



Queen's
UNIVERSITY

CUTE – A low background facility for testing cryogenic detectors

Serge Nagorny

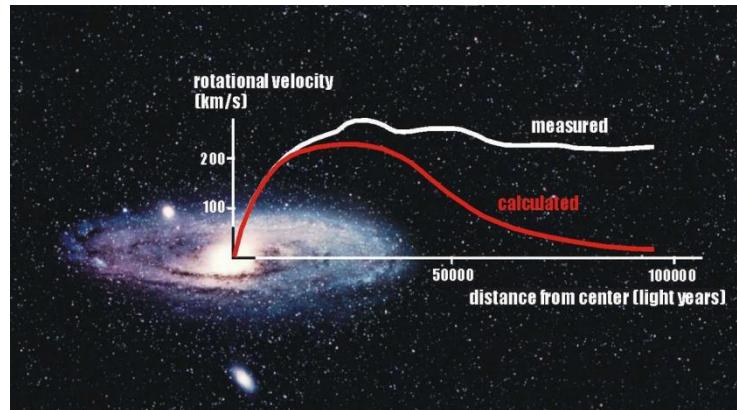
on behalf of the CUTE collaboration

March 14th, 2019

Dark matter evidence



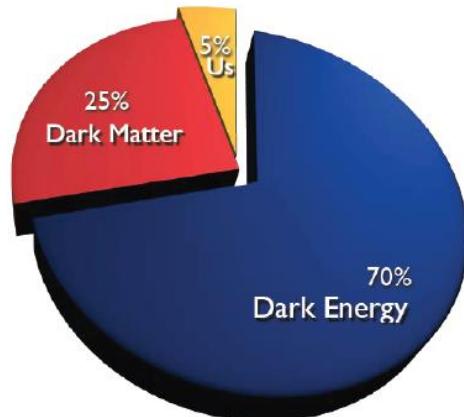
Credit: O. Lopez-Cruz
I. K. Shelton



Credit: cdms.phy.queensu.ca

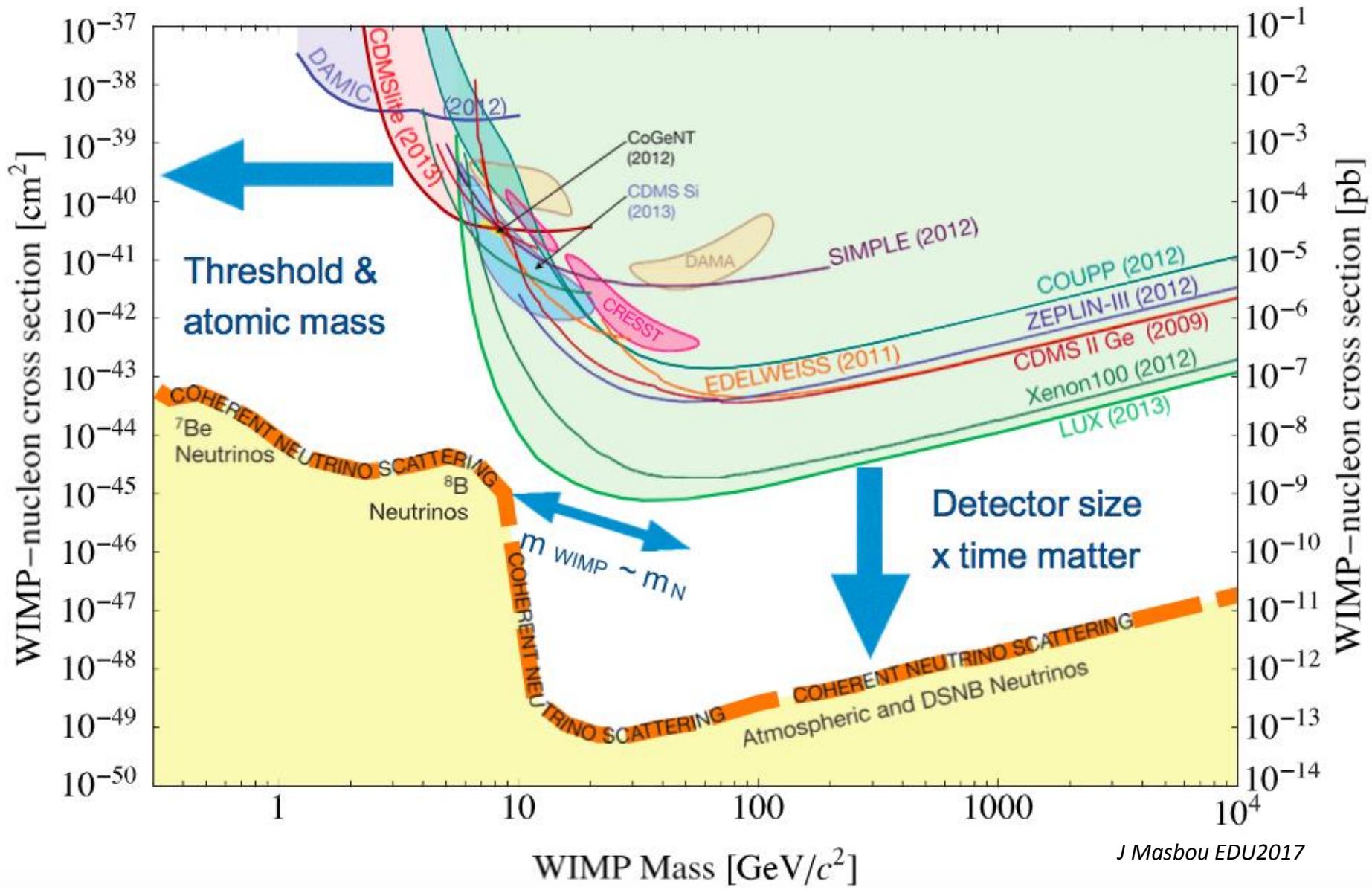


Credit: NASA, CXC, CfA, et al.

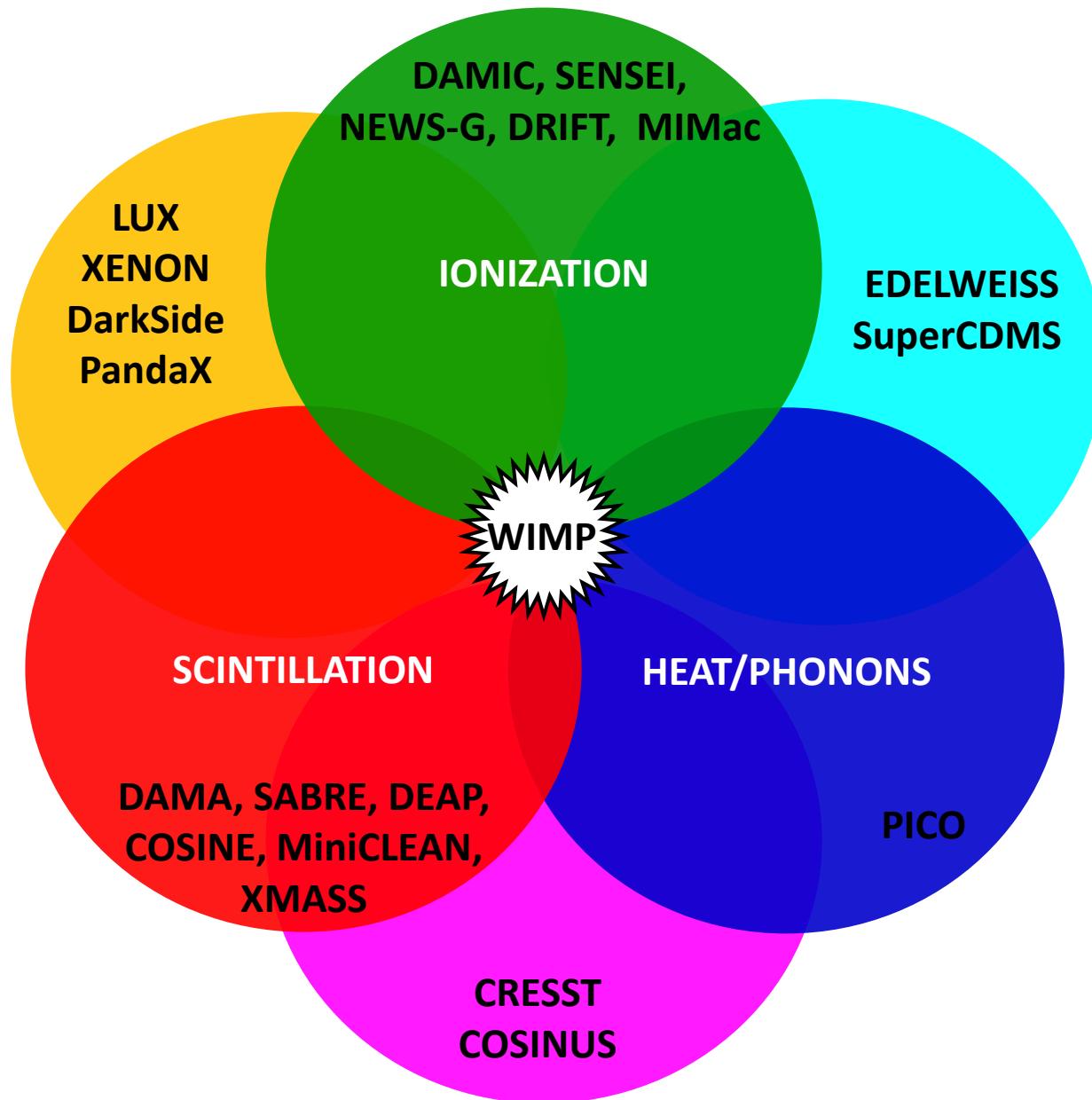


Astronomical and cosmological observations suggest that dark matter composes about 25% of all matter in the universe

Brief reminder of situation in DM search

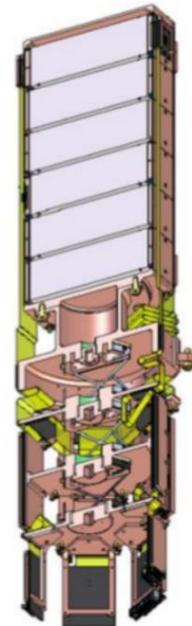
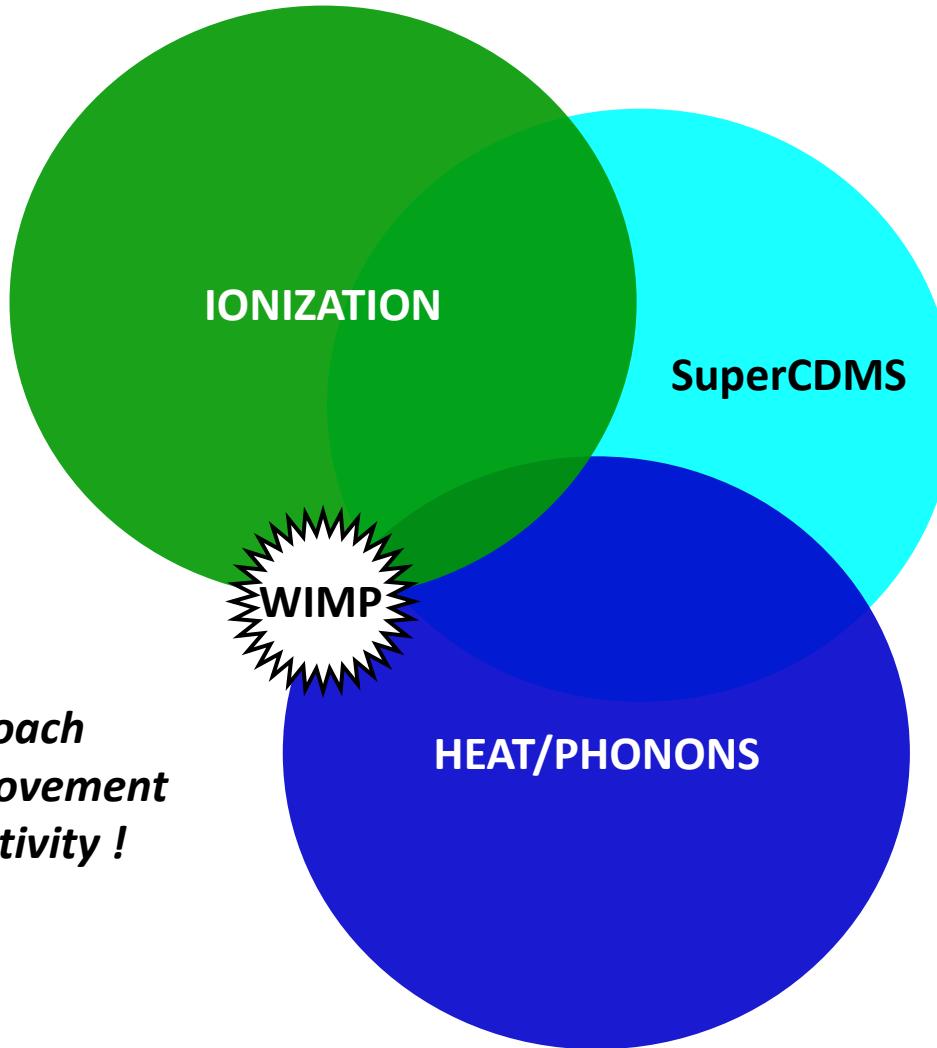


Direct dark matter search

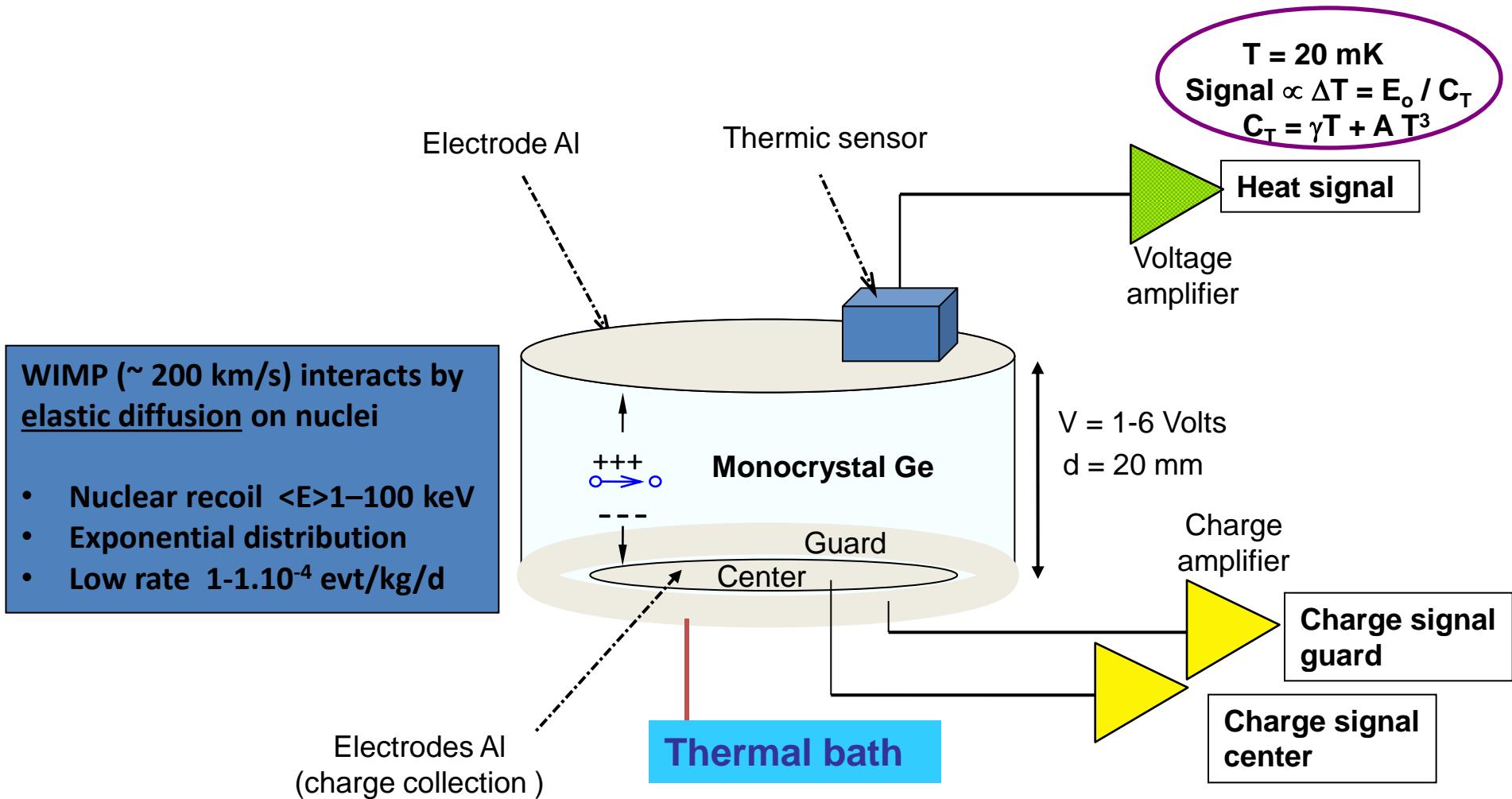


Direct dark matter search

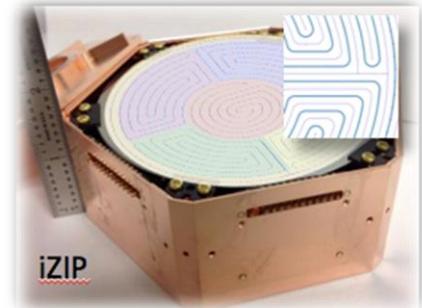
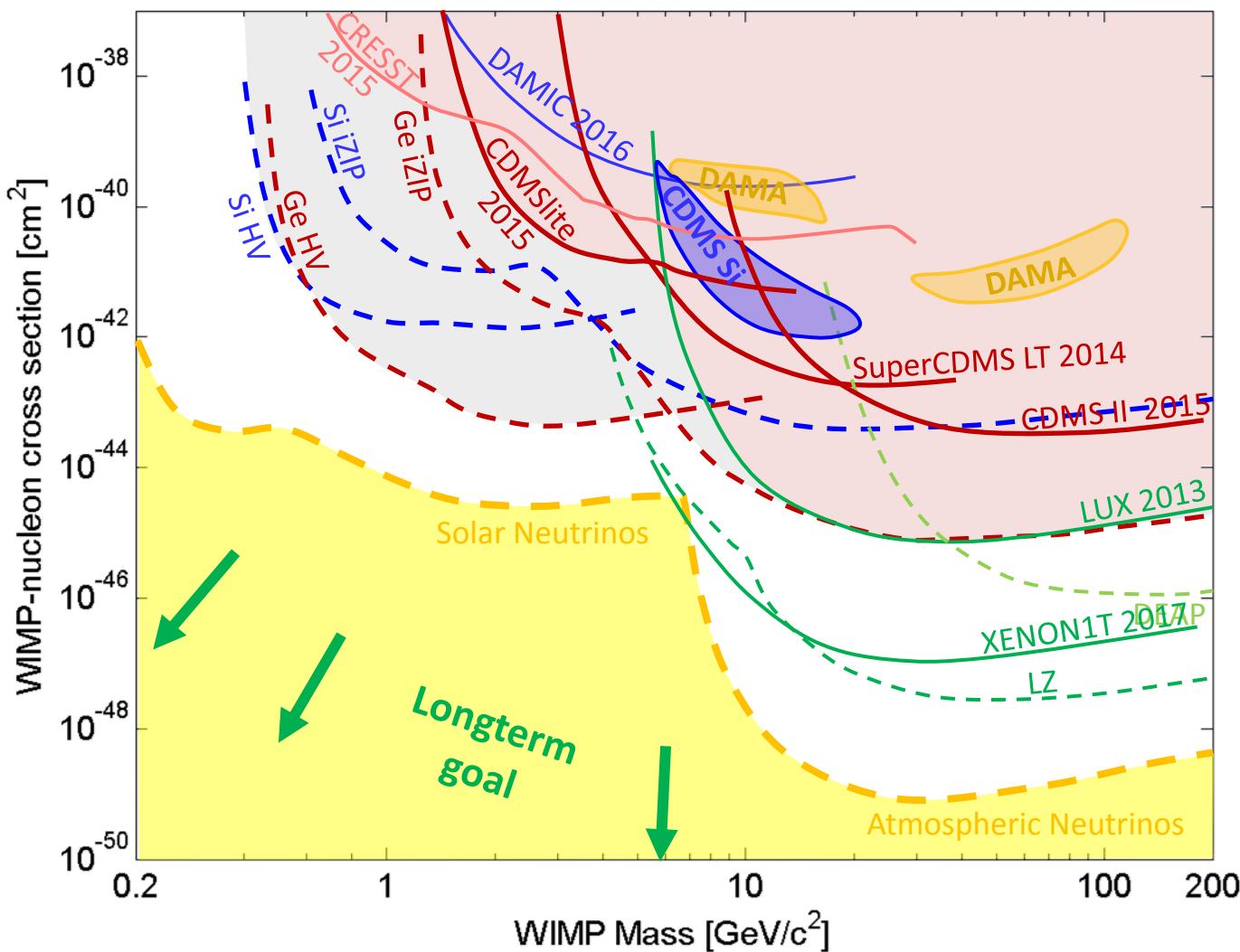
*Two channels approach
allows significant improvement
of experimental sensitivity !*



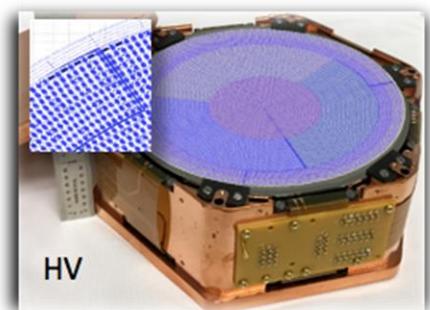
Concept of ionisation-heat (phonon) detectors



SuperCDMS expected sensitivity @ SNOLAB



“iZIP” detectors
Higher threshold
Part.ID.

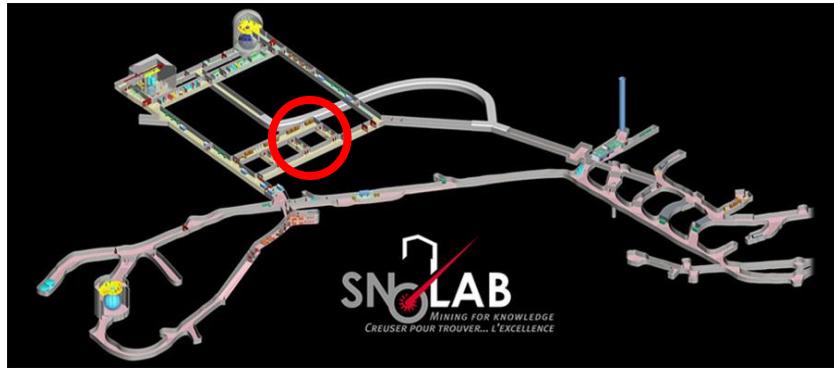


“HV” detectors
Low threshold
No Part.ID.

Motivation

- Provide a moderate size (10 kg detector) handy (few days turnover) well-shielded cryogenics (20 mK) infrastructure for rare event physics
 - Test and validation of entire SuperCDMS detector tower (6 detector + electronics)
 - Measurements in a low background environment avoiding cosmogenic activation of detector's material (${}^3\text{H}$, ${}^{32}\text{Si}$, etc.)
 - Complete SuperCDMS detector characterization to understand its intrinsic background and noise issues
 - Confirmation of screening program and handling procedures
 - Early science run for dark matter search can be performed thanks to low-background environment and low-energy threshold of SuperCDMS detectors
- Testing of various type cryogenic detectors

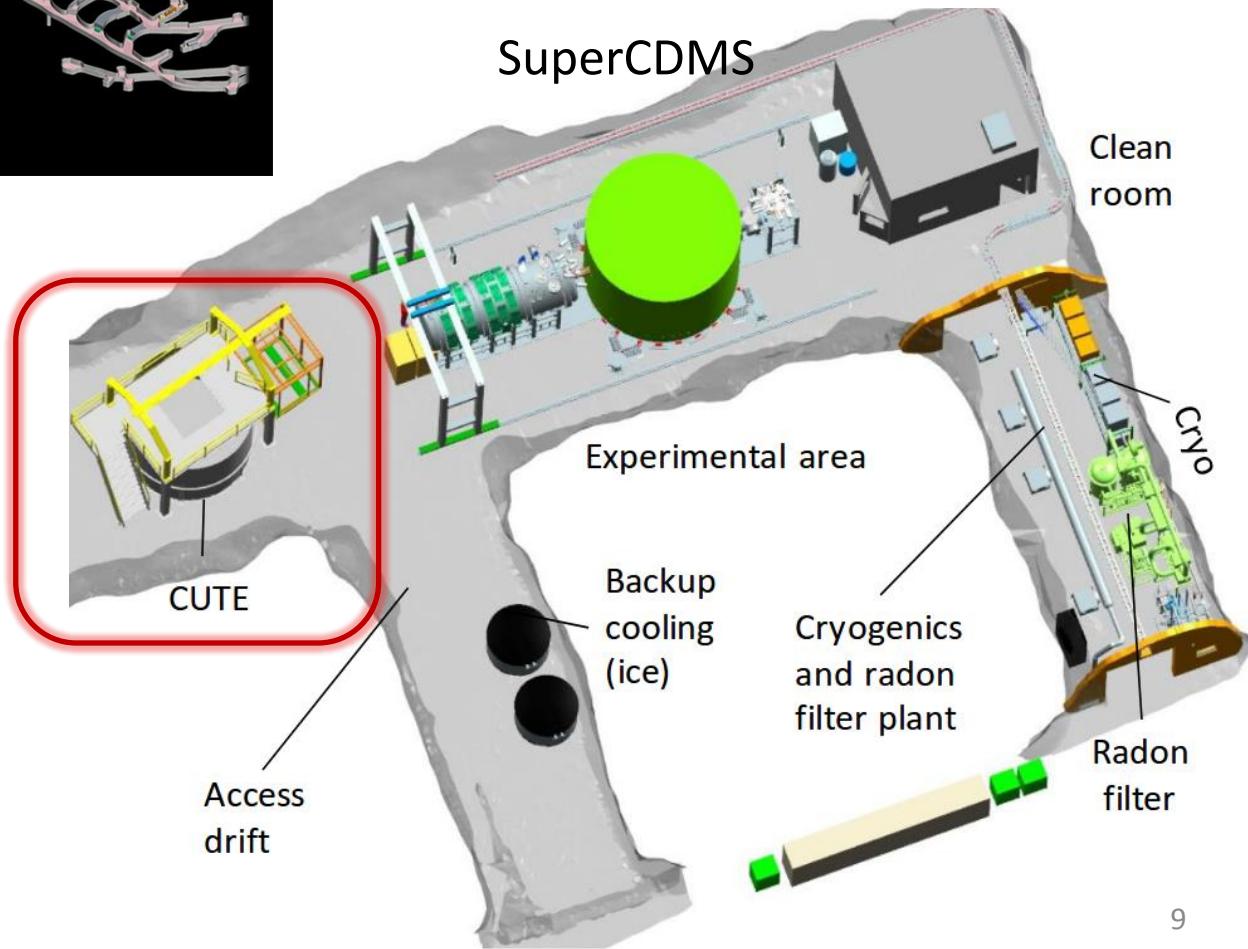
CUTE location at SNOLAB



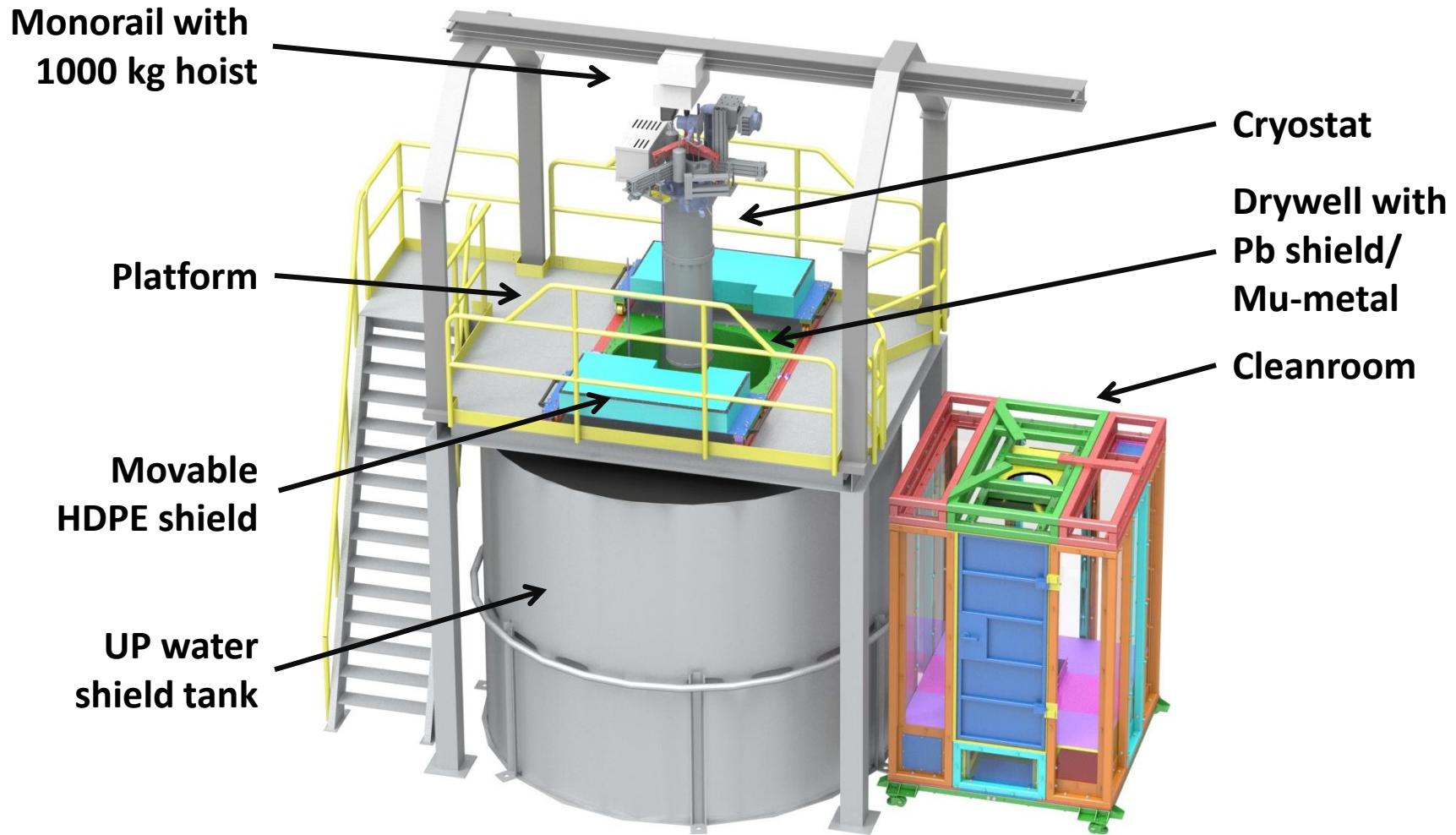
2 km deep

Strong cosmic ray flux suppression

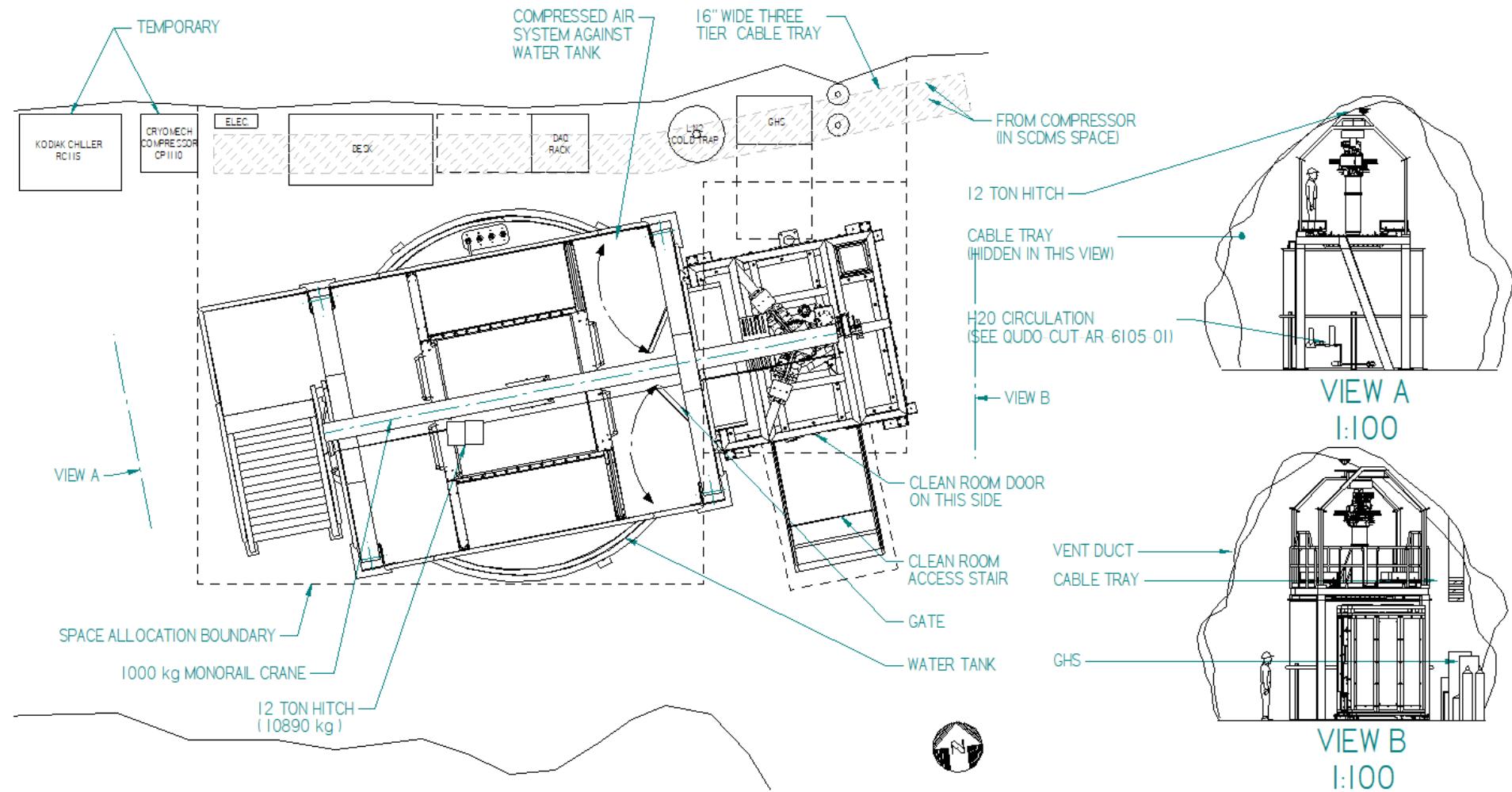
Cleanroom environment



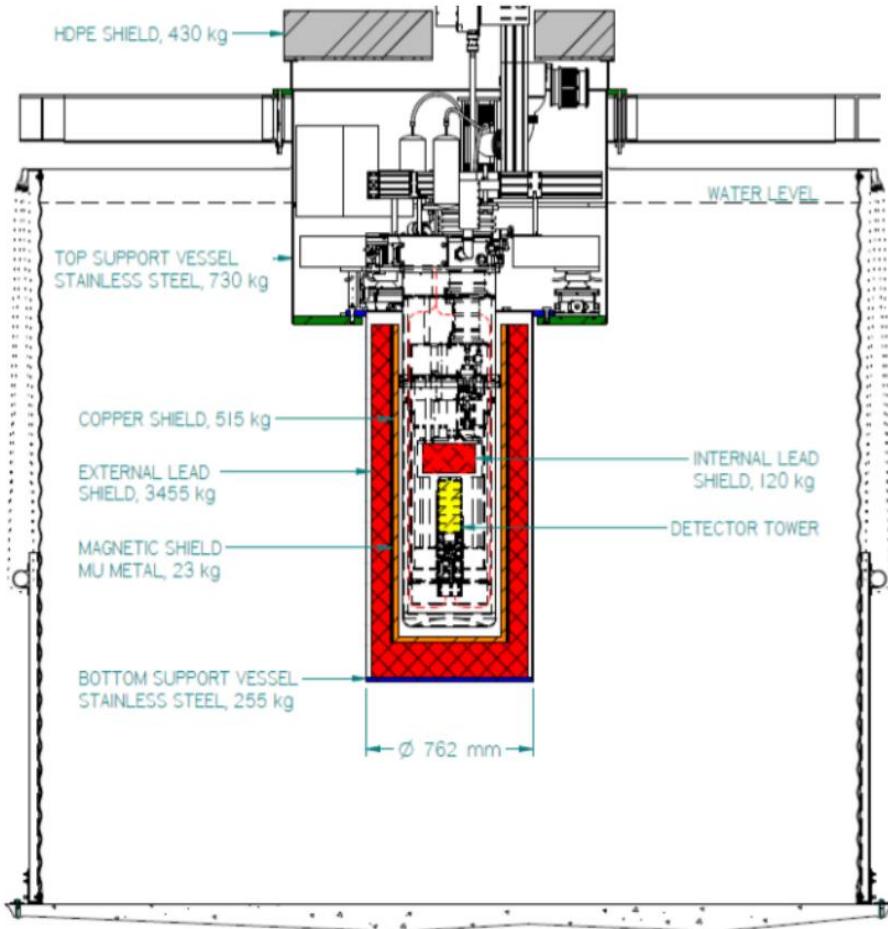
General view of the CUTE facility



Final arrangement

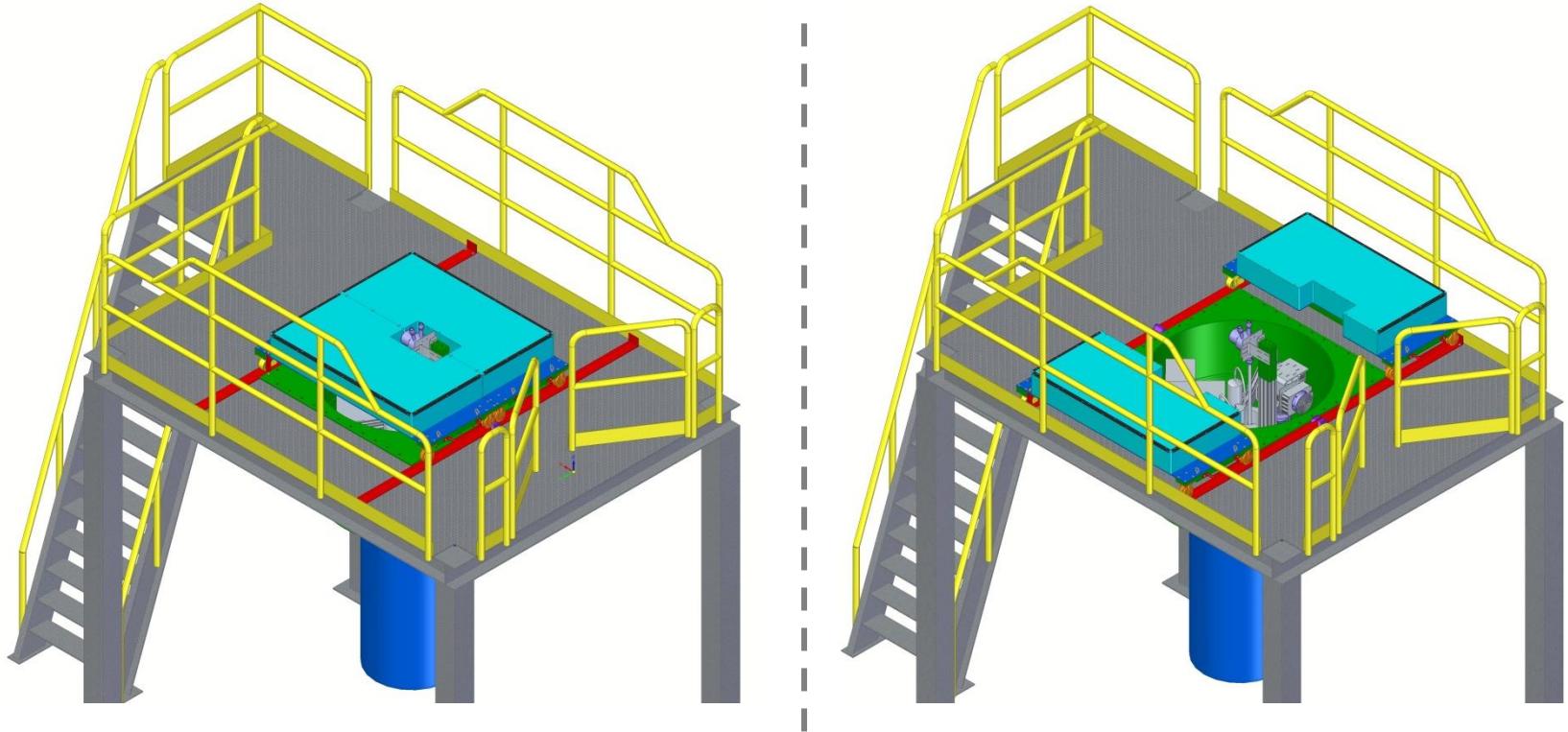


Shielding in the CUTE facility



- Cryostat placed inside the drywell of a water tank
- 1.5 m of water layer at side and 1.0 m at bottom reduces external neutron and gamma flux
- 11-15 cm of low activity Pb reduces residual gammas
- The gap from the top is closed off by 20 cm of HDPE and 15 cm of Pb inside cryostat
- Internal Cu shields block IR photons, which contribute to detector noise

PE shielding



20 cm thick HDPE layer on top of the cryostat for neutron flux suppression

PE shielding

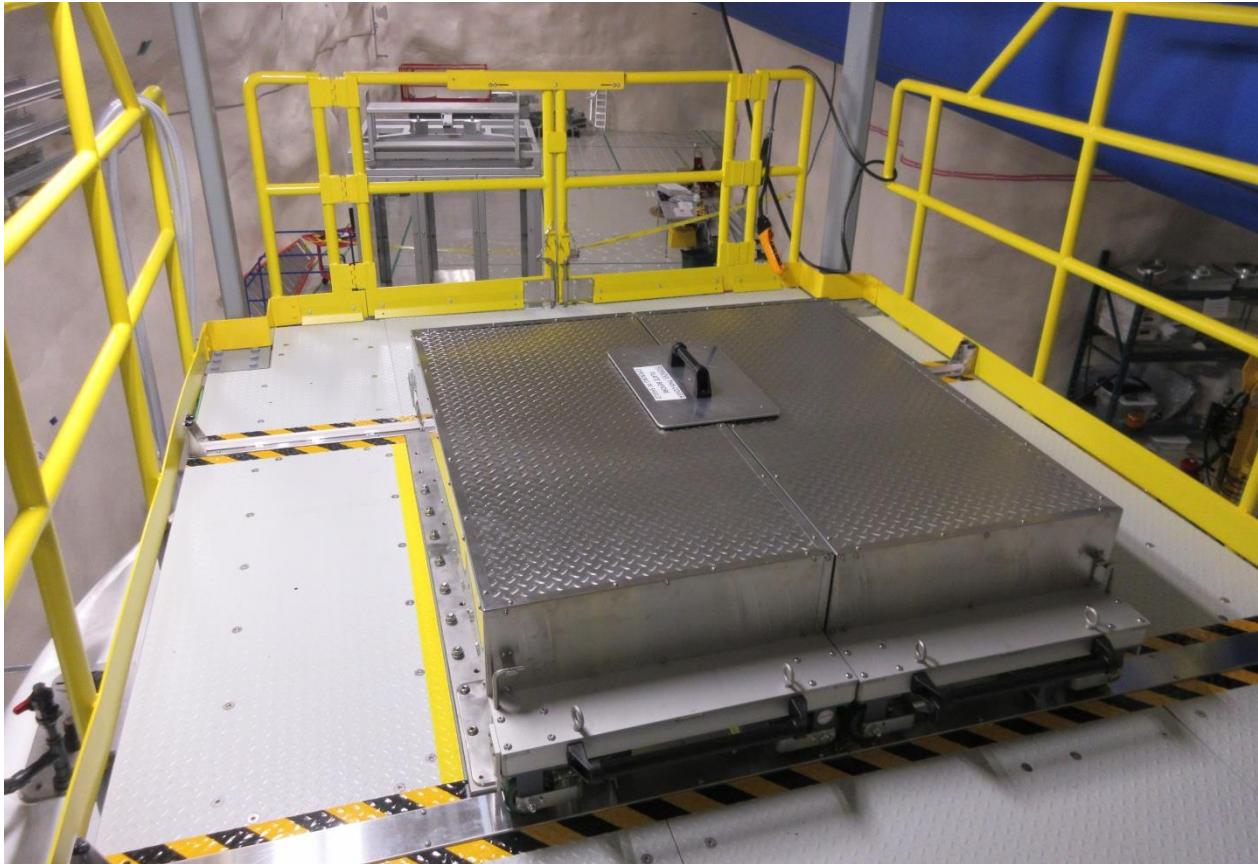


8 layer of 1" HDPE sheet



Rigging/lifting test at producer site

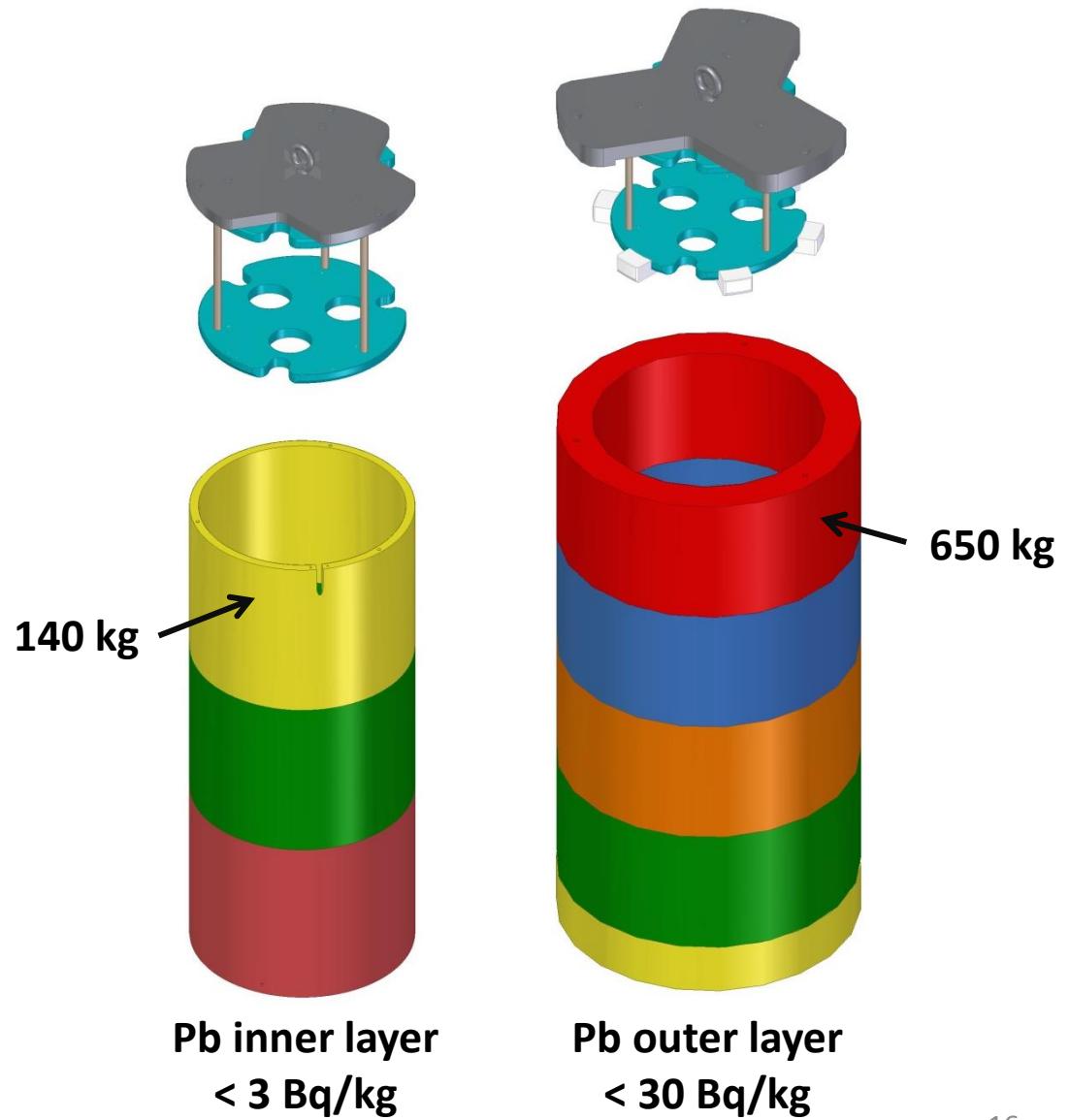
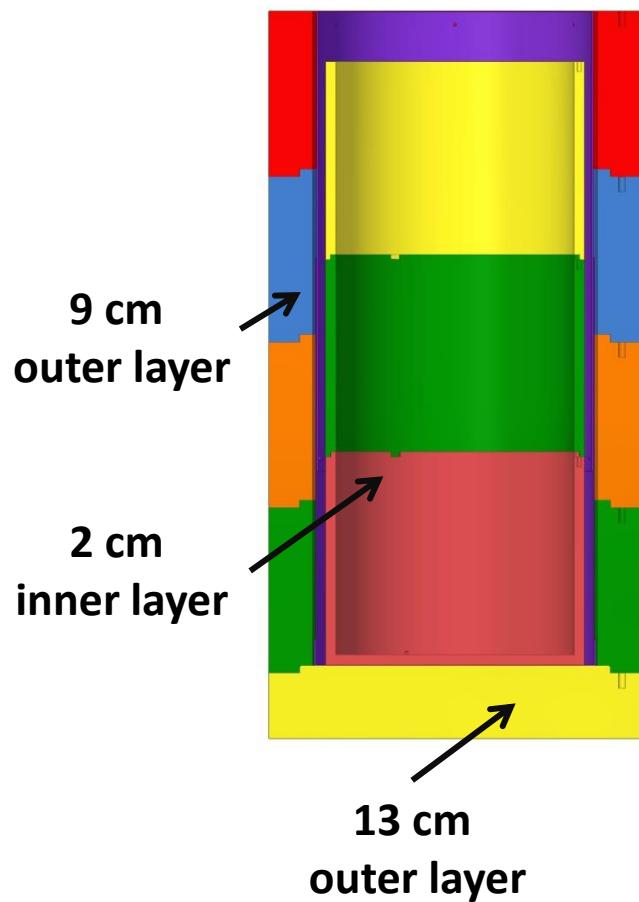
PE shielding



Installed

Fully functional, tested during Pb shield installation, Feb 2019

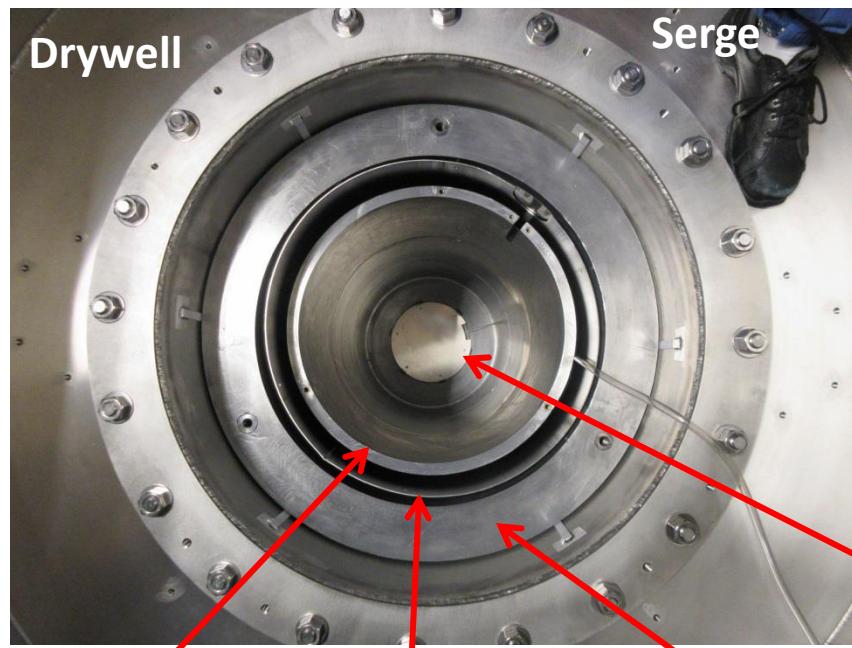
Lead shielding





Lead shielding

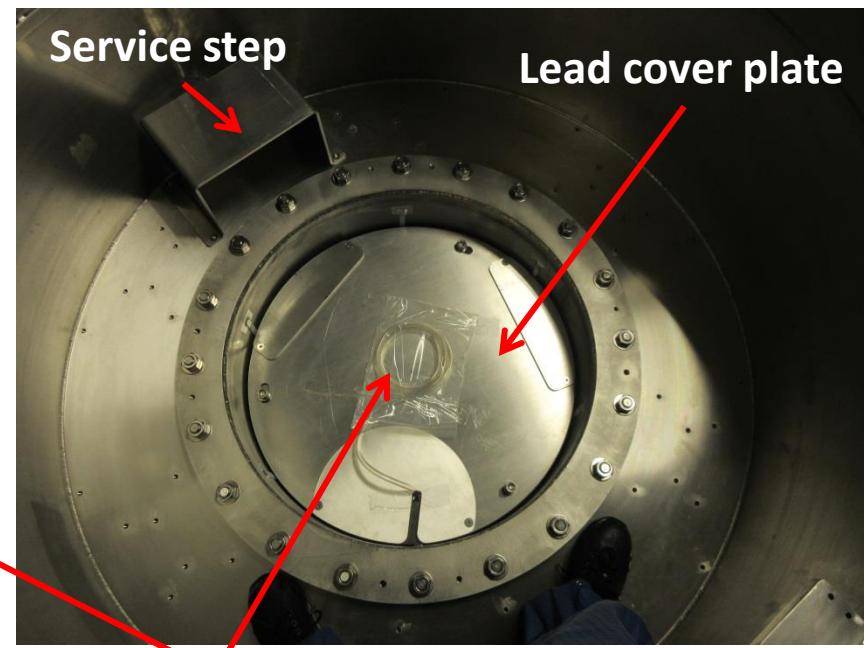
Installed @ Jan 25th, 2019



Inner Pb, 2 cm
 $< 3 \text{ Bq/kg}$

Outer Pb, 9 cm
 $< 30 \text{ Bq/kg}$

Mu-metal



Gas purge system

Background budget in energy range 0-2 keV

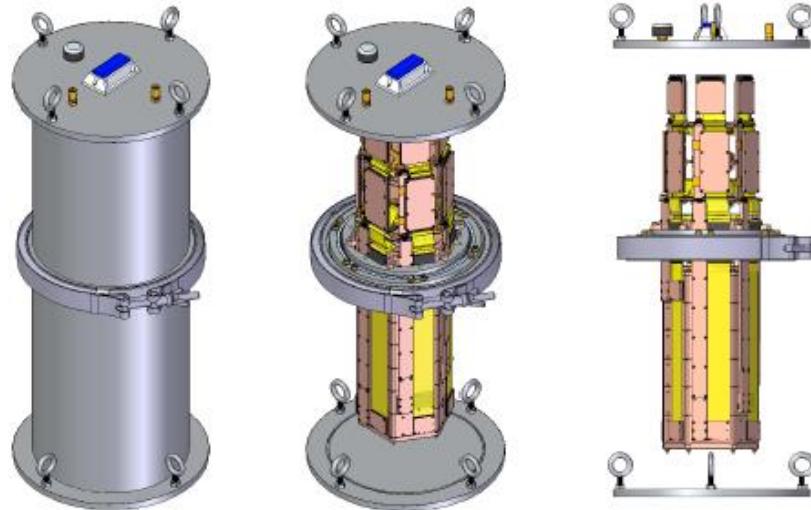
Material	Estimated background, events/(keV·kg·day)
External background (lead walls, etc.)	1.1
External Pb shielding	0.7
Stainless steel vacuum can	0.6
Internal background (cryostat cans, etc.) <i>caused mostly by ^{210}Pb</i>	0.5
Cosmogenic activation (3H , etc.)	< 0.1 (SNOLAB) 0.5 (early detector)
^{32}Si (in silicon detectors)	0.7
Detector housing	< 0.1

*Total background for Ge SuperCDMS detectors in the CUTE facility
is estimated to be ≤ 3 events/(keV·kg·day)
and will be precisely evaluated in the first background runs at SNOLAB*

Cleanroom (Class 500)

to minimize dust and radon exposure of detectors during mounting/dismounting procedures

Acceptable exposure $< 80 \text{ Bq}\cdot\text{h}/\text{m}^3$

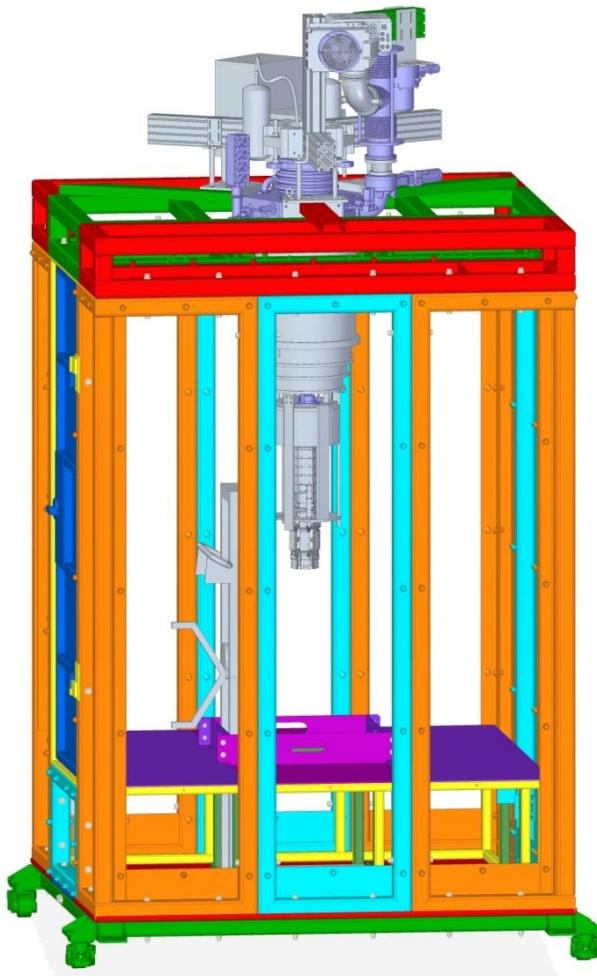


SuperCDMS detector tower will be delivered to SNOLAB in container under N_2 atmosphere and must be opened and installed in cryostat at CUTE cleanroom

Air @ SNOLAB	Underground	Surface
Rn activity	100-130 Bq/m^3	$< 10 \text{ Bq}/\text{m}^3$
Handling time	30-40 minutes	8 hours

} *our goal*

Cleanroom



- Space for two operators
- Aluminum structure with LEXAN panels
- Resistant to seismic events
- Movable
- Lifting device for cryostat cans
- Low Rn air supply ($< 3 \text{ Bq/m}^3$)
- Later SuperCDMS Rn-filter system ($< 0.1 \text{ Bq/m}^3$) will be used
- Crane moves cryostat between cleanroom and drywell

Cleanroom status @ March 1st, 2019



- **95% installation accomplishment**

To be completed:

- Connection to compressed air line
- Anchoring to the floor
- HEPA filter in air supply line
- Sealing with Al-tape
- Final cleaning

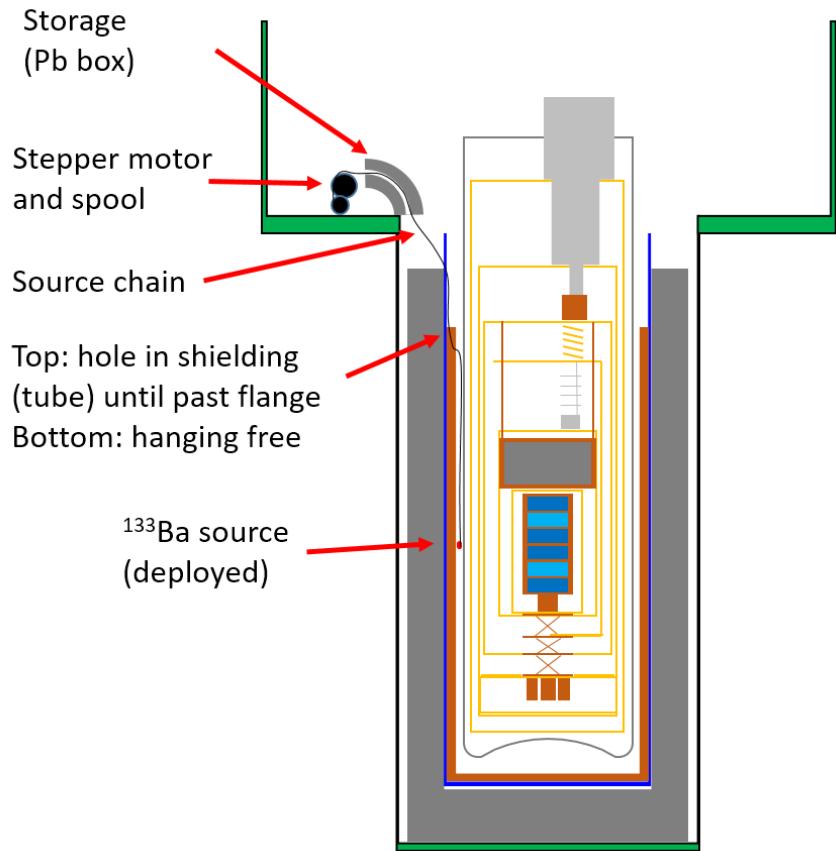
Installation Review, Part 3

(Feb 5th, 2019)

- Calibration system
- Suspension system
- Cryostat installation

All actions are planned to be completed by April 2019

Calibration system concept



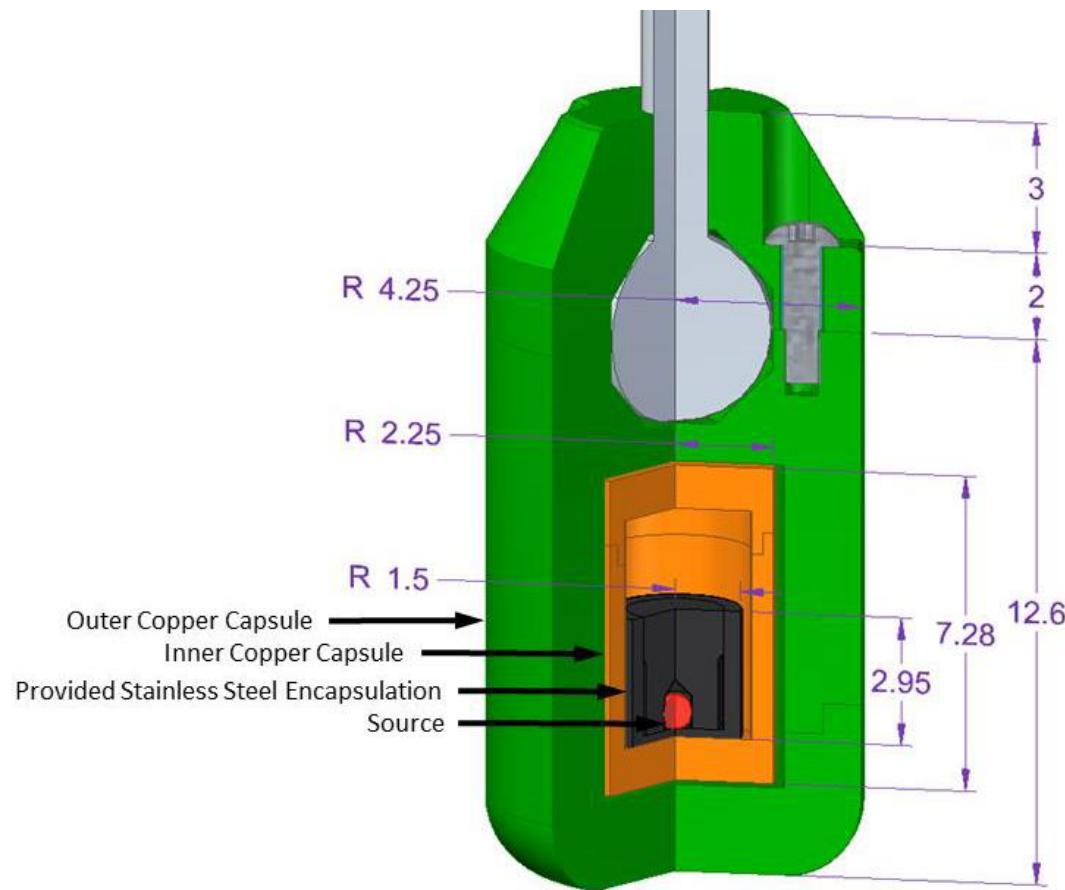
Different radioactive sources will be used to calibrate the energy scale and to monitor stability of detectors performance, as well for characterization of particle interaction types

Gamma source: ^{133}Ba (*this Installation stage*)

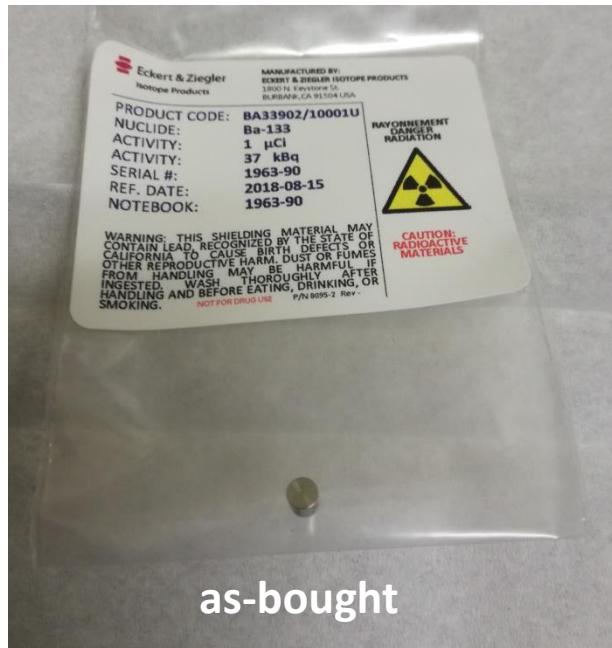
Neutrons source: ^{252}Cf (*next step in a while*)

Sources will be remotely moved from shielded storage box to the measurement position

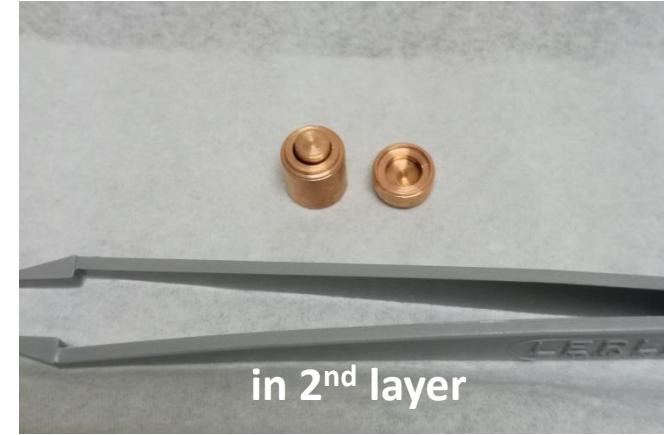
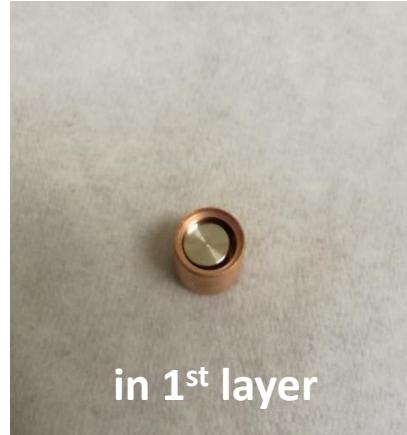
Calibration source design (*tested*)



Calibration source encapsulation

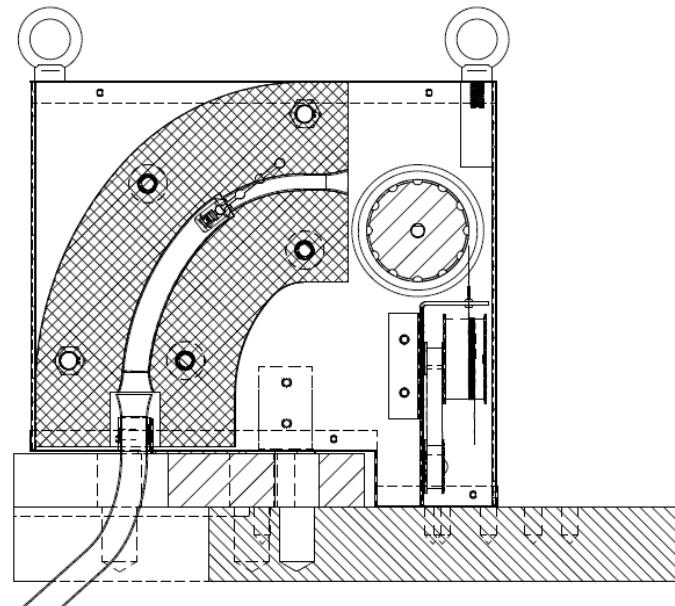
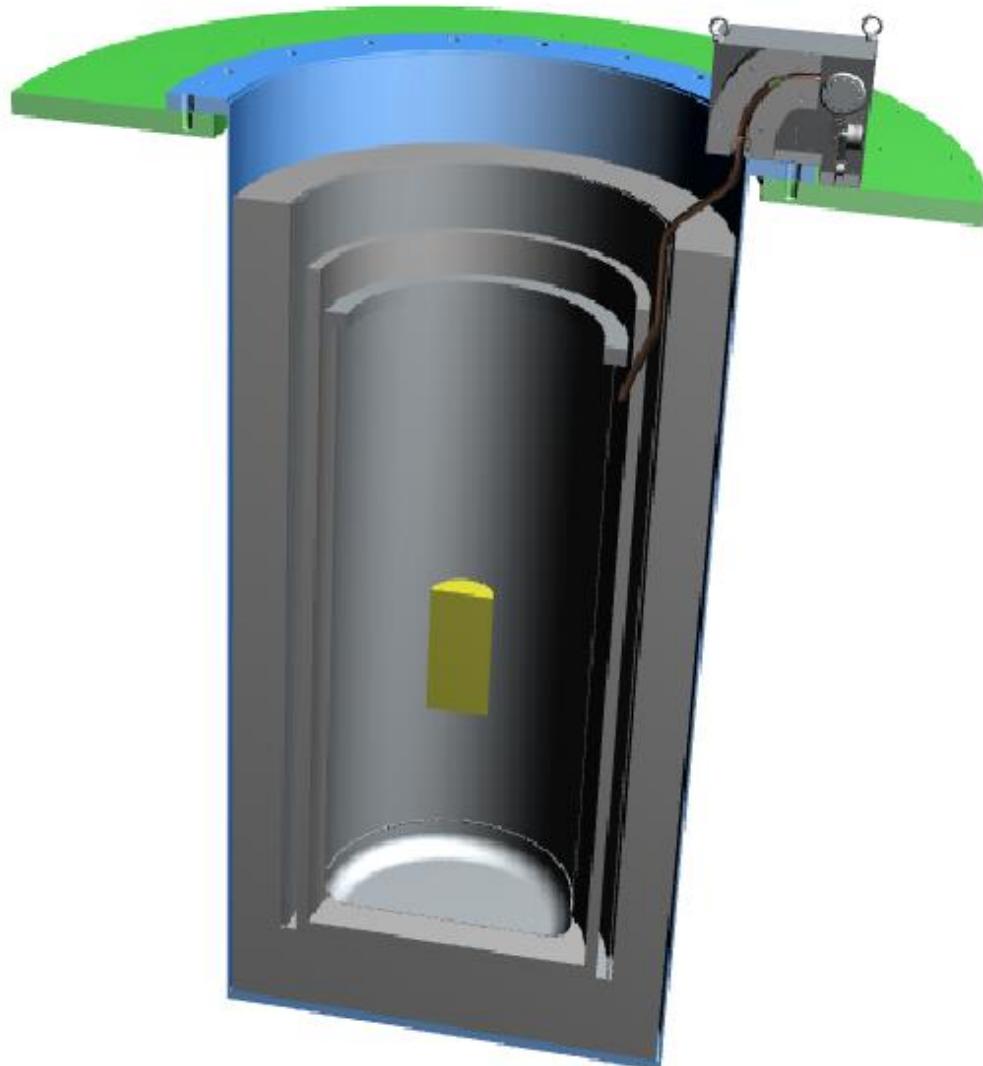


as-bought

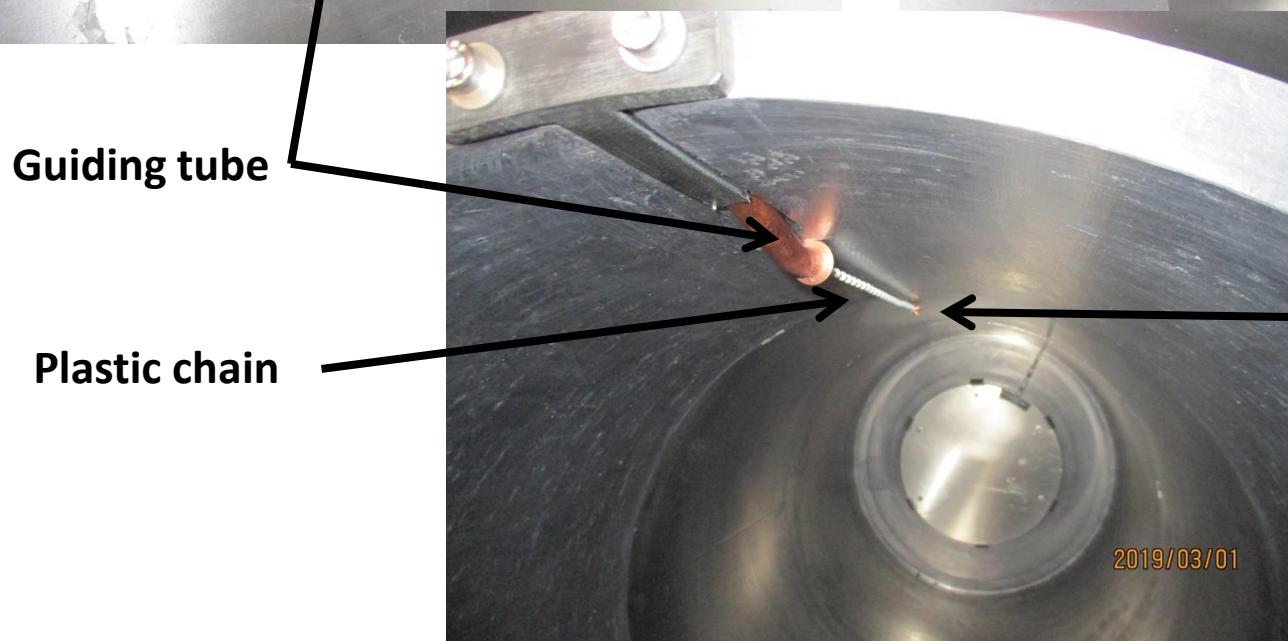
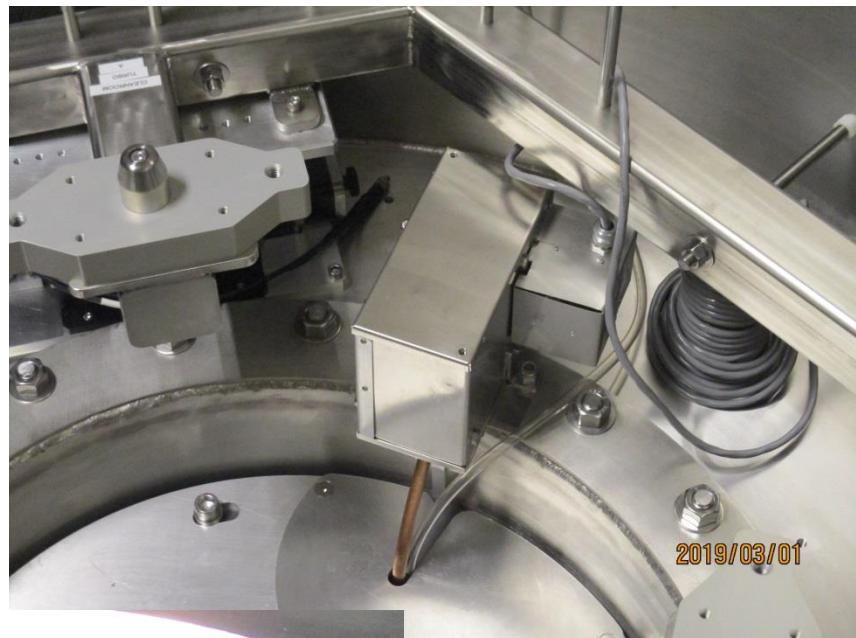


Double layer encapsulated, ready to be assembled

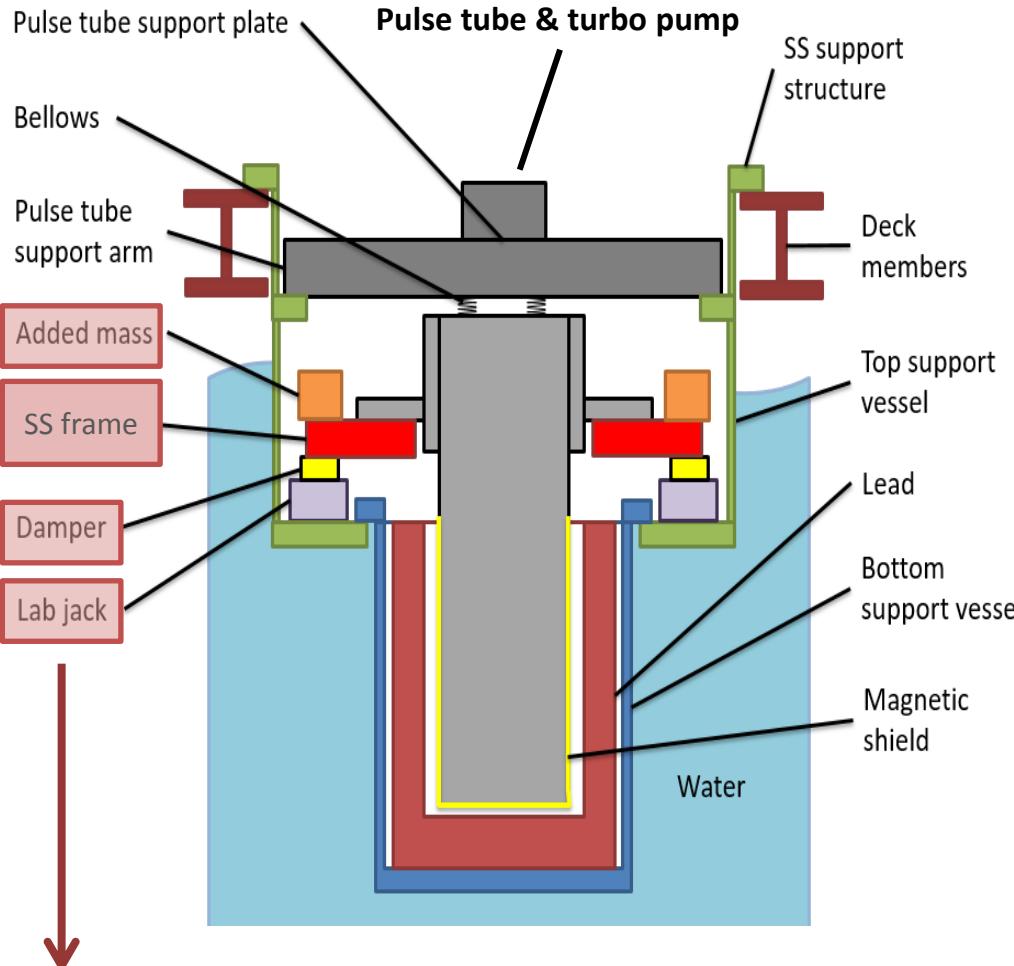
Calibration system: general overview



Calibration system status @ March 1st, 2019



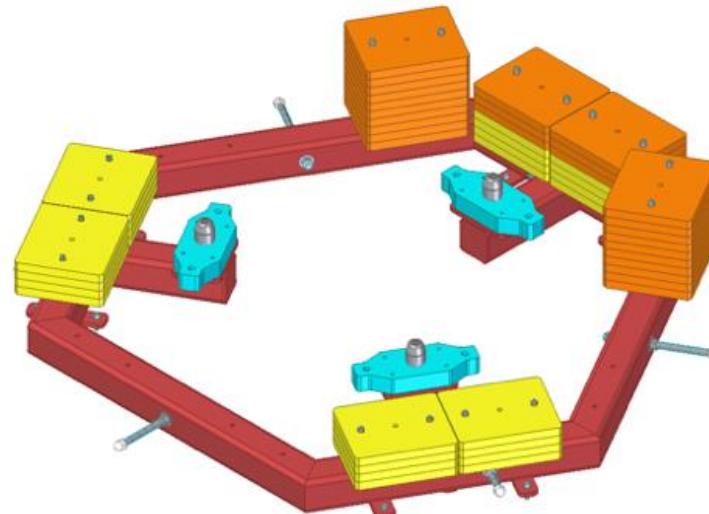
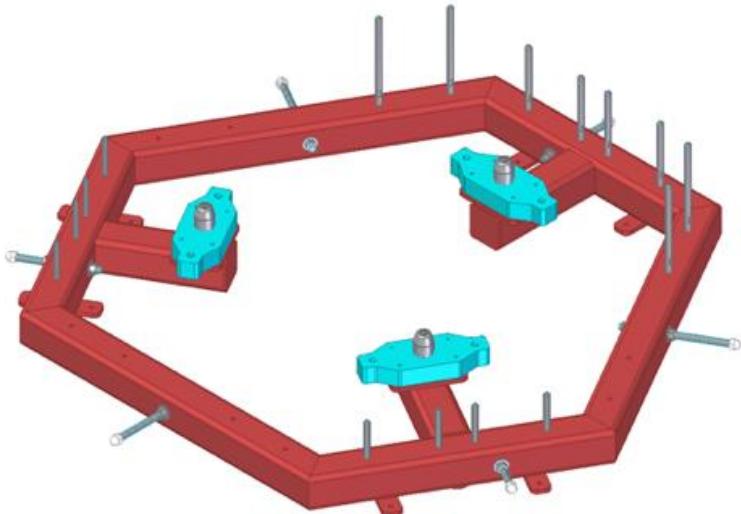
Active two-stages suspension system



Mechanical parts of the Suspension system

- Our detectors are sensitive to mechanical vibrations
- Pulse tube cooler and turbo pump are strong source of vibrations that may compromise detector performance
- Both are mounted on separate plate with soft coupling (bellows) to cryostat to minimize vibrations
- The bellows makes system sensitive to pressure fluctuations in SNOLAB
- Active suspension system tracks/controls cryostat position better than 1 mm

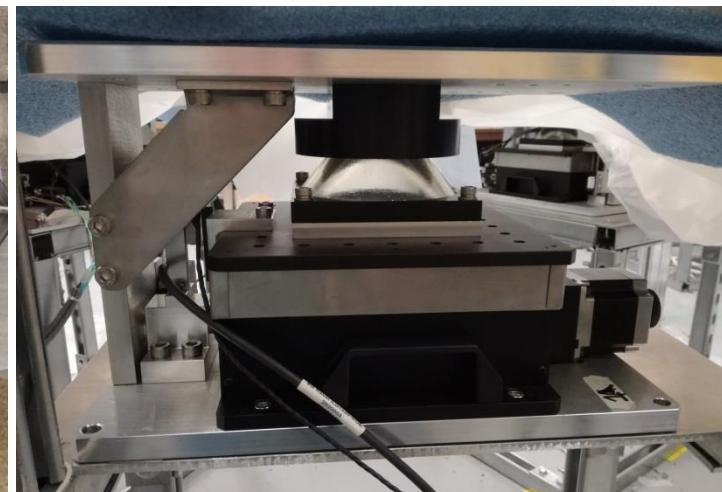
Suspension system



Added masses
(5.9 kg/each)



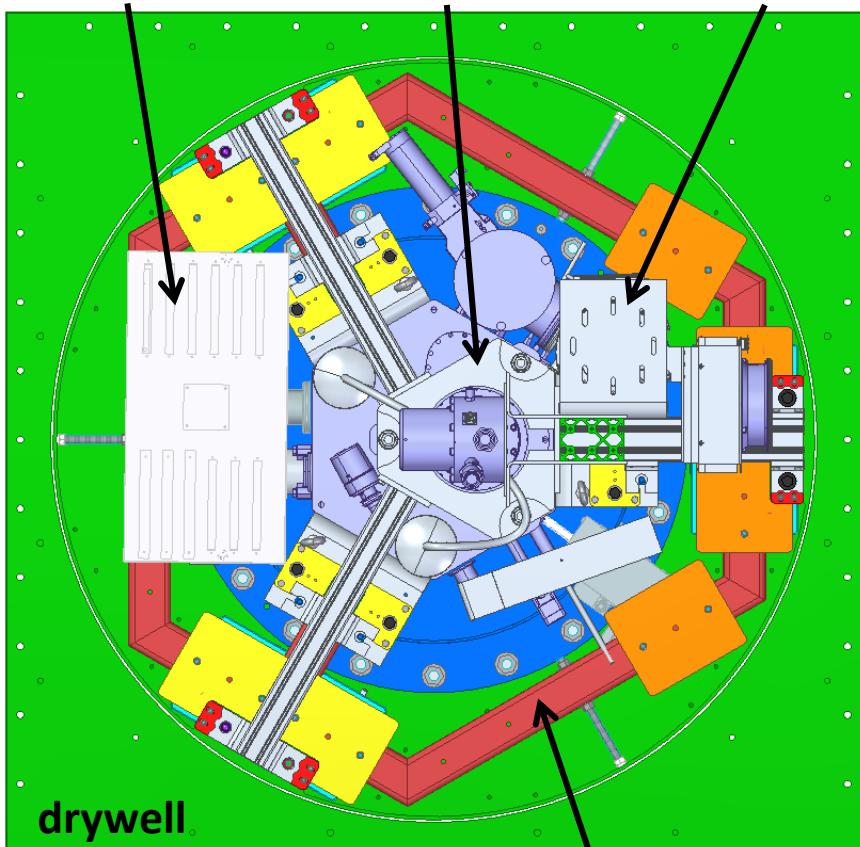
Frame



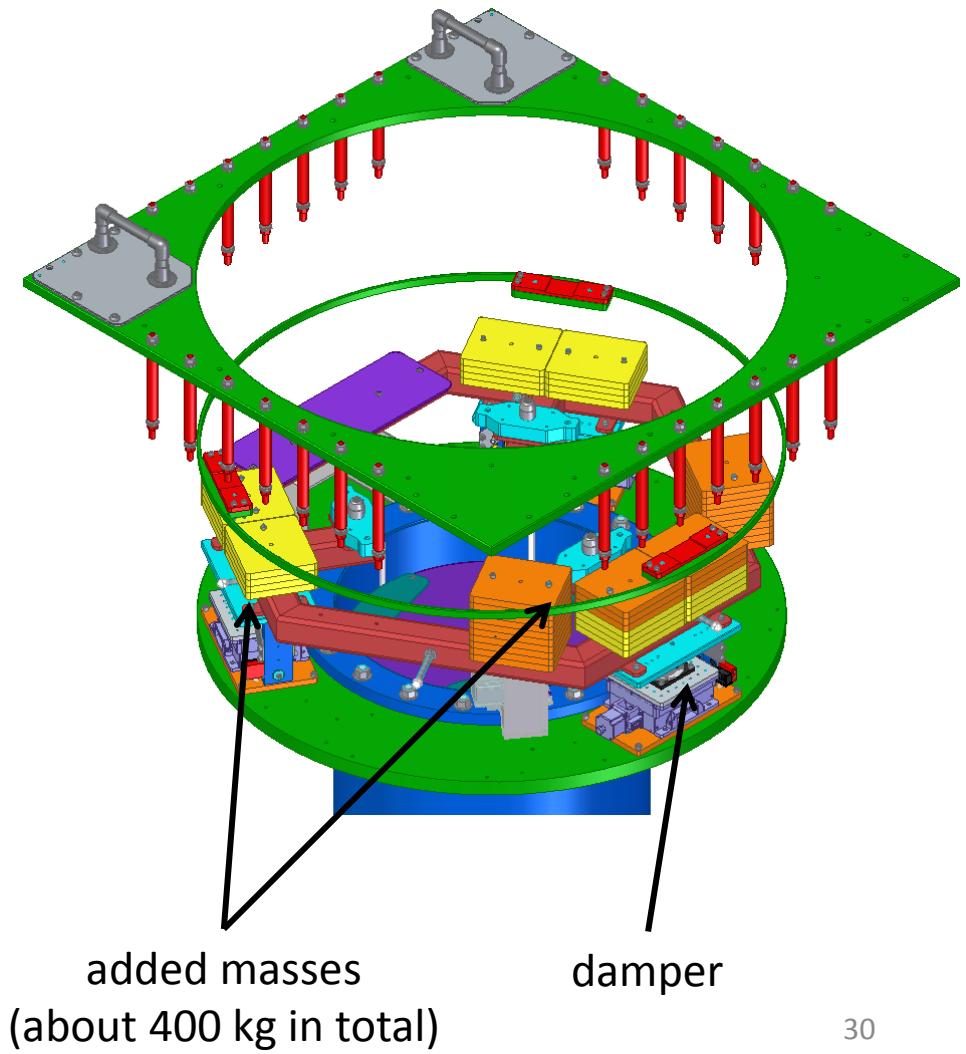
Lab jack

Suspension system assembly

electronics box pulse tube turbo pump

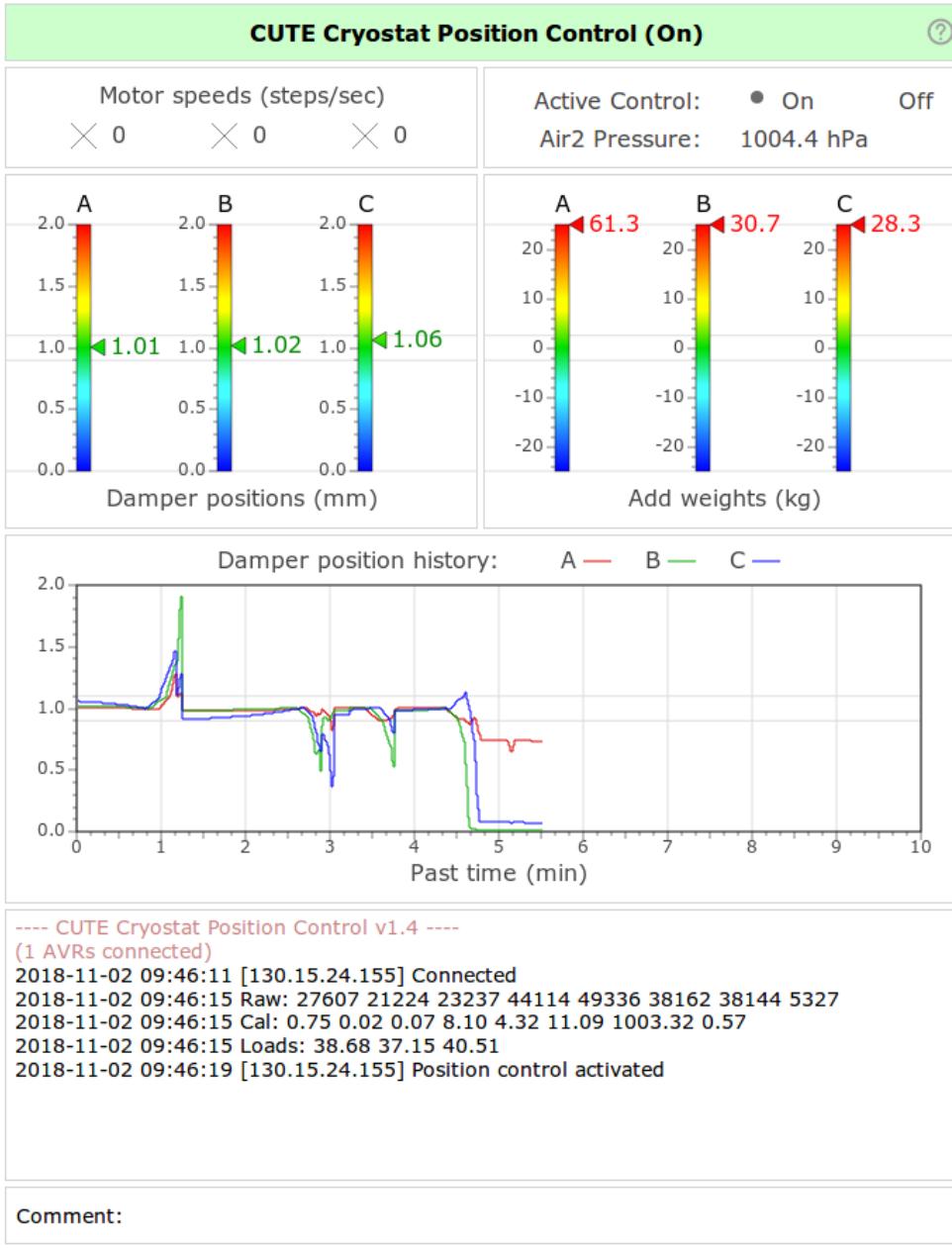


supporting frame



added masses
(about 400 kg in total)

damper



Remote control of suspension system

Tracks environmental condition (pressure, water level, noise level)

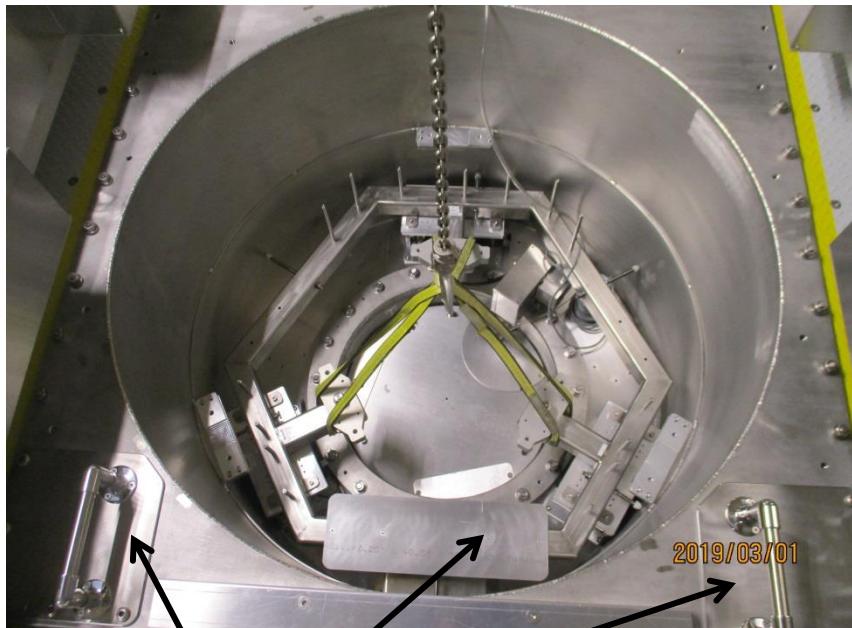
Records of all system parameters into database

Provides possibility to off-line analysis of behavior

Suspension system assembly

installed at March 1st, 2019

Lowering suspension frame into drywell



Suspension frame is installed



Service handles & step

Lab jacks

Cryostat
alignment pins

Calibration
system

Cryostat transportation system

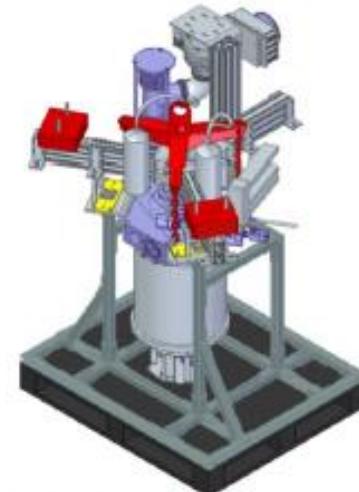
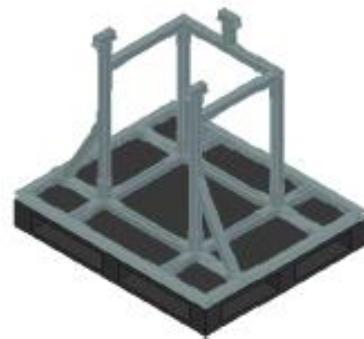
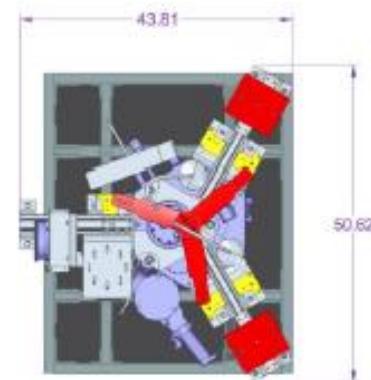
Crate dims: 53”L x 50”W x 78”H ← Forklift transport required



Queen's
Wrap cryostat (with rigging)
in plastic and pack inside
wooden crate



UG Carwash
Transfer cryostat to clean
Unistrut support frame
(secured to plastic pallet)



UG Lab
Move cryostat with pallet
truck to staging area

Testing of cryostat lifting system and transportation stand @ Queen's



Alignment system designed and tested for secure cryostat lifting

Time-schedule

Date (week)	Task
Feb 4, 2019	<ul style="list-style-type: none">• Prepare suspension frame for shipping
Feb 5 th , 2019	<ul style="list-style-type: none">• Installation Review Phase 2B
Feb 11, 2019	<ul style="list-style-type: none">• Assemble, clean, and package of calibration system• Ship suspension and calibration to SNOLAB• Fix last cryostat deficiencies
Feb 18, 2019	<ul style="list-style-type: none">• Clean and package cryostat• Ship suspension system underground
Feb 25, 2019	<ul style="list-style-type: none">• Install calibration and suspension systems
Mar 25, 2019	<ul style="list-style-type: none">• Ship cryostat to SNOLAB and ship underground with CUTE staff present
Apr 1, 2019	<ul style="list-style-type: none">• Continue installation of cryostat• Preparation for Operational Readiness Review
May 2019	<ul style="list-style-type: none">• Operational Readiness Review

CUTE tasks before Early Operation

Date	Step
May, 2019	<ul style="list-style-type: none">• DAQ mounting, and implement DAQ architecture for underground/surface CUTE lab
May, 2019	<ul style="list-style-type: none">• Preparation for Operational Readiness Review
June, 2019	<ul style="list-style-type: none">• Cleanroom operation test<ul style="list-style-type: none">- <i>air quality test</i>- <i>operational test</i>- <i>working procedure improvement</i>
July, 2019	<ul style="list-style-type: none">• Test all procedures , its correction based on the results of first run without/with detectors
July, 2019	<ul style="list-style-type: none">• Evaluation of required manpower for run preparation&running
end of 2019	<ul style="list-style-type: none">• Radio-assay of materials used for CUTE facility production
end of 2019	<ul style="list-style-type: none">• Completion of CUTE background model

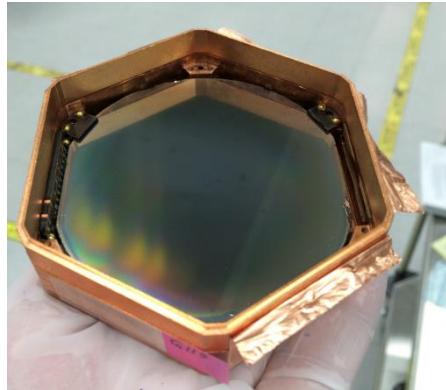
Payload for CUTE

Commissioning

Task	Time Period
Testing of CUTE facility at SNOLAB <ul style="list-style-type: none">• <i>Without detectors</i>• <i>With detectors (G115/TES chip)</i>• <i>Revision/fixing problems/commissioning</i>	<i>May 2019 – June 2019</i>
Testing SuperCDMS detectors <ul style="list-style-type: none">• Si HV Pathfinder• HVeV detector• First tower (6 iZIP Ge Detector)	<i>July 2019 – May 2020</i>
Own R&D activity <ul style="list-style-type: none">• HVeV detector from enriched ^{28}Si• Scintillating bolometers based on YVO_4, ZnSe, ${}^{\text{arch}}\text{PbMoO}_4$ crystals• Advanced light detectors	<i>from Sept 2019</i>

Early operation

Test done @ Queen's University



“G115”

$\varnothing 76 \times 10$ mm

240 g

TES chip

$10 \times 10 \times 1$ mm

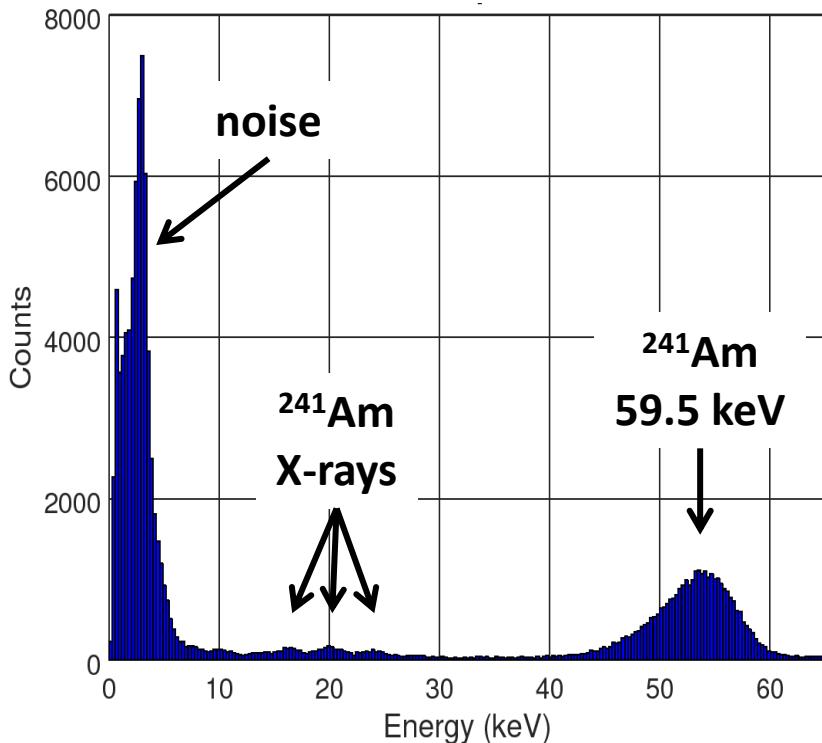
0.5 g

4 phonon channels 4 phonon channels

*Bolometric performance/
External background*

RF noise/Vibration

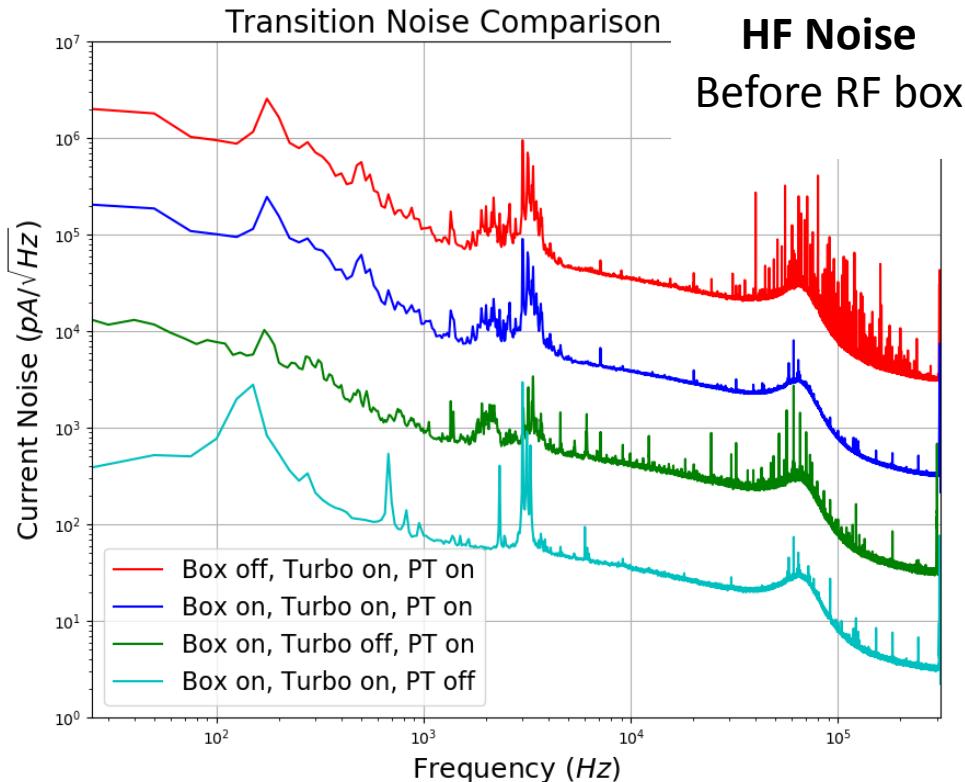
Test done @ Queen's University



$$E_{\text{thr}} = 5 \text{ keV}$$
$$\text{FWHM} = 1 \text{ keV} @ 17.7 \text{ keV}$$

- ^{241}Am source
- Low energy 17.7, 20.7, 26.3 keV X-rays show good energy resolution
- 59.5 keV line appears at a lower energy due to detector saturation effects
- Low energy events are mostly noise induced trigger, improved analysis techniques should remove most of this

Test done @ Queen's University



The noise of TES-chip was studied while they were in the transition between normal and superconducting states, and in normal state

An aluminum box was placed around the read-out electronics, leading to an improvement in high frequency noise

The power supply for the read-out electronics that will be used at SNOLAB was also tested, and it lead to improved high frequency noise performance as well

Normal Noise:

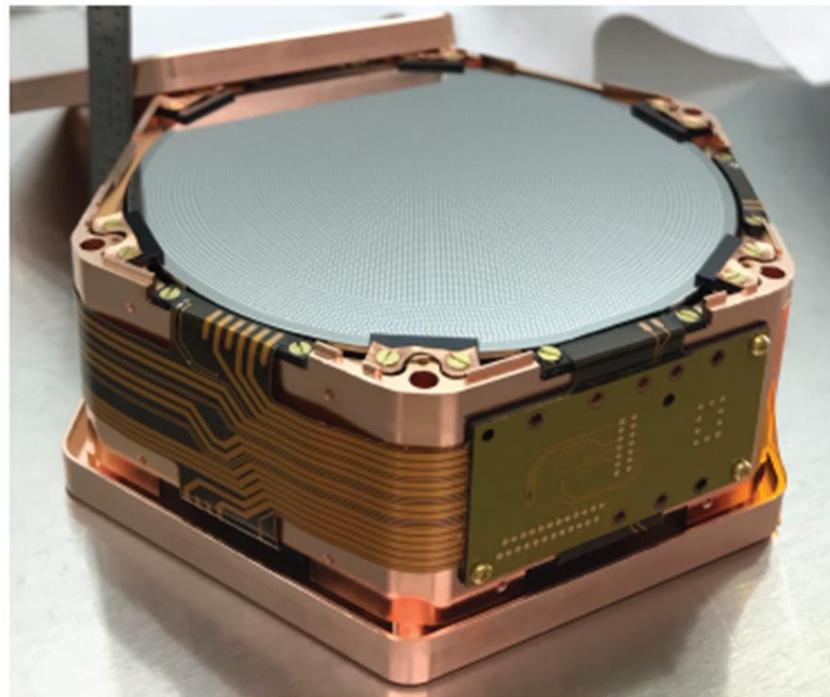
$\sim 5 \text{ pA}/\sqrt{\text{Hz}}$

SC Noise:

$\sim 40 \text{ pA}/\sqrt{\text{Hz}}$

Expected detectors for Early Operation

Si HV Pathfinder Detector



Ge iZIP Prototype Detector



1 detector in Tower

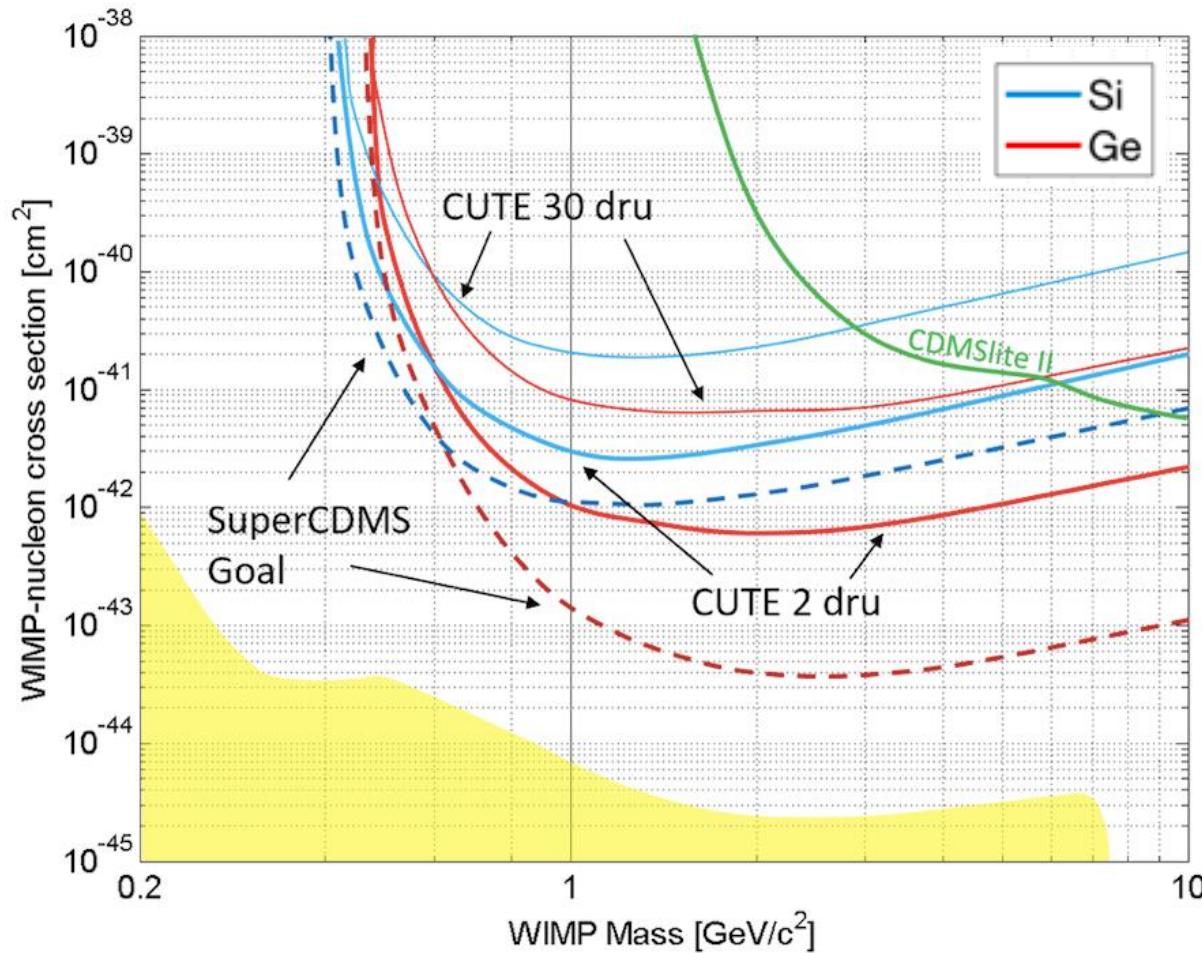
July 2019 – August 2019

6 detectors in Tower

March 2020 – May 2020

Early science at CUTE facility

One Tower of HV-type SuperCDMS (6 detectors) measured for 1 year



SUMMARY

- Test facility for cryogenic detectors is under construction at SNOLAB
- Underground location and background conditions will allow to perform characterization of the internal background and performance various type of cryogenic detectors
- The base temperature 12 mK was achieved in the test long-terms cool-down at Queen's University
- The run with old-type CDMS detector was performed, 5 keV energy threshold and FWHM = 1 keV @ 17 keV were achieved
- Cryostat will be moved to SNOLAB by early April 2019
- Commissioning is planned by June 2019
- Early science is possible with SuperCDMS detectors by end of 2019