The cryogenic design of the SuperCDMS SNOLAB experiment

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Introduction

- SuperCDMS SNOLAB is the latest generation of the Cryogenic Dark Matter Search experiments.

- These experiments aim to detect low mass (<10 GeV/c^2) dark matter particles by measuring the small nuclear recoil energies produced by rare elastic scattering interactions between the dark matter and normal matter targets.

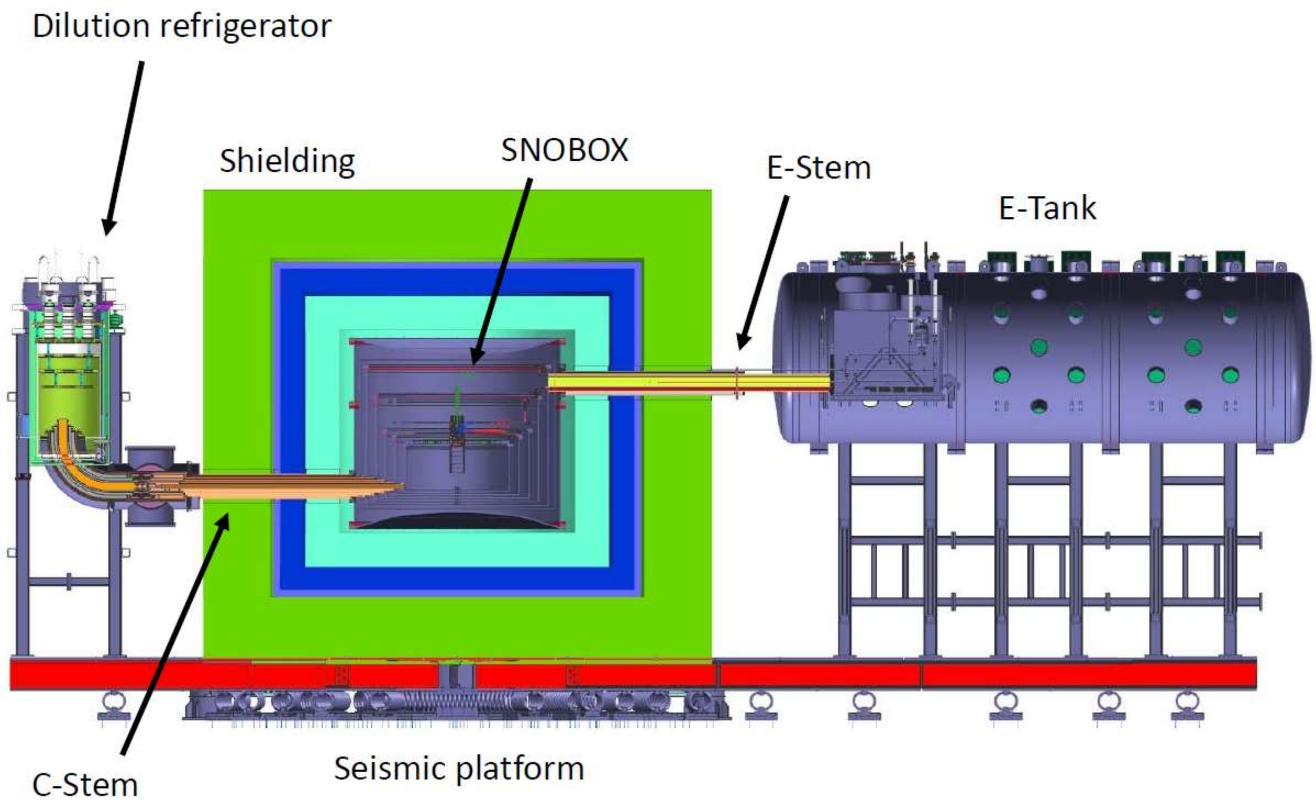
- The experiment will employ silicon and germanium crystals operated at temperatures of 15 mK or colder as the scattering target.

- Currently undergoing final design and initial stages of construction, the experiment is expected to deploy to the SNOLAB facility near Sudbury, Ontario (2070 meters depth) starting in 2019

Requirements of the cryogenic system

- The experiment must run for extended periods (>1 year) with minimal interaction from operators due to limited access to the laboratory facility.
- Cryo system must be closed-cycle (i.e. no expenditure of liquid cryogens) for reliability and to eliminate the need for automated or manual transfer systems.
- To achieve <15 mK base temperature, the system is built around a high-cooling power cryogen-free dilution refrigerator, with additional cooling circuits at the higher temperature stages
- Detectors must reside in a low radiation background, so materials must be carefully selected

Experiment design overview



Overview in cross-section of the SuperCDMS SNOLAB experiment with key features indicated

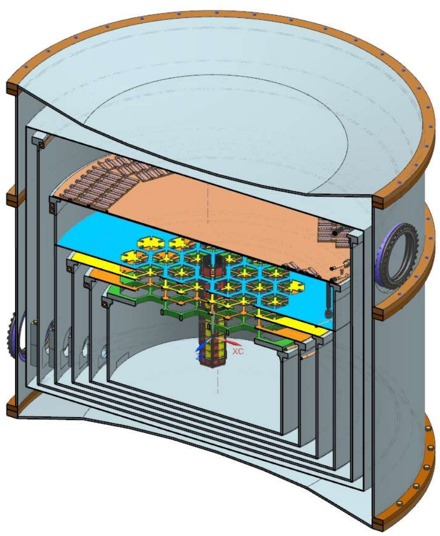
Thermal architecture

- The experiment has 7 thermal stages at decreasing temperature:

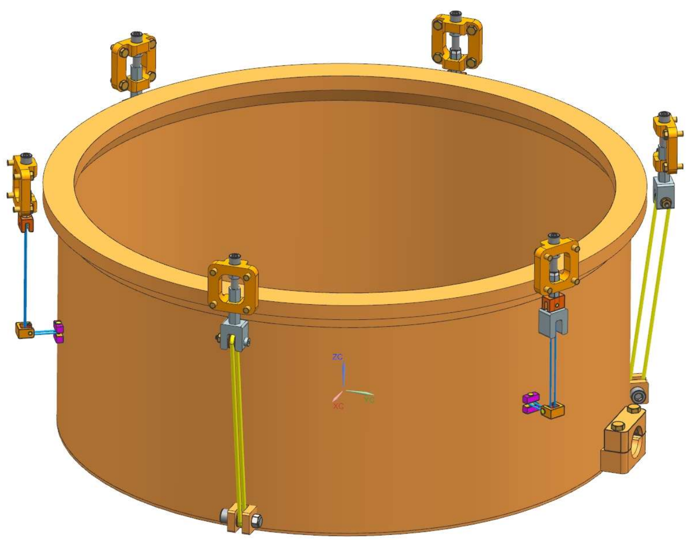
Stage	Nominal temperature	Cooling system
Outer vacuum chamber, “OVC”	300 K	-
Floating shielding, “FS”	255 K	Passive radiation
Shield, “SH”	50 K	Circulated He gas
LH	4.5 K	2-phase helium
Still	1 K	Dilution refrigerator
Cold Plate, “CP”	250 mK	Dilution refrigerator
Mixing Chamber, “MC”	15 mK	Dilution refrigerator

Mechanical design

- Detectors installed in cryostat referred to as the “SNOBOX” with nested cans buffering the heat loads to the next stage
- Fabricated almost entirely from UNS C10100 OFHC copper using e-beam welding
- Layers suspended by a system of aramid ropes



Cross-section through SNOBOX vessel. Vessel is 1.84 m diameter and 1.7 m tall



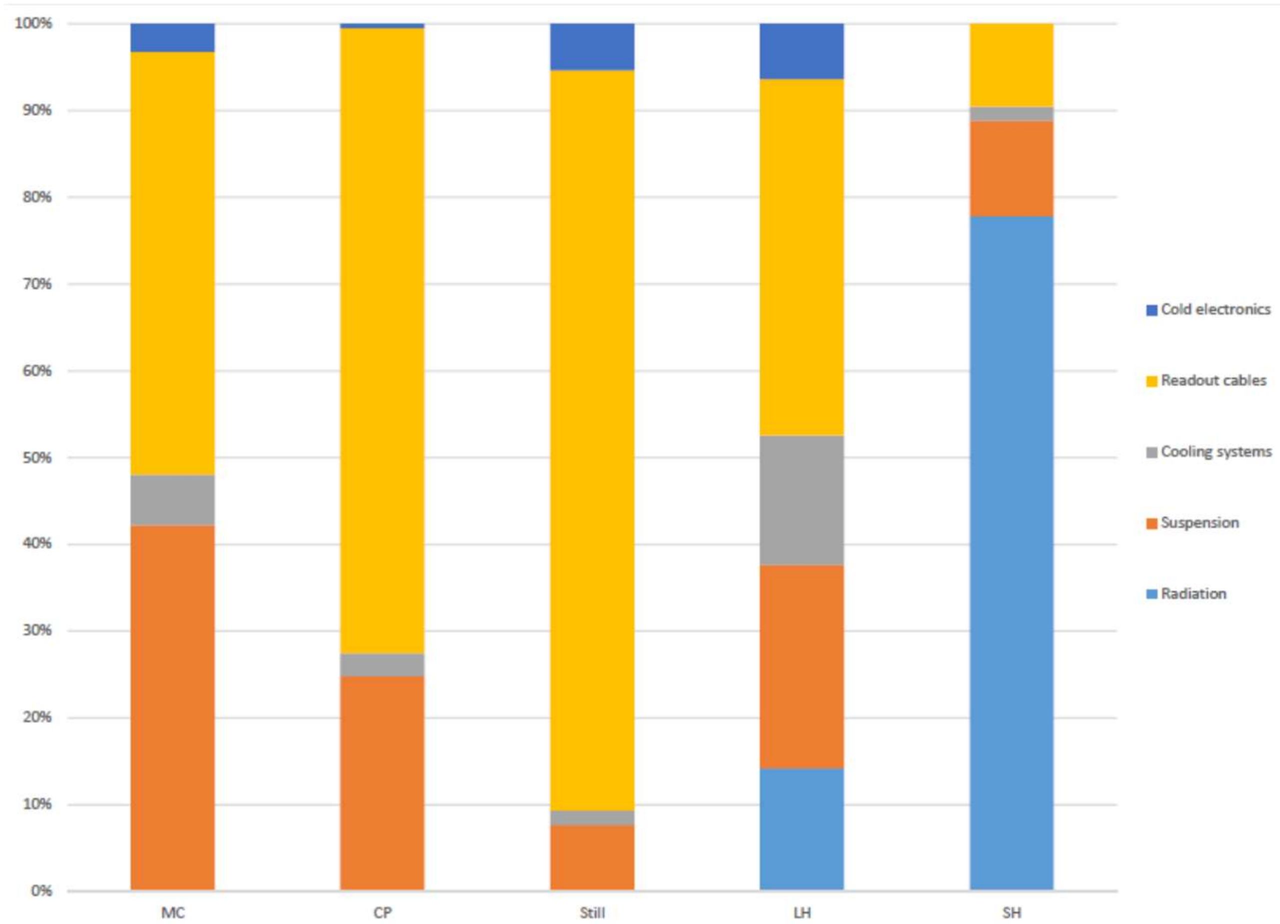
Can with aramid rope suspension system

Thermal modelling

- Careful account of all thermal transfer mechanisms to establish required cooling capacity at each thermal stage.

	MC	CP	Still	LH	SH
Radiation	17 pW	6.1 nW	3.7 μW	165 mW	69.1 W
Suspension	650 nW	28.5 μW	0.31 mW	273 mW	9.8 W
Cooling system	90 nW	3.0 μW	70 μW	173 mW	1.4 W
Readout cables	750 nW	82.8 μW	3.5 mW	478 mW	8.5 W
Electronics	50 nW	0.57 μW	0.22 mW	74 mW	n/a
Total	1.54 μW	115 μW	4.1 mW	1.16 W	88.8 W

Thermal modelling (cont.)



Relative contributions of each heat transfer mechanism

Available cooling capacities

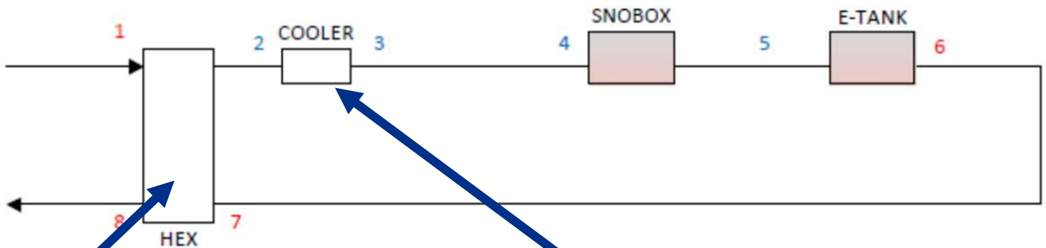
- System has been designed with a minimum factor 2 margin on the available cooling capacity.

Stage	Nominal temperature	Model heat load	Available cooling power
SH	50 K	88.8 W	180 W
LH	4.5 K	1.16 W	2.8 W
Still	1 K	4.1 mW	15 mW
CP	250 mK	115 μW	350 μW
MC	15 mK	1.54 μW	5 μW

50-K cooling system

- 50-K cooling uses He gas at 100 psig circulated at 8 g/s with a warm compressor thru a counterflow heat exchanger and passed a single-stage cryocooler

Cryomech
CP-1000
compressor
package

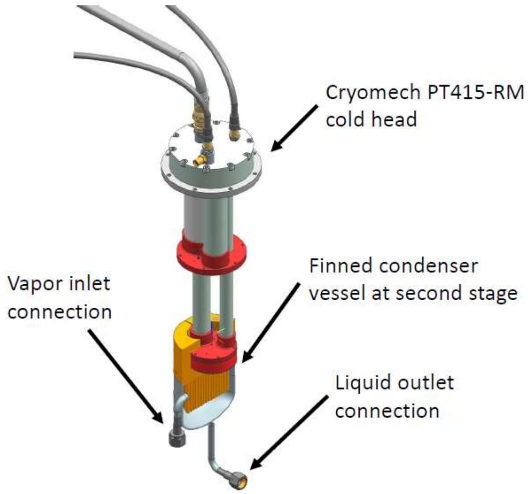


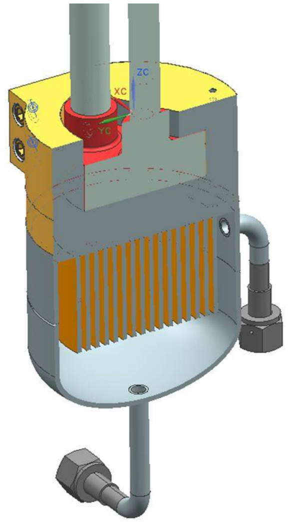
Stainless steel brazed
plate heat exchanger

Cryomech
AL300 G-M
cooler

4-K cooling system

- Cooling at the LH layer is provided by a 2-phase helium thermosiphon. Helium vapor from the return leg of thermosiphon is re-condensed using Cryomech PT415 pulse tube coolers





- Thermosiphon flow is mostly horizontal.
- Flow is slow, 4.5 g/s 2-phase flow with ~1% vapor

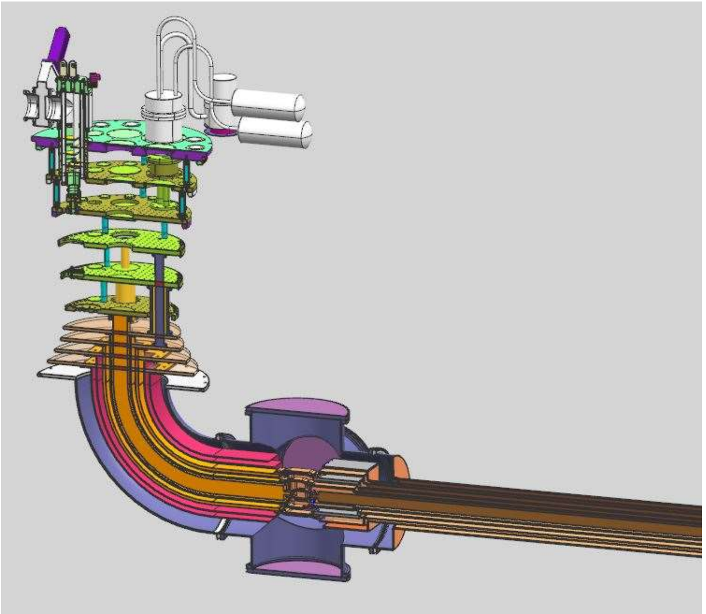
Helium recondenser system attached to PT415 cryocooler

Fermilab

The dilution refrigerator

- Refrigerator is a modified version of Leiden Cryogenics CF-2100-Maglev-2PT large frame fridge, capable of reaching a 7 mK base temperature.
- Fridge connects to SNOBOX via multi-layer C-Stem assembly (see companion poster/paper C3PoB-08 by Ram Dhuley).

CAD model of fridge assembly connected to C-Stem



Unmodified LC CF-2100-Maglev-2PT dilution refrigerator

Summary

- The SuperCDMS SNOLAB experiment is a latest in a series of cryogenic direct detection dark matter experiments.
- The experiment is designed to run a payload of up to 186 Ge and Si detectors at a temperature of 15 mK for up over 1 year at a time, using a large cryogen-free dilution refrigerator and supporting cryogenic systems.
- Due to begin deployment to the SNOLAB facility in 2019 and begin operations in 2020, the experiment is currently undergoing final design and preliminary construction

Thank you

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