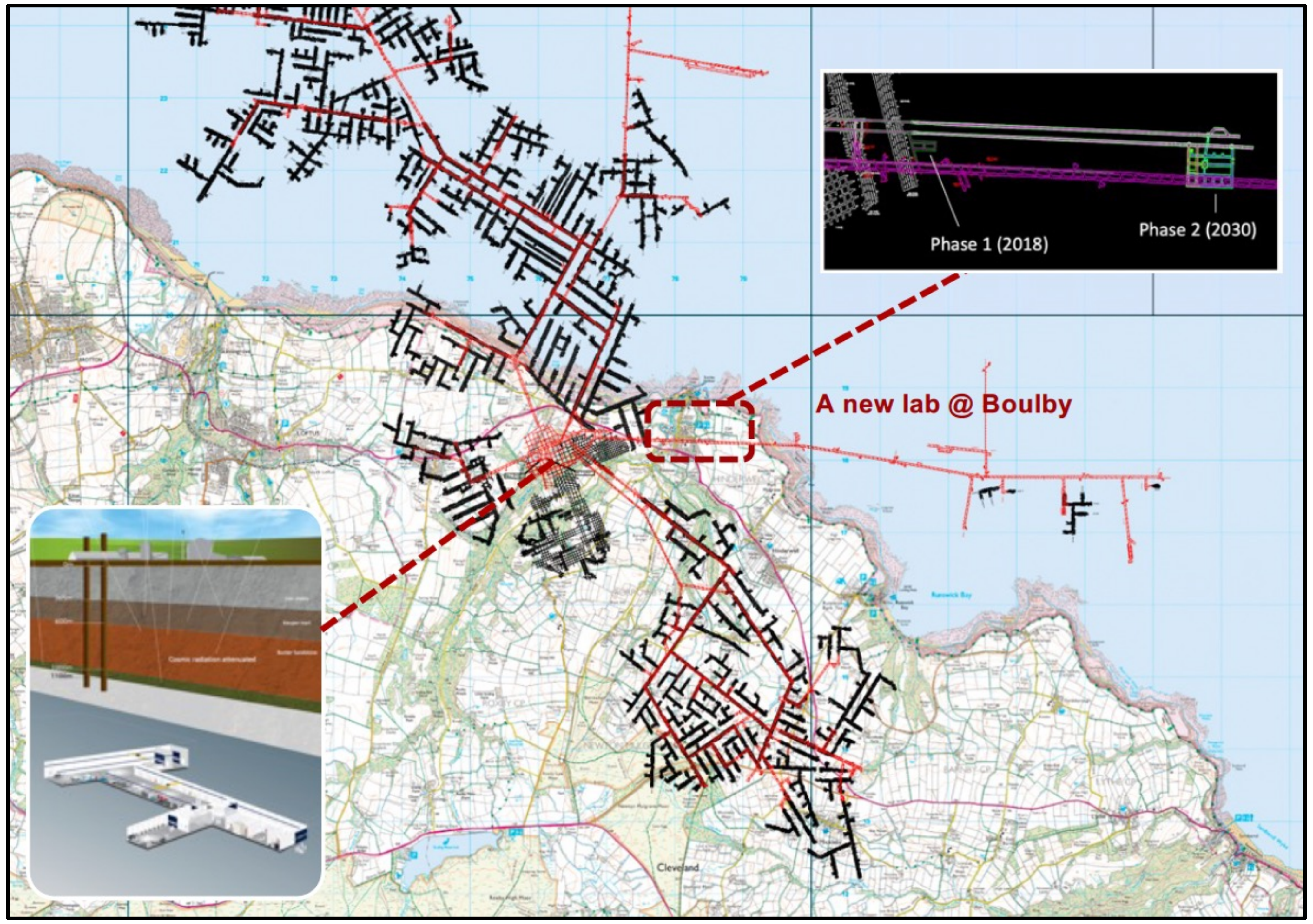
Underground Laboratory Space Inventory



Jaret Heise Snowmass CSS July 18, 2022

Demand for Large Space

- New underground space for LBNF/DUNE and HyperK exists or will exist soon.
- 3rd Generation Dark Matter (2 experiments currently proposed)
  - Boulby Laboratory in the UK working toward a major expansion of their facilities
  - SURF in the US is advocating for an expansion
  - Existing spaces at SNOLAB and LGNS may suit the needs
  - Kamioka is also a potential sites.
- Next Generation $0\nu\beta\beta$ decay experiments
  - LGNS and SNOLAB have existing space dedicated to these experiments.
- Beyond Tonne-Scale $0\nu\beta\beta$ decay experiments
  - Likely not able to accommodate with existing infrastructure
  - Depth will become a limiting factor



S. Paling, PAUL Symposium

Space for Staging, Assembling, and Storing of Materials

Need for dedicated underground low-radon cleanrooms for assembly, and staging

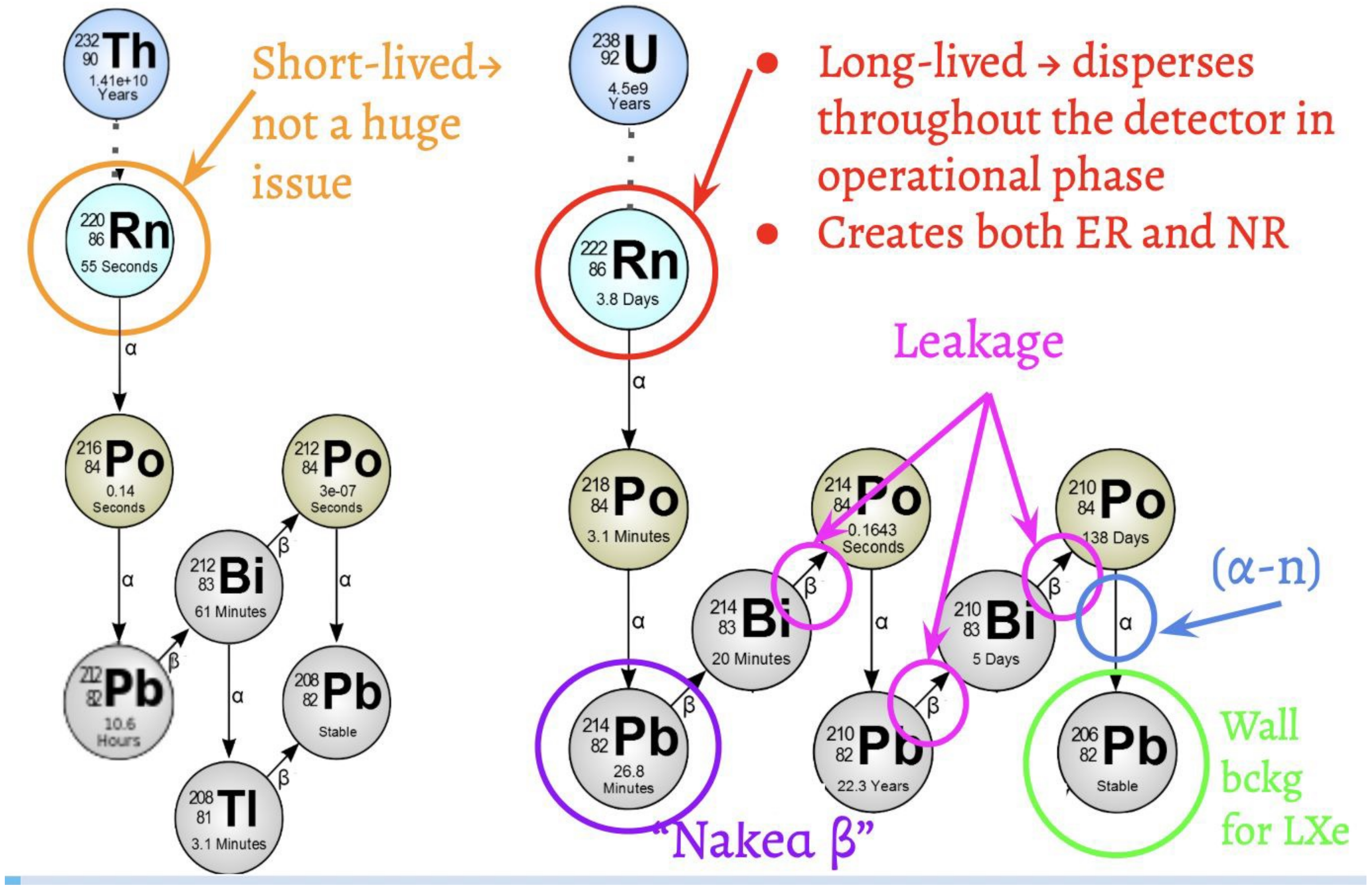
SuperCDMS towers in storage in low radon cleanroom within SNOLAB

Infrastruture at LGNS

Underground space for storing materials to avoid cosmic activation

Cranes and vertical space.

Why underground and low radon cleanrooms?



A. Kamaha et al, Snowmass 2022

Dust contains urianum and thorium whose daughter particles are backgrounds for rare event searches.

- Radon emanation from dust
- Radon plate-out onto surfaces and subsequent decays.

Why care about cosmic activation of materials?

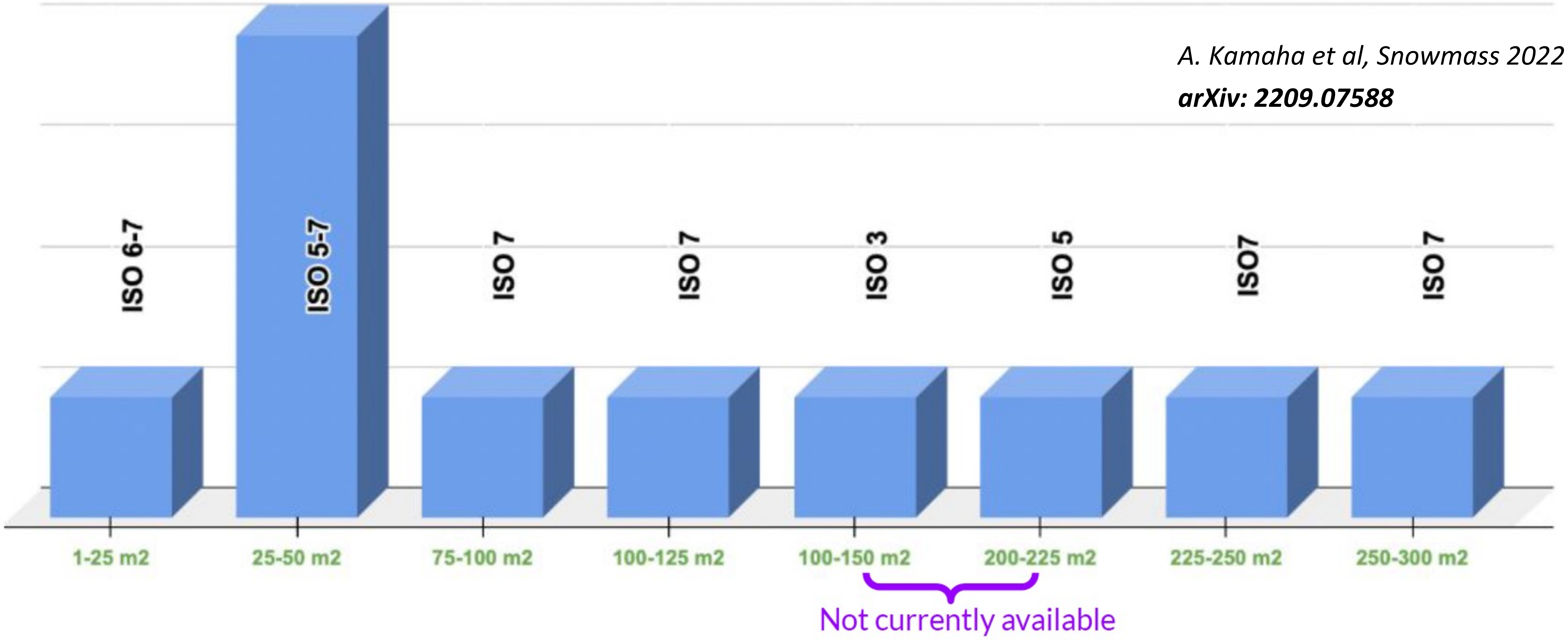
- Activation of a detector or materials close to the detector (i.e. shield) during production or transportation at Earth's surface can also produce backgrounds as isotopes de-excite.
- Production is dominated by neutron (n,x) reactions (~95%)
- Examples: ^{3}H is a major interest in Si detectors. ^{39}Ar is a concern for argon targets.

Depth (m) in rock	Target material	Product Isotope	Production rate (/kg/day)
0 (at sea-level)	Si	Tritium	112 ± 24 (Richard et al. 2020) 125 (Prof. A. Robinson, U. of Montreal)
5	Si	Tritium	9.5×10^{-2}
7	Si	Tritium	7.8×10^{-2}
12	Si	Tritium	5.4×10^{-2}
20	Si	Tritium	2.6×10^{-2}
30	Si	Tritium	1.7×10^{-2}

Depth (m) in rock	Target material	Product Isotope	Production rate (/kg/day)
0	Ar	^{39}Ar	759 ± 128 (Richard et al. [8], 625 (our calculation with TALYS, neutron only)
5	Ar	^{39}Ar	0.93
7	Ar	^{39}Ar	0.70
12	Ar	^{39}Ar	0.45
20	Ar	^{39}Ar	0.25
30	Ar	^{39}Ar	0.10

Sagar Sharma Poudel, APS 2024

What are the cleanliness requirements for future experiments?

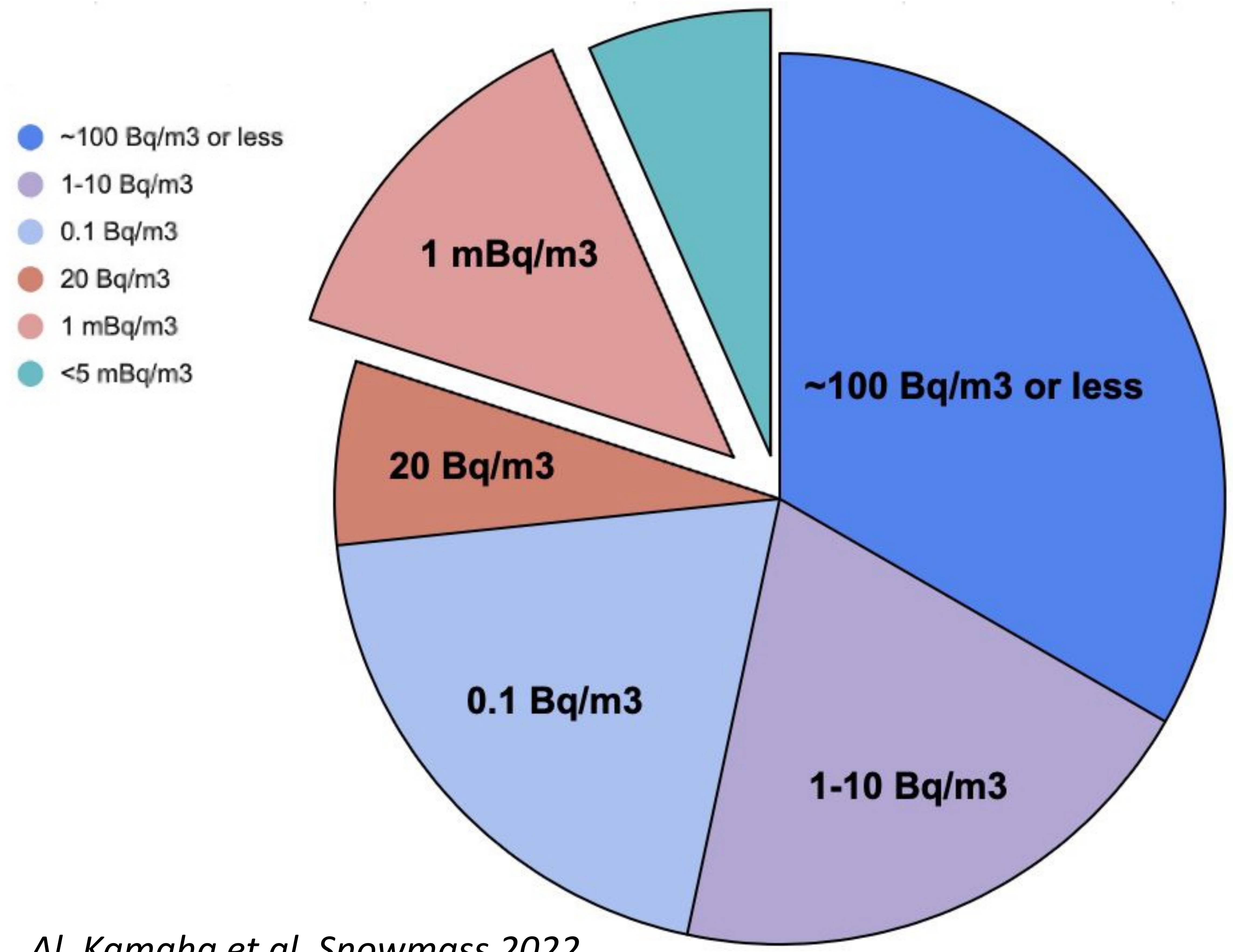


A. Kamaha et al, Snowmass 2022

arXiv: 2209.07588

Large sized cleanrooms (100 – 300 m^2) needed by G3 dark matter exist at LGNS, SNOLAB, SURF – but do not meet ISO constraint.

What is the future demand for reduced radon air?



Al. Kamaha et al, Snowmass 2022

arXiv: 2209.07588

Laboratory	Depth (mwe)	CR Area (m^2)	CR ISO Class	Rn Concentration (mBq/m^3)
Canfranc, Spain [11]	2400	70	ISO 5-6	<5
Gran Sasso, Italy	3100	13	ISO 7	10
Gran Sasso, Italy	3100	86	ISO 6	50
Gran Sasso, Italy	3100	32	ISO 6	50
Gran Sasso, Italy	0	325	ISO 6	(in progress)
Gran Sasso, Italy	0	62	ISO 6	(in progress)
Modane, France	4800	16		(planned)
SNOLAB, Canada	6000		ISO 6	(in progress)
SURF, SD, U.S.	4300	45	ISO 7	100
SURF, SD, U.S.	0	55	ISO 5-6	500
Y2L	1750	46	ISO 7	1000
Yemilab (planned)	2500	23	ISO 5	planned
Yemilab (planned)	2500	80	ISO 7	planned

Large underground CR (footprint >100 m2) with lower Rn level (~1mBq/m3) does not currently exist.

Supporting Infrastructure

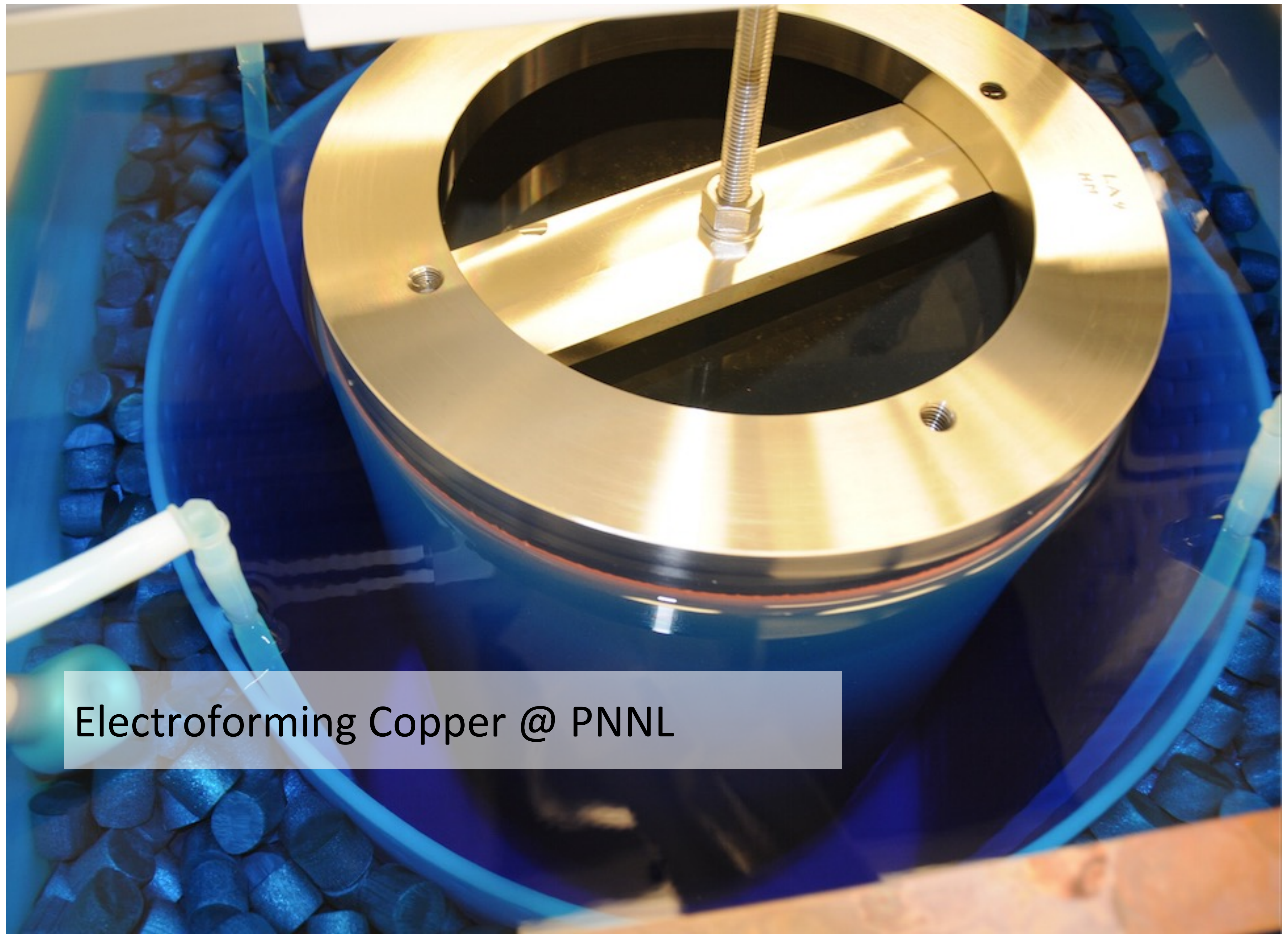
Asssay Capabilities

- Assays serve two purposes: (i) inform material selection and (ii) validate cleaning processes.
- **HPGe** : >68 HPGe detectors serving underground experiments worldwide which can meet demand. Sensitivity ~10 µBq/kg is not adequate for next generation experiments.
- **ICP-MS**: Most underground labs have ICP-MS capabilities. Current best limit for ICP-MS for underground science is ~100 nBq/kg.
- **Alpha Screening**: Improved sensitivity (beyond XIA Ultra-Lo 1800) would be beneficial. Current best underground sensitivity for XIA Ultra-low 1800 is ~1 mBq/m^2. Future experiments require down to .001 mBq/m^2.
- **Radon Emanation**: Improvements in sensitivity (current standard 0.2 mBq) and/or ability to emanate large volumes of materials would be beneficial to future experiments

Snowmass 2022
arXiv:2203.07623

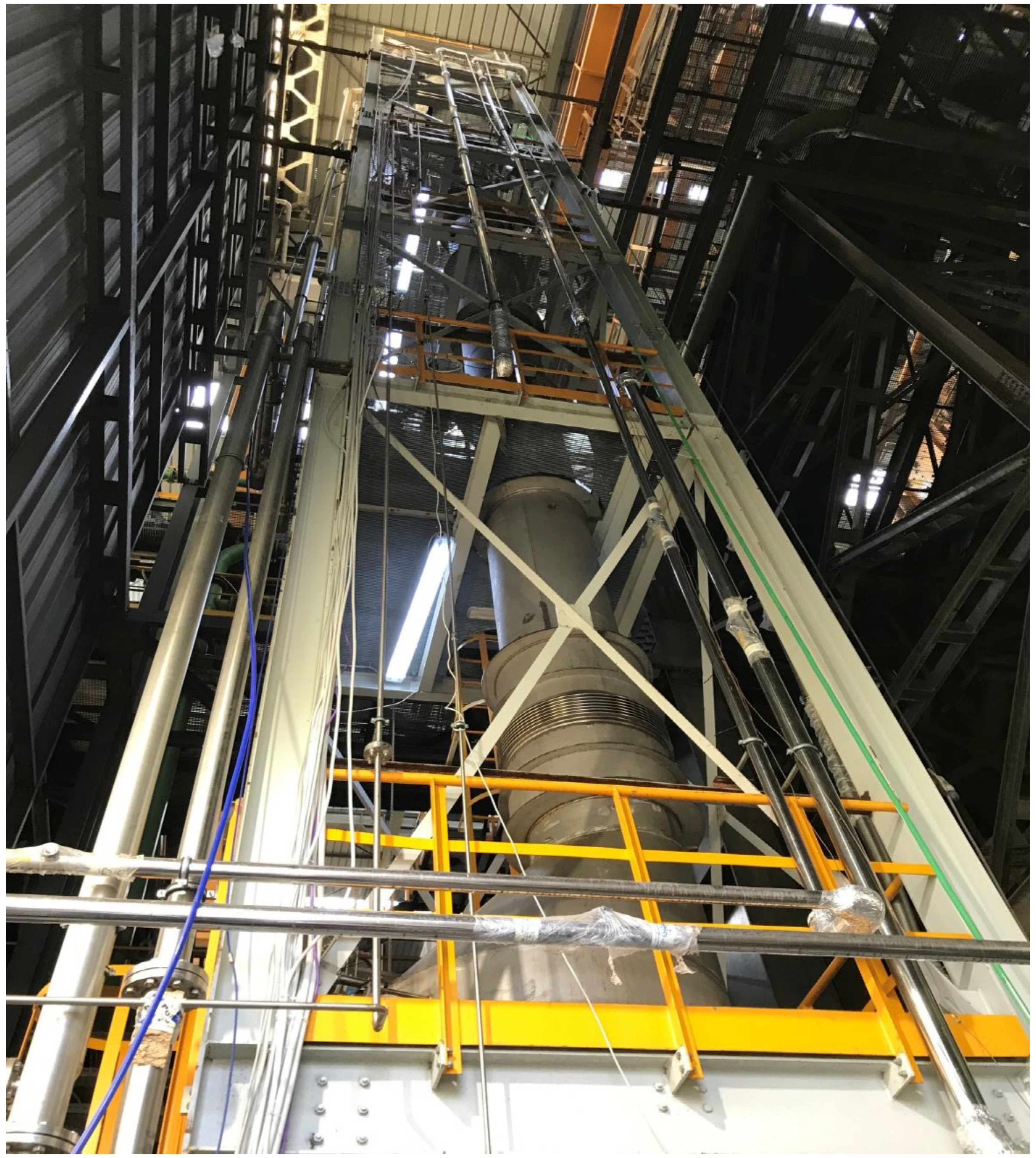
Material Needs

- Underground material production:
  - Electroforming and electroplating of copper - increased demands
  - Crystal growth
- Underground machining facilities currently exists at LGNS, SNOLAB, SURF, but need for such facilities is growing.
- Commercially available polymers with appropriate radiopurity and structural properties.
- 3D printing of radiopure materials/components in a cleanroom environment



Underground Plants, Purification Facilities

- UG material purification facilities including
  - Water purification and Rn removal from water
  - Scintillator purification and degassing
  - Isotopic purification (^{85}Kr and ^{37}Ar)
- Underground production of liquid nitrogen, liquid helium, and liquid argon
- Extraction, purification and storage of underground argon
- The facilities exist in some underground labs, but there will be increased demand.



Seruci-0 cryogenic distillation column

Cryogenic Systems

- Increase demand for general use cryogenic detector test platforms aimed at R&D and testing of dark matter detector prototypes and QIS.
  - CUTE facility at SNOLAB, CRYO-P and ACryL under development at LGNS
- These facilities requires staff with expertise to operate.
- Require seismic isolation, isolation from electronic and magnetic fields.

CUTE Fridge @ SNOLAB

Other Considerations

- Handling of neutron-veto scintillators
  - Not all the underground labs are allowing usage of liquid scintillator,
  - Alternatives include Gd-doped water and liquid argon vetos
- Robust utilities such as electrical power, cooling power, etc.
- Underground cleanroom machine shops
- Robust onsite computing and network infrastructure
- Lab accessibility for all scientists

Underground Cleanroom Machine Shop in SNOLAB

Conclusions

- The experimental demand for large caverns, staging areas, and clean underground areas for material storge is increasing. The community is responding with plans and proposals for underground laboratory expansions.
- Future experiments would need an expansion of cleanroom space with higher ISO standards and more radon reduced areas that currently exist. This could be reduced radon cleanrooms within clean labs, glove boxes, etc.
- Most of the assay requirements of future experiments could be addressed by existing infrastructure.   This will require cooperation between facilities and experiments world-wide to exploit existing material assay instrumentation. *However*, development of improved assay sensitivity for bulk and surface radioactivity, especially radon emanation and more sensitive surface-screening methods for radon-daughter plate-out will be required.
- Attention must be paid to supporting infrastructure, such as utilities, plants, computing, machine shops, and general-purpose cryogenic test facilities.
- ***Addressing these challenges will require international coordination of underground laboratory resources***.