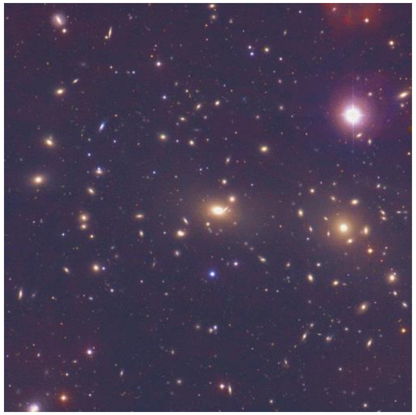
CUTE – A low background facility for testing cryogenic detectors

Serge Nagorny

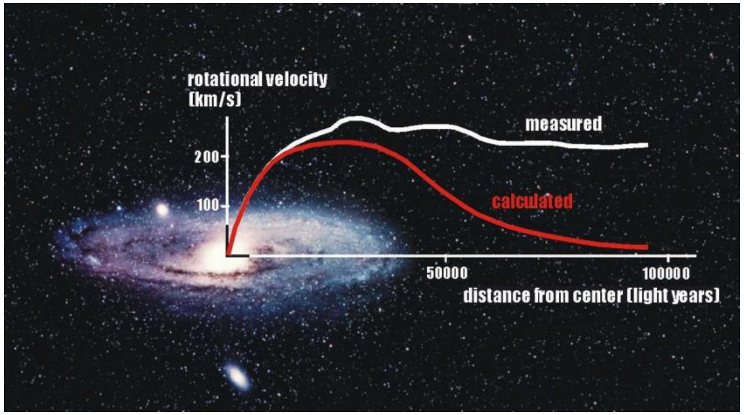
on behalf of the CUTE collaboration

March 14th, 2019

Dark matter evidence

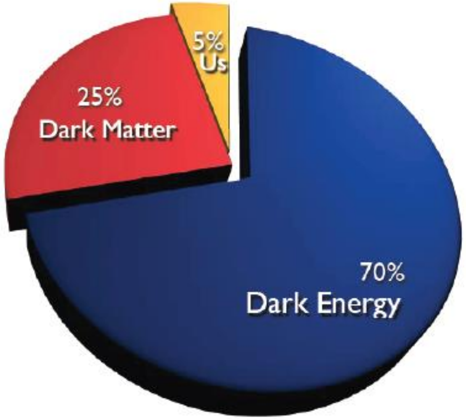


Credit: O. Lopez-Cruz
I. K. Shelton



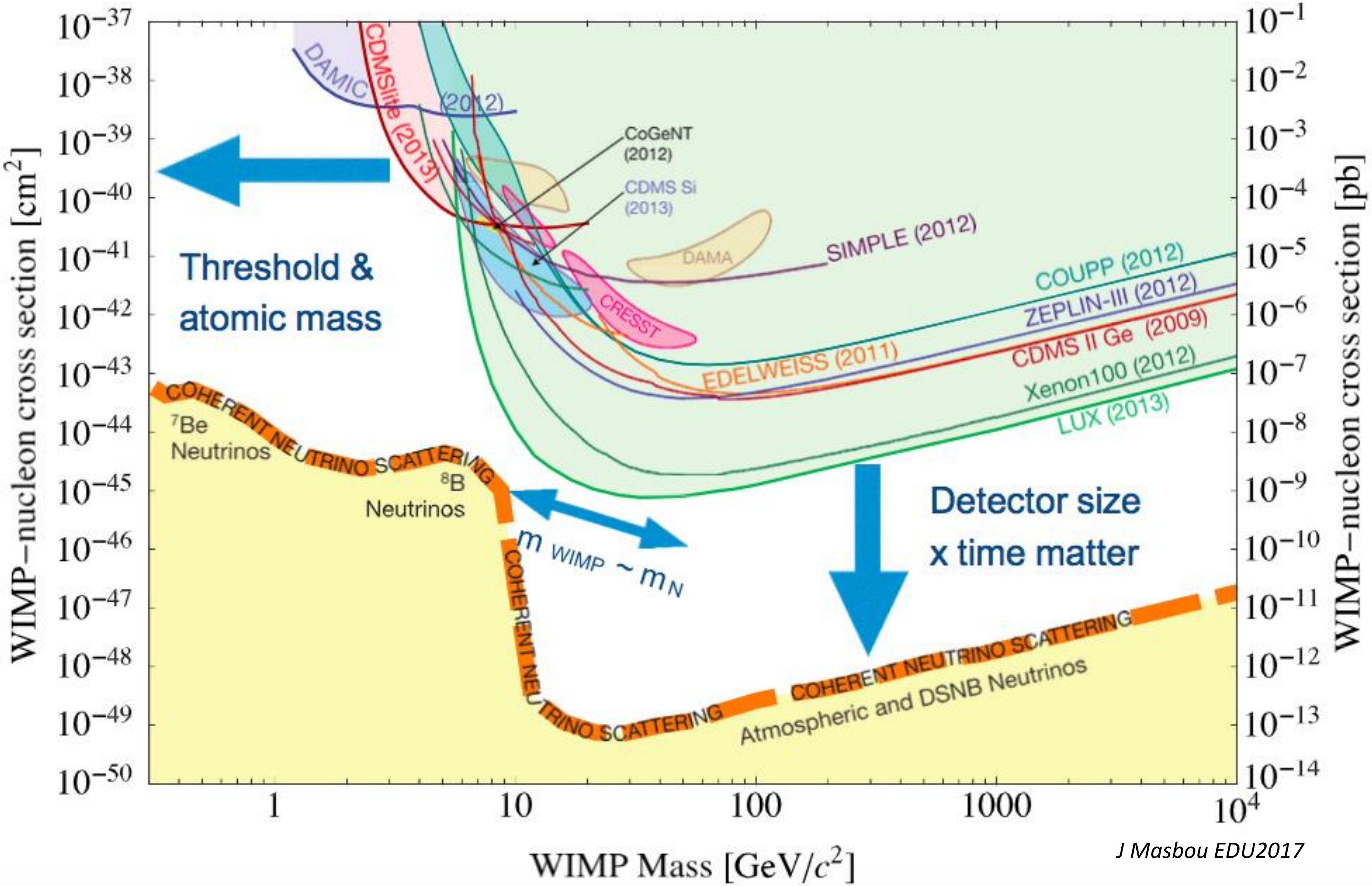
Credit: cdms.phy.queensu.ca

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

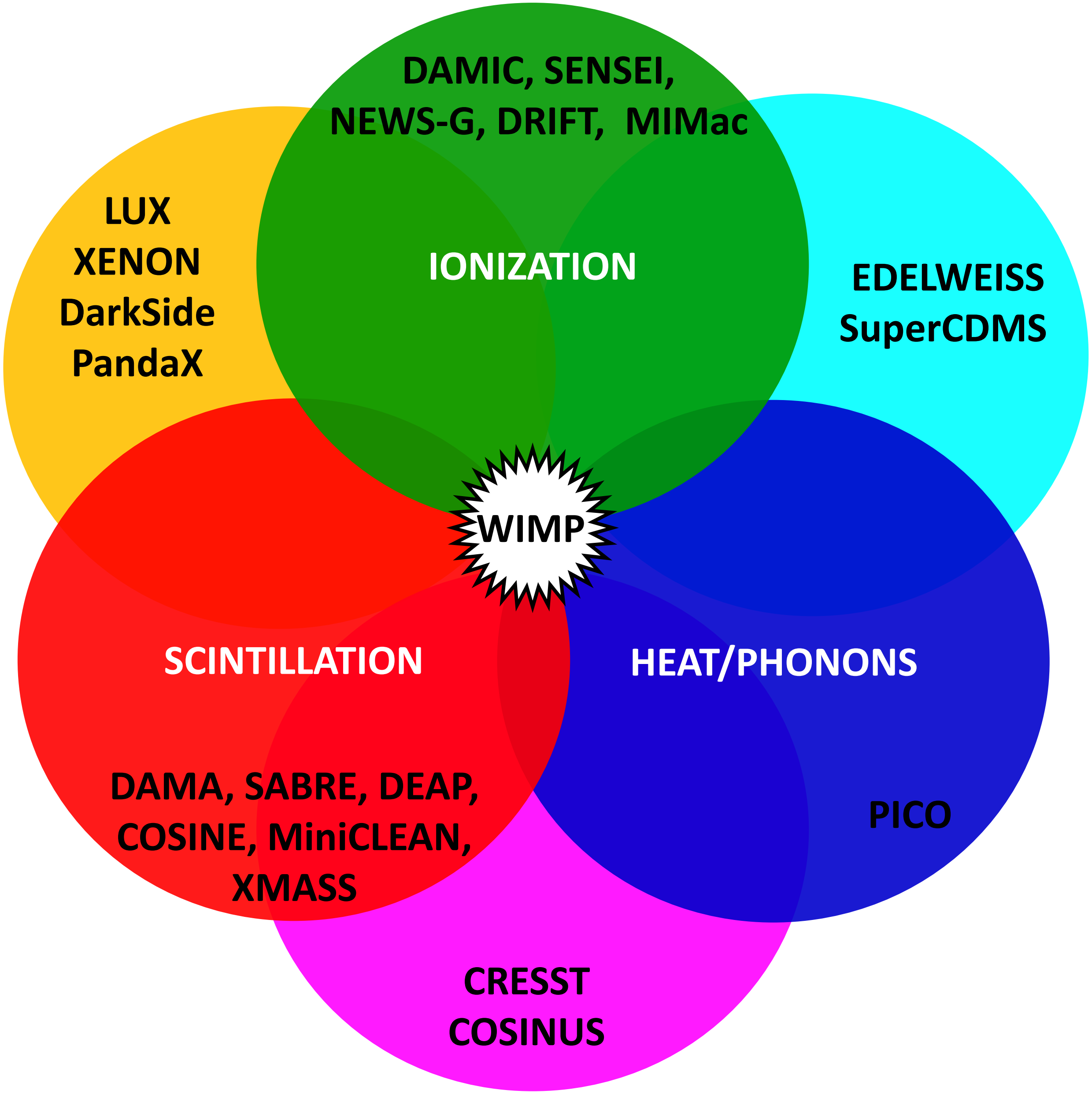


Threshold & atomic mass

Detector size x time matter

J Masbou EDU2017

Direct dark matter search



DAMIC, SENSEI,
NEWS-G, DRIFT, MIMac

IONIZATION

LUX
XENON
DarkSide
PandaX

EDELWEISS
SuperCDMS

WIMP

SCINTILLATION

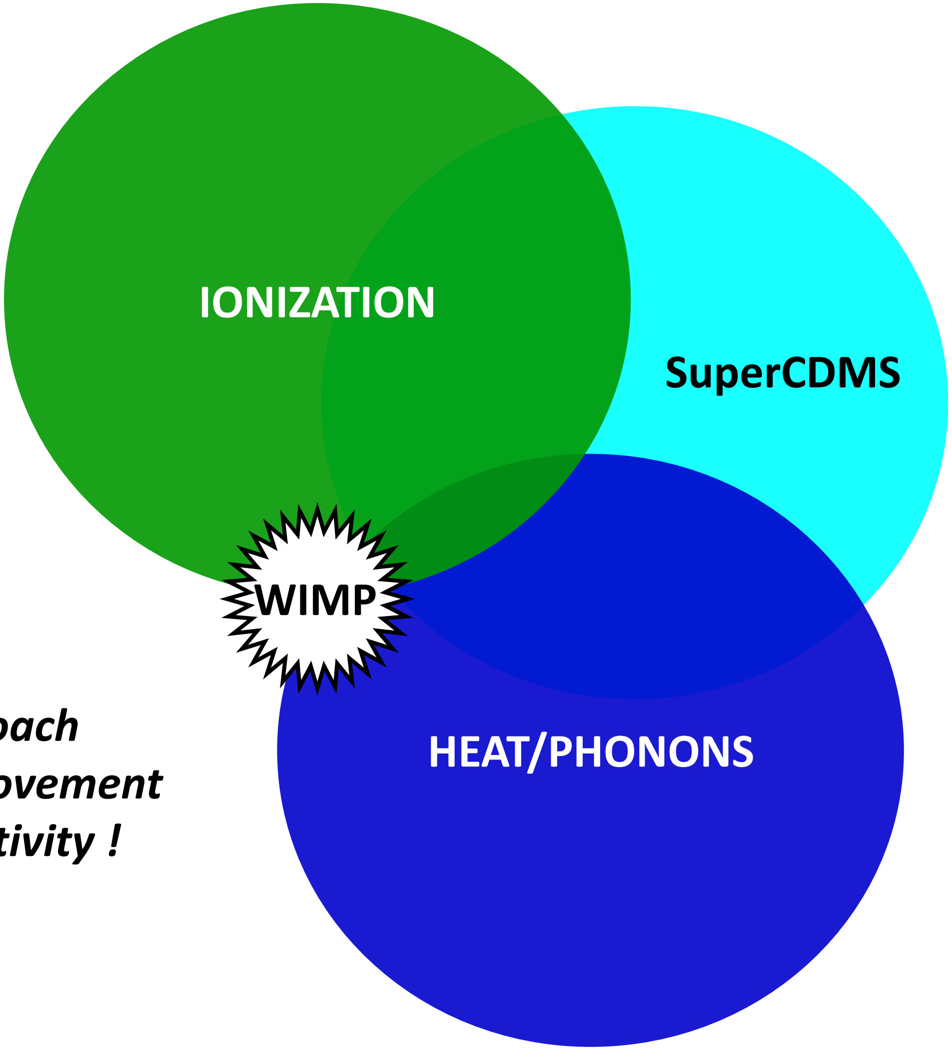
HEAT/PHONONS

DAMA, SABRE, DEAP,
COSINE, MiniCLEAN,
XMASS

PICO

CRESST
COSINUS

Direct dark matter search

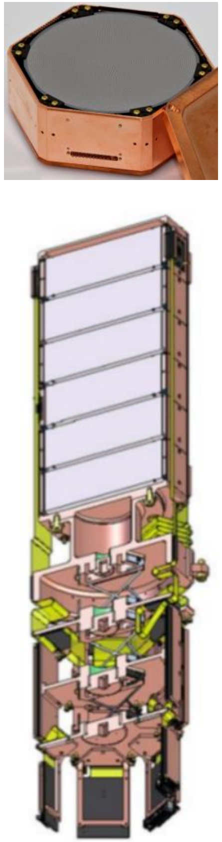


IONIZATION

SuperCDMS

WIMP

HEAT/PHONONS

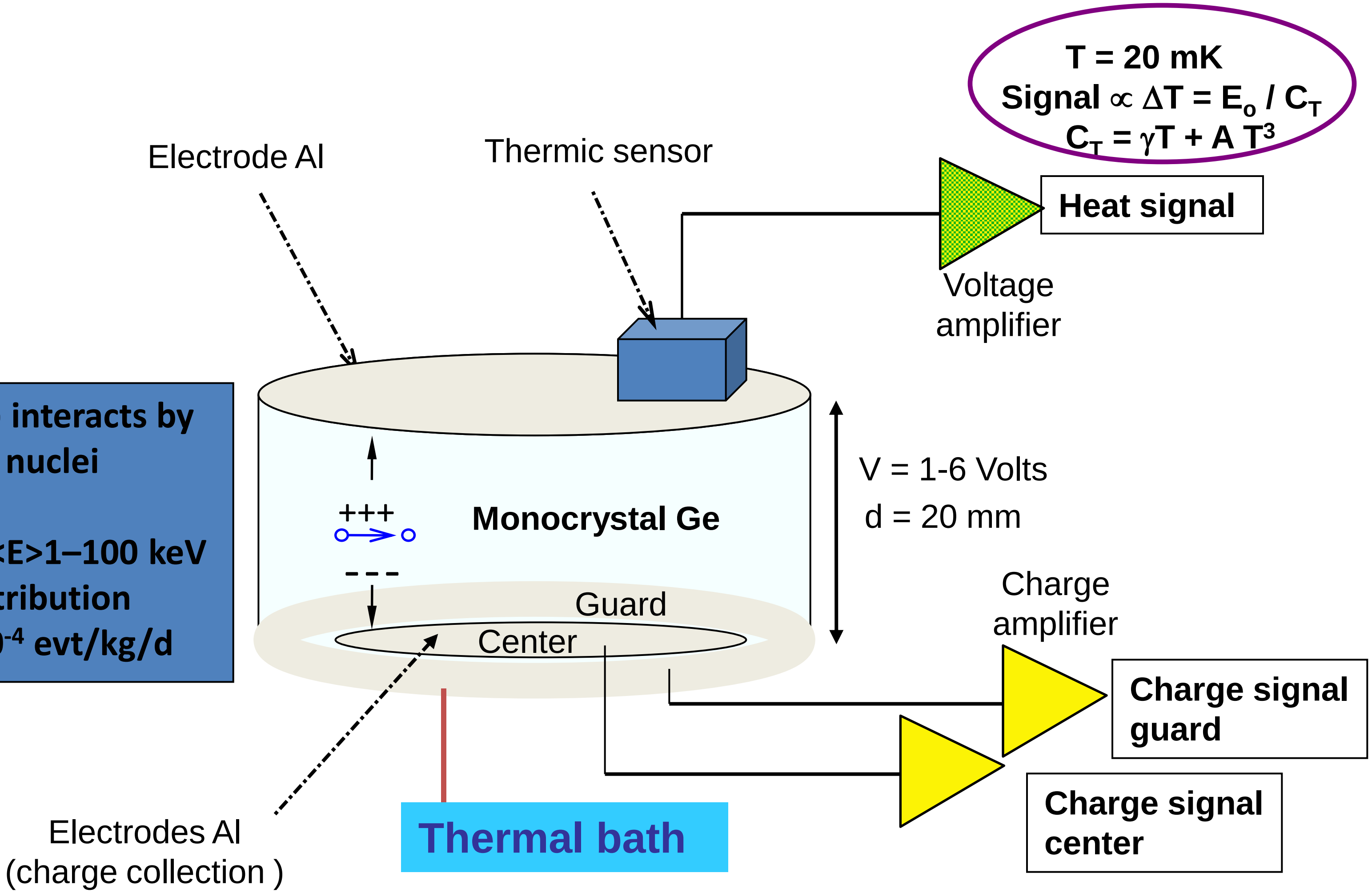


Two channels approach
allows significant improvement
of experimental sensitivity !

Concept of ionisation-heat (phonon) detectors

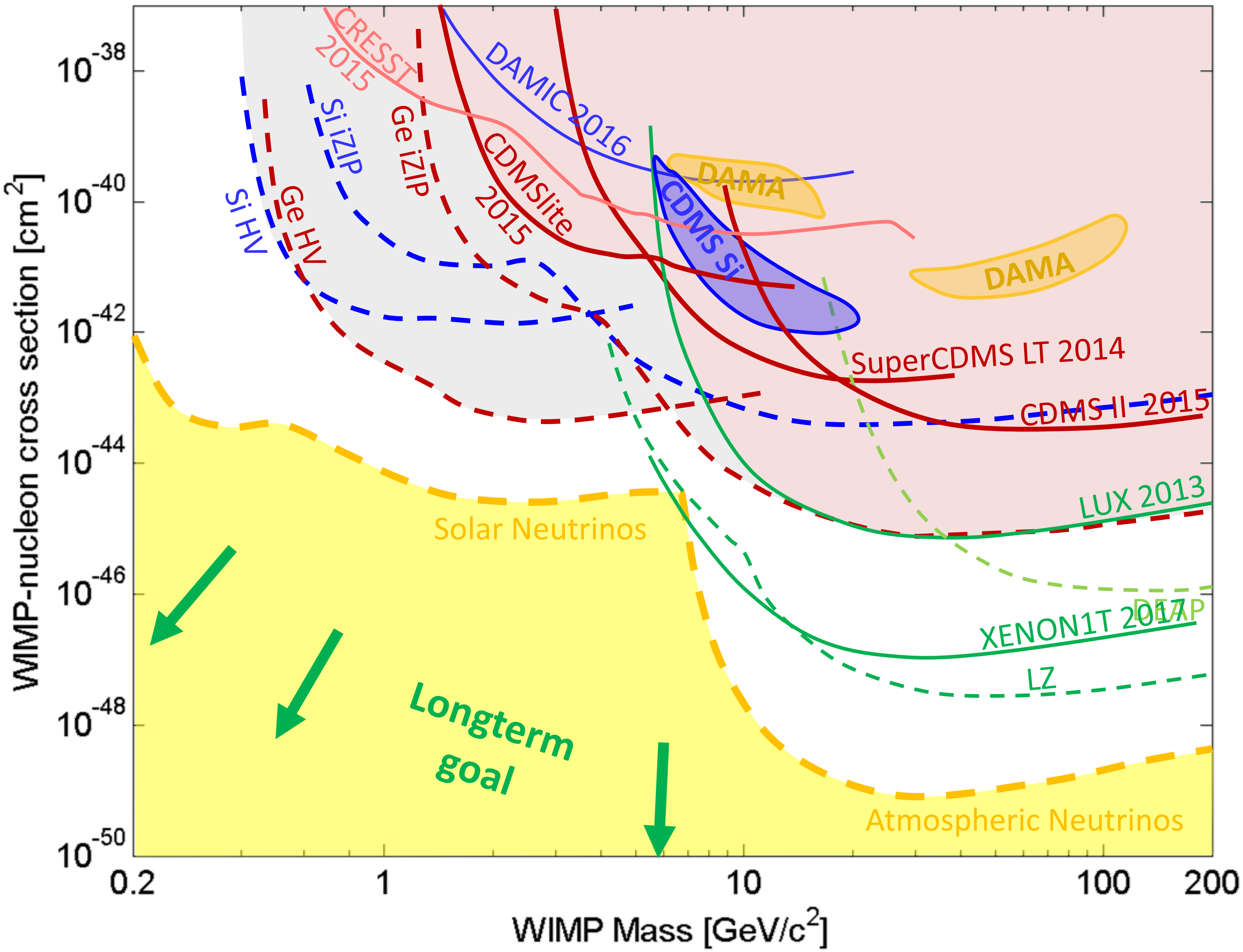
WIMP (~ 200 km/s) interacts by <u>elastic diffusion</u> on nuclei

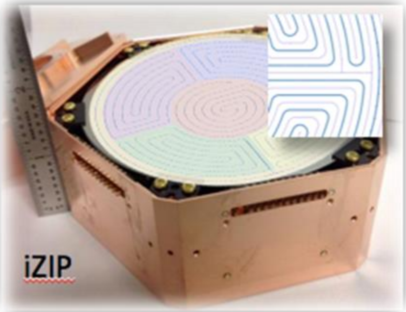
- **Nuclear recoil <E>1–100 keV**
- **Exponential distribution**
- **Low rate 1-1.10^{-4} evt/kg/d**



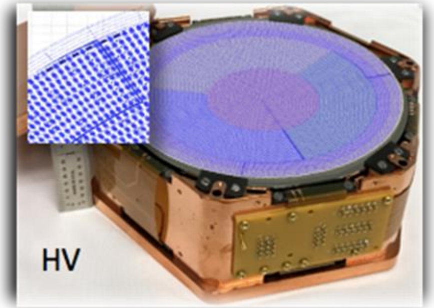
Courtesy of Prof.G.Cergbier

SuperCDMS expected sensitivity @ SNOLAB





“iZIP” detectors
Higher threshold
Part.ID.



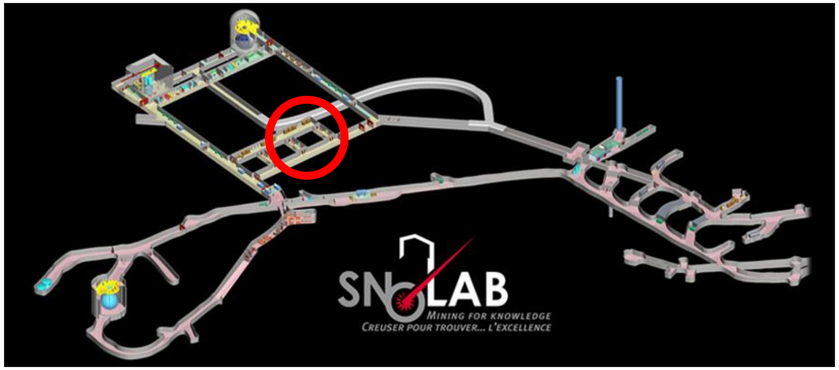
“HV” detectors
Low threshold
No Part.ID.

arXiv:1610.00006

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}H, ^{32}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

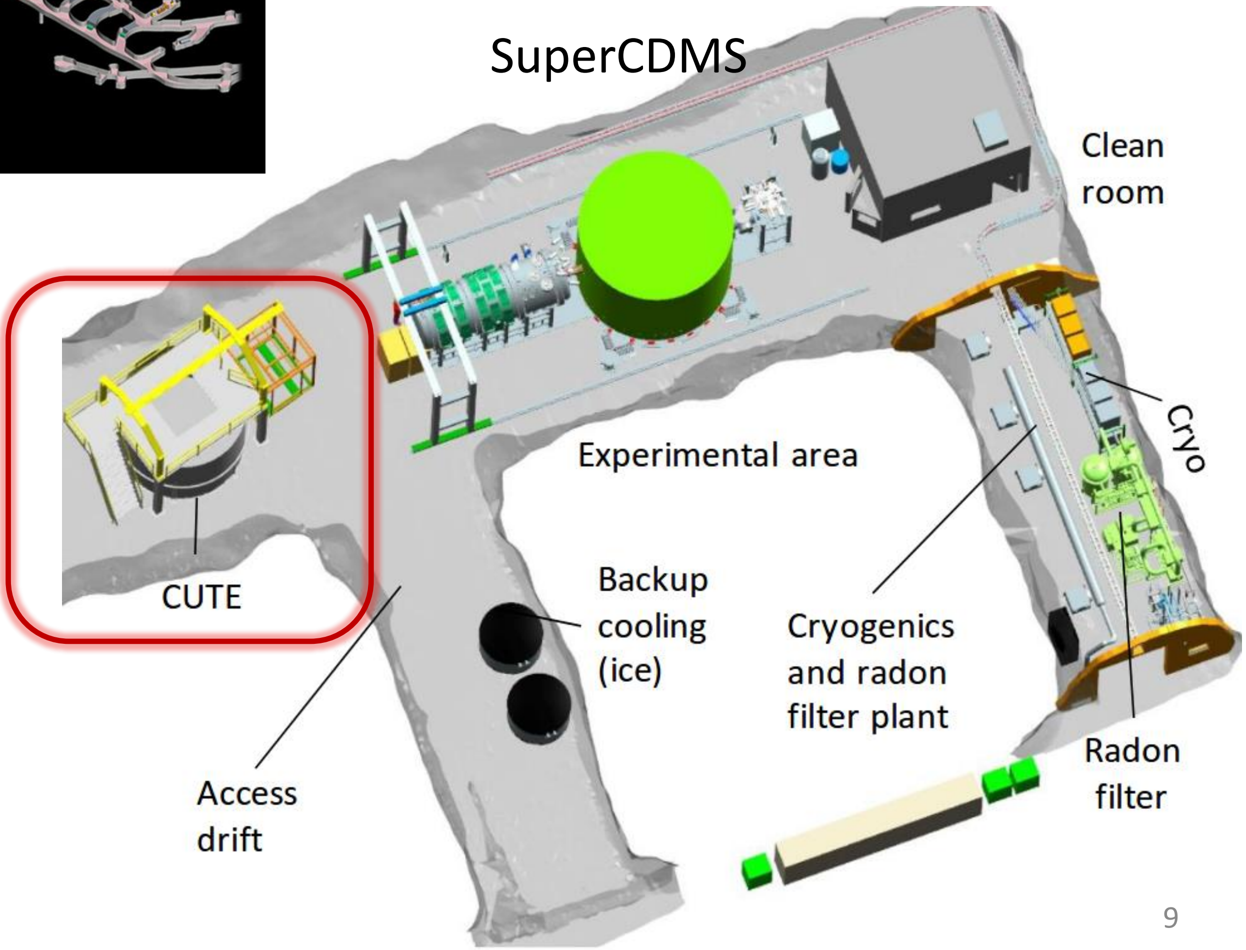
CUTE location at SNOLAB



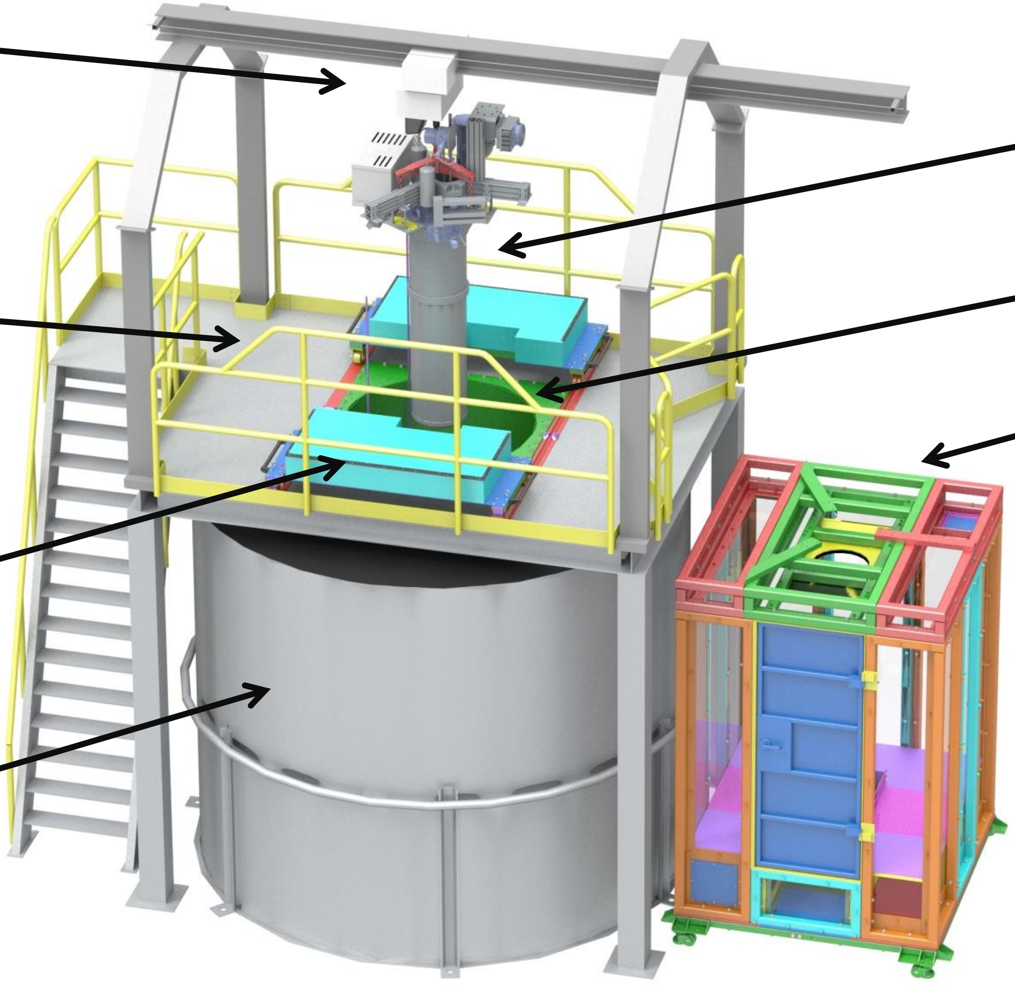
2 km deep

Strong cosmic ray flux suppression

Cleanroom environment



General view of the CUTE facility



Monorail with 1000 kg hoist

Platform

Movable HDPE shield

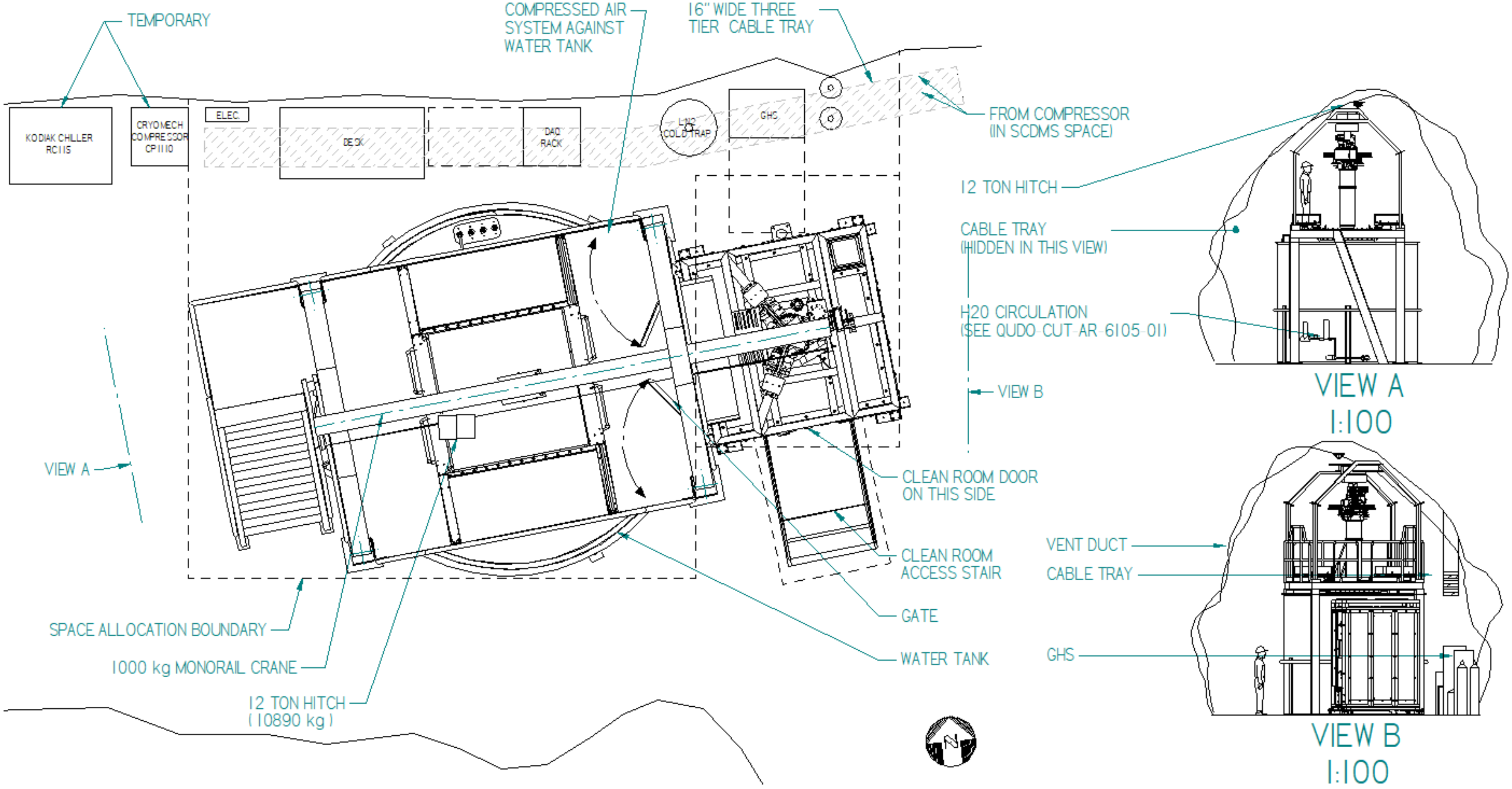
UP water shield tank

Cryostat

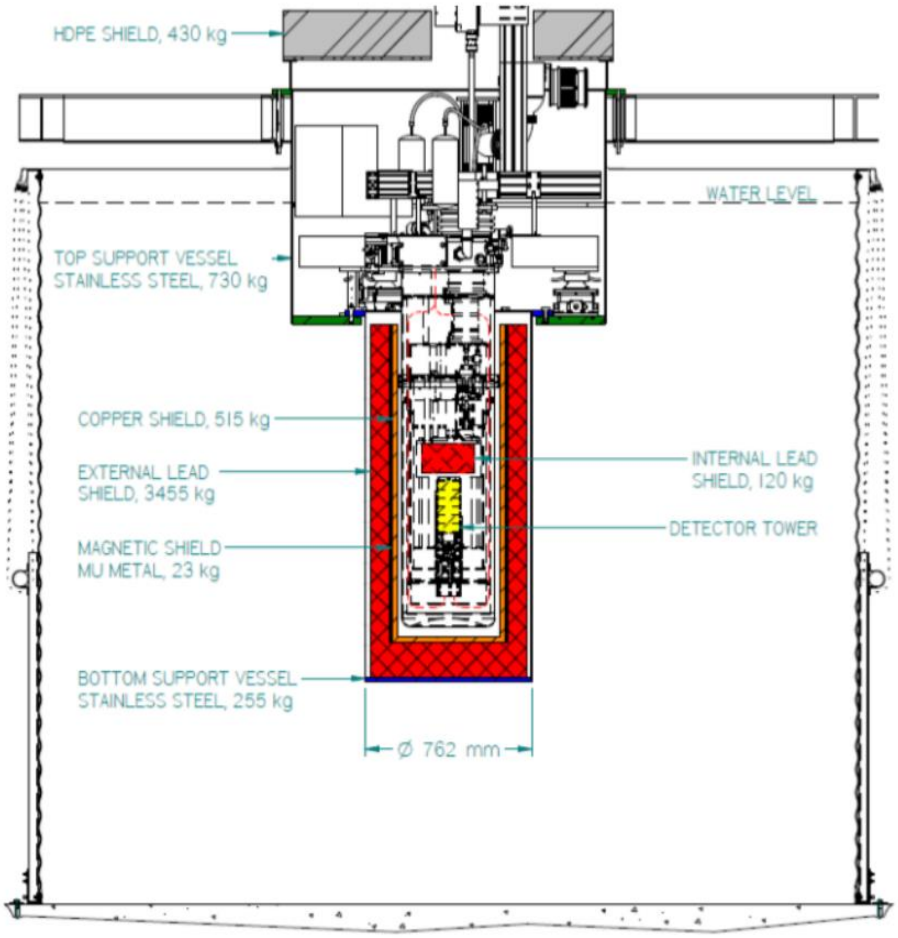
Drywell with Pb shield/ Mu-metal

Cleanroom

Final arrangement

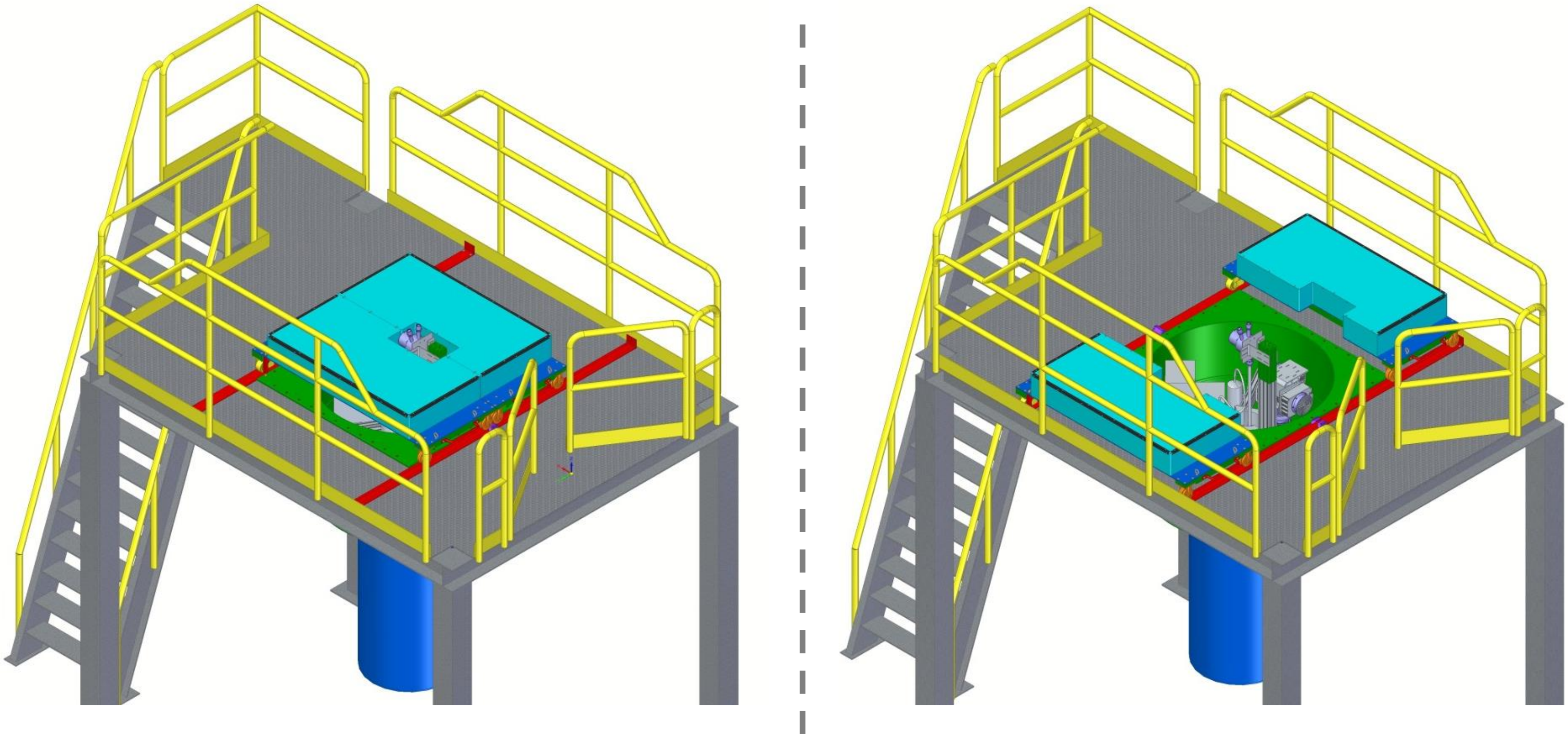


Shielding in the CUTE facility



- 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



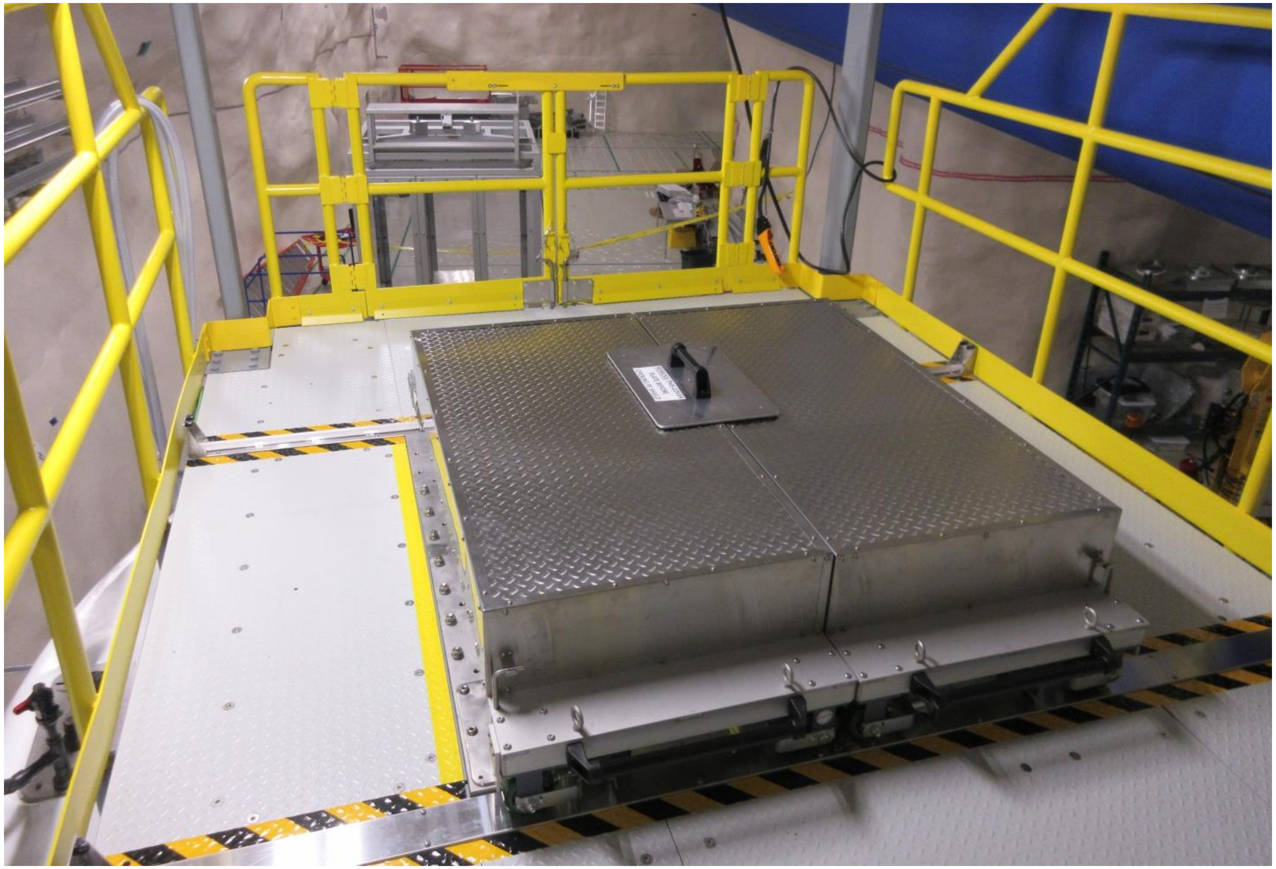
20 cm thick HDPE layer on top of the cryostat for neutron flux suppression

PE shielding

8 layer of 1” HDPE sheet

Rigging/lifting test at producer site

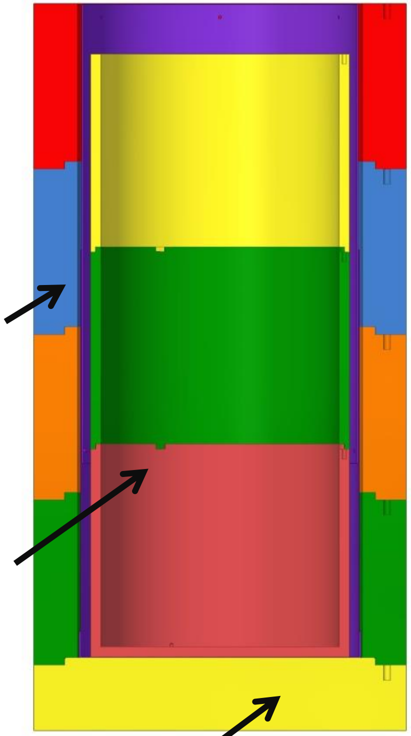
PE shielding



Installed

Fully functional, tested during Pb shield installation, Feb 2019

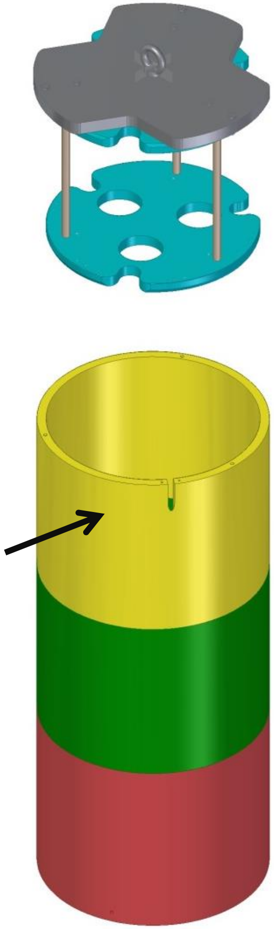
Lead shielding



9 cm
outer layer

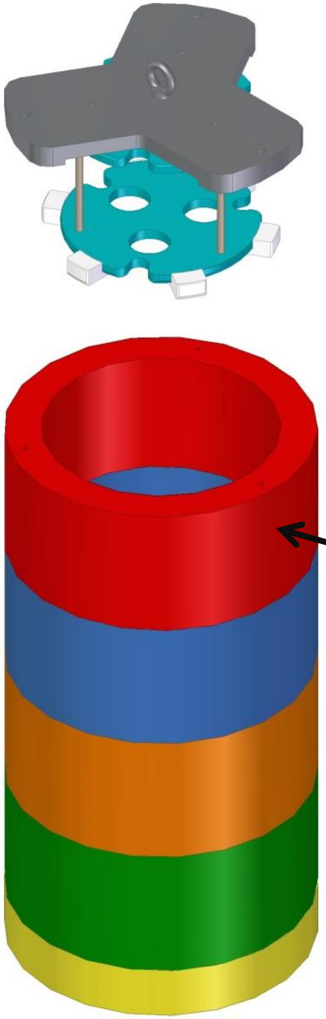
2 cm
inner layer

13 cm
outer layer



140 kg

Pb inner layer
< 3 Bq/kg

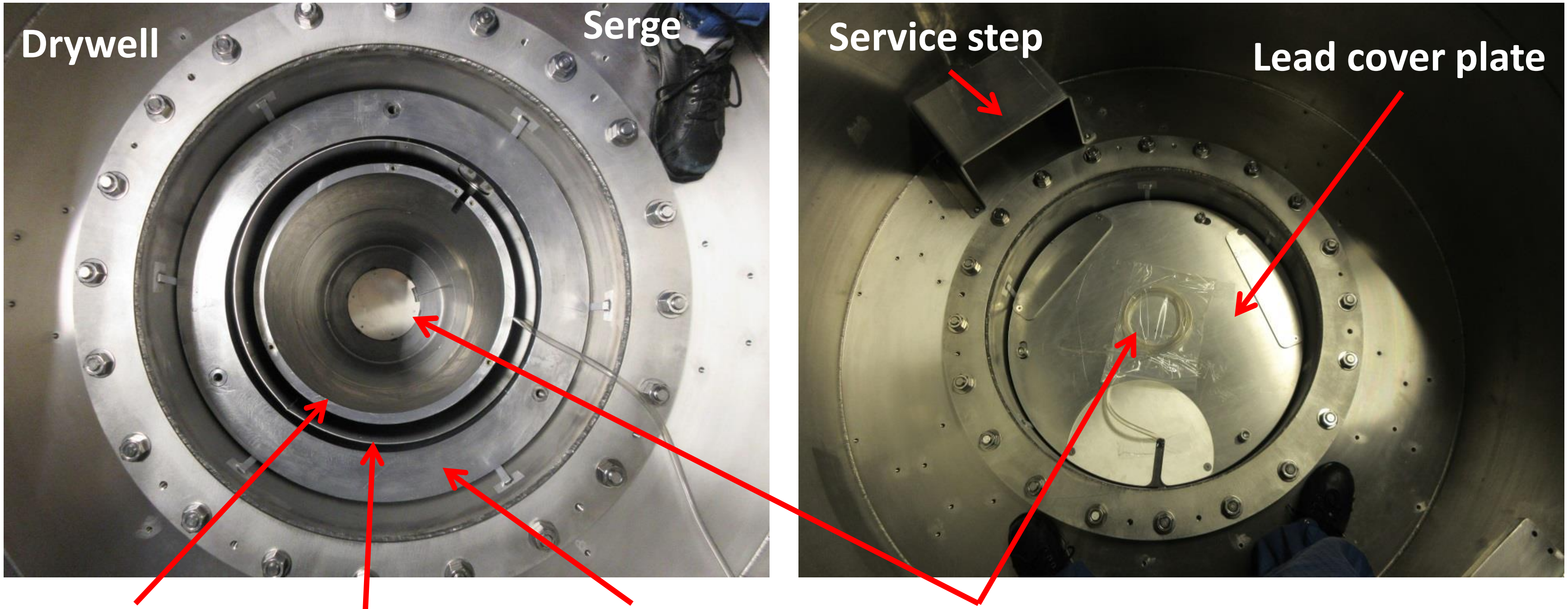


650 kg

Pb outer layer
< 30 Bq/kg

Lead shielding

Installed @ Jan 25th, 2019



Inner Pb, 2 cm
< 3 Bq/kg

Mu-metal

Outer Pb, 9 cm
< 30 Bq/kg

Gas purge system

Background budget in energy range 0-2 keV

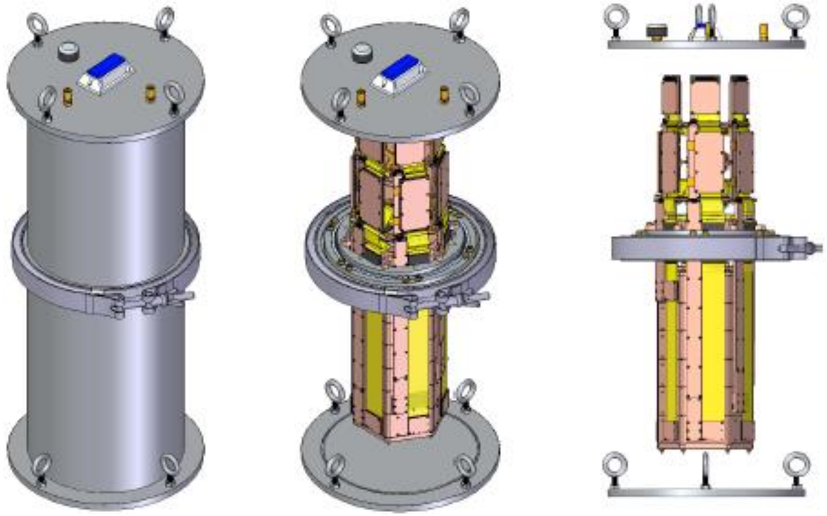
Material	Estimated background, events/(keV·kg·day)
External background (lad walls, etc.)	**1.1**
External Pb shielding	**0.7**
Stainless steel vacuum can	**0.6**
Internal background (cryostat cans, etc.) *caused mostly by ^{210}Pb*	**0.5**
Cosmogenic activation (^{3}H, etc.)	**< 0.1** (SNOLAB) **0.5** (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 Bq·h/m^3

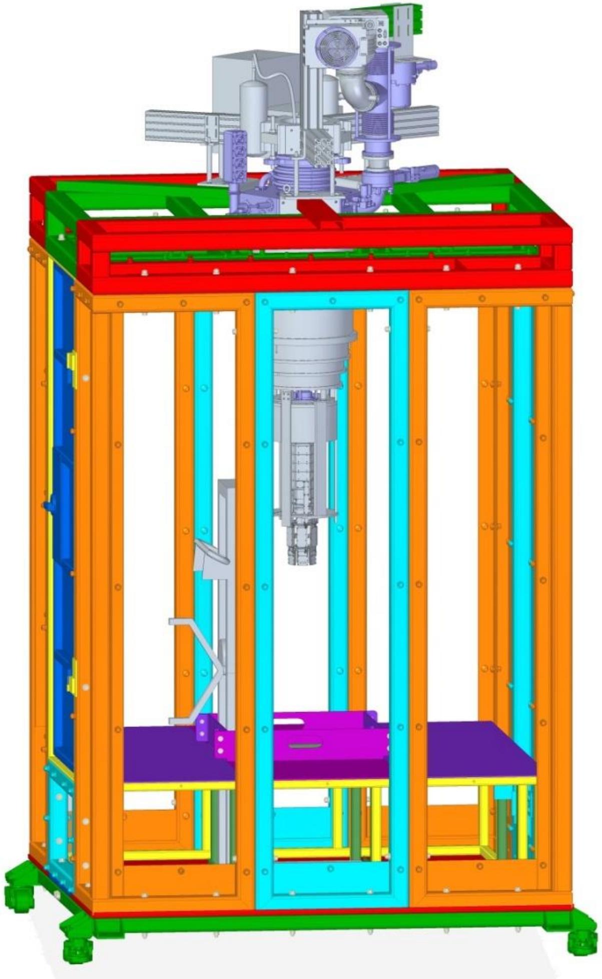


SuperCDMS detector tower will be delivered to SNOLAB in container under N_2 atmosphere and must be opened and installed in cryostat at CUTE cleanroom

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

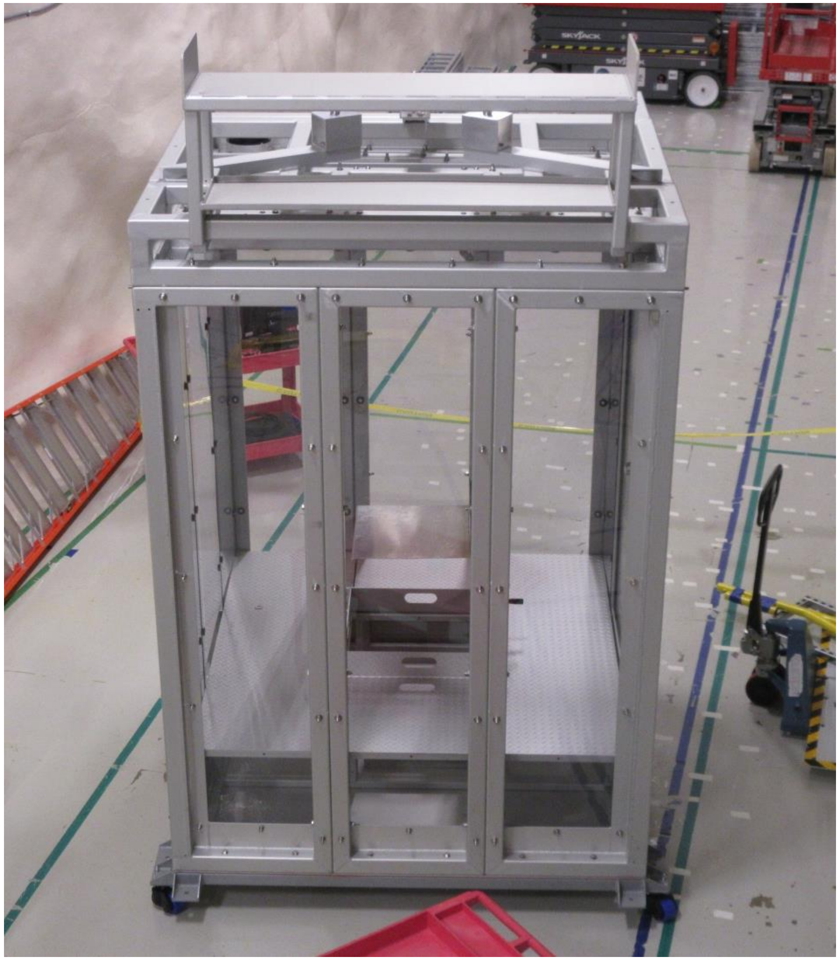
our goal

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 Bq/m^3)**
- **Later SuperCDMS Rn-filter system (< 0.1 Bq/m^3) will be used**
- **Crane moves cryostat between cleanroom and drywell**

Cleanroom status @ March 1st, 2019



- **95% installation accomplishment**

<u>*To be completed:*</u>

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

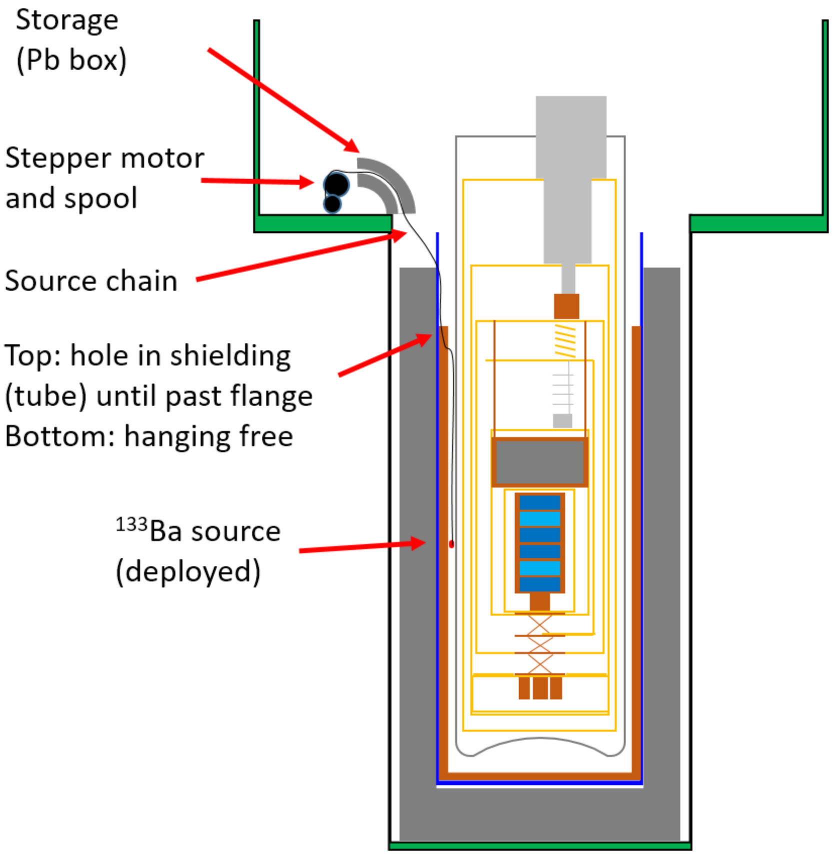
Installation Review, Part 3

(Feb 5th, 2019)

- Calibration system
- Suspension system
- Cryostat installation

All actions are planned to be completed by April 2019

Calibration system concept



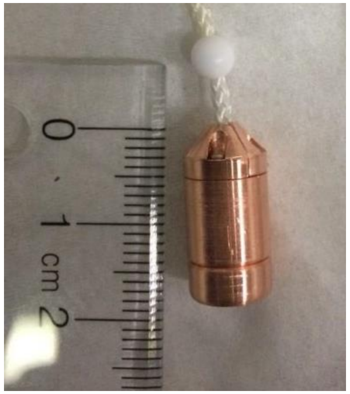
Different radioactive sources will be used to calibrate the energy scale and to monitor stability of detectors performance, as well for characterization of particle interaction types

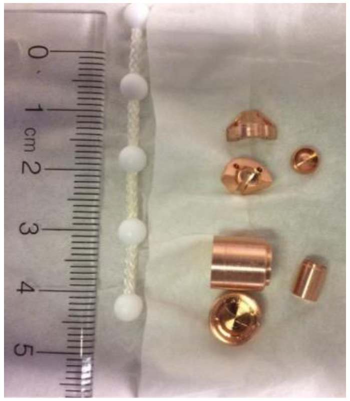
Gamma source: **^{133}Ba** *(this Installation stage)*

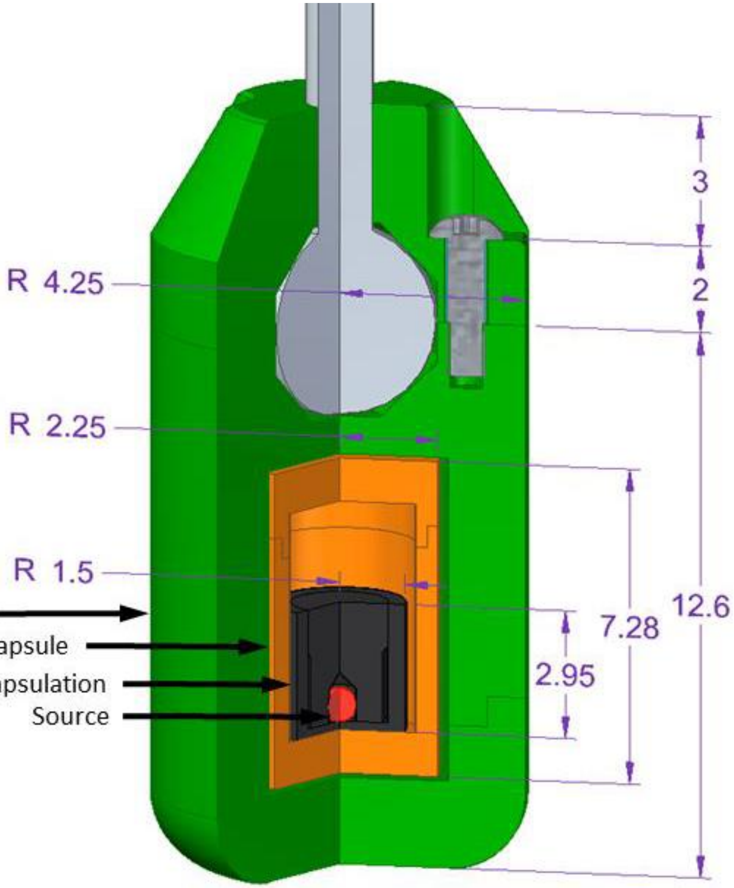
Neutrons source: **^{252}Cf** *(next step in a while)*

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

Calibration source design *(tested)*







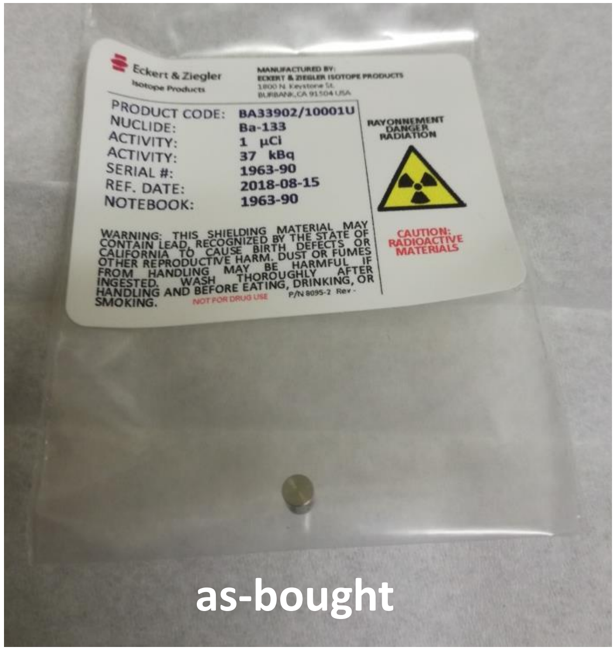
Outer Copper Capsule

Inner Copper Capsule

Provided Stainless Steel Encapsulation

Source

Calibration source encapsulation


Eckert & Ziegler
Isotope Products

MANUFACTURED BY:
ECKERT & ZIEGLER ISOTOPE PRODUCTS
1800 N. Keystone St.
BURBANK,CA 91504 USA

PRODUCT CODE:	BA33902/10001U
NUCLIDE:	Ba-133
ACTIVITY:	1 µCi
ACTIVITY:	37 kBq
SERIAL #:	1963-90
REF. DATE:	2018-08-15
NOTEBOOK:	1963-90

RAYONNEMENT DANGER RADIATION

WARNING: THIS SHIELDING MATERIAL MAY CONTAIN LEAD, RECOGNIZED BY THE STATE OF CALIFORNIA TO CAUSE BIRTH DEFECTS OR OTHER REPRODUCTIVE HARM. DUST OR FUMES FROM HANDLING MAY BE HARMFUL IF INGESTED. WASH THOROUGHLY AFTER HANDLING AND BEFORE EATING, DRINKING, OR SMOKING.

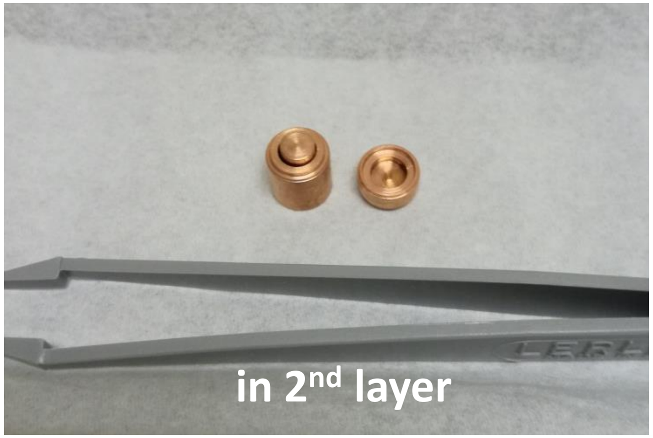
NOT FOR DRUG USE

P/N 8095-2 Rev -

CAUTION: RADIOACTIVE MATERIALS

as-bought

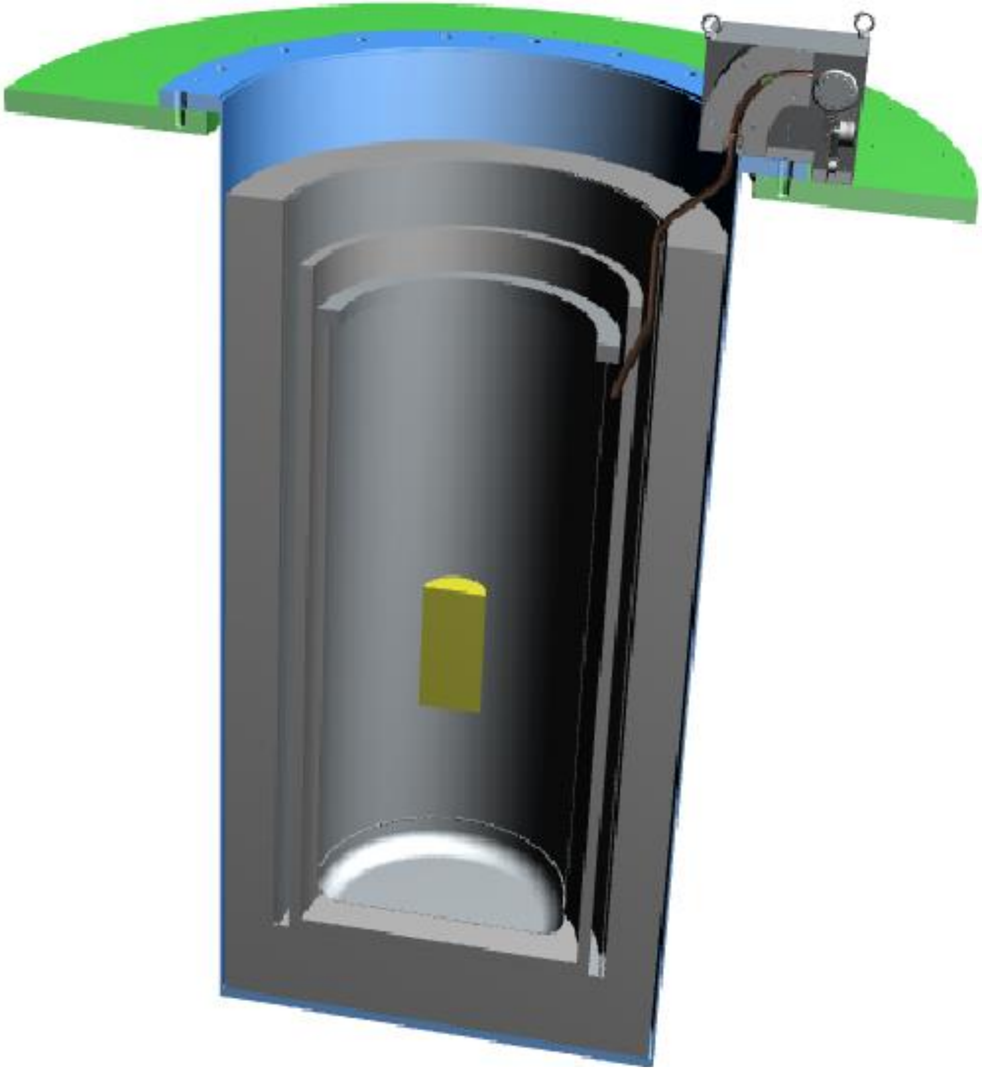

in 1st layer

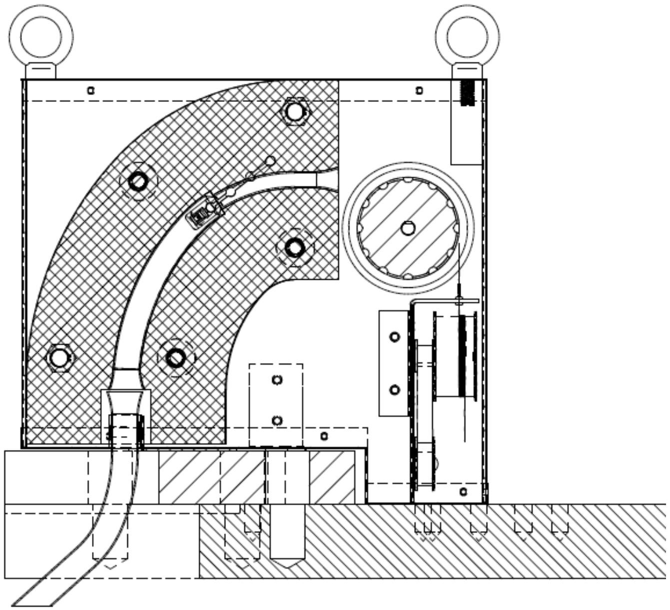


in 2nd layer

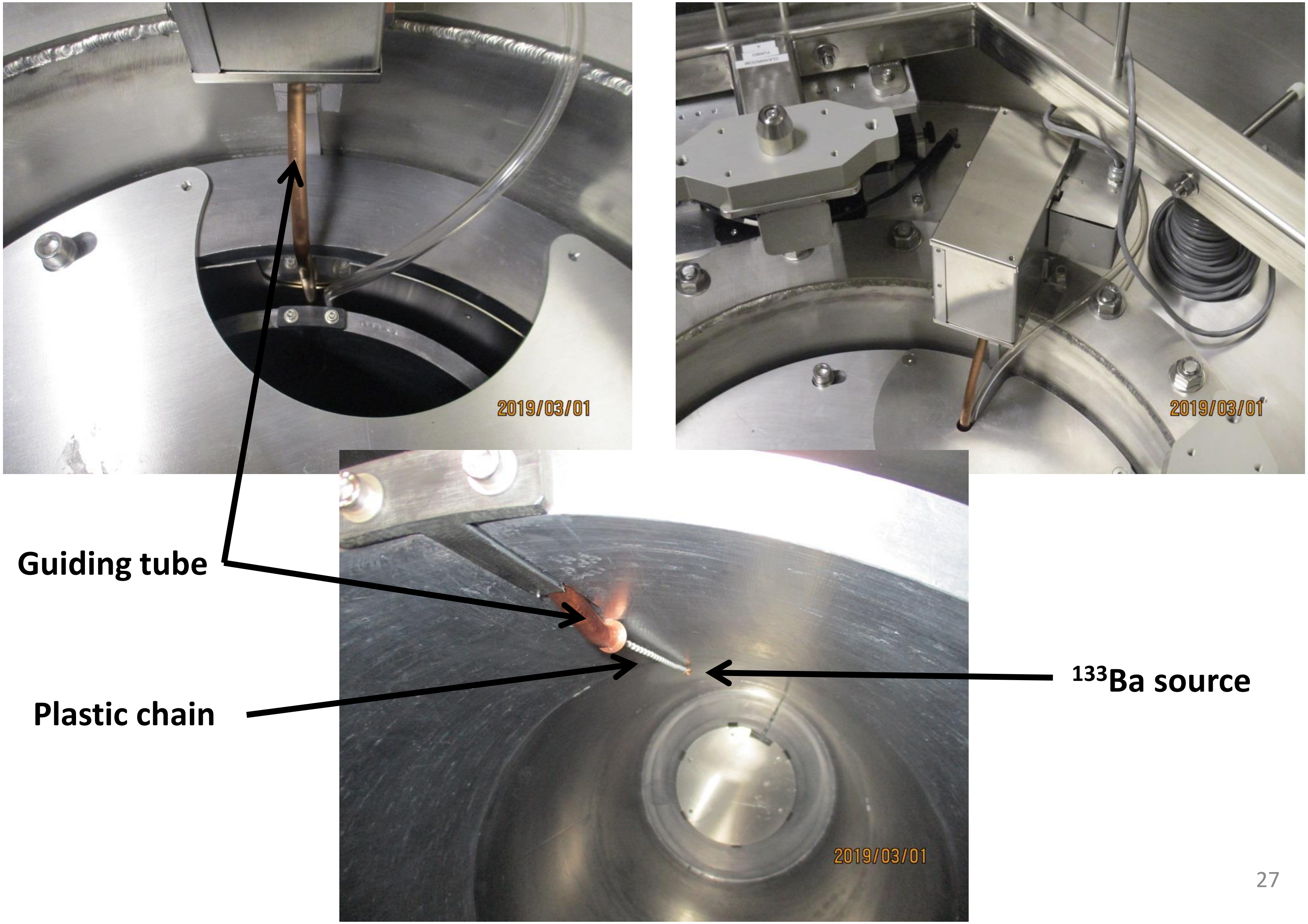

Double layer encapsulated, ready to be assembled

Calibration system: general overview





Calibration system status @ March 1st, 2019

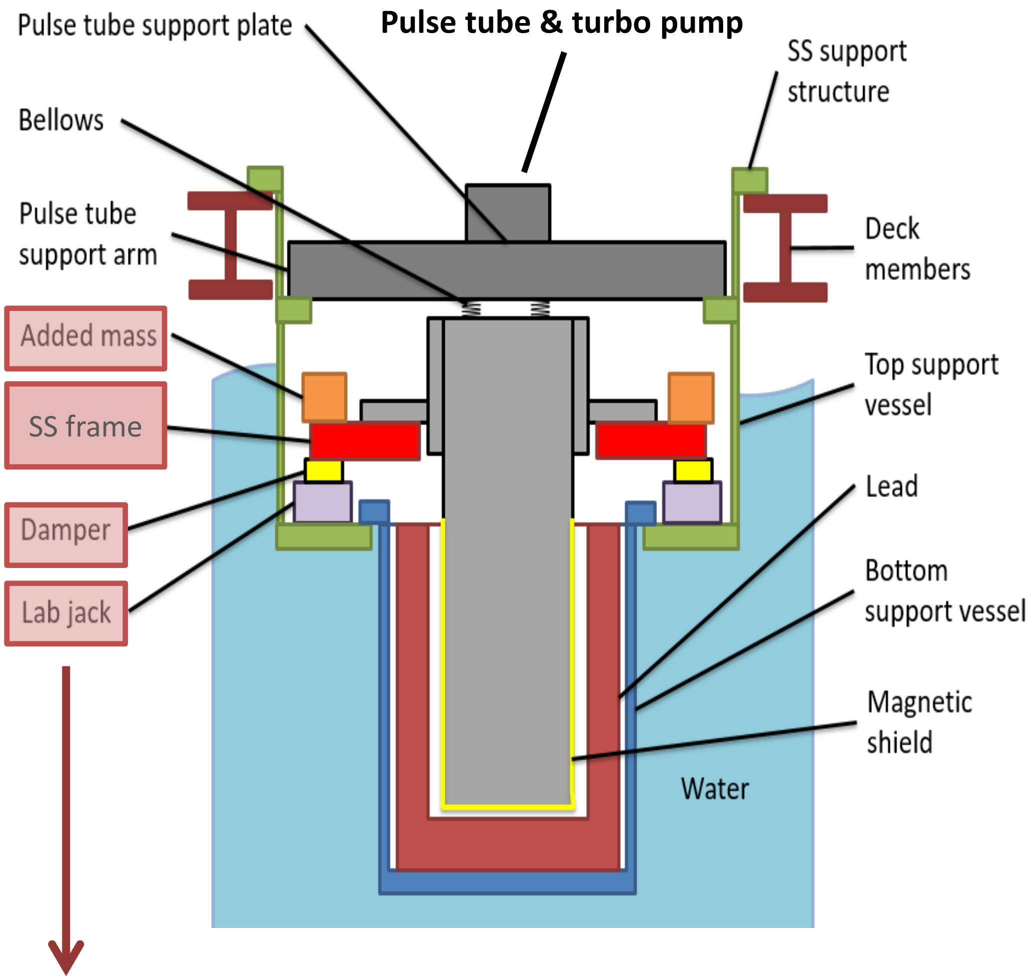


Guiding tube

Plastic chain

^{133}Ba source

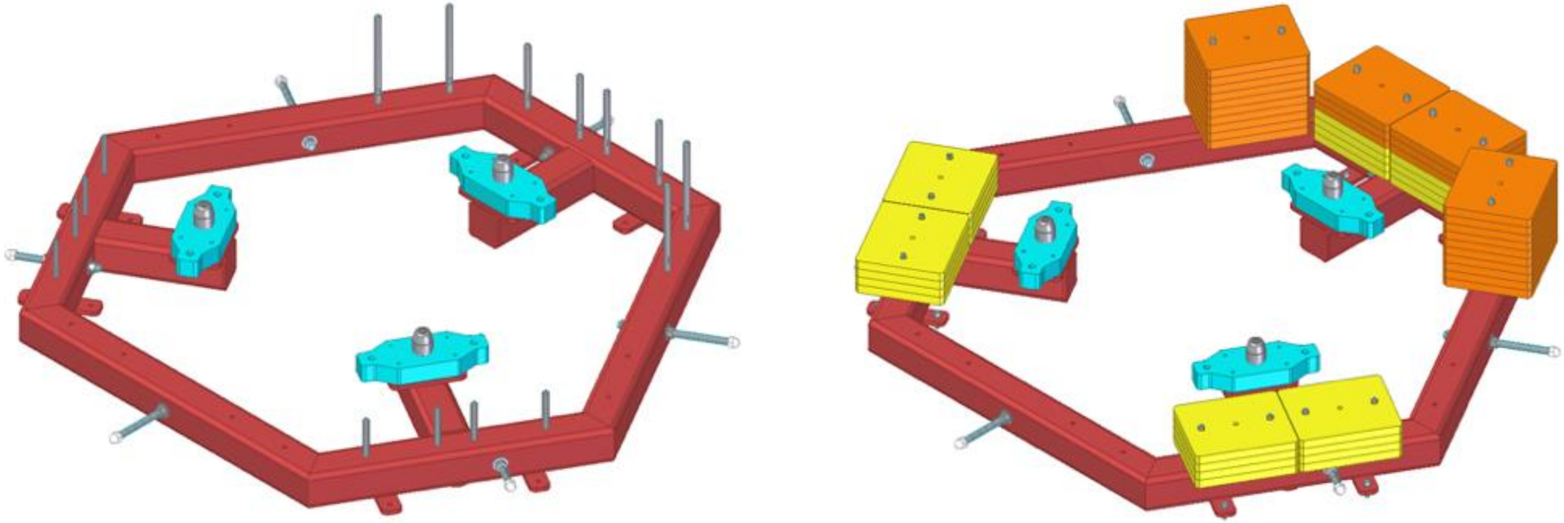
Active two-stages suspension system



Mechanical parts of the Suspension system

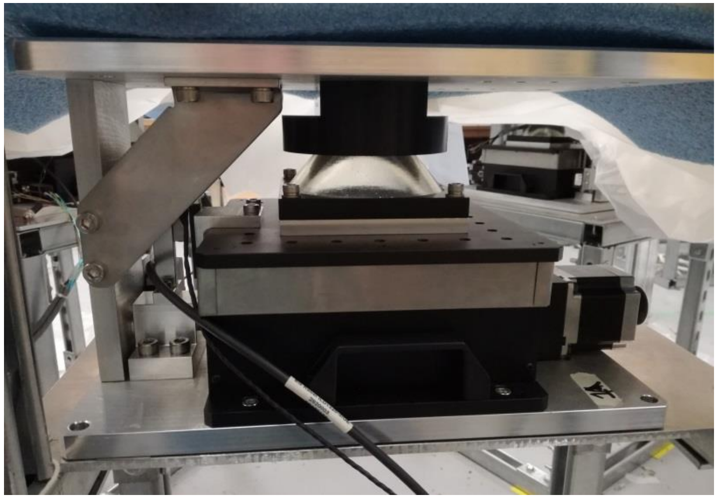
- Our detectors are sensitive to mechanical vibrations
- Pulse tube cooler and turbo pump are strong source of vibrations that may compromize detector performance
- Both are mounted on separate plate with soft coupling (bellows) to cryostat to minimize vibrations
- The bellows makes system sensitive 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



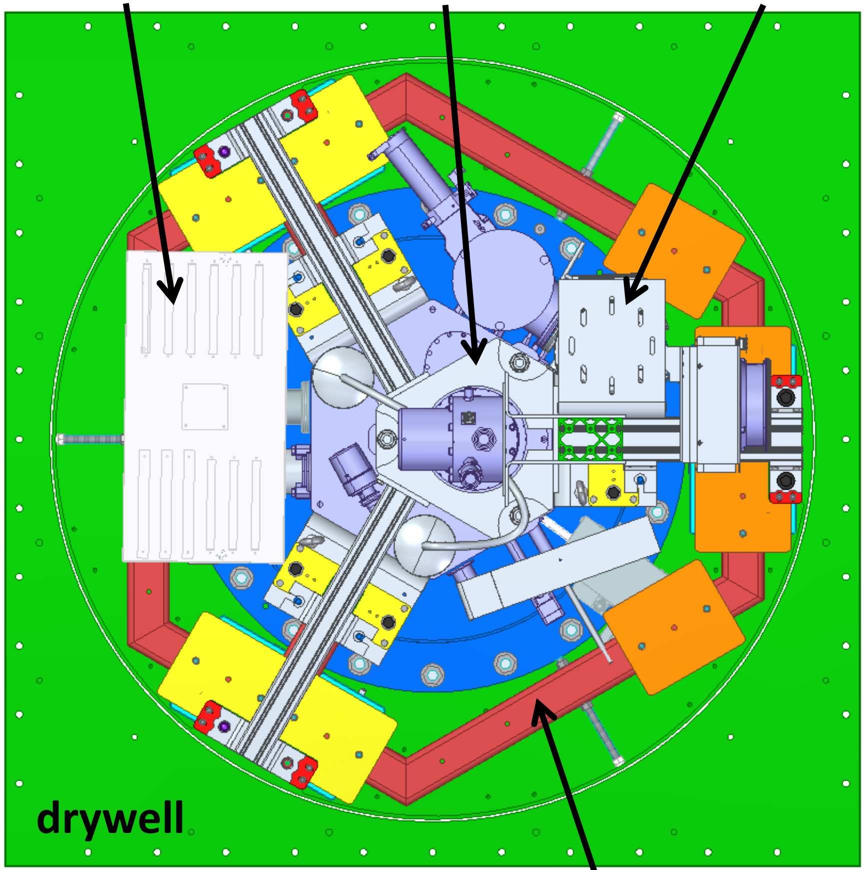
Lab jack

Suspension system assembly

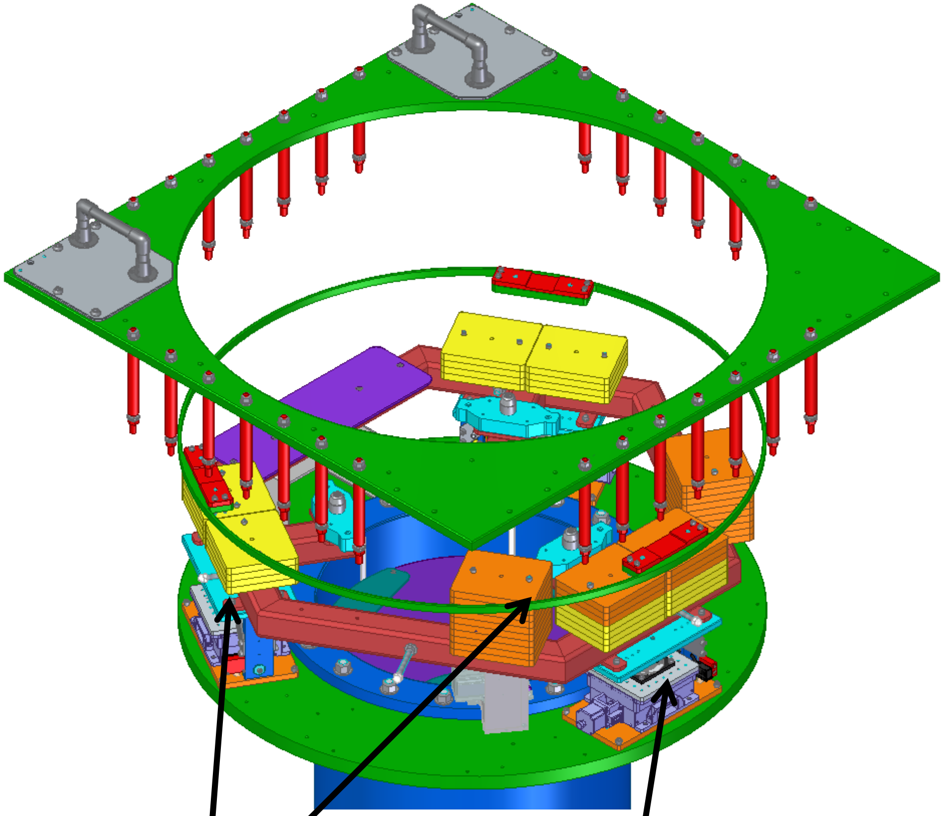
electronics box

pulse tube

turbo pump

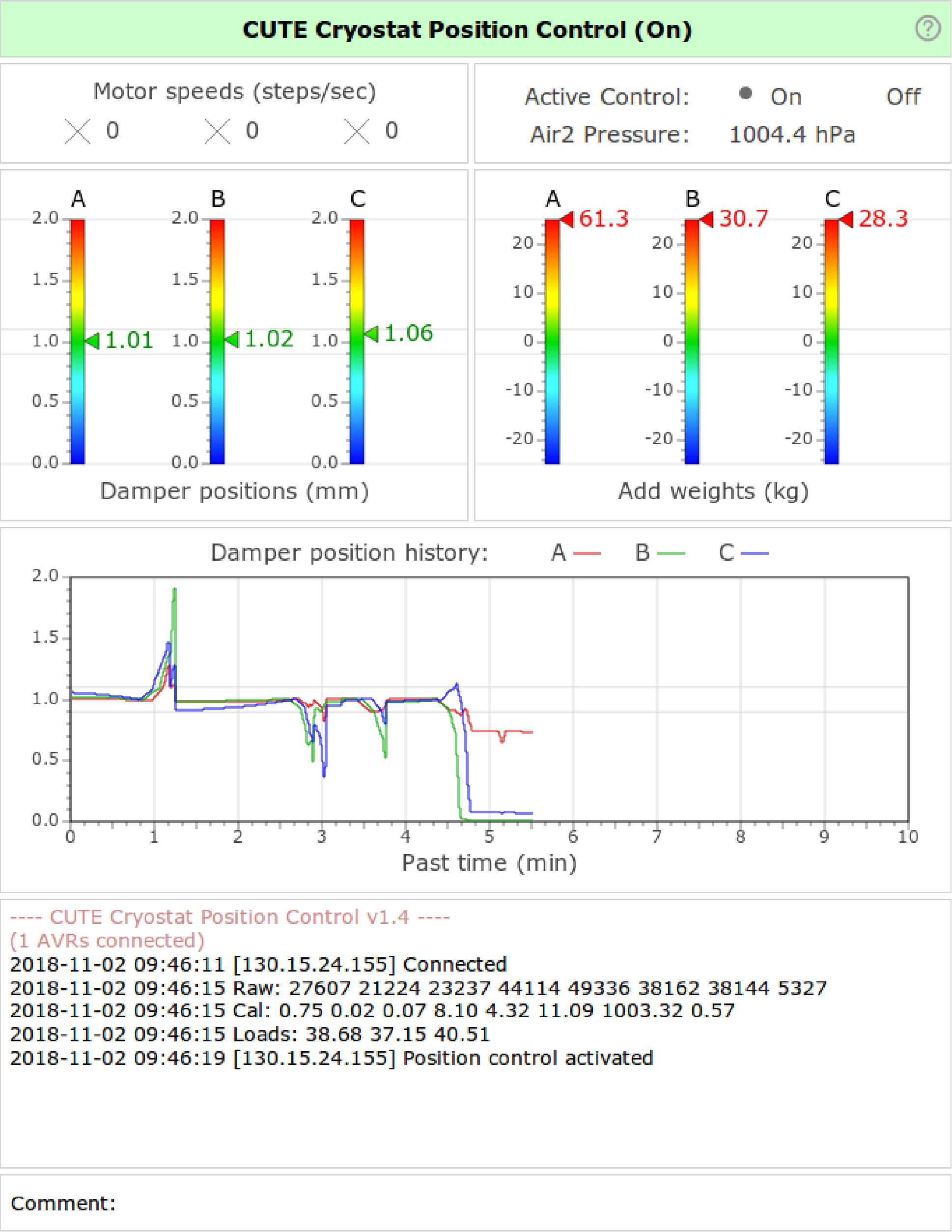


supporting frame



added masses
(about 400 kg in total)

damper



Motor speeds (steps/sec): 0 0 0

Active Control: ● On Off

Air2 Pressure: 1004.4 hPa

Damper positions (mm): A 1.01, B 1.02, C 1.06

Add weights (kg): A 61.3, B 30.7, C 28.3

```
---- CUTE Cryostat Position Control v1.4 ----
(1 AVRs connected)
2018-11-02 09:46:11 [130.15.24.155] Connected
2018-11-02 09:46:15 Raw: 27607 21224 23237 44114 49336 38162 38144 5327
2018-11-02 09:46:15 Cal: 0.75 0.02 0.07 8.10 4.32 11.09 1003.32 0.57
2018-11-02 09:46:15 Loads: 38.68 37.15 40.51
2018-11-02 09:46:19 [130.15.24.155] Position control activated
```

Comment:

Remote control of suspension system

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

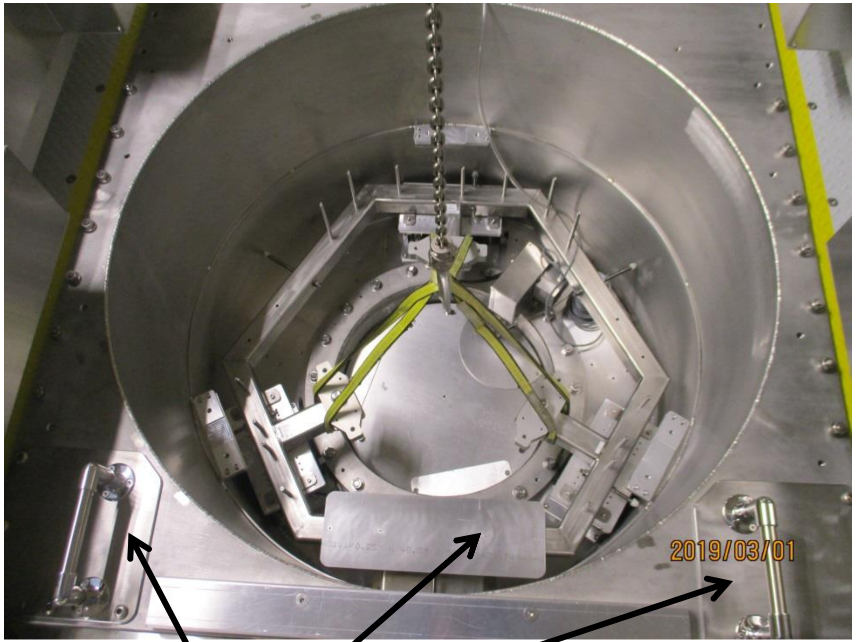
Records of all system parameters into database

Provides possibility to off-line analysis of behavior

Suspension system assembly

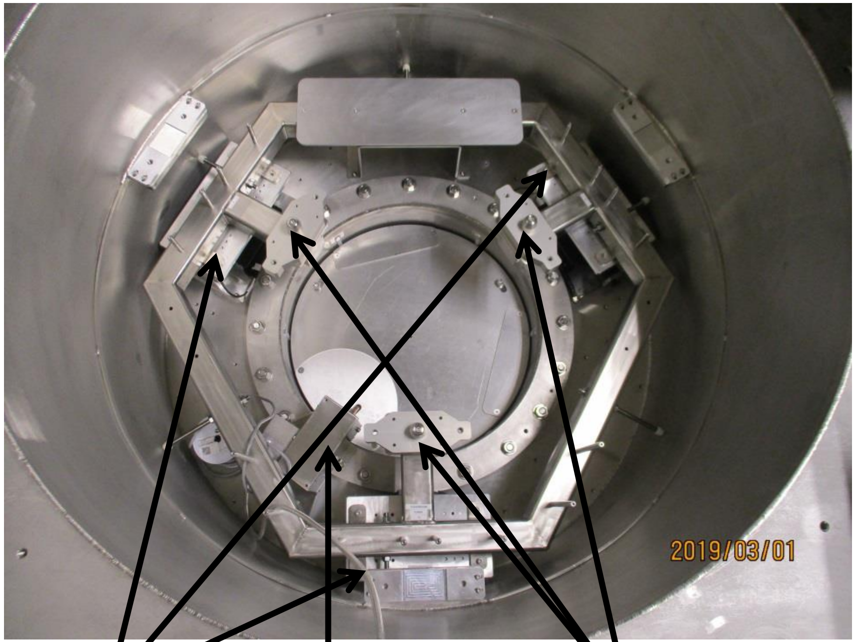
installed at March 1st, 2019

Lowering suspension frame into drywell



Service handles & step

Suspension frame is installed



Lab jacks

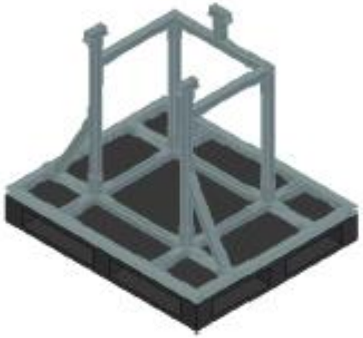
Cryostat alignment pins

Calibration system

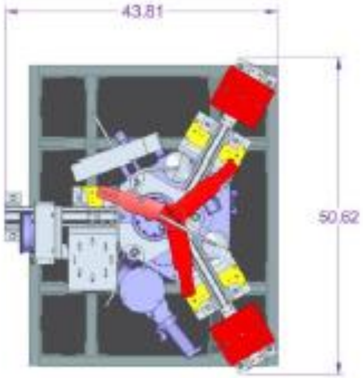
Cryostat transportation system

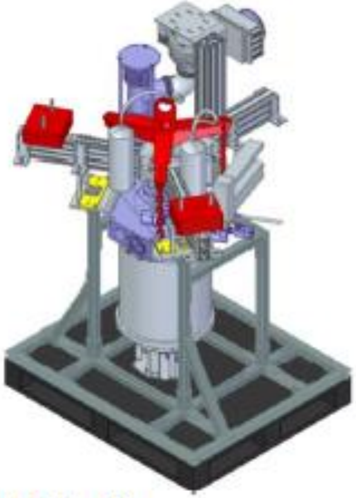
Crate dims: 53”L x 50”W x 78”H ← Forklift transport required

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	• Prepare suspension frame for shipping	✓
Feb 5th, 2019	• Installation Review Phase 2B	✓
Feb 11, 2019	• Assemble, clean, and package of calibration system • Ship suspension and calibration to SNOLAB • Fix last cryostat deficiencies	✓
Feb 18, 2019	• Clean and package cryostat • Ship suspension system underground	✓
Feb 25, 2019	• Install calibration and suspension systems	✓
Mar 25, 2019	• Ship cryostat to SNOLAB and ship underground with CUTE staff present	
Apr 1, 2019	• Continue installation of cryostat • Preparation for Operational Readiness Review	
May 2019	• Operational Readiness Review	

CUTE tasks before Early Operation

Date	Step
May, 2019	• DAQ mounting, and implement DAQ architecture for underground/surface CUTE lab
May, 2019	• Preparation for Operational Readiness Review
June, 2019	• Cleanroom operation test - *air quality test* - *operational test* - *working procedure improvement*
July, 2019	• Test all procedures , its correction based on the results of first run without/with detectors
July, 2019	• Evaluation of required manpower for run preparation&running
end of 2019	• Radio-assay of materials used for CUTE facility production
end of 2019	• Completion of CUTE background model

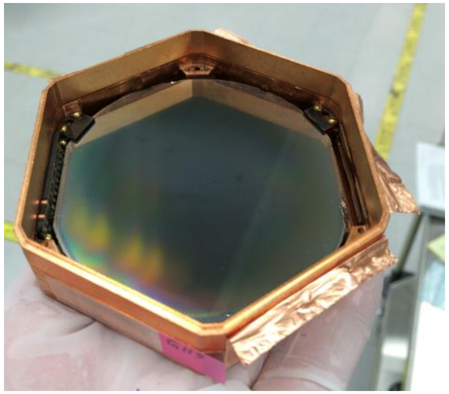
Payload for CUTE

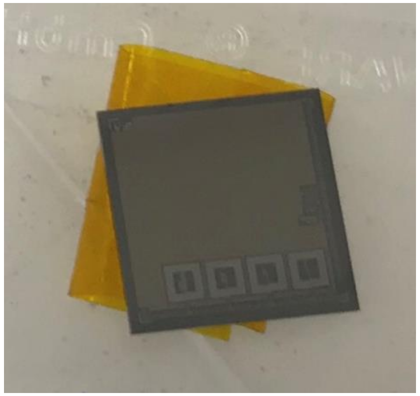
Commissioning

Task	Time Period
Testing of CUTE facility at SNOLAB • *Without detectors* • *With detectors (G115/TES chip)* • *Revision/fixing problems/commissioning*	*May 2019 – June 2019*
Testing SuperCDMS detectors • Si HV Pathfinder • HVeV detector • First tower (6 iZIP Ge Detector)	*July 2019 – May 2020*
Own R&D activity • HVeV detector from enriched ^{28}Si • Scintillating bolometers based on YVO_4, ZnSe, $^{arch}PbMoO_4$ crystals • Advanced light detectors	*from Sept 2019*

Early operation

Test done @ Queen's University



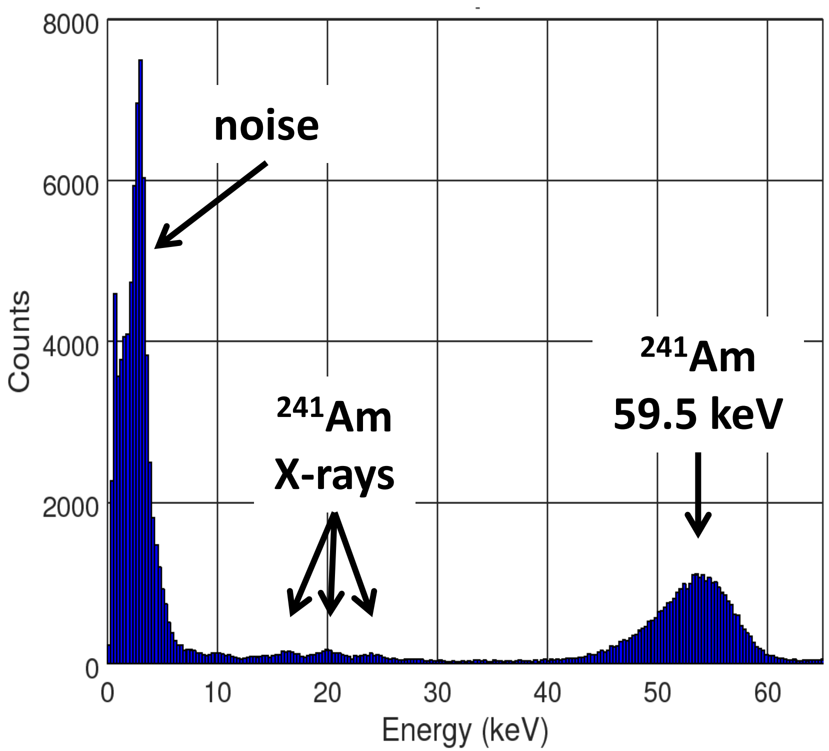


"G115"	**TES chip**
∅ 76 × 10 mm	10 × 10 × 1 mm
240 g	0.5 g
4 phonon channels	4 phonon channels

Bolometric performance/ External background

RF noise/Vibration

Test done @ Queen's University

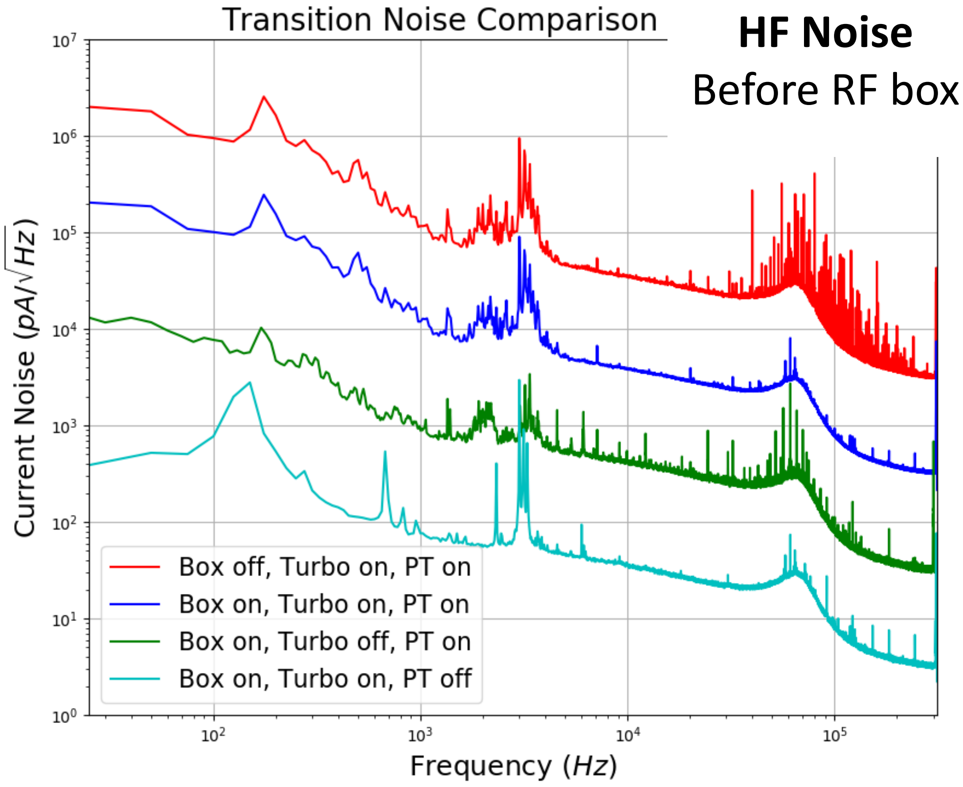


E_{thr} = 5 keV

FWHM = 1 keV @ 17.7 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



HF Noise
Before RF box

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

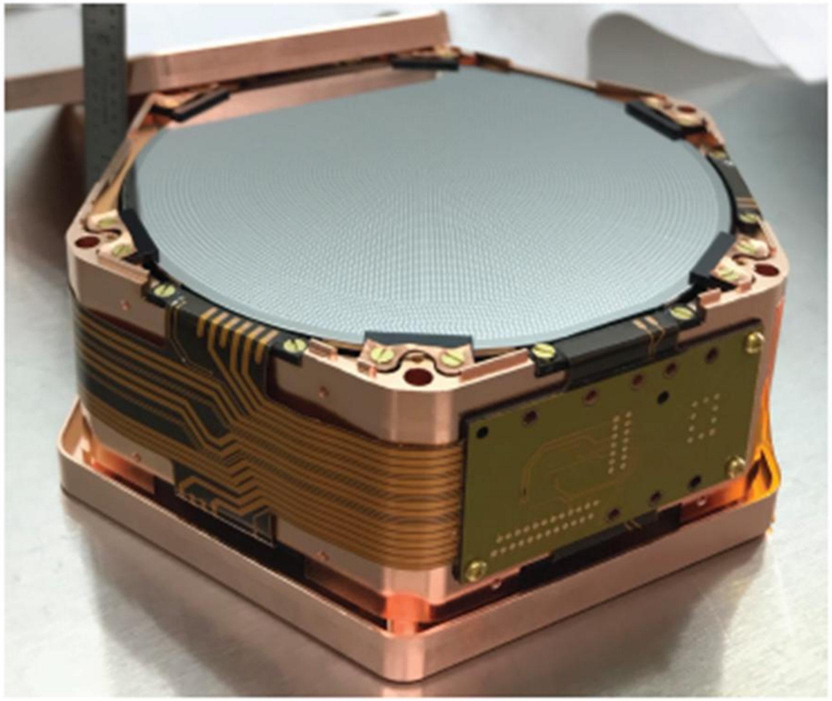
The power supply for the read-out electronics that will be used at SNOLAB was also tested, and it lead to improved high frequency noise performance as well

Normal Noise: **~5 pA/√Hz**

SC Noise: **~40 pA/√Hz**

Expected detectors for Early Operation

Si HV Pathfinder Detector



1 detector in Tower

July 2019 – August 2019

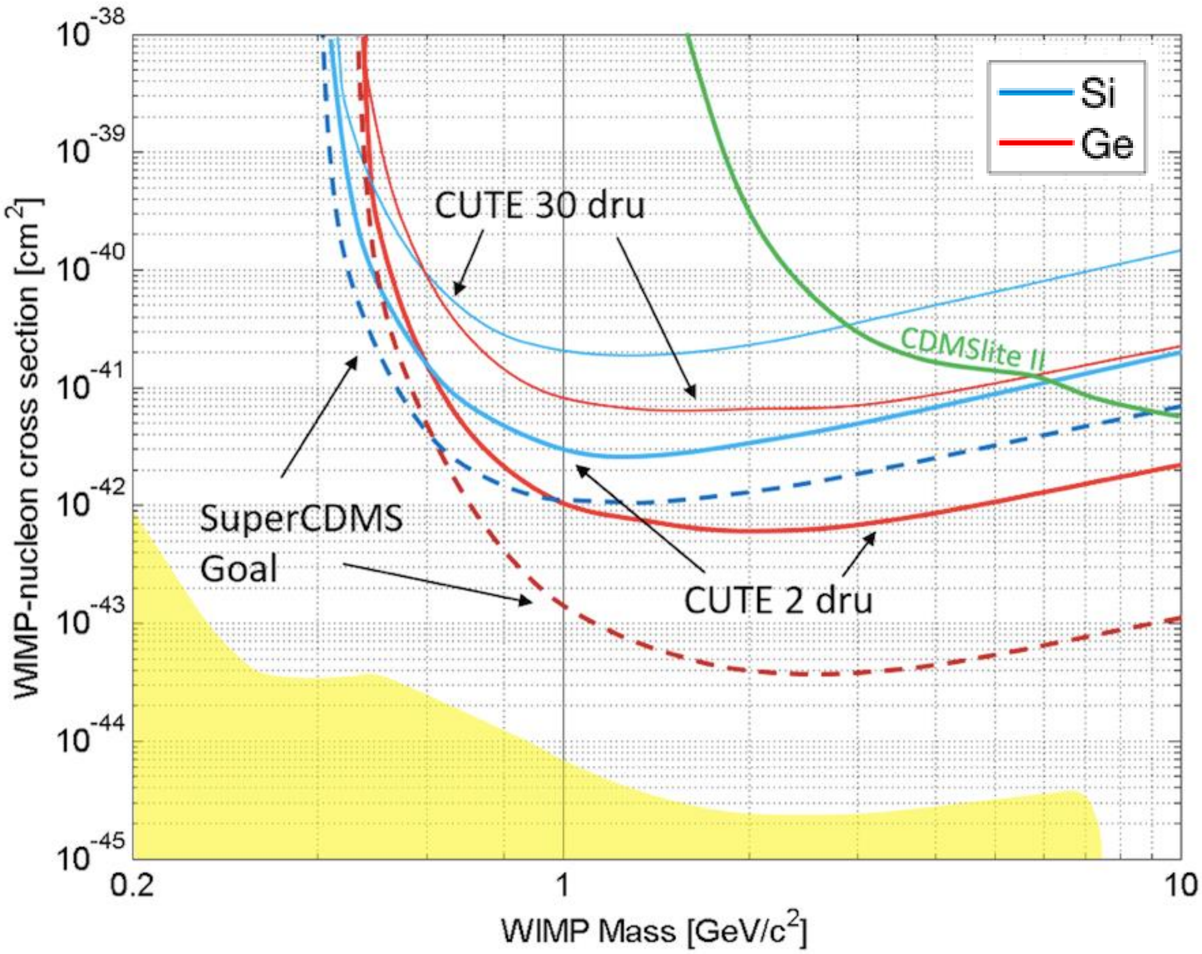
Ge iZIP Prototype Detector

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