2024/05/27

SNOLAB – Overview and New Initiatives

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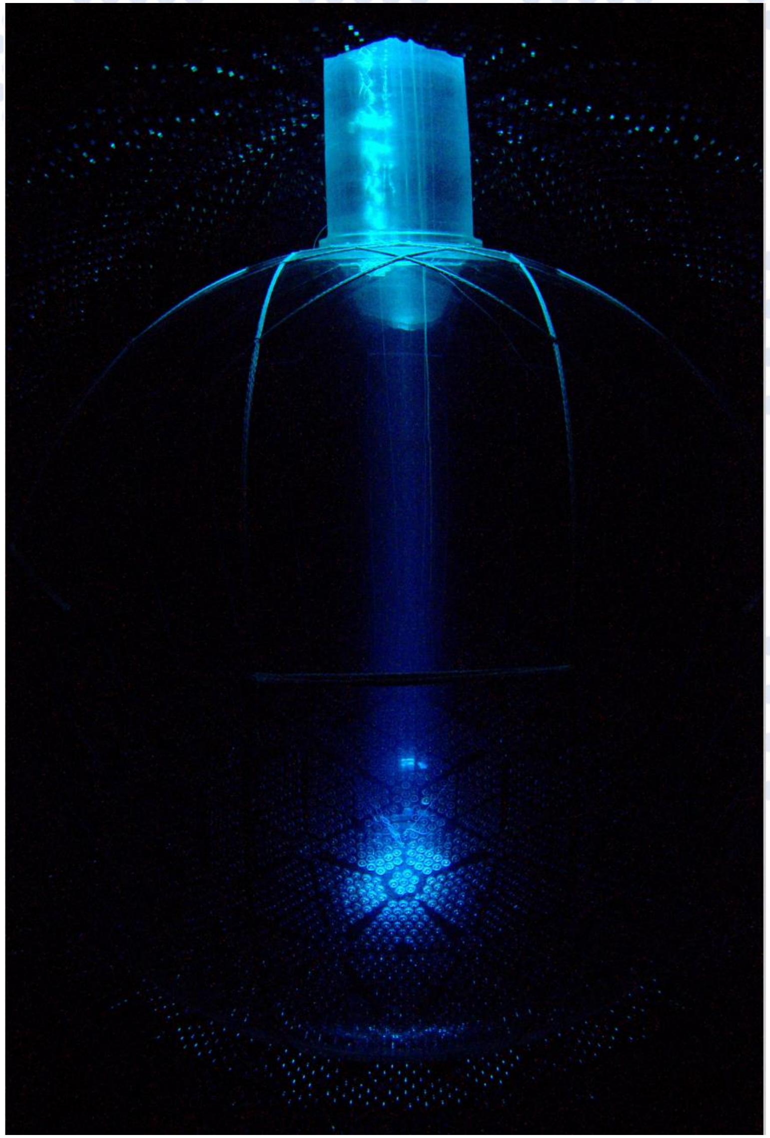


2024 CAP Congress, Western University

LaurentianUniversity UniversitéLaurentienne

SNOLAB

LAND ACKNOWLEDGEMENT

SNOLAB is located on the traditional territory of the Robinson-Huron Treaty of 1850, shared by the Indigenous people of the surrounding Atikmekshen Anishnawbek First Nation as part of the larger Anishinabek Nation. We acknowledge those who came before us and honour those who are the caretakers of this land and the waters.

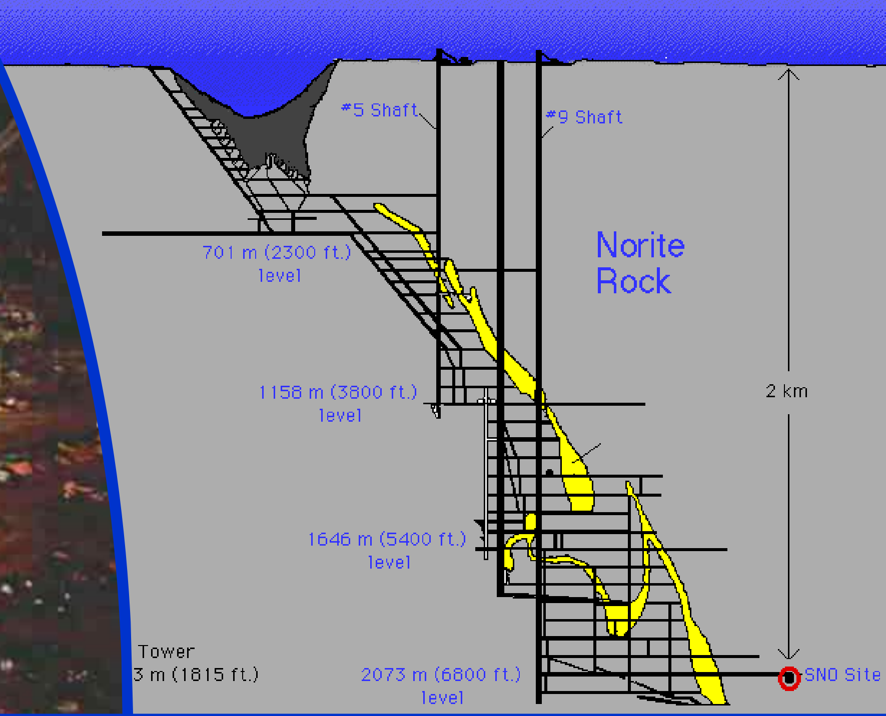
SNOLAB

SNOLAB is operated jointly by University of Alberta, Carleton University, Laurentian University, Université de Montréal, and Queen's University.

SNOLAB hosts **rare event searches** and measurements. Science is focused around **Neutrinos and Dark Matter**.
It's located 2 km underground in the active **Vale Creighton nickel mine near Sudbury**, Ontario, Canada.

SNOLAB operations are funded by the Province of Ontario, and the Canada Foundation for Innovation.

SNOLAB at Creighton Mine, Sudbury, ON, Canada



SNOLAB - underground

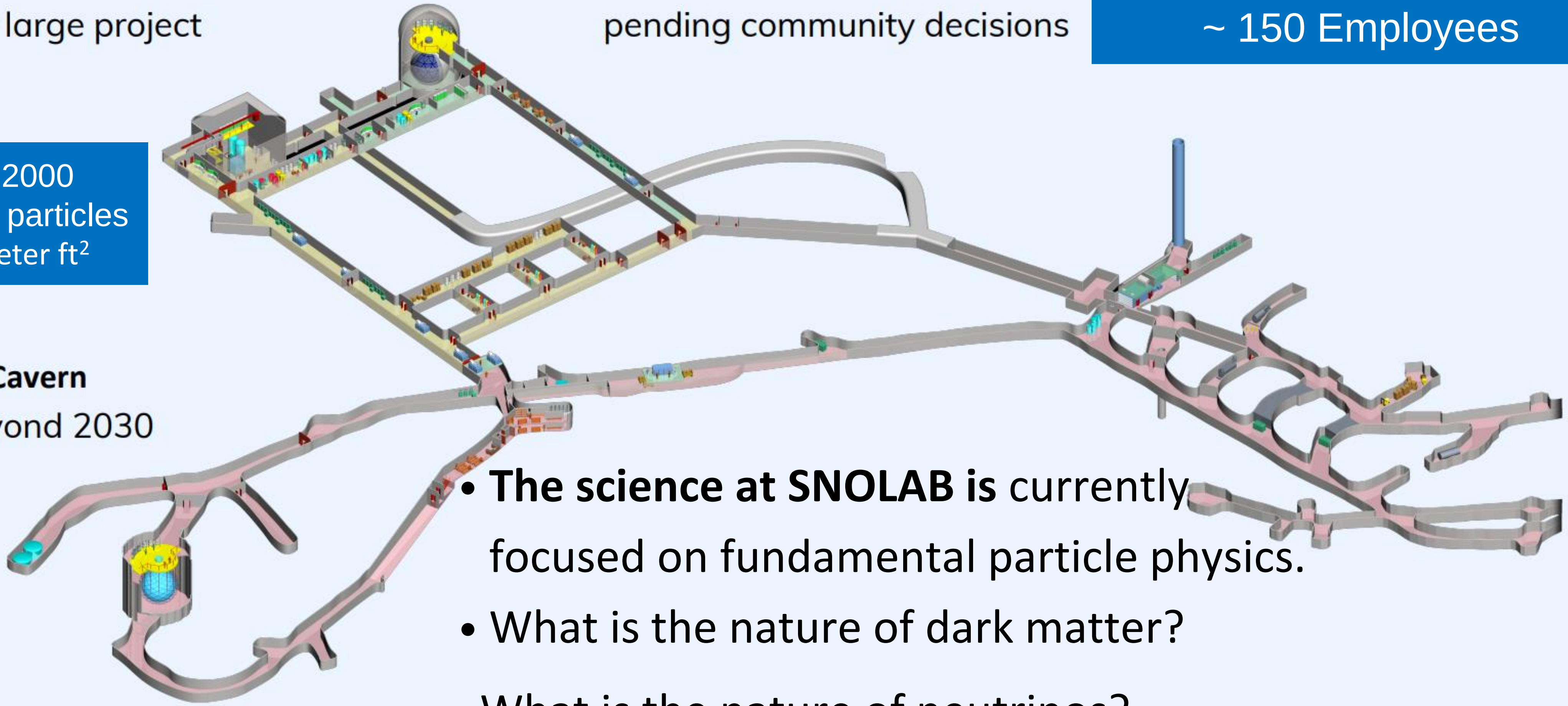
Over 1000 users worldwide
11 active experiments
128 Institutions
23 Countries
~ 150 Employees

Cube Hall
DEAP-3600, PICO500, NEWS-G
potential for large project

Cryopit
Ton-scale 0vbb beyond 2030
pending community decisions

5000 m^2 class 2000 cleanroom (<2000 particles >0.5 μm in diameter ft^2

SNO Cavern
SNO+ beyond 2030



- **The science at SNOLAB is** currently focused on fundamental particle physics.
- What is the nature of dark matter?
- What is the nature of neutrinos?

What makes SNOLAB unique

- Invite all scientists that can use the unique capabilities of SNOLAB

- Depth → low muon flux
- Cleanliness → clean technologies
- Working Mine → partnership
- Low Backgrounds → key

1. Strong team – support for users
2. “Nothing works until it works underground”
3. Pushing boundaries – new technologies

1

Excellent science

Drive breakthrough discoveries at the frontiers of underground science.

Expected outcomes:

- Cementing of Canada's leadership in deep underground science
- A stronger, more competitive Canada in scientific discovery
- More Canadian researchers positioned as global leaders

2

Cutting-edge infrastructure

Continuously improve our research infrastructure to remain state of the art.

Expected outcomes:

- Attraction of the most advanced international experiments to Canada
- Greater global impact and enhanced reputation of Canada's underground science infrastructure

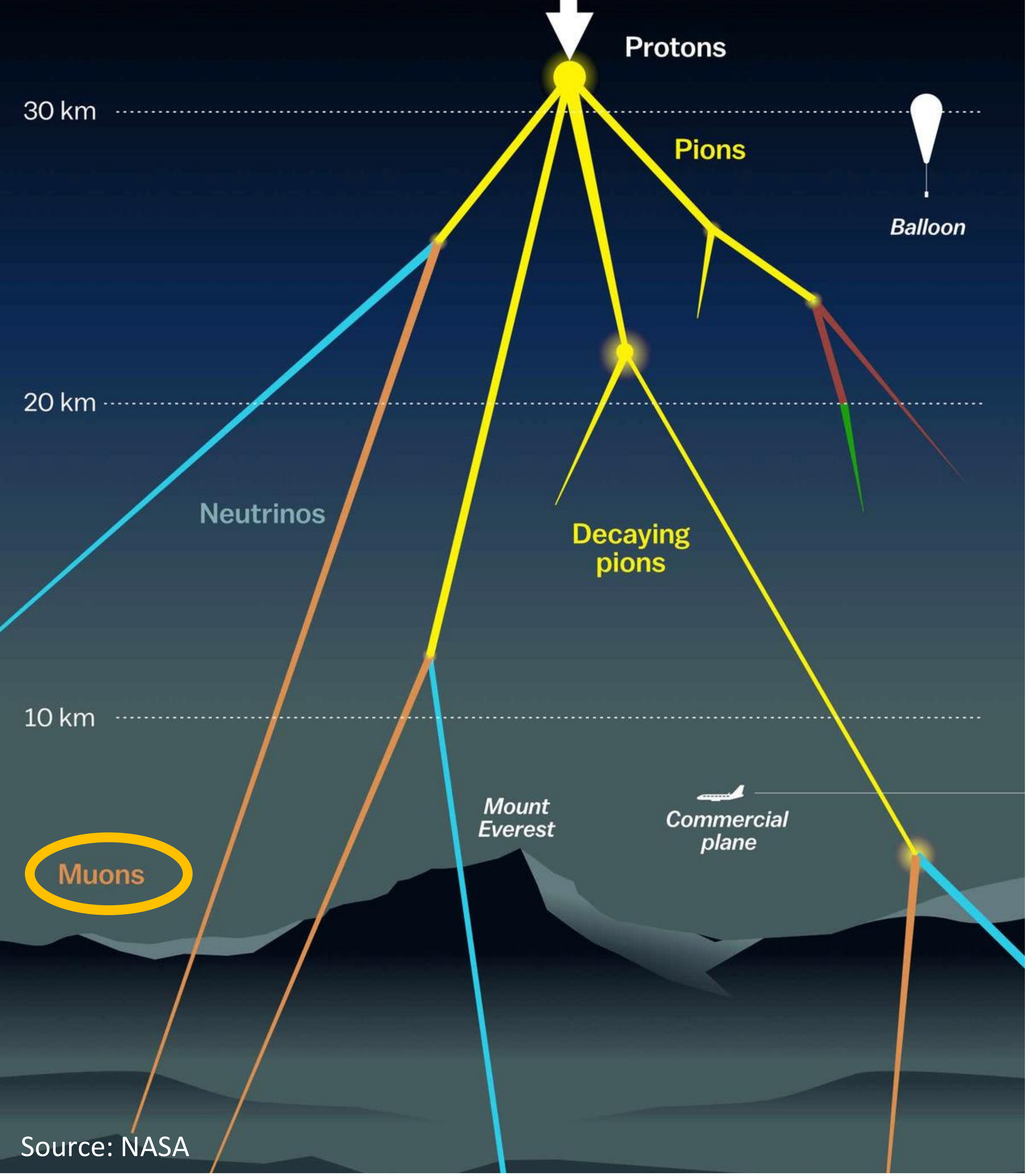
3

Skilled people

Foster and develop diverse talent in an inclusive environment.

Expected outcomes:

- Canadian leadership in advancing EDI in research facilities
- A new generation of HQPs prepared to discover and innovate in a global economy
- Greater access to STEM skills and opportunities in Northern Ontario



Source: NASA

The more shielding, the lower the activity from cosmic radiation that could mimic the signals in these rare event type experiments

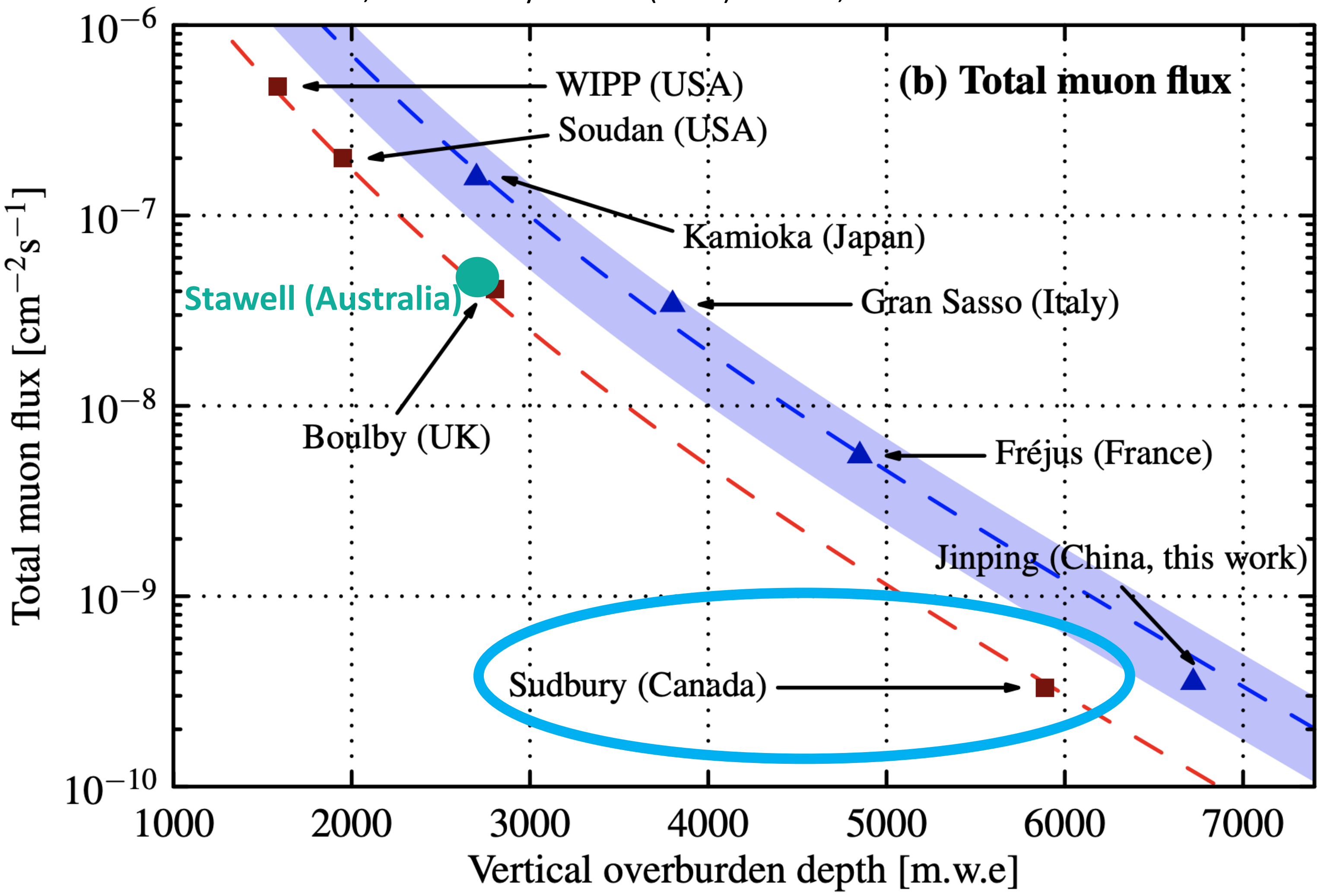
Acrylic vessel volume – muon rate reduced to 3 per hour compared to many thousands on surface

Underground Laboratory Shielding

- Typical deep labs reduce the muon flux by 10^5 - 10^8

3/h in SNO+

Guo et al., Chinese Physics **C45** (2021) 025001, arXiv:2007.15925v2



Low background – what does it really mean …

Many pieces are needed to complete a puzzle …

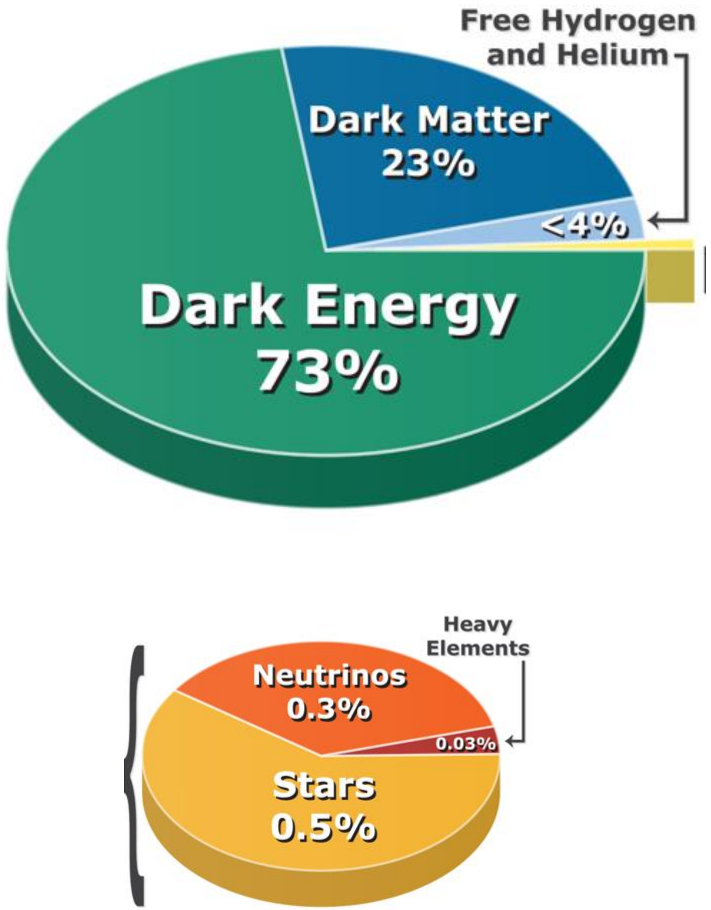
- Ultra-high precision cleaning – acrylic vessel fingerprints
- Milligrams – small amounts of dust
- Radon (higher UG) – often needs to be reduced – it's in the air
- Storing materials "long" before use for cooldown, can reduce radioactivity by orders of magnitude
- Measuring these small numbers is hard – assays
- Making things UG - electroforming copper

Dark Matter – what is the Universe made of?

We know from indirect evidence that dark matter exists – but need to understand the nature of it – is it a particle, which one?

- How matter moves in galaxies (flat rotational curves)
- Distribution of hot gas in clusters of galaxies (larger potential well)
- Weak gravitational lensing
- Fluctuations in CMB (baby picture of the universe)

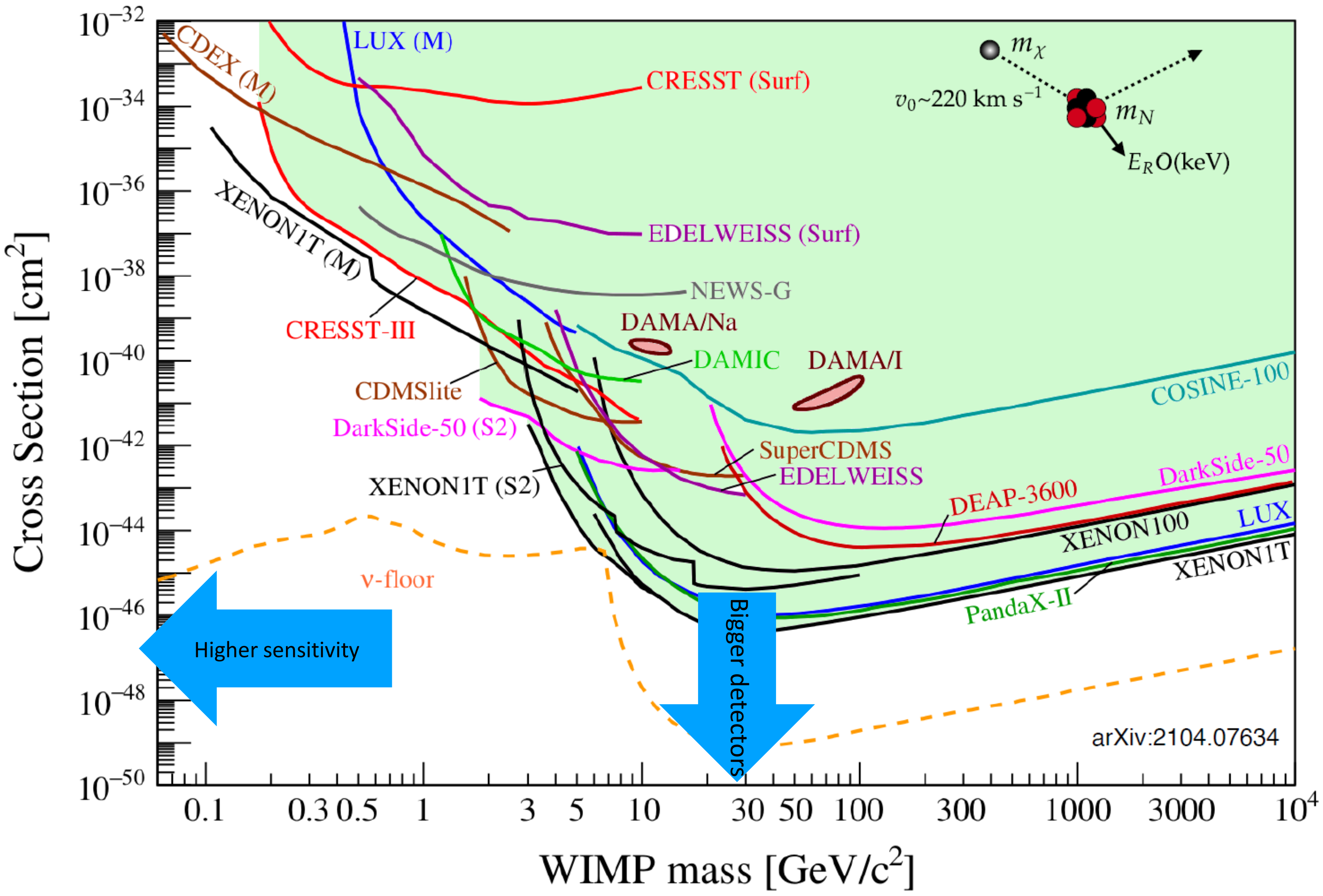
1. Focus at SNOLAB on WIMPs – direct detection
2. Complementary to other (indirect) searches (accelerators)
3. Moving to lower energy WIMPs



What is the nature of Dark Matter?
Direct detection – available results over neutrino fog

We know from indirect evidence that dark matter exists – but need to understand the nature of it – is it a particle, which one?

Reasonably large target, very clean

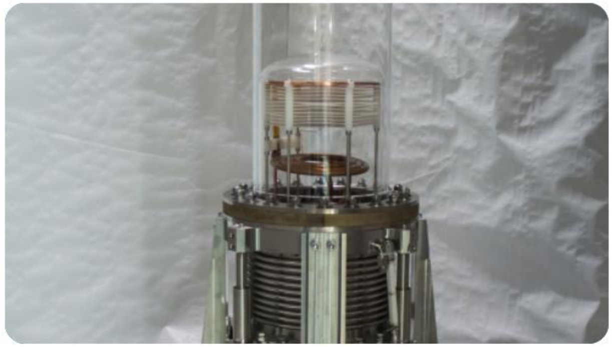


Complementary to other (indirect) searches (accelerators)

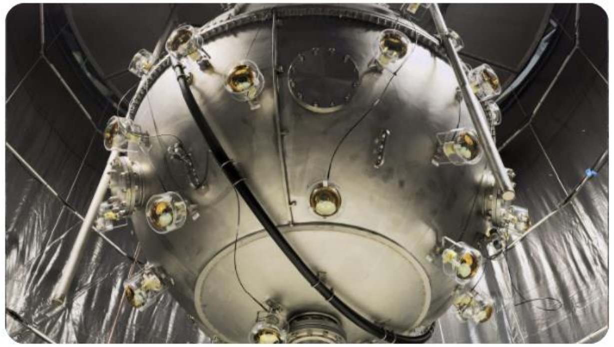
Planned larger detectors are pushing down to the neutrino fog

Looking for dark matter at SNOLAB

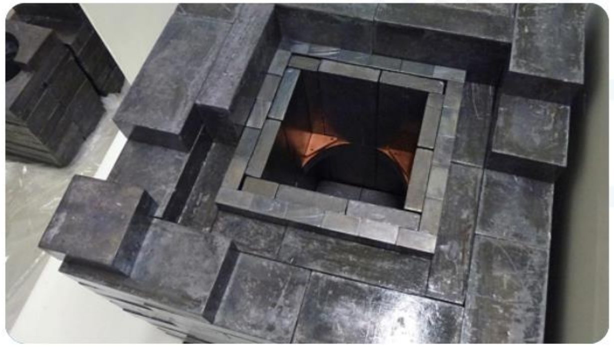
It is matter – so it should cause a signal when it "bumps" into a target – multiple approaches



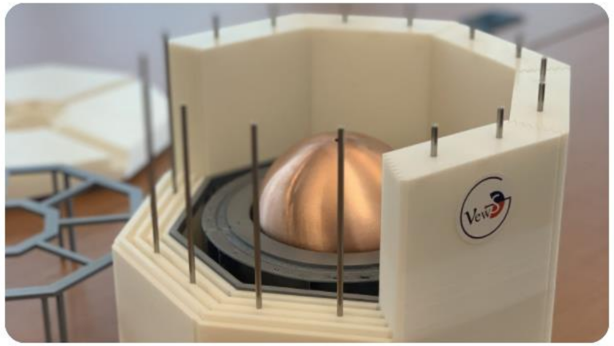
PICO



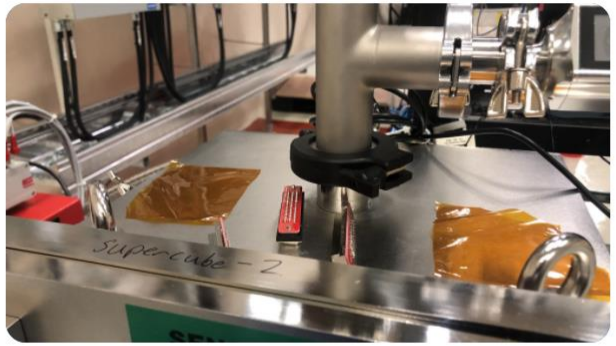
DEAP-3600



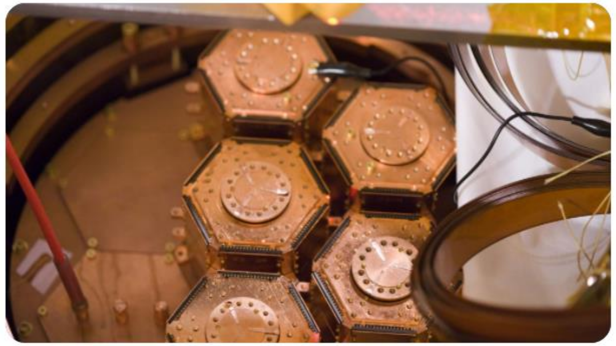
DAMIC



NEWS-G



SENSEI



SuperCDMS

Listed as Flagship experiments Canadian subatomic Physics LRP

Future: large volume Experiment with Major result at SNOLAB

Depleted Ar, R&D for Darkside/Argus

Student talks NEWS-G

CUTE – Cryogenic Underground TEst facility

Science opportunities (quantum computing) and good student projects

Features:

Operational temperature down to 12 mK

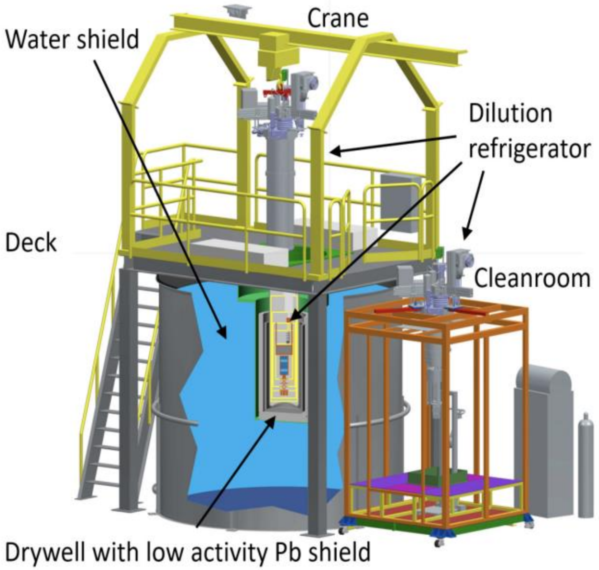
Low radioactive background

Minimal mechanical vibrations, electromagnetic interference

Low-radon cleanroom space (class 300) to change payload (Rn level <15 mBq/m^3)

Calibration sources

Full remote operations



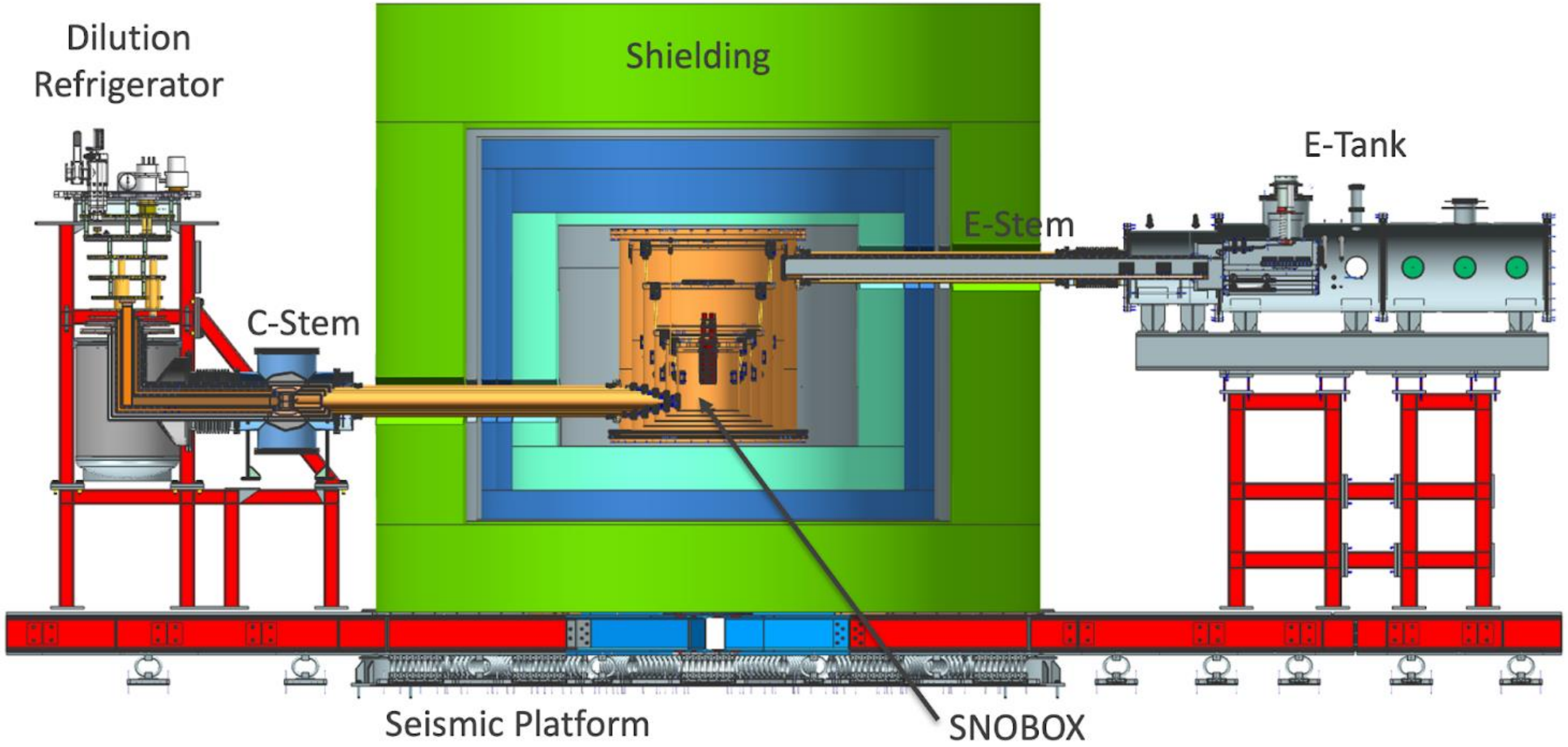
Available for projects, it is a SNOLAB facility

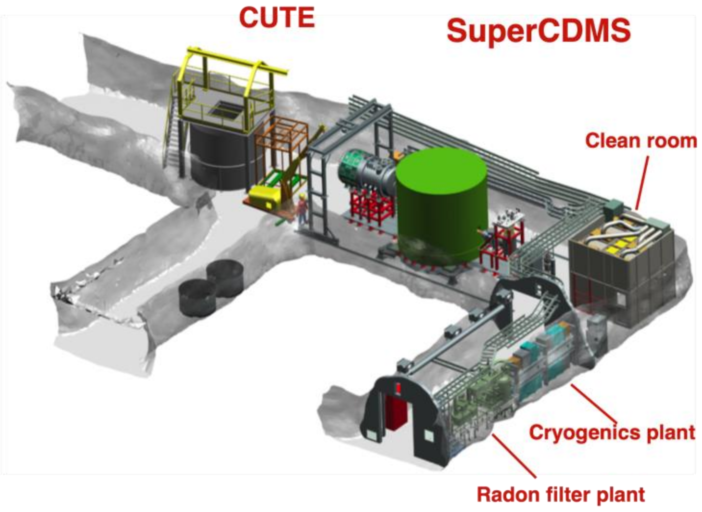
- HVeV devices <- **Happening Now!**
- Single photon IR sensors (Nanowire)
- **Testing effect of backgrounds on superconducting qubits**

Talk by Dr. Matt Strukel

SuperCDMS:

Super **C**ryogenic **D**ark **M**atter **S**earch





- **Currently in Installation and Integration Phase**
- **Testing towers accumulated several month of data**
- **Expected to be ready for first data taking Summer 2025**

Noble liquid detector – DEAP 3600

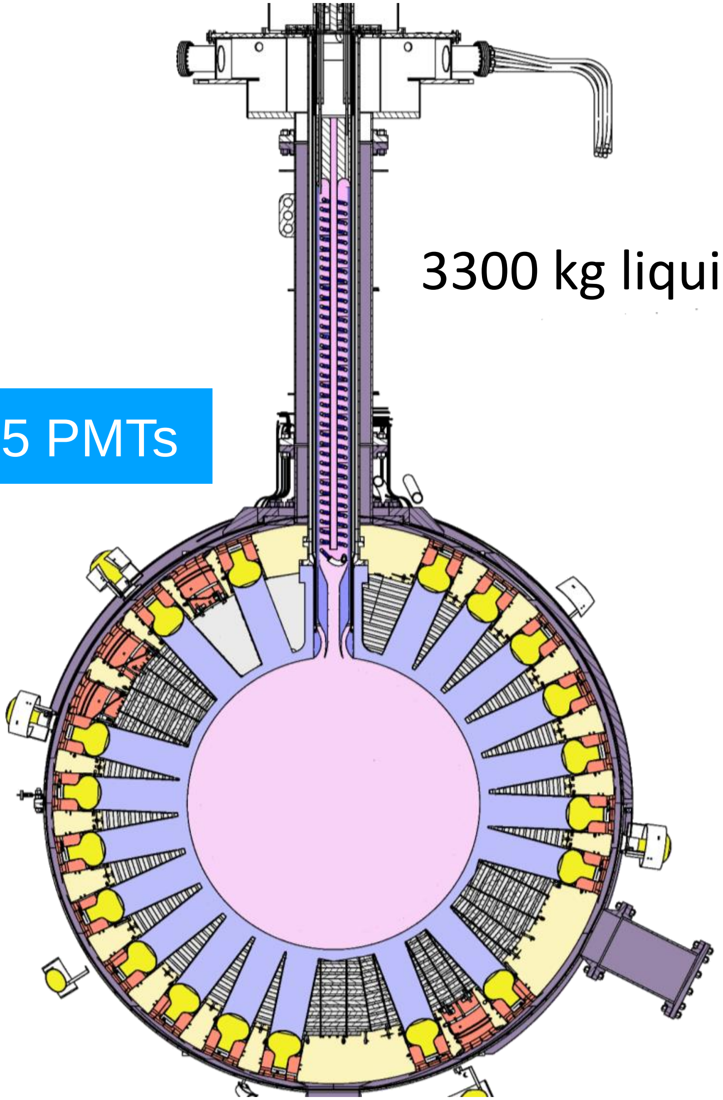
Talk by Dr. Chris Jillings (DEAP, Darkside 20k, Argo)

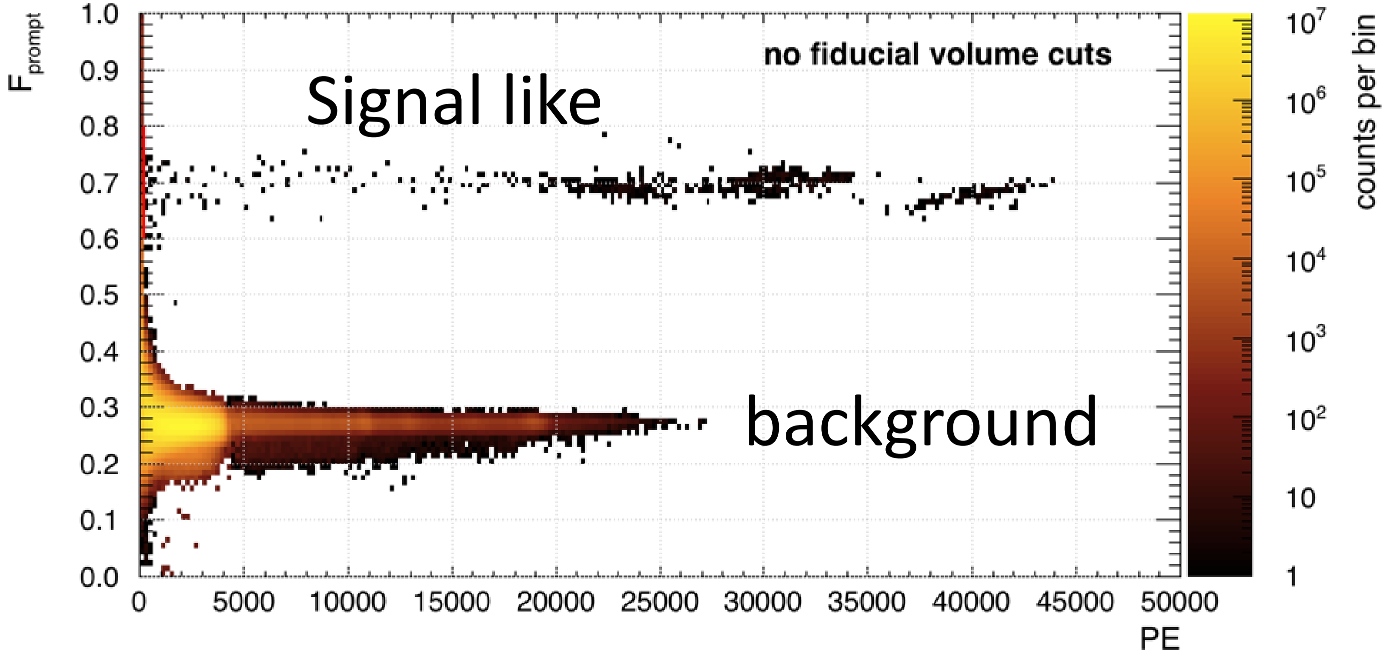
Detect scintillation light (128 -> 420 nm with TPB layer)

3300 kg liquid argon

Pulse shape discrimination (nucleon interactions ns, electron interactions ms)

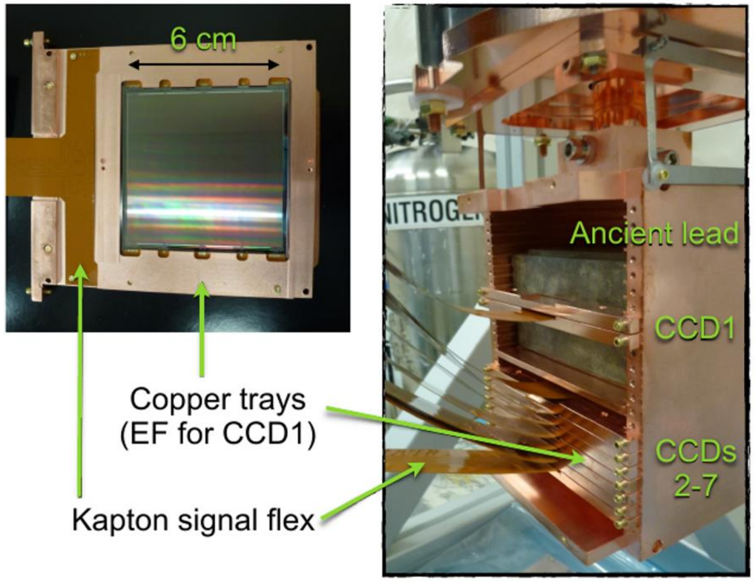
255 PMTs



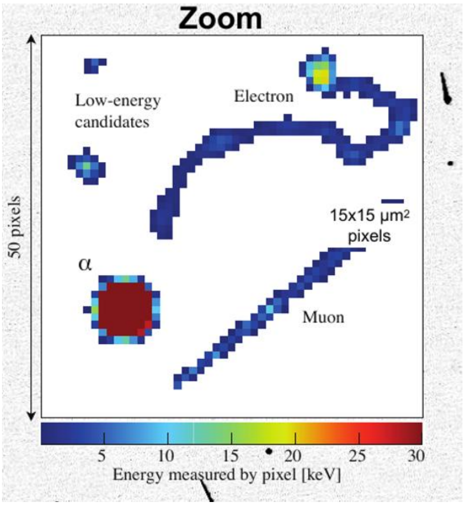


DAMIC and SENSEI (OSCURA)

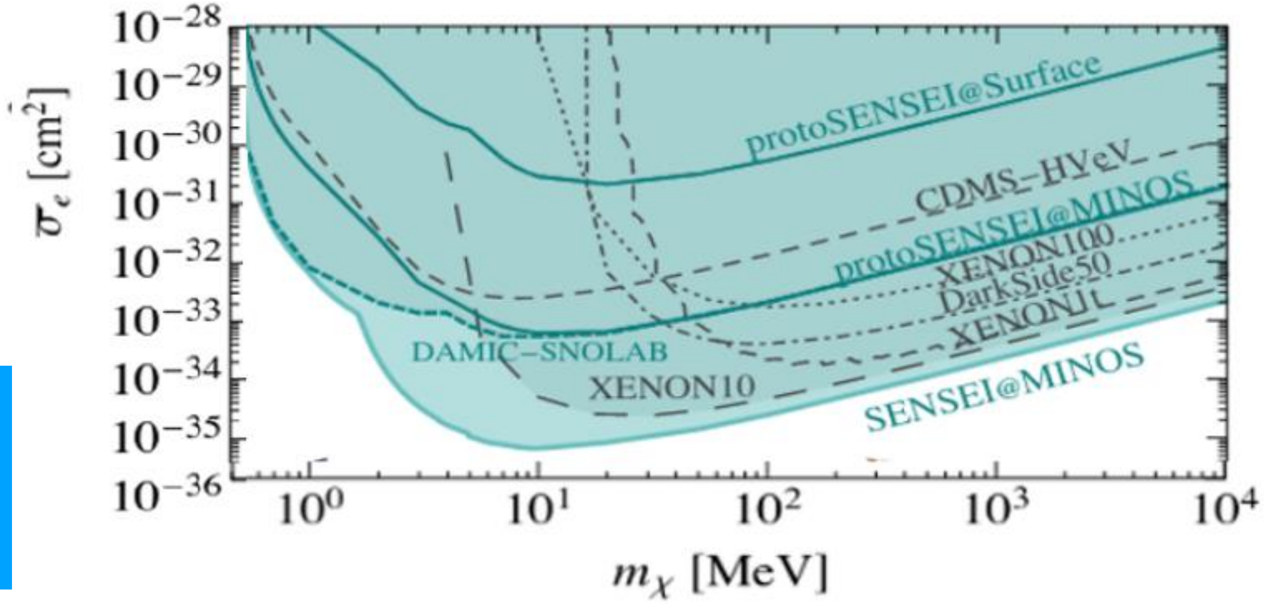
CCD – Charge Couples Devices



New skipper CCDs – significantly reduced readout noise → lower threshold



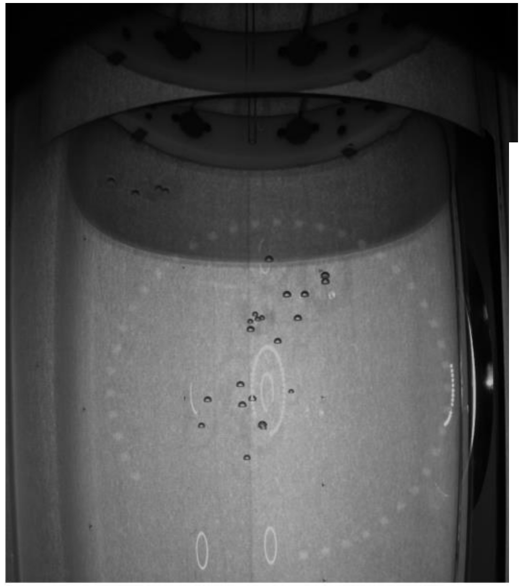
Small detector – world leading results

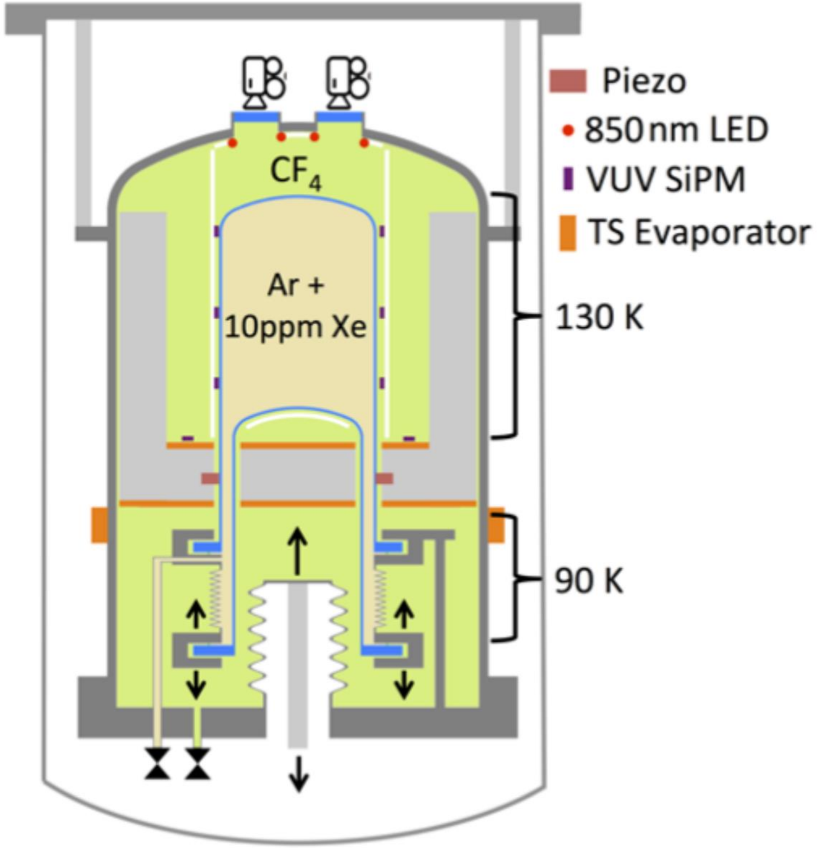


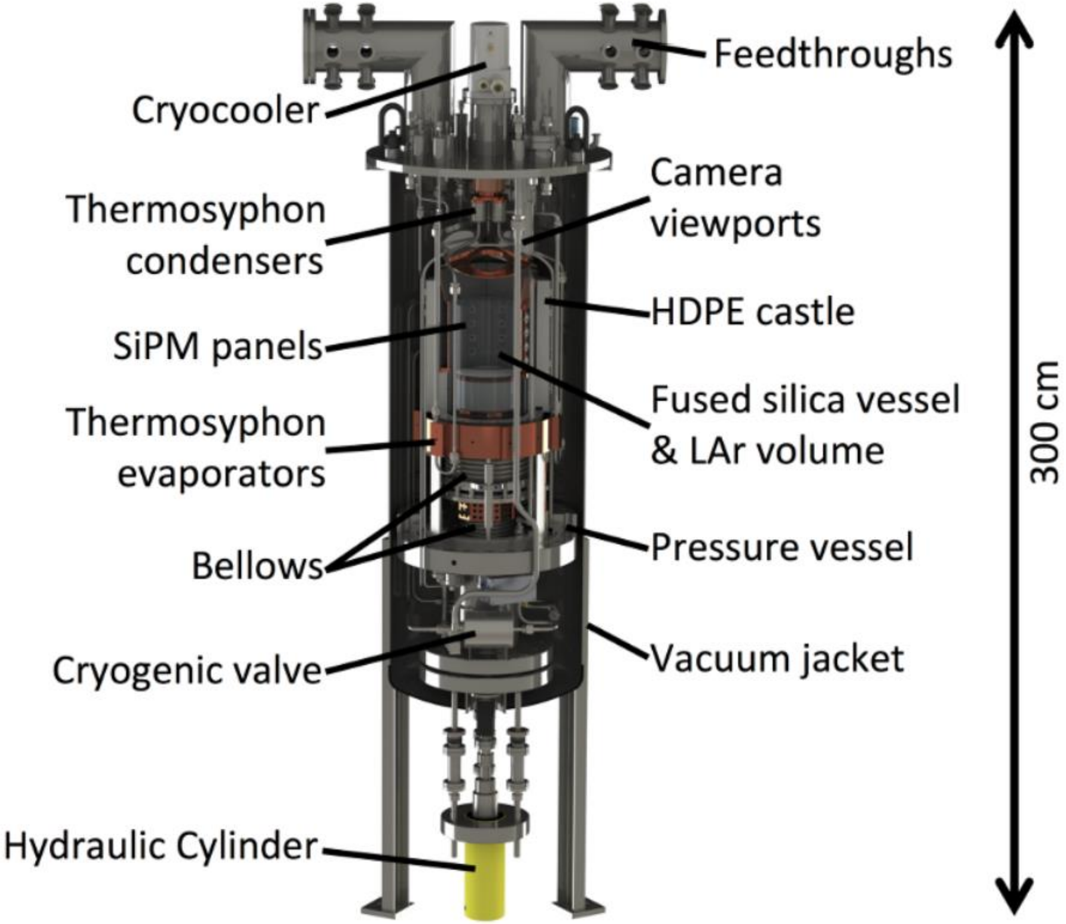
SBC – Scintillating Bubble Chamber

Superheated fluid, detect bubble formation visually or acoustically

Build on experience from Picasso, COUPP and PICO

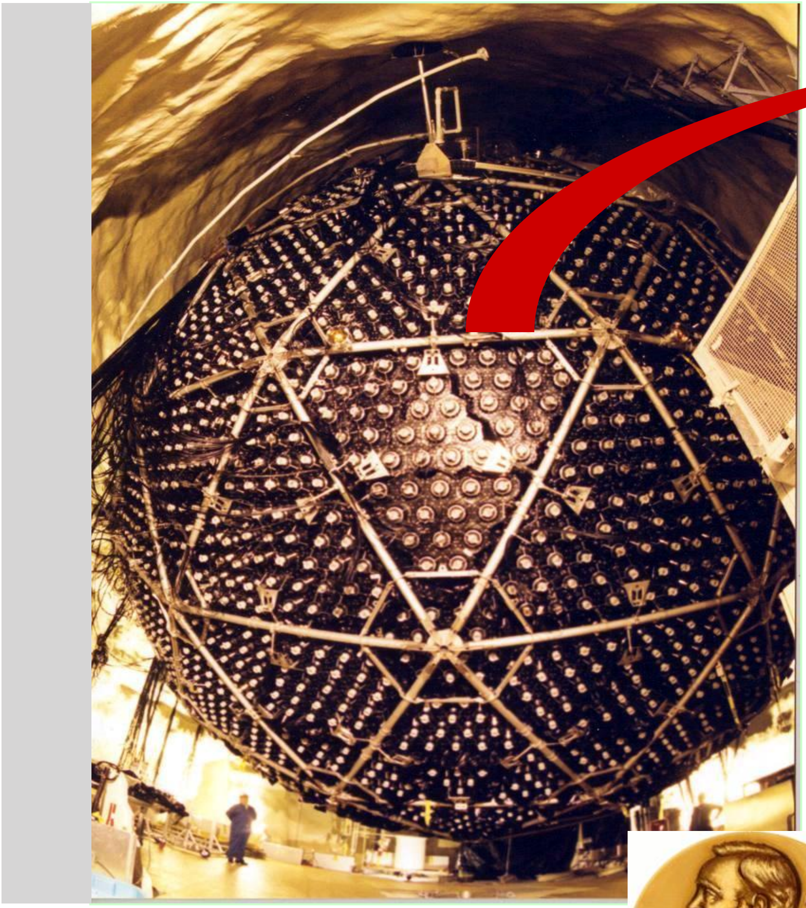


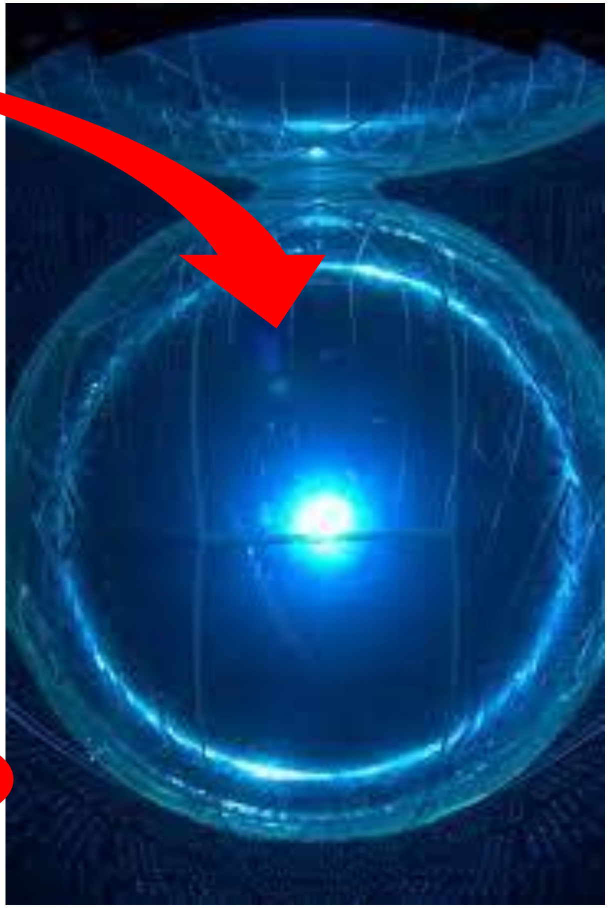




Space for R&D, prototypes

Neutrinos at SNOLAB





HALO

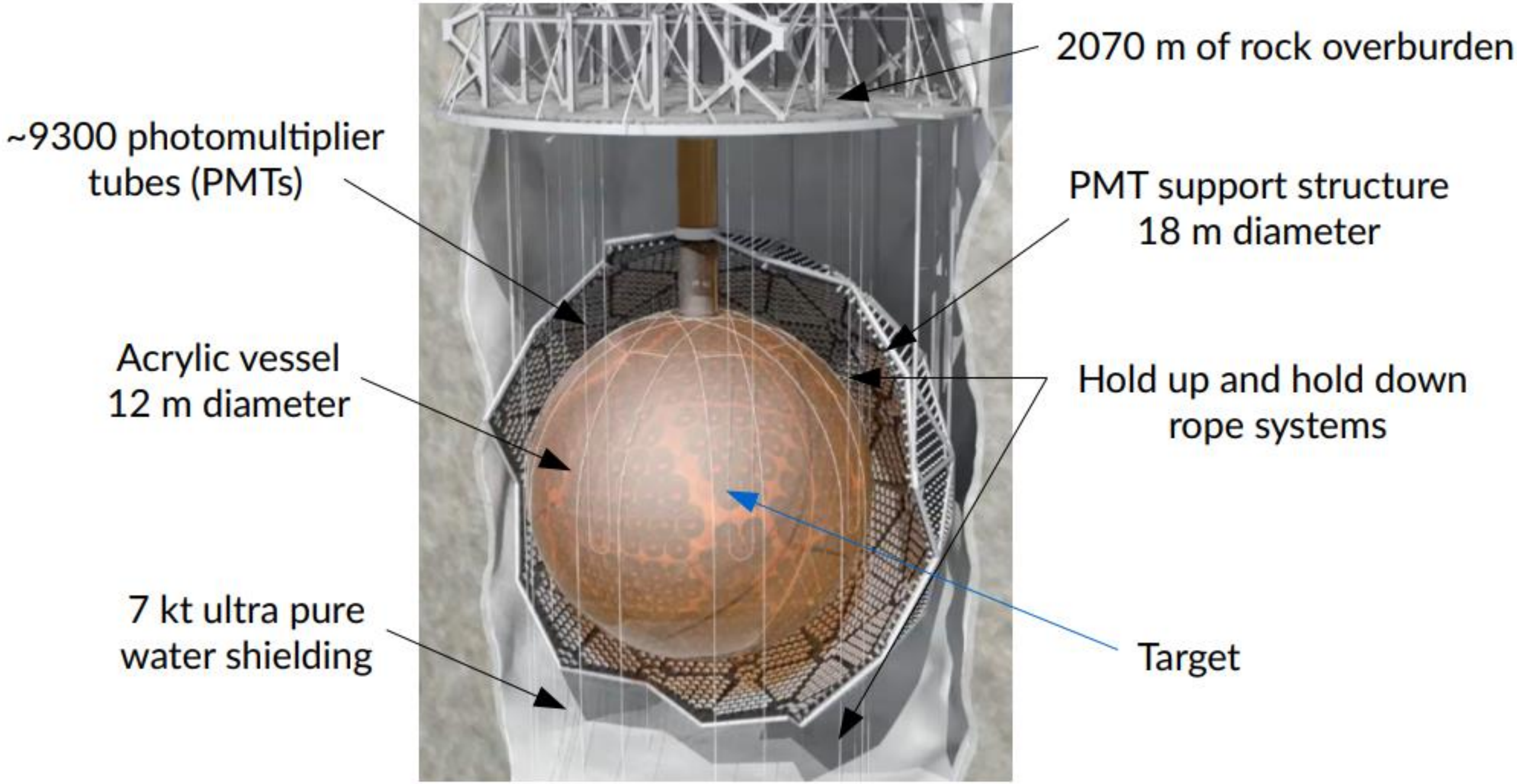
SNO

SNO+

Listed as Flagship experiment

Canadian subatomic Physics LRP

SNO+ detector



SNO+ phases and physics program

Phases are determined by active detection material in acrylic vessel

Water phase
(May 2017 – October 2019)

- **Nucleon decay**
- **Solar neutrinos**
- **Reactor antineutrinos**
- Supernova neutrinos

Scintillator phase
(April 2021/2022 – 2024?)

- Solar neutrinos
- Reactor antineutrinos
- Geo-antineutrinos
- Supernova neutrinos

Tellurium phase
(2025? –)

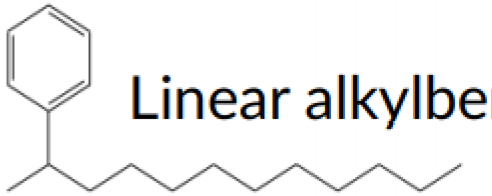
Double Beta Decay
Anti-neutrinos

Bonus: Partial Fill
(March 2020 – October 2020)

365 tonnes of scintillator on top of water (47%)

SNO+ has about two years of scintillator data.

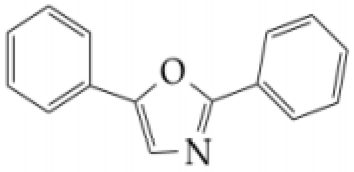
Liquid scintillator



Linear alkylbenzene (LAB)

+

2,5-diphenyloxazole (PPO)

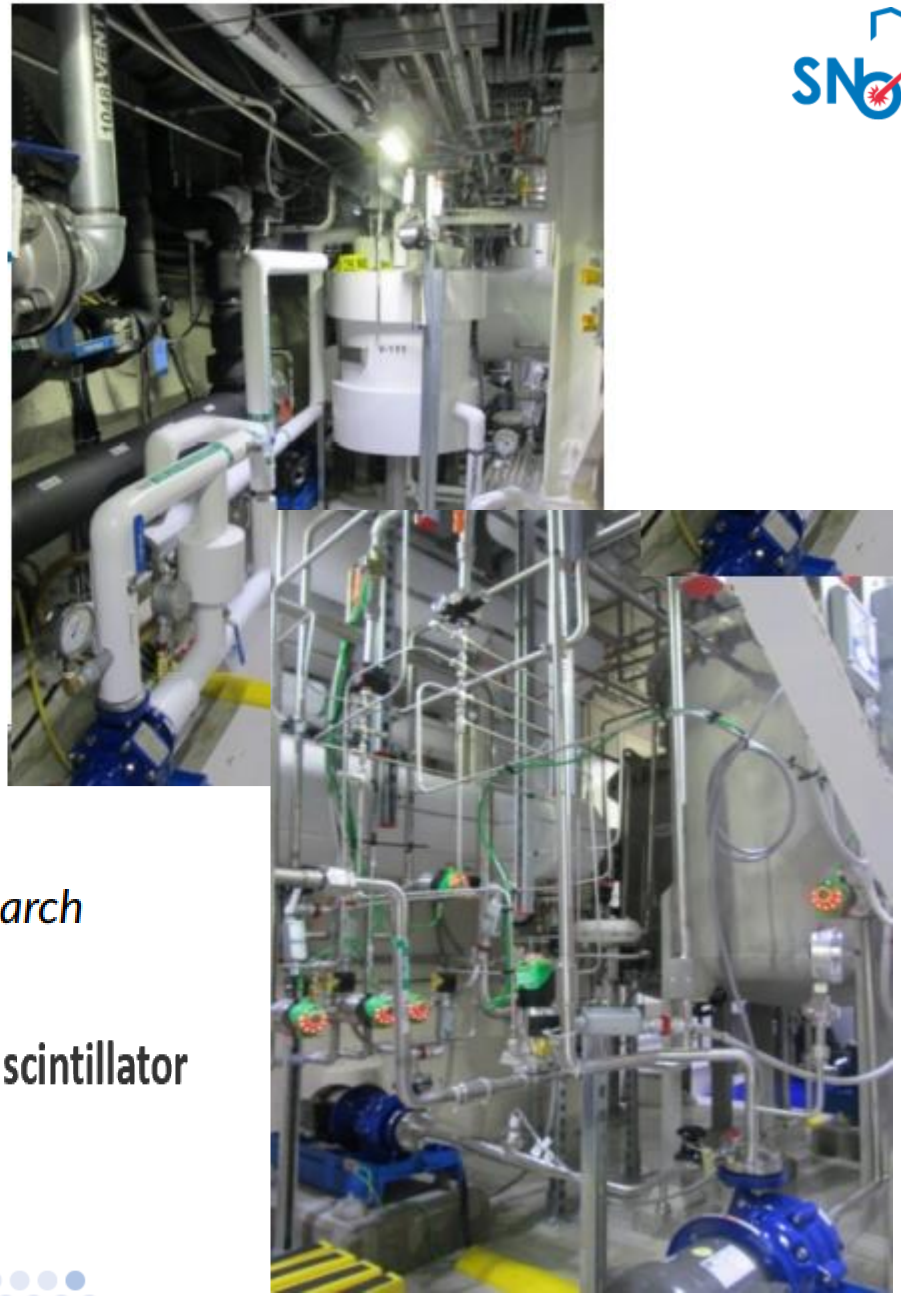


Measured the scintillator purity in situ

O(10^{-17}) g/g for both ^{238}U and ^{232}Th chains

→ *on target for neutrinoless double beta decay search*

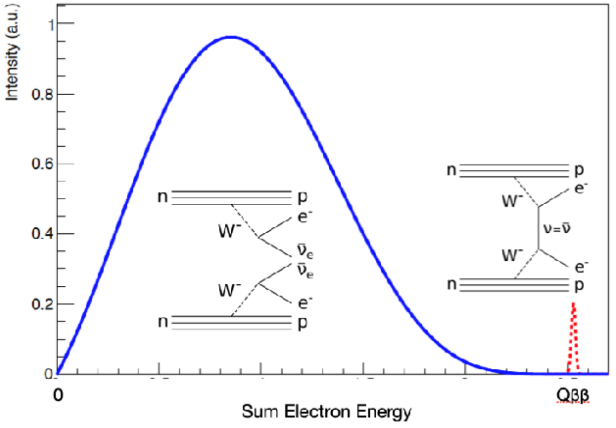
Published: Development, characterisation, and deployment of the SNO+ liquid scintillator (JINST 16 P05009, 2021)



Search for Neutrinoless Double Beta Decay:
the door to the nature of neutrinos and BSM

0νββ

Discovery of 0νββ would be BSM: Majorana ν & lepton number violation

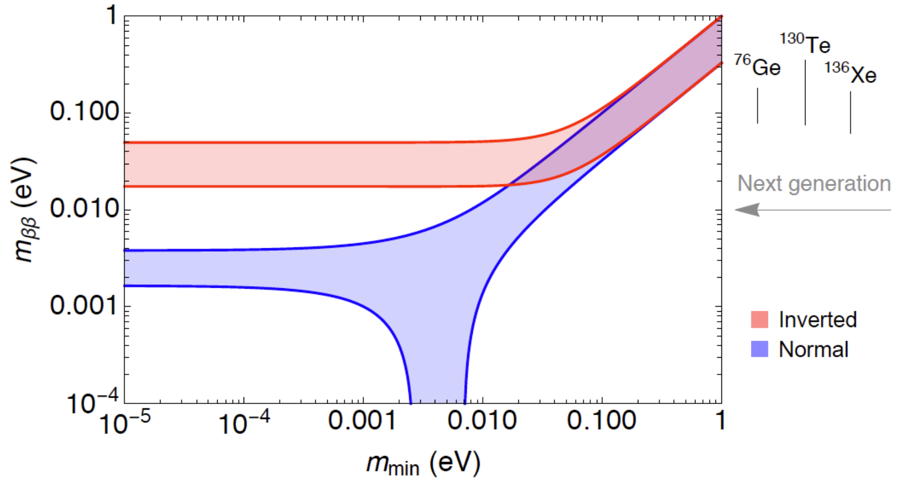


G. Fantini, ICHEP 2022

$$\Gamma^{0\nu} = G_{0\nu}(Q,Z) \cdot |M_{0\nu}(A,Z)|^2 \cdot m_{\beta\beta}^2$$

Exp. sensitivity:

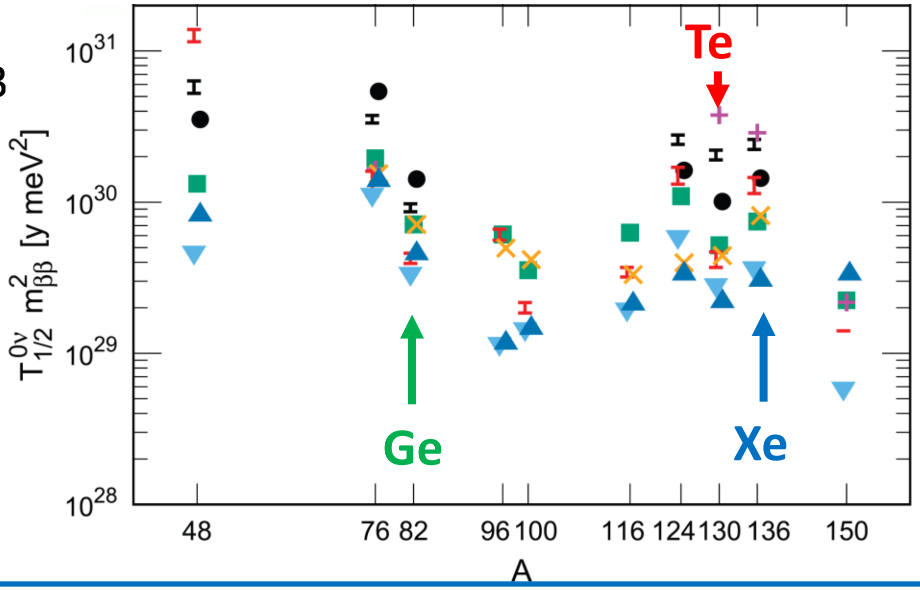
$$T_{1/2}^{0\nu} \propto \begin{cases} a \cdot \varepsilon \cdot M \cdot t & \text{for bg B} = 0 \\ a \cdot \varepsilon \cdot \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} & \text{for bg B} > 0 \end{cases}$$



Nuclear matrix elements;

$M_{0\nu}(A,Z)$ uncertainty: factor 2-3

here shown is $1/(G_{0\nu} \cdot |M_{0\nu}|^2)$



Disclaimer:

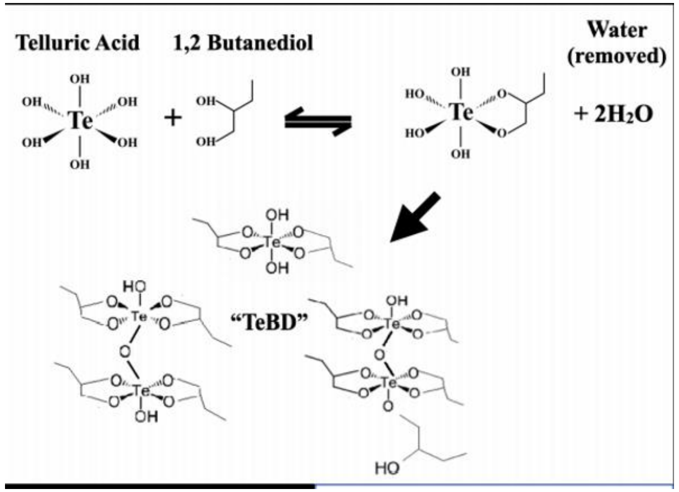
$m_{\beta\beta}$ limits are valid only, if 0νββ dominantly via ν exchange

Double Beta Decay Phase:
need to load scintillator with Tellurium, 34% isotope ^{130}Te (Q=2.528MeV)

- Form organometallic compound from telluric acid and butandiol -> transparent, soluble in LAB and stable over many years
- Long $2\nu\beta\beta$ half-life (7.0×10^{20} yrs)
- Expect ~460 p.e./MeV for 0.5% loading (amount stored underground)

Telluric acid purification

Te-diol synthesis

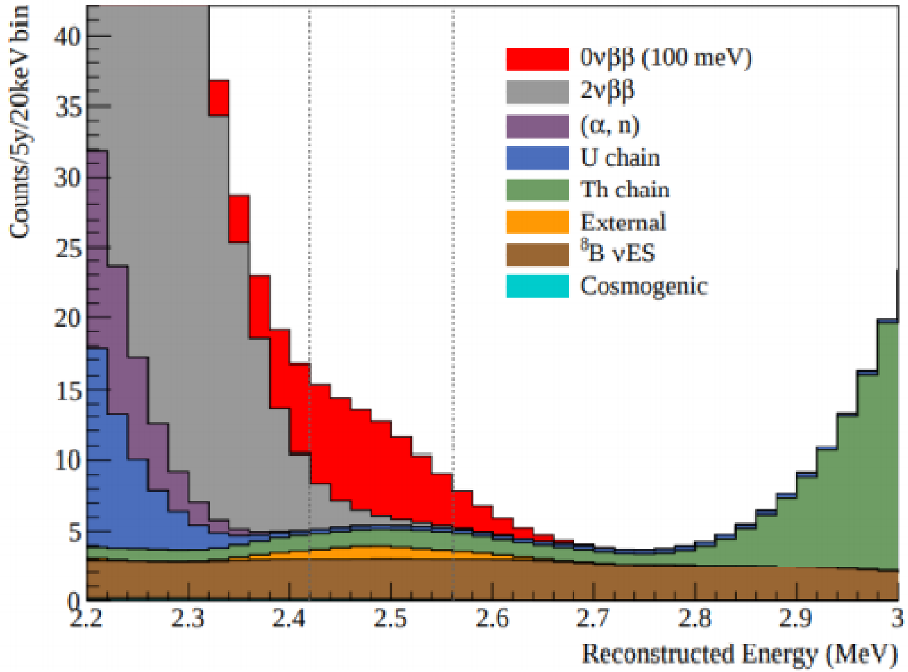


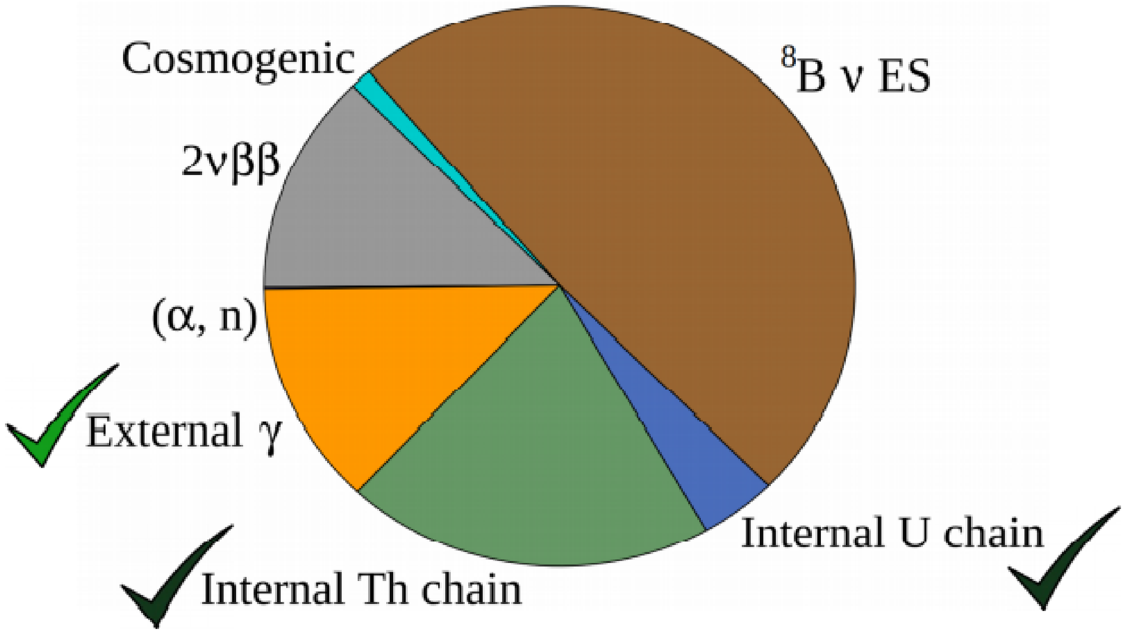
LAB + 2.2 g/L PPO + 5 mg/L bisMSB + BHT + TeBD + DDA (0.5 molar ratio DDA:Te)
"Dimethyldodecylamine" as stabilizer"

Test batch (TeA plant) underway

Neutrinoless double beta decay

Target: Liquid scintillator doped with 4 t natural tellurium





9.47 background counts/yr → $T_{1/2}$>2.1 x 10^{26} yrs

after 5 yrs with 0.5 % Te (Phase I)

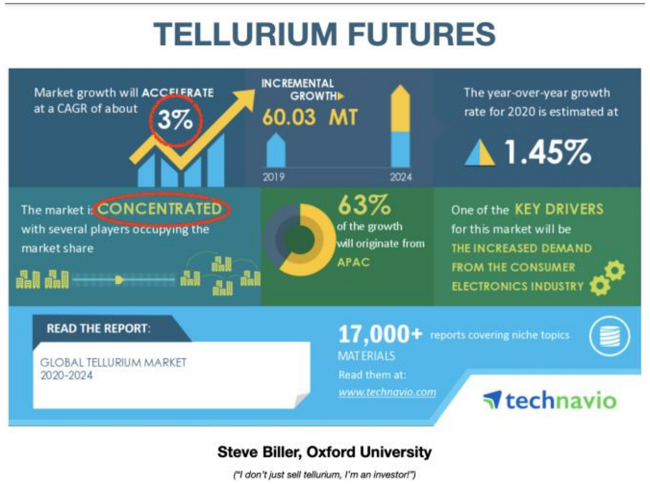
Measured and on target

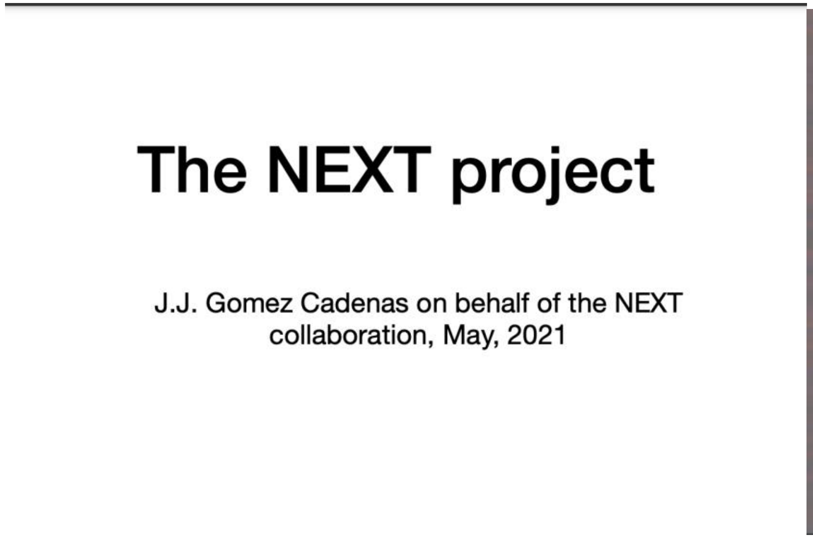
Measured and on target for LAB

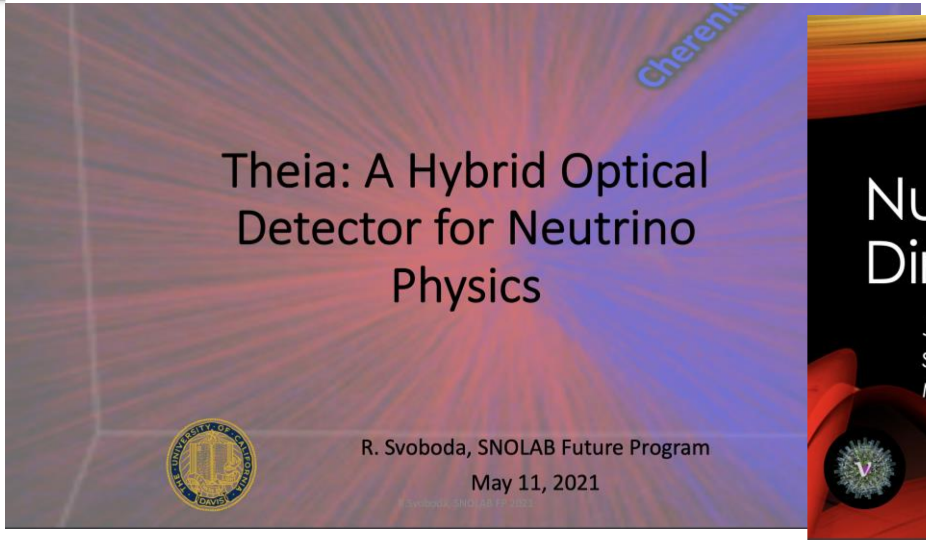
Transition – higher loading (1.5% or 2.0% maybe more)

Many active collaborations are advancing the 0vbb science

Internationally rated as flagship next generation experiments – goal is to host at least one of them at SNOLAB



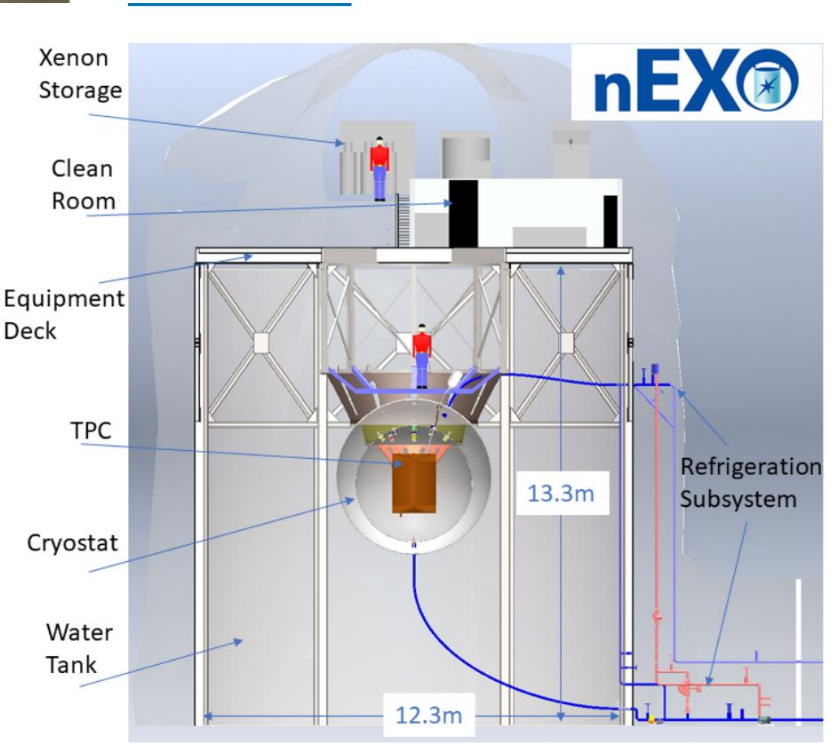


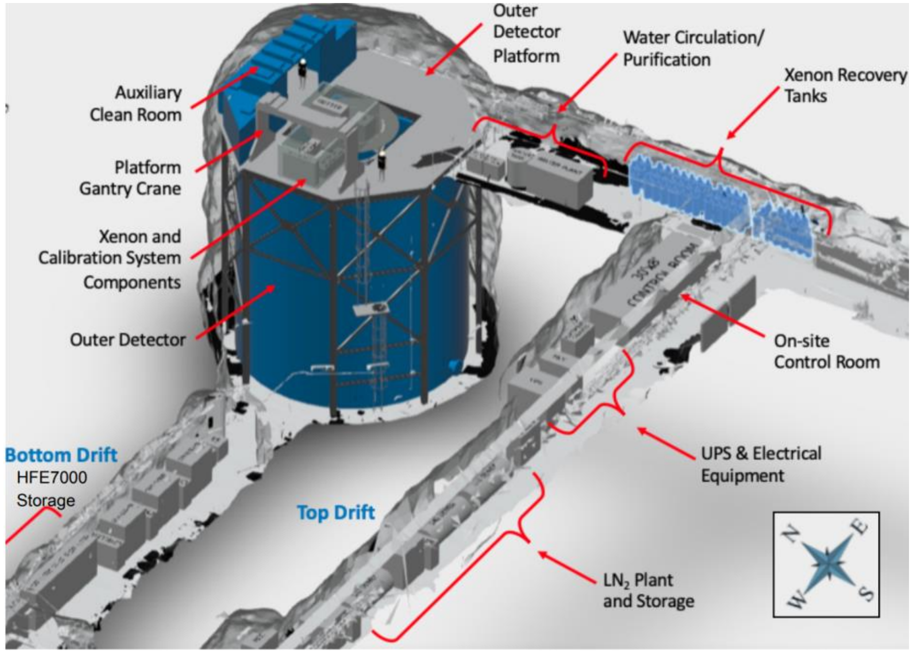


A selection of talks with 0vbb focus from the **SNOLAB Future Projects Workshop**, other important efforts not listed!

nEXO and Legend expressed interest in cryopit

Empty cryopit





Pictures provided for recent reviews at SNOLAB

Talks on nEXO and Legend

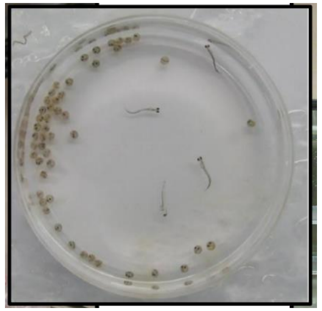
Double Beta summit hosted at SNOLAB in April 2023

Life Science and Emerging Technologies

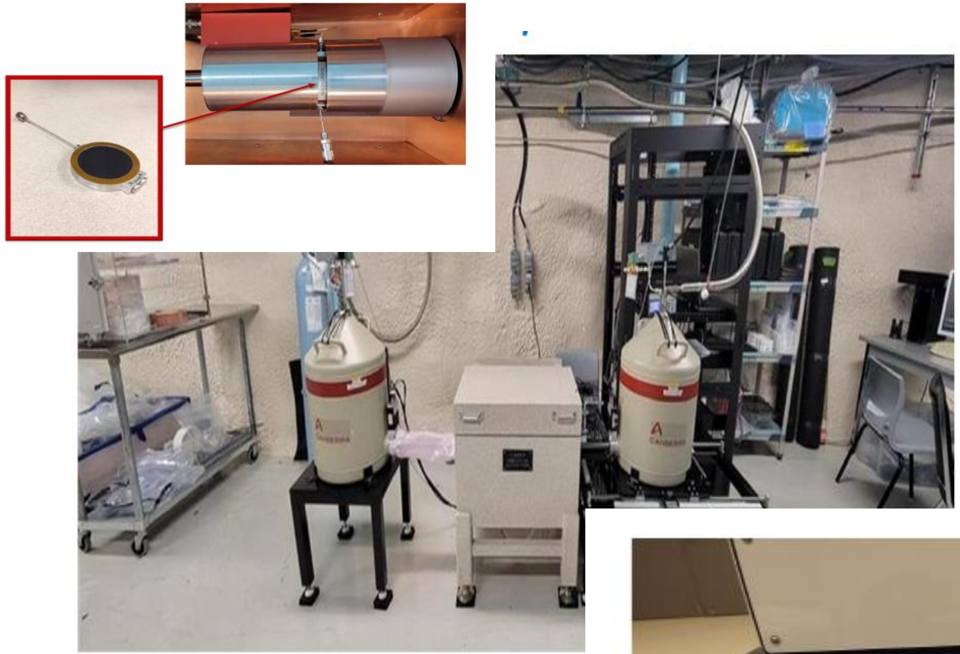
Anybody utilizing unique underground environment is welcome.
Seek out additional opportunities.

Future workshop slides

- Life Science experiment: FLAME, REPAIR
- Seismic studies
- Quantum Technology
- Nuclear Security



Background Characterization Capabilities

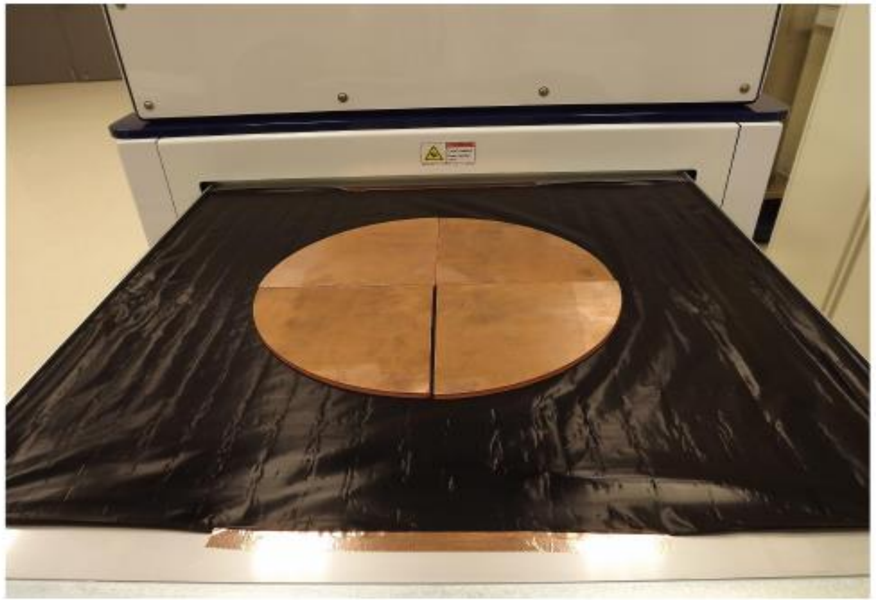


Assay Capabilities

- HPGe Counters
- XIA Alpha counter (surface)
- Radon emanation measurements
- New ICPMS
- Radon monitoring

Underground Background Measurements

- Radon (Durridge RAD7 continuous monitoring)
- Neutron Backgrounds (Bubble Technology BDS System - 144 detectors at 6 thresholds)
- Gamma Backgrounds: (2 NaI Detectors – Detailed spectra up to 3 MeV)
- EMI Backgrounds: (RIGOL Spectrum Analyzer – 9 kHz to 7.5 GHz)



See talk by Ian Lawson's in the Underground Lab session 2

ICP-MS

Inductively Coupled Plasma Mass Spectrometry

- Agilent 8900 ICP-QQQ
- Analytical technique used to quantify trace level elements.
- SSG have developed a method for UPW samples: Analysis of ultra trace level samples acidified with only high purity grade nitric acid, produced on site using a sub-boiling acid purification unit.

UPW working well

Surface Low Background Counting

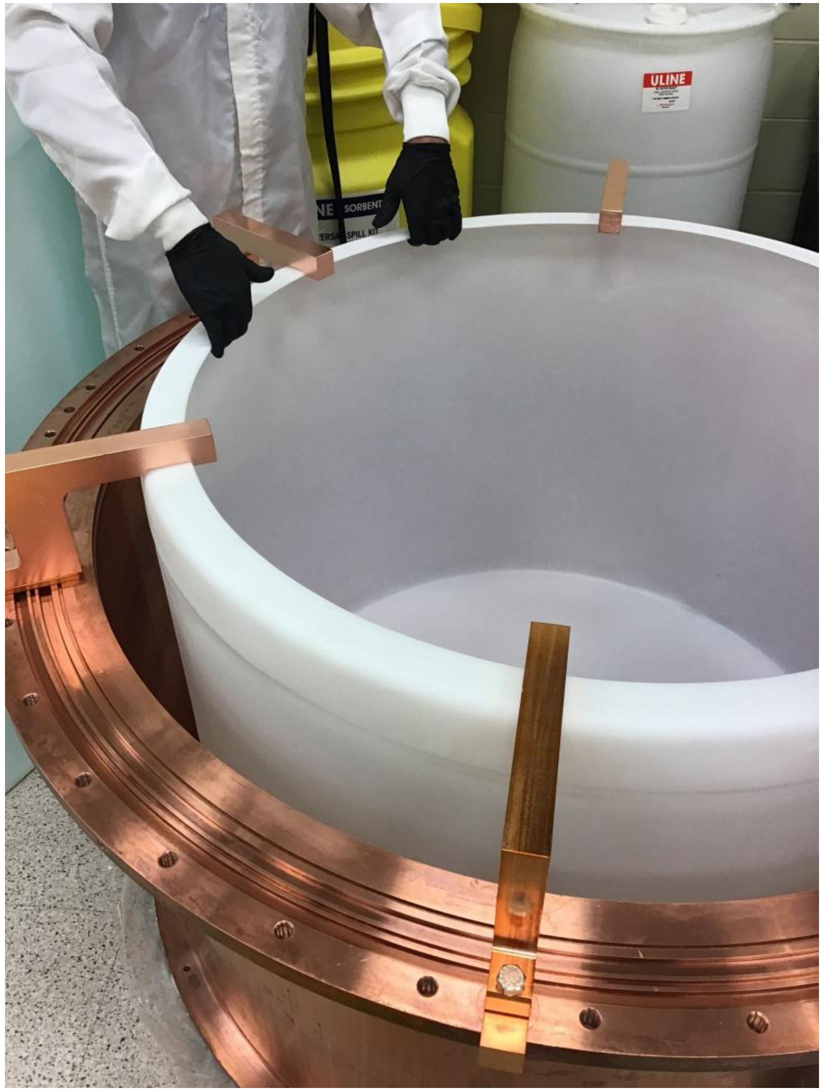
- ESCs (Electrostatic Counters)
- XIA UltraLo-1800 Alpha Counter
- Rn Emanation Chamber
- Lucas Cell PMT Counters with a DAQ system

Surface Clean Lab Space

All surface labs have HEPA filtration designed for 10 air changes per hour with the Clean Assembly lab designed for 30 air changes per hour.

SNOLAB cleanroom standards are maintained at Class 2,000 level for both the Surface and Underground facility

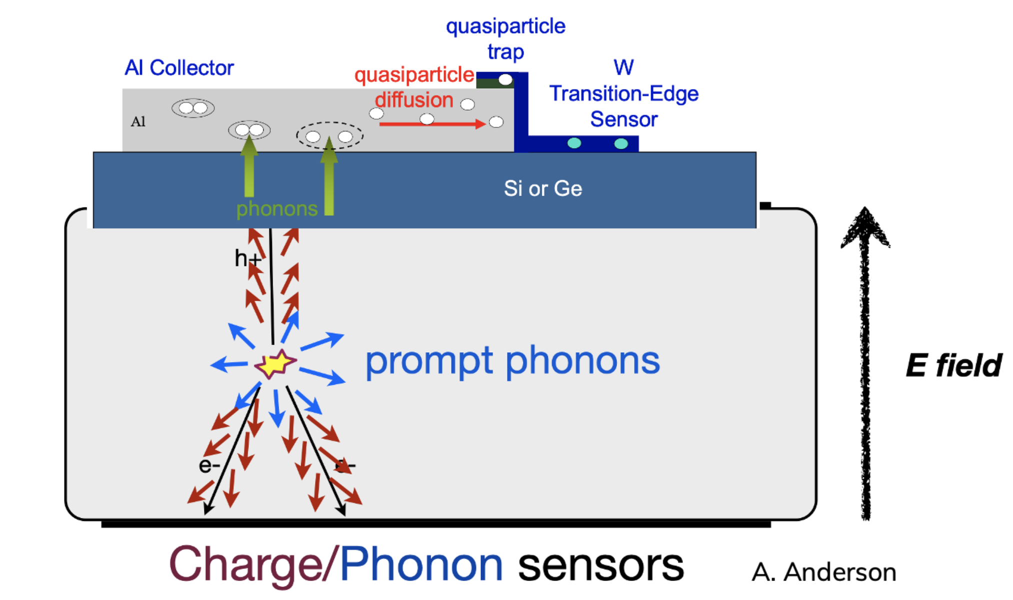
Lab space is available for staging experiments, clean assembly work, detector development, chemical purification processes.



Cleaning and Etching of the SuperCDMS cryostat. Getting ready to etch in this photo. Work ongoing this summer.

Superconducting qubits are underperforming due to couplings to the environment

- Quantum computers are based on qubits
- Qubits are made from low energy systems
- Environmental backgrounds are a source of decoherence in qubits
- There are no radiation-hard design rules for quantum technologies
- Underground scientists can help address this challenge



In SuperCDMS, particle interactions generate phonons, which generate quasiparticles in superconducting films, which can be counted

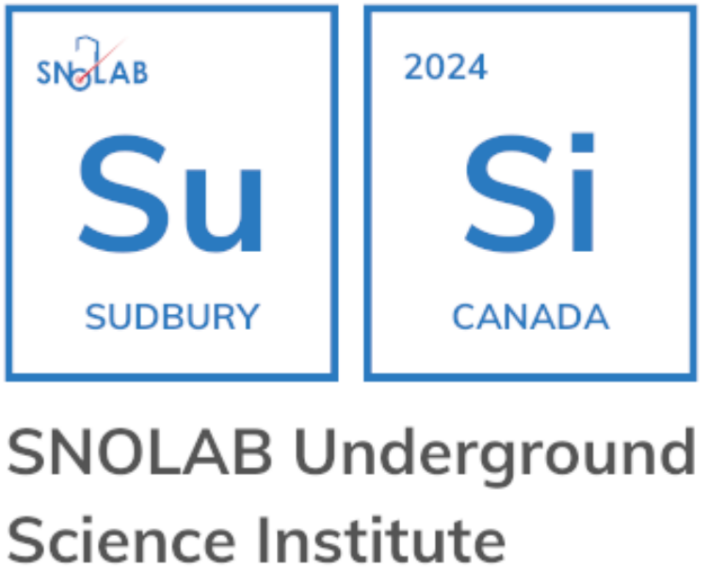
Community - Students

Students attending the 2023 Canadian Astroparticle Summer Student Talk competition (CASST)
Sponsored by SNOLAB, McDonald Institute and Laurentian University.

Special Prize – CAP talk: Yusuf Ahmed (Radon trapping) and Ashley Ferreira (ALPHA exp.)

Rotating cohort of 15 co-op students are critical to the capability development

Sudbury Underground Science Institute (SuSi)



Pilot program

Three topics:

- Dark Cosmos
- Neutrino Science
- Quantum Technology

[SuSi 2024 | SNOLAB]

June 24 to Aug 16, 2024

SNOLAB

Dark matter

The only evidence for dark matter is through its gravitational influence. Our underground experiments aim to catch rare interactions between dark matter and the detectors by controlling and removing all known sources of radiation.

Current experiments

DAMIC, DEAP-3600, NEWS-G, Oscura, PICO-40, PICO-500, SENSEI, and SuperCDMS

Neutrinos

Studying the properties of the neutrino provides insights into the dominance of matter over antimatter and the nature of radioactive decay. Our very large neutrino detectors are needed because interactions are very rare.

Current experiments

HALO, LEGEND-1000, nEXO, and SNO+

Nuclear monitoring

We measure low levels of industrial radioactivity using our existing capabilities for measuring natural radioactivity in the materials that make up our detectors.

Current experiments

Collaboration with Health Canada, led by Canadian Nuclear Safety Commission

Quantum computing

Our low-radiation environment is ideal for studying the performance of qubits, which are fundamental to quantum computing but easily disturbed. Ionizing radiation is a key component of the noise in today's best qubits.

Current experiments

Collaboration with Institute for Quantum Computing, University of Waterloo

Life sciences

We collaborate with researchers to study the impact of low-background environments on biological systems. Radiation can damage cells in large doses, but we need to better understand the effects of sub-background radiation.

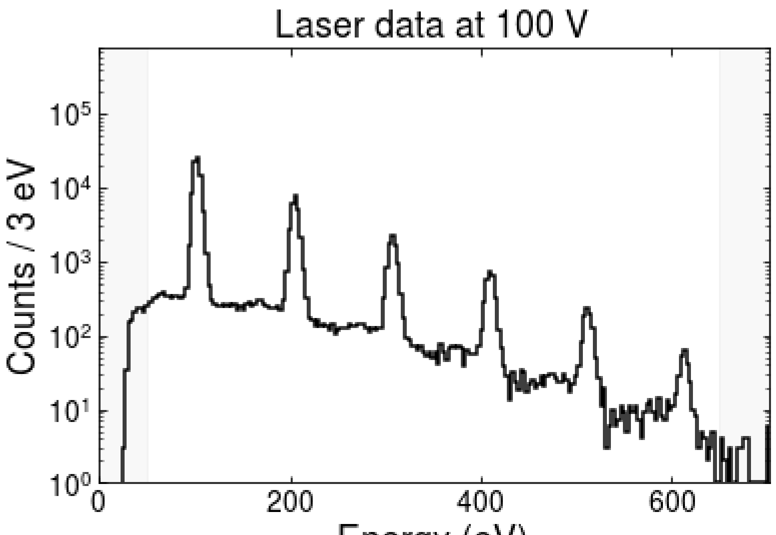
Current experiments

REPAIR, FLAME

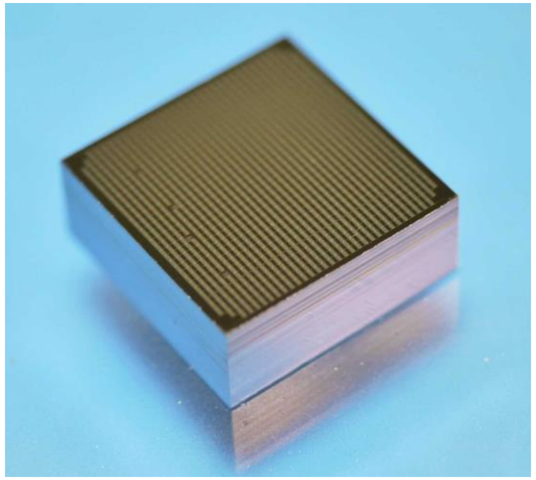
Questions ….

Another Facility for HVeV Operations

- **HVeV Detectors Underground in CUTE**
  - **5 Detectors Currently running in CUTE**
  - **Will help track down the "Low Energy Excess" seen in multiple experiments**



1 electron-hole (e-h) pair
Fill-in between peaks: charge trapping and impact ionization



D. W. Amaral *et al.*, Phys. Rev. D 102, 091101(R), 2020
F. Ponce, et al., Phys. Rev. D 101, 031101(R), 2020
R. Ren et al., Phys. Rev. D 104, 032010, 2021

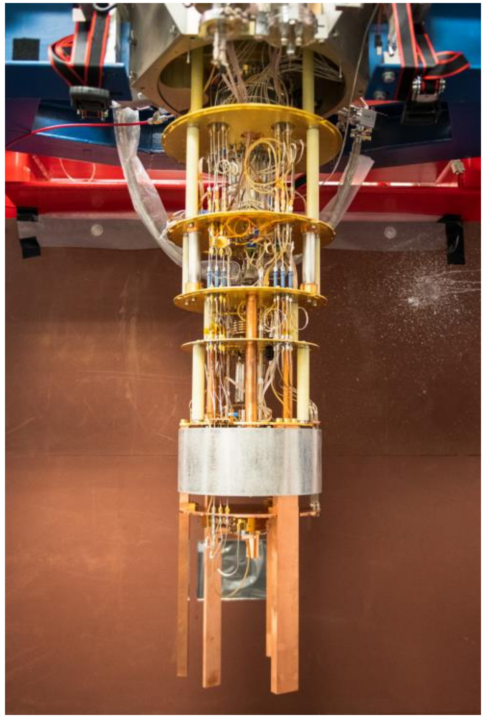
Qubits in CUTE

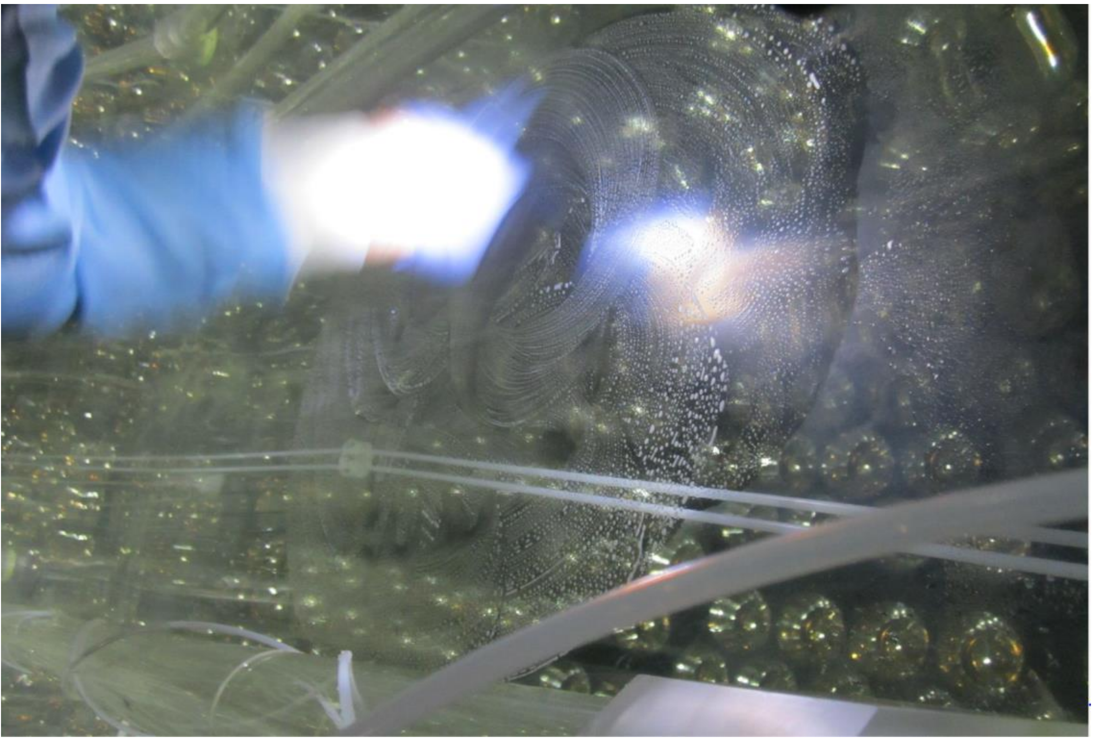
Funded proposal to study Qubits in a low radiation underground environment

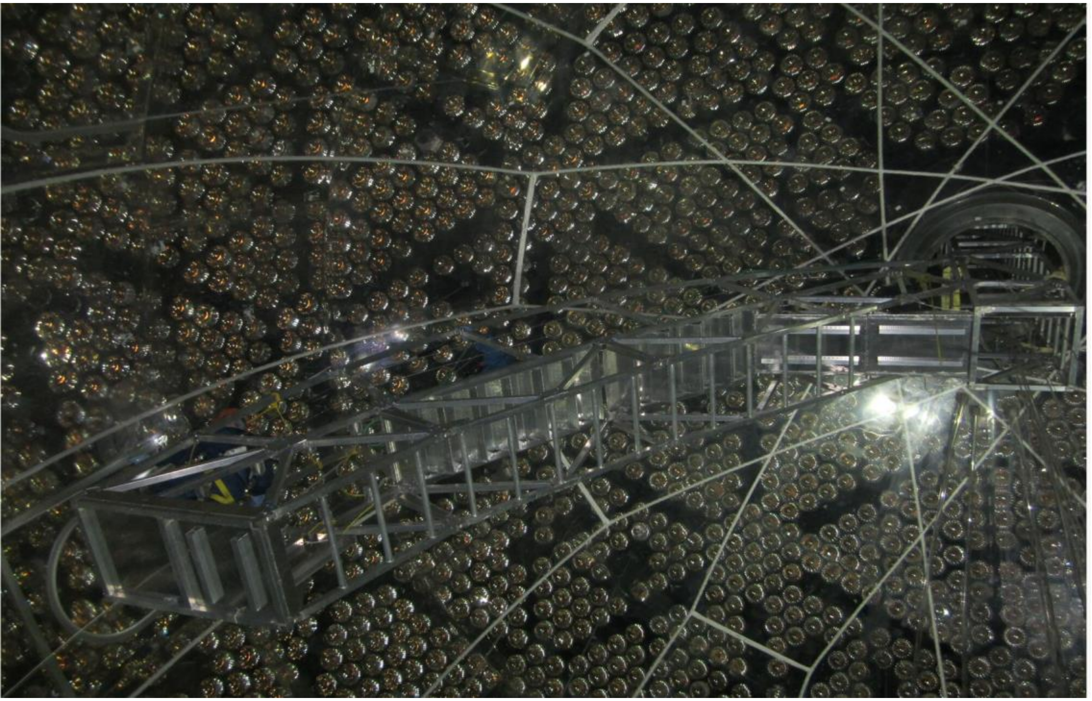
- Funded by US Army Research Office
- Collaboration between SNOLAB, University of Waterloo, and Chalmers University of Technology
- Prof. Chris Wilson at the IQC is the project leader
- Chalmer’s University will produce superconducting qubit arrays
- CUTE facility offers excellent opportunity to study ionization effects on coherence
- Upgrades to CUTE fridge to accommodate are funded and underway
- Similar upgrades for similar work on same fridge model at NEXUS (see photo)

This is NEXUS (same fridge model)

For Illustrative purposes only







Why clean?

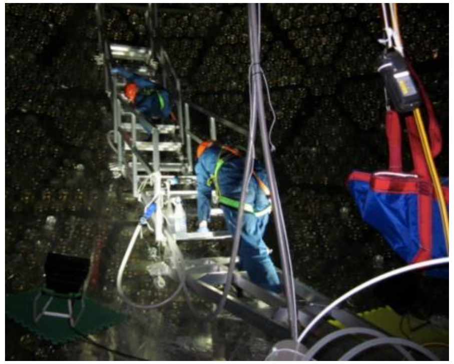
Reducing backgrounds

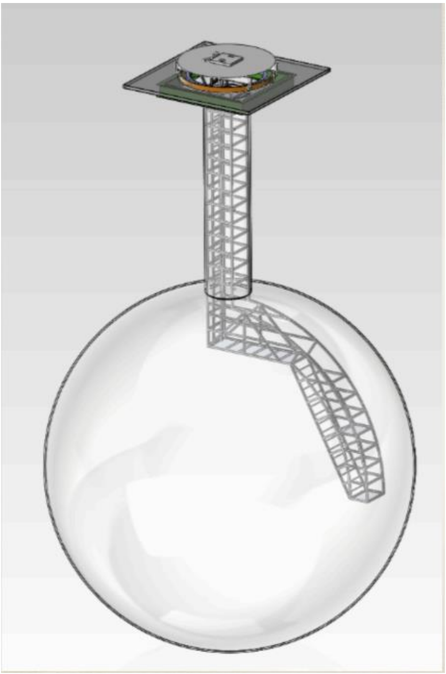
They can mimic signals

Material Selections and production

SNOLAB is a leader in ultra-high precision cleaning

Cleaning the entire inner surface of the AV





Neutrinoless Double Beta Decay - Spectrum

Large detectors, extremely clean (low background)
Measure half-life: Extremely long ~ 10^{28} years

Single beta decay ~1930

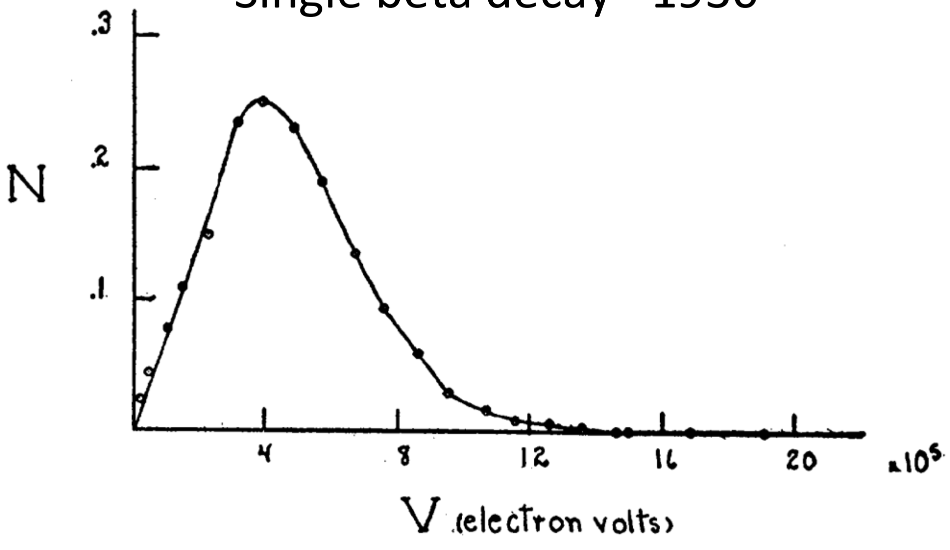
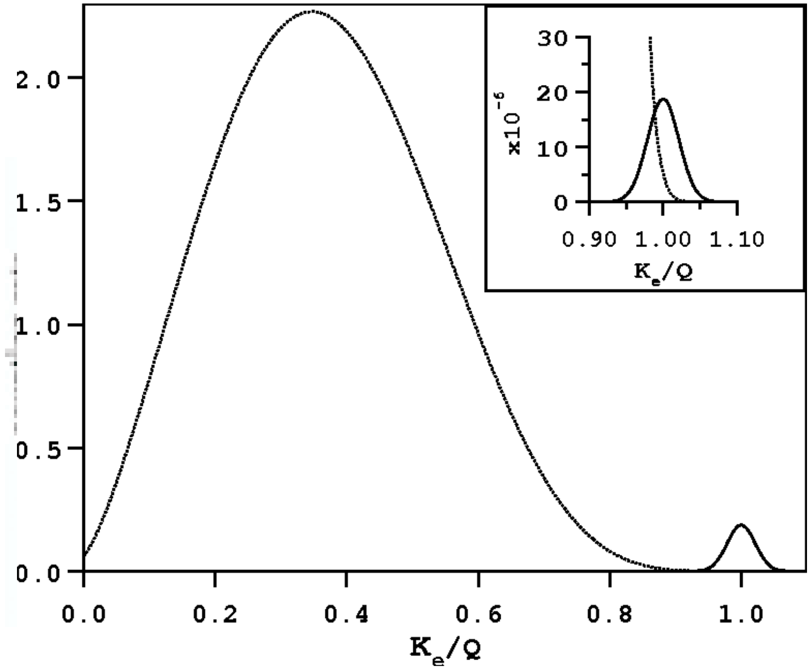


FIG. 5. Energy distribution curve of the beta-rays.

Double beta decay - principle



Experiment timescale - decade

Energy resolution, Statistics