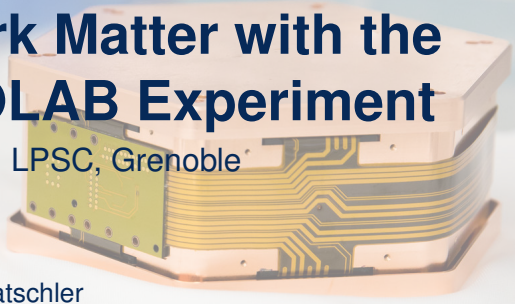
Searching for Dark Matter with the SuperCDMS SNOLAB Experiment

Post-doc seminar, LPSC, Grenoble



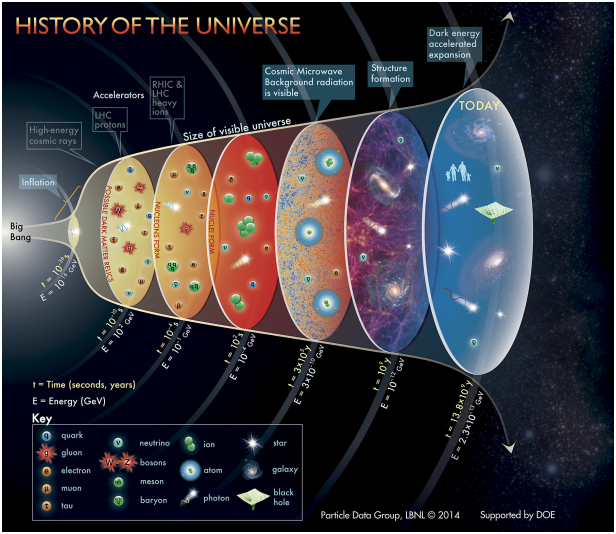
Birgit Zatschler

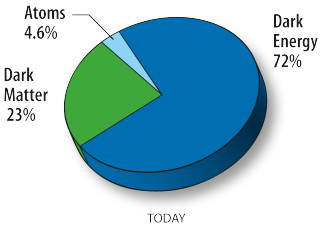
16th January 2024

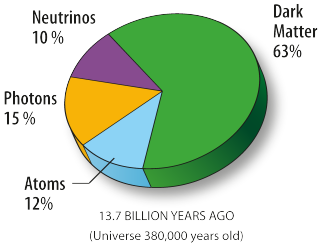
Outline

- Introduction to Dark Matter
- The SuperCDMS experiment at SNOLAB
- Background simulations for SuperCDMS

Evolution of the Universe



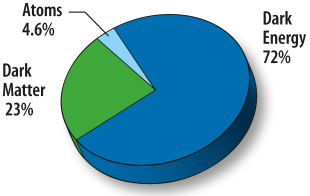




NASA / WMAP Science Team

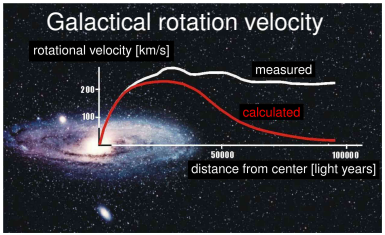
Introduction to Dark Matter

- Strong evidence for DM exist within the universe.
- There is five times more DM than normal matter.



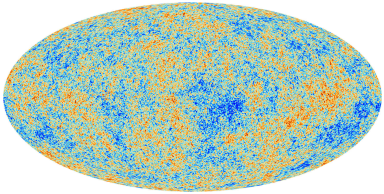
Composition of the universe

NASA / WMAP Science Team

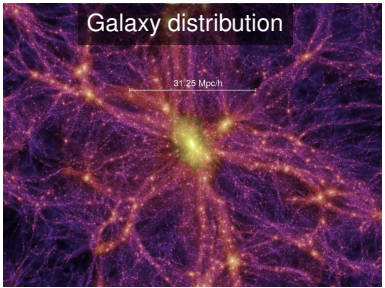


https://phys.org

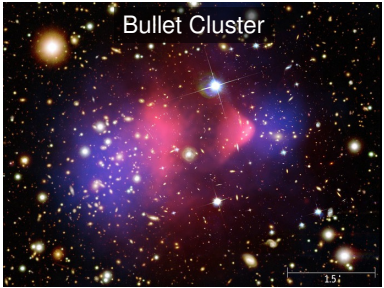
Cosmic microwave background



ESA and the Planck Collaboration



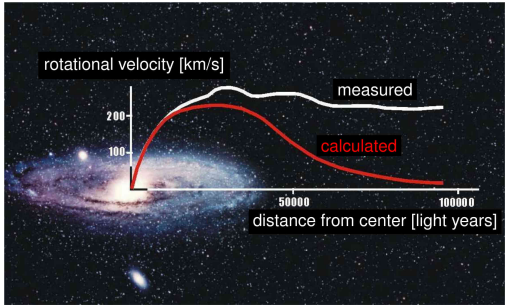
DOI: 10.1038/nature03597



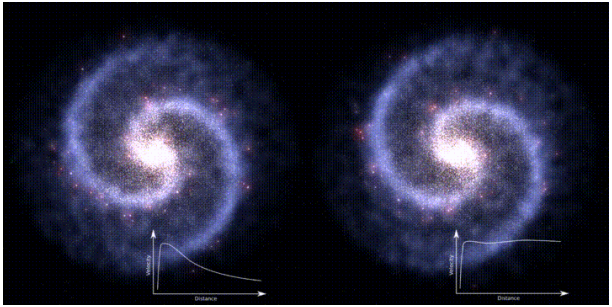
NASA

Galaxy rotation velocity

- Predicted rotational velocity decreases with the distance from the galaxy's center, but the observed rotation curve is flat.
- A DM halo superimposing with the galaxy's visible matter can explain flat rotation curves.



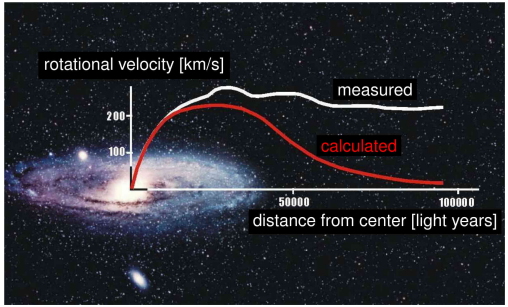
https://phys.org



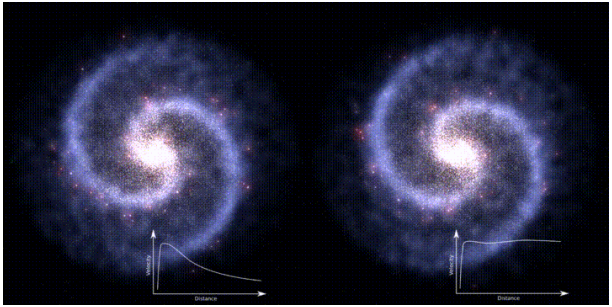
https://commons.wikimedia.org

Galaxy rotation velocity

- Predicted rotational velocity decreases with the distance from the galaxy's center, but the observed rotation curve is flat.
- A DM halo superimposing with the galaxy's visible matter can explain flat rotation curves.

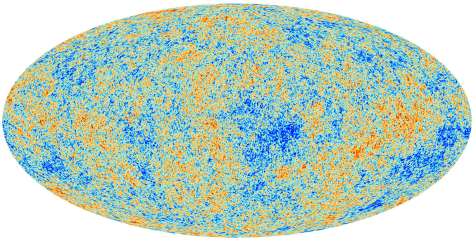


https://phys.org

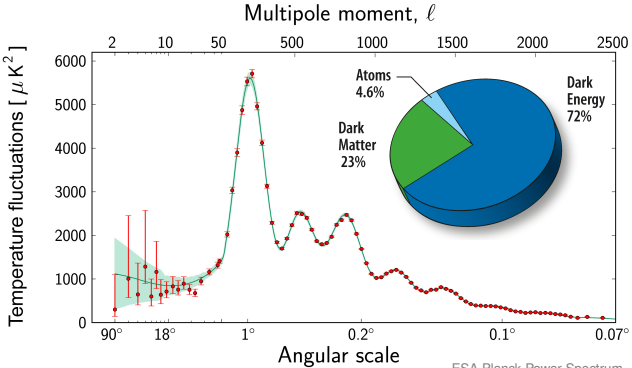


https://commons.wikimedia.org

Cosmic microwave background (CMB)



ESA and the Planck Collaboration

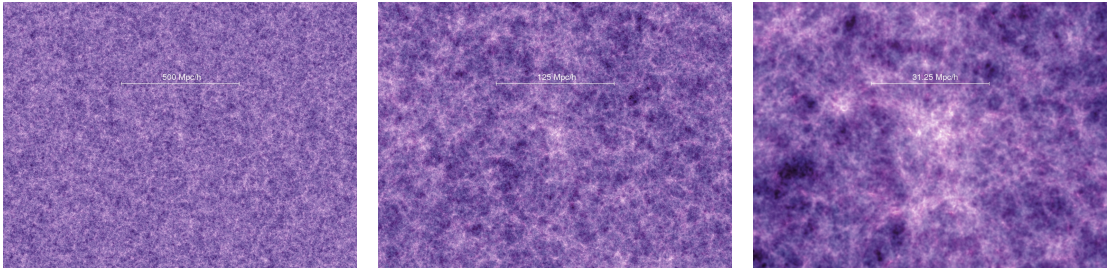


ESA Planck Power Spectrum

- Planck mission by ESA measured the temperature fluctuations of the CMB with unprecedented precision.
- The power spectrum shows fluctuations around the average temperature of today's universe of 2.7 K.
- The peaks in the power spectrum give information about the curvature of the universe and the DM density.

Galaxy distribution – Millennium Simulation

Time = 0.21 Gyr

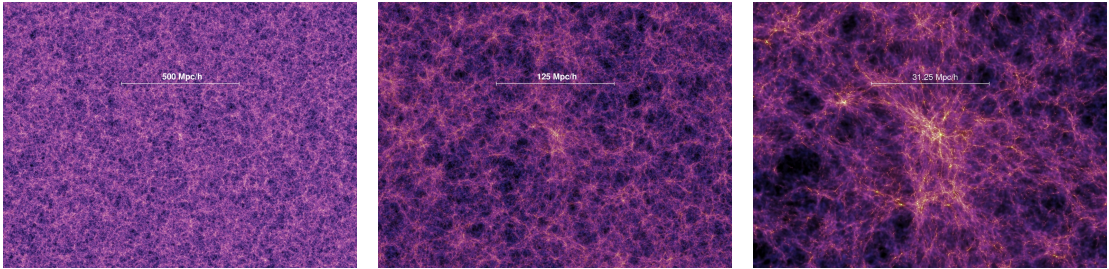


Max Planck Institute for Astrophysics

- Using more than 10^{10} particles with an origin distribution following the fluctuations of the CMB.
- These particles interact only via gravitational force to study the evolution of the matter distribution.
- The result closely resembles today's structures of the universe.

Galaxy distribution – Millennium Simulation

Time = 1.0 Gyr

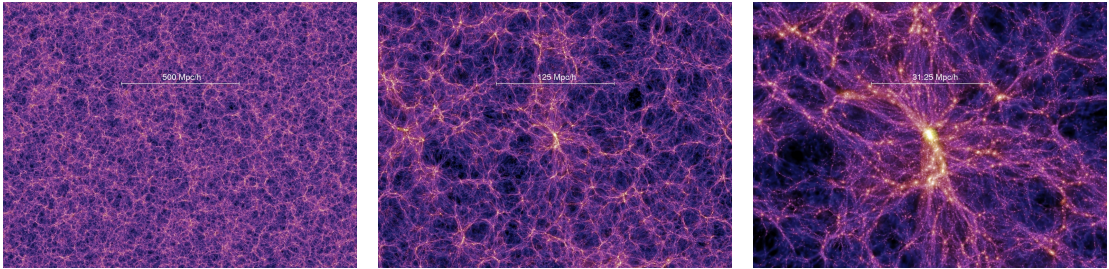


Max Planck Institute for Astrophysics

- Using more than 10^{10} particles with an origin distribution following the fluctuations of the CMB.
- These particles interact only via gravitational force to study the evolution of the matter distribution.
- The result closely resembles today's structures of the universe.

Galaxy distribution – Millennium Simulation

Time = 4.7 Gyr

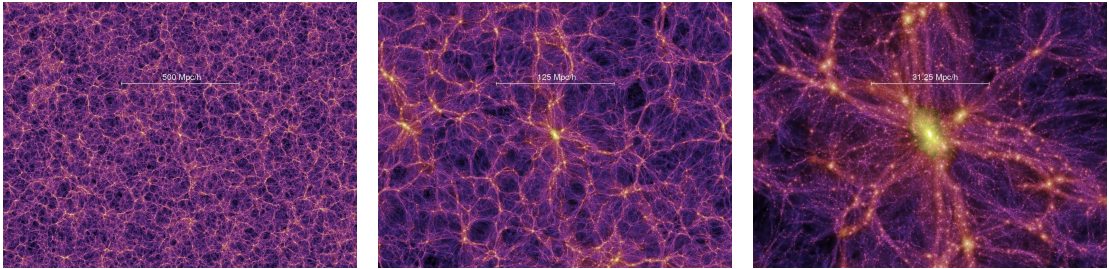


Max Planck Institute for Astrophysics

- Using more than 10^{10} particles with an origin distribution following the fluctuations of the CMB.
- These particles interact only via gravitational force to study the evolution of the matter distribution.
- The result closely resembles today's structures of the universe.

Galaxy distribution – Millennium Simulation

Time = 13.6 Gyr

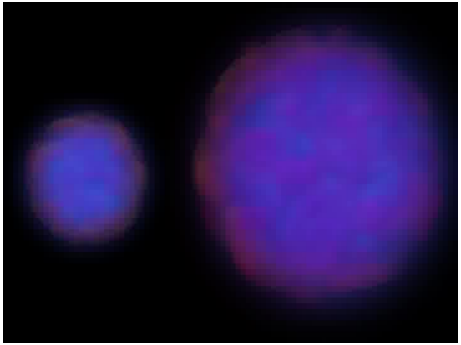


Max Planck Institute for Astrophysics

- Using more than 10^{10} particles with an origin distribution following the fluctuations of the CMB.
- These particles interact only via gravitational force to study the evolution of the matter distribution.
- The result closely resembles today's structures of the universe.

Bullet Cluster

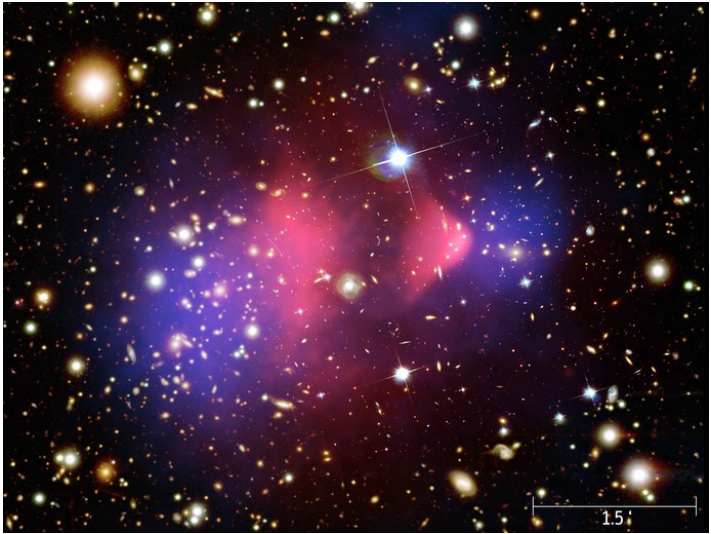
- Two clusters of galaxies collided 150 million years ago.
- Intergalactic gases (X-ray, pink) interact electromagnetically.
- The galaxies pass by each other practically undisturbed.
- DM distribution is calculated from gravitational lensing (blue).
- Supports predictions that DM only interacts gravitationally and allows limit setting on the cross section of its self-interaction.



NASA

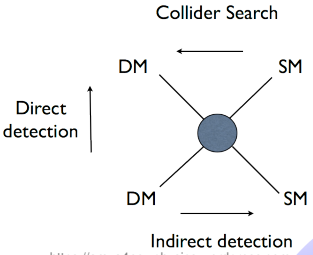
Bullet Cluster

- Two clusters of galaxies collided 150 million years ago.
- Intergalactic gases (X-ray, pink) interact electromagnetically.
- The galaxies pass by each other practically undisturbed.
- DM distribution is calculated from gravitational lensing (blue).
- Supports predictions that DM only interacts gravitationally and allows limit setting on the cross section of its self-interaction.



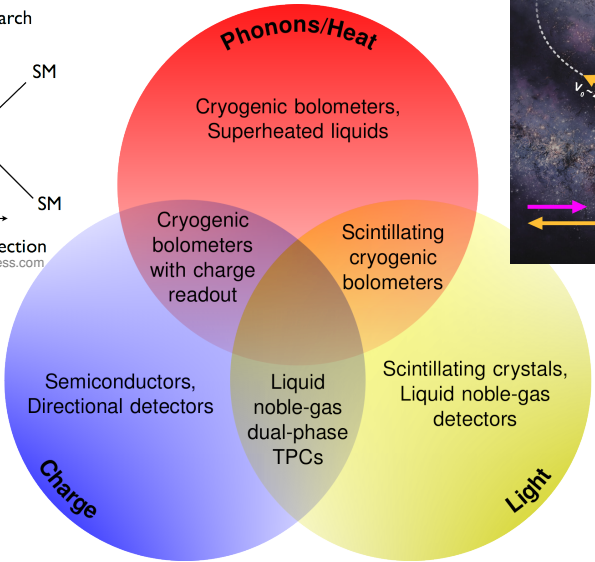
NASA

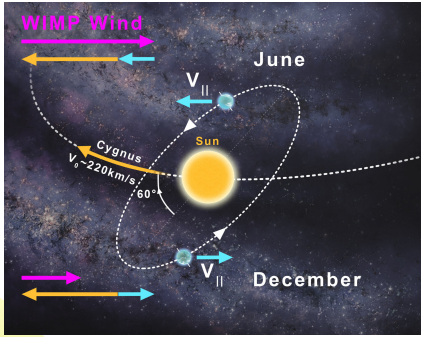
DM Detection methods



https://amva4newphysics.wordpress.com

▲ Ways to search for DM





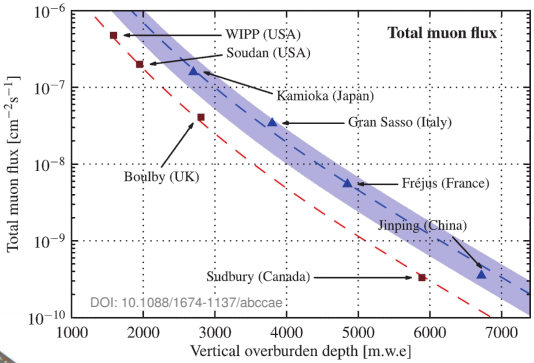
Josephides J 2019 WIMP Wind Infographic

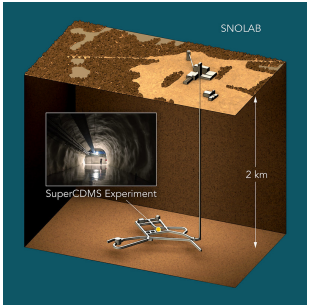
▲ Solar system moving through galactical DM halo

◄ Direct DM detection channels

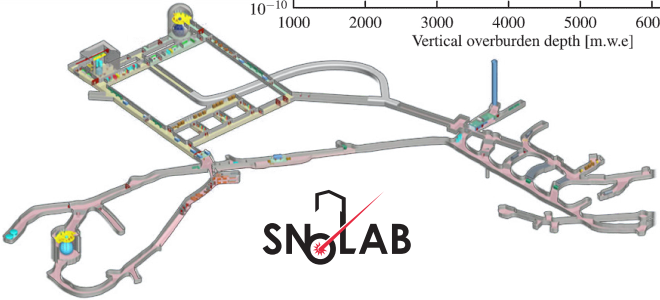
SNOLAB underground facility

- Located in Sudbury, Canada, inside an active mine.
- Rock overburden of 2 km shields from cosmic radiation.
- Muon flux reduced by a factor of 50 million.
- Hosting DM and neutrino experiments in need of low background environment.





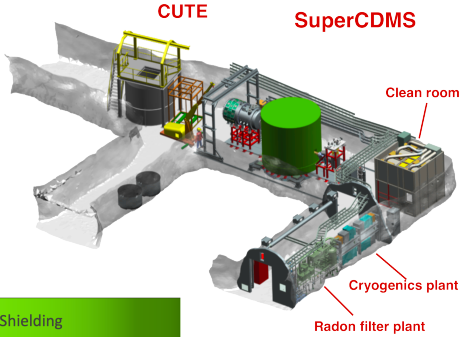
https://supercdms.slac.stanford.edu

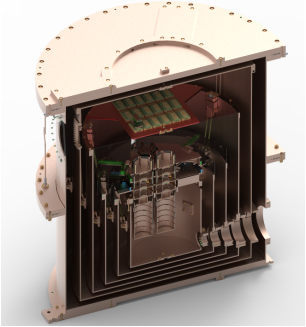


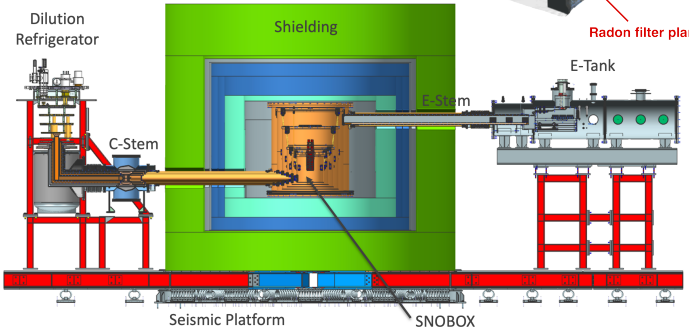
https://www.snolab.ca

SuperCDMS experiment at SNOLAB

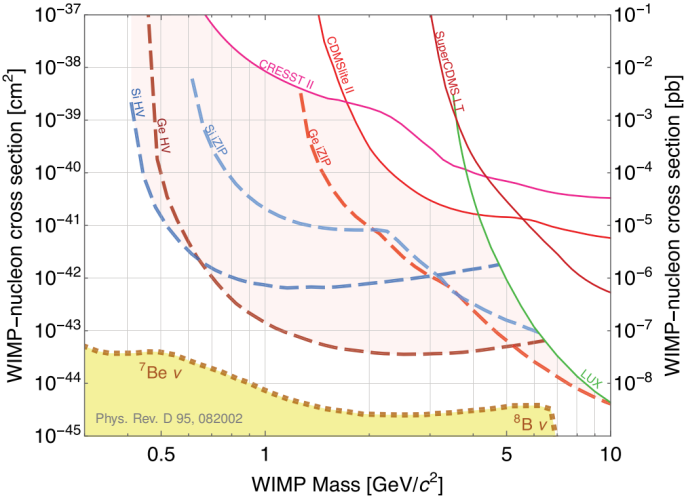
- The **Super** **C**roygenic **D**ark **M**atter **S**earch experiment is aiming for direct detection of DM interactions with Standard Model matter.
- Operating 18 Ge and 6 Si detectors in cryogenic conditions following a complementary approach.
- Commissioning is planned for late 2024.





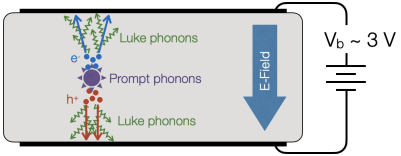


SuperCDMS projected sensitivity



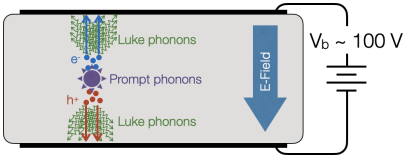
iZIP (interleaved Z-sensitive Ionization and Phonon) detectors

- Measure charge and phonons.
- Discrimination between NR and ER.

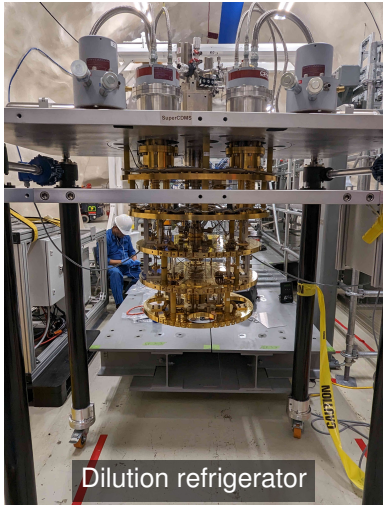


HV (High Voltage) detectors

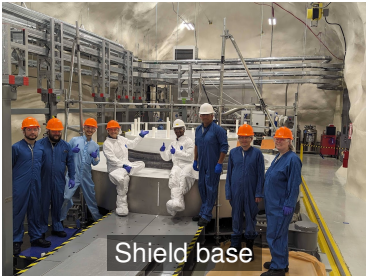
- Amplified NTL phonon production.
- Better energy resolution and lower threshold.

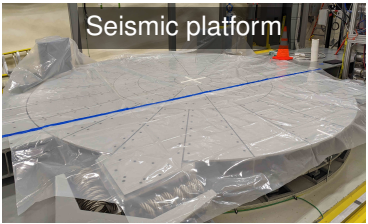


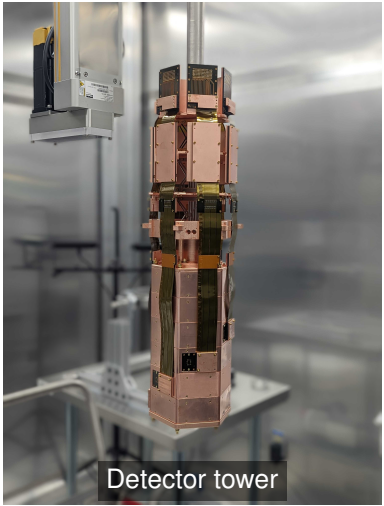
Construction Status



Dilution refrigerator


Shield base

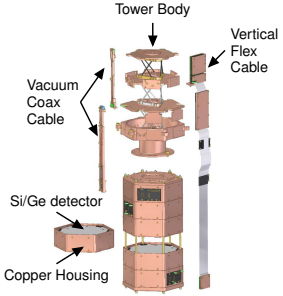

Seismic platform


Detector tower

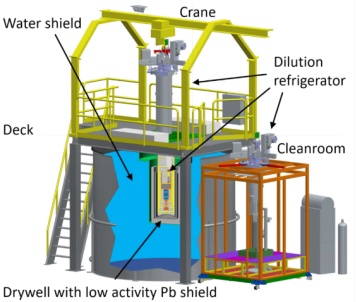
Tower testing at CUTE FACILITY

- The **C**ryogenic **U**nderground **TE**st facility is located in SNOLAB next to SuperCDMS.
- Close collaboration between CUTE and SuperCDMS.
- Testing one SuperCDMS HV tower hosting 4 Ge and 2 Si detectors right now.
- Possibility to achieve early science results.

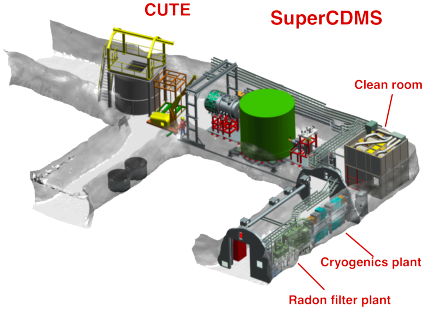
Detector tower



CUTE



SNOLAB



Background types in SuperCDMS

Radioactive contamination

- Long-lived radioactive isotopes are contained in traces in all materials.
- Some of those isotopes make up the beginning of natural decay chains.

Radon exposure

- Air above surface and underground contains traces of ^{222}Rn.
- Daughter isotope ^{210}Pb is implanted in surfaces.

Cosmogenic activation

- Neutrons originating from cosmic showers can activate materials residing on Earth's surface.
- Spallation by high energy neutrons ($\sim$ MeV): ^{70}Ge (n,t) ^{68}Ga
- Absorption of thermal neutrons ($\sim$ meV): ^{70}Ge (n,γ) ^{71}Ge

Dust on surfaces

- Dust contains radioactive contaminants and accumulates on surfaces.

Developing a background model

Assays

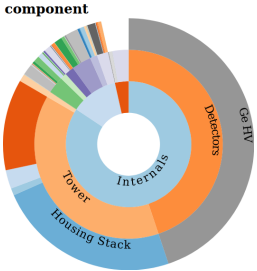
- Measurements, upper limits, calculations
- Bulk and surface contaminations

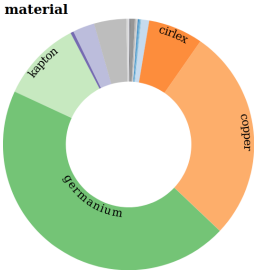
Simulations

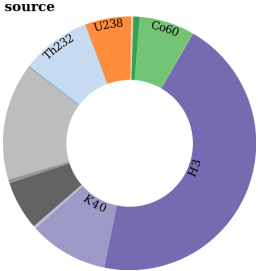
- Geometry, materials
- Decays, particle propagation
- Detector hits, spectra

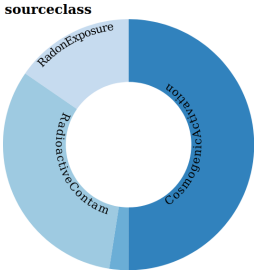
Analysis

- Fit simulation to data
- Determine sensitivity and set limits





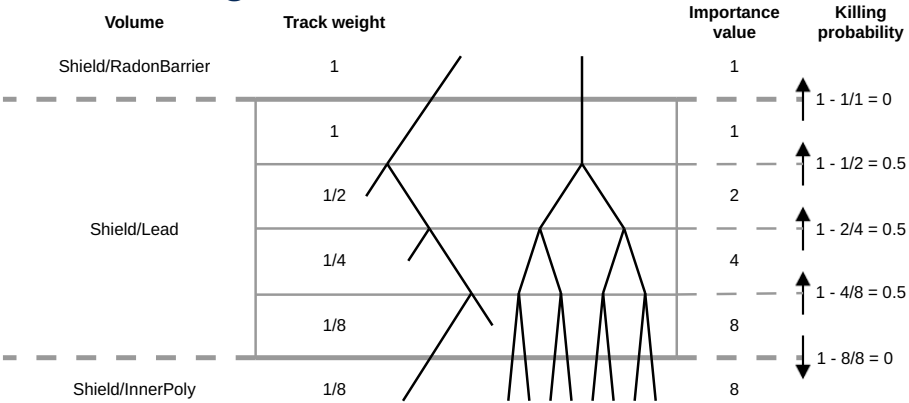




SuperCDMS lead shield simulation in SuperSim

- Lead shield has a total thickness of 20 cm.
- Simulating ^{210}Pb in lead shield would consume more than 2k cpu years to achieve sufficient statistics.
  - Simulation procedure needs to be more efficient.

Importance Biasing

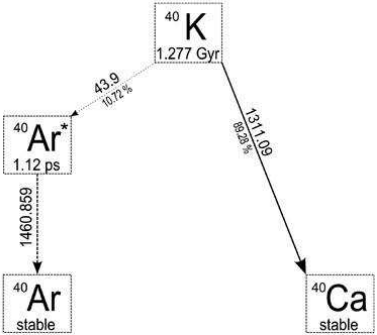


- GEANT4's importance biasing splits (kills) particles going to (away from) the detectors.
- The split particle is an identical copy of the original particle, both their weights are halved.
- A backwards going particle is either killed or its weight is adjusted.
- Only one particle type is biased, i.e. in our case gammas inside the lead shield.

Efficiency of Importance Biasing

- Count events leaving the lead shield per runtime with and without Importance Biasing.
- Efficiency boost strongly depends on number and thickness of importance layers.
- Importance layer thickness needs to be adjusted depending on the gamma energy.

Decay	# Layers	Thickness	Eff. boost
^{40}K	16	1.25 cm	22697
^{232}Th	16	1.25 cm	17173
^{210}Pb	20	1.00 cm	>6787

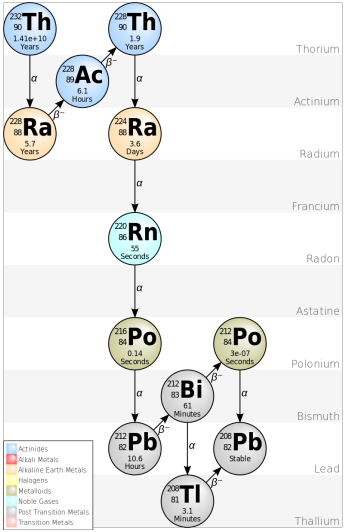


DOI: 10.1016/j.physrep.2007.09.001.

Efficiency of Importance Biasing

- Count events leaving the lead shield per runtime with and without Importance Biasing.
- Efficiency boost strongly depends on number and thickness of importance layers.
- Importance layer thickness needs to be adjusted depending on the gamma energy.

Decay	# Layers	Thickness	Eff. boost
^{40}K	16	1.25 cm	22697
^{232}Th	16	1.25 cm	17173
^{210}Pb	20	1.00 cm	>6787

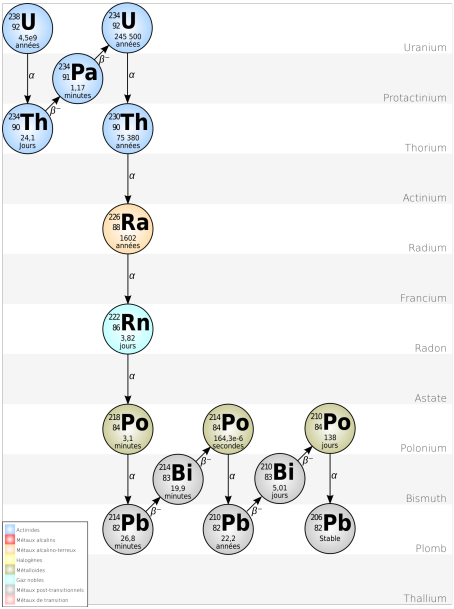


https://commons.wikimedia.org

Efficiency of Importance Biasing

- Count events leaving the lead shield per runtime with and without Importance Biasing.
- Efficiency boost strongly depends on number and thickness of importance layers.
- Importance layer thickness needs to be adjusted depending on the gamma energy.

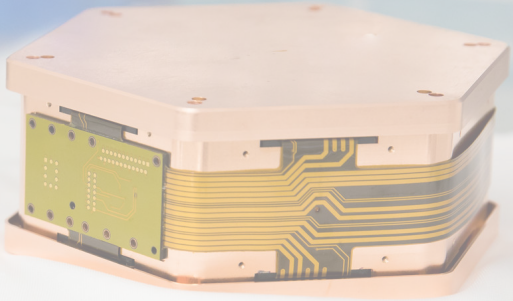
Decay	# Layers	Thickness	Eff. boost
^{40}K	16	1.25 cm	22697
^{232}Th	16	1.25 cm	17173
^{210}Pb	20	1.00 cm	>6787



https://fr.m.wikipedia.org

Summary & Outlook

- SuperCDMS is currently under construction at SNOLAB.
- Plan to begin commissioning in late 2024.
- Complementary detector technologies and crystal materials allow:
  - a broadband DM search and
  - sensitivities down to unprecedented cross sections.
- It is crucial to understand the experiment's background composition.
- For this, dedicated extensive Monte Carlo simulation studies are performed.



Flag icons from flaticon.com

SuperCDMS Collaboration

134 77 5 4 4 2 1

@SuperCDMS

https://supercdms.slac.stanford.edu