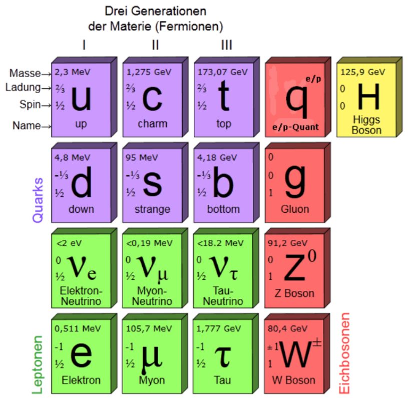
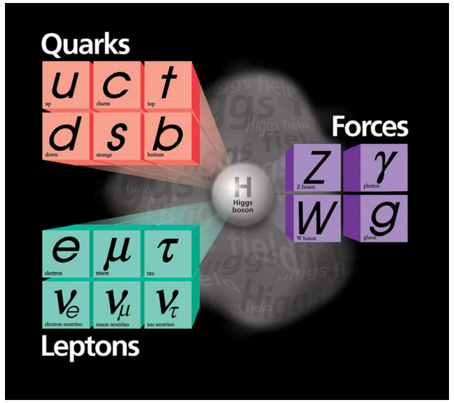
TRIUMF and SNOLAB-based Astroparticle Physics Projects

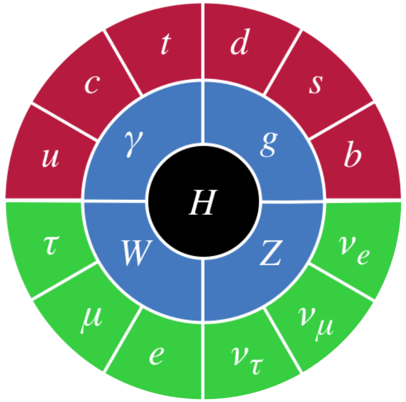
Wolfgang Rau

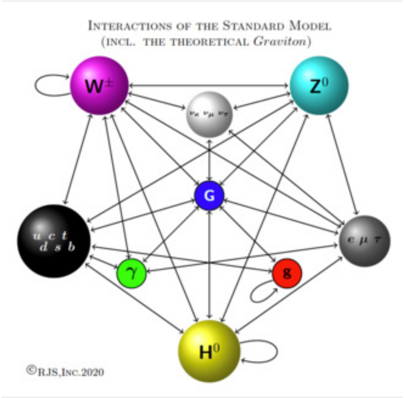
The Standard Model

… provides us with a beautiful scheme of particles and forces:









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Cryogenic Dark Matter Search

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ArGO

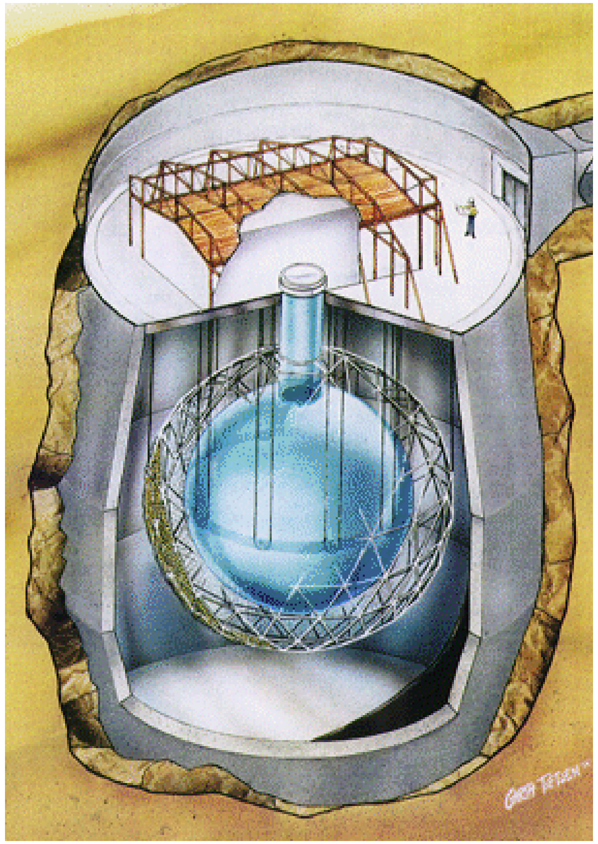
36 quarks: 3 families, 2 electric charge values, 3 colors, quark and anti-quark
6 charged leptons: e, μ, τ and their antiparticles
6 massless neutrinos
3 forces and their carriers (EM, weak, strong) and the Higgs

But it

is in trouble

Astroparticle Physics

- Neutrino measurements (solar/atmospheric) revealed that neutrinos have mass
- Astronomical and cosmological observations show that 80 % of the mass in the universe is contributed by massive stable particle that only interact weakly (Dark Matter)



Neither is covered by the standard model

Astroparticle physics questions:

- What are the neutrino masses?
- Are they dirac or majorana particles?
- What is dark matter?
- How does it interact?

AP discovered SM limitations
and searches for the answers: it

Advances the Standard Model

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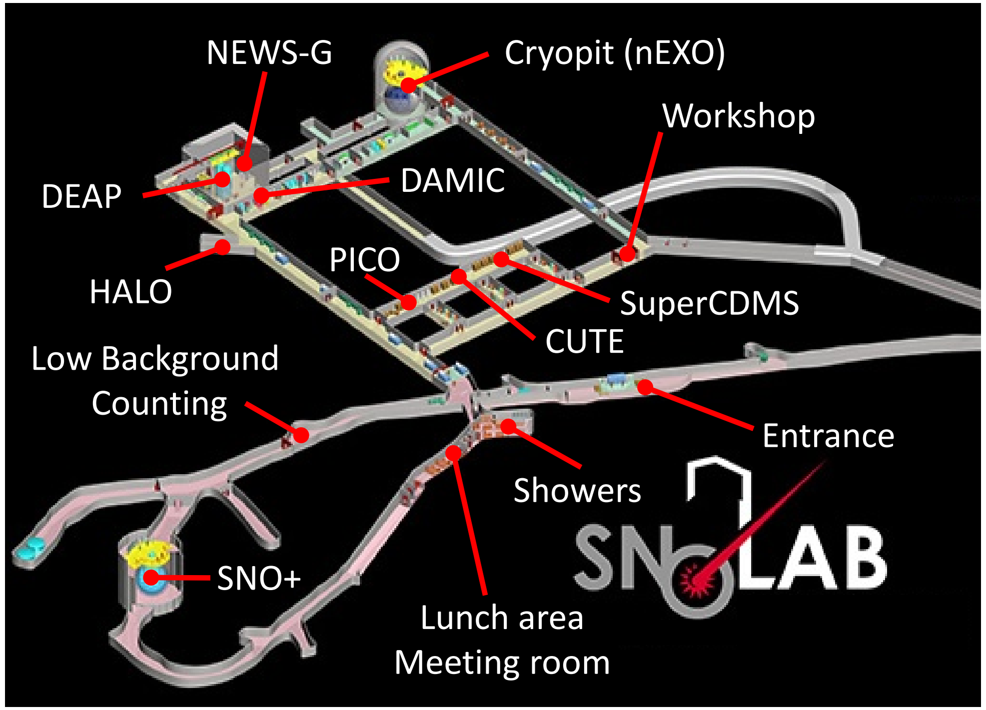
SNOLAB and TRIUMF

SNOLAB

- 2 km underground near Sudbury, ON in an active Ni-mine
- ~3000 m^2 of lab space (cleanroom to minimize contamination) with additional surface labs
- Support for experiments (installation, operations)
- 10 staff scientist
- Hosting many experiments (mostly DM and neutrinos)
- SNOLAB provides ideal conditions for DM/neutrino experiments
- TRIUMF provides technical and science support (R&D, detector development, DAQ…)



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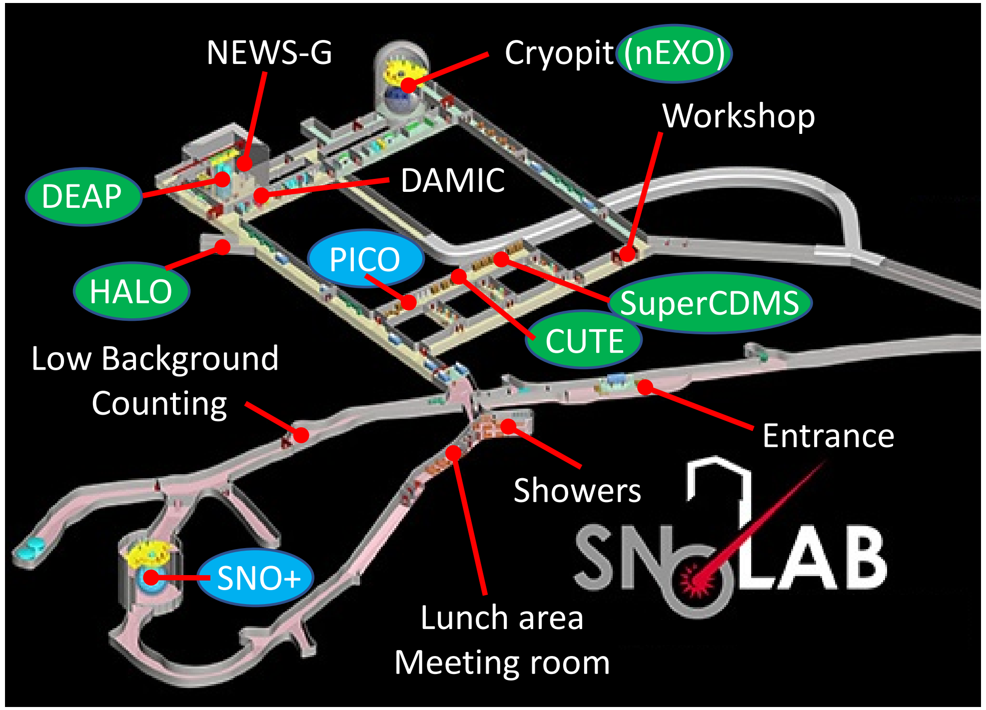

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Astroparticle Physics Experiments with TRIUMF participation

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HALO – Supernova Neutrino Observatory

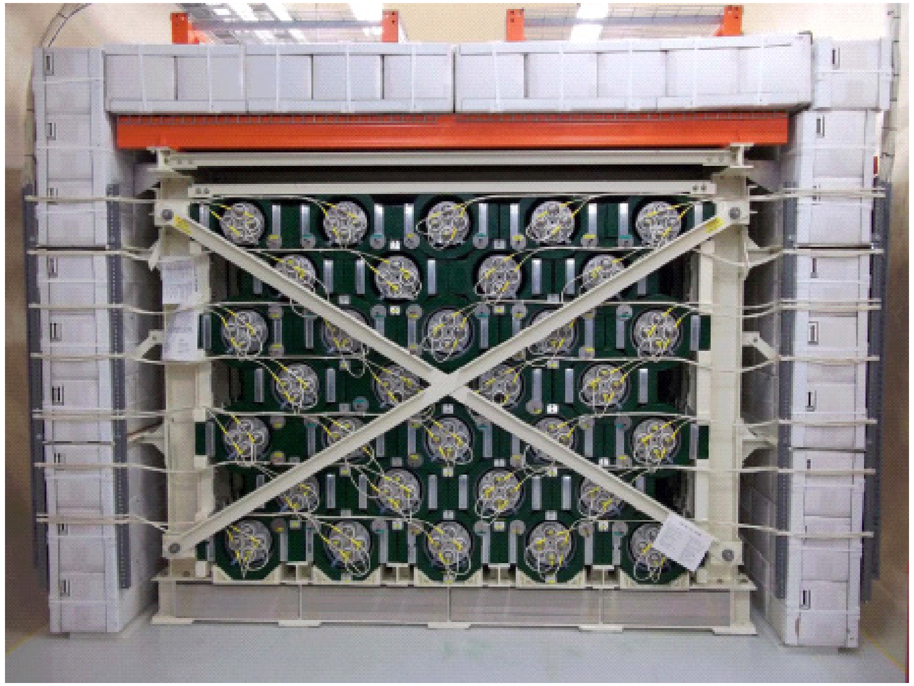
- Main target for Supernova neutrinos: Pb

$$\nu_e + Pb \rightarrow Bi^* + e^-;\ \ Bi^* \rightarrow Bi + \gamma + n$$
$$\nu_x + Pb \rightarrow Pb^* + \nu_x;\ \ Pb^* \rightarrow Pb + \gamma + n$$

$\Rightarrow$ Primarily sensitive to neutrinos, not antineutrinos

- Neutron detection with ^3He detectors (inherited from SNO)

$$^3He + n \rightarrow\ ^3H + p\ (Q = 764\ keV)$$



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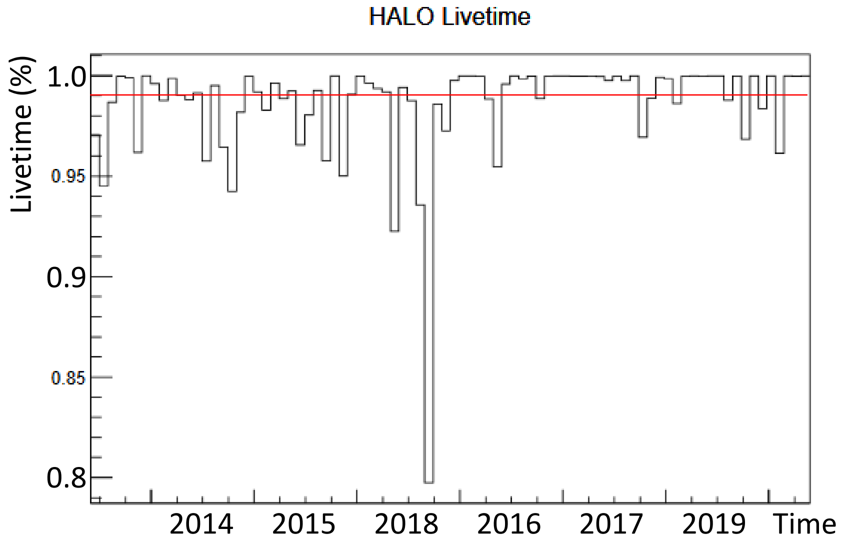
HALO – Supernova Neutrino Observatory

- Complementary to scintillation/Cherenkov detectors (sensitivity to $\bar{\nu}$)
- Member of the Supernova early warning system (SNEWS) since 2015
- Uptime ≈99 % (important for SN detector (will improve with generator)



- Low-maintenance detector; performance stable over past eight years
- Expected to run long-term with small improvements (DAQ, SNEWS alerts, measuring ν-Pb cross section …)
- Together with other SN detector: Learn about supernova dynamics and neutrino properties (ν mass, $\nu\nu$-interactions …)

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nEXO – Searching for Majorana Neutrinos

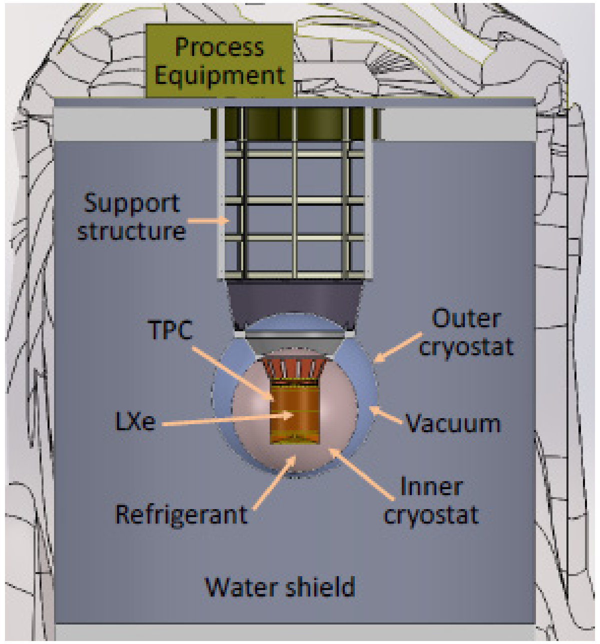
- Particles and anti-particles have opposite charge, ν have no charge, could be their own anti-particles (“Majorana particles”)
- In double-β decay, two neutrons convert simultaneously into protons:

$$^{X}Z \rightarrow {}^{X}(Z+2) + 2e^{-} + 2\bar{\nu}$$

- If neutrinos are Majorana particles, the process can happen without neutrino emission ($0\nu\beta\beta$) and all energy goes into the electrons.
- Probability depends on neutrino mass

The Enriched Xenon Observatory:

- Used 200 kg of liquid enriched ^{136}Xe to search for $0\nu\beta\beta$
- The next EXO (nEXO) will have a fiducial mass of ~3.5 tons ^{136}Xe
- Funding decision in the US expected soon



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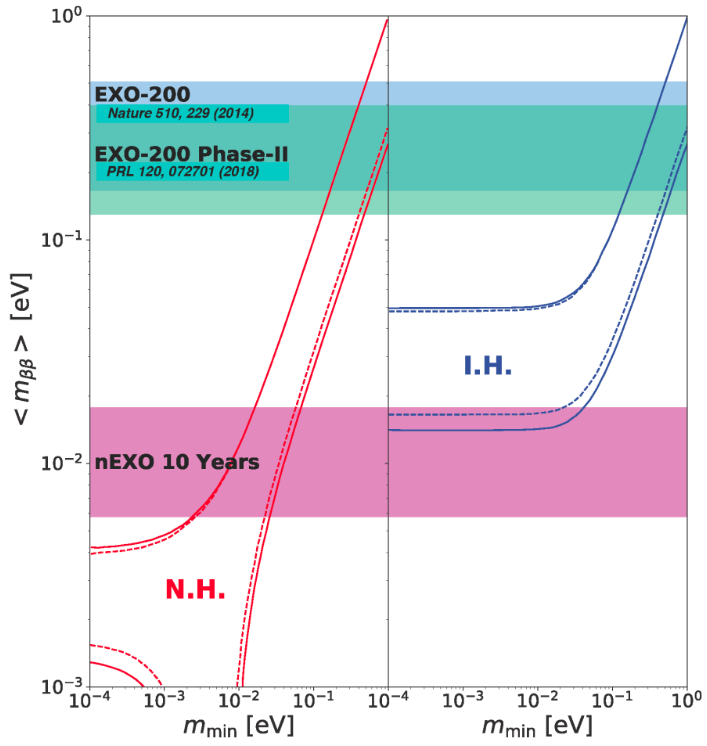
nEXO – Searching for Majorana Neutrinos

- Time scale: 3-5 years until first science, 10 year of operation
- Sensitivity (neutrino mass): ~10 meV
- TRIUMF contribution: detectors for readout of UV scintillation light (development, testing), photon transportation study



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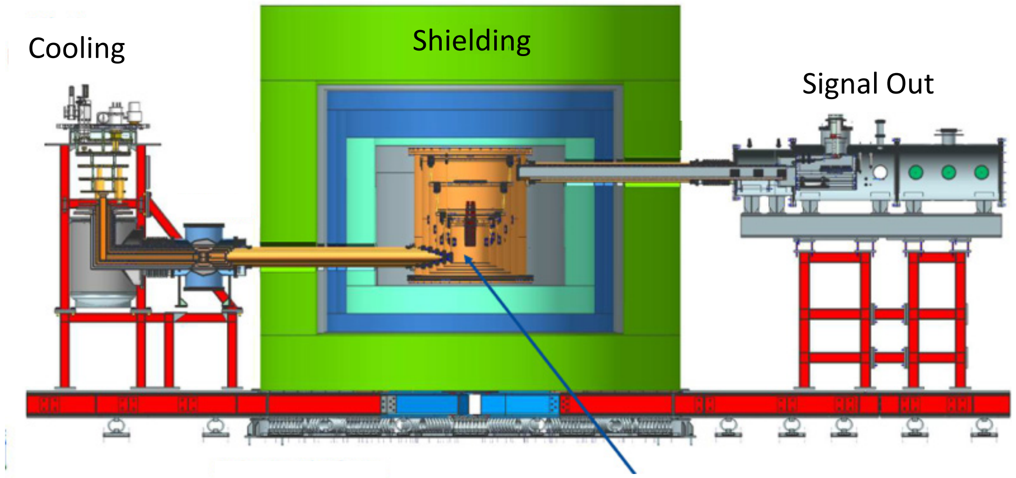
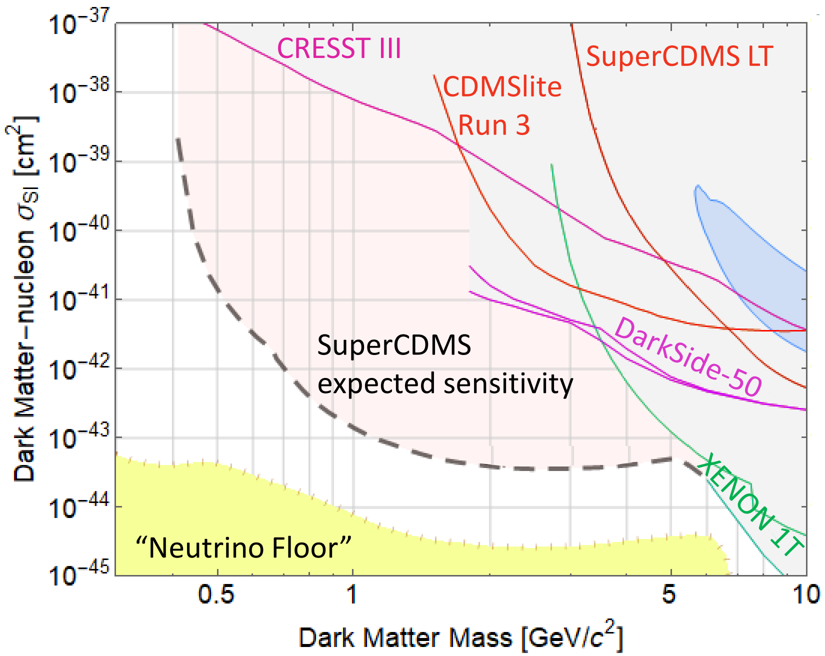
SuperCDMS

- SuperCDMS searches for interaction of dark matter particles in cryogenic Ge and Si detectors
- Ideal for low-mass DM particles (few GeV range and below) due to good energy resolution and low threshold
- Construction is underway at SNOLAB; science start in 2022
- Initial phase ~5 years





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CUTE

- CUTE (Cryogenic Underground TEst facility) designed to test SuperCDMS detectors under low-background conditions
- Well shielded; background of order of a few events/keV/kg/day
- Operational since 2019

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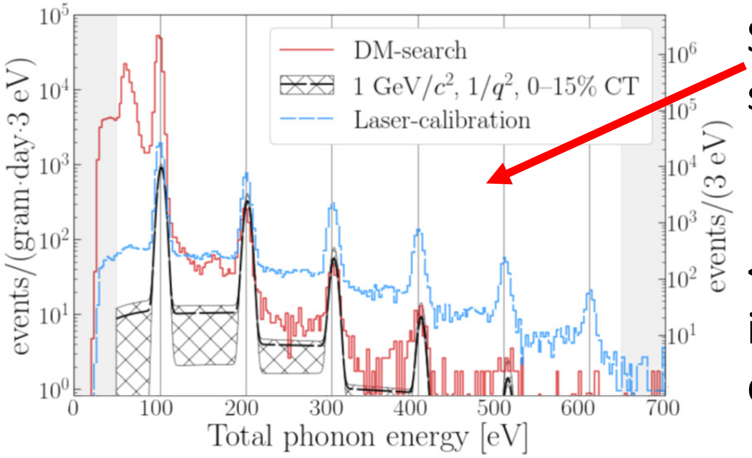
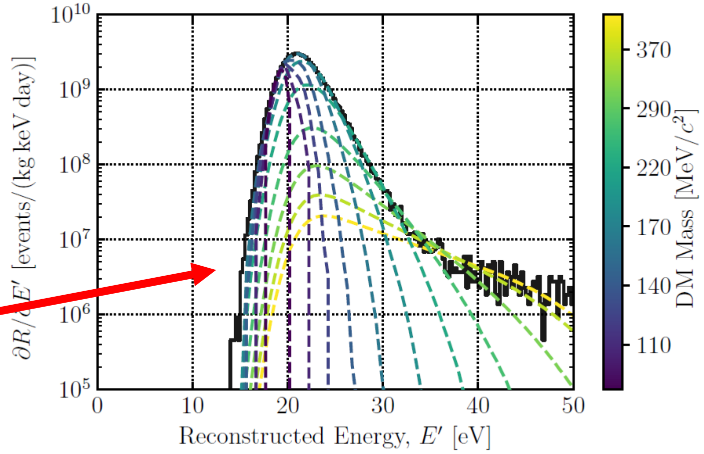
SuperCDMS and CUTE Longterm Plans

- SuperCDMS: R&D to reach even lower masses and cross section: Reduce threshold, new materials, improved background discrimination
  - Aim for neutrino floor in few GeV range
  - Push mass range down to MeV range
  - Improve sensitivity for electron-interacting DM
- Data from small-scale low-energy detectors recently published
- CUTE: after start of SuperCDMS SNOLAB available for low-rate experiments & R&D with cryogenic detectors (including but not limited to test for future SuperCDMS phases)



Single eh-pair sensitive device

<20 eV threshold in pure phonon detector (11 g)



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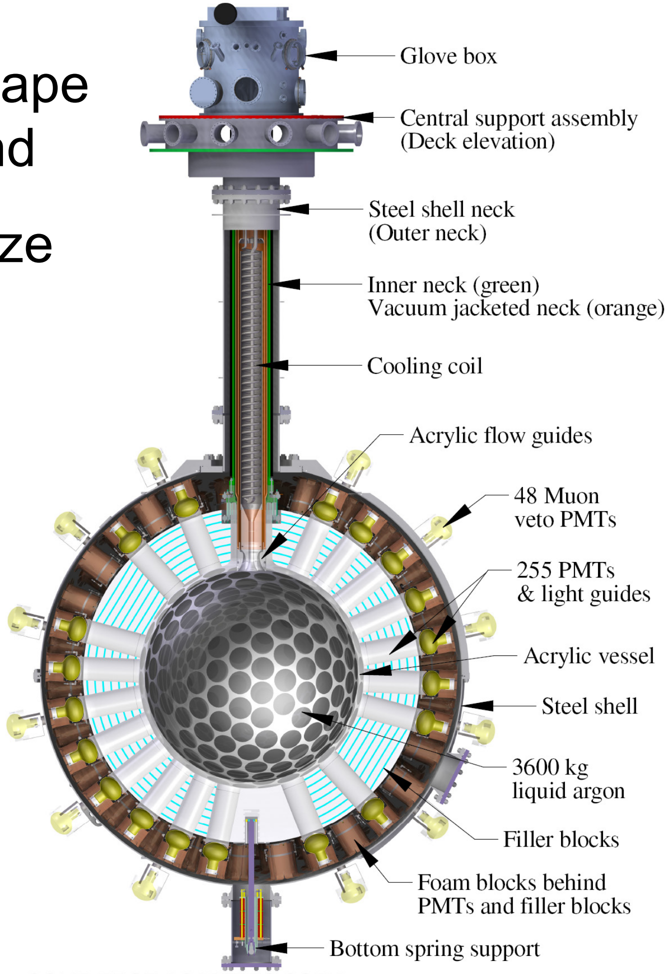
Argon Dark Matter Searches

- DEAP: ~3 t of liquid argon to detect high-mass DM particles, surrounded by shielding
- PMTs detect scintillation light; use pulse shape analysis to discriminate against background
- Natural radioactivity (^{39}Ar) limits detector size
- Taking DM data since ~4 years



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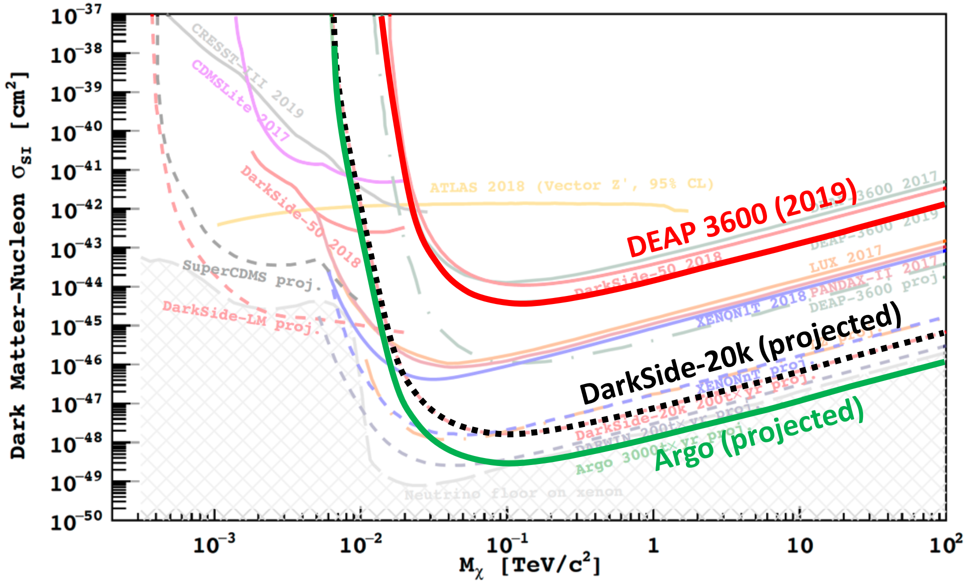
Argon Dark Matter Searches

- DarkSide-20k: DEAP joint forces with DarkSide-50 and others to build a 40 t 2-phase LAr detector at LNGS, Italy.
- Uses Ar from underground sources with much less ^{39}Ar
- Start of operations planned for 2023
- ARGO: planned follow-up to DarkSide with 300 t of underground argon, located at SNOLAB
- TRIUMF contributions:
  - DAQ for DEAP/DarkSide-20k
  - Photo detector development for Argo
- More details on Ar detectors: P. Giampa's talk on Thursday
- Photo detectors: F. Retier's talk on Thursday



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Conclusion

- Astroparticle Physics is making important contribution to our understanding of particle physics and answer questions form astrophysics and cosmology
- SNOLAB is one of the world's best locations for low-energy astroparticle physcis experiments
- TRIUMF plays key roles in a large number of dark matter and neutrino experiments at SNOLAB, past, ongoing and future (including some I didn't talk about):
  - SNO/SNO+ (Solar neutrinos, $\beta\beta$-decay, geo neturinos …)
  - HALO
  - nEXO
  - SuperCDMS and CUTE
  - DEAP, ARGO
  - PICO (DM)
  - Scintillating Bubble Chamber (DM)